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NAO-like variability and the impact of thermal land-sea contrast.

MOLTENI Franco

European Centre For Medium-Range Weather Forecasts (ECMWF)
Shinfield Park
Berkshire
RG2 9AX Reading
UNITED KINGDOM

NAO-like variability and the impact of thermal land-sea contrast

Franco Molteni
European Centre for Medium-Range Weather Forecasts, Reading

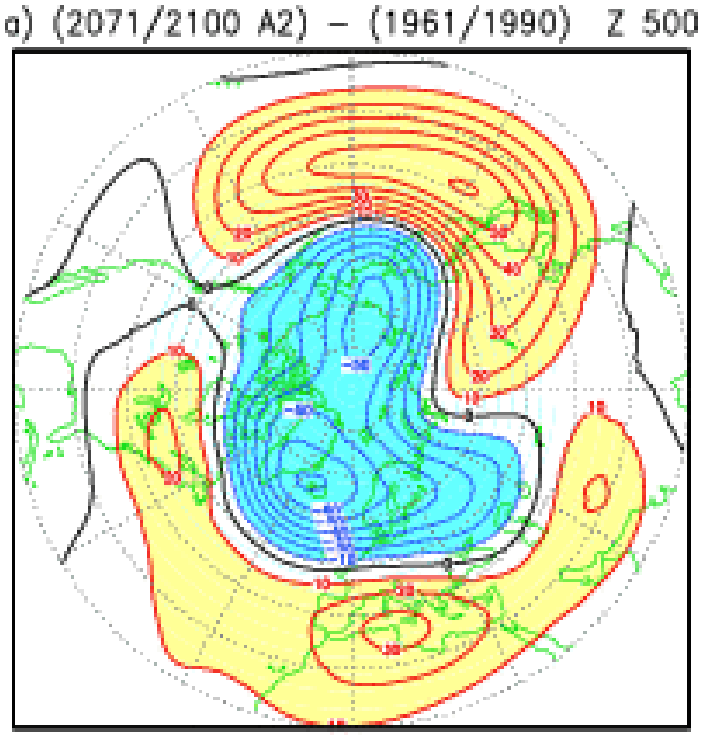
Fred Kucharski
Abdus Salam Int. Centre for Theoretical Physics, Trieste

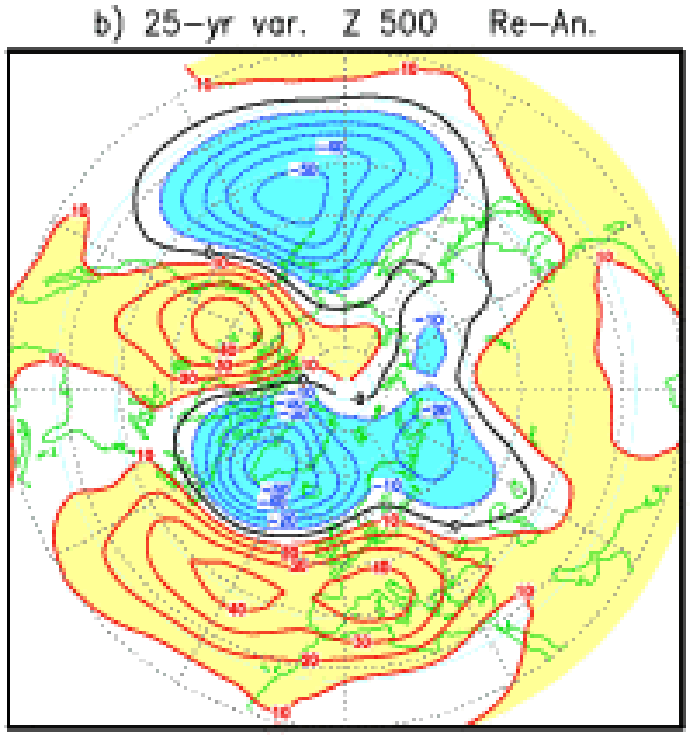
Martin P. King
Monash University, Selangor, Malaysia

Inter-decadal NAO variability: forced vs. natural

Z 500 variation in A2 scenario run
(2071/2100) – (1961/1990)
Global mean removed

Z 500 from NCEP/NCAR re-an.
(1976/2000) - (1951/1975)





