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Department of Meteorology
MISU

Teleconnections and link to regional scale precipitation

Abdel Hannachi

Thanks to Z. Bargaoui, L. Chafik, F. Syed, M. Latif,
N. Trendafilov, I. Zveryaev & T. Woollings

Background

Atmospheric flow and large scale features

Teleconnection & relation to precipitation

Teleconnection & extremes

Conclusion

Who are we & what do we do?

MISU in winter!

misu.su.se

- Established back in 1947 by G. Rossby (Bert Bolin)
- Extensive research programme:
  - BL & turbulence
  - Dynamic meteorology & climate
  - Atmospheric chemistry
  - Atmospheric physics/upper atmosphere
  - Oceanography
- Offers Bachelor, Master and PhD degrees

1. Background

1.1 Weather vs climate

⇨ *Weather*

- Actual state of the atmosphere @ given place

⇨ *Climate*

"Climate is what we expect, but weather is what we get"

- Climate: Aggregation of daily weather -- Collection of all long-term statistical properties of the atmospheric state (Ed Lorenz, 1970)
- Climate: The memory we keep about agrregated weather

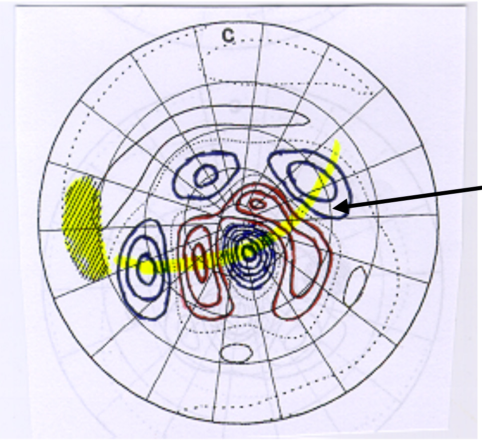
2. Large scale flow & Rossby waves

Looks at propagation of (small amplitude) waves and perturbations (linear & quasi-linear framework)

- Essentially based on the linearised equations of dry hydros. Bouss. Eqs.
- Simple frame: linearised beta-plane vorticity eq (e.g. Hoskins 1983):

-> Explain Rossby wave prop./atmospheric response to various forcings.

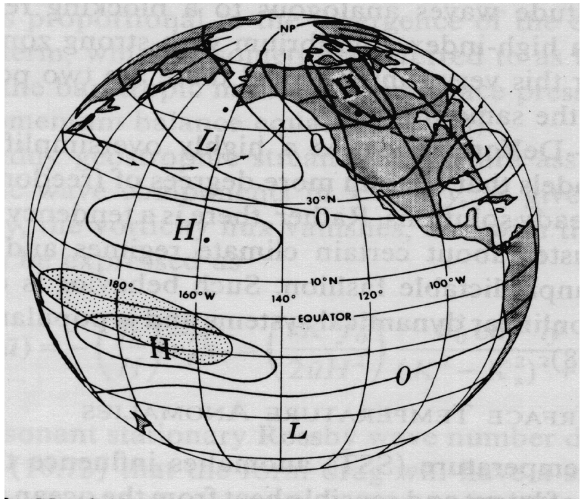
Rossby waves propagate westward wrt to the mean flow



propagation along great circles (geodesics)

(Hoskins & Karoly 1981)

Steady linear atmospheric response to thermal forcing



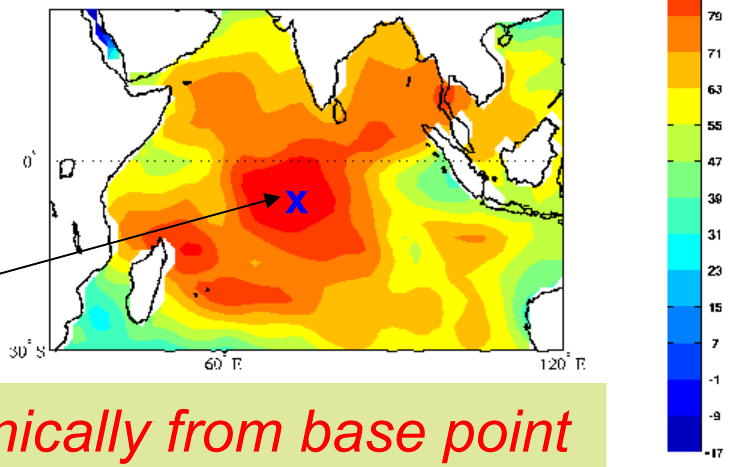
PNA (Horel & Wallace 1981)

3. Teleconnection

✓ *What is the problem ?*

Point correlation of IO SSTA

Monthly IO SST



Base point (correlation =1)

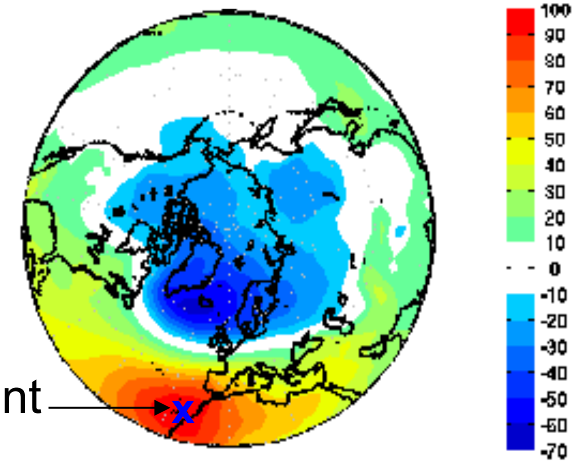
Correlation decreases nearly monotonically from base point

Correlation of DJF NCEP/NCAR SLP (1948-2003)

Monthly SLP

Result - there are anticorrelated regions in SLP: some sort of see-saw btw Azores & Iceland

The North Atlantic Oscillation (NAO)

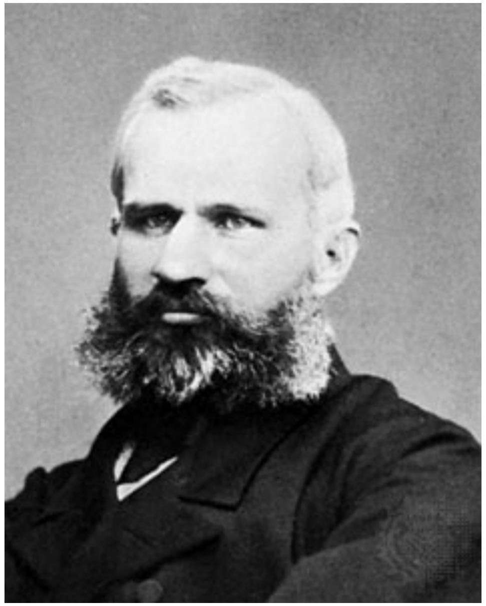


Base point

✓ *A bit of history*

A. Ångström (1935) Teleconnections of climatic changes in present time, *Geogr. Annal.*, **17**, 243-258.

“the weather at a given place is not an isolated phenomenon but is intimately connected with the weather at adjacent places”

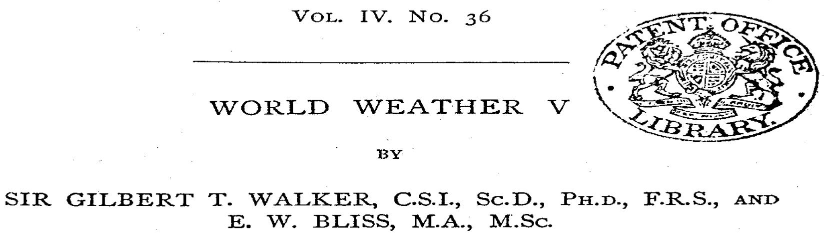


Anders Ångström (1814-1874)
Physicist in Uppsala University

The idea of global scale oscillation in SLP seems to go back to Hilderbransson in 1897 and Lockyer in1906: SLP seesaws between SE Australia and Southern South America.

“The relationships between weather over the Earth are so complex that it seems useless to try to derive them from theoretical considerations; and the only hope at present is that of ascertaining the facts and of arranging them in such a way that interpretation shall be possible.”

Gilbert Walker (1908)

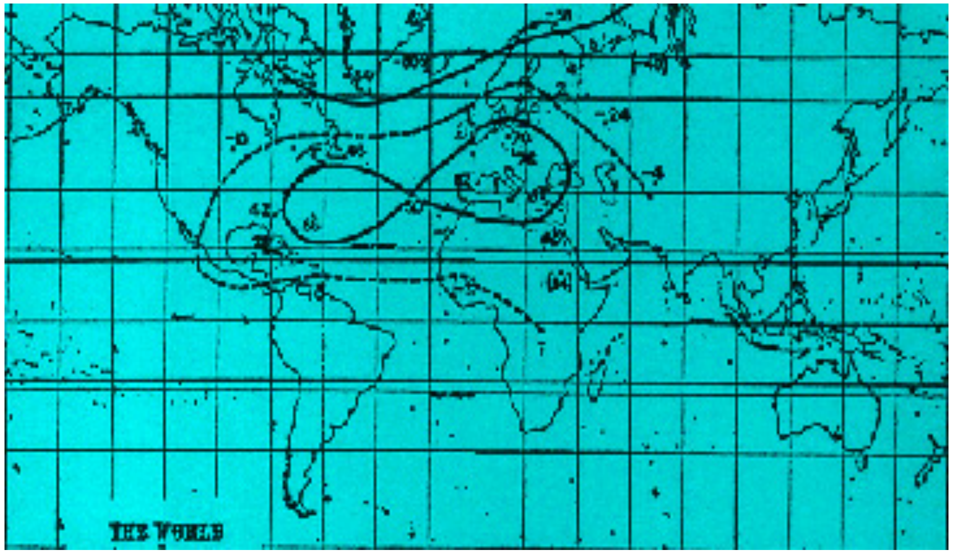


MEMOIRS OF THE ROYAL METEOROLOGICAL SOCIETY,
VOL. IV. NO. 36

WORLD WEATHER V

BY

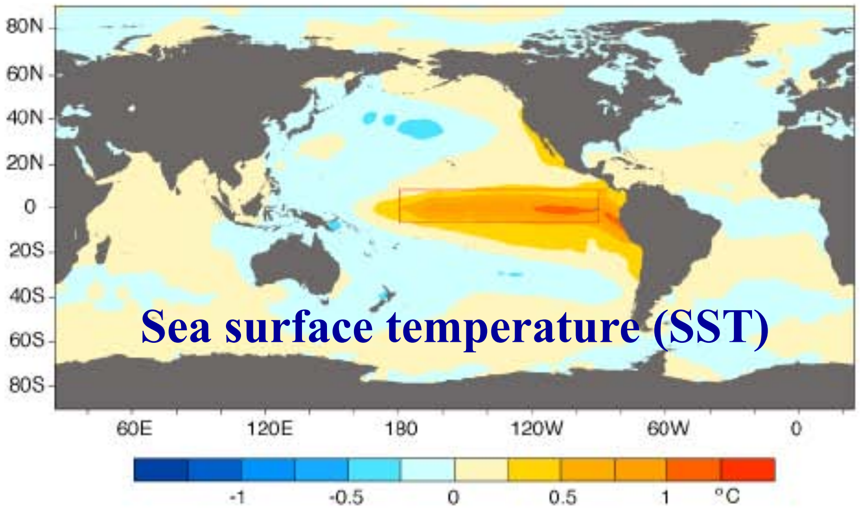
SIR GILBERT T. WALKER, C.S.I., SC.D., PH.D., F.R.S., AND
E. W. BLISS, M.A., M.SC.

