A Stochastic Skeleton Model for the MJO and ENSO

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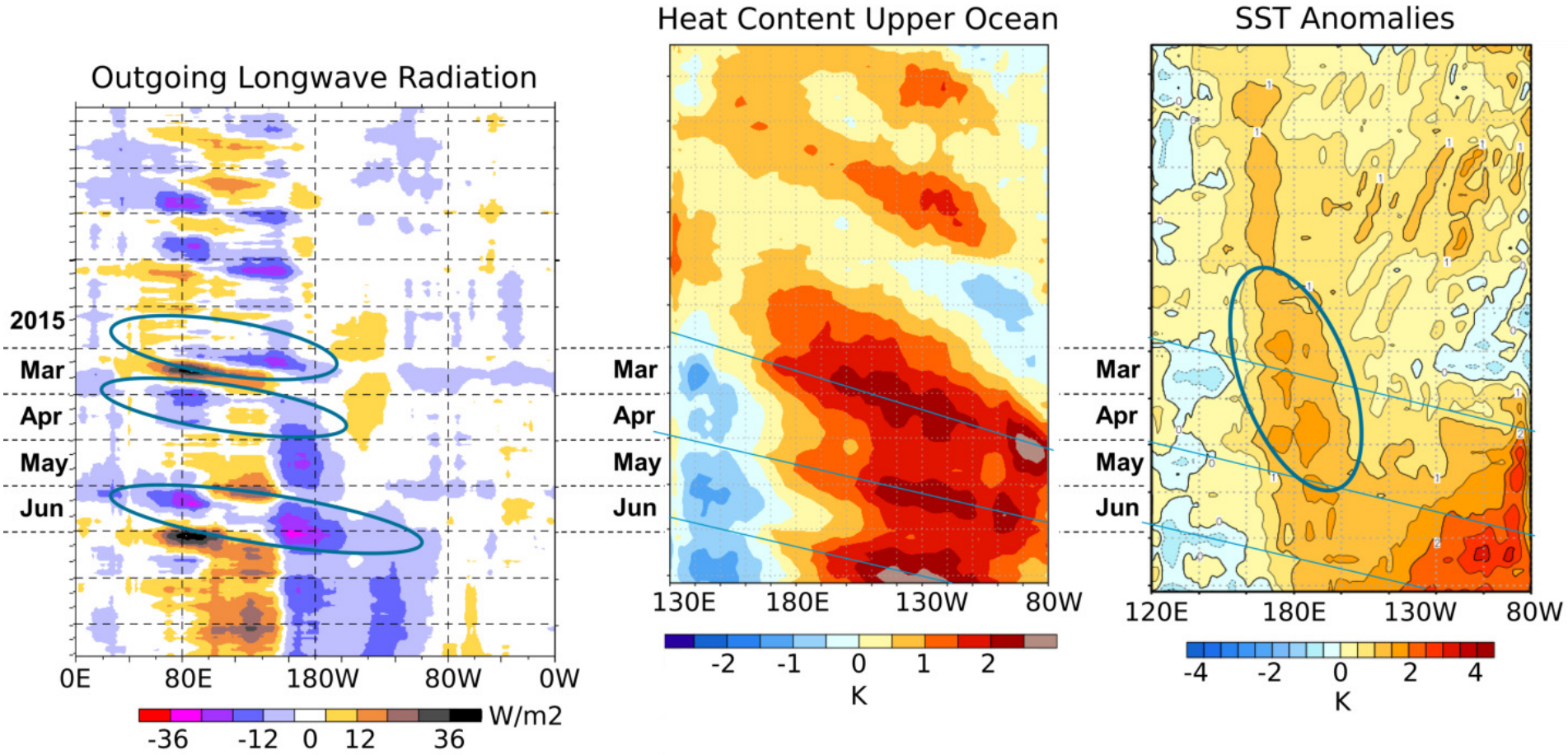
Role of organized/coherent intraseasonal variability and wind bursts on the ENSO ?
e.g. Madden-Julian Oscillation (MJO) wavetrain during El Niño 2015 onset

