Impact of tropical ocean sea surface temperatures on the variability and predictable components of seasonal atmospheric circulation in the North Atlantic–European area

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Motivation and analysis

- Detecting the potential impact of tropical sea surface temperatures (SST) on midlatitude atmospheric variability and predictable components
- EOF analysis → extracts individual modes of variability occurring in the ensemble of numerical simulations
- Signal-to-noise optimal patterns method → identifies patterns that maximize signal-to-noise ratio, as described in Straus et al. (2003)[1]
- Considered variables: geopotential height at 200 hPa (GH200) and total precipitation (RR)
- JFM season (January – February – March) represents boreal winter → focus in literature[2,3]

1. Straus D et al. (2003): Predictability of the Seasonal Mean Atmospheric Circulation during Autumn, Winter and Spring. *J Climate* **16**, 3629-3649.
2. Wallace JM, Gutzler DS (1981): Teleconnections in the Geopotential Height Field during the Northern Hemisphere Winter. *Mon. Wea. Rev.* **109**, 784–812.
3. Mo KC, Livezey RE (1986): Tropical-extratropical geopotential height teleconnections during the Northern Hemisphere winter. *Mon. Wea. Rev.* **114**(12), 2488-2515.

ICTP AGCM experiments are designed to test the effect of the SST boundary forcing on the North Atlantic-European area.

- ICTP AGCM (SPEEDY; T30L8)[4] → five experiments with different areas of SST boundary forcing
- Clim experiment → experiment without SST boundary forcing
- Each experiment is a 35-member ensemble of numerical simulations for the period 1855−2010
- Additional 2xCO2 Ctrl experiment: identical boundary forcing as Ctrl experiment with double the amount of CO_2 concentration
- Area of interest: North Atlantic−European area (20° N−80° N, 90° W−60° E)
- SST from NOAA ERSST V2 dataset

