*Editorial, continued from front page*

- Identify the important feedbacks which operate to amplify, or reduce the influence of changes occurring in a specific part of the climate system;
- Identify mechanisms of climatic coupling between hemipheres.

Since the publication of the PANASH-PEP science plan (PAGES 95–1, 1995) the international paleoscience community has made immense progress in coordinating regional research activities and linking regional paleoenvironmental and paleoclimate information along these transects. Several publications testify to the success of these coordinated interhemispheric paleoclimate activities (PEP I: Markgraf, 1998 in press; PEP II: Mikami *et al.* 1995; Dodson & Guo, 1998; PEP III: Gasse *et al.*, 1997). The time scales considered by these activities range from seasonal to decadal and millennial, using instrumental, historical, and multi-proxy paleoenvironmental records. Much effort has been spent to develop records that cover the last 250,000 years to document glacial-interglacial variations during two complete climatic cycles, which appear to have had very different characteristics. Another major effort addresses the need for high temporal resolution of records that cover the more recent past, the last 20,000 years (i.e. since the last glacial maximum), and the last 2000 years (times when human impact became a global feature).

While addressing interhemispheric paleoclimate questions separately for each transect, it became apparent that several of the major atmospheric circulation features that operate zonally, linking the transects, were not dealt with in a holistic fashion. Although to some degree this aspect has been addressed by the PAGES initiatives specifically focusing on past variability in the tropics (ARTS), of ENSO and the monsoons, it seemed timely to consider the whole Earth system and its linkages. For this reason the Inter-PEP meeting was convened in September 1999, supported by PAGES and the US NSF. The major goals of the meeting were to

- Illustrate the present and past character of climate linkages between the interhemispheric transects, and
- Identify questions that can only be addressed by further enhancing scientific collaboration between the interhemispheric transects.

The report of this meeting represents a summary of some of the major points raised. It will be up to the scientific community to take up the challenges and incorporate them into already ongoing activities.

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## WORKSHOP REPORT

# Inter-PEP

### Appenberg, Switzerland, 1–2 September, 1999

To further strengthen the inter-hemispheric (N–S) paleoclimate research activities represented by the PEP (Pole-Equator-Pole) and IMAGES (International Marine Global Change Study) transects, a meeting was convened in September 1999, that focused on zonal (E–W) paleoclimate linkages. The aim of the meeting was to enhance those aspects of climate dynamics that are optimally addressed by comparison of paleoclimate records between the PEP and IMAGES transects. In terms of present and past climate variability, several themes clearly link paleoclimate patterns zonally. The most prominent and probably best studied global zonal climate links are related to El Niño/Southern Oscillation (ENSO) anomalies (Diaz & Markgraf, 1992). Mechanisms that link the different monsoon systems of East Asia, India, Africa, and perhaps even the Americas, and further link them to ENSO anomalies, are still the subject of debate (Sirocko, 1996). There are also clear links between these tropical climate systems and circulation in extra-tropical latitudes, such as the westerlies (Ganeshram & Pedersen, 1998; Markgraf *et al.*, 1992) whereas the influence on tropical climates by extra-tropical phenomena is less clear. When discussing intra- and interhemispheric linkages in the paleoclimatic context, it is important to remember that climate systems operate at different time scales, reflecting climate variability at inter-annual, decadal and centennial scales. The different temporal scales reflect the different processes and interactions between the atmosphere, ocean and land.

Combined with the inter-hemispheric PEP and IMAGES programs, the zonal Inter-PEP approach will ultimately lead to a more holistic view of global climate change by allowing an assessment of changes in global latitudinal gradients in surface and land-sea temperatures. These gradients act as the principal driver behind all large-scale atmospheric and oceanic motions as well as latitudinal heat and moisture fluxes. For example, modeling experiments (Rind 1998) indicate that atmospheric dynamics primarily respond to gradient changes, both latitudinal and longitudinal, and not to changes in mean annual temperature.

To address the Inter-PEP concept the meeting dealt with tropical circulation systems, including ENSO, monsoons and their interaction, and with mid- and high-latitude circulation systems, including the westerlies and their linkages with the polar systems, especially the Arctic. The following review of the discussions provides a framework for an increasingly global view of paleoclimate research.

