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Climate of the Past Discussions

Interactive comment on "Simulated climate variability in the region of Rapa Nui during the last millennium" *by* C. Junk and M. Claussen

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The authors would like to thank the reviewer for her/his constructive suggestions and the time he/she devoted in carefully reading the manuscript. In the following, we would like to reply to her/his comments.

Reviewer 3: "However, the authors have failed to convince me that the models being used can adequately address this problem. How well does each model reproduce pre-industrial climate?"

Authors: We agree that a thorough discussion of the model's ability to reproduce climate variability is important. Therefore, we will extend our manuscript accordingly. Only very few simulations of the last millennium using comprehensive coupled climate models are available to address this topic (e.g. Ammann et al., 2007; Servonnat et al., 2010; Swingedouw et al., 2010). Therefore, the simulations with ECHAM5/MPIOM and ECHO-G are an important contribution for understanding pre-industrial climate variability in the Pacific region.

The ensemble simulations carried out with ECHAM5/MPIOM including a fully interactive carbon cycle reproduce the pre-industrial temperature variability consistent with the range of reconstructions (Jungclaus et al., 2010). Coupled climate simulations for the pre-industrial with ECHO-G are documented in Zorita et al. (2005) and Zorita et al (2004). Both studies find that broad patterns of global temperature variability are well captured by the model compared with reconstructions. Furthermore, Liu et al. (2009) analyse global monsoon precipitation during the last millennium and find that the precipitation climatology is well captured by ECHO-G compared with NCEP reanalysis.

Since both models are able to reproduce the observed climate well, we are confident that ECHAM5/MPIOM and ECHO-G are suitable tools to tackle the problem under consideration.

Reviewer 3: "Can these models be used to address ENSO changes (a prerequisite if it is to be used to test Orliac and Orliac's (1997) argument)?"

Authors: Here, we refer to existing literature about the ENSO-like behavior of the models. Min et al. (2005) analyse ENSO variability in a 1000-yr control simulation with ECHO-G. In the control simulation, the model reasonably simulates ENSO structures (like the tropical SST climate) and atmospheric responses to ENSO - Min et al. (2005) even state that ECHO-G belongs to the coupled atmosphere-ocean climate models that best reproduce atmospheric responses to ENSO. However, the ENSO-like

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variability has stronger than observed amplitudes and is too frequent and regular. Jungclaus et al. (2006) analyse the tropical variability in a 300-yr control simulation with ECHAM5/MPIOM and show that the models simulate a dominant ENSO period of 4 yrs which is more realistically simulated than in ECHO-G. The tropical sea surface temperature climatology is well simulated in ECHAM5/MPIOM. However, ENSO is still too regular in amplitude and frequency (i.e. the model underestimates the degree of nonlinearity) (Jungclaus et al., 2006). We conclude that simulations with both ECHO-G and ECHAM5/MPIOM can be used to analyse climatic variability in the southeast Pacific during the last millennium since both models exhibit an ENSO-like behavior and reproduce the SST climatology of present times well. This discussion will be added to the revised paper.

Reviewer 3: "Do the models faithfully reproduce paleoclimate conditions during 'benchmark' periods in the past (i.e. 3, 6, 9, 12, 15, or 21 ka)?"

Authors: ECHAM5/MPIOM and ECHO-G have been successfully applied to the following different paleoclimate states:

- Paleoclimate simulations with ECHAM5/MPIOM:
  - Mid-Holocene climate and transient Holocene climate simulations e.g. in Fischer and Jungclaus (2010), Otto et al. (2009), Dallmeyer et al. (2010) and Vamborg et al. (2011)
  - Last Glacial Maximum simulations e.g. in Mikolajewicz (2011) and Arpe et al. (2011)
  - Eemian climate simulations e.g. in Fischer and Jungclaus (2010) and Schurgers et al. (2006)
  - Eocene climate simulations e.g. in Heinemann et al. (2009)

- Paleoclimate simulations with HOPE-G:
  - Last Interglacial simulations in Felis et al. (2004)
  - Holocene simulations in e.g. Kim et al. (2004) and Rimbu et al. (2004)

Reviewer 3: "Can the models reproduce both atmospheric and ocean anomalies/currents/processes/etc. reasonably well for the pre-industrial, thus providing confidence in their ability to do it in the past?"

Authors: Jungclaus et al. (2006) analysed the ocean circulation and tropical variability in ECHAM5/MPIOM in a 300-yr-long control integration. They conclude that the simulation of SST and sea ice is realistic and global-scale heat and freshwater-transport are in agreement with observations. As stated above, ECHAM5/MPIOM simulations including a fully interactive carbon cycle reproduce the pre-industrial temperature variability consistent with the range of reconstructions (Jungclaus et al., 2010).

