Clouds in GFS

Ruiyu Sun
IMSG/EMC/NCEP

Acknowledgement: Yu-tai, Moorthi, Jongil, Fanglin, Huiya, Jun, Mark, and other colleagues in the Global Branch, the CPT team, and the Sandy funds, Dr. Songyou Hong

Clouds in GFS

- The prognostic cloud condensate was implemented into GFS in 2001 (Moorthi et al, 2001, T170L42)
- The grid-scale cloud condensation and evaporation is based on Zhao and Carr (1997) and Sundqvist et al (1989)
- Deep convection and shallow convection contribute to total cloud condensate through detrainment.
- Cloud condensate is mixed by the turbulent mixing process in the boundary layer.
- Cloud condensate is converted into precipitation.
- There is no mixed-phase cloud. Cloud ice and water partition is based on temperature and the cloud condensate at the upper level.

Grid-scale Condensation (partial cloudiness)

Sundqvist et al (1988, 1989), Zhao and Carr (1997)

$$\frac{\partial q}{\partial t} = A_q + E_c - C_g$$

$$\frac{\partial T}{\partial t} = A_t - \frac{L}{C_p}E_c + \frac{L}{C_p}C_g$$

$$q = fq_s$$

$$q_s = \epsilon e_s/p$$

$$de_s/dT = \epsilon L e_s/RT^2$$

$$C_g = \frac{M - q_s f_t}{1 + (f\epsilon L^2 q_s/RC_pT^2)} + E_c$$

$$f_t = \frac{2(1-b)(f_s - f_0)[(1-b)M + E_c]}{2q_s(1-b)(f_s - f_0) + m/b}$$

two assumptions

$$M = A_q - \frac{f\epsilon L q_s}{RT^2}A_t + \frac{fq_s\partial p}{p\partial t}$$

$$b = 1 - \left(\frac{f_s - f}{f_s - f_0}\right)^{1/2}$$

Grid-scale Cloud Evaporation

- Cloud evaporation (Ec) is allowed to take place only when relative humidity (f) is smaller than the critical relative humidity, f_0 (no condensation occurring at this grid).

$$E_c = \frac{q_s(f_0 - f)}{\Delta t(1 + \frac{\epsilon L^2 f_0 q_s}{RT^2 C_p})}$$

- In case all cloud condensate (m) is evaporated before f_0 is reached the following formula is used.

$$E_c = \frac{m}{\Delta t}$$

Clouds and Precipitation Interactions

- The conversion of the condensate (if it is water) to rain follows Sundqvist (1989) and is modified to include the accretion of cloud water by rain and snow.
- The conversion of the condensate (if it is ice) to snow is based on Lin et al. (1983).
- Condensate (if it is ice) is collected by snow (function of precipitation and cloud condensate).
- Other precipitation processes include evaporation of rain and snow, melting of snow. Precipitation is not stored in the atmosphere but falls out instantaneously. Snow and rain are distinguished.

Cloud Properties in Radiation

- The cloud cover is calculated based on Xu and Randall (1996).

