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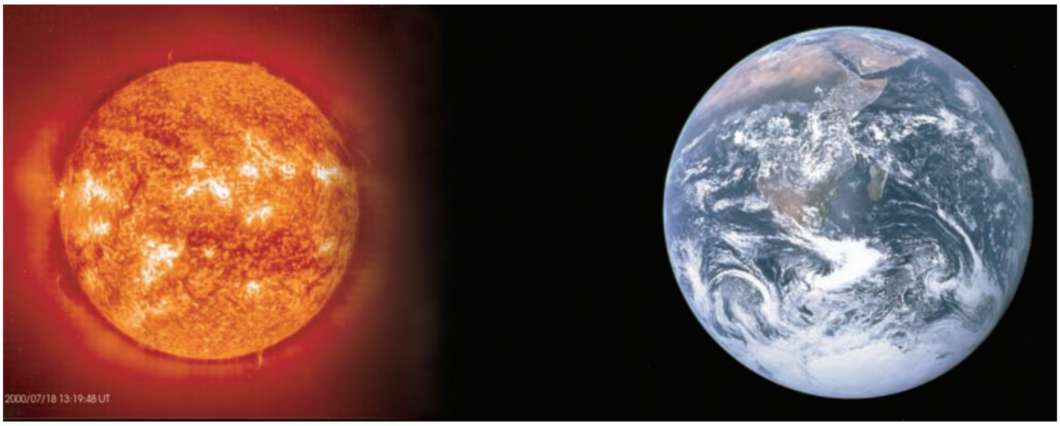
Exchanges

INTERSECTION

Joint Edition of the IGBP Past Global Changes Project (PAGES[1]) News and the WCRP[2] Climate Variability and Predictability Project (CLIVAR) Exchanges

CLIMATE FORCINGS

Sun - Earth system with climate forcing factors:



POWER: $4*10^{26}$ W Solar	Orbital	$2*10^{17}$W Greenhouse gases Volcanic aerosols Dust Land use

The sun emits a total power of $4*10^{26}$ watts, a billionth of which arrives at the top of the atmosphere. The climate system responds to changes in the solar emissions (solar forcing), the relative position of the sun and the Earth (orbital forcing), the radiative properties of the atmosphere (greenhouse gases, aerosols, dust), and the Earth's surface (land use). In addition variability is further introduced by the energy distribution processes of the climate system (internal forcing).

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CLIVAR/PAGES Intersection Panel: Understanding natural climate variability through integrating the climate dynamics and paleoclimate communities

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Understanding the mechanisms and history of natural climate variability is important for improving climate predictability and properly attributing ongoing climate changes to human and natural forcings. The paleoclimate record contains a much wider range in terms of duration and amplitudes of climate changes, than the instrumental record, and can provide insights into how the climate system responds when forced by non-anthropogenic forcings. In order to capitalize on this record it is imperative that the scientists analysing the paleoclimate records are well integrated with the communities involved in studies of ongoing climate change and in providing future scenarios. Thus the CLIVAR/PAGES Intersection Working Group has been formed, jointly sponsored by the Past Global Changes (PAGES) project of the IGBP and the Climate Variability and Predictability (CLIVAR) project of the WCRP. The panel aims to play an important role in developing and implementing the research programmes of both CLIVAR and PAGES. The objectives of the panel are:

- To promote improved high resolution, well-dated, quantitative paleoclimate records with seasonal to interannual resolution in regions which are of direct relevance to IGBP and WCRP.
- To formulate and promote, in collaboration with PAGES and CLIVAR, a programme for analyzing and synthesizing paleoclimatic data in order to reveal evidence of patterns of variability within the climate system over seasonal to millennial time scales.
- To promote improved quantitative methods of model-data comparison and evaluation in order to understand the variability present in both the paleoclimatic record and the models.
- To promote the use of paleoclimate data to examine issues of climate predictability.
- To coordinate with other modelling activities of relevance to IGBP and WCRP.

The panel has produced a 5 year vision document (see www.clivar.org/organisation/pages/doc/visionTOC-Final.pdf) and identified key scientific issues, which will promoted via a set of initiatives:

- Climate variability over the last few millennia
- Abrupt climate change
- Hydrologic, biospheric, and land-surface interactions
- Tropical-extratropical links including ocean and atmospheric teleconnections.

Aside from this issue of the joint CLIVAR / PAGES newsletter on climate forcings, which we hope will stimulate further developments of accurate climate forcing histories, the panel will in 2006 organise two special workshops:

1. Past Millennia Climate Variability: proxy based reconstructions, Modelling and Methodology – Synthesis and Outlook, June 7-10, Wengen, Switzerland.

2. Abrupt changes and the 8.2 ka event. Co-organised with the UK RAPID Programme, 24-27 October in Birmingham, UK.

Further plans for the following years are to initiate synthesis activities on hydrologic, biospheric and land-surface interactions, and a potential workshop on interactions between the Southern Ocean and the lower latitudes. The panel is also very eager to stimulate further progress in forward modelling of paleoclimate proxies, and aims to bring together scientists working on developing this promising field.

If you have comments or ideas for the panel, please contact the panel chairs or the PAGES and CLIVAR project offices.

Editorial

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The Earth's climate system is driven by solar power. Since the low latitudes receive a larger share of this power, the climate system redistributes it by transporting heat continuously through the ocean and the atmosphere towards the polar regions. In this way, any perturbation to the radiative budget of the Earth induces a reaction of the climate machine, involving amplifying or stabilising effects within the climate system. This climate machine consists of many complex dynamic components that interact with each other on very different timescales: atmosphere and ocean circulation, cryosphere and biosphere. In order to understand the climate system, it is crucial to identify and investigate the main processes that are responsible for changes. These forcings can be natural as well as man-made and play a central role in past, present and future climate change. However, there is also an 'unforced' component which is due to internal variability of the climate system. Climate models are useful tools for studying the complex relationship between the various forcings and the corresponding response of the climate system.

On geological timescales, much more powerful forcings were active. The solar luminosity changed by some 30%, the composition of the atmosphere and the distribution of the continents, as well as the build-up of mountain ranges, were completely different. On behalf of the PAGES/CLIVAR Intersection Panel, established in November 2004 in Canada, we present several aspects of climate forcings on annual-to-millennial timescales in this special joint issue of PAGES News and CLIVAR Exchanges. When considering climate change with the modern distribution of land and ocean, the primary forcing over tens of thousands of years is related to the orbital parameters of the Earth that modulate the seasonal and latitudinal distribution (obliquity and precession) and the total amount of incoming solar radiation (eccentricity). Orbital forcing, caused by the gravitational forces of the planets, is the only forcing that can be calculated precisely for several million years back into the past as well as forward into the future. As far as the response is concerned, the situation is much less favourable. Current efforts are focused on the understanding of the suite of reactions triggered by orbital forcing on the various components of the climate system.

On shorter timescales, a variety of climate forcings are at play, including changes in solar activity, occurring on decadal-to-millennial timescales. Changes in the optical properties of the stratosphere due to volcanic activity and dust play a role on interannual-to-decadal scales. In more recent times, human activities have no longer been negligible and affect the boundary conditions of the climate system. At the global scale, human activities are modifying the land surface properties ("land use forcing") and the aerosol and greenhouse content of the atmosphere. These modifications are so intense that the current period is now defined as the "anthropocene". Simultaneously making better use of the archives provided by nature (ice, sediments, tree rings, etc..) leads to new reconstructions of past climate forcings and more realistic representations of forcings in climate models.

Current measurements of solar forcing and attempts to relate it to the observed and reconstructed solar activity is discussed by Judith Lean; indications for a centennial solar effect on the Antarctic atmospheric circulation based on dust records from ice cores are presented by Barbara Delmonte. Volcanic eruptions during the last centuries and their effects on the radiative balance in the atmosphere are the subject of Erich Fischer's contribution; Joël Savarino proposes a new method to identify and possibly quantify the amount of sulphur injected in the stratosphere by volcanic eruptions. Emiliano Castellano and co-authors use high-resolution continuous flow methods on new Antarctic ice cores to reconstruct past changes in volcanic activity, and discuss the possible interaction between this activity and ice sheet extent. Similarly, continuous methods enable new reconstructions of atmospheric dust deposition in Greenland over the last glacial cycle, owing to the NorthGRIP ice core. Fortunat Joos reviews the concept of radiative forcing and climate sensitivity, and the orders of magnitude of current perturbation of the atmosphere radiative balance due to anthropogenic greenhouse gases. Ulrike Lohmann describes the complex role of natural and anthropogenic aerosols on the radiative balance. Even before industrialisation, human activities could have affected the climate system through land use. This issue is addressed by Sandy Harrison.

Today, there are still many open questions regarding climate forcing and response but we can be optimistic that within the next decade we will have better data, improved models and even clearer answers from nature itself.

Paleoreconstruction of volcanic history inferred from glacio-chemical ice core analyses

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The study of the link between volcanism and climate and the understanding of the actual direction of their cause-effect relationship has been a matter of debate for several years, revealing many aspects not yet well understood. The general scientific approach deals with two main topics:

1. The impact of volcanic emissions (mainly SO , dust, ash) on climate through changes in the Earth's radiative balance, via absorption and scattering of the incoming solar radiation;

2. The possible effect of climate-induced environmental variations (rapid melting or growing of ice sheets with consequent unbalance of the hydrologic cycle—including sea level changes—and of the isostatic pressure on the Earth's crust) on volcanic activity, reflected in changes in frequency and intensity of volcanic events. In reality, the climate-volcanism relationship is more complex and there are several different mechanisms involved, including possible positive feedback mechanisms.

Throwing light on this topic requires the reconstruction of as long and as synchronised paleo-volcanic and paleo-climatic records as possible. In this regard, deep ice cores from the inner regions of Antarctica and Greenland provide a unique archive because they record both past volcanic events (identified by conductivity or sulfate spikes), and indices of past environmental and climatic conditions (e.g. stable isotopes, greenhouse gases, dust).

EPICA Dome C (EDC) ice-core drilling, in the framework of the EPICA (European Project for Ice Coring in Antarctica) project, recently reached bedrock (75°06'S, 123°24 E, 3233 m a.s.l., East Antarctic Plateau), allowing the reconstruction of about 900 ky of past climatic history. Chemical and isotopic measurements were carried out at very high temporal resolution, so that single volcanic events (spanning a few years) and fast climatic changes can be reconstructed in large detail over the whole core (EPICA community members, 2004).

The best way to reconstruct paleo-volcanic records from ice cores is to perform high-resolution sulfate measurements. Volcanic eruptions inject huge amounts of SO_2 into the atmosphere and, in the case of large explosive eruptions, into the stratosphere, where they can be globally dispersed. Once in the atmosphere, SO_2 is oxidised to H_2SO_4 within a few weeks, altering the atmospheric composition for months to a few years, and resulting in the contrasting effects of stratospheric heating and tropospheric cooling. H_2SO_4 is deposited over polar ice sheets and buried by snow, which accumulates and gradually compresses into solid ice, thereby recording volcanic H_2SO_4 signatures.

In the past years, volcanic stratigraphies have often been inferred from continuous acidity records from Electric Conductivity Measurements (ECM) or DiElectric Profiling (DEP) (Udisti et al., 2000). However, the original acidic load can be partially neutralised in the atmosphere or after deposition by buffering effects (e.g. by dust). Conversely, sulfate records are insensitive to snow acidity changes and volcanic spikes are irreversibly preserved in the snow, except for very slow processes of diffusion that are only significantly active at great depths.

For these reasons, the paleo-volcanic record of the EDC ice core was reconstructed from sulfate measurements performed in the field by Fast Ion Chromatography (FIC), a method for high-resolution analysis of sulfate, obtained by coupling an ion-chromatographic method with a flow-injection analysis apparatus (Udisti et al., 2000).

EDC-FIC temporal resolution is nearly annual during the whole Holocene, varies from 1 to 5 years during the last 400 ky and then increases up to 25 years at the bottom of the core. Such resolution is high enough to detect most past volcanic events (at least for the last 400 ky), except for events occurring within a very short time, with only a minor impact on the determination of past volcanic frequencies.

The Holocene EDC ice core sulfate profile (Castellano et al., 2005) is presented in Figure 1a, while Figure 1b shows the depositional fluxes of sulfate spikes resulting from volcanic eruptive activity. Sulfate volcanic signals are superimposed on a background of mainly biogenic, marine and crustal origin (see Fig. 1a). The method used for the discrimination between volcanic spikes and background contributions was recently presented (Castellano et al., 2004).

For older periods (>400 ky BP), volcanic reconstruction is progressively affected by sulfate diffusion processes, resulting in broader signatures, and by thinning ice-layers, leading to a progressive decrease of volcanic fluxes and of the number of events detected. The possibility to use the volcanic signatures recorded in the whole EDC ice core in the future will depend on the ability to set up models of volcanic peak deconvolution. In any case, 4-5 reliable glacial/interglacial cycles of volcanic history are already available for correlation with other paleo-climatic records.

Focusing on the younger part of the EDC volcanic record, the comparison between the Holocene volcanic profile with other reconstructions from several Antarctic ice cores indicates that differences in depositional fluxes among different Antarctic locations can be the effect of changes in regional atmospheric circulation, as well as of different mechanisms of atmosphere/snow exchange (Castellano et al., 2005).

In addition, volcanic stratigraphies are useful tools for ice-core dating. The high-resolution synchronisation between Vostok and Dome C volcanic records formed the basis for the construction of a common age scale for the last 45 ky, and enabled the detection of changes in the ratio of snow accumulation rates at the two sites (Udisti et al., 2004).

Lately, attention has been focused on studying the climate-volcanism relationship over a longer period of time. Figure 2 shows the comparison between the volcanic frequencies and δD, used as a proxy of past atmospheric temperature for a period spanning the last glacial/interglacial cycle (0-150 ky BP).

The volcanic frequency and δD profiles indicate a general inverse correlation between number of volcanic events per millennium and paleo-temperature. A higher occurrence of volcanic signatures is detected around the LGM, MIS 4 and after the Eemian, evidencing the possible enhancement of volcanic activity during cold periods or during phases of rapid climatic transition. This is an interesting aspect of the volcanism-climate relationship that is not yet fully understood and still poorly explored.

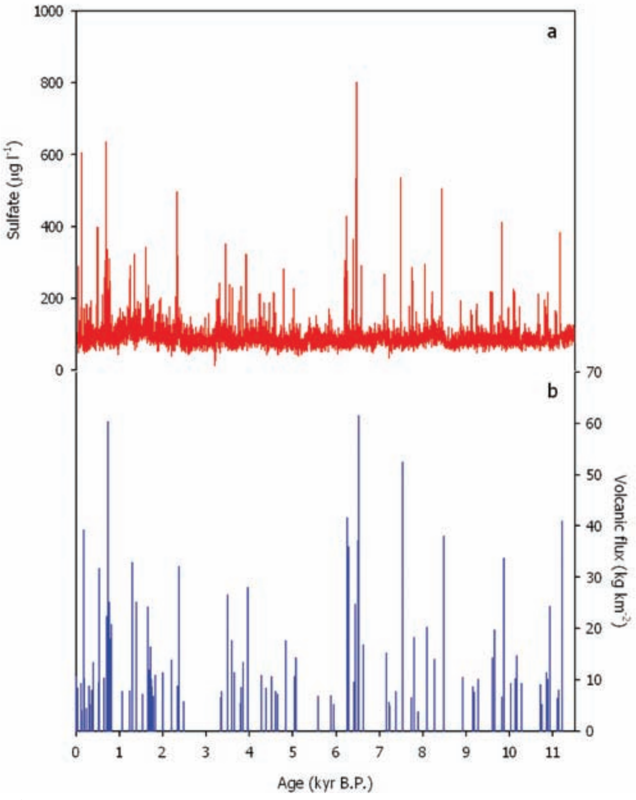

Figure 1
EDC ice core sulfate concentrations (a) and volcanic fluxes (b) spanning the whole Holocene (Castellano et al., 2005).

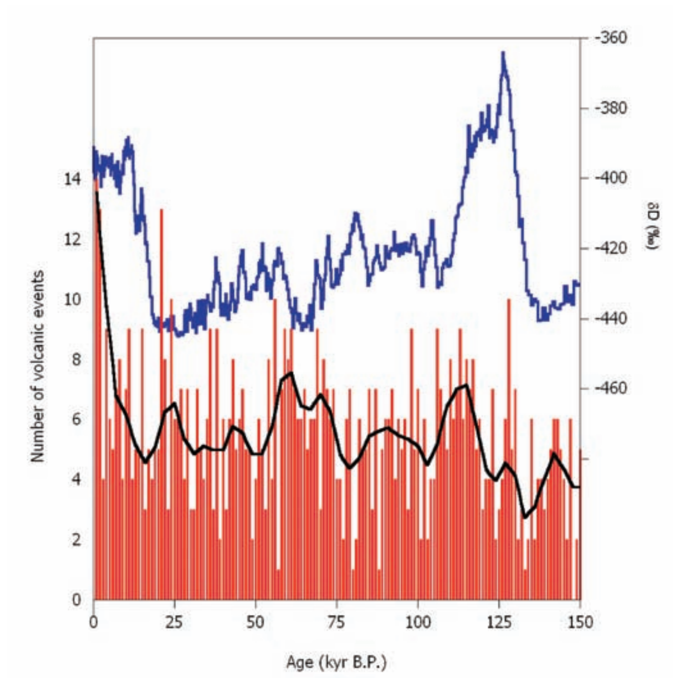

Figure 2
Correlation between number of volcanic events per millennium (red bars, the black solid line represents their smoothed profile) and deuterium (blue line) along the EDC ice core (unpublished data).

