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Arctic climate and sea ice history - perspectives from the central Arctic Ocean sediment record

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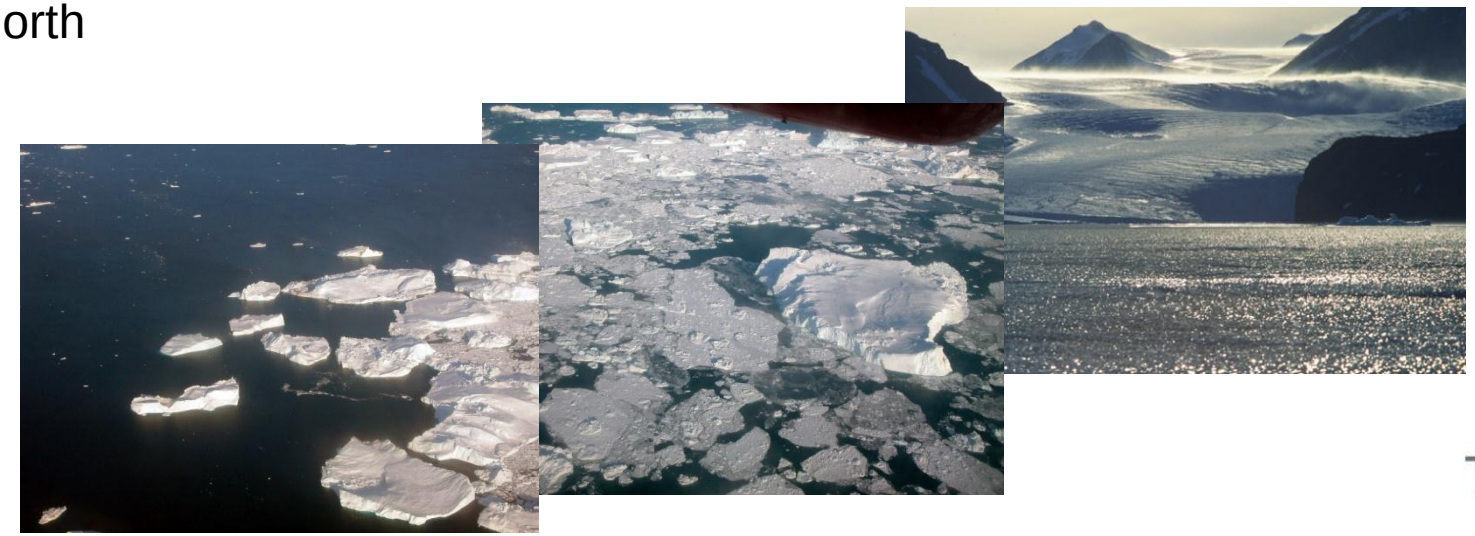
Background information

- Polar ice is an important component of the earth climate system, affecting global sea-level, ocean circulation, heat transport and marine productivity among other things
- A reduction in sea ice will promote Arctic warming through a feedback mechanism between ice and its reflectivity
- This reduction in sea ice will thus influence also weather systems in the North



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Sea ice and its relation to climate change

- The best records of past sea ice and its relation to climate change are provided by marine sediments from areas that are or have been covered by floating ice
- The size of sediment grains is commonly analyzed to identify ice-rafted debris.
- The entrainment of sediments in sea ice is largely restricted to silt and clay-size sediments and rarely contains larger grains
- Coarser ice-rafted debris is mostly transported by floating icebergs
- Distinguishing between iceberg and sea ice transport of sediment in marine sediment can be addressed by examining surface textures of sand-sized quartz grains and clay minerals
- Marine planktonic organisms live in or on sea ice or are otherwise associated with ice and their remnants in sediments are indicative of the condition of ice cover above the study site.

Studies related to the central Arctic Ocean sediment record

- Until recently, most cores relevant to the history of sea ice cover were collected from low-Arctic marginal seas but recent advances in scientific drilling the floor of the Arctic Ocean - notably the first deep-sea drilling in the central Arctic Ocean (IODP Exp 302 - ACEX) and some shallow coring expeditions (e.g. AO96) provide new, high-quality material from the Arctic Ocean proper to characterize variations in ice cover during the late Cenozoic (the last few million years)
- Our study covers the Middle Miocene (13.9 million years ago) to recent succession at Site M0002 of the ACEX and show that mineralogical characteristics of the sediments, like clay and heavy minerals as well as quartz grain surface textures can well be used to evaluate critical climate transitions

