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Uncertainty of Causes and Climate Variability during Past Centuries – Regional and Climate Mode Response

The "Little Ice Age" component applies an extended time perspective beyond the limited instrumental record to the assessment of cause and climatic response characteristics during the climatic changes of recent historical times:

A key focus is on ***establishing uncertainty characteristics in climatic forcing series as well as proxy-based climate reconstructions***. This work improves our understanding of pre-industrial climates and its variability and builds a foundation to the detection process of anthropogenic climate changes.

An emphasis on ***regional and climate mode response*** is pushing the frontiers of current paleoclimatic research aimed at evaluating and establishing spatial response patterns to radiative forcing. This research directly tests fundamental assumptions commonly used in proxy-based climate reconstructions procedures.

Climate of the recent past lends itself well for ***education & outreach*** purposes. Expanding on NCAR's new Climate Discovery Exhibit, we developed a prototype for a comprehensive teachers guide that provides scientific background and lesson plans with inquiry based activities at the middle and high-school levels.

Fingerprinting of external forcing

Clear separation of anthropogenic from naturally forced climate changes is a fundamental prerequisite for any successful impact assessment of potential future climate change. The available instrumental record is both too short and contaminated through competing natural and anthropogenic forcings. An expansion of the records over many centuries provides a more appropriate framework for establishing an understanding of the magnitude and spatio-temporal characteristics of natural forcings. But searching for the impact of past external forcing is also an outstanding uncertainty showcase: On one hand the forcings are known only through proxies, not absolute measures, while at the same time the climate records that contain the climatic response signals are often restricted to individual proxy records from point sources. Two tracks for approaching this problem are under active investigation.

Description of forcings (solar variations and explosive volcanism) using all available independent proxy records for isolation of characteristic statistical properties of the series. Tailored statistical tools were developed and published that allow for flexible but efficient signal extraction. Solar variations that include relatively smooth quasi-oscillations at numerous frequencies are isolated with the

multi-resolution wavelet technique. Compared to Fourier analyses, wavelets capture the local characteristics of the time series. Additionally, the new Empirical Mode Decomposition method was employed for comparison. Volcanic forcing is of a very different temporal nature as explosive eruptions instantaneously inject large amounts of aerosol into the stratosphere. Between eruptions, no aerosol might be present. To appropriately represent this problem, a bi-distribution state-space model is applied. For the first time such a statistically based 'spike-detection' extracts pulse-like signals automatically from any time series. Next to the magnitude of the spikes (cooling in temperature, or sulfate deposition spike in ice cores), the model also provides an objective measure of confidence through a posterior probability. The advantages of both techniques include their flexibility, their automatic employment as well as their independence from arbitrary measures of thresholds. We provide both tools through the WEB to a wide community dealing with detection of these or similar forcing and climate signals. Currently the two techniques are being combined into a single procedure. The next step is to address spatial signal detection. Along a different line, we evaluate uncertainty characteristics of detecting the 11-year solar cycle in surface climate of the GCMs. We evaluate single to multi-ensemble simulations to test signal to noise relationships. (Naveau/Oh/Ammann)

A sequence of coupled simulations with differently scaled solar forcing has been performed for the last Millennium. While the lack of knowledge on the real world climate sensitivity paired with the unknown magnitude of the natural forcings pose significant problems for model-data intercomparison in general, a climatically based interpretation of the model results is pointing towards a real world solar forcing of only limited magnitude. The sensitivity of the NCAR-Climate System Model (CSM) is at the low end of the spectrum of climate models (2 degrees Celsius for doubling CO2). When forced with different solar irradiance change magnitudes, it is the smaller rather than the larger amplitudes that generate climate variations in the model that are most consistent with reconstructions. If the model's sensitivity would be correct, then no or only a relatively small solar background trend is required to clearly generate the centennial scale climate variations of the past millennium, including the Little Ice Age. However, if the real world climate sensitivity were larger, then solar variations would have to be indeed very small. This conclusion was presented at a Solar Workshop (SORCE Science Meeting, Sonoma, Dec. 2003) and found matching results from the solar community using up to 4 independent lines of evidence all now suggesting that the 11-year cycle (as observed by satellites since 1978) might contain essentially the full range of solar irradiance variations. Implications are substantial for the Climate Change debate. Further studies, particularly including dynamical feedback mechanisms for signal translation into the climate system are under investigation. (Ammann/Joos/Oh/Naveau)

Examination and Reduction of Uncertainty in Proxy Climate Data

One of the fundamental assumptions in paleoclimate research is based on stationarity: The relation of climate proxies to their approximated climate

variables is most often assumed to be linear and constant in time. This issue is not limited to individual proxy records but also includes links over large distances (teleconnections) through dynamical coupling in the atmosphere or ocean. Once established, the remote links from individual location to the dominating modes of climate variability are used both in reconstructing past climate conditions as well as for regional climate change predictions. However, the limited real world data did not allow for a solid test of the assumption that dynamical links remain stable over time, even when climate is changing. The coupled climate experiments provide a unique opportunity to test this assumption of stationarity. Initial focus is on the link between known proxy locations and the tropical El Nino/Southern Oscillation system and it is tested if the relationship uniformly holds or if the 150-year instrumental record is too short for an adequate calibration. Using Monte Carlo replication to be able to examine mean behavior as well as that of individual realizations, results indicate that stationarity is not automatic and mis-information can be drawn from biased proxy records. Modern-period validations of reconstructions based on relatively poor-quality proxies can give a false sense of security about the likely long-term reliability of these reconstructions. This is particularly important to know for the tropical circulation for which only limited solid information exists. These outcomes have generated significant excitement among paleo-reconstruction experts. (Wahl/Ammann/Graham)

