Atmospheric circulation patterns and terrestrial desert distributions in the past "greenhouse" periods

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Abstract

Understanding the behavior of the global climate system, in particular, the atmospheric circulation pattern and terrestrial desert distribution during the past "greenhouse" period has profound implications for the modeling of future global warming. Our recent research results concerning the long-term relationships between Hadley circulation width, global temperatures, and atmospheric pCO_2 during the Cretaceous "greenhouse" period suggest the existence of a threshold in atmospheric pCO_2 and/or global temperature beyond which Hadley circulation shrinks drastically. In search for supporting evidence of such drastic shrinking of the Hadley circulation during the past "greenhouse" period, reconstruction of the paleo-position of the subtropical high-pressure belt from the marine record is essential. Eolian dust records and sea-surface salinity records in marine sediment will provide us information on the changes in latitudinal distributions of the subtropical high-pressure belt in the past. We propose a systematic and coordinated drilling approach (e.g., examine the latitudinal transects of marine sediment cores) to reconstruct the terrestrial climate and atmospheric circulation systems during the past "greenhouse" period, by utilizing IODP and ICDP.

Research Background:

Early and unequivocal signs of modern global climate change have been the warming of the high-latitude air and ocean, thawing of permafrost, and melting of ice in the Arctic. In addition, recent studies show that the hydrological cycle in the tropics and subtropics is also changing. Several lines of evidence suggest that over the past few decades the tropical humid belt and/or subtropical arid belt have expanded polewards (e.g., Seidel *et al*., 2008; *Nature Geoscience* **1**, 21–24). Most importantly, poleward movement of large-scale atmospheric circulation systems, such as widening of the Hadley circulation cells and poleward movement of jet streams and storm tracks, could result in shifts in precipitation patterns and desert distributions, which in turn affecting natural ecosystems, agriculture, and water resources. Thus, with the anticipation of future climate change, changes in the pattern of atmospheric circulation and the distribution of terrestrial desert zones are becoming an increasing concern among scientists. The observed recent rate of such changes are greater than climate model projections over the twenty-first century, which suggests that there is still much to be learned about this aspect of global climate change. It is therefore necessary to understand the behaviors, time-scales and amplitudes of the variability of atmospheric circulation patterns, hydrological cycles, and terrestrial desert distributions in response to global climate change.

Hypothesis: drastic shrinking of the Hadley circulation during the mid-Cretaceous

Our resent research results concerning the long-term relationships between Hadley circulation width, global temperatures, and atmospheric pCO_2 during the Cretaceous "greenhouse" period suggest the existence of a threshold in atmospheric pCO_2 and/or global temperature beyond which Hadley circulation shrinks drastically (Hasegawa *et al*., in submitted). We reconstructed temporal changes in the latitude of the subtropical high-pressure belt and its divergence axis (which marks the poleward margin of the Hadley circulation) during the Cretaceous, based on a reconstruction of spatio-temporal changes in the latitudinal distribution of deserts and the prevailing surface-wind patterns in the Asian interior (**Fig. 1**). We found a poleward shift in the subtropical high-pressure belt during the early and late Cretaceous, suggesting a poleward expansion of Hadley circulation. In contrast, an equatorward shift of the belt was found during the mid-Cretaceous extremely warm "greenhouse" period, suggesting drastic shrinking of Hadley circulation (**Fig. 2**). These results, in conjunction with recent observational studies that present Hadley circulation as expanding poleward in response to increasing atmospheric pCO_2 and consequent global warming (e.g., Seidel *et al*., 2008), suggest a non-linear response of Hadley circulation width to atmospheric pCO_2 increase and global warming. Namely, Hadley circulation gradually expands poleward with increasing global temperatures and atmospheric pCO_2 until these values exceed a certain threshold, beyond which Hadley circulation shrinks drastically (**Fig. 3**).

Expected outcome and Proposal:

The possibility of such a drastic switch in atmospheric circulation system with increasing pCO_2 has profound implications for future climate change, and should be explored in more detail in other geological episodes characterized by extremely warm "greenhouse" conditions (e.g., the Paleocene/Eocene Thermal Maximum (PETM) and/or the Early Eocene Climatic Optimum (EECO)). However, terrestrial records of adequate age and sensitivity are limited. Therefore, in search for supporting evidences of such drastic shrinking of the Hadley circulation during the past "greenhouse" periods, reconstruction of the paleo-position of the subtropical high-pressure belt from the marine record and its comparison with terrestrial records are essential. Therefore, we propose to conduct latitudinal transects of marine sediment cores of the early Eocene intervals from the central Pacific and/or central Atlantic. Eolian dust records (grain-size, flux, lithologic composition) and sea-surface salinity records in marine sediment will provide us with information on the changes in latitudinal distributions of the subtropical high-pressure belt at that time. We are proposing a systematic and coordinated drilling approach to provide a detailed reconstruction of the terrestrial climate and atmospheric circulation systems in the past "greenhouse" period, by utilizing IODP and ICDP.

