National Climate Indicators System Report

National Climate Assessment and Development Advisory Committee
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Indicators System Report Authors

Coordinating Lead Authors
Melissa Kenney, PI for USGCRP National Climate Indicators System (University of Maryland)
Tony Janetos, Chair Indicators Work Group (Boston University)

Authors (detailed list of all contributing authors in Appendix D)
Indicators Work Group
Indicators Coordination and Research Office
Agriculture Indicators Technical Teams
Energy Indicators Technical Teams
Forests Indicators Technical Teams
Freshwater Ecosystems Indicators Technical Teams
Grasslands Indicators Technical Teams
Health Indicators Technical Teams
Infrastructure Indicators Technical Teams
Greenhouse Gas Emissions and Mitigation Indicators Technical Teams
Oceans and Coasts Indicators Technical Teams
Physical Climate and Variability Indicators Technical Teams
Seasonal Timing and Phenology and Seasonal Indicators Technical Teams
Water Cycle and Management Indicators Technical Teams

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Introduction and Pilot System

Overall Purpose

The National Climate Assessment (NCA), a component of the U.S. Global Change Research Program (USGCRP), is designed to produce periodic scientific assessments of the vulnerability of important sectors in the U.S. to climate change and variability, and to report on response strategies for responding to and coping with change. An important feature of the NCA is to develop climate-relevant information for use by a wide variety of stakeholders in the public and private sectors and in the scientific community. The development of a national system of indicators is an essential feature of such information, and provides a foundation for assessing change on an ongoing basis.

The National Climate Assessment Development and Advisory Committee (NCADAC) chartered an Indicators Working Group (IWG) to create a set of physical, ecological, and societal indicators that would inform decision-makers and the public about our nation's changing climate. The IWG engaged over 150 scientists, practitioners, and managers from the USGCRP agencies, universities, the national laboratories, and industry to develop the scientific basis for the selection of indicators using conceptual models and recommendations of indicators that link to these conceptual models. The IWG's specific charge has been to develop recommendations for this system for consideration by the USGCRP, as the implementing organization. This document constitutes those recommendations.

The system of indicators is designed includes the most important climate changes, impacts, vulnerabilities and preparedness, and mitigation responses, including changes that occur in a multi-stressor context, meaning those indicators that have both climate and non-climate stressors. These components serve as categories within which to organize an end-to-end system of indicators:

The goals for the indicators are to:

- Provide meaningful, authoritative climate-relevant measures about the status, rates, and trends of key physical, ecological, and societal variables;
- Inform decisions on management, research, and education;
- Identify climate-related conditions and impacts to help develop effective mitigation and adaptation measures; and
- Provide analytical tools by which user communities can derive their own indicators for particular purposes.

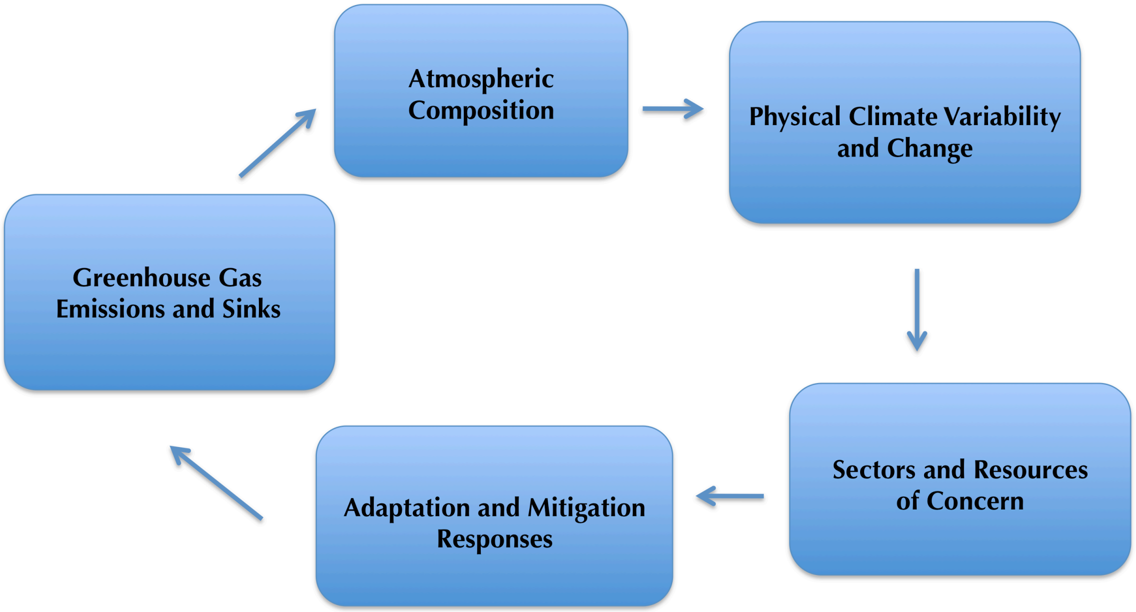
Teams of experts have been formed to cover different sectors and systems and to ensure consideration of key indicators across physical, ecological, and societal contexts. The teams have identified indicators within their area of expertise through the development of conceptual models that encapsulate the climate and non-climate drivers of their system and the indicators that they have identified. The Indicators Working Group, an oversight and advisory body, has considered these recommendations to identify indicators for a pilot system, the initial Indicators System, and development of research priorities.

Overall Conceptual Model

The overall conceptual model, originally proposed in the Indicators System Technical Input Report to the National Climate Assessment (Janetos et al., 2012), for the indicators system is shown below. It exemplifies the philosophy of the indicators forming an end-to-end system – a system that includes indicators of sources, changes, impacts vulnerabilities, and responses across physical and natural systems as well as human sectors.

At the broadest level, the components of the end-to-end system of indicators include:

- Greenhouse Gas Emissions and Sinks
- Atmospheric Composition
- Physical Climate Variability and Change
- Sectors and Resources of Concern
- Adaptation and Mitigation



Categories of Indicators: Framework for the National Climate Indicators System. *Physical, ecological, and societal indicators could fall into different categories of this end-to-end framework. The framework includes the linkages between sources and sinks to impacts to responses, which over time can impact sources and sinks. Because this system is not designed for cause and effect research, indicators that are within a multi-stressor context where climate is one of many stressors can also be included.*

These broad categories encompass two features of indicator systems that have, in our view, equal importance. One is that they should rely on an underlying conceptual model of the sources, changes, consequences, and responses to climate variability and change, both in the physical and ecological systems themselves, and also in the socioeconomic and political systems that govern decision-making for responses. The other is that they explicitly acknowledge that values of decision-making communities and stakeholders are important to acknowledge.

It is infeasible to develop and report indicators of all possible impacts of change. User preferences that have been expressed in some way must play a role in deciding which of the many possible sectors of concern are represented, and indeed which of the many possible indicators within those sectors should be reported. Economic values, ecosystem services, and the recognized importance of supporting services all need to be factored in to these selections.

The broad conceptual model depicted in the figure also requires that some components be more finely delineated. For example, sectors and resources of concern should at a minimum consider the major sectors that assessment efforts have identified as being important for decision-making and stakeholder communities: e.g., agriculture, forestry, water resources, energy, infrastructure, and health. They also need to have an interdisciplinary view of the types of indicators that should be reported. Indicators of extent, state, and system processes are clear candidates, but the system would ideally also include indicators of sensitivity/vulnerability and/or resilience. Adaptation responses should have indicators of preparedness as well as of actual responses to climate or weather events. The domains of potential indicators, therefore, extend beyond the physical and ecological sciences into socioeconomic characteristics.

This framing has several advantages. It can be used to identify the different components of the end-to-end climate issue of interest to both decision-makers and researchers. It is independent of scale, and therefore allows the indicators themselves to be described at spatial scales that are the most relevant for their intended use. National decision-makers may find indicators of national greenhouse gas emissions to be informative; however, state or local decision-makers have the freedom in this framework to define indicators of state, regional, or local greenhouse gas emissions that are more relevant to their concerns. The framework is also independent of time scale and topics within the broad categories. It therefore allows indicators of different sectors to be developed, and allows the consideration of both indicators of current state, past trends, and possible future conditions. Finally, it is flexible enough to allow research to continue and potentially to define new indicators, which must be tested before they are fully implemented, both for their qualities in representing status and trends, and for their utility to decision and policy-making communities.

Sectors and Systems of Concern

To help to identify indicators across the physical, natural, and social sciences that would be important for developing the end-to-end Indicators System described in the conceptual model section above, we initially identified 12 system or sector topic areas that would cover the scope of the changes, impacts, vulnerabilities and preparedness that would be important to address. These are loosely linked to sectors in the 3rd National Climate Assessment, with modifications to assure that we had the coverage for critical indicator topics or areas of particular interest to agencies:

- Agriculture
- Climate Change and Variability
- Energy System
- Freshwater Ecosystems

- Forests
- Grasslands, Rangelands, and Pastures
- Human Health
- Infrastructure
- Mitigation and Greenhouse Gas Emissions
- Oceans and Coasts
- Seasonal Timing and Phenology
- Water Cycle and Management

Each of these teams has met since January 2013 to develop a conceptual model for their system or sector that is used to identify the critical indicator topics. The conceptual models are broadly consistent with the overall goals of this system. Each teams has also proposed their recommendations of existing indicators that should be included in the Indicators System and research priorities, both of which are linked to their proposed conceptual model.

Two additional teams have been formed to address two topics that could not be adequately covered by the current 12 technical teams – adaptation and biodiversity. The adaptation team started meeting during summer 2013. This team is focusing primarily on adaptive capacity and vulnerability of human and natural systems. For adaptation indicators, we have chosen to have an initial workshop phase to develop a stronger conceptual basis for indicators, and to identify indicators and research priorities that can be (or have been) implemented on a routine basis over time. At the July 2013 Indicator WG meeting, the group decided that it was important to add a technical team focused on both animal and plant biodiversity across a range of terrestrial and aquatic systems. We are in the process of identifying team leads and hope to have recommendations ready for implementation by the launch of the Indicators System.

Criteria for Selection of Indicators

Criteria for identifying candidate indicators for the overall Indicators system have been developed and approved by the Indicators Working Group. The criteria for indicators included in the system are:

- Scientifically defensible
- Link to conceptual framework
- Defined relationship to climate
- Nationally important
- Scalable, where possible
- Build on or augment existing agency efforts, when possible

For indicators that will be included in the pilot system, we asked the technical teams to consider one additional criterion – to recommend indicators that can be implemented almost immediately, without further research and analysis. This criterion is necessary because there will not be time to develop, refine, or vet indicators that do not currently exist and have them included in the system by Spring/Summer 2014. For the launch of the system in 2015, this criterion does not necessarily need to apply because there will be some additional time for refinement.

Pilot Indicators System Recommendations

Phasing and Purpose of Pilot and Initial Launch

Each of the technical teams was asked to develop a conceptual model and to recommend indicators that should be included or developed for the Indicators System. To make the move from the development to the implementation of the system a more reasonable effort and to collect preliminary data on the potential uses of the Indicators System, we decided to move forward with a two-phase development of the initial system (process and timeline Appendix C):

1) the development of a pilot system for Spring/Summer 2014, which is a sub-set of the indicators that can be closely linked to issues discussed in the NCA report that will allow us to understand the ease or challenges with moving indicators from agency platforms to the Global Change Information System (GCIS), and to evaluate the initial access and uses of the indicators by both scientific communities and a wide spectrum of decision-maker user communities in both public and private sectors, and
2) the launch of the system in 2015, which would expand upon the pilot indicator set, particularly for socio-economic indicators that need additional refinement time, add in dynamic updates when data are updated by the agencies, and add strategic customization of indicators for those features that would be most useful to decision-makers.

We asked each team to identify which of the indicators need no additional development or modifications, those that may need some modifications, and those indicator areas that are important research priorities. The indicator recommendations that the team provided that needed no further development are being considered for the Pilot Indicators System, and are included in this report; the additional recommendations for the full Indicators System will be considered by the Indicators Work Group in Spring/Summer 2014.

The full indicators system launched in 2015 will not be static, but will add or subtract indicators as necessary, through consideration of their use and advances in the underlying science. There are currently research projects and RFPs that have been designed or have identified one of the potential products of the research findings as consideration for inclusion in the Indicators System.

Proposed Indicators for the Pilot Indicators System (Spring 2014)

The proposed Indicators System includes a small set of global context indicators and a more comprehensive set of system and sector specific indicators. The indicators system requires a small number of indicators to provide a global context for other national or regional indicators. For some processes or systems, e.g. GHG emissions or some indicators of change in the physical climate system, the global indicators are required for national or regional indicators to make sense. The system and sector indicators are those that are nationally important and help to identify key changes, impacts, and vulnerabilities. Additionally, those indicators that are at the intersection of the systems or sectors will be tagged appropriately when it is on the web so that it doesn't matter which team recommended the indicator – decision-makers will be able to access the information that is most useful for their decisions.

Global Context Indicators		
	Sea Surface Temperature	Average global sea surface temperature is a fundamental measurement of the thermal status of the top 10-20 m of the ocean. While its definition is complex, and there are many variants, it has been recognized internationally and by NOAA as one of the Essential Climate Variables whose trends over time are important to measure and understand as an indicator of change in the physical climate system. This indicator looks at how closely observed trends in the average temperature of ocean water from the surface to 20 meters deep are tracking multi-decadal climate models. Data are collected regionally at temporal scales that allow for near-real time forecasting.
	Sea Ice Extent	Arctic sea ice is both a fundamental component of the physical climate system, playing an important role in regulating heat exchange and albedo in far northern latitudes, and a part of the system that is itself affected by climate change, in this case more rapidly than had been anticipated. An indicator of the monthly sea ice index, derived from passive microwave satellite data, provides a way of evaluating trends in this critical Earth system component routinely over time. This indicator is an index measure of changes in consistent sea ice extent over time for the entire Arctic. Data can be scaled down to smaller regional areas (e.g., near Barrow, in the Bering Strait Region) and updated on a yearly basis.
	Global Average Surface Atmospheric Temperature	Perhaps the best recognized of all the global indicators of change in the physical climate system is global annual average surface temperature. This can be represented either as absolute values or as anomalies from an agreed-on baseline, and is routinely calculated by NOAA for global analysis, as well as for national and regional analysis. This indicator would focus on using surface observational data, although similar indicators for other levels of the atmosphere depend primarily on satellite microwave retrievals.
	Global Emissions by Gas	The most fundamental indicator of the human perturbation of the physical climate system is the suite of global emissions of greenhouse gas emissions, delineated for each gas. Data include CO_2, CH4, N2O, and other non- CO_2 greenhouse gases, and include all anthropogenic sources. Other metrics can easily be derived from this primary indicator, e.g. per capita emissions.
	Global Atmospheric Concentrations of CO_2	As with global GHG emissions, perhaps the most fundamental indicator of the critical change in the Earth's atmosphere is the time series of global CO_2 concentrations. This is not the only anthropogenically driven change in GHG concentrations, but serves a useful purpose as a summary indicator of human impact on the atmosphere.
	Aggregated Greenhouse Gas Index	This indicator measures the average total radiative forcing of 20 greenhouse gases, including carbon dioxide, methane, and nitrous oxide. NOAA also translates the total radiative forcing of these measured gases into an index value called the Annual Greenhouse Gas Index. This number represents the ratio of the radiative forcing for a particular year compared with the radiative forcing in 1990, which is a common baseline year for

		global efforts to measure greenhouse gas concentrations.
	Global Sea Level	Another fundamental measure of the impacts of changes in the physical climate system is global sea level rise, derived both by satellite altimetry and by extensive analysis of tide gages around the world. Global sea-level rise has been a standard product from NOAA laboratories for more than 60 years. Current rates and magnitude of sea level rise are largely determined by thermal expansion of the oceans due to increased heat content, and melting of land ice.
System/Sector Specific Indicators		
Climate	**Surface Temperature for the U.S.**	A corollary to the Global Surface Temperature indicator is an equivalent indicator specifically for the US. This is meant to be indicative of changes in the physical climate system, albeit not a full description of those changes.
	Snow Cover Extent	The Northern Hemisphere Snow cover extent record is a catalogue of maps generated from remote sensing instrument observations that show the position of snow-covered land throughout the Northern Hemisphere. Historically, trained meteorologists drew these maps by hand but the process is now computer based. Data from the graphics can be combined to form products displaying hemisphere wide trends on monthly and annual timescales.
	Palmer Drought Severity Index	The PDSI is one of the best-known drought indices. Drought is one of the great challenges for agriculture, availability of water for cooling of thermoelectric power generation, availability of water for industrial and household use, and other uses of water. There are many different drought indices, which can be calculated for specific uses or reasons, and although the PDSI has known weaknesses, it has been calculated by NOAA and others for many years, and provides a consistent time series for analysis and decision-making.
Water Cycle and Management	**Heavy Precipitation**	Precipitation is an essential climate variable (ECV) and heavy precipitation is critical for assessing changes in flood risk. The proposed indicator is from the EPA climate indicator report is a graph of the percentage of land area where a much greater than normal proportion of total annual precipitation has come from an extreme one-day precipitation events in the continental U.S.
	Streamflow Indicators	Streamflow volume and timing affect both ecological and human systems. Extremes in flow are indicative of floods and droughts, and climate and other stressors can affect streamflow as a result of changes in precipitation, surface-to-groundwater interactions, vegetation cover, and snowpack. This proposed indicator includes metrics of low flow (volume of 7-day minimum), high flow (volume of 3-day maximum), and the timing of flow (center of mass January-May). These metrics can be calculated similar to those in the EPA climate indicators report from USGS Hydro-Climatic Data Network (HCDN) data.

	Annual and Monthly Precipitation	Precipitation is an essential climate variable (ECV) and systematic changes over time have effects on the hydrosphere, natural and managed systems, and water management. The proposed approach is to use the NOAA gauge data sources as the data for a gridded map depicting precipitation as a percent of normal using PRISM (Parameter-elevation Regressions on Independent Slopes Model).
Oceans and Coasts	**Regional and Local Sea Level Rise**	This indicator is a direct measure of the relative influences of global sea-level rise and vertical land motions (either subsidence or rising); it is meant to help characterize current vulnerability and trends. It is derived from both satellite altimetry and tide gauge measurements. Sea level rise is directly related to vulnerability of coastal infrastructure and many ecosystem changes. This indicator would be reported in the eleven regions identified in the Oceans and Coastal systems technical report. It is important to note that we do not intend this indicator to be compared to scenarios – it is meant to help characterize current vulnerability and trends.
	Ocean Chemistry and Acidification (Aragonite Saturation State)	Ocean acidification is a result of the absorption of CO_2 by the oceans with increasing atmospheric levels of CO_2. This change in ocean chemistry has the potential to affect marine organisms that build calcium carbonate shells or skeletons. Aragonite saturation state (ΩA) is a measure of this changing ocean chemistry, indicating the availability of minerals needed for calcification by marine organisms. This indicator is calculated from measurements in non-estuarine marine waters over time at large basin scales for the open ocean.
	Chlorophyll Concentrations in Surface Ocean Waters – Proxy for Planktonic Primary Producers	The assessment of ocean primary productivity is a fundamental feature of understanding the biological status of ocean ecosystems, and their relationship to the global carbon cycle. While primary productivity is not measured directly, the concentration of chlorophyll has been measured by a series of NASA satellite instruments (SeaWiFS and MODIS) going back to the 1980's (and earlier in some places, although the earlier CZCS instrumentation data are less reliable). The satellite retrievals can be used to derive an additional index of phytoplankton biomass and ocean primary productivity. The scope of this indicator is global, but it has reasonably good spatial resolution (ca. 1 km pixels), and the time series can be easily reported on whatever time frame is desired, down to monthly (or less in some cases). This is now a standard data product. This indicator tracks total phytoplankton biomass (initially estimated from satellite chlorophyll measurements) at regional spatial scales and, depending on the data set, measurements are taken at weekly to monthly temporal resolutions.
	Coral Thermal Stress	The bleaching of corals from accumulated temperature stress is one of the best-documented biological consequences of changes in the thermal environment of the oceans due to variability and change in the climate system. The particular indicator proposed for the pilot is Degree Heating Weeks, which NOAA has developed to monitor thermal stress that corals are known to be sensitive to. It is satellite-derived, and reported on a 50 km2 grid for areas of corals that are

		potentially sensitive to thermal stress.
Freshwater	**Freshwater Temperature**	One of the most important physical indicators in freshwater ecosystems is temperature. Water temperature affects water chemistry including dissolved oxygen and the abundance and distribution of biota. Water temperature is highly correlated with air temperature. This indicator would use the real-time tracking from the USGS Water Quality Watch network of ~1000 streams. Though the temporal records vary for each site, this network of observational sites provides coverage across the U.S. and its territories for a range of watershed sizes. In the future, other temperature NSF supported data sources, such as GLEON, NEON, LTER, LTREB, GLTC (http://www.laketemperature.org/), and biological field stations can be added to improve the coverage for this indicator.
	Lake Ice	Ice cover and duration in lakes is seasonal and is correlated with the surface air temperature in the month or two preceding thawing as well as other precipitation and seasonal climate indicators. This proposed indicator would build off the representation of lake ice included in the EPA climate indicators report, using observational data from National Snow and Ice Data Center Global Lake and River Ice Phenology Database, to represent ice cover duration, date of first freeze, and date of ice thaw. In the future, remotely sensed water temperature readings can be considered as an indicator.
	Dissolved Oxygen	Dissolved oxygen indicator would use the real-time tracking from the USGS Water Quality Watch network of ~1000 streams. Though the temporal records vary for each site, this network of observational sites provides coverage across the U.S. and its territories and in a range of watershed scales. In the future, other dissolved oxygen NSF supported data sources, such as GLEON, NEON, LTER, LTREB, and biological field stations can be added to improve this indicator.
Seasonal Timing and Phenology	**Seasonal Climate Indicators**	This indicator is a suite of metrics (e.g. last spring frost/freeze, # of frost/freeze days) derived from daily temperature and precipitation to track changes in the seasonality of climate. These indicators are expressed in “day of year” or “days per year” that affect the timing of other physical or biological variables, and the data are from ground-based meteorological data.
	Potential Growing Season	This indicator tracks the predominant frozen and non-frozen condition of the land surface and the non-frozen season defines the potential growing season. The data come from satellite microwave remote sensing that are global daily measurements over 30 years.
	Extended Spring Indices	These indices refer to a suite of models developed to simulate the timing of the onset of spring in native and cultivar plants. The data are ground-based meteorological data validated by observations of cloned and common plant species, in part using uses citizen data for lilac and honeysuckle.

	Snowmelt Runoff	This indicator describes the timing of the pulse of runoff water in watercourses that drain snowmelt-dominated watersheds. The metric recommended is the winter/spring center of volume in timing. The data are from ground-based stream-gage data for daily stream discharge.
Forests	**Forest Area Extent**	This indicator tracks changes in land use and land cover, based on forest area in hectares. Forest area responds to climate directly (through increased mortality and/or enhanced recruitment) and indirectly (through increased prevalence of fire and insect outbreaks). The NLCD, MODIS, FIA and NRI datasets or derived datasets from NASA can be used in conjunction to increase mapping accuracy.
	Wildfire Effects - Burned Area	This indicator has a well-documented relationship with climate such that an increase in air temperature will increase the area burned in most states, and extent of wildfire in forests is primarily associated with drought conditions. The data on area burned are available on some federal lands since 1916; data for other public and private lands are sporadic.
	Forest Growth/Productivity	This indicator tracks net annual growth in US forests and can be affected by changes in temperature, water availability, length of growing season and increases in atmospheric CO_2. The data are available at national, subnational, ecological unit, and state from USDA-USFS FIA (since 1952 in some cases and 2000 for others).
Grasslands, Rangelands, and Pastures	**Grazing Livestock Numbers**	This indicator tracks the number of commercial sheep, cattle, and goats (available at the county level) that graze grasslands, rangelands, and pastures. The number of grazing livestock is affected by heat stress, drought, severe winter storms, and indirectly by the amount and seasonality of precipitation. Socio-economic indicators can be derived using this indicator.
	Grassland, Rangeland, Pastureland Extent	This indicator tracks changes in land use and land cover, based on a definition of grassland (i.e. grassland, rangeland, pastures, and shrubland) versus forest. The NLCD, MODIS, FIA and NRI datasets or derived datasets from NASA can be used in conjunction to increase mapping accuracy.
Agriculture	**Crop Condition, Progress, and Production**	This indicator describes metrics for crop yield and can be related to the impacts of weather (temperature, precipitation and solar radiation) during the growing season among years. Data for weekly crop condition and progress for major commodities, comparison to the previous 4 years, historical yield data for each county, and county level yields at the end of the crop season are available.
	Rainfall Erosivity	This indicator can be measured in numerous ways and tracks both natural and anthropogenic processes that degrade soils. One metric is the product of total rainstorm energy and maximum 30-minute rainfall intensity during a storm. The erosivity can be calculated annually from precipitation data.
	Livestock Deaths Due to Thermal Stress	This indicator is the number of deaths that are environmental/weather related to track livestock heat stress and related economic losses. USDA data are reported since 1991 for cattle; data for other domestic species is available but vary by year and degree of reporting.

Energy	**Heating and Cooling Days**	Direct measurements of electricity demand are difficult to obtain routinely on a regional basis. But energy demand is closely associated with heating and cooling requirements, so heating and cooling degree days are a good indicator of changes in overall energy demand as it varies with weather, and over time, as it varies with climate. Heating and cooling degree days are calculated by NOAA on state, regional and national levels, based on a reference of 65 degrees F, and weighted by population. Monthly averages on a regional basis, and national averages are reported as current indicators with good trend information.
	Stress Index of Electricity Generation	One of the important consequences of electricity supply responses to extreme weather conditions is the number of times and extent of power outages. Outages are clearly related to conditions of extreme stress, although they are also a function of preparedness and hardiness of existing infrastructure. But even given these caveats, and given the difficulty of acquiring data, the North American Electricity Reliability Corporation (NERC) calculates a composite system reliability index (SRI), which incorporates a number of features of the electricity generation and distribution system. Values above 5.0 are considered to be "high stress" events, and the indicator chosen for the pilot is national in scale, and is simply the number of days per year that the SRI exceeds this value.
Infrastructure	**Disaster and Emergency Declarations by FEMA**	An indicator that is qualitatively related to the types of events of concern is the number of times that FEMA declares major disasters and emergencies (two out of their three-point scale). This indicator is reported at a national level and can be tracked easily. More targeted indicators remain to be derived.
	Status of the Nation's Infrastructure	A reasonable, although imperfect pilot indicator is the "Report Card on America's Infrastructure," published annually by the American Society of Civil Engineers (ASCE). It provides qualitative grades for sixteen infrastructure categories, and a comprehensive report is published every four years, although particular infrastructure categories can be the subject of special reports in between comprehensive assessments.
Health	**Rates of Heat Related Mortality**	The rate of heat-related deaths is directly related to extreme heat events in the US and, therefore, directly associated with a weather-related impact of climate change. The data are reported on death certificates as the underlying cause or a contributing factor. They are collected by the CDC's NCHS and displayed on the NEPHT website. The indicator data are available from 1979 through the present and can be displayed in the forms of graphs, charts, tables, or maps down to the state level. These data can be analyzed to the county or metropolitan level.
	Incidences of *Vibrio*	*Vibrio* can rapidly increase in size in warm marine water and as a result it has been suggested that there will be a rise in *Vibrio*, both population and geographic range, with a rise in sea surface temperatures (SST). In the U.S., laboratory confirmed incidences of *Vibrio* infection are reported to the CDC by state health departments. Prior to 2007, only *Vibrio cholerae* was reported. All incidences of *Vibrio* confirmed

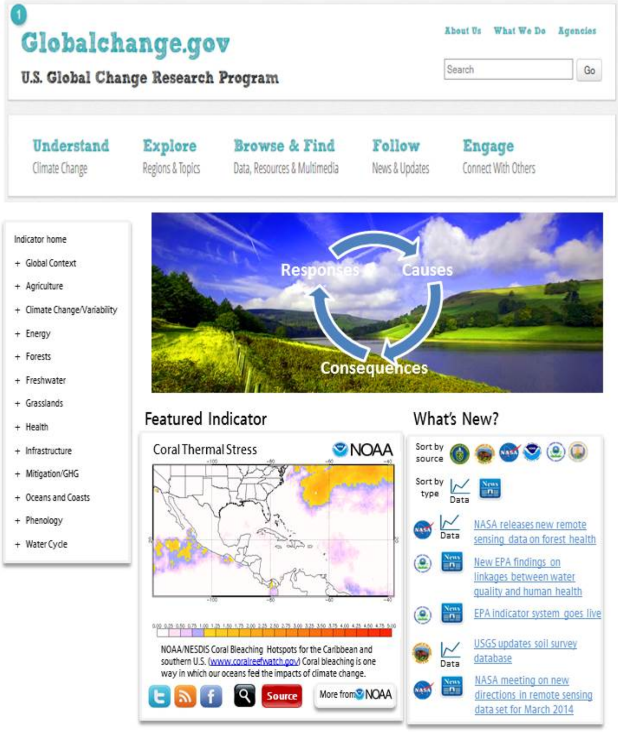
		infections have been reportable nationally since 2007, but there is likely underreporting because incidences of *Vibrio* are not easily identified on routine enteric media in the laboratory.
	Lyme Disease	There is evidence that the Lyme disease is spreading because warmer temperatures (minimum and maximum) increase habitat suitable for ticks that carry the disease. The proposed indicator is the number of confirmed and possible cases of Lyme disease in the U.S. using data from the CDC.
Mitigation/ GHG	**Total GHG Emissions by Source and Gas**	At a national level, this indicator is a fundamental measure of the anthropogenic sources of all relevant GHG emissions. Differentiation by source and gas is a key component that is important to policy and decision-making stakeholders at national and state levels, and in the private sector. This indicator uses EPA's U.S. Inventory of Greenhouse Gas Emissions and Sinks and is often reported as CO_2-equivalents.
	Fossil and Industrial CO_2 Emissions	CO_2 emissions are the largest single component of anthropogenic GHG emissions, and have dominated the mitigation policy discussion for many years. Data since 2010 is available through the EPA GHG Reporting Program and the DOE Energy Information Administration (EIA).
	Annual Terrestrial Net CO_2 Emissions	The US calculates annual net emissions of CO_2 from land-cover and land-use change as part of its annual emissions inventory, which is reported periodically to the Framework Convention on Climate Change, and is used domestically in a wide range of mitigation and carbon cycle discussions and research. The annual calculation is done primarily through USDA and DOI programs that calculate inventory change in several land classes, and thus evaluate both sources and sinks of CO_2 due to land-use change.
Adaptation/ Hazards		The adaptation and hazards team are developing a workshop to identify datasets, potential indicators, and a research agenda for adaptation process and effectiveness indicators.

Development, Implementation and Evaluation of Indicators System

Links and Use of the Global Change Information System (GCIS)

The pilot indicator system, and ultimately the full system will be part of the Global Change Information System (GCIS), accessible through globalchange.gov. In the pilot phase, there will be a baseline capability of presenting figure(s) and/or tables describing the selected indicators, links to underlying data and methods of analysis used to create the indicators, references, and website analytics. Display capability, searching, visualization, and re-analysis capabilities will be limited in the beginning, but these capabilities will be strategically built into the system, in part from the analysis of data from the evaluation of the pilot, for the launch of the Indicators System in 2015.

The sample pages below provide examples of the globalchange.gov site concept for accessing and displaying Indicators information in GCIS.



NOAA/NESDIS Coral Bleaching Hotspots for the Caribbean and southern U.S. (www.coralreefwatch.gov) Coral bleaching is one way in which our oceans feel the impacts of climate change.

NASA releases new remote sensing data on forest health

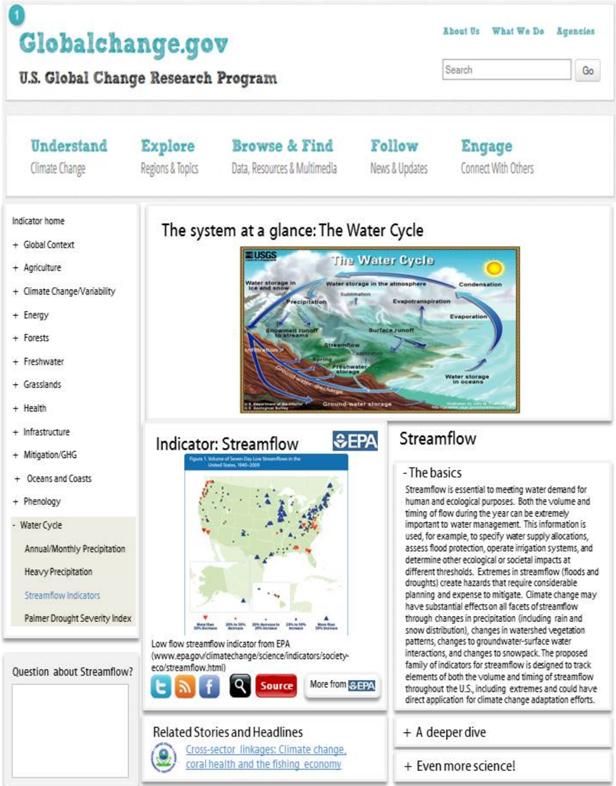
New EPA findings on linkages between water quality and human health

EPA indicator system goes live

USGS updates soil survey database

NASA meeting on new directions in remote sensing data set for March 2014

The GCIS web platform: home page



Low flow streamflow indicator from EPA (www.epa.gov/climatechange/science/indicators/society-eco/streamflow.html)

Streamflow is essential to meeting water demand for human and ecological purposes. Both the volume and timing of flow during the year can be extremely important to water management. This information is used, for example, to specify water supply allocations, assess flood protection, operate irrigation systems, and determine other ecological or societal impacts at different thresholds. Extremes in streamflow (floods and droughts) create hazards that require considerable planning and expense to mitigate. Climate change may have substantial effects on all facets of streamflow through changes in precipitation (including rain and snow distribution), changes in watershed vegetation patterns, changes to groundwater-surface water interactions, and changes to snowpack. The proposed family of indicators for streamflow is designed to track elements of both the volume and timing of streamflow throughout the U.S., including extremes and could have direct application for climate change adaptation efforts.

Cross-sector linkages: Climate change, coral health and the fishing economy

The GCIS web platform: Streamflow indicator page

Evaluation of the Indicators System

For the pilot system and in the future with the launch of the full indicators system, we recommend a series of evaluation activities during the rollout of the site. The goal of the evaluation research is to collect information that will allow for data-driven improvements of the indicator information system and the individual indicators. This allows us to continue to improve the system to support decision-making by better understanding user needs and the decision contexts where such indicators could be useful for informing decisions.

The evaluation will be focused on identifying information for several different areas needed for the development and refinement of the indicators and the system. Areas of evaluation that are scoped include:

- evaluating the selection and mix of indicators to determine whether there should be modification,
- information system use and design,
- understanding and value of information of indicators,
- identifying potential biases or gaps in the underlying indicator data, and
- use of indicators in particular decision contexts.

Research Needs

Because the Indicators System is designed not to be static, each technical team has been asked for recommendations for further research and inclusion in future iterations of the Indicators System. In some sectors and systems these research recommendations are quite critical because we are currently unable to adequately address the impacts and vulnerabilities.

There have been some initial contributions by agencies to support research for the Indicators System. For example, NASA recently released a solicitation on the "Development and Testing of Potential Indicators for the National Climate Assessment". The research recommendations are targeted at those topics that would be high priority for further development and analysis of potential indicators for target systems, or possibly for indicators of new systems to be in included in the Indicators system in the future. These recommendations are still preliminary, and will not be a focus of the Indicators Working Group discussion at the end of September.

Secretariat and Advisory Committee

Part of the challenge of transitioning from the current developmental phase of the Indicators System to an operational phase will be the establishment of a small, but permanent secretariat and the transition of the current Indicators Working Group to a more permanent, interagency advisory structure.

A small secretariat will be necessary to maintain the integrated nature of the Indicators System, beginning with the Pilot Indicator System. The secretariat should be led by a senior scientist and have several senior scientists and an administrative assistant. The purpose of the secretariat is to coordinate major components of the Indicator System and conduct research and scientifically rigorous evaluation to improve the individual indicators and the Indicators System as a whole, similar to the need for senior staff to coordinate activities in support of the quadrennial assessment and ongoing assessment activities. Such positions can, and probably should be filled on a full-time basis by a combination of grants and secondments from the participating USGCRP

Agencies. Because the transition from Pilot to the Full Indicators System will also require substantial additional sophistication in the web deployment, it would additionally be wise to have a full-time staff member with experience in IT and visualization and communication of complex scientific information, in addition to the support of the GCIS staff and graphic design support (currently supplied through a subcontract by NOAA's NCA TSU).

The best location for a small secretariat would be joint with the USGCRP Coordination Office, in order to maintain the essential interagency atmosphere. It will be critical, however, for Indicators staff to be devoted to the Indicators System activity, and not try to serve the program on a part-time basis. While the activities of a large number of part-time volunteers has been useful for the developmental phase, it is not sustainable over the long periods of time that the Indicators System should operate, as it becomes operationalized within agencies' and USGCRP activities.

A similar transition must occur for the Indicators Working Group. Because this group is chartered by the NCADAC, it will cease to exist in its current form when the current NCADAC's charter expires. The transition to USGCRP management will mean that the USGCRP will need to establish some interagency governance to advise the Indicators System. We leave the final choice of structure to the USGCRP Principals, but some form of interagency committee, possibly analogous to other Interagency Working Groups in the USGCRP, might be feasible. It will be important to have such a group, though, for oversight and advice to the implementing secretariat, much as the current Indicators Working Group has provided such oversight and guidance to the current Indicators Coordination and Research Office.

Appendix A:
Proposed Pilot Indicators – Global Context

Note: The text that is included in this appendix is the text that was written by the technical team that provided the recommended indicator. With the exception of formatting and some minor edits, we have kept the text in the original form.

Purpose of Global Context Indicators

The indicators system requires a small number of indicators to provide a global context for the other, national or regional indicators. For some processes or systems, e.g. GHG emissions or some indicators of change in the physical climate system, the global indicators are required in order for national or regional indicators to make sense. For the pilot system, we have selected six global indicators to serve this purpose.

Sea Surface Temperature

Summary

Average global sea surface temperature is a fundamental measurement of the thermal status of the top 10-20 m of the ocean. While its definition is complex, and there are many variants, it has been recognized internationally and by NOAA as one of the Essential Climate Variables whose trends over time are important to measure and understand as an indicator of change in the physical climate system. This indicator looks at how closely observed trends in the average temperature of ocean water from the surface to 20 meters deep are tracking multi-decadal climate models. Data are collected regionally at temporal scales that allow for near-real time forecasting.

What is it? This indicator is a measure of the change in water temperature close to the ocean's surface over time. The exact meaning of surface varies according to the measurement method used, but can be from the surface to up to 20 meters below the surface.

What is the scale? Current data collection methods span global, regional, and coastal spatial scales and depending on the data set, measurements are taken at hourly to monthly temporal resolutions for near-real time forecasting to multi-decadal climate studies.

What does a change in this indicator mean? Shifts in sea surface temperature (even small shifts) can have far reaching consequences for weather, climate patterns, and sea level rise.

General description of what is being measured

Sea surface temperature (SST) is the temperature of water at or near the ocean's surface. It is a key physical attribute of the world's oceans and climate system. SST is a challenging parameter to define precisely as the upper ocean (~10 m) has a complex and variable vertical temperature structure that is related to ocean turbulence and air-sea fluxes of heat, moisture and momentum. Balancing this complexity with what can actually be measured, the international community has agreed upon a set of SST definitions (skin SST, sub-skin SST, foundation SST, and SST at a specified depth) that together more adequately describe the surface ocean thermal structure. SST is a core indicator used by various groups to track climate and climate change (e.g., IPCC, NOAA State of the Climate, EPA). The proposed indicator tracks SST globally and regionally over time.

What are the drivers of this indicator and what are its impacts?
The primary drivers of SST are absorption of solar radiation and greenhouse gas concentrations (as previously mentioned). As listed above, changes in SST on various temporal and spatial scales have a wide range of impacts on climate, biogeographic, economic and sociocultural variables of great diversity. The figure below illustrates some of the drivers and impacts of SST; through, it is not meant to be an exhaustive list.

Has this indicator been used as an indicator by anyone else, if so who and how was it used and when was it initiated?
SST is an Essential Climate Variable, as defined by the Global Climate Observing System (GCOS) to support the work of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC).

The Environmental Protection Agency (EPA) used SST as a climate change indicator as summarized in their 2012 report. Specifically, they used global trends in SST from 1880-2011.

The National Oceanic and Atmospheric Administration (NOAA) also uses SST as an indicator. NOAA assesses global and regional trends in SST and SST variations in association with climate patterns, creating indices for climate patterns such as ENSO, the Atlantic Multidecadal Oscillation (AMO), and the Pacific Decadal Oscillation (PDO). SST is summarized in annual "*State of the Climate*" reports released by NOAA that are published as a special supplement in the *Bulletin of the American Meteorological Society*.

Relevant to management decisions
The user community of the SST indicator includes climate scientists (ranging from physical to atmospheric, biological, chemical, and cryospheric), ocean modelers, ecosystem resource managers, policymakers (ranging from local to state, and federal), and commercial businesses (such as weather hazard insurance, ship routing, and coastal hazard management). SST is used as a critical indicator of climate change within the IPCC report for the purpose of informing policymakers.

Data
A number of SST datasets exist for a variety of spatial and temporal scales, as well as observing platforms (e.g., drifting and moored buoys, ships, and satellites). A subset of these fall within the Group for High Resolution Sea Surface Temperature (GHRSST), which coordinates development of global, multi-sensor, high-resolution SST products with quality indicators and estimates of uncertainties, and consistent metadata.

Stability/Longevity of dataset and Indicator
The historical database of SST observations contains varying relative biases due to different instrumentation data sources and quality assurance tests. Satellite observations also suffer from geographic and temporal biases, biases experienced during an individual sensor's lifetime and between sensors, and those caused by episodic events such as major volcanic eruptions which change the properties of the atmosphere between the satellite and ocean surface. Both sources of

measurements (*in situ* and satellite) are also affected by measurement uncertainties and under-sampling of variability. These biases are adjusted and uncertainties are estimated.

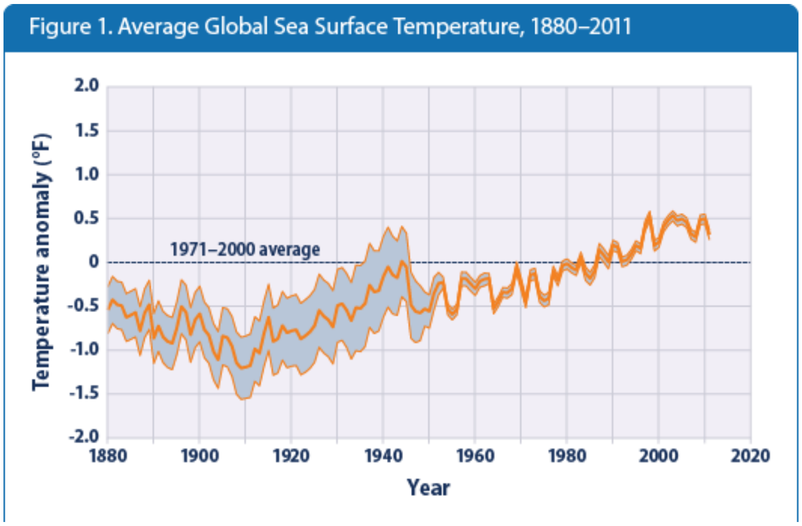
Spatial and temporal scalability
The SST indicator is spatially and temporally scalable, already existing in a variety of spatial and temporal resolutions. However, the appropriate scaling method from one to another may not be self-evident or straightforward.

Advantages
SST was one of the first oceanographic variables to be measured, and thus has a long time record. Temperature is a basic variable in the SI system of measurements and therefore has a well-defined physical reference, the temperature scale, which allows the combination of SST measurements from many sources. It also allows the rigorous assessment of measurement uncertainties. Satellite measurements provide consistent, accurate global measurements of SST.

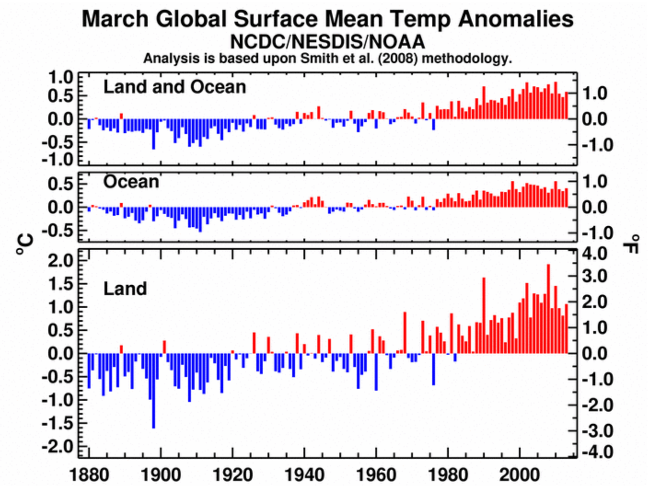
GHRSST developed a set of SST definitions, or framework, to understand the relationship between various SST measurements from different observing platforms. Definitions and more information can be found at: www.ghrsst.org/ghrsst-science/sst-definitions/. The GHRSST definitions thus provide an advantage to users as compared to other variables with less international consensus.

Disadvantages
SST does not have a unique definition, given complexities in the vertical temperature structure of the upper ocean (i.e., diurnal heating, air-sea fluxes, ocean turbulence, and wind mixing). As a result, the definition of SST, or depth of the SST measurement, varies between datasets (as previously mentioned).

It is possible that increasing SST is “bounded” in some sense by increasing evaporation and cloudiness at higher air temperatures. Careful monitoring of the global record should give any indications of this “thermostat” effect.



Average Global Sea Surface Temperature. *This graph shows how the average surface temperature of the world's oceans has changed since 1880. This graph uses the 1971 to 2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time. The shaded band shows the range of uncertainty in the data, based on the number of measurements collected and the precision of the methods used. Source: http://www.epa.gov/climatechange/science/indicators/oceans/sea-surface-temp.html*



March Global Surface Mean Temp Anomalies. *The global ocean temperature was among the ten warmest for March, ranking ninth in the 134-year period of record at 0.41°C (0.74°F) above the 20th century average.*

Source: www.ncdc.noaa.gov/sotc/global/

Sea Ice Extent

What is it? This indicator is an index measure of Arctic-wide changes in consistent sea ice extent over time based on values from 1979 to the present.

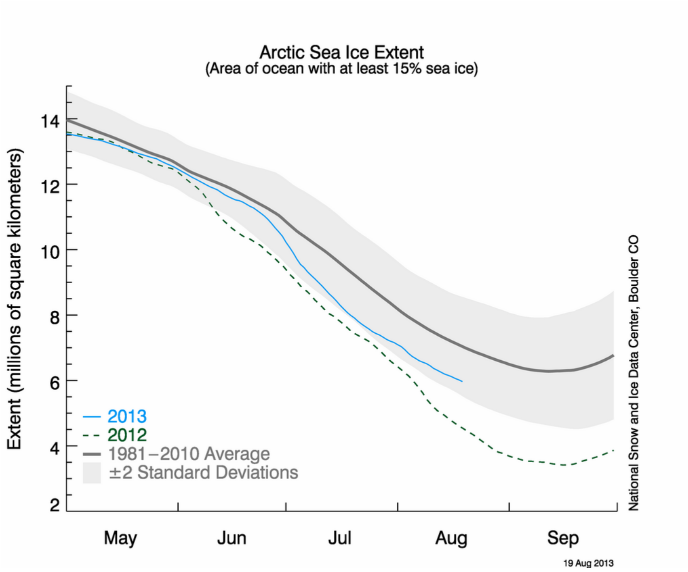
What is the scale? The indicator can be used for the entire Arctic area as well as be scaled down to smaller regional areas (e.g., near Barrow, in the Bering Strait Region). Data sets exist at daily and monthly time scales but the indicator is updated on a yearly basis.

What does a change in this indicator mean? Shifts in sea extent may lead to reduced habitat for animals like seals and polar bears, reduced reflection of the sun's radiation leading to increased absorption by the surrounding waters which can increase the oceans heat content, as well as changes in the hydrological cycle which impacts climate patterns.

Summary

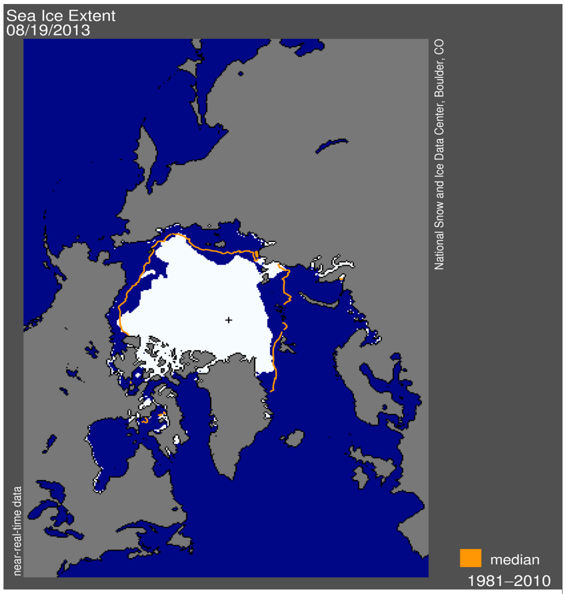
Arctic sea ice is both a fundamental component of the physical climate system, playing an important role in regulating heat exchange and albedo in far northern latitudes, and a part of the system that is itself affected by climate change, in this case more rapidly than had been anticipated. An indicator of the monthly sea ice index, derived from passive microwave satellite data, provides a way of evaluating trends in this critical Earth system component routinely over time. This indicator is an index measure of changes in consistent sea ice extent over time for the entire Arctic. Data can be scaled down to smaller regional areas (e.g., near Barrow, in the Bering Strait Region) and updated on a yearly basis.

Description: Currently, a Sea Ice Index is produced daily using satellite information from the passive microwave satellites available at NSIDC (development and maintenance of index supported by NOAA; data from NASA and NSIDC). This index is produced on a monthly basis and shows Arctic-wide changes in sea ice, including consistent ice extent and concentration images and data values from 1979 to the present. Monthly images show sea ice extent with an outline of the median extent for that month. Other monthly images show sea ice concentration and anomalies and trends in concentration. The best developed indicator that is currently available is the monthly Arctic-wide change in sea ice extent and change in sea ice concentration from 1979 to the present.



Arctic Sea Ice extent and trend for August 19, 2013. Available: http://nsidc.org/arcticseaicenews/

The Sea Ice Index images depict ice cover and trends in ice cover in the Arctic. Sea Ice Index data files tabulate ice extent in numbers based upon passive satellite observations. The images and data are produced in a consistent way that makes the index time-series appropriate for use when looking at long-term trends in sea ice cover. Both monthly and daily products are available.



Arctic Sea Ice extent map for August 19, 2013. Available: http://nsidc.org/arcticseaicenews/

Scientific Defensibility: The Sea Ice Index is built on the highest quality, fully vetted and continuing polar satellite observations. The index has been extensively peer reviewed and transparently maintained the National Snow and Ice Data Center (NSIDC) available at http://nsidc.org.

Relevance to Management Decisions: A key climate variable; sea ice extent and concentration as mapped over polar regions provides a straightforward means for assessing the temporal and spatial variability of the climate system. There are also important transportation, natural resource and political issues associated with the extent and other characteristics of polar sea ice. Cutting edge research is exploring possible linkages between profound changes in summer and fall sea ice extent and hemispheric atmospheric circulation anomalies

Data/Methods: Data record begins in 1979. All Sea Ice Index images and data are derived from daily or monthly gridded sea ice concentration that come NRTSI/NSIDC and Goddard Space Flight Center (GSFC) satellite observation derived products. The NRTSI product is available at a daily temporal resolution, and the GSFC product is available at a daily and monthly resolution. For thorough metadata for this product see:
http://nsidc.org/data/docs/noaa/g02135_seaice_index/

Global Average Surface Atmospheric Temperature

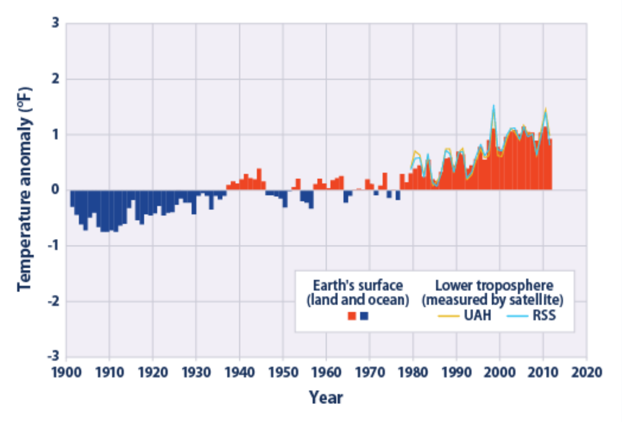
Summary

Perhaps the best recognized of all the global indicators of change in the physical climate system is global annual average surface temperature. This can be represented either as absolute values or as anomalies from an agreed-on baseline, and is routinely calculated by NOAA for global analysis, as well as for national and regional analyses. This indicator would focus on using surface observational data, although similar indicators for other levels of the atmosphere depend primarily on satellite microwave retrievals.

