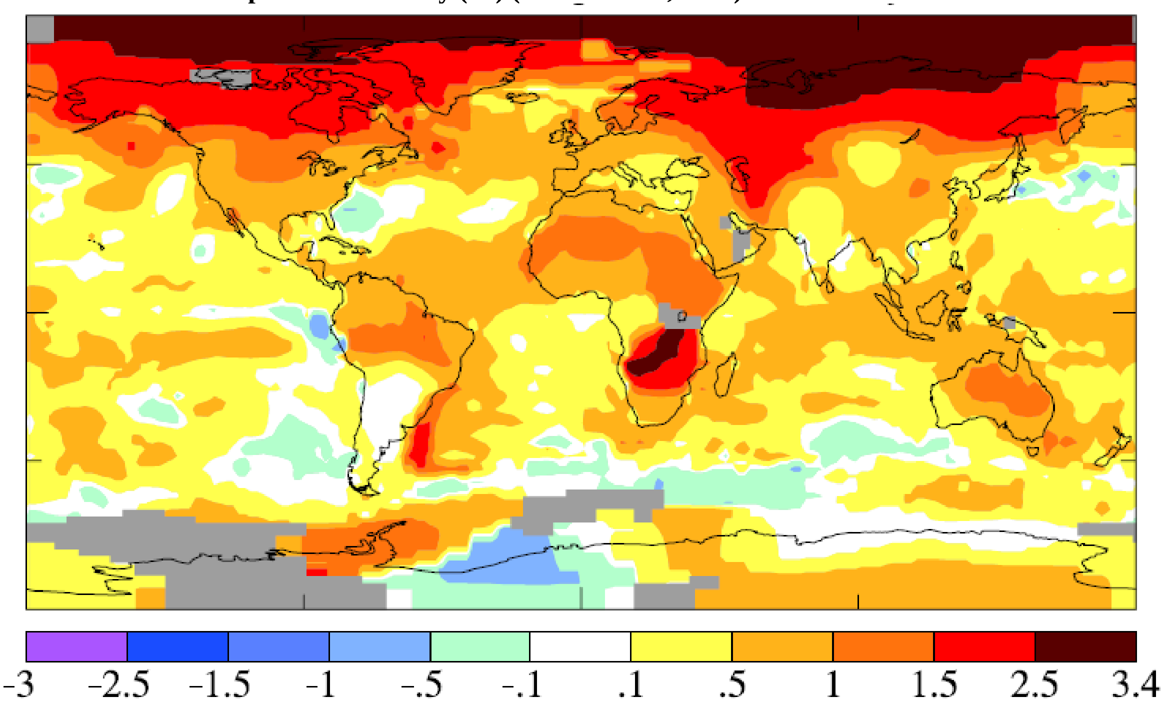
Global Warming Science Update
July 2006

Daniel A. Lashof, Ph.D.
Science Director, Climate Center
dlashof@nrdc.org

Hotter & hotter:

In early 2006, NASA released data confirming that the 10 warmest years on record have all occurred since 1990, extending the warming trend of recent decades. This trend includes 2005, which NASA confirmed as tied with 1998 for the hottest year on record. Last year's warmth is particularly significant as global temperatures in 1998 received a boost of up to 0.2ºC from El Niño. No such large scale ocean-atmospheric phenomenon occurred in 2005. The main reasons for the high globally-averaged temperature in 2005 were the anomalously high temperatures seen in the high northern latitudes (*figure 1*). This Arctic warming is not expected from natural variability alone and supports the conclusion that the record warmth was primarily caused by a build-up of heat-trapping pollution in the atmosphere.

Figure 1: 2005 surface temperature anomaly (˚C) (Hansen et al., 2006)



Hansen, J., R. Ruedy, M. Sato and K. Lo (2006) GISS Surface Temperature Analysis, Global Temperature Trends: 2005 Summation, NASA's Goddard Institute for Space Studies, available at: http://data.giss.nasa.gov/gistemp/2005/

The hockey team keeps winning:

In addition to the data available from instrumental records, reconstructions of past temperature from temperature-sensitive proxies, such as tree rings, ice cores and coral reefs indicate that the globally-averaged surface temperature has been greater in the past few decades than during any comparable period during the preceding 400 years. After global warming deniers questioned the validity 'hockey stick' curve[1], the National Research Council was directed to review past climate reconstructions. They concluded that although uncertainties exist due to the nature of proxy records it is plausible that the Northern Hemisphere was warmer during the last few decades of the 20th Century than during any comparable period during the preceding millennium. Other groups have also reached similarly conclusions recently. Osborn and Briffa (2006) analyzed a number of multi-proxy data sets and concluded that Northern Hemispheric warming is now greater than it has been in the last 1,200 years and that the spatial extent of recent warming is of a greater significance than other periods of warmth, such as the Medieval Warm Period. And Thompson et al. (2006) determined that the current warming at high elevations in the mid to low latitudes is unprecedented for at least the last two thousand years based on analysis of isotope geochemistry and mass-balance histories of tropical ice cores.