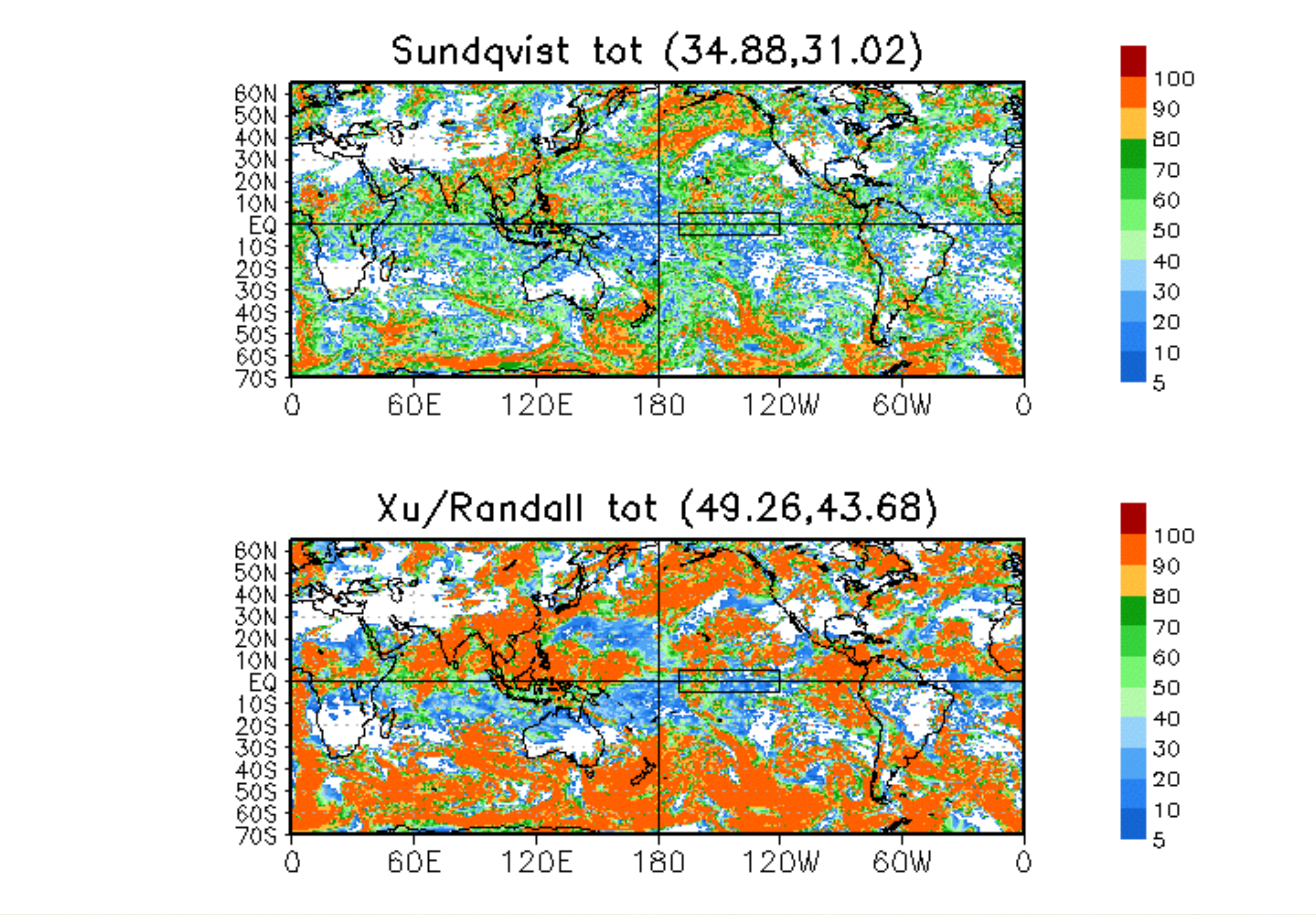
$$\sigma = RH^{k_1}\left[1-\exp\left(-\frac{k_2 q_l}{[(1-RH)q_s]^{k_3}}\right)\right]$$

where RH is relative humidity, ql is the cloud condensate, qs is saturation specific humidity, k1(=0.25), k2(=100), k3(=0.49) are the empirical parameters.

- The cloud condensate is partitioned into cloud water and ice in radiation based on temperature.
- Cloud drop effective radius ranges 5-10 microns over land depending on temperature. Ice crystal radius is function of ice water content (Heymsfield and McFarquhar (1996)).
- Maximum cloud overlapping is used in both long-wave radiation (RRTM) and short-wave radiation (RRTM2). Convective clouds are not considered in radiation.