Description: The Temperature Indicator would follow the temperature indicator outlined in the EPA Climate Change Indicators technical document. The temperature indicator is a measure of the surface and atmospheric temperature anomaly. An anomaly represents the difference between an observed value and the corresponding value from a baseline period and provides the ability to determine surface and atmospheric temperature trends. It is easily understood by both scientists and non-scientist and can be used to understand cause and affect relationships between climate drivers, societal mitigation, and temperature at the earth's surface and important atmospheric layers.

Scientific Defensibility: The temperature data is fully vetted, on-going observations of standard meteorological instruments and satellite data. The data sets are used in numerous publications by scientists around the world and are key components of assessments (*e.g., IPCC, State of Climate Report, etc.*) The measurements have been vetted repeatedly in the literature (*Christy et al. (2000, 2003), Mears et al. (2003), Schabel et al. (2002),* Menne et al. (2009)). NOAA has outlined their technical methodology for surface data in the *EPA Climate Change Indicators in the United States, 2012*. All data sets are based solely on observations and do not have the uncertainties associated with model assumptions.

Figure 2. Temperatures Worldwide, 1901–2011



Relevance to Management Decisions: Many nations, states, provinces, cities, businesses, and industries use temperature analysis to understand how their populations use energy and resources to adjust to warm and cold climate changes. Additionally, understanding of societal effects such as relocation and mass migration due to temperature changes or the crop production/temperature relationship can be used by governments around the world to mitigate widespread climate impacts.

Data and Methods: NOAA provides surface and satellite data for global temperatures. GHCN-M Version 3.1 contains monthly climate data from weather stations worldwide. Monthly mean temperature data are available for 7,280 stations, with homogeneity-adjusted data available for a subset (5,206 mean temperature stations). Satellite-based measurements are for the period from 1979 to present. These satellite data were collected by NOAA's polar-orbiting satellites, which take measurements across the entire globe.

NOAA's satellites use the Microwave Sounding Unit (MSU) to measure the intensity of microwave radiation given off by various layers of the Earth's atmosphere. The intensity of radiation is proportional to temperature, which can therefore be determined through correlations and calculations. NOAA uses different MSU channels to characterize different parts of the atmosphere. NOAA's satellites measure microwave radiation at various frequencies, which must be converted to temperature and adjusted for time-dependent biases using a set of algorithms. Various experts recommend slightly different algorithms, primarily by two different organizations: the Global Hydrology and Climate Center at the University of Alabama in Huntsville (UAH) and Remote Sensing Systems (RSS). In this indicator, temperature would be presented primarily as trends in anomalies. An anomaly represents the difference between an observed value and the corresponding value from a baseline period. The choice of baseline period will not affect the shape or the statistical significance of the overall trend in anomalies. For temperature (absolute anomalies), it only moves the trend up or down on the graph in relation to the point defined as "zero."

Global Emissions by Gas

Summary

One of the most fundamental indicators of the human perturbation of the physical climate system is the suite of global emissions of greenhouse gas emissions, delineated for each gas. Data include CO_2, CH4, N2O, and other non- CO_2 greenhouse gases, and include all anthropogenic sources. Other metrics can easily be derived from this primary indicator, e.g. per capita emissions.

Background

"Since preindustrial times, increasing emissions of greenhouse gases due to human activities worldwide have led to a noticeable increase in atmospheric concentrations of long-lived and other greenhouse gases. Every country around the world emits greenhouse gases into the atmosphere, meaning the root causes of climate change are truly global. Some countries produce far more greenhouse gases than others, and several factors such as economic activity, population, income level, land use, and climatic conditions can influence a country's emissions levels. Tracking greenhouse gas emissions worldwide provides a global context for understanding the United States and other nations' roles in climate change" (EPA 2012).

This indicator focuses on global emissions by gas (carbon dioxide, methane, nitrous oxide, and several F-gases). These GHGs are covered by the United Nations Framework Convention on Climate Change (UNFCCC), which requires participating countries to develop and periodically submit an inventory of emissions. Each GHG covered by this indicator will be normalized by its CO_2 equivalent (CO_2-e). The process for this conversion is documented below.

Data and Methods: World Resources Institute's (WRI) Climate Analysis Indicators Tool (CAIT) compiles data from peer-reviewed and international GHG inventories developed by EPA and other government agencies worldwide. Global estimates for carbon dioxide are published annually, but estimates for other gases, such as methane and nitrous oxide, are available only every fifth year. UNFCCC has more comprehensive data; however the data are only for highly developed countries, which only accounts for about half of global GHG emissions. CAIT includes NCGGs by type (CH_4, N_2O, several F-Gases) and source (energy, industrial processes, agriculture, waste, land use, etc.). The Emissions Database for Global Atmospheric Research (EDGAR) also provides global past and anthropogenic emissions of GHGs by country. EDGAR and CAIT are highly comparable as they share many of the same data sources (EPA 2012).

This indicator will be broken up into U.S. emissions and Rest of World (ROW). WRI's Climate Data Explorer has data on emissions by gas broken down by country. To calculate ROW emissions, U.S. emissions can be subtracted from total global emissions. Note that the figure above shows only global emissions and not U.S. and ROW.

In order to provide useful information to decision makers, this indicator will report emissions by gas normalized by CO_2 equivalent (CO_2-e). CO_2-e is used to compare different GHG emissions based on their global warming potential (GWP). GWP is a measure of the amount of energy that a gas absorbs over a period of time compared to CO_2. For example, the 20 year GWP for N_2O is 289 (IPCC 2007), which means that one ton of N_2O will trap 289 times more heat than one ton of CO_2 over the next 20 years. CO_2-e can be calculated by multiplying the tons of the gas by its GWP: CO_2-e = (tons of given gas) * (GWP of the gas). It is important to keep in mind that there is some degree of uncertainty when comparing GHG emissions using this metric as there is no universally agreed upon value for the GWP of the gases covered by this indicator. Furthermore, different time horizons provide drastically different CO_2-e values. For example, the 20 year GWP for methane is 72, while the 100 year GWP is only 25. This illustrates the importance of reporting CO_2-e values across several time horizons for each gas. For this indicator we will use GWP values from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC) calculated for the 100-year time horizon.

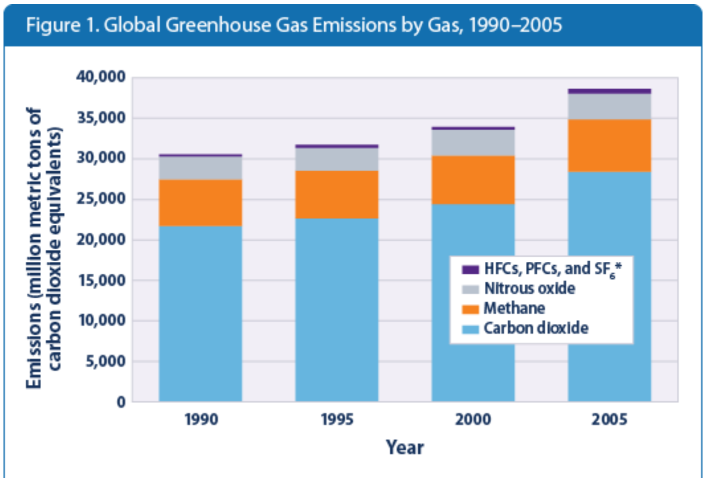


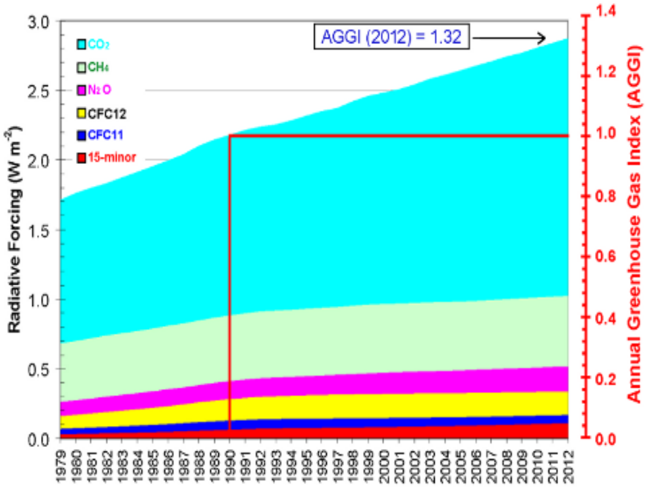
Figure 1. Global Greenhouse Gas Emissions by Gas, 1990–2005

Global GHG Emissions by Gas (1990-2005)

Aggregated Greenhouse Gas Index

Summary

This indicator measures the average total radiative forcing of 20 greenhouse gases, including carbon dioxide, methane, and nitrous oxide. NOAA also translates the total radiative forcing of these measured gases into an index value called the Annual Greenhouse Gas Index. This number represents the ratio of the radiative forcing for a particular year compared with the radiative forcing in 1990, which is a common baseline year for global efforts to measure greenhouse gas concentrations.



Description: The NOAA Aggregated Greenhouse Gas Index (AGGI) is a measure of the warming influence of long-lived trace gases and how that influence is changing each year. The index was designed to enhance the connection between scientists and society by providing a normalized standard that can be easily understood and followed. The warming influence of long-lived greenhouse gases is well understood by scientists and has been reported through a range of national and international assessments. Nevertheless, the language of scientists often eludes policy makers, educators, and the general public. This index is designed to help bridge that gap. The AGGI provides a way for this warming influence to be presented as a simple index**.**

Scientific Defensibility: The AGGI is built from the highest quality, fully vetted, on-going observations of long-lived atmospheric greenhouse gases. The data sets comprising it are used in numerous publications by scientists around the world and are key components of assessments (*e.g., IPCC, WMO/UNEP, State of Climate Report, etc.*) The index is comprehensive, encompassing all long-lived gases, including carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and other lesser contributors. The measurements have been vetted repeatedly in the literature and the AGGI procedures and findings published as well (*Hofmann et al, 2006, Tellus 58B:614–619*). It is based solely on observations and does not have the uncertainties associated with model assumptions.

Relevance to Management Decisions: Although there currently is no all-encompassing, global agreement to reduce greenhouse gas emissions, many nations, states, provinces, cities, businesses, and industries are seeking ways to reduce their carbon footprint. However, atmospheric carbon dioxide has been increasing at record rates in 2013 despite these efforts, and other gases continue to rise as well. To adjust accordingly, society needs robust measures to know how well they are doing in reducing greenhouse gas emissions and these measures must be on scales to support decisions where they are made. The AGGI does not provide regional scale information, but it does provide a measure of how well the world as a whole is doing. The AGGI gets attention from the Department of State, Environmental Protection Agency, and national security agencies; the WMO also publishes and distributes it in five languages.

Data and Methods: The NOAA Global Monitoring Division provides high-precision measurements of the global abundance and distribution of long-lived greenhouse gases that are used to calculate changes in radiative forcing of climate change. Air samples are collected through NOAA's global air sampling network, including a cooperative program which provides weekly paired samples from ~70 globally distributed sites, including measurements at 5 degree latitude intervals from ship routes. Weekly data are used to create a smoothed north-south latitude profile from which global averages are calculated. Radiative forcing is then computed from these values using formulae in the IPCC 2007 Assessment, summed, and normalized to 1990 to provide a simple index.

Global Atmospheric Concentrations of CO_2

Summary

Another important indicator of the critical change in the Earth's atmosphere is the time series of global CO_2 concentrations. This is not the only anthropogenically driven change in GHG concentrations, but serves a useful purpose as a summary indicator of human impact on the atmosphere.

Background

Increases in CO_2 are responsible for 85% of the increase in radiative forcing from long-lived greenhouse gases over the past decade. This indicator focuses on what is by far the biggest and most unwieldy contributor. It is the one given the most attention by policy makers and environmental managers. Data come from dozens of globally distributed, remote atmospheric sampling sites and are of the highest quality. Data sets are updated and posted daily with plots of the global average updated monthly. An example of this data is provided in the figure from Mauna Loa Observatory, part of NOAA's Earth System Laboratory and one station from the global network.

Scientific Defensibility

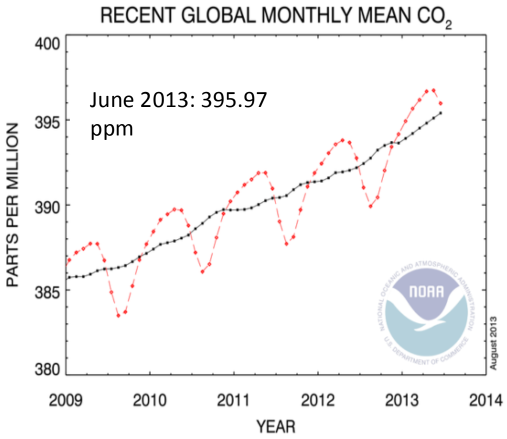
NOAA's measurements of atmospheric CO_2 are among the best in the world and recognized as so. Its Global Monitoring Division maintains the World Calibration Scale for CO_2, serving as the Central Calibration Laboratory and World Calibration Center for the World Meteorological Organization's Global Atmospheric Watch Program. NOAA distributes standards to national and international partners and conducts on-going quality control of worldwide CO2 observations. All data and comparisons are open for viewing and used by scientists worldwide. A recent *Science* letter lamenting the loss of about 10% of NOAA's CO_2 monitoring sites was signed by 50 national and international scientists (*Houweling et al., 2012 Science, 337:1038-1040*).

Relevance to Management Decisions

According to the IPCC Fourth Assessment Report (AR4-2007), "Warming of the climate system is unequivocal", "Most of the increase in global temperatures . . . is very likely due to the observed increasing anthropogenic greenhouse gas concentrations", and "Carbon dioxide is the most important greenhouse gas". The atmospheric burden of CO_2 has been increasing exponentially for the past two centuries (*D.J.Hofmann et al. Atmospheric Environment, 2009, 43;2084–2086*) and continues to do so with a doubling time of ~35 years. While various elements of society work to reduce CO_2 emissions, this indicator serves as a global scorecard. It is used to inform Department of State, Environmental Protection Agency, National Security Agency, and the World Meteorological Organization.

Data and Methods

The Global Monitoring Division of NOAA's Earth System Research Laboratory has measured CO_2 and other greenhouse gases for several decades at a documented, globally distributed network of air sampling sites, today comprising about 70 locations *(T.J. Conway et al., 1994, J. Geophys. Research, vol. 99, 22831-22855)*. A global average is constructed from the remote sites by first fitting a smoothed curve as a function of time to each site, and then the smoothed value for each site is plotted as a function of latitude for 48 equal time steps per year. A global average is calculated from the latitude plot at each time step (*Masarie and Tans, 1995, J. Geopys. Research, vol. 100, 11593-11610)*. Measurements are of the highest quality, with an accuracy of 1 in 8000 for an individual measurement and 1 in 4000 for instrument compatibility.



Global Sea Level Change

Summary

Another fundamental measure of the impacts of changes in the physical climate system is global sea level rise, derived both by satellite altimetry and by extensive analysis of tide gauges around the world. Global sea-level rise has been a standard product from NOAA laboratories for more than 60 years. Current rates and magnitude of sea level rise are largely determined by thermal expansion of the oceans due to increased heat content, and melting of land ice.

Background

Global sea level, stable from about 3,000 BC (?) to the 19th century, has been rising in the 20th century at a rate of about 1.7 mm/year. Primary contributors to the rise are expansion of water molecules with warming (~25%) and melting of land ice (less than 50%). Global sea level is expected to accelerate over the next 100 years, as indicated by a mid-range emissions scenario.

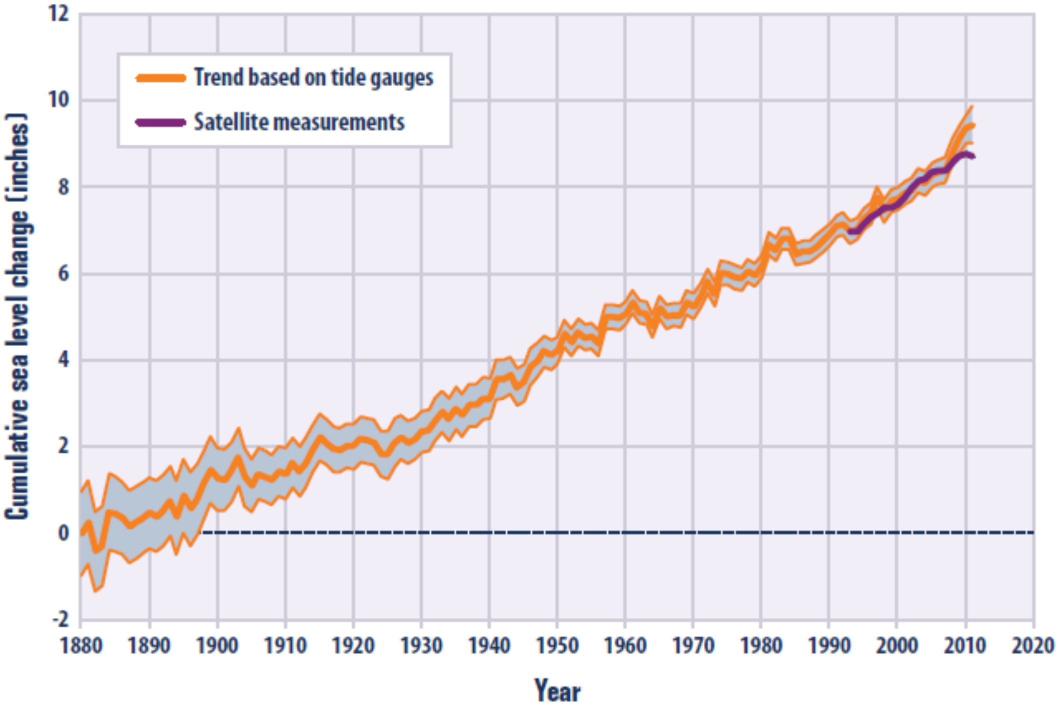
Scientific Defensibility: Global sea level data from tide gauges and satellites have been published by the Permanent Service for Mean Sea Level (PSMSL) since 1933 for almost 2000 stations world-wide.

Relevance to Management Decisions: Global sea level trends are necessary to understand how climate change is affecting the world-wide water cycle and deep ocean current patterns.

Data and Methods: All station data are compared to those measured with satellites (satellites are calibrated with station data and available since 1992) and checked for consistency. The PSMSL conducts global sea level analyses based on stations with at least 70% annual data available, which are adjusted to a common datum and quality-checked.

Figure 1. Global Average Absolute Sea Level Change, 1880–2011

This graph shows cumulative changes in sea level for the world's oceans since 1880, based on a combination of long-term tide gauge measurements and recent satellite measurements. This figure shows average absolute sea level change, which refers to the height of the ocean surface, regardless of whether nearby land is rising or falling. Satellite data are based solely on measured sea level, while the long-term tide gauge data include a small correction factor because the size and shape of the oceans are changing slowly over time. (On average, the ocean floor has been gradually sinking since the last Ice Age peak, 20,000 years ago.) The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used.



Data sources: CSIRO, 2012;[12] NOAA, 2012[13]

Image source: Climate Change Indicators in the United States, 2012.

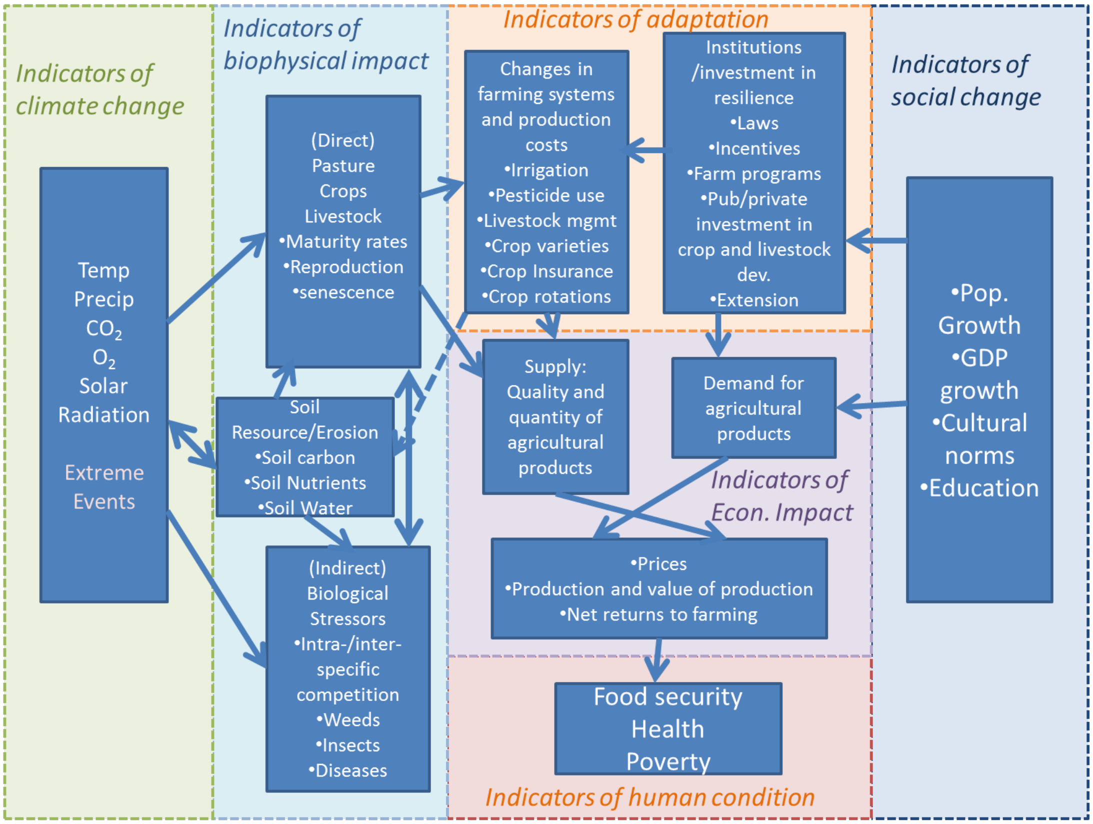
Appendix B:

Proposed Pilot Indicators – Sector/System Specific Indicators

Note: The text that is included in this appendix is the text that was written by the technical team that provided the recommended indicator. With the exception of formatting and some minor edits, we have kept the text in the original form.

Agriculture

Agriculture Conceptual Model



Agricultural response to climate change represents a complex set of interactions which include both direct and indirect impacts (shown on the diagram as Indicators of Biophysical Impact) and the interactions between the direct and indirect responses. Indicators of the direct and indirect effects along with the soil resource examine the linkage between climate variables and the response of the biological and physical system (soil and water). Within the Indicators of Biophysical Impact the outcomes are agricultural productivity and quality of the product which directly link to the Indicators of Adaptation and Indicators of Economic Impact; however, these indicators are also affected by social change as indicated by the far right hand box on the diagram and often are the more important Most of the efforts have focused on indicators which quantify the direct effects of climate on agricultural systems which is primarily related to production outputs and to a lesser extent the indirect effects and the soil resource. Indicators which extend the capabilities of assessing climate impacts on a broader set of agricultural metrics will be valuable to quantify trends in agricultural response. Indicators for agriculture were developed from the potential candidates as:

Indicators of Climate Change

- Extreme Daily Rainfall

Indicators of Biophysical Impact

- Livestock deaths that are environmental/weather related
- Comprehensive Climate Index thermal stress indicators for animals
- Crop Condition, Progress, and Production
- Using the National Resource Inventory as a Climate Indicator for Soil Erosion and Land Use
- Rainfall Erosivity
- Tracking extreme daily rainfall as a climate indicator affecting soil erosion and crop flooding
- Monitoring soil carbon and agricultural productivity over large areas using field experiments, remote sensing, modeling, and soil sampling technologies
- Climate, CO_2 and Chemical Control of Pests

Indicators of Economic Impact

- Economic Impacts of Climate Change: Extreme events
- Economic Impacts of Climate Change: Production Vulnerability

Each of these indicators provides a view of the agricultural system response to climate change using indicators which provide an analysis of the short- and long-term reactions to climate. All of these indicators would provide information for producers, decision-makers, and policymakers on the state of agricultural systems and trends.

Crop Condition, Progress and Production

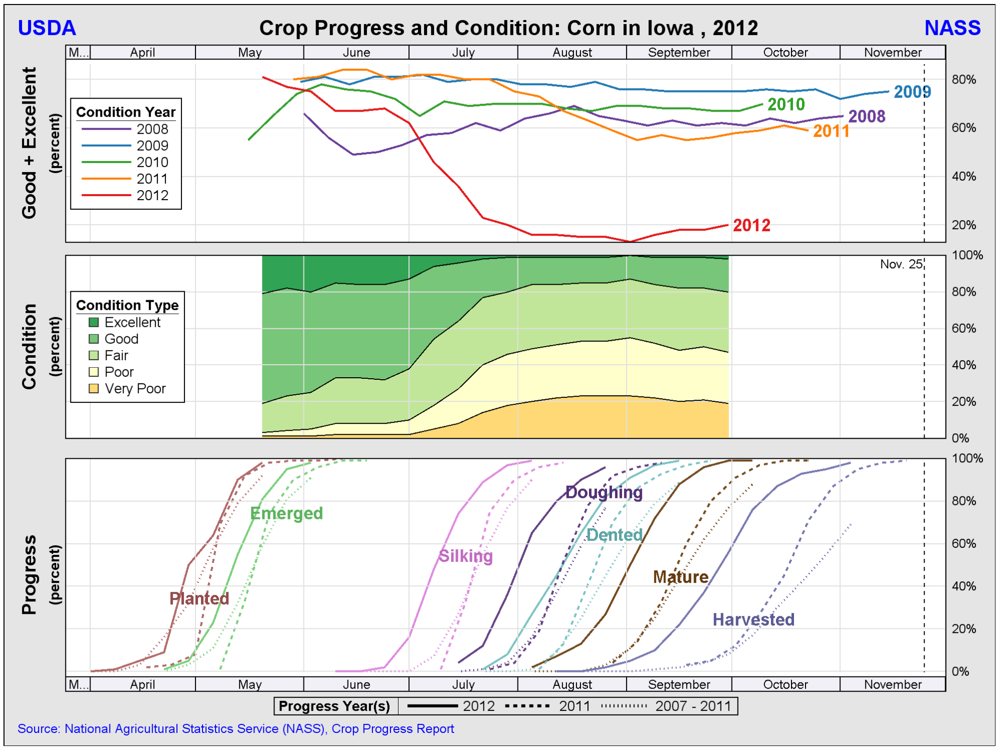
Summary

This indicator describes metrics for crop yield and can be related to the impacts of weather (temperature, precipitation and solar radiation) during the growing season among years. Data for weekly crop condition and progress for major commodities, comparison to the previous 4 years, historical yield data for each county, and county level yields at the end of the crop season are available.

Background

Crop production systems respond to the weather conditions within a growing season and over time show responses to changes in the climate. Crop yields are one of the most utilized indicators of the impact of weather during the growing season, and county, state, and national yields have been extensively used to evaluate weather effects through statistical and simulation models. An example of statistical analysis approaches are provided in Runge (1968), Muchow et al. (1990), Lobell (2007), Lobell and Field (2007), and Hatfield (2011) in which different parameters, e.g., temperature, precipitation, or solar radiation, have been related to the variation in crop yield among years. Use of simulation models to assess future effects of projected climate have been reported in Lobell et al (2006) and Hatfield et al. (2011) and there are ample references detailing the utility of different methods.

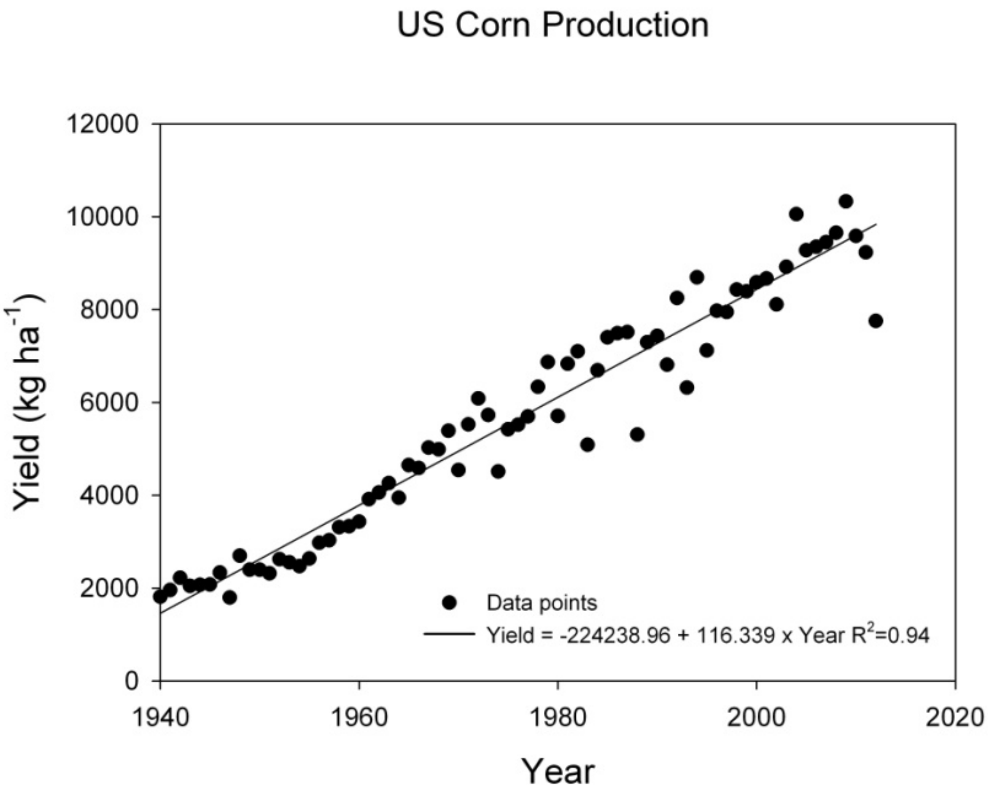
Indicators of climate impacts on agriculture can utilize the existing data bases available from USDA-National Agriculture Statistics Services (www.nass.usda.gov) which report weekly crop condition and progress for major commodities, comparison to the previous four years, historical yield data for each county, and county level yields at the end of the crop season. These combined records offer a comprehensive data base for the analysis of climate effects and have been used in the studies cited in this summary. A complement to these databases is the planted and harvested area for each county which allows for a direct determination of the shifts in crop distribution across the US. The area harvested and the yield per area provides a direct measure of total productivity and potential stocks of grain, forage, feed, fuel, and fiber which are useful for decision-makers and policy-makers. Examples of the current information on crop condition and yields are shown in the following graphs.



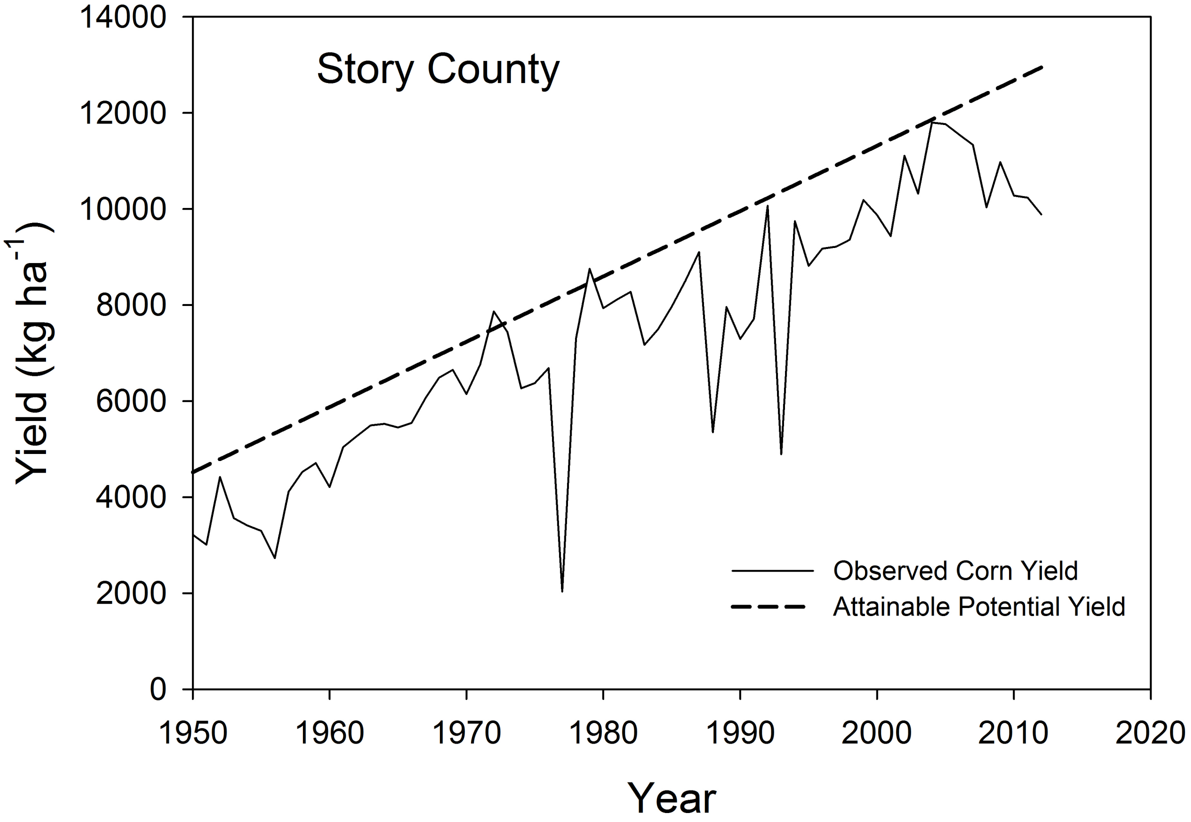
Source: National Agricultural Statistics Service (NASS), Crop Progress Report

Crop progress is related to a combination of weather events during the growing season and is indicative of whether the weather patterns are affecting the general condition of the crop. The middle graphic shows the assessment of the corn crop for Iowa throughout the 2012 growing season. The deviations in the upper graph among years shows the effects of the seasonal weather conditions.

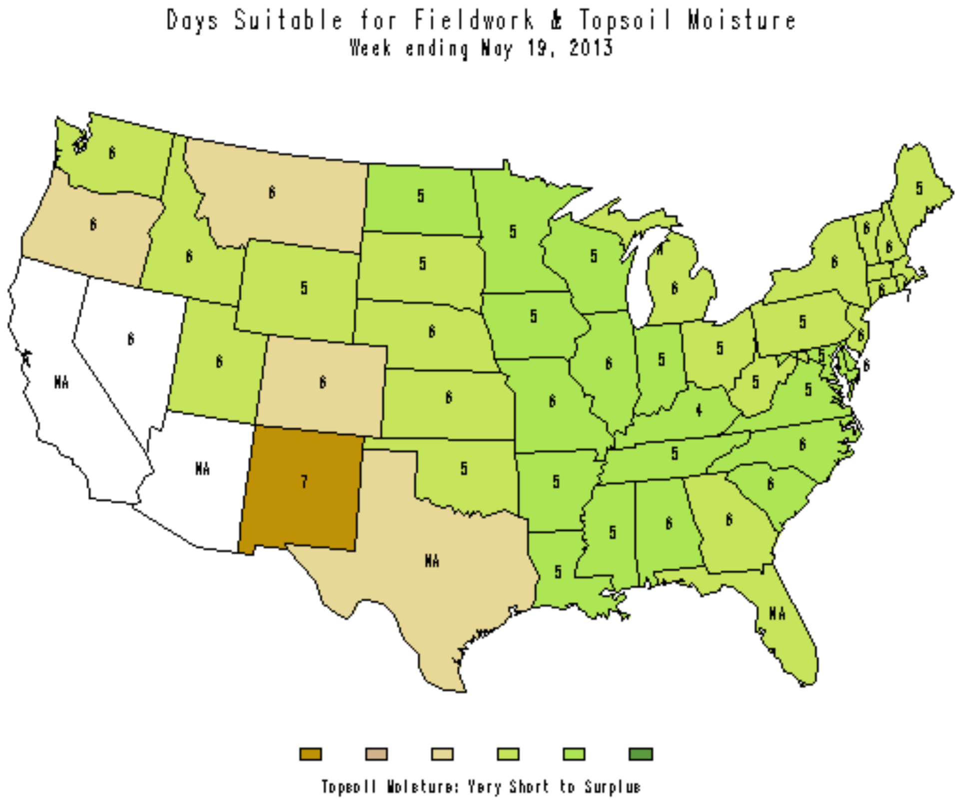
Production data from each county in the US can be divided into two aspects, the attainable potential yield and the actual yield harvested. The techniques for the estimation of the potential can be constructed as a library for each county using quantile regression analysis and updated each year and when combined with the actual yield can be used to quantify the magnitude of the yield gap detailed by Hatfield (2011). An example for corn yields and deviations from attainable potential yield are shown in the following figures. Yield variations within a given year can be related to weather anomalies, e.g., high temperatures or water stress; however, these effects are more detectable at the county level than at the national level because weather events are more local than national. An example of this can be seen in the contrast between US corn production and Story county, Iowa production over the same period. The interannual variation in yields is larger at the county level and become less detectable at the national scale unless there are extreme weather events, e.g., drought of 1988 and 2012. Yield gaps can be related to variations in climate and can be used to assess whether the ability to achieve potential yield is comprised by changes in crop progress and crop condition each year and trends in yield gaps and yields directly related to climate variables at the county level. Variation in production per area and total production for the different commodities in response to seasonal weather these data are currently available and represent a pilot system of indicators. The weather data are available from the NOAA observation network. The use of yield gap analysis provides a direct measure of the deviations from an attainable potential yield which allows for a comparison among years as a method of normalizing the yield trend. There has been a steady increase in crop yields and direct use of yield doesn't allow for a comparison of climate effects on yields among years. The inclusion of the weather data for each season then provides an indication if the shifts in field conditions are due to the change in the seasonal climate similar to the reports on changes in workable field days in the spring for Iowa as reported in Walthall et al. (2012) and shown on the graph for May 2013 across the US. These sources of information can be characterized as an initial system because we have these different components but have not completely integrated them into a single indicator for agriculture. http://www.nass.usda.gov



Trend in US corn production from 1940 through 2012. The deviations of yield below the trend line are a result of major weather events which occurred over a large portion of the corn *growing area to significantly affect grain production. One example is the deviation of the 2012 yields which were a result of the widespread drought across the US.*



Trends in corn yields from Story county, Iowa and the estimated attainable potential yield based on quantile analysis. These deviations from the attainable potential yield line are a result of weather events during the season. Weather has had a significant impact on corn yields in this county since 2006 because of a combination of rainfall patterns and temperature stress.



Number of workable days for the week from May 12th to 19th 2013. Reductions in the number of workable field days can cause a delay in planting which would be reflected in the crop progress calendar shown in the first graph in this section.

Rainfall Erosivity

Summary

This indicator can be measured in numerous ways and tracks both natural and anthropogenic processes that degrade soils. One metric is the product of total rainstorm energy and maximum 30-minute rainfall intensity during a storm. The erosivity can be calculated annually from precipitation data.

Background

Several processes, both natural and anthropogenic, act to degrade soils. These processes include erosion, compaction, salinization, toxification, and net loss of organic matter. Of these, soil erosion may be the one most directly impacted by climate change, and also the most pervasive. Excessive rates of erosion decrease soil productivity, increase loss of soil organic carbon and other essential nutrients, and reduce soil fertility. Soil erosion rates may change in response to changes in climate for a variety of reasons, including climatic effects on rainfall, wind, land cover, and shifts in land use necessary to accommodate a new climatic regime (Williams et al., 1996).

The USDA-Natural Resources Conservation Service has collected field data at thousands of sites on land use, soil erosion rates by water and wind, and the "state of the land" based on a national statistical sampling on a periodic basis since 1982 (Nusser and Goebel, 1997). The data is collated, upscaled, and reported on a periodic basis (USDA, 2009). This National Resource Inventory (NRI) includes soil erosion estimates based on ground-based observations of crop and soil conditions using models. The models used are the Revised Universal Soil Loss Equation (Renard et al., 1997) and the Wind Erosion Equation. The climate inputs to RUSLE were first mapped in the mid-1950s through the 1960s based on data from previous decades. Those national maps were updated in the 1990s. In order to track climate change impacts the methods will require periodic updates to the climatic inputs for the models used to analyze the data.

The National Resource Inventory is the USDA's best program and system for monitoring the "state of the land" on all non-federal agricultural and range lands across the country. However, the program was initially designed assuming a static climate. This proposal suggests that with a modification to the program with an emphasis on updating climate (R-factor and wind input data) and management (C-factor) inputs, on a decadal basis, would provide a set of powerful indicators for tracking change.

The resultant indicators would include averages and distributions of estimated soil erosion rates by land use type for every state in the nation.

Livestock Deaths Due to Thermal Stress

Summary

This indicator is the number of deaths that are environmental/weather related to track livestock heat stress and related economic losses. USDA data are reported since 1991 for cattle; data for other domestic species is available but vary by year and degree of reporting.

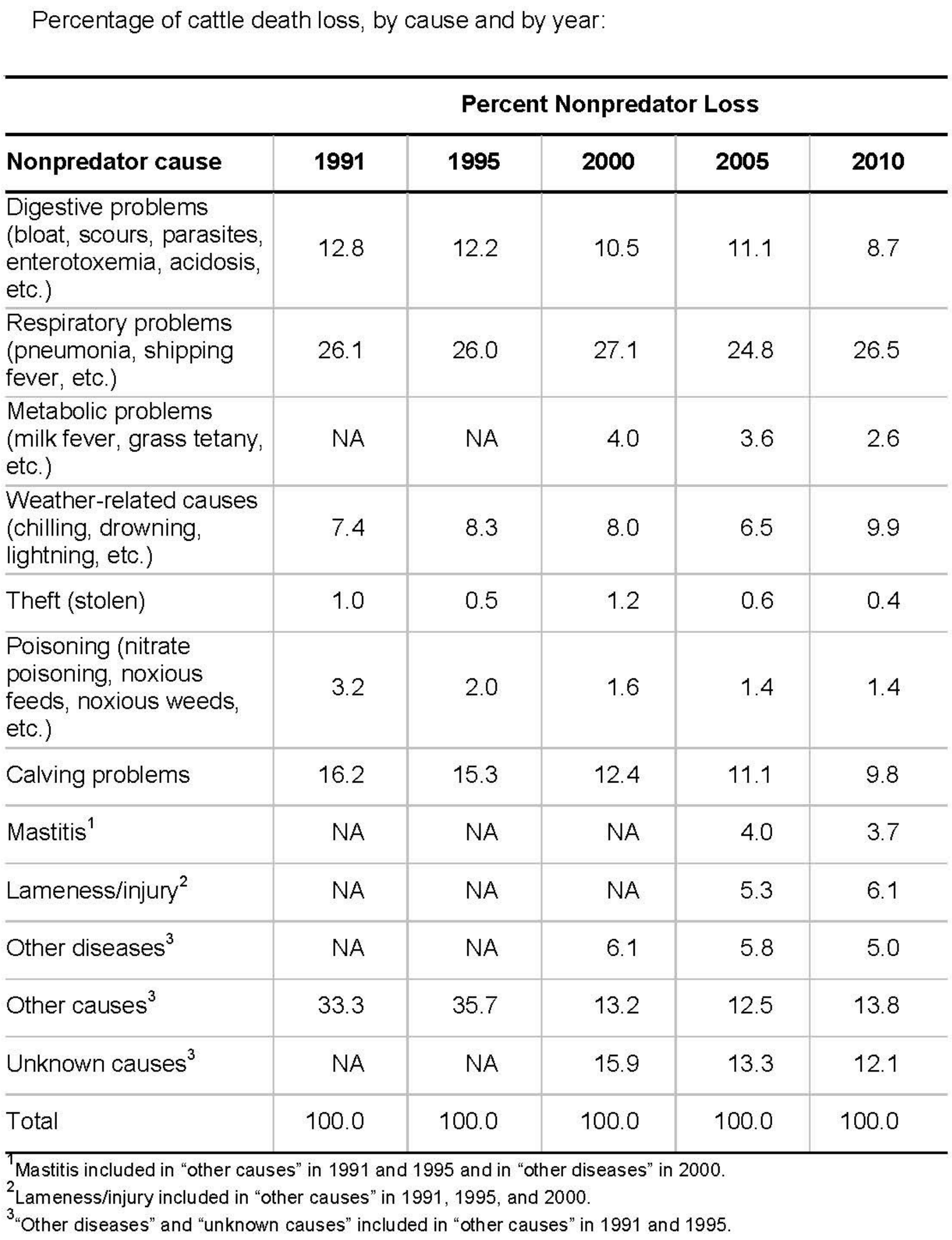
Background

In the Midwest and Plains states, the heat waves of 1995, 1999, 2006, 2009, and 2010 were particularly severe with documented cattle losses approaching 5,000 head each year. However, during the summer of 2011, nearly 15,000 head of cattle perished across five states as a result of heat stress. The winters of 1992 to 93, 1996 to 97, 1997 to 98, 2006 to 07, and 2008 to 09 also caused hardship for cattle producers with some feedlots reporting losses in excess of 1,000 head. Up to 50% of the newborn calves were lost in many areas with over 75,000 head of cattle lost in the Northern Plains states during the 1996 to 97 and 2008 to 2009 winters. Late fall and early winter snowstorms in 1992, 1997, and 2006 resulted in the loss of over 25,000 head of feedlot cattle each year in the Central and Southern Plains of the United States.

In Australia, a heat wave in 2000 resulted in the death of 24 people and over 2,000 cattle. Poultry losses were estimated to exceed 15,000. Numerous horses and dogs also died during this event. During the heat wave which occurred in Europe during summer 2003, over 35,000 people and thousands of pigs, poultry and rabbits died. In 2004 during an Australian heat wave over 900 cattle died. In 2006, a major heat wave moved across the USA and Canada. This heat wave resulted in the death of over 225 people, 25,000 cattle, and 700,000 poultry in California alone. Heat waves in Europe in 2006 and 2007 resulted in the deaths of more than 2000 people. However the number of animal deaths could not be established. Clearly adverse weather events affect pet and domestic livestock, as well as humans.

Economic losses from reduced performance of livestock experiencing severe environmental stress exceed losses associated from cattle death by 5- to 10-fold (Mader, 2012). Each year environmental heat stress alone costs the dairy industry over $900 million and beef and swine industry over $300 million each year (St. Pierre et al., 2003). During the winter, catastrophic losses typically occur during severe snowstorms.

Data adopted from publications such as USDA, National Agricultural Statistics Services (NASS), livestock non-predator death losses in the US would be useful as a climate change indicator to measure impacts of changing weather on domestic livestock deaths. Additional measures of mitigation strategies and costs would also be useful for characterizing impact of climate change and would be useful for caretakers to help animals cope with adverse climatic conditions.



Percentage of cattle death loss, by cause and by year:

	Percent Nonpredator Loss				
Nonpredator cause	**1991**	**1995**	**2000**	**2005**	**2010**
Digestive problems (bloat, scours, parasites, enterotoxemia, acidosis, etc.)	12.8	12.2	10.5	11.1	8.7
Respiratory problems (pneumonia, shipping fever, etc.)	26.1	26.0	27.1	24.8	26.5
Metabolic problems (milk fever, grass tetany, etc.)	NA	NA	4.0	3.6	2.6
Weather-related causes (chilling, drowning, lightning, etc.)	7.4	8.3	8.0	6.5	9.9
Theft (stolen)	1.0	0.5	1.2	0.6	0.4
Poisoning (nitrate poisoning, noxious feeds, noxious weeds, etc.)	3.2	2.0	1.6	1.4	1.4
Calving problems	16.2	15.3	12.4	11.1	9.8
Mastitis[1]	NA	NA	NA	4.0	3.7
Lameness/injury[2]	NA	NA	NA	5.3	6.1
Other diseases[3]	NA	NA	6.1	5.8	5.0
Other causes[3]	33.3	35.7	13.2	12.5	13.8
Unknown causes[3]	NA	NA	15.9	13.3	12.1
Total	100.0	100.0	100.0	100.0	100.0

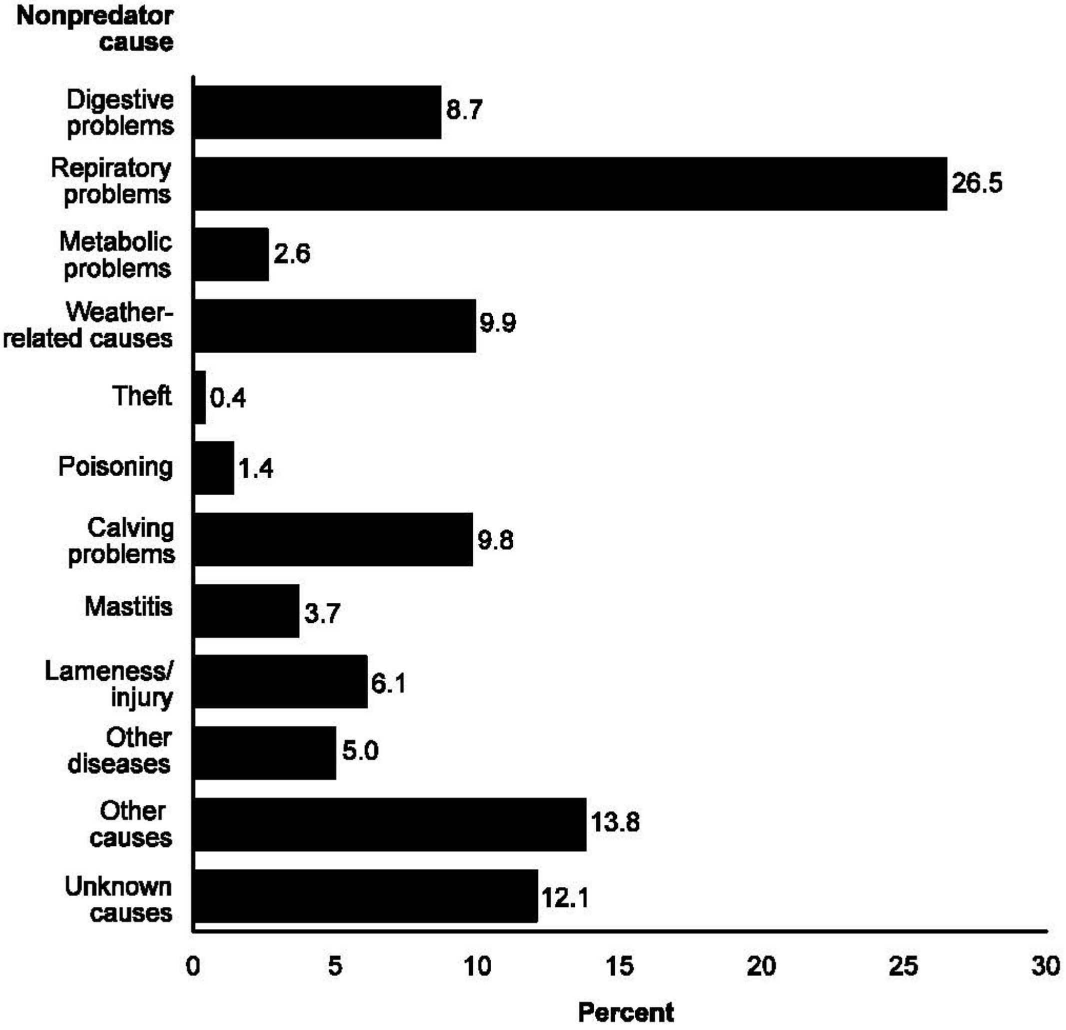
[1] Mastitis included in “other causes” in 1991 and 1995 and in “other diseases” in 2000.

[2] Lameness/injury included in “other causes” in 1991, 1995, and 2000.

[3] “Other diseases” and “unknown causes” included in “other causes” in 1991 and 1995.

USDA APHIS via NAHMS, Dec. 2011

Percentage of 2010 cattle death loss, by cause



“Other” causes accounted for one-fifth of cattle losses on beef operations (20.6 percent). Losses due to weather-related causes increased from 9.1 percent in 2005 to 14.8 percent in 2010. Not surprisingly, the percentage of losses due to mastitis was higher on dairy operations than on beef operations (13.1 and 0.3 percent, respectively). Mastitis also accounted for 8.6 percent of losses on mixed operations, likely because 5.6 percent of the dairy cow inventory was on mixed operations (see table 2a, p 18). Respiratory problems accounted for over half of nonpredator losses (64.3 percent) on “other” operations; many operations in this category are feedlots, which commonly experience problems with bovine respiratory disease.

