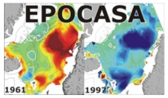
Bjerknes Centre for Climate Research

BJERKNES FTI



A role for volcanoes in future climate assessments?

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Sebastian Wagner, Michael Sigl, Odd Helge Otterå

UNIVERSITY OF BERGEN uni Research NERSC Nansen Center, Bergen HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH

Outline

Background

- Volcanic impact on climate
- Future climate projections

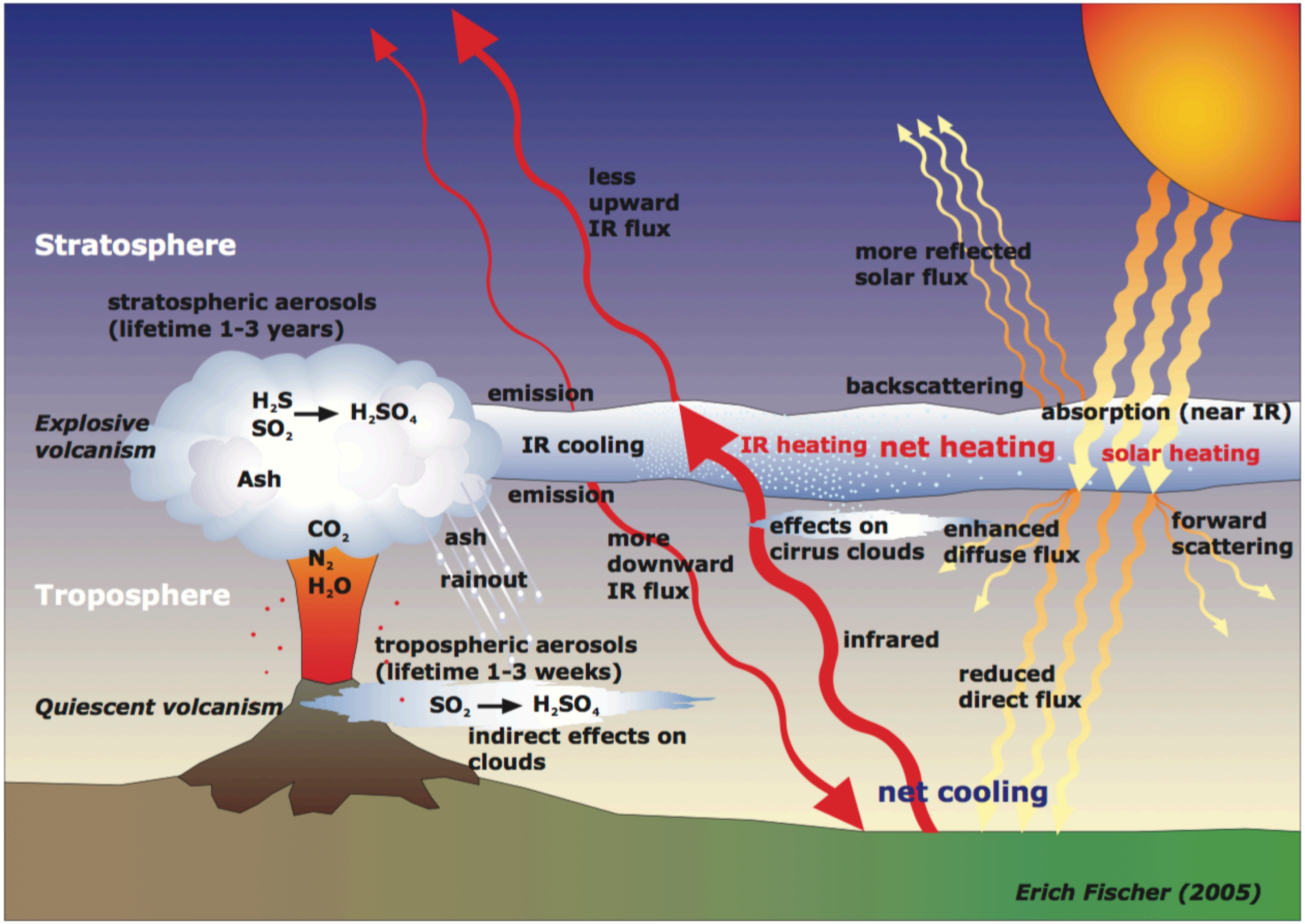
Methods

- proxy-based future volcanic forcing for use in climate projections

Results

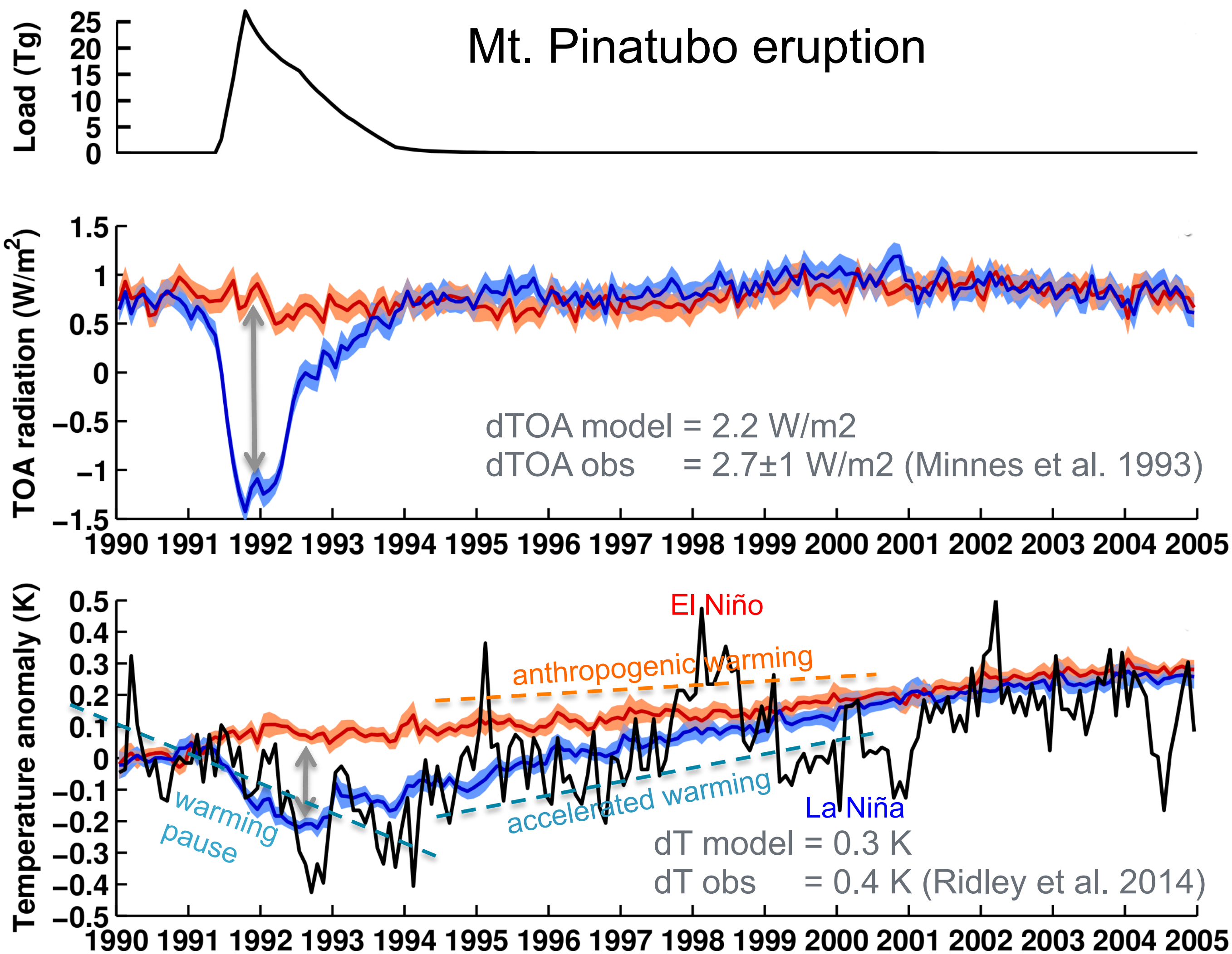
- 21^{st} Century simulations with proxy-based volcanic forcing versus standard projections with zero or constant volcanic forcing

Volcanic impact on climate



- **Reflects incoming shortwave radiation (cooling at surface)**
- **Absorbs longwave radiation from surface (warming in stratosphere)**

Global radiation and temperature response



HIST

- 60 member NorESM all-forcing ensemble

NO-PINATUBO

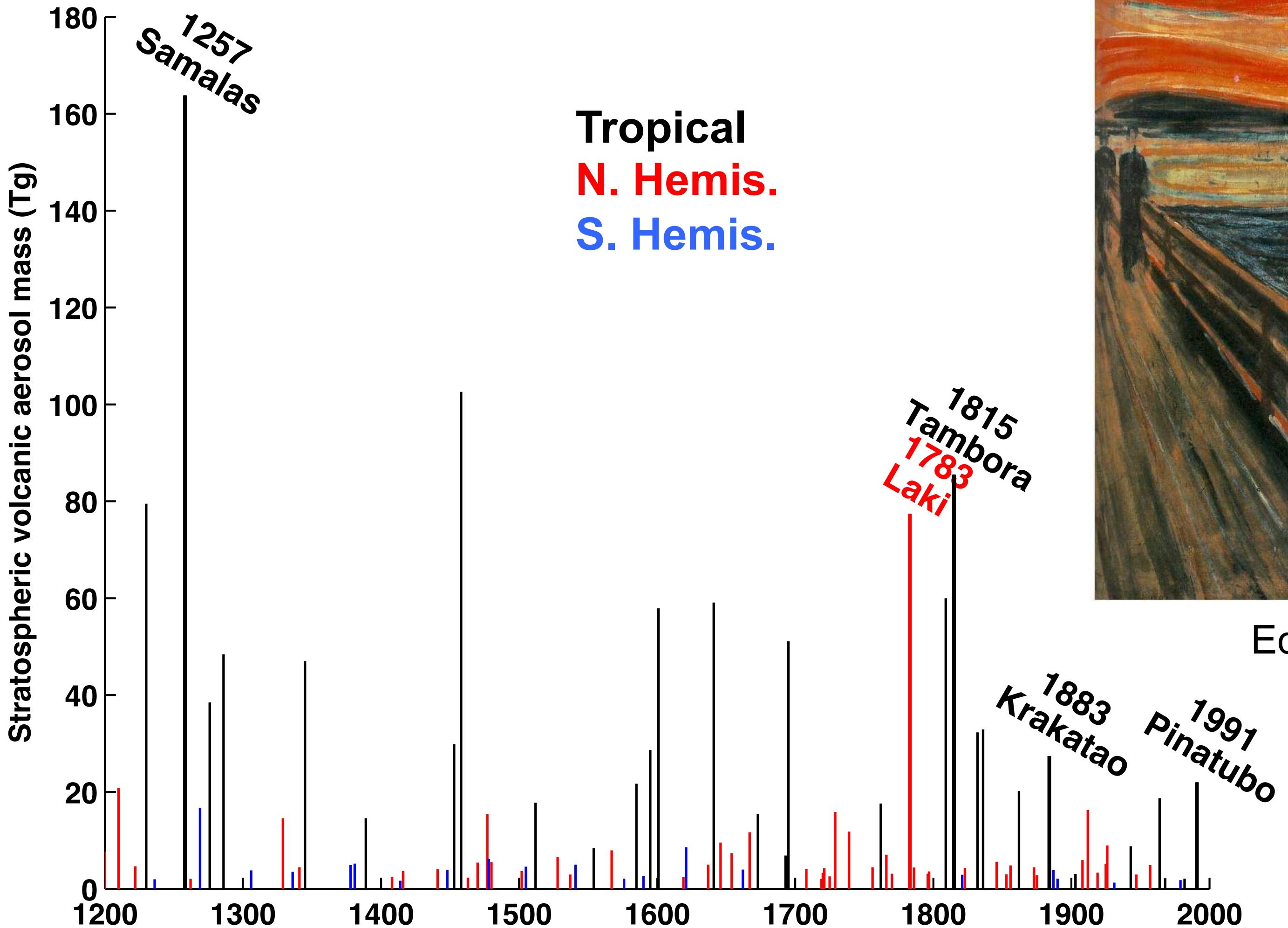
- as HIST, but no Mt. Pinatubo forcing

NASA GISS OBS

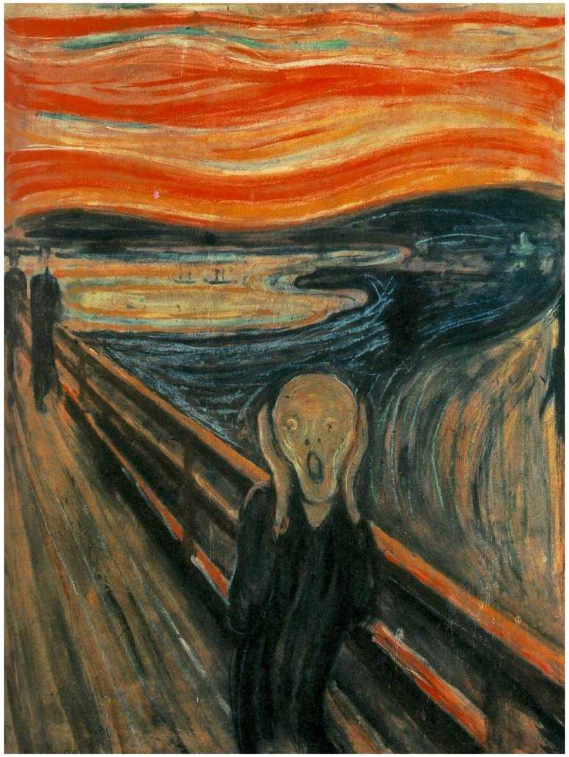
anomalies computed

- relative to 1990
- de-seasoned
- ensemble averaged

Size matters!

