How well do climate models represent the MJO?

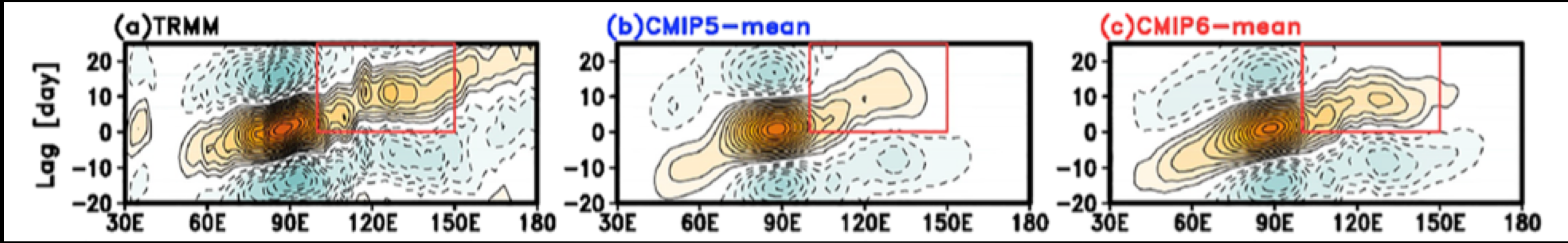
MJO in Climate Models

- Realistic simulations of the MJO is a general challenge to global models, but model performance has been improved over years.
- Slingo et al. (1996) examined 15 models in the Atmospheric Model Intercomparison Project (AMIP) models. It was found that although some models showed eastward propagating anomalies in the 200-hPa velocity potential field, no models were able to capture the observed dominance of the intraseasonal oscillation.
- Lin et al. (2006) analyzed MJO variability in 14 Coupled Model Intercomparison Project-3 (CMIP3) models and showed that only 2 models had MJO variance comparable to observations while the MJO variance in the other 12 models was less than half of the observed value. Additionally, most models failed to produce highly coherent eastward progradation of the MJO.
- Huang et al. (2013) compared the simulation of the MJO in the CMIP3 and CMIP5 models. They found that the CMIP5 models showed an overall improvement in simulating the MJO: the CMIP5 models produced larger MJO variance and a more realistic ratio of the variance of the MJO to that of its westward propagating counterpart. However, only one third of the CMIP5 models produced the spectral peak of the MJO precipitation between 30-70 days and only one of the 20 models simulated the realistic eastward propagation of the MJO.

MJO in Climate Models (cont'd)

- Anh et al. (2020) showed that the simulation of the MJO propagation is significantly improved in CMIP6 models when compared to CMIP5 models.

Time-longitude diagram of precipitation



Lag-longitude diagram of precipitation for (a) TRMM, (b) 30 CMIP5 mean, (c) 34 CMIP6 mean. The lag-longitude diagram is obtained as lag-regression of 10°S to 10°N averaged 20- to 100-day band-pass-filtered precipitation anomalies against its time series averaged over the 85–95°E and 5°S to 5°N. (from Anh et al. 2020)

Evaluation of Model Simulations Against Observations

Evaluation diagnostics for model simulations of the MJO (Zhang 2005) :

- Examine the time-spatial spectrum of the MJO (such as wave-number frequency analysis)
- Extract the MJO mode objectively using EOF or SVD: the MJO mode should be separable from the others
- Examine the primary features of the MJO: zonal scale, propagation speed and 3D structure
- Examine the spatial distribution and seasonal cycle of the MJO variance

The MJO diagnostics: The US CLIVAR MJO working group (MJOWG) developed a standardized set of diagnostics to evaluate MJO simulations in climate models (Kim et al. 2009). Using these diagnostics, Kim et al. (2009) examined the MJO simulations in eight climate models.

