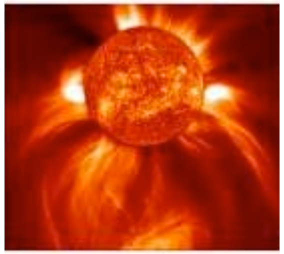
# *Modelling the climate of the last millennium in the LSCE : the ESCARSEL project*


Eruption solaire


Pinatubo 1991

## ***CLIM*** (modélisation du CLIMat) & ***ESTIMR*** (Extrêmes, STatIstiques et Modélisation Régionale) teams

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***Questions :***

**Climate variability on the last millennium:**

**-> Medieval Warm Period**

**-> Little Ice Age**

**-> How (where and which amplitude), and causes**

***Climate models used to study the last millennium for the AR4:***

**- GCM = 6/12**

**- Intermediate complexity = 5/12**

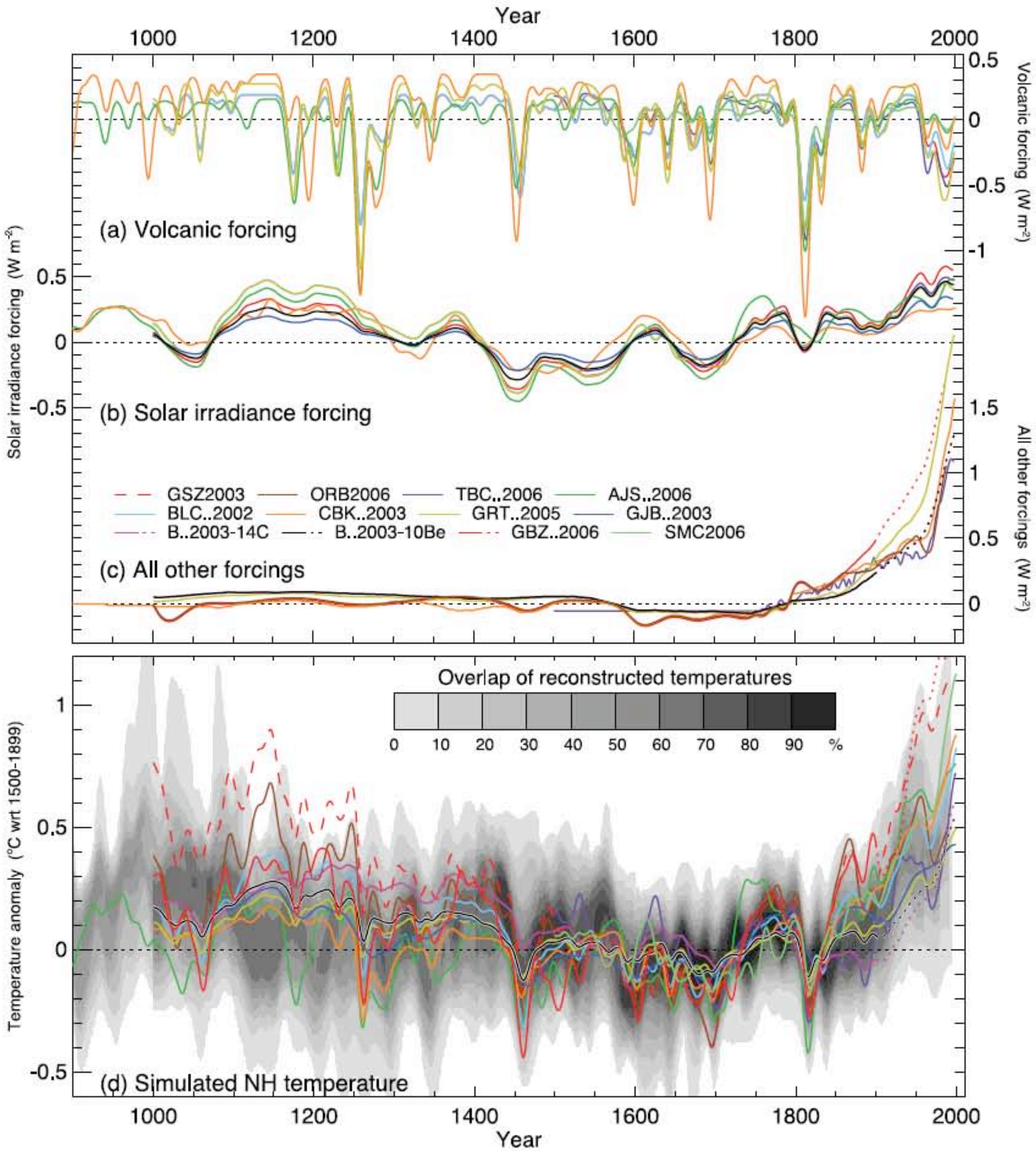
**- EBM = 1/12**

***Forcings :***

**- Solar irradiance**

**- volcanic aerosols**

**- land use (too many uncertainties)**




***IPCC AR4, chapt 6***

Two main forcings : solar and volcanic

