ITCZ/Monsoon Model Intercomparison Project

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4 August 2015: Clarified whether fields should be saved as means over the output period or as snapshots.

14 July 2015: The land setup is revised and has changed with respect to earlier versions. We also now include plots for the ECHAM6.1 AquaControl and LandControl simulations for reference.

This document describes the simulation setup and the requested simulations for the model-intercomparison project organized within the 2015 WCRP Grand Challenge workshop on ITCZ and monsoons. Five simulations in idealized aquaplanet and idealized continent setup are performed to study the dynamics and model robustness of how carbon dioxide, land and the orbital configuration affect the ITCZ and the monsoons as well as the interaction between the two. We note that this MIP is not part of CMIP6, but we are very much interested in discussions and exchanges with CMIP6 activities related to monsoons and the ITCZ.

1 Model setup

The models are to be coupled to a slab ocean with time-mean zonal-mean ocean heat transport ("q-flux") given in section 4. The boundary conditions largely follow the CMIP5 aquaplanet protocol except for interactive sea-surface temperatures and the inclusion of a seasonal cycle in insolation. The following parameters should be specified:

- CO_2: 348 ppmv
- CH_4: 1650 ppbv
- N_2O: 306 ppbv
- No Halocarbons (CFCs)
- Ozone following values for the AquaPlanet Experiment (see `http://www.met.reading.ac.uk/~mike/APE/ape_ozone.html`)
- Total solar irradiance: 1365 Wm^{-2}
- No radiative effects of aerosols
- Diurnal cycle in insolation

- Calendar: a 360 days calendar (each month has 30 days) is desirable, but if such a calendar is not available then a 365 days calendar without leap years should be used (second preference) or a 365 days calendar with leap years (third preference)
- Orbit: zero eccentricity, 23.5°obliquity, NH spring equinox on March 21; modelling groups should check the timing of the NH spring equinox by looking at daily TOA shortwave data because a correct timing is essential to meaningfully compare different models (a deviation from March 21 by 1-2 days is considered acceptable)
- Slab ocean depth: 30 m
- Sea-ice formation should be inhibited, and ocean temperatures should be allowed to cool below the freezing temperature of sea water (see, e.g., Kang et al., 2008; Voigt et al., 2014)

For the land simulations, a rectangular continent extending from 30° S to 30° N and 0° E to 45° E should be introduced. The q-flux should be zeroed out over this region, which requires a small uniform correction of the q-flux over ocean areas of -0.59 Wm^{-2} (see Sect. 4). Land should be represented as a very shallow ocean of depth 0.1 m with increased surface albedo and with decreased evaporation.

Regarding the land surface albedo: the land albedo should be the ocean albedo plus 0.07. So if the ocean has an albedo of 0.06, the land should have an albedo of 0.13. For some models the ocean albedo is not a constant number but depends on the zenith angle and the ratio of diffuse vs. direct radiation. In this case, the land albedo should be the ocean albedo calculated for the specific conditions plus 0.07.

Regarding decreased evaporation over land: over land we aim at a reduction of evaporation compared to ocean. This is achieved by rescaling the moisture transfer coefficient, C_q, which affects the surface evaporation via

$$E = C_q|\vec{V_1}|(q_1 - q_s), \tag{1}$$

with subscripts 1 and s denoting values at the lowest model level and at the surface. Over land, the transfer coefficient C_q should be halved, i.e.,

$$C_q \rightarrow C_q \cdot \frac{1}{2}, \tag{2}$$

which assuming no changes in surface wind speed and boundary-layer humidity will reduce the evaporation by a factor of 2. Over ocean the transfer coefficient must not be decreased.

For the LandOrbit simulations, the orbital parameters should be set to

- eccentricity: 0.02
- obliquity: 23.5°

- NH spring equinox on March 21
- longitude of perihelion=270°, implying that NH solstice occurs during aphelion.

This orbit roughly corresponds to Earth's comtemporary orbit (Joussaume and Braconnot, 1997). The solar constant and greenhouse gases should be as in the other simulations.

Table 1 – List of requested simulations.

Simulation	years	specifications
AquaControl	15+30	aquaplanet control simulation (includes 15 years of spin up)
Aqua4xCO2	40	as AquaControl but with quadrupled CO_2, to be restarted from end of AquaControl (Dec 30 of year 45)
LandControl	40	as AquaControl but with idealized continent, to be restarted from end of AquaControl (Dec 30 of year 45)
Land4xCO2	40	as LandControl but with quadrupled CO_2, to be restarted from end of LandControl (Dec 30 of year 40)
LandOrbit	40	as LandControl but with changed orbital parameters, to be restarted from end of LandControl (Dec 30 of year 40)

2 Requested simulations

Table 1 lists the requested simulations. To quantify the transient response and the adjusted radiative forcing, all of the simulations except AquaControl should be restarted from another simulation as described in the table.

