Reconstructing paleoclimate using a data assimilation method

challenges and problems

Gerard van der Schrier & Jan Barkmeijer

.... Outline

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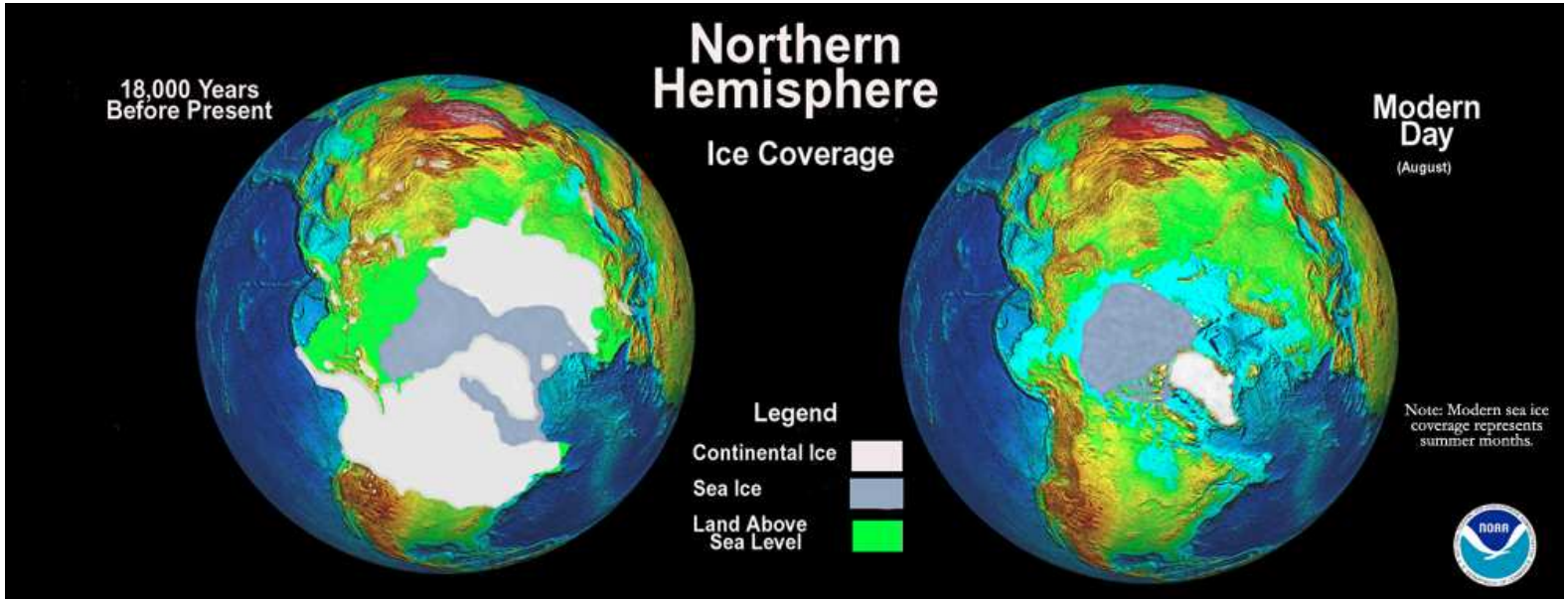
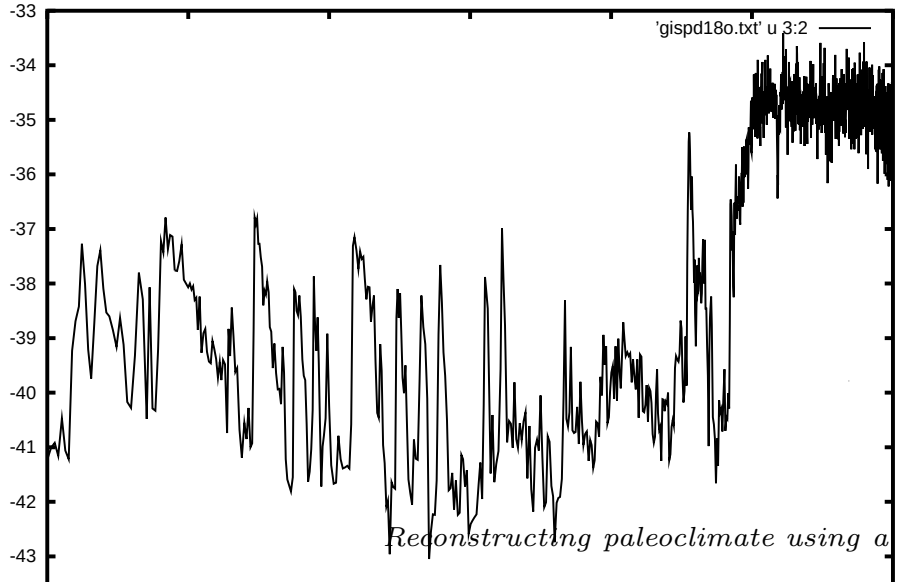
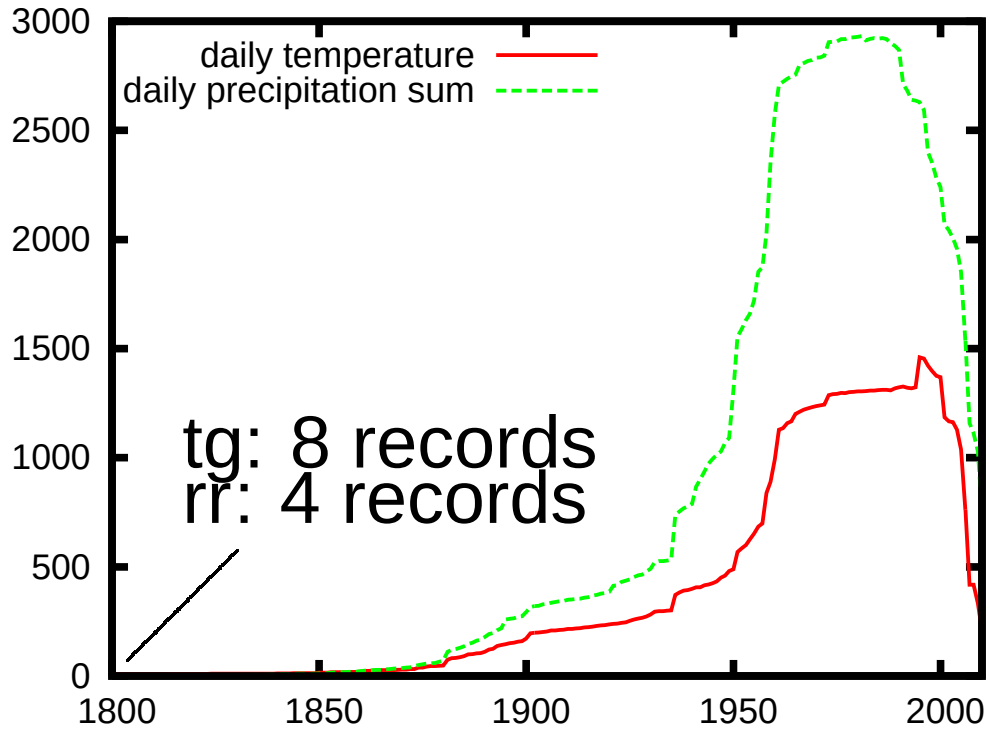


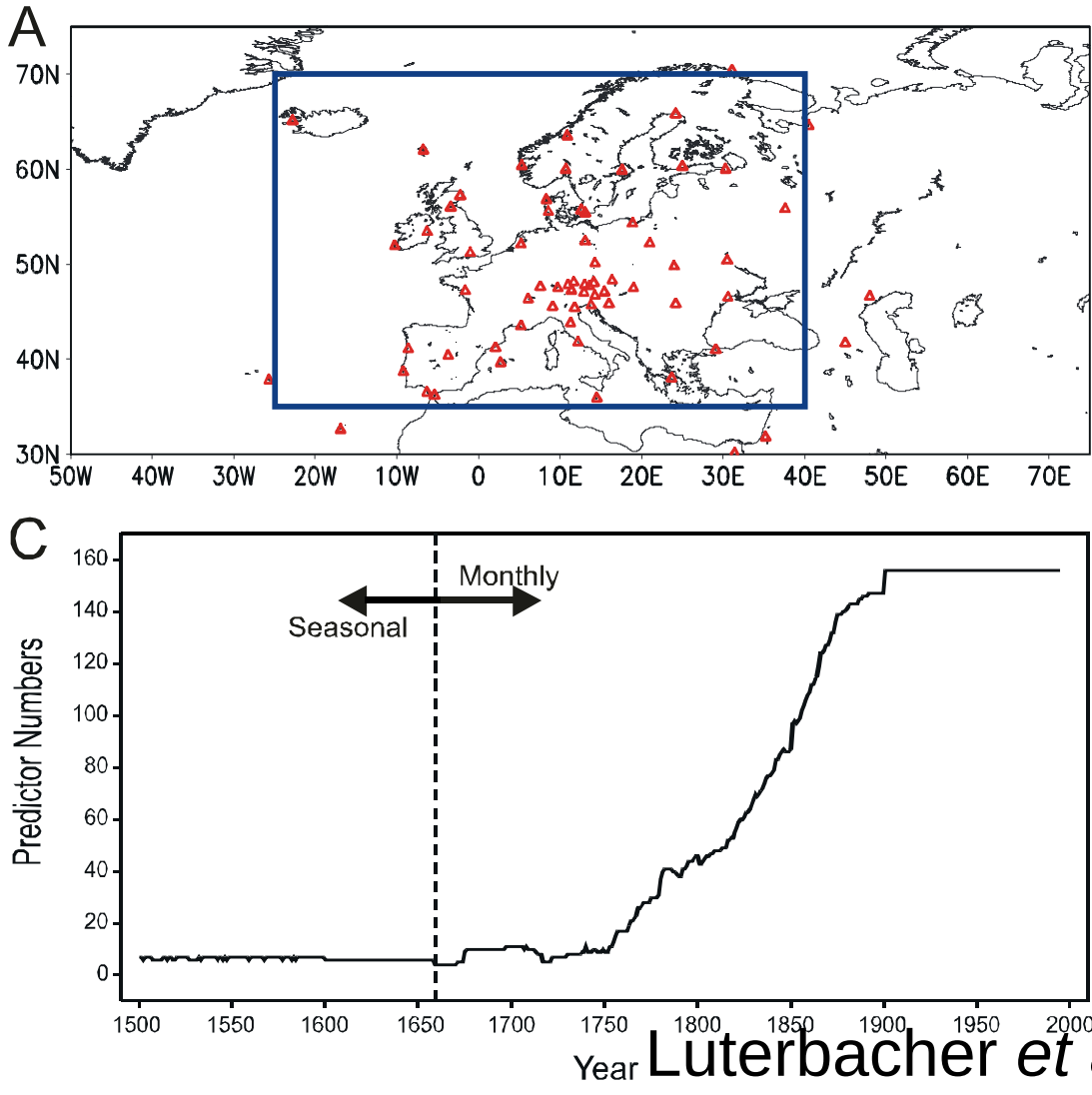


.... early instrumental data - poor coverage



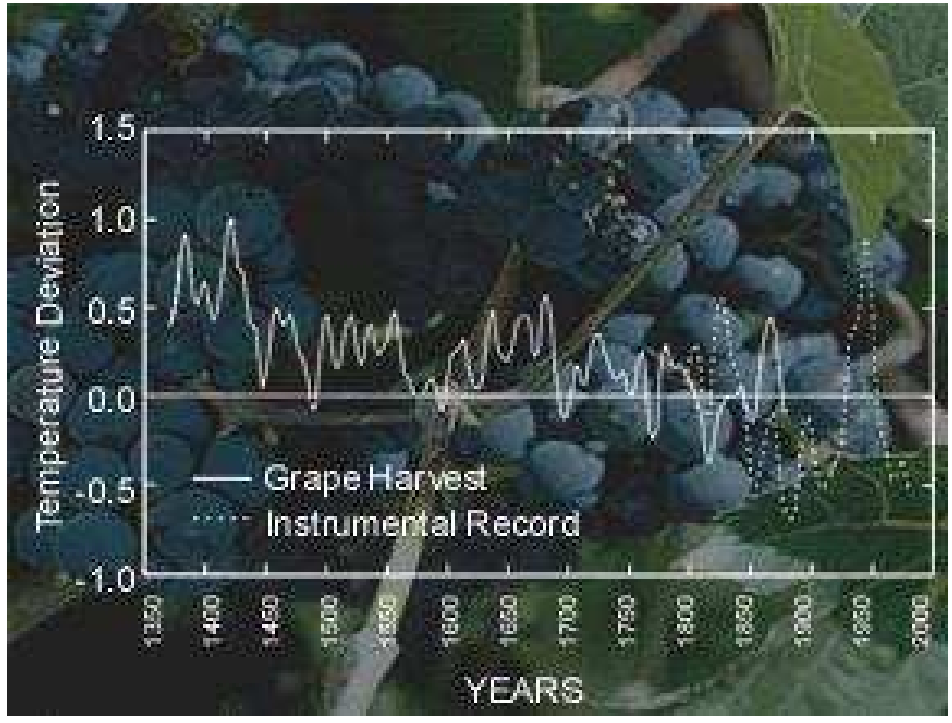
eca.knmi.nl

.... proxy data - poor coverage



Luterbacher *et al.* 2004

.... paleodata



documentary data

Bradley (1991)

.... paleodata

before ca. 1750: proxy data only

.... interpretation of paleodata is hazardous

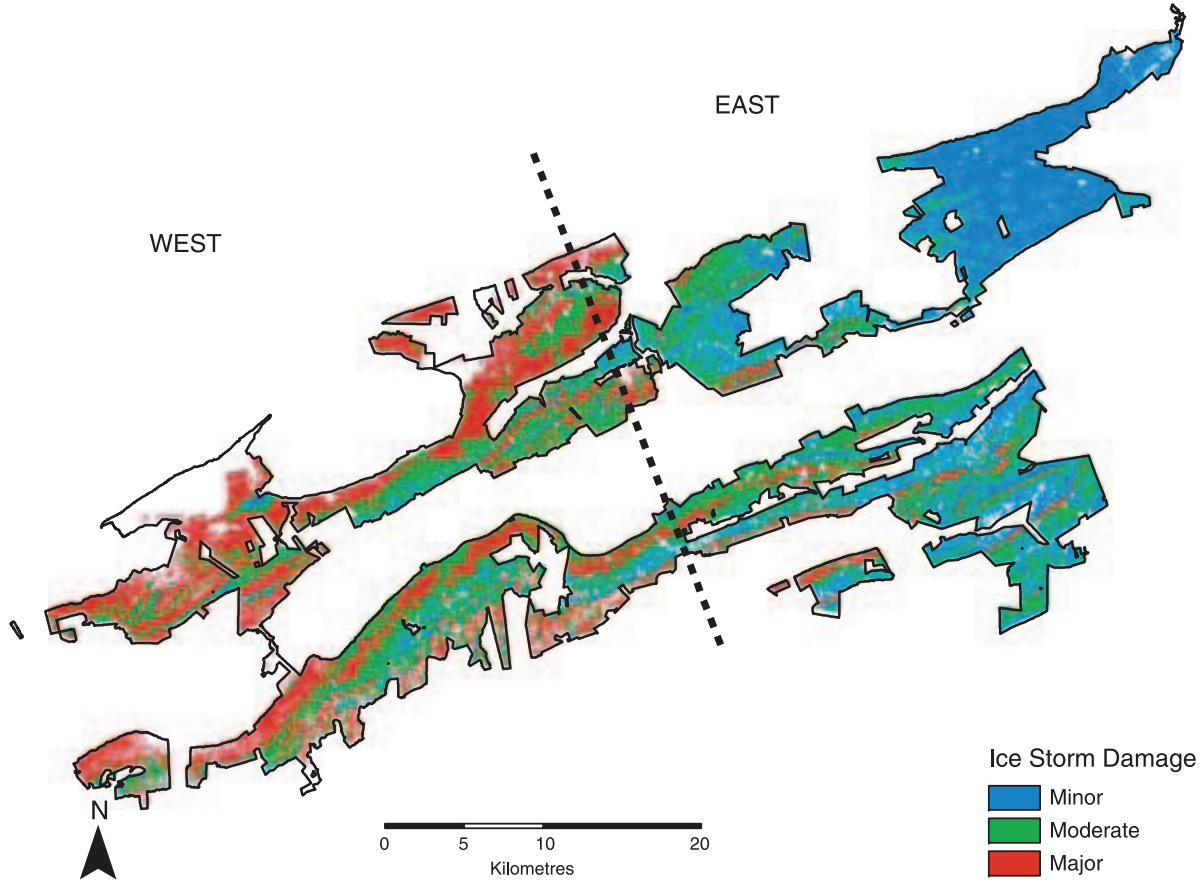


Figure 3 Ice storm damage inferred for the western New River Ranger District. White areas within the national forest boundaries are pixels excluded because of clouds, logging, coniferous forest or NDVI difference values <–0.1 or >0.2. The heavy dashed line indicates the division between the western and eastern sections, which were analysed separately

