Response to Review of "Description and basic evaluation of BNU-ESM version 1" *by* D. Ji et al.

We first thank the reviewer for his/her insightful comments, which helped us clarify and greatly improve the paper. Comments from the reviewer are in black, and our responses are in blue.

General comments:

This study documents BNU-ESM's setups and performance. As the authors mentioned, BNU-ESM has participated in CMIP5 and its results have been analyzed in many studies. A thorough documentation like this study would be beneficial and relevant to the climate science community and GMD's readers. I recommend its publication after some revisions.

Along the line of publishing a through documentation for the scientists that analyze CMIP5 data and the model developers in other centers, I have a few suggestions that hopefully would further improve the manuscripts:

Specific comments:

1. Before evaluating BNU-ESM's internal variability, a systematic analysis of mean state would be helpful. In the current manuscript, only surface temperature and precipitation over the ocean are shown. In order for the readers to compare BNU-ESM's performance with those in other models, more fields are required. A good reference for thorough evaluation would be Chapter 9 in the IPCC report (Flato et al. 2013), which includes annual mean surface air temperature, precipitation (over land and ocean), shortwave and longwave cloud radiative forcing, and the seasonality of surface air temperature. Trenberth and Fasullo (2010) also show some great figures that demonstrate models biases in terms of annual mean and seasonality.

Agree and thanks for this suggestion. We response these comments in three sections:

(1) On mean state, we've done further analysis on zonal mean temperature, specific humidity, zonal wind from BNU-ESM and deviations from that of the ERA-Interim reanalysis, and global distribution of cloud fraction compared to

observational ISCCP D2 products. Please refer to our response to referee#1 minor comment 3. We've also performed a systematic analysis with Taylor diagrams for selected 24 fields by comparing to ERA-Interim and JRA-55 reanalysis products and various observations. Please refer to our response to referee#2 specific comment 2.

(2) Annual mean surface air temperature, precipitation and their biases in Fig.3, Fig.4 are improved to include biases over land, statistical significance tests and climatological annual mean of observations according to referee#1 minor comment 2, referee#2 minor comment 8 & 9. The following are improved figures:

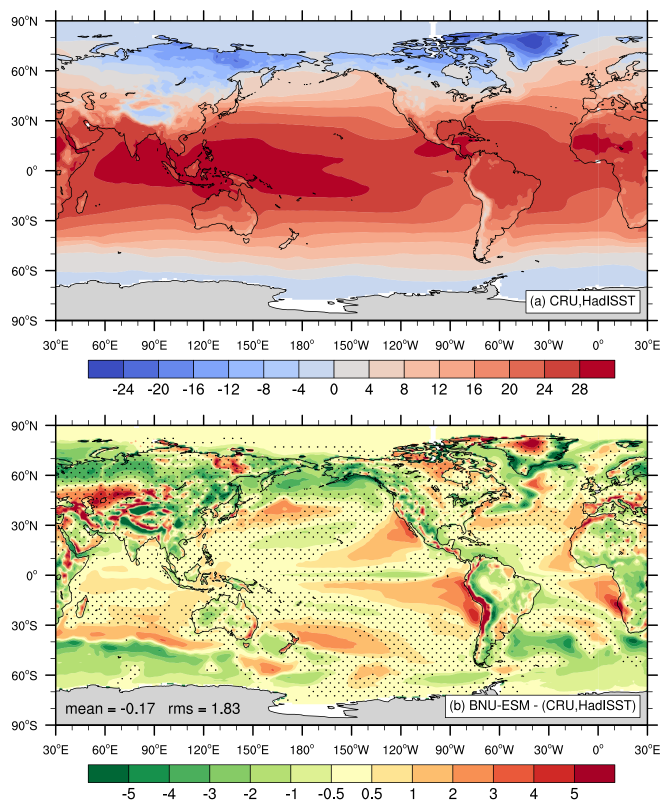

Figure 3. Climatological mean surface temperature from the 0.5°×0.5° CRU TS 3.1 (Harris et al., 2013) and 1°×1° HadISST (Rayner et al., 2003) observations (a) for the period 1976-2005. Annual mean surface temperature bias (°C) of BNU-ESM relative to the CRU TS 3.1 and HadISST data sets for the period 1976-2005 (b). All data sets are regridded to 1°×1° resolution. Dotted area indicates non-significant regions at the 95% confidence level.