Variance of 20–100-day band pass filtered Precip and U850 (contour)

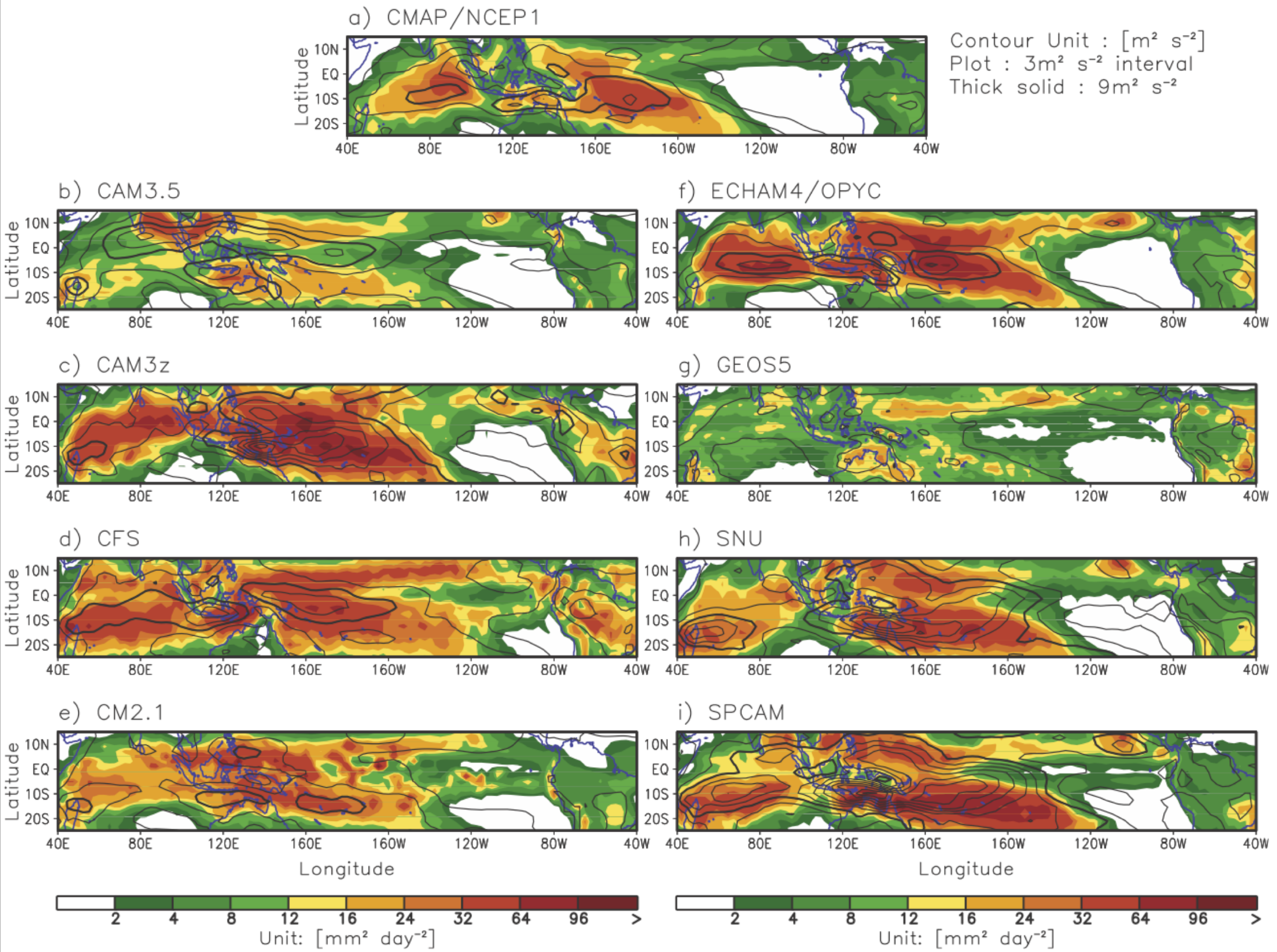
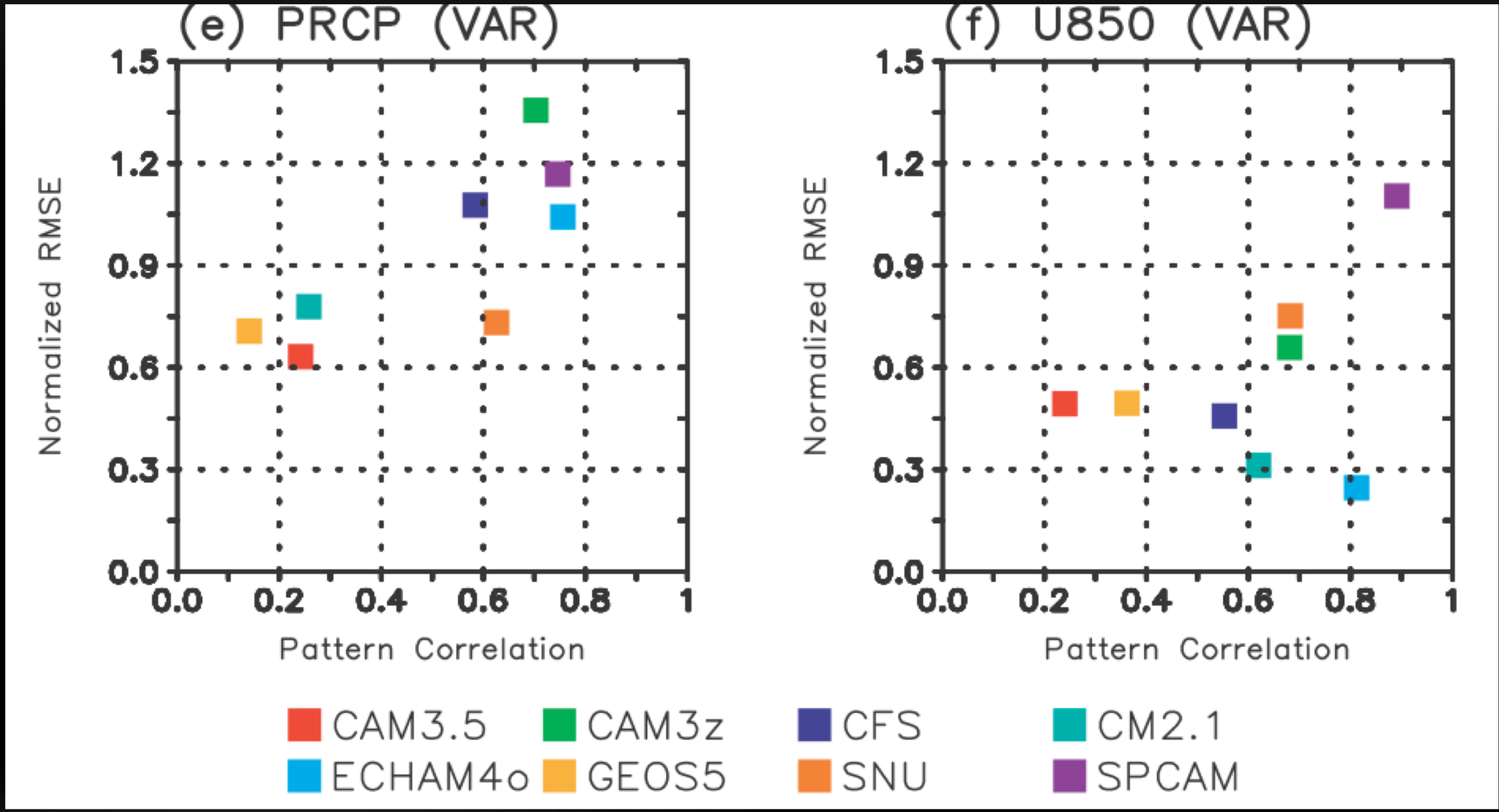


