Stratospheric Predictability and the Arctic Polar-night Jet Oscillation

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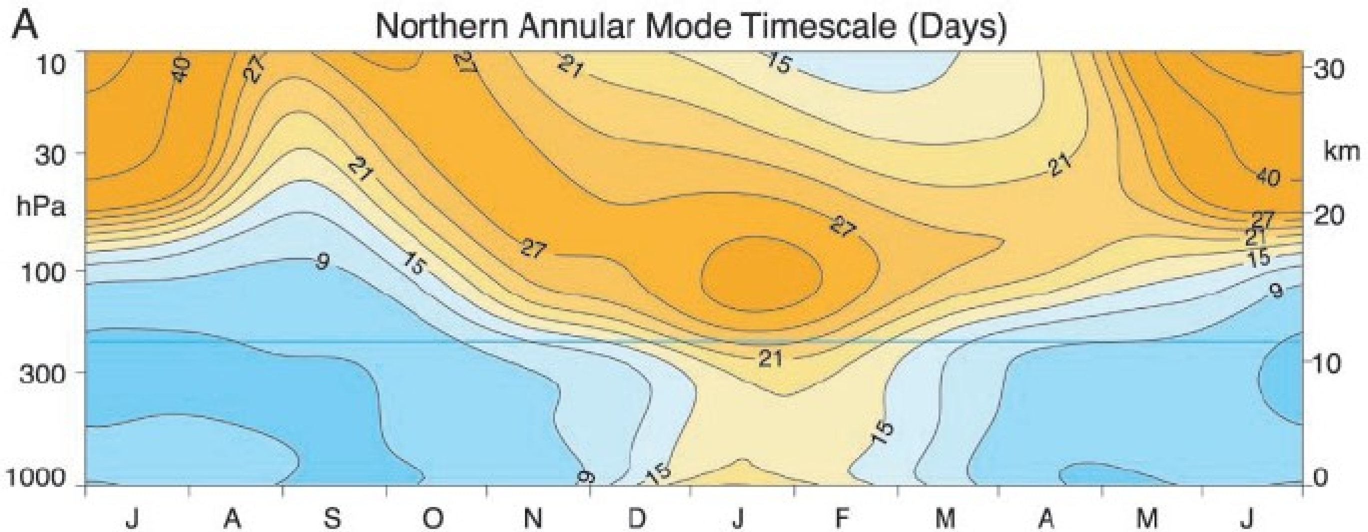
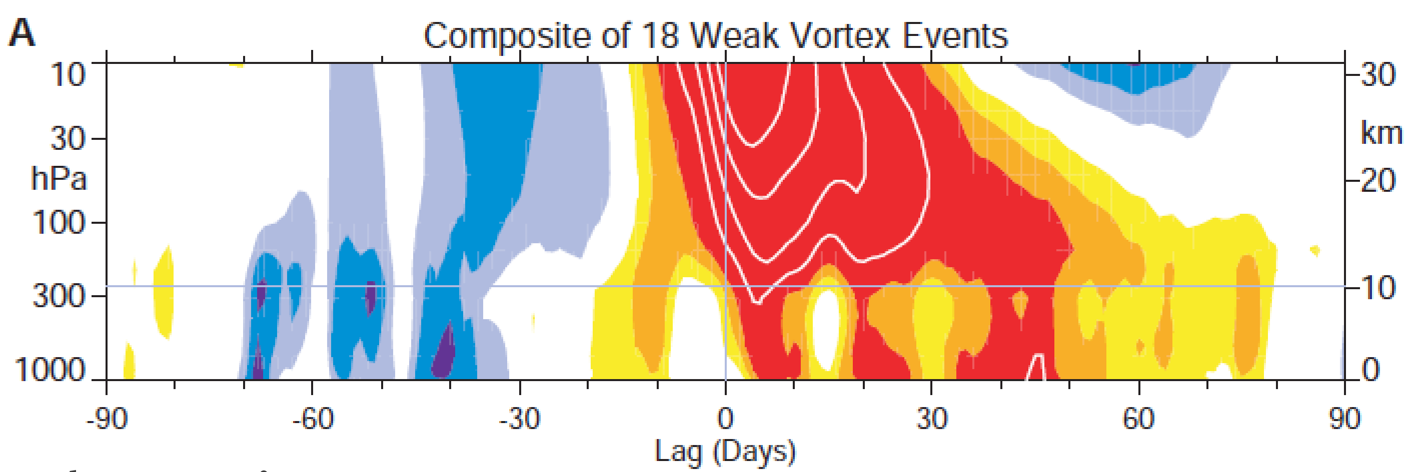
NAM Decorrelation Timescales



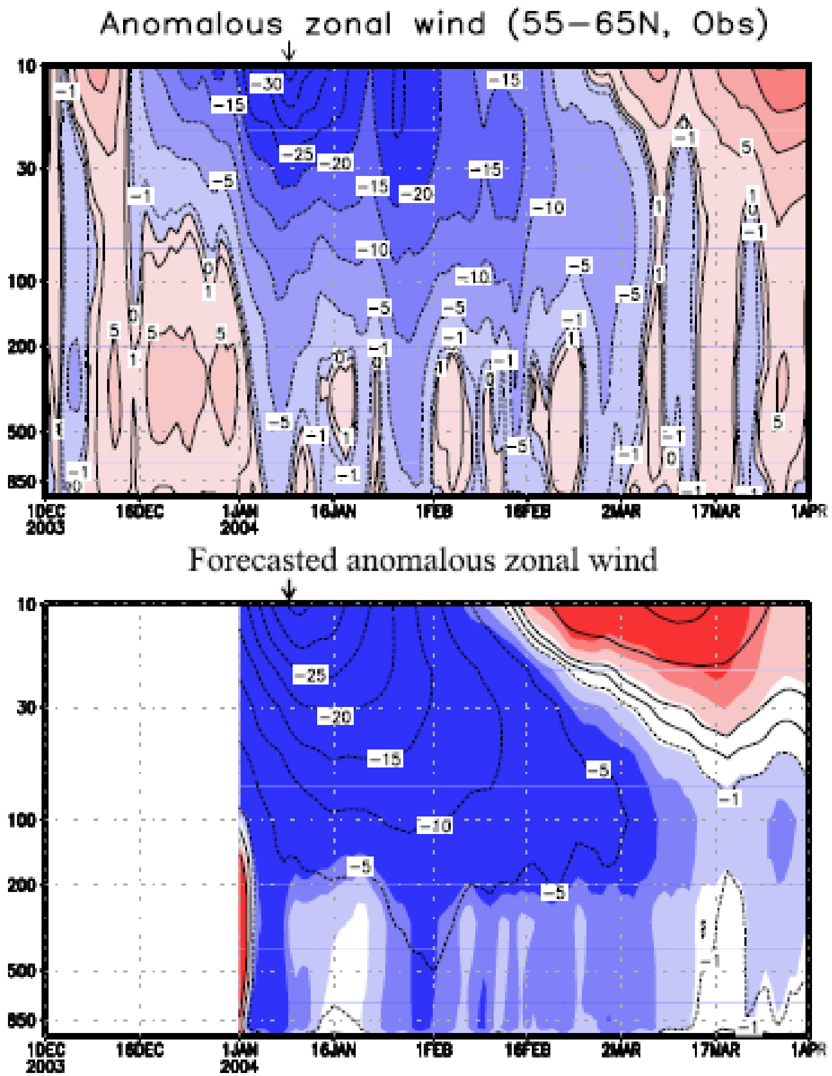
Baldwin et al. Science 2003

Can we exploit the longer stratospheric timescales to improve predictability of the troposphere?



Baldwin and Dunkerton Science 2001

Sometimes Yes...