Both fields are from Jan-Feb. averages

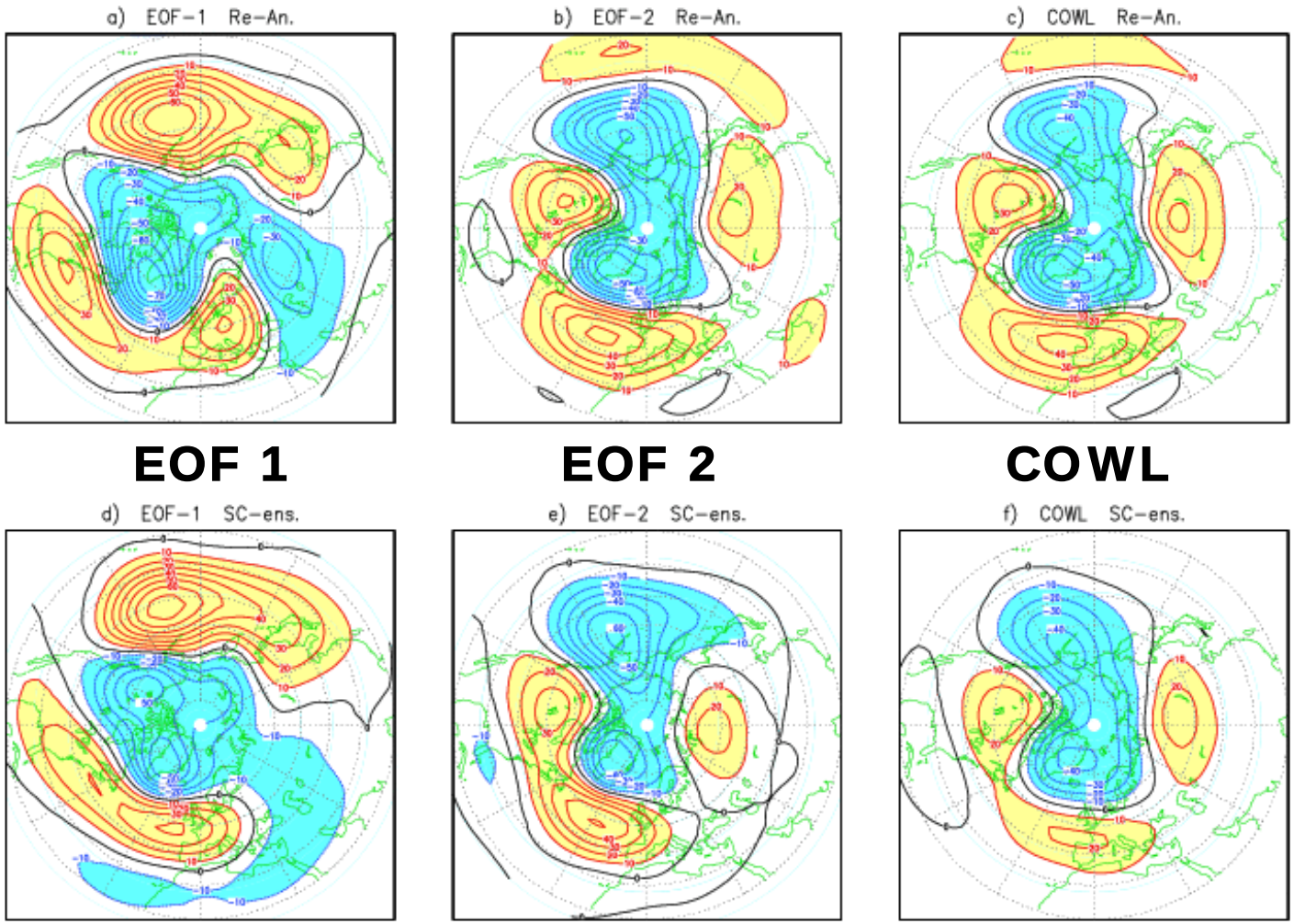
Re-analysis data and numerical model

- Analysed data:
  - NCEP-NCAR re-analysis, 1950-2002 *(shown here)*
  - ERA-40 re-analysis, 1960-2002 *(not shown, used to check robustness of inter-decadal signals)*

- Numerical model /simulations:
  - ICTP intermediate-complexity AGCM (SPEEDY v.40)
    T30 hor. resolution, 8 vertical levels
    (Kucharski et al. 2006, 2007, 2008; see:
    http://users.ictp.it/~kucharsk/speedy-net.html)
  - 20-member ensemble with globally-prescribed SST from HadISST dataset, 1950-2002
  - 1200-month perpetual winter simulations (described later)

Empirical variability patterns: EOFs and COWL

COWL (cold ocean – warm land) index after Wallace et al. (1995)



Z 500 hPa
JF 1950-2002

NCEP/NCAR
Re-Analysis

ICTP AGCM
simulations
forced by
HadISST

Dynamical modes of variability

- **Annular mode variability**:

  zonally symmetric variability induced by baroclinic or planetary waves – zonal mean flow interactions

  - Feldstein and Lee 1996
  - Limpasuvan and Hartmann 2000
  - Kimoto, Jin, Watanabe and Yasutomi 2001
  - Eichelberger and Holton 2002

- **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)

Dynamical modes of variability: indices

- **Annular Mode index**:

  AM = Difference in zonally-averaged MSLP anomaly,
  [30-45 N] – [55-90 N]

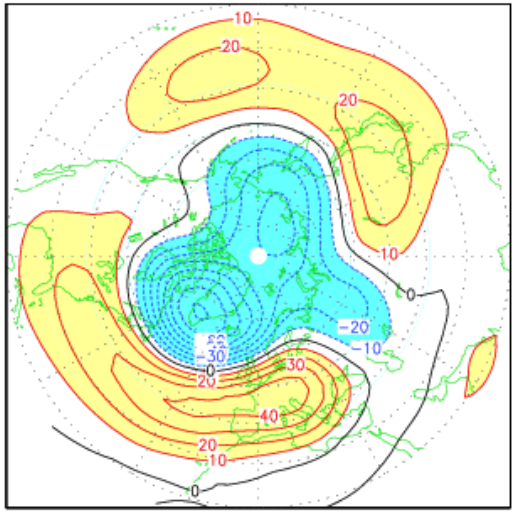
- **Thermal-balance Wave index (positive in COWL phase)** :

  Zonal wanenumber-2 component of net surface heat flux (NSHF, positive upward) in the [45-70 N] latitudinal band:

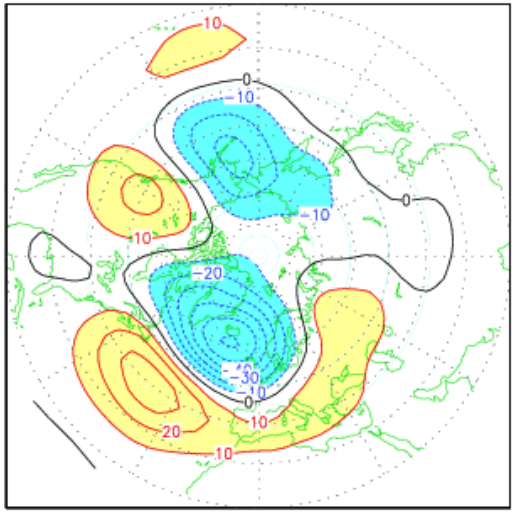
  TW = NSHF [60W-30E] - NSHF [30E-120E] +
  NSHF [120W-150W] - NSHF [150W-60W] -

Regression of Z 500 onto AM and TW indices

a) reg(gh_500, AM) Re−An.



b) reg(gh_500, TW) Re−An.

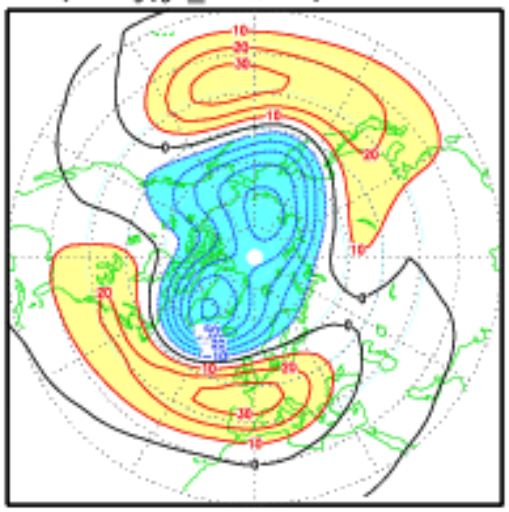


Z 500 hPa
JF 1950-2002

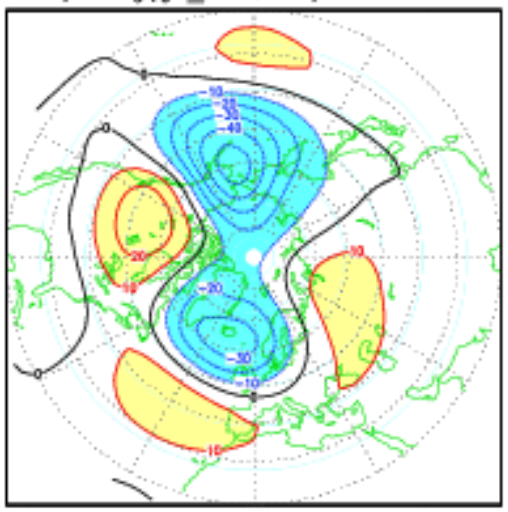
NCEP/NCAR
Re-Analysis

AM

a) reg(gh_500, AM) SC−ens.



b) reg(gh_500, TW) SC−ens.



