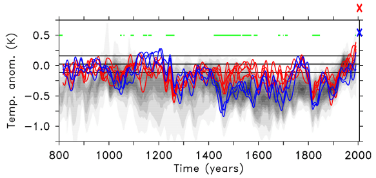

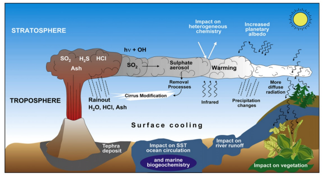

Volcanically Forced DCV

A Historical Perspective Based on Ensemble Climate Simulations

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with contributions from VolMIP, the Millennium, MiKlip and SuperVolcano groups at the Max Planck Institute for Meteorology, Hamburg, Germany

Università Ca'Foscari Venezia

CLIVAR-ICTP Workshop on Past and Future Climate Shifts:
Decadal Climate Variability and Predictability
November 16 - 24, 2015, Miramare - Trieste, Italy

The IPCC-AR5 report states (WG1, Ch. 8):

“Volcanic eruptions […] are the dominant natural cause of externally forced climate change on the annual and multi-decadal time scales […]”

“The volcanic RF [radiative forcing] has a **very irregular temporal pattern** and for certain years has a strongly negative RF”

“Although the effects of volcanic eruptions on climate are largest in the 2 years following a large stratospheric injection […] there is **new work indicating extended volcanic impacts** via long-term memory in the ocean heat content and sea level […]”

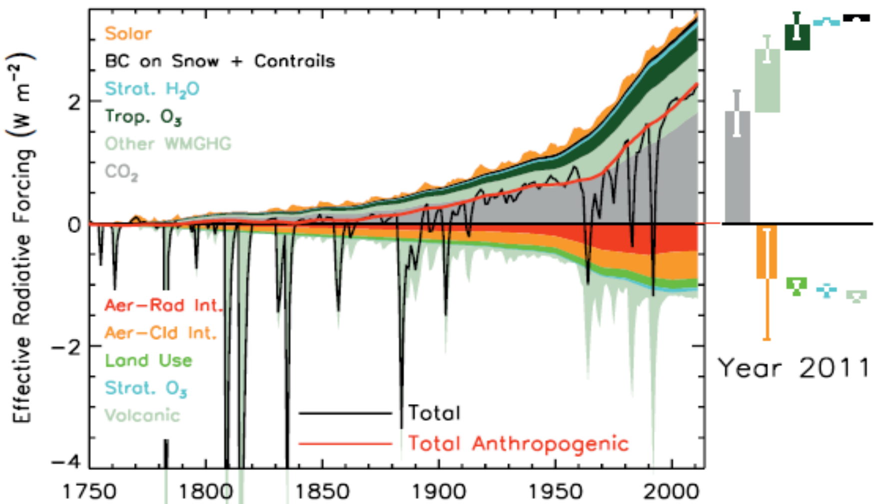
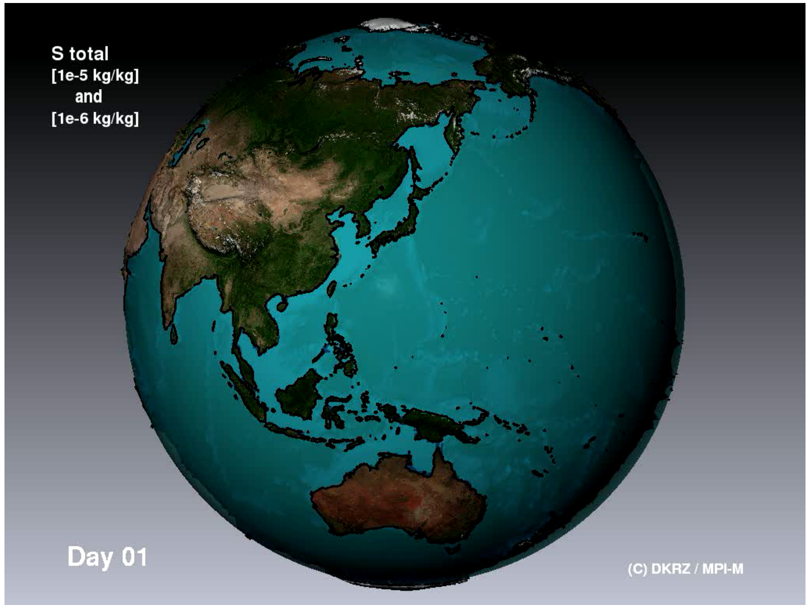


Figure 8.18 from Myhre et al., 2013 | **Time evolution for anthropogenic and natural forcing mechanisms**

Simulated evolution of a volcanic aerosol cloud (MAECHAM-HAM)

First month after a Toba (100x Pinatubo) eruption:



U. Niemeier, C. Timmreck, M. Boettinger *(MPI-M and DKRZ)*

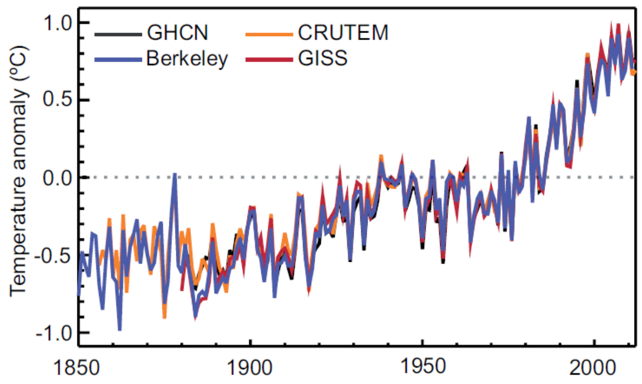


Figure 2.14 from Hartmann et al., 2013 | **Observed global average annual *land*-surface air temperature**