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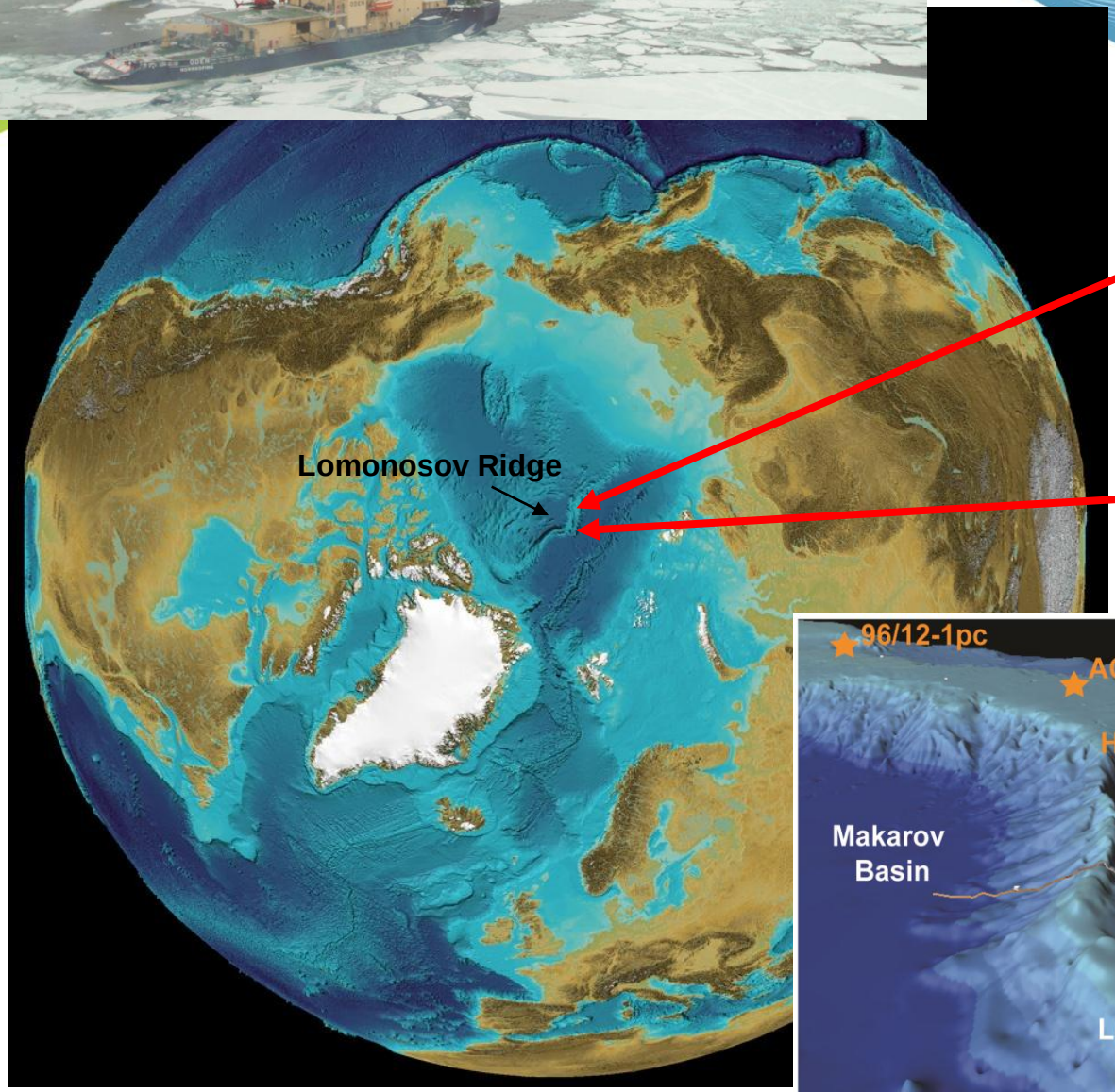
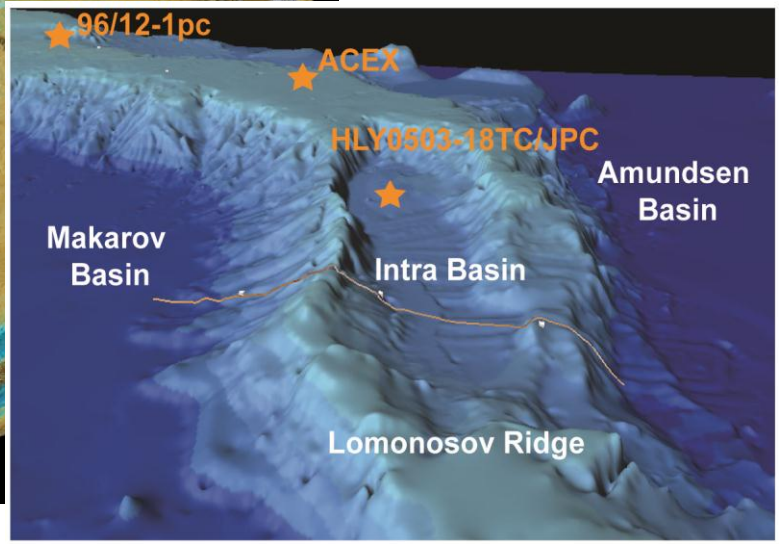
Drilling sites