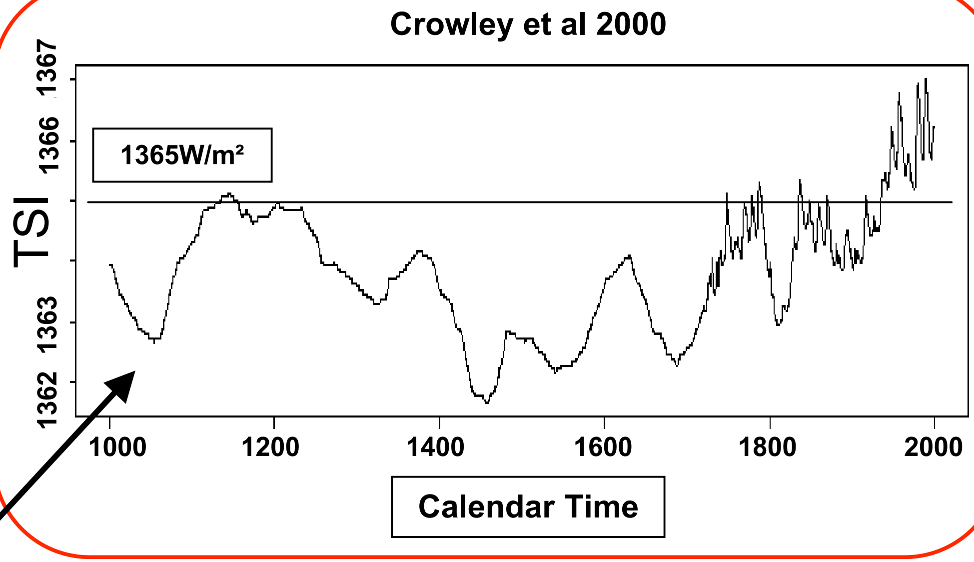
## *Models and simulations*

- **ISPLCM4v2** 96 / 72 / 19

-1 CTRL, 1 solar run and 1 volcanic run

-**CNRM CM3** T63 / L31

- 1 CTRL and 1 simulation with both solar and volcanic forcing



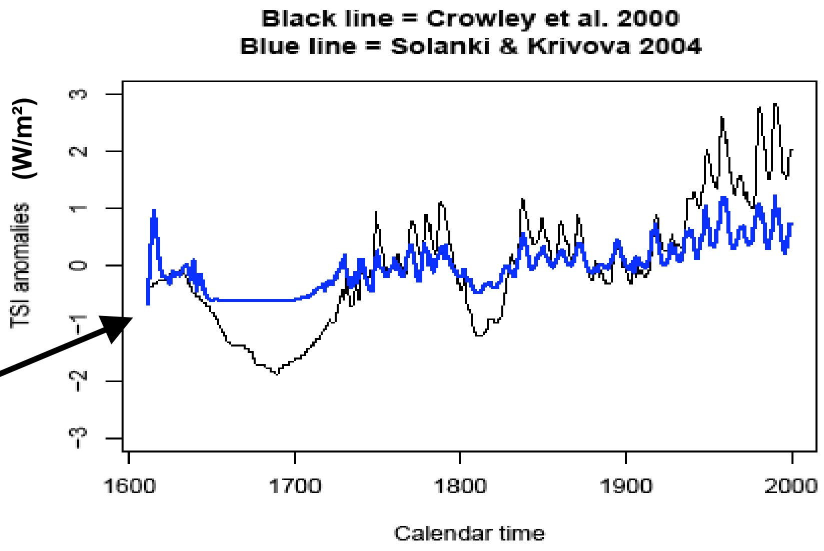

## *Solar forcing*

- Crowley et al 2000 (based on Bard et al 2000 & Lean et al 1995)

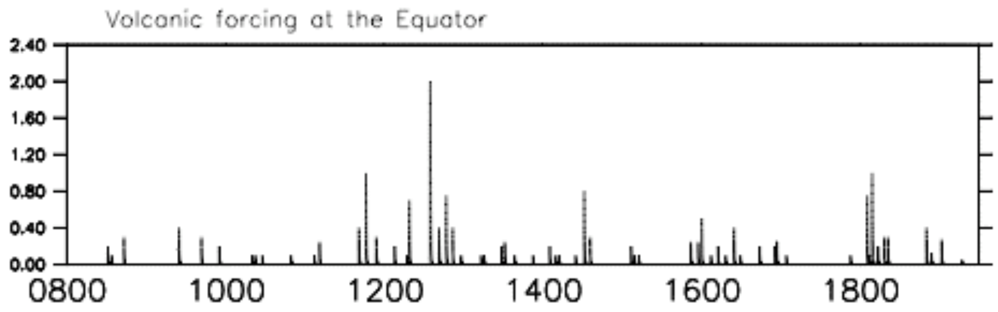
- anomalies calculated from the 1850-2000 mean (ENSEMBLES)

- **- 0.25%** of the TSI for the Spörer minimum

- Solar variability = 0.1% TSI ?



## *Volcanic forcing*

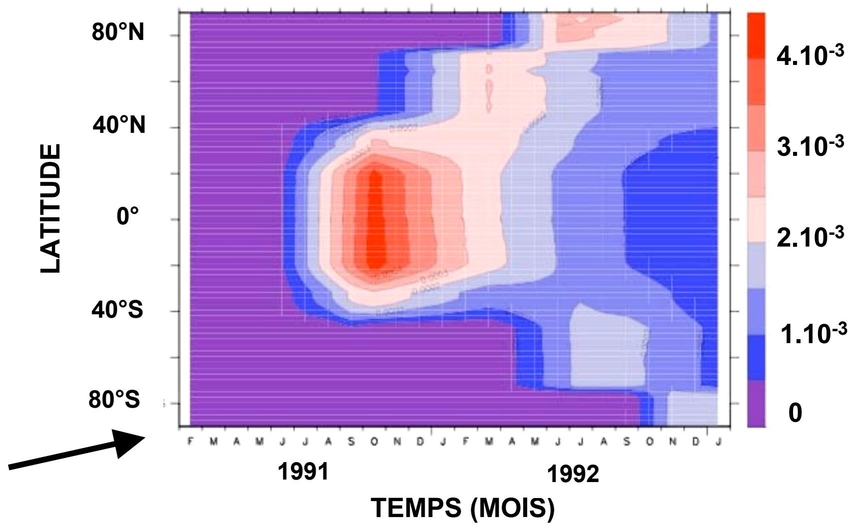



- IPCC AR4 = tuning of the solar irradiance

- 2D Reconstitution (latitude-time) of the aerosols optical parameters (Ammann et al 2008) of the main eruptions

