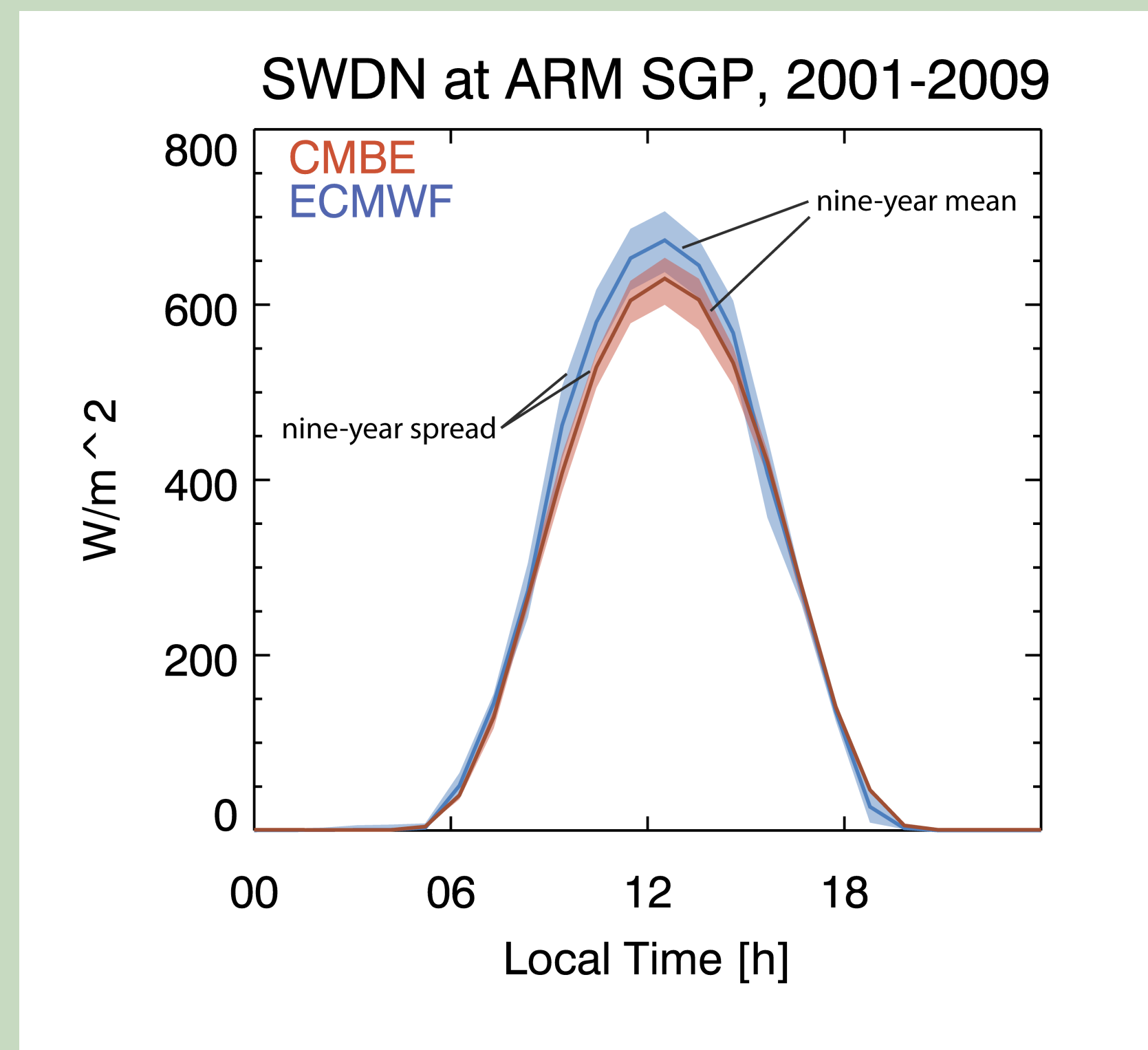


## Introduction

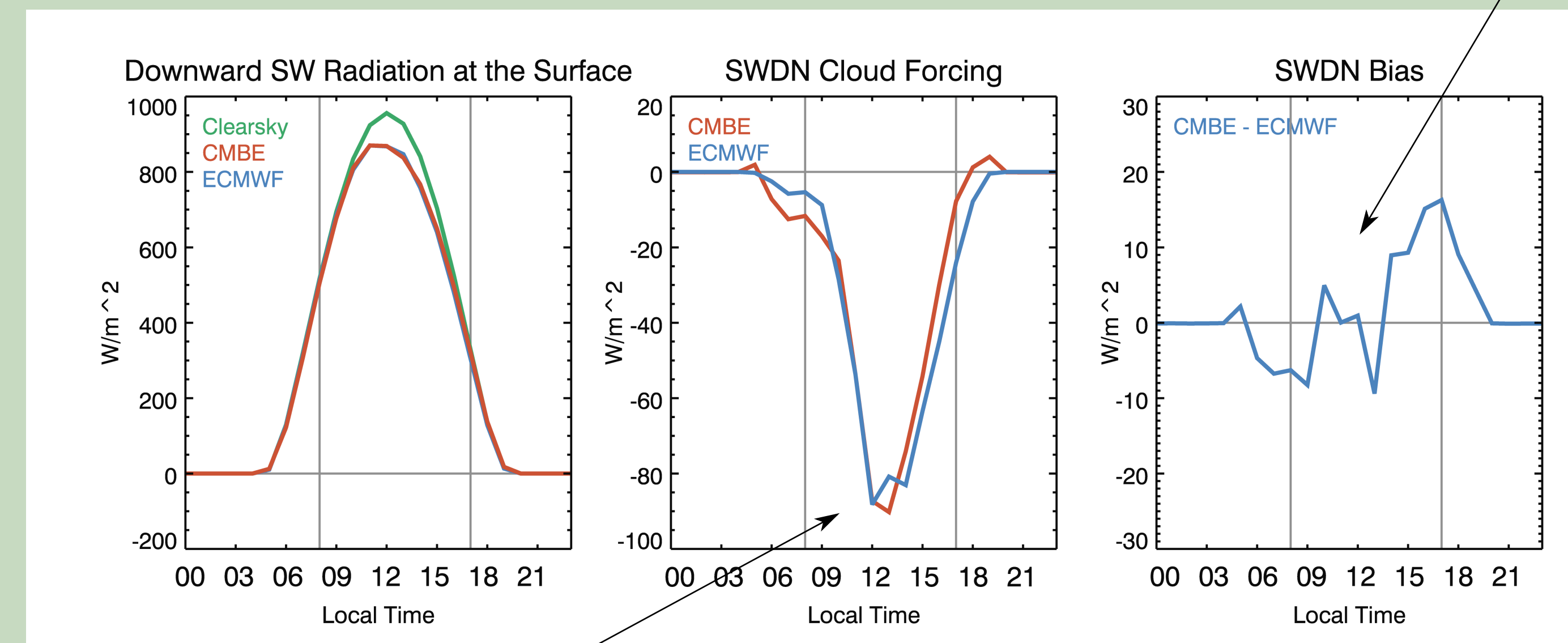
Routine global evaluation using CERES observations suggests that the ECMWF model lacks shortwave cloud forcing over land. This appears to be consistent with an annual mean surface shortwave bias at the ARM SGP site over the period spanned by the CMBE record. Previous studies have suggested that lack of shallow cumulus cloud cover might contribute significantly to this bias, but results were based on relatively short time periods in the face of highly variable shallow cumulus cover from year to year.



**Fig. 1** In the multi-year annual mean, the magnitude of the model's surface shortwave radiation bias is approximately  $50 \text{ W m}^{-2}$  at noon.

## Shortwave radiation bias of shallow cumulus regime

Shortwave bias on the order of  $10 \text{ W m}^{-2}$ , changing sign throughout the day.

