Stratosphere-Troposphere Coupling and Extratropical-to-Tropical Interactions

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Underlying focus:

Stratosphere-troposphere coupling in the context of tropical-extratropical interactions

(1) Basic characteristics of stratosphere-troposphere coupling

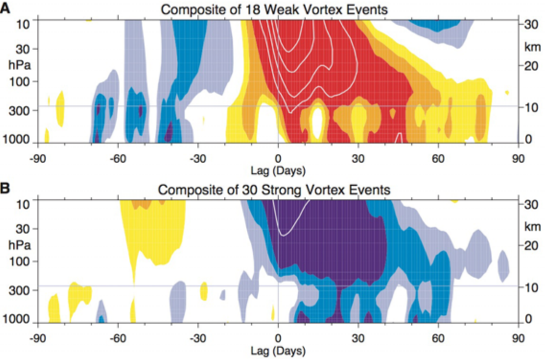
(2) Probabilistic S2S predictability involving the sudden stratospheric warmings (SSWs)
   - Impact of SSWs versus ENSO
   - Equatorial quasi-biennial oscillation (QBO) and SSWs

(3) Mechanisms behind stratosphere-troposphere coupling
   - Difficulties with prediction in the context of these coupling mechanisms

Stratosphere-troposphere interactions:

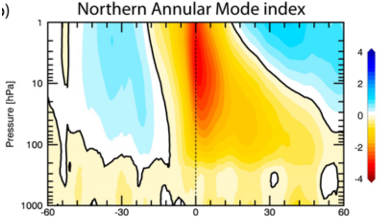
The ‘dripping paint’ diagram...

Strong and weak stratospheric vortex composite:



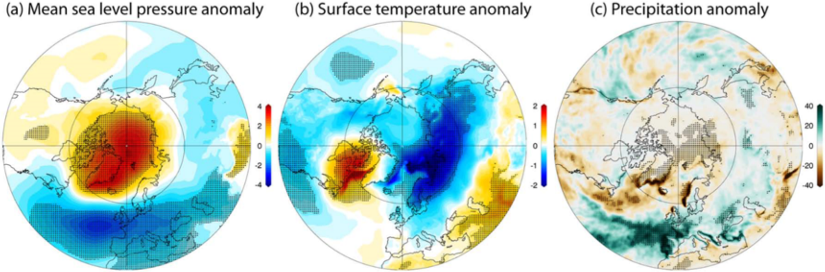
(Baldwin and Dunkerton Science 1999)

Sudden stratospheric warming composite:



(Butler, Sjoberg, Seidel, Rosenlof ESSD 2017)

Tropospheric response to sudden stratospheric warmings (SSWs)

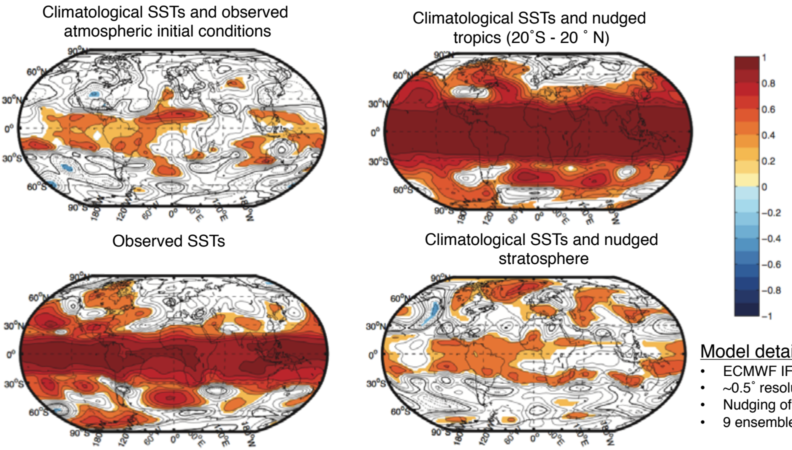


(Butler, Sjoberg, Seidel, and Rosenlof EESD 2017)

Enhanced tropospheric predictability: DJF

Stratosphere versus tropics and SSTs

DJF 500 hPa Geopotential Height Anomaly Correlation Coefficient

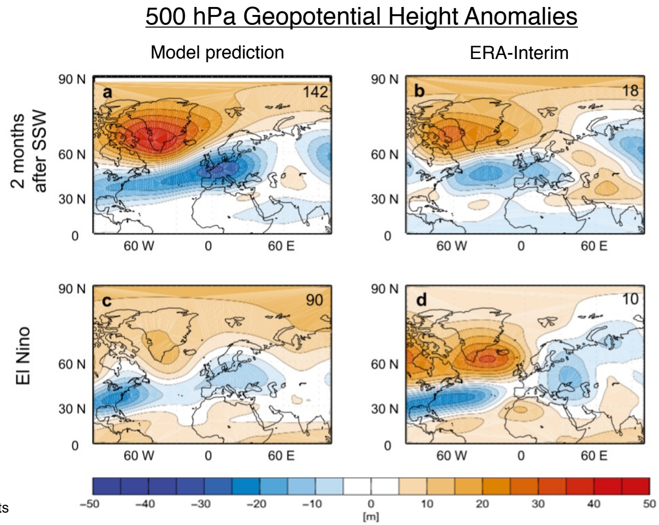


(Hansen, Greatbatch, Gollan, Jung, Weisheimer QJRM 2017)

Model details:

- ECMWF IFS
- ~0.5˚ resolution
- Nudging of SSTs, tropics, stratosphere
- 9 ensembles per year (1979-2013)

Tropospheric response to SSWs and ENSO

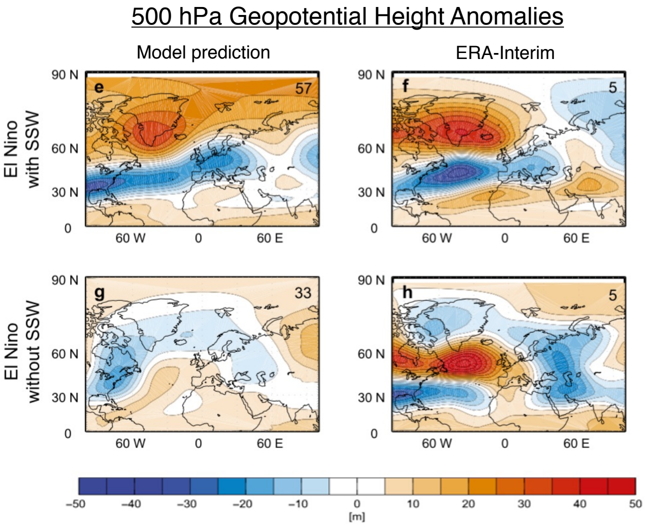


(Domeisen, Butler, Fröhlich, Bittner, Müller, Baehr JClim 2015)

