Tree mortality and forest die-off responses to climate change stresses at regional to global scales.

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Ongoing climate changes (increases in mean temperatures as well as frequencies, durations, and severities of extreme drought and heat) can amplify tree physiological stress, and may drive increases in both background tree mortality rates and episodes of rapid, broad-scale forest die-off. Recent examples of regional-scale forest die-off involving many tree species are presented from western North America, particularly including the southwestern US. Collaborative work with many colleagues world-wide resulted in publication in 2010 of a global synthesis of >160 studies that document 88 episodes of tree mortality since 1970 attributed to drought and/or heat, from all continents in forest types ranging from tropical moist forests and savannas to boreal forests – this presentation will include additional examples from more recent literature and observations. These documented mortality episodes may reflect increasing global risks of forest die-off in response to warming temperatures and more extreme droughts, even in environments not normally considered water-limited. However, large knowledge gaps currently hinder our ability to predict forest mortality in response to climate change, including the absence of a globally coordinated observation system.

Climate Sensitivity and Climate Feedbacks

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For more than forty years, the Earth's surface temperature response to the doubling of carbon dioxide was considered to be a metric to be used whilst determining the sensitivity of the climate to changes to radiative forcing. Mathematically, the sensitivity of the climate system has been represented as a ratio of two quantities: the system response sans feedback, and the comprehensive, feedback-laden system response. In general, it is difficult to categorize each system feedback separately, but it is possible to recognize the relative strengths of feedback processes upon comparing them to the direct influences of a set of forcings. The concept of climate sensitivity is still under scientific discussion and development; I shall touch upon some notable elements thereof.

Benefits of 15 years of continuous surface radiation budget measurements from NOAA's SURFRAD network

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Any form of climate change ultimately involves alteration of the surface radiation budget (SRB) and thus it is as important to monitor as greenhouse gases. NOAA’s Surface Radiation Budget Network (SURFRAD) is now the longest continuously running operational U.S. surface radiation network. It began with four stations in 1995, two were added in 1998, and a seventh was installed in 2003. The basic product is the SRB measured by independent high-quality measurements of upward- and downwarddirected longwave and shortwave radiation. Quality assurance is key to the continuous nature of the past fifteen years of SRB data. For example, instruments are exchanged with freshly calibrated units on an annual basis. Their calibrations are traceable to world standards including the World Radiometric Reference (WRR) and the World Infrared Standard Group (WISG) in Davos, Switzerland. Ancillary measurements and products are made to help interpret the radiation data and foster research. These include the atmospheric state, spectral solar, photosynthetically active radiation, UVB, total sky images, fractional sky cover, rawinsonde soundings (interpolated), aerosol optical depth (AOD), and a clear-sky product. Most SURFRAD data sets are freely available in near-real time and the basic measurements are routinely sent to formal archives including the Baseline Surface Radiation Network (BSRN) in Bremerhaven Germany, NOAA's National Climatic Data Center, and the World Radiation Data Center in St. Petersburg Russia.

A common thread among the many applications of SURFRAD data is the availability of long-term, continuous, high quality SRB data and support products at climatologically diverse sites, as opposed to the limited focus of the campaign approach to science. Long-term high quality measurements from SURFRAD have been used for evaluating satellite-based surface products, resource assessments, validating and improving hydrologic, climate, and weather models, and to monitor trends. SURFRAD data were used by NCEP to improve the albebo parameterization used in the GFS operational model. It was also a major contributor to the National Renewable Energy Laboratory's updated National Solar Radiation Database 1991-2005. With 15 years of continuous measurements, this novel data set has been used to document features that would not have been possible from ordinary operational data. For example, a network-wide increase of surface net radiation has been identified from 1995 through 2009 and was attributed primarily by a systematic increase in downwelling SW and LW. The increase in SW indicates general brightening over the U.S., and is consistent with many other measurements globally over that same period. By using SURFRAD's ancillary data we were able to attribute the brightening to a general decrease in cloud cover, as opposed to an aerosol effect. The U.S. AOD climatology was updated for the first time since the 1960's using SURFRAD data, enabling the documentation of the effects of climate change and environmental policy on AOD tendencies in the U.S. This new climatology also documented a small but steady increase in background aerosol over the last decade, confirming and extending global results recently reported in *Science*. SURFRAD data have been successfully used to validate and improve a number of satellite-based products from MODIS, CERES, and GOES. It now has a highly visible role in algorithm development for the future GOES-R. Clearly, NOAA's investment in operational SRB measurements has paid off.

GLOBAL AND REGIONAL CLIMATE CHANGE RESEARCH AT NSF: CURRENT ACTIVITY AND FUTURE PLANS

Anjuli S. Bamzai, PhD

Program Director, Climate and Large-scale Dynamics Program

National Science Foundation

This presentation will provide an overview of programs addressing issues on climate variability and change across the National Science Foundation. Under the recent NSF-wide initiative, Science Engineering and Education for Sustainability (SEES), several interdisciplinary projects have been initiated through solicitations, e.g. Water Sustainability and Climate and the NSF-DOE-USDA interagency Earth System Modeling at Decadal and Regional Scales. A sampling of exciting projects that are currently underway will be provided. A heads-up on potential funding opportunities will also be provided.

Using Prediction Markets to Evaluate Various Global Warming Hypotheses

Mark Boslough, Sandia National Laboratories

Intrade is an online trading exchange that has created a family of 17 climate prediction markets for an experiment to be presented at the AGU Fall 2011 Meeting. Each contract can be described as "Global temperature anomaly for 2012 to be greater than x °C or more," where the figure x ranges in increments of .05 from .30 to 1.30 (relative to the 1951-1980 base period), based on data published by NASA GISS. Each market will settle at $10.00 if the published global temperature anomaly for 2012 is equal to or greater than x, and will otherwise settle at $0.00.

Global warming hypotheses can be cast as probabilistic predictions for future temperatures. The first modern such climate prediction is that of Broecker (1975), whose temperatures are easily separable from his CO_2 growth scenario—which he overestimated—by interpolating his table of temperature as a function of CO_2 concentration and projecting the current trend into the near future.

For the currently-expected 2012 concentration of 395 ppm, Broecker's equilibrium temperature anomaly prediction relative to pre-industrial is 1.05 °C, or about 0.75 relative to the GISS base period. His neglect of lag in response to the changes in radiative forcing was partially compensated by his low sensitivity of 2.4 °C, leading to a slight overestimate. Simple linear extrapolation of the current trend since 1975 yields an estimate of .65 ± .09 °C (net warming of .95 °C) for anthropogenic global warming with a normal distribution of random natural variability.

To evaluate an extreme case, we can estimate the prediction Broecker would have made if he had used the Lindzen & Choi (2009) climate sensitivity of 0.5 °C. The net post-industrial warming by 2012 would have been 0.21 °C, for an expected change of -0.09 from the GISS base period. This is the temperature to which the Earth would be expected to revert if the observed warming since the 19th century was merely due to random natural variability that coincidentally mimicked Broecker's anthropogenic change prediction for the past 36 years.

Assertions made outside the scientific literature can also be cast into predictions for 2012 temperatures, for example Carter's (2006) argument for a lack of warming since 1998 can be extrapolated to a 2012 value of 0.56 °C (net warming of .86 °C), and Easterbrook's (2010) claim of global cooling can be extrapolated to a 2012 value of .42 °C (net warming of .72 °C).

All 17 contracts in the newly-opened market ensemble are consistent with net warming from pre-industrial temperatures. They are also capable of distinguishing the level of acceptance of the various global warming hypotheses, even by their respective proponents. Moreover, they can be used to determine a consensus estimate of future warming and climate variability that is weighted according to level of risk taken on by those providing the estimates, while filtering out the opinions of individuals unwilling to accept any financial risk associated with being wrong.

Does the Sun contribute to Climate Change? An update.

Pål Brekke

Norwegian Space Centre

Numerous attempts have been made over the years to link various aspects of solar variability to changes in the Earth's climate. Since the Sun's output of electromagnetic radiation and energetic particles varies, and since the Sun is the ultimate driver for the climate system, it seems natural to link the two together and look for the source of climate variability in the Sun itself. In recent years there has been a growing concern about the possible anthropogenic forcing of climate change through the increasing atmospheric content of greenhouse gases. As a result the connection between solar variability and global climate change is sometimes considered a very controversial area of research. Over the past 150 years the Earth has experienced a warming of about 0.8 degrees. In the same period both the concentrations of greenhouse gases in the atmosphere and the level of solar activity have increased. Thus, it is not a trivial task to detangle the two effects. To further complicate the picture there are several ways the Sun may impact the climate; through the electromagnetic radiation (Total Solar Irradiance) — or some component of it such as the ultra violet (UV), through the direct solar wind via magnetosphere/atmospheric coupling, and/or through the galactic cosmic radiation, which is modulated by solar shielding and possibly influences cloud formation. In addition there are other natural cycles in the climate system.

This presentation will summarize our current understanding of these mechanisms. The recent dimming of the Sun will also be discussed and its possible implication on the future climate.

Carbon balance of an old-growth Central Amazon forest landscape

Jeffrey Chambers, LBL

Published studies have concluded that old-growth tropical forests are net sinks of more than one billion tons of atmospheric carbon, of sufficient magnitude to offset ~20% of all anthropogenic CO_2 emissions. However, old-growth forest ecosystems comprise a mosaic of patches in different successional stages, and it is not clear if existing forest sample plots have appropriately sampled this mosaic. This talk will focus on the spatial scale over which an old-growth Amazon forest steady-state mosaic develops. The study combines extensive forest field plot data, remote sensing derived disturbance probability distribution functions, and simulation modeling to place plot-level results into a landscape context. Results demonstrate that attributes of small plots are often not representative of landscape-scale behavior, and long trends of biomass accumulation may be an artifact of limited sampling that fails to adequately account for episodic disturbance events. Thus the large old-growth Amazon forest carbon sink inferred from the forest plot network is uncertain, in contrast to an unequivocal deforestation source.

Greenland ice core evidence for spatial and temporal variability of the Atlantic Multidecadal Oscillation

Petr Chylek[1], Chris Folland[2], Leela Frankcombe[3], Henk Dijkstra[3], Glen Lesins[4], and Manvendra Dubey[5]

The Arctic $\delta^{18}O$ ice core record is used as a proxy for Arctic surface air temperatures and to interpret Atlantic Multidecadal Oscillation (AMO) variability. An analysis of $\delta^{18}O$ data from six Arctic ice cores (five from Greenland and one from Canada's Ellesmere Island) suggests significant AMO spatial and temporal variability within a recent about 660 years. A dominant AMO periodicity near 20 years is clearly observed in the southern (Dye3 site) and the central (GISP2, Crete and Milcent) regions of Greenland. This 20-year variability is, however, significantly reduced in the northern (Camp Century and Agassiz Ice Cap) region. A longer time scale AMO component of 45-65 years is detected only in central Greenland. The absence of the longer time scale in the southern Greenland region suggests the possibility of different origins for the two basic time scales of AMO variability. An analysis of Arctic temperature in three similar regions in a 500-year control simulation of the NOAA GFDL CM2.1 coupled atmosphere–ocean general circulation model agrees qualitatively with the results of the ice core analysis.

Knowledge gained about marine stratocumulus and the aerosol indirect effect from studies of ship tracks

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Over the past two decades, cloud properties retrieved from multispectral satellite imagery in studies of ship tracks have demonstrated that Twomey was essentially correct. Clouds in hazy environments have larger droplet number concentrations but the droplets are smaller than in clouds in similar environments that are relatively clean. Parameterizations of the aerosol indirect effect in most climate models suggest that the smaller droplets in polluted clouds suppress precipitation, giving rise to clouds with more liquid water and enhancing the cloud albedo increase originally described by Twomey. Studies of ship tracks, on the other hand, have shown that when an extensive region is overcast by marine stratus, the polluted clouds lose liquid water when compared with nearby unpolluted clouds. The loss occurs because clouds with smaller droplets experience enhanced entrainment rates which lead to greater rates of droplet evaporation. When the clouds are broken, however, polluted clouds retain liquid water while the surrounding unpolluted clouds dissipate, presumably losing liquid water through drizzle. MODIS imagery combined with CALIPSO lidar data and meteorological analyses show that strong temperature inversions and dry free tropospheres favor extensive overcast by marine stratus while weak inversions and moist free tropospheres promote broken clouds. With weak inversions and moist free tropospheres, the increased entrainment rate for the polluted ship tracks allows them to grow into the subsiding free troposphere while the nearby unpolluted clouds not only dissipate but remain at lower altitudes. With strong inversions and dry free tropospheres, the polluted clouds associated with ship tracks have the same altitudes as the nearby unpolluted clouds. Here, the response of already polluted clouds to additional particle pollution is studied using intersections where two ship tracks cross. Aircraft observations linking droplet concentrations in low-level clouds to subcloud particle concentrations suggest that the increase in droplet concentrations decreases as the particle concentration in the subcloud layer increases. In the case of ship track crossings, the effect of the additional pollution is determined from the cloud properties retrieved for the area occupied by the crossing and those predicted from the gradients at the crossing in the properties along the two ship tracks. Compared with the response of the clouds to pollution by either of the ships, the changes that occur at the crossing confirm that the additional response for already polluted clouds is much smaller than that for the unpolluted clouds. The increase in the column droplet number concentration caused by a ship decreases as the droplet number concentration of the pre-existing cloud increases. Owing to the variety of environmental conditions and polluting ships included in this study, the observations exhibit considerable scatter. Nonetheless, the changes in the column droplet number concentrations caused by ships trends with the droplet concentrations in the unpolluted clouds in the same way as the trend derived from aircraft observations.

Potential impacts of aerosols on water resources in the Colorado River Basin

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The emphasis in this talk is on the attribution of human activity to water resources in the Colorado River Basin(CRB). While there have been recent attempts to quantify projected forcings by anthropogenic greenhouse gas emissions (McCabe and Wolock, 2007; Christensen et al., 2004; Christensen and Lettenmaier, 2007) on CRB water resources, there has been few attempts to quantify impacts of aerosol pollution and dust on water resources in the CRB. In this talk I summarize our group's research on how aerosol pollution may be affecting water resources in the CRB. I then discuss estimates of how dust on snowpack may be influencing CRB water resources. But dust also serves as ice nuclei, cloud condensation nuclei, and giant cloud condensation nuclei, which alters precipitation processes in the CRB. I finish by discussing the need to do an evaluation of how anthropogenic aerosol pollution, and dust affecting snow albedo and as cloud nucleating aerosol impact water resources in the CRB.

A critical look at the IPCC AR4 climate change detection and attribution assessment

Judy Curry

School of Earth and Atmospheric Sciences
Georgia Institute of Technology

Climate change detection and attribution deduced by the coupled atmosphere-ocean general circulation models used in the IPCC AR4 assessment is discussed.