The NRC report also notes that surface temperature reconstructions are only one of the multiple lines of evidence supporting the conclusion that heat-trapping pollution is primarily responsible for the recent warming trend. Other primary evidence includes the large increases in carbon dioxide (CO_2) and other global warming pollutants starting in the middle of the 19th century; energy balance calculations associated with heat-trapping gas increases and climate feedback mechanisms; numerical experiments performed by state-of-the-art climate models; and stratospheric cooling and ocean warming that match the predicted spatial and temporal pattern of human-induced warming.

National Research Council (2006) Surface Temperature Reconstructions for the Last 2,000 Years, Committee on Surface Temperature Reconstructions for the Last 2,000 Years, Board on Atmospheric Sciences and Climate, Division on Earth and Life Sciences, National Research Council of the National Academies, The National Academies Press, Washington, D.C., available at: http://www.nap.edu/catalog/11676.html

Osborn, T.J. and K.R. Briffa (2006) The Spatial Extent of 20th-Century Warmth in the Context of the Past 1200 Years, *Science*, **311**, p. 841 – 844.

Thompson, L.G., E. Mosley-Thompson, H. Brecher, M. Davis, B. León, D. Les, P. Lin, T. Mashiotta and K. Mountain (2006) Abrupt tropical climate change: Past and present, *Proceedings of the National Academy of Sciences*, **103(28)**, p.10536-10543, doi:10.1073/pnas.0603900103.

Rapid build up:

Recent data indicate that CO_2 is accumulating in the atmosphere at a greater rate than in the past. In 2005 the concentration of CO_2 in the atmosphere increased by 2.5 parts per million (ppm), the third largest annual increase ever recorded. Although there is considerable inter-annual variability in the rate of increase in atmospheric CO_2, the rise has been more than 2 ppm in 3 of the last 4 years. Prior to 1995, an annual increase of more than 2 ppm was seen only 4 times since the record began in

[1] The 'hockey stick' curve was first produced by Mann, Bradley and Hughes in 1998 and, through complex statistical techniques, illustrates that global temperatures were relatively steady for about 900 years and then turned upwards sharply during the 20th Century.

1959. As a result of recent jumps, the current atmospheric concentration of CO_2 is now over 380 ppm. This is an increase of more than 100 ppm since the start of the Industrial Revolution and ice core records show that it is the highest concentration of atmospheric CO_2 for at least the last 650,000 years.

Siegenthaler, U., T.F. Stocker, E. Monnin, D. Lüthi, J. Schwander, B. Stauffer, D. Raynaud, J. Barnola, H. Fischer, V. Masson-Delmotte, and J. Jouze (2005) Stable Carbon Cycle-Climate During the Late Pleistocene, *Science*, **310**, p. 1313 – 1317.

Tans, P. (2006) Trends in Atmospheric Carbon Dioxide, NOAA ESRL, available at: http://www.cmdl.noaa.gov/ccgg/trends/

A tipping point at the Poles?

Figure 2: March 2006 Cover of Science Magazine

In March 2006, Science magazine led with the cover "Climate Change – Breaking the Ice" (*figure 2*). The edition included articles covering important new research on warming at both poles which is leading to changes in the ice system. These changes are occurring faster than previously observed or expected, therefore indicating that both the Arctic and Antarctic may be approaching a "tipping point" after which dangerous transformations will become unavoidable. Markers of such changes are being seen in Greenland and in the Antarctic ice sheet, both of which are melting and thinning more rapidly than in the past. Velicogna and Wahr (2006) found that the mass of the Antarctic ice sheet has decreased significantly since 2002. The ice sheet has lost mass at a rate of 152 ± 80 cubic kilometers (36 ± 19 cubic miles) of ice per year, which is equivalent to a global sea level rise of 0.4 ± 0.2 millimeters (0.01 ± 0.008 inches) per year. A similar rapid loss of ice mass has been shown in the Arctic, where Rignot and Kanagaratnam (2006) found that the loss of mass from the Greenland ice sheet doubled between 1996 and 2005 to 224 ± 41 cubic kilometers (54 ± 10 cubic miles) per year. For comparison, the city of Los Angeles uses 1 cubic kilometers (0.23 cubic miles) of water per year.