Model details:

- MPI ECHAM6
- ~1.875˚ resolution
- Interactive land, ocean, ice components
- 9 ensembles per year (1980-2011)

Tropospheric response to SSWs and ENSO



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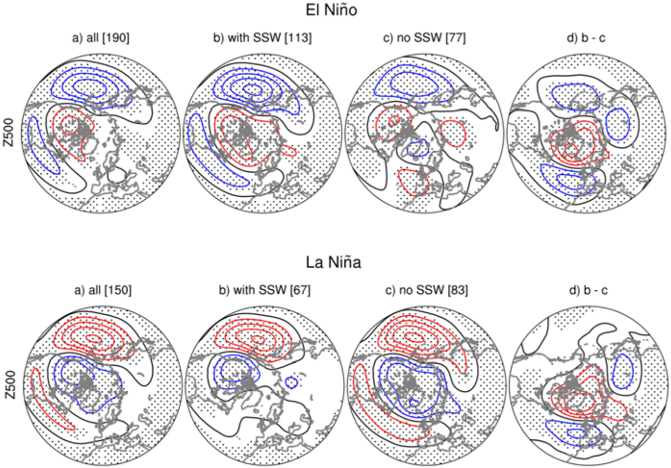
Model details:

- MPI ECHAM6
- ~1.875˚ resolution
- Interactive land, ocean, ice components
- 9 ensembles per year (1980-2011)

Tropospheric response to SSWs and ENSO

El Niño versus La Niña



(*Polvani, Sun, Butler, Richter, Deser JClim 2017*)

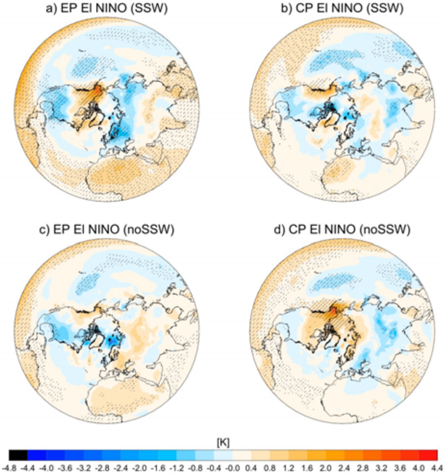
Model details:

- NCAR CAM5
- 100 km resolution
- Observed SSTs and sea-ice
- 10 ensembles x 1952-2003

Tropospheric response to SSWs and ENSO

East Pacific El Niño versus central Pacific El Niño

Surface temperature anomalies



(Calvo, Iza, Hurwitz, Manzini, Peña-Ortiz, Butler, Cagnazzo, Ineson, Garfinkel JClim 2017)

Model details:

- 11 high-top CMIP-5 models
- Coupled atmosphere-ocean models
- 1 ensembles per model (1951-2005) with historical climate forcings

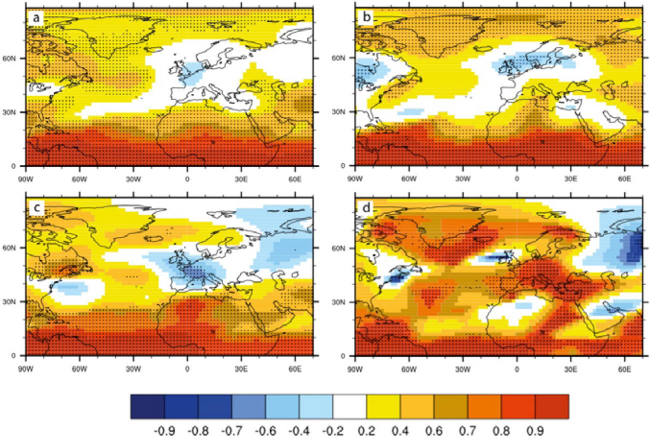
Enhanced tropospheric predictability: SSWs versus ENSO

<u>500 hPa Geopotential Height Anomaly Correlation Coefficient</u>

Only years with a SSW

All years

El Niño years

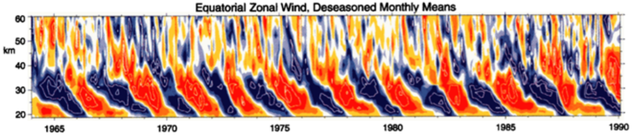


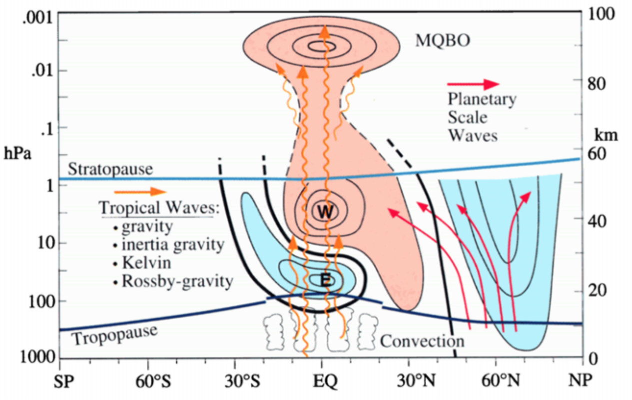
(Domeisen, Butler, Fröhlich, Bittner, Müller, Baehr JClim 2015)

<u>Model details:</u>

- MPI ECHAM6
- ~1.875˚ resolution
- Interactive land, ocean, ice components
- 9 ensembles per year (1980-2011)