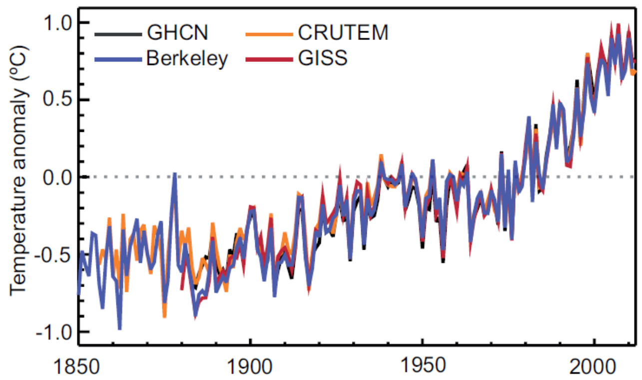


Figure 2.14 from Hartmann et al., 2013 | **Observed global average annual *land*-surface air temperature**

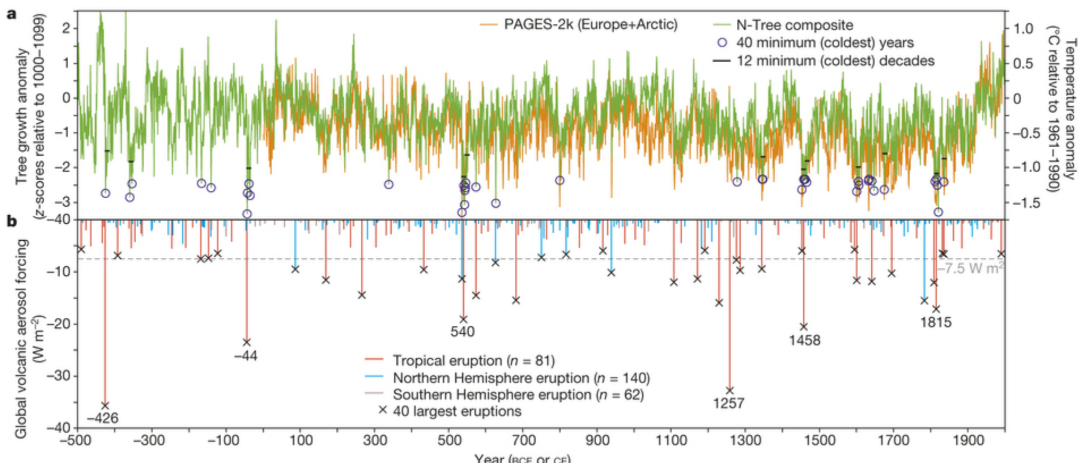


Figure 3 from Sigl et al., 2013 | **Global volcanic aerosol forcing and Northern Hemisphere temperature variations for the past 2,500 years**

Reconstructed long-term climate response to strong volcanic eruptions

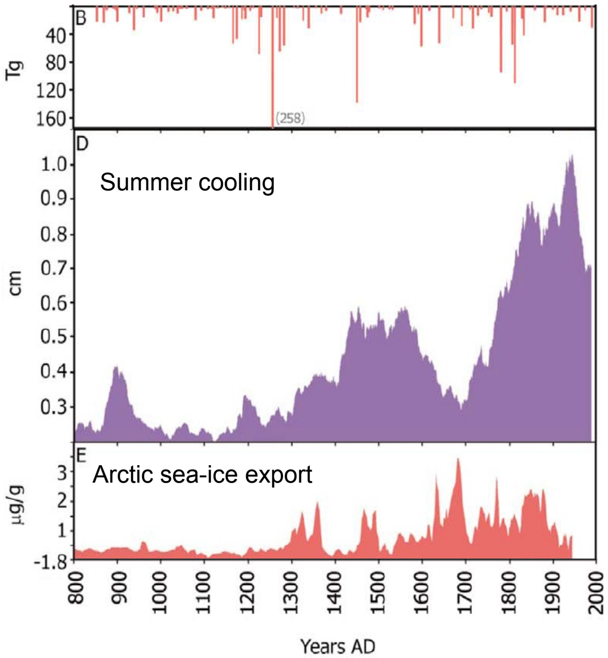


Figure 2 from Miller et al., 2012 | **Onset of Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks.** Global stratospheric sulfate aerosol loadings (**B**), 30-year running mean varve thickness in Iceland sediment core HVT03-2 (**D**), Arctic Ocean sea ice recorded in a sediment core on the North Icelandic shelf (**E**).