AO96, core 96/12-1pc

IODP Arctic Coring Expedition 302 (ACEX), Sites M0002 & M0004





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Climate history

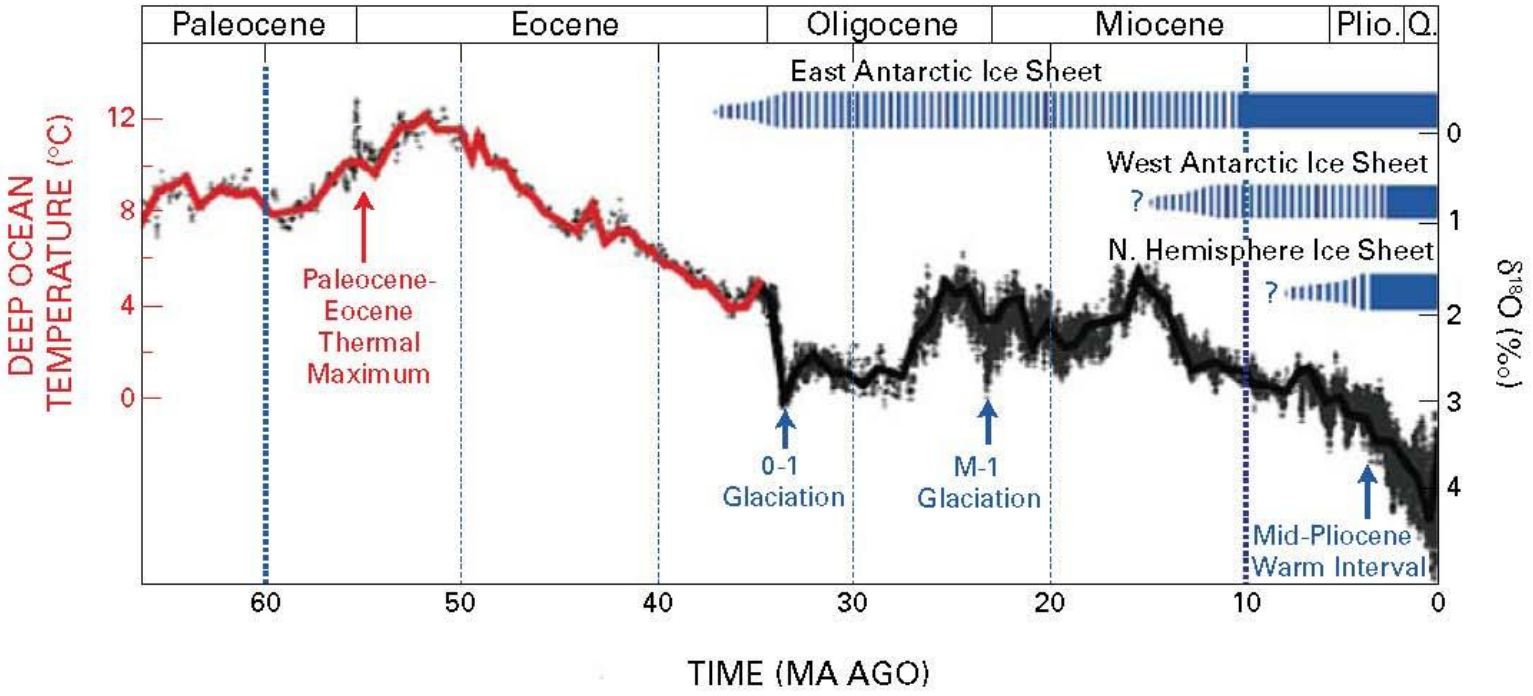

Figure 2.8. Global compilation of more than 40 deep sea benthic $\delta^{18}O$ isotopic records taken from Zachos et al. (2001), updated with high-resolution Eocene through Miocene records from Billups et al. (2002), Bohaty and Zachos (2003), and Lear et al. (2004). Lefthand y-axis refers only to solid red portion of the curve, when the oceans were ice free. Dashed blue bars = times when glaciers came and went or were smaller than now; solid blue bars = ice sheets of modern size or larger. [Figure and text modified from IPCC Chapter 6, Paleoclimate, Jansen et al., 2007, in IPCC, 2007, Figure 6.1.]

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Last interglacials and glacials

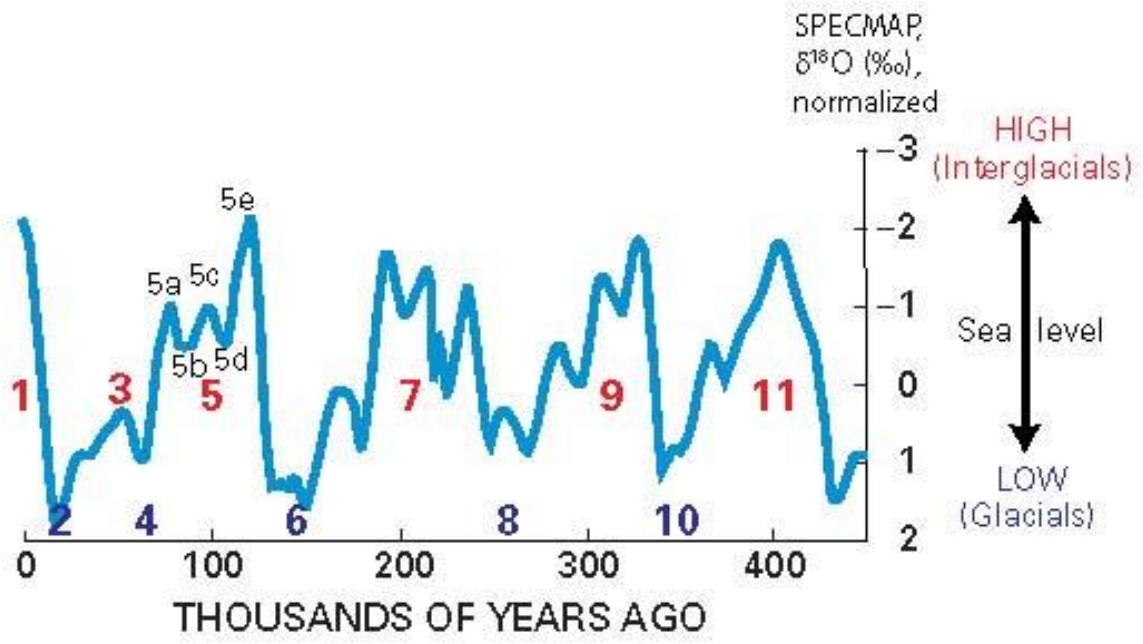

Figure 2.11. Marine Isotope Stage nomenclature and chronology used in this report (after Imbrie et al., 1984; Martinson et al., 1987). Red numbers = interglacial intervals; blue numbers = glacial intervals.

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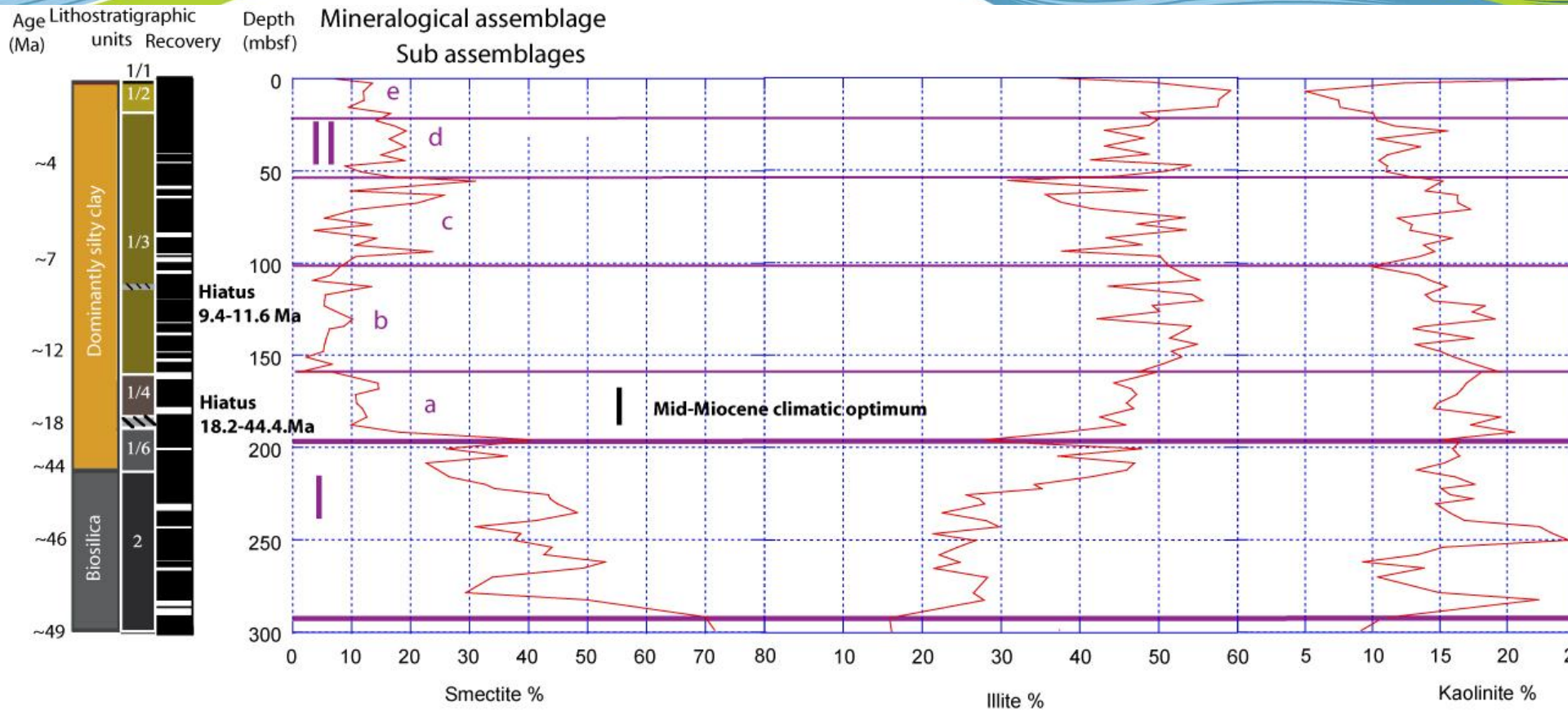