Records of past ice-sheet melting indicate that the rate of future melting and the related sea-level rise could be faster than widely thought according to Overpeck et al. (2006). Key to this sea level rise is the instability of the Greenland Ice Sheet (GIS) and the West Antarctic Ice Sheet (WAIS). Overpeck et al. (2006) find that during the last interglacial period (approximately 130,000 to 127,000 years ago) sea level was 4 to over 6 meters (13 to over 20 feet) higher than today. Unfortunately climate models project that by 2100 the high northern latitudes will be as warm, or warmer, than they were during the last interglacial unless heat-trapping emissions are curbed, i.e. temperatures in the late 21st Century would be warm enough to melt at least large portions of Greenland and quite probably portions of West Antarctica. If such melting occurs, millions of people would be vulnerable to flooding and displacement from the resulting sea level rise, and the economic loss associated with coastal inundation would be devastating.

Similarly, Otto-Bliesner et al. (2006) quantified the contribution of melting from Greenland and other Arctic ice fields to sea-level rise during the last interglacial period. They evaluated ice cap retreat by analyzing results from a global climate model, a dynamic ice sheet model and paleoclimatic data. Otto-Bliesner et al. (2006) found that melting in the western Arctic ice-fields and Greenland contributed between 2.2 and 3.4 meters (7.2 and 11.2 feet) of sea-level rise during the last interglacial period and while this was due to natural variations in global climate, human-induced global warming over the next century could lead to similar, substantial impacts on the polar environment.

Unfortunately it's not just the ice system that is changing – changes in the permafrost, or the permanently frozen ground, also reflect a warming trend in the Arctic. Recent runs of the National Center for Atmospheric Research's Community Climate System Model (CCSM3) project that under business-as-usual greenhouse gas emission scenarios there will be a decline in near-surface permafrost of up to 80% by 2100. Even if the extent of permafrost melt is not as large as projected by this scenario and model, these results imply that large-scale changes in permafrost will occur in the future. Melting permafrost is a concern because of the damage that is caused to structures built on permafrost when the ground beneath them melts, and because permafrost traps methane gas in the ground. If melting of the permafrost occurs, it may result in the rapid release of large quantities of methane, which is a potent global warming pollutant.

Lawrence, D. and A. Slater (April 5th, 2006) A Global Climate Model Projection of Severe Degradation of Near-Surface Permafrost: Potential Feedbacks on Climate, presentation at: Stanford EE Computer Systems Colloquium, available at: http://www.cgd.ucar.edu/ccr/dlawren/permafrost.ccsm3.stanford.2006.pdf

Otto-Bliesner, B.L., S.J. Marshall, J.T. Overpeck, G.H. Miller, A. Hu and CAPE Last Interglacial Project members (2006) Simulating Arctic Climate Warmth and Icefield Retreat in the Last Interglaciation, *Science*, **311**, p. 1751 – 1753.

Overpeck, J.T., B.L. Otto-Bliesner, G.H. Miller, D.R. Muhs, R.B. Alley and J.T. Kiehl (2006) Paleoclimatic Evidence for Future Ice-Sheet Instability and Rapid Sea-Level Rise, *Science*, **311**, p. 1747 – 1750.

Rignot, E. and P. Kanagaratnam (2006) Changes in the Velocity Structure of the Greenland Ice Sheet, *Science*, **311**, p. 986 – 990.