3 Requested Output

We request output following the standard output of CMIP5 (see `http://cmip-pcmdi.llnl.gov/cmip5/docs/standard_output.pdf`). To facilitate the analysis of the simulations, the data should be "cmorized". By cmorizing we here mean that the variables are named according to the CMIP5 names and have the same units as in CMIP5, and that 3d-data is interpolated to the 17 CMIP5 pressure levels (1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 hPa)

- Monthly-mean output: all fields of the CMOR Table Amon except fields related to carbon mass flux and mole fractions of ozone etc., saved for all years and simulations except the 15 years of initial spinup for AquaControl
- Daily output: same fields as for monthly-mean output, saved for the last 10 years of each simulation

- 3-hourly output: same fields as for monthly-mean output, saved for the last 3 years of each simulation

As for whether fields should be saved as means or snapshots, we adapt the CMIP5 conventions. For the monthly and daily output streams, all fields should be means over the output period. For the 3-hourly output stream, T (including surface and atmosphere), u, v, ω, q, z (geopotential height), should be snapshots whereas all other fields should be means.

4 Specification of the ocean q-flux

The slab ocean allows interactive sea-surface temperatures without the large computational burden from coupling to a dynamic three-dimensional ocean model. The q-flux is derived from present-day observations, with details given below. It is provided as a netcdf file that includes the q-flux for the aquaplanet simulations and a corrected q-flux for the simulations with land. The q-flux can also be implemented in the models by using the polynomial representation that is given in section 4.1. Fig. 1 shows the q-flux and the corresponding ocean heat transport, and compares the two with the present-day values. The q-flux is constant in time. For the aquaplanet simulations, the q-flux is zonally-symmetric. For the land simulations, the q-flux is zonally-symmetric over ocean regions and zero over land.

4.1 Derivation of the q-flux

For the q-flux we make use of present-day observations of the annual-mean TOA radiation budget and reanalysis estimates of the atmospheric energy transport (ATM). From the observed time-mean estimate of the total ocean heat transport,

$$q_{\text{obs}}(\lambda, \varphi) = TOA(\lambda, \varphi) - ATM(\lambda, \varphi), \tag{3}$$

we calculate the zonal-mean time-mean q-flux

$$\overline{q}_{\text{obs}}(\varphi) = \frac{1}{2\pi} \int_0^{2\pi} q_{\text{obs}} d\lambda. \tag{4}$$

For the zonal average, land points are included with their q-flux being set to zero. I.e., the zonal average is not weighted by the sea-land mask. Then, we fit $\overline{q}_{\text{obs}}$ by a hemispherically-dependent polynomial of degree four to smooth out smaller-scale wiggles in the mid- and high-latitudes. This is done to avoid that these wiggles aggravate model differences in the jet position, and to avoid an imprint on these observed wiggles on the extratropical atmospheric circulation in the idealized simulations pursued here. Specifically, the q-flux is given by

$$q(\varphi) = p_0 + p_1 \cdot \varphi + p_2 \cdot \varphi^2 + p_3 \cdot \varphi^3 + p_4 \cdot \varphi^4. \tag{5}$$

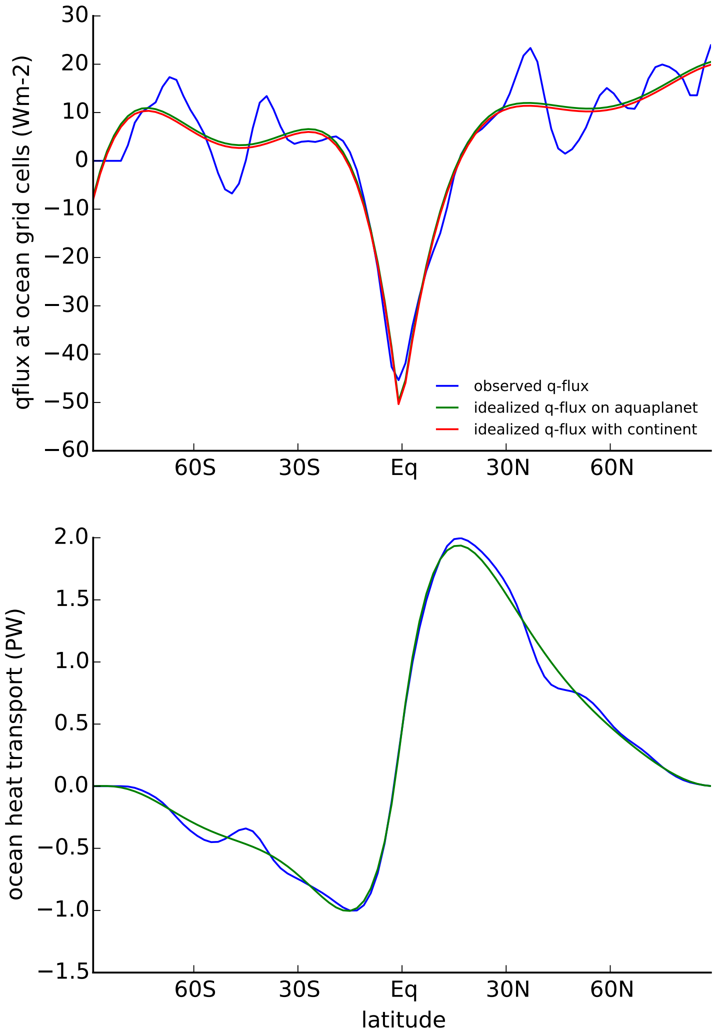

Figure 1 – Q-flux and ocean heat transport from observations (blue) and the fit used in the MIP (green). The q-flux for simulations with land is given in red; note that in the case of land the q-flux shown is not the zonal-mean q-flux but the q-flux over ocean points only.