Stueve *et al.* (2007)

.... problem with assimilating paleodata

no ‘ordinary’ data-assimilation excercise

- low-temporal resolution
- low-density network
- low-quality data
  - reliable information for slowly varying large-scale patterns only

.... problem with assimilating paleodata II

3D-var/4D-var methods useless

- adjoint methods are applicable to short time ranges only
- longer assimilation periods give secondary minima in the cost function

.... Forcing Singular Vectors I

two-step approach

- upscaling:
  estimate large-scale patterns of anomalous atmospheric circulation

.... Forcing Singular Vectors I

two-step approach

- upscaling:
  estimate large-scale patterns of anomalous atmospheric circulation
- assimilate large scale patterns

.... Forcing Singular Vectors II

reconstruction of streamfunction ψ_{past}:

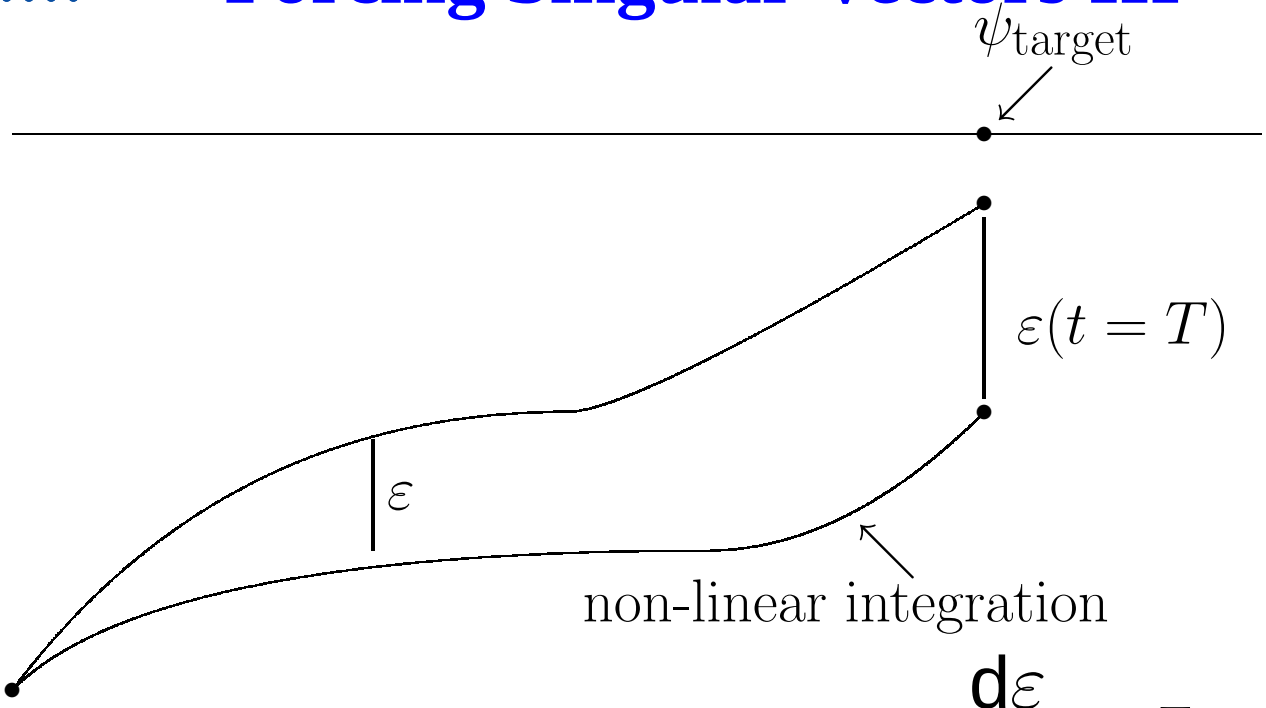
$$\psi_{\text{past}} = \psi_{\text{clim}} + \psi_{\text{target}}$$

streamfunction ψ at time t_0:

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

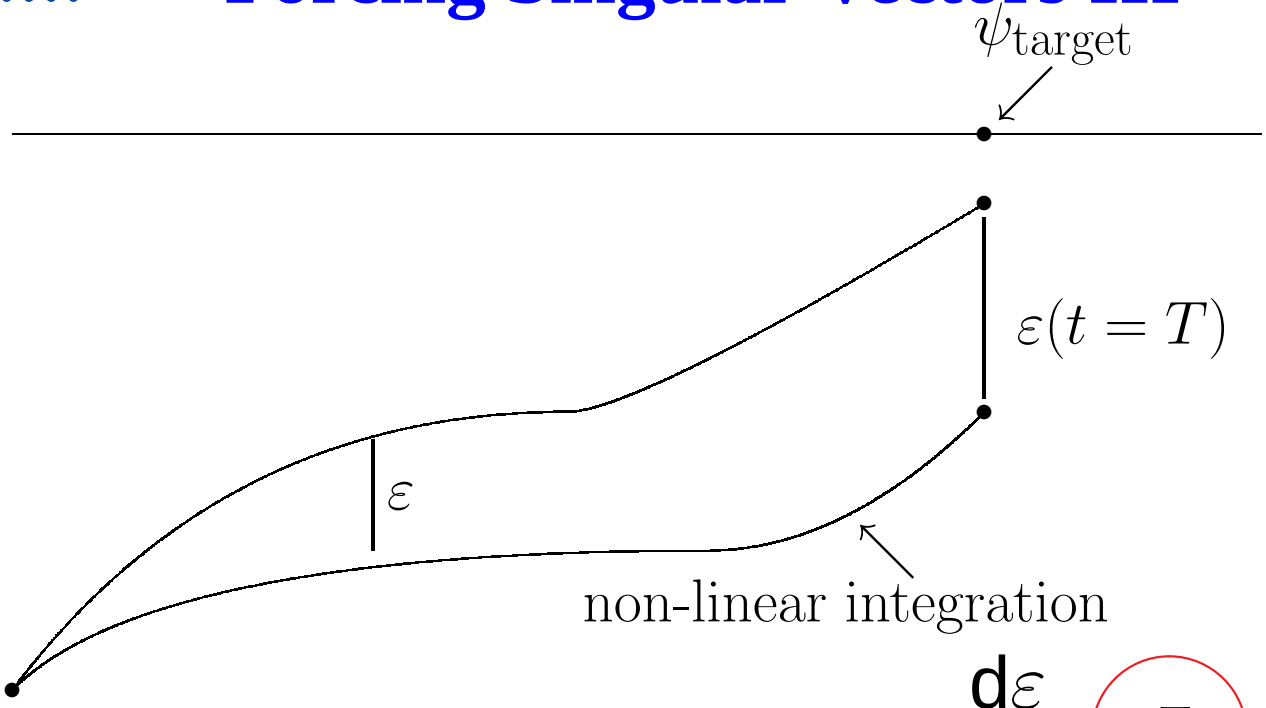
objective: $\langle \psi(t_0 + T, \mathbf{x}), \psi_{\text{target}} \rangle = 1$

.... Forcing Singular Vectors III



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

.... Forcing Singular Vectors III

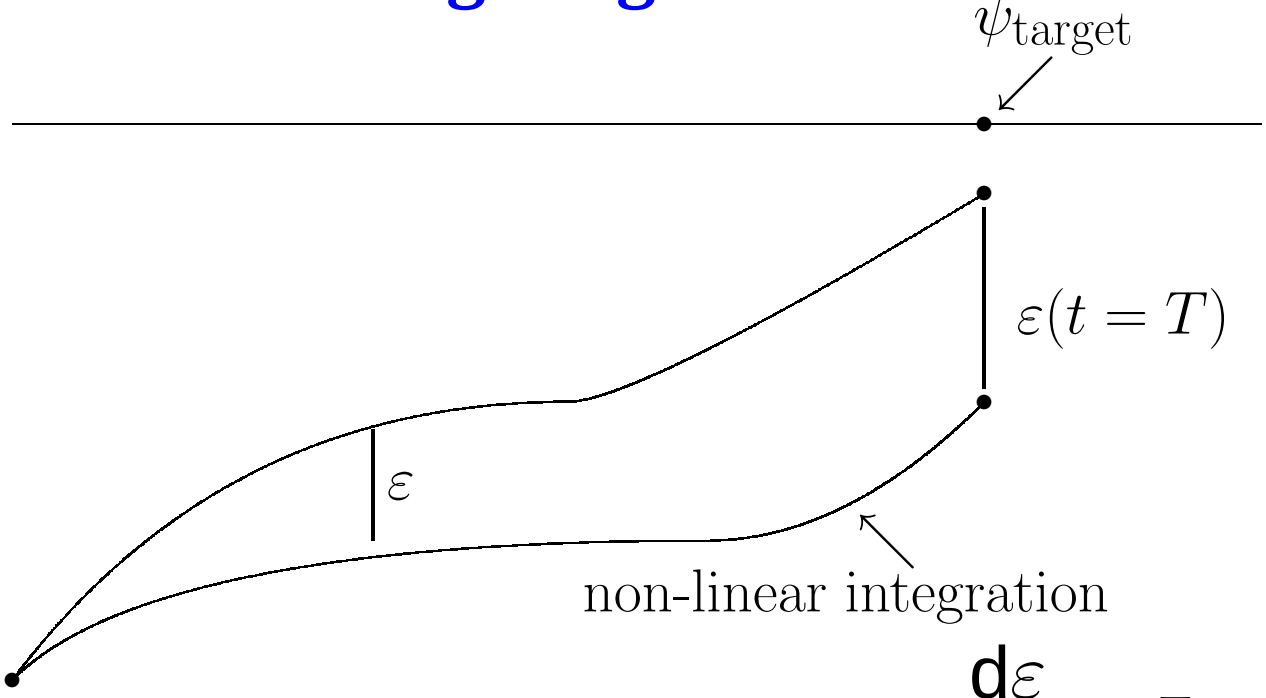


$$\frac{\mathrm{d}\varepsilon}{\mathrm{d}t} = \mathbf{L}\varepsilon + \mathbf{f}$$

Jacobian

tendency perturbation

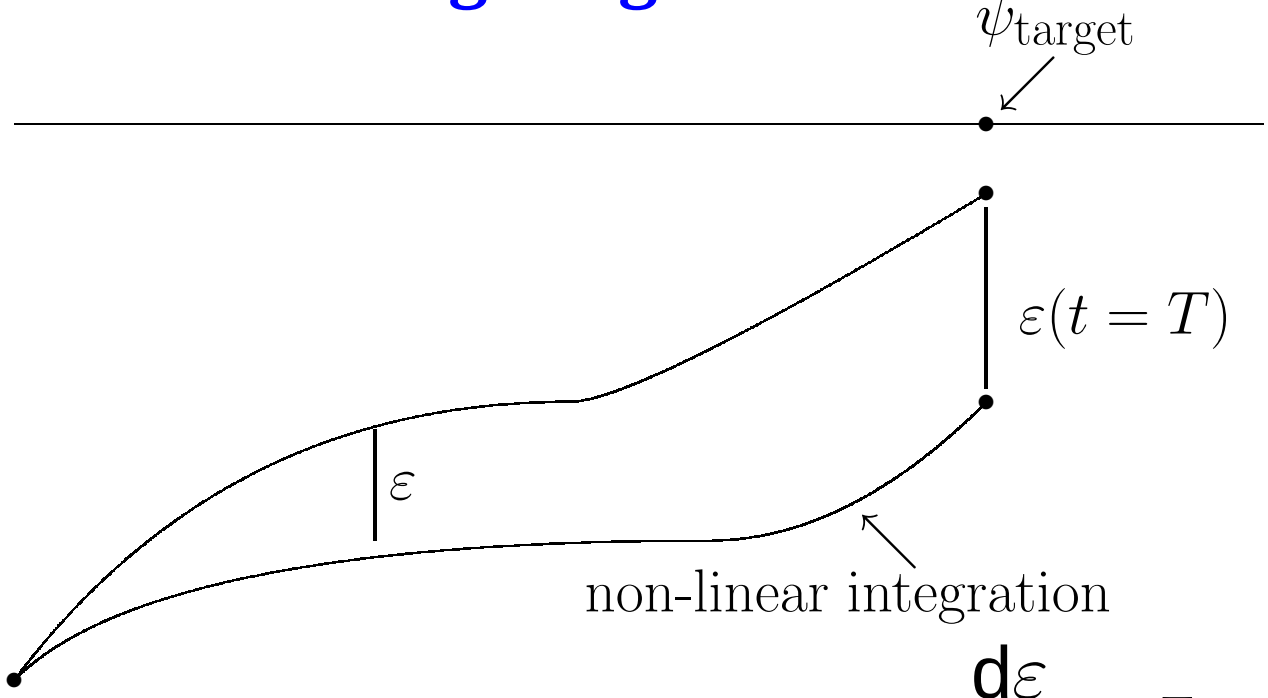
.... Forcing Singular Vectors III



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

$$\varepsilon(T) = \mathbf{M}(0,T)\varepsilon(0) + \int_0^T \mathbf{M}(s,T)\mathbf{f}\,ds$$

.... Forcing Singular Vectors III

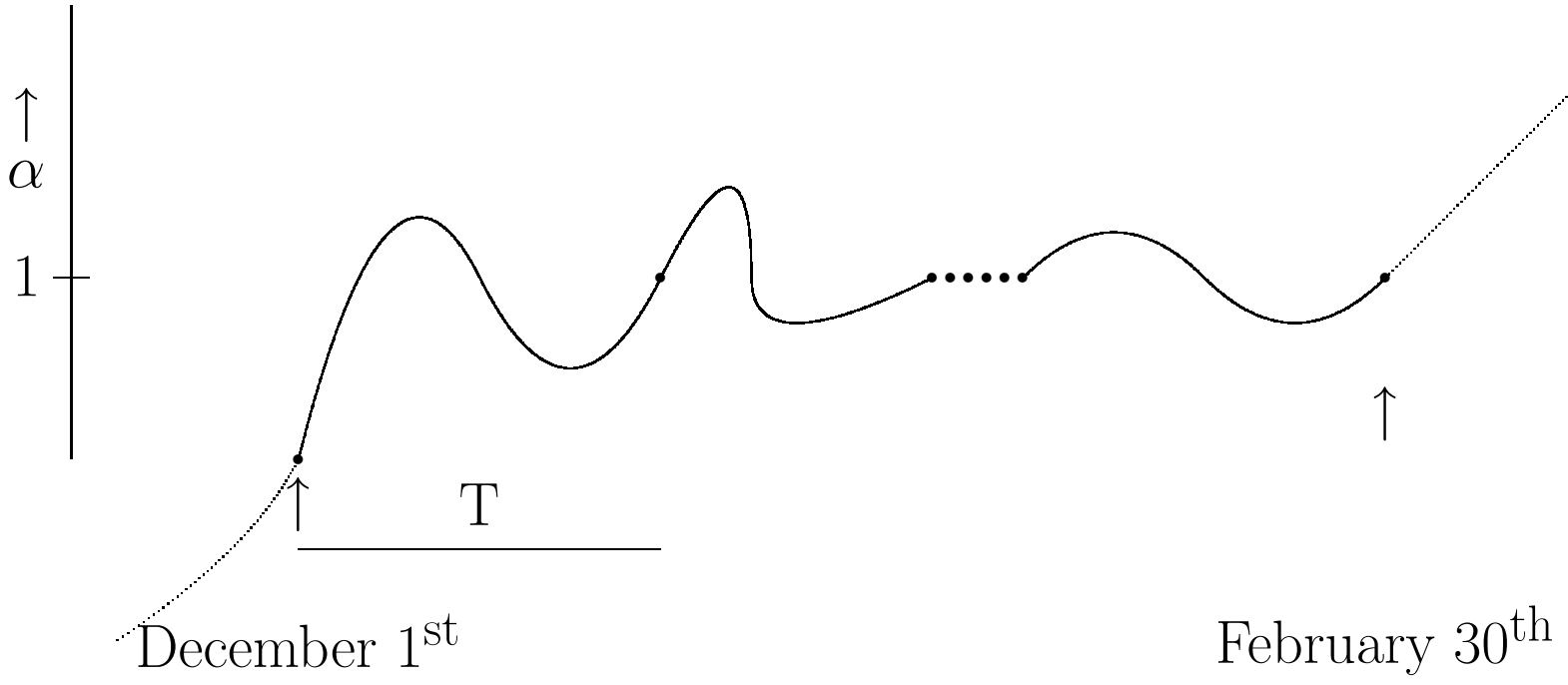


$$\frac{\mathrm{d}\varepsilon}{\mathrm{d}t} = \mathbf{L}\varepsilon + \mathbf{f}$$

