Nathan Arnold[1], Donifan Barahona[1], and Deepthi Achuthavarier[1,2]

1. NASA GMAO, Goddard Space Flight Center
2. USRA / GESTAR

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## Summary

Weather and climate models have long struggled to realistically simulate the Madden-Julian Oscillation (MJO). Here we present a significant improvement in MJO simulation in NASA's GEOS atmospheric model with the implementation of 2-moment microphysics and the UW shallow cumulus parameterization. Comparing ten-year runs (2007-2016) with the old (**1mom**) and updated (**2mom+shlw**) model physics, the updated model has increased intra-seasonal variance with increased coherence. Surface fluxes and OLR are found to vary more realistically with precipitation, and a moisture budget suggests that changes in rain re-evaporation and the cloud longwave feedback help support heavy precipitation. Preliminary results also show improved MJO hindcast skill.
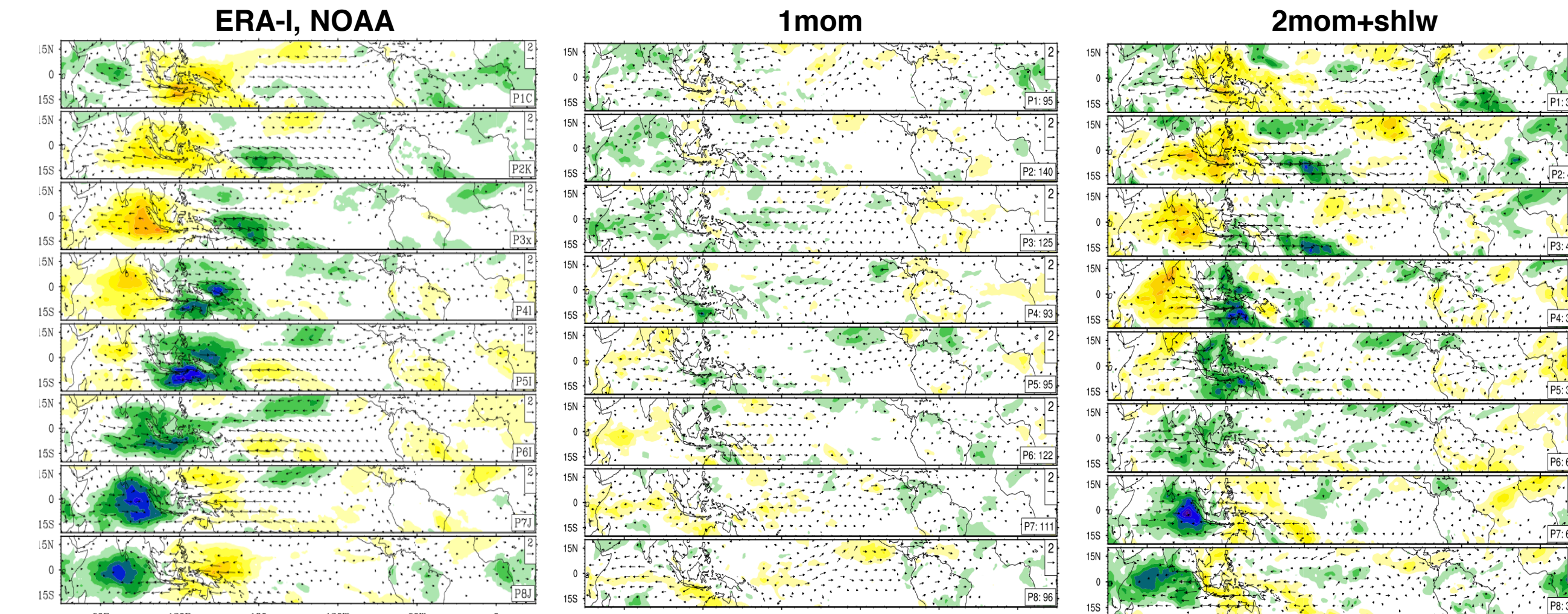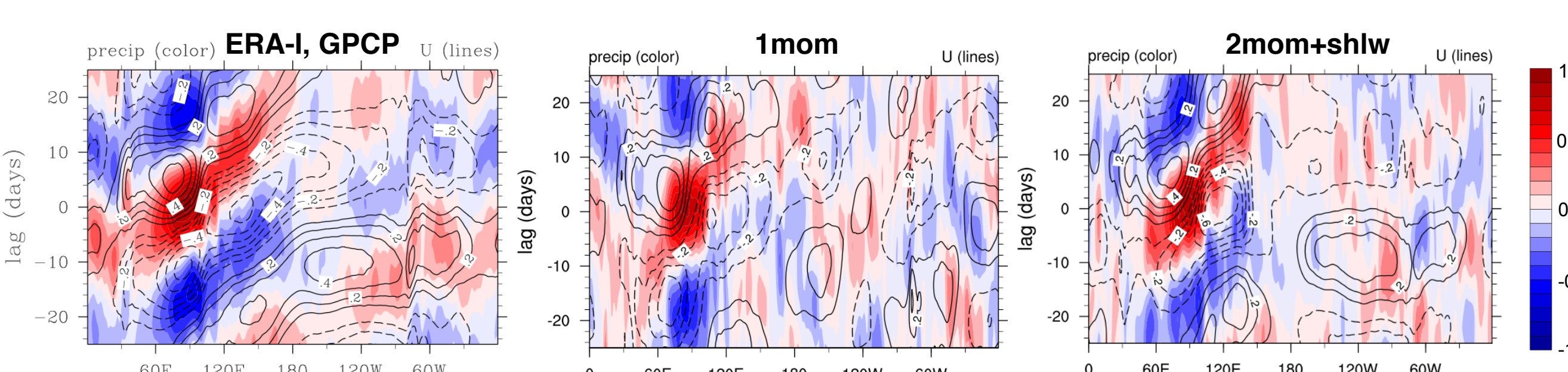
### Mean Precipitation



