Observational and Model Estimates of Cloud Amount Feedback over the Indian and Pacific Oceans

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Background

- Cloud Feedback is the largest uncertainty in estimates of climate sensitivity

- The uncertainty is largest for low-level clouds and for SW cloud feedback (cloud amount)

- Lack of long-term observational constraints on the sign and magnitude of cloud feedback
Cloud Observations

**Ship observations**

EECRA, derived from ICOADS*
1954-2008

*Hahn and Warren 2009, Eastman et al. 2011

**Pros:** Long-term (55 years), better at observing low/total cloud cover

**Cons:** Sparse, subjective, only cloud amount and cloud type

**Satellites**

ISCCP and PATMOS-X (AVHRR)*
1984-2009

*corrected, Norris and Evan 2015

**Pros:** Objective, known biases, information on vertical properties

**Cons:** Short-term (30 years), problems at identifying low clouds
Total Cloud Amount change 1954-2005

Computed as linear trend multiplied by # of years (52 years)

- 4 regions where the obs trend is statistically significant
- Overall pattern similar to the multi-model (forced) mean
Comparing with Satellite Obs

Blue: EECRA (ships)
Red: ISCCP
Green: Patmos-X (AVHRR)

<table>
<thead>
<tr>
<th>Correlation coefficient</th>
<th>EECRA-ISCCP</th>
<th>EECRA-PATMOSX</th>
<th>ISCCP-PATMOSX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Indian</td>
<td>0.24</td>
<td>0.20</td>
<td>0.64</td>
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<tr>
<td>Western Pacific</td>
<td>0.81</td>
<td>0.78</td>
<td>0.79</td>
</tr>
<tr>
<td>Northeast Pacific</td>
<td>0.83</td>
<td>0.77</td>
<td>0.82</td>
</tr>
<tr>
<td>Central Pacific</td>
<td>0.75</td>
<td>0.78</td>
<td>0.86</td>
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</tbody>
</table>
Estimate of Cloud Amount Feedback

\[ \text{CAF} = \frac{k \Delta c}{\Delta T_s}. \]

Where:

- \( c \) = Total Cloud Amount
- \( T_s \) = Surface Temperature
- \( k \) = Cloud Amount Radiative Kernel

\[ k = \frac{\text{CRE}}{\overline{c}}, \]
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\[ k = \frac{\text{CRE}}{\overline{c}}, \]

- Only the cloud amount part of the total cloud feedback
- Does not include the effect of changes in vertical and optical properties of the clouds
Cloud Amount Radiative Kernel

\[ k = \frac{\overline{\text{CRE}}}{\overline{c}}, \]

Cloud Radiative Effect = net SW+LW all-clear sky at TOA

Negative = cooling
Positive = warming

(a) Cloud amount radiative kernel (EECRA)

(b) Cloud amount radiative kernel (CMIP5)

EECRA (ship) observations

CMIP5 historical multi-model mean
(42 models run with prescribed time varying historical forcings)

Positive = warming
Negative = cooling

\[ \text{W/m}^2/\% \]

-0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1
that models simulate too few and too bright clouds (Nam et al. 2012), so that the numerator of the cloud amount radiative kernel (i.e., CRE) is too large (negative) while the denominator (i.e., cloud amount) is too small, making the cloud amount radiative kernel larger and more negative in models than in observations. The largest discrepancies between the multimodel mean and observational estimates occur over the central and western tropical Pacific and southern Indian Ocean, where clouds in observations have a smaller cooling effect than in models (Fig. 3).

We note that the observational estimate shown in Fig. 3a is sensitive to cloud climatology. For instance, if we use ISCCP or PATMOS-X instead of EECRA, the cloud amount radiative kernel looks slightly different, although we still get less negative values than the multimodel mean, especially in the western Pacific. These slight differences do not influence our conclusions because we use cloud amount radiative kernel not to evaluate model performance, but rather to weigh the radiative impact of cloud cover changes in relation to the mean cloud cover. For example, if in a particular location of the world cloud cover is larger in ISCCP (e.g., 80%) than in EECRA (e.g., 60%) for the same value of CRE, then a 5% change in cloud cover will have relatively larger impact on cloud amount feedback computed from EECRA than from ISCCP, because the fraction of cloud change to mean cloud cover is larger in EECRA (5%/60%) than ISCCP (5%/80%). The same applies to intermodel differences, although models simulate different cloud climatology due to different model parameterizations rather than different retrieval methods.

After obtaining the cloud amount radiative kernel, we compute model and observational estimates of cloud amount feedback, which are shown in Fig. 4. Figure 4 is calculated multiplying long-term trends in cloud cover by cloud amount radiative kernel, and then dividing by tropical mean SST change. Model estimates of cloud amount feedback are computed for each model, and then the multimodel mean is obtained by averaging all model estimates. Contours in Fig. 4 represent total cloud cover climatology, while stippling indicates where the changes are statistically significant. Observational cloud amount feedback is statistically significant where cloud trends shown in Fig. 1a are, that is, over the northeast Pacific and western Pacific where cloud amount feedback is positive, and central Pacific and western Indian Ocean where cloud amount feedback is negative. Model cloud amount feedback is only significant over the southeast Pacific where there is intermodel agreement in cloud trends. The multimodel mean cloud amount feedback (Fig. 4b) is less than half the observational values (Fig. 4a); nevertheless, the sign of the feedback is consistent with observations over most of the Indian and Pacific Oceans.

