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Observed vegetation-climate feedbacks in the Australian and Chinese monsoon regions

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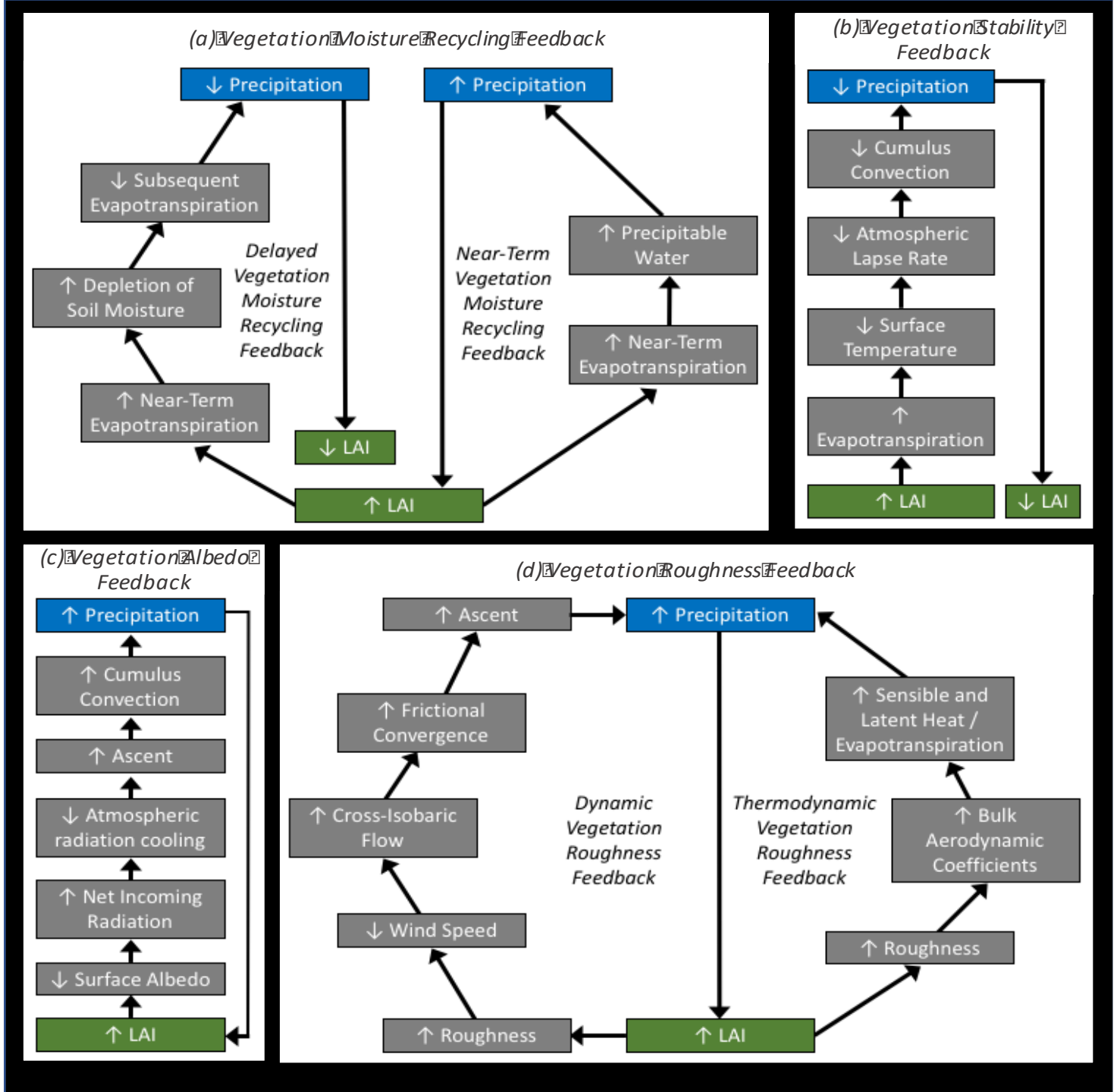
Background

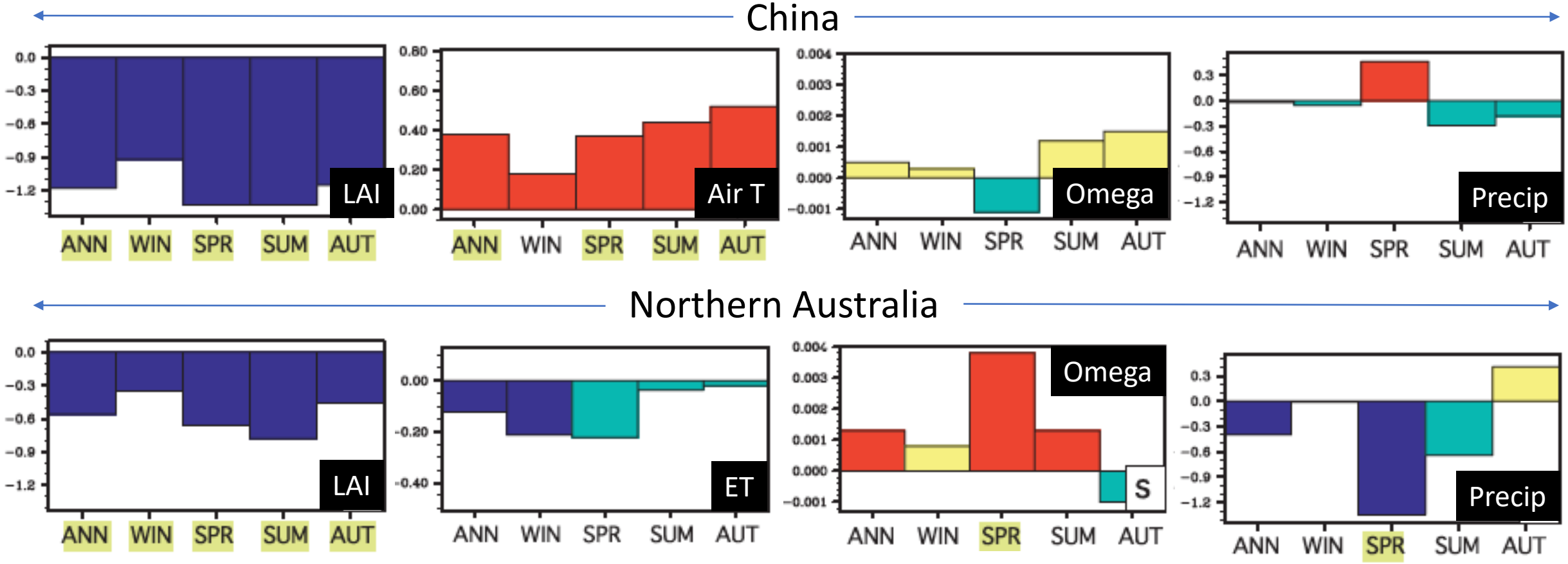
Vegetation affects the atmosphere through biophysical feedbacks by altering albedo, roughness, and transpiration and thereby modifying energy, momentum, and moisture exchanges with the atmosphere.