Zorita et al. (2005) and Zorita et al. (2004) find that broad patterns of global temperature variability are well captured by the model compared with reconstructions Furthermore, ECHO-G reasonably simulates ENSO structures (like the tropical SST climate), atmospheric responses to ENSO, the single ITCZ in the tropical eastern Pacific and the subsurface ocean behavior such as equatorial Kelvin and off-equatorial Rossby waves (Min et al., 2005). Min et al. (2005) also show that correlation and regression patterns for e.g. 2m-temperature and mean sea level pressure with the NAO index are successfully simulated.

Reviewer 3: "My other major concern with the model results is the ability for the model to accurately reproduce climate, in this case precipitation and temperature, for a single grid point. Again, had the authors provided the regional climatology around Easter Island it could have strengthened their argument that climate from 800-1750 AD was

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not significantly changing enough to have caused the local vegetation changes on Easter Island. Even providing information on the adjacent grid cells would have at least allowed the reader to get a sense of what was going on in the model simulations."

Authors: This comment is indeed very important and will be discussed in the revised manuscript. First, we want to refer to our response to anonymous referee #2 which we repeat here for the readers' convenience:

"Model evaluation is a challenge in this case. Firstly, we suggest to not compare simulated rainfall with rainfall measured on Easter Island as the island effect is not resolved in the coarse-scale climate model (we will point out this issue more clearly in the revised version of our paper). Hence we compare rainfall estimated by satellite climatologies with simulated rainfall in the region around Easter Island. Moreover, we will show measured and simulated precipitation pattern of the equatorial and southern Pacific (Fig. 1,2 and 3).

Fig. 1 (already in the discussion paper) shows the climatological mean (1987-2005) of the precipitation rates in the Pacific region from the HOAPS-3 climatology. For the region around Easter Island, the precipitation is approximately 2.0 mm/d. Andersson et al. (2011) compare the precipitation climatology of HOAPS-3 with other climatologies like ERA-INTERIM, GPCP V2 and TRMM 3B43. Around Easter Island, ERA-INTERIM precipitation is ∼0.12 mm/d (6%) higher compared to HOAPS-3 precipitation while TRMM 3B43 (GPCP V2) precipitation is ∼0.36 mm/d or 18% (∼0.14 mm/d or 7%) lower. Since the differences of the precipitation rates in the HOAPS-3 climatology are relatively small compared to ERA-INTERIM, GPCP V2 and TRMM 3B43, we think that the HOAPS-3 climatology is useful for the comparison with simulated rainfall. Moreover, HOAPS-3 is the only precipitation climatology which is consistently derived from the same type of satellite instrument.

Fig. 2 shows the climatological mean (1987-2005) of the precipitation rates in the

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Pacific region from the Millennium simulations with time dependent forcings with the ECHAM5/MPIOM model. The mean precipitation rates (1972-1990) from the simulations Erik1 and Erik2 with ECHO-G are shown in Fig. 3. Since the simulations Erik1 and Erik2 were not extended beyond 1990 AD, we show the climatological mean of 1972-1990 and tentatively compare it with the HOAPS-3 climatology of 1987-2005. We argue that in comparison to the HOAPS-3 climatology, both models reproduce the ITCZ well and reveal the typical pattern of the SPCZ and the eastern Pacific dry zone. However, the SPZC is more zonally orientated in the ECHAM5/MPIOM model compared to HOAPS-3 precipitation data. Therefore, ECHAM5/MPIOM tends to underestimate precipitation in the region around Easter Island while ECHO-G tends to overestimate the precipitation since the SPCZ reaches further southeastwards in this model. In ECHAM5/MPIOM, the climatological precipitation rate around Easter Island is ~1.5 mm/d which is 25% less compared to HOAPS-3 precipitation while ECHO-G simulates ~3 mm/d which is 50% higher.

The simulations with both ECHO-G and ECHAM5/MPIOM indicate a relatively constant position of the ITCZ during the Little Ice Age and the entire Millennium (not shown here). Since 500 km is just a little more than the length of one grid cell in our models, the question arises if simulations with higher resolution of the atmosphere model (which do not yet exist) would change this result."

A closer look to the adjacent grid cells of Easter Island confirms the result for the grid cell covering Easter Island: There are no significant trends in precipitation or temperature in any of these grid cells (Fig. 4, 5 and 6). Hence the results obtained for just one grid cell appear to be qualitatively robust.