Two Cloud Covers

Offline calculation of instantaneous cloud covers

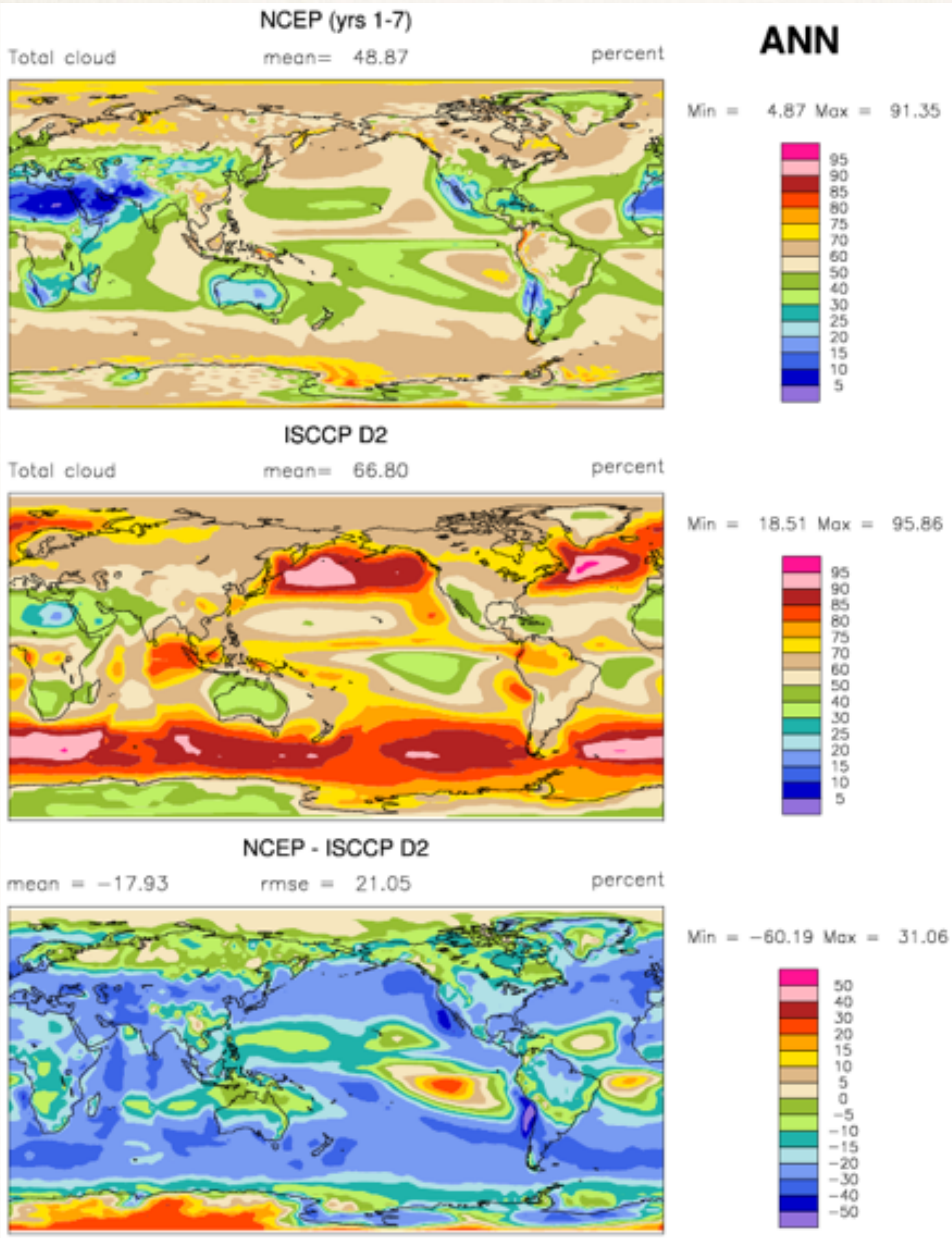