TW

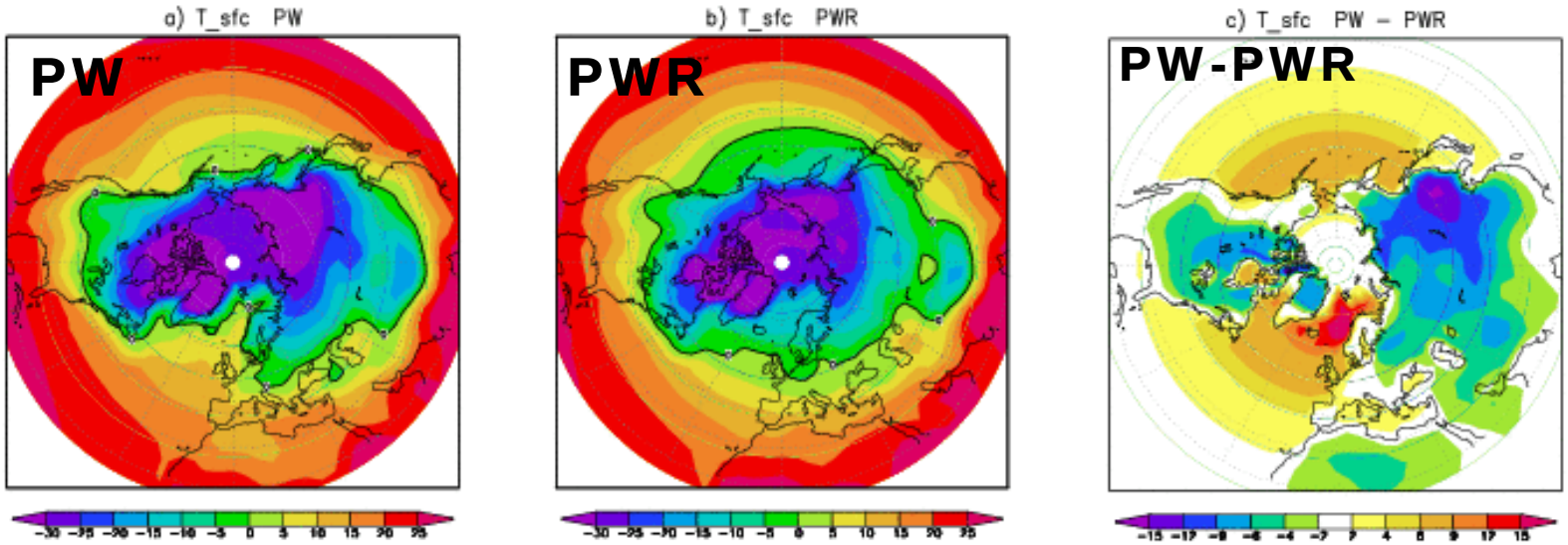
ICTP AGCM
simulations
forced by
HadISST

Are AM and TW variations independent?

- In the presence of thermal land-sea contrast, zonal-mean wind variations induce variability in the location and amplitude of surface heat fluxes, especially on the western side of the northern oceans
- In thermal equilibration theory, the phase of the streamfunction/ geopotential response depends on the zonal mean wind: upper-level troughs over warm oceans are associated with stronger zonal wind (e.g. Marshall and So 1990)
  - Correlation (AM, TW) in re-analysis: **0.45** *(trends are in phase!)*
  - Correlation (AM, TW) in ICTP AGCM: **0.31** *(weaker trends)*
- If longitudinal thermal contrasts were reduced, the AM pattern should display a stronger zonal symmetry, and be more distinct from planetary-wave variability

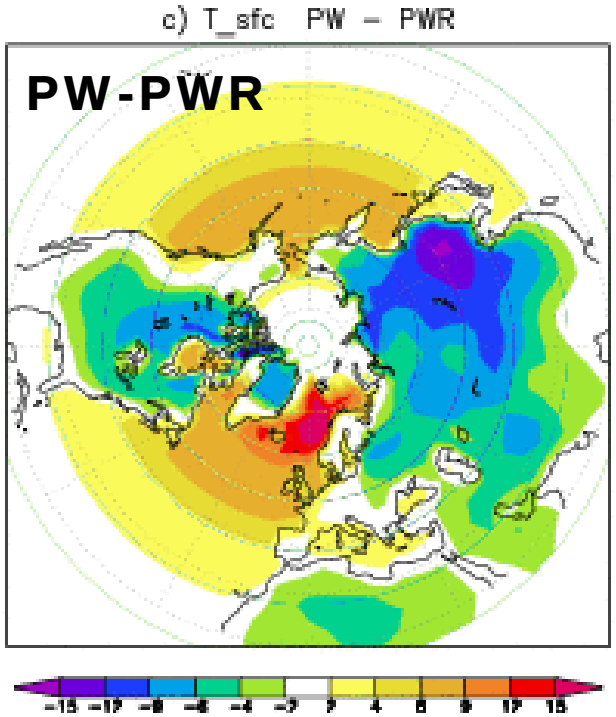
Perpetual JF runs with actual/reduced land-sea contrast

- PW experiment: two 1200-month runs of the ICTP AGCM (perp. Jan + perp. Feb) with surface temperature prescribed from 50-year seasonal-cycle experiments
- PWR experiment: two runs as as above, but with
  - land surface T from April climatology in NH (weighted by *sin lat)*;
  - zonal T variations damped over the Arctic;
  - zonal-mean surface T reset to Jan-Feb values.



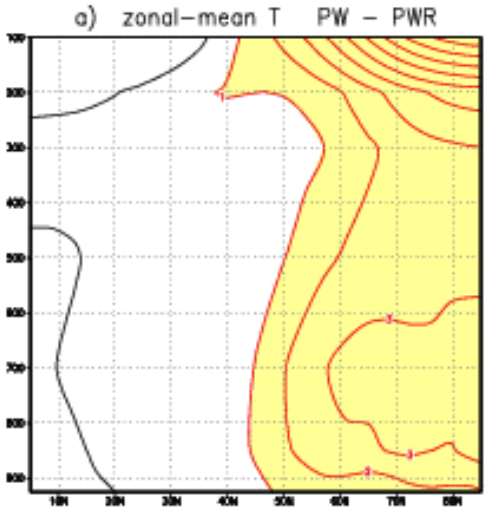
Surface Temp.

Response to land-sea contrast in ICTP AGCM

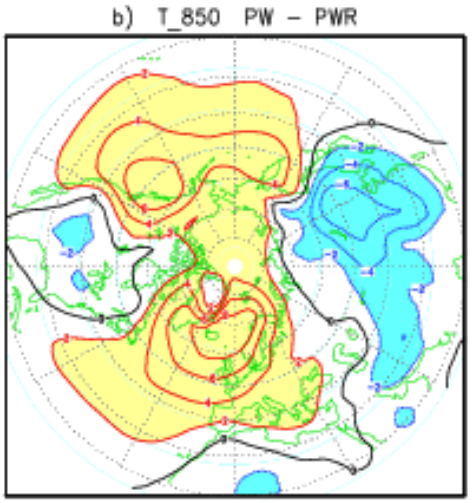


Surface Temp.