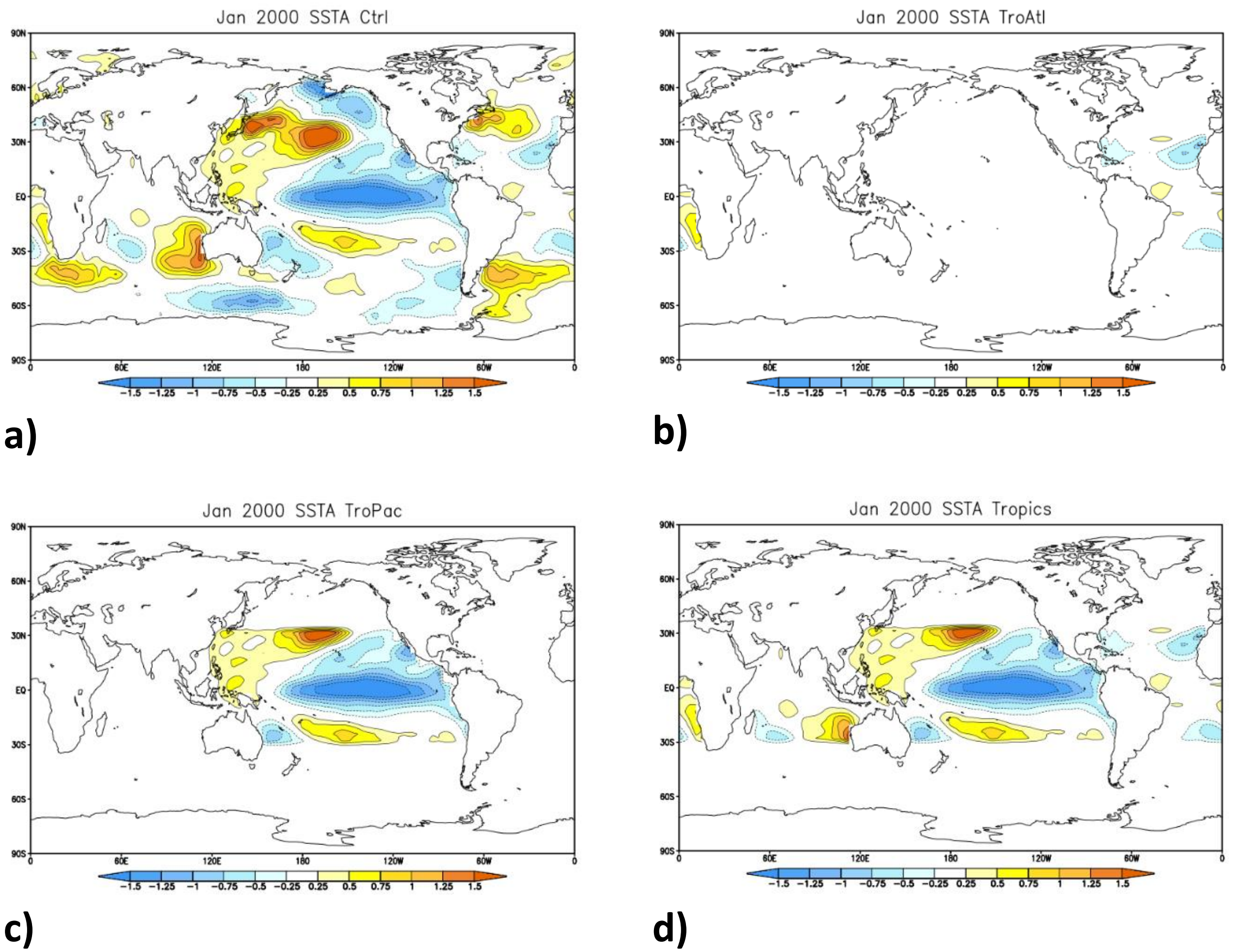

FIG. 1 SST anomalies in January 2000 as an illustration of ICTP AGCM setup of boundary forcing for different experiments: **a)** Ctrl, **b)** TroAtl, **c)** TroPac, and **d)** Tropics experiment.

4. Kucharski F et al. (2013): On the Need of Intermediate Complexity General Circulation Models: A “SPEEDY” Example. *Bull. Amer. Meteor. Soc.*, **94**, 25–30.

Winter EOF1 & EOF2 GH200 patterns are not affected by different areas of SST boundary forcing.

