Low-frequency climate variability of an aquaplanet

Eileen Dahms[1,2], Frank Lunkeit[2], and Klaus Fraedrich[1,2]

(1) Max Planck Institute for Meteorology; (2) KlimaCampus, Meteorological Institute, University of Hamburg

Eileen Dahms
Max Planck Institute for Meteorology
Grindelberg 5
20144 Hamburg
eileen.dahms@zmaw.de

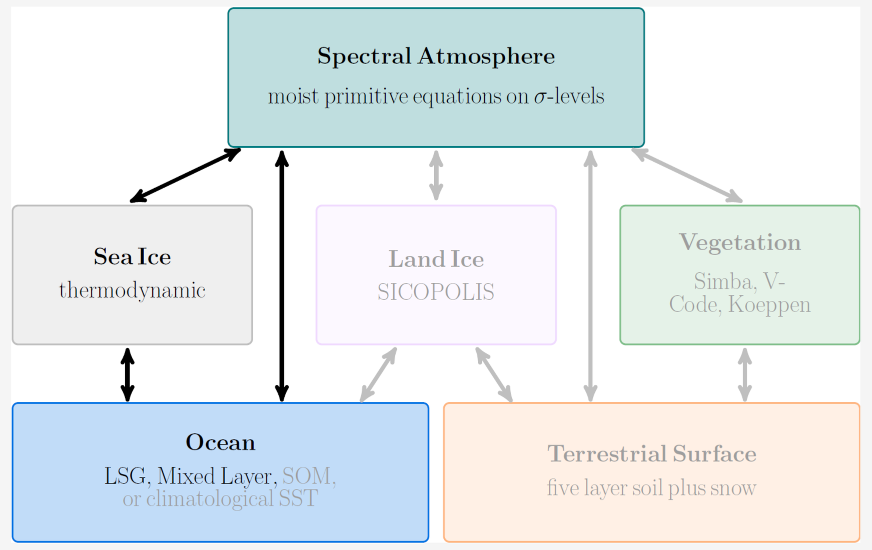
Summary

The variability of a coupled atmosphere-ocean climate system is analyzed in a long-term aquaplanet simulation with a global atmospheric circulation model (the Planet Simulator) coupled to an ocean circulation model (the Hamburg Large Scale Geostrophic model, LSG).

Different states of coupled aquaplanet climates have been found in previous studies. While Smith et al. (2006) analyzed a warm greenhouse climate, Marshall et al. (2007) and Enderton & Marshall (2009) studied aquaplanets with polar ice cover down to the mid-latitudes. Ferreira et al. (2010) present both a warm and a cold solution. In a following study (Ferreira et al., 2011), they discuss the multiple equilibria of an aquaplanet. Even though multiple states in aquaplanet simulations have been analyzed before, there is no previous study which describes an oscillation between cold and warm climates, as the one presented here.

A low-frequency oscillation is found in our coupled aquaplanet simulation: Warmer climates without polar sea ice cover and weaker oceanic overturning alternate with colder climates with a sea ice cover down to 65°N/S and a stronger MOC. The period of the oscillation is approximately 700 years and the oscillation occurs in both hemispheres in-phase.

Planet Simulator GCM



The atmospheric GCM used in this study is the Planet Simulator (*Fraedrich et al., 2005*), which is coupled to the Hamburg Large Scale Geostrophic (LSG) ocean model (*Maier-Reimer et al., 1993*).

Key features:
- portable
- fast
- open source
- parallel
- modular
- easy to use
- documented
- compatible

Information and downloads:
http://www.mi.uni-hamburg.de/plasim

Figure: Schematic diagram of model compartments of the Planet Simulator (vegetation, terrestrial surface, and land ice are not included in the aquaplanet set-up)

Aquaplanet set-up

a planet, where the entire surface of the earth is covered by one ocean with a flat bottom and without any geometrical constraints

The coupled model is run for 20,000 years. The first 10,000 years are spin-up time and the years 15,001 to 20,000 are used for the analyses.