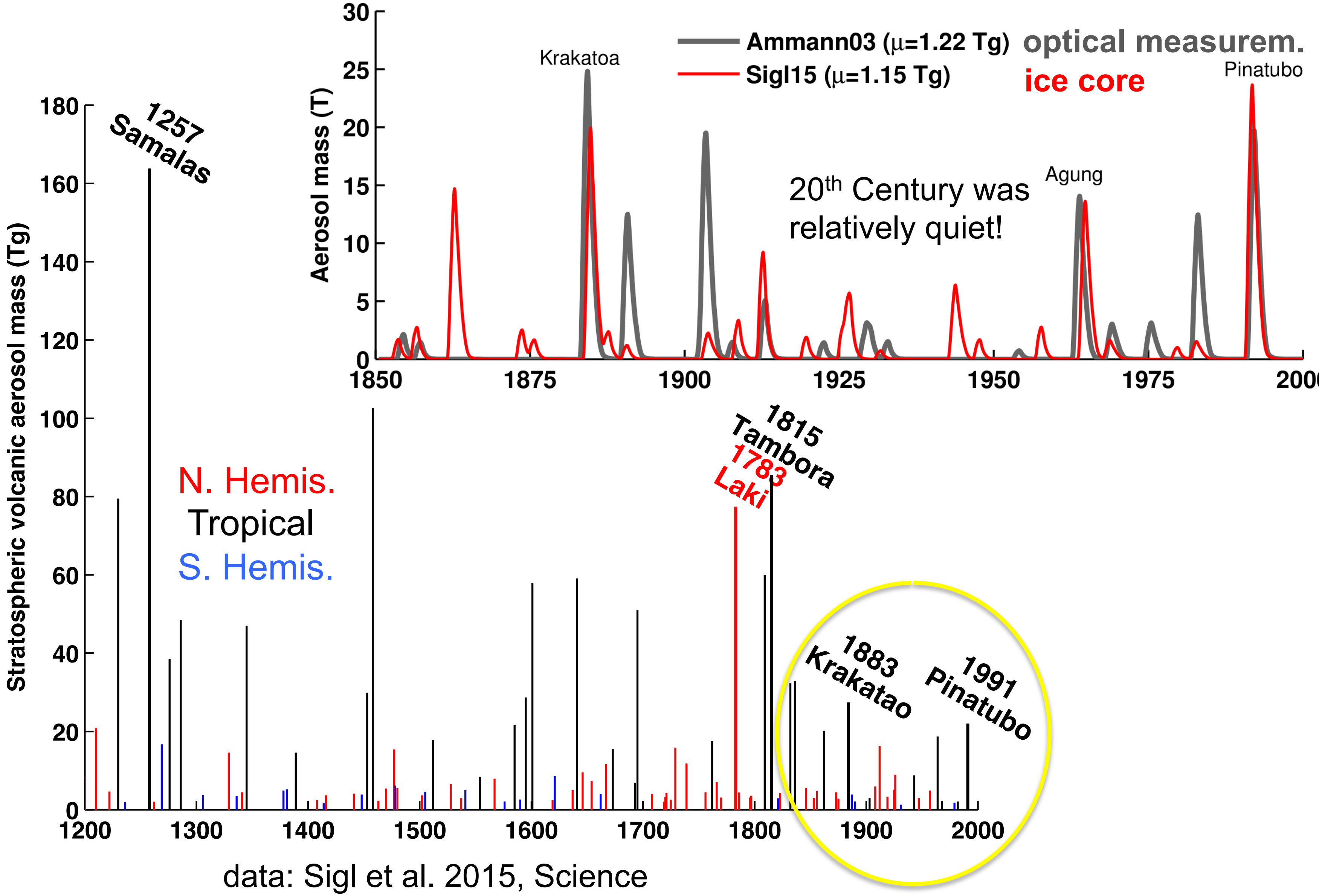


data: Sigl et al. 2015, Science



Edvard Munch 1893

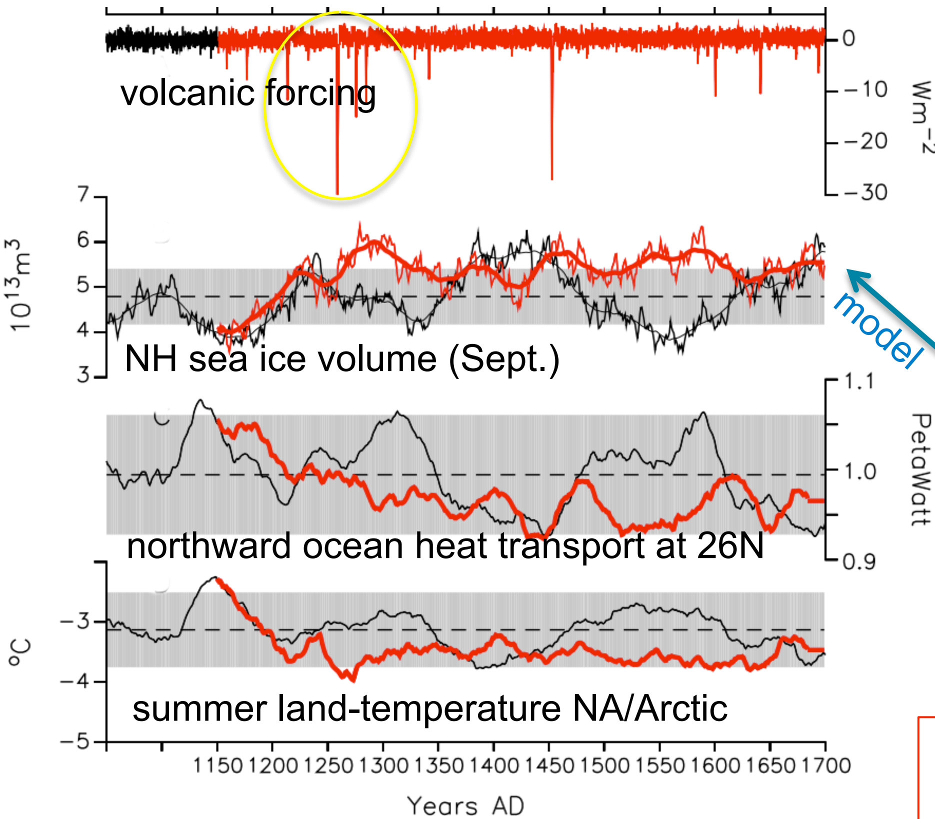
Size matters!

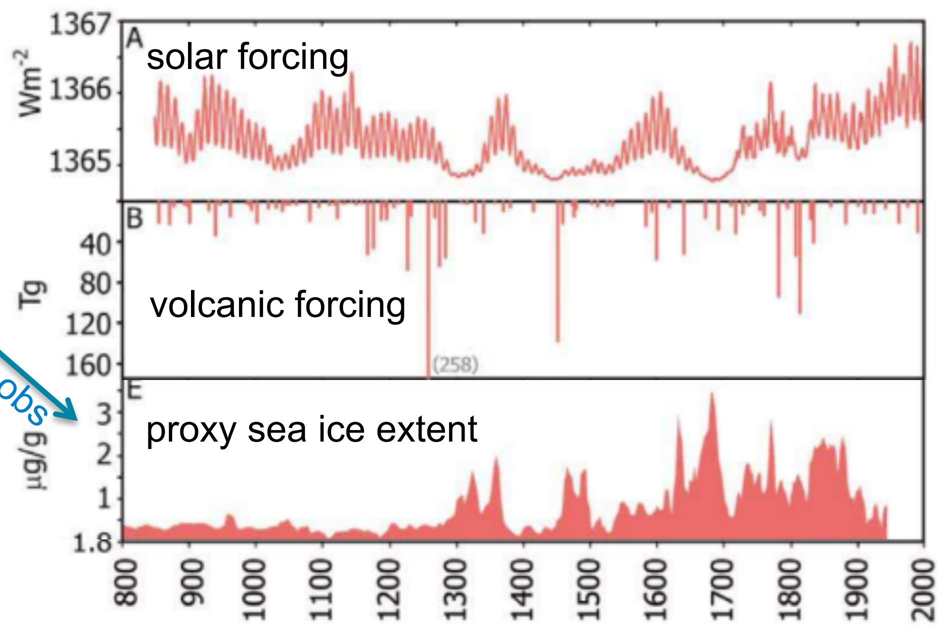


data: Sigl et al. 2015, Science

Little ice age triggered by volcanism?

Last millennium simulations with/without volcanic forcing (Miller et al. 2012, GRL)

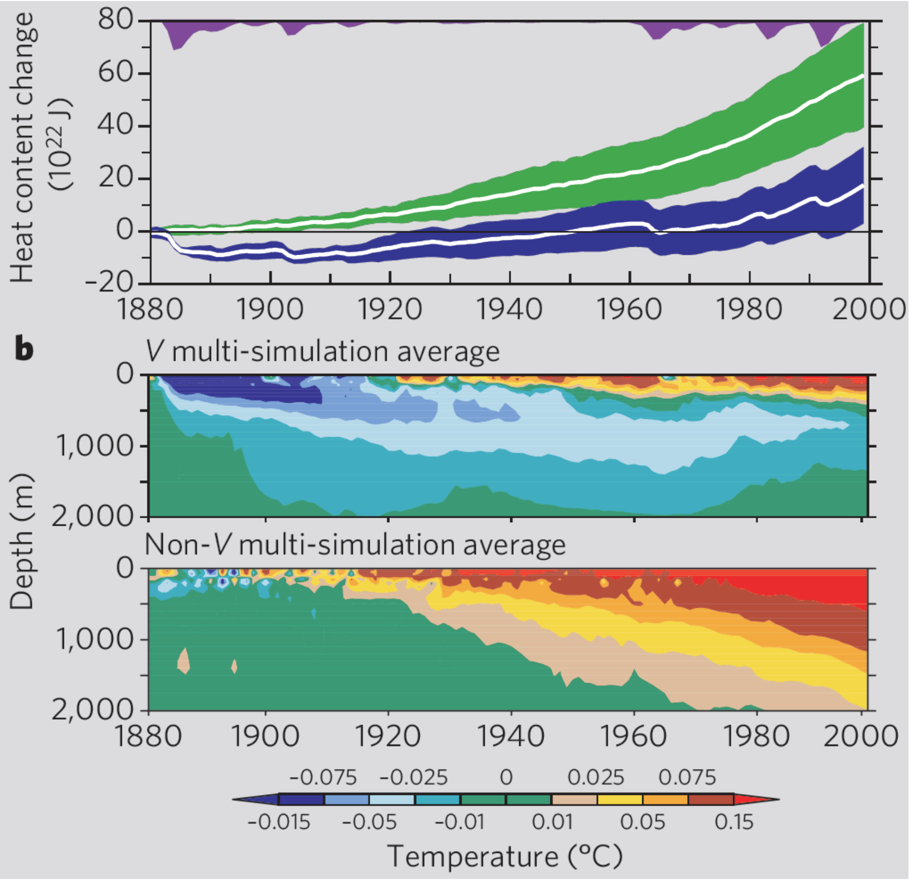




- cluster of large eruptions pushed climate over tipping point
- positive sea ice feedbacks important for sustaining cold climate