For the aquaplanet simulations, the polynomial coefficients are in the Northern hemisphere ($\varphi > 0$)

$$\begin{aligned}
p_0^{NH} &= -50.1685 \\
p_1^{NH} &= 4.9755 \\
p_2^{NH} &= -1.4162 \cdot 10^{-1} \\
p_3^{NH} &= 1.6743 \cdot 10^{-3} \\
p_4^{NH} &= -6.8650 \cdot 10^{-6},
\end{aligned}$$

where φ has units of deg latitude. In the Southern hemisphere ($\varphi < 0$),

$$\begin{aligned}
p_0^{SH} &= -56.0193 \\
p_1^{SH} &= -6.4824 \\
p_2^{SH} &= -2.3494 \cdot 10^{-1} \\
p_3^{SH} &= -3.4685 \cdot 10^{-3} \\
p_4^{SH} &= -1.7732 \cdot 10^{-5}
\end{aligned}$$

As described above, for the land simulation the q-flux is set to zero over land. This requires a small uniform correction of -0.59 $\mathrm{Wm^{-2}}$ to guarantee that the global-mean q-flux is zero. The uniform correction is applied to all ocean points (but not to the land points) by setting $p_0^{NH} \to p_0^{NH} - 0.59$ and $p_0^{SH} \to p_0^{SH} - 0.59$.

5 ECHAM6.1 reference plots

This section provides plots for the ECHAM6.1 AquaControl and LandControl simulations as a reference for other modelling groups. This does not mean that other models must show similar or the exact same results, but the plots might provide guidance to check whether the setup was implemented correctly. We particularly encourage modelling groups to check the top-of-atmosphere solar insolation, the land surface albedo diagnosed from the surface shortwave fluxes, and the q-flux over ocean, which can be diagnosed as the sum of shortwave and longwave radiative fluxes and the latent and sensible heat fluxes.

5.1 TOA shortwave downward insolation

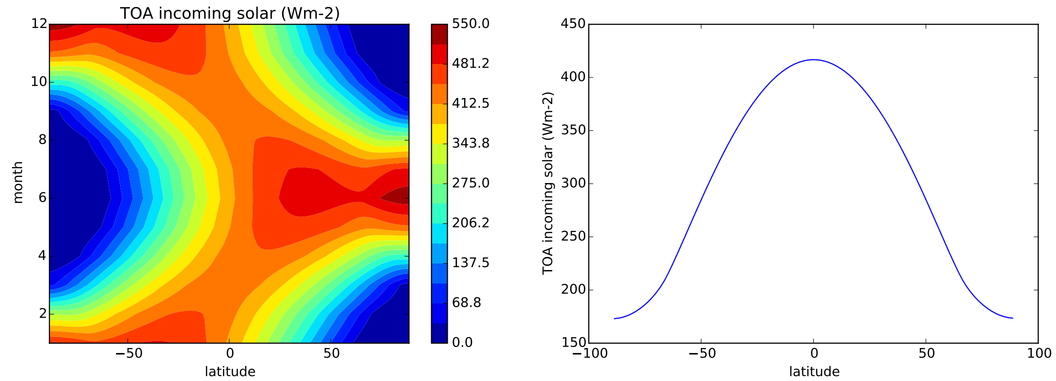

Figure 2 – Top-of-atmosphere downward shortwave irradiance.

5.2 AquaControl

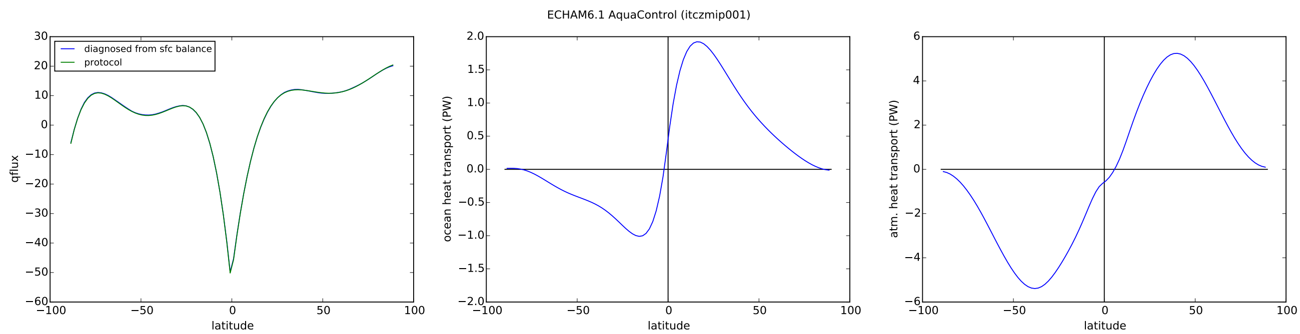

Figure 3 – ECHAM6.1 AquaControl: ocean q-flux (right) and meridional energy transport of the ocean (middle) and the atmosphere (right).

