Climate of the Last Millennium: Observations, Proxies and Modelling

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The ESTIMR Team

Extrême, **ST**atistiques, **IM**pacts et **R**égionalisation

www.lsce.ipsl.fr/Phocea/Vie_des_labos/Ast/ast_groupe.php?id_groupe=110

ESTIMR Research Activities

Methodologies

- Statistics of extremes (multivariate EVT, records, sampling design…)
- Statistical downscaling (Weather generators)
- Weather regimes & clustering

$$P(X < x) = \exp\left(-\left[1 + \frac{\xi(x-\mu)}{\sigma}\right]^{-\frac{1}{\xi}}\right)$$

Paleoclimate (last millennium to LGM)

- Global and regional modeling
- Paleo-environment
- Historical data rescue
- Statistical data analysis

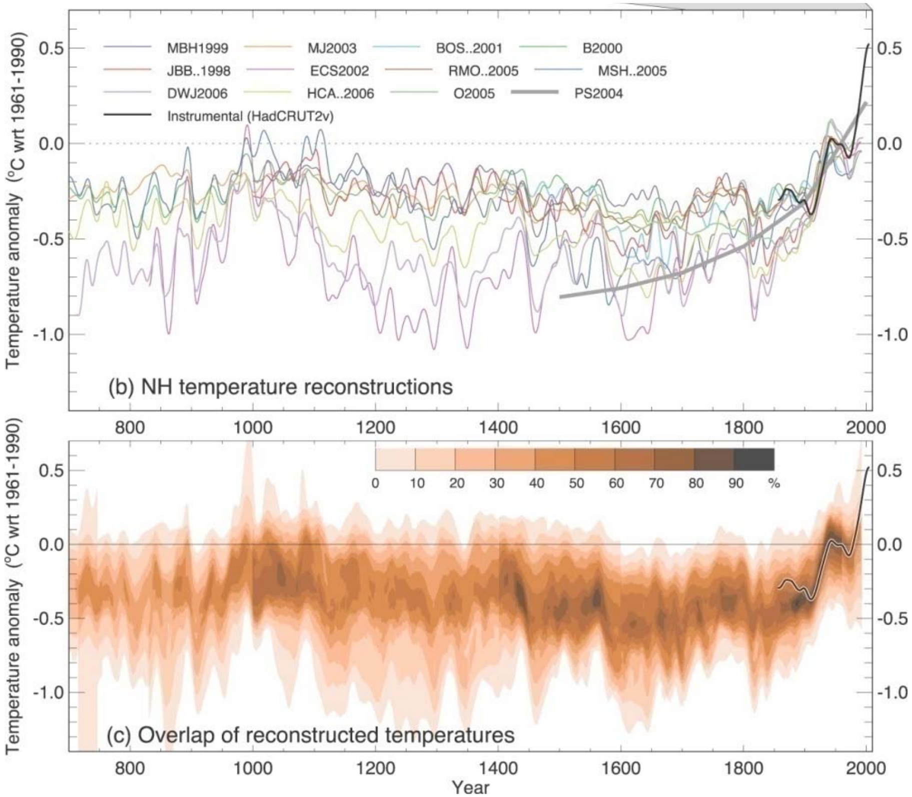
Climate extremes (case studies)

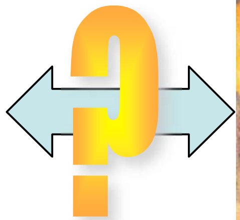
- Extra-tropical storms & no wind
- **Heatwaves** and cold spells
- Intense precipitation & droughts
- Applications to health, ecosystems & energy

The Last Millennium: A new scientific discipline?

- An interface between
  - History
  - Geochemistry & Physics
  - Modelling
  - Statistics

A Bridge between Sciences





Ex voto inondation Rhône 1840

Why is it challenging?

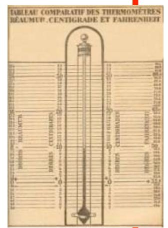
- **Weak signal to noise ratio** of mean temperatures
- Influence of **extreme events** on society and eco-systems
- **Perspective of recent climate change**

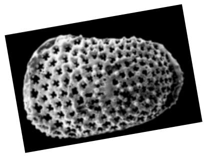
Scientific Challenges

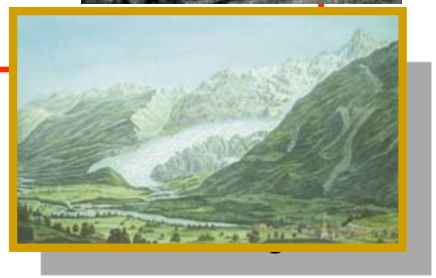
- Detection and attribution of forcings (natural and anthropogenic) in climate change
  - Statistical methods
  - Fine scale data
- Millennium long climate simulations
- Climate downscaling
- Impacts on society, risk and resilience

Typology of Observations

	Natural archives	***Societal archives***
Direct data	none	Chronicles Instrumental records
Indirect or proxy data	*Organic* Tree rings Pollens, corals etc.	*Organic* Vegetation development
	Non organic Ice cores Sediments Glaciers etc.	*Non organic* Ice, snow, water



Historical sources

Direct data

Descriptions**:** Anomalies, Natural catastrophes, development of meteorological conditions

Instrumental records**:** Pressure, temperature, precipitation, river flow

Indirect data

Organic**:** Flowering of cultivated plants, harvest dates, harvest volume & sugar content

Non organic**:** water levels, ice cover, snowfall, snow cover duration

Religious sources

Epigraphic marks**:** floods

Illustrative sources

Temperature reconstructions

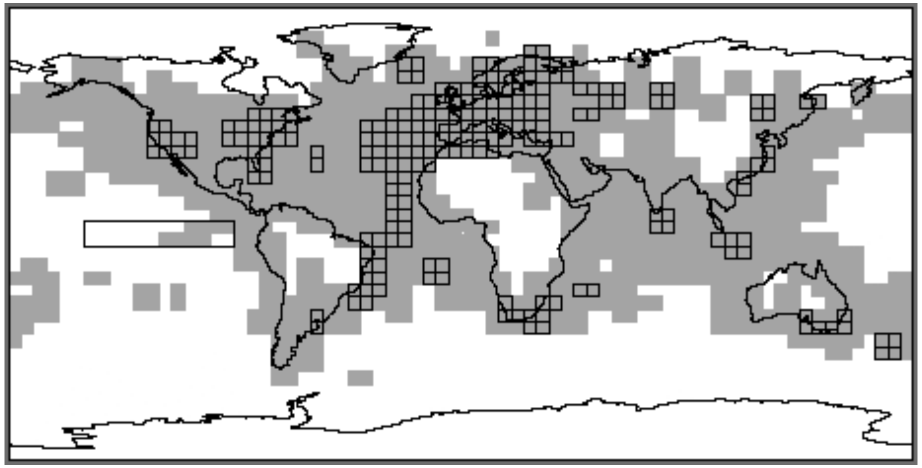
- Statistical multi-proxy reconstructions
- Mechanistic models
- Climate and past extremes

Statistical multi-proxy reconstructions

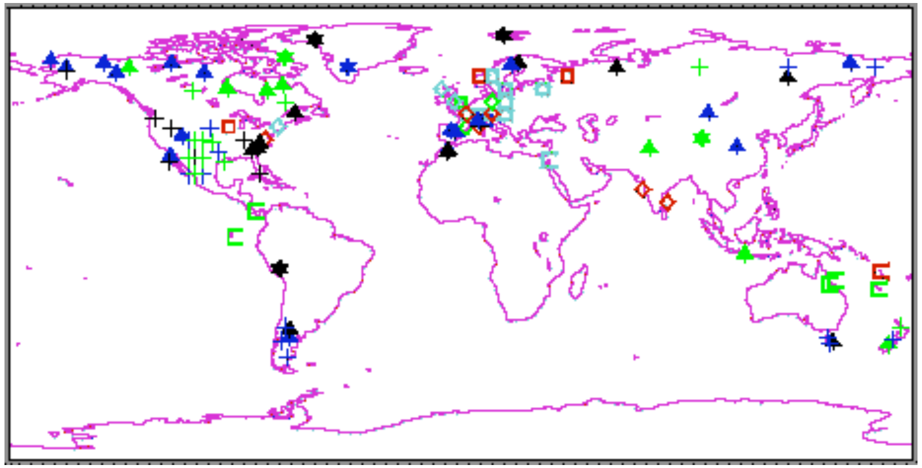
- Spatial reconstruction of temperature for the last millennium?
- Temperature database since 1850
- Databases on tree rings, isotopes, archives… over the last millennium