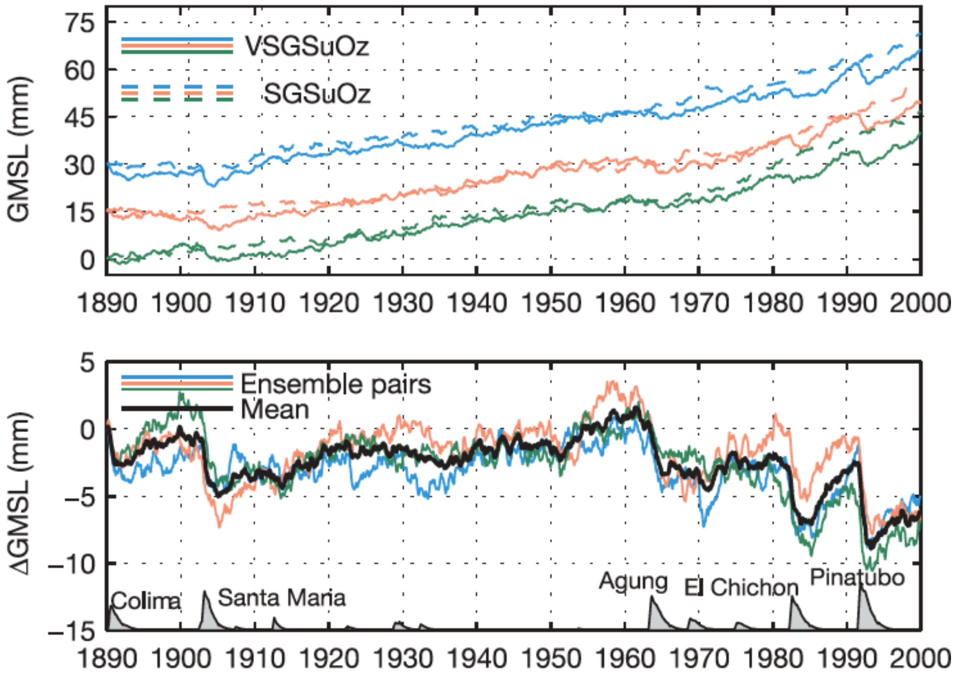
Persistent volcanic signatures in the world oceans

Global ocean heat content



Gleckler et al. 2006, Science

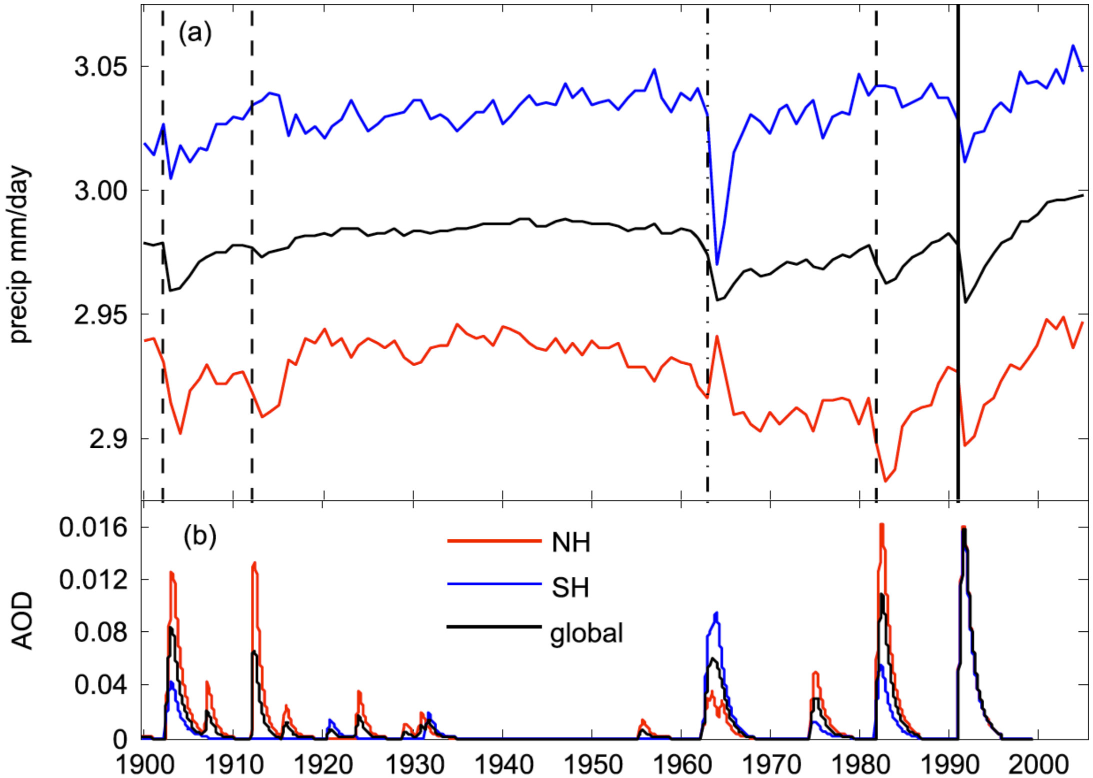
Global mean sea level



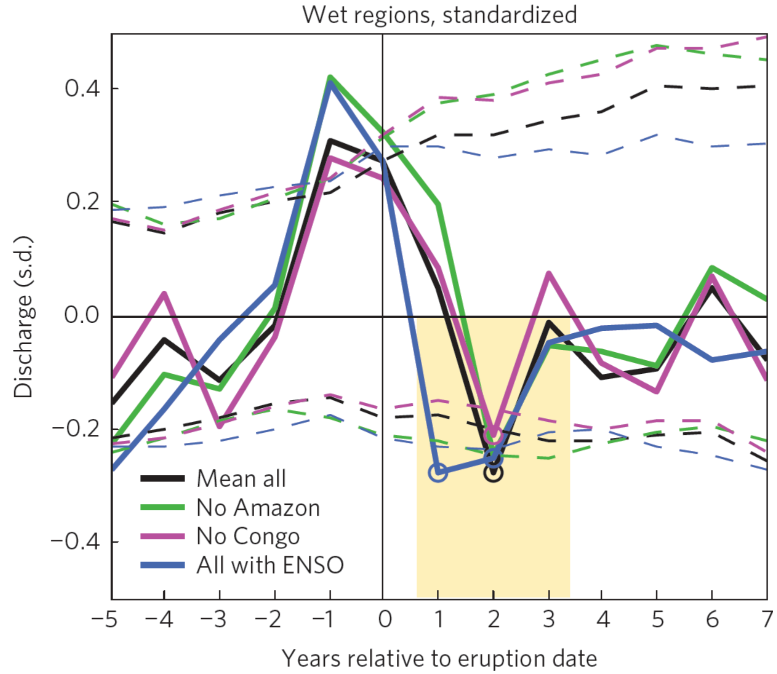
Church et al. 2005, Nature

Spin-down of the global hydrologic cycle

Global and hemispheric precipitation from CMIP5 models



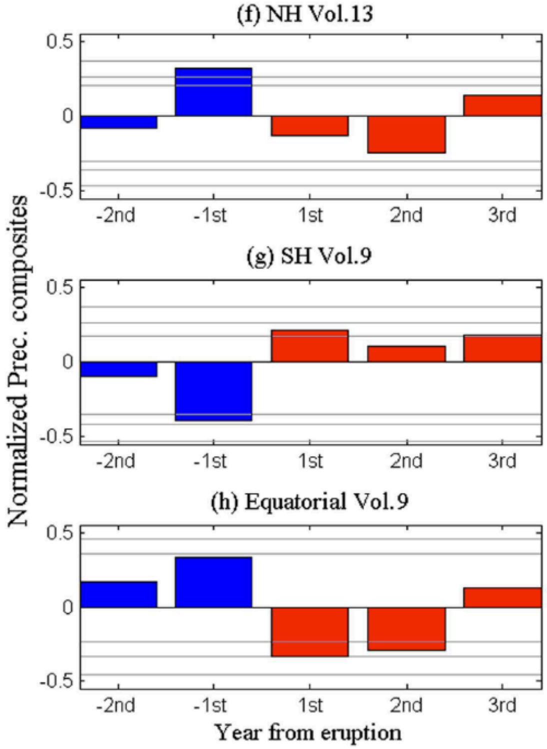
Iles et al. 2014, Environ. Res. Lett.



Iles et al. 2014, Nat. Geosci.

Monsoon response to hemispherically asymmetric forcing

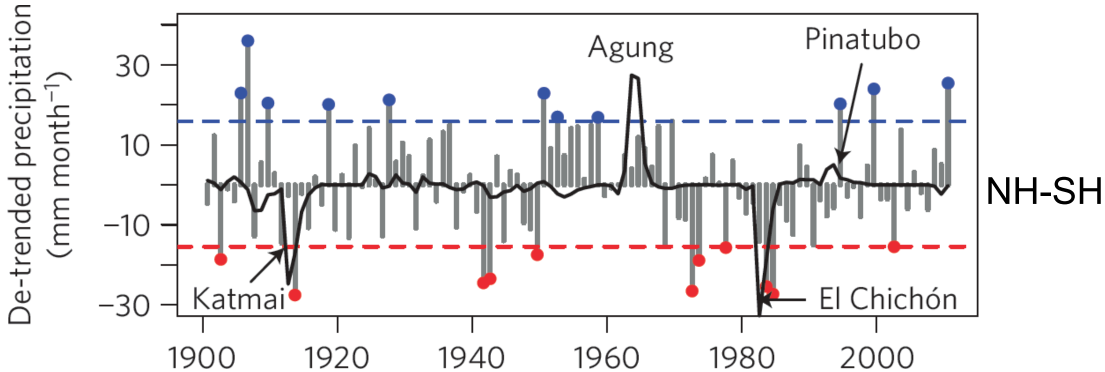
East Asian summer monsoon



1470–1999 Recon. Prec.

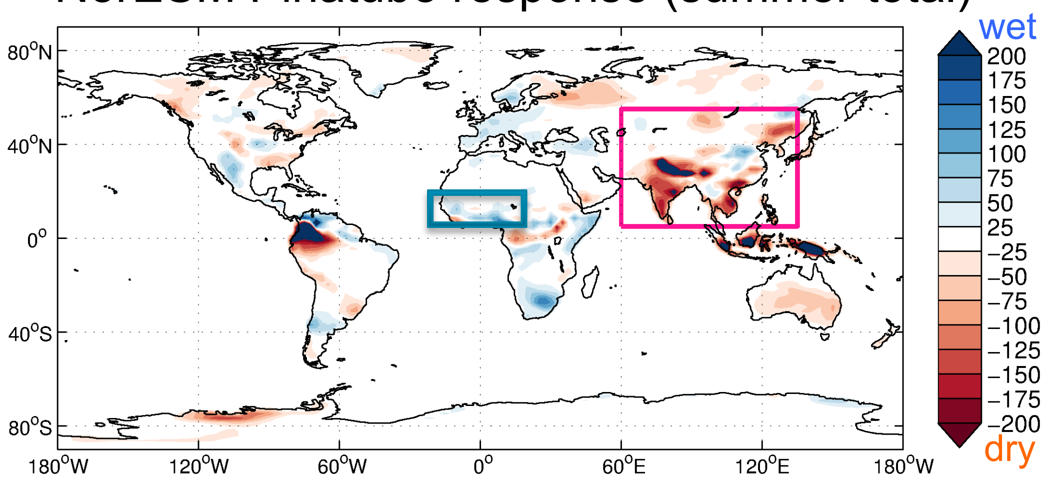
Liu et al. 2016, Nature

Sahelian rainfall



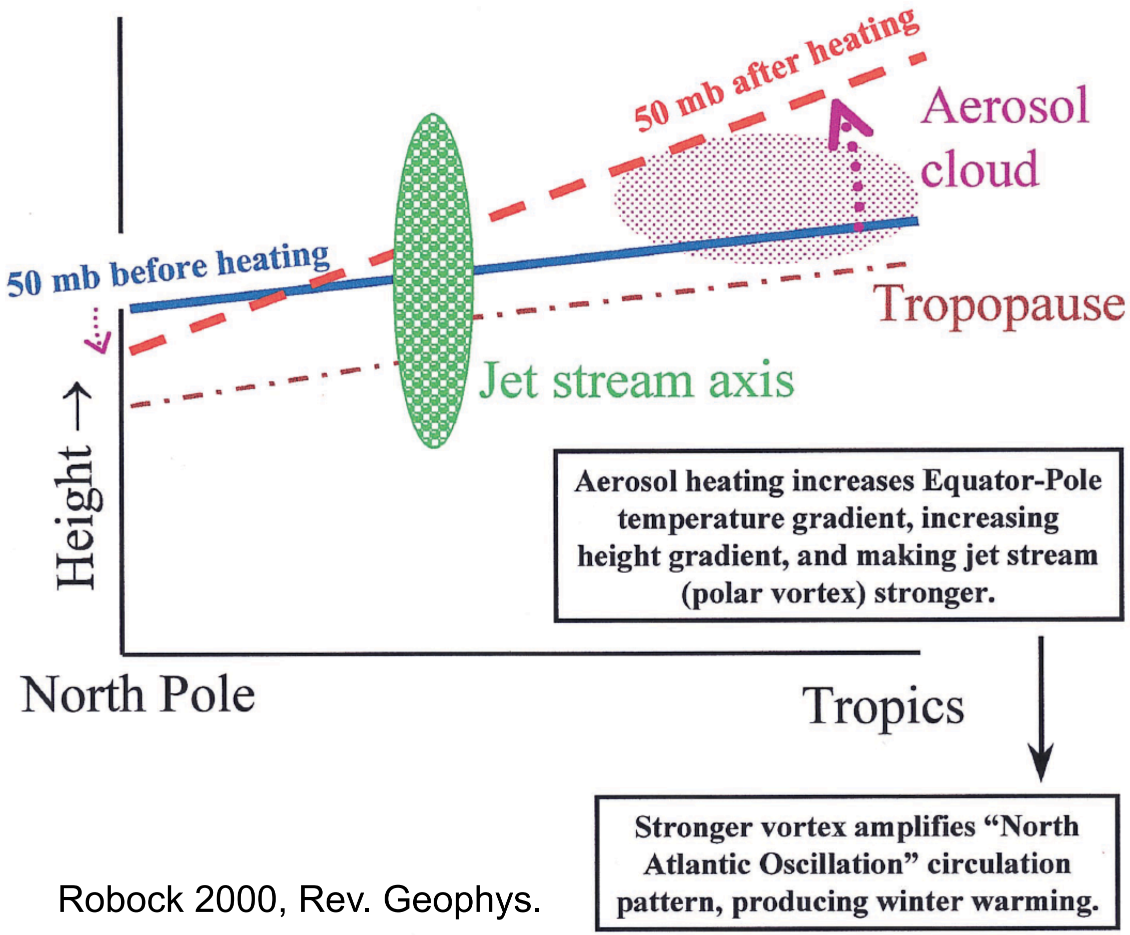
Haywood et al. 2013, Nat. Clim. Change

NorESM Pinatubo response (summer total)