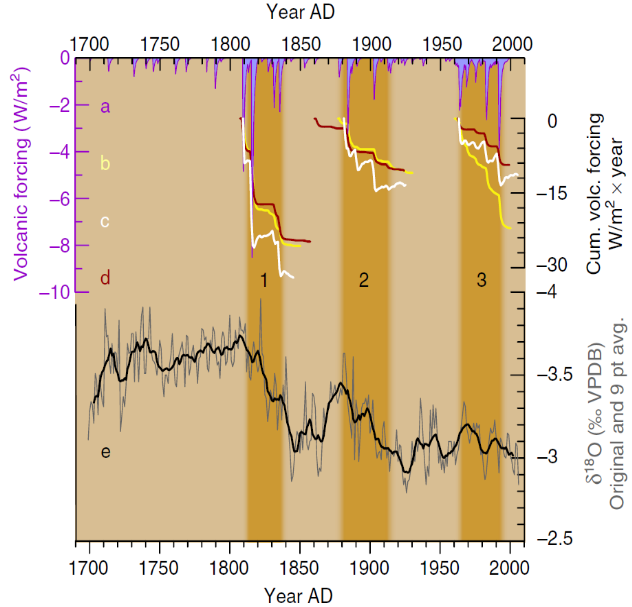


Figure 5 from Winter et al., 2015 | **Persistent drying phases over Mesoamerica and volcanic forcing.** Volcanic radiative forcing (**a**), different estimates of cumulative TOA radiative flux anomalies (**b-d**), annual time series of speleothem GU-Xi-1 d^{18}O, proxy for precipitation (**E**).

Delayed winter warming

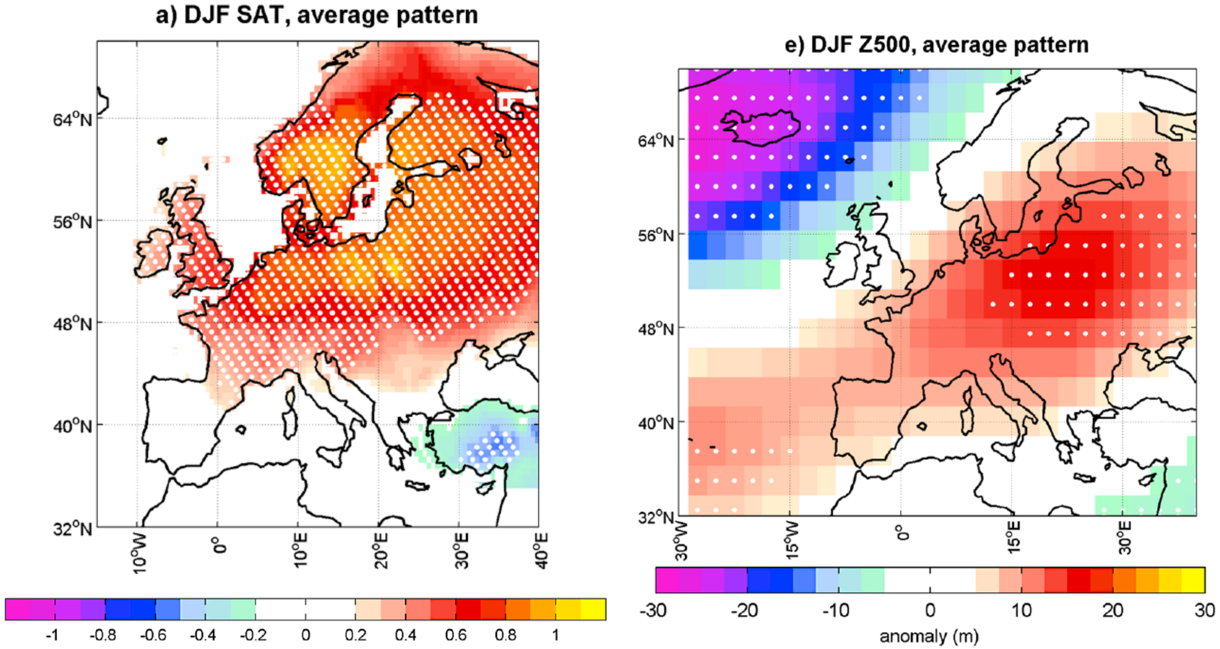


Figure 2 from Zanchettin et al., 2013 | Reconstructed surface (2 m) air temperature (SAT) and 500 hPa geopotential height (Z500) anomalies at the peak of delayed winter warming (9th–13th post-eruption winters).

