NOAA NESDIS
Center for Satellite Applications and Research

Satellite Meteorology and Climatology Division Roadmap

NOAA/NESDIS/STAR
Satellite Meteorology and Climatology Division

Roadmap

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EXECUTIVE SUMMARY

The Satellite Meteorology and Climatology Division (SMCD) is one of three units in the NOAA NESDIS Center for Satellite Applications and Research. It conducts research and develops new satellite products to improve and expand the use of satellite data for monitoring global meteorological, climatological and environmental conditions. The Division conducts an end-to-end program ranging from planning new satellite instruments to developing advanced satellite products and applications and transitioning these innovations to operations in NOAA's weather, climate, and environmental monitoring and prediction systems.

The Division's research capabilities are concentrated in the sciences associated with satellite remote sensing of the Earth's atmosphere, surface, and climate. Most of the Division's research and development falls into the following discipline areas: atmospheric variables – temperature, humidity, winds; land surface variables – vegetation, snow and ice cover; hydrological cycle variables - precipitation, clouds, water vapor; environmental hazards – aviation hazards, air quality, fires, heavy rainfall and flash floods, and drought: and climate variables – ozone, Earth radiation budget, aerosols, and greenhouse gases.

In addition to developing new and improved products, SMCD conducts the following crosscutting activities: calibrating satellite instruments; transitioning research products to operational production; developing radiative transfer models for NWS NWP satellite data assimilation systems; developing and analyzing long-term satellite data sets for studying and assessing climate change; and planning and preparing for new satellite instruments.

Aside from legal mandates and interagency agreements, the Division's R&D program over the next 5 years and beyond will be driven by emerging trends in satellite technology and user requirements. Major trends in instrument technology that will challenge but offer new opportunities to SMCD scientists include:

- Hyperspectral sounding and imaging instruments on Metop, NPP, NPOESS, and GOES-R with finer wavelength, spatial, and temporal resolution, but with orders of magnitude for more data, that will provide atmospheric and surface measurements of unprecedented information content, timeliness, and detail.
- Active instruments such as GPS/RO, Cloudsat, Precipitation Radars, Calipso, and ALADIN (Atmospheric Laser Doppler Instrument) that will provide detailed measurements of the vertical structure of the atmosphere, including temperature and moisture, cloud and precipitation properties, and aerosols.
- New operational passive instruments such as the NPOESS APS, ERBS, and TSIS, that will provide the first space-based information on aerosol composition and continue indefinitely into the future the observations of solar irradiance and Earth radiation budget initiated by NASA's research satellite.

Trends in requirements will reflect increasing pressures to improve NOAA's weather, climate, and environmental hazards analysis and prediction capabilities. SMCD will support NOAA's Weather and Water Goal performance measures to increase lead time and accuracy for weather and water warnings and forecasts and improve predictability of the onset, duration, and impact of hazardous and severe weather and water events. Satellite data, together with improvement in data assimilation, NWP models, and computer power have enabled forecast accuracy to improve at a rate of about one day per decade over the last few decades – i.e., today's 5-day forecasts are as accurate as 4-day forecasts were just 10 years ago. But the data being used are largely for clear skies, and rain and snow forecasts are still difficult. SMCD will develop the tools to assimilate observations of cloudy and precipitating areas. New SMCD initiatives in air pollution measurements from satellites will support NOAA's emerging air quality forecast program.

NOAA's mission for the next century includes a bold new Climate Goal to Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond. Among NOAA's strategies for achieving this goal are: 1) Improve the quality and quantity of climate observations, analyses, interpretation, and archiving by maintaining a consistent climate record and by improving our ability to determine why changes are taking place, and 2) Improve the quantification and understanding of the forces bringing about climate change by examining relevant human-induced increases in atmospheric constituents. SMCD will contribute to implementation of both strategies.

The Aviation Weather Program of NOAA's Commerce and Transportation Goal focuses on improving observation, forecast and training capabilities to deliver long term reduction in the number of weather related aviation mishaps and the number and extent of weather related flight delays. SMCD contributes to the Aviation Weather Program by developing tailored satellite-based aviation weather hazards products for the air transportation sector.

Responding to these satellite technology and user requirements drivers, SMCD has developed Roadmaps for 17 focused projects. These Roadmaps will guide the Division's R&D program over the next 5 years and beyond. Each Project Roadmap has its own goals, objectives, and timeline. The Project Roadmaps' milestones represent the building blocks that are necessary for achieving the individual Project Goals.

To monitor the success of the its research and development program, SMCD has adopted a number of overarching Performance Targets as well as Performance Targets for each of the NOAA goals to which it contributes.

SMCD, through the satellite-based products and data sets it develops and generates, and its science, contributes to most of NOAA's strategic goals. A chapter of this document summarizes how SMCD helps NOAA meet many of the objectives under these goals.

Achievement of SMCD's Performance Targets will be facilitated by a dramatic increase in satellite observing capabilities over the next 5 years, its world-class core of civil servant scientists and an extremely competent cadre of supporting contractors and post-docs/visiting scientists, its collegial atmosphere, and advances in computing and communications technologies. Potential constraints include lack of sufficient computing power, limited scientific capability in new instrument areas: active instruments, APS, ERBS, TSIS, limited ground truth, and anticipated loss of senior scientific staff as a result of retirement.

The challenges are great - the opportunities greater.

1. INTRODUCTION

Overview of The Satellite Meteorology and Climatology Division

Setting within NOAA

NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) is dedicated to providing timely access to global environmental data from satellites and other sources to promote, protect, and enhance the Nation's economy, security, environment, and quality of life.

To fulfill its responsibilities, NESDIS acquires and manages the Nation's operational environmental satellites, provides data and information services, and conducts related research.

The Satellite Meteorology and Climatology Division (SMCD) is one of three Units in the Center for Satellite Applications and Research (STAR). STAR is the science arm of NOAA's National Environmental Satellite, Data and Information Service (NESDIS) and provides leadership, guidance, and direction for NESDIS research, development, and applications activities with respect to satellites and satellite data. The main objectives of the STAR are to ensure that satellite remote sensing data and information products are of the highest quality possible and to enhance their utilization to enable NOAA to fulfill its mission to understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs. STAR conducts research and develops satellite products for meteorological, climatological, oceanographic, and land surface applications by NOAA's operational and research components. Aside from the SMCD, the STAR includes the Satellite Oceanography Division (SOD), which provides the primary research and development support for oceanic remote sensing within NOAA and a Cooperative Research Program (CoRP) that provides oversight, management, and direction to a coast-to-coast government and university-based research coalition for remote sensing of the environment.

Mission

SMCD conducts research and develops new satellite products to improve and expand the use of satellite data for monitoring global meteorological, climatological and environmental conditions. The Division conducts an end-to-end program ranging from planning new satellite instruments to developing new satellite products and applications and transitioning these developments to operations in NOAA's weather, climate, and environmental monitoring and prediction systems. Most of the Division's research and development falls in the following discipline areas:

- Atmospheric variables – temperature, humidity, winds
- Land surface variables – vegetation, snow and ice cover
- Hydrological Cycle variables - precipitation, clouds, water vapor
- Environmental hazards – aviation hazards, air quality, fires, heavy rainfall and flash floods, drought
- Climate variables – ozone, Earth radiation budget, aerosols, greenhouse gases

In addition to developing new and improved products, SMCD conducts the following crosscutting activities:

- Calibrating satellite instruments
- Transitioning research products to operational production
- Developing radiative transfer models for the National Weather Service (NWS) Numerical Weather Prediction (NWP) satellite data assimilation systems
- Developing and analyzing long-term satellite data sets for studying and assessing climate change
- Planning and preparing for new satellite instruments

To execute its activities, SMCD has a vigorous visiting scientist program and an extensive task order contract support system, which provides scientists and software specialists to support the SMCD investigators. Its scientists also collaborate with colleagues both nationally and internationally.

Organization, Personnel, Resources

SMCD consists of three Branches: Sensor Physics Branch, Environmental Monitoring Branch, and Operational Products Development Branch. The Division also manages the funding for the NESDIS budget line item for the NOAA-National Aeronautics and Space Administration (NASA)-US Department of Defense (DoD) Joint Center for Satellite Data Assimilation (JCSDA), and a number of Division scientists are active in JCSDA research programs.

Organization

Sensor Physics Branch

The Sensor Physics Branch oversees the calibration of all of NOAA's Earth observing satellite instruments and develops many of the atmospheric products derived from satellite observations. It researches state-of-the-art algorithms for profiling atmospheric temperature and water vapor, ozone, air quality, carbon cycle and hydrological products from operational and research satellite instruments. It develops, upgrades, and maintains the Community Radiative Transfer Model. This is used for data assimilation in the numerical weather prediction models of the NWS, NASA, and DoD. It is developing, testing and implementing the next-generation of satellite data retrieval systems for The National Polar-orbiting Operational Environmental Satellite System (NPOESS) and Geostationary Operational Environmental Satellite (GOES-R) sensor applications. The Sensor Physics Branch strongly supports the NOAA climate goal through its retrospective reprocessing of satellite observations of ozone and atmospheric temperature to produce Climate Data Records. It also participates in the design, planning, and preparation for next generation satellite systems.

Environmental Monitoring Branch

The Environmental Monitoring Branch develops satellite-based land surface, climate, and environmental hazards products. Its vegetation, snow and ice cover products are used as initial or boundary conditions for NWS weather prediction models. The Branch's Earth Radiation Budget, cloud, and aerosol products help scientists to better understand critical climate processes. Its heavy rainfall, fire, and drought products provide early warnings for destructive environmental hazards. The Branch also constructs long-term satellite-based data sets of Earth Radiation Budget, clouds, aerosols, vegetation, and atmospheric temperature for monitoring global climate change. It also participates in the design, planning, and preparation for next generation satellite systems.

Operational Products Development Branch

The Operational Products Development Branch is the main conduit for transferring new science into NESDIS operations for both geostationary and polar satellites, and provides support in training NWS and DoD forecasters to correctly utilize and interpret satellite products. The Operational Products Development Branch transitions research products to operations. The Branch transitions the science algorithms developed by STAR for atmospheric sounding, wind, and convection intensity products to operational processing systems for the NESDIS Office of Satellite Data Processing and Distribution (OSDPD). It also develops satellite products for use by the aviation sector, such as aircraft icing, volcanic ash hazards, and fog and low ceiling events.

NOAA-NASA-DoD Joint Center for Satellite Data Assimilation (JCSDA)

SMCD manages the NOAA line item budget, which supports the JCSDA Executive Office, STAR researchers working on JCSDA Directed Research programs, and the extramural community through an A/O.

The JCSDA was established by NOAA, NASA, and DoD to accelerate and improve the quantitative use of research and operational satellite data in weather and climate analysis and prediction models. The JCSDA is part of the Environmental Modeling Program, under NOAA's Weather and Water Goal, which provides model-based estimates of current and future states of the environment at multiple time scales. These estimates are based upon a wide array of observational data and ever more refined modeling techniques. The program maintains a suite of operational models to meet current needs as well as a research and development program for improved performance and new capabilities in future generations of environmental models.

The vision of the JCSDA is a numerical weather prediction community empowered to effectively assimilate increasing amounts of advanced satellite observations. The goals of the JCSDA are to:

- Reduce from two years to one year the average time for operational implementation of new satellite technology
- Improve and increase uses of current and future satellite data in NWP models
- Assess the impacts of data from advanced satellite instruments on weather and climate predictions

2. TRENDS AND DRIVERS FOR RESEARCH

Trends and drivers consist of three types: Legal, Technology and Requirements. Legal drivers are the laws, mandates, and agreements that obligate NOAA to perform certain activities. The legal drivers specifically directed at SMCD programs are listed in this section.

Technology trends and drivers consist of the planned and expected advances in satellite instrument observing capabilities. By creating new capabilities, these technology drivers enable SMCD scientists to push the state of the art and develop enhanced and new satellite products and applications.

Requirements trends and drivers are the requirements for satellite-based information to achieve NOAA's strategic goals. These requirements are developed by the users of the satellite products and applications. NOAA's requirements for upgraded and new products are constantly becoming more demanding as it strives to improve its services.

Legal Drivers

Weather and Water

- *H.R. 4 Energy Policy Act of 2002 (Senate Amendment) S. 517, Part II, Section 1383, Forecasts and Warnings and appropriations in later years*: NOAA shall issue air quality forecasts and perform regional air quality assessments
- *The "Great Waters" Section of the 1990 Clean Air Act Amendments (Section 112(m), Title III) Atmospheric Deposition to Great Lakes and Coastal Waters*: NOAA shall identify and assess the extent of deposition of atmospheric pollutants to significant water bodies
- *The "Ecosystem Research" Section of the 1990 Clean Air Act Amendments (Section 901(e), Title IX)*: NOAA shall conduct a research program to improve understanding of the short-term and long-term causes, effects, and trends of ecosystems damage from air pollutants on ecosystems.
- *The Organic Act of October 1, 1890*, which created the National Weather Bureau, established NOAA's mission to provide weather and water information and services to the Nation.
- *Federal Plan for Meteorological Services and Supporting Research FY2003*– Citation: Public Law 87-843 (1963), Federal Coordinator for Meteorology FCM-P1-2002 is a Congressional mandate providing for government research and development programs that directly support and improve meteorological services in an effective and efficient manner.
- *U.S. Weather Research Program (USWRP) Authorization Act:* The U.S. Weather Research Program (USWRP) is mandated to accelerate forecast improvements of high impact weather and facilitate full use of advanced weather information.
- *Memorandum of Understanding between NOAA and the Environmental Protection Agency (EPA) signed by the Deputy Secretary of Commerce and the Administrator of EPA (May 2003)*: NOAA and EPA will collaborate on air quality research.

- *Memorandum of Agreement between NOAA and EPA signed by the Deputy Secretary of Commerce and the Administrator of EPA (May 2003)*: NOAA and EPA will collaborate on air quality forecasting. NOAA deliverables include improved air quality forecast models and air quality forecast guidance. EPA deliverables include providing emissions inventory and monitoring data.

Climate:

- *Public Law 95-95, Clean Air Act Amendments, 1990.* NOAA (and NASA) is required to "… continue programs of research, technology, and monitoring of the phenomena of the stratosphere for the purpose of understanding the physics and chemistry of the stratosphere and for early detection of potentially harmful changes in the ozone in the stratosphere …" Further, NOAA (and NASA) is required to report "… on the current average tropospheric concentration of chlorine and bromine and on the level of stratospheric ozone depletion."

- *U.S. Carbon Cycle Science Plan (USGCRP, 1999) and associated implementation plans.* This plan defined five goals, of which three pertain directly to NOAA expertise: "Quantify and understand the Northern Hemisphere terrestrial carbon sink", "Quantify and understand the uptake of anthropogenic CO_2 in the ocean", and "Provide greatly improved projections of future atmospheric concentrations of CO_2". NOAA's Climate Forcing Program is designed to help meet those goals.

- *The North American Carbon Program (2002).* This plan defines major program elements needed to determine the carbon balance of North America and adjacent ocean basins. They include "Expand atmospheric monitoring: vertical concentration data, column CO_2 inventories, continuous measurements," "Conduct field campaigns over North America, and eventually over the adjacent oceans, using aircraft linked to enhanced flux tower networks and improved atmospheric transport models," and "Improve inverse models and strengthen connections between atmospheric model inferences and direct terrestrial and oceanic observations."

- The Global Change Research Act of 1990 (P.L. 101-606, 15 U.S.C. 2921 et. seq.)

- U.S. Climate Change Science Program (CCSP)

Technology Drivers

Satellites already in the pipeline or planned will drive the types of research and applications activities that SMCD will undertake in the future. Figure 1 shows the schedule for launches of NOAA satellites to 2020. In addition to these, SMCD scientists will continue to experiment with and exploit research satellite data to support NOAA's services and to prepare for future operational satellite implementations.

Major trends in instrument technology that will challenge but offer new opportunities to SMCD scientists include:

- Hyperspectral sounding and imaging instruments with finer wavelength, spatial, and temporal resolution, but with orders of magnitude for more data, that will provide atmospheric and surface measurements of unprecedented information content, timeliness, and detail.
- Active instruments such as Global Positioning System/Radio Occultation (GPS/RO), Cloudsat, Precipitation Radars, Calipso, and Atmospheric Laser Doppler Instrument (ALADIN) that will provide detailed measurements of the vertical structure of the atmosphere, including temperature and moisture, cloud and precipitation properties, and aerosols.
- New operational passive instruments such as the National Polar-orbiting Operational Environmental Satellite System Aerosol Polarimeter Sensor (NPOESS APS), Earth Radiation Budget Sensor (ERBS), and Total Solar Irradiance Sensor (TSIS), that will provide the first space-based information on aerosol composition and continue indefinitely into the future the observations of solar irradiance and Earth radiation budget initiated by NASA's research satellite.

SMCD scientists will exploit the capabilities of these advanced instruments to provide critical support to NOAA's Weather and Water, Climate, and Commerce/Transportation Strategic Goals. This will involve evaluation of the data and development of product, applications, and assimilation systems.

Figure 1 shows a timeline of launches of NOAA satellites and satellite missions in which NOAA is a partner; i.e., NPOESS and METOP (Meteorological Operations Platform). Major milestones in this series of launches will occur with the first launches of METOP, NPOESS, and GOES-R, when advanced and completely new instruments are introduced.

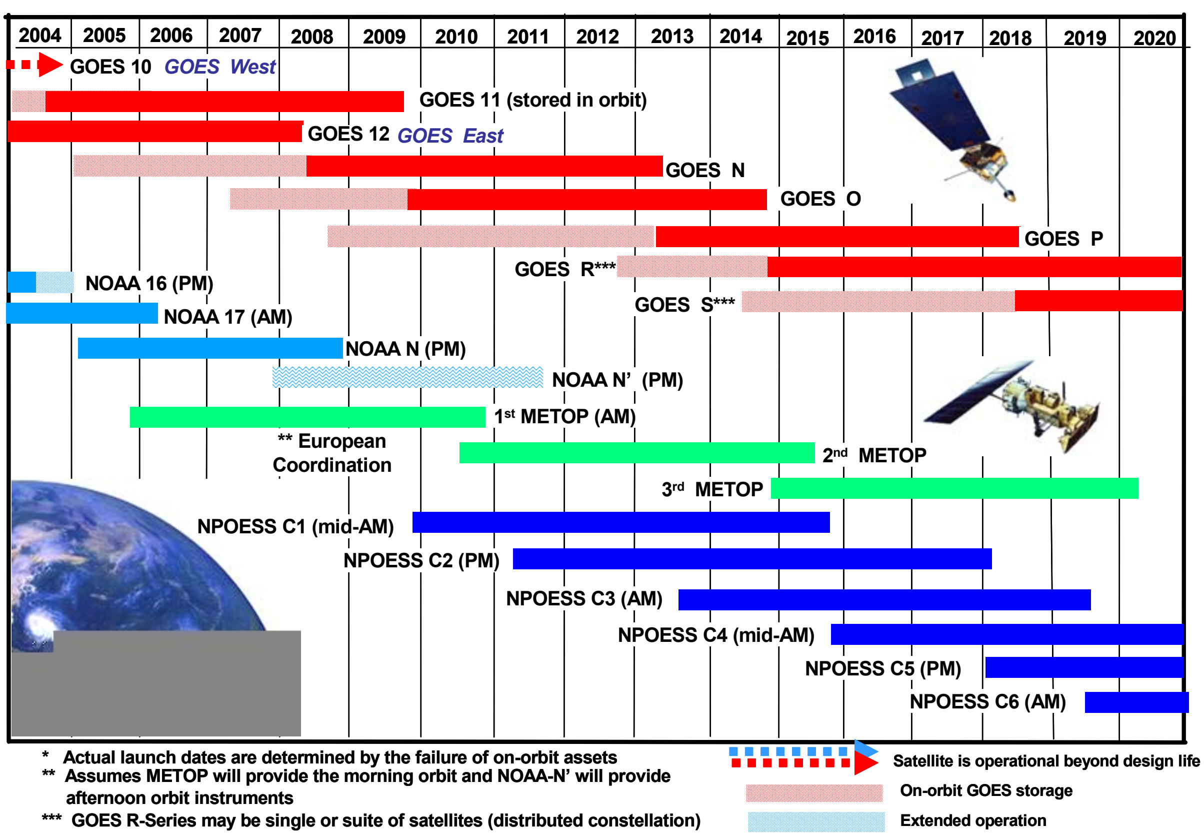


Figure 1: Schedule for Launches of NOAA Satellites through 2020.

Initial Joint Polar System: NOAA-N, N' and METOP-1,2,3

NOAA and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) are working together to maintain continuity of polar orbiting operational environmental satellites. The Initial Joint Polar System (IJPS) will comprise the continuation of the current NOAA satellite series with NOAA-N and -N', together with the new EUMETSAT satellite series Metop-1, -2, -3, the first of which is scheduled for launch in 2005. Major instrument advances in the IJPS include: global Advanced Very High Resolution Radiometer (AVHRR) observations at 1 km horizontal resolution (compared to current sampled 4 km resolution) for detailed surface vegetation and ocean temperature measurements; first operational advanced IR sounders for high vertical resolution temperature and moisture structure, and the first operational GPS/OS system for observing the fine structure of atmospheric temperature in the upper troposphere and lower stratosphere.

Additional details on the IJPS payloads are contained in Appendix 1.

NPP and NPOESS

NPOESS will converge existing polar-orbiting satellite systems under a single national program. NPOESS, with a first launch in 2009, will carry a new generation of environmental satellite instruments, some of which will be flown on a risk-reduction mission, NPOESS Preparatory Program (NPP), in 2006. These instruments will provide new capabilities in visible, infrared, and microwave imaging; infrared and microwave sounding; ozone mapping and profiling; and measurements of solar irradiance, the Earth's radiatition budget, and aerosols that make significant contributions to NOAA's Climate Goal.

Additional details on the NPP and NPOESS payloads are contained in Appendix 1.

GOES-R

The major Earth observing instruments of the GOES-R System, planned for launch in 2012, are: the Advanced Baseline Imager (ABI) and the Hyperspectral Environmental Suite (HES). The Advanced Baseline Sounder (ABS) will have 16 channels observing at higher spatial resolution and frequency than today's 5-channel GOES Imager. The HES will have 1500 IR sounding channels compared to the current 19 channel GOES sounder.