- idealized test environment
- zonally symmetric
- symmetric about the equator
- perpetual equinoctial conditions (no seasonality)

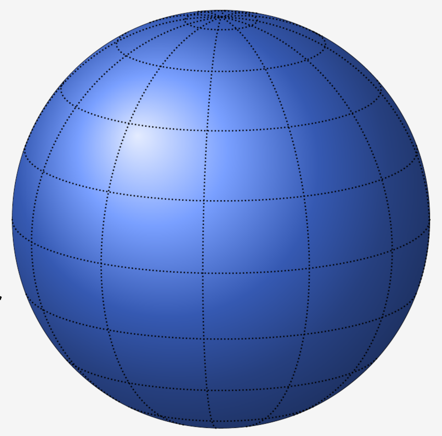
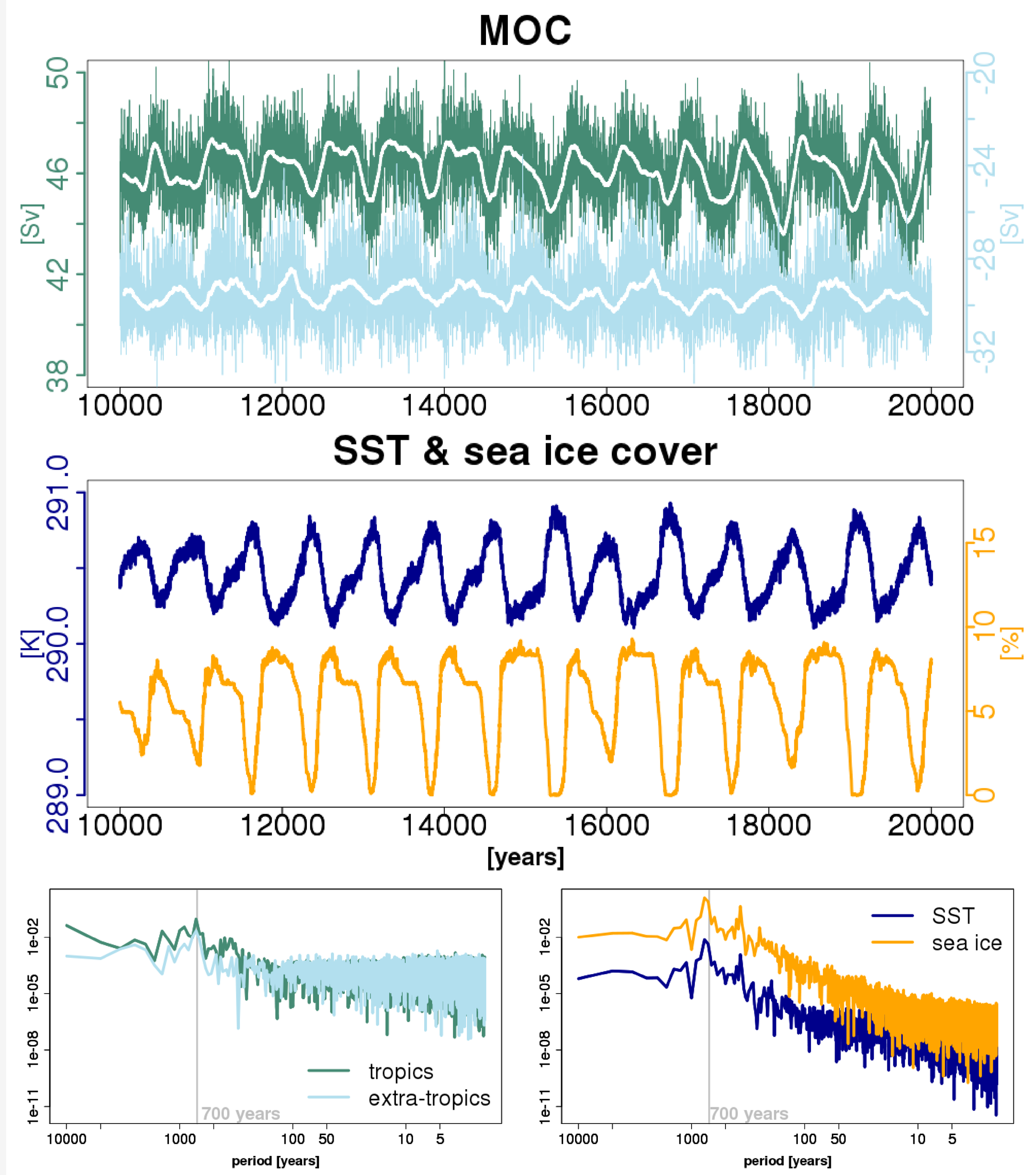