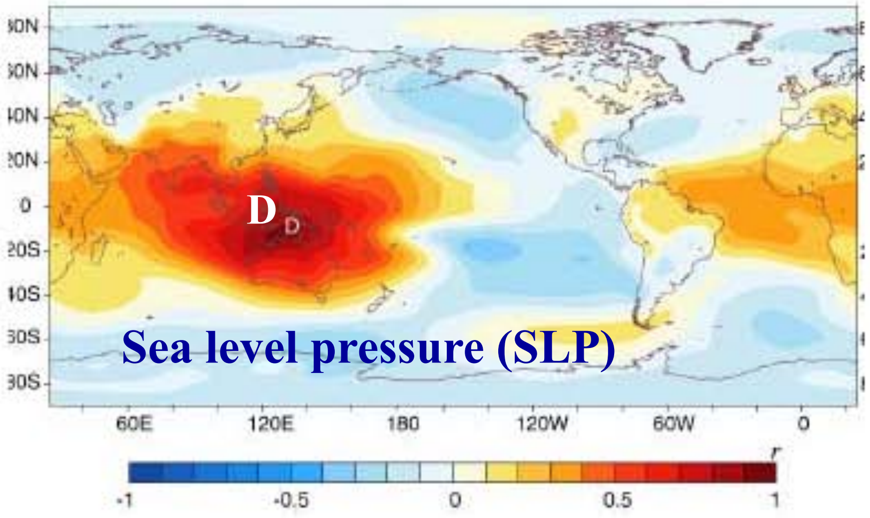


Gilbert Walker was supposed to study the Indian summer Monsoon, he ended instead discovering the SO & the NAO

✓ *Main teleconnections*

El-Nino Southern Oscillation (ENSO)


Sea surface temperature (SST)


Sea level pressure (SLP)

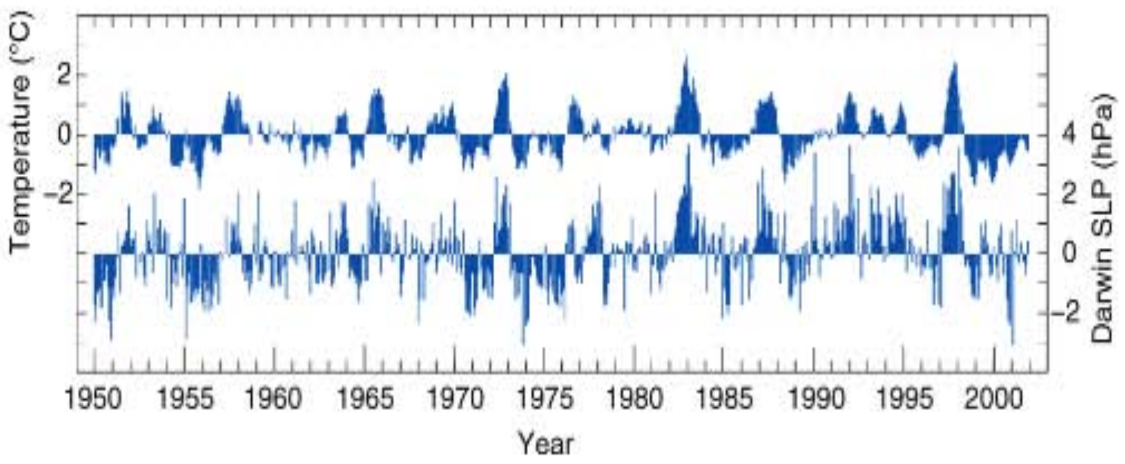
ENSO is a coupled phenomenon between the Pacific ocean and the global atmosphere.

Normal conditions: warm west Pacific & cold east Pacific SST.

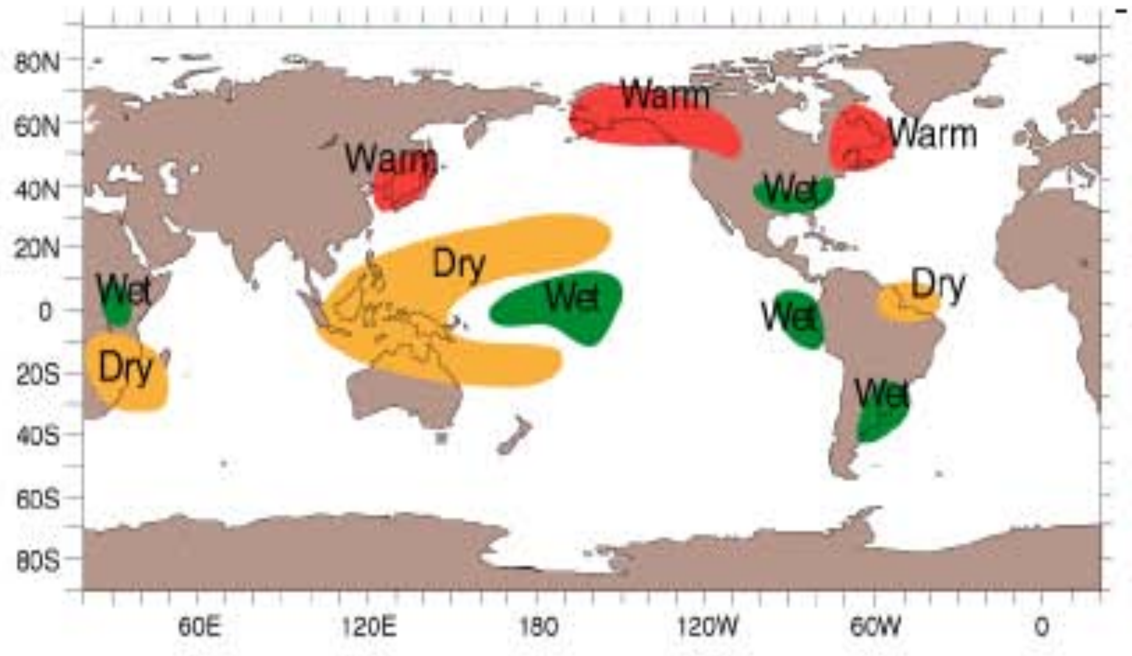
Warm conditions: warming of east Pacific El-Nino

El-Nino is associated with High SLP over Austral-Asia and low SLP eastward

Nino-3 SST and Darwin sea level pressure

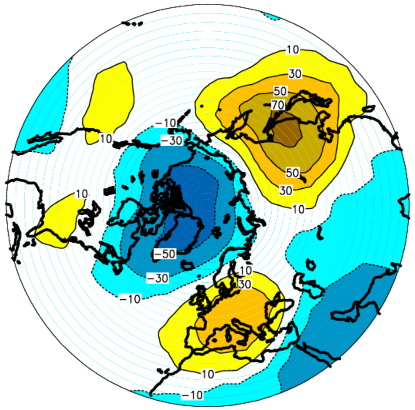


Coherence between East tropical Pacific SST & west equatorial SLP (southern oscillation)

