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Atmospheric teleconnections and atmospheric regime behaviour under future climate projections

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Atmospheric regime behaviour under future climate projections

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Circulation Regimes

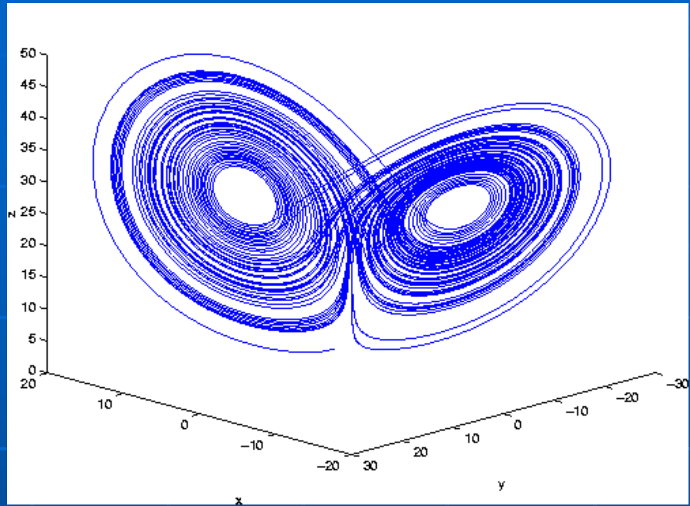
- Since Rossby (1939):
  - Atmospheric variability characterised by few **recurrent/persistent** large-scale anomalous circulation patterns over defined region
  - Atmospheric variability due to (irregular) transitions
- Concept of Regimes
  - approach for understanding low-frequency variability
  - dynamical mechanisms underlying the regimes

Circulation Regimes

- Regimes associated with large-scale structure of the chaotic attractor

(a) Stationary solutions

→ Lorenz-Model



→ Barotropic models (e.g. Charney & DeVore, 1979, Legras & Ghil, 1985)

(b) Bifurcation Cascade →Chaotic itinerancy

→ Regimes identified with the ruins of multiple attractors

that have merged to a single attractor

→Baroclinic models (Itoh & Kimoto, 1996)

→Baroclinic model with realistic regimes → (Sempf et al., 2007)

Climate regimes under future projections

- Does low-frequency variability, simulated by coupled AOGCMs, resemble regime-like behaviour?
- Does external forcing change only the frequency of occurence of preferred regimes or the regime structure itself?
- Can we detect differences between different model realizations ?

IPCC AR4 Coupled Atmosphere-Ocean GCM Simulations

	MPI-ECHAM5/OM1	UKMO-HadCM3	NCAR-CCSM3	CCCma-CGCM3
Atmosphere	ECHAM5 T63, L31	HadAM3 2.75x3.75^o grid (approx. T42), L19	CAM3 T85, L26	AGCM3 T47, L31
Ocean	MPI-OM1 1.5x1.5^{o}grid L40	 1.25x1.25^{o}grid L20	POP 1.4.3 1.125x(0.27-1.0)^o L40	Based on MOM 1.85x1.85^{o}grid L29
Coupling	No flux adjustment	No flux adjustment	No flux adjustment	No flux adjustment

Analysed Experiments

Preindustrial control simulation (PICTRL) 340 years	Constant forcing, preindustrial values
20th century simulation (20CM3) 1870-1999	Anthropogenic forcing: CO2,CH4,N2O, F11,F12,O3,sulfate
21th22nd century simulation (SRESA1B) 2000-2199	Anthropogenic forcing: CO2 (about 700ppm by 2100),CH4,N2O, F11F11,F12,O3,sulfate Constant forcing after year 2100

Data and Data preprocessing

- Analyses of Climate Regimes
  - → Monthly mean data
- Analyses of midtropospheric circulation
  - → 500hPa geopotential height fields (GPH500)
- Analyses of dynamically active season of Northern Hemisphere (NH)
  - → December, January, February data (DJF)
- Fields from 20º-90º N
- seasonal cycle removed
- linear trends removed

- For comparison: NCEP/NCAR Reanalysis

Determination of climate regimes in a low-dimensional (3D) state space
(see e.g. Crommelin, 2004)

- Basis functions of the common 3D-state space
  → common Principal Component Analysis (PCA)
- Projection of PC-data α_1, α_2, α_3 onto unit sphere (ρ=1)

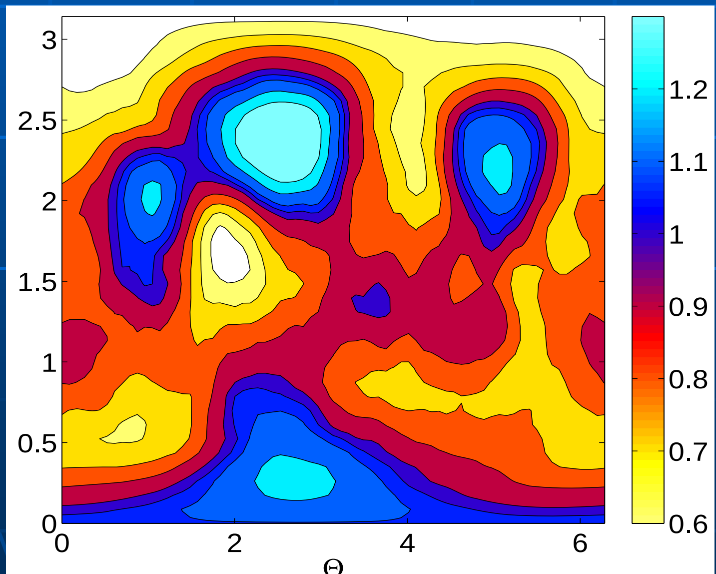
$$\begin{aligned}\alpha_1 &= \rho \cos\theta \sin\phi \\ \alpha_2 &= \rho \sin\theta \sin\phi \\ \alpha_3 &= \rho \cos\phi\end{aligned}$$

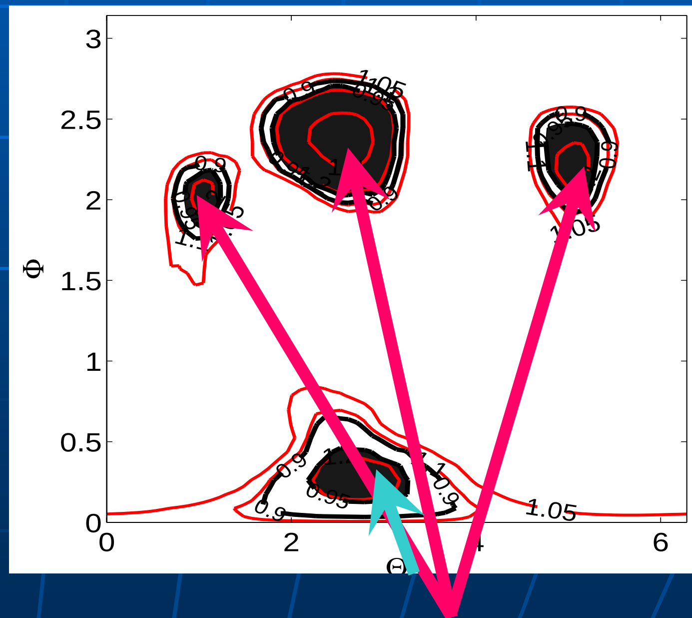
with

$$\begin{aligned}&0 \le \rho \\ &0 \le \theta \le 2\pi \\ &0 \le \phi \le \pi\end{aligned}$$

Determination of climate regimes in a low-dimensional (3D) state space
(see e.g. Crommelin, 2004)

- Spherical probability density function (SPDF) f(θ,ϕ) by kernel density estimation
- 1000 Monte Carlo simulations of random Gaussian PCs (same μ, σ, AR1) → 1000 SPDFs of simulated PCs → 90%(95%) confidence levels



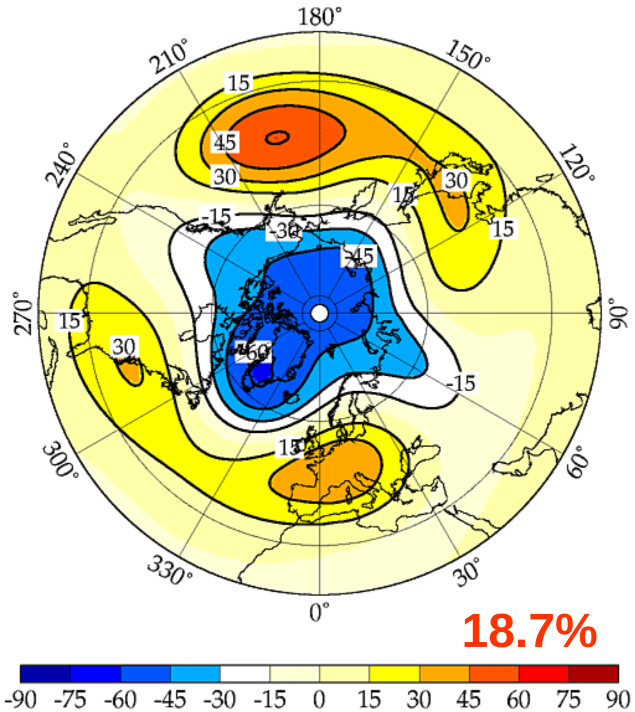


- SPDF normalized by value for Gaussian distribution
- Unexpected high recurrence prob.