PDF clouds

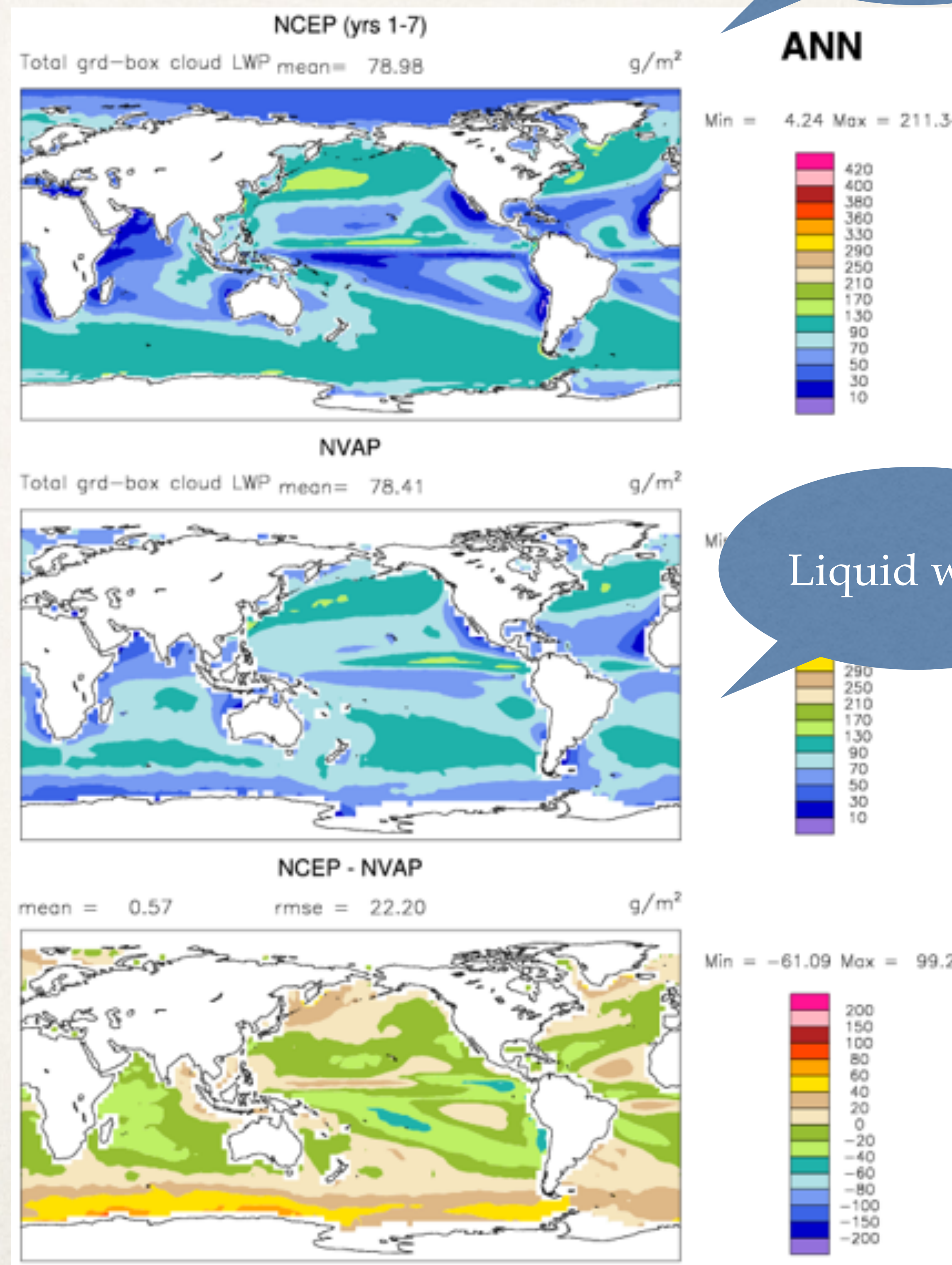
Cloud Cover and Condensate

in the GFS-MOM4 Couple Run