Global monsoon regions respond uniquely to vegetation feedbacks (Xue et al. 2010; Notaro et al. 2011).



Background

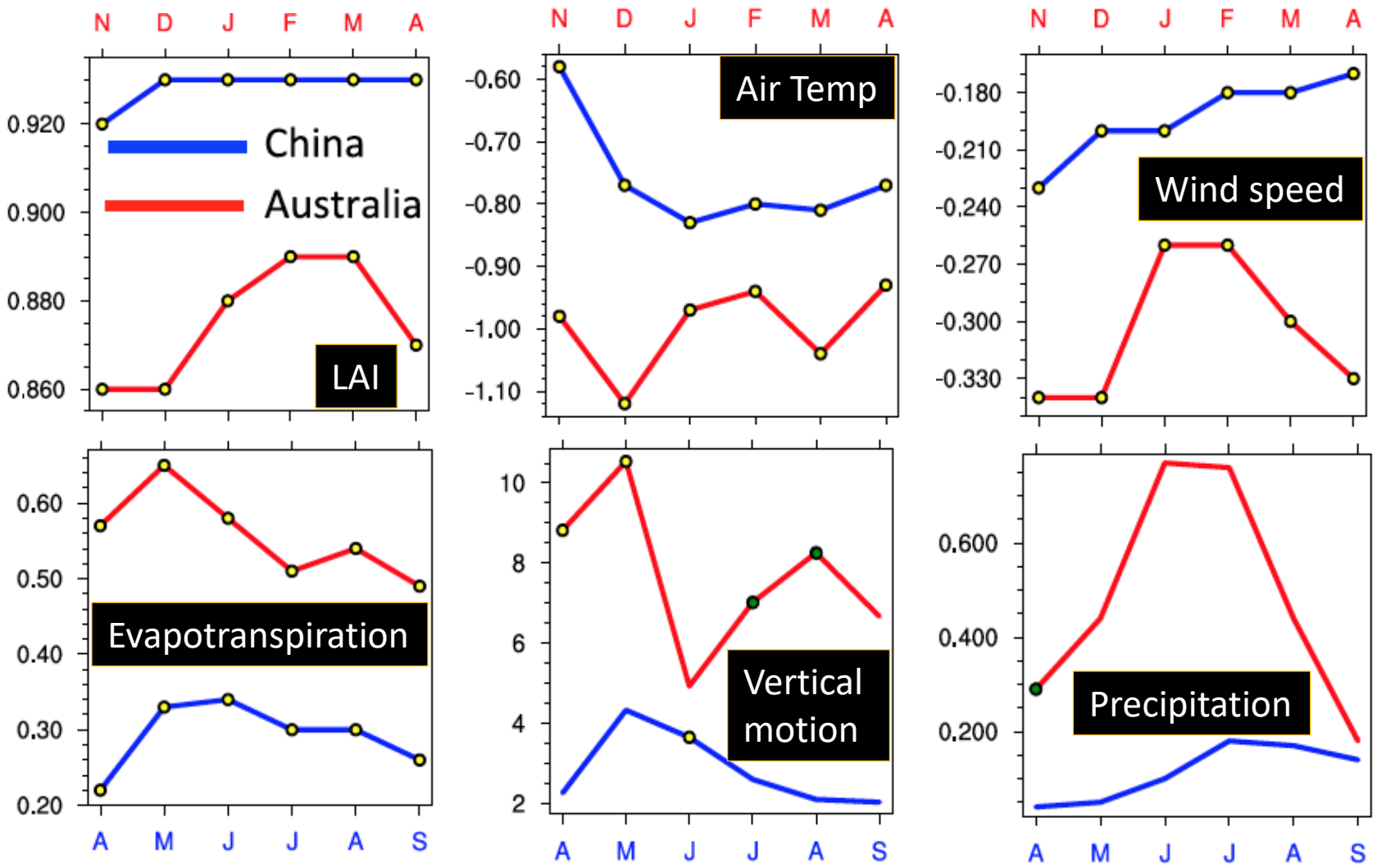
CCSM3.5-CLM simulated opposite precipitation responses in China and northern Australia to reductions in vegetation cover (Notaro et al. 2011).



Decrease (p<0.1) Decrease (p>0.1) Increase (p>0.1) Increase (p<0.1)

Background

RegCM4-CLM simulates different responses (Notaro et al. 2017).



Mostly insignificant precipitation response in both regions due to competing feedback mechanisms.