As a preliminary result, such experimental evidence seems to support a close relationship between volcanism and climate, with a sensitivity of volcanic activity to fast temperature changes. This could point to a relevant role of changes in cryosphere and hydrosphere systems (growing or melting of polar ice sheets with consequent change of sea level) in controlling volcanic activity. On the other hand, the fact that the highest number of events are recorded during the two last millennia, something common to several Antarctic ice cores (Castellano et al., 2005), when climatic conditions have been relatively stable, raises new hints and questions for future discussions.

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Secular variability and 200-year diploar oscillations in an atmospheric circulation over East Antarctica during the Holocene

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Deep ice cores from the East Antarctic Plateau are unique archives of climate history spanning the Late Quaternary (e.g. EPICA Community Members, 2004; Petit et al., 1999). Insoluble, long-range windblown mineral dust from the Southern Hemisphere continents to the East Antarctic Plateau and archived in the ice layers can be used as a tracer for documenting environmental and atmospheric circulation changes in the Southern Hemisphere at different time scales.

Dust mainly consists of the terrigenous minerals clay, quartz and feldspars. The total concentration in polar ice depends on numerous factors, such as source strength, hydrological cycle, residence time of aerosols, atmospheric transport and snow accumulation rate on the ice sheet. Interestingly, ice core investigations from East Antarctica showed that the grain-size of aeolian minerals is a very useful indicator for atmospheric transport, displaying modes of variability independent from the total dust input (Delmonte et al., 2004). Looking at ice core dust data from these two complementary points of view opens up new perspectives towards improved documentation and better understanding of the dynamics induced by climate forcing at high southern latitudes over the late Quaternary.

A recent dust investigation of two ice cores from East Antarctica (Fig. 1), one from EPICA Dome C (EDC, 75°06'S 123°21'E), the other from Vostok (Vostok-BH7, 78°28'S 106°48'E) allowed the depiction of secular and multi-secular modes of dust size and atmospheric circulation variability during most of the Holocene (Delmonte et al., 2005). The dust concentration and size profiles along with the water stable isotope content, reported in Fig 1, display clear differences. The total dust input in Antarctic ice is tightly related to environmental conditions at the source regions and a good example is the ~800-1,000-year-long dust minimum occurring before the Holocene onset (between 12 and 11 kyr BP), likely related to humid conditions in South America, the dominant dust source region for the Antarctic Plateau. Such an event was also found in two other East Antarctic ice cores (Delmonte et al., 2004) and may represent a robust stratigraphic marker. After this event, both EDC and Vostok records display a short-term variability superposed on a main Holocene decreasing trend.

The patterns of dust size changes from both cores (Fig. 1c and 1d) are clearly different with respect to concentration profiles and characterised by a high-frequency (secular to sub millennial) mode of variability. Also, there are evident discrepancies between Vostok and EDC dust size records and the short-term (secular-scale) variations are differently structured in apparent multi-secular and millennial-scale cycles in the two records.

Spectral analyses of the two dust size series for the period of overlap (9.8 to 3.5 kyr BP) pointed out significant secular-scale periodical modes of variability and an interesting common periodicity around ~200 years.

A series of volcanic markers randomly distributed over the common part of the records allowed the establishment of a tight stratigraphic and chronological link (± 30 years) between the two records. Interestingly, dust size changes are often asynchronous and out of phase. With respect to the 200-year component, in particular, dust size changes appear out of phase (over 25 cycles from a total of 29) for about 5.5 kyr duration between 9.8 to 4.2 kyr BP.

Regional variability of dust transport and atmospheric circulation patterns over East Antarctica

The slight dust size fractionation observed in polar ice should depend mostly on transport time and it is likely insensitive to air temperature or water saturation pressure. Therefore, grain-size changes could be associated with the

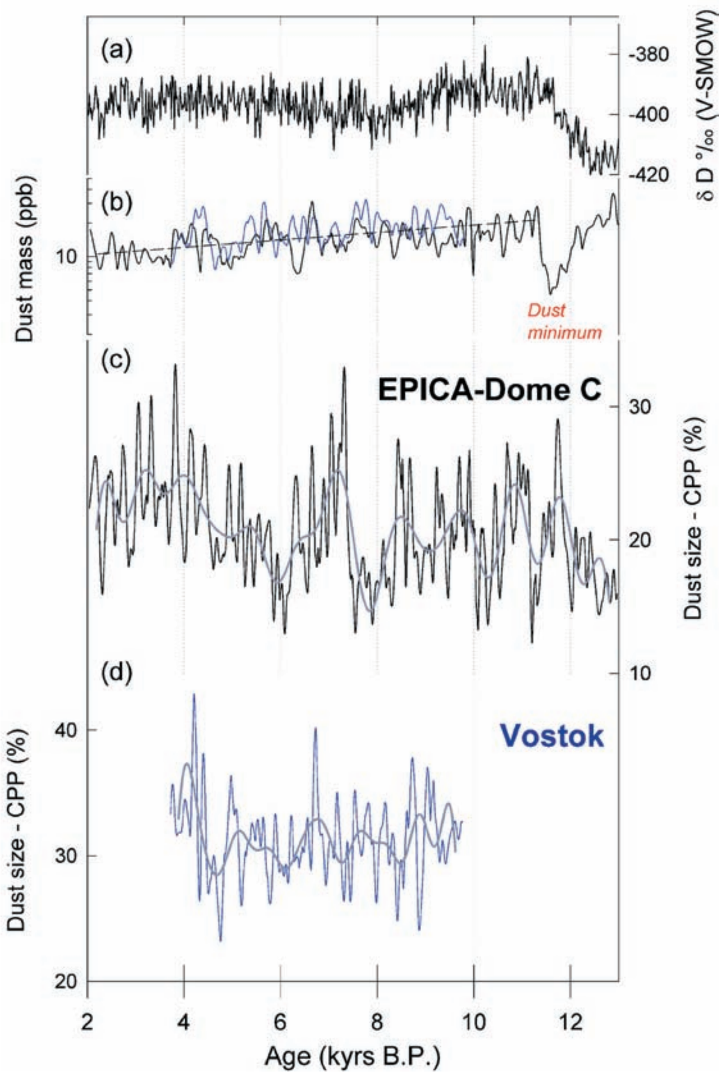

Fig. 1: Holocene records from Vostok and EDC ice cores (from Delmonte et al., 2005, modified).
(a) EDC Deuterium record (δD expressed in ‰ with respect to Vienna-SMOW), from Jouzel et al., 2001.
(b) Total dust mass concentrations (ppb or 10^{-9} g/g) from EDC (black line) and Vostok (blue line) ice cores, analysed with a time resolution of about 1 sample per ~50 years (running average over 70 years). The pre-Holocene dust minimum is indicated (12-11 kyr BP) along with the general Holocene decreasing tendency of the series (dashed line).
(c) EDC dust size record (running average and lowpass filtered data for periodicities shorter than 1,000 years), expressed as Coarse Particle Percentage (CPP, %) of the total dust mass. As particles are typically smaller than 5 µm in diameter, the CPP parameter was calculated in the 3-5 µm interval for EDC.
(d) The same as (c) but for the Vostok ice core. Coarse particles were calculated in the 2.5-5 µm diameter interval, as dust in the Vostok ice core is slightly smaller.

variability of atmospheric transport pathways. Fine dust is likely related to subsidence and sinking from upper air and/or to longer trajectories, while relatively coarse dust size indicates advection of air masses from lower levels in the troposphere.

While southern South America is the dominant source for the glacial period, the dust source regions are not well constrained for the Holocene period. Therefore, the asynchronous dust size variations can possibly be attributed to different transport paths from a common dust source or to an alternate influence of two or more sources on one site or the other. Whatever the cause, the differences observed between the two East Antarctic sites, which are only 600 km apart on the Plateau, suggest a regional (mesoscale) variability of atmospheric circulation regimes.

The out-of-phase changes between the two sites depicted in the common 200-year band of variability suggest that an asymmetric (or dipolar) mode of variability was operating over East Antarctica during most of the Holocene. Indeed, regional differences of dust size and atmospheric circulation changes between the EDC-Komsomolskaya region and the Dome B-Vostok region were also unequivocally observed during the last glacial maximum to Holocene transition (Delmonte et al., 2004). These were interpreted as being related to the general reorganisation of the atmospheric circulation during the climatic transition, linked also to Southern Ocean conditions, and leading to a gradual change in the eccentricity of the polar vortex (i.e., the distance of its centre from the geographical south pole).

The 200-year mode of variability

The relative chronology of the two records was tightened by volcanic markers, allowing simple combinations of dust size parameters. The sum (∑) and the difference (Δ) of EDC and Vostok CPP parameters allowed the construction of two composite indicators suitable for characterising the symmetric (∑) and the asymmetric (Δ) mode of atmospheric circulation variability, respectively. On the one hand, the symmetric mode, which could be associated with the strength of the Antarctic Oscillation, contains a continuum of periodicities spread from 140 to 500 years (Fig 2a), likely reflecting oscillations of the Southern Ocean climatic system. On the other hand, the Δ (asymmetric) parameter is associated with the relative difference of air mass influencing Vostok and EDC regions, and contains pronounced secular-scale modes of variability around 200 years (Fig 2).

The 200-year periodicity is of particular interest as it is usually associated with the variability of solar activity (205-year, so-called DeVries solar cycle) and is one of the most prominent periodicities in the Holocene $\Delta^{14}C$ record, and is also imprinted in the ^{10}Be record of polar ice (e.g. Beer et al., 1991). Indeed, the solar climate connection could likely be mediated by the Southern Ocean system, this later playing the role of "pseudo-oscillator", integrating, amplifying and embedding into its internal variability mode a possible external forcing. The 200-year band of variability strongly expressed in the atmospheric (dust size) records from Vostok and EDC might represent the final expression of an ocean-atmosphere amplification of solar forcing at secular periodicities, influencing sea surface temperature, sea ice extent and the climatological position of highs and lows. Finally, the climatic response on the East Antarctic can be expected to be delayed with respect to solar forcing, as the Southern Ocean and sea ice cover introduce thermal inertia into the system.

Model studies of atmosphere-ocean-sea ice interactions, along with the study of the regional impacts of solar forcing, as well as ^{10}Be concentration measurements from Vostok or EDC ice core samples, will be very helpful in documenting this relationship and testing such speculations.

Acknowledgements

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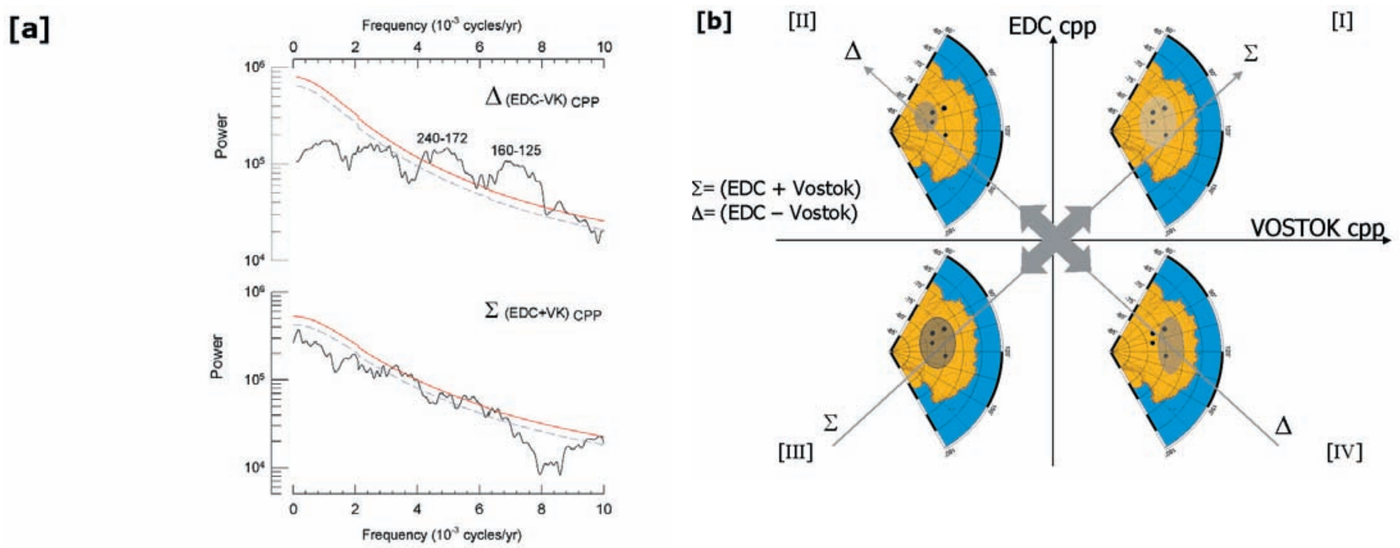

Fig 2: Symmetric and asymmetric modes of variability of atmospheric circulation over East Antarctica during the Holocene. (a): Spectral analysis (Multitaper Method) of the difference Δ (top) and the sum ∑ (bottom) of dust size parameter from EDC and Vostok. The 95% and 99% confidence levels with respect to a red noise signal are shown. (b): Vostok CPP and EDC CPP dust parameters are represented by the x and y axes, respectively. The 60°E-180°E sector of the East Antarctic Plateau with location of drilling sites is shown. The ∑ (sum) and Δ (difference) composite dust parameters are represented by the first and second diagonals. The arbitrarily rounded grey area represents the major centre of subsidence. Along the ∑ axis, is a symmetrical mode of variation from generally enhanced (quadrant III) to reduced (quadrant I) subsidence. Along the Δ axis (asymmetric mode), the area of subsidence varies from an eccentric location (quadrant IV) to a more poleward position (quadrant II). This may correspond to an atmospheric dipole over East Antarctica having a pronounced 200-year periodicity. Dots are locations of the drilling sites, clockwise from bottom right: EPICA Dome C, Vostok, Dome B and Komsomolskaya

Climate response to major volcanic eruptions

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It is a fundamental challenge to understand how much of the observed climate variability is a response to natural variations, as opposed to anthropogenic contributions or internal variability. Volcanic eruptions are one important cause of natural climate variations through radiative, chemical, dynamical and thermal perturbations in the climate system. Since major eruptions exert a strong short-term influence on climate, they are ideal to study the detection, isolation and attribution of a climate signal.

The climatic effect of volcanic eruptions is mainly due to injection into the lower stratosphere of large amounts of SO2, which are converted to sulphate aerosols. The tropospheric component is removed from the atmosphere within 1-3 weeks and has no significant long-term climatic effect. The stratospheric aerosols substantially perturb the Earth's radiative balance, causing warming and cooling at the same time. Increased absorption of radiation in the near-infrared results in a strong radiative heating in the lower stratosphere. On the other hand, strongly enhanced reflection of incoming solar radiation causes a global annual net cooling at the surface for typically 1-3 years (see Fig. 1).

The response of the climate system shows large hemispherical-to-continental, as well as seasonal, differences. The hemispherical differences are to some extent related to the latitudinal dispersal of volcanic aerosols into each hemisphere. The latitudinal transport is slower than the zonal dispersal and asymmetrical as a function of time of the year, location of the intertropical convergence zone (ITCZ) and the quasi-biennial oscillation (QBO).

The seasonal differences of the climate response are largest at the continental scale following tropical eruptions. Over northern hemispheric (NH) land regions, radiative cooling is dominant only in the summer half-year. During boreal winters, dynamical effects prevail, associated with anomalously warm conditions. GCM studies have shown that volcanic aerosols, which heat the tropical lower stratosphere through absorption, enhance the meridional stratospheric temperature gradient, which results in a strengthened polar vortex (Robock, 2000, and references therein). Stenchikov (2002) suggested an additional effect in the troposphere: Reduced solar radiation causes cooler tropospheric temperatures in the subtropics, which decreases the meridional tropospheric temperature gradient. This results in a reduction in the amplitude of planetary waves and allows the further strengthening of the polar vortex. Both processes force a positive phase of the Arctic Oscillation/North Atlantic Oscillation (AO/NAO) causing winter warming over the NH land masses through enhanced advection of mild maritime air.

The volcanic signal is robust only on relatively large spatial scales and could easily be contaminated or completely obscured by other forcings or climate variability (e.g. strong ENSO events). Therefore, not every eruption is expected to cause a strong, immediate cooling (warming) but rather to bias the probability of occurrence of cold (warm) anomalies in post-eruption summers (winters). We visualise this shift in probability by analysing the volcanic signal in a European land temperature reconstruction by Luterbacher et al. (2004) going back to AD 1500. Figure 2 shows temperature anomalies for the summer (JJA, blue lines) and winter (DJF, red lines) in year 1 following 16 major tropical eruptions with respect to a 5-year pre-eruption period (see Fischer et al., 2006 for details). The black lines depict the corresponding anomalies in non-volcanic periods together with a fitted Gaussian distribution. A clear tendency to colder (warmer) conditions can be observed in post-eruption summers (winters). All 16 post-eruption summer episodes show a cooling (mean -0.48°C). Winter warming is not observed in all the cases but there is a clear shift (mean warming +0.73°C) in the probability of anomalous conditions (Fischer et al., 2006). Analysis of independent NAO index reconstructions reveal that the winter warming has often been associated with a positive phase of the NAO (not shown). A similar, yet less-pronounced, temperature signal is found in year 0, both in the summer and winter immediately following the eruptions.

In contrast to tropical eruptions, aerosols from mid and high-latitudinal eruptions often remain in the hemisphere into which they were injected. Hence, in these cases, the above-mentioned dynamical effect does not apply and radiative effects, which produce cooling, are dominant in winters following non-tropical eruptions (Oman et al., 2005). The two major high-latitudinal eruptions, Laki 1783 and Katmai/Novarupta 1912, were followed by anomalously cold NH winters.