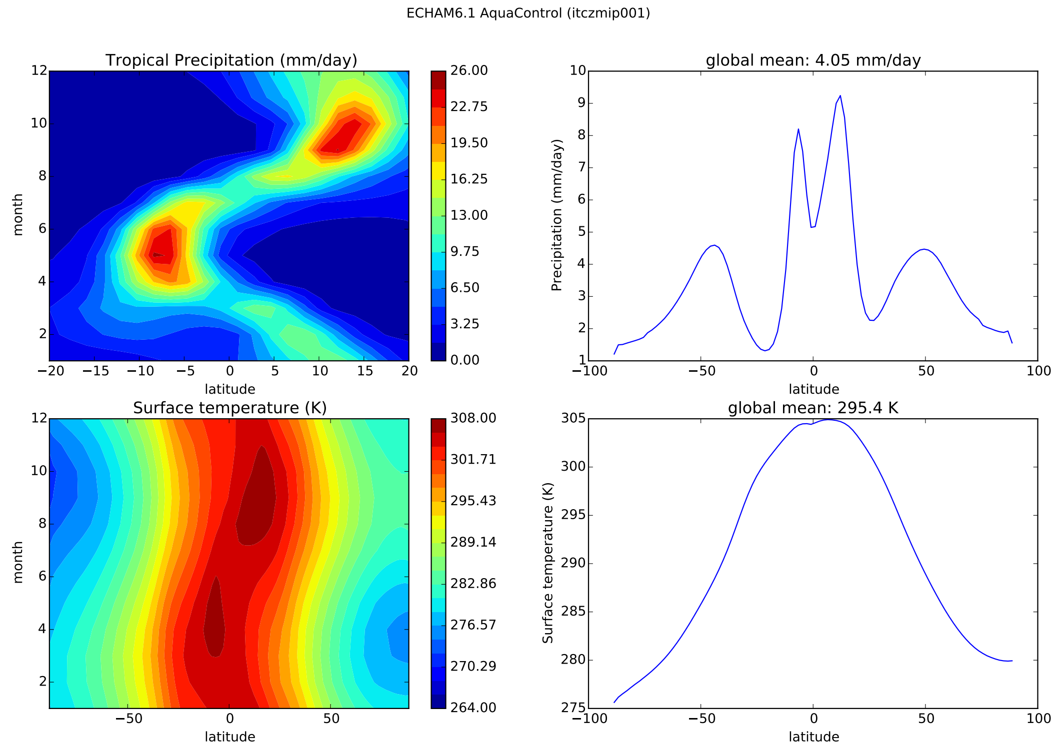

Figure 4 – ECHAM6.1 AquaControl: seasonal cycle of tropical precipitation (top left) and surface temperature (bottom left). Right: time-mean zonal-mean precipitation and surface temperature; global-mean values are given on top of the plots.

5.3 LandControl

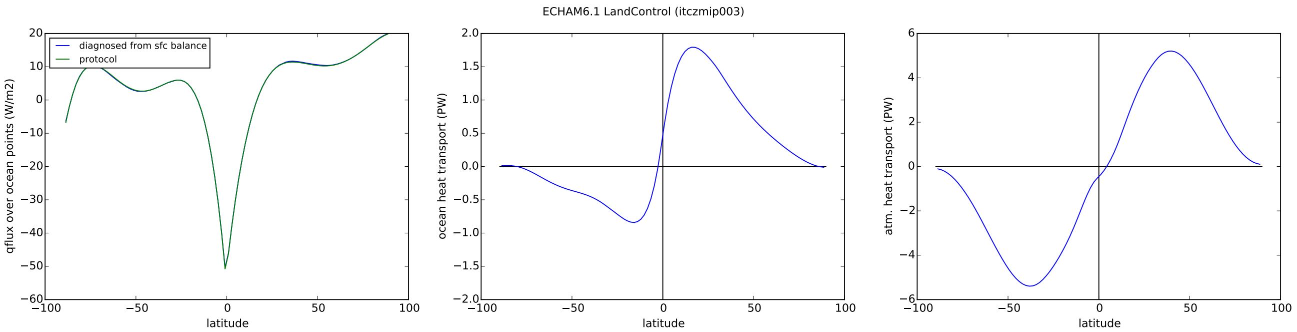

Figure 5 – ECHAM6.1 LandControl: ocean q-flux over ocean points (right), and meridional energy transport of the ocean (middle) and the atmosphere (right).