Cloud amount feedback [Eq. (5)] can be split into contributions from $1/D T_s$, $D C$, and $k$. To roughly estimate which of these terms contributes the most to weaker model cloud amount feedback, we compute the fractional change in cloud amount feedback (CAF) in the four boxed regions of Fig. 4. The fractional change...
5. Discussion

amount feedback (Figs. 5 and 6).

spread in the simulation of cloud cover changes and cloud

than the uncertainty that arises from the large intermodel

vations (Marchand et al. 2010) seems to be much smaller

definitions of total cloud fraction in models and obser-

cover over the western Pacific and increase over the

the present) computed from ICOADS (Deser et al. 2010)
similar to century time scale cloud cover changes (1900 to

change pattern in the western Pacific was consistent with

TABLE 4. Legend of model numbers for Figs. 5 and 6.

1. ACCESS1-0 15. GFDL-CM3 29. MIROC-ESM-CHEM
2. ACCESS1-3 16. GFDL-ESM2G 30. MIROC-ESM
3. BNU-ESM 17. GFDL-ESM2M 31. MIROC4h
4. CCSM4 18. GISS-E2-H-CC 32. MIROC5
5. CESM1-BGC 19. GISS-E2-H 33. MPI-ESM-LR
6. CESM1-CAM5 20. GISS-E2-R-CC 34. MPI-ESM-MR
7. CESM1-FASTCHEM 21. GISS-E2-R 35. MPI-ESM-P
8. CESM1-WACC 22. HadCM3 36. MRI-CGCM3
9. CNRM-CM5–2 23. HadGEM2-AO 37. MRI-ESM1
10. CNRM-CM5 24. HadGEM2-CC 38. NorESM1-ME
11. CSIRO-MK3-6-0 25. HadGEM2-ES 39. NorESM1-M
13. FGOALS-g2 27. IPSL-CM5A-MR 41. BCC-CSM1-1
14. FIO-ESM 28. IPSL-CM5B-LR 42. INM-CM4
feedback are consistent with some of the mechanisms contribute as well to enhance this minimum warming.

Cloud amount feedback in the southeast Pacific could arise from a strengthening of the trade winds (Falvey and Garreaud 2009). Our results suggest that negative cloud fraction decreases during the transition resulting in positive cloud amount feedback.

In the northeast Pacific and other subtropical stratocumulus regions, studies have shown a decrease in cloud amount and the resulting positive cloud amount feedback. The decrease in cloud amount and the resulting positive cloud amount feedback have been studied extensively, with a focus on the role of low-level clouds in the tropics.

The only region where there is intermodel agreement is the western Indian and (b) western Pacific, while Fig. 6 shows the individual model estimates according to the legend in Table 3, which shows that the largest contribution to weaker differences between models and observations. The fractional difference between the computed multimodel mean and the LHS of this equation to be equal to the differences between observed and multimodel mean values. We estimate the radiative effect of clouds (Fig. 3). We do not expect the LHS of this equation to be equal to the differences between observed and multimodel mean values. We estimate the radiative effect of clouds (Fig. 3). We do not expect the LHS of this equation to be equal to the differences between observed and multimodel mean values. We estimate the radiative effect of clouds (Fig. 3). We do not expect the LHS of this equation to be equal to the differences between observed and multimodel mean values.

We computed similar bar charts for changes in cloud type. In the central Pacific (Fig. 6b), 25 models (71%) agree in sign with observations, 8 fall within the error range, and 2 exceed the upper extent of the error range. In the western Pacific (Fig. 5b), 24 models (57%) agree in sign with observations, 57% agree in sign with observations, 8 fall within the error range, and 2 exceed the upper extent of the error range. The region of exceedence with observations, 3 fall within the error range, and 1 exceeds the upper extent of the error range. In the eastern Pacific (Fig. 5a), 23 models (38%) agree in sign with observations, 8 fall within the error range, and 2 exceed the upper extent of the error range. Therefore, some models are able to simulate similar magnitude cloud amount feedback as observed, whereas this is not the case for all models. It is also noteworthy that the observations agree with observations, 3 fall within the error range, and 1 exceeds the upper extent of the error range. In the western Indian (Fig. 5a), 22 models (10%) agree in sign with observations, 8 fall within the error range, and 2 exceed the upper extent of the error range. The only region where there is intermodel agreement is the western Indian and (b) western Pacific, while Fig. 6 shows the individual model estimates according to the legend in Table 3, which shows that the largest contribution to weaker differences between models and observations. The fractional difference between the computed multimodel mean and the LHS of this equation to be equal to the differences between observed and multimodel mean values. We estimate the radiative effect of clouds (Fig. 3). We do not expect the LHS of this equation to be equal to the differences between observed and multimodel mean values. We estimate the radiative effect of clouds (Fig. 3). We do not expect the LHS of this equation to be equal to the differences between observed and multimodel mean values. We estimate the radiative effect of clouds (Fig. 3). We do not expect the LHS of this equation to be equal to the differences between observed and multimodel mean values. We estimate the radiative effect of clouds (Fig. 3). We do not expect the LHS of this equation to be equal to the differences between observed and multimodel mean values. We estimate the radiative effect of clouds (Fig. 3). We do not expect the LHS of this equation to be equal to the differences between observed and multimodel mean values.

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Summary

- The biggest uncertainty in estimates of climate sensitivity is due to the sign and magnitude of cloud feedback, especially in regions of low-level clouds.

- Constraining the sign and magnitude of cloud feedback is difficult because observations are limited and affected by biases.

- Here we examined ship-based observations, which are longer, covering about 55 years.

- Observed trends in cloud cover are significant over 4 regions: NE Pacific, Central Pacific, Western Pacific, Western Indian.

- We estimated cloud amount feedback from observations and compared with historical simulations. Some models get the sign and magnitude right, but there is not any one model that gets it right over all 4 regions.
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Thank you
