The Change in Low Cloud Cover in a Warmed Climate Inferred from AIRS, MODIS and ERA-Interim

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McCoy, D. T., R. Eastman, D. L. Hartmann, and R. Wood, 2017: The Change in Low Cloud Cover in a Warmed Climate Inferred from AIRS, MODIS, and ERA-Interim. *J. Climate*, **30,** 3609-3620.

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Low Cloud Feedback

- Climate sensitivity is the most important policy relevant question in climate science.
- The most uncertain aspect of climate sensitivity is cloud feedback.
- Low Cloud changes have the greatest leverage on cloud feedback in the current generation of climate models.
- IPCC AR5 said cloud feedback is likely positive (66%)

What Models Do

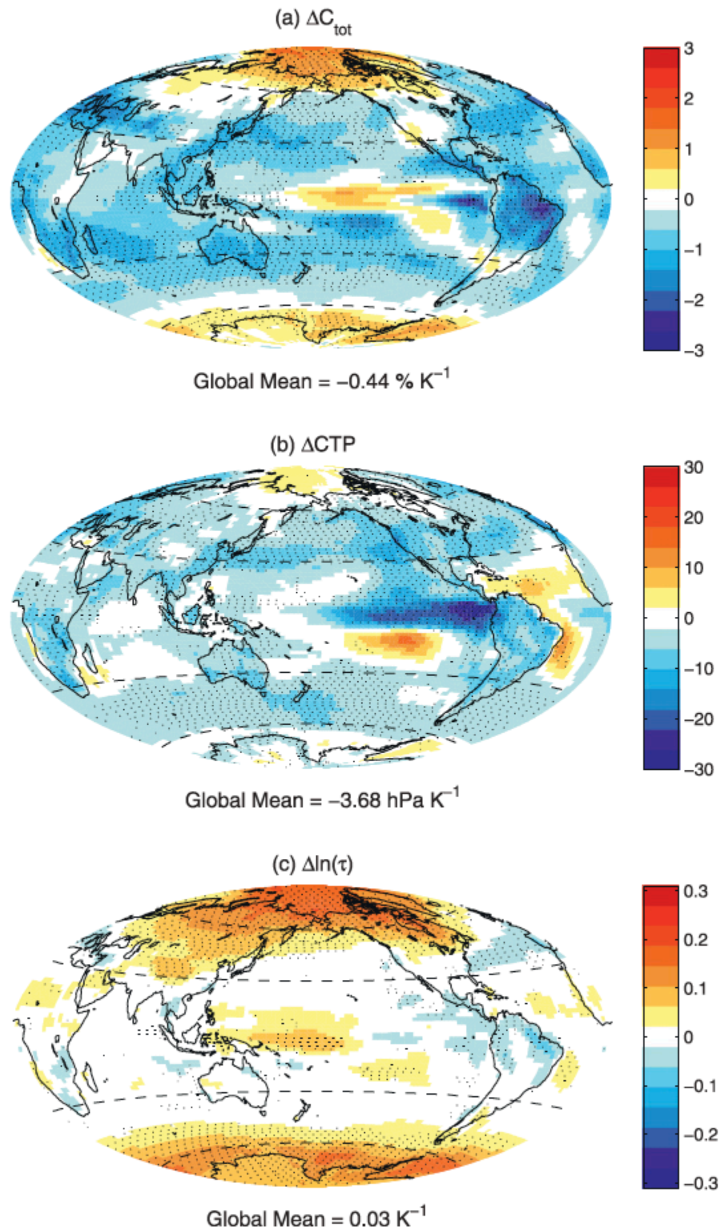


FIG. 1. Annual and ensemble mean change in (a) cloud fraction, (b) cloud fraction–weighted cloud-top pressure, and (c) cloud fraction–weighted natural logarithm of optical depth per degree global average surface air temperature increase. Stippling indicates regions where ≥75% of the models agree on the sign of the field plotted. The dashed lines are the ±30° and ±60° latitude lines.

Results from 11 CFMIP models that output ISCCP-like data.

Zelinka, M. D., S. A. Klein, and D. L. Hartmann, 2012: Computing and Partitioning Cloud Feedbacks Using Cloud Property Histograms. Part II: Attribution to Changes in Cloud Amount, Altitude, and Optical Depth. *J. Climate*, **25,** 3736-3754.

