# The Highs and Lows of Cloud Radiative Feedback

## Comparing Observational Data and CMIP5 Models


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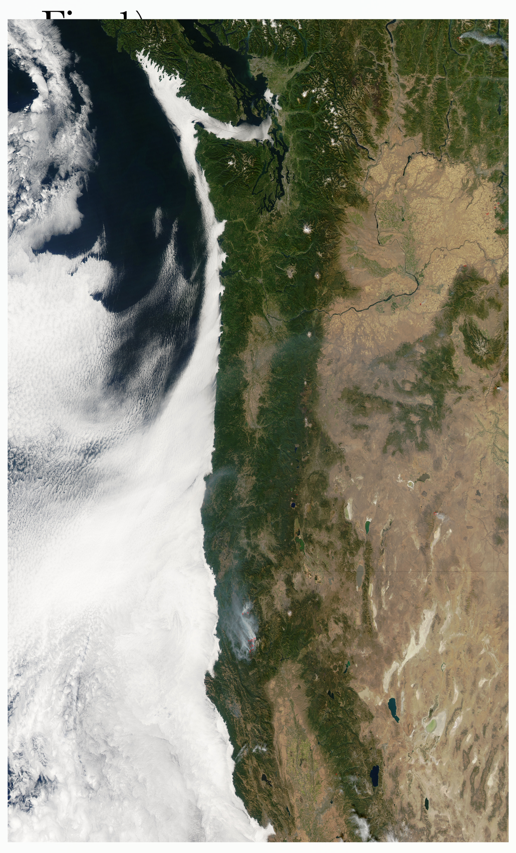
## Introduction

Clouds play a complex role in the climate system, and remain one of the more difficult aspects of the future climate to predict. In the tropical oceans over the West Pacific, high convective anvil tops emit radiation back to space at particularly low temperatures. Hartmann and Larson (2002) postulate that in the presence of warming surface temperatures, these cloud tops will remain at a fixed temperature (Fixed Anvil Temperature, FAT, hypothesis). Such a hypothesis has significant implications for cloud feedbacks and climate modeling. On the other side of the ocean, over the eastern ocean basins next to California, Peru, and SW Africa, low marine stratocumulus clouds (MSC) help to reduce the amount of solar radiation that reaches the surface. The climate feedback associated with both cloud types is thought to be positive (see Fig. 1).



Left: Marine stratocumulus clouds off the Oregon coast. *NASA image courtesy the MODIS Rapid Response Team at NASA GSFC.*
Right: Cumulonimbus clouds form an anvil top. *Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center. ISS016-E-27426*