Uncertainties and open questions

The findings presented above originate either from studies using instrumental data and multiproxy reconstructions or from climate model studies. Both approaches offer different potential but involve uncertainties and limitations, some of which will be highlighted in this section.

Volcanic record

A prerequisite to studying the impact of volcanic eruptions on climate is an exact record of the date, magnitude and location of eruptions. Most volcanic indices, such as the dust veil index (DVI) and the volcanic explosivity index (VEI), have limitations for use in climate studies. In recent years, Robertson et al. (2001) and Ammann et al. (2003) defined forcing data sets, based on sulphate records in ice-cores, which include estimates of the latitudinal distribution of volcanic aerosols. It is desirable that these promising approaches are supplemented with new high-resolution ice-core data from Greenland and Antarctica, as well as from glaciers in the mid- and low-latitudes, in order to account for the noise in the individual cores and to improve the representation of latitudinal aerosol dispersion. Furthermore, it is important to monitor the dispersion of aerosols from future eruptions by satellite and ground-based observations. Robock (2004) proposed the development of a data assimilation system using atmospheric models to produce a stratospheric aerosol data set out of the diversity of observations.

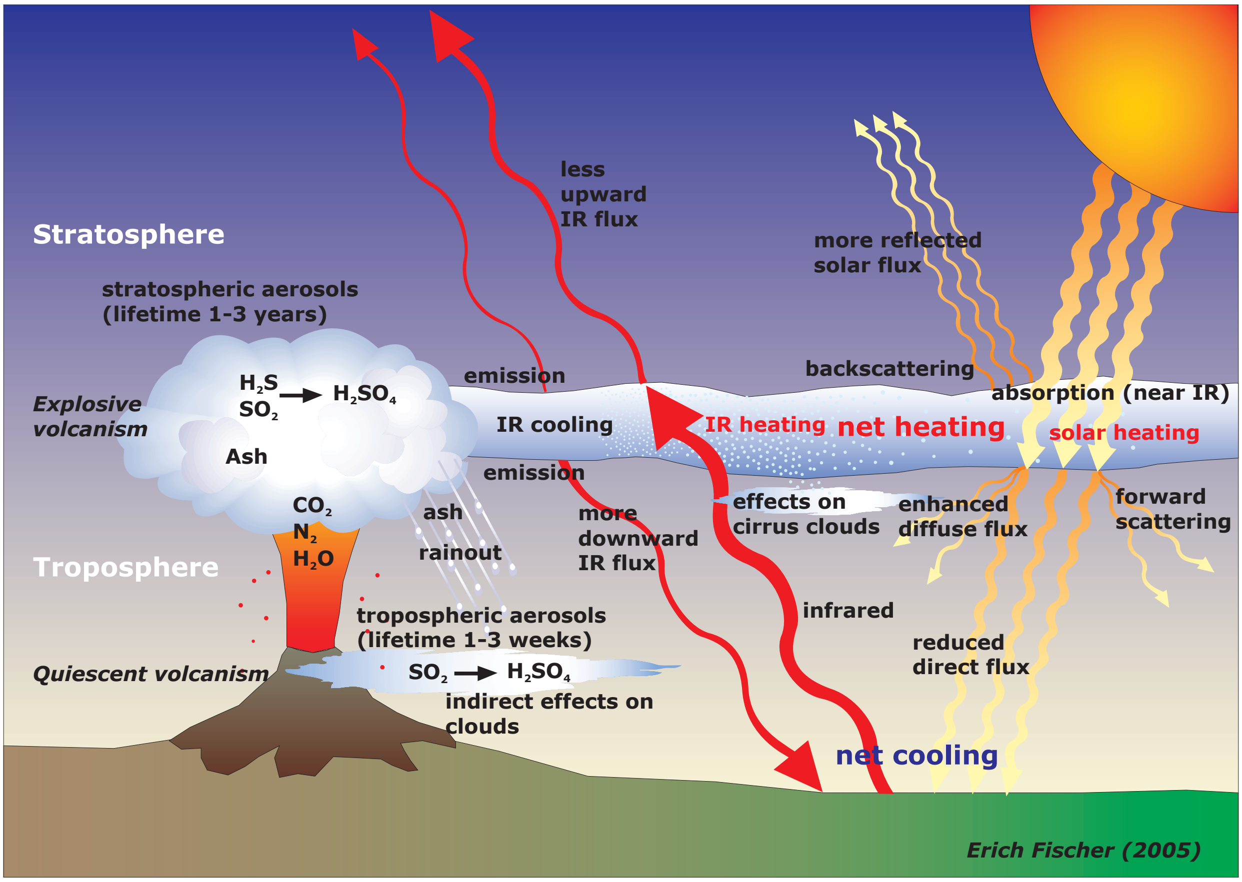

Figure 1: Schematic diagram of the impact of quiescent and explosive volcanism on the Earth's radiative balance. Redrawn after Robock (2000).

Observational and multi-proxy studies

Most studies using reconstructions or observations to determine volcanic influence are based on a single event or a set of a few events. Different post-eruption periods are often superposed to isolate the volcanic signals by averaging out non-volcanic variations. This method applies well to relatively large sets of eruptions. This implies long climate time series, as the frequency of major eruptions was relatively small in the past. Additionally, a good representation of interannual variability and seasonal resolution of the climate time series is required to account for the different effects in summer and winter. Recent high-resolution multi-proxy reconstructions allow detailed analysis of regional differences of the volcanic impact on climate (Luterbacher et al., 2004, Xoplaki et al., 2005). Care should be taken when deriving the temperature response directly from tree rings, since diffuse radiation may obscure the signal (Robock 2005).

Climate model studies

Additional benefit from an improved volcanic record could be derived for use in climate models. There are two main approaches to representing volcanic impacts in models. In some models, the volcanic influence is simply represented by a reduction of the effective solar constant. Annual global-to-zonal estimates of aerosol optical depth, derived from ice-cores, are translated to short-wave radiative forcing. With this method, the potentially important regional and timing information is not communicated to the model. Furthermore, dynamical effects through stratospheric warming and chemical effects cannot be simulated. Despite all the limitations, these models are still found to realistically simulate large-scale direct radiative volcanic effects.

Other models include a more sophisticated representation of volcanic aerosols in the form of stratospheric chemistry models. Time-height specification of the latitudinal aerosol concentrations and properties are imposed on the climate model. These models allow the analysis of the indirect effect of volcanic emissions on cirrus clouds (e.g. Lohmann et al., 2003). Robock (2004) formulates the ultimate goal as being the coupling of conduit models of magma, plume models and microphysical and transport models in the stratosphere to climate models, to predict the impact of the next large eruption as soon as it occurs.

There are still many processes in the climate response to past volcanic eruptions to be understood in more detail. For instance, the volcanic effects on precipitation are poorly known. Furthermore, it will be a challenge to predict the climate response to volcanic eruptions in a future climate with increased greenhouse and changing stratospheric ozone concentration. The key to a better understanding is a combination of model and observational studies, together with detailed monitoring of future volcanic eruptions.

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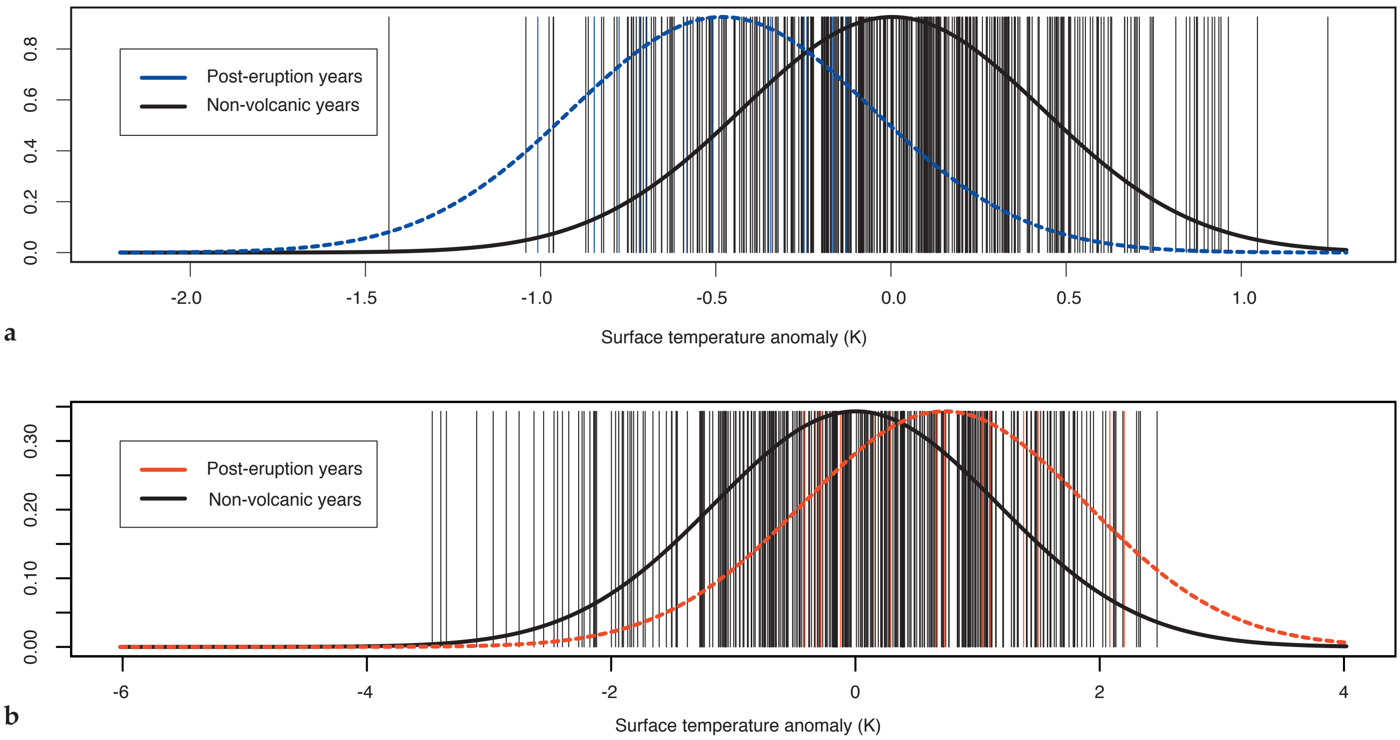

Figure 2: Temperature anomalies in the summer (JJA, blue vertical lines, Fig. 2a) and winter (DJF, red vertical lines, Fig. 2b) in year 1 following 16 major tropical eruptions over the last 500 years with respect to a 5-year pre-eruption period. Black vertical lines depict the corresponding anomalies in non-volcanic periods. Temperature reconstructions by Luterbacher et al. (2004) are averaged over European land regions (25°W-40°E, 35°N-70°N) and cover the past half-millennium. The Gaussian distribution fitted to the non-volcanic seasons is indicated in black. Blue (red) dashed lines visualise the same distribution shifted by the mean anomaly in the post-eruption summer (winter). Note that the absolute temperature departure in summer is somewhat weaker than in winter. However, the substantially larger winter temperature variability has to be taken into account. Since the small number of volcanic events allows no statement on the variability in post-eruption seasons, we assume no change in the standard deviations.

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Radiative forcing and the ice core greenhouse gas record

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Many books and articles deal with the numerous feedbacks and links in the climate-biogeochemical system and their consequences for our society. Here, the focus is on one particular link between the physical climate system and biogeochemical cycles, that is, the radiative forcing imposed on the physical climate system through altered greenhouse gas concentrations and other radiative perturbations.

Polar ice cores analysed by different groups around the world leave no doubt that cold polar ice faithfully records past atmospheric concentrations of major greenhouse gases (Fig. 1 over page) (Stauffer et al., 2002). The well-known finding is that the rate of increase in atmospheric carbon dioxide and methane is without precedence at least over the past few tens of millennia, and that CO_2 and CH_4 concentrations today are larger than at any time over the past 650,000 years, the period spanned by the ice core records. Atmospheric concentration of N_2O, another greenhouse gas, is also higher than ever measured, though its ice core record is less complete. Humans, by burning fossil fuels and through land use changes and other activities, are altering the state of the atmosphere.

Increasing concentrations of greenhouse gases cause global warming. Greenhouse gases such as CO_2 absorb part of the long-wave radiation emitted from the earth surface, thereby altering the temperature on the ground and the temperature distribution in the atmosphere. The greenhouse gas theory was already well established in the 19th century and by the end of the century, Arrhenius had calculated that a doubling of the atmospheric CO_2 concentration would cause a global-mean surface warming of about 4°C. In comparison, this climate sensitivity, termed ΔT_{2x}, evaluated with the current set of comprehensive and spatially-resolved climate models falls generally within the range of 1.5 to 4.5°C.

Climate scientists use a concept termed 'radiative forcing' to compare the climatic influence of a variety of greenhouse gases, as well as that of other radiative agents such as aerosols or other externally imposed perturbations on the radiative energy budget of the planet (Ramaswamy et al., 2001). The basic concept of radiative forcing is relatively simple: It is the change in the radiation flux entering the lower atmosphere-surface system through the tropopause immediately after a perturbation (e.g. after a step-like increase in atmospheric CO_2).

The definition of radiative forcing is not without complexity and slightly different versions are found in the literature. IPCC uses the following: "The radiative forcing of the surface-troposphere system due to the perturbation in or the introduction of an agent (say, a change in greenhouse gas concentrations) is the change in net (down minus up) irradiance (solar plus long-wave; in Wm^{-2}) at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values". Radiative forcing is typically on the order of a few Watts per square meter ($W\ m^{-2}$). For example, a doubling of the pre-industrial CO_2 concentration from 280 ppm to 560 ppm causes a radiative forcing, $RF(2xCO_2)$, of 3.7 $W\ m^{-2}$.

Climate feedbacks such as the change in water vapour and cloud cover in response to climate change are not included in the definition of radiative forcing. The strength of these climate feedbacks defines the climate sensitivity. The change in global mean surface temperature, $\Delta T_{s,\infty}$, and radiative forcing, RF, are linked through the equilibrium climate sensitivity, ΔT_{2x}. When the climate system has reached a new (quasi-) equilibrium, the change in surface temperature equals the product of the climate sensitivity and the change

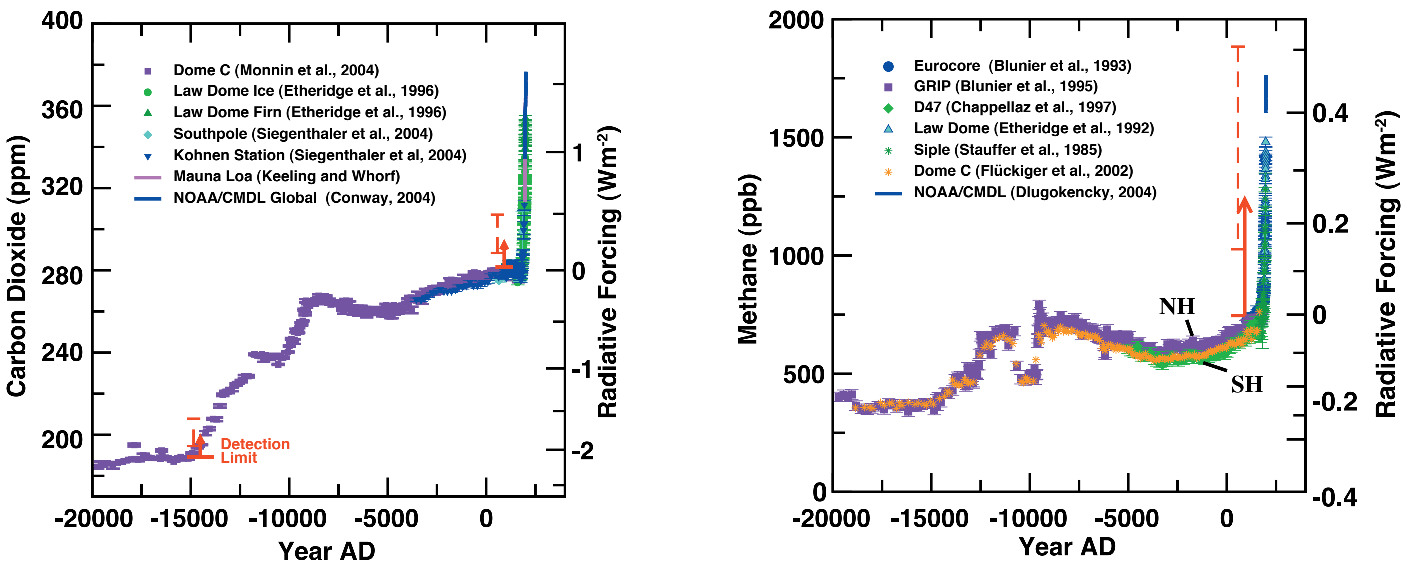

Figure 1: Evolution of atmospheric CO_2 (right) and CH_4 (left) over the last 20,000 years. Right-hand axes show radiative forcing relative to 1750 A.D. associated with the concentration changes as calculated from Table 1. Note that the radiative forcing scale is non-linear. Red arrows indicate the theoretical detection limit of a forcing (relative to Last Glacial Maximum and pre-industrial conditions) within a climate system model, assuming an internal climate variability or detection threshold of 0.2°C, climate equilibrium, and a mid-range climate sensitivity of 3°C. Dashed red arrows indicate the uncertainty of the detection threshold associated with the climate sensitivity range of 1.5 to 4.5°C.

in radiative forcing divided by $RF(2xCO_2)$:

$$(1)\quad \Delta T_{s\infty} = \Delta T_{2x} \frac{RF}{RF(2xCO_2)}$$

Calculations of radiative forcing are done in a 3-D setting taking into account the non-uniform distribution of temperature, pressure and of other variables in the atmosphere, as well as the absorption spectrum of individual molecules. The radiative forcing fields vary over space and time. It has been shown that the globally and annually averaged radiative forcing provides a good measure for the resulting surface temperature changes even for forcings with very different spatial distributions. Table 1 provides a set of equations that allows the direct estimation of the radiative forcing relative to the pre-industrial period or any other reference for the most common greenhouse gases. These formulations summarise the results of comprehensive radiation models (Ramaswamy et al., 2001). CO_2 forcing increases logarithmically with concentration as CO_2 is relatively abundant and self-shading effects occur. Radiative forcing by CH_4 and N_2O increases with the square root of the concentration. This means that an identical concentration increase is more effective at lower concentrations than at higher concentrations for these three gases. On the other hand, radiative forcing increases linearly with concentration for gases with a low abundance such as halocarbons and SF_6. These gases have been added to the atmosphere by humans only over recent decades.