Climate Change and Variability

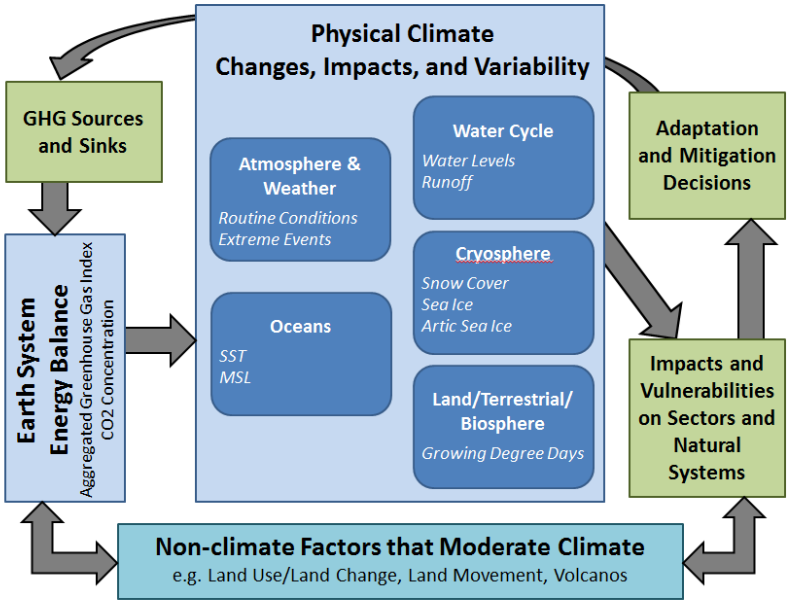
Climate Conceptual Model

Major Thematic Areas

Earth's Energy Balance: These indicators represent major components of the planetary scale energy balance, including, incoming energy, and the large-scale distribution of energy within the system, and relevant forcing agents within the system, such as atmospheric composition.

Physical Climate Impacts: These indicators, generally, track changes in the mean state and extremes of climate system variables and phenomena. They represent both state or quasi-state variables and "experienced" phenomena. In order to ensure a fairly diverse coverage of the climate system, these impacts were further subdivided into five constituent categories, roughly encompassing familiar components of the climate system.

- *Atmosphere and Weather:* These contain many "experienced phenomena" that have direct impacts on human systems.



- *Oceans:* A large component of the climate system, the state of the oceans is an important consideration of changes in the climate system as a whole. The team understands that more physical indicators may be selected by other teams, but did wish to identify key indicators that signify change and variability in the larger climate system.
- *Cryosphere:* The Cryosphere is in general very sensitive to large-scale climate change and has to date shown some of the most visible and understandable markers of change. Ice, in its several forms, plays an important role as a buffer through the physics of phase change, albedo effects and direct influence on other variables.
- *Water Cycle:* The hydrosphere is important as a physical indicator as it also impacts, and is sensitive to, changes in other variables. Extremes within the water cycle have monumental human impacts as well.
- *Biosphere / Terrestrial:* This is another major component of the climate system, human and natural landscape.
- *Non-Climatic Confounding Factors:* There are many environmental changes and human activities that directly or indirectly influence climate outcomes. Some physical examples are land-use/land-change, managed systems (water, etc.) and so on. These are important considerations, and much work has been done and will be done to understand and define relationships between these factors and components of the climate system.

Surface Temperatures for the U.S.

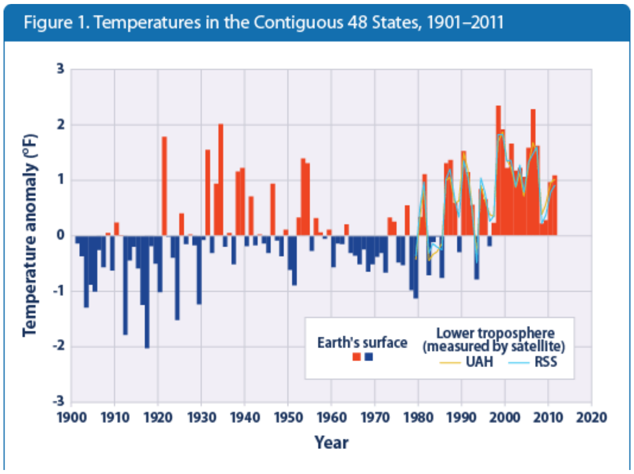
Summary

A corollary to the Global Surface Temperature indicator is an equivalent indicator specifically for the US. This is meant to be indicative of changes in the physical climate system, albeit not a full description of those changes.

Description: The Temperature Indicator would follow the temperature indicator outlined in the EPA Climate Change Indicators technical document. The temperature indicator is a measure of the surface and atmospheric temperature anomaly. An anomaly represents the difference between an observed value and the corresponding value from a baseline period and provides the ability to determine surface and atmospheric temperature trends. It is easily understood by both scientists and non-scientist and can be used to understand cause and effect relationships between climate drivers, societal mitigation and temperature at the earth's surface and important atmospheric layers.

Scientific Defensibility: The temperature data is fully vetted, on-going observations of standard meteorological instruments and satellite data. The data sets are used in numerous publications by scientists around the world and are key components assessments (*e.g., IPCC, State of Climate Report, etc.*) The measurements have been vetted repeatedly in the literature (*Christy et al. (2000, 2003), Mears et al. (2003), Schabel et al. (2002),* Menne et al. (2009)). NOAA has outlined their technical methodology for surface data in the *EPA Climate Change Indicators in the United States, 2012*. All data sets are based solely on observations and do not have the errors associated with model assumptions.

Figure 1. Temperatures in the Contiguous 48 States, 1901–2011



Relevance to Management Decisions: Many nations, states, provinces, cities, businesses, and industries use temperature analysis to understand how their population uses energy and resources to mitigate warm and cold climate changes. Additionally, understanding societal effects such as relocation and mass migration due to temperature changes or the crop production/temperature relationship can be used by governments around the world to mitigate widespread sustainment emergencies.

Data and Methods: NOAA provides surface and satellite data for both the Contiguous 48 States and worldwide analysis. USHCN Version 2 contains monthly averaged maximum, minimum, and mean surface temperature data from approximately 1,200 stations within the contiguous 48 states. The period of record varies for each station but generally includes most of the 20th century. Satellite-based measurements are for the period from 1979 to present. These satellite data were collected by NOAA's polar-orbiting satellites, which take measurements across the entire globe.

NOAA's satellites use the Microwave Sounding Unit (MSU) to measure the intensity of microwave radiation given off by various layers of the Earth's atmosphere. The intensity of radiation is proportional to temperature, which can therefore be determined through correlations and calculations. NOAA uses different MSU channels to characterize different parts of the atmosphere. NOAA's satellites measure microwave radiation at various frequencies, which must be converted to temperature and adjusted for time-dependent biases using a set of algorithms. Various experts recommend slightly different algorithms, primarily by two different organizations: the Global Hydrology and Climate Center at the University of Alabama in Huntsville (UAH) and Remote Sensing Systems (RSS). In this indicator, temperature would be presented primarily as trends in anomalies. An anomaly represents the difference between an observed value and the corresponding value from a baseline period. The choice of baseline period will not affect the shape or the statistical significance of the overall trend in anomalies. For temperature (absolute anomalies), it only moves the trend up or down on the graph in relation to the point defined as "zero."

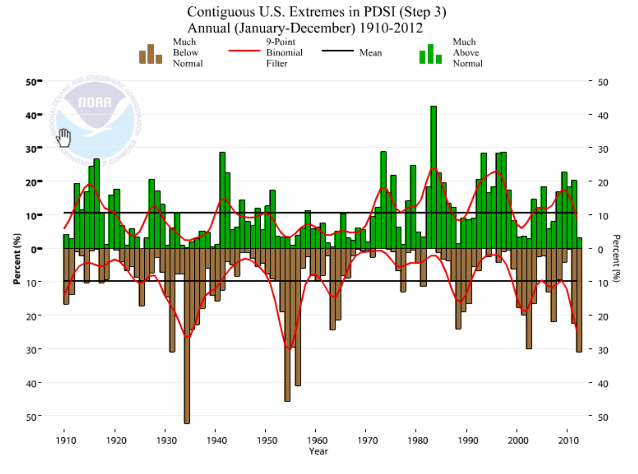
Palmer Drought Severity Index

Summary

The PDSI is one of the best-known drought indices. Drought is one of the great challenges for agriculture, availability of water for cooling of thermoelectric power generation, availability of water for industrial and household use, and other uses of water. There are many different drought indices, which can be calculated for specific uses or reasons, and although the PDSI has known weaknesses, it has been calculated by NOAA and others for many years, and provides a consistent time series for analysis and decision-making.

Background

Drought is one of the costliest natural disasters, and tracking changes in the area covered by drought is an important indicator of water quantity impacts. Wayne Palmer (1965) created The Palmer Drought Severity Index (PDSI) with the intent to describe the total moisture status as the cumulative departure (relative to local mean conditions) in atmospheric moisture supply and demand at the surface. It incorporates soil moisture, antecedent precipitation, moisture supply, and moisture demand into a hydrological accounting system. The index is one of the most intensively used and analyzed drought indices. The index has been calculated for discrete points, geographical regions, and gridded fields for the past (beginning in 1870 (Dai, et al. 2004) in the United States) and for the future (forecasts). Its widespread use comes from its integrative approach, the good availability of the underlying variables (temperature, precipitation) at nearly all spatial and temporal scales, and its usefulness in yielding derived summary products such as the percentage of the United States in drought.

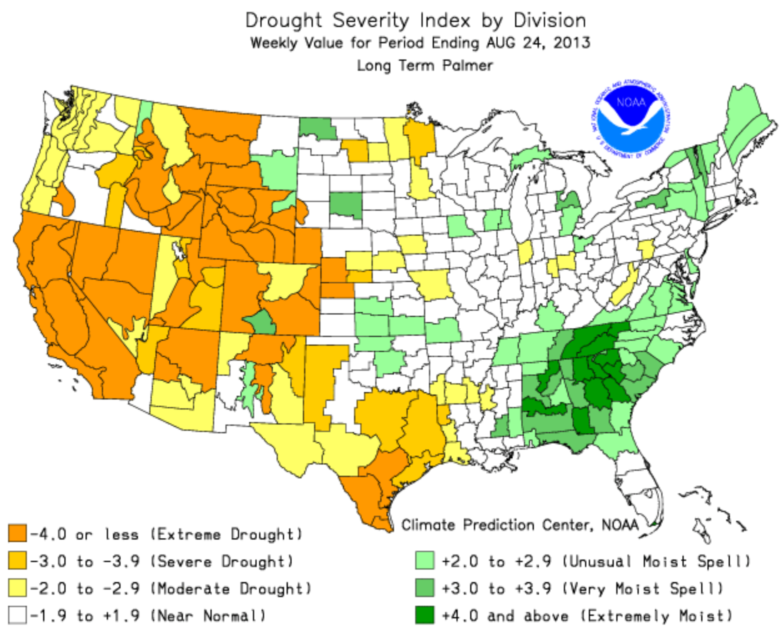


Brown bar: The percent area of the contiguous United States in extreme (tenth percentile) drought since 1910.

The Palmer Drought Severity Index (PDSI) assesses water demand versus water supply (total moisture status) by means of a water budget accounting method utilizing a 2-layer soil moisture model. Drought is measured as a departure from average conditions, and is calculated from temperature, precipitation, and soil moisture holding capacity. It can be calculated for discrete locations or general geographic areas. Index values near zero represent average moisture; positive conditions indicate wetter than average, and drought conditions are indicated by negative index values. Drought conditions are labeled as abnormally dry (≤-0.5), mild drought (≤-1.0 and > -2.0), moderate drought (≤-2 and > -3), severe drought (≤ -3 and > -4), and extreme drought (≤ -4).

The PDSI uses precipitation (P) to compute water supply and temperature to estimate water demand (potential evapotranspiration, PE, based on the Thornthwaite method). These quantities are compared in a monthly water budget accounting process. If P < PE, soil moisture is extracted to meet the demand. If P > PE, the excess P is used to recharge soil moisture. If any P remains after the soil is saturated, it is treated as runoff. Palmer applied what he called Climatologically Appropriate for Existing Conditions (CAFEC) quantities to normalize his computations so he could compare the dimensionless index across space and time. The index is calculated for climate divisions throughout the US, for gridded fields, and on regional and global scales. The PDSI is used to forecast drought based on model predicted temperature and precipitation.

While the PDSI was a landmark in the development of drought indices; it is not without limitations (Heim, 2002). The index was specifically designed to treat the drought problem in semiarid and dry subhumid climates where local precipitation is the sole or primary source of moisture and was originally calibrated for those areas; extrapolation beyond these conditions may lead to unrealistic results. The model does not take into account distribution of precipitation within a month, changes in vegetation cover and root development, state of the ground (frozen or unfrozen), or form of precipitation (in the real world, precipitation falling as snow will not enter into the calculations until it melts, which could be months later). The actual PDSI index values are sensitive to the weighting factor used to make it comparable between different months and regions, the value specified for the available water capacity of the soil, and the calibration period used to compute the CAFEC quantities. Better formulations can be used to estimate evapotranspiration. Subsequent researchers have addressed some of these issues (for example, the self-calibrating PDSI). In spite of these limitations, the PDSI still produces useful results.



Northern Hemisphere Snow Cover Extent Climate Data Record

Summary

The Northern Hemisphere Snow cover extent record is a catalogue of maps generated from remote sensing instrument observations that show the position of snow-covered land throughout the Northern Hemisphere. Historically, trained meteorologists drew these maps by hand but the process is now computer based. Data from the graphics can be combined to form products displaying hemisphere wide trends on monthly and annual timescales.

Description: The Northern Hemisphere Snow cover extent record is a catalogue of maps generated from remote sensing instrument observations that show the position of snow-covered land throughout the Northern Hemisphere (Figure 1). Historically, trained meteorologists drew these maps by hand but the process is now computer based. Data from the graphics can be combined to form products displaying hemisphere wide trends on monthly and annual timescales as shown in figure 2. These products are updated on a daily basis made available by NOAA's National Operational Hydrologic Remote Sensing Center

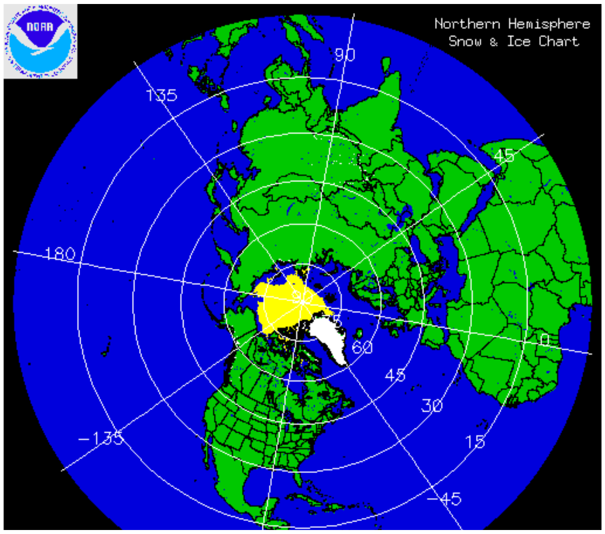


Figure 1: Northern Hemisphere snow & Ice chart for August 19, 2013. Available: http://www.nohrsc.noaa.gov/nh_snowcover/

(NOHRSC) and generated by the National Ice Center (NIC).

Scientific Defensibility: The Northern Hemisphere Snow Cover extent is built on the highest quality, fully vetted and continuing satellite observations. The index has been extensively peer reviewed and transparently maintained.

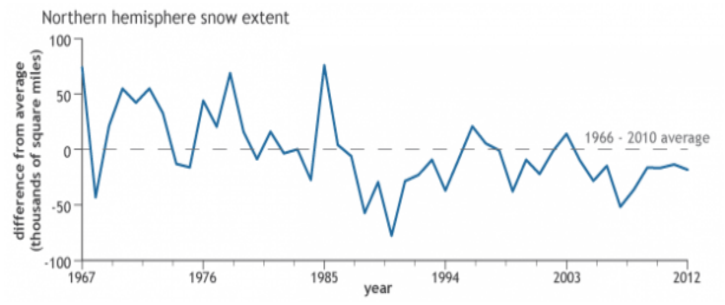


Figure. Difference from average annual snow extent since 1971, compared to the 1966-2010 average (dashed line). Snow extents have largely been below-average since the late1980s. Graph adapted from Figure 1.1 (h) in the 2012 BAMS State of the Climate report. Available: http://www.climate.gov/news-features/understanding-climate/2012-state-climate-snow-northern-hemisphere

Relevance to management decisions: The impact of snow on humans and the environment is considerable. Snow covers approximately 30% of the Earth's land surface on a seasonal basis, with additional coverage over polar ice sheets and sea ice. Snow that is lying on the ground or on ice influences hydrologic, biologic, chemical, and geologic processes. Snow exerts an impact on activities as diverse as engineering, agriculture, travel, recreation, commerce and safety. In turn, the presence or state of snow is influenced by weather, climate, topography, proximity to water bodies and humankind.

The low heat conductivity, high thermal emissivity, low vapor pressure and high reflectance of snow differ greatly from snow-free land. The accurate forecasting of local daily temperatures, regional climatic anomalies and the location and strength of cyclonic systems relies, in part, on knowledge of the distribution and state of regional snow cover. Model simulations of a CO_2/trace-gas induced climate change show that spatial changes in snow extent amplify global warming.

Data/Methods: Data record begins in 1966. Data prior to June 1999 are based on satellite-derived maps of weekly Northern Hemishphere (NH) Snow Cover Extent (SCE) produced by trained NOAA meteorologists. These maps were primarily based on a visual interpretation of photographic copies of shortwave imagery. This imagery initially consisted of observations from meteorological satellites with a subpoint resolution of ~4 km. Beginning in October 1972, the Very High Resolution Radiometer (VHRR) provided imagery with a spatial resolution of 1.0 km. As time progressed, analysts continued to incorporate various sources of imagery into the SCE mapping process as they became available (e.g., Advanced VHRR, VAS, etc.).

Energy

Energy Conceptual Model

The four major energy sector impact assessments during the past five years report a consensus on the major implications of climate change for US energy supply and use, which include:

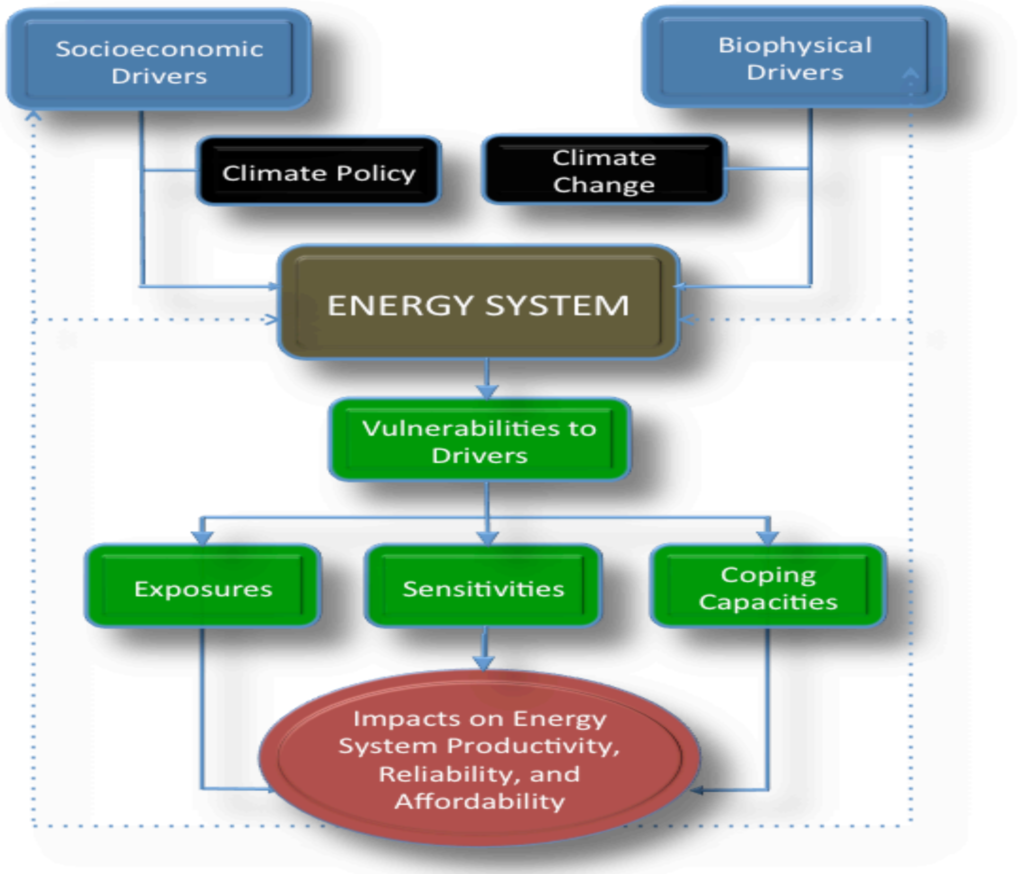
- The major near-term risk is from episodic disruptions due to extreme weather events, especially in some particularly vulnerable regions
- Increases in temperatures will affect both electricity demand and electricity supply
- Seasonal and/or chronic water supply constraints pose threats to reliable energy supplies in many regions
- Geographic patterns of renewable energy supply potentials will be affected

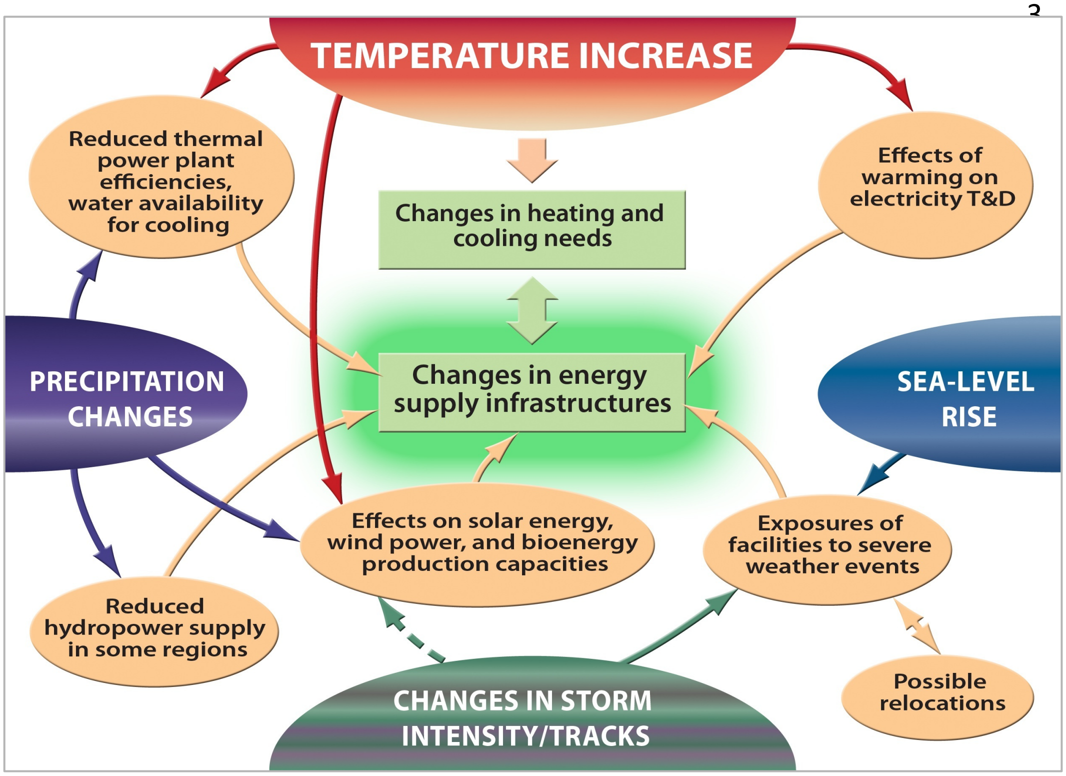
These findings emerged from analytic-deliberative group processes, not from applications of conceptual models. Implied by the process, however, is the conceptual framing illustrated by figure. The energy system is driven by a number of socioeconomic drivers, including climate policy, and a number of biophysical drivers, including climate change. Impacts of these drivers on energy system productivity, reliability, and affordability – interacting in a complex, interconnected multi-driver context – are shaped by system vulnerabilities.

Vulnerabilities are associated with three factors: exposures, sensitivities, and coping capacities (Clark et al., 2000). For example, energy supply and use systems differ in their exposures to climate change effects: coastal facilities are exposed to sea-level rise, while inland facilities are not (at least directly). Systems differ in their sensitivities: electricity transmission lines are sensitive to high winds from storms, while power plants generally are not. Systems differ in their coping capacities as well, i.e., institutional and social capacities to respond to risks and impacts: they may differ in emergency preparedness and response capacities, and they may differ in access to risk-sharing through insurance.

Vulnerabilities can be reduced by reducing exposures (e.g., relocating out of vulnerable areas), by reducing sensitivities (e.g., by moving above-ground urban transmission lines underground), and/or by improving coping capacities (e.g., adding early warning systems and system backups).

For example, climate change effects on electricity and other energy supply infrastructures include temperature changes, precipitation changes, changes in storm intensity and/or tracks, and sea-level rise. These direct effects can become impacts on infrastructures and energy services in ways such as those illustrated by figure which is mainly concerned with implications for electricity supply.


Socioeconomic Drivers
Biophysical Drivers
Climate Policy
Climate Change
ENERGY SYSTEM
Vulnerabilities to Drivers
Exposures
Sensitivities
Coping Capacities
Impacts on Energy System Productivity, Reliability, and Affordability


TEMPERATURE INCREASE
Reduced thermal power plant efficiencies, water availability for cooling
Changes in heating and cooling needs
Effects of warming on electricity T&D
PRECIPITATION CHANGES
Changes in energy supply infrastructures
SEA-LEVEL RISE
Effects on solar energy, wind power, and bioenergy production capacities
Exposures of facilities to severe weather events
Reduced hydropower supply in some regions
Possible relocations
CHANGES IN STORM INTENSITY/TRACKS

Heading and Cooling Days

Summary

Direct measurements of electricity demand are difficult to obtain routinely on a regional basis. But energy demand is closely associated with heating and cooling requirements, so heating and cooling degree days are a good indicator of changes in overall energy demand as it varies with weather, and over time, as it varies with climate. Heating and cooling degree days are calculated by NOAA on state, regional and national levels, based on a reference of 65 degrees F, and weighted by population. Monthly averages on a regional basis, and national averages are reported as current indicators with good trend information.

Background

Changes in heating and cooling days (i.e., days in which building occupants are motivated to heat or cool their building spaces) are the most direct indicator of temperature effects on energy demand and, to a lesser degree, energy production to meet that demand. Heating and cooling days are defined as days when heating or cooling is needed to provide adequate human comfort in interior building spaces. It is assumed that interior requirements are directly proportional to outside air temperature. Heating days imply demands for space heating. Cooling days imply demands for space cooling.

The four recent energy impact assessments all project a decrease in heating days, both nationally and regionally, which would reduce demands for the energy sources for heating – which include sources other than electricity. They project an increase in cooling days, increasing demands for electricity. Combined, the projection is an increase in electricity demand nationwide, especially in summers, including in some regions where cooling demand has historically been relatively small.

Heating and cooling days are monitored by NOAA/NCDC, which issues monthly reports for states, regions, and the nation as a whole. Estimates are degree day averages, relative to a base temperature of 65 degrees F, weighted for state averaging toward more highly populated parts of the state. Recent trends in heating and cooling days for the nation are shown in Tables 1 and 2 (national degree day totals are derived by population-weighting daily average temperatures for the nine census regions, which in turn add population-weighted totals for their respective states).

Heating and cooling days are widely used as indicators of changes of temperature due to climate variability and change. For example, they are the climate change variable most often incorporated in Integrated Assessment Models to indicate changes in climate over time as a determinant of energy demand/consumption. Table 1 includes the heating degree days, so expected trends are for the large numbers in wintertime possibly to decline over time.

Current or leading indicator: Heating and cooling days are indicators of current and historic conditions and can be projected as a leading indicator.

Geographic and temporal scope and scale of analysis: Monthly at state, regional, and national scales.

Nature of supporting data: See NCDC reports for methodology, which has been standardized for many years.

Composition (how the indicator is created): See NCDC reports: compares observed average daily temperatures, weighted for population distribution, with a base temperature level.

Table 1. Heating Degree Days.

Time Period July-June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
2011-2012	5	8	55	252	469	728	775	638	380	292	94	27
2001-2002	8	6	69	260	396	689	776	669	622	281	184	23
1992-1993	14	24	74	301	564	822	860	827	664	368	128	38

Table 2. Cooling Degree Days.

Time Period July-June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
2011-2012	407	349	173	49	15	9	10	11	44	45	152	232
2001-2002	370	332	202	57	11	5	5	7	24	30	110	187
1992-1993	286	228	150	49	13	7	13	5	11	19	91	207

Advantages/disadvantages: The principal advantages are that heating and cooling days are widely used in analyzing variabilities and changes in climate and weather conditions, they are based on data streams that are relatively detailed both spatially and temporally, and they are relatively simple and understandable as an indicator. The principal disadvantages are that climate change effects extend beyond temperature changes alone, that internal climate conditioning requirements are shaped by more than external temperatures alone (e.g., use of insulation), and that some experts disagree with the 65 degree base temperature.

NOAA/NCDC data: http://www.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html

Stress Index of Electricity Generation

Summary

One of the important consequences of electricity supply responses to extreme weather conditions is the number of times and extent of power outages. Outages are clearly related to conditions of extreme stress, although they are also a function of preparedness and hardiness of existing infrastructure. But even given these caveats, and given the difficulty of acquiring data, the North American Electricity Reliability Corporation (NERC) calculates a composite system reliability index (SRI), which incorporates a number of features of the electricity generation and distribution system. Values above 5.0 are considered to be “high stress” events, and the indicator chosen for the pilot is national in scale, and is simply the number of days per year that the SRI exceeds this value.

Background

To the degree that it can be measured, the level of stress (e.g., limits to coping capacities) is a key indicator of the vulnerability of electricity supply systems to climate change impacts. Equivalent measures are not available for oil and gas supply systems in the United States.

Stress is related to such variables as reserve margins to provide coping capacities in the event of interruptions in fuel supplies or electricity production. In practice at larger scales, however, it is generally associated with observations of electricity outages and their reasons: more outages is a clear indicator of current system stresses under varying external conditions.

The US institution responsible for providing data related to electricity system stress is the North American Electric Reliability Corporation (NERC). It provides a “system reliability index” for the bulk electricity system in the US (SRI), which is a daily blended metric aggregating transmission losses, generation losses, and load loss events. NERC also issues annual long-term reliability assessments, including such data as reserve margins by region, along with seasonal assessments for upcoming summer and winter peak demand periods.

NERC has agreed to provide an indicator that shows, for the nation, the number of days in a year above an SRI level of 5.0. NERC uses 5.0 as a threshold indicating high impacts, or “stress,” for the national bulk electricity system. For example including weather-initiated events and other supply disruptions, 2012 had three high-stress days (a daily SRI greater than 5.0): October 29 and 30 during Hurricane Sandy and June 29 during Thunderstorm Derecho. The years of 2008-2011 showed yearly values ranging from zero to seven days. It would be possible to discuss with NERC the use of a lower threshold, such as 4.0 or 4.5, if that would be more informative for the national indicators system.

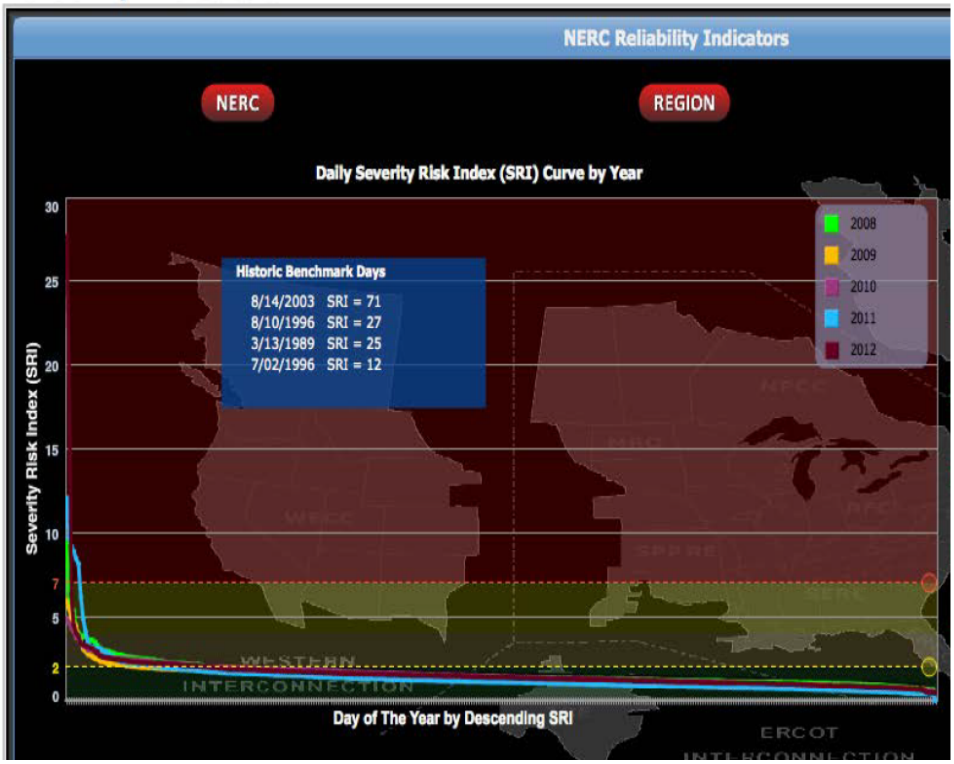
Geographic and temporal scope and scale of analysis: The SRI is a national indicator, estimated daily, generally reported as an annual curve showing the frequency distribution of SRI values from high to low. In addition, NERC annual long-term reliability assessments provide data at a regional scale annually.

Composition (how the indicator is created): NERC methodologies are publicly available on the NERC web site, e.g.:

http://www.nerc.com/comm/PC/Performance%20Analysis%20Subcommittee%20PAS%20DL/Integrated_Bulk_Power_System_Risk_Assessment_Concepts_Final.pdf

Advantages/disadvantages: Advantages of SRI include simplicity, industry credibility, and the daily scale of estimation. The main disadvantage is that access to its values requires logging in to the NERC web site, which is password protected. Other disadvantages are that it is limited to observed outages, without attempting to estimate other sources of stress, and that it is available only at a national scale.

Data:
http://www.nerc.com/comm/PC/Performance%20Analysis%20Subcommittee%20PAS%20DL/SRI_Equation_Refinement_May6_2011.pdf

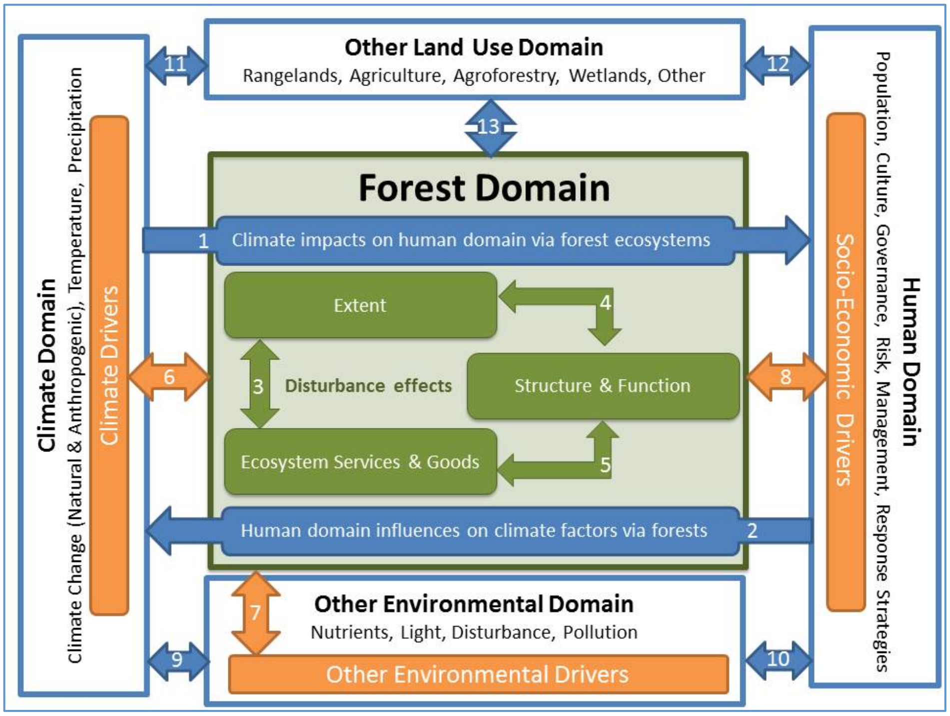


Historic Benchmark Days
8/14/2003 SRI = 71
8/10/1996 SRI = 27
3/13/1989 SRI = 25
7/02/1996 SRI = 12

National SRI curves by year.

Forests

Forests Conceptual Model



Conceptual model of the forest domain and important drivers and linkages. See text explanation of numbered arrows.

Within the human domain, people gather and assess information about all domains, and risks to those domains associated with climate variability and change. Based on these risks, adaptation and mitigation response strategies are formed and response actions can then feedback to the forests and other domains.

Different climatic, anthropogenic, and natural drivers can transition different areas between land use types. Forests can be converted to agriculture or agroforestry by socio-economic drivers. Conversely abandoned rangelands or agriculture areas can transition back to forests over time. These different land-uses can be fluid in a given area depending on climatic, other environmental and socio-economic drivers affecting forest ecosystems.

Major drivers of forest change are climatic variability, environmental change, disturbances such as wildfire, natural forest growth and dynamics, and economic forces which result in changes in land use and management practices. As a result, forest extent, structure, and function, ecosystem services and goods, and disturbance effects are major factors defining forests, interacting over time and across the landscape of the forest domain. These components encapsulate major aspects, relationships and characteristics of forest systems that are and will be affected by environmental change including climate change. One example of a driver is a strong hurricane (disturbance) that blows down or breaks off the tops of many trees (structure), some of which are harvested (goods), thereby affecting forest growth (function) and carbon sequestration (service), increasing biomass of dead wood (structure), with some of the disturbed forest area potentially being further cleared and developed, reducing forest area (extent). Extent defines the area designated as forestland, which is dynamic and can change to and from other land use types (arrow 13). Structure and function are core characteristics of forests. Ecosystem services and goods are measures of the global to local environmental and societal benefits that forests provide. Disturbances permeate throughout the forest domain, and their effects show up in extent, structure and function, and ecosystem services and goods.

Forest Area Extent

Summary

This indicator tracks changes in land use and land cover, based on forest area in hectares. Forest area responds to climate directly (through increased mortality and/or enhanced recruitment) and indirectly (through increased prevalence of fire and insect outbreaks). The NLCD, MODIS, FIA and NRI datasets or derived datasets from NASA can be used in conjunction to increase mapping accuracy.

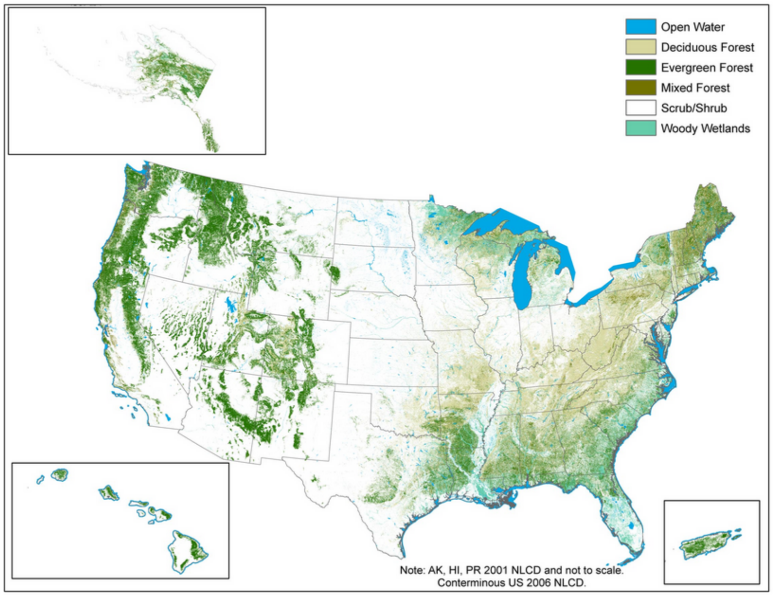
Background

Extent of forest is important as an indicator because it defines forest boundaries and the area involved. The amount of forestland can be locally dynamic due to human activities and can vary due to differences in definition or estimation approach. Climate affects vegetation and amount of forestland directly (extended drought may cause tree mortality or impede regeneration; long-term changes in climate may alter the continental distribution of forests) and indirectly (climate may influence insect outbreaks that cause broad-scale tree mortality). Forest area and area change over time is especially important for climate mitigation because decreases in forest land translates directly into increased greenhouse gas emissions from the forest sector. Scenario projections indicate that decreases in forestland are likely in the future (USDA Forest Service, 2012). We propose that two approaches be used in determining forestland extent, one focused on forest land use and the second focused on forest cover.

The main metric would be based on forest land use because this is the traditional approach used for the official forest statistics for the United States, based on data from the USDA Forest Service, Forest Inventory and Analysis (FIA) Program (2013). This approach employs the same definition of forest land used in the national greenhouse gas inventories submitted annually by the US to the United Nations Framework Convention on Climate Change. Forest area in the United States is about 304 million hectares in 2010 (USDA Forest Service, 2011). Since 2003, forest land area has shown a net increase by about 3.2 million hectares. In coastal areas, forest land is decreasing due to urban development, whereas in the interior US, an increase in forest area is attributed to woody plant encroachment in rangeland areas resulting from fire suppression, changes in grazing patterns, or abandonment of agricultural lands. Forest area gained is generally of lower productivity than the area converted to non-forest. The national estimates are updated approximately every 5 years. As noted in the introduction, the FIA definition of forest land does not include narrow corridors and/or small patches of trees, and thus may not include riparian corridors, agroforestry or urban forests.

The National Land Cover Dataset (NLCD; Homer et al. 2012) based on remote sensing can provide a second, geospatial indicator of forest cover. Forests mapped in the coterminous US using the NLCD approach are shown in figure. Timberland is considered productive forest, and other forest may be labeled shrublands in the NLCD. (In the FIA data-based metric, these general areas are defined as forest capable of producing 20 cubic feet per acre per year or less.) The NLCD approach is used to determine urban forest extent (for example, see Nowak et al. 2008), but there are methodological issues as described in Nowak and Greenfield (2010). A remote sensing approach has advantages including a wall-to-wall consistent approach, and identification of gross forest cover changes, but interpretation can still be misleading especially regarding temporary loss of cover that is identified as conversion to nonforest (Hansen et al. 2010).

The National Land Cover Dataset is also used in conjunction with the Forest Service ground data estimates to increase mapping accuracy. Methods continue to be refined which will improve the results and interpretation, so the approaches used for this indicator may likely need to be periodically updated, and the metrics recalculated for consistency over time.



Example of indicator map of forest area as defined by forest cover by forest class using the National Land Cover Dataset (MLRC 2013). The class woody wetlands is included although it may not be classified as forest. Conterminous U.S. map associated with the year 2006; Alaska, Hawaii, and Puerto Rico associated with the year 2001. Map created by Elizabeth LaPoint, USDA Forest Service, Durham NH.

Wildfire Effects-Burned Area

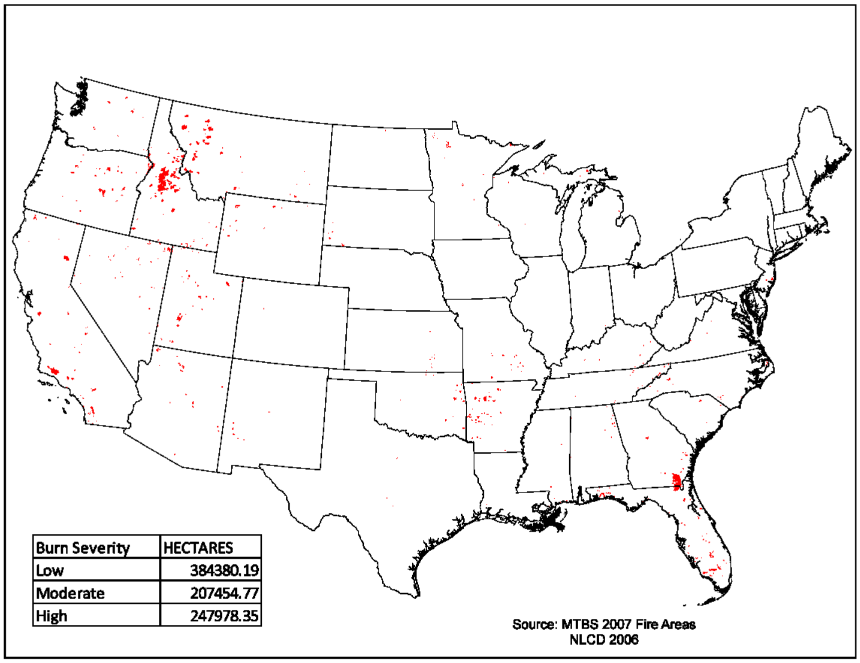
Summary

This indicator has a well-documented relationship with climate such that an increase in air temperature will increase the area burned in most states, and extent of wildfire in forests is primarily associated with drought conditions. The data on area burned are available on some federal lands since 1916; data for other public and private lands are sporadic.

Background

Wildfire is one of the two most significant disturbance agents (the other being insects) in U.S. forest ecosystems, and in a warmer climate, will drive changes in forest composition, structure, and function. Although wildfire is stochastic in space and time, sufficient data exist to establish clear relationships between fire characteristics and climatic parameters.

Burned area has a well-documented relationship with climate. Empirical analysis of annual area burned (1916 to 2003) for federal lands in the West projected that, for a temperature increase of 1.6 °C, area burned will increase 2-3 times in most states (McKenzie et al., 2004). Most of the variability in historical area burned was attributed to combinations of seasonal temperature and precipitation. In most forest ecosystems, fire area is primarily associated with drought conditions, specifically, increased temperature and decreased precipitation in the year of fire and seasons before the fire season. In arid forests and woodlands in the Southwest, fire area is influenced primarily by the production of fuels in the year prior to fire and secondarily by drought in the year of the fire. The burned area indicator can be supplemented with information related to fire severity and number of large fires.



Burn Severity	HECTARES
Low	384380.19
Moderate	207454.77
High	247978.35

Source: MTBS 2007 Fire Areas
NLCD 2006

Example of indicator map for areas burned by wildfire on forest lands in the conterminous U.S., 2007 (MTBS 2013). Fire severity class of each area is also available.

Map created by Elizabeth LaPoint, USDA Forest Service, Durham NH.

MTBS. 2013. Monitoring Trends in Burn Severity (MTBS) website, national geospatial data. Available online at http://www.mtbs.gov/products.html, last accessed 16 August, 2013.

Forest Growth/Productivity

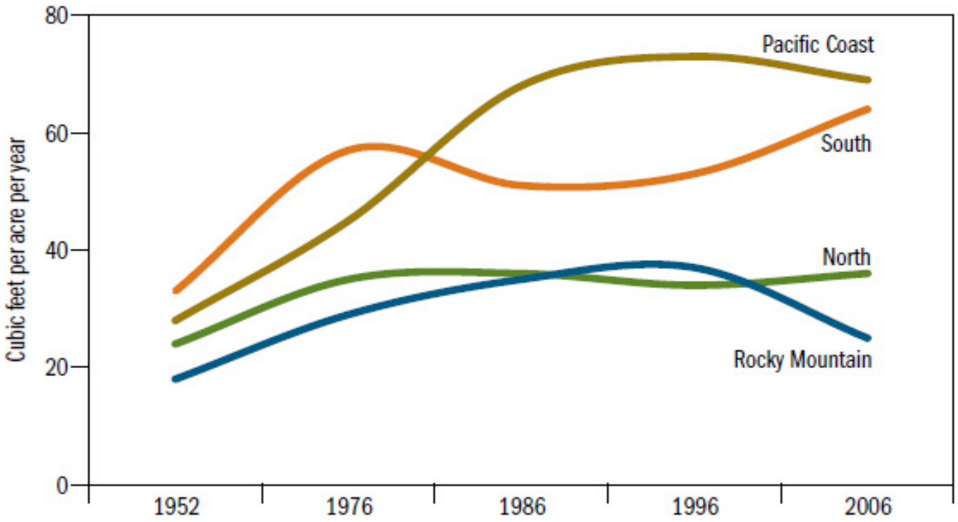
Summary

This indicator tracks net annual growth in US forests and can be affected by changes in temperature, water availability, length of growing season and increases in atmospheric CO_2. The data are available at national, subnational, ecological unit, and state from USDA-USFS FIA (since 1952 in some cases and 2000 for others).

Background

Net annual growth in US forests totaled nearly 26.7 billion cubic feet in 2006, which is about three-and-one-half times the rate of mortality. Net growth is an important indicator because it can be affected by changes in temperature, water availability, length of growing season and increases in atmospheric CO2. The result may be an increase or a decrease in net growth (USDA Forest Service 2011). Management activities can also affect growth, including species composition, so results should be carefully interpreted. Net annual growth is defined as the average annual net increase in volume of trees during the period between inventories. The volume of trees that died or that became nonmerchantable over the period are subtracted from the growth, which means net growth may be a negative number.

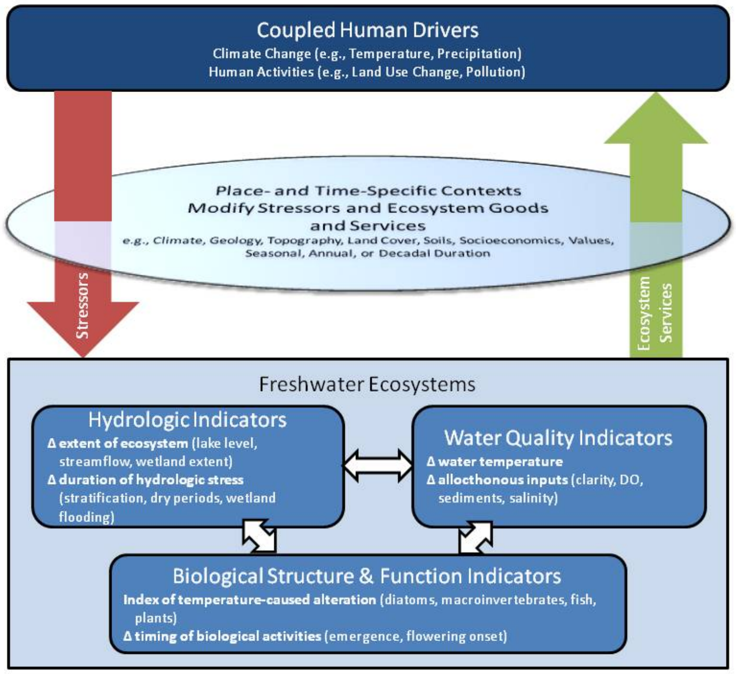
Net annual growth can be estimated from USDA Forest Service, Forest Inventory and Analysis Program data (USDA Forest Service, 2013). It can be calculated for a range of geographic levels: national, subnational, ecological unit, and state for example (for example, see figure). The smaller the area, the larger the uncertainty around the estimate, so smaller geographic resolution should be carefully considered. Field data are remeasured no less than 5-years apart so growth changes are reported as averages over the period and changes cannot be easily attributed to any one year, which is often of interest when looking at climate events. Initial measurements of date begin in 1952, with a number of 5- to 10 year growth periods occurring through to current measurements. A new annualized inventory design was initiated state-by-state starting in different years in the 2000s, with net growth now being calculated from remeasured plots rather than changes in results aggregated over landscapes.



Average net annual growing-stock growth per acre (cubic feet per acre per year) by region and inventory year. SOURCE: Smith et al. 2009.

Freshwater

Freshwater Conceptual Model



Conceptual model of major drivers, including climate change, impacting freshwater ecosystems.

The conceptual model in the figure shows the overarching drivers of the physical, chemical and biological features of freshwater ecosystems, such as lakes, streams, and wetlands, including climate change, other human activities, and the specific geographic and temporal contexts. Together these drivers and contexts determine the stressors that can alter the natural structure and function of freshwater ecosystems and influence the types of goods and services derived from them. Changes in the structure and function of freshwater ecosystems can be determined through indicators that fall into three broad categories: hydrologic, water quality, and biotic indicators. Hydrologic indicators include freshwater habitat availability and the duration of hydrologic stress. Habitat availability is determined by lake level, streamflow measures of discharge, and wetland extent. Periods of hydrologic stress are particularly important for organisms and directly influence the amount of goods and services, such as fisheries production or clean water, derived from freshwater ecosystems. While hydrologic stresses occur naturally, changes in the frequency and duration of these stresses are related to human drivers. Measurements of stress include lake thermal stratification, duration of dry or low flow periods in streams, and duration of wetland flooding. Water quality indicators describe important aspects of freshwater ecosystems relevant to both organisms and human uses, and include changes in water temperature, ice cover, and watershed (or allochthonous) inputs. Physiochemical indicators include lake transparency, sediments in streams, dissolved oxygen (DO), and salinity. Biotic indicators respond to important changes in both hydrology and water quality. Examples include (1) changes in the structure of algal and invertebrate assemblages, (2) changes in ecosystem goods such as coldwater fisheries for commercial and recreational uses, and (3) changes in phenology, such as insect emergence and the onset of flowering in wetlands. Together, the indicators in these three categories (hydrology, water quality, and biotic) describe the status and trends of freshwater ecosystems under a changing climate.

