Final publishable summary report

A. Objectives of Past4Future

Paleo-climatic records contain a wealth of information on the stability and variability of climate and its ability to perform abrupt changes. The challenges for the multi-disciplinary Past4Future team are to better understand the climate system, to improve the prediction of future climate changes and to advance the knowledge on abrupt climate changes in interglacial periods.

The key objective for Past4Future are formulated in the following questions:

- What are the dynamics of the climate over interglacial periods?
- What causes climate changes and abrupt changes over the course of interglacial periods?
- What causes climate changes and abrupt changes over the course of interglacial periods?
- Can we understand the greenhouse gas records of the interglacial periods?
- What can the past tell us about risks for climate changes/threats in the future?

B. Key Questions

To meet the objectives the Past4Future program will address the following challenging key questions:

- What is the risk of abrupt changes in interglacials?
- Can we understand the greenhouse gas records of the interglacial periods?
- What is the risk of rapid collapse of ice sheets?
- Were there significant changes in ocean circulation during previous interglacial periods?

C. Key project results

Past4Future combines past-climate datasets from ice sheets, ocean sediments, cave deposits, Past4Future is a Collaborative Project under the 7th Framework Programme of the European Commission. The Past4Future project investigates the climate and environment of past warm periods (interglacials) to inform on future climate and possible abrupt changes. The overarching motivation for all 22 Past4Future partners working with paleo-science archives (ice sheets, ocean sediments, cave deposits, corals, and pollen) is the ambition to understand the climate system and the importance of predicting future climate changes, using the extended perspective offered by observations and modelling of the climate history over the Quaternary era.

Past4Future has clearly shown how important past interglacials are for improving understanding of climate under conditions similar to or warmer than today (as expected in the next century). This is illustrated by the fact that interglacials are discussed many times in the palaeo-climate chapter of IPCC [IPCC, 2013, Chapter 5], and form a major part of the discussion about ice sheets and sea level in the future.

Comparisons between models and data show that it is possible to understand the climate trends during the present interglacial, the last 11.7 thousand years. The trends are relatively weak, so this is not providing a very strong constraint. On the other hand for the last interglacial, the period from 128 thousand to 115 thousand years before present, where temperatures where higher than the present has great potential to understand the climate trends. Here the limitations are fewer observations with less constrained dating.

Three key results of the Past4Future project have stood out as being of particular importance relative to the future. The first one is that the Past4Future results unambiguously demonstrate that abrupt climate changes are not limited to glacial conditions, but can also occur in a warm world.

Changing ocean circulation, increasing greenhouse gas concentrations and instabilities of the remaining polar ice sheets are candidates for causing future abrupt changes.

The second issue concerns sea level and ice sheets. It has become increasingly accepted that sea level was 5-10 m higher than the present in the last interglacial, implying substantial reduction of the Greenland and/or Antarctic ice sheets. Indeed to obtain numbers in the mid and high range both Greenland and West Antarctica would have to be substantially retreated. Substantial progress was made, through the analysis of the NEEM ice core in Greenland and Antarctic ice cores, and through ice sheet modelling advances.

The third issue is the very clear documentation from palaeo-records (especially ice cores) that the greenhouse concentration have not reached levels similar to the present in the past 800.000 years although temperatures have been significantly warmer than the present. If the CO2 trend (and its stable carbon isotopic ratio) over the Holocene can be reasonably reproduced with Earth system models incorporating carbon cycle components, it is not the case for the last interglacial. This means that possibly the representation of terrestrial mechanisms such as the dynamics of peatlands and permafrost soils is not correct in these models.

The strength of the project relied on the interdisciplinary team of experts that was formed, bringing together the paleo-climatic data and modeling communities. Strong emphasis was put on communicating the project results to an audience including scientists within and external to the climate science community, as well as policymakers and the public. Two volumes of the Magazine PAGES present the results short and concisely for a broader audience.

1. A summary description of project context and objectives

Records from palaeo-archives, such as marine sediments and ice sheets, have demonstrated that, during the last several million years, the most dramatic climate changes were the coming and going of glacial and interglacial periods with temperature changes of 5 - 6 °C globally and up to 25 °C in the High Arctic.

While the cold glacial periods were characterised by abrupt temperature changes of up to 10 - 15 °C over a few decades in the Arctic, the subsequent interglacial warm climates exhibited abrupt regional changes of temperature even if the amplitude of these were substantially smaller. This relative climate stability may be part of the reason for the impressive evolution of human culture and technology in our present interglacial period.