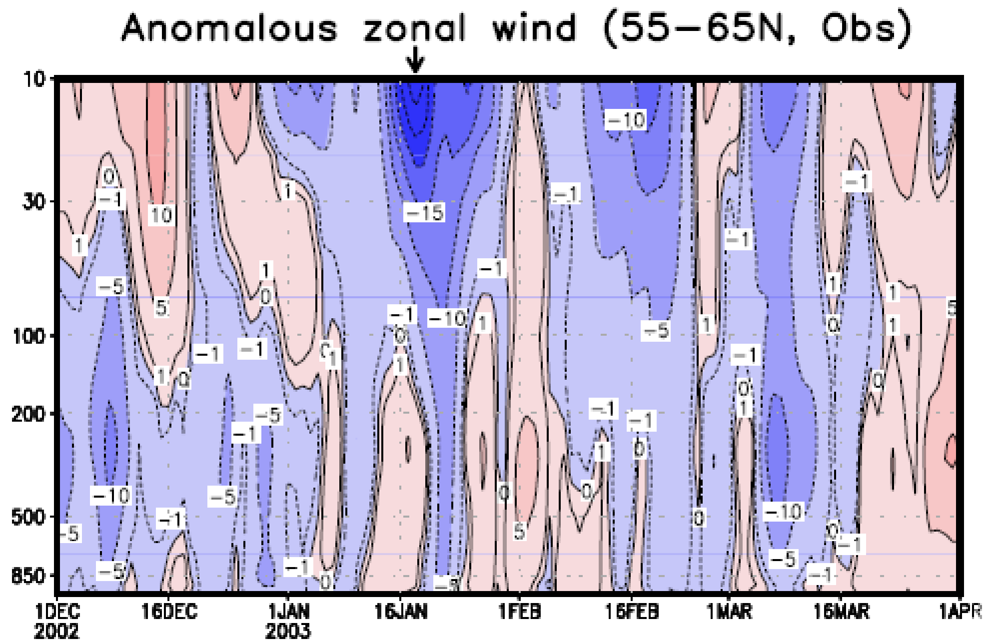


Zonal wind, 60 N
Winter 2003-2004

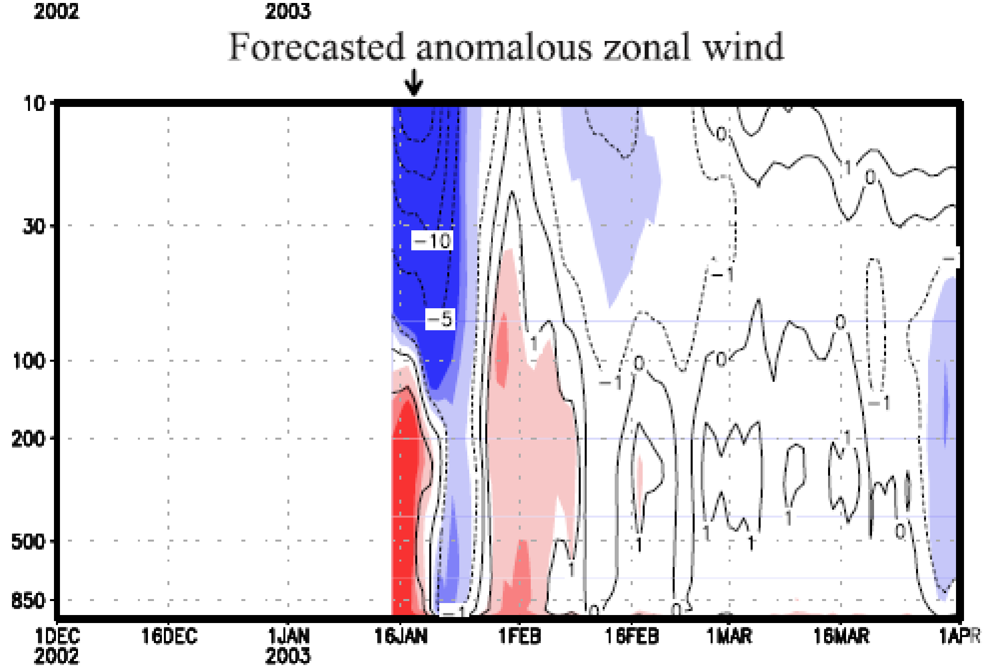
Ensemble forecast of winds, begun btw. 27 Dec and 1 Jan 2003

Kuroda, GRL 2008

… but sometimes No



Zonal wind, 60 N
Winter 2002-2003



Ensemble forecast
of winds, begun btw.
27 Dec and 1 Jan 2002

Kuroda, GRL 2008

Questions

- From where does this predictability arise?
- Why does the enhanced skill seem to arise only after particular sudden warmings?

Outline

- PJO Events
  - definition and characterization
  - zonal mean dynamics
- Conclusions

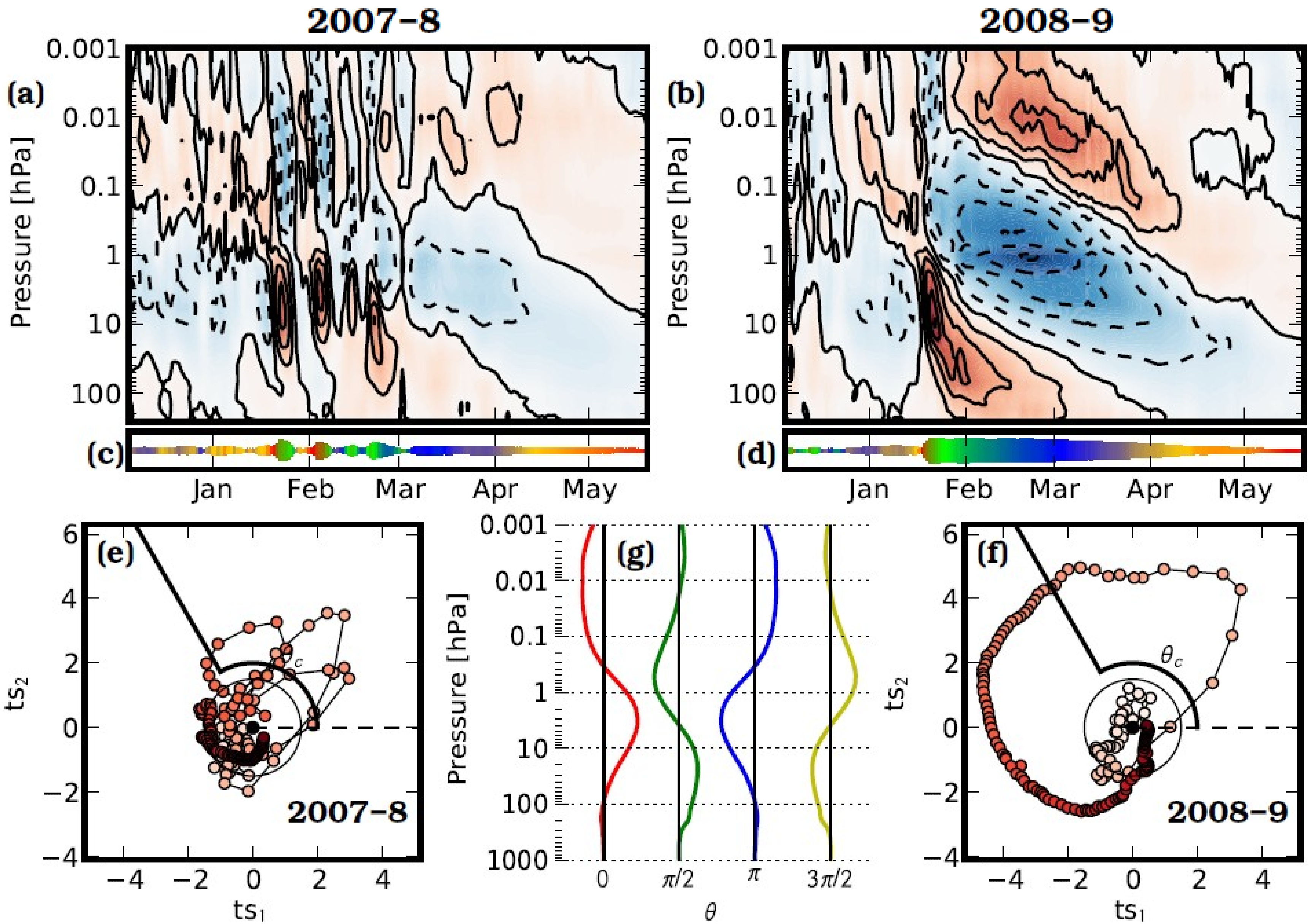
Hitchcock, Shepherd and Manney, J. Clim. (sub.)

Hitchcock and Shepherd, JAS (sub.)

Datasets

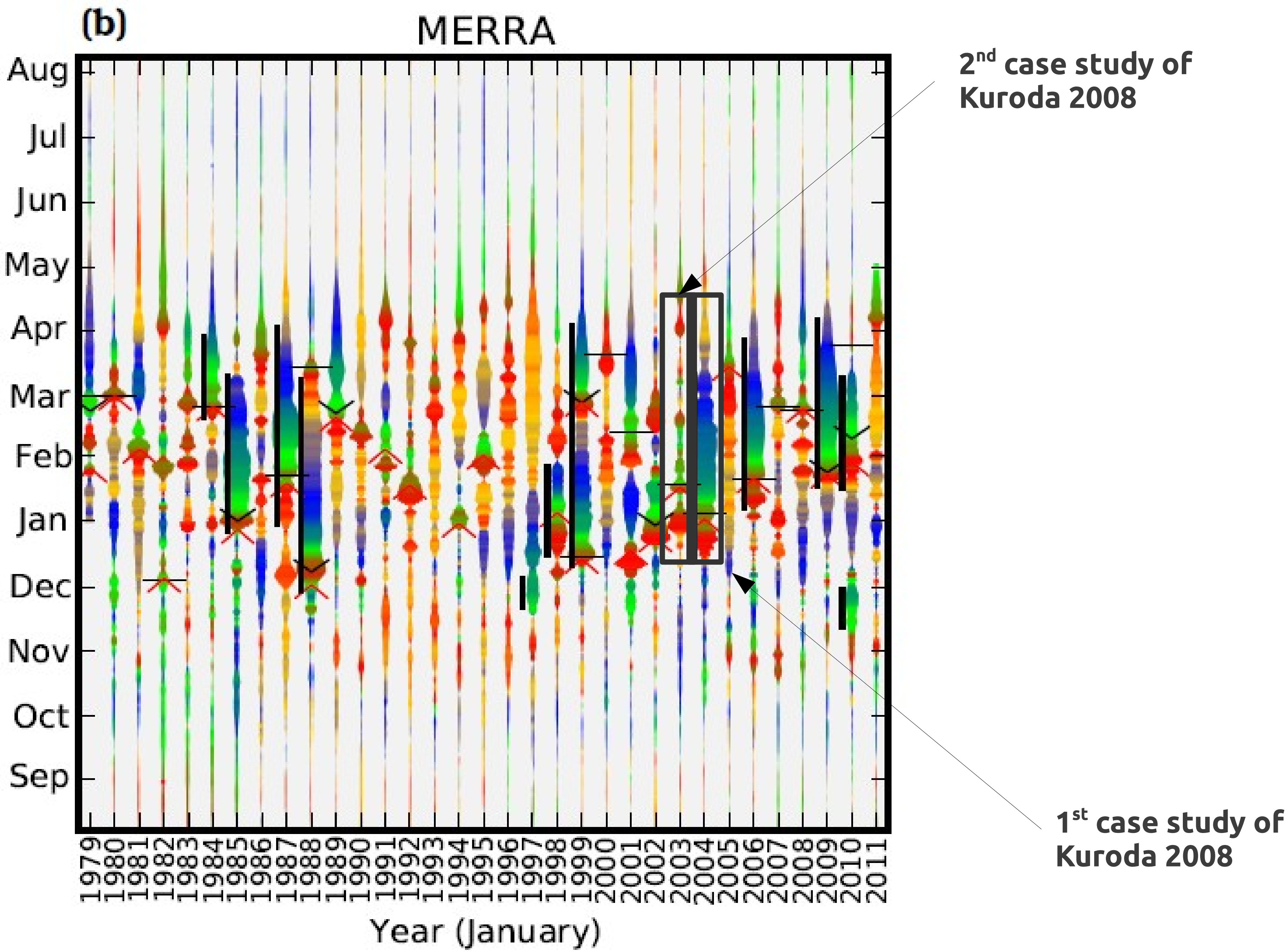
- Observations
  - Aura MLS: 300 to 0.001 hPa, 2004-2011
- Reanalyses
  - ERA40: 1000 to 1 hPa, 1957-2002
  - MERRA: 1000 to 0.1 hPa, 1979-2011
- Model
  - Canadian Middle Atmosphere Model (CMAM)
    - 1000 to 0.001 hPa, 1960-2100 (x3)
    - Time-dependent GHGs and ODSs
    - Interactive strat. chemistry, specified SSTs
    - REF2 Ensemble from CCMVal 1

