Modelling the influence of the extratropics on the MJO

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ITCP Trieste, Oct 2017

Predictability of Madden-Julian events in a regional model

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Evidence for tropical-extratropical coherence

Yanai and Lu: 1983, Liebmann and Hartmann: 1984, Knutson and Weikmann: 1987, Strauss and Lindzen: 2000, Zhou and Miller: 2005, L'Heureux and Higgins: 2008, Weikmann and Berry: 2009, Kerns and Chen: 2014, Adames et al: 2014

Mechanisms

Hsu, Hoskins and Jin: 1990, Frederiksen and Frederiksen: 1997, Hoskins and Yang: 2000, Revell et al: 2001, Frederiksen: 2002, Pan and Li: 2008, Roundy: 2012, Frederiksen and Lin: 2013

Models

Gustafson and Weare: 2004, Lin, Brunet and Derome: 2007, Ray et al: 2009, Ray and Zhang: 2010, Vitart and Jung: 2010 Ray et al: 2011, Ray and Li: 2013, Zhao et al: 2013

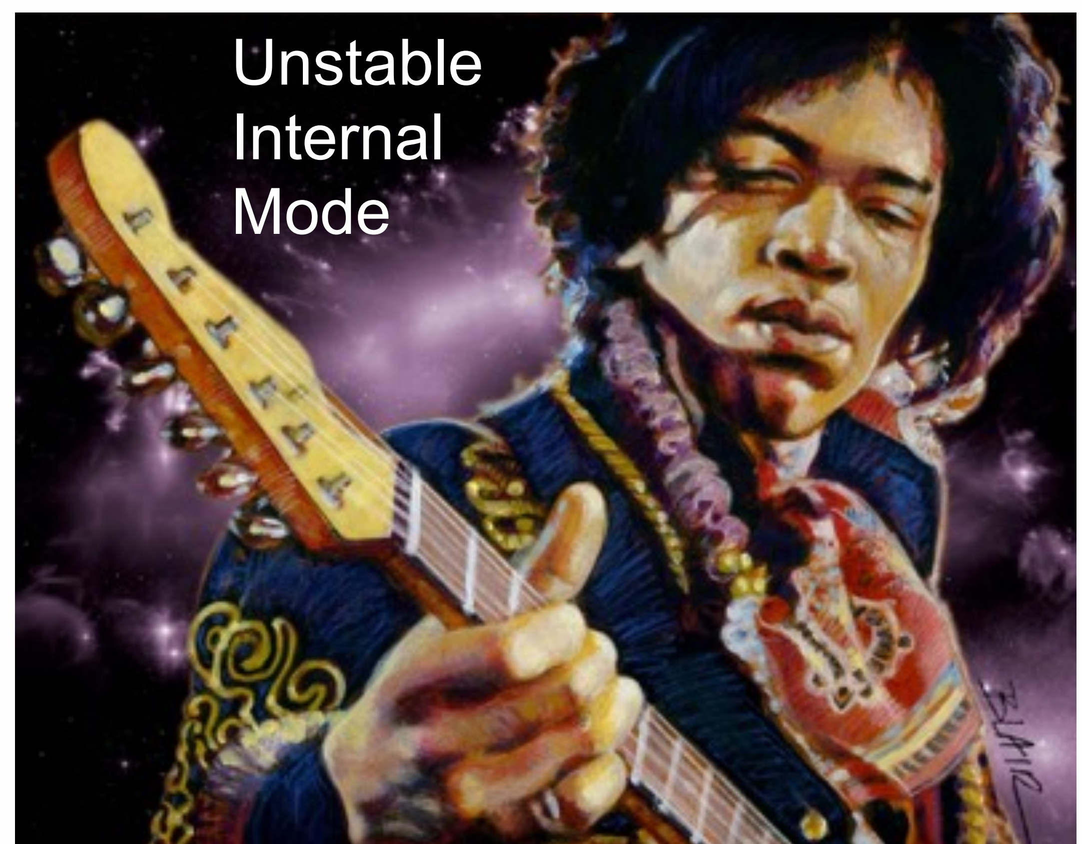
Our contribution

Longer runs with a tropical channel model to try and explore generic / systematic behaviour

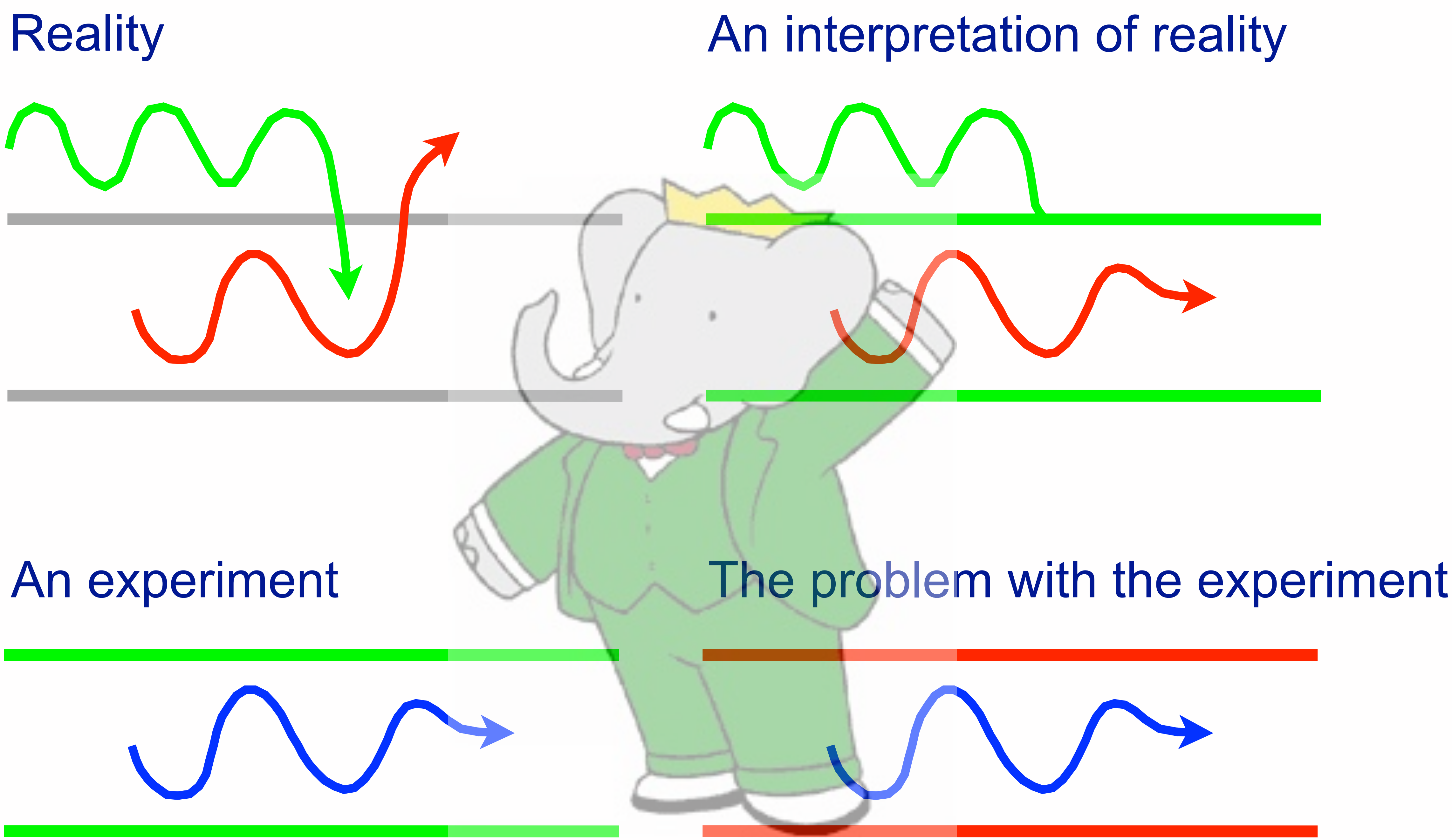
The nature of the extratropical influence

Stochastically
Excited
Internal
Mode

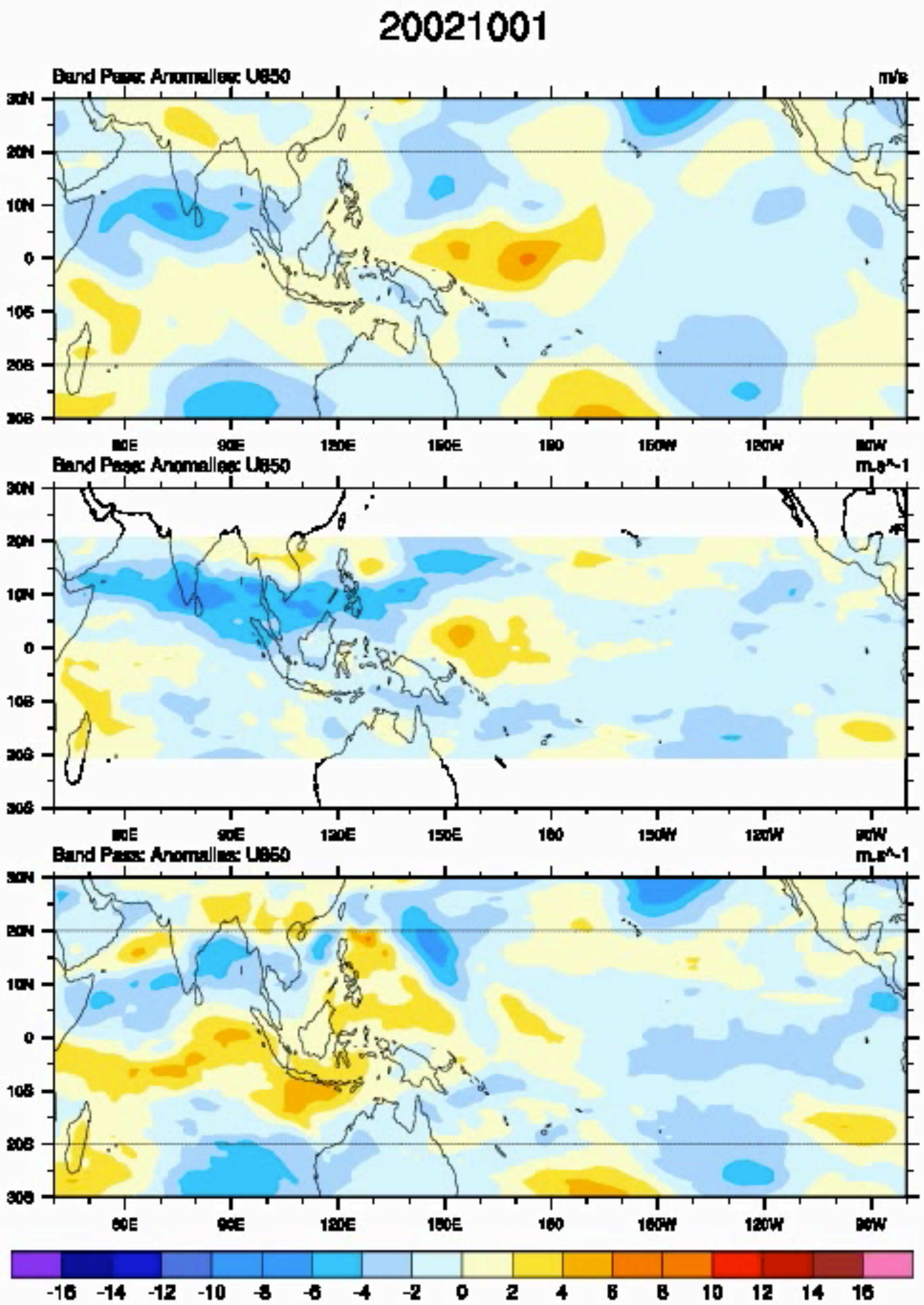
Resonant
Response



Separating the extratropical influence



u850

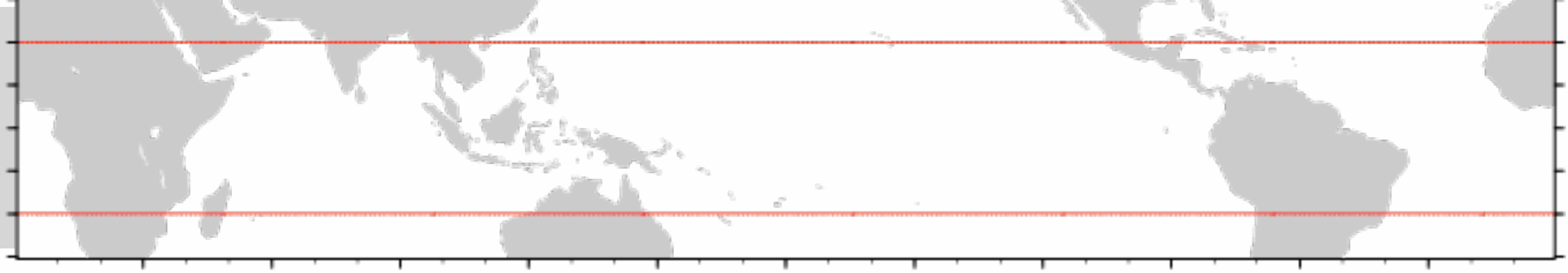


obs

WRF 20

WRF 30

Experiments with WRF



WRF 3.3.1 configuration:
1°x1° tropical channel between 30 ° N and S, 32 vertical levels.
Lateral boundary forcing: NCEP2 reanalysis.
Convection scheme: Betts-Miller-Janjic (BMJ).
Planetary boundary layer: Yonsei University (YSU),
SST Reynolds with a skin temperature diurnal cycle calculated by WRF.