## Radiative Impacts of High and Low clouds

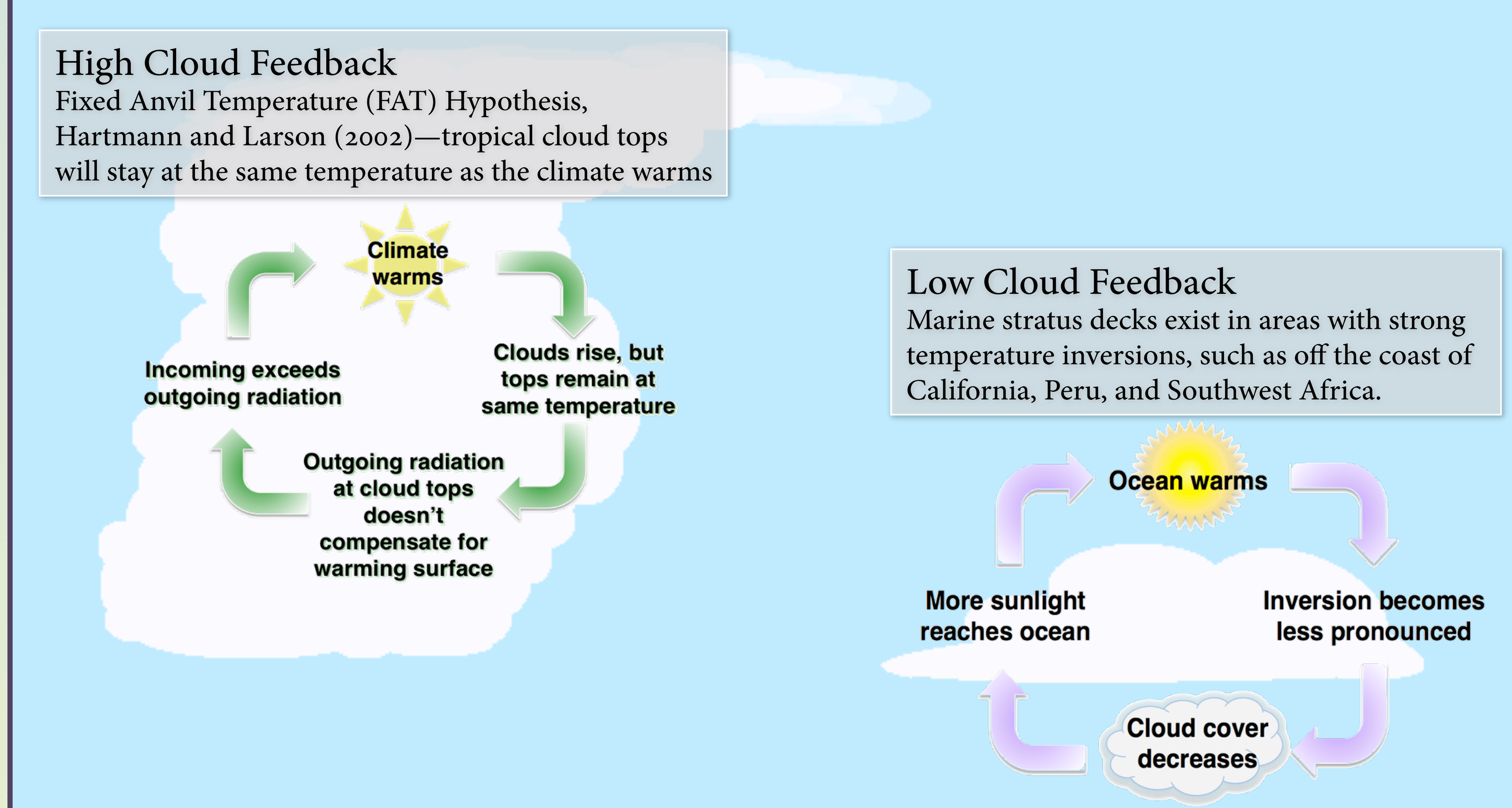



*Figure 1. Schematic of the climate feedbacks associated with high and low clouds.*

## Key Questions

*High clouds:*

- Can we find observational evidence for the FAT hypothesis?

*Low clouds:*

- Using the relationship between lower tropospheric stability (LTS) and shortwave cloud forcing (SWCF) in the present climate, can the model-predicted climate change of one variable explain the change in the other?
- Using LTS and SWCF as measures, do the models predict a +/- cloud-climate feedback?
- Do the models agree?

## Methods

Data used:

- Observations: CERES EBAF-TOA and ERA-Interim monthly means
- CMIP5 Models: HADGEM2-AO, CCSM4, and CanESM2 monthly means, rcp8.5
  Models were selected based on findings by Lin et al. (2014)

*Low clouds*

LTS = $\theta_{700mb} - \theta_{surface}$ (Klein and Hartmann 1993)