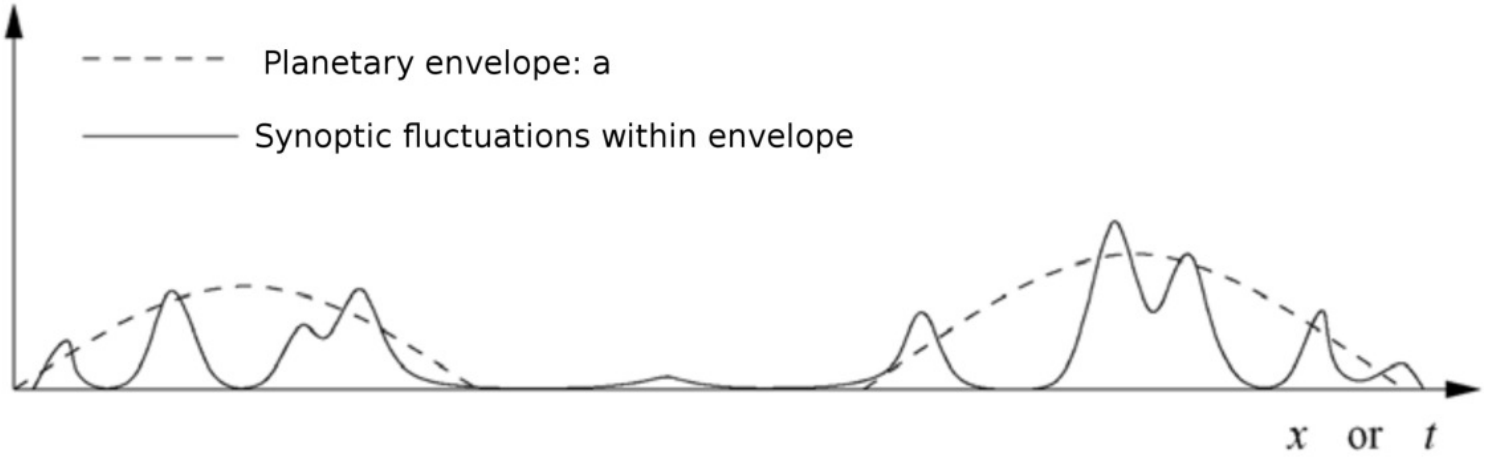


(Marshall 2016 ARCCSS)

We model the relationship using a simple **skeleton model atmosphere** for the MJO,

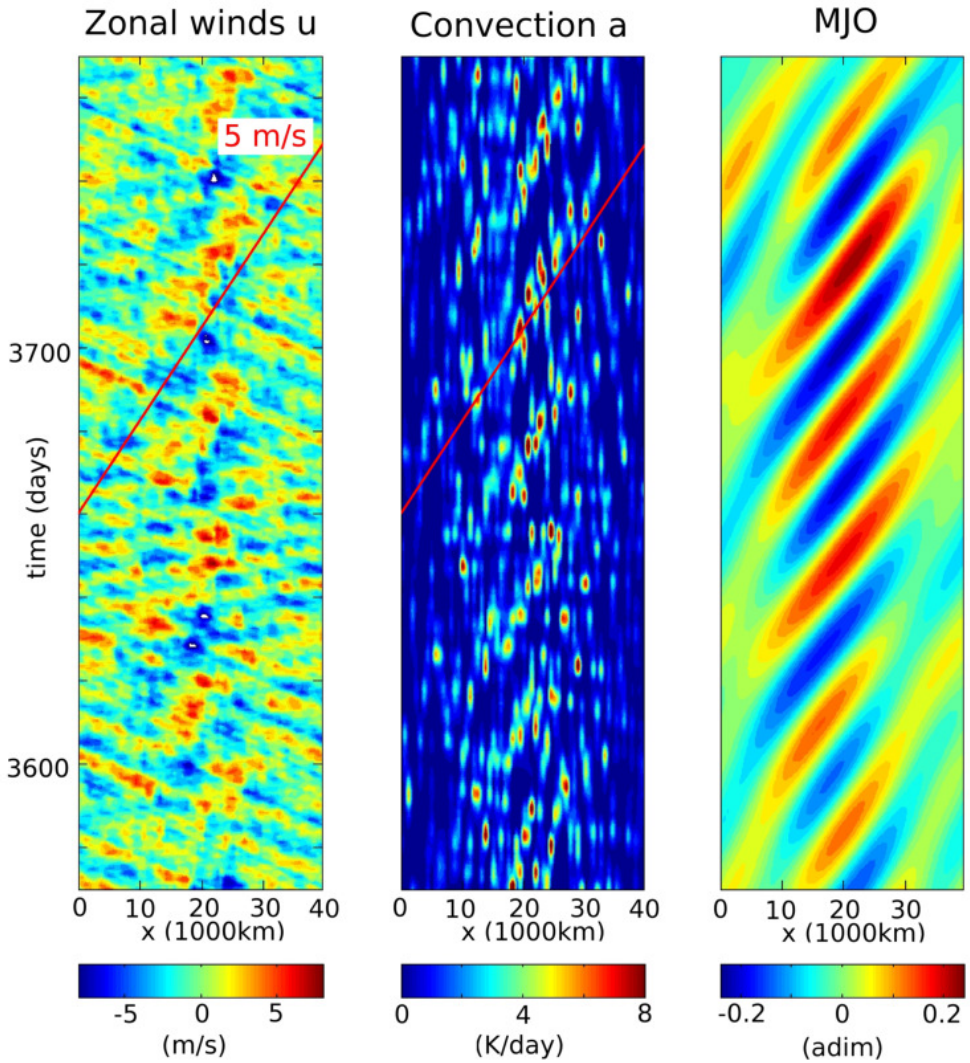
Dry Dynamics:	$(\partial_t + e)u - yv - \partial_x \theta = 0$	u, v: winds
	$yu - \partial_y \theta = 0$	θ: temperature
	$(\partial_t + e)\theta - (\partial_x u + \partial_y v) = \overline{H}a$	
Moisture:	$(\partial_t + e)q + \overline{Q}(\partial_x u + \partial_y v) = -\overline{H}a + E_q + \sigma_q \dot{W}$	q : moisture
Convection:	$(\partial_t + e)a = \Gamma q(s + a) + \sigma_a \dot{W}$	E_q: latent heat