PJO Events

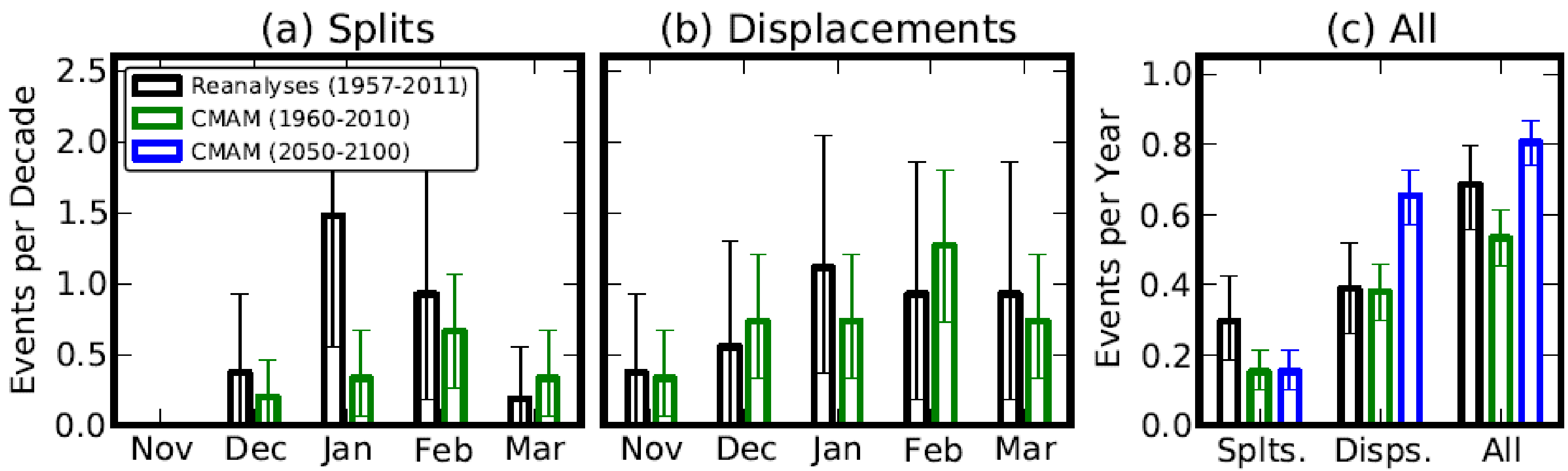


Polar cap T' from MLS Satellite Obs. (10 K interval)

Abacus plots

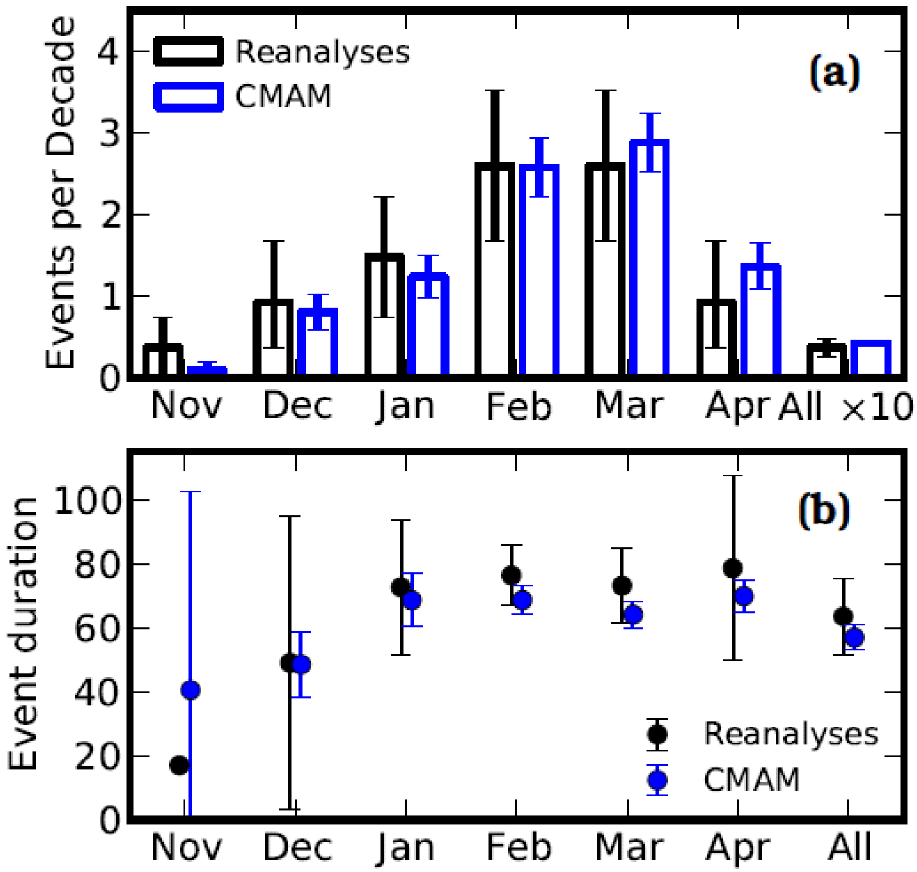


CMAM Sudden Warmings

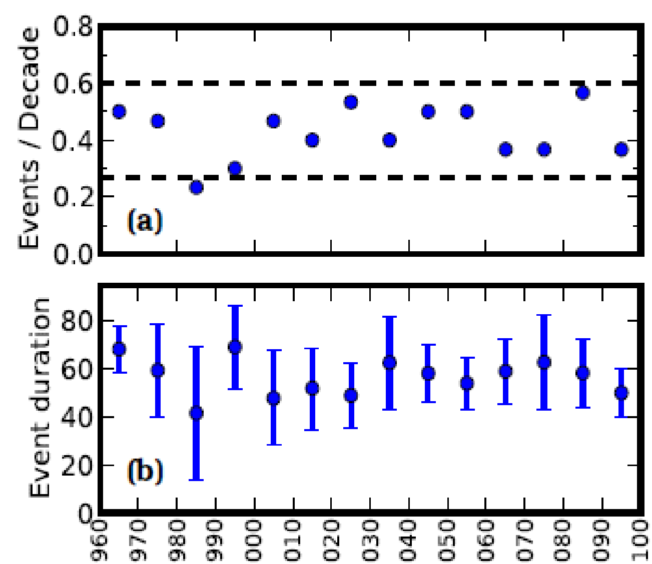


- Sudden warming occurrence rates agree with observational records to within sampling uncertainty
- Fraction of splits and displacements also reproduced