Observed and proxy temperatures

INSTRUMENTAL TEMPERATURE RECORD



GLOBAL PROXY CLIMATE RECORDS



Mann et al. Nature, 1998

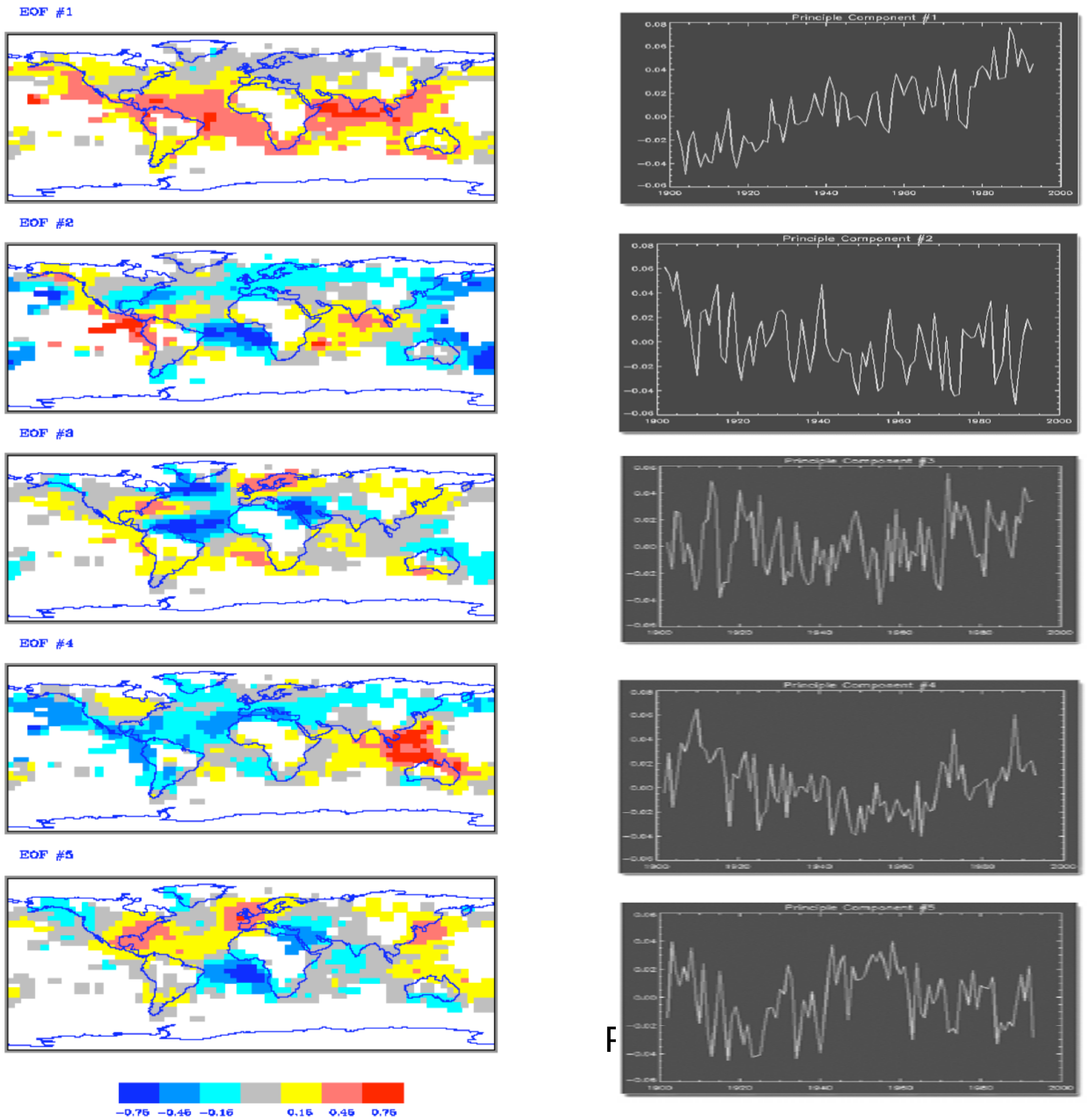
EOFs in a nutshell

- Determination of orthogonal maps (EOFs) that maximize variance in each direction for *X*(*t*,*x*), i.e. separate space and time

$$X(t,x) = \sum_k a_k(t) E_k(x)$$

- E_k (EOF): the eigenvectors of the data covariance matrix
- a_k (PCs): the loadings of the EOFs
- The variance of a_k is the eigenvalue of E_k

First EOFs of annual temperatures



Five leading patterns of global temperature variation during the 20th century.

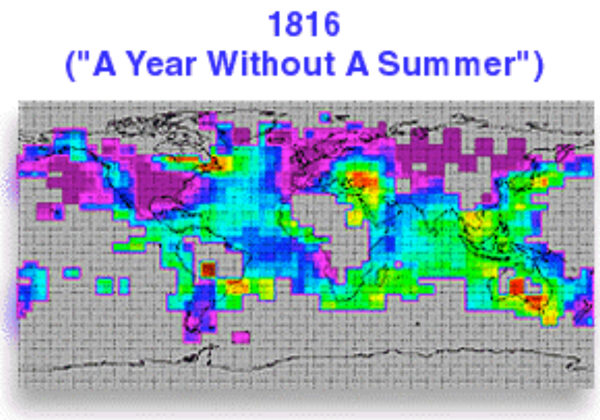
Mann, M.E., Bradley, R.S., Hughes, M.K., Global-Scale Temperature Patterns and Climate Forcing Over the Past Six Centuries, *Nature*, 392, 779-787, 1998.

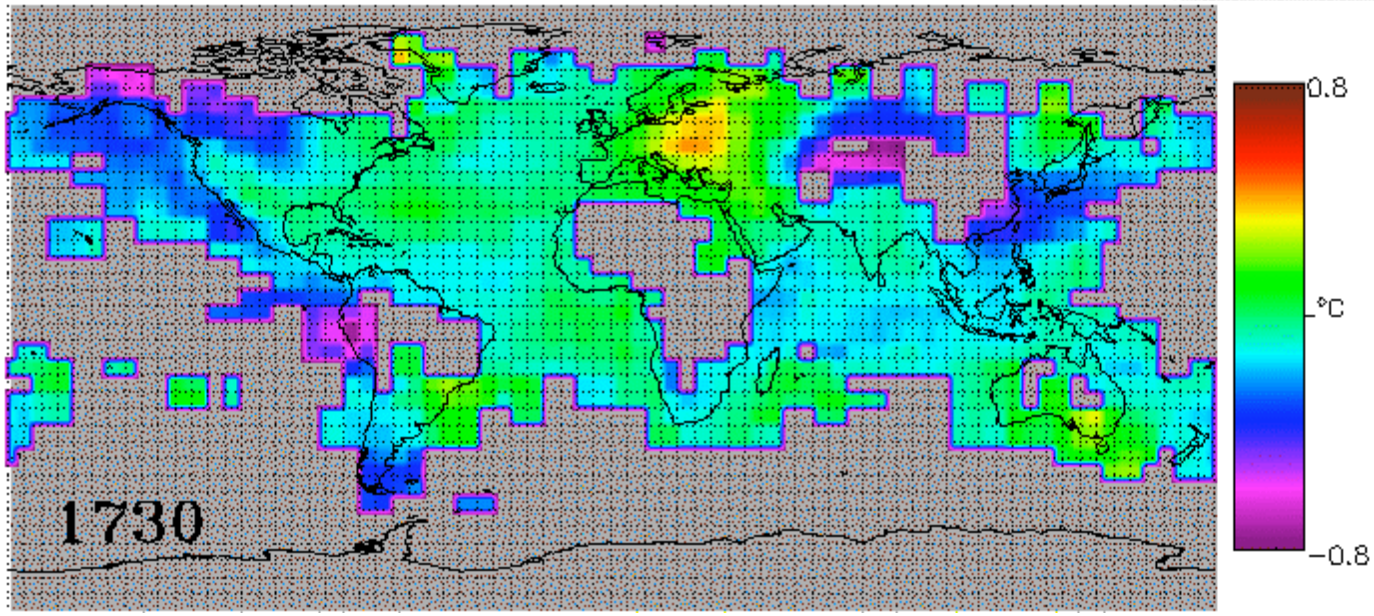
Strategy of Mann et al. 1998

- Calculate PCs/EOFs of observed temperature since 1850 over the globe, NH, SH
  - 5 first EOF explain 83% of variance.
- Regression with proxy records (tree rings, sediments, corals…) for each PC of temperature over a learning period (20th century).
- Verify reconstruction on 1850-1900.
- Compute reconstruction for the last millennium
- **Compute confidence intervals due to missing data**

