Interaction of physical and dynamical processes in atmospheric teleconnections

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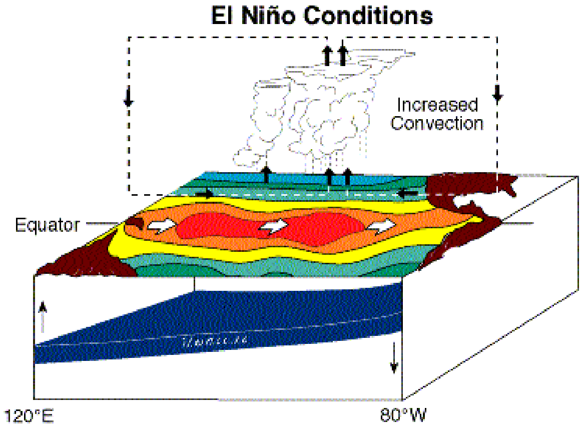
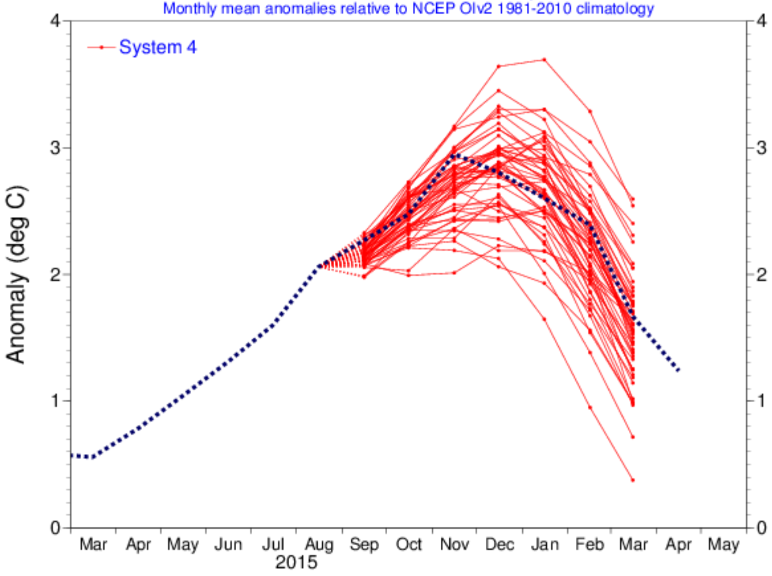
ECMWF System 4 forecast for DJF 2015/16



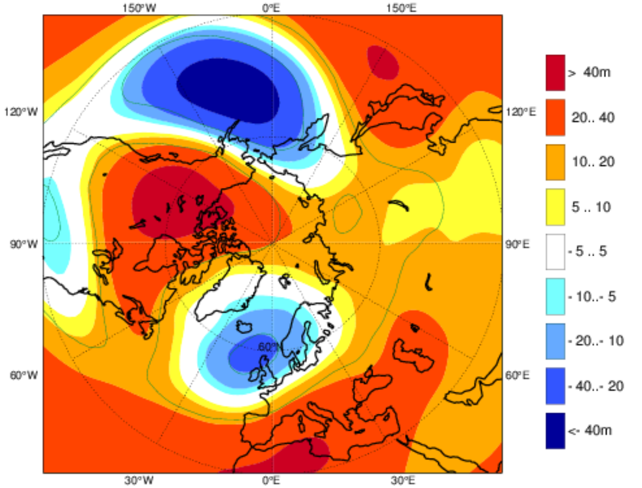
NINO3.4 SST anomaly plume
ECMWF forecast from 1 Sep 2015
Monthly mean anomalies relative to NCEP OIv2 1981-2010 climatology



IC: 1 Sep 2015

ECMWF Seasonal Forecast
Mean Z500 anomaly
Forecast start reference is 01/09/15
Ensemble size = 51, climate size = 450

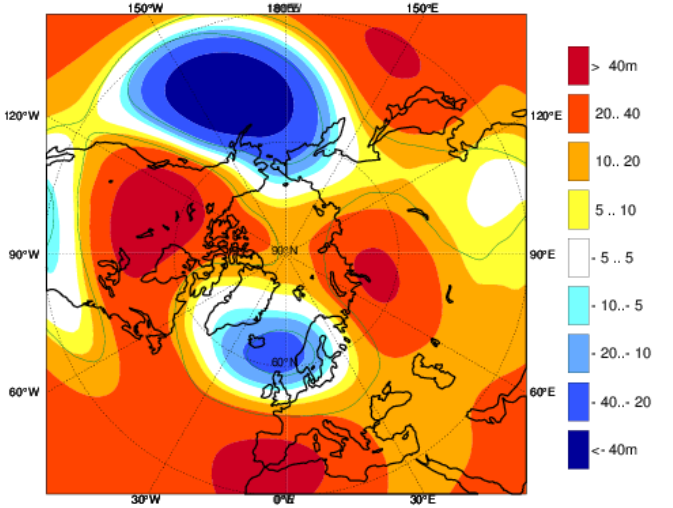
System 4
DJF 2015/16
Solid contour at 1% significance level

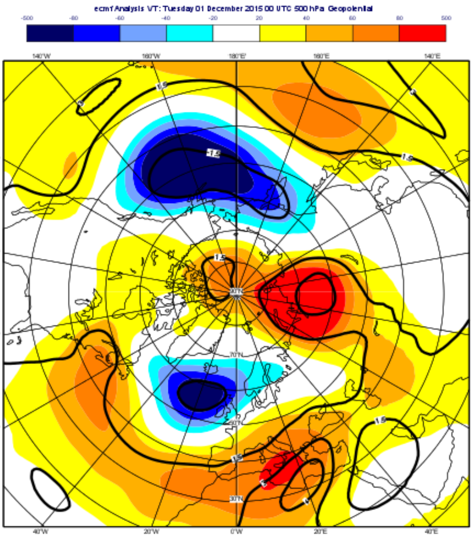


IC: 1 Nov 2015

ECMWF Seasonal Forecast
Mean Z500 anomaly
Forecast start reference is 01/11/15
Ensemble size = 51, climate size = 450

System 4
DJF 2015/16
Solid contour at 1% significance level





ERA Interim

Foundations: Wallace and Gutzler 1981

The Pacific / North American (PNA) pattern: correlations

APRIL 1981 JOHN M. WALLACE AND DAVID S. GUTZLER 799

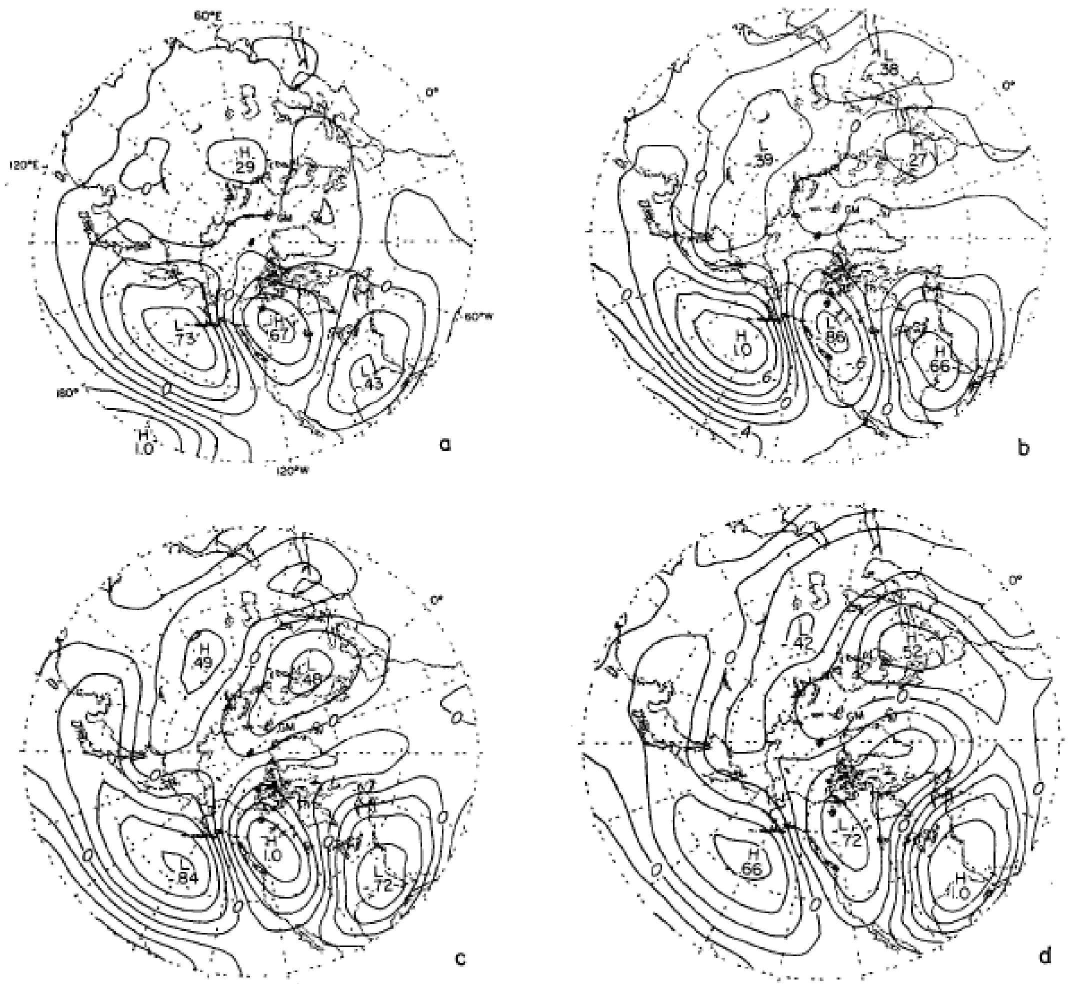
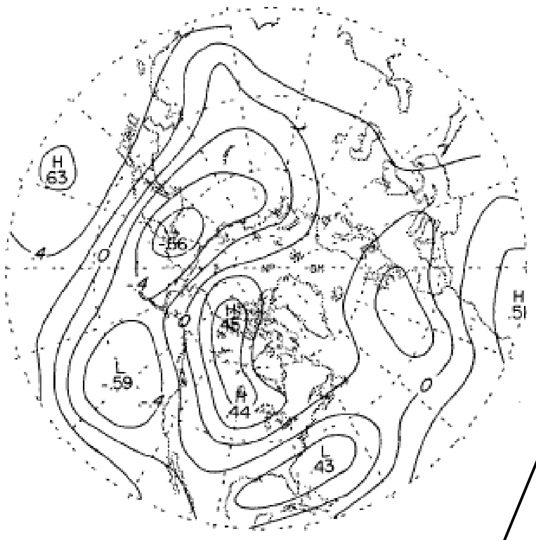


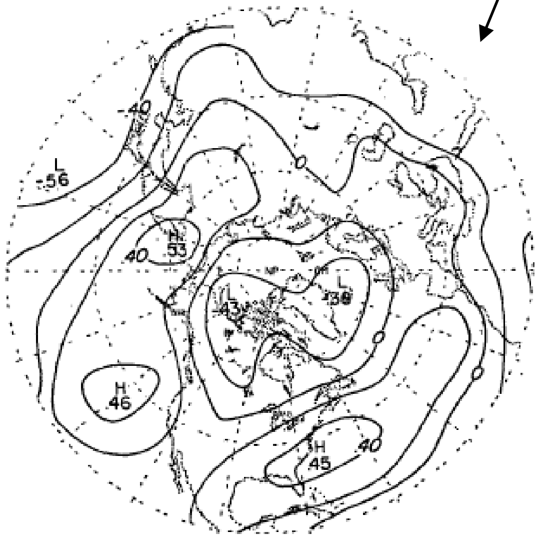
FIG. 16. As in Fig. 12, but for base grid points (a) 20°N, 160°W; (b) 45°N, 165°W; (c) 55°N, 115°W; (d) 30°N, 85°W.