Atmospheric aerosol nucleation in the CLOUD experiment at CERN

Joachim Curtius

Frankfurt University

Globally, a significant source of cloud condensation nuclei for cloud formation is thought to originate from new particle formation (aerosol nucleation). Despite an extensive research effort, many questions remain about the dominant nucleation mechanisms. The potential influence of ions from galactic cosmic rays on the atmospheric aerosol nucleation processes may play an important role relevant for aerosol production, cloud formation and climate. Variability of

galactic cosmic rays due to modulating influences from the sun therefore may affect (regional) climate on various time scales. Similarly, a quantitative understanding of the dependence of the nucleation rate on the concentration of the nucleating substances such as gaseous sulphuric acid, ammonia, water vapour and others has not been reached. This is of relevance for climate as the atmospheric concentrations of sulphuric acid, ammonia and other nucleating agents are strongly influenced by anthropogenic emissions.
In this presentation first an overview is given of the potential processes by which cosmic rays may affect climate and examples of the correlations of atmospheric and paleo-climatic parameters suggesting this connection are briefly reviewed. Then, the first results from the CLOUD experiment at CERN are presented. CLOUD is a new aerosol chamber facility at CERN. The chamber can be exposed to a pion beam from the CERN Proton Synchrotron to simulate various levels of atmospheric ionization. CLOUD has been set up to investigate aerosol and cloud processes under well-controlled laboratory conditions. We find that cosmic ray ionisation substantially increases the nucleation rate of sulphuric acid/water particles. For mid-tropospheric temperatures, typical atmospheric concentrations of H_2SO_4 and H_2O are sufficient for nucleation to take place via an ion-induced binary nucleation mechanism. For the warmer temperatures of the boundary layer we find that neither binary (H_2SO_4/H_2O) nor ternary (H_2SO_4/NH_3/H_2O) nucleation with or without ions are able to explain typical atmospheric observations of nucleation events. In the CLOUD experiment, for the first time, chemical composition of the growing ion clusters and the nucleation mechanism at the molecular level are revealed. Our results constitute quantitative measurements of purely-neutral and ion-induced nucleation for various chemical systems. Besides a discussion of the role of sulphuric acid and ammonia, preliminary results for the role of amines and terpene oxidation products for nucleation in the atmospheric boundary layer are given. Potential impacts of our findings for cloud formation and climate are discussed.

Cloud and Aerosol Remote Sensing: Thinking Outside the Photon State-Space Box

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Atmospheric particulates, cloud droplets/crystals and aerosols, are of paramount importance in the climate system, both for their role in the energy budget and the in hydrological cycle. In fact, the complex interactions of (at least partially anthropogenic) aerosols and clouds have been singled out as the most significant sources of uncertainty in predictive climate modeling. This makes them very high-value targets in current and near-future satellite remote sensing missions at NASA and elsewhere. It has been suggested that polarization is the “last frontier” of space-based remote sensing targeting quantities and properties of atmospheric particulates, either inside or outside of cloud masses. I will show that this statement only makes sense in the current operational framework for processing remote sensing data on a pixel-by-pixel basis—an unnecessarily limited perspective. Indeed, looking at a single photon detected from a single pixel all we have to work with is its wavelength (photon energy) and direction of propagation (photon wavevector). Upon cumulation of many photons, these attributes lead respectively to multi-spectral and multiangular retrieval techniques. A closer look at the detected photon population statistics gives access to polarization information, tracing back to the individual photon’s third and last quantum property, namely, its spin. We have thus exhausted the possibilities offered by photon state space statistics. But have we exhausted the possibilities offered by remote sensing observations? The answer is negative, but there is a computational price to access two wide-open frontiers in remote sensing: multi-pixel techniques and time-domain techniques.

The natural physics-based signal prediction model used for pixel-by-pixel radiance (and polarization) processing in the solar through thermal spectrum uses steady-state (vector) radiative transfer theory implemented in plane-parallel slab geometry, a.k.a. 1D (v)RT modeling. So, in spite of the finite—and sometimes tiny—horizontal size of individual pixels, their multiply-scattered signal is assumed to originate from a horizontally infinite and uniform medium. In contrast, EM radiation in nature flows through the Earth’s molecular and particulate atmosphere according to the laws of 3D (v)RT, with relevant spatial variability scales ranging potentially from the altitude of the highest cloud tops down to the Kolmogorov dissipation scale. Computationally feasible 3D (v)RT covers only a fraction of this range, and yet is already a challenge for present resources. However, computationally fast—even analytical— approximation techniques are increasingly available. Thus we can contemplate physics-basedmulti-pixel remote sensing supported by 3D (v)RT, from both space and ground. Several examples will be presented at the conference.

Finally, if we also think beyond spatially distributed steady-state sources (i.e., pulsed lasers) then time-domain and space/time-domain modalities open even more possibilities where classic lidar techniques (single backscatter, with time-of-flight-to-range conversion) are only the starting point. Moreover, the required technology for these advanced concepts is already available. In particular, we’ll see that differential oxygen-line/-band absorption spectroscopy in the solar spectrum is a viable surrogate for pulsed laser sources (only without the narrow beam). Groundbased DOE facilities and upcoming NASA missions will soon be exploiting this opportunity.

The Greenhouse Effect of Clouds: Observations and Theory

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Over the last 11-12 years, we have been able to measure the interannual fluctuations in effective cloud-top heights with a sampling error that is finally less than the observed fluctuations. This has been accomplished using stereo retrievals from MISR on the Terra satellite, using a technique that is largely insensitive to sensor calibration. The observations by themselves are quite interesting on the short term as they correlate well with other variables available from reanalysis data, such as surface pressure, surface temperature and ENSO indices. They also raise the possibility of long-term changes that over the last decade appear to have an effect on equilibrium temperature that is about twice that expected of the increase in carbon dioxide concentration over the same time period.

The observed changes over only one decade may well prove to be ephemeral, but serve as motivation for a theoretical analysis of the role of the cloud greenhouse effect. At the heart of this analysis is an examination of the metric that is most relevant. It appears significant to consider not just the differential longwave flux from surface to the top of the atmosphere, but rather the effect on equilibrium surface temperature, at least allowing for convective adjustment, since convective time constants are far shorter than those for radiation. The height profiles of the absorbers are also relevant, as clouds in the lower troposphere are largely irrelevant compared to those at the top of the troposphere.

By inserting a global average distribution of cloud fraction as a function of effective cloud-top height, as measured in detail by MISR, into a radiative-convective equilibrium model, the nature of the cloud greenhouse can be examined in some depth, together with relative roles of water vapor and carbon dioxide. Both the standard solution and perturbed solutions are considered.

The Present-Day Arctic Atmosphere in CCSM4

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Changes to Arctic Climate observed in the present day have resulted in increased focus on understanding and predicting Arctic climate processes and their future states. Of models used to analyze future Arctic climate, the fourth version of the National Center for Atmospheric Research's (NCAR) Community Climate System Model (CCSM4) is among the most popular. Included in CCSM4 are several component models, including the Community Atmosphere Model version four (CAM4), the Los Alamos Sea Ice Model (CICE), the Community Land Model (CLM), and the Parallel Ocean Program Ocean Model, version two (POP2). In preparation for the fifth phase of the Coupled Model Intercomparison Project (CMIP5), several 20th century CCSM4 simulations have been completed. Included are five ensemble runs with monthly mean output, and a high frequency output simulation featuring results at three- and six-hourly as well as daily frequencies, depending on variable. In this work, we analyze the CCSM4 CMIP5 simulations to evaluate the model's ability to accurately portray the present-day Arctic Climate (1981-2005). Included are comparisons of observed and simulated Arctic (70-90 N) atmospheric surface temperature, sea level pressure, cloud occurrence and phase, energy budget, hydrological cycle, and lower tropospheric stability. The high-frequency output simulation provides added insight into the variability of these properties on various scales. In this presentation we will illustrate the model's strengths and weaknesses in simulating the above-listed features of the Arctic Atmosphere through direct comparison with observations and reanalysis products. We will also provide interpretation of results and potential implications on simulation of future climate, along with discussion on simulated atmospheric variability.

Multi-scale Greenhouse Gas Monitoring and Modeling: From Fossil Energy Emissions to Climate Feedbacks

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In 2011, LANL deployed a solar tracking high-resolution Fourier Transform Spectrometer (FTS, Bruker 125HR) in Four Corners, NM a semi arid region with two coal-fired power plants, significant fossil energy exploration and a mid-size city. High-resolution solar spectra in the near infrared and visible are collected every 2 minutes and analyzed using stringent requirements of the Total Column Carbon Observing Network (TCCON) to retrieve columnar green house gases (CO_2, CH_4, N_2O) and pollutants (CO). In situ measurements of CO2, CH4 and CO are made using a Picarro Cavity ringdown spectrometer and NO2, SO2, O3 and particulates are measured using EPA protocols. We also have a meteorological station, a ceilometer to measure boundary layer heights and a Cimel to measure aerosol optical depths. Our system was calibrated using in situ HIPPO vertical profile trace gas measurements taken on 7 June 2011. We report the power-plant signals and their diurnal cycles and how they depend on the local meteorology. Typically, our FTS observes 2 to 8 ppm increases in CO_2 and our *in situ* Picarro measures increases of 10 to 50 ppm when a power plume is blowing towards our site. *In situ* CH_4 reveal large nocturnal increases of 4-5 ppm (>300%) that together the 0.05-0.09 ppm (3-5%) FTS column increase in the morning suggests a large dispersed source. We hypothesize that this could be seepage of fugitive emissions from extensive gas and coal mining activities in the region. In contrast to CH_4 *in situ* CO_2 increases at night are small since the power plant stacks are higher than boundary layer. We have also developed a plume to regional chemistry-carbon model for Four Corners. Multi-scale foreword modeling simulations are compared with our column and *in situ* observations for specific days. We also examine satellite data (CO_2 and CH_4 from GOSAT and NO_2 from OMI) for signals over Four Corners and assess the value added for longer-term trend analysis. We will discuss the deployment of our FTS to Manaus, Brazil in 2014 to monitor the Amazonian carbon-water cycle, and partnerships to expand monitoring in the Arctic for the early detection of carbon release from the warming tundra.

The influence of ion-induced nucleation on atmospheric aerosols based on data from the CERN CLOUD experiment

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A range of observations support a connection between cosmic ray intensity and the Earth's climate, on timescales from days (Pudovkin and Veretenenko, 1995) to centuries (Eichler *et al*, 2010) to millennia (Bond *et al*, 2001). Away from the surface, ion concentrations are controlled by cosmic-ray induced ionization. One likely candidate for the mechanism connecting cosmic rays and the climate is the ion-induced nucleation of aerosol. Because ions stabilise sub-critical nuclei, ioninduced nucleation is likely to dominate as a nucleation pathway in remote regions with low concentrations of precursor vapours. When determining the impact of this phenomenon on the climate, a global aerosol microphysics model is a vital tool due to its inclusion of the various processes which affect particle growth and deposition.

The CERN CLOUD experiment is designed to accurately measure both ion-induced and neutral nucleation rates in unprecedented detail (Kirkby *et al*, 2011). The experiment has found that the presence of both ions and ammonia enhance nucleation rates beyond the binary neutral, but that inorganic precursor vapours are not sufficient to reproduce atmospheric observations of new particle formation events.

Using the GLOMAP aerosol microphysics model, we quantify the contribution of ion-induced nucleation to global aerosol based on new results from the CLOUD experiment at CERN. We will present the results of the implementation within a global model of the first parametrization of ion-induced nucleation based on experimental observations rather than theoretical predictions. This parametrization is the result of work in the ternary H2SO4-NH3-H2O system by the CLOUD collaboration at CERN.

The ternary and ion-induced nucleation parametrization causes a non-negligible increase in CN (diameter > 3 nm) and CCN (diameter > 70 nm) at the surface when compared with a simulation which uses a binary neutral nucleation mechanism.

We would like to thank CERN for supporting CLOUD with important technical resources, and for providing a particle beam from the CERN Proton Synchrotron. This research has received funding from the EC's Seventh Framework Programme under grant agreement no. 215072 (Marie Curie Initial Training Network "CLOUDITN"), from the German Federal Ministry of Education and Research (project no. 01LK0902A), from the Swiss National Science Foundation, and from the Academy of Finland Center of Excellence program (project no. 1118615).
Bond, G.C., B. Kromer *et al* (2001) *Persistent solar influence on North Atlantic climate during the Holocene*. Science 294:2130–2136
Eichler, A., S. Olivier *et al* (2009) *Temperature response in the Altai region lags solar forcing*. Geophysical Research Letters
Kirkby et al. (2011) *Role of sulphuric acid, ammonia and galactic cosmic rays in atmospheric aerosol nucleation.* Nature

Pudovkin, M.I., Veretenenko, S.V. (1995) *Cloudiness decreases associated with Forbush decreases of galactic cosmic rays.* Journal of Atmospheric and Terrestrial Physics

Ice core isotope data, glacial fluctuations, decadal sea surface temperature changes, solar variations, and historic measurements: Evidence of recurring climate cycles and their implications for the cause of global warming and likely climate changes in the coming century: The past is the key to the future

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Global, cyclic, decadal, climate patterns can be traced over the past millennium in oxygen isotope ratios in ice cores, glacier fluctuations, sea surface temperatures, and historic observations. The recurring climate cycles clearly show that natural climatic warming and cooling have occurred many times, long before increases in anthropogenic atmospheric CO_2 levels. The Medieval Warm Period and Little Ice Age are well known examples of such climate changes, but in addition, at least 23 periods of climatic warming and cooling are recorded in the GISP2 Greenland ice core in the past 500 years. Each period of warming or cooling lasted about 25-30 years (average 27 years).

Temperatures during most of the last 10,000 years were somewhat higher than at present until about 3,000 years ago. For the past several centuries, the Earth has been coming out of the Little Ice Age and generally warming with alternating warm/cool periods. Glaciers advanced from about 1890-1920, retreated rapidly from about 1925-1945, re-advanced from about 1945-1977, retreated during the recent warm cycle (1978-1998), and some glaciers are now beginning to readvance in response to cooling during the past decade.

Comparisons of historic global climate warming and cooling, glacial fluctuations, changes in warm/cool mode of the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO), and sun spot activity over the several past centuries show strong correlations and provide a solid data base for future climate change projections.