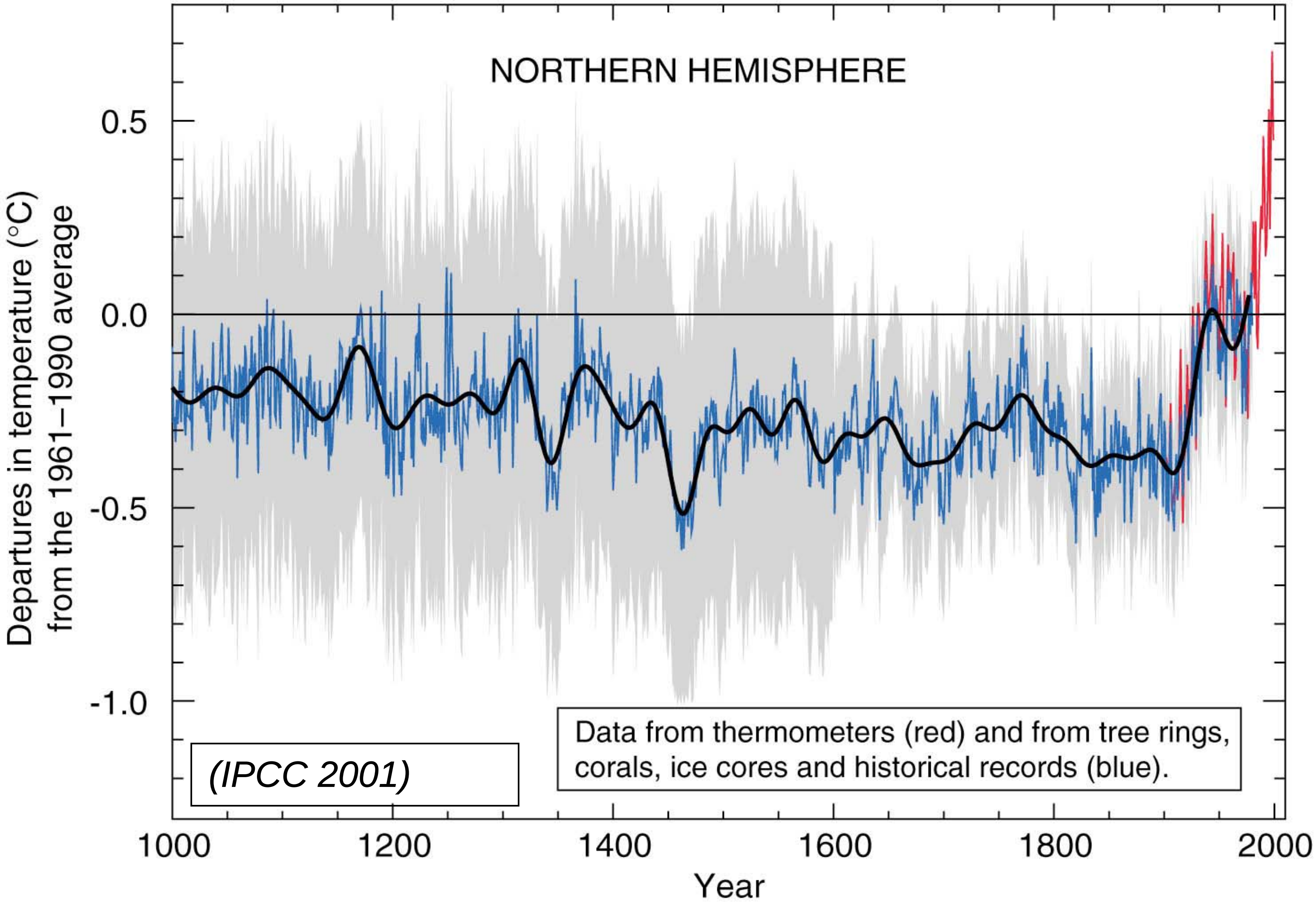
Examples

After the Tambora eruption





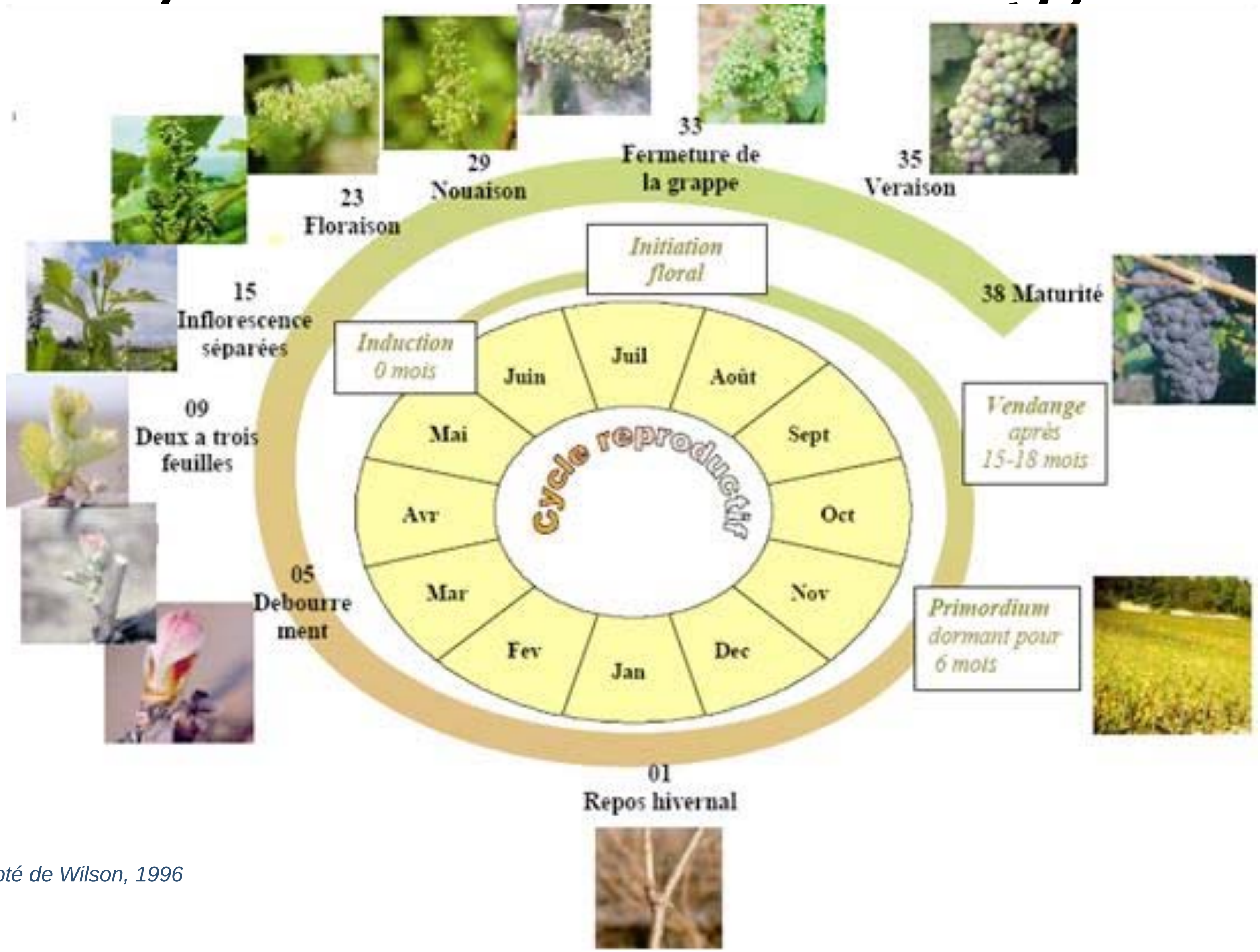
NH Temperatures



A Mechanistic approach for temperature reconstructions

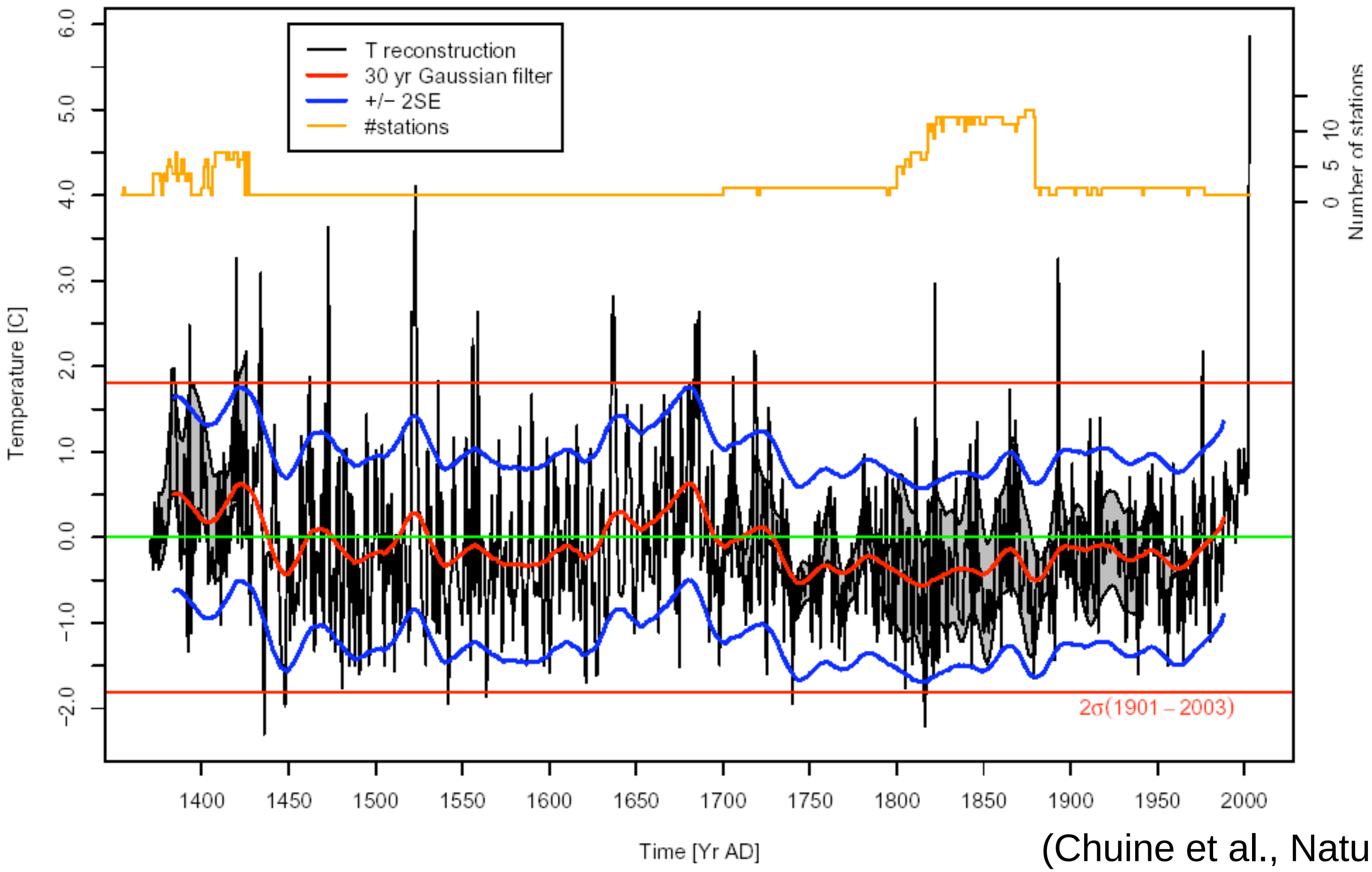
- Simulation of vine phenology in response to climate variations
- Important steps of vine growth, controlled by temperature:
  - Flowering
  - Veraison
- Calibration over thorough measurements of climate and phenologial data from INRA

Cycle of Vine Phenology



Adapté de Wilson, 1996