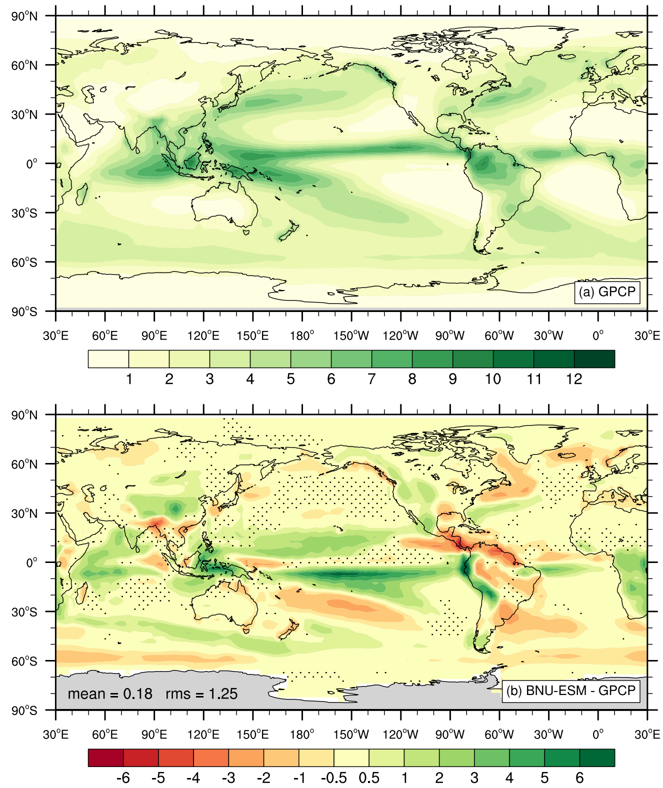

Figure 4. Climatological mean precipitation from the GPCP observations (a) and annual mean precipitation bias (mm/day) of BNU-ESM relative to the GPCP climatology for the period 1979-2005 (b). Dotted area indicates non-significant regions at the 95% confidence level.

(3) On shortwave and longwave cloud radiative forcing (SWCF and LWCF), we will add the following paragraph in the final revised paper:

Clouds have a significant impact on the global radiative balance that is often accessed using TOA shortwave cloud forcing (SWCF) and longwave cloud forcing (LWCF) (Ramanathan et al., 1989). In BNU-ESM, the simulated shortwave cooling effect of clouds is too strong in the tropics and too weak in the mid-latitudes (Fig. R1), especially over oceans, these biases are common in climate models (Trenberth and Fasullo, 2010). BNU-ESM also overestimates LWCF in the tropics due to the presence of a double ITCZ, and it largely offsets the bias of SWCF in the tropics. In AMIP simulation with sea surface temperature and sea ice boundary conditions specified, the SWCF biases in BNU-ESM (not shown) resemble that in CAM4, except for Eurasian continent (Kay et al., 2012).

Over Eurasia, BNU-ESM simulates moderate shortwave cooling effects, while CAM4 simulates opposite warming effects. In South Africa and Amazon regions, both models exhibit strong shortwave cloud cooling effects.

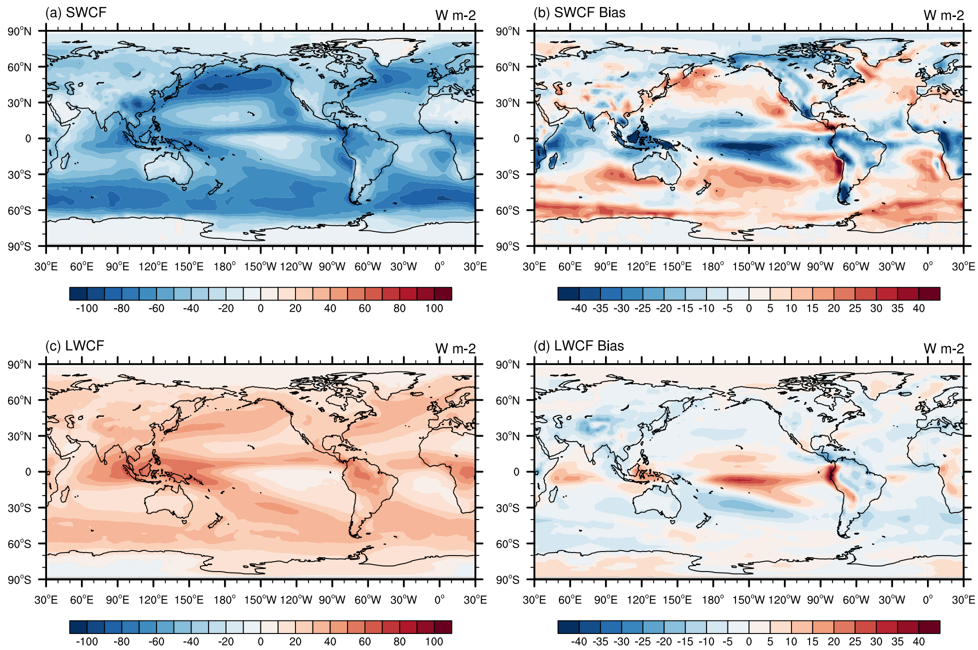

Figure R1. Global map of shortwave cloud forcing (SWCF) and longwave cloud forcing (LWCF): (a) observed CERES-EBAF, (b) BNU-ESM SWCF bias relative to CERES-EBAF, (c) observed CERES-EBAF, (d) BNU-ESM LWCF bias relative to CERES-EBAF.