TRMM | 1mom | 2mom+shlw

mm/day: 0 1 2 3 4 5 6 7 8 9 10 11
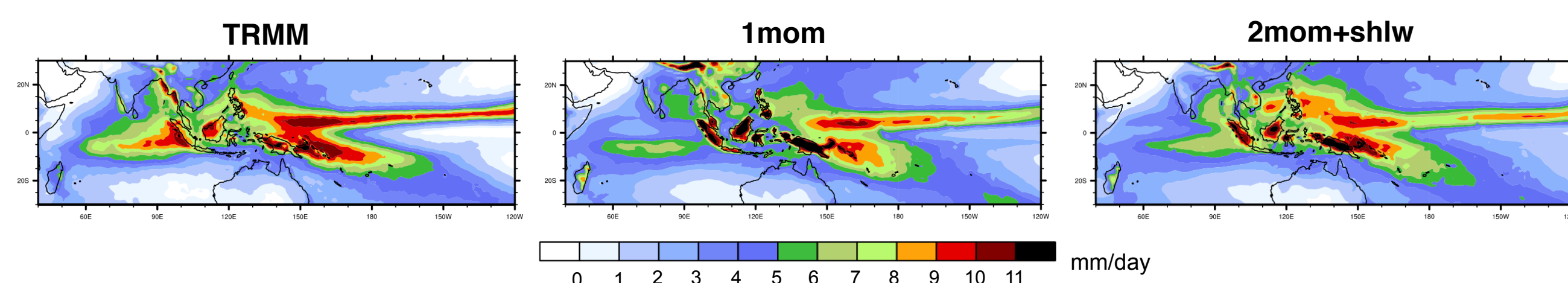
### Stronger intraseasonal variability

Maps of intraseasonal (20-100d) standard deviation.