Central Arctic Ocean clay record (ACEX Site M0002)

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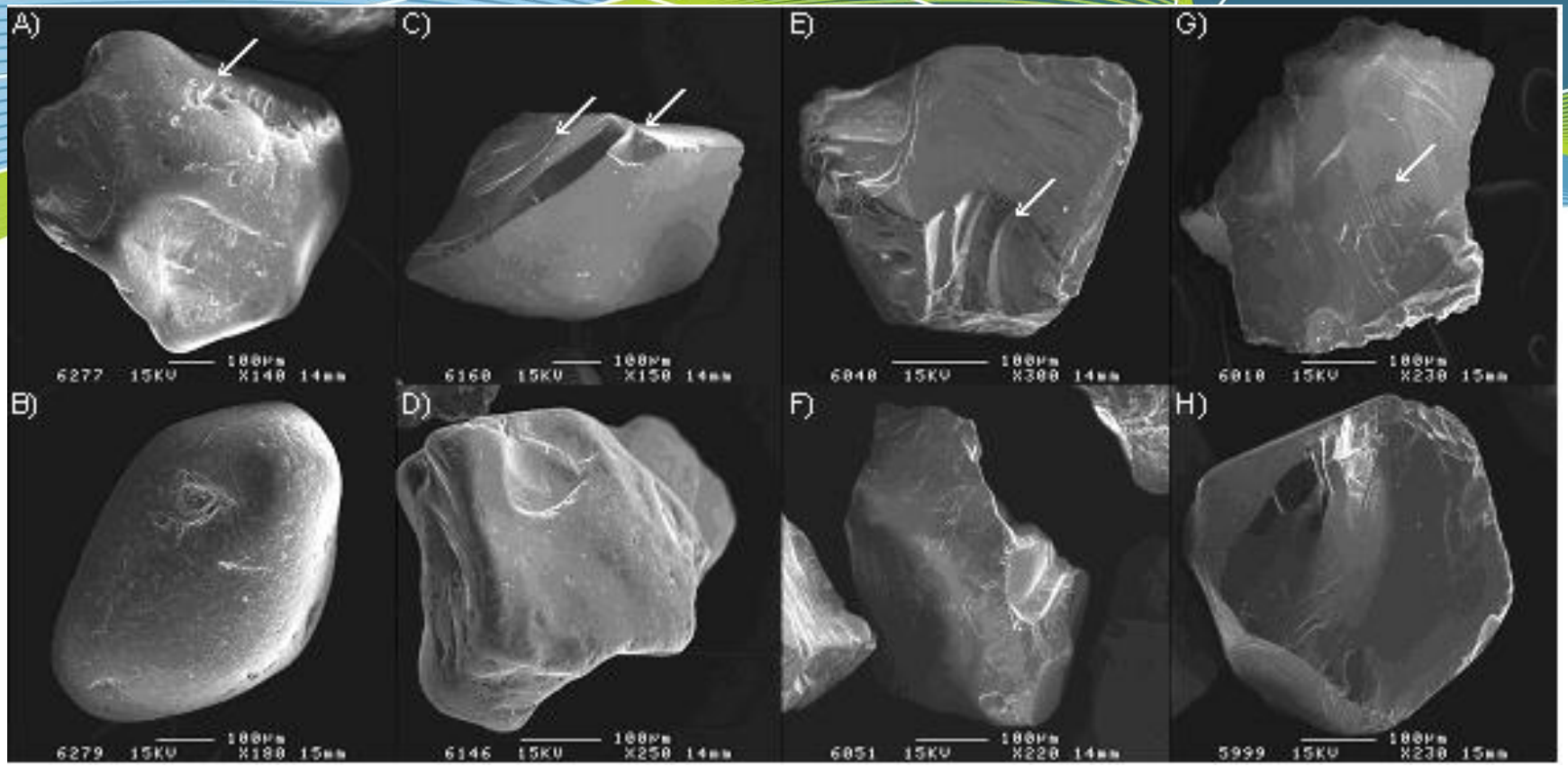
Miocene intensification of glaciation

- The clay fraction input soon after the Middle Miocene warmth can be related to the transport mechanisms by sea ice and by oceanic currents.
- The smectite content shows an abrupt decrease. This may mean stop of active melting of sea-ice in the central Arctic Ocean. This change can be seen also as a start of significant fluctuation in the amount of kaolinite probably indicating glacial influence.
- Year-round ice in the Arctic possibly developed in that time as the establishment of the modern hydrographic circulation in the Arctic Ocean



ACEX Site M0002 quartz grain surface textures: ***Grains A and B from 195.72 mbsf show subrounded and rounded outline. Arrow points to impact V-pits in grain A, Grains C and D from 175.90 mbsf show angular and subangular outline. Arrows in grain C point to subparallel linear fractures (left) and conchoidal fracture (right), Grain E and F from 159.14 mbsf show angular and very angular outline. Arrow in grain E points to steps, Grains G and H from 151.06 mbsf show very angular and angular outline. Arrow in grain G points to subparallel linear fractures.***