Freshwater Temperature

Summary

One of the most important physical indicators in freshwater ecosystems is temperature. Water temperature affects water chemistry including dissolved oxygen and the abundance and distribution of biota. Water temperature is highly correlated with air temperature. This indicator would use the real-time tracking from the USGS Water Quality Watch network of ~1000 streams. Though the temporal records vary for each site, this network of observational sites provides coverage across the U.S. and its territories for a range of watershed sizes. In the future, other temperature NSF supported data sources, such as GLEON, NEON, LTER, LTREB, GLTC (http://www.laketemperature.org/), and biological field stations can be added to improve the coverage for this indicator.

Background

Water temperature is a critically important feature of freshwater ecosystems. Long-term trends in thermal regimes are therefore a useful indicator of the environmental and ecological consequences of climate change (Woodward et al. 2010). Thermal regimes directly affect water quality and limit physiological processes of biota as well as rates of ecosystem metabolism. Water temperature also indirectly influences habitat suitability by affecting levels of dissolved oxygen (see dissolved oxygen pilot indicator summary below). These direct and indirect effects influence both the fitness of individual taxa and the spatial and temporal distributions of most aquatic species (e.g., Vannote and Sweeney 1980, Isaak and Reimen 2013).

Water temperatures are strongly correlated with air temperatures (e.g., Mohseni et al. 1998) and are therefore expected to warm over the next century as air temperatures increase. In fact, several observational studies from the USA (Kaushal et al. 2010, Isaak et al. 2012), the UK (Webb 1996), Europe (Hari et al. 2006), and Australia (Chessman 2009) suggest that water temperatures have paralleled warming trends in air temperature during the last century. Continuous monitoring of water temperature will be required to assess the effects of climate change on future water temperatures. These high-resolution observations can be summarized and aggregated into several useful metrics that characterize different aspects of the thermal regime (e.g., Olden and Naiman 2010). These temperature data will be critical in interpreting climate-induced changes in key biological indicators and strengthening the causal linkage between climate, water temperature, and ecological responses.

River and lake ice cover is closely related to water temperature and is similarly responsive to climate change. For example, freeze and break-up dates on lakes and rivers provides strong evidence for later freezing and earlier break-up in the Northern Hemisphere over the period 1846-1995 (Magnuson et al. 2000). Concurrent with increasing temperatures during the period 1975-2005, earlier break-up and later freezing have been observed for both lakes (Benson et al. 2012) and rivers and streams (Magnuson et al. 2000, Prowse et al. 2011). Projections indicate further delays in freeze-up and earlier break-ups with increasing temperature. Because ice dynamics play essential roles in geomorphology and habitat quality in freshwater ecosystems, careful monitoring is needed to track the impact of climate change on ice and the subsequent consequences for freshwater ecosystems.

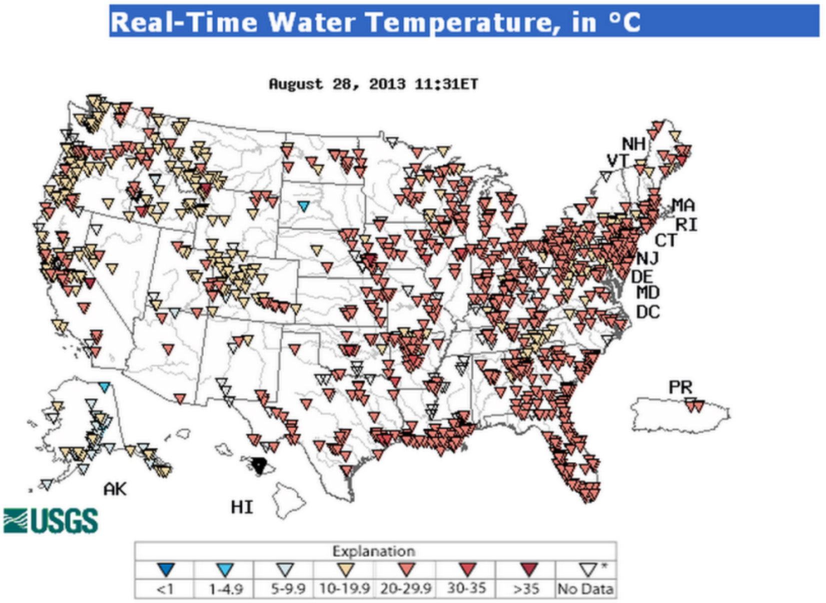
Data Sources

Within the USA, ~1000 USGS monitoring sites currently collect continuous water temperature data (http://waterwatch.usgs.gov/wqwatch/), although few of these sites have long-term records (see figure). The Global Lake Temperature Collaboration (GLTC, http://www.laketemperature.org/) is collating long-term temperature data on lakes in the USA and globally. Other federal agencies (e.g., US Forest Service in the Pacific Northwest), state agencies, field stations, tribes and others also operate numerous monitoring sites that could provide temperature data from a variety of freshwater habitats. To be most useful, all currently monitored sites will need to be evaluated to identify those sites that are most useful for climate-related monitoring. In addition, temperature metrics will need to be evaluated and selected based on their responsiveness to climate change and ecological relevance. Attributing changes in water temperature to climate change will also require that we account for potentially confounding effects of changing land use (e.g., Hill et al. 2013). Initially, the USGS stream temperature data (http://waterdata.usgs.gov/usa/nwis/rt) should provide a robust data set for the pilot indicator analyses.

Near surface water temperature measurements can be remotely sensed. Water column temperatures are usually measured using chains or strings of temperature sensors located at a range of depths through the water column. The Global Lake Temperature Collaboration has assembled a large dataset to investigate water temperature measurements in lakes around the globe. Information is available online at: http://www.laketemperature.org/. Additionally, the EPA has temperature profile measurements from over 1,000 lakes throughout the United States sampled as part of the National Aquatic Resources Surveys. Data from these lakes are available online at: http://water.epa.gov/type/lakes/lakessurvey_index.cfm. The Global Lake Ecological Observatory Network (GLEON) also records lake temperature data on a number of lakes around the world. Data for a subset of lakes are available online at: http://www.gleon.org/Data.php. Data for a series of north temperate lakes are also available online through a U.S. National Science Foundation (NSF) funded Long Term Ecological Research (LTER) facility. Data are available online at: http://lter.limnology.wisc.edu/datacatalog/search.

Management Implications

River, stream, and lake water temperature and ice data are relevant to a number of management purposes. For example, warmer water temperatures make power plants less efficient as thermoelectric power plants depend on water for cooling (van Vliet et al. 2012). Variability and changes in the timing and duration of river ice can affect flood frequencies. In north-flowing rivers, the largest floods occur when early snowmelt produce spring floods that collide with still intact ice in downstream reaches. Changes in the north-south temperature gradient can affect severity of break-up and associated flooding. Greater warming at higher than lower latitudes will likely produce less severe ice breakups and flooding as the spring floods push northward (Prowse et al. 2007). These types of floods occur abruptly and are difficult to predict, posing significant risk to life, property and infrastructure. Economic costs of river ice jams average US$250M/yr. Changes in the timing of freeze-up and break-up can impact in-channel operations (hydropower, bridges, pipelines, transportation).



Lake Ice

Summary

Ice cover and duration in lakes is seasonal and is correlated with the surface air temperature in the month or two preceding thawing as well as other precipitation and seasonal climate indicators. This proposed indicator would build off the representation of lake ice included in the EPA climate indicators report, using observational data from National Snow and Ice Data Center Global Lake and River Ice Phenology Database, to represent ice cover duration, date of first freeze, and date of ice thaw. In the future, remotely sensed water temperature readings can be considered as an indicator.

Background

Water temperature is a fundamental regulator of aquatic ecosystems and is an essential descriptor of seasonality in the hydrosphere and biosphere. The temperature of water, the presence of ice, and thermal (density) stratification regulate biogeochemical cycling, food webs, species diversity, and many ecosystem services. Several studies have shown that temporal changes in the date of ice formation and ice-out, as well as the duration of ice cover, can be used as indicators of climate change (Magnuson et al 2000; Hodgkins et al. 2002; Benson et al. 2012).

Ice cover is responsive to climate changes. For example, concurrent with increasing temperatures during the period 1975-2005, ice cover losses also have changed more rapidly than long-term trends over 100 or 150 years (Benson et al. 2012). Across a suite of 75 lakes throughout the Northern Hemisphere, ice cover has been changing rapidly, with rates of change (days per decade) including the date of freezing 0.3-1.6 days later, 0.5-1.9 days earlier thawing, and 0.7-4.3 days shorter in terms of ice cover duration. (Benson et al. 2012). Seasonal timing in regional ice cover also has been shown to track large-scale modes in inter-annual and decadal-scale climate variability. Projections indicate further delays in freeze-up and earlier break-ups with increasing temperature.

Ice cover is closely correlated with air temperatures in the month to two month period preceding thawing (Hodgkins et al. 2002). However, ice cover is also affected by a number of processes including rain and snowfall and cyclical dynamics associated with phenomena such as sunspots, and regional climate patterns such as El Niño/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) (Sharma et al. 2013). Thus, careful analysis is needed to understand the role of these multiple processes in driving trends and residuals in ice cover.
The temperature of the water column and the strength and duration of stratification regulate lake ecosystems in important ways. Lakes are often divided up into depth categories based on differences in temperature, including the epilimnion, the metalimnion, and the hypolimnion. In the epilimnion, during ice-free periods, wind driven-mixing creates an isothermal layer. The metalimnion is the portion of the water column where temperature changes rapidly with depth, while in the hypolimnion the temperature changes much more slowly.

Here, we recommend several lake temperature measurements including:

- Ice cover. Ice cover measurements include:
- Ice onset (freeze date)
- Ice out (thaw date)
- Ice duration

Data Sources

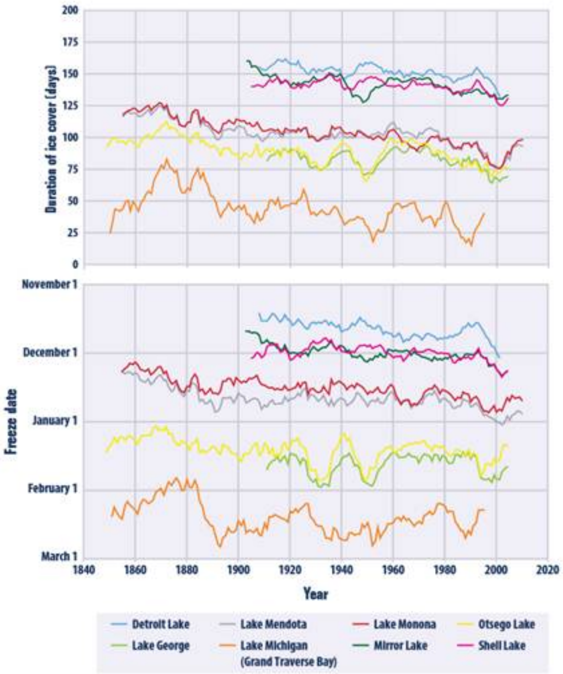
Water temperature records have been recorded for centuries and many datasets are currently available publicly. For example, records of ice cover have been recorded for centuries in many cases (Magnuson et al. 2000) and ice characteristics are used by the US Environmental Protection Agency (EPA) as an indicator of climate change, as shown in the figure (EPA 2013). Water temperature characteristics such as the near-surface temperature and ice cover can also be remotely sensed, thereby providing substantially more data in the modern era.
The Global Lake and River Ice Phenology Database contains freeze and breakup dates and other ice cover descriptive data for 865 lakes and rivers. Of the 542 water bodies that have records longer than 19 years, 370 are in North America and 172 are in Eurasia; 249 have records longer than 50 years; and 66 longer than 100 years. A few have data prior to 1845. These data, from water bodies distributed around the Northern Hemisphere, allow analysis of broad spatial patterns as well as long-term temporal patterns (see figure). These data are available online at: http://nsidc.org/data/lake_river_ice/

One of the primary limitations of ice cover as an indicator of climate change is that these measurements are not yet at continental scales and ice cover is not applicable across all US latitudes. However, despite these limitations, ice cover is controlled by climate and hence have a strong climate signal. Additionally, measurements have been made for, in some cases, hundreds of years, making this a long term measurement while few environmental direct long-term measurements exist. We recommend that this indicator is included in the pilot system where it is available, but also recommend that efforts are made in future programs to make this indicator work at broader scales – by increasing the spatial scale of datasets and records.

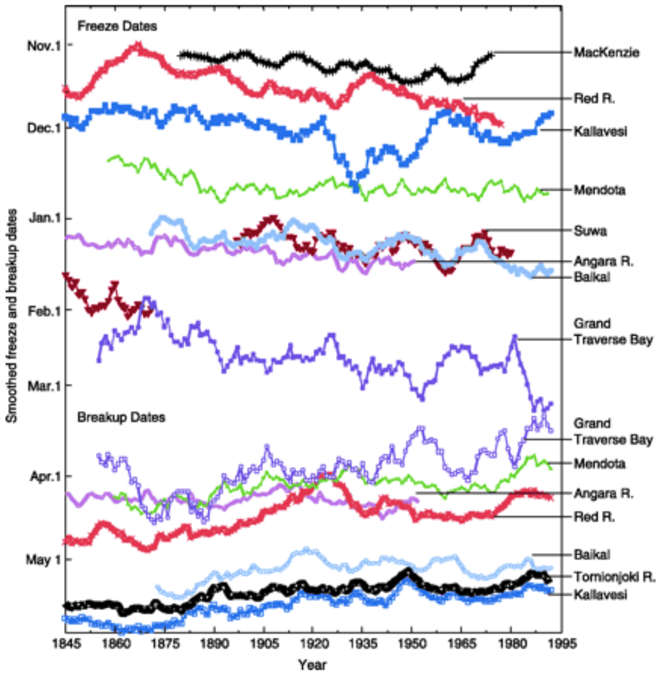
Management implications

Water temperature and ice cover on lakes is relevant to a number of management purposes. For example, warmer water temperatures make power plants less efficient as thermoelectric power plants depend on water for cooling (van Vliet et al. 2012). Changes in the timing of freeze-up and break-up can impact the frequency of toxic algae blooms and biological productivity in drinking water and recreational lakes and reservoirs through changes in temperature and light levels, water circulation patterns, and UV radiation exposure. The life cycles of most aquatic organisms in cold-regions are linked with ice cover and temperature.

The EPA, IPCC, UN, and other entities have used this indicator to illustrate variations, trends, and future risks of freshwater ice relative to climate variability and change in cold regions. Timing of freeze-thaw in rivers and lakes is a critical component of the conceptual framework for phenology or seasonal timing.



Duration of ice cover (top), date of first freeze (bottom), 1850-2010. Images taken from EPA Climate Change Indicators in the United States Available online at: *http://www.epa.gov/climatechange/science/indicators/snow-ice/lake-ice.html*



Times series of freeze and breakup dates for selected Northern Hemisphere lakes and rivers (1846-1995). Data were smoothed with a 10-year moving average. Image from Magnuson et al. 2000.

Dissolved Oxygen

Summary

Dissolved oxygen indicator would use the real-time tracking from the USGS Water Quality Watch network of ~1000 streams. Though the temporal records vary for each site, this network of observational sites provides coverage across the U.S. and its territories and in a range of watershed scales. In the future, other dissolved oxygen NSF supported data sources, such as GLEON, NEON, LTER, LTREB, and biological field stations can be added to improve this indicator.

Background

Dissolved oxygen is an extremely important determinant of freshwater quality, with broad implications for water chemistry and for habitat quality in general. Oxygen concentrations in freshwater systems are directly linked to atmospheric conditions and are governed by a number of links to climate drivers including water temperature via air temperature. Low oxygen concentrations can result from a number of processes including decay of organic material. Enhanced by nutrient pollution, phytoplankton blooms can result in high oxygen demand and consequent water quality impairment. In deeper waters atmospheric oxygen is unable to replenish the dissolved supply, and oxygen concentrations can remain depressed for long periods with important consequences for habitat quality and aquatic organisms.

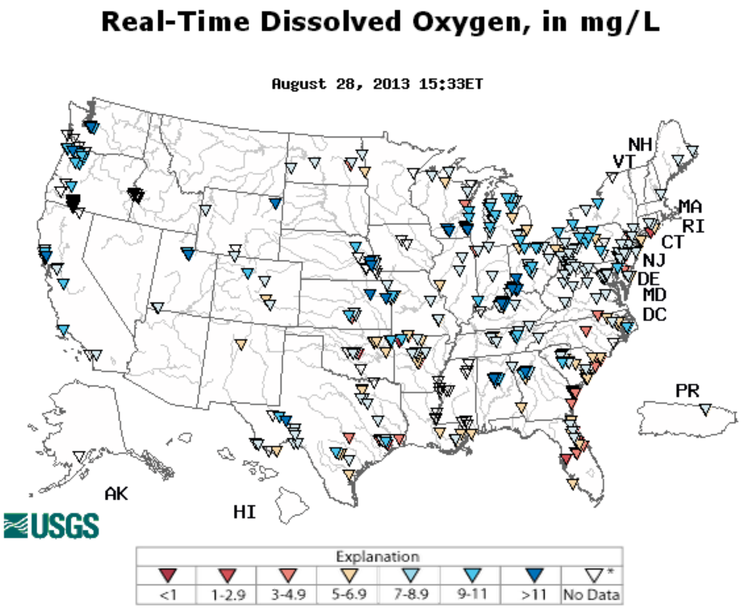
Climate warming has the potential to change the amount of oxygen freshwaters can contain (oxygen saturation), the depth of lake thermal stratification (which will affect the amount of oxygen replenishment from the atmosphere), and the amount of precipitation that regulates terrestrial inputs of nutrients and organic matter. Indeed, climate induced changes in lake thermal structure has been observed in studies in the U.S. (Schneider et al. 2009) and worldwide (Schneider et al. 2010). As a consequence, replenishment of atmospheric oxygen to deep water in lakes will happen less frequently. Climate change is one of several factors leading to higher dissolved organic carbon (DOC) concentrations in many inland waters (Couture et al. 2012 Environ Sci Pollut Res (2012) 19:361–371). These higher DOC concentrations increase oxygen demand, and decrease water transparency, both of which lead to oxygen depletion in deeper waters. Additionally, climate will lead to changes in the timing and frequency of extreme events leading to dramatic changes in sediment and nutrient delivery to lakes, all of which will influence oxygen depletion in these systems. These climate effects can be exacerbated by other stressors such as land use change and anthropogenic pollution.

Data Sources

There are currently a number of networks collecting dissolved oxygen data in both streams and lakes in the U.S. In addition to the USGS gauging network (see figure) which collects near real-time water quality data in streams and reservoirs at more than 1000 monitoring sites across the U.S. (http://waterdata.usgs.gov/nwis/current/?type=quality), the EPA- NARS (National Aquatic Resource Surveys - http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm) provide dissolved oxygen data for lakes, rivers, streams and wetlands, each every 5 years. Numerous smaller networks exist that collect lake oxygen data. Among these are the GLEON network (http://www.gleon.org/Data.php) and the North Temperate Long Term Ecological Research Network (LTER - http://www.lternet.edu/sites/ntl). Once NEON data is streaming it will be integrated into the dataset as well (http://www.neoninc.org/science/domains). In addition to these, many state and municipal agencies maintain water quality databases and moving forward, integration of existing data sources will likely provide a comprehensive dataset of U.S. dissolved oxygen concentrations. Of the existing data sources, there is a trade-off between spatial and temporal coverage. Although the EPA National Lakes Assessment through NARS has excellent spatial coverage with 904 lakes, ponds and reservoirs sampled (EPA 2012), it is conducted only every five years. While this gives an excellent snapshot of lake oxygen conditions, it does not provide the temporal resolution that is important for ecological monitoring. By contrast, GLEON provides good temporal resolution at very few sites. This is uniquely important for lakes, as we can get a wealth of information from 10-20 key locations that reflect climate impacts on a regional basis.

Management Implications

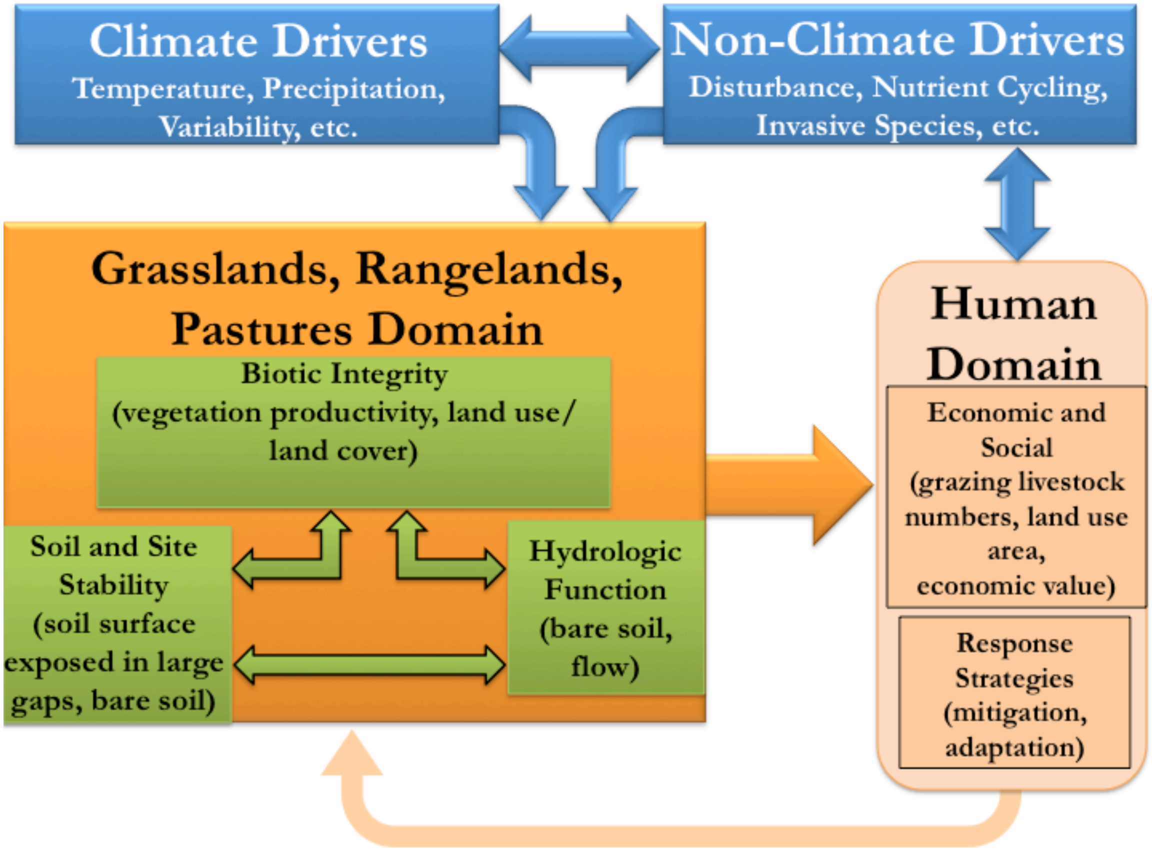
The implications of reduced oxygen concentrations in freshwaters are far reaching with important consequences for fish and other aquatic organisms, for aesthetics and for human health (see figure).



Dissolved oxygen concentrations at USGS gauges (http://waterwatch.usgs.gov/wqwatch/).

Grasslands

Grasslands Conceptual Model



Extensively managed rangelands (e.g. grasslands, shrublands, woodlands) and intensively managed pasturelands (e.g. areas requiring seeding, fertilization, and/or irrigation) encompass enterprises ranging from ranching, mixed ranching-farming, dairy, tourism, lease-hunting, recreation and others with integrated biophysical and social-ecological components, all of which are likely to be impacted by climate variability and change. These systems generate a number of services that support, and in turn are affected by, diverse and interrelated livelihoods. Key provisioning services include forage production, foodstuffs (meat and milk products), game and non-game wildlife and habitat, water quantity (e.g. streamflow, groundwater and aquifer recharge) and quality, air quality (e.g. dust, pollen and allergen production). These are coupled to regulating (e.g. carbon sequestration) and cultural services (tourism, recreation, aesthetics) and vary with changes in production services tied to primary production, nutrient cycling and biodiversity to affect livelihoods, management decisions, and policy. Traditionally, livestock grazing has been the predominant land use in these systems in the US and abroad. However, in recent decades activities on these lands have become increasingly diversified to include lease-hunting, biodiversity conservation, nature-based tourism, and exurban development. These shifts in land use and concomitant changes in climate, climate variability and invasion by non-native species have important, but poorly quantified influences on the services.

Grazing Livestock Number

Summary

This indicator tracks the number of commercial sheep, cattle, and goats (available at the county level) that graze grasslands, rangelands, and pastures. The number of grazing livestock is affected by heat stress, drought, severe winter storms, and indirectly by the amount and seasonality of precipitation. Socio-economic indicators can be derived using this indicator.

Background

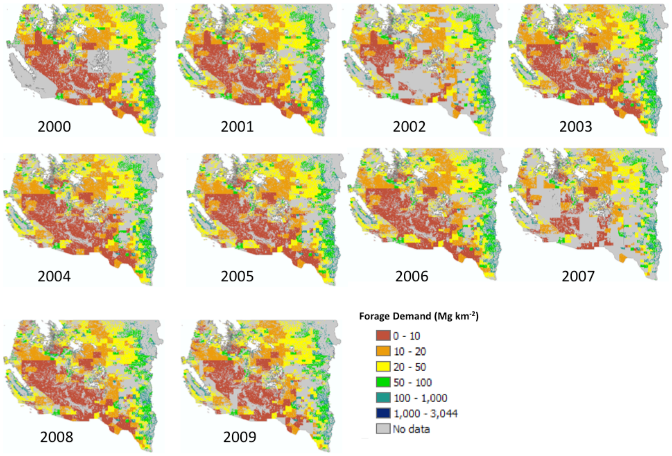
Grazing livestock is defined here as the commercial sheep, cattle, and goats that graze rangeland, grassland, and pastures. The number of each of these livestock types can be standardized to serve as a surrogate for change in livestock number (Forde et al. 1998), forage demand (Evans et al. 2010, Reeves and Mitchell 2012), livestock productivity/weight, mass of meat or fibre produced (Walker et al. 2005, Wilcox et al. 2012), and livestock herd value. The estimate of livestock number will be used to provide a linkage to socio-economic aspects of enterprises associated with grasslands, rangelands, and pastures. Livestock numbers respond to a complex set of factors associated with both natural and social capital resources. These factors include forage production (vegetation productivity) and forage quality (e.g., nitrogen content) and are affected by land use and climate factors such as precipitation and temperature. Drought has a profound impact on livestock numbers (Dean and Macdonald 1994) with major reductions during periods of prolonged episodes of abnormally low levels of precipitation. In addition, social-economic trends also affect livestock numbers due to market pressures and cultural value changes. So interpretation of this indicator will need to keep these interactions in mind to evaluate trends in the number of livestock.

Changes in livestock numbers are readily available from USDA National Agricultural Statistics Service (NASS, Forde et al. 1998, Walker et al. 2005, Wilcox et al. 2012). For example, NASS collects survey data twice a year in January and July for cattle and also collects livestock data during US censuses. NASS has data for sheep (1965 to present), cattle (1873 to present), and goats (1966 to present) including their spatial distribution by school district, county, and state. This data can be directly acquired from the NASS website in tabular (comma delimited) file format (http://www.nass.usda.gov/index.asp,) or customized datasets can be acquired directly from researchers at NASS. Walker et al. (2005) used the NASS data to show the trend in sheep and cattle herds on the Edwards Plateau, TX. Wilcox et al. (2012) used NASS data to show the trend in Texas, and the Heinz Report (2005) looked at the trends in the national livestock herd. Evans et al. (2010), Reeves and Mitchell 2012, and USFS 2012 converted the NASS national grazing livestock data for the grazable portion of US drylands to forage demand at the county and state resolution, i.e., the 6-month forage requirement of an Animal Unit (AU), and produced a time series of spatial maps from 1982 to 2009 of livestock distribution (see figure).

We have compared the forage demand (FD) to the forage available (FA) to livestock in the grazable, i.e., rangelands, of the US from 2000 to 2009 by

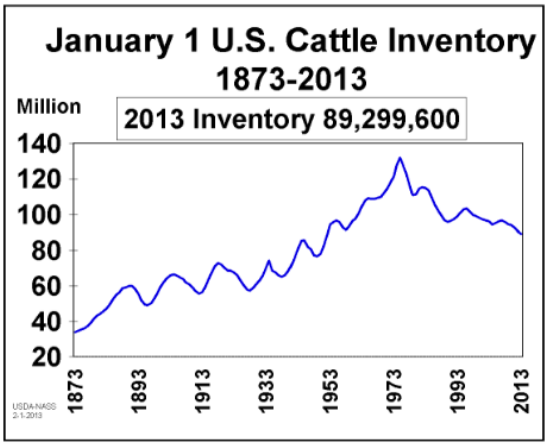
$$\text{FA} - \text{FD} = \text{livestock appropriation of above-ground biomass (LAAGB)}$$

Estimate of the mean impact for this time period indicated minimum impact from livestock (FD) (Reeves and Mitchell 2012). We attributed this to lower numbers of livestock on rangelands due to the drought of the last 10 years in the southwestern United States (Fig. XXXX). In the future we intend to estimate the % of forage appropriated by livestock and wild herbivores in US rangelands in a study comparable to that conducted by Imhoff et al. (2004). These numbers will provide trends on animal sales and weights of livestock products. This information would be useful for both social economic analysis and for relationships to climate trends across the US. Also, modeling efforts suggest that livestock production in the southwestern US will decline as a consequence of predicted climate impacts, while production in northern states may increase (Baker et al. 1993). For example, US livestock numbers in the recession strapped 21st century are at their lowest point of record since the droughts of the 1950's, a period that had similar extreme drought conditions to the southwestern United States in the present (Breshears et al. 2005, Cook et al. 2004, see figure).



The 1-km pixel resolution county-level cattle forage demand (FD) in US drylands from 2000 to 2009. Unpublished data prepared by Washington-Allen, R.A., R. W. Kulawardhana, M.C. Reeves, R. Lankston, & J.E. Mitchell.

Cattle: Inventory on January 1 by Year, US



The US cattle inventory from 1873 to 2013. Values are composite of beef and dairy cattle annual January 1 census estimates from the NASS website. Although more useful at state and regional levels, beef cattle numbers reflect reflects changes precipitation and trends in social-economic factors such as livestock market prices and land use. The 21st century numbers are comparable to the 1950s

Grassland, Rangeland, Pastureland Extent

Summary

This indicator tracks changes in land use and land cover, based on a definition of grassland (i.e. grassland, rangeland, pastures, and shrubland) versus forest. The NLCD, MODIS, FIA and NRI datasets or derived datasets from NASA can be used in conjunction to increase mapping accuracy.

Background

The amount of rangeland at any instant and the associated changes over time are important metrics because they provide the spatial and temporal framework from which all other indicators will be considered. Analysis of this indicator requires a nationally accepted definition of rangeland that encompasses change in land cover, where land cover is the ecological state and physical appearance of the land surface, e.g., grassland, savanna, or shrubland (Dale et al. 2000). Change in land cover is a conversion of land of one type of cover to another (Dale et al. 2000). Lund (2007) has shown that over 300 definitions exist for rangelands with a global extent ranging from 18 – 80% of the terrestrial surface and estimates of degradation ranging from 680 million ha to 3.3 billion ha. Rangeland extent is estimated at 1,035 million acres or 418,849,637 ha using the 2001 National Land Cover Data (NLCD, Homer et al. 2007). The common thread for the agglomerative approach is that rangeland is a "natural" vegetation complex dominated by grasses, grass-like plants, forbs, and (or) shrubs. Thus, by definition, rangelands include indigenous grassland, savanna, shrubland, desert, tundra, alpine, marsh, and meadow ecosystems as well as introduced pasture systems, such as crested wheatgrass, that are managed as "natural" ecosystems. Information has been compiled about the area of rangeland in the United States, but the methods used to estimate said area and detect change have varied. The most consistent and most commonly used assessment of non-federal rangeland area and change has been the Natural Resource Conservation Service (NRCS) National Resources Inventory (NRI) that has been collected since the 1970s (Nusser and Goebel 1997). Of interest here are the reported changes in rangeland area between the five-year periodic inventories (USDA Soil Conservation Service 1987; USDA Natural Resource Conservation Service 1995; Mitchell 2000, p 19, Table 26). On the other hand, no periodic inventory of federally owned rangelands is available. Further, the extent of federal rangeland has not been consistently determined across agencies and over time (Mitchell 2000). A consistent methodology assessing the area of rangeland and the temporal change in area could be implemented across the US, offering a repeatable method to track rangeland area.

The internationally accepted definition of Drylands is a biophysical quantitative definition called the aridity index (AI) which is the ratio of mean annual precipitation (MAP) to mean annual potential evapotranspiration (MAPET) (United Nations Environmental Program (UNEP) 1993, United Nations Environmental Program (UNEP) 1997, Reynolds 2001, Millennium Ecosystem Assessment (MEA) 2005). The AI has a range between 0.0 and 0.65 and 195 countries were party to and agreed upon this definition in 1994 as an integral part of the United Nations Convention to Combat Desertification (UNCCD), including the USA. The MEA (2005) recognized different land use types within Drylands, including rangeland and cropland. Land use refers to the purpose for which land is put, e.g., grazing land or forestry for timber (Dale et al. 2000). Within the USFS (2012) and Reeves and Mitchell (2012), the grazeable area of the US or rangeland is defined as the intersection of the Dryland AI and the rangeland cover types in the 2001 NLCD (see figure). This allowed comparisons to international assessments of US Dryland condition and incorporated the Heinz reports land cover components.

There are four sources of data that can be readily used for this indicator: 1) the 2001 and 2006 NLCD (Homer et al. 2007, Fry et al. 2011, http://www.mrlc.gov/, see figure); 2) the remotely sensed Moderate Resolution Imaging Spectroradiometer (MODIS) 500-m Yearly (from 2001 to 2010) Global Land Cover Product (see figure); 3) the previously mentioned NRCS NRI data for non-federal lands and the currently the most commonly used assessment data; and 4) the USFS FIA data which includes some rangeland sites.

The NRI current sampling and analysis procedures have evolved over time and now incorporate the use of aerial photography to provide remote sensing information as well as ground-based inventories. The NRI data analyses now include enhanced estimation techniques for missing values and weighting procedures that incorporate controls from other data sources and from previous surveys (Nusser and Goebel 1997). The NRI estimates now offer the opportunity to use GIS-based semi-quantitative interpolation methods to map rangeland area (Herrick et al. 2010). The Forest Service also conducts inventories of public and private land, primarily focusing on forestland attributes.

A remote sensing approach has advantages including a wall-to-wall consistent approach, and identification of gross forest cover changes, but interpretation can still be misleading especially regarding temporary loss of cover that is identified as conversion to nonforest (Hansen et al. 2010).

The National Land Cover Dataset and the MODIS LULC datasets can be used in conjunction with the FIA and NRI estimates to increase mapping accuracy. Methods continue to be refined which will improve the results and interpretation, so the approaches used for this indicator may likely need to be periodically updated, and the metrics recalculated for consistency over time.

Health

Health Conceptual Model

Attached are a series of conceptual models that relate the impacts of climate change to indicators of human health, including a general model (see figure). There are also indicator specific models for extreme heat, incidence of *Vibrio* cases, and *Lyme* disease (not included in this summary).

These conceptual models demonstrate how human health is affected by natural and anthropogenic climate change, moderating (non-climate) factors, the determinants of risk, and pathways that influence health effects and contribute to indicators of human health. These models summarize how exposure and the vulnerability of people to climate variability and change together with hazards associated with climate change determine the nature and extent of the risk to human health. These models also consider the role of prediction and prevention as these processes intervene in the pathways of effects, their interactions with health effects, and ultimately with health indicators. In addition, these models suggest how adaptation and mitigation strategies may directly address both anthropogenic climate change and other non-climate factors.

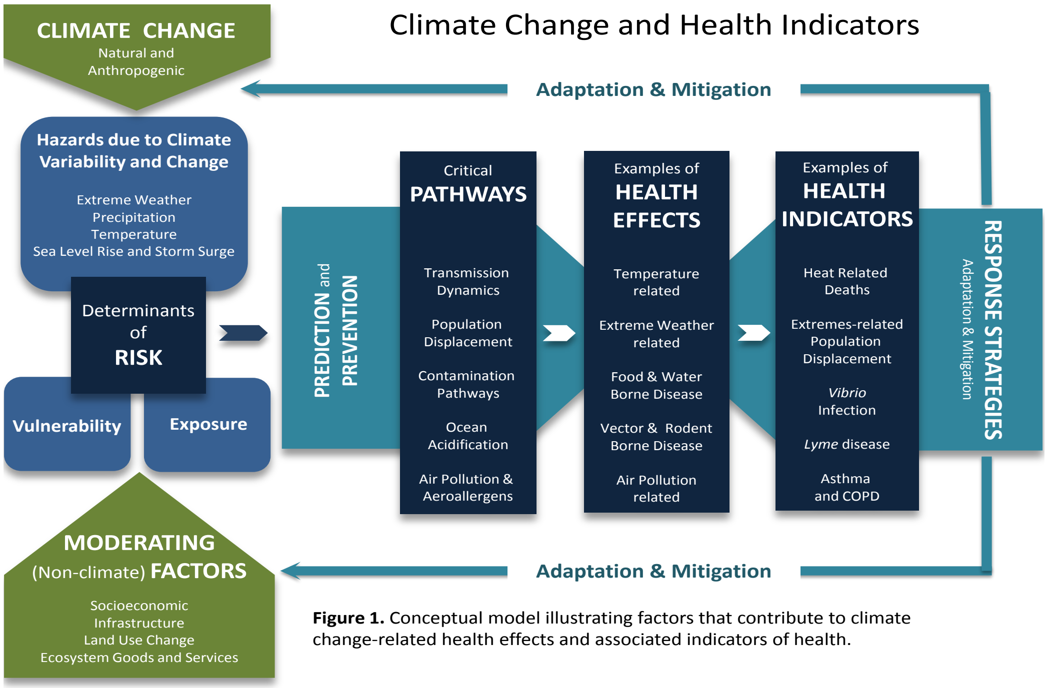


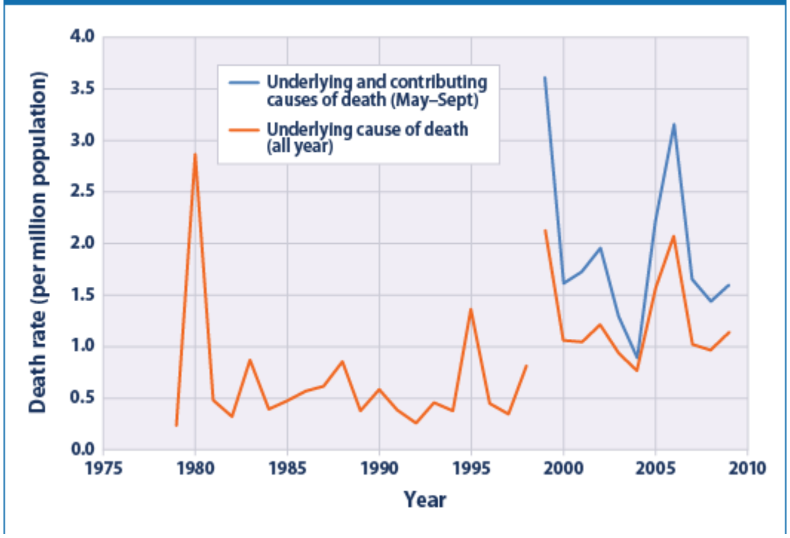
Figure 1. Conceptual model illustrating factors that contribute to climate change-related health effects and associated indicators of health.

Rates of Heat Related Mortality

Summary

The rate of heat-related deaths is directly related to extreme heat events in the US and, therefore, directly associated with a weather-related impact of climate change. The data are reported on death certificates as the underlying cause or a contributing factor. They are collected by the CDC's NCHS and displayed on the NEPHT website. The indicator data are available from 1979 through the present and can be displayed in the forms of graphs, charts, tables, or maps down to the state level. These data can be analyzed to the county or metropolitan level.

Figure 1. Deaths Classified as "Heat-Related" in the United States, 1979–2009



Background

Extreme heat events, characterized by consecutive summer days of high maximum and minimum daily temperatures, are the most prominent cause of weather-related human mortality in the U.S., responsible for more deaths than flooding, lightning, hurricanes, tornados, and earthquake combined. From 1999 to 2003, a total of 3442 heat-related deaths were reported in the U.S. People most vulnerable for dying during a heat event include the elderly, poor, urban dwellers, socially isolated, and those suffering from some pre-existing health conditions such as heart disease and obesity. Increasing urbanization combined with an aging population and limited support networks for the poor will increase both the size and the vulnerability of the at-risk populations in coming decades.

Climate change is already increasing temperatures in the U.S. and globally. The Intergovernmental Panel on Climate Change (IPCC) has determined that it is very likely that there has been an increase in the number of warm days and nights globally since 1950 and likely that these increases have been seen in North America. The IPCC also projects that it is very likely that the length, frequency, and intensity of heat waves will increase throughout the 21st century with 1-in-20 year hottest day events likely to become 1-in-2 year events in North America. Numerous studies have shown that increased temperatures during heat waves are directly related to increased mortality in many urban areas.

Incidence of *Vibrio* Cases

Summary

Vibrio can rapidly increase in size in warm marine water and as a result it has been suggested that there will be a rise in Vibrio, both population and geographic range, with a rise in sea surface temperatures (SST). In the U.S., laboratory confirmed incidences of Vibrio infection are reported to the CDC by state health departments. Prior to 2007, only Vibrio cholerae was reported. All incidences of Vibrio confirmed infections have been reportable nationally since 2007, but there is likely underreporting because incidences of Vibrio are not easily identified on routine enteric media in the laboratory.

Background

In the U.S., pathogenic *Vibrio* species cause human infections and disease through two main water-based exposure pathways: consumption of shellfish and exposure of wounds to seawater. Because of their typical transmission routes, incidence of *Vibrio* cases are currently reported by the CDC as part of both foodborne and waterborne (recreational) illness disease summaries. In 1988, CDC began compiling data on waterborne disease outbreaks associated with recreational water exposure. Information on outbreaks attributable to *Vibrio* was added in 2003 (Yoder et al. 2008). Separately, CDC collaborated with the Gulf Coast states (Alabama, Florida, Louisiana, Texas, and Mississippi) prior to 2007 to collect information on *Vibrio vulnificus* and other *Vibrio* infections associated with food (Centers for Disease Control and Prevention, 2011-4). Since 2007, incidence of *Vibrio* cases have been included in the list of nationally notifiable diseases (Centers for Disease Control and Prevention, 2011-3 and 2011-4) although it is widely believed that *Vibrio*-attributable cases are underreported (Centers for Disease Control and Prevention, 2011-3 and 2011-4; Dechet et al. 2008).

Vibrio, unlike many other human pathogens, grows naturally in marine waters (i.e., a human host is not required). Because coastal waters and associated marine organisms (e.g., oysters, plankton, including copepods) are their primary habitat, under appropriately warm conditions these bacteria can quickly expand their population size through a fast replication time (as temperatures increase so does replication rate). In some cases, *Vibrio* population levels (abundance) can double within in a few hours.

Given the links between increasing water temperatures, increasing *Vibrio* replication rates, and the seasonality of *Vibrio*-attributable disease, it has been suggested that the anticipated rise in sea surface temperatures associated with climate change may expand the geographic and temporal range of *Vibrio* pathogens and the associated disease/illness (Martinez-Urtaza et al., 2009). Recent observations suggest the geographic range of *Vibrio* species is already expanding. While the highest rates of *Vibrio*-attributable disease in the United States are still observed in Gulf Coast states, disease surveillance data from 2001-2008 show an increase in the proportion of cases from more temperate areas, especially Pacific coast states (COVIS, 2008).

In addition to expansion in geographic range, evidence suggests the temporal range of *Vibrio*-attributable illness/disease may also be expanding. Recent surveillance data suggest incidence of *Vibrio* cases in the United States are increasing in the historically ‘tailing’ months of April and November in the distribution of *Vibrio* cases. For example, prior to 1997 most *Vibrio*-attributable cases, especially those attributable to *Vibrio vulnificus*, were confined to the months of May through October (Martinez-Urtaza et al., 2009). However, from 1997 - 2008, the number of April days where water temperatures exceeded 20^{o}C increased by an average of 5 days in the northern Gulf of Mexico. At the same time, a three-fold increase in incidence of *Vibrio vulnificus* cases was observed in this region (Martinez-Urtaza et al., 2009).

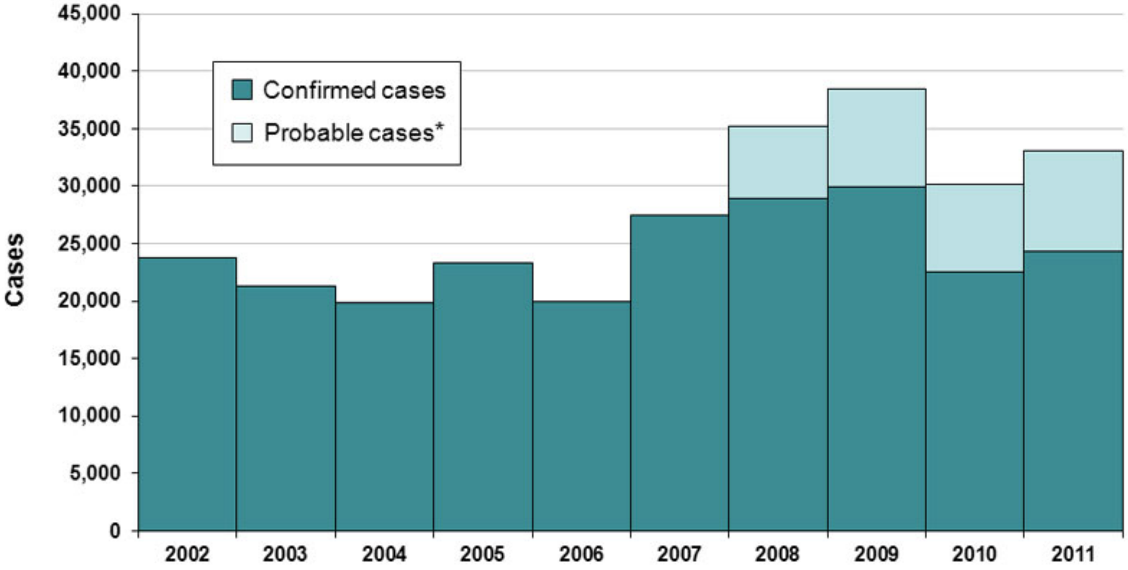
Lyme Disease

Summary

There is evidence that the Lyme disease is spreading because warmer temperatures (minimum and maximum) increase habitat suitable for ticks that carry the disease. The proposed indicator is the number of confirmed and possible cases of Lyme disease in the U.S. using data from the CDC.

Background

Lyme disease first emerged as a distinctly diagnosed disease in Connecticut in the late 1970s, although it may have been present much earlier in North America (Steere et al. 1978). Lyme disease is the most commonly reported vector-borne illness in the US and was the sixth most frequently reported nationally notifiable disease in 2011 (CDC 2012). The national counts of confirmed cases of Lyme disease varied over time; from 2000 to 2006 annual counts were roughly 17,000–24,000 cases per year. The number of recorded confirmed cases increased from 27,544 cases in 2007, 28,921 cases in 2008, and 29,959 cases in 2009, and then decreased in 2010 to 22, 561. There were 24,364 confirmed cases and 8,733 probable cases in 2011. Thirteen states accounted for 96% of all new confirmed cases in 2011; these states are in the northeastern mid-Atlantic and Minnesota-Wisconsin region.



Lyme disease is caused by the bacteria *Borrelia burgdorferi*. The bacterium is maintained primarily in small mammalian and avian reservoir hosts (Gray 1998). Transmission mainly occurs from the bite of an infected blacklegged tick [deer tick]. *Ixodes scapularis* is the primary human transmission vector for the bacterium, particularly in the eastern United States. *Ixodes pacificus* (the western blacklegged tick) is the second most common vector and is believed to be responsible for the majority of new confirmed cases of Lyme disease among residents in the Pacific region (Dennis et al. 1998).

Blacklegged ticks have a two-year, three-stage lifecycle requiring a blood meal to pass through to each life stage (from larva to nymph and nymph to adult). Human transmission depends primarily on three factors: blacklegged tick survival, pathogen survival, and opportunities for human-tick interaction. These factors, in turn, are determined by other factors, such as the abundance of deer and other larger mammals to support development of adult ticks and the presence of suitable reservoir hosts for the *Borrelia*, which include small mammals and birds.

Blacklegged tick survival is directly affected by environmental conditions, with weather conditions, such as minimum and maximum temperatures, playing a key role in tick activity. Climate also influences tick habitat, including the type and abundance of local vegetation, soil, and topography, therefore influencing tick survival. Similarly, climate and weather can affect small mammals and deer, both of which are important sources of blood meals for ticks (Guerra et al. 2002).

The survival of the *B. burgdorferi* bacteria depends on maintaining sufficient population densities of blacklegged ticks and of reservoir hosts, and the number and quality of opportunities for the bacteria to be transmitted to the ticks during feeding. Larvae, nymphs, and adult female blacklegged ticks can acquire *B. burgdorferi* while feeding on an infected reservoir host or when uninfected ticks feed together with infected ticks on the same reservoir host (Gern and Rais 1997; Ogden et al. 1997; Nuttall et al. 2000).

Transmission of the bacteria to humans ultimately depends on a sufficient number of encounters between infected blacklegged ticks and humans.

The geographic distribution of Lyme disease in the U.S. has increased significantly over the last 15 years, and there is evidence that the disease is spreading from currently endemic locations in the northern U.S. into Canada (Ogden et al. 2008; Hamer et al. 2010; CDC 2012). Ticks can be transported while feeding on host animals (e.g. mice, deer, birds). As a result, much of the spread of Lyme disease may be attributable to the creation and maintenance of habitats that are suitable for host species and blacklegged ticks.

Factors associated with current and potential future distributions of *Ixodes* ticks (primarily *I. scapularis*) include (Brownstein et al. 2003; Diuk-Wasser et al. 2010; Ogden et al. 2008):

- Maximum, minimum, mean temperature
- Monthly vapor pressure
- Degree days > 0°C
- Habitat forest cover
- Migrating birds
- Altitude

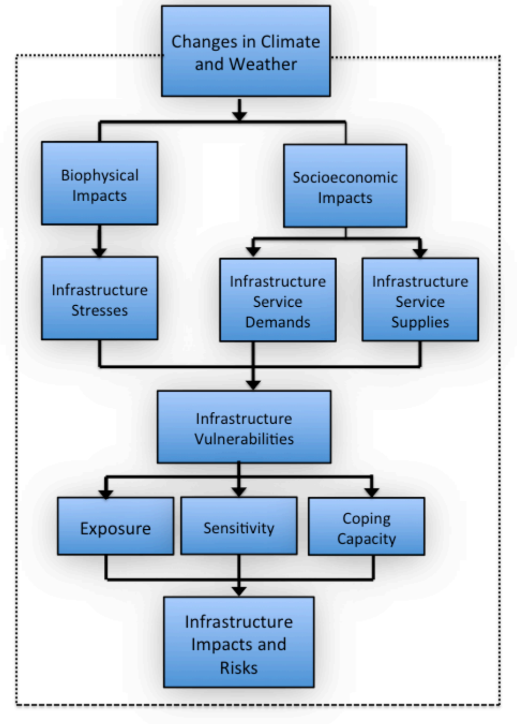
Within these studies, warmer temperatures associated with climate change may mean that the total accumulated heat energy, often referred to as degree days, required by ticks to complete their physiological development will be reduced in some regions, notably the Appalachians region. Further, changes in vegetative cover resulting from a climate change induced earlier spring and later fall seasons could increase the temporal activity of *I. scapularis*.