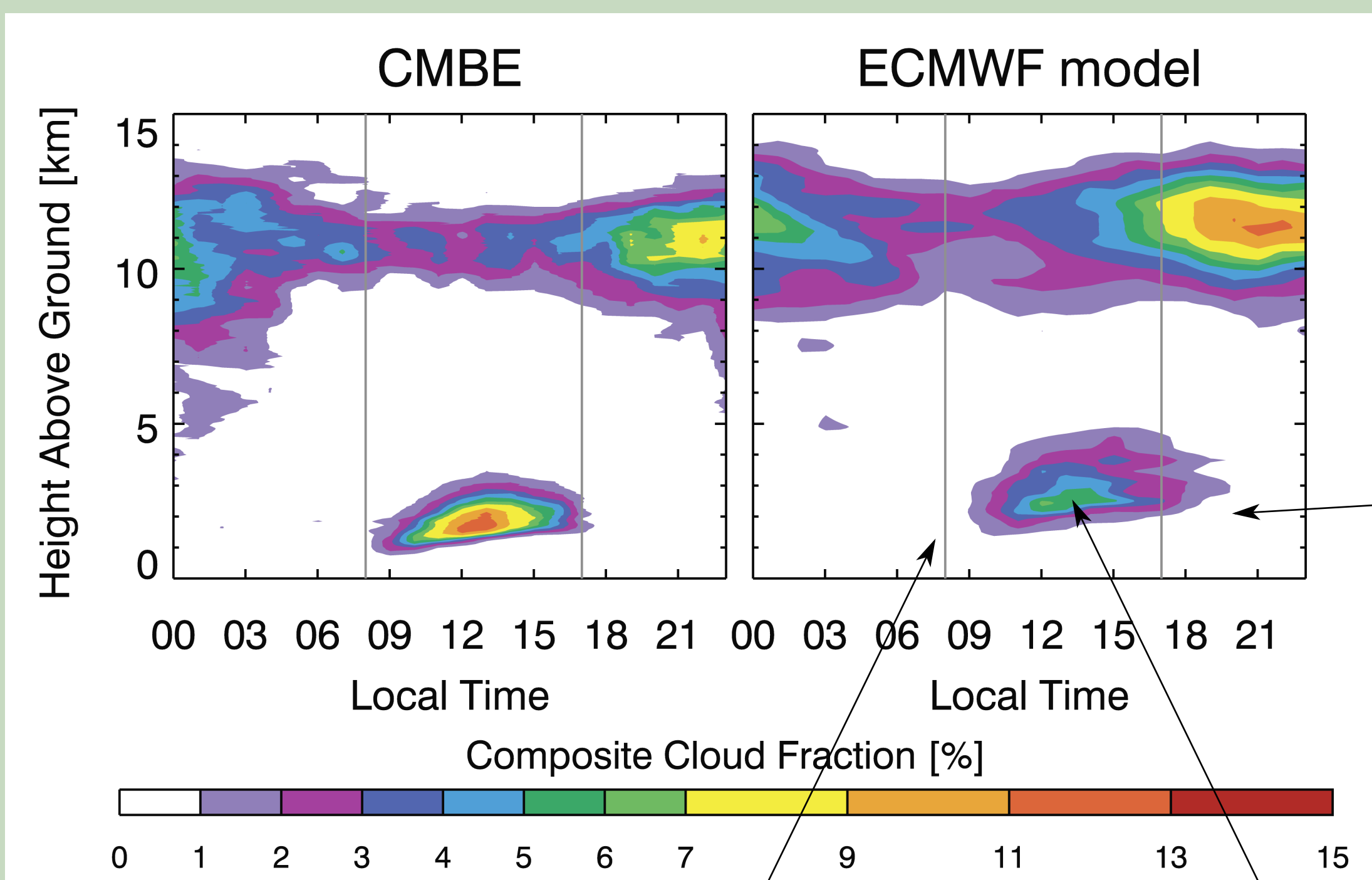


Maximum cloud forcing in good agreement, but too strong in the afternoon, weak in the early morning.

**Fig. 3** Composite downward shortwave (SWDN) radiation at the surface.

## Time series for shallow cumulus days

Between 1997 and 2009, 146 days are identified in the CMBE record as dominated by shallow convective clouds ([1] Zhang & Klein). A recently operational version of the ECMWF model (CY36R4) is run for these days at T511L91 resolution to provide consistent forecasts over the entire time period.



Overall low-cloud characteristic well captured, but...

Cloud base high by about 500 m.

Cloud fraction underestimated.

Late onset of cloud, late decay.