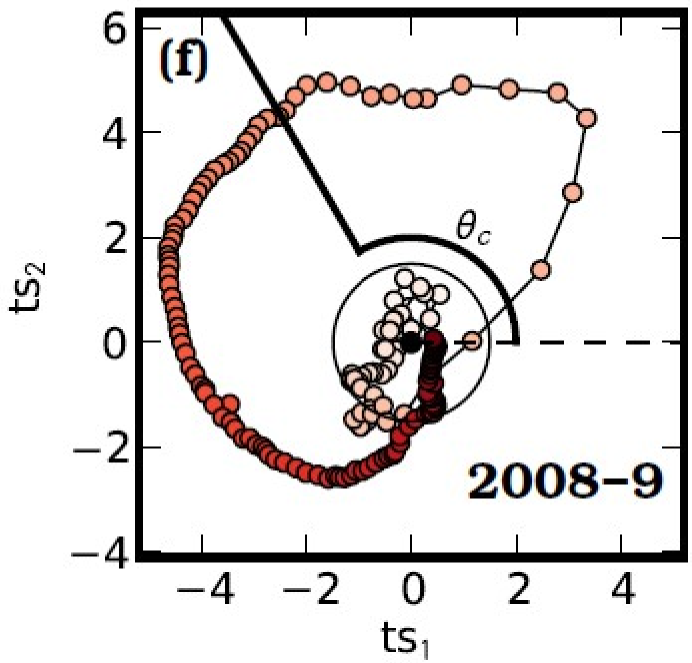
CMAM PJO Occurrence

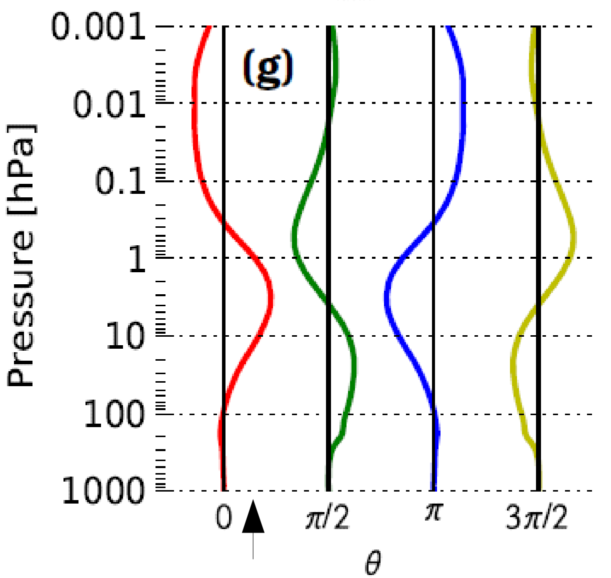


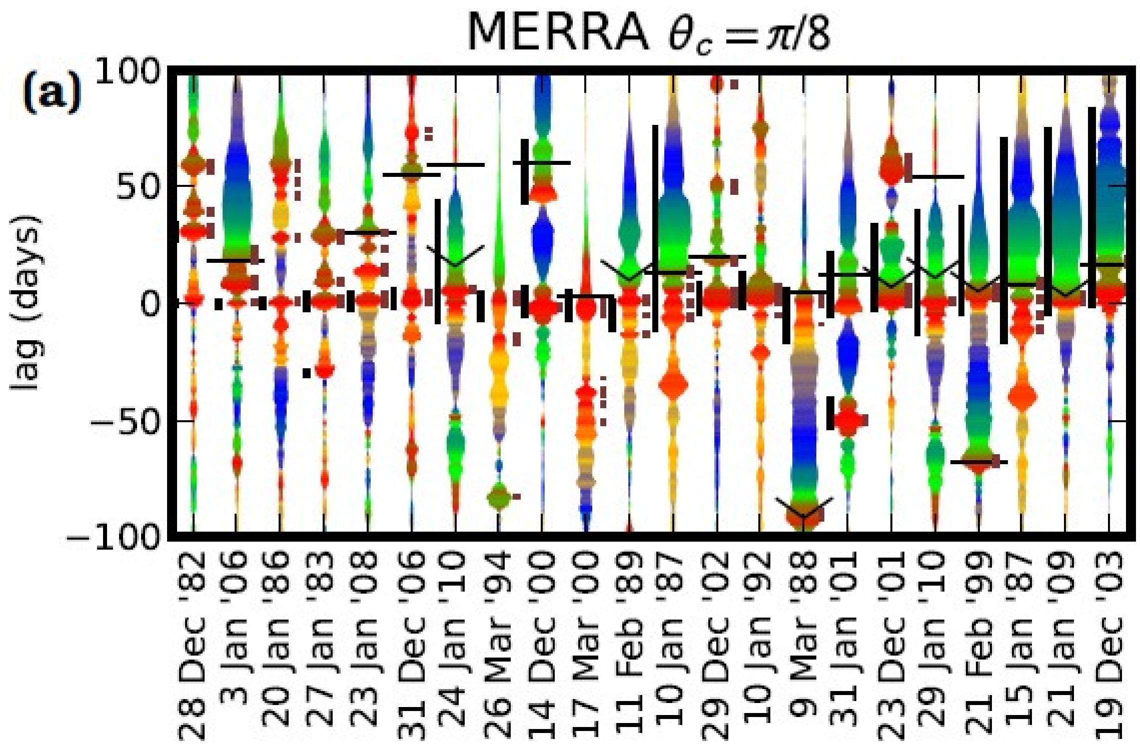
- PJO occurrence frequency and average duration also well reproduced
- No sign of a trend in either