An expansion of the stationarity evaluation is underway through efforts to quantify uncertainty ranges coupled to large-scale climate reconstruction techniques applied in the paleo community. So far, a rigorous investigation of the error bars has been missing. Through reproduction of the most commonly applied reconstruction techniques and employment of the coupled climate model output, we can provide objective measures of the strength and weaknesses of each approach. This work is also fundamental for a more appropriate and fair model to data comparison. The reconstruction algorithms written in freely available statistics language “R” will be provided to the community through a WEB interface. (Wahl/Ammann/Nychka/Tebaldi)

Receiver Operating Characteristic (ROC) and Monte Carlo replication methods were also developed for characterization and optimal reduction of uncertainty in microfossil-based climate and ecosystem reconstructions (based on pollen, foraminifera, diatoms, etc.). These analyses are being recognized in the pollen-based paleoecological community as contributing one of the most important steps forward in application of the modern analog technique (MAT) in the last 20 years. ROC analytical methodology is used to systematically explore the joint minimization of false positive and false negative identifications of modern analogs for fossil assemblages of pollen, foraminifera, etc.; and it gives a rational basis for accepting more of one kind of error to reduce the other in specific situations. This work is the first of its kind in this field, and utilizes existing theory and practice from signal testing, medical testing, and weather forecast evaluation as its foundations. We have also used Monte Carlo techniques to examine the interactions of optimum analog selection, analyst effort given to counting

microfossils (sample size), and reconstruction precision. Use of optimizing analog selection thresholds (i.e., a proper balance between low false positives and low false negatives) allows analyst effort (sample sizes) to be reduced by nearly an order of magnitude, with no loss of precision! (Wahl)

Regional fidelity of climate simulations compared with proxy data:

E-Asia (China): 3 selected time windows around significant volcanic or solar forcing periods as well as the drought episode that brought the Ming Dynasty to its knees. GCM (NCAR-CSM and GISS) analysis and Regional Modeling using GCM boundary conditions with MM5. (Bradbury/Wang/Ammann)

Europe: Evaluation of dominating circulation regimes isolated in historical reconstructions and model. NAO and blocking cases with comparable behavior in control and low-solar case. No blocking was found in high-solar situation because of a too strong polar vortex. (Casty/Luterbacher/Ammann) and volcanic signal in circulation over Europe (Eicher/Ammann).

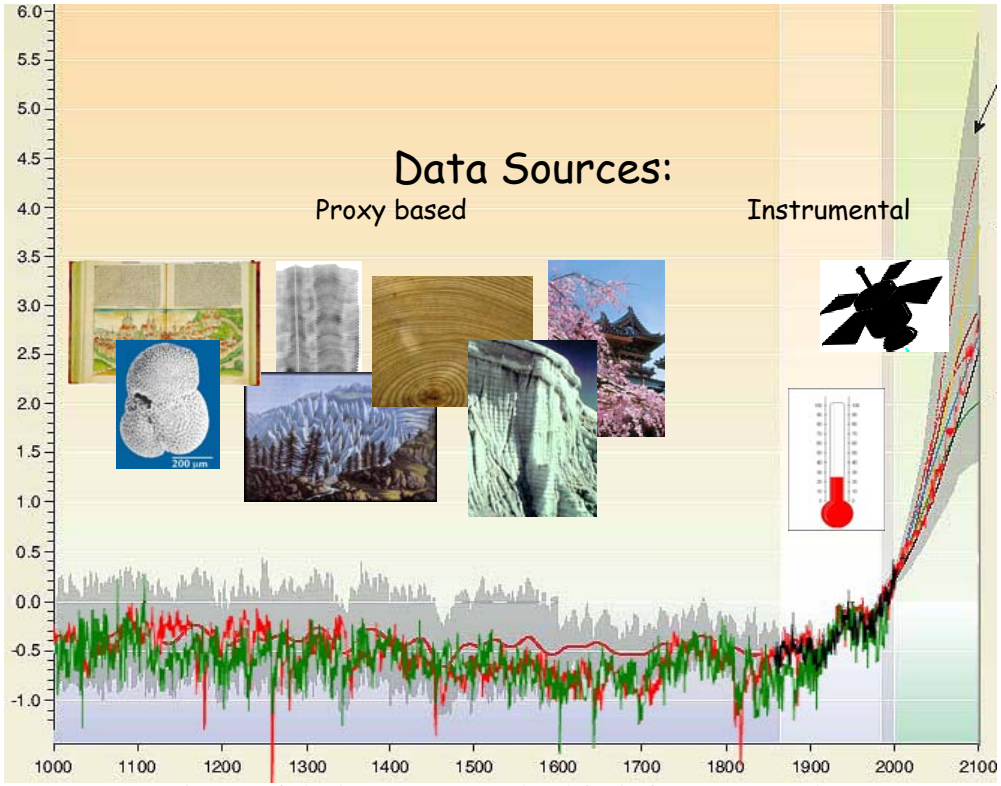
Centennial scale ocean anomalies: A strong ~125-year oscillation in the N-Atlantic ocean was found. Since no similar oscillations are known in the real world (except of about half the frequency), significant effort was put in to understand this variation. The impact is far reaching in atmosphere and ocean, including the thermohaline overturning. (Tomas/Graham/Ammann)