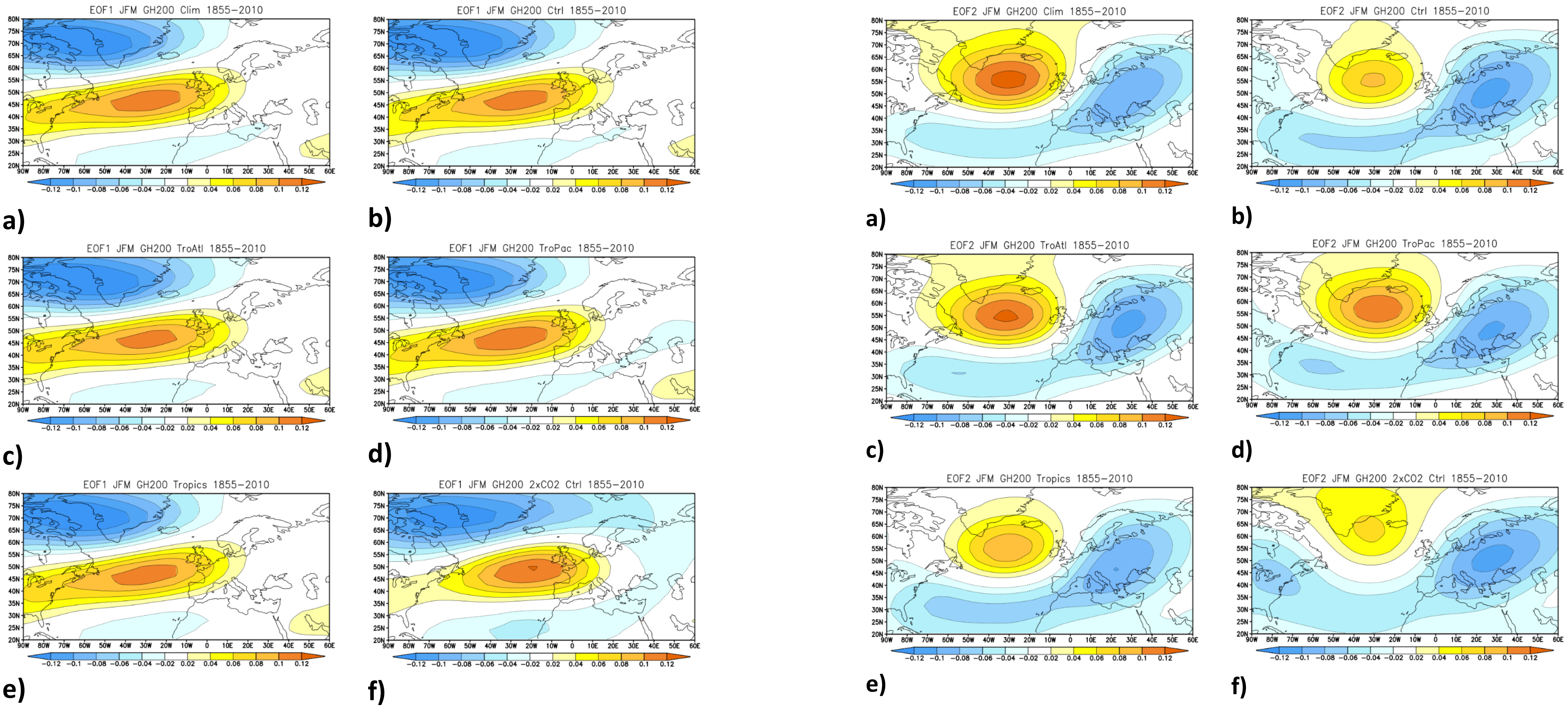

FIG. 2 EOF1 patterns (left) and EOF2 patterns (right) of JFM geopotential height at 200 hPa in **a)** Clim, **b)** Ctrl, **c)** TroAtl, **d)** TroPac, **e)** Tropics, and **f)** Ctrl experiment with double CO_2 concentration for 1855-2010.

Winter EOF1 precipitation patterns are not affected by different areas of SST boundary forcing.