Warm Season Temperature Reconstruction in Burgundy

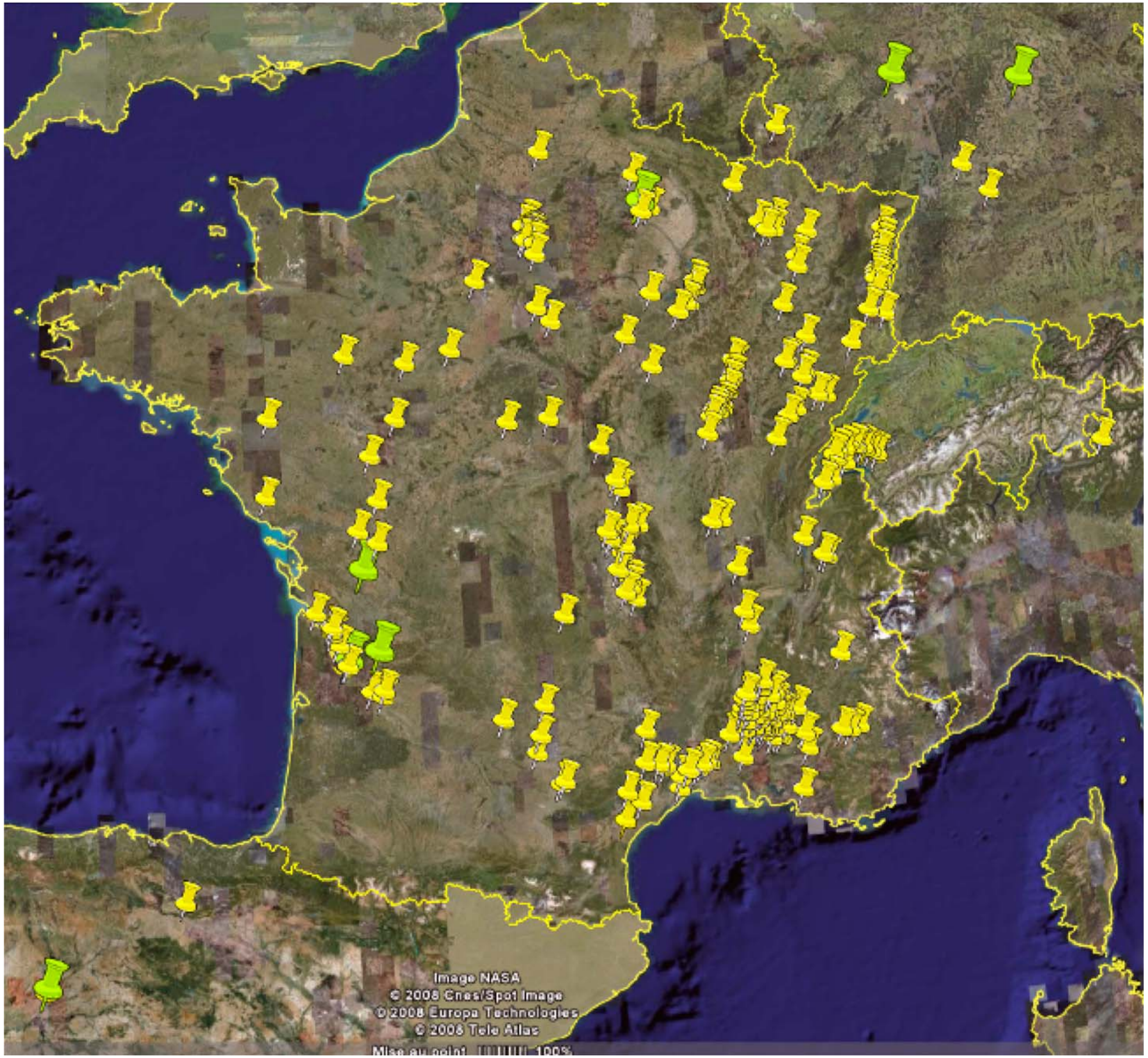


(Chuine et al., Nature, 2004)

A Generalization to other regions

- Importance of vine type ("cépage")
  - Burgundy essentially cultivates pinot noir
  - For other regions, a vine type separation has to be done to reconstruct temperatures from harvest dates
  - ➢ Necessity to work with agronomists
- Socio-economic and political context might induce non-climatic biases (wars, train, demand for quality, diseases…)
  - ➢ Necessity to work with historians

