REPRESENTING AND REDUCING UNCERTAINTIES IN HIGH-RESOLUTION PROXY CLIMATE DATA

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Representing and reducing uncertainties in high-resolution proxy climate data

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Executive Summary

- *High-resolution (monthly to decadal resolution) proxy climate records are obtained from various physical (lake and marine sediments, speleothems, ice cores), biological (corals, tree rings) and human (documentary records) archives. These archives contain either physical (i.e. tree ring width) or geochemical (i.e. coral oxygen isotopes) signals that can be calibrated against the instrumental record of climate to ascertain past climate changes.*
- *High-resolution proxy climate records have significantly contributed to our understanding of the nature and causes of past climate variability, and could play a key role in reducing the uncertainties surrounding future climate change impacts. Areas where high potential exist include: 1) global climate sensitivity, 2) the response of regional hydrology to climate change, and 3) the evolution of coupled climate modes under greenhouse forcing.*
- *Each high-resolution proxy type is subject to a unique combination of uncertainties that obscures the climate signals of interest. Such uncertainties must be identified, quantified, and ultimately minimized in order to maximize the potential of high-resolution proxy data.*
- *Many of the largest sources of uncertainties are best addressed through a coordinated strategy guided by shared goals among the members of the high-resolution proxy community, beginning with proxy-by-proxy discussions that subsequently include the paleoclimate modeling and multi-proxy reconstruction communities.*
- *The Trieste workshop brought together representatives from various proxy climate data types, climate modelers, climate reconstructors and database specialists. Areas of consensus include:*
    - *i) the urgent need for increased replication of high-resolution proxy records*
    - *ii) clear benefits from integrating models with proxy data (forward modeling of proxy records, climate model hindcasts, water isotope modeling)*

iii) database infrastructure improvements are required to facilitate the representation of proxy uncertainties

Workshop Background

The need for the June 2008 Trieste Workshop was identified at an international workshop held in Wengen, Switzerland, June 7-10th 2006: Past Millennia Climate Variability: Proxy based reconstructions, modeling and methodology – Synthesis and Outlook, sponsored by PAGES/CLIVAR, EPRI and NCCR Climate). A significant outcome of the Wengen Workshop has been a major review of high-resolution paleoclimatology (Jones et al., in press[1]). It was recognized at the Wengen Workshop that although there have been great advances in recent decades in developing and exploiting high-resolution paleoclimatic records, significant uncertainties associated with high-resolution proxy climate data limit their potential in climate change research that is increasingly based on model simulations and projections. Recognizing that major classes of uncertainty are shared among the different high-resolution proxy types, the Trieste Workshop was planned with the goal of developing strategies in the paleoclimatic community to better represent and ultimately reduce paleoclimatic data uncertainties so as to provide more reliable data products for the global climate change community.

Workshop Goals

High-resolution[2] paleoclimatic data play an increasingly critical role in the detection and attribution of regional, and global climate changes associated with anthropogenic warming, and in testing and validating global climate models for 21st century climate prediction. Such applications, which typically involve using high-resolution paleoclimate data in multi-proxy syntheses and data-model comparison efforts, demand a quantitative, transparent, and thorough representation of uncertainties associated with such high-resolution proxy climate data. Some uncertainties are specific to a particular

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[1] *Jones PD, KR Briffa, TJ Osborn, JM Lough, TD van Ommen, BM Vinther, J Luterbacher, E R Wahl, FW Zwiers, ME Mann, GA Schmidt, CM Ammann, BM Buckley, K M Cobb, J Esper, H Goosse, N Graham, E Jansen, T Kiefer, C Kull, M Küttel, E Mosley-Thompson, JT Overpeck, N Riedwyl, M Schulz, A W Tudhope, R Villalba, H Wanner, E Wolff and E Xoplaki (in press) High-resolution paleoclimatology of the last millennium: a review of current status and future prospects. The Holocene.*

[2] *High-resolution in the context of this workshop includes all sources of proxy climate information with annual to decadal temporal resolution.*

source of proxy climate data (i.e. corals, ice cores, sediments, tree rings, documentary, etc), while others are common to all proxy archives (e.g. limited number of records, regional-scale representativeness, etc). The Trieste Workshop was designed to make significant, shared progress towards the following goals:

1. *Identify proxy-specific sources of uncertainty and search for cross-cutting sources of uncertainty*
2. *Identify IPCC-relevant questions that could be addressed by reducing high-resolution paleoclimate data uncertainties, and outline research strategies to begin reducing these sources of error*
3. *Develop a set of recommendations for how paleoclimate databases might facilitate the representation and reduction of uncertainties in high-resolution paleoclimate data.*

Workshop Format

Groups represented at the workshop included paleoclimate scientists working on obtaining proxy climate data from tree rings, corals, ice cores, speleothems, lake sediments, marine sediments and documentary data sources. These were complemented by paleoclimate data users specializing in multi-proxy climate reconstructions, paleoclimate modeling and paleoclimate databasing.

