Seasonal Sensitivity of (Tropical) Volcanic Climate Impacts

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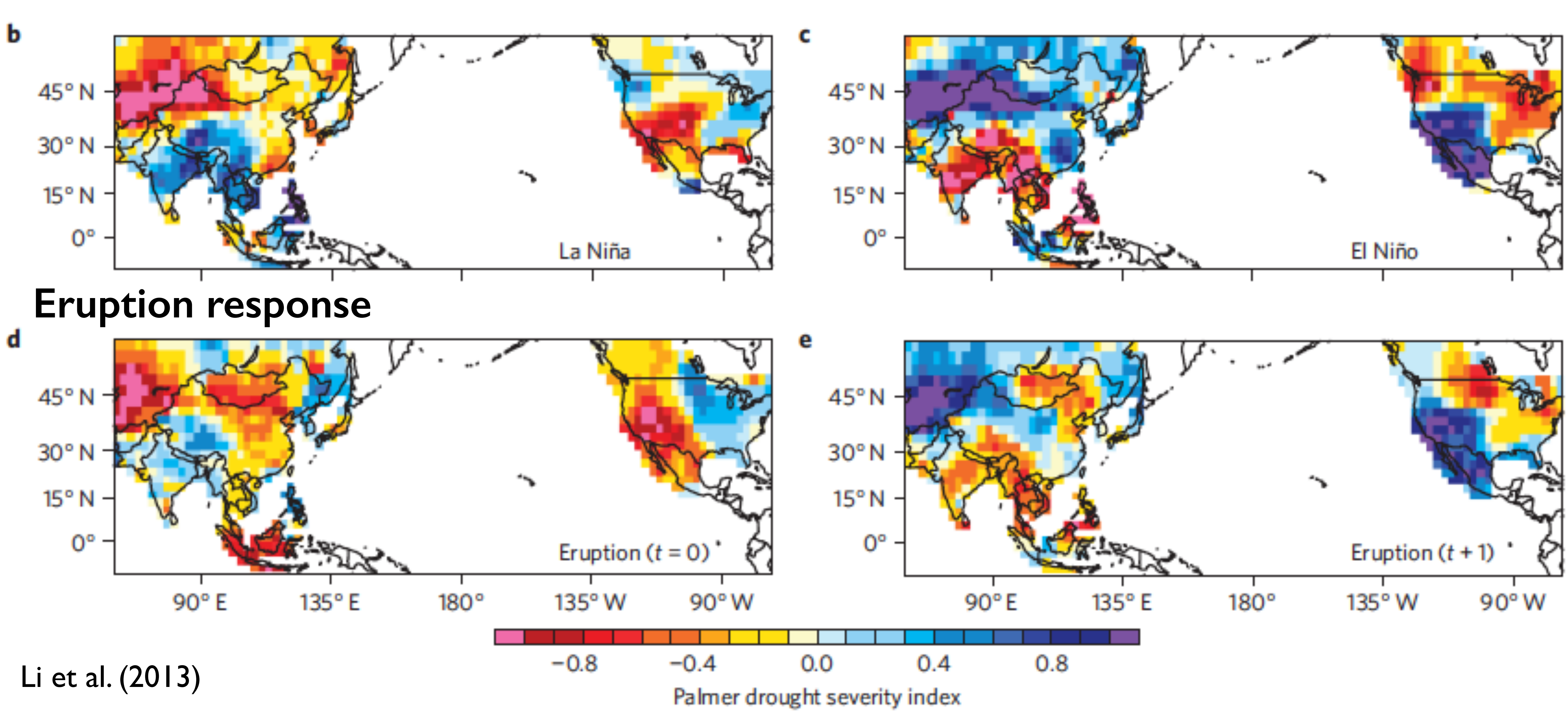
Proxy reconstructions: eruption year "La Niña", delayed "El Niño"

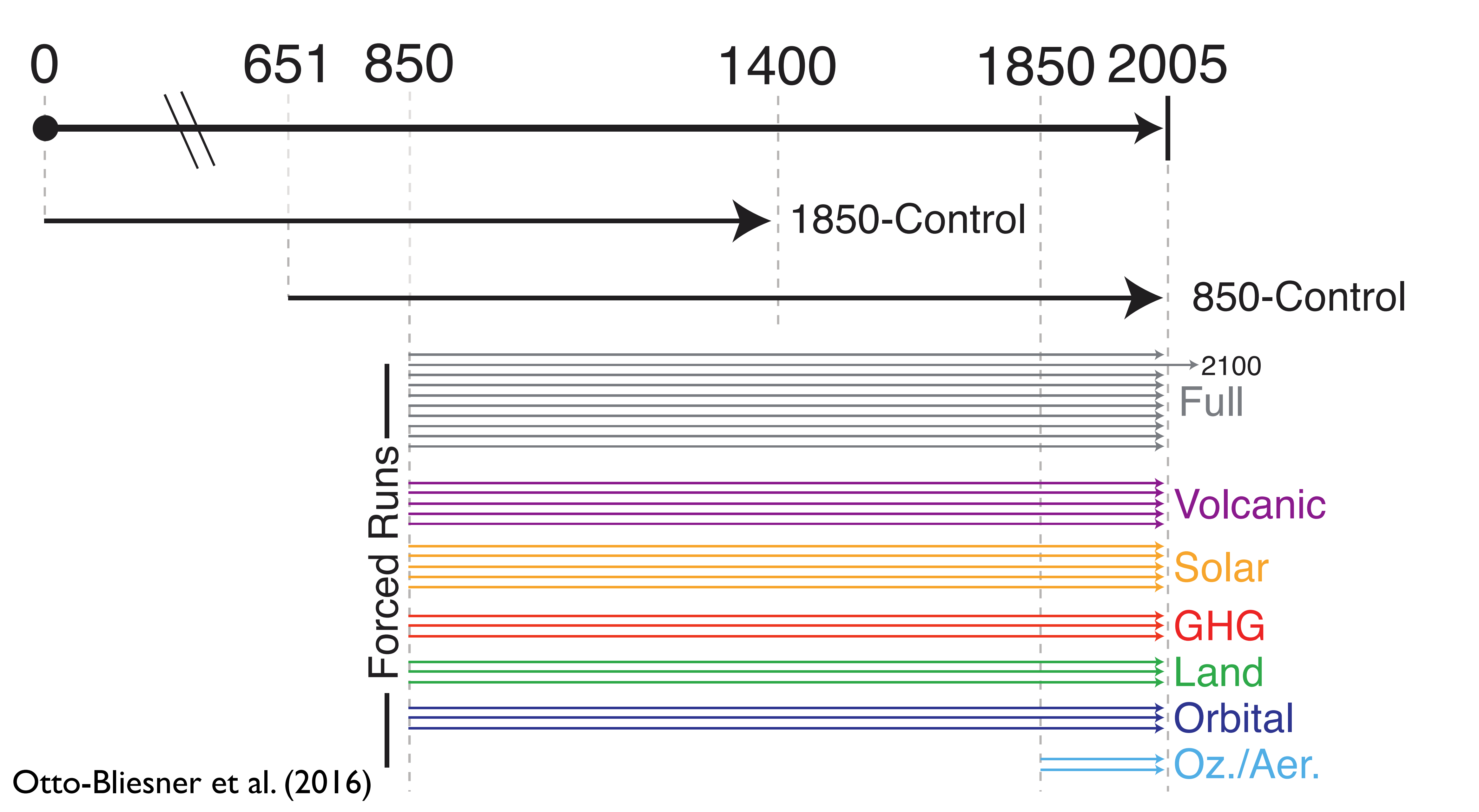
ENSO teleconnection



Li et al. (2013)

(red = dry, blue = wet)