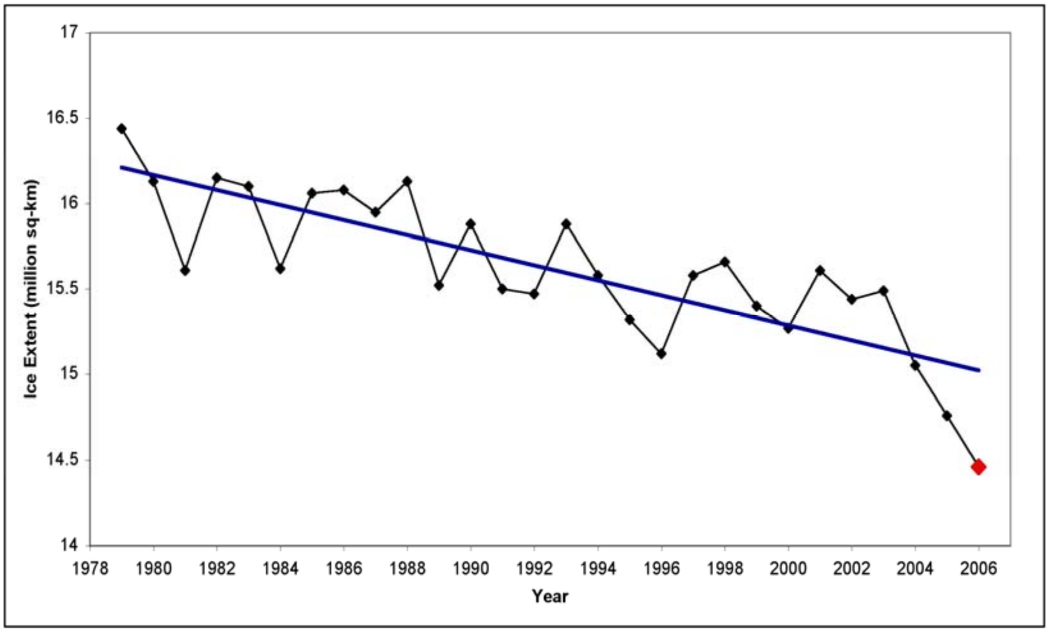
Velicogna, I. and J. Wahr (2006) Measurements of Time-Variable Gravity Show Mass Loss in Antarctica, *Science*, **311**, p. 1754 – 1756.

Continued meltdown of Arctic sea ice:

At the beginning of April scientists at the National Snow and Ice Data Center released results showing that March 2006 had the lowest Arctic winter sea ice extent since 1979, the beginning of the satellite record (*figure 3*). March sea ice represents the maximum cover for the year, and the record low in 2006 is particularly significant as it illustrates that for two years running Arctic sea ice has failed to recover to its previous maximum levels during the winter months. The long-term mean March sea ice extent is 6.06 million square miles, whereas 2005 and 2006 set two new record lows at

5.72 million square miles and 5.60 million square miles, respectively. This decline in 2006 wintertime sea ice below the long-term average is approximately equivalent to three times the area of California.

Figure 3: March (wintertime rebound peak) mean sea ice extent (NSIDC, 2006)



Although the decline in winter sea ice (i.e. the annual maximum) is not as marked as that of summer sea ice decline (i.e. the annual minimum), low winter sea ice extents mean that the ice is freezing later in the fall and growing at a slower pace during the winter. This decline in the winter recovery season has implications for overall annual declines and we can expect this summer to continue the trend of all-time lows in sea ice extent. In fact, Stroeve et al. (2005) recently found that four out of the five lowest years of sea ice extent have occurred since 2002. This accelerated decline in summertime sea ice led Jonathan Overpeck and his colleagues to conclude that the Arctic could be completely free of summer sea ice well before the end of this century, a state that has not occurred over at least the last million years.

National Snow and Ice Data Center, NASA and University of Washington (September 28th, 2005), Sea Ice Decline Intensifies, joint press release, available at: http://nsidc.org/news/press/20050928_trendscontinue.html

National Snow and Ice Data Center (2006) Winter Sea Ice Fails to Recover, Down to Record Low, available at: http://nsidc.org/news/press/20060404_winterrecovery.html

Overpeck, J.T., M. Sturm, J.A. Francis, D.K. Perovich, M.C. Serreze, R. Benner, E.D. Carmack, F.S. Chapin III, S.C. Gerlach, L.C. Hamilton, L.D. Hinzman, M. Holland, H.P. Huntington, J.R. Key, A.H. Lloyd, G. M. MacDonald, J. McFadden, D. Noone, T.D. Prowse, P.Schlosser and C. Vörösmarty (2005) Arctic System on Trajectory to New, Seasonally Ice-Free State, *EOS*, **86**, 309, p. 312 – 313.

Stroeve J.C., M.C. Serreze, F. Fetterer, T. Arbetter, W. Meier, J. Maslanik, and K. Knowles (2005) Tracking the Arctic's shrinking ice cover: Another extreme September minimum in 2004, *Geophysical Research Letters*, **32**, L04501, doi:10.1029/2004GL021810.

Are we underestimating global warming?

New research from multiple groups suggests that current climate models may *underestimate* global warming projections because of a failure to account for positive feedbacks including increased greenhouse gas concentrations in response to global warming (Torn and Harte, 2006; Scheffer et al., 2006), polar stratospheric clouds and hurricane-induced ocean mixing (Sluijs et al., 2006). It is therefore entirely plausible that current climate models underestimate the extent of warming throughout the globe.