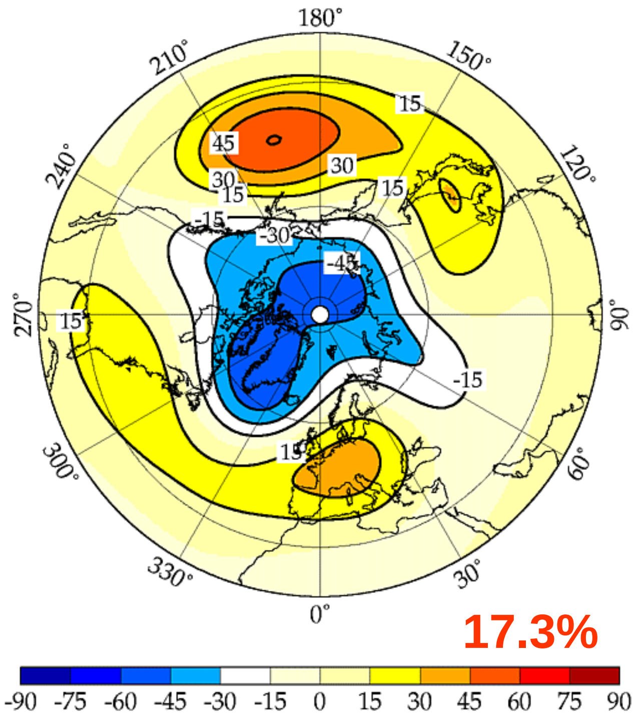
(900 of 1000 sim. PDFs have lower p-values)

Dominant spatial patterns for NH 20-90ºN: All models EOF1

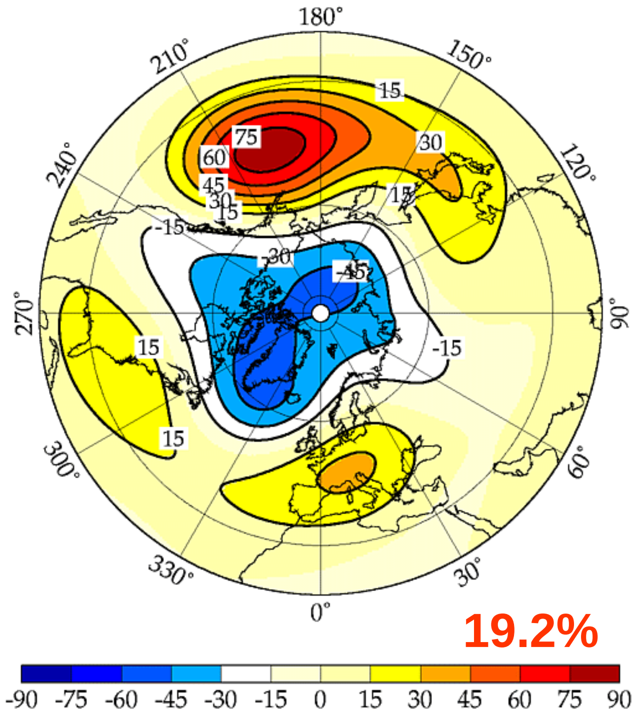
Control Run



Run 20CM3 (1870-1999)

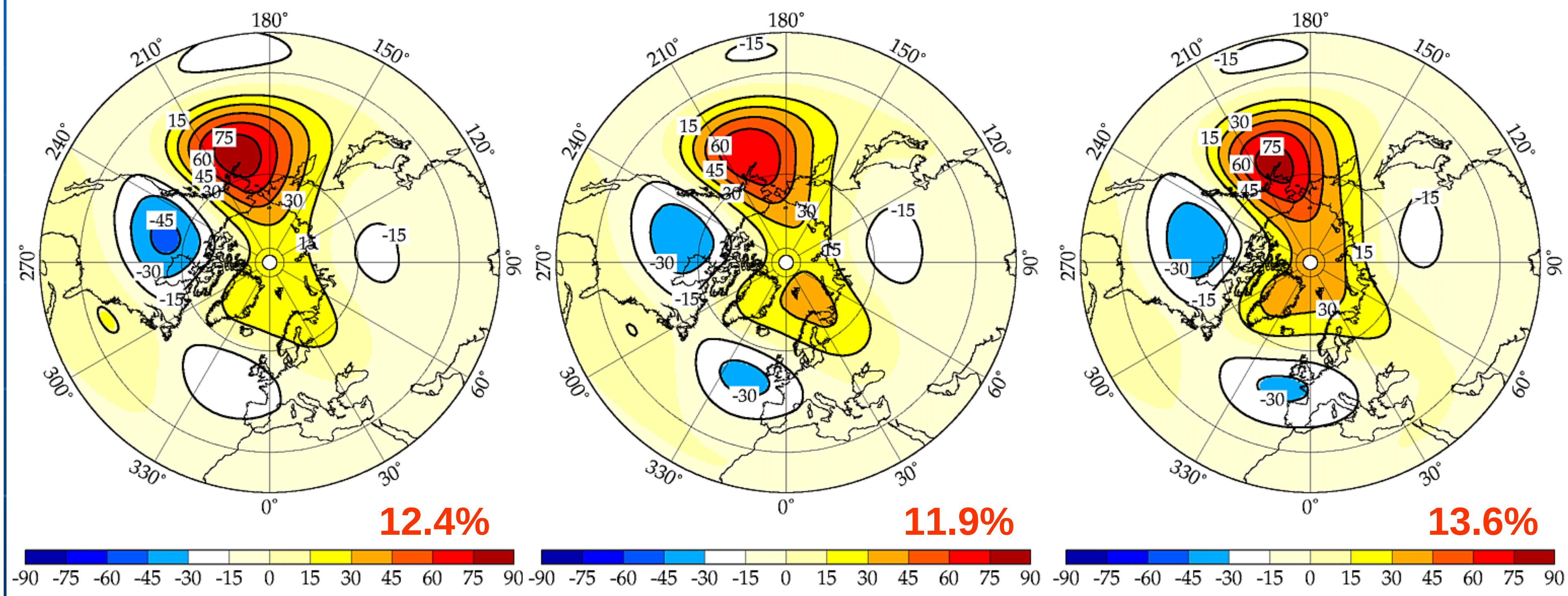


Run SRESA1B (2000-2199)

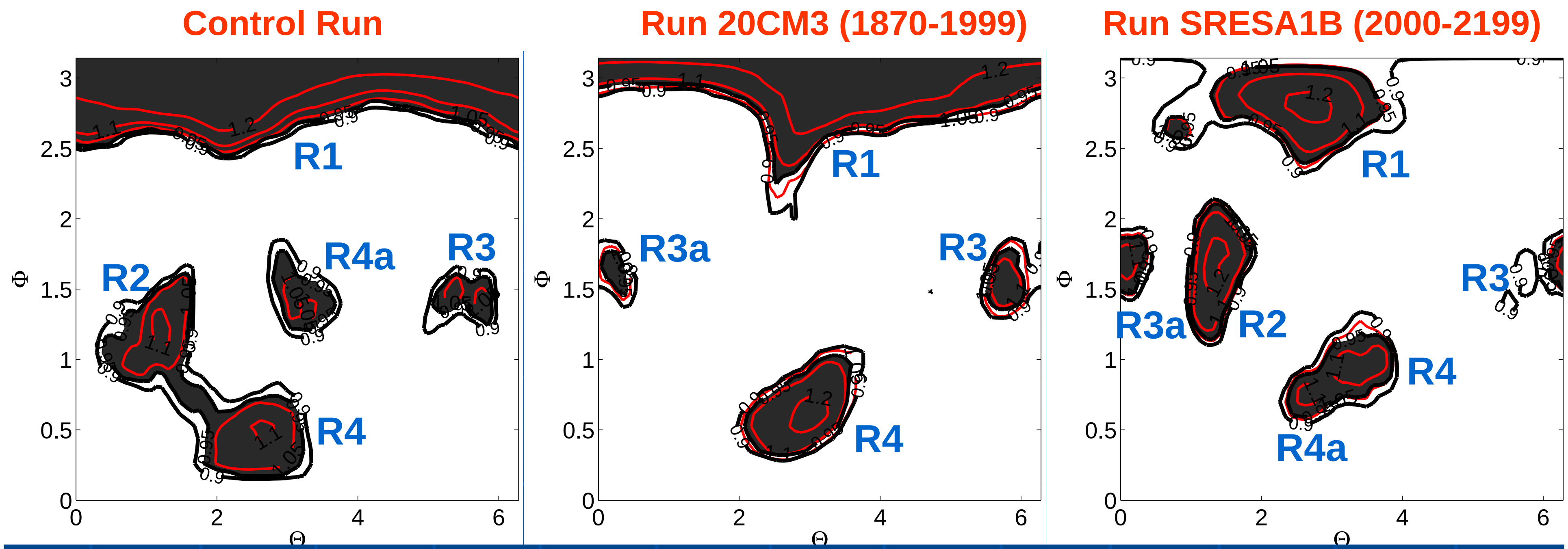


Dominant spatial patterns for NH 20-90°N: All models EOF2

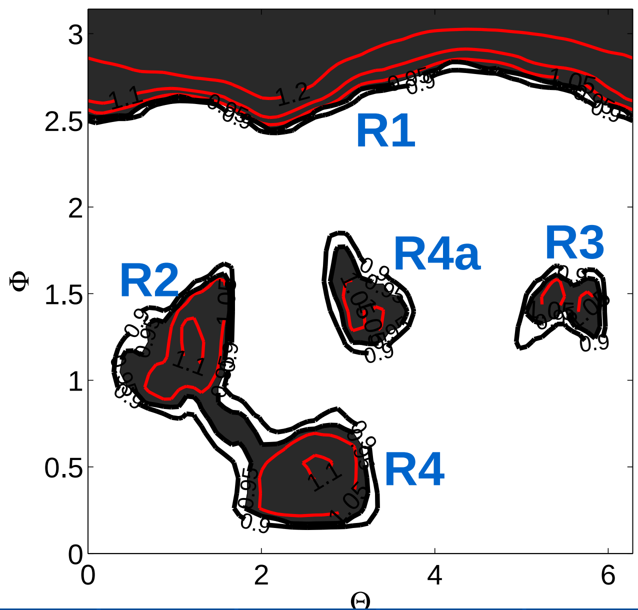
Control Run | **Run 20CM3 (1870-1999)** | **Run SRESA1B (2000-2199)**



