Bavarian Riots, 1819

A Future Year Without A Summer

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Outline / Science Questions

- **The 1815 Eruption of Mt Tambora**
- **What happened as a consequence?** Anecdotal accounts. {Proxy reconstructions.}
- **What is the CESM's forced response?** Does it jibe with historical accounts? How do local YWAS anecdotes fit into the broader global climate response?
- **Does the forced response change in a warmer climate?** If so, how? {relative scarcity of model runs}

Mt Tambora's 1815 Eruption

- Occurred on 10 Apr 1815 in Indonesia (island of Sumbawa, 8°S)
- Upper 5000 ft of Mt Tambora was lost during the event. (Longs Peak ➠ Bear Peak)
- One of the major eruptions of the last millennium (VEI=7)
- 70K local deaths, many more globally (~100K total).

8°S

Ascribed Impacts
(by association)

Historically cold conditions in New England and Europe "*Year without a Summer*", "red fog" aerosols ➠ YWAS

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Historically cold conditions in New England and Europe "*Year without a Summer*", "red fog"
~~aerosols ➡ YWAS~~
simplistic

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But are these attributions warranted?

Simulations

CESM Last Millennium Ensemble

CESM-CAM5; 2-deg atm; 1-deg ocean; 850-2005; full-forcing (13) and single forcing members (5 volc)

Future (Volcanic) Runs

Identical model configuration as LME ; RCP 8.5; identical volcanic aerosol prescription as LME except in **2085**; 4 volcanic runs, 8 “all but” volcanic runs; (now expanding)

CLIMATE VARIABILITY AND CHANGE SINCE 850 CE

An Ensemble Approach with the Community Earth System Model

BY BETTE L. OTTO-BLIESNER, ESTHER C. BRADY, JOHN FASULLO, ALEXANDRA JAHN, LAURA LANDRUM, SAMANTHA STEVENSON, NAN ROSENBLOOM, ANDREW MAI, AND GARY STRAND

The Community Earth System Model-Last Millennium Ensemble (CESM-LME) modeling project gives the research community a resource for better understanding both proxy records and climate variability and change since 850 CE.

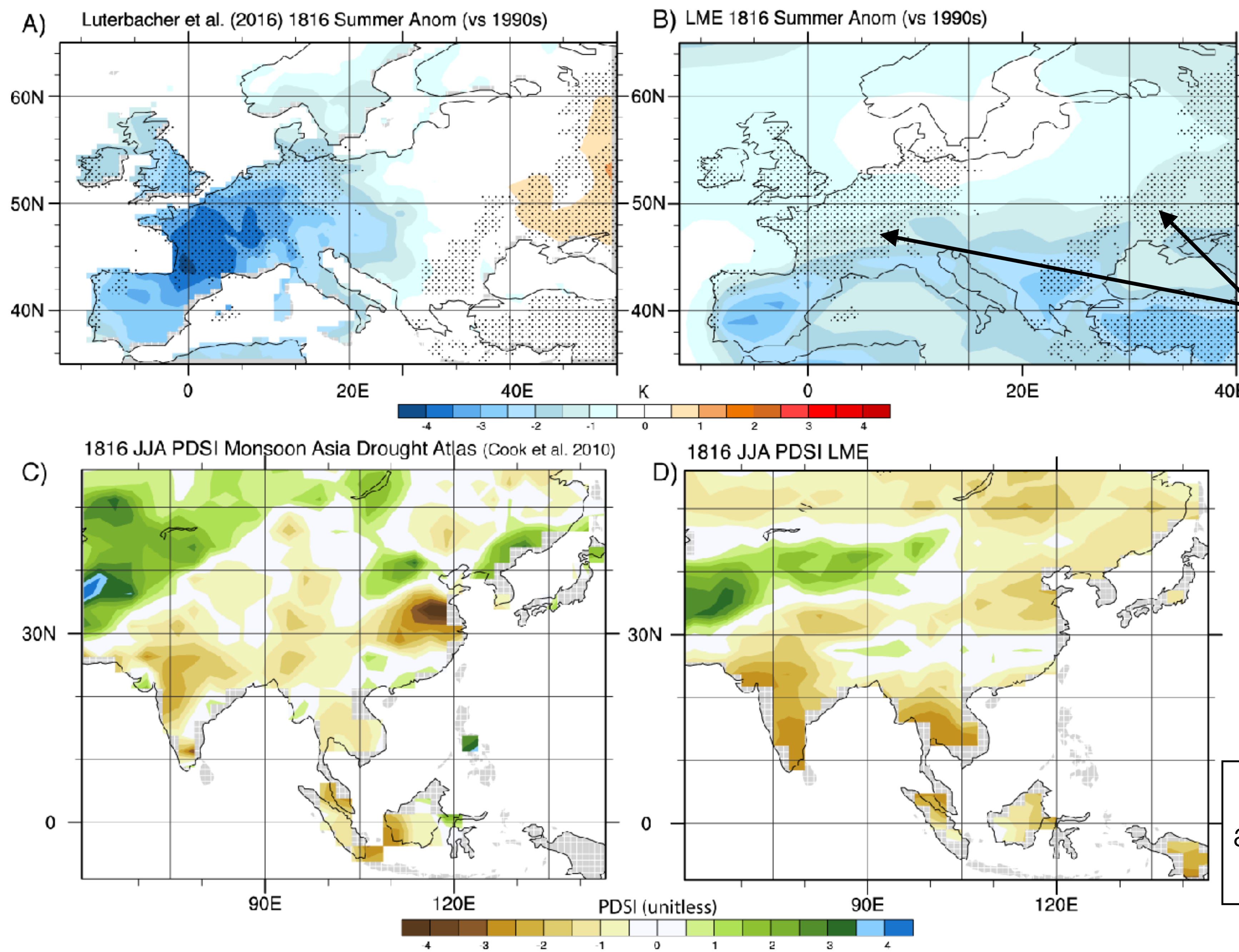
Otto-Bliesner et al. 2016, BAMS

Proxy Data vs CESM

JJA Reconstruction   LME 18-mem Mean

Surf. T

strong cooling / zonal gradient



no LME members reproduce (stip)