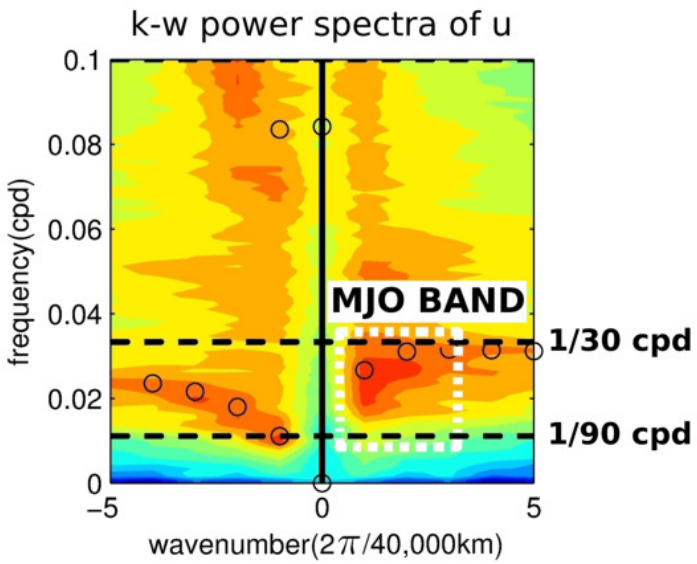
where a is the planetary envelope of convective/synoptic fluctuations.

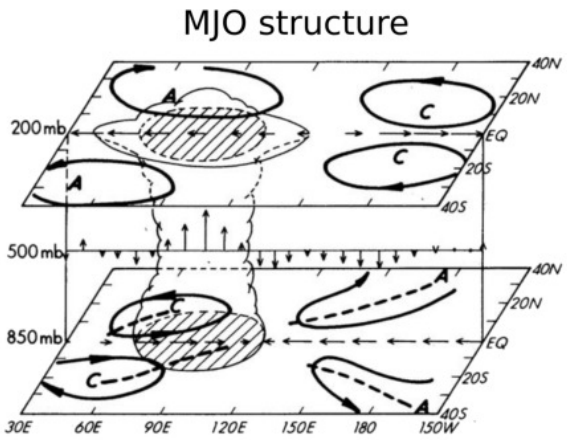


(Majda and Stechmann 2009)

The skeleton model captures the main features of the MJO:
e.g. phase speed $\approx 5\, m.s^{-1}$, period ≈ 40 days, intermittent wavetrains and structure







(Thual et al. 2014; Zhang 2005)

A multiple time approach yields the interannual evolution of the skeleton atmosphere:

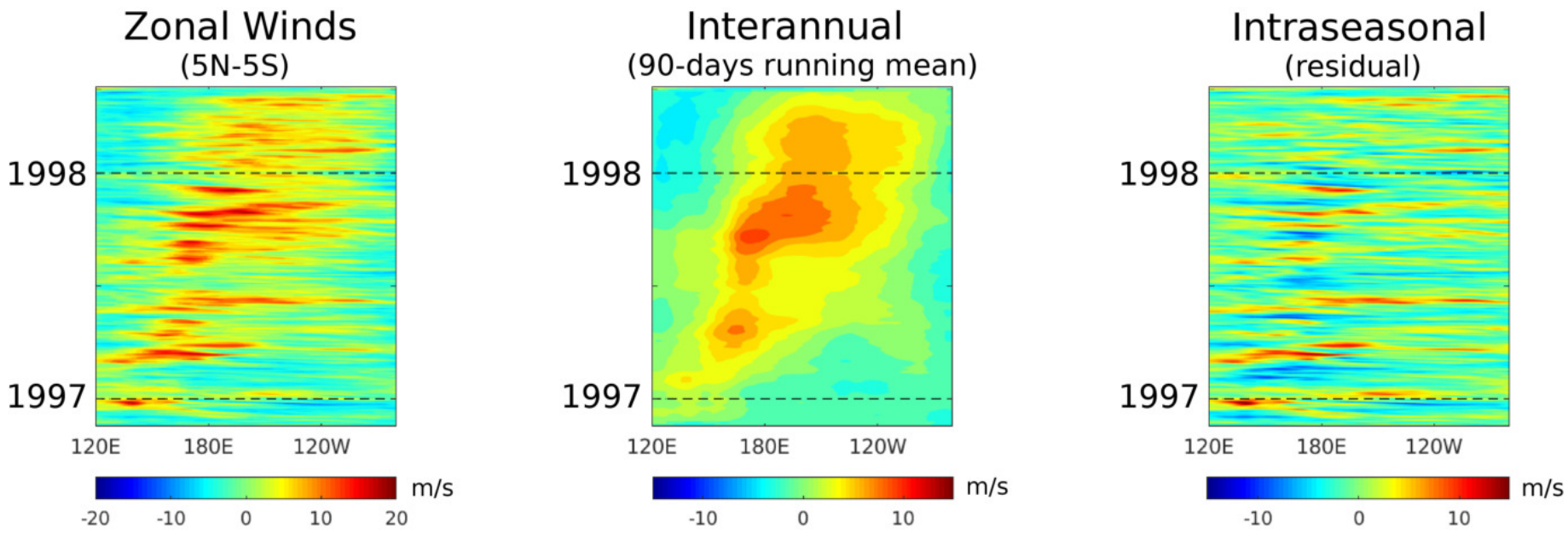
$$u = \overline{u}(x, y, \tau) + u'(x, y, t, \tau)$$