Longwave Cloud Feedback mostly due to rising clouds

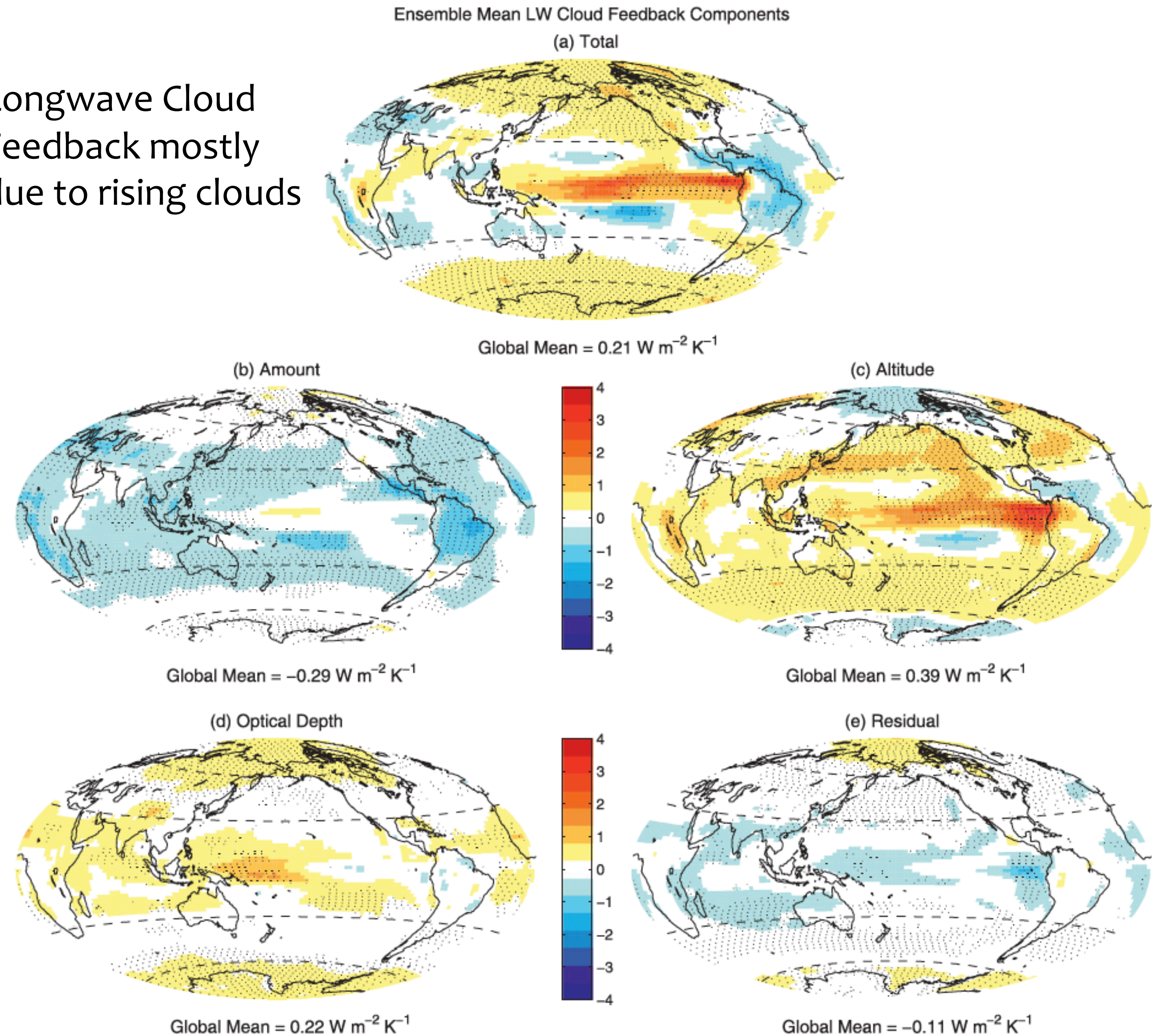


FIG. 3. Annual and ensemble mean (a) LW cloud feedback and components due to the (b) proportionate change in cloud fraction, (c) change in cloud vertical distribution, (d) change in cloud optical depth distribution, and (e) residual term. Stippling indicates regions where ≥75% of the models agree on the sign of the field plotted.

Shortwave Cloud Feedback due to decreased cloud fraction in lower latitudes and increased optical depth in high latitudes.