Dot: significant response ($p<0.1$)

Method: Stepwise Generalized Equilibrium Feedback Assessment (SGEFA)

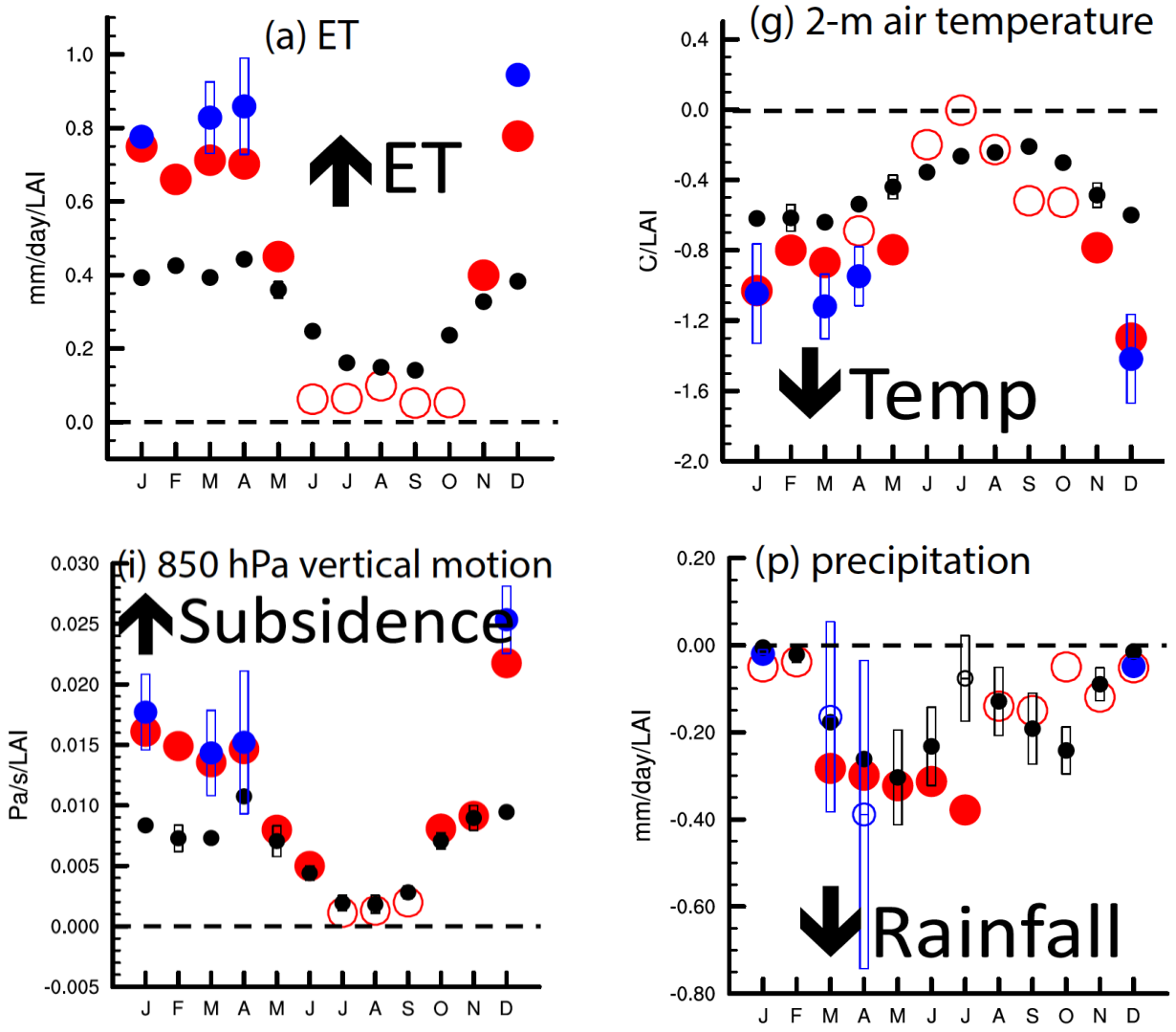
- Multivariate statistical method (Liu et al. 2008): Extracts the observed or simulated forcing of slowly-evolving variable (SST, LAI) on rapidly-changing atmosphere.
- The response of an atmospheric variable at time *t*, **A**(*t*), to a terrestrial variable, **V**(*t*), can be deduced as the feedback matrix **B**.

$$B = \frac{\langle A(t), V(t-\tau)\rangle}{\langle V(t), V(t-\tau)\rangle}$$

<A, V> is the covariance between A and V. τ is time scale, exceeding atmospheric adjustment time (here τ=1 month)

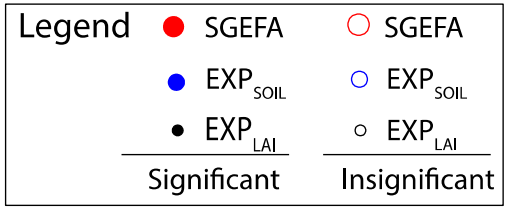
- To minimize sampling error, unimportant forcings are eliminated using an Akaike Information Criterion-based stepwise selection.
- Statistical significance of **B** is assessed using Monte Carlo bootstrap method.
- Forcings include: area-average NDVI over northern and southeastern Australia, southeastern and northeastern China, for Australia and China, respectively, and leading 2 EOFs of SSTs in 8 ocean basins.
- Responses from multiple observational datasets is assessed and weighted based on regional data reliability.