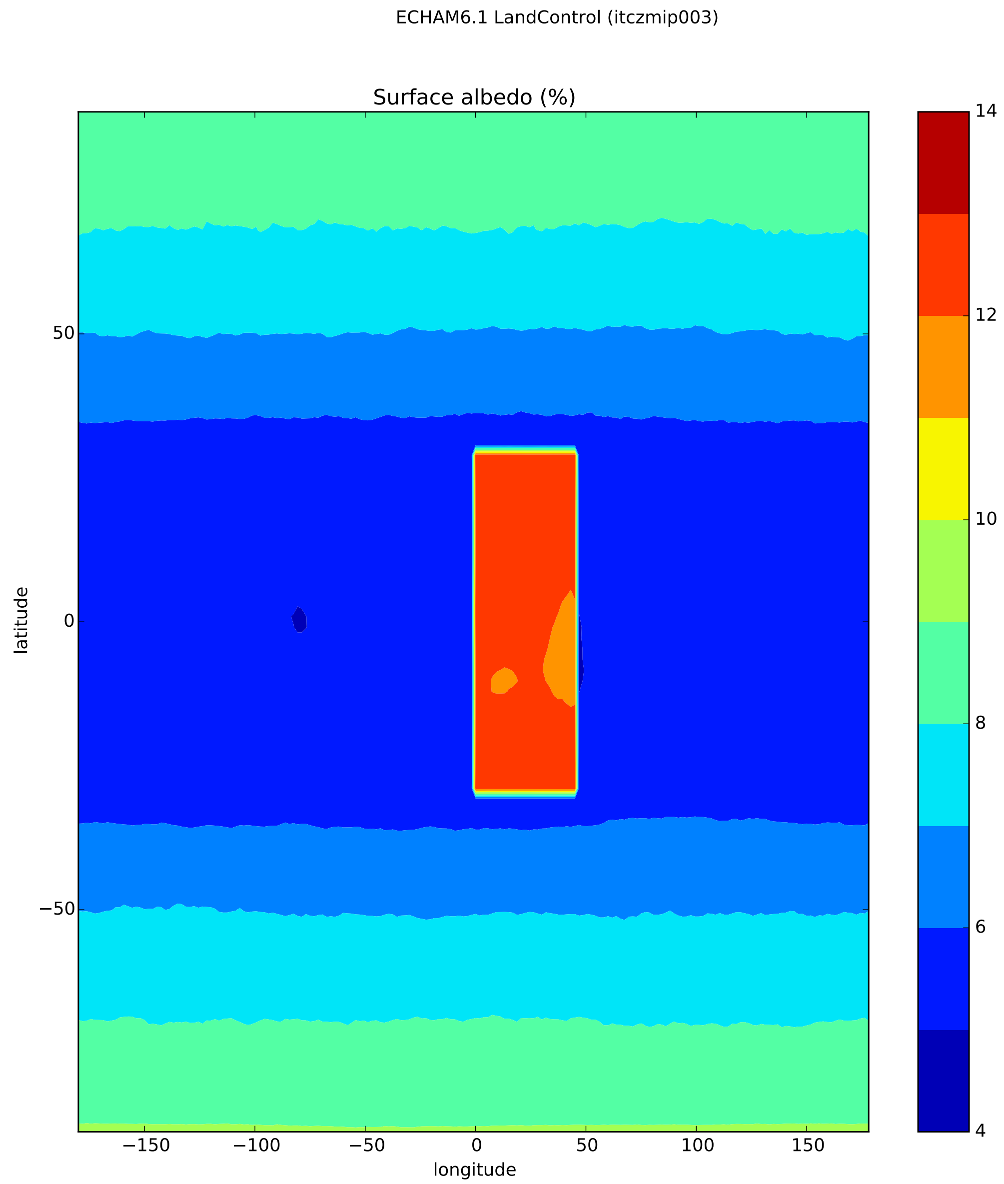

Figure 6 – ECHAM6.1 LandControl: time-mean surface albedo calculated by the surface downward and upward shortwave radiative flux.