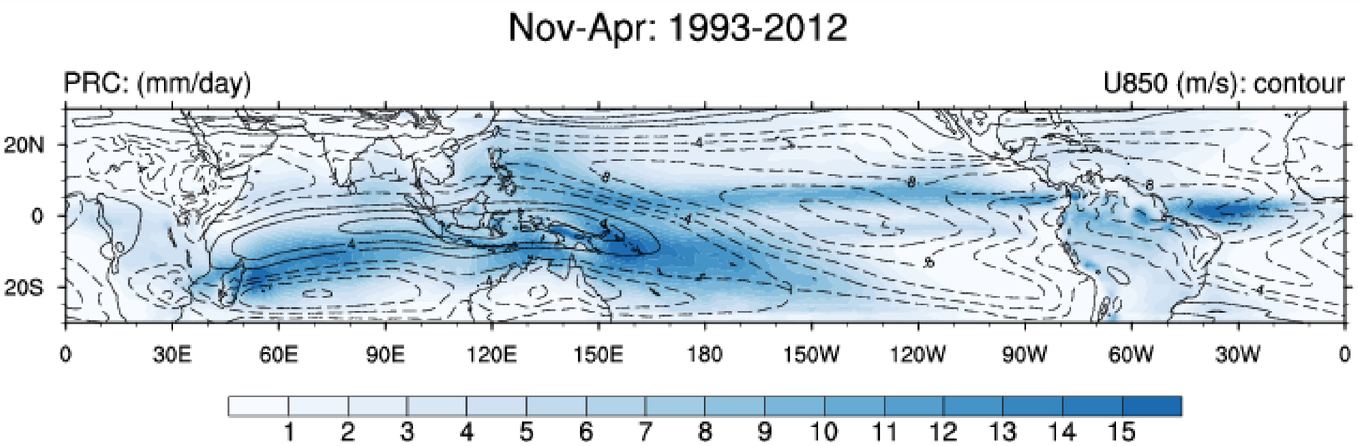
- 20-year runs: 1993-2012
- Twin experiments for each run: identical boundary conditions, different intial conditions

Boundary Condition	Includes	Excludes
Ref	everything	nothing
Notch	diurnal cycle, synoptic variability, annual cycle, interannual var.	intraseasonal 20-100d
Clim	diurnal cycle, repeated annual cycle	synoptic/intraseasonal 2-100d, interannual variability
Ref*	As Ref but with SSTs from Notch	
Notch*	As Notch but with SSTs from Ref	

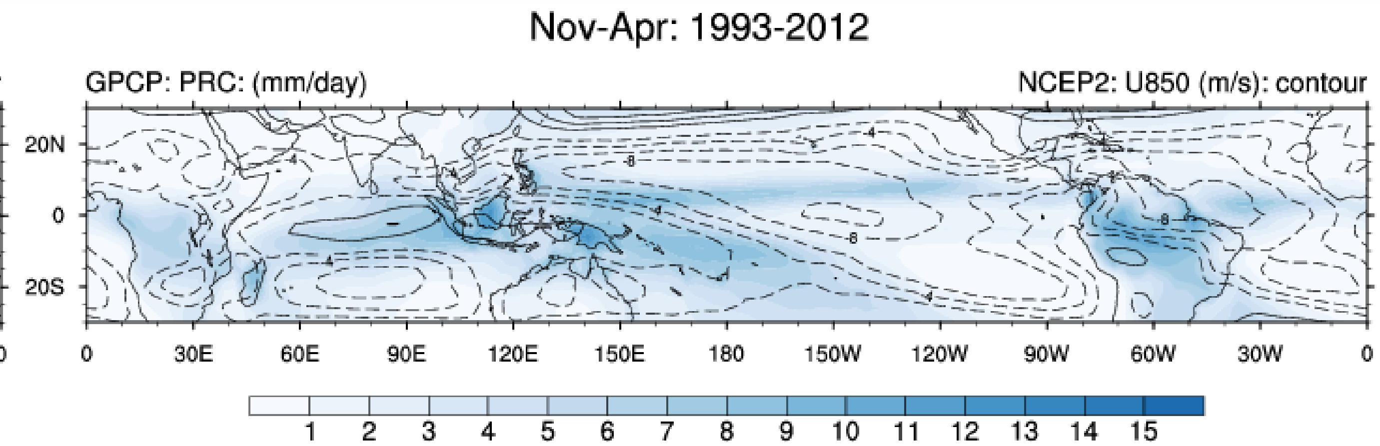
Winter mean state: u850+precip

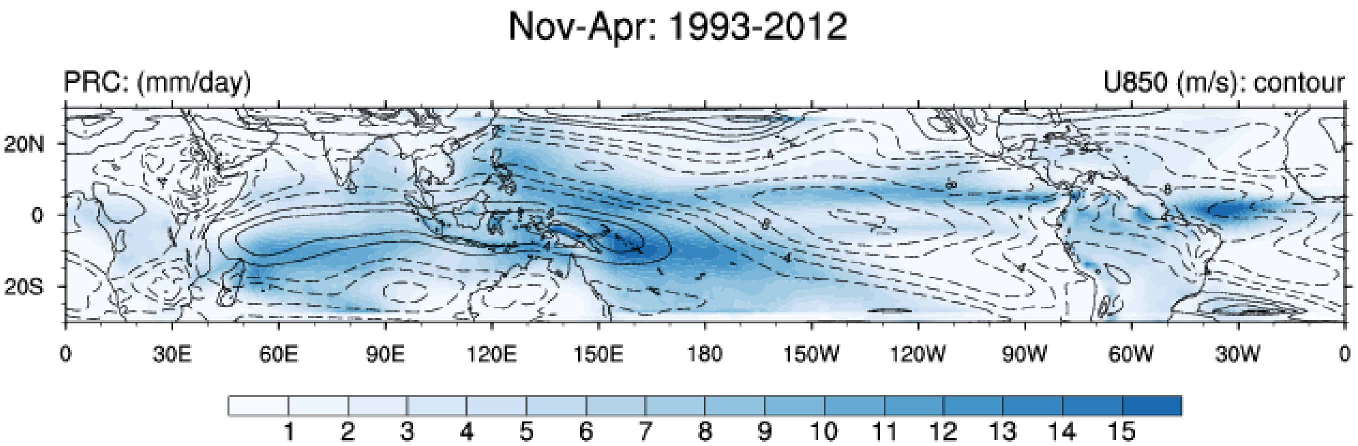
contours: 850 hPa zonal wind (November-April mean)
shading: precipitation

Ref

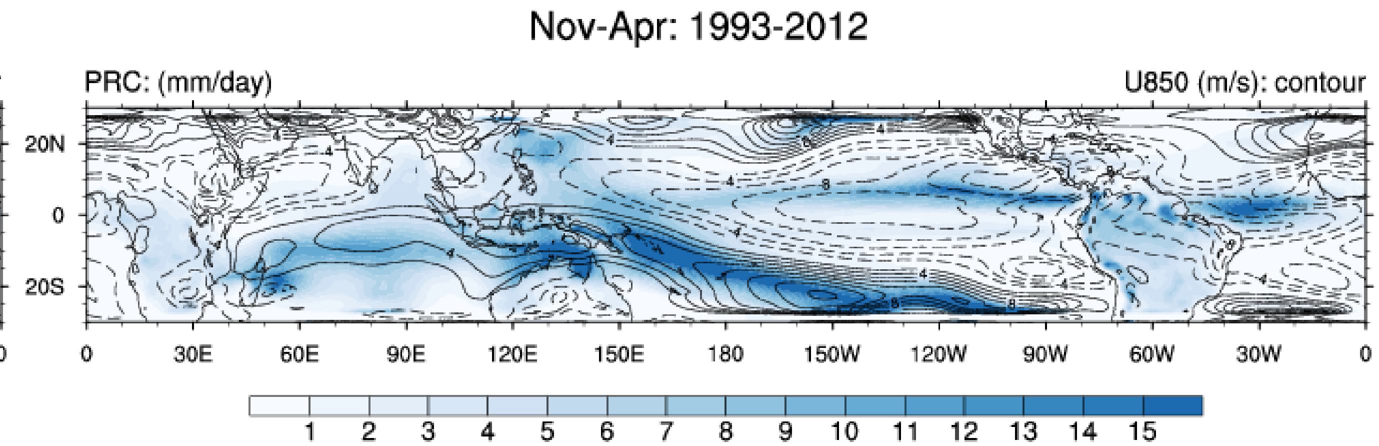


Obs





Notch



Clim

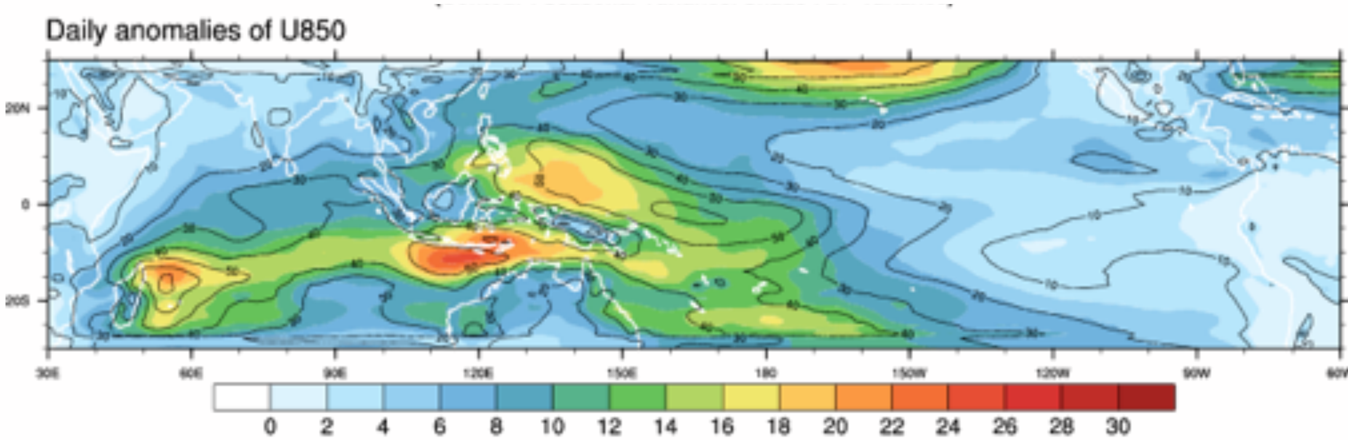
Winter variance: u850

Expect: Ref1 ~ Ref2,   0 < Diff < 4 x Ref

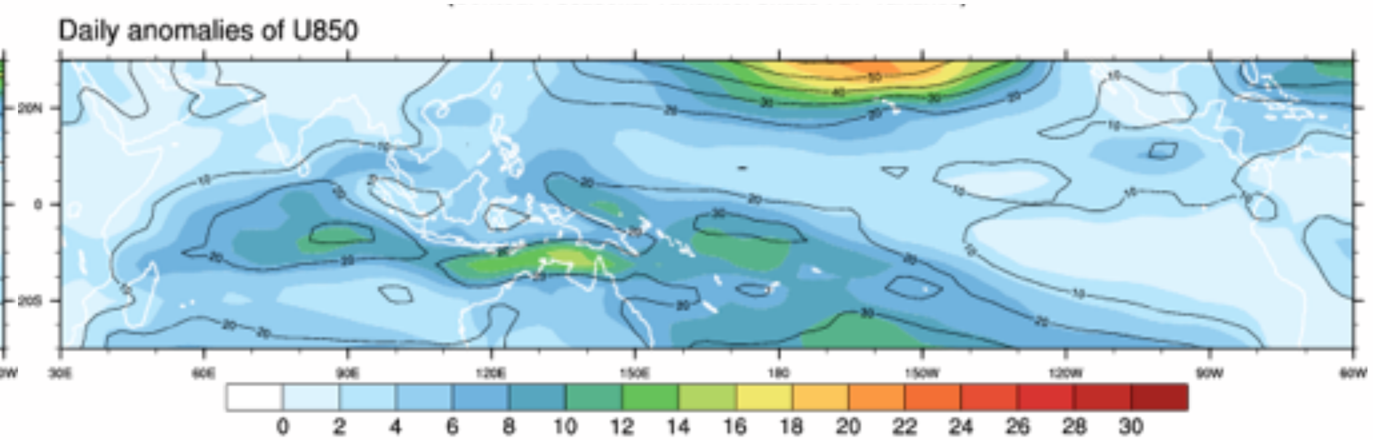
Purely forced: Diff ~ 0
Purely internal: Diff ~ 2 x Ref

var (x - y) = var(x) + var(y) - 2 covar(x,y)

Ref1



Obs



Variance: Winter (N-A): 1993-2012

(Contour : Seasonal Variance. Shade : BP variance)

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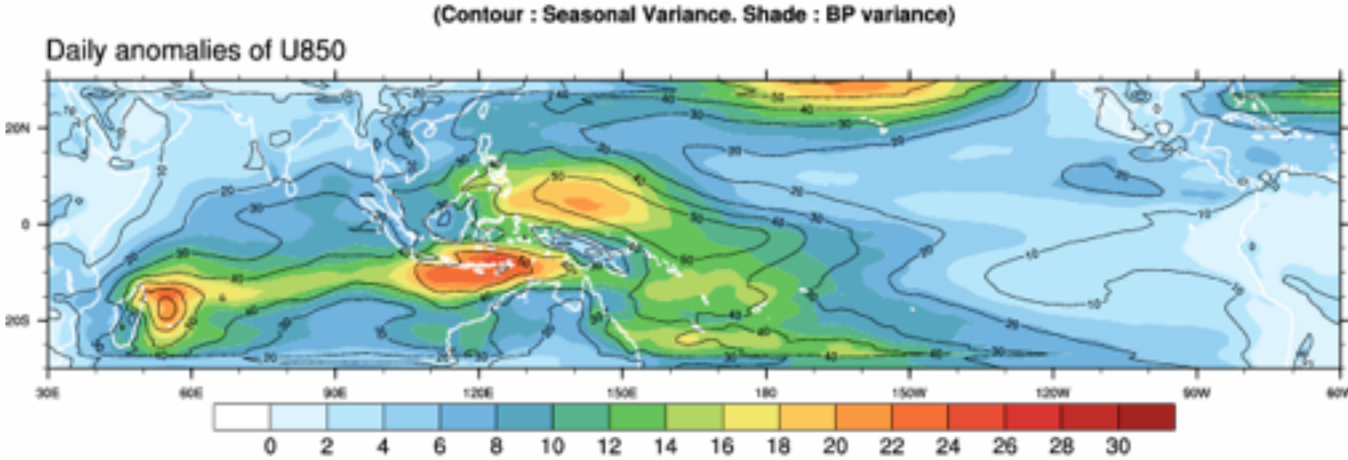
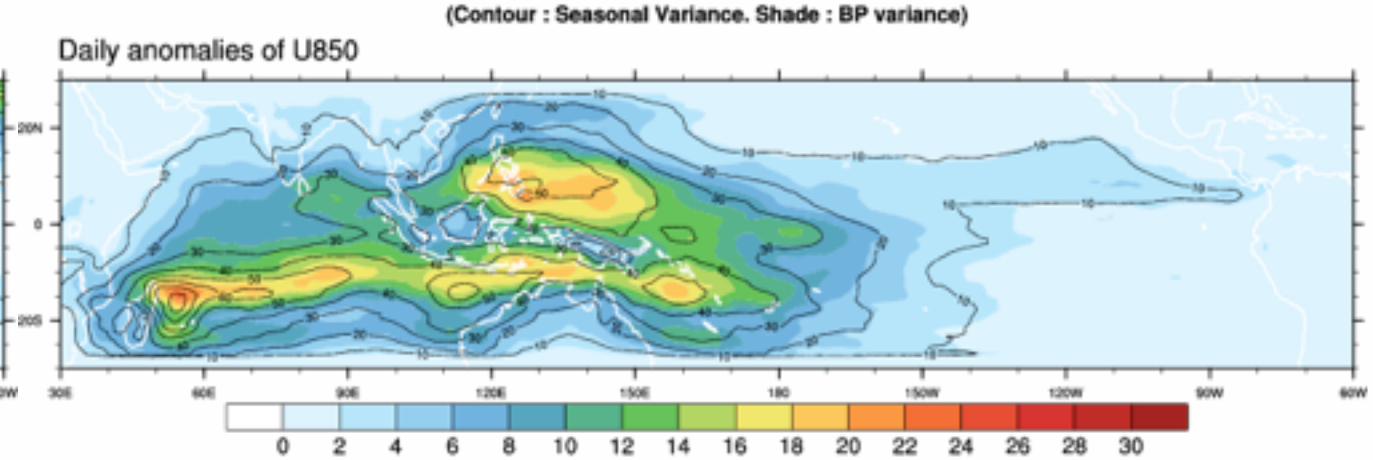