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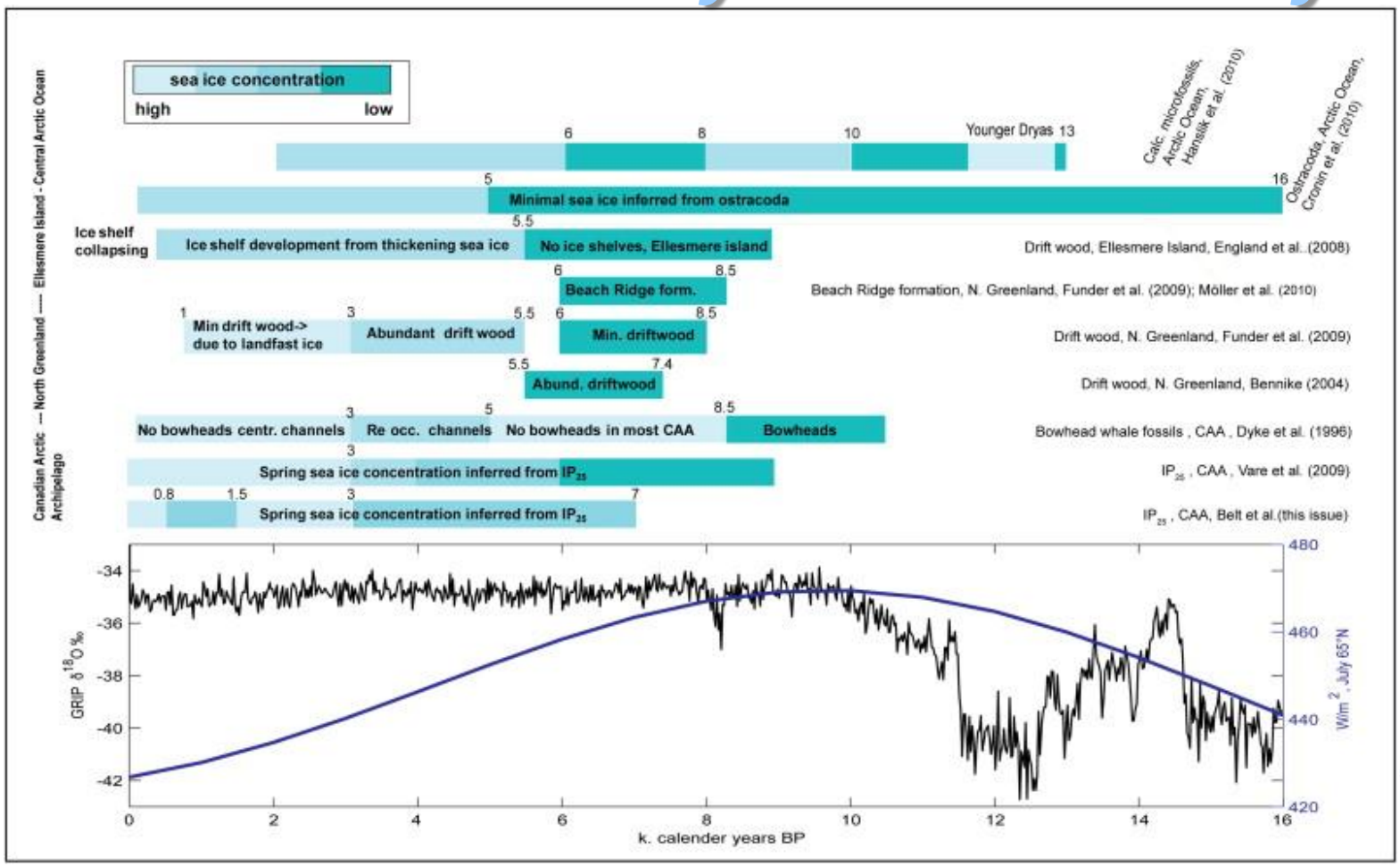
Mineralogical characteristics of the central Arctic Ocean sediments

- Surface features of glacially transported (i.e., iceberg) grains are dominated by those produced by mechanical breakage, including angular edges, high relief, conchoidal fracture, breakage blocks, and step-fractures, whereas surface features of sea ice transported grains display more rounded edges and chemical features, such as silica-dissolution and precipitation
- A periodic high content of smectite indicates changes to more open marine conditions. The increased content of smectite, pyroxenes and amphiboles of the sediments indicate that during interglacials, transport mechanisms were a combination of sea-ice and oceanic currents, reflecting also a significant freshwater input from the great Siberian rivers

Arctic sea ice history for last 16 000 years



Jakobsson et al., 2010. Quaternary Sci. Rev. 29, 3349-3358

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Insolation anomalies for last 20 000 years

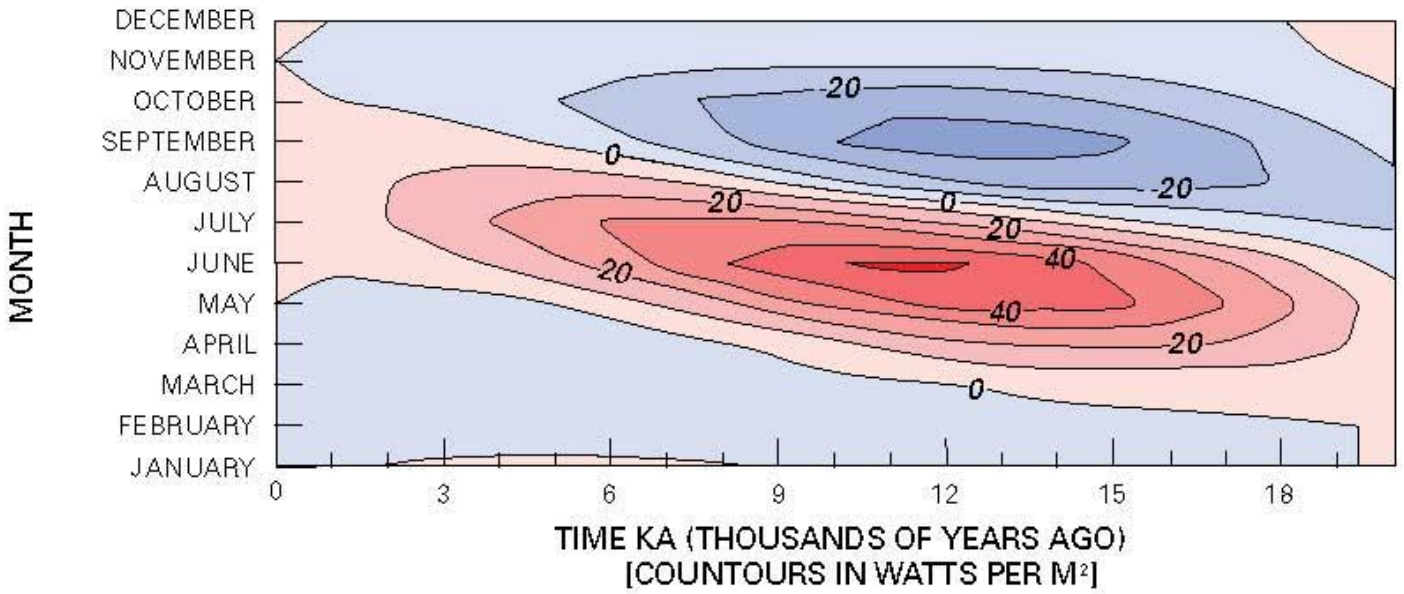

Figure 2.3. Milankovitch-driven monthly insolation anomalies (deviations from present), 20–0 ka at 60°N. Y axis, calendar months. Contours and numbers depict a history of insolation values. Contours in watts per square meter (W/m^2) (data from Berger and Loutre, 1992). Midsummer insolation values at 11 ka exceeded 40 W/m^2, whereas current values are less than 10 W/m^2.