GPCP | 1mom | 2mom+shlw

mm/day: 0 1 2 3 4 5

NOAA OLR | 1mom | 2mom+shlw

W/m²: 2 5 10 15 20 24
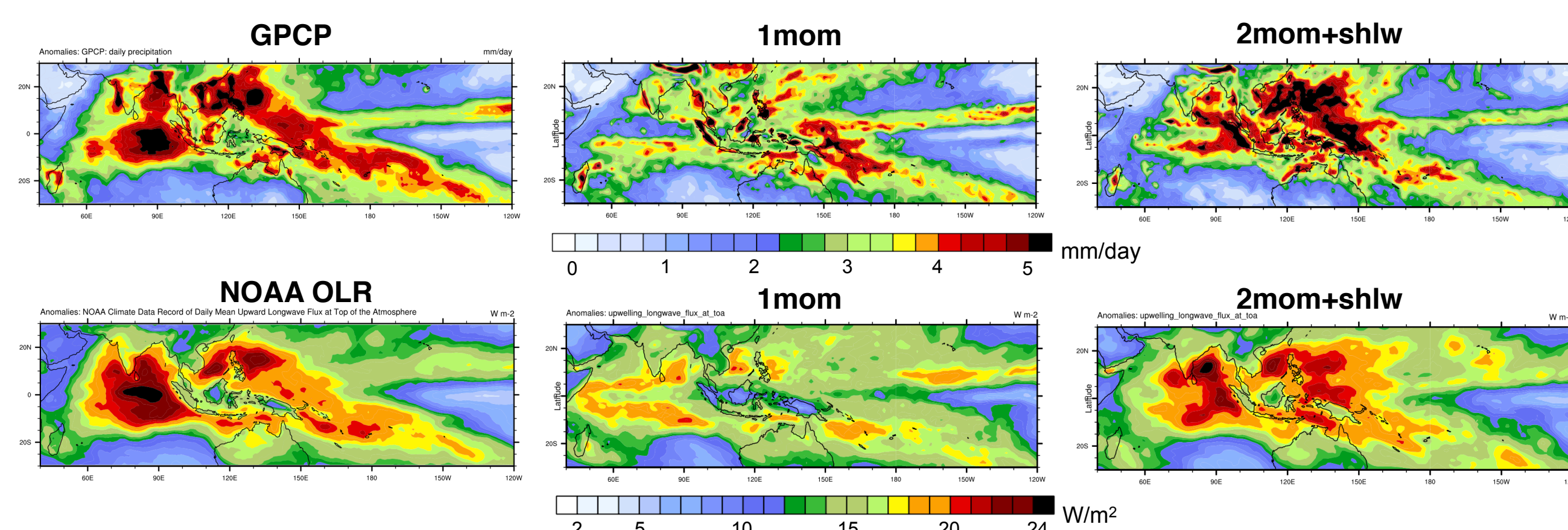
Composites of OLR and 850hPa wind for eight phases of the RMM index.



ERA-I, NOAA | 1mom | 2mom+shlw

Lag-correlation of precipitation (shading) and U850 (contours) against 20-100d precip at 90E.



ERA-I, GPCP | 1mom | 2mom+shlw

### Enhanced eastward moistening tendency

Anomaly fields regressed against 20-100 day precip averaged 80-100E, 10S-10N.