CESM Last Millennium Ensemble

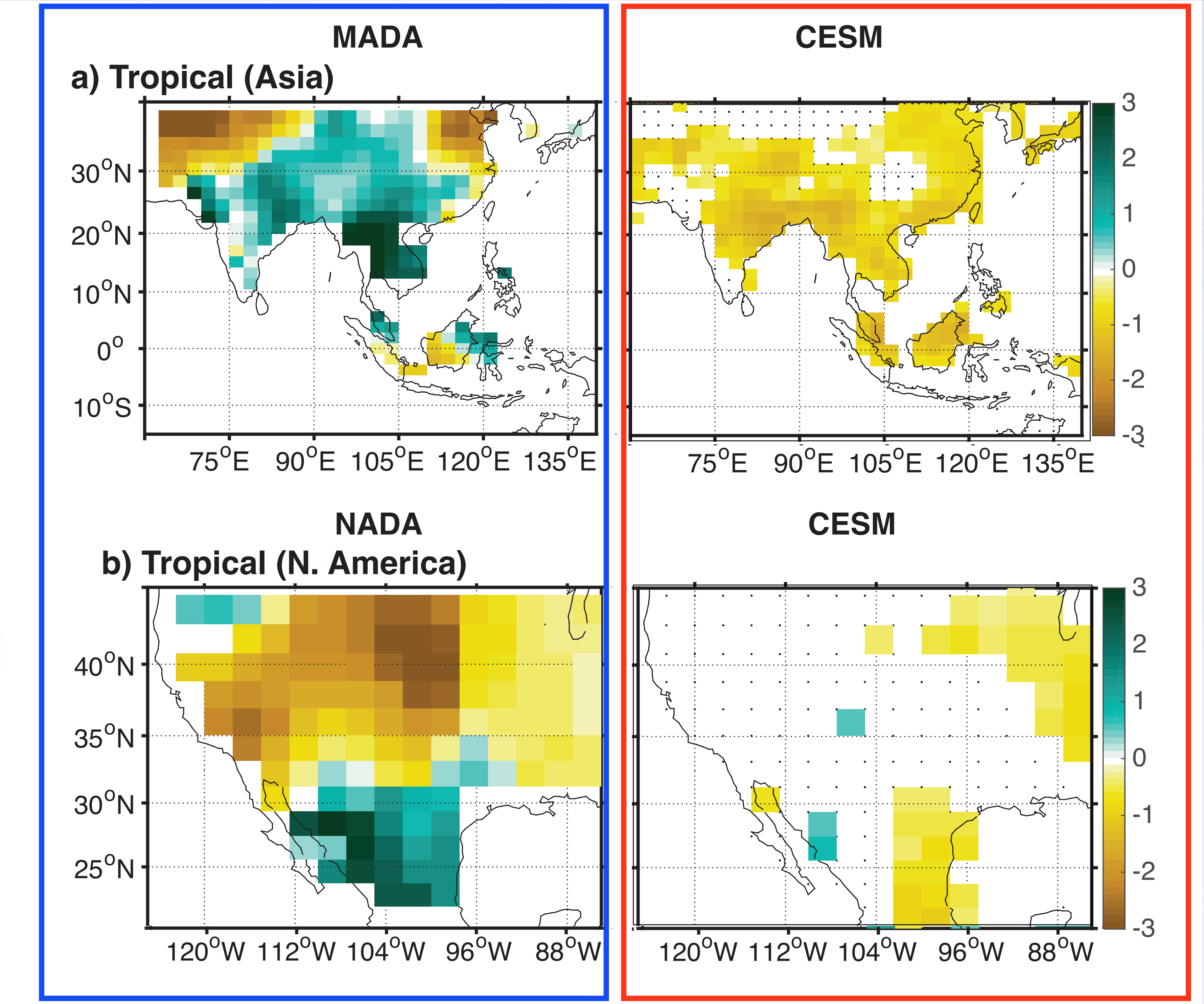


NCAR Community Earth System Model
Multiple ensembles, varying sizes: different combinations of climate forcings (35+ members)
850-2005 for most ensembles, 1850-2005 for ozone/aerosol only
Some extensions to 2100 available; isotope-enabled experiment planned

CESM tends not to reproduce eruption-year proxy composites

Monsoon Asia and North American Drought Atlases (MADA, NADA):

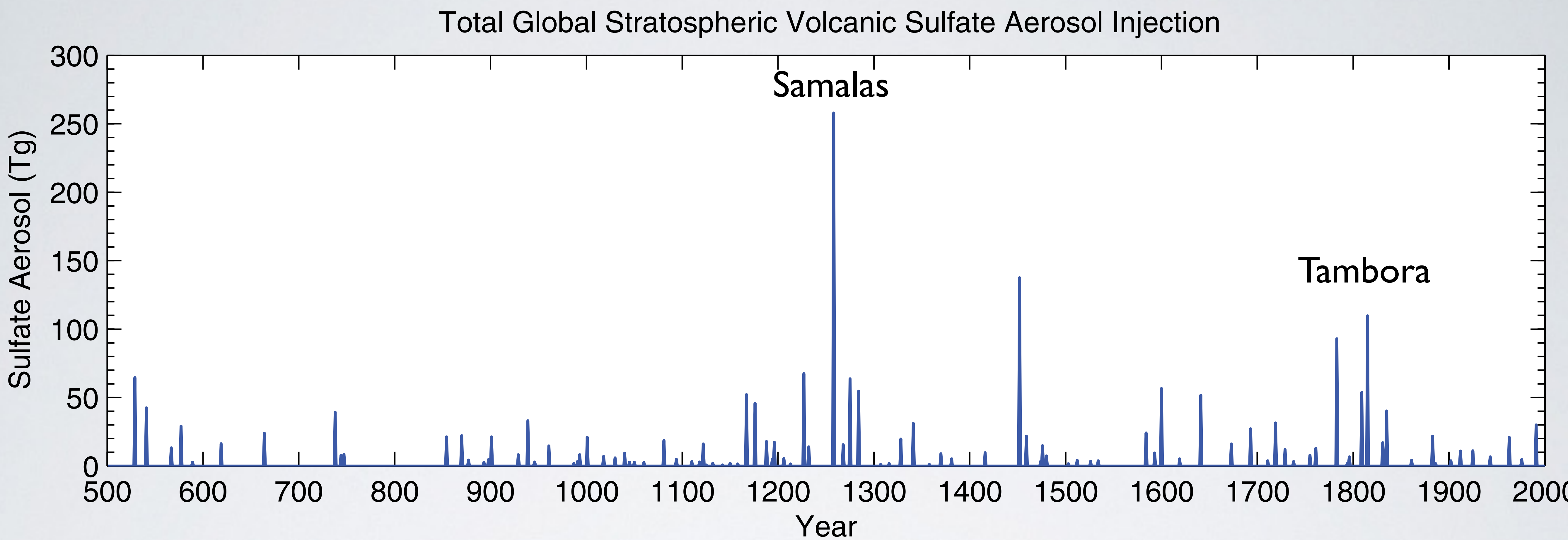
"La Niña-like" responses (wetter Southeast Asia, drier western US)



CESM: "El Niño-like" responses (drier Southeast Asia, not much in North America)

Stevenson et al. (2016a)