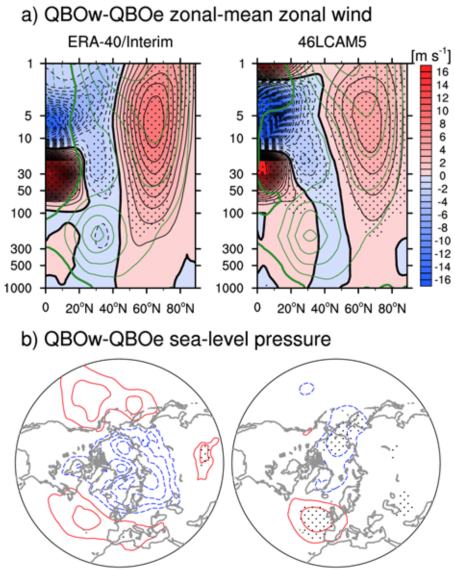
Equatorial quasi-bienniel oscillation (QBO)





(Baldwin et al. Rev. Geophys. 2001)

Tropospheric response to the QBO

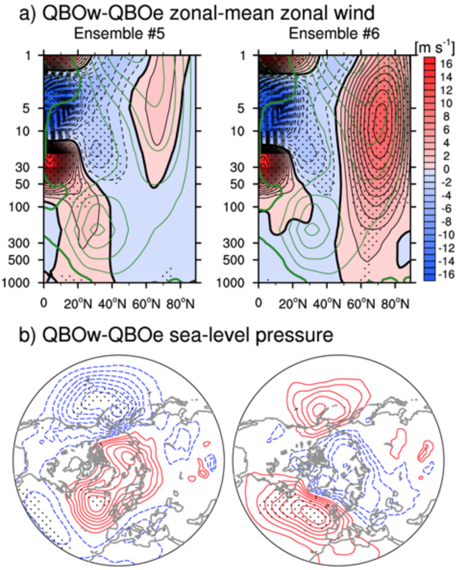


Model details:

- NCAR CAM5
- 100 km resolution (∼ 1°)
- Observed SSTs and sea ice
- 10 ensembles x 1957-2015 with historical climate forcings

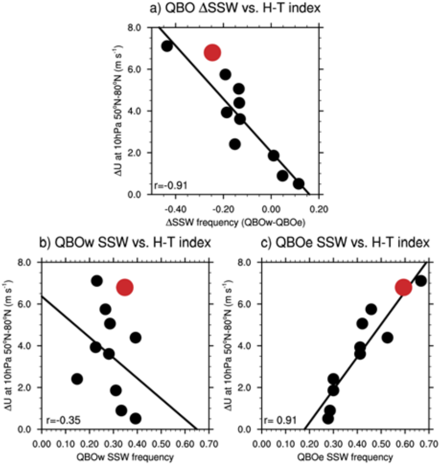
(Perlwitz, Sun, Richter, Albers, and Bacmeister in prep.)

Tropospheric response to the QBO



(Perlwitz, Sun, Richter, Albers, and Bacmeister in prep.)

Probabilistic SSW predictability via ENSO and QBO



(Perlwitz, Sun, Richter, Albers, Bacmeister in prep.)

Probabilistic SSW predictability via ENSO and QBO

(Perlwitz, Sun, Richter, Albers, Bacmeister in prep.)

ERSSTv3

	# of winters	SSWs per winter
El Niño	19	0.79
La Niña	18	0.72

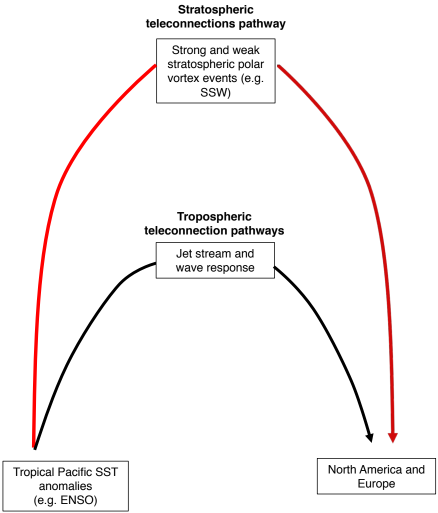
(Butler, Polvani, Deser ERL 2014)

ERSSTv4

	# of winters	SSWs per winter
El Niño	20	0.8
La Niña	16	0.63

(Polvani, Sun, Butler, Richter, Deser JClim 2017)

Stratosphere-to-troposphere coupling mechanisms

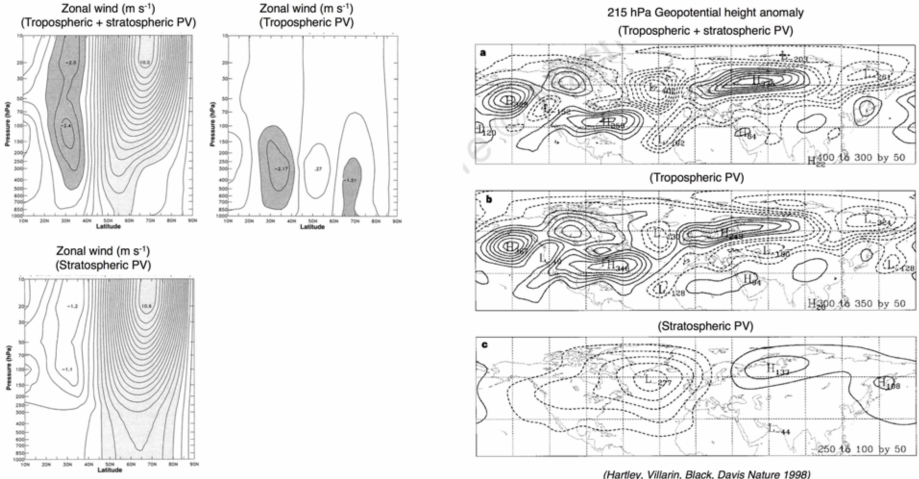


Stratosphere-to-troposphere communication:

1. Communicate signal downwards to tropopause
   - Downward propagating zonal mean zonal wind anomalies
     (e.g., Holton Mass JAS 1976, Christiansen JAS 1999)
   - 'Downward control'
     (Haynes et al. JAS 1991)
   - Wave reflection
     (e.g., Perlwitz and Harnik JClim 2003)
   - Remote response to stratospheric PV anomalies
     (e.g., Hartley et al. Nature 1998, Black JClim 2002, Ambaum and Hoskins JClim 2002)
2. Amplify the response
   - Synoptic eddy feedbacks amplifying the stratospheric induced upper tropospheric perturbations
     (e.g., Song and Robinson JAS 2004, Hitchcock and Simpson JAS 2014)