Simulated decadal climate response to tropical volcanic eruptions

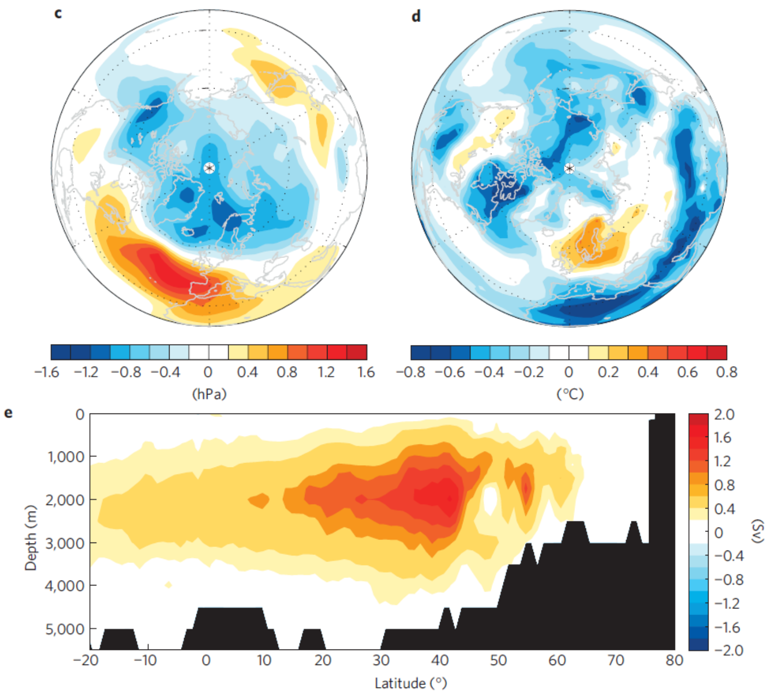


Figure 4 from Ottera et al., 2010 | **Simulated responses to volcanic forcing.** Composite analysis showing the mean NH winter **SLP** (**c**) and **SAT** (**d**) anomalies in the two winters following large tropical eruptions in EXT600. **e**, The same as **c**, but for **the Atlantic meridional stream-function**, averaged over years 5–10 following the volcanic eruption

"[…] volcanoes play a particularly important part in the phasing of the multidecadal variability through their direct influence on tropical sea-surface temperatures, on the leading mode of northern-hemisphere atmosphere circulation and on the Atlantic thermohaline circulation." [*Otterå et al., 2010, Nat Geosci]*

Simulated decadal climate response to tropical volcanic eruptions

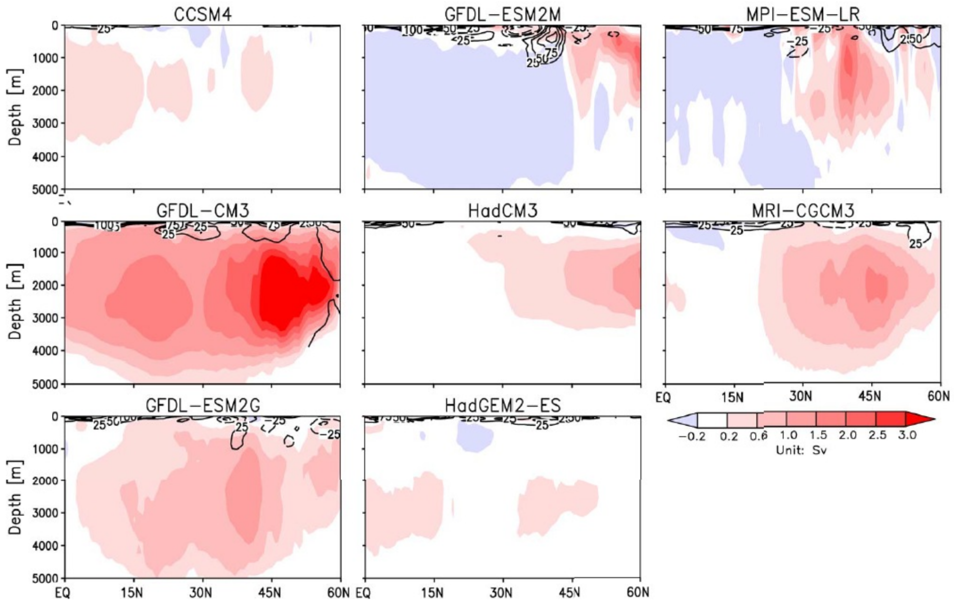


Figure 12 from Ding et al., 2014 | **AMOC response to the Krakatau eruption simulated by different models to volcanic forcing.** . Ensemble mean zonal integrated Atlantic meridional overturning transport stream function estimated from the difference between the 2 year average (years 7–8) following the eruption minus the average during the 6 years prior to the eruption

Dependency of forced response on background conditions

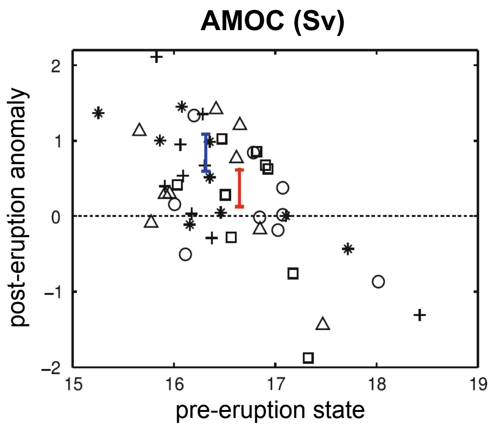


Figure 15 from Zanchettin et al., 2012 | **Role of initial conditions.** Scatterplot of average pre-eruption values versus post-eruption anomalies (10-14 years after eruption) of Atlantic Meridional Overturnin Circulation index for 45 eruptions in the 5-member ECHAM5/MPIOM ensemble of weak-TSI last millennium simulations.