Prior to the workshop, a representative from each group was charged with collecting input from colleagues and writing a short "white paper" that addressed the following questions:

1. *What are the sources of uncertainty in the climate proxy and how can these be quantified and represented?*
2. *What strategies can be developed to reduce these sources of uncertainty?*
3. *What are the database and data archiving needs and ideas relevant to the climate proxy?*

Lead authors for the white papers were:

Corals	*Sandy Tudhope*
Trees	*Keith Briffa*
Ice cores	*Eric Steig*
Speleothems	*Dominik Fleitmann*
Documentary	*Christian Pfister*
Databases	*Dave Anderson*

The first day of the workshop consisted of 30 minute presentations by the lead authors of the white papers, followed by 10 minutes of questions and discussions. The remainder of the workshop was organized around Breakout sessions with participants allocated to one of three groups to discuss and report back on the three key workshop goals. In the final workshop session participants discussed Workshop outputs and follow-up activities (see Workshop Program – Appendix x).

Major cross-cutting themes

From the presentations and discussions on Day 1, the following cross-cutting themes common to different sources of high-resolution proxy climate data were identified:

1. *Sample replication: Most proxy climate data uncertainties are best quantified through sample replication. This has rarely been rigorously accomplished in the past, outside of dendroclimatology and even in this field, there was a call for greater numbers of samples. Recognition of the need for increased sample density and replication is, however, growing for other proxy climate data archives (e.g. International Partnerships in Ice Coring Sciences (IPICS) initiative for ice cores[1]). Collection of more samples (from whatever paleoclimatic archive and location) invariably involves additional expenses and there is still resistance to obtaining multiple records. This approach is, however, essential to improving the quality of proxy climate reconstructions as well as quantifying and reducing uncertainties in these records.*
2. *Model-proxy data integration: Improved collaborations between climate modelers and generators of proxy climate data is of mutual benefit. Reliable*

[1] *IPICS http://www.pages.unibe.ch/ipics/index.html*

high-resolution proxy climate records can help assess and validate climate models, hence improving their ability to model future climates and detect climate changes. Climate models can help target particular locations, variables and seasons for paleoclimatic research.

3. *<u>Forward modeling of proxy climate data</u>: The goal of forward (process) modeling is to accurately account for the various influences on a given proxy record, such that given a set of environmental variables, the proxy response can be accurately reproduced. This approach can provide significant insights into proxy climate archive responses to environmental stimuli and thus the uncertainties in the resulting measured variables as climatic proxies. Forward modeling is still rare and would benefit from on-site environmental monitoring as well as advances in downscaling global climate modeling output.*
4. *<u>On-site calibration/monitoring efforts</u>: Reconstructing climate variables from paleoclimatic archives usually depends on calibration and verification against instrumental climate data. Gridded instrumental climate data, while user-friendly, is less than ideal for several reasons. First, instrumental climate observations are sparse in many areas, leading to large uncertainties in gridded fields in those areas. Second, the local climate signals represented in the proxy record may be quite different than regional-scale climate signals. Third, many high-resolution paleoclimate proxies (such as oxygen isotopic composition) are multi-variate functions of several environmental variables. Fourth, proxy records can be biased to certain seasons (e.g. speleothems and ice cores, whose formation relies on precipitation which falls during a particular season). The best way to quantify the different sources of proxy uncertainties is to calibrate the proxy record against timeseries of environmental and, when appropriate, geochemical variables collected at the proxy site. These types of on-site calibration timeseries are exceedingly rare and poorly funded, despite their importance in quantifying proxy uncertainties.*
5. *<u>Representing uncertainties in databases</u>: The World Data Center for Paleoclimatology hosted by NOAA has, through archiving paleoclimatic data and reconstructions, facilitated an explosion of paleoclimate-related research.*

The down side of this significant archive is that data can easily be obtained and analysed without knowledge of the limitations and uncertainties contained within individual paleoclimate data sets. Such knowledge, at present, usually resides with the contributing researcher and there is a need to archive within the database standard measures of proxy data uncertainty. Additional common databasing requirements identified were better metadata to accompany each dataset and archiving of original measurements from the different proxy archives. The latter allows for subsequent improvements in techniques for data standardization (e.g. dealing with growth trends in tree rings), chronological control, better instrumental data for calibration purposes, improved knowledge of climate controls. This is particularly critical for proxy records whose age models evolve through time (through higher-resolution dating and/or radiometric re-calibrations performed after the initial publication of the record).