Stratosphere-to-troposphere coupling mechanisms

Piecewise PV inversion



(Black JClim 2002)

(Hartley, Villarin, Black, Davis Nature 1998)

Stratosphere-to-troposphere coupling mechanisms

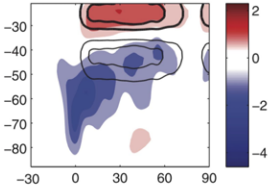
Model and composite details:

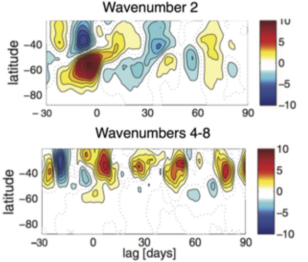
- GFDL dry dynan. core
- 93 SSWs in full model runs
- 63 SSWs in wave truncated model runs

Zonal wind anomalies (250 hPa)

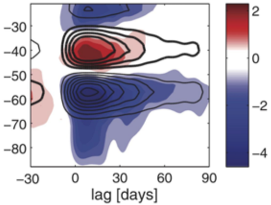
Momentum flux anomalies (250 hPa)

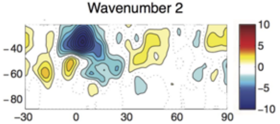
All wavenumbers included





Wavenumbers >3 truncated



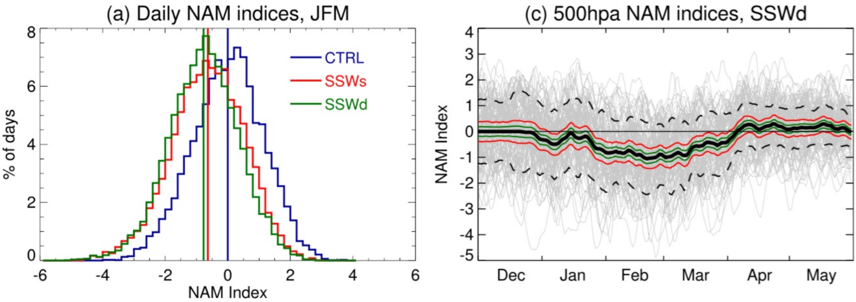


(wavenumbers 4-8 truncated)

(Domeisen, Sun, Chen GRL 2013)

Stratosphere-to-troposphere coupling mechanisms

Stratosphere influence versus tropospheric internal variability

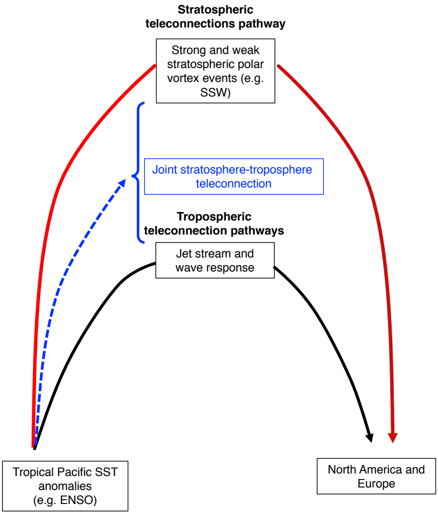


Model details:

- CMAM
- $\sim 1.8^\circ$ resolution
- Annually repeating observed SSTs and sea ice
- 100 year time slices per run type

(Hitchcock and Simpson JAS 2014)

Stratosphere-to-troposphere coupling mechanisms



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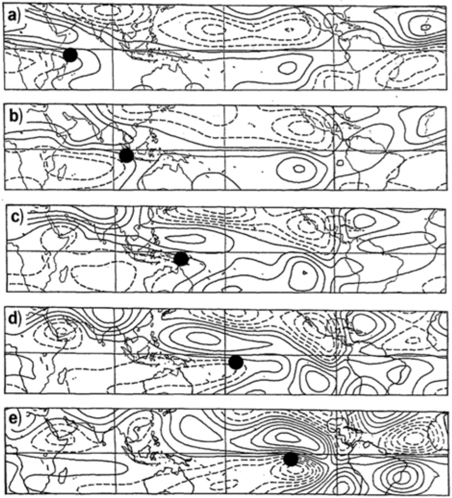
2. Amplify the response
   - Synoptic eddy feedbacks amplifying the stratospheric induced upper tropospheric perturbations
     (e.g., Song and Robinson JAS 2004, Hitchcock and Simpson JAS 2014)

3. Direct coupling via vertically deep PV deformations
   (Albers et al. JAS 2016)

Locational dependence of divergence forcing

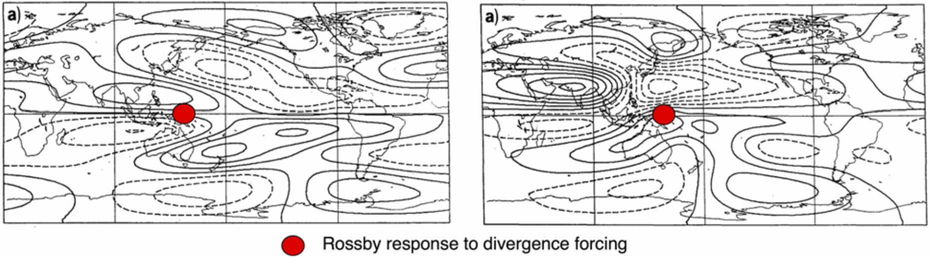


(Sardeshmukh and Hoskins JAS 1988)

Basic state dependence of Rossby response to divergence forcing

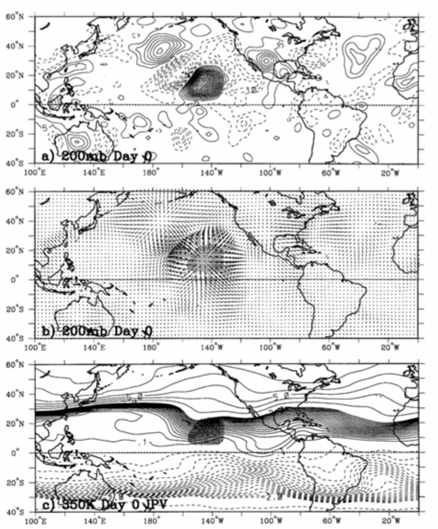
December-February basic state

June-August basic state



(Sardeshmukh and Hoskins JAS 1988)