Ref2



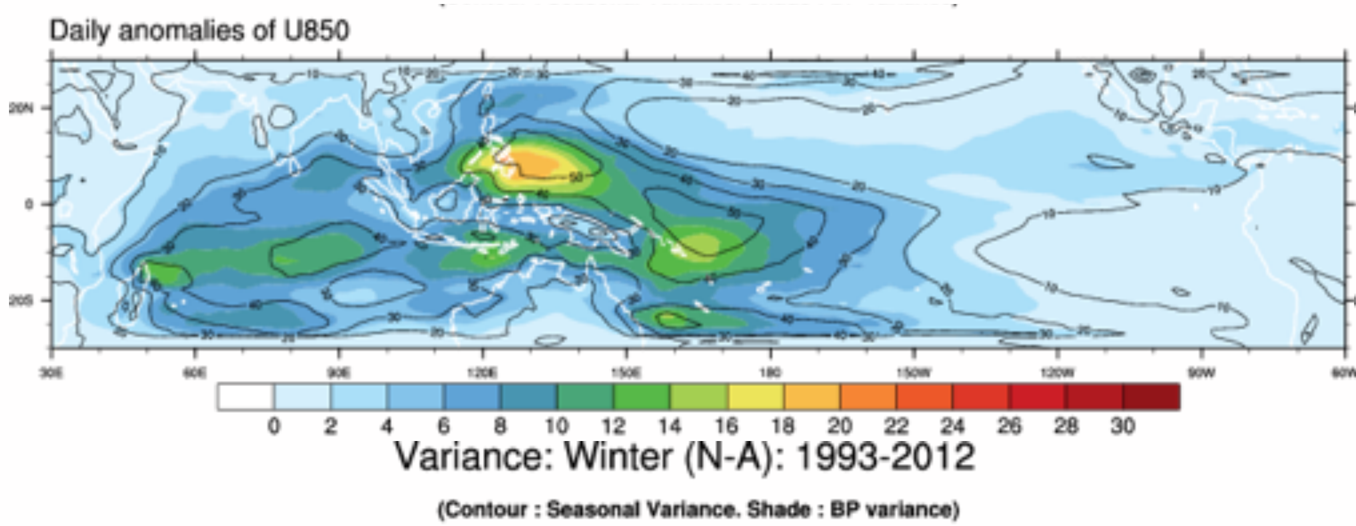
Diff

Winter variance: u850

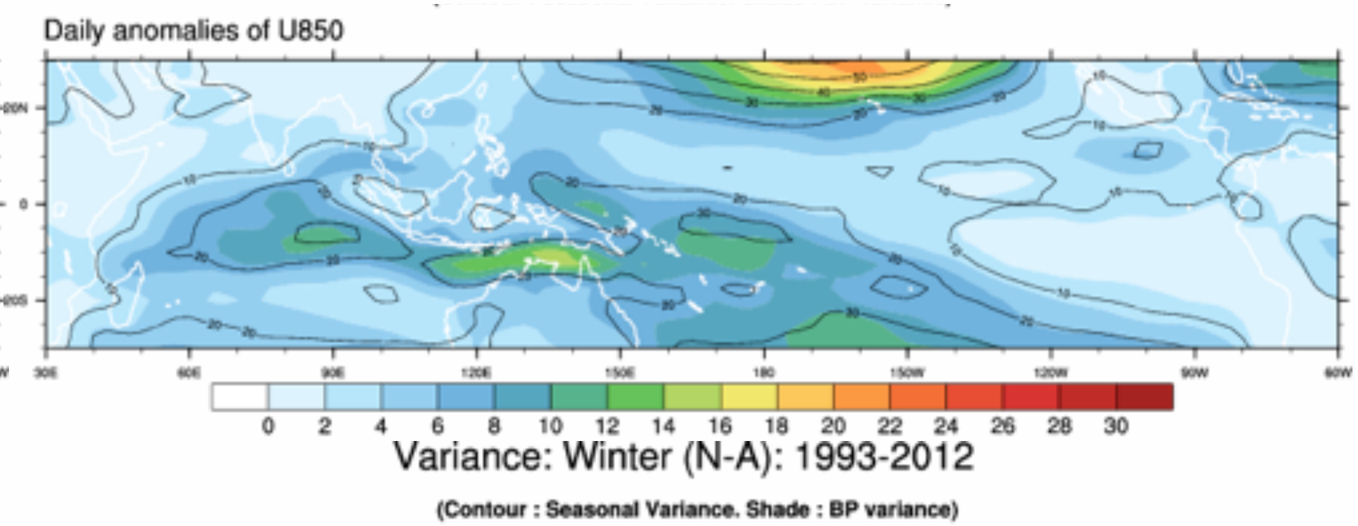
Purely forced: Diff ~ 0
Purely internal: Diff ~ 2 x Notch

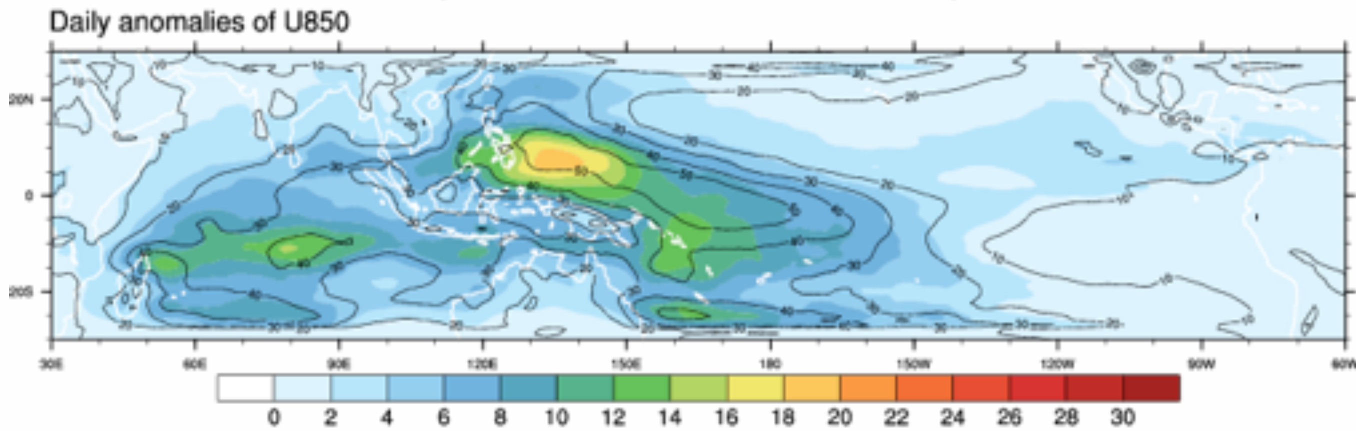
var (x - y) = var(x) + var(y) - 2 covar(x,y)

Notch1

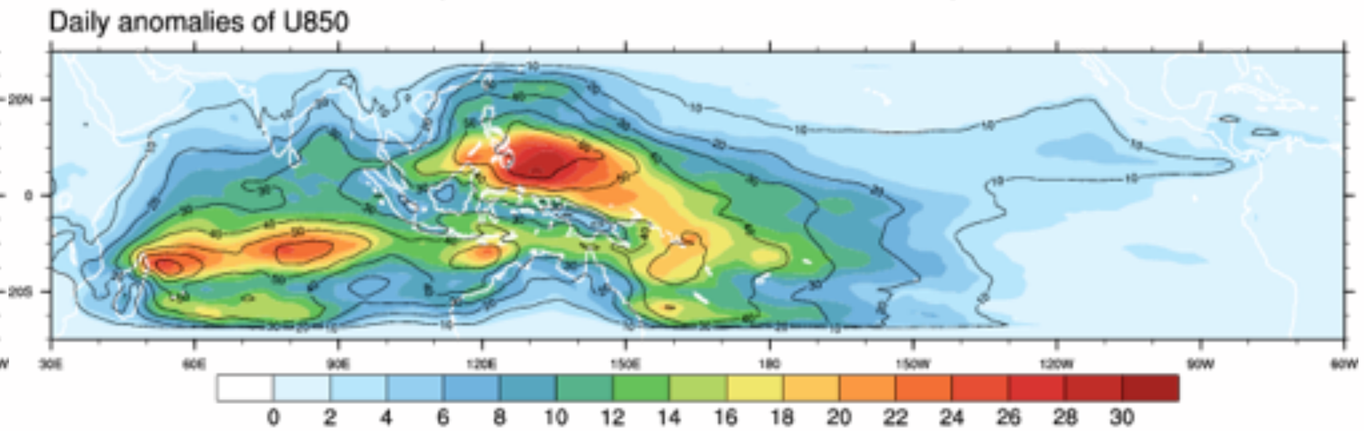


Obs





Notch2



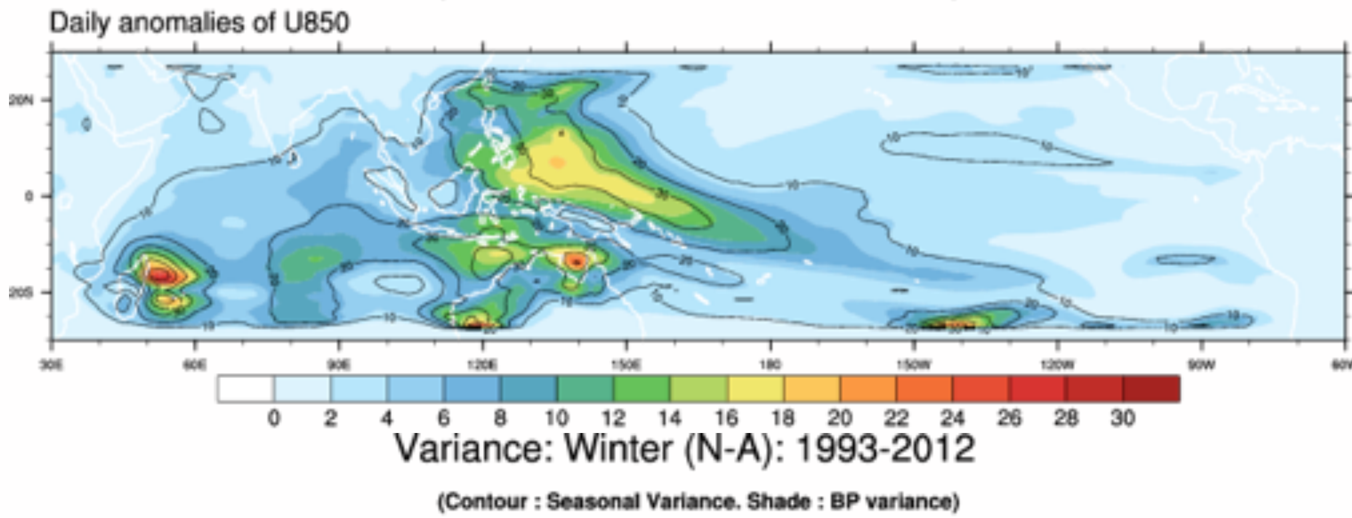
Diff

Winter variance: u850

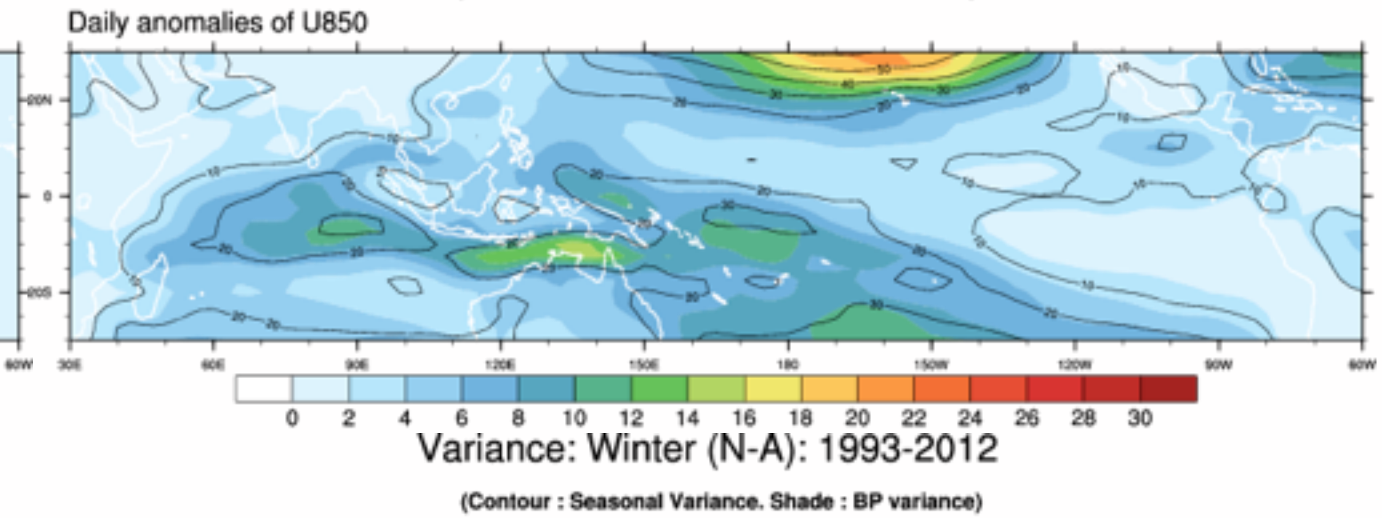
Purely forced: Diff ~ 0
Purely internal: Diff ~ 2 x Clim

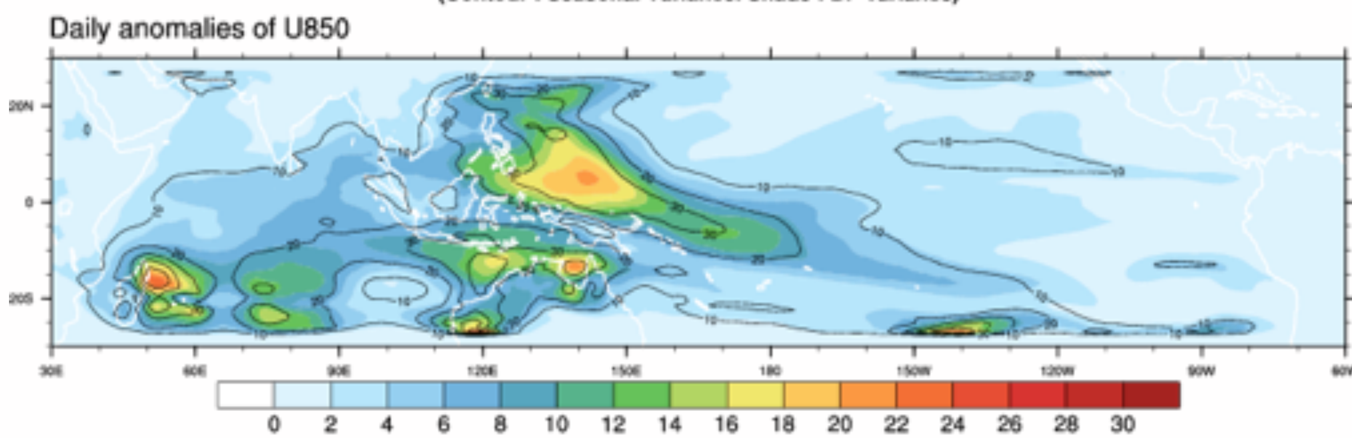
$$var(x - y) = var(x) + var(y) - 2\,covar(x,y)$$