Regime Detection Northern Hemisphere 20-90ºN
Spherical PDF- Areas of unexpected high recurrence probability

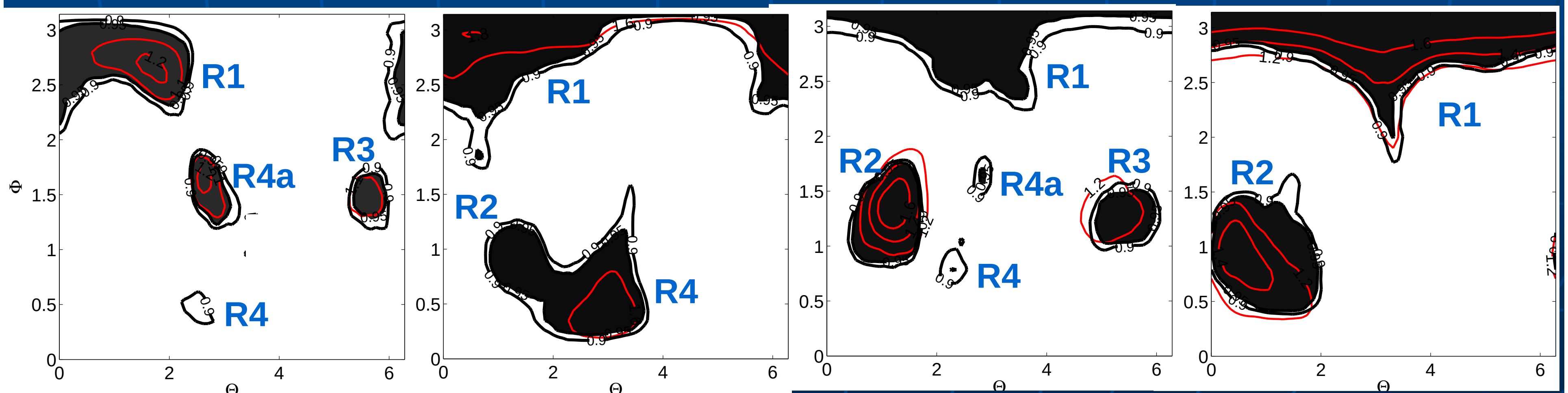


Regime Detection Northern Hemisphere 20-90ºN
Spherical PDF- Areas of unexpected high recurrence probability



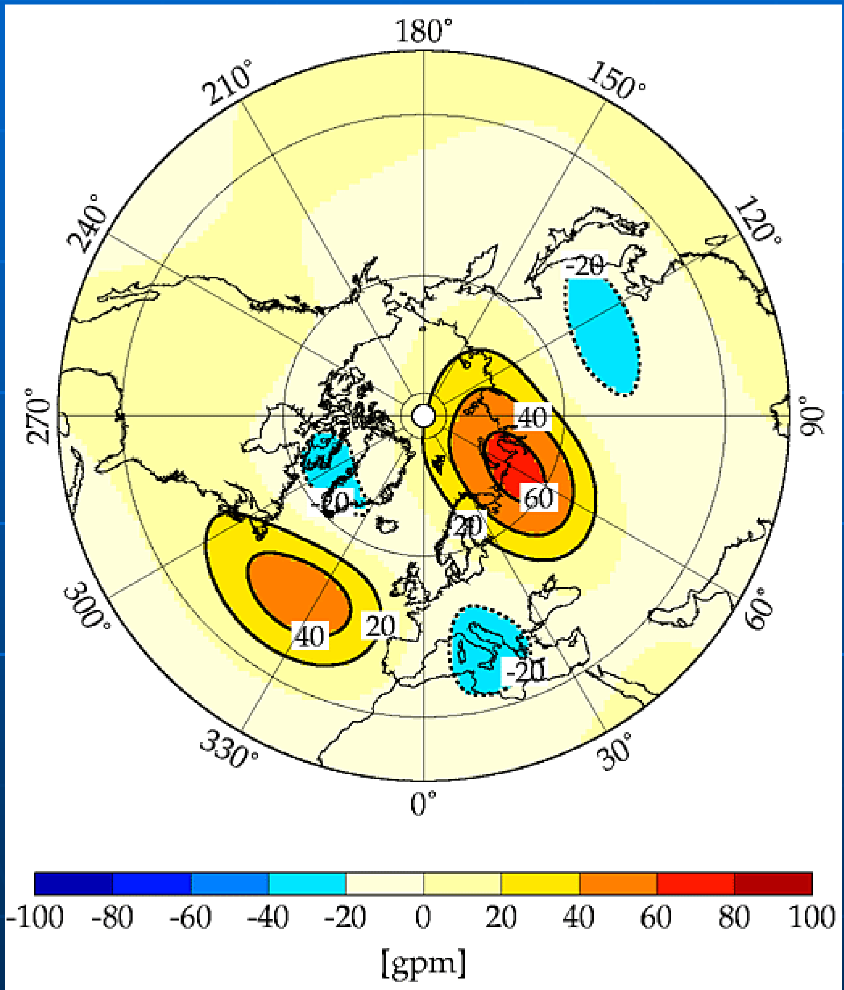
CTRL: All models

CTRL: ECHAM5/OM1 | HadCM3 | CCSM3 | CGCM3

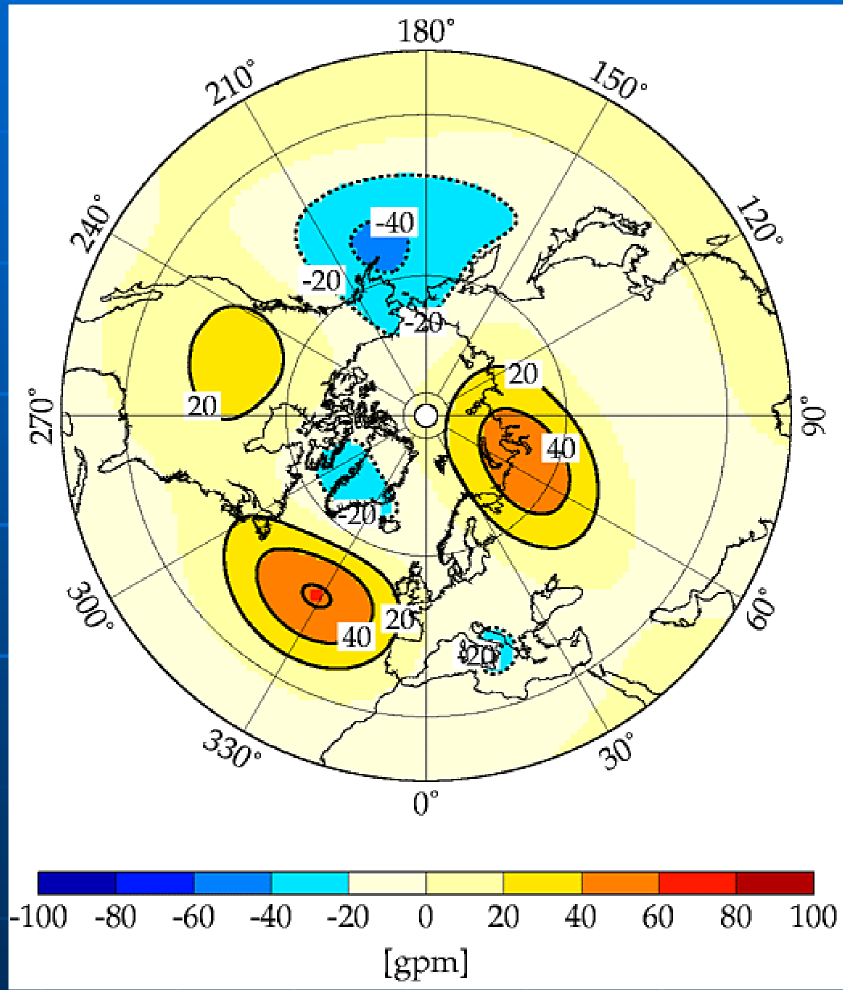


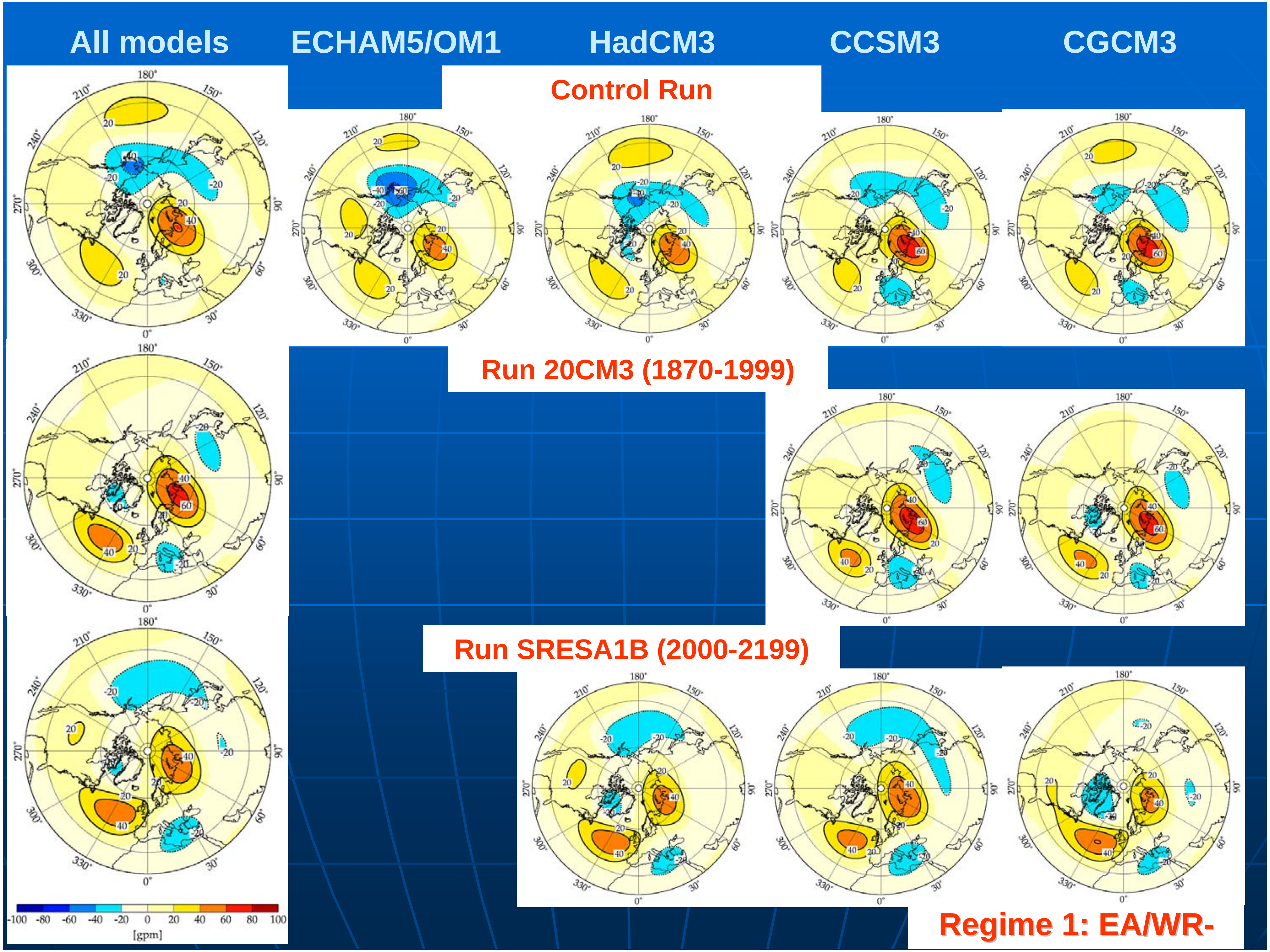
GPH 500hPa anomaly patterns of Regime 1: EA/WR-