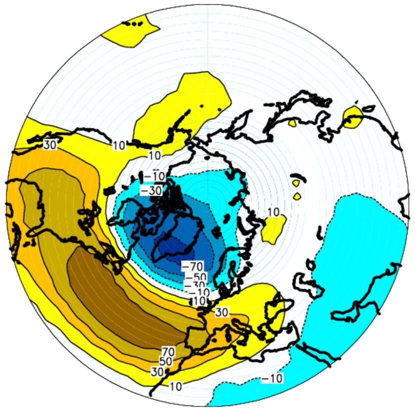


Worldwide effect of El-Nino phenomenon

Northern hemispheric teleconnections

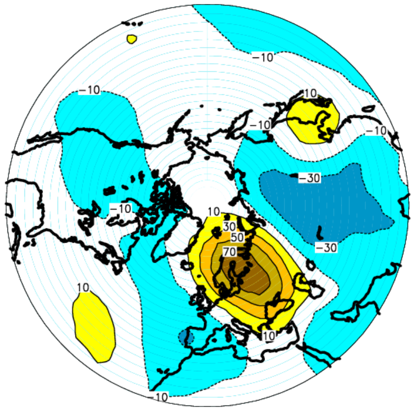


a) Polar–Eurasian Pattern



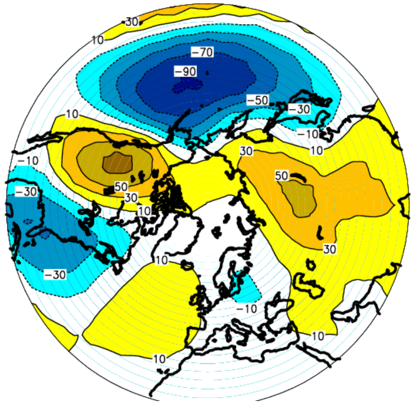
NAO

b) North Atlantic Oscillation



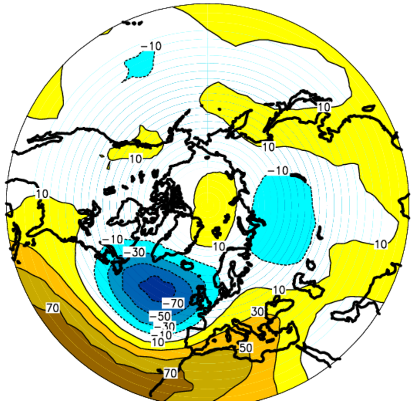
SC

c) Scandinavian (EU–1) pattern



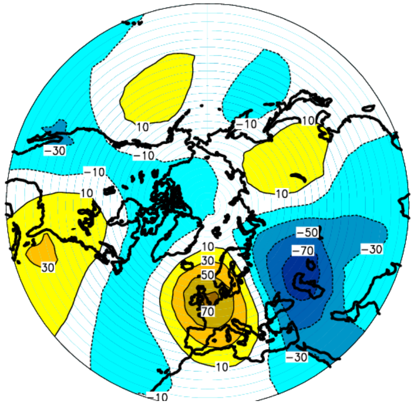
PNA

d) Pacific/North America pattern



EA

e) East Atlantic Oscillation



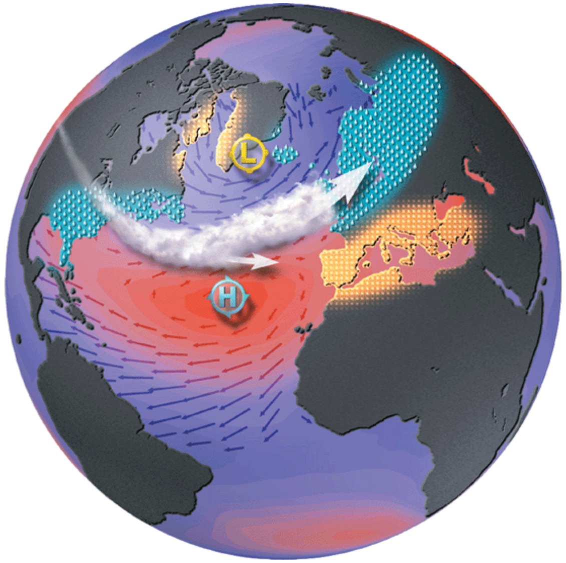
EA-WR

f) East Atlantic/West Russia pattern

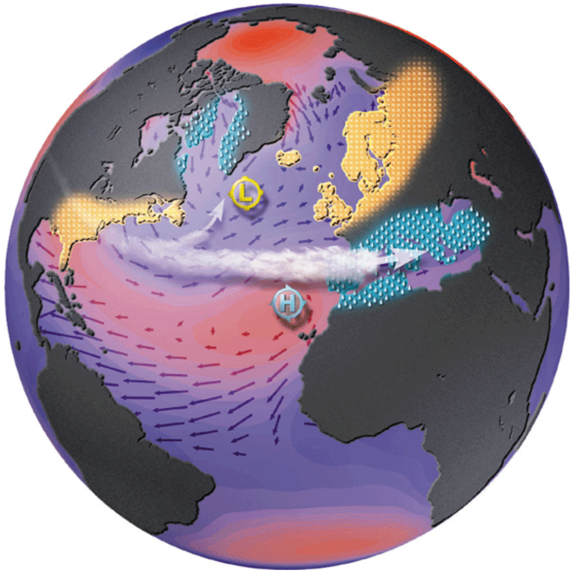
Source: CPC/NOAA

The North Atlantic Oscillation (NAO)

Meridional seesaw in the atmospheric mass between subtropical high & polar low (pressure difference between Iceland & the Azores

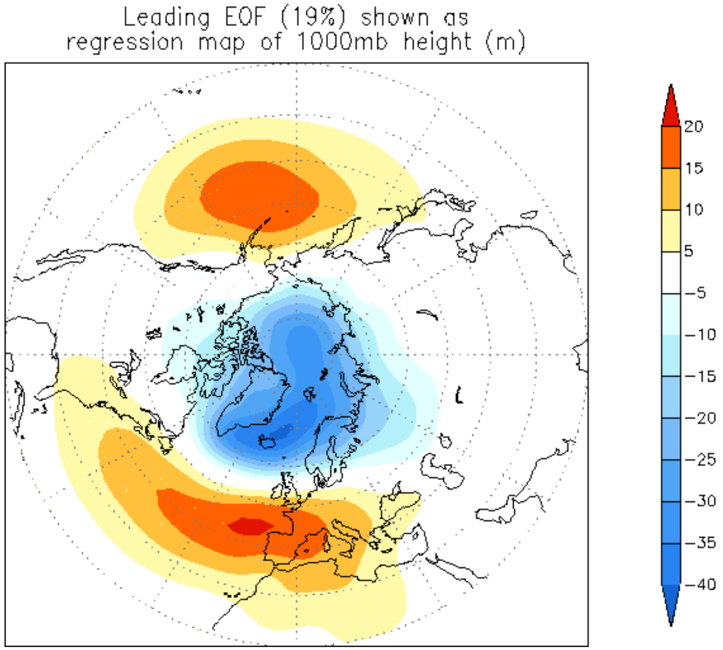


Positive Phase



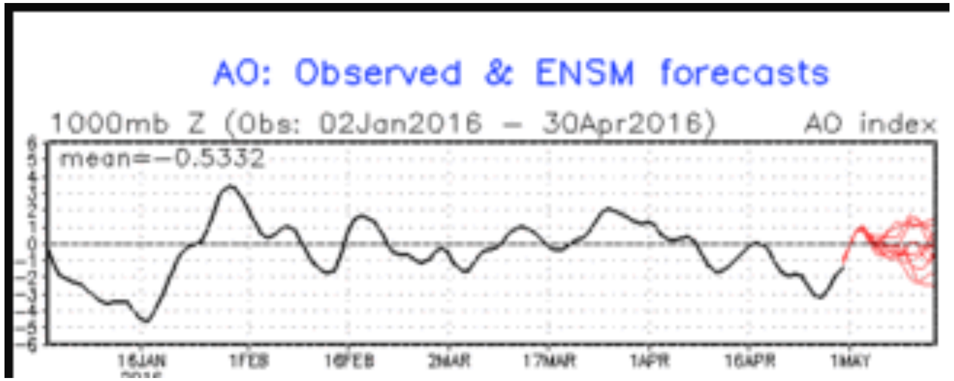
Negative Phase

Northern Annular mode/Arctic Oscillation (NAM/AO)



Hemispheric version of the NAO

NAO/AO dichotomy: Ambaum et al. 2001



16 Jan 16 Feb 17 Mar 16 Apr

Observed time series 2 Jan - 30 Apr 2016

NOAA CPC

✓ *Importance of teleconnection patterns*

- They link remote locations on the Earth
- They have a large impact on surface weather/climate including surface extremes
- They describe large amount of atmospheric variability
- They can be used for extended range (eg seasonal) prediction
- They can be used for downscaling

etc.

✓ *How to obtain teleconnections ?*

- Station-based regression
- One-point correlation (Wallace & Gutzler 1981)
- Empirical orthogonal function (EOFs), rotated EOFs, optimally interpolated patterns (Hannachi et al. 2007)
- Nonlinear EOFs (Monahan et al. 2000)
- Empirical teleconnections (Van den Dool et al. 2000, Franzke and Feldestein 2005)
- Cluster analysis
- Composite analysis

etc.

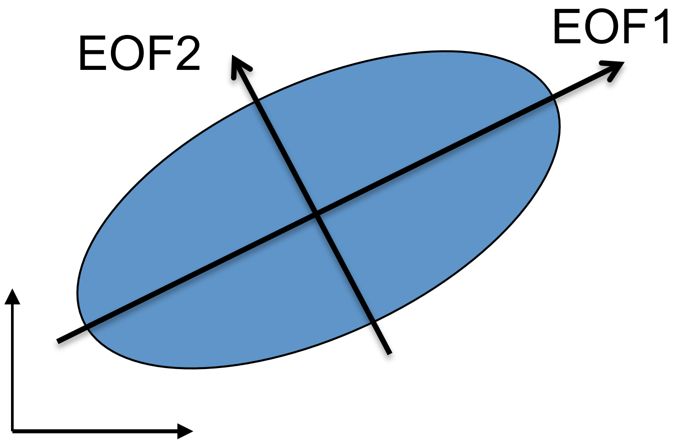
Empirical Orthogonal Functions (EOFs)

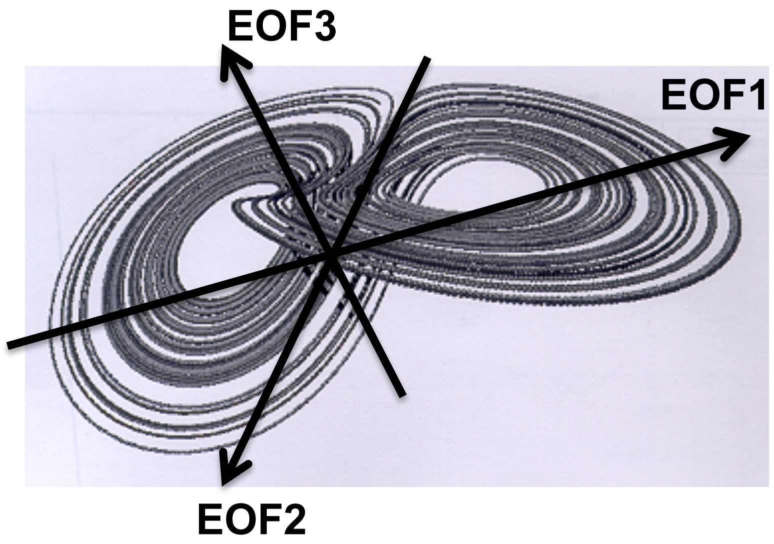
EOFs: $\mathbf{C}\,\mathbf{u} = \lambda\mathbf{u}$, $\mathbf{C} = \langle \mathbf{x}\mathbf{x}^{\mathrm{T}} \rangle$ Is the covariance matrix

EOFs: **orthogonal** & PCs $a_k(t) = \mathbf{x}_t^{\mathrm{T}}\mathbf{u}_k$ **uncorrelated**

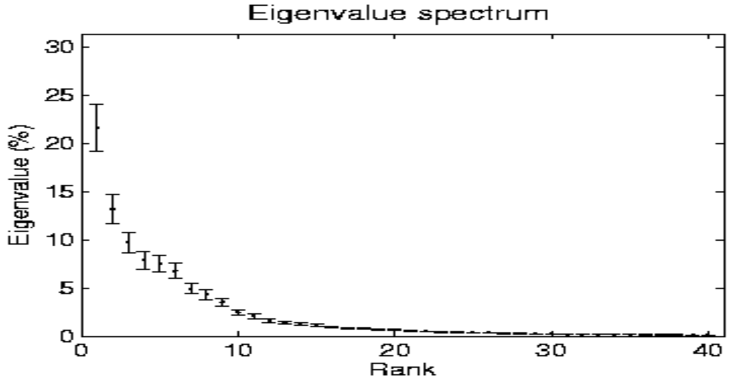
Decomposition: $\mathbf{x}_t = \sum_{k=1}^{p} a_k(t)\mathbf{u}_k$