Clim1

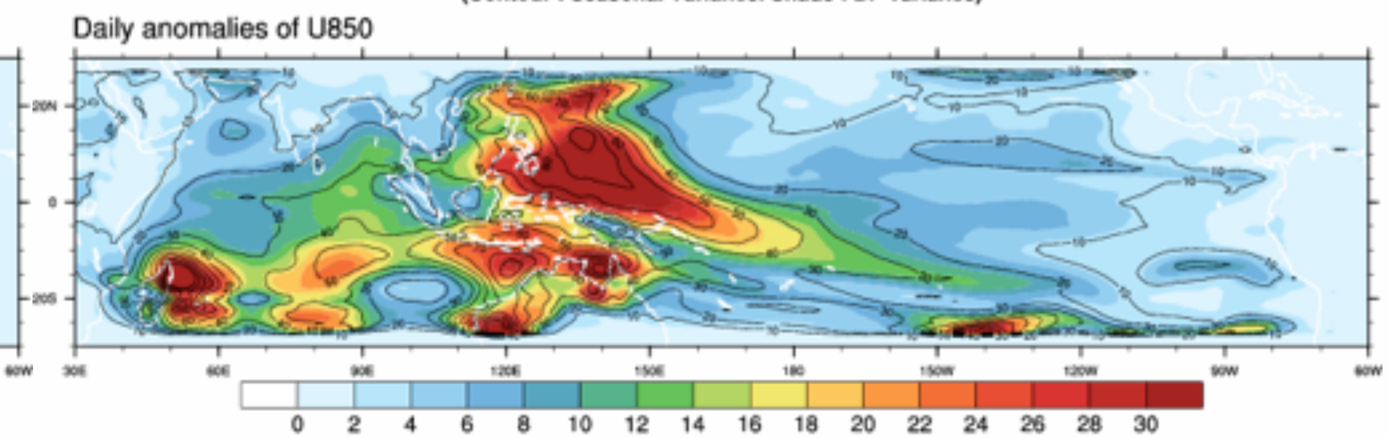


Obs





Clim2



Diff

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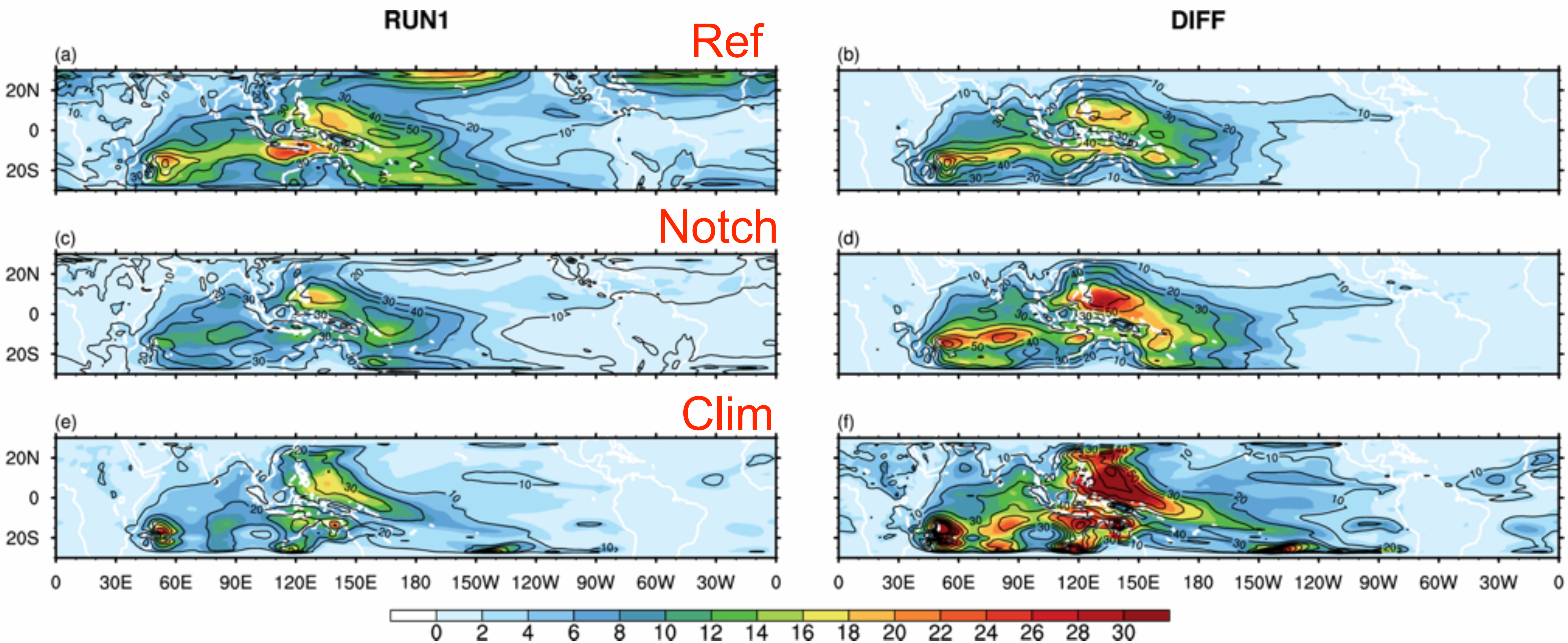
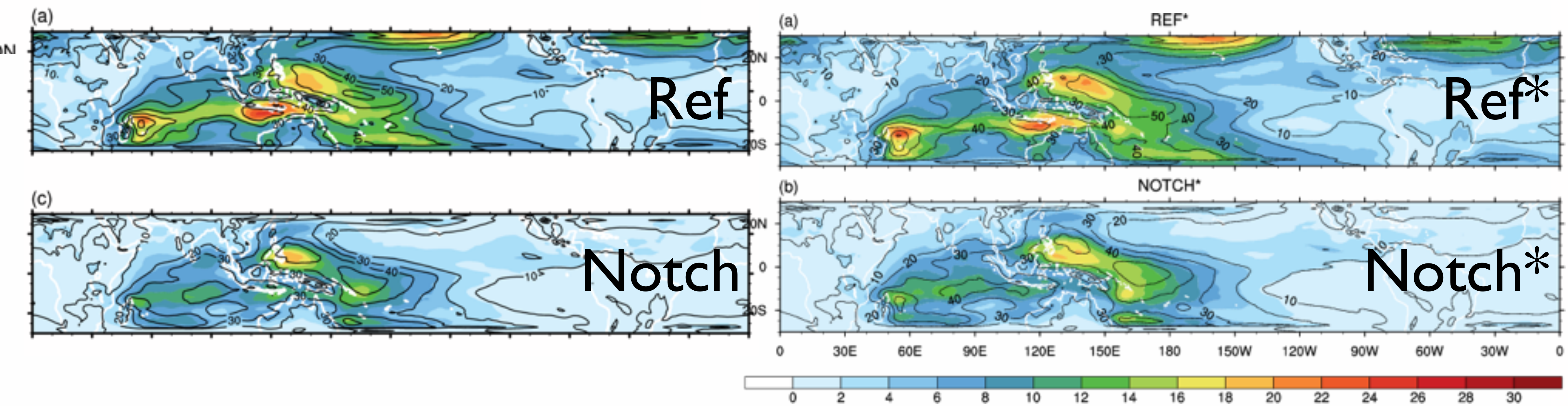


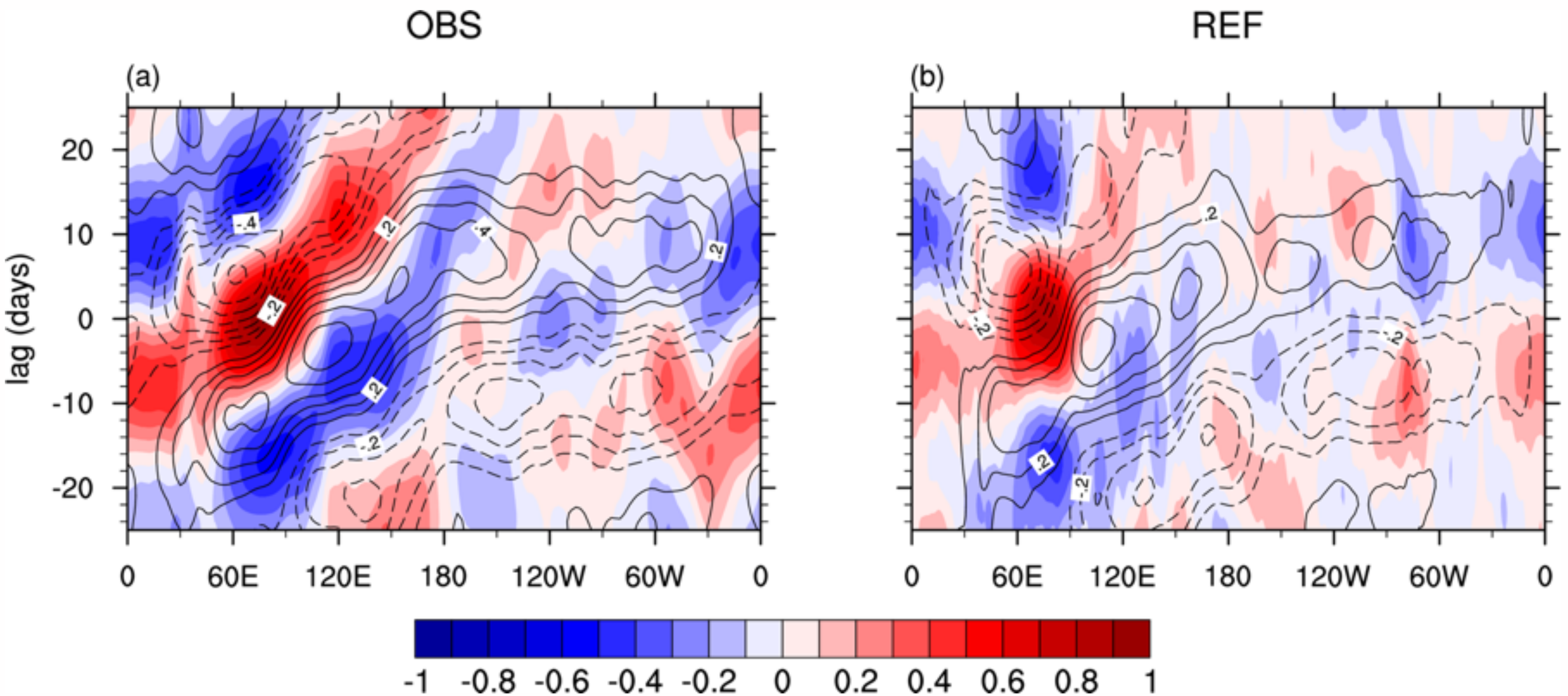
Mixed boundary conditions

separate effects of SSTs and lateral boundary conditions

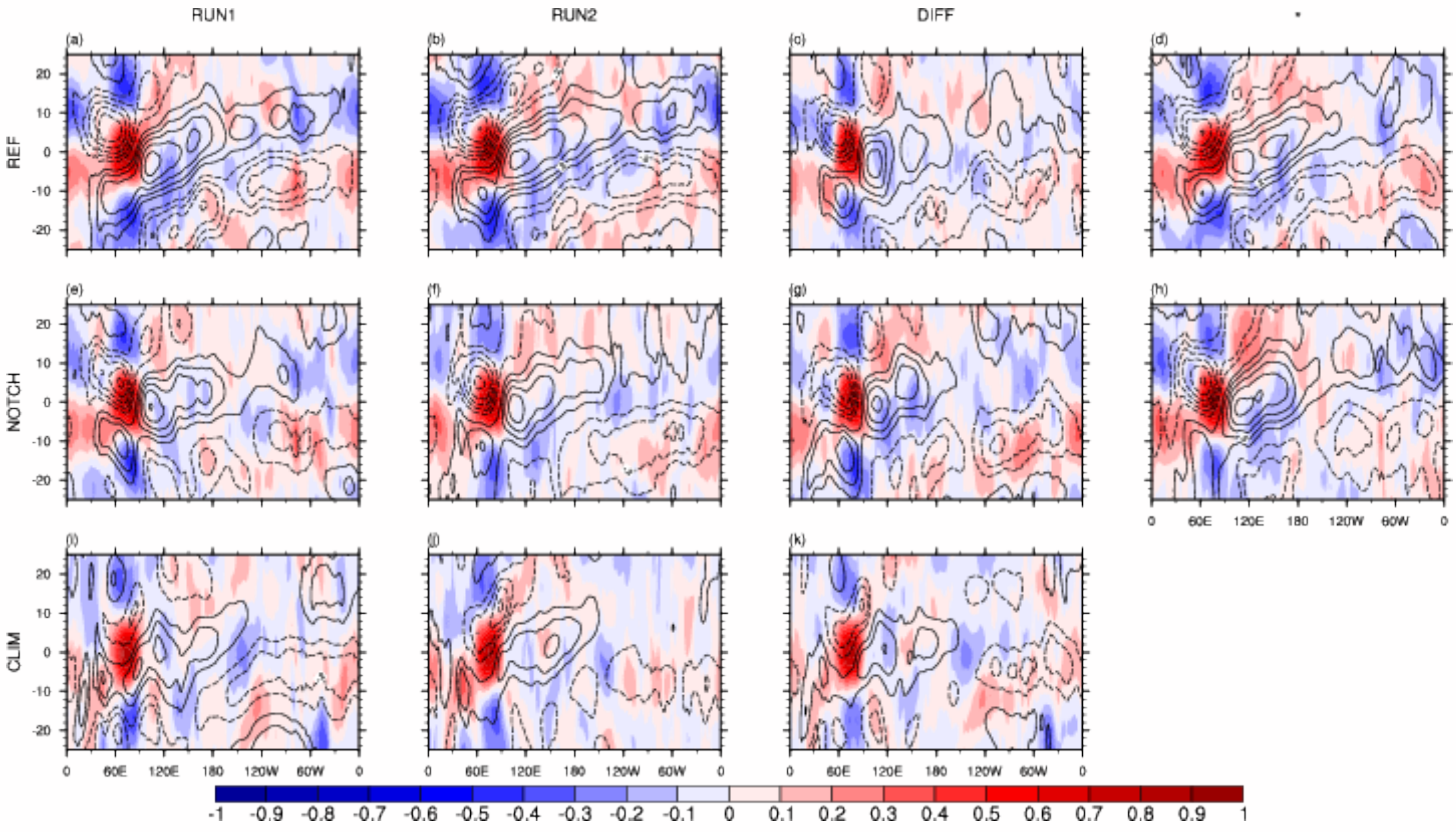


Propagation

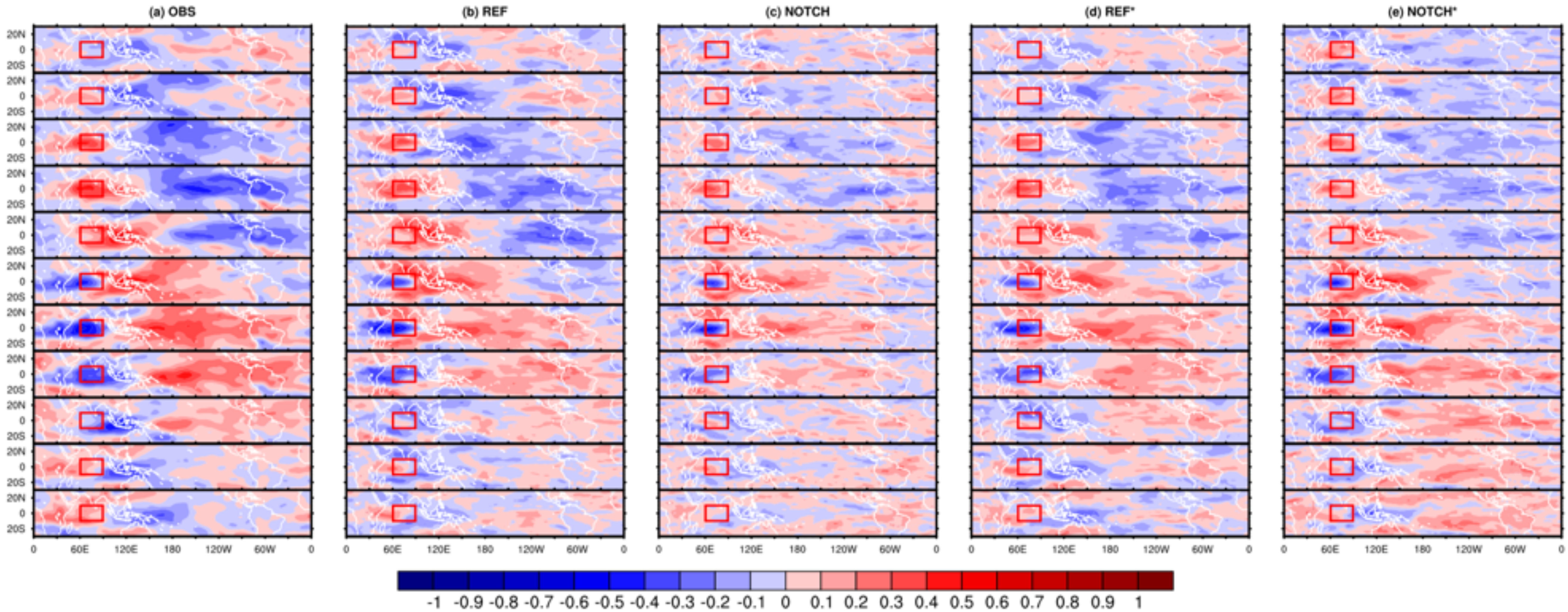
Colours OLR autocorrelation
Contours u850 correlation with OLR