Interannual Atm:

$$-y\overline{v} - \partial_x \overline{\theta} = 0$$
$$y\overline{u} - \partial_y \overline{\theta} = 0$$
$$-(\partial_x \overline{u} + \partial_y \overline{v}) = \overline{E}_q/(1 - \overline{Q})$$
$$\overline{H}\overline{a} = s + \overline{E}_q/(1 - \overline{Q})$$

Intraseasonal Atm:

$$(\partial_t + e)u' - yv' - \partial_x \theta' = 0$$
$$yu' - \partial_y \theta' = 0$$
$$(\partial_t + e)\theta' - (\partial_x u' + \partial_y v') = \overline{H}a'$$
$$(\partial_t + e)q' + \overline{Q}(\partial_x u' + \partial_y v') = -\overline{H}a' + \sigma_q \dot{W}$$
$$(\partial_t + e)a' = \Gamma q' \overline{a} + \sigma_a \dot{W}$$



A skeleton ENSO model is obtained by coupling ocean dynamics and a SST heat budget,

Interannual Atm:

$$-y\overline{v} - \partial_x\overline{\theta} = 0$$
$$y\overline{u} - \partial_y\overline{\theta} = 0$$
$$-(\partial_x\overline{u} + \partial_y\overline{v}) = E_q/(1-\overline{Q})$$
$$\overline{H}\overline{a} = s + E_q/(1-\overline{Q})$$

Intraseasonal Atm:

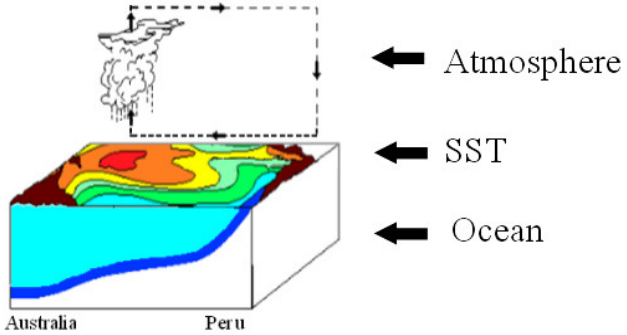
$$(\partial_t + e)u' - yv' - \partial_x\theta' = 0$$
$$yu' - \partial_y\theta' = 0$$
$$(\partial_t + e)\theta' - (\partial_x u' + \partial_y v') = \overline{H}a'$$
$$(\partial_t + e)q' + \overline{Q}(\partial_x u' + \partial_y v') = -\overline{H}a' + \sigma_q\dot{W}$$
$$(\partial_t + e)a' = \Gamma q'\overline{a} + \sigma_a\dot{W}$$

Ocean:

$$\partial_t U - cYV + c\partial_x H = c\gamma(\overline{u} + u')$$
$$YU + \partial_Y H = 0$$
$$\partial_t H + c(\partial_x U + \partial_Y V) = 0$$