Although the direct effects of CO_2 and other global warming pollutants on the Earth's temperature are well understood, the indirect effects are more complicated due to feedback mechanisms in the earth system. For instance, higher temperatures may lead to increased releases or reduced uptake of carbon dioxide and/or methane by the ocean, forests, and soils. This self-reinforcing cycle may not be fully accounted for in climate models, and until recently few studies have tried to quantify it. Torn and Harte (2006) have now found that by incorporating the CO_2 and methane positive feedback, the warming associated with doubling of CO_2 due to human activities is amplified from the range of 1.5 – 4.5˚C to 1.6 – 6.0˚C. Similarly, Scheffer et al. (2006) analyze the evidence that higher global temperatures promote greenhouse gas levels through processes such as the increased release of CO_2, methane and N_2O from terrestrial systems. They find that the century-scale positive feedback of rising temperatures on atmospheric carbon dioxide concentrations will further enhance warming by an extra 15 to 78%. Although both groups of researchers recognize the limitations and uncertainties of their projections, their independent results, which use different methods, suggest that warming over the coming century may in fact be greater than recent trends and could be larger than that projected by the Intergovernmental Panel on Climate Change (IPCC).

In addition to this, research published in the June 1st issue of *Nature*, showed that 55 million years ago the Arctic region resembled the climate of Florida and therefore that the climate system is unlikely to have a natural "thermostat" to prevent extreme warming. The Arctic Coring Expedition analyzed sediments from the Palaeocene/Eocene thermal maximum (PETM) and found that polar temperatures during this period were more than 18˚F warmer than those predicted by current climate models and that the Arctic is capable of warming to over 73˚F and being ice free. This illustrates that higher-than-modern greenhouse gas concentrations must have operated in conjunction with additional feedback mechanisms, currently unaccounted for in climate models, to amplify warming in the past. Sluijs et al. (2006) suspect that polar stratospheric clouds and hurricane-induced ocean mixing could have lead to the high-latitude warming and tropical cooling found in the records.

Brinkhuis, H., S. Schouten, M.E. Collinson, A.Sluijs, J.S. Sinninghe Damsté, G.R. Dickens, M. Huber, T.M. Cronin, J. Onodera, K. Takahashi, J.P. Bujak, R. Stein, J. van der Burgh, J.S. Eldrett, I.C. Harding, A.F. Lotter, F. Sangiorgi, H. van Konijnenburg-van Cittert, J.W. de Leeuw, J. Matthiessen, J. Backman, K. Moran and the Expedition 302 Scientists (2006) Episodic fresh surface waters in the Eocene Arctic Ocean, *Nature*, **441**, doi:10.1038/nature04692.

Moran, K., J. Backman, H. Brinkhuis, S.C. Clemens, T. Cronin, G.R. Dickens, F. Eynaud, J. Gattacceca, M. Jakobsson, R.W. Jordan, M. Kaminski, J. King, N. Koc, A. Krylov, N. Martinez, J. Matthiessen, D. McInroy, T.C. Moore, J. Onodera, M. O'Regan, H. Pälike, B. Rea, D. Rio, T. Sakamoto, D.C. Smith, R. Stein, K. St John, I. Suto, N. Suzuki, K. Takahashi, M. Watanabe, M. Yamamoto, J. Farrell, M. Frank, P. Kubik, W. Jokat and Y. Kristoffersen (2006) The Cenozoic palaeoenvironment of the Arctic Ocean, *Nature*, **441**, doi:10.1038/nature04800.

Torn, M.S. and J. Harte (2006) Missing feedbacks, asymmetric uncertainties, and the underestimation of future warming, *Geophysical Research Letters*, **33**, L10703, doi:10.1029/2005GL025540.

Scheffer, M., V. Brovkin and P.M. Cox (2006) Positive feedback between global warming and atmospheric CO2 concentration inferred from past climate change, *Geophysical Research Letters*, **33** L10702, doi:10.1029/2005GL025044.

Sluijs, A., S. Schouten, M. Pagani, M. Woltering, H. Brinkhuis, J.S. Sinninghe Damsté, G. R. Dickens, M. Huber, G-J Reichart, R. Stein, J. Matthiessen, L.J. Lourens, N. Pedentchouk, J. Backman, K. Moran and the Expedition 302 Scientists (2006) Subtropical Arctic Ocean temperatures during the Palaeocene/Eocene thermal maximum, *Nature*, **441**, doi:10.1038/nature04668.