The OPHELIE grape harvest Data Base



28 Regions
France, Italy, Germany, Switzerland and Spain

338 data series

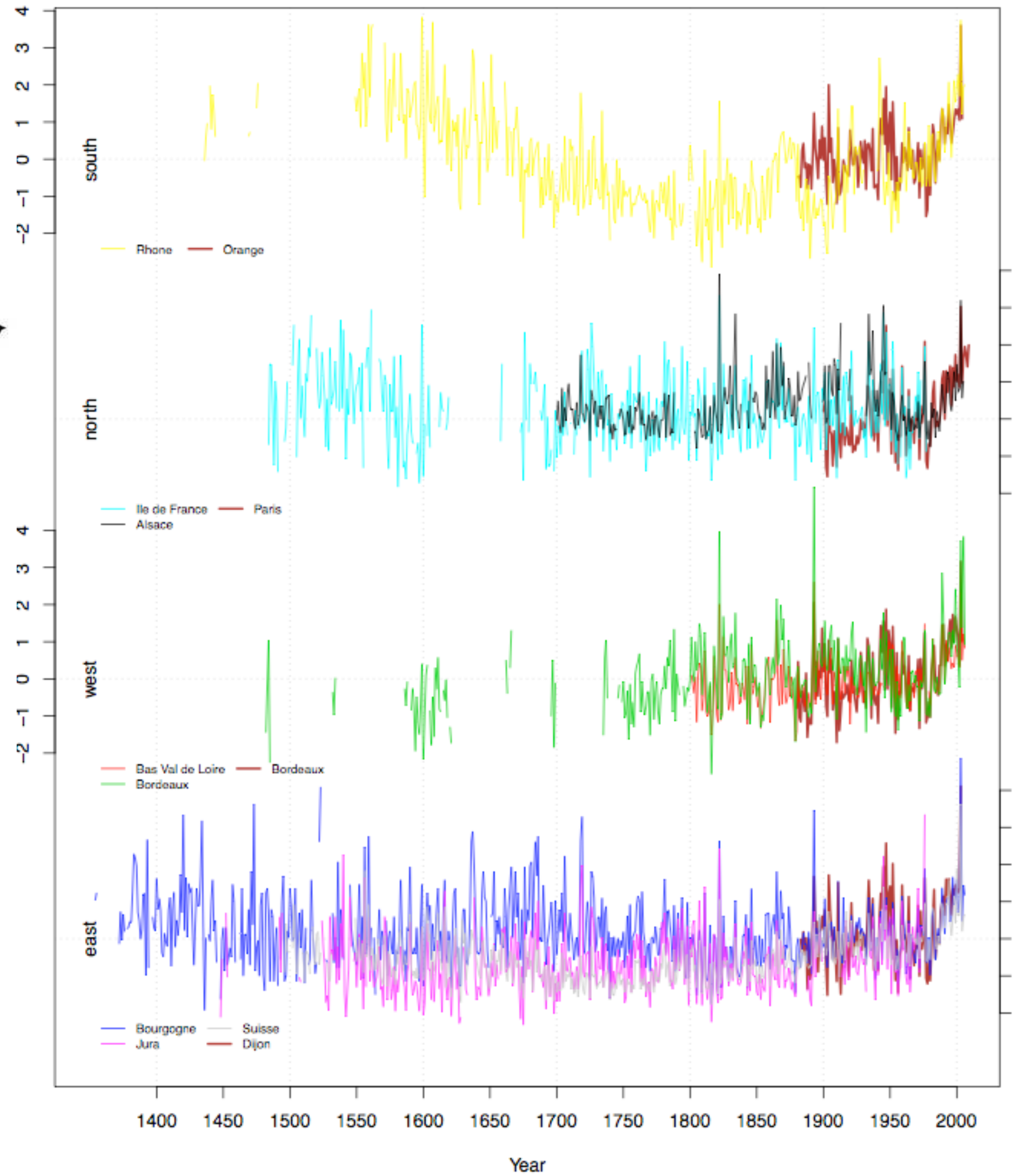
Period covered
1349 - 2008

Temperature reconstructions

- Reconstruct temperature anomalies for 8 regions following the Chuine et al. (2004) methodology
- Identification of 44 main grape varieties cultivated in the 8 regions during the period studied
- Calibration of a phenology model for each variety using an important data base of budbreak, flowering, veraison, and maturity dates for grapevine (>2000 observations for each stage; >100 varieties)
- Estimation of anomaly uncertainty : integration of phenology model error and uncertainty on the harvest dates (estimated with STICS crop model using the different past agricultural practices of each region).

Garcia de Cortazar-Atauri et al. (Holocene, 2010)

AMJJA T reconstructions



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Climate and Harvest dates?

- General coherence between temperature anomaly reconstructions
  - Especially for some identified extremes
- Extensive European data base of grape harvest dates
  - When possible: context and meta data.
    - Garnier et al., *Clim. Change*, DOI: 10.1007/s10584-010-9810-0, 2010
    - I. García de Cortázar-Atauri, *Holocene*, doi:10.1177/0959683609356585, 2010
    - V. Daux et al., *Clim. Past* (2012)
  - Use of ancient agronomy monographs (16th to 19th centuries) in French and Spanish for cultural practises.

Example of Met Archives

Jour	Heure	Barom.	Thermomètres dedans	Thermomètres dehors	Hygr.	Vents	force des vents	Etat du ciel
				Decembre				1783
1	1	27. 4, 3	1, 0	−1, 8	15, 3	—	1	couvert
	7	27. 3, 8	0, 9	−1, 4	15, 5	SE	1	== brouill.
	10½	27. 3, 7	0, 9	−0, 7	16, 0	SE	1	==
	2	27. 3, 3	1, 2	1, 0	17, 0	SE	1	==
	5	27. 3, 2	1, 2	0	16, 1	SE	1	≡ profqs beau
	9½	27. 3, 4	1, 1	0, 1	15, 5	SE	1	==
2	1	27. 3, 4	1, 2	0, 5	15, 2	—	1	==
	7	27. 3, 5	1, 1	0, 5	13, 9	SE	1	== Brouill.
	10½	27. 3, 7	1, 1	1, 1	13, 3	SE	0	Brouillard
	1½	27. 3, 5	1, 3	2, 0	13, 4	SE	1	idem
	5	27. 3, 6	1, 2	1, 3	12, 8	SE	1	idem
	9¾	27. 4, 1	1, 1	0, 8	12, 2	—	0	==
3	1	27. 4, 1	1, 2	0, 8	12, 5	—	1	==
	7	27. 3, 9	1, 1	−0, 6	12, 6	SE	1	beau ⊙
	9	27. 4, 0	1, 2	−0, 6	14, 0	SE	1	⊙
	10½	27. 4, 1	1, 7	0, 2	15, 6	E	1	⊙
	12¼	27. 4, 0	3, 2	2, 6	19, 6	E	1	⊙
	2	27. 3, 7	3, 9	2, 5	21, 2	E	1	⊙
	5	27. 3, 5	2, 7	0, 9	19, 7	NE	1	⊙
	8	27. 3, 5	2, 3	−0, 2	18, 1	NE	1	⊙

Jour	H.	Barom.	Thermomètres dedans	Thermomètres dehors	Hygro.	Vents	force des vents	Etat du ciel. 57
4	1	27. 3, 0	1, 9	−1, 3	17, 9	NE	1	⊙
	7	27. 2, 7	1, 6	−2, 6	17, 7	NE	1	⊙
	10½	27. 2, 9	2, 4	0	20, 6	NE	1	⊙
	12	27. 2, 8	3, 4	2, 6	24, 1	NE	0	⊙
	2	27. 2, 4	4, 2	2, 4	25, 80	NE	1	⊙
	5	27. 2, 3	2, 9	0, 6	24, 7	NE	1	⊙
	8	27. 2, 3	2, 5	−0, 4	23, 5	NE	1	⊙
5	1	27. 2, 2	2, 1	−1, 7	23, 2	NE	1	⊙ ☽
	7	27. 1, 6	1, 6	−2, 0	23, 8	NE	1	⊙
	10½	27. 1, 3	2, 3	0, 2	26, 7	NE	1	⊙
	12	27. 0, 9	2, 8	2, 0	30, 7	NE	1	nuageux
	2	27. 0, 6	2, 8	2, 4	30, 0	NE	1	
	5	27. 0, 4	2, 4	0, 8	28, 5	NE	1	
	8	27. 0, 5	2, 0	0	27, 2	NE	1	
6	1	27. 0, 7	1, 7	−1, 3	26, 8	NE	1	couvert. ☽
	7	27. 0, 9	1, 5	−1, 4	25, 4	NE	1	nuageux
	10½	27. 1, 3	2, 2	0	26, 2	NE	1	beau
	12	27. 1, 2	2, 9	1, 8	29, 4	E	1	=
	2	27. 1, 0	3, 4	2, 0	30, 3	E	1	≡
	5	27. 1, 2	2, 5	−0, 2	27, 8	NE	1	
	8	27. 1, 3	2, 2	0	26, 4	NE	1	couvert