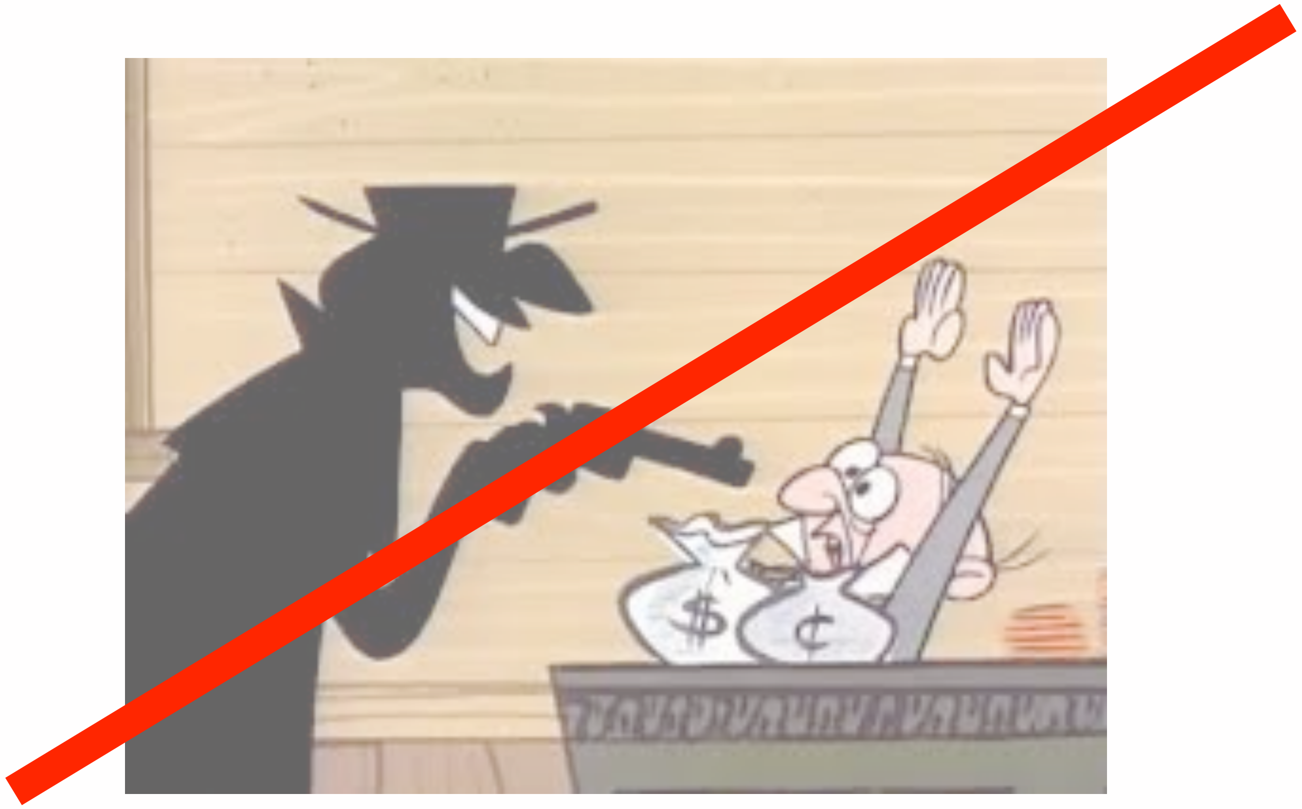
Propagation properties for all runs



Cross correlation: OLR, u850

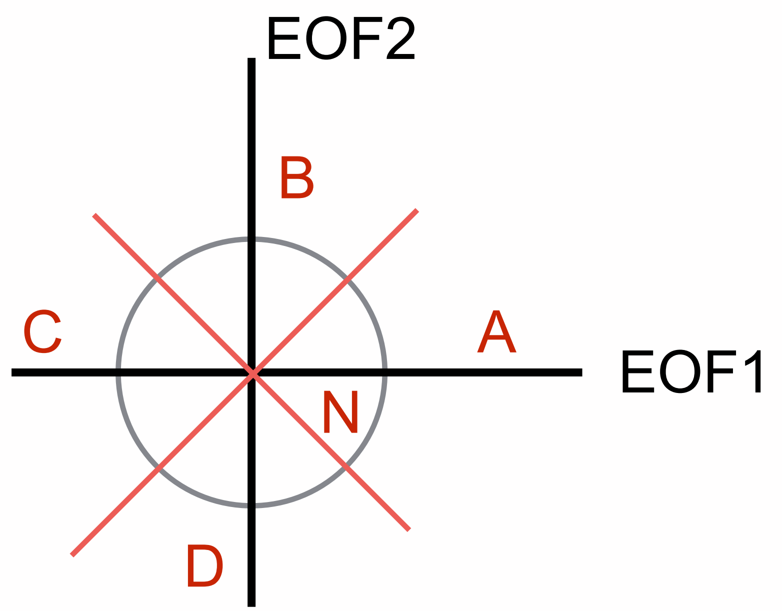


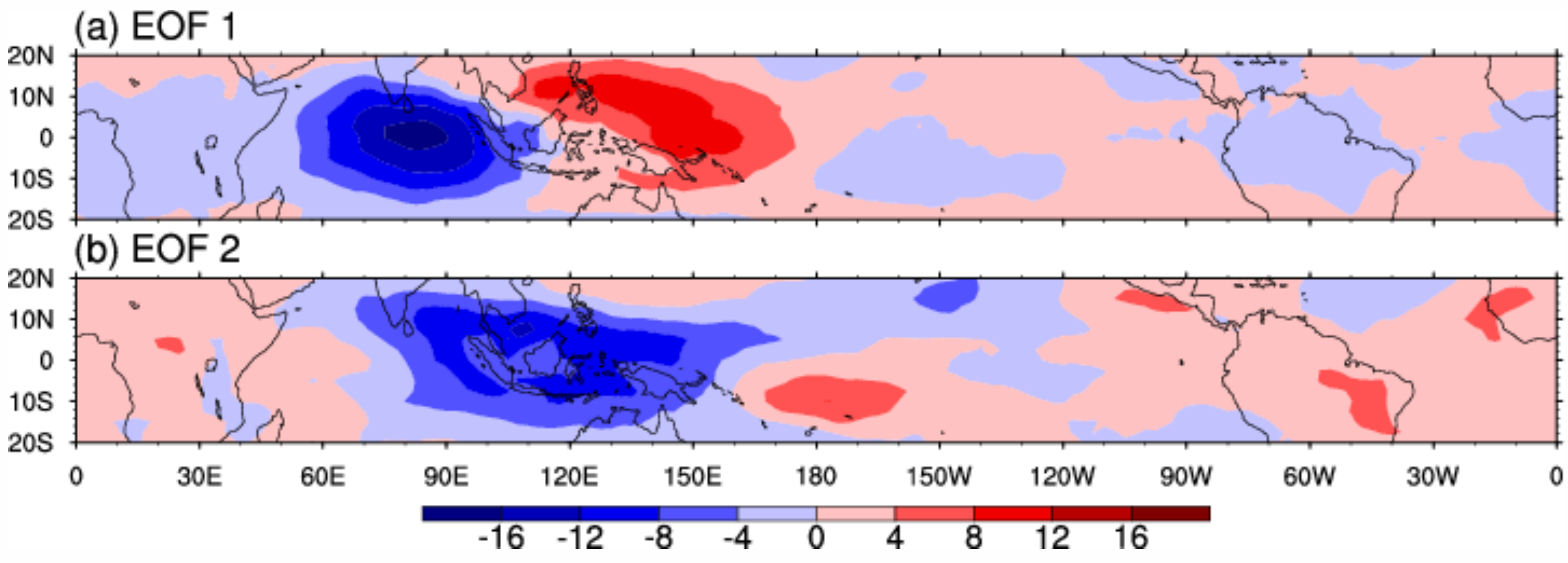
Conclusions for variance



RMM basis

EOFs of observed OLR - define RMM phases above threshold amplitude

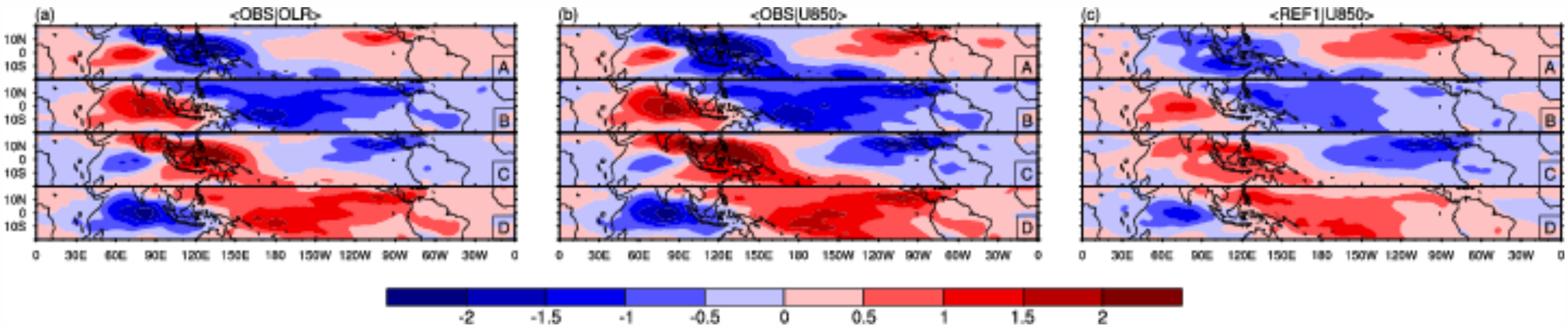




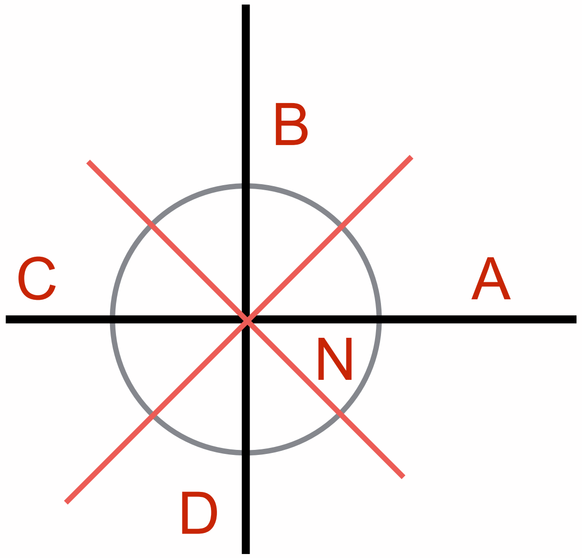
Composites for projections

The problem is to find a measure of convectively coupled phase based on modelled wind

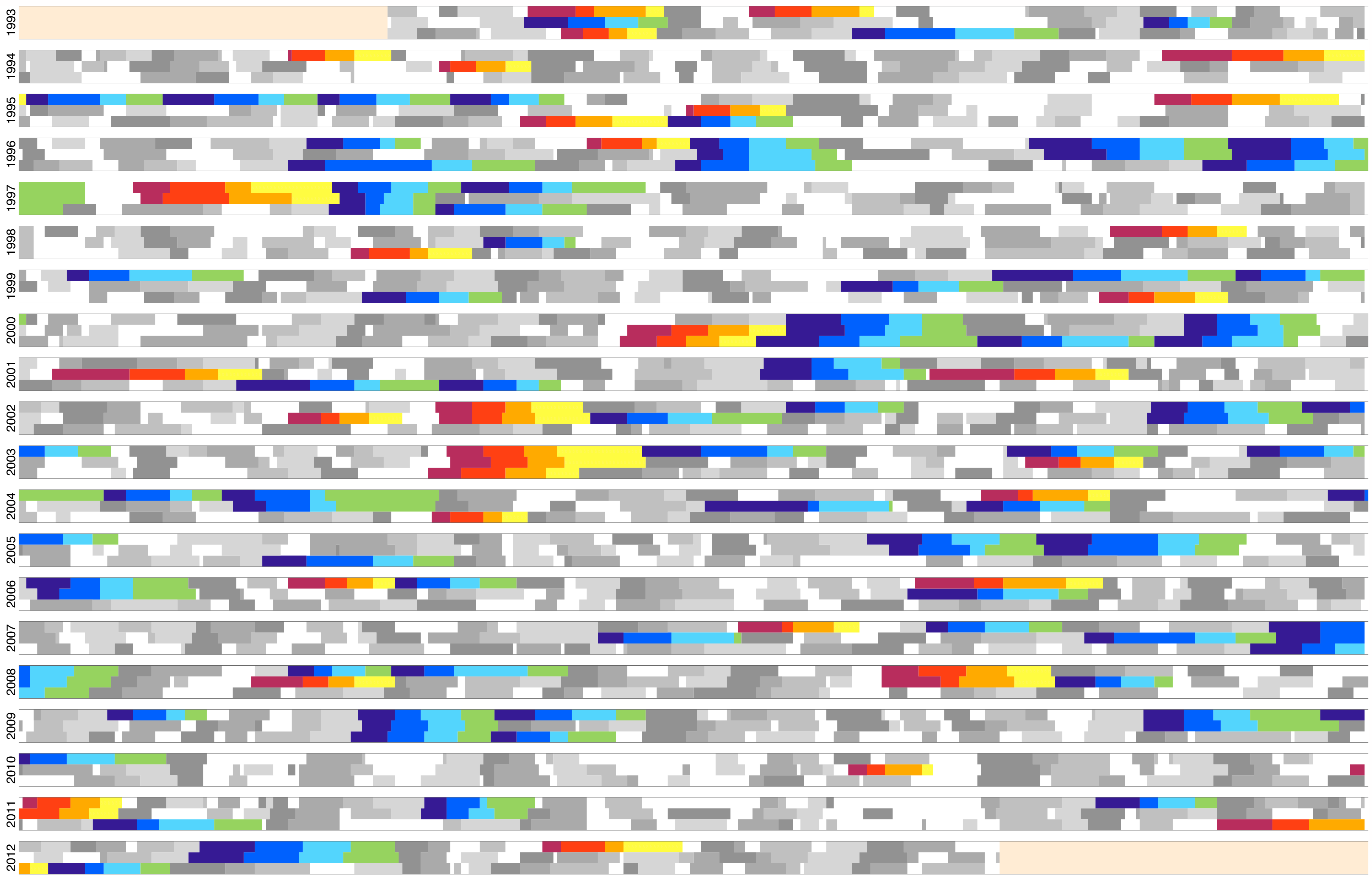
a) composites of observed u850 for the four phases based on OLR EOFs
b) composites of observed u850 based on phases defined by projection onto composites in (a)
c) composites of modelled u850 using same approach



Results



Red-yellow: primary, blue-green: successive. Four shades give ABCD phases. Events are deemed to start with the A phase.



Overall model skill

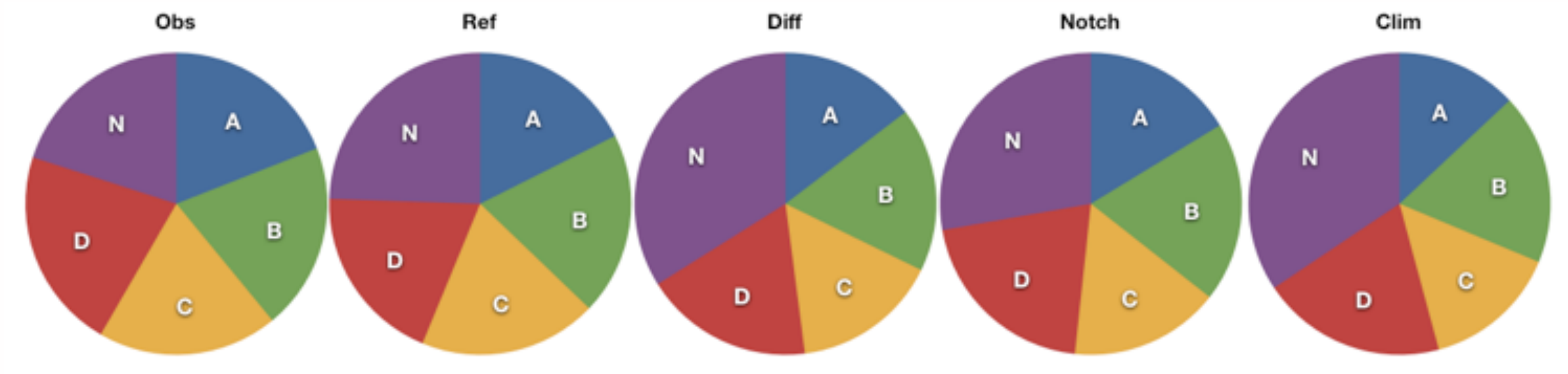
How well does the model do compared to chance at reproducing events and phases ?