- Tropical eruptions ; Volcanic Explosive Index > 4

- Implementation in the radiative code of LMDz (2 levels above the tropopause)




$$I/I_0 = e^{-(tau)}$$

***Optical thickness (tau) of the volcanic aerosols From the Mt Pinatubo eruption (DJF 1991-1992)***

# ***Northern Hemisphere Temperature***

## ***Global agreement***

- Good!
- Missing volcanoes
- Problem 1000-1200

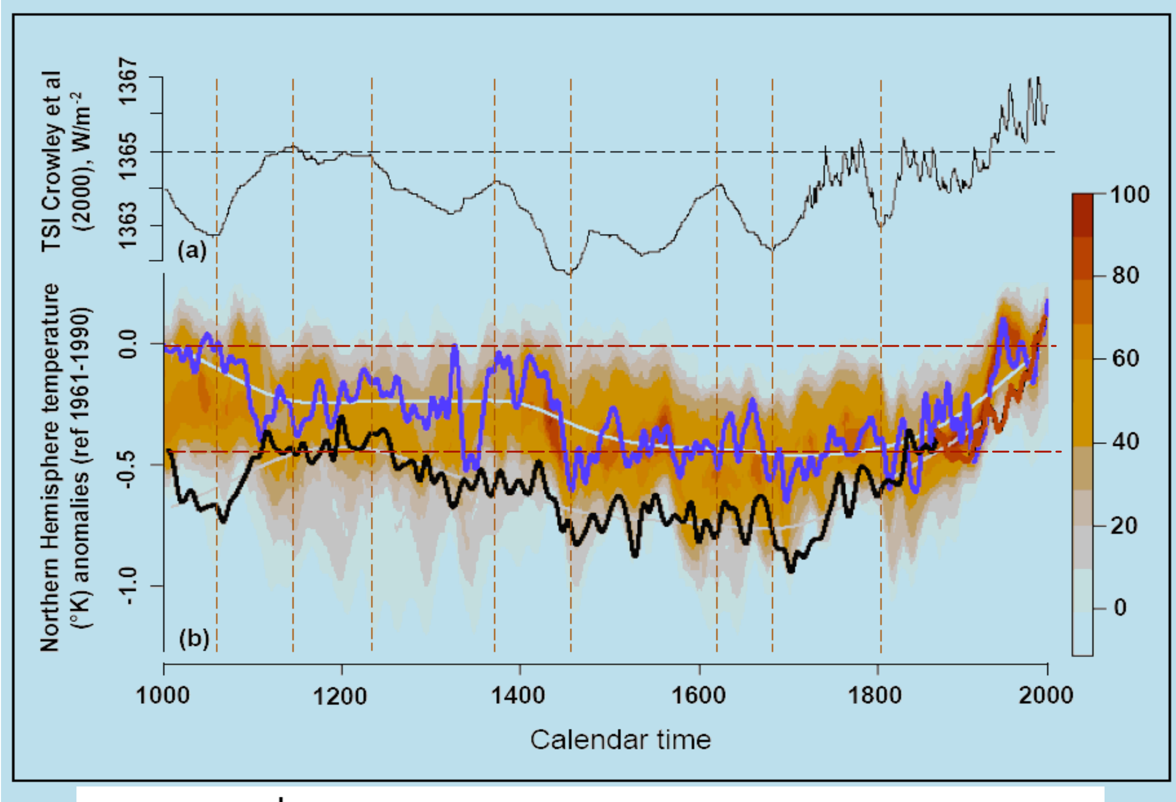
## ***Correlations***

- with NH temp reconstructions = between **0.31 & 0.61**

## ***Variability***

- Low frequency Max-Min on 1200-1850 = **0.34**
- Standard deviation of the residuals = **0.071**

=> TSI variability = 0.1 or 0.25% ?




(a)

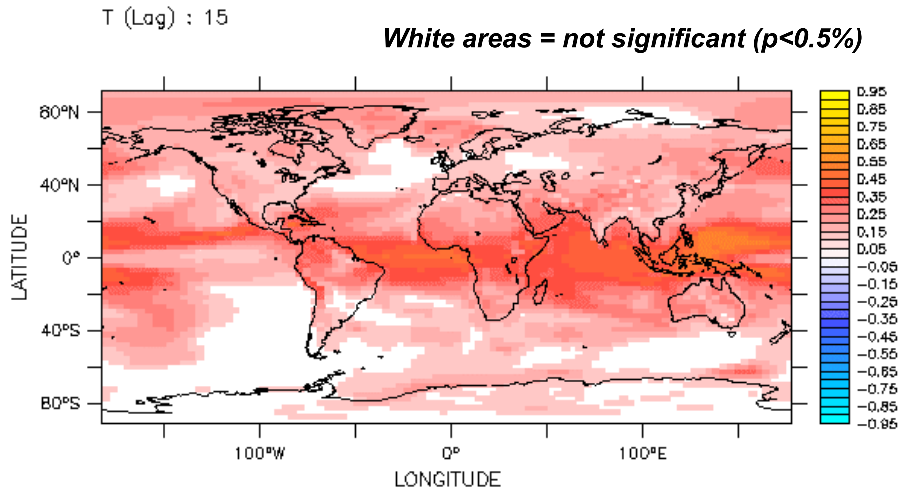
| Correlation with solar simulation | Mann et al 2008 (EIV land + ocean) | Moberg et al 2005 | Crowley&Lowery 2000 | Ammann&Wahl 2007 | Preind. CTRL |
|---|---|---|---|---|---|
| 1001-1850 | **0.40** | **0.58** | **0.52** | **0.36** | **-0.1** |
| 1201-1850 | **0.54** | **0.61** | **0.50** | **0.32** | -0.05 |
| Residuals (1001-1850) | **0.21** | **0.30** | **0.1** | 0.04 | **-0.12** |
| Residuals (1201-1850) | **0.37** | **0.26** | **0.15** | **0.13** | -0.07 |

(b)