### Tropical Systems

As an example of the linkages of the tropical systems the cover figure shows schematically the flow of the Asian-Australian monsoon system and the Walker circulation in the context of the interhemispheric transects. Trying to understand the coupling between these circulation systems and its causes has been the subject of climate and paleoclimate research for many years (Barnett *et al.*, 1991; Clemens *et al.*, 1996; Charles *et al.*, 1997; Webster *et al.*, 1998). Although it has been shown by modeling experiments and spectral analysis of records that changes in insolation and solar activity affect the strength of either monsoons (e.g. Prell & Kutzbach, 1992) or ENSO (Anderson, 1992), the relationship between the variability of these climate systems is not straightforward. Only recently, Kumar *et al.* (1999) documented that the inverse relationship between ENSO and Indian summer monsoon that existed for the last 140 years broke down in the mid-80's. Could interaction of the Hadley cells and Walker circulation play a role in modulating the coupling between monsoon and ENSO in response to changes in tropical sea-surface temperatures (SST)? This was suggested by Liu *et al.* (1999) who presented a mechanistic model for explaining both coupling and de-coupling between the monsoon and ENSO. They proposed that the monsoon's effect on the Pacific trade winds would also affect ENSO variability by changing the upwelling intensity which in turn would lead to a change in SST in the tropical Pacific. Would this mechanism also hold on Quaternary (PAGES Stream II) time scales, when boundary conditions were dramatically different from the present? Or would the tropical circulation changes on millennial time scales have responded instead to extra-tropical phenomena, such as changes in North Atlantic SST or extent of Northern Hemisphere ice sheets? This was suggested from meteorological (Huang *et al.*, 1998) as well as paleoenvironmental data, including lake level records from Africa (Gasse & van Campo, 1994, Liu & Ding, 1999), and East Asian loess, ocean and ice records (e.g., Overpeck *et al.*, 1996; Porter & An, 1995; Guo *et al.*, 1998; Naruse & Ono, 1997; An & Thompson, 1998). This supposed linkage between East Asian monsoon intensity and North Atlantic climate change is exemplified in Fig. 2, showing synchroneity between rapid cooling events (Heinrich events) seen in the Greenland $\delta^{18}O$ (GRIP) ice core record and changes in the amount of eolian dust deposited in the Japan Sea (Ono, 1999; Tada, 1999).

From this discussion on climate and paleoclimate linkages between the extra-tropics and the tropics, it is evident that a coordinated effort is needed involving close collaboration in the study of both terrestrial and marine records, giving especial attention to the chronological aspects of such correlations (see e.g. Crowley, 1999). Clearly linking marine and terrestrial records from in and near the South East Asian Warm Pool has enormous potential (van der Kaars *et al.*, 1998; Hantoro, 1997; Moss & Kershaw, in press). Records from other tropical areas have yielded equally important information on land-sea interaction (Prell & van Campo, 1986; de Menocal & Rind, 1996; Hooghiemstra *et al.*, 1993; Rodbell *et al.*, 1999). In addition, coupled ocean-atmosphere models that include land feedbacks can be used to understand processes linking continental and marine records (e.g. de Noblet *et al.*, 1996).

## Open Questions

1. How has the mosaic of wet and dry regions varied in time and space in tropical regions, especially during times of contrasting climate modes? Modeling experiments for the Glacial Maximum (e.g. Hostetler & Mix, 1999) and paleoclimate records show markedly different distribution of precipitation patterns compared to today. How many different modes of regional contrasts in moisture regimes existed in the past and how did they differ from the present?

2. How might these patterns be related to changes in the intensity and spatial distribution of upwelling in the tropical oceans?

3. If the monsoons are primarily insolation driven the different monsoon systems in the Americas, Africa and Asia should have varied diachronously in the respective hemispheres in the past (e.g., monsoon regions of Africa and Asia at the end of the early Holocene wet period (Petit-Maire *et al.*, 1995)). New evidence suggests that there might also be other forcing parameters that caused monsoon variability at millennial scales in both glacial and interglacial intervals (Lu *et al.* 1999). What is the timing and variability of monsoon in the different regions of the continents?

4. How do climate changes in tropical mountain regions, commonly interpreted as temperature changes, relate to changes in the lowlands, generally defined as moisture changes? Is the recent warming at high elevations, representing a possible amplification of tropical SST increases, unprecedented (Diaz & Graham, 1996)? Is this recent trend suggestive of multiscale changes or different source mechanism in the ENSO system (Dettinger *et al.* in press, Enfield & Mestas-Nuñez, in press) or can other atmospheric phenomena be involved when boundary conditions are different?