The eigenvalues provide successively the % of explained variance

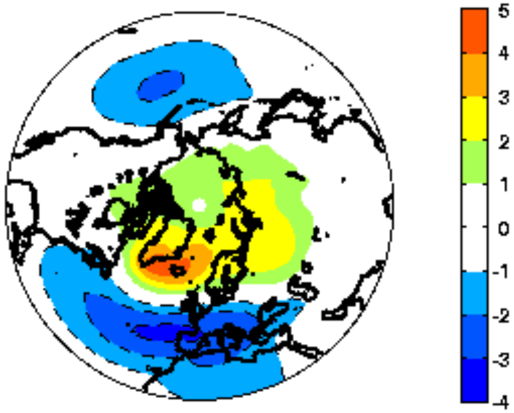




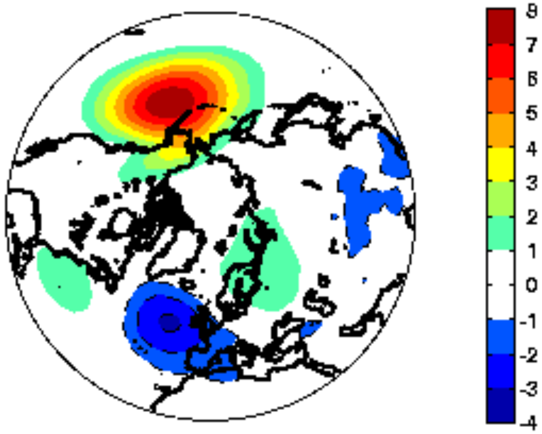
Empirical Orthogonal Functions (Cont)



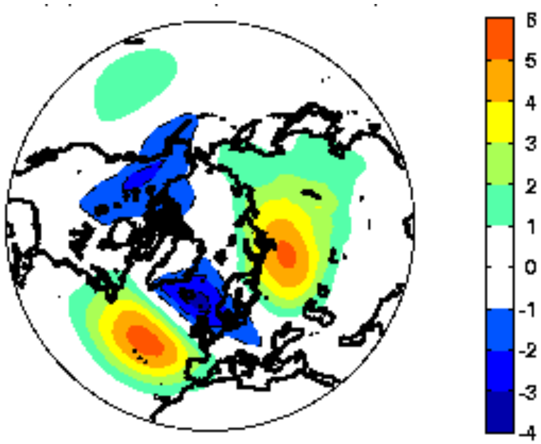
Eigenvalues of the covariance matrix in % of explained variance of monthly DJF 1948-2000 NCEP/NCAR SLP



EOF1 (21%)
Arctic Oscillation



EOF2 (13%)
Pacific Pattern

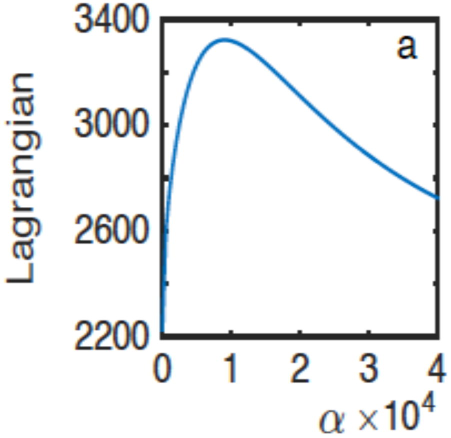


EOF3 (9%)
Scandinavian Pattern

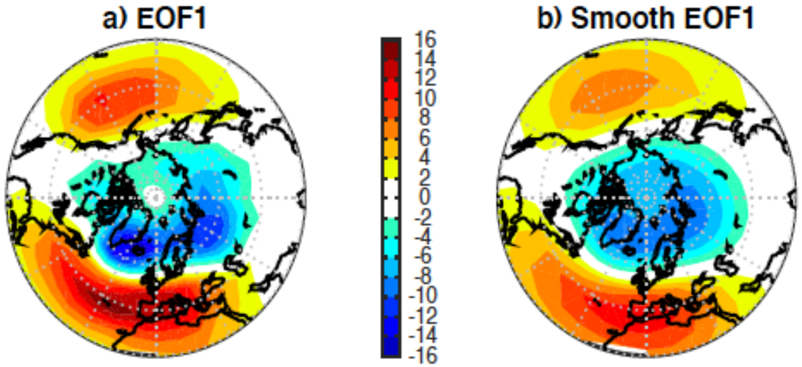
Regularised EOFs

Solves instead a generalised eigenvalue problem (Hannachi 2016) and overcomes some of the drawbacks of EOFs, e.g. **time and space orthogonality** – helps in addressing the NAO-AO dichotomy

$$\mathbf{C}\ \mathbf{u} = \mu(\mathrm{I}+\lambda D^4)\mathbf{u}$$

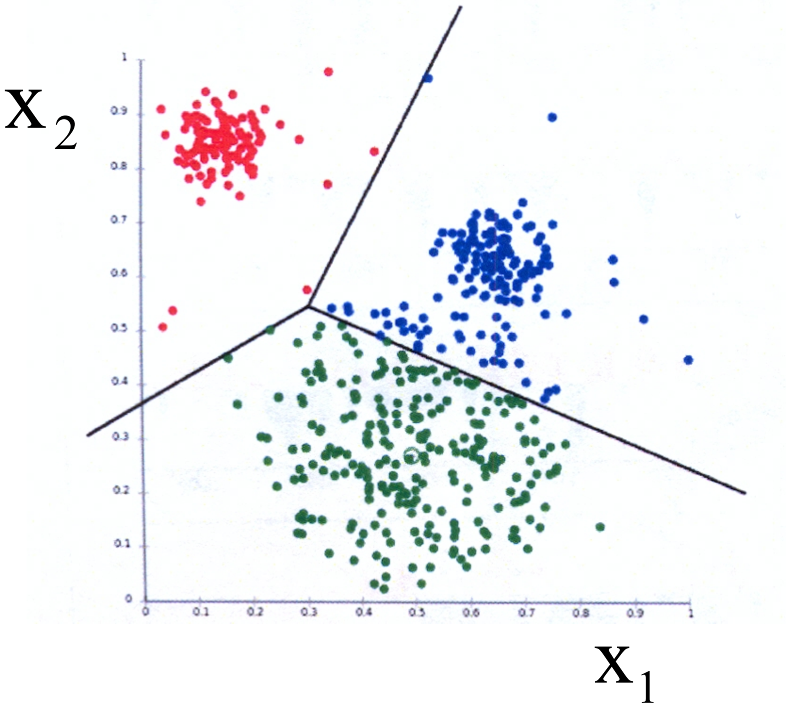


Smoothing parameter (Lagrangian)

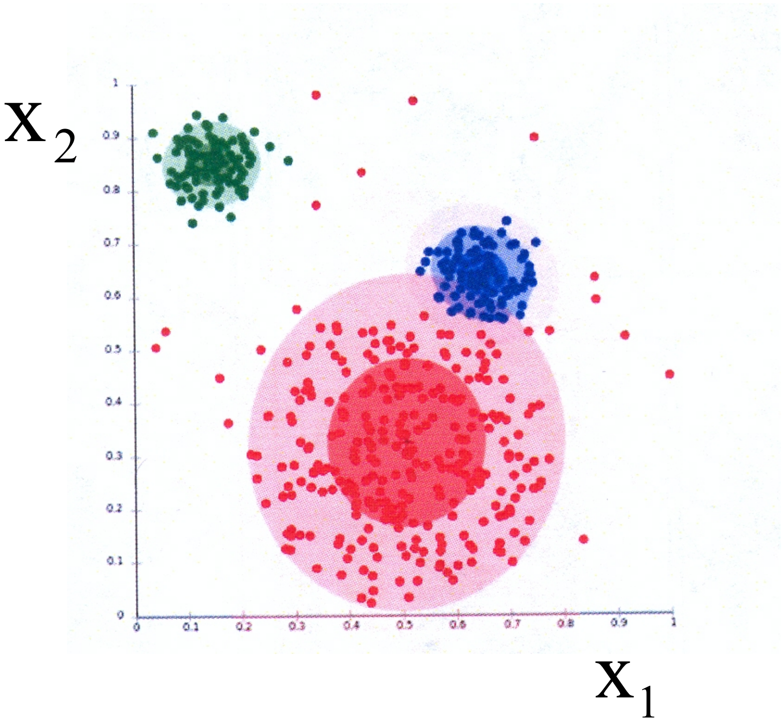


EOF1 vs regularised EOF1

Cluster analysis



K-means



Gaussian mixture models

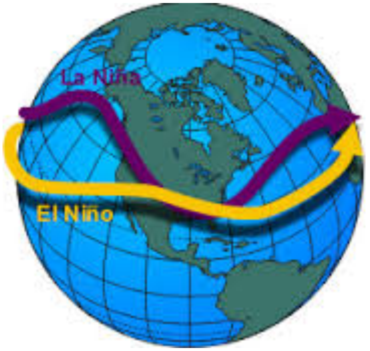
✓ *Teleconnections and jet streams*

The jet stream is a belt of high wind speed around the earth in the upper troposphere (10-15 km)

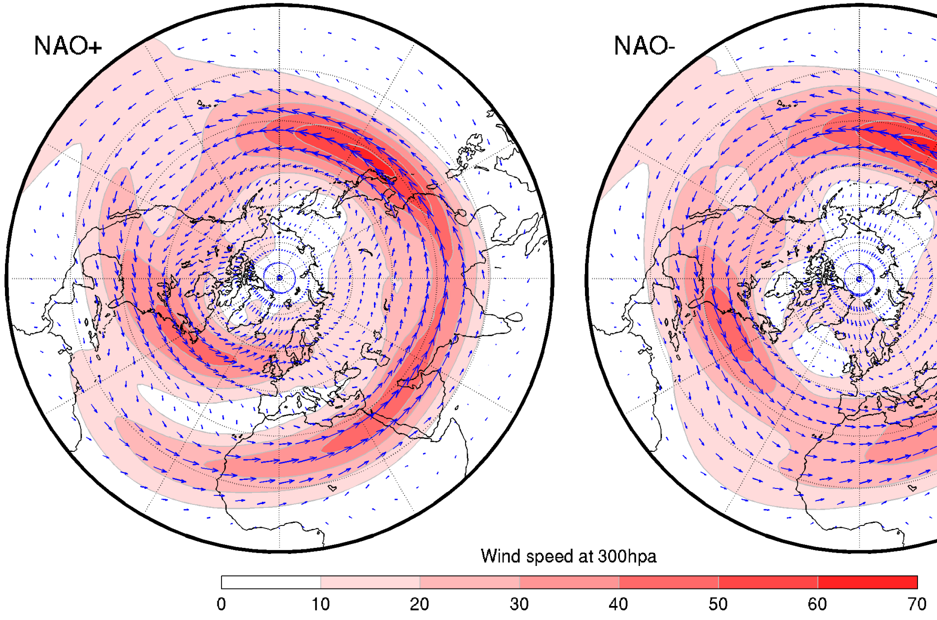
Jet stream

The COMET Program / NASA

Polar/subtropical jet



Jet & ENSO



Zonal wind

Woollings
et al (2010)