Run 20CM3 (1870-1999): All models



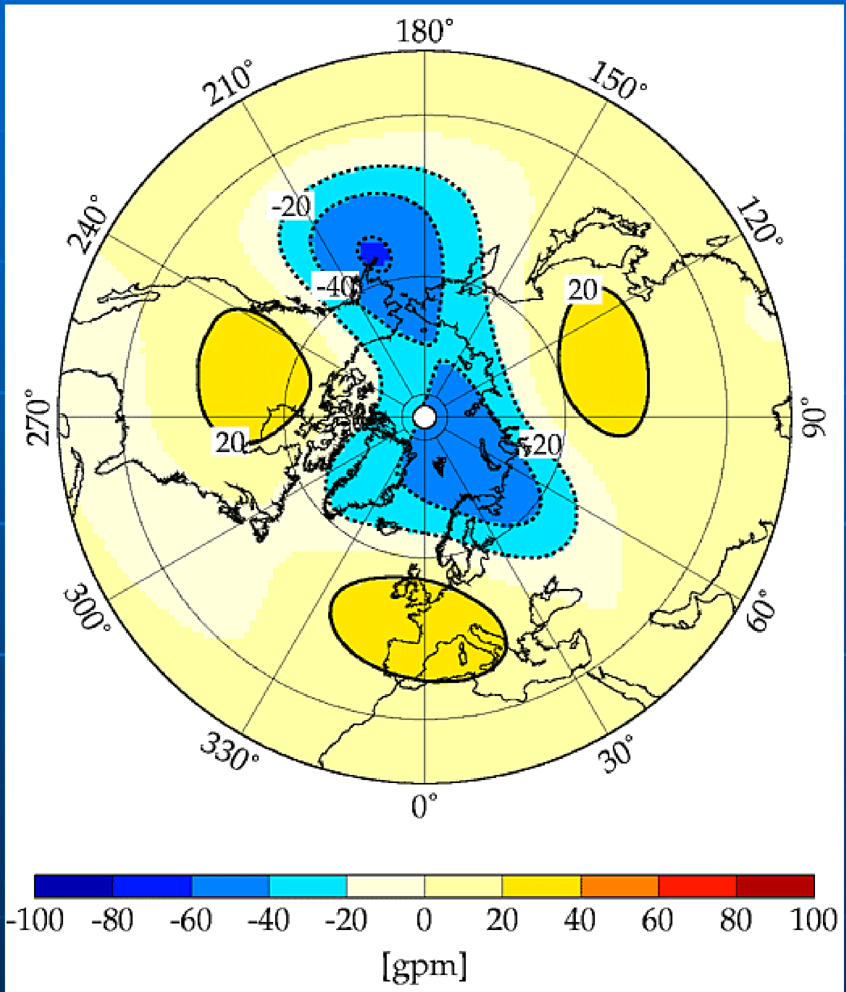
NCEP/NCAR Reanalysis

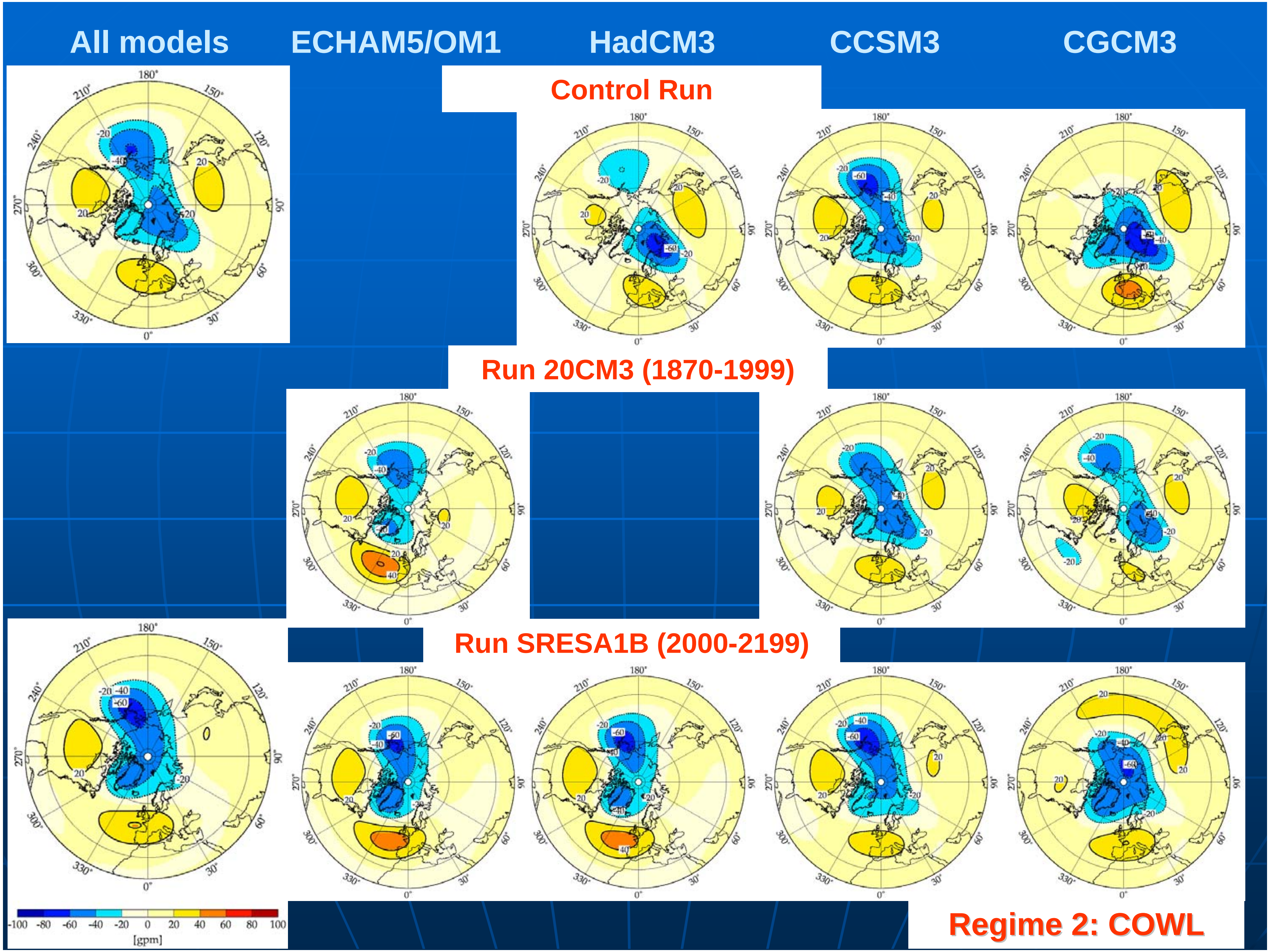



All models
ECHAM5/OM1
HadCM3
CCSM3
CGCM3
Control Run
Run 20CM3 (1870-1999)
Run SRESA1B (2000-2199)
Regime 1: EA/WR-
-100 -80 -60 -40 -20 0 20 40 60 80 100
[gpm]