Duration vs. depth of warming

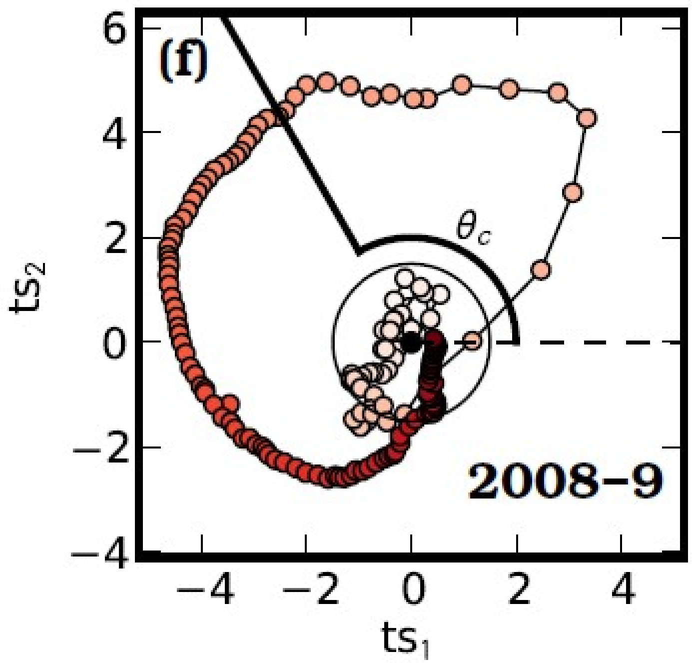


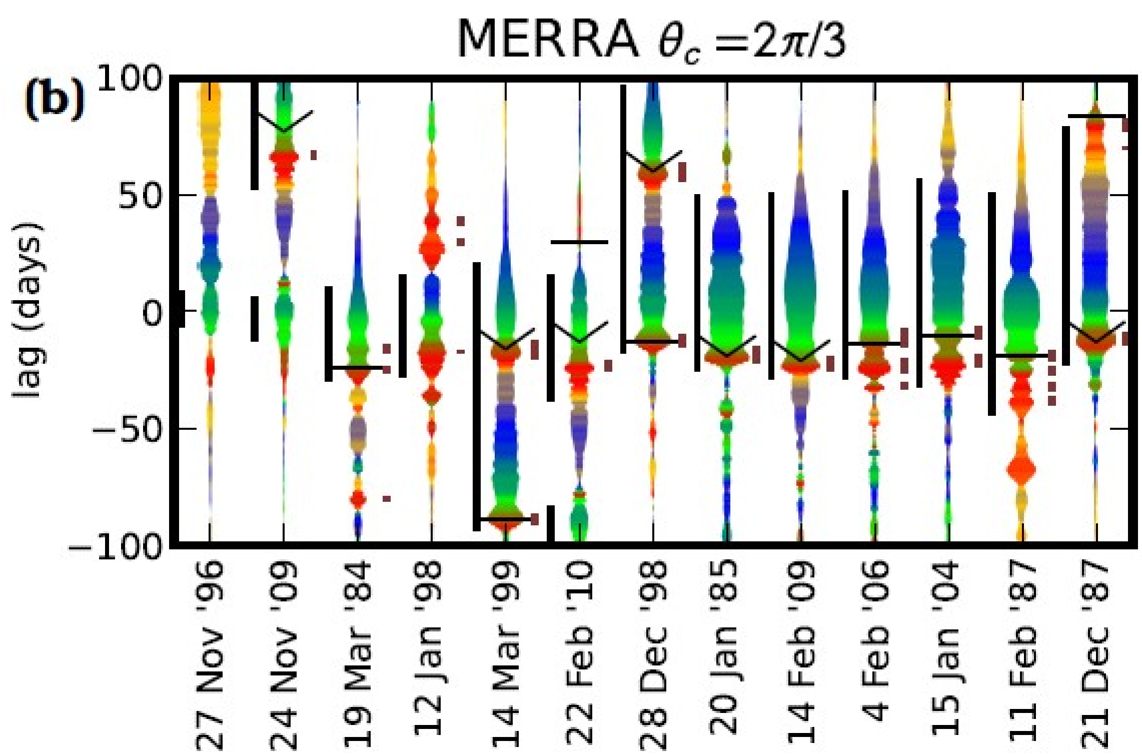


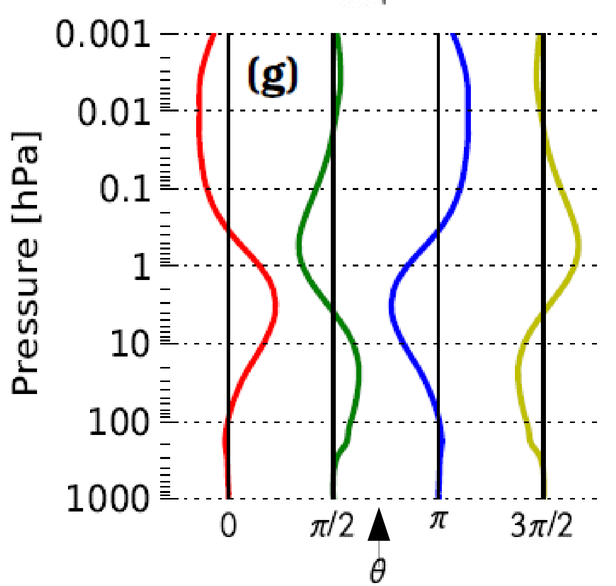


Upper stratospheric warmings -> short timescales

Duration vs. depth of warming

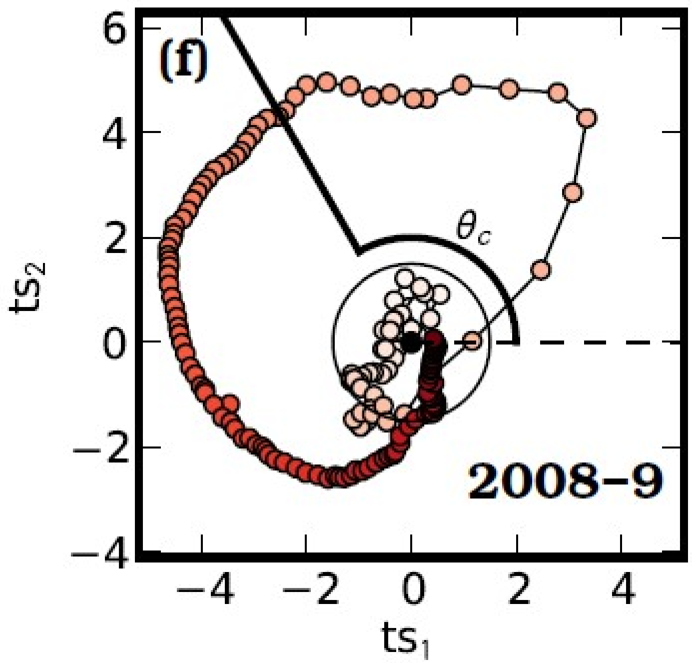


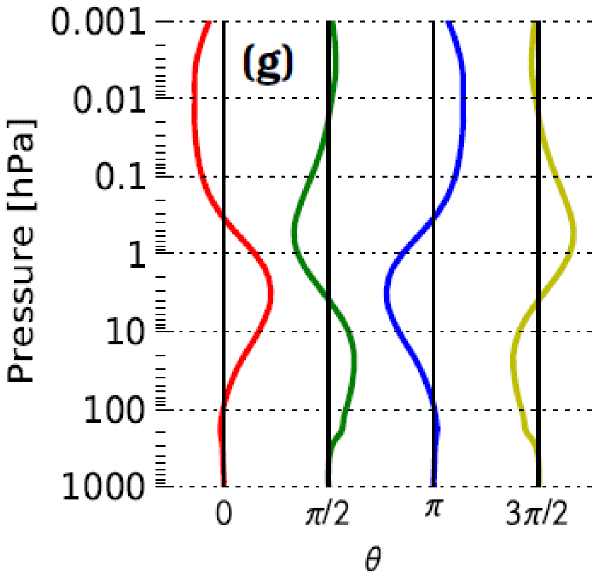


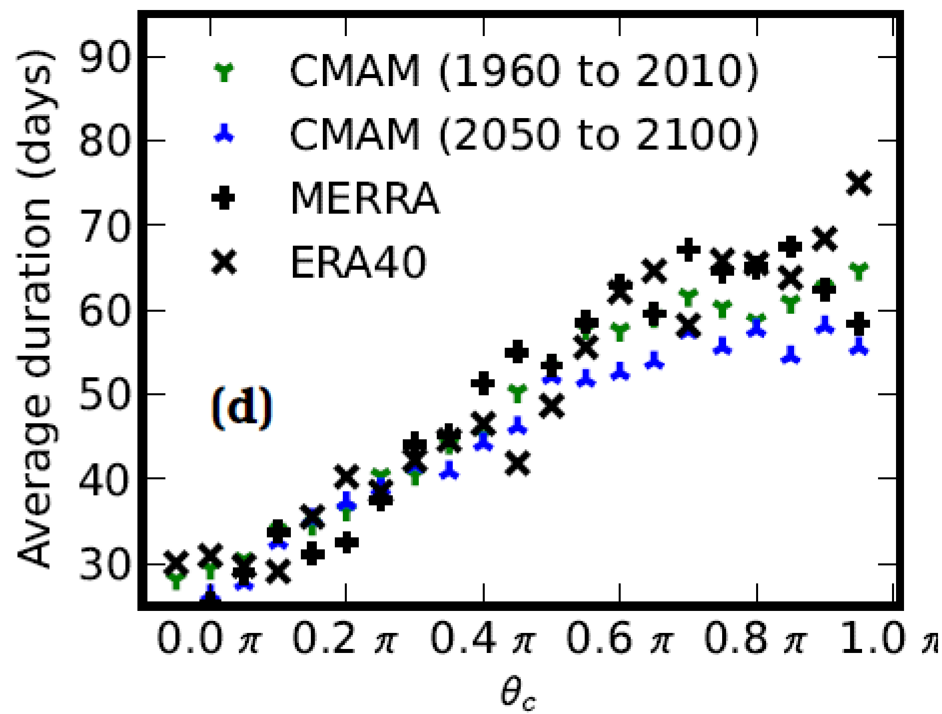


Lower stratospheric warmings -> long timescales

Duration vs. depth of warming







Persistence of stratospheric anomaly is correlated with the depth to which the initial warming descends

PJO events and vortex splits

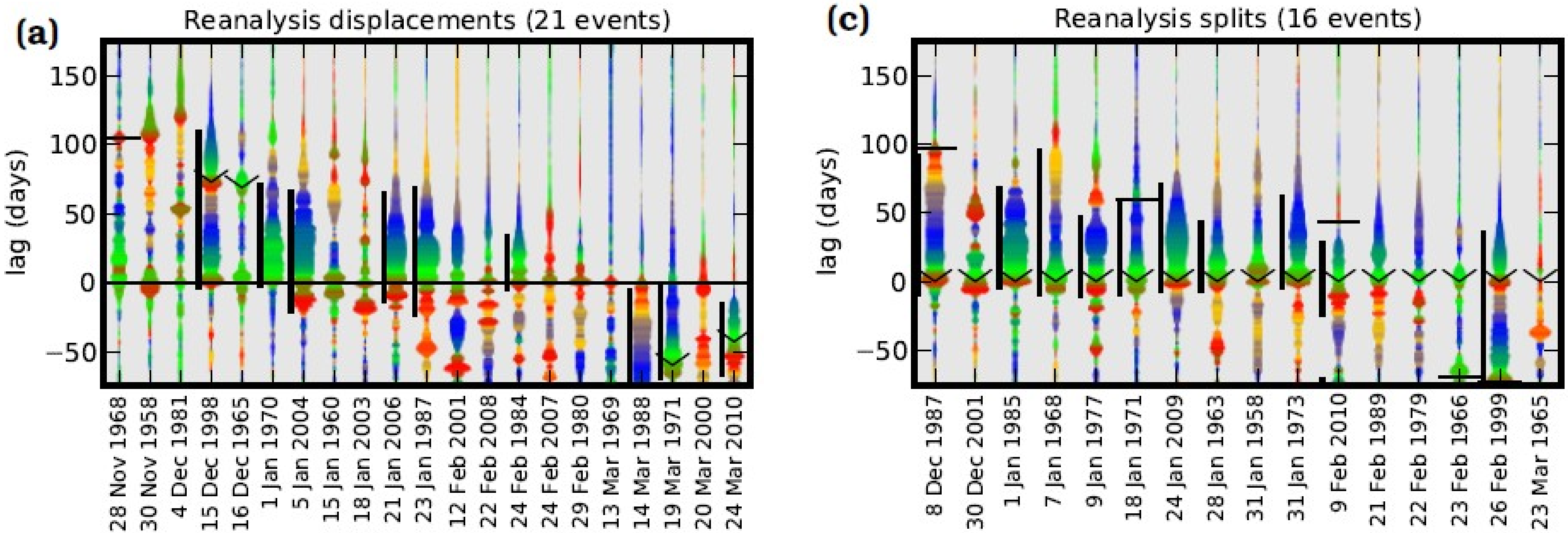
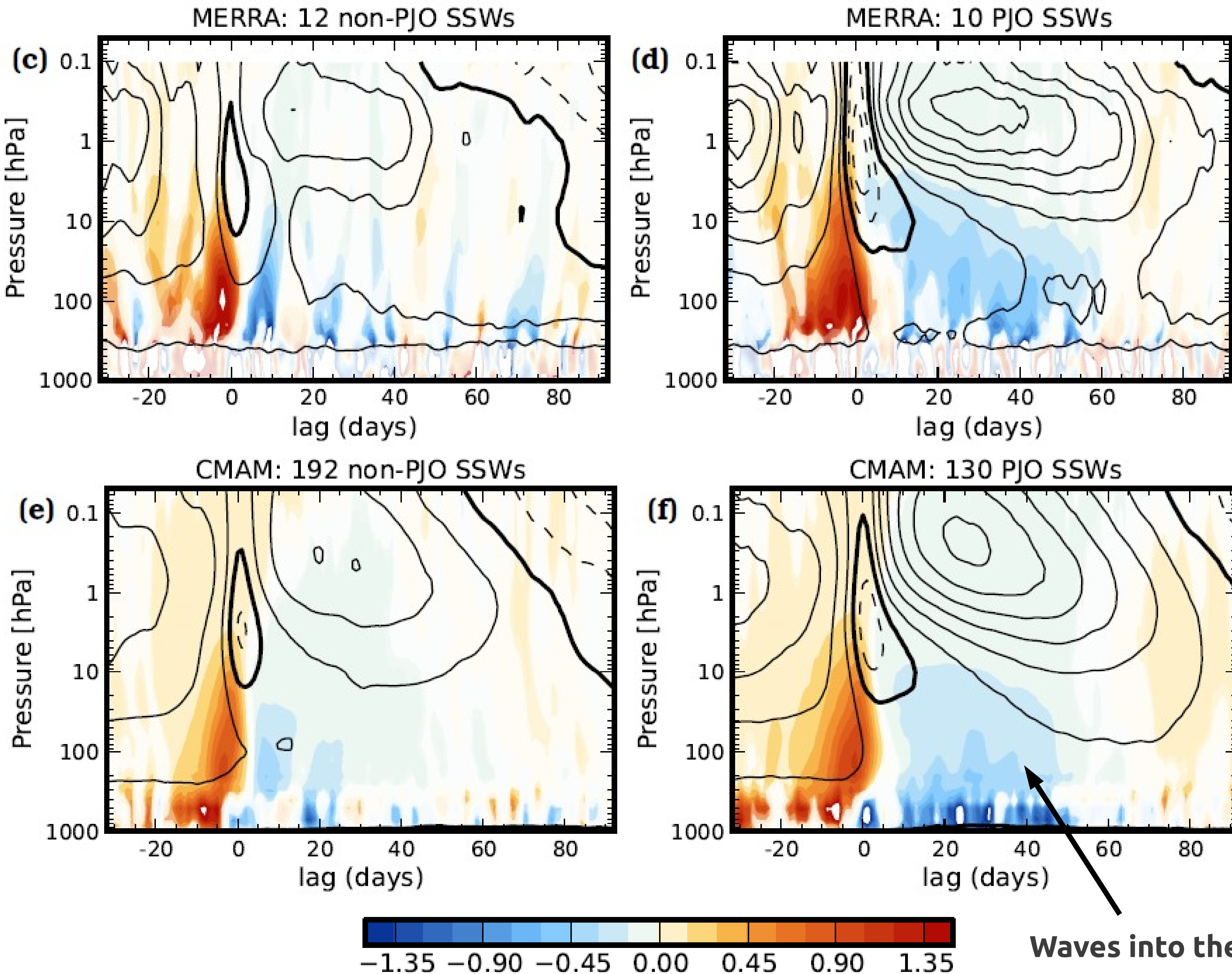


TABLE 3. PJO occurrence following sudden warmings

	Fraction followed by PJO events		Duration of PJO events (days)	
Event type	CMAM	Reanalyses	CMAM	Reanalyses
all	0.40 ± 0.06	0.43 ± 0.16	65 ± 4	72 ± 10
split	0.56 ± 0.12	0.6 ± 0.3	62 ± 7	71 ± 15
displacement	0.36 ± 0.06	0.3 ± 0.2	66 ± 5	75 ± 20