Radiative forcing can be calculated over the paleorecord from ice core concentrations. Figure 1 details the evolution of CO_2 and CH_4 and their radiative forcing over the last deglaciation and the current warm period, the Holocene. Atmospheric CO_2 increased from about 190 ppm at the Last Glacial Maximum to about 265 ppm at the beginning of the Holocene. Variations during the Holocene were small. Similarly, CH_4 increased by about 350 ppb over the transition and underwent modest changes during the Holocene. Natural fluctuations of CO_2 and CH_4 have remained within relatively narrow limits during glacial/interglacial cycles. Their concentrations have stayed below 300 ppm and 800 ppb, respectively. In contrast, over less than two centuries, atmospheric CO_2 has increased by almost 100 ppm and CH_4 by 1,000 ppb. The radiative forcing (relative to 1750 A.D.) by CO_2 was -2 W m^{-2} at the Last Glacial Maximum and +1.6 W m^{-2} today. The forcing from the CH_4 changes is considerably smaller, reaching about +0.5 W m^{-2} today.

The warming commitment from today's radiative forcing by CO_2 and CH_4 of 2.1 W m^{-2} is readily evaluated from equation (1). For a mid-range climate sensitivity of 3°C, one expects an equilibrium warming of 1.7°C relative to pre-industrial conditions. However, a considerable part of the greenhouse gas forcing is offset by the cooling influence of aerosols and the climate system lags the forcing due to the large thermal inertia of the ocean.

Figure 2 puts the radiative forcing from greenhouse gases in the context of the known perturbations for the Last Glacial Maximum and today. The increase in albedo due to larger ice sheets is the largest individual forcing at the Last Glacial Maximum, whereas changes associated with the biogeochemical system (greenhouse gases, dust, vegetation changes) are responsible for more than half of the total Last Glacial Maximum forcing. Today's total radiative forcing is the result of partly offsetting contributions from the well-mixed greenhouse gases (CO_2, CH_4, N_2O, CFCs), stratospheric and tropospheric ozone, a mix of different aerosols, and changes in land use and solar irradiance. CO_2 is clearly the most important agent among the well-mixed greenhouse gases. Over the coming decades, atmospheric CO_2 will become of even greater relative importance, as emitted CO_2 accumulates over time in the climate system and recent sulfur emission control measures limit the growth in (cooling) aerosol forcing.

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agent	equation	C_o
CO_2	RF = 5.35 W m^{-2} $\ln(CO_2/CO_{2,o})$	278 ppm
CH_4	RF = 0.036 W m^{-2} $\left(\sqrt{CH_4} - \sqrt{CH_{4,0}}\right) - \left(f\left[CH_{4,}, N_2O_0\right] - f\left[CH_{4,0,}, N_2O_0\right]\right)$	742 ppb
N_2O	RF = 0.12 W m^{-2} $\left(\sqrt{N_2O} - \sqrt{N_2O_0}\right) - \left(f\left[CH_{4,o,}, N_2O\right] - f\left[CH_{4,0,}, N_2O_0\right]\right)$	272 ppb
CFC-11	RF = 0.25 W m^{-2} (*CFC-11* – *CFC-11*$_0$)	0 ppt
CFC-12	RF = 0.32 W m^{-2} (*CFC-12* – *CFC-12*$_0$)	0 ppt

Table 1: Equations to calculate radiative forcing relative to a pre-industrial (1750 A.D.) reference concentration (C_0). Overlap in absorption bands between N_2O and CH_4 is taken into account using the overlap function $f(M,N)=0.47\ ln(1+2.01x10^{-5}(MN)^{0.75}+5.31x\text{-}M(MN)^{1.52})$. For practical purposes, this correction term can be neglected. Formulations for additional greenhouse gases can be found in Joos et al. (2001) and Ramaswamy et al. (2001).

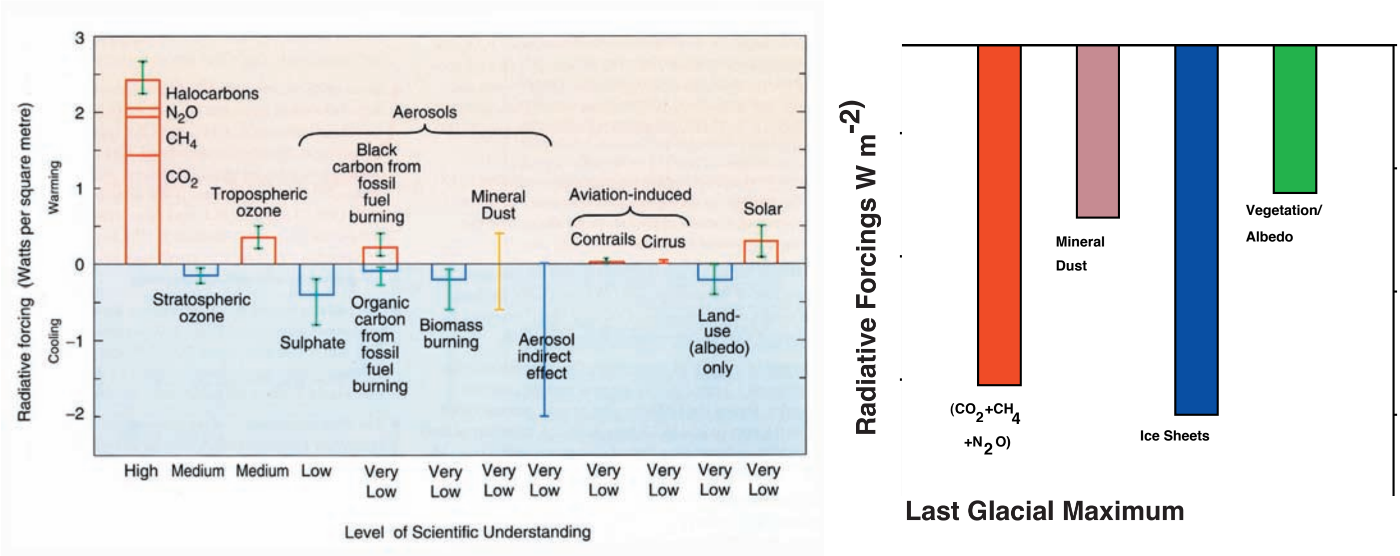

Figure 2: Radiative forcing for today (Ramaswamy et al., 2001, IPCC report 2001) (left) and the Last Glacial Maximum (right) relative to 1750 A.D. for the range of known perturbations.

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Solar forcing of climate change: Current status

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1. Solar Irradiance Variability

Observations

Space-based radiometers have monitored the Sun's total irradiance since 1978, providing a record that now covers more than two 11-year solar activity cycles. Composite irradiance time series have been constructed by combining individual measurements after first adjusting for instrumental differences. In the irradiance composite shown in Figure 1 (upper panel), levels are comparable (within 0.01%) in the two most recent cycle minima, which suggests the absence of a secular trend in recent times (Fröhlich and Lean, 2004). This record agrees with models that parameterise irradiance variations in terms of sunspot and faculae, which respectively deplete and enhance local radiative output (Fröhlich and Lean, 2004).

Since 2003, instruments on SORCE (Solar Radiation and Climate Experiment) have been monitoring the Sun's total and spectral irradiance across ultraviolet, visible and near infrared regions, for the first time from space. On average, SORCE measures absolute total solar irradiances 5.2Wm^{-2} (0.4%) lower than other radiometers. As expected, solar irradiance varies at all wavelengths in ways that reflect the different solar origins of the emissions from a range of temperatures and structures within the solar atmosphere. Maximum energy changes occur at wavelengths from 400 to 500 nm, whereas fractional changes are greatest at UV wavelengths, where the energy change is, however, considerably smaller. A model that linearly combines sunspot and facular effects, incorporating the spectral dependence of their contrasts, provides close (but imperfect) tracking of both total and spectral irradiance variations (Lean et al., 2005).

Reconstructions

Until recently, reconstructions of historical solar irradiance assumed that longer-term variations are larger than during the 11-year cycle, since proxy indicators of solar activity (the aa index, ^{14}C and ^{10}Be cosmogenic isotopes in tree rings and ice cores, and the range of variability in Sun-like stars) suggest that the Sun is capable of a greater range of activity than witnessed in recent times. With this approach, total irradiance during the 17th century Maunder Minimum is reduced in the range of 0.15 to 0.4% (2 to 5 Wm^{-2}) below contemporary cycle minima values. But stellar data have been reassessed, instrumental drifts are suspected in the *aa* index, and it has been shown that long-term trends in the *aa* index and cosmogenic isotopes (generated by the open magnetic flux from the Sun that pervades the heliosphere) do not necessarily imply equivalent long-term trends in solar irradiance (which track closed magnetic flux within the solar atmosphere). In the irradiance reconstruction shown in Figure 1 (bottom panel), which is based on solar considerations alone (Wang, Lean and Sheeley, 2005), the amplitude of the background component is 0.27 times that of Lean (2000). As a result, total solar irradiance, increases about ~0.5 Wm^{-2} from the Maunder Minimum to the present-day quiet Sun. The larger amplitude secular irradiance changes of the initial reconstructions are therefore likely upper limits of long-term solar irradiance variability.

2. Climate Response to Solar Variability

Mechanisms

Distinctly different mechanisms are surmised for climate's response to solar radiative forcing. Direct "short-wave" heating of the surface, ocean and troposphere generates geographical and seasonal inhomogeneities that may alter land-atmosphere-ocean interactions. Climate may respond indirectly to stratospheric ozone changes driven by varying solar ultraviolet radiation. The altered altitudinal temperature gradient (from the troposphere to the stratosphere) and latitudinal gradient in the stratosphere (from the equator to the poles) couples the stratosphere to the troposphere radiatively and dynamically (Rind, 2002). A result of both direct and indirect solar forcing is thought to be the alteration of atmospheric circulation patterns, including the Hadley, Walker and Ferrel cells, with subsequent effects on, for example, rainfall patterns in tropical regions. A third mechanism involves modulation of the frequency and occurrence of internal modes of climate variability. Pacific sea surface temperature gradients arising from the deeper thermocline in the west Pacific Ocean relative to the east can affect ENSO. Solar UV irradiance changes may alter the high latitude stratosphere and the polar vortex, thereby affecting the NAO, which is observed to expand longitudinally to the Arctic annual oscillation during solar maxima. Furthermore, since the climate system exhibits significant “noise”, the forcing may be amplified by stochastic resonance. Also possible are non-linear interactions of the forcing with existing cyclic modes.

Empirical Evidence

A linear combination of solar, anthropogenic, volcanic and ENSO influences accounts for approximately 50% of the observed variance in global surface temperature between 1979 and 2004, based on multivariate linear regression. As Figure 2 (left panel) shows, the surface warms 0.1°C at solar cycle maxima (forcing of 0.2 Wm^{-2}) and 0.39°C overall from anthropogenic influences (forcing of 1 Wm-2). ENSO and volcanic activity produce episodic fluctuations that can exceed 0.2°C. A 0.1°C surface temperature response to solar forcing approximately in-phase with the solar cycle is inconsistent with current understanding that oceanic thermal inertia strongly dampens (by a factor of five) decadal forcing. Thus, the effect likely involves the atmosphere and surface but does not engage the deep ocean. Consistent with this, the solar signal strength grows with altitude in the Earth’s atmosphere, to 0.3°C at 10 km and 1°C at 50 km. The right panel of Figure 2 indicates solar cycle changes of 0.4°C in lower stratospheric temperatures measured by the Microwave Sounding Unit. At these altitudes, the variations track the solar UV irradiance, ENSO effects are minimal (<0.05°C) and volcanic influences can exceed 1°C.

The relative influences of solar and other climate forcings are less certain prior to the era of space-based observations. Solar-related global warming since the 17th century Maunder Minimum is likely of order 0.1°C, or less, which is smaller than suggested by previous studies in which reconstructed solar irradiance changes were larger. On longer timescales, coherent variations in high-resolution paleo-records at quite different geographical locations in phase with solar activity (as indicated by the ^{14}C and ^{10}Be cosmogenic isotopes) suggest a global response to solar forcing. Drought and rainfall seem particularly sensitive to solar variability, especially in vulnerable geographical regions such as those in the vicinity of the ITCZ. Crucial for interpreting paleo Sun-climate relationships is improved understanding of ^{14}C and ^{10}Be modulation processes. The isotope records actually reflect solar-induced changes that impede the passage of cosmic rays through the plasma environment near the Earth, not the closed magnetic fields in sunspots and faculae that modulate irradiance. Since climate itself can affect the deposition of the cosmogenic isotopes in ice and trees, the cosmogenic records may also indicate ocean (rather than solar) variability. Ultimately, a complete specification of the physical processes within the entire Sun-Earth system is needed to resolve these issues.

Acknowledgments

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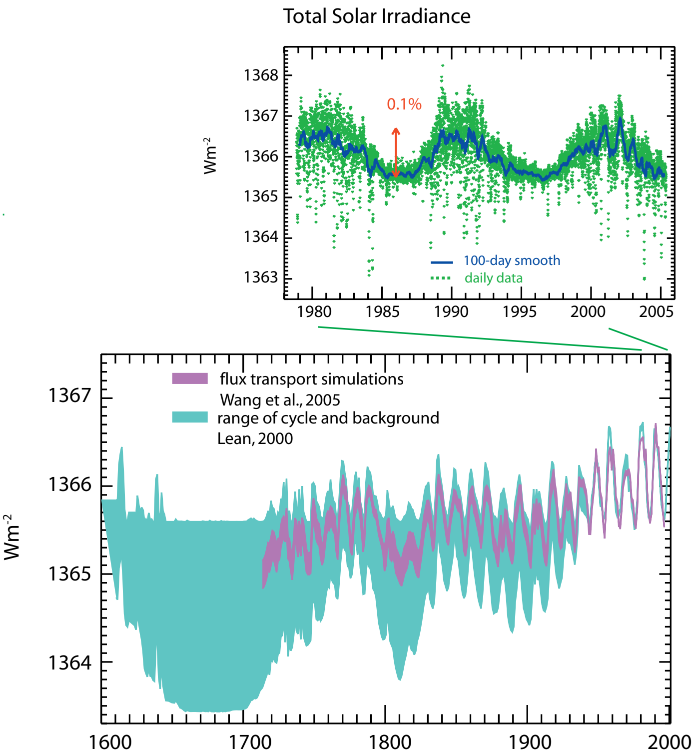
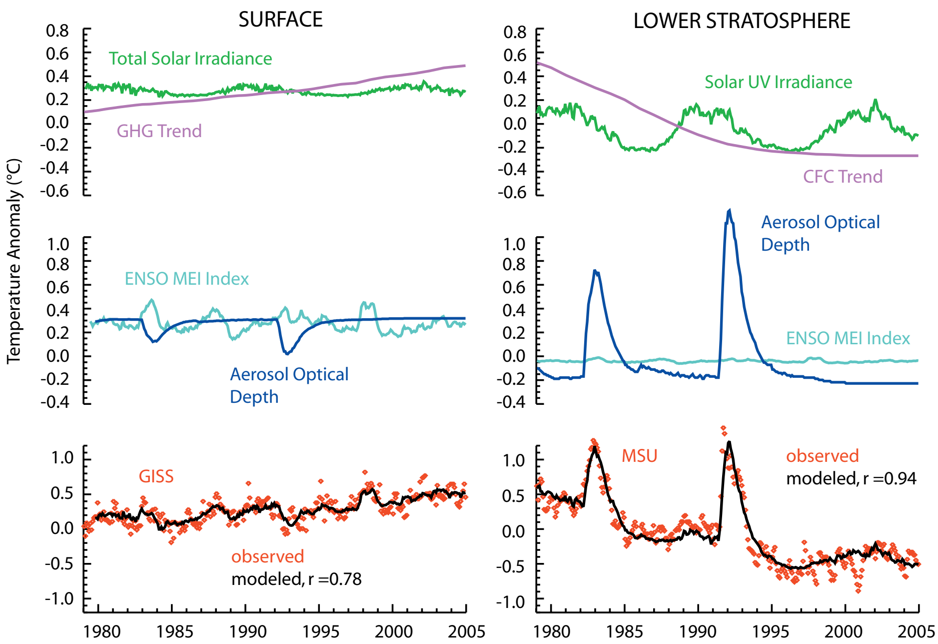


Figure 1. Shown in the top panel is the observational record of total solar irradiance of Fröhlich and Lean (2004). In the bottom panel, the upper envelope of the shaded region is total solar irradiance variations arising from the 11-year activity cycle. The lower envelope is the total irradiance reconstructed by Lean (2000), in which the long-term trend was inferred from brightness changes in Sun-like stars. In comparison is the recent reconstruction of Wang, Lean and Sheeley (2005), using a flux transport model to simulate the long-term evolution of the closed flux that generates bright faculae.

