CLIMATE CHANGE AND STORMS: THE ROLE OF DEEP OCEAN WARMING

Paul R. Epstein, M.D., M.P.H.
Center for Health and the Global Environment
Harvard Medical School

Summary

Storms are increasing in severity and in associated economic damages, at a time when climate is changing. The logarithmic rise in economic losses from the 1980s to the 1990s, and again a half log in 2004/2005 cannot be explained alone by social factors, including population shifts, rising real estate prices and greater insurance penetration. Moreover, the increases in multiple types of extreme weather events, major outliers, correlated events related to climatic factors, and the diminished return times and recovery periods between events all indicate that climate change is playing a mounting role in driving up insured and uninsured losses from catastrophic weather. The underlying scientific finding that helps to explain the unexpected pace and magnitude of climate change and its impacts is that the oceans have warmed 22 times more than has the atmosphere over the past half century.

Methodology for Assessing Global Change

Studying whole systems requires integrative approaches. While these forms of analyses are not applied in this work, they are presented as concepts that may prove useful for future collaborative assessments of climate-related events. As climate changes, the distribution of events and extremes may continue to change over time; with the spread of tails in both directions (i.e. anomalies greater than one or two standard deviations from the mean. Assessment of changes occurring in multiple arenas – events, impacts and costs -- requires following emerging patterns and trends, and agreement between data and models ("fingerprint studies"), which are related by way of plausible mechanisms. Bayesian thinking (using prior probabilities derived by composite assessments and meta-analyses) can also improve the generation of plausible scenarios and improve predictive capability.

In addition, multilevel analysis/modeling is a new tool derived from the field of epidemiology (see Galea and Ahern 2006). This methodology can aid in assessing trends that span multiple fields with multiple types of events, and those occurring in multiple arenas and along multiple dimensions.

Multilevel analysis and modeling is a methodology that extends regression analysis for individual data sets, and can be used to analyze processes and events operating on multiple levels and in multiple settings. In studying climate-related events, multilevel modeling enables one to consider the full import and combined impacts of observations; in particular, those indicating increased frequency of anomalies of multiple types, involving multiple data sets; e.g. hurricanes, winter windstorms, heat waves, droughts and floods.

Multilevel analysis also affords a framework in which to develop new indices, such as 1. sequences of extremes, 2. the short lapse times, 3. the concurrence of severe events occurring across the globe, and 4. the wide swings from one extreme to another (e.g. heavy downpours) – in which the first event (e.g. intense drought and soil drying) can create more vulnerable conditions to the full impacts (flooding) of the second event.

Assessing Systemic Stability: As anomalies and major outlier events may also be seen as "strange attractors," in system theory parlance, an assessment of events occurring in multiple realms also offers a way of examining systemic stability. The new indices to assess the full sweep of impacts can also be helpful in assessing systemic and sensitivity to an abrupt change or thresholds or "tipping points" (NAS 2002; Epstein and McCarthy 2004; Walker 2006). Such indices can include rates of change, volatility, anomalies and outliers, and, in addition to these first derivatives, second derivatives, such as changes in rates of change, and changes in the rates of anomalies and major outliers.

Storm Destructiveness and Deep Ocean Warming

Storm intensity has increased significantly since the 1980s and economic damages from storms have also escalated. Increases in coastal populations, rising real estate values and greater insurance penetration have all played significant roles; *along with* more and more intense storms and anomalies of multiple types. Recent research finds a strong association between the increasing severity of storms and warming of the oceans (Emanuel 2005; Webster et al. 2005; Hoyos et al. 2006). Emanuel points to the increase in SSTs *and* in the deep ocean to explain the increase in storm destructiveness (a function of peak winds and storm duration); Webster et al. found that category 4 and 5 storms had nearly doubled since 1950 as ocean temperatures warmed; while Hoyos et al. (2006) reached the conclusion that increased ocean temperatures far outweighed all other factors in explaining the observed increased intensity of storms.