It's official: Satellite and surface temperature records agree:

A recent report issued by the U.S. Climate Change Science Program (CCSP) concludes that over the 25-year satellite record, the surface and mid-troposphere have both warmed by approximately 0.15˚C per decade. Global warming deniers had frequently challenged the reality of human-induced global warming and the reliability of climate models by citing previously reported discrepancies between the amount of warming at the surface in comparison to warming higher in the atmosphere. The original discrepancies were reported by John Christy, Roy Spencer and their team at the University of Alabama-Huntsville based on microwave emissions from the atmosphere recorded by satellites. But this argument is invalidated once errors in satellite and radiosonde data have been identified and corrected; and new temperature time series for the surface and atmosphere are consistent with each other. The University of Alabama-Huntsville team also acknowledged their previous errors in late 2005. This reconciliation of previous discrepancies led to a News of the Week article in *Science* titled "No Doubt About It, the World is Warming."

Christy, J.R. and R.W. Spencer (2005) Correcting Temperature Data Sets, *Science*, **310**, p. 972.

Karl, T.R., S.J. Hassol, C.D. Miller, and W.L. Murray (*eds.*) (2006) Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences, A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC, available at: http://www.climatescience.gov/Library/sap/sap1-1/finalreport/default.htm

Kerr, J. (2006) No Doubt About It, the World Is Warming, *Science*, **312**, p. 825.

Warmer seas mean more intense hurricanes:

In addition to research released last year, further evidence is accumulating to suggest that hurricanes are becoming more intense due to global warming. Research by Michael Mann from Penn State and Kerry Emanuel from MIT suggests that warming of the tropical Atlantic due to human activity is responsible for the recent increase in tropical cyclone activity. In addition, they conclude that there is no statistically significant evidence for natural cycles, such as the Atlantic Multidecadal Oscillation (AMO), playing a role in long-term tropical North Atlantic sea surface temperature (SST) variations, which are well correlated with tropical cyclone intensity. Mann and Emanuel (2006) find that the dependency of tropical Atlantic SST on the AMO is not statistically robust, and that any trend recently accredited to the AMO may actually be a result of global warming in conjunction with cooling associated with tropospheric aerosol pollutants, such as SOx and NOx. They validated their model by performing a regression analysis which skillfully predicted the variations in SST observed over the past 30 years. As such, Mann and Emanuel (2006) conclude that there is no evidence to support natural climate oscillations, including the AMO, contributing to long-term tropical North Atlantic SST variations, and hence tropical cyclone intensity, and that instead SST increases are due to human-induced global warming.

Two researchers from Purdue University also independently concluded that mean annual tropical temperatures directly regulate the integrated intensity of tropical cyclones. By using observational data from the European Centre for Medium-Range Weather Forecasts Reanalysis (ERA-40) Project, Sriver and Huber (2006) find that the power dissipation of tropical cyclones (a measure of maximum wind speeds over the duration of the storm) correlates with both air temperature and mean annual tropical SST, and that a substantial portion of variance in globally integrated power dissipation can be attributed to changes in mean tropical temperatures. In fact, by using a regression fit, they calculate that an increase of 0.25˚C in mean annual tropical SST corresponds approximately to a 60% increase in global power dissipation of tropical cyclones.

Analysis of the record-breaking 2005 hurricane season also reveals that higher than usual global SSTs, a signature of global warming, were responsible for the majority of the record high SSTs documented in the tropical North Atlantic during the summer of 2005. Trenberth and Shea (2006) attribute approximately half of the record warmth in the tropical North Atlantic to global SSTs, whereas only a third of the warmth was caused by the AMO and El Niño combined. Although both the AMO and El Niño were in positive stages during the 2005 hurricane season, thereby adding to the warm global SSTs, the baseline global SST signature appears to have had a larger role and it is increasing with global warming. Therefore as the background levels of global SSTs continue to climb, greater hurricane activity can be expected in future.

Mann, M.E. and K.A. Emanuel (2006) Atlantic Hurricane Trends Linked to Climate Change, *Eos,* **87 (24)**, p. 233 – 244.

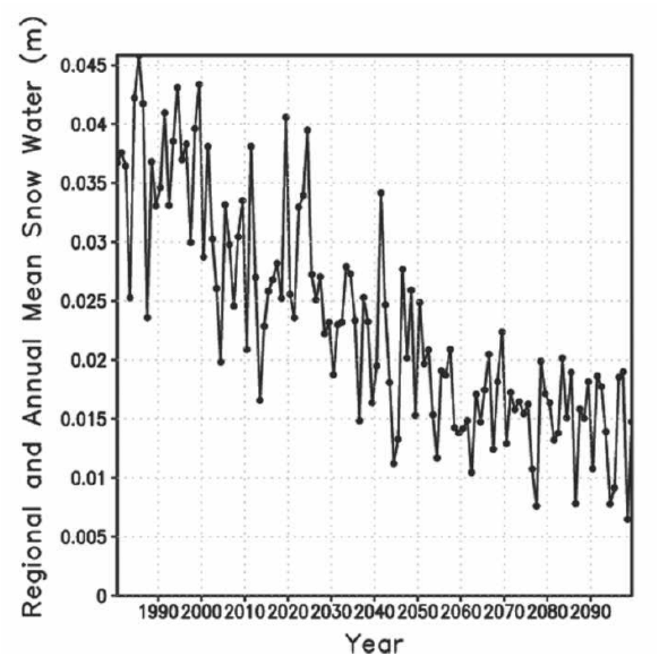
Sriver, R. and M. Huber (2006) Low frequency variability in globally integrated tropical cyclone power, *Geophysical Research Letters*, **33**, L11705, doi: 10.1029/2006GL026167

