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Interactive comment on "Improving subtropical boundary layer cloudiness in the 2011 NCEP GFS" *by* J. K. Fletcher et al.

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The authors thank Reviewer 1 for helpful comments and questions

The authors write in the abstract that model has bias in clouds, but it is not obvious whether the model overestimates or underestimates low clouds. As Figs 6 and 7 show, low clouds are underestimated just off the coasts but overestimated in the open ocean. 'Biased' does not sound an appropriate word to summarise these errors. The model rather fails to reproduce low cloud fraction contrast between off the coast and the open ocean.

Figures 6 and 7 show that the model has a negative bias in low clouds everywhere in the Pacific except the tropical/subtropical southeastern Pacific. We very much agree

that the model fails to represent the coastal/open ocean contrast in cloud cover in the southeast Pacific, and we discuss it in detail in section 6.2.

We also address the positive cloud bias in the SE Pacific in this sentence from the introduction: "On the other hand, one of the few regions in which cloud cover and radiative effects were overestimated in GFS is in the stratocumulus to cumulus transition regions, especially the East Pacific between the equator and 30° S." In light of this comment, we have added the following to this sentence: "[T]he model fails to accurately represent the coastal/open ocean contrast in cloud cover in addition to a globally averaged low bias"

However, given that the bias in the rest of the Pacific is one of lack of clouds, and given the high positive bias in global mean shortwave cloud focing, we do think that "bias" is still an appropriate word to summarise the errors in clouds in a global (or hemispheric) sense.

Global model sensitivity tests Figs.6&7 Explanation is needed how clouds and cloud radiative effects for 1948/long term mean (1948-1998) can be evaluated using 2006-2010 data.

We have added the following to section 6.2: While it would be ideal to compare model simulations to observations over the same time period, we found it technically much simpler to initialise the short GFS runs with the same initial conditions as the 50-year run rather than with initial conditions from the satellite era. Long-term trends and decadal variability in global mean downwelling surface radiation are on the order of +0.25 W/m2 and +/- 3-5 W/m2, respectively (Hinkelman et al, 2009), one to two orders of magnitude smaller than the GFS shortwave bias. Additionally, the decade 2000-2010 was one of weak ENSO variability (http://www.esrl.noaa.gov/psd/enso/mei/). This gives us confidence that the difference in decades for which we compare means will not substantially affect our results.

Definition of cloud fraction from satellite data is different from model's cloud fraction. Is the model cloud fraction from Cloudsat/CALIPSO fraction from COSP?

Unfortunately, COSP has not been implemented into the GFS. As mentioned in Section 6.2, we attempt to minimise error associated with low cloud under middle and high clouds in satellite observations by using the maximum low cloud fraction from GEOPROF and GOCCP. We also note that GOCCP has been developed specifically for use in comparing to climate models.

L3 There is no sensitivity test focused on the efficiency of conversion of updraught condensate in a grid layer to precipitation and detrains it to grid scale condensate. Why NewEntr has to be with efficiency of conversion to precipitation?

I'm afraid I'm not sure what this question is asking. As we discuss in section 5.2.2, we did perform single parameter change experiments in the single column model, but we found – as expected – that the parameters are tuned to cancel each others' errors:

"Our initial sensitivity tests only involved single parameter changes. This quickly uncovered compensating errors – multiple parameters incorrectly tuned such that their effects cancel each other – in the shallow cumulus scheme. For example, only increasing the updraught lateral entrainment rate resulted in a simulation with an improved mass flux profile but far too small updraught condensate amount, while only decreasing the precipitation and detrainment conversion rates reduced excess precipitation but produced too much condensate. Furthermore, only reducing one of c0 or c1 simply shifts precipitation between the shallow convection and stratiform microphysics schemes, with little reduction in overall precipitation. It is necessary to change all of these parameters together in order to address these compensating errors, so we only show results from simulations in which multiple parameters were changed."

For the sake of simplicity in presentation, we do not show these results but simply report on them.