(source: Soc. Palatina, Manheim)

Reconstructions of past droughts

No rain in Normandy between Easter (~April) and "Halloween" (November)

Evénement	Chaleur + Sec + Vent(dir)
Source	Duval. L : *Phénomènes météorologiques et variations atmosphériques*
Site d'observation	Argentan
Caractéristiques du site	
Année	1559
Date	De Pâques à Toussaint (d'avril à novembre)
Commentaire	« Depuis la feste de Pâques 1559, il fist de fort grandes et véhémentes chaleurs ; [...] toutes fois le vent se toutost tanyôt vers le midy, puis vers le north ou septentrion, de façon qu'il ne pleust jusques viron la feste de Toussaint »

Evénement	Sécheresse
Source	*Le journal de Simon Le Marchand (1610-1693)*, p22
Site d'observation	14. Caen et ses campagnes
Caractéristiques du site	
Année	1615
Date	15 avril au début juillet.
Commentaire	« nous avons esté sans avoir de l'eau du ciel, autre que de la rozée depuis le quinzième jour d'Avril audit an, chose qui fut bien contraire aux biens de dessus la terre [...] prioient Dieu que ce fust son plaisyr de nous donner de l'eau ; ce qui nous estoyt fort nécessaire : ce qui fut ce dit jour pour la gloire de Dieu »

Around 12 recorded dry spells between 1556 and 1785 (no precipitation for more than 3 months between April and September) in Normandy

(source: E. Garnier)

Meteorological Processions

Procession *pro pluvia* à Paris 1694

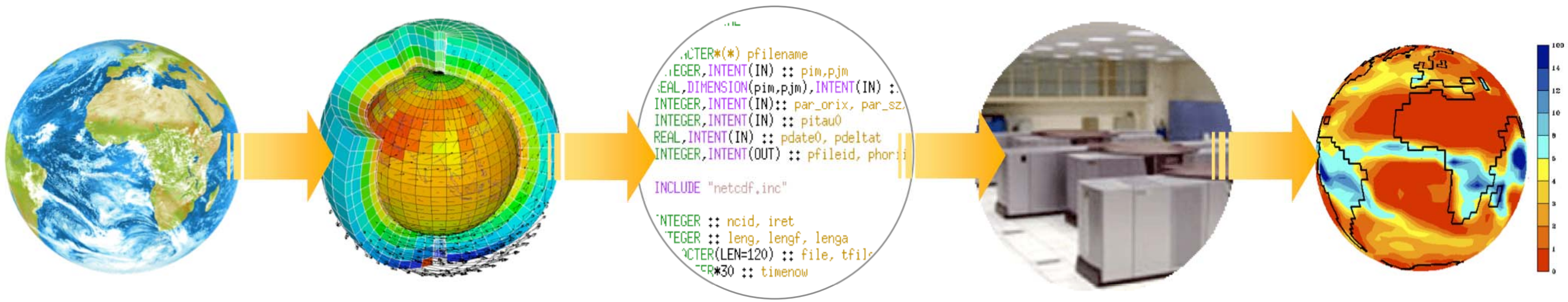
Procession en Russie (région de Voronej) contre la sécheresse de l'été 2010

(source: E. Garnier)

Procession dans les PO (66) pour faire cesser la sécheresse, été 2008

Numerical simulations

- Challenges
- Results



Natural vs. Forced Variability

- Simulations without forcing, control simulations
  - Constant GHG, no volcanoes, no solar activity
- Simulations with natural and anthropic forcings
  - Volcanoes
  - Solar activity
  - Insolation (Milankovitch)
  - GHG and sulfates

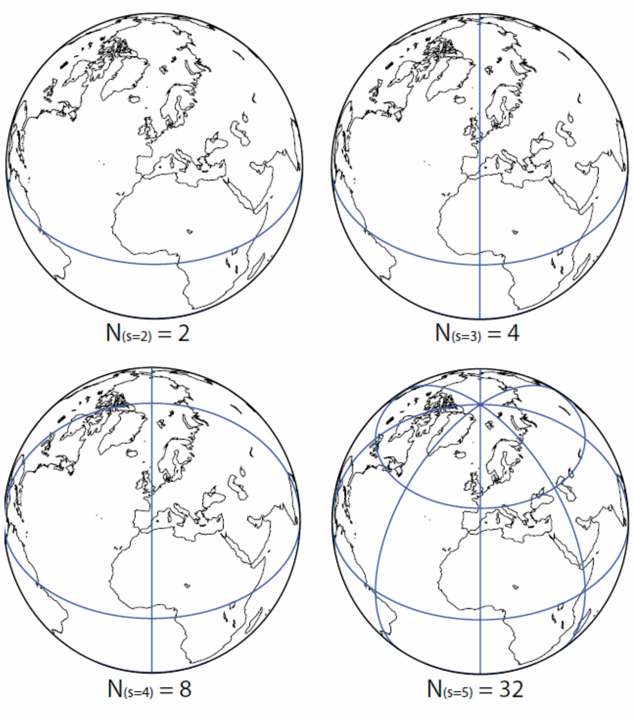
Physical Difficulties

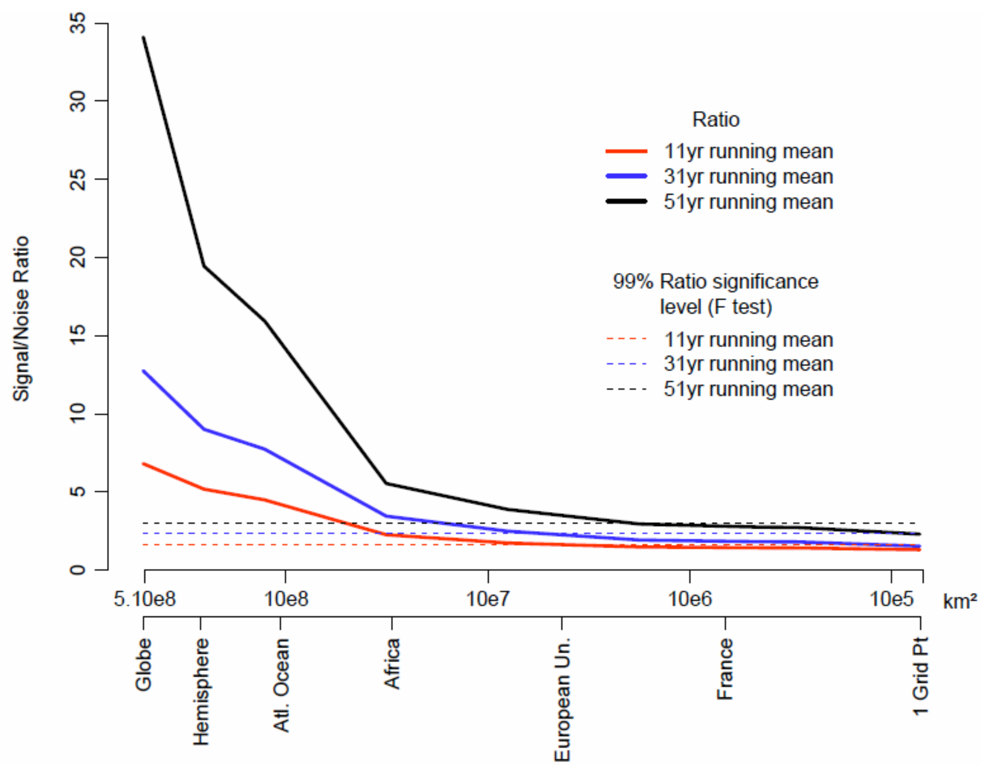
- Influence of solar activity is not well constrained. Roles in:
  - Stratospheric photo-chemistry
  - Nucleation of clouds (strato? tropo?)
  - Modulation of solar constant of at most 0.2W/m2
- Main effects of volcanic forcings in lower stratosphere with some effects on troposphere:
  - Impact on optical depth variations (space and time)

Mathematical Difficulties

- Initial conditions are not known or ill-constrained (ocean)
- The chronology of a simulated trajectory cannot be directly compared with observations, because of meteorological chaos
  - Compare integrated diagnostics, not events
  - *Ensembles* of simulations
- How to compare a simulation with observations?
  - Problem with spatial and temporal resolutions

Spatial scales?