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

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

.... Forcing Singular Vectors IV



here: T = 24 - 96h T is a tuneable parameter

.... Forcing Singular Vectors V

What is actually needed is:

$$\int_0^{N\text{years}} \langle \psi(t, \mathbf{x}), \psi_{\text{target}} \rangle \, \mathrm{d}t = 1$$

and not that

$$\langle \psi(t, \mathbf{x}), \psi_{\text{target}} \rangle = 1$$

at discrete points in time

.... Forcing Singular Vectors V

The uncertainty in the amplitude and/or the pattern of ψ_{target} is not taken into account

.... ECBilt-Clio model

ECBILT

- Quasi-geostrophic atmospheric model (T21, 3 levels)
- Simplified representations of diabatic-heating processes
- Explicit hydrological cycle
- Prescribed cloudiness
- Soil-plus-snow model

VECODE

- Dynamical terrestrial vegetation model
- 3 plant functional types: forest, desert, grass

CLIO

Sea-ice model

Thermodynamics using a 3-layer snow–ice model + leads

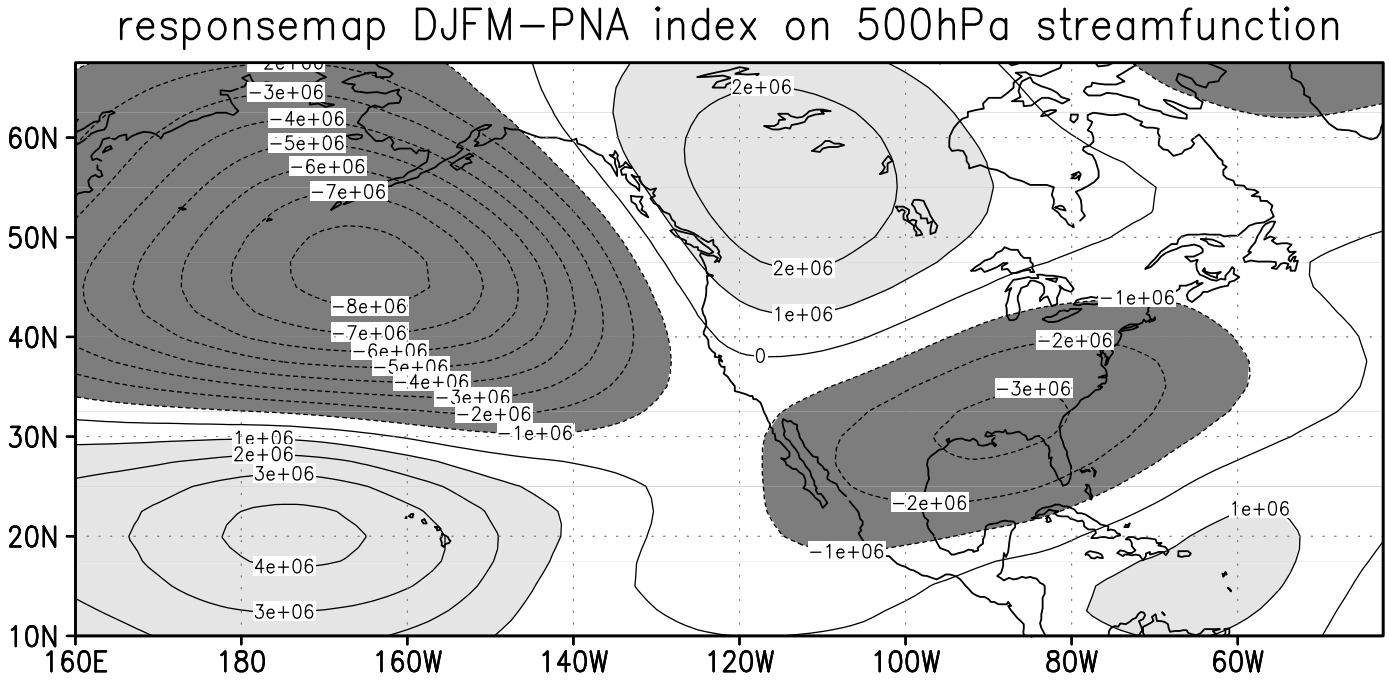
Dynamics including viscous-plastic rheology

Ocean general circulation model

- Primitive equations – free surface
- Mellor and Yamada's level-2.5 turbulence-closure scheme
- Parameterisation of density-driven downslope flows
- 20 vertical levels

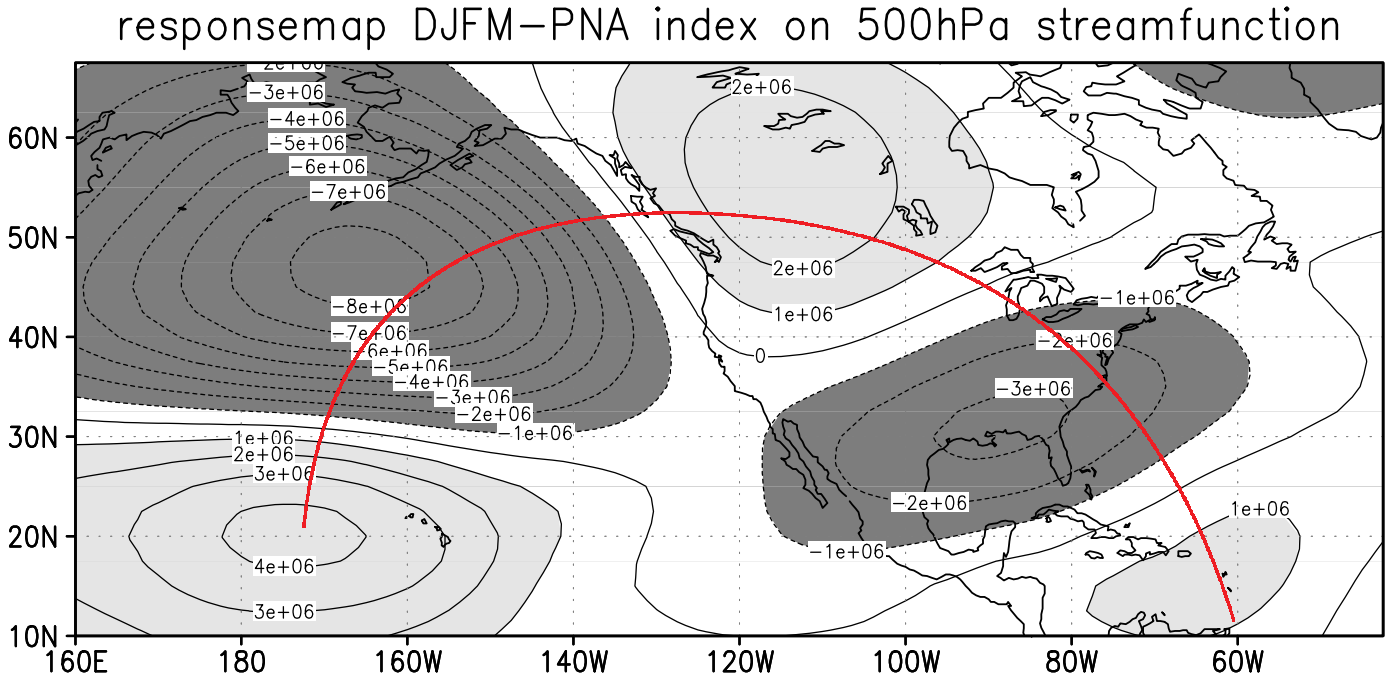
Horizontal resolution: 3° x 3°

.... example 2: assimilate PNA pattern



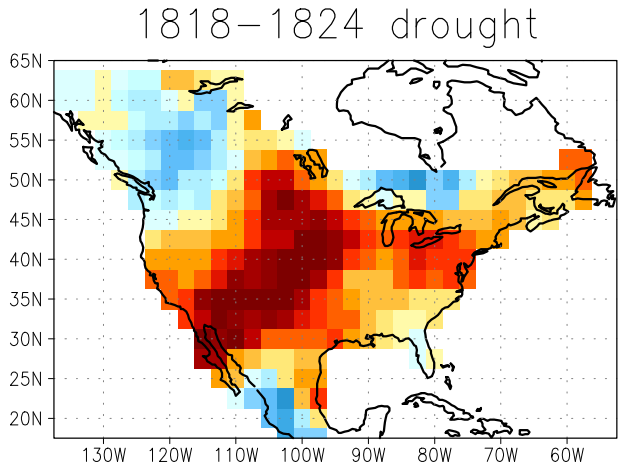
regression of PNA-index on 500hPa streamfunction (NCEP reanalysis)

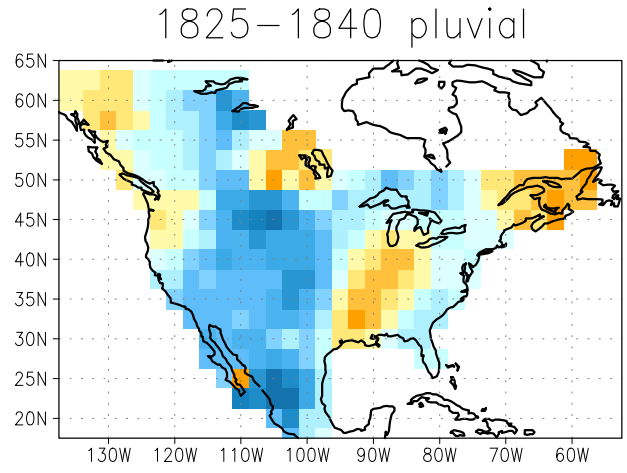
.... example 2: assimilate PNA pattern



regression of PNA-index on 500hPa streamfunction (NCEP reanalysis)

.... Periods of interest





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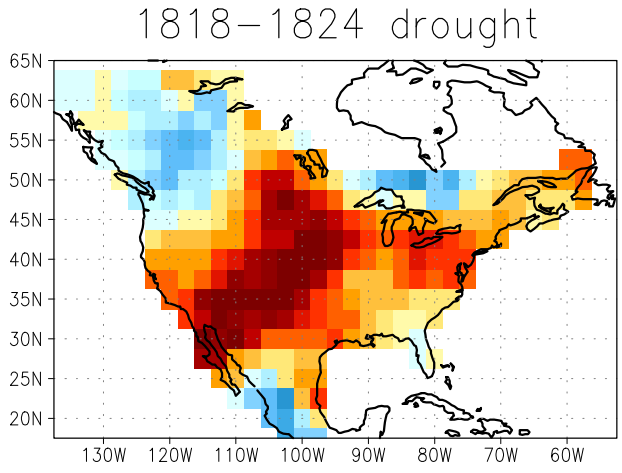

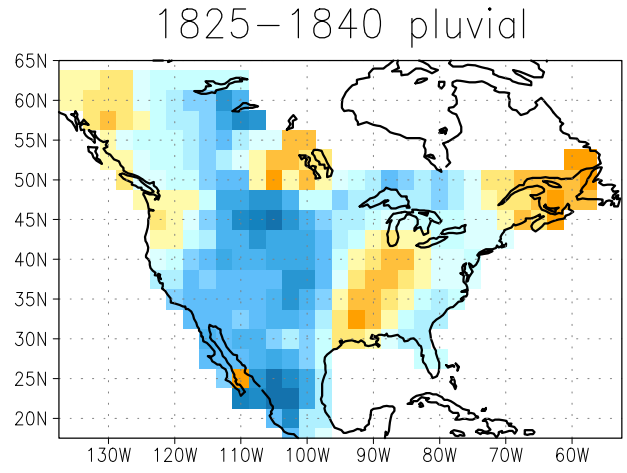

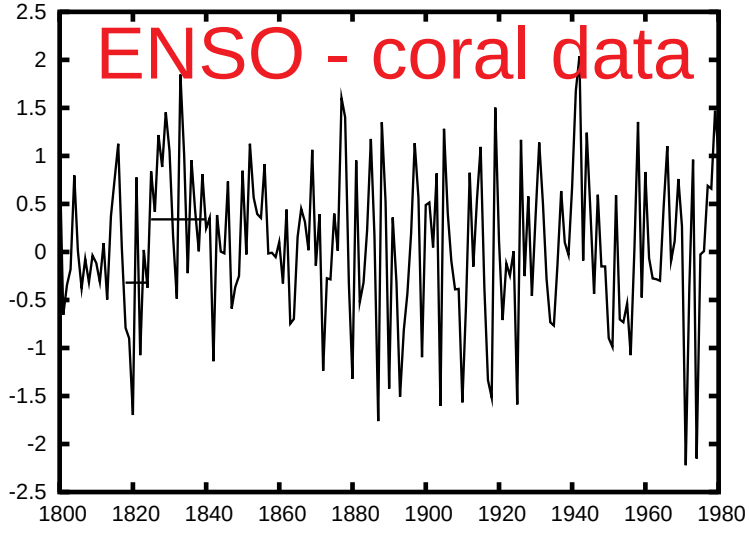

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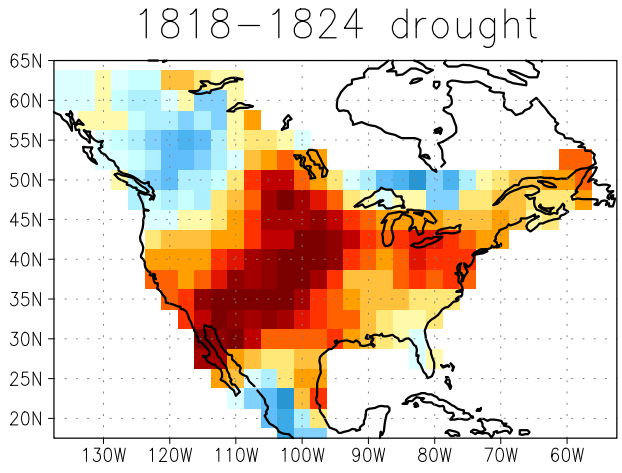