FIG. 3. As in Fig. 1 but for variance of 20–100-day bandpass filtered precipitation (mm^2 day^{-2}) and 850-hPa zonal wind (m^2 s^{-2}). Contours of 850-hPa zonal wind variance are plotted every 3 m^2 s^{-2} with the 9 m^2 s^{-2} line represented by the thick solid line.

Many models have difficulty realistically representing the spatial pattern or magnitude of intraseasonal variability of precipitation and U850.

Pattern correlation and normalized RMSE for 20–100-day filtered variance of Precipitation (left) and U850 (right)

- Higher pattern correlations and lower NRMSE are desirable.
- No model is the best for both the variables. For example, ECHAM4/OPYC shows good skill in simulating low-level wind but has large RMSE in simulating precipitation variance.



Wavenumber–frequency spectra: Precip and U850 (contour)

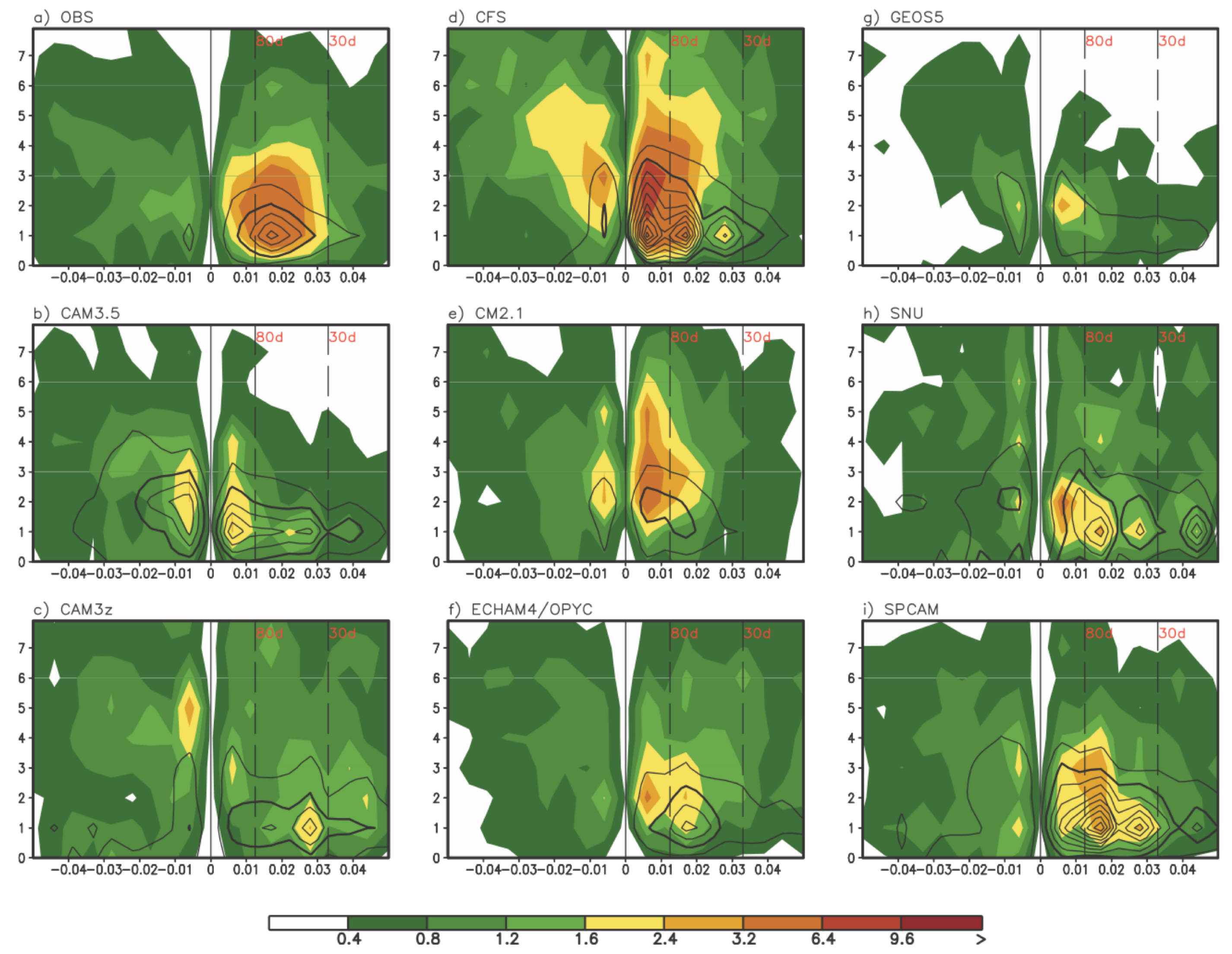


FIG. 4. November–April wavenumber–frequency spectra of 10°N–10°S averaged precipitation (mm^2 day^{-2}) (shaded) and 850-hPa zonal wind (m^2 s^{-2}) (contoured) for the (a) CMAP/NCEP/NCAR, (b) CAM3.5, (c) CAM3z, (d) CFS, (e) CM2.1, (f) ECHAM4/OPYC, (g) GEOS5, (h) SNU, and (i) SPCAM. Individual November–April spectra were calculated for each year and then averaged over all years of data. Only the climatological seasonal cycle and time mean for each November–April segment were removed before calculation of the spectra. The bandwidth is (180 days)$^{-1}$.

- The fraction of the variance is smaller than observed for all models.
- Although a model may capture the dominance of the large-scale variability (between wv# 1-3), the spectral power may peak outside of the MJO (30–80-day) frequency band in many models.
- The propagation speed of the MJO signals may be unrealistic. (i.e., phase speed = frequency / wavenumber)

East–west ratio of spectral power

- The east/west ratio is calculated by dividing the sum of eastward propagating spectral power by the westward propagating counterpart within wavenumbers 1–3 for precipitation (1–2 for zonal wind), period 30–80 days.
- All models have a smaller east/west ratio of precipitation than observed