Figure: Schematic picture of an aquaplanet (without continents and entirely covered by one ocean)

Time Series

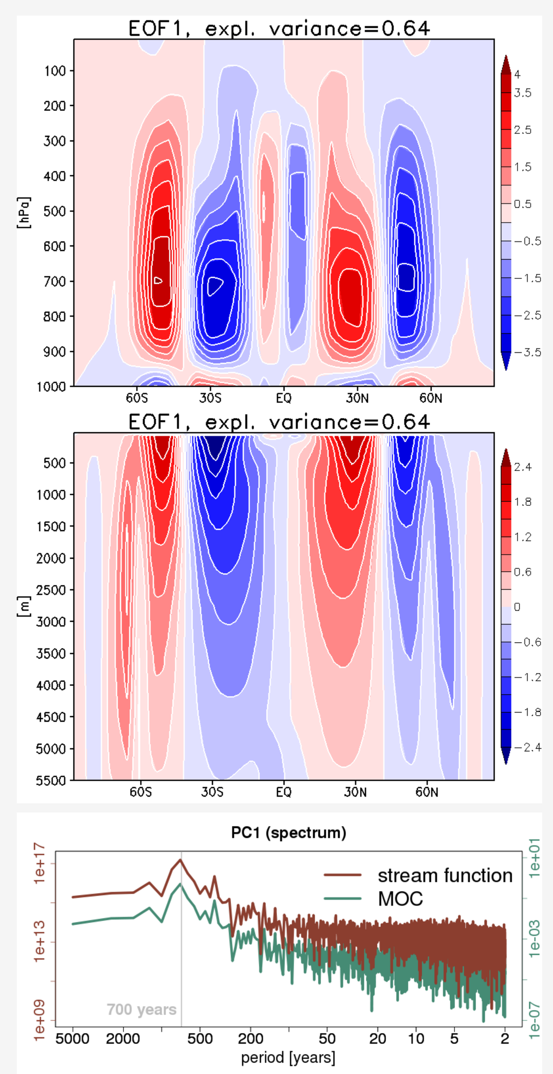
Time series of the maximum MOC (meridional overturning circulation) strength (tropical cell: green, extra-tropical cell: light blue) and of global mean SST (sea surface temperature, dark blue) and sea ice cover (orange) are shown.

A dominant low-frequency oscillation can be observed in all atmospheric and oceanic fields. The period is approximately 700 years, which can be obtained from the spectra. The climate alternates between two different states:
- *warm climates with hardly any sea ice go along with a weak MOC*
- *during colder climates, sea ice covers the poles and the MOC is stronger*