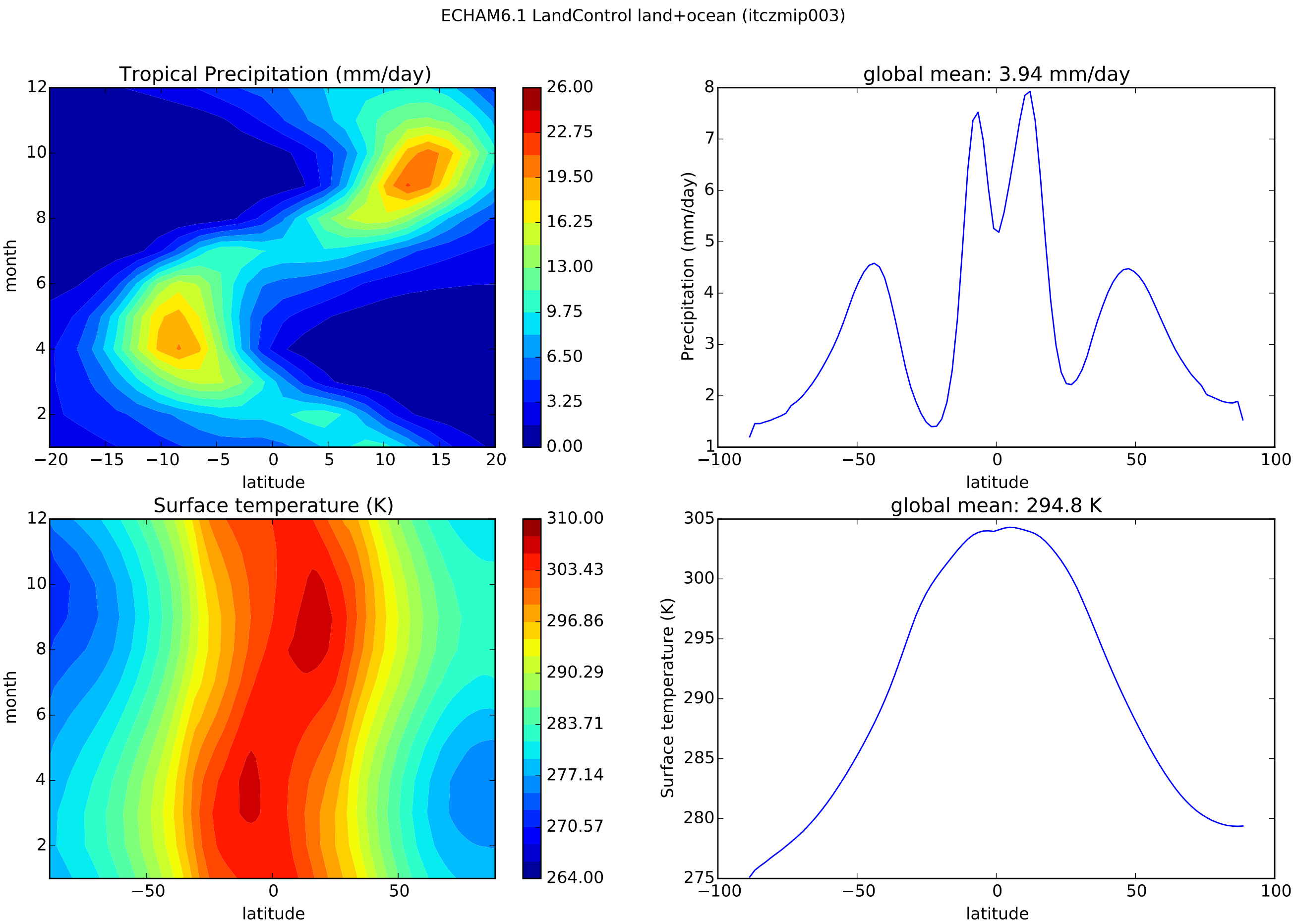

Figure 7 – ECHAM6.1 LandControl: seasonal cycle of tropical precipitation (left) and surface temperature (bottom left). Right: time-mean zonal-mean precipitation and surface temperature; global-mean values are given on top of the plots.