- The NAO essentially describes variations in the latitude of the North Atlantic eddy-driven jet.
- Much of extratropical weather/climate variability is associated with jet stream.
- Link btw jet stream & circulation patterns.
- Importance for climate change effect on large scale flow

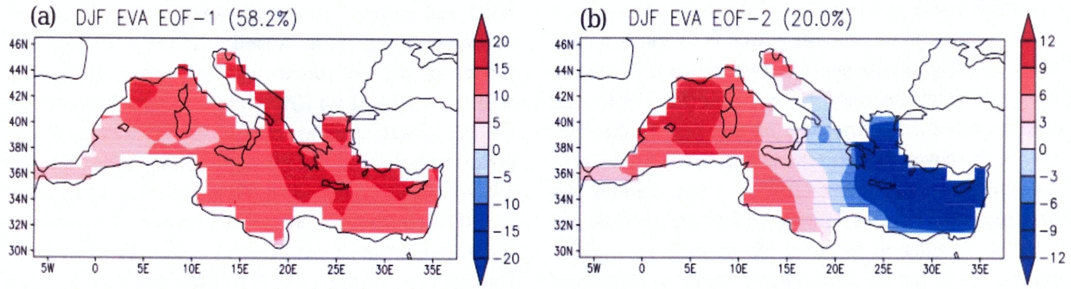
4. Precipitation and teleconnection

✓ *Interannual variability of Mediterranean evaporation*

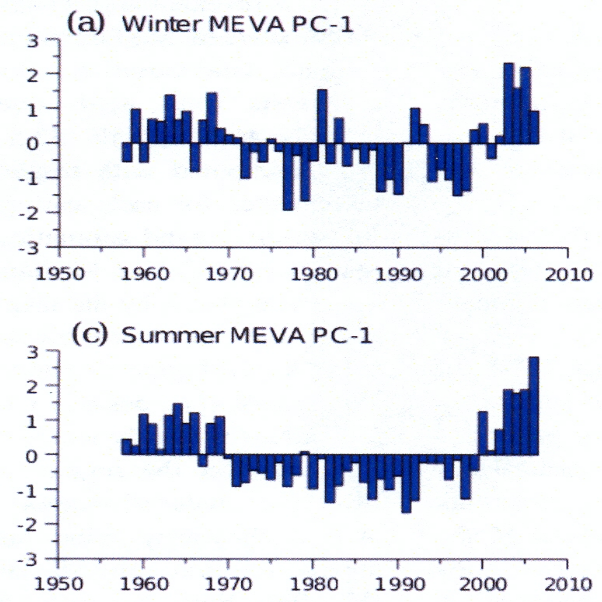
Data: Med. Evap. From Woods Hole
Ocean. Inst., Cru precip & ERA40

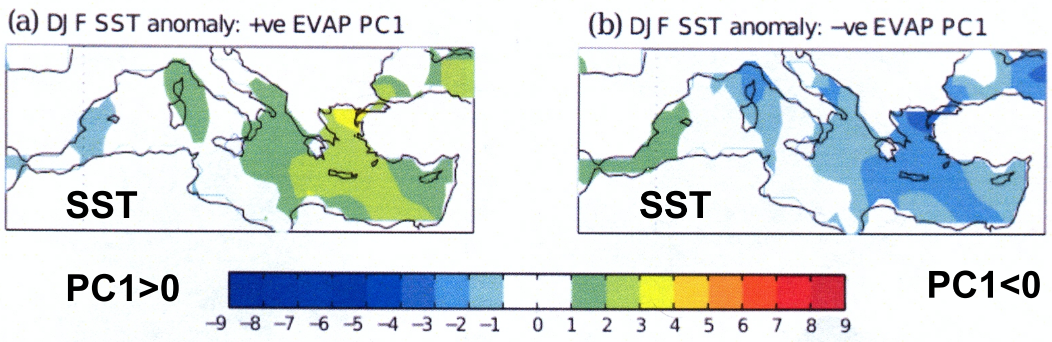
(Zveryaev & Hannachi
2013, 2016)

EOF1 **EOF2**



Interann. & interdec. variability

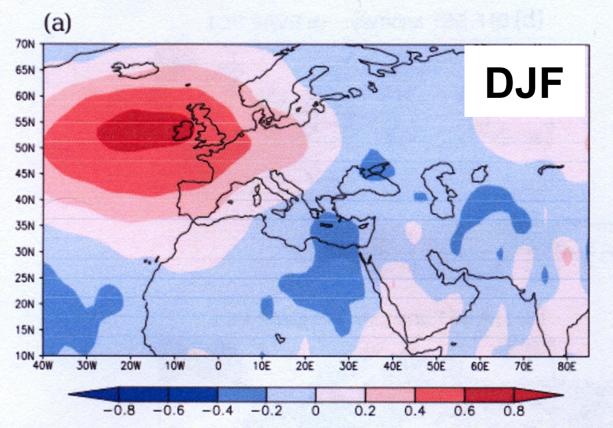




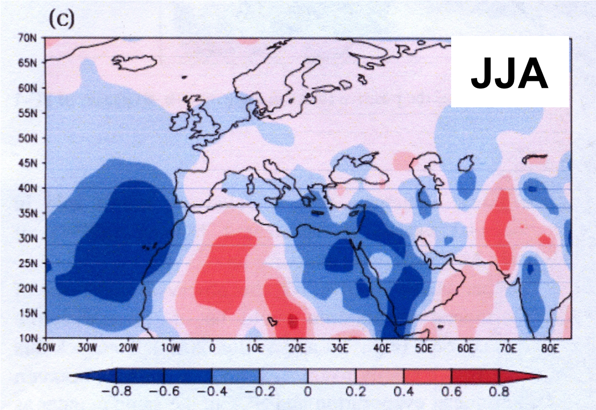
SST **SST**

PC1>0 **PC1<0**

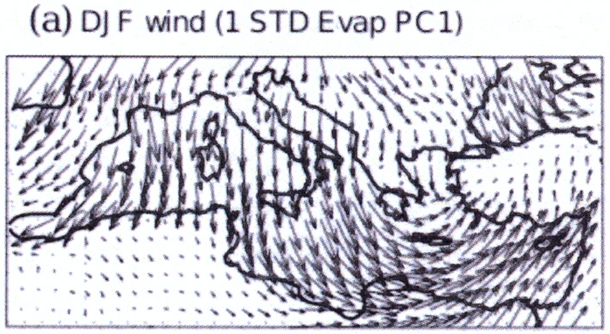
Corr (Evap PC1, SLP)



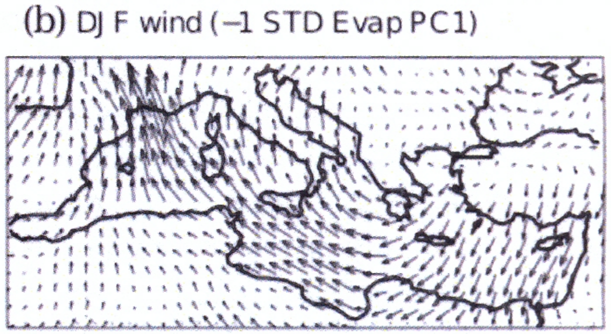
East Atlantic teleconnection pattern



Tropical origin

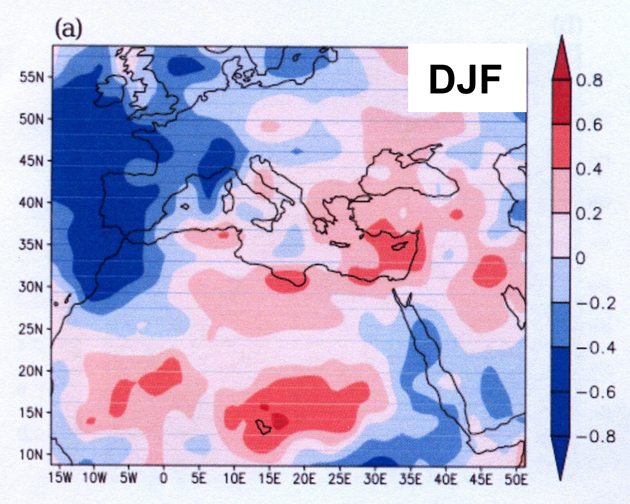


DJF Surface wind (PC1 > 0)

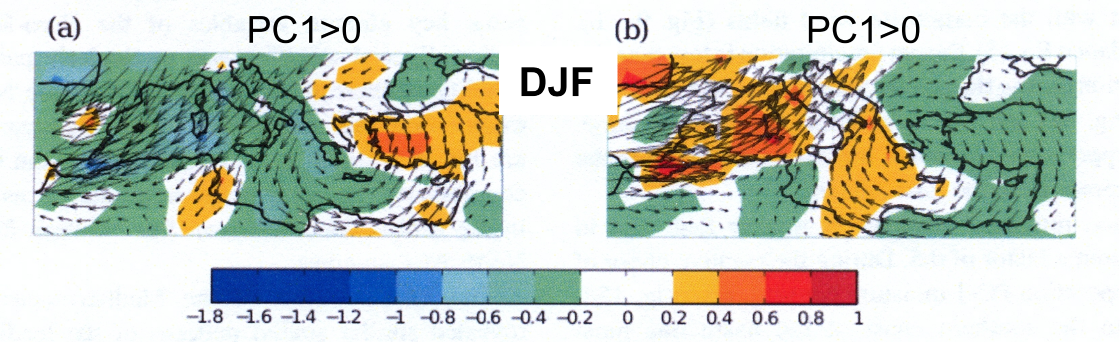


DJF Surface wind (PC1 < 0)

Corr (Evap PC1, Precip)



Integrated moisture transp $\overline{\mathbf{q}}$ *& its convergence*



$$\frac{\partial w}{\partial t} + \nabla.\mathbf{q} = E - P, \quad w = \int_0^{p_s} q \frac{dp}{g} \ \& \ \mathbf{q} = \int_0^{p_s} q\mathbf{v} \frac{dp}{g}$$