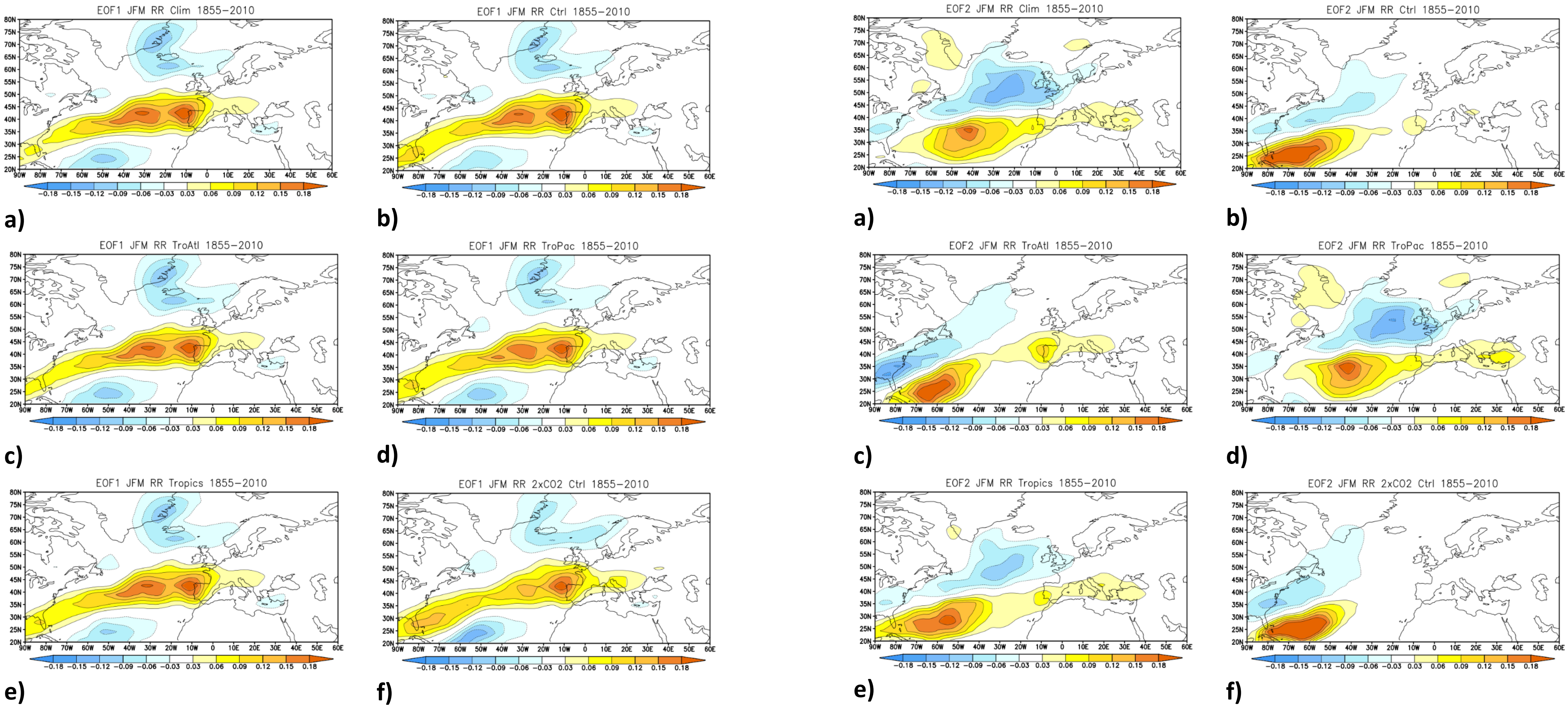

FIG. 3 EOF1 patterns (left) and EOF2 patterns (right) of JFM total precipitation in **a)** Clim, **b)** Ctrl, **c)** TroAtl, **d)** TroPac, **e)** Tropics, and **f)** Ctrl experiment with double CO_2 concentration for 1855-2010.

EOF patterns in other seasons are similar among different AGCM experiments.