EXP	%A	%B	%C	%D	%N	Score 1 ABCDN	Score 2 N or not N	Score 3 ABCD
OBS(OLR)	20.8	18.7	19.9	20.2	20.4	61.8 (20.9±0.5)	77.9 (68.0±0.4)	76.5 (26.2±0.7)
OBS(U850)	19.0	20.0	19.3	21.6	20.0	100.0 (23.1±0.5)	100.0 (69.6±0.4)	100.0 (28.2±0.7)
REF 1	17.6	19.6	19.1	19.3	24.5	38.8 (20.6±0.5)	70.5 (65.8±0.4)	49.7 (25.5±0.7)
REF 2	18.1	19.4	18.4	19.4	24.6	38.4 (20.4±0.5)	69.6 (65.5±0.4)	50.1 (25.5±0.7)
REFsn	15.3	19.8	16.7	20.6	27.5	33.5 (20.3±0.5)	66.2 (63.8±0.4)	45.0 (25.3±0.7)
REF DIFF	14.6	17.6	15.7	18.1	33.9	21.1 (20.3±0.5)	59.9 (59.6±0.4)	26.9 (25.5±0.7)
NOTCH 1	16.3	19.3	16.1	20.5	27.8	23.9 (20.3±0.5)	63.5 (63.7±0.4)	31.6 (25.1±0.7)
NOTCH 2	16.3	18.0	17.8	18.9	28.9	21.4 (20.1±0.5)	62.4 (62.8±0.4)	27.7 (25.0±0.7)
NOTCHsr	17.6	21.1	17.3	21.7	22.2	29.3 (20.1±0.5)	67.0 (66.7±0.4)	39.6 (25.1±0.6)
NOTCH DIFF	15.8	19.2	16.3	18.6	30.1	18.3 (19.9±0.5)	61.5 (62.0±0.4)	22.4 (24.8±0.7)
CLIM 1	13.0	18.3	14.5	19.8	34.4	21.5 (20.2±0.5)	59.7 (59.7±0.4)	27.4 (24.9±0.7)
CLIM 2	12.3	17.2	13.5	19.4	37.6	21.3 (20.1±0.5)	57.3 (57.4±0.4)	27.7 (25.1±0.7)
CLIM DIFF	12.4	18.9	14.3	20.0	34.3	19.6 (19.9±0.5)	58.5 (59.4±0.4)	25.3 (24.7±0.7)

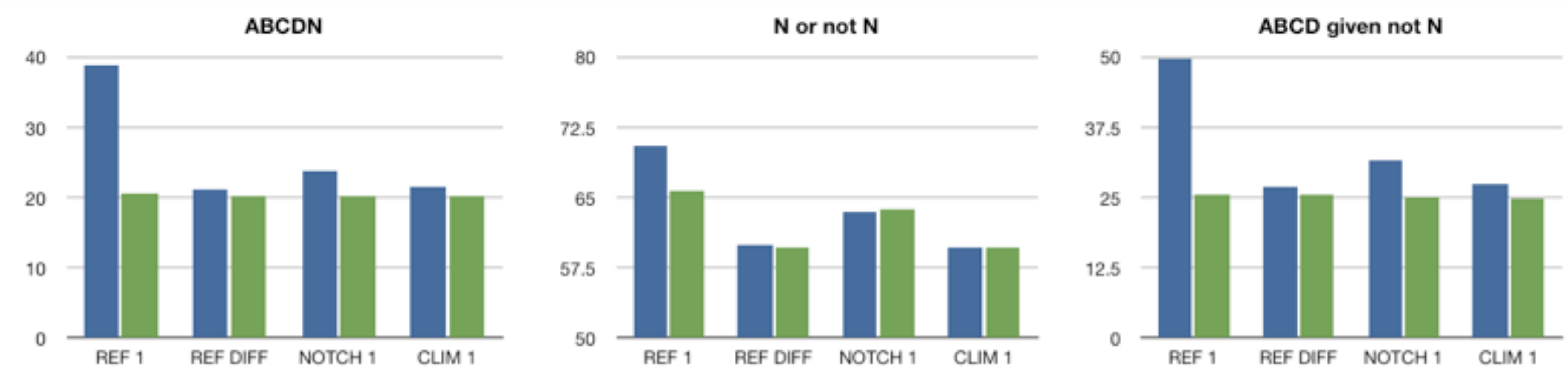
Overall model skill

How well does the model do compared to chance at reproducing events and phases ?

percentage of phase occupation:



percentage of correct phase occupation compared to monte-carlo simulations:



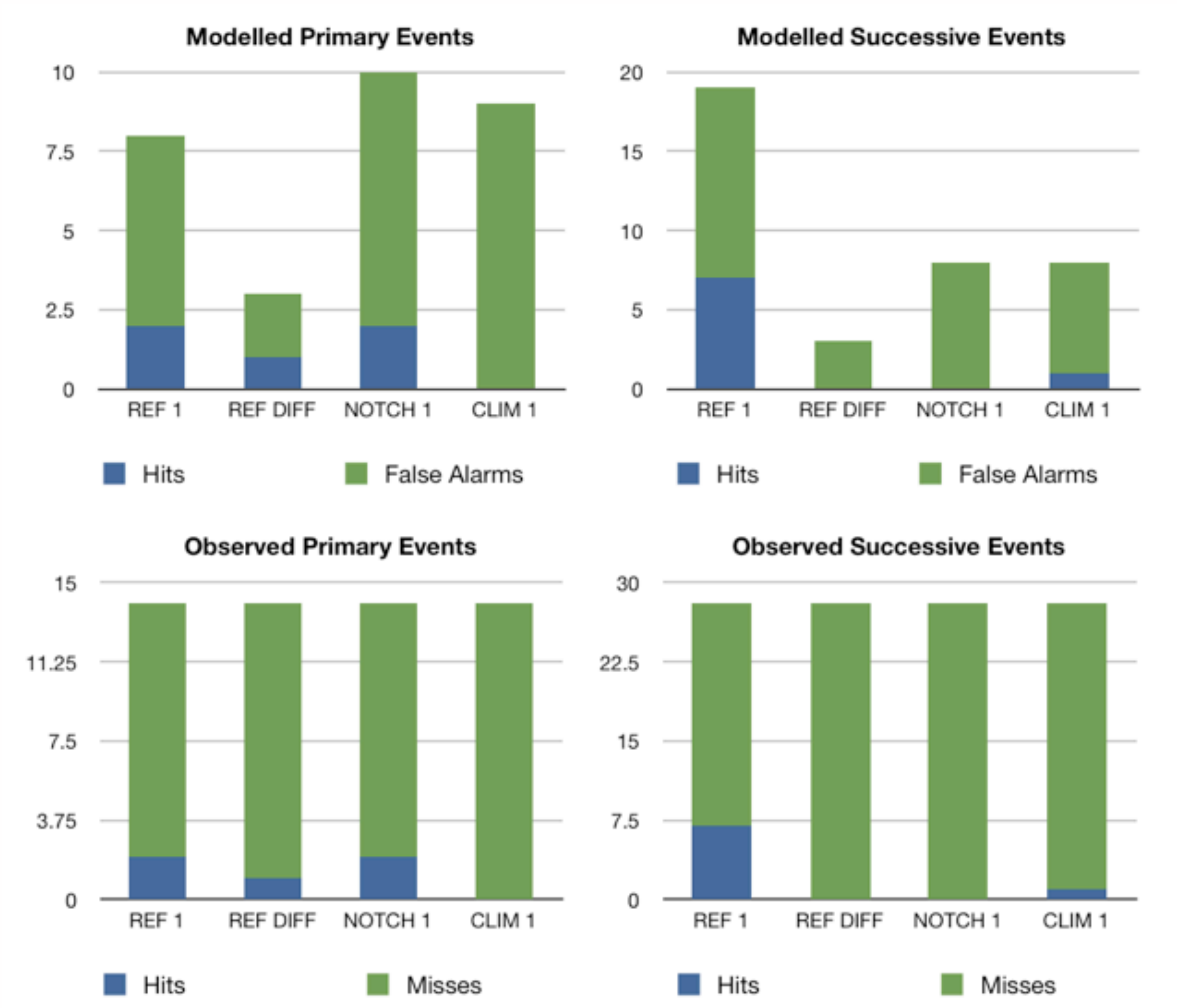
Event skill

How well does the model identify primary and successive events ?

EXP	Successive events	Hits	Misses	False Alarms	Primary events	Hits	Misses	False Alarms
OBS(OLR)	41	18	10	23	17	5	9	12
OBS(U850)	28				14			
REF 1	19	7	21	12	8	2	12	6
REF 2	18	9	19	9	8	2	12	6
REFsn	16	6	22	10	6	1	13	5
REF DIFF	3	0	28	3	3	1	13	2
NOTCH 1	8	0	28	8	10	2	12	8
NOTCH 2	10	3	25	7	9	1	13	8
NOTCHsr	10	5	23	5	11	1	13	10
NOTCH DIFF	6	2	26	4	9	2	12	7
CLIM 1	8	1	27	7	9	0	14	9
CLIM 2	11	3	25	8	8	2	12	6
CLIM DIFF	10	2	26	8	5	1	13	4

Event skill

How well does the model identify primary and successive events ?



Conclusions

The WRF model produces propagating tropical signals that are weakly coupled to convection.

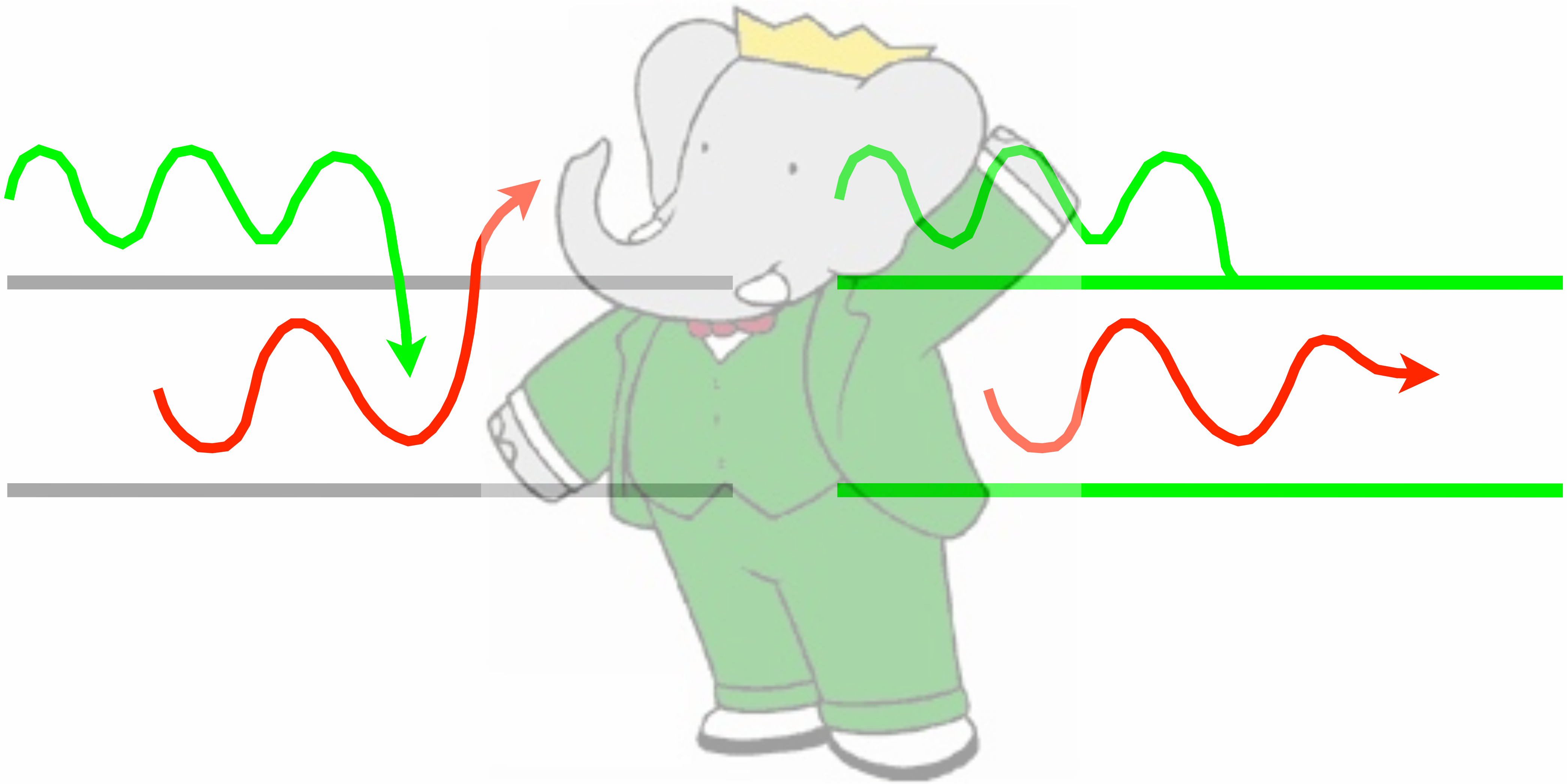
Twin experiments can preserve the model climatology and produce clean assessments of the relative strength of internal versus boundary forced variability for a variety of boundary forcing frequencies.

Our experiments point to an important role for MJO-band extratropical disturbances in triggering propagating tropical disturbances.

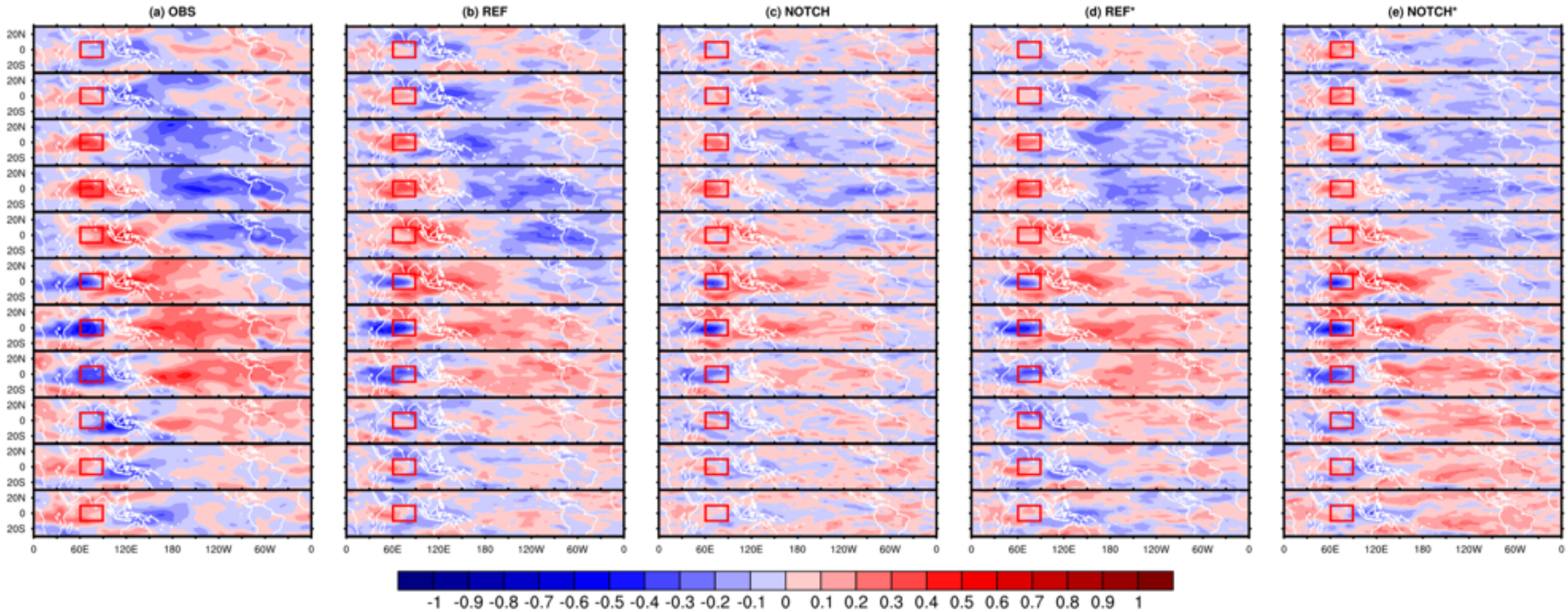
Boundary influence appears to provide organised upstream precursors, particularly for convectively coupled signals.