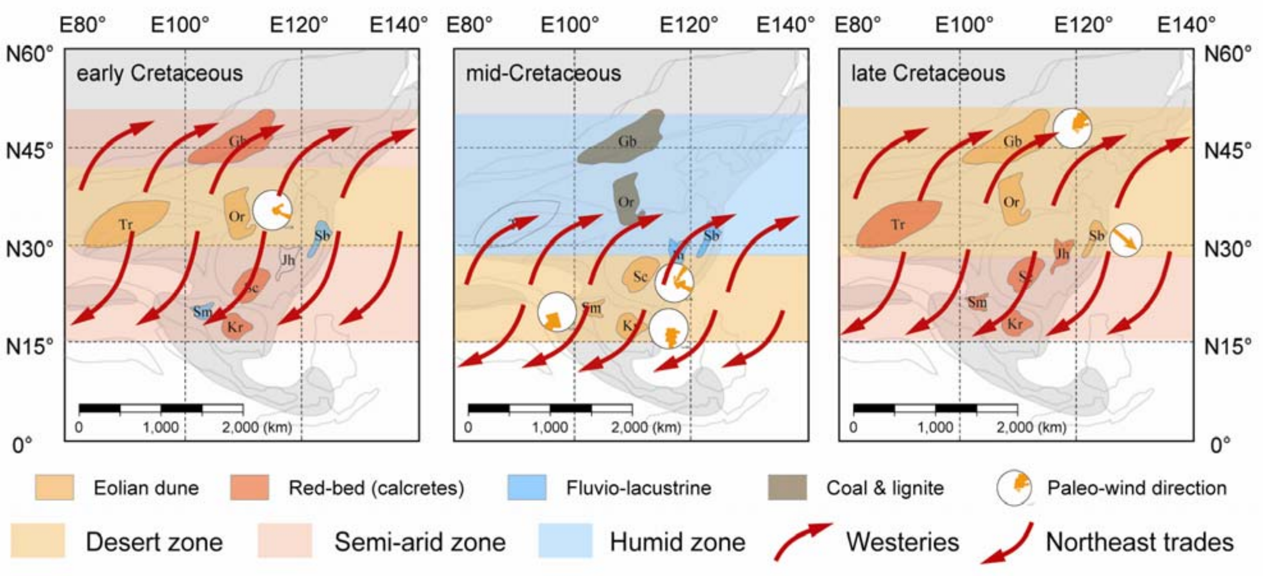

Fig. 1 Spatio-temporal changes in the distribution of climate- sensitive sediments and paleowind directions in the Asian interior during the Cretaceous “greenhouse” period.