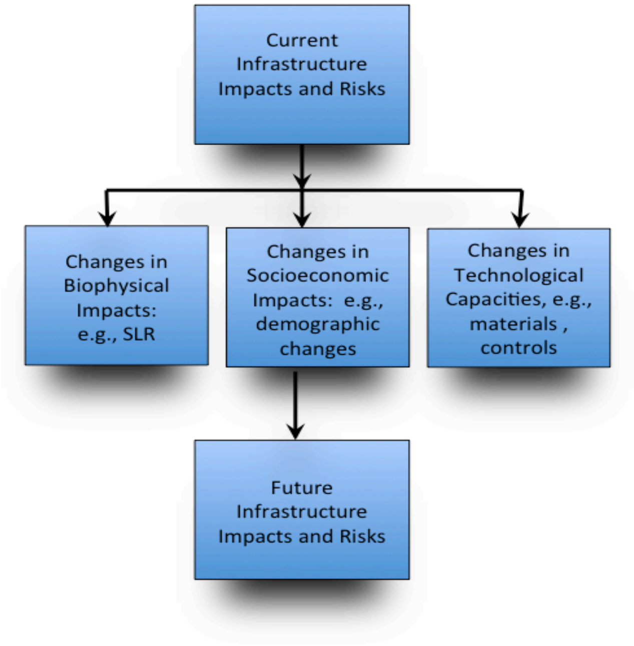
Infrastructure

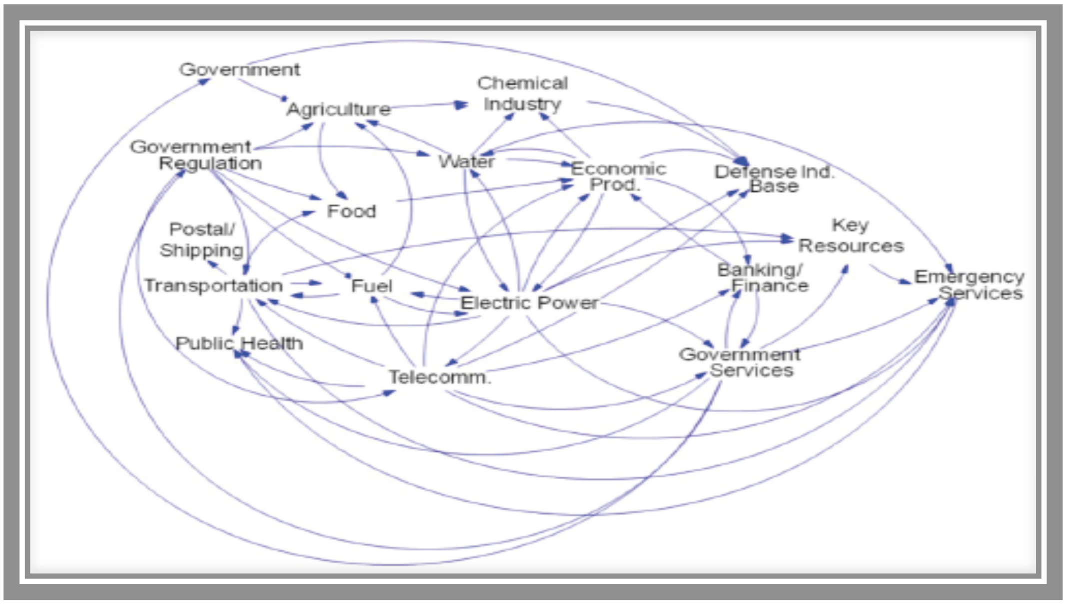
Infrastructure Conceptual Model

Because cross-sectoral infrastructure impacts of climate variability and change have not been a focus of significant published research – but rather have been informed by sector-specific studies, private sector reports, and responses to disruptive events – these indicators are supported by a consensus of government, private-sector, NGO, and academic experts, as represented by the 2012 technical input report to DOE for the National Climate Assessment (ORNL, 2012) and subsequent conference and workshop discussions (e.g., the annual Carbon Management Technology Conferences of the nation's engineering associations and a conference in January 2013 on Climate Change and America's Infrastructures, Tempe, AZ). In most cases, published research literature on recommended indicators is only a beginning, not a mature rationale.

After these indicators, the team suggests several types of contextual information needed to support impact and response assessments (i.e., to evaluate the significance of changes in indicator values), and it suggests several additional variables that should be tracked for future reference.







(ORNL, 2012)

Many of these categories of information are likewise developmental, in some cases requiring R&D focus (e.g., on defining "resilience") and other cases probably calling for experiments with innovative approaches. Examples of innovative approaches could include expert elicitation and data-mining of reports from internet sites, in both cases utilizing standardized methodologies to support replication and comparison over time.

Disaster and Emergency Declarations by FEMA

Summary

An indicator that is qualitatively related to the types of events of concern is the number of times that FEMA declares major disasters and emergencies (two out of their three-point scale). This indicator is reported at a national level and can be tracked easily. More targeted indicators remain to be derived.

Background

The primary indicator of changes in impacts through time is a measure of infrastructure service outages, although driving forces include factors other than climate effects alone. Data on outages are collected for some infrastructures on a sector-specific basis, especially telecommunications: e.g., electricity supply, transportation, and water – often by the industries themselves rather than the federal government. Such emergency response agencies as FEMA maintain data bases on major disruptions, and the insurance/reinsurance industry maintains data bases on economic costs of disruptions. But there is no comprehensive US government data base on infrastructure outages, in which the range of sectors is addressed in a consistent manner.

Developing a composite indicator of levels and trends in infrastructure outages and costs, reflecting cross-sectoral relationships and interdependencies, would provide a valuable tool for strategic planning, iterative risk management, and discussions of investment needs and priorities.

Geographic scope and scale of analysis: Could be developed at national and regional scales for annual or quarterly time periods, given comprehensive outage data and a composite indicator.

Nature of supporting data: Comprehensive multi-sectoral data on infrastructure service outages and costs.

Composition (how the indicator is created): To be determined – a developmental objective.

Advantages/disadvantages: The advantage would be a simple descriptor of US infrastructure impacts and vulnerabilities, for monitoring status and changes. As with any composite indicator, the disadvantage would be a lack of detail about sectoral impacts and relationships (see supplementary indicators below).

Data: Such an indicator would require continuing data collection and storage regarding infrastructure service outages in at least a number of critical infrastructures, consistent across sectors in the metrics, time frames, and conceptual structures.

The best prospect for an interim indicator of infrastructure outages is FEMA’s data regarding disasters and other disruptive incidents. FEMA’s National Response Coordination Center (NRCC) is supported by a Situational Awareness Section (SAS), which collects, analyzes, and reports on “incidents” at three different activation levels (according to the seriousness of the event). The best summary statistic appears to be the number of major disaster declarations and emergency declarations by FEMA by year: see http://www.fema.gov/disasters/grid/year (see table).

U.S. Disaster Declarations by Year, FEMA

Year	Major Disaster Declarations	Emergency Declarations	Total
2012	47	16	62
2011	99	29	128
2010	81	9	90
2009	59	7	66
2008	75	17	92
2007	63	13	76
2006	52	5	57
2005	48	68	116
2004	68	7	75
2003	56	19	75
2002	49	0	49
1992	45	2	47
1982	24	3	27

Status of the Nation's Infrastructure

Summary

A reasonable, although imperfect pilot indicator is the "Report Card on America's Infrastructure," published annually by the American Society of Civil Engineers (ASCE). It provides qualitative grades for sixteen infrastructure categories, and a comprehensive report is published every four years, although particular infrastructure categories can be the subject of special reports in between comprehensive assessments.

Background

It is widely agreed that a comprehensive measure of the resilience of infrastructure is the most important indicator of infrastructure vulnerability and coping capacity, if it can be measured (e.g., ORNL, 2012). Unless and until it is possible to assess whether one infrastructure is more or less resilient than another, and whether a particular infrastructure is becoming more or less resilient, and whether a proposed intervention is likely to increase resilience by a desired degree, implications of climate change (and other driving forces) can only be evaluated in a partial, piecemeal fashion related to particular threats.

As "resilience" has become a widely used term, connoting positive accomplishments in contrast to negative connotations of "vulnerability," efforts to propose definitions and metrics have also emerged. Examples include Cutter, 2008; Wilbanks and Kates, 2010; and Vugrin et al., 2010. But potential users of such metrics – such as public and private finance and insurance decision-makers – do not yet see metrics that are robust enough to serve as a basis for resource allocations. We are not there yet. At a meeting of the Infrastructure Subcommittee, Homeland and National Security Committee, OSTP, on March 13, 2012, it was agreed that developing better resilience measures and resilience evaluation approaches is among the nation's highest R&D priorities for improving capacities to answer high-priority national infrastructure questions.

Geographic scope and scale of analysis: A developmental issue. An annual national indicator, with potentials to be applied regionally and sectorally.

Nature of supporting data: To be determined.

Composition (how the indicator is created): To be determined.

Data: Widely accepted metrics do not exist: e.g., measures of infrastructure and community resilience, sheltering capacities, healthcare facilities, transportation network alternatives in case of disruptions – although work is under way for some infrastructures in some locations. OSTP/DHS are interested in developing a workable approach for such an indicator in order to assess priorities for improvements and to track changes through time.

A way forward in the near term: The American Society of Civil Engineers (ASCE) issues a periodic Report Card on sixteen infrastructure categories, each of which get a letter grade based on a combination of quantitative and qualitative criteria (e.g., number of bridges that have been declared structurally deficient). Comprehensive assessments are produced for the nation every four years, along with periodic assessments for states and sectors using the same methodology. For example, ASCE released a study on the nation's water infrastructure in 2011, midway between the all-infrastructure report cards in 2009 and 2013. Grades are based on eight criteria (capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation). A is defined as exceptional, B as good, C as mediocre, D as poor, and F as failing. Along with the grades, ASCE estimates cumulative investment needs by infrastructure category in order to achieve a grade of B, based on current trends. The table shows examples of report cards since 1998.

One approach for NCA infrastructure indicators in the short run, while better resilience metrics are developed, would be to adopt the ASCE assessment results as an interim indicator of US infrastructure resilience. This appears to be the only existing periodic assessment of US infrastructure vulnerabilities that applies a consistent methodology across the range of infrastructure sectors.

ASCE US Infrastructure Report Cards http://www.infrastructurereportcard.org

	1998	2001	2005	2009	2013
Bridges	C-	C	C	C	C+
Dams	D	D	D+	D	D
Drinking water	D	D	D-	D	D
Energy	-	D+	D	D+	D+
Roads	D-	D+	D	D-	D

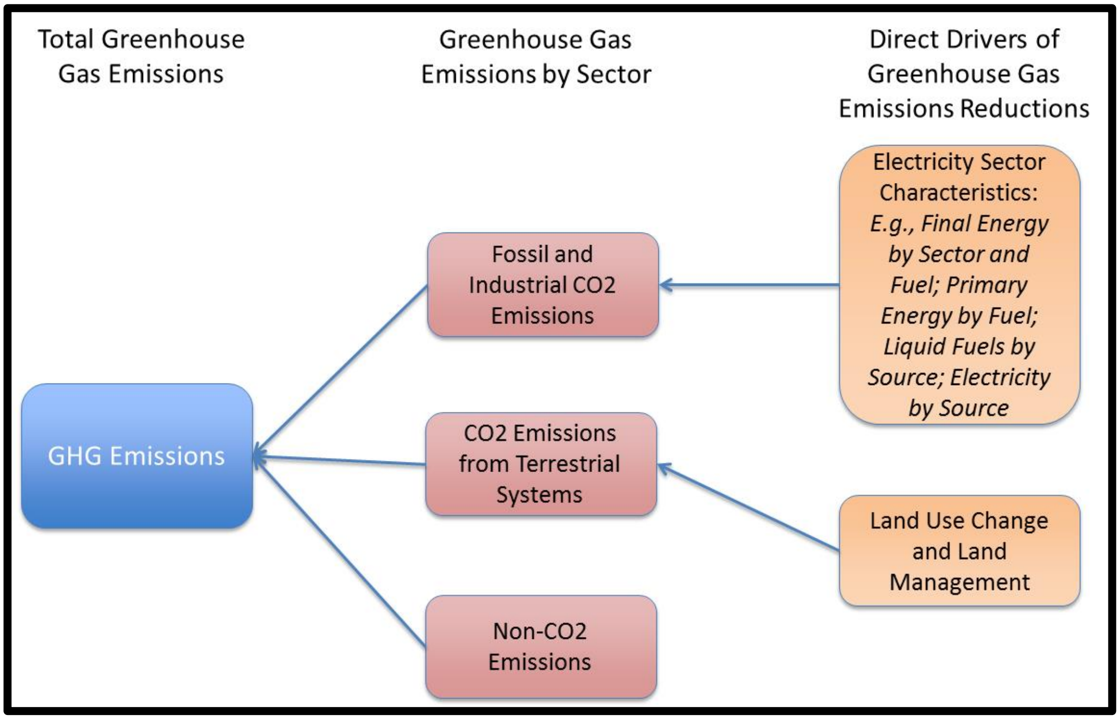
Solid waste	C-	C+	C+	C+	B-
Wastewater	D+	D	D-	D-	D
National Infrastructure GPA	D	D+	D	D	D+
Cost to Improve, in $ Trillion	-	1.3	1.6	2.2	3.6

Mitigation/GHG

Mitigation/GHG Conceptual Model

There are three categories of core indicators (see figure) proposed for the pilot indicators system: (1) total greenhouse gas emissions, (2) greenhouse gas emissions by sector and (3) selected direct drivers of greenhouse gas emissions. Total greenhouse gas emissions can be used to generate aggregate metrics such as emissions per capita or emissions per unit of economic output. Greenhouse gas emissions by sector are separated into three categories: CO_2 emissions from fossil fuel and industrial sources, CO_2 emissions from terrestrial systems, and non-CO_2 emissions. There are an enormous number of drivers of greenhouse gas emissions. The core indicators focus on key indicators of the energy system and key indicators of land use change and land management activities.

The remainder of this section discusses the nature of each of these different categories, sources of information, and issues that would need to be addressed in collecting these indicators. A more thorough discussion of each indicator individually is provided in the appendix to this report. In each of the following sections, we identify primary and secondary indicators along with a discussion of issues and gaps. The primary indicators are those that would be featured prominently on the indicators website. Secondary indicators are those that are also valuable, but may not rise to the level of primary indicators given space constraints. We recommend both the primary and secondary indicators for the pilot indicators system, but if a smaller set is required, then the split between primary and secondary indicators provides a means to develop a smaller set.



Overview of Core Indicators

Total GHG Emissions by Source and Gas

Summary

At a national level, this indicator is a fundamental measure of the anthropogenic sources of all relevant GHG emissions. Differentiation by source and gas is a key component that is important to policy and decision-making stakeholders at national and state levels, and in the private sector. This indicator uses EPA's U.S. Inventory of Greenhouse Gas Emissions and Sinks and is often reported as CO_2-equivalents.

Background

Greenhouse gases absorb heat and warm the planet. Human activities are responsible for almost all of the increase in greenhouse gases in the atmosphere over the last 150 years (IPCC 2007). EPA currently has an indicator of all GHGs covered under the UNFCCC (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) by type and source. EPA's indicator has been cited by decision makers in both the public and private sector and across the political spectrum in order to illustrate anthropogenic impacts on climate change.

This indicator will cover the same gases as the EPA indicator broken down by their emission source. In all probability, this will be electricity, other energy conversion, the three end uses individually (buildings, industry, and transportation), and land use and land use change. The indicator will represent direct emissions from these sources, which means that electricity emissions will be accounted for in the electricity sector rather than in the end use sectors. The indicator could be accompanied by normalized indicators (e.g., emissions per unit of GDP or emissions per capita). Only national level emissions for the U.S. will be included in this indicator.

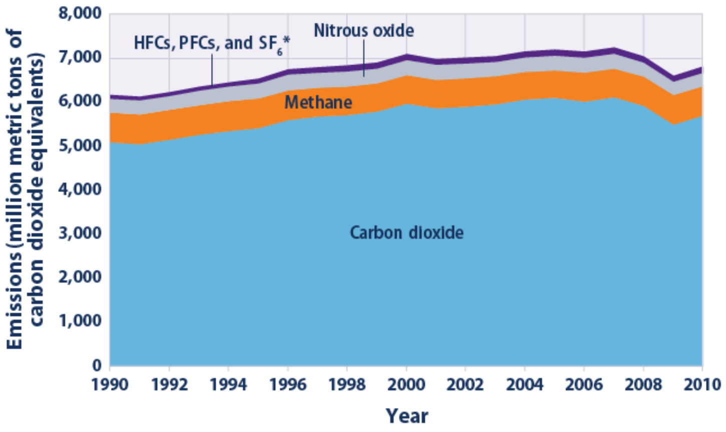
Data and Methods

World Resources Institute's (WRI) Climate Analysis Indicators Tool (CAIT) compiles data from peer-reviewed and international GHG inventories developed by EPA and other government agencies worldwide. Global estimates for carbon dioxide are published annually, but estimates for other gases, such as methane and nitrous oxide, are available only every fifth year. UNFCCC has more comprehensive data; however these data are only for highly developed countries, which only accounts for about half of global GHG emissions. CAIT includes GHGs by type (CO2, CH4, N2O, several F-Gases) and source (energy, industrial processes, agriculture, waste, land use, etc.). The Emissions Database for Global Atmospheric Research (EDGAR) also provides global past and anthropogenic emissions of GHGs by country. EDGAR and CAIT are highly comparable as they share many of the same data sources (EPA 2012).

In order to provide useful information to decision makers, this indicator will report emissions by gas normalized by CO_2 equivalent (CO_2-e). CO_2-e is used to compare different GHG emissions based on their global warming potential (GWP). GWP is a measure of the amount of energy that a gas absorbs over a period of time compared to CO_2. For example, the 20 year GWP for N_2O is 289 (IPCC 2007), which means that one ton of N_2O will trap 289 times more heat than one ton of CO_2 over the next 20 years. CO_2-e can be calculated by multiplying the tons of the gas by its GWP: CO_2Eq = (tons of given gas) * (GWP of the gas). It is important to keep in mind that there is some degree of uncertainty when comparing GHG emissions using this metric as there is no universally agreed upon value for the GWP of the gases covered by this indicator.

Furthermore, different time horizons provide drastically different CO_2-e values. For example, the 20 year GWP for methane is 72, while the 100 year GWP is only 25. This illustrates the importance of reporting CO_2-e values across several time horizons for each gas. For this indicator we will use GWP values from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC) calculated for the 100-year time horizon

U.S. Greenhouse Gas Emissions by Gas, 1990–2010



Data source: U.S. EPA (U.S. Environmental Protection Agency). 2012. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2010. USEPA #EPA 430-R-12-001. www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

U.S. GHG Emissions by Gas, 1990-2010

Fossil and Industrial CO_2 emissions

Summary

CO_2 emissions are the largest single component of anthropogenic GHG emissions, and have dominated the mitigation policy discussion for many years. Data since 2010 is available through the EPA GHG Reporting Program and the DOE Energy Information Administration (EIA).

Background

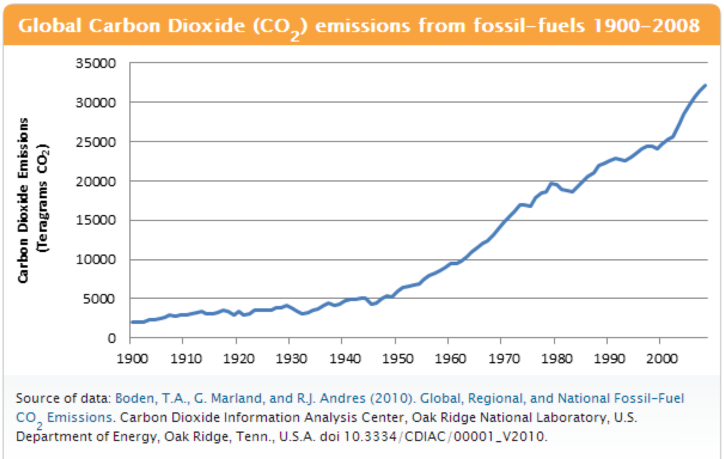
Emissions from fossil fuel burning represent the largest anthropogenic source of carbon to the atmosphere and are an important contributor to elevated atmospheric CO_2 levels (ORNL). Many industrial processes emit CO_2 through fossil fuel combustion. However, some industrial processes emit CO_2 through chemical reactions (e.g. the production and consumption of mineral products such as cement, the production of metals such as iron and steel, and the production of chemicals) Fossil fuel combustion from various industrial processes accounted for about 14% of total U.S. CO_2 emissions and 12% of total U.S. greenhouse gas emissions in 2011. (EPA 2013).

Annual U.S. CO_2 emissions fell by 419 million metric tons in 2009 (EIA 2011). One of the key factors of this decrease included an economic recession with a decrease in GDP of 2.6%. An indicator for fossil and industrial CO_2 emissions is therefore useful for monitoring trends in emissions, especially as the economy begins to recover.

Data and Methods

Both EPA and EIA provide information on CO_2 emissions. However, these two sets are not fully consistent. Differences include the following: coking coal is an industrial process emission under the EPA nomenclature; there are some differences in the calculation of emissions and carbon capture from non-energy uses of fossil fuels; the EPA value does not include bunker fuels per international protocol; the EIA data set does not include U.S. Territories. In addition, the two sets are developed on different time scales. Finally, it is worth noting that EIA no longer estimates industrial emissions, only those from the energy sector. This means that industrial CO_2 emissions would need to be developed from EPA data. In certain cases the two agencies employ differing carbon factors.

Publications containing historical energy statistics make it possible to estimate fossil fuel CO_2 emissions back to 1751 (see Boden et al. 2012 for list of sources). The Carbon Dioxide Information Analysis Center (CDIAC) has compiled these data sources to provide a full record of historical fossil fuel CO_2 emissions (Boden et al. 2010). Each year, CDIAC generates estimates of carbon releases from fossil-fuel consumption. CDIAC provides data for CO_2 emissions from fossil fuels broken down by fossil and industrial sector. Most likely, the fossil and industrial sectors will be electricity generation, other energy conversion, and the three end uses (buildings, industry, and transport). Cement may be removed from the industrial sector and treated separately.



Source of data: Boden, T.A., G. Marland, and R.J. Andres (2010). Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2010.

Global CO_2 Emissions from Fossil Fuels (1900-2008)

Change in Terrestrial C Stock

Summary

The US calculates annual net emissions of CO_2 from land-cover and land-use change as part of its annual emissions inventory, which is reported periodically to the Framework Convention on Climate Change, and is used domestically in a wide range of mitigation and carbon cycle discussions and research. The annual calculation is done primarily through USDA and DOI programs that calculate inventory change in several land classes, and thus evaluate both sources and sinks of CO_2 due to land-use change.

Background

Climate change and increasing GHG emissions have recently drawn attention to the need to assess and monitor trends in the amount of carbon that is present in terrestrial systems. Changes in terrestrial carbon stocks reflect the net impact of many factors that cause both emissions of greenhouse gases from the land and removal of greenhouse gases from the atmosphere. The net changes are reported separately for the 4 different land classes, and historically, the net change in agricultural carbon stocks represents a source of emissions to the atmosphere while the net change in forest carbon stocks represents a net removal of carbon from the atmosphere that is significantly larger than the emissions from agriculture, making the entire land base a net carbon sink. Because not all causes of changes in carbon stocks are reported for all land classes, it is difficult to attribute observed changes to any specific mitigation activities.

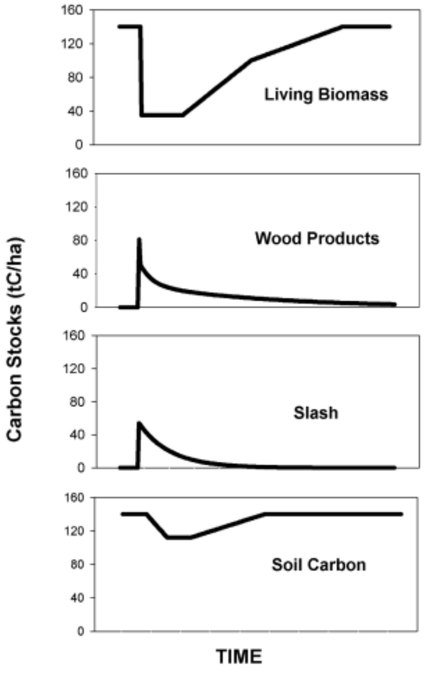


Figure 1. A set of idealized response curves showing the per hectare changes in carbon that follow the clearing of forest for cropland and, subsequently, the recovery of forest on abandoned cropland. Negative slopes indicate a loss of carbon to the atmosphere; positive slopes, the accumulation of carbon on land.

Data and Methods

This indicator is composed of annual estimates of the net exchange of CO_2 between the land and the atmosphere for the US, reported each year by EPA based on individual land sector inventories, using a "stock-change" approach. The EPA estimates document the net exchange by land class (forest, cropland, grassland, and urban trees) and some specific causes of observed changes such as timber harvesting and wildfire, but not all specific causes such as land-use (or land-cover) change and changes in forest management practices.

There are some geographic gaps in availability of land inventory data particularly for Interior Alaska and some public grasslands in the Continental Western States. More intensive monitoring of some specific land classes or sub-classes (urban, grasslands and shrublands, and wetlands) would improve the estimates. The multi-agency National Land Cover Database mapping project is finalizing plans to intensify grassland and shrubland monitoring by 2016. In addition, to improve the ability to attribute observed changes to land management and mitigation activities, it is important to have more complete data about the impacts of different disturbances (insects, weather, and land-use change) on carbon stocks and how they will change in the future as disturbed areas recover. Some of this information is currently available for specific areas, but no comprehensive national synthesis has yet been completed.

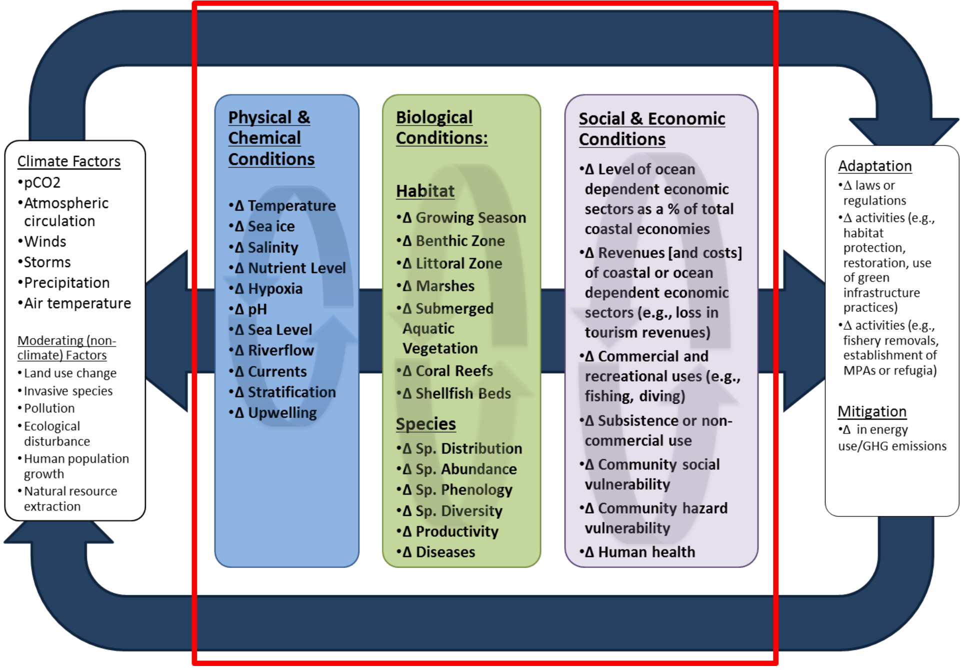
Oceans and Coasts

Oceans and Coasts Conceptual Model

Here we provide a conceptual framework that illustrates how changes in climate can impact the physical/chemical and the biological components of coastal and marine ecosystems, and how those changes can in turn impact human communities and drive human responses and actions.

The conceptual model we developed is a simplified representation of climate and non-climate stressors in coastal and ocean ecosystems. It illustrates the general path, through impacts on ecosystems, human health and functions, eventually leading to management responses in the forms of adaptation and mitigation. Describing the causal chain from stressors to impacts and responses is a complex task, but the conceptual framework is useful in describing the relationships between the origins and consequences of environmental problems. This framework will be utilized throughout the document to drill down into the specific upstream drivers and downstream impacts for each recommended indicator. These climate stressors, interactions between them, and interactions between non-climate and climate stressors need to be considered in assessing how the system may respond to change, as well as guide our actions as we prepare for and adapt to those changes.

Indicators of Change to Coastal and Marine Systems



Conceptual Model for Coastal and Marine Systems. General conceptual framework of climate-related impacts on ocean and coastal ecosystems. This framework is organized around climate and non-climate drivers that act on ocean and coastal ecosystems at regional and global scales and how those drivers impact the physical, biological, and social systems dependent on those ecosystems and ecosystem services. This graphic is not an exhaustive list, instead it is meant to give a high level view and does not show the range of all the climate and non-climate factors or all the direct and indirect pathways by which these components interact.

Regional and Local Sea Level Rise

Summary

This indicator is a direct measure of the relative influences of global sea-level rise and vertical land motions (either subsidence or rising); it is meant to help characterize current vulnerability and trends. It is derived from both satellite altimetry and tide gauge measurements. Sea level rise is directly related to vulnerability of coastal infrastructure and many ecosystem changes. This indicator would be reported in the eleven regions identified in the Oceans and Coastal systems technical report. It is important to note that we do not intend this indicator to be compared to scenarios – it is meant to help characterize current vulnerability and trends.

What is it? This indicator is an index measure of Arctic-wide changes in consistent sea ice extent over time based on values from 1979 to the present.

What is the scale? The indicator can be used for the entire Arctic area as well as be scaled down to smaller regional areas (e.g., near Barrow, in the Bering Strait Region). Data sets exist at daily and monthly time scales but the indicator is updated on a yearly basis.

What does a change in this indicator mean? Shifts in sea extent may lead to reduced habitat for animals like seals and polar bears, reduced reflection of the suns radiation leading to increased absorption by the surrounding waters which can increase the oceans heat content, as well as changes in the hydrological cycle which impacts climate patterns.

Background

This indicator would involve the tracking of observed regional and local sea level rise for various coastal regions of the U.S. and assessing what the observational record is showing with respect to the various National Climate Assessment (NCA) Sea-Level Rise Scenarios. Along with the global and regional sea level rise predictions found in the EPA Indicator Project, it would help answer questions regarding how well the observations are comparing with the climate sea-level rise scenarios over time.

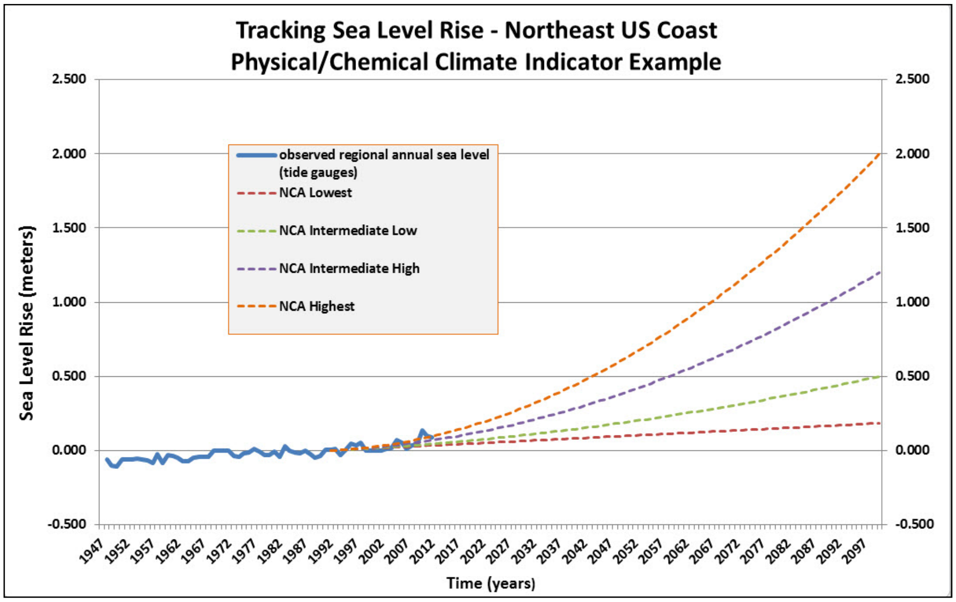
The latest national consensus of global sea level rise has been published in a NOAA technical report (NCA, 2012) in preparation for the NCA. The figure below showing the observed sea-level record and global sea-level rise scenarios is taken from NOAA (2012) and illustrates the nature of this indicator. Even in the most conservative estimate, sea-level is projected to rise. There are no projections for sea-level fall. The two intermediate ranges for sea-level rise by 2100 to be between 0.5 and 1.2m are consistent with results from other peer reviewed literature (IPCC, 2007; NRC, 2012).

Although global sea level rise is generally projected to be one value for the entire globe for climate modeling purposes, it is also known that actual global sea level change has a strong regional signature. This geographic variability suggests a regional indicator may be required to understand impacts of sea-level change at the local level.

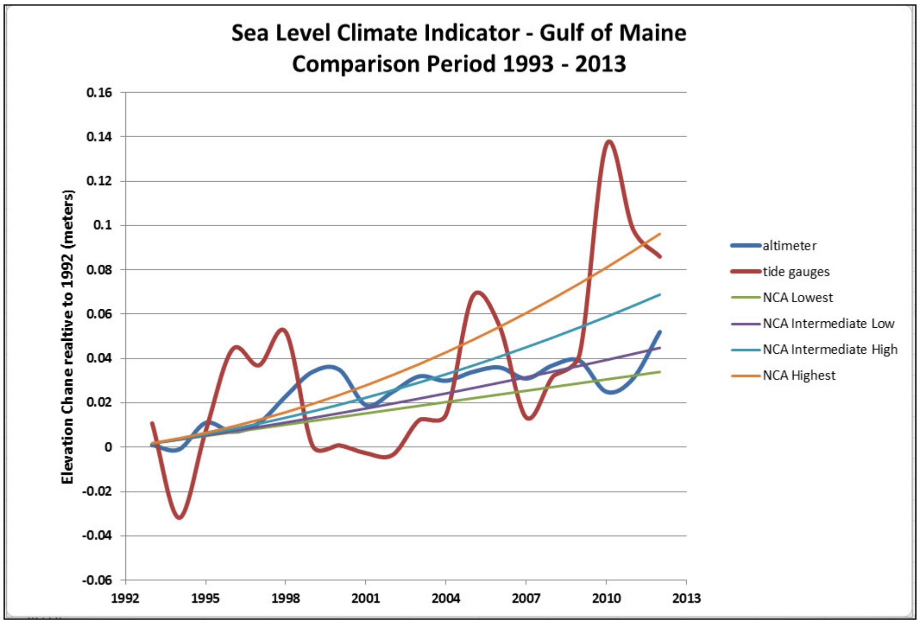
The goal would be to indicate on a continuous basis how the regional rates of sea level rise are tracking with the NCA global sea level rise scenarios out to 2100. An example for the Gulf of Maine Region is shown in the figures below in which the observed data series start in 1947.

The indicator would have plots showing these comparisons for each of the eleven (11) regions. At this scale with such a short time period, it is seen that the tide gauge data and the altimeter data are very “noisy” compared to the scenario curves. However, over time, the climate models suggest that the acceleration rate will emerge as the predominant signal in the observational record as well. This indicator will help with that determination. The eleven geographic regions proposed for this analysis are:

- Gulf of Maine
- Mid-Atlantic Bight
- South Atlantic Bight
- Eastern Gulf of Mexico
- Western Gulf of Mexico
- Puerto Rico and U.S. Virgin Islands
- Hawaii
- Southern and Central California
- Northern California, Oregon and Washington
- Southeastern Alaska
- Southern Alaska and Aleutian Islands



Northeast coast sea level rise climate indicator example.

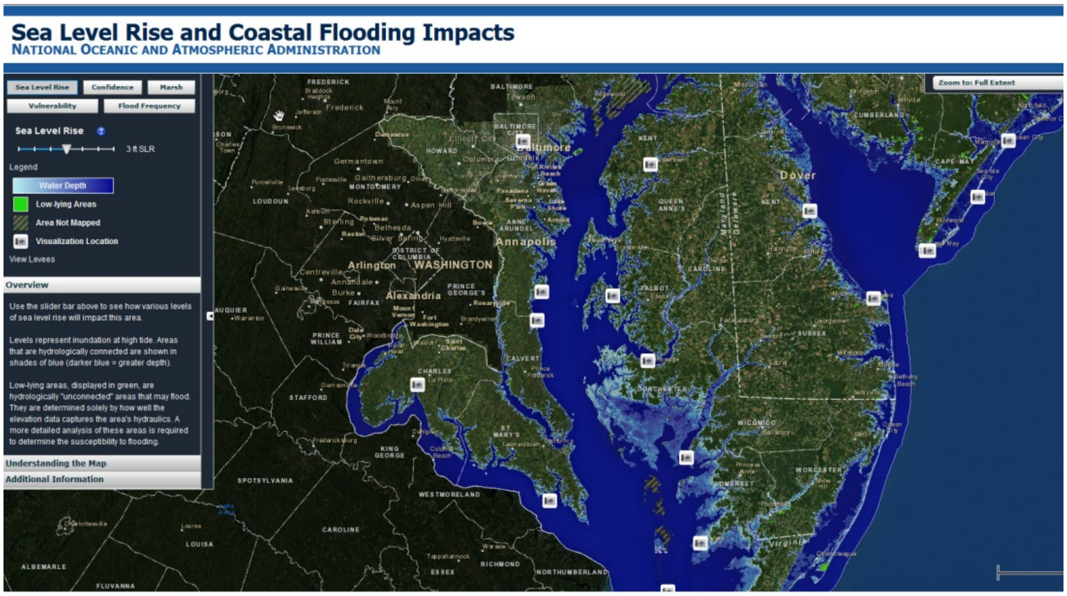


Northeast US Coast example enlarged using only 1993 – 2013.

Relevant to management decisions

This type of indicator would be useful to a large spectrum of user communities and applications. This indicator will provide information for users to continually assess their original basic assumptions on climate change impacts and will enable them to re-assess their projections based on the latest information. Agencies, such as the USACE (2011) have formulated and continue to formulate policy for incorporating sea-level change into guidance for the design and planning of USACE coastal projects. These projects may include, for instance, improvement of resilience of backshore facilities for navigation projects; upgrading and strengthening of structures for coastal storm damage reduction and flood risk projects; and constructing sediment management systems for ecosystems projects. They have actively developed a tool for incorporating observed sea level trends and climate-driven sea-level rise scenarios to estimate elevation change of the sea out to 2100 (USACE 2013).

Regional and location specific sea-level indicators may be applied to existing tools such as the NOAA Sea Level Rise Mapper (CSC, 2013). As shown in the figure, this tool can assist in assessing potential impacts for various estimated of sea-level rise.



Use the slider bar above to see how various levels of sea level rise will impact this area.

Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth).

Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

NOAA sea-level rise viewer showing estimated flooding impacts using a 3-foot rise in sea level.

Stability/Longevity of dataset and Indicator

The tide gauge network has been in place (and expanding) since the mid-1800's and remains fully funded by NOAA with over 210 continuously operating stations (including the Great Lakes) as of 2013. The data undergo continuous daily, monthly, yearly and decadal quality assurance and routine production of data products. Verified data products and historical records are provided though web pages and web services.

The regional and global altimeter data and products are maintained and made available through several agencies, including NOAA and CCAR (Colorado) and AVISO (France). Improvements in the altimeter observations themselves are also anticipated. For example, NASA's SWOT mission in 2020 (http://swot.jpl.nasa.gov/) will improve spatial resolution near coasts and inland waters. This will lead to stronger comparative analyses with shore-based tide gauge measurements.

The NCA sea-level rise scenarios curves and coefficients were established in 2012. The NCA and IPCC assessments are routinely updated; the sea-level scenario curves are expected to change over time and will be extended beyond 2100, most likely within the next 5-years. This indicator can be adjusted to track whatever scenario the user needs; however, it is expected that this indicator would be updated to incorporate new scenarios as the NCA process continues in the future.

The present spatial distribution of tide stations is adequate for regional indices for all coastal areas (including ocean island territories) except for western and northern Alaska. Adequate numbers of tide stations have long enough records to describe past sea level change during the last century and funding for future continuous operation, while never guaranteed, continues to be adequate to ensure data and datum continuity in the future for most of the existing stations.

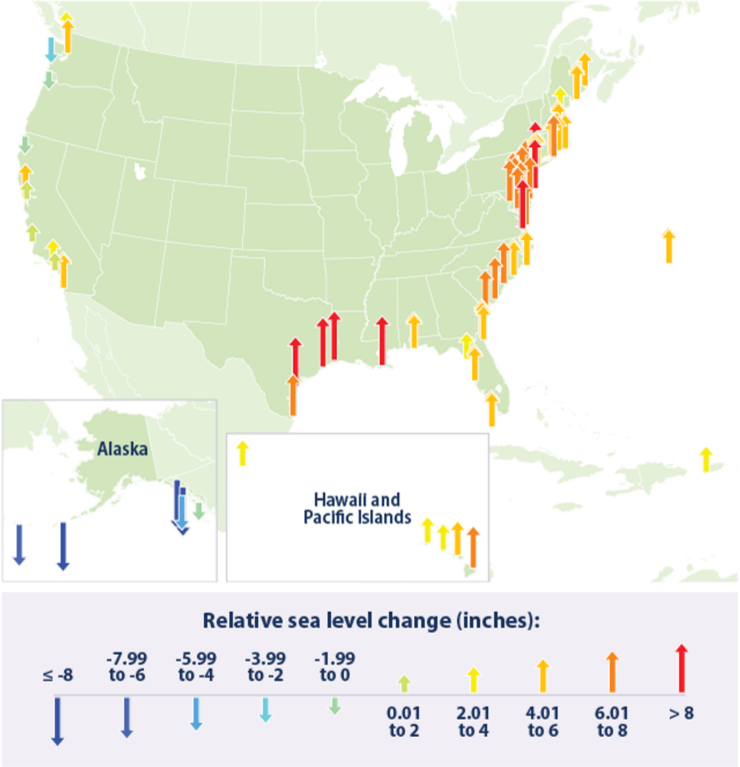
Spatial and temporal scalability

Spatial Scalability: This indicator is essentially a regional down-scaling exercise of the global mean values often found in the literature. It is expected that this indicator could also be extended to provide information at the local level for each tide station.

Temporal scalability: This indicator could be updated on an annual basis, within 3-months of the previous calendar year of tide gauge and altimeter data analyses.

Composition and Methodology

The indicator is constructed by obtaining monthly mean sea level data from a regional set of tide gauges relative to year 1992 and averaging the data annually; obtaining combined altimeter data averaging 10 day cycle outputs over annual time periods and adjusting them relative to the 1992 time period; and constructing NCA scenario data annual time steps using the NCA scenario formulas. All data sets are then plotted using the same vertical elevation and time scales.



Relative Sea Level Change Along U.S. Coasts, 1960-2012. This map shows cumulative changes in relative sea level from 1960 to 2012 at tide gauge stations along U.S. coasts. Relative sea level reflects changes in sea level as well as land elevation. Source: NOAA, 2013

Ocean Chemistry (Aragonite Saturation State)

Summary

Ocean acidification is a result of the absorption of CO_2 by the oceans with increasing atmospheric levels of CO_2. This change in ocean chemistry has the potential to affect marine organisms that build calcium carbonate shells or skeletons. Aragonite saturation state (ΩA) is a measure of this changing ocean chemistry, indicating the availability of minerals needed for calcification by marine organisms. This indicator is calculated from measurements in non-estuarine marine waters over time at large basin scales for the open ocean.

What is it? This indicator of ocean acidification involves the tracking of aragonite saturation state (ΩA; “omega”) in non-estuarine marine waters over time. ΩA is one of several ways to index the seawater carbonate system, but is often favored by biologists because of its value as an indicator of biomineral availability for calcification by marine organisms.

What is the scale? Currently this indicator is designed at a large basin scale for the open ocean. It is possible to downscale the indicator to near-shore regional scales with increased measuring efforts.

What does a change in this indicator mean? A decrease in aragonite saturation would be detrimental to marine organisms that depend on it to build their shells. This may have negative impacts on certain habitat structures (coral reefs and oyster beds), the food chain (primary producers and shellfish), and the shellfish industry. Studies on the impacts to fin-fish and non-calcifying organisms are in their infancy.

Low Ω_A indicates low availability of the aragonite form of calcium carbonate, with dissolution occurring when Ω_A is less than one. Changes in Ω_A are directly affected by chemical changes, including acidification, that are induced by absorption of CO_2 by the oceans. These relationships can be seen in the figures below from the Hawaiian Ocean Time Series (HOTS) and the Caribbean Coral Reef Watch Program. The decline in ocean pH due to increased atmospheric CO_2 since 1750 was a “robust finding” of the IPCC 2007 synthesis report (IPCC, 2007).

What is the link to climate variability and change?

The absorption of CO_2 by the oceans affects the concentration of greenhouse gases in the atmosphere. The rate of this absorption is affected by carbon fixation, oxidation, sinking of fixed carbon to the deep ocean, air-sea gradients in inorganic carbon concentration, and climate-driven mineral weathering over both long and short time scales. Each of these is in turn directly or indirectly affected by atmospheric and sea surface temperature, sea ice, salinity, and the climate-induced changes in air and ocean circulation that drive these physical conditions.

Through these mechanisms, reduced ocean uptake of atmospheric CO_2 in a warming ocean and under changing carbonate chemistry has potentially important feedbacks on the proportion of anthropogenic CO_2 that remains in the atmosphere. The magnitude of this feedback was considered a "key uncertainty" for assessing emissions scenarios in the AR 4 synthesis (IPCC, 2007). Continued measurement of the carbonate system parameters for calculating Ω_A would reduce this uncertainty.

In addition to anthropogenically driven variation in seawater carbonate chemistry, there is considerable natural variation. Daily and seasonal cycles in photosynthesis and respiration, circulation, upwelling, and stratification can all contribute to variation. Gradients in geochemistry are important, such as those related to delivery of alkalinity from terrestrial sources and distant basins with differing geology and mineral weathering patterns (e.g., Wang *et al.*, 2013). Also, saturation states are lower in at colder temperatures, so Ω_A patterns are partly associated with depth and latitude.

What are the drivers of this indicator and what are its impacts?

Changes in Ω_A are driven primarily by the absorption of CO_2 by the ocean. The key processes are the dissociation reactions that occur during dissolution of CO_2, leading to lower carbonate ion availability and higher hydrogen ion concentration (lower pH). NSF's Biological and Chemical Oceanography Data Management Office describes Ω_A as "a measure of the thermodynamic potential for aragonite to form or to dissolve, and is defined as the product of the concentrations of dissolved calcium and carbonate ions in seawater, divided by their product at equilibrium." Over short time scales (i.e., diurnal and seasonal), Ω_A can vary due to uptake and release of CO_2 during photosynthesis and respiration, respectively. However, these cycles occur against a background of detectable longer term trends in carbonate chemistry that directly affect Ω_A. On regional scales, changes in circulation and terrestrial weathering (e.g., alkalinity) associated with land use and climate change may also contribute to variability in Ω_A (e.g., see US east coast study by Wang *et al.*, 2013).

Knowledge about the biological effects of changes in carbonate chemistry is extensive and growing, but most is from laboratory studies of calcification in marine organisms (e.g., see Kroeker *et al.*, 2010). These biological effects could significantly impact marine ecosystems, but testing of ecological predictions is impeded by a lack of long term or spatially extensive data on carbonate chemistry in affected environments. Detection and prediction of evolutionary adaptation and ecosystem reorganization in response to ocean acidification, for example, requires carbonate chemistry data collected at ecologically and evolutionarily relevant scales of time and space. This challenge is illustrated by the OMEGA project (http://omegas.science.oregonstate.edu/), in which evolutionary ecologists have found it necessary to assemble their own observation networks to support ecological studies rather than relying on oceanic survey programs and IPCC projections. The indicator proposed here will not address this need, but the OMEGA example illustrates the challenges that emerge for finer scale ecological work.

Chlorophyll Concentrations in Surface Ocean Waters – Proxy for Planktonic Primary Producers

Summary

The assessment of ocean primary productivity is a fundamental feature of understanding the biological status of ocean ecosystems, and their relationship to the global carbon cycle. While primary productivity is not measured directly, the concentration of chlorophyll has been measured by a series of NASA satellite instruments (SeaWiFS and MODIS) going back to the 1980's (and earlier in some places, although the earlier CZCS instrumentation data are less reliable). The satellite retrievals can be used to derive an additional index of phytoplankton biomass and ocean primary productivity. The scope of this indicator is global, but it has reasonably good spatial resolution (ca. 1 km pixels), and the time series can be easily reported on whatever time frame is desired, down to monthly (or less in some cases). This is now a standard data product. This indicator tracks total phytoplankton biomass (initially estimated from satellite chlorophyll measurements) at regional spatial scales and, depending on the data set, measurements are taken at weekly to monthly temporal resolutions.

What is it? This indicator tracks total phytoplankton biomass (initially estimated from satellite chlorophyll measurements). While total phytoplankton biomass (via satellite chlorophyll data) is a currently available indicator, it does not provide information on the exact composition and trophic food-quality of the phytoplankton community itself. This indicator should be supplemented in the future with in situ phytoplankton abundance and composition sampling.

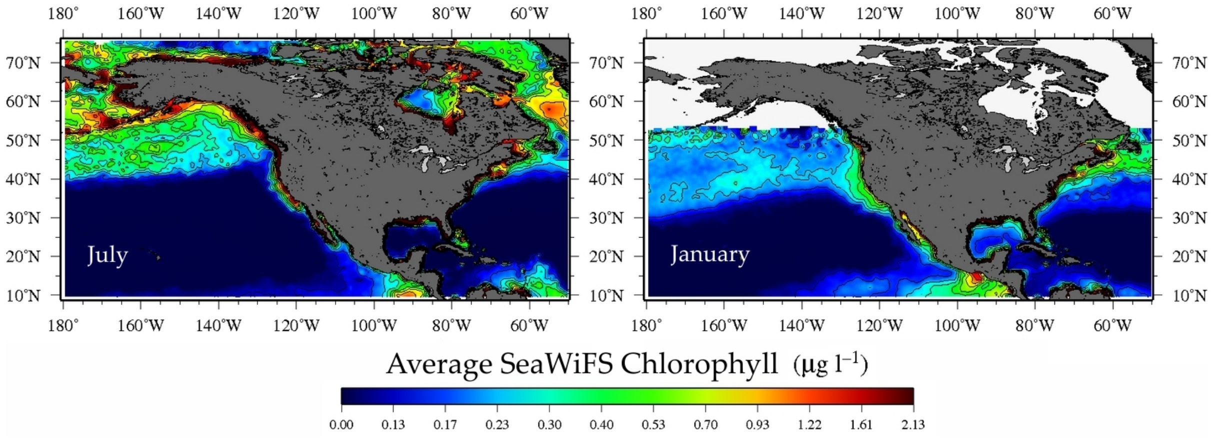
What is the scale? Current data collection methods span global and regional spatial scales and depending on the data set, measurements are taken at weekly to monthly temporal resolutions.

What does a change in this indicator mean? Shifts in primary production timing and concentration impacts the food chain. These shifts could be beneficial (e.g., a strong bloom sending more materials sinking down to the benthic communities) or detrimental (e.g., a delayed spring phytoplankton bloom) resulting in a delayed or lesser zooplankton/fish population thus reducing available food for coastal and marine organisms as well as negatively impacting the fishing industry.

Primary production is the most basic ecosystem process through which energy-rich organic carbon molecules are fixed by photosynthesis and made available to the higher trophic levels. The world's marine ecosystems (e.g., oceans, coasts, and estuaries) are responsible for ~50% of the global net primary production (Falkowski & Raven, 2007; Field et al., 1998; Longhurst et al., 1995). Of the entire global ocean, coastal and continental shelf areas make up only 15% of the total area, yet are responsible for 50% of the total oceanic primary production (e.g., nearly 25% of the planet-wide primary production). These same coastal and shelf regions in turn have the largest secondary (and higher) productivity, where over half of the World's marine landings are caught. Analyses by Longhurst et al. (1995) further suggest that over 90% of oceanic primary production can be attributed to planktonic primary producers, which include "phytoplankton" (larger photosynthetic plankton taxa such as diatoms and dinoflagellates) and "microbial plankton" (smaller taxa such as photosynthetic cyanobacteria and picoplankton). For the purposes of this report the term "phytoplankton" will be used to encompass both photosynthetic plankton groups.

The amount of phytoplankton (e.g., its biomass) within the water column is relatively simple way of representing primary production potential within those waters. Compared to the complex *in situ* incubation experiments needed to measure primary production, phytoplankton biomass can be measured in two basic ways. The exact composition, abundance, and/or biomass of these phytoplankton communities can be determined by examining bottle or net water samples with a microscope. This method is exact but time consuming. More commonly, the concentration of chlorophyll (the dominant phytopigment found in phytoplankton cells) in the water column can be used to estimate the total biomass of the phytoplankton population. *In situ* chlorophyll methods can use chemical or fluorometric methods to measure these pigment(s). Remote chlorophyll measurements are determined by measuring a suite of light wavelengths captured from the reflected light from the water surface (as seen via satellite or aircraft sensors). Remote sensing reflectance algorithms are then used to translate these remote measurements into estimates of chlorophyll concentration (and thus total phytoplankton biomass) in the near surface water.

Satellites can capture data at short temporal and large spatial scales (e.g., weekly measurements with near global coverage) that would be impossible (or extremely cost prohibitive) using only *in situ* means. This proposed indicator tracks the status of planktonic primary producers (initially estimated from satellite chlorophyll, supplemented later with *in situ* phytoplankton observations) at global and regional spatial scales, measured at weekly to monthly time scales.