Reviewer 3: "Title: Rapa Nui is chosen in the title over Easter Island. To be consistent in the body of the paper, the authors may consider using Rapa Nui over Easter Island in the text as well."

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Authors: We will take up this suggestion.

Reviewer 3: "It is stated that the horizontal resolution of the model is 3.75° x 3.75°. My read of the ECHAM5 model is that it has T63 grid spacing (1.75 x 1.75) (Roeckner et al., 2003)."

Authors: For the millennium simulations, the atmosphere model ECHAM5 is run at T31 resolution (3.75° x 3.75°) with 19 vertical levels (Jungclaus et al., 2010). For the scenario simulations for the IPCC, however, ECHAM5 was run at a finer resolution (Jungclaus et al., 2006).

Reviewer 3: "It is stated that -0.4°C is much weaker than the global cooling trend. Is the global cooling trend being referenced for the model simulations or for the proxy data? If the later, a reference is needed."

Authors: It is referenced for the model simulations Erik1 and Erik2 (Fig. 1 in Gonzalez-Rouco et al., 2006). However, the figure in Gonzalez-Rouco et al. (2006) shows the Northern Hemispheric surface air temperature cooling trend, not the global cooling trend. We will correct this in the revised paper.

Reviewer 3: "Fig 2 and 3: The x-axes need to be labeled."

Authors: We labeled the x-axes.

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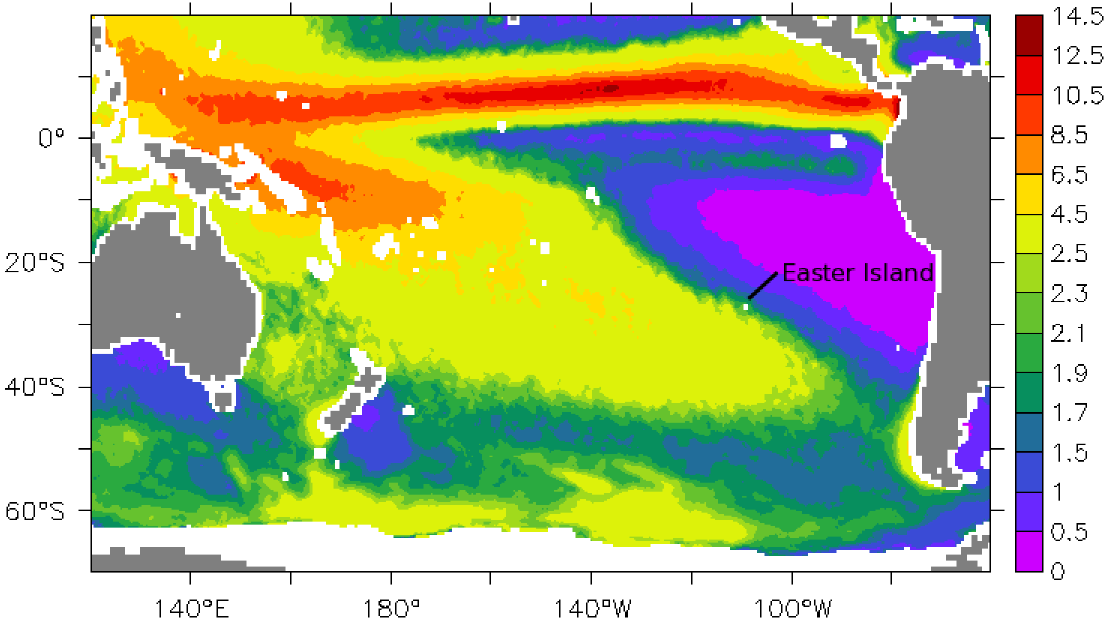

Fig. 1. Climatological mean (1987-2005) of the precipitation rates [mm/d] in the Pacific region from HOAPS-3 data.