Research Satellites

SMCD also uses the observations of research satellite instruments to carry out its mission. Noteworthy current examples are the Atmospheric InfraRed Sounder (AIRS), Moderate Resolution Imaging Spectroradiometer (MODIS), and Ozone Monitoring Instrument (OMI) instruments on NASA's Earth Observation System (EOS) satellites, GPS/OS on the Challenging Mini Satellite Payload (CHAMP), and Global Ozone Monitoring Experiment (GOME) on European Remote Sensing (ERS-2). Research missions in the pipeline that will drive SMCD research include active instruments that will provide the first data on: the global, three dimensional distribution of hydrometeors, aerosols, and winds in the atmosphere; soil moisture; and time continuous monitoring of temperature, moisture, and winds from geostationary altitude.

Additional details on the NPP and NPOESS payloads are contained in Appendix 1.

Requirements Drivers

NOAA Weather and Water Goal: Serve Society's Needs for Weather and Water Information

Flooding and storm related damage account for $11 billion annually in the United States. One of NOAA's mission goals, to Serve Society's Needs for Weather and Water, has ultimately led to NOAA's increasing role in understanding, observing, forecasting, and warning of severe weather events.

SMCD must support NOAA's Weather and Water performance measures to increase lead time and accuracy for weather and water warnings and forecasts and improve predictability of the onset, duration, and impact of hazardous and severe weather and water events. Satellite observations already provide over 90% of the data used to initialize global forecast models. These data, together with improvement in data assimilation, NWP models, and computer power have enabled forecast accuracy to improve at a rate of about one day per decade over the last few decades – i.e., today's 5-day forecasts are as accurate as 4-day forecasts were just 10 years ago. But the data being used are largely for clear skies. There is a growing need to develop the tools to assimilate observations of cloudy and precipitating areas.

Protecting the public against environmental hazards demands increased awareness on the need to predict changes in people's exposure to extreme weather events, adverse air quality, and to hazardous pollutants. NOAA provides forecasts and warnings of various natural hazards related to the atmosphere and ocean and, is developing better understanding of the underlying environmental processes and predictive methodologies of natural hazards.

A primary air quality concern is the increasing human health risk associated with exposure to adverse air quality, and to hazardous pollutants. EPA and NOAA signed a Memorandum of Understanding (MOU) on Air Quality Research and the parallel Memorandum of Agreement (MOA) on Air Quality Forecasting on May 6, 2003. The major purpose of these agreements is to facilitate the routine preparation and dissemination of air quality forecasts. Satellite observations of low level pollutants such as smoke and other aerosols are needed as input to NWP modules specifically designed to make such air quality forecasts.

NOAA Climate Goal: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

NOAA's mission for the next century includes a bold new Climate Goal to Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond as one of four central goals. Strategies for achieving this goal include: 1) Improve the quality and quantity of climate observations, analyses, interpretation, and archiving by maintaining a consistent climate record and by improving our ability to determine why changes are taking place, and 2) Improve the quantification and understanding of the forces bringing about climate change by examining relevant human-induced increases in atmospheric constituents. SMCD will contribute to implementation of both strategies.

Under Strategy 1, SMCD is a co-lead of the Scientific Data Stewardship (SDS) component of the Climate Observations & Analysis Program of NOAA's Climate Goal. For environmental satellite observations, SDS priorities include:

A. **Observing System Performance Monitoring**
   i. Documenting measurement practices and processing practices (metadata)
   ii. Providing feedback on observing system performance, including recommending corrective action for errant or non-optimal operations.

A. **Climate Data Records**
   i. Reprocessing (incorporate new data, apply new algorithms, perform bias corrections, integrate/blend data sets from different sources or observing systems)
   ii. Inter-comparison of data sets for validation

Under Strategy 2, SMCD contributes to the objectives of the Climate Forcing Program of NOAA's Climate Goal, whose objectives are:

Reduce uncertainty in climate projections through timely information on the forcings and feedbacks contributing to changes in the Earth's climate:

- Attain a timely understanding of **atmospheric and oceanic carbon dioxide** trends, both natural and human, that may be directly applied to climate projection and to policy decisions regarding climate management that are related to limiting unwanted effects of future climate change.
- Provide timely and adequate information on the climate roles of the **radiatively important trace atmospheric species** (e.g., fine-particle aerosols and ozone) that is needed to broaden the suite of non-carbon options available for policy support regarding the climate change issue.

NOAA Commerce and Transportation Goal: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Safe and efficient transportation systems are crucial to the U.S. economy. The Aviation Weather Program of the Commerce and Transportation Goal focuses on improving observation, forecast and training capabilities to deliver long term reduction in the number of weather related aviation mishaps and the number and extent of weather related flight delays. SMCD contributes to the Aviation Weather Program by developing tailored satellite-based aviation weather hazards products for the air transportation sector. SMCD is also responsible for providing technical support for integrating satellite observation products into aviation weather observation and forecast systems.

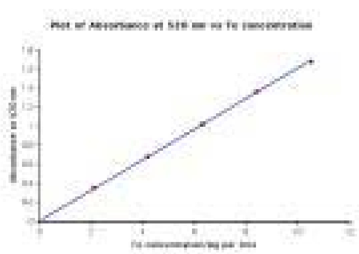
3. RESEARCH CAPABILITIES

SMCD's Branches exploit a number of science and technology areas in fulfilling its broad mission of transforming raw satellite observations into the accurate, quantitative information that is needed to predict weather, monitor climate, and detect environmental hazards. The science and technology area of each of SMCD's branches are described here.

Sensor Physics Branch

The weighty responsibilities for ensuring that NOAA's satellite observations are as accurate and stable as possible falls on the shoulders of the Sensor Physics Branch. The first challenge is to transform the raw satellite readings into accurate physical measurements of radiant energy – the process of instrument calibration. The second challenge is to transform these radiant energy measurements into atmospheric information products – e.g., temperature, precipitation, ozone, air quality, carbon dioxide – to predict weather, monitor climate, and detect environmental hazards.

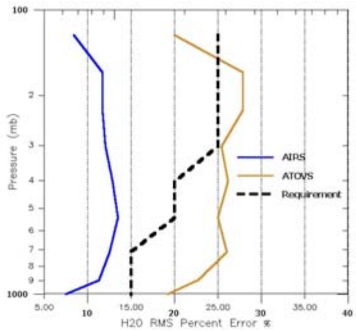
Calibration



Requirements for more accurate satellite information products are steadily increasing. As numerical weather prediction models become more reliable, their appetite for more accurate data input steadily increases. As the requirements for monitoring global climate become clearer – temperature changes as tiny as a few tenths of a degree per decade, ozone trends as small as 1%/decade – the measurements become more demanding. To create the stable long-term data sets needed for monitoring climate change it becomes vital to inter-calibrate sensors on different satellites. These are some of the challenges facing SMCD's calibration scientists.

SMCD oversees the calibration of all of NOAA's Earth observing satellite instruments, including the Polar-orbiting Operational Environmental Satellites High-Resolution Infrared Radiation Sounder (POES HIRS), Microwave Sounding Unit (MSU), Advanced Microwave Sounding Unit (AMSU), Solar Backscatter Ultraviolet Spectral Radiometer (SBUV), and AVHRR and the GOES Imager and Sounder. The calibration process begins in the laboratory prior to instrument launch. SMCD scientists specify the requirements for instrumental accuracy, oversee the calibration, and analyze the laboratory measurements to derive an operational calibration algorithm for the instrument. Once the instruments are in orbit, SMCD scientists continuously monitor their performance by comparing the measurements with those of other satellites, simulations, and stable Earth targets.

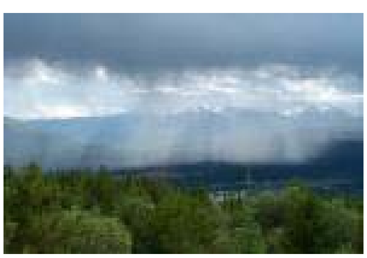
Hyperspectral Infrared Soundings



Hyperspectral infrared (IR) sounders are providing unprecedented high spectral resolution capable of resolving individual absorption lines. This new capability provides vastly improved accuracy and vertical resolution of derived temperature and moisture profiles. In comparison with the HIRS instrument, the precision of AIRS derived profiles are improved by 50% for temperature (1 degree C vs. 2 degree C), and 50% for water vapor (15% relative humidity vs. 30%). Vertical resolution is improved from 5 km (HIRS) to 1 – 2 km. At NOAA/NESDIS, the NASA Atmospheric Infrared Sounder (AIRS) is the first hyperspectral IR sounder to be provided to users for operational applications. Hyperspectral IR sounders following AIRS, and processed at NESDIS, include the Infrared Atmospheric Sounding Interferometer on the EUMETSAT's METOP satellite in 2006, and the Cross-track Infrared Sounder (CrIS) on NPP and NPOESS in 2008. In the next decade, NOAA will have a hyperspectral IR sounder in geostationary orbit (GOES-R) providing additional capability such as winds. In addition to temperature and moisture profiles, hyperspectral IR measurements provide information on ozone and other greenhouse gases such as carbon dioxide, carbon monoxide and methane, clouds, aerosols, and surface characteristics such as temperature and emissivity. Cloud corrected radiances are also derived. The direct assimilation of AIRS radiances by operational numerical weather prediction centers has resulted in significant improvements in forecasting.

SMCD scientists are members of the AIRS, Infrared Atmospheric Sounding Interferometer (IASI) and CrIS science teams. SMCD developed many of the algorithms used for processing AIRS data and developed the AIRS processing system used at NESDIS. SMCD scientists are adapting the AIRS system to process IASI and CrIS observations.

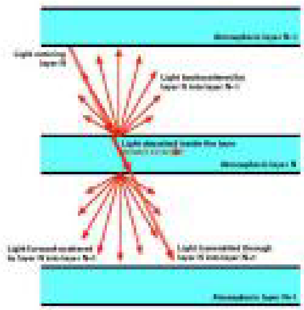
Microwave Products



Satellite microwave instruments are playing vital roles in improving weather and climate prediction as measurements are less affected by clouds than IR, visible, or UV observations and are directly related to geophysical parameters. In the past decade, use of satellite microwave measurements in numerical weather prediction models has resulted in major positive impacts on weather forecasts, helping to extend forecast range by an additional day. Temperature time series constructed from POES microwave observations are the key source of information on global temperature trends.

SMCD microwave scientists continue to improve operational algorithms for microwave products and develop radiative transfer schemes for cloudy skies and a model for surface radiative properties. Another major challenge is developing the tools to exploit the enhanced microwave observing capabilities of the Conical Microwave Imager and Sounder (CMIS) on NPOESS.

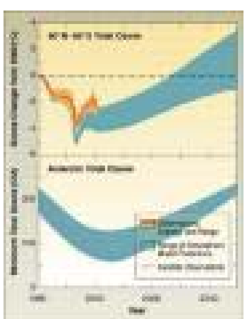
Radiative Transfer Models



Satellite data now comprise over 90% of the observations that feed the NWS forecast models. This remarkable fact is in no small measure due to the development of accurate and fast radiative transfer models by SMCD scientists. Largely due to these observations today's 3-day weather forecasts are just as accurate as 2-day forecasts were just a decade ago. These radiative transfer models facilitate the direct assimilation of satellite observed radiances in the numerical prediction initialization process. To date, the models have been for clear skies only. This means that observations of cloudy areas – where much of the weather occurs - are not assimilated. Developing a radiative transfer model for cloudy skies is an outstanding challenge.

SMCD researchers, working through the JCSDA, have initiated a project to add the capability of modeling radiative transfer in cloudy/and or precipitating atmospheres to the current Community Radiative Transfer Model for clear skies. Additionally, the current radiative transfer models have no component to model surface properties. Successful completion of this project will make possible assimilation of the observations for the half of the globe that is usually cloud-covered. It will also permit more effective use of observations of the surface boundary layer. These achievements can be expected to lead to additional gains in forecast skill.

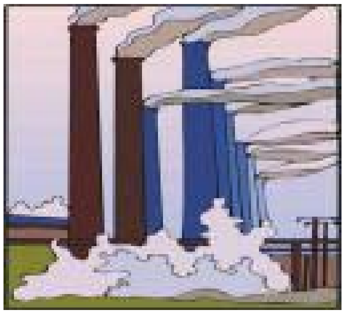
Ozone



As a result of the phase-out of CFCs, the ozone layer is expected to make a gradual recovery to pre-CFC levels. The rate of the expected recovery is based on theoretical calculations. NOAA's ozone measurements are critical to checking whether the ozone layer is indeed returning to normal values and how quickly. Another challenge arises from phase-out of NASA's ozone observing program through NPP to NPOESS. NPOESS will carry the nation's ozone monitoring instruments and NOAA will be largely responsible for a reliable national ozone measurement program.

SMCD scientists support calibration, algorithms and validation of the existing SBUV/2 and Advanced TIROS Operational Vertical Sounder (ATOVS) ozone products and prepare for future instruments in IJPS and NPOESS (GOME-2 and the Ozone Mapping and Profiler Suite - OMPS, respectively). The SMCD ozone program leverages capabilities at NASA in ultraviolet sensor calibration and developing retrieval algorithms, and NOAA/NWS/ Climate Prediction Center (CPC) experience in constructing and analyzing ozone CDRs. Program scientists also participate in science teams for research instruments, e.g., Stratospheric Aerosol and Gas Experiment III (SAGE III) and OMI, development of validation sources, e.g., ground-based Umkehr measurements, and are preparing for the advanced ozone sensor, OMPS, on NPP and NPOESS. They have produced long-term ozone data sets by stitching together the measurements of overlapping satellites. These data sets captured the slow destruction of ozone in the 1980s and 1990s caused by industrial CFCs. SMCD also monitors the annual ebbing and waning of the Antarctic ozone hole and issues timely reports on the phenomena.

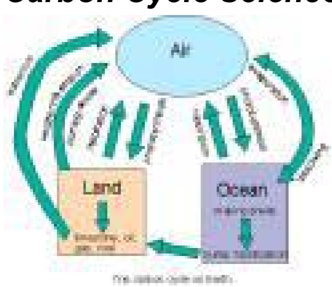
Air Quality



NOAA's Air Quality Program, under its Weather and Water Goal, is a key component of the Nation's effort to address and respond to air pollution. The Program provides environmental policy makers and resource managers with information on the causes of poor air quality and tools to support effective decision-making. The Program also produces timely and accurate air quality forecasts so the public can take appropriate action to limit adverse effects of poor air quality. NOAA plans to accelerate nationwide implementation of ozone Air Quality forecasting capability from FY 2009 to FY 2008 and to deliver an initial particulate matter forecasting capability by FY 2011.

In support of these goals, SMCD has initiated a multi-year baseline project to utilize GOES Aerosol and Smoke Product (GASP) in air quality monitoring and forecasting. This project is closely tied to ongoing activities at the EPA and the NWS to issue national air quality forecast guidance. The project goals are to (1) evaluate the GOES aerosol and smoke product, (2) to demonstrate its value in air quality monitoring, (3) to use the product in the NWS air quality forecast verification, and (4) direct assimilation of satellite-derived aerosol products into NWS forecast models to improve forecasts by improving model initial conditions.

Carbon Cycle Science



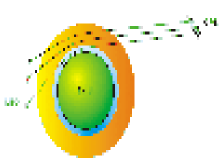
The amount of carbon released into the atmosphere by industrial sources is reasonably well known. So is the steadily increasing mean atmospheric CO2 concentration. What is not known well is the rest of the carbon cycle – the magnitudes of the natural sources and sinks of CO2 at the Earth's surface. Incomplete knowledge of the carbon budget is an impediment to understanding and predicting global climate change. Government agencies are exploring a number of intensive observation campaigns and missions to better define the carbon cycle, including dedicated space missions to measure atmospheric carbon and its variations over the globe. The measurement of atmospheric carbon in this content requires unprecedented precision.

SMCD scientists are exploring the possibilities of measuring carbon dioxide and other greenhouse gases from infrared sounders. These sounders, designed to measure global temperature and moisture for weather and climate applications, have sensitivity to atmospheric carbon. The accuracy of these measurements is a strong function of the vertical thermal gradient and uncertainties in other components of the geophysical state, such as moisture, ozone, and surface parameters. It may be possible to derive estimates of carbon sources and sinks at the continental and oceanic scale from AIRS atmospheric carbon products using atmospheric transport models. Given that thermal sounders measure atmospheric carbon in the mid-troposphere, where variability of these gases is very small, deriving sources and sinks from AIRS will be a very difficult task.

Active Instruments: Doppler Wind Lidar and Global Positioning System/Radio Occultation (GPS/RO)

According to the Strategic Plan for the U.S. Integrated Earth Observation System high-resolution lower-atmosphere global wind measurements from a spaceborne optical sensor would dramatically improve a critical input for global prediction models, improving long-term weather forecasting.

SMCD investigators face unprecedented challenges in the long road to transition the completely new active measurements - GPS/RO and Doppler Wind Lidar (DWL) - to operational use. Historically operational atmospheric remote sensing from satellites has been based on radiometric sounders and imagers. In the future, active remote sensors are expected to complement these instruments, providing accurate observations of unsurpassed vertical resolution. Prototype GPS/RO instruments are used to measure atmospheric refractivity variations that result from the temperature and humidity variations of the atmosphere, and the first operational missions are expected in 2005/2006. DWLs have the potential to sense the motion of atmospheric molecules or aerosols to measure the horizontal wind. Surface and aircraft instruments DWLs are being used as technology test-beds, and the first space-based demonstration is expected in 2007.



Working with the JCSDA, SMCD is developing and testing the software tools needed to assimilate upcoming GPS/RO observations in NWP models. SMCD is also evaluating the accuracy of ground based DWL measurements as part of a program to determine the feasibility of developing space-based instruments.

Environmental Monitoring Branch

As numerical weather prediction models become more sophisticated and improve their treatment of surface atmosphere interactions, the need for good measurements of surface conditions – snow cover, ice cover, vegetation conditions, surface radiation budget, and precipitation – is accelerating. One of the major uncertainties in projections of climate change is the role of atmospheric aerosols, and data are urgently needed on their global distribution, characteristics, and time trends.

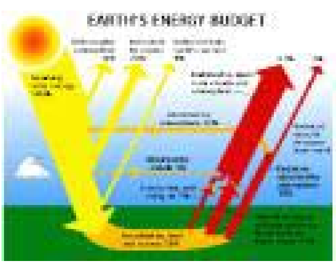
Surface condition products, Earth Radiation Budget, and aerosol products are the responsibility of the Environmental Monitoring Branch. The Branch faces the challenge of developing high quality products to meet these challenging demands as well as others in an ever-increasing range of applications for its weather, climate, and hazards products. The Environmental Monitoring Branch also faces the challenge – as does the rest of SMCD - of preparing for the entirely new suite of instruments on NPOESS.

Vegetation Products

Surface vegetation conditions are important for monitoring drought, providing boundary conditions for weather prediction models, forecasting agricultural yields, monitoring land surface changes, and understanding the global carbon cycle. Over the last few decades, SMCD researchers have led the development and application of vegetation products, primarily from the AVHRR instrument.

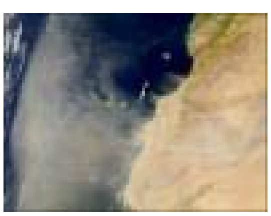
Among the products developed by SMCD scientists are the: Normalized Difference Vegetation Index (NDVI), the two channel AVHRR "greenness" index that serves as the basis for all other vegetation products; green vegetation fraction, defined as the fractional area of active vegetation per unit horizontal area; Vegetation Condition Index (VCI), a measure of drought conditions; and FR, a fire risk index.

Earth Radiation Budget and Aerosols



The Earth's radiation budget (ERB) represents the balance between incoming energy from the Sun and outgoing longwave (OLR) and reflected (shortwave) energy from the Earth (planetary albedo). Changes in the radiative energy balance of the Earth-atmosphere system (caused, for example, by increasing amounts of carbon dioxide and aerosols) can cause long-term changes in climate. Satellites orbiting above the atmosphere are ideal for measuring the radiative energy streams into and out of Earth-atmosphere system. Over the years they have contributed to narrowing the uncertainty in the planetary albedo and outgoing longwave radiation, and improved our understanding of the energy budget.

SMCD scientists developed the original algorithm for estimating OLR from POES IR imagers back in the early 1970s. The OLR data set is now over three decades long, and has played a crucial role in both real-time monitoring and retrospective studies of El Nino Southern Oscillation (ENSO) events. SMCD personnel are actively involved in deriving traditional and new ERB parameters, and in improving the algorithms used to estimate them.



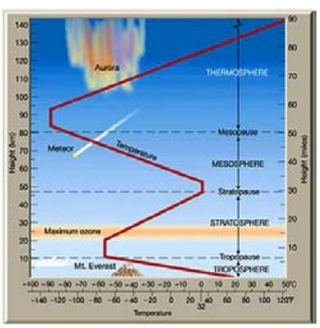
The important role of aerosols in shaping the environment and climate is now well recognized as well as the fact that current estimates of aerosol radiative forcing represent one of the largest uncertainties in assessing global climate change. This recognition is reflected in various research plans, such as the 2001 US Climate Change Research Initiative, which identified the "Development of reliable representations of climate forcing resulting from atmospheric aerosol" as one of its top priority goals. Atmospheric aerosols affect the radiation budget by either reflecting solar radiation back to space, absorbing long-wave radiation, or affecting cloud properties - which would also influence the ERB. In addition, increased levels of aerosols adversely affect human health. Monitoring also provides information, among others, for visibility analysis, validation of aerosol transport models and for aerosol-correction of sea surface temperature. Satellite-derived aerosol data should also improve regional and global assessment and forecast of air quality.

SMCD scientists developed the AVHRR aerosol product that has been used to monitor global aerosol distributions and the dust ejected into the atmosphere by intense volcanic eruptions, such as Mount Pinatubo in 1991. They continue to improve our capability to measure aerosols from satellite observations.

Operational Products Development Branch

The Operational Products Development Branch performs most of the Division's transition of research to operational products. This includes the sounding products for the POES ATOVS system and the GOES sounder, as well as the atmospheric motion vectors (winds) derived from tracking cloud and water vapor features in sequential satellite images. The Branch also develops GOES satellite products for use by weather service field meteorologists in nowcasting and short range weather forecasts, such as the Wet Microburst Severity Index (WMSI) and other atmospheric stability products. It also works closely with the NESDIS Office of Satellite Data Processing and Distribution to ensure reliable software for operational production of satellite products and provide timely science fixes for in-flight instrument problems.

Transition of Sounding Products to Operations



SMCD has supported the NESDIS POES sounding program since 1966 and the GOES sounders since 1994. SMCD has transitioned all new sounding systems and upgrades that STAR has developed into operations. It continues to monitor, validate, and improve the quality of the basic temperature and moisture profiles derived from the sounder observations, and provide science support and troubleshooting for many instrument anomalies. The soundings are distributed to weather services throughout the world via the World Meteorological Organization's (WMO) Global Telecommunications System (GTS). In October 2002, the GOES sounder retrieved products were added to the NWS Advanced Weather Interactive Processing System (AWIPS). SMCD is preparing for the next generation of sounders on the METOP, NPP, and NPOESS satellites.