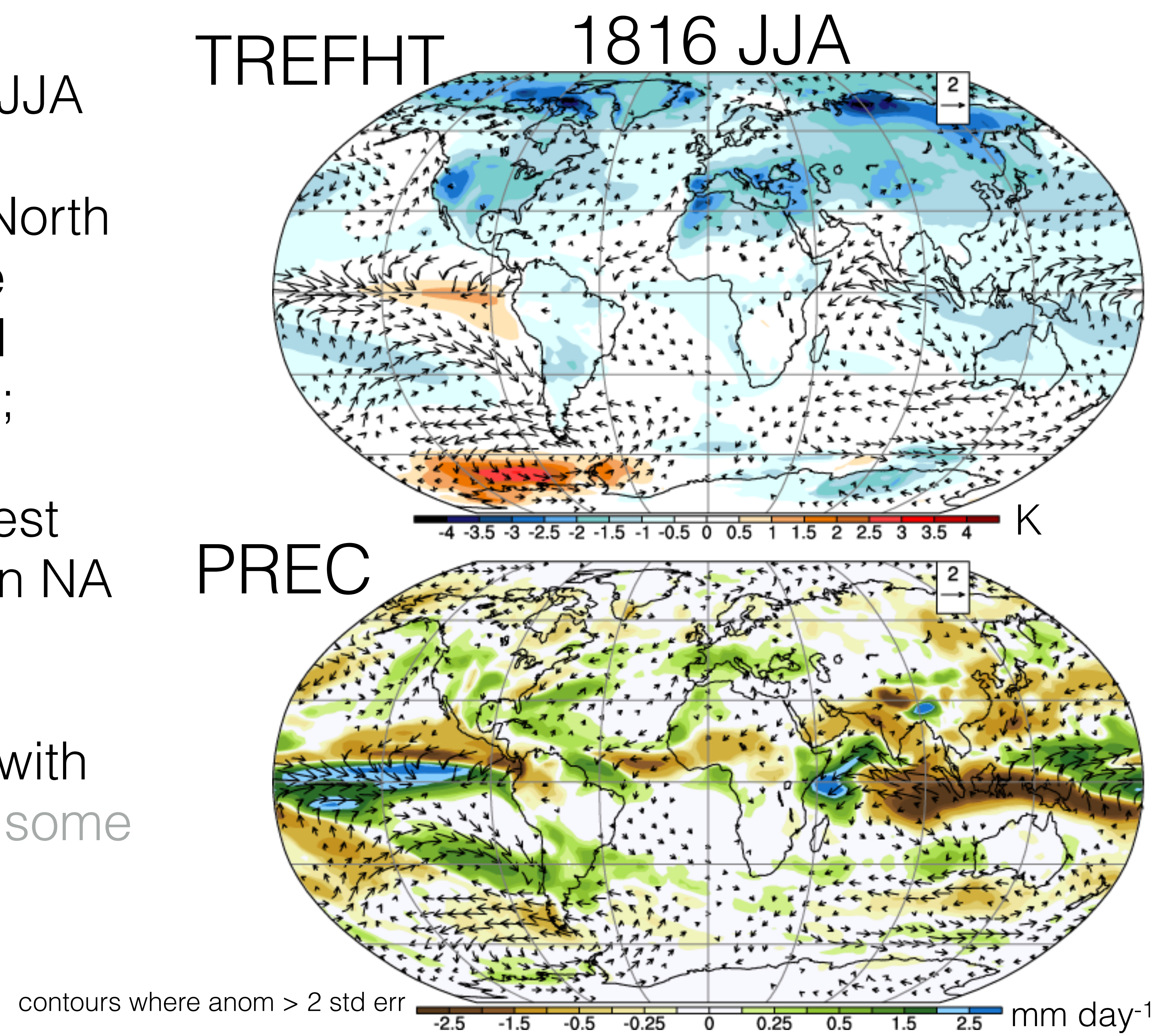
PDSI

pervasive SE Asian drought

general LME agreement; but large ensemble spread

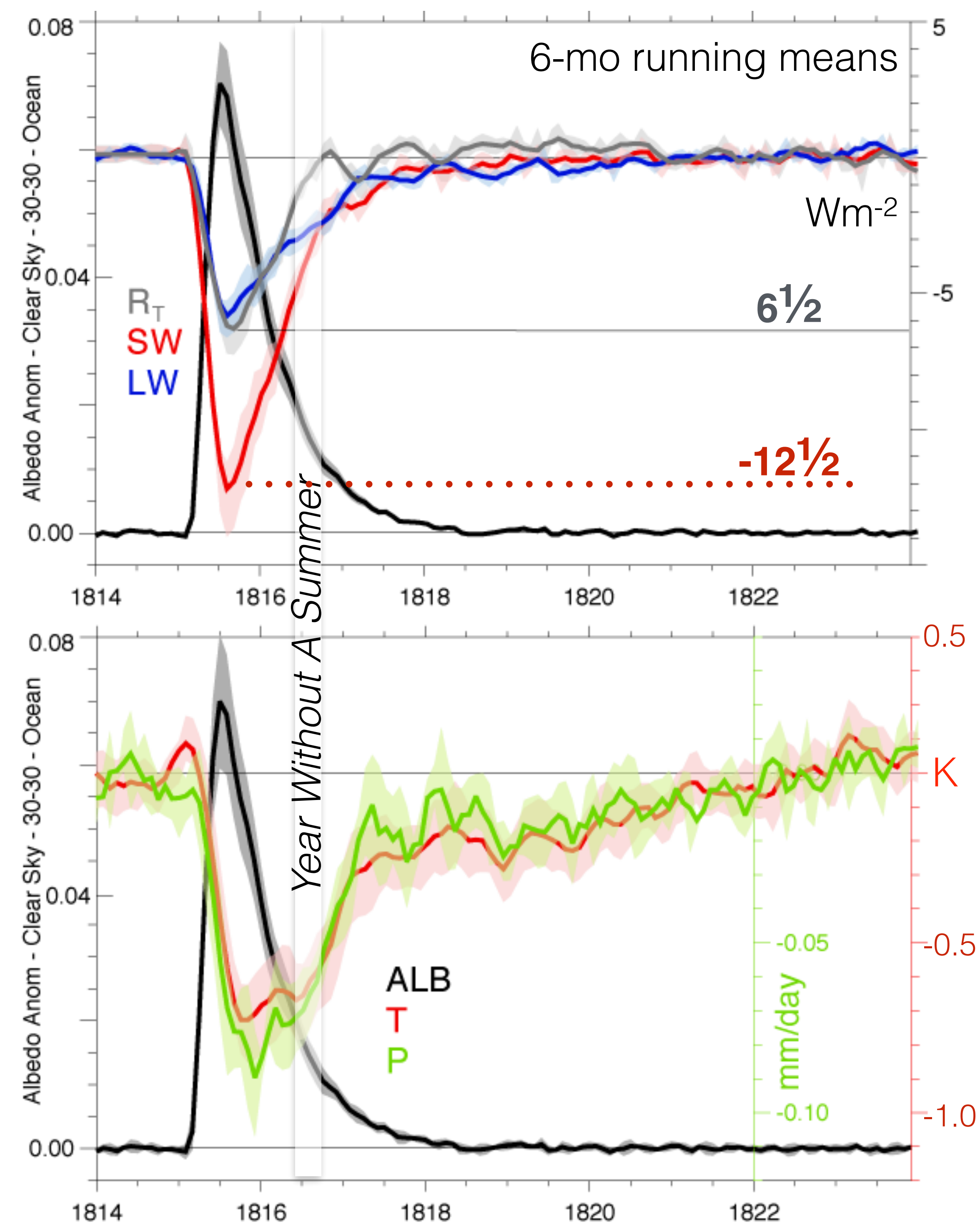
Simulated YWAS

- 18-member Mean 1816 JJA
- Expected Anoms: cold North America and Europe are simulated; “wet ungenial summer”; Asian drought;
- Additional insight: greatest cooling in Arctic, western NA and Eurasia, El Niño
- Quantitative agreement with reconstructions {though some large disagreement in preceding winter}



Eruption Energetics

- Clear-sky albedo increases
- Absorbed sunlight decreases (-12½ Wm^{-2}) and so does outgoing long wave radiation (-6 Wm^{-2}) ➟ (6½ Wm^{-2}) Net Cooling
- Temperature drops (¾K)
- Less sunlight reaching surface results in decreased water cycle (**Q1**: *only* 3%).
- **Q2**: by YWAS, >⅔ aerosols gone. why so cold if driven directly by aerosols?



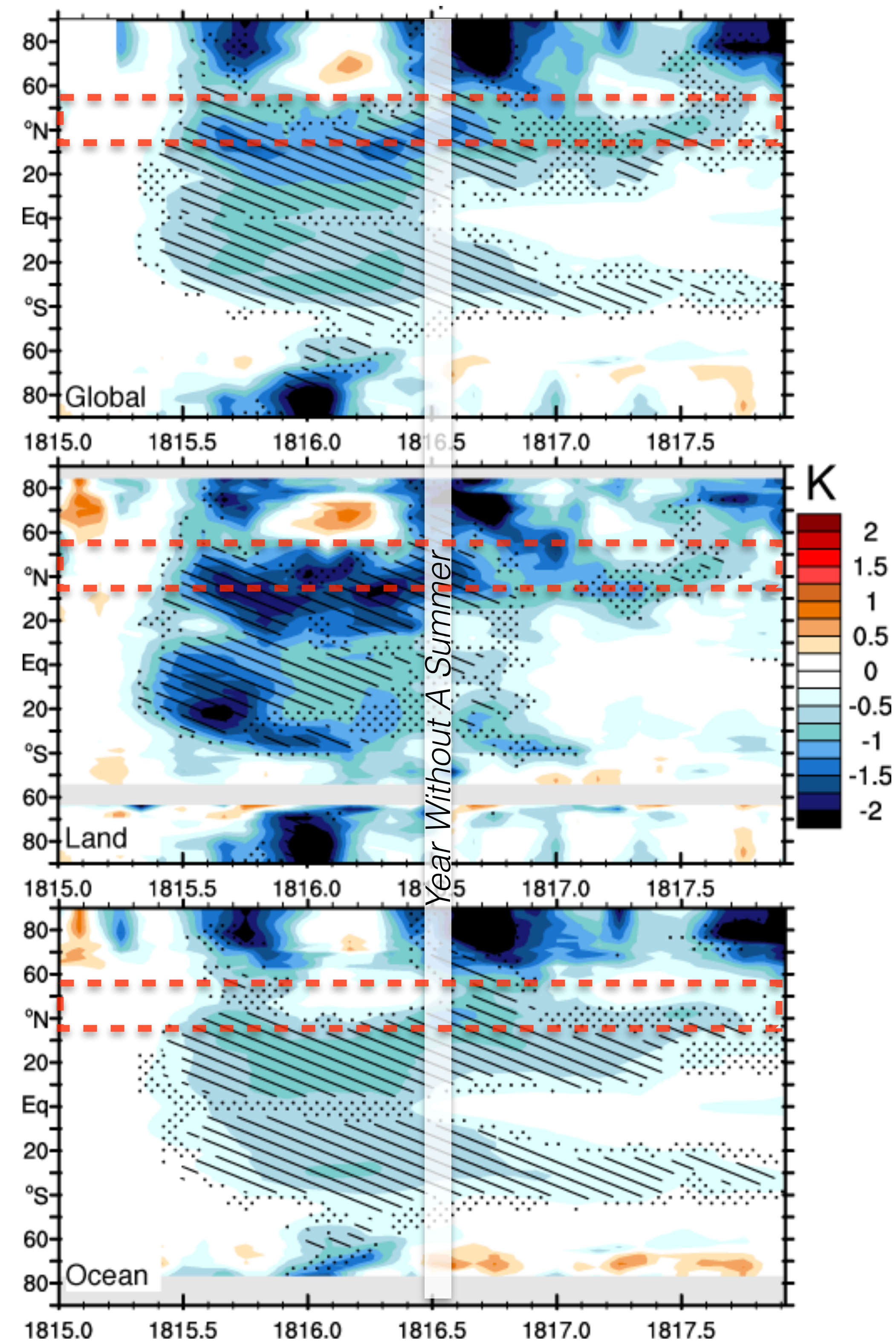
Surface Temperature

- **Strong structure**; Strong land-ocean contrast in cooling and variation by latitude
- Land cools immediately and disproportionately after eruption
- Cooling is particularly strong and persistent in the NH (cryospheric feedbacks)
- Ocean cooling is initially weaker but also more persistent.
- Ocean / cryosphere set the stage for the YWAS. Not aerosols directly.

All

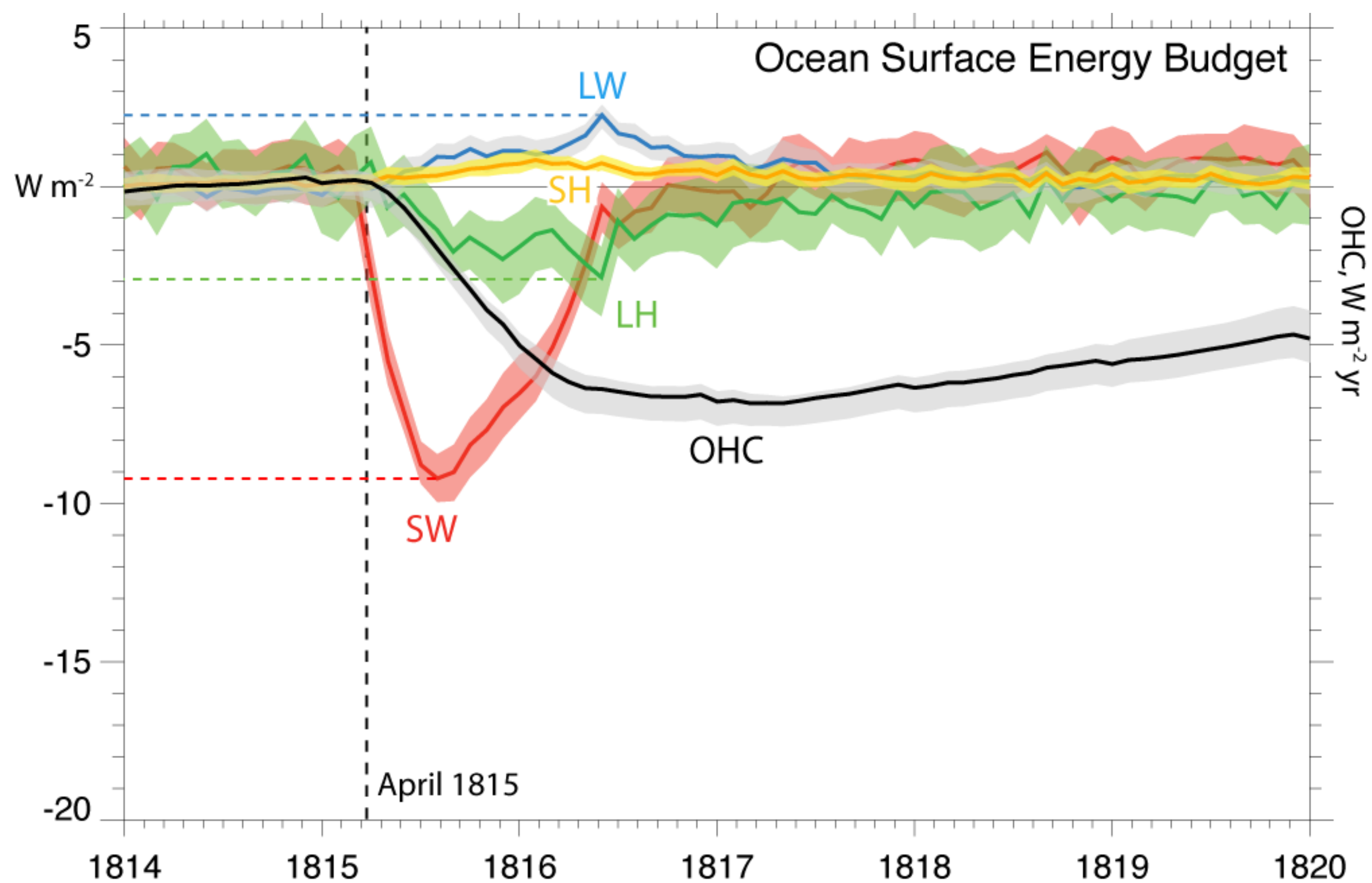
Land

Ocean



Q1: Why Isn't the Water Cycle Weakened More Substantially?