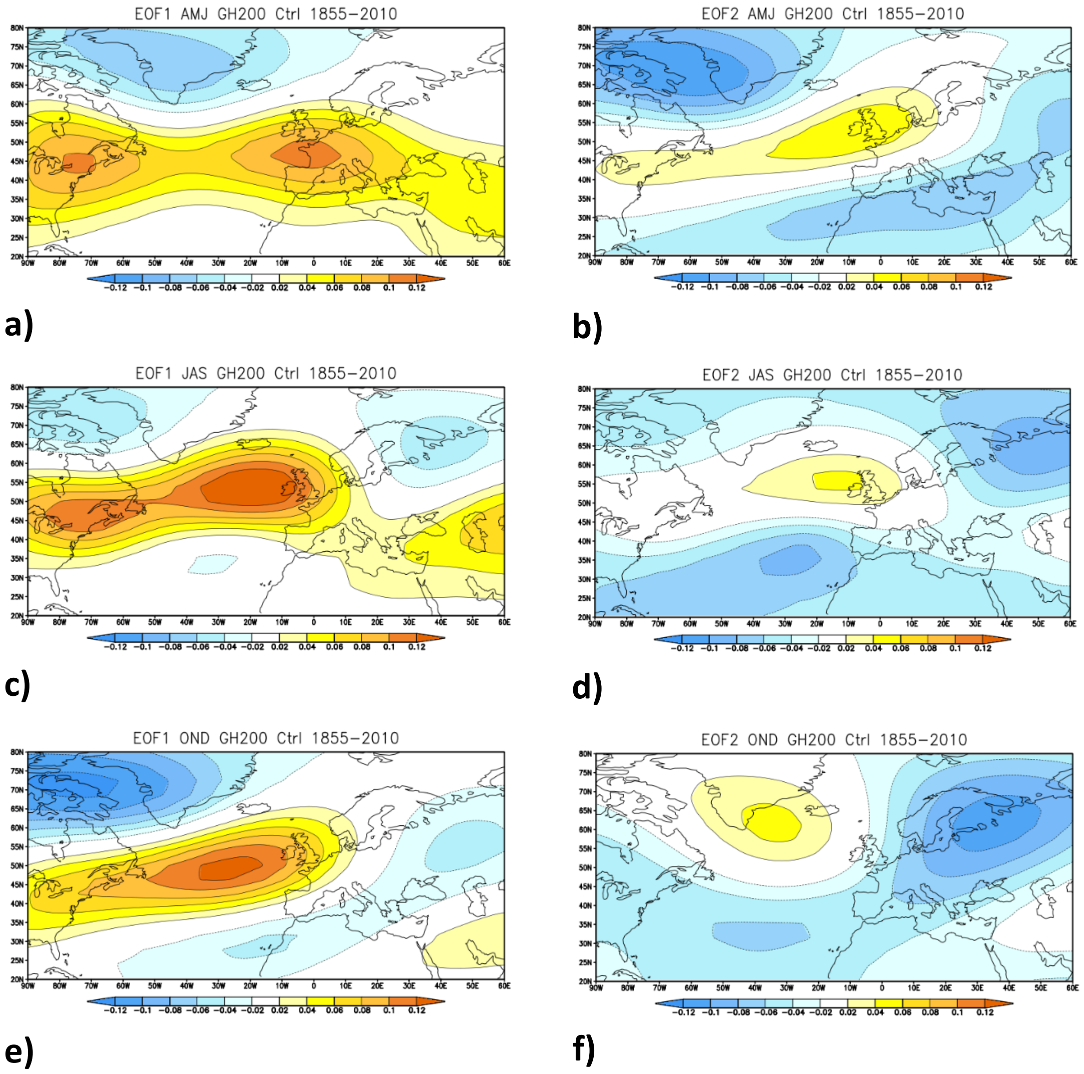

FIG. 4 EOF1 and EOF2 patterns of geopotential height at 200 hPa in Ctrl experiment for **a)-b)** AMJ, **c)-d)** JAS, and **e)-f)** OND season for 1855-2010.

- AMJ (April – May – June) → boreal spring
- JAS (July – August – September) → boreal summer
- OND (October – November – December) → boreal autumn
- Ctrl experiment taken as a representative → EOF patterns of other experiments are similar
- Results for precipitation follow GH200
- OND results especially close to JFM

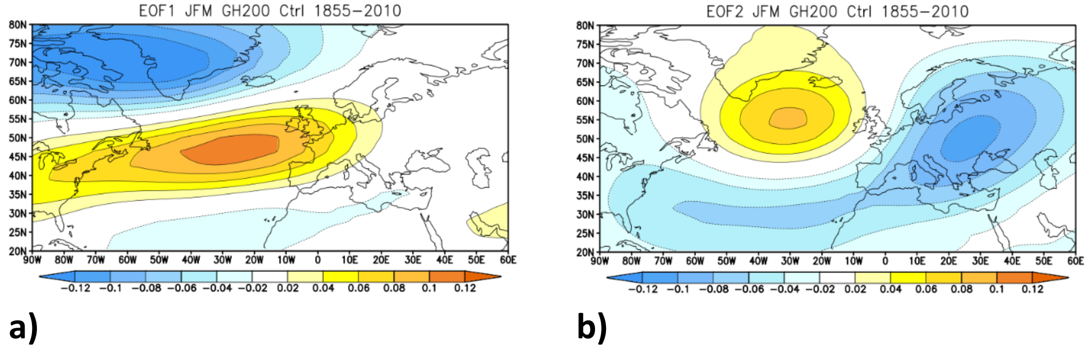

FIG. 5 a) EOF1 and **b)** EOF2 patterns of geopotential height at 200 hPa in Ctrl experiment for JFM season for 1855-2010

Doubled CO_2 concentration reduces the percentage of explained variance in EOF1, which is largest in winter for both GH200 and RR.