GPH 500hPa anomaly patterns of Regime 2: COWL

Control run

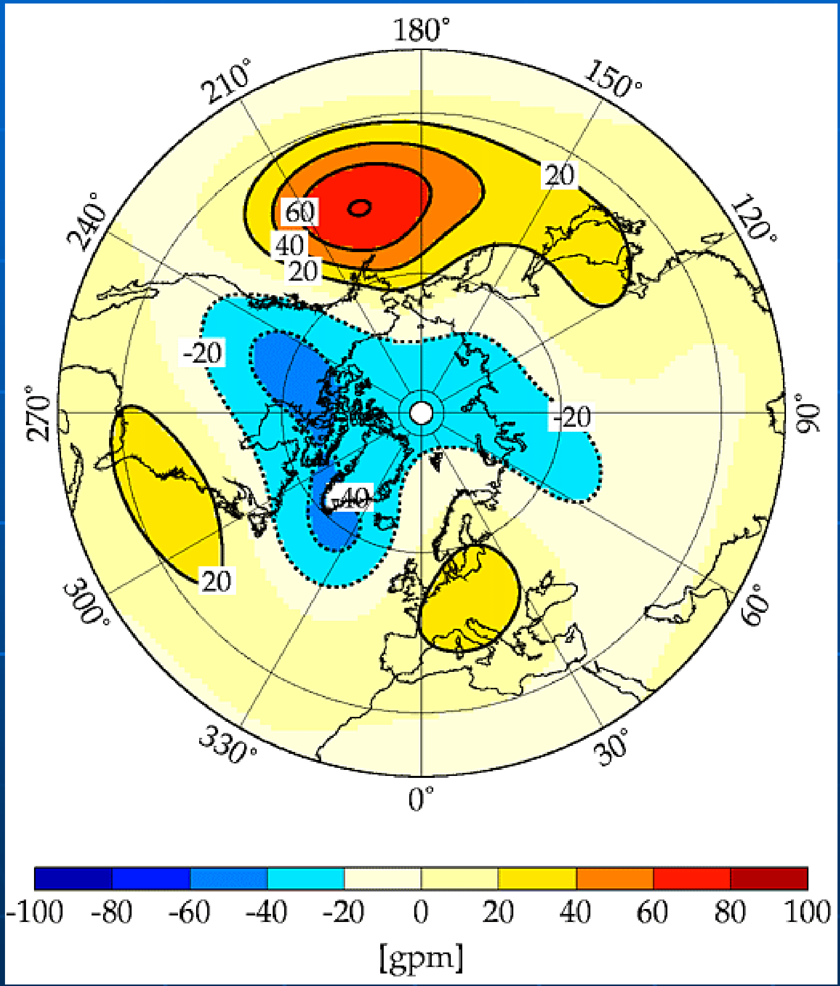




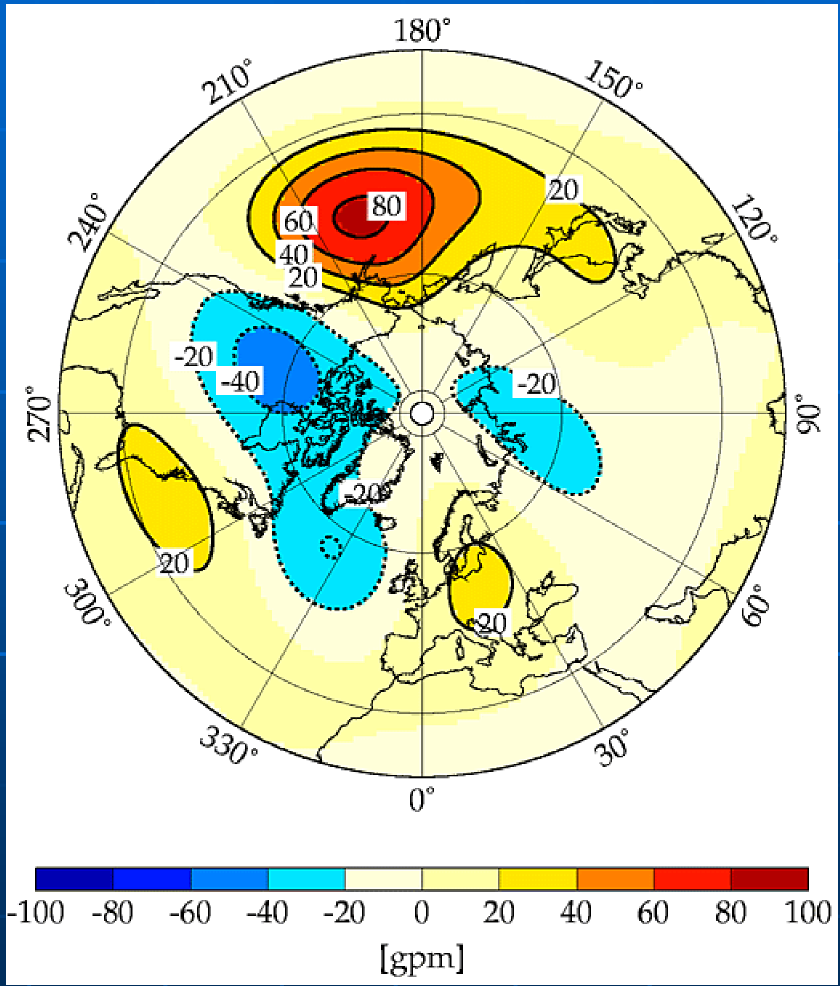
All models
ECHAM5/OM1
HadCM3
CCSM3
CGCM3
Control Run
Run 20CM3 (1870-1999)
Run SRESA1B (2000-2199)
-100 -80 -60 -40 -20 0 20 40 60 80 100
[gpm]
Regime 2: COWL

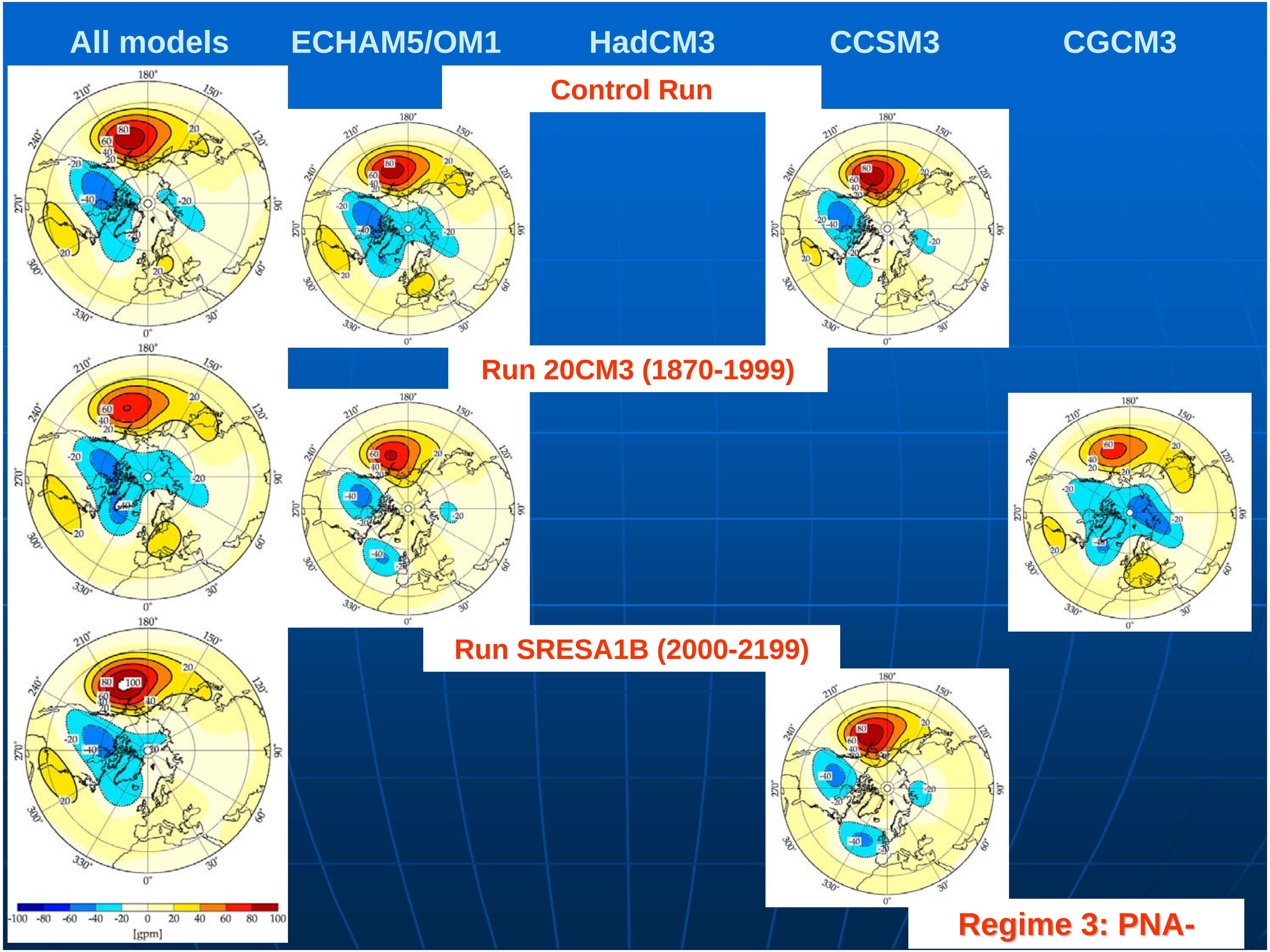
GPH 500hPa anomaly patterns of Regime 3: PNA-