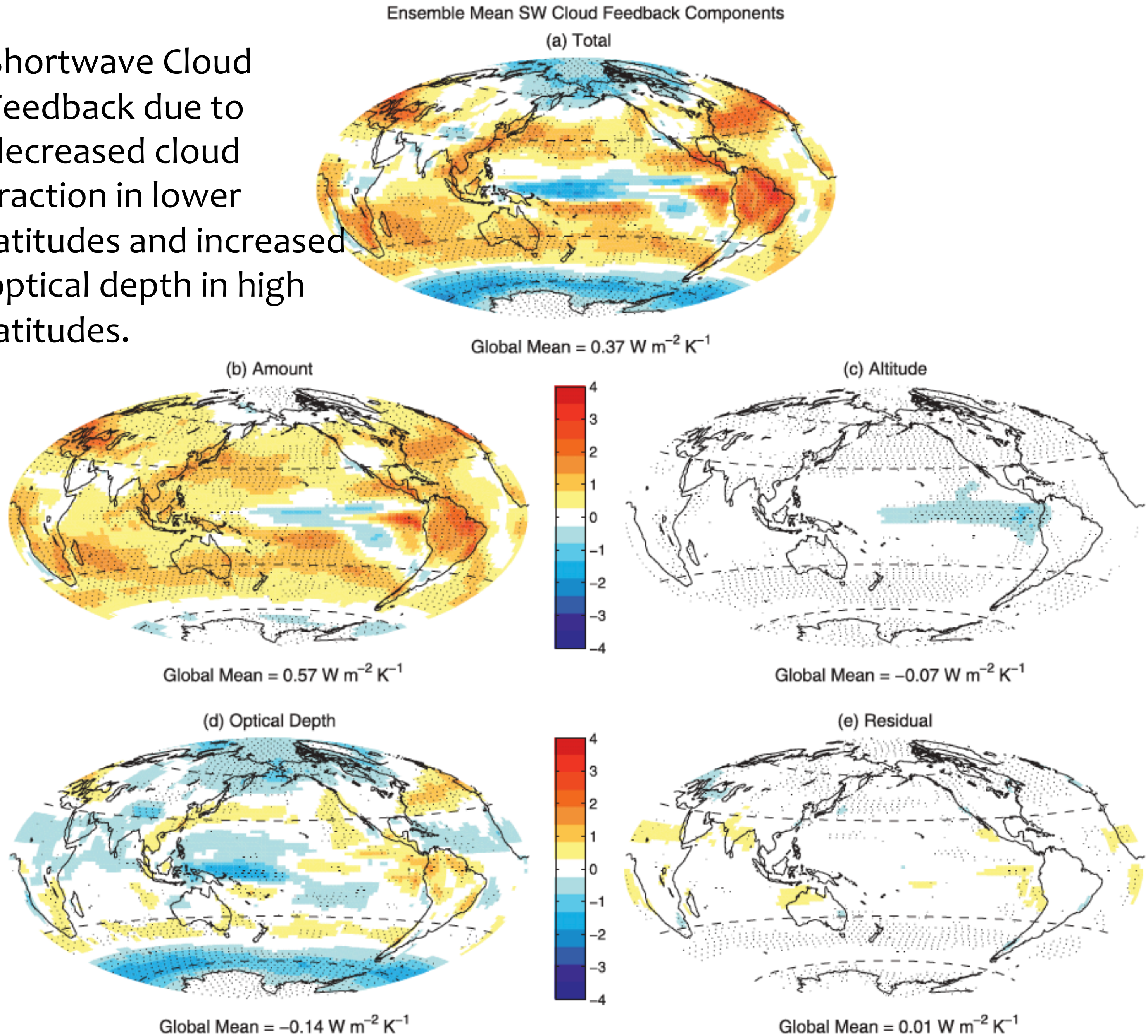


FIG. 4. As in Fig. 3, but for the SW cloud feedback partitioning.

Net Cloud Feedback due to decreased cloud fraction in lower latitudes and increased optical depth in high latitudes.

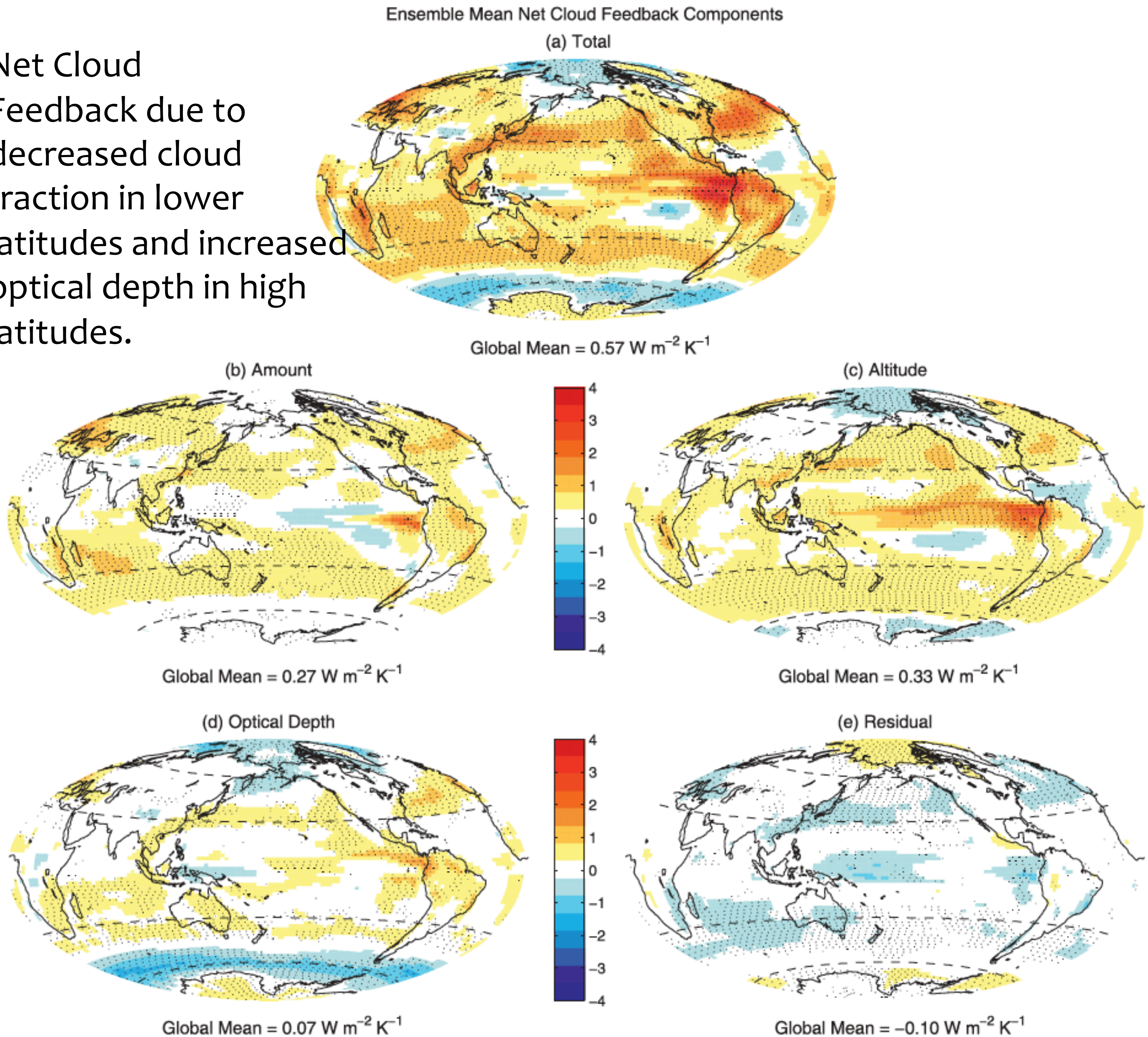


FIG. 5. As in Fig. 3, but for the net cloud feedback partitioning.