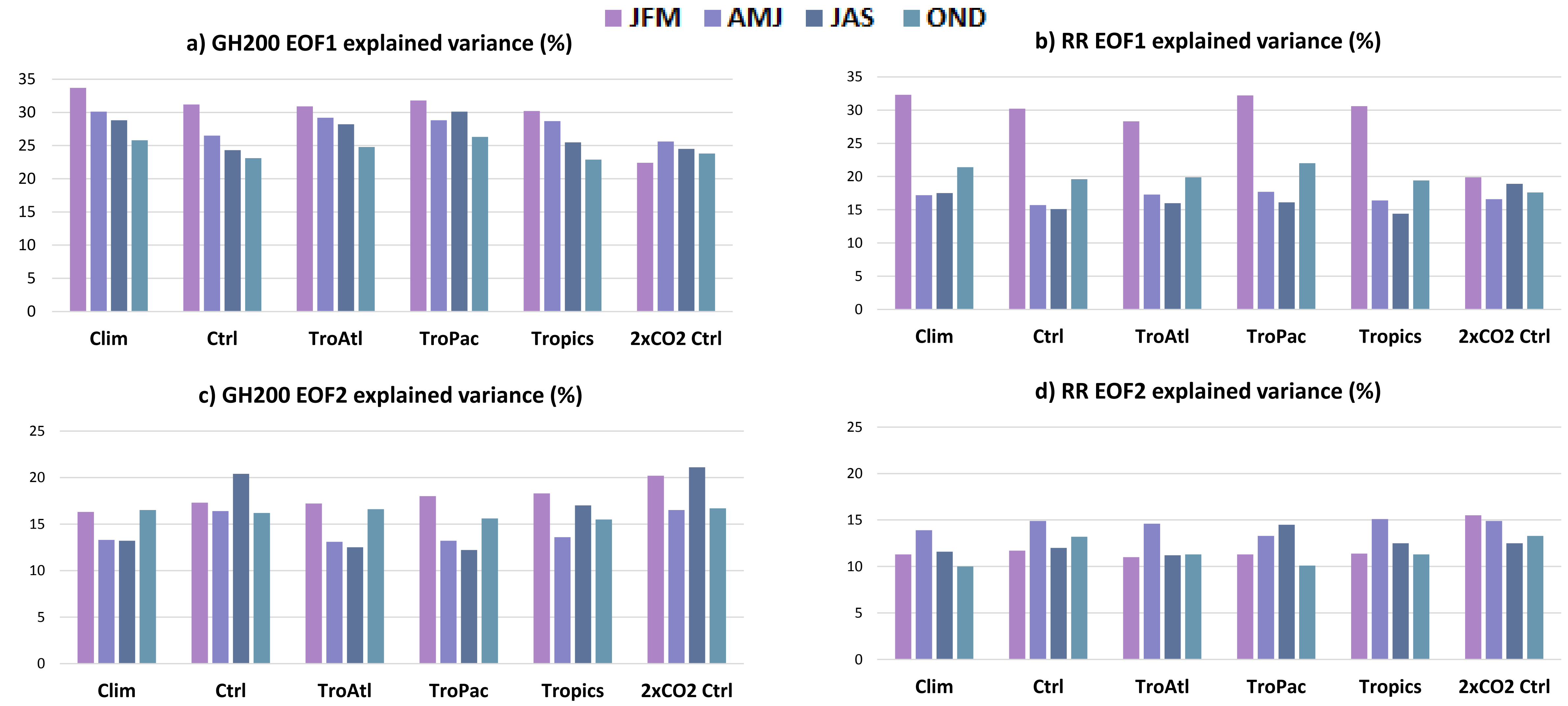

FIG. 6 Percentage of explained variance for EOF1 and EOF2 patterns of **a)** and **c)** geopotential height at 200 hPa, **b)** and **d)** total precipitation in Clim, Ctrl, TroAtl, TroPac, Tropics, and Ctrl experiment with double CO_2 concentration in JFM, AMJ, JAS, and OND season.

Signal-to-noise ratio is larger for GH200 and modified by the area of SST boundary forcing.