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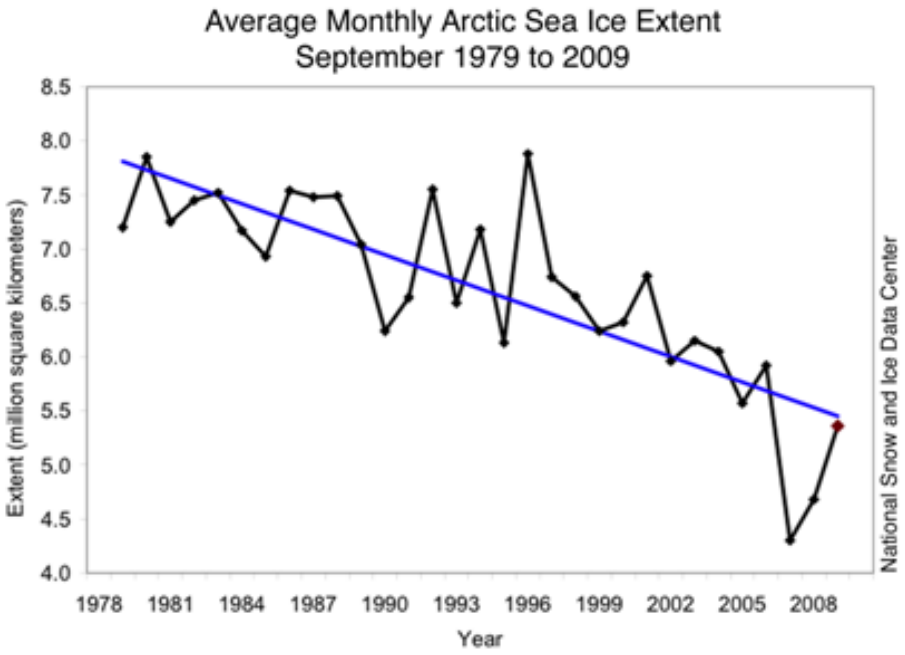
Arctic sea ice extent from 1979 to 2009



http://nsidc.org/news/press/20091005_minimumpr.html#fig3
October 2009

Predictions (IPCC, 2007)

- The Arctic is very likely to warm during this century in most areas, and the annual mean warming is very likely to exceed the global mean warming.
- Warming is projected to be largest in winter and smallest in summer.
- Arctic sea ice is very likely to decrease in extent and thickness.

Is this a 'normal' situation (occurred in the past) or is this an extreme development?

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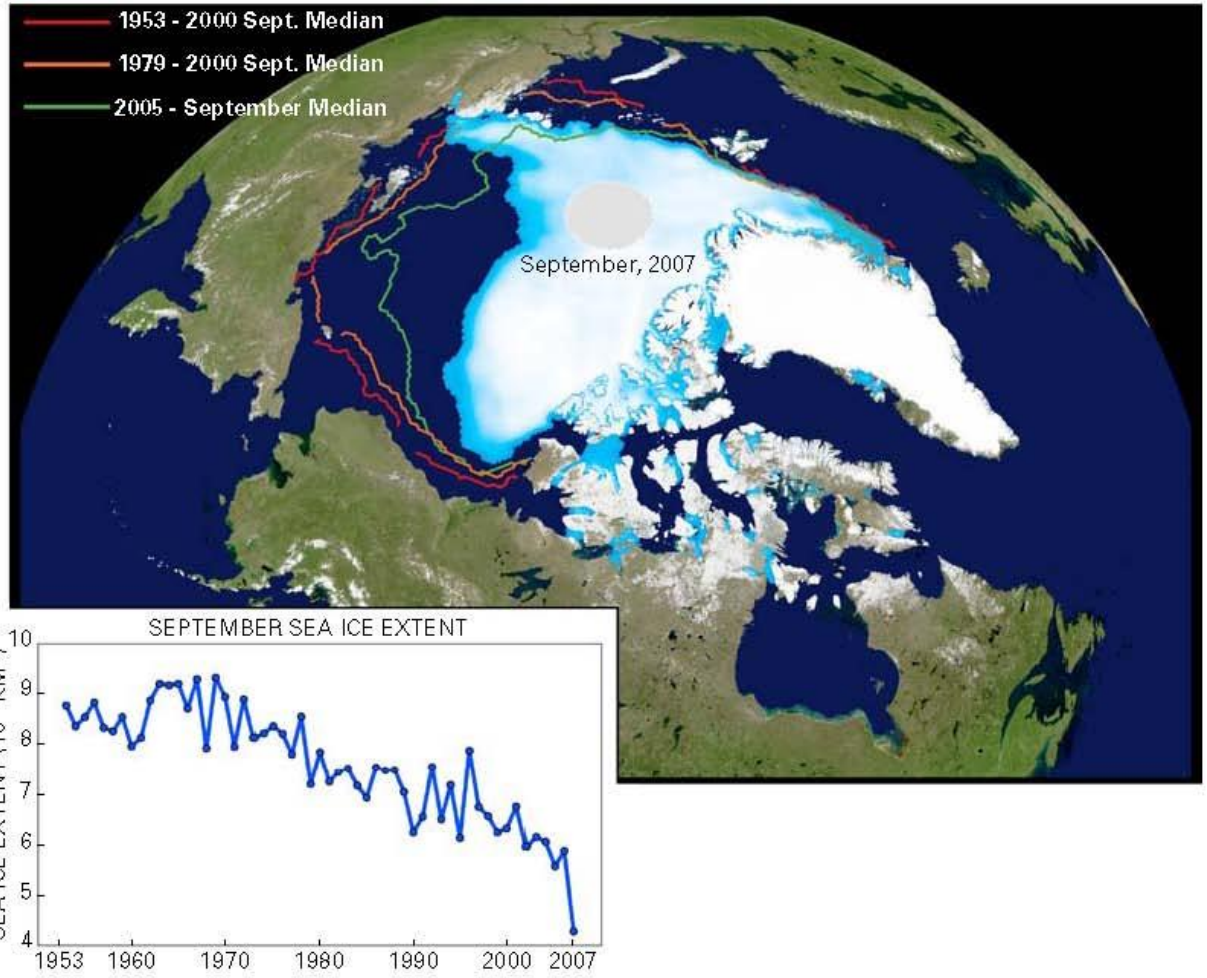
Arctic sea ice extent in 2007