5. How might the Inter Tropical Convergence Zone (ITCZ) have operated in the past, especially during fullglacial times when evidence from all tropical terrestrial records suggests that precipitation patterns were fundamentally different from today (e.g. Johnson, 1996; Bradbury, 1997; Ledru *et al.*, 1996, van der Kaars, 1998)? What is the relation of these different precipitation patterns to the suggested temperature lowering (Bush *et al.*, in press; Colinvaux *et al.*, 2000)? Or were reduced atmospheric $CO_2$ levels a cause for glacial aridity (Street-Perrott *et al.* 1997)?

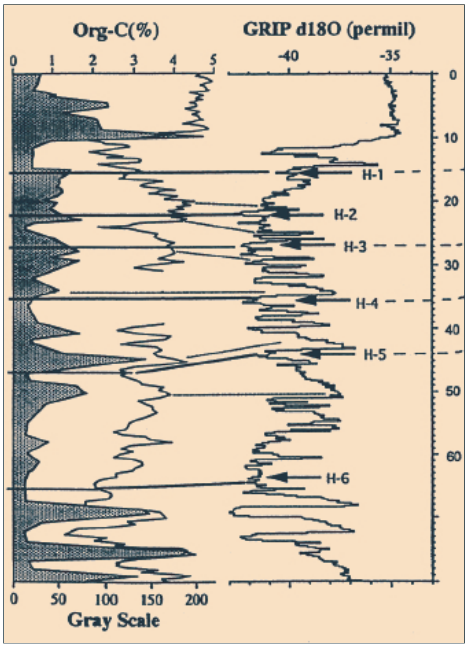


*Figure 2: Comparison of organic carbon content (in %; data by Dr. Oba) and sediment darkness from a Sea of Japan core, interpreted to show changes in eolian dust input, with the $\delta^{18}O$ record from Greenland ice core GRIP, showing Heinrich events (with permission by R. Tada; after Tada, 1999).*

6. What are the times when temperature or precipitation changes from the northern and southern tropics show in- or out-of-phase relationships? Lateglacial (Martin *et al.*, 1997) and Holocene (Seltzer *et al.*, 2000; Fig. 3 for the Americas; Finney *et al.*, 1996 for East Africa) paleoenvironmental records, showing out-of-phase relationships of climate trends, have been interpreted to reflect the precession-driven differences in insolation. However, records from these continents also show times of inter-hemispheric synchroneity of climate change. What might be the causes responsible for an in-phase inter-hemispheric climate change?

7. How does tropical and sub-tropical climate variability affect present and past high latitude climates in either hemisphere and vice versa? Climate studies have shown clear evidence for tropical forcing, not only at the interannual (ENSO) scale (e.g. on Antarctica: Smith & Stearns, 1993; South America: Villalba *et al.*, in press; Dettinger *et al.*, in press), but also at the interdecadal scale (e.g. Graham *et al.*, 1994). There is also strong evidence for high latitude forcing of tropical climate patterns; e.g. during the lateglacial in northern South America (Seltzer *et al.*,

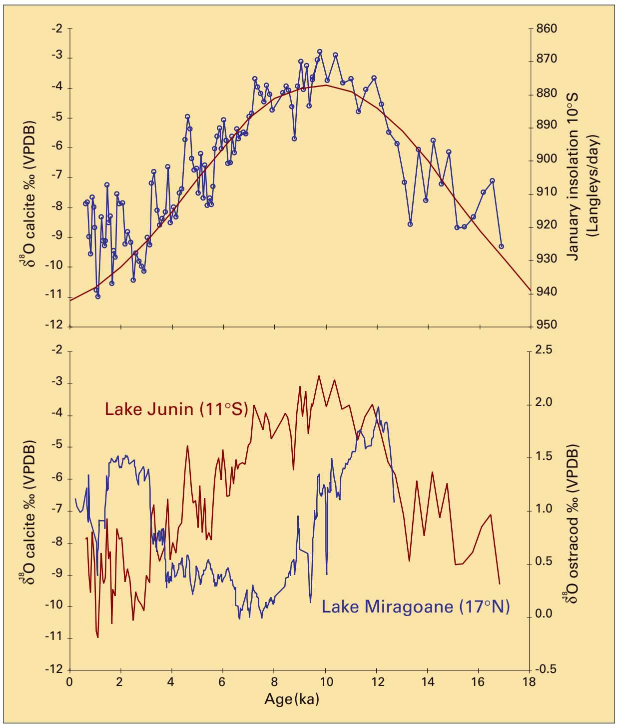


*Figure 3: Comparison of $\delta^{18}O$ in calcite from Lake Junin, Peru (11°S) with $\delta^{18}O$ in ostracodes from Lake Miragoane, Haiti (17°N)(from Seltzer et al., 2000). The figure shows out-of-phase of temperature trends during the Holocene, thought to relate to differences in precession driven insolation.*

2000) or during the early Holocene in Brazil (Ledru *et al.*, 1996).