diagnosed by the CPT team



Total condensation

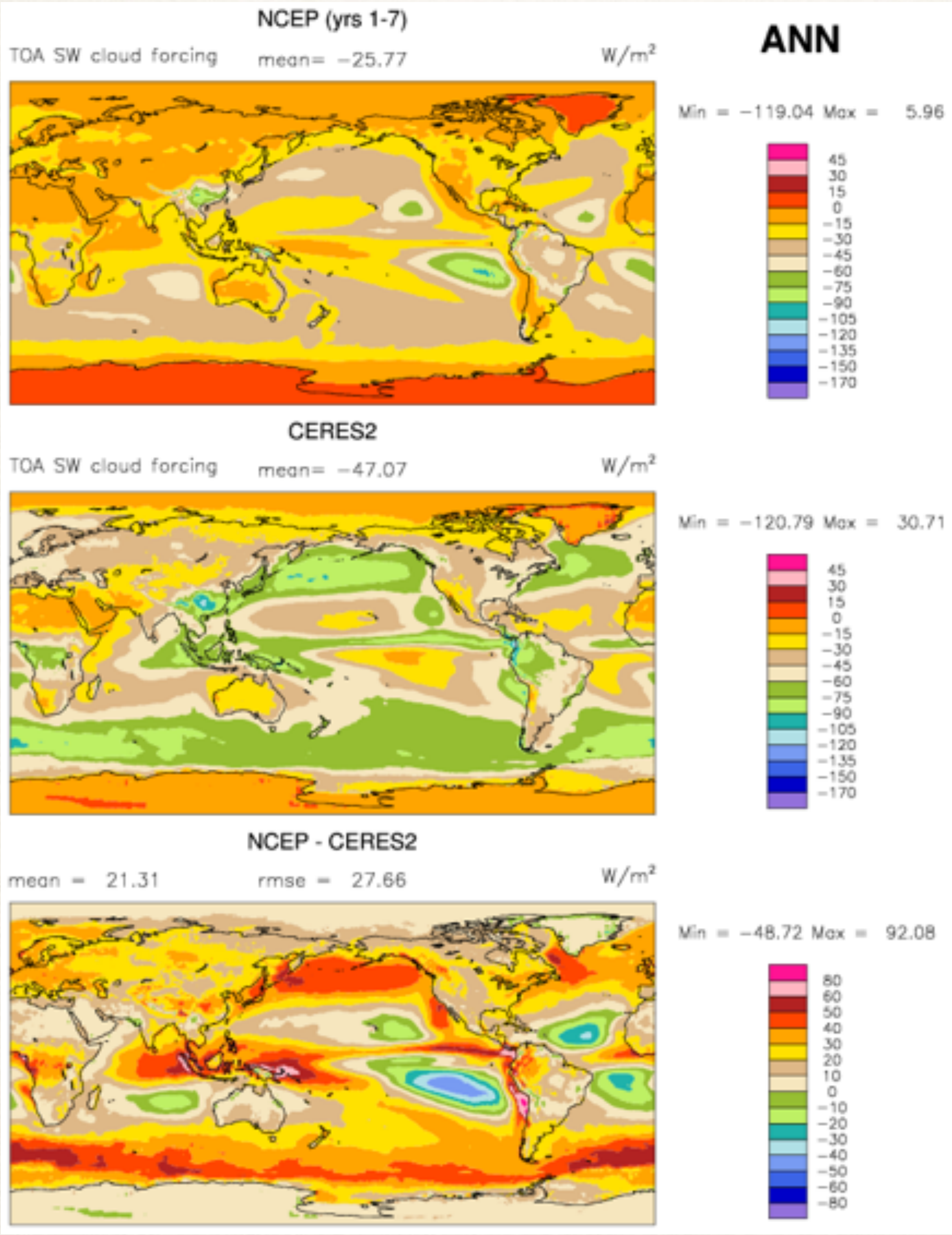