Validation of SGEFA in assessing vegetation feedbacks in Sahel



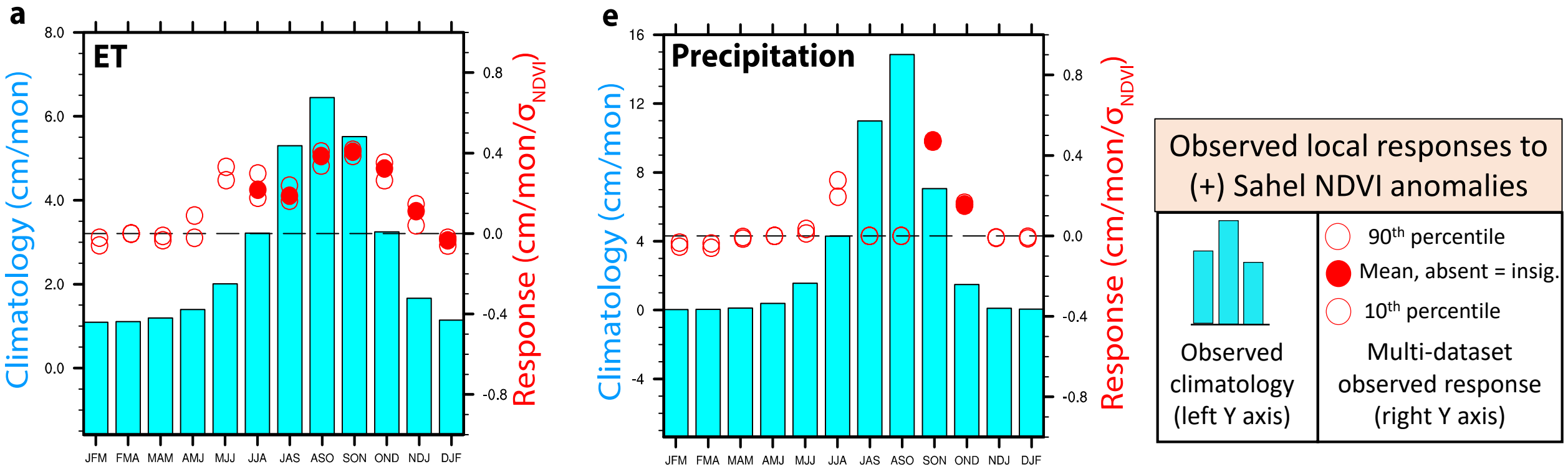
Seasonal cycle of local responses to (+) Sahel LAI anomalies from EXP_{LAI}, EXP_{SOIL}, and SGEFA applied to CTRL in CESM

Statistical GEFA assessment in the CTRL is much more consistent with dynamical assessment from EXP_{SOIL} than EXP_{LAI}, suggesting that GEFA captures the combined impact of vegetation and soil moisture anomalies (Yu et al. 2018).



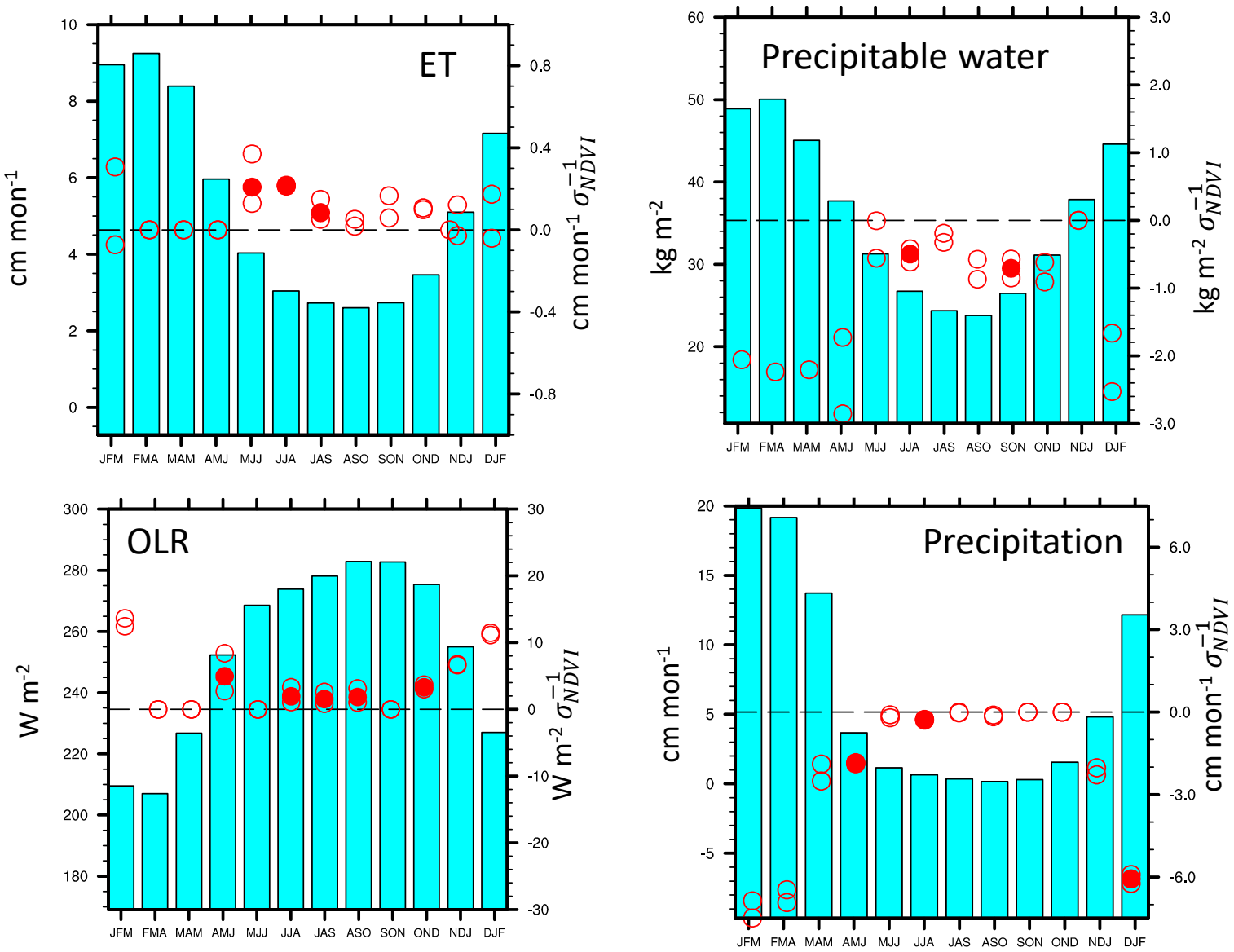
Boxes: 90% confidence interval

SGEFA identifies observed positive vegetation-rainfall feedbacks in the Sahel

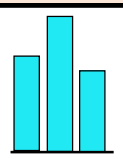


Based on SGEFA applied to multiple observational, satellite, and reanalysis data, positive anomalies of Sahel vegetation during the late and post-monsoon season favor enhanced ET, precipitable water, convective activity (reduced OLR), precipitation frequency, and total precipitation amount, indicative of amplified moisture recycling (Yu et al. 2017).