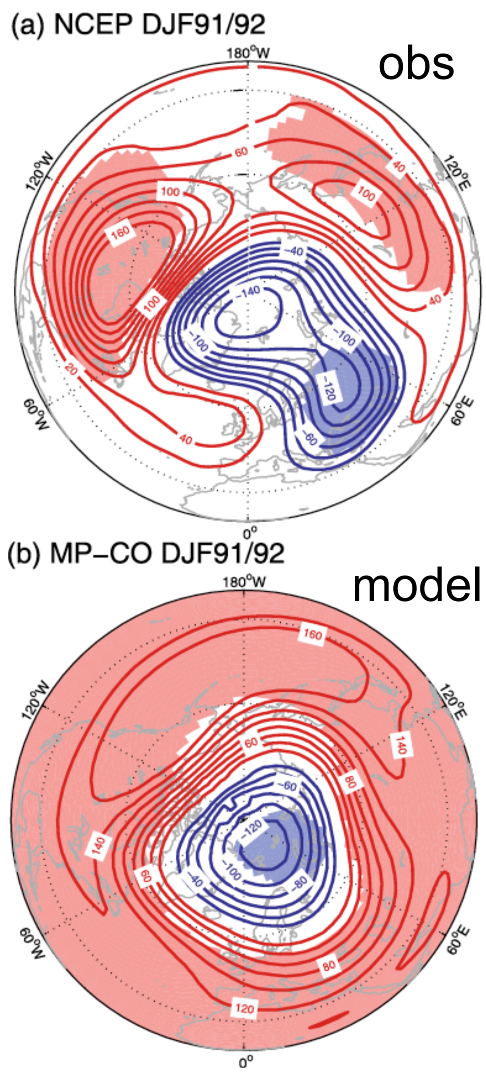


NH/tropical eruption -> wet Sahel, dry East Asia
SH eruption -> dry Sahel, wet East Asia

Positive NAO atmospheric circulation response

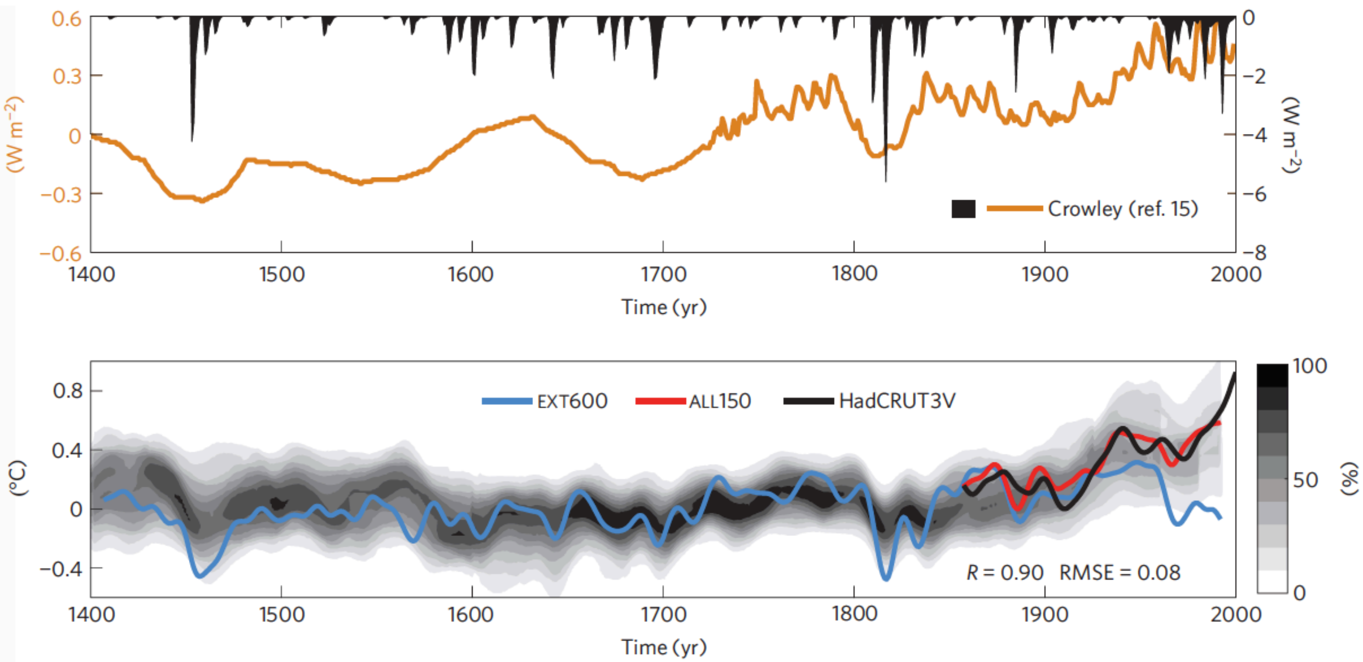


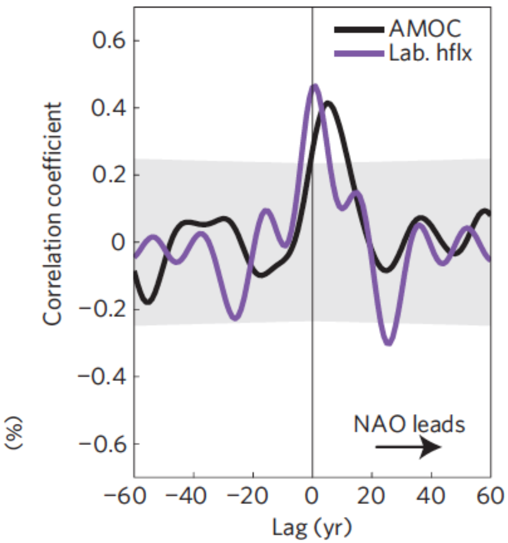
Robock 2000, Rev. Geophys.

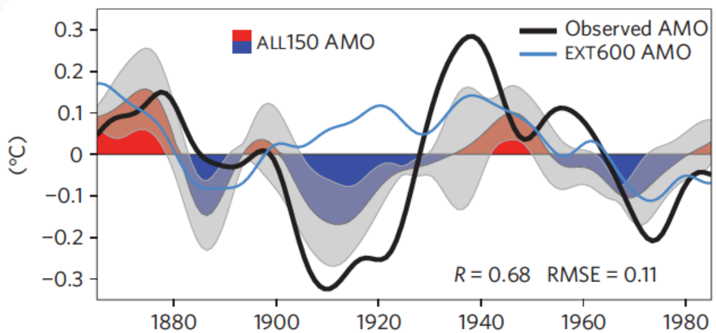


Otterå 2008, Adv. Atmos. Sci.

Atlantic Multidecadal Variability





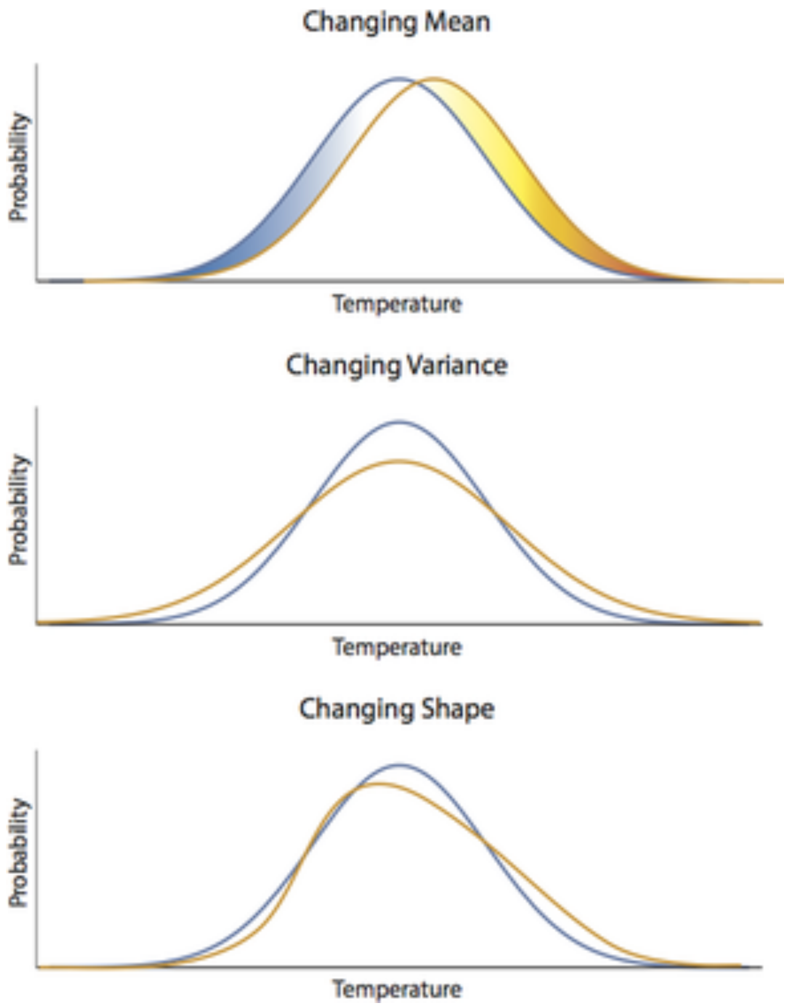


Historical AMV reproduced in all-forcing simulations with the Bergen Climate Model

Otterå et al. 2010, Nat. Geosci.

Future climate projections

Changes in climate probability distribution

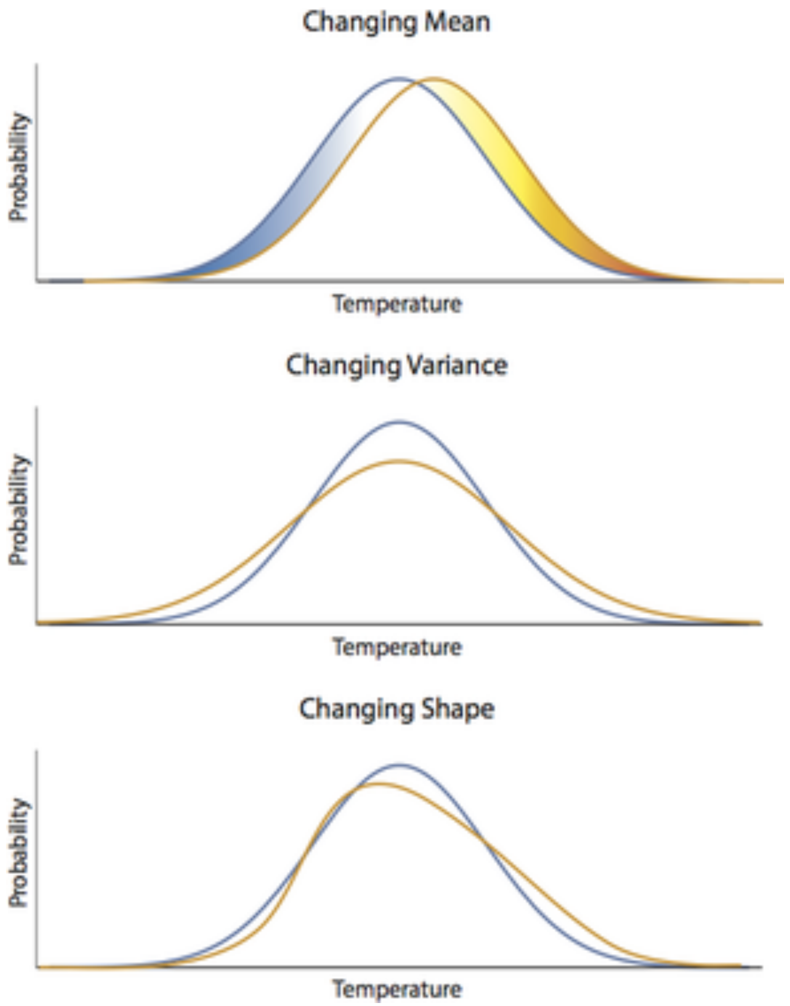


Changes in the frequency of climate extremes aren't just about the average. (Andy Rhines)