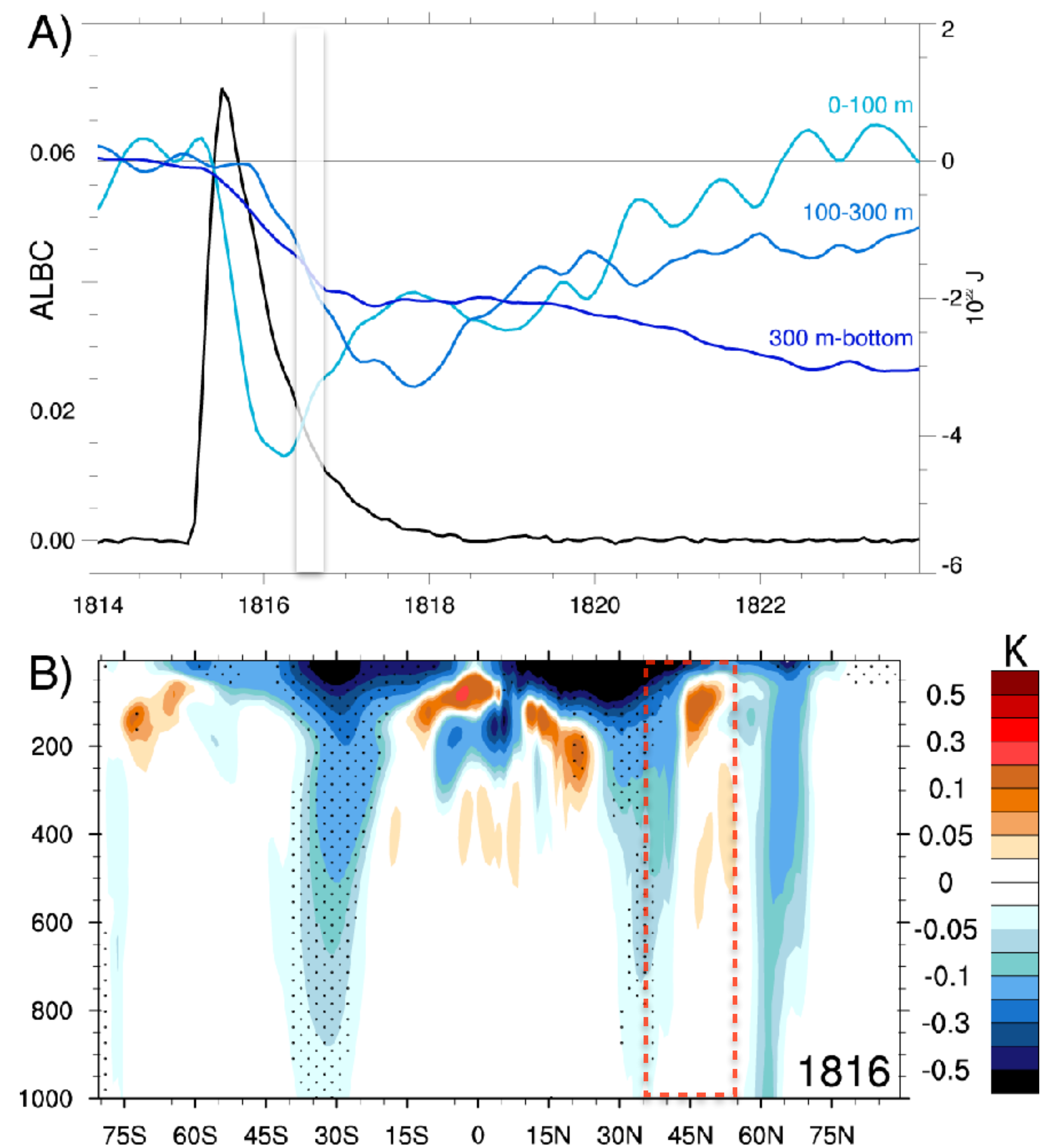
- Surface SW reduction alone implies ~9 Wm^{-2} weaker water cycle (11%)
- Simulated P reduction is <⅓ (~3%)
- Feedbacks from other surface fluxes are positive (increase surface cooling).
- Cooling of the ocean supplies much of the energy needed to sustain E and therefore P.



Q2: Why was cooling so strong during YWAS?

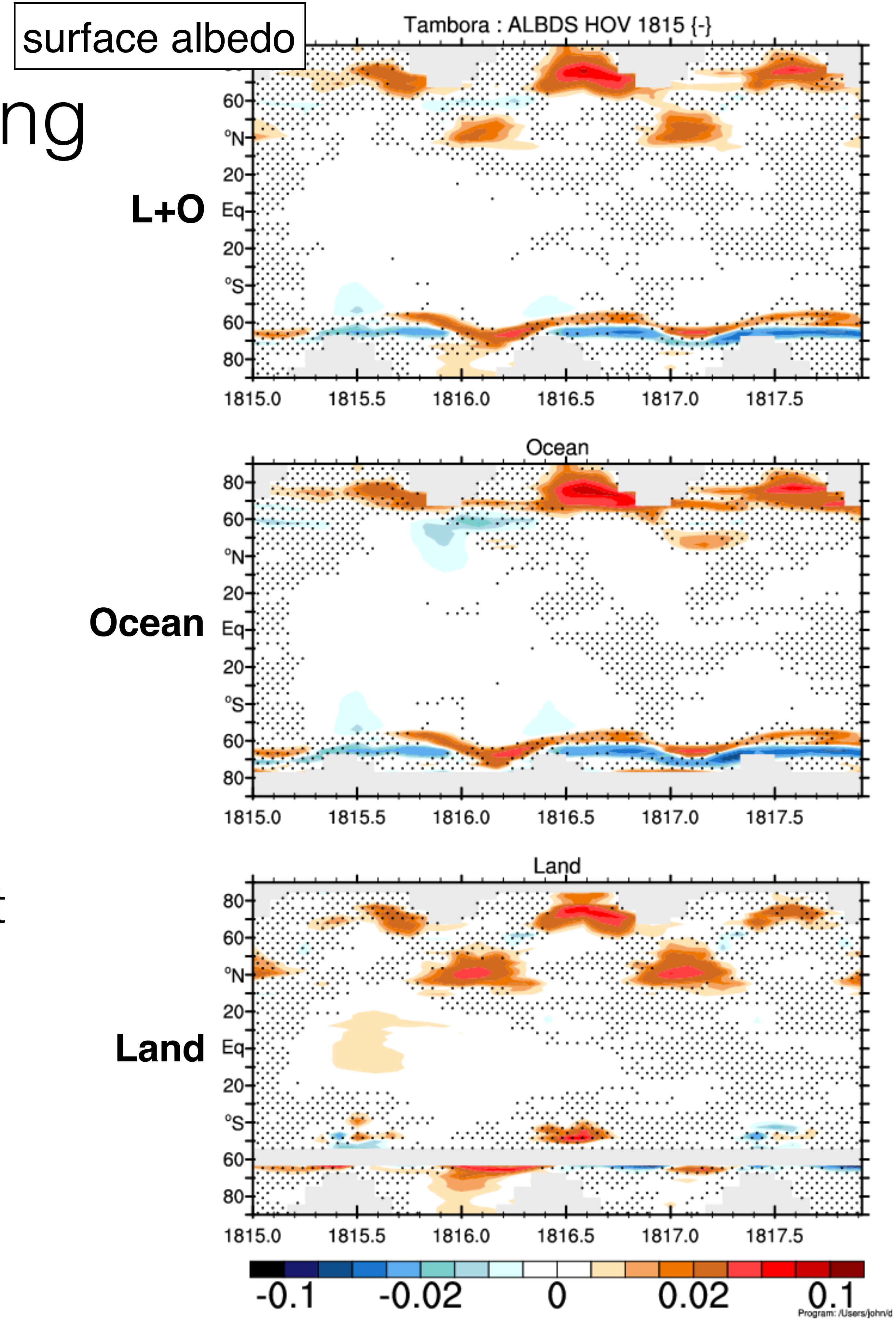
- **Ocean cooling** played a key role. Response is not uniform: Cooling in the upper 100m is rapid and almost immediate - **peaks just prior to the YWAS**

- Despite it being a SH eruption - cooling greatest in NH. Ocean cooling response is most intense and extends to depth just south of YWAS latitudes, also strong but weaker upper ocean cooling from 25-40S. **Similar energetic imbalance yields greater SST reduction in NH due to less ocean extent.**