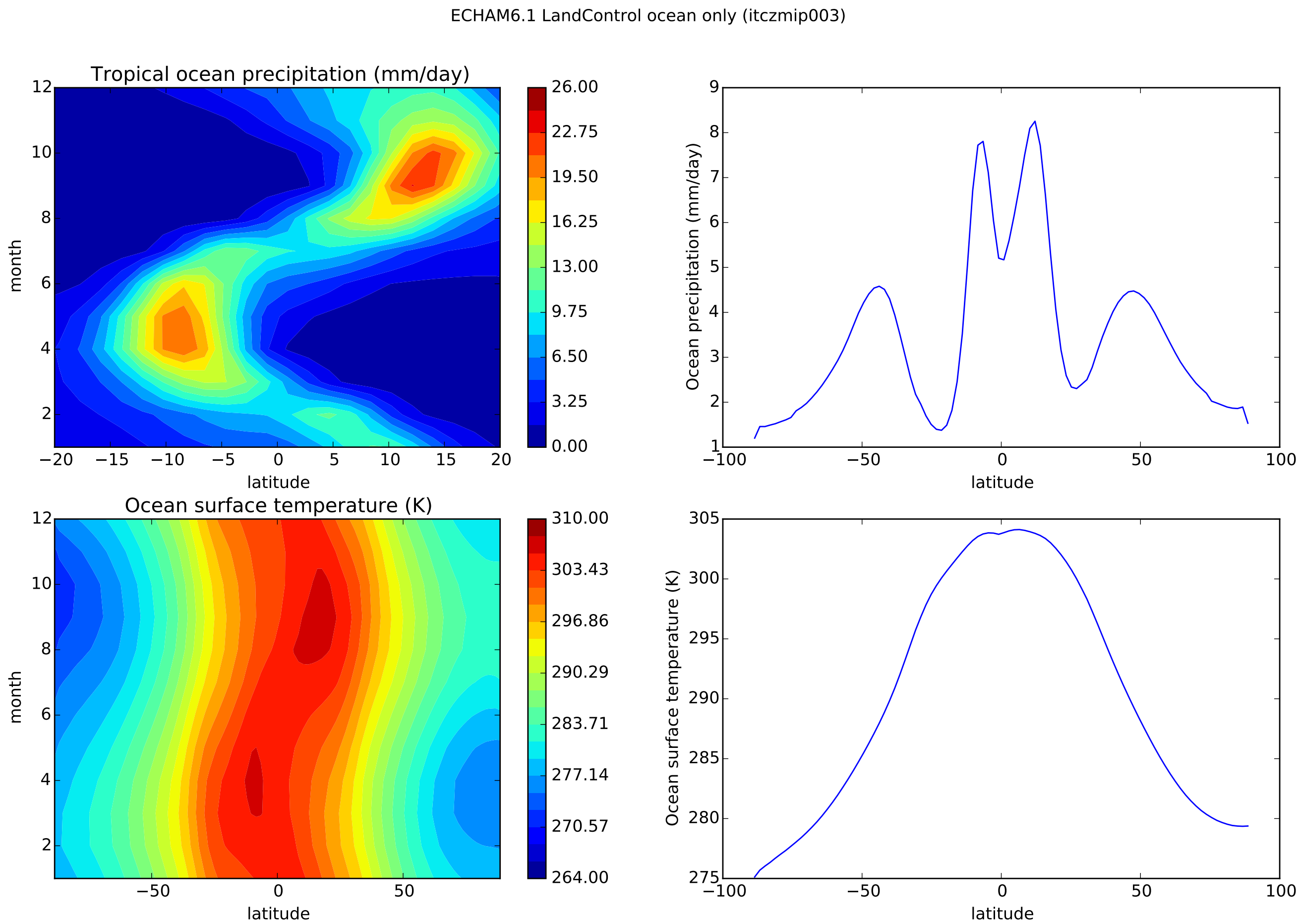

Figure 8 – ECHAM6.1 LandControl: seasonal cycle of tropical precipitation (left) and surface temperature (bottom left) only over ocean points. Right: time-mean zonal-mean precipitation and surface temperature only taking into account ocean points.

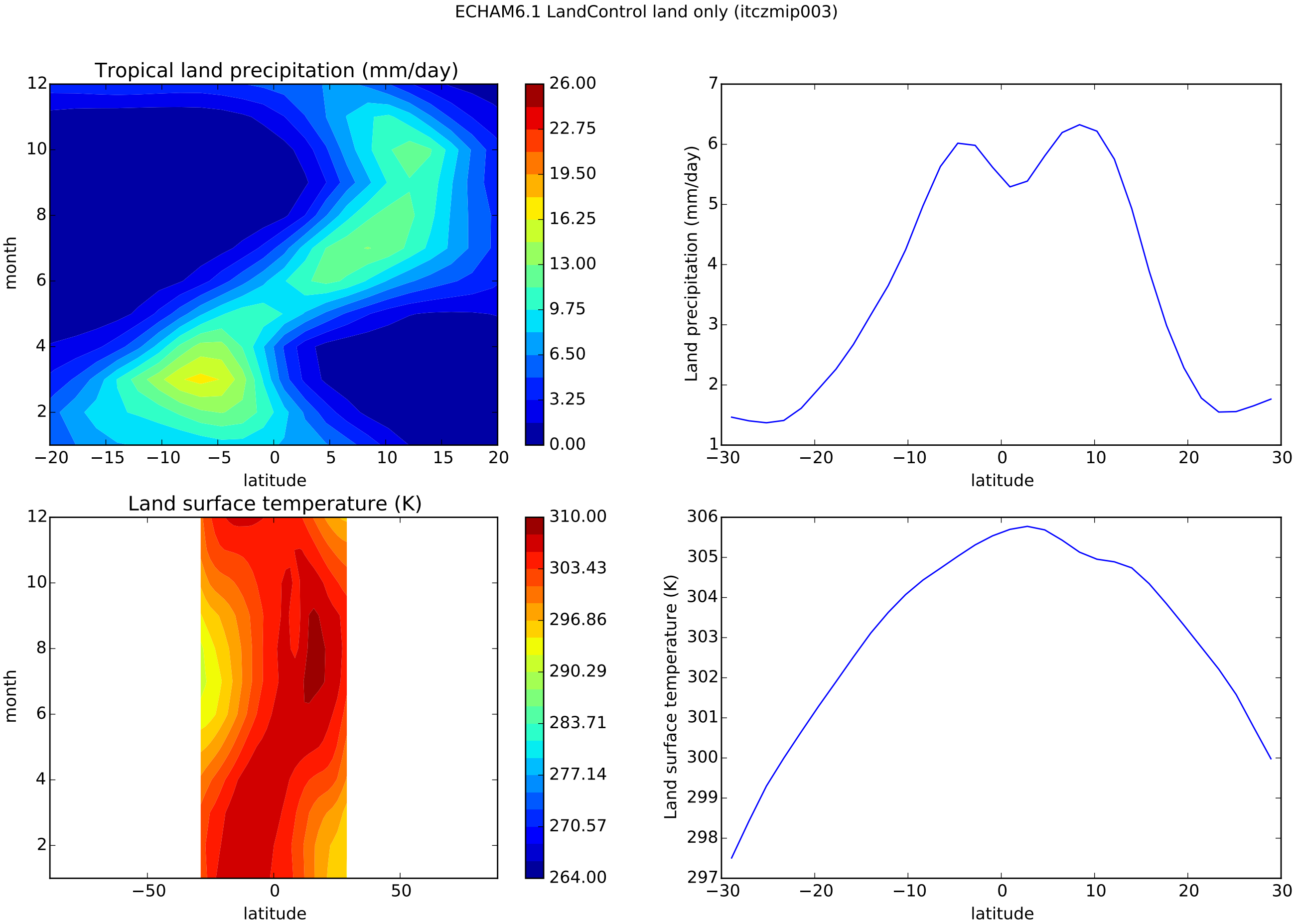

Figure 9 – ECHAM6.1 LandControl: seasonal cycle of tropical precipitation (left) and surface temperature (bottom left) only over land points. Right: time-mean zonal-mean precipitation and surface temperature only taking into account land points.