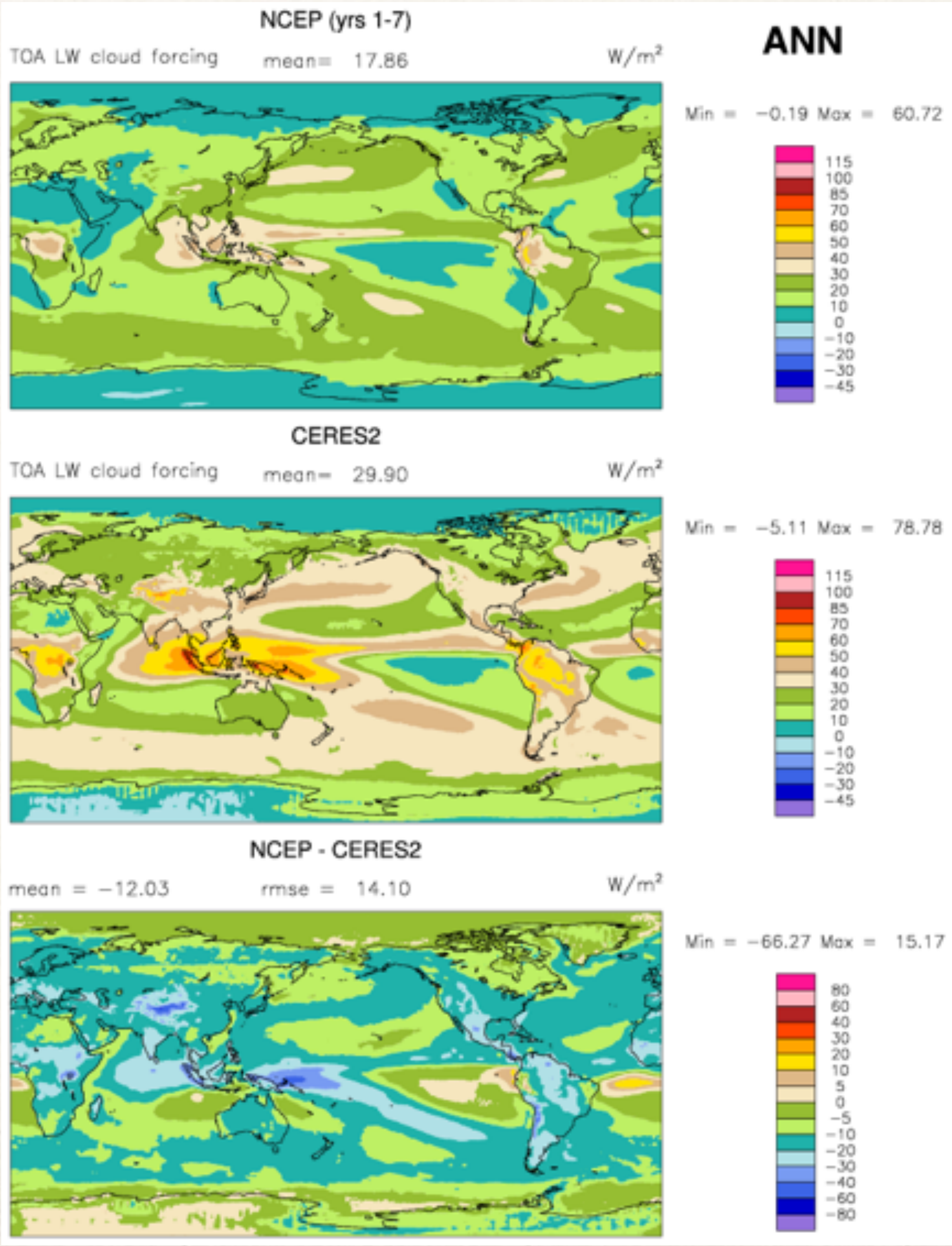
Liquid water

Radiative Effects

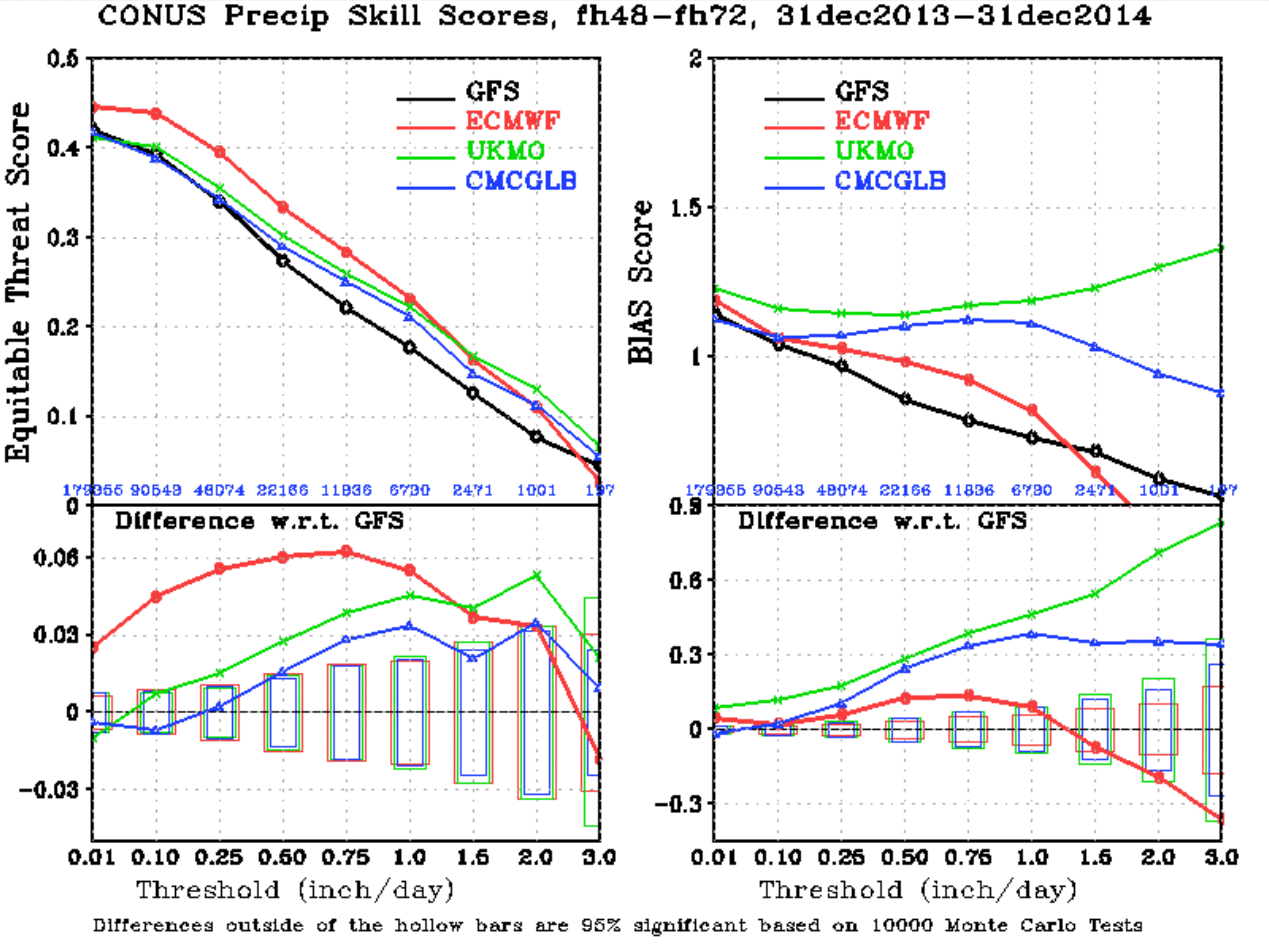
in the GFS-MOM4 Couple Run

diagnosed by the CPT team





Precipitation Skill Score (LS and Conv)