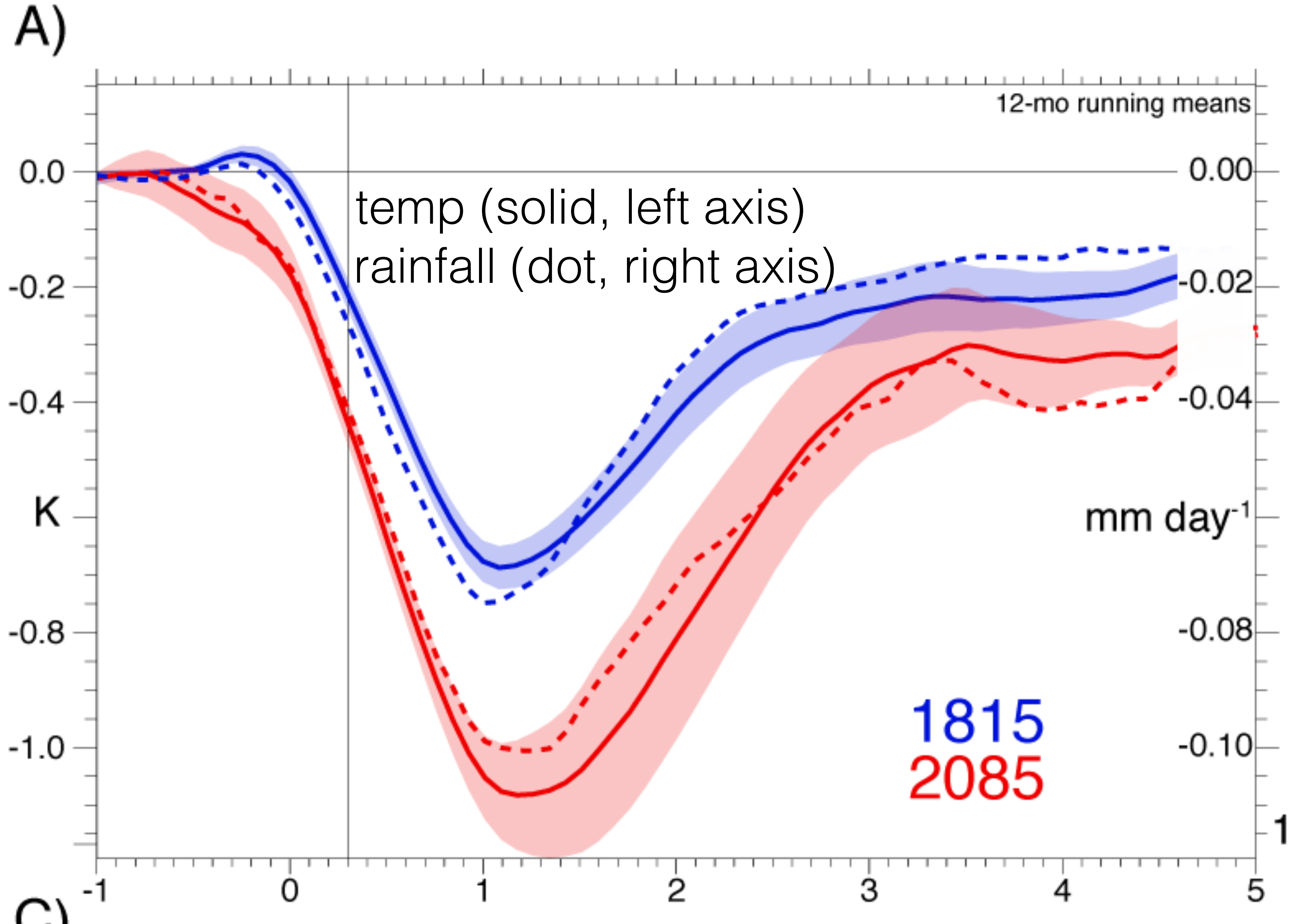
Q2: Why was cooling so strong during YWAS?

- In addition to ocean asymmetry, **Cryospheric responses** in the northern hemisphere were large and enhanced the radiative anomalies.
- Increase in surface albedo (ALBDS), reflect more sunlight and cool the surface.
- At YWAS latitude, snow cover is the primary influence.

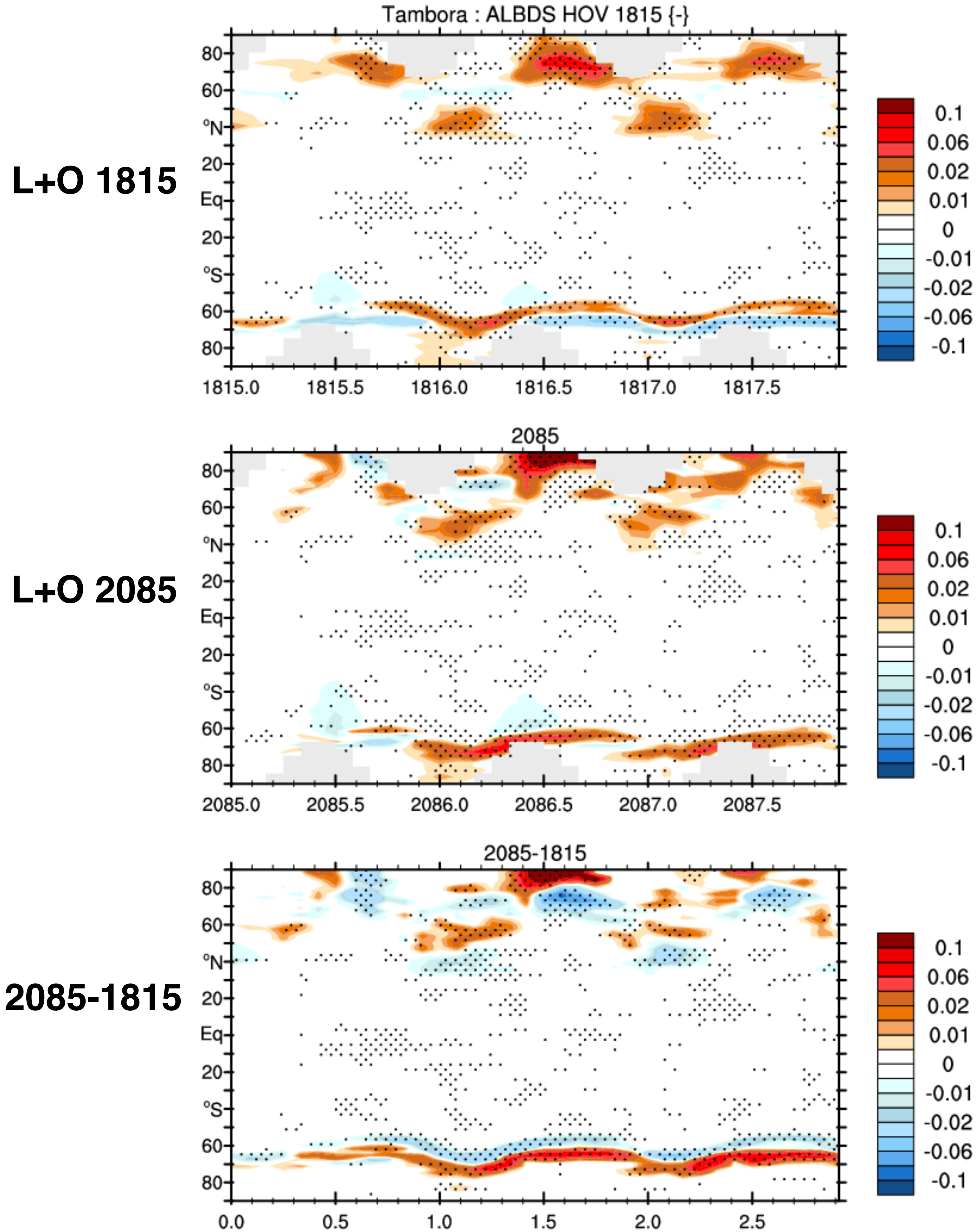


Amplification of Surface Response

Q3: 40% greater in 2085; Why?

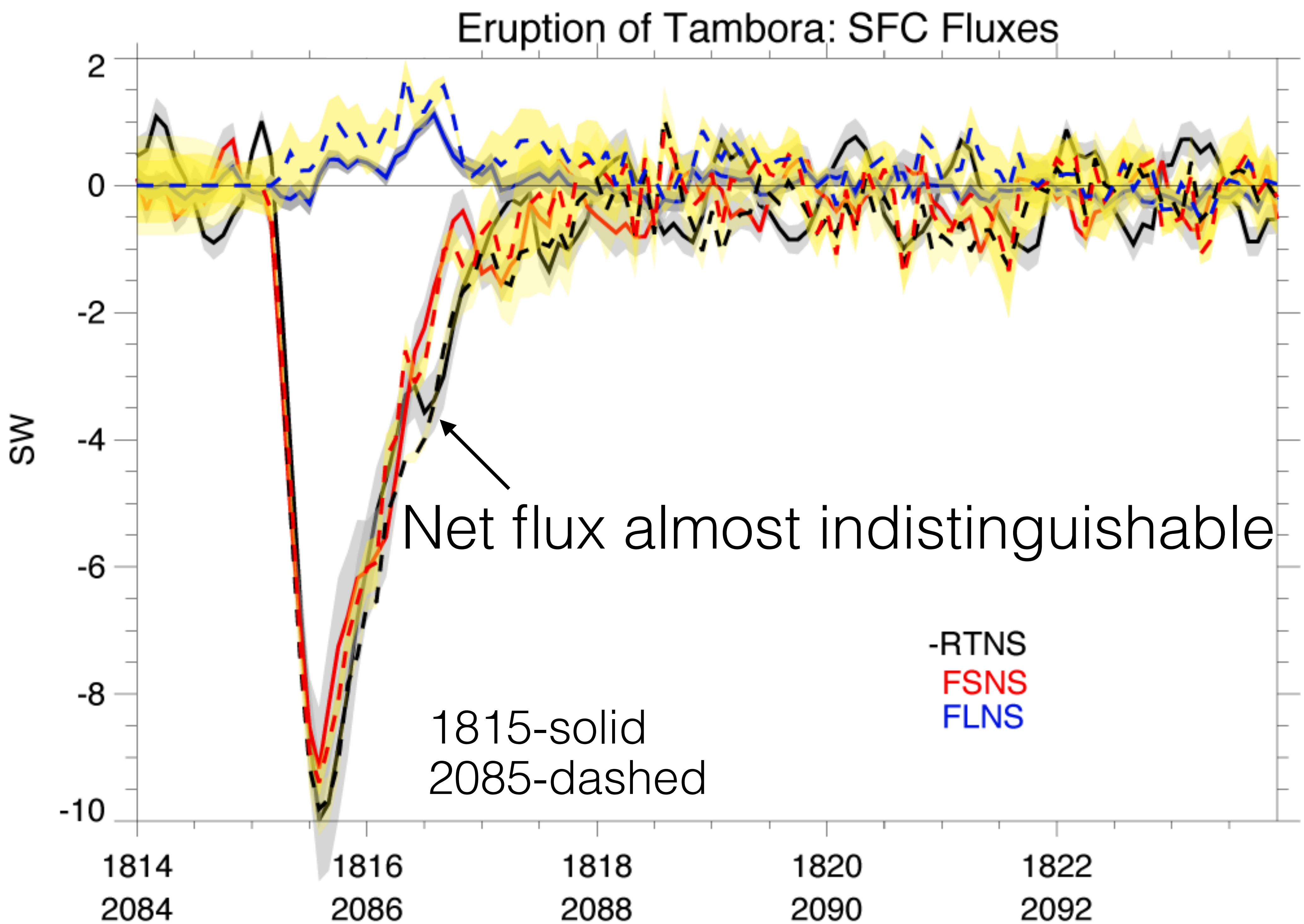


Was it the cryosphere?



