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# *Assimilation on climatic timescales*

*An application to the 'Little Ice Age'*

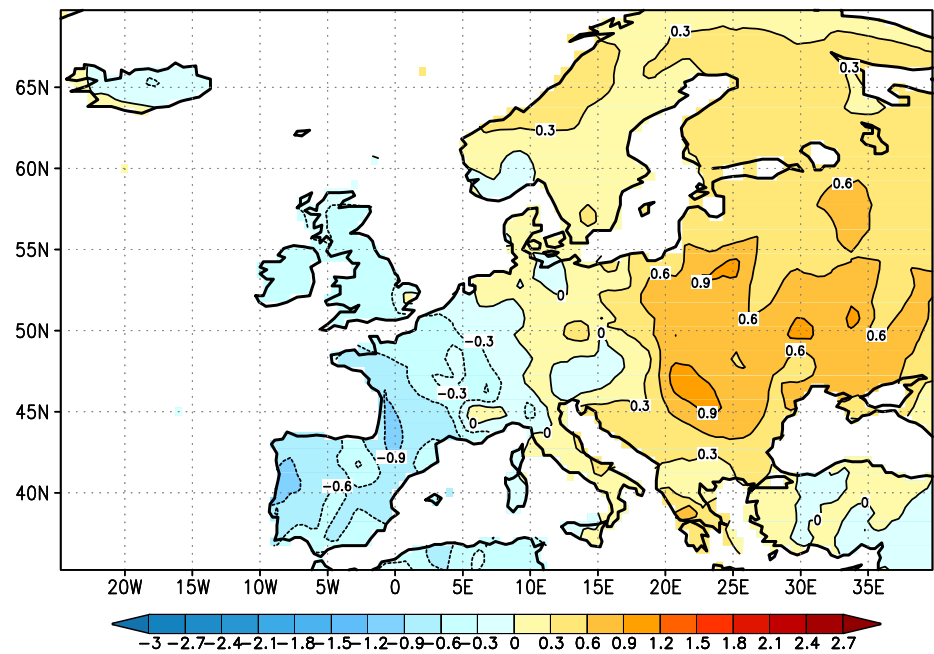
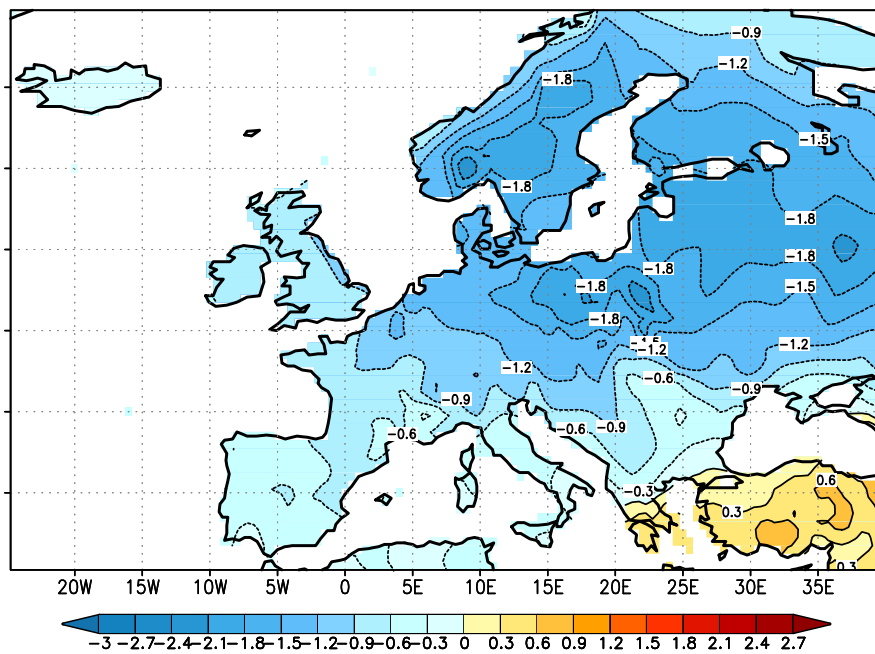
Gerard van der Schrier & Jan Barkmeijer

.... **‘Little Ice Age’ climate in Europe**



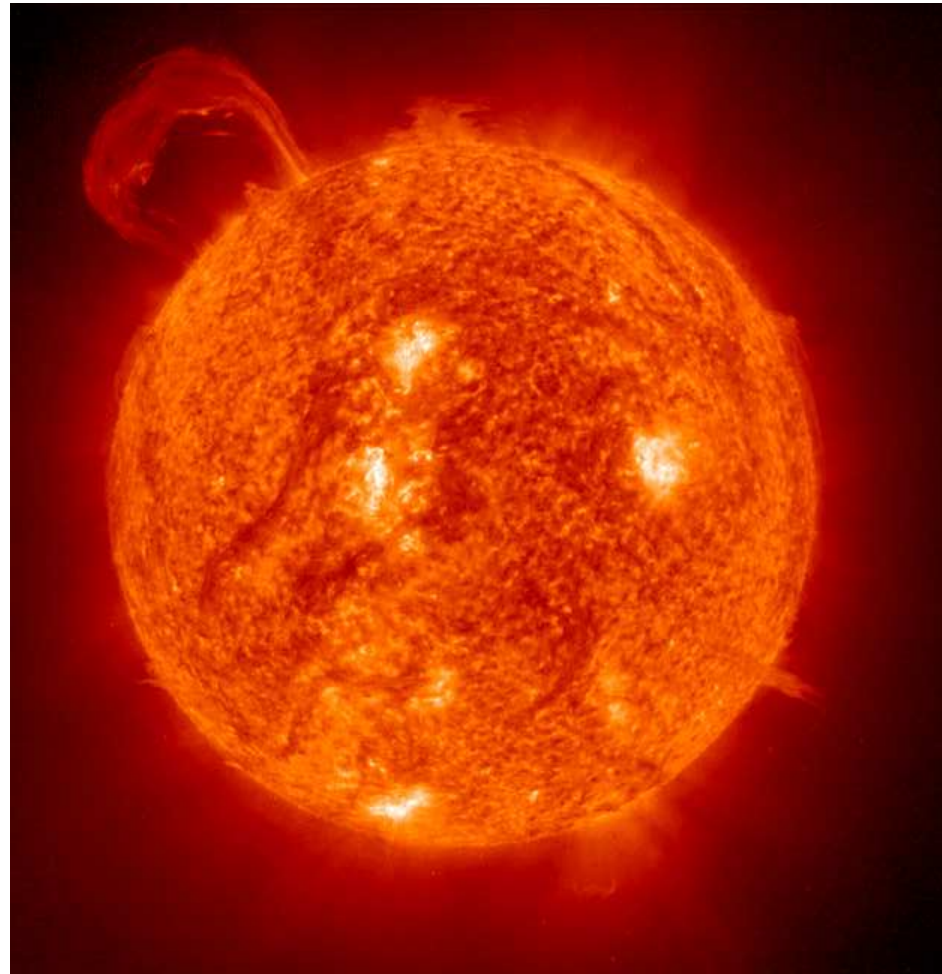
.... Dalton Minimum (ca. 1790-1820)