6. *Updating existing and exploiting new paleoclimate data archives: The participants noted that many paleoclimatic data sets (e.g. tree rings, ice cores, corals) were collected 10-30 years ago and require updating. In addition many sources of paleoclimatic data remain unexploited (e.g. documentary records).*

Reports from Breakout Sessions:

I. ***What are the major areas of uncertainty identified in IPCC AR4 that could be addressed by reducing uncertainties in high-resolution proxy climate data?***

Networks of annually to decadally-resolved paleoclimate data can be used to reconstruct large-scale patterns of temperature and hydrological variability in the recent past. These, in turn, can be compared to output from global climate models forced by natural and anthropogenic factors. Such networks of paleoclimatic data will be most useful when they are focused on those patterns of climate variability that explain the largest amount of temperature and hydrological variability. To maximize high-resolution paleoclimatic contributions to the 5th IPCC Assessment Report, workshop participants identified the three following climate themes that *could be significantly better understood if high-resolution paleoclimatic data uncertainties are reduced:*

1. ***Modes of climate variability***
   a. ***El Niño-Southern Oscillation (ENSO)****: Global climate model predictions of ENSO variability in an enhanced greenhouse world vary widely, such that many aspects of future climate change (especially for the tropics) remain poorly constrained. ENSO-sensitive proxies can be used to address the response of the coupled tropical Pacific ocean-atmosphere system to specific forcings, including Milankovitch, solar insolation, volcanic and aerosol forcings.*
   b. ***North Atlantic Oscillation (NAO)/Atlantic Multidecadal Oscillation (AMO)/Annular Modes (AM)****: Climate variability, extremes and trends in the extratropics are strongly influenced by interannual to decadal-scale modes of variability that originate in high-latitude oceans. Significant uncertainties in current global climate model projections for circum-North Atlantic and Antarctic climate variability could be reduced by reconstructing these modes of climate variability over the last few millennia.*

2. ***Regional hydrological extremes***

Changes in regional hydrological variability are likely to present the largest societal impacts of ongoing anthropogenic climate change. Global climate models, at present, provide little consensus (with a few exceptions) as to how hydrological variability will change at the regional scale. Annual to decadally-resolved paleoclimate records have already documented very large excursions in past regional hydroclimatic variability (most notably the mega-droughts in western North America). Of increasing attention are potential changes in the ITCZ and regional monsoon systems, which lower-resolution paleoclimate data suggest are sensitive to climate forcing. Improved paleohydroclimate reconstructions with known and reduced levels of uncertainties would contribute to *determining the global extent of such anomalies and their associated forcings which, at present, are unknown.*

3. Global temperature reconstructions and climate sensitivity

Multi-proxy reconstructions of large-scale average temperatures provide much-needed targets for paleoclimate modeling simulations which test the climate system's sensitivity to natural (solar and volcanic) and anthropogenic radiative forcings. Such reconstructions are also useful for estimating global climate boundary conditions for observed changes in mode variability, hydrological trends, and climate teleconnections. Although significant advances have been made in robust techniques for the development of global temperature reconstructions covering the past millennium, they are currently constrained by a) lack of temporal depth (resulting in wide error bars prior to ~1500 A.D.), b) Northern Hemisphere bias, c) reliance on a relatively small (often the same) set of paleoclimatic records. Quantifying and reducing uncertainties in existing paleoclimatic archives combined with development of new, longer and reliable paleoclimate data series can only improve the reliability of these multi-proxy reconstructions and their climatic applications.