L5, What does '. . .cloud water and cloud fraction from both the stratiform microphysics

scheme and the radiation scheme' mean? Does the model cloud fraction from two schemes?

Yes, this is discussed in section 4.2, page 10, lines 4-16.

L14, Why cloud fraction needs to be defined in two schemes? How cloud fraction in the microphysics scheme and that of the radiation scheme are defined and used?

This is discussed in section 4.2, page 10, lines 4-16. We have added the following to this section to further clarify:

The cloud fraction used in the Sundqvist scheme affects the model indirectly through the autoconversion and large-scale condensation rates. To maintain consistency with the rest of the scheme the Sundqvist formulation must be used. However, the Xu and Randall scheme matches observations better in general and is preferable for the radiation scheme.

L23 What does 'convection is oftentimes only one or two grid levels deep' mean?

We mean that the vertical extent of the shallow convection is only one or two grid levels above cloud base. We've replaced "only one or two grid levels deep" with "extends only one or two grid levels above cloud base" to make this more clear.

L20 If background diffusivity same as the operational GFS is used, does the single model results show the same biases that the global coupled model shows in the Northeast Pacific?

We found that cloud cover was still quite high in the single column model with the old background diffusivity.

L25 Please explain why the oscillations happens with shallow convection scheme is active.

The following sentence has been added to section 5.3.2, p 17, line 26: These oscillations result from convective precipitation stabilising the subcloud layer and reducing convective mass flux, and hence detrained convective condensate, in the subsequent time step.

L6 Please clarify which parameter changes are included in Shortrun1 and Shortrun2.

All parameter changes in the global model experiments are given in Table 2; however, this contained a typo that we thank you very much for catching.

L28 What does 'This method enhances the cloud fraction.' mean?

It means that, in regions where GEOPROF would tend to under-estimate the low cloud fraction, we use the GOCCP data. This results in greater cloud fraction in those regions.

L4 The sentence needs clearer explanation. The authors write that reduced cloud radiative forcing biases in the deep convective region help weaken the Walker circulation. -The authors do not show longwave cloud radiative effect. Errors in clouds in the deep convective region often are related to deep convective clouds and reduction of the error in deep convective clouds reduces error in cloud radiative effect not only in shortwave but also in longwave. How errors in longwave cloud radiative effect contribute to the deep convective region and the South East coast in these runs? -If the basin-wide Hadley-Walker circulation pattern is sensitive to changes in marine low clouds, isn't is more appropriate to say that improvement to the boundary layer clouds drive weakening of the Walker circulation and reducing errors in cloud radiative effects?

Your point is well-taken, and we have re-written this section:

"It is unlikely that changes in cloud radiative forcing directly caused the SST changes in deep convective regions, where the substantial change in shortwave cloud forcing was largely offset by a change in longwave cloud forcing (not shown). However, reductions in excess cloud cover in the offshore southeast Pacific may contribute to the increase in SST in that region and subsequent reduction in zonal SST gradient associated with a weakening of the Walker circulation. This can also be seen in the change in SST

off the Peruvian and Chilean coasts, where positive SST biases worsen despite an increase in cloud cover. This is likely due to a weakening in coastal upwelling. We found found that changes in wind stress also suggest a weakening of this circulation, with a decrease in surface easterlies in the central and west Pacific and a reduction of northerlies in the southeast Pacific (not shown). Such sensitivity of the basin-wide Hadley-Walker circulation pattern to changes in marine low clouds associated with parameter changes in shallow convection and moist turbulence parametrisation is also found in other GCMs (e.g., Ma et al 1994, Xiao et al 2014)."

L5 Please describe how the horizontal wind changes in the new version.

please see above

Technical Corrections Table 2. As for Shortrun2, doesn't DYCOMS study suggest PBL Bckgrnd Diff 0.3, rather than 1.0?

Yes, this was a typo in the manuscript; the background diffusion in Shortrun2 was reduced from 0.3 to 0.1 as in the DYCOMS case (not 1.0). Thanks very much for catching it!

Interactive comment on Geosci. Model Dev. Discuss., 7, 2249, 2014.