Reinforcing these findings, Sriver and Huber (2006) found that tropical SSTs are regulating the integrated intensity of tropical cyclones, and the findings of these studies were again reinforced by Robert Scott, a University of Texas oceanographer, and Steven Lambert of Canada's Meteorological Service, addressing the 40th annual Canadian Meteorological and Oceanographic Society (CMOS) congress in Toronto in June 2006. Scott demonstrated that the area that spawns hurricanes has grown dramatically in recent years; since 1970 the eastern side of the Atlantic, near the coast of Africa, has become warmer, topping the 26.5ºC temperature threshold for hurricanes to form, and hurricanes have been getting started an average of 500 Km further east since 1970, thus spending more time over warmer water.

In addition, novel events are occurring in places that have not, in the historical records since the 1870s, previously experienced hurricanes (and consequently have no insurance to buffer the risks). A hurricane appeared in the Southern Hemisphere in 2004, forming off the NE of Brazil, and, in 2005, hurricanes hit Spain and Morocco. In addition, Atlantic winter windstorms are penetrating deep into Europe. In 1999 Lothar (26 Dec) and Martin (28 Dec) windstorms did extensive damage to France's forests and reached Zurich (RMS 2002), while in January, 2005 windstorm Erwin felled a year's worth of harvests in southern Sweden. The European summer heat wave of 2003 was six standard deviations from the norm; and Stott et al. (2004) concluded that global warming has increased the probability of such an event two to three fold. That event killed 21-35,000 people, spread wildfires, damaged crops, killed livestock, shut down hydroelectric power, led to nuclear plant shutdowns (due to warming water) and melted 10% of the Alpine glacial mass (that had been losing about 0.7%/yr previously (Epstein and Mills 2005).

Climate change has profound implications for all industries, including public utilities, timber, automotive, electrical appliances, energy sector infrastructure; and for finance (insurers, banks, pension and mutual fund managers, raters and brokers). The financial sector, given its broad portfolio and sensitivity to risk, is especially aware of emerging trends (CROBriefing 2006).

Leading reinsurers have asserted that a third year of losses on the level of those in 2004 and 2005 could bankrupt many insurance companies. And all four hurricane prediction centers – NOAA's National Hurricane Center (NHC); the Tropical Storm Risk (TSR, Benfield, London); Accurate Environmental Forecasting (AEF); and Colorado State University (Wm. Gray) -- are predicting a severe fall storm season.

Weather is a function of natural variability and climate change; as well as deep ocean warming-driven changes in natural cycles, such as the El Niño/Southern Oscillation (ENSO), the monsoons, the North Atlantic Oscillation, etc. Long-term natural cycles appear to be aligned. There is 1. the 20-30 year Pacific Decadal Oscillation, which may have shifted to a cool phase around 1998; 2. possibly a warm Atlantic Multidecadal Oscillation that began about 1995 [Note: the existence of this oscillation vs. long term warming and salinization (Curry et al. 2003) of the tropical Atlantic is questionable (Emanuel and Mann 2006)]; and 3. the current ENSO-neutral conditions (June 2006); mean relatively reduced strength of westerlies and increased the force of easterlies. All these factors – some of which may have been influenced by climate change and deep ocean warming -- are lined up to compound the influence of the baseline shift created by the deep ocean warming and warming (and increasing salinity -- due to greater evaporation) of the tropical Atlantic and Caribbean sea surfaces; all leading to projections of a high number of intense storms in the fall of 2006.

The studies of Emanuel (2005) and Webster et al. (2005) demonstrate that hurricanes have increased in intensity and destructiveness in the past three decades. And absent from these analyses are measurements of hurricane breadth and moisture content; and lapse times, sequences and recovery periods. Thus, they may be underestimates of the true destructiveness of storms and the vulnerability inflicted by sequential storms. The assessments of the increasing Accumulated Cyclone Energy (ACE) Index used by the three Cat Modeling Groups -- Risk Management Services (RMS), AIR World Corporation (AIR) and EQECAT – are consistent with these studies.