- **Cryospheric responses** are displace northward in the future.
- In total extent, they become greater (less ice covered area in future mean state) but are exposed to less sunlight (higher lat).

But Associated Surface Radiative Fluxes Changes are Small



What Drives the Increased Future Response?

A) Global surface temperature response ⬆ 40%

B) Future climate upper ocean is more stratified.

C) Increased temperature response mainly in the tropics, lasts several years.

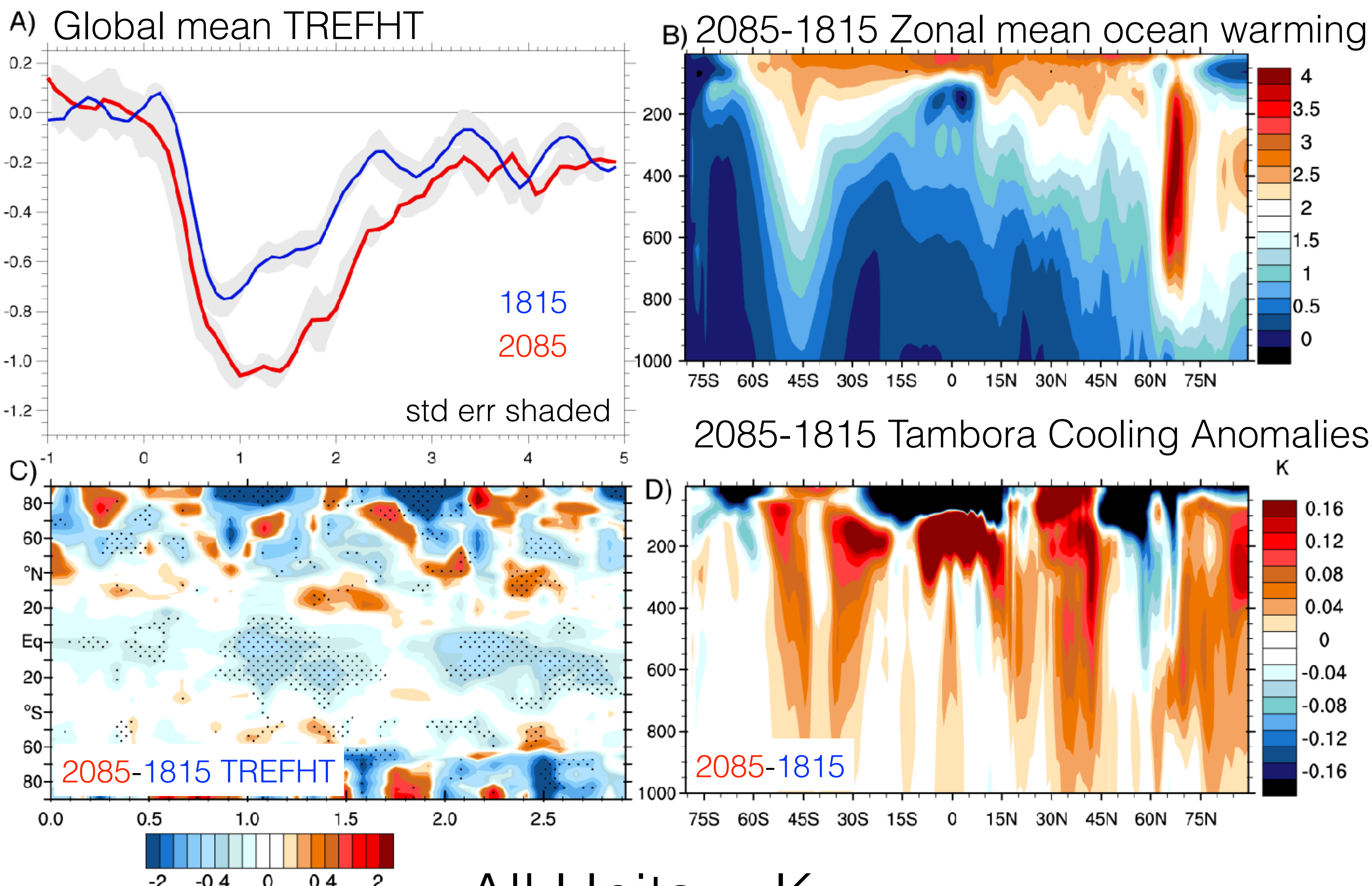
D) Less cooling at depth.

⬆ Stratification ⬇ Winds

Freshening of surface may also contribute to pattern:

⬆ stratification in Pacific.

⬇ stratification in Atlantic.



All Units = K

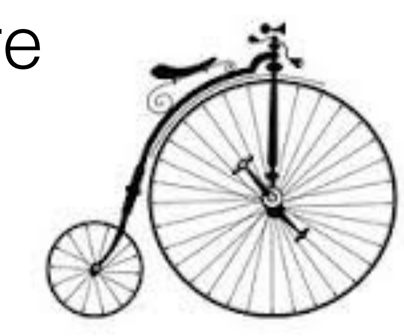
Take Home Points

- The global impact of the 1815 Tambora eruption was ***scary***. CESM provides insight into many aspects.

- The eruption's direct radiative effects had largely dissipated by the time of the "Year Without A Summer" - **cold ocean / cryospheric feedbacks set the stage**.

- **Ocean cooling played a key mediating role** in buffering atmospheric energy and water cycle responses.

- **Enhanced 21st C upper-ocean stability may limit the future ocean's buffering efficacy** ➠ likely to trap cooling near surface, increase the surface temperature and rainfall responses.

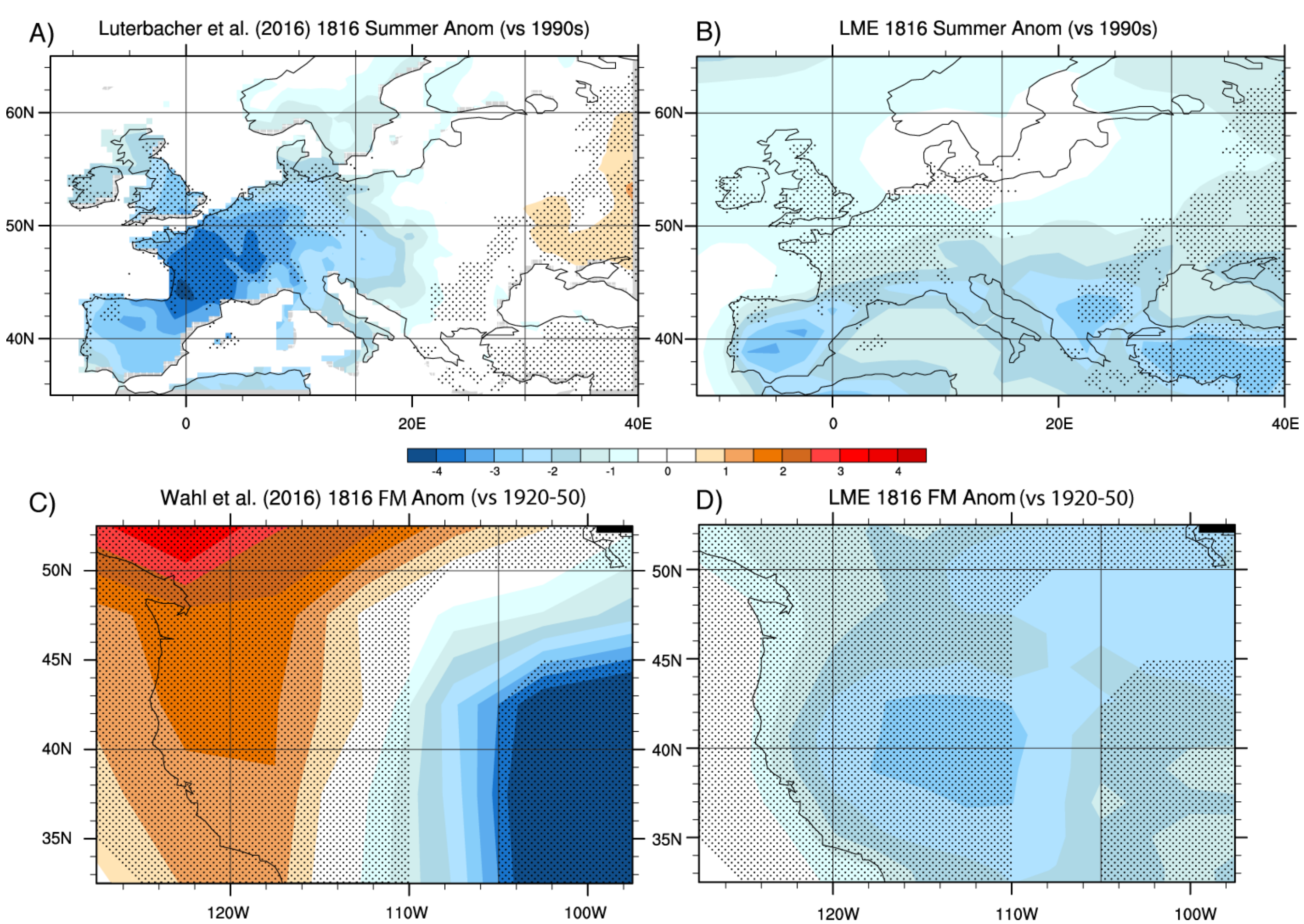


Ongoing Work

How can proxy reconstructions (showing heterogeneity in Tsfc response over land) be reconciled with models (which show little)?