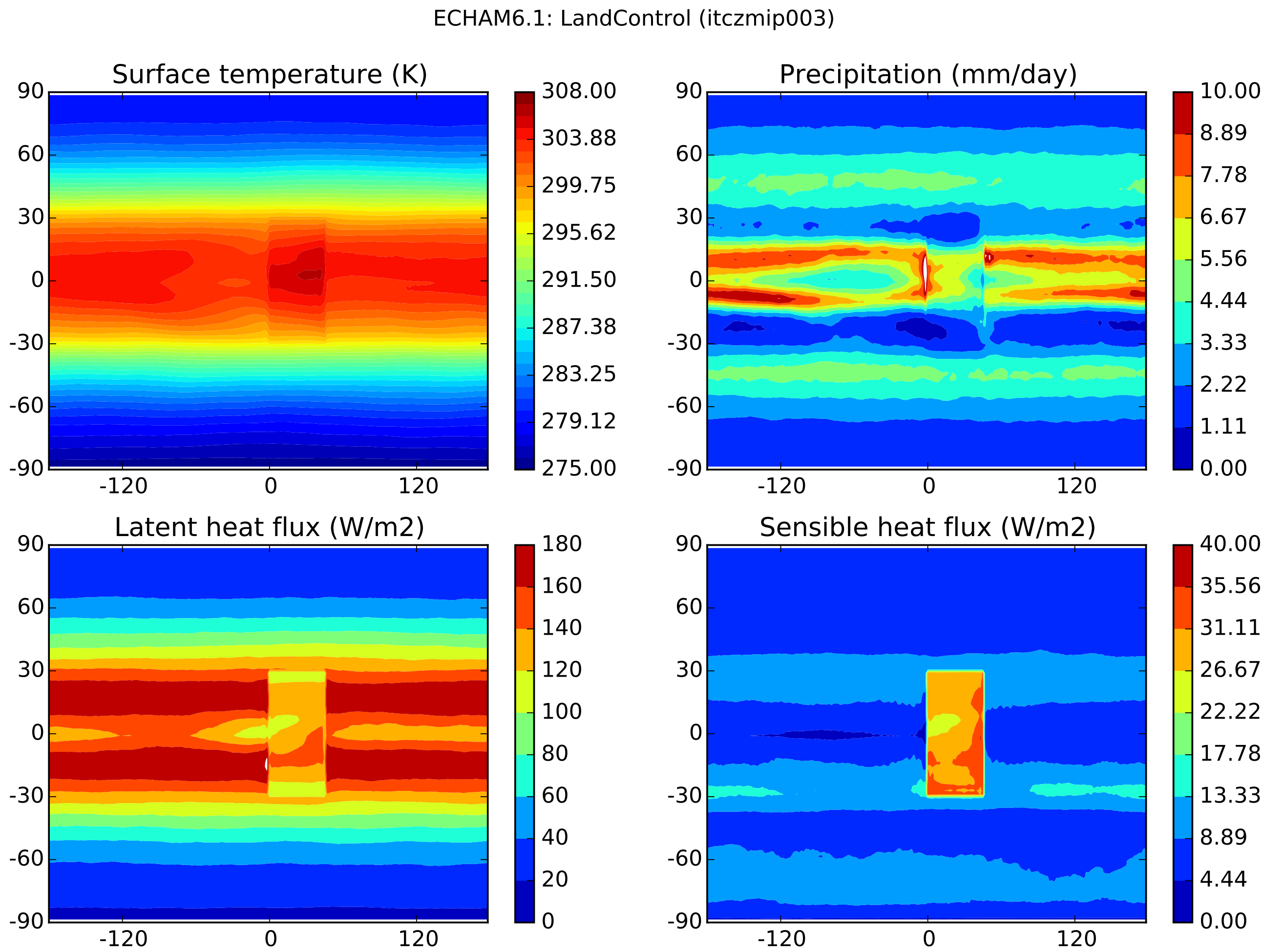

Figure 10 – ECHAM6.1 LandControl: time-mean surface temperature, precipitation and surface latent and sensible heat fluxes.

References

Joussaume, S. and P. Braconnot, 1997: Sensitivity of paleoclimate simulation results to season definitions. *Journal of Geophysical Research: Atmospheres*, **102 (D2)**, 1943–1956, doi:10.1029/96JD01989.

Kang, S. M., I. M. Held, D. M. W. Frierson, and M. Zhao, 2008: The Response of the ITCZ to Extratropical Thermal Forcing: Idealized Slab-Ocean Experiments with a GCM. *J. Climate*, **21**, 3521–3532, doi:10.1175/2007JCLI2146.1.

Voigt, A., B. Stevens, J. Bader, and T. Mauritsen, 2014: Compensation of hemispheric albedo asymmetries by shifts of the ITCZ and tropical clouds. *J. Climate*, **27**, 1029–1045, doi:10.1175/JCLI-D-13-00205.1.