Run 20CM3 (1870-1999): All models



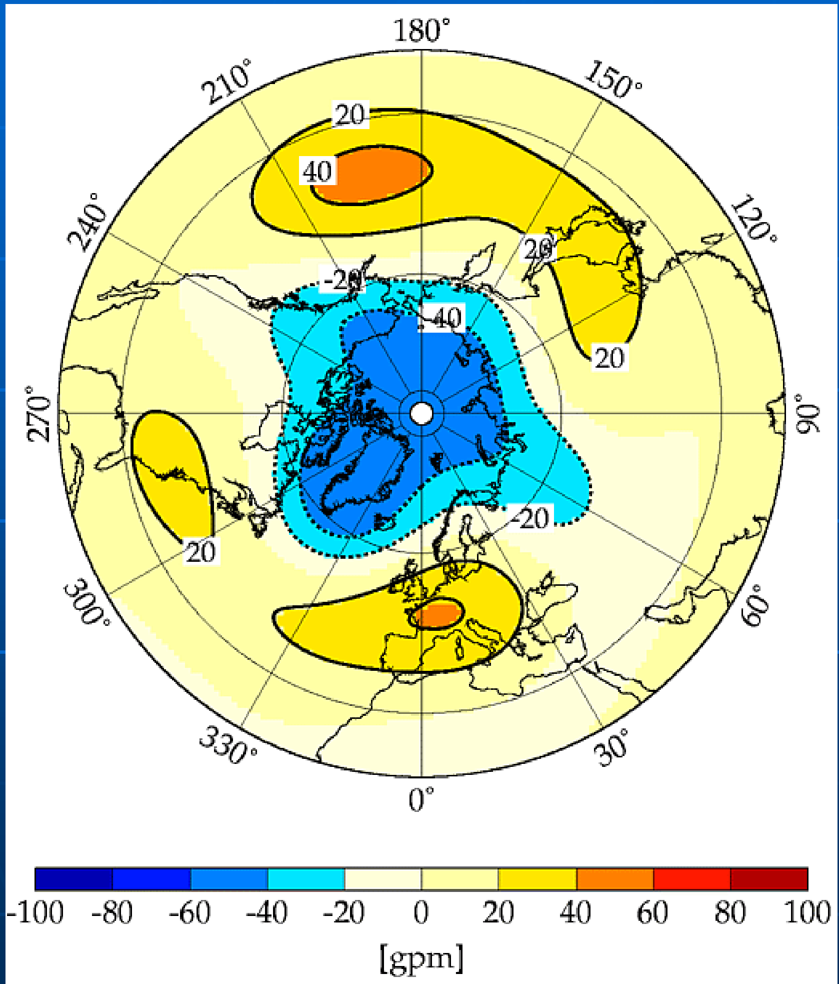
NCEP/NCAR Reanalysis



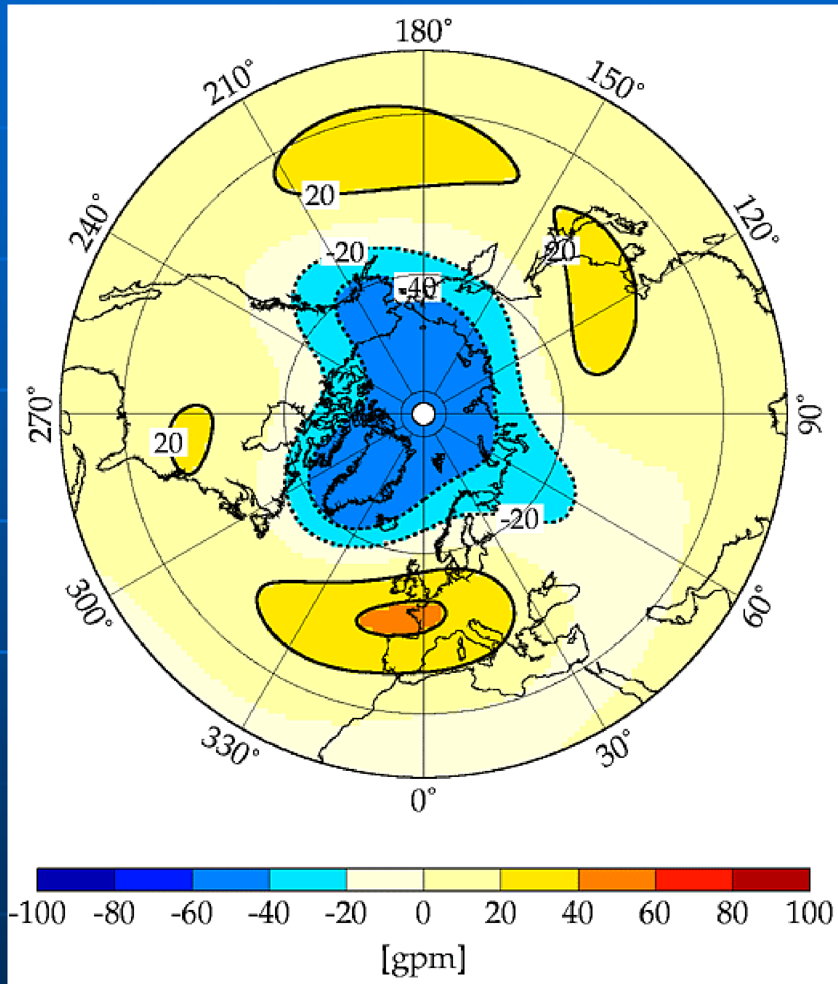

All models
ECHAM5/OM1
HadCM3
CCSM3
CGCM3
Control Run
Run 20CM3 (1870-1999)
Run SRESA1B (2000-2199)
Regime 3: PNA-
-100 -80 -60 -40 -20 0 20 40 60 80 100
[gpm]

GPH 500hPa anomaly patterns of Regime 3a: AO+

Run 20CM3 (1870-1999): All models

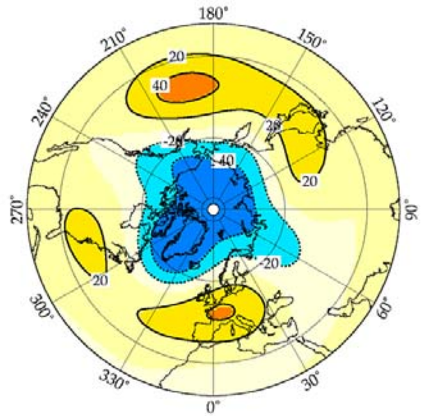


NCEP/NCAR Reanalysis

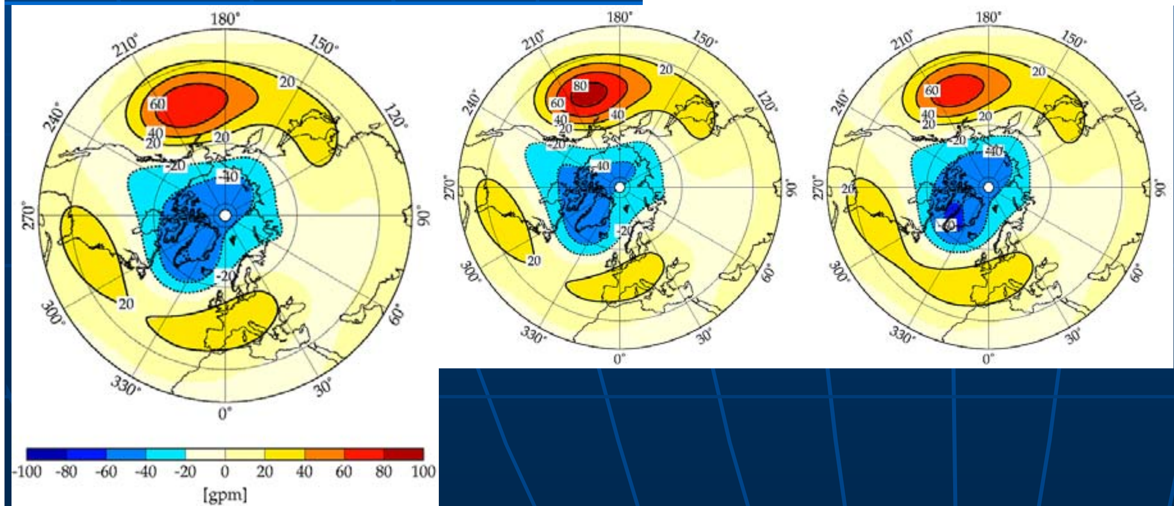


All models | ECHAM5/OM1 | HadCM3 | CCSM3 | CGCM3

Run 20CM3 (1870-1999)



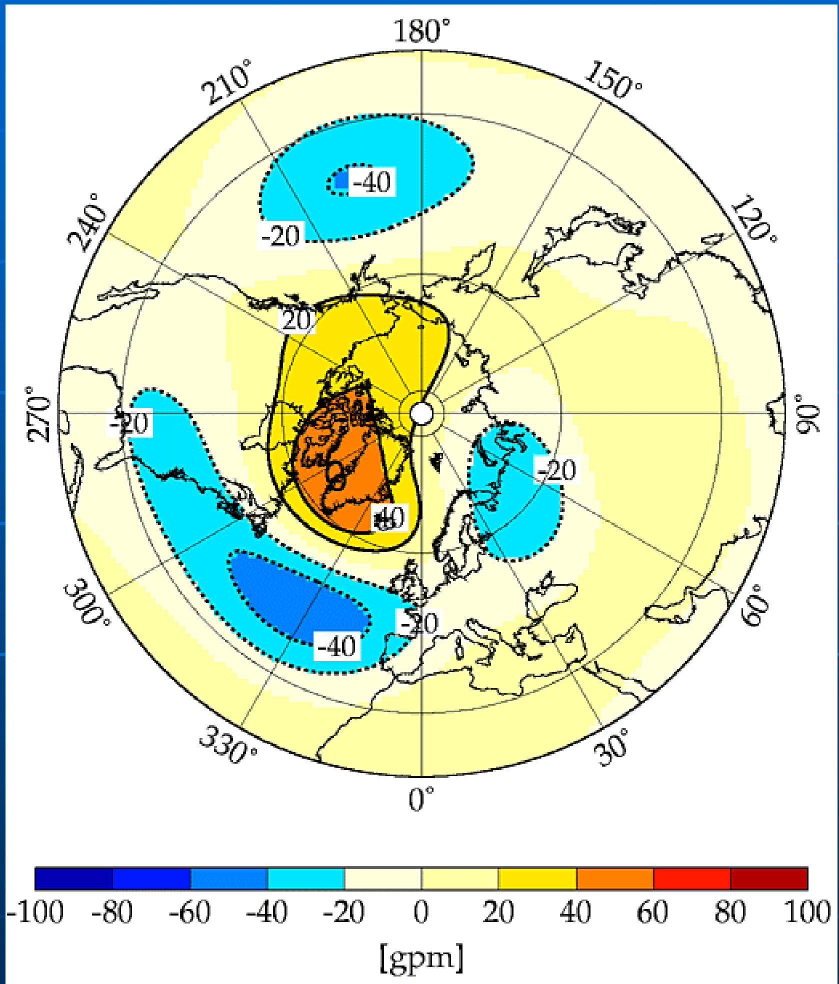
Run SRESA1B (2000-2199)



