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Moisture transport and associated MJO prediction skill in a global model

~ Impact of the revised relative-humidity-dependent convection scheme ~

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1. Introduction and motivation

- Whilst every effort have been made to improve MJO prediction skill of the operational Global Spectral Model (GSM) at the Japan Meteorological Agency (JMA) because it is crucial to link operational weather and climate models, verification results suggest there are still plenty of room for improvement.
- In this study, we investigate the prediction skill of GSM, focusing on the moisture transport due to organized cloud-clusters, tropical cyclones, and MJO during the Dynamics of the Madden-Julian Oscillation (DYNAMO) period.
- Comparison with radiosonde and radar observations at the special observation sites suggests poor prediction skill of GSM in the convectively suppressed phase when dry air intrudes into the eastward propagating MJO. Accordingly, revision of the convection and cloud schemes in GSM is required.

2. Revised convection and cloud schemes and SCM experiment

- The operational JMA's global NWP model
  - Prognostic Arakawa-Schubert (AS) convection scheme with a spectral cloud ensemble
  - Large-scale cloud scheme with PDF type based on Smith (1990) with modifications
- Revised schemes
  - Introduction of new relative-humidity (RH) -dependent formulation of the entrainment rate $\varepsilon(z,i)$, inspired by Bechtold et al. (2008), in the convection scheme:

$$\varepsilon(z,i) = \varepsilon'(i)\cdot \boxed{f\left(\overline{RH}(z)\right)} \qquad f\left(\overline{RH}(z)\right) = Max\left(\frac{RH_c - \overline{RH}(z)}{\overline{RH}(z)}, 1.0\right) \times \left(\frac{q_s(z)}{q_s(z_b)}\right)^{\alpha}$$

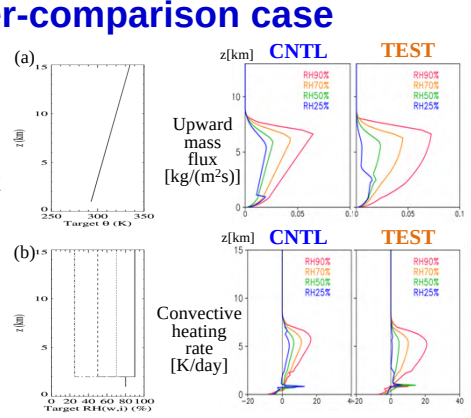
Newly-introduced part

where $RH_c = 110\%$ and $\alpha = 1.0$. $\varepsilon'(i)$ is diagnosed for each convective plume i depending on the environmental profile of moist static energy. $\overline{q}$ and $\overline{q_s}$ are the environmental and saturation specific humidity, respectively. The first and second terms in the newly-introduced part makes $\varepsilon(z,i)$ have RH-sensitive and bottom-heavy profiles, respectively.

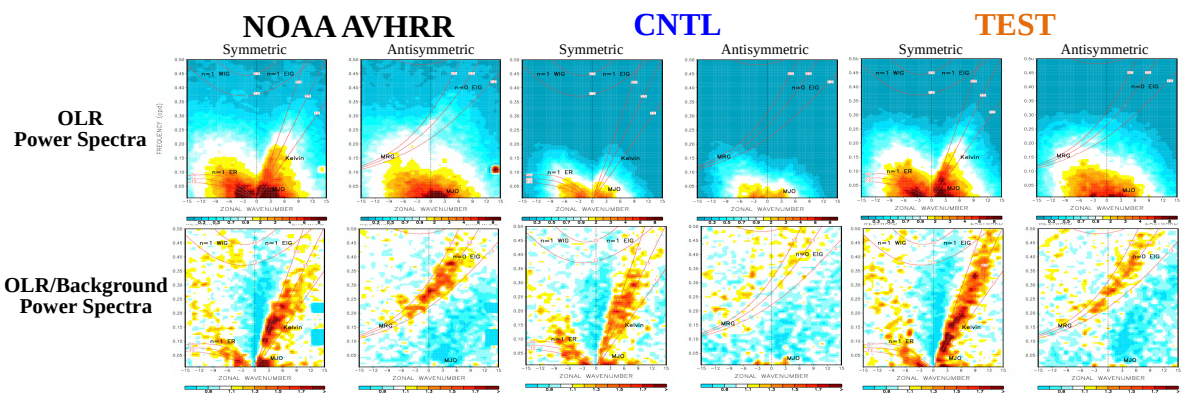
  - Modification of the time-scale parameter of snow in the large-scale cloud scheme, resulting in less snow falling to surface.