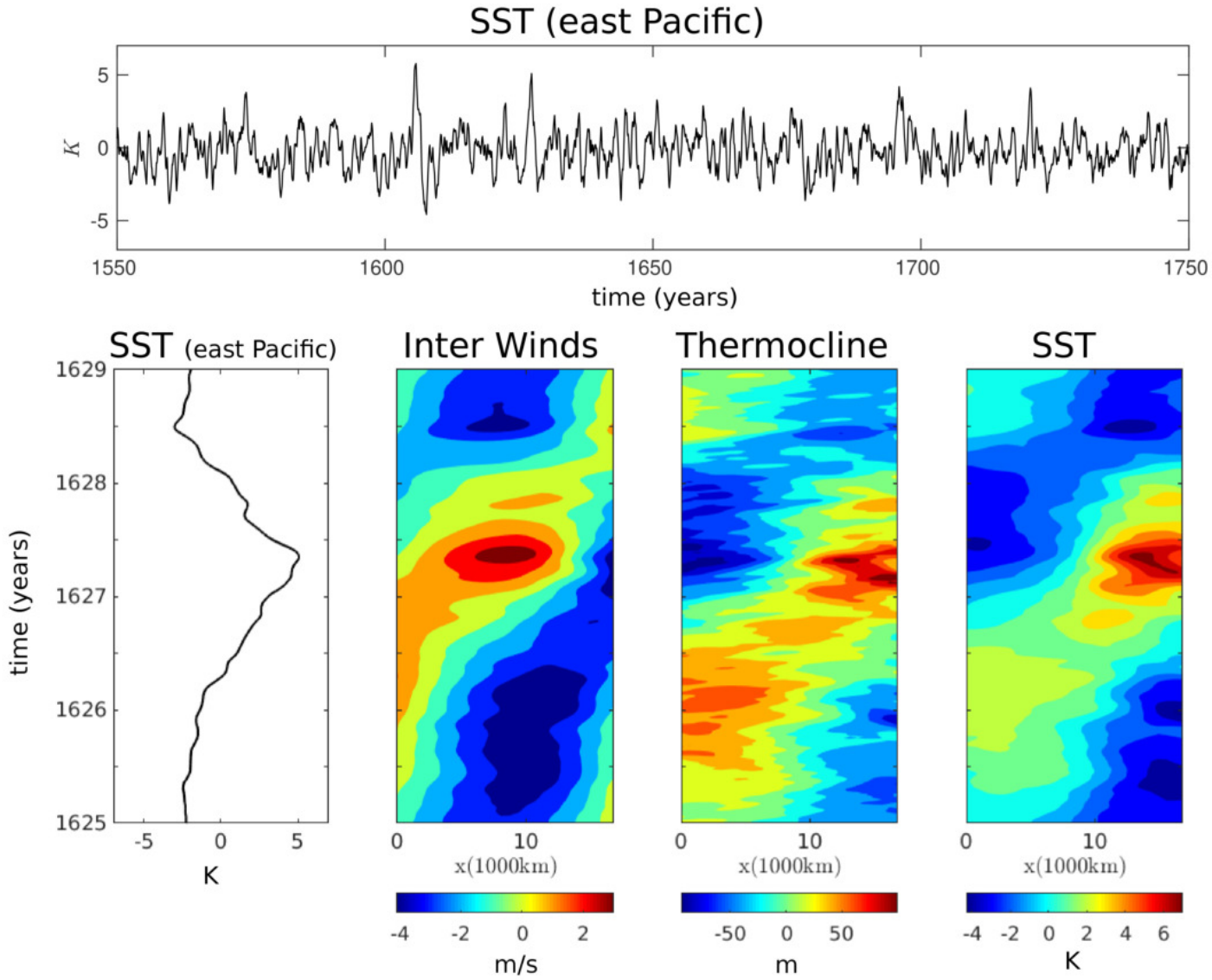
SST:

$$\partial_t T = -\zeta E_q + \eta H$$
$$E_q = \alpha T$$

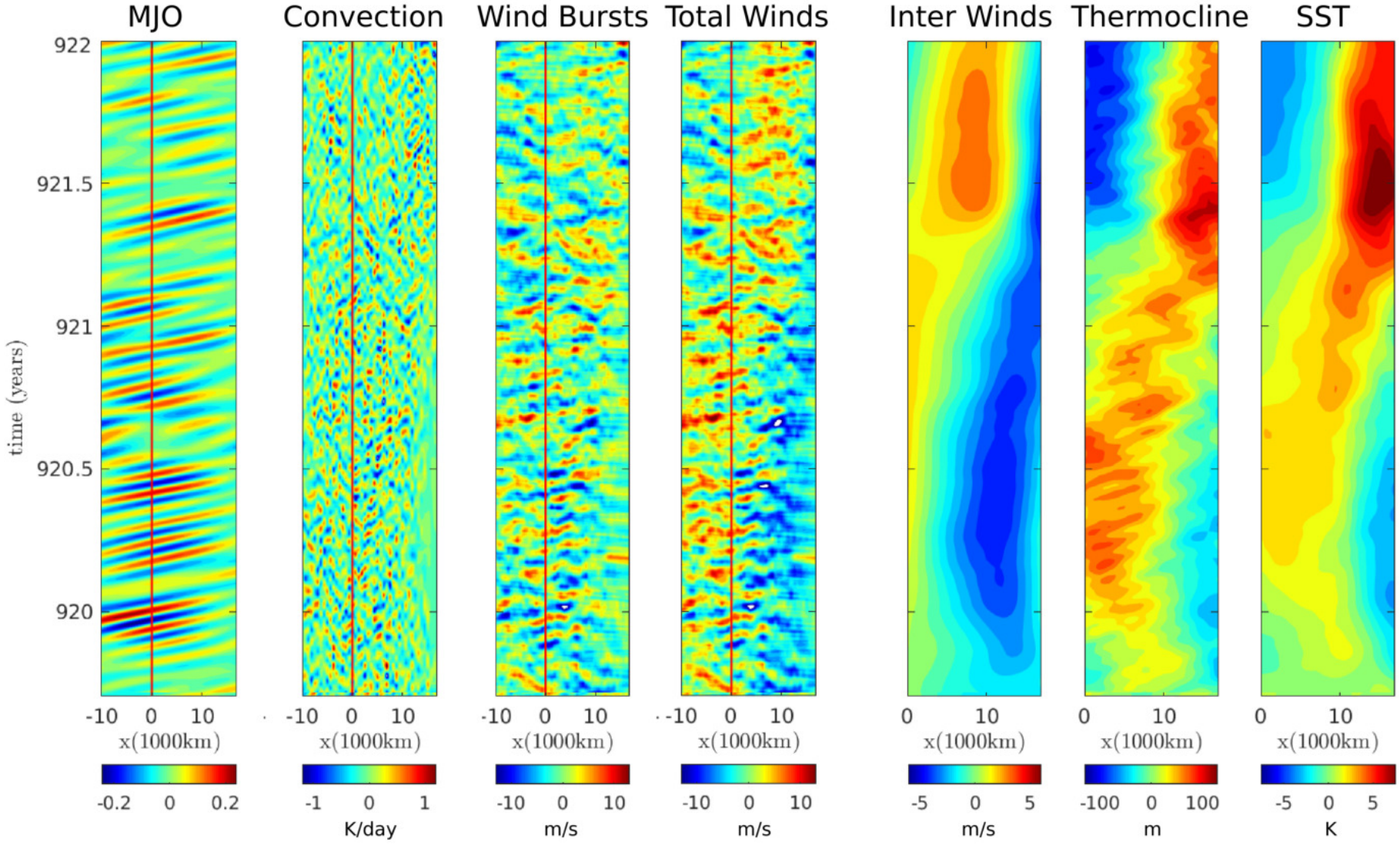


(solutions are computed for first meridional structures/waves≈ 350 degrees of freedom)

Model solutions (2000 years) with intermittent El Niño events of varying strength.

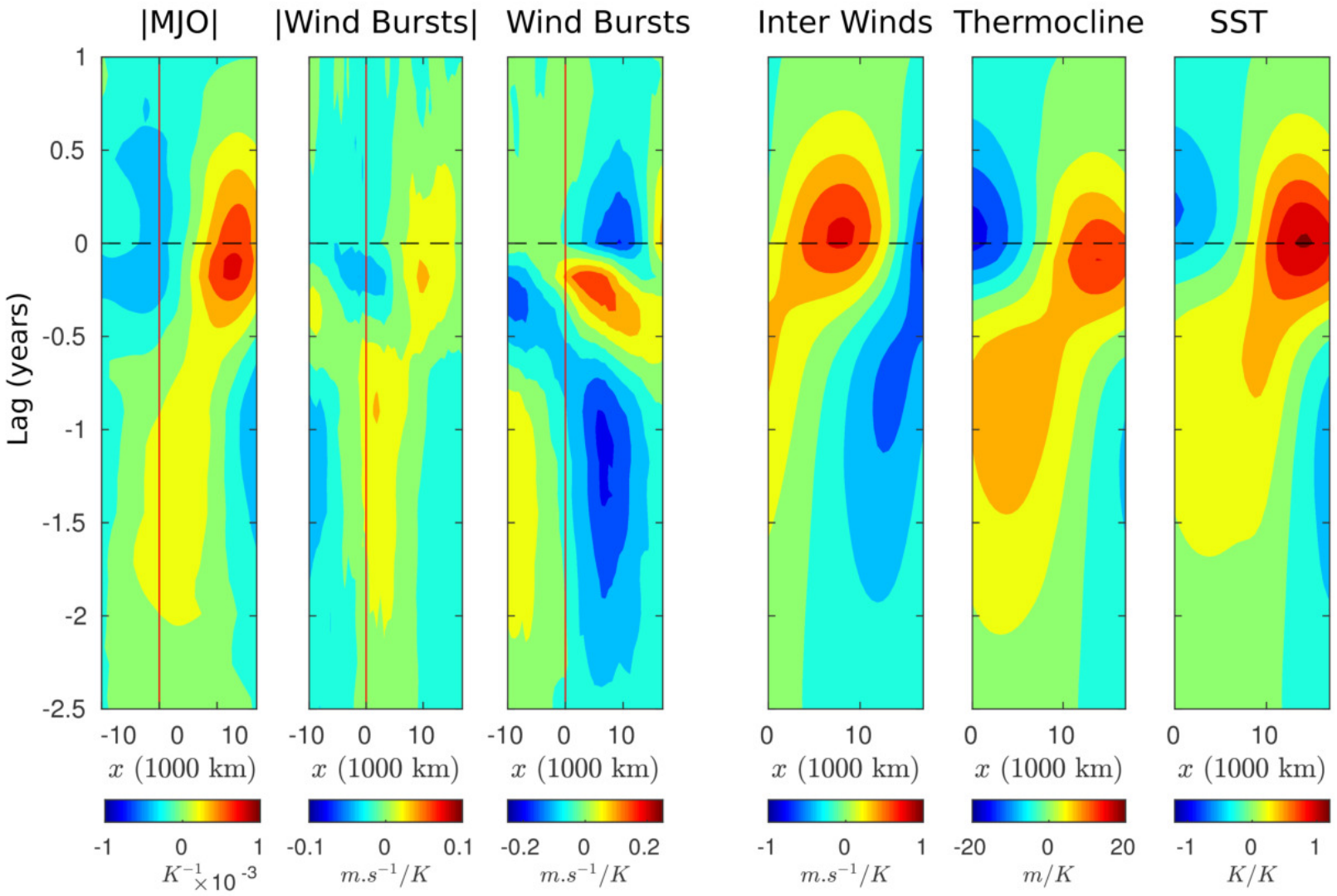


Intraseasonal variability increases and expands eastward during El Niño onset.