Reconstructions vs LME

stippled where proxy is outside of LME range



Guillet et al. 2016, *Nat. Geo.*

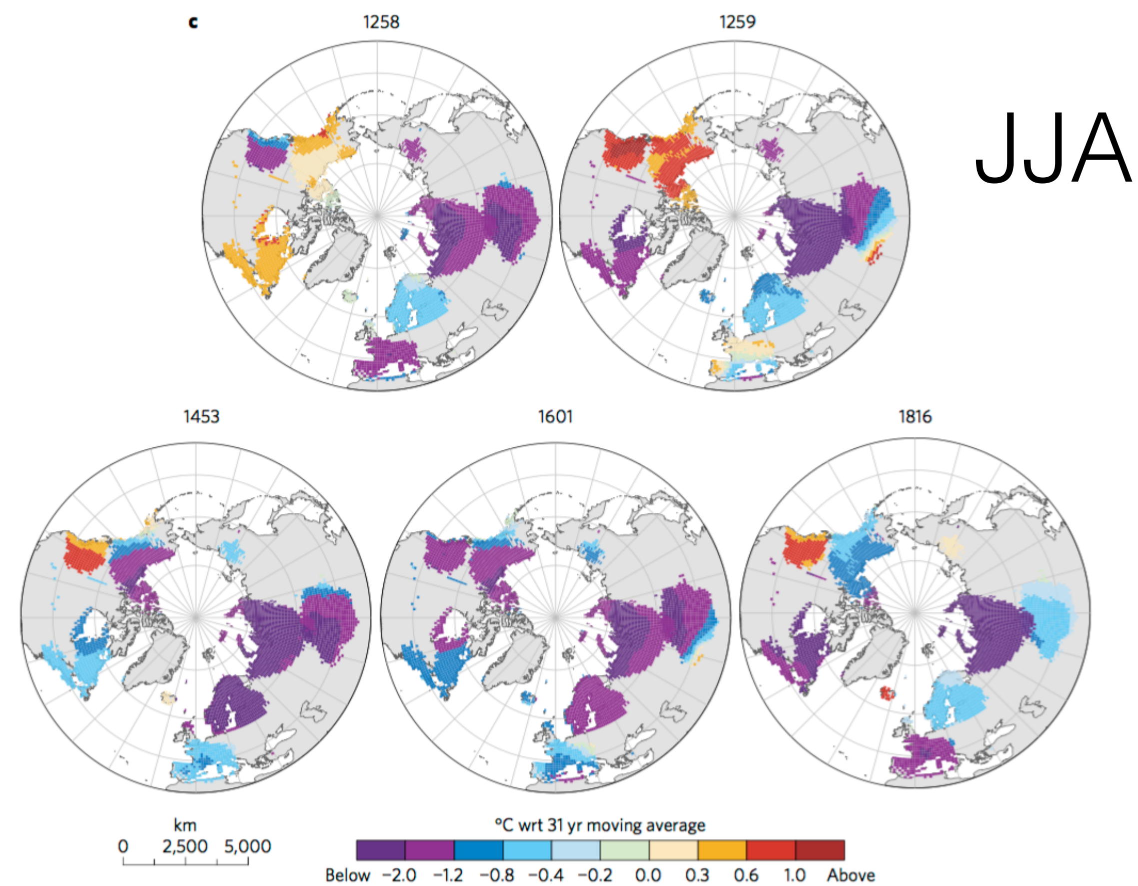
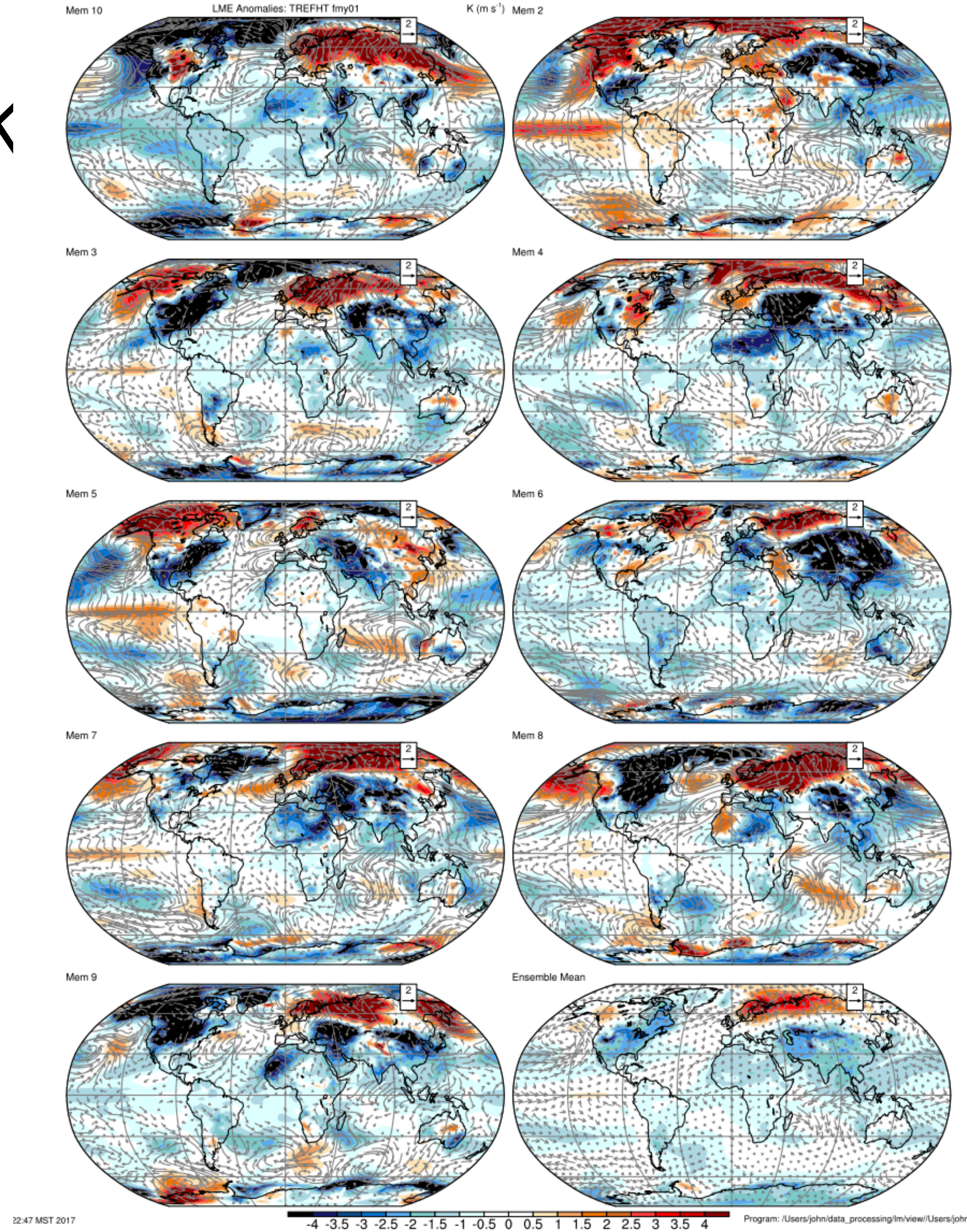


Figure 4 | Tree-ring reconstructions of NH extratropical land (40°–90° N) summer temperature anomalies since AD 1000. a, Summer (JJA) temperature anomalies following the 1257 Samalas eruption in 1258 and 1259 (blue) as compared with cumulative distribution functions for all major volcanic eruptions (that is, 1109, 1453, 1601, 1641, 1695, 1783, 1809, 1816, 1835, 1884 and 1912; black) and for all non-volcanic years (red) since AD 1000. **b,** The same as in **a,** but for groups of two consecutive years following major eruptions. **c,** Spatial extent of the JJA temperature anomalies induced by the Samalas (cooling shown for 1258 and 1259), unknown (1453), Huaynaputina (1601) and Tambora (1816) eruptions. For details see Methods.

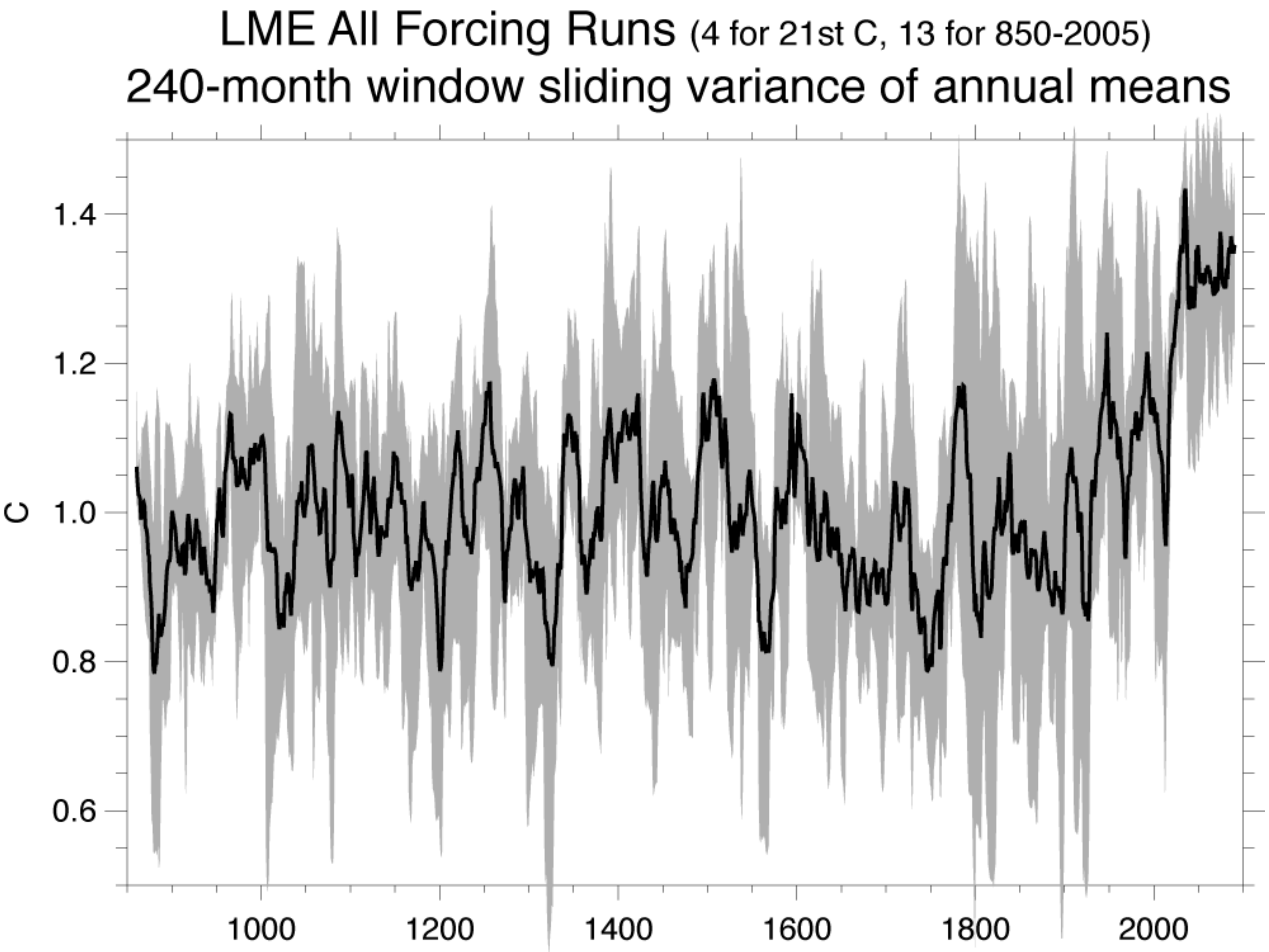
Ongoing Work

Feb/Mar 1816 in the LME fails to replicate the proxy estimated U.S. warm west (2-4C) / cool east gradient.