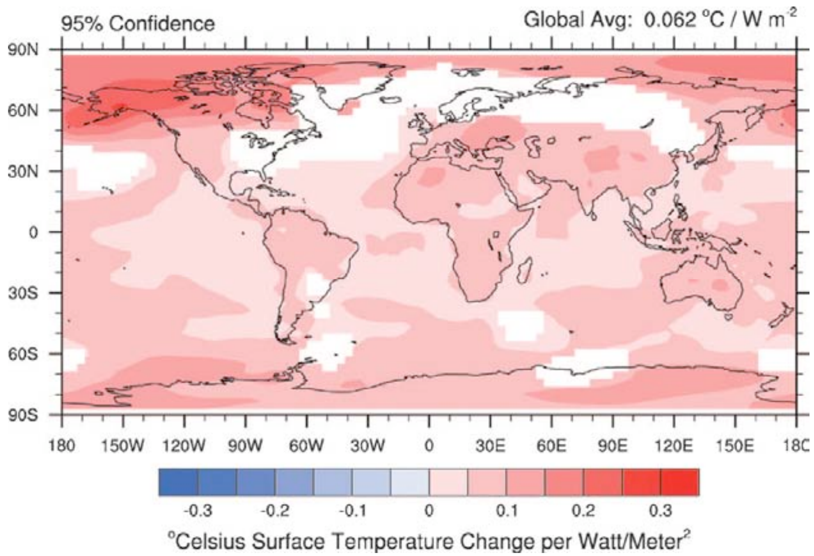
| | Solar simulation IPSLCM4v2 | Preind. CTRL | Mann et al 2008 (EIV land + ocean) | Moberg et al 2005 | Crowley&Lowery 2000 | Ammann&Wahl 2007 |
|---|---|---|---|---|---|---|
| Standard deviation of the residuals | 0.071 | 0.054 | 0.106 | 0.107 | 0.045 | 0.067 |
| Range (max-min) of the LF trend (1001-1850) | 0.34 | 0.063 | 0.46 | 0.644 | 0.225 | 0.156 |
| Range (max-min) of the LF trend (1201-1850) | 0.34 | 0.022 | 0.23 | 0.432 | 0.195 | 0.135 |

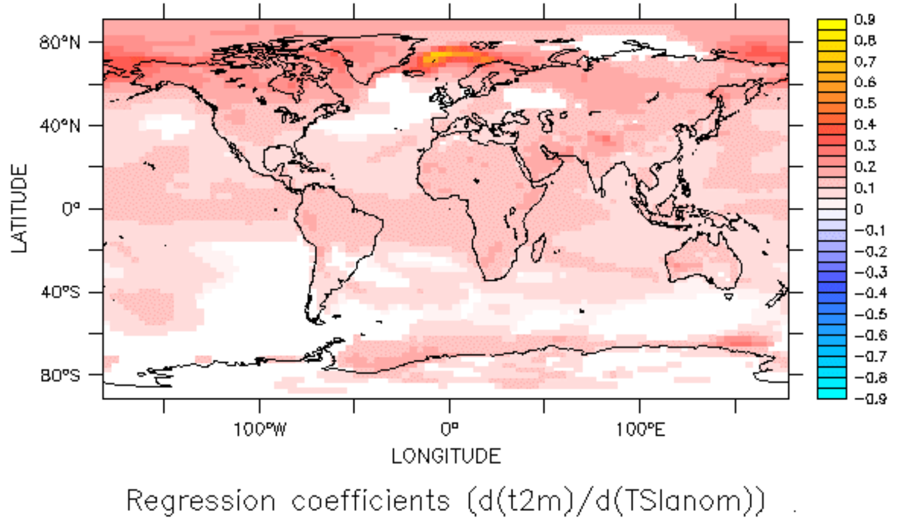
## *Regression and correlation between TSI & temperature*

- 1000-1800
- annual temperature
- Max with 15yr lag
- Sensitivity coefficient = 0.09°K/Wm$^{-2}$ (lag 0)
- important reaction of the arctic sea ice




Correlation coefficients




**Ammann et al. 2007 PNAS**

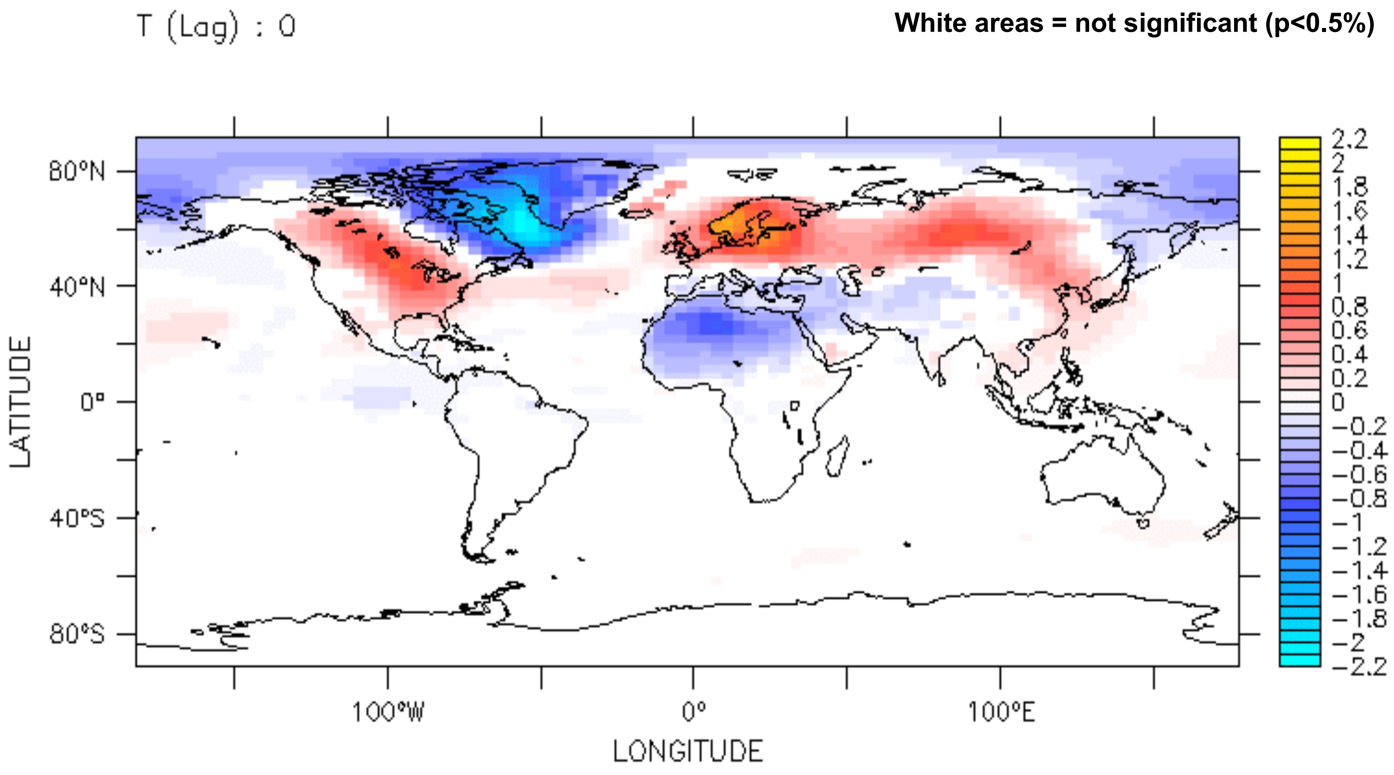
**NCAR-CSM1.4 ; T31**

**Solar simulation IPSLCM4v2**

## Regression t2m vs NAO

- 1000-1800
- NAO pattern (regression t2m(DJF) / NAO index)

