How Stationary Waves Influence the Northern Annular Mode Response to Tropical Forcing

Christopher Fletcher
Dept. of Geography, University of Waterloo

Paul Kushner
Dept. of Physics, University of Toronto

Tropical SST/NAM Linkage

High latitude zonal mean circulation appears sensitive to tropical SST spatial structure.

Tropical Pacific warming from El Niño linked to Arctic high pressure and midlatitude low pressure, and a deep vertical externsion of these anomalies: negative AO/NAM (Cagnazzo and Manzini, Free and Seidel, Ineson and Scaife, Garfinkel and Hartmann)

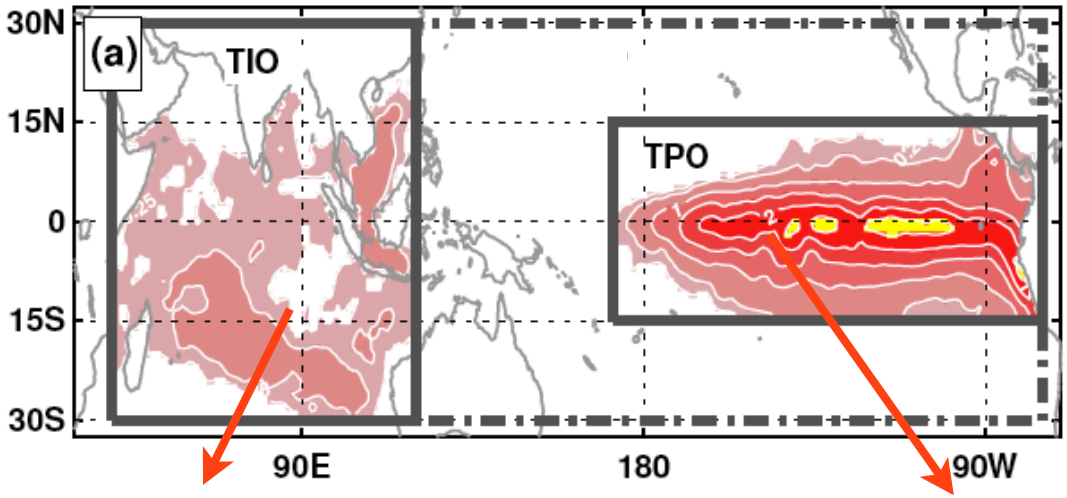
Tropical Indian Ocean warming is linked to *positive* NAM (Hoerling et al.).

- Challenging to interpret because Indian and Pacific Ocean temperatures are themselves linked.

Here's a clean model example in a somewhat idealized setting (Fletcher and Kushner 2011):

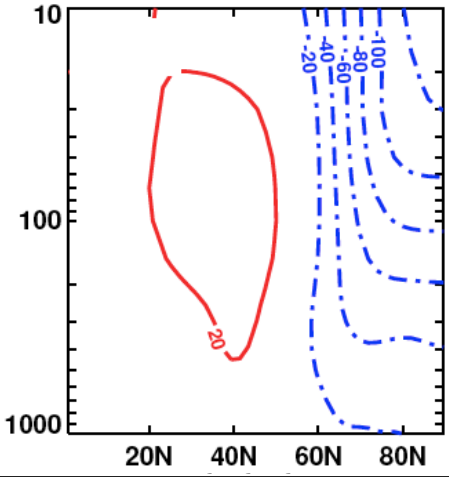
Tropical SST/NAM Linkage

Wintertime Warm SST Anomalies Based on Observed El Niño

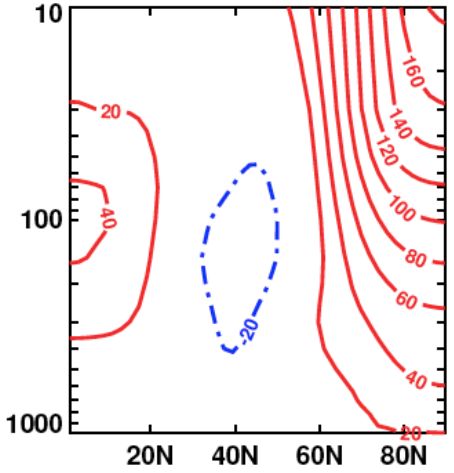


Warming from 5 strongest El Niño's

TIO



TPO



Zonal Mean Geopotential Response to these SST Anomalies

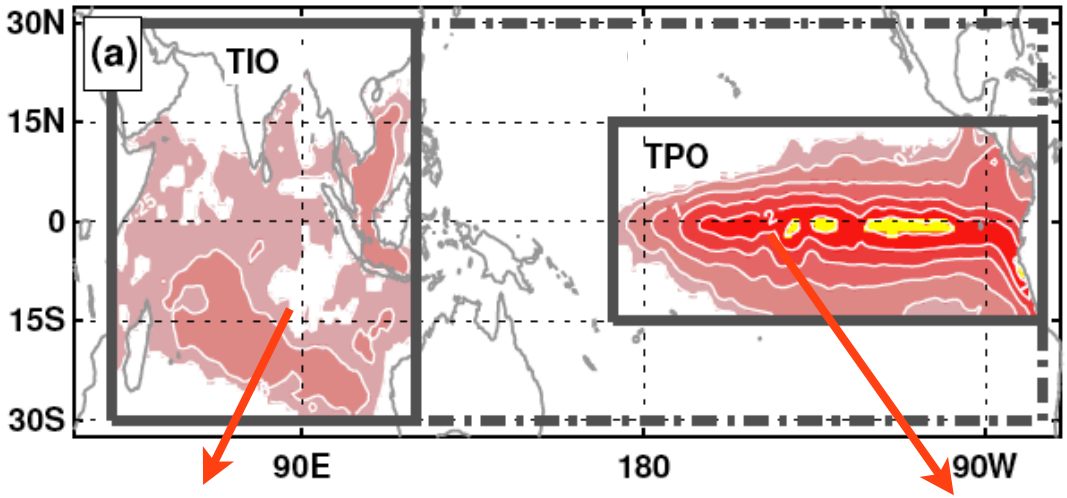
GFDL AM2.1

100 member ensembles,

Switch on forcing in December, analyze January-February

Tropical SST/NAM Linkage

Wintertime Warm SST Anomalies Based on Observed El Niño

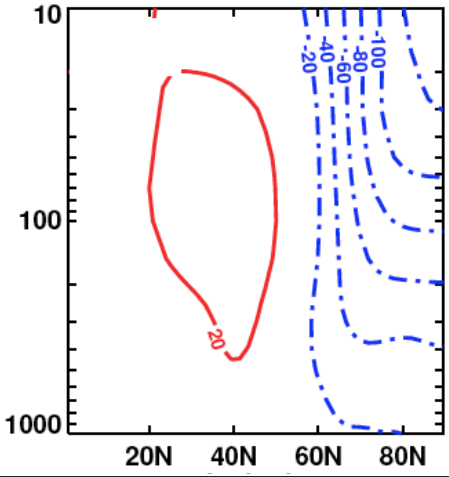


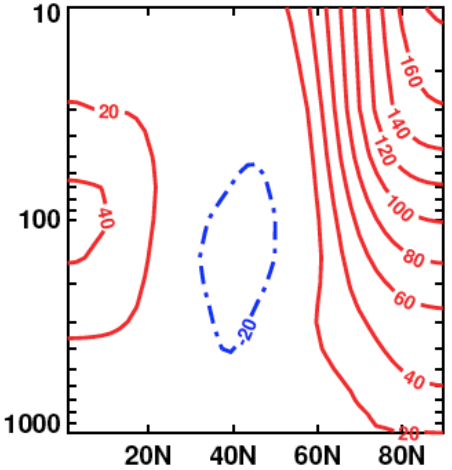
Warming from 5 strongest El Niño's

TIO

TPO

Zonal Mean Geopotential Response to these SST Anomalies





GFDL AM2.1

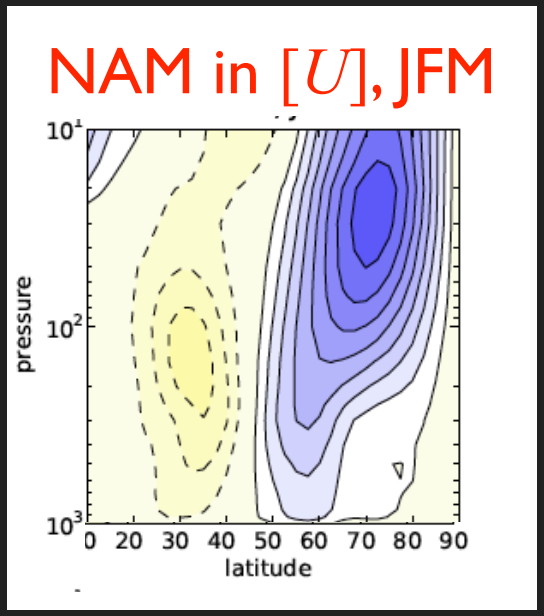
100 member ensembles,

Switch on forcing in December, analyze January-February

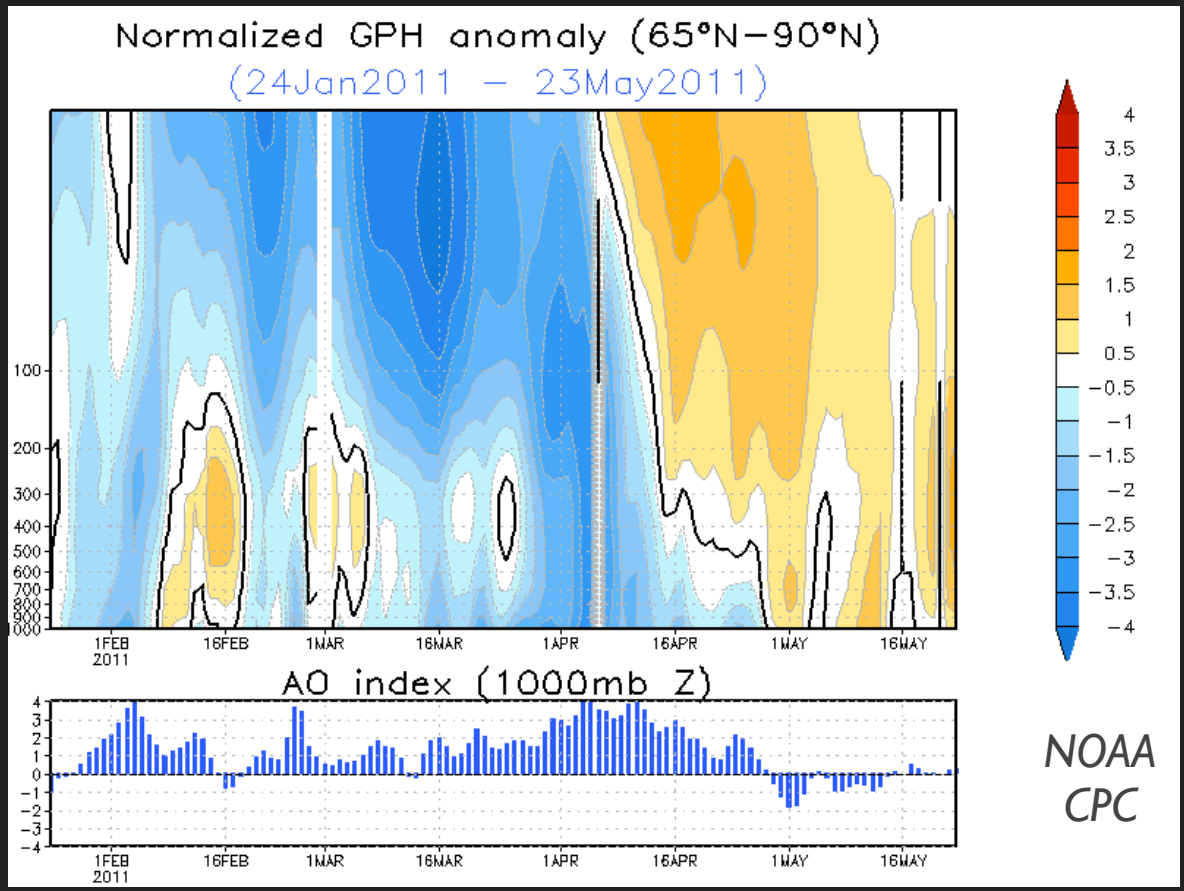
Why does TIO force positive Northern Annular Mode response, and TPO force the opposite?