Detecting a signal can only be done on a continental (e.g. Europe) scale for a spatial resolution of 2-3° lon-lat!

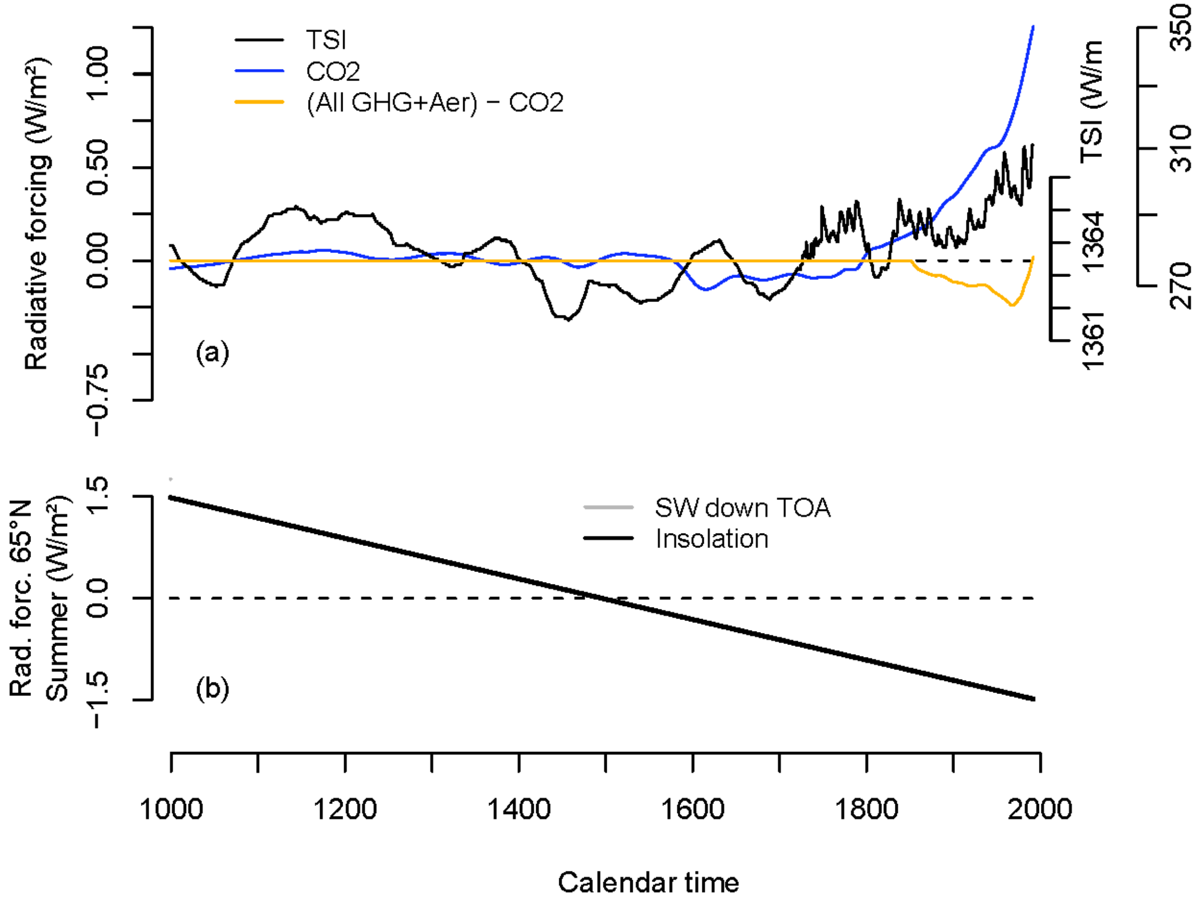
J. Servonnat et al., Clim Past, 2010

Some Results

- A millennium simulations with solar activity, insolation and GHG with IPSL model

- Spatial resolution ~2-3° long./lat.