Hindcast skill is poor, but clearly influenced by boundary conditions, especially for successive events.

Back to the elephant



Cross correlation: OLR, u850



Adames et al, JAS 2014

Schematic of "background flow" (geopotential height and winds) due to sources of vorticity and divergence outside the tropical band (30ºN-S).

Simultaneous with active MJO over maritime continent.

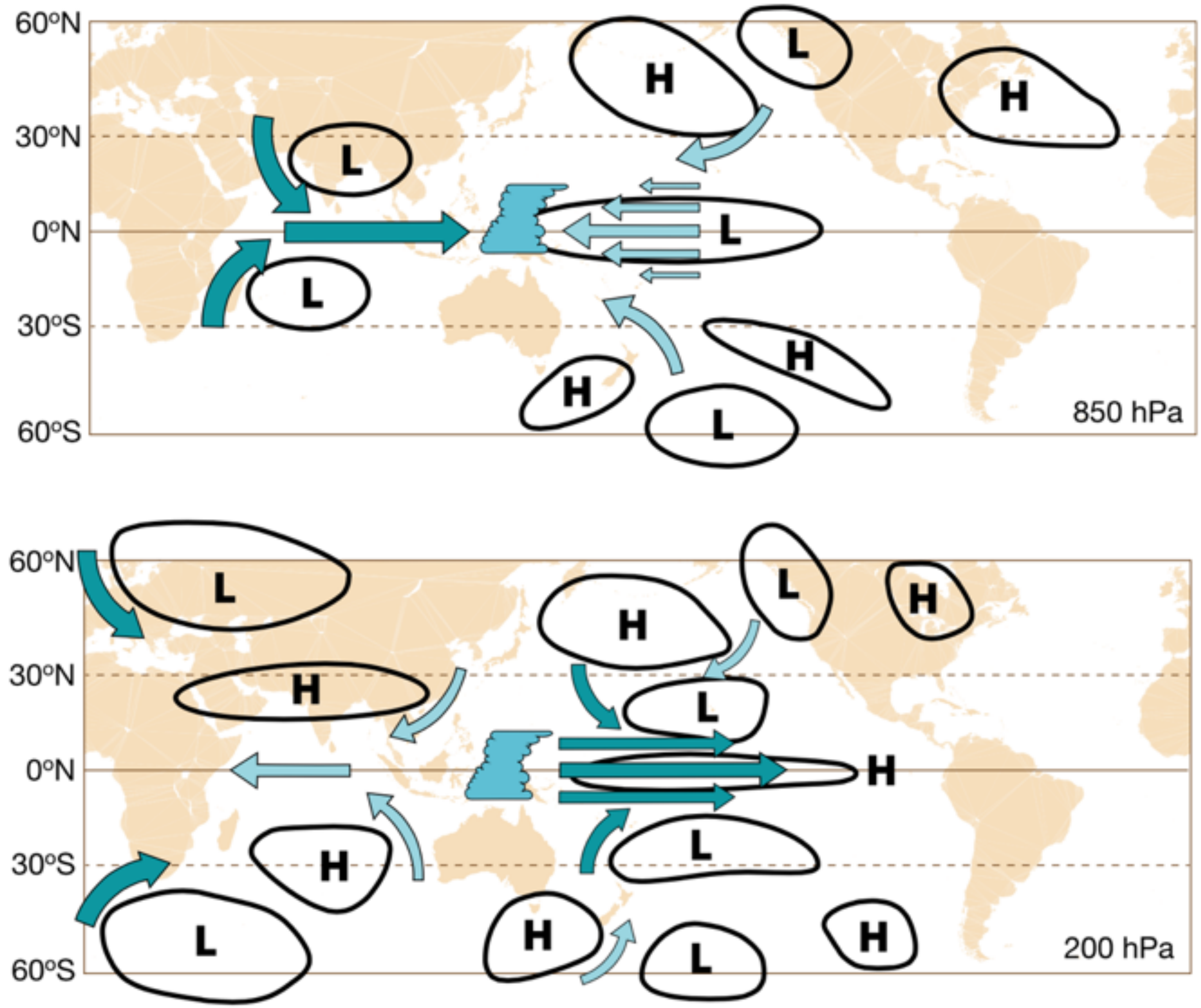
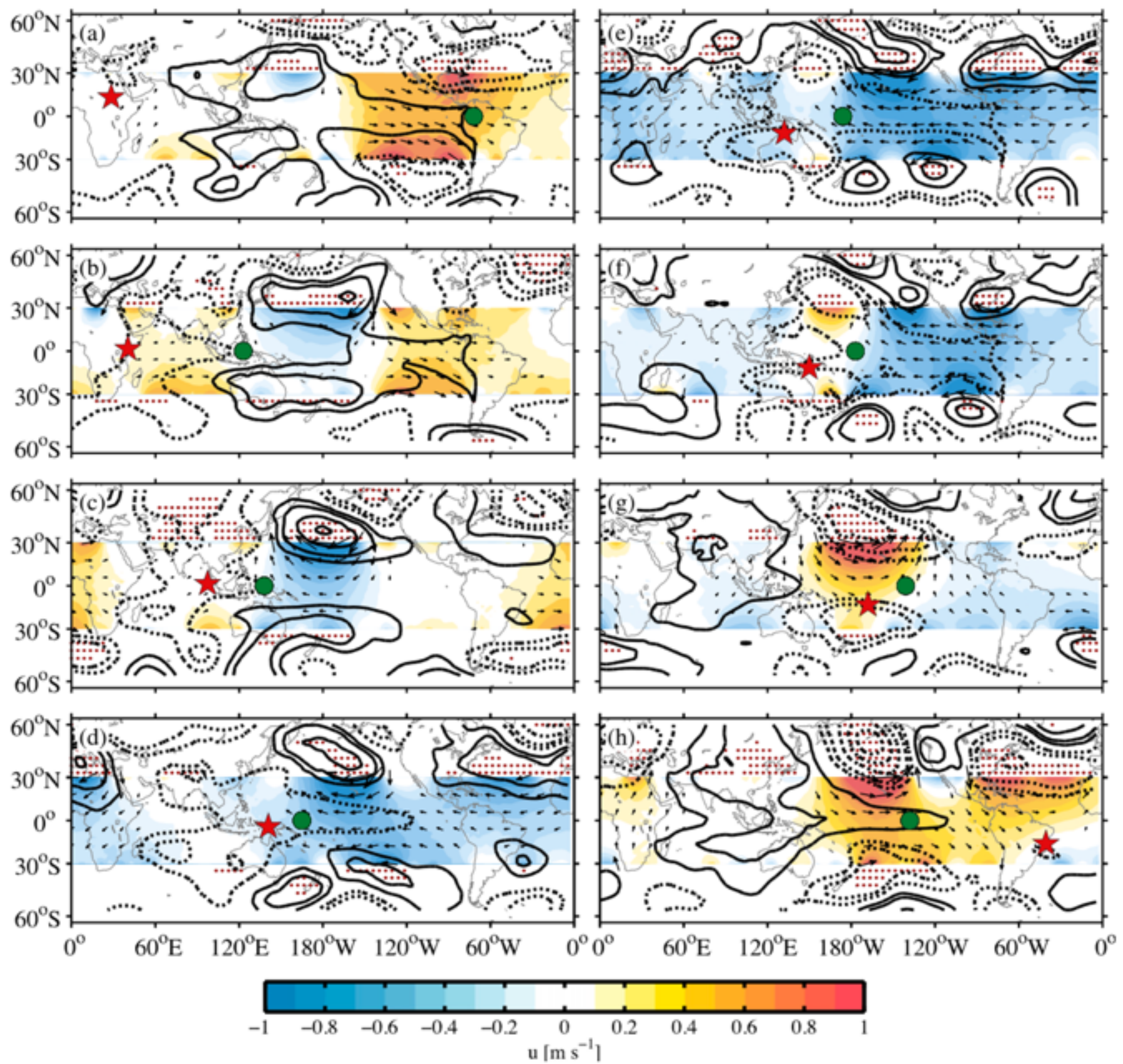


FIG. 13. Schematic of the global geopotential height field during an active MJO over the Maritime Continent. The L denotes negative height anomalies and the H denotes positive height anomalies at (top) 850 and (bottom) 200 hPa.

Adames et al, JAS 2014

"Background flow" (u 850) composites for RMM phases of MJO.



A simple GCM with an annual cycle

The observed state of the atmosphere Φ can be said to develop according to

$$\frac{d\mathbf{\Phi}_i}{dt} + \mathcal{A}\mathbf{\Phi}_i = -\mathcal{D}\mathbf{\Phi}_i + \mathbf{f}(t)$$

We can define a development equation of the model state Ψ as

$$\frac{d\mathbf{\Psi}}{dt} + \mathcal{A}\mathbf{\Psi} = -\mathcal{D}\mathbf{\Psi} + \mathbf{g}$$

The forcing **g** is an empirically derived approximation to the annual cycle of **f**.

$$\mathbf{g} = \overline{(\mathcal{A}+\mathcal{D})\mathbf{\Phi}} + (\widetilde{\mathcal{A}+\mathcal{D}})\mathbf{\Phi} + \widetilde{\frac{d\mathbf{\Phi}}{dt}}$$

The first two terms can be derived from single timestep forecasts with the unforced model intialised with observed states Φ_i. The last term we neglect for the moment, plan to derive directly from data for future versions.

To do this we calculate average **g** for calendar dates (including 29 Feb) and then apply low-pass > 90d filter to the 28yr (cyclic) timeseries of **g**.

*=> Smooth cyclic forcing with 366 distinct values of **g** distributed over 28 years.*

This way the model can run to same schedule as observed 28-year timseries and we can treat model output in exactly the same way as reanalysis data.

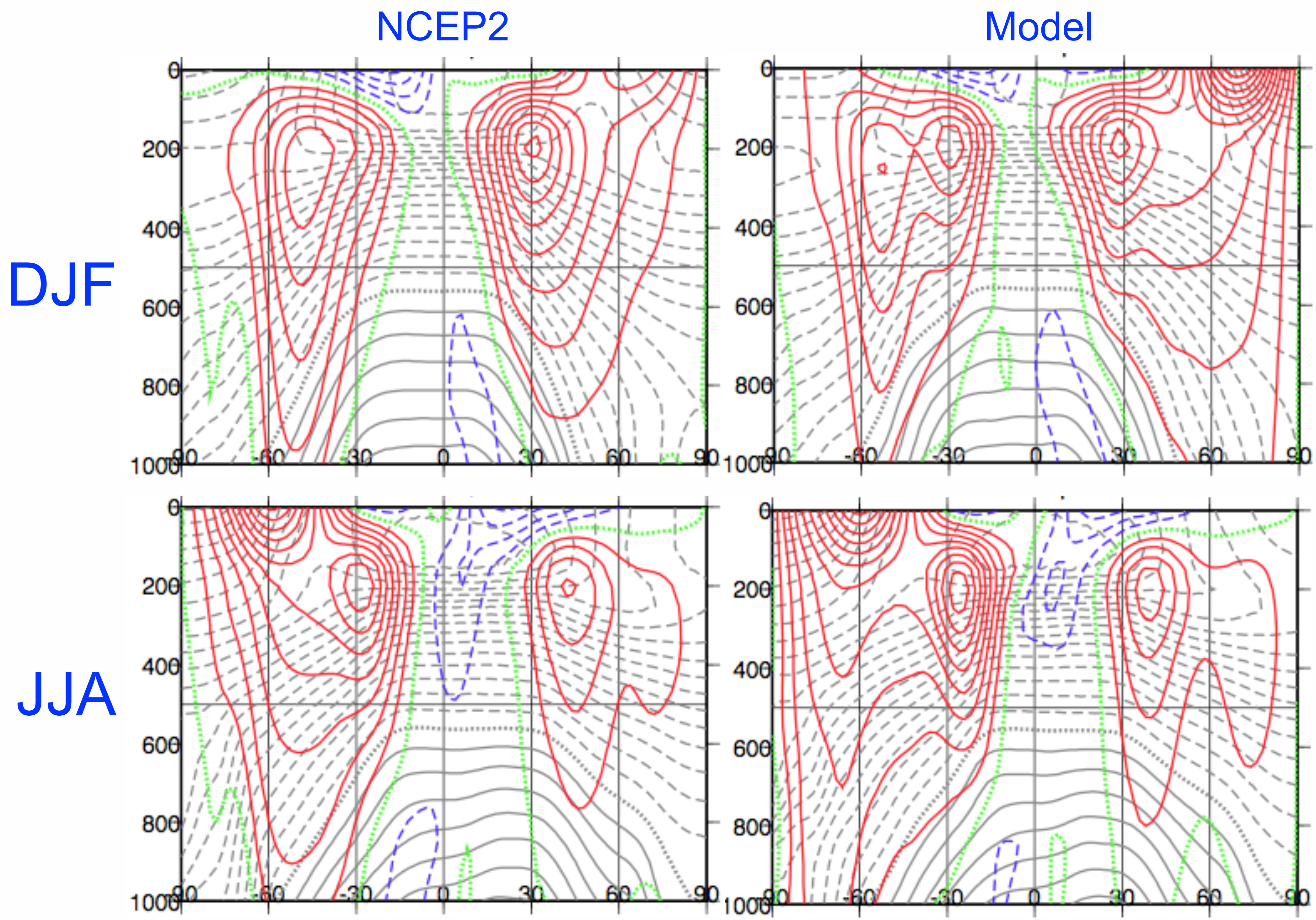
Data: NCEP2 1979-2006 daily data
28 years = 10227 days => exactly 365.25 days / year

Model: global dry primitive equations, spectral representation of z,d,T,p, T31L10*

Produce 28-year model runs.
Initialise from 1 jan 1979.

Validation: general circulation

Zonal mean wind and temperature for winter and summer, ci = 5m/s, 4ºC.



Nudge nudge

"say no more !"