Figure 3.1. Median extent of sea ice in September 2007, compared with averaged intervals during recent decades. Red curve = 1953–2000; orange curve = 1979–2000; green curve = September 2005. Inset: sea ice extent time series plotted in square kilometers, shown from 1953–2007 in the graph below (Stroeve et al., 2008). The reduction in Arctic Ocean summer sea ice in 2007 was greater than that predicted by most recent climate models. [Copyright 2008 American Geophysical Union, reproduced by permission of American Geophysical Union.]



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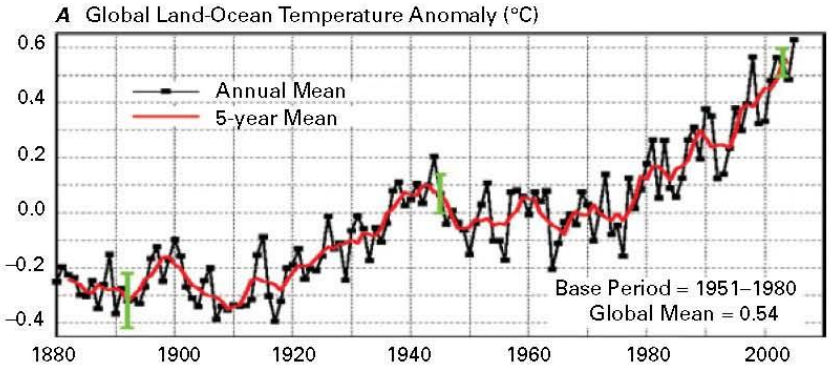
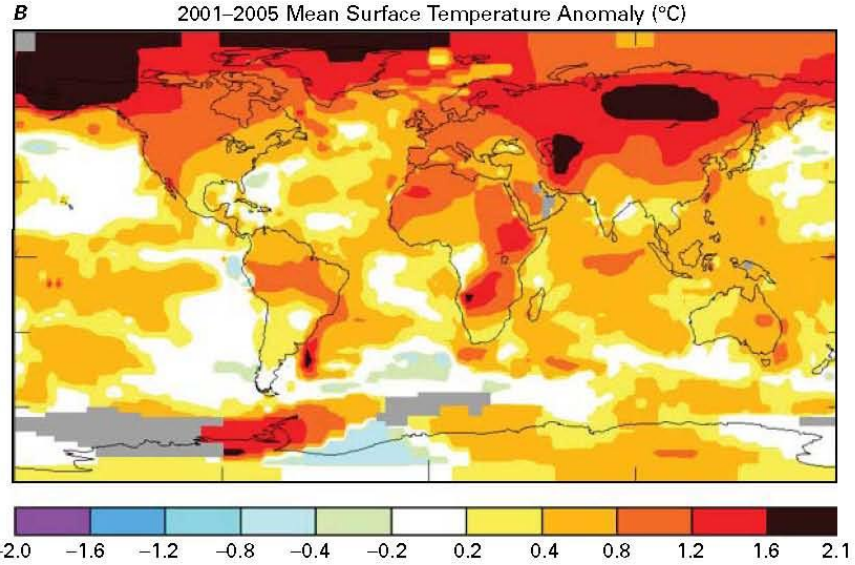
Climate: current and predicted changes





Terrestrial systems:

- Climate change is rapid on a evolutionary time scale
- 1.4 - 5.8 ^{o}C by 2100 relatively to 1990
- Continental areas and high latitudes are projected to warm more than coastal regions
- Evaporation and precipitation are projected to increase

Marine systems:

- Temperature increase, sea-level change and changes in ocean circulation affect marine organism
- Sea-level rise of 0.09 -0.88 m
- Effects on ocean circulation and potential climate feedbacks cause large uncertainty
- Extremes are expected to increase

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Last interglacial temperatures