- For LWCF cancellation between colder clouds and fewer clouds.
- For SWCF consistent positive feedback due to reduction in cloud coverage.
- Net Cloud Feedback is robustly positive because of fractional area decrease, especially of low clouds.

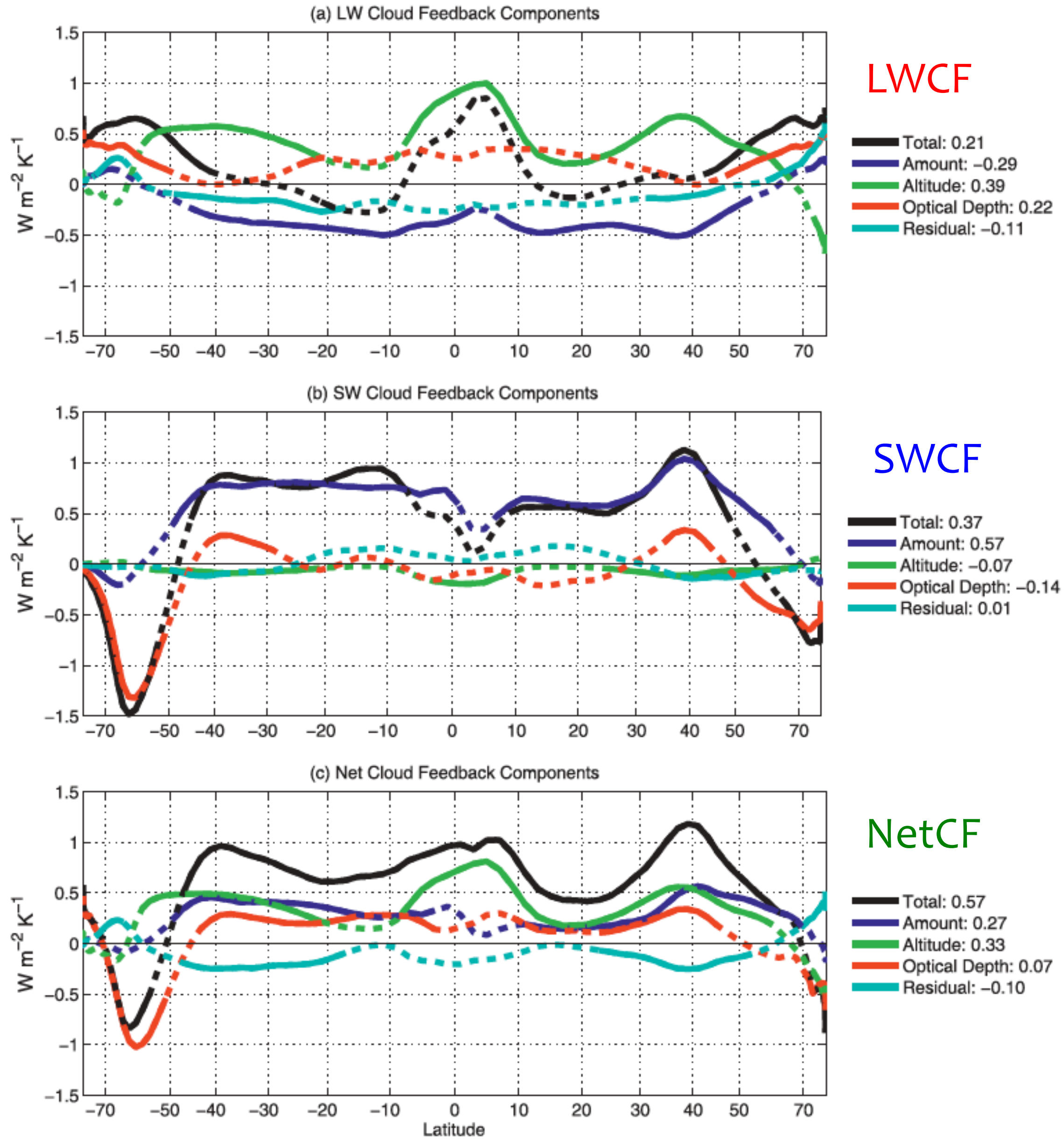


FIG. 8. Zonal, annual, and ensemble mean (a) LW, (b) SW, and (c) net cloud feedbacks partitioned into components due to the change in cloud amount, altitude, and optical depth, and the residual term. Lines are solid where ≥75% of the models agree on the sign of the field plotted, otherwise dashed. The abscissa is the sine of latitude, so that the visual integral is proportional to watts per kelvin of mean surface air temperature change.

What gives us confidence?

* GCMs consistently do it.
* We have a robust theory that explains it.
* We have observational evidence that supports it.

Robust Theory?