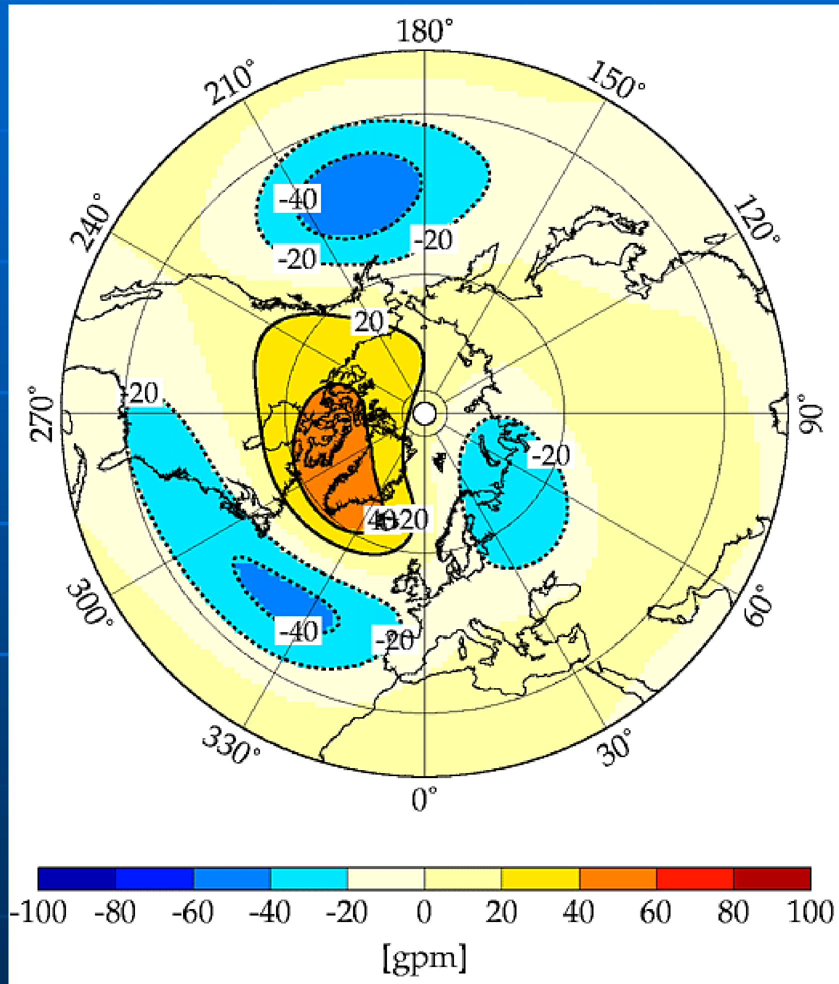
Regime 3a: AO+

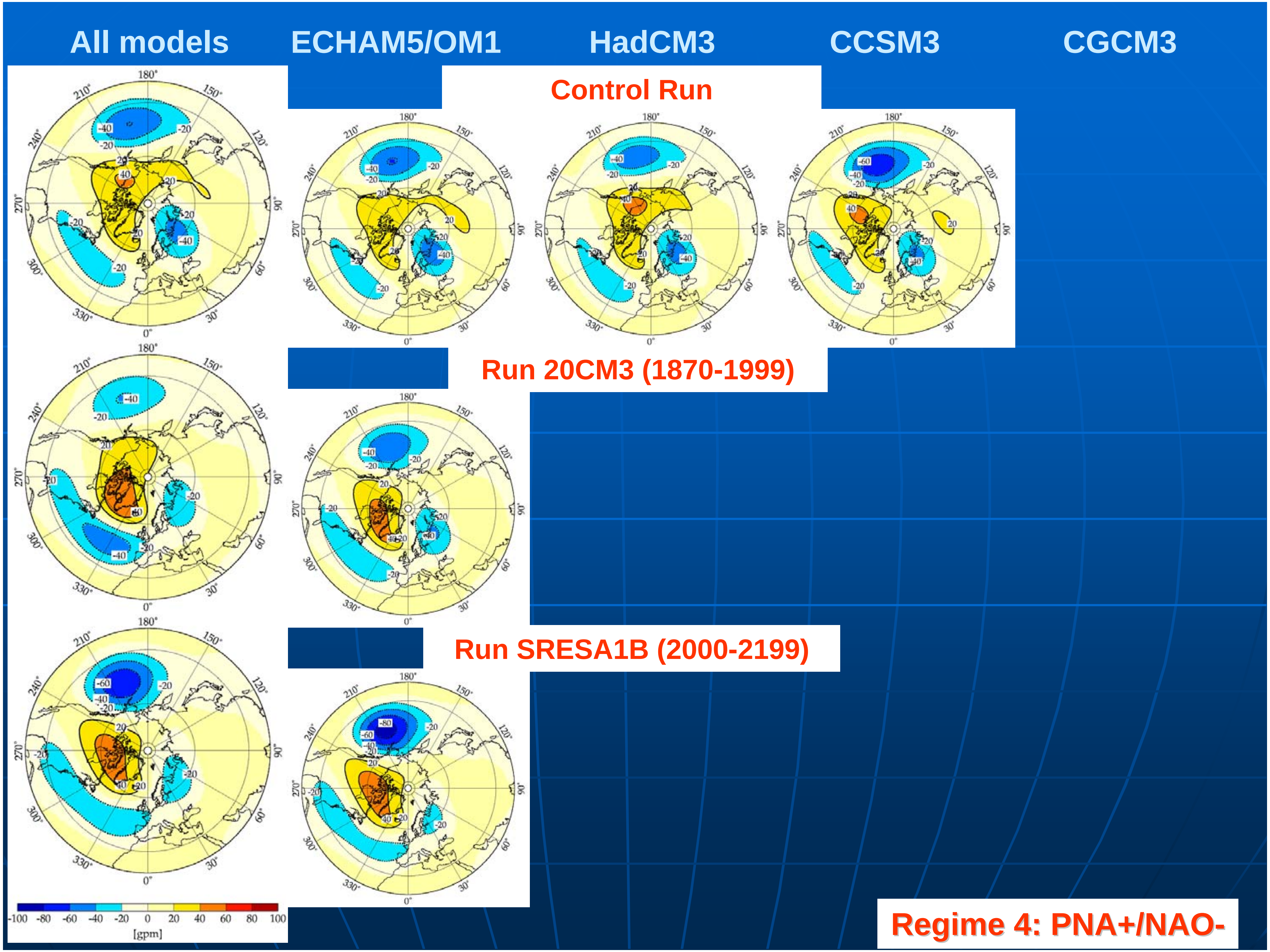
GPH 500hPa anomaly patterns of Regime 4: PNA+/NAO-