Observed vegetation-climate feedbacks in northern Australia



Observed local responses to (+) NDVI anomalies



Observed climatology (left Y axis)

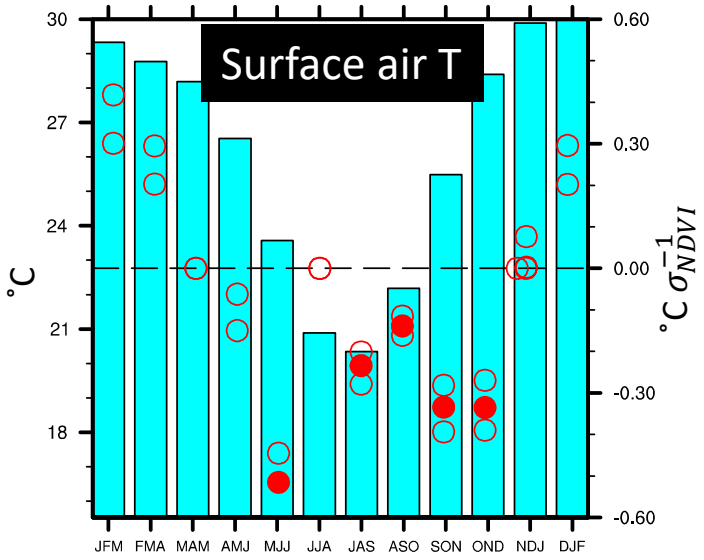
90th percentile

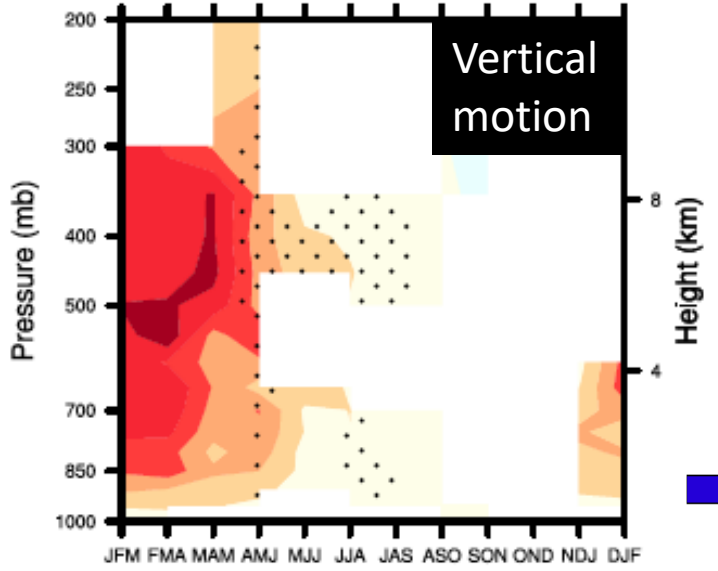
Mean, absent = insig.

10th percentile

Multi-dataset observed response (right Y axis)