Complex situation? regional and seasonal variations



Luterbacher et al. (2004)

.... **A solar connection?**



.... **Impact of volcanic eruptions**



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.... **Bjerknes' hypothesis**

*Anomalous **ocean-atmosphere** interaction*

starting point:

atmospheric circulation reconstruction (1790-1820)

- anomalous surface ocean circulation

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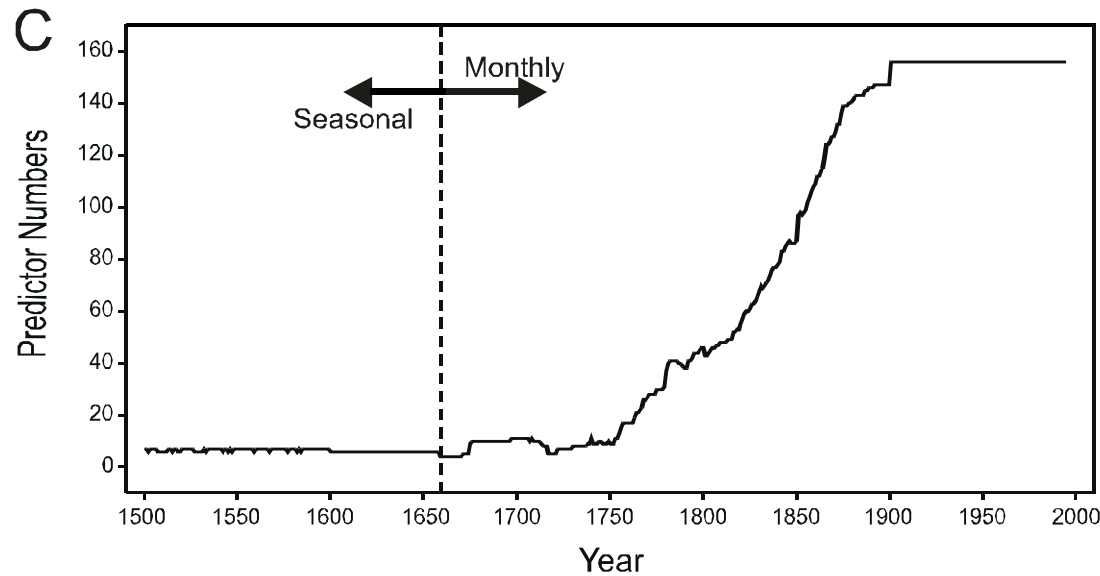
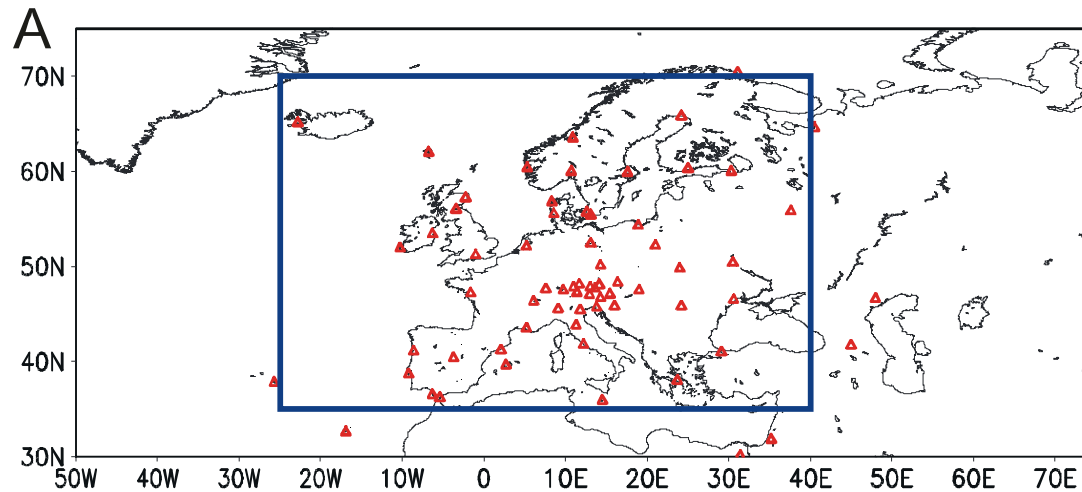
starting point:

atmospheric circulation reconstruction (1790-1820)

- anomalous surface ocean circulation
- anomalous SSTs
- cooling of Europe
- .....

....

# problem with assimilating paleodata I



resolution: monthly-seasonal-yearly

## .... **problem with assimilating paleodata II**

no 'ordinary' data-assimilation exercise

- 3D/4D-var methods useless:
  - low-temporal resolution
  - low-density network
  - low-quality data

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no 'ordinary' data-assimilation exercise

- 3D/4D-var methods useless:
  - low-temporal resolution
  - low-density network
  - low-quality data
- require a method which adjusts *mean* climate
  - synoptic scale variability adjusts dynamically consistent

## .... **problem with assimilating paleodata III**

two-step approach

- upscaling:
  - estimate large-scale patterns
  - anomalous atmospheric conditions

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two-step approach

- upscaling:
  - estimate large-scale patterns
  - anomalous atmospheric conditions
- assimilate large scale patterns