Recent dynamics of arctic tundra vegetation: Field observations, remote sensing, and simulation modeling

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Over the past several decades, summer air temperatures in the Arctic have increased, sea ice extent on the Arctic Ocean has declined, and tundra vegetation has “greened.” Here we summarize some of the most recent analyses

of arctic tundra vegetation dynamics, arising from the various methodologies of remote sensing, field observations, and simulation modeling. From 1982-2008, the maximum Normalized Difference Vegetation Index (NDVI) increased by 9% in the North American Arctic and 2% in the Eurasian Arctic. A strong logarithmic relationship between aboveground tundra biomass and NDVI, developed from extensive field-harvested measurements of vegetation, yields aboveground biomass increases of 37% for North America and 16% for Eurasia (20% for the entire Arctic). The southernmost tundra subzones (C-E) dominate the increases in biomass, ranging from 20-26 %, although there was a high degree of heterogeneity across regions, floristic provinces, and vegetation types. Concomitant with this increase in biomass are earlier starts to the growing season, later vegetation senescence, and thus longer growing seasons overall. Field observations to date support the increased tundra biomass, with particularly strong evidence of tall shrub expansion in the southernmost tundra. Simulation modeling of warming tundra environments is also consistent with the field and remote sensing observations, however, spatial variability of soils and land management (e.g. reindeer grazing) yields varying degrees of vegetation change. An estimated total sequestration of 0.40 Pg C over the past three decades is substantive, albeit quite small relative to anthropogenic C emissions. However, the 20% average increase in aboveground biomass has major implications for nearly all aspects of tundra ecosystems including hydrology, active layer depths, permafrost regimes, wildlife and human use of arctic landscapes. While spatially extensive on-the-ground measurements of tundra biomass supported these analyses, validation is still impossible without more repeated, long-term monitoring of arctic tundra biomass in the field.

Regime Algebra and Climate Theory

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While there has been plenty of important theoretical work on climate, it is noteworthy that there is still no physical theory for climate. There is, of course, a plethora of heuristic didactic models, often referred to in the jargon as “simple models,” from which much has been learned. But for very practical reasons, empirical computer models have been the default substitute for a theory for at least three decades. During that time, direct theoretical work has faded, and even been forgotten, as generations of theoreticians have gradually stepped aside in favor of the big empirical models. There are now even "simple models" of the big models. Nonetheless, it is worth revisiting the problem of very long term forecasting from a fundamental standpoint. What can we learn from discoveries in other fields of physics to guide us? One thing they tell us is that passing between physical regimes theoretically, as one does sometimes with averaging, is a deep and subtle matter. But in contrast averaging is nearly a clich\'e in the study of climate. The popular definition of climate as ``averaged weather," while charming, is not adequate. We need to know what to average over. In what way should we average? Is there a function relating resulting averages to each other, or do the averages satisfy differential equations instead? Are these averaged quantities analogues to the physical variables we are used to, or are they something completely new, outside of our intuition? While it is easy to produce an average, finding non-heuristic, non-empirical physical equations that can stand on their own in terms of averaged quantities only is not. Does such a relationship even exist in Nature? These questions and more will be raised in this talk.

Quantifying CO_2 fluxes across gradients of permafrost and soil moisture in boreal and arctic Alaska

Eugénie S. Euskirchen[1], Marion S. Bret-Harte[1], Colin Edgar[1], Jennifer W. Harden[2], A. David McGuire[3], Gus R. Shaver[4], Merritt R. Turetsky[5]

Changes in vegetation and soil properties across gradients of soil moisture and permafrost may cause changes in net carbon uptake, either by stimulating primary productivity due to changes in vegetation composition or by stimulating soil microbial decomposition. In order to better understand these dynamics, we established six sites in boreal and arctic Alaska. The sites in boreal Alaska span a permafrost and soil moisture gradient across a black spruce ecosystem with cold soils and stable permafrost to a moist permafrost collapse scar with thermokarst formation, and a moderately rich wet fen lacking near surface permafrost. The sites in arctic Alaska span a moisture gradient from relatively dry heath tundra to moist tussock tundra to wet sedge tundra, with all sites having stable permafrost. Measurements at all the sites include year-round eddy covariance estimates of CO_2, water, and energy fluxes as well as the associated micrometeorological variables. During winter, the ecosystems each released approximately 15 – 25 g C m^{-2} mo^{-1}, and all the sites except the black spruce ecosystem remained net sources of CO_2 until early to mid-June. The black spruce ecosystem began to take up CO_2 as soon as air temperatures increased in the spring, with an estimated accumulation of ~23 g C m^{-2} from late March to early May. While the black spruce ecosystem continued to act as a

net sink of CO_2 in the summer, taking up 2.5± 1 g C m^{-2} d^{-1}, the thermokarst and fen ecosystems remained CO_2 sources, respectively releasing 2.4 ± 0.8 g C m^{-2} d^{-1} and 1.9 ± 1.1 g C m^{-2} d^{-1}. Ecosystem respiration (ER) was similar in the boreal ecosystems during the summer (4.8 ± 1.0 g C m^{-2} d^{-1}), while gross primary productivity (GPP) was much higher in the spruce ecosystem (7.3 ± 1.4 g C m^{-2} d^{-1}) compared to the thermokarst (2.5 ± 0.9 g C m^{-2} d^{-1}) and fen (3.0 ± 1.1 g C m^{-2} d^{-1}). In the tundra, there was also variability in the CO_2 fluxes, with the wet sedge ecosystem exhibiting the greatest amounts of both GPP (2.4 ± 0.4 g C m^{-2} d^{-1}) and ER (1.3 ± 0.5 g C m^{-2} d^{-1}) compared to the drier heath and tussock tundra, where there was less GPP (1.9 ± 0.4 g C m^{-2} d^{-1}) and ER (1.0 ± 0.3 g C m^{-2} d^{-1}). These results suggest that in these boreal peatland ecosystems, permafrost thaw and thermokarst development will increase CO_2 emissions to the atmosphere due to decreases in gross primary productivity. Furthermore, the sites in the boreal gradient are in close proximity to one another, as are those in the arctic gradient, yet both exhibit locally wide variation in CO_2 fluxes. Therefore, an accurate assessment of the spatial heterogeneity of carbon and water fluxes and stores by regional models should include ecosystems under a localized range of permafrost and soil moisture influence.

Arctic climate: Unique vulnerability and complex response to aerosols

Mark G. Flanner
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Aerosols play a unique and complex role in Arctic climate. Here we summarize the current understanding of Arctic aerosol forcing mechanisms and present recent studies characterizing the Arctic climate response to aerosol forcings exerted over different spatial and temporal domains. Because of the pervasiveness of reflective clouds, snow, and sea-ice within the Arctic, direct radiative forcing by aerosols is inherently more positive in the Arctic than elsewhere. Over pure snow, essentially all aerosol mixtures other than pure sulfate exert a positive top-of-atmosphere forcing. Extremely small concentrations of absorptive aerosols (including black carbon, brown carbon, and mineral dust) exert further positive forcing when they deposit to snow and sea-ice because multiple scattering of photons by ice grains enhances the probability of photon— impurity encounters. Indirect aerosol forcings are also unique and uncertain. Counteracting the first and second indirect effects on shortwave cloud forcing, Arctic aerosols also exert a positive longwave forcing by increasing the emissivity of clouds. This effect is only substantial in optically thin clouds, which prevail over much of the Arctic. Despite the likelihood of positive aerosol forcing within the Arctic, it is still unclear how local climate responds to Arctic forcing. Observations show slight declines in absorptive aerosols within the Arctic atmosphere and snowpack over the last 30 years, coincident with strong Arctic warming. One source of complexity in linking radiative forcings to local climate effects is that the seasonality of Arctic insolation and surface energy components is extreme, implying very different roles for shortwave and longwave forcing mechanisms. One set of GCM studies indicates that Arctic surface air may cool in response to positive atmospheric aerosol forcing, owing to changes in meridional energy transport that result from direct atmospheric heating (*Shindell and Faluvegi*, 2009). This result demonstrates an important role for dynamics in linking local Arctic climate change to forcings. Conversely, strong warming is expected in response to surface forcings caused by cryosphere darkening because 1) the forcing tends to be largest coincidentally with maximum seasonal melt rates, helping drive snow/ice albedo feedback that amplifies surface energy anomalies, and 2) atmospheric stability in the Arctic helps constrain surface energy anomalies to the near-surface atmosphere, enhancing the local temperature response. Here we will discuss recent experiments that apply the NCAR Community Earth System Model to characterize the sensitivity of Arctic climate to within-Arctic and extra-Arctic atmospheric forcing and surface darkening from absorptive aerosols

High skill of global surface temperature trends and variations from six forcing and internal variability factors, 1891-2010

Chris K. Folland*, Andrew Colman, Olivier Boucher, John. J. Kennedy, Jeff Knight, David E. Parker, Peter Stott, and Jean-P. Vernier

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We show that the three current main instrumental global surface temperature (land surface air temperature and sea surface temperature (SST)) data sets (ST) are structured consistently with six physical forcing and internal variability factors from 1891-2010, except during and especially just after World War II, when large global SST biases are known to exist. We use physically-based reconstructions using a multiple application of cross validated linear regression to minimise artificial skill and assess the time-varying uncertainties in the contribution of each factor to ST variations. Cross validation is a technique originally developed for long-weather range forecasting. The reconstructions have total cross validated total correlations since 1891 of 0.93-0.95, interannual components of correlation of 0.72-0.75 and total root mean square errors near 0.06ºC, close to observational uncertainties. We show that the Atlantic Multidecadal Oscillation contributes a statistically significant cooling signal to ST about 1965-1975 of near 0.1ºC, and a slower significant warming signal of about the same magnitude between about 1977 and the early 2000s. A cross validated analysis of three transient runs of the HadCM3 coupled climate model from 1888-2002 shows nearly the same skill at reconstructing the overall model ST changes, and a good if somewhat lower level of skill at reconstructing ST interannual variability. Here, a similar set of six forcing and internal variability factors, appropriate to the three model experiments, are used to those for observations. The reconstructions of observed ST also captured the

observed recent weak warming very well, partly due to a downturn in the solar cycle, when the El Nino-Southern Oscillation dominated interannual variability. In view of their popular interest, we show that decadal ST trends have varied greatly over the last 50 years but all can be largely explained by our technique.

Atlantic Multidecadal Variability from a stochastic dynamical systems point of view

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If the North Atlantic ocean is described using a simple primitive equation ocean model then variability arises through a normal mode which destabilises the background state through a Hopf bifurcation. This internal ocean mode has a multidecadal time scale, westward propagating temperature anomalies, and a spatial pattern at the surface which resembles observations of the Atlantic Multidecadal Oscillation. The variability, although damped when using realistic surface boundary conditions in the ocean model, can be excited by noise.

When comparing this normal mode to the AMO as it is found in climate models as well as in observations, two main time scales emerge. A 20-30 year time scale is found several long observational and proxy records around the North Atlantic such as the Central England Temperature record, tide gauges along the European and North American coasts, and ice cores from Greenland. This time scale is also found in westward propagating temperature anomalies in the North Atlantic, leading to the hypothesis that the normal mode from the minimal model is associated with this time scale. The longer 50-70 year time scale of variability which is also found in both observations and climate models may then be associated with variability in the Arctic, where a different internal mode with a multidecadal time scale has also been found in an idealised model.

On the warming in the tropical upper troposphere: Models versus observations

Qiang Fu[1], Syukuro Manabe[2], and Celeste M. Johanson[1]

IPCC (Intergovernmental Panel on Climate Change) AR4 (Fourth Assessment Report) GCMs (General Circulation Models) predict a tropical tropospheric warming that increases with height, reaches its maximum at ~200 hPa, and decreases to zero near the tropical tropopause. This study examines the GCM-predicted maximum warming in the tropical upper troposphere using satellite MSU (microwave sounding unit)-derived deep-layer temperatures in the tropical upper- and lower-middle troposphere for 1979-2010. While satellite MSU/AMSU observations generally support GCM results with tropical deep-layer tropospheric warming faster than surface, it is evident that the AR4 GCMs exaggerate the increase in static stability between tropical middle and upper troposphere during the last three decades.

Can we provide thermodynamic constraints for the long-term coupled evolution of the economy and the atmosphere?

Tim Garrett
University of Utah

A primary input to any long-range climate forecast is some scenario for how anthropogenic emissions of carbon dioxide will evolve over time. Typically, what is used are "SRES scenarios", which base projections on sophisticated calculations of population, standard of living, energy efficiency and energy carbonization. Each of these components is supposed to be subject to a range of policy decisions that society might make. In a recent study in Climatic Change (Garrett, 2011), I approached this problem without specific reference to people or policy, but more through application of simple thermodynamic reasoning. If civilization consumes potential energy and matter, fundamentally its evolution should be constrained by basic physical principles. At the core of the study is a finding that, while the ratio of GDP (units value per time) to energy consumption has been steadily increasing, global economic wealth (units value) has been linked to its rate of consumption of primary energy through a constant of about 10 milliwatts per inflation-adjusted 1990 dollar. Effectively, current rates of energy consumption by civilization are fundamentally coupled to wealth, where wealth is expressed as an accumulation of past inflation-adjusted economic productivity. Because the past production cannot be erased, wealth and energy consumption can therefore be interpreted as being "reddened" time integral quantities that have inertia and do not change quickly. This is important, because it implies that, for one, energy consumption and the economy cannot be decoupled, and also that future trajectories of energy consumption are unlikely to change very quickly, two properties that are not fully accounted for in the SRES scenarios. This presentation will illustrate some of the thermodynamic basis behind this result, and explore their implications for civilization wealth and CO_2 emissions in a civilization whose evolution is tied to climate change, as well as to energy reservoir discovery and depletion.

Recent multi-century climate changes are hypothesized to be primarily a result of variations in the global ocean's deep Meridional Overturning Circulation (MOC), not from CO_2 increases.

By William M. Gray
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Most of the Global Climate Model (GCM) simulations indicate that there will be a 2-5°C (4-9°F) increase in global mean surface temperature by the time a doubling of atmospheric CO_2 takes place near the end of this century. Such large CO_2 driven warming scenarios are not possible. The GCMs greatly exaggerate CO_2's potential warming influence. These exaggerations are due too:

1. GCM models show that a doubling of atmospheric CO_2 will cause a weak global warming and a small increase in global precipitation. We all accept this. But the GCMers then go much further and hypothesize that these initial CO_2 induced changes will bring about an additional much larger (or positive feedback) increase in upper tropospheric temperature and water vapor. The models assume that this additional positive feedback process will produce a global warming 2-3 times larger than the CO_2 influence by itself. New observations by satellite (ISCCP) and NOAA/NCEP reanalysis data do not support such large GCM's positive feedback assumptions. The GCMs also do not deal with the large albedo increases that occur in convective rain and cloud areas or the extra evaporation cooling resulting from increases in global precipitation.

2. GCMs do not currently model (or if they do – not accurately) the globe's deep ocean circulation or Meridional Overturning Circulation (MOC). Accurately modeling this MOC circulation is fundamental to any realistic understanding of global temperature change. Ocean MOC changes control global temperature through a combination of ocean advection, upwelling, and the precipitation differences they engender. MOC

changes are primarily driven by the global ocean's salinity variations of which CO_2 plays no direct role.

Only small changes (0.3-0.5°C) in global mean temperature should be expected from a doubling of CO_2 near the end of the 21st century. Certainly not the 2-5°C increases projected by the GCMs.