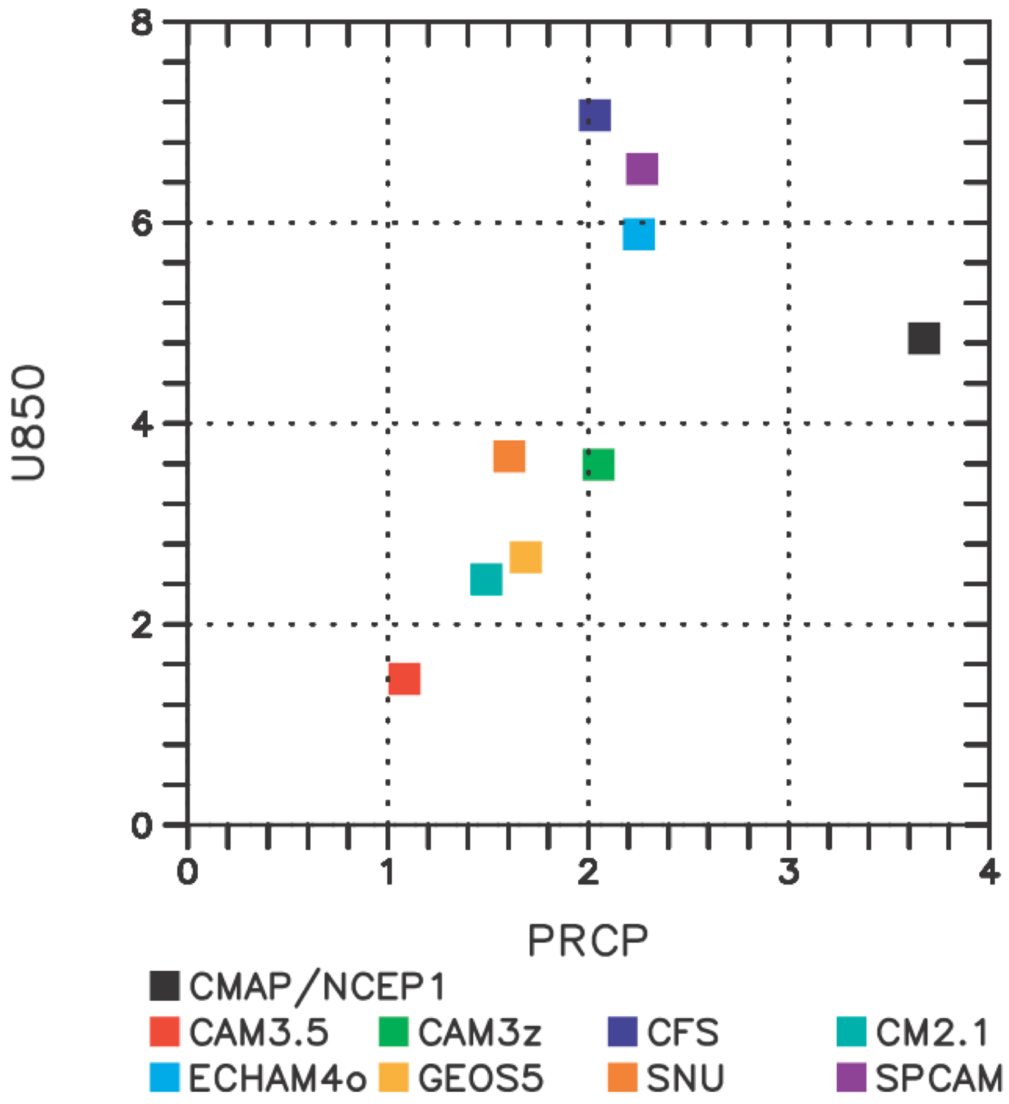


FIG. 5. Scatterplot of east/west ratio of power based on the data in Fig. 4. The east/west ratio is calculated by dividing the sum of eastward propagating power by the westward propagating counterpart within wavenumbers 1–3 (1–2 for zonal wind), period 30–80 days.