**Fig. 2** shows the composite cloud fraction from (left) CMBE and (right) the ECMWF model for shallow cumulus days.

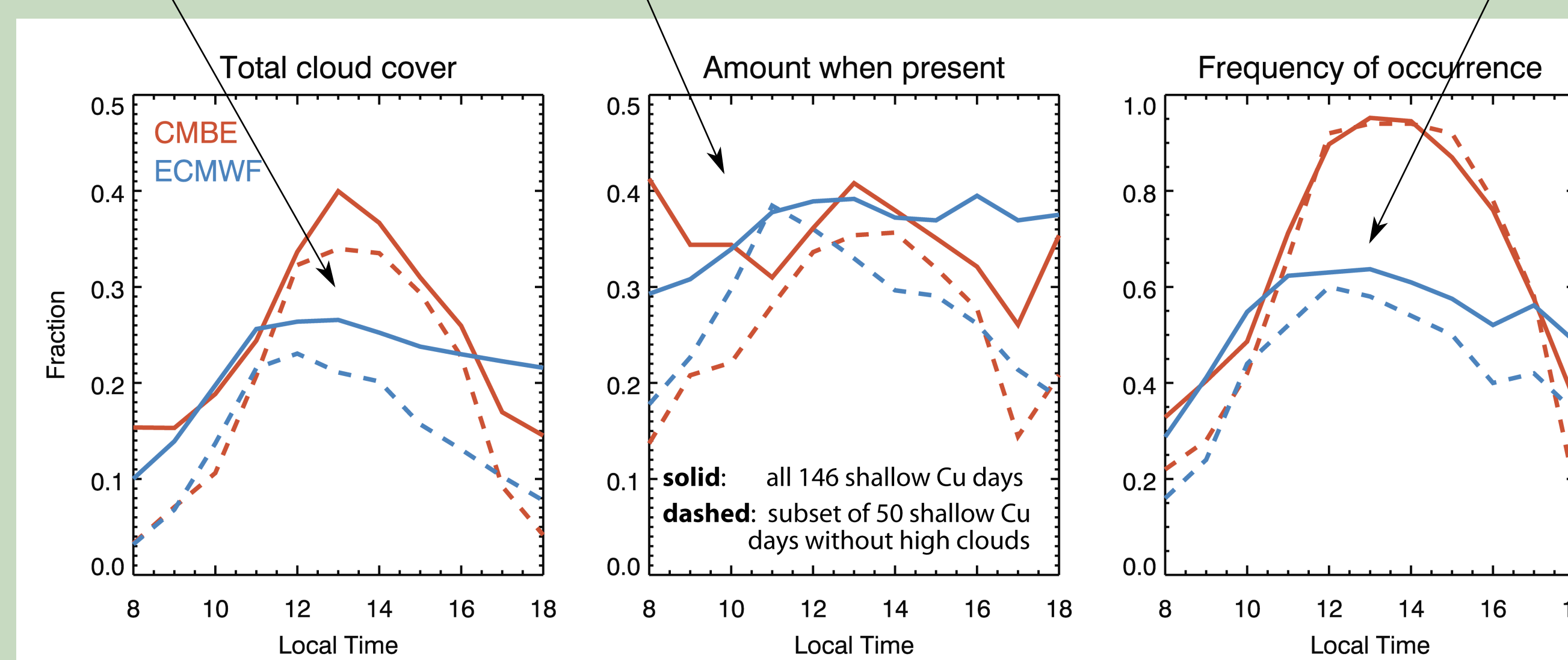
[1] Zhang and Klein, poster at this session: The Difference Between Thin and Thick Fair-weather Shallow Cumulus inferred from ARM Observations over the Southern Great Plains.

