Paleoceanographic Evidence for an Upwelling-Seesaw Effect During Heinrich Events

Little et al. (1997) analyzed relative abundances of the cold-water planktonic foraminifer Neogloboquadrina pachyderma (left coiling) in sediment cores from the Benguela-Namibia upwelling system over the last 140,000 years. Short periods of low abundance, indicating reduced coastal upwelling, coincide with Heinrich Events. This correlation is particularly striking for Heinrich Events 2 and 4.

For the Mauritanian upwelling zone, high-resolution proxy records for the last 35,000 years were presented by Zhao et al. (2000). A low percentage of the coccolithophorid Florisphaera profunda during Heinrich Event 2 suggests a weak surface water stratification due to enhanced upwelling intensity. Kiefer (1998) estimated primary productivity over the last glacial period from a core located southwest of the Canary Islands, about 450 km off the coast of northwestern Africa. Peaks in paleoproductivity coincide with Heinrich Events 2-5. A possible explanation for these peaks is that an increased amount of nutrient-rich upwelling water was advected from the coast towards the core location.

A Coastal Upwelling-Seesaw in the Pliocene?

Utilizing results from Ocean Drilling Program Site 1084, situated off the coast of Namibia, Marlow et al. (2000) reconstructed the upwelling history from the early Pliocene to the late Pleistocene. Around 4 million years ago, increases in mass accumulation rates of organic carbon, diatom abundance, and the proportion of upwelling species in the diatom assemblage coincide with the final stages of the CAS closure. We hypothesize that the increase in upwelling intensity off Namibia during the Pliocene is attributable to the closure of the CAS, the resulting increase in northward oceanic heat transport (cf. Fig. 1) and the operation of the Atlantic coastal upwelling seesaw. Unfortunately, no unequivocal Pliocene reconstruction exists for the upwelling region off northwestern Africa. For an improved understanding of Pliocene climate processes, future studies should focus on upwelling proxies for the Mauritanian upwelling zone.

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Call for a PAGES Initiative on "Past Regional Climate Variability"

H. Wanner

NCCR Climate*, University of Bern, 3012 Bern, Switzerland; wanner@giub.unibe.ch

Understanding past environmental variability is a prerequisite for the understanding of future environmental change. If we intend to diagnose, for instance, past climate variability, we have to be aware that a variety of natural and anthropogenic forcing mechanisms, as well as mechanisms inducing internal variability, act together and form a "cocktail" composition that is temporally very variable. The pattern of interaction in figure 1 attempts to document this fact. The upper boxes show how the forcings, together with natural variability, jointly influence the different subsystems of the climate system. As a result of these interactions, a variety of large-scale circulation patterns, modes and regimes are generated. These modes or regimes

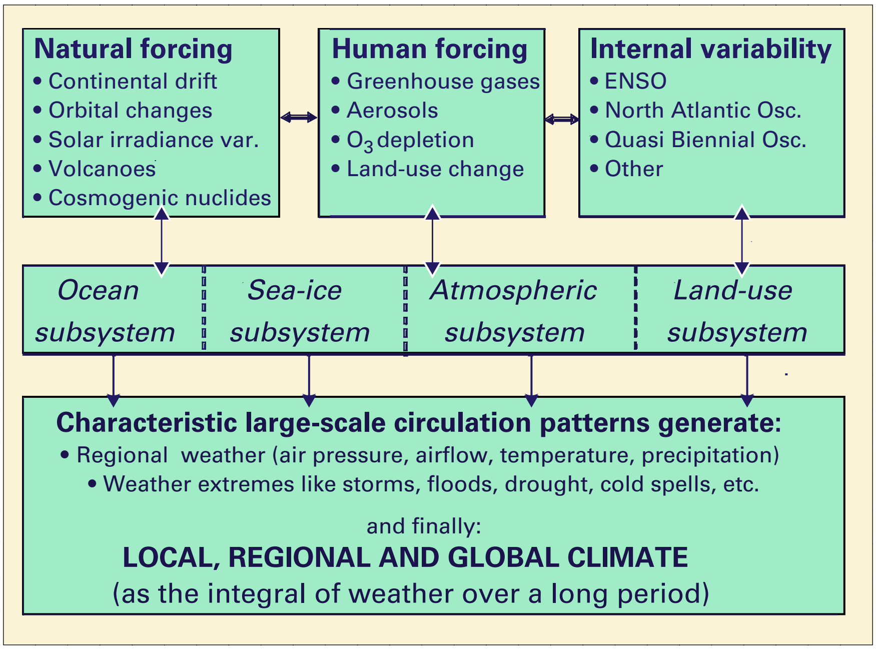

Fig. 1: Pattern of interaction demonstrating how the different natural and anthropogenic forcing factors, together with internal variability, generate local and global climate variability and change.

together cause the generation of mean and extreme local weather. The integral of these local weather phenomena over time and space results in that which we call local, regional and global climate.