- For low clouds to exist.
- 1) radiative cooling of the boundary layer
- 2) drives cloud formation
- 3) Convection in PBL drives turbulence and entrainment at the top of the cloud.
- 4) Entrainment drying becomes more efficient due to thermodynamics at higher temperatures.
  - more efficient generation of entrainment with warming
  - bigger humidity jump at inversion with warming
- 5) Entrainment mixing of dry air suppresses cloud fraction with warming, especially in trade cumulus cases.

- e.g. Bretherton, 2015, Phil.Trans.Roy.Soc.,

Physical Mechanisms - Low Clouds

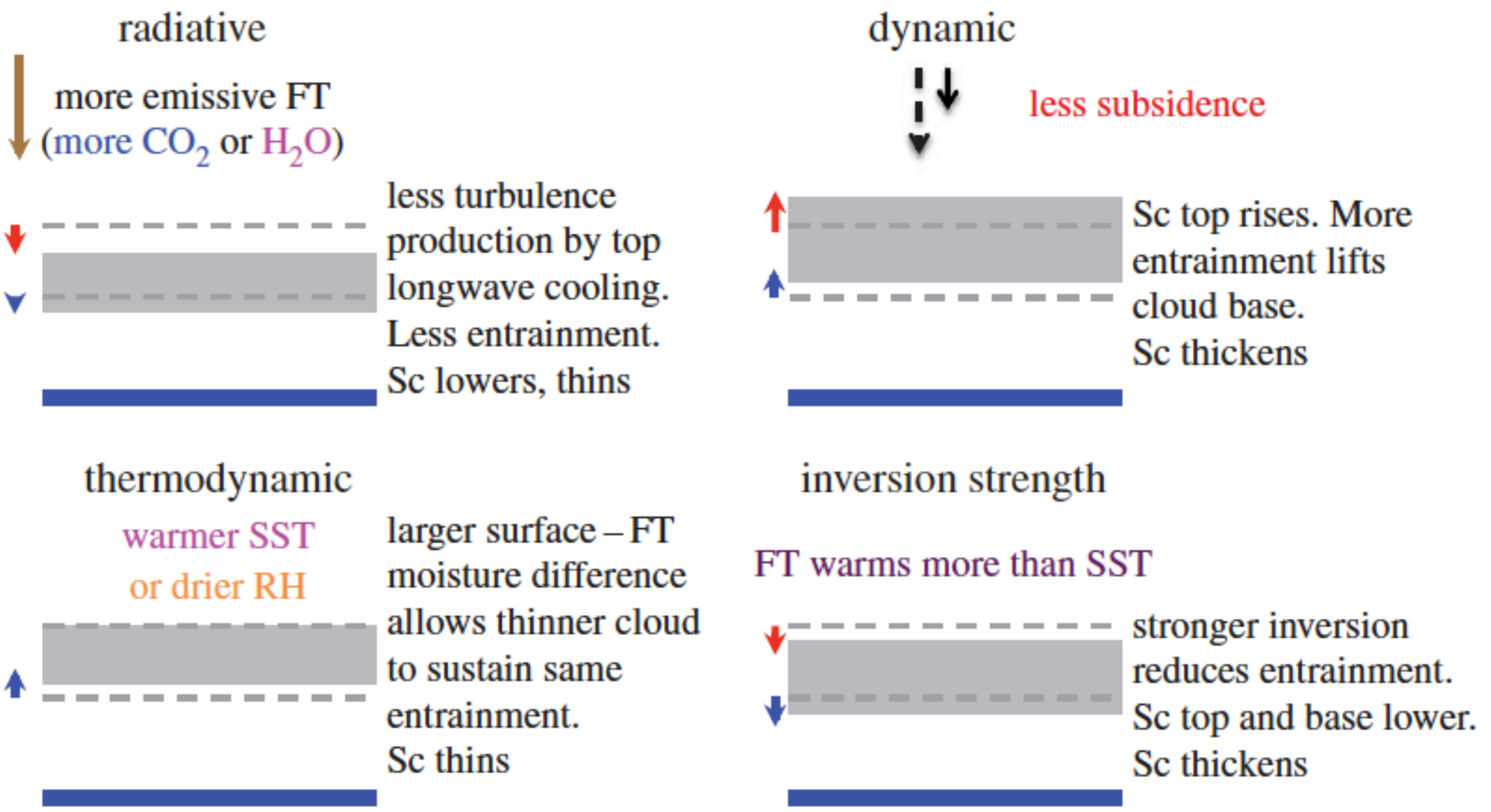


Figure 1. Marine boundary-layer stratocumulus cloud feedback mechanisms. In the figure, Sc denotes stratocumulus, RH denotes relative humidity, and FT denotes the free troposphere. Adapted from [23]. (Online version in colour.)

Bretherton, 2015, Phil.Trans.Roy.Soc.,

Observational Analysis Assumption

* Natural variations of the current climate can provide relationships between variables that guide our understanding of climate change.
* This can be tested with climate models, for which it seems to work.
* Thus we have some confidence that observed natural variations in the current climate can give us insights in to climate feedbacks.

Observations

- °Low Cloud Coverage – MODIS c-6, random overlap
- Temperature – AIRS
- Estimated Inversion Strength – AIRS (T and q)
- Free troposphere Humidity – AIRS 650-450hPa
- Vertical Velocity – ERA-I omega 550hPa*
- Wind Speed – ERA-I 10meter wind speed*

- Primary analysis was conducted with 8-day means of
- 1°x1° spatial averages

*the reanalysis variables turn out to be less important, so the result is almost entirely remote sensing and independent of climate models.

