The Abdus Salam International Centre for Theoretical Physics

Year of Tropics-Midlatitude Interactions & Teleconnections 2017-2019

Review of Teleconnections on Intra-seasonal Time Scales

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Outline

- The influence of the tropics on the midlatitudes
  - Observations in the Northern and Southern Hemisphere
  - Modeling studies in the Northern and Southern Hemisphere
- The influence of the midlatitudes on the tropics
- The two-way interactions and feedbacks
- Forecasting teleconnections on intra-seasonal time scales
- Remaining challenges

Observations – Early Days

Riehl, 1950

"The most outstanding of these features are the breakdown of the tropical atmosphere into a train of vortices and the complete interlocking of flow between the high and low latitudes."

"It would seem more than difficult to draw a line separating polar and tropical zones."

"Heat is injected into the polar zones in few and narrow strips of longitude… in part, changes of flow configurations and intensity in higher latitudes must depend on the availability of low latitudes disturbances to form extended troughs."

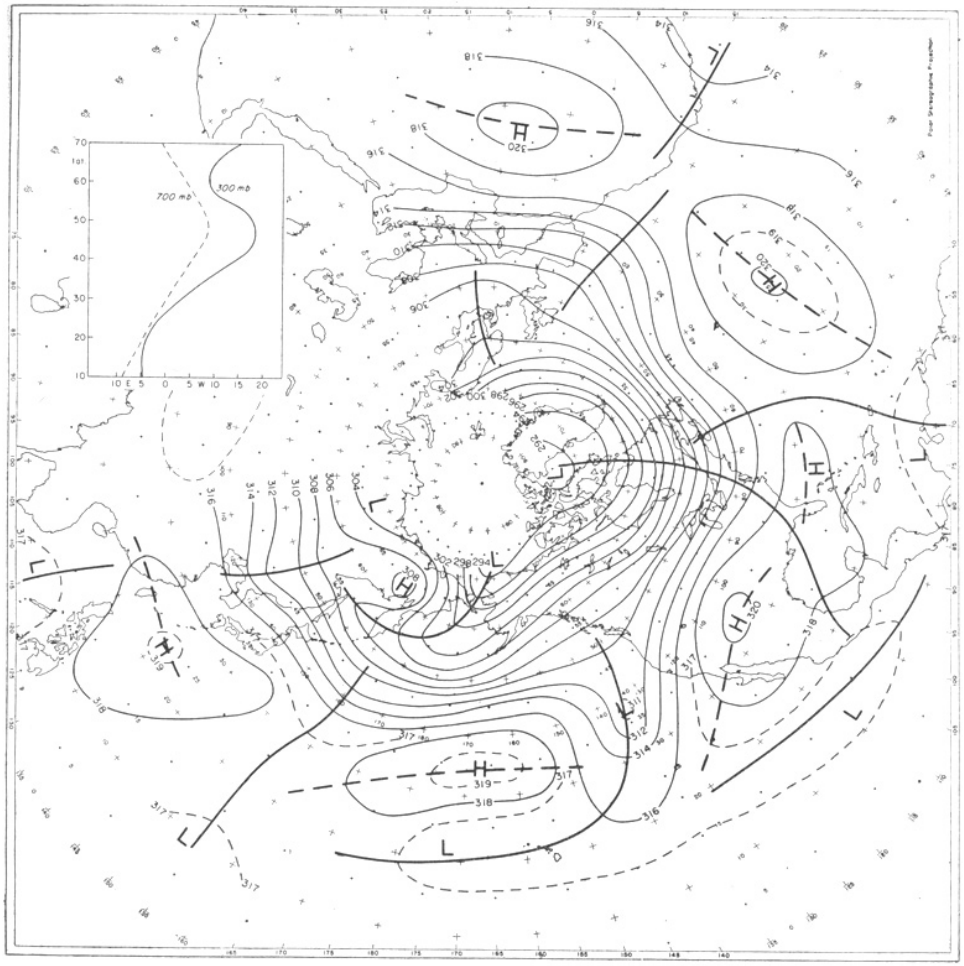


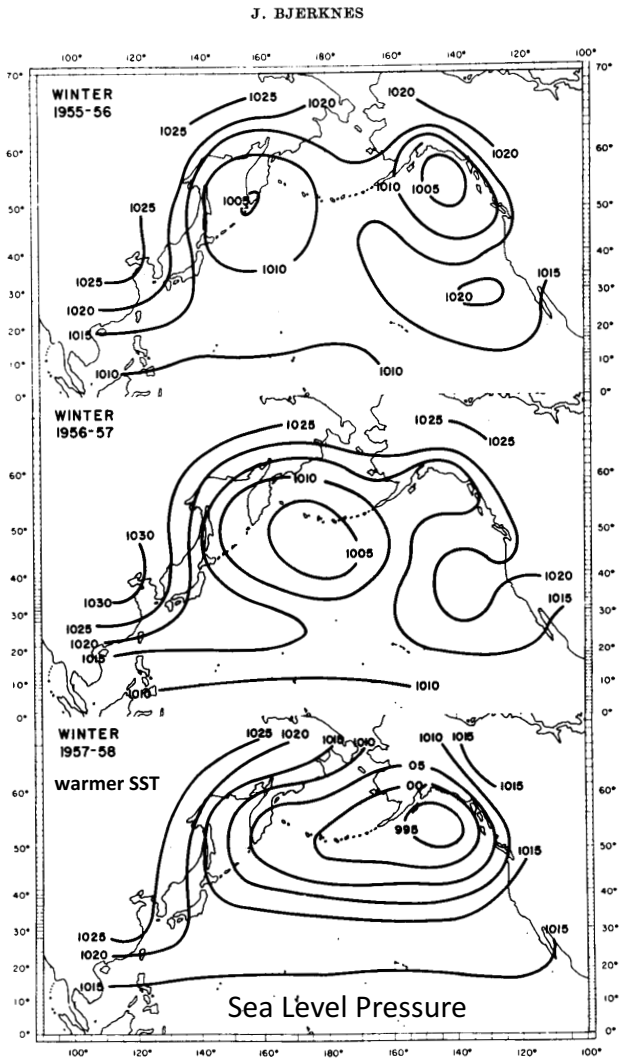
Fig. 2. Topography of the 300-mb surface (100's feet), August 26, 1945, 0600Z. Insert: meridional profile of the zonal wind (mps) at 300 and 700 mb computed between longitudes 20° E and 110° E via western hemisphere.

The role of Tropics in the general circulation of the atmosphere. Tellus.

Observations – Foreseeing the potential for seasonal forecast

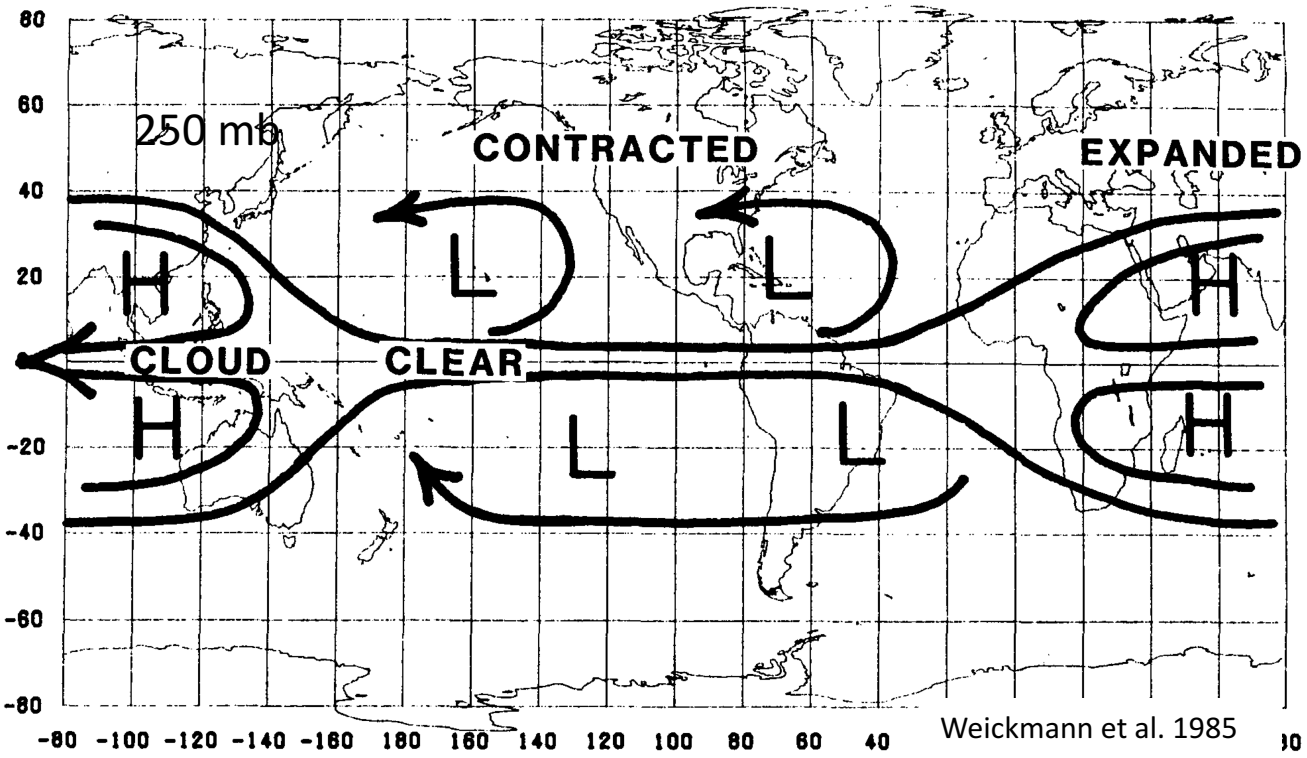
J. Bjerknes, 1966

- Large positive SST anomalies in the eastern Equatorial Pacific strengthen the zonal winds in the Northern Hemisphere winter.
- "A close watch of the temperature anomalies arising over the eastern tropical Pacific is likely to play an important part on the future ***seasonal forecasting*** of climatic anomalies, over North America and over Europe."



Observations – Establishment of teleconnections

Weickmann 1983; Weickmann et al. 1985; Lau and Phillips 1986; Knutson and Weickmann 1987



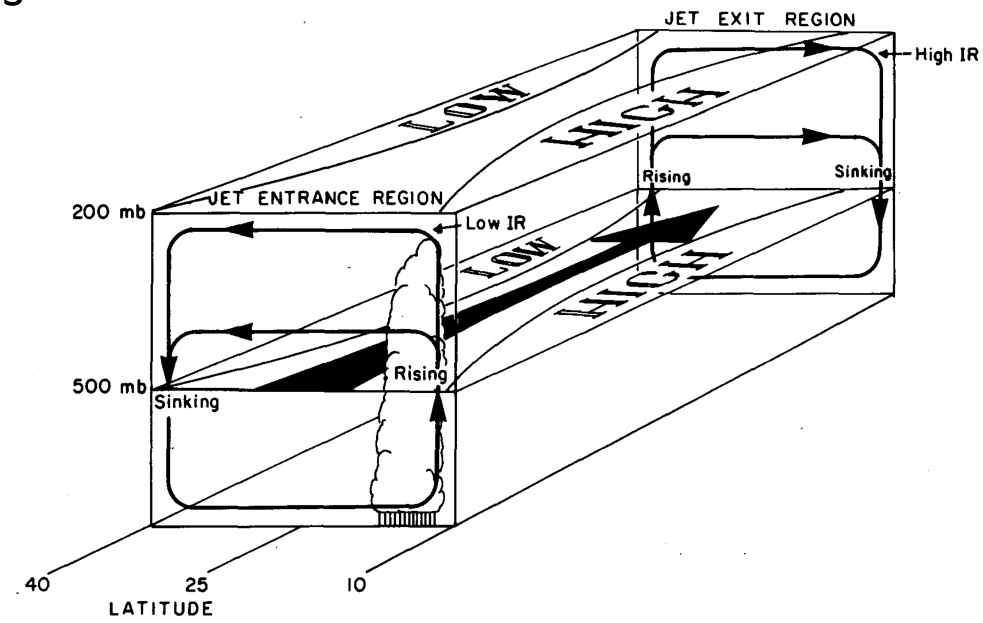
Weickmann et al. 1985

Observations – Explaining the observed teleconnections

Liebmann and Hartmann, 1984

- Region of winter monsoon rainfall over the far western Pacific is forcing the midlatitude flow

- No relationship between regions of equatorial cloudiness and circulation anomalies over North American and Atlantic regions



Observations

Question

1. What are the geographical regions where tropical forcing is most effective in exciting extratropical circulation anomalies?

Observations – Reanalysis Era

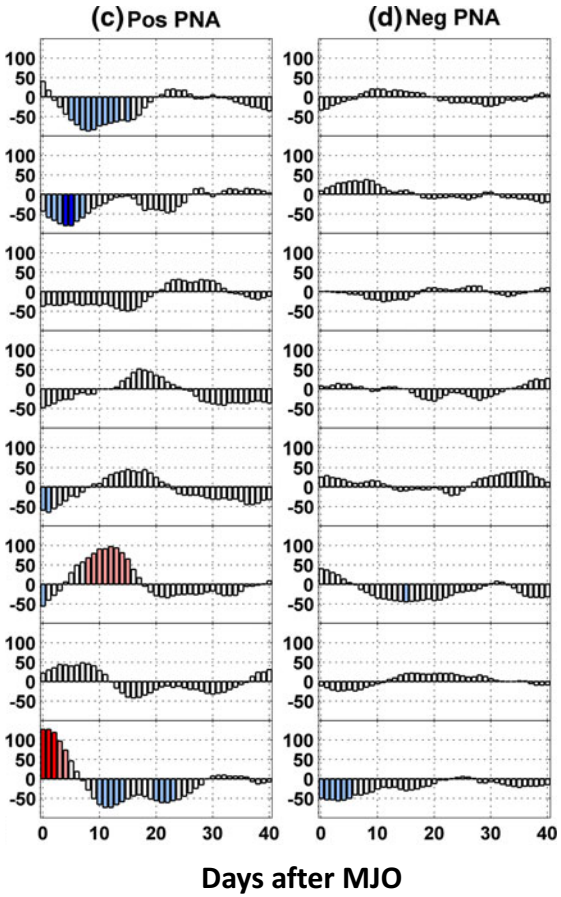
Ferranti et al. 1990; Gill and Mo 1991a,b; Higgins and Mo 1997; Mathews and Kiladis 1999;

- Variability of the climate patterns of midlatitudes, such as NAO and PNA is linked to the convective activity in the tropics
- In the Northern Hemisphere, there are two modes of oscillation with periods of about 48 and 23 days
- North Pacific circulation anomalies develop 1-2 weeks after the appearance of anomalous convection over the tropical Pacific

MJO as a forcing of midlatitude teleconnections

Mori and Watanabe 2008; Lin et al. 2009; Riddle et al. 2013

- Phase locking between PNA and MJO; convective activity associate with the MJO initiation explains 30% of PNA variability
- MJO may not excite a pure PNA pattern, but rather a PNA-like response



Riddle et al., 2013

MJO as a forcing of midlatitude teleconnections

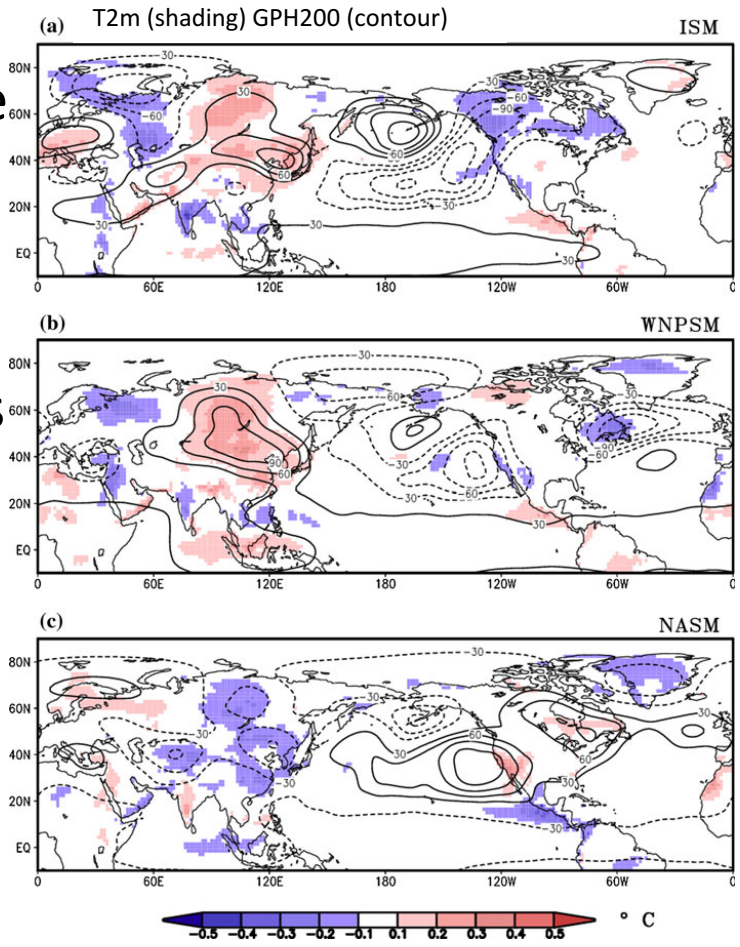
Cassou 2008; **Deng and Jiang 2011**; **Lee and Lim 2012; Grise et al. 2013**; **Frederiksen and Lin 2013**; **Lin 2014; Yadav and Straus, 2016.**

- NAO is influenced by tropical convection when MJO is in either phase 2-4 (Indian Ocean-Maritime Continent) or 6-8 (Western Pacific)
- The activity of North Pacific storm track during winter is modulated by the tropical convection associated with MJO variability
- The winter SAT over North America is characterized by a 70-day oscillation forced by MJO
- MJO phase speed affects the midlatitude teleconnection patterns

Boreal Summer

Moon et al. 2013

- During the active phase of ISM, WNPSM, and NASM extratropical circulation and surface temperature anomalies develop.
- BSISO teleconnections show both quasi-stationary and eastward propagation characteristics

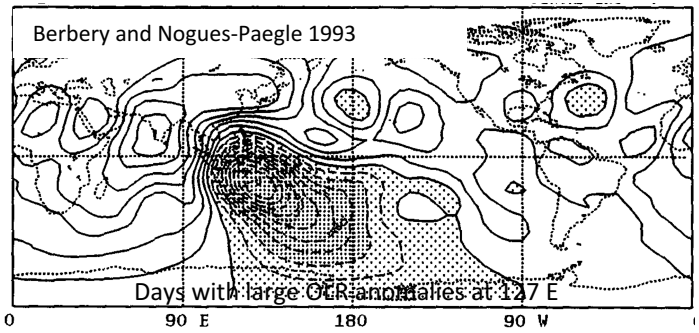


Observations

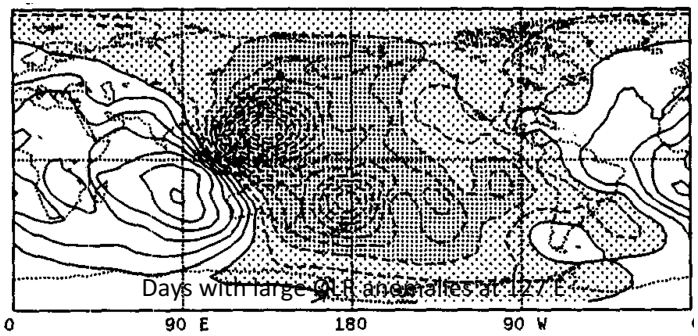
Nogues-Paegle and Mo 1988; Gil and Mo 1991; Berbery and Nogues-Paegle 1993; Hsu 1996

- No significant correlation between the Southern Hemisphere circulation and tropical heating
- The impact of tropical heating on midlatitudes has a seasonal dependence

SH Summer



SH Winter

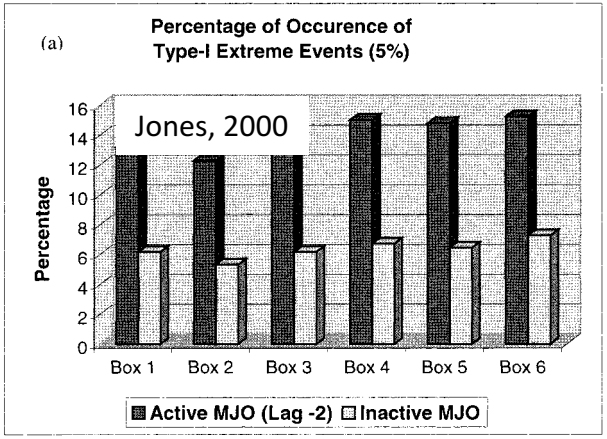


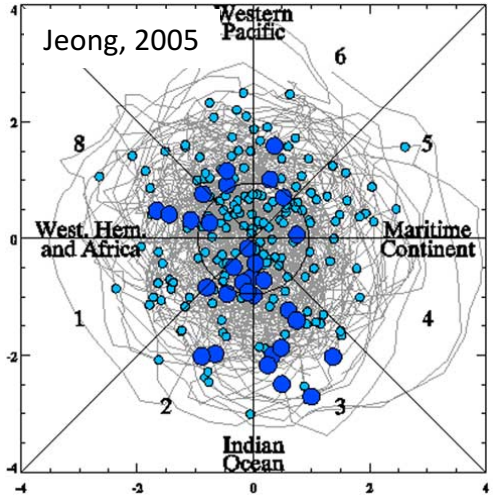
200 hPa Velocity Potential

Midlatitude Extreme Weather

Mo and Higgins 1998; Jones 2000; Bond and Vecchi 2003; Jeong 2005; He et al. 2011; Zhou et al. 2012

- Winter extreme precipitation events over U.S. West Coast and below-average SAT are favored by MJO in phase 2
- Extreme cold surges in the surface air temperature over east Asia are favored by MJO convective activity located over the Indian Ocean

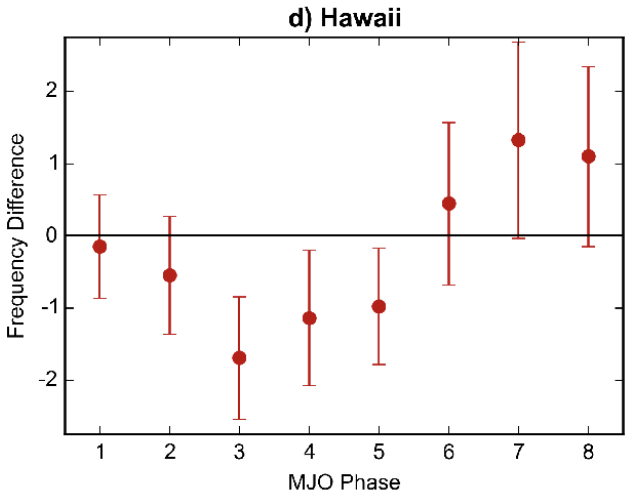




Atmospheric Rivers

Ralph et al., 2011; Guan et al. 2012, 2013; Zhang, 2013; Payne and Magnusdottir, 2014; Guan and Waliser, 2015; Mundhenk et al. 2016;

- A coherent relationship has been demonstrated among the MJO, associated Rossby waves , and atmospheric rivers associated with U.S. West Coast flooding
- MJO in phase 6, when convection is located in the west Pacific favor the development of AR
- MJO modulates AR activity in Korea and Japan, Alaska, Europe and in Southern Hemisphere



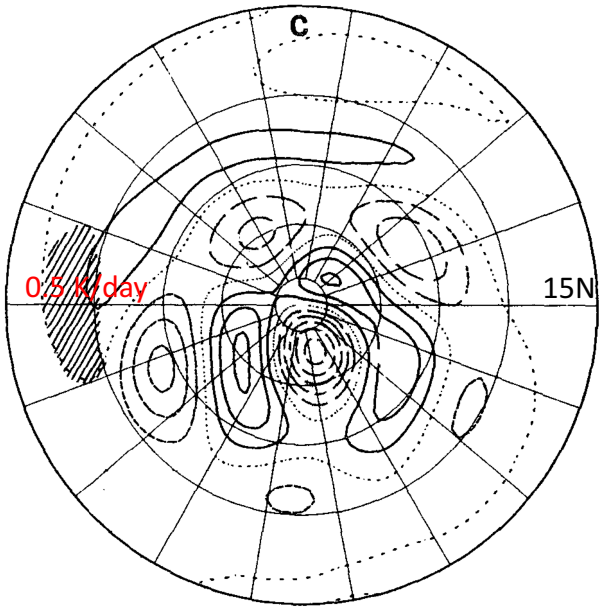
Mundhenk, Barnes, Maloney (2016)

Modeling Studies – Early Days

Opsteegh and Van den Dool 1980; Hoskins and Karoly 1981; Webster 1981

- Linear steady state models with prescribed or numerical schemes for atmospheric heating
- In the upper troposphere, the tropical heating source generates a train of Rossby waves propagating poleward and eastward

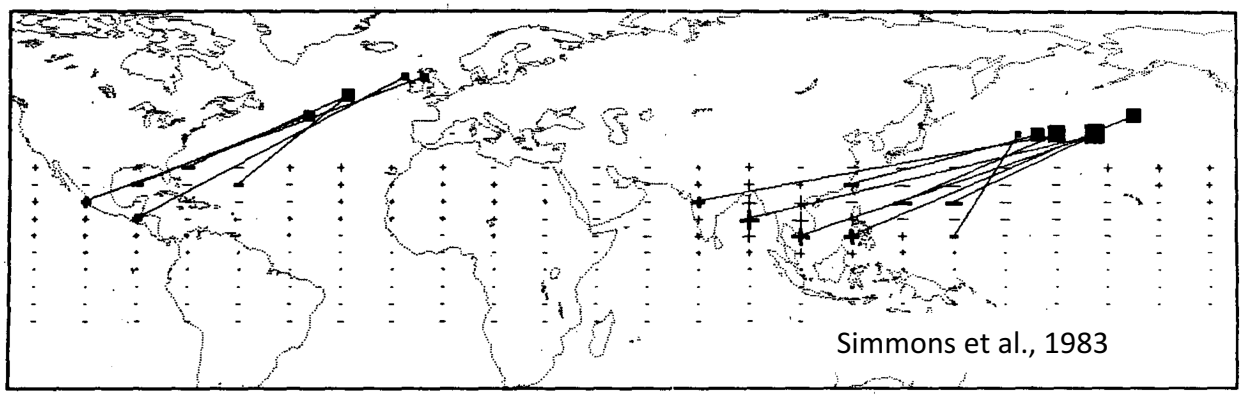
300-hPa Height



Hoskins and Karoly, 1981

Modeling Studies – Non-divergent Baroclinic Models

Simmons et al. 1983; Branstator 1985



- Perturbations over the northeastern Pacific are *excited* by tropical forcing located over Southeast Asia and tropical western Pacific

- The Atlantic perturbations are *excited* by the tropical forcing located to the southwest

Modeling Studies

Sardeshmukh and Hoskins 1988;

- The midlatitude perturbations are associated with the fast growing mode of barotropic instability of the midlatitudes excited by the Rossby wave trains
- The atmospheric anomalies in the extratropics have an equivalent barotropic structure
- The variability of the midlatitude large-scale flow due to tropical forcing is dominated by a 28-72 day oscillation

Modeling Studies

Question

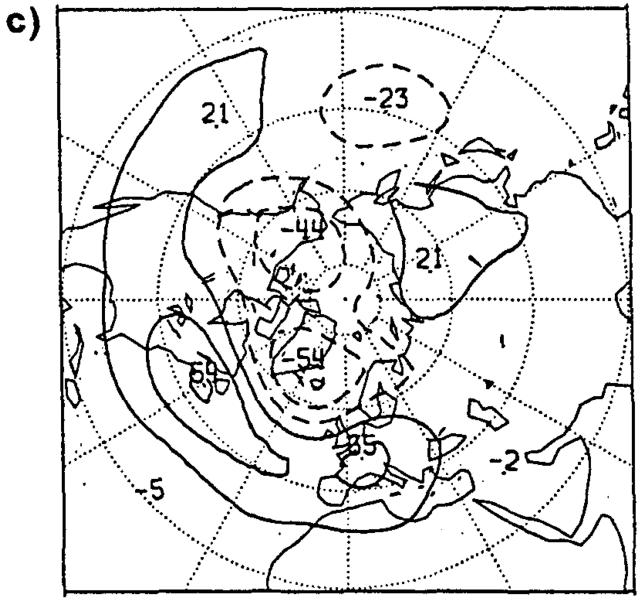
2. How and why do the baroclinic atmospheric anomalies in the tropics transition to barotropic anomalies by the time they reach the extratropics?

Modeling Studies -

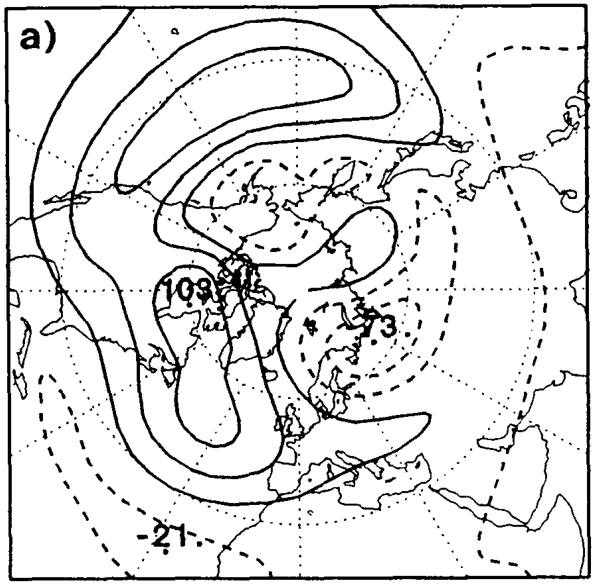
Ferranti et al. 1990

$$F(\mathbf{x},t) = \frac{\| F \|}{\| E_1^* \|} E_1^*(\mathbf{x}) \exp(i\omega_1 t)$$

Observations



Barotropic model



500 hPa Geopotential Height

Modeling Studies – GCMs Era

Schubert and Park, 1991

- Global initialized analyses (ECMWF)

- PNA appears to have its main energy source in midlatitudes, and the link to the tropics manifests as a phase locking with anomalies forced by tropical convection located in the western and central Pacific

Modeling Studies - Sensitivity type experiments

Jin and Hoskins 1995;

- Propagation of Rossby waves train is sensitive to the zonally varying basic state, with preferred paths in regions with prevailing westerlies
- The response of the Northern Hemisphere to tropical heating is much stronger than in the Southern Hemisphere
- The Rossby wave response to a fixed tropical heating establishes in 10-15 days

Modeling Studies

Lin et al. 2007

- Primitive equation dry atmospheric model can simulate tropical intraseasonal variability with a Kelvin wave structure; The divergent flow in the tropical western Pacific generates wave activity into the PNA region

- *Hayashi and Suni, 1986: "No moist processes result in the abrupt disintegration of the 30 day oscillation into Kelvin and Rossby waves.* ***Strong mode coupling between the equatorial free waves is required to maintain the 30-day oscillation***

Modeling Studies – GCMs' biases

Higgins and Schubert 1996; **Hsu 1996**;

- GCM simulations tend to reproduce the observed relationships between tropical anomalous convection and midlatitude circulation anomalies during boreal winter

- GCM simulations also show differences from observation, resulting especially from the model inability to reproduce the observed location of the tropical heating anomalies

Modeling Studies – Intervention Experiments

Blade and Hartmann 1995; **Mathews et al. 2004**; **Branstator 2014**; **Straus et al. 2015**

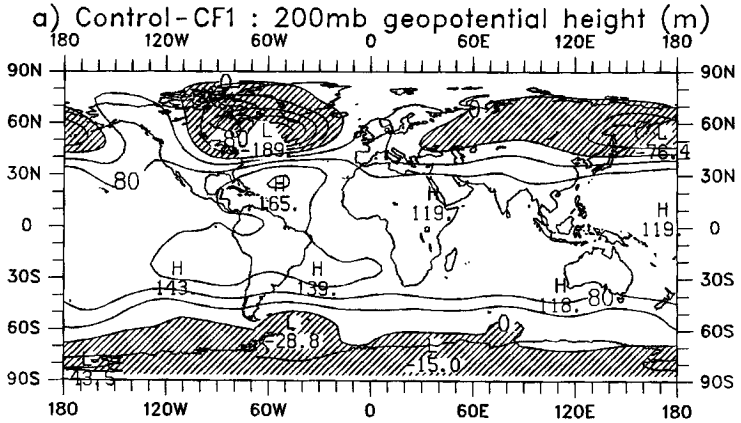
- Extratropical response is sensitive to the phase speed of the forcing
- The tropical convection outflow anomalies lead to Rossby waves, which then interact with the midlatitude mean flow and in preferred locations extract energy from the mean flow, in a manner similar to that of unstable barotropic modes.
- The midlatitude response to the MJO depends on the history of heating and cooling and is not just a response to heating at some longitude with some lag.
- Short pulses of tropical heating also affect the midlatitudes and the effect persists for more than two weeks.

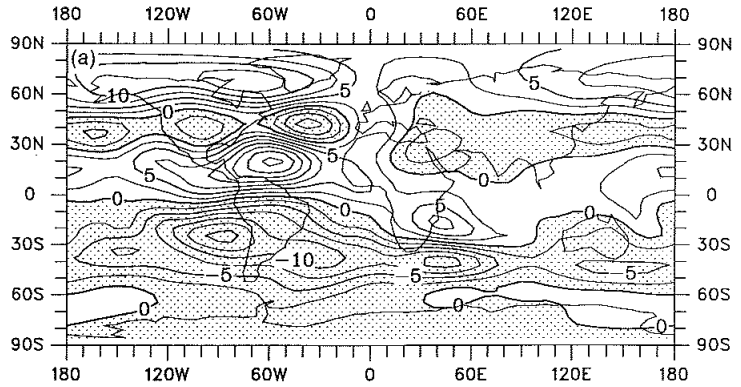
Modeling Studies – Another Perspective

Slingo and Slingo 1988, 1991

- Longwave cloud radiative forcing in the Tropics accelerates the sub-tropical jets and generates height perturbations in midlatitudes with a barotropic structure.

- The longwave cloud forcing over South America induces barotropic cyclonic circulation in the midlatitudes and anticyclonic structures in the polar regions of the NH.

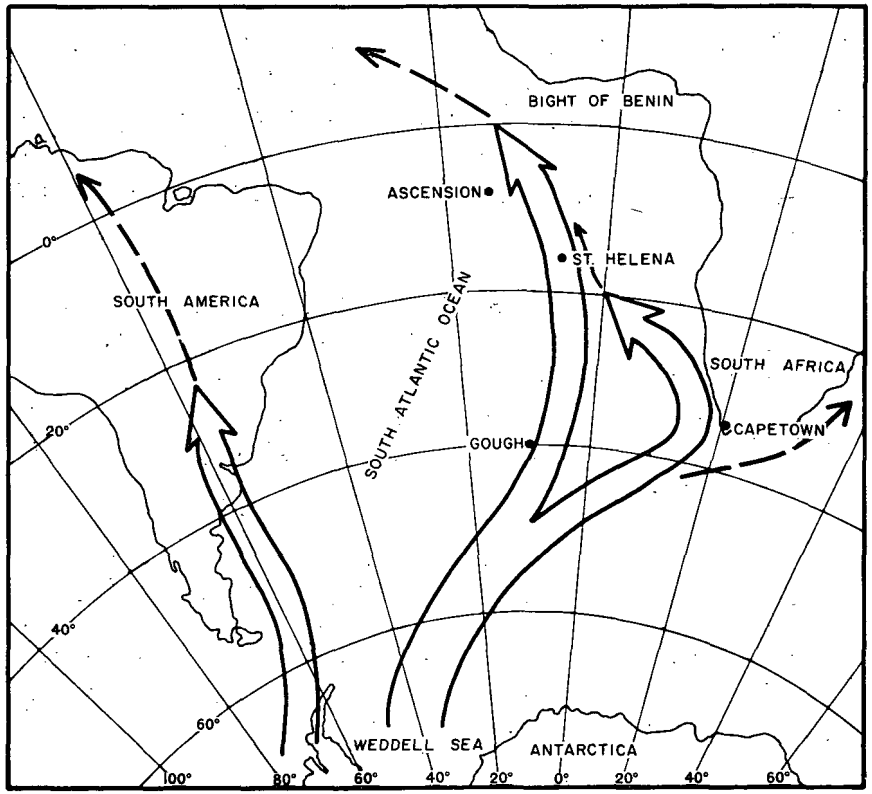




200-mb streamfunction. CLAF applied everywhere
Minus CLAF applied everywhere except South America.

Observations – Early Days

- Original motivation: the need to explain the energy source for the observed tropical waves
- Formation of hurricanes in the eastern North Atlantic linked to the northward surge of Antarctic anticyclone over the South Atlantic.



The most frequent tracks of Antarctic air into the tropical South Atlantic. Morgan, 1965.

Observations

Nitta 1970; **Zangvil and Yanay 1980**; **Yanai and Lu 1983; Libmann and Hartmann 1984**; **Randel 1992**;

- Only extratropical waves with westward phase speeds larger than the zonal mean wind can propagate into the tropics
- Equatorial upper tropospheric waves are excited by meridional propagation of extratropical waves
- The strongest influence manifests over the Pacific and Atlantic Oceans

Observations

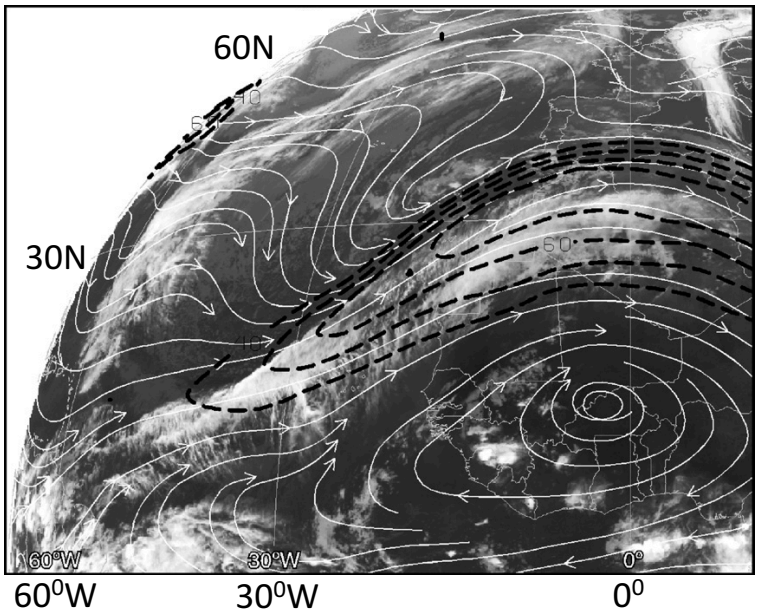
Matthews and Kiladis 1999; **Straus and Lindzen 2000**; **Lin et al. 2000**;

- Baroclinically unstable disturbances of midlatitudes modulate the tropical convection
- Midlatitude storms maintain the intra-seasonal variability of the tropics

Impact on ITCZ, SPCZ, and SACZ

De Souza et al. 2005; Castro Cunningham and De Albuquerque Cavalcanti 2006; Knippertz 2007; van der Wiel et al. 2016;

- Extratropical transient upper level troughs propagating eastward and equatorward (PV streamers) have been linked to elongated tropical cloud bands in the ITCZ, SPCZ, and SACZ
- During boreal winter a Rossby wave train dominates in the NH and during the boreal summer the Rossby wave train prevails in the SH



Knippertz 2007

Summer Monsoon Breaks

Ramaswamy 1962, 1969; *Raman and Rao* 1981; *Yasunari* 1986; Chattopadhyay et al. 1994*; Kripalani et al*. 1997; Srivastava et al. 2014; Samanta et al., 2016

- Midlatitude circulation regimes with large amplitudes favor the troughs in the westerlies to extend over India causing monsoon breaks, which can last between 3-5 days or 17-20 days

Vizy and Cook 2009, 2014; Chauvin et al. 2010; Roehring et al. 2011;

- West African monsoon experiences dry spells (2-10 days) associated with midlatitude intrusions of cold, dry air from Europe

Cold Air Surges

- **Asia Pacific region**
- **South Pacific and South America**
- **Central America and the Caribbean**
- **Africa**
- **Indian Ocean and the Maritime Continent**
- **Along the east coast of Australia**
- **North America**

Modeling

Charney 1969; Bennett and Young 1971; Webster and Holton 1982; **Zhang and Webster 1989**; **Zhang 1993**; **Frederiksen and Frederiksen 1997; Hoskins and Yang 2000**;

- Propagation in the meridional direction in the presence of mean easterly flow was only possible if the phase velocity of the midlatitude wave is more easterly than the mean flow
- Large-scale disturbances generated in the northern middle latitudes may have a significant influence on equatorial regions and the opposite hemisphere if a westerly duct is present
- The equatorial response to extratropical forcing does not rely on the presence of westerly winds, but is due to a direct projection of the forcing onto equatorially trapped waves.

The influence of the Midlatitudes on the Tropics

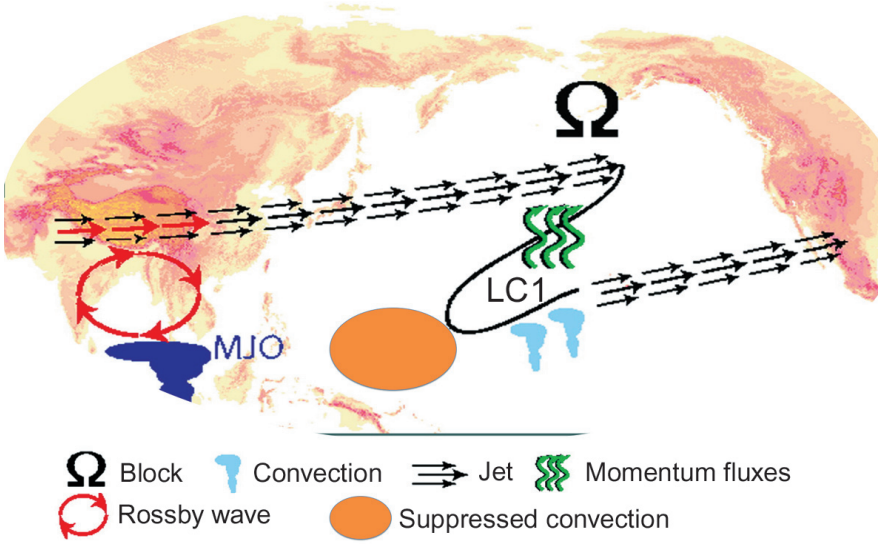
Question

3. What are the systematic aspects and mechanisms of extratropical initiation and maintenance of organized tropical convection?

Observations and Modeling

Lau and Phillips 1984; Straus and Lindzen 2000; Krishnan et al. 2009; Moore et al. 2010; Frederiksen and Lin 2013

- Rossby waves excited by MJO convective activity break in the subtropics and further modulate the convective activity in the Tropics



Roundy, 2011

- Monsoon breaks – midlatitude circulation feedbacks lead to long-lasting droughts over India

Two-way Interactions and Feedbacks

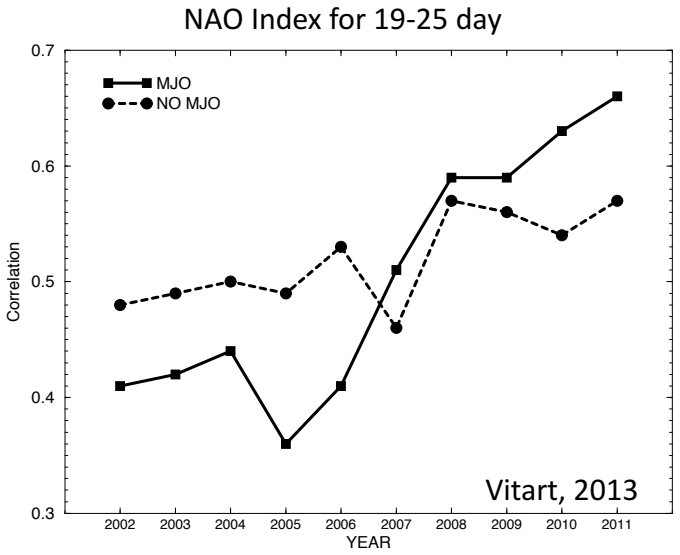
Questions

4. To what extent are the dominant tropical and extratropical intraseasonal oscillation connected?

The influence of Tropics onto Midlatitudes in Forecasts

Feranti et al. 1990; Waliser et al. 2003; Vitart and Molteni 2010; Riddle et al. 2013; Vitart 2013; Molteni et al. 2015; Vitart 2017

- Extended-range forecasts of midlatitude large-scale circulation with small errors in the simulation of tropical heating are skillful



- MJO has significant impact on the midlatitude forecast especially for days 19-25

Remaining Challenges

- *Can we understand midlatitude teleconnections from the fluctuating tropical heating as time-lagged stationary wave responses to the heating, or does time-dependent wave interface play a role in the response?*
- *How do intense midlatitude storms and poleward propagating tropical storms interact with the polar vortex and alter the annular modes on sub-seasonal time scales?*
- *To what extent are the dominant tropical and extratropical intraseasonal oscillation connected?*
  - *What aspects of intra-seasonal heating arising from tropical convection are most important for forcing extra-tropical responses?*

Remaining Challenges

- *What is the sensitivity to vertical and horizontal structure and to temporal evolution of the heating, and why?*
- *Does tropical forcing amplify the intrinsic extratropical intraseasonal variability or excite new perturbations?*
- *What explains the hemispheric asymmetry of the responses to tropical forcing?*
- *Role of the basic state errors in simulation of tropical-midlatitude interactions*