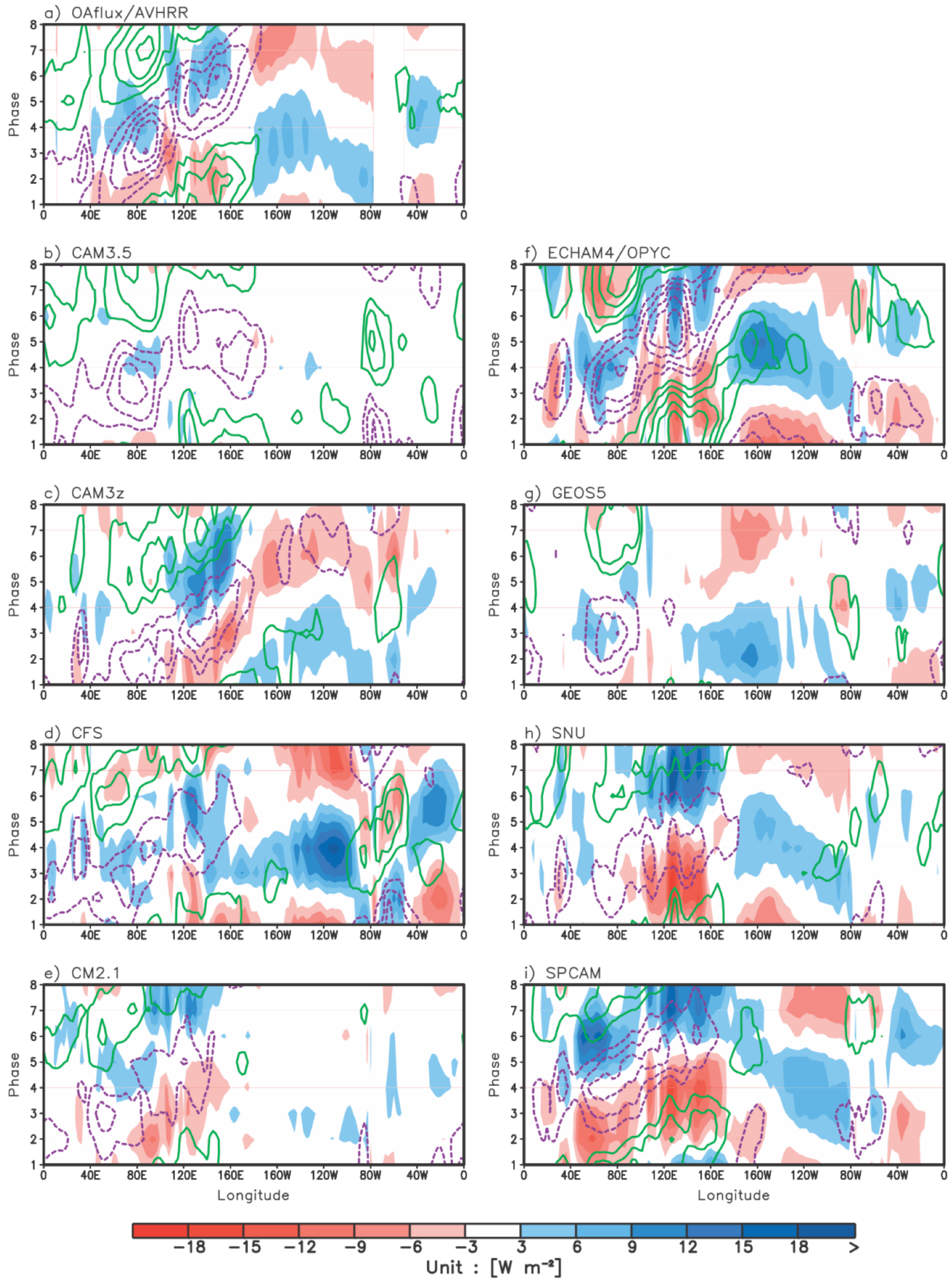


FIG. 9. Phase–longitude diagram of OLR [contour plotted every 5 W m^{-2}, positive (green) and negative (purple)] and surface latent heat flux (W m^{-2}, shaded). Phases are from MJO life cycle composite and values averaged between 5°S and 5°N.

Phase–longitude diagram of OLR

- Many models fail to produce coherent eastward propagating signals.
- The MJO fails to propagate across the Maritime Continent in many models or the signals weakened too much after moving over to the western Pacific.

Possible causes of model deficiencies

- Unrealistic heating profiles: under-representation of shallow convection and stratiform processes due to deficiencies in cumulus parameterization or coarse resolution
- Resolution: not adequate for the multi-scale structure of the MJO
- Unrealistic mean state of the GCMs: mean background state has been considered crucial to the dynamics of the MJO.
- Lack of air-sea interaction: including air-sea coupling may help improve the MJO performance in a model.

Zhang et al. 2005

Useful Links