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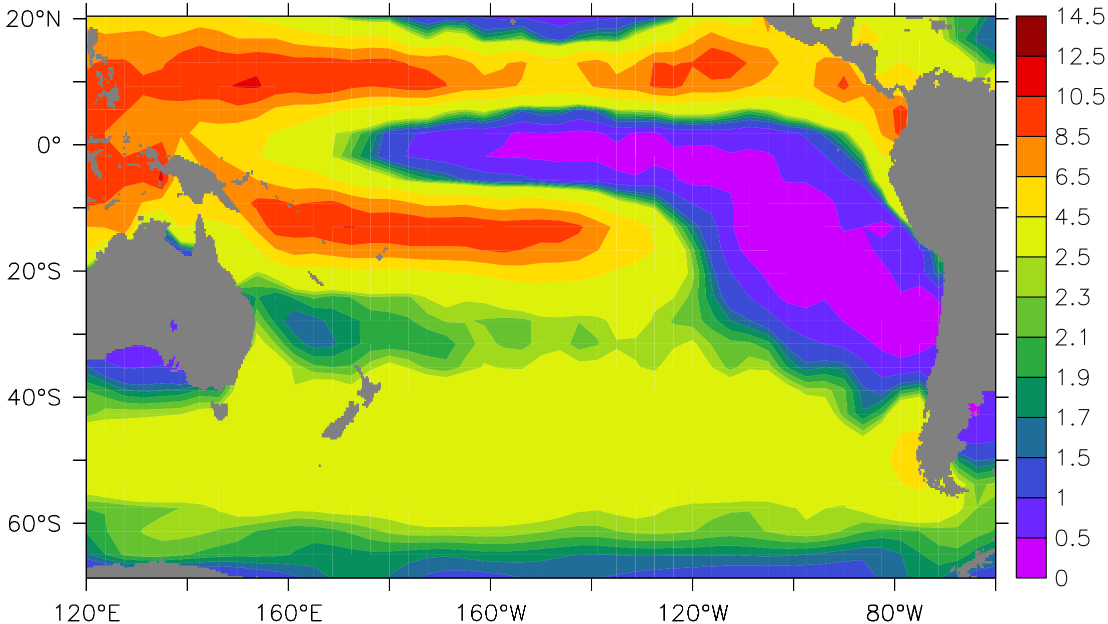

Fig. 2. Climatological mean (1987-2005) of the precipitation rates [mm/d] in the Pacific region from the Millennium simulations mil0010, mil0012 and mil0013 carried out with ECHAM5/MPIOM.

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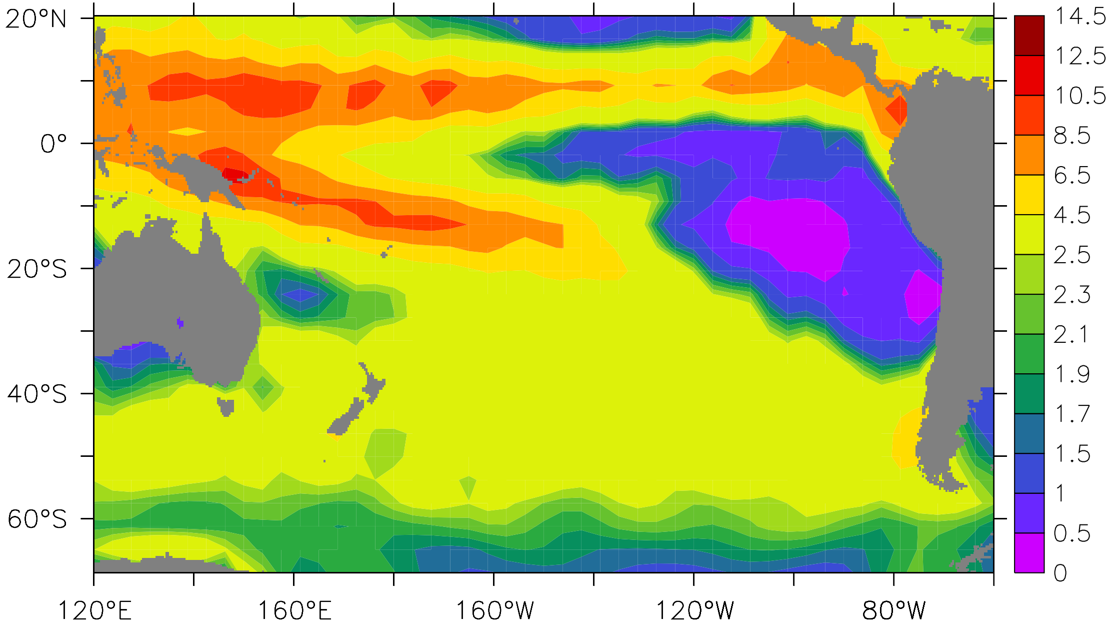

Fig. 3. Climatological mean (1972-1990) of the precipitation rates [mm/d] in the Pacific region from the simulations Erik1 and Erik2 with ECHO-G.