Foundations : Horel and Wallace 1981

Correlation of 700hPa height with
a) PC1 of Eq. Pacific SST
b) SOI index

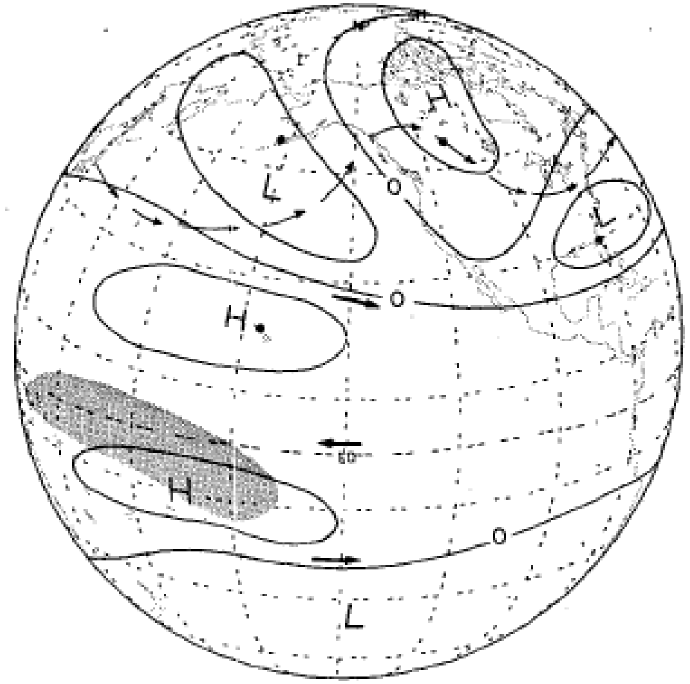


a



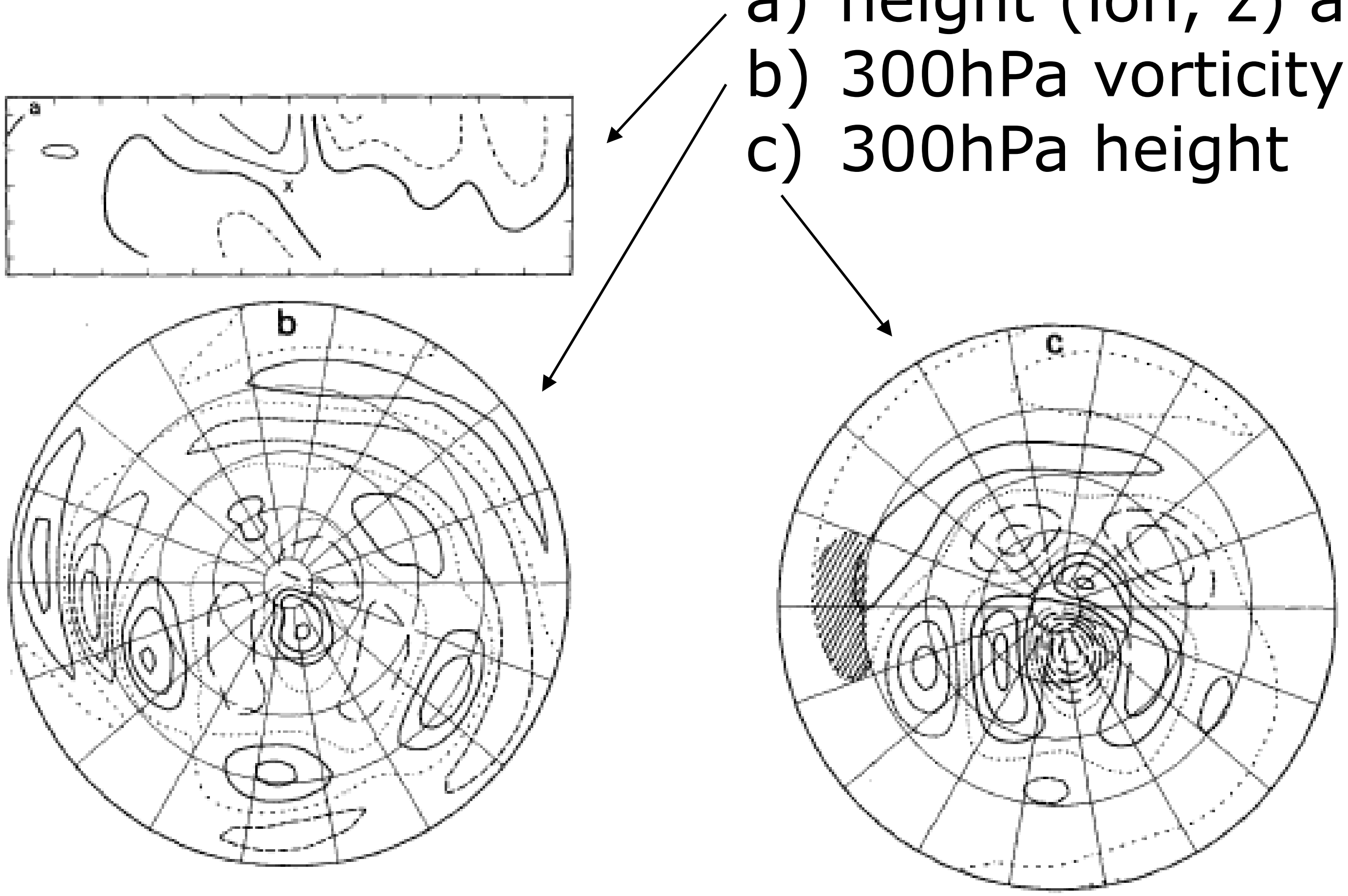
c

Schematic diagram of tropical-extratropical teleconnections during El Niño



Foundations : Hoskins and Karoly 1981

Response to a tropical heat source (15N):

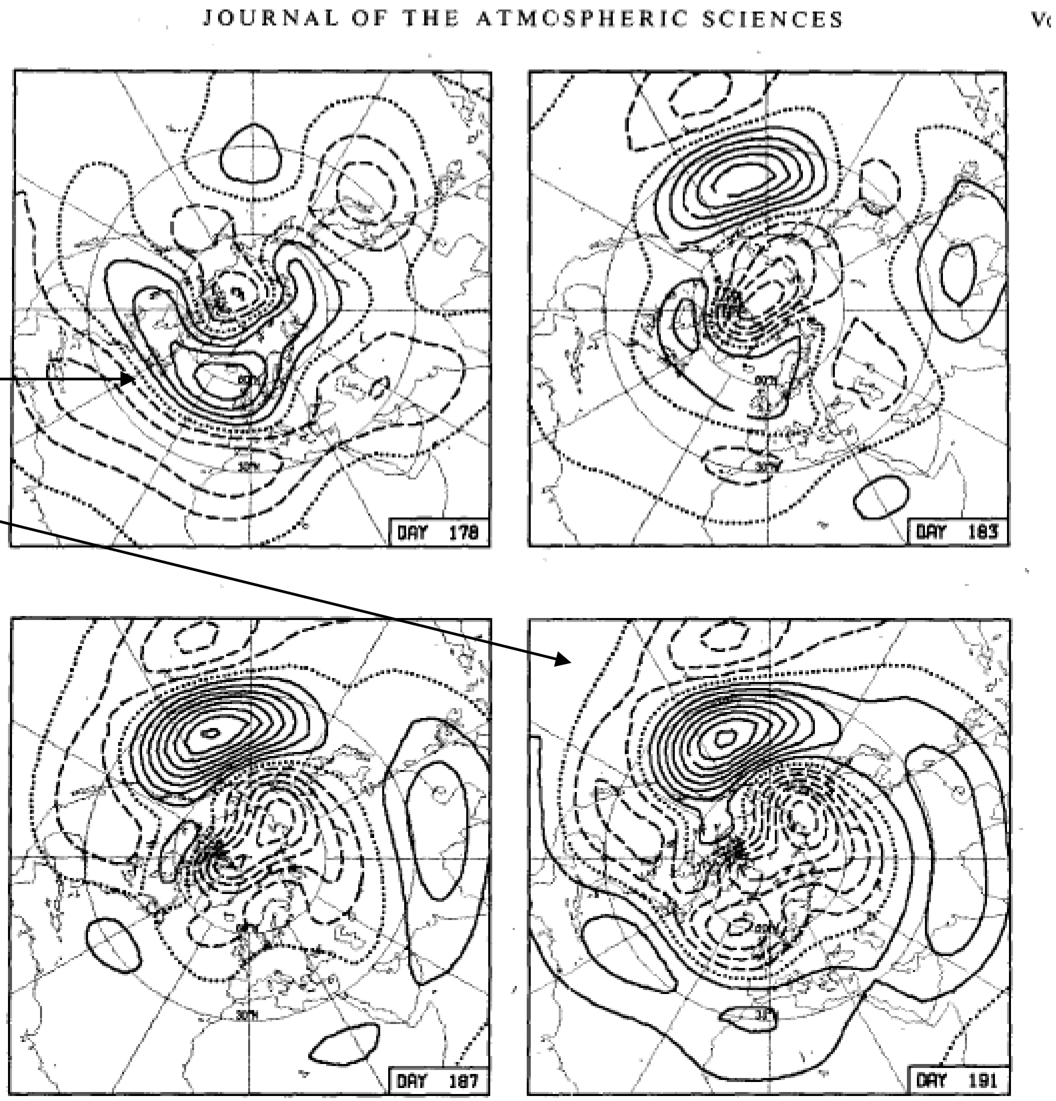


a) height (lon, z) at 18N
b) 300hPa vorticity
c) 300hPa height

Foundations : Simmons Wallace Branstator 1983

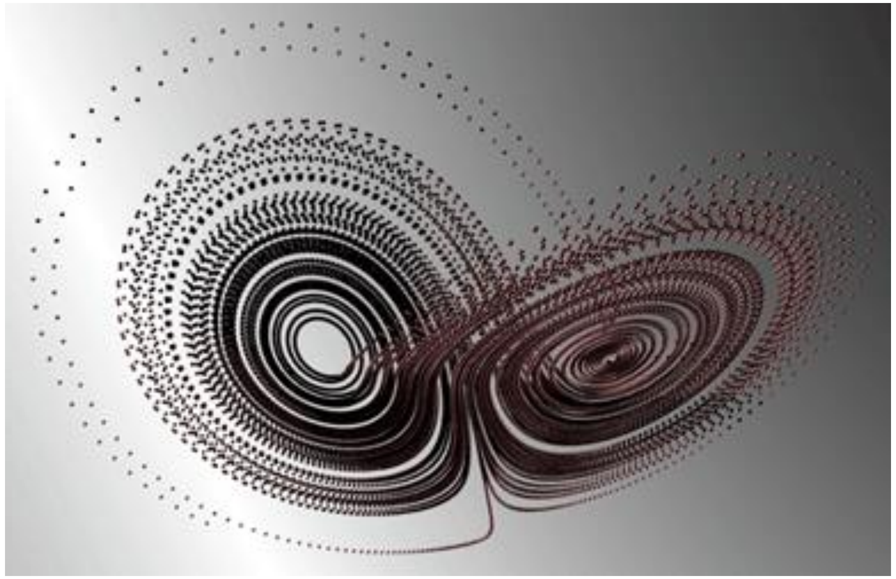
First barotropic normal mode at four times during a half-cycle:

East. Atlantic phase
PNA phase

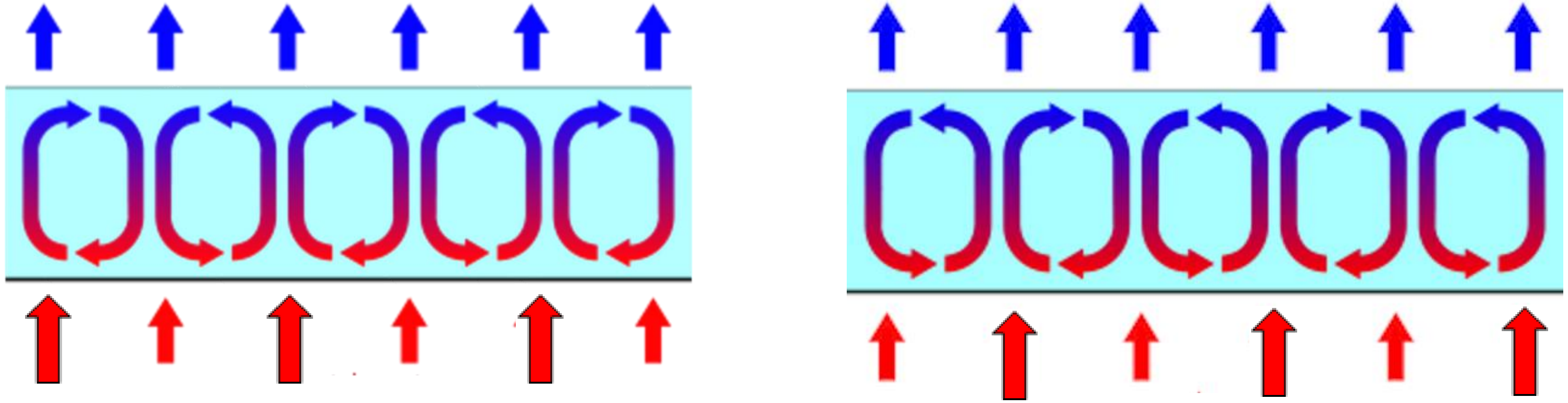


Impact of anomalous forcing on flow regime frequency

Lorenz (1963) truncated convection model with additional forcing (Molteni et al. 1993; Palmer 1993; Corti et al. 1999)



- $dX/dt = \sigma (Y - X)$
- $dY/dt = - X Z + r X - (Y - Y^*)$
- $dZ/dt = X Y - b Z$



$Y^* > 0$ $Y^* < 0$

A number of dynamical processes affect teleconnections:

- Diabatic heating anomalies are not necessarily “forced” by SST anomalies
- Anomalous heating sources do not occur in isolation; signals originated from different parts of the tropics may interfere in a constructive or destructive way
- Extratropical equilibration mechanisms are relevant to both the spatial pattern and the stability (persistence) of the extra-tropical response
- Wave propagation from the tropics to the extra-tropics may be significantly affected by interactions with the stratosphere

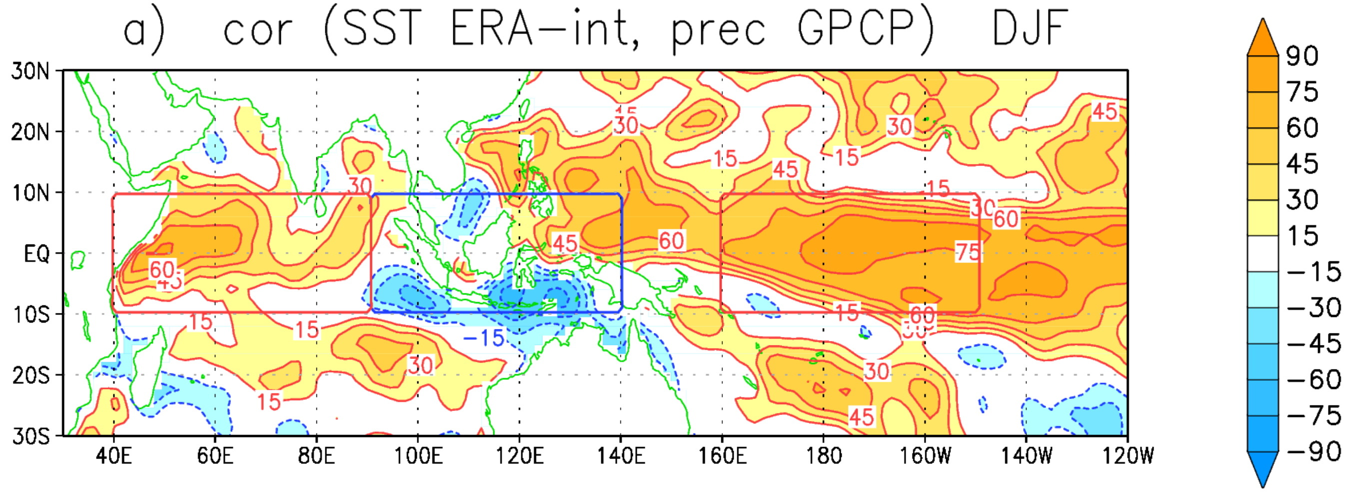
Observational and model data

- Observational data:
  - ERA-Interim re-analysis, 1979-2014
  - GPCP 2.2 monthly mean precipitation, 1979-2014