White areas = not significant (p<0.5%)




Regression coefficients (d(t2m)/d(NAO))

# ***Perspectives***

## *In progress…*

- Model sensitivity to solar forcing
- volcanic simulation

## *Up to come…*

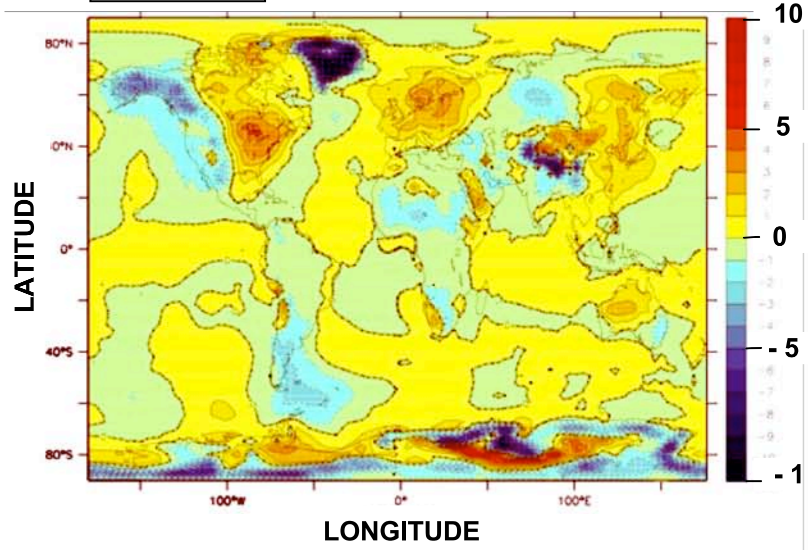
- run with both forcings = solar + volcanic
- ensembles on selected periods (LIA, MWP)

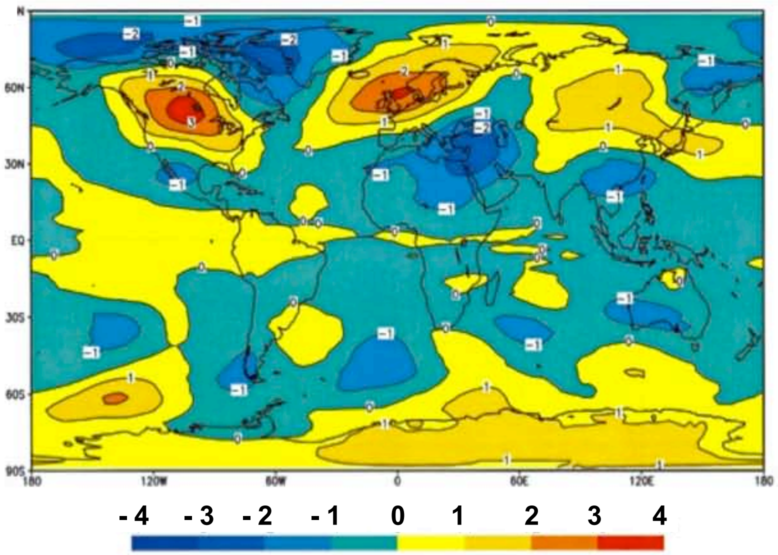
# Tests with LMDz on Pinatubo (1991) : results on DJF 1991-1992 (winter after eruption)

***LMDz***

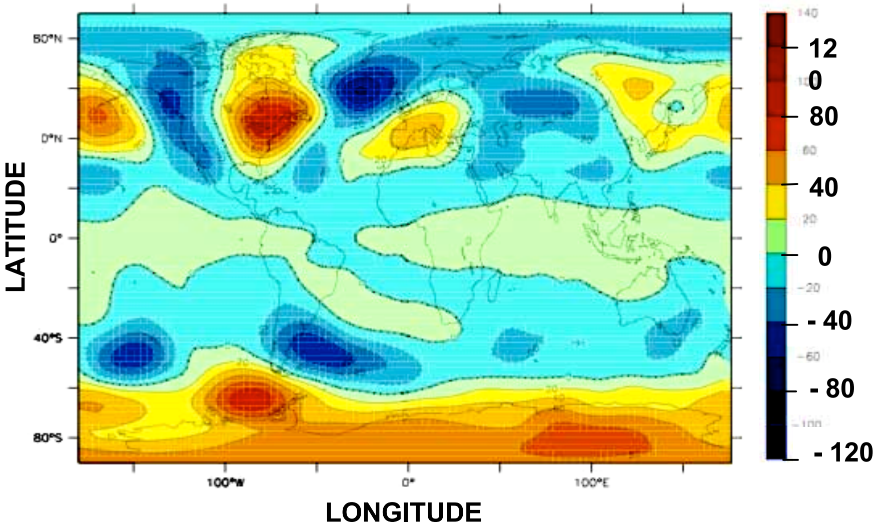
***Observations***

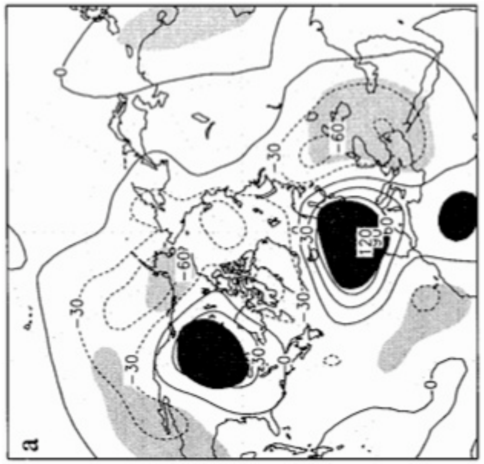
**Temperature anomalies in the low troposphere**