Satellite coverage for chlorophyll concentrations in January and July. *In winter months, cloud cover is much more likely to block satellite measurements, particularly at higher latitudes, requiring multi-day or multi-week composites to be used for full spatial coverage.*

Coral Thermal Stress

Summary

The bleaching of corals from accumulated temperature stress is one of the best-documented biological consequences of changes in the thermal environment of the oceans due to variability and change in the climate system. The particular indicator proposed for the pilot is Degree Heating Weeks, which NOAA has developed to monitor thermal stress that corals are known to be sensitive to. It is satellite-derived, and reported on a 50 km2 grid for areas of corals that are potentially sensitive to thermal stress.

What is it? There are two indicators derived from Coral Reef Watch's products that monitor thermal conditions to determine when and where corals are at risk for thermally-induced mass coral bleaching: Coral Bleaching Hotspots and Degree Heating Weeks.

What is the scale? These indicators are measured globally at a 50-km spatial scale and are updated twice weekly. The Coral Bleaching Hotspot indicator can provide instantaneous measures of coral thermal stress while the Degree Heating Weeks indicator provides a cumulative measure of thermal stress intensity and duration**.**

What does a change in this indicator mean? The indicators are based on anomalies from SST maximum monthly mean. A positive increase in the anomaly indicates increased chance of coral bleaching.

Background

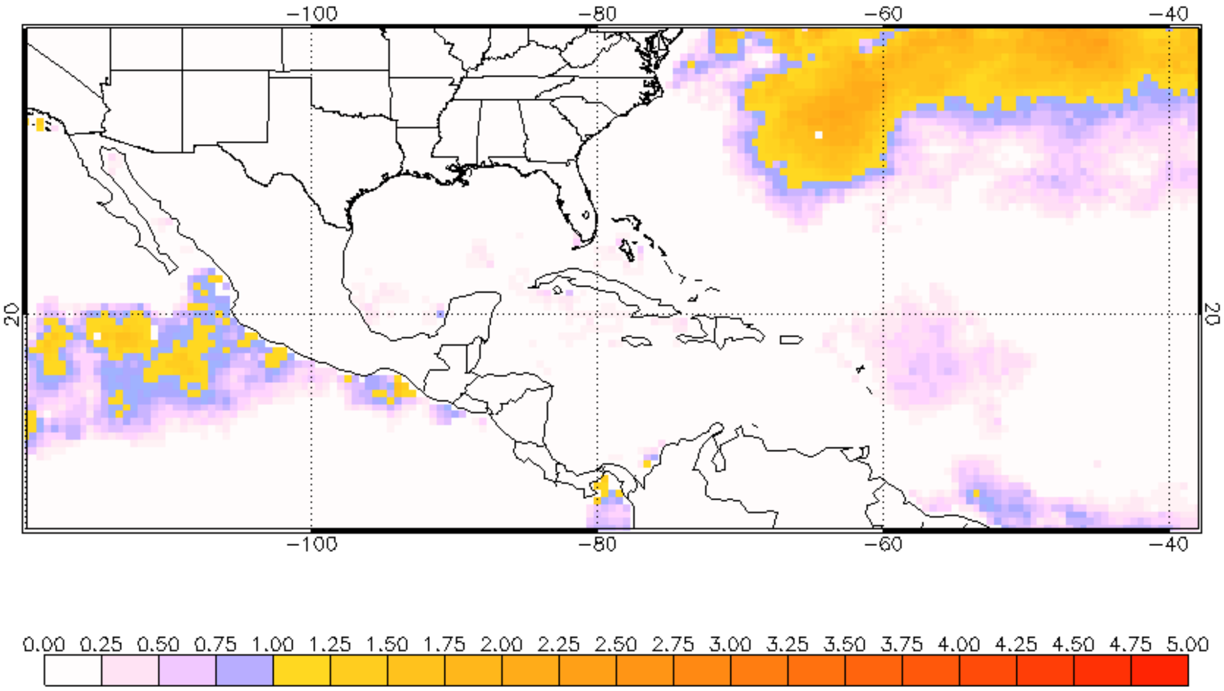
Two of Coral Reef Watch's products are especially useful as indicators of climatic stress on coral reef ecosystems: Coral Bleaching HotSpots and Degree Heating Weeks.

Corals are vulnerable to bleaching when water temperature exceeds the temperatures normally experienced in the hottest month in their location. CRW's Coral Bleaching HotSpots product was released experimentally in early 1997 as the world's first satellite-based coral stress monitoring product. CRW's HotSpot is currently produced operationally at a 50 km spatial and twice-weekly temporal resolution. The HotSpots product measures occurrence and magnitude of instantaneous thermal stress, potentially resulting in coral bleaching. It is an anomaly product based on an atypical climatology – the climatological mean SST of the hottest month (i.e., MMM SST climatology).

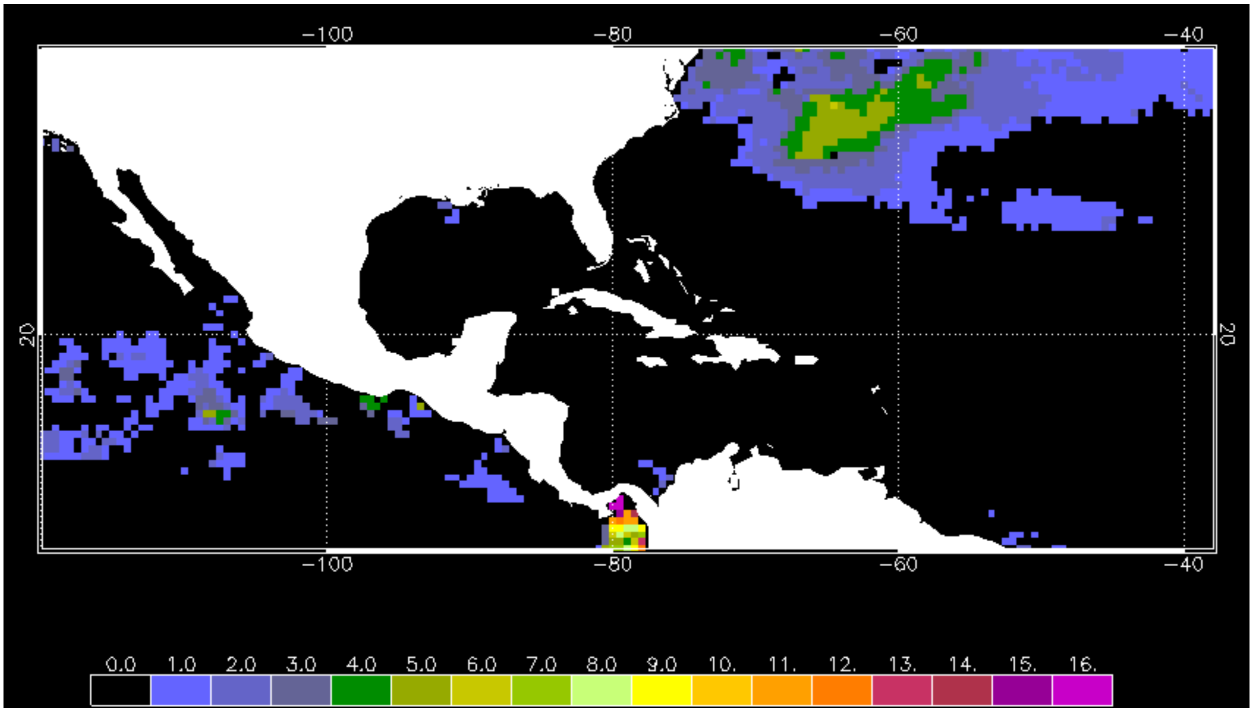
While the Coral Bleaching HotSpots product provides an instantaneous measure of thermal stress, evidence suggested that mass coral bleaching is caused by prolonged periods of thermal stress. In 2000, CRW developed and implemented a satellite-based coral bleaching Degree Heating Weeks (DHW) product for monitoring the accumulation of instantaneous thermal stress measured by HotSpots. Published with the same spatial (50 km) and temporal (twice-weekly) resolution as the HotSpots, CRW's DHW is a cumulative measure of thermal stress intensity and duration during the most-recent 12-week period. It is expressed in the unit °C- weeks. One week of HotSpot values at 2 °C and two weeks of HotSpot values at 1 °C would contribute 2 °C-weeks, equally, to a DHW accumulation. Significant (or "mass"), visible coral bleaching usually occurs when DHW values reach 4 °C-weeks. By the time DHW values reach 8 °C-weeks, widespread bleaching is likely and significant mortality can be expected.

As early as 1997, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) began producing web-accessible, satellite-derived near-real-time SST-based products for monitoring thermal conditions around the globe to pinpoint areas where corals are at risk for thermally-induced mass coral bleaching and to assess the potential intensity of bleaching.

CRW's satellite thermal stress monitoring technique has been successful in now-casting coral bleaching episodes around the globe since its inauguration in 1997. As a result, during the period September 2002 to February 2003, most of CRW's core products were gradually transitioned from "experimental" to "operational" status. The "operational" products are supported and delivered by NESDIS on a 24-hour/7-day basis, permitting reliable and regular global monitoring of environmental conditions harmful to corals.



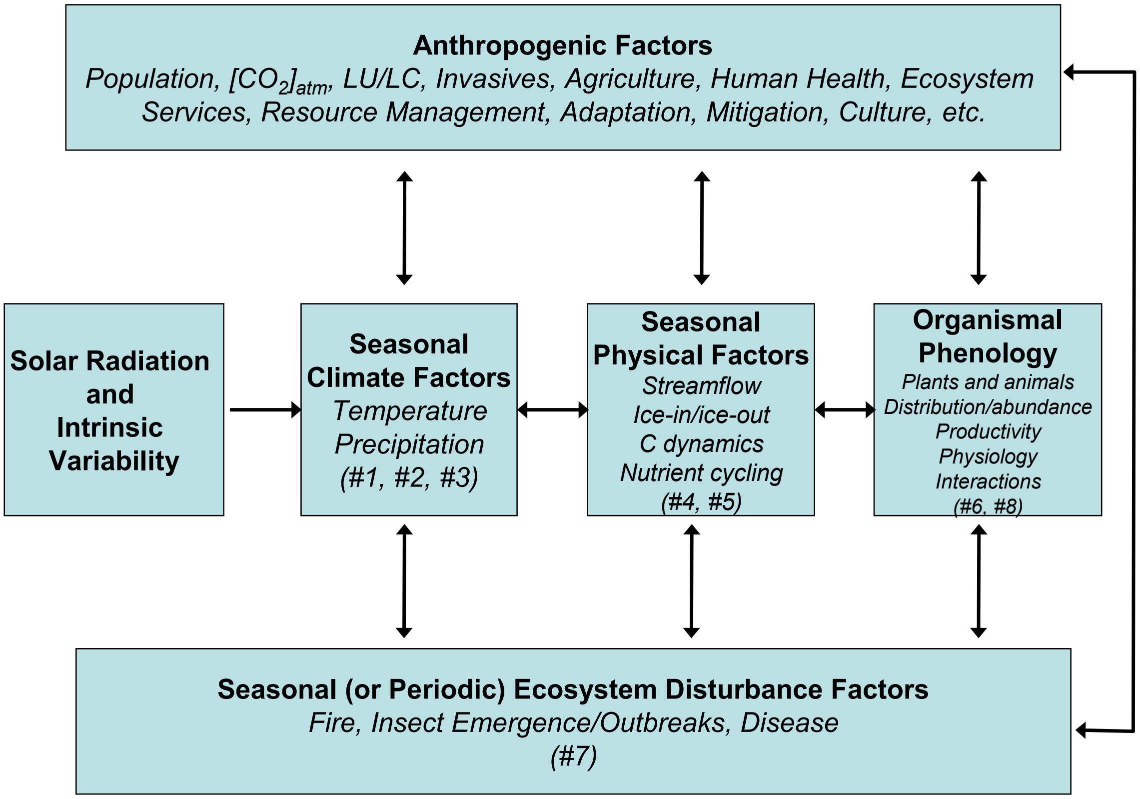
NOAA/NESDIS Coral Bleaching Hotspots for the Caribbean and southern U.S.. The HotSpot product shows areas where corals are currently under thermal stress. The scale goes from 0 to 5 *degrees C. Areas above the bleaching threshold are in orange to red colors. Spatial resolution is one-half degree. (www.coralreefwatch.gov)*



NOAA/NESDIS Degree Heating Weeks (DHW) for the Caribbean and southern U.S. The DHW product shows accumulated thermal stress, which can lead to coral bleaching. The scale goes from 0 to 16 degree-weeks. Spatial resolution is one-half degree. Significant (or "mass"), visible coral bleaching usually occurs when DHW values reach 4 °C-weeks. (www.coralreefwatch.noaa.gov).

Seasonal Timing and Phenology

Seasonal Timing and Phenology Conceptual Model



Through radiative forcing and intrinsic processes in the climate system, climate variability and change affect seasonal timing across physical and biological systems within a multi-stressor context. In turn, variation and change in seasonality and phenology affect a wide variety of ecological processes and human activities. Finally, there are strong interactions and feedbacks among physical and biological processes, ecosystem disturbances, and anthropogenic factors that can either drive phenology (e.g., greenhouse gas emissions or changes in land cover) or respond to phenological change (e.g., agricultural practices). A simple conceptual model that describes these relationships is provided, and additional details are provided in the expanded caption for the figure.

As shown in the figure, indicators that consider linkages between seasonality and phenology, as both drivers and responses that operate across scales within an integrated system, will enable assessment and communication of climate change impacts on our biosphere, and will facilitate a deeper scientific understanding of the many interacting factors that control the response of the integrated Earth system to anthropogenic forcings. Indicators should be relevant to the potential growing season for active phenology and vegetation growth, the quantity and quality of terrestrial and aquatic habitats, population dynamics, species interactions, the frequency, severity and extent of ecological disturbances, rates of biogeochemical cycling, and surface-atmosphere exchanges and feedbacks. Indicators should also be relevant to a host of ecosystem services, including water availability and quality, food and fiber production, atmospheric carbon sequestration, human health, recreation and tourism.

Seasonal timing, and specifically phenology, offers a unique opportunity to engage and empower the public and a broad range of stakeholders in formulating and facilitating adaptive responses to climate change. First, humans are keen observers, and they can easily identify with so-called season creep in weather, snow and ice hydrology, leafing, flowering, and senescence of plants, and the arrival or emergence of animals and insects. Second, if seasonal timing in weather and biology is shifting, this by definition necessitates human adaptation. Humans use calendars both to understand the natural world and to plan their lives. Some examples of adaptive strategies include Native Americans in Alaska changing their annual harvesting cycles, farmers in the Upper Midwest planting crops better suited for an earlier spring, a ski resort in the Rockies purchasing more artificial snowmakers to hedge its bets, and an American family shifting the date of its annual vacation. Third, seasonal timing is a vital sign in the natural world that is relatively simple for anyone to record and understand. Probably more than any other aspect of climate variability and change, seasonal timing and phenology offer the best opportunity to broadly engage industry, government and the general public in both monitoring and adaptive management.

Given scientific uncertainties about both climate variability and change, it is critical to establish an integrated, analytical, and continental-scale framework for understanding and tracking seasonal timing in both physical and biological systems. The basis for this framework is a comprehensive suite of national indicators to track conditions, anticipate vulnerabilities, and facilitate intervention or adaptation to the extent possible. Observed, modeled, and forecasted seasonal timing metrics can inform a wide spectrum of decisions on federal, state, and private lands in the U.S., and will be pivotal for international efforts to understand, anticipate, detect, attribute, and mitigate or adapt to the impacts of both climate variability and change.

Seasonal Climate Indicators

Summary

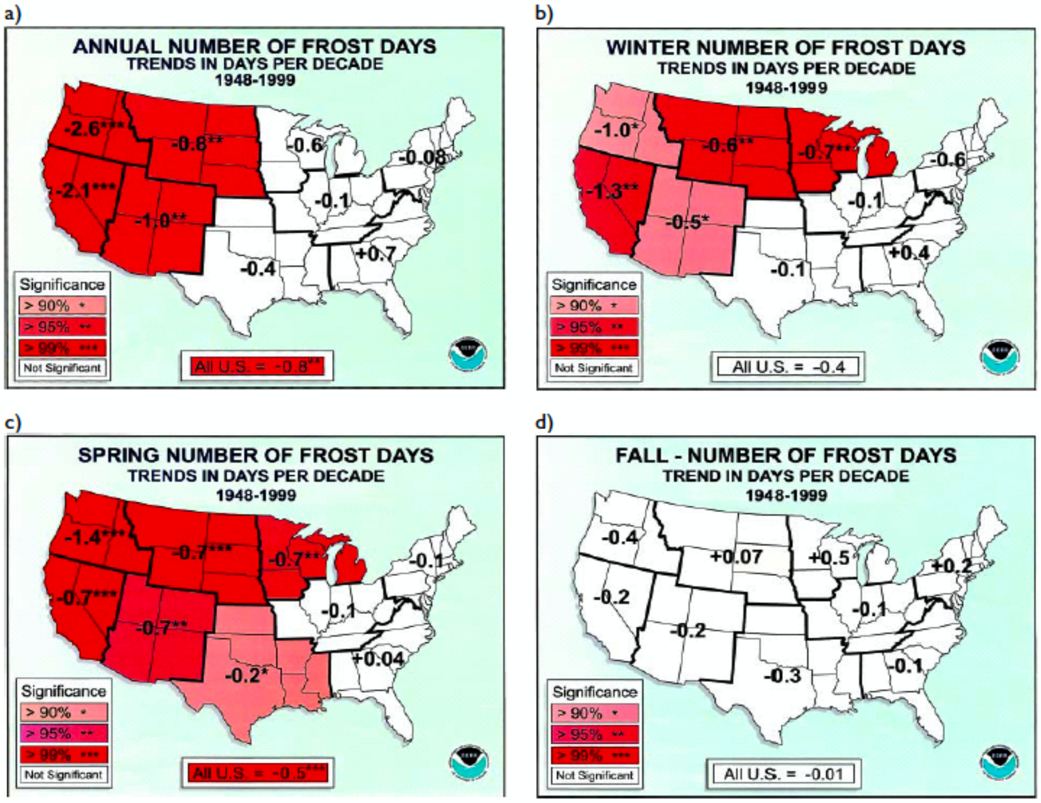
This indicator is a suite of metrics (e.g. last spring frost/freeze, # of frost/freeze days) derived from daily temperature and precipitation to track changes in the seasonality of climate. These indicators are expressed in “day of year” or “days per year” that affect the timing of other physical or biological variables, and the data are from ground-based meteorological data.

Indicator Metrics:

- Last Spring Frost/Freeze, First Fall Frost/Freeze, Frost/Freeze Free Season, # of Frost/Freeze Days
- Exceedance Dates for Percentiles of Cumulative Annual Heating or Precipitation
- Heat Stress Season (Start, End, Duration)

Data Source: Ground-based meteorological data

We propose a suite of Seasonal Climate Indicators (SCI) derived from daily temperature and precipitation data from the Global Historical Climatology Network (GHCN) to diagnose changes in the seasonality – or timing – of climate, with a focus on variables most likely to be relevant to ecological processes. The SCIs are differentiated from the similar Physical Climate Indicators in that SCI variables are expressed in units of "day of year" or "days per year," reflecting their role as driving variables that affect timing of other physical or biological variables. This suite of Indicators includes: date of last frost/freeze in the spring, date of first frost/freeze in the fall, length of the frost/freeze free season, number of frost/freeze days per year, exceedance dates for 10%/25%/50% percentile of cumulative annual heating (growing degrees days) or precipitation, number of days with maximum temperature above 30° C (heat stress), and first/last day of the year with a maximum temperature above 30° C (beginning/end of the heat stress season).


a) ANNUAL NUMBER OF FROST DAYS TRENDS IN DAYS PER DECADE 1948-1999

b) WINTER NUMBER OF FROST DAYS TRENDS IN DAYS PER DECADE 1948-1999

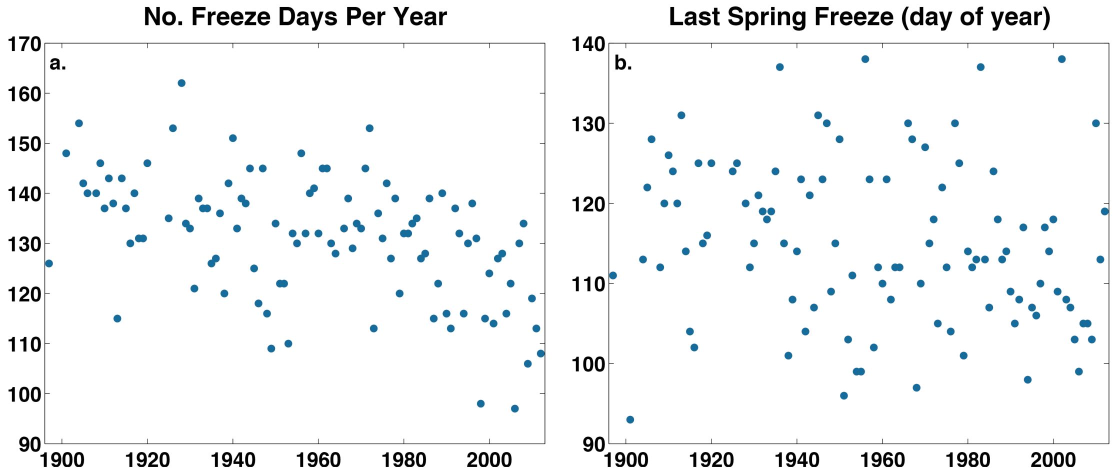
c) SPRING NUMBER OF FROST DAYS TRENDS IN DAYS PER DECADE 1948-1999

d) FALL - NUMBER OF FROST DAYS TREND IN DAYS PER DECADE 1948-1999

Fig. 1. Trends in number of frost days (days where the min temperature was below 0°C) in days decade^{-1} for (a) annual, (b) winter, (c) spring, and (d) fall.

Trends in number of frost days (days where the min temperature was below 0°C) in days decade−1 for (a) annual, (b) winter, (c) spring, and (d) fall. From Easterling 2002.

Data underlying the SCIs comes from a primary dataset (GHCN) that is continuously maintained and updated, quality-controlled, free, and publicly available. The GHCN data have excellent spatial and temporal coverage, extending back decades and distributed over most of the continental United States. Because these source data are continually updated, the SCIs themselves can also be updated in near real-time. The methods for calculating the SCIs are relatively simple and straightforward, and the SCIs and GHCN data have already seen wide use in the climatological and ecological literature. As such, they should therefore be familiar to most experts in the field. Given this familiarity, and the well-established nature of these indices, they should be easily communicated within the research community.



Example seasonal climate indicators from the GHCN station at Mohonk Lake, New York: a) number of freeze days (Tmin<=0) per year and b) the date (day of year) of last spring freeze. The number of freeze days at Mohonk Lake has been steadily declining with warming trends over the last century, while the date of last spring freeze has not shifted significantly. From Ben Cook, unpublished data.

Potential Growing Season

Summary

This indicator tracks the predominant frozen and non-frozen condition of the land surface and the non-frozen season defines the potential growing season. The data come from satellite microwave remote sensing that are global daily measurements over 30 years.

Indicator Metrics:

- Frozen and Non-Frozen Seasons (Start, End, Duration)
- Primary Spring Thaw and Fall Freeze Timing
- Frost Days (Timing, Frequency, Duration)

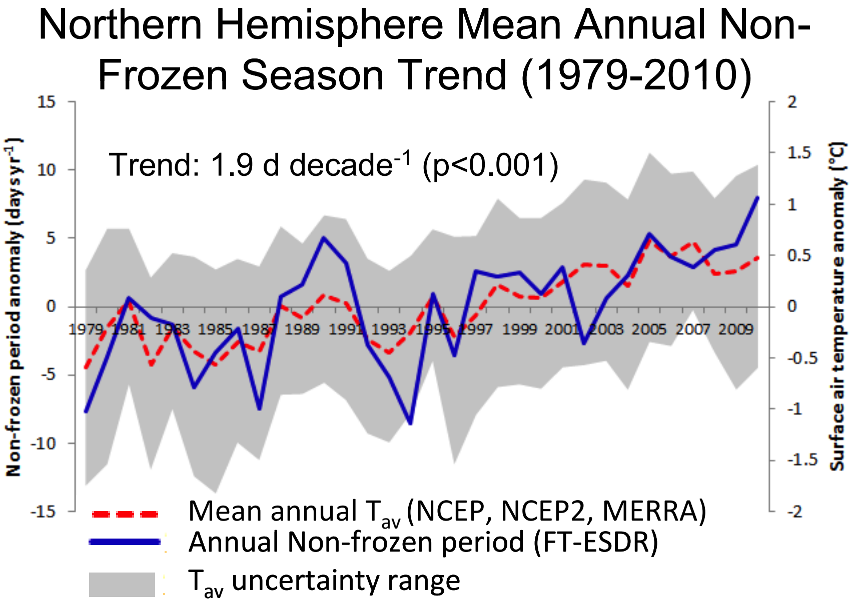
Data Source: Satellite microwave remote sensing

The freeze-thaw (FT) signal from satellite microwave remote sensing quantifies the predominant frozen or non-frozen condition of the land surface within the sensor footprint. The non-frozen season (expressed as start and end dates, and duration in number of days) derived from these data defines the potential growing season for active vegetation growth, soil decomposition and respiration processes, ecosystem CO_2 uptake and surface water mobility. The non-frozen season defined from these data is a sensitive climate indicator documenting global trends toward earlier and longer growing seasons, and relaxing frozen temperature constraints to ecosystem processes.

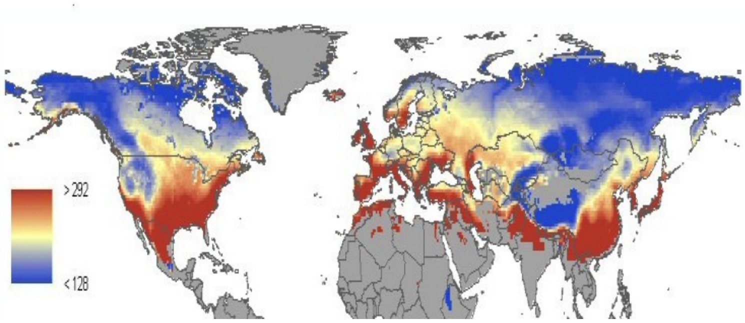
The NASA MEaSUREs (Making Earth System Data Records for Use in Research Environments) program developed and maintains a consistent global daily FT Earth System Data Record (FT-ESDR) over 30 years long that represents one of the longest, continuous global satellite Earth observation records. The FT classification domain is contiguous, encompassing all vegetated land areas where seasonal frozen temperatures are a major constraint to annual productivity. The FT-ESDR is publicly distributed through the NASA NSIDC DAAC, including detailed product accuracy and data quality documentation (http://nsidc.org/data/nsidc-0477.html).

The ecological significance of the FT-ESDR and non-frozen days metric is well documented by numerous peer-reviewed scientific publications. Strong microwave sensitivity to surface moisture and insensitivity of satellite microwave retrievals to solar illumination and atmosphere contamination enable precise land parameter retrievals suitable for climate change studies. The FT-ESDR non-frozen days parameter corresponds with temperature based freeze and thaw metrics (see Seasonal Climate Indicators) determined from relatively sparse weather station records. Other FT-ESDR derivatives related to Surface Climate Phenology and the non-frozen days parameter include the frozen season duration (days), timing (day of year) of primary spring thaw and fall freeze events, and frequency and duration of frost events.

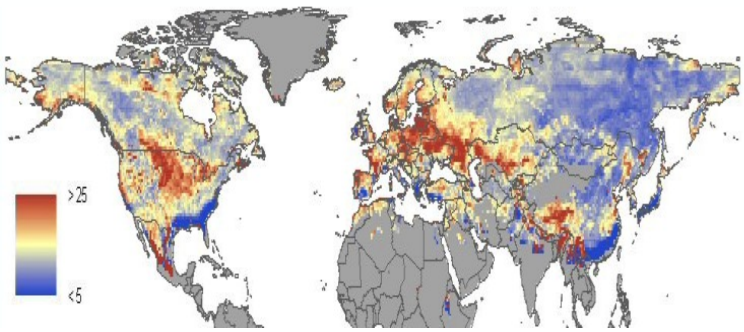
The general public (e.g., gardeners, amateur naturalists) easily understands the FT-ESDR non-frozen season metric and derivatives. These products are likely to have strong applications to agriculture sectors, including in agricultural production (frost risk, FAO productivity assessment, cropping and growth suitability zone guidelines), natural resource management of forests and rangelands (vegetation dormancy, growing season and productivity assessments, life cycle and habitat conditions for pathogens and insects, wildfire risk). In addition, these products would be useful to other sectors including transportation (frost damage, safety, exploration) and human health (lifecycle status and habitat quality for disease vectors and vector borne disease risk).



Mean Non-frozen Season
(days)



Non-frozen Season Variation
(SD, days yr^{-1})



Mean annual non-frozen season (days) and non-frozen season variability (SD, days yr-1) derived from calibrated and merged daily satellite microwave brightness temperature (37 GHz) retrievals from SMMR and SSM/I sensors over a 32-year (1979-2010) record. The satellite microwave freeze-thaw (FT) signal provides a surrogate measure of frozen temperature constraints to water mobility and biological activity, while the non-frozen season metric bounds the potential growing season and has a major impact on vegetation phenology and productivity. The FT classification domain extends over more than 66 million km2 and encompasses all global vegetated land areas where seasonal frozen temperatures are a significant constraint to annual productivity. The mean Northern Hemisphere non-frozen season trend defined from the satellite record is increasing (p<0.001) with global warming indicated by mean daily gridded surface air temperature (Tav) records from ensemble global reanalysis data, including NCEP/NCAR, NCEP2 and GMAO MERRA products. The satellite FT record has a mean annual spatial classification accuracy >90% relative to global weather station network observations, while the reanalysis Tav record shows relatively large uncertainty (ensemble range in grey at left). The FT Earth System Data Record (FT-ESDR) is publicly available through the NSIDC DAAC (http://nsidc.org/data/nsidc-0477.html) and supported under the NASA MEaSUREs (Making Earth System Data Records for use in research environments) program. From Kim et al. 2012.

Extended Spring Indices

Summary

These indices refer to a suite of models developed to simulate the timing of the onset of spring in native and cultivar plants. The data are ground-based meteorological data validated by observations of cloned and common plant species, in part using uses citizen data for lilac and honeysuckle.

Indicator Metrics:

- Timing of the Onset of Spring (First Leaf, First Bloom)

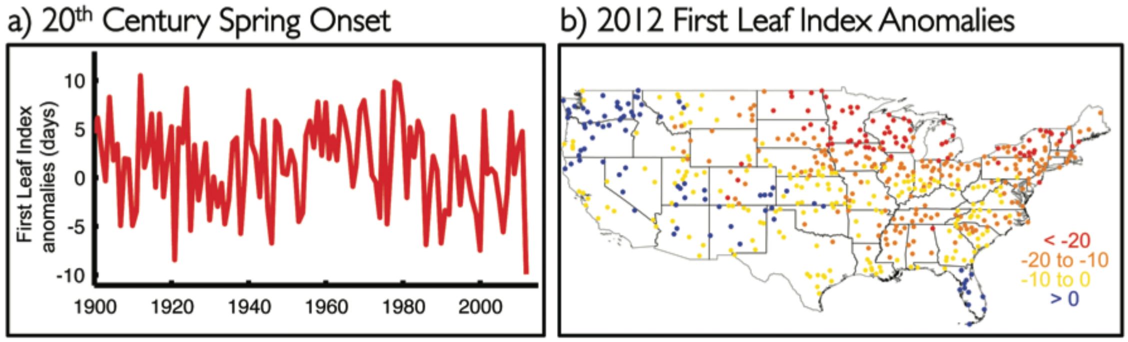
Data Source: Ground-based meteorological data validated by observations of cloned and common plant species, uses citizen data for lilac and honeysuckle

The Extended Spring Indices (SI-x) refer to a suite of models developed to simulate the timing of the onset of spring in native and cultivated plants. The SI-x metrics include First leaf, First bloom, and a somewhat less-developed Vegetation Damage Index (derived from first leaf index minus last freeze). SI-x can be calculated for any weather station that collects daily minimum and maximum temperatures, and thus the indices can be evaluated consistently over much longer time spans and larger areas than available phenological observations. Metrics are expressed as day of year or departures from a long-term mean in number of days.

SI-x algorithms were developed from the empirical relationship between historical weather records and phenological observations (1956-present) made for clonal (and therefore genetically-consistent) lilac and honeysuckle plants at hundreds of sites in North America. SI-x can be related to timing of spring transitions in a number of species, as well as other physical and ecological processes, that are primarily sensitive to temperature. Moreover, estimation of SI-x is independent of biological effects and land use, and only "sees" the atmosphere, enhancing its value for exploring relationships between large-scale climate modes of variability and spring onset.

Weather data underlying the SI-x come from the Historical Climate Network, a primary dataset that is continuously maintained and updated, quality-controlled, free, and publicly available from NOAA's National Climate Data Center. Phenological data used to develop and validate the SI-x algorithms are available through the USA National Phenology Network (USA-NPN; www.usanpn.org). Scientists affiliated with USA-NPN are working to further improve the SI-x code, vet the algorithm, and develop nationally-gridded products for use in research, assessment, and management applications.

The onset of spring is a concept well recognized by the public, particularly since springtime phenological events are often visible to the eye and have implications for people's daily lives. Moreover, spring onset has implications across several economic sectors, including natural resource management (e.g., snowpack, streamflow, fire season, invasive species, biodiversity, etc.), recreation (e.g., the ski industry, fall color watching, hunting and fishing), and agriculture (e.g., the citrus industry, Maine lobster industry). Given the importance of spring onset, the SI-x can be used to monitor, assess, and forecast regional to national-scale variations and trends in onset. Accordingly, the SI-x First leaf and First bloom indices were featured in the EPA Report on Climate Change Indicators in the United States (2012). Ault et al. (2013) also used the SI-x to place the record-breaking spring of 2012 in national and historical contexts. Although the specific nature of the relationships between the SI-x and forest or wildlife species remains somewhat uncertain, this research is underway and will likely reveal key findings within the next 2-3 years.



Left panel: Time series of station-based extended spring index (first leaf) anomalies with respect to the 1981-1010 climatology from 1900 through 2012 and averaged over the conterminous United States; Right panel: Map of first leaf index anomalies (in days) with respect to the 1981-2010 climatology. From Ault et al. 2013.

Change in average SI-x first leaf date by station (in days) between 1951-1960 and 2001-2010. From Schwartz et al. 2012.

Snowmelt Runoff

Summary

This indicator describes the timing of the pulse of runoff water in watercourses that drain snowmelt-dominated watersheds. The metric recommended is the winter/spring center of volume in timing. The data are from ground-based stream-gage data for daily stream discharge.

Indicator Metrics:

- Winter/Spring Center of Volume Timing

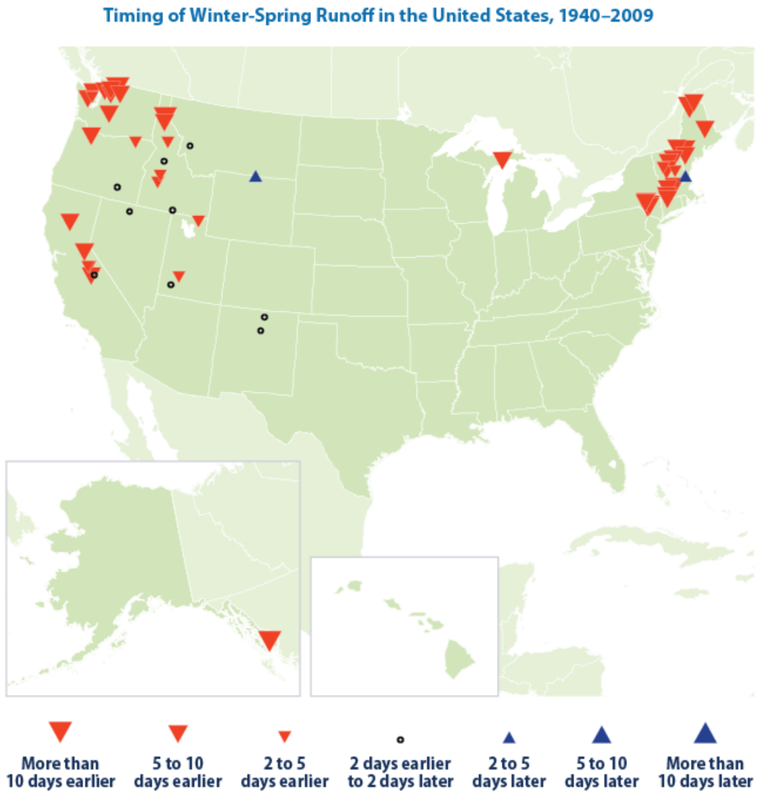
Data Source: Ground-based stream-gage data

This indicator describes the timing of the pulse of runoff water in watercourses that drain snowmelt-dominated watersheds, and is based on established daily stream discharge datasets.

There are competing metrics for snowmelt runoff, including quantiles in cumulative daily discharge, Center of Mass in Timing (COM or CT) and Center of Volume in Timing (COV). Winter/Spring Center of Volume in Timing (COV) was adopted for the 2012 EPA Climate Indicator Report, and is recommended here pending a more complete evaluation. While the center of volume is not an intuitive measure of seasonality, it should be readily understood and can be communicated effectively.

Winter/Spring COV is defined as the date when half of the streamflow between January 1 and May 31 of each year (1940-2009) passed a particular gage. The base data for defining the snowmelt pulse are daily stream discharges measured at individual gages in snowmelt-dominated basins in the western U.S. that are minimally affected by reservoir regulation, water diversions and land-use changes. These streamflow data, archived and served by USGS, are collected to consistent national standards and span long periods of time. COV and competing metrics have shown that a ~1°C warming since 1950 has shifted snowmelt runoff earlier in the season by more than 1-4 weeks in the Western U.S. An additional 2°C warming is projected to shift snowmelt runoff earlier by 20 days or more by the end of the 21st Century. Significant changes toward earlier snowmelt-related runoff during the last century also were found at many rivers (north of 44°N) in the East.

In the western U.S., the spring snowmelt runoff pulse contributes up to 75% of total annual runoff for snowmelt-dominated basins. The timing and pattern of snowmelt plays a critical role not only in runoff generation and flood protection, but also in the geochemical and biogeochemical composition of stream water in alpine catchments. Mountain runoff is captured in reservoirs during late winter and early spring, and then transported over great distances to sustain large agricultural areas and urban centers through the growing season and hot summer. The impact of earlier snowmelt and high spring flow may be less important for water supplies in the eastern U.S., where rainfall and streamflow are more evenly distributed throughout the year. Adverse impacts, however, include potential increases in frequency or severity of winter ice jams and associated floods, as well as mismatches in timing of high spring flow and anadromous fish (e.g., spring spawning Atlantic salmon). Earlier snowmelt runoff could exacerbate low flows, high stream temperatures, and decreases in dissolved oxygen in summer, with adverse impacts to aquatic organisms.



Data source: USGS (U.S. Geological Survey). 2012. Analysis of data from the National Water Information System.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

Changes in the timing of peak spring flow carried by rivers and streams, based on the long-term rate of change from 1940 to 2009. This analysis focuses on parts of the country where streamflow is strongly influenced by snowmelt. It is based on the winter-spring center of volume, which is the date when half of the streamflow between January 1 and May 31 of each year has passed. From EPA (2012), and at *<u>http://www.epa.gov/climatechange/science/indicators/society-eco/streamflow.html</u>*

Water Cycle

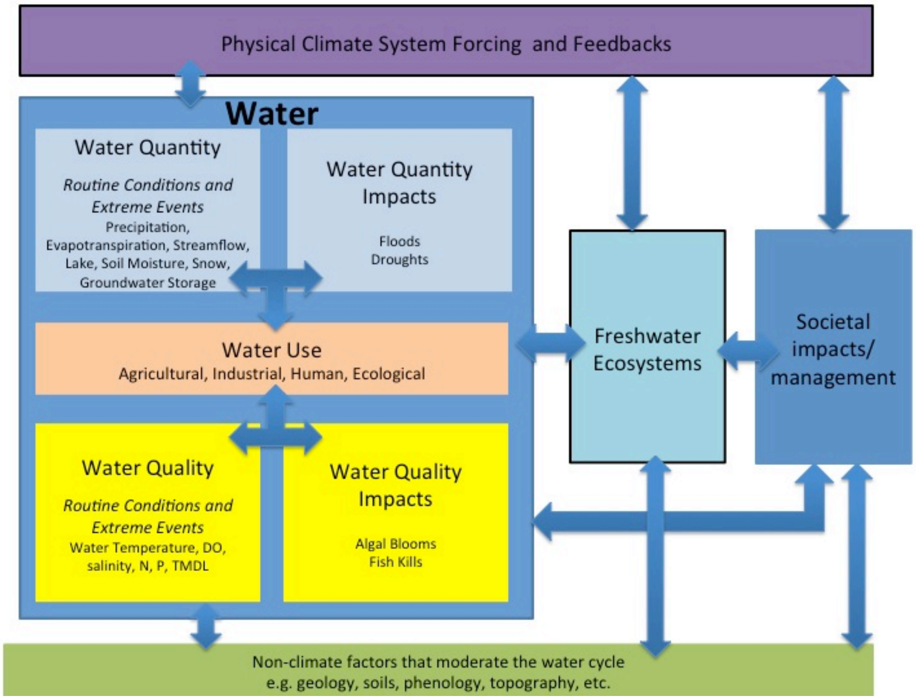
Water Cycle Conceptual Model

Water is vital to life and human economies. Managing water is one of the primary economic activities of humanity, and is expected to become even more critical as demand and climate alter its availability and quality.

Water is sensitive to climate phenomena on multiple scales, so several physical climate indicators are included on this list. We chose to most fully develop those that are most germane to the assessment and management of water resources. Water management issues may arise in minutes to hours (flash floods) or they may develop over years (drought, desertification). Like other climate-sensitive constructs, the impact of climate-scale changes on water management "issues" may also be expressed as changes in the frequency, magnitude or duration of extreme events (floods, droughts, etc.).

These indicators are not intended to inform day-to-day decisions. However, they may be used to help adjust long-term plans and inform shorter term planning decisions ("five year" plans, etc.), for which climate inputs are increasingly important, yet not widely used.

The conceptual framework utilized by the team was developed so that major and auxiliary components of the water cycle and management practices were identified, in addition to interactions and feedbacks with the physical climate system and freshwater ecosystems.



Conceptual Framework for Water Cycle and Management

The water cycle and management system is characterized by water quantity and quality, as well as water use and the related interactions with freshwater ecosystems and societal impacts and management. This conceptual model describes the two-way interactions of the water cycle with the physical climate system, which provides forcing through changes in precipitation, radiation, wind speed, temperature, and humidity, and feedbacks such as changes in evapotranspiration due to soil moisture limitation and upwelling radiation due to albedo changes. Non-climate factors that moderate the water cycle include geology, soils, phenology, and topography, in addition to population growth and increasing water demand.

Together, these interactions and moderating factors determine the water cycle and influence the impacts of extreme events or routine conditions that affect freshwater ecosystems or water resources management strategies. Indicators of water quantity, quality and use and their impacts can be determined through diverse sets of measurements. Water quantity indicators are based on measurements of precipitation, evapotranspiration, streamflow, and storage in lakes/reservoirs, snow, soil moisture, and groundwater. Water quantity impacts such as floods and droughts are indicated by extreme values of precipitation and streamflow, as well as composite indicators that reflect extreme water deficits such as droughts. Water quality indicators describe important aspects of the quality of habitat for organisms and human uses, and indicators include measurements of water temperature, lake transparency, sediments in streams, dissolved oxygen (DO), and salinity, in addition to concentrations or Total Maximum Daily Loads (TMDLs) of high-impact constituents such as Nitrogen (N) and Phosphorous (P). Water quality impacts are characterized through maximum or threshold values of these indicators. Water use indicators describe the total water used by various sectors including agricultural, industrial, human and ecological. Together, all indicators in these three categories—water quantity, quality, and use—describe the status and trends of water cycle and management under a changing climate.

Annual and Monthly Precipitation

Summary

Precipitation is an essential climate variable (ECV) and systematic changes over time have effects on the hydrosphere, natural and managed systems, and water management. The proposed approach is to use the NOAA gauge data sources as the data for a gridded map depicting precipitation as a percent of normal using PRISM (Parameter-elevation Regressions on Independent Slopes Model).

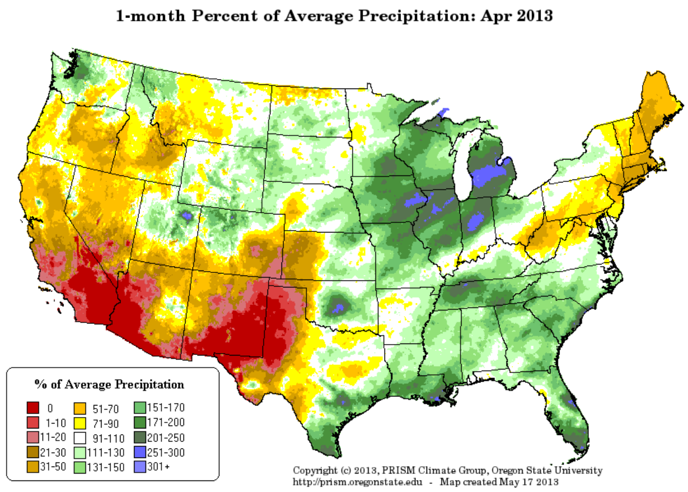
Background

Precipitation is one of the most easily recognizable and essential of the basic climate variables. This particular indicator deals only with precipitation as a straightforward index. Precipitation would be displayed as percent of normal. Any number of precipitation aggregations are possible. A CONUS-wide precipitation is one obvious indicator, updated seasonally or annually. Spatial detail could include: statewide precipitation, climate division precipitation, or all the way down to gridded manifestations, such as that achieved through PRISM (Parameter-elevation Regressions on Independent Slopes Model) is a knowledge-based system that uses point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly climatic parameters.

Scientific Defensibility: This indicator and the underlying data are established through peer-reviewed documentation. The data used to develop the indicators are of high quality, documented fully, transparent as to origin and any analysis that has been performed. The data from the county level and up are publicly available.

Relevance to Management Decisions: Precipitation is an essential climate variable and has wide-ranging effects on human well-being and ecosystems. Rainfall, snowfall, and the timing of snowmelt can all affect the amount of water available for drinking, irrigation, and industry, and can also determine what types of animals and plants (including crops) can survive in a particular place. Changes in precipitation can disrupt a wide range of natural processes, particularly if these changes occur more quickly than plant and animal species can adapt.[1]

Data and Methods: Multiple sources: NOAA/NCDC for gauge data and certain political-bounded aggregates (statewide averages, climate divisions). For a gridded approach: PRISM. PRISM is a gridded implementation of precipitation measurements and was the indicator preferred by a majority of the task team. PRISM (Parameter-elevation Regressions on Independent Slopes Model) is a knowledge-based system that uses point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly climatic parameters. Basic (rain gauge) precipitation data from NOAA and USDA is analyzed onto a 4km grid, using a scheme that takes into account topographic and circulation information to provide dynamic estimates on the grid (e.g., in mountainous areas, local conditions are part of the analysis). Further specifics on PRISM are available at http://www.prism.oregonstate.edu/.



A map depicting PRISM's analyzed rainfall versus a 1981-2010 normal for April 2013. Data is available for download.

Heavy Precipitation

Summary

Precipitation is an essential climate variable (ECV) and heavy precipitation is critical for assessing changes in flood risk. The proposed indicator is from the EPA climate indicator report is a graph of the percentage of land area where a much greater than normal proportion of total annual precipitation has come from an extreme one-day precipitation events in the continental U.S.

Background

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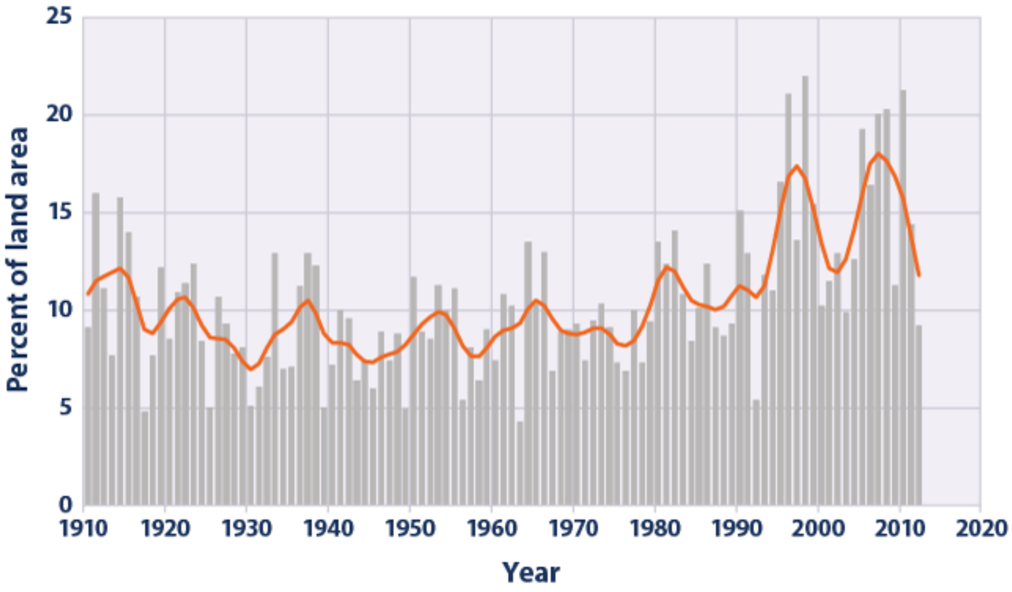
[1] This section taken from EPA indicators site on precipitation: http://www.epa.gov/climatechange/science/indicators/weather-climate/precipitation.html.

Precipitation is one of the most easily recognizable and essential of the basic climate variables. This particular indicator deals only with heavy precipitation, which is critical for assessing changes in flood risk. "Heavy precipitation" refers to instances during which the amount of precipitation experienced in a location substantially exceeds what is normal. What constitutes a period of heavy precipitation varies according to location and season.

In recent years, a larger percentage of precipitation has come in the form of intense single-day events. Eight of the top 10 years for extreme one-day precipitation events have occurred since 1990 (see the figure). The prevalence of extreme single-day precipitation events remained fairly steady between 1910 and the 1980s, but has risen substantially since then. Over the entire period from 1910 to 2012, the portion of the country experiencing extreme single-day precipitation events increased at a rate of about half a percentage point per decade (5 percentage points per century) (see the figure). The percentage of land area experiencing much greater than normal yearly precipitation totals increased between 1895 and 2012. However, there has been much year-to-year variability. In some years there were no abnormally wet areas, while a few others had abnormally high precipitation totals over 10 percent or more of the contiguous 48 states' land area (see the figure). For example, 1941 was extremely wet in the West, while 1982 was very wet nationwide. These figures are both consistent with other studies that have found an increase in heavy precipitation over timeframes ranging from single days to 90-day periods to whole years.



Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2012

Data source: NOAA (National Oceanic and Atmospheric Administration). 2013. U.S. Climate Extremes Index. Accessed March 2013. www.ncdc.noaa.gov/extremes/cei.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

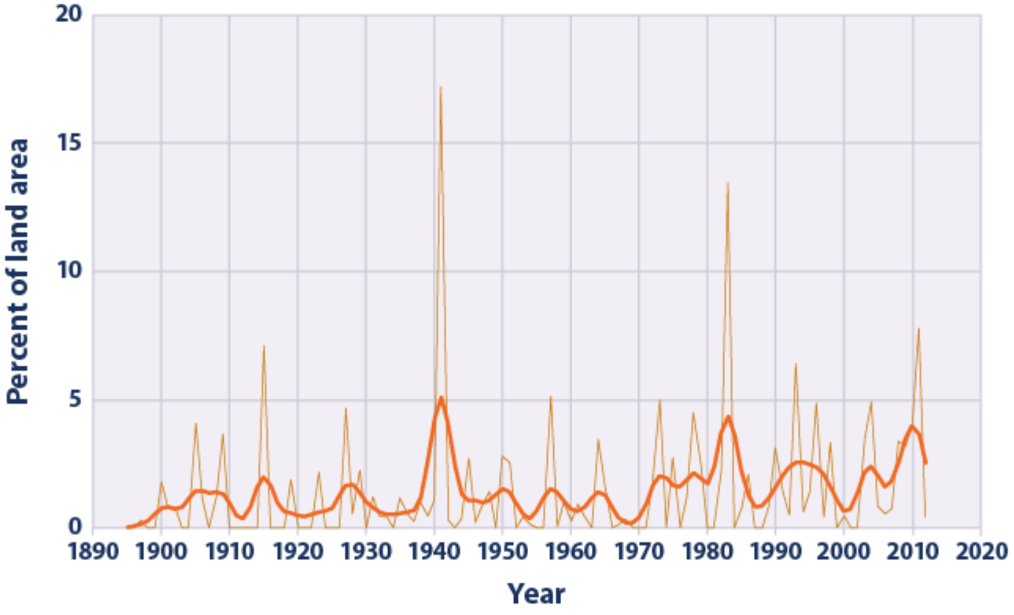
This figure shows the percentage of the land area of the contiguous 48 states where a much greater than normal portion of total annual precipitation has come from extreme single-day precipitation events. The bars represent individual years, while the line is a nine-year weighted average.