Attributing climate change to NOx emissions:
Challenges for evaluating mitigation measures

Volker Grewe, Katrin Dahlmann, Sigrun Matthes
DLR-Oberpfaffenhofen

Climate change is a challenge to society. Identifying promising mitigation measures requires a good understanding of the contribution from anthropogenic emissions, e.g. from transport (aviation, road, shipping) to climate change. Non-CO2 emissions, like NOx, perturb greenhouse gases like ozone highly non-linearly.
Recent reviews have estimated the contribution from transport to climate change.
Their approach uses state-of-the art numerical models and compares a base case with "all emissions" to a perturbation run with "changed emissions".
But it was questioned whether this so-called "perturbation-approach" is appropriate and a "tagging approach" was instead suggested,which is an accounting system following emitted species and their chemical reaction pathways.
In this study we indeed show that the contribution of road traffic to climate change via ozone formation, hence its potential mitigation gain, is systematically underestimated, when using the "perturbation approach", since the gain is partly compensated by a mitigation loss of other sectors due to increased ozone formation.
Therefore, we argue that individual mitigation gains have to be regarded simultaneously with implications on other sectors.

Observed and projected hydroclimatic variability and change
in the southwestern United States

David S. Gutzler
University of New Mexico

We present a summary of recent research on regional climate change in the southwestern U.S., emphasizing precipitation and other hydroclimatic variables. Paleoclimatic reconstructions of precipitation and streamflow illustrate that there have been very pronounced decadal-scale climatic variations in the Southwest throughout the past millennium. A growing body of empirical and model-based evidence points to tropical ocean fluctuations as a likely primary cause of interannual/decadal anomalies, via the effects of tropical SST anomalies on shifts in the cold season storm track across western North America. The extreme drought during the first half of 2011, in concert with a strong La Niña event, is certainly consistent with this concept.

Future model-based projections of climate change associated with increasing greenhouse gases suggest a modest downward century-scale trend in regional cold season precipitation and no clear trend at all in summer precipitation. Pronounced interannual/decadal variability provides considerable "noise" in the precipitation record, compared to which existing projections of forced long-term trends in 21st Century precipitation are relatively small.

Nevertheless other hydroclimatic variables that are more directly associated with surface temperature -- including snowpack, soil moisture and streamflow -- are projected to change very considerably during this century. Projected temperature increases, if realized, would generate very significant decreases in hydroclimatic variables even in the absence of regional precipitation decreases. Preliminary analyses of recent decadal variability suggests that these hydroclimatic changes are underway, despite no clear trends, but lots of variability, in observed precipitation.

A perspective on some strengths and weaknesses of ocean climate models

Matthew Hecht

Los Alamos National Laboratory

A brief survey is presented of challenges that have concerned those who apply ocean models to coupled climate studies. Parameterization of eddy mixing figures prominently, first as one of the major advances that allowed air/sea "flux corrections" to be eliminated in the 1990's, and now more recently to the issue of realistic response of the Southern Ocean to changes in wind stress. Vertical processes also underly some of the principal challenges. Due to the difficulty of obtaining measurements deep within the ocean, computer modeling plays a particularly important part in the discovery of ocean circulation and processes, and in the understanding of the role the oceans in climate.

Machine learning methods in climate and weather research

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Having originated from the field of artificial intelligence, machine learning (ML) methods (e.g. artificial neural networks) have been increasing used in the environmental sciences, as they nonlinearly generalize the classical statistical methods such as regression, classification, principal component analysis and canonical correlation analysis. The advantages and limitations of ML methods in climate and weather applications are illustrated by several examples.
Our recent work has been on using linear regression (LR) and Bayesian neural network (BNN) methods to downscale global climate model output. For 10 weather stations located in Quebec and Ontario, daily values of maximum and minimum temperatures were obtained from downscaling for the period 1961-2000. Six annual indices of extreme weather (e.g. number of frost days, heat wave duration, etc.) were also computed from the downscaled temperature output. The results show that the nonlinear BNN models usually outperform LR in simulating daily variability and, to a greater extent, in the annual climate indices for extreme weather. Work is

underway to assess the performance of the two methods in future climate, with regional climate model (RCM) output used as "pseudo-observations" to verify the downscaled model data.

Regional temperature predictions from a minimalist model

Peter Huybers

Department of Earth and Planetary Sciences
Harvard University

The general circulation models (GCMs) used to simulate future climate are under-constrained, as evidenced by the fact that factor-of-two changes in rates of ocean heat uptake magnitudes of radiative forcing anomalies and the strength of various feedbacks can be traded off against one another to yield results that all agree with observations. This indeterminacy, although inevitable given finite observations and incomplete theory, prompts the question of whether retaining many of the inherently under-constrained processes represented within GCMs is useful for predicting future climate. Here we present a simple energy balance model (EBM) that is tuned only to the seasonal cycle and driven by the same radiative perturbations as each of 18 GCMs, and show that it reproduces the spatial and temporal record of inter-annual surface temperature between 1850 and 2009 better than any of the GCMs or their ensemble average. A major discrepancy appears in the Arctic over land, where the GCMs give more warming than observed or produced by the EBM. On the basis of a better fit with the historical observations, and noting that both the GCMs and EBM predict warming patterns that are essentially linear extrapolation of their historical anomaly patterns, we suggest that the EBM's predictions of regional temperature anomalies may be more accurate than those of the GCM's.

Direct Radiative Forcing over the North East Atlantic

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The Mace Head World Meteorological Organisation Global Atmospheric Watch research station provides the best facility in Europe for the study of aerosol properties associated with the cleanest marine air being imported into Europe along with the study of polluted air being exported out of Europe into the North East Atlantic. Mace Head receives a number of consistent air masses with characteristic aerosol physico-chemical and radiative properties: namely, marine

polar (mP), maritime Arctic (mA), maritime tropical (mT), continental polar (cP) and continental marine polar (cmP). The continental air masses are predominantly polluted while the marine air masses are typically clean. Based on the aforementioned air mass properties, the direct radiative forcing at Mace Head is evaluated for midday (i.e. peak solar intensity) during summer time of year 2008 (mid-May to mid-June). For the Mace Head latitude at this time of year, the average Top Of Atmosphere (TOA) insolation was 1345 Wm^{-2} at noon. For the same noon-time periods, albeit up to a week apart, the surface insolation in polluted (cP & cmP) air masses was 876 W m^{-2} while for the cleanest marine air mass (cP), surface insolation was 1142 W m^{-2}. The difference between the polluted and cleanest air mass amounts to 266 W m^{-2}. In terms of percentage transmission of TOA insolation, 65% reaches the surface at midday under polluted conditions while 84% reaches the surface under clean air conditions – that is to say, 23% less global radiation is recorded at midday for polluted air masses during peak summertime at Mace Head as compared to cleanest marine air.

MISR decadal aerosol observations: examples of property characterization and climate applications.

Olga V. Kalashnikova[1], Michael A. Garay[1,2], Ralph Kahn [3], David J. Diner[1], Irina Sokolik[4], A. Lyapustin[4], Jae Lee[1], Omar Torres[4], and Manuel de la Torre Juarez[1]

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The Multi-angle Imaging SpectroRadiometer (MISR) instrument on the Terra satellite provides 11+ years of Earth observations, and is a unique source of data for aerosol characterization. In addition to high-quality retrievals of aerosol optical depth (AOD) and its long-term variability, MISR's multiple view angles allow sensitivity to aerosol properties over both land and water. MISR also provides stereographic views of thick aerosol plumes, allowing heights and instantaneous winds to be derived at spatial resolutions on the order of 1 km.

We provide an overview of our current MISR aerosol data applications to climate studies and describe initial steps toward using MISR radiances for detailed regional aerosol property characterization. In particular, we present a satellite perspective on dust climatology in Asian deserts and discuss MISR unique strengths and well as current product biases over these bright source regions. MISR observations reveal no statistically significant trends over the natural deserts in the last decade; rather, natural aerosol loadings seem to be predominantly affected by large-scale climatological factors such as the Arctic Oscillation (AO) and El Niño/Southern Oscillation (ENSO). We will also show MISR characterization of fraction spherical evolution during Trans-Atlantic transport. MISR does not detect changes in dust properties during trans-Atlantic dust events. Exploring MISR stereo capabilities, we will demonstrate how MISR aerosol plume heights, which do not rely on any external information concerning aerosol properties, enable study of aerosol injection and wind speeds in desert regions during dust events. Ground-based observations are frequently impossible due to blowing dust and space-based lidar signals are often saturated. A new climatology of dust plume heights and associated wind speeds in the Bodélé source region for all dust events observed by MISR from March 2000 through March 2010 (over 500 events) will be shown in context of regional dust dynamics.

Finally, we analyze capabilities of MISR radiances themself to provide information on the particle phase function that can be exploited to infer aerosol characteristics in regions that are traditionally challenging, for instance, areas of high humidity or where the aerosol types and mixing are complex. We pay particular attention to the effects of changing view/illumination geometry, which varies with latitude and season. Through radiative transfer simulations and carefully selected case studies performed in regions with appropriate ground-based and suborbital measurements, we show how the MISR radiances enable direct inference of the optical properties of real aerosols.

Solar Forcing of Climate: A Review

Charles "Chick" Keller
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Los Alamos National Laboratory

Attempts to determine variations in solar forcing have been made since the advent of satellite observations of Total Solar Irradiance (TSR). These have been influenced by variations in apparent proxies such as sunspot numbers and understanding of solar magnetodynamics. Perhaps a second order proxy is the so-called Maunder and Sporer Minima during which there were few sunspots for decades, a time accompanied by cool global temperatures—the so-called Little Ice Ages. Two major determinations (Hoyt and Schatten, 1993, and Lean 1995) showed a relatively large forcing variation. More recent studies, which showed that basic assumptions from these early determinations were incorrect, (Wang et al, 2005) suggested that forcing variations were much smaller--of the order of what has been observed in a decadal sunspot cycle. Still more recently another study (Schmidt et al, 2011) reverses this and indicates a larger variation. In addition regression studies of observed temperatures disagree on the amount of forcing—linear regressions (Lean and Rind 2008 & Camp and Tung 2007) finding approximately twice the TSI forcing (suggesting an indirect component), while non-linear ones indicate essentially TSI forcing only. The recent stillstand in global temperatures during the abnormally low activity portion of the solar cycle makes determination of solar forcing more important than previously thought. This talk will review these papers and discuss possible implications from computer simulations.

Quantifying the distribution of short-term climate model projected trends of global temperature and a comparison with observations

Paul C. Knappenberger (presenter), P. J. Michaels, J. R. Christy, C. S. Herman, L. M. Liljegren, J. D. Annan

Assessing the consistency between short-term global temperature trends in observations and climate model projections is a challenging problem. While

climate models capture many processes governing short-term climate fluctuations, they are not expected to simulate the specific timing of these somewhat random phenomena–the occurrence of which may impact the realized trend. Therefore, to assess model performance, we develop distributions of projected temperature trends from a collection of climate models running the IPCC A1B emissions scenario. We evaluate where observed trends of length 5 to 15 years fall within the distribution of model trends of the same length. We find that current trends lie near the lower limits of the model distributions, with cumulative probability-of-occurrence values typically between 5% and 20%, and probabilities below 5% not uncommon. Our results indicate cause for concern regarding the consistency between climate model projections and observed climate behavior under conditions of increasing anthropogenic greenhouse-gas emissions.

High variability of Greenland temperature over the past 4000 years estimated from occluded air in ice core

T. Kobashi[1,2], K. Kawamura1, J. P. Severinghaus[2], J.-M. Barnola[3] , T. Nakaegawa[4], B. M. Vinther[5], S. J. Johnsen[5] & J. E. Box[6]

In 2010, Greenland experienced a record high temperature and substantial ice loss by melting; adding a concern that anthropogenic warming was further impacting the Greenland ice sheet and thus accelerating sea-level rise. However, it remains imprecisely known how much warming is caused by increasing atmospheric greenhouse gasses and/or natural variability, especially for Greenland. Here, we reconstruct Greenland temperature variability over the past 4000 years at the GISP2 site (near the Summit of the Greenland ice sheet; hereafter referred to as Greenland temperature) with a method that utilises argon and nitrogen isotopic ratios in occluded air ‘bubbles’. The average Greenland temperature for the past 4000 years was -30.7 ºC with a standard deviation of 1.0 ºC and a long-term decrease by 1.5 ºC. The current decadal average surface temperature (2001-2010) at the Summit GISP2 site is -29.9 ºC, which is in the 84th percentile of the past 4000-year Greenland temperatures, meaning that approximately 16 % out of the past 4000 years was warmer than the present decade. Warmer temperatures including century-long nearly 1 C warmer periods were the norm in the earlier period of the past 4000 years during the Holocene Thermal Maximum. Therefore, we conclude the current decadal mean temperature in Greenland has not exceeded the natural variability of the 4000 years. However, climate models indicate if anthropogenic greenhouse gas emission continues, the Greenland temperature would exceed the natural variability of the past 4000 years by 2100.

Solar Irradiance and Climate

Greg Kopp

Laboratory for Atmospheric and Space Physics, Univ. of Colorado

The main driver of Earth's climate, providing 2500 times the amount of energy of all other input sources combined, is the Sun. Fortunately the Sun's energy input to the Earth is fairly stable, but even small fluctuations in this energy can affect global and regional temperatures on all time scales, and solar variability plus other natural influences have historically been the Earth's primary climate drivers. Even with these natural influences currently overshadowed by anthropogenic effects, in order to understand climate and set appropriate regulatory policies, determining the solar contributions to climate change remains a key international priority. I'll discuss the climate-driven method of deriving requirements for these extremely accurate solar radiometric measurements, assess the status of current irradiance measurements including very recent progress improving the accuracy of the existing 33-year solar climate data record, show estimated global and regional climate sensitivities to solar forcing, and suggest what future progress should be made to measurements and climate models.

High-Latitude Terrestrial Climate Change Feedbacks in an Earth System Model

David Lawrence[1], Andrew Slater[2], Sean Swenson[1], Hanna Lee[1]

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The Arctic is currently experiencing rapid environmental change. Numerous studies have shown clear evidence of change that is pervasive throughout the terrestrial Arctic system including widespread permafrost thaw and associated thermokarst initiation, changes in lake distribution, shifts in vegetation community composition, as well as changes in a host of other ecosystem processes. Threshold and non-linear responses associated with phase change between ice and water leave the Arctic particularly susceptible to swift and disruptive change. The fate of the Arctic carbon cycle including the potential release of soil carbon as carbon dioxide or methane, as well as any counterbalancing carbon accumulation via enhanced vegetation growth, is fundamentally governed by present and future soil hydrologic states. Comprehensive Earth System Models (ESMs), such as the Community Earth System Model (CESM), are required to assess the integrated Arctic and global response to terrestrial Arctic change; the integrated effect of these terrestrial

Arctic feedbacks remains difficult to quantify and the extent to which they might interact with each other is even less understood. We will describe recent efforts to model Arctic terrestrial climate change feedbacks in CESM and give an example of an Arctic feedback in the form of an analysis of the impact of anticipated expansion of shrubs on Arctic surface climate and permafrost.