Run 20CM3 (1870-1999): All models



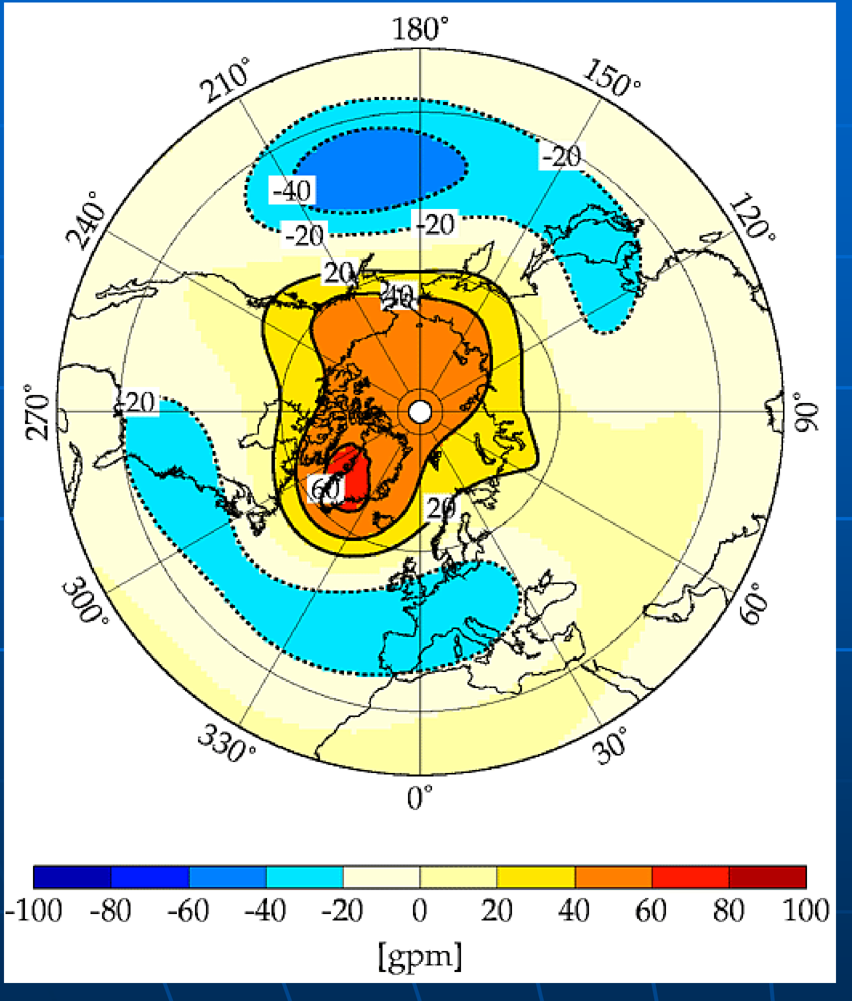
NCEP/NCAR Reanalysis

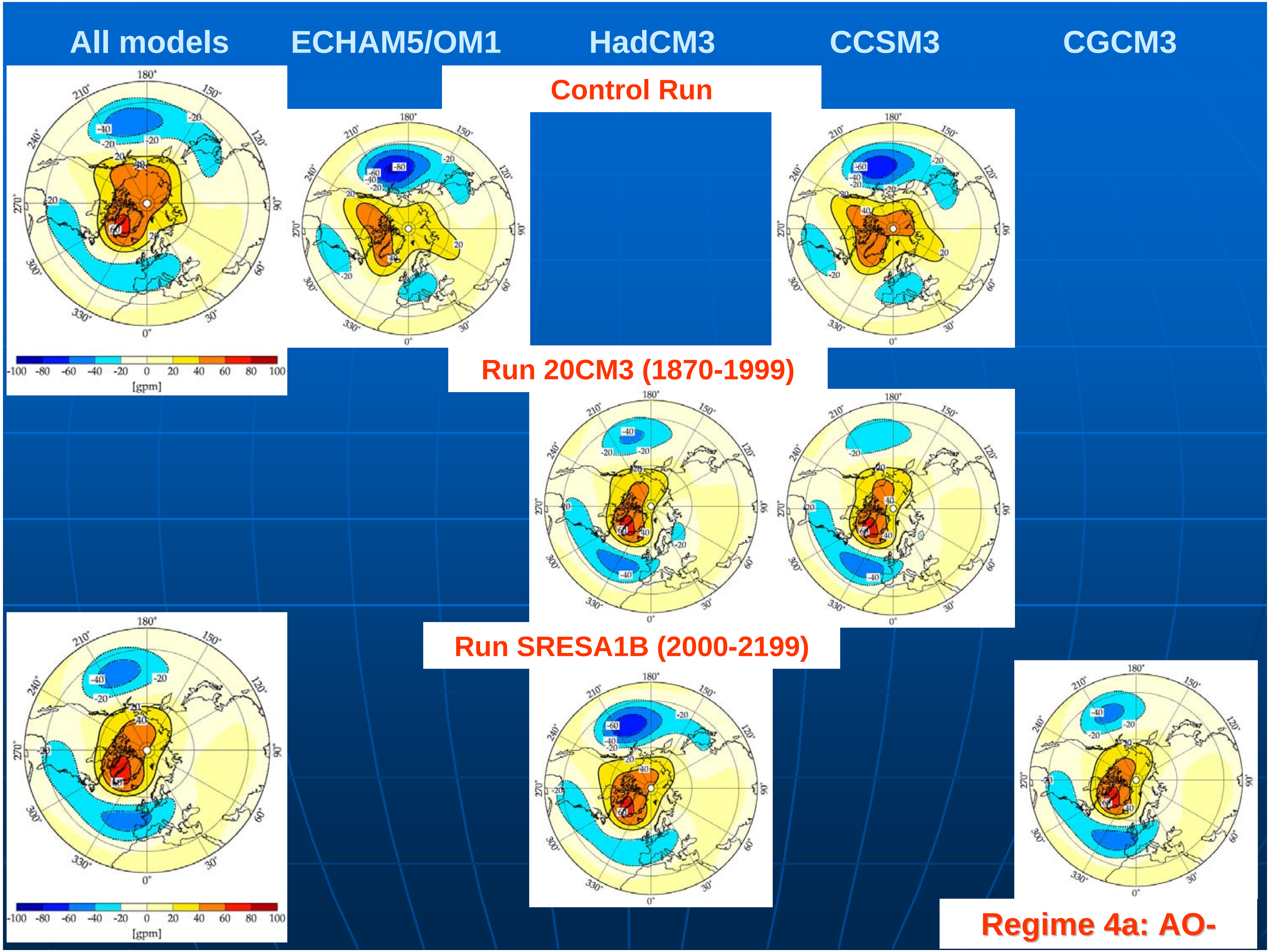



All models
ECHAM5/OM1
HadCM3
CCSM3
CGCM3
Control Run
Run 20CM3 (1870-1999)
Run SRESA1B (2000-2199)
-100 -80 -60 -40 -20 0 20 40 60 80 100
[gpm]
Regime 4: PNA+/NAO-

GPH 500hPa anomaly patterns of Regime 4a: AO-

Control run




All models
ECHAM5/OM1
HadCM3
CCSM3
CGCM3
Control Run
Run 20CM3 (1870-1999)
Run SRESA1B (2000-2199)
Regime 4a: AO-
-100 -80 -60 -40 -20 0 20 40 60 80 100
[gpm]

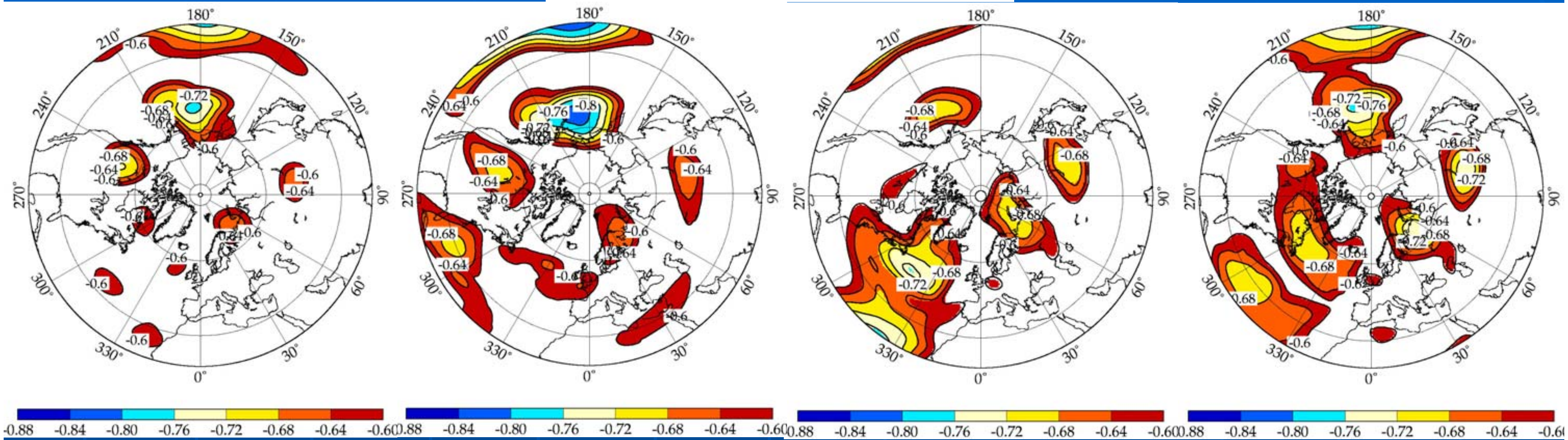
Summary and Conclusions

- Coupled AOGCMs are capable to reproduce regime-like behaviour
- Control runs
  → 5 regimes (EA/WR-, PNA-, PNA+/NAO-, COWL, AO-)
- 20th century
  → additional regime AO+
  → common regimes resemble NCEP regimes (EA/WR-, PNA-, PNA+/NAO-, AO+)
- Scenario runs
  → Changes in the frequency of occurrence of regimes
  (COWL more frequent, regimes with annular structure more frequent, PNA- less frequent)
  → Regime structure slightly changed (PNA-, PNA+/NAO-, AO+)
- Differences between models concerning number of regimes
  → Response to forcing different among the models
- ECHAM5/OM1 tendency to preferred regional Pacific patterns
- HadCM3, CGCM3 tendency to preferred annular and European patterns

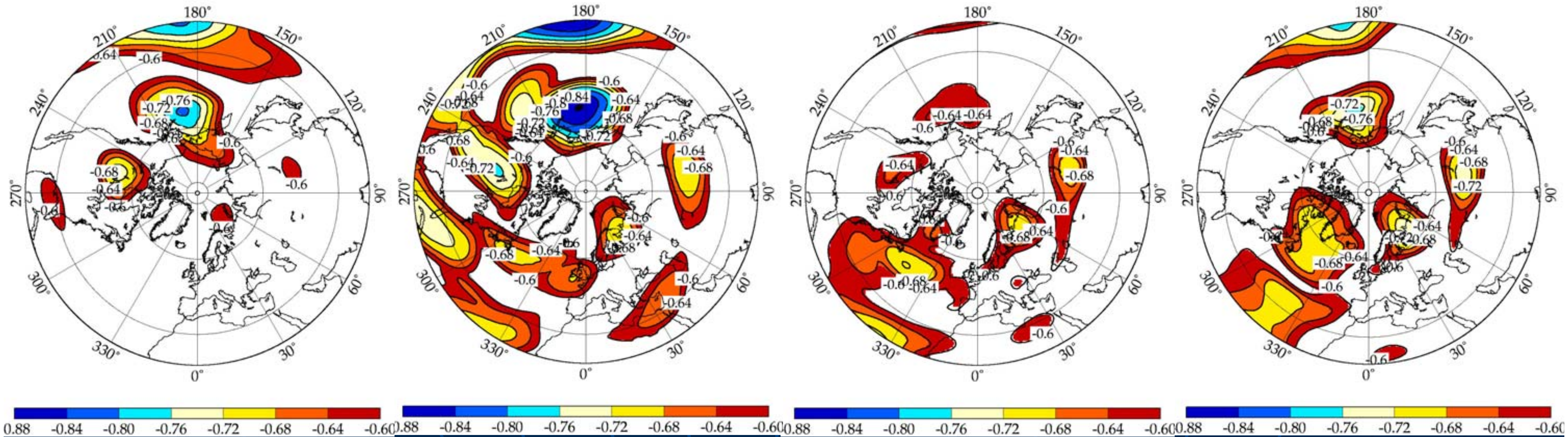
Maps of Teleconnectivity

MPI-ECHAM5/OM1 | NCAR-CCSM3 | UKMO-HadCM3 | CCCma-CGCM3

Run 20CM3 (1870-1999)



Run SRESA1B (2000-2199)



Outlook

- Understanding differences between different models
  - → Quantifying the influence of internally generated climate variability by analyses of ensemble simulations
  - → Study of dynamical causes for changed climate regimes
- Robust method for regime detection??