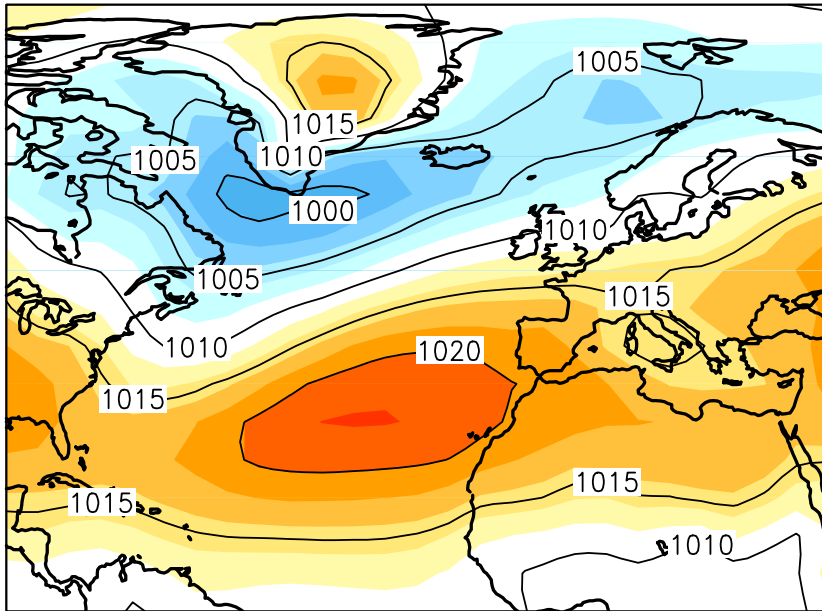
## .... Approach

Test Bjerknes' hypothesis by:

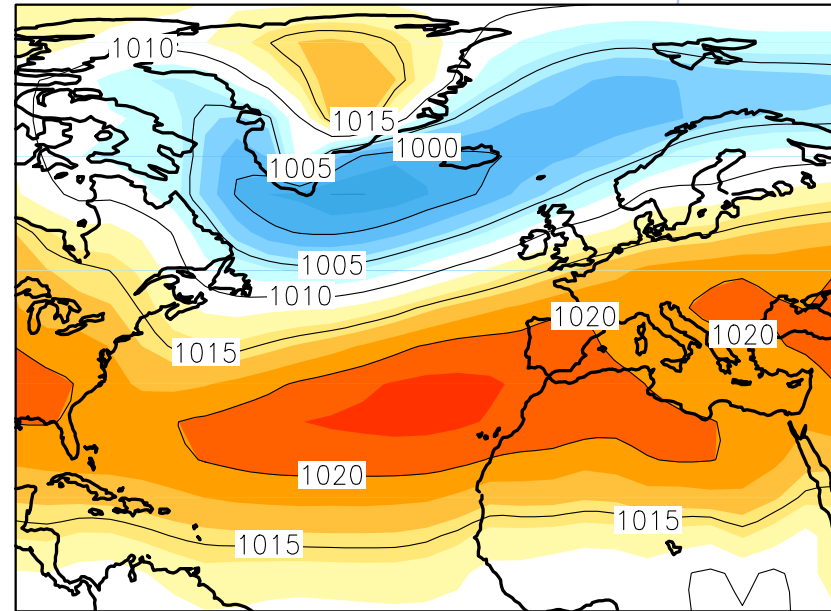
- reconstruct average January Sea Level Pressure field for 1790-1820
- assimilate field in GCM
- assess climate response
  - SST change?
  - SAT change?

.... **winter SLP reconstruction 1790-1820**

SLP january 1790–1820



january SLP 1971–2000

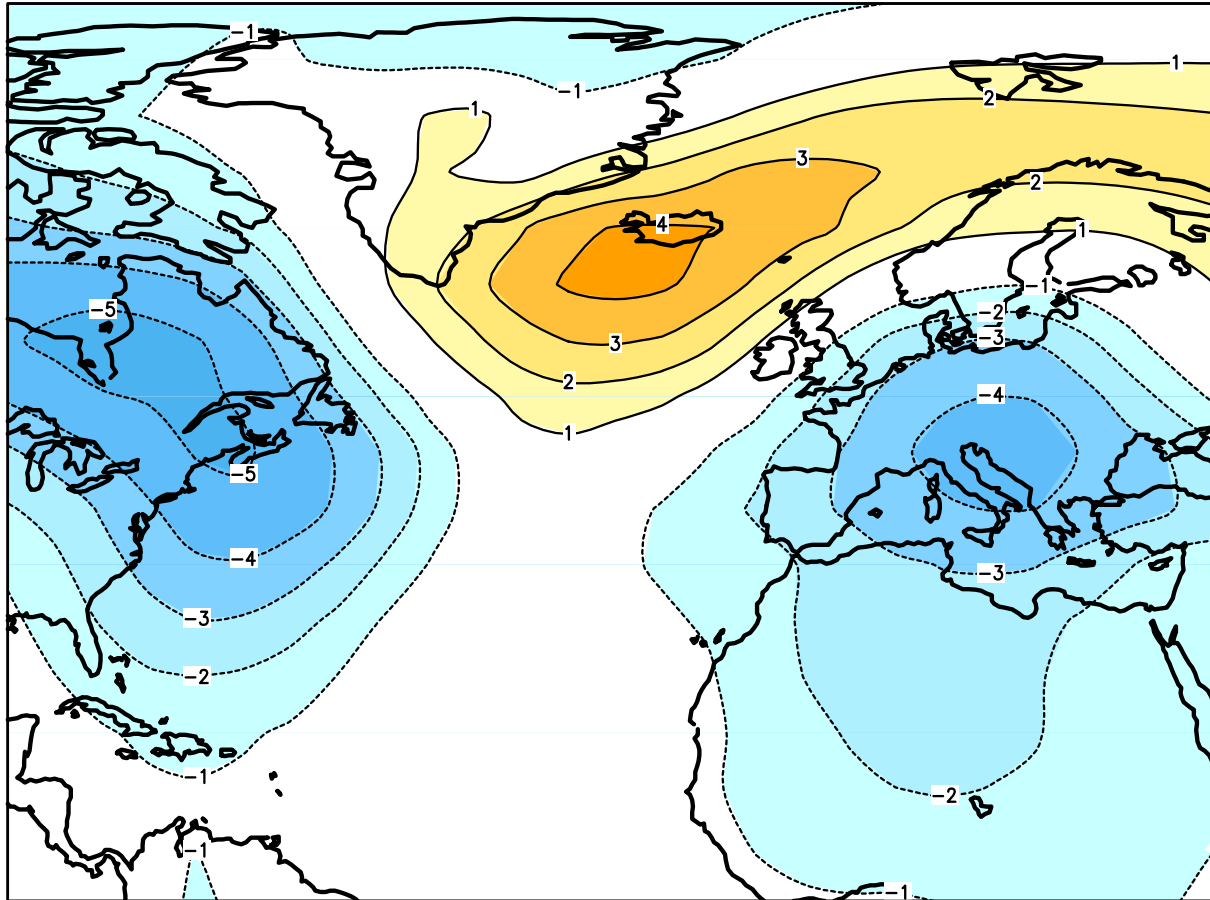


data from: Luterbacher et al, 2002; van der Schrier & Jones, 2008

....