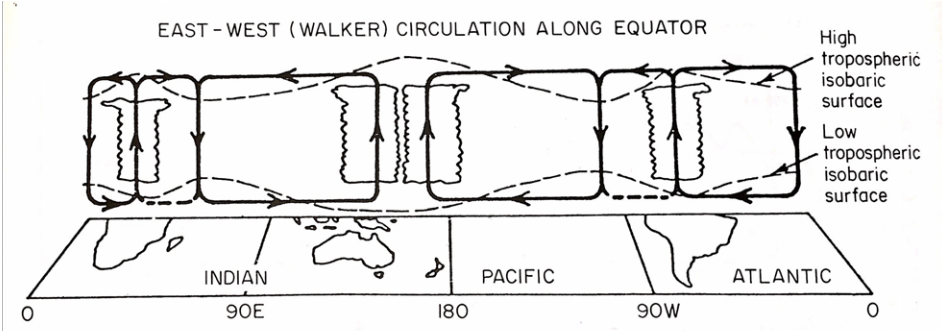
Tropical-extratropical tropospheric teleconnections
Extratropical-to-tropical disturbances



(Kiladis JAS 1998)

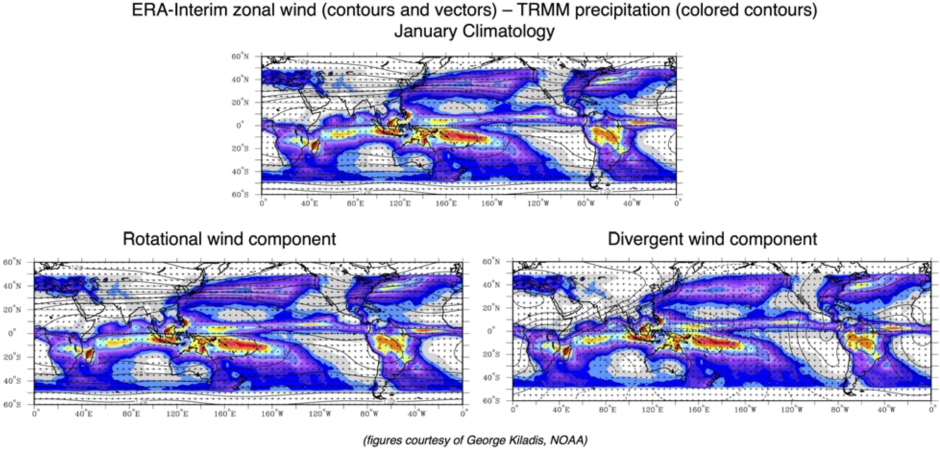
Why are the westerly ducts where they are?

Walker-like circulation?



(P. Webster in AP 1983, Ed. Hoskins and Pearce)

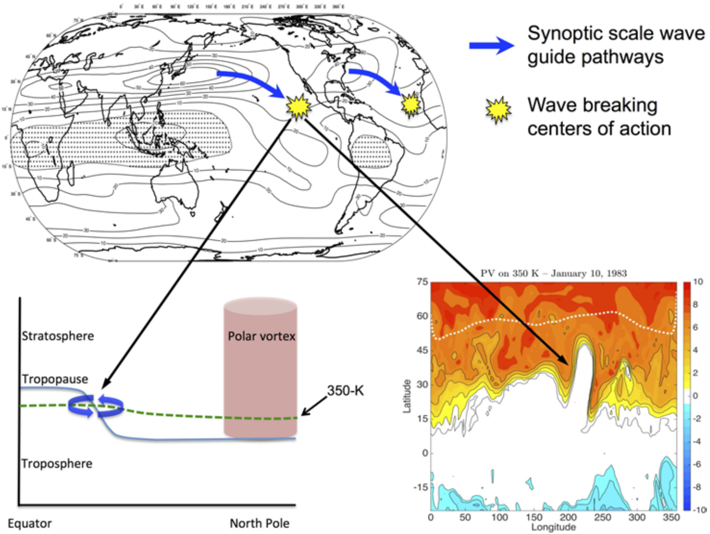
Tropical-extratropical tropospheric teleconnections
Westerly ducts formation



(Figures courtesy of George Kiladis, NOAA)

Tropical-extratropical tropospheric teleconnections

Westerly ducts and extratropical-to-tropical disturbances



What does this have to do with SSWs?

- Local station data showed intense gravity wave activity emanating from a PV intrusion over Gadanki, India during 2009 SSW

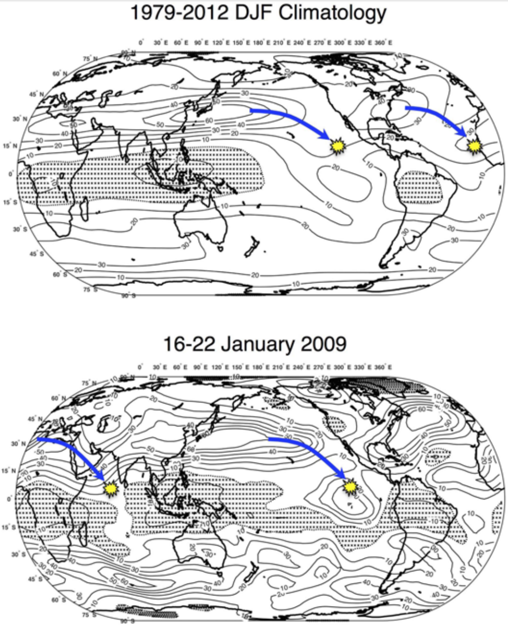
  (Nath et al. 2013)

- Vortex location during SSWs have a geographic preference

  (Matthewman et al. 2009)

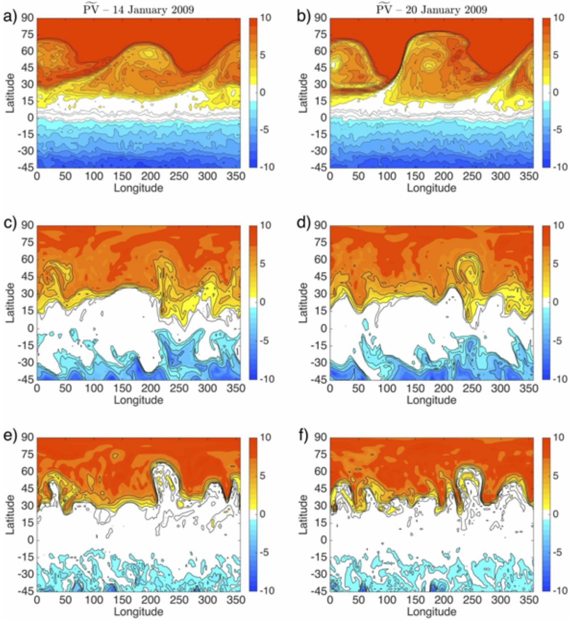
Question: Is there a systematic connection between SSWs and deep extratropical-tropical PV intrusions?