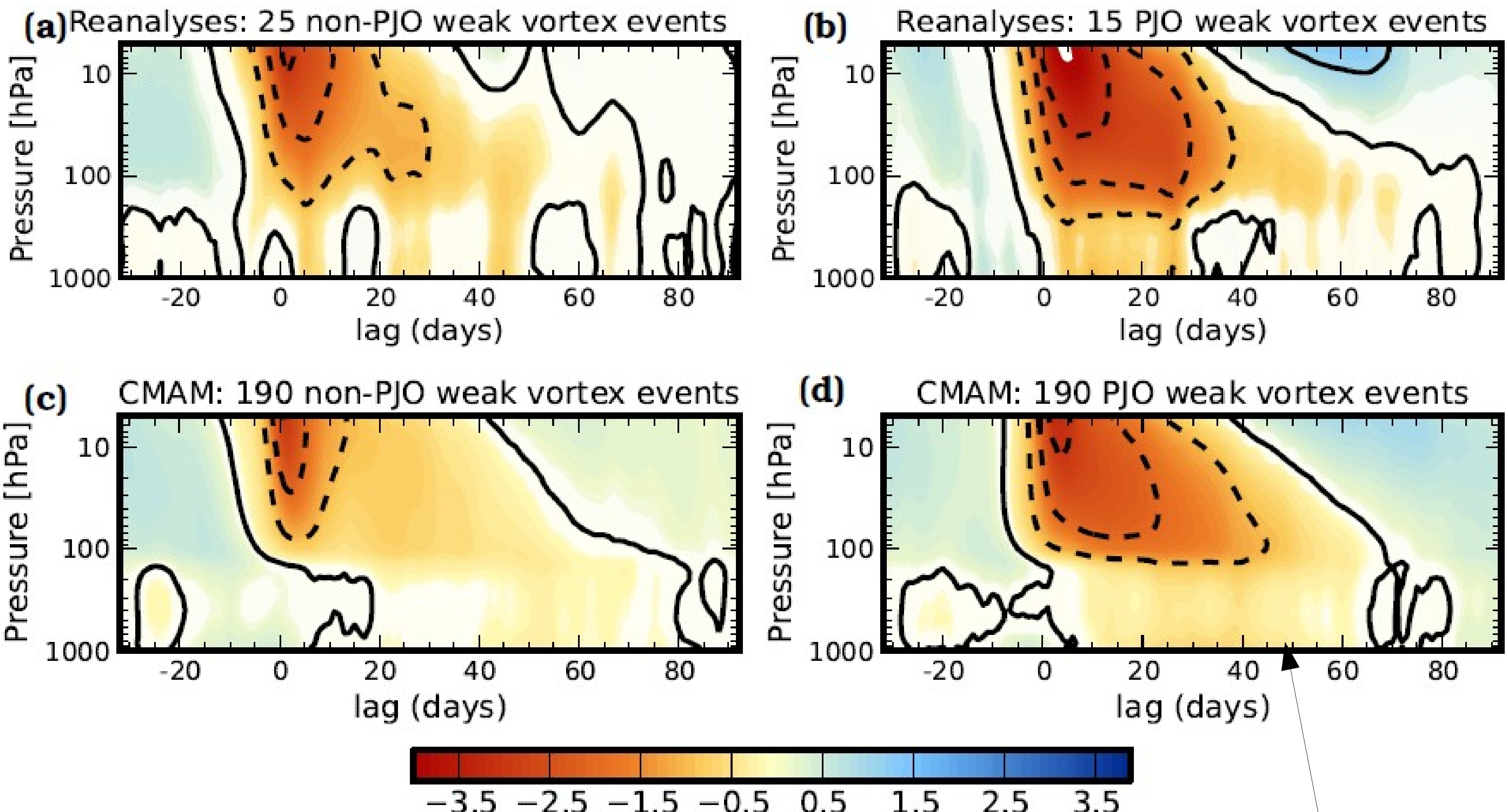
PJO events more likely following splits...

...but if they occur, they are no more persistent!



Waves into the vortex are suppressed

Tropospheric impact



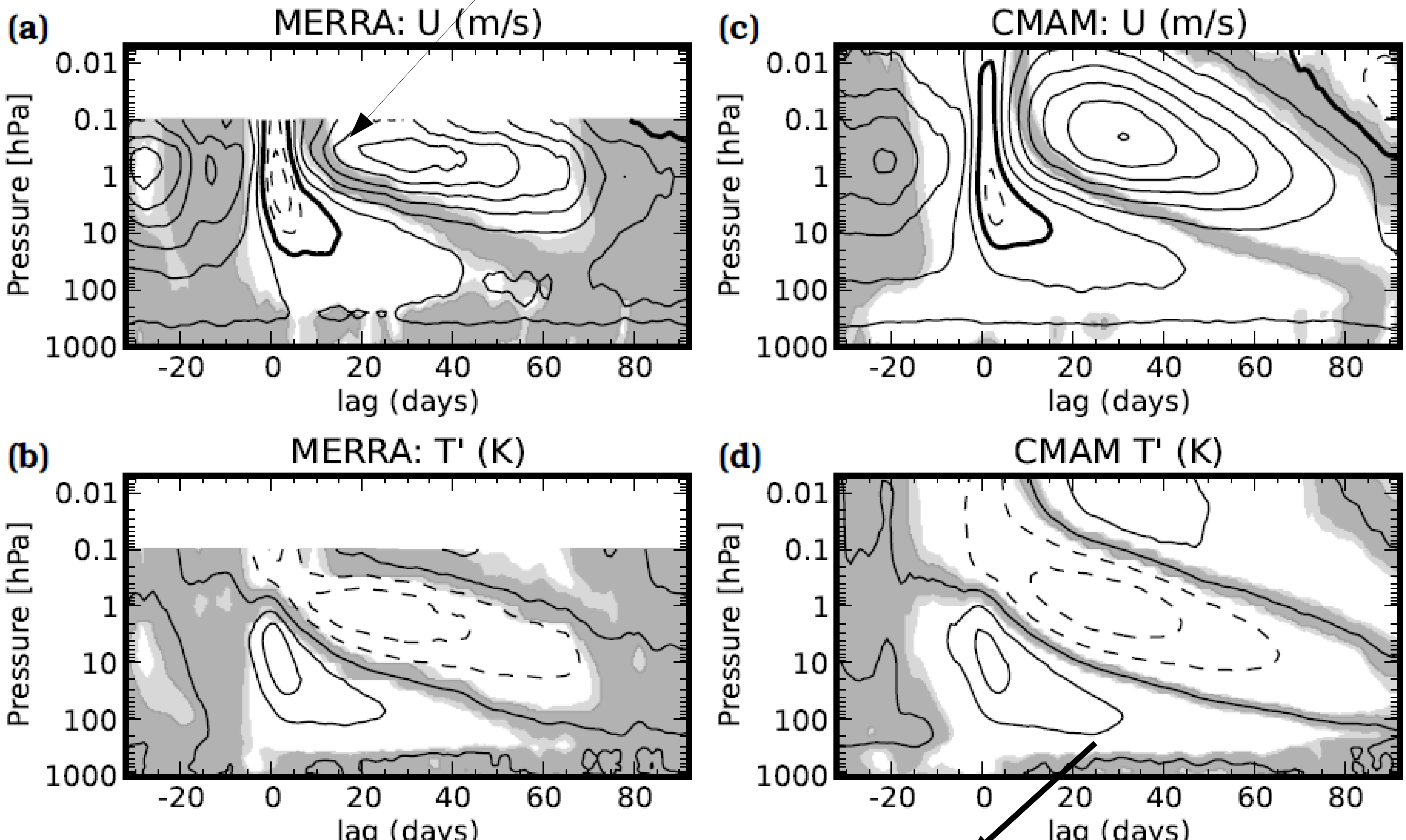
Tropospheric jet shift persists with stratospheric anomaly

Conclusions Part I

- ~50% of sudden warmings are followed by PJO events, or extended recovery periods
- Their timescale is related to the depth to which the vortex is disrupted
- They are more likely to follow splits
- Wave driving is strongly suppressed during the recovery phase
- The tropospheric jets shift more persistently equatorwards during PJO events

PJO event composites

Bias near reanalysis lid identified by Manney et al. JGR 2008



Where does this persistence come from?

Time dependence of zonal mean T

$$\overline{T}_t = F(\nabla\cdot\tilde{F}, \overline{\psi}^*, Q)$$ **Depends on EP Flux convergence, residual circulation, radiative heating**

$$\overline{\psi}^* = \Psi(\nabla\cdot\tilde{F}, Q)$$ **Eliassen 1951; Plumb 1982**

$$\overline{T}_t = F(\nabla\cdot\tilde{F}, \Psi(\nabla\cdot\tilde{F}, Q), Q)$$

$$\equiv F'(\nabla\cdot\tilde{F}, Q)$$ **Depends on EP Flux convergence, radiative heating**

$$Q = Q_c - \alpha\overline{T}'$$ **Rodgers and Walshaw 1966; Hitchcock et al. 2010**

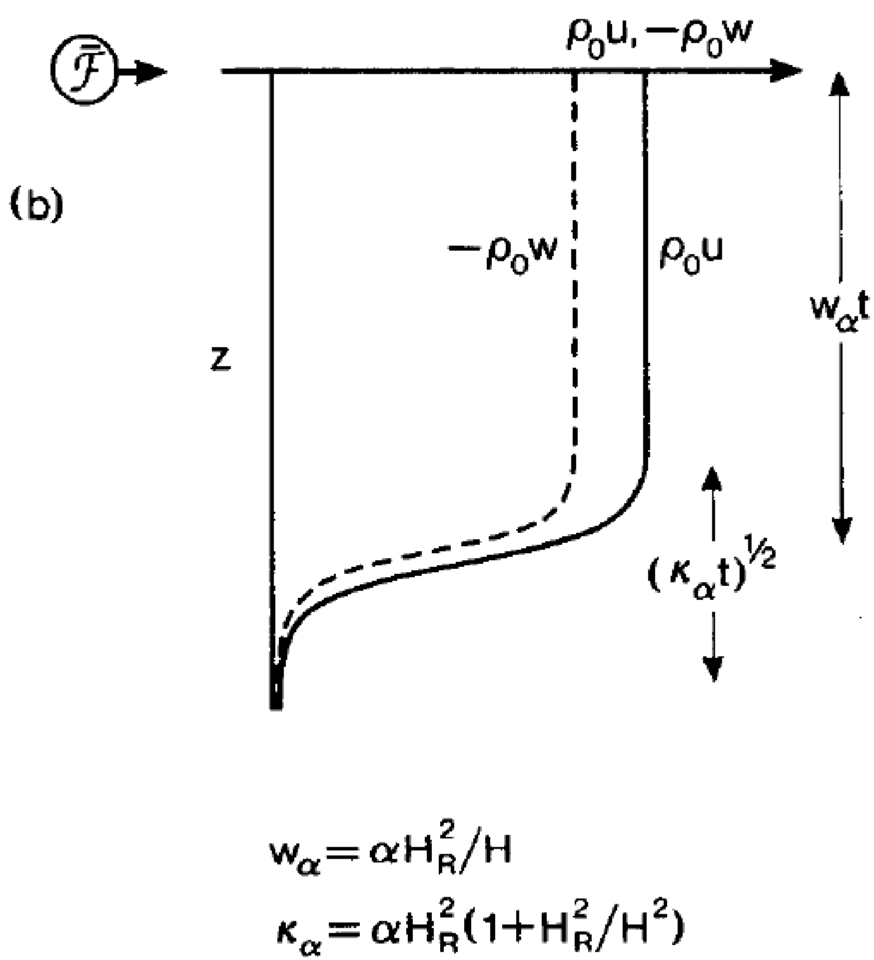
$$\overline{T}_t = F'(\nabla\cdot\tilde{F}, Q_c - \alpha\overline{T}')$$ **Haynes et al. 1991**

$$\overline{T}' \equiv F''(\nabla\cdot\tilde{F})$$ **Depends on EP Flux convergence alone**

$$= F''(\mathscr{F}_p) + F''(\mathscr{F}_s) + \ldots$$

The response can thus be decomposed

Adjustment to the DC limit



Instantaneously, the residual circulation is driven by the torques and the diabatic heating:

$$\mathcal{L}\overline{w}^*_{QG} = \mathcal{L}_{\mathcal{F}}\mathcal{F} + \mathcal{L}_Q Q$$