# anomalous winter SLP fields

averaged pressure anomaly



## .... Forcing Singular Vectors I

reconstruction of streamfunction  $\psi_{\text{past}}$ :

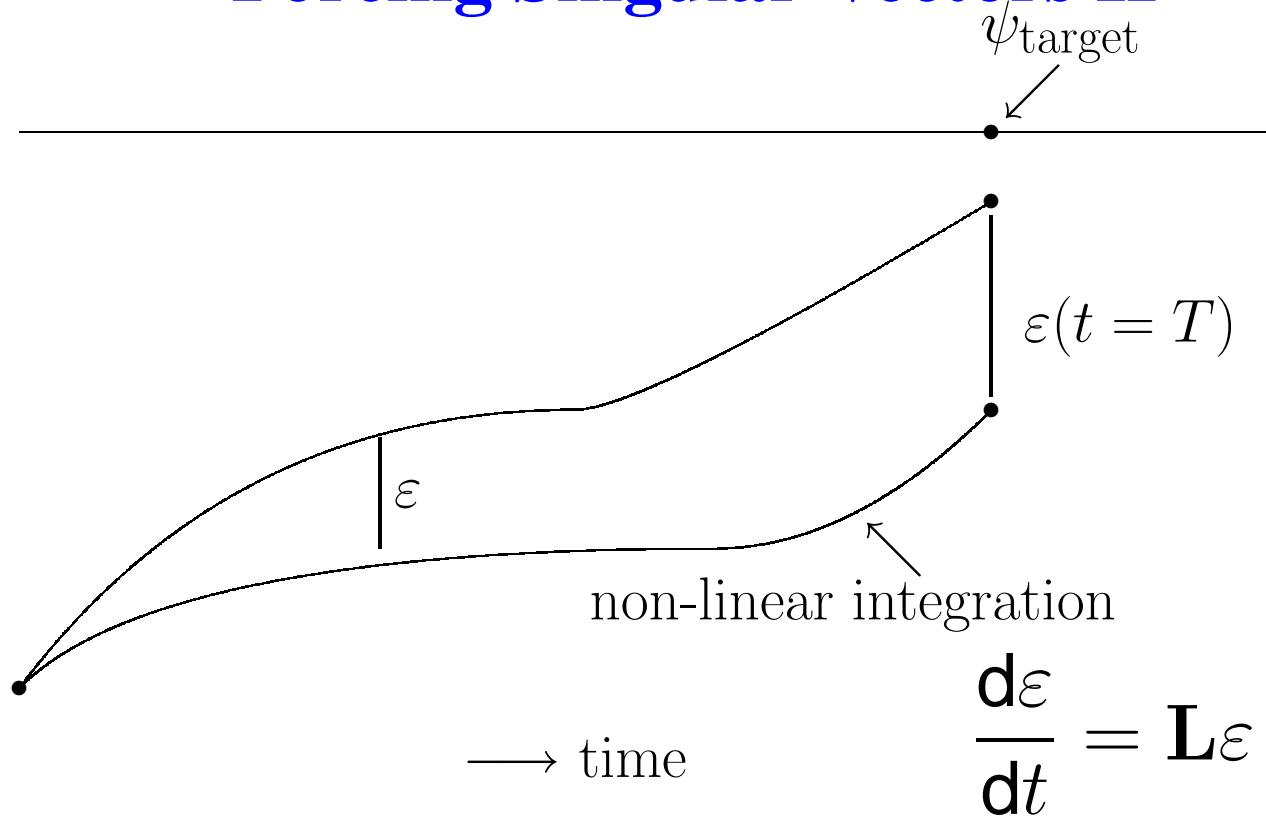
$$\psi_{\text{past}} = \psi_{\text{clim}} + \psi_{\text{target}}$$

streamfunction  $\psi$  at time  $t_0$ :

$$\psi(t_0, \mathbf{x}) = \psi_{\text{clim}}(\mathbf{x}) + \alpha(t_0)\psi_{\text{target}}(\mathbf{x}) + \sum_{n=2} \alpha_n(t_0)\psi_n(\mathbf{x})$$

objective:  $\langle \psi(t_0 + T, \mathbf{x}), \psi_{\text{target}} \rangle = 1$

# .... Forcing Singular Vectors II

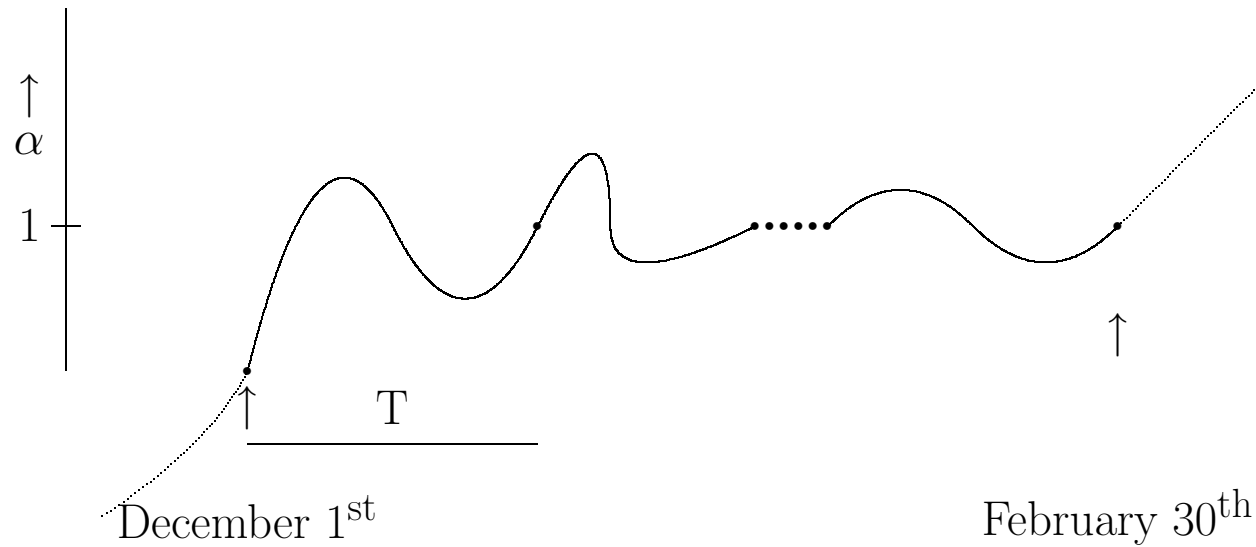


$$\frac{d\varepsilon}{dt} = \mathbf{L}\varepsilon + \mathbf{f}$$

$$\varepsilon(T) = \mathcal{M}\mathbf{f} \text{ with } \mathcal{M} = \int_0^T \mathbf{M}(s, T) ds$$

$$J(\mathbf{f}) = |P(\mathcal{M}\mathbf{f} - (1 - \alpha)\psi_{\text{target}})|$$