Formalizing uncertainty about climate feedbacks

Derek Lemoine

University of Arizona

Uncertainty about biases common across models and about unknown and unmodeled feedbacks is important for the tails of temperature change distributions and thus for climate risk assessments. I will summarize two recent papers that seek to formalize uncertainty about feedbacks. The first paper develops a hierarchical Bayes framework that explicitly represents uncertainty about shared biases and omitted feedbacks. It uses models' estimates of individual feedbacks' strength to generate posterior probability distributions for equilibrium temperature change. The second paper then uses paleoclimatic data to estimate climate-carbon (or carbon cycle) feedback strength by disentangling the causal effect of interest from the effects of reverse causality and autocorrelation. The response of carbon dioxide to variations in orbital forcing over the past 800,000 years suggests that millennial-scale climate-carbon feedbacks are significantly positive and significantly greater than century-scale feedbacks. Combining these estimates of feedback strength with the first paper's statistical model demonstrates the important role empirical feedback estimates can play in constraining distributions for feedback strength.

Climate v. Climate Alarm

Richard Lindzen

Massachussetts Institute of Technology

The underlying physics of climate contains important elements that are widely agreed on though frequently misunderstood. In this talk, the basic physics of greenhouse warming are simply described. It will be shown that the dynamic mixing of the troposphere is essential to the mechanism. It will further be shown that there is nothing intrinsically alarming in the basic physics. Alarm depends critically on the assertion that the climate system is dominated by large positive feedbacks that greatly amplify such warming as may be due to increasing CO2 alone. The nature of possible feedbacks will be described, and the conditions for observationally determining such feedbacks will be explained. It will be seen that the feedback factors, themselves, can be subject

to fluctuations, so that large positive feedbacks could occasionally lead to instability. A variety of attempts to evaluate such feedbacks will be described. Some will be shown to be clearly incorrect. The remaining approaches suggest that feedbacks are small and even negative, suggesting little basis for alarm.

Climate Change Attribution

Using Empirical Decomposition of Climatic Data

Craig Loehle

Nicola Scafetta

The climate change attribution problem is addressed using empirical decomposition. Cycles in solar motion and activity of 60 and 20 years were used to develop an empirical model of Earth temperature variations. The model was fit to the Hadley global temperature data up to 1950 (time period before anthropogenic emissions became the dominant forcing mechanism), and then extrapolated from 1951 to 2009. The residuals showed an approximate linear upward trend after 1942. Herein we assume that this residual upward warming has been mostly induced by anthropogenic emissions, urbanization and land use change. The warming observed before 1942 is relatively small and is assumed to have been mostly naturally induced. The resulting full natural plus anthropogenic model fits the entire 160 year record very well. Residual analysis does not provide any evidence for a substantial cooling effect due to sulfate aerosols from 1940 to 1970. The cooling observed during that period may be due to a natural 60-year cycle, which is visible in the global temperature since 1850 and has been observed also in numerous multisecular climatic records. New solar activity proxy models are developed that suggest a mechanism for both the 60-year climate cycle and a portion of the long-term warming trend. Our results suggest that because current models underestimate the strength of natural multidecadal cycles in the temperature records, the anthropogenic contribution to climate change since 1970 should be around half of that previously claimed by the IPCC. A 21st Century forecast suggests that climate may warm less than 1 ºC by 2100.

Impact of the Atlantic Meridional Overturning Circulation (AMOC) on Arctic Sea-ice Variability

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The Atlantic Meridional Overturning Circulation (AMOC) is often thought to be a major source of decadal/multidecadal variability in the climate system. Here, we investigate the role of the AMOC on the Arctic sea-ice cover. Observations show an accelerating decline of Arctic sea-ice cover and a rise in surface air temperature in recent decades. The attribution of recent Arctic warming and sea-ice decline to enhanced anthropogenic greenhouse gas emissions or low frequency oceanic variability is under current investigations. We study the simulated impact of the AMOC on the low frequency variability of the Arctic Surface Air temperature (SAT) and sea-ice extent with a 1000 year-long segment of a control simulation of GFDL CM2.1 climate model. The simulated AMOC variations in the control simulation are found to be significantly anti-

correlated with the Arctic sea-ice extent anomalies and significantly correlated with the Arctic SAT anomalies on decadal timescales in the Atlantic sector of the Arctic. The maximum anti-correlation with the Arctic sea-ice extent and the maximum correlation with the Arctic SAT occur when the AMOC Index leads by one year. An intensification of the AMOC is associated with a sea-ice decline in the Labrador, Greenland and Barents Seas in the control simulation, with the largest change occurring in the winter. The recent declining trend in the satellite observed sea-ice extent also shows a similar pattern in the Atlantic sector of the Arctic in the winter, suggesting the possibility of a role of the AMOC in the recent Arctic sea-ice decline in addition to anthropogenic greenhouse gas induced warming. However, in the summer, the simulated sea-ice response to the AMOC in the Pacific sector of the Arctic is much weaker than the observed declining trend, indicating a stronger role for other climate forcings or variability in the recently observed summer sea-ice decline in the Chukchi, Beaufort, East Siberian and Laptev Seas. Statistical decadal forecast models constructed from AMOC fingerprints predict that the AMOC strength might decline in the next few years. A declining AMOC could potentially slowdown the rate of decline of the Arctic sea-ice in the Atlantic sector by partially offsetting the effects of the anthropogenic greenhouse gas induced global warming in the coming years.

Climate, vegetation mortality, and the carbon cycle.

Nate McDowell

Los Alamos National Laboratory

There is recent evidence of globally-widespread vegetation mortality events, that these events are increasing in recent decades, and fear that the events will lead to positive feedbacks on climate. Understanding of the mechanisms driving mortality, and the consequences upon the Earth system, are poorly quantified thus far. New datasets and modeling analyses are pointing towards common driving mechanisms but variable final thresholds leading to mortality, as well as a new understanding of the magnitude of the consequences on the carbon cycle and climate. I will review the state of knowledge on these subjects, with an emphasis on distinguishing between theories that have strong versus weak support.

Accelerated melting and disappearance of glaciers and ice caps

[1] Sebastian H. Mernild, [2] William H. Lipscomb, and [3] David B. Bahr

Glaciers and ice caps (GIC) are losing mass and raising global sea level. The rate of glacier retreat has been difficult to quantify because long-term mass-balance observations have been available for only a few dozen of the Earth's estimated 300,000 to 400,000 GIC. An easily measured property, especially for remote sensing, is the AAR, the ratio of the accumulation area to the total area of a glacier. For a glacier in balance with its local climate, the average mass balance is zero and the AAR is equal to its equilibrium value, AAR_0. Given a sustained value of

$AAR < AAR_0$, a glacier will retreat from lower elevations until the AAR is restored to its equilibrium value. Here, we present a data set of 84 observed GICs from 1995–2009 and show that most GICs are even farther from equilibrium than previously estimated. For the past decade, 2000–2009, these GICs have an average AAR of 35%, far below the mean equilibrium value of 58%. Our analysis suggests that in order to be in balance with the present climate, the Earth's GICs must lose ~40% of their volume, raising global sea level by ~240 mm. Extrapolation of recent trends suggests that if the climate continues to warm for another two decades, GIC volume will ultimately decline by 75% or more.

Sea Level Changes in the Indian Ocean: Observational facts

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In order to assess the reality of sea level changes in the Indian Ocean, we need (here like everywhere else) investigations carried our by real sea level specialists in firm field studies in areas under discussion themselves. Computer modelling by persons not even having visited the sites in questions is simply not good enough. In year 2000, we started an international sea level project in the Maldives, where several distinguished sea level specialists took part. Personally, I have been there six times, out of which three were as leader of major research expeditions.

What is to be seen in nature itself, from island to island, is clear and straightforward: there is no ongoing rise in sea level at all. At about 1970, sea level fell by about 20 cm, and has remained quite stable there after (i.e. for the last 30-40 years). We have investigated several different shore environments (open coasts, rock-cut platforms, sandy shores in erosion as well as in progradation, lagoons, lakes, fens, etc.) with respect to stratigraphy, morphology, biology and chronology (with 55 new C14-dates). Such an overwhelming mass and quality of observational facts must, of course, outdo idle talk (like what is being claimed by IPCC and exaggerated by President Nasheed). Scientific reports are published in, for example, *Global and Planetary Change* (v.40, p.177-182, 2004), *Internationales Asienforum* (v.38, p.353-374, 2007) and Chapters 6 and 7 in. "*Evidence-based Climate Science*", D.J. Easterbrook, Ed. (Chapter 6, p. 185-196, Chapter 7, p. 197-209, Elsevier, 2011)

In 2009, I visited the Sunderban delta area in Bangladesh and was able to observe clear evidence of strong coastal erosion but no rise in sea level. The stratigraphy, morphology, vegetational evolution and habitation record a minor sea level lowering at around 1960, followed by 40-50 years of stable sea level. Those sources of information are superior to local tide-gauges in the Sunderban delta, which seem quite unstable. A scientific report is published in *Energy & Environment* (v.213, p.249-263, 2010).
It seems significant that both the tide-gauge of Mombai and Visaakhapatam in India record a significant sea level drop in 1955-1962 followed by 50 years of stable sea level (*op.cit.*). In the Laccadives, the locals are quite aware of the fact that sea level is not at all in a rising mode today, rather that new land has been added, leaving previous shore to become overgrown and invaded by terrestrial snails.

In conclusion, there is no sea level rise going on at the moment in the Indian Ocean. All talk about an alarming ongoing rise in sea level is nothing but an illusion (further developed in *Global and Planetary Change*, v.40, p.49-54, 2004, *Quaternary International*, v. 221, p.3-8 and *21st Century Science & Technology*, v. Winter 2010/11, p.7-17, 2011) to be abandoned the sooner the better, because ***it steals the limelight from real problems in the real world***.

Is CO2 mitigation cost-effective?

Christopher Monckton of Brenchley

A metric derived from results of the Intergovernmental Panel on Climate Change (IPCC) permits policymakers to estimate the quantum of global warming that a proposed policy to reduce CO2 emissions may forestall, as well as the policy's mitigation cost-effectiveness in dollars per Kelvin forestalled, its global abatement cost (as a percentage of GDP) in forestalling predicted global warming to a target year, and its climate action/inaction ratio. Case studies, including a study of the Australian Government's draft CO2 tax policy, illustrate the metric's utility in comparing competing policy options. Government estimates of the cost of climate action are found to be greatly understated, while official estimates of the welfare loss from climate inaction are overstated. At intertemporal discount rates from 0.1-5%, the global abatement cost of the Australian carbon tax is found to be 4-40 times the welfare loss from inaction. Mitigation policies inexpensive enough to be affordable will be ineffective, while policies costly enough to be effective will be unaffordable. It is unlikely that any CO2 mitigation policy will prove cost-effective solely on grounds of the welfare benefit foreseeable from mitigating global warming. Focused adaptation to any adverse consequences of future global warming is more cost-effective than attempted mitigation.

Aerosol Optics, Direct Radiative Forcing, and Climate Change

Hans Moosmüller

Aerosols influence the earth's direct radiative forcing and climate largely through modifying the planetary albedo, which is the whiteness of the planet as seen from the sun. If aerosols are whiter than the underlying scene, as seen from space, they increase the planetary albedo, have a negative radiative forcing and cause cooling (more solar energy is scattered back into space); otherwise if they appear darker, they decrease the planetary albedo, have a positive radiative forcing and cause heating (more solar energy is retained by earth). In addition, aerosols can continue to cause radiative forcing after deposition. In particular, dark aerosols can strongly decrease surface albedo after deposition on high-albedo surfaces such as snow and ice.

The dominant aerosol optical property that determines radiative forcing is their single scattering albedo (SSA) integrated over the solar spectrum with an additional contribution from the asymmetry parameter or hemispherical backscatter ratio (Chýlek and Wong, 1995}. The SSA is the ratio of scattering to extinction coefficient, with the extinction coefficient being the sum of scattering and absorption coefficient. To determine the SSA, two of these three coefficients need to be determined, preferentially one small one and one large one, absorption and scattering or extinction coefficient for the fairly white (SSA near 1) aerosols.

The ambient aerosols with the most uncertainty in their SSA spectrum are carbonaceous aerosols emitted by combustion processes and entrained mineral dust. Here, we discuss multiwavelengths measurements of scattering and absorption coefficients for these aerosols with a focus on the dominant biomass burning aerosols containing light absorbing black and brown carbon and mineral dust aerosols whose light absorption is generally dominated by iron oxides strongly absorbing in the blue-green spectral region. Spectral properties are discussed in terms of the Ångström coefficients of absorption, scattering, extinction, and SSA.

References:

Chýlek, P., and J. Wong (1995). Effect of Absorbing Aerosol on Global Radiation

Budget. Geophys. Res. Lett., 22, 929-931.

The Berkeley Earth Surface Temperature Land Results – Analysis of Effects from Urbanization and from Variable Station Quality, and Correlations with Oceanic Indices.

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We will report additional results from the Berkeley Earth project. We have made an independent estimate of the Earth Land Surface Temperature Tavg using only sites that are distant from regions identified as “urban” by the Modis satellite team. This gives an independent assessment of the potential urban heat island bias on the global record. We have analyzed the US land record according to station quality (as ranked by the team of Anthony Watts) and analyze potential biases. We have created a new Tavg based solely on data not previously used by the other groups, to determine which of the fluctuations on the 2 to 15 year time scale are truly variations (rather than statistical fluctuations). We will show the correlation of Tavg with oceanic indices (including ENSO, AMO, PDO, and others) and will show our analysis

[1]The Berkeley Earth Project was organized under the auspices of Novim. The team members who contributed to this work are David Brillinger, Judith Curry, Don Groom, Robert Jacobsen, Elizabeth Muller, Richard Muller, Saul Perlmutter, Robert Rohde, Arthur Rosenfeld, Charlotte Wickham, Jonathan Wurtele

Looking for Climate Signals in Ice Core Data

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We have examined the O18 record from several sites in Greenland and Antarctica. We use old fashioned time series analysis to investigate activity in several frequency bands. All spectra resemble that of an AR1 process with some peaks that are significantly above this continuum noise level. In particular, we detect the 11 yr solar cycle which is faint but statistically significant in all the cores. By use of band pass filtering about this peak we can trace the strength of the signal back several centuries and compare it with independent data sets related to solar activity (C14 and Be10). The ENSO cycle is also present especially in Greenland. The dominant frequency patterns of ENSO (between 2 and 6 yr period) vary on centennial time scales.