- Ahn, M.-S., Kim, D., Kang, D., Lee, J., Sperber, K. R., Gleckler, P. J., et al. (2020). MJO propagation across the Maritime Continent: Are CMIP6 models better than CMIP5 models? *Geophysical Research Letters*, *47*, e2020GL087250. https://doi.org/ 10.1029/2020GL087250
- Kim, D., Sperber, K., Stern, W., Waliser, D., Kang, I.-S., Maloney, E., Wang, W., Weickmann, K., Benedict, J., Khairoutdinov, M., Lee, M.-I., Neale, R., Suarez, M., Thayer-Calder, K., & Zhang, G. (2009). Application of MJO Simulation Diagnostics to Climate Models, Journal of Climate, 22(23), 6413-6436.

- NOAA CPC MJO composites: http://www.cpc.noaa.gov/products/precip/CWlink/MJO/mjo.shtml#composite
- NOAA CPC MJO Forecast: http://www.cpc.noaa.gov/products/precip/CWlink/MJO/mjo.shtml#forecast
- Australian Bureau of Meteorology: http://www.cawcr.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/
- Australian Bureau of Meteorology, Monitoring and Prediction of Modes of Coherent Tropical Variability: http://www.cawcr.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR_modes/index.htm
- CLIVAR-MJO Science: MJO Science: http://www.usclivar.org/mjosci.php