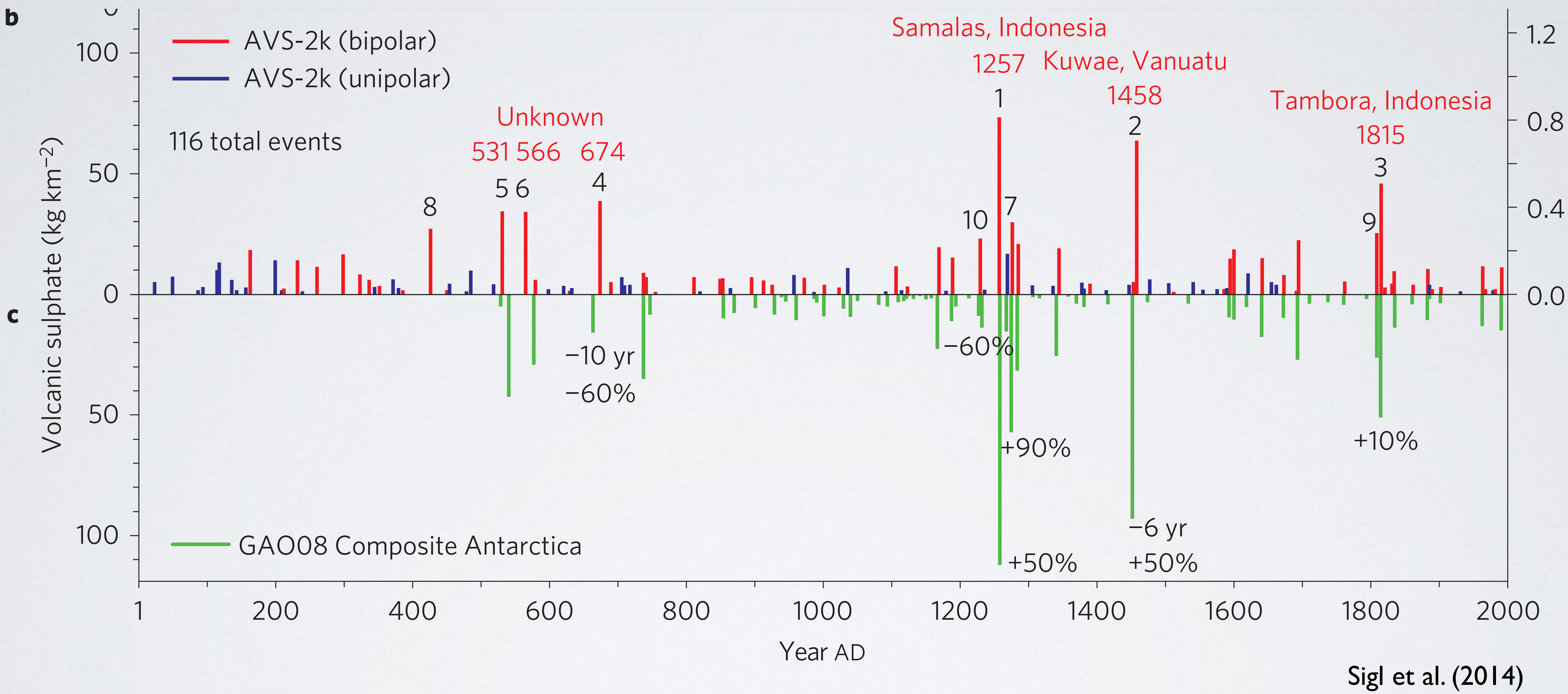
Volcanic forcing in CESM: Gao et al. (2008)



Gao et al. (2008)

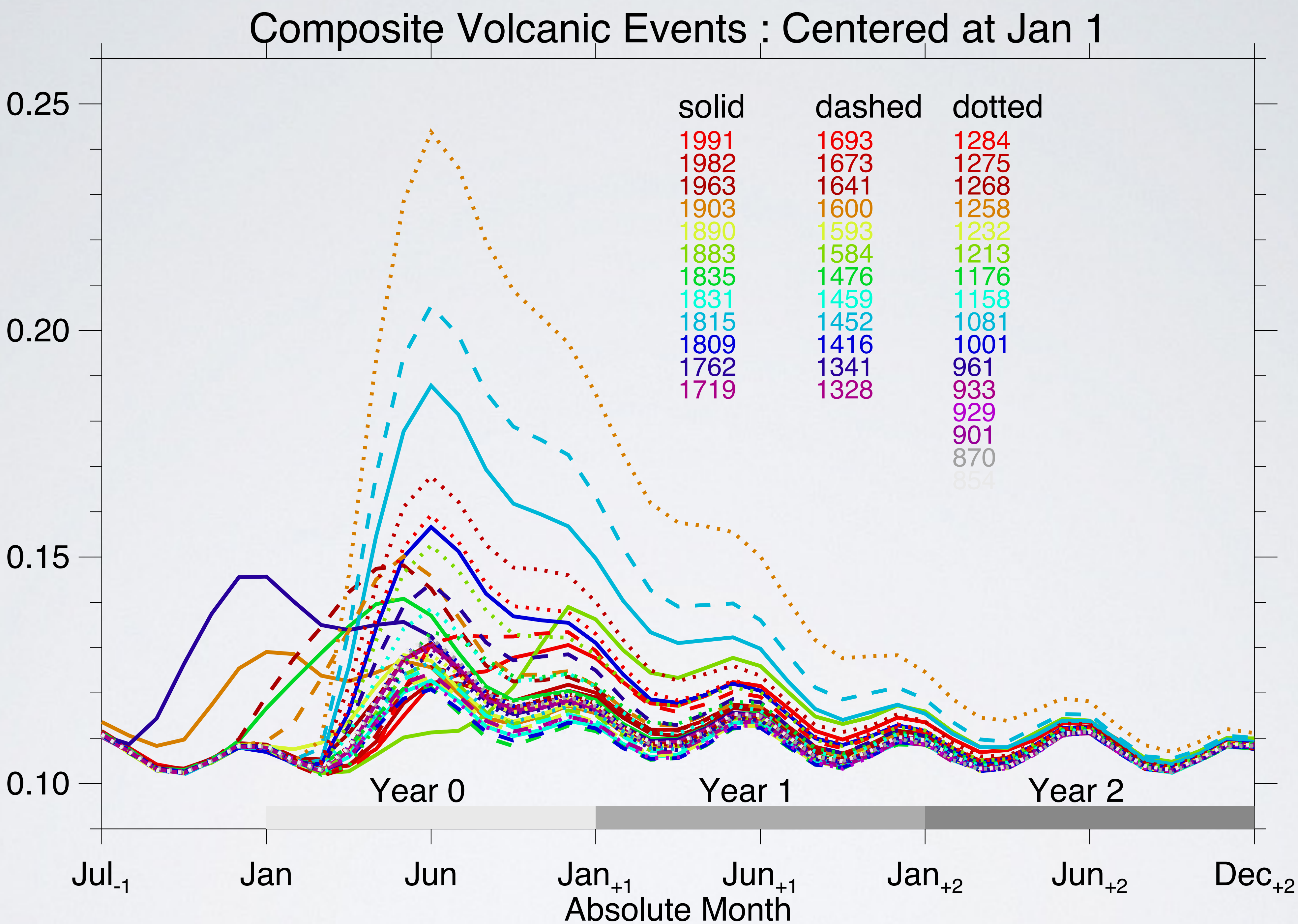
Hemispheric aerosol deposition estimated from Greenland, Antarctic ice cores
Seasonally variable stratospheric transport model describes subsequent spreading (16 lat bands)
Linear buildup, exponential decay for each eruption
Vertical distribution, aerosol sizes based on 1991 Pinatubo eruption

Uncertainties in volcanic forcing can be substantial



Latest reconstruction results: total eruption strength can differ from Gao et al. by a factor of 2!