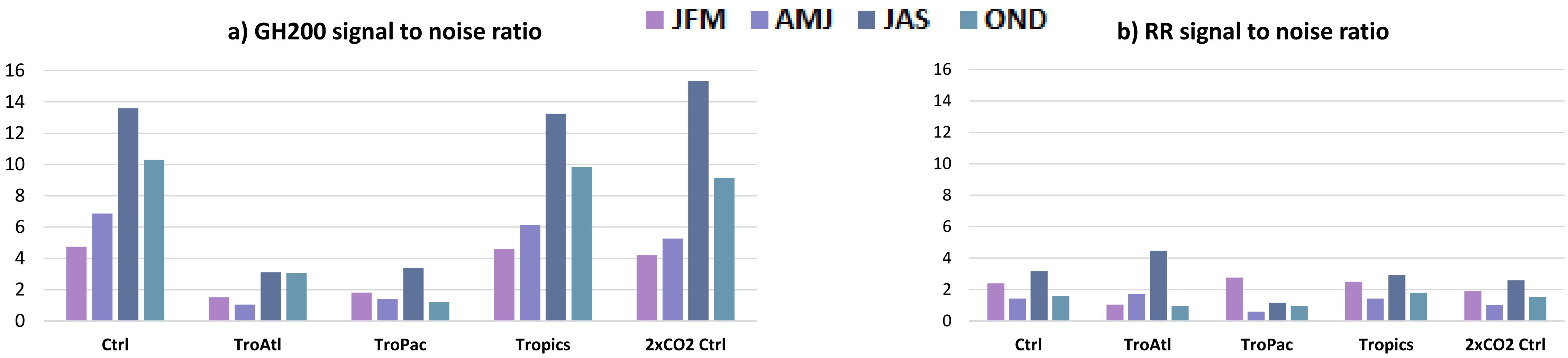

FIG. 7 Signal-to-noise ratio (SNR) of **a)** geopotential height at 200 hPa and **b)** total precipitation in Ctrl, TroAtl, TroPac, Tropics, and Ctrl experiment with double CO_2 concentration for 1855-2010 in JFM, AMJ, JAS and OND season (columns from left to right). SNR values in Clim experiment (0.05, not shown) are constant in all seasons for both variables. All SNR values are considered statistically significant according to the F-test for the ratio of variances on the 95% confidence level.

A realization of a numerical model consists of signal and noise. Signal (1) is defined by ensemble means, while the deviations from the ensemble mean define the noise (2). Here, M represents the number of ensemble members, and N the number of years.[5]

$$\sigma_s^2 = \frac{1}{M}\sum_{j=1}^{M}\left(\bar{x}_j - \bar{x}\right)^2 \qquad (1)$$

$$\sigma_n^2 = \frac{1}{M}\sum_{j=1}^{M}\left[\frac{1}{N}\sum_{i=1}^{N}\left(x_{i,j} - \bar{x}_j\right)^2\right] \qquad (2)$$

5. Branković Č, Molteni F (2004): Seasonal climate and variability of the EMCWF ERA-40 model. *Clim. Dyn.* **22**, 139-155.

JFM EOFOPT patterns show the spatial distribution that maximizes the signal-to-noise ratio.