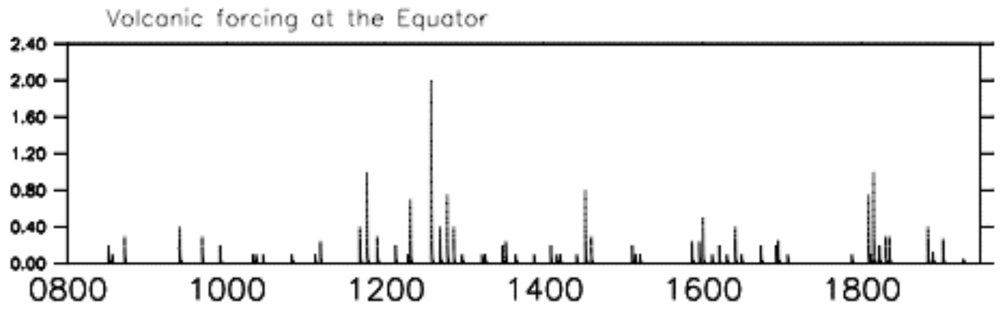



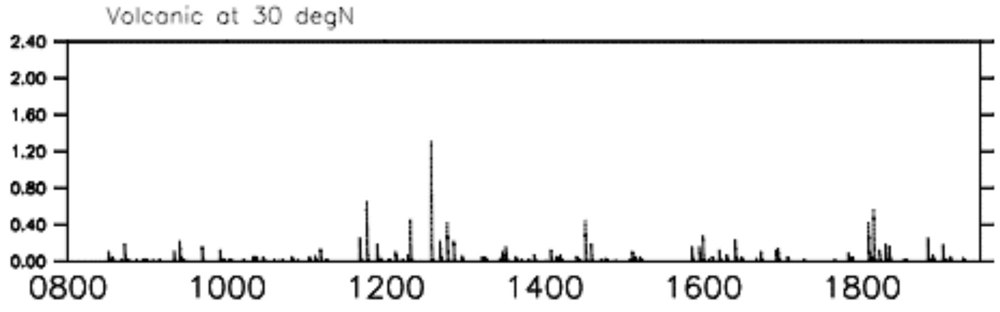

**Geopotential height (500mb) anomalies**

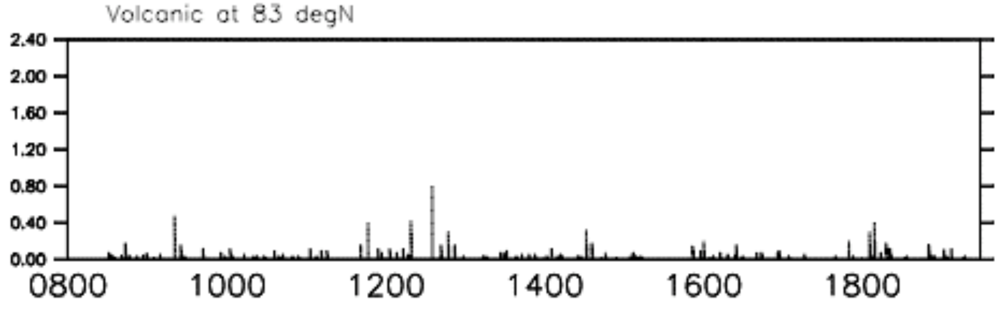


(Robock, 2000)


Volcanic forcing at the Equator
2.40
2.00
1.60
1.20
0.80
0.40
0.00
0800
1000
1200
1400
1600
1800


Volcanic at 30 degN
2.40
2.00
1.60
1.20
0.80
0.40
0.00
0800
1000
1200
1400
1600
1800


Volcanic at 83 degN
2.40
2.00
1.60
1.20
0.80
0.40
0.00
0800
1000
1200
1400
1600
1800

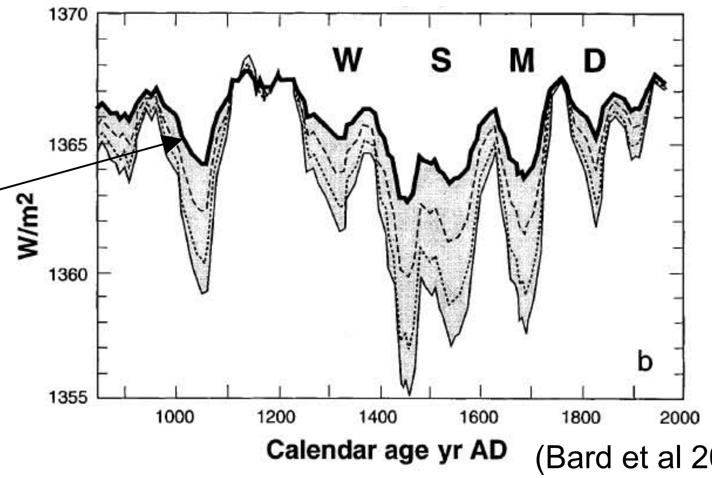
# *Solar forcing*

## *Variability of the total solar irradiance (TSI)*

- **Sun spots …** : Sum [ Sun spots + faculae ] > 0 ; 11yr cycle

- Link between the TSI and the solar magnetic activity (Willson & Hudson 1988 ; Willson 1997)
- Reconstitution based on cosmo nucleides ($^{10}Be$ & $^{14}C$)

=> **Bard et al. 2000 ( scaling = - 0.25% TSI for the Maunder Minimum (Lean et al 1995)**




(Bard et al 2000)

- … + a multidecadal variability

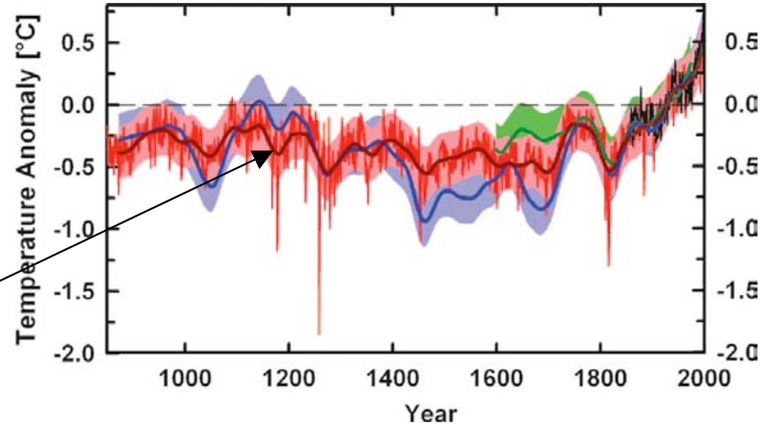
Ammann et al. 2007 = test of different scaling on the TSI reconstruction provided by Bard et al 2000, with a GCM (NCAR)