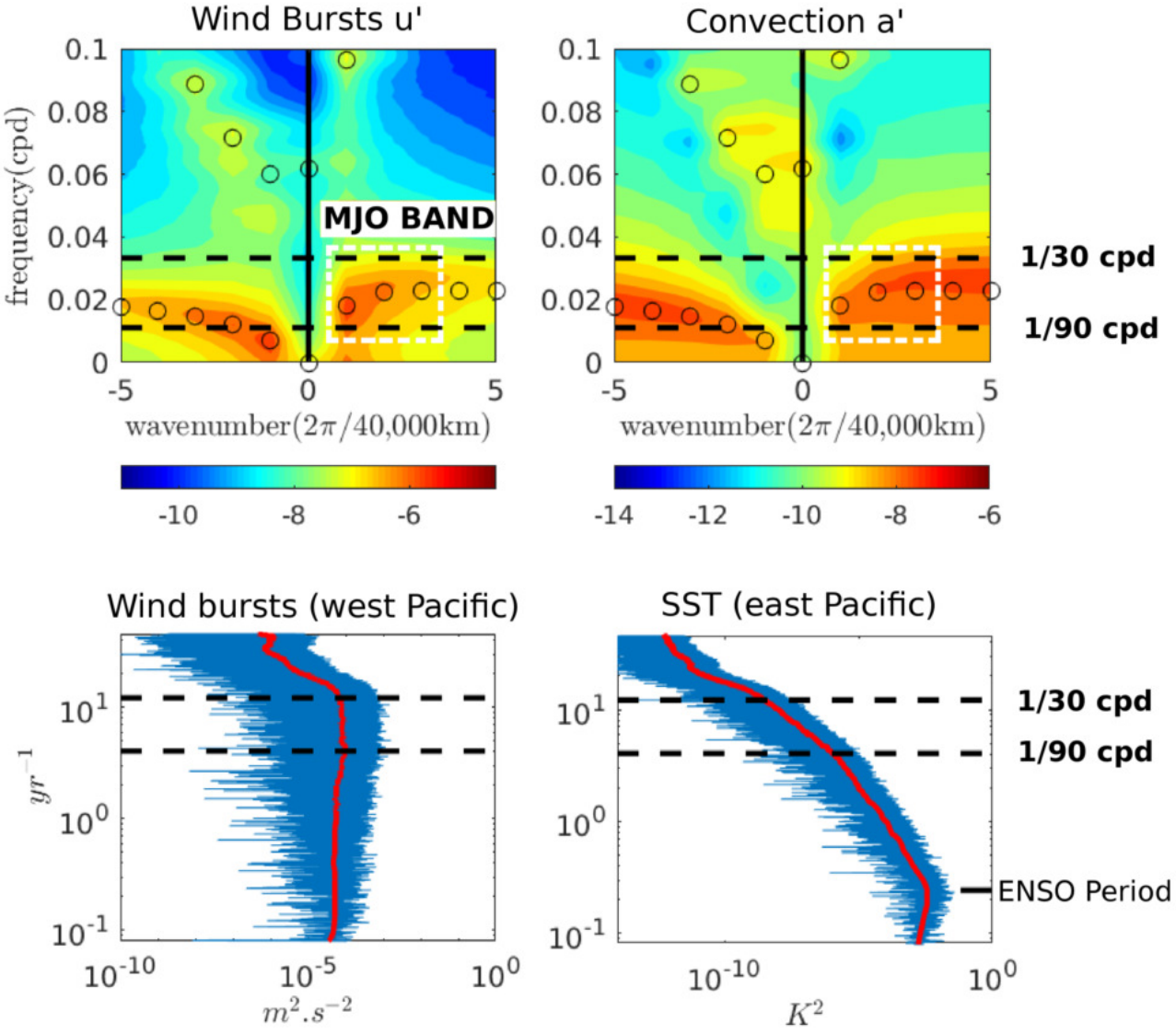
(Thual et al. 2018 JClim)

Lagged regressions on eastern Pacific SST: increased MJO and wind bursts during onset