Analysis

* Partial least squares analysis, to minimize problems with colinearity, e.g. Temperature and EIS
* Separate analysis of different regions
  * 40˚N-40˚S
  * 20˚x20˚ subregions
  * Dynamical subregions – trade cumulus, stratocumulus, and all

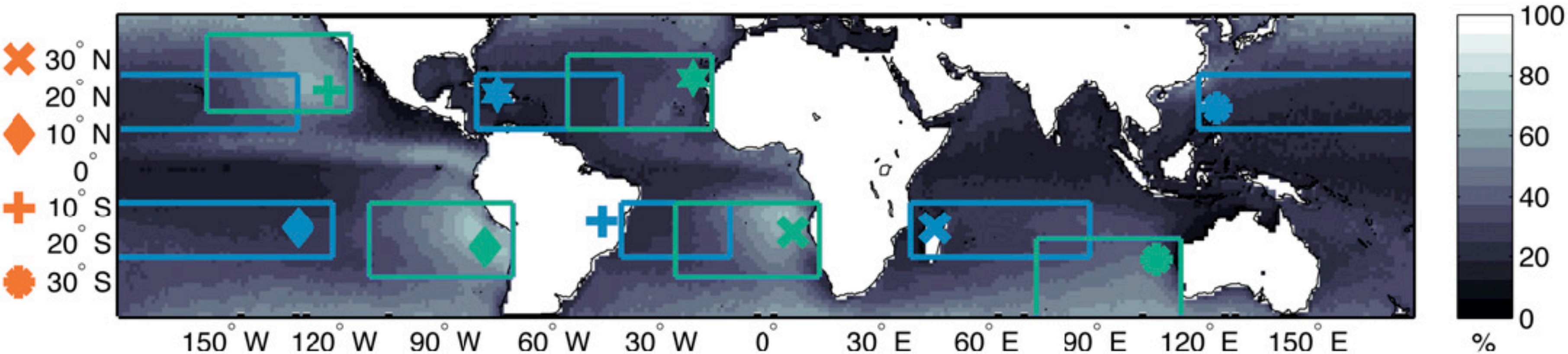


FIG. 2. The climatological LCC from MODIS from 8-day-averaged data. The regression model is trained using data from each of the 20°-latitude bands between 40°S and 40°N (orange symbols), each of the stratocumulus-dominated regions that capture the TrCu-Sc transition (Qu et al. 2015) (shown in green), and each of the subtropical TrCu regimes (shown in blue). These regions are listed in Table 2. The colored symbols next to each region correspond to the symbol used in the remaining figures to denote that region.

Many separate regions are used to test sensitivity of the results to sampling.
Both trade cumulus regions and traditional stratocumulus regions.

TABLE 2. Latitude and longitude ranges of the regional subsets analyzed in this study. These regions are shown in Fig. 2.

Region	Lat range	Lon range
40°S–40°N	40°–20°S	All longitudes
	20°S–0°	All longitudes
	0°–20°N	All longitudes
	20°–40°N	All longitudes
TrCu-Sc (Qu et al. 2015)	10°–30°S	110°–70°W
	10°–30°S	25°W–15°E
	20°–40°S	75°–115°E
	15°–35°N	155°–115°W
	10°–30°N	55°–15°W
TrCu	10°–25°S	180°–120°W
	10°–25°S	40°–90°E
	10°–25°S	40°–10°W
	10°–25°N	120°E–130°W
	10°–25°N	80°–40°W