http://www.stochtastic.com/climate-variability-and-extremes.html

Future climate projections

Changes in climate probability distribution



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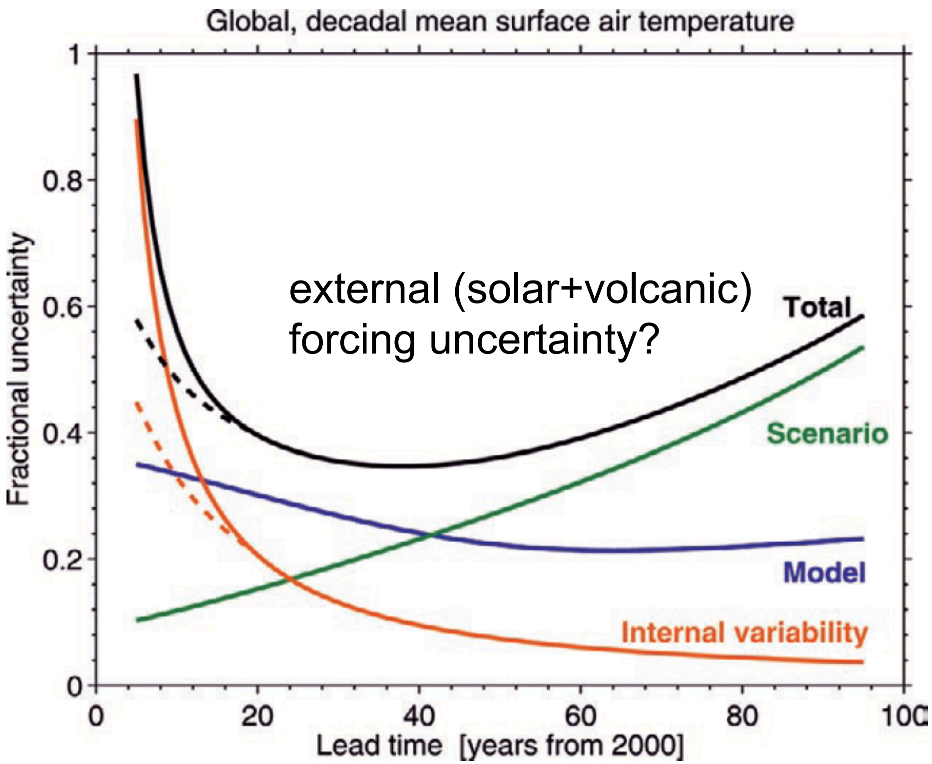
Projection uncertainty



Hawkins & Sutton 2009, AMS

Climate assessments do currently NOT consider future volcanic forcing uncertainty!

Future climate projections

IPCC AR5 on near-term climate predictions (Kirtman et al. 2013):

Volcanic eruptions are a potential source of uncertainty in our predictions.

Eruptions cannot be predicted in advance, but they will occur, causing shortterm climatic impacts on both local and global scales.

In principle, this potential uncertainty can be accounted for by including random eruptions, or eruptions based on some scenario in our near-term ensemble climate predictions.

This area of research needs further exploration.

Bjerknes Fast Track Initiative

Project Title	Assessing the role of volcanoes in future climate prediction (VOLCANOES4FUTURE)
Host Institute	Uni Climate
Project Leader	Ingo Bethke
Key Personnel	Stephen Outten, Peter Thorne, Odd Helge Otterå
Duration	January to December 2015

Motivation and objective

Volcanic activity and solar variability constitute natural climate forcings that have been found to play important roles in past climate evolution. As these forcings are difficult to predict, they have been omitted or at best crudely represented in state-of-the-art future climate projections. With the preparation of CMIP6 being underway, it is timely to assess the potential impact from their poor representation and to explore model strategies to better account for their effects in future climate projections. This project will assess the effect of including volcanoes in future climate predictions through a large ensemble of 21st Century climate change simulations that use synthetic (proxy-based) volcanic forcing. It will serve as a preparatory study for the CMIP6 component VolMIP, which will conduct a general assessment of the climatic response to volcanic forcing.

Activities

In the first part, we will evaluate existing records (proxy and instrumental) of volcanic activity to provide a statistical description of past volcanic forcing activity - including eruption size distributions, return periods and other quantities of interest. By assuming invariance in the statistical distribution of volcanic occurrences, we will design a statistical model for generating plausible future forcing as synthetic time series.

In the second part, we will apply these synthetic forcing times series in a large (minimum 30 member) ensemble of 21st Century climate change simulations performed with NorESM1-M. Apart from the volcanic forcing, the simulations will follow the CMIP5 protocol. In addition, we will perform a reference ensemble with no volcanic forcing.

Our output analyses will focus on global and hemispheric surface temperatures. Specifically, we will address the following issues: Does the inclusion of volcanoes significantly inflate the ensemble spread, i.e. the prediction uncertainty? If yes, what are the implications for climate change detection? Is the lower distribution tail changed and if yes, how would this affect decadal timescale variability and the chances for future "warming pauses/hiatuses"? Is the ensemble mean changed? All of these questions have obvious implications for adaptation decision making and emerging climate services. We need to provide advice that takes into account the likelihood of large volcanic eruptions occurring in the 21st Century and what impacts that may have. Inclusion of plausible natural forcings is hence arguably important in making informed adaptation decisions.

Outcomes

1. Methodology for generating synthetic volcanic forcing with realistic statistical properties
2. 21st Century simulation ensembles (one with and one without volcanic forcing) hosted and available for use upon publication by the science community
3. Report/publication on possible role of volcanoes in future climate prediction, including recommendations for treatment of volcanic forcing in CMIP6 future scenarios
4. (Stretch Goal) Extension of study to future solar variability

The project will strongly benefit from expertise gained in ensemble modelling and implementation of forcings during the now finalized EXPLAIN SKD FTI project. We are therefore confident that our goals are feasible.

Budget

The project aims for a budget of 200kNok, to be used by Stephen Outten to fund the analysis of volcanic records and design of synthetic forcings. Contributions from Ingo Bethke, Peter Thorne (remotely) and Odd Helge Otterå will be in-kind.

APPROVED

Objective

Demonstrate that it's possible to account for future volcanic forcing uncertainty in probabilistic climate assessments (proof-of-concept).

Identify socio-economically relevant aspects of climate change projections for which the inclusion of volcanic effects makes a significant difference.

Approach

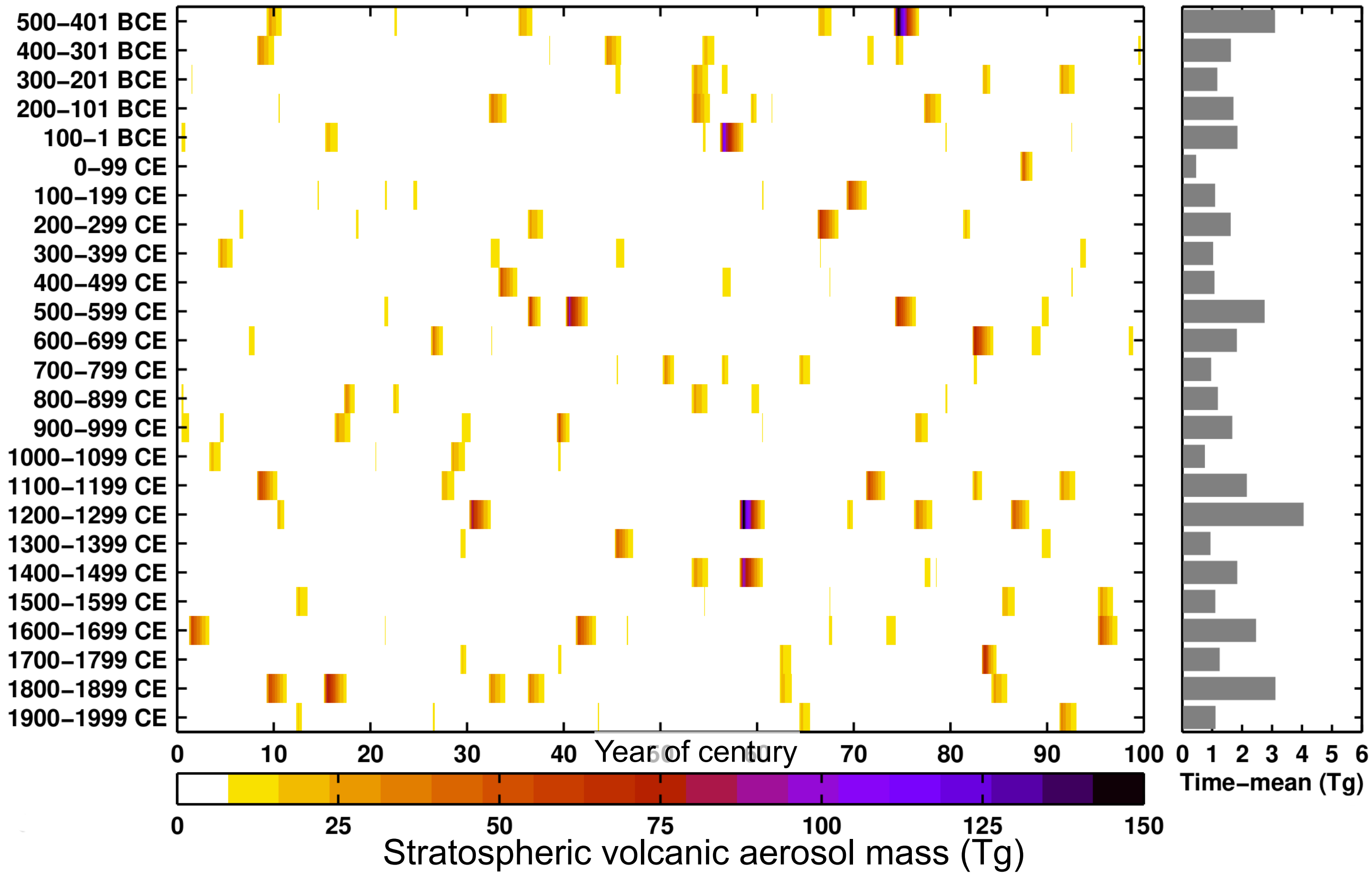
Perform a large ensemble of 21st Century simulations that sample from a proxy-constrained probability space of future volcanic forcing.

How to include volcanoes in climate projections?

Construction of proxy-based volcanic forcing futures

Step 1 – establish catalogue of historical eruptions

- **283 historical eruptions events** over last **2,500 years** with information on **magnitude** (maximum stratospheric volcanic aerosol load) and **location** (tropical vs NH/SH extratropical)



data source: Sigl et al. 2015, Nature

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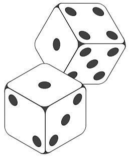
Step 2 – create 21st Century eruption chronologies by re-sampling

- for each month, test if one or more of the 283 historical eruption events are triggered – use pseudo-random numbers and assume probability of 1/(2500x12) for each event (i.e. 2,500-year return period)



- repeat for a total of 60 forcing futures

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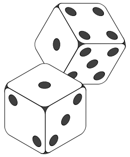

- repeat for a total of 60 forcing futures

Stengths
- simple algorithm with few subjective choices
- statistitics converge against proxy-distribution
- forcing futures are uncorrelated
- future eruptions have historical reference

Cons
- representation of very large eruptions not robust because they are very rare
- small eruptions not captured in ice cores

Alternatives
- volcanic forcing generator based on extreme value theory (Ammann & Naveau 2010, JGR)