Eruption season not well constrained in many cases

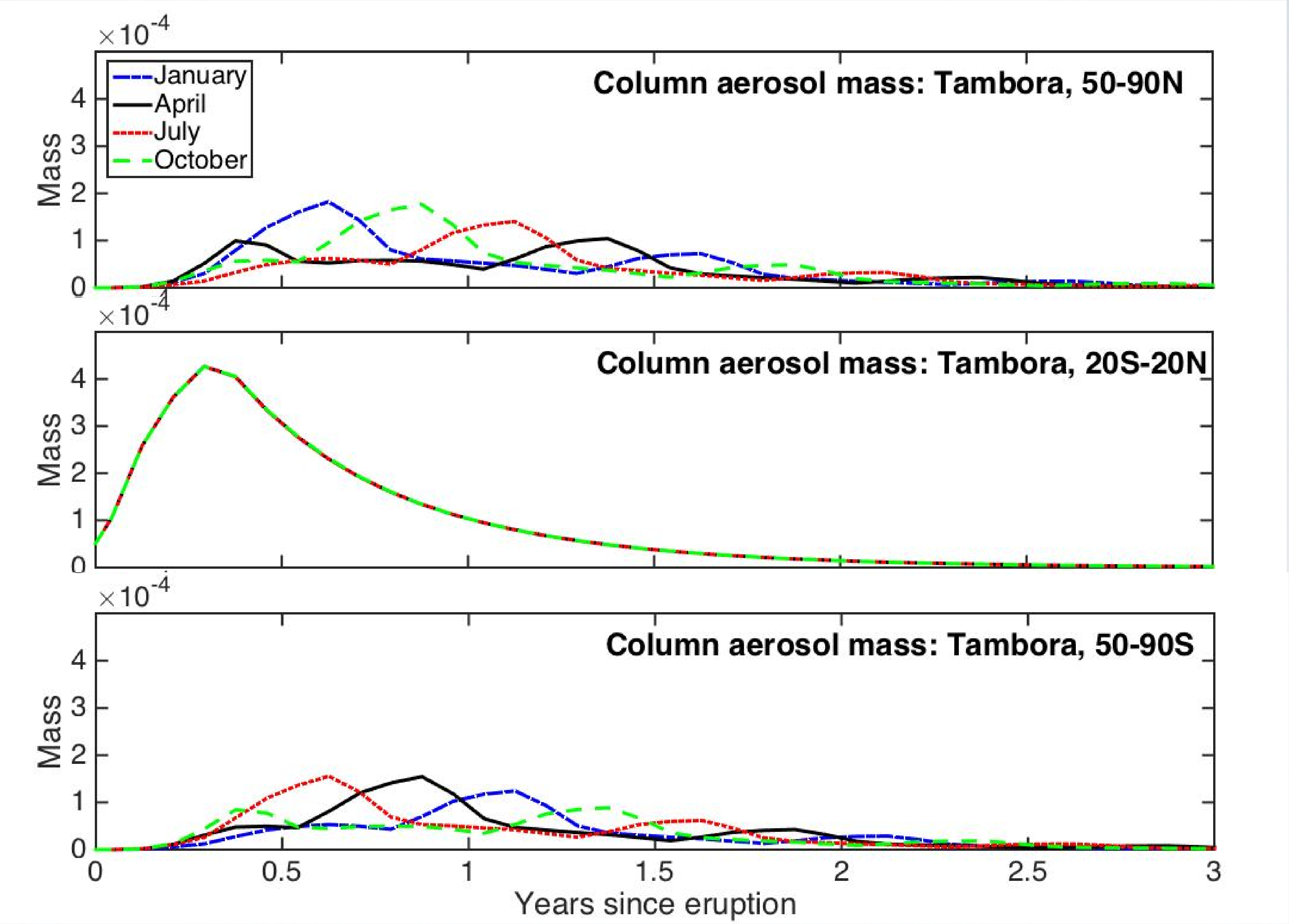


Stevenson et al. (2016a)

30N-30S clear-sky albedo for LME volcanic eruptions

Starting month often unknown: if in doubt, it happened in April!

Testing the impact of eruption season: "Tambora", "Samalas"



Stevenson et al. (2016b)

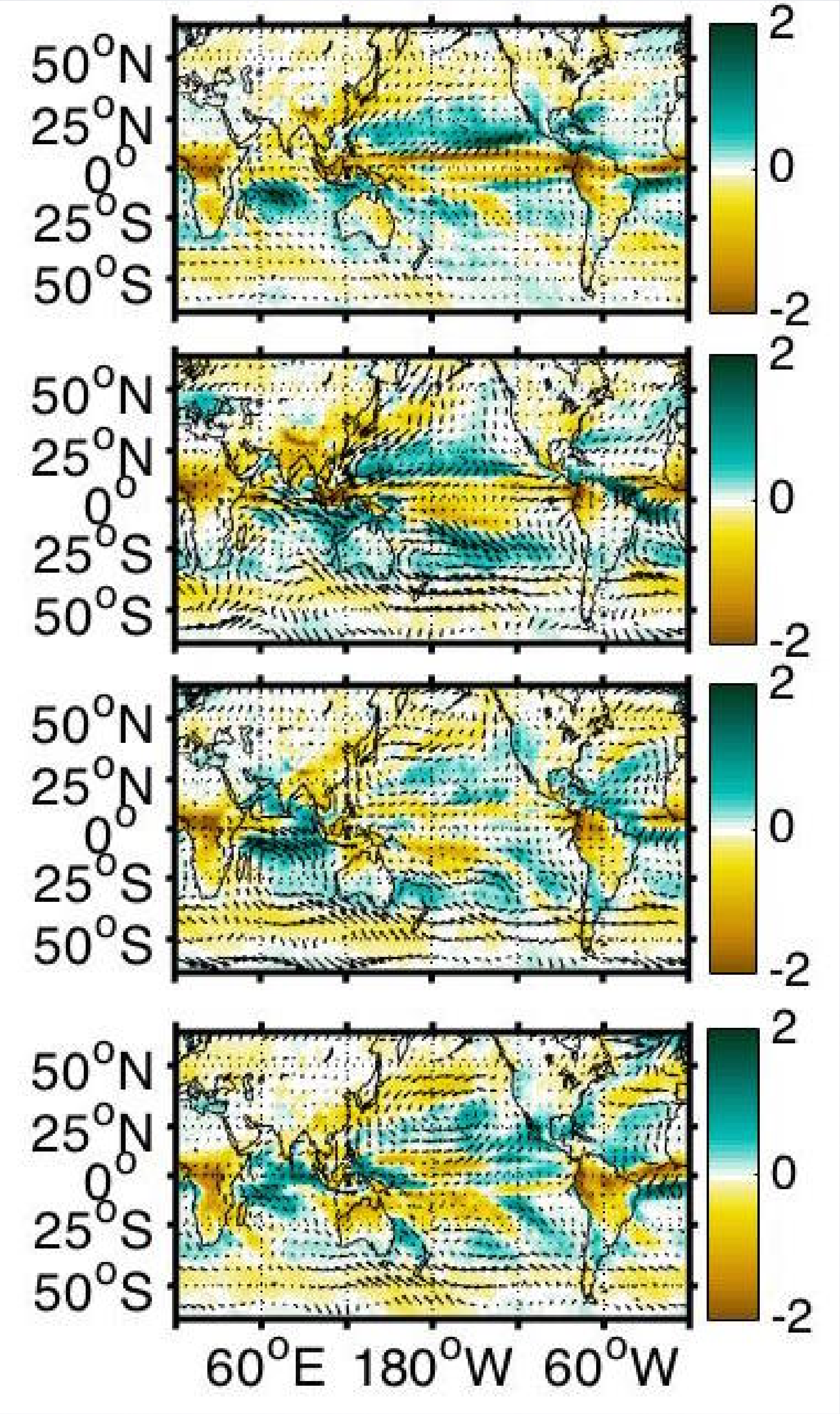
Suite of idealized experiments: reran Gao et al. algorithm for Tambora, Samalas in January/April/July/October

10-15 ensemble members per eruption per season

Eruption-year circulation response differs based on starting month

Composite precipitation (colors) and 850 hPa winds (arrows), 0-5 months following eruptions