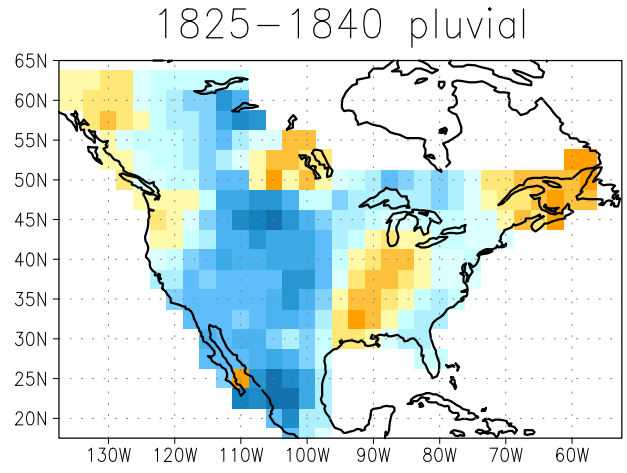

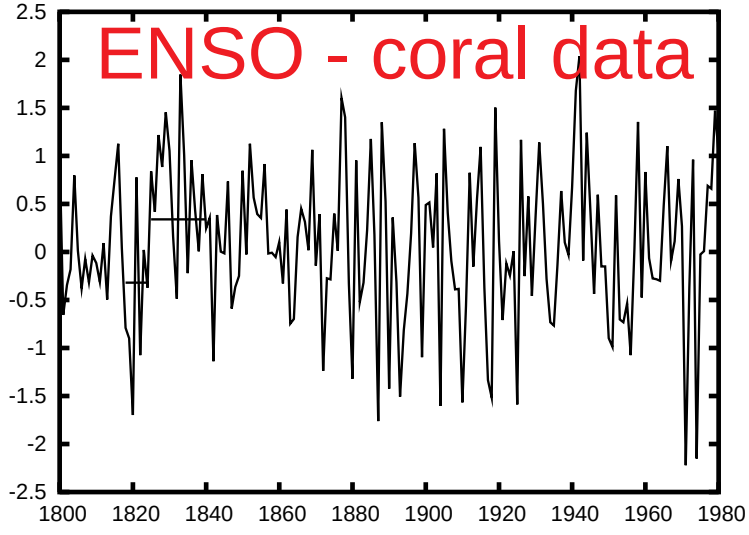

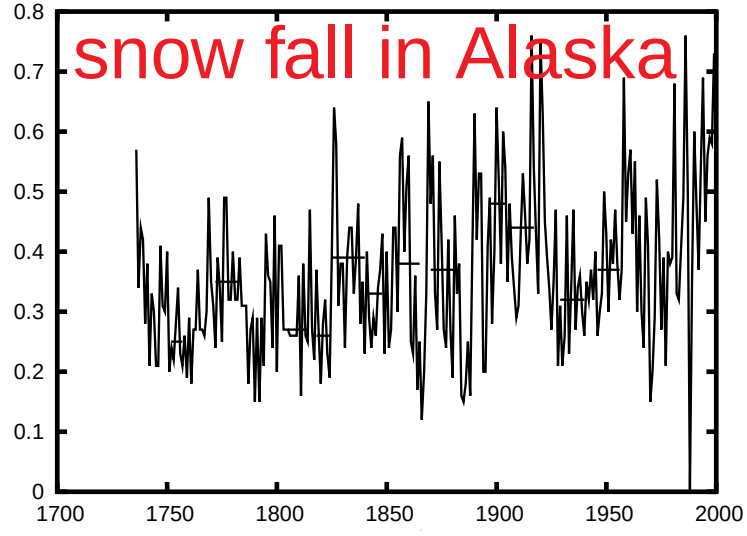

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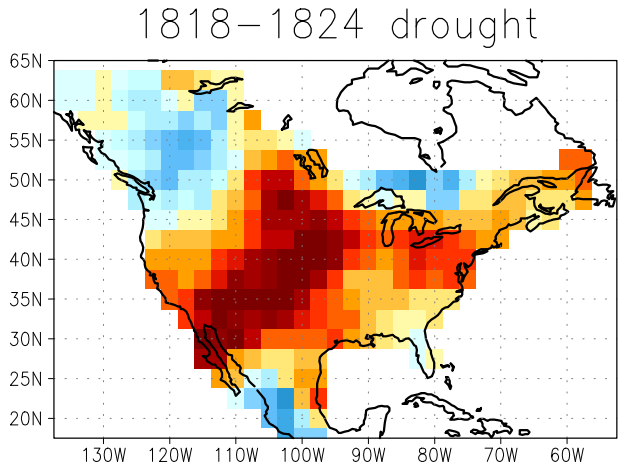
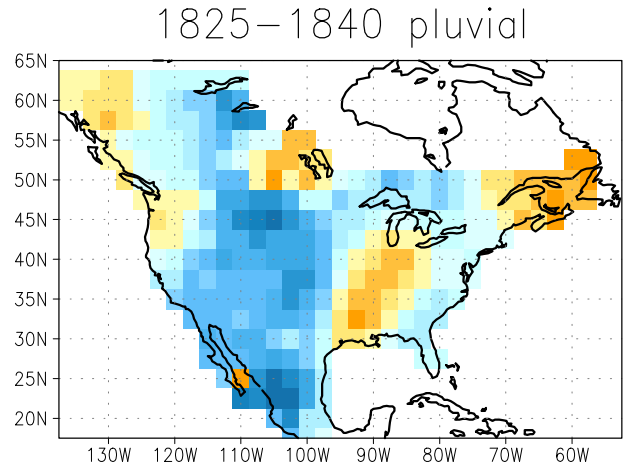
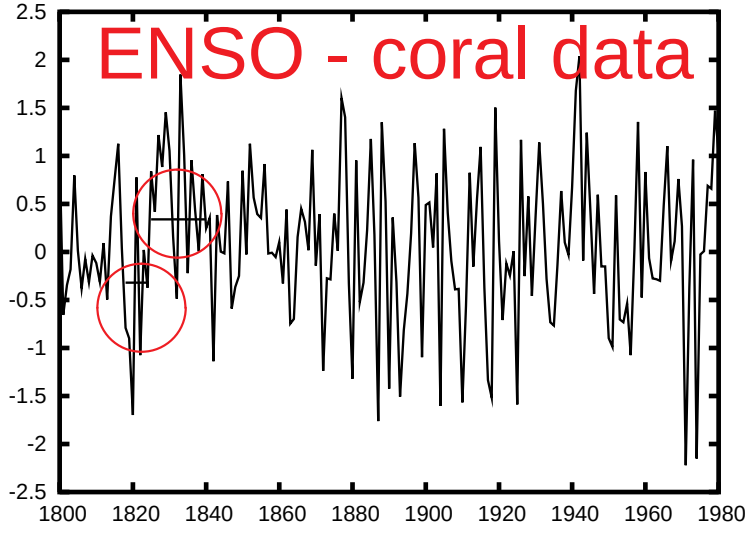
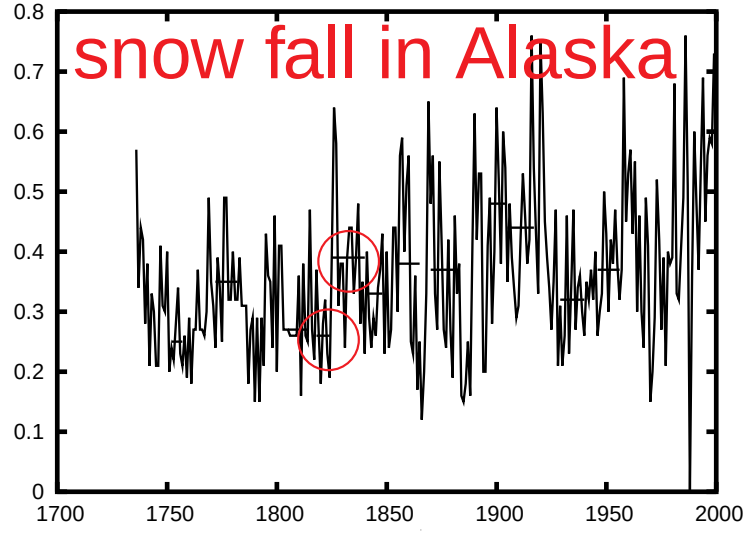
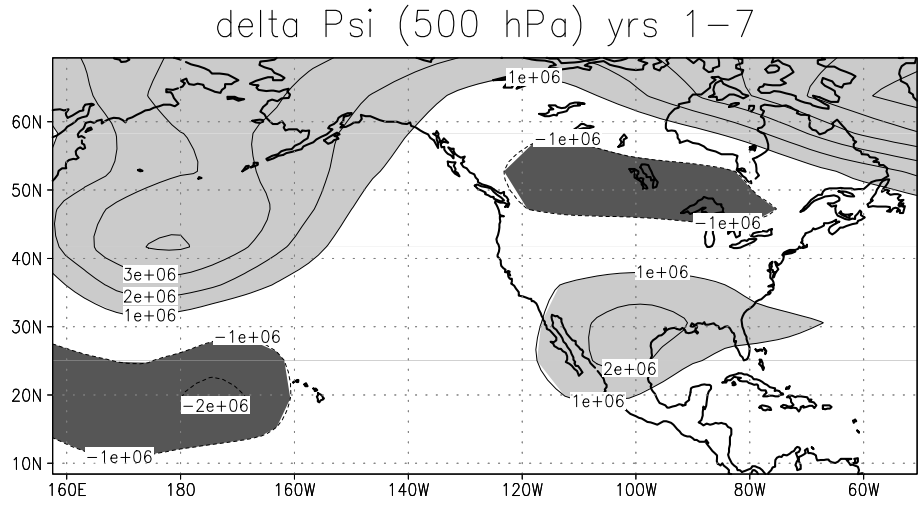


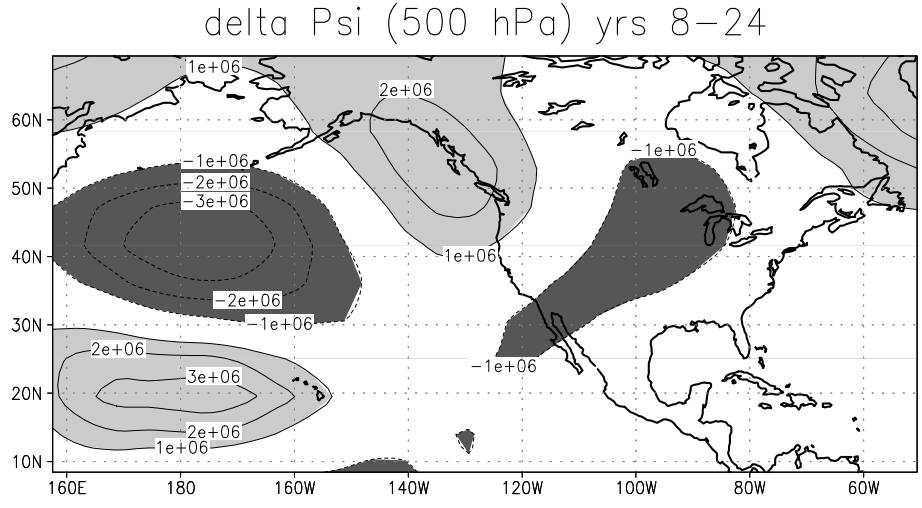






.... Does the data-assimilation work?





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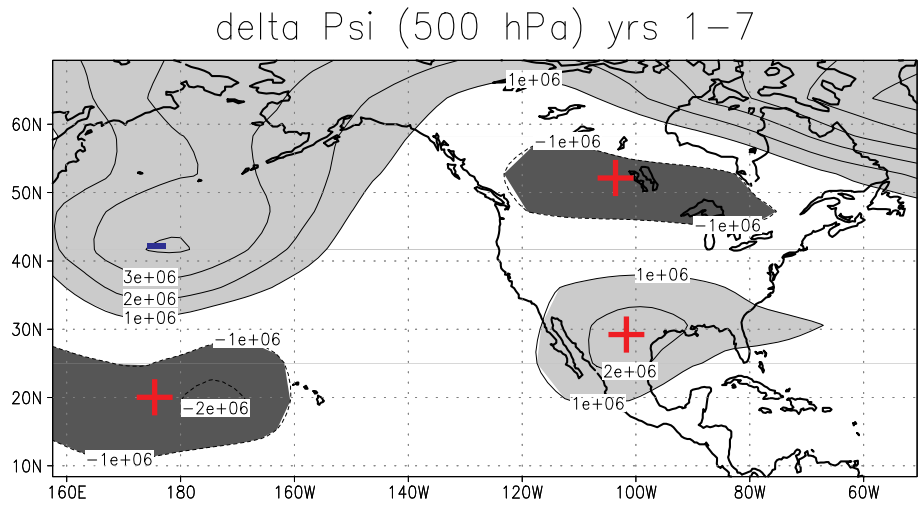