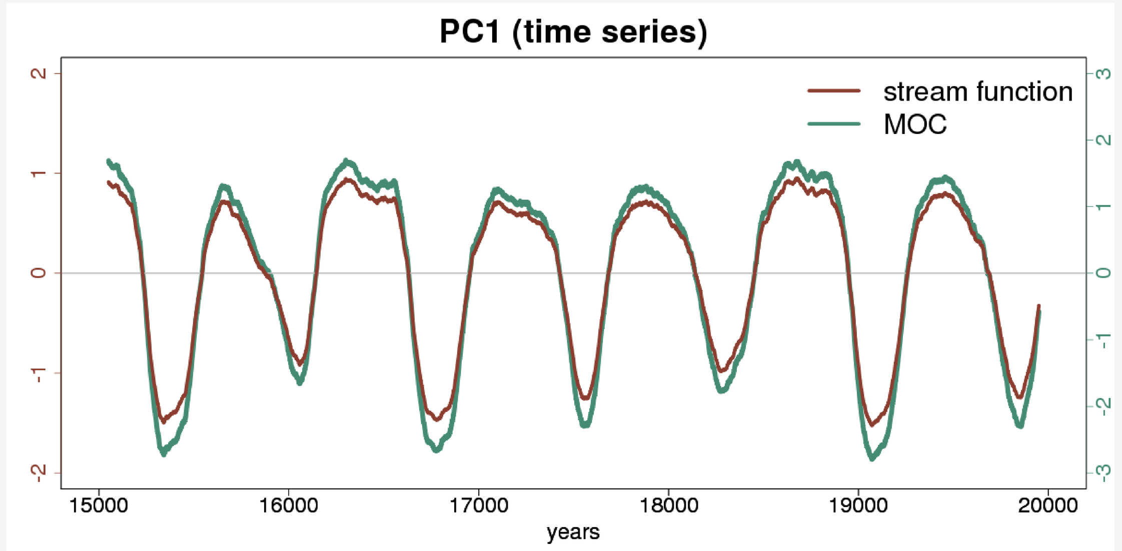


Figures: (above) Time series and spectra of MOC, SST and sea ice cover

EOF analysis



Figures: EOFs1 and PCs1 (time series and spectra) of atmospheric stream function & MOC