Figure 2. Comparison of different sources of variance in Earth's recent surface (left) and lower stratospheric (right) temperatures, deduced from multivariate linear regression. The volcanic aerosols and ENSO indices are lagged by 6 months, and solar irradiance by one month, relative to the observed surface temperatures, but in the lower stratosphere all lags are zero.



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Aerosol effects on clouds and climate

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The burning of fossil fuels and biofuels due to human activities has greatly increased the amount of particulate matter in the atmosphere. The major aerosol components are mineral dust, sea salt, sulfates, nitrates, black carbon (also termed soot) and particulate organic matter (POM). The natural aerosol species, mineral dust and sea salt, dominate the mass concentration in the atmosphere. On average, they contribute 39 mg/m^2 and 13 mg/m^2, respectively, whereas the anthropogenic components, sulfate, POM and black carbon only contribute 3.9, 3.3 and 0.4 mg/m^2, respectively, to the annual global average as deduced from 20 different global models (Kinne et al., 2005). So far, nitrate is not included in most models because of its semi-volatile nature.

Optically, mineral dust and sea salt are less important because of their larger size. Thus, they each contribute only as much to the aerosol optical depth as sulfate does (25%). Black carbon, which contributes only 3% to the optical depth, is the main aerosol type that absorbs solar radiation and can lead to a warming of the surrounding air. This warming can prevent cloud formation because the atmosphere becomes more stable, or even lead to an evaporation of cloud droplets. This semi-direct effect thus counteracts some of the negative aerosol forcings from scattering aerosols, such as sea salt and sulfate, at the top of the atmosphere (e.g., Lohmann and Feichter, 2005).

At the Earth's surface, however, both scattering and absorbing aerosols work in the same direction to reduce the amount of solar radiation reaching the surface. Since pre-industrial times, increasing emissions of aerosols as a result of human activity have caused a reduction of solar radiation at the surface ("solar dimming") by increasing aerosol and cloud optical depth. Such a reduction of 1.3% per decade over the land surfaces from 1961 to 1990 has been observed in many regions worldwide (e.g., Wild et al., 2004). Recent surface observations, however, show that the long term decline in solar radiation at land surfaces turned into an increase in surface solar radiation during the 1980s (Wild et al., 2005), in agreement with recent emission trends in the "old" industrial regions in the northern hemisphere (Krüger and Graßl, 2002), as well as with long-term black carbon trends in the Canadian Arctic (Sharma et al., 2004), and sulfate deposition declines over Europe and North America since 1978 (E. Holland, pers. comm.).

Aerosols also act as centres for cloud droplets and ice crystals, thereby changing cloud properties. If more aerosols compete for the uptake of water vapour, the resulting cloud droplets do not grow as large. More smaller cloud droplets have a larger surface area than fewer larger cloud droplets for the same amount of cloud water. Thus, a polluted cloud reflects more solar radiation back to space, resulting in a negative radiative forcing at TOA (cloud albedo effect). In addition, these more numerous but smaller cloud droplets collide less efficiently with each other, which reduces the precipitation efficiency of polluted clouds and prolongs their lifetime. It also implies more scattering of solar radiation back into space, thus reinforcing the cloud albedo effect. Whether the cloud lifetime or the cloud albedo effect is more important is still an open question. Whereas some models predict that the cloud albedo effect is four times as important as the cloud lifetime effect, other models predict that the cloud lifetime effect dominates over the cloud albedo effect (Fig. 1).

The global mean magnitude of the cloud albedo effect since pre-industrial times is estimated between -0.5 and -1.9 W/m² from different climate models and the cloud lifetime effect to be between -0.3 and -1.4 W/m² (Lohmann and Feichter, 2005). The semi-direct effect, which could in principle counteract part of this negative forcing at TOA, is predicted to be only between -0.5 and +0.1 W/m², where the negative values result from black carbon being located above the cloud. If the individual indirect effects values are summed up, the indirect effect could amount to almost -3 W/m². This exceeds estimates from simple inverse models that start from the observed land temperature rise and increased ocean heat uptake in the 20th century, which bracket the overall indirect aerosol effect to be between 0 and -2 W/m² (Anderson et al., 2003). Thus, either climate model predictions of the cloud albedo and/or cloud lifetime effect are too large, or a counteracting effect is missing.

A proposed counteracting effect could include the ice phase (glaciation effect). Here increases in ice nuclei in the present-day climate result in more frequent freezing of supercooled clouds. As the precipitation formation in ice clouds is faster than in water clouds, this would increase the overall amount of precipitation. A climate model prediction including this effect resulted in reduced cloud cover at mid and high latitudes of the northern hemisphere and more solar radiation absorbed within the Earth-atmosphere system, thus partly offsetting the indirect effects on warm clouds (Lohmann, 2002). Other possibilities refer to aerosol effects on convective clouds (Rosenfeld and Woodley, 2000) that have not been considered in climate models so far.

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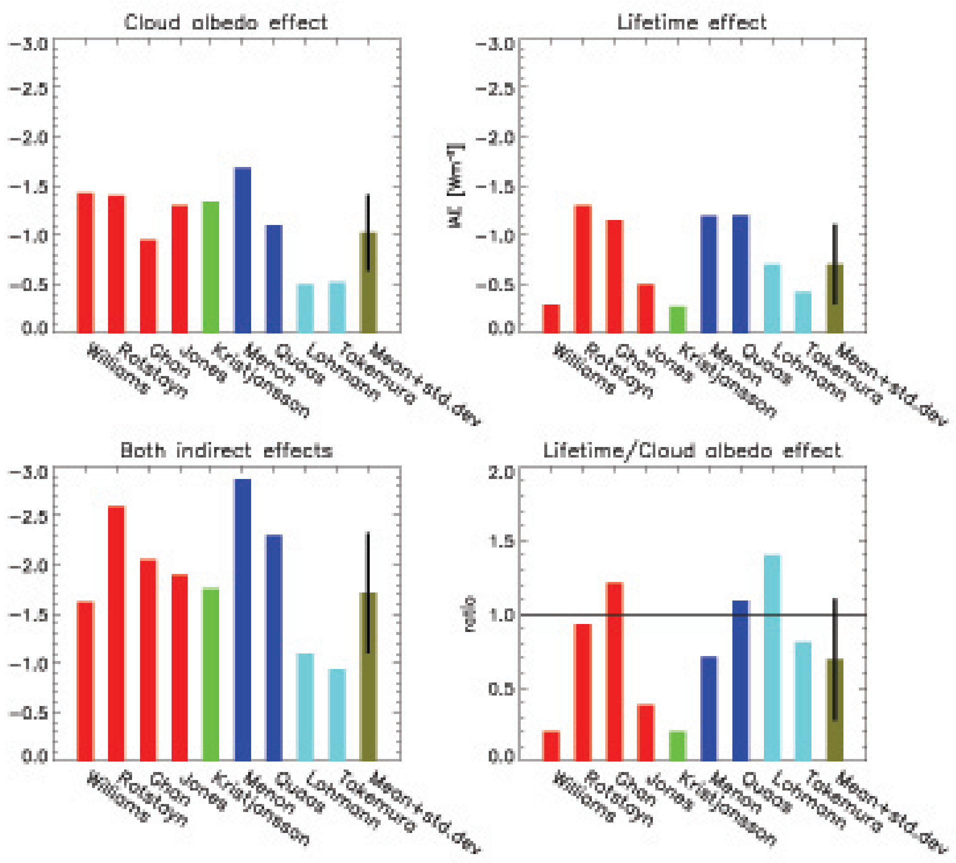

Figure 1: Global mean cloud albedo effect, lifetime effect, both effect and the ratio lifetime effect/cloud albedo effect for different models considering only anthropogenic sulfate aerosols (red bars), anthropogenic sulfate and black carbon (green bars), anthropogenic sulfate and organic carbon (blue bars), anthropogenic sulfate, and black and organic carbon (turquoise bars) and the mean plus standard deviation from all simulations (olive bars), adapted from Lohmann and Feichter (2005).

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Mineral dust records from Greenland ice cores

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Mineral dust plays an important role in climate research today. Through its radiative properties, mineral dust aerosol directly influences the radiative balance of the atmosphere. Furthermore, mineral dust is believed to be climatically active in a number of indirect ways. These include its ability to act as cloud-condensation nuclei with consequences for the amount and characteristics of cloud cover, as well as its potential to control primary bioproductivity in remote ocean and land areas that would otherwise be nutrient limited (fertilisation). Although not all of these processes are yet well understood the great dynamics of the mineral dust cycle in the past allows for an important feedback loop for climatic changes. On this question it is not yet certain whether the great concentration increase during glacial times, as observed in polar ice cores, is restricted to the high latitudes or whether it is representative for larger parts of the atmosphere.

Terrestrial, marine and ice-core archives of windblown mineral dust can be used to infer past climate conditions relevant to the dust cycle. For this purpose, it is very fortunate that—at least for Greenlandic ice cores—the source regions of mineral dust have been very well localised: The East Asian deserts in Western China and Inner Mongolia have been identified through isotopic and mineralogical studies as predominant sources for recent times as well as for the last glacial period (Fig. 1) (Svensson et al., 2000, Bory et al., 2003). Therefore, dust from ice cores is distinct from most other proxy parameters for which the sources are neither well known nor localised in space. Accordingly, an idealised concept for interpreting Greenlandic ice core dust records consists of (i) mobilisation of dust in the source and uplift into the free troposphere, (ii) long-range transport with the westerly jets over a source-free area, (iii) loss processes en route due to gravitational settling and wash-out, and (iv) deposition onto the ice sheet. The total mineral dust load is divided into a soluble fraction, which is best approximated by Ca^{2+} ion concentrations, and an insoluble fraction, which for practical reasons is most commonly inferred from the volume of water-insoluble particles in molten ice-core samples. Usually, both fractions vary alike and point to only small though significant compositional variations. Apart from the concentration, the size distribution of insoluble dust particles can also be measured, which provides unique information on changes of past atmospheric long-range transport.

Continuous time series of insoluble dust particle concentration and size distribution from the North-GRIP ice core are shown in Figure 2 (Ruth et al., 2003). The concentration exhibits a strong interglacial-glacial increase by a factor of ~100 and an interstadial-stadial increase by a factor of typically ~10. The changes are very rapid and therefore point to atmospheric processes as their main drivers. The two most likely mechanisms to produce high ice core dust levels are (a) increased mobilisation in the source area due to higher wind speeds or more frequent dust storms, and (b) increased long-range transport efficiency due to shorter transit times or less wash-out en route. It is a matter of debate which one of these mechanisms is the more important, with considerable paleoclimatic implications: If the observed increase was primarily due to more efficient long-range transport then the large increase would be limited to the remote regions; if however the increased dust flux was primarily due to increased source strength, then the increase would scale proportionally along the whole atmospheric transport pathways.

A first indication can be deduced from the ice core dust record itself: The size distribution—here given as the lognormal mode (i.e. maximum) of the volume distribution—shows larger particles during colder periods. This indicates shorter transport durations during colder periods because larger particles undergo stronger gravitational settling than small ones and are thus less depleted during times of short transport durations. Given the stationary location of the sources, a shorter transport duration implies faster transporting winds unless the pathway has changed. Quantitative estimates based on a simple 1-D transport model suggest a reduction of transport time by ~25% for LGM compared to Holocene and by ~10% for stadials compared to interstadials. Assuming exponential decrease of concentration during transport and a decrease of the hydrological cycle during LGM by a factor of two, this implies concentration increases by a factor of ~4 and ~2 for Holocene/LGM and interstadial/stadial, respectively (Ruth et al., 2003). Thus, only a small fraction of the observed concentration increase can be explained by enhanced transport efficiency during cold times.

Another indication can be obtained from Chinese loess archives, which are close to the source areas for Greenland ice core dust and are influenced by the same monsoonal circulation regimes. The mean diameter of loess grains is indicative of the strength of the transporting winds, which are expected to correlate with the strength of dust storms that cause the mobilisation of Greenland ice core dust. Therefore, the grain size record of the Luochuan loess section (Xiao et al., 1999) is compared to the North-GRIP dust concentration in Figure 2. Despite its inferior time resolution, it shows remarkable similarities with the North-GRIP particle concentration. It is difficult to quantify how a change in loess granulometry should relate to the source strength for Greenland ice core dust. However, the data together with our knowledge about present-day climatology suggests a causal link between regional loess transport within China and dust mobilisation for intercontinental export of dust during the last glacial period. This notion is supported by the observed increase

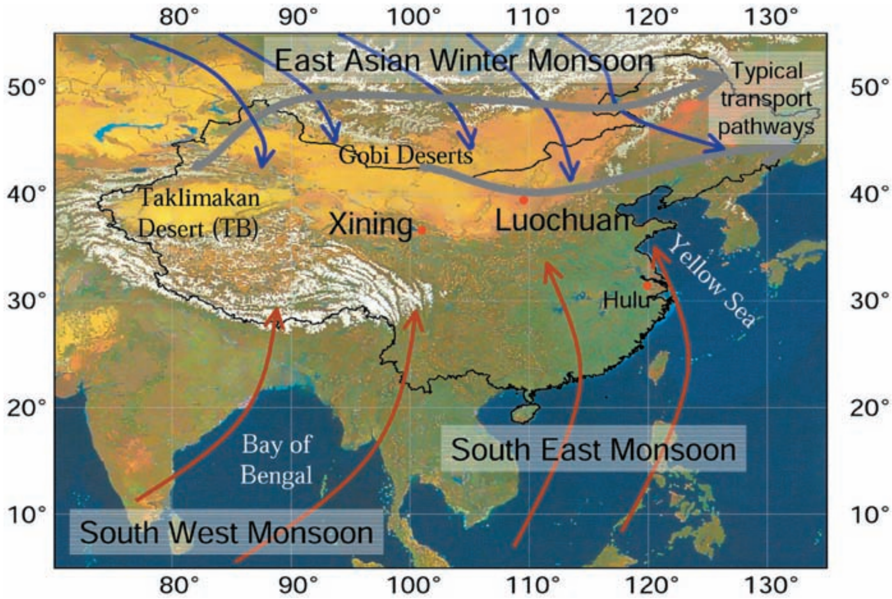

Figure 1: Map of East Asia
The Taklimakan Desert and the deserts of Inner Mongolia have been identified as the main source areas for Greenland ice core dust (TB is Tarim Basin). The loess profile discussed here is from Luochuan. Typical monsoonal circulation is illustrated along with typical transport pathways for intercontinental export of dust.

of dust flux to large regions of continental Asia and to the Pacific during the last glacial, which challenges the idea that the increased dust concentration in Greenland during that time was predominantly caused by reduced wash-out en route due to the reduced hydrological cycle.

Therefore, while bearing in mind that long-range transport also changed and did have an influence on the dust concentration in Greenland, we can interpret Greenland ice core dust concentration as a semi-quantitative proxy for occurrence and strength of dust storms in East Asia. Besides the implications for ice core interpretation, this also means that during the last glacial period the atmospheric dust load was strongly increased all along the transport pathways downwind from the sources. Thus, the proposed direct and indirect climatic impact of the dust aerosol must be considered on a hemispheric scale and not only for the high latitudes.

Further work on the composition of the dust should reveal more detailed information about possible regional changes of, and variable climate conditions in, the source areas. More high-resolution and well-dated continental climate records from East Asia are desirable to further refine the interpretation of the Greenlandic ice core dust records.

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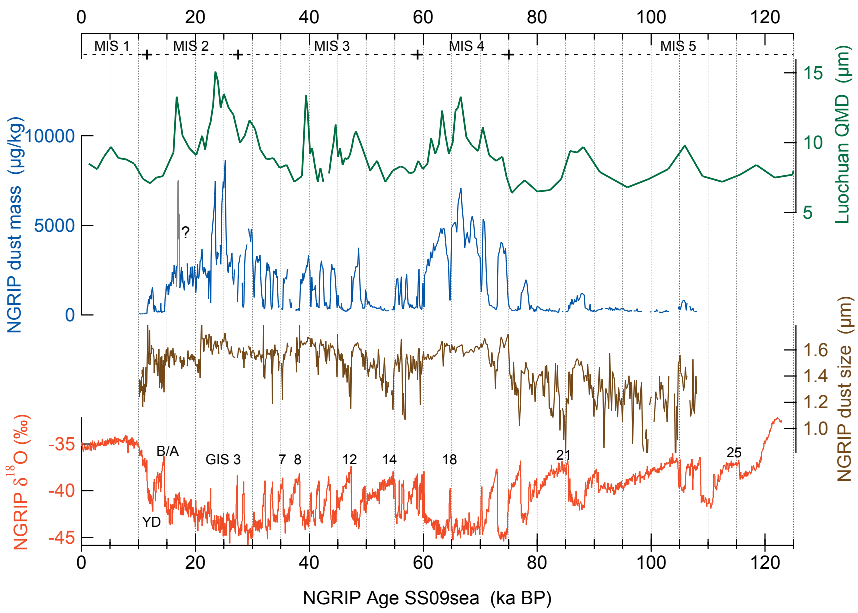

Figure 2: Time series of ice core and synchronised loess data on the NGRIP SS09 sea age scale
Ice core δ18O (NGRIP-members, 2004), dust (insoluble particles) mass concentration and mean particle size (lognormal mode of volume distribution, diameter) (Ruth et al., 2003) together with loess grain size (quartz mean diameter, QMD) for Luochuan (Xiao et al., 1999). The loess profile has been fine-tuned to the NGRIP dust concentration profile keeping the age corrections for the loess within the reported dating uncertainties. Some stratigraphic information is given: MIS is Marine Isotope Stage, YD is Younger Dryas, B/A is Bolling/Allerod, GIS is Greenland Interstadial. Dust calibration is uncertain for the peak marked "?" at 17.0 ka.

A new insight into the climatic impact of volcanic explosion: A lesson from the sulfur stable isotopes

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Large violent volcanic explosions throughout Earth's history, such as the eruption of Tambora in Indonesia in 1815, have significantly impacted human societies, killing thousands of people directly by the blast or indirectly by famine, shaping religion in Hawaii, mythology in Greece, folklore, poetry and literature in all societies. During the massive energy release, megatons of ash, liquid and gaseous materials from the Earth's interior are directly injected into the stratosphere in just a few days. Mainly sul‡fur-containing volcanic gases are responsible for the climate effects of explosive volcanic eruptions. The formation of a sulfuric acid cloud that can reside in the stratosphere for years and cover the entire globe profoundly modifies the radiative budget of the atmosphere and seriously impacts the ozone layer. There is no other internal Earth process that disturbs the atmosphere with the power, the speed, and the extent of a stratovolcano, and massive cooling resulting eventually in starvation is definitely a possibility, even today.

It is estimated that at least once every 2 years, a volcanic eruption penetrates the tropopause, thus, the long-term impact of volcanoes on natural climate variability must also be considered. But such an exercise is difficult for the past. Ice core records have been intensively used to assess such climate effects because they have the capability to record the fingerprint of volcanic events in the form of unusually high sulfuric acid levels in snow and ice layers (Hammer, 1977). Figure 1 shows an example of a sulfate concentration profile as recorded in a Greenland ice core. For the past 800 years, with the notable exception of the 20th century, due to anthropogenic emissions, the background concentration of sulfate has been rather stable and comes equally from the oxidation of dimethylsulfide (DMS), a product of the marine biota, and non-eruptive volcanic emissions. On top of this background, spikes of sulfate concentration represent a violent volcanic eruption. However, despite such high-resolution records of volcanic events, it is very difficult to establish a volcanic climatic effect (Zielinski, 1995). No obvious distinction between global stratospheric and regional tropospheric eruptions can be made, and quantification of the amount of sulfate emitted by a volcano is not directly linked to the depositional flux of sulfate to the ice surface. Thus, two major issues persist with ice cores: Identification and quantification; both severely limit the use of volcanic glaciological records to reconstruct the volcanic forcing in the past.

Sulfur isotopic chemistry

Stable isotopic chemistry has been used for decades to constrain source emission. Sulfur is characterised by 4 stable isotopes or 3 isotopic ratios: $^{33}S/^{32}S$, $^{34}S/^{32}S$ and $^{36}S/^{32}S$. Classically, these ratios are expressed in δ notation, where $\delta\,{}^{x}S\ (‰) = [({}^{x}S/{}^{32}S)_{sample}/({}^{x}S/{}^{32}S)_{CDT}) - 1] \times 1000$ and CDT (Canyon Diablo Triolite) is the international sulfur isotope standard. The δ scale expresses the deviation of a given sulfur isotope ratio of a sample from the CDT standard. Thermodynamic, kinetic and biological processes produce isotopic fractionations that depend on the relative mass differences between the different isotopes of sulfur. As

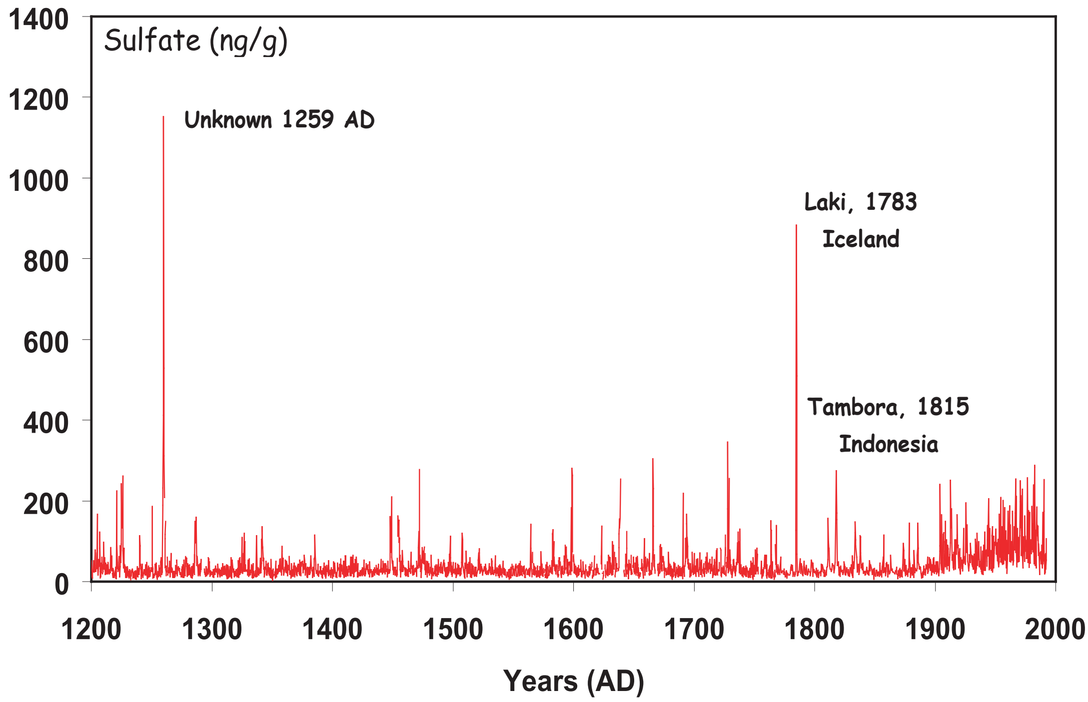

Figure 1: Sulfate concentration profile of a Greenland ice core. Except during the 20th century, which is dominated by anthropogenic emissions, the background sulfate concentration is rather stable. Sharp peaks are the manifestation of volcanic events recorded in the ice. For Greenland, most of them are tropospheric eruptions from Iceland and North America. However, few of them are clearly identified as stratospheric eruptions (1259: unknown; 1815: Tambora, for instance). From such concentration measurements alone, it is a very difficult task to estimate the impact of volcanoes on climate because the peak height is not directly linked to the magnitude of the eruption (Joël Savarino, unpublished data).

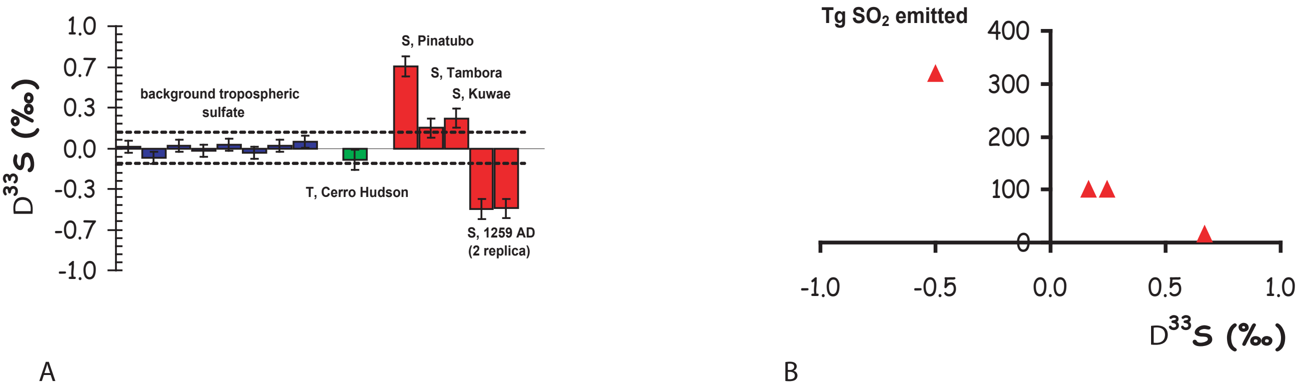

Figure 2: A) Sulfur isotopic anomalies of stratospheric and tropospheric sulfate. From this limited data set, we can clearly see that only stratospheric volcanic sulfate carries a $\Delta^{33}S$ that is significantly different than 0. This isotopic fingerprint might be used to classify the nature of any volcanic eruption independently of its depositional flux. The two dashed lines represent the two standard deviations (± 0.1 ‰) of the isotopic references. S and T stand for stratosphere and troposphere. B) Plot of $\Delta^{h}S$ versus amount of sulfur injected into the stratosphere. This kind of plot might be used in the future to quantify unknown volcanic explosions and assess their climatic impact; information that is unavailable so far.

a result, observed isotope variations are highly correlated with $\delta^{33}S \approx 0.515\ \delta^{34}S$ and $\delta^{36}S \approx 1.90\ \delta^{34}S$, so that usually only $\delta^{34}S$ is reported, since the two other isotopic ratios are redundant information. In pioneer work, Farquhar et al. (2000) discovered that such correlations were violated for minerals older than 2.2 billion years. The quantities $\Delta^{33}S$ and $\Delta^{36}S$ reflect the deviation of measured isotopic compositions from mass fractionation arrays ($\Delta^{33}S \approx \delta^{33}S$ - 0.515 $\delta^{34}S$ and $\Delta^{36}S \approx 36S$ - 1.90 $\delta^{34}S$). Soon after, we showed that those sulfur isotopic anomalies ($\Delta 33S$ and $\Delta 36S \neq 0$) could be reproduced in the laboratory when SO_2 gas was subjected to intense UV photolysis (Farquhar et al., 2001). As a way to test the causality between UV and sulfur isotopic anomalies, we decided to sample well-known stratospheric volcanic horizons buried in South Pole snow and ice. Indeed, before being converted to sulfate, SO_2 is intensively subjected to UV radiation in the stratosphere, similar to the Archean troposphere. Our first strategy was to test Farquhar's proposition, which has important implications for the oxygenation of the atmosphere.

Snow and ice signatures

We extracted volcanic and background sulfate from South Pole snow and ice (Savarino et al., 2003). Because of the quantity needed to perform such isotopic analyses, only major events could be sampled. Ion chromatography is used to isolate, concentrate and purify the volcanic and background sulfate. After chemical operations, sulfate is converted to SF_6, from which all sulfur isotopes can be measured (fluorine is a mononuclear element). Five volcanoes were sampled: The well-observed stratospheric Pinatubo eruption (June 1991, Indonesia) and tropospheric Cerro Hudson (September 1991, Chili), the Tambora (1815, Indonesia), the Kuwae (1450, Vanuatu) and the biggest eruption of the past 1,000 years but still unidentified, the stratospheric 1259 eruption. Backgrounds were extracted from ice surrounding the volcanoes and from tropospheric aerosol filters. Isotopic results are displayed in Figure 2a. It seems evident that based on this limited data set, sulfates produced in the stratosphere show an anomalous ^{33}S isotopic composition, while all other sulfate samples have $\Delta^{33}S$ not significantly different than zero. The precise mechanism responsible for this unique isotopic composition is not yet well understood but it undoubtedly takes place in the stratosphere where short wavelengths are present. Therefore, it should be kept in mind that the sulfur isotopic anomaly is independent of the starting isotopic composition of the volcanic source. As far as we know, no sulfur isotopic anomalies have been reported for sulfur oxides produced in the troposphere.

Another interesting feature of the sulfur isotopes is the linear correlation between the ^{33}S anomaly and the estimated amount of sulfur emitted by the stratovolcano (Fig. 2b). We do not know exactly why such correlation exists but we can reasonably argue that the penetration of UV photons into the SO_2cloud will dependent both on the amount of SO_2 present and on the altitude of the cloud; two parameters closely linked to the power of the eruption. If such observations prove to be correct in the future, then sulfur isotopic measurements might constrain the two major uncertainties in estimating the climatic impact of volcanoes from ice cores; that is the stratospheric or tropospheric nature of a volcano and the amount of sulfur injected into the stratosphere. More work is needed before a new, more sensitive tracer for stratospheric eruptions can be claimed but sulfur isotope measurements at least provide new direction to tackle this important issue of the volcano-climate relationship. To confirm these preliminary observations, other well-identified stratospheric eruptions such as Krakatoa (1883) or the Toba (~ 75 ky BP) must be examined, as well as the spatial and temporal homogeneities of such isotopic signatures; two research directions that are currently underway in our lab.

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Land–surface changes: feedbacks and climate forcing

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Climate changes affect vegetation productivity and distribution, surface hydrology including the extent of lakes and wetlands, and soil moisture regimes and, through these, susceptibility to erosion by wind and water. These changes in land-surface conditions in turn affect the physical properties which control water- and energy-fluxes between the land and the atmosphere, and hence can amplify or mitigate the impact of the original climate change. In this sense, land-surface changes can be regarded as feedbacks within the climate system. However, anthropogenic changes in land-surface conditions, caused for example by urbanization, deforestation or agricultural exploitation, produce similarly large changes in physical properties and such changes must be regarded as an independent forcing of the climate system.

The palaeorecord leaves us in no doubt that there have been substantial and often dramatic changes in land-surface conditions (e.g. Kohfeld and Harrison, 2000). The dramatic conversion of the Sahara into a landscape with large lakes, extensive wetlands and shrubby vegetation during the earlier part of the Holocene (ca 11,000 to 5500 years ago), or the large-scale replacement of boreal and temperate forests by steppe-tundra vegetation across Eurasia during the last glacial maximum (ca 21,000 years ago), are well documented. Palaeoenvironmental and isotopic evidence document the existence of freshwater lakes and moisture-demanding vegetation in central Australia between 30,000 and 65,000 years ago. During the last interglacial (ca 125,000 years before present) boreal forests extended to the Arctic coastline and wetter conditions associated with expansion of the northern hemisphere monsoons produced large lakes in northern Africa. Earlier periods in the Earth's history provide even more dramatic examples of land-surface changes, including the existence of forest in polar regions until ca 3 million years ago. It is hardly surprising, then, that some of the earliest work to demonstrate the importance of land-surface feedbacks in the climate system were concerned with past times.

Investigations of the role of land-surface changes on regional palaeoclimates have tended to focus on iconic features, for example, the amplification during interglacial periods of arctic warming by northward extension of boreal forest and of northern-hemisphere monsoons by the expansion of moisture-demanding vegetation (see e.g. Kutzbach et al., 2001; Wohlfahrt et al., 2004). Despite the very different types of models and experimental approaches used in these studies, a number of robust conclusions about the way land-surface changes affect climate have emerged.

In the high latitudes, the most important influence of land-surface conditions on the climate system is through changes in surface albedo. Albedo during the winter season is much lower in regions characterized by tall vegetation (high shrubs, trees) than in regions without such vegetation because of the masking effect of vegetation on the underlying snow. Northward expansion of forest vegetation, in response to orbitally-induced warming in the mid-Holocene or last interglacial, resulted in a reduction in albedo and hence increased surface warming. The impact of this vegetation-snow-albedo feedback is most marked during spring, when radiation receipts are increasing but the ground is still snow covered, but has a non-negligible effect during other seasons such that vegetation reduces the cooling due to orbital forcing in winter and produces year-round warming in the high northern latitudes. There is still considerable uncertainty about the magnitude of the warming due to vegetation feedback: early experiments suggested that vegetation-induced changes were substantially larger than those due to orbital forcing, but later studies indicate that realistic changes in vegetation cover produce a summer warming of 50-90% of that induced by orbital changes alone.

Albedo changes are also important in monsoonal regions. Studies of the impact of land-surface changes in northern Africa during the mid-Holocene, initially induced by orbitally-forced changes in the monsoon, indicate that vegetation-induced lowering of albedo led to warming of the continent, enhancing land-sea contrast and increasing onshore advection of moisture. When compared to the effects of mid-Holocene insolation changes, the presence of vegetation enhances warming in spring and hence initiates an early onset of monsoonal precipitation. Vegetation cover also prolongs the monsoon season in autumn, in large part because it decreases the reliance on moisture advection and maintains monsoonal conditions through enhanced moisture recycling. Other land-surface changes, including the expansion of lakes and wetlands, also increase moisture recycling. The impact of land-surface changes on the African monsoon is comparable in magnitude to the increase due to orbital forcing during the mid-Holocene.

Given the importance of land-surface feedbacks in regional palaeoclimates, it is natural to expect that climate-induced changes in natural vegetation will play a role in future climate change. Recent warming in the Arctic has indeed led to reductions in snow cover and the expansion of shrub and tree cover. Chapin et al. (2005) have suggested that these changes in land-surface conditions have led to local increases in atmospheric heating by up to 3 Wm-2 per decade. However, considerably more attention has been focused on the potential impacts of direct anthropogenic modification of land-surface conditions on the climate system. There have been large changes in the nature of the land surface during the last 300 or so years of the post-industrial period. Estimates suggest 20% of the world's forests and woodlands have disappeared during this period, and that some 33% of the natural land surface has been cleared. Today, some 3 million km2 are occupied by urban areas, 18 million km2 is in permanent cultivation, and 34 million km2 is used for grazing. Individual studies have shown that the growth of urban areas, deforestation and re-afforestation, and the expansion of agricultural and grazing land affect surface temperature, precipitation and atmospheric circulation at a regional scale. There is, also, a growing appreciation that these regional changes have an impact on the global circulation and hence on global climate regimes. However, there is still controversy about the importance of land-use changes in affecting both regional and global climates. Model studies (see e.g. Betts et al., 2004) suggest, for example, that the effect of the reduction and fragmentation of forest cover in Amazonia is to reduce evapotranspiration, which in turn reduces rainfall because some 25-30% of the precipitation falling over Amazonia is due to recycling, raises surface temperatures and changes regional circulation patterns. The simulated changes in atmospheric circulation have an impact on precipitation patterns in the mid- to high-latitudes of the northern hemisphere. Both meteorological observations and satellite data confirm some aspects of these simulations, most notably the increase in surface temperature but are less clear about the simulated reduction in precipitation over Amazonia.