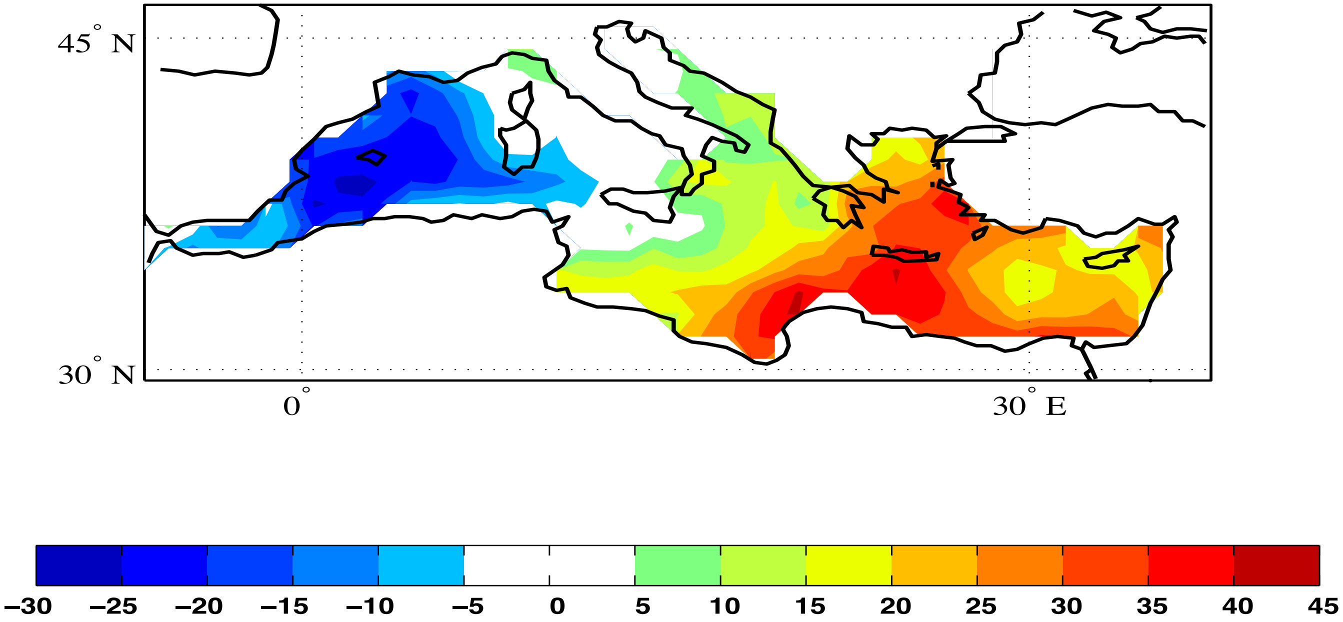
Time average: $\nabla.\overline{\mathbf{q}} = \overline{E} - \overline{P}$

q=specific humidity (WV mass/total mass) and $\mathbf{q} = (qu, qv)$

During +ve PC1 evap: main moisture convergence over minor Asia – Moisture source: East Med.

During -ve PC1 evap: main moisture cv over west/central Med (max 0.8 mm/day North Tunisia) – Moisture source from East North Atlantic

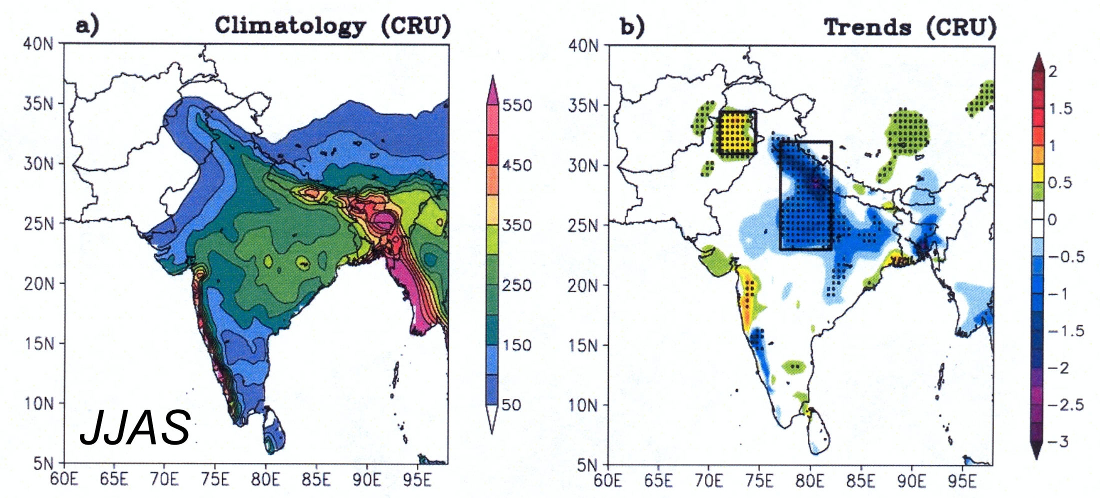
Asian Monsoon – Mediterranean evaporation



Correlation between AIR (all India rainfall) – South Asian monsoon index – and Mediterranean evaporation for the summer 1958 – 2014.

Strong Asian summer Monsoon associated with enhanced (reduced) eastern (western) Mediterranean evaporation

✓ *Rainfall trends over the Indo-Pak Summer Monsoon*

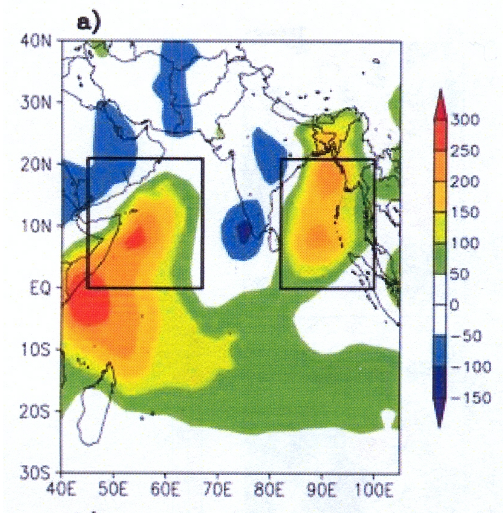


(Latif et al. 2016)

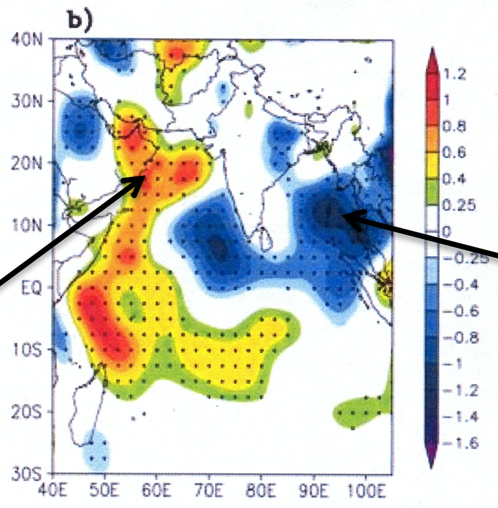
a) 1951-2012 CRU precip climatology (mm/month)

b) JJAS precip trend (mm/month/yr)

Decreasing trend over Central north India (CNI) and increasing trend over the core monsoon region over Pakistan (CMRP)



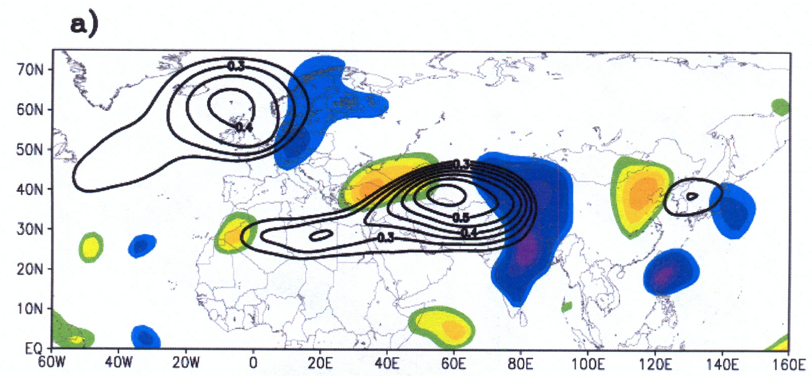
VIMMT climatology $(kgm^{-1}s^{-1})$



Arabian Sea (AS)

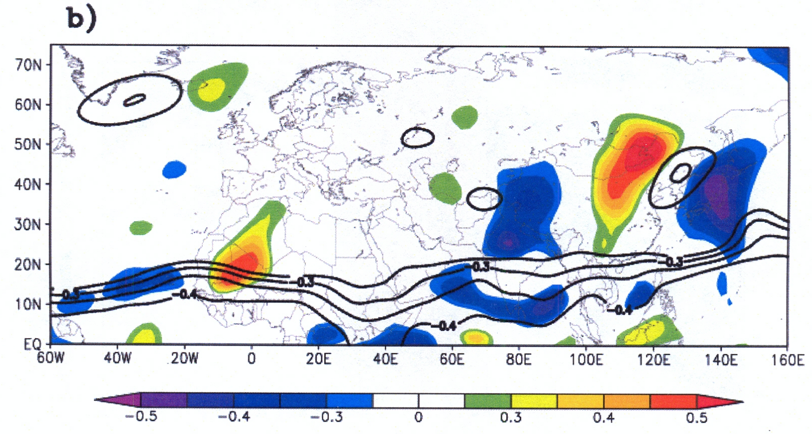
Bay of Bengal (BoB)

VIMMT trend



Correlation between Pakistan precipitation and meridional wind (shaded) and 200-hPa geopotential height (contour)

Circumglobal teleconnection (CGT)



Correlation between Indian precipitation and meridional wind (shaded) and 200-hPa geopotential height (contour)

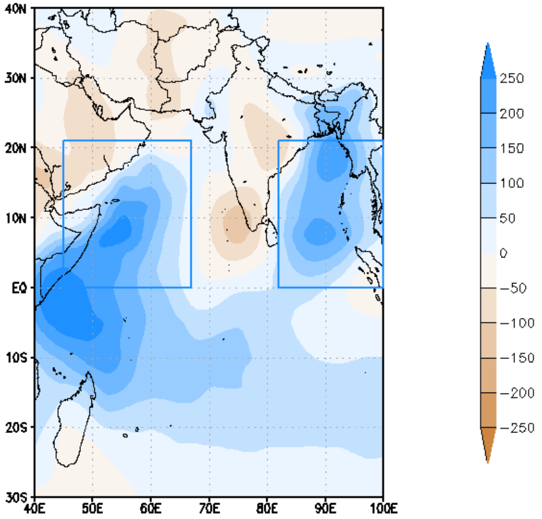
positive trend in Pak precip & negative trend of Indian precip

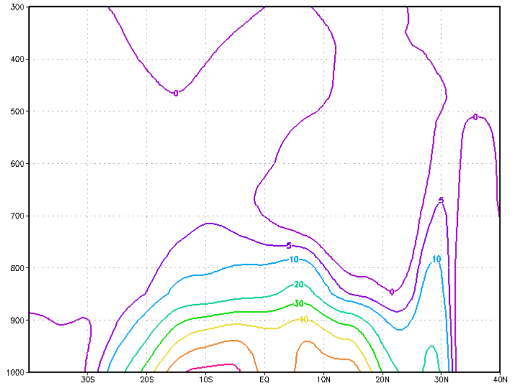
Similar +ve & –ve trend of VIMMT over the AS and the BoB