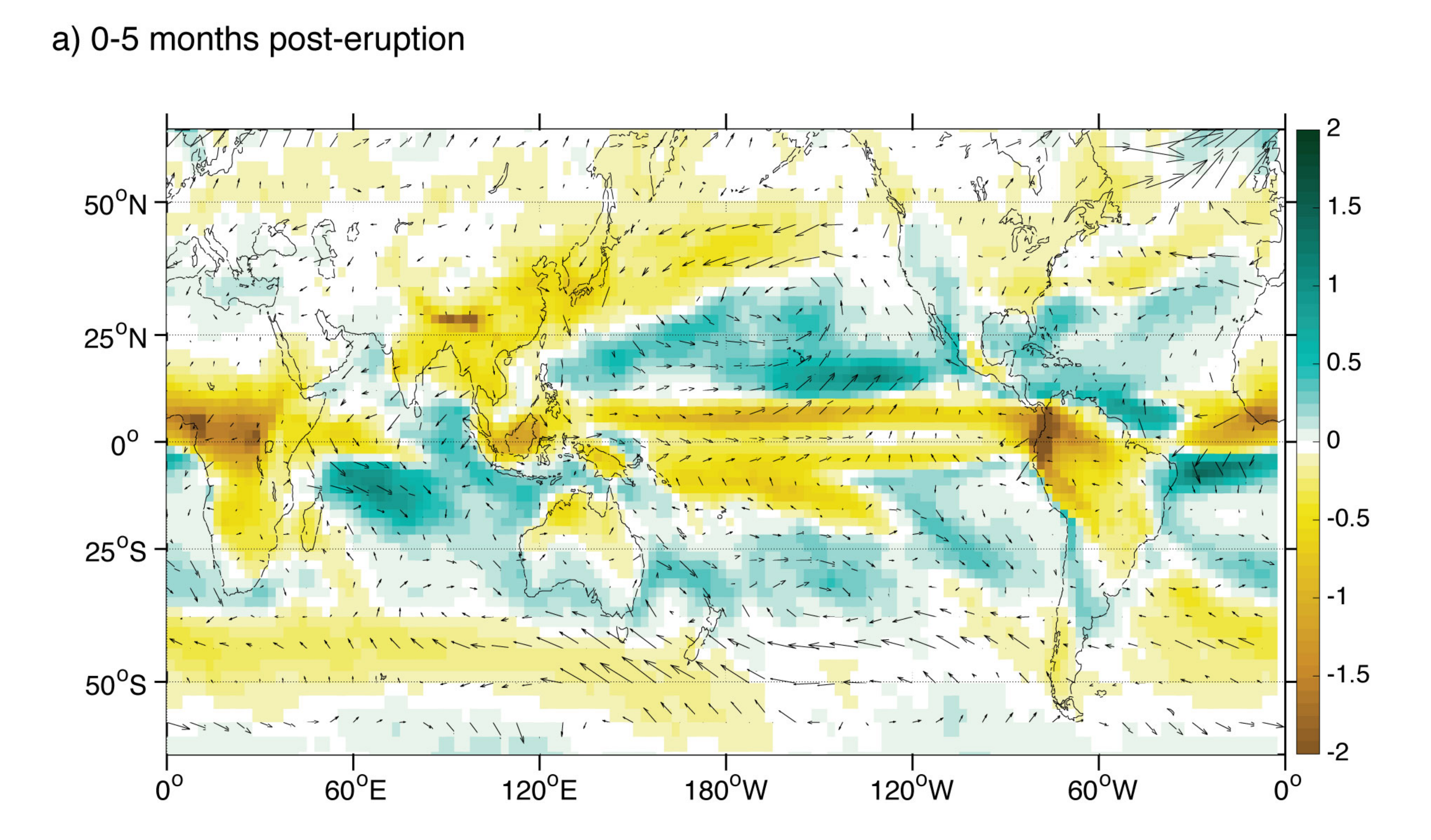
General tendency for suppressed equatorial precipitation, consistent with poleward ITCZ shift



Stevenson et al. (2016b)

Sam Stevenson

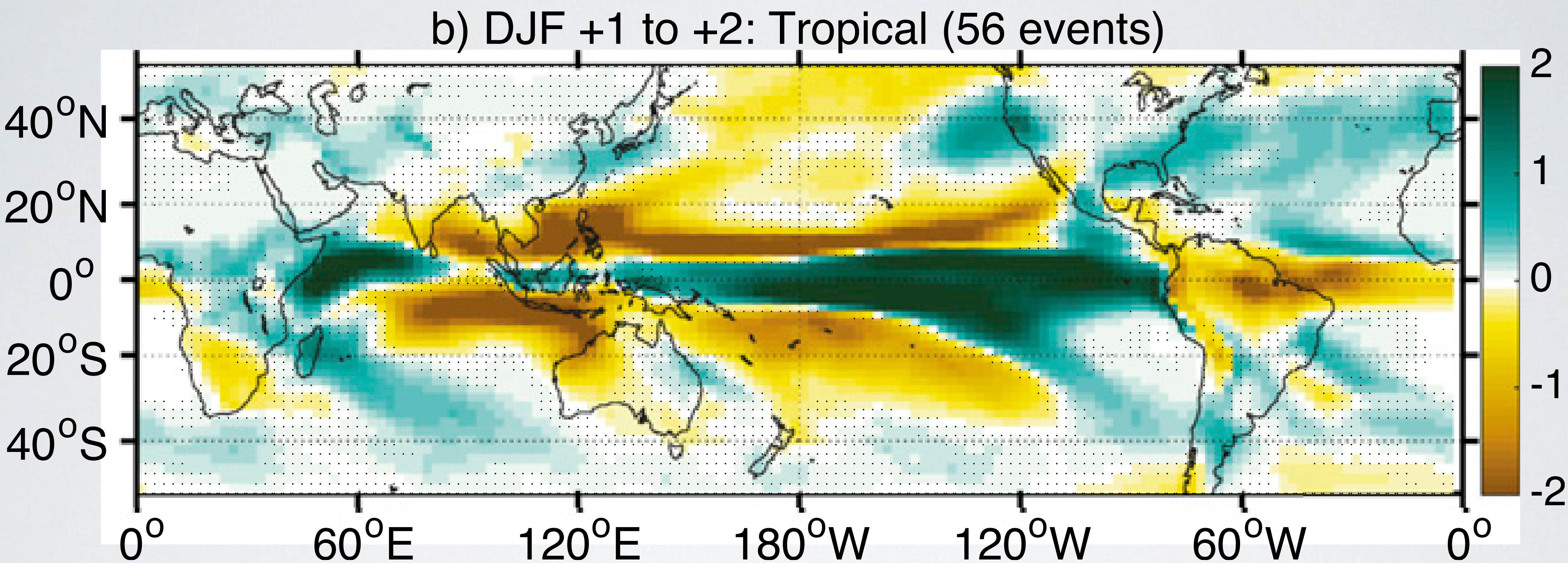
Circulation response 'La Niña-like' over ocean, 'El Niño-like' on land



850 hPa wind (arrows) and precipitation anomalies (colors) after idealized Tambora/Samalas eruptions; mean across all erution seasons

Stevenson et al. (2016b)

Delayed (Year +1) circulation response: El Niño-like



Stevenson et al. (2016a)

LME: DJF precipitation changes, boreal winter immediately following eruption

Stippling indicates change insignificant relative to internal variability

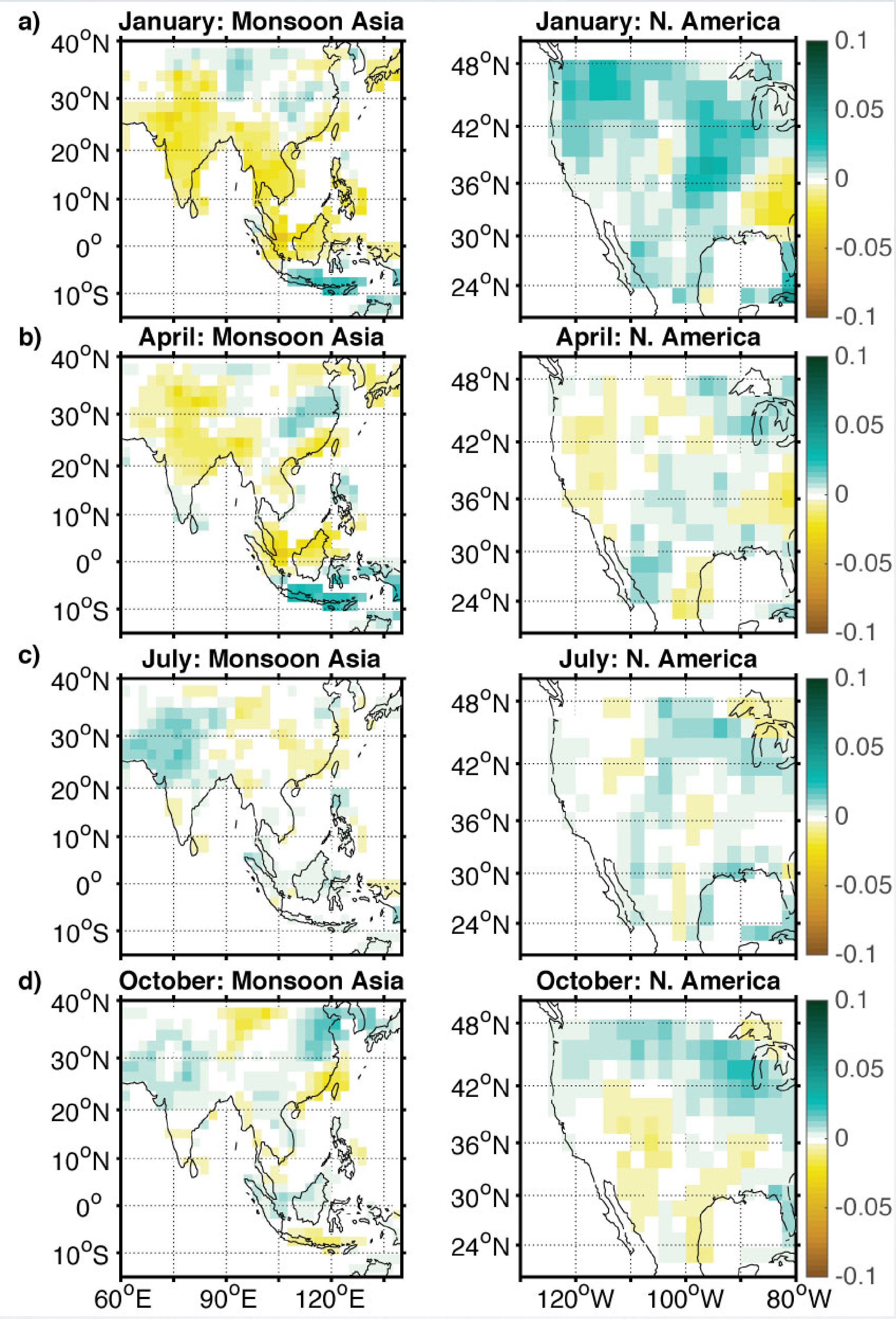
Eruption season strongly influences immediate hydroclimate response