In steady state, the residual circulation is given by downward control:

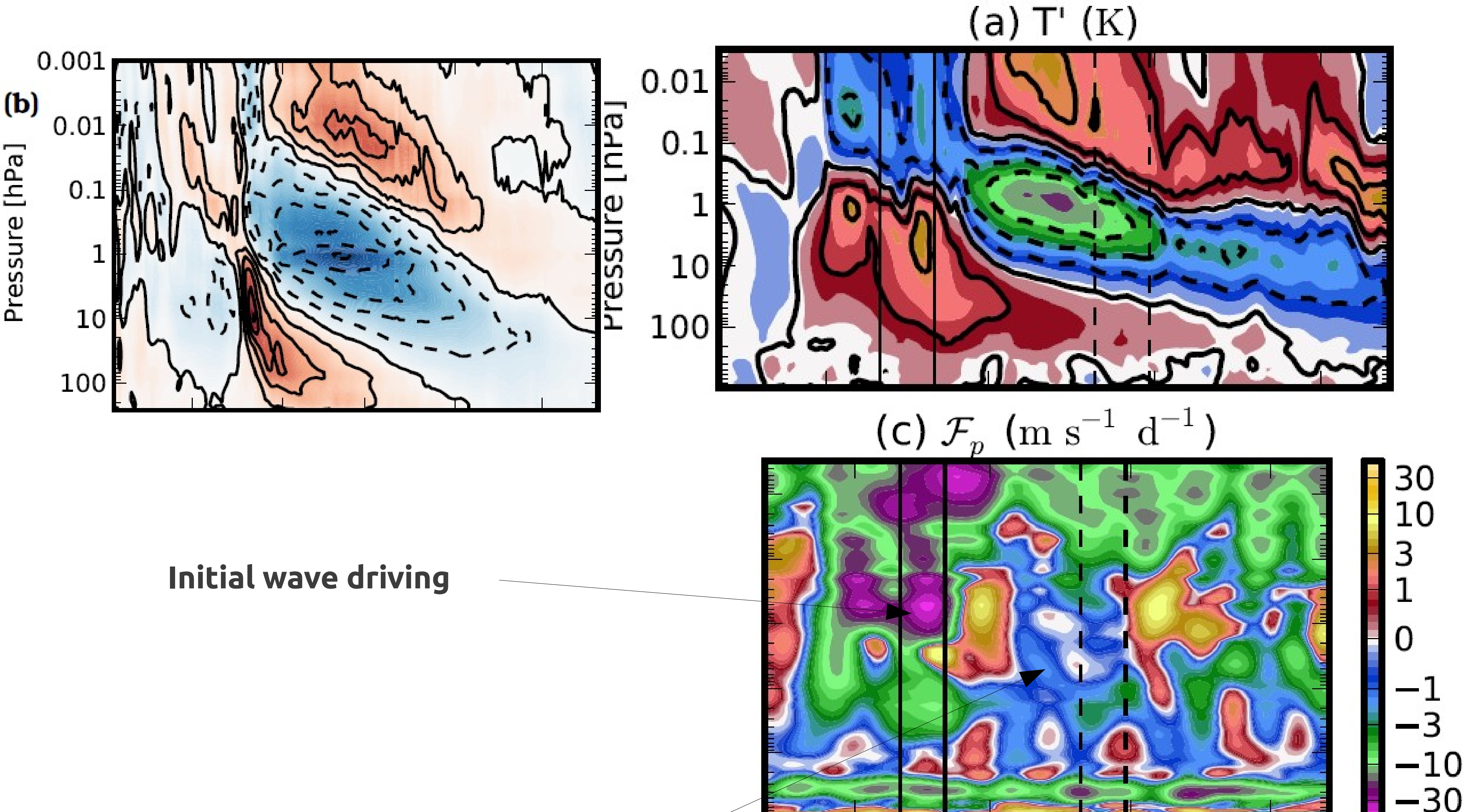
$$\overline{w}^*_{DC} = \frac{1}{\rho_0 a \cos\phi} \int_z^\infty \frac{\partial}{\partial \phi}\left(\frac{\rho_0 \cos\phi \mathcal{F}}{f}\right) dz$$

The adjustment to a switch-on forcing at a given level 'burrows' downward, as the temperatures (and thus Q) adjusts; the timescale for this to occur below the forcing is given by:

$$t_\alpha(\Delta z) \sim \frac{\Delta z H}{\alpha {H_R}^2}$$

Haynes et al. 1991

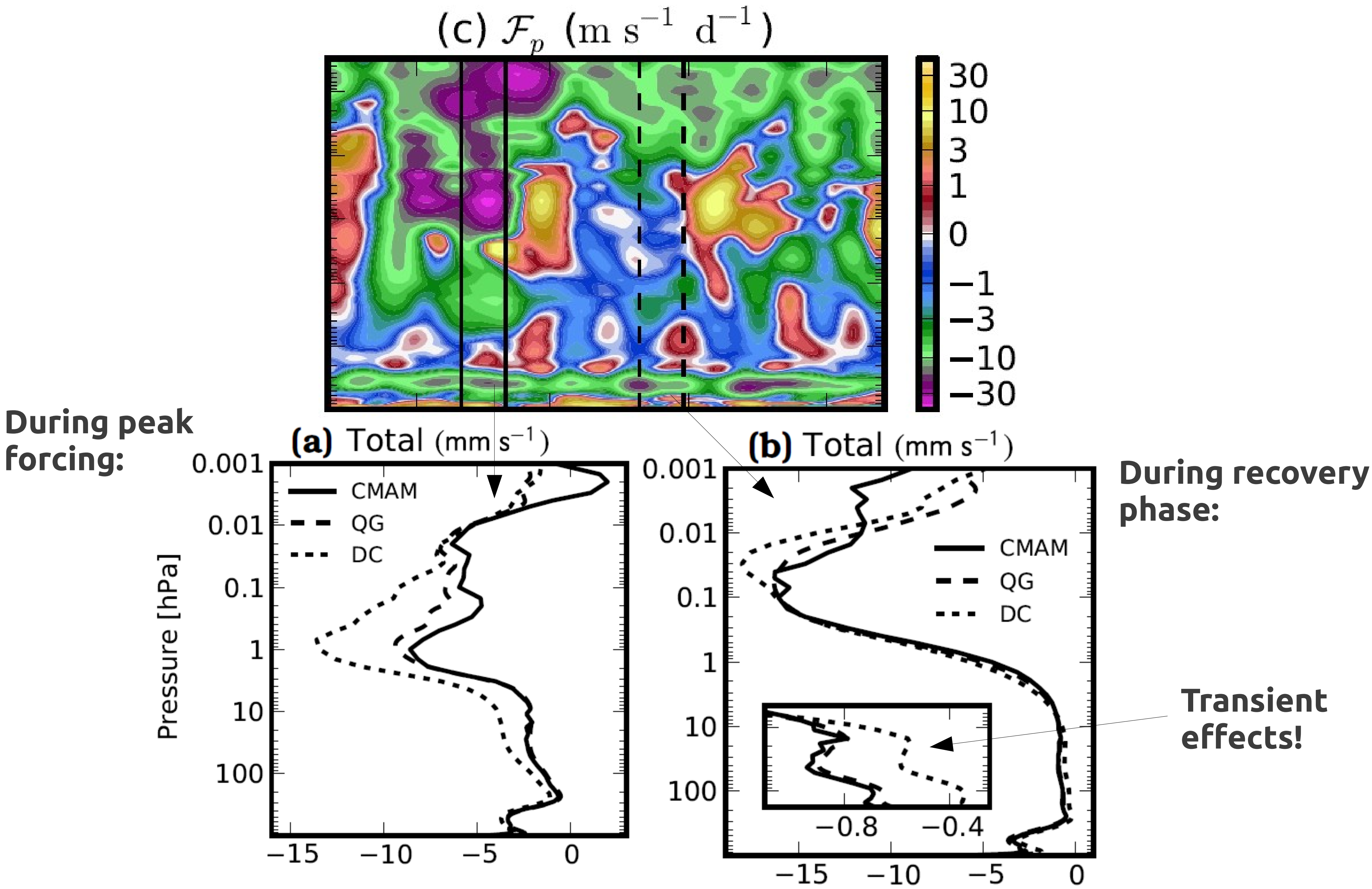
CMAM case study



Initial wave driving

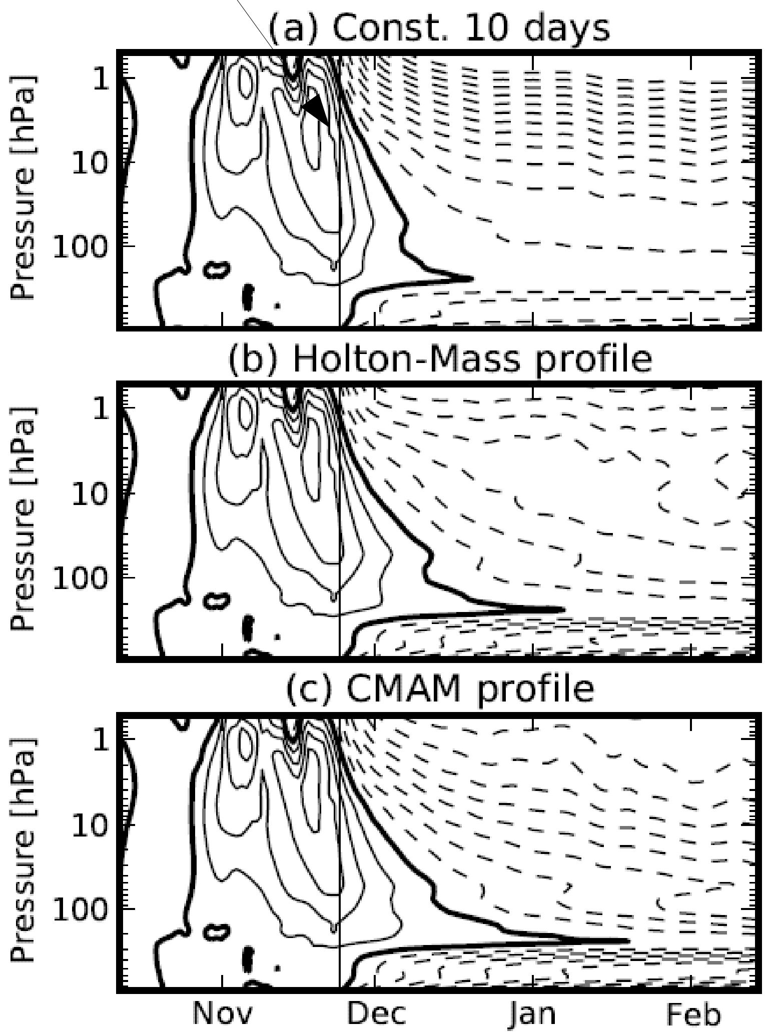
Subsequent shut-off

Residual circulation

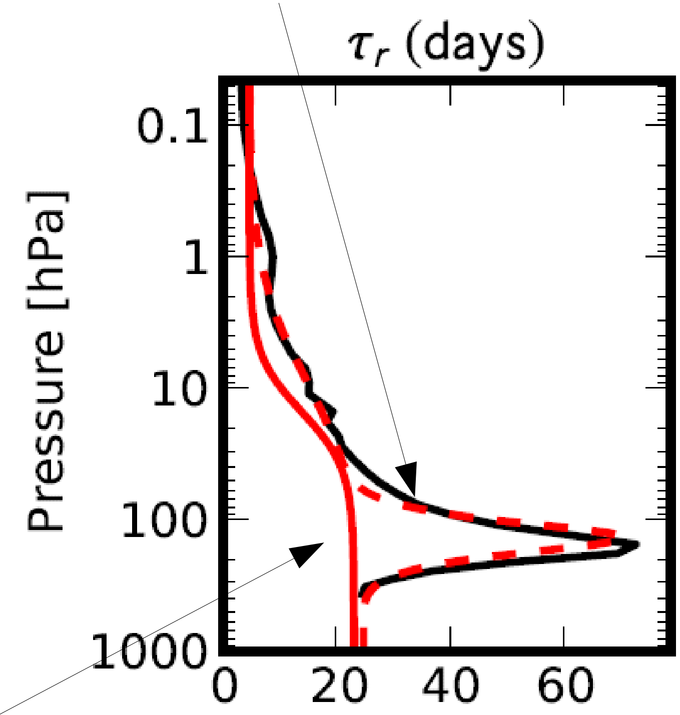


Pure Radiative damping

Initialized after peak warm anomaly



CMAM (Hitchcock et al. JAS 2010)

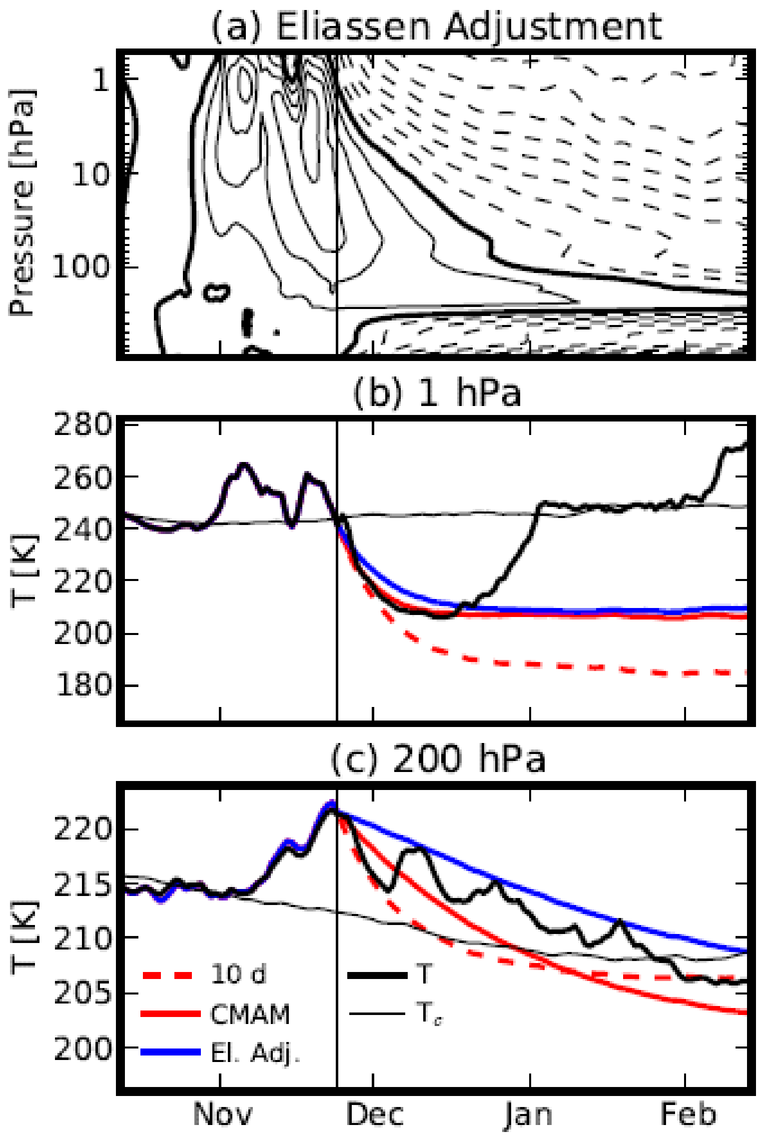


Holton and Mass 1976

$$\frac{\partial T'}{\partial t} = Q_c - \frac{\partial T_c}{\partial t} - \alpha T'$$

'Fixed Dynamical Heating' with the dynamical heating set to 0

Radiative damping with Eliassen adjustment

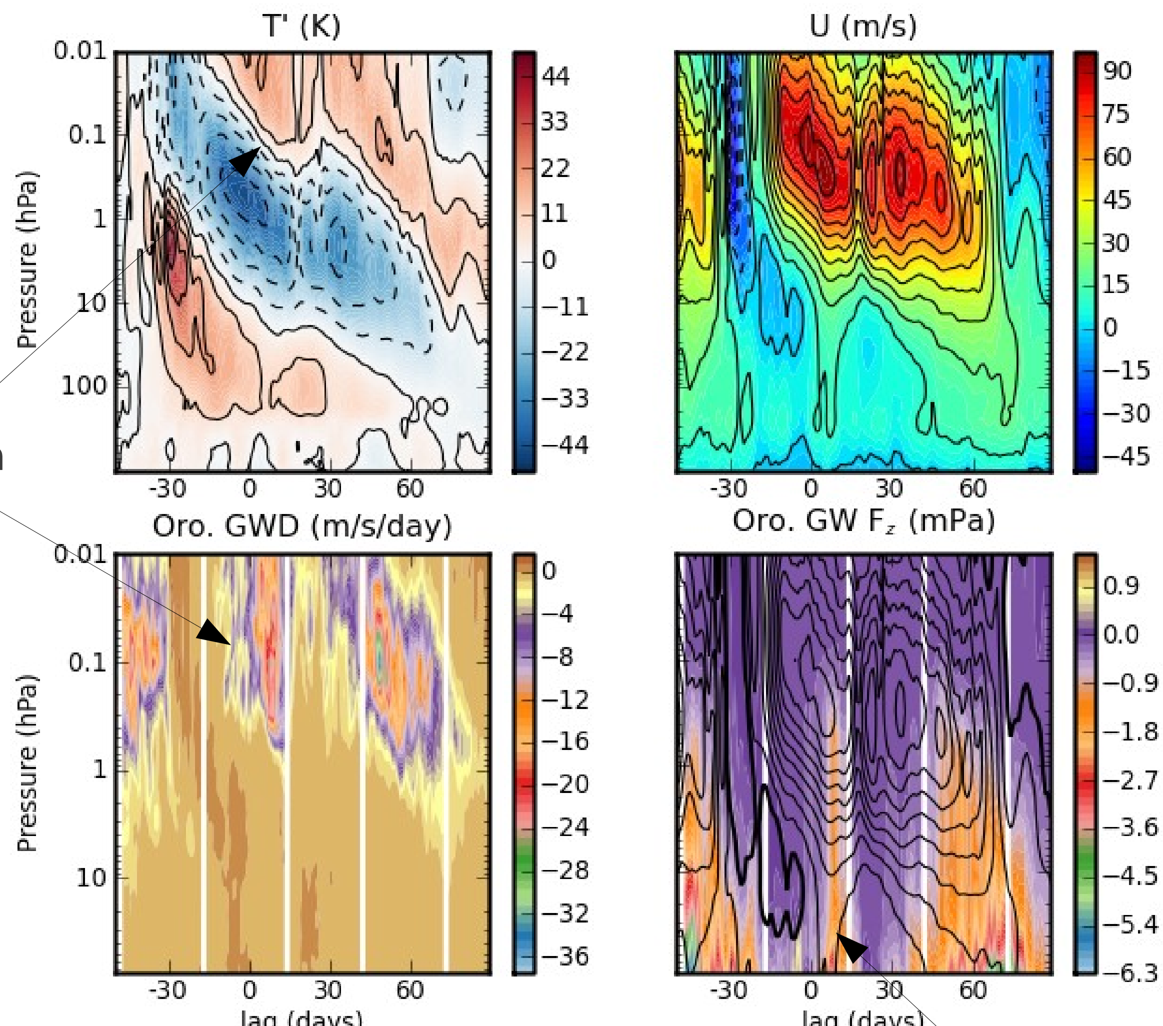


Diabatic heating itself induces a (transient) residual circulation:

$$\frac{\partial T'}{\partial t} = Q_c - \frac{\partial T_c}{\partial t} - \alpha T' - S\overline{w}^*_{QG}$$

Persistence of lower stratospheric anomaly is radiative, with an enhancement due to the Eliassen adjustment to the radiative heating

Descent of the Stratopause



Descent of stratopause driven by orographic gravity waves

Gravity wave flux strongly controlled by lower stratospheric winds

Conclusions Part 2

- Suppression of planetary waves in the vortex leads to robustly similar evolution during all PJO events -- **why?**
- Radiative processes are easier to predict than wave-driven processes
- Enhancement of predictability arises from the suppression of waves