Why is the TIO response as large as it is?

Stepping Back: Observed NAM Variability

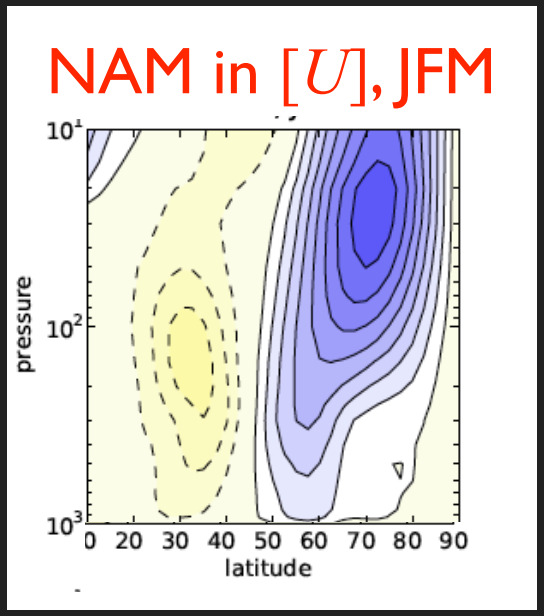


Thompson & Wallace 2000

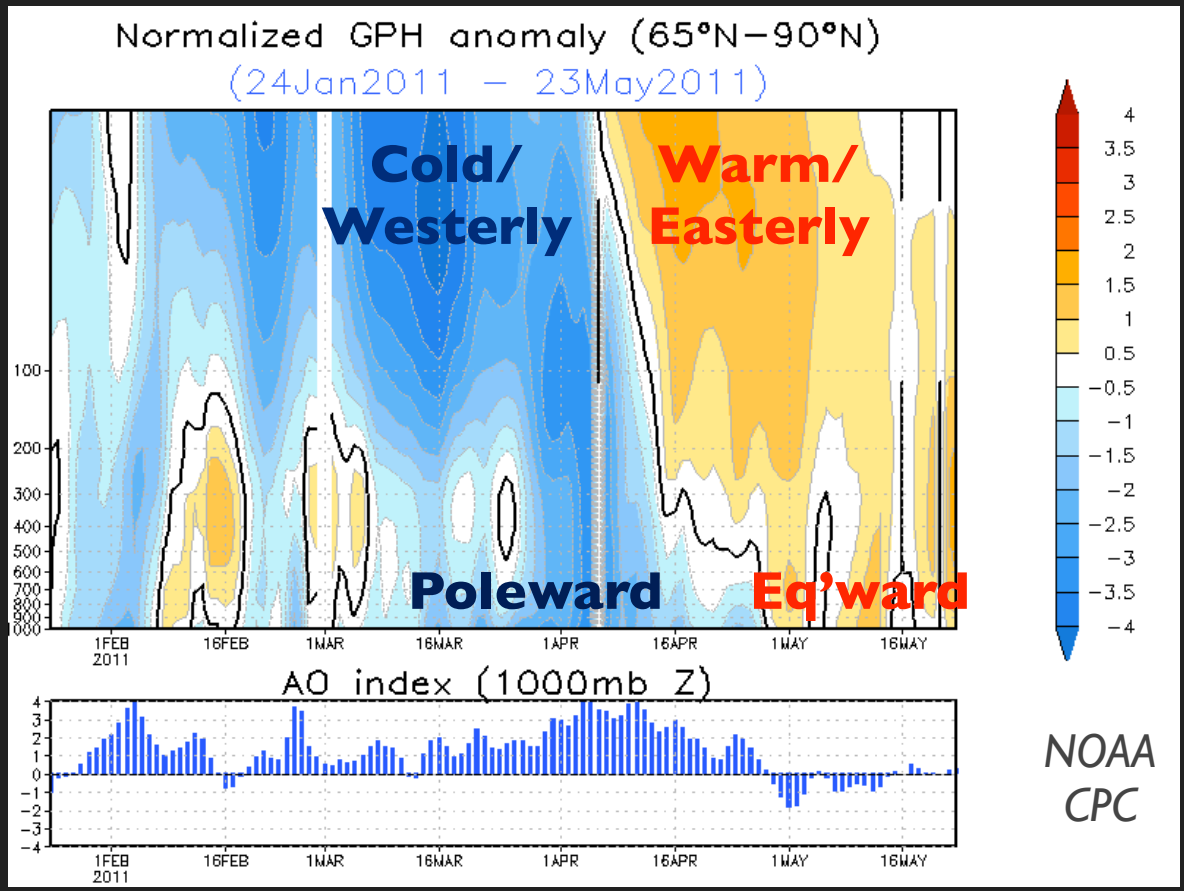


NOAA CPC

Stepping Back: Observed NAM Variability

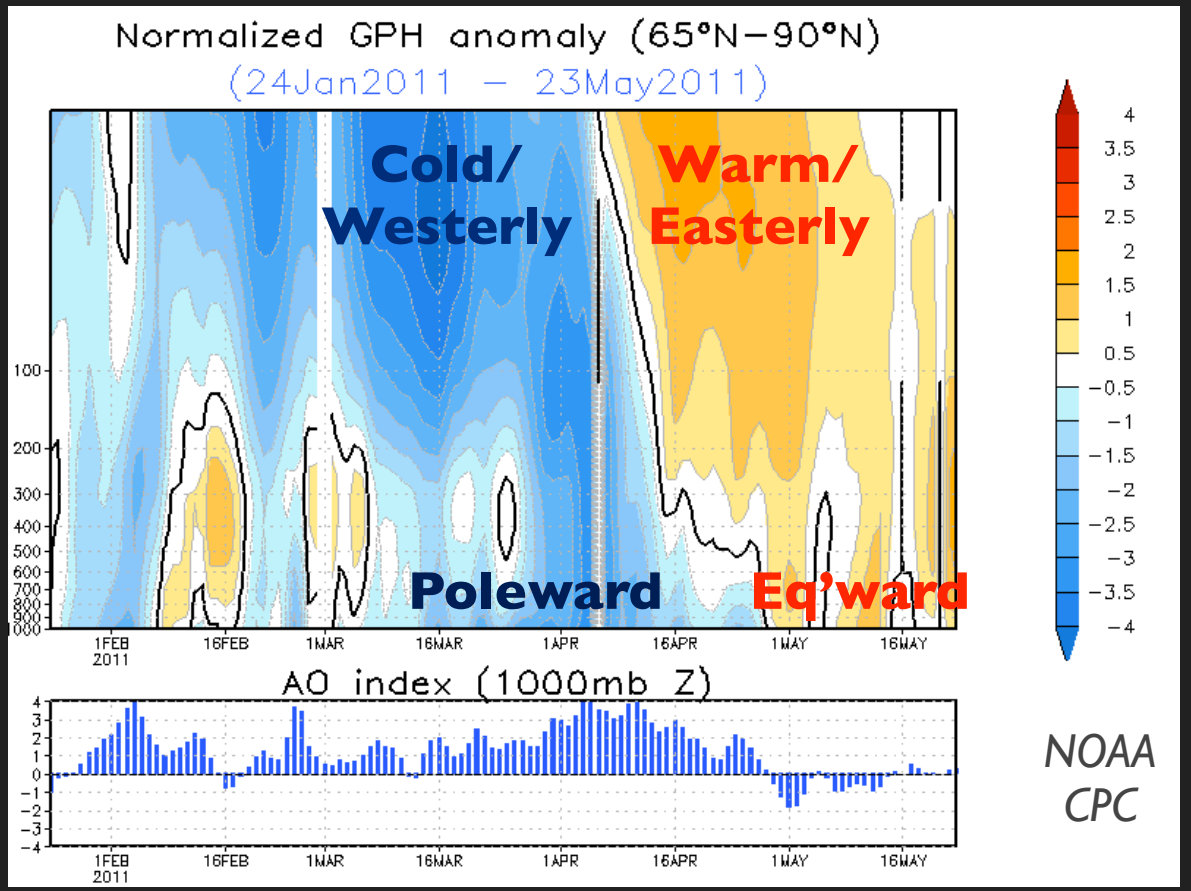


Thompson & Wallace 2000

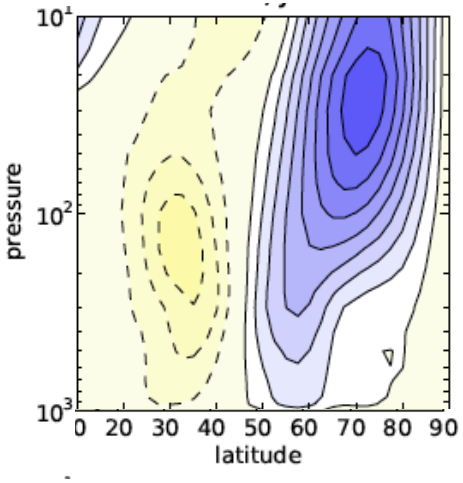


NOAA CPC

Stepping Back: Observed NAM Variability

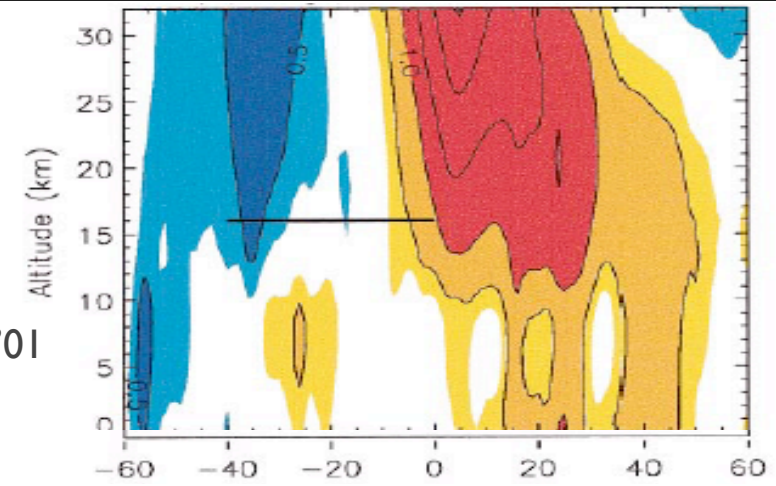


NAM in $[U]$, JFM



Thompson & Wallace 2000

Composite NAM Evolution



Baldwin & Dunkerton '01
Polvani & Waugh '04

NAM Variability: The Role of Waves

❶

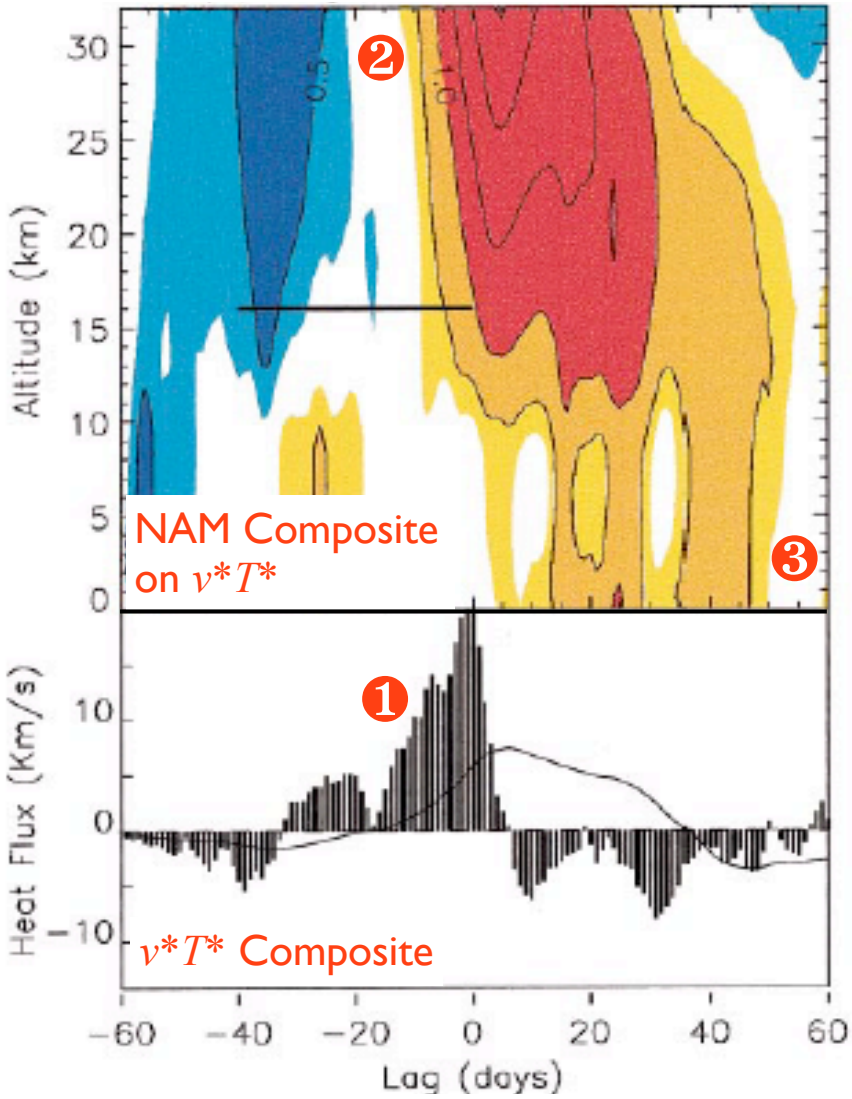
Anomalous upward planetary wave activity propagates from troposphere to stratosphere ($[v^*T^*]' > 0$).

❷