January

April

July

October

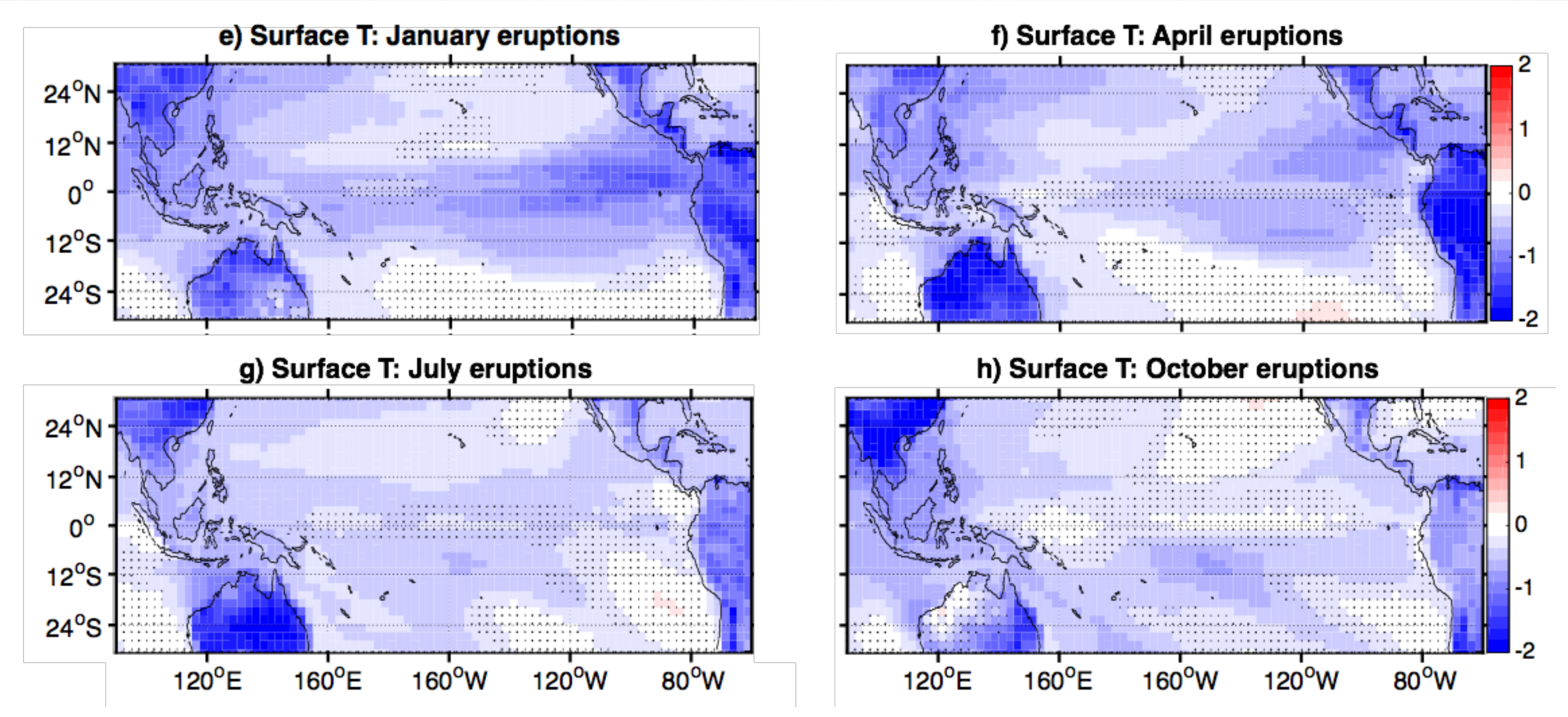


Stevenson et al. (2016b)

Composite 0-30cm soil moisture anomaly for Year 0 JJA (average of Tambora and Samalas); only significant departures plotted

Patterns depend strongly on season: January more "El Niño like", July/Oct more "La Niña like"

Eruption-year cooling is not 'La Niña-like'