SWCF = TOA clear-sky outgoing SW radiation − TOA all-sky outgoing SW radiation

## Low Clouds

### Shortwave Cloud Forcing and Lower Tropospheric Stability

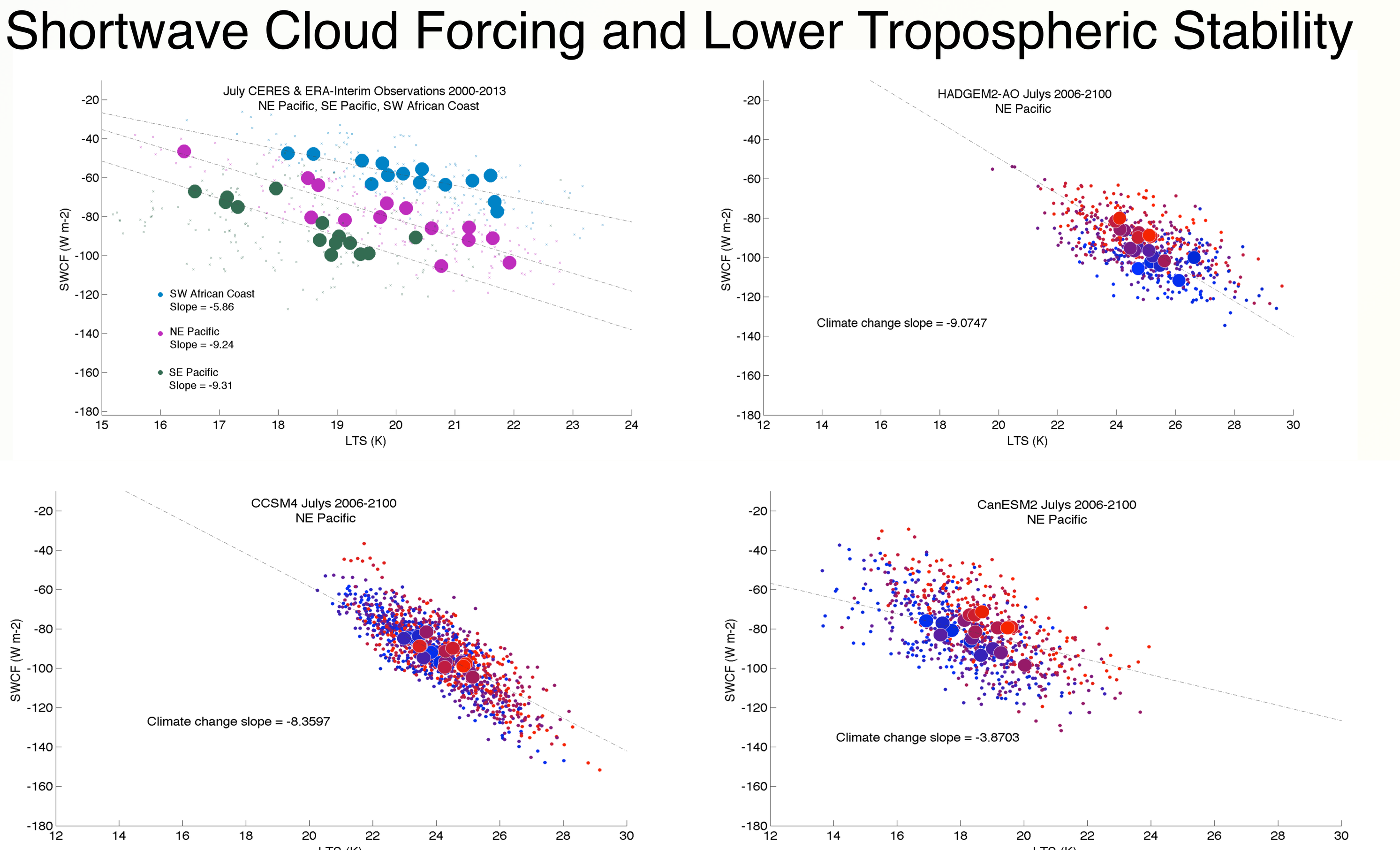



Figure 2. SWCF vs LTS over the NE Pacific shown for observations (top left), HADGEM2-AO (top right), CCSM4 (bottom left), and CanESM2 (bottom right). Large dots represent 5 year averages (1 year averages for observations, top left). "Slope" is the relationship between SWCF and LTS, in $Wm^{-2} K^{-1}$. For the model plots, blue represents the beginning of the run and fades into red, which represents the end.

The Hadley Center model (HADGEM2-AO) predicts a shift toward less stability and less clouds, while CCSM4 suggests a shift towards the opposite direction. These plots were repeated for the two other regions of MSC, the SE Pacific and SW African Coast. Only two of the nine model plots (six not shown) suggest a positive low cloud feedback (shift from more stable, more negative SWCF towards less stable, less negative SWCF).


Figure 3. SWCF(orange) and LTS(purple) vs time over the NE Pacific shown for observations (top left), HADGEM2-AO (top right), CCSM4 (bottom left), and CanESM2 (bottom right). The dark line follows five year averages (1 year averages for observations, top left). Thin, pale lines represent individual points within the region.

In all plots, including those made for the SE Pacific and SW African Coast (not shown here), values of LTS and SWCF for individual points fluctuate together, LTS more so than SWCF. This suggests SWCF, and thus clouds, depend on more variables than LTS alone. Also, for the this region, the Hadley Center model and CCSM4 seem to overestimate LTS slightly.