Scale-specific patterns of phase coherence between solar/geomagnetic activity and climate variability

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Detection and extraction of quasi-oscillatory dynamical modes from instrumental records of meteorological variables, climatological proxies and proxies of solar activity, or other geophysical data became a useful tool in analysing variability of observed phenomena reflected in complex, multivariate geophysical signals. Recent development in nonlinear dynamics, namely in chaotic synchronization brought a possibility of novel ways to study relations between such modes representing a part of atmospheric variability and possible external influences. Palus & Novotna [1] proposed the enhanced Monte Carlo Singular System Analysis (MC SSA) in which, in addition to the signal covariance structure, regularity and predictability of the SSA modes is quantified and tested. Applying the enhanced MC SSA on monthly time series of sunspot numbers, geomagnetic activity aa index, North Atlantic Oscillation (NAO) index and near-surface air temperature from several mid-latitude European stations they detected a number of oscillatory modes, some of them with common periods [2]. Instantaneous phases of the detected modes underwent synchronization analysis. In the case of the modes with the period 7-8y statistically significant phase coherence, beginning from 1950's, has been observed [3].

Here we study scale-specific North Hemisphere patterns of phase coherence between solar/geomagnetic activity and NCEP/NCAR and ERA40 near-surface air temperature. Both the reanalysis datasets provide consistent patterns of areas with marked, statistically significant coupling between solar/geomagnetic activity and climate variability observed in continuous monthly data, independent of the season, how- ever, con_ned to the temporal scale related to oscillatory periods about 7-8 years [4]. The patterns of coupling between the solar/geomagnetic activity and temperature variability are compared with patterns of coherence between the NAO index and the temperature data. Using the concept of partial phase synchronization [5] we investigate the role of the NAO in transferring solar signatures from the stratosphere to the troposphere.

Does the Climate Change the Economy? An Empirical Investigation of the Local Economic Impacts of Extreme Weather Events in Southwestern American Counties

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Do extreme weather events have an impact on local economies? Has local governments' public finance been impacted by climate change? Can the complex dynamics between climate and economic threaten the feasibility of local adaptation policies? These are the main questions this presentation will focus on.

While the existent literature has generally adopted an extremely case-based approach that focuses on a few most sensible economic sectors and spatial areas, in this work we overcome the lack of generalization by using an empirical econometric study. We analyzed the last twenty years of regional climate, extreme weather events, economic and financial indicators of more than 500 counties in the South-West of USA (from California to Texas). The analysis is conducted on monthly values and the data comes from several sources such as the National Climatic Data Center, the Census Bureau, the Department of Labor, the Federal Reserve and the Municipal Security Rule-making Board.

The outcomes of our analysis show that different extreme events have completely different impacts on the economy: events that create strong immediate damages generally give raise to counter-intuitive short-term economic bursts and different sectors have different degrees of resiliency. Our study also shows that federal funds, private insurance and local public bonds are all impacted by extreme weather events: extreme events increase the cost of debt of local governments because municipal bonds issued after extreme events pays higher costs for short term maturities.

In conclusion, the outcome of our analysis of the Southwest confirms that climate change has already had a relevant impact on the local economy. This work provides the first quantitative elements of a future model assessing local risks due to climate change, and it questions the financial sustainability of public policies aimed either at recovering damages created by extreme weather events or at adapting the local economy to climate change.

Rapid Climate Change and the Arctic: The Case of the Younger-Dryas Cold Reversal

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Beginning at approximately 12, 800 years before present, during the transition from cold glacial to warm interglacial conditions, the climate system "suddenly" returned to a state of near full glacial extreme cold in the northern hemisphere, at state in which t remained for over a thousand years before finally making the transition into the Holocene. The original explanation of this event suggested it to have been due to a diversion of the run-off from glacial Lake Agassiz from an

initially southward route into the Gulf of Mexico to an eastern route through the Great Lakes system and the St Lawrence River onto the North Alantic Ocean. This freshwater outflow would have been transported by the North Atlantic drift into the Greenland- Iceland-Norwegian (GIN) Seas.where it would have significantly reduced the rate of the deep water formation and thus the strength of the thermohaline overturning circulation, thereby cooling the entire northern hemisphere. This suggestion was shown to be highly suspect in a short paper by Lowell et al (2005) who, having searched for the spillway that would have been required to transport Lake Agassiz water to the east into Lake Superior, failed to find any evidinece on the landscape supporting this scenario. Tarasov and Peltier (2005) published almost simultaneously an analysis of the runoff routing that should have been operative during deglaciation and suggested. that the required freshwater outflow at the onset of the Y-D event would have switched to the north through the Mckenzie River outlet into the Arctic Ocean rather than to the east onto the Atlantic through the Great Lakes. In Peltier et al (2006) and Peltier (2007) coupled climate model simulations were employed to examine the impact upon the THC that Arctic freshenig would be expected to have had. These analyses demonstrated that Arctic freshening would have been as efficient a means of causing a reduction in THC strength as would direct freshening of the Atlantic. In this case he freshwater added to the Arctic would be transported by the transpolar drift through Fram Strait and thereafter onto the GIN Seas. I will describe an exhaustive set of new coupled climate model simulations intended to further test the "Northern Route Hypothesis". These furher emphasize the importance of the Arctic Ocean as a source of rapid climate change, at least during glacial conditions.

Recent and long-term changes in the Arctic climate system

Igor V. Polyakov

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The Arctic Ocean is characterized by large amplitude multi-decadal variability (MDV) in addition to a long-term trend, making the link to climate drivers from observed changes in the ecosystem problematic. Our analyses demonstrate a strikingly coherent pattern of long-term variations of the key Arctic climate parameters and strong coupling of long-term changes in the Arctic climate system on large spatiotemporal scales. The arctic surface air temperature, Arctic Ocean freshwater content (FWC) and intermediate Atlantic Water (AW) temperature and fast-ice thickness show coherent low-frequency variations. Associated with this variability, the FWC and AW temperature records show two periods in the 1920-30s and in recent decades when the central Arctic Ocean was saltier and warmer and two periods in the earlier century and in the 1940-70s when it was fresher and cooler. Recent observations documented fundamental changes in the high-latitude systems. One of the examples of these changes is an almost synchronous reduction of the on-going warm anomaly in various regions of the Arctic Ocean, which suggests that local atmosphere-ocean and shelf-basin interactions influenced by anomalous openings in ice cover likely play an important role in ventilating the ocean's interior. Whether these recent changes signify an irreversible shift of the Arctic Ocean to a new climate state is yet to be seen. However, it is evident that elucidating the mechanisms behind these changes will be critical to our understanding of the complex nature of climate changes and projection of these changes on ecosystem. Addressing these and other questions requires a carefully orchestrated combination of *sustained* observations and advanced modeling.

Addressing the Leading Scientific Challenges in Climate Modeling

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There is an increasing need and urgency to understand and advance the knowledge on climate change, and explore the predictability of the system on climate timescales. Leading problems sought to be addressed include: the forcing and feedback factors driving the atmospheric composition and climate change of the 20th Century and how they would affect the course of the climate system in the 21st Century, in essence the roles of the natural and anthropogenic factors; changes in the atmospheric composition, chemistry and climate from global and continental space scales to the regional scales, and the ability to characterize the scientific uncertainties;

and the evolution of the climate system over the next few decades arising under the action of unforced and forced mechanisms.

To address these challenges, NOAA/ GFDL is undertaking research into distinct modeling streams and arrive at an improved characterization of the physical and chemical processes governing climate change. The aim is the mathematical simulation of the climate system with increasing realism and accuracy. The results of the research thrusts include simulations performed for the World Climate Research Program's Coupled Model Intercomparison Project (CMIP5). In particular, long-lived greenhouse gases, and the short-lived species such as ozone and aerosols, are numerically modeled with increased consistency. Through these numerical simulations, there is a better diagnosis of the roles that trace gases and aerosols have likely played in the global-to-regional scale climate change over the past 50 years, and the potential roles of the species in the 21st Century. The variables investigated include surface temperature, precipitation and the hydrologic cycle, and extremes. Additionally, high-spatial-resolution climate modeling is providing important information concerning transport of short-lived species away from source regions, and yielding better descriptions and insights into the interactions governing the climate system. Characterization of the uncertainties surrounding climate response, from emissions of species to their transformation and removal to the feedbacks, is an important step in evaluating the extent of the influences by the different factors. These considerations also motivate the research exploration into the predictability of climate on decadal timescales.

Exploration of aerosol, cloud and dynamical feedbacks in the climate-cryosphere system

Phil Rasch

Abstract. I will describe our recent efforts to identify the role of various processes responsible for aerosol, water and heat transports into the arctic. These processes influence radiative forcing, atmospheric stability and sensitivity, and climate feedbacks in high latitudes. We use the NCAR CESM (global) and WRF-Chem (regional) Community models to explore transport and feedback processes in the Arctic and climate response. Some our simulations are allowed to evolve freely allowing climate feedbacks to operate strongly; others have been strongly constrained to agree with observed meteorological fields constraining model behavior. Aerosols sources have also been tagged by sector and geographic region to help in attribution and interpretation. The studies help in teasing out mechanisms for forcing and response models, and indicate some systematic biases in aerosol source, transport and sink mechanisms.

A New Estimate of the Earth Land Surface Temperature Spanning 1800 to the Present

Robert Rohde

Berkeley Earth Surface Temperature Project[1]

We have developed a new mathematical framework for producing maps and large-scale averages of temperature changes from land based thermometer records. Our method allows inclusion of short and discontinuous temperature records, so that the analysis can include nearly all of the 40,000 stations records available. A weighting process lets the quality and consistency of a spatial network of temperature stations to be assessed as an integral part of the averaging process, permitting data with varying levels of quality to be used without compromising the accuracy of the resulting reconstructions. The process is extensible to spatial networks of arbitrary or locally varying density while maintaining expected spatial relationships. We will show new results for land temperature from 1800 to present with error uncertainties that include many key effects, and will compare our results with those of the three other major groups at NOAA, NASA, and the Hadley Center Climate Research Group collaboration.

[1]The Berkeley Earth Project was organized under the auspices of Novim. The team members who contributed to this work are David Brillinger, Judith Curry, Don Groom, Robert Jacobsen, Elizabeth Muller, Richard Muller, Saul Perlmutter, Robert Rohde, Arthur Rosenfeld, Charlotte Wickham, Jonathan Wurtele

Number of activated CCN as a key property in measurements and parameterization of cloud-aerosol interactions and their climate effects

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The microphysical evolution of convective clouds is affected by a large number of factors, including CCN supersaturation activation spectra, updraft speeds at cloud base and at higher levels, extent of mixing with the ambient dry air, coalescence and development of warm rain, and finally mixed phase processes. This appears as an extremely complex system, which has been recognized as a major challenge for understanding the climate system. In particular, the impacts of aerosols on cloud microstructure have been perceived as a major cause for uncertainty of our understanding of the anthropogenic forcing of the climate system.

We show here that the understanding of convective clouds can be distilled to few very simple and fundamental quantities that can be used in turn for describing and explaining the complexities presented in the opening statement above. Much of the complexity in clouds and highly non linear dynamics are caused by the response of the clouds to aerosol impacts on precipitation. For example, there is growing body of evidence that the transitions between open and closed cell regimes in marine stratocumulus are triggered by the onset or suppression of heavy drizzle (Rosenfeld et al., 2006). Cloud drop effective m for onset of heavy drizzle (Gerber, 1996).μradius has to exceed about 14 This threshold is exceeded at greater heights for clouds having larger number concentrations of drops (Gerber, 1996). Similarly, delaying the height for onset of warm rain to above the freezing level was shown to allow releasing the extra latent heat of freezing and cloud invigoration (Rosenfeld et al., 2008). This causes the cloud to grow colder and the anvils to expand to larger areas and form greater cover of cirrus (Koren et al., 2005 and 2010). This potentially induces strong positive radiative forcing that may balance the negative forcing by the shallow clouds. The net effect is a difference between two large and highly uncertain numbers of opposite signs, rendering the climate forcing highly uncertain even for its sign. Furthermore, the spatial separation between the areas of cooling and warming can propel atmospheric circulation systems.

The fundamental driver of these effects can be boiled down to the depth that convective clouds need to grow to for start developing precipitation by drop coalescence. It has been debated if such threshold depth exists at all, and if so, what would determine it. Theoretically, cloud base drop concentrations would be linear with the critical depth for onset of rain, D_c in growing convective clouds, if:

1. All cloud drops nucleate near cloud base.
2. The shape of cloud drops size distribution remains nearly the same up to the height of D_c. This is so because there is a tight

linear relationship between the mean volume radius, r_v, and cloud drop effective radius, r_e.

3. r_e increases with height as in adiabatic parcel. This requires extreme inhomogeneous mixing.
4. Adiabatic water mixing ratio, q_L, increases linearly with Depth above cloud base.
5. D_c, Depth for reaching a critical r_v increases linearly with N_a, number of activated drops near cloud base.
6. Rain onset occurs for a given m.μRe of ~14

By analyzing large amounts of cloud physics aircraft data that made vertical profiles of cloud microstructure and CCN below cloud base in various locations around the world we demonstrate that these theoretical assumptions are practically occurring in reality to sufficiently close approximation to be very useful.

Furthermore, it is shown here that the fundamental cloud property is Na, the number of activated CCN at cloud base. This is so because Na is determined by the combined effects of cloud base CCN and updrafts. Due to the nearly extreme inhomogeneous nature of the mixing of the cloud with ambient air, mixing evaporates completely the affected drops and leaves little changed the remaining drops. Therefore, r_e remains almost as in adiabatic cloud parcel, while cloud liquid water content (LWC) and drop concentrations can dilute strongly. Because the adiabatic r_e depends only on the thermodynamic property of adiabatic water LWC and on Na, there is a unique relation between Na and r_e as a function of depth above cloud base. Brenguier et al. (2000) developed the idea of using vertical profiles of cloud effective radius to calculate the number density of activated cloud condensation nuclei (Na) at the base of shallow cumulus clouds. Then, Freud et al. (2011) generalized the idea to deeper clouds.

Therefore, for a given cloud base temperature and pressure Na determines uniquely the height for reaching r_em, which occurs at the cloud depth for onset of warmμ=14 rain, D_c. The value of Dc is not affected by variability of updraft speeds above cloud base, because, by definition, the clouds undergo mainly diffusional growth before significant coalescence starts.

Na encapsulates the effects of both CCN spectra and cloud base updraft. It is the most fundamental extensive property of growing convective clouds.

References:

Brenguier, Jean-Louis, Hanna Pawlowska, Lothar Schüller, Rene Preusker, Jürgen Fischer, Yves Fouquart, 2000: Radiative Properties of Boundary Layer Clouds: Droplet Effective Radius versus Number Concentration. J. Atmos. Sci., 57, 803-821.

Freud, E., D. Rosenfeld, D. Axisa, and J. Kulkarni (2011), Resolving both entrainment mixing and number of activated CCN in deep convective clouds, Atmospheric Chemistry and Physics Discussions, 11, 9673-9703.