Atmospheric Motion Vectors

Atmospheric motion vectors (AMVs) derived from a sequence of satellite images are an important source of global wind information, particularly over the world's oceans and more remote continental areas where conventional weather observations are lacking in time and space. These data are routinely used by the major NWP centers in the world and assimilated into regional and global NWP models. These data are also made routinely available to NWS forecasters responsible for providing the public with day-to-day weather forecasts. These products are distributed over the GTS and the NWS's AWIPS.

SMCD transitions to operational production the AMV algorithms developed by STAR scientists. AMVs have been typically derived from the GOES imagery providing approximately full disk coverage from 60S to 60N. The current operational GOES wind products include infrared (IR) cloud-drift winds, water vapor (WV) motion winds, and visible (VIS) cloud-drift winds. More recently, SMCD has transitioned a MODIS wind algorithm to operations.

Flash Floods

Precipitation information is critical for a wide variety of applications, ranging from predicting flash floods to analyzing long-term precipitation patterns for agriculture and water resource concerns. Rain gauges have traditionally been the primary source of precipitation data, but their coverage is quite poor, and radar observations have their own limitations.

To support operational forecasters in the US and the NOAA Weather and Water Goal, SMCD has developed and produces the Hydro-Estimator (H-E) – automated estimates of rainfall for the entire Continental United States (CONUS) based on infrared window cloud-top temperatures and supplementary information from numerical weather models. The H-E is available operationally to NWS forecasters via the AWIPS, and H-E fields are produced worldwide (using data from the three GOES satellites and the two Meteosat satellites) and distributed via the Internet on an experimental basis. In addition, a number of experimental algorithms are under development and/or evaluation at NESDIS, including the GOES Multi-Spectral Rainfall Algorithm (GMSRA), which uses data from four GOES Imager channels to extract additional information about cloud properties that are pertinent to rainfall, and the Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR) which also uses data from multiple GOES Imager channels and calibrates against microwave rain rate estimates in real-time.

Aviation Hazards

Aviation hazards include volcanic ash, in-flight icing, and fog and low ceilings. An encounter with an airborne volcanic ash cloud can result in millions of dollars in damage to jet engines and the airframe, as well as the risk of engine stalls, so avoidance is critical. In-flight icing results in significant aerodynamic drag, and causes 5-10% of all fatal air crashes for smaller, general aviation and commuter class aircraft. Fog and low ceilings are a major reason for aviation delays, resulting in >$2B annual economic loss, and account for about 25% of fatal aviation and maritime accidents.

SMCD scientists have developed and continue to improve the following aviation hazards products:

- Nighttime fog and low clouds from GOES and POES IR imagery
- In-flight icing from GOES imagery
- Various wind downburst indices from GOES sounder observations
- Volcanic ash from the GOES Imager

JCSDA

Scientific projects undertaken at the JCSDA are aligned with several high priorities. The goals of these priorities and their impact on data assimilation capability are given below.

- **Improve Radiative Transfer Models.** Radiative transfer models represent the glue that connects the satellite observations to the meteorological variables of the numerical prediction models. Under this priority, JCSDA will improve the accuracy and capability of fast forward radiative transfer models, by including additional physical processes (e.g., atmospheric scattering) and better numerical techniques. JCSDA will also improve emissivity modeling to allow more satellite data affected by surface to be properly assimilated.

- **Prepare for Advanced Instruments.** As shown in Section 2, JCSDA must prepare for many new satellite sensors to be launched over the next 5 years. JCSDA will develop software algorithms for calibration, navigation, data selection, simulating observations, processing and quality control in advance of launch to reduce elapsed time from launch to operational use.

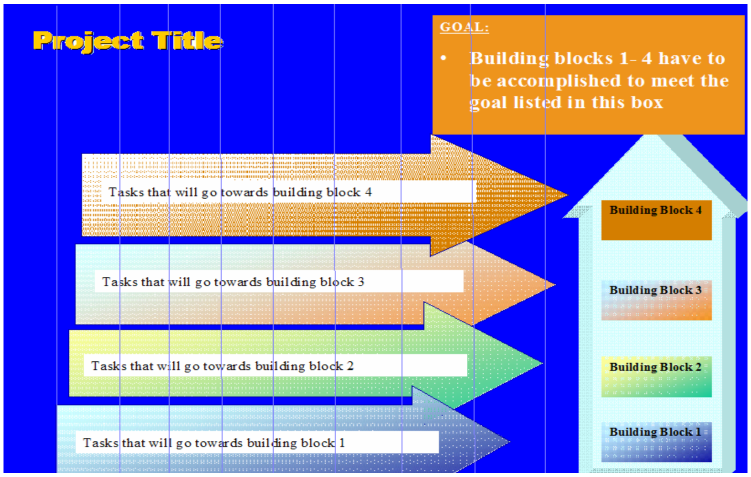
- **Advance Techniques for Assimilating Cloud and Precipitation Information.** Satellite observations of clouds and precipitation are not currently assimilated in NWP models. JCSDA will develop a capability to assimilate satellite data in cloudy and precipitation regions by improving radiative transfer models and NWP cloud prediction schemes, thereby significantly increasing the fraction of satellite data being ingested into the assimilation systems.

- **Improve Uses of Satellite Land Products.** Improved land surface products (e.g., green vegetation fraction, snow cover, snow pack parameters, surface albedo, land, and sea surface temperature) will make forecasts more accurate and increase the fraction of satellite data used.

- **Improve Use of Satellite Data for Ocean Data Assimilation.** Provide assimilated ocean data sets to the community for research purposes and provide access to and support of (a version of) an operational ocean data assimilation system.

- **Assimilate Satellite Derived Atmospheric Chemical Species.** NWP models are being enhanced to model stratospheric processes and perform air quality forecasting. Satellite observations of aerosols, ozone and other trace gases will be assimilated.
- **Implement 4D Variational Data Assimilation (4D Var).** Based on results from several NWP centers around the world, implementation of 4D Var should significantly improve forecast skill.

4. ROADMAP



In this section, we summarize the research projects the Division will be working on. For each project, we list its Title, Objective(s), and Significance. The contribution(s) of each project to Objectives of NOAA Goals is contained in Section 8: Impact on Society and NOAA Goals. More detailed information on project tasks, timelines, building blocks, milestones, etc. is contained in Appendix 2: Roadmap Diagrams

1. **Active Remote Sensors**

   Objectives
   - Develop prototype and first-generation active sounder algorithms
   - Evaluate and assess observations and data products delivered by active sounders
   - Transition the space-based active sensor observations to operational use

   Significance
   - After 45 years of passive remote sensing from satellites, active sensors will add new capabilities
   - Temperature and wind fields with unprecedented vertical resolution will be achieved

2. **Aerosol Remote Sensing from Operational Satellites**

   Objectives
   - Construct long term aerosol datasets for climate research.
   - Monitor aerosol forcing from space.
   - Develop aerosol products for air-quality applications for current and future sensors on NPOESS and GOES-R.

   Significance
   - Can anthropogenic aerosols cancel the effects of greenhouse warming? These data sets will help answer this crucial question.
   - Increasingly accurate measurements are needed to correct satellite observations of sea surface temperature and provide input to air quality assessments and forecasts

3. **Air Quality Applications of Satellite Data**

   Objectives
   - Demonstrate the applicability of satellite-derived products for air quality monitoring and forecasting

- Improve current aerosol retrieval algorithms and develop new algorithms for future advanced sensors
- Develop capabilities for global air quality monitoring from current and future operational NOAA/IJPS/NPOESS instruments
- Develop capabilities to transition NASA research satellite data into NESDIS operations
- Develop chemical data assimilation capabilities to improve air quality forecasts

Significance

- This project will develop the space observations component of NOAA's air quality forecasts

4. Aviation Hazards

Objective

- Develop, improve, and evaluate potential new products or techniques derived from GOES or Polar multi-spectral Imager or Sounder data to improve the detection and short range forecasting of aviation hazards. Examples of aviation hazards included in this project are: fog and low clouds, aircraft icing, turbulence, volcanic ash, and convective wind gusts. Research will focus on the development of algorithms for optimum detection of conditions suitable for the occurrence of these hazards based on satellite and ancillary data.

Significance

- Although passenger aircraft are safer than ever, larger capacity aircraft and more people flying create increasing vulnerabilities to environmental conditions.
- This focused project will substantially improve the detection of environmental hazards for aircraft and reduce loss of life and property

5. Community Radiative Transfer Model

Objective

- Develop the community radiative transfer model that can be directly implemented at the U.S. NWP centers in their NWP models by including atmospheric and surface radiative transfer processes for all sky conditions, including clouds and precipitation.

Significance

- Radiative transfer is the glue that connects satellite observations to atmospheric and surface variables of interest
- This project's all-sky radiative transfer model will lead to improved predictions of clouds and precipitation, two weather conditions difficult to forecast

6. GOES Surface Ultraviolet Radiation

Objective

- Develop a reliable surface ultraviolet irradiance product derived from GOES that will serve as a reference for the evaluation of the NWS UV Index forecast, and at the same time provide much needed data for research in the fields of climate, biology, agriculture, fishery, and industry.

Significance
- This project is one of SMCD's initiatives to expand the use of satellite observations to assess and predict environmental hazards

7. **Instrument Calibration**

Objective
- Provide calibration support for NOAA's satellite operations, which include both the polar-orbiting and geostationary systems, each has 2-3 spacecrafts in operation at any time, and each spacecraft has a number of instruments. To meet the operation continuity requirements, this project also provides calibration support for NOAA's satellite operations in the past and future.

Significance
- Well calibrated instruments are the foundation of quantitative remote sensing.
- This project will keep pace with the increasing demands of the weather, climate, and ocean sectors for well calibrated observations

8. **Ozone**

Objective
- Produce high-quality operational and reprocessed ozone estimates from SBUV/2 and TOVS for use in numerical weather models, UV forecasts, ozone assessments and other studies.
- Develop the systems to produce total ozone products from the start of GOME-2 operations and ozone profile products within one year after the start of operations, to incorporate GOME-2 products into our long-term monitoring ozone time series, and to produce new atmospheric chemistry products for ozone science and air quality applications.
- Prepare for the OMPS instruments on NPP and NPOESS.
- Assist the EOS Aura OMI Science Team in validating level 1 UV measurements and level 2 ozone products from OMI.
- Obtain ozone estimates from the GOES Sounder and EOS AIRS instruments.

Significance
- These ozone data will measure the rate of recovery of the ozone layer from the losses sustained by decades of CFC pollution
- Ozone is a key contributor to the NWS UV forecasts

9. **Precipitation and Floods**

Objective
- Improve the accuracy of satellite-based estimates of rainfall and to enhance their application by forecasters (both domestic and overseas) and other parties of interest such as the numerical weather modeling community.

Significance

- More accurate rainfall estimates for hurricanes and severe storms will facilitate warnings and mitigation efforts in flood prone regions

10. Radiance Products and Atmospheric Soundings from Advanced Infrared and Microwave Sensors for Weather and Climate Applications

Objectives

- Develop an integrated processing system for AIRS, CrIS and IASI which includes other instruments such as AMSU, Advanced Technology Microwave Sounder (ATMS) - which provides soundings in total overcast conditions and used in infrared clouding clearing, and MODIS and VIIRS (used to improve cloud detection and clearing).
- Develop an improved cloud clearing scheme for obtaining clear radiances for AIRS.
- Develop algorithms for deriving mixing ratios for carbon monoxide (CO), carbon dioxide (CO_2) and methane (CH_4) from AIRS.
- Explore techniques for extracting information content of IASI's 8600 channels.
- Evaluate expected accuracy and yield of IASI cloud cleared radiances and carbon-cycle products.
- Explore the utility of imager data and/or forecast models to provide cloud clearing for the GOES-R infrared instrument. In this case of GOES-R, a microwave instrument is unlikely and the techniques that are explored for AIRS, IASI, and CrIS will be of fundamental value.

Significance

- Exploitation of advanced IR and microwave sounders will extend the useful range of weather predictions and provide critical information on greenhouse gases associated with global climate change

11. Satellite Data Assimilation (JCSDA)

Objectives

- Reduce from 2 to 1 year the time from launch to use of satellite data;
- Increase the fraction of research and operational satellite data used in NWP;
- Extend satellite data assimilation systems to other Environmental Prediction Models in the GEOSS era

Significance

- The JCSDA's activities will lead to a 20 % increase in useful satellite lifetime and earlier implementation of new observing capabilities in numerical weather prediction

12. Snow Cover

Objectives

- Improve snow cover boundary condition products for NWP
- Validate and make operational 4-km GOES snow fraction product.

- Validate and put into routine production snow depth product.
- Develop MODIS climatology of maximum snow albedo for NWP models
- Construct 39 year snow climatology (and NDVI) for the climate community.
- Develop and describe method of removing the offset in the snow cover climate record introduced by the IMS system.
- Derive snow water equivalent (from AMSU) and blend into the IMS.

Significance
- Improved snow products will allow specification of more accurate boundary conditions in NWP and construction of a long term CDR for snow

13. Vegetation

Objectives
- Update the operational vegetation fraction algorithm after testing is completed by NWS/NCEP/EMC and CPC, and accommodate new sensors (e.g., MODIS, VIIRS) within the vegetation processing stream and associated reprocessing.
- Improve NDVI and products derived from it (Global Vegetation Fraction - GVF, drought indices, etc)

Significance
- Improved vegetation products will provide more accurate surface conditions for NWP models and drought monitoring

14. Winds

Objectives
- Develop and maintain a robust, repeatable technology transition process that results in the timely and successful transition of new and/or updated product algorithms from the research and development environment to the operational production environment
- Support transition of MODIS winds capability into NESDIS operational environment at OSDPD.
- Perform quality assessment and error characterization of geo and leo satellite wind products
- Improve and validate existing satellite derived wind product algorithms
- Develop algorithms for future satellite systems, including GOES-R.

Significance
- Winds are a critical part of the initial conditions for forecast models
- MODIS winds represent a breakthrough in observing winds in polar regions

15. Earth Radiation Budget

Objective
- Develop OLR retrieval algorithms from sounder channels (HIRS, AIRS, CRIS) to provide a time series of OLR compatible with the ERBS instrument on NPOESS.

The new OLR estimates will be improved over what is now available from AVHRR.

Significance
- The OLR is a major component of the Earth's Radiation Budget, which drives the atmospheric circulation.
- This project will improve and continue the NOAA time series of OLR measurements going back to the 1970s, providing climatologists with a record of the Earth's heat balance in the age of global warming

16. GOES Sounder Products

Objectives
- Develop an improved integrated GOES sounder product system that will provide the National Weather Service (NWS) with full resolution (approximately 10km x 10km) GOES sounder products for use in NWP and the Advanced Weather Interactive Processing System (AWIPS).
- Develop and maintain a robust, repeatable technology transition process that results in the timely and successful transition of new and/or updated product algorithms from the research and development environment to the operational production environment.
- Prepare GOES sounder product system(s) for GOES-N and perform validation studies of GOES-N sounder radiance and derived products during the GOES-N science test.

Significance
- High temporal GOES products are needed to monitor severe events such as tornadoes, thunderstorms, and hurricanes.
- Resolving the diurnal cycle also contributes to climate studies.

17. POES Sounder Products

Objectives
- Develop and maintain a robust, repeatable technology transition process that results in the timely and successful transition of new and/or updated product algorithms from the research and development environment to the operational production environment.
- Support the transition of METOP, NOAA-NPP, and NPOESS sounding systems to operations.
- Develop integrated validation systems for monitoring and assessing quality of sounder products from multiple sensors such as ATOVS, AIRS, IASI, CrIS, and GPS Radio Occultation.
- Provide validation datasets to NOAA and external researchers.

Significance
- Hyperspectral soundings from upcoming polar satellites will significantly improve medium range forecasts, as shown by the AIRS impact on NWP

5. CURRENT RESEARCH

In this section, we highlight some recent research achievements of the Division. More detailed summaries are contained in the Division's bi-annual Reports.

Sensor Physics Branch

Powerful New Tool for Inter-satellite Instrument Calibration

A powerful method has been developed to quantify the inter-satellite calibration biases for radiometers on polar-orbiting satellites. The method is based on Simultaneous Nadir Overpass (SNO) observations. An SNO occurs when the nadir points of two polar-orbiting satellites cross each other within a few seconds. Such crossings occur at the orbital intersections of the satellites in Polar Regions. At each SNO, radiometers from each pair of satellites view the same place at the same time at nadir, thus eliminating uncertainties associated with the atmospheric path, view geometry, and time differences. Their measurements should be identical. By comparing the measurements of the two satellites during SNOs, it's possible to determine the bias of one instrument with respect to the other.

The SNOs allow us to resolve small calibration biases at or below the combined instrument noise for many channels (Figure 2).

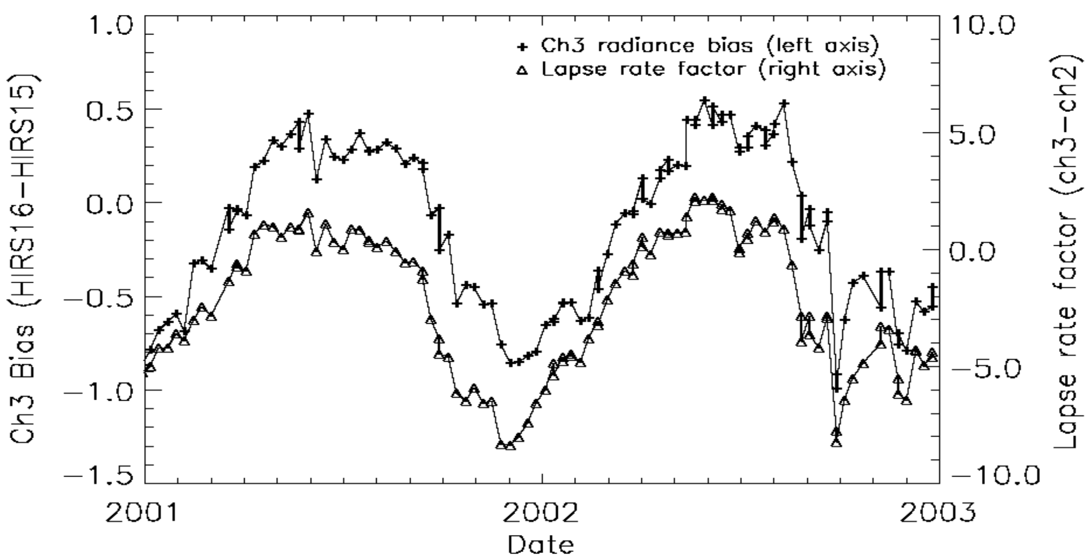


Figure 2: Intersatellite radiance biases between HIRS on NOAA-15 and -16 show excellent agreement with uncertainties below the combined instrument noise. It also shows that seasonal variations in the bias are highly correlated with the lapse rate, indicating small spectral response differences between satellites.

The Next Generation Microwave Integrated Retrieval System (MIRS)

To prepare for future NPOESS microwave instruments such as CMIS and ATMS, SMCD has begun development of the next generation retrieval system - the microwave integrated retrieval system (MIRS). This physically-based system will derive the profiles of atmospheric parameters such as temperature, water vapor, and cloud hydrometeors over land and oceans by using the measurements from the microwave imager and sounder. An advanced radiative transfer model including atmospheric and surface scattering and polarization is being developed and integrated as part of the MIRS. With the microwave surface emissivity model developed by SMCD, water vapor and cloud water can be also retrieved over land. These advanced RT models will enable combined use of microwave window and sounding channels to simultaneously derive the cloud water profiles in addition to temperature and water vapor profiles. This integrated approach will lead to more robust advanced microwave products from current and future satellite microwave instruments having both imaging and sounding channels.

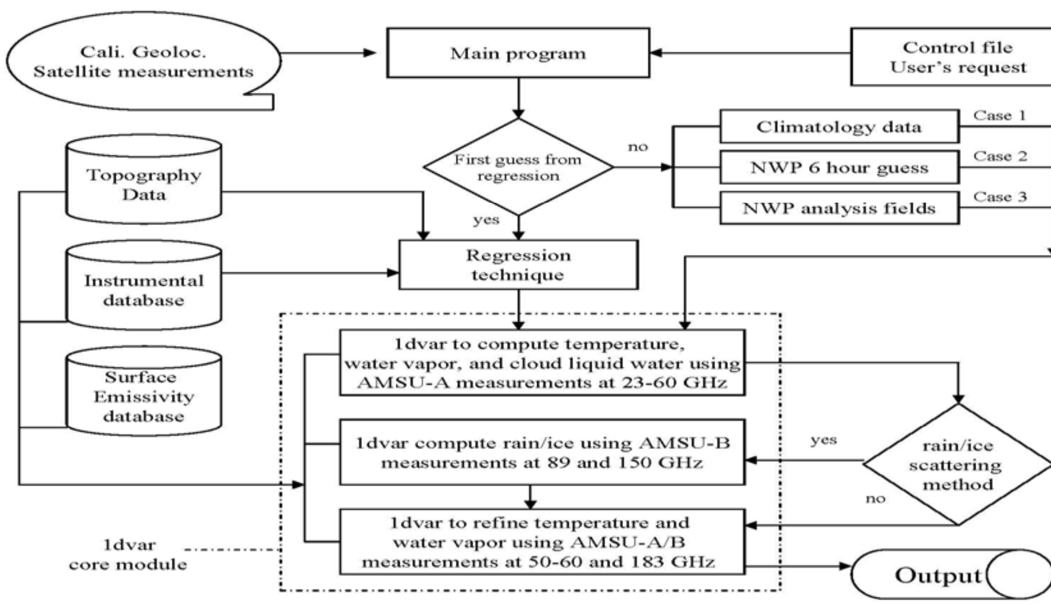


Figure 3: Flowchart of microwave integrated retrieval (MIR) system developed for future NPOESS era sensors such as ATMS and CMIS. The core module describes the retrieval procedures

The 2004 Antarctic Ozone Hole

SMCD scientists, working closely with scientists at NOAA's Climate Prediction Center, continue to closely monitor the Antarctic ozone hole. Extensive ozone depletion was again observed over Antarctica during the Southern Hemisphere winter/spring of 2004, with widespread total ozone anomalies of 45 percent or more below the 1979-1986 base period. The area covered by extremely low total ozone values of less than 220 Dobson Units, defined as the Antarctic "ozone hole" area, in September reached maximum size of greater than 19 million square kilometers, with an average size in September of 17.4 million square km, smaller than most recent years.