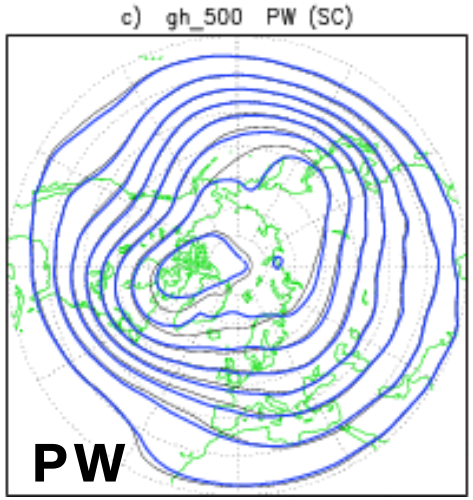
<T>

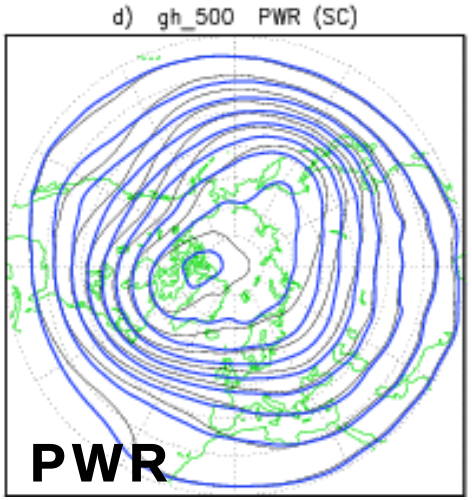


T 850



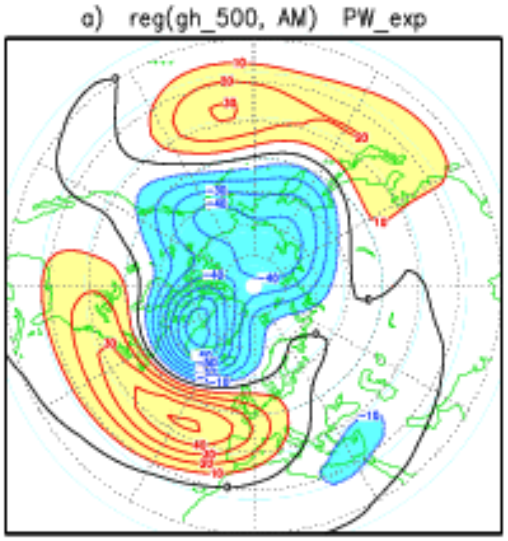
Z 500

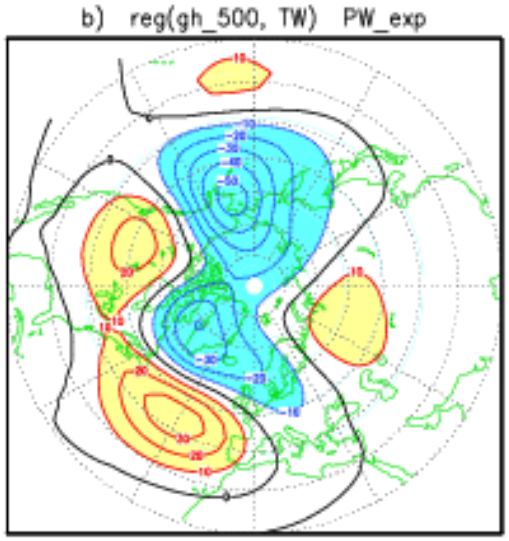




Regression onto AM and TW indices : Z 500

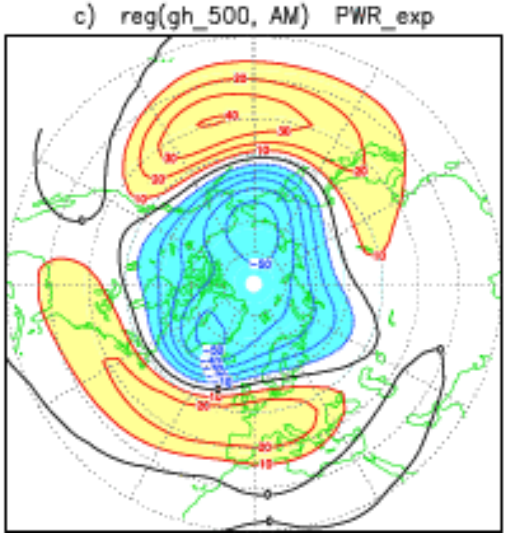
AM
PW exp.

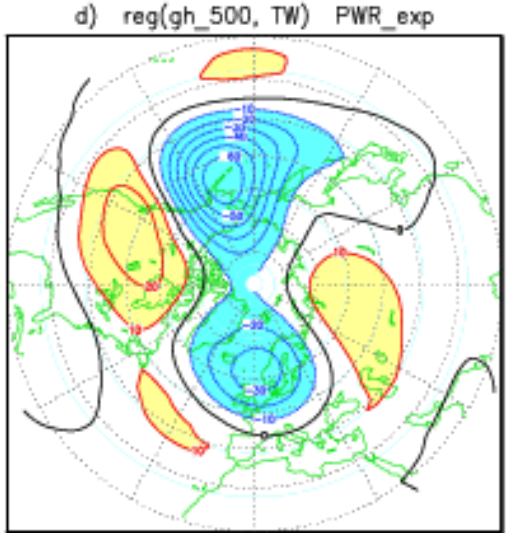




TW
PW exp.

AM
PWR exp.

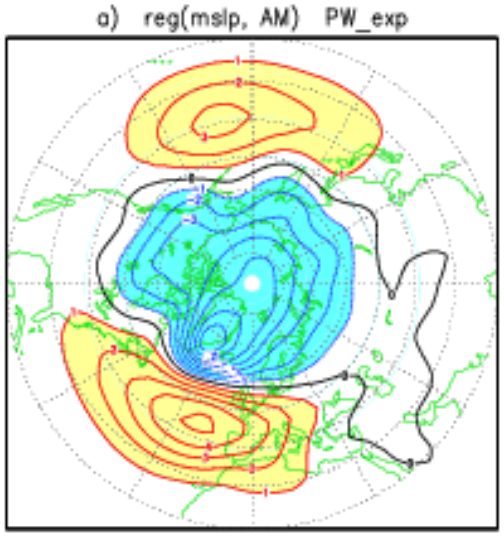


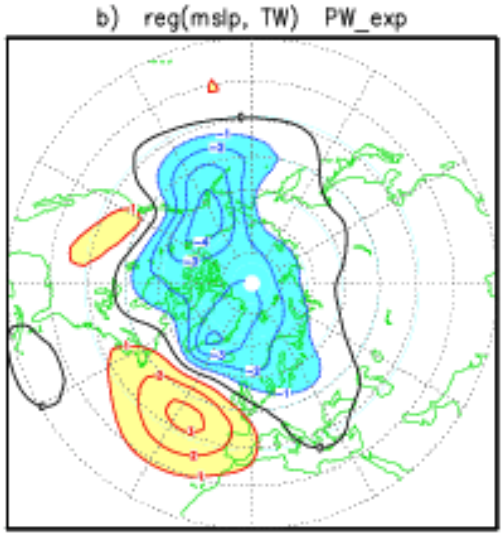


TW
PWR exp.

Regression onto AM and TW indices : MSLP

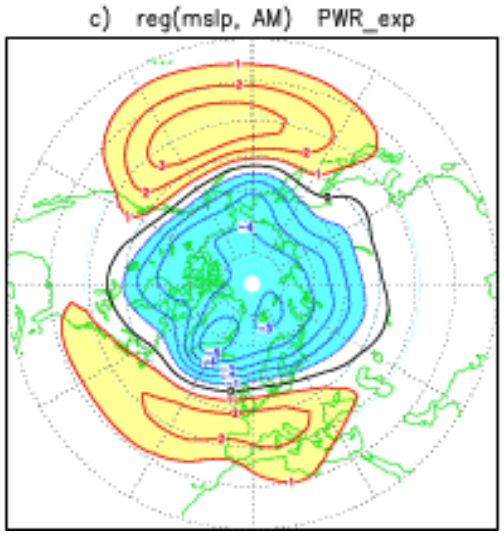
AM
PW exp.