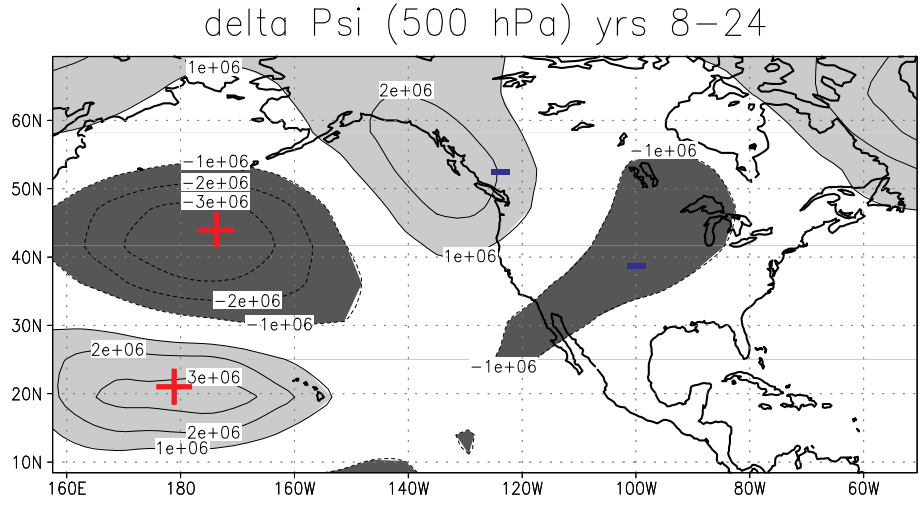

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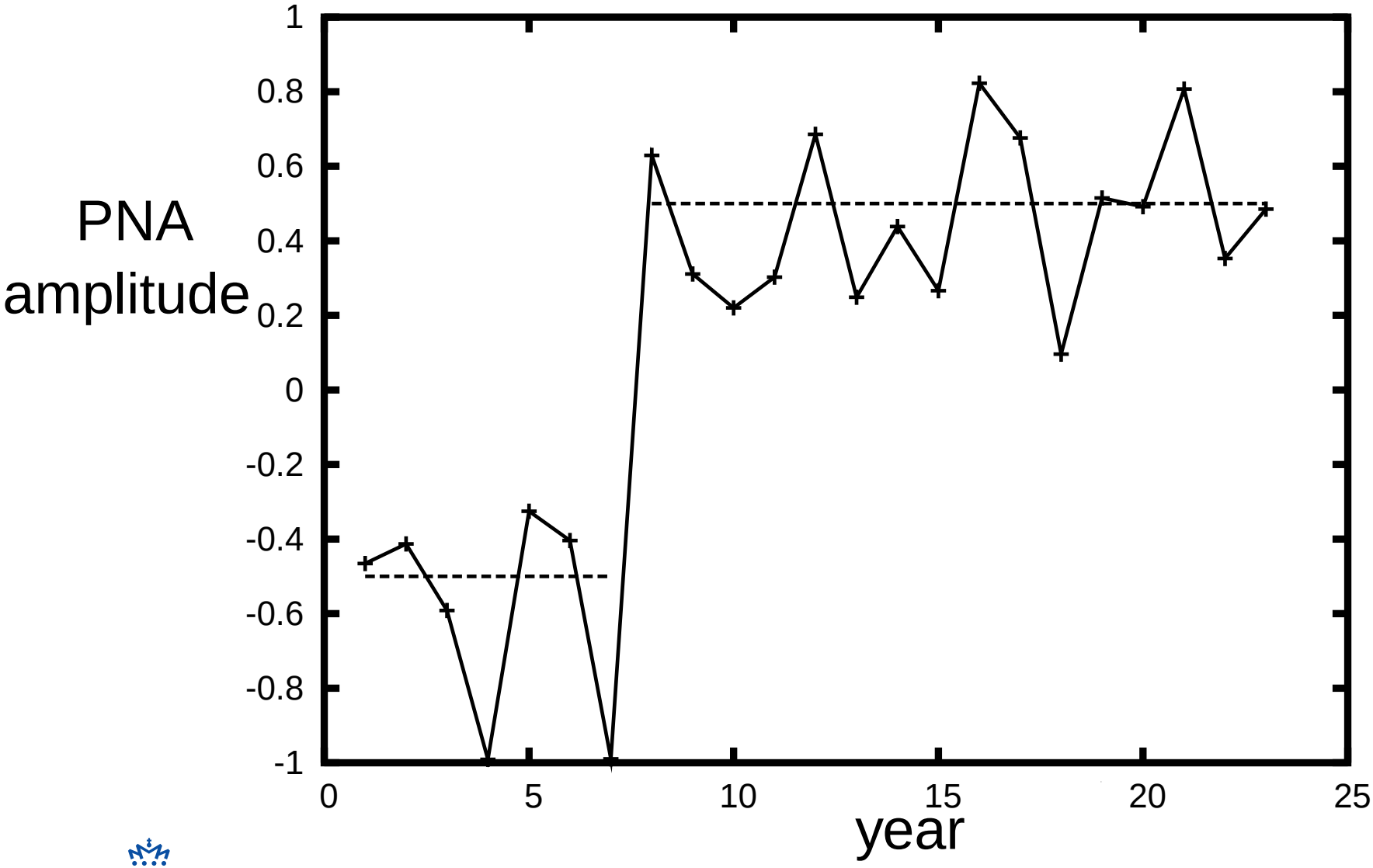
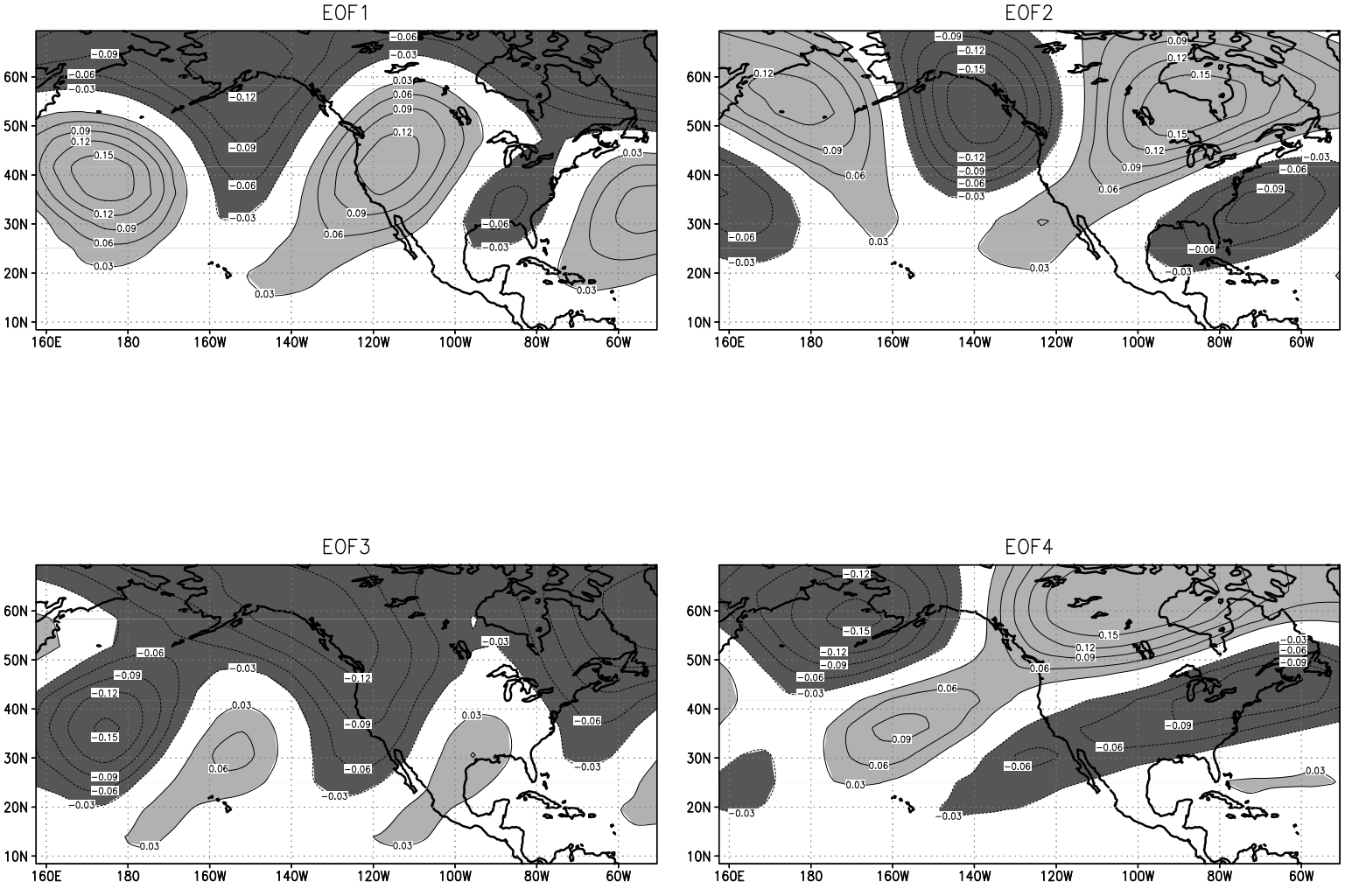


.... quirky model variability



.... quirky model variability

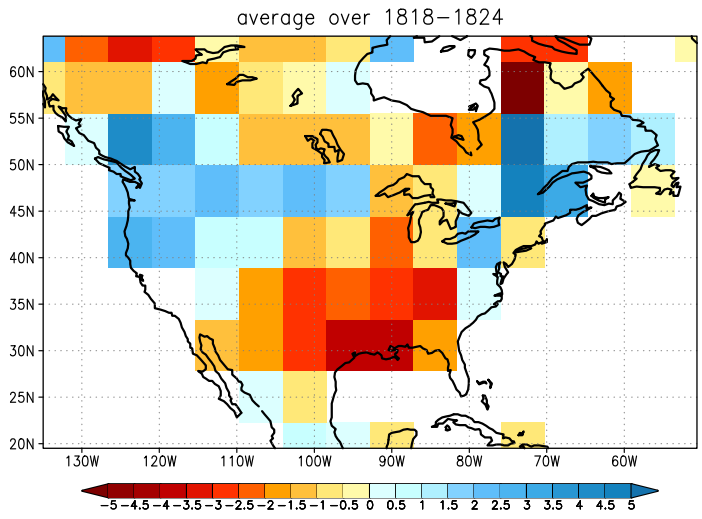
none of the model's EOFs resembles the PNA pattern

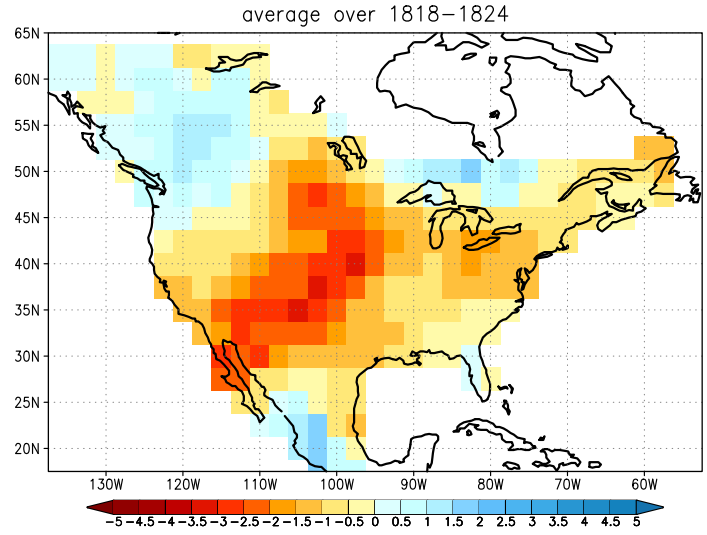
interaction between the target pattern and the model's modes of variability

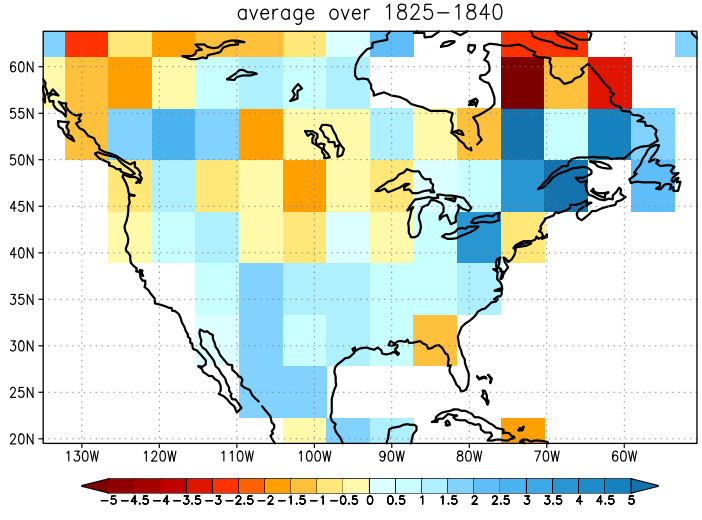
$\Rightarrow$

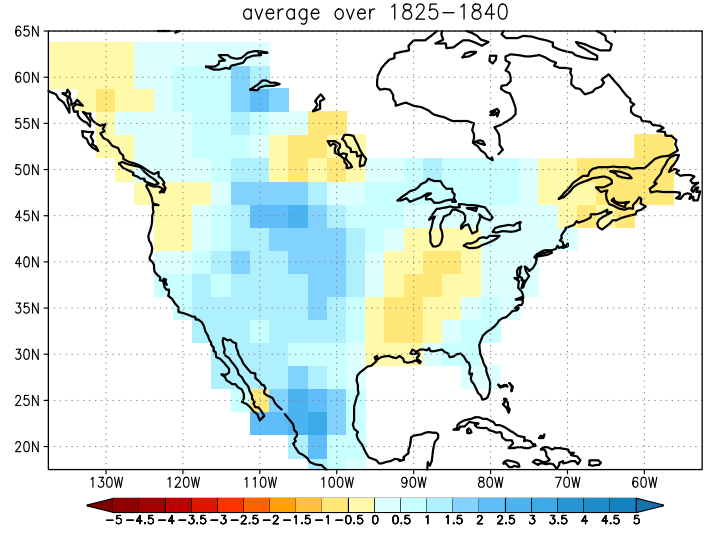
overamplification/suppression of parts of PNA pattern

.... comparison with PDSI reconstruction

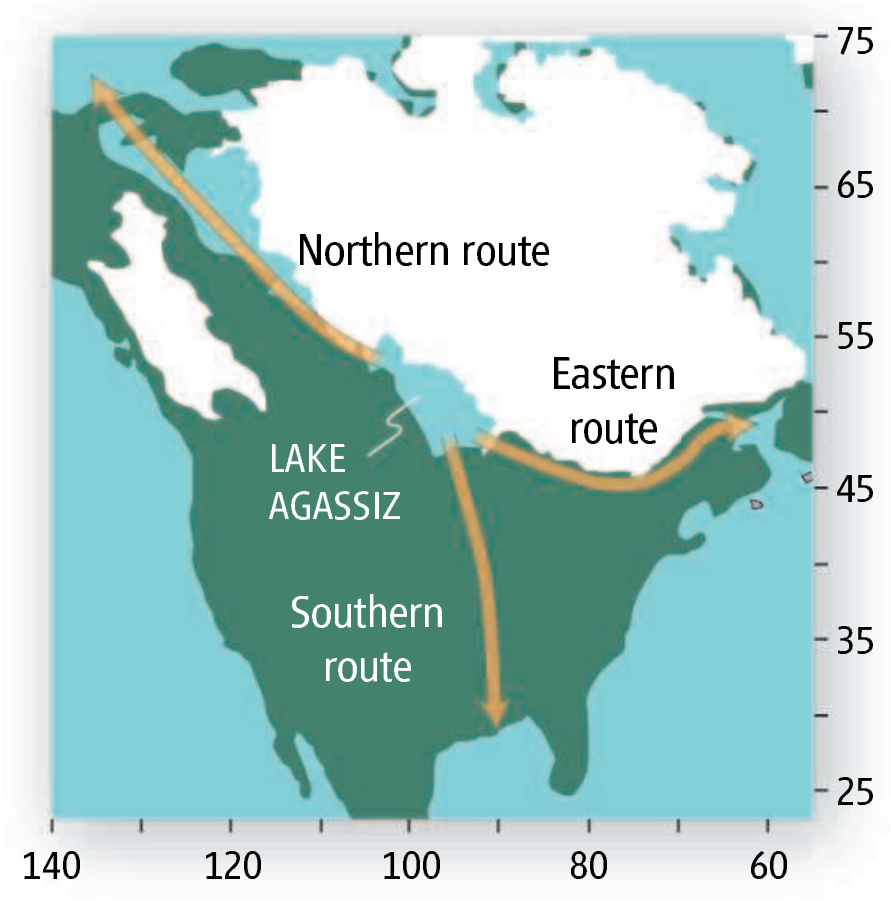








.... Drainage pathways from Lake Aggasiz



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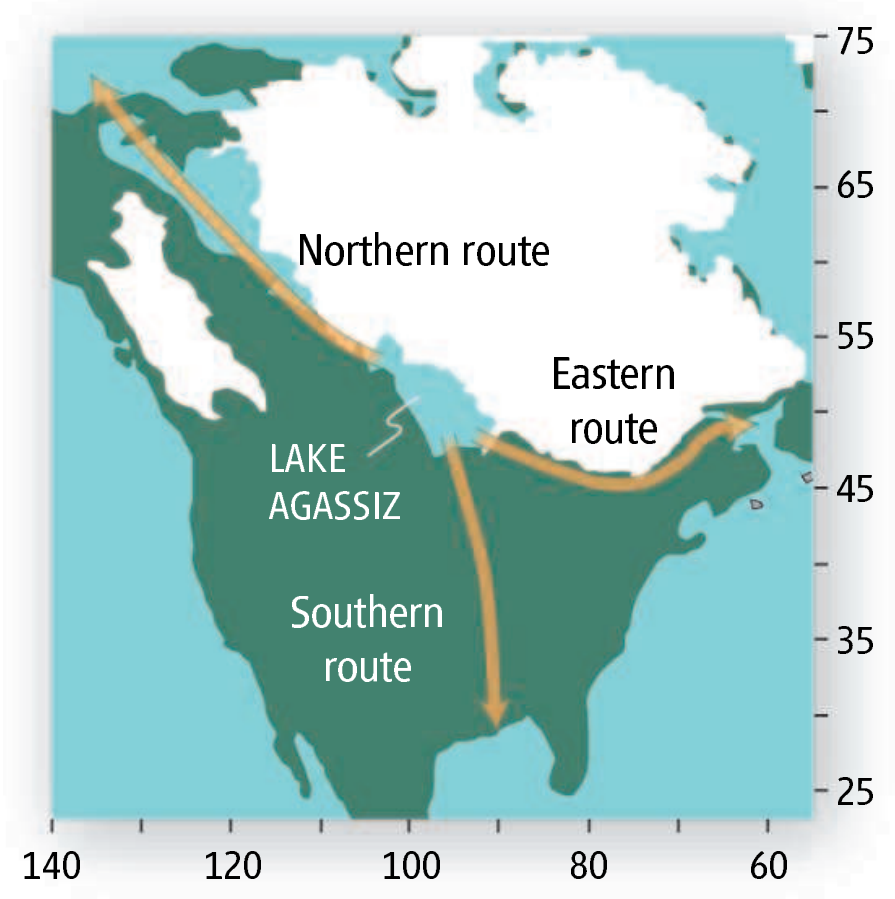
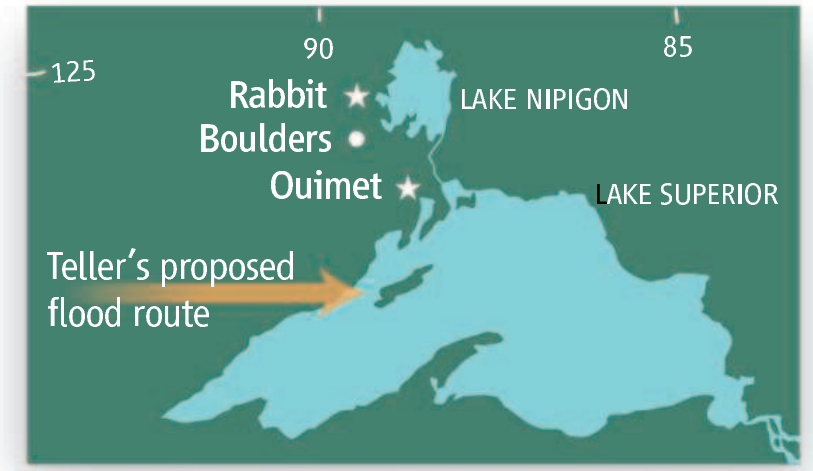


Broecker (2006): 'no visual evidence that might support the flood scenario [via the Eastern route]'

.... Younger Dryas

Broecker (2006):

‘lesser floods produced spectacular canyons’



.... example 3: sensitivity experiments

hypothesis: zonal repositioning of Atlantic eddy-driven jet $\Rightarrow$ rapid climate change?