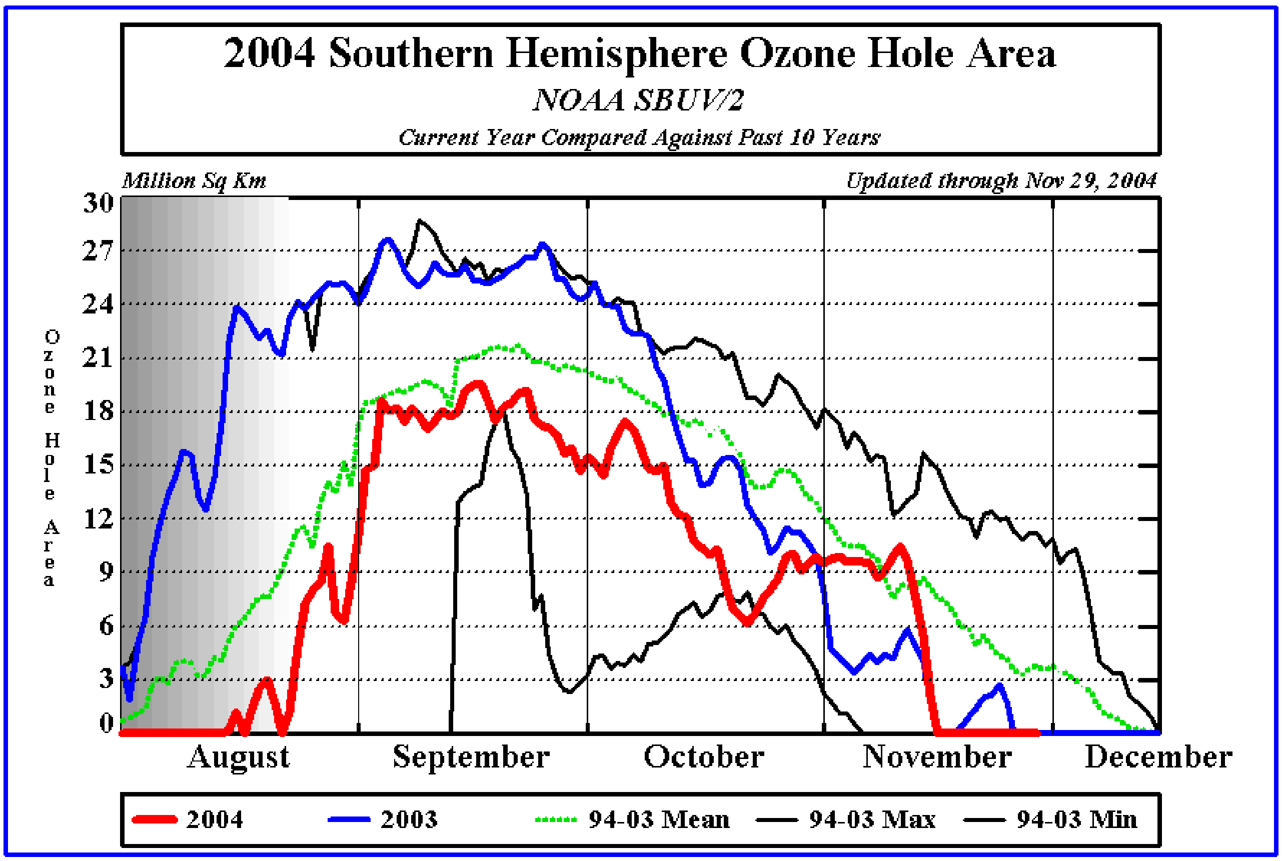


Figure 4

Carbon Cycle Science: An Emerging Product Suite

Working with collaborators at University of Maryland, Baltimore County (UMBC), SMCD investigators have shown that CO is a robust and useful product from AIRS. An example of the AIRS CO product for a single day is shown in Fig. 5. CO is important because it is a component of air pollution, is a measure of biomass burning, and contributes to the greenhouse effect. In addition to CO, SMCD is also developing algorithms for deriving other carbon cycle products, such as CO_2 and CH_4, from advanced IR sounders.

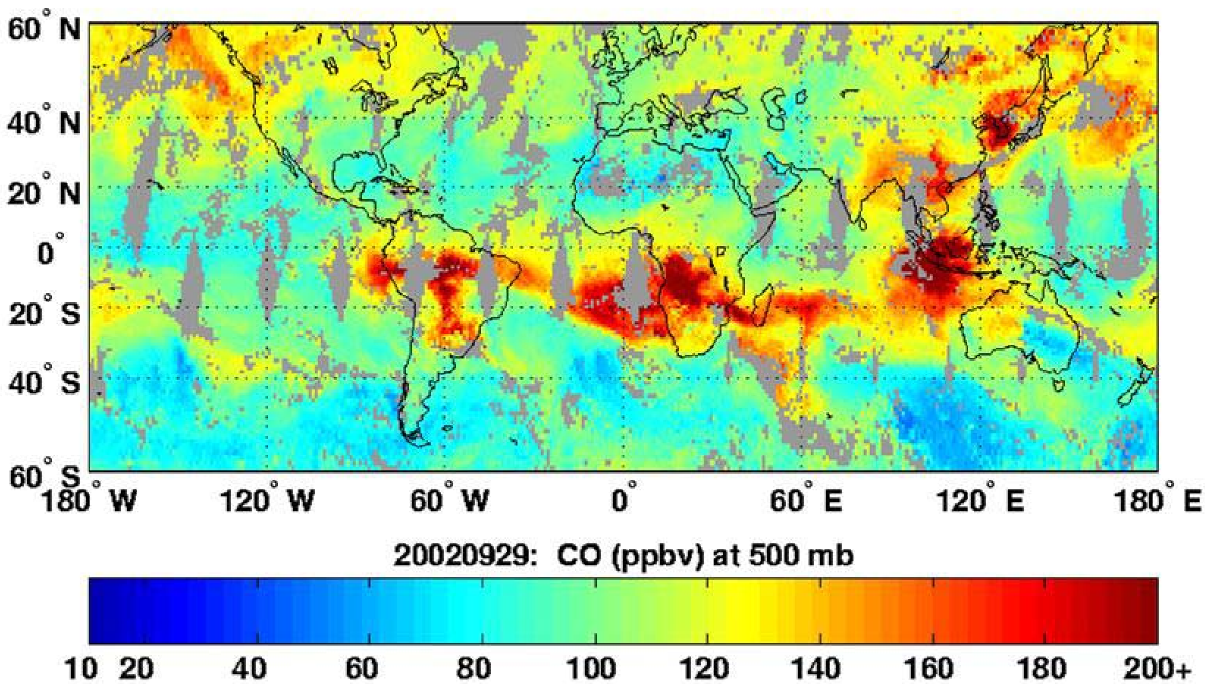


Figure 5: Global CO distribution at 500 mb derived from Aqua AIRS (9/29/2002)

Environmental Monitoring Branch

New Vegetation Products Transitioned to Operations

A VCI product that measures the condition of local vegetation world-wide and a Global Vegetation Fraction (GVF) that provides data on the fraction of green vegetation in a global array of grid boxes have been successfully transitioned from research to operations in 2004. Both products are based on AVHRR observations and are produced weekly.

The VCI indicates whether the health, vigor and amount of vegetation in a particular area are above normal or below normal for that time of year. Together with satellite observations of land surface temperatures, the VCI can be used to monitor drought conditions globally.

The GVF shows how much of the land surface is covered with actively growing vegetation. It is used in NWP Models to calculate the rates of heat and moisture transfer from the surface to the atmosphere. An example of the GVF for North America for June 16, 2003 is shown below.

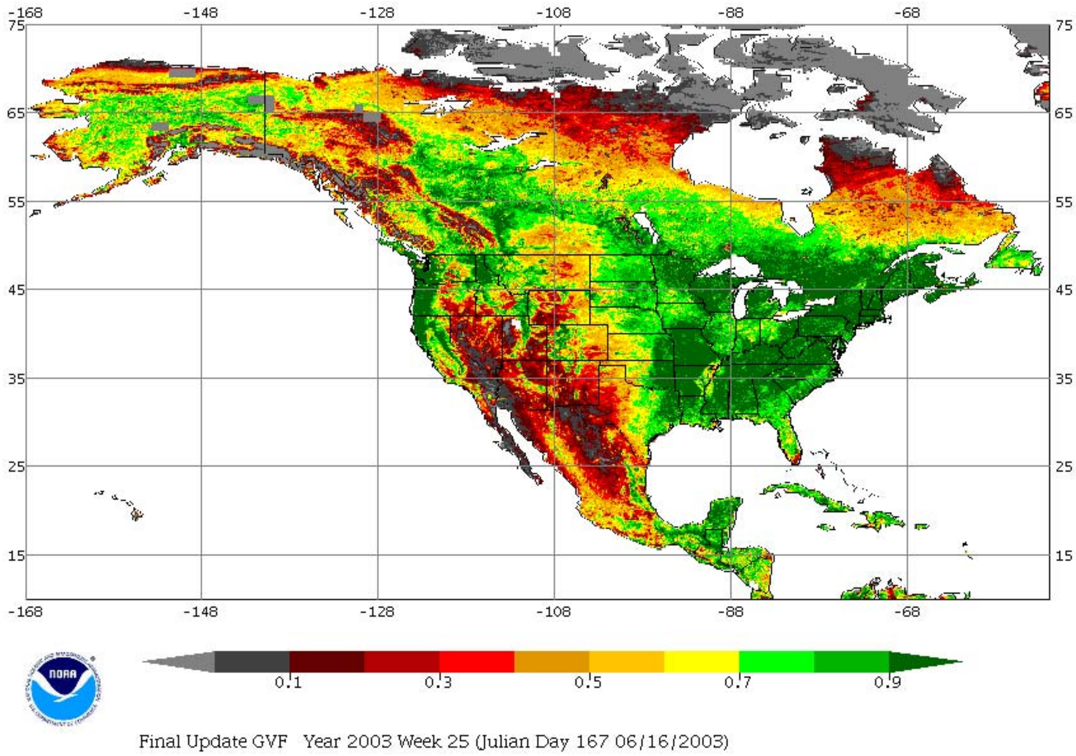


Figure 6: Green Vegetation Fraction for the week of June 16, 2003.

Detection of Severe Drought in Horn of Africa

Using the AVHRR Vegetation Condition Index, SMCD scientists have detected areas of extreme drought conditions in parts of Kenya, Ethiopia and Somalia for the sixth year in a row. These conditions leave the region with threats of starvation, water shortages, widespread crop losses and disease outbreaks.

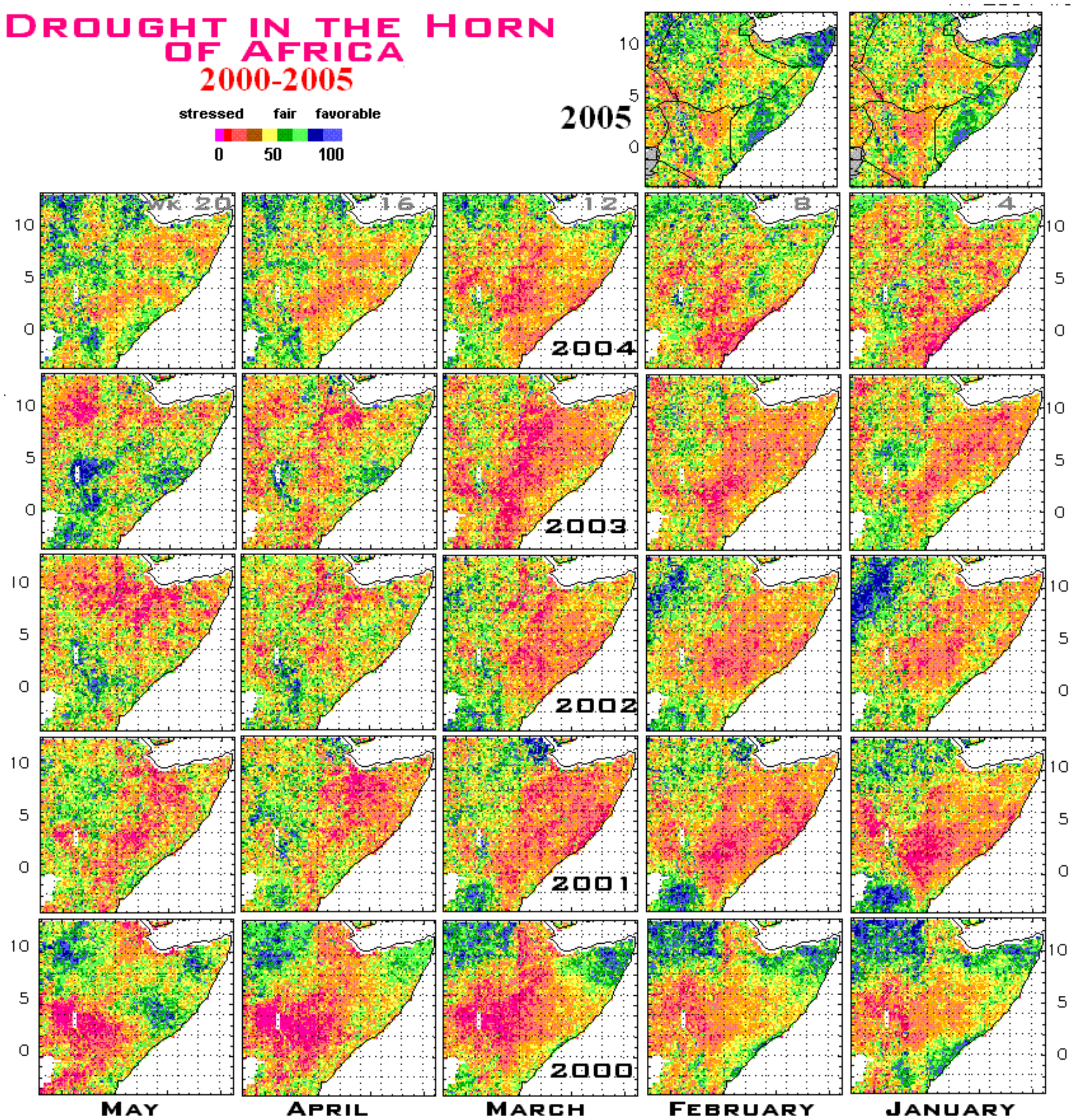


Figure 7

A New Capability: Automated Ice Cover Maps

SMCD has developed an algorithm to identify and map ice cover using observations from GOES Imager and NOAA AVHRR. Ice distribution is derived over seas and oceans surrounding North America as well as over internal water bodies (lakes, reservoirs, etc.).

The retrieval results are validated against snow and ice cover maps generated within snow and ice maps prepared at the NOAA National Ice Center (NIC). Ice cover will be added to currently operational North America automated snow cover maps after a year-round validation of the product is completed.

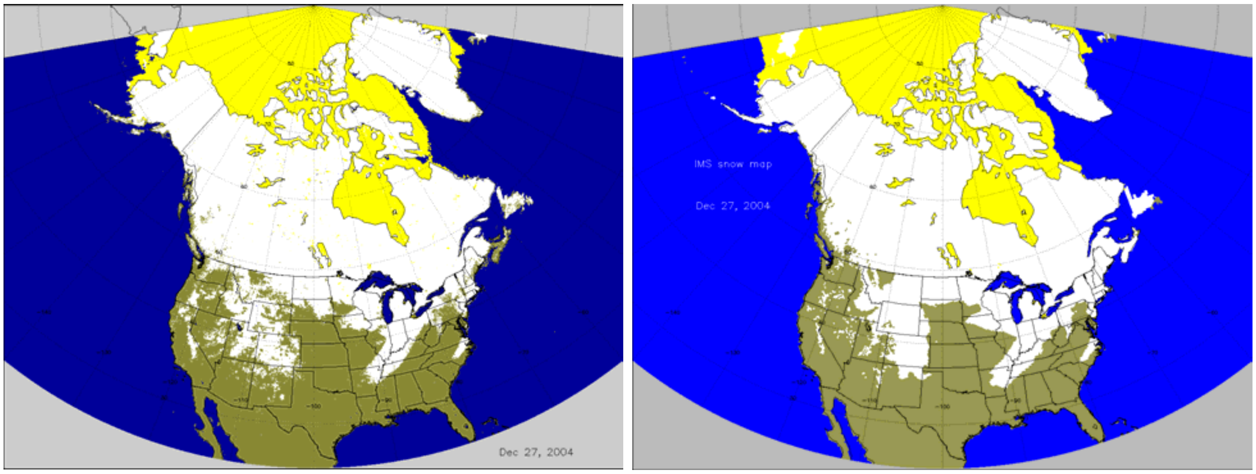


Figure 8: Comparison of snow/ice maps produced using the new SMCD automated algorithm (left) and the NOAA Interactive Multisensor Snow and Ice Mapping System (IMS) for December 27, 2004.

Operational Products Development Branch

Aircraft Icing Product Achieves High Reliability

As a result of several upgrades to the GOES aircraft icing product, the probability of detecting hazardous icing conditions is now consistently high - in the 55-70% range compared to 40-65% previously – for the Continental U.S.

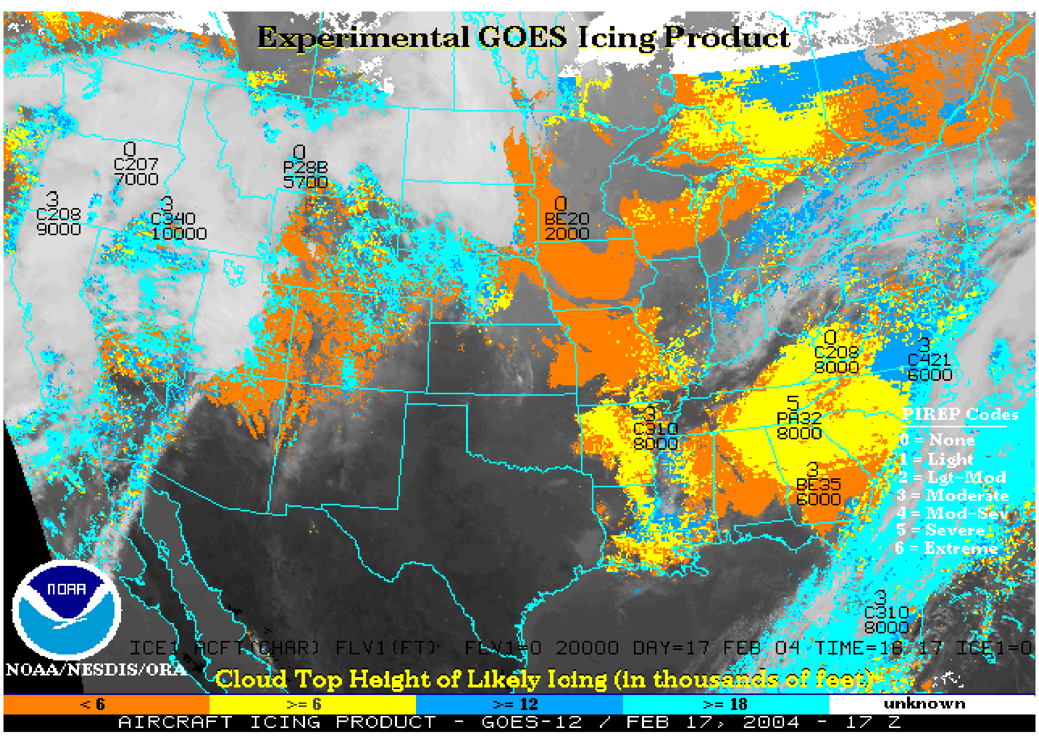


Figure 9: Example of an Icing Enhanced Cloud-top Altitude Product (ICECAP) image is shown, valid at 1700 UTC, on February 17, 2004. Areas of potential icing are color-coded in intervals of 6,000 ft to show maximum cloud top altitude. Pilot reports of icing are superimposed showing: numerical icing intensity (0 to 5), aircraft type, and altitude in feet. Severe icing (code 5) at 8,000 ft was reported in eastern Tennessee within two hours of the GOES product. Some icing (such as that shown in northwest U. S.) is obscured by high cloud layers and cannot be detected.

Significant Advance in Satellite Wind Measurements

Winds derived from tracking cloud and water vapor features in geostationary satellite observations have been produced for decades. However, because of the limitations of geostationary satellite viewing, these wind retrievals are not available for Polar Regions. To overcome this problem, a new capability has been developed that takes advantage of the frequent observations of Polar Regions by the MODIS on the NASA Terra and Aqua satellites. First developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), it is based upon established methodologies and algorithms used to derive wind observations from the GOES series of satellites. MODIS cloud-drift and water vapor wind observations provide unprecedented coverage in the polar regions of the globe, areas where wind observations are sorely lacking. Figure 10 shows an example of the MODIS water vapor motion wind products in the Northern Hemisphere polar region. In 2004, the Operational Products Development Branch (OPDB) integrated the MODIS winds capability within the existing operational NESDIS winds processing system. Recent work by the JCSDA shows that these polar region winds have a positive impact on weather forecasts.

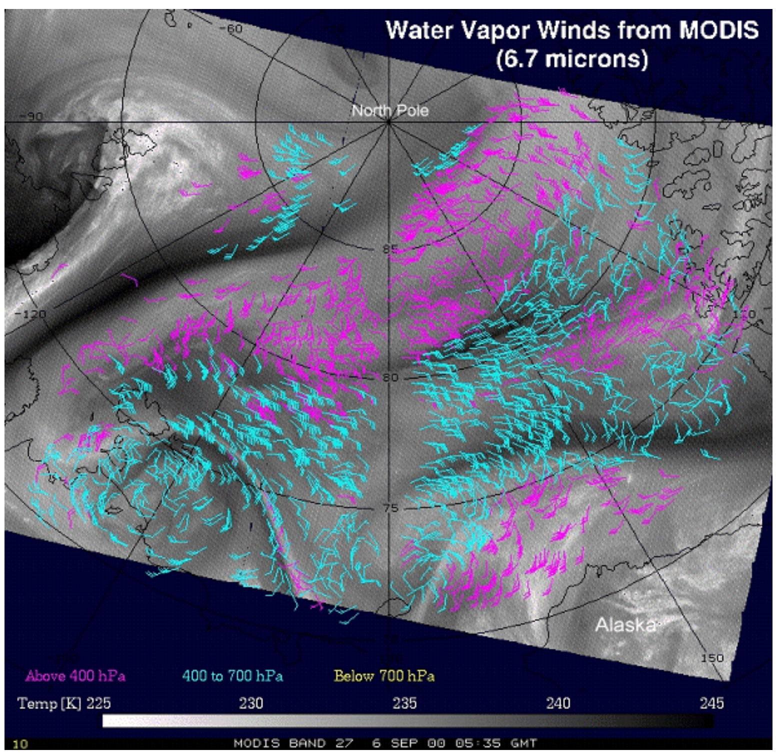


Figure 10: MODIS water vapor motion winds over the Northern Hemisphere polar region.