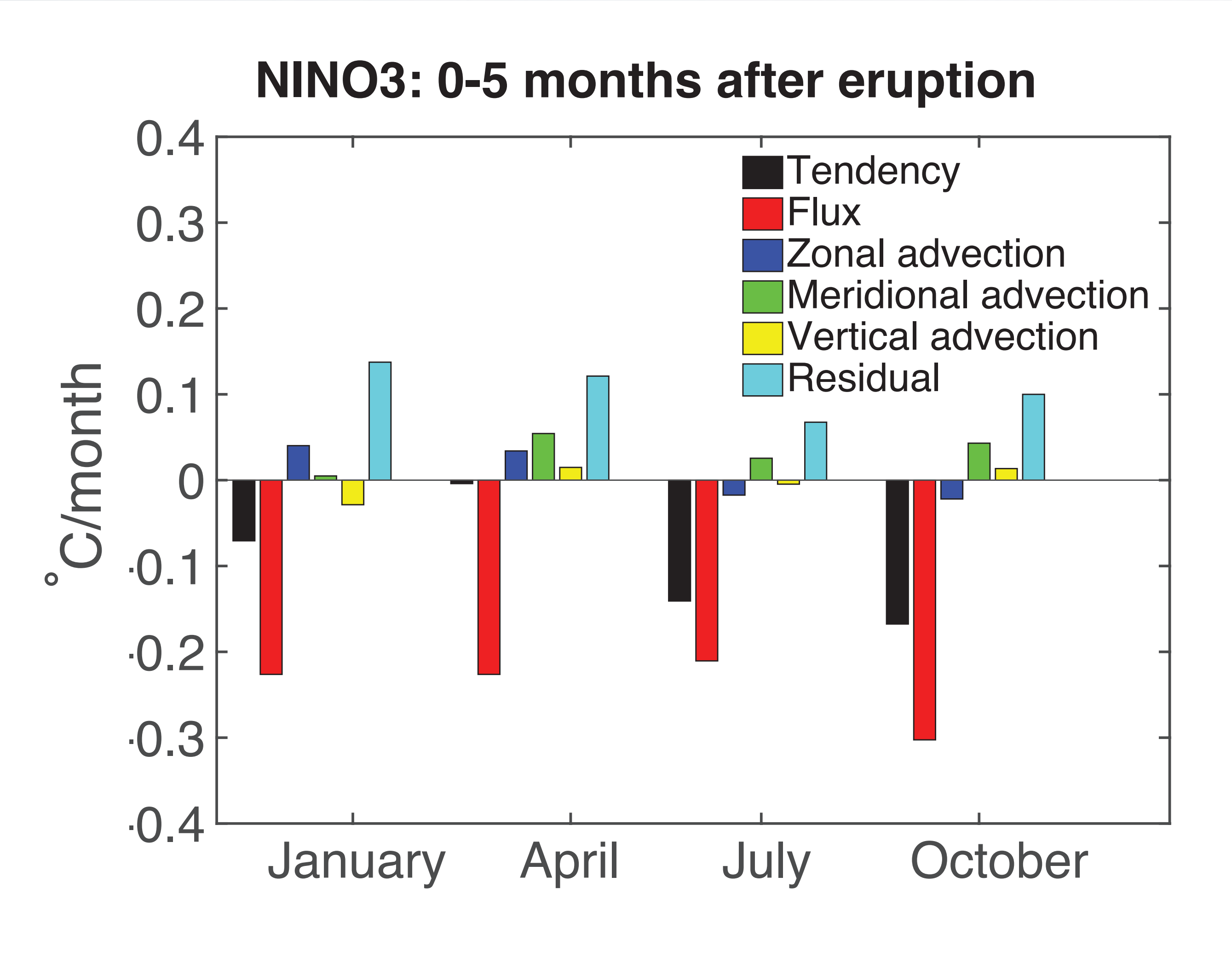


Stevenson et al. (2016b)

Surface air temperature anomaly, (C) 0-5 months after idealized seasonal eruptions
Stippling indicates precipitation differences insignificant at 90%

Eruption-year cooling is not 'La Niña-like'

$$\frac{\partial T'}{\partial t} = Q' - \bar{u}\cdot\nabla T' - u'\cdot\nabla\bar{T} - u'\cdot\nabla T' + \overline{u'\cdot\nabla T'} - w'\frac{(\overline{T_{MLD}} - \overline{T_{sub}})}{H} - \bar{w}\frac{T'_{MLD} - T'_{sub}}{H} - w'\frac{(T'_{MLD} - T'_{sub})}{H}$$



Stevenson et al. (2016b)

Response is driven mostly by radiative cooling rather than ocean dynamics

Eruption-year cooling is not 'La Niña-like'

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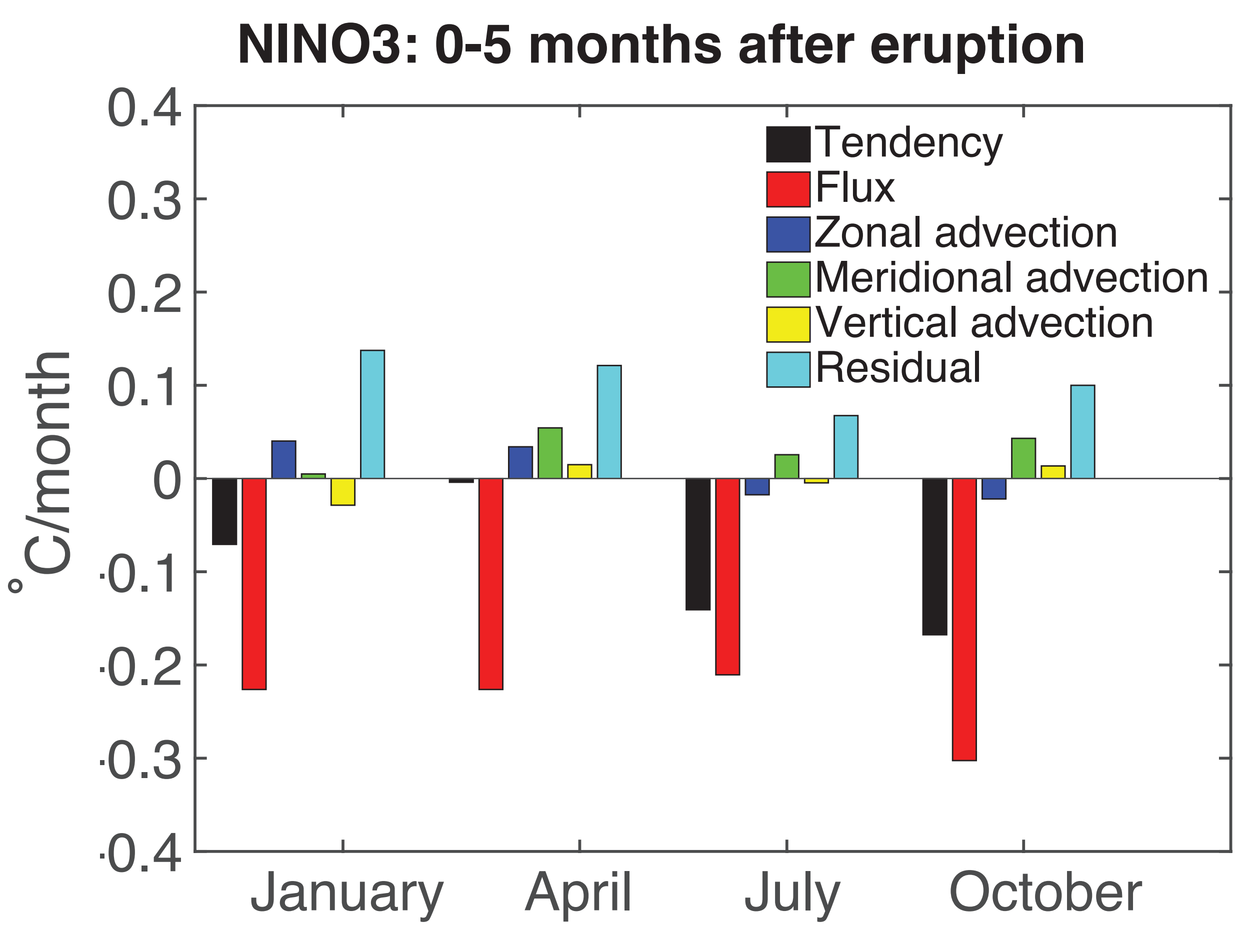

