1. Motivation

Stratocumulus clouds play an important role in the seasonal cycle of the Eastern Pacific and the global climate. These optically thick clouds have a strong albedo, and they strongly reduce the incoming shortwave radiation at the surface. As a result, they have a cooling effect on the surface compared to clear sky.

These clouds are very complex to parameterize in GCMs. Figure 1 compares the AM2 (GFDL model) and CAM3 (NCAR model) annual mean stratocumulus cloud amounts to the satellite estimates of ISCCP. The two models capture the large-scale features of the Eastern Pacific stratocumulus regions; where the clouds are located in approximately the right location in the AM2, while CAM3 places the stratocumulus too close to the coast, and over-predicts the cloud amount in the East Equatorial region. AM2 underestimates the stratocumulus and the clouds are too far from the coast.

The error in the stratocumulus amount yield errors in the SWCF up to 30 W/m2 as shown in Figure 1 in which the simulated SWCF is compared to the ERBE dataset. Because of their large impact on the shortwave radiation budget, it is important for global atmospheric models to simulate the correct amount of stratocumulus. In addition, when coupling atmospheric models with ocean models, it is important to produce these clouds at the right locations.

Here, we define three regions in the Eastern Pacific as shown on Figure 1 (North, Equatorial and South) and we discuss which large-scale quantities affect the stratocumulus amounts in these regions. We compare AM2 runs (i.e. the model is forced with observed monthly means SSTs) of CAM3 and AM2 versus observations and reanalysis. The datasets used in this study are described in Table 1.

2. Observations and reanalysis results

a. Schematics of some processes that influence stratocumulus clouds

Of the many processes that influence the stratocumulus clouds in the Eastern Pacific, we will examine the rate of subsidence, buoyancy flux, boundary layer height and inversion strength. The stratocumulus form over cold SSTs and are capped by a strong inversion (see Figure 2). The inversion is maintained by subsidence. Strong radiative cooling at the top of the cloud causes the turbulence that is necessary to maintain the cloud and the buoyancy flux brings moisture from the sea surface into the boundary layer. The static stability, defined as the difference between the potential temperature at 700 mb and the surface, provides an estimate of the strength of the inversion.

b. Annual cycle of the stratus amount versus other quantities

Figure 3 shows the annual cycle of the domain-averaged monthly means of stratocumulus, in the three regions defined in Figure 1.

• The stratocumulus clouds show a pronounced annual cycle in all three regions.
• In the South and Equatorial regions, the amount of stratocumulus is negatively correlated with the SSTs, as can be expected since the stratocumulus reduces the amount of shortwave radiation reaching the surface. In the North region, the SST annual cycle is positively correlated with the stratocumulus cycle and the maximum in SST follows that of the stratocumulus by two months.
• The annual cycle of static stability is strongly correlated with that of stratocumulus. The relationship between static stability and stratocumulus amount follows the Klein Line (Klein and Hartmann, 1993). A least-squares fit of the seasonal domain averages indicates that the stratocumulus amount increases about 5% per degree increase in static stability, which compares well to the Klein Line’s slope (0.5% per degree).
• In the North region, the boundary layer height is anti-correlated with the stratus amount as one can expect: a shallower boundary layer has a higher cloud fraction than a deeper one. This relation is not verified in the Equatorial and South regions. In these regions, notice that the amplitude of the cycle of the boundary layer height is much smaller than in the North.
• The stratocumulus amount is correlated to the buoyancy flux in the Equatorial region. In the other regions, the relationship between the buoyancy flux and stratocumulus is unclear.

c. Static stability as a predictor of stratocumulus amount

From these plots, the only predictor of the stratocumulus amount that is consistent for the three regions is the static stability. CAM3 is using the Klein Line as a predictor of the static stability. However, there are issues with using the static stability to predict the stratocumulus.

• The correlation between the static stability and the stratus cloud amount does not hold well when one looks at smaller domains. If we look at single grid cells instead of the domain average, the correlation coefficient between static stability and stratocumulus is not uniform and can be fairly small (see Figure 4). Moreover, the slope of the linear relationship between stratocumulus amount and stability varies from one location to another.
• The correlation between stratocumulus and stability decreases with the timescale averaging (not shown here). We acknowledge there may be sampling problems when going to shorter timescales.
• Studies show that a warmer climate will be accompanied by an increased static stability and therefore, an increase in stratocumulus clouds (e.g. Miller, 1997). However, a warmer climate will be accompanied by changes in other quantities that are also linked to the amount of stratocumulus (such as the subsidence strength or the surface fluxes). Therefore, there is no guarantee that the change in stratocumulus will follow the Klein Line in a warmer climate scenario.

3. GCM results

The two models treat the cloud fraction in different ways. The CAM3 stratocumulus cloud amount is diagnosed from the Klein Line while the cloud fraction in AM2 is treated as a prognostic variable following the parameterization of Twisdale (1995).

Figure 5 shows the annual cycle of stratocumulus compared to other quantities. Notice that:

• The two models fail to reproduce the annual cycle of stratocumulus amount in the South region. The annual cycle predicted by AM2 is in phase with observations in the North and Equatorial regions but the predicted cloud fractions are underestimated. CAM3 fails to predict the annual cycle in the Equatorial region but agrees very well with observations in the North.
• Both models simulate the shape of the annual cycle of static stability correctly but not its strength.
• The vertical velocity at 500mb is poorly predicted by both models in the North region.
• The boundary layer height is underestimated in CAM3 compared to the ERA40 data.

Figure 6 also shows the monthly means of the SWCF from ERBE and the LWP from SSM/I. The SWCF shows large values of the LWP for small amounts of the stratocumulus. These values must be due to convective clouds moving into this region. CAM3 (AM2) overestimates (underestimates) the SWCF.

The AM2 overestimates stratocumulus amount and places clouds too far from the coast while CAM3 predicts clouds too close to the coast.

4. Conclusion

We have analyzed the stratocumulus annual cycle in three regions of the Eastern Pacific.

We show that the mechanisms that determine the cloud amount are very different in the three regions. The static stability is the only predictor that is consistent in the three regions. However, the correlation between stability and cloud fraction are not as good when we go to smaller domains or timescales.

The two GCMs have problems predicting the cloud amount in these regions. This yields large errors in the radiation budget: AM2 underestimates stratocumulus amount and places clouds too far from the coast while CAM3 predicts clouds too close to the coast.

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