Observed vegetation-climate feedbacks in northern Australia

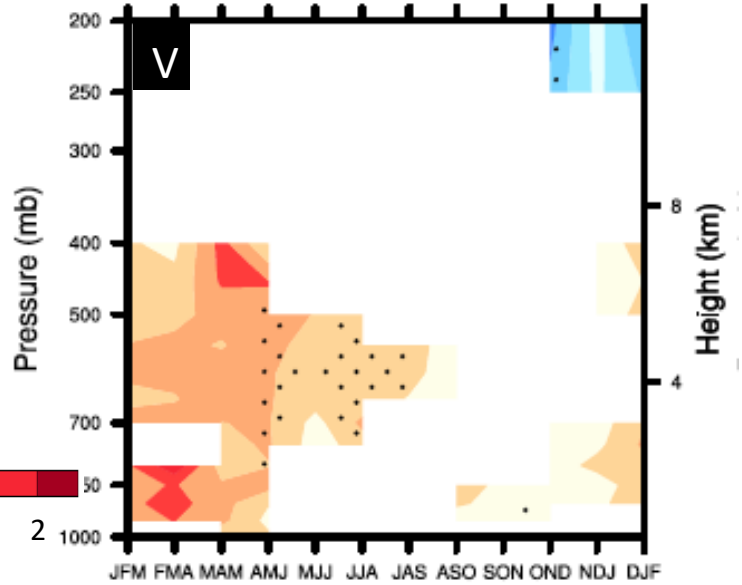




Observed local responses to (+) NDVI anomalies

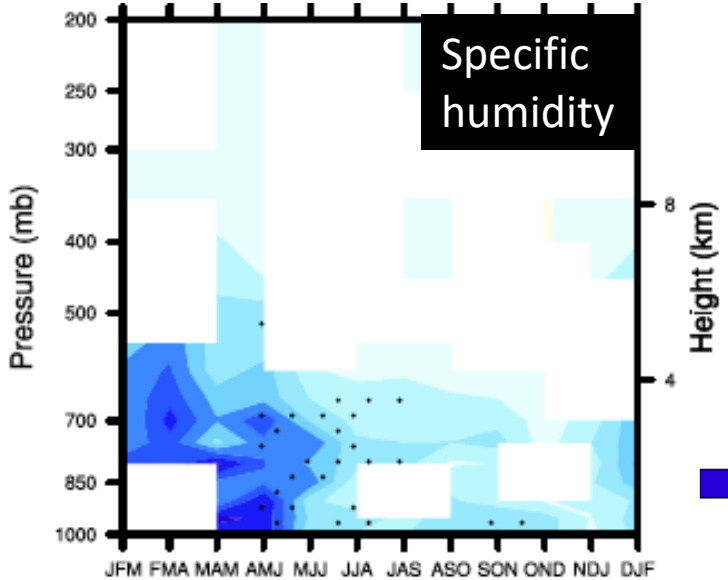
10^{-3} Pa s^{-1} σ_{NDVI}^{-1}

-4 -3 -2 -1 0 1 2 3 4



m s^{-1} σ_{NDVI}^{-1}

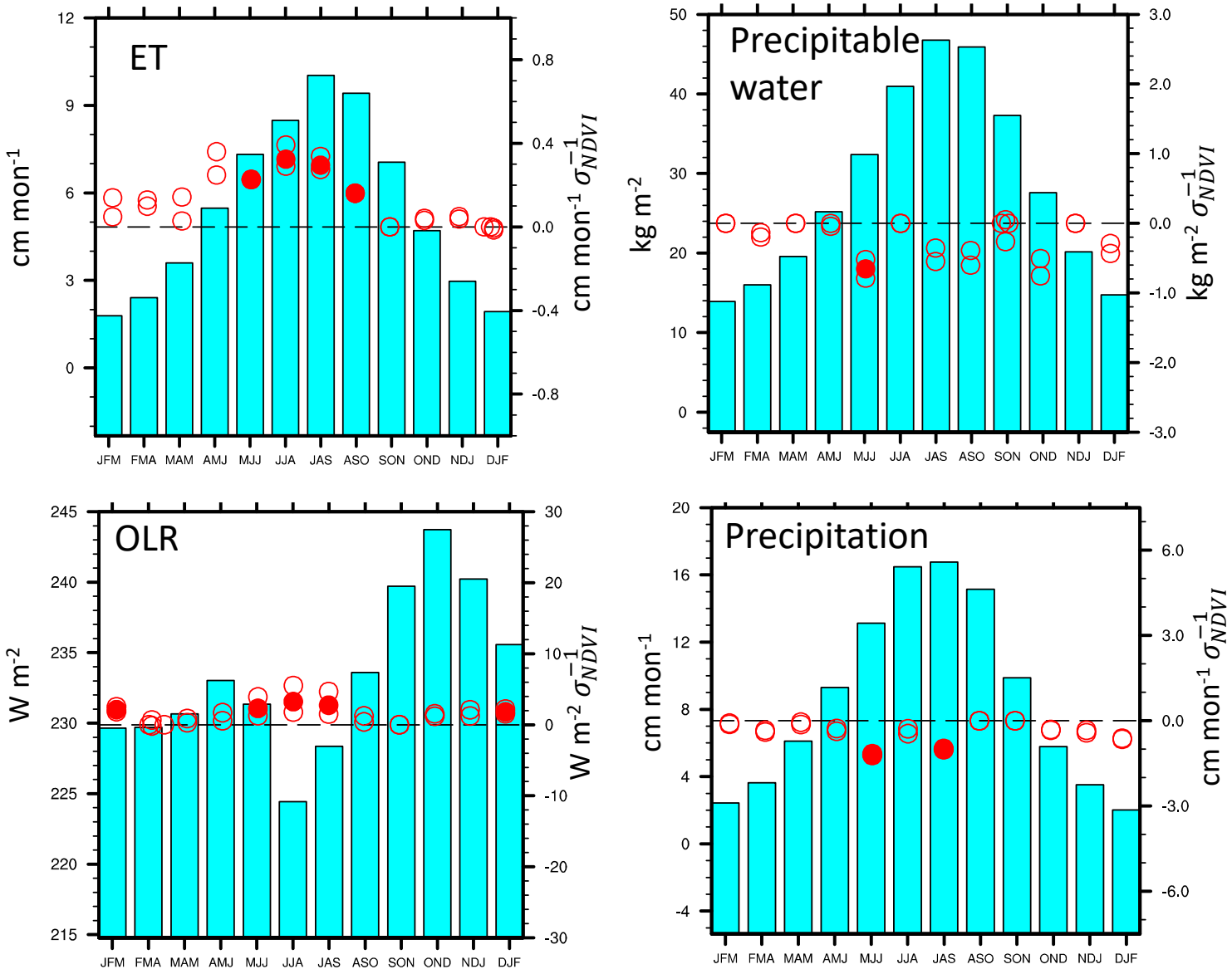
-2 -1.2 -0.4 0.4 1.2 2



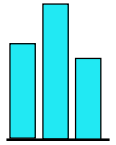
g kg^{-1} σ_{NDVI}^{-1}

-1.2 -0.8 -0.4 0 0.4 0.8 1.2

Observed vegetation-climate feedbacks in eastern China



Observed local responses to (+) NDVI anomalies



Observed climatology (left Y axis)