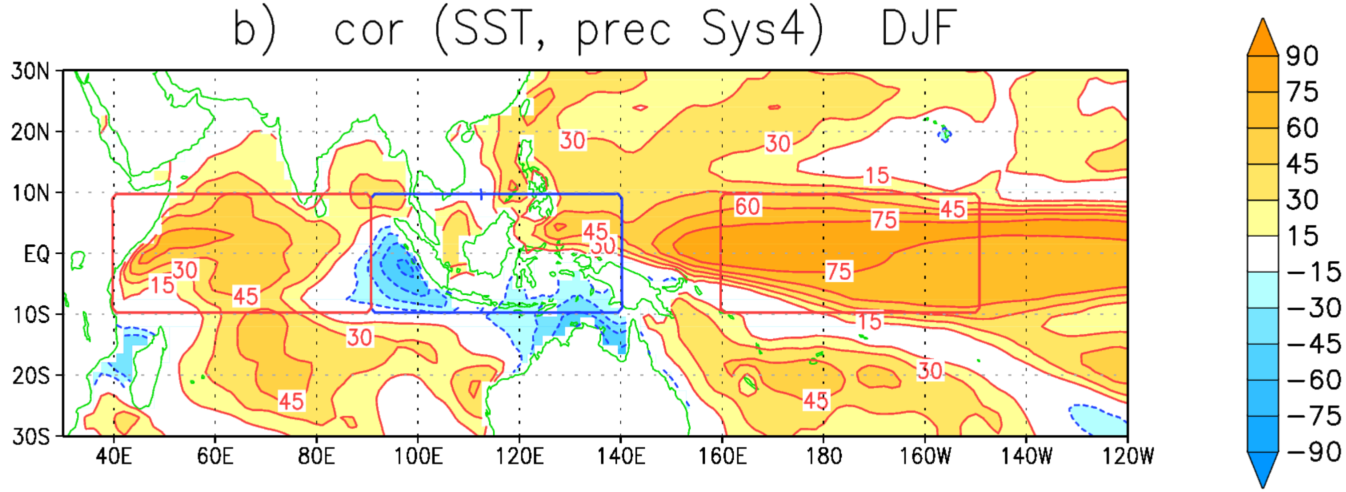
- Numerical model /simulations:
  - ECMWF System-4 re-forecasts + operational forecasts
  - 1981-2010 + 2011-2013
  - DJF season from 1 Nov. runs (fc. months 2-4)
  - 51-member ensembles

Local correlation between SST and rainfall anomalies

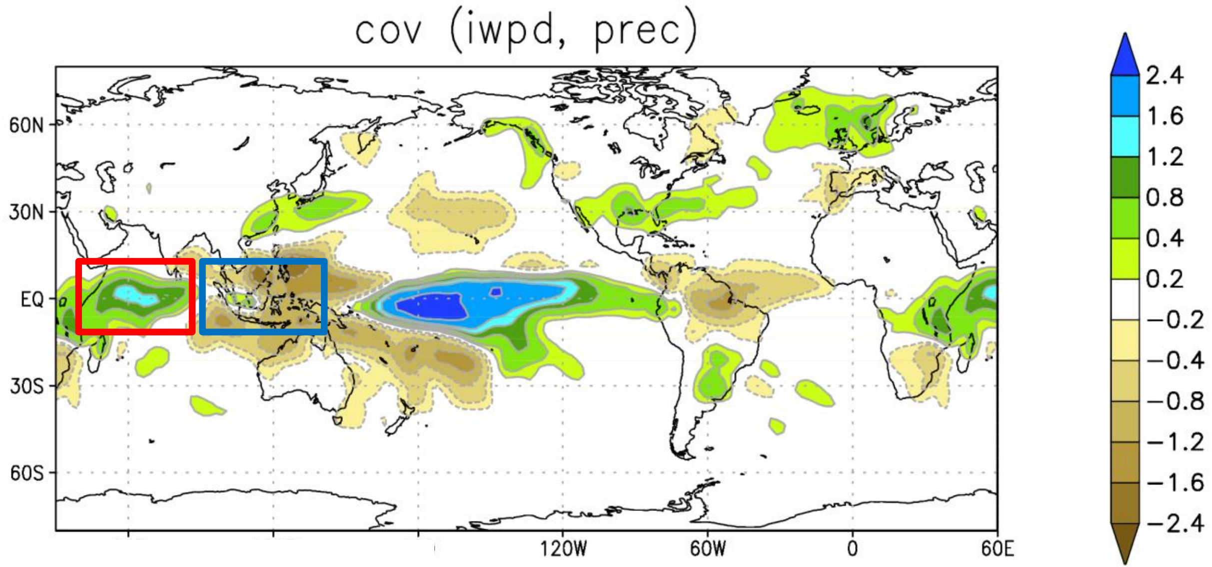
a) cor (SST ERA–int, prec GPCP) DJF



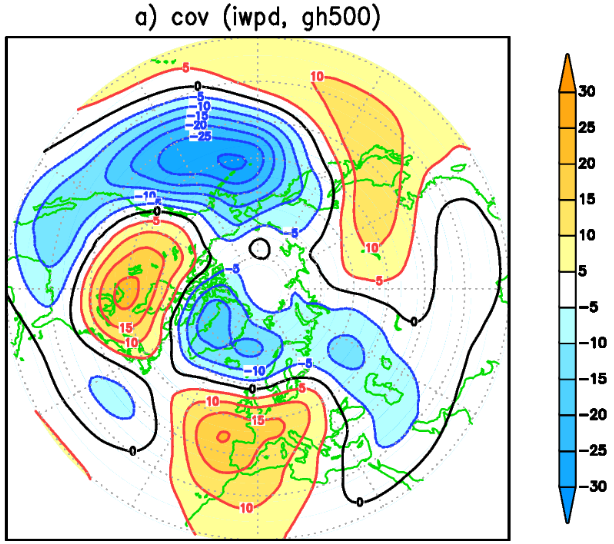
b) cor (SST, prec Sys4) DJF

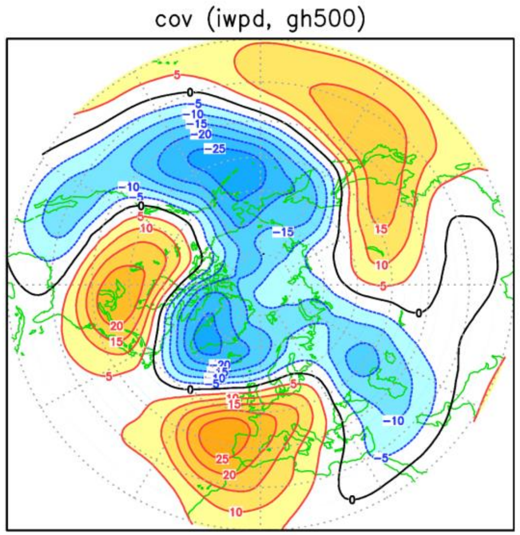


Teleconnections from Indian Ocean & West Pacific


cov (iwpd, prec)

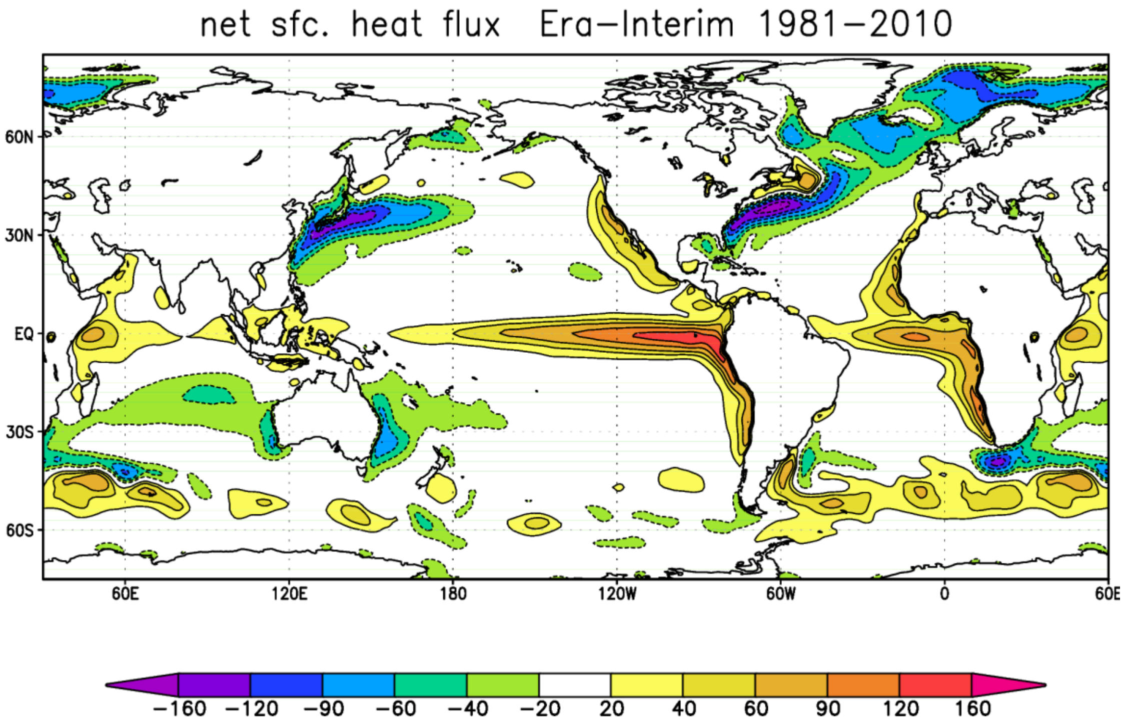
DJF

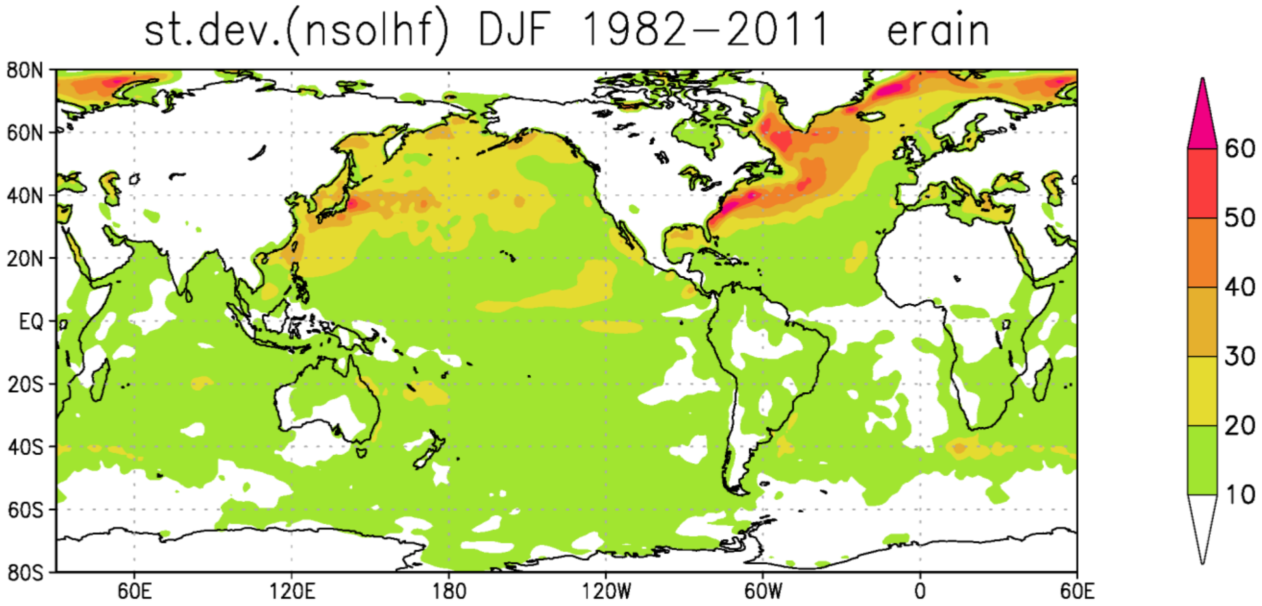

a) cov (iwpd, gh500)


cov (iwpd, gh500)