2. Following the previous comment, comparing with figures in Flato et al. 2013, there are some biases in BNU-ESM that are commonly shared in many other CMIP5 models, whereas some biases seems to be unique in BNU-ESM. The authors have identified some of these in the text; however, it would be worth elaborating more. A few features that catch my eyes:

(1) Most models have SST over Southern Ocean being higher than those in observations. However, BNU-ESM has cold biases in the region. The authors have mentioned two possible reasons: ACC strength and clouds. It would be helpful to show shortwave cloud radiative forcing biases. A band of excessive precipitation over Southern Ocean (and east of South America) seems to be related with this cold bias, whereas other models have deficient precipitation in the region.

Agree. BNU-ESM model actually produces less cloud fraction over Southern Ocean (see Figure R2 below). We were wrong on concluding clouds are one possible reason for cold SST biases, and will delete the relevant sentence (Page 1613, line2) in the final revised paper. Figure R1 in the third point of our response to specific comment 1 indicates the shortwave cloud radiation effect has a small positive bias in the cold band between 40° S and 50° S and is consistent with less total cloud fraction here. So we argue that the ocean dynamics is the main factor of the cold SST biases over Southern Ocean. In dissection of the surface temperature biases in the CESM, Park et al. (2013) also indicated oceanic dynamics is overall the most important factor in determining regional sea surface temperature bias.

The band of excessive precipitation over the Southern Ocean between the southernmost of Southern Africa (about at 35° S, 30° E) to southwest of Australian is more consistent with the spatial pattern of warm SST biases and is along the northern flank of a cold SST bias, which probably produces more convective precipitation.

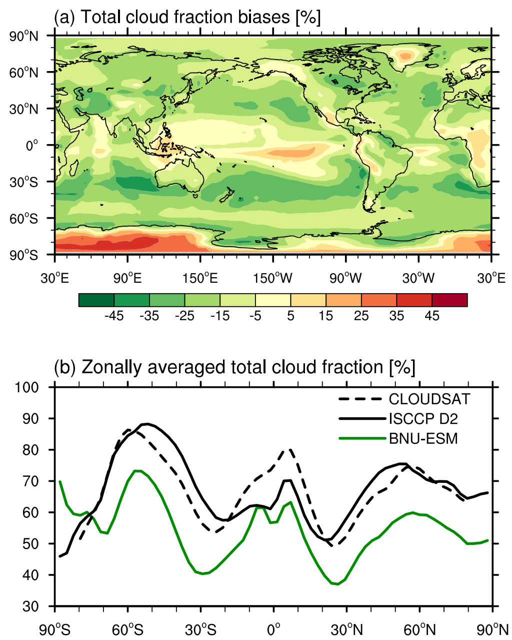

Figure R2. (a) Total cloud fraction bias relative to ISCCP D2 retrievals (Rossow and Schiffer, 1999; Rossow and Dueñas, 2004). (b) Zonally averaged total cloud fraction compared to ISCCP D2 retrievals and CLOUDSAT retrievals (L'Ecuyer et al., 2008.)

(2) There are a few different aspects of the double ITCZ problem, and the current

manuscript doesn't articulate this clearly. Some models simulate too much precipitation off equator (in both NH and SH) and too little precipitation at the EQ, but BNU-ESM only shows significant excessive precipitation at around 5N. The SPCZ being to equaterward and too horizontal is another aspect of the double ITCZ problem, which appears in BNU-ESM and many other models. It would be helpful to articulate these similarities and differences comparing with other models, as the descriptions for AMOC in line 1~5 on page 1616. (A few references for the double ITCZ problem: Li and Xie 2014, Hwang and Frierson 2013, Lin 2007)

Agree and thanks for this suggestion. The description of the double ITCZ problem being rewritten as following:

"In common with many climate models (e.g. Li and Xie, 2014, Lin, 2007), we note a bias in precipitation, characterized by a double Intertropical Convergence Zone (ITCZ) structure over much of the Tropics. This produces excess precipitation over the Northern Hemisphere's ITCZ, Southern Hemisphere's South Pacific convergence zone (SPCZ), the Maritime Continent and the tropical Indian Ocean, together with insufficient precipitation over the equatorial Pacific. BNU-ESM displays the characteristic pattern of the double ITCZ problem with too much precipitation in the central Pacific near 5°S and too little precipitation in the west and central Pacific between 15°S and 30°S which is similar to CCSM4 (Gent et al., 2011). BNU-ESM underestimates precipitation at 5°N latitude but overestimates it along the 5°S parallel in the tropical Atlantic. Compared with observations, the BNU-ESM develops too weak a latitudinal asymmetry in tropical precipitation and SST over the eastern Pacific and Atlantic Oceans."