## Why the cloud fraction underestimate?

Consistent with Fig. 2, total cloud cover is underestimated

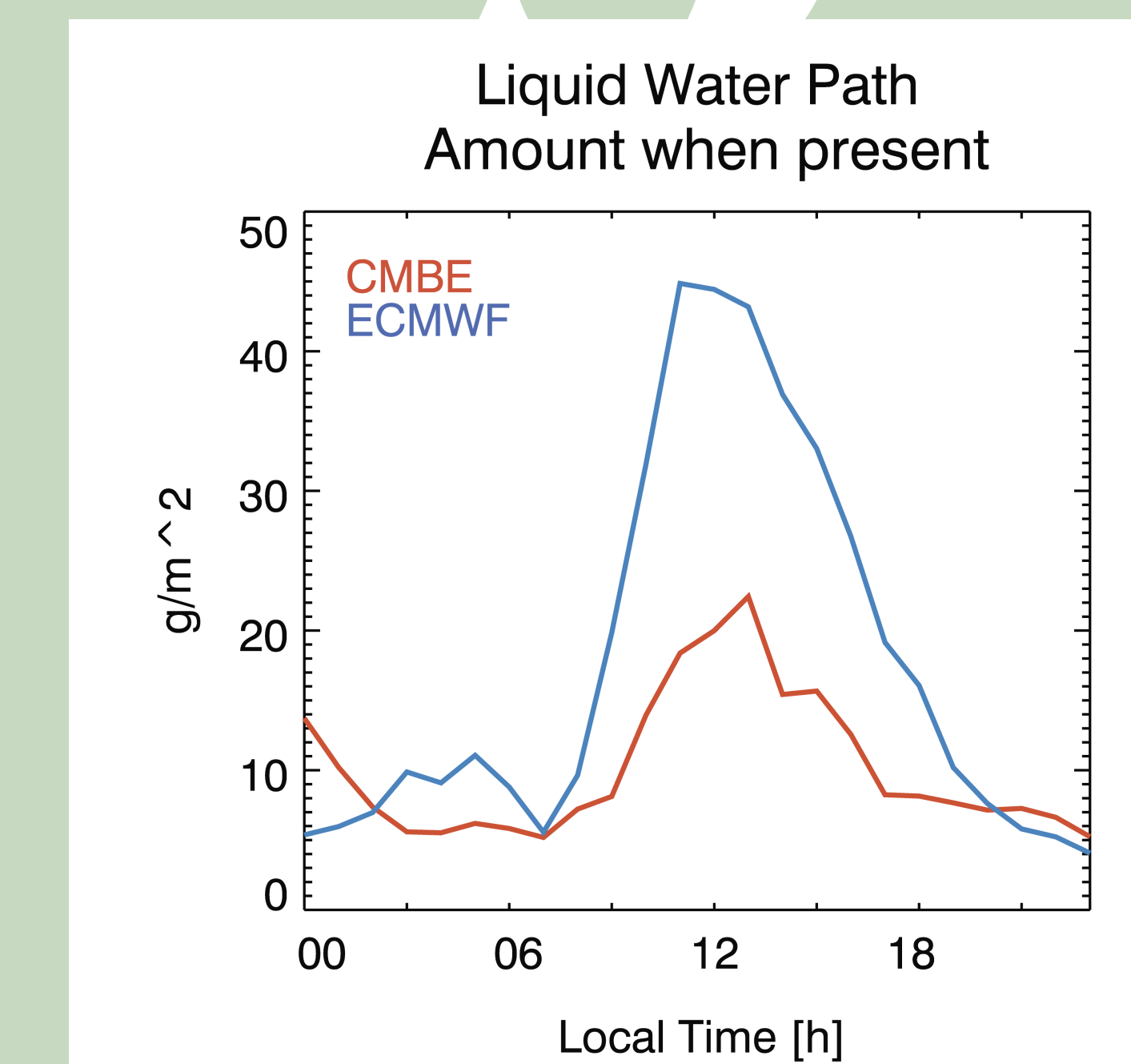
When cloud present, amount agrees reasonably well.

Cloud-free days in the model are the reason for cloud cover underestimate.



**Fig. 4** Composite total cloud cover, cloud amount when present and cloud frequency of occurrence.

The model's liquid water path is about twice as large as observed, leading to more reflective clouds.



**Fig. 5** Composite liquid water path amount when total cloud cover exceeds 2%.

## Conclusion

The ECMWF model's shortwave radiation bias is small for the shallow cumulus regime and cannot explain the multi-year annual mean bias. Clouds in the model grow and decay approximately an hour later than observed, which leads to a reversal of the shortwave bias from morning to afternoon. Individual model clouds hold too much liquid water and overestimate the shortwave forcing. This is compensated by days where the model fails to produce low clouds.