(Seager *et al.* 2002)

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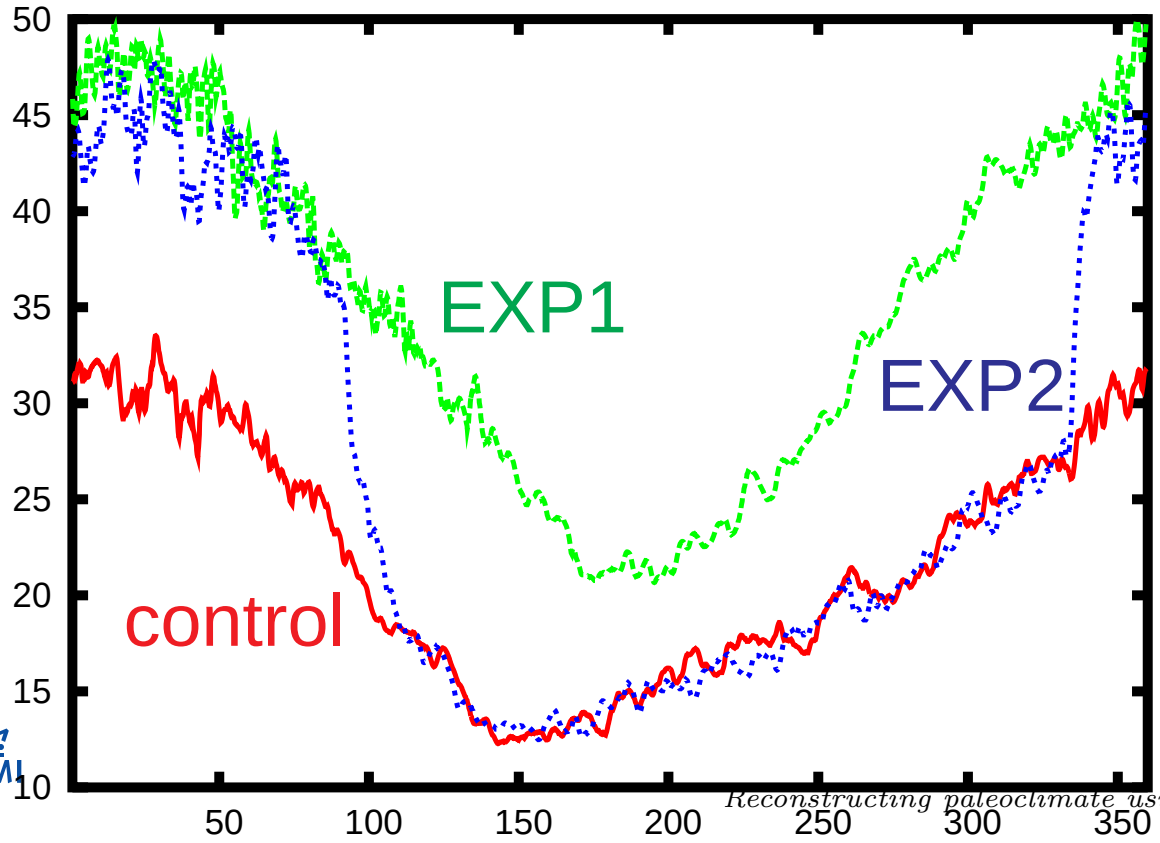

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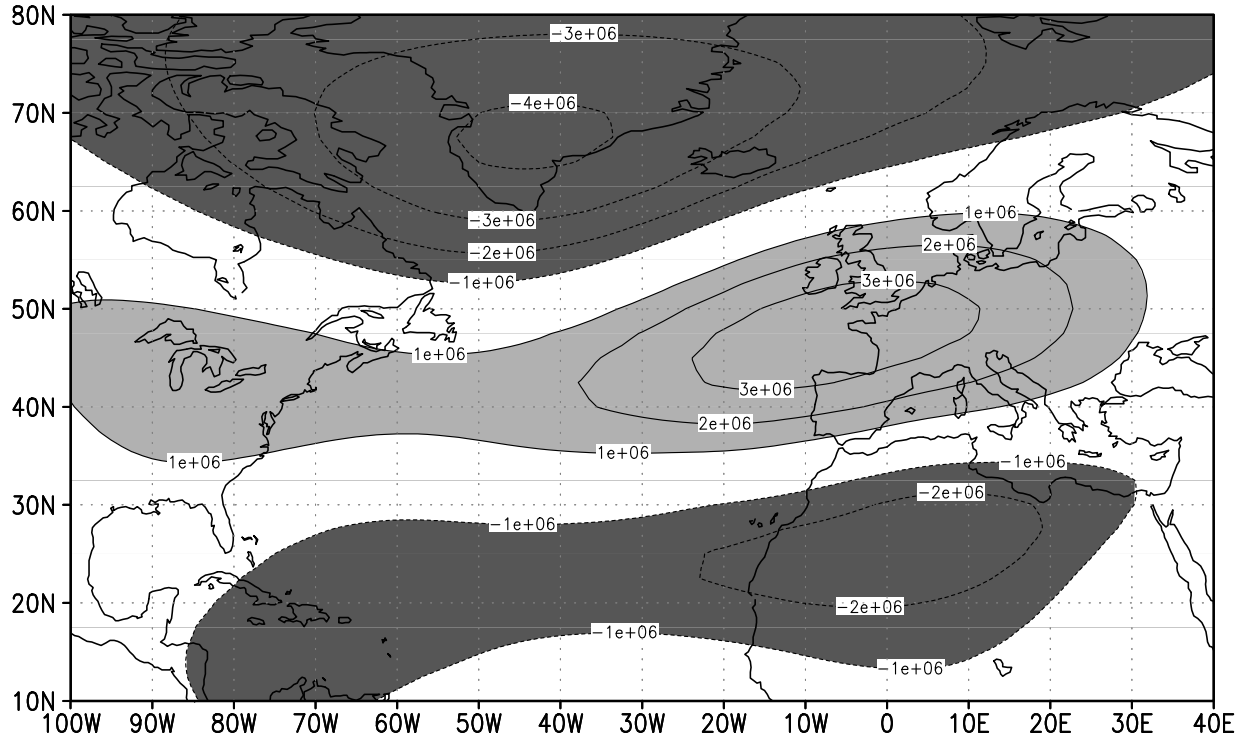
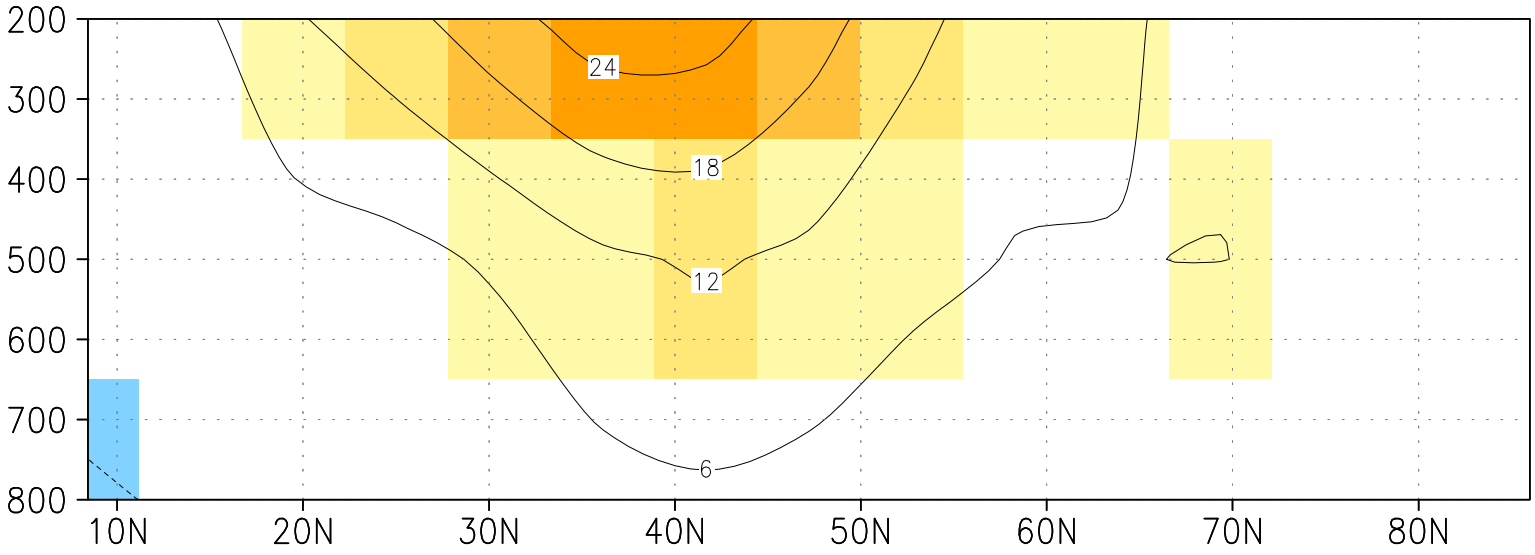
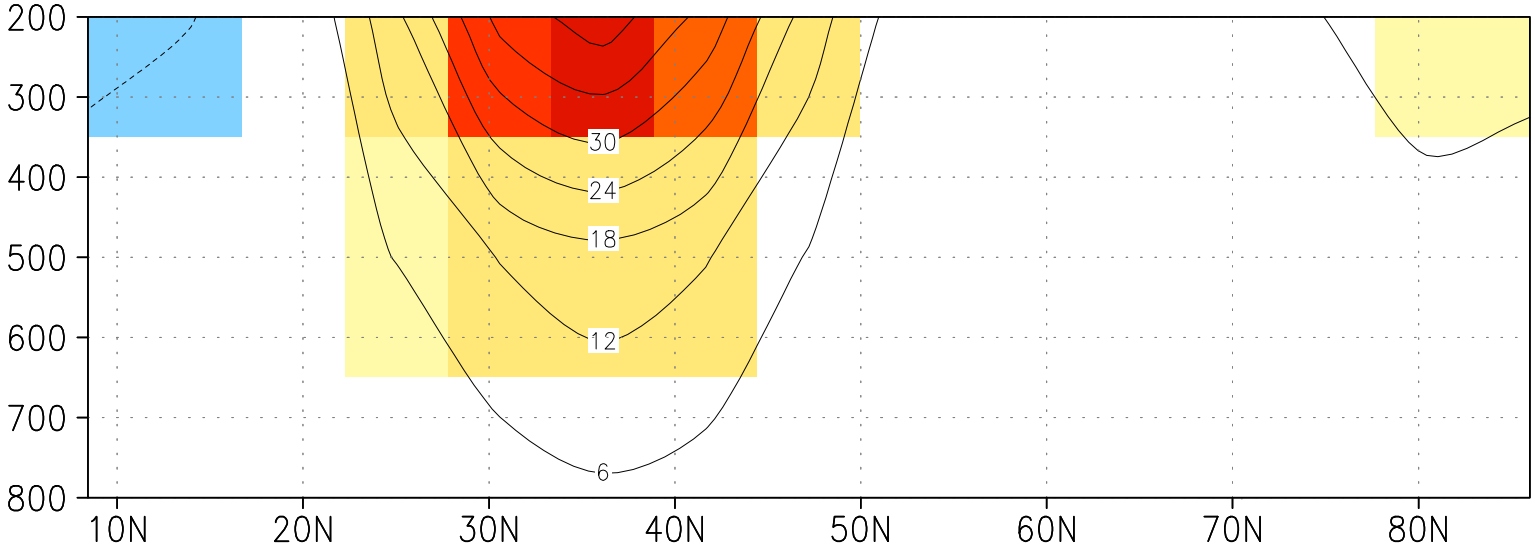
.... ‘assimilate’ NAO-pattern at 200hPa

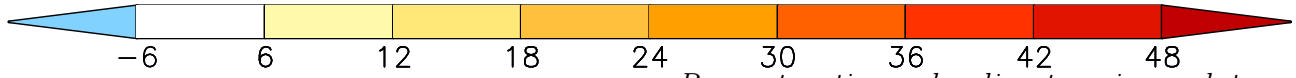


force a persistently negative ‘NAO’ at 200hPa only.