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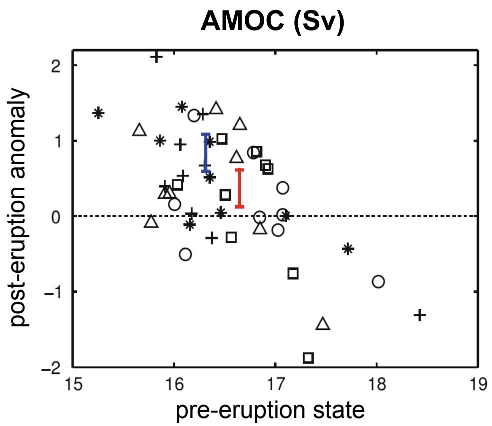

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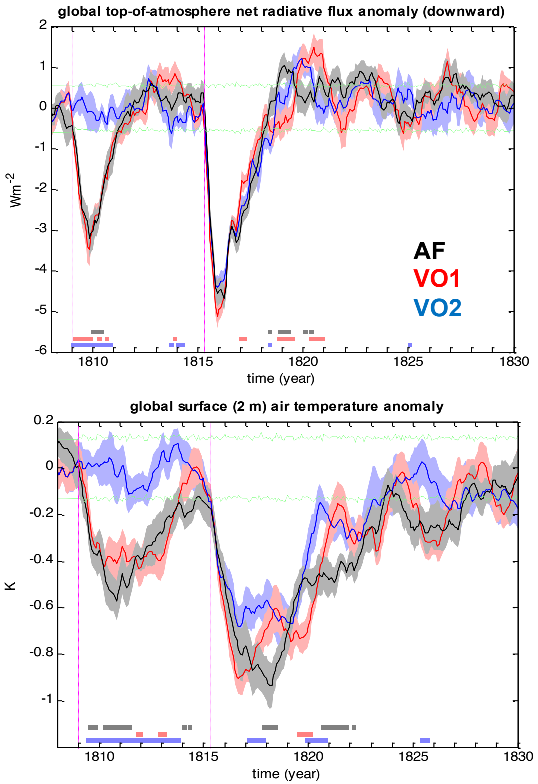
Tambora experiments (ECHAM5/MPIOM), *Zanchettin et al., 2013*

ENSEMBLE (10x)	FORCING
AF	**all-forcing (natural and anthropogenic)**
VO1	**volcanic forcing–only**
VO2	**volcanic forcing–only, no 1809 eruption**



Adapted from Figures 4 and 5 from Zanchettin et al., 2013 |
Evolution of selected climatic variables around the 1815 Tambora eruption in different climate simulation experiments.
Top: TOA net radiative flux anomaly; bottom: global surface air tem-perature anomaly. Green dashed lines are the internal variability range

Tambora experiments (ECHAM5/MPIOM),
Zanchettin et al., 2013

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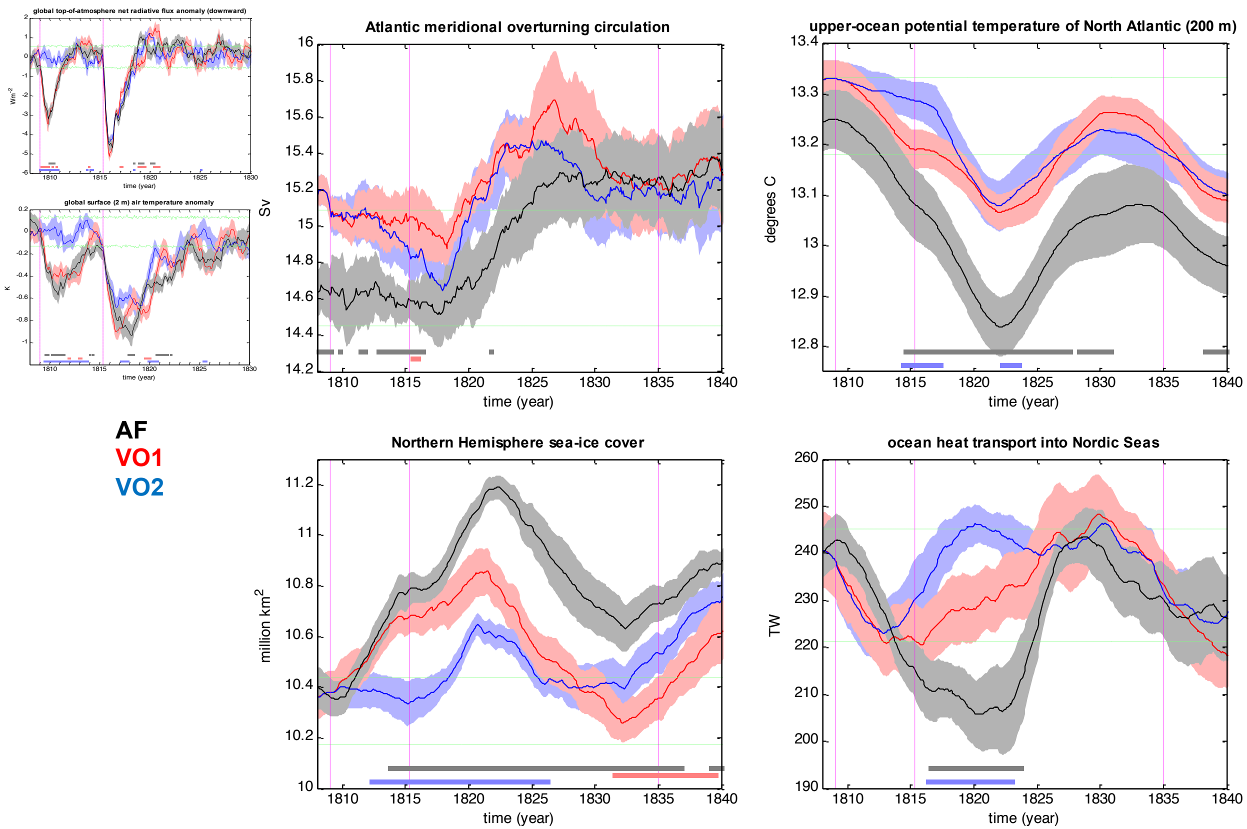