AIRS Data Significantly Improve Weather Forecasts

Experimental weather forecasts at the JCSDA using AIRS radiance observations indicate significant improvements in global forecast skill compared to the operational system without AIRS data. The improvement in forecast skill at 6 days is equivalent to gaining an extension of forecast capability of several hours. This magnitude of improvement is quite significant when compared to the rate of general forecast improvement over the last decade. A several hour increase in forecast range at 5 or 6 days normally takes several years to achieve at operational weather centers.

The AIRS impact study consists of two parallel series of 27 consecutive daily weather forecasts, each extending out to 10 days during the month of January 2004. To specify the initial conditions for each forecast, the *control* series assimilates all conventional and satellite observations except for AIRS observations; the *experimental* series assimilates all the data used in the *control* run plus the AIRS observations.

The skill of the forecasts was evaluated by comparing the forecasts with the verifying analyses of the observations using anomaly correlations. Anomaly correlation is a statistical measure for evaluating large-scale/medium-range forecast skill and provides a reliable indication of overall model skill. The anomaly correlation is the correlation between observed (verifying analysis) and predicted deviations from climatological conditions. It is clear from the accompanying figure that AIRS data have a consistent and significant effect on forecast skill

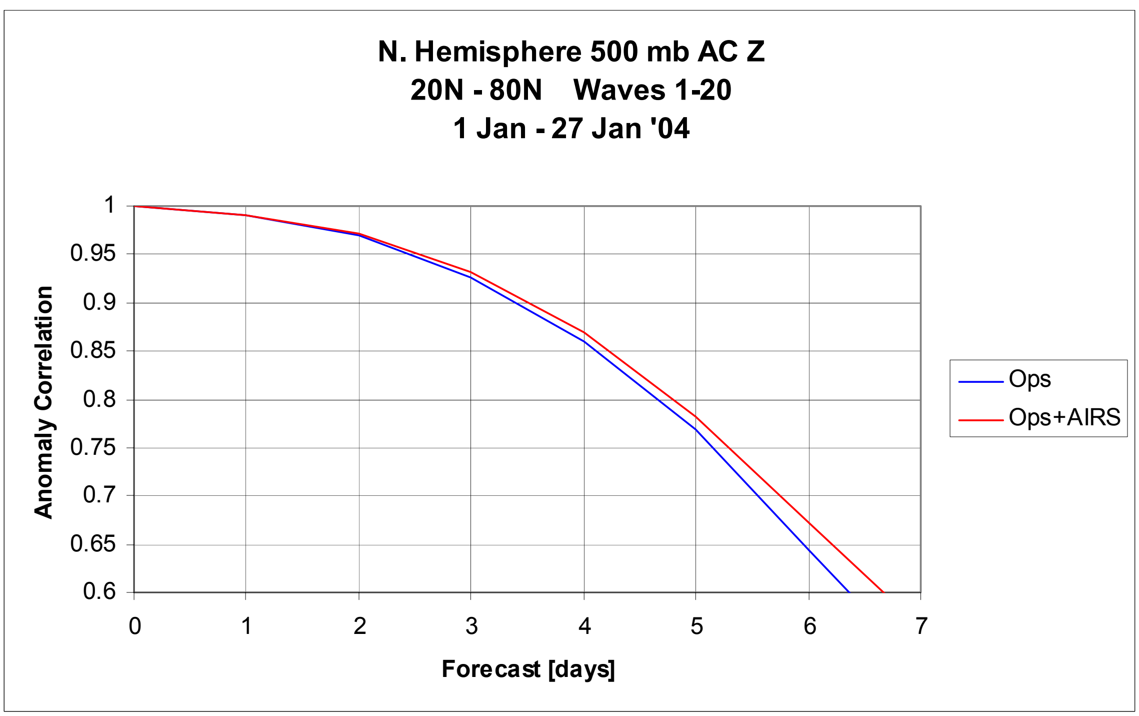


Figure 11: 500hPa Z Anomaly Correlations with (Ops.+AIRS) and without (Ops.) AIRS data, Northern hemisphere, January 2004

6. PERFORMANCE TARGETS

The Division has adopted a number of overarching performance targets, as well as targets for each of the NOAA Goals that it contributes to. These targets will be used to monitor the success of the SMCD research and development program. Performance targets for SMCD's individual projects are contained within the SMCD's Research Project Plans (RPPs).

Overarching Performance Targets

1. Number of new or improved algorithms developed for satellite products or applications
2. Number of new or improved products transitioned to NESDIS Office of Satellite Data and Distribution for operational production
3. Number of published papers;
   a. On calibration, product, and applications algorithms
   b. On better understanding of meteorological and climatological variations and processes
4. Reduction in time to transition product algorithms to operational production
5. Number of satellite instruments intercalibrated

Weather and Water

6. Number of new or improved satellite data sets used in NWS forecast models, Hydrology Program hydrologic models, or Air Quality Program
7. Reduction of average time for operational NWP implementations of new satellite technology from two years to one year

Climate

8. Number of new or improved Climate Data Records constructed
9. Number of climate quality algorithms developed to measure the atmospheric component of the carbon cycle, ozone trends, aerosol properties, and the Earth's radiation budget from the advanced satellite instrument observations of Metop, NPP and NPOESS

Commerce and Transportation

10. Number of new or improved products developed for Aviation Weather Program

To achieve the Performance Targets, SMCD faces the following **Performance Challenges.**

Weather and Water

1. Development of surface emissivity/reflectivity models across the spectrum from visible to microwave

2. Development of fast radiative transfer models for clouds, precipitation, and aerosols

3. Development of methods for compressing data volume of hyperspectral instruments while maintaining information content

4. Development of assimilation systems for all new data types
5. Development of algorithms for processing global 1km data from Metop AVHRR
6. Development of enhanced environmental data records (EDRs) for NPP/NPOESS VIIRS, CMIS, and CrIS/ATMS
7. Development of algorithms for processing GOES-R ABI and HES
8. Preparation for active instruments: GPS/OS, Cloudsat, Calipso, and Aladin
9. Application of satellite data to improve NWP model physics – surface and cloud/precip models
10. Development of algorithms and processing systems for integrating multi-sensor, multi-platform observations
11. Development of satellite-based air quality products – smoke, other aerosols, low level ozone – for assimilation in NOAA/EPA air quality forecast model
12. Development of improved vegetation, fire, and drought monitoring system using VIIRS and possible NPOESS Landsat type imager
13. Development of a satellite inter-calibration program

Climate

1. Development of a Climate Data Record (CDR) processing system
2. Development of a satellite inter-calibration program
3. Preparation for new climate instruments on NPOESS: APS, ERBS, and TSIS
4. Initiation of a GPS/RO Climate Data Record
5. Development of algorithms for generating atmospheric carbon cycle products from IR hyperspectral sounders
6. Production of seamless ozone records from legacy instruments and NPP and NPOESS OMPS
7. Development of systems for assimilating satellite data in climate models

Commerce and Transportation

1. Development of improved and enhanced aviation hazards products

7. CONSTRAINTS AND ENABLERS

Aside from funding and human resources, the Division's work will be constrained by:

- Limited access to NWS NWP systems
  SMCD scientists require access to the NWP models and diagnosis systems to test advanced radiative transfer system and new satellite products in realistic weather prediction environments. Limitations on access will delay evaluation and implementation of new satellite developments in operational NWP.

- Not enough parallel computing systems at SMCD for all satellite products produced by NESDIS OSDPD
  All new or improved satellite products developed by SMCD should be tested on product processing systems that are duplicates of those running at OSDPD. Without sufficient parallel computing capability, transition of research to operations will be slowed.

- Lack of a networked, parallel processing system linking STAR's Unix/Linux computers
  Without such a networked, parallel system, SMCD scientists are hampered by inefficiencies in computing resources.

- Limited scientific capability in new instrument areas: active instruments, APS, ERBS, TSIS
  Over the last few decades SMCD has built up strong scientific expertise in passive remote sensing to match the capabilities of the satellite instruments in operational use. Active systems, such as GPSOS, lidars and radars are the wave of the future. In addition, NPOESS with its complement of climate instruments that have never flown on earlier operational satellites presents additional challenges.

- Limited ground truth
  Validation of satellite remote sensing products requires ground based observations. In many cases, these are available from the standard weather observing network. In others, however, SMCD is dependent on the observational programs of other groups, and these may not suffice to fully characterize the accuracy of some of the satellite products.

  Anticipated loss of senior scientific staff as a result of retirement
  The demographics of the Division are such that members of the senior scientific staff are retiring at a relatively high rate. Loss of this wealth of experience and expertise will impact the Division's performance but also open opportunities to entrain bright new talent.

Enablers consist of:

- Dramatic increase in satellite observing capabilities over the next 5 years (see Section on Trends and Drivers)
  Hyperspectral sounding and imaging instruments on Metop, NPP, NPOESS, and GOES-R, active instruments such as GPS/RO, Cloudsat, Precipitation Radars, Calipso, and

ALADIN (Atmospheric Laser Doppler Instrument), and new operational passive instruments such as the NPOESS APS, ERBS, and TSIS will provide unprecedented observing capabilities.

- Competent core of SMCD civil servant scientists and supporting contractors and post-docs/visiting scientists
  SMCD's scientists are world-class. They are frequently selected as invited speakers at national and international scientific events, appointed to scientific committees, requested to review papers and proposals, and serve as editors of scientific journals.

- Advances in computing infrastructure and communications
  Continuing advances in computing hardware and software and in high speed communications will facilitate the Division's work.

- A good working environment
  SMCD's collegial atmosphere is conducive to creative work. Its participation in the Demonstration Program Personnel System provides incentives – rapid promotion, salary increases, or bonuses- for high achievers.

8. IMPACT ON SOCIETY AND NOAA GOALS

SMCD, through the satellite-based products and data sets it develops and generates, and its science, contributes to most of NOAA's strategic goals. This section summarizes how SMCD helps NOAA meet many of the objectives under these goals. The column labeled Role of SMCD Science/Technology in Meeting Objective includes a generic one sentence description of the SMCD contribution followed by a list of the SMCD projects, along with their numbers as listed in chapter 4, contributing to the Objective.

Goal: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Goal Objective	Role of SMCD Science/Technology in Meeting Objective
Describe and understand the state of the climate system through integrated observations, analysis, and data stewardship	Develop satellite – based products and generate long-term data sets of climate system variables **(1) Active Remote Sensors** **(2) Aerosol Remote Sensing from Operational Satellites** **(6) GOES Surface Ultraviolet Radiation** **(7) Instrument Calibration** **(8) Ozone** **(10) Radiance Products and Atmospheric Soundings from Advanced Infrared and Microwave Sensors for Weather and Climate Applications** **(12) Snow Cover** **(15) Earth Radiation Budget**
Improve climate predictive capability from weeks to decades, with an increased range of applicability for management and policy decisions	Develop products needed for initialization and boundary conditions of climate prediction models. **(12) Snow Cover** **(13) Vegetation**
Reduce uncertainty in climate projections through timely information on the forcing and feedbacks contributing to changes in the Earth's climate	Develop algorithms and generate long-term satellite-based data sets of climate forcing and feedback variables such as aerosols, carbon dioxide, ozone, clouds, and surface snow and ice cover **(2) Aerosol Remote Sensing from Operational Satellites** **(8) Ozone** **(12) Snow Cover** **(13) Vegetation** **(15) Earth Radiation Budget**
Increase number and use of climate products and services to enhance public and private sector decision-making	Generate key data sets for decision making, e.g., ozone depletion and the Antarctic ozone hole, and the expected recovery of the ozone layer as a result of the phase-out of CFCs, and atmospheric temperature, for monitoring global climate change **(8) Ozone**

Goal: Serve Society's Needs for Weather and Water Information

Goal Objective	Role of SMCD Science/Technology in Meeting Objective
Increase lead time and accuracy for weather and water warnings and forecasts	Over 90 % of the data now used in numerical weather prediction models comes from satellite observations. SMCD is constantly improving current products and developing new ones for assimilation into the models **(1) Active Remote Sensors** **(5) Community Radiative Transfer Model** **(7) Instrument Calibration** **(8) Ozone** **(9) Precipitation and Floods** **(10) Radiance Products and Atmospheric Soundings from Advanced Infrared and Microwave Sensors for Weather and Climate Applications** **(11) Satellite Data Assimilation (JCSDA)** **(12) Snow Cover** **(13) Vegetation** **(14) Winds** **(16) GOES Sounder Products** **(17) POES Sounder Products**
Improve predictability of the onset, duration, and impact of hazardous and severe weather and water events	Develop satellite-based heavy precipitation estimates for flash flood warnings, and air quality products **(2) Aerosol Remote Sensing from Operational Satellites** **(3) Air Quality Applications of Satellite Data** **(6) GOES Surface Ultraviolet Radiation** **(8) Ozone** **(9) Precipitation and Floods**
Increase application and accessibility of weather and water information as the foundation for creating and leveraging public (i.e., Federal, state, local, tribal), private and academic partnerships.	SMCD was instrumental in the establishment of the NOAA-NASA-DoD Joint Center for Satellite Data Assimilation (JCSDA) and is now a major science contributor **(11) Satellite Data Assimilation (JCSDA)**
Increase development, application, and transition of advanced science and technology to operations and services	SMCD is streamlining transition of its algorithms and science to NESDIS Satellite Data Processing and, through the JCSDA, to the NWS forecast models **(11) Satellite Data Assimilation (JCSDA)** **(16) GOES Sounder Products** **(17) POES Sounder Products**

Goal: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Goal Objective	Role of SMCD Science/Technology in Meeting Objective
Reduce weather-related transportation crashes and delays	SMCD is developing satellite based aircraft icing, fog/low visibility and volcanic ash products to increase air transportation safety **(4) Aviation Hazards**

Goal: Provide Critical Support for NOAA's Mission

Goal Objective	Role of SMCD Science/Technology in Meeting Objective
Increase quantity, quality, and accuracy of satellite data that are processed and distributed within targeted time	SMCD's major responsibility is improving the quantity, quality, and accuracy of satellite data and information products **(1) Active Remote Sensors** **(2) Aerosol Remote Sensing from Operational Satellites** **(3) Air Quality Applications of Satellite Data** **(4) Aviation Hazards** **(5) Community Radiative Transfer Model** **(6) GOES Surface Ultraviolet Radiation** **(7) Instrument Calibration** **(8) Ozone** **(9) Precipitation and Floods** **(10) Radiance Products and Atmospheric Soundings from Advanced Infrared and Microwave Sensors for Weather and Climate Applications** **(11) Satellite Data Assimilation (JCSDA)** **(12) Snow Cover** **(13) Vegetation** **(14) Winds** **(15) Earth Radiation Budget** **(16) GOES Sounder Products** **(17) POES Sounder Products**

9. SUMMARY

The Satellite Meteorology and Climatology Division has a distinguished history of developing and transitioning satellite products and applications to NOAA operations and services. SMCD scientists have developed most of the satellite products currently produced by the NOAA/NESDIS Office of Satellite Data Processing and Distribution. They have also been responsible for the calibration of all of NOAA's satellite instruments.

The Roadmap presented in this document will guide the Division's research and development activities over the next 5 years and beyond. The Roadmap is placed in context by discussions of the Division's mission, setting within NOAA/NESDIS, research and development capabilities and highlights of recent research achievements. The Roadmap is driven by expected trends in satellite technology – easy to predict because of long lead times for satellite mission planning – and user requirements – more difficult to forecast because of unforeseen expanding and new requirements.

The Roadmap consists of a number of individual research and development projects designed to help NOAA achieve its long term mission goals in Weather and Water, Climate Variability, and Commerce and Transportation. Each project has its goals, objectives, tasks and associated timelines, and milestones in the form of the building blocks needed to accomplish project goals. The contributions of these projects to the objectives of NOAA's goals are detailed. A group of Overarching and NOAA Goal - specific Performance Targets will permit SMCD managers to monitor progress.

The Division's accomplished scientific staff looks forward to the new challenges and exiting opportunities of the next 5 years and beyond.

9. APPENDICES

APPENDIX I: TECHNOLOGY TRENDS AND DRIVERS: CHARACTERISTICS OF FUTURE ADVANCED SATELLITE INSTRUMENTS

Instrument Payloads for the Initial Joint Polar System

INSTRUMENT on Metop-1,2,3	INSTRUMENT on NOAA-N,N'	FULL NAME	PRIMARY FUNCTION
AVHRR/3*	AVHRR/3	Advanced Very High Resolution Radiometer	Global imagery of clouds, the ocean and land surface
HIRS/4	HIRS/3	High Resolution Infrared Radiation Sounder	Temperature and humidity of the global atmosphere in cloud-free conditions
AMSU-A*	AMSU-A	Advanced Microwave Sounding Unit-A	Temperature of the global atmosphere in all weather conditions
MHS	MHS	Microwave Humidity Sounder	Humidity of the global atmosphere
IASI		Infrared Atmospheric Sounding Interferometer	Enhanced atmospheric soundings
GRAS		Global Navigation Satellite System Receiver for Atmospheric Sounding	Temperature of the upper troposphere and in the stratosphere with high vertical resolution
ASCAT		Advanced Scatterometer	Near-surface wind speeds over the global oceans
	SBUV	Solar Backscattered Ultraviolet ozone probe	Total atmospheric ozone
GOME-2*		Global Ozone Experiment-2	Monitoring Profiles of ozone and other atmospheric constituents

NPP and NPOESS

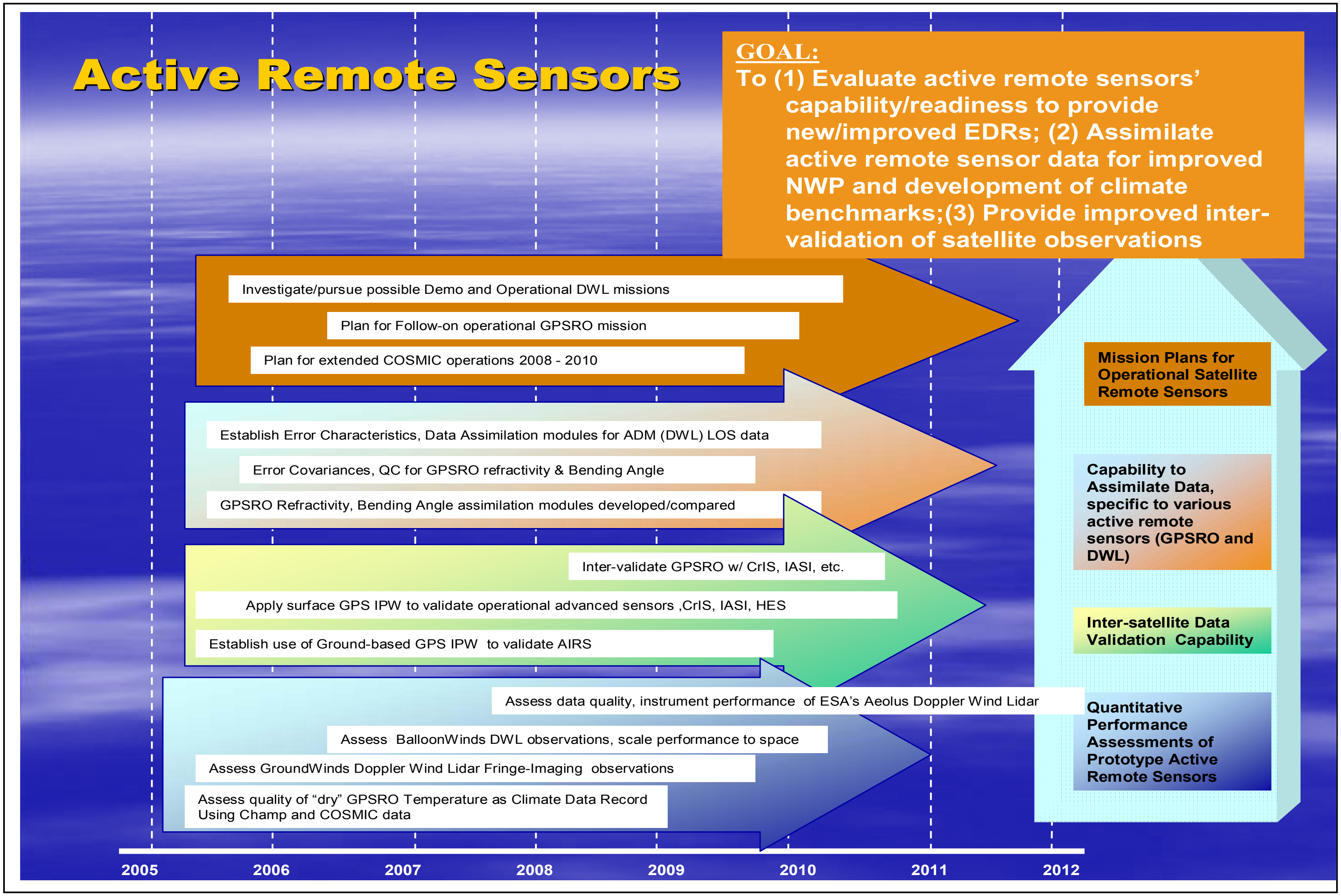
INSTRUMENT	SATELLITE	LAUNCH	PRIMARY FUNCTION
VIIRS	NPP	2006	Visible and infrared radiometric imager for: clouds, Earth radiation budget, land/water and sea surface temperature, ocean color, and low light imagery
CrIS	NPP	2006	Hyperspectral infrared sounder for temperature, humidity, greenhouse gases
OMPS	NPP	2006	UV and visible measurements for atmospheric ozone mapping and profiling
VIIRS	NPOESS	2009	Visible and infrared radiometric imager for: clouds, Earth radiation budget, land/water and sea surface temperature, ocean color, and low light imagery
CMIS	NPOESS	2009	Microwave imagery and soundings for temperature, humidity, ocean surface winds, precipitation , cloud properties, soil moisture, snow and ice cover, SST