## High Clouds

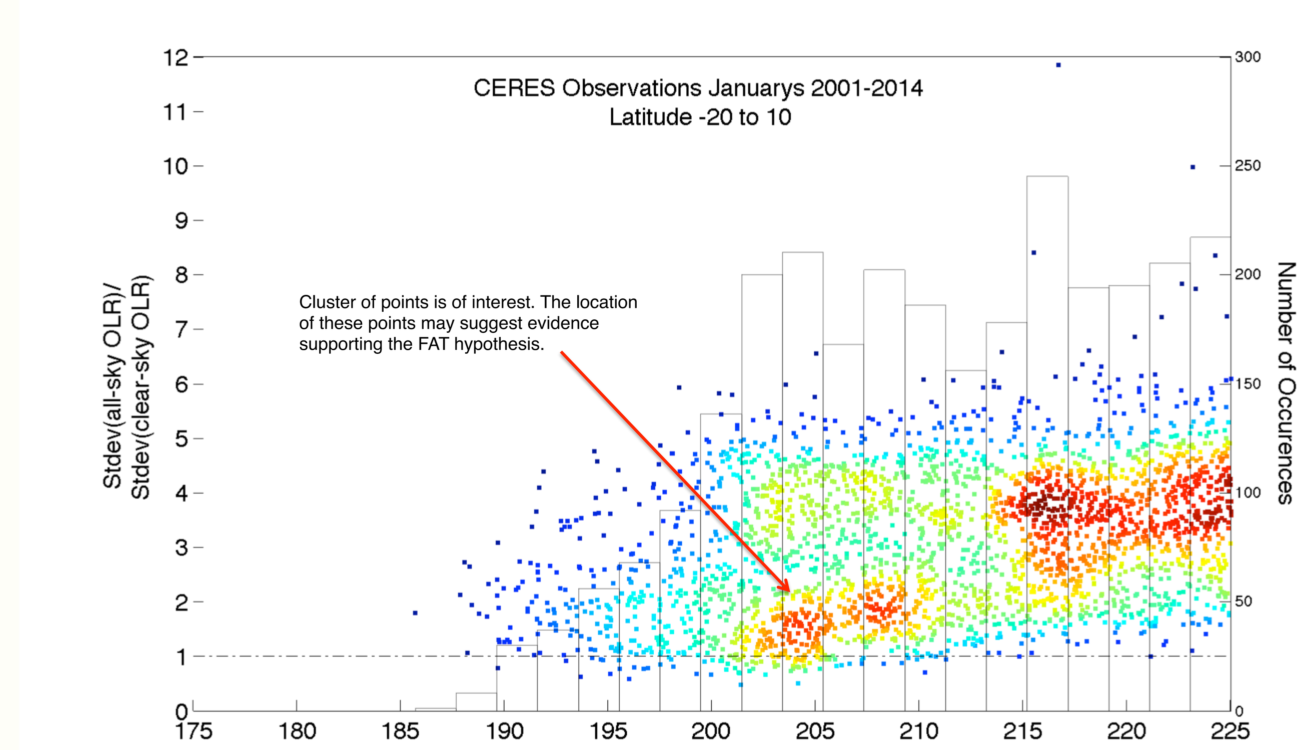



Figure 4. The ratio between the standard deviation of all-sky and clear-sky OLR plotted against mean OLR. Each point represents a grid point from the data. Color represents density of points on the graph, dark red being the most dense.

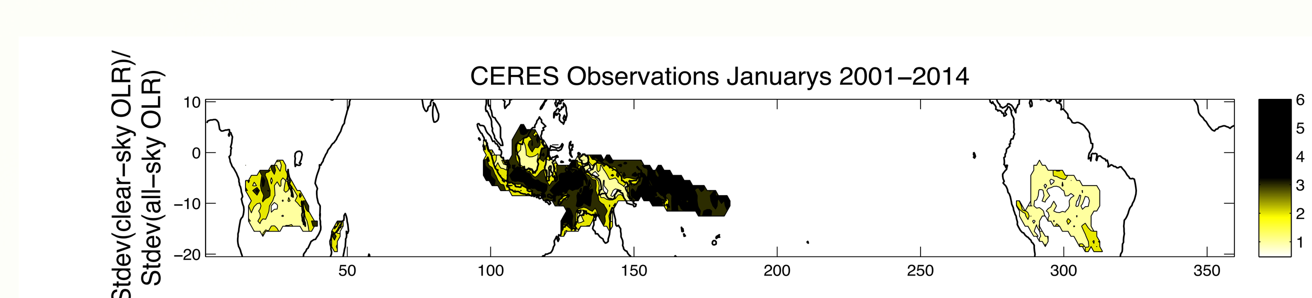



Figure 5. The distribution of the points within the region of interest pointed to in Fig. 4. All points from Fig. 4 with mean OLR < 212.5 $Wm^{-2}$ are plotted. Yellow contours represent standard deviation ratios near or below 2.

The points within the region of interest are almost entirely located over land, thus providing no evidence either for or against the FAT hypothesis.

## Conclusions

*High clouds*: We did not find evidence either for or against the FAT hypothesis.

*Low clouds:* There is not enough evidence to suggest that the observed relationship between lower tropospheric stability and shortwave cloud forcing can predict the change in the future climate. Most of the models used in this project agree that the future climate in areas of marine stratocumulus clouds will shift towards more stable conditions with a more negative shortwave cloud forcing. This means that the positive low-cloud feedback that the models produce is not due to changes in the LTS, or that it is due to changes in trade cumulus clouds rather than changes in marine stratocumulus clouds.

## References & Acknowledgements


Hartmann, D. L., and K. Larson, 2002: An important constraint on the tropical cloud−climate feedback. Geophys. Res. Lett., 29.1951, doi: 10.1029/2002GL015835.

Klein, S. A., and D. L. Hartmann, 1993: The seasonal cycle of low stratiform clouds. J. Climate, 6, 1587−1606.

Lin, J., T. Qian, and T. Shinoda, 2014: Stratocumulus clouds in southeastern Pacific simulated by eight CMIP5−CFMIP global climate models. J. Climate, 27, 3000-3022.



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