Construction of proxy-based volcanic forcing futures

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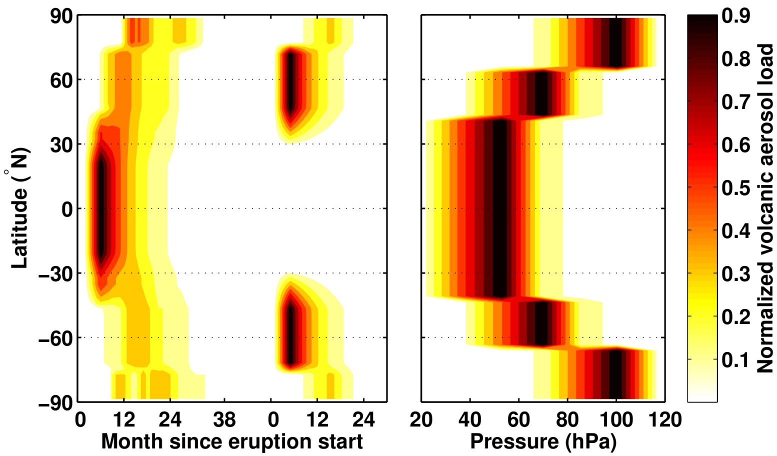
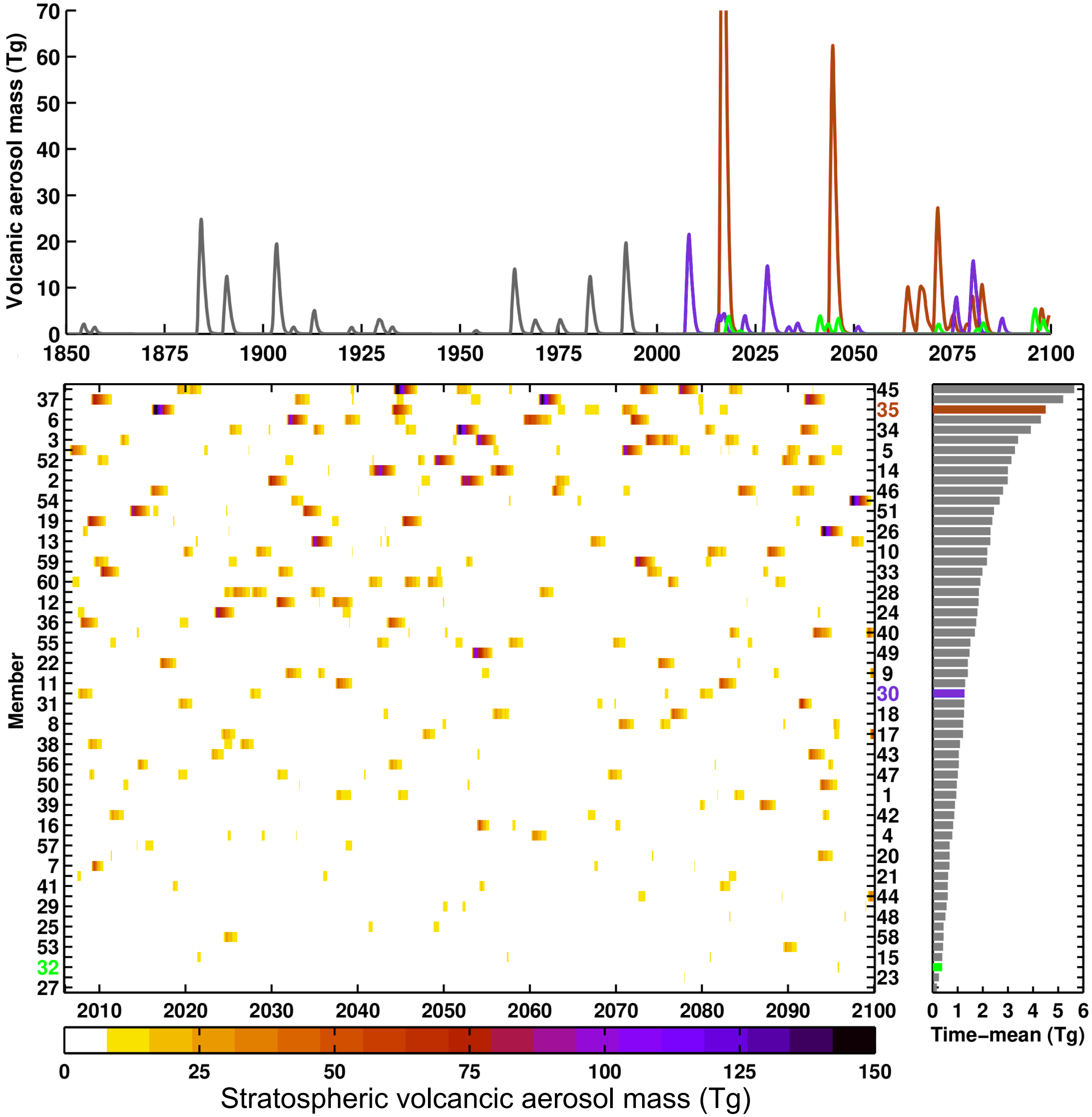
- repeat for a total of 60 forcing futures

Step 3 – convert cronologies into model forcing

- use fixed shape functions that describe spatiotempermal dispersal of volcanic aerosols (Ammann et al. 2003, GRL)



Proxy-based volcanic forcings



21st Century experiments

VOLC

- 60 member ensemble using plausible volcanic futures
- RCP4.5 GHG scenario forcing

NO-VOLC

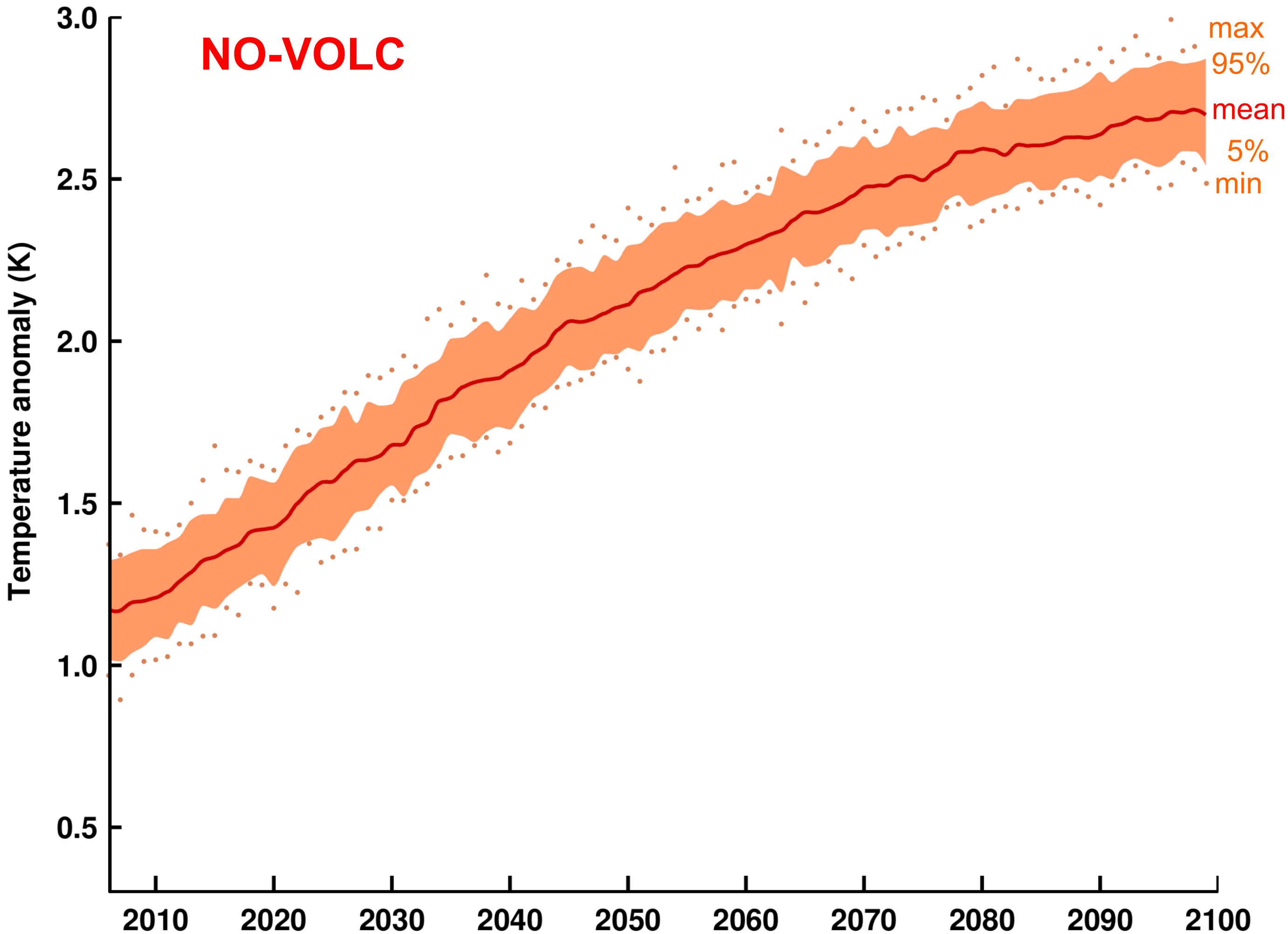
- as VOLC but with volcanic forcing switched off

VOLC-CONST

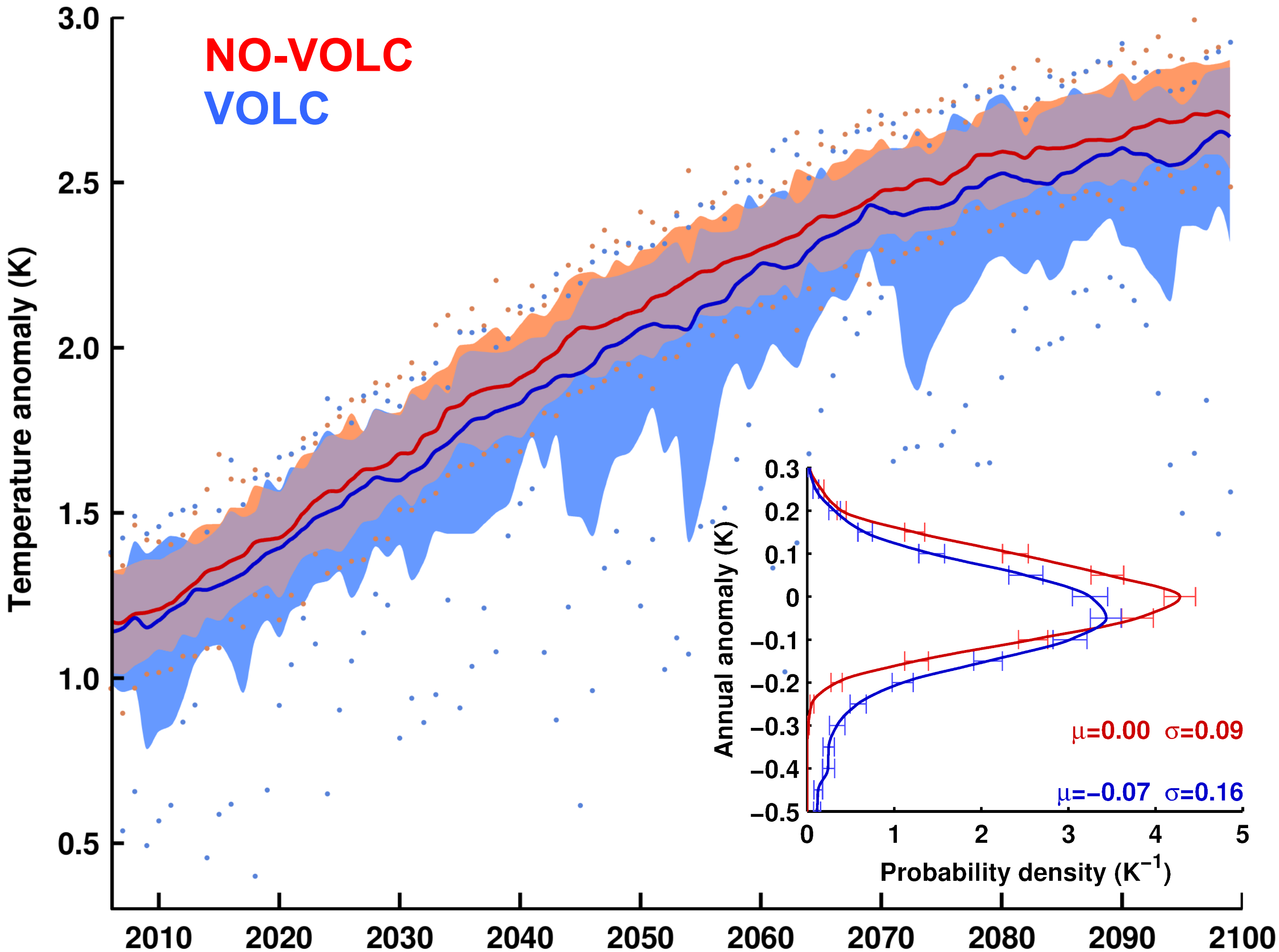
- 20 member ensemble with volcanic forcing set constant using 1850-2000 average

Does it make a difference?