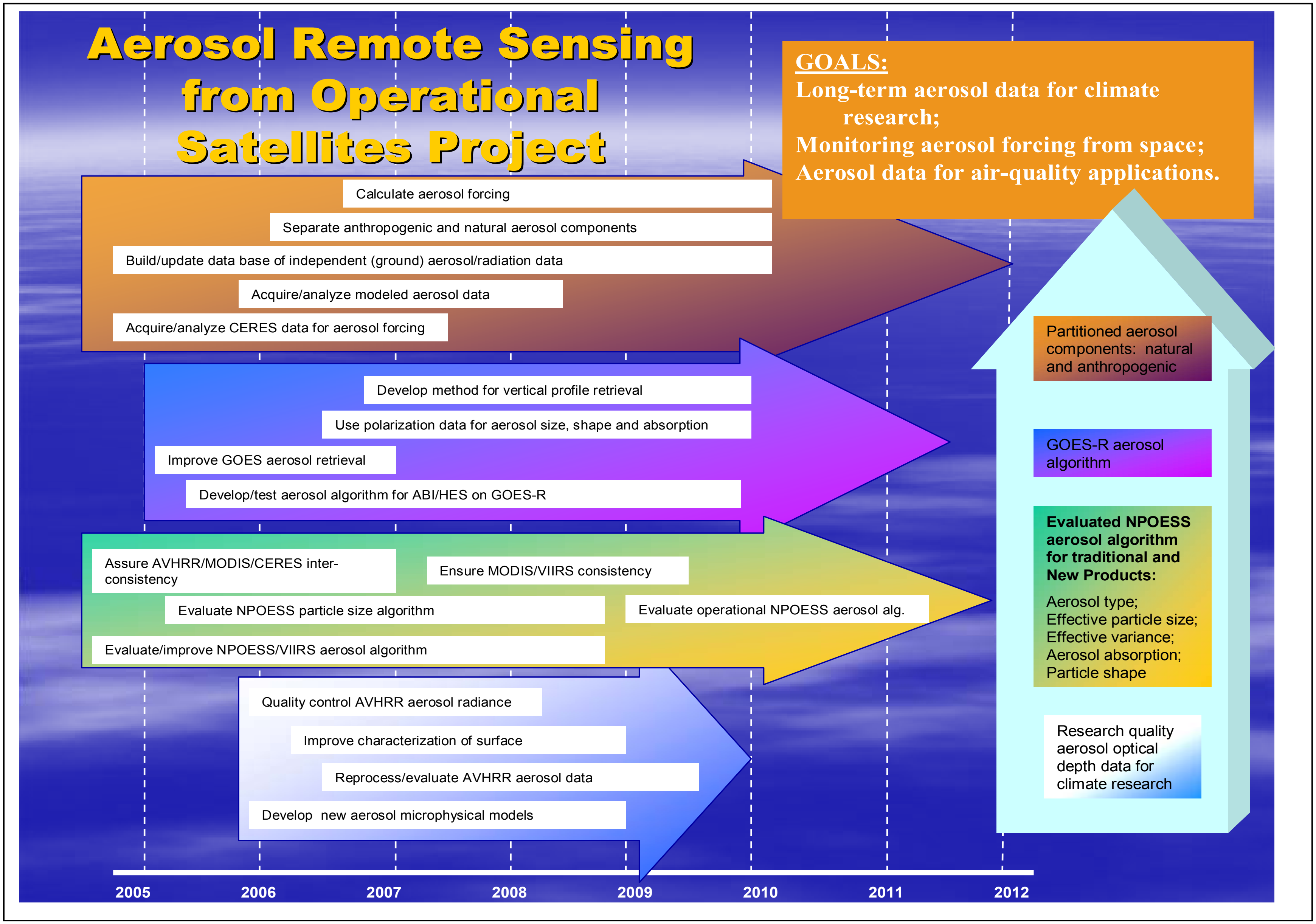
CrIS	NPOESS	2009	Hyperspectral infrared sounder for temperature, humidity, greenhouse gases
OMPS	NPOESS	2009	UV and visible measurements for atmospheric ozone mapping and profiling
SESS	NPOESS	2009	Observations of neutral and charged particles, electron and magnetic fields, and optical signatures of aurora.
APS	NPOESS	2009	Aerosol and cloud parameters using multispectral photopolarimetry
ATMS	NPOESS	2009	Microwave soundings of temperature and moisture
ERBS	NPOESS	2009	Earth Radiation Budget
RADAR Altimeter	NPOESS	2009	Sea level height
TSIS	NPOESS	2009	Total solar irradiance monitor and 0.2- 2 micron solar spectral irradiance

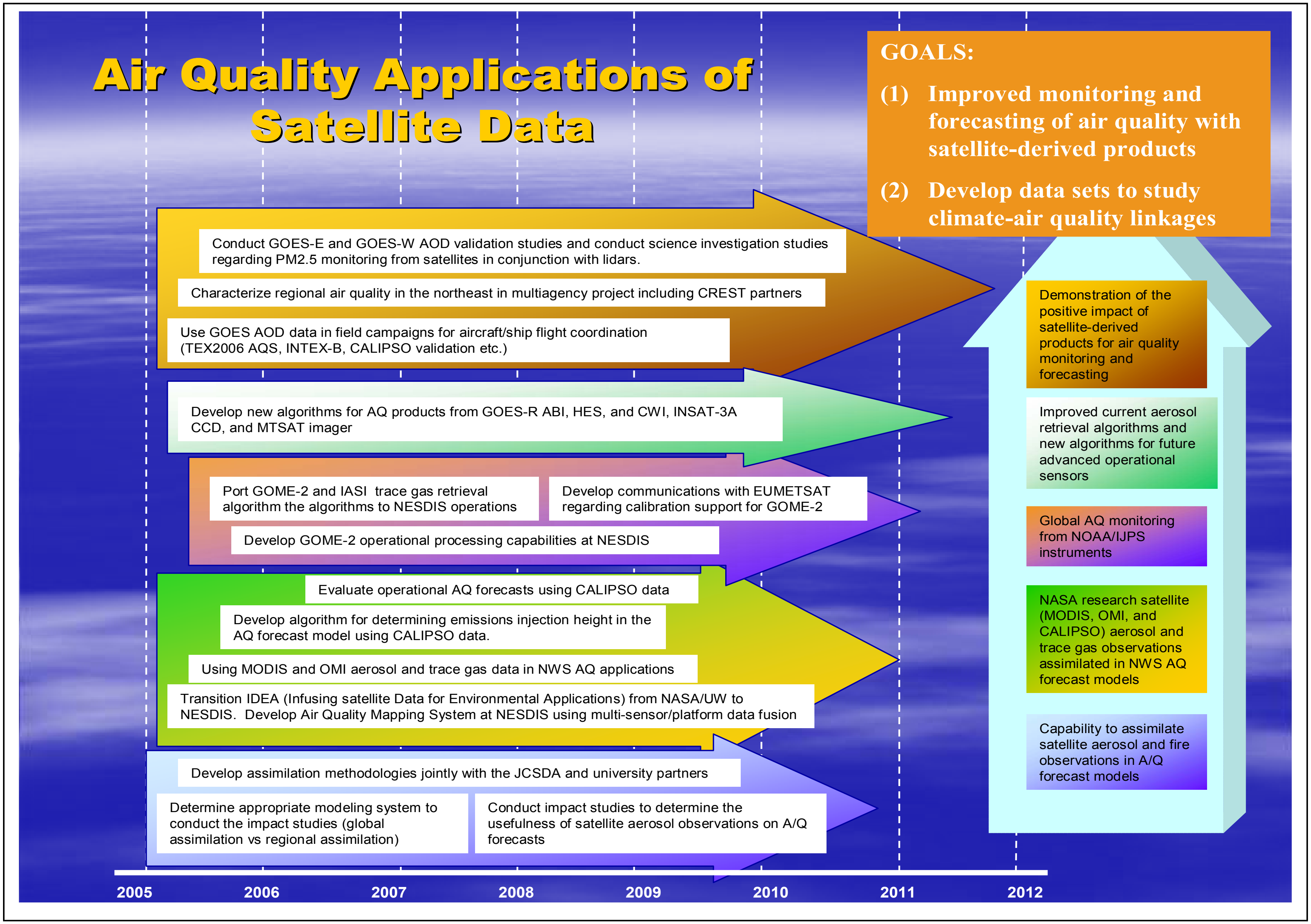
Research Satellites

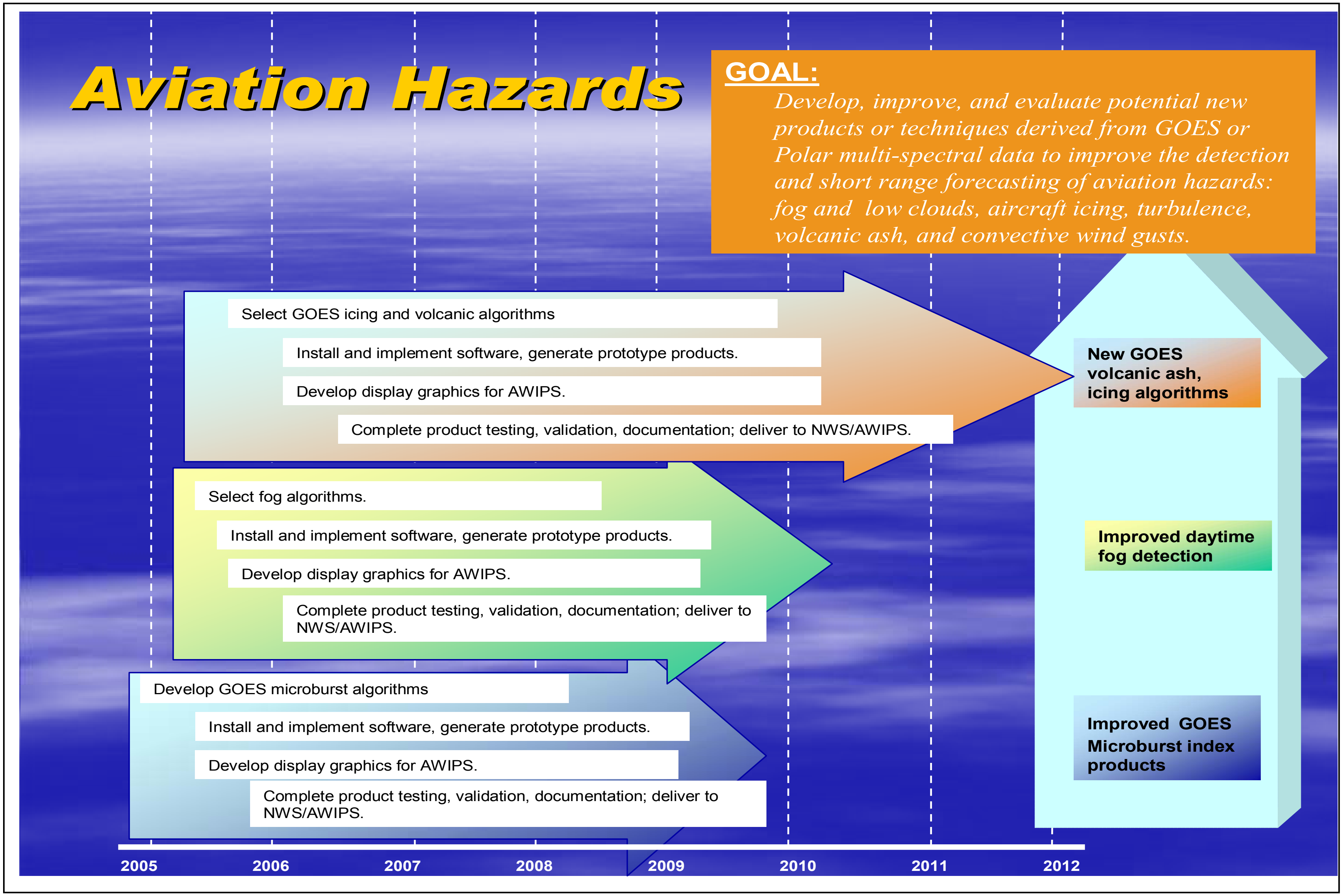
INSTRUMENT	SATELLITE	LAUNCH	PRIMARY FUNCTION
POLDER	Parasol	2005	Observations of directionality and polarization of reflected sunlight for radiative and microphysical properties of clouds and aerosols
CPR	CloudSat	2005	Radar observations of vertical profiles of cloud liquid water and ice water contents and related cloud physical and radiative properties
CALIOP	CALIPSO	2005	Lidar observations of aerosols and thin cloud profiles
GPS/OS	COSMIC	2006	Radio occultation soundings of temperature and humidity
MIRAS	SMOS	2007	Long wavelength microwave observations of soil moisture and ocean salinity
Doppler lidar	ADM	2009	Lidar observations of winds
GMI, DPR	GPM	2010	Passive microwave and radar observations of precipitation
GIFTS	EO-3/IGL	TBD	Hyperspectral, high spatial resolution temperature, water vapor, and wind soundings

APPENDIX II: ROADMAP DIAGRAMS




Aerosol Remote Sensing from Operational Satellites Project
GOALS:
Long-term aerosol data for climate research;
Monitoring aerosol forcing from space;
Aerosol data for air-quality applications.
Calculate aerosol forcing
Separate anthropogenic and natural aerosol components
Build/update data base of independent (ground) aerosol/radiation data
Acquire/analyze modeled aerosol data
Acquire/analyze CERES data for aerosol forcing
Develop method for vertical profile retrieval
Use polarization data for aerosol size, shape and absorption
Improve GOES aerosol retrieval
Develop/test aerosol algorithm for ABI/HES on GOES-R
Assure AVHRR/MODIS/CERES inter-consistency
Ensure MODIS/VIIRS consistency
Evaluate NPOESS particle size algorithm
Evaluate operational NPOESS aerosol alg.
Evaluate/improve NPOESS/VIIRS aerosol algorithm
Quality control AVHRR aerosol radiance
Improve characterization of surface
Reprocess/evaluate AVHRR aerosol data
Develop new aerosol microphysical models
Partitioned aerosol components: natural and anthropogenic
GOES-R aerosol algorithm
Evaluated NPOESS aerosol algorithm for traditional and New Products:
Aerosol type; Effective particle size; Effective variance; Aerosol absorption; Particle shape
Research quality aerosol optical depth data for climate research
2005
2006
2007
2008
2009
2010
2011
2012


Air Quality Applications of Satellite Data
GOALS:
(1) Improved monitoring and forecasting of air quality with satellite-derived products
(2) Develop data sets to study climate-air quality linkages
Conduct GOES-E and GOES-W AOD validation studies and conduct science investigation studies regarding PM2.5 monitoring from satellites in conjunction with lidars.
Characterize regional air quality in the northeast in multiagency project including CREST partners
Use GOES AOD data in field campaigns for aircraft/ship flight coordination (TEX2006 AQS, INTEX-B, CALIPSO validation etc.)
Develop new algorithms for AQ products from GOES-R ABI, HES, and CWI, INSAT-3A CCD, and MTSAT imager
Port GOME-2 and IASI trace gas retrieval algorithm the algorithms to NESDIS operations
Develop communications with EUMETSAT regarding calibration support for GOME-2
Develop GOME-2 operational processing capabilities at NESDIS
Evaluate operational AQ forecasts using CALIPSO data
Develop algorithm for determining emissions injection height in the AQ forecast model using CALIPSO data.
Using MODIS and OMI aerosol and trace gas data in NWS AQ applications
Transition IDEA (Infusing satellite Data for Environmental Applications) from NASA/UW to NESDIS. Develop Air Quality Mapping System at NESDIS using multi-sensor/platform data fusion
Develop assimilation methodologies jointly with the JCSDA and university partners
Determine appropriate modeling system to conduct the impact studies (global assimilation vs regional assimilation)
Conduct impact studies to determine the usefulness of satellite aerosol observations on A/Q forecasts
Demonstration of the positive impact of satellite-derived products for air quality monitoring and forecasting
Improved current aerosol retrieval algorithms and new algorithms for future advanced operational sensors
Global AQ monitoring from NOAA/IJPS instruments
NASA research satellite (MODIS, OMI, and CALIPSO) aerosol and trace gas observations assimilated in NWS AQ forecast models
Capability to assimilate satellite aerosol and fire observations in A/Q forecast models
2005
2006
2007
2008
2009
2010
2011
2012


Aviation Hazards
GOAL:
Develop, improve, and evaluate potential new products or techniques derived from GOES or Polar multi-spectral data to improve the detection and short range forecasting of aviation hazards: fog and low clouds, aircraft icing, turbulence, volcanic ash, and convective wind gusts.
Select GOES icing and volcanic algorithms
Install and implement software, generate prototype products.
Develop display graphics for AWIPS.
Complete product testing, validation, documentation; deliver to NWS/AWIPS.
Select fog algorithms.
Install and implement software, generate prototype products.
Develop display graphics for AWIPS.
Complete product testing, validation, documentation; deliver to NWS/AWIPS.
Develop GOES microburst algorithms
Install and implement software, generate prototype products.
Develop display graphics for AWIPS.
Complete product testing, validation, documentation; deliver to NWS/AWIPS.
New GOES volcanic ash, icing algorithms
Improved daytime fog detection
Improved GOES Microburst index products
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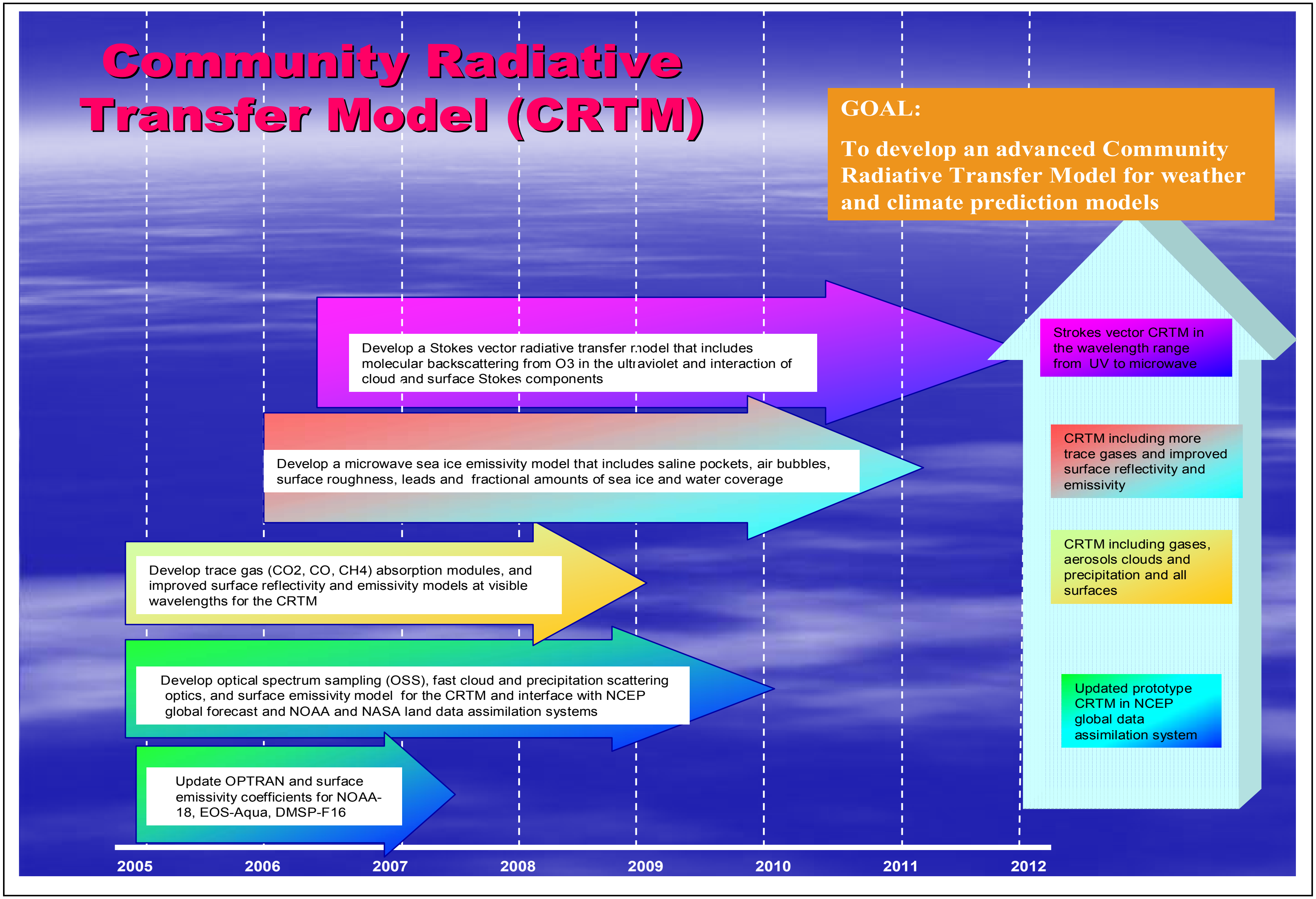