In the IPCC Third Assessment Report, the change in global, annual mean climate forcing due to changes in land cover during the industrial era (since ca 1700 A.D.) was estimated as between -0.1 to -0.2Wm-2, corresponding to a global cooling of a few tenths of a degree (Ramaswarmy et al., 2001). More recent estimates based on simulations with several different models indicate that the radiative forcing due to historical land cover changes could be up to -0.5 Wm-2 (Brovkin et al., in press). However, focusing on the radiative impacts of changes in land cover does not provide a realistic assessment of the importance of land-surface changes for climate forcing, since it fails to take vegetation-induced changes in the water- and carbon-cycles into account. Although there are many studies that have demonstrated the potential significance of these effects for regional and global climate, there are still many open questions that will need to be addressed before we have a comprehensive understanding of the influence of natural and anthropogenic changes in land-surface conditions on the climate.

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MedCLIVAR: Mediterranean CLImate VARiability and predictability project

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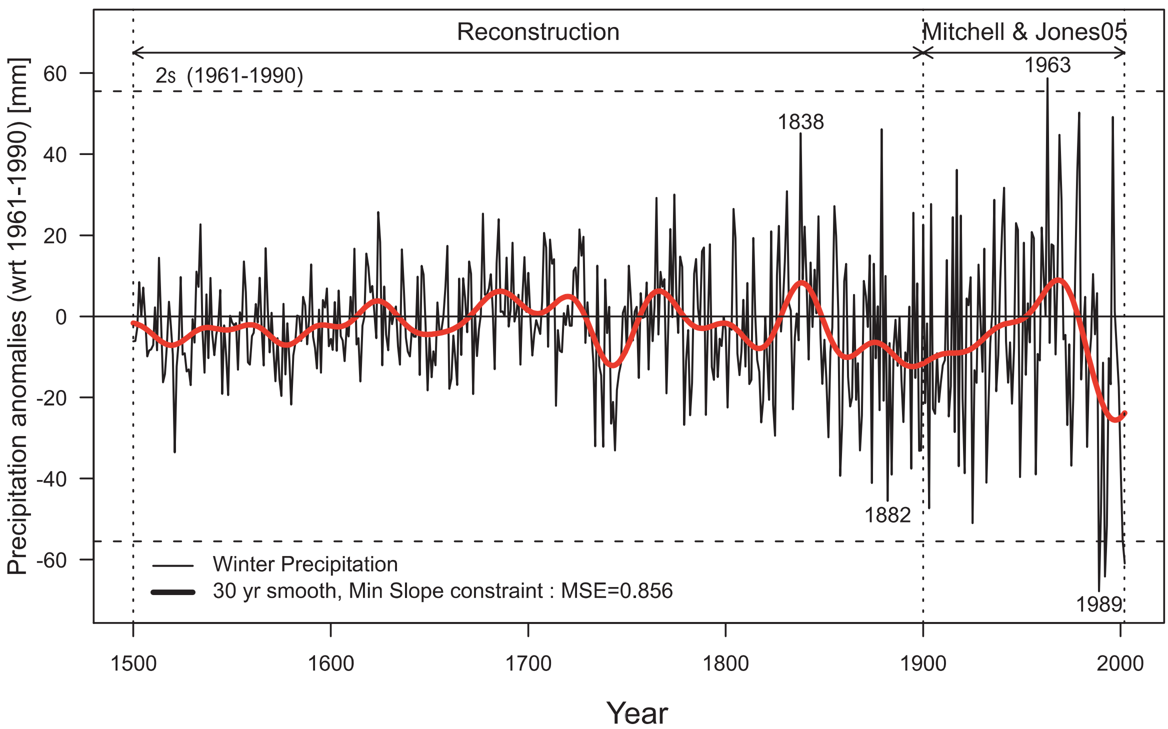
MedCLIVAR is a project that promotes coordination of the large scientific community engaged in Mediterranean climate research. The main goals of MedCLIVAR include reconstruction of Mediterranean past climate variability and extremes and natural hazards, the description of patterns and mechanisms characterising its space-time variability, the identification of the forcing parameters responsible for the observed changes, and its response to future emission scenarios. The project focuses on long instrumental data as well as documentary and natural proxy evidence resolving different time and spatial scales. All these data sources are important for the construction of high quality data sets, in order to extend the record of past Mediterranean climate variability over decadal and centennial timescales.

Progress in the understanding of the Mediterranean climate has important environmental, societal and economical implications. The Mediterranean region is characterised by large cultural, economical, political, and demographic gradients in a situation already under environmental stress (heat waves, highly variable precipitation, limited water resources), where inadequate evaluation of climate change impacts and the lack of readiness and of adequate adaptation strategies could result in critical situations.

The idea of the MedCLIVAR project was proposed during the ESF (European Science Foundation) Exploratory Workshop on "Mediterranean Climate Variability and Predictability" held in Rome, 17-19 May 2004. Subsequently, the project was endorsed by CLIVAR and a Scientific Steering Group (SSG) was formed, which meets regularly for its management.

Activities of MedCLIVAR include the organisation of meetings, schools and workshops, the organisation and support of research projects, and the establishment and strengthening of links to other national and international programs relevant to Mediterranean climate. MedCLIVAR will support a "Mediterranean Climate Variability" session at the EGU General Assembly in Vienna, April 2006. This will be the fourth time such a session is represented in the program. A first result of MedCLIVAR, a book entitled "Mediterranean Climate Variability" and published by Elsevier, will be available at the beginning of 2006. It is a multi-author book that provides an updated description of climate variability in the Mediterranean basin, focusing on its strong inter-annual to decadal features.

MedCLIVAR has important links and cooperates closely with PAGES, who has a representative on the MedCLIVAR SSG. Reconstruction of past Mediterranean climate will be the subject of the first MedCLIVAR workshop to be held in 2006. More information on MedCLIVAR goals, results, activities, upcoming events and how to join the project is available on the ENEA-hosted webpage: http://clima.casaccia.enea.it/medclivar.



Winter (Dec-Jan-Feb) averaged-mean Mediterranean precipitation anomalies (with reference to the period 1961-1990) from 1500 to 2002, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (thin black line). The values for the period 1500 to 1900 are reconstructions. The thick black line is a 30-year smooth 'minimum slope' constraint. The dashed horizontal lines are the 2 standard deviations of the period 1961-1990. The driest (1989) and the wettest (1963) Mediterranean winters are denoted. (figure from Luterbacher et al., 2005, in "Mediterranean Climate Variability" published by Elsevier, Amsterdam)

INSIDE PAGES:

During the past months, there have been major developments in the PAGES office and the PAGES project.

PAGES Project:
The busy summer was fully focused on the PAGES 2nd Open Science Meeting, which was held in Beijing from 10-12 August. A short report on this very successful meeting can be found on page XX of this issue.

At the meeting, a plenary discussion on the future of PAGES provided direct feedback from scientists from the international paleo-community. Subsequently, the PAGES Scientific Steering Committee, together with the IPO, began to prepare a revised science plan, which will culminate in the submission of a new proposal to PAGES funding agencies (Swiss and US NSF) by the end of the year. Details are open for discussion amongst the PAGES community. Please visit our website (www.pages-igbp.org) to read about the proposed changes and add your comments. We invite you to participate in the process of defining PAGES scientific scope for the future. Your expertise and input is required to ensure that PAGES is well positioned to successfully serve paleoscientific research over the coming years.

PAGES Office:
The PAGES office experienced a change in staff last month, when Selma Ghoneim, PAGES Finance Manager, whom many of you will know, left to take up a position in the private sector. PAGES benefited greatly from her knowledge on how best to manage the sometimes complex financial needs of scientists, projects and the PAGES program as a whole. Her competence and cheerful smile will be missed. In her place, we are happy to welcome Michelle Kaufmann (www.pages-igbp.org/people/staff/kaufmann.html), who in only a short time has already integrated into the PAGES team.

In addition to organisational changes, you may have noticed that we have launched a new-look website. As well as a new design, the structure has also been somewhat changed. These modifications, based on feedback from many people, were introduced in the hope of improving site navigation and overall ease of use. The website overhaul is not yet complete. Things to look out for in the coming months include online forms for the submission of calendar and job entries, and easier access to your personal record and the PAGES Product Database.

Newsletter:
After this joint PAGES/CLIVAR issue, PAGES News will return to its usual format. The spring 2006 special issue will highlight ice core research but will also have an open section for workshop reports, program news and science highlights. We encourage you to continue to submit to the newsletter and take advantage of the fact that every special issue now also includes an open section for your contributions. The next deadline for submissions is 30 April 2006. Guidelines can be found at:
www.pages-igbp.org/products/newsletters/instructions

LOTRED-SA Long-Term climate REconstruction and Dynamics of (southern) South America: A collaborative, high-resolution multi-proxy approach

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A small group of scientists from various disciplines gathered in Mendoza, Argentina (8-9 October 2005) to set up the organizational framework for the new PAGES Research Initiative LOTRED-(southern) South America (PAGES News Vol. 13 No. 2). Guidelines for collaboration, contributions and formats are available at www.pages-igbp.org/science/initiatives/lotred-sa.

The scientific goals were specified as (i) to collate, maintain and share a common state-of-the-art protected database (for contributors only) with available high-resolution multi-proxy data sets for the last 500–2,000 years, (ii) to produce, as a collective of authors, a series of research results and papers that exceed the capacity of individuals within the group, and (iii) to compare multi-proxy reconstruction with results from GCM runs for the last ca. 2,000 years or selected windows of interest.

There are good reasons to contribute: It is increasingly within the policy of funding agencies that supported projects make their results and data sets available. You benefit from co-authorship of important contributions, your work is cited and made public. Original data sets remain protected (if you wish), only metadata will be published. The results are expected to achieve wide recognition, thus funding agencies might be interested in evaluating who contributed and which types of archives serve best for climate reconstructions.

Contributing with sets of original data to a database is a very sensitive issue and will be handled with the utmost care. The data policy of IGBP and principles and guidelines of ICSU will apply.

A first science meeting will be held in Mendoza, Argentina from 4-7 October 2006. The state of research and data sets will be presented and discussed.

From the Holocene to the Anthropocene: Climate of the last 1,000 Years

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The 4th International NCCR Climate Summer School was held from 28 August to 2 September in picturesque Grindelwald, Switzerland. The Summer School attracted a record number of applicants and was attended by 72 participants from 14 countries across four continents.

Twelve keynote speakers—leaders in the fields of climate analysis, reconstruction, and attribution—highlighted research on climate change and variability over the past millennium. Thematic poster sessions gave the participants ample opportunity to discuss their own research projects with peers and experienced researchers. Four elective workshops gave participants hands-on experience of both the strengths and pitfalls of paleoclimate reconstruction using modelling, and terrestrial, lacustrine and historical proxy records. A resounding message of this year's Summer School was that the current climate is outside the realm of natural variability as observed over the past 1,000 years and definitely perturbed by human activities.

The Summer School took place just one week after the massive summer floods that ravaged the Central and Eastern Alps. On the bus ride to Grindelwald, participants witnessed firsthand the destructive power of the climate system. During the week, the development of hurricane Katrina lent an additional sense of urgency to the proceedings. Heinz Wanner, NCCR Climate Director, commented that discussions on climate change had been much more intense than in previous years. The Summer School itself was blessed with excellent late-summer mountain weather and participants took advantage of excursions to the ridge tops, forests and glacial canyons surrounding Grindelwald.

NCCR Climate strongly promotes the education of young researchers. Created to encourage exchanges between PhD students, post-docs and leading climate researchers, the International NCCR Climate Summer School has become a highly appreciated opportunity to share scientific ideas and create cross-disciplinary links. Each Summer School consists of keynote lectures, workshops, poster sessions and excursions to research sites, and is open to young researchers worldwide. A small number of grants are available for students from developing countries.

For details on the 2006 Summer School please see:
www.nccr-climate.unibe.ch/events_summerschool06

The participants group of the 4th International NCCR Climate summer school in Grindelwald - Switzerland

PAGES 2nd Open Science Meeting – Beijing, China – 10–12 August 2005

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After the 1st PAGES Open Science Meeting (OSM) in London seven years ago, the PAGES community finally gathered again for the 2nd OSM, this time in Beijing. More than 370 scientists from 45 countries attended to discuss scientific issues around the theme "Paleoclimate, Environmental Sustainability and Our Future". The broad questions that were addressed by oral and poster presentations and a panel discussion included: What is the pre-industrial historical context of present and future global change? How did land, ocean and ice interrelate during climate transitions? How did people in the past interact with environment and climate? What specific answers do Asian regional scale studies provide?

It is noticeable that the set of questions would have been just as timely for the first OSM in 1998. However, it is equally obvious that the answers are much more detailed now than 7 years ago, owing to substantial progress in the field of past global change, such as in climate-environment reconstructions for the late Holocene, reconstructing and modelling past global changes across remote regions and hemispheres, understanding the relevance of climate modes in the past, and quantifying feedback mechanisms of past environmental change on climate, etc.

There were numerous scientific highlights, not only presentations of the state-of-the-art in specific fields of paleoscience from invited speakers but also new high-quality studies and datasets from less well-known scientists. Young research talent was acknowledged by selecting three posters for short presentation to the plenary and by prizes to five students for their poster contributions.

There were other highlights beyond the purely scientific results. My subjective, non-comprehensive list has to include the remarkable harmony that was attained between modelling and reconstruction approaches, providing a promising foundation for data-model based paleoresearch in the future. Several presentations contained direct comparisons of data and models. Moreover, the climate modellers made a successful effort to communicate their methods and results, and to put forward their wish list to the data community.

The similar process of convergence between disciplines in the study of the human aspects of past global change was furthered at the meeting. Many contributions included humans as a component of the Earth System, both as an additional information source (the most obvious example being documentary data) and to demonstrate the relevance of paleoresearch.

Another more general success was in community building, achieved especially through the attendance and integration of many scientists from Asia and developing countries, and researchers in early career stages. This effort was supported by funding from START, APN, TWAS, the Indian Department of Science and Technology, the Chinese Academy of Sciences and the National Natural Science Foundation of China.

The meeting culminated in a lively plenary discussion on the future role of PAGES, an essential and valuable discussion from the point of view of the PAGES project. Suggestions to better address southern hemisphere changes, to focus on the past water cycle, to further data synthesis and their accessibility, to disseminate the importance of paleoscience, and many other ideas were taken on board and may be considered for future activities in the framework of PAGES.

The 2nd OSM provided a much too rare opportunity to discuss the various core themes relevant to PAGES and to foster a community spirit that encourages participation and hence drives PAGES. Instead of waiting another 7 years for such an opportunity, PAGES plans to hold the next OSM 4 years from now in 2009 in the United States.

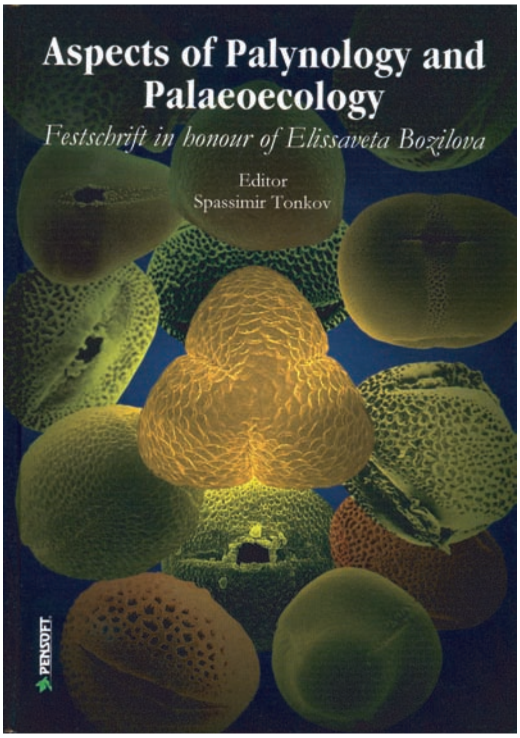
The OSM abstract book is available to download free of charge from the PAGES online Product Database (www.pages-igbp.org/products). There is also an online poster exhibition (www.pages2005.org/posters.html), with currently around 70 of the OSM posters available to view and download. A collection of the plenary lectures is planned for publication in the new open-access journal of EGU "Climate of the Past".

PAGES Section

New Book

Aspects of Palynology and Palaeoecology

Festschrift in honour of Elissaveta Bozilova
Edited by: S. Tonkov; 2003. Sofia–Moscow, 165x240, tables, maps, pollen diagrams, graphs, b/w and color photos, references,
In English. Hdb, 282pp. Price USD 58.5.
To Order : http://www.pensoft.net/howto/first.htm



The book is a compilation of 15 papers by European, North American and Asian palynologists and paleoecologists with whom Professor Bozilova has kept close scientific contact for many years. One group of papers covers various aspects of palynology and inferences drawn from pollen-based research. The other group deals with paleocological case studies from selected areas of Europe, starting from the Scandinavian countries in the north, and ending in the south-east, the Balkan peninsula. For this latter area, new detailed information related to the postglacial vegetation development, climate change, environmental history and human impact is provided. The book will be of use to scientists working in the fields of palynology, paleoecology, paleogeography, geology, climatology, archeology and forestry.