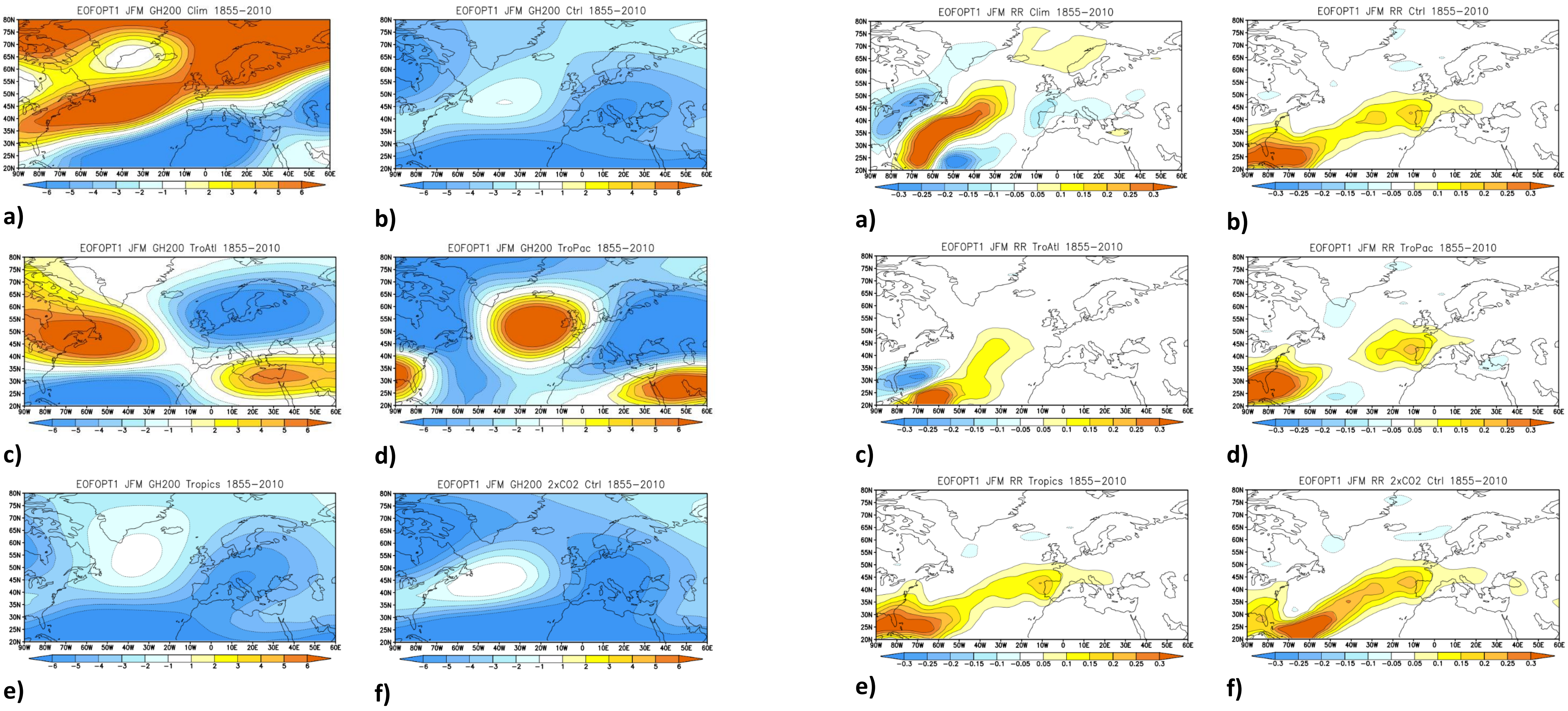

FIG. 8 EOFOPT1 patterns of JFM height at 200 hPa [m] (left) and JFM total precipitation [mm/day] (right) in **a)** Clim, **b)** Ctrl, **c)** TroAtl, **d)** TroPac, **e)** Tropics, and **f)** Ctrl experiment with double CO_2 concentration for 1855-2010. EOFOPT patterns are calculated using the first 20 EOF modes as input.

Conclusions

- Winter GH200 EOF patterns
  - EOF1 pattern projects onto North Atlantic Oscillation (NAO)
  - EOF2 pattern projects onto East Atlantic pattern[6]
- Signal-to-noise ratio generally increases with the increase of ocean area with prescribed SST anomalies
- Signal-to-noise ratio → tropical oceans influence the predictability of the atmosphere in the North Atlantic-European area
- Ctrl experiment → oceans outside the tropical zone influence the predictable component
- 2xCO2 Ctrl experiment → warmer climate conditions impact signal-to-noise ratio and the percentage of explained variance of EOF modes

6. Barnston AG, Livezey RE (1987): Classification, Seasonality and Persistance of Low-Frequency Atmospheric Circulation Patterns. *Mon. Wea. Rev.*, **115**, 1083-1126.