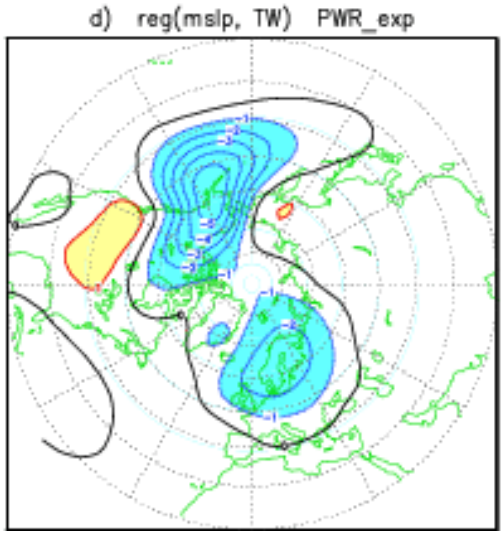




TW
PW exp.

AM
PWR exp.



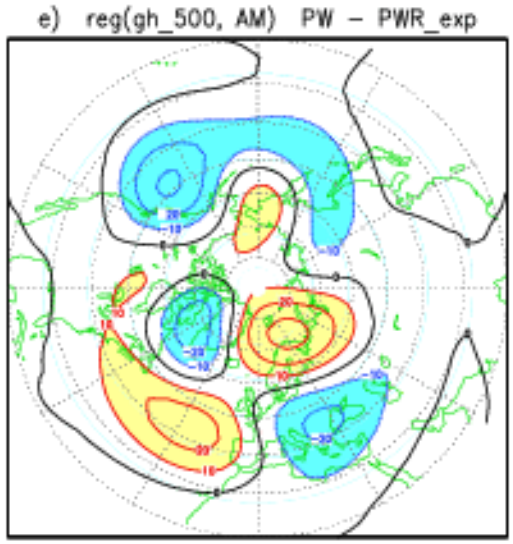


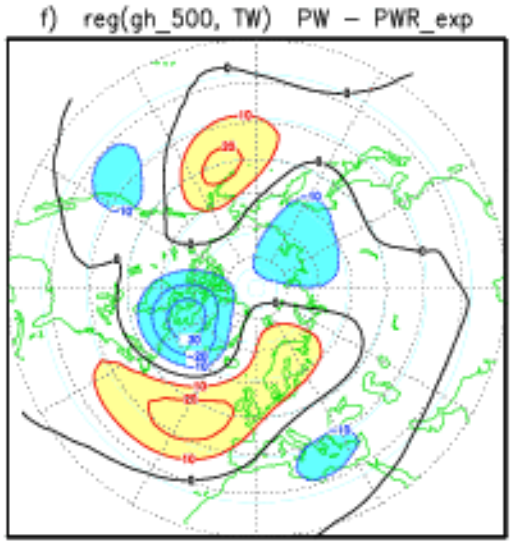
TW
PWR exp.

AM and TW reg. patterns: response to land-sea contrast

AM
PW - PWR

Z 500

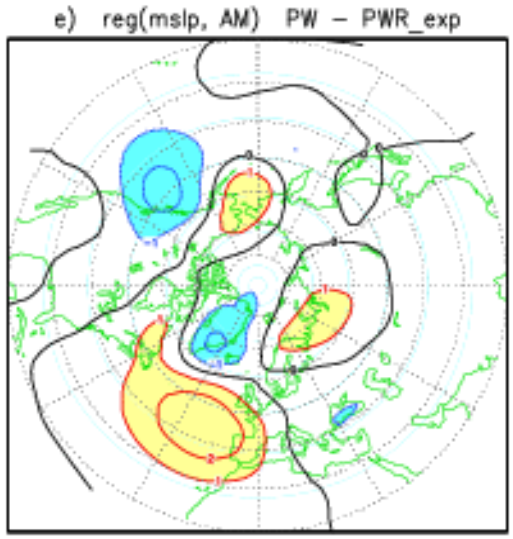


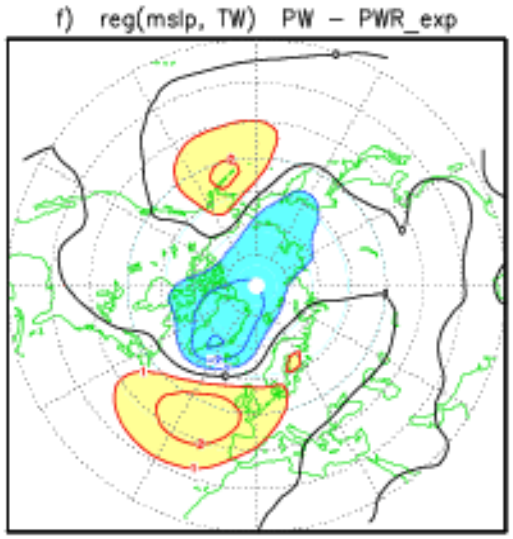


TW
PW - PWR

Z 500

MSLP





MSLP

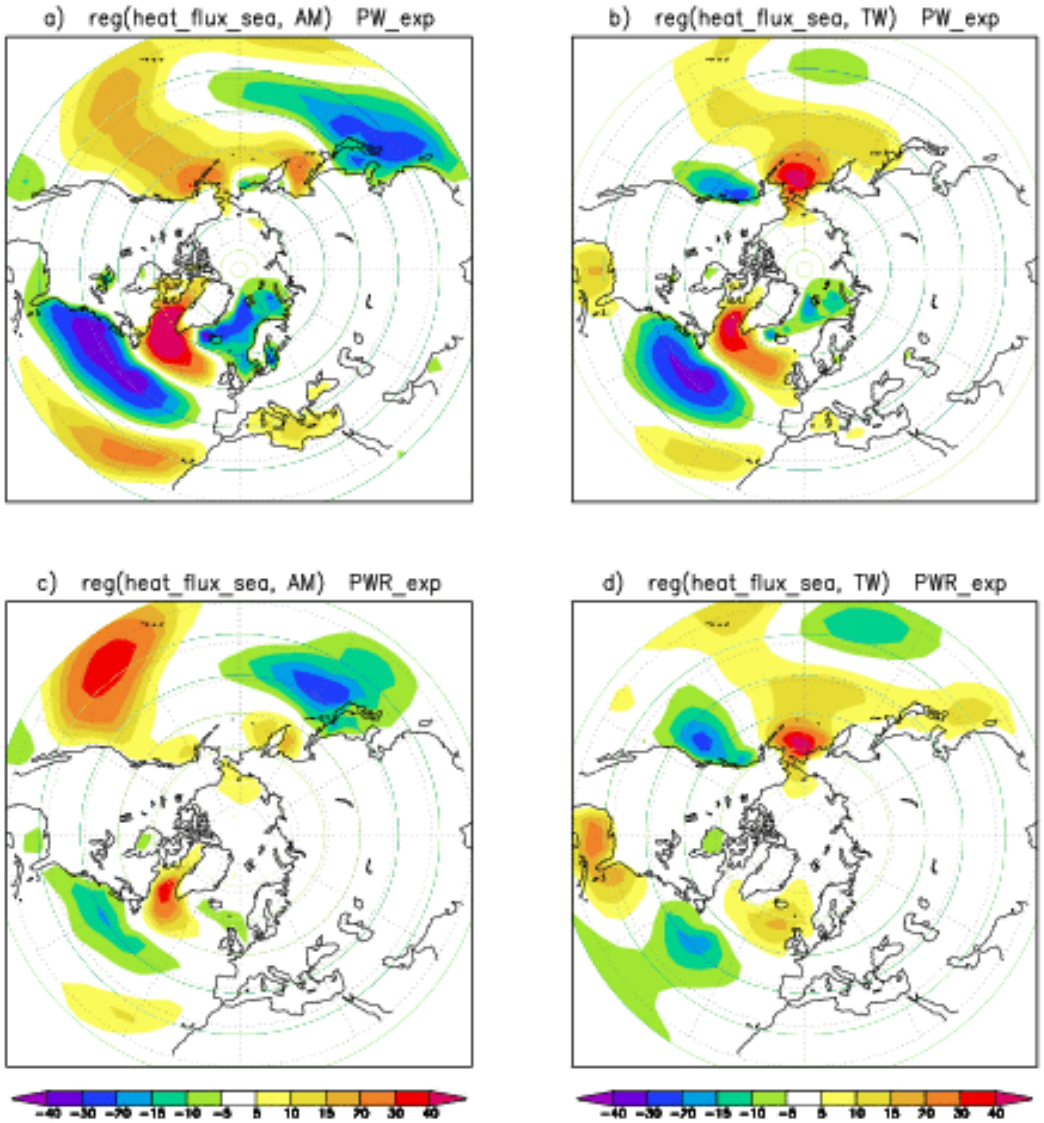
Regression onto AM and TW indices: sfc. heat flux