January 2009 Wavenumber 2 SSW



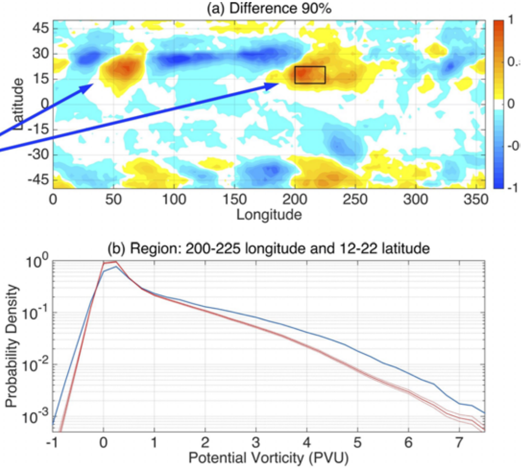
- Entirely new westerly duct over the Indian ocean formed

January 2009 Wavenumber 2 SSW



PDFs of PV anomalies two weeks before all SSWs:

Reorganized anomalous wave breaking pattern

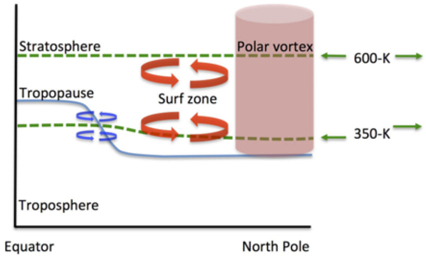


PDF of two week period before all SSWs

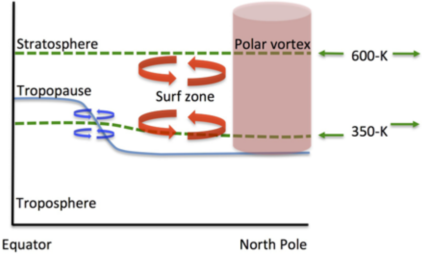
PDF of random two week periods with 95% confidence interval

(Albers, Kiladis, Birner, Dias JAS 2016)

Hypothesized mechanisms:
Example: Split SSW



Hypothesized mechanisms:
Example: Split SSW



Hypothesized mechanisms:
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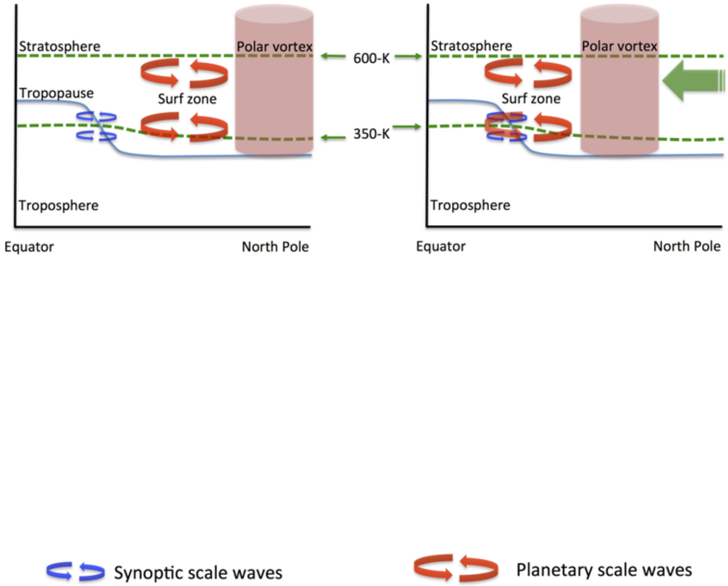
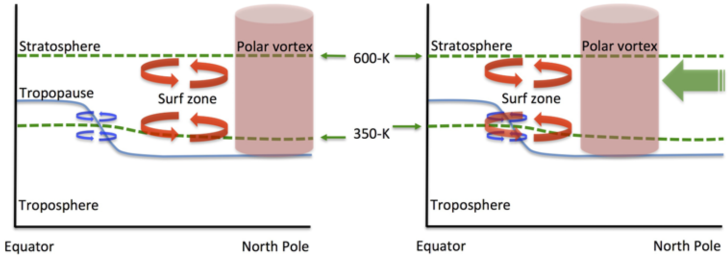
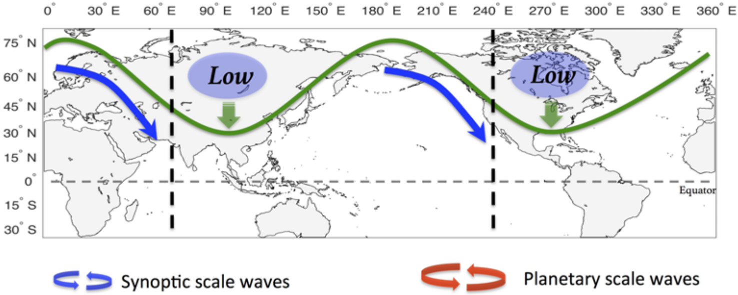