Scientific Defensibility: This indicator and the underlying data are established through peer-reviewed documentation. The data used to develop the indicators are of high quality, documented fully, transparent as to origin and any analysis that has been performed. The data from the county level and up are publicly available.

Relevance to Management Decisions:
Climate change can affect the intensity and frequency of precipitation. Warmer oceans increase the amount of water that evaporates into the air. When more moisture-laden air moves over land or converges into a storm system, it can produce more intense precipitation—for example, heavier rain and snow storms. The potential impacts of heavy precipitation include crop damage, soil erosion, and an increase in flood risk due to heavy rains. In addition, runoff from precipitation can impair water quality as pollutants deposited on land wash into water bodies.

Heavy precipitation does not necessarily mean the total amount of precipitation at a location has increased—just that precipitation is occurring in more intense events. However, changes in the intensity of precipitation, when combined with changes in the interval between precipitation events, can also lead to changes in overall precipitation totals.

Unusually High Annual Precipitation in the Contiguous 48 States, 1895–2012



Data source: NOAA (National Oceanic and Atmospheric Administration). 2013. Standardized Precipitation Index data files. Accessed March 2013. ftp://ftp.ncdc.noaa.gov/pub/data/cirs.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

This figure shows the percentage of the land area of the contiguous 48 states that experienced much greater than normal precipitation in any given year, which means it scored 2.0 or above on the annual Standardized Precipitation Index (SPI). The thicker orange line shows a nine-year weighted average that smoothes out some of the year-to-year fluctuations.

Data and Methods

Heavy precipitation is currently an indicator in the US EPA Climate Change Indicator suite; hence it is suitable for the NCA Indicator Pilot. As described on the EPA web site (http://www.epa.gov/climatechange/science/indicators/weather-climate/heavy-precip.html), the data used for this indicator come from a large national network of weather stations and were provided by the National Oceanic and Atmospheric Administration's National Climatic Data Center. The first figure is based on Step #4 of the National Oceanic and Atmospheric Administration's U.S. Climate Extremes Index; for data and a description of the index, see: www.ncdc.noaa.gov/ extremes/cei. The other figure is based on the U.S. SPI, which is shown in a variety of maps available online at: www.ncdc.noaa.gov/oa/ climate/research/prelim/ drought/spi.html. The data used to construct these maps are available from the National Oceanic and Atmospheric Administration at: ftp://ftp.ncdc.noaa.gov/ pub/data/cirs.

Streamflow Indicators

Summary

Streamflow volume and timing affect both ecological and human systems. Extremes in flow are indicative of floods and droughts, and climate and other stressors can affect streamflow as a result of changes in precipitation, surface-to-groundwater interactions, vegetation cover, and snowpack. This proposed indicator includes metrics of low flow (volume of 7-day minimum), high flow (volume of 3-day maximum), and the timing of flow (center of mass January-May). These metrics can be calculated similar to those in the EPA climate indicators report from USGS Hydro-Climatic Data Network (HCDN) data.

Background

Streamflow is essential to meeting water demand for human and ecological purposes. Both the volume and timing of flow during the year can be extremely important to water management. This information is used, for example, to specify water supply allocations, assess flood protection, operate irrigation systems, and determine other ecological or societal impacts at different thresholds. Extremes in streamflow (floods and droughts) create hazards that require considerable planning and expense to mitigate. Climate change may have substantial effects on all facets of streamflow through changes in precipitation (including rain and snow distribution), changes in watershed vegetation patterns, changes to groundwater-surface water interactions, and changes to snowpack. The proposed family of indicators for streamflow is designed to track elements of both the volume and timing of streamflow throughout the U.S., including extremes and could have direct application for climate change adaptation efforts.

For the *pilot indicators*, the EPA suite of 3 streamflow indicators is recommended:

- Low flow: Volume of 7-day minimum streamflow
- High flow: Volume of 3-day maximum streamflow
- Timing of flow: Center of mass of streamflow, Jan – May
- (http://www.epa.gov/climatechange/science/indicators/society-eco/streamflow.html)

All of these indicators can be derived from a hydrograph of streamflow, as shown in the figure. The EPA suite of indicators uses data for the period 1940-2009. Additional flexibility in the period of record used can be added into the tools for full implementation.

Dataset

All streamflow indicators will be calculated using data from the USGS Hydro-Climatic Data Network, or HCDN (Lins, 2012). The purpose of the network is to provide a streamflow dataset suitable for analyzing hydrologic variations and trends in a climatic context. The HCDN was updated in 2012 and includes a subset of the gages identified as "reference quality" in the GAGES-II dataset developed by Falcone and others (2010). Additional criteria such as length of available record are required for inclusion. HCDN-2009 consists of 743 streamgages with at least 20 years of record up through water year 2009. Many gages have considerably more data. Additional review and update of the HCDN is planned for the future and the streamflow indicators should be adjusted to reflect changes to streamgages included in the HCDN. The USGS data has been collected with the same basic methods, but improved equipment, software, etc. through time. USGS quality assurance controls are in place to vet new equipment to make sure records stay consistent.

Display

Spatial variability is important to understanding the broader potential impacts of streamflow changes, which may be different in different parts of the country, so each indicator will be calculated at individual streamgages and mapped. The figures are examples from the EPA indicators, and full implementation would make modifications to allow use of more HCDN gages. It may be possible to develop tools to click on an individual gage to look at the time series for that gage. National and regional composites could also be developed to visualize typical changes over a broad region. Such tools for calculation and display of streamflow indicators can be developed by expanding on the existing capabilities of USGS WaterWatch (http://waterwatch.usgs.gov).

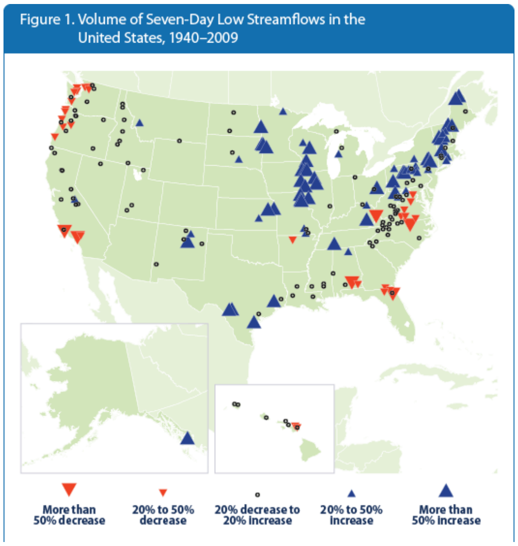


Figure 1. Volume of Seven-Day Low Streamflows in the United States, 1940–2009

Example map of low flow streamflow indicators, as shown on the EPA indicators website (http://www.epa.gov/climatechange/science/indicators/society-eco/streamflow.html)

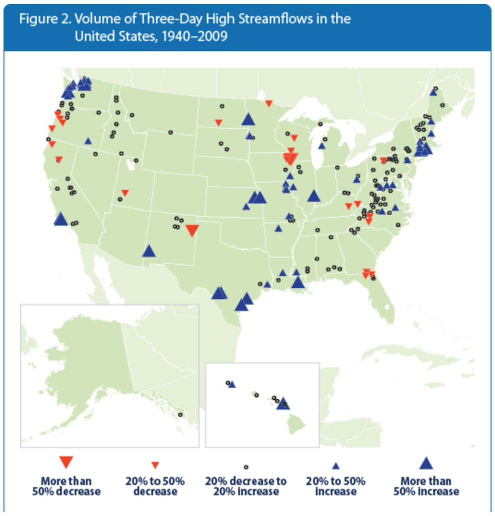


Figure 2. Volume of Three-Day High Streamflows in the United States, 1940–2009

Example map of high flow streamflow indicators, as shown on the EPA indicators website (http://www.epa.gov/climatechange/science/indicators/society-eco/streamflow.html)

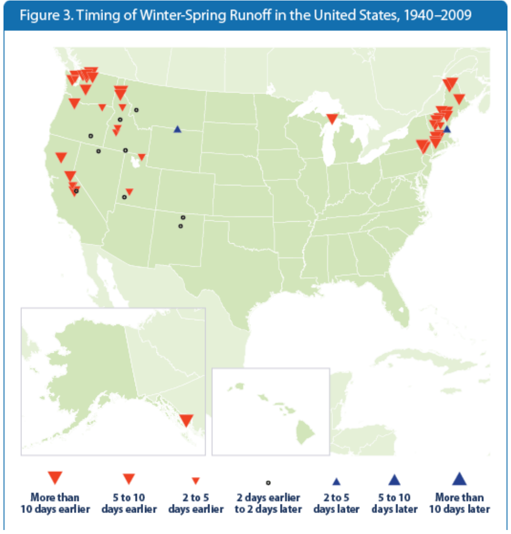
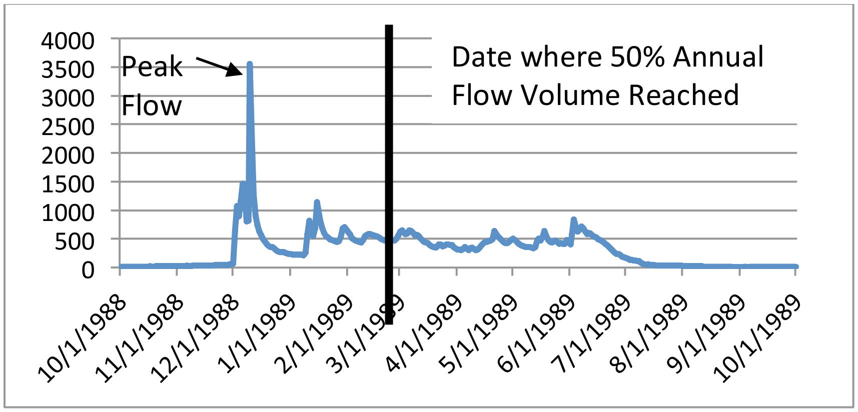


Figure 3. Timing of Winter-Spring Runoff in the United States, 1940–2009

Example map of indicator for streamflow timing, as shown on the EPA indicators website (http://www.epa.gov/climatechange/science/indicators/society-eco/streamflow.html)

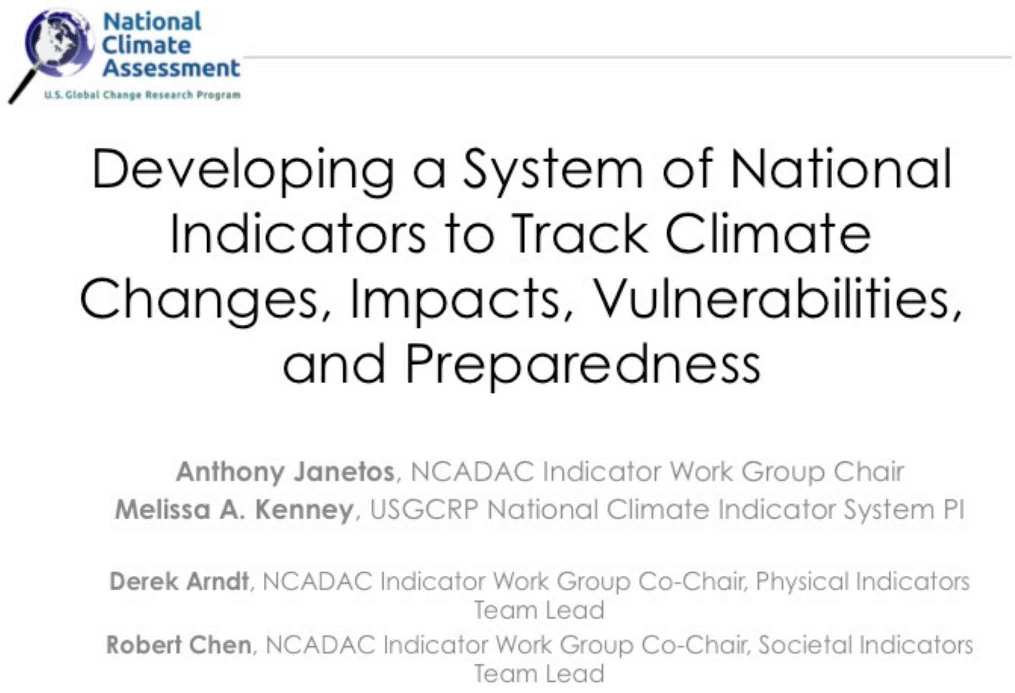


*Daily streamflow for Smith River at Fort Jones with potential indicators highlighted. *

Appendix C: Indicators System Process and Timeline – Indicator Webinar Slides

Indicators Process and Timeline

To provide details about the process and timeline, the Indicators System Webinar briefings to the NCADAC are included in this appendix.



National Climate Assessment
U.S. Global Change Research Program

Developing a System of National Indicators to Track Climate Changes, Impacts, Vulnerabilities, and Preparedness

Anthony Janetos, NCADAC Indicator Work Group Chair
Melissa A. Kenney, USGCRP National Climate Indicator System PI

Derek Arndt, NCADAC Indicator Work Group Co-Chair, Physical Indicators Team Lead
Robert Chen, NCADAC Indicator Work Group Co-Chair, Societal Indicators Team Lead

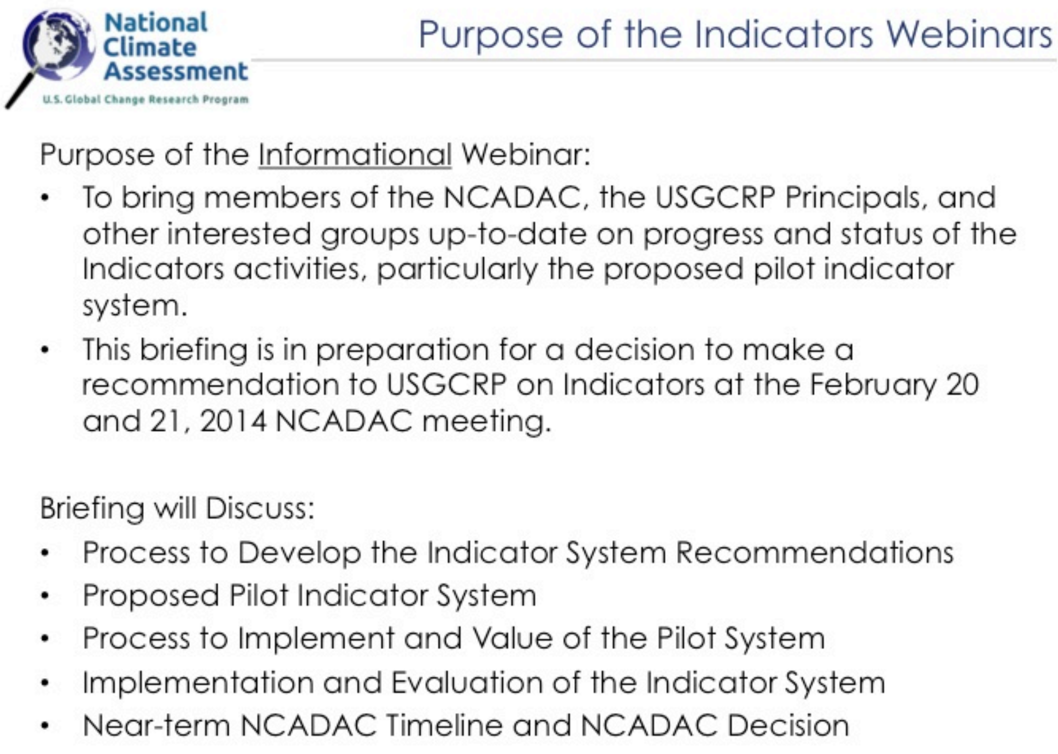
National
Climate
Assessment
U.S. Global Change Research Program

Documents to Review

The documents were sent in the Webinar reminder.
You can also access them at:

http://tinyurl.com/IndicatorsWebinarsJan2014

Comments on the Indicator Pilot System Proposal Due by Friday, February 7 COB.



National
Climate
Assessment
U.S. Global Change Research Program

Purpose of the Indicators Webinars

Purpose of the Informational Webinar:

- To bring members of the NCADAC, the USGCRP Principals, and other interested groups up-to-date on progress and status of the Indicators activities, particularly the proposed pilot indicator system.
- This briefing is in preparation for a decision to make a recommendation to USGCRP on Indicators at the February 20 and 21, 2014 NCADAC meeting.

Briefing will Discuss:

- Process to Develop the Indicator System Recommendations
- Proposed Pilot Indicator System
- Process to Implement and Value of the Pilot System
- Implementation and Evaluation of the Indicator System
- Near-term NCADAC Timeline and NCADAC Decision

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Decision on Indicators for the NCADAC

The NCADAC recommends that the U.S. Global Change Research Program develop and implement a system of indicators to provide decision-relevant information on physical, natural, and social climate changes, impacts, vulnerabilities, and preparedness and to contribute to a sustained assessment process. NCADAC adopts the proposal developed by the Indicator Work Group, which includes recommendations for the implementation of a pilot set of indicators as the first step towards a sustained indicator system.

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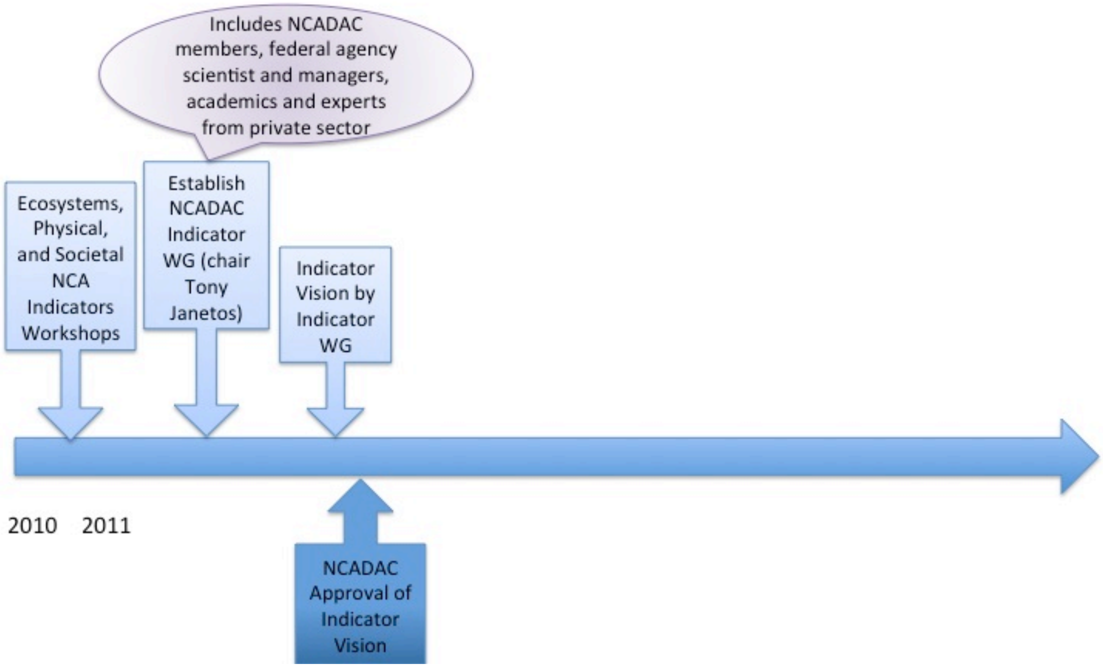
Indicators Milestones



Includes NCADAC members, federal agency scientist and managers, academics and experts from private sector

Ecosystems, Physical, and Societal NCA Indicators Workshops

Establish NCADAC Indicator WG (chair Tony Janetos)

Indicator Vision by Indicator WG

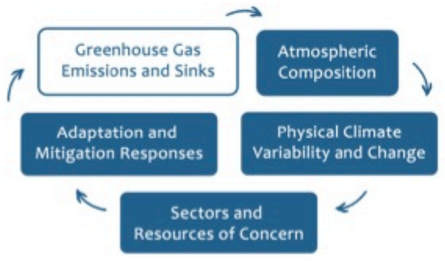
2010 2011

NCADAC Approval of Indicator Vision

National Climate Indicators System

A system of physical, ecological, and societal indicators that communicate key aspects of climate changes, impacts, vulnerabilities, and preparedness.

- Provide meaningful, authoritative climate-relevant measures about the status, rates, and trends of key physical, ecological, and societal variables and values;
- Inform decisions at multiple scales
- Identify climate-related conditions and impacts
- Provide analytical tools by which user communities can derive their own indicators for particular purposes.



Categories of Indicators: Framework for the National Climate Assessment Indicator System

indicators@usgcrp.gov

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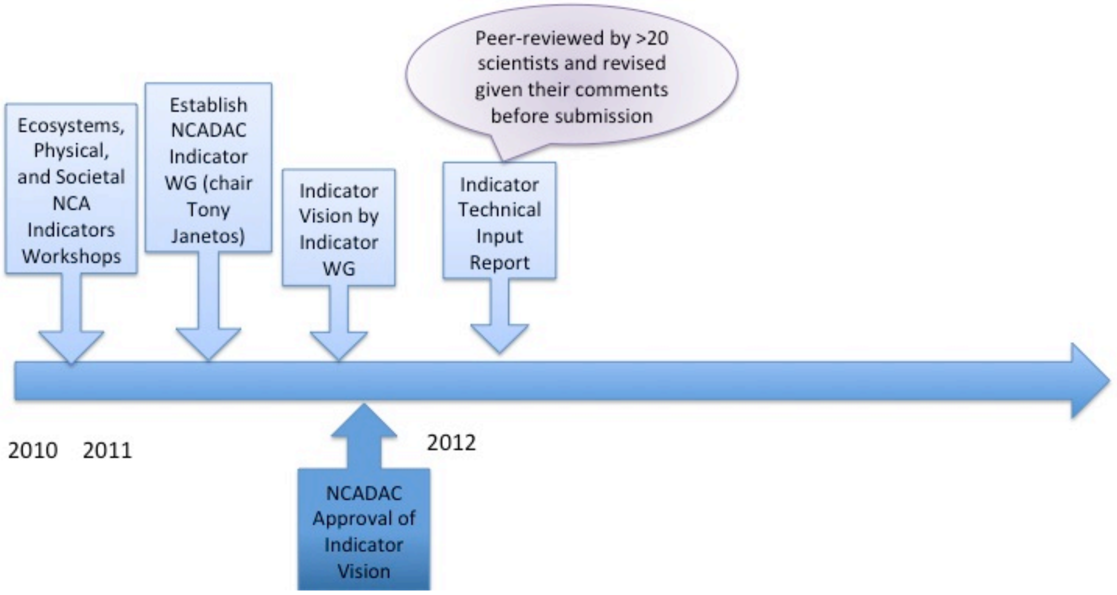
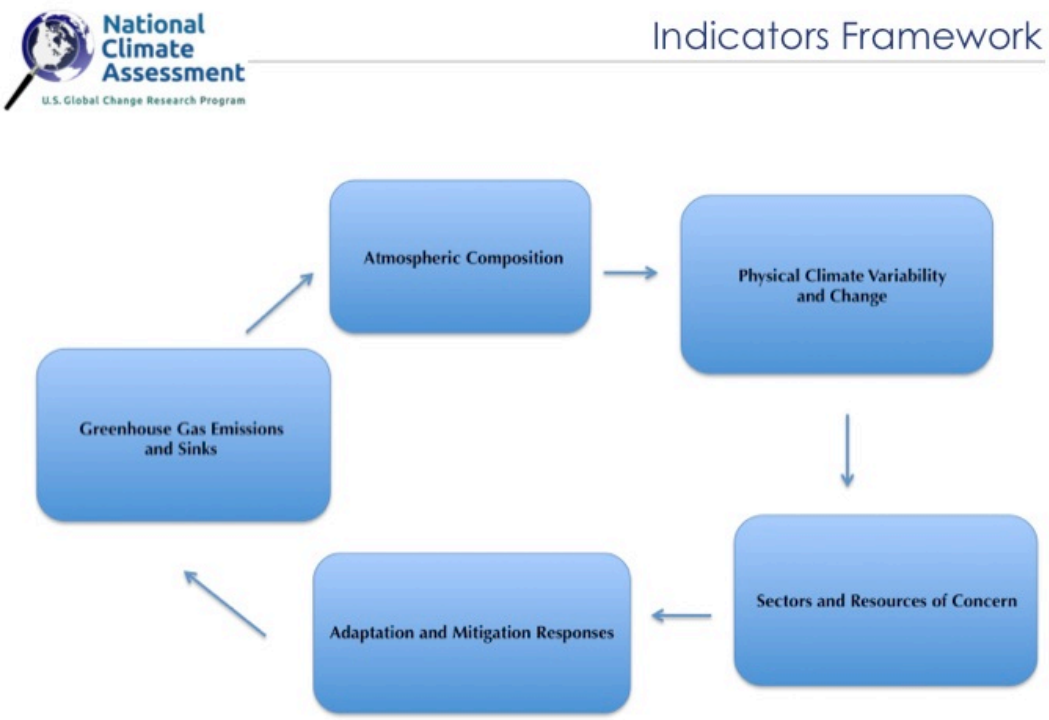
Indicators Milestones





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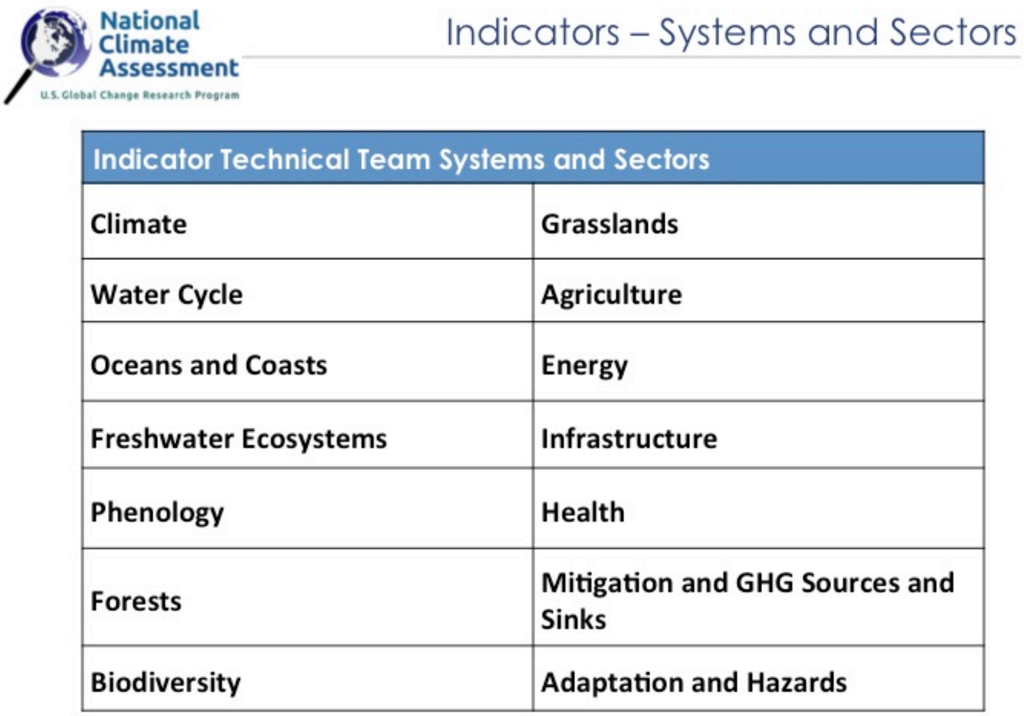
Indicators Framework

Atmospheric Composition → Physical Climate Variability and Change → Sectors and Resources of Concern → Adaptation and Mitigation Responses → Greenhouse Gas Emissions and Sinks → Atmospheric Composition



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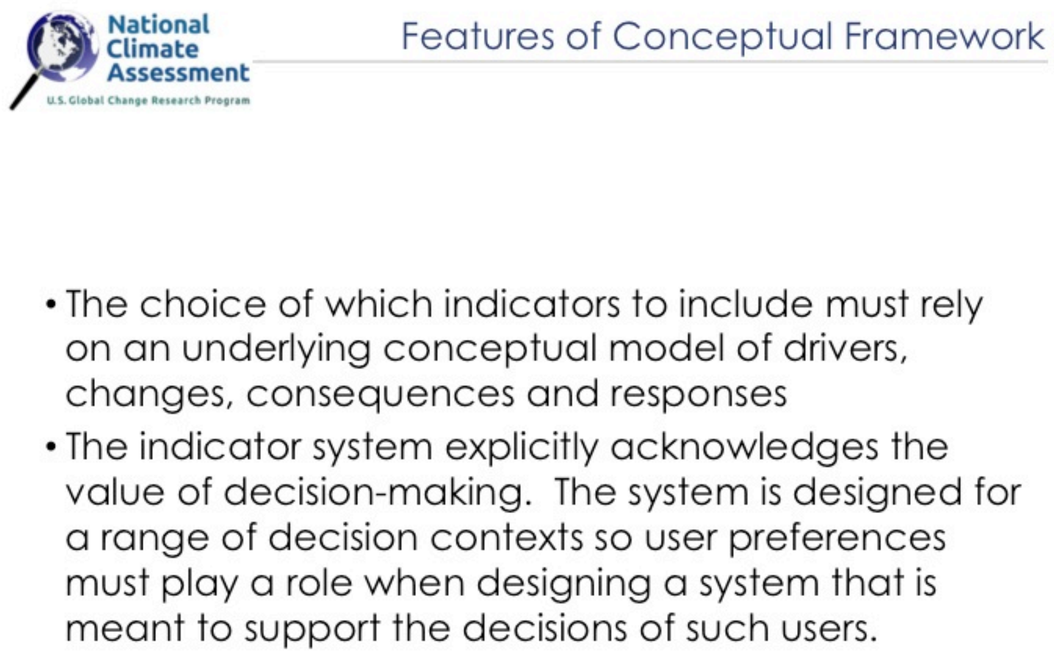
Indicators – Systems and Sectors

Indicator Technical Team Systems and Sectors	
Climate	Grasslands
Water Cycle	Agriculture
Oceans and Coasts	Energy
Freshwater Ecosystems	Infrastructure
Phenology	Health
Forests	Mitigation and GHG Sources and Sinks
Biodiversity	Adaptation and Hazards



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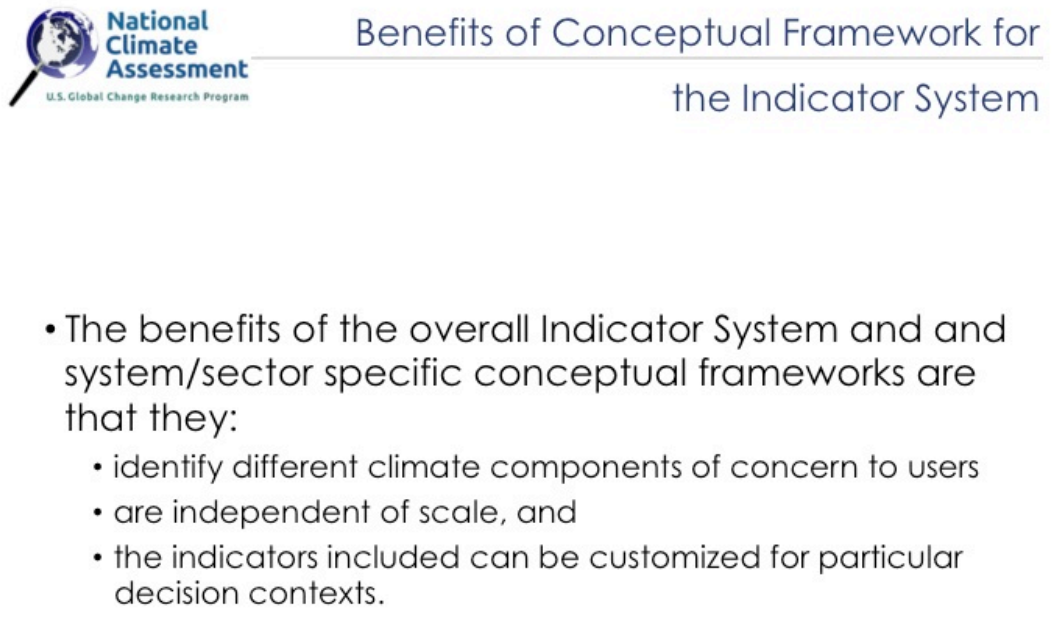
Features of Conceptual Framework

- The choice of which indicators to include must rely on an underlying conceptual model of drivers, changes, consequences and responses
- The indicator system explicitly acknowledges the value of decision-making. The system is designed for a range of decision contexts so user preferences must play a role when designing a system that is meant to support the decisions of such users.



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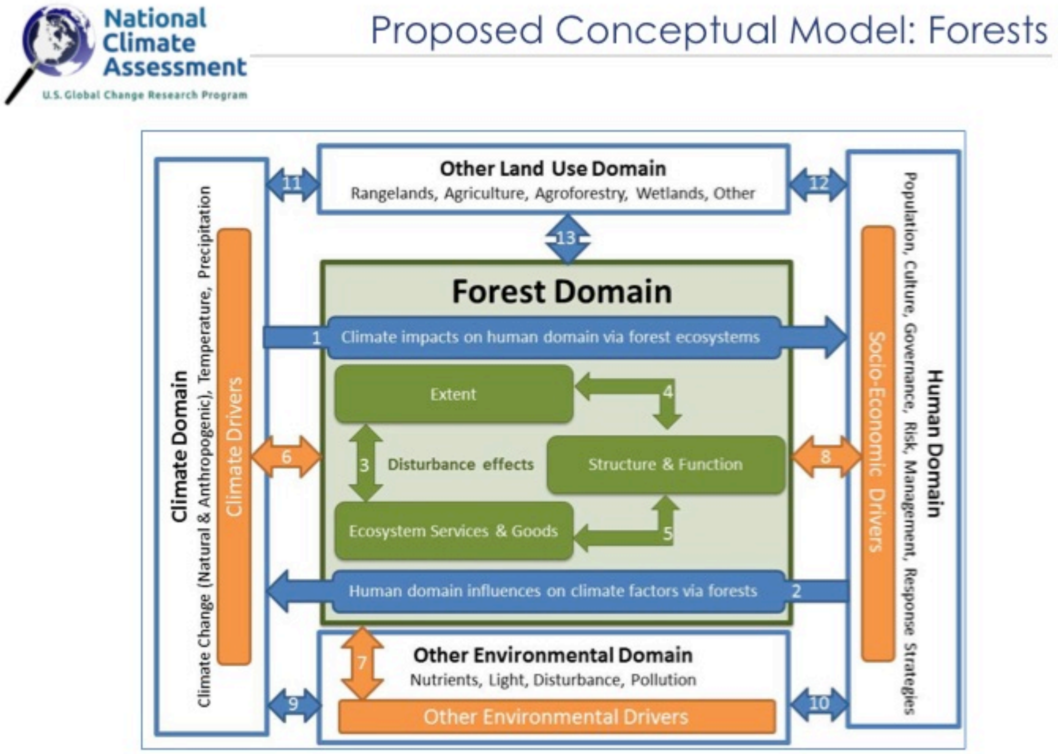
Benefits of Conceptual Framework for the Indicator System

- The benefits of the overall Indicator System and and system/sector specific conceptual frameworks are that they:
  - identify different climate components of concern to users
  - are independent of scale, and
  - the indicators included can be customized for particular decision contexts.



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Proposed Conceptual Model: Forests

Other Land Use Domain
Rangelands, Agriculture, Agroforestry, Wetlands, Other

Forest Domain

1 Climate impacts on human domain via forest ecosystems

Extent

Disturbance effects

Structure & Function

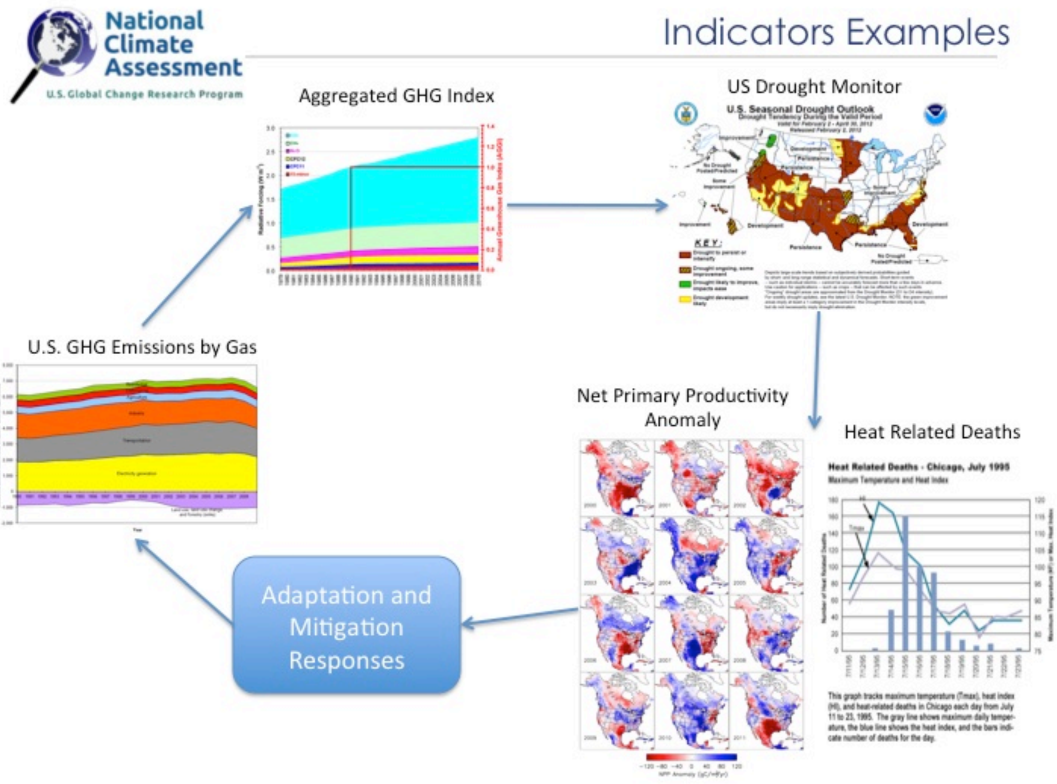
Ecosystem Services & Goods

Human domain influences on climate factors via forests 2

Climate Domain
Climate Change (Natural & Anthropogenic), Temperature, Precipitation
Climate Drivers

Human Domain
Population, Culture, Governance, Risk, Management, Response Strategies
Socio-Economic Drivers

Other Environmental Domain
Nutrients, Light, Disturbance, Pollution
Other Environmental Drivers



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Indicators Examples

Aggregated GHG Index

US Drought Monitor

U.S. Seasonal Drought Outlook
Drought Tendency During the Valid Period
Valid for February 2 - April 30, 2012
Released February 2, 2012

U.S. GHG Emissions by Gas

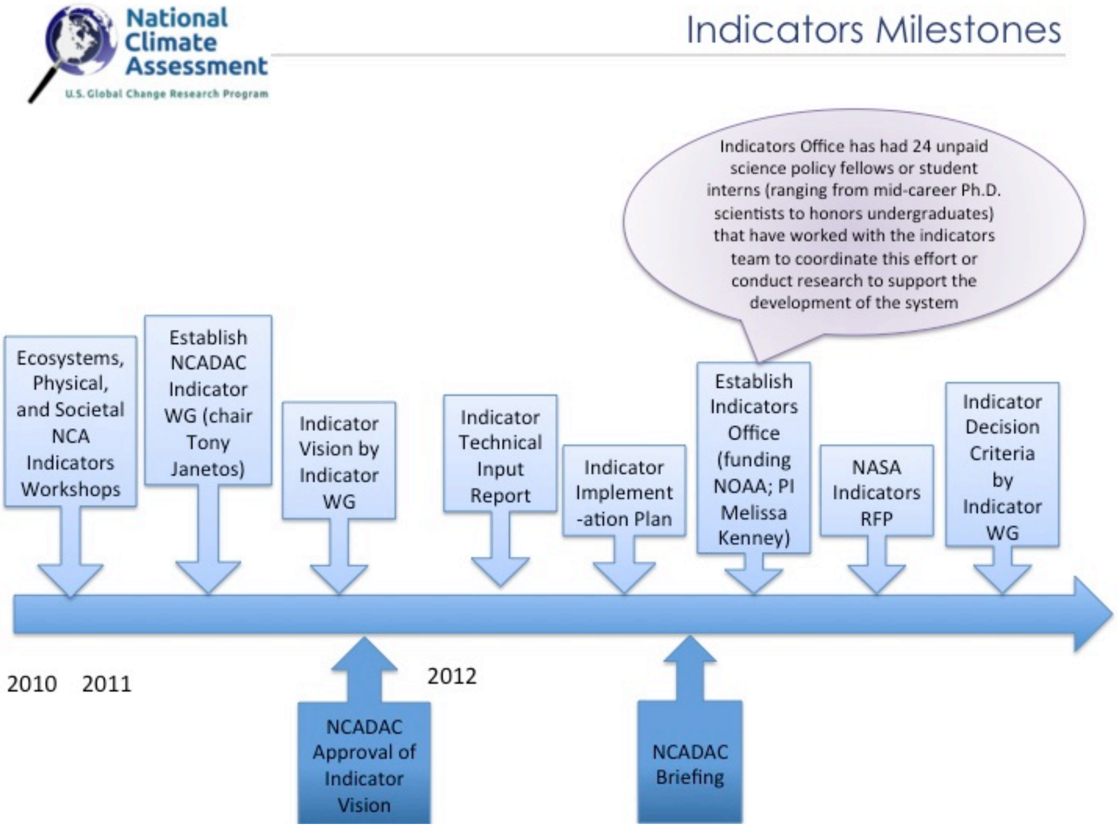
Net Primary Productivity Anomaly

Heat Related Deaths

Heat Related Deaths - Chicago, July 1995
Maximum Temperature and Heat Index

This graph tracks maximum temperature (Tmax), heat index (HI), and heat-related deaths in Chicago each day from July 11 to 23, 1995. The gray line shows maximum daily temperature, the blue line shows the heat index, and the bars indicate number of deaths for the day.

Adaptation and Mitigation Responses



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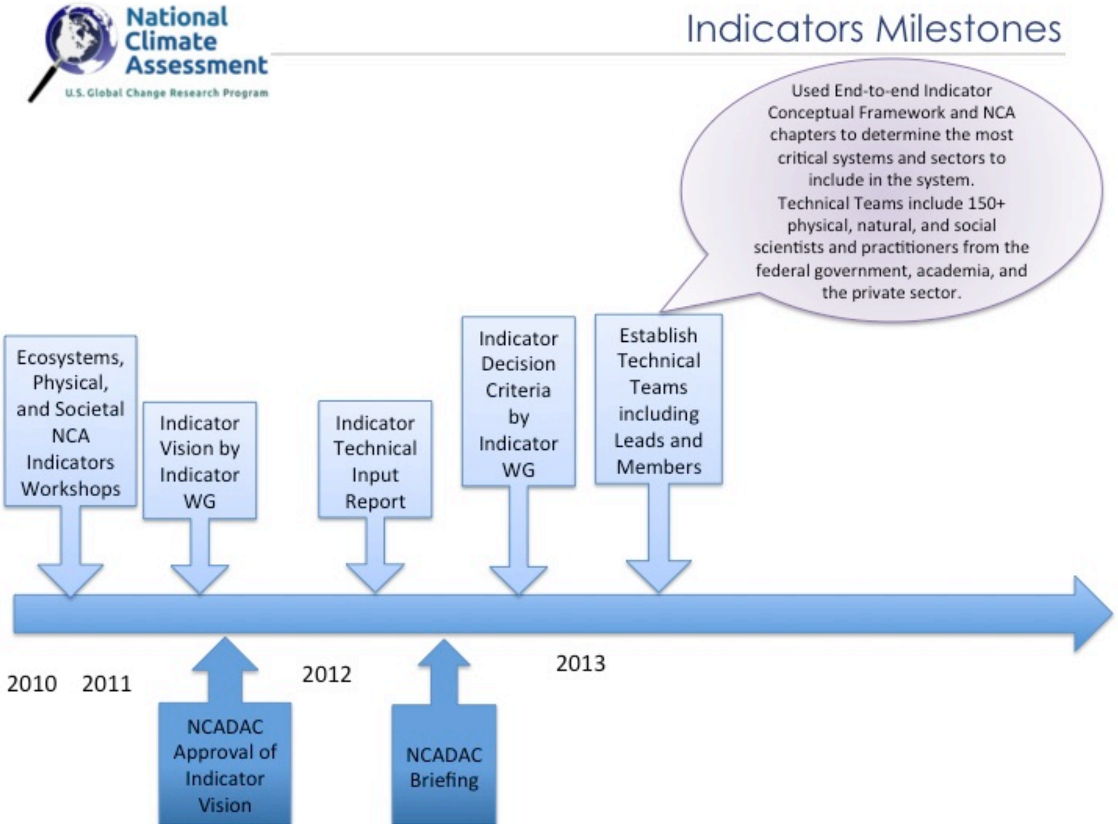
Indicators Milestones

Indicators Office has had 24 unpaid science policy fellows or student interns (ranging from mid-career Ph.D. scientists to honors undergraduates) that have worked with the indicators team to coordinate this effort or conduct research to support the development of the system

- Ecosystems, Physical, and Societal NCA Indicators Workshops
- Establish NCADAC Indicator WG (chair Tony Janetos)
- Indicator Vision by Indicator WG
- Indicator Technical Input Report
- Indicator Implement-ation Plan
- Establish Indicators Office (funding NOAA; PI Melissa Kenney)
- NASA Indicators RFP
- Indicator Decision Criteria by Indicator WG

2010 2011 2012

- NCADAC Approval of Indicator Vision
- NCADAC Briefing



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Indicators Milestones

Used End-to-end Indicator Conceptual Framework and NCA chapters to determine the most critical systems and sectors to include in the system. Technical Teams include 150+ physical, natural, and social scientists and practitioners from the federal government, academia, and the private sector.

- Ecosystems, Physical, and Societal NCA Indicators Workshops
- Indicator Vision by Indicator WG
- Indicator Technical Input Report
- Indicator Decision Criteria by Indicator WG
- Establish Technical Teams including Leads and Members

2010 2011 2012 2013

- NCADAC Approval of Indicator Vision
- NCADAC Briefing

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Participating Federal Agencies

9 of the 13 USGCRP Agencies

Estimated Participants from the Agencies on Indicator Work Group or Technical Teams	
DOC NOAA	25
EPA	10
USDA	17
DOI	20
NASA	7
DOE	13
HHS	3
NSF	2
DOD	6

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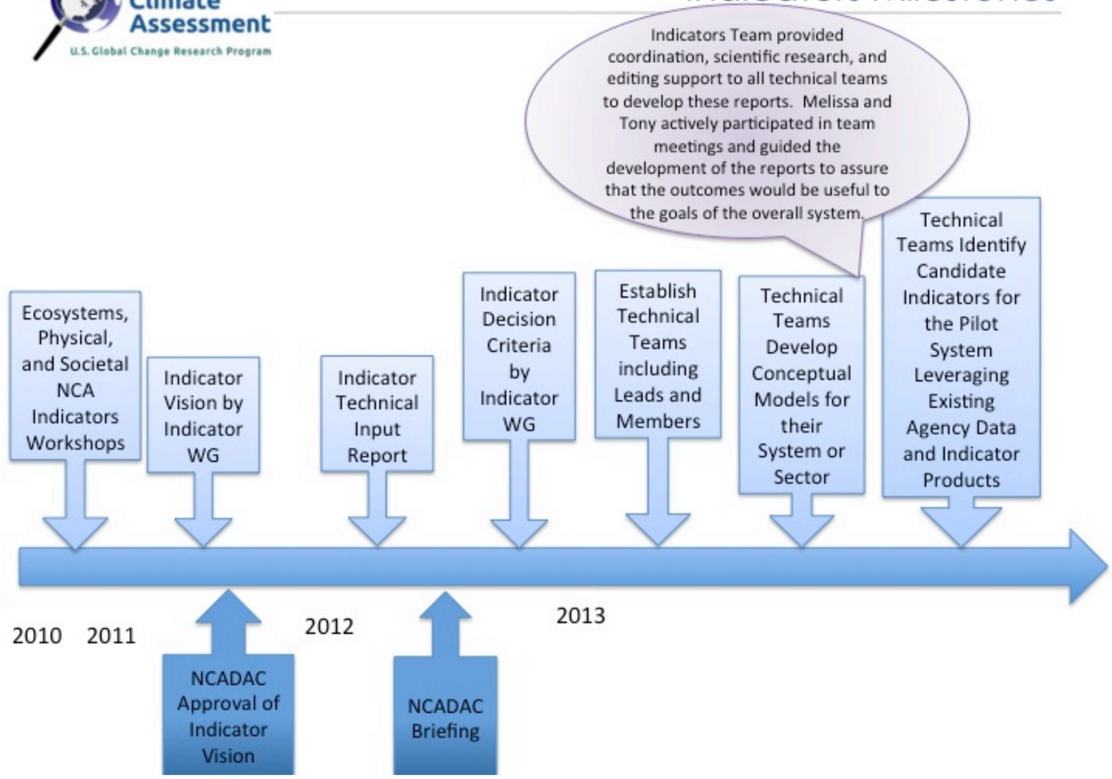
Indicators Milestones



Indicators Team provided coordination, scientific research, and editing support to all technical teams to develop these reports. Melissa and Tony actively participated in team meetings and guided the development of the reports to assure that the outcomes would be useful to the goals of the overall system.

Ecosystems, Physical, and Societal NCA Indicators Workshops

Indicator Vision by Indicator WG

Indicator Technical Input Report

Indicator Decision Criteria by Indicator WG

Establish Technical Teams including Leads and Members

Technical Teams Develop Conceptual Models for their System or Sector

Technical Teams Identify Candidate Indicators for the Pilot System Leveraging Existing Agency Data and Indicator Products

NCADAC Approval of Indicator Vision

NCADAC Briefing

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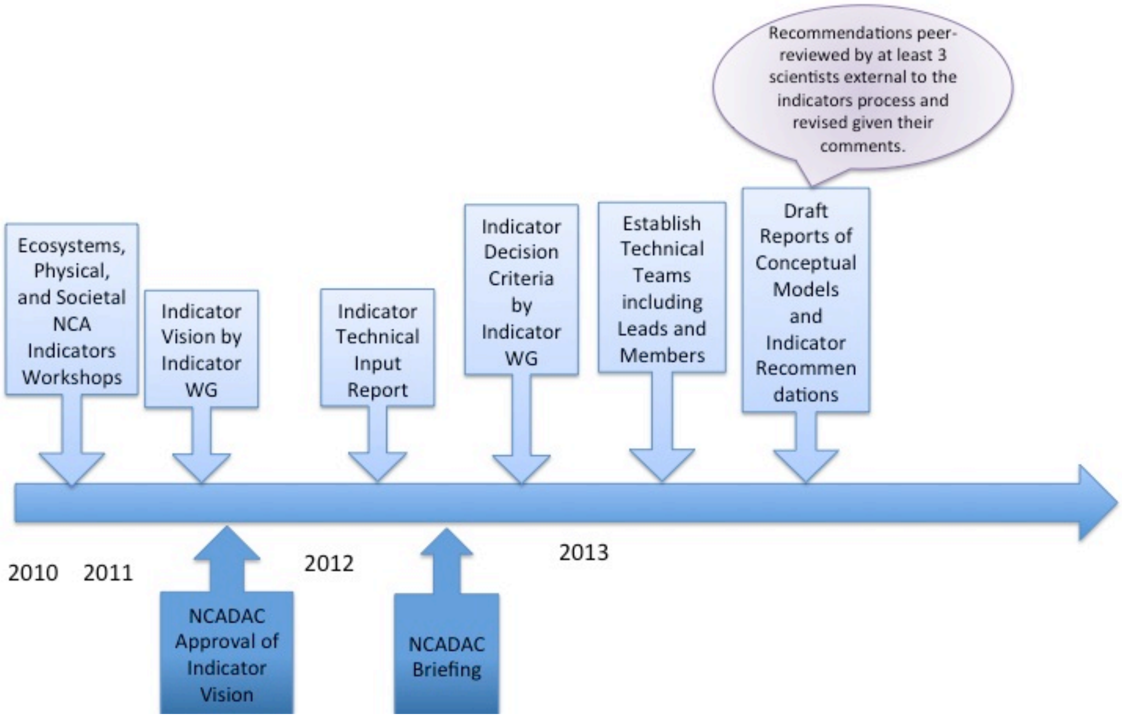
Indicators Milestones



Recommendations peer-reviewed by at least 3 scientists external to the indicators process and revised given their comments.