Gerber H.: Microphysics of marine stratocumulus clouds with two drizzle modes, J. Atmos. Sci., 53, 1649-1662, 1996.

Koren I., Y. J. Kaufman, D. Rosenfeld, L. A. Remer1, Y. Rudich, 2005: Aerosol invigoration and restructuring of Atlantic convective clouds. Geophys. Res. Lett., 32, L14828.

Koren I. et al., 2010: Aerosol-induced changes of convective cloud anvils produce strong climate warming. Atmos. Chem. Phys., 10, 5001-5010, 2010.

Rosenfeld D., Y. Kaufman, and I. Koren, 2006: Switching cloud cover and dynamical regimes from open to closed Benard cells in response to aerosols suppressing precipitation. Atmos. Chem. Phys., 6, 2503-2511.

Rosenfeld, D., U. Lohmann, G.B. Raga, C.D. O'Dowd, M. Kulmata, A. Reissell, M.O.. Andreae, Flood or drought: How do aerosols affect precipitation? Science, 321, 1309-1313, 2008.

Impact of Aerosols, Ocean Circulation, and Internal Feedbacks on Climate

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We examine globally averaged surface temperature (T), from 1900 to present, in terms of the historical change in external factors that drive radiative forcing (RF) at the tropopause, such as greenhouse gases, anthropogenic aerosols, solar irradiance, volcanic aerosols, and sea surface temperature. The inferred impact of volcanic aerosols on T is sensitive to how variations in sea surface temperature are treated: this finding has potentially important implications for geo-engineering of climate. We show, as noted previously by Kiehl (2007) and

Schwartz et al. (2007), that IPCC (2007) climate models have likely been tuned to match the observed surface temperature record by balancing internal climate feedback (CF) and the RF due to anthropogenic aerosols (RF_{AER}), both of which are quite uncertain. This tuning of climate models is perhaps benign for our understanding of past climate because observed T can be simulated nearly equally well for a wide range of CF and RF_{AER}. However, RF_{AER} will likely be ameliorated during this century due to air quality concerns. The computed increase in T for doubled CO_2 (commonly known as the climate sensitivity) will therefore depend solely on CF. We suggest uncertainties in the projection of future climate would be considerably reduced if the community could precisely define the net radiative forcing at the tropopause due to anthropogenic aerosols for the present-day climate, because this would provide an important constraint on our knowledge of CF.

The climate oscillations: analysis, implications and their astronomical origin

Nicola Scafetta, ACRIM & Duke University

During the last century the global surface temperature has warmed by about 0.8 ^{o}C. General Circulation Model (GCM) simulations have been used to interpret the observed global warming and have concluded that most of it, more than 90% according to the *Intergovernmental Panel on Climate Change* (IPCC), has been induced by anthropogenic greenhouse gas emissions such as CO_2, as a consequence of the industrial development of the world. This is known as the Anthropogenic Global Warming (AGW) theory. The same GCMs produce alarming estimate projections for the 21st century and these theoretical results are currently used for suggesting global climate change mitigation policies. However, numerous recent studies are challenging the validity of the AGW and the accuracy of the current GCMs by suggesting that natural climate changes may have been seriously underestimated. Herein, we will review some of these new results by showing evidences that climate is regulated by multiple chaotic quasi-periodic natural cycles at all time scales. We will focus on decadal, secular and millennial time scales.

We show that several global surface temperature records since 1850 and astronomical records deduced from the orbits of the planets present very similar power spectra. Eleven frequencies with period between 5 and 100 years closely correspond in the terrestrial and astronomical records. Among them, large climate oscillations with peak-to-trough amplitude of about 0.1 K and 0.2 K, and periods of about 20 and 60 years, respectively, are synchronized to the orbital periods of Jupiter and Saturn. Schwabe and Hale solar cycles are also visible in the temperature records. At least a 9.1-year cycle is synchronized to the Moon's orbital cycles. On multi-secular and millenarian time scales other astronomical cycles appear to be synchronized with known solar activity and the most recent paleoclimate temperature reconstructions. A phenomenological model based on these astronomical cycles can be used to well reconstruct the temperature oscillations since 1850 and to make partial forecasts for the 21st century. It is found that about 60% of the global warming observed since 1970 has been induced by the combined effect of the 20 and 60-year natural climate oscillations and about 50% of the trending of the secular warming since 1850 has been induced by multi-secular and millennial natural cycles. A partial forecast for the 21st century is proposed. It suggests that climate may stabilize or cool in the following decades. The empirical solar/planetary model is shown to outperform typical IPCC GCMs in reconstructing climate oscillations and suggests that these models are missing fundamental mechanisms that have their physical origin and their ultimate justification in astronomical phenomena, and in interplanetary and solar-planetary interaction physics.

N. Scafetta, "Empirical evidence for a celestial origin of the climate oscillations and its implications". *Journal of Atmospheric and Solar-Terrestrial Physics* (2010), doi:10.1016/j.jastp.2010.04.015 PDF

N. Scafetta, "Climate Change and Its Causes, A Discussion About Some Key Issues", Nicola Scafetta, SPPI original paper, March 4 (2010). PDF

N. Scafetta, "Empirical analysis of the solar contribution to global mean air surface temperature change," *Journal of Atmospheric and Solar-Terrestrial Physics 71, 1916-1923 (2009)*, doi:10.1016/j.jastp.2009.07.007. PDF

C. Loehle and N. Scafetta, "Climate Change Attribution Using Empirical Decomposition of Climatic Data", The Open Atmospheric Science Journal *5, 74-86 (2011) http://benthamscience.com/open/toascj/articles/V005/74TOASCJ.htm*

N. Scafetta, "Total Solar Irradiance Satellite Composites and their Phenomenological Effect on Climate," chapter 12, pag 289-316. (In "Evidence-Based Climate Science: Data opposing CO2 emissions as the primary source of global warming" edited by Don Easterbrook, Elsevier) (2011). PDF

A. Mazzarella and N. Scafetta, "Evidences for a quasi 60-year North Atlantic Oscillation since 1700 and its meaning for global climate change," Theor. Appl. Climatol., DOI 10.1007/s00704-011-0499-4 (2011). PDF

Vulnerability of Permafrost Carbon Research Coordination Network

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Approximately 1700 Pg (billion tons) of soil carbon are stored in the northern circumpolar permafrost zone, more than twice as much carbon than currently contained in the atmosphere. Permafrost thaw, and the microbial decomposition of previously frozen organic carbon, is considered one of the most likely positive feedbacks from terrestrial ecosystems to the atmosphere in a warmer world. Yet, the rate and form of release is highly uncertain but crucial for predicting the strength and timing of this carbon cycle feedback this century and beyond. Here we report on the formation of a new research coordination network (RCN) whose objective is to link biological C cycle research with well-developed networks in the physical sciences focused on the thermal state of permafrost. We found that published literature in the Science Citation Index identified with the search terms 'permafrost' and 'carbon' have increased dramatically in the last decade. Of total publications including those keywords, 86% were published since 2000, 65% since 2005, and 36% since 2008. Interconnection through this RCN is designed to produce new knowledge through research synthesis that can be used to quantify the role of permafrost carbon in driving climate change in the 21st century and beyond. An expert elicitation conducted as part of the RCN activities revealed that the total effect of carbon release from permafrost zone soils on climate is expected to be up to 30-46 Pg C over the next three decades, reaching 242-324 Pg C by 2100 and potentially up to 551-710 Pg C over the next several centuries under the strongest warming scenario presented to the group. These values, expressed in billions of tons of C in CO_2 equivalents, combine the effect of C released both as CO_2 and as CH_4 by accounting for the greater heat-trapping capacity of CH_4. Much of the actual C release by weight is expected to be in the form of CO_2, with only about 3.5% of that in the form of CH_4. However, the higher global warming potential of CH_4 means that almost half of the effect of future permafrost zone carbon emissions on climate forcing was expected by this group to be a result of CH_4 emissions from wetlands, lakes, and other oxygen-limited environments where organic matter will be decomposing. These results demonstrate the vulnerability of organic C stored in near surface permafrost to increasing temperatures. Future activities of this network include synthesizing information in formats that can be assimilated by biospheric and climate models, and that will contribute to future assessments of the IPCC.

Earth's transient and equilibrium climate sensitivities: How much can we learn from observations?

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Earth's equilibrium climate sensitivity, S_{eq}, the change in global mean surface temperature (GMST) that would result from a given forcing F, normalized to that forcing, is a widely used metric for comparing climate models or for assessing the amount of carbon dioxide that might be added to the atmosphere consistent with a given allowable increase in global temperature. However, because of the large heat capacity of the deep ocean the time scale for reaching the equilibrium temperature change following imposition of a forcing is about 500 yr, during which time there is net heat flow from the upper compartment of the climate system that is radiatively coupled to space to the deep ocean; this heat flow diminishes the response of the upper compartment to imposed forcings. Observationally the rate of increase in ocean heat content over the past 50 years has been proportional to the increase in GMST, with proportionality constant κ of about 1.0 W m^{-2} K^{-1}. This proportionality leads to a relation between transient and equilibrium climate sensitivity , where the transient sensitivity S_{tr} is the constant of proportionality between GMST and forcing. The increase in GMST observed over the twentieth century is found to be proportional to F for several published forcing data sets but with S_{tr} depending strongly on the forcing data set employed, ranging from 0.19 to 0.42 K (W $m^{-2})^{-1}$, increasing with decreasing forcing. The corresponding equilibrium sensitivity ranges from 0.24 to 0.75 K (W $m^{-2})^{-1}$. These values are lower to well lower than the IPCC (2007) estimated range for equilibrium sensitivity. The long time scale for reaching equilibrium sensitivity suggests that the measure of climate sensitivity relevant to policy considerations is the lower, transient sensitivity.

Impact of a reduced Arctic sea-ice cover on lower latitudes

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The Arctic sea-ice cover declined during the last few decades. The missing insulating layer in the Arctic Ocean increases the heat flux from the Ocean to the atmosphere. The resulting changes in temperature over the Arctic are influencing the geopotential height fields and subsequently the storm tracks and temperature distribution over the extratropics. Furthermore, the salinity and temperature of the ocean are changed.
From a suite of different general circulation model simulations we show that a one year sea-ice concentration anomaly such as in 2007, triggers a `Great

Salinity Anomaly' in he ocean and shifts the storm tracks to the south changing the temperature over Eurasia. Further we propose that the declining sea-ice cover in the Barents Sea has the potential to strengthen heat waves over Eurasia such as observed in summer 2010 over Russia.

Present and past solar irradiance: a quest for understanding

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The solar irradiance is known to change on time scales of minutes to centuries, and it is suspected that its substantial fluctuations are partially responsible for climate variations. We have developed a Code for Solar Irradiance (COSI) that allows the physical modeling of the entire solar spectrum composed of quiet Sun and active regions.

COSI is used as a tool for modeling the variability of the solar irradiance. We assume that the minimum state of the quiet Sun in time corresponds to the observed quietest area on the present Sun. Then we use available long-term proxies of the solar activity, which are ^{10}Be isotope concentrations in ice cores and 22-year smoothed neutron monitor data, to interpolate between the present quiet Sun and the minimum state of the quiet Sun. This allowed us to obtain a time-dependent reconstructed solar spectrum from 7000 BC to the present with a temporal resolution of 22 years. From 1610 onward we have additional information from sunspot number, which allowed the reconstruction of the spectral solar irradiance with a yearly resolution. These basic assumptions led to a total and spectral solar irradiance that was substantially lower during the Maunder minimum than observed today. The difference between present and Maunder minimum irradiance is remarkably larger than other recent estimations.

We discuss the main sources of the uncertainties in the reconstructions of the solar irradiance to the past and observational programs which can help to constrain the estimations of the solar long-term variations. We compare the reconstructed solar variability with the records of stellar photometric variability.

Is the reported global surface warming of 1979 to 1997 real?

S. Fred Singer
SEPP

We find that the IPCC record (based mainly on land thermometers) is not supported by other evidence, including atmospheric data (radiosondes and satellites) and various proxy data. It is essential also to interpret measurements of SST and ocean heat content, and to account for published 'puzzles,' such as a possible disparity with solar activity [Lockwood and Froehlich] and 'strange' lapses of atmospheric lapse rates [Santer et al 2005]. We will also comment on the major independent effort by the

'Berkeley Earth Project' to examine directly the procedures used and results obtained from weather station data in order to form the global surface temperature record. The issue is of fundamental importance for determining the importance of the human contribution to climate change.

Decadal predictability (and uncertainty) of tropical Indo-Pacific Ocean temperature trends due to anthropogenic forcing

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Climate forecast uncertainty on decadal time scales is dominated by uncertainty in the modeled response of the climate system to increased anthropogenic forcing (see Hawkins and Sutton 2009). For climate forecasts to be useful it is necessary to quantify this uncertainty. More specifically, it is necessary to identify strategies that can be used to assess the different responses across models from a process perspective. In this talk, we present results from studies that utilize initialized decadal climate hindcasts and forced transient climate simulations to quantify this uncertainty and identify the predictable component of the climate response to anthropogenic forcing on decadal time scales.

Clouds, aerosol, radiation, rain and climate

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The cloud systems of our planet fundamentally shape our climate in the way they affect the flow of radiation in and out of the planet and in the way they connect key processes together to form the hydrological cycle. Despite the many years of cloud observations from space, we have not gained much insight into these key roles. Information about cloud particle size from satellite radiometers, for example, has been derived now for more than two decades but we still have not convincingly determined if this information is in fact related to real cloud physical properties. Nevertheless correlation between this remote sensing particle size information and aerosol content now serves as a basis for parameterization of the so-called indirect effects in climate models, a key tuning knob of model sensitivity. Similarly we have also observed precipitation from space for many years but have not been able to tie these observations to actual cloud physical processes and thus precipitation observations alone offer little real insight into how precipitation is likely to be shaped by the broader environment in which it forms. In this talk the more recent observations from the A-Train of satellites will be reviewed and it will be argued that combinations of data from radar, lidar and radiometers now provide the tools to advance understanding moving beyond these past limitations. The microphysical content of satellite observations will be revealed and the ability to probe into the rain formation processes will be highlighted. These new insights will also be overlain on the performance of current climate models and the predictions of precipitation change associated with global warming.

The Cloud Conundrum

Bjorn Stevens

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In this talk we review how clouds contribute the largest uncertainty to our understanding of the response of the climate system to external perturbations. Because the fast response of clouds determines the effective forcing, we argue that clouds limit our understanding of climate forcing to a degree far greater than previously appreciated, and that the aerosol likely is less important as a climate forcing agent than has been previously thought.