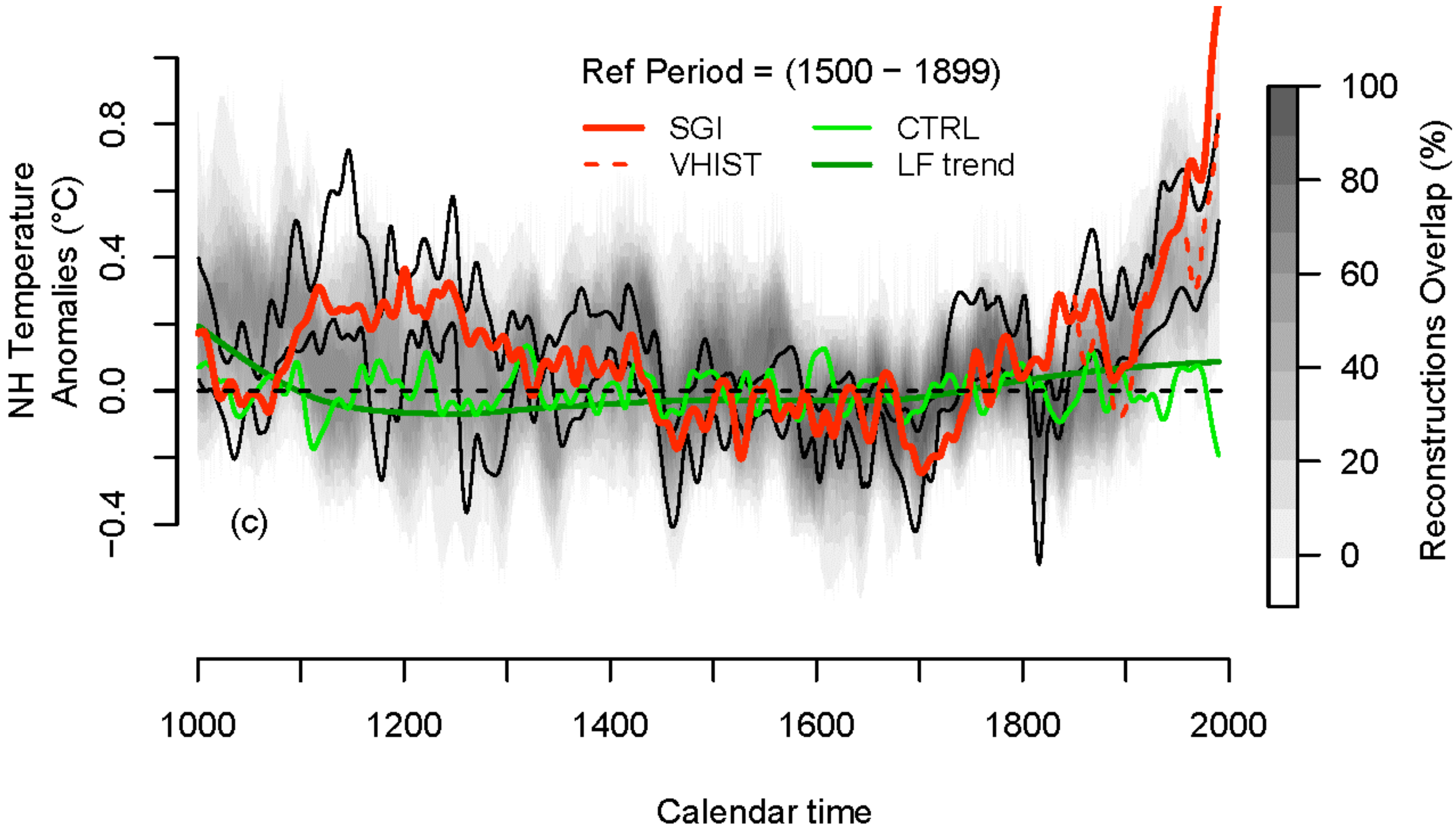
Last millennium simulations



Forçages solaire, insolation, GHG

J. Servonnat et al., Clim Past, 2010

Last millennium simulations



J. Servonnat et al., Clim Past, 2010

Signature of Forcings

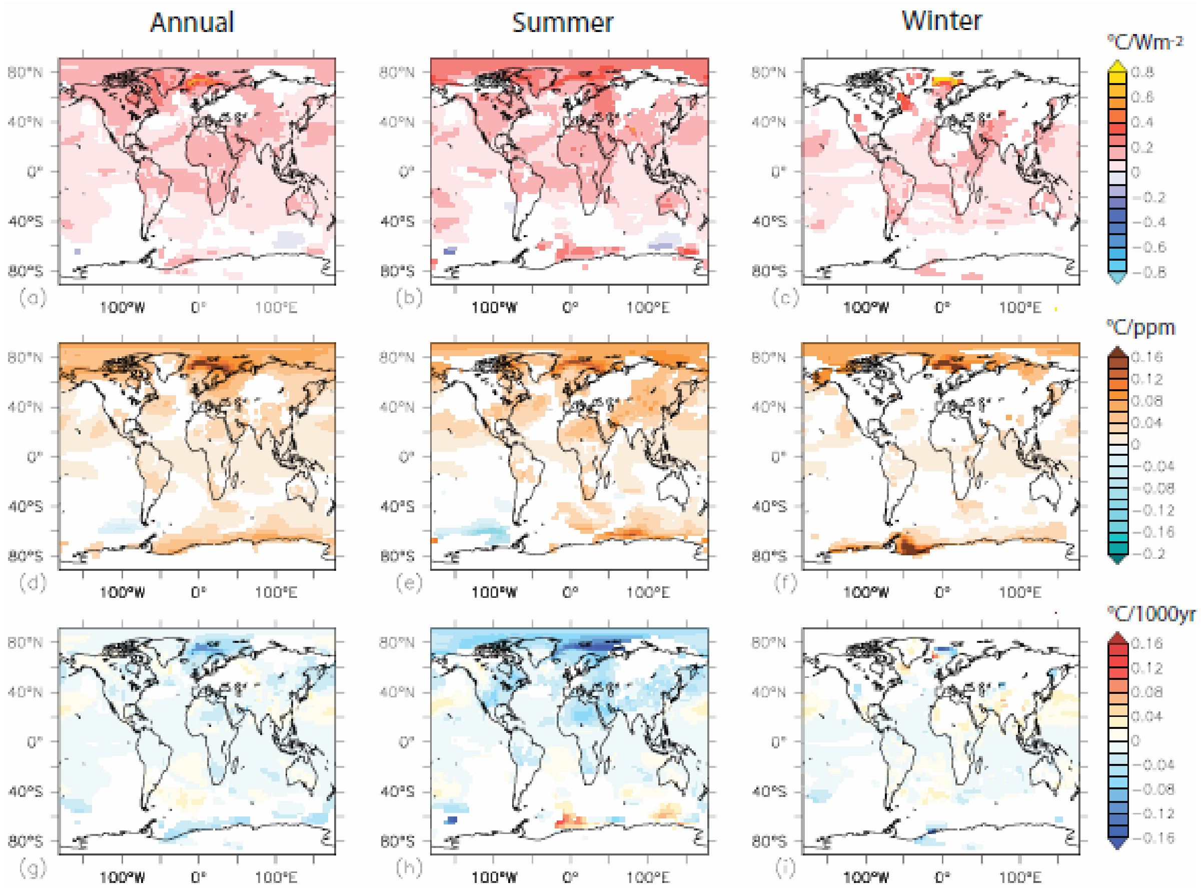
First order linear sensitivity

$$T'(t) = \boxed{C_1} \times TSI'(t) + \boxed{C_2} \times [CO_2]'(t) + \boxed{C_3} \times t + \varepsilon_4(t)$$

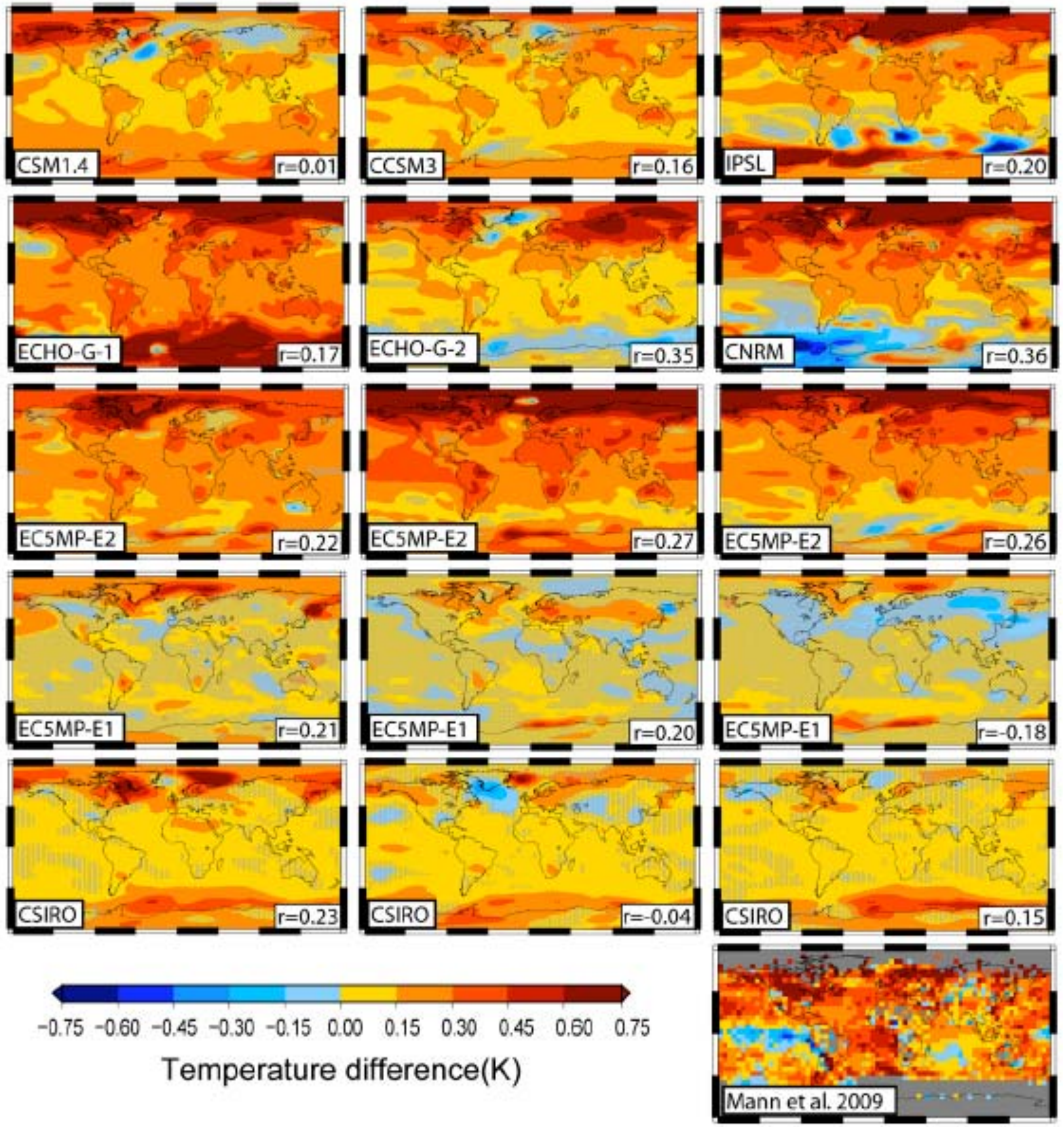
⇒ Sensitivity in the Arctic

⇒ Solar: tropics

⇒ orbital : Arctic in Summer



PMIP3 initiative



Millennium simulation intercomparison

Fernandez-Donato, Clim. Past, 2013

Room for Improvement

- Ocean initialization
- Impossible to perform long ensembles, or focus on some periods of the past
- Uncertainty on solar forcing
- Include land use?
- Model dependence of the responses (necessity of PMIP style comparisons)

New Directions

- Atmospheric variability & modes during the last millennium
  - Weather regimes
- Perspective on extreme events (heatwaves & storms)
- Dynamics of heatwaves in model simulations & observations

Opening PhD position at LSCE

- PhD at LSCE to investigate past extremes in climate simulations
  - Focus on Europe & North Atlantic

- Apply now!

Thank you