.... **Forcing Singular Vectors III**

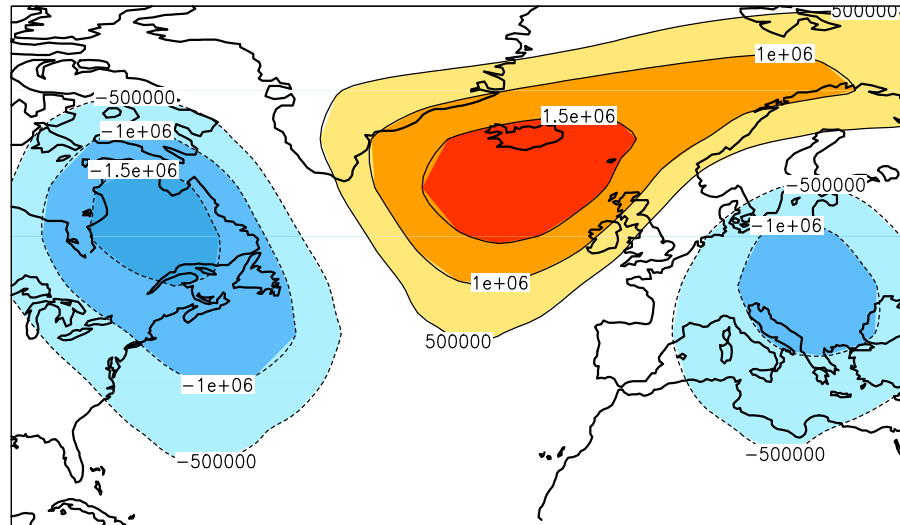


Here:  $T = 3$  days

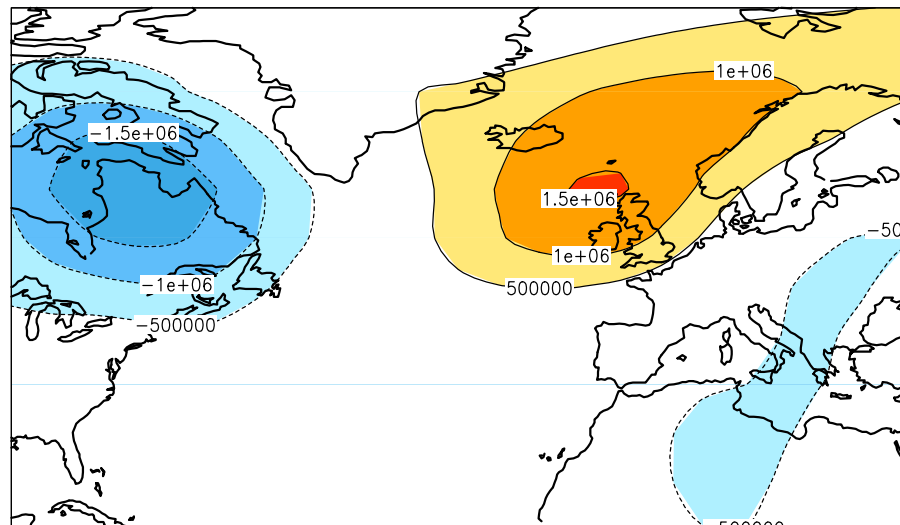
....

# Does the data-assimilation work?

target pattern



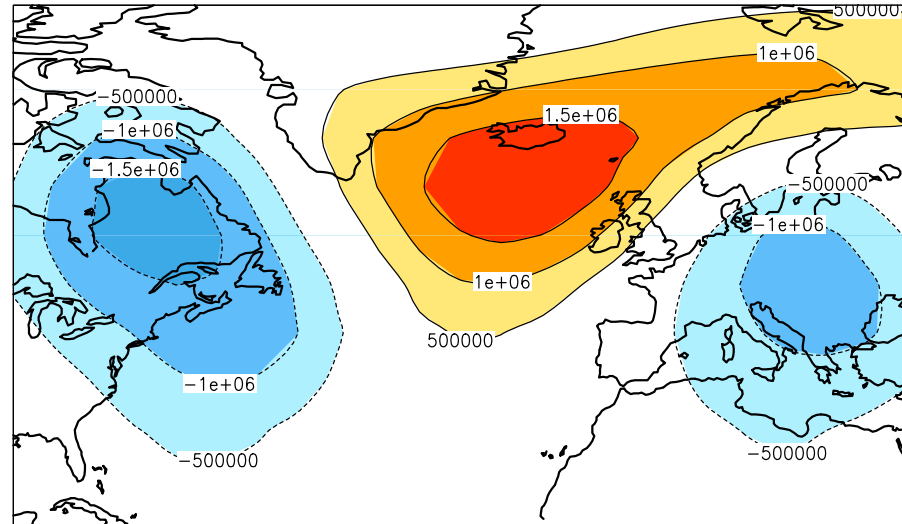
simulation



....