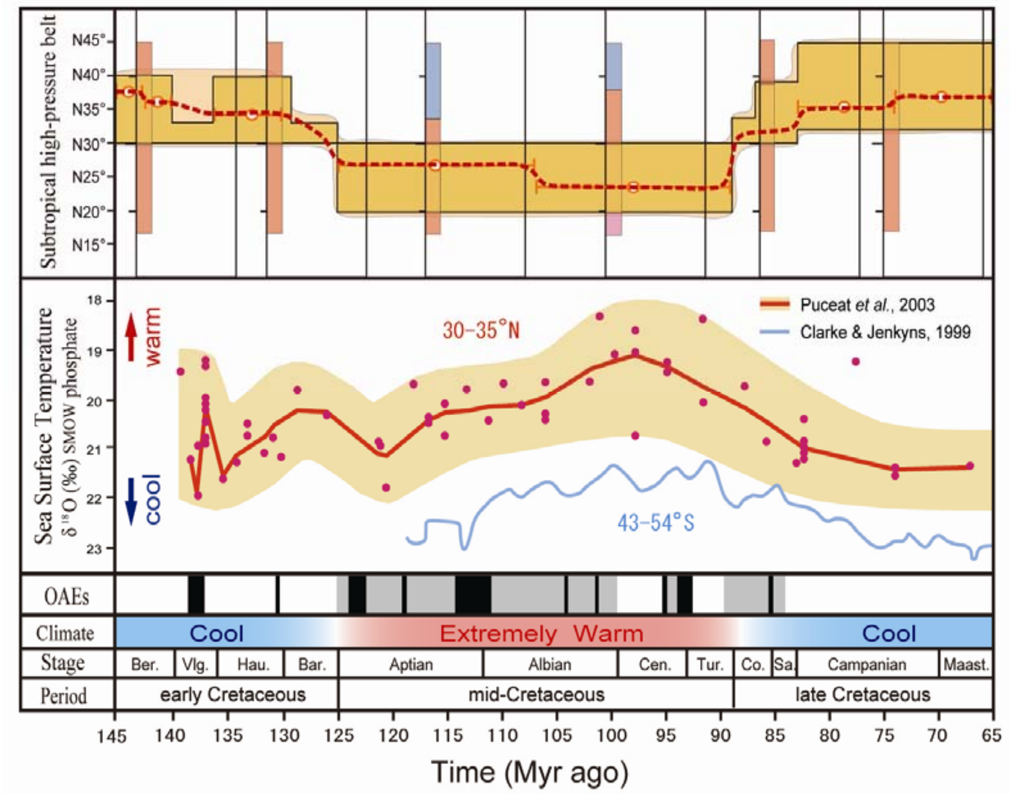

Fig. 2 Temporal changes in the latitude of the subtropical high- pressure belt, calculated sea surface temperatures (SSTs), and occurrences of ocean anoxic events (OAEs) during the Cretaceous “greenhouse” period.

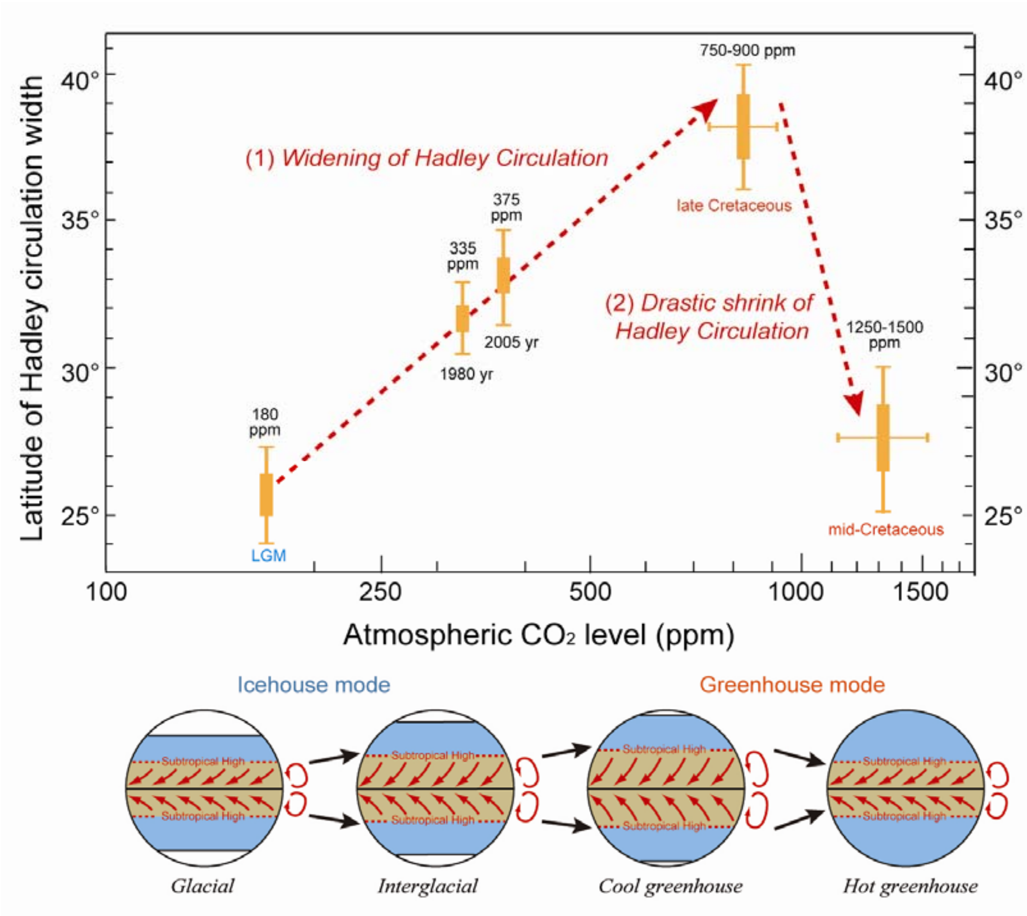

Fig. 3 Inferred evolutionary trends of the changing atmospheric circulation pattern in response to climatic warming (from icehouse to greenhouse), and the conceptual scheme of the latitudinal changes in Hadley circulation width vs. atmospheric CO_2 levels.