DJ

Net heat flux at ocean surface from ERA-interim



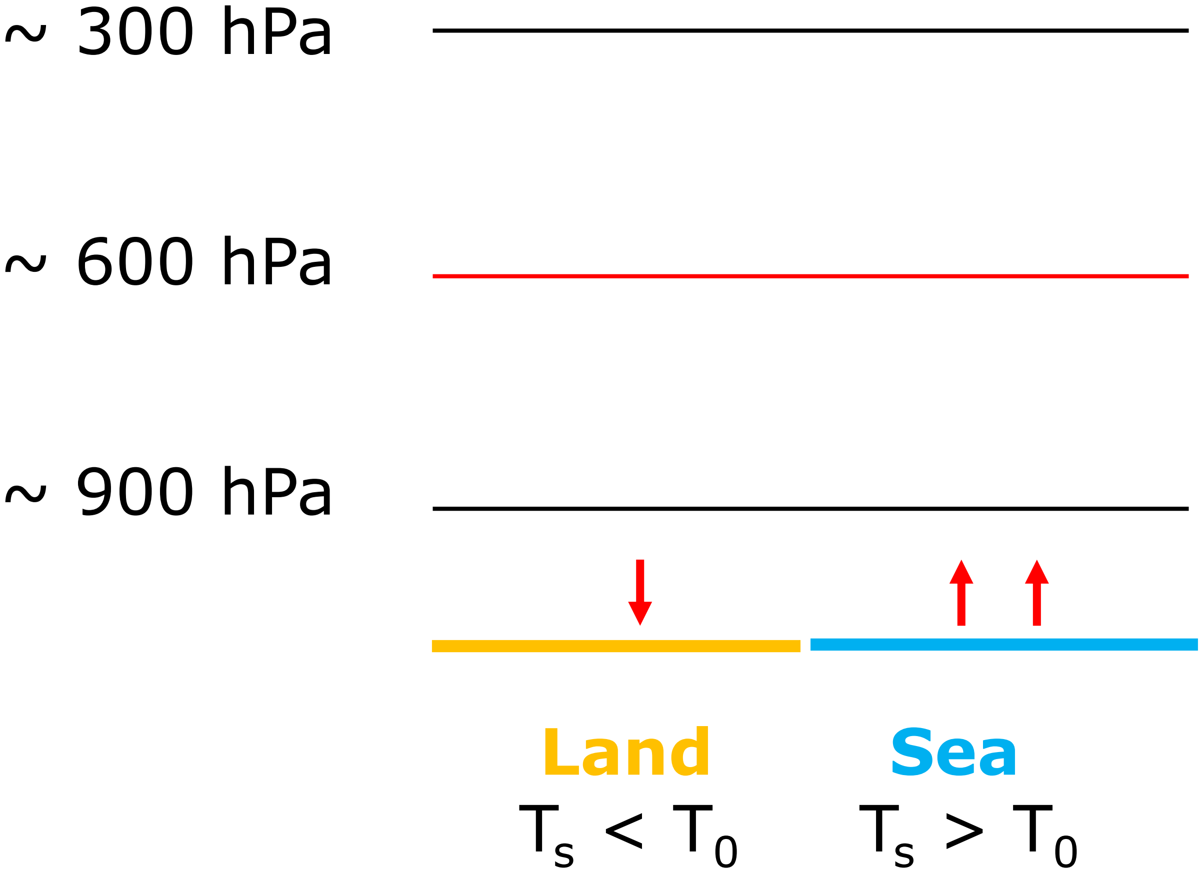


Influence of land-sea contrast on planetary wave variability

- **Thermal equilibration of planetary waves**: Variability in the phase of planetary waves with respect to the surface temperature distribution
    - Mitchell and Derome (1983)
    - Shutts (1987)
    - Marshall and So (1990)

- **The Cold Ocean Warm Land pattern**: observations and dynamics
    - Wallace, Zhang and Bajuk (1996)
    - Molteni, King, Kucharski and Straus (2011)

A QG model of thermal equilibration



$$\partial_t \zeta_2 = - \underline{\mathbf{V}}_\mathbf{2} \cdot \mathit{grad}\, (\zeta_2 + f) - f\, D_2$$

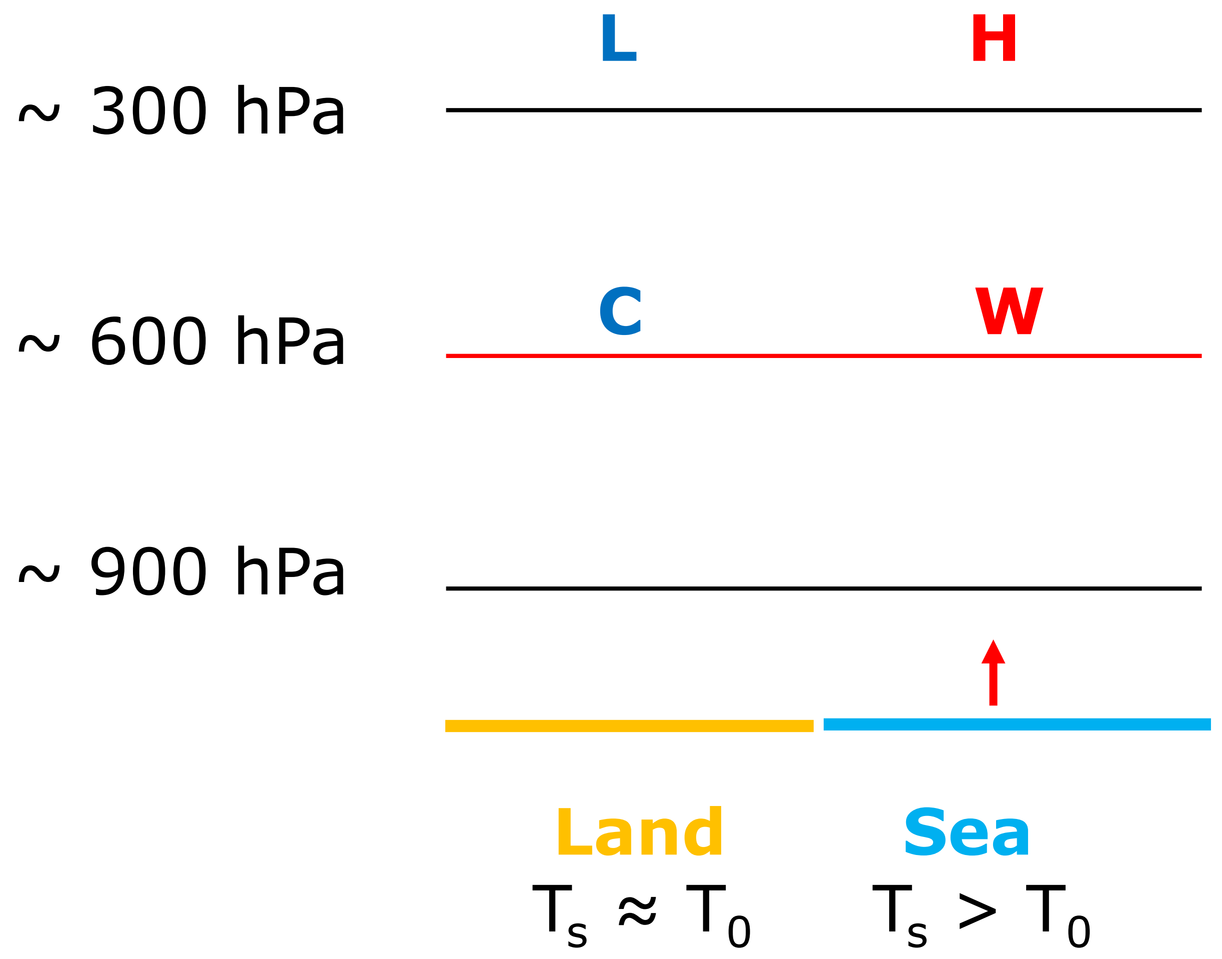
$$\partial_t T_1 = - \underline{\mathbf{V}}_\mathbf{1} \cdot \mathit{grad}\, T_1 + S\, \omega + c_p^{-1} H$$

$$\partial_t \zeta_0 \approx 0 \approx - f\, D_0 - k_{drag}\, \zeta_0$$

$$D_2 \approx -D_0 \approx - \omega / \Delta p$$

$$H = k_{rad}\, (\varepsilon\, T_s - T_1) + g\, \partial_p F_H$$

a) Thermally equilibrated solution



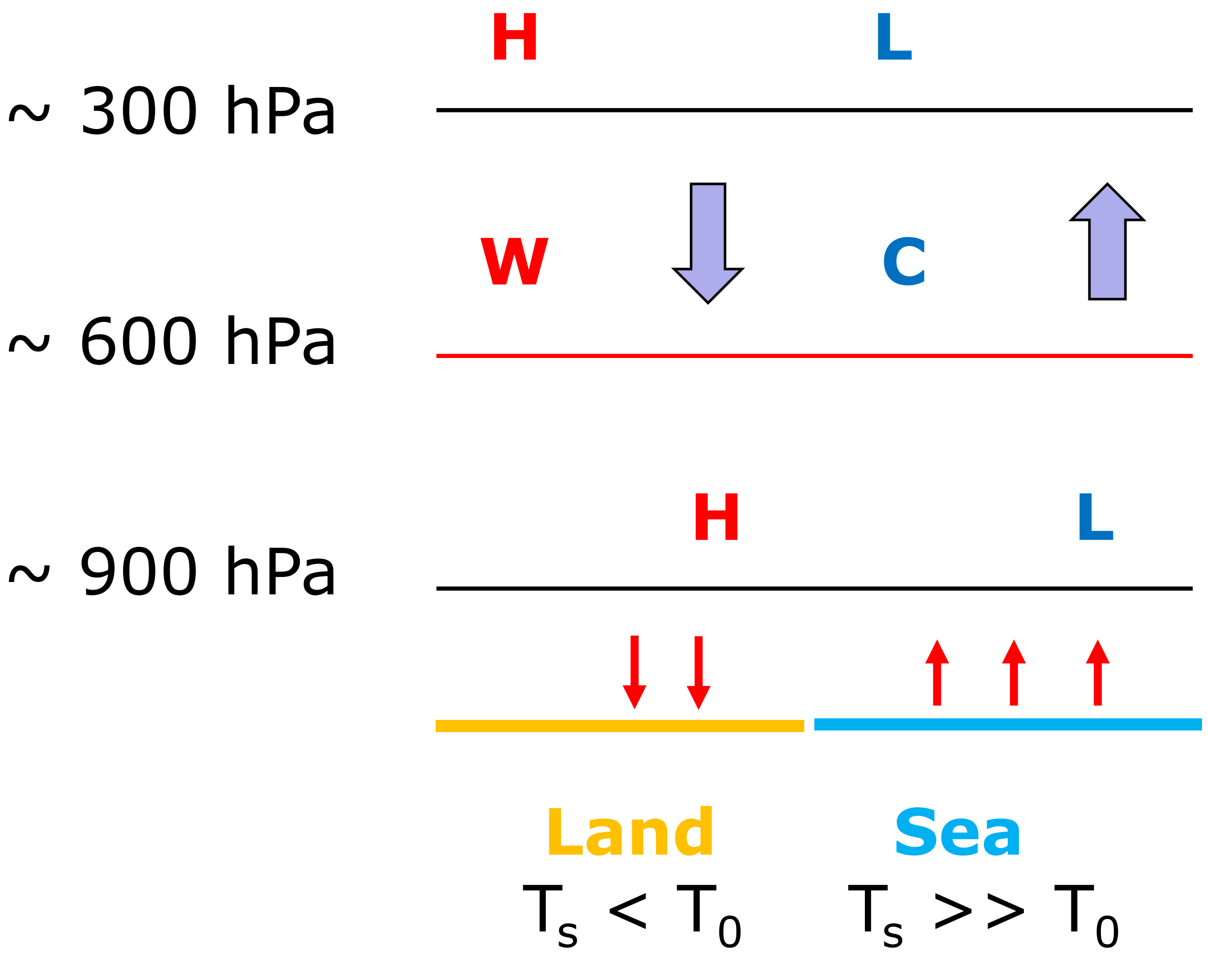
$- \underline{\mathbf{V}}_{\mathbf{2}} \cdot \mathit{grad}\,(\zeta_2 + f) \approx 0, \quad -f\,D_2 \approx 0$

$- \underline{\mathbf{V}}_{\mathbf{1}} \cdot \mathit{grad}\,T_1 + S\,\omega \approx 0, \quad c_p^{-1} H \approx 0$

$-f\,D_0 \approx 0, \quad -k_{drag}\,\zeta_0 \approx 0$

$U_2 = \beta / n^2 = \partial_y f / n^2$

b) Thermally forced solution



$$- \underline{\mathbf{V}}_{\mathbf{2}} \cdot \mathit{grad}\, (\zeta_2 + f) \approx f D_2$$

$$- \underline{\mathbf{V}}_{\mathbf{1}} \cdot \mathit{grad}\, T_1 + S\,\omega \approx - c_p^{-1} H$$

$$- f D_0 \approx k_{drag}\, \zeta_0$$

$$U_2 > \beta / n^2 = \partial_y f / n^2$$

A simple diagnostic for thermal equilibration

- **Thermal balance Wave index (TW) :**

Zonal wanenumber-2 component of net surface heat flux (NSHF, positive downward) in the 40-70 °N latitudinal band:

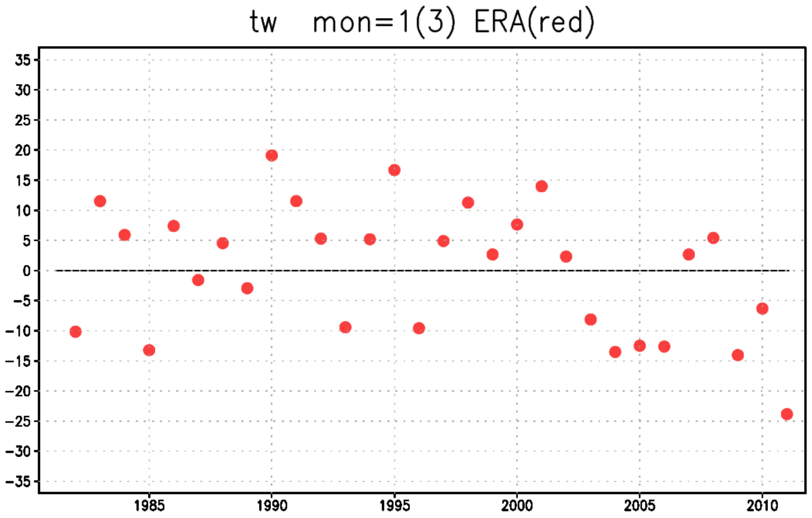
(Molteni, King, Kucharski and Straus, Clim. Dyn. 2011)

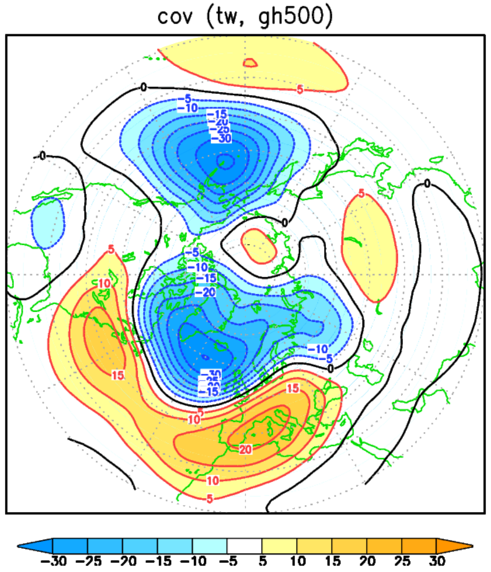
TW = 0.5 * (NSHF [30E-120E] + NSHF [150W-60W]
- NSHF [120E-150W] - NSHF [60W-30E])

TW anomalies are: positive in the forced phase (COWL pattern)
negative in the equilibrated phase

The TW index and co-varying patterns in ERA-Interim

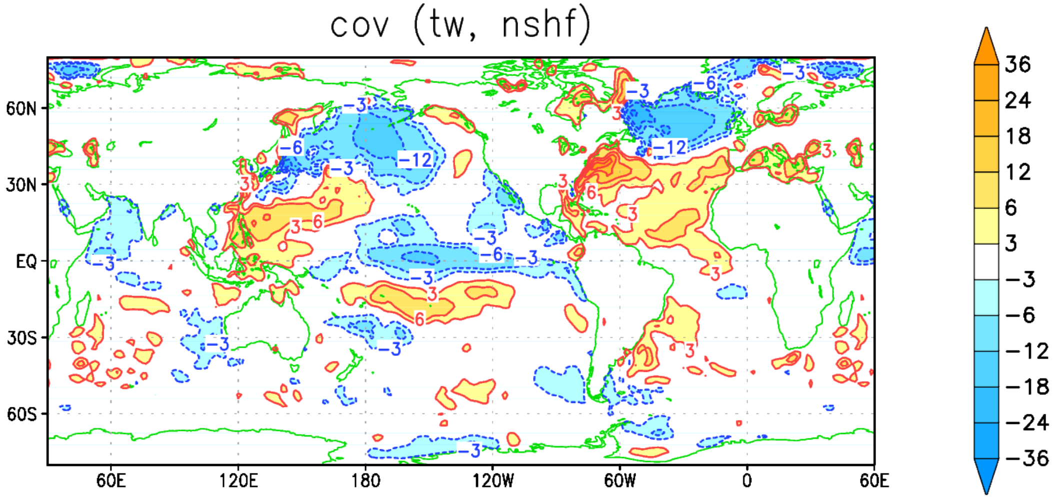
Thermally-balanced Wave index (positive in COWL phase) in DJF 1982 - 2011





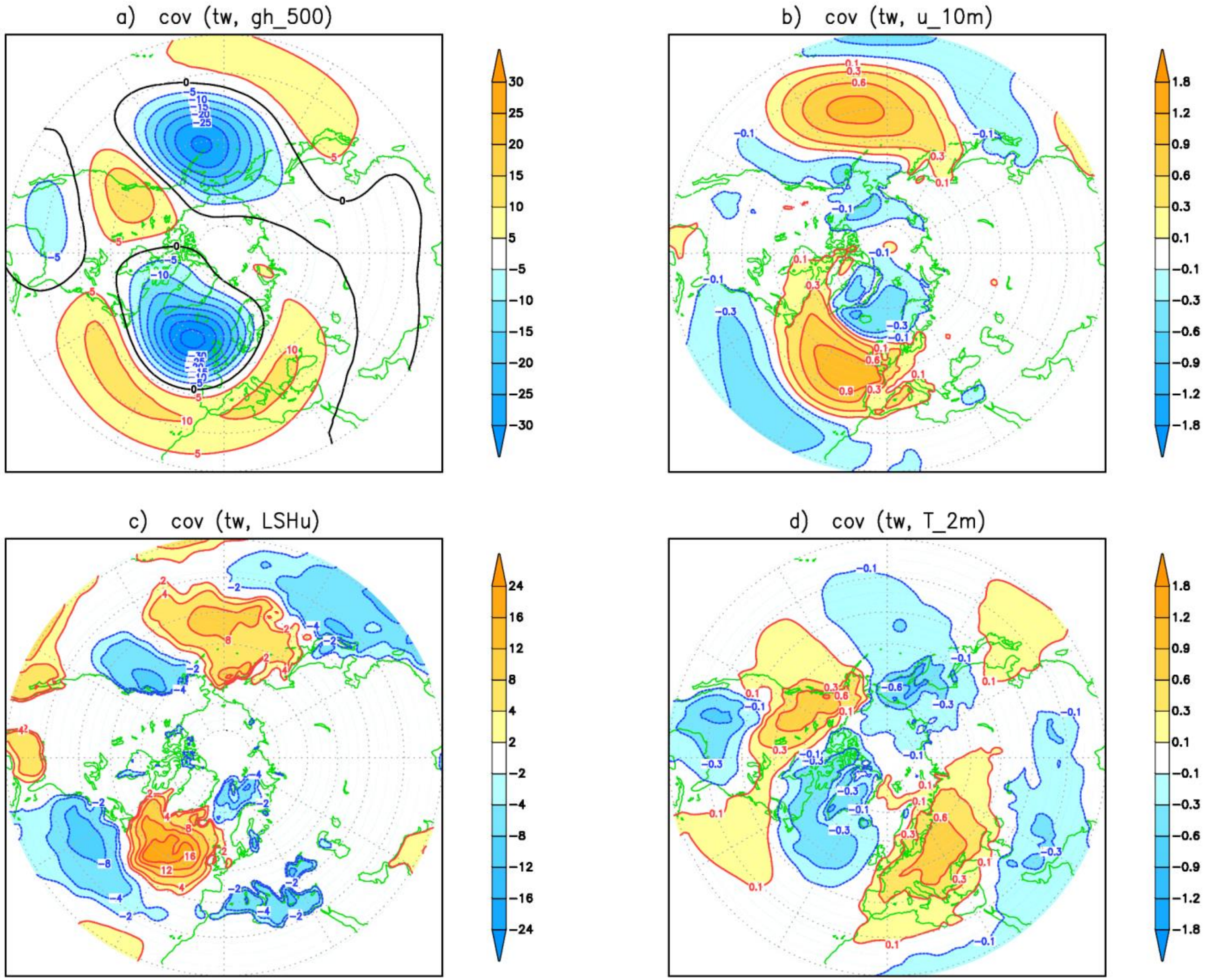
Covariance with TW index in DJF:

Z 500 hPa



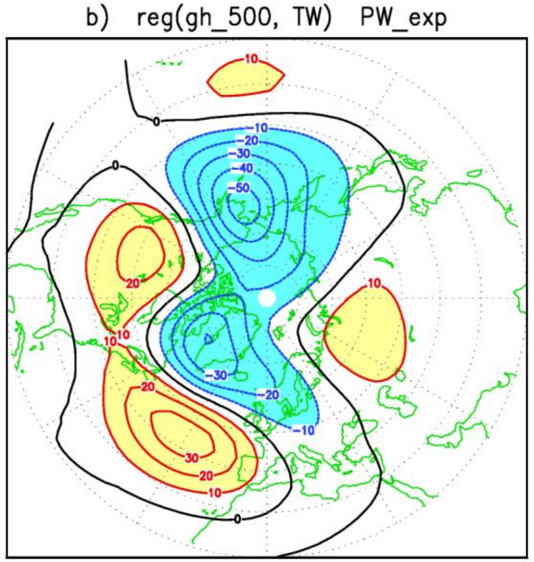
Net surface Heat flux

Covariances with TW index in S4

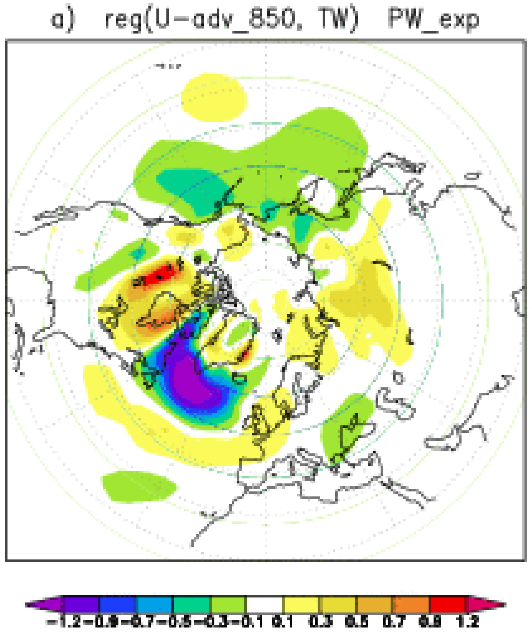


TW pattern: heat balance at 850 hPa

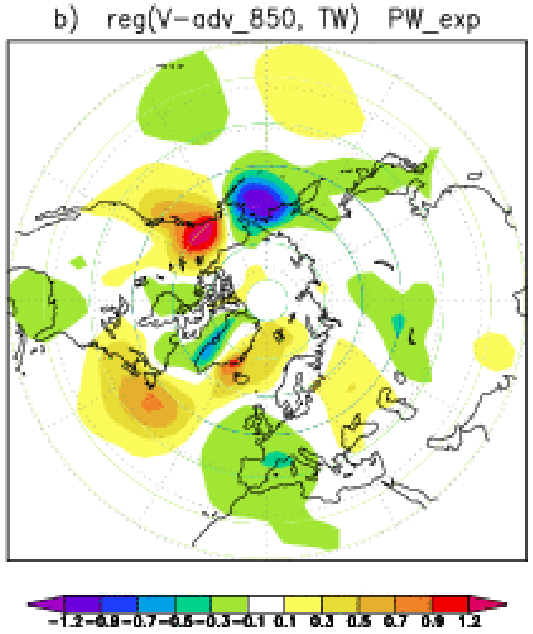
From an ensemble of
perp. winter runs
with the ICTP AGCM



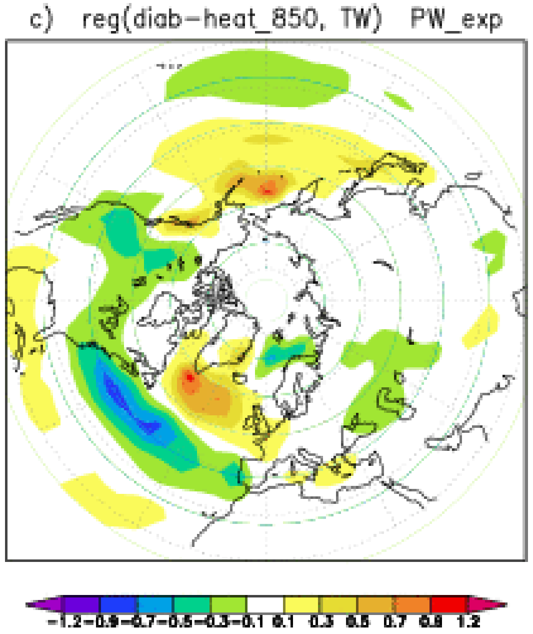
U-advection



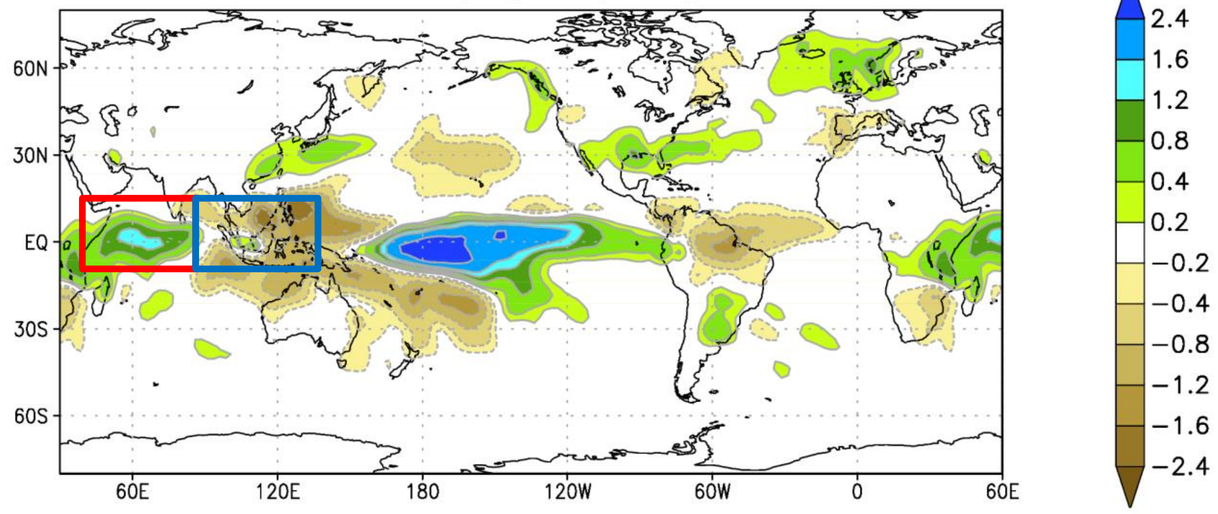
V-advection

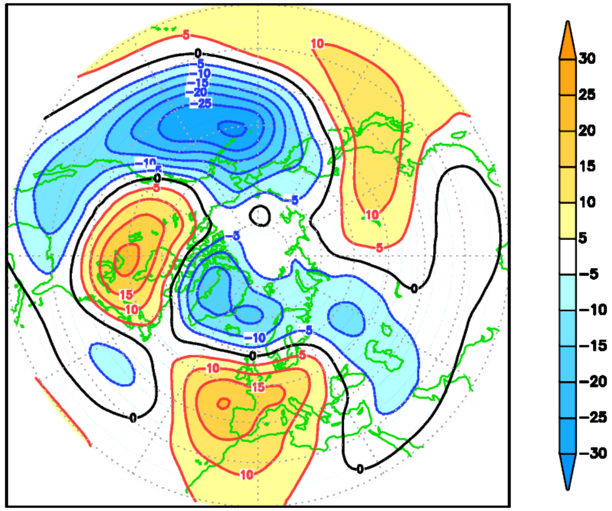


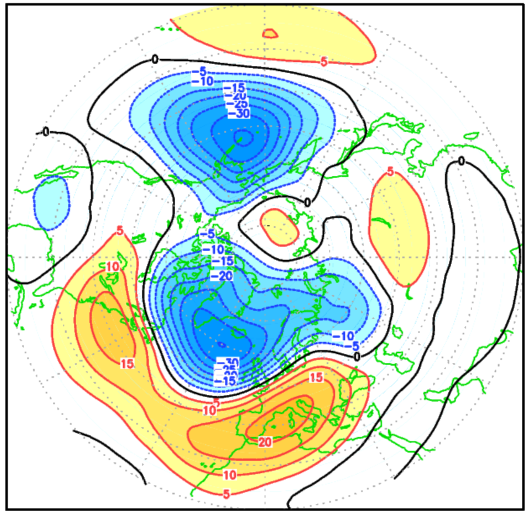
diab. heating



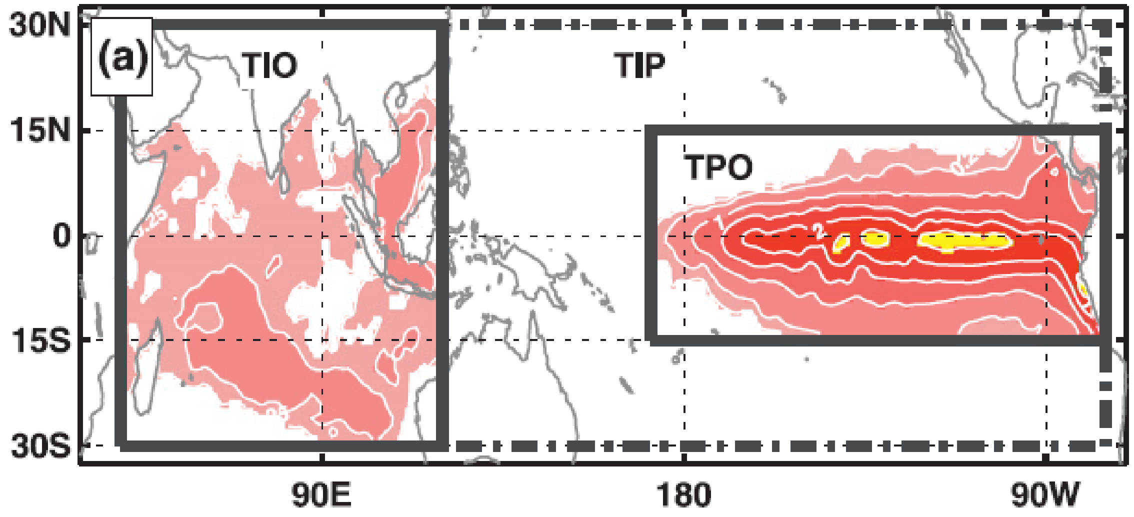
TW pattern and the teleconnection from Ind.Oc. – W.Pac. in DJF


cov (iwpd, prec)


a) cov (iwpd, gh500)


cov (tw, gh500)

A role for the stratosphere (Fletcher, Kushner, Cassou 2010/2013/2015)



Fletcher & Kushner 2010

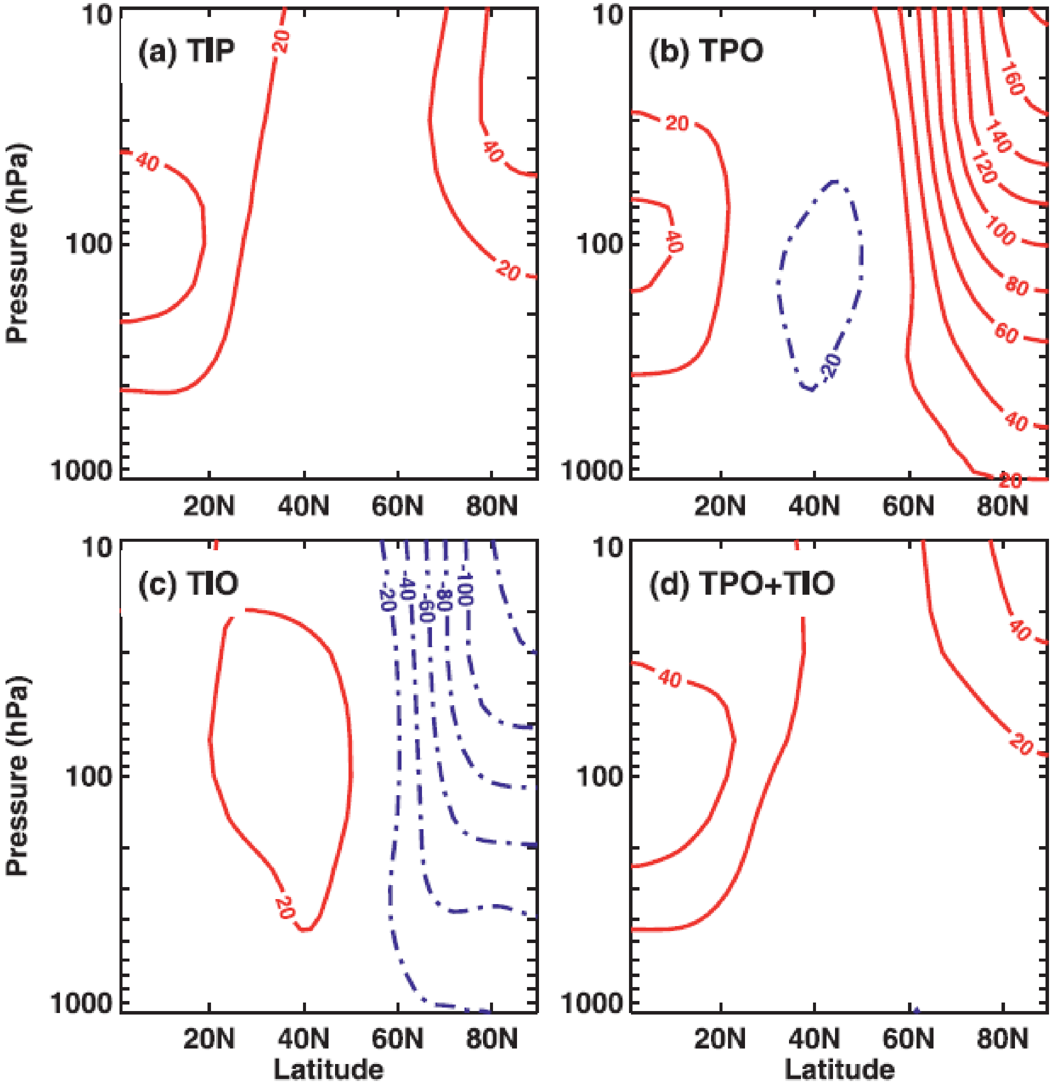
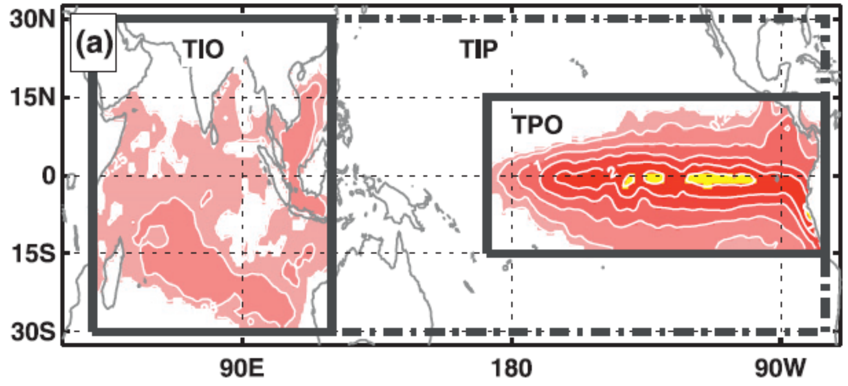
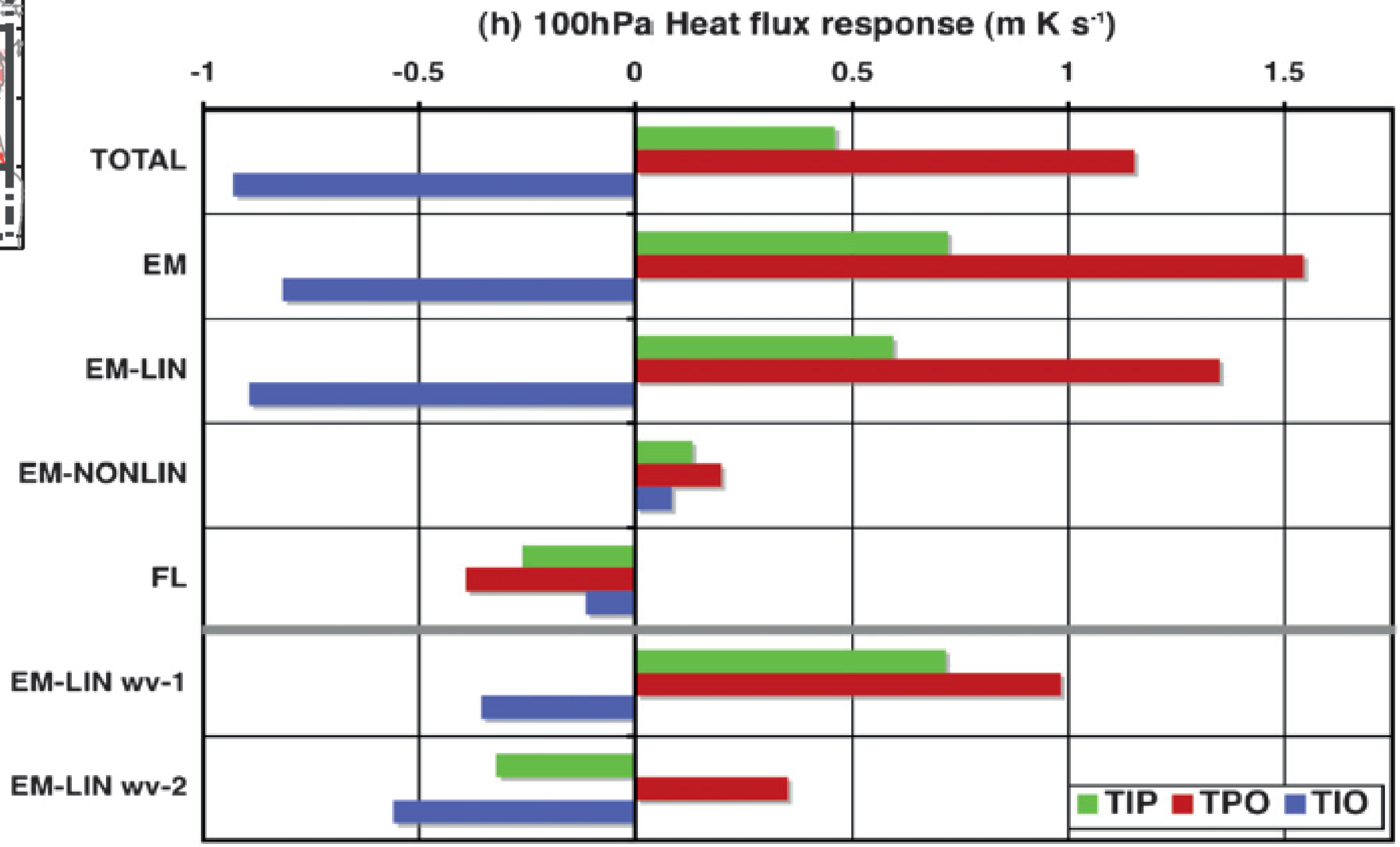


FIG. 5. The ensemble-mean JF zonal mean geopotential height response as a function of latitude and pressure in (a) TIP, (b) TPO, (c) TIO, and (d) the sum of the TPO and TIO responses. The contour interval is 20 m and negative contours are dashed.

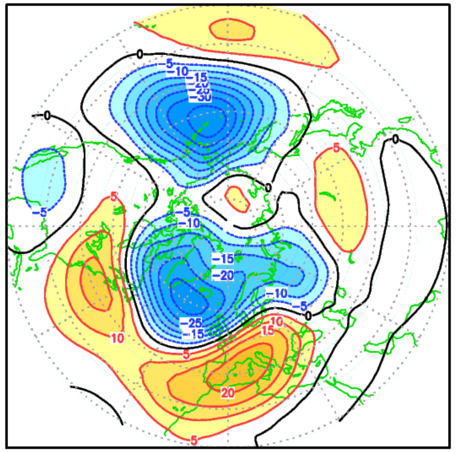
Zonal mean heat transport [v*T*] in the lower stratosphere



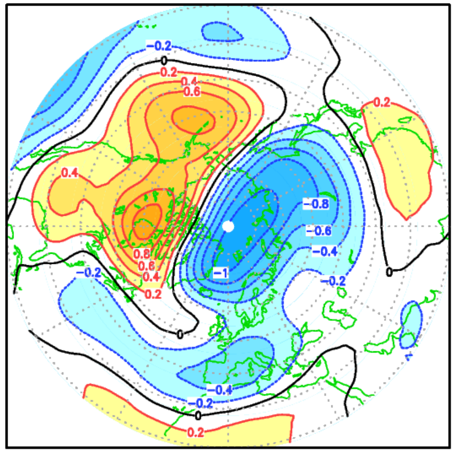


100 hPa temp. covariance with TW index

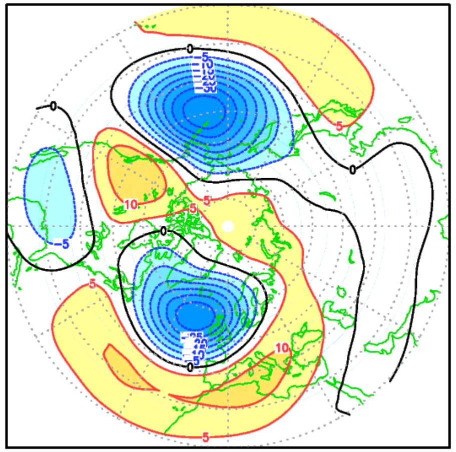
cov [tw, gh500] erain
djf 1982 2011



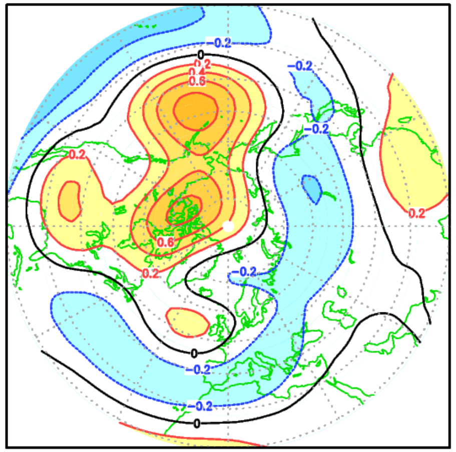
cov [tw, temp100] erain
djf 1982 2011

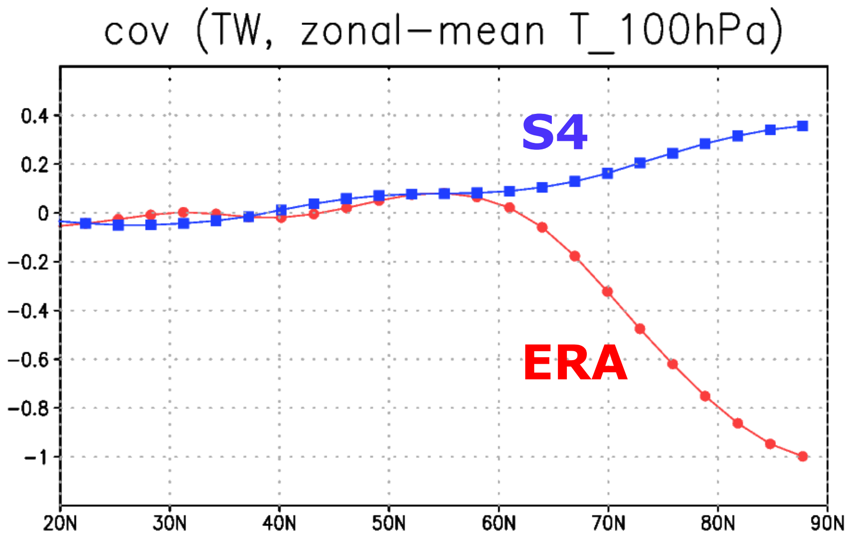


cov [tw, gh500] sys4
djf 1982 2011



cov [tw, temp100] sys4
djf 1982 2011





Decadal near-sfc. temperature variability: the “hiatus”

Trenberth et al 2014, Nature Climate Change

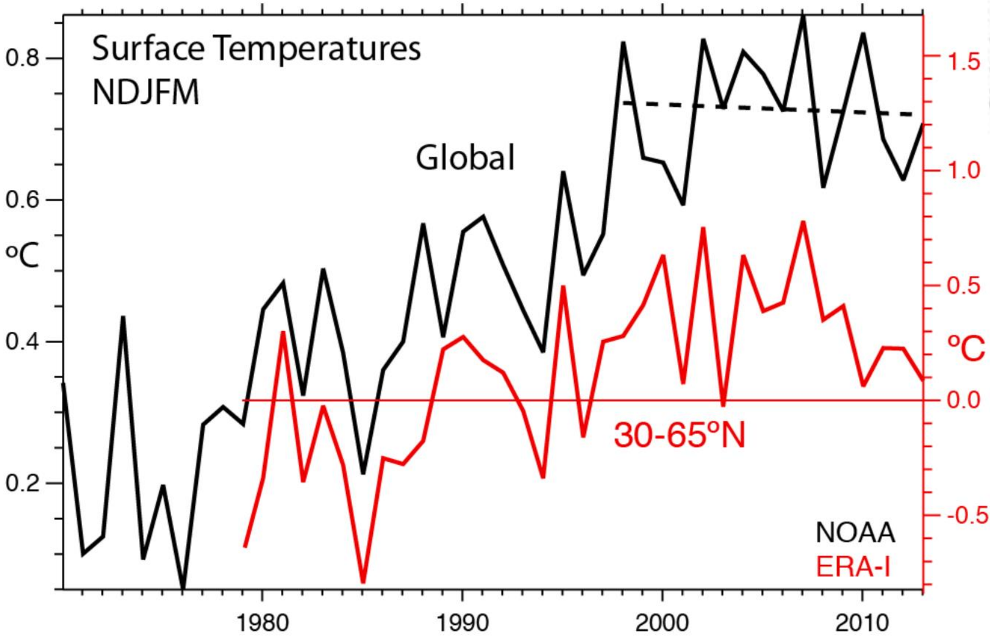
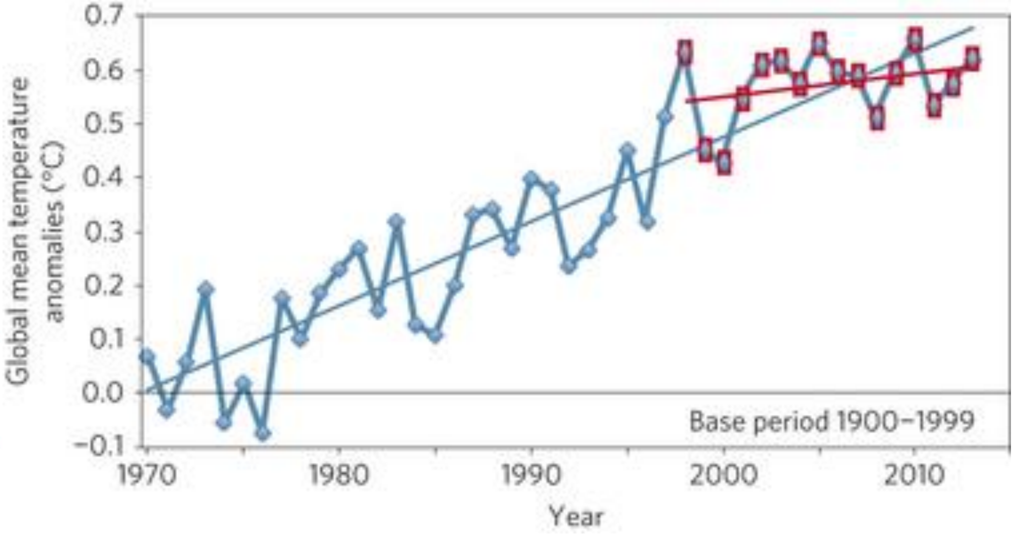
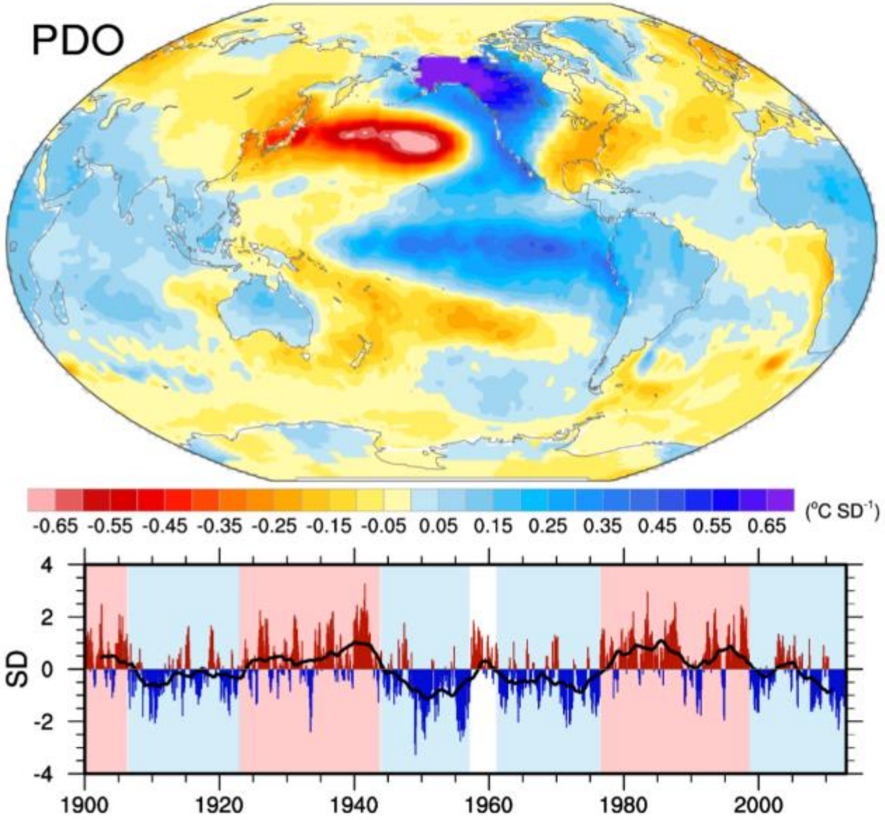


Fig. S1. For NDJFM, the global mean temperature for 1970 to 2013 and the linear trend for 1998-2013 (using NOAA data relative to the base period 1900-1999). Also shown in red are the temperature anomalies for 30-65°N relative to the mean for 1979-2013 from ERA-I data. In northern winter, when ENSO is strongest, the slight cooling trend in the 2000s exacerbates the hiatus and the coldest values are in La Niña years, however the coldest years for 30-65°N are years of negative NAO (see Figure S5).

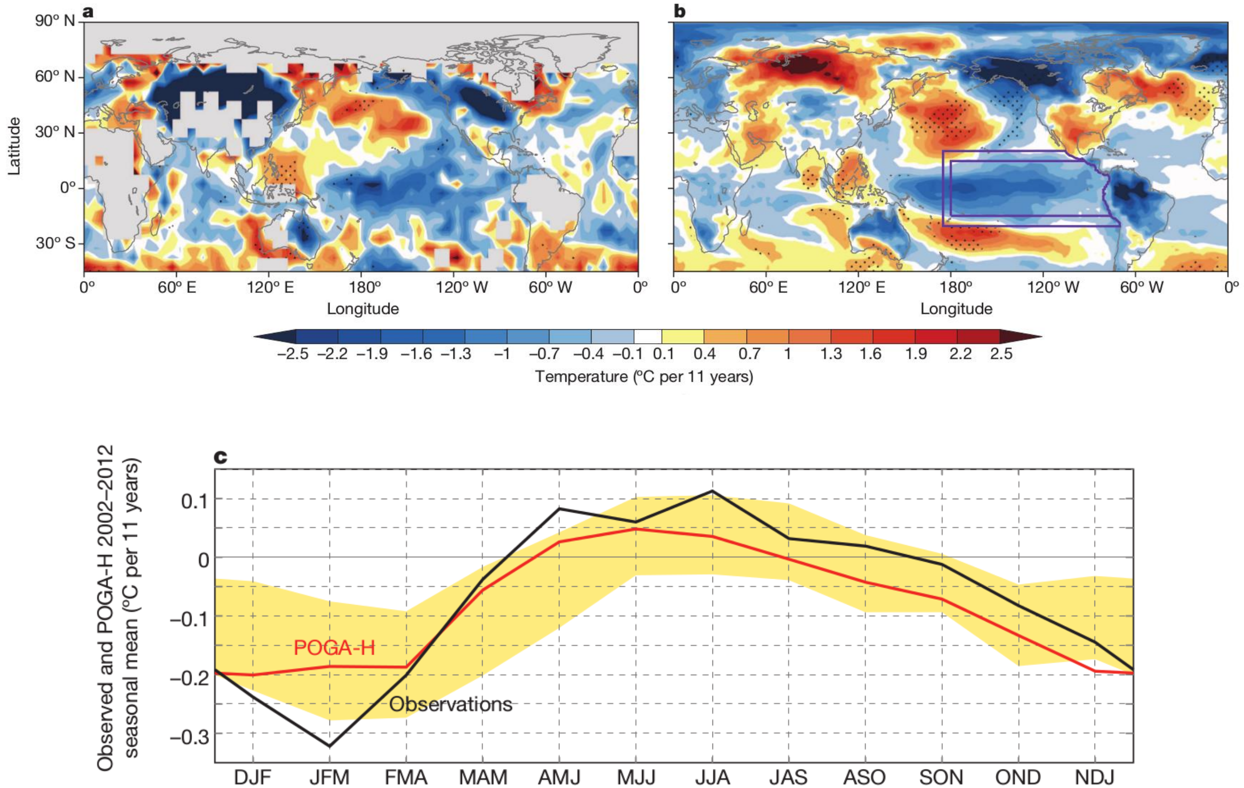


Linear trends from HadCRUT:
1984-1998: 0.26 °C/decade
1998-2012: 0.04 °C/decade

Impact of PDO variability

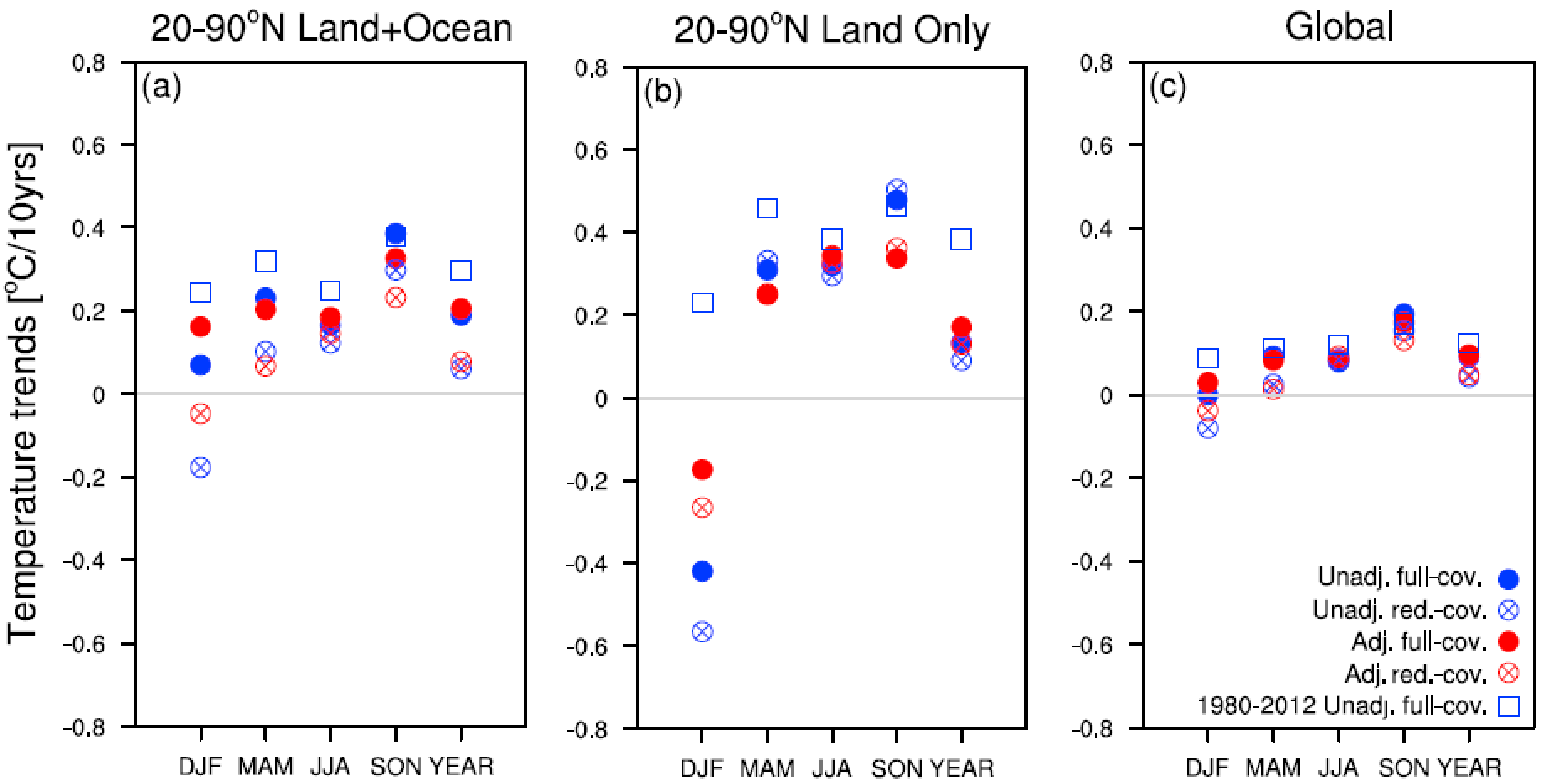


Kosaka and Xie (Nature 2013)



Impact of N.Hem. extratropical variability

Saffioti et al 2015: Statistical correction of ERA-interim trends



Weighted ensemble means of S4 re-forecasts

- For each year and ensemble member, we define two weights as function of the re-forecast TW index :
  - W_A : largest when the TW index of the ensemble member is close to the TW index from ERA
  - W_0 : largest when the TW index of the ensemble member is close to 0

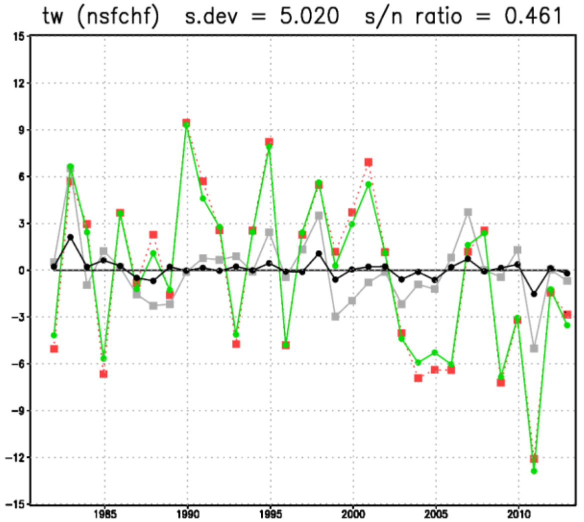
- For each year, we compute two weighted ensemble means:
  - **Ens_A** : weighted average according to W_A weights
  - **Ens_0** : weighted average according to W_0 weights

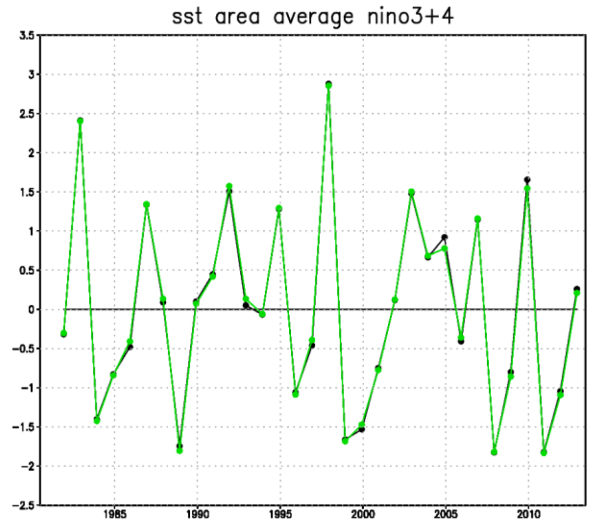
- Computation of trends:
  - From 5-year or 5-winter running means (to filter out ENSO)
  - Periods: tr1 = 1984 to 1998, tr2 = 1998 to 2011

DJF variability in weighted S4 ensembles

TW index

ERA-int
Ens_mean
Ens_A
Ens_0



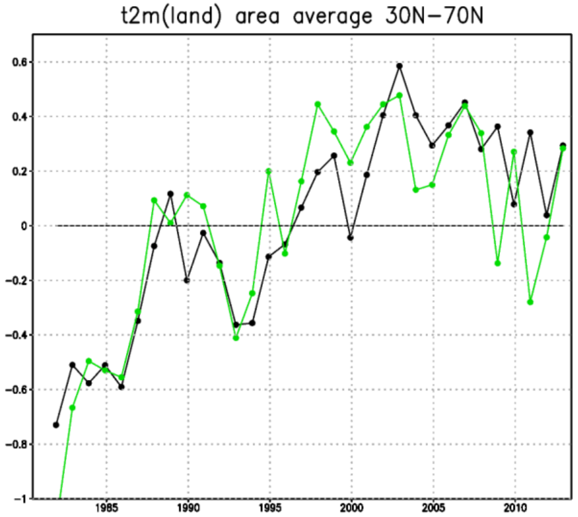


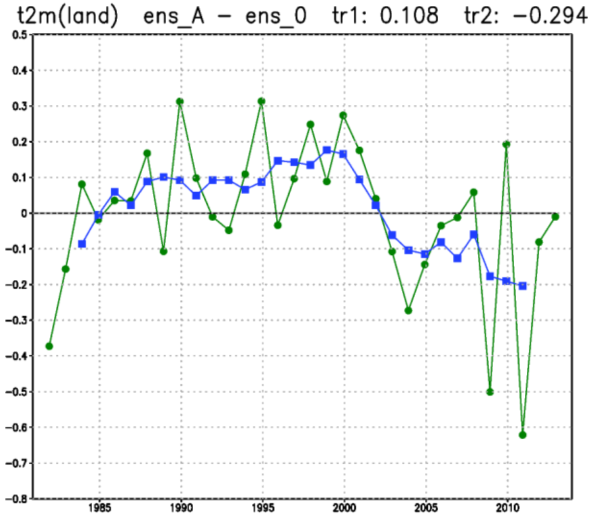
SST Nino3+4

Ens_A
Ens_0

T.2m
NH_land

Ens_A
Ens_0





T.2m
NH_land

Ens_A-Ens_0
5-win mean

tr2 = -0.3°C/10yr

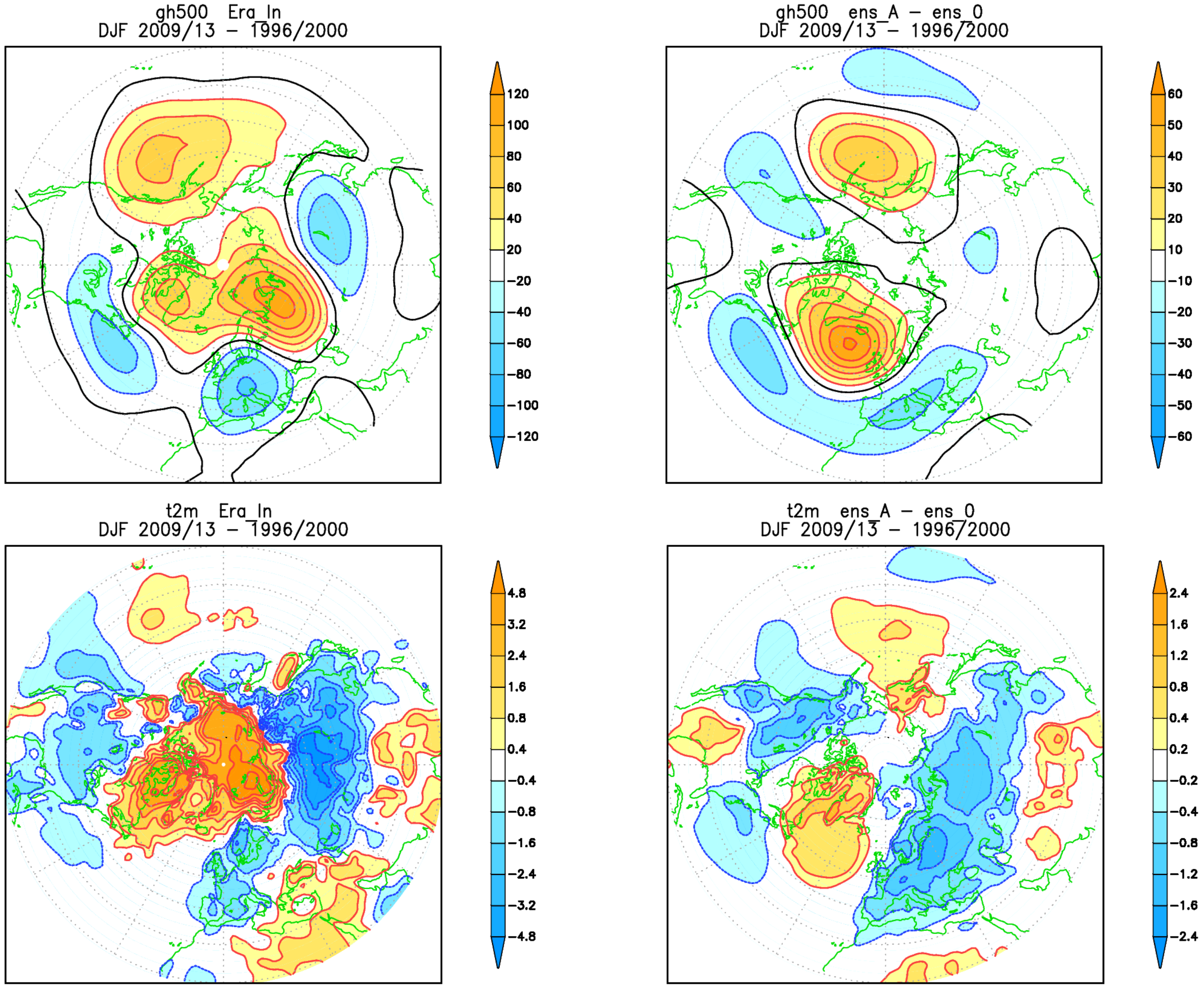
Anomaly change: DJF 2009/13 – 1996/2000: GH 500, T 2m

ERA

GH 500

T 2m

Europe
(20W-40E,
30N-70N):
-0.34°C



Ens_A
- Ens_0

GH 500

T 2m

Europe
Ens_A:
-0.49°C
Ens_0:
0.21°C

Conclusions

- Heat fluxes at the ocean surface play an important role in teleconnections between the tropics and the extratropics. In the tropics, they determine the strength (and sign) of the relationship between SST and rainfall anomalies. In the northern extratropics, they provide a flow-dependent thermal forcing which allows for distinct configurations of quasi-stationary waves.
- The teleconnection pattern associated with rainfall variability in the tropical Indian Ocean and the Maritime Continent shows a close similarity to the pattern of planetary wave variability (COWL) associated with increased/decreased intensity of the heat fluxes over the northern oceans. This suggests that the Indian Ocean teleconnection to the North Pacific & Atlantic may result in the stabilization of one specific equilibrium for the thermal balance of planetary waves.
- The effect of anomalous Indian ocean heating on the heat transport into the NH polar vortex is consistent with the association between zonal mean wind and planetary wave phase predicted by thermal equilibration theory.
- Changes in the phase of the COWL pattern, and the associated heat flux anomalies, gave a significant contribution to the slow-down in warming trends over the northern continents during the winters of the last 15 years. Weighted ensemble means derived from the ECMWF System-4 re-forecasts, which differ in terms of strong vs weak COWL variability, indicate that the change in the prevailing COWL phase accounts for a decrease in the DJF warming trend over land by ~ 0.3 deg/decade during the last 15 years.