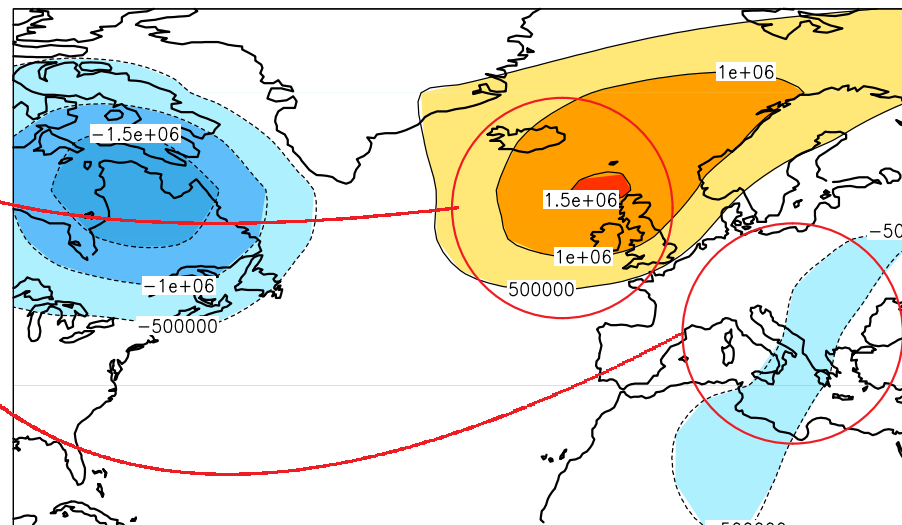
# Does the data-assimilation work?

target pattern



simulation

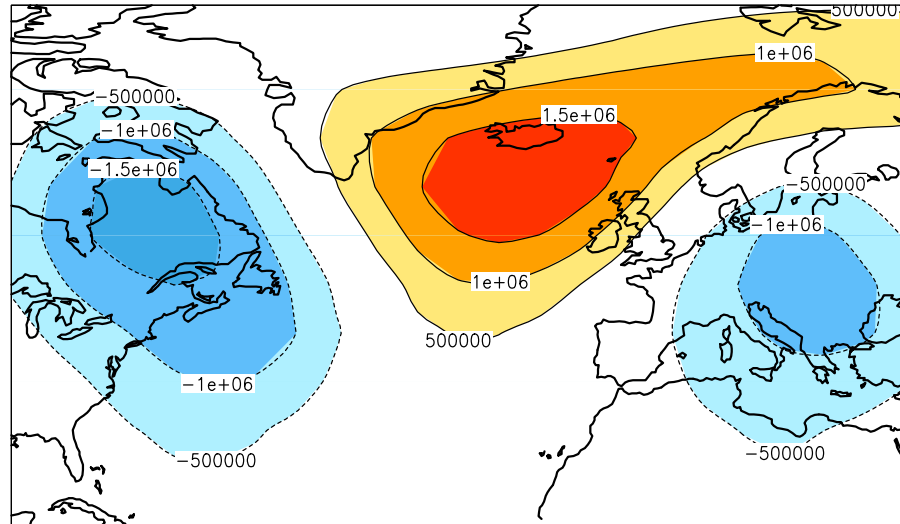
too weak



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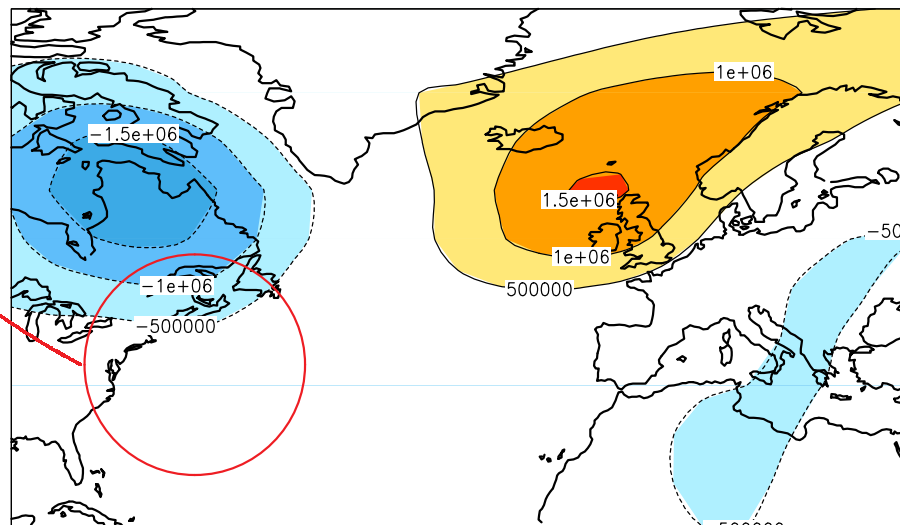
# Does the data-assimilation work?

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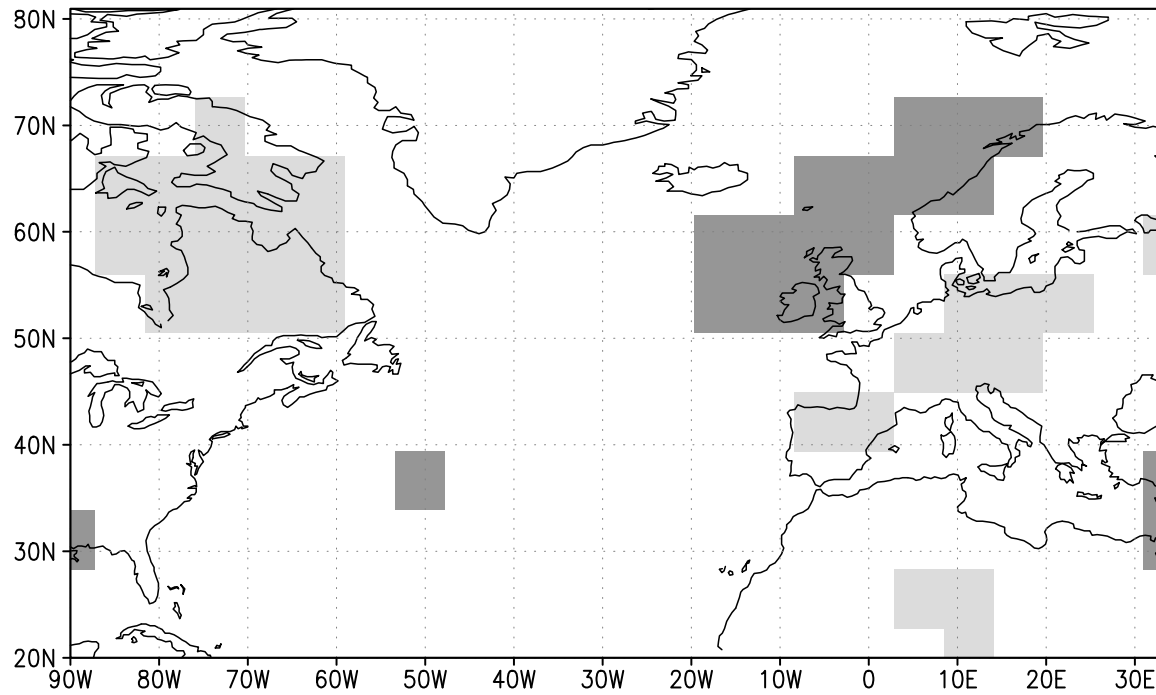
simulation