⇒ **- 0.1%**

⇒ **- 0.25%**

⇒ **- 0.65%**

⇒ **Global temperature : - 0.25%** TSI at the Maunder Minimum




(Ammann et al. 2007 PNAS)

# ***Uncertainties on solar forcing***

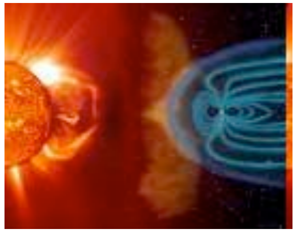
***Is there any secular variability, other than sun spots?***

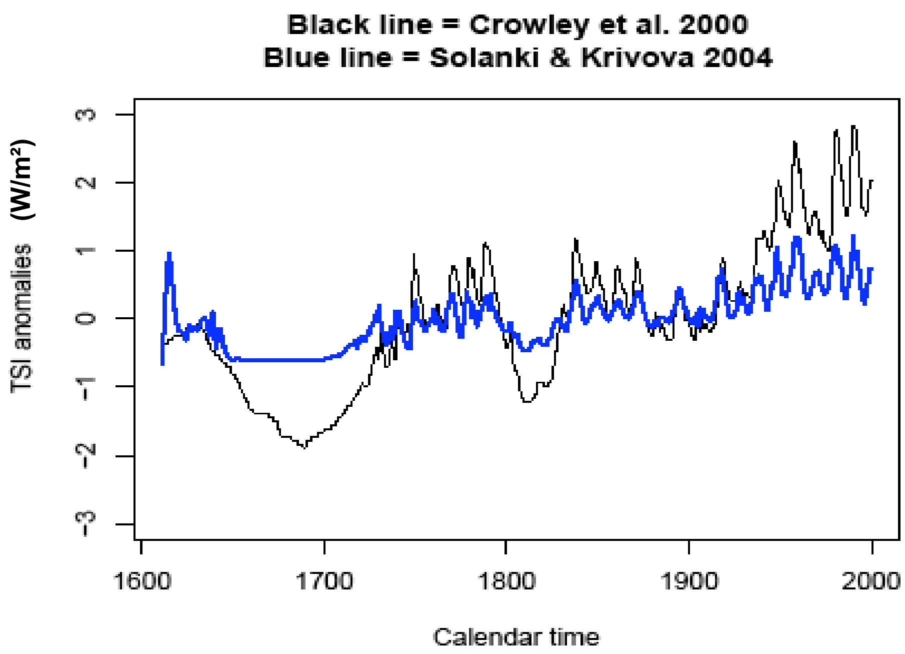
⇒ **Last PMIP3 meeting :**

**- consensus : secular variability less than 0.1% = only sun spots**

**- reconstitution provided by Solanki et Krivova 2004**

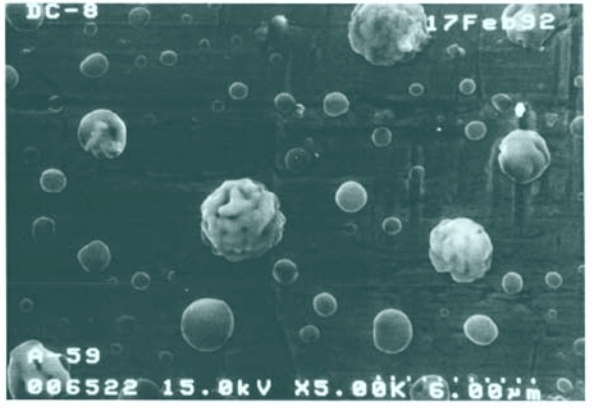
**- still an open debate!**





# Volcanic forcing

Plane view of stratospheric H2SO4/H20 droplets and sulfuric-acid-coated volcanic ash particles collected on February 17, 1992, near (53°N; 67°W) at 10.7 km




- Sulphate aerosols in the stratosphere
- volcanic eruptions with a VEI > 4
- essentially tropical eruptions

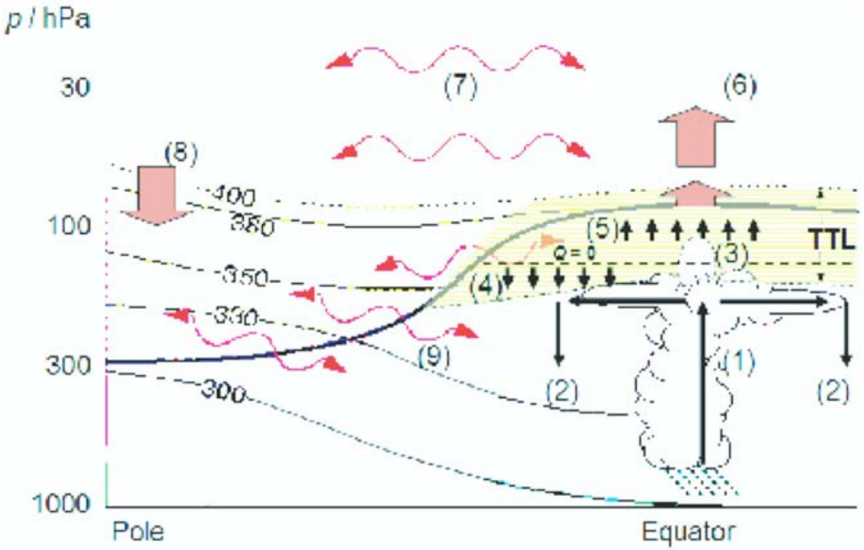
| VEI | HAUTEUR DU PANACHE | VOLUME D'ÉJECTION | CLASSIFICATION | EXEMPLE |
|---|---|---|---|---|
| 0 | <100 m | 1000s $m^3$ | Hawaiano | Kilauea |
| 1 | 100-1000 m | 10000s $m^3$ | Hawaiano/Estromboliano | Stromboli |
| 2 | 1-5 km | 1000000s $m^3$ | Estromboliano/Vulcaniano | Galeras (1992) |
| 3 | 3-15 km | 10000000 $m^3$ | Vulcaniano | Ruiz (1985) |
| 4 | 10-25 km | 100000000s $m^3$ | Vulcaniano/Plineano | Galunggung (1982) |
| 5 | >25 km | 1 $km^3$ | Plineano | St. Helens (1980) |
| 6 | >25 km | 10s $km^3$ | Plineano/Ultra-Plineano | Krakatau (1883) |
| 7 | >25 km | 100s $km^3$ | Ultra-Plineano | Tambora (1815) |
| 8 | >25 km | 1000s $km^3$ | Ultra-Plineano | Toba (74 ka) |