AM
PW exp.

TW
PW exp.

AM
PWR exp.

TW
PWR exp.



downward

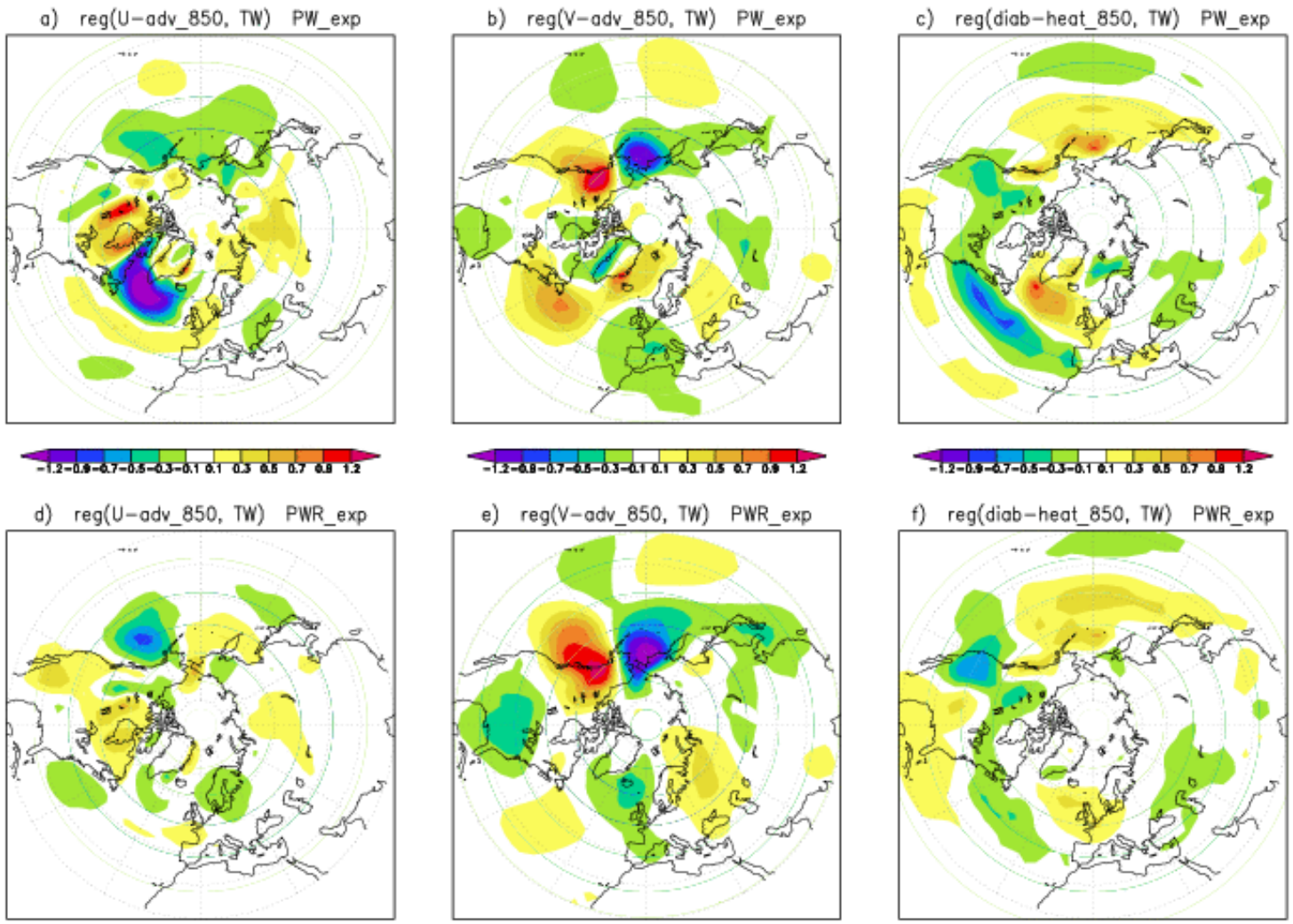
upward

850 hPa T tendency balance in TW anomalies

U-advection **V-advection** **diab. heating**

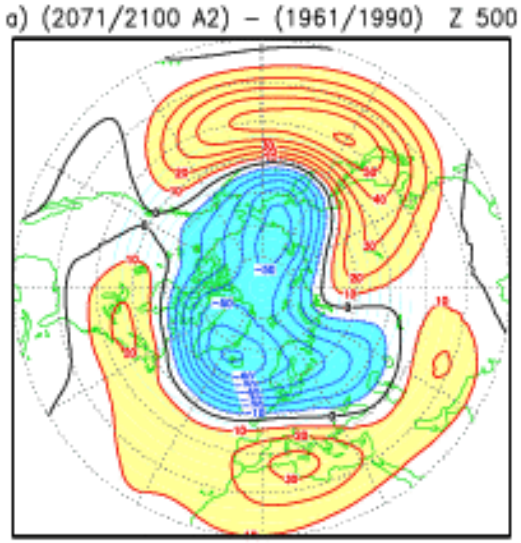
PW

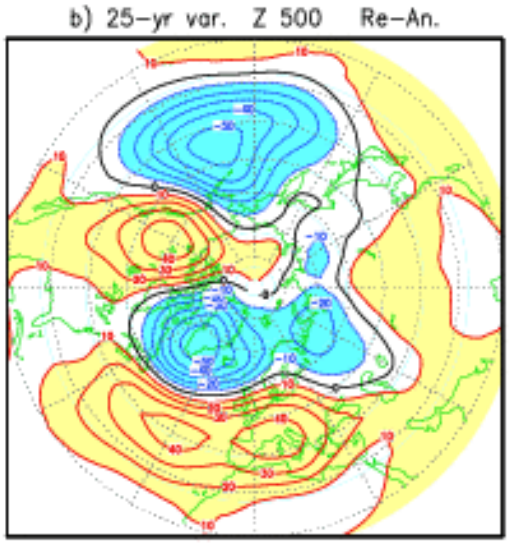
PWR



Is this relevant to climate change ?