Trenberth, K.E. and D.J. Shea (2006) Atlantic hurricanes and natural variability in 2005, *Geophysical Research Letters*, **33**, doi:10.1029/2006GL026894

Mountain snowpack declines mean trouble for the future of the world's water supply:

As the world warms, we are likely to see declines in mountain snowpack, a key water source for many areas of the world including the western U.S. Two researchers from the Pacific Northwest National Laboratory recently scaled down 21st century climate change simulations from the NCAR Community Climate System Model to local-scale results thereby allowing them to determine local-scale hydrological effects based on rising global temperatures, changes in global hydrological cycle *and* local topography.

Figure 4: Annual mean snow water for the period 1980 to 2100 averaged between latitudes 36-49˚N and longitude 125-115˚W (western U. S.)



While Ghan and Shippert (2006) found that changes in precipitation varied from region to region, they found profound impacts in regions with little permanent snow (e.g. New Zealand, Mexico and the Andes) and moderate impacts in regions with both seasonal and permanent snow (e.g. the western U.S.). Their results include a decrease in area mean snow water by over 40% by the end of the century for the western U.S. (*figure 4*), over a 50% decrease for regions such as the Andes, Mexico and Central America and over an 80% decrease for New Zealand. Such decreases could result in severe impacts on the world's water supply as many regions are dependent on spring and summer runoff for irrigation and drinking water.

Ghan, S.J. and T. Shippert (2006) Physically Based Global Downscaling: Climate Change Projections for a Full Century, *Journal of Climate*, **19**, p. 1589 – 1604.

Further evidence for extinctions due to global warming:

Recent mass extinctions of the harlequin frog, endemic to Central America, have recently been linked to disease outbreaks that are tied to global warming, thereby giving further evidence of changes in natural ecosystems due to human-induced global warming. Pounds et al. (2006) conclude with 'very high confidence' (greater than 99% confidence, as per IPCC) that large-scale warming is a key factor in the disappearance of 67% of the approximately 110 species of harlequin frog (*Atelopus*) species. Their study illustrates that biological changes in Monteverde, a mountainous area of Costa Rica, are statistically associated with air temperatures and SST in the tropics, but not with SST fluctuations that are controlled by El Niño alone. They also found that 80% of the species that have disappeared were seen for the last time after a relatively warm year, and statistical tests show that this is not due to chance, altitude, latitude or range size, but that large-scale warming is a key factor. Pounds et al. (2006) conclude that climate-driven epidemics are an immediate threat to biodiversity, and that their results indicate a chain of events whereby global-scale warming can translate into local or microscale temperature shifts that are favorable to changes in ecosystem dynamics.

Similarly, Both et al. (2006) linked population declines in nine populations of a Dutch long-distance migratory bird to the divergence of food peaks, which are well correlated with global warming, and the hatching of nestlings. Their research illustrates that pied flycatchers (*Ficedula hypoleuca*) have declined by about 90% in areas with the earliest peak in caterpillars, a major food source, but by only 10% in areas with the latest food peaks. They predict that this occurs because although species lower on the food chain can more easily adapt to changing climate conditions, species higher on the food chain may not be able to adapt as easily. Although Both et al. (2006) only attempt to analyze nine populations, they suggest that this warming-induced divergence of timing is probably a widespread phenomenon and therefore that global warming can have a profound impact on species population dynamics and ecosystem functioning.

Pounds J.A., M.R Bustamante, L.A. Coloma, J.A. Consuegra, M.P.L. Fogden, P.N. Foster, E. La Marca, K.L. Masters, A. Merino-Viteri, R. Puschendorf, S.R. Ron, G.A. Sánchez-Azofeifa, C.J. Still and B.E. Young (2006) Widespread amphibian extinctions from epidemic disease driven by global warming, *Nature*, **439**, p. 161 – 167, doi:10.1038/nature04246.