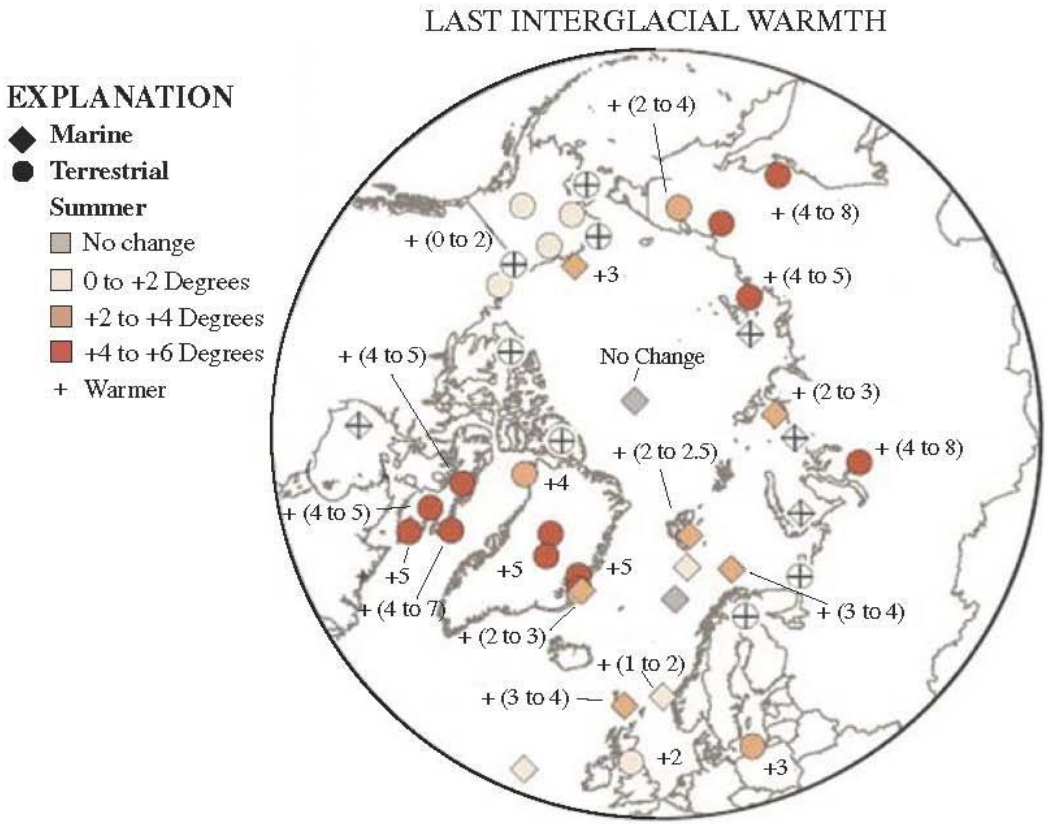

Figure 3.29. Polar projection showing regional maximum last interglacial summer temperature anomalies relative to present summer temperatures; derived from paleotemperature proxies (see Tables 1 and 2 in CAPE Last Interglacial Project Members, 2006). Circles = terrestrial sites; squares = marine sites. [Copyright 2006, reprinted by permission of Elsevier.]

Reduced-ice conditions in the Arctic

- Reduced-ice conditions are well inferred for the previous interglacial and for the onset of the current interglacial, about 130 and 10 thousand years ago and there appear to have been periods of ice free summers in the central Arctic Ocean
- These low-ice periods can be used as ancient analogs for future conditions expected from the marked ongoing loss of Arctic ice cover
- Today, the deep Arctic Ocean area is perennially covered by ice, but the surrounding shelves usually become ice-free during summers
- An area of future focus will be to improve our understanding of conditions during the periods of much reduced ice cover to provide important base-line conditions against which to explore potential future changes in Arctic climate under scenarios of global warming
- Records of the onset of glaciations and sea ice history concerning the Arctic Ocean, however, are still relatively sparse and future expeditions and ocean research focused to this area are needed

The objectives of the Thule Institute

- To set up models of cooperation for novel multidisciplinary research and education
- To promote northern and environmental research by elaborating research strategies internationally
- To aggregate academic education in the field of northern and environmental issues
- To promote interaction between different disciplines and operators within and outside the University

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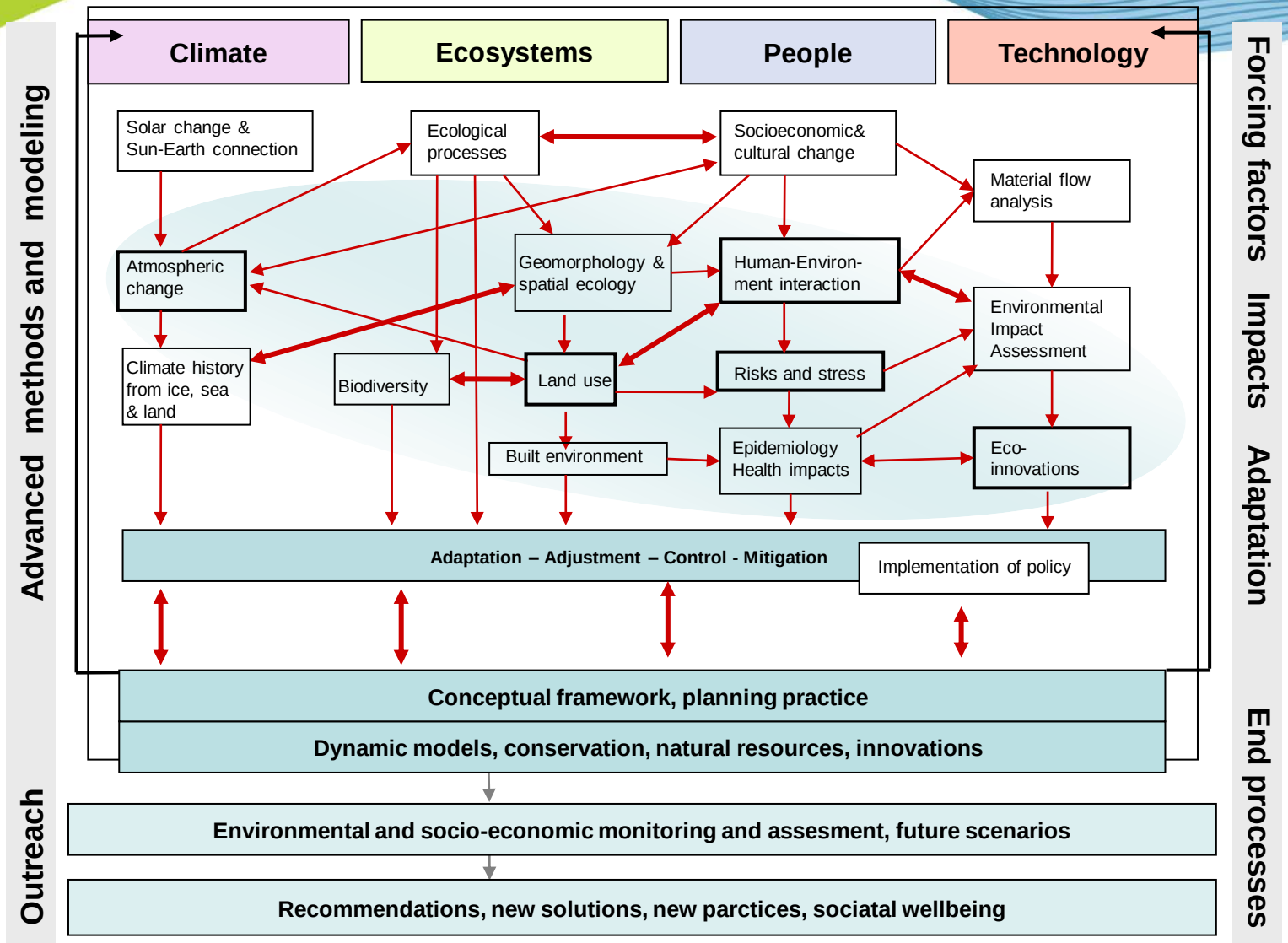
Interaction between different disciplines



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Thank you