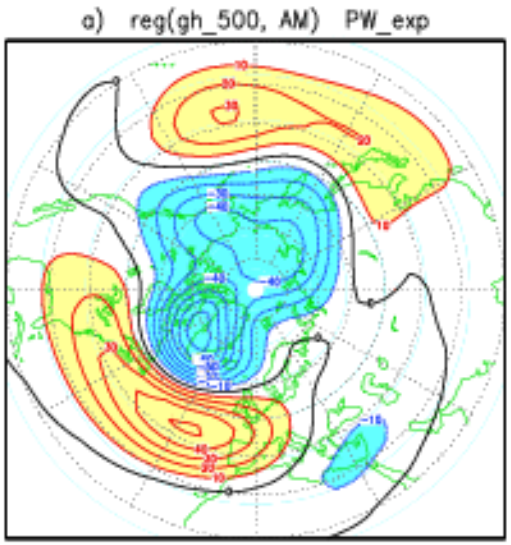
Z 500
variation
in A2
scenario run

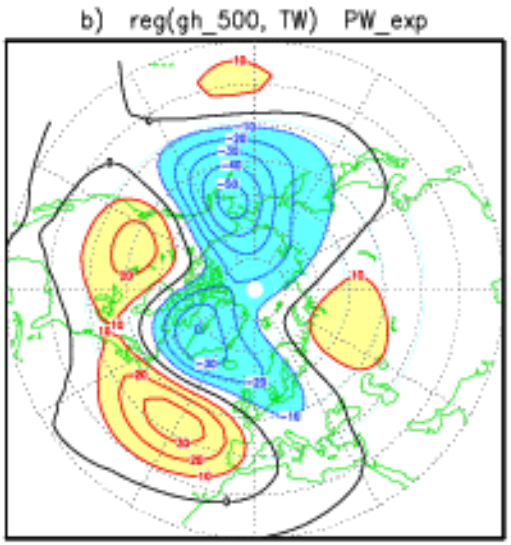




Z 500
(1976/2000)-
(1951/1975)

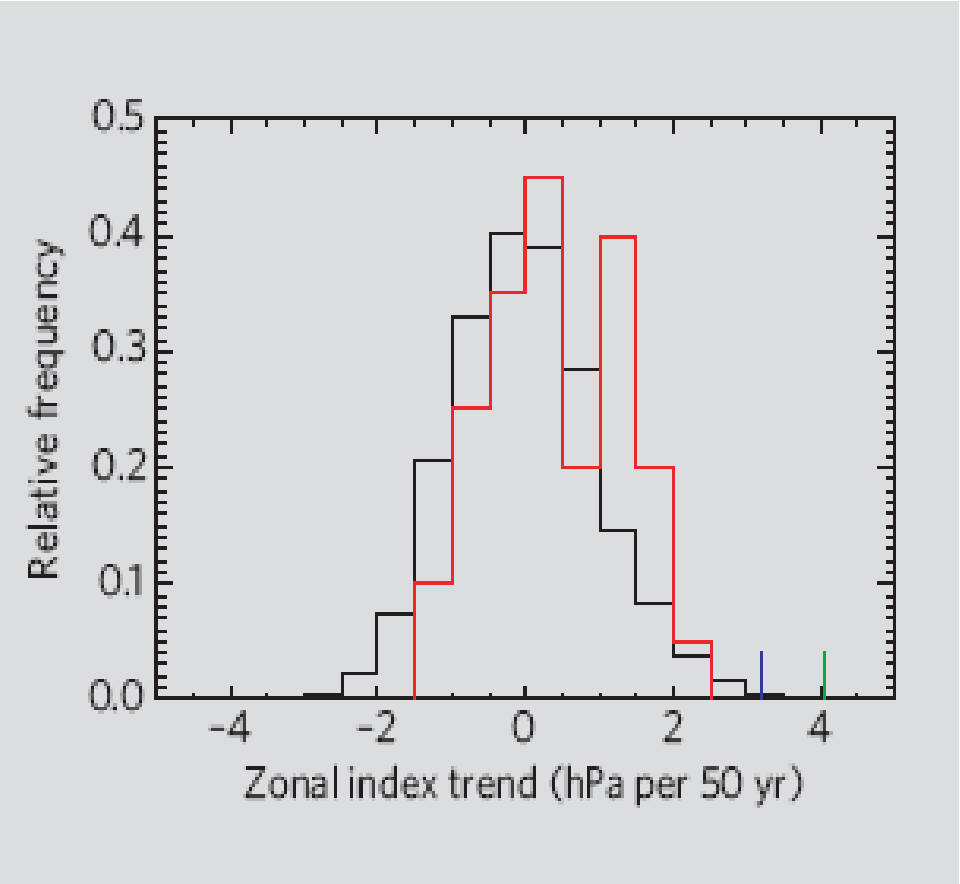
Z 500
AM composite
In PW exp.





Z 500
TW composite
in PW exp.