Wave activity pulse absorbed in stratosphere, exerting an easterly force and inducing warming in stratosphere ($GPH' > 0$, $NAM < 0$).

❸

GPH anomalies propagate into troposphere (wave process uncertain).



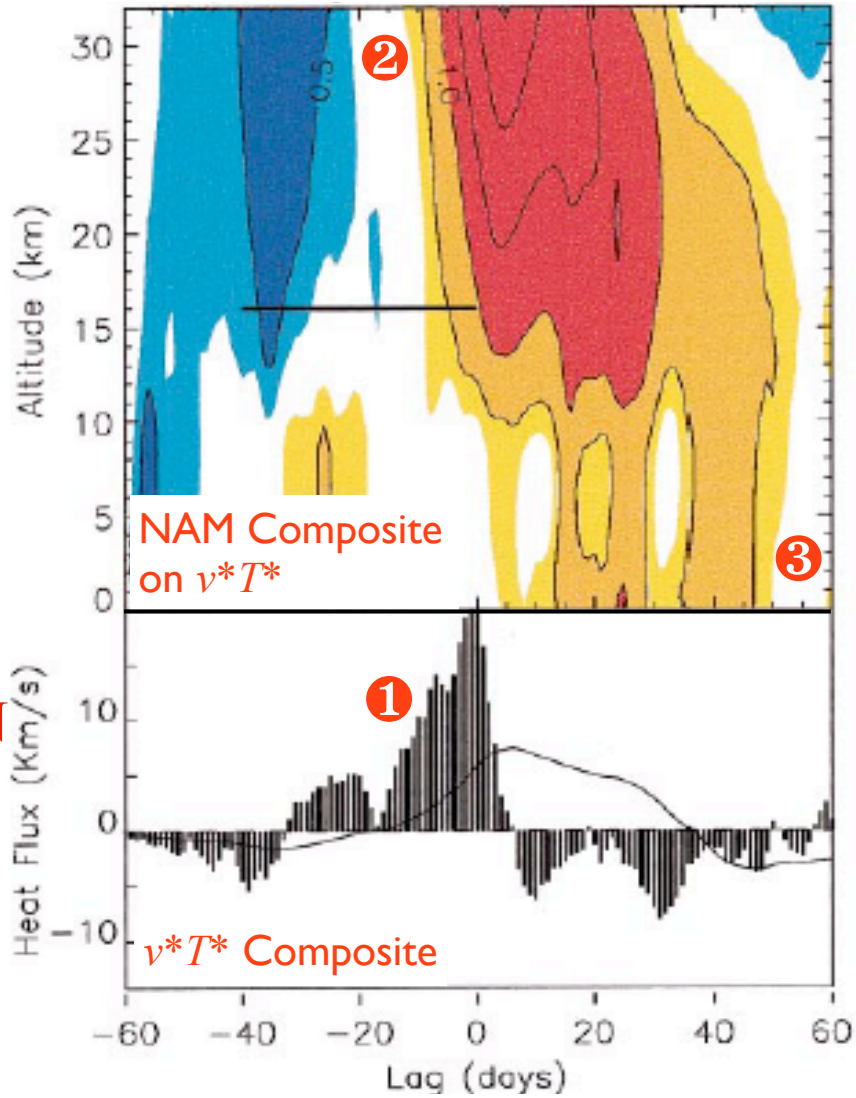
Baldwin & Dunkerton 1998, 2001; Polvani & Waugh 2004

The Role of Waves

Wave activity flux anomalies include linear and quadratic terms:

$$v^* = v_c^* + v^{*\prime},\ T^* = T_c^* + T^{*\prime}$$

$$[v^*T^*]' = \underbrace{[v_c^*T^{*\prime} + v^{*\prime}T_c^*]}_{\text{LIN}} + \underbrace{[v^{*\prime}T^{*\prime}]}_{\text{NONLIN}}$$



Baldwin & Dunkerton 1998, 2001; Polvani & Waugh 2004

The Role of Waves

$$[v^*T^*]' = [v_c^*T^{*\prime} + v^{*\prime}T_c^*] + [v^{*\prime}T^{*\prime}]$$

LIN NONLIN

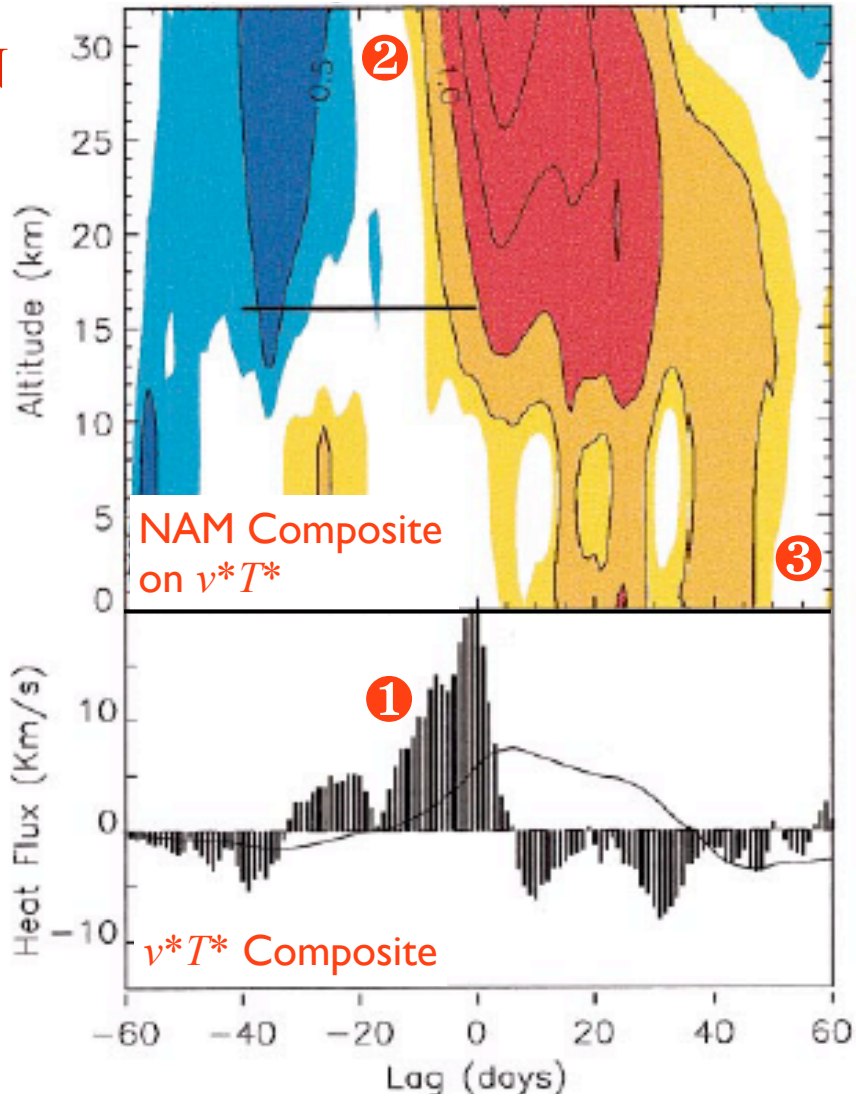
|LIN|>|NONLIN| for small amplitude wave anomalies.