Hypothesized mechanisms:
Example: Split SSW





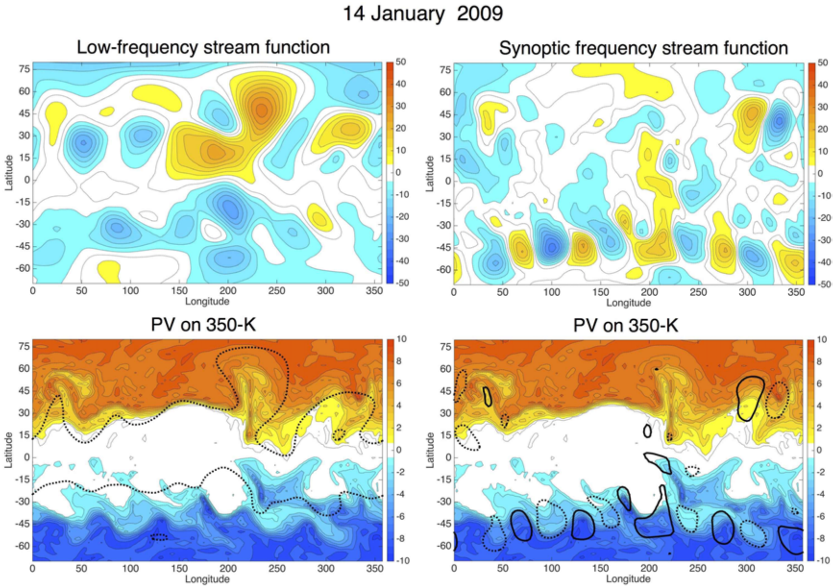
What is causing the largest intrusions along 350-K?

- Synoptic scale wave breaking?
  - High-pass filter $\Longrightarrow$ 1-10 day variability

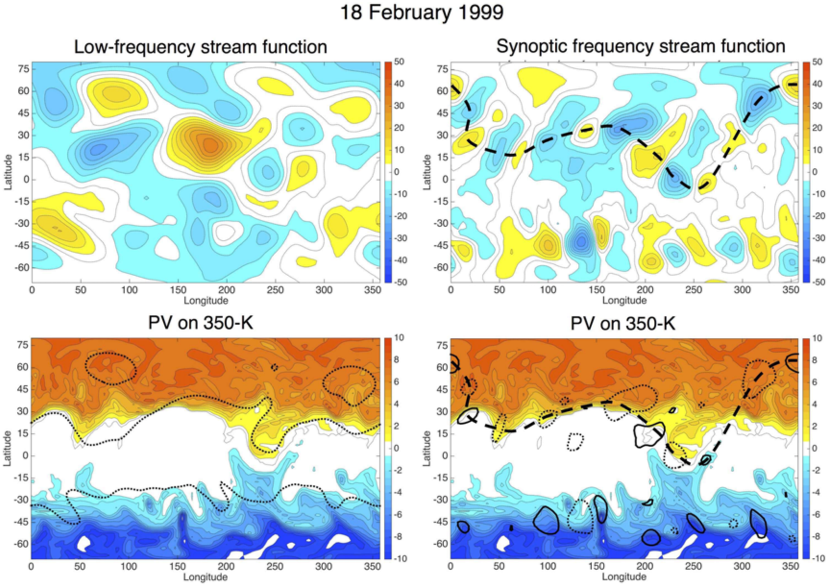
OR

- Large-scale, low frequency wave breaking?
  - Band-pass filter $\Longrightarrow$ 30-120 day variability

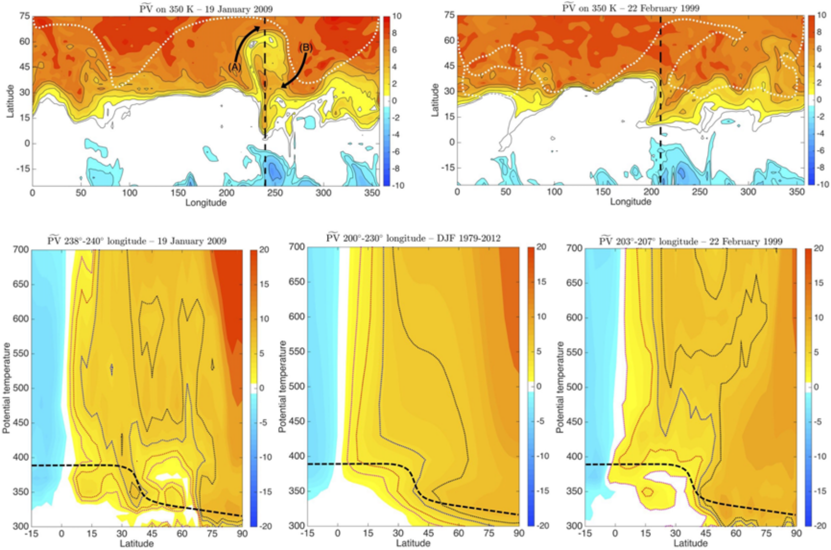
January 2009 split SSW:



February 1999 split SSW:

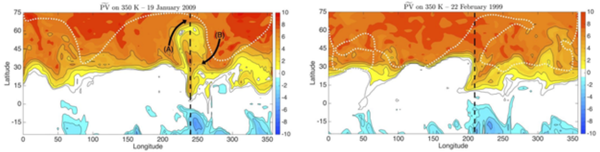


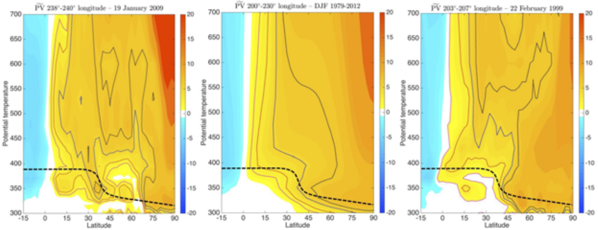
PV cross-sections 1999 and 2009 split SSWs:



(Albers, Kiladis, Birner, Dias JAS 2016)

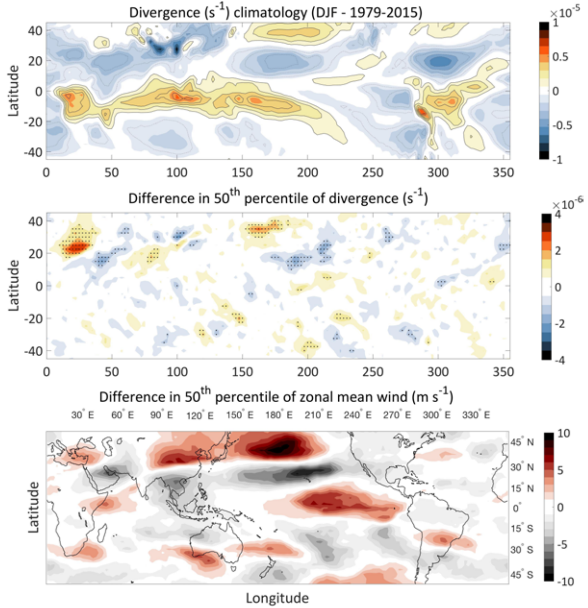
PV cross-sections 1999 and 2009 split SSWs:





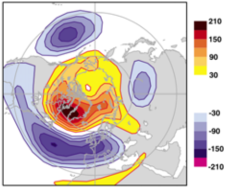
(Fig. 5 – Polvani and Saravanan 2000)

SSW basic state and divergence patterns



500 hPa geopotential height anomalies

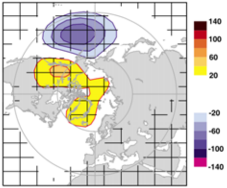
Observations 2009/2010 DJF



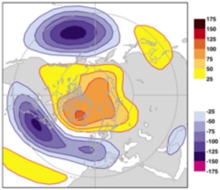
Model details:
- ECMWF seasonal forecast model
- ~ 0.75˚ resolution
- Nudged experiments

(Jung, Vitart, Ferranti, Morcette GRL 2011)

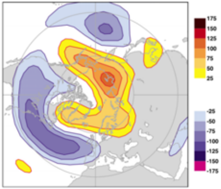
Nudged stratosphere 0.1-85 hPa



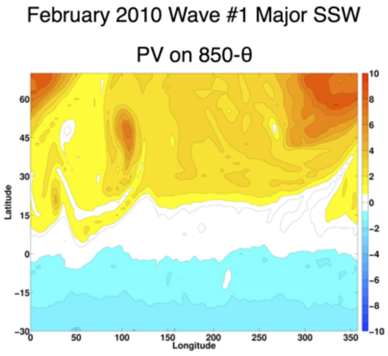
January 14 initialized forecast

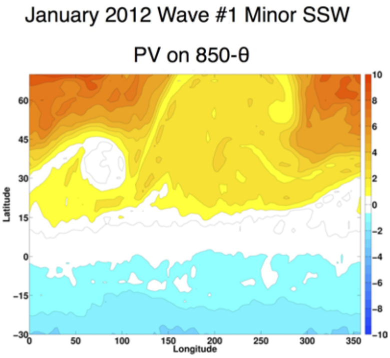


January 14 initialized forecast out of phase SSTs

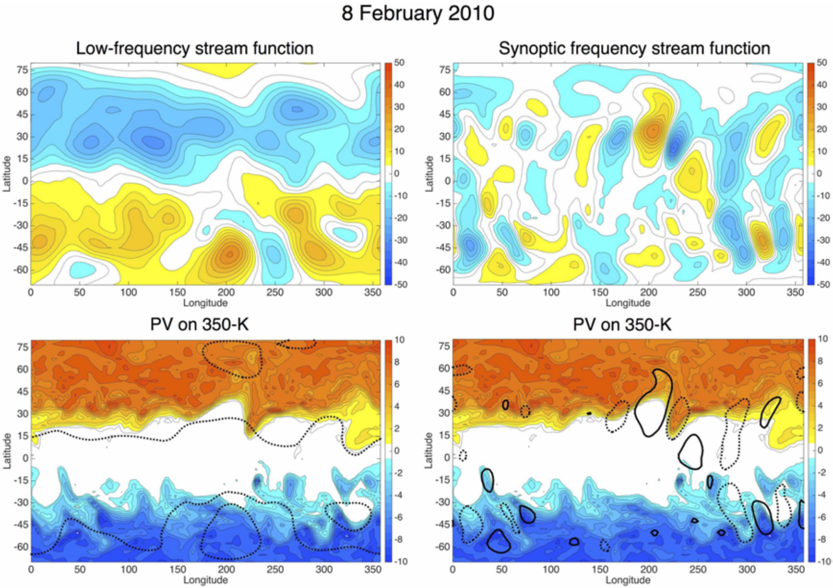


February 2010 and January 2012 Displacement SSWs:

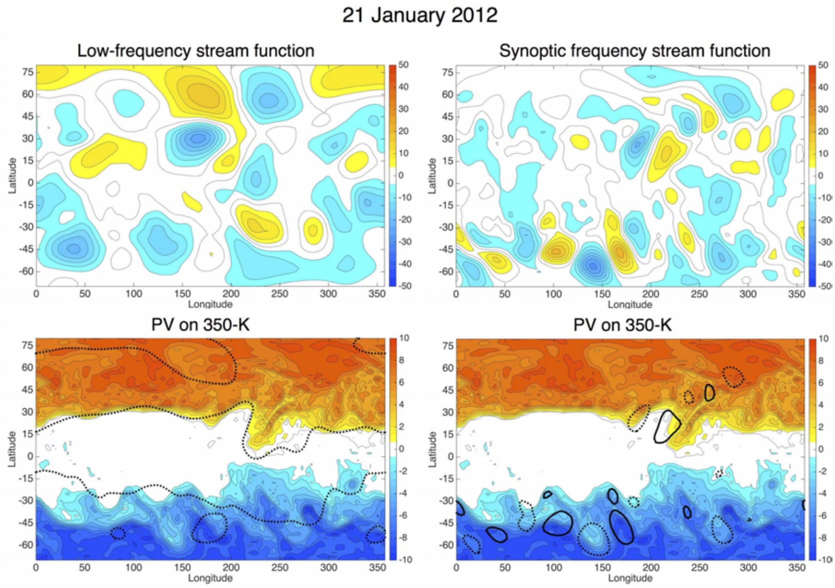




February 2010 Displacement SSW:



January 2012 minor (wave #1) SSW:



To summarize

- Enhanced S2S predictability may be realized via an accurate accounting of stratospheric variability
- The QBO and ENSO both offer avenues for stratospheric-based S2S predictability
- Disentangling ‘stratospheric’ versus ‘tropospheric’ teleconnection pathways remains on ongoing area of research
- Exact mechanisms through which stratosphere-troposphere communication occur also remains an area of ongoing research

References

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