The underlying reason for the miscalculations of the past two seasons can most probably be traced to the warming of the deep ocean. This warming was first reported by Parrilla and colleagues (1994) and Bindoff and McDougall 1994). But these initial transect measurements were confirmed by Sydney Levitus and colleagues of NOAA in 2000 and reinforced by Tim Barnett and colleagues of Scripps in 2005. Levitus et al. (2000; 2005) found that all the world's oceans were heating down to great depths and they concluded in 2005 that the deep ocean is holding 22 times the heat that has built up in the atmosphere. Barnett et al. (2005) – previously quite skeptical about global warming (as was Kerry Emanuel before his latest work) -- found that the pattern of the deep ocean warming is unmistakably attributable to the buildup of greenhouse gases.

That the oceans are the repository for the past century's global warming helps explain the acceleration of the world hydrological cycle. With deep ocean warming comes greater evaporation and atmospheric water vapor levels (Trenberth and Karl 2003). In the US, precipitation levels increased 7% from 1902-2002; while precipitation events greater than 50 mm (or above the 95th percentile) have increased 14%, and events over 10 cm (or above the 99th percentile) have increased 20% (Groisman et al. 2004). And deep ocean warming, together with the disproportionate atmospheric warming in the Arctic (ACIA 2004), help explain the unexpected acceleration of Greenland ice melt; with some outlet glaciers moving at 14 Km a year that were moving at half that speed in 2001 (Rignot and Kanagaratnam 2006).

It is the deep ocean warming that helps explain the sequences of extremes we are experiencing, such as the Katrina, Rita and Wilma, and the 28 named storms, including 15 hurricanes in 2004 and 2005 (see Kerr 2005a; see Figure 2). Warm water at depths replaces that which evaporates to fuel the first storms to fuel the subsequent ones. Modelers (Tom Knutson, Munich Re workshop) found that storm intensity is 5 to 7 times what they projected it to be in 2006. The magnitude of changes we are observing were previously projected to occur around 2080.

The North Atlantic

In terms of the North Atlantic, itself, the changes are altering the circulation, the gradients, thus windspeeds, and the locations of hurricanes. Greenland Ice melt and rain falling at high latitudes are leaving warmer, *saltier* tropical seas; and creating *freshwater* films in the region around Iceland (Curry and Mauritzen 2005). Cold, salty water is heavy and dense and sinks; the downward flow creating a pulley system that draws up the Gulf Stream – and drive the worlds ocean "conveyor belt" (thermohaline circulation) that stabilizes the global climate over millennia.

With freshwater, the sinking has slowed. By the most recent calculation, the overflow has slowed some 30% in the past several decades (Bryden et al. 2005). This again was a projection for the magnitude of change we might expect occur in 2080.