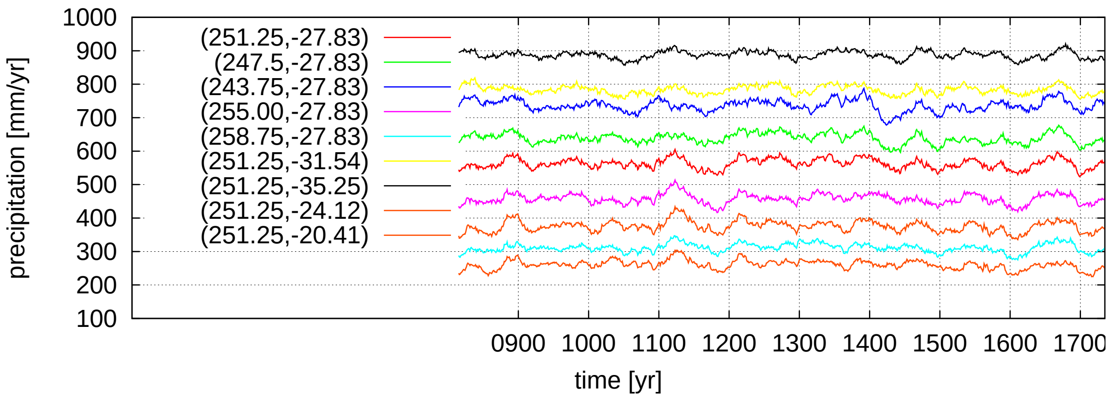

Fig. 4. 30-year running mean of precipitation (800-1750 AD) for the grid points around and the grid point covering Easter Island (centered at 251.25,-27.83) for the Millennium simulations (ensemble mean).

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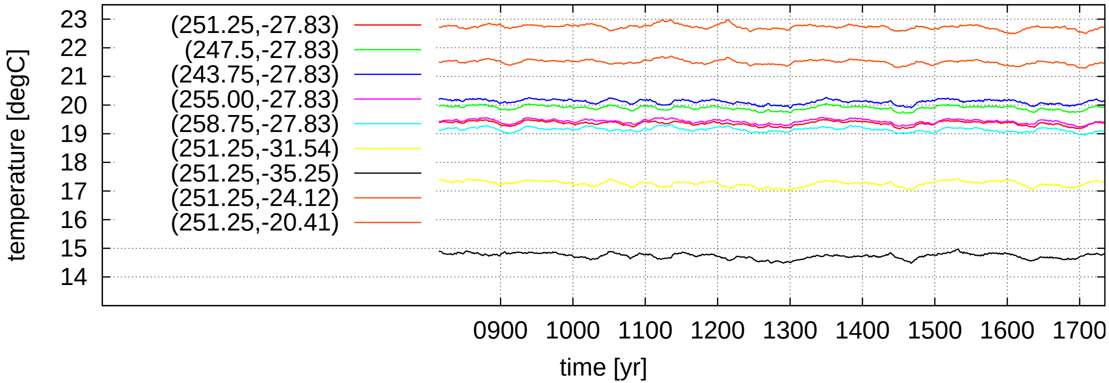

Fig. 5. 30-year running mean of 2m-temperature (800-1750 AD) for the grid points around and the grid point covering Easter Island (centered at 251.25,-27.83) for the Millennium simulations (ensemble mean).

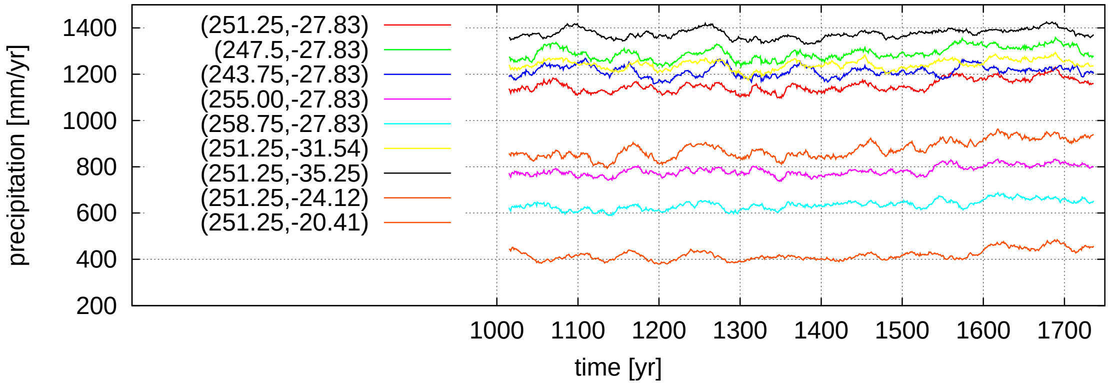

Fig. 6. 30-year running mean of 2m-temperature (1000-1750 AD) for the grid points around and the grid point covering Easter Island (centered at 251.25,-27.83) for the ECHO-G simulations (ensemble mean).

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