Adapted from Figures 8 and 9 from Zanchettin et al., 2013 | **Evolution of selected oceanic variables around the 1815 Tambora eruption in different climate simulation experiments.** Green dashed lines are the internal variability range

Implications for the interpretation of reconstructed climate evolutions

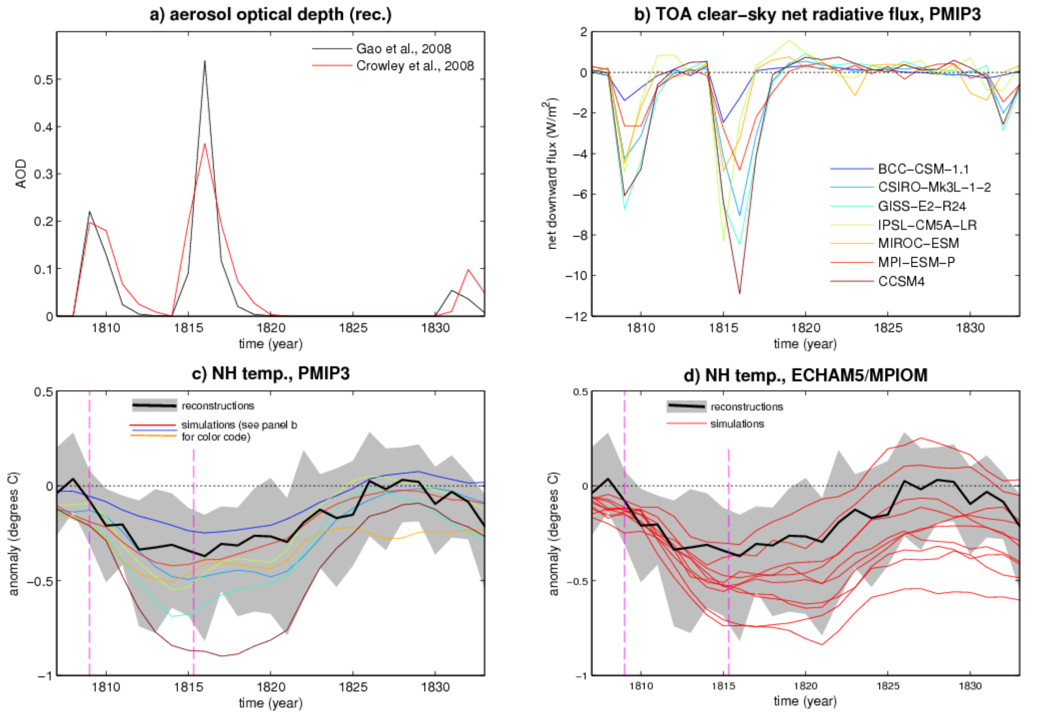

Figure 1 from Zanchettin et al., 2015 | Uncertainty in radiative forcing and climate response for the early-19th-century eruptions. Different models and forcing inputs (**c**) and internal climate variability (**d**) similarly contribute to simulation-ensemble spread.

Implications for decadal climate predictability

"[…] *moderate* volcanic eruptions may reset a 20-year intrinsic variability mode in the North Atlantic"

[Swingedouw et al., 2015]

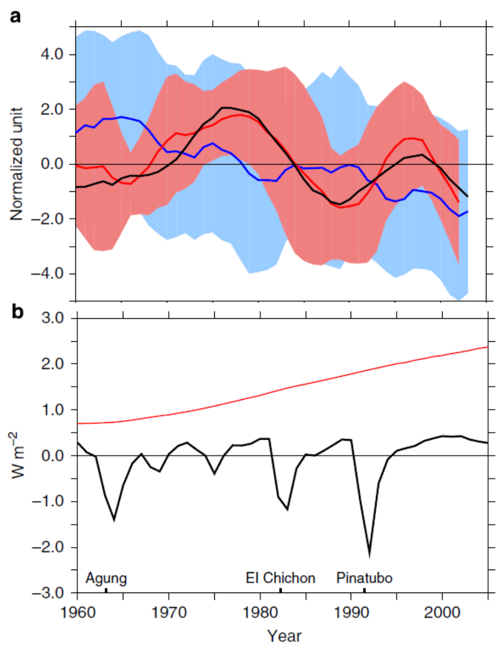

Figure 1 from Swingedouw et al., 2015 | Simulated AMOC changes and radiative forcing. (**a**) AMOC maximum at 48°N: black: IPSL-CM5-LR historical, red: Bi-Dec multi-model CMIP5 ensemble; blue: rest of CMIP5 ensemble. (**b**) external forcing (IPSL-CM5-LR)