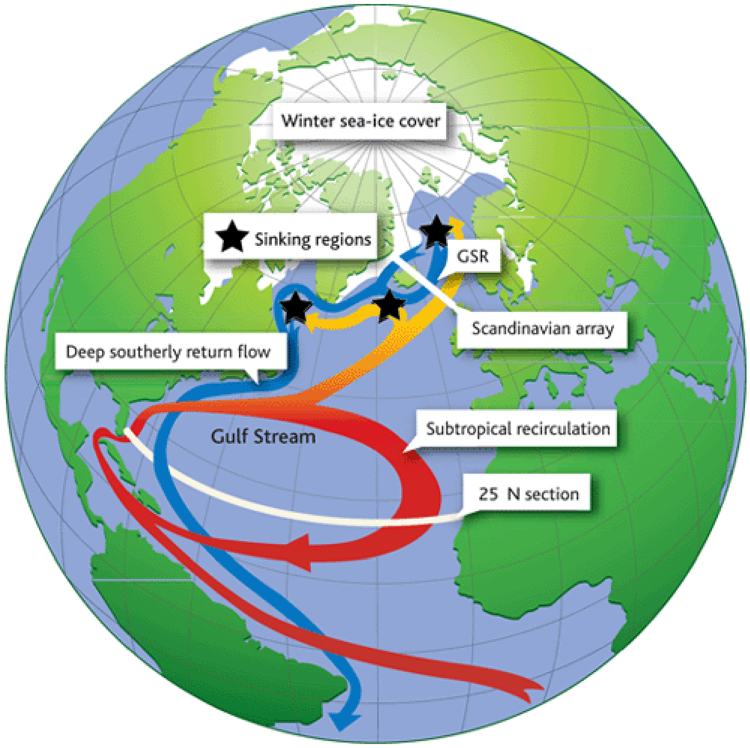


Figure 1. Based on Bryden et al. 2005, the overturning of the thermohaline circulation may have declined some 30% since the late 1950s. In tandem, the Atlantic surface circulation – in red – appears to be speeding up; changes that may be contributing to the increase in hurricanes hitting the US, European heat waves (due to decreased evaporation from the northern North Atlantic), strong European windstorms, and hurricanes hitting the west coast of Africa. (Kerr 2005b)

As you can see from the above diagram, this slowed sinking up north has also sped up the surface circulation – the large gyre of red one sees in the middle of the Atlantic. This may help explain the rapid trajectory of hurricanes hitting the US; the windstorms penetrating deeper than ever into Europe; and the hurricanes forming in Eastern Atlantic down to the Canary Islands and Morocco; and that in the Southern Ocean hitting Brazil in 2004.

Sea Level Rise Projections

As surface melt water flows through crevasses, it is lubricating the base of the Greenland glaciers (Bindschadler 2005). Greenland glaciers are moving in jolts or glacial earthquakes at rates twice what they were just five years ago; and perhaps six times more than they were in 1993 (Ekstrom et al. 2006). In Antarctica, as floating ice shelves attached to the West Antarctic Ice sheet (WAIS) disintegrate, they eliminate back pressure on land-based ice sheets in the WAIS – and they too are accelerating their movement toward the sea.

The acceleration of ice melt puts in doubt all linear projections for sea level rise over this coming century, as depicted in the IPCC 2001 report (Houghton et al. 2001). While no–one is projecting complete collapse of the Greenland ice sheet (which would raise sea levels 20 meters) or collapse of the WAIS (another 20 meters) any time soon, we can project that pieces of each could be discharged; changing sea levels by multiple centimeters over short periods of time; and increasing, in a non-linear fashion, the storm surges associated with storms.

Implications for the Insurance Sector

For the insurance sector the hardest message to digest is that imagining the unmanageable is no longer unimaginable. Escalating costs from recurrent years of storms and extremes – with rapidly diminishing return times between events – could render all nations vulnerable to climate change (Mills 2005). There is every indication that climate processes are less coherent and that the system itself is becoming increasingly unstable, with events less predictable, and more destructive. To improve projections we must integrate historical, statistical models with dynamic models to assess current and near-future conditions.

The financial sector may be viewed as the central nervous system of the global economy and it experiencing the pain. Loses from catastrophes (primarily weather-related) rose from $4 billion a year up through the 1980s to $40 billion/year in the 1990s; then to $125 billion in 2004 and $225 billion in 2005. In addition to these step-wise changes in overall losses, the *insured* losses rose from 10% to 30%; thus from $400 million/yr in the 1980s to $83 billion in 2005 – a rise of 200% -- as more extremes since 2000 are hitting Europe, the US and Japan. (See Figures 3 and 4.) The vast majority of the $83 billion insured losses in 2005 are attributable to the changes in the North Atlantic; and these changes are directly attributable to climate change.