LIN > 0, NAM < 0 when anomalous and stationary waves constructively interfere. And vice versa.

(Garfinkel & Hartmann; Nishii, Orsolini, Nakamura ; Ineson & Scaife; Smith, Kushner and Fletcher)

NONLIN > 0 for surface forced Rossby waves.

We see interference at work in our simulations.



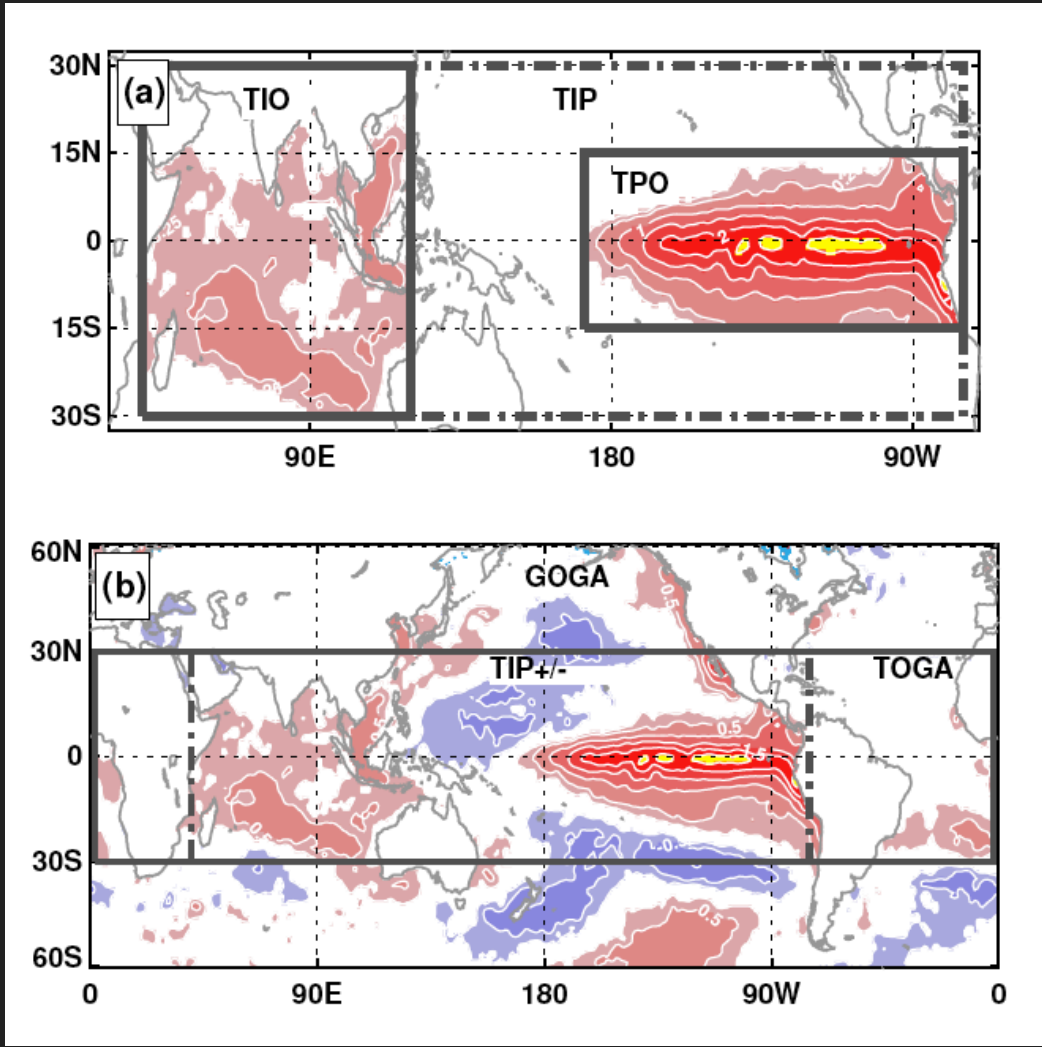
Baldwin & Dunkerton 1998, 2001; Polvani & Waugh 2004

Tropical SST Simulations

We perform TIO, TPO, and several other SST forcing cases (100 member DJF) for:

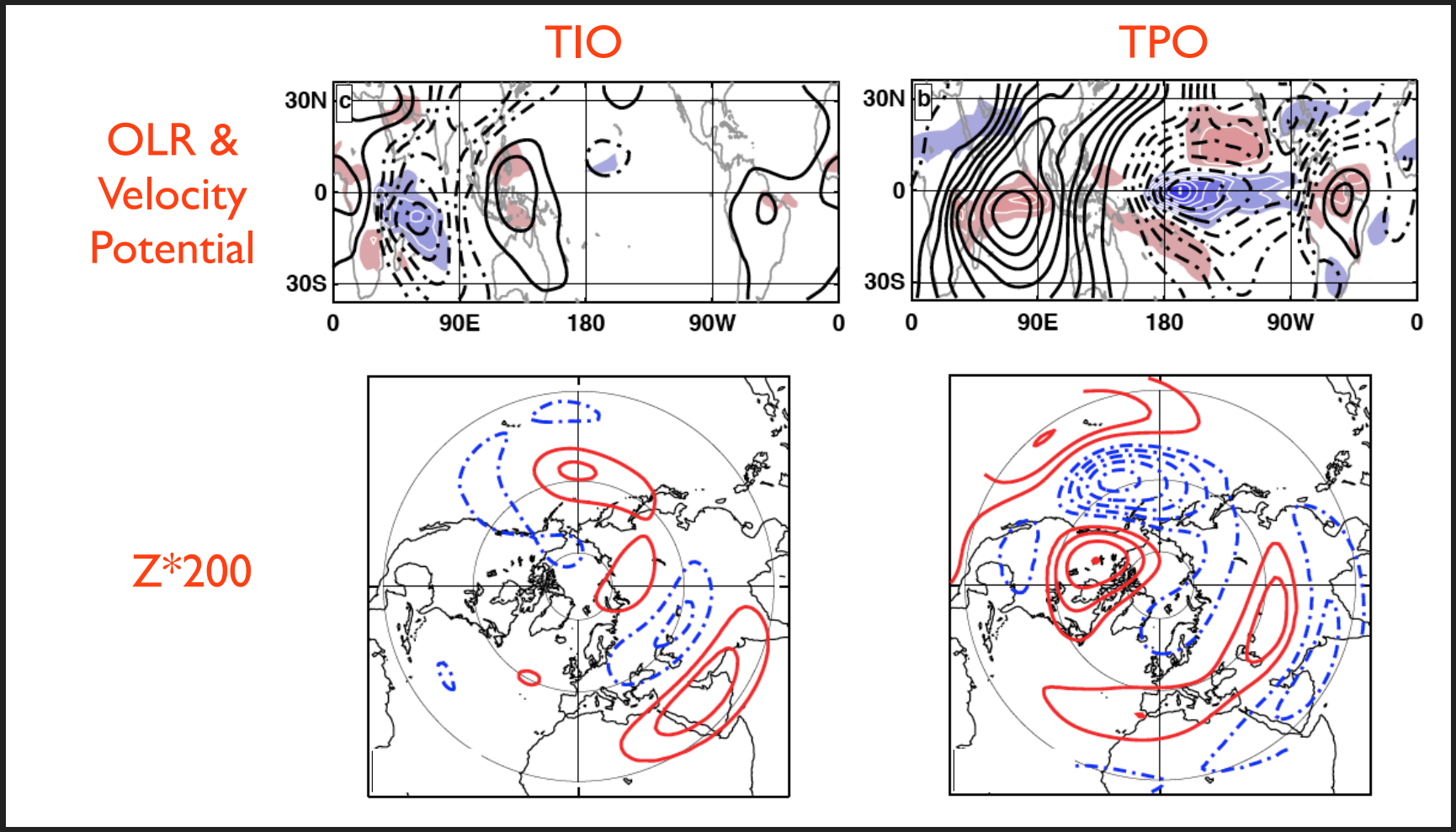
- GFDL AM2.1
- NCAR CAM3.5, 1 degree and 2 degree
- NCAR WACCM, 2 degree, no chem.

Prescribed El Niño SST Anomalies



Fletcher & Kushner 2010

TIO/TPO: Teleconnected Response



Fletcher & Kushner 2010

TPO response large scale, TIO response localized.

TPO and TIO responses opposite in many respects.