3. If the authors see fit, some comparisons (in terms of mean state) with CAM that have similar schemes as in BNU-ESM would be interesting for readers, as those in line 25 p. 1617. For example, how do changes in convection schemes affect clouds, precipitation, or SST?

Thanks for this suggestion. A comprehensive comparison between the atmospheric component of BNU-ESM and CAM is beyond the scope of this paper, although the main difference is in convection schemes. We prefer to summarize this study in another future manuscript with dedicated experiments. And in this study, we present intensity distribution of precipitation from BNU-ESM *historical* simulation as following:

Figure R3 shows frequency versus daily precipitation rate over land in the tropics between 20°N and 20°S, and compared with the observational estimates from the GPCP data set and the TRMM satellite. It is clear that BNU-ESM produces a realistic number of precipitation events at a wide range of precipitation rates, although the model has a tendency to underestimate extreme precipitation events (over 50 mm day^{-1}). We note that CCSM4 also produces similar precipitation characteristics at 1° and 2° resolutions (Gent et al., 2011).

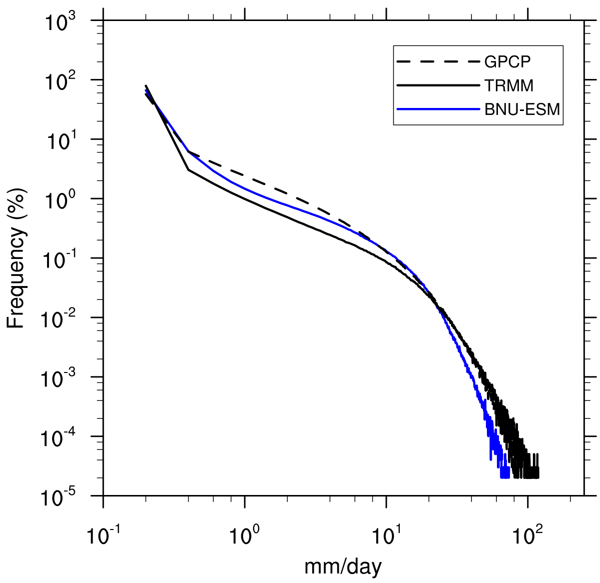

Figure R3. Frequency (%) of daily precipitation rate over land between 20°N and 20°S from BNU-ESM *historical* simulation over the period 1990-1999, the GPCP 1 degree day and TRMM 3B42 daily observations over the period 1999-2008. All data are regridded to the T42 spectral resolution (approximately 2.81°×2.81° transform grid).

4. Again, if the authors see fit, an analysis of monsoon would be very relevant. Base on Figure 1 & 2, the model seems to simulate monsoon pretty well. A monsoon index diagnostic (as in Flato et al. 2013, which follows kim et al. 2011) together with a 2-D map of temperature seasonality might be relevant to the paper, but this is a whole new set of analysis and I leave decision of including it or not to the authors.

Thanks for this suggestion. We prefer to summarize this work in future.

5. p.1611, line 13, There “is” no land cover change ....

Agree and done.

“Note that there no land cover change related to (anthropogenic) land use…”

Revised to:

“Note that there is no land cover change related to (anthropogenic) land use…”

6. Figure 3 & 4, it might be worth showing values over land for readers that are interested.

Agree and done. Please refer to Fig.3 & 4 in above response to comment 1.

7. In the sea ice section, similar to the major suggestion 2.2 above, it would be worth comparing Figure 6 with Figure 9.22 and 9.23 in Flato et al. 2013, especially that BNU- ESM has an ice scheme that’s slightly different from CAM4.

Agree and thanks. We will include the following text in the final revised paper:

In terms of seasonal cycle of sea ice extent, the simulated Arctic sea ice extent for the period 1980-1999 is within the range of 42 CMIP5 models reported by Flato et al. (2013). In Antarctica, BNU-ESM estimates reasonable sea ice extents for February, but overestimates them in September (26 million km^2) which is somewhat above the range of 42 CMIP5 models. BNU-ESM and CCSM/CESM adopt similar sea ice schemes, and both models can simulate both the September Arctic sea ice extent and the rate of Arctic sea ice decline over recent decades better than many other CMIP5 models (Liu et al., 2013). While for Antarctica BNU-ESM and CCSM both have a tendency to overestimate sea ice extent.

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