The first long-term reconstructions were carried out using a variety of suitable proxy data and were mainly based on a global or hemispheric scale (Mann et al., 1998). Because temperature is directly related to the global energy balance, many studies still concentrate on this variable. In an earlier contribution to *PAGES News*, we already campaigned for the inclusion of other important contributory variables of the climate system, like air pressure and precipitation (Wanner and Luterbacher, 2002). We called it a LOTRED (Long Term Reanalysis and Diagnostics) approach. The basic idea is that the complex dynamical processes leading to past and future climate and environmental change can only be understood if we also acquire insight into the regional dynamics, for example, the cooling of the oceans by strong winds, the deflection of airflow by mountains, or the formation of heavy convective precipitation.

Two other facts have to be kept in mind. Firstly, we must consider that climate variability increases if the investigated area decreases. Secondly, the new generation of coupled climate models delivers simulation data at smaller regional scales (Schär et al., 2004). We therefore need highly resolved reconstructions if we intend to verify long-term past climate runs. In areas like Europe, where dense networks with high-quality natural and documentary archive data are available, multi-proxy reconstructions of temperature on a regional basis with higher temporal resolution (seasonal or monthly) are feasible (Luterbacher et al., 2004). The present multiproxy database has sufficient quality and density to allow the first 500-year-long reconstruction of continental precipitation fields (Pauling et al., in prep.).