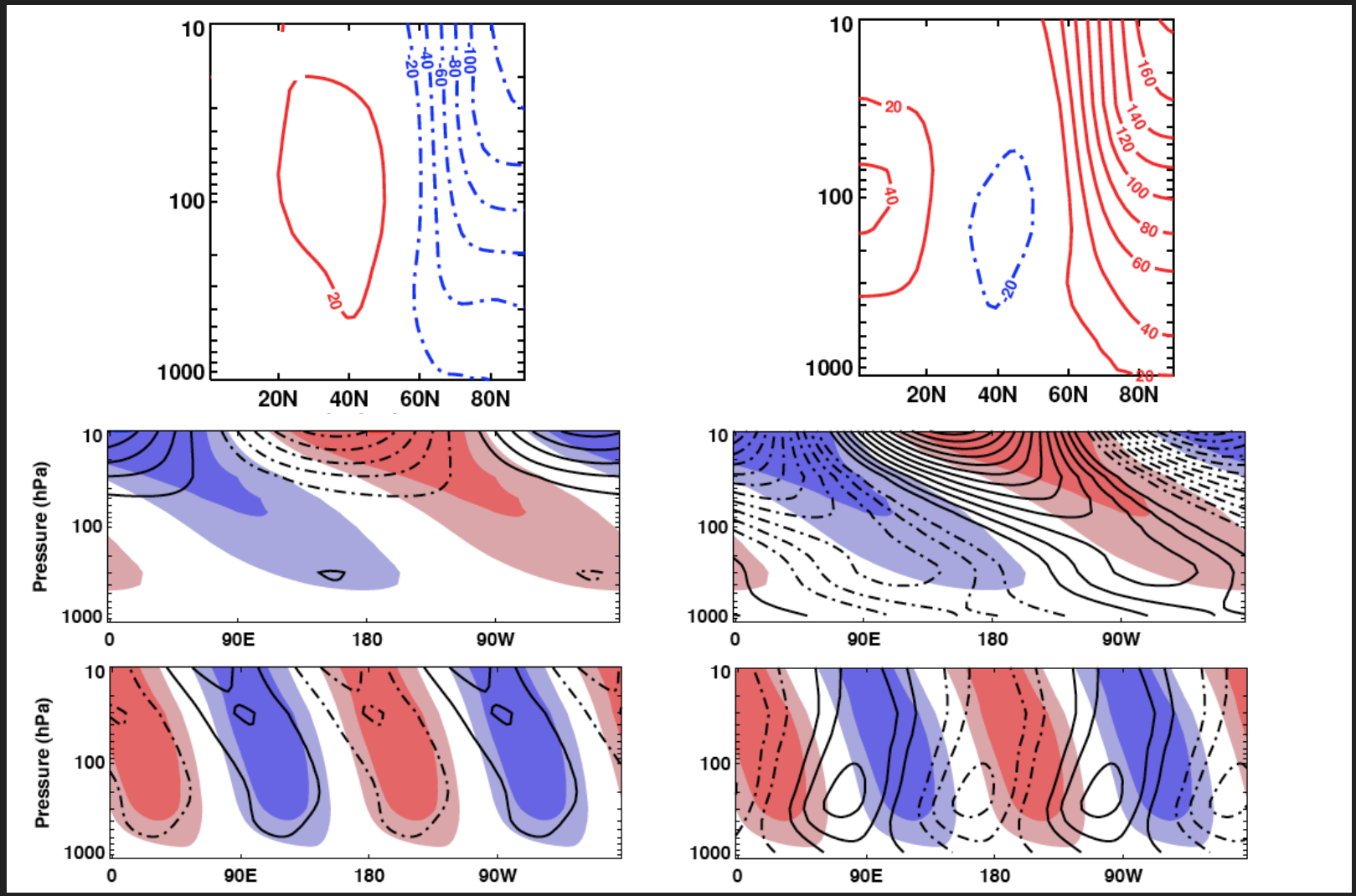
TIO/TPO: NAM Response

TIO TPO

Zonal Mean
Z Response

Wave-1
Z_c* shaded
Z*′ contours

Wave-2
Z_c* shaded
Z*′ contours



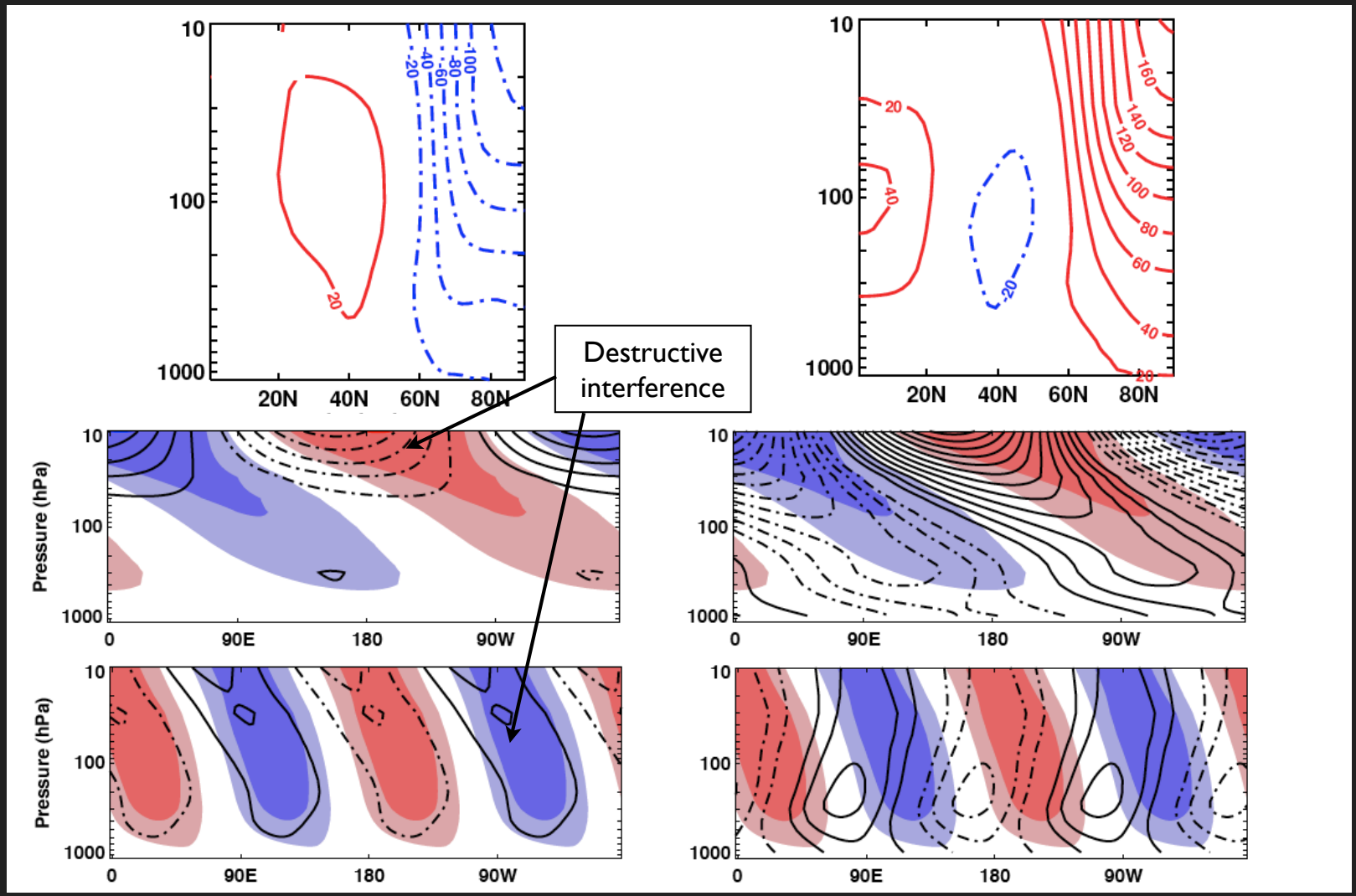
TIO/TPO: NAM Response

TIO TPO

Zonal Mean
Z Response

Wave-1
Z_c* shaded
$Z^{*\prime}$ contours

Wave-2
Z_c* shaded
$Z^{*\prime}$ contours



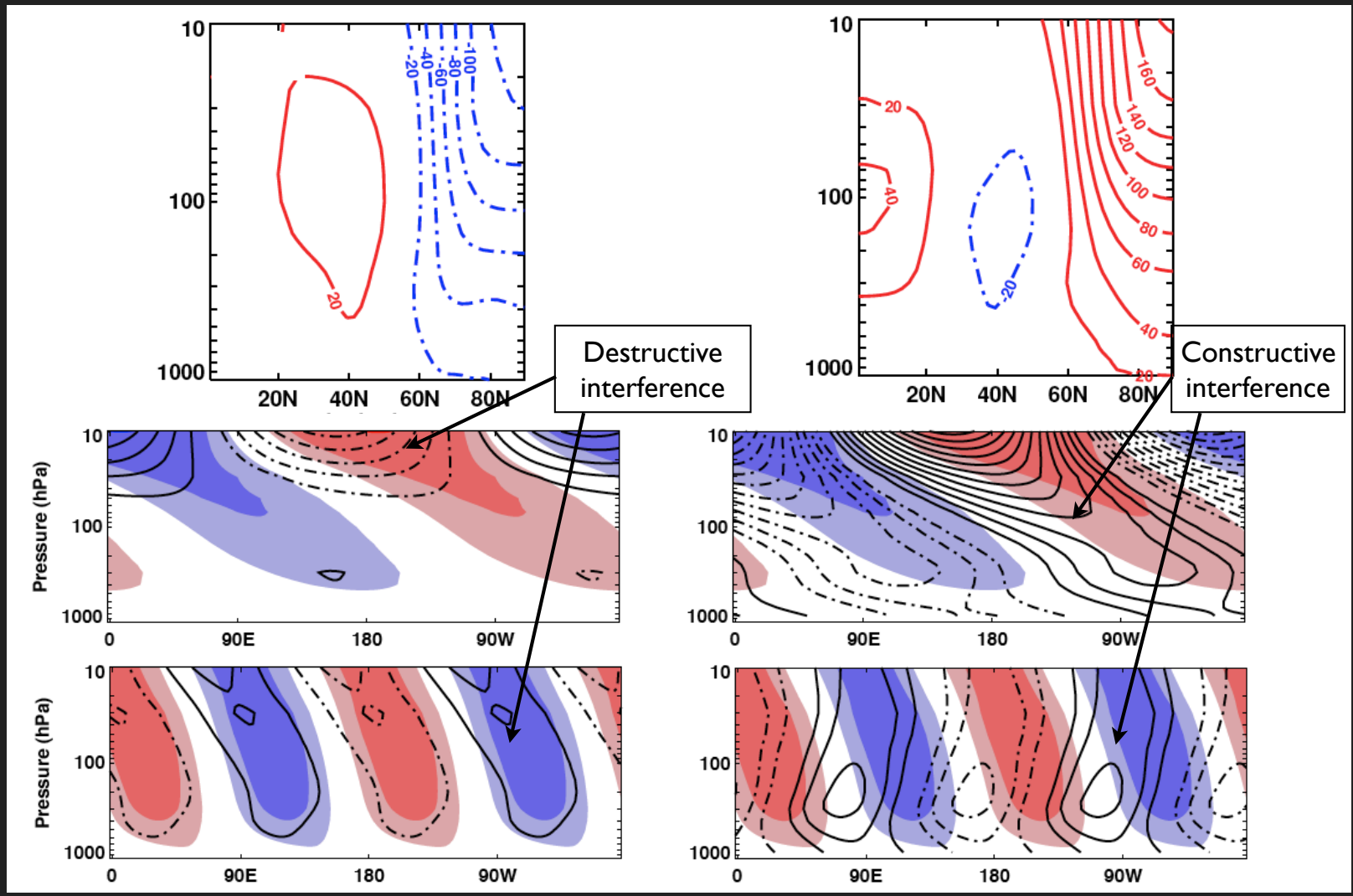
TIO/TPO: NAM Response

TIO TPO

Zonal Mean
Z Response

Wave-1
Z_c* shaded