3. SCM experiment in the EUROCS inter-comparison case

- Performance of the revised schemes are investigated in the ideal single-column model (SCM) experiment in the EUROCS inter-comparison case. Potential temperature and RH profiles are nudged toward the prescribed target profiles (figs (a), (b)) with 1-hour relaxation time.
- As expected, TEST represents more sensitivity to the RH than CNTL, demonstrating the inhibited upward mass-flux and the convective heating rate when the target RH profile is 25%, whereas more mass-flux and the heating rate is reproduced with the 90% profile.

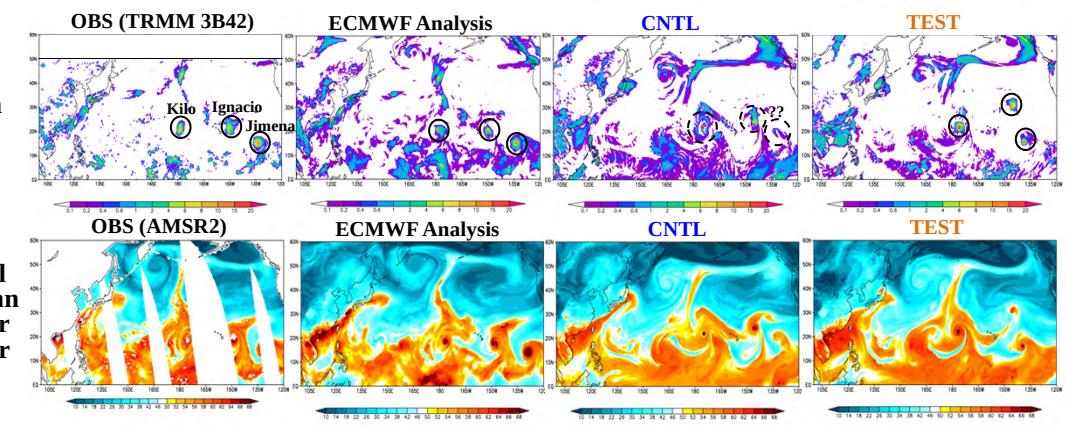


4. Wavenumber-frequency spectral analysis (7-year prediction)



- Wavenumber-frequency spectra in equatorially averaged (15N-15S) OLR for NOAA AVHRR satellite data and models (TL159L100 (~120km) with SST climatology, 2001-2007) demonstrates that TEST improved prediction skill with better-balanced tropical waves, compared with CNTL, for both OLR and OLR/background power spectra.

6. Triple tropical cyclogenesis and their moisture transport (six-day prediction)



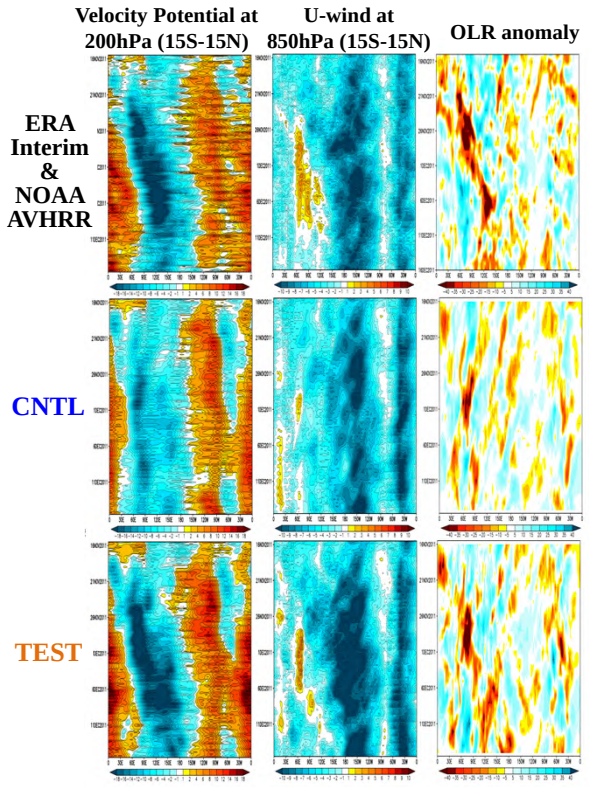
- Six-day prediction of rain and total column water vapor, simulated by GSM TL959L100 (~20km). The complicated triple tropical cyclogenesis results in poor prediction skill of their organizations and associated moisture transports in both CNTL and TEST. Due to the revised schemes, TEST has less spurious light rain and can keep more water vapor than CNTL in tropics. But, accurate prediction of the triple cyclogenesis is still challenging.