Quality of the Regressions

Regressions do a ‘reasonable’ job of reproducing the observed variability

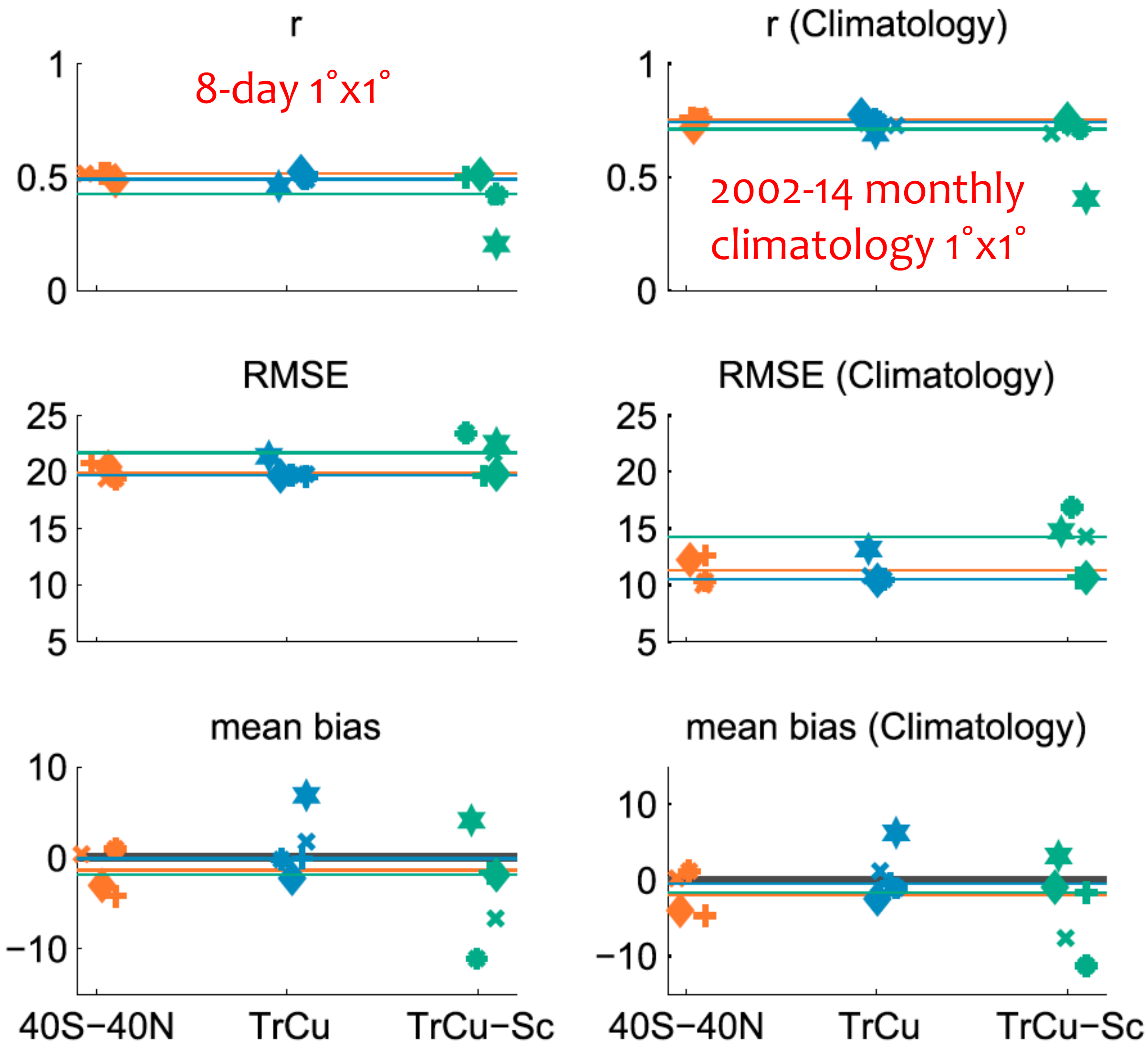
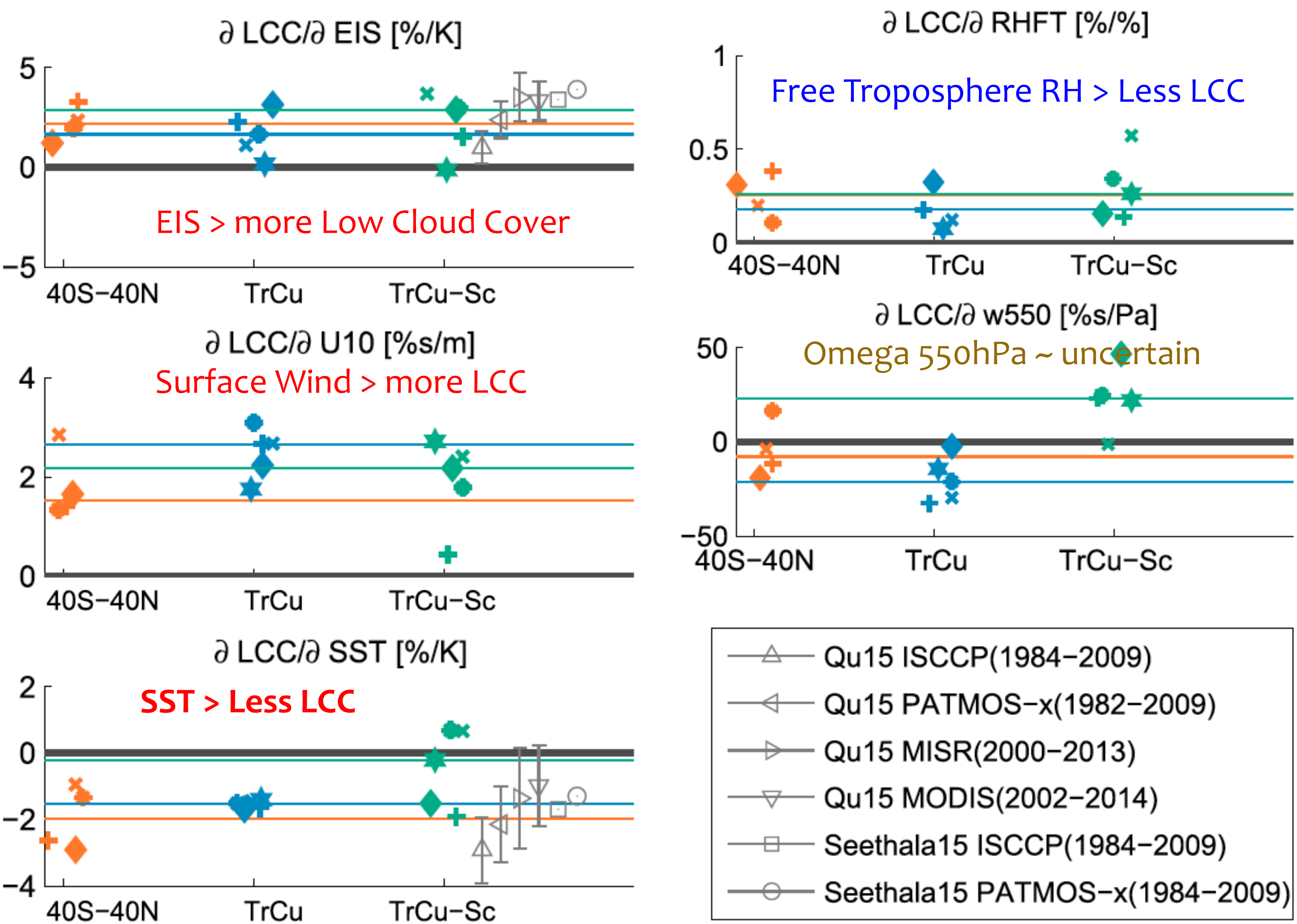