Ecosystems, Physical, and Societal NCA Indicators Workshops

Indicator Vision by Indicator WG

Indicator Technical Input Report

Indicator Decision Criteria by Indicator WG

Establish Technical Teams including Leads and Members

Draft Reports of Conceptual Models and Indicator Recommendations

2010 2011

NCADAC Approval of Indicator Vision

2012

NCADAC Briefing

2013

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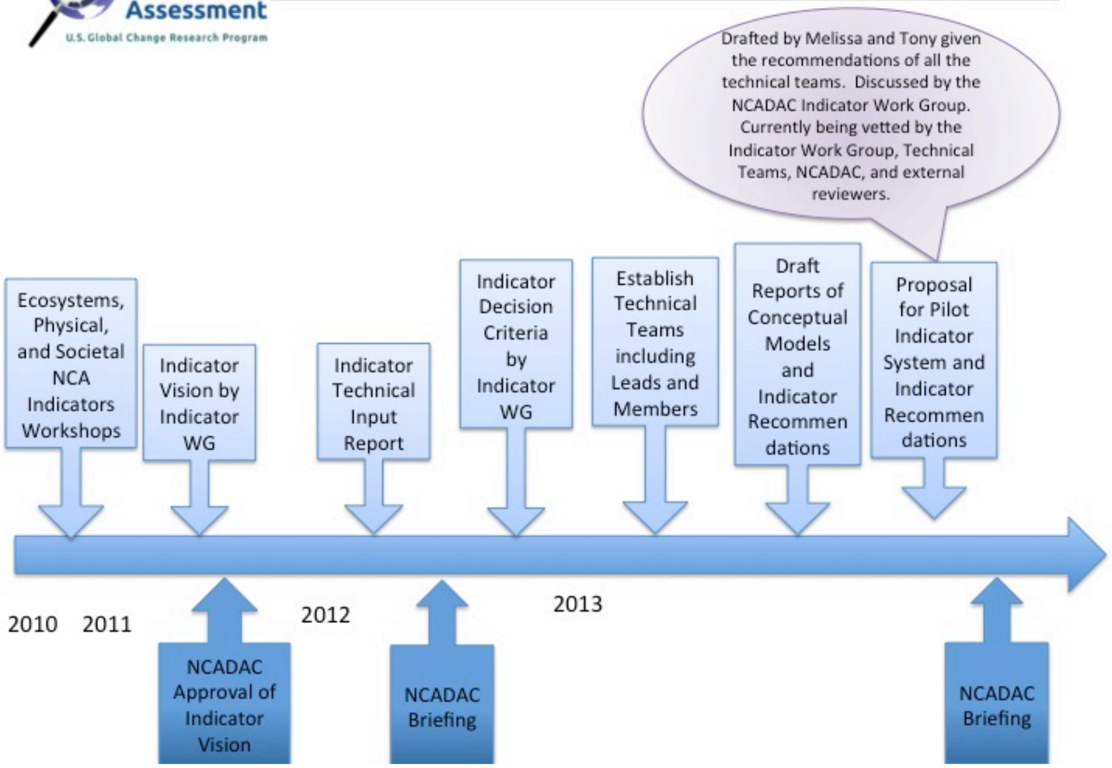
Indicators Milestones



Drafted by Melissa and Tony given the recommendations of all the technical teams. Discussed by the NCADAC Indicator Work Group. Currently being vetted by the Indicator Work Group, Technical Teams, NCADAC, and external reviewers.

Ecosystems, Physical, and Societal NCA Indicators Workshops

Indicator Vision by Indicator WG

Indicator Technical Input Report

Indicator Decision Criteria by Indicator WG

Establish Technical Teams including Leads and Members

Draft Reports of Conceptual Models and Indicator Recommendations

Proposal for Pilot Indicator System and Indicator Recommendations

2010 2011

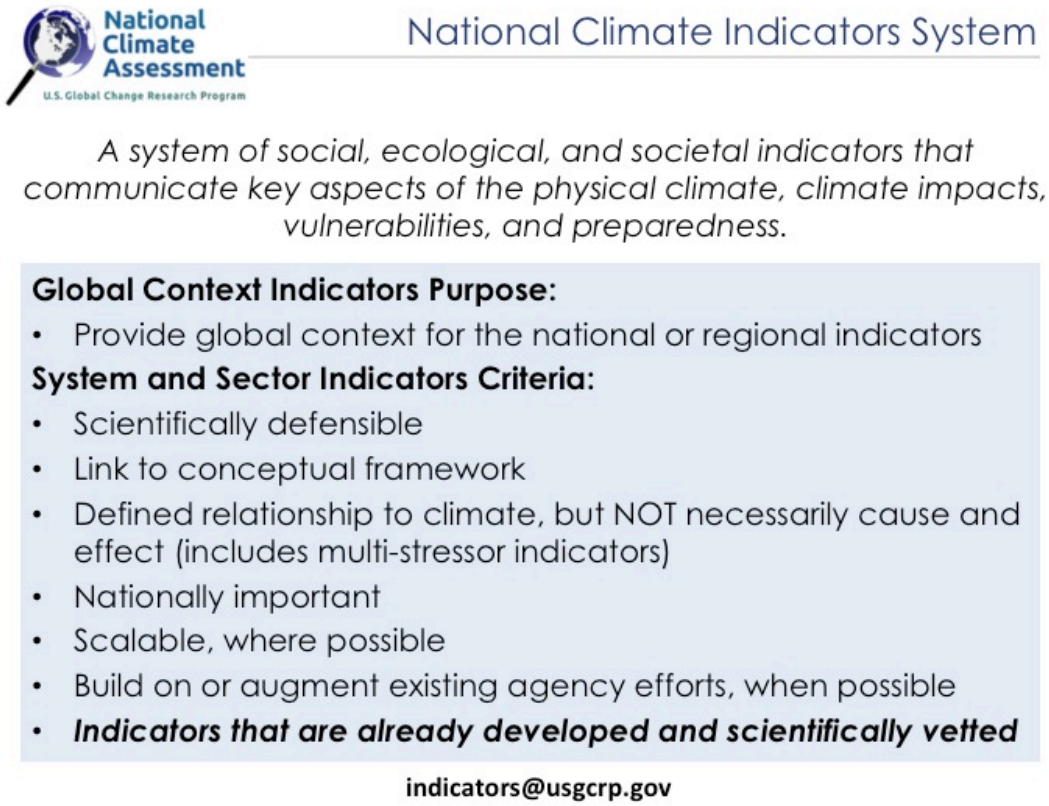
NCADAC Approval of Indicator Vision

2012

NCADAC Briefing

2013

NCADAC Briefing



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National Climate Indicators System

A system of social, ecological, and societal indicators that communicate key aspects of the physical climate, climate impacts, vulnerabilities, and preparedness.

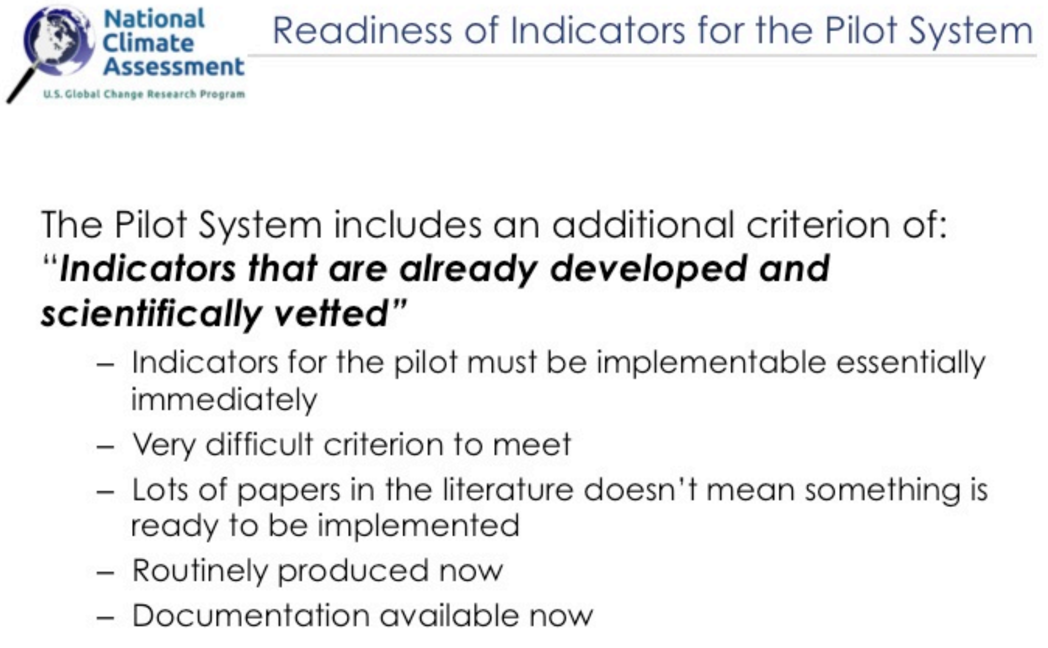
Global Context Indicators Purpose:

- Provide global context for the national or regional indicators

System and Sector Indicators Criteria:

- Scientifically defensible
- Link to conceptual framework
- Defined relationship to climate, but NOT necessarily cause and effect (includes multi-stressor indicators)
- Nationally important
- Scalable, where possible
- Build on or augment existing agency efforts, when possible
- ***Indicators that are already developed and scientifically vetted***

indicators@usgcrp.gov



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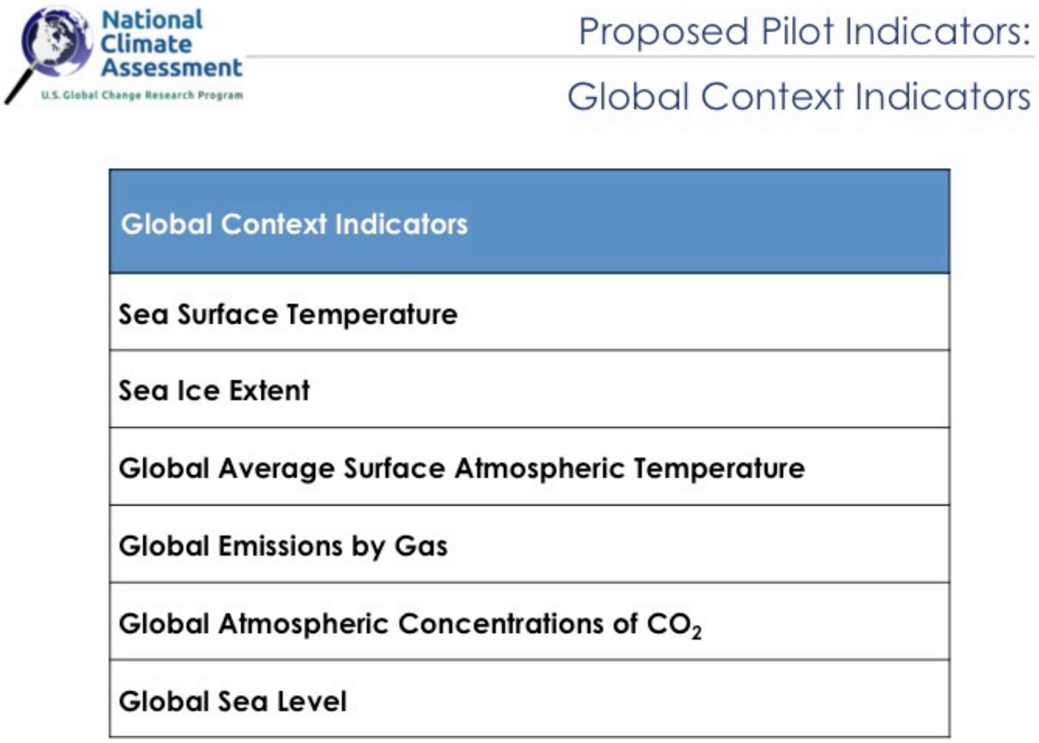
Readiness of Indicators for the Pilot System

The Pilot System includes an additional criterion of:
"***Indicators that are already developed and scientifically vetted***"

- Indicators for the pilot must be implementable essentially immediately
- Very difficult criterion to meet
- Lots of papers in the literature doesn't mean something is ready to be implemented
- Routinely produced now
- Documentation available now



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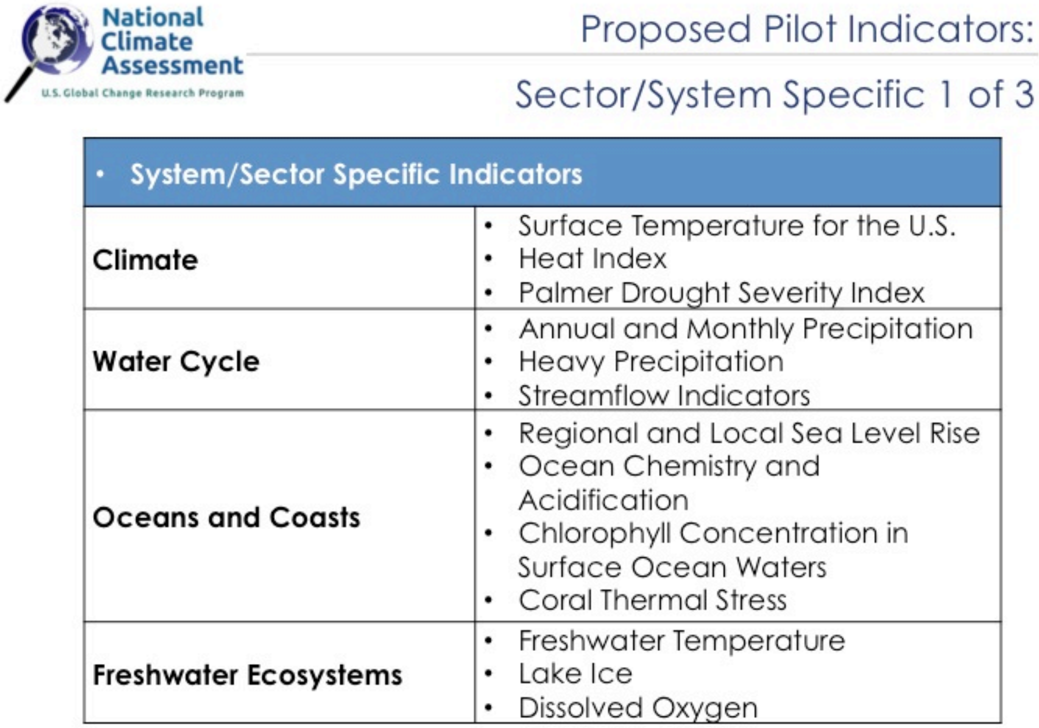
Proposed Pilot Indicators:
Global Context Indicators

Global Context Indicators
Sea Surface Temperature
Sea Ice Extent
Global Average Surface Atmospheric Temperature
Global Emissions by Gas
Global Atmospheric Concentrations of CO_2
Global Sea Level



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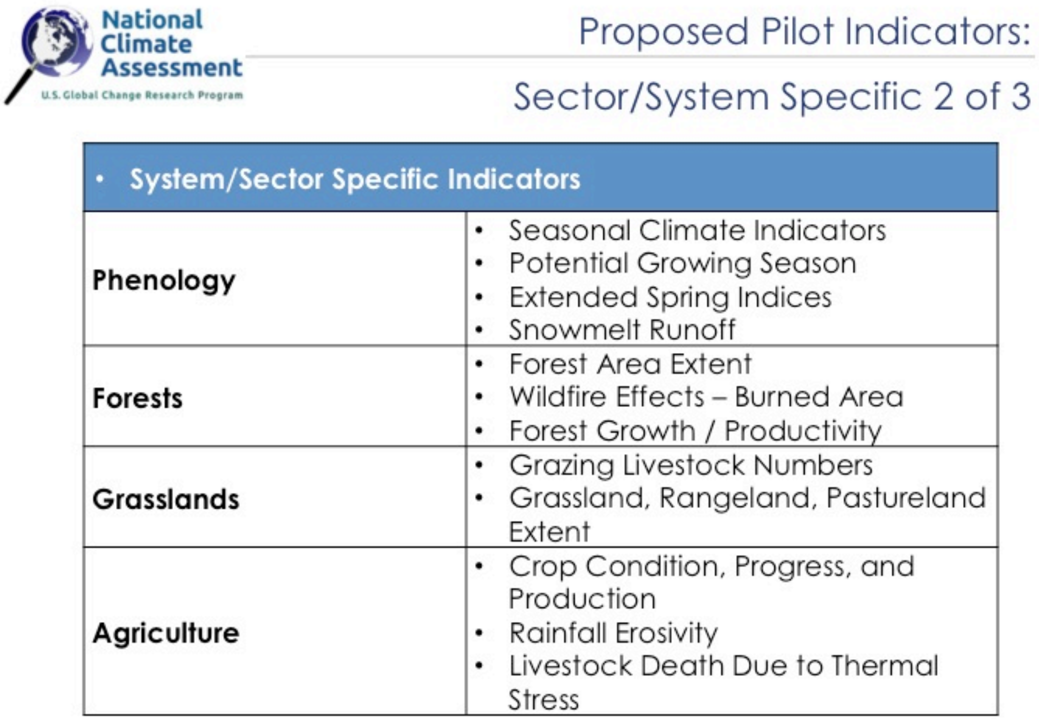
Proposed Pilot Indicators:
Sector/System Specific 1 of 3

• System/Sector Specific Indicators	
Climate	• Surface Temperature for the U.S. • Heat Index • Palmer Drought Severity Index
Water Cycle	• Annual and Monthly Precipitation • Heavy Precipitation • Streamflow Indicators
Oceans and Coasts	• Regional and Local Sea Level Rise • Ocean Chemistry and Acidification • Chlorophyll Concentration in Surface Ocean Waters • Coral Thermal Stress
Freshwater Ecosystems	• Freshwater Temperature • Lake Ice • Dissolved Oxygen



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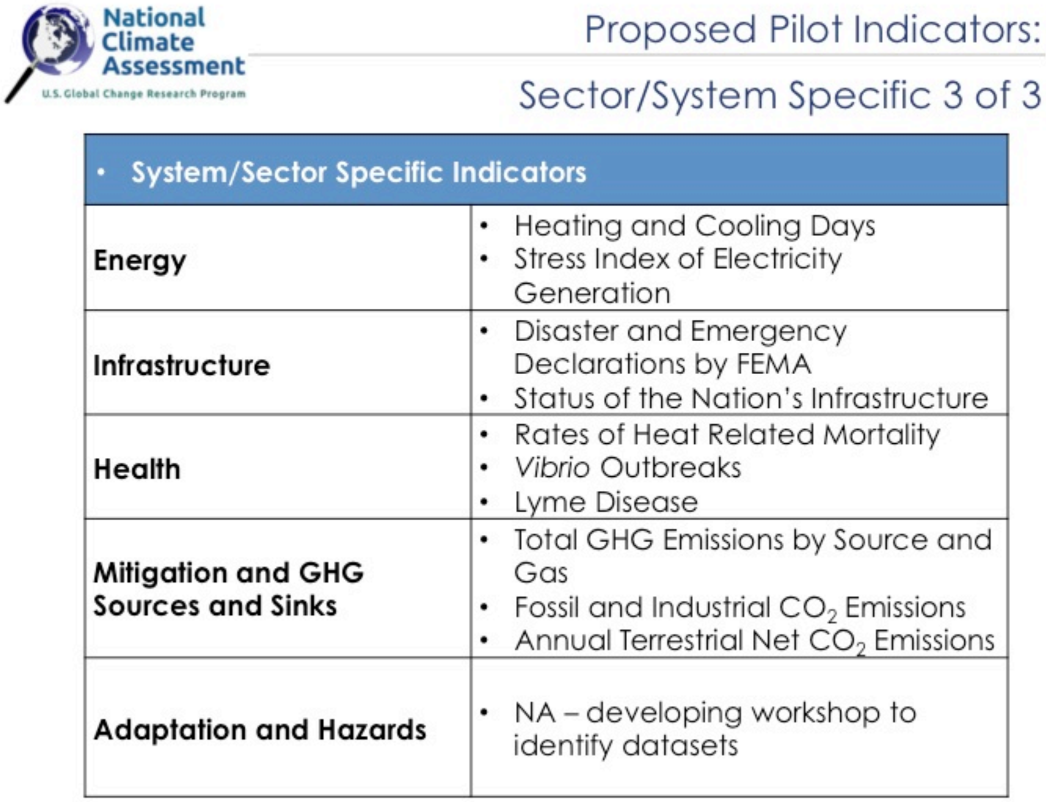
Proposed Pilot Indicators: Sector/System Specific 2 of 3

• System/Sector Specific Indicators	
Phenology	• Seasonal Climate Indicators • Potential Growing Season • Extended Spring Indices • Snowmelt Runoff
Forests	• Forest Area Extent • Wildfire Effects – Burned Area • Forest Growth / Productivity
Grasslands	• Grazing Livestock Numbers • Grassland, Rangeland, Pastureland Extent
Agriculture	• Crop Condition, Progress, and Production • Rainfall Erosivity • Livestock Death Due to Thermal Stress



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Proposed Pilot Indicators: Sector/System Specific 3 of 3

• System/Sector Specific Indicators	
Energy	• Heating and Cooling Days • Stress Index of Electricity Generation
Infrastructure	• Disaster and Emergency Declarations by FEMA • Status of the Nation’s Infrastructure
Health	• Rates of Heat Related Mortality • *Vibrio* Outbreaks • Lyme Disease
Mitigation and GHG Sources and Sinks	• Total GHG Emissions by Source and Gas • Fossil and Industrial CO_2 Emissions • Annual Terrestrial Net CO_2 Emissions
Adaptation and Hazards	• NA – developing workshop to identify datasets

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Example Pilot Indicator:
Sea Ice Extent

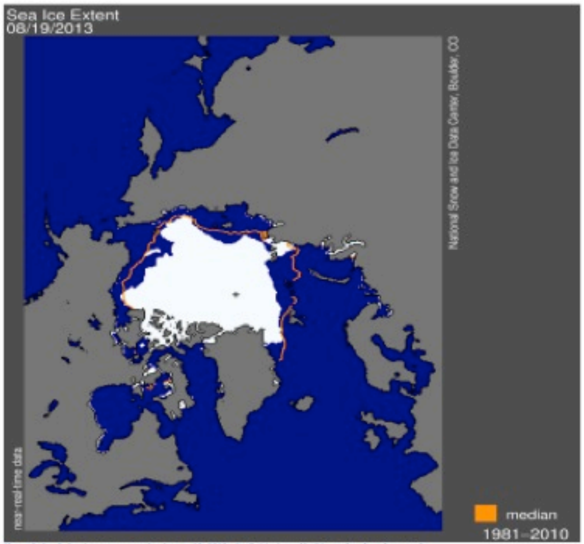

Figure 2: Arctic Sea Ice extent map for August 19, 2013. Available: http://nsidc.org/arcticseaicenews/

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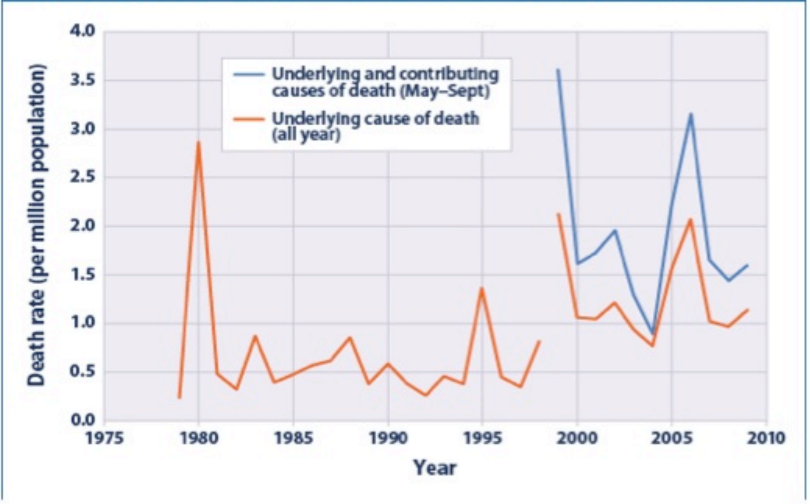
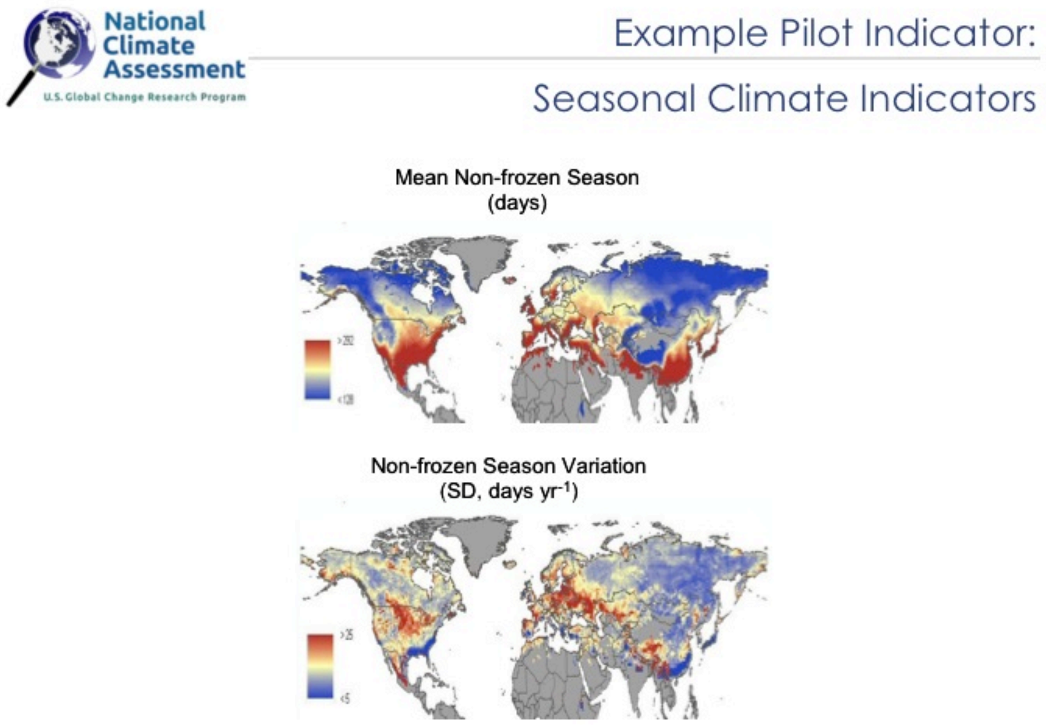
Example Pilot Indicator:
Rates of Heat-Related Human Mortality

Figure 1. Deaths Classified as "Heat-Related" in the United States, 1979–2009





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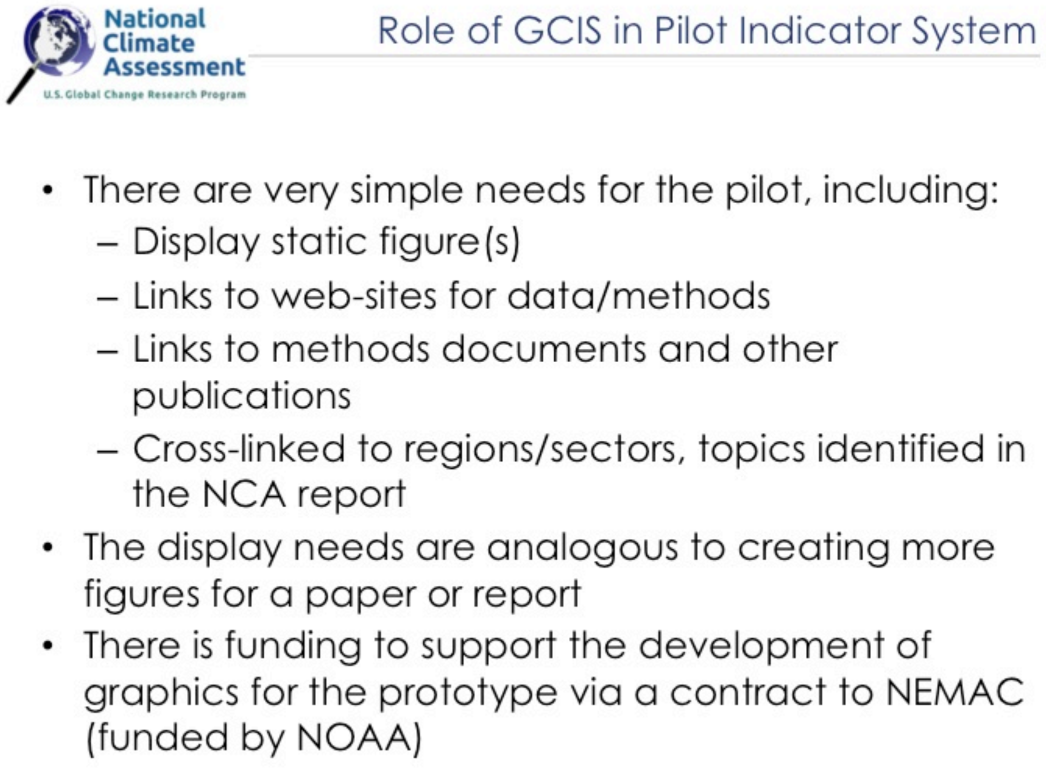
Example Pilot Indicator: Seasonal Climate Indicators

Mean Non-frozen Season (days)

Non-frozen Season Variation (SD, days yr^{-1})



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Role of GCIS in Pilot Indicator System

- There are very simple needs for the pilot, including:
  - Display static figure(s)
  - Links to web-sites for data/methods
  - Links to methods documents and other publications
  - Cross-linked to regions/sectors, topics identified in the NCA report
- The display needs are analogous to creating more figures for a paper or report
- There is funding to support the development of graphics for the prototype via a contract to NEMAC (funded by NOAA)

Example: Indicators Front Page on GCIS

Navigation through indicator system

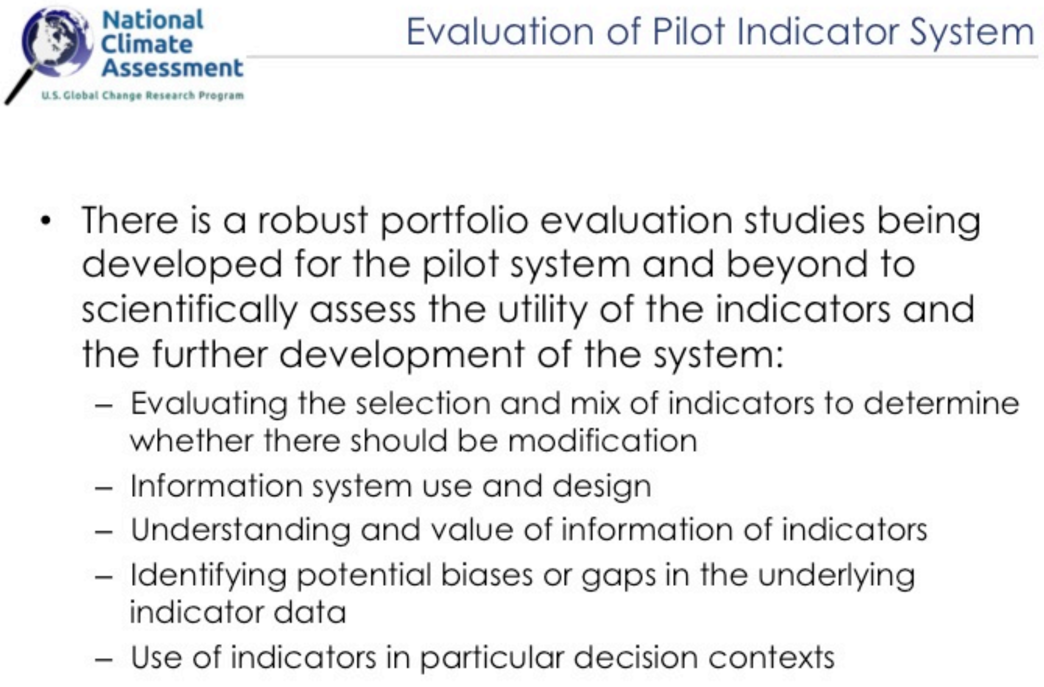
Graphic showing cyclical system concept

Sharing buttons for graphics

Space for news and data updates (with agency attribution)

Value Added of Pilot Indicator System

- Presenting the indicators through the system will allow the users to consider a wider range of indicators than is presented by any one agency
- Decision-makers can include combinations of the indicators that are most useful for their decision-making purposes
- The process allows us to identify critical research gaps that are needed to address an end-to-end framework and decision-maker needs



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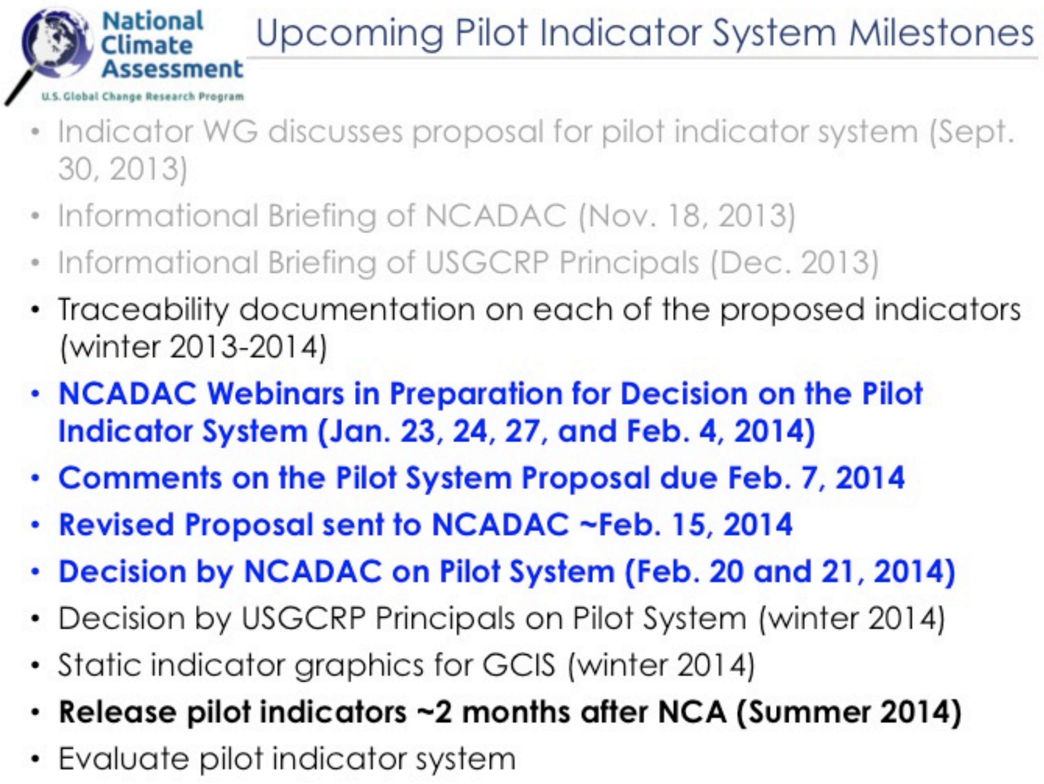
Evaluation of Pilot Indicator System

- There is a robust portfolio evaluation studies being developed for the pilot system and beyond to scientifically assess the utility of the indicators and the further development of the system:
  - Evaluating the selection and mix of indicators to determine whether there should be modification
  - Information system use and design
  - Understanding and value of information of indicators
  - Identifying potential biases or gaps in the underlying indicator data
  - Use of indicators in particular decision contexts



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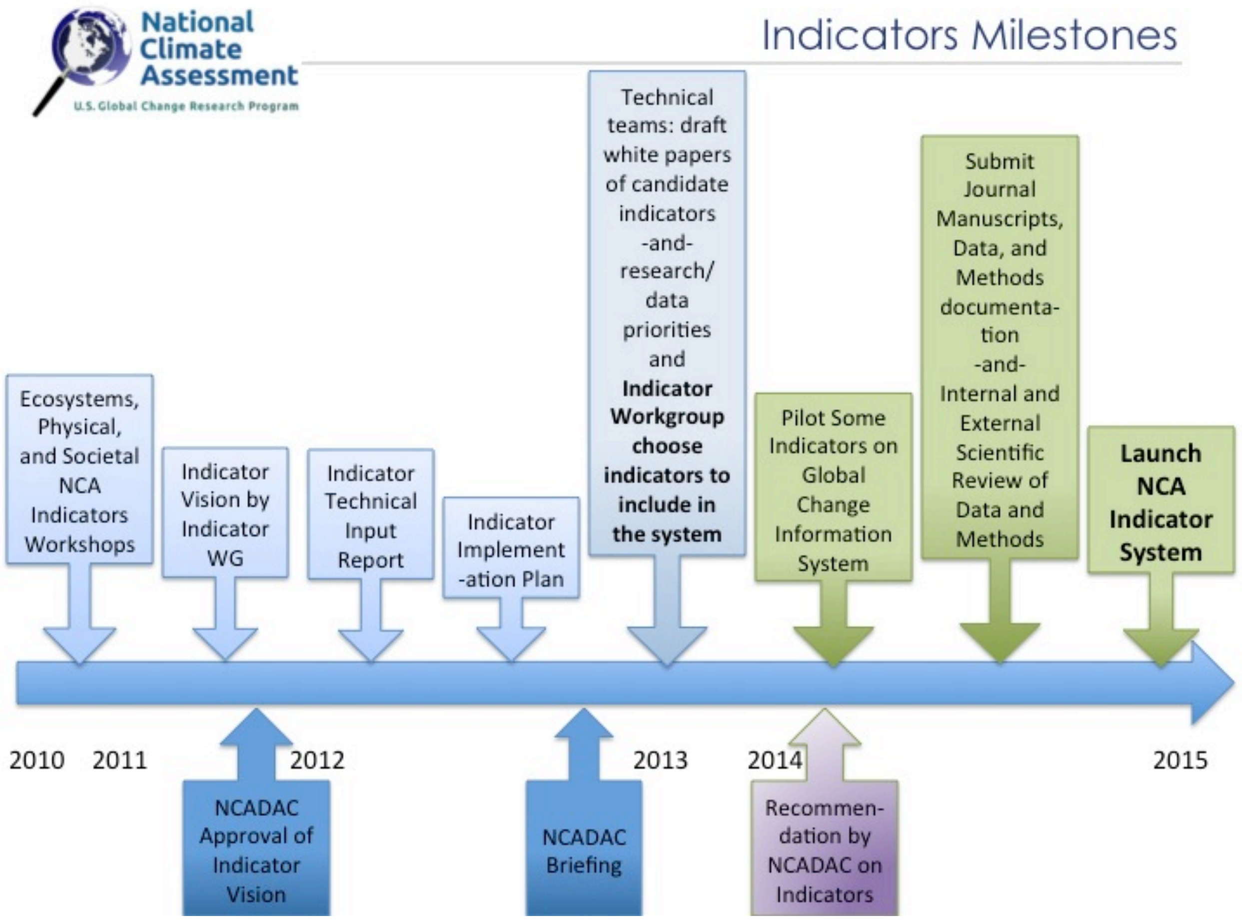
Upcoming Pilot Indicator System Milestones

- Indicator WG discusses proposal for pilot indicator system (Sept. 30, 2013)
- Informational Briefing of NCADAC (Nov. 18, 2013)
- Informational Briefing of USGCRP Principals (Dec. 2013)
- Traceability documentation on each of the proposed indicators (winter 2013-2014)
- **NCADAC Webinars in Preparation for Decision on the Pilot Indicator System (Jan. 23, 24, 27, and Feb. 4, 2014)**
- **Comments on the Pilot System Proposal due Feb. 7, 2014**
- **Revised Proposal sent to NCADAC ~Feb. 15, 2014**
- **Decision by NCADAC on Pilot System (Feb. 20 and 21, 2014)**
- Decision by USGCRP Principals on Pilot System (winter 2014)
- Static indicator graphics for GCIS (winter 2014)
- **Release pilot indicators ~2 months after NCA (Summer 2014)**
- Evaluate pilot indicator system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Indicators Milestones
Ecosystems, Physical, and Societal NCA Indicators Workshops
Indicator Vision by Indicator WG
Indicator Technical Input Report
Indicator Implement-ation Plan
Technical teams: draft white papers of candidate indicators -and- research/ data priorities and **Indicator Workgroup choose indicators to include in the system**
Pilot Some Indicators on Global Change Information System
Submit Journal Manuscripts, Data, and Methods documenta-tion -and- Internal and External Scientific Review of Data and Methods
Launch NCA Indicator System
2010
2011
2012
2013
2014
2015
NCADAC Approval of Indicator Vision
NCADAC Briefing
Recommen-dation by NCADAC on Indicators

Appendix D:
Pilot Indicators System Technical Teams and Authors

Pilot Indicators System Report Authors

Indicators Work Group

Tony Janetos, Chair Indicators Work Group (NCADAC, Boston University)
Deke Arndt, Co-chair Indicators WG and Chair Physical Indicators (NOAA NCDC)
Bob Chen, Co-chair Indicators WG and Co-chair Societal Indicators (NASA and Columbia University, CIESIN)
Richard Pouyat, Chair Ecological Indicators (USDA USFS)
Dan Abbasi (NCADAC)
Tom Armstrong (USGCRP)
Peter Backlund (NCAR)
Ann Bartuska (USDA)
Maria Blair (NCADAC)
Jim Buizer (NCADAC)
Virginia Burkett (NCADAC Ex Officio, DOI USGS)
Tom Dietz (Michigan State University)
Dave Easterling (NOAA NCDC)
Jack Kaye (NASA)
Mike Kolian (EPA)
Mike McGeehin (NCADAC)
Richard Moss (NCADAC, DOE PNNL JGCRI)
Bob O'Connor (NCADAC Ex Officio, NSF)
Robin O'Malley (USGS)
Richard Pouyat (USDA USFS)
Roger Pulwarty (NOAA)
Steve Running (University of Montana)
Anne Steinemann (Scripps Inst. of Oceanography)
Robin Webb (NOAA ESRL)
Jake Weltzin (USGS NPN)

Adaptation and Hazards Indicators Team Leads

Patricia Gober, Co-lead (Arizona State University)
Kathleen Tierney, Co-lead (University of Colorado, Boulder)

Agriculture Indicators Technical Team

Jerry Hatfield, Team Lead (USDA)
John Antle (Oregon State University)
Karen Garrett (Kansas State University)
Cesar Izaurralde (JGCRI, PNNL)
Melissa Kenney (University of Maryland)
Terry Mader (University of Nebraska-Lincoln)
Elizabeth Marshall (USDA ERS)
Mark Nearing (USDA ARS)
G. Robertson (Michigan State University)
Lewis Ziska (USDA ARS)
Rebecca Aicher (University of Maryland)

Energy Indicators Technical Team
Tom Wilbanks, Energy Team Lead (ORNL)
Doug Arent (National Renewable Energy Laboratory)
Marilyn Brown (Georgia Institute of Technology)
Jim Buizer (University of Arizona)
Jan Dell (ConocoPhillips)
Guido Franco (California Energy Commission)
Bob Gough (NativeWind)
Melissa Kenney (University of Maryland)
Richard Newell (Duke University)
Rich Richels (Electric Power Research Institute, Inc.)
Michael Scott (PNNL)
Jeff Williams (Entergy)
Ainsley Lloyd (University of Maryland)

Forests Indicators Technical Team
Linda Heath, Forest Team Lead (USDA - USFS)
Richard Pouyat, Forest Team Co-lead (Lead) (USDA - USFS)
David Cleaves (USDA - USFS)
Ken Cordell (USDA – USFS)
Marla Emery (USDA - USFS)
Jeffrey Hicke (University of Idaho)
Melissa Kenney (University of Maryland)
Jeremy Littell (DOI - USGS)
Alan Lucier (National Council for Air and Stream Improvement)
Jeff Masek (NASA)
Miranda Mockrin (USDA – USFS)
David Peterson (USDA - USFS)
Kevin Potter (North Carolina State University)
Guy Robertson (USDA - USFS)
Jinelle Sperry (DOD USACE)
Susan Stewart (USDA – USFS)
Sarah Anderson (Washington State University)

Freshwater Ecosystems Indicators Technical Team
Britta Bierwagen, Freshwater Ecosystems Team Lead (EPA)
Dave Allan (University of Michigan)
Darold Batzer (University of Georgia)
Scott Bridgham (University of Oregon)
Daren Carlisle (DOI – USGS)
Charles Hawkins (Utah State University)
Melissa Kenney (University of Maryland)
Mary Kentula (EPA)
Dan Nover (AAAS Fellow)
N. Poff (Colorado State University)
Jasmine Saros (University of Maine)

Katherine Smith (USDA – USFS)
R. Jan Stevenson (Michigan State University)
Arnold van der Valk (Iowa State University)
Paul Wagner (DOD USACE)
Bill Wilber (DOI – USGS)
Craig Williamson (Miami University)
Kevin Rose (NSF)

Grasslands, Rangelands, and Pastures Indicators Technical Team
Nancy Cavallaro, Grassland Team Co-lead (USDA NIFA)
Dennis Ojima, Grassland Team Co-lead (Colorado State University)
Robert Washington Allen (University of Tennessee-Knoxville)
Steve Archer (University of Arizona)
Derek Bailey (New Mexico State University)
Jayne Belnap (DOI – USGS)
John Blair (Kansas State University)
Susan Casby-Horton (Texas Tech University)
John Dwyer (DOI – USGS)
James Garrett
Jeff Herrick (New Mexico State University)
Melissa Kenney (University of Maryland)
Elise Pendall (University of Wyoming)
John Tanaka (University of Wyoming)
Bradford Wilcox (Texas A&M University)
Rebecca Aicher (University of Maryland)
Julian Reyes (Washington State University)

Human Health Indicators Technical Team
Mike McGeehin, Health Team Lead (retired)
John Balbus (HHS – NIH)
Kristie Ebi (ESS, LCC)
Paul English (California Department of Public Health)
Janet Gamble (EPA)
Mary Hayden (University Corporation for Atmospheric Research)
Jeremy Hess (Emory University)
Melissa Kenney (University of Maryland)
Kim Knowlton (National Research Defense Council)
Erin Lipp (University of Georgia)
George Luber (HHS – CDC)
Jennifer Parker (HHS – CDC)
Juli Trtanj (NOAA)
Lewis Ziska (USDA ARS)
Marques Gilliam (University of Maryland)

Infrastructure Indicators Technical Team
Tom Wilbanks, Infrastructure Team Lead (ORNL)

JoAnn Carmin (Massachusetts Institute of Technology)
Steven Fernandez (ORNL)
Pablo Garcia (Sandia)
Susan Julius (EPA)
Melissa Kenney (University of Maryland)
Paul Kirshen (University of New Hampshire)
Mike Matthews (Department of Homeland Security)
Matthias Ruth (Northeastern University)
Mike Savonis (ICF International)
Lynn Scarlett (The Nature Conservancy)
Henry Schwartz, Jr.
William Solecki (Hunter College of the City University of New York)
Loren Toole (Los Alamos National Laboratory)
Rae Zimmerman (New York University)
Ainsley Lloyd (University of Maryland)

Greenhouse Gas Emissions and Mitigation Indicators Technical Team
Leon Clarke, Mitigation and GHG Team Lead (DOE PNNL JGCRI)
Richard Birdsey (USDA – USFS)
Melissa Kenney (University of Maryland)
Perry Lindstrom (Energy Information Administration)
Tom Loveland (DOI –USGS)
Richard Newell (Duke University)
Shaun Ragnauth (EPA)
John Weyant (Stanford University)
Ian Sue Wing (Boston University)
Eric Golman (University of Maryland)

Oceans and Coasts Indicators Technical Team
Roger Griffis, Oceans and Coastal Team Co-lead (NOAA)
Laurie Mcgilvray, Oceans and Coastal Team Co-lead (NOAA)
Donald Cahoon (DOI – USGS)
Trish Clay (NOAA)
Enrique Curchitser (Rutgers University)
Katherine Curtis (University of Wisconsin-Madison)
Joseph DeVivo (DOI – NPS)
Benét Duncan (California Ocean Science Trust)
Stephen Gill (NOAA)
Jason Grear (EPA)
Benjamin Halpern (University of California, Santa Barbara)
Jonathan Hare (NOAA)
Amber Himes-Cornell (NOAA)
Jen Howard (Conservation International)
Robert Johnston (Clark University)
Melissa Kenney (University of Maryland)
David Legler (NOAA)

Eric Lindstrom (NASA)
Todd O'Brien (NOAA)
Steven Rumrill (University of Oregon)
Eric Thunberg (NOAA)
Thomas Webler (Social and Environmental Research Institute)
Jordan West (EPA)
Robert Wood (NOAA)
Stephani Zador (NOAA)
Shallin Busch (NOAA)
Elizabeth Fly (South Carolina Sea Grant Program)

Physical Climate and Variability Indicators Technical Team
Deke Arndt, Physical Climate Team Lead (NOAA)
David Anderson (NOAA)
James Butler (NOAA)
Katherine Hayhoe (Texas Tech University)
Paul Higgins (AMS)
Amber Jenkins (NASA)
Barry Keim (Louisiana State University)
Melissa Kenney (University of Maryland)
Mike Kolian (EPA)
Ruby Leung (PNNL)
Robb Randall (Offutt Air Force Base)
David Robinson (Rutgers University)
Julie Rosati (DOD USACE)
Ryan Clark (University of Maryland)

Seasonal Timing and Phenology Indicators Technical Team
Jake Weltzin, Seasonal Timing and Phenology Team Lead (USGS NPN)
Julio Betancourt (DOI USGS)
Benjamin Cook (Columbia University)
Carolyn Enquist (University of Arizona)
John Gross (DOI NPS)
Geoffrey Henebry (South Dakota State University)
Rebecca Kao (Denver Botanic Gardens)
Melissa Kenney (University of Maryland)
John Kimball (University of Montana)
Bradley Reed (DOI – USGS)

Water Cycle and Management Indicators Technical Team
Christa Peters-Lidard, Water Cycle and Management Team Lead (NASA)
Derek Arndt (NOAA)
Michael Anderson (California State Climate Office)
Aaron Byrd (DOD USACE)
Melissa Kenney (University of Maryland)
Julie Kiang (DOI – USGS)

Jim Marron (USDA POR)
David Raff (DOD USACE)
Brad Rippey (USDA OCE)
Michael Strobel (USDA POR)
Kevin Rose (NSF)

National Climate Indicators System Team (current and former)

Melissa Kenney, Lead PI USGCRP National Climate Assessment Indicators System (UMD Research Assistant Professor; NOAA CICS grant)
Rebecca Aicher, Senior Scientist USGCRP National Climate Assessment Indicators System
Ainsley Lloyd, Senior Scientist USGCRP National Climate Assessment Indicators System
Sarah Anderson, Science Policy Fellow Indicators (Ph.D. student, Washington State University)
Richard Pouyat, Chair Ecological Indicators (USDA USFS detailee)
Andrea Maguire, Scientist Indicators (recent M.S. graduate, Michigan State University)
Meyyappan Thenappan, Research Assistant Indicators (honors undergraduate student, University of Maryland, College Park)
Allison Bredder, Research Assistant Indicators (honors undergraduate student, University of Maryland, College Park)
Tahmina Azizova, Research Assistant Indicators (formerly graduate student, SIT Graduate Institute)
Jennifer Howard, Senior Scientist Ocean and Coast Indicators (formerly AAAS Fellow, NOAA NMFS, now Conservation International)
Elizabeth Fly, Senior Scientist Ocean and Coast Indicators (formerly Knauss Fellow, NOAA CPO, now South Carolina Sea Grant Consortium)
Dan Nover, Senior Scientist Freshwater Ecosystem Indicators (formerly AAAS Fellow, EPA ORD)
Marlene Cole, Senior Scientist Adaptation and Biodiversity Indicators (AAAS Fellow, EPA ORD)
Kevin Rose, Senior Scientist Freshwater and Water Cycle and Management Indicators (AAAS Fellow, NSF)
Ryan Clark, Research Assistant Indicators (graduate student, University of Maryland, College Park)
Eric Golman, Research Assistant Energy and Mitigation Indicators (honors undergraduate student, University of Maryland, College Park)
Marques Gilliam, Research Assistant Indicators (undergraduate student, University of Maryland, College Park)
Carla Curran, Science Policy Fellow Indicators (Associate Professor, Savannah State University)
Ella Clarke, Research Assistant Indicators (undergraduate student, University of Maryland, College Park)
Jordan McCammon, Research Assistant Indicators (undergraduate student, Pennsylvania State University)
Katie Henderson, Scientist Indicators (formerly recent M.S. graduate, Utah State University, now EPA ORISE Fellow)
Amudat Shijuade Idowu, Research Assistant Indicators (formerly graduate student, SIT Graduate Institute)

Jeremy Ardanuy, Research Assistant Indicators (honors undergraduate student, University of Maryland, College Park)
Christian McGillien, Research Assistant Indicators (honors undergraduate student, formerly Northern Virginia Community College, now Virginia Tech)
Andres Moreno, Research Assistant Indicators (formerly honors undergraduate student, University of Maryland, Baltimore County)
Mike Specian, Scientist Indicators (Ph.D. Candidate, Johns Hopkins University)