CALENDAR 2006

Feb. 20 - 24 Hawaii, USA
13th Ocean Sciences Meeting sponsored by ASLO, ERF, TOS and AGU
Further information: *www.agu.org/meetings/os06/*

Apr. 4 - 6 Mendoza, Argentina
Climate Change: Organizing the Science in the American Cordillera (CONCORD)
Further Information: *www.ires.ubc.ca/projects/concord/*

Apr. 19 - 21 Hawaii, USA
PICES/GLOBEC Symposium
Further Information: *www.pices.int/meetings/international_symposia/Honolulu2006/default.aspx*

June 5 - 7 Ekaterinburg, Russia
Climate Changes and their Impact on Boreal and Temperate Forests
Further Information: *http://ecoinf.uran.ru/conference/*

June 12 - 15 London, UK
HOLIVAR 2006 Open Science Meeting: Natural Climate Variability and Global Warming
Further information: *www.holivar2006.org/*

June 25 - 29 Duluth, USA
10th International Paleolimnology Symposium
Further Information: *www.geo.umn.edu/paleolim10/*

News from CLIVAR

Howard Cattle

Welcome to the CLIVAR section of this joint edition of IGBP PAGES News and CLIVAR Exchanges. It has been a great pleasure to work with our colleagues from PAGES on this volume and I am grateful to Valerie Masson-Delmotte and Juerg Beer for acting as guest editors for the joint section on "climate forcings".

This autumn has been a busy one, with several CLIVAR-sponsored meetings taking place. Aspects of some of these are outlined below, namely the joint CLIVAR/OOPC/GOOS/Argo Workshop on the South Pacific, the CLIVAR co-sponsored 2nd International Workshop on Advances in the Use of Historical Marine Climate Data, the 7th CLIVAR Atlantic Panel meeting, which immediately followed a Tropical Atlantic Ocean Dynamics Workshop sponsored by both NOAA and CLIVAR (see picture on page 31), and, more recently, the joint IOCCP/CLIVAR International Repeat Hydrography Workshop. In addition, the joint JSC/CLIVAR Working Group on Coupled Modelling (WGCM) held its 9th session at the Met Office in Exeter, UK, from 3-5 October and CLIVAR's Working Group on Ocean Model Development (WGOMD) met on the 8th and 11th November. The WGOMD meeting took place around a two-day Workshop held on 9th & 10th November on Modelling the Southern Ocean, with both events being hosted by the CSIRO Marine and Atmospheric Research Division in Hobart, Australia.

Key WGCM-9 agenda issues included (i) developments in WCRP, in particular the WCRP Coordinated Observation and Prediction of the Earth System (COPES) Strategy; (ii) progress with regional modelling; (iii) IPCC/CMIP activities, in particular the major international global coupled model experiment and multi-model analysis coordinated by the WGCM Climate Simulation Panel. 14 modelling groups from around the world with 21 models have participated in this experiment, the largest ever involving coupled models. Considerable resources have been devoted to this project with PCMDI, which has played a key role, archiving more than 27 terabytes of data so far. Over 200 papers have been submitted to peer-reviewed journals from the analysis phase which has attracted over 400 analysis projects being registered at PCMDI. Results from the experiment are thus now feeding directly into the IPCC AR4.

Other topics on the WGCM agenda covered scenarios for the 5th IPCC assessment (which are now starting to be discussed), data management, the next CMIP activity, other WGCM activities, links to Earth System Modelling, interactions with THORPEX and recent developments at modelling centres. The last afternoon of the meeting was devoted to a joint session with the new overarching COPES WCRP Modelling Panel at which the concept of seamless prediction of the climate system across timescales was much debated.

The WGOMD Southern Ocean Modelling Workshop attracted a pleasingly large number of attendees and was aimed at reviewing the elements essential for modelling the Southern Ocean in climate scale simulations. Extended presentations were given by 10 invited speakers in two overarching sessions on "observations and dynamics" and "processes and climate change". The workshop demonstrated the key role that Southern Ocean processes and dynamics play in the climate system, both for the present day and in the past. It also identified the importance of testing models against both observed water mass distributions in the region and against the fragmentary but growing observational evidence of change in the Southern Ocean. Key regional processes that need to be represented in climate models include coastal polynya dynamics and ice shelf melt. There is also a critical need to properly represent under-ice vertical mixing processes.

Discussion in the WGOMD sessions themselves centred largely around the group's efforts in developing the concept of Coordinated Ocean Reference Experiments (CORE), results from these to date and the need for metrics to gauge the fidelity of the simulations. Through CORE the working group is looking to develop wider links with the CLIVAR ocean basin panels and regional activities in ocean modelling. The group also discussed its role in assessment of the ocean component of IPCC-class coupled model runs and received updates on progress in ocean modelling at the centres represented at the meeting.

Report of the International Repeat Hydrography Workshop

JAMSTEC, the International Ocean Carbon Coordination Project (IOCCP), and CLIVAR co-hosted an International Repeat Hydrography Workshop at the Shonan Village Conference Center in Kamakura, Japan, November 14-16. The workshop brought together 49 participants from 11 countries, with expertise including ocean carbon and biogeochemistry, physical hydrography, modeling and data assimilation, and the Argo program. The workshop reviewed the science framework and implementation status of post-WOCE hydrography, provided guidance for a more coordinated system of data and information management, and established plans to begin data synthesis activities. Further details about workshop objectives and goals, the agenda, and the participant list can be found at: http://ioc.unesco.org/ioccp/RepeatHydrog2005.htm.

The workshop report is in preparation and will be made available as soon as possible.

Report on the 2nd International Workshop on Advances in the Use of Historical Marine Climate Data

Elizabeth Kent[1], Scott Woodruff[2], Nick Rayner[3], Chris Folland[3], David Parker[3], Dick Reynolds[4] and Takashi Yoshida[5]
[1]: National Oceanography Centre, Southampton., [2]: NOAA, Earth System Research Laboratory., [3]: Met Office, Exeter. , [4]: NOAA, National Climatic Data Center., [5]: Japan Meteorological Agency

The 2nd International Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT-II) was hosted by the Met Office, Exeter, UK from 17-20 October 2005. This was the latest in a series of marine workshops held approximately every two years since 1999. MARCDAT (in Boulder 2002 and Exeter 2005) alternates with 'CLIMAR' Workshops on Advances in Marine Climatology (in Vancouver 1999 and Brussels 2003).

These workshops have brought together a wide spectrum of marine data users, and managers of marine data and products, and have included an underlying focus on the continuing evaluation, utilization, and improvement of the International Comprehensive Ocean-Atmosphere Data Set (ICOADS, Worley et al. 2005). In addition to published outcomes (including Diaz et al. 2002, WMO 2003, Parker et al. 2004) the previous workshops have produced and actively tracked a consolidated set of scientific and technical recommendations [icoads.noaa.gov/marcdat2] to help guide the work of this group and provide feedback for the broader research community.

MARCDAT-II attracted more than 60 participants from eight countries for four days of oral presentations, posters and discussion. On the 21 October two more related meetings were held, of the Global Climate Observing System Working Group on Sea Surface Temperature and Sea Ice, and the Working Group on Surface Pressure.

Workshop Goals

The overall aim of the meeting was "To set priorities for the future development of marine climate data and products over the next four years". The meeting had four specific goals, to: (1) develop the timetable for enhancing in situ marine data bases, with a focus on ICOADS, taking account of plans for further digitization and improved processing of the basic observational data; (2) develop strategies for the creation of multi-decadal, homogeneous, gridded data sets for climate applications, and identify priorities for improvement in particular variables; (3) discuss methods for quantifying uncertainties in marine data and create a timetable for the assembly of a suite of gridded marine datasets with associated uncertainties; (4) consider how to define future data requirements.

Presentations

Following a review of progress on the consolidated recommendations, invited and contributed presentations covered subjects including: the reconstruction of ship routes from periods before longitude was measurable; reports on major new data recovery and digitisation projects; new methods for the construction of surface flux datasets using probability distributions; investigating the possibility of generating 100 years of daily reanalysis products with uncertainties similar to those in modern 2 to 3 day forecasts; integrating in situ and remotely-sensed data to produce long climate-quality time series; the effect of dataset reconstruction techniques on climate change estimates; assessments of the adequacy of the surface marine climate observing system; and future plans for the development of the ICOADS.

Discussion and Recommendations

Discussions were held in small groups each focussing on a range of marine variables.

An overarching recommendation was for continuing augmentation of ICOADS with in situ marine meteorological data, and enhanced links to ocean data repositories, such as the World Ocean Database. Perhaps 25 million undigitised data exist for instance in United Kingdom national archives. In view of scarce resources, the need for data inventories and assessments to help identify priorities for digitisation and datasets for incorporation into ICOADS was also highlighted.

Concern was expressed that the marine observation system is in decline. Observations from Voluntary Observing Ships (VOS) have reduced by more than a half since 1990 and we now have less than a third of the number of VOS participating in the program. As a result the uncertainty of in situ surface products is increasing. All of the discussion groups were concerned about the diminishing data quantities, which represent a huge challenge for the future. It is essential that the marine climate community make assessments of its future data requirements and feed this information through to the appropriate operational bodies.

The availability of comprehensive metadata on observational method for all observation platforms was thought to be key to the production of high quality datasets.

The importance of improving communication between scientists and both marine observers and operational centres was stressed.

The need for the production of a variety of well-documented gridded datasets for all marine variables, developed using a range of techniques, is essential to understand biases, structural uncertainties and the impacts of QC and analysis procedures. A number of concrete plans to achieve this were discussed.

The workshop felt that there was much to be gained from regular intercomparisons of datasets produced in near real time and for the continued use of multivariate techniques to improve marine datasets.

Although MARCDAT-II identified large efforts still needed to improve marine climatology, the progress since the first CLIMAR meeting in 1999 is impressive and we look forward to the next in this unique series of productive meetings in 2007.

Further Information

Presentations, meeting outcomes and the full set of recommendations will be published on the MARCDAT website (icoads.noaa.gov/marcdat2/).

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Report of the CLIVAR/OOPC/GOOS/Argo/CPPS Workshop on the South Pacific

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What drives decadal variability in the South Pacific and to what extent can it be predicted? What fraction of decadal variability in the South Pacific is connected with ENSO? What factors influence the ocean/atmosphere interactions that drive changes in the subtropical cell? Is the observing system in the South Pacific adequate in monitoring oceanic and atmospheric features in the region? These were some of the questions addressed at the CLIVAR/OOPC/GOOS/Argo/CPPS workshop on the South Pacific, held at the University of Concepción (UdeC), Chile, on 11-14 October 2005. The workshop had a very good attendance with 59 participants from 13 different countries, and was structured around fours sessions on Climate, Regional Impacts, Prediction and Predictability, and the Observing System. There was also a special session dedicated to the Argo Programme, and the impact it has had on monitoring the South Pacific.

One of the issues discussed relates to the air-sea interaction in the South Pacific, the need to examine this and its importance in underpinning statistical and dynamical forecast systems. This is an area where collaboration among CLIVAR's Pacific Panel, the Variability of the American Monsoon System (VAMOS) Panel, and the Working Group on Seasonal to Interannual Prediction (WGSIP) is desirable, to address, for example, the inter-relationships between tropical and Central South Pacific (CSP) SSTs and atmospheric changes over South America.

Two particular process studies in the Pacific area of great relevance to the South Pacific were presented. The first was the Pacific Upwelling and Mixing Physics (PUMP), which is being organized under US CLIVAR and is designed to improve the understanding of the variety of mechanisms that connect the thermocline to the surface in the equatorial Pacific cold tongue. Its goal is to observe and understand the interaction of upwelling and mixing with each other and with the larger-scale equatorial current system. The outcome of PUMP will be advancements in our ability to diagnose and model both the mean state of the coupled climate system in the tropics and its interannual and interdecadal variability. The second study was the Southwest Pacific Circulation and climate Experiment (SPICE). SPICE is aimed at a regional study of (i) bifurcation of the south equatorial current on the coast of Australia, (ii) the role of the east Australia current for the region, (iii) circulation in the North Coral Sea and includes a module on impacts and outreach. Both projects are still in the planning stages but were strongly encouraged to continue to pursue funding due to their importance for the South Pacific region and our understanding of ocean processes more generally.

Argo was discussed at considerable length. It was noted that there are considerable gaps in the current deployment for the South Pacific but those areas are being targeted for deployments by the US Argo program. The University of Concepción presently has 30 profiling floats in their inventory, some of which include dissolved oxygen sensors. Because the areas targeted by UdeC might have some overlap with the ones targeted by US, it was noted that a close interaction between those involved , with oversight by the Argo Program, was needed. Other deployment strategies were discussed and offers were made by representatives of Peru, Chile Ecuador and Colombia to assist with deployments for the completion of the global array.

All the other components of the observing system in the South Pacific were reviewed, with some important contributions on the efforts of the Pacific Island GCOS, and on data mining and data management. Considerable discussion also centred on the utility of gliders equipped with CTDs to sample the strong currents in the coastal zone. This discussion also noted that Argo is not very well suited to monitoring flow in boundary currents, but gliders are ideally suited. Gliders are poorly suited to sampling many locations in distant parts of the ocean, so there appears to be complementary features between these two systems.

It was also noted that the VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS), which is presently in the planning stages of its field mission, will certainly provide a better understanding of the southeastern Pacific (SEP) coupled ocean-atmosphere-land system, on diurnal to interannual timescales. However, it was felt that VOCALS is very much focused on the marine boundary layer and clouds, therefore there is a strong need for a more sustained and coordinated effort to improve the monitoring of the eastern boundary current in the Southeastern Pacific. It was recommended that a small group could lead the task in gathering information on all the existing oceanographic observations in this region, to consider if there is a need of an additional sustained program that would enable a long term study of the eastern boundary current's impact on the South American continent.

The organising committee is very grateful to all the support provided by WCRP, US CLIVAR, GOOS/OOPC and Argo, which enabled key participants to attend the workshop. It also would like to thank the local support from the Center for Oceanographic Research in the Eastern South Pacific (COPAS), and the Department of Geophysics (DGEO) of the Faculty of Physical Sciences and Mathematics, University of Concepción. Presentations from the workshop can be found at: www.clivar.org/organization/pacific/implementation/south_pac_workshop/south_pac.html

CLIVAR Atlantic Implementation Panel: 7th session

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The 7th session of the CLIVAR Atlantic Implementation Panel (AIP) was held in Venice, ITALY on 20-21 October 2005. The panel meeting followed the 3-day CLIVAR workshop on Tropical Atlantic Ocean Dynamics (http://www.clivar.org/organization/atlantic/wksp_trop_atl.htm) co-sponsored by NOAA. This gave the opportunity to focus on the Tropical Atlantic Variability research area. Important issues related to the Atlantic tropical-extratropical teleconnections as well as the key regions and processes involved were revisited. Such teleconnections were related to events like the European heat wave in 2003 and influence the seasonal to decadal forcing of the NAO and related atmospheric regimes in early winter, and therfore mid-to-high latitude climate. They also represent a source of potential predictability (warm/cold sea surface temperatures, impact on diabatic heating etc) under ENSO forcing influence.

Several activities in the Tropical Atlantic are planned and/or funded:

- AMI, Atlantic Marine ITCZ (July-Sept 2007) aiming at improving representation of convective clouds and meridional circulation in the Atlantic marine ITCZ
- AMMA, African Monsoon Multidisciplinary Analysis (2006-2008) focused on the dynamics of the West African Monsoon from weather to climate time scale. It has a large land component, but also ocean needs
- TACE, Tropical Atlantic Climate Experiment (2007-2012) aiming at improving predictions of SST in the tropical Atlantic. Enhanced observations are planned that will help to define sustained observations needed for predictions

The PIRATA array, as the main permanent observation program in the Tropical Atlantic, will contribute to the overall goals of TACE and AMMA. PIRATA has been enhanced by a southwest extension and will be further enhanced in the northeastern and southeastern tropical Atlantic and by increasing the vertical resolution of temperature and salinity sensors on the ATLAS buoys and also by installing current sensors in the mixed layer. It was recognised that TACE won't be able to address climate variability and predictability issues of the whole tropical Atlantic given its focus on the eastern upwelling area. There is therefore a strong need for an additional project or activity in the western tropical Atlantic to meet the overarching TACE goal.

In the North Atlantic two projects providing enhanced observations and process studies are coming to an end: the Arctic-Subarctic Ocean Flux study (ASOF) and German SFB 460. Some of the ASOF arrays will probably continue under institutional support and the International Polar Year (IPY) initiative. However some important observational sites in the North Atlantic subpolar gyre will disappear in 2006.

The panel welcomed the new proposal to continue monitoring the Meridional Overturning Circulation (MOC) at 26.5°N under the UK RAPID2 project and the successful US CLIMODE (CLIvar Mode water Dynamics Experiment, http://www.climode.org/) process study (2005-2009) on the formation, subduction & dispersal of 18° water (EDW), the principal water mass of the upper subtropical North Atlantic.

A new Arctic Climate Panel (ACP) was formed in October 2004 under the auspices of WCRP's Climate and Cryosphere project (CliC) and is in charge of building on the legacy of the earlier Arctic Climate System Study (ACSYS) and taking a role in promoting and coordinating activities for the IPY. Given the important links with AIP it was strongly suggested that CLIVAR be a co-sponsor of ACP.

The AIP will foster closer links with VAMOS and VACS panels in order to address climate issues related to the South Atlantic.

Regarding links of AIP with other international programs it is worth mentioning the collaboration with IGBP Global Ocean Ecosystem Dynamics (GLOBEC) and Integrated Marine Biogeochemistry and Ecosystems Research (IMBER) programs on issues related to the role of climate variability and change on the ecosystem and prediction of impacts. This will be an important application for CLIVAR research. :

Finally the panel identified the new future challenges for the next 7 years of CLIVAR, in particular in developing:

- Strengths in anthropogenic climate change, in particular in relation to coupled modelling
- A greater focus on predictability
- Stronger relations with operational centres
- Greater interactions with VACS and VAMOS panels

It is essential to address needs of the society and establish a close relationship between research, applications and stakeholders. For this the AIP will take a specific focus on extreme events (e.g. hurricanes), predictability and anthropogenic climate change.

Particpants at the CLIVAR Tropical Atlantic Ocean Dynamics Workshop, Venice, Italy 17-19 October 2005

PAGES PAST GLOBAL CHANGES

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