We can add a nudging term to the model forcing

$$\frac{d\mathbf{\Psi}}{dt} + \mathcal{A}\mathbf{\Psi} = -\mathcal{D}\mathbf{\Psi} + \mathbf{g} + \left(\frac{\mathbf{\Phi}_n - \mathbf{\Psi}}{\tau}\right)$$

where Φ_n is an observed state in a specified subregion of the model

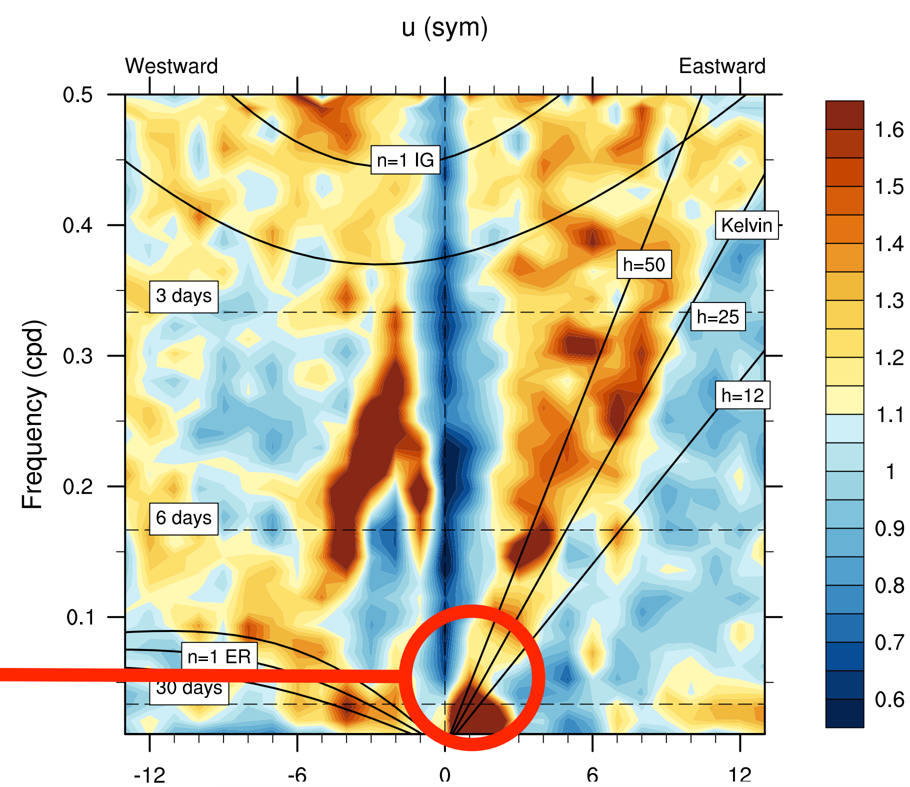
The nudging state can also be filtered in time to examine the effect of different timescales on the flow outside the nudging region.

Where do you draw the line ?

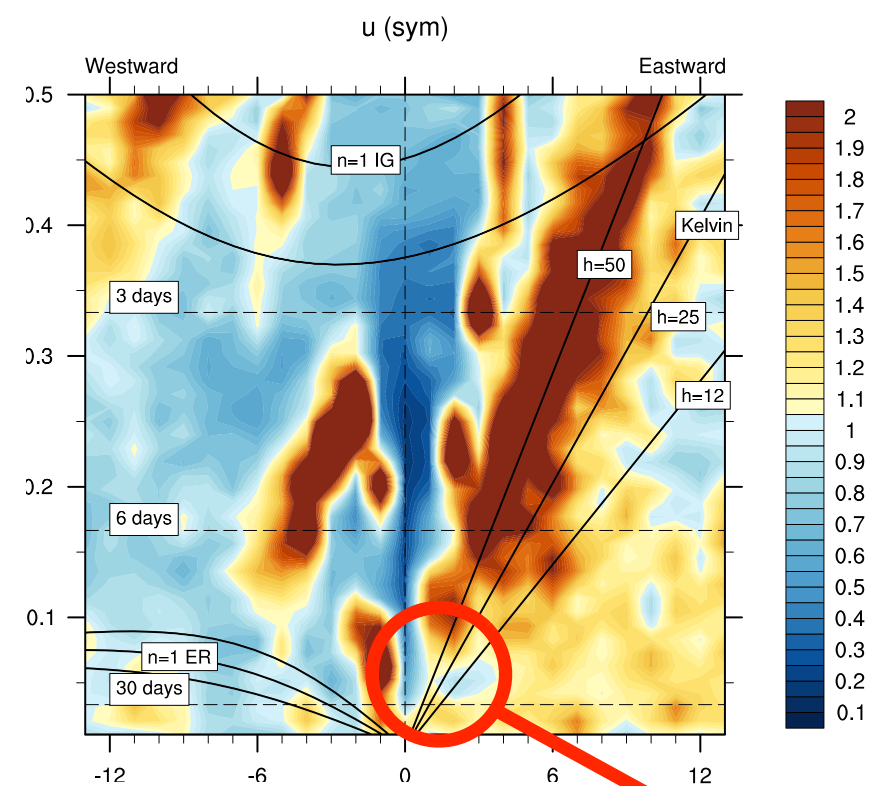
850 hPa zonal wind, DJF, symmetric part, red noise removed.

Idealised dynamical model runs with midlatitudes nudged to daily NCEP2.

MJO



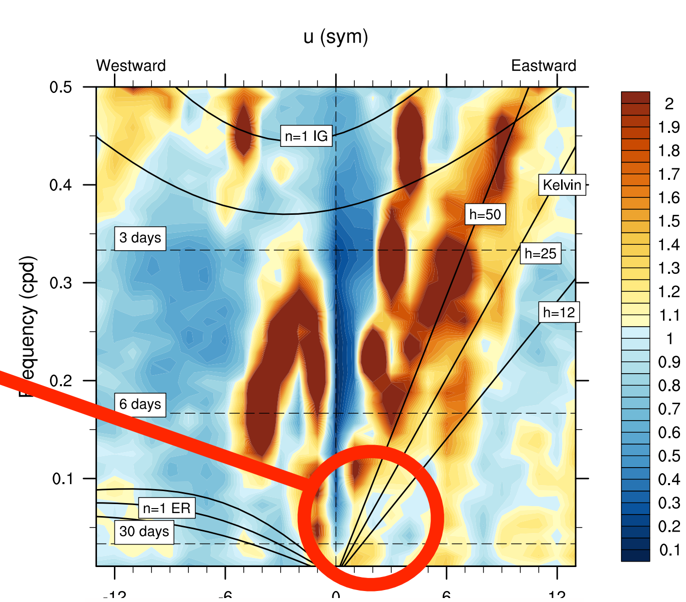
NCEP2 reanalysis



Free model run

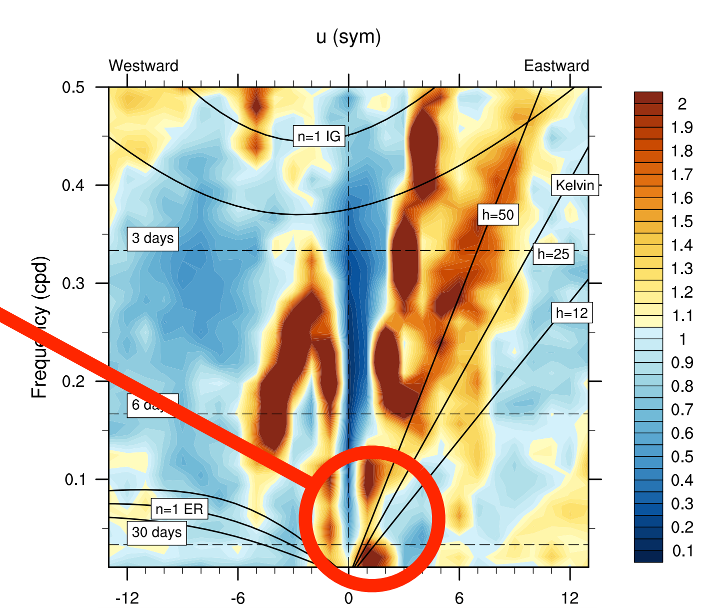
no MJO

no MJO



Nudged outside 30 NS

OMG !



Nudged outside 25 NS

Off topic - nudge the tropics

While we’re here let’s try it the other way round:

Nudge the tropics (20ºN-S) to daily NCEP2 data

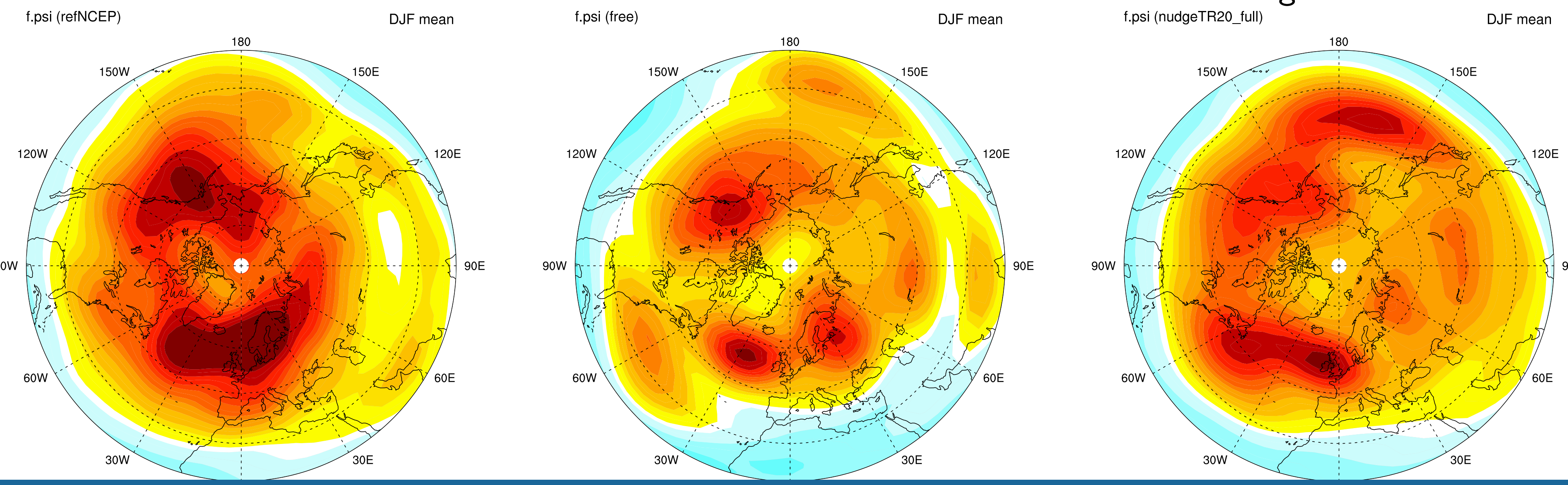
(to be revisited with a longer ERAi dataset at higher resolution)

Intraseasonal variability: DJF, MAM

sigma=.25 f x streamfunction 20-90 day variance, m^2

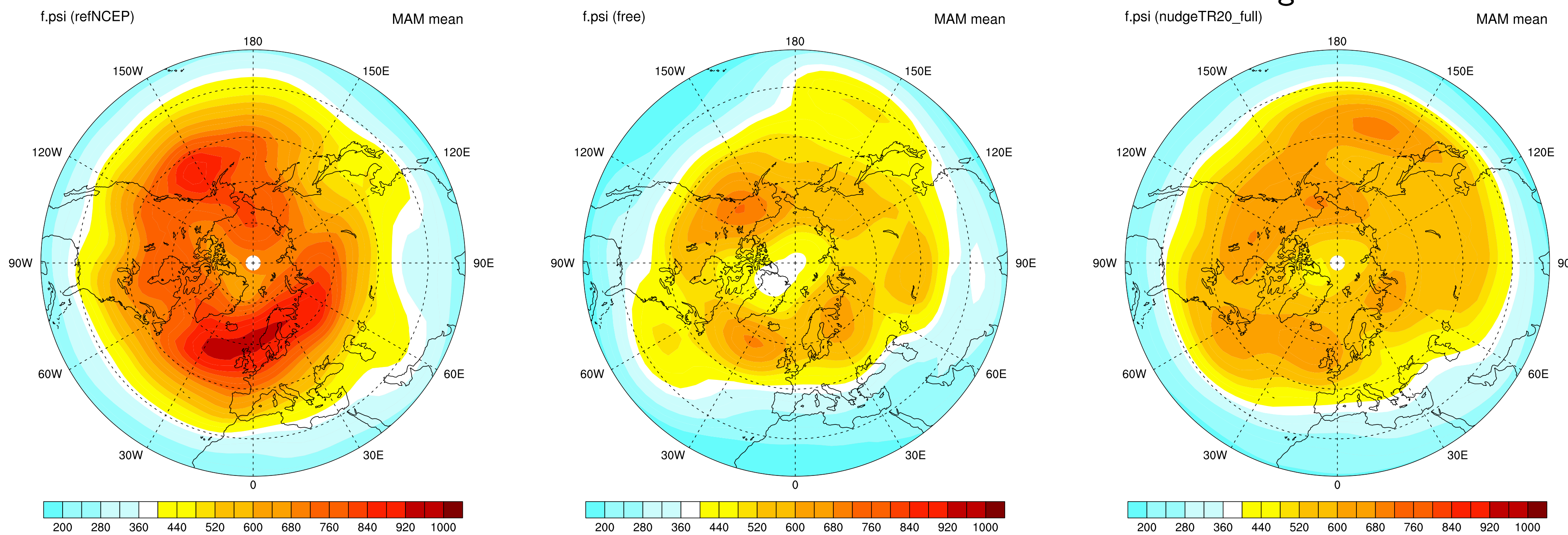
DJF 20-90d f.psi (250 hPa)

obs | free run | nudgeTR20 full



MAM 20-90d f.psi (250 hPa)

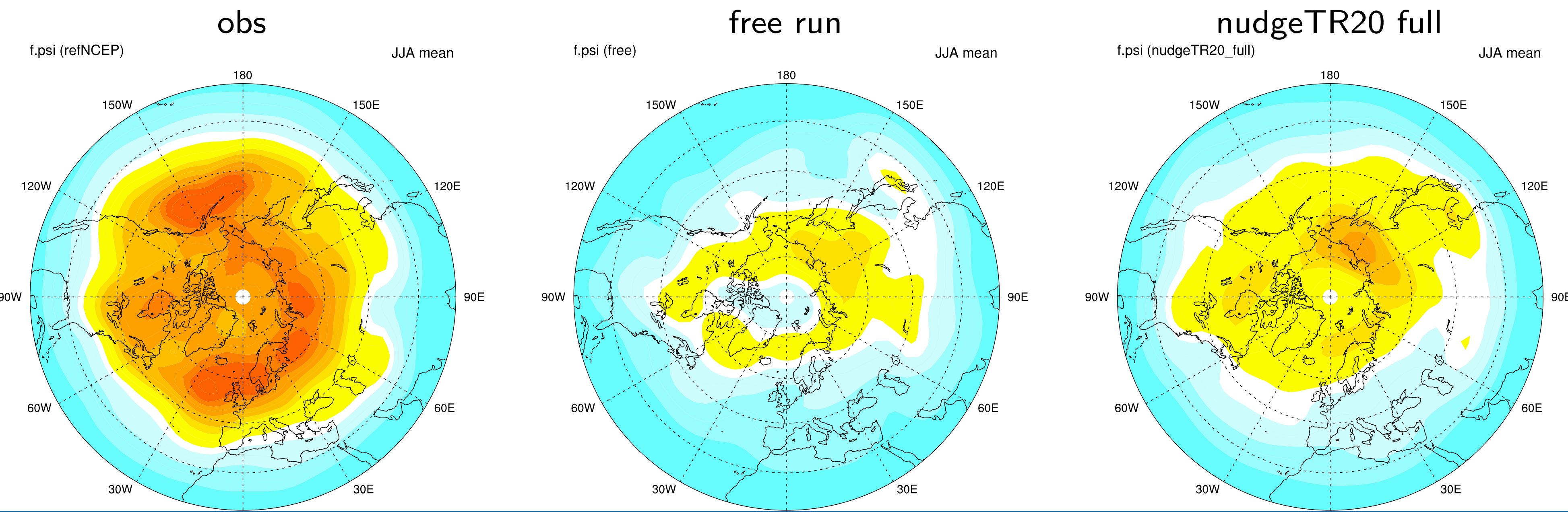
obs | free run | nudgeTR20 full



Intraseasonal variability: JJA,SON

sigma=.25 f x streamfunction 20-90 day variance, m^2

JJA 20-90d f.psi (250 hPa)



SON 20-90d f.psi (250 hPa)