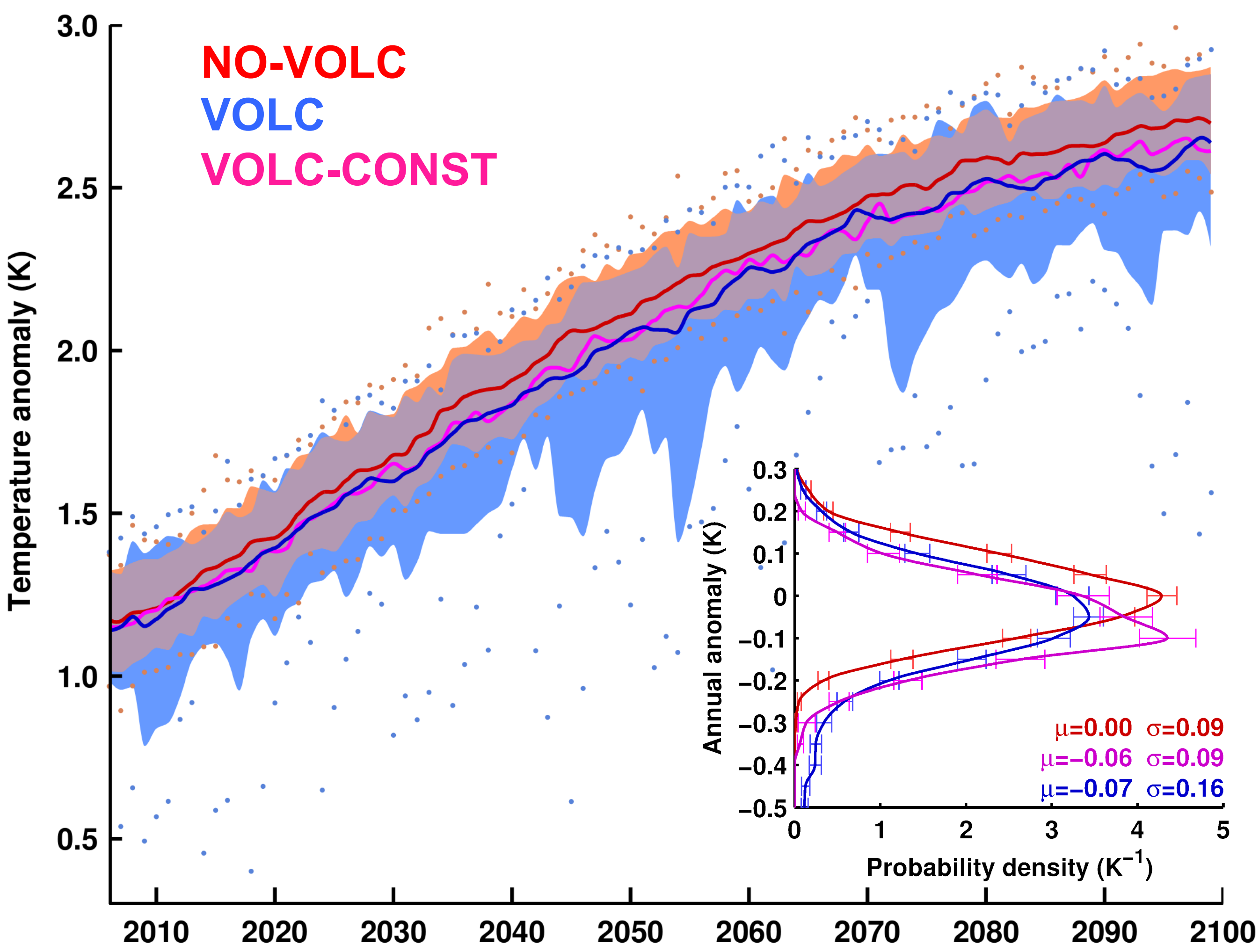
Global-mean annual surface air temperature



Global-mean annual surface air temperature



Global-mean annual surface air temperature



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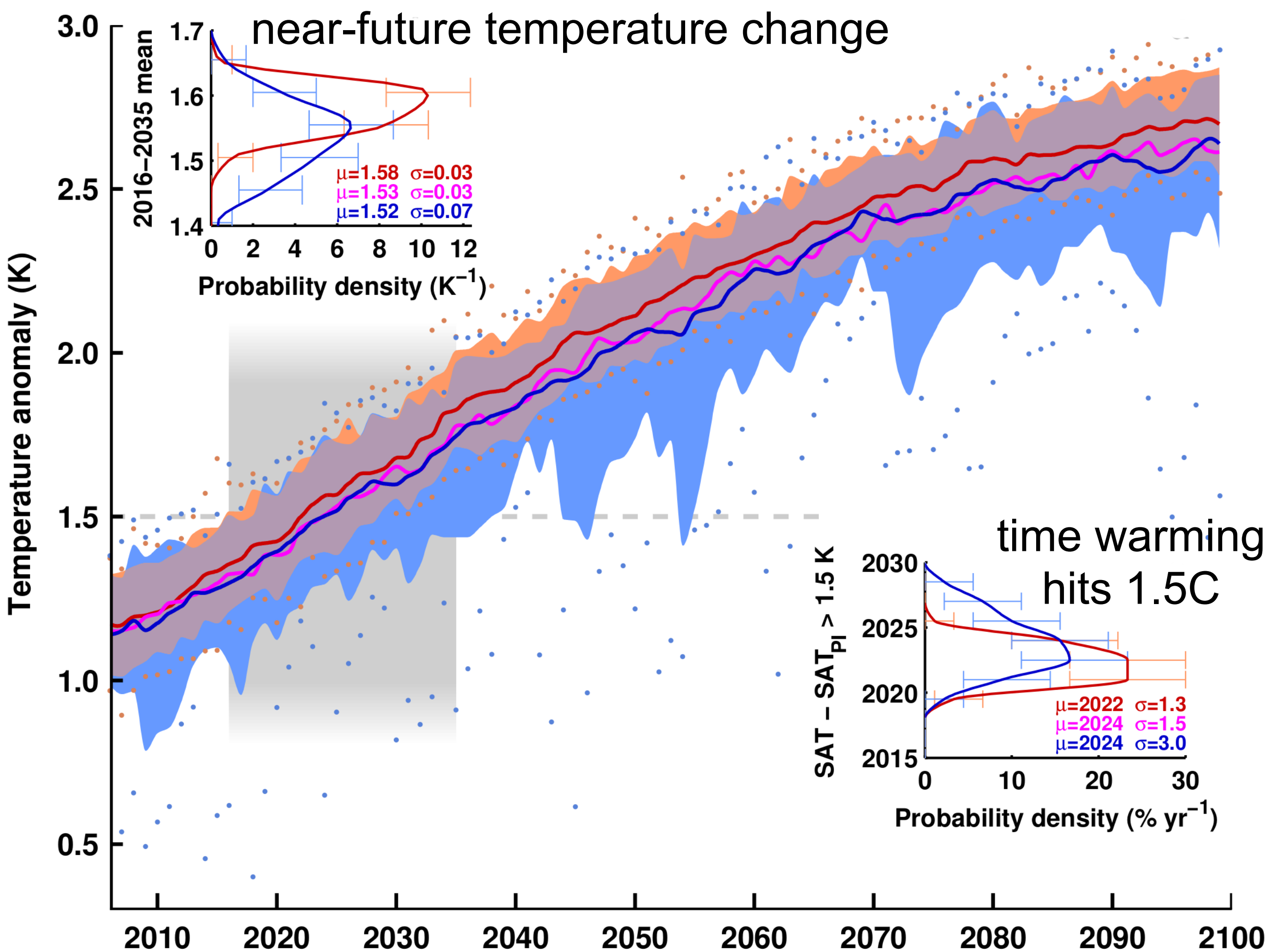
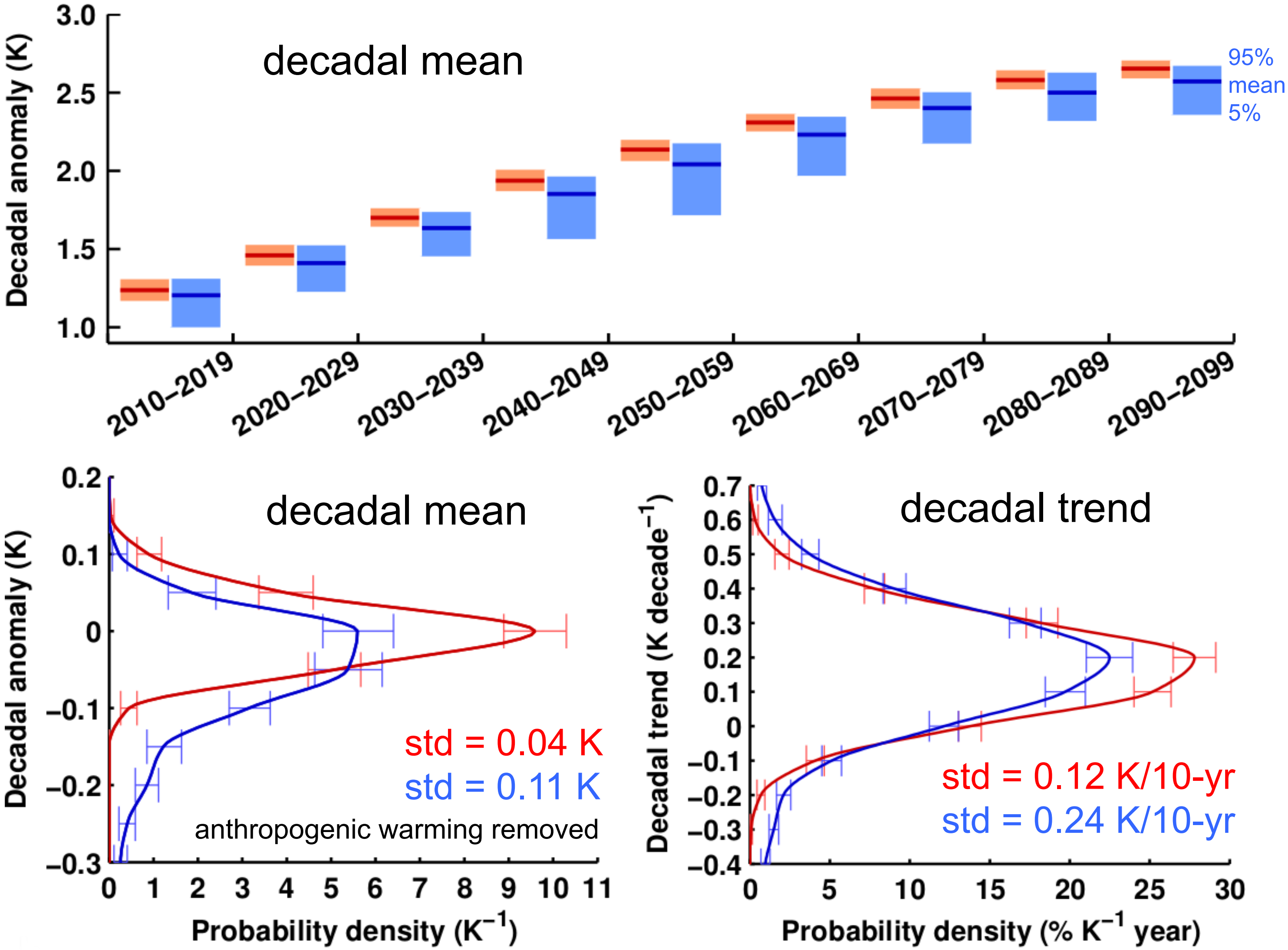
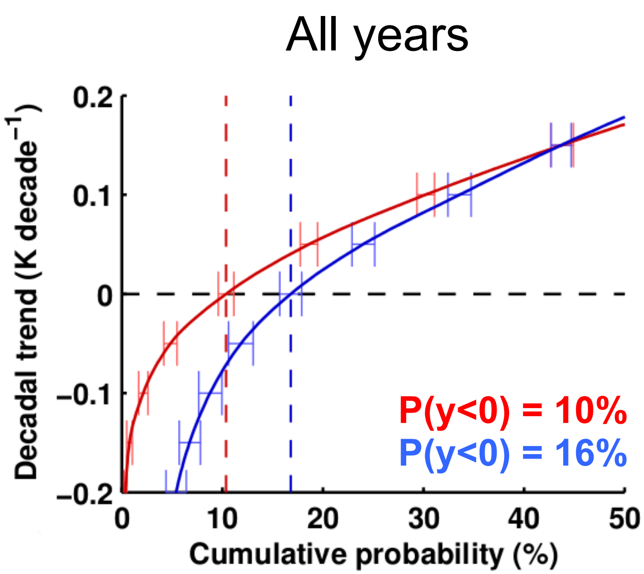