In addition, there are long-term biological damages of the events of 2005 that may lead to "long tails" in insured losses. These include mold and an oil spill the size of the Exxon Valdez of 1989 (11 million gallons) in and around New Orleans. The profound warming of the Caribbean in 2005 also led to extensive coral bleaching, compounded by a coral disease (white plague), with implications for fisheries, livelihoods, shore lines buffering, hotels, travel and tourism. Such impacts have not yet entered into the loss calculations for 2005; and they increase the vulnerabilities to future severe weather (McCarthy et al. 2001). Moreover, a new body of work is developing to analyze the potential for non-linear changes in *impacts*; as examples, forest pest infestations and massive diebacks and fires; collapse of coral reefs; loss of wetlands from accelerated sea level rise (Burkett et al. 2005; Epstein and Mills 2005).

Optimizing Adaptation and Mitigation

Regarding adaptation and mitigation, distributed forms of clean energy generation can increase adaptation as well as drive markets for technologies to mitigate reduce greenhouse gas emissions and ultimately mitigate climate change.

Specifically, distributed generation (DG) with clean and renewable energy systems can increase adaptive capacity and resilience by:

- Feeding into the grid, where available
- Increasing energy security in the face of storms, heatwaves, blackouts
- In developing nations, provide energy sources for:
    - Small enterprises
    - Light for schooling and studying
    - Cooking (thus reducing wood extraction and deforestation)
    - Purifying and pumping water for agriculture (nutrition) and public health (washing, drinking, cooking, bathing).

These measures can also:

- Provide market pull for clean technologies
- Help begin businesses that will forward climate mitigation and stabilization, primary prevention and risk reduction.

Thus, DG clean energy systems can improve energy security, public health and nutrition, and help drive economic growth and poverty alleviation – all of which will decrease vulnerability to climate change. These systems can optimize climate adaptation and mitigation.

Conclusion

Looking across the spectrum of multiple levels and multiple events it is possible to conclude that the recent period is extremely anomalous. Given the plausible explanation -- the deep ocean integrator and repository for the warming of the last century – we may look back at 2004/2005 as having entered a new climate regime. A full assessment suggests that the pace and magnitude of climate change quickened and that the system has become non-linear, with exponential and even step-wise changes occurring in the destructiveness of extreme weather events (Hansen 2005; Hansen et al. 2005).

We have exited the "Holocene" or recent climate and have entered a new era: the "Anthropocene." The most hopeful scenario is that systems do seek new equilibriums. If the conveyor belt does shut down in the coming decades, the full potential impacts of such a shutdown -- a return to an ice age – may be moderated by the degree of global warming and the lack of large ice sheets at present. (We have been going between large and medium size caps for 650,000 years and probably two million, according to ice core records.) If the climate does re-stabilize into a state that affords a modicum of predictability, this may give us a "cooling off " period in which to radically change our energy diet. (This is my own speculative scenario; though shared quietly by several prominent scientists, who are cautious about issuing a hopeful, new equilibrium scenario.)

Risk management and risk transfer must be complemented with primary prevention and risk reduction.

The good news is the enormous opportunities for investments in hybrid and smart technologies, solar, wind, tidal, geothermal, combined cycle energy systems, urban reformation and ecological restoration. These are the businesses of tomorrow and the financial sector, having first sensed the pain, has a special role to play in working with scientists, civil society and UN organizations to develop the national and international policies to enable the transition. Strong policy signals will be needed to facilitate these solutions – new rules, bold incentives and removal of "perverse" subsidies for oil and coal.

Examining the full life cycle of solutions – for public health, safety, environmental and economic costs can help guide investment in and insure "no-regrets" measures, including energy efficiency, smart technologies, geothermal, solar, reforestation, and differentiate those from the ones that need further study (fossil-fuel-based and nuclear). (See figure 5 based on "wedge concept of Pacala and Socolow 2004.)