absent



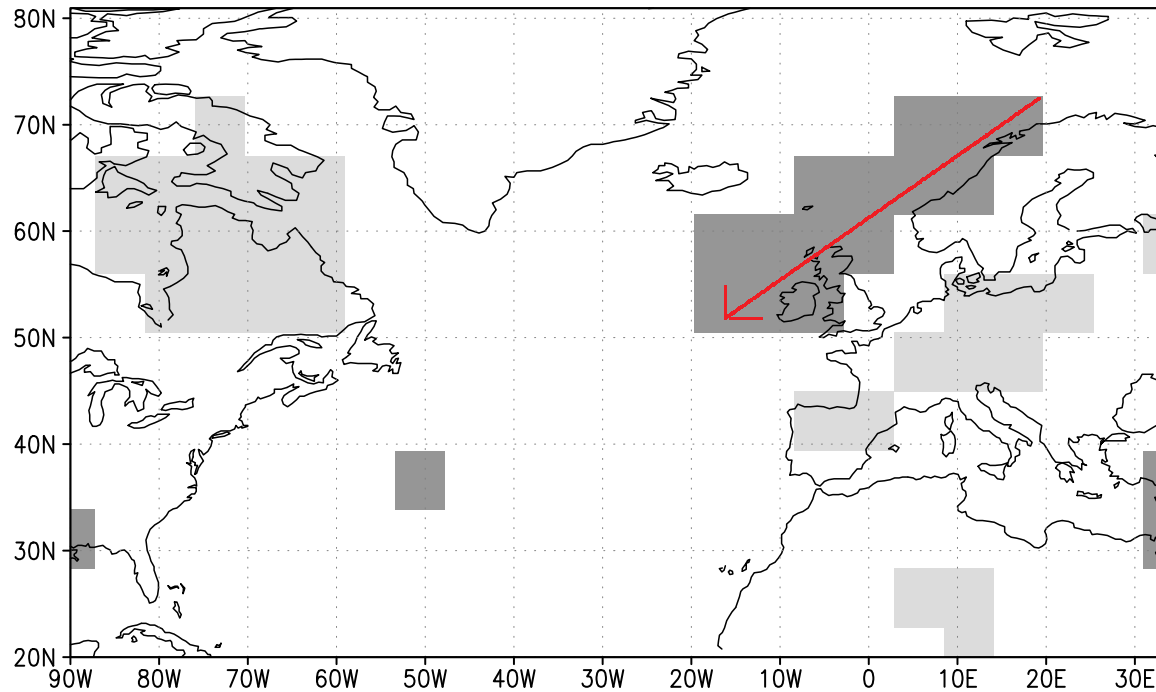
....

# Change in surface ocean circulation



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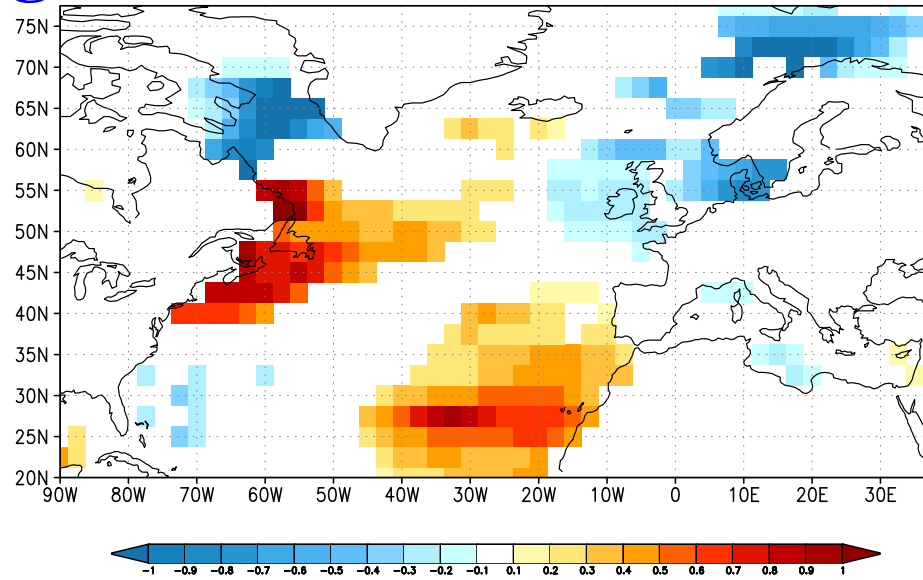
# Change in surface ocean circulation



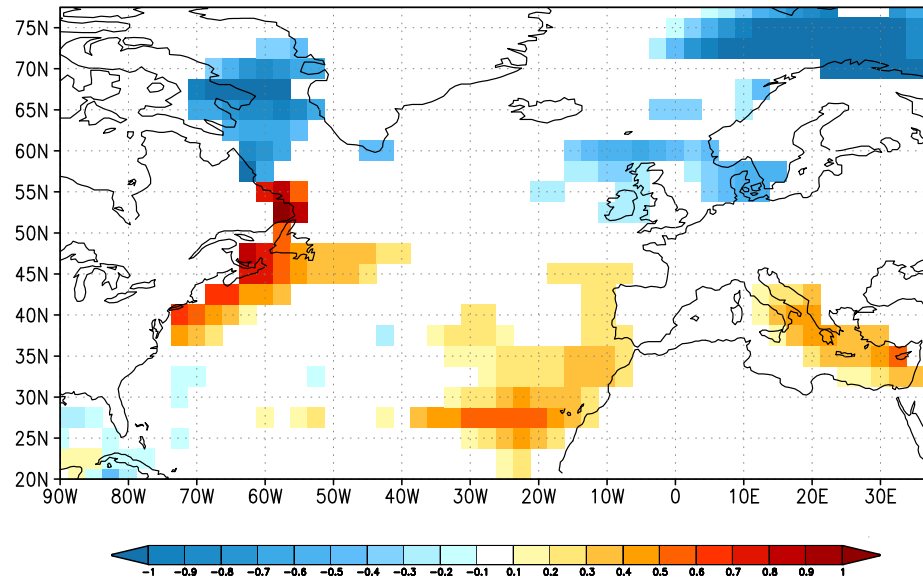
$$v = \nabla \times \tau$$

....