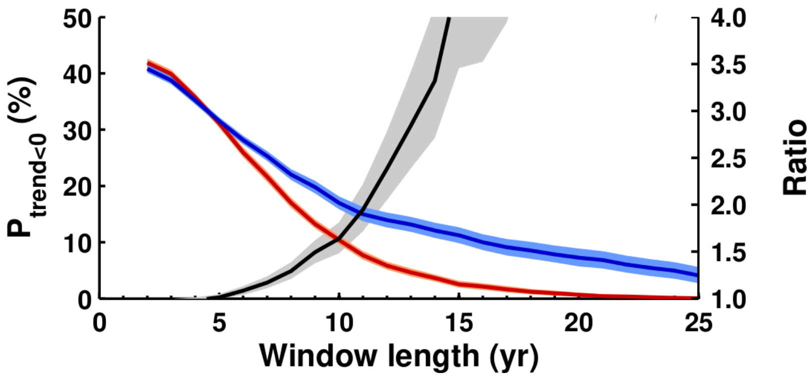
Decadal temperature means and trends



Global warming pause probability

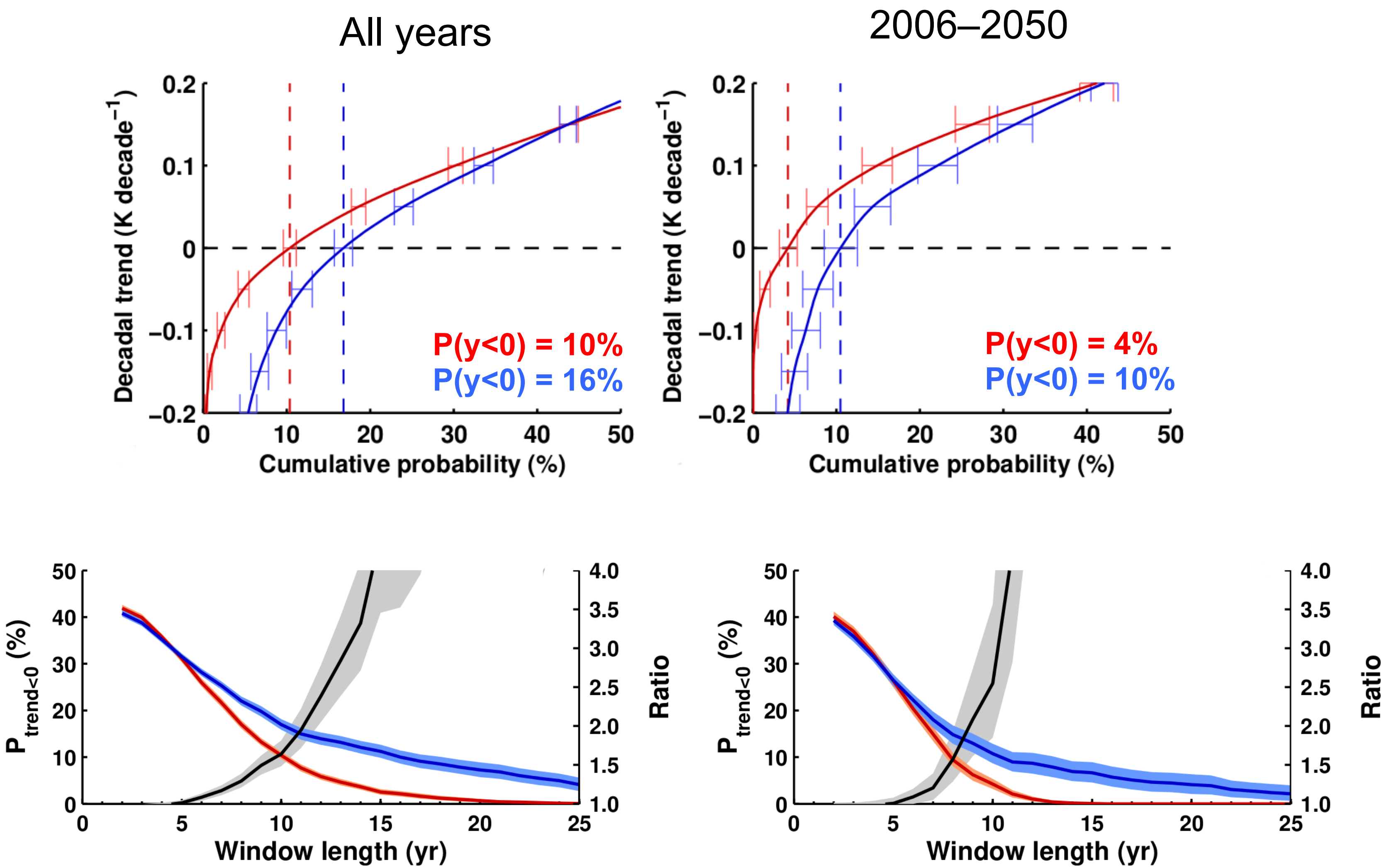


50% increase in hiatus decades



relative importance of volcanoes increases for longer averaging periods

Global warming pause probability



relative impact is sensitive to global warming scenario

Large-scale climate indicators

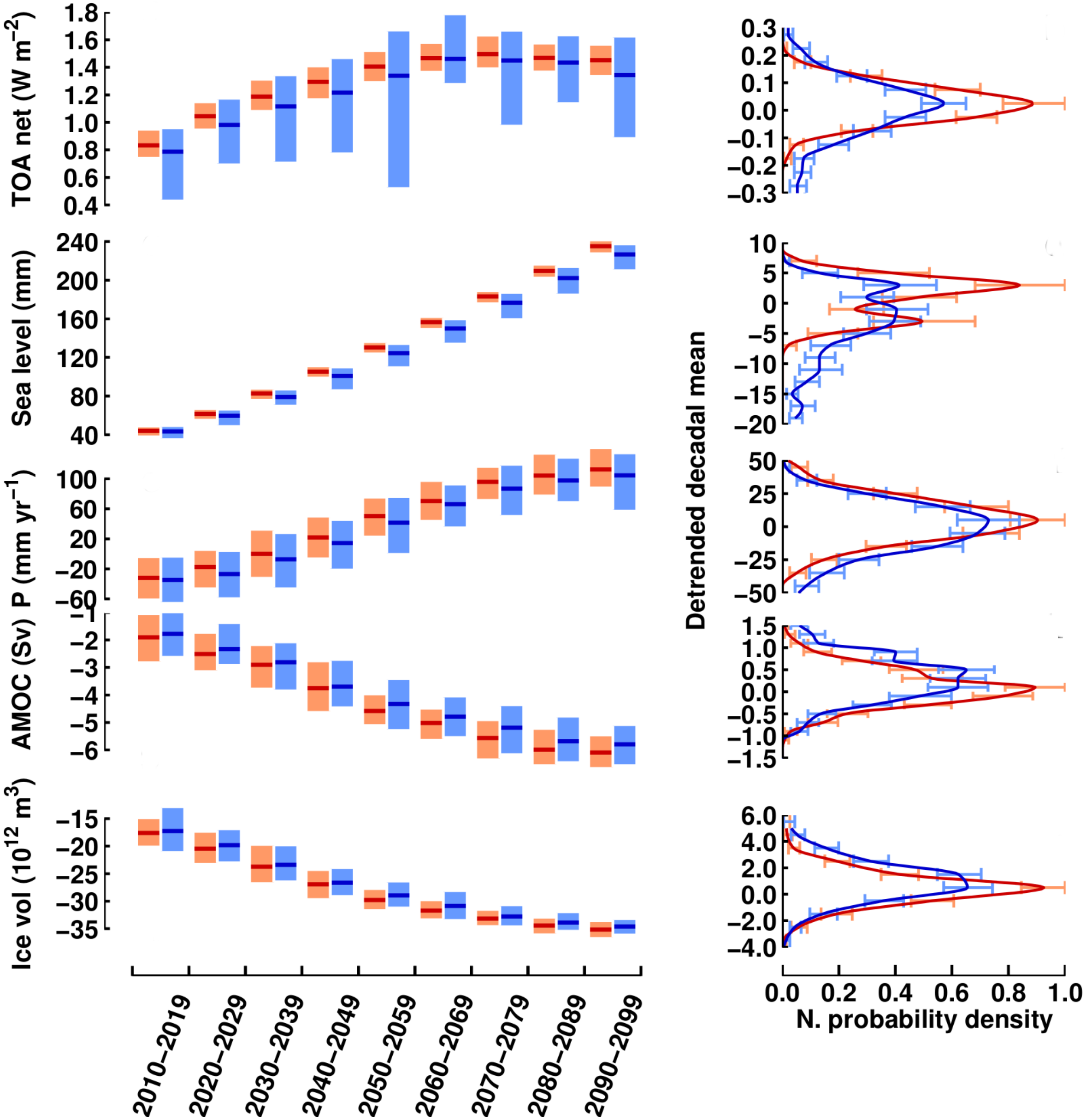
Radiation balance at top of atmosphere

Steric sea level change

East Asia summer monsoon precipitation

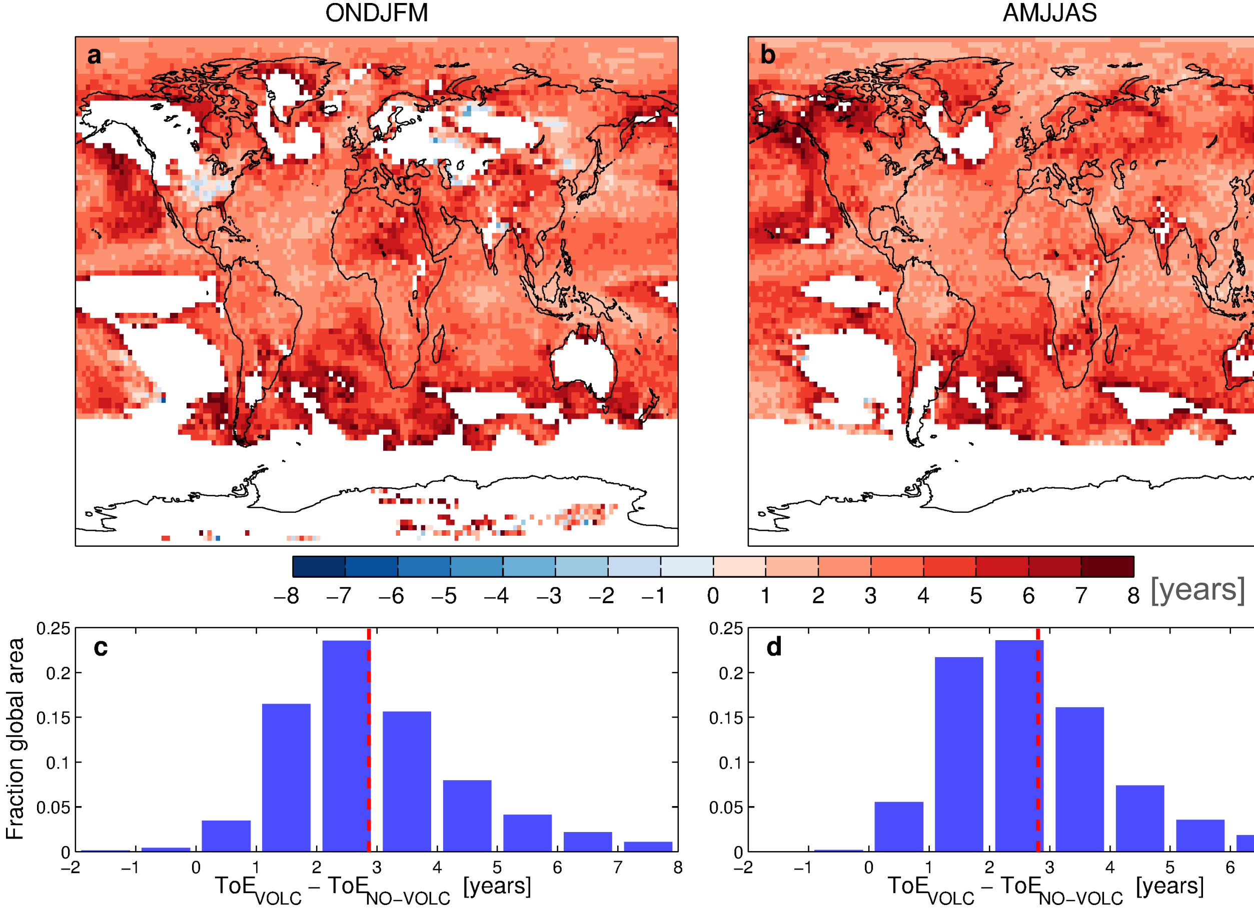
AMOC strength

Arctic sea ice volume



Does it matter locally?

Time of Emergence of global warming (VOLC – NO-VOLC)



local climate change is expected to emerge a few years later if volcanic effects are taken into account

Summary

- demonstrated that volcanic forcing uncertainty can be included in future climate assessments (at high computational cost)
- performed a large ensemble of 21^{st} Century climate simulations that sample the probability space of future volcanic forcing
- compared results to conventional projections with zero or constant volcanic forcing
- found volcanic impacts on important aspects of 21^{st} Century climate projections
  - general increase in projection uncertainty (to-be-quantified)
  - distribution widening for shortterm climate means and trends
  - 50% increase in global warming hiatus decades
- potential implications for climate adaptation decisions and risk assessments that focus on the spread and tails of distributions (to-be-identified)

Outlook

- quantify volcanic contribution to total projection uncertainty and identify information relevant for the upcoming IPCC report
- refine simulation strategy (e.g., combine probabilistic and scenario approaches) and make it more suitable for coordinated multi-model efforts such as VolMIP
- address socioeconomic relevance through collaboration with regional climate impact assessments
- follow up study for solar forcing

Krakatoa 2007