Preferred structures in large-scale circulation and the effect of doubling greenhouse gas concentration in HadCM3

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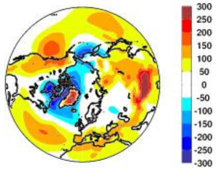
Background

Fig 1: Change in daily winter (DJF) mean surface pressure between $2xCO_2$ and $1xCO_2$. Contour interval 50Pa.



Preferred structures in surface pressure variability are compared between control and doubled CO_2 simulations of the Hadley Centre coupled model HadCM3.

- Daily winter (DJF) surface pressures north of 20˚N are analysed in 100-year simulations of HadCM3 under pre-industrial ($1xCO_2$) and future climate ($2xCO_2$) conditions.
- Doubled CO_2 induces a pressure increase in mid and subtropical latitudes but decreases over Newfoundland and the Bering Strait, making the flow slightly more zonal (Fig 1). No overall shift in seasonality is observed at 3 key locations corresponding to the northern centre of the NAO, the North Pacific Oscillation or the Siberian High.
- A slight increase in the variance explained by the first few EOF patterns occurs at $2xCO_2$ (Fig 2). EOF1 resembles the NAO in the control simulation but looks more like the Arctic Oscillation at $2xCO_2$. EOF2 shows the Pacific pattern in both datasets.
- Preferred structures in planetary wave dynamics are investigated based on the method of Hannachi (2007), using the multivariate Gaussian mixture model applied to PDFs of principal components of daily surface pressure.

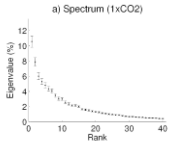
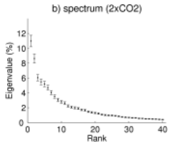


Fig 2: Variance explained by each of the first 20 EOFs in daily winter (DJF) surface pressure for (a) $1xCO_2$ and (b) $2xCO_2$. 95% confidence intervals are shown.



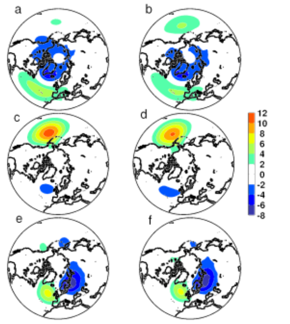


Fig 3: First 3 EOFs of daily winter surface pressure anomalies for (left) control and (right) $2xCO_2$ simulations.

Methodology

- Any PDF can be decomposed by a weighted mixture of multivariate Gaussian density functions (Anderson & Moore, 1979) as in Eqn (1) where α_k are the mixing proportions of the mixture model satisfying Eqn (2); $\boldsymbol{\mu}_k$ and $\boldsymbol{\Sigma}_k$ are the mean and covariance matrix of the *k*th multivariate normal density function g_k as in Eqn (3) and *d* is the state space dimension. More details in Hannachi & O'Neill (2001) and Hannachi (2007).
- Using only the leading two PCs of surface pressure anomalies suggests that the control simulation supports a two-component mixture at the 5% significance level, giving two large-scale flow structures: a high over the North Pacific and a low over the North Atlantic, and its reverse. No such behaviour is obtained at $2xCO_2$ (Fig 4).
- The method is repeated using the leading 3, 4 or 5 EOFs. At $2xCO_2$, the preferred patterns emerge only when at least 4 PCs are used. Both datasets then support only a mixture of two Gaussians, significant at the 2.5% level (see Fig 5).

$$f(\mathbf{x}) = \sum_{k=1}^{c} \alpha_k \; g_k(\mathbf{x}, \boldsymbol{\Sigma}_k, \boldsymbol{\mu}_k), \qquad (1)$$

$$0 < \alpha_k < 1, \;\text{ for } k = 1, \ldots, c, \;\text{ and } \sum_{k=1}^{c} \alpha_k = 1, \qquad (2)$$

$$g_k(\mathbf{x}, \boldsymbol{\Sigma}_k, \boldsymbol{\mu}_k) = (2\pi)^{-d/2} |\boldsymbol{\Sigma}_k|^{-1/2} \exp\left[-\frac{1}{2} (\mathbf{x} - \boldsymbol{\mu}_k)^{\mathrm{T}} \boldsymbol{\Sigma}_k^{-1} (\mathbf{x} - \boldsymbol{\mu}_k) \right], \qquad (3)$$