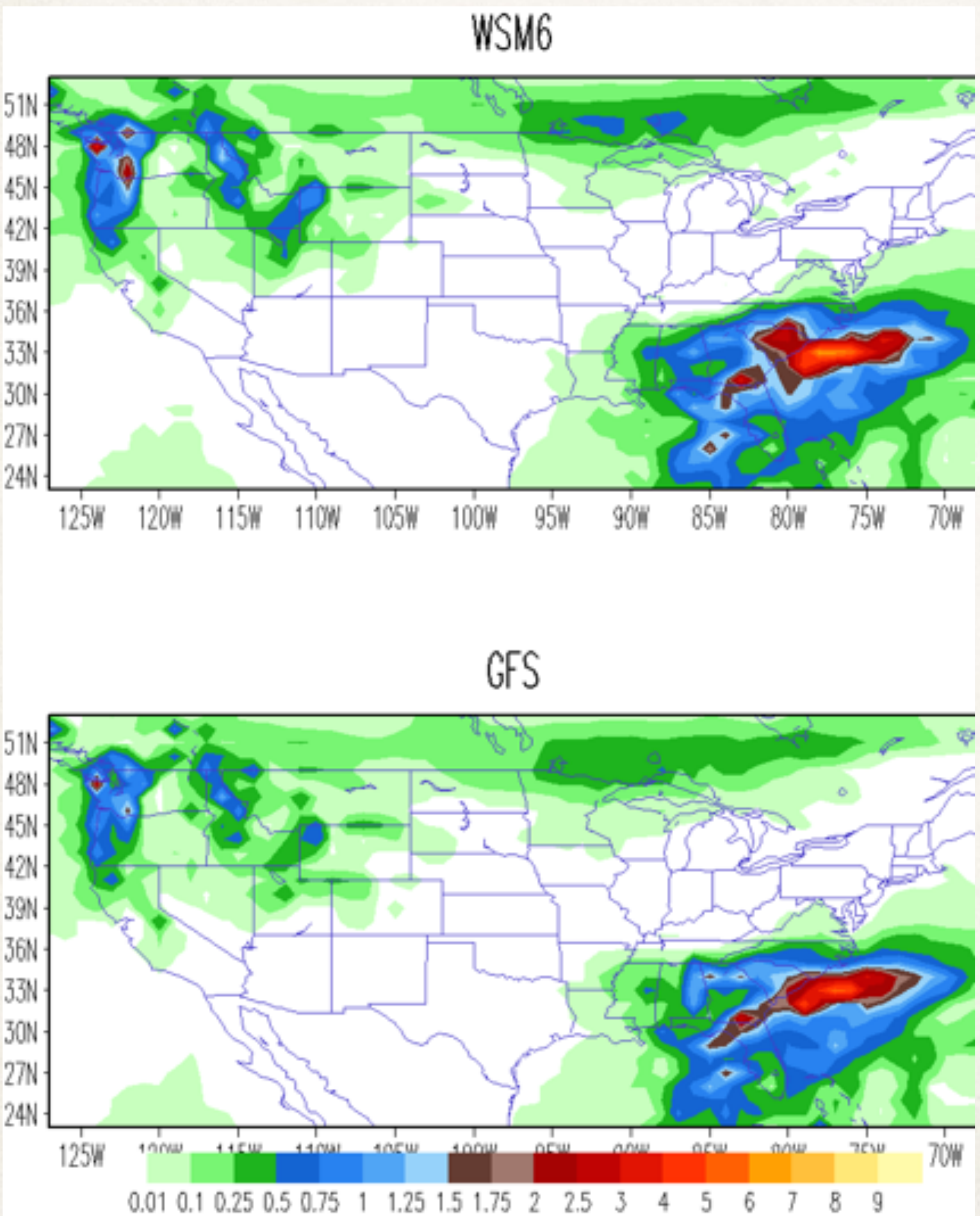
Fanglin Yang's website

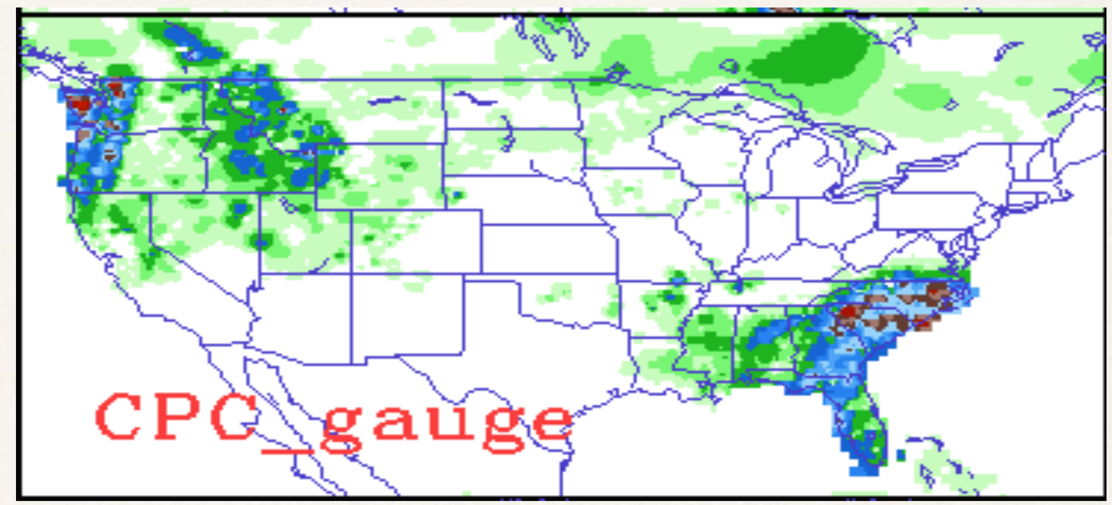
Current Efforts and Future

- Three CPTs (C. Bretherton, S. Krueger, S. Lu) are helping to improve the physics in GFS, including clouds and microphysics, aerosols, PBL, and shallow convection.
- Microphysics options: Ferrier scheme, WSM6/WDM6, Thompson scheme, and Morrison-Gettelman scheme.
  - Previous version of the Ferrier scheme has been in the GFS
  - WSM6 (and WSM5) has recently been tested in the GFS (qv, ql, qi, qr, qs, qg).

12-36h Accumulated Precipitation in GFS and WSM6

One forecast run initialized at 2014030600





Thank you !

Low Cloud Cover

in the GFS-MOM4 Couple Run

diagnosed by the CPT team