GPCP | PRECIP, 1mom | PRECIP, 2mom+shlw (mm/day)
OLR, NOAA | OLR, 1mom | OLR, 2mom+shlw (W/m²)
TPW, MERRA2 | TPW, 1mom | TPW, 2mom+shlw (kg/m²)
dTPW/dt, MERRA2 | dTPW/dt, 1mom | dTPW/dt, 2mom+shlw (kg/m²/day)
dQV/dt, MERRA2 | dQV/dt, 1mom | dQV/dt, 2mom+shlw (g/kg/day)
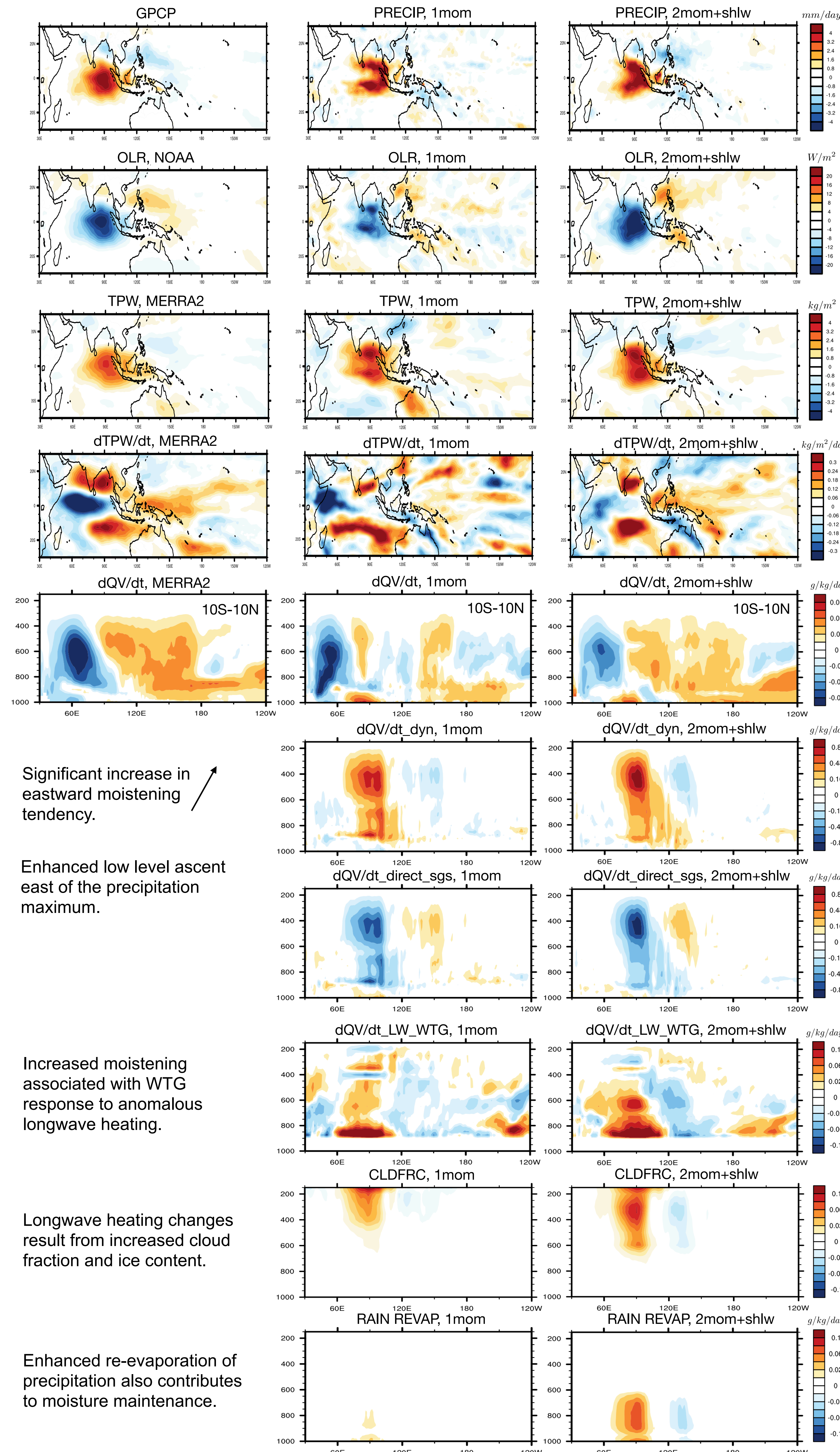
Significant increase in eastward moistening tendency.

Enhanced low level ascent east of the precipitation maximum.



dQV/dt_dyn, 1mom | dQV/dt_dyn, 2mom+shlw (g/kg/day)
dQV/dt_direct_sgs, 1mom | dQV/dt_direct_sgs, 2mom+shlw (g/kg/day)

Increased moistening associated with WTG response to anomalous longwave heating.

Longwave heating changes result from increased cloud fraction and ice content.



dQV/dt_LW_WTG, 1mom | dQV/dt_LW_WTG, 2mom+shlw (g/kg/day)
CLDFRC, 1mom | CLDFRC, 2mom+shlw (g/kg/day)

Enhanced re-evaporation of precipitation also contributes to moisture maintenance.



RAIN REVAP, 1mom | RAIN REVAP, 2mom+shlw (g/kg/day)

### Stronger radiative and surface flux feedbacks

Anomalous OLR (left) and surface enthalpy flux (right) binned by precipitation rate (60-180E, 15S-15N). In updated model, heavy precipitation rates are associated with larger longwave and surface flux anomalies, in better agreement with observations.
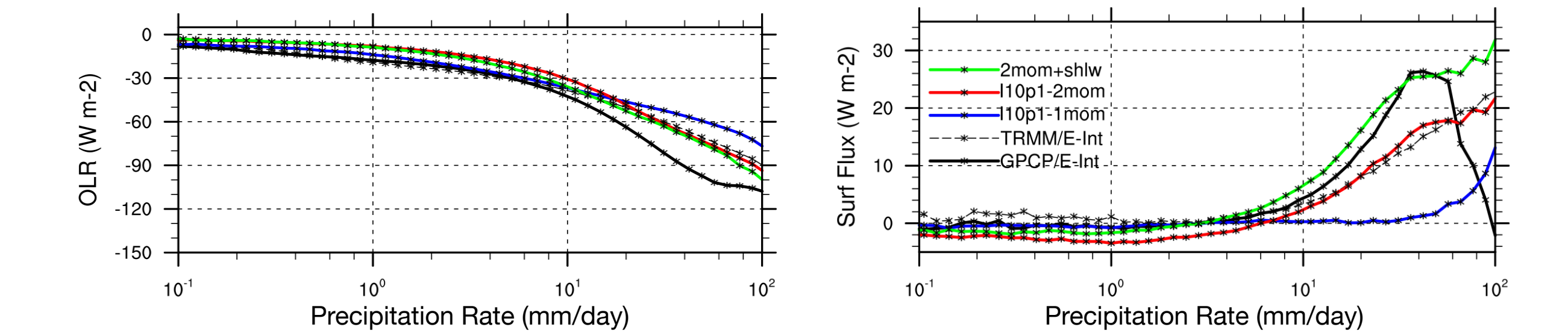


