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

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

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Inter-decadal NAO variability: forced vs. natural

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


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
  - 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:**
  
  \[ AM = \text{Difference in zonally-averaged MSLP anomaly}, \]
  
  \[ [30-45 \text{ N}] - [55-90 \text{ N}] \]

- **Thermal-balance Wave index (positive in COWL phase):**
  
  Zonal wavenumber-2 component of net surface heat flux (NSHF, positive upward) in the [45-70 N] latitudinal band:
  
  \[ TW = \text{NSHF [60W-30E]} - \text{NSHF [30E-120E]} + \text{NSHF [120W-150W]} - \text{NSHF [150W-60W]} - \]
Regression of Z 500 onto AM and TW indices

Z 500 hPa
JF 1950-2002
NCEP/NCAR
Re-Analysis

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 \( \sin \text{lat} \));
  - zonal T variations damped over the Arctic;
  - zonal-mean surface T reset to Jan-Feb values.
Response to land-sea contrast in ICTP AGCM
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.

AM PWR exp.

downward

TW PW exp.

TW PWR exp.

upward
850 hPa T tendency balance in TW anomalies

U-advection

a) $\text{reg}(U-\text{adv} \_850, \text{TW}) \_\text{PW}\_\text{exp}$

b) $\text{reg}(V-\text{adv} \_850, \text{TW}) \_\text{PW}\_\text{exp}$

c) $\text{reg}(\text{diab-heat} \_850, \text{TW}) \_\text{PW}\_\text{exp}$

V-advection

d) $\text{reg}(U-\text{adv} \_850, \text{TW}) \_\text{PWR}\_\text{exp}$

e) $\text{reg}(V-\text{adv} \_850, \text{TW}) \_\text{PWR}\_\text{exp}$

f) $\text{reg}(\text{diab-heat} \_850, \text{TW}) \_\text{PWR}\_\text{exp}$
Is this relevant to climate change?

Z 500 variation in A2 scenario run


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.