FIG. 3. (left) Evaluation of the ability of the regression models trained in each subregion to reproduce the observed LCC over 40°S–40°N at 1° × 1° spatial resolution and 8-day temporal resolution and (right) when the observational record of LCC is averaged to create a 12-month climatology at 1° × 1° spatial resolution. The regression models being evaluated are differentiated by region and subregion (see Fig. 2). The region used to train the regression model noted on the *x* axis. Regression coefficients, RMSE, and mean-bias for the regression models trained in each of the subregions are shown as dots. Scatter along the *x* axis has been added for visual clarity. The units of RMSE and mean bias are in units of percent cloud cover.

Parameter Sensitivity Results



Apply to Global Warming

* 1K global warming in GCM's give approximately these changes.
* **SST +1K**
* **EIS 0.2K**
* Free troposphere relative humidity ~-1%
* Omega ~+0
* Surface wind speed ~-0

Given the regression coefficients obtained, only SST and EIS make a significant difference in LCC

Global Warming

* If we take the predictions of EIS from CMIP5 models for a 1K SST warming, we obtain a robust estimate of a LCC decrease of 1-1.4%/K .
* Changes in Stratocumulus to Cumulus transition zones are more uncertain, consistent with previous estimates.

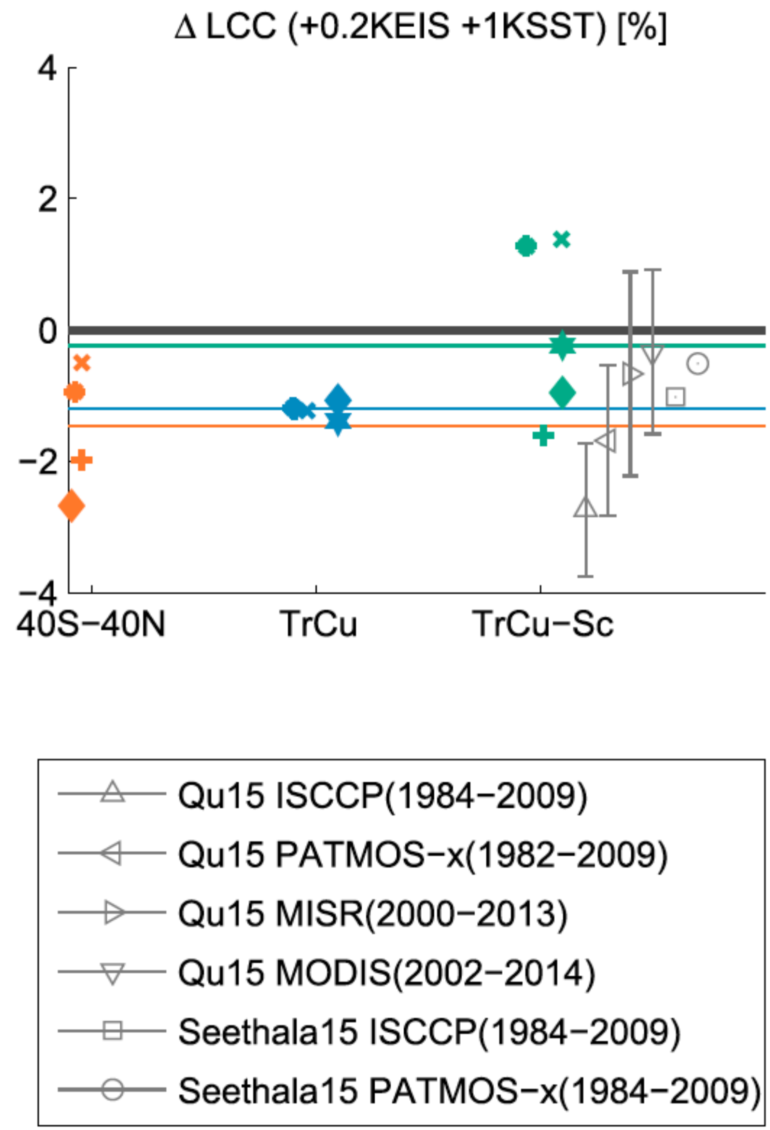


FIG. 5. The change in LCC inferred from a uniform increase in SST of 1 K accompanied by an increase in EIS of 0.2 K. The coefficients from the regression models shown in Fig. 4 are used to calculate the change in LCC. The region that the regression model was trained in is noted on the *x* axis. The LCC change calculated using the coefficients of Qu et al. (2015) and Seethala et al. (2015) for EIS + 0.2 K and SST + 1 K are also shown. The symbols used for each region correspond to the key in Fig. 2.

Conclusion

- AIRS and MODIS data suggest a 1%/K reduction in trade cumulus low cloud fraction with warming, based on 8-day and climatologicial variations of observed SST and EIS, and using a ratio of EIS to SST change of 0.2K/K from GCMs.