Ongoing Work

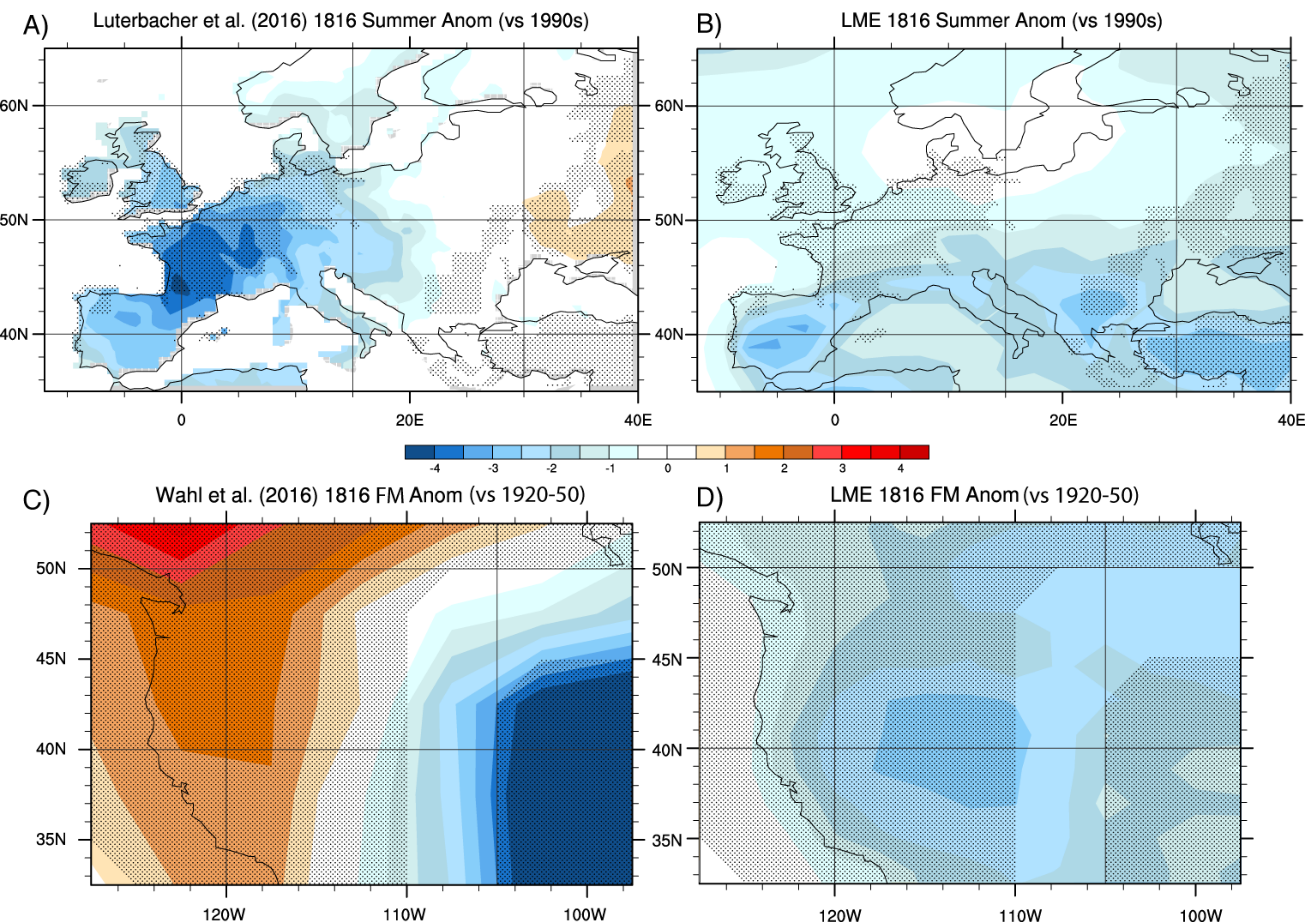
Are 4 members sufficient?