### Reduced column drying with heavy precipitation

Humidity tendency profiles binned by precipitation rate (60-180E, 15S-15N).

**1mom** marked by excessive drying at high precip rates, weak moistening with moderate precip. **2mom+shlw** allows more continuous shallow-deep convection transition, better supports deep convection.
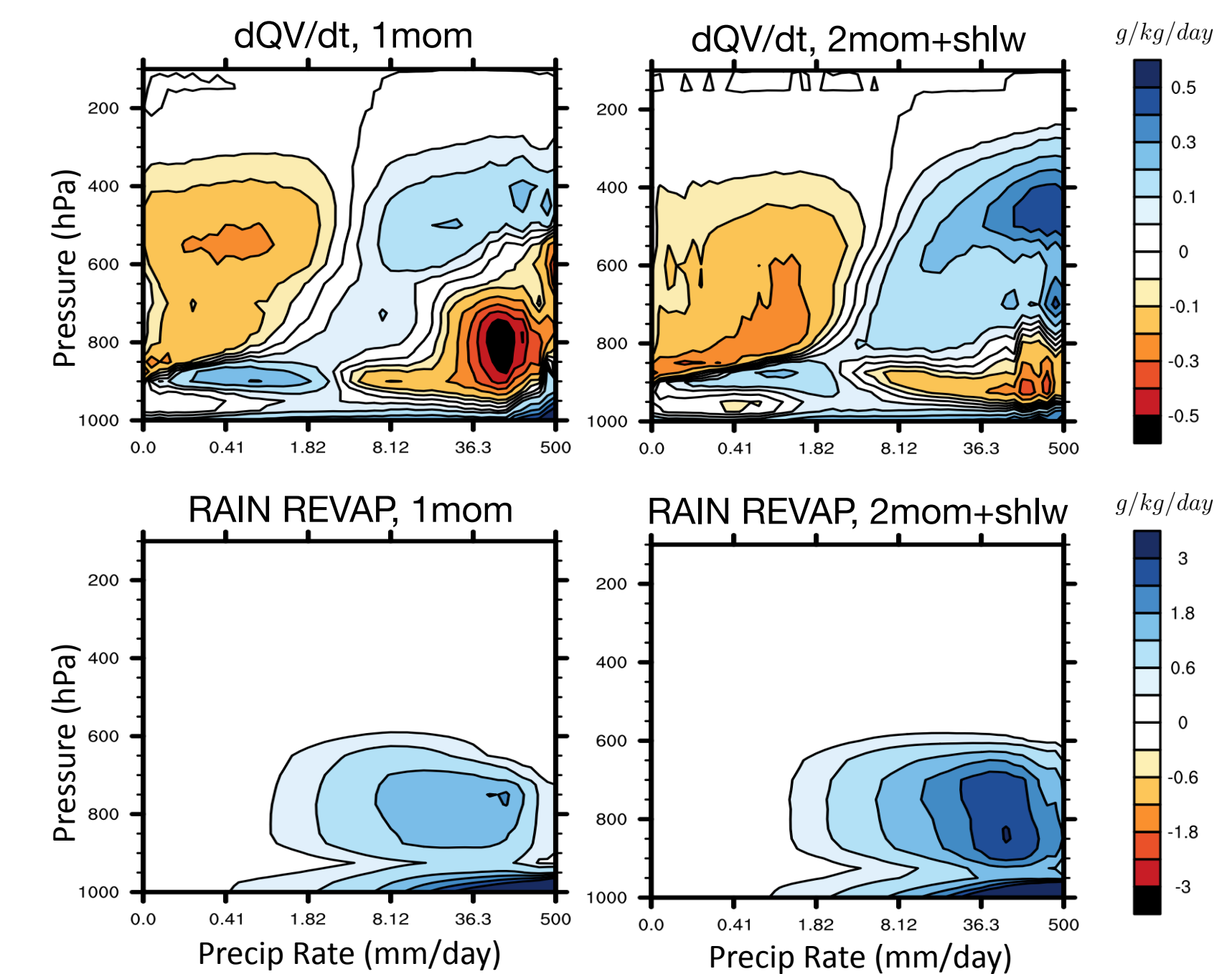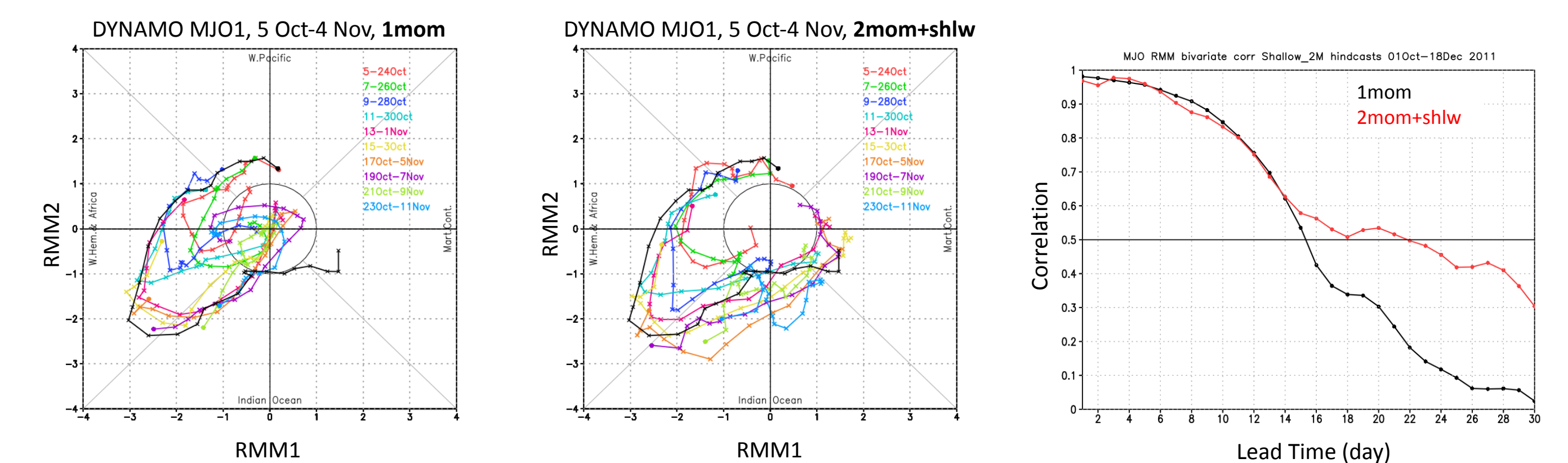
Enhanced re-evaporation of precipitation contributes to the tendency changes.