Link of the summer monsoon Pakistan precip to the CGT

✓ Monsoon moisture transport and global SST

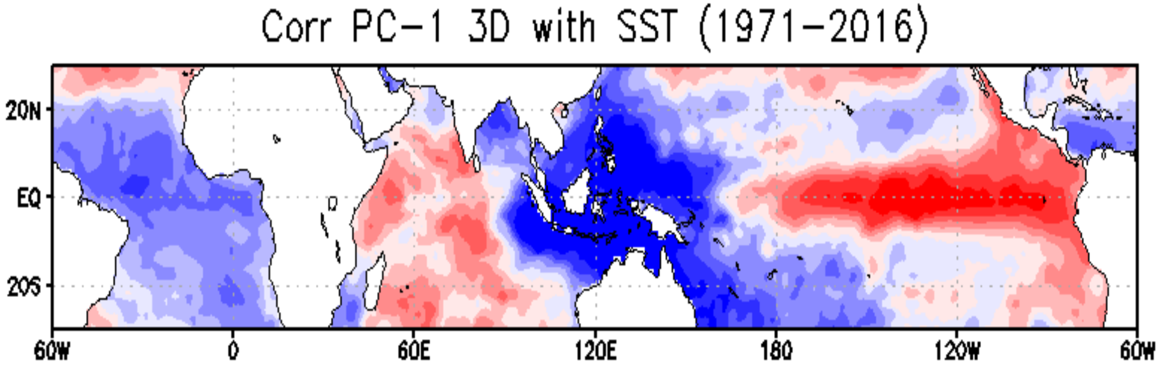
Climatology JJAS
VIMMT (kg/m/s)





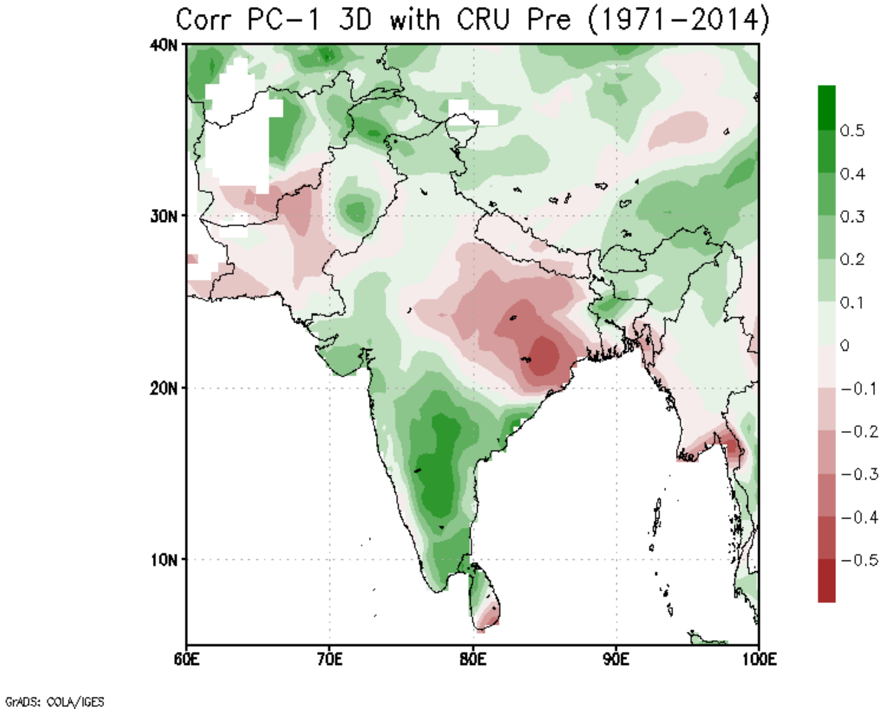
Zonal average of MMT

Correlation of PC1 of
vertically intergrated
Moisture transport
with SST

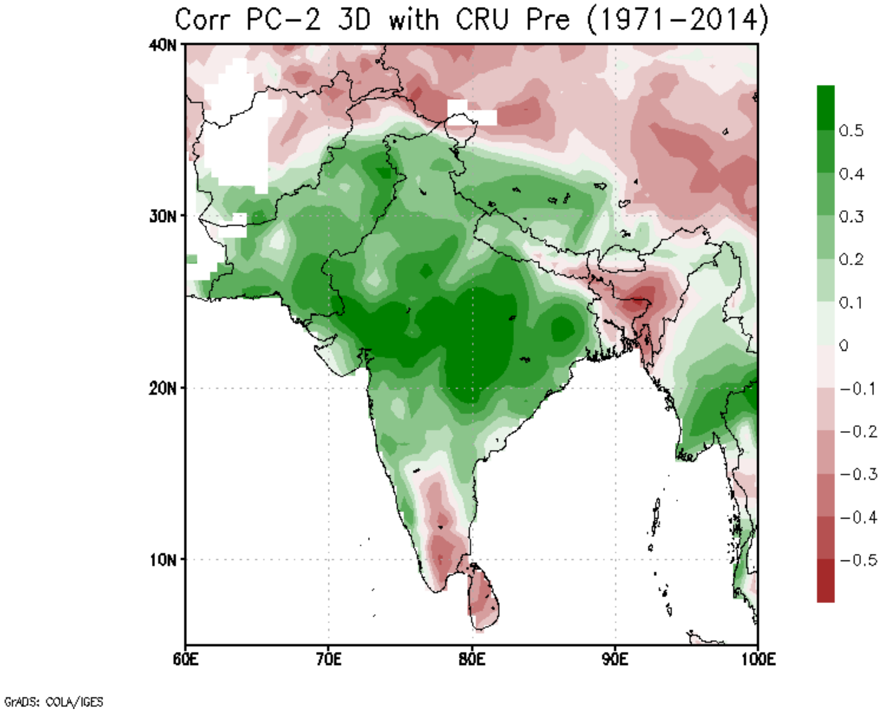


El-Nino forces moisture transport of the Arabian Sea monsoon branch

The IO dipole forces moisture transport over the Bay of Bengal.



Correlation of PC1 VIMT with All India rainfall



Correlation of PC2 VIMT with All India rainfall

South India precipitation forced by El-Nino

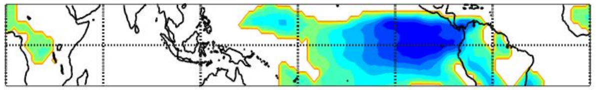
Central India and Pakistan precipitation forced by La-Nina

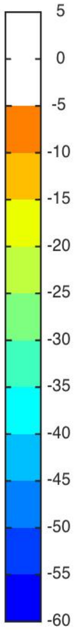
✓ *Some examples of Tunisian precipitation*

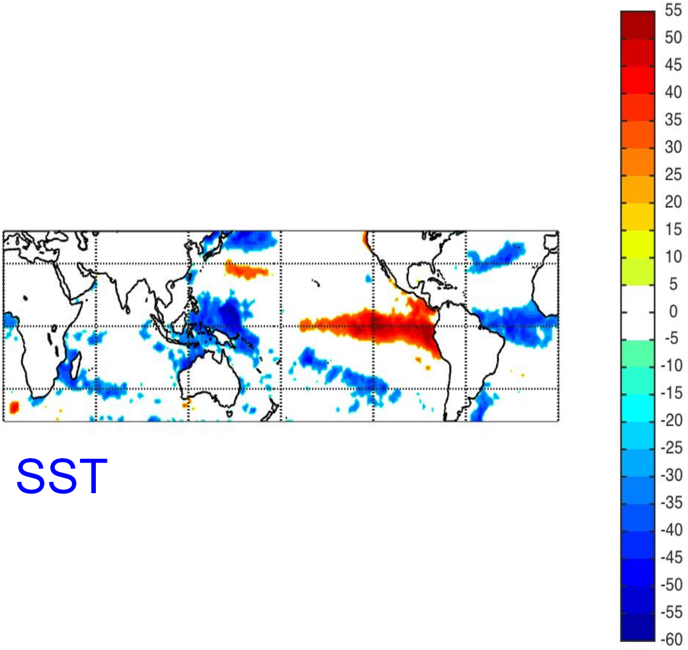
Bizerte precipitation

Lagged Correlation

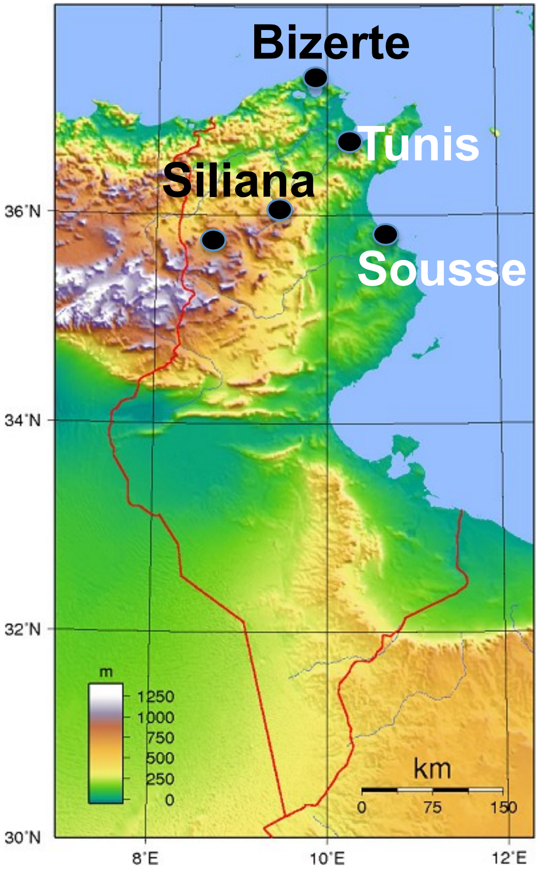
Oct precip/Sep SLP





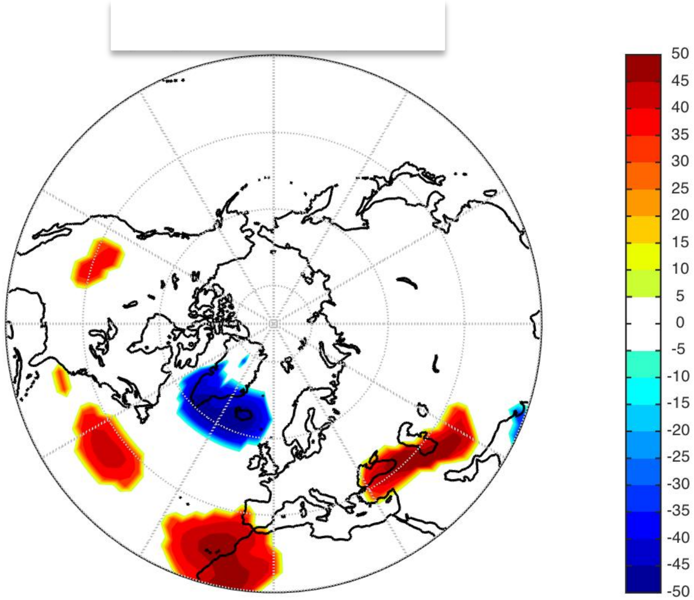


Oct precip/Sep SST



Siliana precipitation

Nov Precip / Nov SLP



NAO

5. Teleconnection & extremes

- EOFs et al. have a number of drawback, and do not treat extremes in any special way. An alternative is provided by archetypal analysis, AA, (Hannachi & Trendafilov 2017)
- AA approximates the data in terms of “pure types” located on its convex. It seeks probability matrices A and B:

$$\{\mathbf{A},\mathbf{B}\} = \underset{\mathbf{A},\mathbf{B}}{\operatorname{argmin}} \|\mathbf{X} - \mathbf{A}^T\mathbf{B}^T\mathbf{X}\|_F^2$$