Tropical climate variability response to forcing: Previously regarded as most independent mode, ENSO variations over the recent past seem to contain significant externally forced response behavior: cooling in E equatorial Pacific during increase solar irradiance, but higher occurrence of warming during low-solar irradiance as well as after large volcanic eruptions (Graham/Ammann/Cobb/Mann/Adams)

Education and Outreach

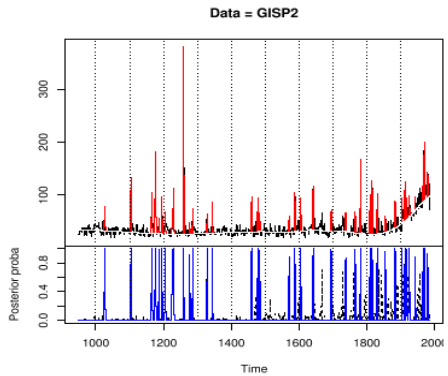
Based on the new Climate Discovery Exhibit at NCAR's Mesa Laboratory, we developed a prototype for a comprehensive teachers guide with a special application to the Little Ice Age period. The template is intended to stimulate further activities at NCAR to successively develop educational materials for the whole exhibit. Detailed lecture plans are provided that include inquiry based learning modules around how we can reconstruct climate in the recent past and what might have been responsible for some of the climatic changes. In-depth information is provided to the teachers and serves as professional development material in addition to pre-, and post-visit instructions (Johnson/Foster/Carbone/Haller/Ammann)

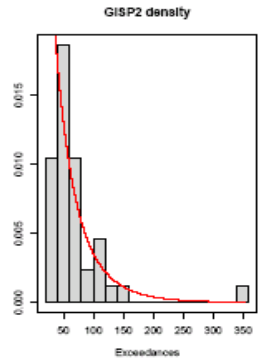
Expansion of the baseline as foundation for Climate Assessment



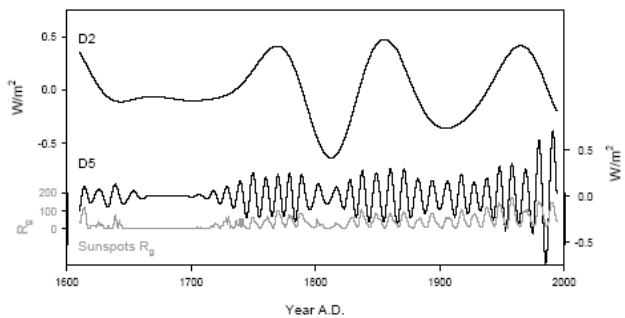
Climate of the last 1000 years (modified after IPCC 2001):
Variations in Mann et al (1999), Jones et al. (1998) and Ammann et al. (submitted)

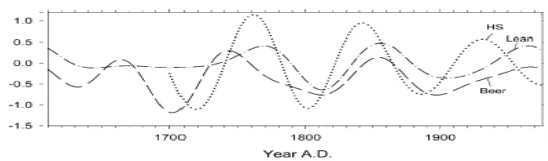
Forcing Characteristics





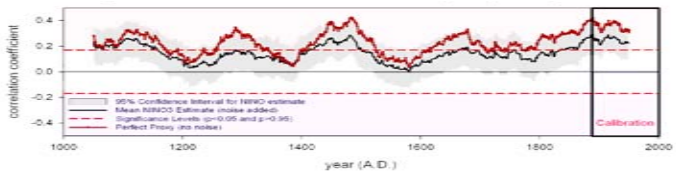
Volcanic Signal Detection and distribution of magnitudes



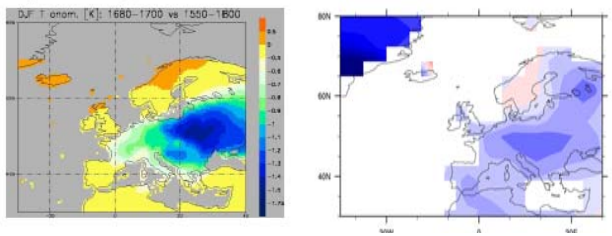


Solar signal characterization and intercomparison

Forcing Characteristics



Evaluation of Stationarity in single point location



Regional and and climate mode comparison