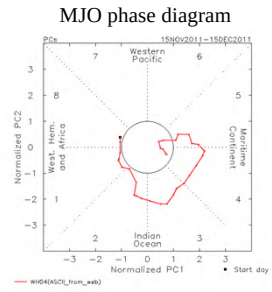
Reference

- Bechtold, P., Köhler, M., Jung, T., Doblas-Reyes, F., Leutbecher, M., Rodwell, M. J., Vitart, F. and Balsamo, G. (2008), Advances in simulating atmospheric variability with the ECMWF model: From synoptic to decadal time-scales. Q.J.R. Meteorol. Soc., 134: 1337–1351.

5. One-month prediction skill

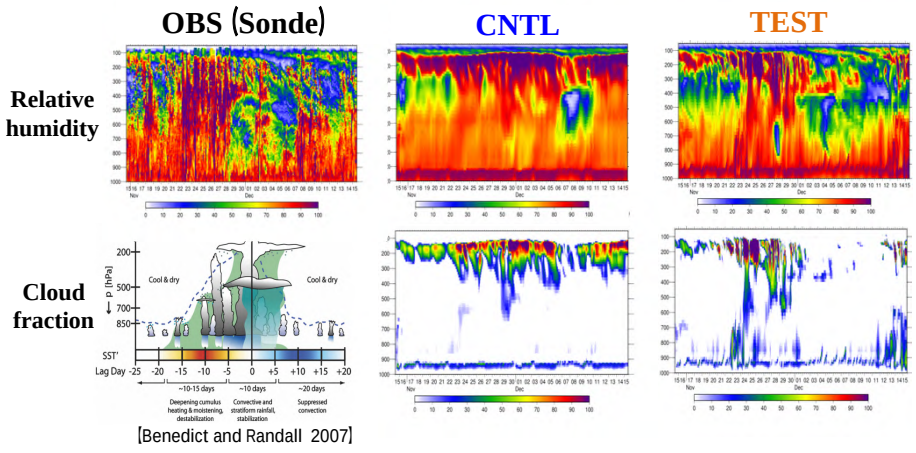
5-1. Eastward propagation of MJO





- One-month prediction by TL959L100 (~20km) with persistent SST anomaly for the MJO during DYNAMO (15 Nov 2011 to 15 Dec 2011, initiated in Indian Ocean and weakened over Maritime Continent).
- TEST significantly performs better for the eastward propagation of the MJO than CNTL, but still somehow under-estimated in the 850hPa westerly wind compared with ERA-Interim.

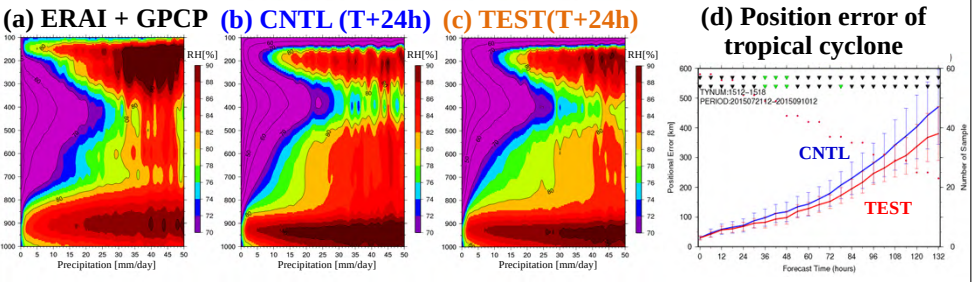
5-2. Backward tilting structure of MJO

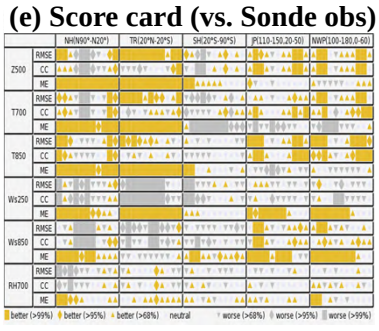


[Benedict and Randall 2007]

- Pressure-time cross sections of RH and cloud fraction at Gan island for the Sonde observation and the simulated results by CNTL and TEST.
- TEST successfully reproduces the MJO backward tilting structure with transition from shallow to deep convection, mainly due to the introduction of new RH-dependent entrainment, whereas CNTL has many erroneous deep convection occurrences regardless of the environmental RH.

7. Data assimilation and forecast cycle experiments





- Data assimilation and forecast cycle experiment during Aug 2016 enables to composite vertical profiles of RH over 10S-10N at T+24h, averaged for each bin of precipitation on x-axis (figs (a), (b), (c)). With reference of ERA-Interim and GPCP, TEST simulated better RH profiles than CNTL, showing the heavy precipitation is inhibited until the column is sufficiently moistened around 30-40 mm/day.
- TEST successfully reproduces smaller error than CNTL in the tropical cyclone track forecast over western-north Pacific region (fig (d)).
- The score card up to D+11 (fig (e)) reveals that TEST outperforms CNTL statistically (yellow color), in many elements and regions.