$Z^{*\prime}$ contours

Wave-2
Z_c* shaded
$Z^{*\prime}$ contours



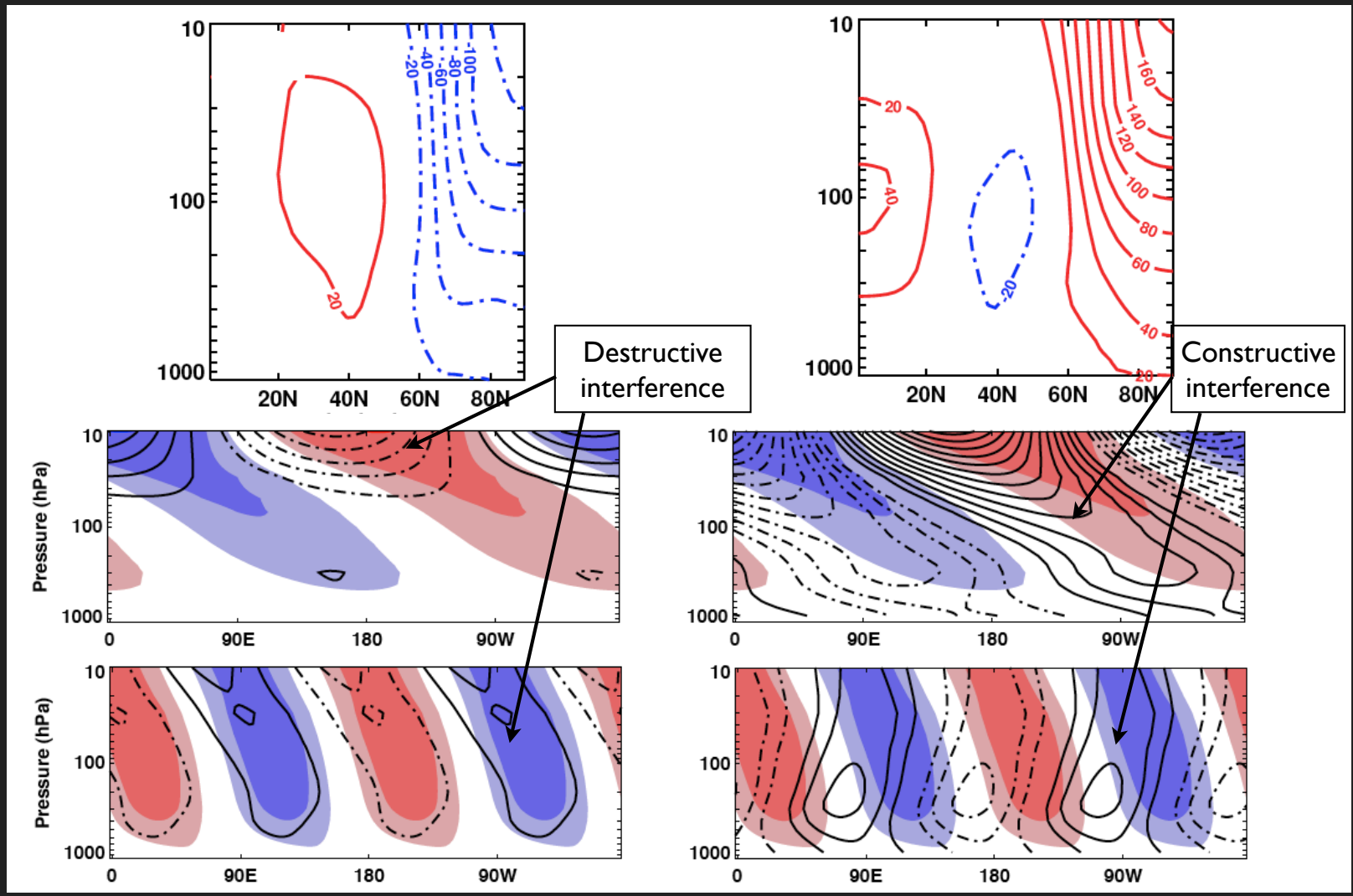
TIO/TPO: NAM Response

TIO TPO

Zonal Mean
Z Response

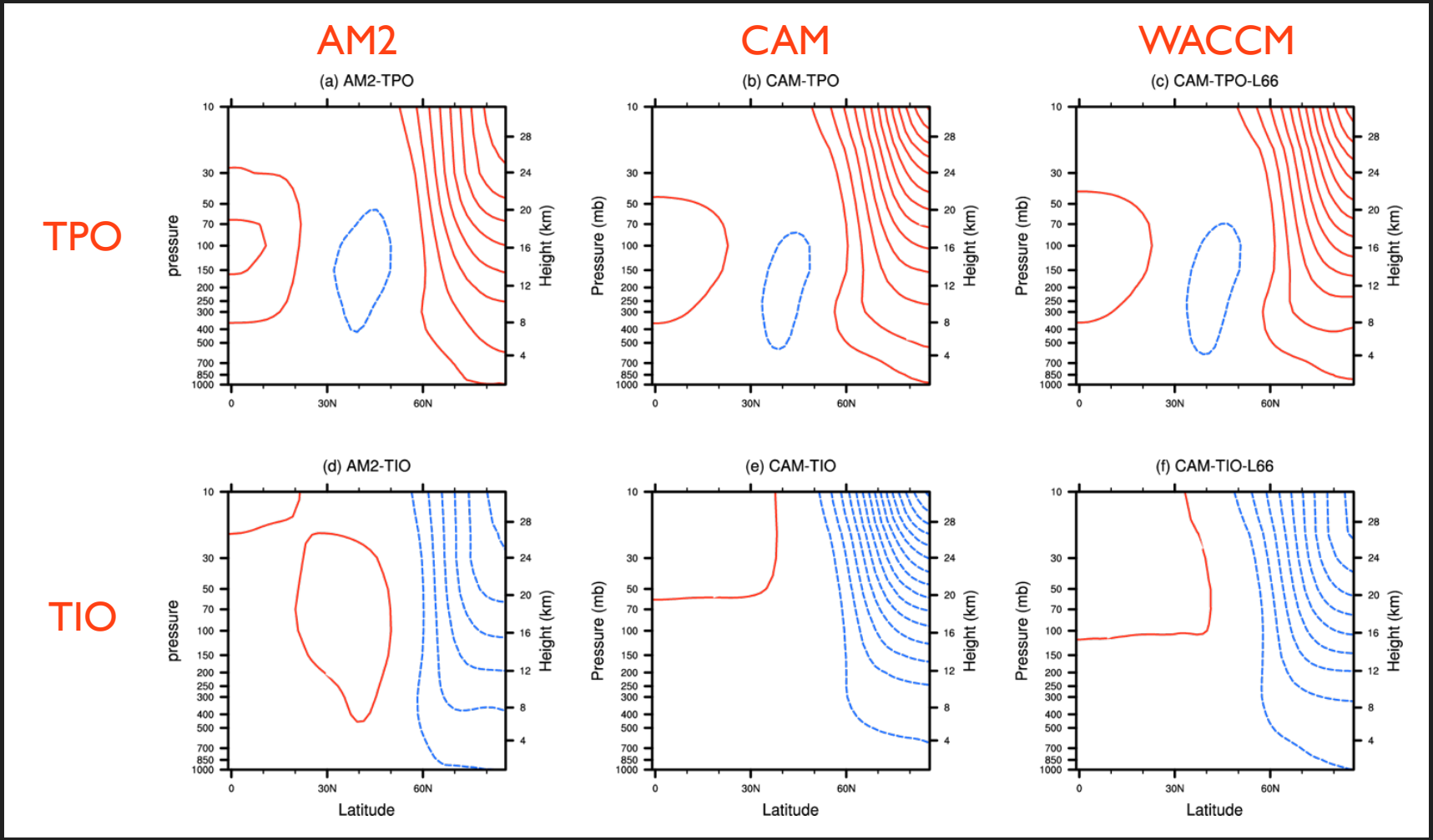
Wave-1
Z_c* shaded
$Z^{*\prime}$ contours

Wave-2
Z_c* shaded
$Z^{*\prime}$ contours



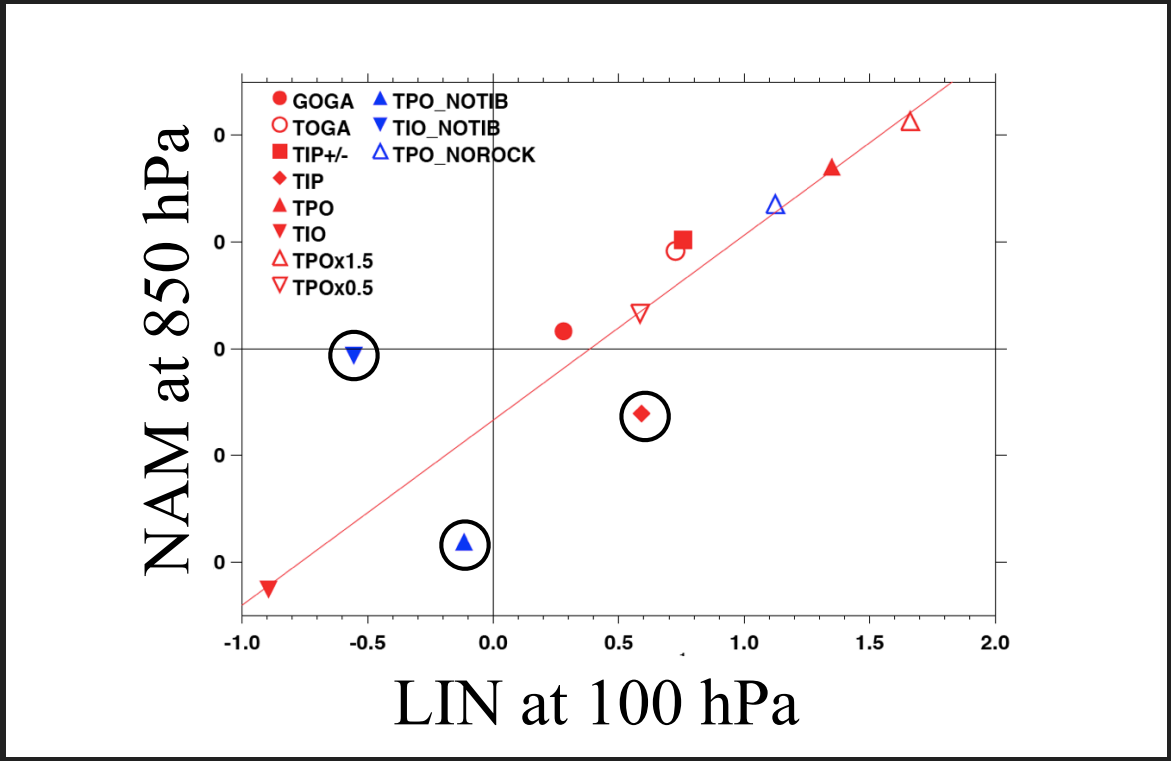
NAM response to TIO surprisingly large, dominated by Wave 2.

Robustness to Model, Stratospheric Representation



Fletcher & Kushner in prep.