Community Radiative Transfer Model (CRTM)
GOAL:
To develop an advanced Community Radiative Transfer Model for weather and climate prediction models
Develop a Stokes vector radiative transfer model that includes molecular backscattering from O3 in the ultraviolet and interaction of cloud and surface Stokes components
Develop a microwave sea ice emissivity model that includes saline pockets, air bubbles, surface roughness, leads and fractional amounts of sea ice and water coverage
Develop trace gas (CO2, CO, CH4) absorption modules, and improved surface reflectivity and emissivity models at visible wavelengths for the CRTM
Develop optical spectrum sampling (OSS), fast cloud and precipitation scattering optics, and surface emissivity model for the CRTM and interface with NCEP global forecast and NOAA and NASA land data assimilation systems
Update OPTRAN and surface emissivity coefficients for NOAA-18, EOS-Aqua, DMSP-F16
Strokes vector CRTM in the wavelength range from UV to microwave
CRTM including more trace gases and improved surface reflectivity and emissivity
CRTM including gases, aerosols clouds and precipitation and all surfaces
Updated prototype CRTM in NCEP global data assimilation system
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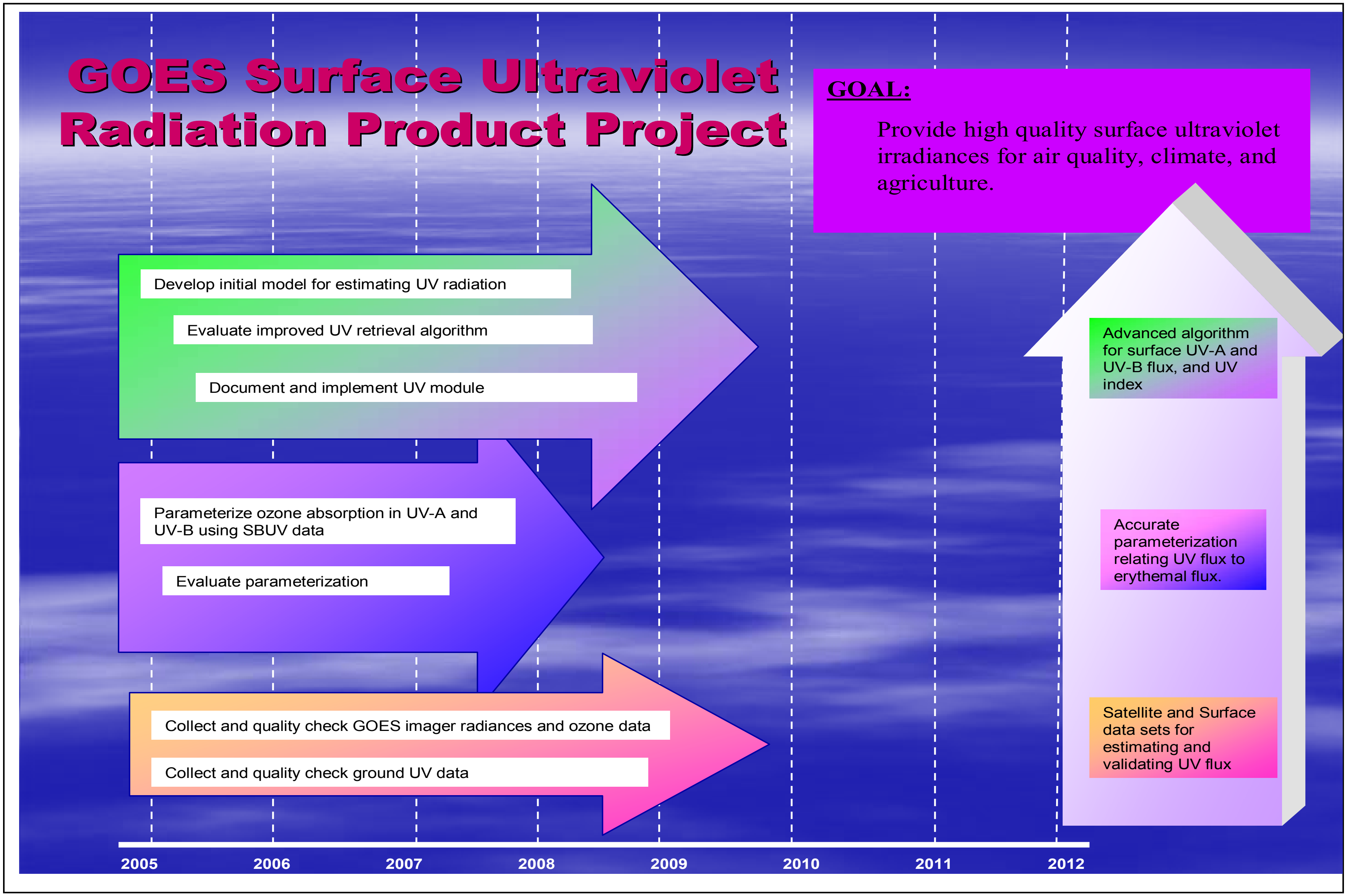
GOES Surface Ultraviolet Radiation Product Project
GOAL:
Provide high quality surface ultraviolet irradiances for air quality, climate, and agriculture.
Develop initial model for estimating UV radiation
Evaluate improved UV retrieval algorithm
Document and implement UV module
Parameterize ozone absorption in UV-A and UV-B using SBUV data
Evaluate parameterization
Collect and quality check GOES imager radiances and ozone data
Collect and quality check ground UV data
Advanced algorithm for surface UV-A and UV-B flux, and UV index
Accurate parameterization relating UV flux to erythemal flux.
Satellite and Surface data sets for estimating and validating UV flux
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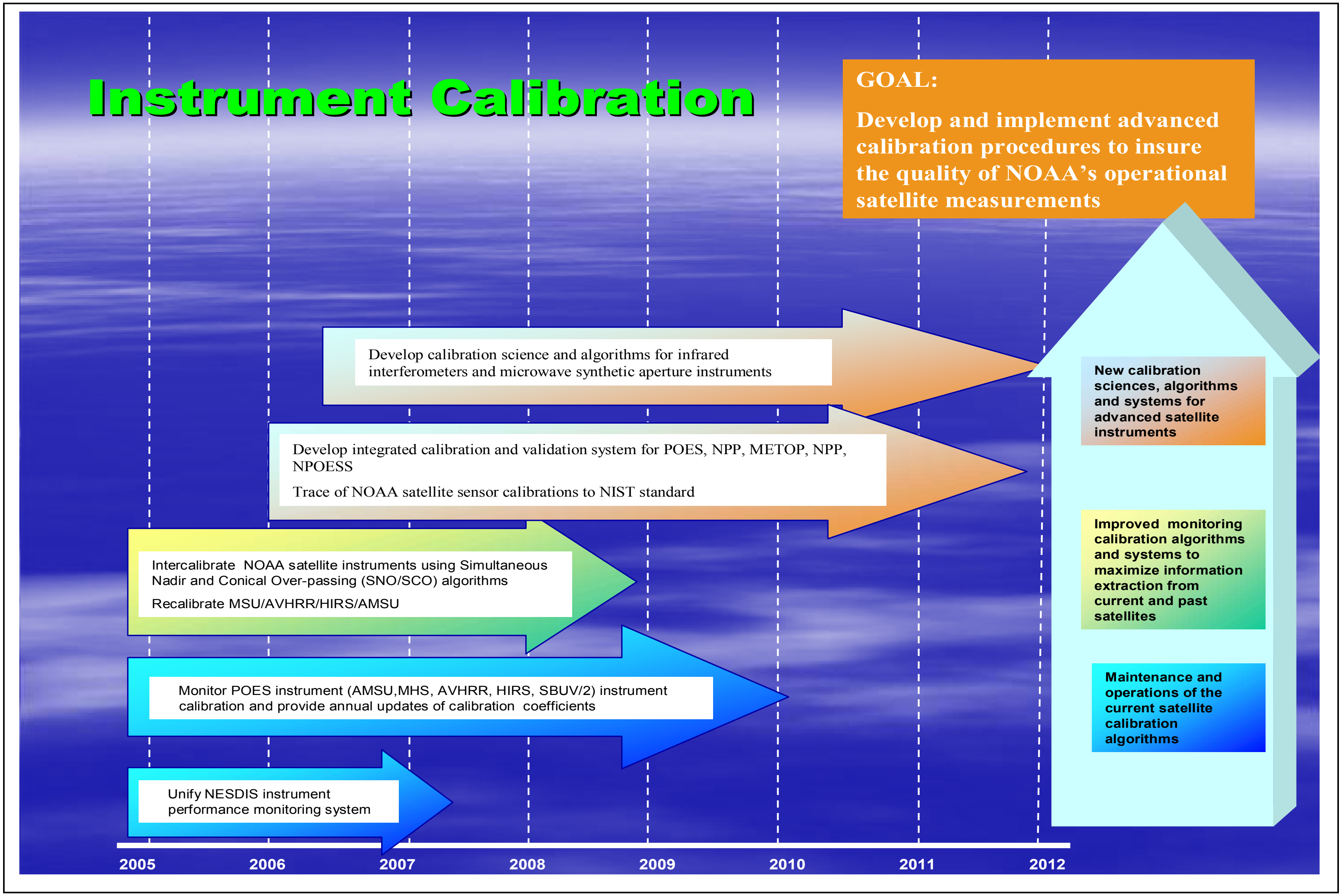

Instrument Calibration
GOAL:
Develop and implement advanced calibration procedures to insure the quality of NOAA's operational satellite measurements
Develop calibration science and algorithms for infrared interferometers and microwave synthetic aperture instruments
Develop integrated calibration and validation system for POES, NPP, METOP, NPP, NPOESS
Trace of NOAA satellite sensor calibrations to NIST standard
Intercalibrate NOAA satellite instruments using Simultaneous Nadir and Conical Over-passing (SNO/SCO) algorithms
Recalibrate MSU/AVHRR/HIRS/AMSU
Monitor POES instrument (AMSU,MHS, AVHRR, HIRS, SBUV/2) instrument calibration and provide annual updates of calibration coefficients
Unify NESDIS instrument performance monitoring system
New calibration sciences, algorithms and systems for advanced satellite instruments
Improved monitoring calibration algorithms and systems to maximize information extraction from current and past satellites
Maintenance and operations of the current satellite calibration algorithms
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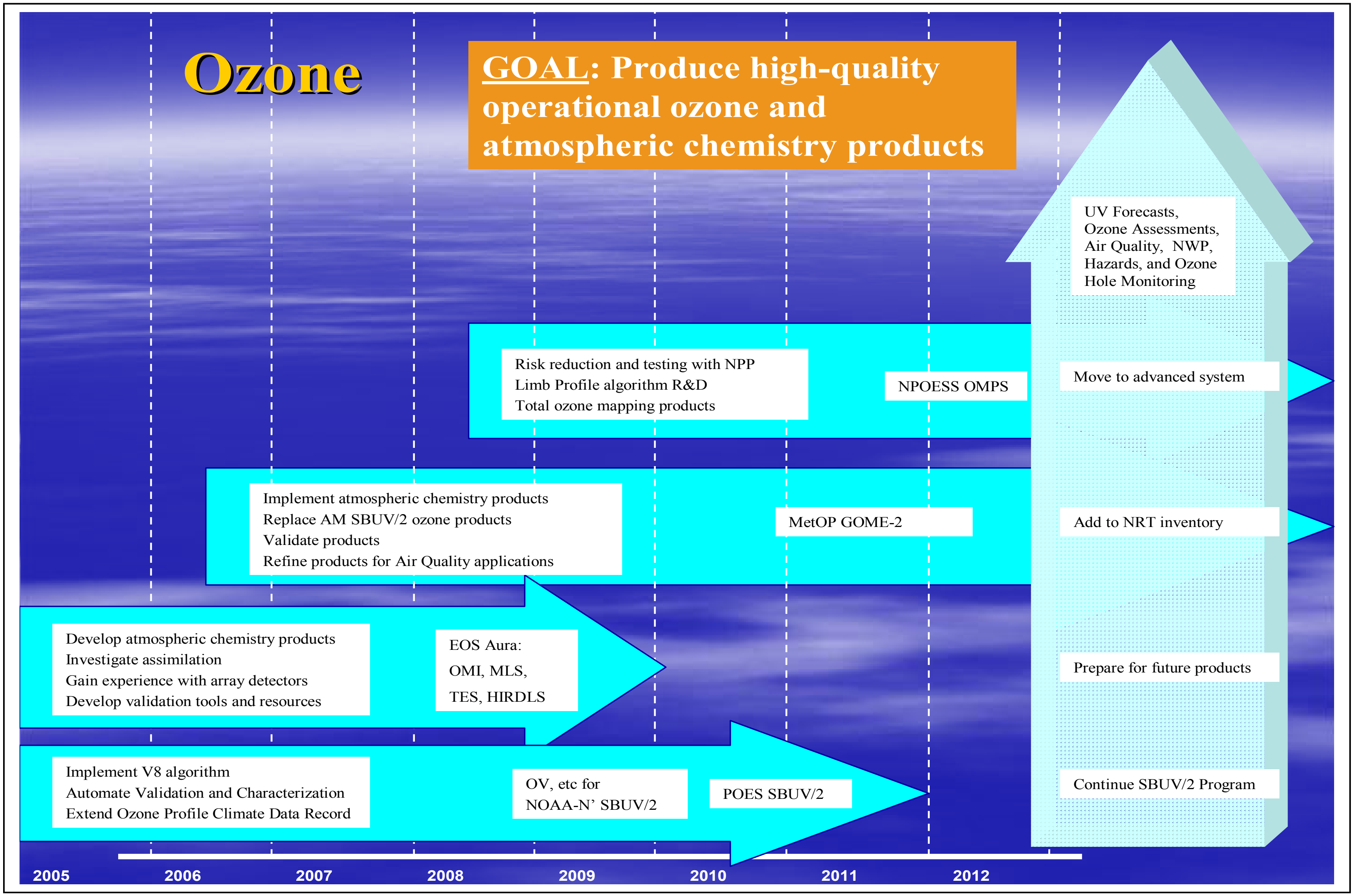
Ozone
GOAL: Produce high-quality operational ozone and atmospheric chemistry products
UV Forecasts, Ozone Assessments, Air Quality, NWP, Hazards, and Ozone Hole Monitoring
Risk reduction and testing with NPP
Limb Profile algorithm R&D
Total ozone mapping products
NPOESS OMPS
Move to advanced system
Implement atmospheric chemistry products
Replace AM SBUV/2 ozone products
Validate products
Refine products for Air Quality applications
MetOP GOME-2
Add to NRT inventory
Develop atmospheric chemistry products
Investigate assimilation
Gain experience with array detectors
Develop validation tools and resources
EOS Aura:
OMI, MLS,
TES, HIRDLS
Prepare for future products
Implement V8 algorithm
Automate Validation and Characterization
Extend Ozone Profile Climate Data Record
OV, etc for NOAA-N' SBUV/2
POES SBUV/2
Continue SBUV/2 Program
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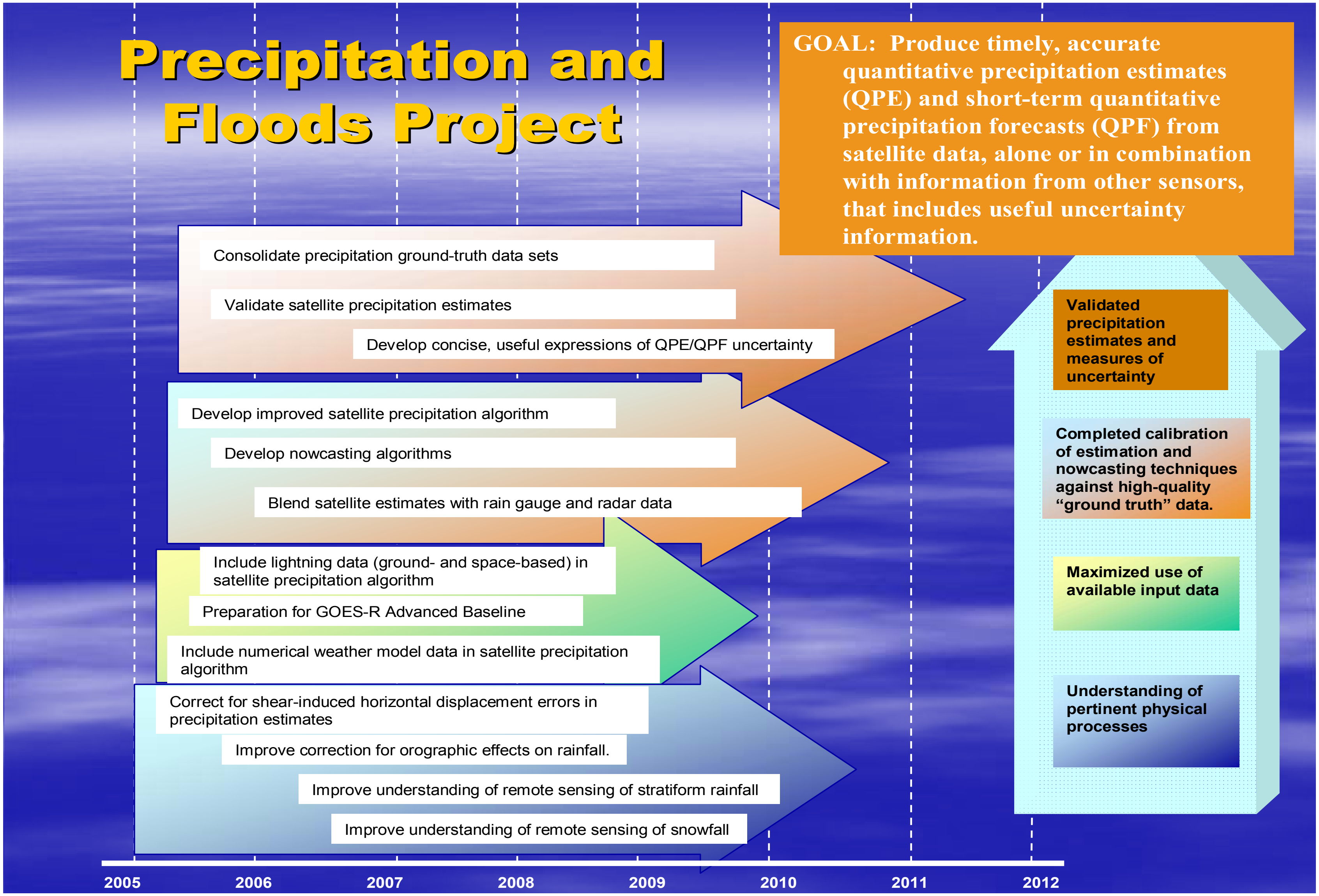