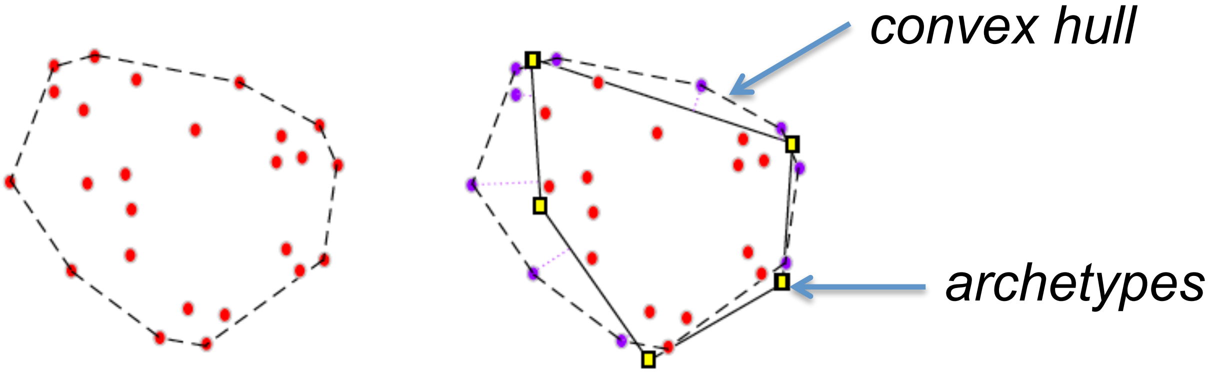
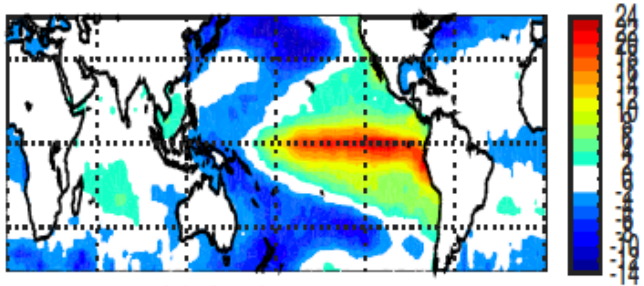


Illustration of archetypes

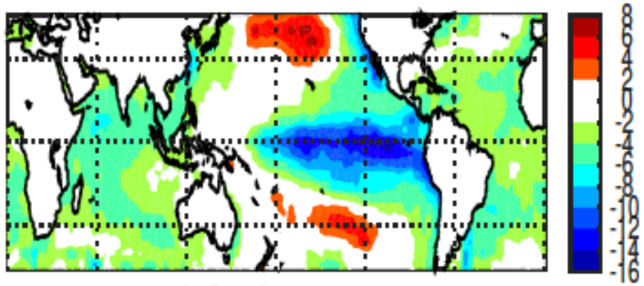
Three archetypes are found for SSTs

a) Archetype 1



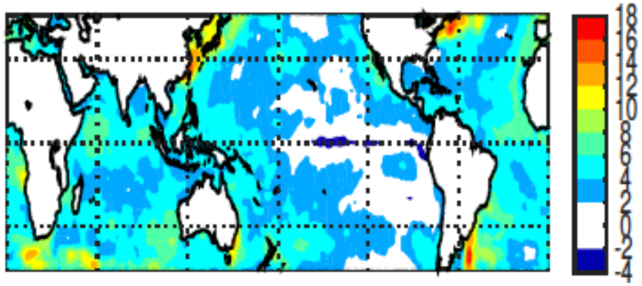
El-Nino

b) Archetype 2

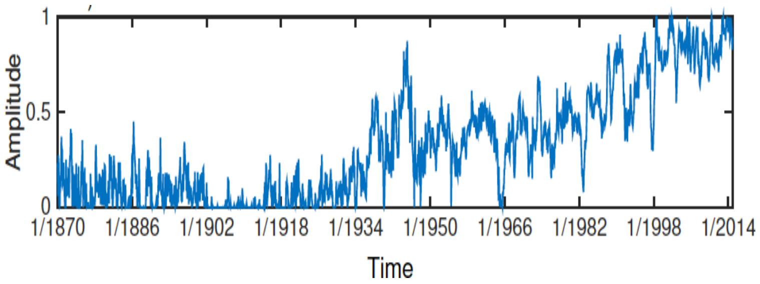


La-Nina

c) Archetype 3

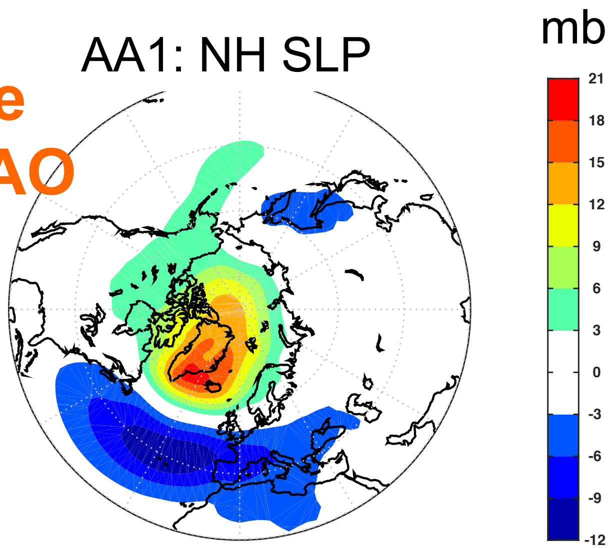


WBC



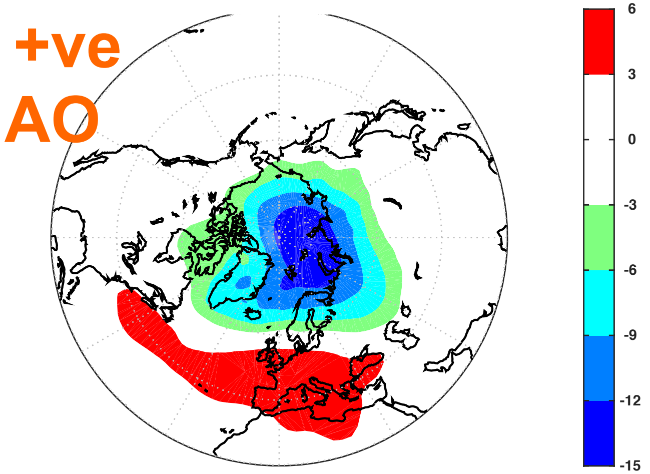
Four archetypes for 1948-2015 NH SLP anomalies

AA1: NH SLP



-ve NAO

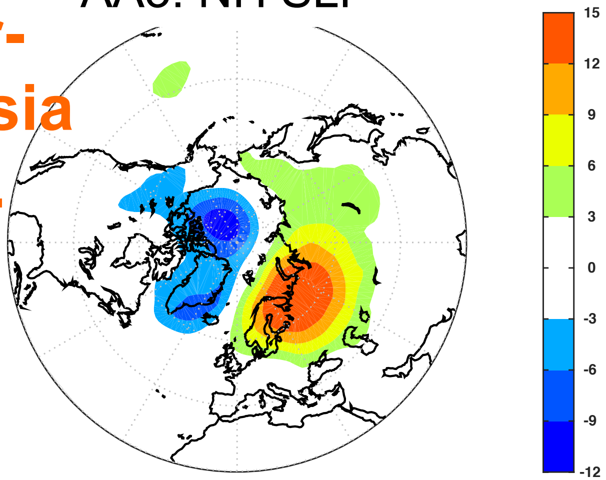
AA2: NH SLP



~ +ve NAO

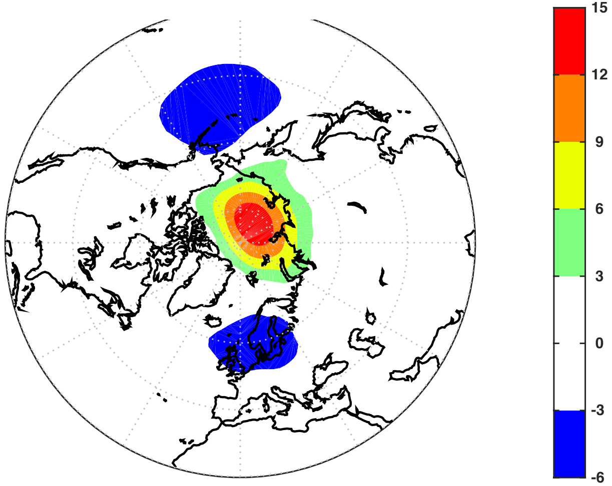
Eurasia-Medit. arch.

AA3: NH SLP



Polar-Eurasia Arch.

AA4: NH SLP



6. Summary & Conclusion

- Dichotomic relationship between weather & climate
- Importance of atmospheric large scale and the role of large scale Rossby waves
- Teleconnections:
  - Linking places far apart
  - Explain large amount of atmospheric variability
  - Control surface climate
  - Very useful, e.g., prediction, downscaling, etc.
  - NAO, PNA, ENSO, etc.
- Link to regional scale precipitation
- Teleconnection and extremes

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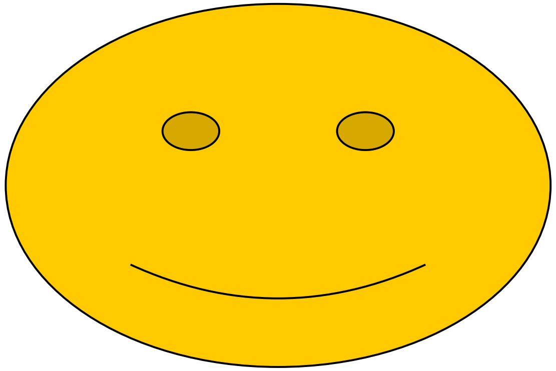

Thanks