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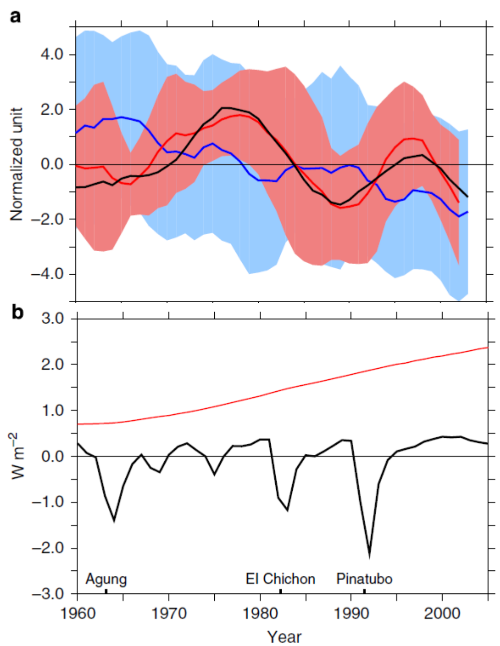

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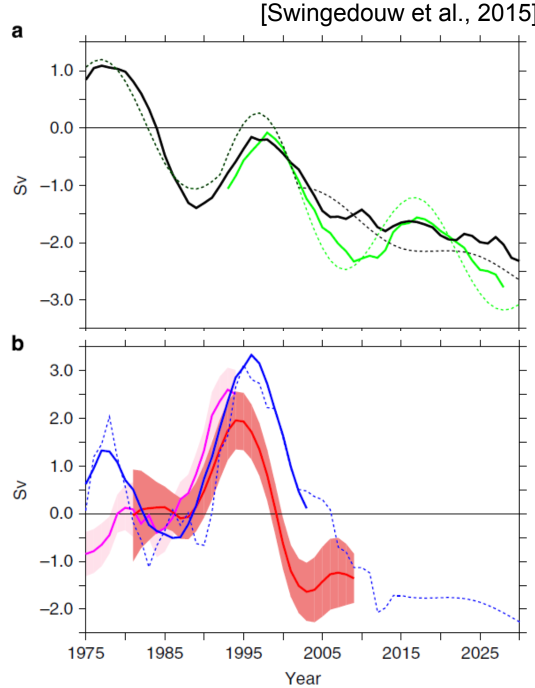


Figure 8 from Swingedouw et al., 2015 | Destructive interference by Pinatubo. (**a**) Simulated AMOC evolution under full forcing (black) and removing the 1991 Pinatubo (green). (**b**) Different estimates of AMOC evolution showing the rapid AMOC increase in the 90s

An ongoing attempt to constrain uncertainties: VolMIP (volmip.org)

Co-chairs: Davide Zanchettin, Claudia Timmreck, Myriam Khodri

VolMIP is a **CMIP-endorsed** activity which defines a common protocol focused on **multi-model assessment of climate models' performance under strong volcanic forcing conditions**.

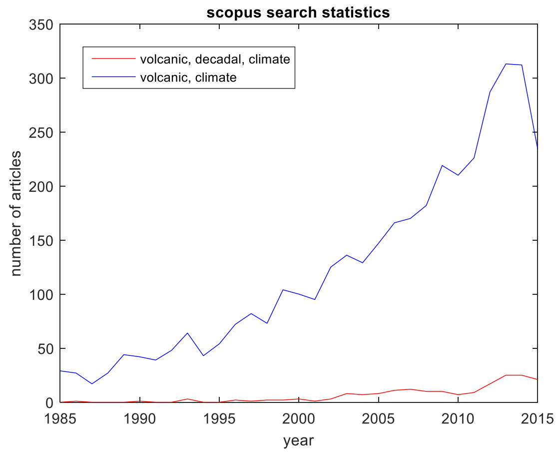
Experiments focused on decadal response

Name	Description	Ens. Size x years
VolLongS60EQ	Idealized equatorial eruption corresponding to an initial emission of 60 Tg of SO_2. This eruption has a magnitude roughly corresponding to the **1815 Tambora** eruption, the largest historical tropical eruption	9x20
VolLongS100HL	Idealized high-latitude (60°N) eruption emitting 100 Tg of SO_2 over five months. The eruption's strength and length roughly correspond to that of the **1783-84 Laki** eruption.	9x20
VolLongC19thC	**Early 19th century cluster** of strong tropical volcanic eruptions, including the 1809 event of unknown location, and the 1815 Tambora and 1835 Cosigüina eruptions.	3x50
VolShort20EQini/ DCPP C3.4	**1991 Pinatubo** forcing as used in the CMIP6 *historical* simulations, but as decadal prediction runs. Joint experiment with DCPP.	10 (5)x5