Both C., S. Bouwhuis, C.M. Lessells and M.E. Visser (2006) Climate change and population declines in a long-distance migratory bird, *Nature*, **441**, p. 81 – 83, doi:10.1038/nature04539.

Avoiding dangerous climate change:

The United Nations Framework Convention on Climate Change (UNFCCC) establishes the objective of preventing "dangerous anthropogenic interference with the climate system." While a "non-dangerous" concentration level has not been defined under the UNFCCC, the European Union has set a goal of avoiding an increase of more than 2˚C from pre-industrial levels, in order to avoid the most dangerous changes to climate. This 2˚C target finds strong support in papers recently released in follow-up to a conference hosted by Prime Minister Tony Blair at the Hadley Center, Exeter, in February 2005. For example, Warren (2006) analyzed global warming impacts at levels at or above 2˚C and, among other results, found that:

- 1 to 2.8 billion people will experience an increase in water stress;
- Up to 26 million people will be displaced by sea level rise and increased storm intensity;
- Up to 220 million additional people will be at risk of hunger as agricultural yields fall;
- There will be a total loss of summer Arctic sea ice and we will have likely committed to the complete meltdown of the Greenland Ice Sheet;
- 97% of the globe's coral reefs will be lost;
- 50% of major wetlands in Bangladesh and Australia will be lost;
- And, ocean acidification may disrupt ocean ecosystem function.

Meinshausen (2006) carried out probabilistic tests to analyze the likely global temperature increase for stabilizing and peaking heat-trapping gas concentrations at 400, 475 and 550 ppm CO_2-equivalent. He concluded that CO_2 concentrations need to be stabilized at 400 ppm CO_2-equivalent (after peaking at 475 ppm CO_2-equivalent) in order to provide a high level of confidence that the 2˚C target will not be exceeded in this century. To achieve this goal we need to start taking action now to reduce emissions of CO_2 so as to avoid having to make larger, more expensive cuts in the future. In short, by starting to slow, stop and reverse global warming pollution now we can avoid a crash (or burn) finish.

Meinshausen, M. (2006) What Does a 2˚C Target Mean for Greenhouse Gas Concentrations? A Brief Analysis Based on Multi-Gas Emission Pathways and Several Climate Sensitivity Uncertainty Estimates, in H. Schellnhuber, et al., (*eds*.) *Avoiding Dangerous Climate Change*, Cambridge University Press, New York.

Warren, R. (2006) Impacts of Global Climate Change at Different Annual Mean Global Temperature Increase, in H. Schellnhuber, et al., (*eds*.) *Avoiding Dangerous Climate Change*, Cambridge University Press, New York.

Wildfires in the West:

Wildfires in the western U.S. are widely thought to have increased over the past few decades, but until recently the extent of recent changes had never been analyzed. In July 2006, a team of scientists from the Scripps Institute, University of California and the University of Arizona published research which fully analyzed western fires against both hydro-climatic and land-surface data. Westerling et al. (2006) found that there has been a four-fold increase in the number of western wildfires with 6.5 times as much area burned when comparing 1987 – 2003 to 1970 – 1986. The length of the wildfire season has also increased by 78 days, or 64%, and the average burn duration of large fires has increased from 7.5 to 37.1 days over the same time period. They conclude that although land use history is an important factor in wildfire risk, the broad-scale increase in wildfire frequency across the western U.S. is primarily driven by changes in climate, specifically increased spring and summer temperatures and earlier spring snowmelt.

Although Westerling et al. (2006) don't directly attribute the past increase in wildfire activity to human-induced global warming, increases in spring and summer temperatures and earlier spring snowmelt are tell-tale signs of global warming. In addition, Westerling et al. (2006) warn that regardless of past trends, virtually all climate models project warmer springs and summers for the region in the future, thereby increasing the tendency towards earlier spring snowmelt and longer fire seasons. The team also briefly discusses how increased biomass burning in the future may result in a carbon release from forest ecosystems thereby potentially changing western forests from a sink for CO_2 to a source. This could have large scale implications for the terrestrial carbon cycle in the U.S. as western forests are currently responsible for 20 to 40% of total U.S. carbon sequestration.

Running, S.W. (2006) Is Global Warming Causing More, Larger Wildfires? *Science*, published in Science Express on 6 July 2006, doi:10.1126/science.1130370

Westerling, A.L., H.G. Hidalgo, D.R. Cayan and T.W. Swetnam (2006) Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity, *Science*, published in Science Express on 6 July 2006, doi:10.1126/science.1128834