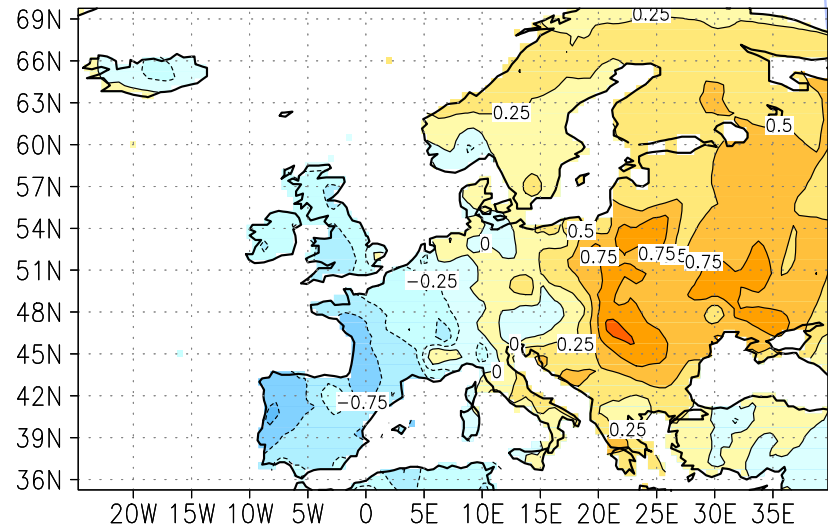
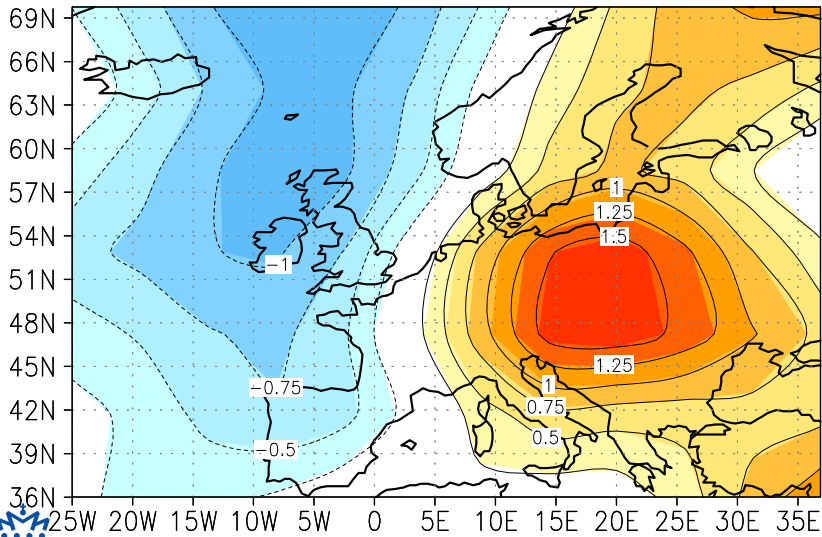
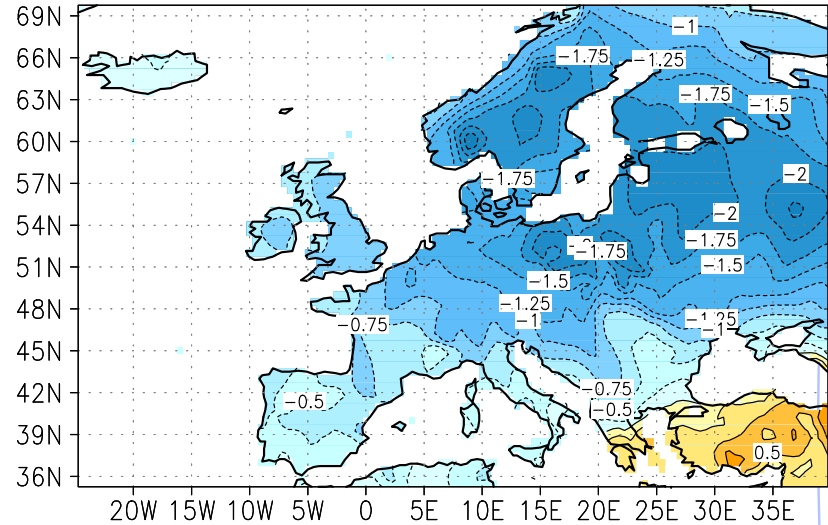
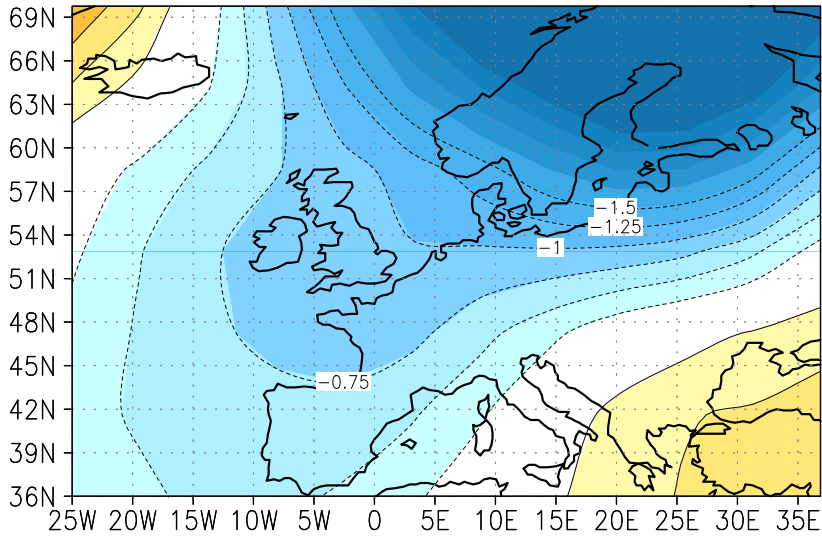
# Change in SSTs delta SST DJF



delta SST JJA



.... modelled and reconstructed SAT



## .... Outlook

### The Forcing Singular Vectors approach

- has been applied to other paleoclimatic problems

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- can it be applied to the early 20<sup>th</sup> century as well?
  - Stefan Brönnimann's monthly reconstructions could be used
  - KNMI EC-Earth model (based on ECMWF model)

.... **What changes are dynamically consistent?**