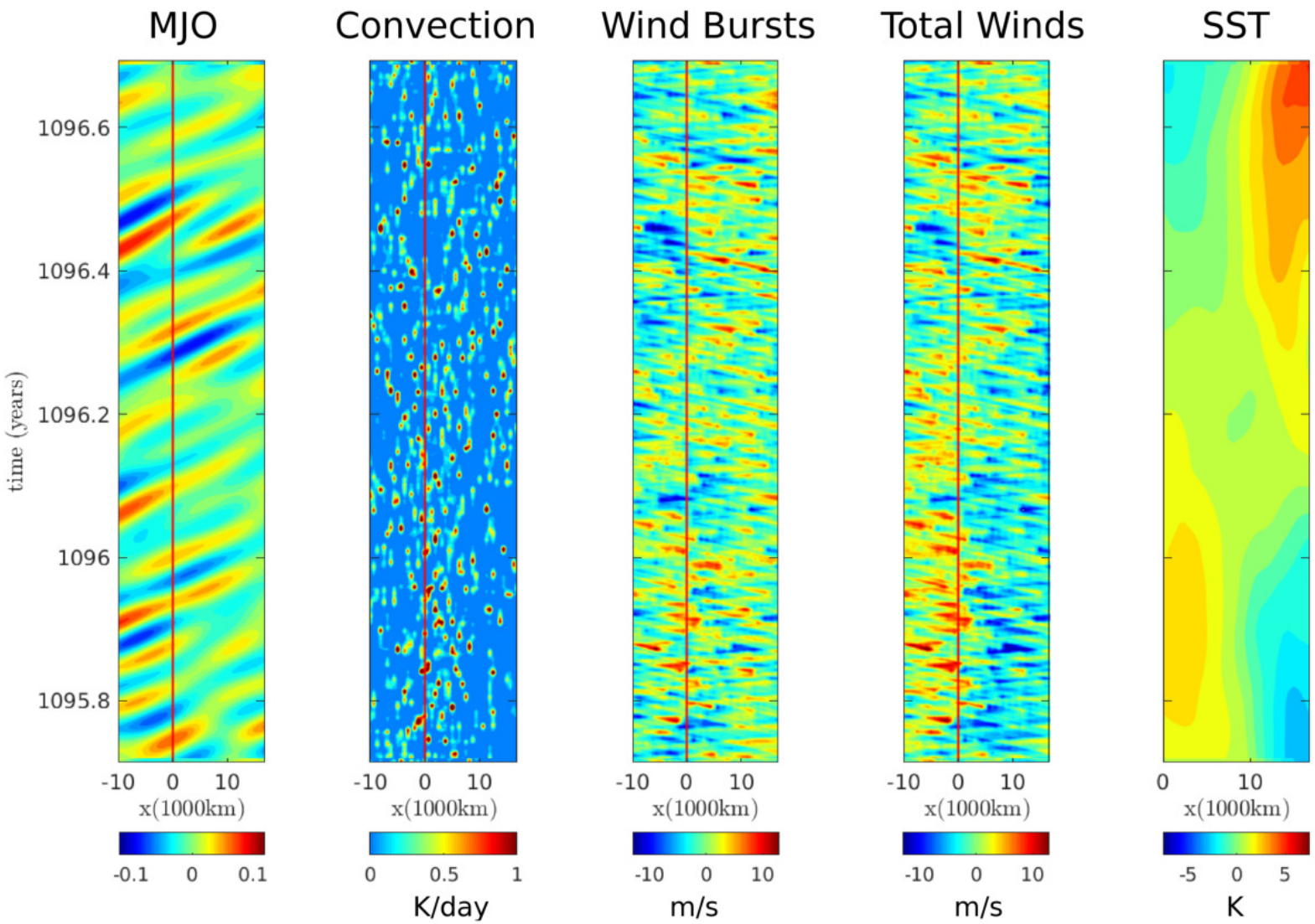
(Thual et al. 2018 JClim)

Realistic $k - \omega$ power spectra and time-integration of intraseasonal noise by the ocean.



(Thual et al. 2018 JClim)

Tested for improved stochastic convective parameterizations:
e.g. with nonlinearities, multiplicative noise: $(\partial_t + \lambda)a' = \Gamma q'(\overline{a} + a') + \sqrt{\lambda(\overline{a} + a')\overline{a}}\dot{W}$



A Stochastic Dynamical Skeleton model for the MJO and ENSO

Role of organized/coherent intraseasonal variability and wind bursts?

Model Formulation:

1) Starting skeleton atmosphere for the MJO
2) Interannual dynamics from a multiple-time approach
3) Shallow-water ocean dynamics and SST heat budget

Features:

1) Intraseasonal variability increases and expands eastward during El Niño onset
2) Realistic $k-\omega$ power spectra and time-integration of intraseasonal noise by the ocean
3) Testbed for improved stochastic convective parameterizations/GCM prototype

Perspectives:

1) Eastern vs Central Pacific El Niño
2) Seasonality of MJO-ENSO interactions
3) Other intraseasonal modes: convectively coupled rossby, kelvin waves, etc.

Refs: *Thual, Majda, and Chen (2018 Jclim; 2016 PNAS), Thual, Majda and Stechmann (2014 JAS), Majda and Stechmann (2009 PNAS).*