Impacts on the environment, human health and society in Europe demonstrate how grave the still rather modest global warming during the last 100 years is:

- The temperature increase since 1900 has been 0.8 °C globally, but in Europe the increase was 1.0 °C over the same period.
- During the past five decades, Europe has experienced 300 flood events that led to massive loss of lives and damages at the 100 billion € level. Acontinued rise in temperature over Europe will likely increase the frequency of extreme flood events in this region.
- Annual precipitation trends in Europe in the 20th century show the contrasting picture of 10 - 40% wetter in northern Europe and up to 20% drier in southern Europe.
- Since 1850, glaciers in the European Alps have lost 2/3 of their volume with loss accelerating in the last three decades. In 2050, only 25% of the glaciers in the Swiss Alps will likely still be there.
- The minimum summer sea-ice extent in the Arctic was reduced by 50% in 2007 compared to the minimum extent in the 1950s.
- The length of the growing season for plants in Europe increased by 10 days between 1962 and 1995, and is projected to increase in the future.

A global warming of 0.8 °C is still rather moderate. However, the predicted warming of 1.4 - 4 °C globally, and 1 - 5.5 °C in Europe, by the year 2100, is dramatic and this will violently impact the environment, human health and society in Europe, as well as profoundly affect the increasingly globalized world.

Understanding of the future changes, their risks and the costs connected with the climate-induced changes, is a necessity for maintaining Europe's quality-of-life and international competitiveness. The required knowledge and insight can be achieved through reliable and sound climate change projections, in particular those with significantly reduced uncertainties on key aspects, processes and mechanisms. This will be especially true for projections dealing with ocean circulation, sea ice, ice sheets, and monsoons in response to changing global climate, as these have not yet been well constrained.

To relieve this situation, it is imperative to understand past climate and impacts. How can we expect good predictions of the future if the predictive tools are not able to model the past? Many of the processes and modes of variability, that are key to uncertainties about how European climates may evolve, are of a more long-term nature for which the instrumental database is too short-term. The instrument-based observations are registered during times of mixed natural and human influences; therefore, gaining a thorough understanding of the natural aspects of climate change, intercalated with man-made ones, requires data and model simulations of climate states that are similar to the modern, but without significant human influence. Our philosophy is that models used for predictions must demonstrate solid capacity to model the past especially that of recent warm periods. The past offers an opportunity both to improve models, and constrain the range of predictions with longer timescales through observation.

2. The following key questions succinctly summarise the key objectives of Past4Future:

What are the dynamics of the climate over interglacial periods?
At the global scale, the interglacial climate variability is small compared to the changes during glacial periods. Nonetheless, it has caused significant changes in the Earth system and at regional scale. The difference between the warmest period of the last interglacial and the typical climate of the present interglacial is comparable to the change in temperature expected by year 2100. These dynamics are responding to 1) changing external forcing factors, such as orbital forcing, changing solar irradiance, and volcanic eruptions, and to 2) the reaction of internal factors, such as large-scale ocean circulation and shifts of the Inter Tropical Convergence Zone. Past4Future-generated palaeo-data, in unprecedented resolution, allow studying the inter-annual climate-change variability representing an essential ground-truthing of climate models.

What causes climate changes and abrupt changes over the course of interglacial periods?
Reconstructing the past climate clearly demonstrates its ability to change abruptly and at a rate fast enough to impact ecosystems and societies. We know that these abrupt changes (also known as regime shifts or large-scale ecosystem transitions) have occurred during both our current interglacial and the previous one, the latter being a period with many climate features similar to those projected for our future. Yet, the underlying causes of these changes, their thresholds for activation, the rate at which they occur, and even the full extent of the impacted regions, have been poorly understood. In order to improve our understanding of the likelihood and possible impacts of such transitions and climate changes in our future, Past4Future critically assesses their past occurrences and underlying mechanisms using an innovative and combined data-model approach.

Can we understand the greenhouse gas records of the interglacial periods?
Prior to the anthropogenic period, greenhouse gases mirrored the climate changes with lower concentrations in cold periods and higher concentrations in warmer periods. Some differences between climate changes and greenhouse gas concentrations have been puzzling: Why do the greenhouse gases overshoot at the onset of interglacial periods and why do the gas records in the present interglacial dip 5000 years BP? – Understanding the dynamics of biogeochemical cycles in the past is crucial for predicting the future.

What can the past tell us about risks for climate changes/threats in the future?
In its Fourth Assessment Report, the IPCC made estimates of climate changes and their impacts, focused on those expected in the next century. However, some predictions with high societal relevance were highly uncertain, mainly because of uncertainties in greenhouse gas emission scenarios, non-linear behavior, and a limited understanding of some processes. The study of past warmer periods, for which increasingly detailed datasets are now available, offers the possibility to test and limit the range of such predictions. Indeed, looking back at the past is the only way to observe processes, such as ice sheet dynamics, that have timescales far longer than the observational record. The last interglacial period represents a particular value in this regard because, during millennia, the temperature, especially in the Arctic and Antarctic, was at levels similar to those expected towards year 2100. That interglacial period can, therefore, be used as a test-case of the effects of a warm climate, and to test whether events currently considered to have low probability actually did occur. In IPCC's Fifth Assessment Report, published in the final Past4Future year, the modelling of selected past periods are explicitly included. In relation to this IPCC assessment, Past4Future is timing the publication of key results in order to deliver data benchmarking the models, to coordinate the European modelling efforts, and to implement new methods for data-model comparison.