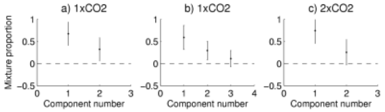


Fig 4: 95% confidence intervals of mixing proportion means in a mixture of (a) 2 bivariate Gaussians and (b) 3 bivariate Gaussians at $1xCO_2$ and (c) 2 bivariate Gaussians at $2xCO_2$.

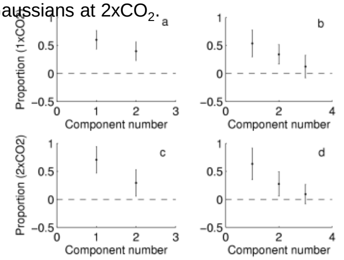


Fig 5: 95% confidence limits of mixing proportions in mixtures of 2 (left) and 3 (right) Gaussians using the leading four principal components of the (top) control and (bottom) $2xCO_2$ simulations.

Results

- Preferred patterns constructed from the first 4 EOFs are similar to those derived from only 2 EOFs at $1xCO_2$. For the Atlantic there is a weak dipole over Eurasia and west of the Iberian peninsula (Fig 6a,b). At doubled CO_2, the Pacific centre is accompanied by a weaker centre over northern Russia and southern Greenland (Fig 6c,d).
- The difference (Fig 7) shows a decrease in the Aleutian low especially in the first regime. This is robust even when the difference between the climatologies is removed. Further tests using higher degenerate PCs are in agreement with these results.

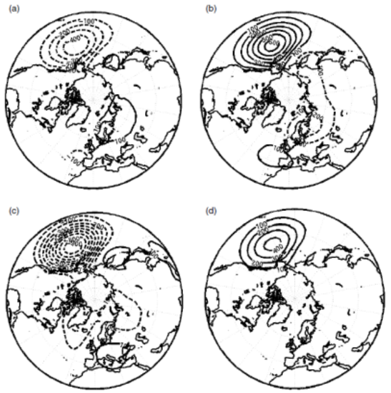


Fig 6 (left): Preferred circulation patterns obtained by fitting a two component multivariate Gaussian mixture model using the leading four PCs from (top) $1xCO_2$ and (bottom) $2xCO_2$ simulations. Contour interval 100Pa.

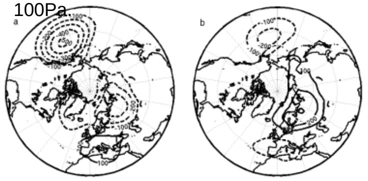


Fig 7 (above): Difference in preferred circulation patterns between $2xCO_2$ and $1xCO_2$ (from Figs 6c-6a and 6d-6b).

Conclusions

- Doubling greenhouse gas concentration affects frequency and pattern structures of preferred circulation regimes in the northern hemisphere during winter.
- The less frequent regime becomes amplified (suggesting an increase in future extremes) but the more frequent regime weakens, involving significant weakening of the Aleutian low at $2xCO_2$.
- Over the Euro-Atlantic sector, changes are consistent with strengthening and an eastward shift of the NAO in one case and weakening of the NAO in the other.
- Thus in this model, an increase in CO_2 concentration affects not only the climatology but also climate variability, decreasing the large-scale regime behaviour.

References: Hannachi A, Turner AG (2008, this work) *Q.J.R.Meteorol.Soc.* **134**: 469—480. // Hannachi A (2007) *J.Atmos.Sci*. **64**: 3521—3541. // Anderson BD, Moore JB (1979) *Optimal Filtering*. Prentice Hall: New Jersey. // Hannachi A, O'Neill A (2007) *Q.J.R.Meteorol.Soc*. **127**: 939—958.

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