Characterization and Direct Radiative impact of Arctic Aerosols: observed and modeled

R. S. Stone[1, 2]

Abstract

The Arctic climate is influenced by aerosols that affect the radiation balance at the surface and within the atmosphere. Impacts depend on the composition and concentration of aerosols that determine opacity, which is quantified by the measure of aerosol optical depth (AOD). For over a decade, the NOAA Global

Monitoring Division (GMD) has monitored AOD at the Barrow Observatory (BRW, 71.3°N) in conjunction with measurements of the surface radiation budget (SRB). From such observations the direct aerosol radiative forcing (DARF) by different types of aerosol have been estimated. Several case studies have been performed to quantify DARF empirically and verify model results through closure experiments. Incursions of dust, smoke and haze, transported from lower latitudes, have been analyzed. Although their radiative impacts vary, all tend to cool the surface. Cooling is found to increase as surface albedo decreases. The degree of cooling is most likely greater than surface warming caused by increased solar absorption attributed to the deposition of black carbon (soot). Therefore, it is unlikely BC in the Arctic atmosphere and deposited at the surface has contributed significantly to the decline in Arctic sea ice as has been claimed. Independent studies reveal that concentrations of BC have decreased in the Arctic over the past three decades. Implications of the decline in BC will be discussed in conjunction with the presentation of empirical results that document the cooling effect of aerosols.

In addition, a dataset of AOD derived from airborne photometric observations made during spring 2009 have been used to better characterize Arctic aerosols on a basin-wide scale. Measurements were made during a flight from Svalbard, Norway to Pt. Barrow, Alaska, passing near the North Pole. These, along with ancillary measurements of particle size and BC concentrations, provide a three-dimensional characterization of the aerosols encountered along track. The horizontal and vertical distribution of Arctic haze, in particular, was evaluated. During April 2009, the Arctic atmosphere was variably turbid with total column AOD (at 500 nm) ranging from ~ 0.12 to > 0.35, where clean background values are typically < 0.06. The haze was concentrated within and just above the surface-based temperature inversion layer. BC was observed at all levels at moderately low concentrations compared with historical records. Few, distinct elevated aerosol layers were observed, although lidar observations revealed evidence of volcanic aerosol at the upper levels. Enhanced aerosol loading within the stratosphere may be why global (greenhouse) warming has leveled off in the last decade, a topic currently being debated in the literature. An overview of the 2009 campaign will be given with results presented in the context of historical observations and current thinking about the impact aerosols have on the Arctic climate.

The effects on CCN concentrations, and possibly on climate, of cosmic rays and current flow in the global electric circuit

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Atmospheric ionization due to the galactic cosmic ray influx varies by up to 20% at high latitudes with solar activity, and acts to both nucleate ultrafine aerosol particles (ion-mediated nucleation, or IMN) and as a source of atmospheric conductivity. Regional changes in ionosphere-earth current density J_z are due to changes in atmospheric conductivity, and these can also be caused by relativistic electron precipitation and solar energetic particles. J_z can also be modulated by ionospheric potential changes due to solar wind electric fields, and by global thunderstorm activity. Clear correlations of atmospheric dynamics and cloud cover on the day-to-day timescale of each of the above five J_z-modulators have been observed. Four of the five do not involve changes in cosmic ray flux or tropospheric ionization or solar irradiance, leaving only J_z changes common to all.

The flow of J_z through conductivity gradients in clouds or aerosol layers creates space charge, in accordance with Ohm's Law and Gauss's Law, and this space charge partitions between droplets, aerosol particles, and ions. The charges on the droplets and aerosol particles change the rates of scavenging processes otherwise due to Brownian and phoretic scavenging (charge modulation of aerosol scavenging, or CMAS).

I will discuss the CERN CLOUD results, and evaluate the uncertainties in both IMN and CMAS processes for producing significant changes in CCN concentrations and size distributions. Sufficiently large changes would explain observed changes in atmospheric dynamics and cloud cover on decadal and multidecadal, as well as day-to-day timescales.

A new dynamical mechanism for major climate shifts

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We construct a network of observed climate indices in the period 1900-2000 and investigate their collective behavior. The results indicate that this network synchronized several times in this period. We find that in those cases where the synchronous state was followed by a steady increase in the coupling strength between the indices, the synchronous state was destroyed, after which a new climate state emerged. These shifts are associated with significant changes in global temperature trend and in ENSO variability. The latest such event in the 20th century is known as the great climate shift of the 1970s. Extending this analysis in the 21st century confirms that another synchronization of these modes, followed by an increase in coupling occurred in 2001/02. This suggests that a break in the global mean temperature trend from the consistent warming over the 1976/77-2001/02 period may have occurred. We also find the evidence for such type of behavior in three forced and unforced climate simulations using state-of-the-art models. This is the first time that this mechanism, which appears consistent with the theory of synchronized chaos, is discovered in a physical system of the size and complexity of the climate system.

Accurate estimation of the stratospheric aerosol optical depth for climate simulation: a new insight about its variability and origin from satellite observations

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Improving the accuracy of earth climate simulation requires the evaluation of all external and internal radiative forcing factors that influence the global surface temperature. Among these forcings, stratospheric aerosol, plays an important role by scattering back into space solar shortwave radiation. These aerosol are mainly formed of sulfuric acid droplets which can be enhanced by as more than a factor of 100 by major volcanic eruptions. Even at background levels, however, the variability of the stratospheric aerosol layer can have a significant impact on climate fluctuations, so that accurate measurements of its burden are needed at all times.

Global remote satellite observations over the last quarter of century offer the possibility to determine, even at low aerosol loading levels, the optical depth of the stratospheric aerosol layer and evaluate its corresponding forcing. Herein, we will present a new stratospheric aerosol dataset from 1985 to the present built with the space-based, global measurements of SAGE II, GOMOS and CALIPSO which provide a unique view regarding the spatio-temporal variability of stratospheric aerosols. The new record will be used to discuss the origin of the increase of the stratospheric aerosol burden during the past decade with a focus on the influence on small-scale volcanic eruptions that are a significant source of aerosols in the absence of major events. In addition, we will show that upper tropospheric aerosol associated with the Southern Asian Monsoon, that likely to be human-derived, may also contribute significantly to the stratospheric aerosol burden. Finally, the new stratospheric aerosol record will be compared with the current GISS dataset widely used by the climate community and we will discuss how differences between both could result in significant errors in climate simulations.

On the 20 year sea level fluctuation mode in Atlantic Ocean and the Atlantic Multidecadal Oscillation

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A bipolar multidecadal oscillation mode linking the Arctic and Antarctic regions was recently found in the 20th century detrended air temperature data, and subsequently analysis of Greenland-Arctic ice cores spanning more than 500 years determined that an oscillation of approximately 20 years is the dominant multidecadal mode of variability.This is consistent with the independent findings based on Tide Gauge (TG) sea level (SL) data from the eastern and western boundaries of the North Atlantic, supported by simulations using the GFDL CM2.1 model. Although the 20-30 year period band is already known as dominant in the North Atlantic, in the South Atlantic only recently variability in this same band has been reported (Vianna and Menezes, 2011) by detection of a approximately 20 year mode in a SL analysis based on altimetric data and western boundary TGs. The geographic distribution of this mode is concentrated in the double-cell structure of the Subtropical Gyre and associated circulation structures, which supports the conjecture that this mode might pertain to the Atlantic Meridional Overturning Circulation (AMOC) in the South Atlantic. This work is now being extended into whole Atlantic Ocean, using the same methodology of decomposing the data into period bands by EOF/Singular Spectrum Analysis (SSA) reconstructions. The datasets being analyzed are the same AVISO 16 year two-satellite monthly altimeter sea level anomaly data mapped in a 1/3^{o} resolution grid, and the sea level monthly one degree resolution 2D TG-based sea level reconstruction (SLRec, Church et al.,2004; Church and White, 2011) for the period 1950-2009. In this presentation we show the preliminary results, which suggest that indeed the multidecadal-dominating 20 year mode of SL variance might be related to the interhemispheric water exchange linking the North to the South Atlantic Ocean, (the Atlantic Meridional Overturning Circulation-AMOC) and the strong eddy-dominated circulation areas. It is shown in particular that the variability found in the altimetric data in the subtropical gyre in the South Atlantic is in phase with most of the circulation structures of the North Atlantic and the Sub-Polar Gyre, but in opposite phase with a narrow band around the Gulf Stream. It explains 4.6% of the total variance for the whole Atlantic and Sub-Arctic circulation structures, and is shown to be dominated by a 20 year mode obtained by induction in a "non-frequentist" Maximum Entropy Method (MEM) spectral estimation. This is consistent with the results of the coastal TG data analysis. Amplitude maxima reaches about 8 cm in eddy-dominated currents (e.g. the Gulf Stream, Subtropical Countercurrent, Azores Current, North Equatorial Countercurrent, South Subtropical Cell-South Atlantic Subtropical Gyre, Agulhas Leakage, Zapoiola Gyre, Sub-Polar Gyre). Results of analysis of the SLRec data largely confirm those obtained from altimetry, with the SLRec giving 3.6% of the total variance in the 20 year mode, albeit with smaller amplitudes as expected in this kind of reconstruction. The SLRec gave a 71% of the variance corresponding to a nonlinear growing trend in SL, with about same kind of geographical distribution as the one observed for the 20 year mode. In these upper-layer ocean analysis we did not study multidecadal propagation of patterns, which should be investigated by including subsurface datasets in the analysis.

Added value generated by regional climate models

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Abstract

An important challenge in current climate modeling is to realistically describe small-scale weather statistics such as topographic precipitation, coastal wind patterns or regional phenomena like polar lows. Global climate models simulate atmospheric processes with increasingly higher resolutions, but still regional climate models have a lot of advantages. They consume less computation time due to their limited simulation area and thereby allow for higher resolution both in time and space as well as for longer integration times. Using regional climate models for dynamical downscaling purposes, their output data can be processed to produce higher resolved atmospheric fields, allowing the representation of small-scale impacts (such as storm surges along coasts).

But does the higher resolution lead to an added value when compared to global model results? Most studies implicitly assume that dynamical downscaling leads to output fields superior to the driving global data, but few work has been done to substantiate these expectations. Here, we review the benefit of dynamical downscaling by explicitly comparing results of global and regional climate model data to observations. Regional climate model generally performs better for the medium spatial scales, but not always for the larger spatial scales – specifically when a large-scale constraint such as spectral nudging, is invoked.

We conclude that regional models may indeed provide added value, but only for certain variables, scales and locations; in particular when influenced by regional specifics such as coasts, or when meso-scale dynamics like Polar Lows is involved. Therefore the utility of a regional climate model depends crucially on the scientific question.

The talk is based on the article
Feser, F., B. Rockel, H. von Storch, J. Winterfeldt, and M. Zahn: Regional climate models add value. Submitted to Bulletin of Amer. Meteo. Soc.

Dynamical impact of the warming pattern

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It is well established that an increase in greenhouse gas concentration does not lead to a homogeneous tropospheric warming, but a warming pattern characterized by a stronger warming in the upper tropical troposphere and near the surface at the northern high-latitudes than elsewhere in the troposphere (Fig.10.7 in Meehl et al. 2007). Such a warming pattern can significantly impact the dynamical state of the atmosphere. But what exactly is this dynamical impact? Does the warming pattern imply a more energetic atmosphere with enhanced storm activity?

The questions are difficult to answer, mainly because the warming pattern reveals various counteracting effects. For instance, the tropical warming favors not only an increase in meridional temperature gradient but also a decrease in static stability. While the former tends to enhance baroclinic activity, the latter acts to suppress it. Held (1993) pointed out another pair of competing effects involving the increase in meridional temperature gradient in the upper troposphere due to the upper tropical warming and the decrease in temperature gradient near the surface due to the high-latitude surface warming. In general, the effect of temperature-gradient change has been perceived as being more important than that of the static-stability change.

In the present paper, we discuss a new approach used to assess the dynamical impact of the warming pattern. The approach is based on specially designed experiments with coupled atmosphere-ocean GCM.We will demonstrate that that it is the changes in static stability, not those in temperature gradient, that control the response of the dynamical state to the warming pattern.

CHALLENGES IN DECONVOLUTING INTERNAL AND FORCED CLIMATE CHANGE

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With short climate data sets and imperfect models, one of the important challenges is determining what climate change is associated with increases in greenhouse gas concentrations and what can be ascribed to natural internal variability. We concentrate on the large amplitude warming that took place early in the arctic in the 1920-1940 period that spread globally in the latter part of the period. We note that the magnitude of the arctic warming was of similar magnitude to the high latitude warming during the late 20^{th} century. Furthermore, we question that anthropogenic aerosol loading caused the 1940-1970 cooling, noting that the cooling was a factor of two greater in the southern hemisphere during this period. We close with a discussion of the last decade of global temperature change and discuss whether or not it is consistent with increases greenhouse gas emissions or internal variability, or both.

HIAPER Pole-to-Pole Observations (HIPPO): fine-grained, global-scale measurements of climatically important atmospheric gases and aerosols

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The HIAPER Pole-to-Pole Observations (HIPPO) program carried out five aircraft transects spanning the Pacific from 85N to 67S latitude, with vertical profiles every approximately 2.2 degrees of latitude.

Measurements include greenhouse gases, long-lived tracers, reactive species, O2/N2 ratio, black carbon (BC), aerosols and CO2 isotopes. HIPPO data show dense pollution and BC at high altitudes over the Arctic, imprints of large N2O sources from tropical lands and convective storms, methane emissions in the Arctic from terrestrial and marine sources as well as pollution, and other, sometimes unexpected, phenomena. Global chemical signatures of atmospheric transport are imaged, showing remarkably sharp horizontal gradients at air mass boundaries, weak vertical gradients and inverted profiles (maxima aloft) in both hemispheres. These features pose challenges to satellite algorithms, global models and inversions.

Ensemble Spread and Its Implication for the Evaluation of Temperature Trends from Multiple Radiosondes and Reanalyses Products

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Based on the ensemble spread, a methodology of measuring uncertainty in weather forecasts, the temperature trend and spread have been estimated using five radiosonde data sets and seven reanalysis products beginning in 1989. The results show that the magnitude of warming or cooling depends on the data sources, atmospheric heights, and geophysical latitudes. Over low-middle latitudes, the cooling varies from -2.6 K/decade in NCEP-DOE to -0.8 K/decade in HADAT2 in the lower stratosphere. The warming weakly changes from 0.2 through 0.4 K/decade in the middle troposphere. Over Antarctica, there is a pronounced warming in the low-middle troposphere in the three NCEP reanalyses and the RATPAC radiosonde data sets, and cooling in the other eight products. Over the Arctic, the warming is observed from the lower troposphere to the lower stratosphere in all twelve data sets. Significant cooling is identified over the middle stratosphere (above 50 hPa) in all five radiosondes. For global mean temperature, the trend is approximately 0.2 K/decade in the troposphere and −0.8 K/decade in the stratosphere. The spread increases significantly with atmospheric height from approximately 0.1 K/decade at 850hPa to 0.8 K/decade at 30hPa. The spread in the reanalyses data sets is much larger than in the radiosondes in the stratosphere. In contrast, the spread in both the reanalyses and radiosondes data sets is very small and shows the trend in better agreement with each other in the troposphere.