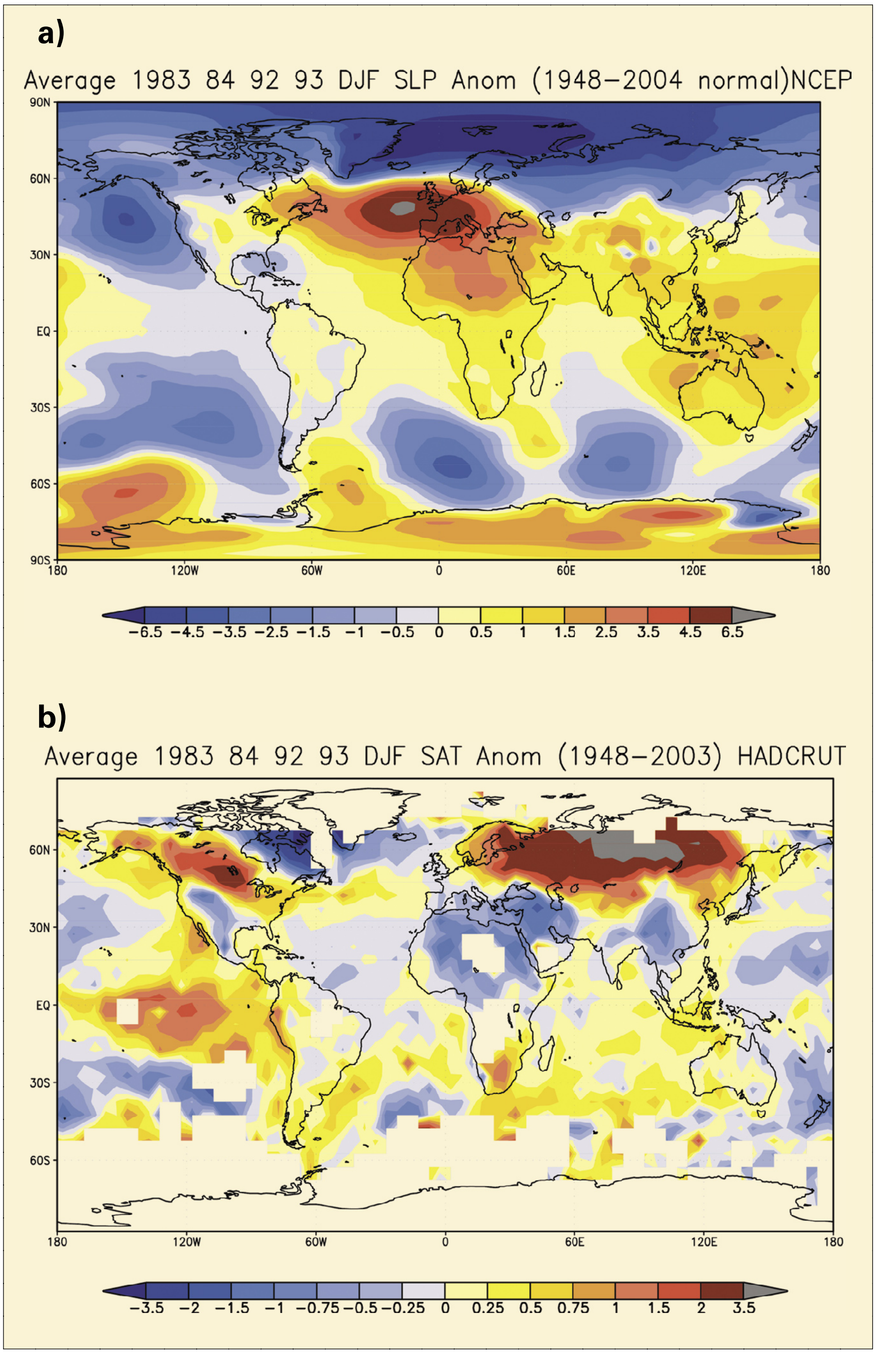

Fig. 2: Influence of the forcing by the El Chichón and Pinatubo eruptions on the global winter (DJF) surface pressure (a) (hPa) and temperature (b) (°C) anomaly fields in the first and second winter after the eruption (analysis by Paul Della Marta, based on NCAR/NCEP data for SLP and HADCRUT2 data for SAT; Kistler et al. 2001, Rayner et al. 2003).

One basic procedure to try to understand how the complex mix of natural and anthropogenic forcings, as well as internal variability, influence climate modes or regimes is to isolate one of these forcing factors that is remarkably strong, and to study the reaction of the climate system. In the case of model simulations, it is rather easy to generate a single specific forcing or to study natural variability under fixed forcing conditions. When using high-resolution reconstructed data, we have to define a period where one of the factors in the uppermost boxes of figure 1 was remarkably pronounced. By studying the anomalies during such periods, we can start to understand the dominating processes. And, indeed, most of these processes cause complex regional patterns. As an example, figure 2 indicates the influence of the forcing of the El Chichón and Pinatubo eruptions on the global winter (DJF)

Table 1: Influence of selected forcings and the two most important natural modes of climate variability in regional climate (SAT: surface air temperature, SST: sea surface temperature).

	Northern hemisphere	Tropics	Southern hemisphere	Timescale	Reaction of ENSO	Reaction of NAO (winter)
Natural forcings:						
Solar irradiance minimum	Warm oceans, cold continents (winter, SATs)	SSTs slightly higher	Southern oceans cooler (SATs)	Decadal to centennial	?	Negative state
Explosive tropical volcanic eruptions	Cold oceans, warm continents (also cool in N. Africa and China in winter)	Positive temperature anomalies in Eastern Pacific (SATs)	Deepening of midlatitude lows	Inter-annual	Can trigger ENSO events	Positive state
Anthropogenic forcings:						
Increasing GHGs and aerosols	Marked warming in all seasons (stronger in northern areas and over land), mainly increasing precipitation amounts	Slight warming (more in central and eastern equatorial Pacific), inconsistent precipitation trends	Warming (inconsistent magnitude), precipitation trend uncertain (exception: positive trend in Antarctic area)	Already decadal	Little change or small increase (uncertain)	Very uncertain (small trend to negative state)
Ozone depletion in polar areas	Similar to southern polar area but more complex processes	?	Cooling of Antarctic stratosphere, higher wind speeds	Decadal	?	Slight trend to positive state (?)
Land-use change	Urbanized areas: slight temperature rise Deforested areas: slight temperature decrease	Drier in deforested areas	Similar to northern hemisphere (but smaller because of reduced area)	Decadal to centennial	?	?
Modes of natural variability:						
ENSO warm episode	Wet: Florida, Gulf of Mexico Dry: NW India, Hawaii	Wet: Central Pacific, S. India, Uganda and surroundings Dry: Indonesia, Philippines, Central America	Wet: E Argentina, Uruguay Dry: SE Africa, E. Australia – Melanesia	Quasi-periodic: 3-7 yrs	-----	Negative state is possible
NAO (positive state)	Enhanced westerlies – Warm and moist: N. Eurasia, NE USA, E.. Canada Cooler and partly drier: S. Europe and N. Africa, NW Atlantic Ocean	Marked northern hemispheric trades	?	Quasi-periodic: 6-10 yrs	?	-----
NAO (negative state)	Weaker westerlies – Rather cool and moist: S. Europe and N. Africa Cold and dry: N. Europe, NE USA, E. Canada	Weaker northern hemispheric trades	?	Quasi-periodic: 6-10 yrs	?	-----

pressure and temperature fields. The pressure distribution (Fig. 2a) not only shows a deepening of the midlatitude lows on both hemispheres but also a positive pressure anomaly southwest of Great Britain. The influence of these anomalies on wintertime heat transport is reflected in the temperature anomaly map (Fig. 2b), for example, in the form of a strongly positive temperature anomaly over Eurasia (Shindell et al., 2004).

Finally, Table 1 gives an overview of a selection of possible regional effects on circulation patterns or surface temperature and precipitation anomalies, generated by typical forcings or by the modulation of the two dominating internal modes of variability listed in figure 1. We hope that this summary will encourage many PAGES scientists to perform more regional reconstruction and modeling studies of climate variability and other environmental issues!

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