dQV/dt, 1mom | dQV/dt, 2mom+shlw (g/kg/day)
RAIN REVAP, 1mom | RAIN REVAP, 2mom+shlw (g/kg/day)

### Impact on MJO Hindcasts for the DYNAMO period

Bivariate RMM correlation vs. hindcast lead time (right), and RMM phase diagrams (left). **2mom+shlw** maintains larger MJO amplitudes and extended period of skill.

$$COR(\tau) = \frac{\sum_{t=1}^{N} [a_1(t)b_1(t) + a_2(t)b_2(t)]}{\sqrt{\sum_{t=1}^{N}[a_1^2(t) + a_2^2(t)]}\sqrt{\sum_{t=1}^{N}[b_1^2(t) + b_2^2(t)]}}$$



DYNAMO MJO1, 5 Oct-4 Nov, **1mom** | DYNAMO MJO1, 5 Oct-4 Nov, **2mom+shlw**

## Conclusions

- The addition of 2-moment microphysics and a shallow cumulus parameterization leads to much stronger MJO activity in the GEOS model.
- The proximate cause is greater moistening coincident with and east of intra-seasonal precip over the Indian Ocean.
- Coincident moistening seems due to enhanced re-evaporation of precipitation, and shallow WTG ascent associated with an improved longwave feedback.
- Mechanisms of eastward moistening are less clear, but due in part to enhanced shallow ascent.

*E-mail:* nathan.arnold@nasa.gov | *Web:* gmao.gsfc.nasa.gov

National Aeronautics and Space Administration