Summary of GFDL Simulations

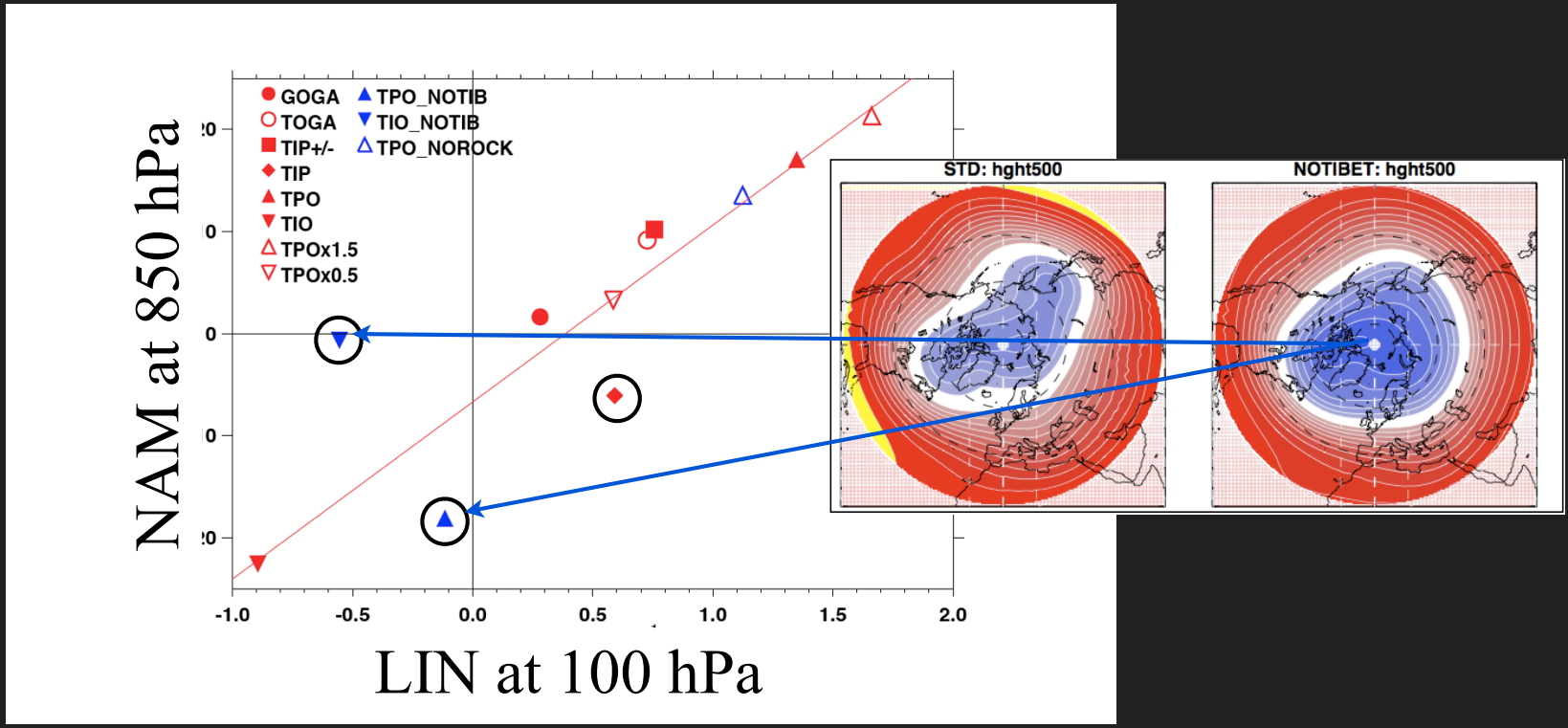


Fletcher & Kushner 2010

Most integrations fall along similar sensitivity curve.

Lower stratospheric LIN term predicts tropospheric NAM response.

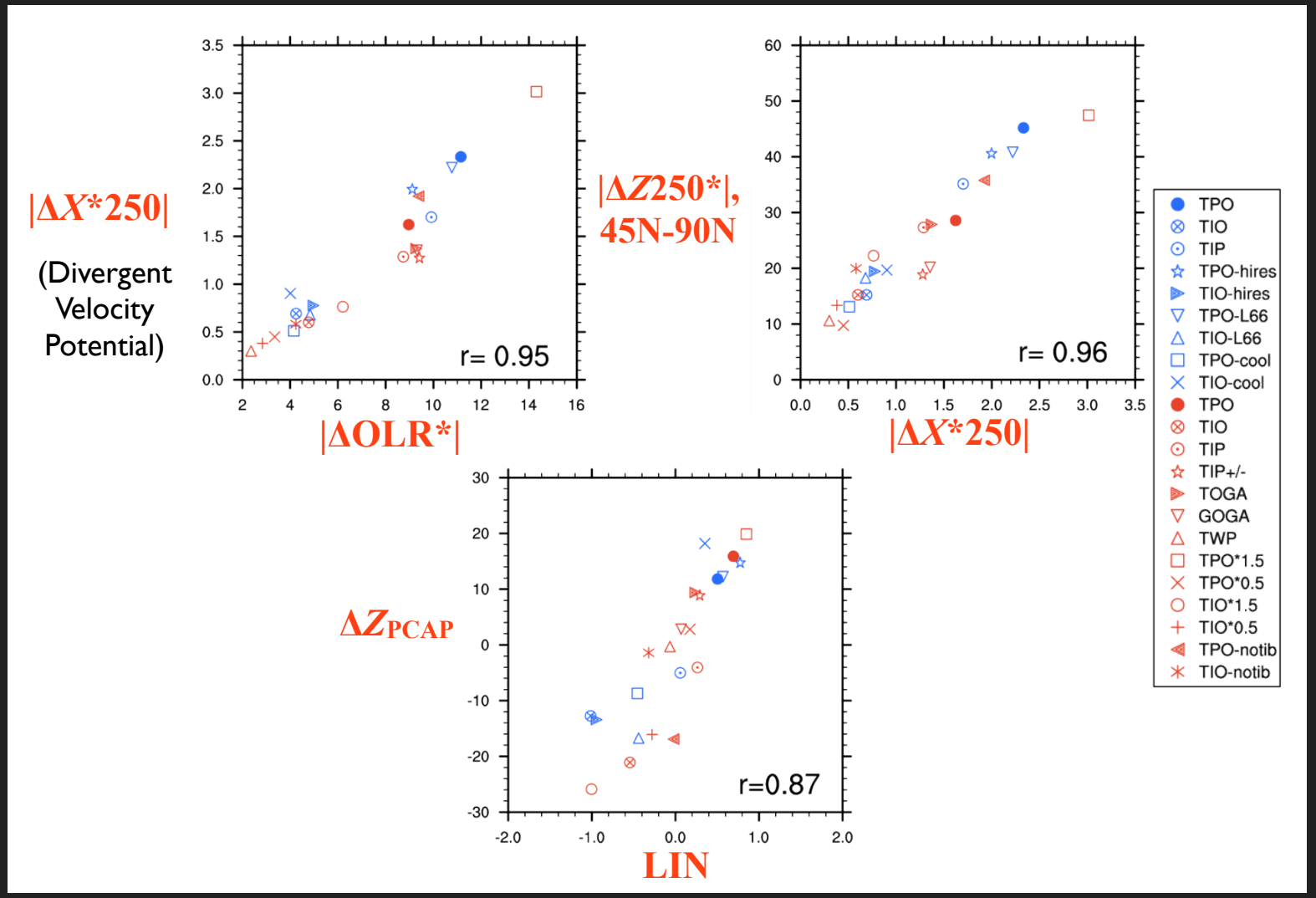
Summary of GFDL Simulations



Fletcher & Kushner 2010

Linear interference effect can be tuned by tuning background wave or forcing.

General Scaling for Response



Fletcher & Kushner in prep.

|Tropical convection| ~ |Tropical divergence| ~ |Extratropical waves|

Tropospheric NAM ~ LIN, which depends on stationary wave structure.

Conclusions

NAM variability and forced response features linear interference effect.

Depends on LIN component of planetary wave flux from troposphere to stratosphere.

Predicting wave response typically a nonlinear problem.

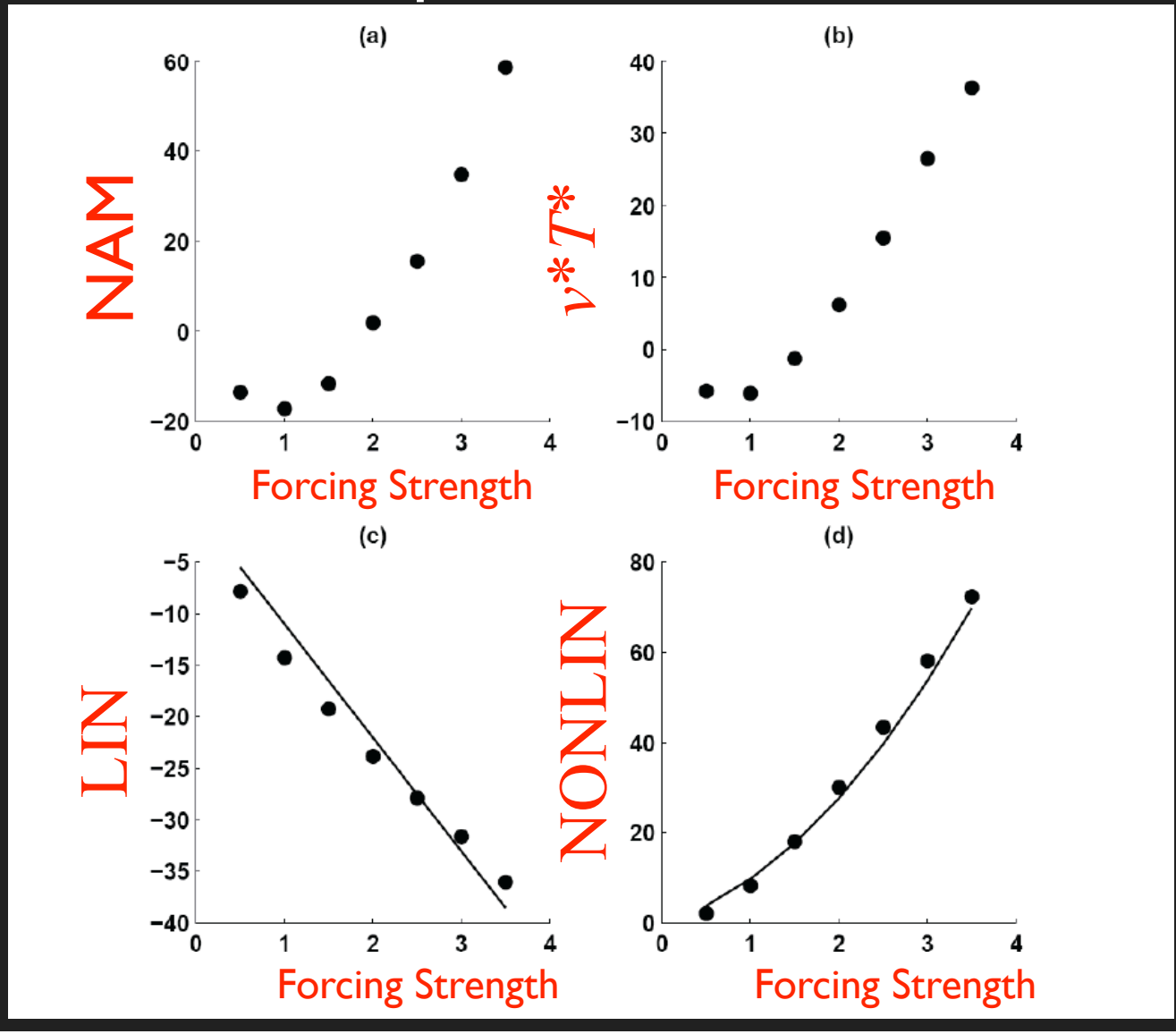
- But given wave response, can diagnose important part of high latitude zonal mean response.

Might be a source of spread across GCMs.