.... Does it work? jetstream







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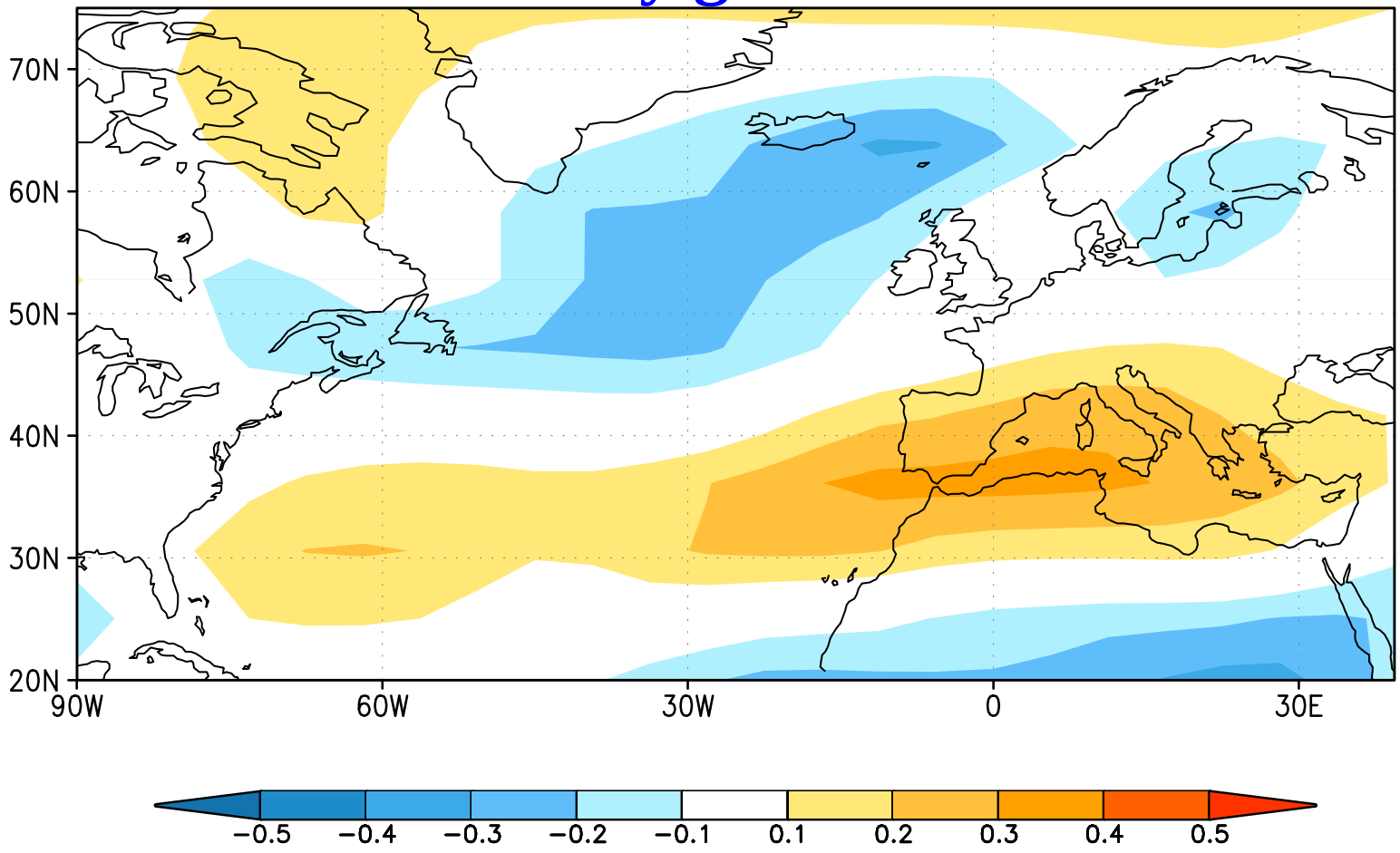
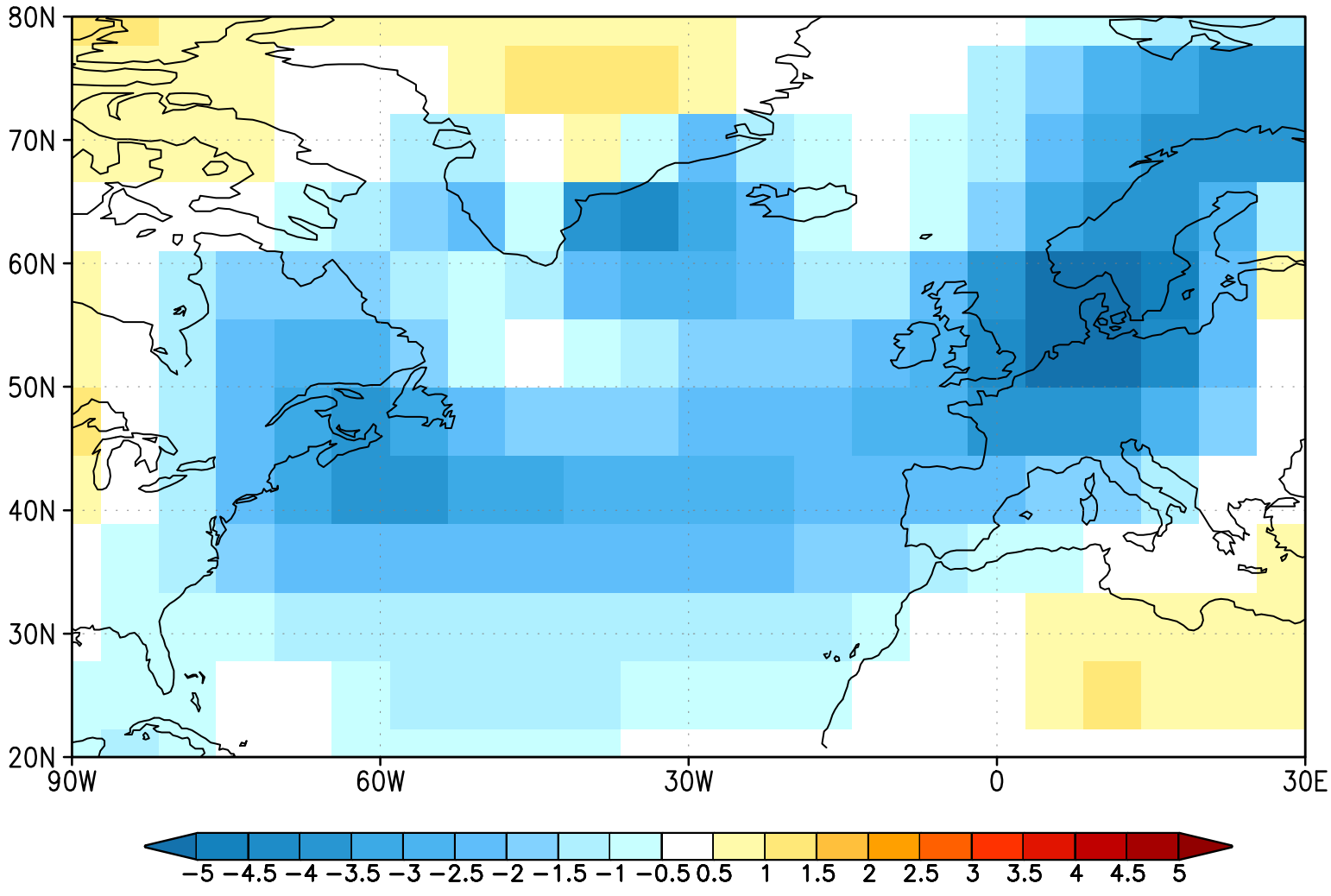
.... maximum Eady growth rate 650hPa



.... Change in SAT



.... Conclusions

Forcing Singular Vectors work:

- assimilate paleo-climatic reconstructions
  - full interaction between climatic components
  - without suppressing internal variability
- consistent with other reconstructions

.... Conclusions

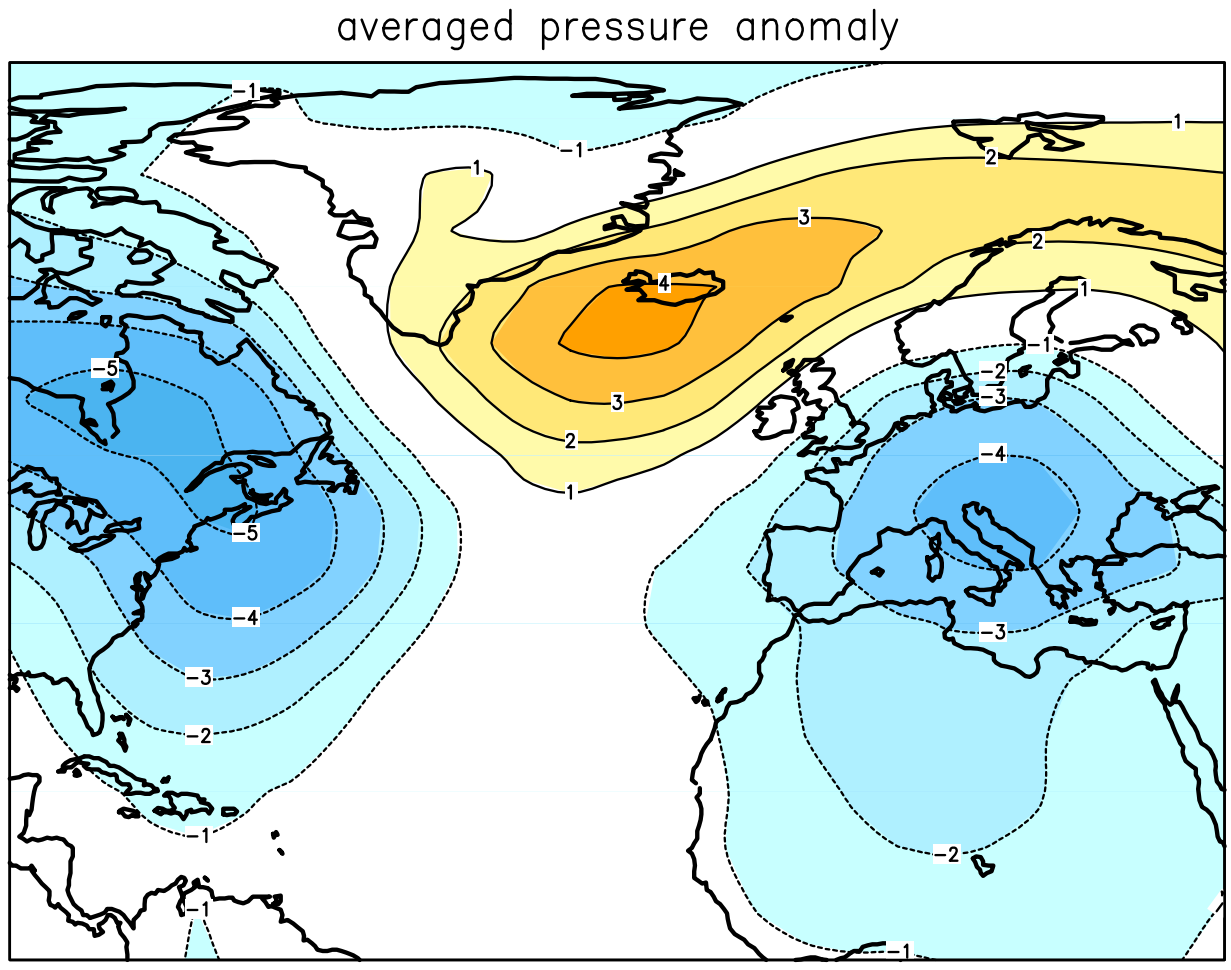
Forcing Singular Vectors work:

- assimilate paleo-climatic reconstructions
  - full interaction between climatic components
  - without suppressing internal variability
- consistent with other reconstructions

However:

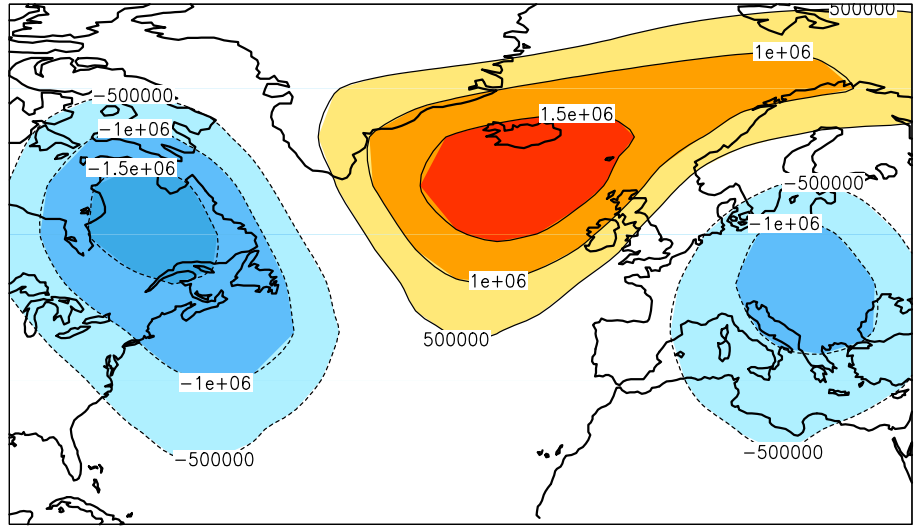
- interpretation of proxy data is a problem
- how to use an error covariance matrix?
- less-than-perfect model variability might overwhelm the assimilated signal

.... example 3: 'Little Ice Age' climate

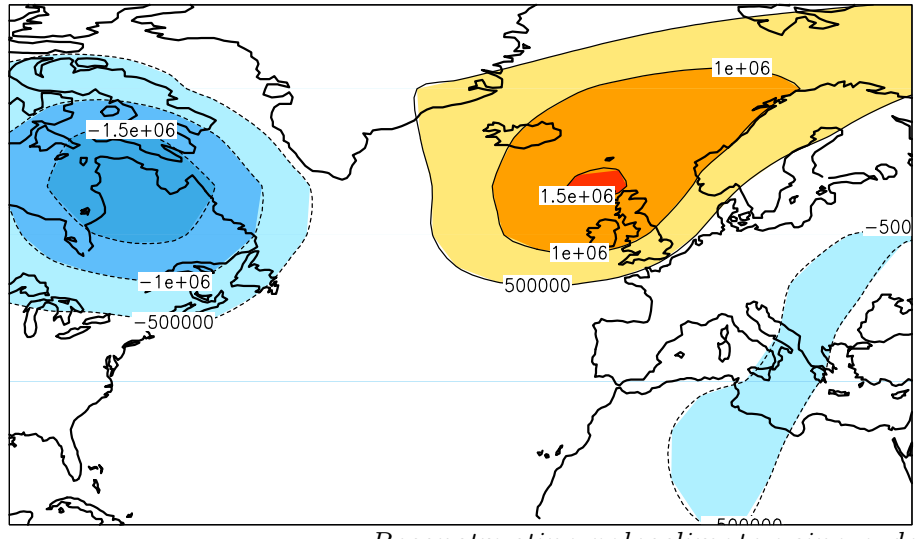


.... Does the data-assimilation work?

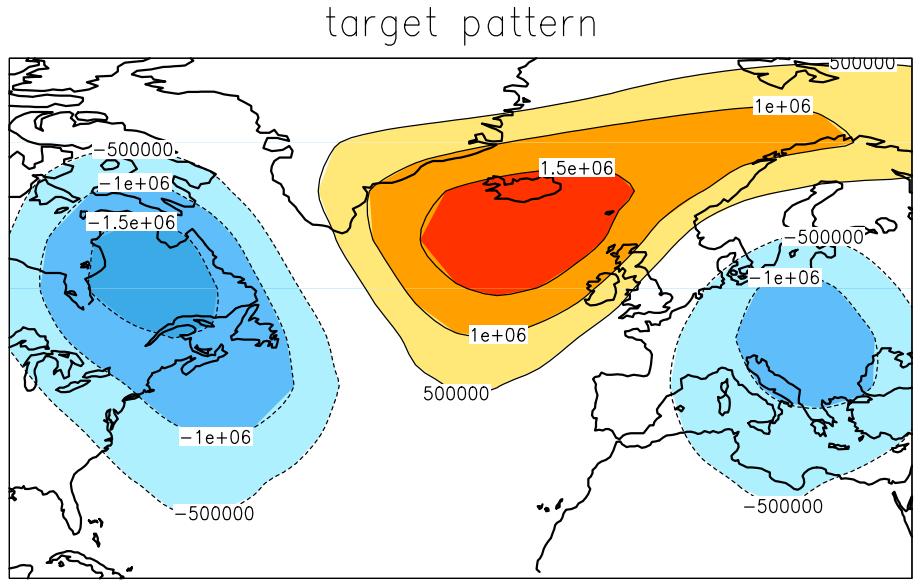
target pattern



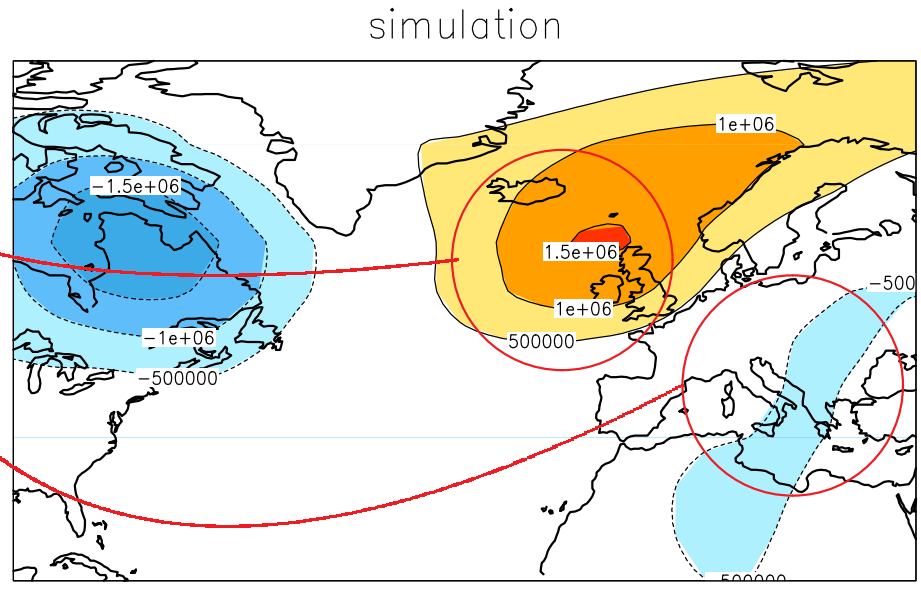
simulation



.... Does the data-assimilation work?