90th percentile

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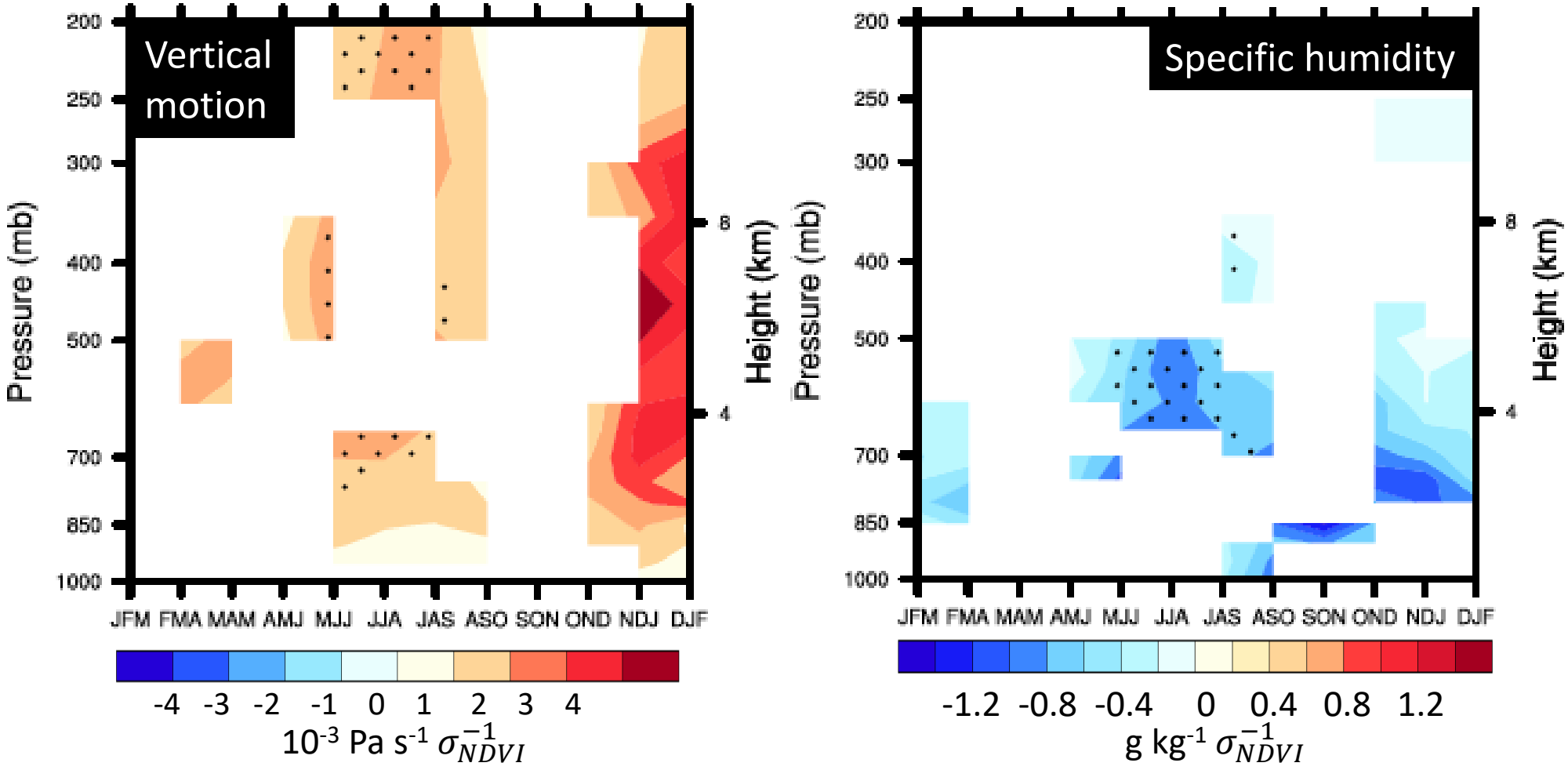
Multi-dataset observed response (right Y axis)

Observed vegetation-climate feedbacks in eastern China

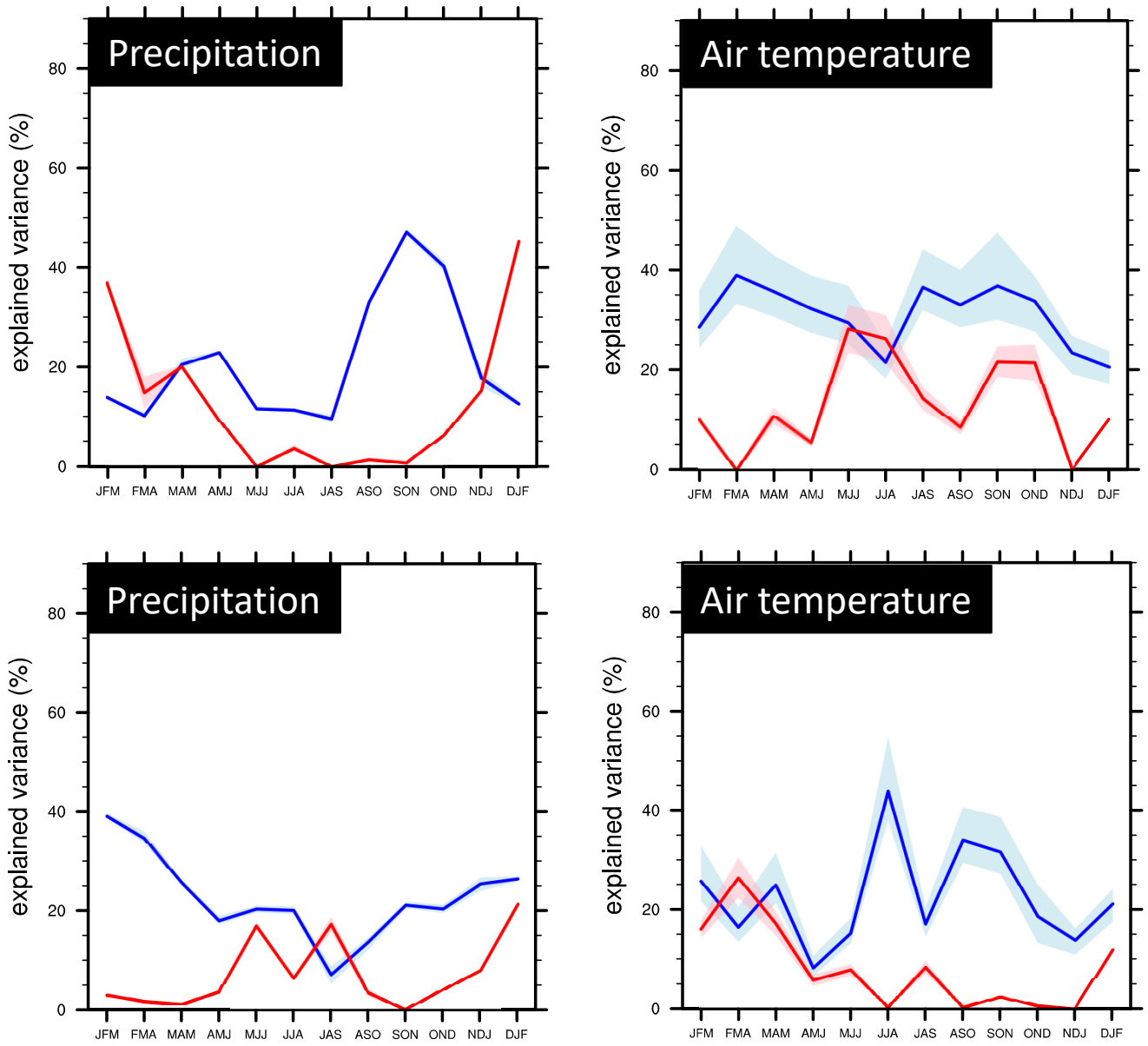
Observed local responses to (+) NDVI anomalies