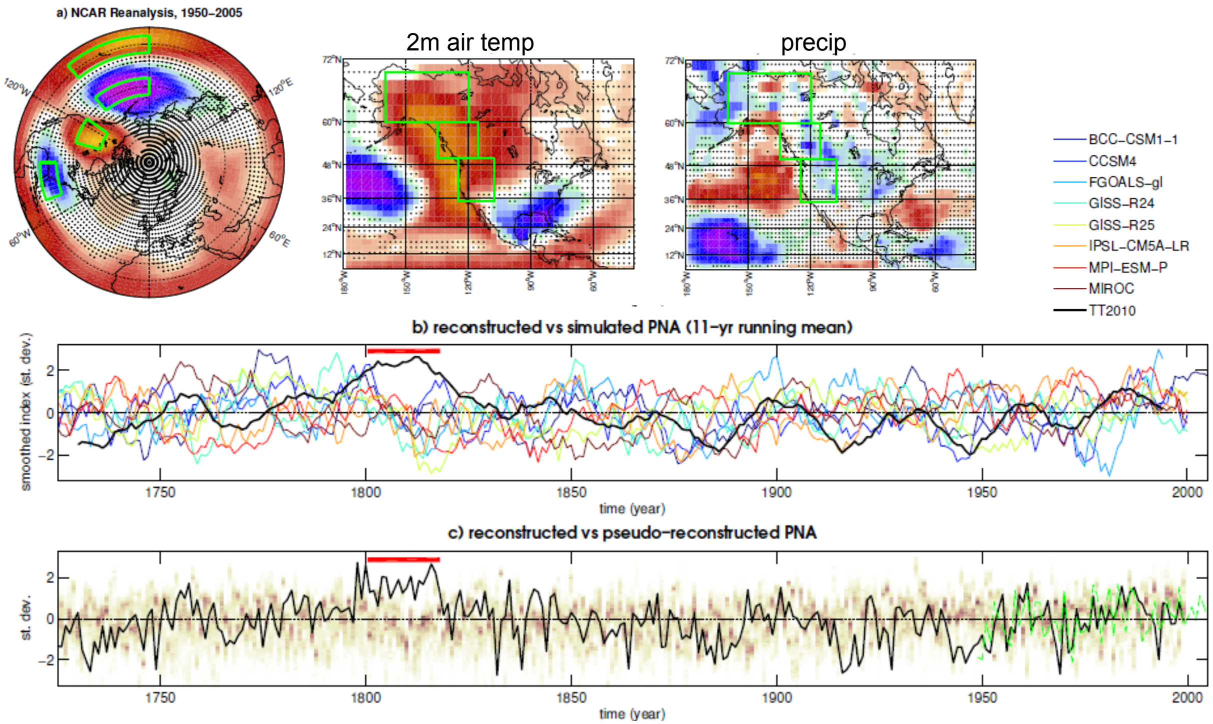
Concluding remarks

Multiple lines of evidence from climate reconstructions, simulations and observations point to decadal climatic impacts of volcanic eruptions.

However, uncertainties and gaps of knowledge are large, as we have just started to slot in the many different pieces of the puzzle.

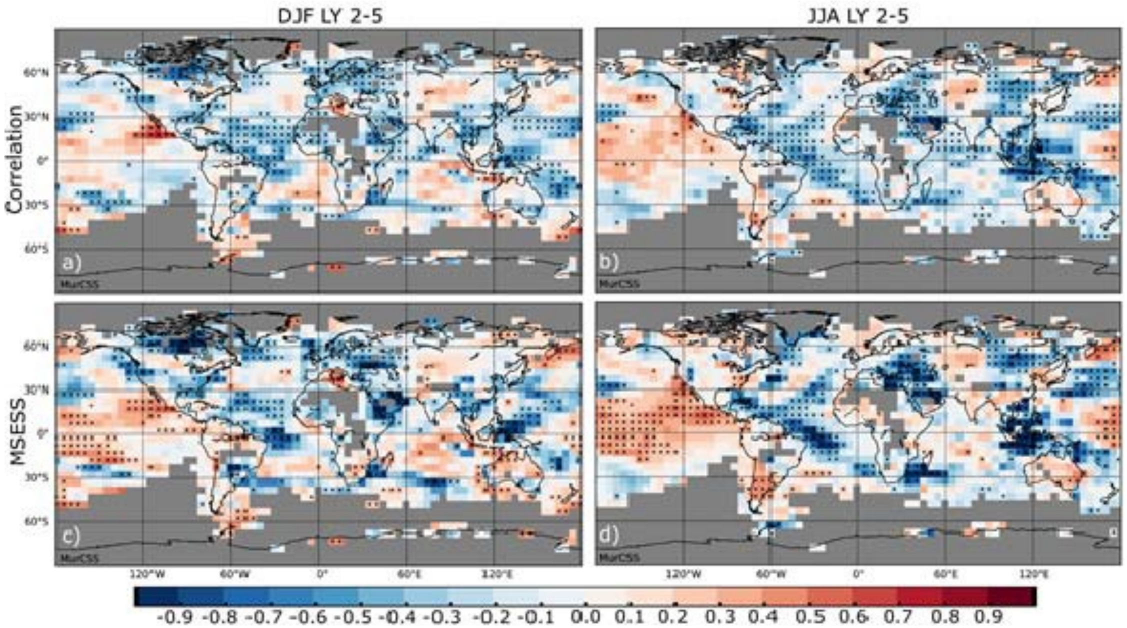


Discrepancy between simulated and reconstructed regional features



Adapted from Figures from Zanchettin et al., 2015 | Discrepancy between simulated and reconstructed Pacific North American index (PNA) during the early 19th century. PNA pattern in NCAR Reanalyses (**top**) and comparison between reconstructed (Trouet and Taylor, 2010, black) and simulated (PMIP3 ensemble) index (**bottom**). The red line marks the discrepancy.

Implications for decadal climate predictability



Claudia Timmreck, personal communication | Impact of volcanic forcing on seasonal skills of the MiKlip prototype system for decadal climate predictions. Mapped are differences between skills at 2-5 lag years from hindcasts without volcanic forcing and from the reference (full forcing) system. Red shading corresponds to improved skills if volcanoes are removed.