too weak



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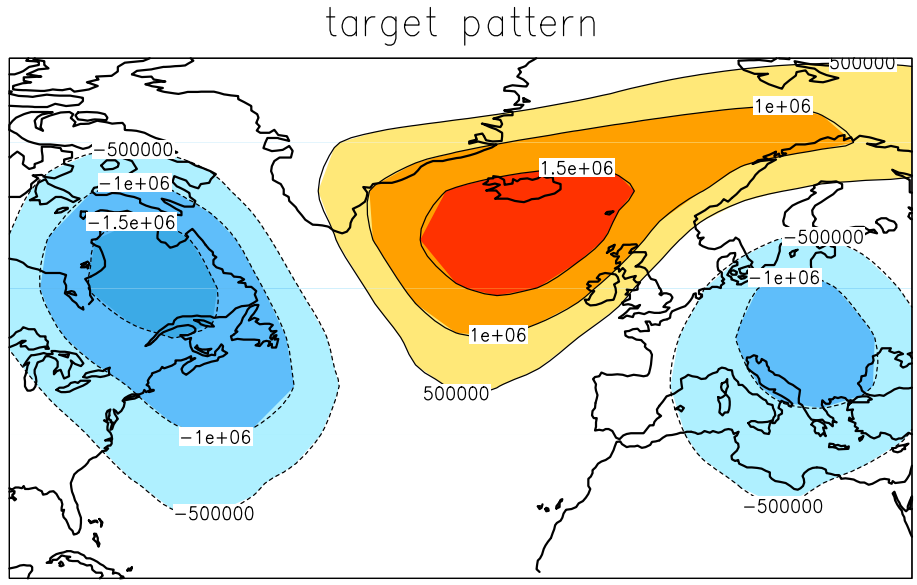
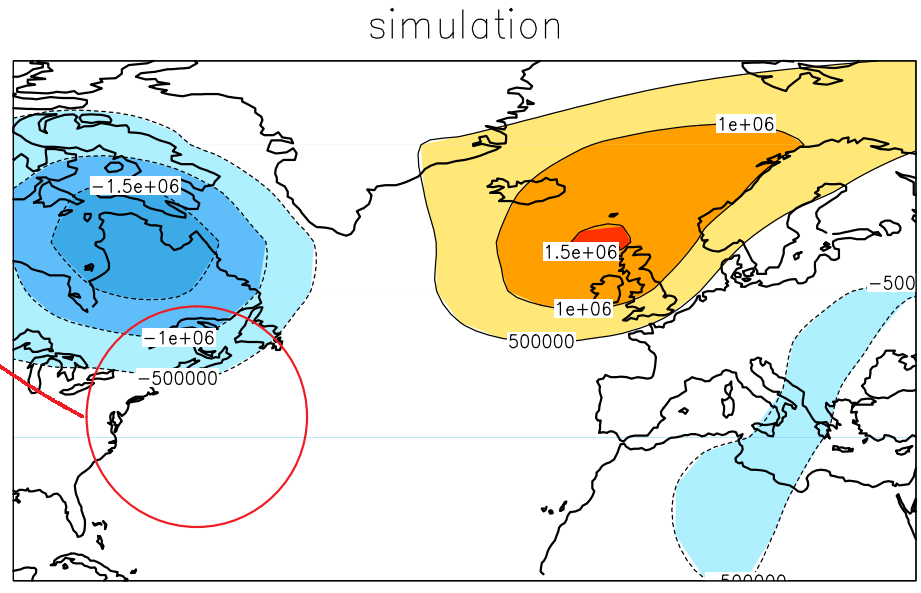
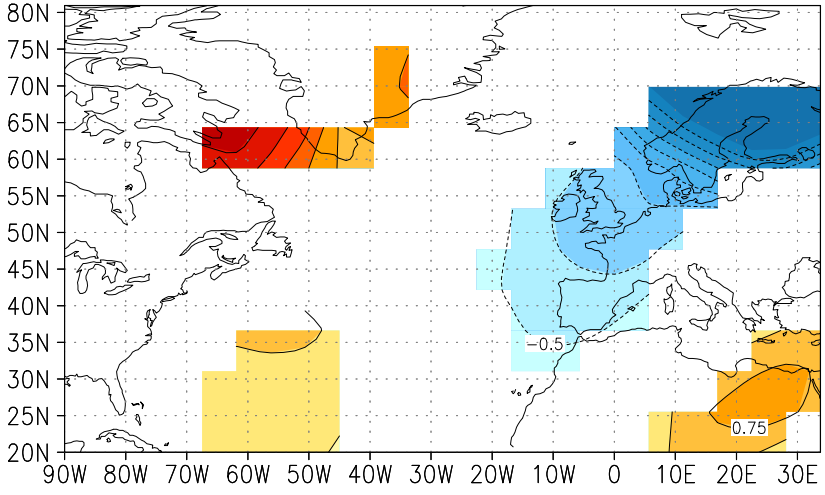
.... Does the data-assimilation work?

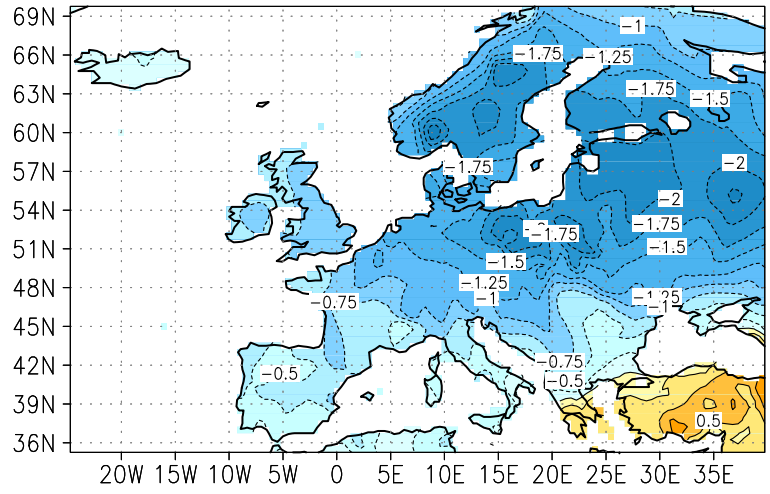


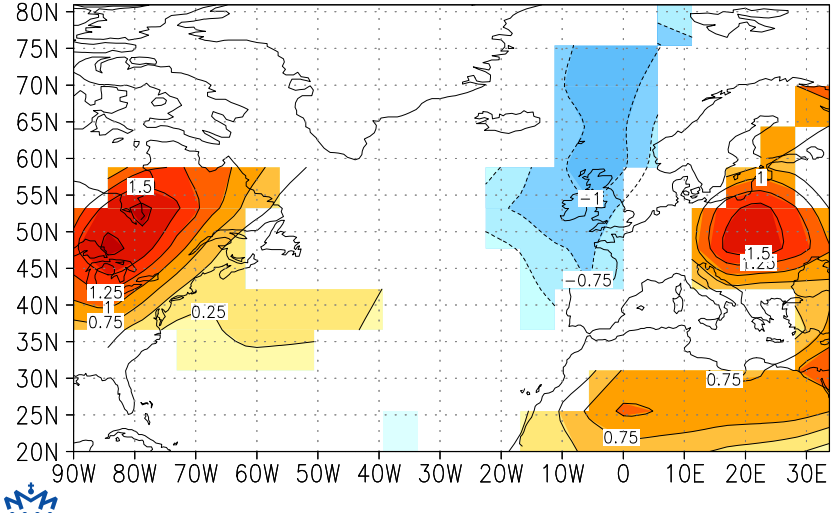
absent

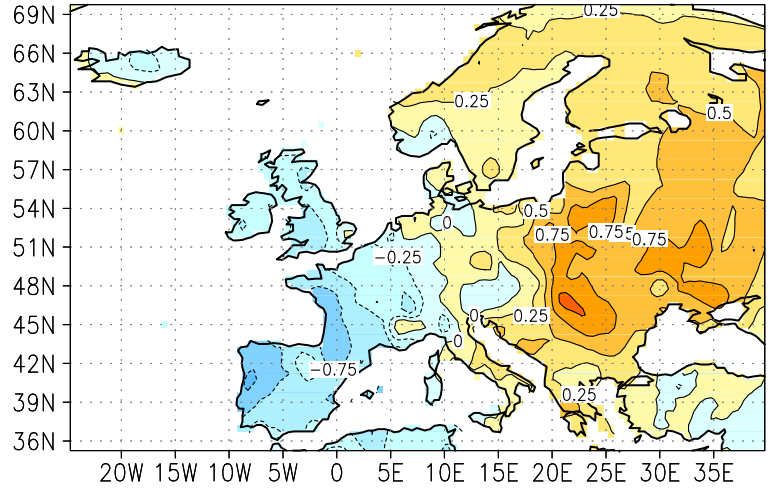


.... modelled and reconstructed SAT









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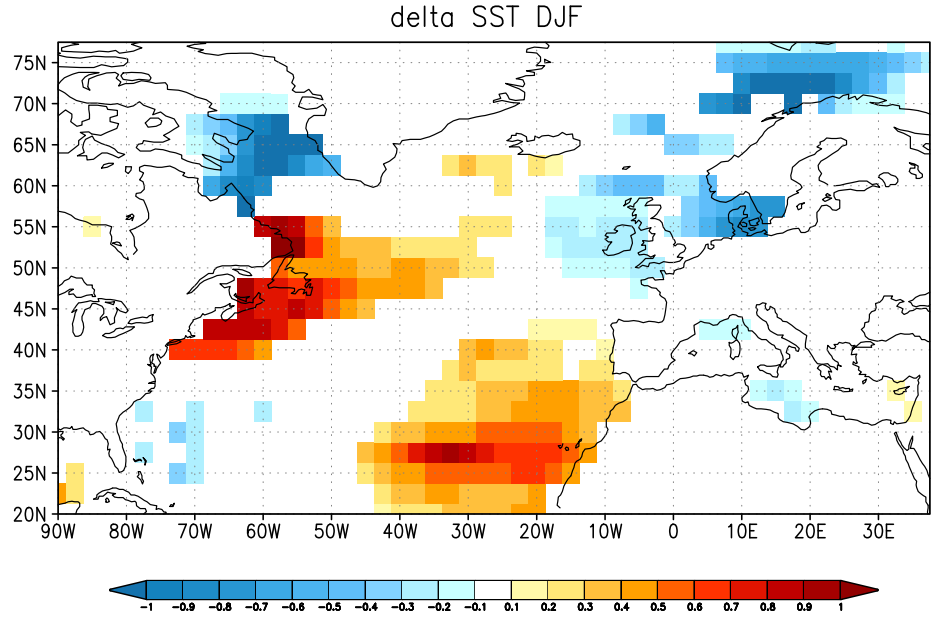
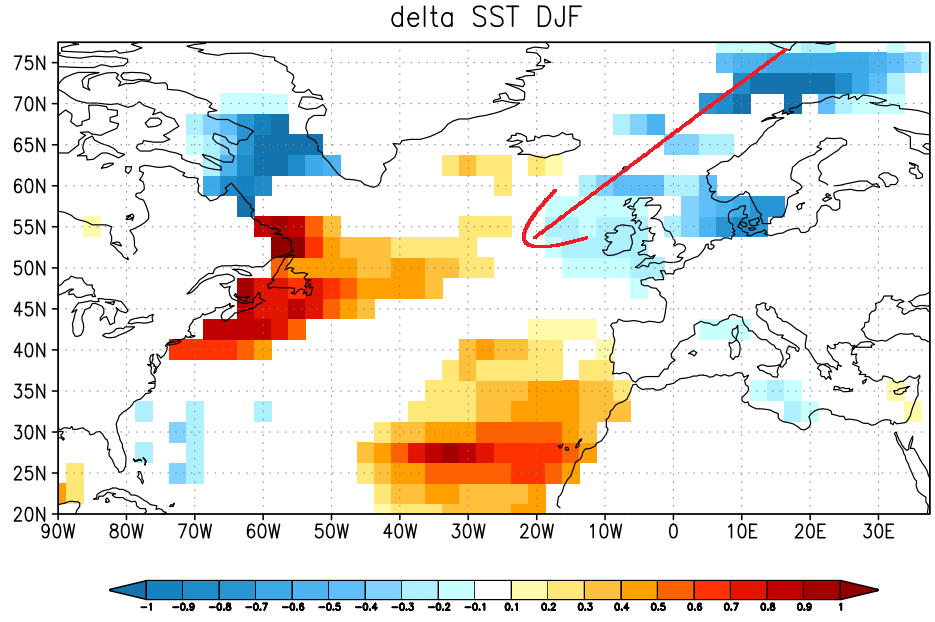
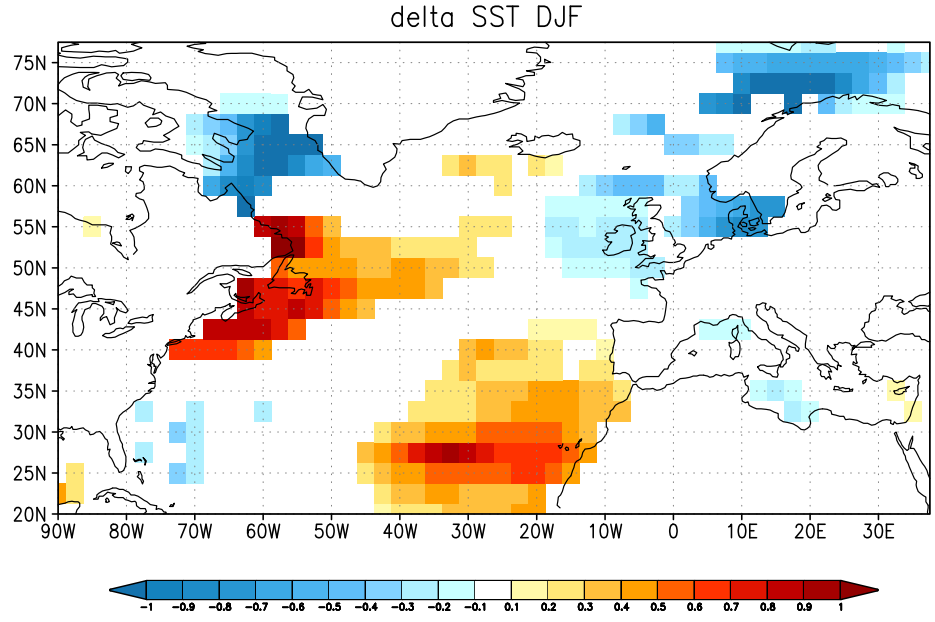
.... Change in SSTs

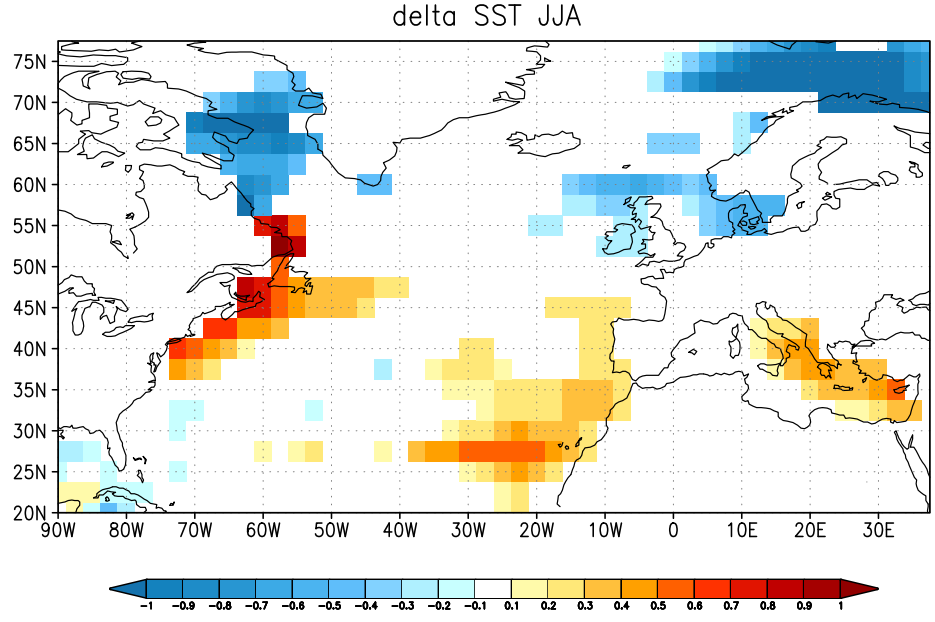


.... Change in SSTs



.... Change in SSTs





.... What changes are dynamically consistent?