Observed relative importance of oceanic versus terrestrial drivers

Australia

China



Legend

Ocean

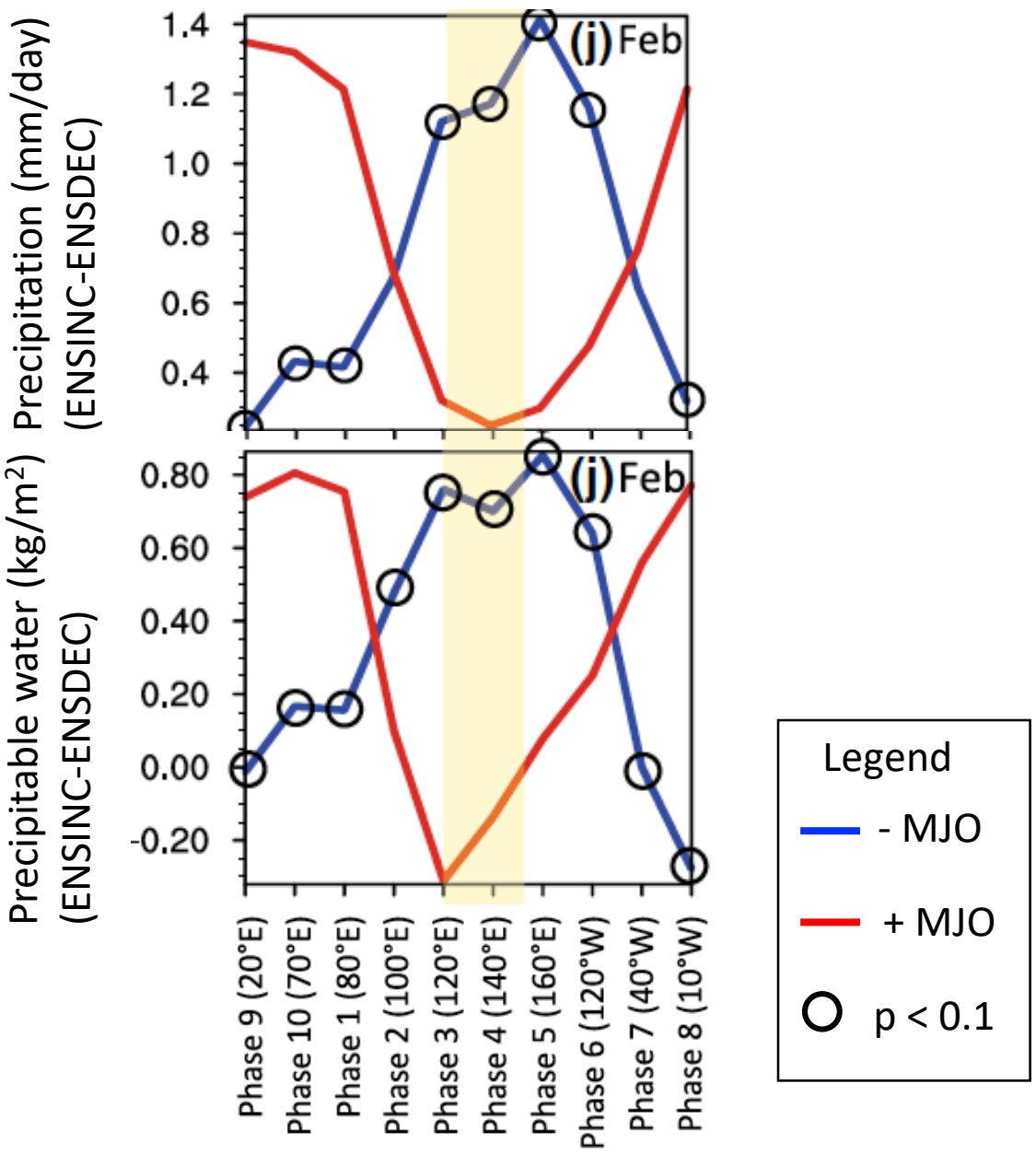
Land

Line: multi-dataset average

Shading: multi-dataset uncertainty range (10th and 90th percentiles)

Vegetation-climate feedbacks depend on background atmospheric state

Convectively-active Madden-Julian Oscillation phases support enhanced positive vegetation-rainfall feedbacks on the Australian summer monsoon through intense low-level convergence and efficient precipitable water conversion, based on RegCM4 (Notaro 2018).



Summary

- SGEFA-based observational evidence supports the RegCM4 findings (Notaro et al. 2017) regarding the vegetation moisture recycling and vegetation stability feedbacks in the Australian and Chinses monsoon regions.
- Unlike the RegCM4 conclusions, observational analysis suggest negative vegetation-rainfall feedbacks in both monsoon regions, due to the dominant stability mechanism. In addition, positive NDVI anomalies in northern Australia support surface cooling and weaker land-ocean heat contrast, thereby leading to earlier withdrawal of summer monsoon.

Future work

- The hypothesis regarding MJO's modulation on the vegetation-rainfall feedbacks in northern Australia (Notaro et al. 2018) needs to be tested in observations.
- Further investigation the dependence of vegetation-climate feedbacks on background atmospheric state.
- Identify regions where each vegetation-rainfall feedback mechanism dominates.