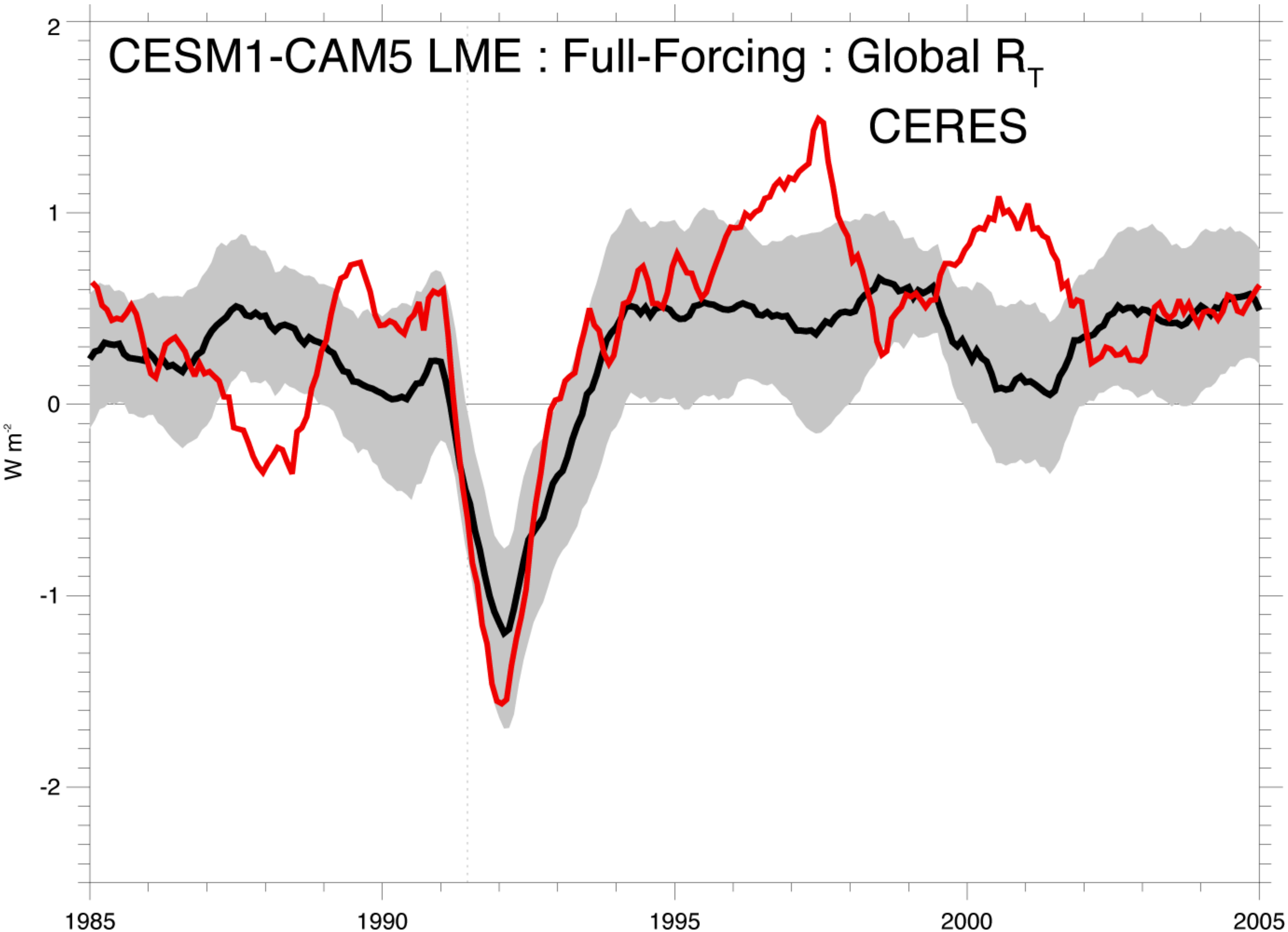


LME 21C
> 2x Obs

Obs ≅0.65

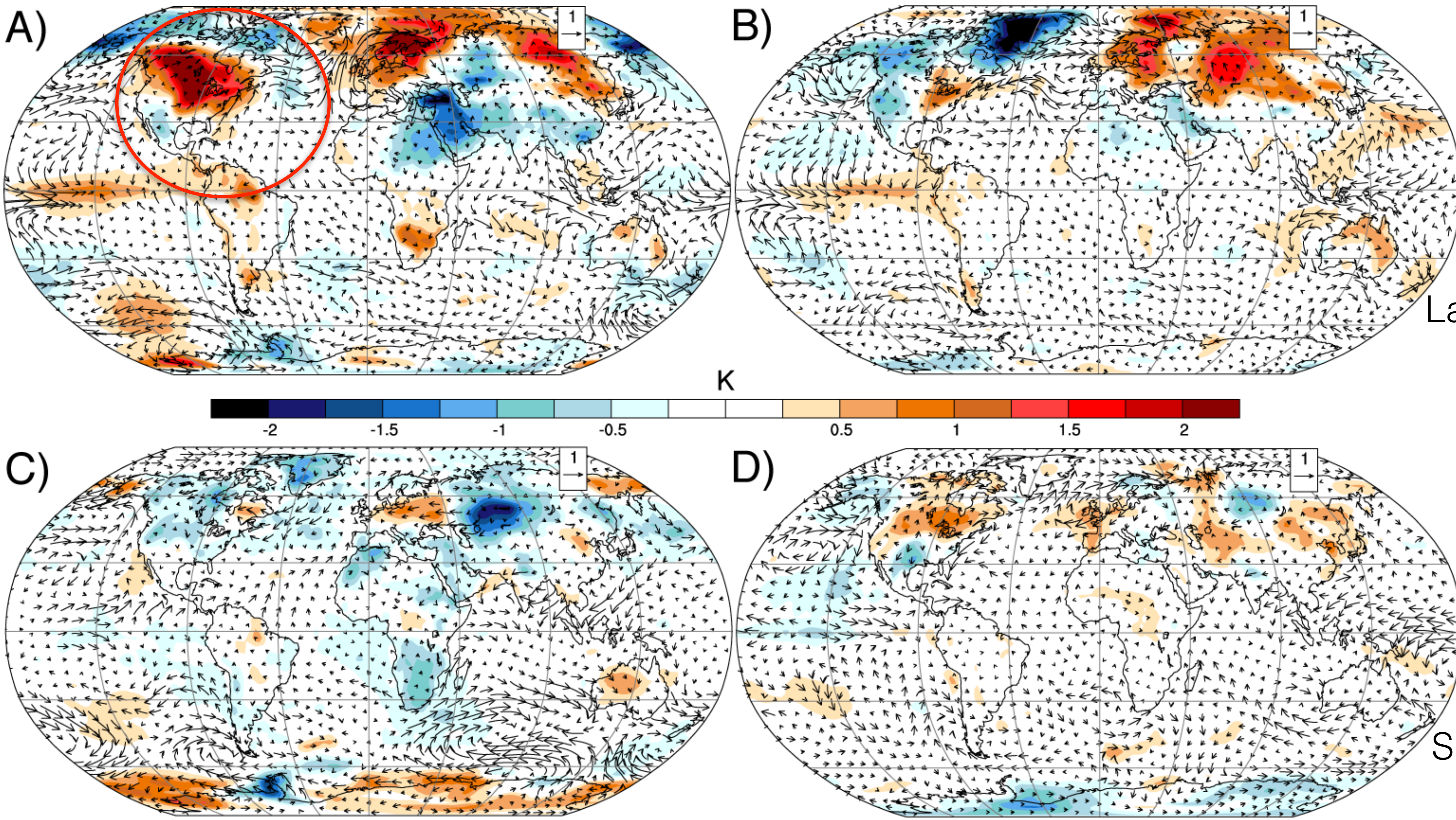
END


A)
Luterbacher et al. (2016) 1816 Summer Anom (vs 1990s)
B)
LME 1816 Summer Anom (vs 1990s)
60N
50N
40N
0
20E
40E
-4
-3
-2
-1
0
1
2
3
4
C)
Wahl et al. (2016) 1816 FM Anom (vs 1920-50)
D)
LME 1816 FM Anom (vs 1920-50)
50N
45N
40N
35N
120W
110W
100W



CESM1-CAM5 LME : Full-Forcing : Global R_T
CERES
2
1
0
-1
-2
W m^{-2}
1985
1990
1995
2000
2005

20th C Reanalysis Composite (NOAA-ERA20C similar)



Large Eruptions
1860-2010

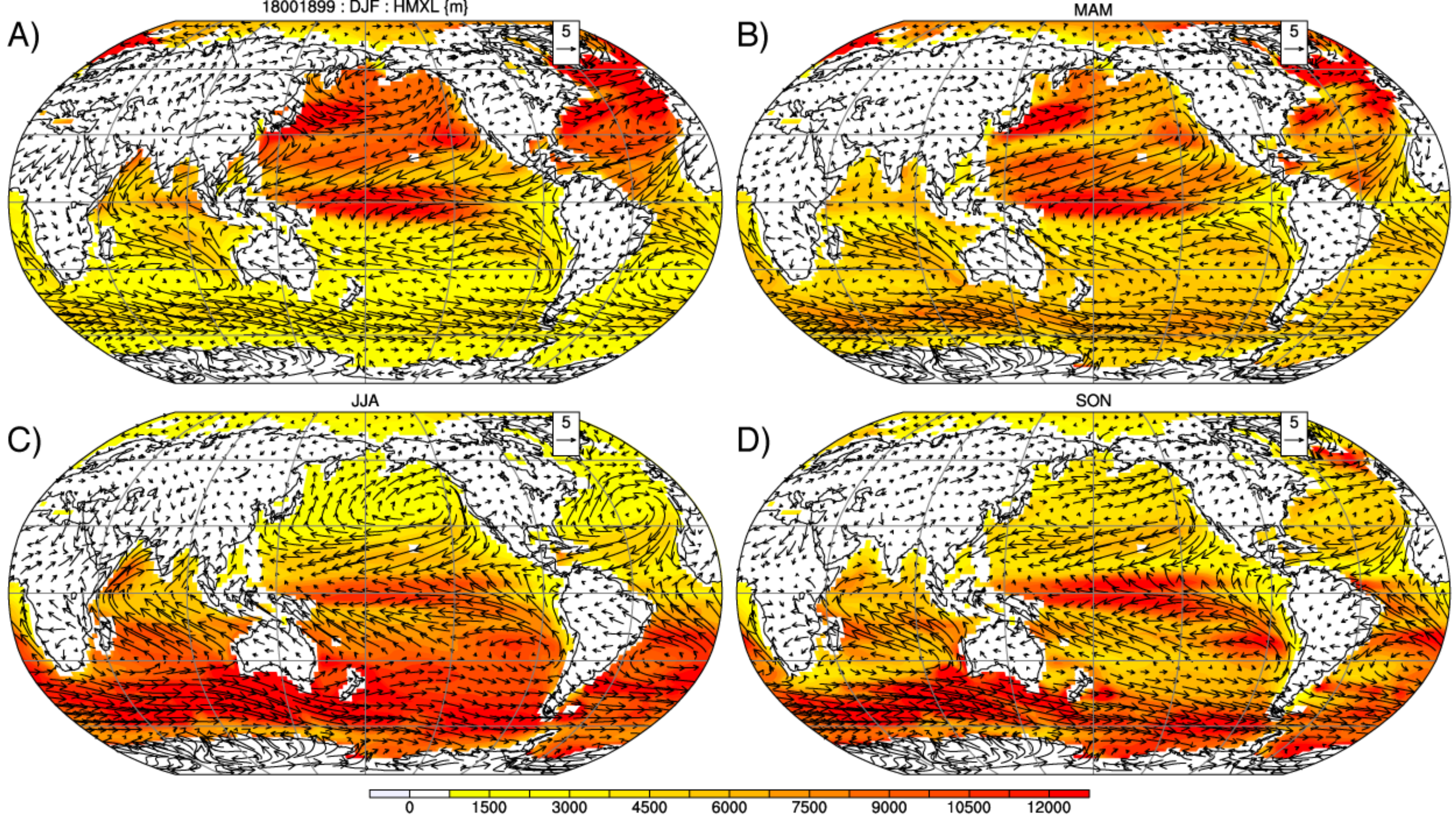
Small Eruptions
1860-2010

DJF Response

JJA Response

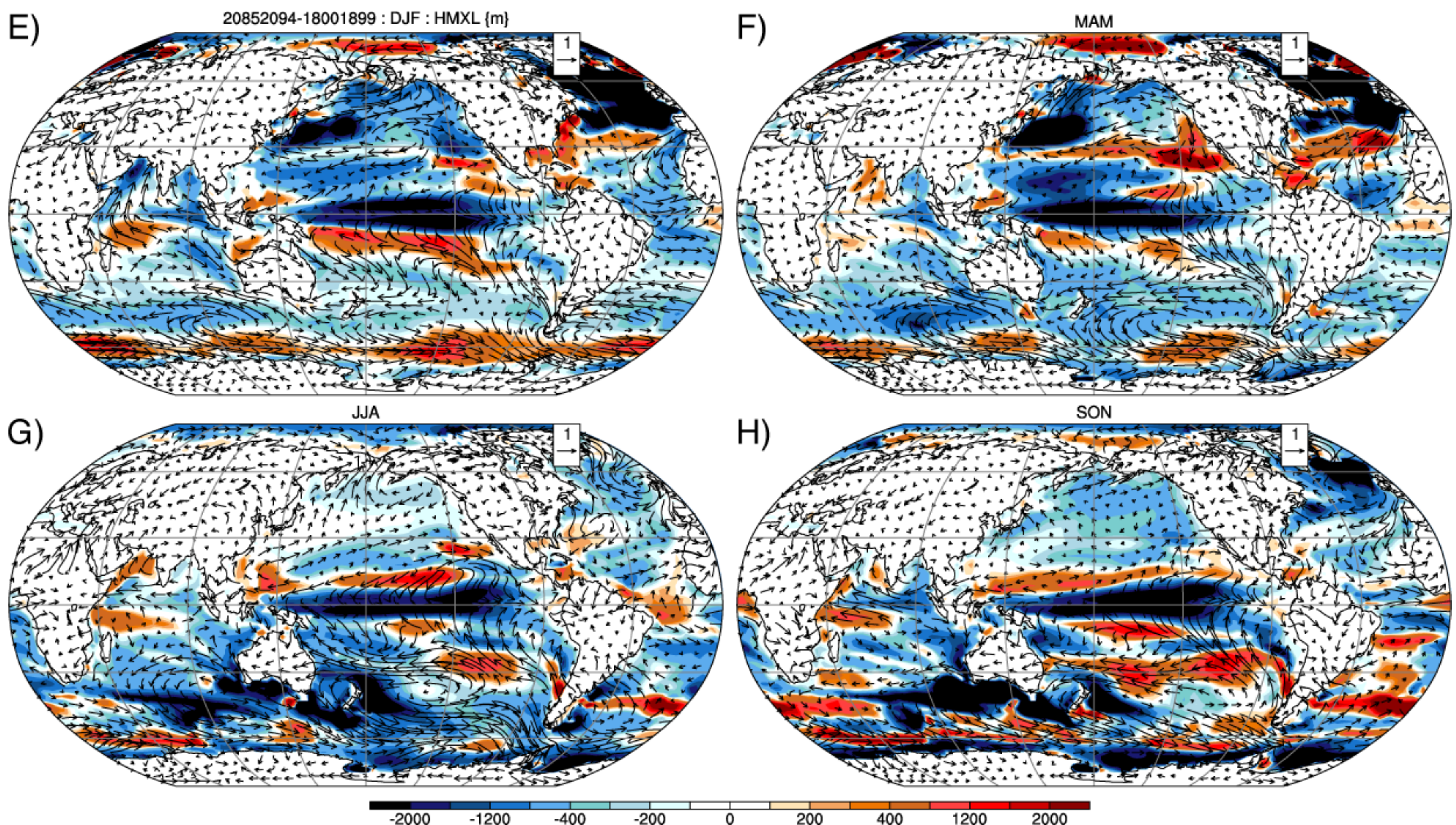
Mean State Mixed Layer Depth

Mixed layer depth is strongly seasonal, greatest in the winter hemisphere, where net surface heating is negative.



Changes 2090-1800s

Changes are a function of location and season but are generally blue reflecting a reduction in surface wind speed



Mean State 10 m Wind Speed

Surface wind speed is greatest in the sub polar regions and seasonally in the subtropics.

Changes 2090-1800s

Changes are a function of location and season but are generally blue reflecting a reduction in surface wind speed