## Extratropical Systems

The westerlies are a major feature of zonal atmospheric circulation. Climate and paleoclimate data have shown that the intensity, latitudinal position and a number of circulation anomalies (such as North Atlantic Oscillation (NAO, Fig. 1), Pacific Decadal Oscillation (PDO), Pacific North American Oscillation (PNA)), are strongly influenced by the latitudinal temperature gradient and ocean-atmosphere-land interactions. In addition to the tropical influences, changes in the polar regions are critical to understanding the behavior of mid-latitude climate variability. The PARCS (1999) report presents a critical review of paleoclimate research in circum-Arctic regions, with in-depth discussion on future research needed to address the role of the Arctic in the global context. The ongoing work of the European QUEEN program linked with Russian outgrowths of the US PARCS/PALE and the international CAPE programs provides initial links across the Eurasian Arctic especially relevant to assessing the distal influence of the North Atlantic heat pump into the arctic regions at various temporal scales (QUEEN: Svendsen *et al.*, 1999). Also important in this context are changes in the influence of the monsoon vs. the westerlies across the Siberian subarctic at finer spatial and temporal scales. Confirmation of teleconnections between Dansgaard-Oeschger/Heinrich oscillations and the Younger Dryas event recorded in El'gygytgyn Crater Lake, northeast Siberia (Brigham-Grette *et al.*, 1999) suggests lasting downwind influences undeterred by the presence or waning stages of the Scandinavian/Barents ice Complex. Maturing programs now studying lake records from Mongolia, Lake Baikal and El'gygytgyn could prepare for syntheses of Stream II and Stream I issues while integrating shorter records relevant to millennial to decadal timescales. Climatic contrasts across the Bering Strait today (Mock *et al.*, 1998) are a hint of the challenging heterogeneity found in paleoclimate records across the mid-to high latitudes. Syntheses provided by the forthcoming Beringian volume (in *Quarternary Science Reviews*) demonstrate the out-of-phase response of this subcontinent in concert with other parts of the arctic and subarctic climate system at times of global climate transition.

The PEP and IMAGES transects, focusing on an inter-hemispheric comparison of paleo-proxy climate records, are an optimal approach to provide information on the history of the westerlies and their response to different boundary conditions, such as continental ice sheets and sea-ice, insolation, atmospheric composition, etc. (Ganeshram & Pedersen, 1998; Thompson *et al.*, 1993; Markgraf *et al.*, 1992; Markgraf, 1998; Markgraf *et al.*, 2000). Past latidudinal shifts of the southern westerlies, especially during the LGM, continue to be a topic of controversy. It will be critical to integrate the terrestrial and the marine record (see Lamy *et al.*, this issue) to begin to understand this complex system. A complementary approach is provided by paleo-modeling experiments that may help to diagnose the possible causes of changes in the mid-latitude circulation (Wright *et al.*, 1993; Wyrwoll *et al.*, 2000).

## Open Questions

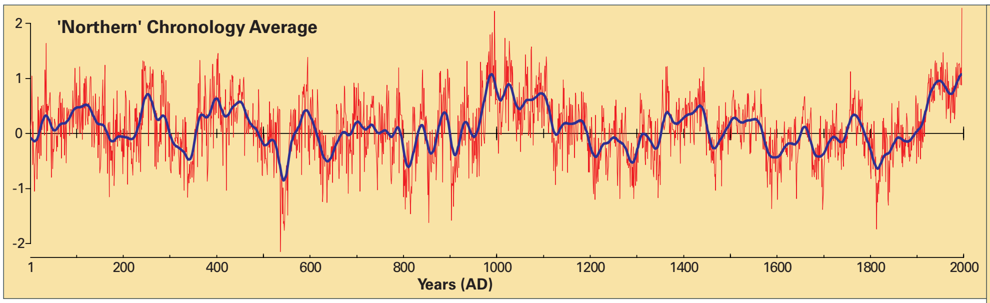
Major aspects however remain to be studied to understand the overall response and feedback of mid- and high-latitude climates to global change. To name some of the pertinent questions raised at the workshop:

1. What are the circulation modes and decadal-scale variability of the westerlies and of other mid- and high-latitude climate anomalies?
2. How do teleconnections within the zone of the westerlies produce synchronous or diachronous regional climates (Briffa, 2000; Fig. 4; Rittenour *et al.* 2000)?
3. Is there inter-hemispheric symmetry and synchroneity in the behavior of the westerlies (for Australia versus north-eastern Asia: Dodson & Ono, 1997; North America versus South America: Whitlock *et al.*, in press)?
4. What role do changes in the thermohaline circulation play in inter-hemispheric climate synchronization (Broecker, 1998)?
5. How do seasonal-to-decadal climate anomalies propagate in and out of mid latitudes? How and how far does the NAO, a major player in the circum-North Atlantic climate variability (Appenzeller *et al.*, 1998), extend its influence globally? Which region might be sensitive to record this climate anomaly?
6. What is the role of sea-ice and of fresh-water outflow from circum-Arctic river systems on mid and low latitude climate variability and is the thermohaline circulation the only mode of propagation of a signal? Are all high-amplitude and rapid climate change events (e.g. 8.2k, Younger Dryas) related to a shut-down of the thermohaline circulation?

## Conclusions and Outlook

In concluding the Inter-PEP workshop discussions several major points were raised that are a pre-requisite for global paleoclimate research in general, and that are perceived to be of especial importance for Inter-PEP research initiatives.

1. The PEP and IMAGES initiatives need to be coupled with zonal initiatives, such as exemplified by the various Arctic programs.
2. Research must be cross-disciplinary and cooperative; extensive data sharing and data archiving activities in collaboration with data centers are of critical importance (e.g. NOAA-NGDC WDC-A for Paleoclimatology).



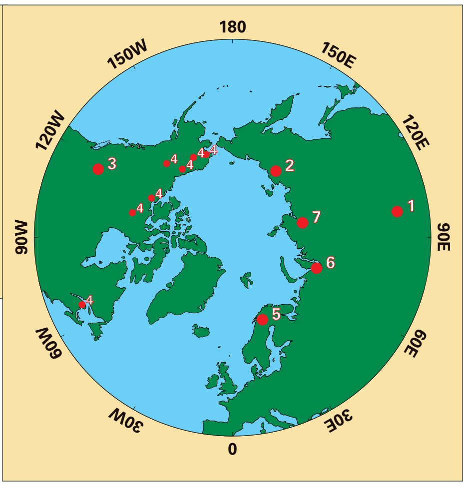


*Figure 4: The average growth shown by a number of temperature-sensitive tree-ring width chronologies spread across the Northern Hemisphere (after Briffa, 2000). The locations of the sites from which the data are drawn are shown on the map: 1, Tarvagatory, Mongolia (Jacoby et al. (1996), Science* ***273****, 771–773); 2, Yakutia, Siberia (Hughes et al. (1999) Holocene* ***9****, 629–634); 3, Alberta, Canada (Luckman et al. (1997) Holocene* ***7****, 375–389); 4, An annual temperature reconstruction based on data from 7 sites in Alaska and Canada (D'Arrigo and Jacoby (1992) in Climate Since AD 1500 (R.S. Bradley and P.D. Jones, Eds.), 296–311, Routledge, London; 5, Torneträsk, Sweden (Grudd et al., Holocene, in press); 6, Yamal, Siberia (Hantemirov, 1999) Siberian Ecological Journal* ***6****, 185–191); 7, Taimyr, Siberia (Naurzbaev and Vaganov (1999) Siberian Ecological Journal* ***6****, 159–168). The data, plotted as normalized mean density anomalies expressed in units of standard deviation, have been rescaled prior to averaging to give equal mean and variance over the 1601–1974 common period. The blue line shows 50-year smoothed values. This composite high northern latitude tree growth curve shows the very high temperature increase in the 20th century and the only marginally lower temperatures in the late 10th and 11th centuries.*

3. Cross-disciplinary comparisons of records need to be based on a critical assessment of independent chronologies, and not on curve-matching.

4. Major effort needs to focus on quantification of proxy climate indicators in order to provide means for cross-disciplinary comparisons. Proxies need to be identified that help provide land – sea correlations.

5. Paleorecords need to be updated to extend through the present to examine any change in system response that might shed light on anthropogenic effects of recent climate change.

6. Paleoclimate modeling experiments need to be based on realistic past climate scenarios, especially including well-known land-ocean interactions and feedbacks.

7. Climate-model sensitivity tests should be performed, both for modern climates and paleoclimates, which would help identify the mechanisms for climate patterns and climate variability. Also needed are paleoclimate "sequence" simulations (not only time window snapshots) that would help understand the temporal variations seen in the paleoclimate record.

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