Distribution of NAM index in AR4 coupled models



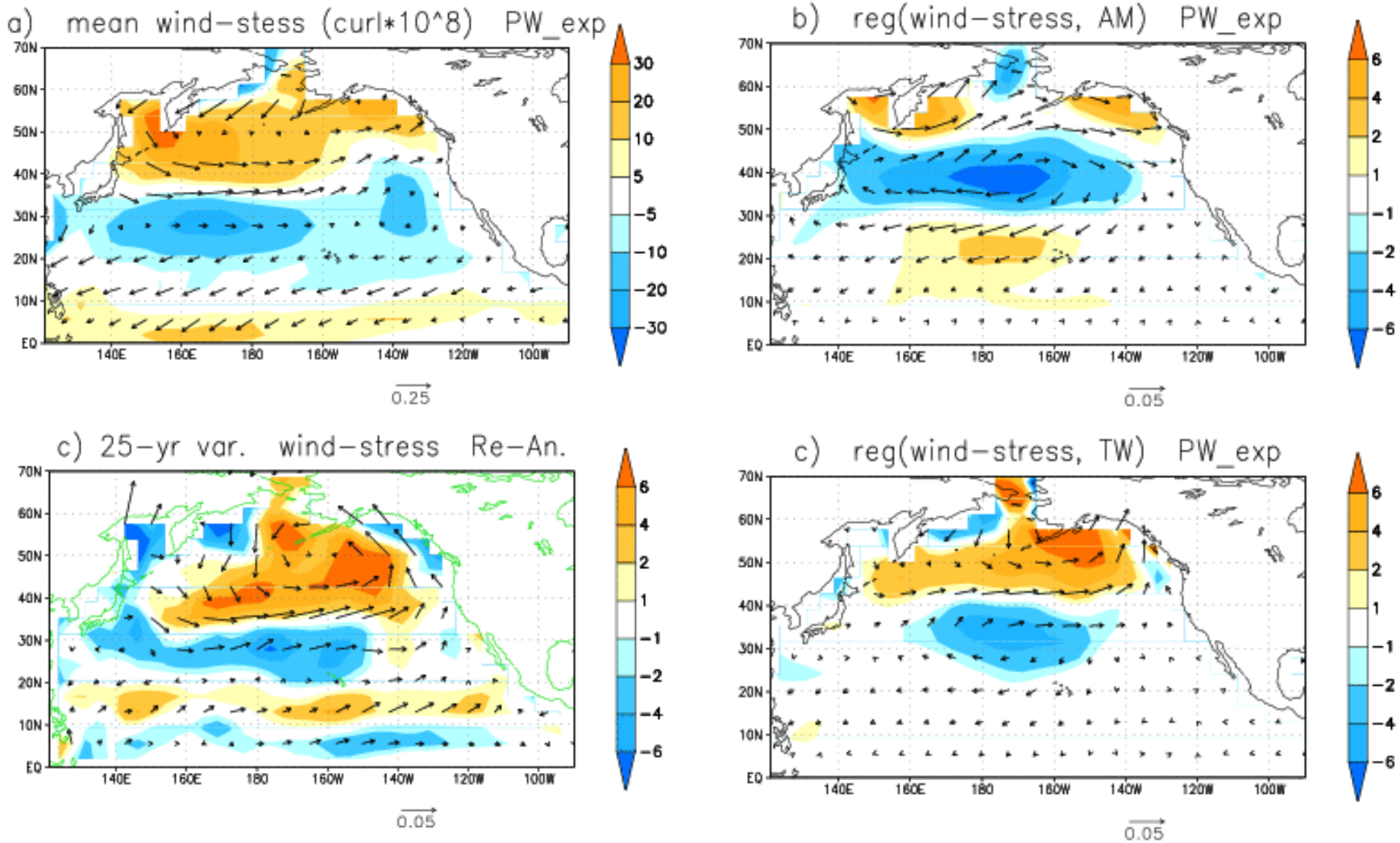
SLP(0-45N) – SLP(45-90N)
DJF 1955-2005
(Gillett, Nature 2005)

Obs (NCEP)
Obs (HadSLP2r)

Distribution from control simulations (fixed forcing)

Distribution from 20C simulations (time-varying GHG/aerosol/ozone/solar)

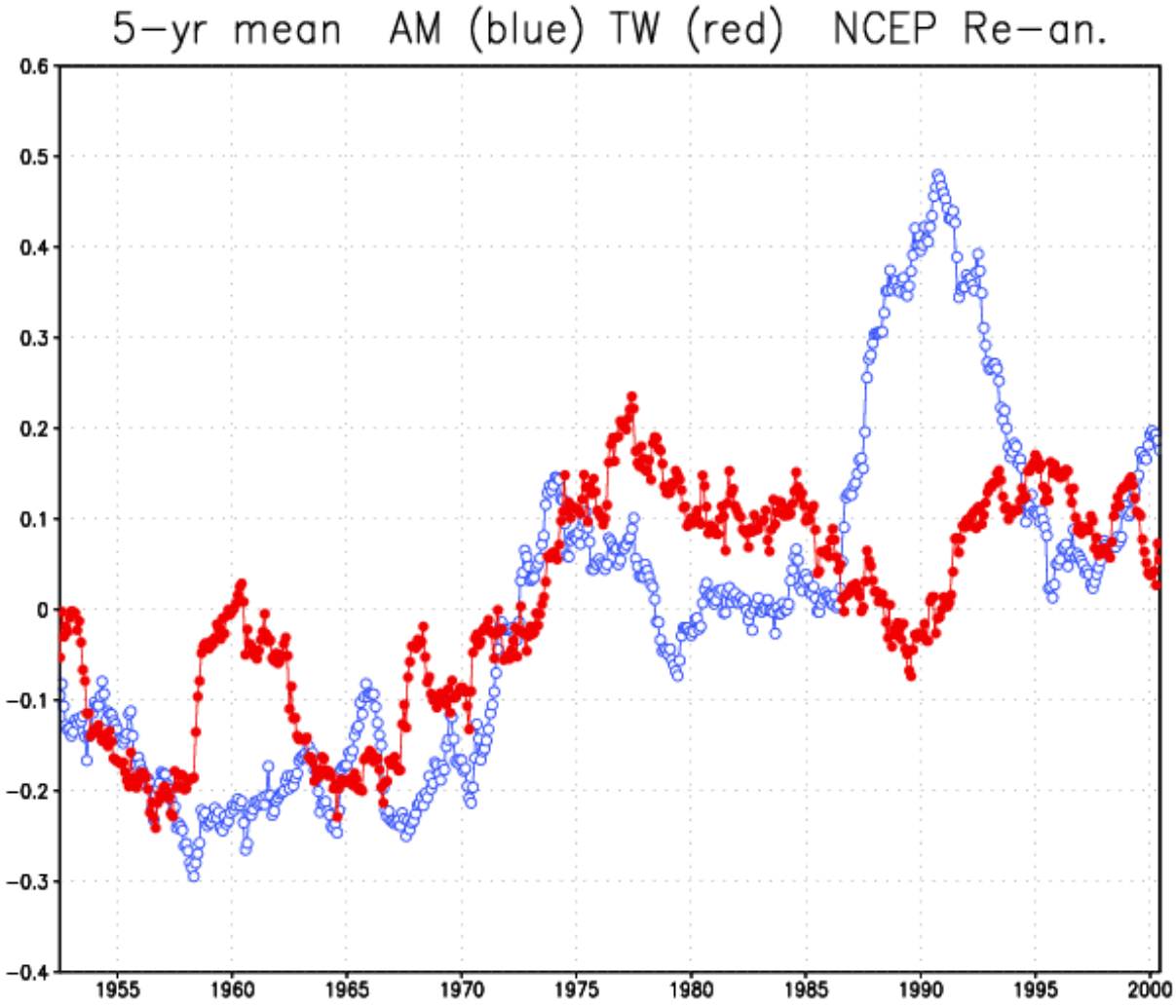
Is this relevant to changes in ocean circulation?



e.g. Di Lorenzo et al: North Pacific Gyre Oscillation links climate and ecosystem …

Conclusions

- Indices related to annular-mode variability (AM) and thermal equilibration of planetary waves (TW) can be used to describe interannual and interdecadal variations in NH-winter circulation
- The regional circulation anomaly associated with variations in thermal balance over the NW Atlantic has a NAO-like structure
- Since the strongest sfc. T gradient in the N. Atlantic is in the E-W direction, zonal wind variations induced by both zonally-symmetric (AM) and zonal-wn2 variations (TW) induce a NAO-like response; the two modes are distinct in the N. Pacific where the strongest sfc. T gradient is in the meridional direction.
- While related to both of them, the NAO should not be *identified* with either AM or TW modes; this distinction is relevant to climate attribution and ocean circulation/ecosystem change studies.


5-yr mean AM (blue) TW (red) NCEP Re-an.
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
GrADS: COLA/IGES