II. <u>What strategies for the representation and reduction of proxy uncertainties could be used to make rapid and sizeable progress towards the climate questions posed in Breakout Session I?</u>

1. Modes of climate variability

One strategy towards this goal requires a more systematic treatment of uncertainty in existing paleoclimatic data. This requires better metadata, more data synthesis studies, better and more standardized documentation of known proxy data biases and proxy-specific efforts to quantify known sources of error. A second, and equally important strategy, is to collect more data of a higher quality by i) using pseudoproxy studies and model output to guide choices of sampling sites, ii) establishing and disseminating "industry standards" for ongoing high-resolution paleoclimate data generation (i.e.

minimum replication needs, collection of relevant metadata, consistent treatment of radiocarbon dates, etc).

a) ***El Niño-Southern Oscillation (ENSO)****: The main limitations to achieving robust estimates of climate forcing (natural and anthropogenic) and responses of the tropical Pacific ocean-atmosphere system are i) lack of proxy replication and, therefore, accurate error bars, and ii) the inability to independently quantify temperature and hydrological variability in coral oxygen isotope records (the main tropically-based archive for ENSO reconstructions). It was recommended that model output be used to guide site selection for ENSO-targeted proxy climate variables; emphasis on improved on-site monitoring systems for particularly oceanic proxies (could link with various Ocean Observing Systems); more Sr/Ca records from corals (which have a purer temperature signal than coral oxygen isotope records); multiple modern coral samples from key sites to establish the level of reproducibility of climate signals. Many other ENSO reconstructions rely on stationarity of ENSO teleconnections through time, as assumption that could be assessed with climate model simulations.*

b) ***North Atlantic Oscillation (NAO)/Atlantic Multidecadal Oscillation (AMO)/Annualar Modes (AM)****: While past efforts have attempted to reconstruct the atmospheric component of the NAO and AMO, more ocean-based sea surface temperature (SST) reconstructions are needed to determine the impact of SSTs on atmospheric variability in the North Atlantic region. Some newer high-resolution sediment cores can provide data with decadal-resolution but improved chronological constraints are needed before these data can be applied to muti-proxy reconstructions of the AMO. The Southern Annular Mode could be pursued through a network of high-resolution Antarctic ice cores, but the short instrumental climate records from this region pose a serious limitation to this approach.*

In this sense, tree rings from Patagonia would be a valuable complement to Antarctic ice core-based SAM reconstructions.

2. Regional hydrological extremes

There is great potential to reconstruct large-scale hydrological variability (and associated SST patterns) during periods associated with i) mega-droughts of the last 1-2k years, and ii) Intertropical Convergence Zone (ITCZ)- and monsoon-related signals observed during the mid-Holocene. Both of these scenarios represent an opportunity to test the relationship between radiative forcing, resulting anomalous surface temperature patterns, and regional-scale hydrological responses – a causal chain that would likely constrain how continued global warming is likely to impact regional hydrological variability. The main strategy towards this goal is the generation of well-replicated records from hydrologically-sensitive areas, at the same sampling resolution, and with sufficient age control for the target in question. For example, annual to decadally-resolved data with chronological control better than ± 10 years are required to build a large-scale context for the last millennium's mega-droughts, and decadal to centennially-resolved data with chronological control better than ± 50 years are required for the mid-Holocene study. Such data could then be used in multi-proxy synthesis studies and integrated into modeling experiments that test mechanistic relationships among forcing, temperature response, and hydrological response.

Precipitation exhibits much greater variability in space and time compared to temperature and this has flow-on effects to hydrological reconstructions. In addition, each type of proxy has its own sources of uncertainty with respect to precipitation and drought reconstructions. These include seasonal biases, biological artifacts, interpretation of precipitation isotopes, relationship of local precipitation to regional-scale precipitation, level of replication required, etc. These uncertainties must *be quantified before such data can be used to develop reliable large-scale precipitation reconstructions. While some proxies are quite sophisticated in this respect (i.e. tree rings), other very promising paleo-precipitation proxies (e.g. speleothem $\delta^{18}O$) require further calibration and replication studies before they can be systematically used for large-scale precipitation reconstructions. The utility of proxies that require more development (such as speleothems) would be dramatically increased with: i) improved coordination of research projects with a focus on replication of annual to decadal-scale records over the last 2k years, ii) field expeditions to allow collection of rainfall $\delta^{18}O$ and in situ meteorological records, and iii) development of accepted standards for the representation of uncertainties.*

3. Global temperature reconstructions and climate sensitivity

The usefulness and accuracy of large-scale temperature reconstructions would dramatically improve with a more thorough treatment of uncertainties in high-resolution paleoclimate data. These uncertainties broadly fall into four categories:

1. *Sampling uncertainties – limited number of sampling sites, less than ideal locations*
2. *Calibration uncertainties – weak/unclear relationship between proxy record and climate parameter(s)*
3. *Process uncertainties – the mechanisms whereby the measured proxy variable translates to a climate signal are poorly known*
4. *Methodological uncertainties – techniques currently used to measure the proxy variable are inadequate and/or inaccurate*

Sampling uncertainties can potentially be addressed with pseudo-proxy studies, whereby individual time series from climate models are transformed into proxy climate records, usually by addition of white or red noise. These pseudo-proxies are then used to reconstruct a known climate *target, such as global average temperatures and the level of uncertainty can then be quantified.*

Calibration uncertainties can be quantified through calibration and verification tests, where the relationships between the overlapping instrumental and proxy records are examined for separate subperiods (various such tests are commonly used in dendroclimatic reconstructions).

Process uncertainties can be studied in the context of "forward modeling" of proxy records, with the goal of understanding and quantifying the relationship between environmental variables and proxy response. Both calibration uncertainties and process-level uncertainties would benefit from the collection of timeseries of environmental variables at the proxy site (e.g. in-situ temperature on a coral reef is a better target for calibration and a better input for forward modeling than gridded instrumental SST.)

Methodological uncertainties are typically small with respect to the aforementioned sources of proxy uncertainty, although chronological uncertainties are typically limited by the precision of radiometric dates (whether by radiocarbon or uranium-thorium). Different sample preparation procedures (cleaning protocols for Mg/Ca-based paleotemperature reconstruction in forams, for example) may also impact the fidelity of proxy records.

There are several related strategies for improving the quality and quantifying the uncertainties of paleoclimatic data entering large-scale temperature reconstructions. These strategies were common themes repeatedly identified during the course of the workshop:

i. *Increased replication of high-resolution proxy climate data*
ii. *Inclusion of adequate and standardized metadata in paleoclimatic databases*
iii. *Downscaling global climate model output to appropriate regional scales to allow identification of the climate sensitivity and regional representativeness of specific proxy climate records*

iv. Development of forward models for specific proxy climate records to quantify the relative contributions of climatic vs. non-climatic signals in the measured proxy variable.

III. How can the data archival process be improved to encourage more thorough documentation of proxy uncertainties and the adoption of "best practices" in the high-resolution paleoclimate community?

High-resolution paleoclimatology requires both rigorous development of high quality proxy records and climate reconstructions and dissemination of these records to the wider paleoclimatic and climatic community. This is generally achieved through submission of published data to global paleoclimatic databases (though it was noted that the NOAA Paleoclimate Database, for example, probably contains < 10% of published paleoclimatic records). Workshop participants agreed to the importance of improving the representation of uncertainties accompanying contributions to such databases. A key component to such better representation of uncertainties in high-resolution paleoclimate data is to adapt the archival process to encourage the collection, quantification and documentation of proxy-specific uncertainties and associated metadata and enhance the availability of high-resolution proxy climate data to multi-proxy synthesis efforts and model-data intercomparison studies.

Several creative and exciting ideas emerged during this Breakout Session, mostly centred on creating solutions for adapting the NOAA Paleoclimate Data Base to a) provide better incentives for archiving data, and b) improving the representation of uncertainties and the quality of metadata associated with high-resolution paleoclimate data submissions to the database. Common problems and suggested solutions included:

1. ***Problem: lack of incentives for archiving data could be solved by creating a citable digital object identifier ('doi') for each data set**: It is imperative that the paleoclimatic community recognize the importance of providing data to*

international databases, thus making the data available for current and future studies. Providing a doi for each data set would encourage a greater level of commitment to this objective. This could be achieved by either linking NCDC entries with unique doi's (which could be tracked and cited as per peer-reviewed publications) or by creating a new peer-reviewed journal for the publication of paleoclimatic datasets and associated metadata. The Workshop participants strongly agreed that either of these options which enabled datasets to be cited would create new incentives for investigators to archive their data. Ideally, this approach could be combined with a policy from major funding agencies to withhold funding to investigators who have not archived their data at NCDC (much as funds are withheld until project reports are filed). Participants noted that the 'doi' system as it currently exists is not well designed to deal with evolving proxy datasets but that something analogous could be designed