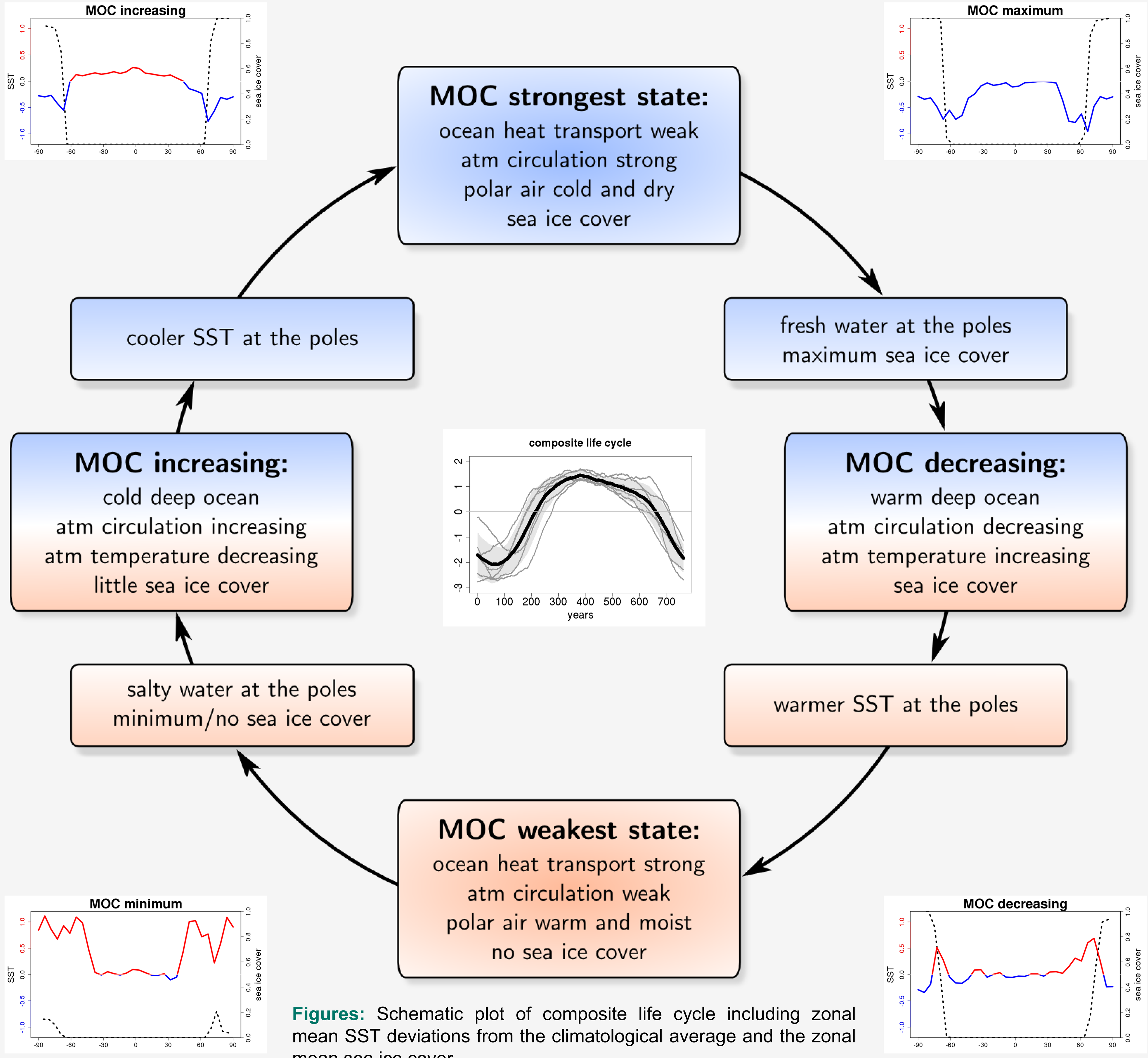


EOF (empirical orthogonal function) analyses are applied to individual zonal mean fields of atmosphere and ocean. The low-frequency variability is described by EOF1 (e.g. circulation) with:
- *an equatorial symmetric spatial pattern with strong positive/negative anomalies,*
- *and a time series (PC) which oscillates with a period of approx. 700 years.*

For some variables, EOF2 also describes part of the oscillation (e.g. oceanic temperature).

Composite Life Cycle

A composite life cycle of the oscillation is constructed based on the variation of the MOC. The composite life cycle is shown below as an ensemble of 6 oscillation cycles and as a schematic cycle of events. The deviations of the zonal mean SST from the climatological average and the zonal mean sea ice cover are shown at the maximum, minimum, and at the increasing and decreasing states as examples. Further examples can be found in Dahms et al. (2012).



Figures: Schematic plot of composite life cycle including zonal mean SST deviations from the climatological average and the zonal mean sea ice cover

Main characteristics of the oscillation:
- *When the MOC is at its weakest state, the ocean is relatively warm because of an enhanced meridional oceanic heat transport.*
- *With an increasing MOC, the ocean (which is still ice-free) cools.*
- *A cold climate state develops, where the oceanic heat transport is relatively weak and the poles are covered by sea ice.*
- *When the MOC decreases again, the deep ocean warms first and afterward the entire coupled climate system, especially at the poles, changes into a warm state.*

References

1. *Dahms, E., F. Lunkeit, K. Fraedrich, 2012:* Low-frequency climate variability of an aquaplanet. J. Clim., *in review*
2. *Enderton, D., J. Marshall, 2009:* Explorations of Atmosphere-Ocean-Ice Climates on an Aquaplanet and Their Meridional Energy Transports, J. Atmos. Sci., 66, 1593-1611
3. *Ferreira, D., J. Marshall, J.-M. Campin, 2010:* Localization of Deep Water Formation: Role of Atmospheric Moisture Transport and Geometrical Constraints on Ocean Circulation, J. Climate, 23, 1456-1476
4. *Ferreira, D., J. Marshall, B. Rose, 2011:* Climate determinism revisited: multiple equilibria in a complex climate model, J. Climate, 24, 992-1012.
5. *Fraedrich, K., H. Jansen, E. Kirk, U. Luksch, F. Lunkeit, 2005:* The Planet Simulator: Towards a user friendly model. - Meteorol. Z., 14, 299-304.
6. *Maier-Reimer, E., U. Mikolajewicz, K. Hasselmann, 1993:* Mean Circulation of the Hamburg LSG OGCM and Its Sensitivity to the Thermohaline Surface Forcing, J. Phys. Oceanogr., 23, 731-757
7. *Marshall, J., D. Ferreira, J.-M. Campin, D. Enderton, 2007:* Mean Climate and Variability of the Atmosphere and Ocean on an Aquaplanet, J. Atmos. Sci., 64, 4270-4286
8. *Smith, R. S., C. Dubois, J. Marotzke, 2006:* Global Climate and Ocean Circulation on an Aquaplanet Ocean-Atmosphere General Circulation Model, J. Climate, 19, 4719-4737

Max-Planck-Institut für Meteorologie

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG