
Connecting tropics and extra-tropics: interaction of physical and dynamical processes in atmospheric teleconnections

Franco Molteni,

Tim Stockdale, Laura Ferranti

European Centre for Medium-Range Weather Forecasts, Reading, U.K.

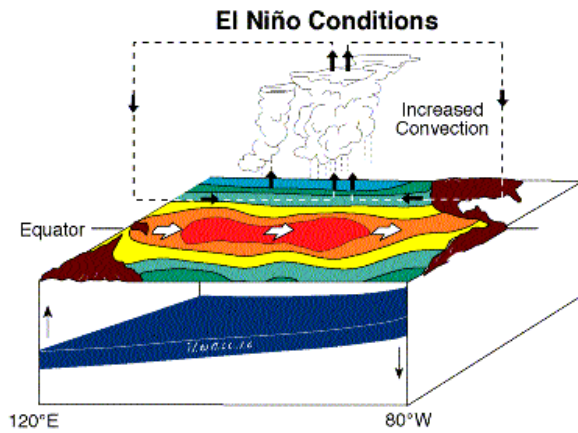
Fred Kucharski, Riccardo Farneti

Abdus Salam Int. Centre for Theoretical Physics, Trieste, Italy

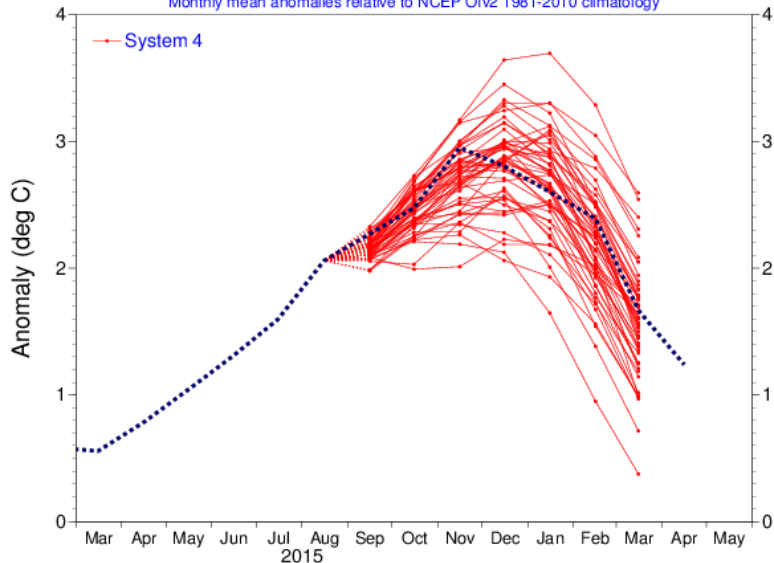
David Straus

COLA/George Mason University, Fairfax, VA, USA

ECMWF System 4 forecast for DJF 2015/16

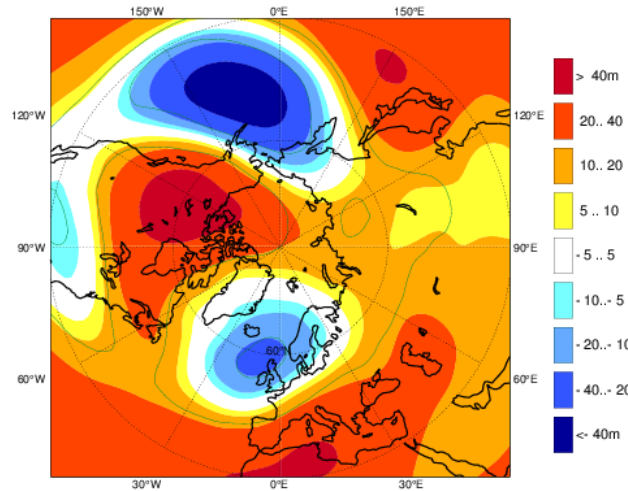


NINO3.4 SST anomaly plume
ECMWF forecast from 1 Sep 2015
 Monthly mean anomalies relative to NCEP Olv2 1981-2010 climatology



IC: 1 Sep 2015

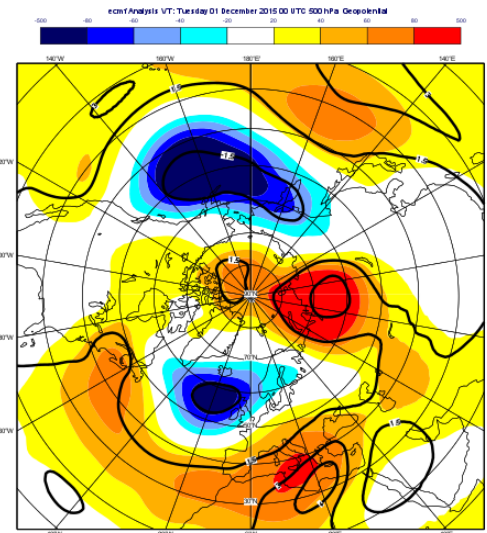
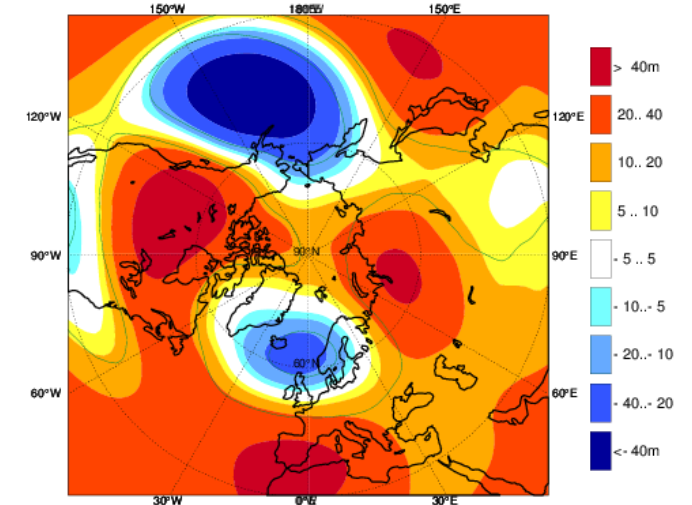
ECMWF Seasonal Forecast
 Mean Z500 anomaly
 Forecast start reference is 01/09/15
 Ensemble size = 51, climate size = 450



IC: 1 Nov 2015

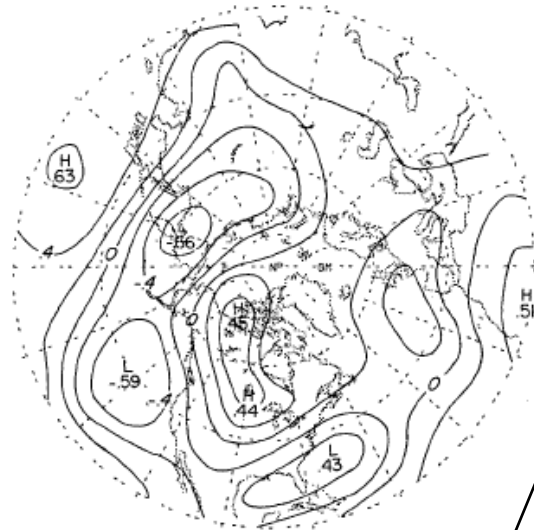
ECMWF Seasonal Forecast
 Mean Z500 anomaly
 Forecast start reference is 01/11/15
 Ensemble size = 51, climate size = 450

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

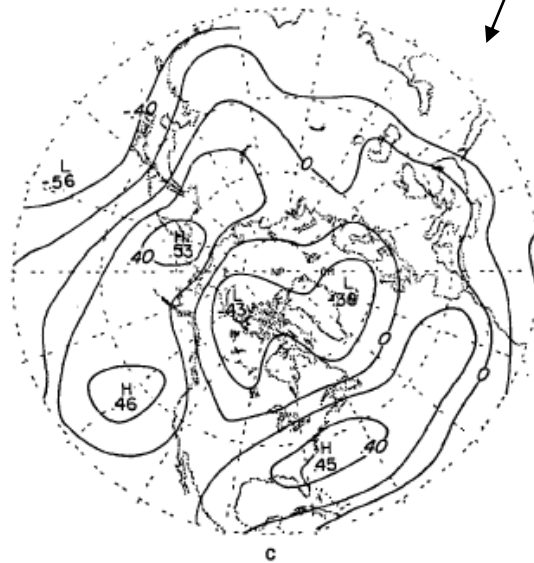


ERA Interim

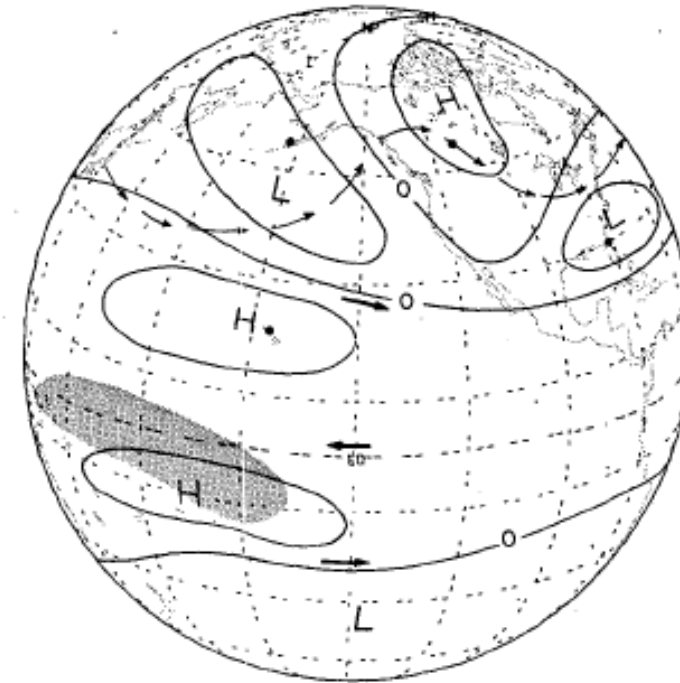
Foundations : Horel and Wallace 1981



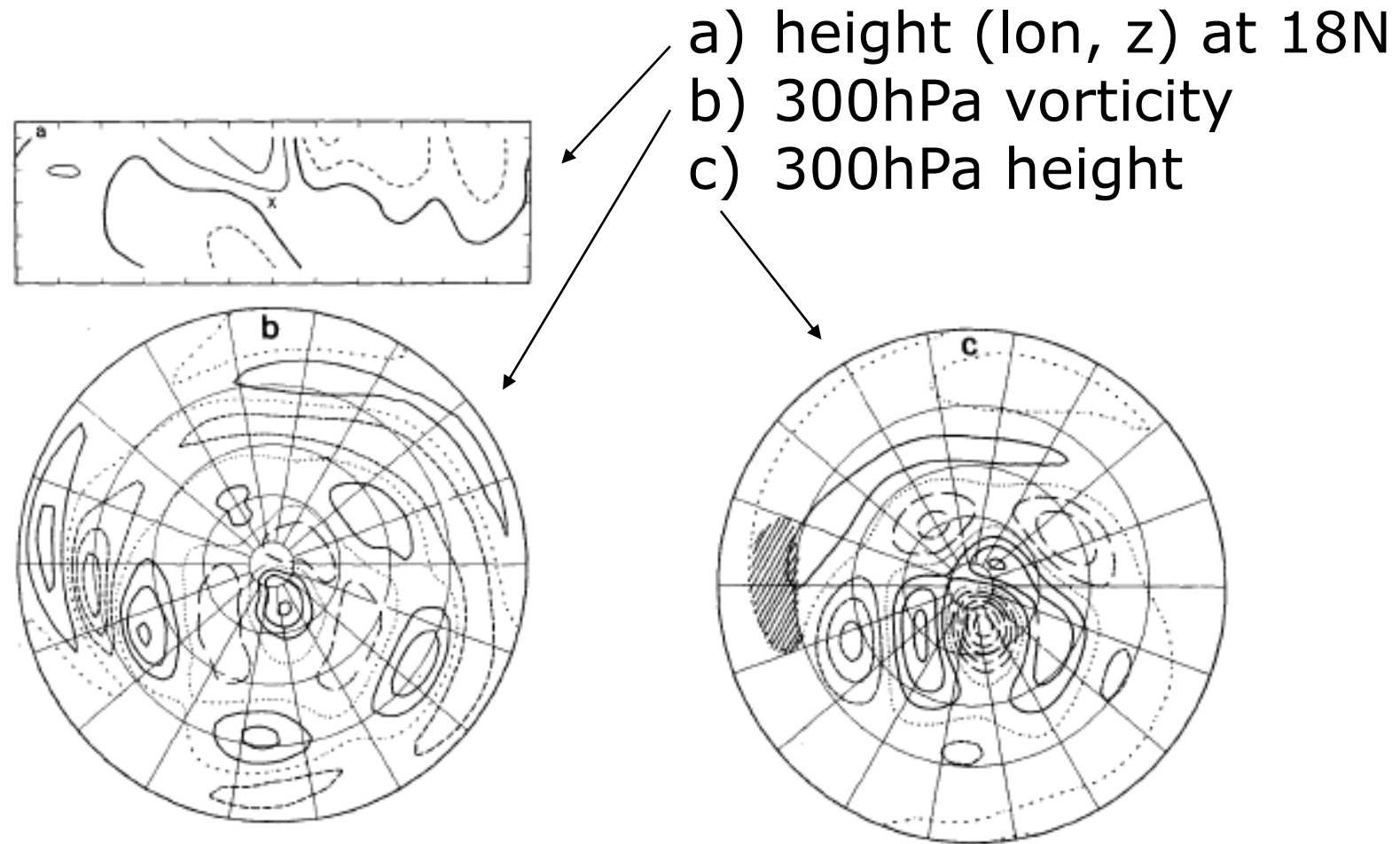
Correlation of 700hPa height with
a) PC1 of Eq. Pacific SST
b) SOI index



Schematic diagram of tropical-extratropical teleconnections during El Niño



Response to a tropical heat source (15N):



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

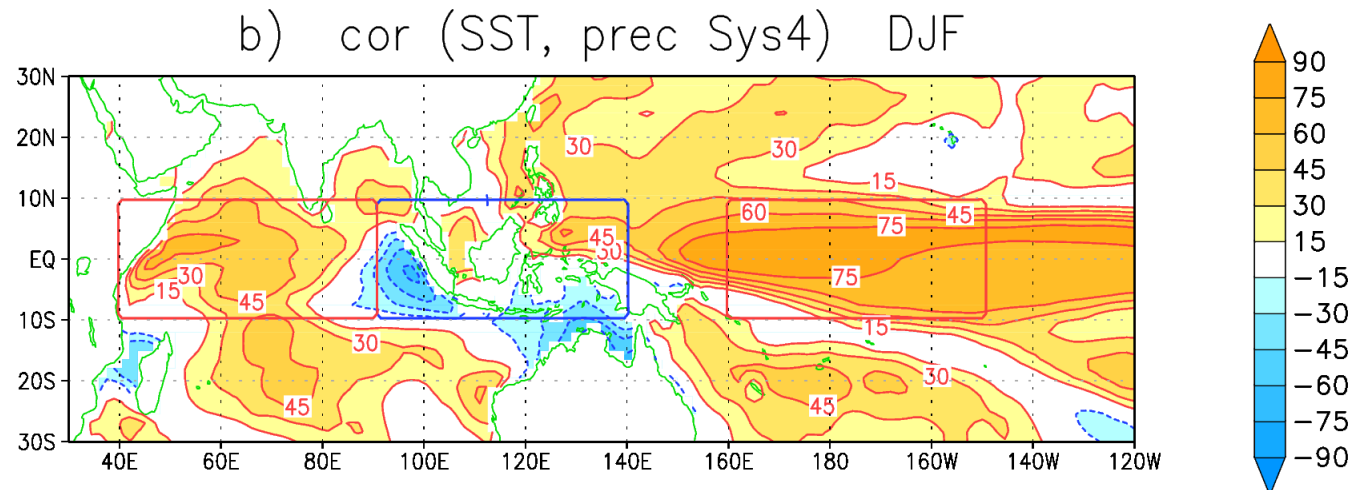
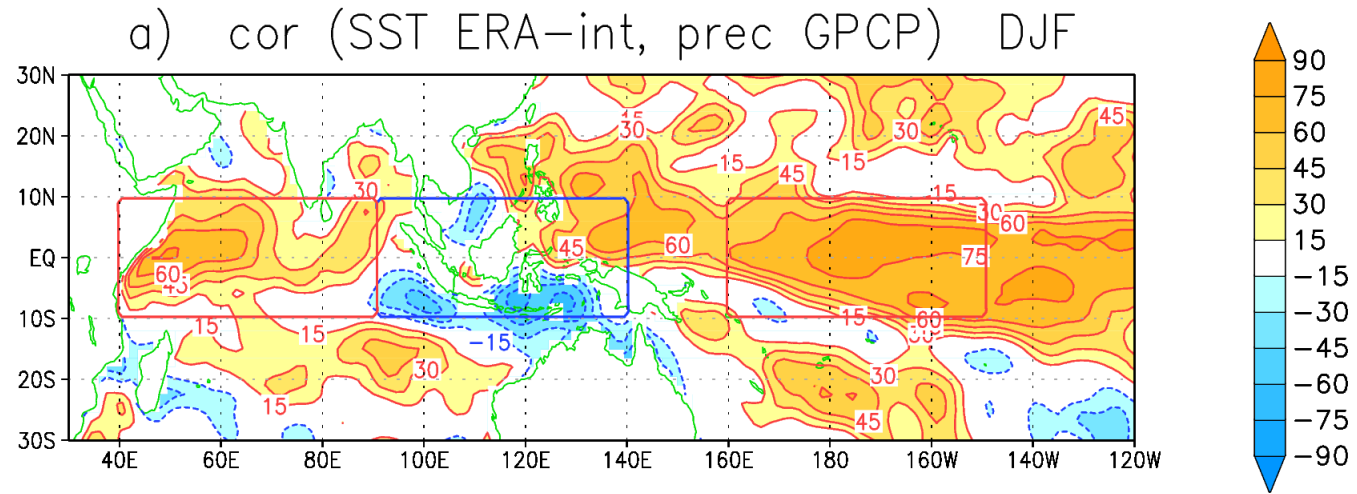
- **Observational data:**

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

- **Numerical model /simulations:**

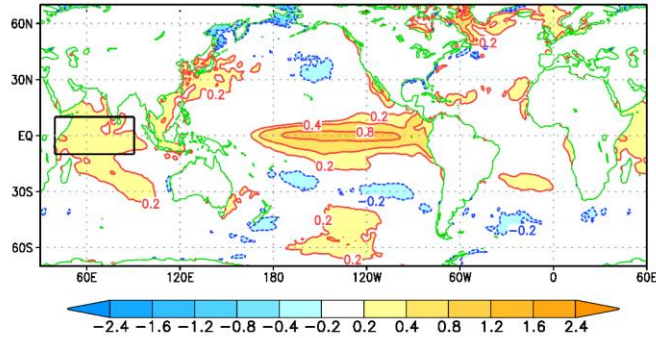
- ECMWF System-4 re-forecasts + operational forecasts
- 1981-2010 + 2011-2013
- DJF season from 1 Nov. runs (fc. months 2-4)
- 51-member ensembles

Local correlation between SST and rainfall anomalies

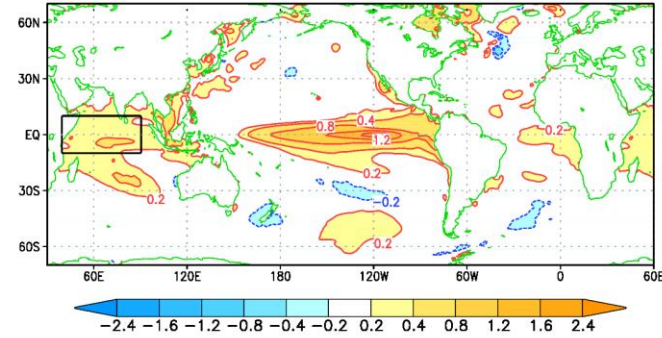


Covariance of Indo-Pac. SST and rainfall indices

cov [sst(wcio), sst] erain djf 1982 2011

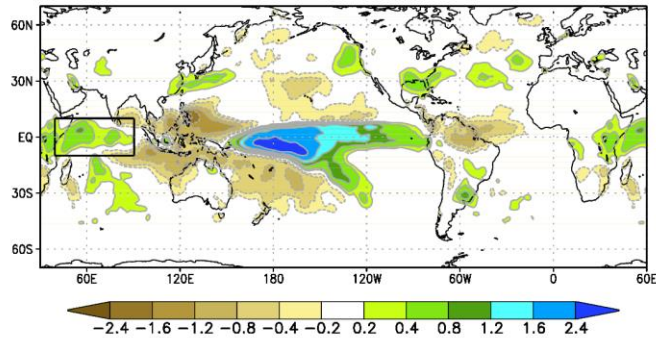


cov [sst(wcio), sst] sys4 djf 1982 2011

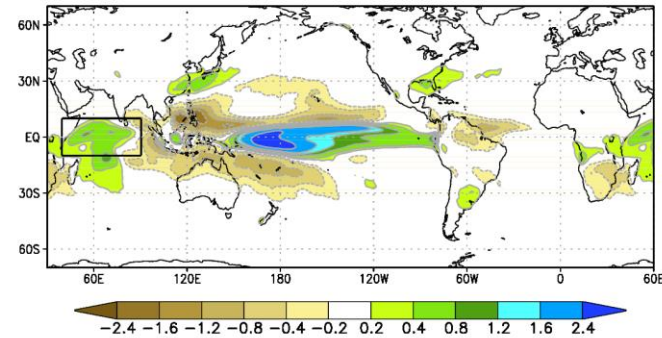


ERA-int

cov [sst(wcio), prec] erain djf 1982 2011

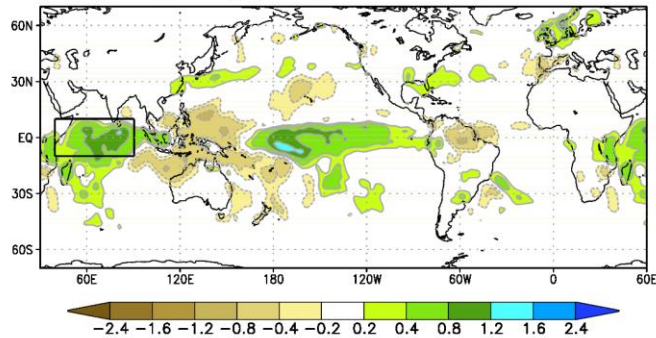


cov [sst(wcio), prec] sys4 djf 1982 2011

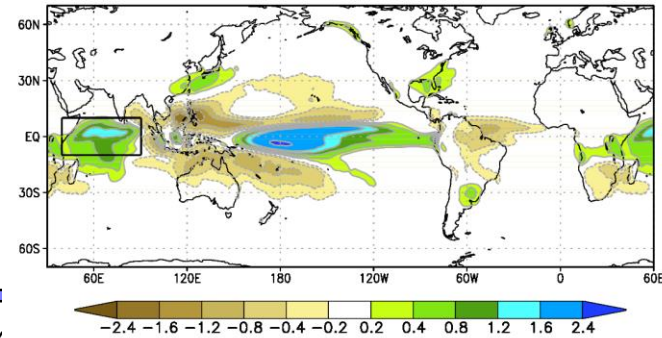


System 4

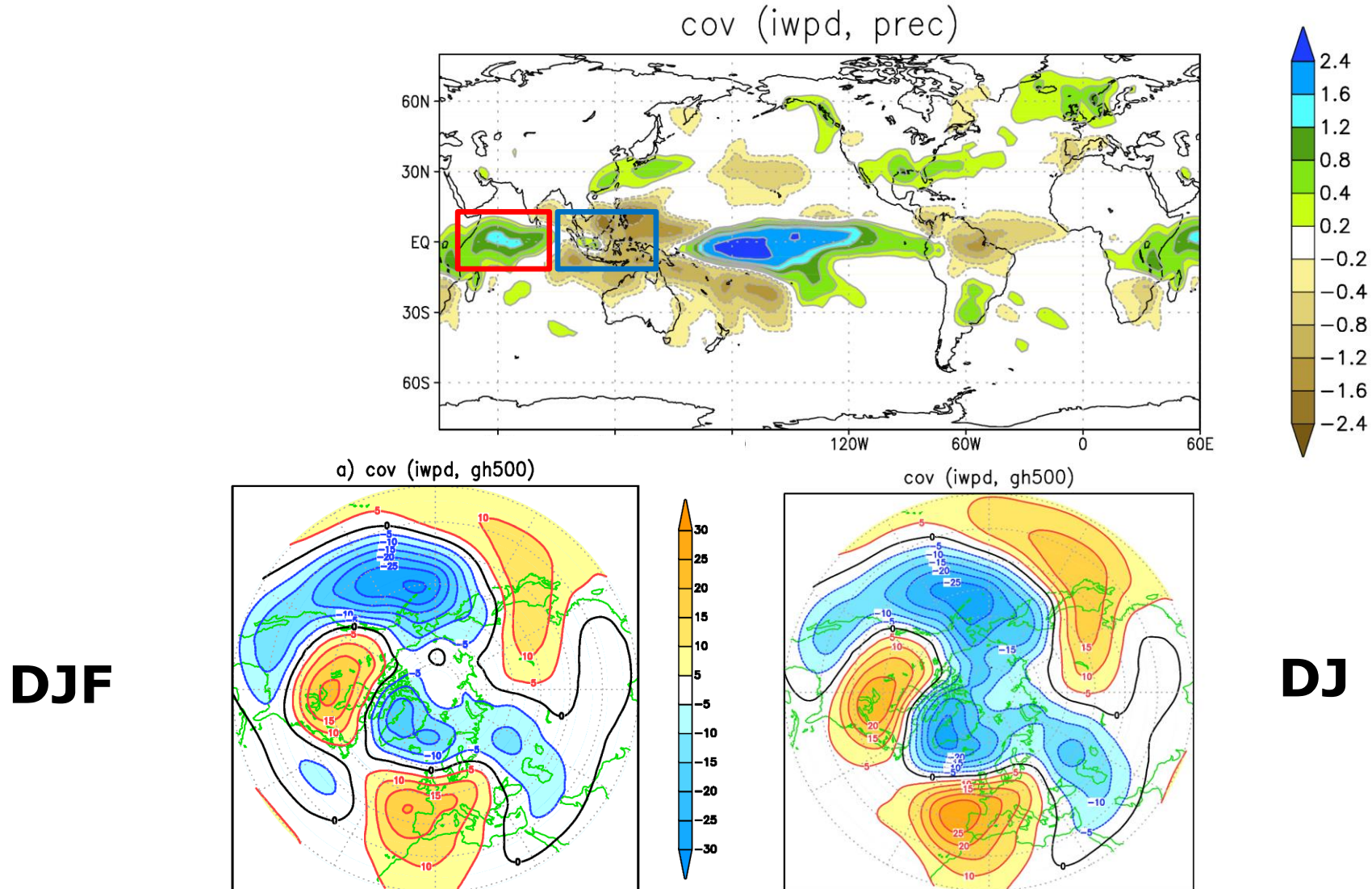
cov [prec(wcio), prec] erain djf 1982 2011



cov [prec(wcio), prec] sys4 djf 1982 2011



Teleconnections from Indian Ocean & West Pacific



- **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 simple diagnostic for thermal equilibration

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

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

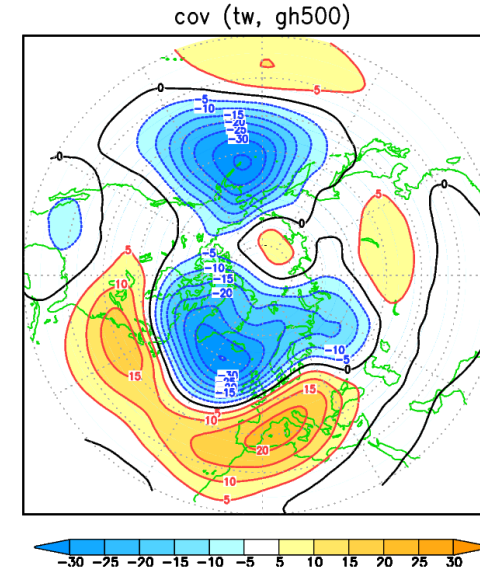
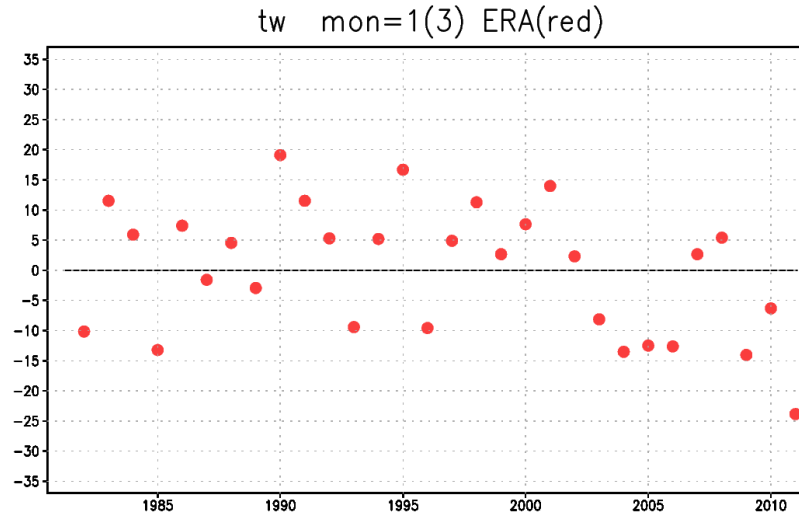
(Molteni, King, Kucharski and Straus, *Clim. Dyn.* 2011)

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

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

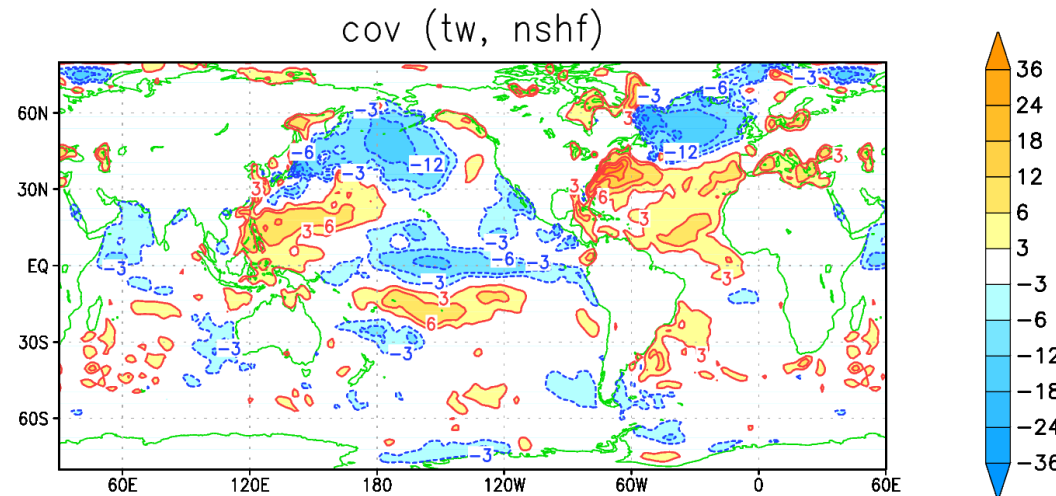
The TW index and co-varying patterns in ERA-Interim

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



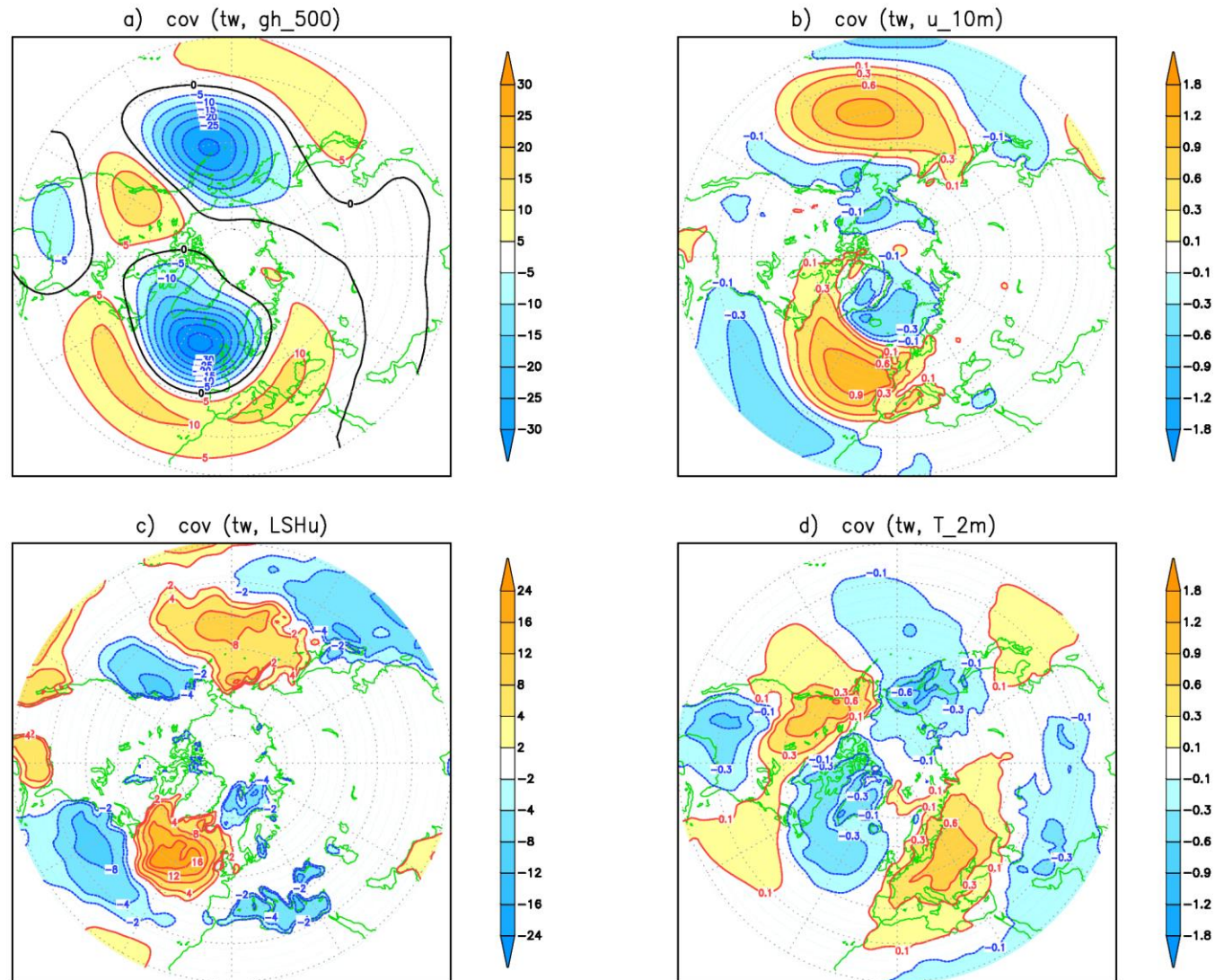
**Covariance with
TW index in DJF:**

Z 500 hPa

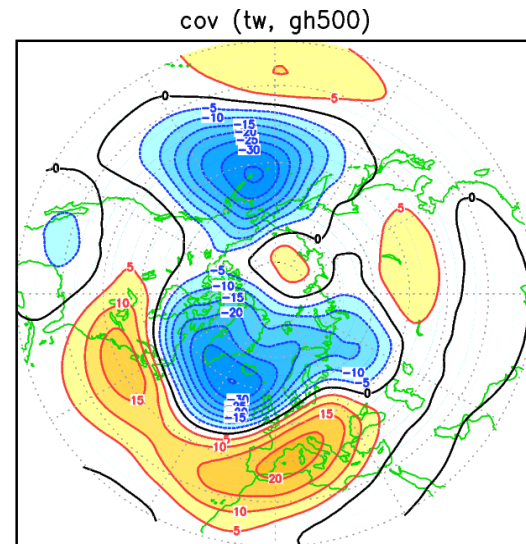
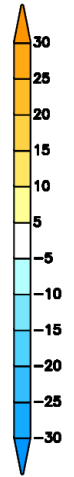
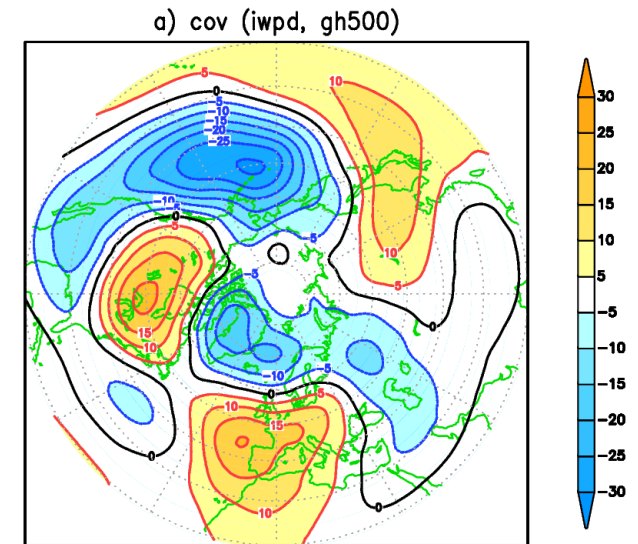
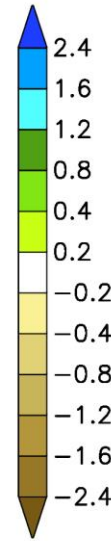
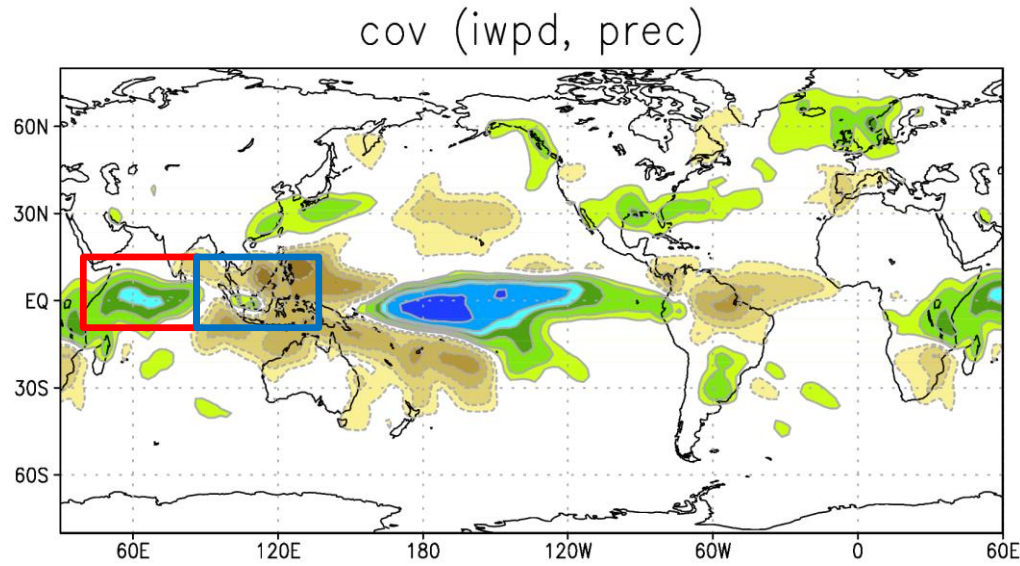


**Net surface
Heat flux**

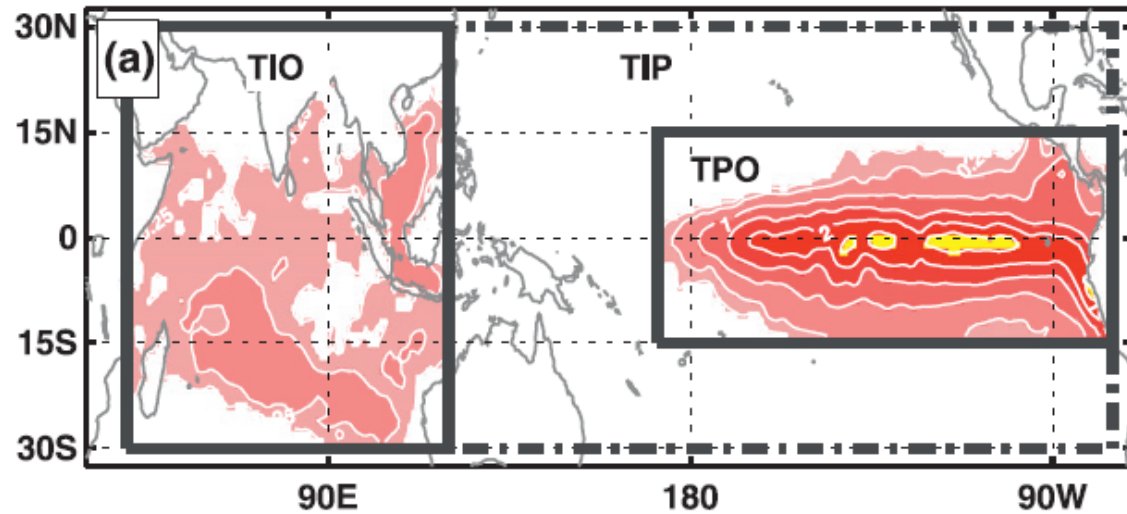
Covariances with TW index in S4



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



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



Fletcher & Kushner 2010

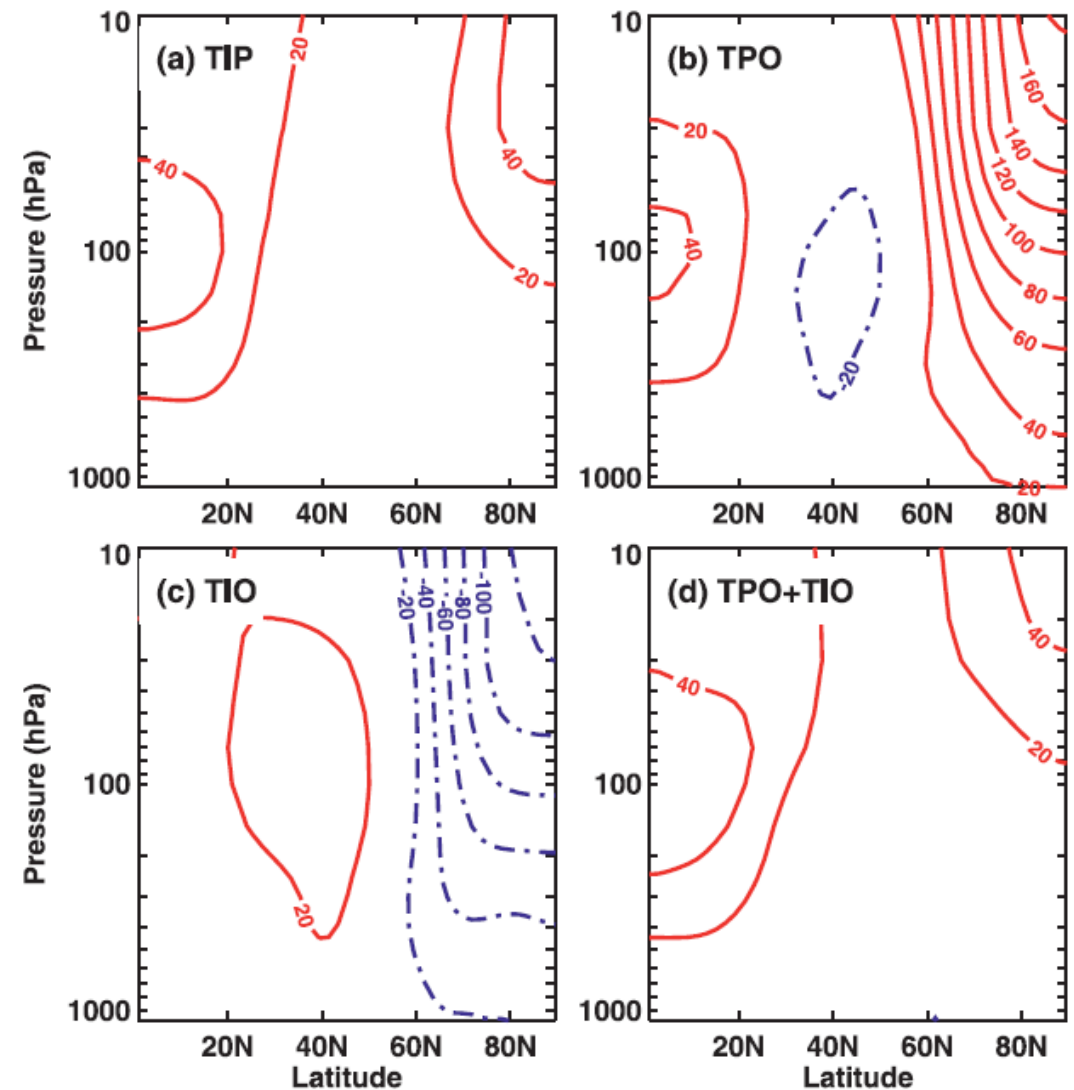
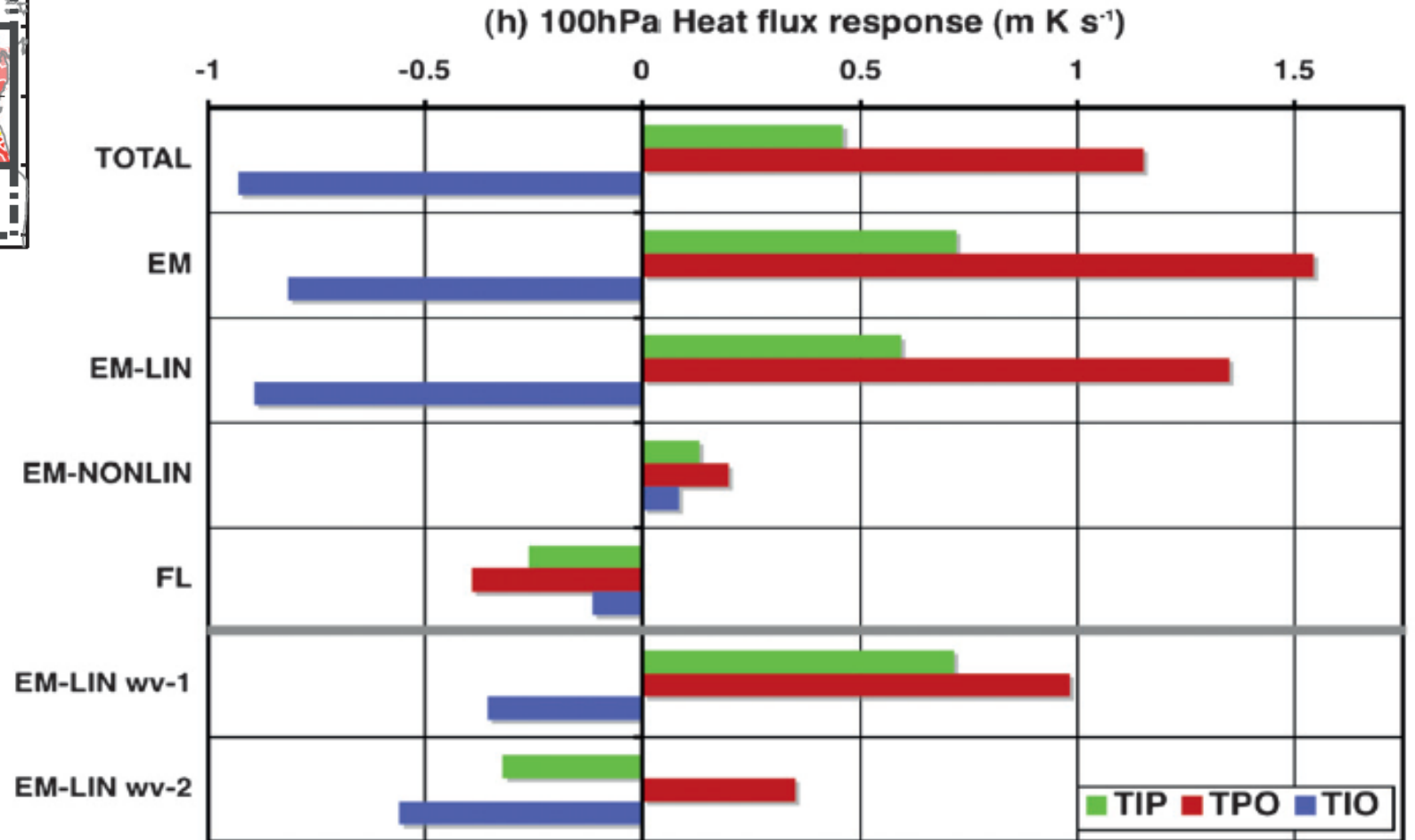
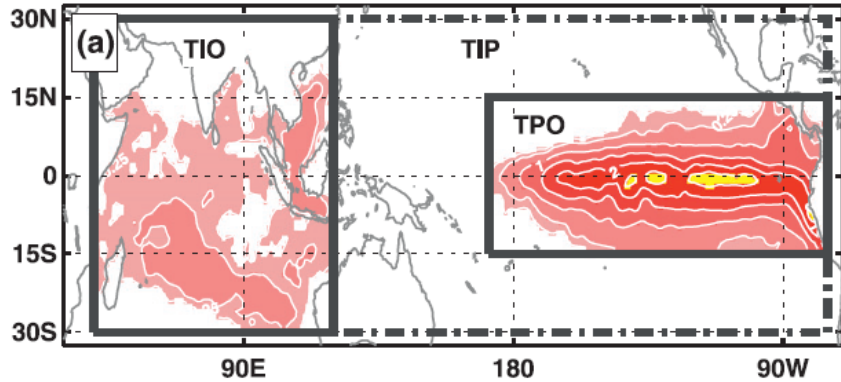


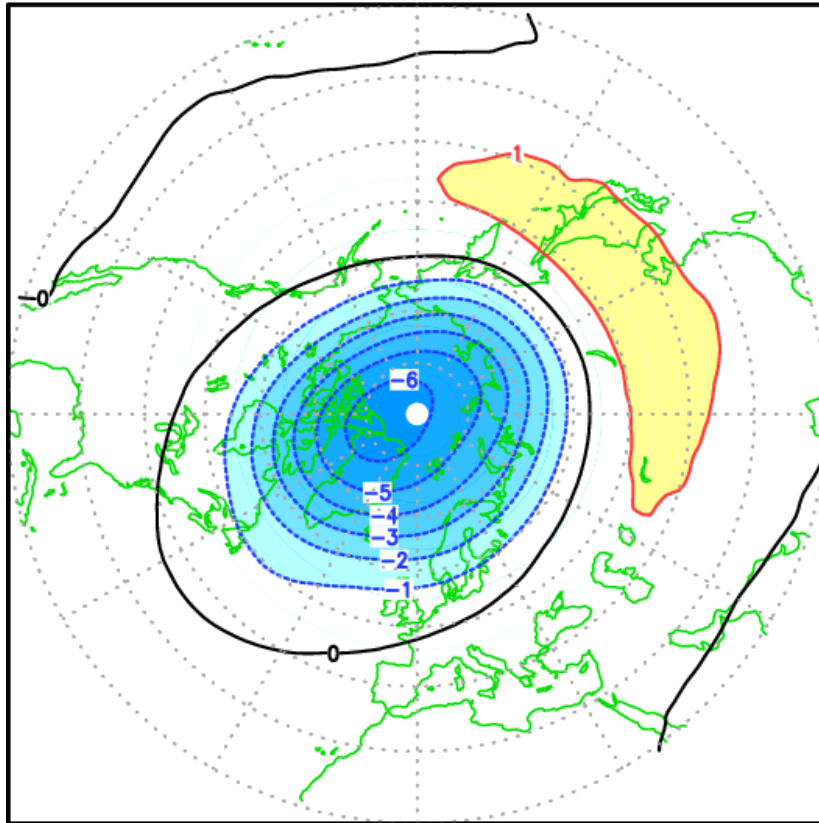
FIG. 5. The ensemble-mean JF zonal mean geopotential height response as a function of latitude and pressure in (a) TIO, (b) TPO, (c) TIO, and (d) the sum of the TPO and TIO responses. The contour interval is 20 m and negative contours are dashed.

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

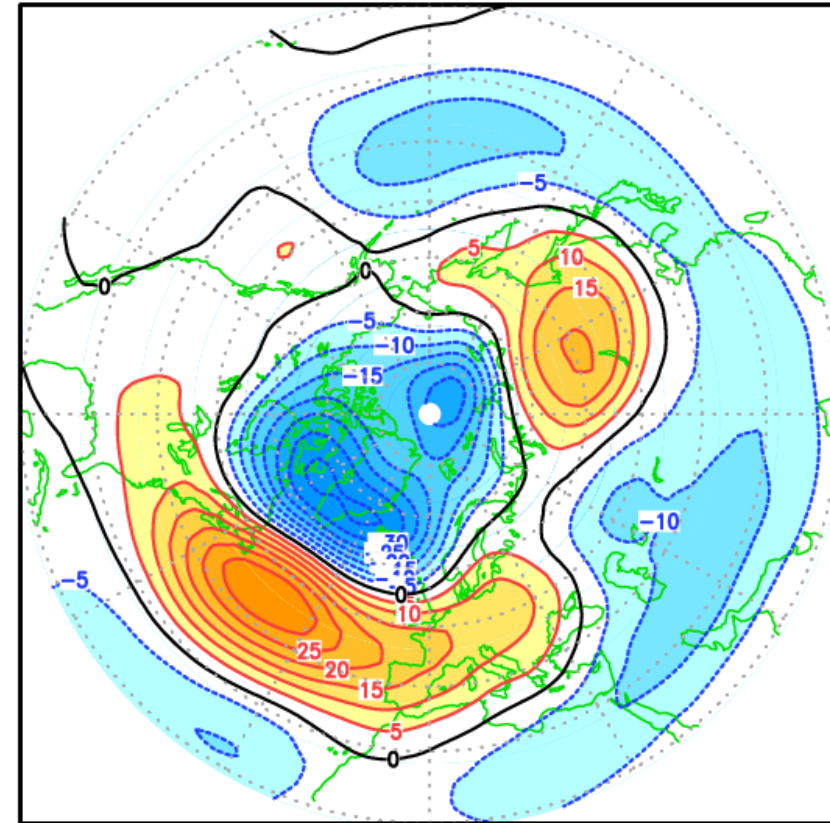


1st EOF of T 100 hPa in DJF and its covariance with Z 500 hPa

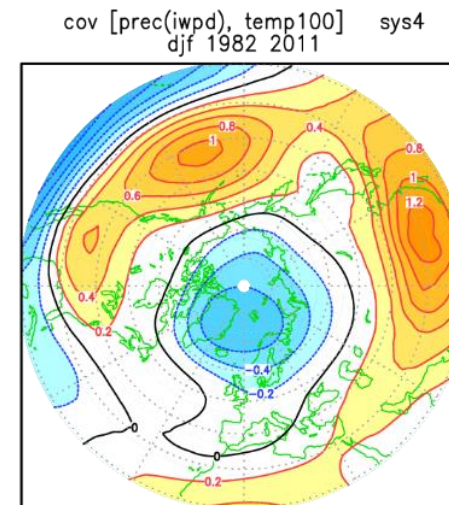
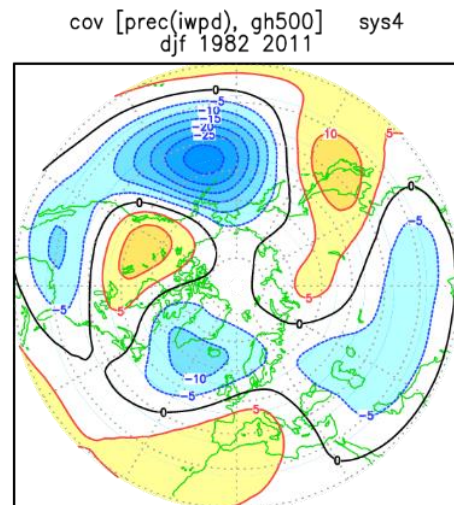
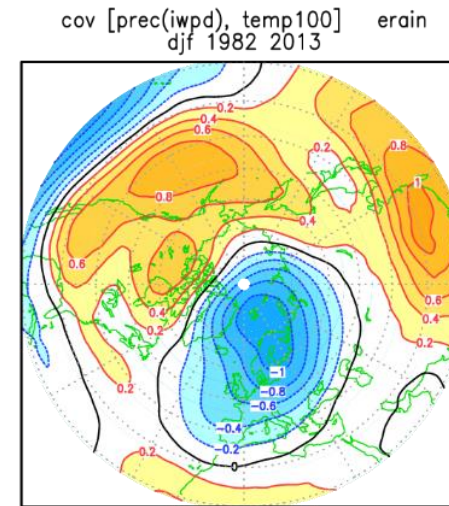
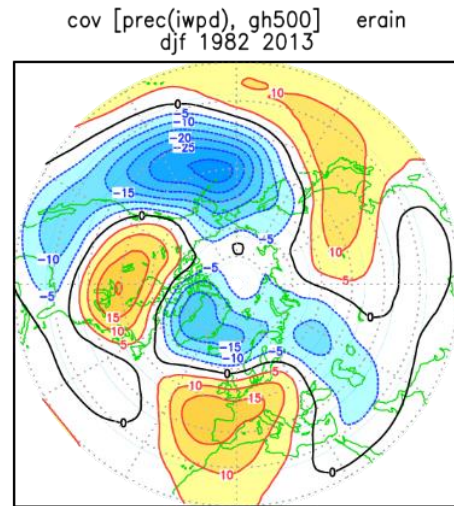
EOF-1 T 100 hPa D-J-F



cov (T_100 PC1, gh 500 hPa)

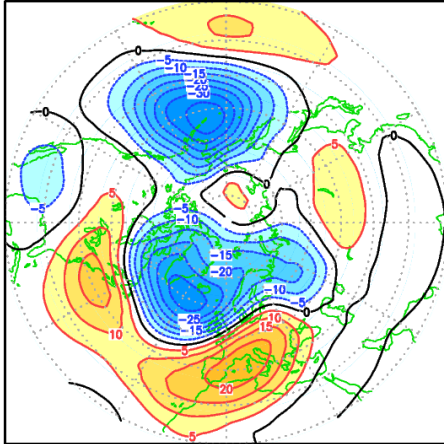


Covariances of Z 500/ T 100 hPa with Indo-Pac. rainfall in S4

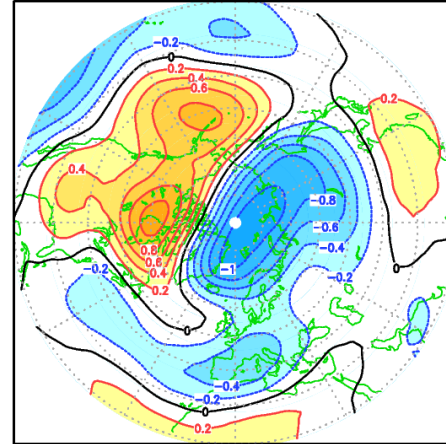


100 hPa temp. covariance with TW index

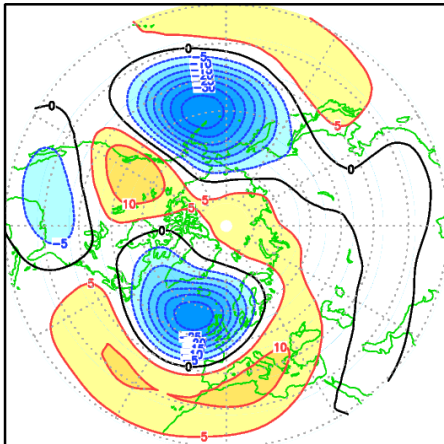
cov [tw, gh500] erain
djf 1982 2011



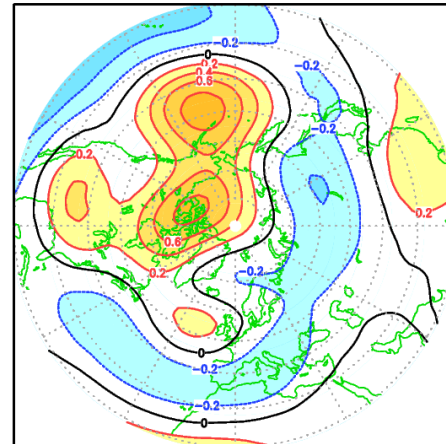
cov [tw, temp100] erain
djf 1982 2011



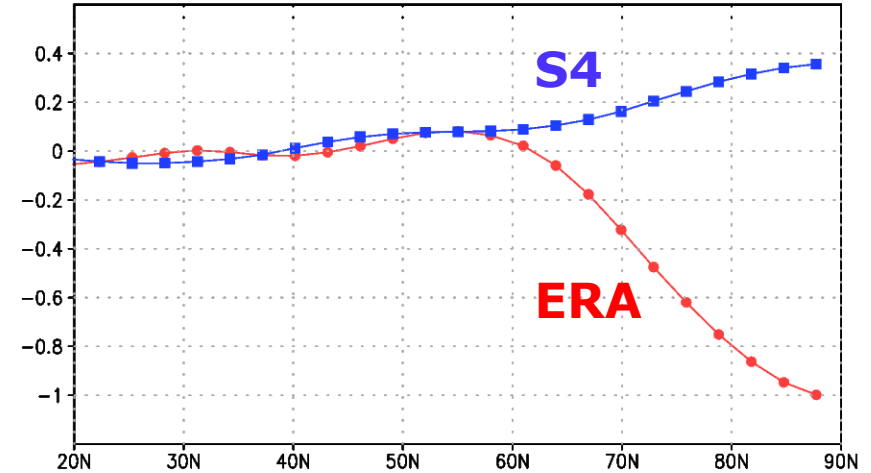
cov [tw, gh500] sys4
djf 1982 2011



cov [tw, temp100] sys4
djf 1982 2011



cov (TW, zonal-mean T_100hPa)



Summary

- 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.
- In the ECMWF System 4, teleconnections between Indo-Pacific heat sources and North Atlantic circulation patterns are affected by (at least) two main deficiencies: a) too strong correlation between Indian Ocean and central Pacific rainfall; b) weak connections between tropospheric and lower-stratospheric phenomena in the Euro-Atlantic sector.