The climate and energy crises – energy security, conflicts over oil, peaking of supplies and climate instability -- are converging to create a confluent agenda to alter the international financial architecture and enable private industry to flourish with new incentives as well as new constraints. And the clean energy transition becomes the first and necessary step toward greater governance and rearrangement of financial incentives to drive sustainable development, *writ large*, including forestry, farming and fisheries?

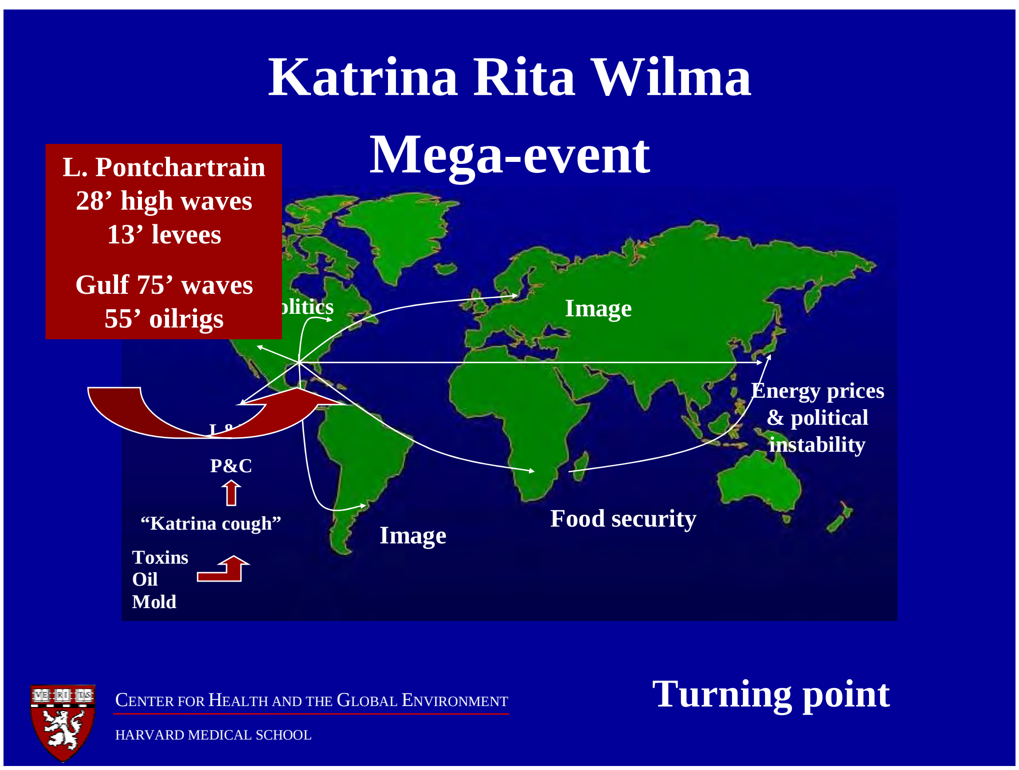


Figure 2. The cascading consequences of Katrina

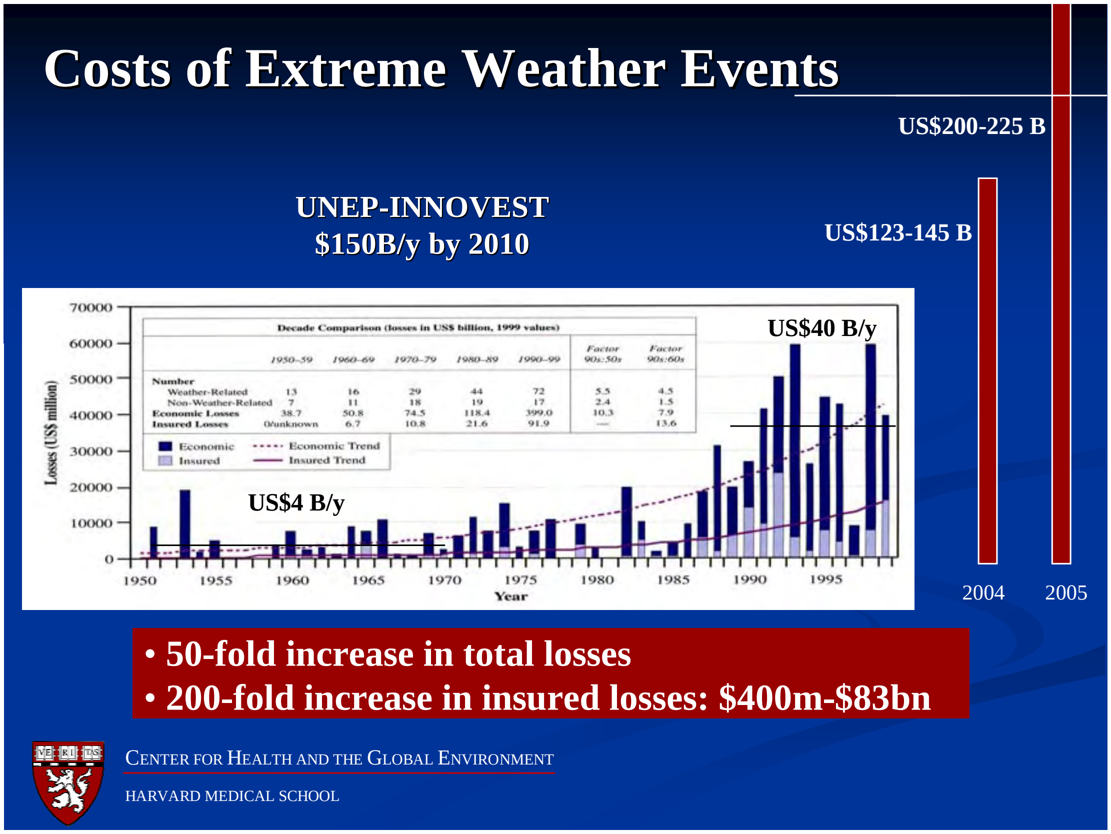


Figure 3. Calculating the costs of natural catastrophes

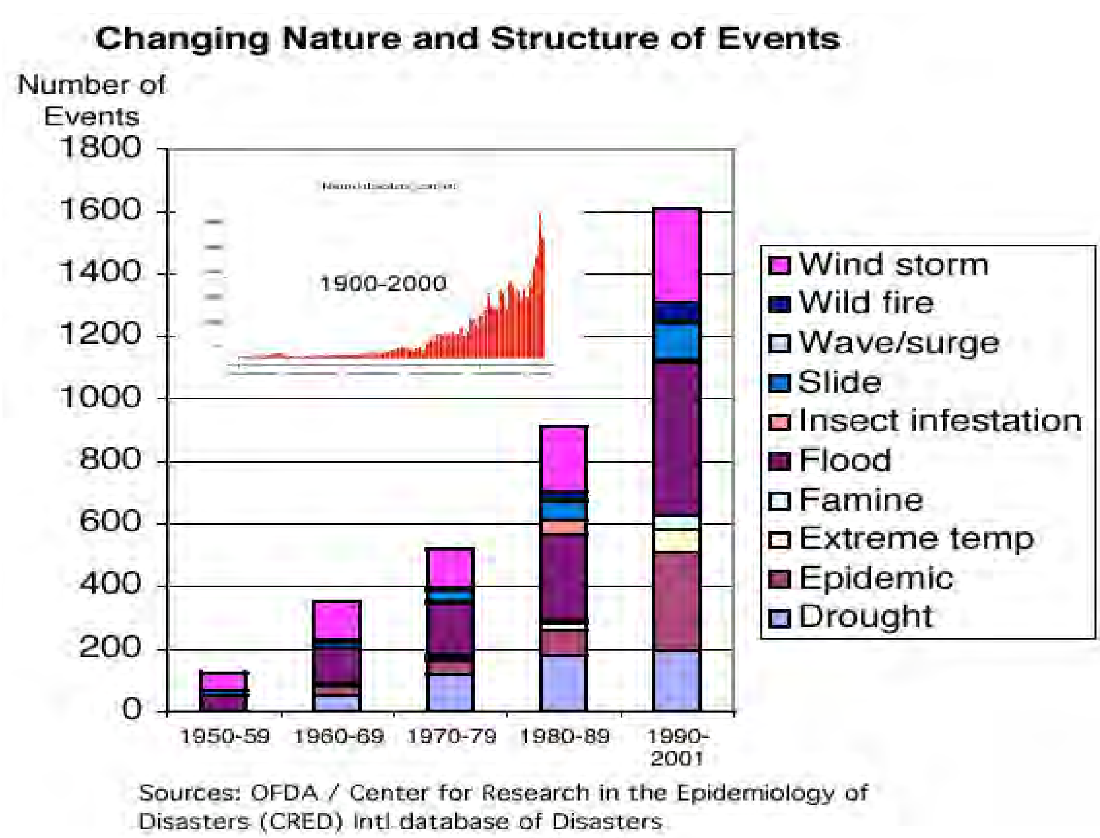
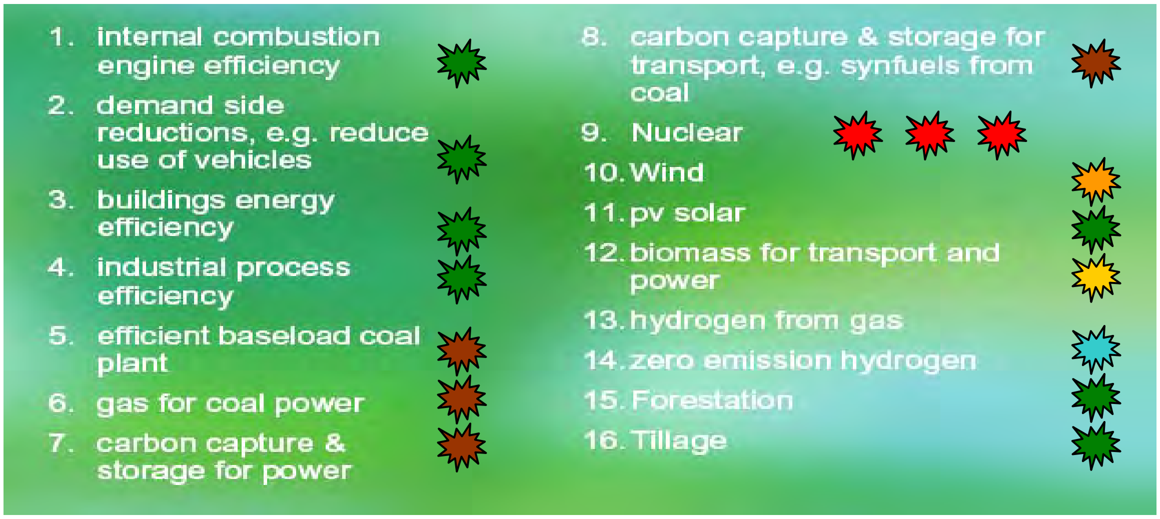


Figure 4. Trends in extreme weather events

Figure 5. Rating the wedges: First pass.
Given the potential of plug-in hybrids for transport, and combined power and heat for buildings, cleaning the grid becomes the central problem. Combining clean wedges of distributed generation measures that feed into national grids is one approach. "Smart technologies" can play a pivotal role in development of a more efficient and resilient grid, by focusing energy delivery to regions at times of maximum usage, for example.



No regrets

Positive; siting issues

LCA for sub-wedges

R&D needed

Fossil fuel

Major issues

safety **security** **storage**

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