Precipitation and Floods Project
GOAL: Produce timely, accurate quantitative precipitation estimates (QPE) and short-term quantitative precipitation forecasts (QPF) from satellite data, alone or in combination with information from other sensors, that includes useful uncertainty information.
Consolidate precipitation ground-truth data sets
Validate satellite precipitation estimates
Develop concise, useful expressions of QPE/QPF uncertainty
Develop improved satellite precipitation algorithm
Develop nowcasting algorithms
Blend satellite estimates with rain gauge and radar data
Include lightning data (ground- and space-based) in satellite precipitation algorithm
Preparation for GOES-R Advanced Baseline
Include numerical weather model data in satellite precipitation algorithm
Correct for shear-induced horizontal displacement errors in precipitation estimates
Improve correction for orographic effects on rainfall.
Improve understanding of remote sensing of stratiform rainfall
Improve understanding of remote sensing of snowfall
Validated precipitation estimates and measures of uncertainty
Completed calibration of estimation and nowcasting techniques against high-quality "ground truth" data.
Maximized use of available input data
Understanding of pertinent physical processes
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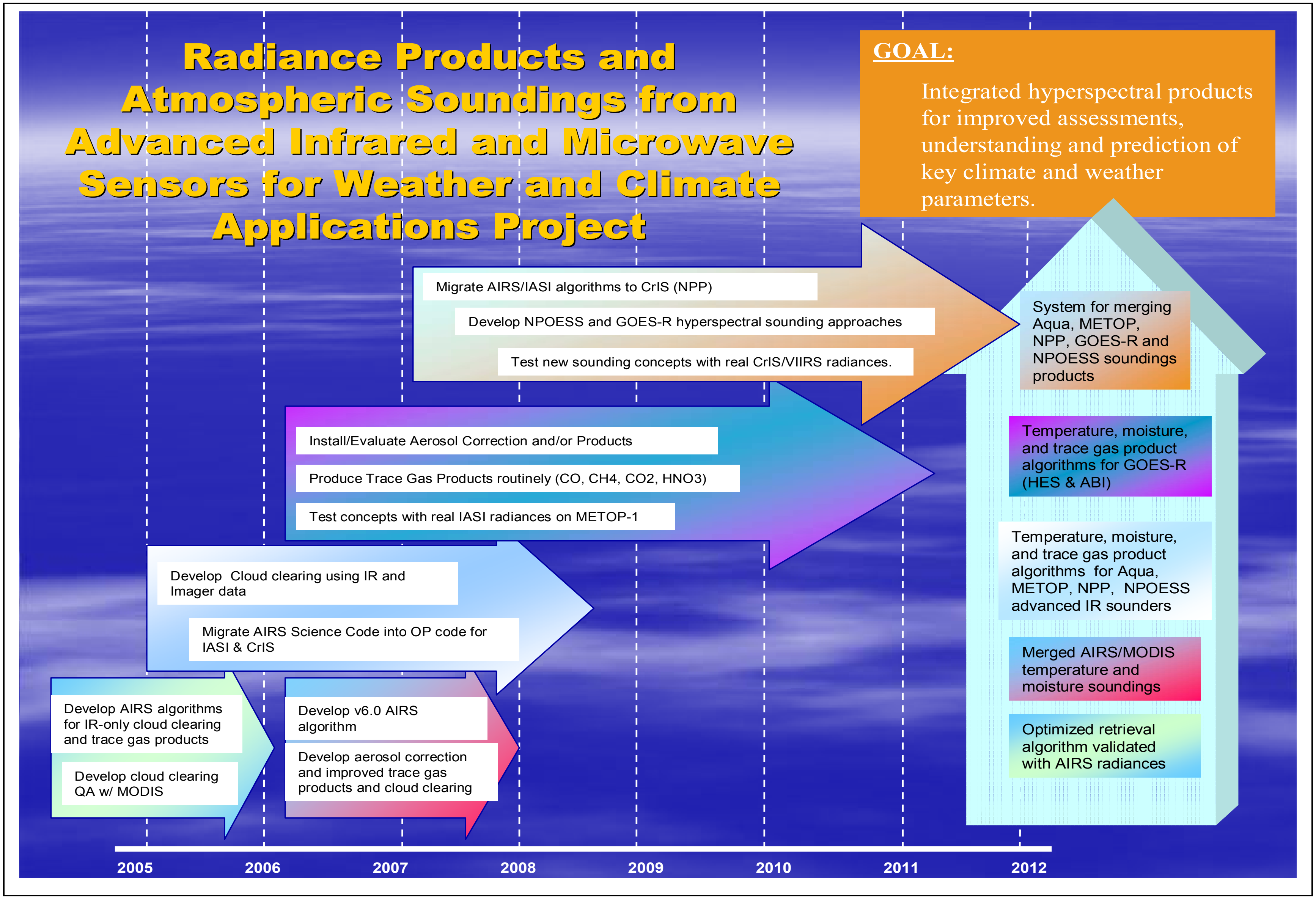
Radiance Products and Atmospheric Soundings from Advanced Infrared and Microwave Sensors for Weather and Climate Applications Project
GOAL:
Integrated hyperspectral products for improved assessments, understanding and prediction of key climate and weather parameters.
Migrate AIRS/IASI algorithms to CrIS (NPP)
Develop NPOESS and GOES-R hyperspectral sounding approaches
Test new sounding concepts with real CrIS/VIIRS radiances.
System for merging Aqua, METOP, NPP, GOES-R and NPOESS soundings products
Install/Evaluate Aerosol Correction and/or Products
Produce Trace Gas Products routinely (CO, CH4, CO2, HNO3)
Test concepts with real IASI radiances on METOP-1
Temperature, moisture, and trace gas product algorithms for GOES-R (HES & ABI)
Develop Cloud clearing using IR and Imager data
Migrate AIRS Science Code into OP code for IASI & CrIS
Temperature, moisture, and trace gas product algorithms for Aqua, METOP, NPP, NPOESS advanced IR sounders
Develop AIRS algorithms for IR-only cloud clearing and trace gas products
Develop cloud clearing QA w/ MODIS
Develop v6.0 AIRS algorithm
Develop aerosol correction and improved trace gas products and cloud clearing
Merged AIRS/MODIS temperature and moisture soundings
Optimized retrieval algorithm validated with AIRS radiances
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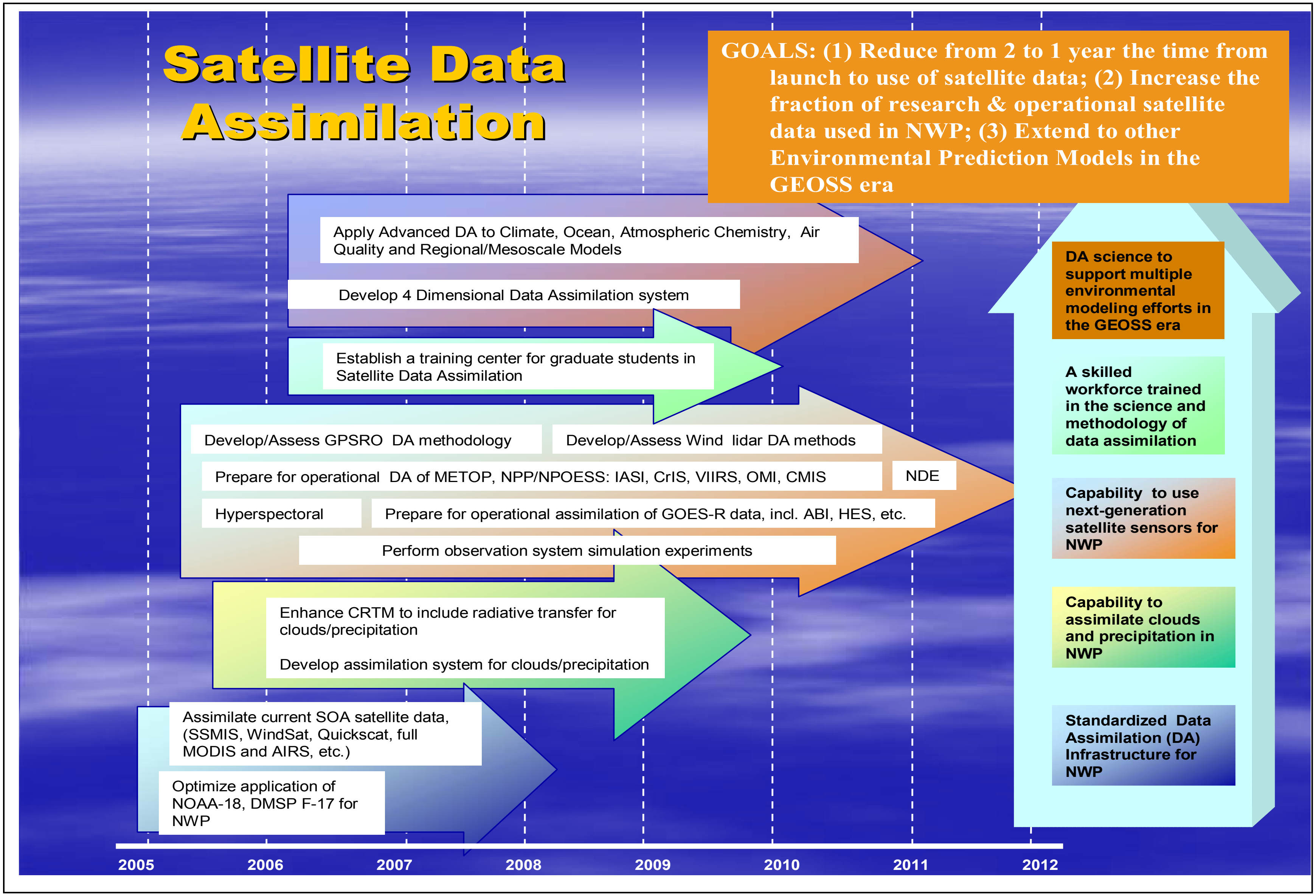
Satellite Data Assimilation
GOALS: (1) Reduce from 2 to 1 year the time from launch to use of satellite data; (2) Increase the fraction of research & operational satellite data used in NWP; (3) Extend to other Environmental Prediction Models in the GEOSS era
Apply Advanced DA to Climate, Ocean, Atmospheric Chemistry, Air Quality and Regional/Mesoscale Models
Develop 4 Dimensional Data Assimilation system
Establish a training center for graduate students in Satellite Data Assimilation
Develop/Assess GPSRO DA methodology
Develop/Assess Wind lidar DA methods
Prepare for operational DA of METOP, NPP/NPOESS: IASI, CrIS, VIIRS, OMI, CMIS
NDE
Hyperspectoral
Prepare for operational assimilation of GOES-R data, incl. ABI, HES, etc.
Perform observation system simulation experiments
Enhance CRTM to include radiative transfer for clouds/precipitation
Develop assimilation system for clouds/precipitation
Assimilate current SOA satellite data, (SSMIS, WindSat, Quickscat, full MODIS and AIRS, etc.)
Optimize application of NOAA-18, DMSP F-17 for NWP
DA science to support multiple environmental modeling efforts in the GEOSS era
A skilled workforce trained in the science and methodology of data assimilation
Capability to use next-generation satellite sensors for NWP
Capability to assimilate clouds and precipitation in NWP
Standardized Data Assimilation (DA) Infrastructure for NWP
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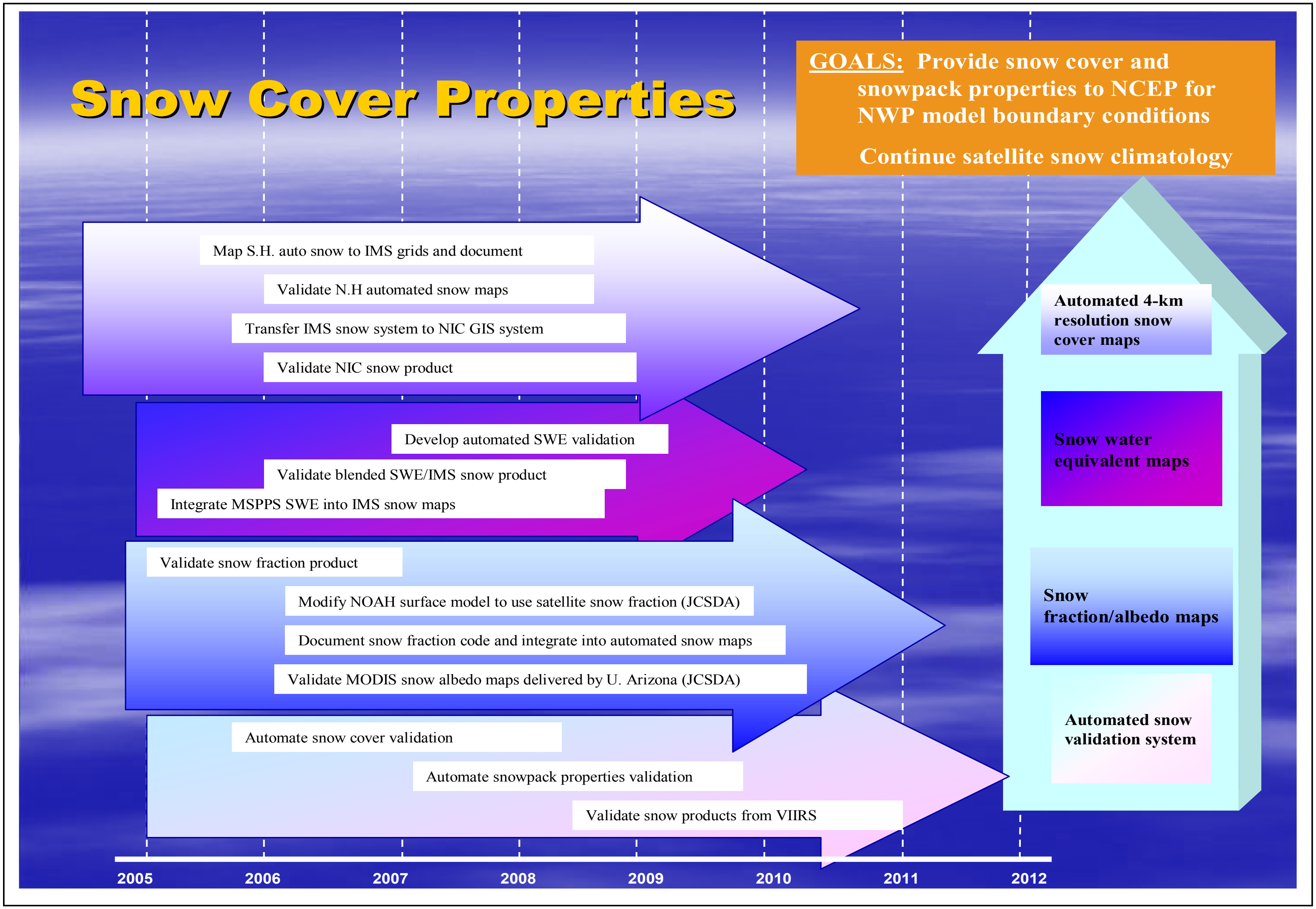
Snow Cover Properties
GOALS: Provide snow cover and snowpack properties to NCEP for NWP model boundary conditions
Continue satellite snow climatology
Map S.H. auto snow to IMS grids and document
Validate N.H automated snow maps
Transfer IMS snow system to NIC GIS system
Validate NIC snow product
Develop automated SWE validation
Validate blended SWE/IMS snow product
Integrate MSPPS SWE into IMS snow maps
Validate snow fraction product
Modify NOAH surface model to use satellite snow fraction (JCSDA)
Document snow fraction code and integrate into automated snow maps
Validate MODIS snow albedo maps delivered by U. Arizona (JCSDA)
Automate snow cover validation
Automate snowpack properties validation
Validate snow products from VIIRS
Automated 4-km resolution snow cover maps
Snow water equivalent maps
Snow fraction/albedo maps
Automated snow validation system
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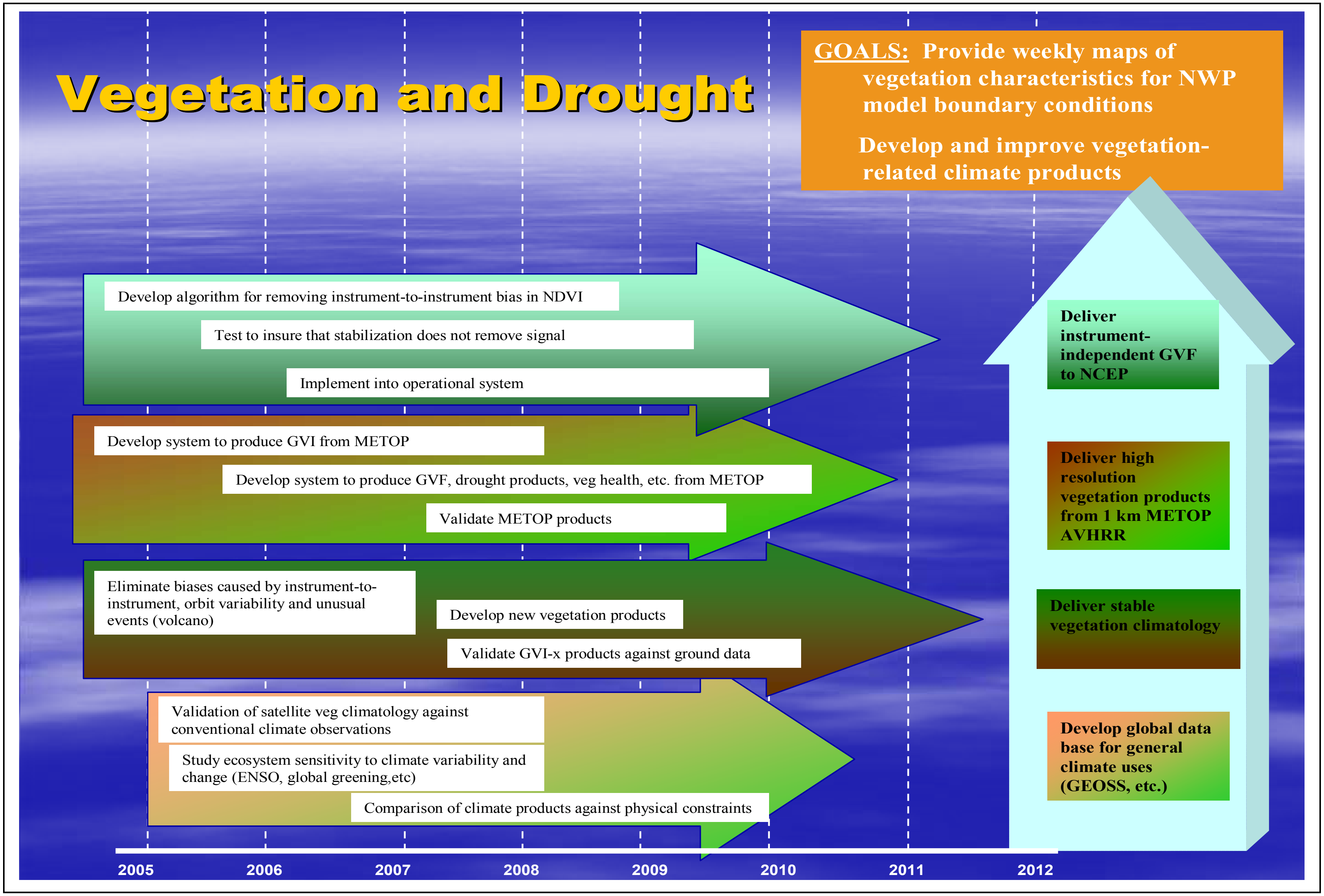

Vegetation and Drought
GOALS: Provide weekly maps of vegetation characteristics for NWP model boundary conditions
Develop and improve vegetation-related climate products
Develop algorithm for removing instrument-to-instrument bias in NDVI
Test to insure that stabilization does not remove signal
Implement into operational system
Develop system to produce GVI from METOP
Develop system to produce GVF, drought products, veg health, etc. from METOP
Validate METOP products
Eliminate biases caused by instrument-to-instrument, orbit variability and unusual events (volcano)
Develop new vegetation products
Validate GVI-x products against ground data
Validation of satellite veg climatology against conventional climate observations
Study ecosystem sensitivity to climate variability and change (ENSO, global greening,etc)
Comparison of climate products against physical constraints
Deliver instrument-independent GVF to NCEP
Deliver high resolution vegetation products from 1 km METOP AVHRR
Deliver stable vegetation climatology
Develop global data base for general climate uses (GEOSS, etc.)
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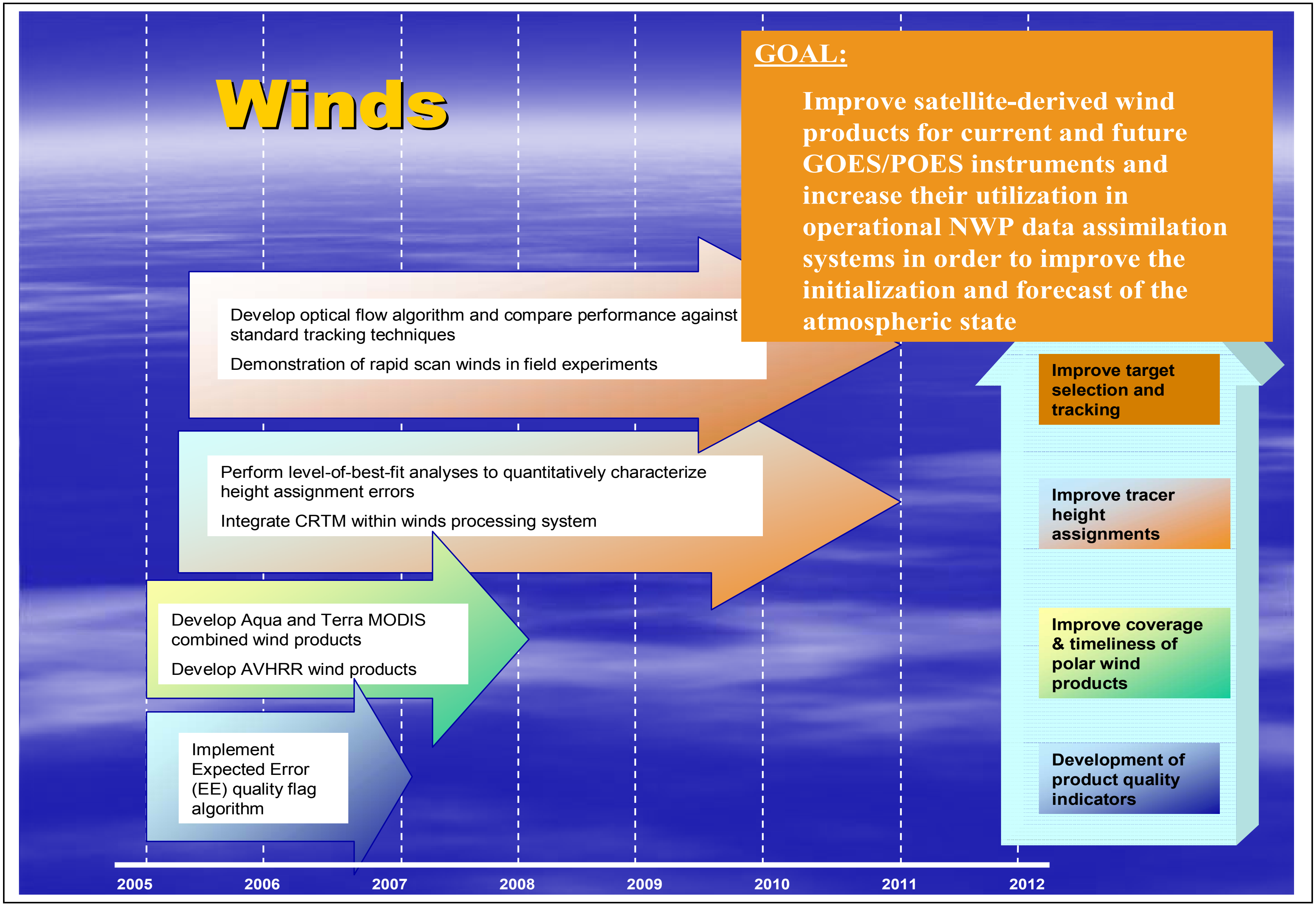
Winds
GOAL:
Improve satellite-derived wind products for current and future GOES/POES instruments and increase their utilization in operational NWP data assimilation systems in order to improve the initialization and forecast of the atmospheric state
Develop optical flow algorithm and compare performance against standard tracking techniques
Demonstration of rapid scan winds in field experiments
Perform level-of-best-fit analyses to quantitatively characterize height assignment errors
Integrate CRTM within winds processing system
Develop Aqua and Terra MODIS combined wind products
Develop AVHRR wind products
Implement Expected Error (EE) quality flag algorithm
Improve target selection and tracking
Improve tracer height assignments
Improve coverage & timeliness of polar wind products
Development of product quality indicators
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APPENDIX III: ABBREVIATIONS AND ACRONYMS

ABI	Advanced Baseline Imager
ABS	Advanced Baseline Sounder
AIRS	Atmospheric Infrared Sounder
ALADIN	Atmospheric Laser Doppler Instrument
AMSU	Advanced Microwave Sounding Unit
AMSU-A	Advanced Microwave Sounding Unit-A
AMW	Atmospheric Motion Vectors
APS	Aerosol Polarimeter Sensor
ATMS	Advanced Technology Microwave Sounder
ATOVS	Advanced TIROS Operational Vertical Sounder
AVHRR	Advanced Very High Resolution Radiometer
AWIPS	Advanced Weather Information Display System
CDR	Climate Data Record
CHAMP	Challenging Mini Satellite Payload
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CMIS	Conical Microwave Imager and Sounder
CONUS	Continental United States
CoRP	Cooperative Research Program
CPC	Climate Prediction Center
CrIS	Cross-track Infrared Sounder
DoD	Department of Defense
DWL	Doppler Wind Lidar
EDR	Environmental Data Record

ENSO	El Nino Southern Oscillation
EOS	Earth Observation System/Satellite
EPA	Environmental Protection Agency
ERB	Earth Radiation Budget
ERBS	Earth Radiation Budget Sensor
ERS	European Remote Sensing
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GMSRA	GOES Multi-Spectral Rainfall Algorithm
GOES	Geostationary Operational Environmental Satellite
GOME-2	Global Ozone Monitoring Experiment
GPS/OS	GPS Occultation Sensor
GPS/RO	Global Positioning System/Radio Occultation
GTS	Global Telecommunications System
GVI	Global Vegetation Index
GVF	Global Vegetation Fraction
H-E	Hydro-Estimator
HES	Hyperspectral Environmental Suite
HIRS	High-Resolution Infrared Radiation Sounder
IASI	Infrared Atmospheric Sounding Interferometer
IJPS	Initial Joint Polar System
JCSDA	Joint Center for Satellite Data Assimilation
METOP	Meteorological Operations Platform
MIRS	Microwave Integrated Retrieval System
MODIS	Moderate Resolution Imaging Spectro-Radiometer
MSU	Microwave Sounding Unit

NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NESDIS	National Environmental Satellite, Data, and Information Service
NIC	NOAA National Ice Center
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Program
NWP	Numerical Weather Prediction
NWS	National Weather Service
OLR	Outgoing Longwave Radiation
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
OPDB	Operational Products Development Branch
OSDPD	Office of Satellite Data Processing and Distribution
POES	Polar-orbiting Operational Environmental Satellites
RPP	Research Project Plan
RT	Radiative Transfer
SAGE	Stratospheric Aerosol and Gas Experiment
SBUV/2	Solar Backscatter Ultraviolet Spectral Radiometer, MOD 2
SCaMPR	Self-Calibrating Multivariate Precipitation Retrieval
SDS	Scientific Data Stewardship
SOD	Satellite Oceanography Division
SMCD	Satellite Meteorology and Climatology Division
SNO	Simultaneous Nadir Overpass
SST	Sea Surface Temperature

STAR	Center for Satellite Applications and Research
TIROS	Television and Infrared Observation Satellite
TOVS	TIROS Operational Vertical Sounder
UMBC	University of Maryland, Baltimore County
USGCRP	U.S. Carbon Cycle Science Plan
USWRP	United States Weather Research Program
VCI	Vegetation Condition Index
VIIRS	Visible/Infrared Imager/Radiometer Suite
VIRS	Visible Infrared Scanner
WMSI	Wet Microburst Severity Index
WMO	World Meteorological Organization