2. ***Problem: lack of incentives for archiving uncertainties and detailed metadata with dataset contributions could be partly solved by flagging those datasets containing this information****: Investigators have to spend a significant amount of time compiling metadata and expressing uncertainties for their paleoclimatic datasets. Such effort could be rewarded by the designation of "Level 1" datasets within the NCDC database, thus flagging those datasets that are likely to be more useful to the broader climate community. Such "Level 1" datasets would, therefore, be more frequently cited (see Solution #1, above). Ideally, the "Level 1" classification would recognize that the dataset meets the minimum requirements for documentation of uncertainties associated with the particular proxy type (see Solution # 3, below).*
3. ***Problem: lack of guidelines for the treatment and representations of uncertainty in paleoclimate data could be solved by developing proxy-specific guidelines for representation of uncertainties****: This solution requires the broader paleoclimate community to embrace a set of "best practices" regarding uncertainties on a proxy-by-proxy basis. Although there may be a few measures common to different proxy types, the nature of uncertainties differs appreciably among the various high-resolution proxy types. Developing and ensuring general*

uptake of such standards is an ambitious goal but one that workshop participants believed necessary and achievable through the following steps:

i. *Modify the Trieste white papers to include a list of the sources of uncertainty in each proxy type and their approximate quantification. These could be posted on the NCDC paleoclimate website for comment by the broader paleoclimate community. Once agreed upon, these could be advertised (through NCDC, PAGES/CLIVAR etc) as recommended standards for each proxy type.*

ii. *Form an ad hoc committee (with representatives from each type of high-resolution proxy) to facilitate the transfer of the community's recommendations of key proxy-specific uncertainties to NCDC database modifications.*

Workshop products and follow-up activities

Workshop participants agreed that coordinated follow-up activities are critical to translating the workshop ideas into real-world improvements in the treatment and representation of uncertainties in high-resolution paleoclimate data. These will help both improve the quality, reliability and usefulness of high-resolution proxy climate data and enhance the contribution of high-resolution paleoclimatology to the 5th IPCC assessment. Follow-up activities include:

1. ***Completion of white papers for web posting and commentary:*** *the white papers should include a list of specific uncertainties, their approximate quantification and, ideally, some concrete examples. These papers would then be posted somewhere on the NCDC paleoclimate web-site for community review and input.*
2. ***Group-authored EOS article****: the article would summarize key discussions from the Trieste Workshop and hopefully facilitate engagement of the broader paleoclimate community in the discussion of uncertainties and the development (via the NCDC web-site) of proxy-specific "best practices". The article would argue for a community-wide focus on high-resolution climate reconstructions of the last 1-2 k years and at 6k years. These time intervals would provide much-needed constraints that are relevant to uncertainties in IPCC climate projections for a warming world. The article would also stress what emerged as a common and*

unifying theme of the workshop for reducing and quantifying paleoclimate data uncertainties - the need for replication.

3. ***Consideration of future workshops dealing with model/proxy data integration:*** *Specific ideas included: i) workshop on use of regional downscaling and forward modeling of proxy time series, ii) workshop on the reconstruction and modeling of water isotopes in precipitation, and iii) workshop on developing strategies for using model output to guide formation of proxy data sampling networks and quantifying process-level uncertainties*
4. ***Propose an AGU session for (NH) fall 2009 on model-based and observation-based approaches to quantifying and representing uncertainties in high-resolution paleoclimate data:*** *this would require 3-4 (ideally cross-disciplinary researchers) to commit to take the lead.*

Key Recommendations

- ***increase replication of high-resolution paleoclimate records so that uncertainties can be explicitly quantified; encourage through peer-review of proposals and manuscripts***

- ***on-site monitoring of environmental parameters will enable more accurate estimates of proxy uncertainties, as well as facilitate forward modeling of proxy records***

- ***the improved integration of proxy data with modeling efforts is required to ensure that paleoclimate proxy data play a meaningful role in IPCC-related activities; promising avenues for such efforts include:***
    - ***the use of pseudoproxy studies to guide the formation of proxy networks and their associated uncertainties***
    - ***forward modeling as a means to quantify proxy climate influences and uncertainties***

- *comparisons of global coupled model hindcasts with individual proxy records or multi-proxy syntheses*

- *develop standards for the representation and archival of high-resolution proxy metadata in order to facilitate their incorporation into large-scale multi-proxy synthesis and climate modeling efforts; begin with proxy-by-proxy discussions, and consider key improvements to NCDC architecture to support this advancement*

- *consider additional community-wide activities that address cross-cutting needs in the high-resolution paleoclimate community, including international standards and structures for sample archival and the urgency of collecting disappearing paleoclimate archives for future work*