**Volcanic eruptions with stratospheric impact : VEI > 4**

# Transport of stratospheric aerosol

**Stratospheric transport**

**Schematic of the aerosol life cycle (Hamill et al., 1997)**



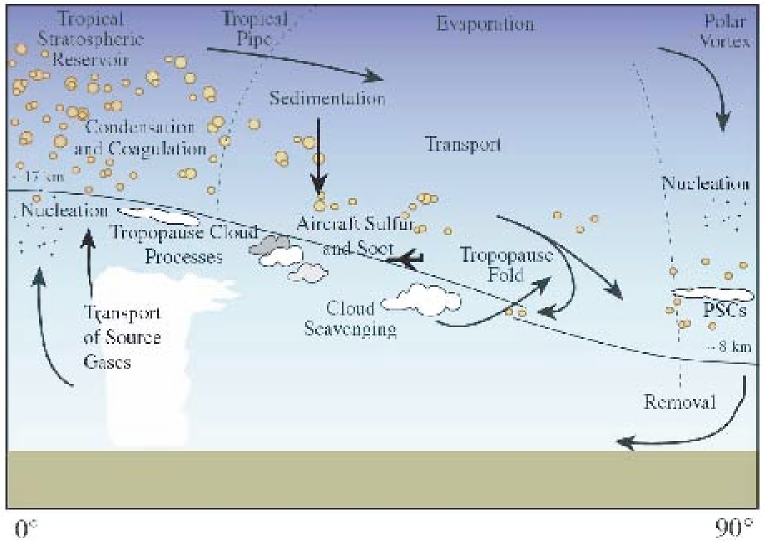




**Illustration of major transport processes in the troposphere/stratosphere system. The Tropical Tropopause Layer (TTL) is given in yellow. Black solid line: (cold-point) tropopause. Thin dashed line: zero net radiative heating level (*Q* = 0). Numbers at contours: potential temperature levels. The TTL is between approximately 340-400 K potential temperature. Bracketed numbers: (1) Deep convection lifting low level air into the upper troposphere, horizontal arrows indicating main detrainment. (2) Downward branches of tropospheric Hadley circulation. (3) High cloud tops penetrating TTL. (4) Descent in TTL below *Q* = 0. (5) Radiatively driven ascent in TTL above *Q* = 0. (6) Upward branch of Brewer-Dobson circulation (tropical pipe). (7) Stratospheric stirring and meridional transport by breaking waves. (8) Large scale subsidence. (9) Quasi-adiabatic exchange across tropopause. (Th. Peter, personal communication, modified after Holton et al. [1995].)**

## Major volcanic eruptions of the past 250 years with stratospheric impact (Pitari et al., 2002)

| Volcano | Latitude | Year | VEI | DVI | SO2 (Tg) | IVI | ΔT (K) |
|---|---|---|---|---|---|---|---|
| Laki | 64 N | 1783 | 4 | 2300 | 43–65 | 0.19 | −0.14* |
| Tambora | 8 S | 1815 | 7 | 3000 | 34–175 | 0.50 | 0.18* |
| Cosiguina | 13 N | 1835 | 5 | 4000 | | 0.11 | −0.32* |
| Askja | 65 N | 1875 | 5 | 1000 | | 0.01 | |
| Krakatau | 6 S | 1883 | 6 | 1000 | 15 | 0.12 | −0.25* |
| Tarawera | 38 S | 1886 | 5 | 800 | | 0.04 | |
| SantaMaria | 15 N | 1902 | 6 | 600 | | 0.05 | −0.14* |
| Ksudach | 52 N | 1907 | 5 | 500 | | 0.02 | |
| Katmai | 58 N | 1912 | 6 | 500 | 12 | 0.15 | |
| Agung | 8 S | 1963 | 4 | 800 | 12 | 0.06 | −0.31* |
| St.Helens | 46 N | 1980 | 5 | 500 | 2.1 | 0.00 | |
| El Chichon | 17 N | 1982 | 5 | 800 | 3.3–10 | 0.06 | −0.12+ |
| Pinatubo | 15 N | 1991 | 6 | 1000 | 20 | 0.13 | −0.20+ |

VEI = volcanic explosivity index; DVI = dust veil index;
IVI = ice core volcanic index; ‘*’ = Northern Hemisphere; ‘+’ = Global

# Implémentation de l'impact radiatif des aérosols volcanique dans MDZ

➢ Code de Mie:

Calcul de l'albédo de simple diffusion (cg) et le facteur d'asymétrie (piz) pour les aérosols stratosphériques sulfatés en phase aqueuse (forme binaire H2SOA/H2O: 75%/25%)
El Chichon + Pinatubo (SO4 droplet):

# R : rayon modal en nm : **500.0**
# Sigma : largeur de distribution: **1.30**

# w1 w2 : albedo de simple diffusion sur les 2 bandes du visible **: 1.000    0.995**
# g1 g2 : paramËtre d'assymÈtrie sur les 2 bandes du visible : **0.7079    0.7548**

➢ Implémentation de l'épaisseur optique (Tau) sur les 2 couches atmosphériques au dessus de la tropopause

Epaisseur optique des aérosols volcanique
Pour l'éruption du Mt Pinatubo (1991-1992)