Conclusions

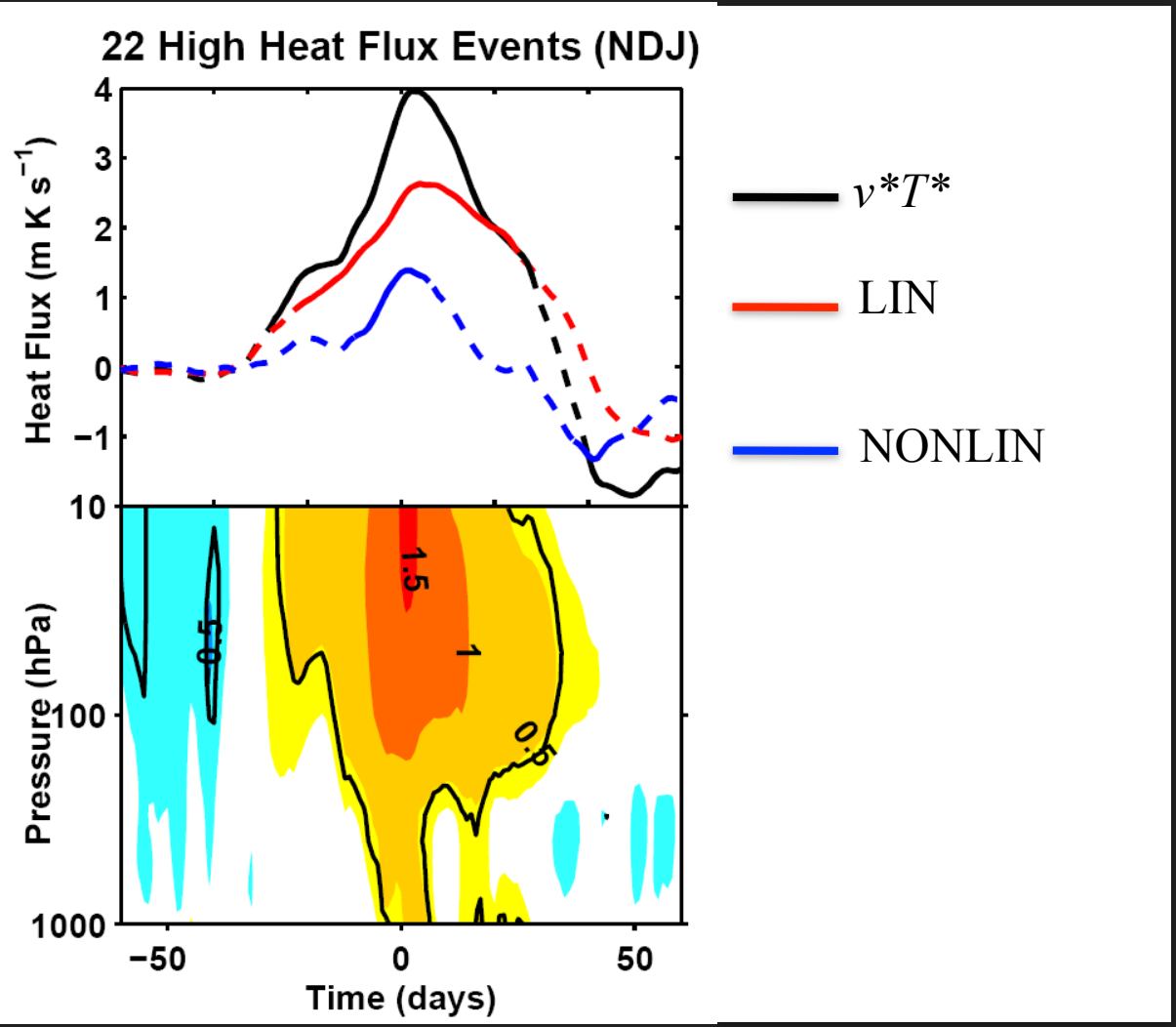
In models, this effect is easy to tune, as in "No Tibet" cases. Another example from Smith et al.:

Response to extratropical regional surface cooling in simple GCM (snow-like forcing).



Thanks to NCAR ASP and CGD/CAS/TSS for a great sabbatical!

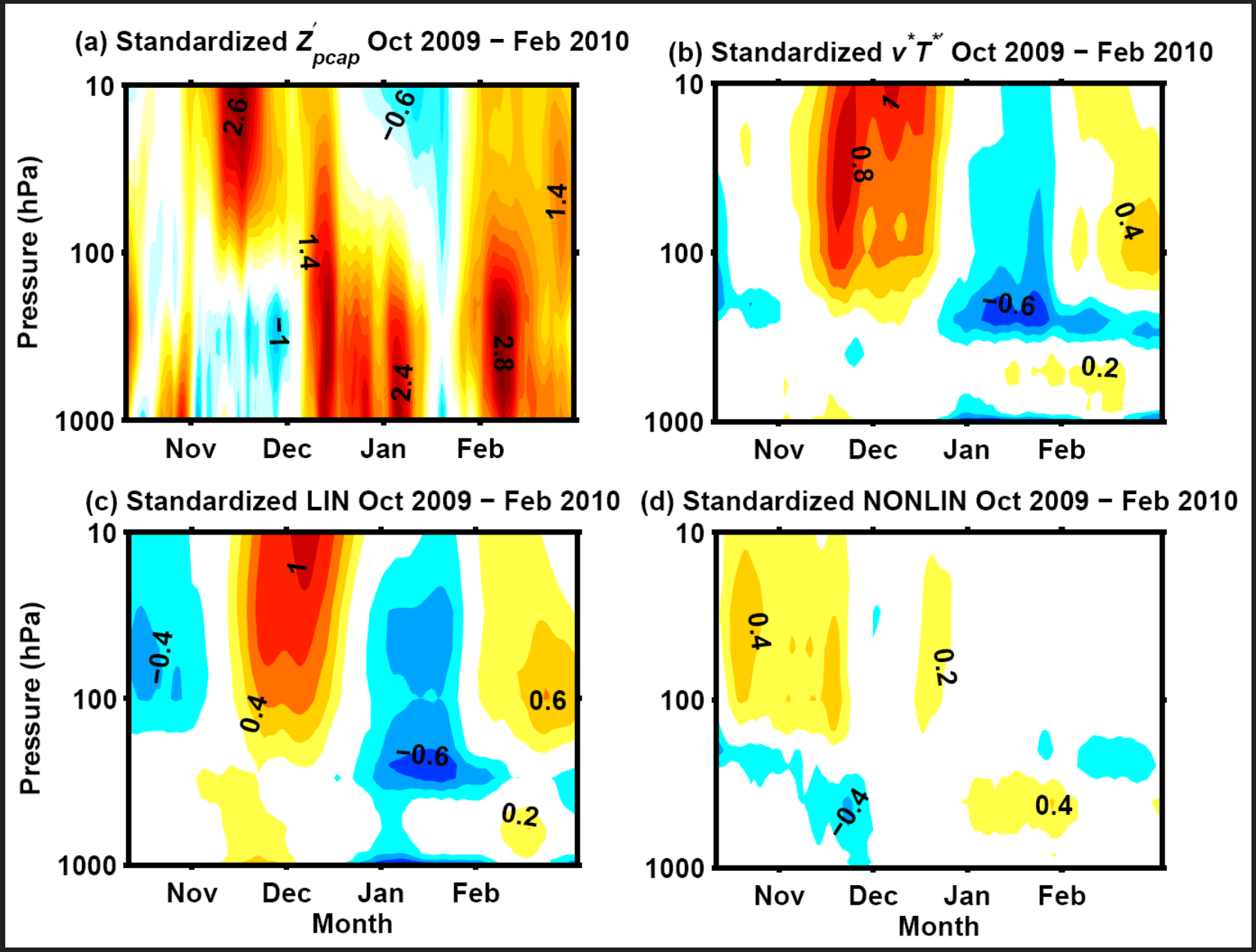
Anomalous LIN Events and the NAM



Smith et al. in press

Wintertime wave activity flux events feature large and often dominant LIN component.

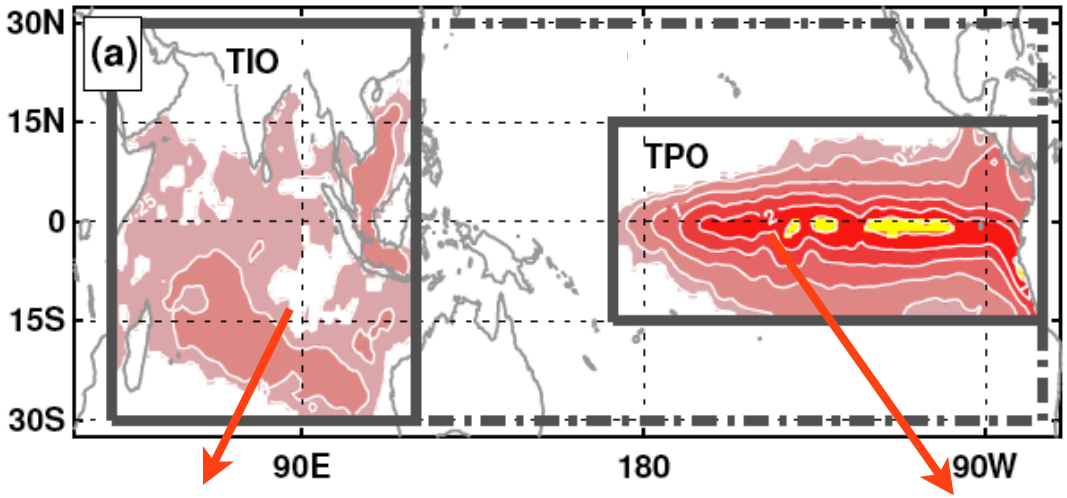
2009-2010 Negative NAM: a LIN Event



Smith et al. in press

Tropical SST/NAM Linkage

Wintertime Warm SST Anomalies Based on Observed El Niño

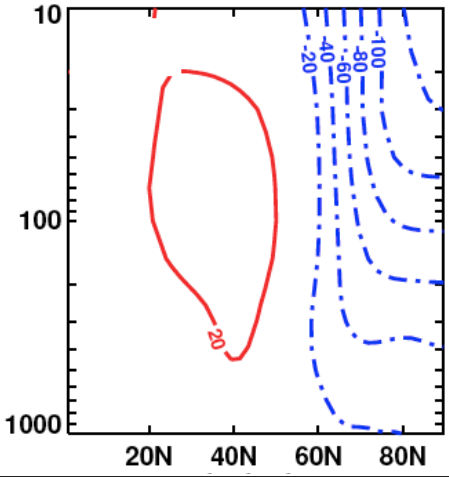


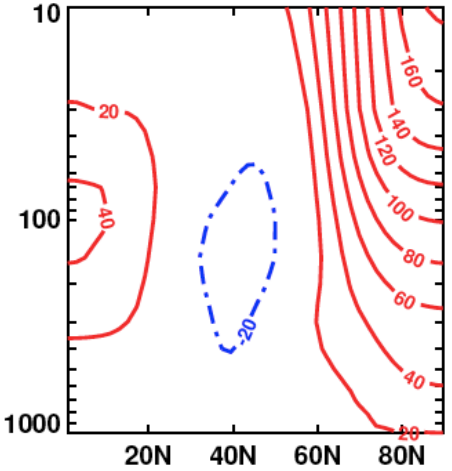
Warming from 5 strongest El Niño's

TIO

TPO

Zonal Mean Geopotential Response to these SST Anomalies





GFDL AM2.1

100 member ensembles,

Switch on forcing in December, analyze January-February

Key: zonal phasing between forced and stationary planetary waves.

Constructive/destructive interference determines sign and amplitude of NAM response.