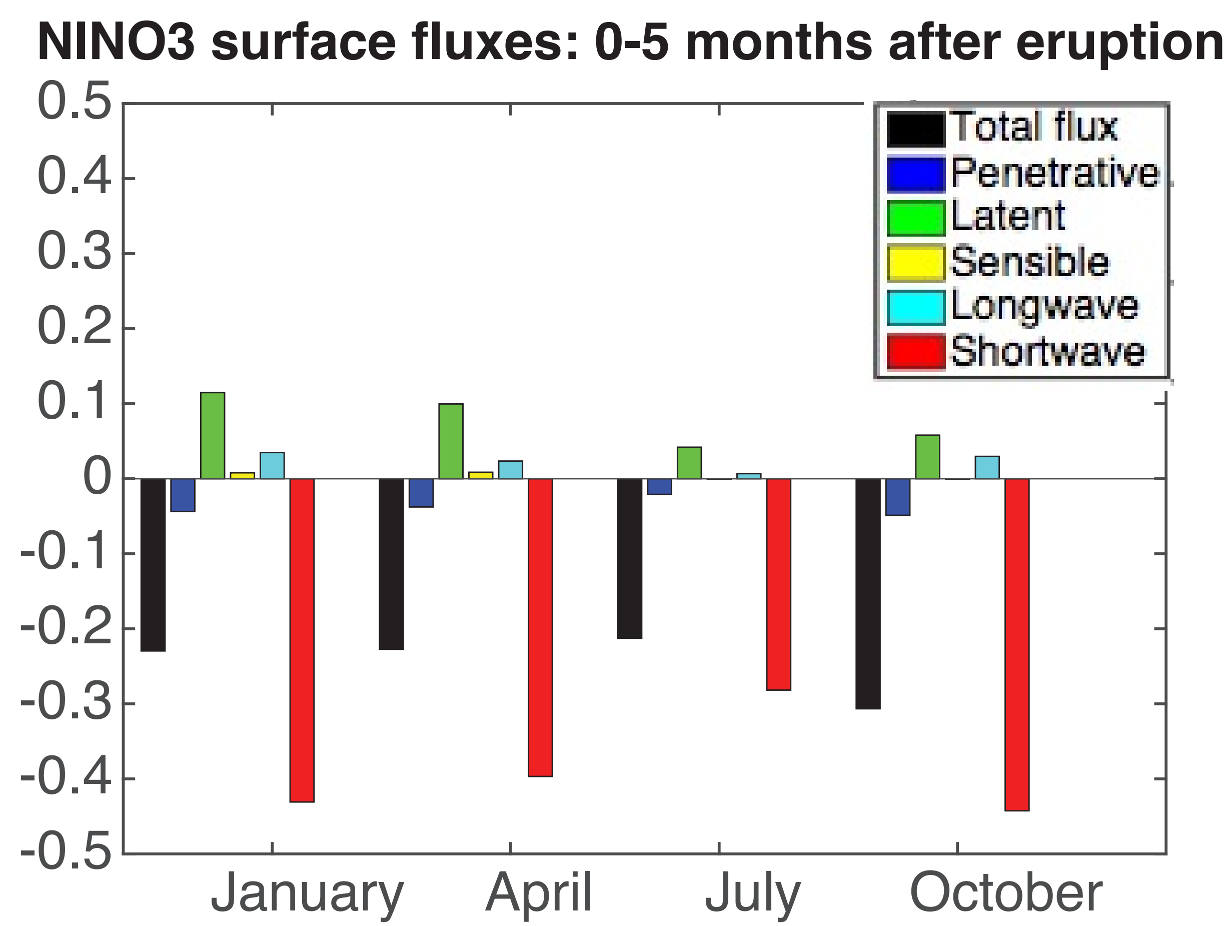

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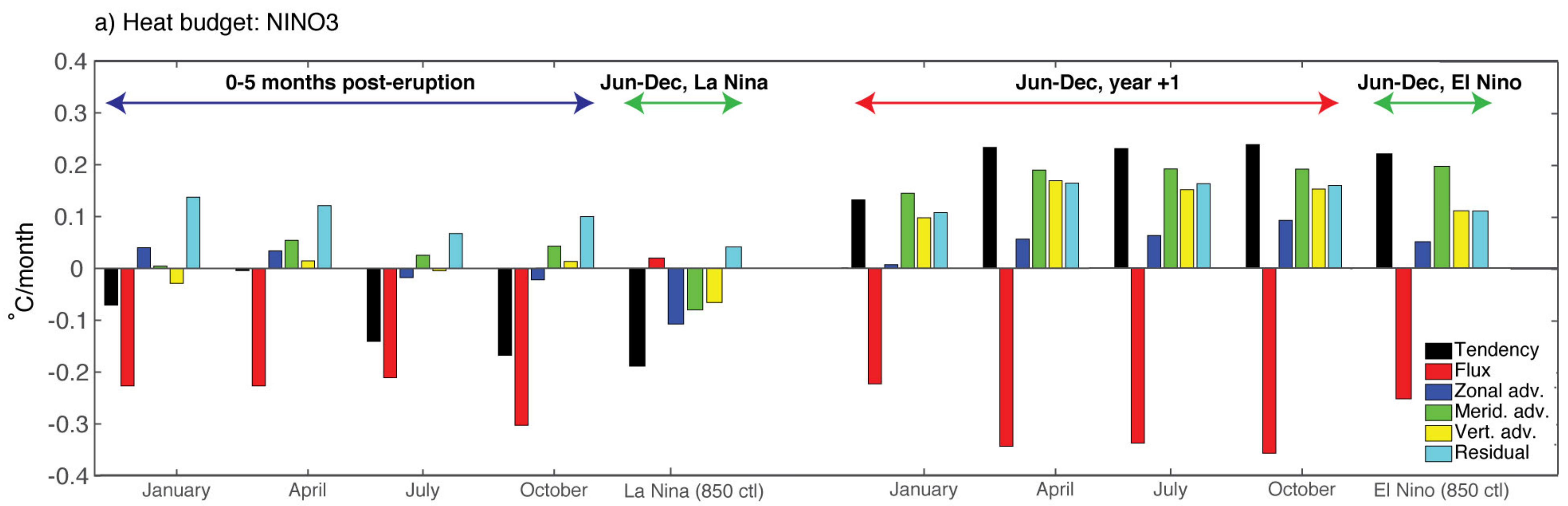
Response is driven mostly by radiative cooling rather than ocean dynamics

Post eruption-year cooling is 'El Niño-like'

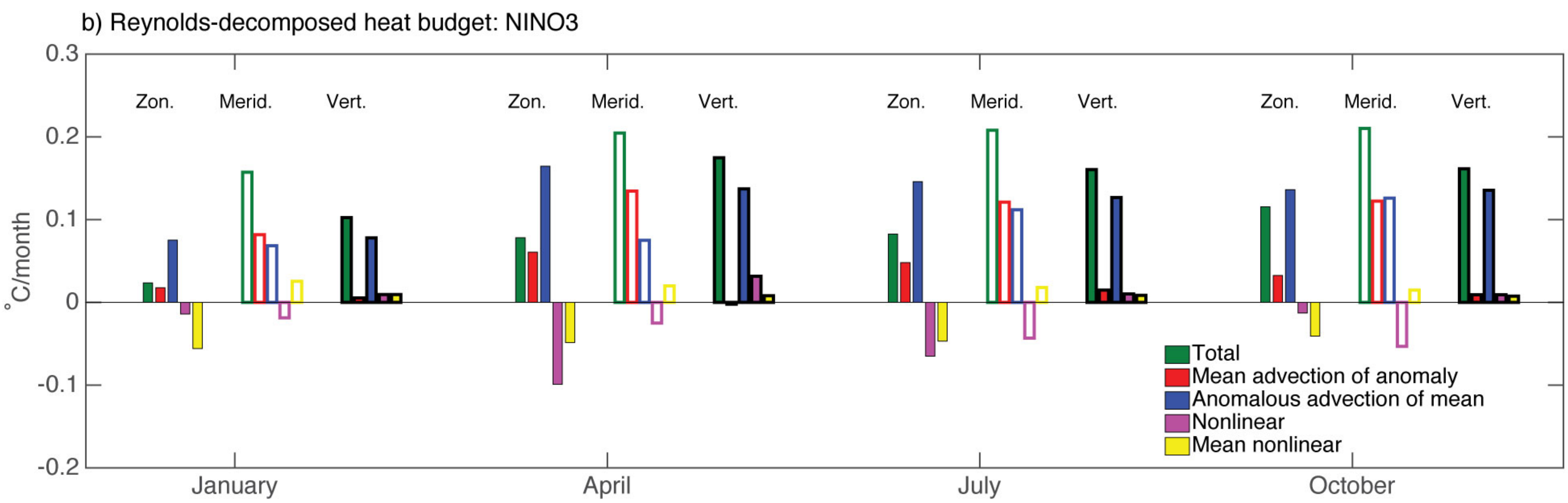
$$\frac{\partial T'}{\partial t} = Q' - \bar{u}\cdot\nabla T' - u'\cdot\nabla\bar{T} - u'\cdot\nabla T' + \overline{u'\cdot\nabla T'} - w'\frac{(\overline{T_{MLD}} - \overline{T_{sub}})}{H} - \bar{w}\frac{T'_{MLD} - T'_{sub}}{H} - w'\frac{(T'_{MLD} - T'_{sub})}{H}$$



Response is driven by ocean dynamics similar to El Niño events

Post eruption-year cooling is 'El Niño-like'

$$\frac{\partial T'}{\partial t} = Q' - \bar{u}\cdot\nabla T' - u'\cdot\nabla\bar{T} - u'\cdot\nabla T' + \overline{u'\cdot\nabla T'} - w'\frac{(\overline{T_{MLD}} - \overline{T_{sub}})}{H} - \bar{w}\frac{T'_{MLD} - T'_{sub}}{H} - w'\frac{(T'_{MLD} - T'_{sub})}{H}$$

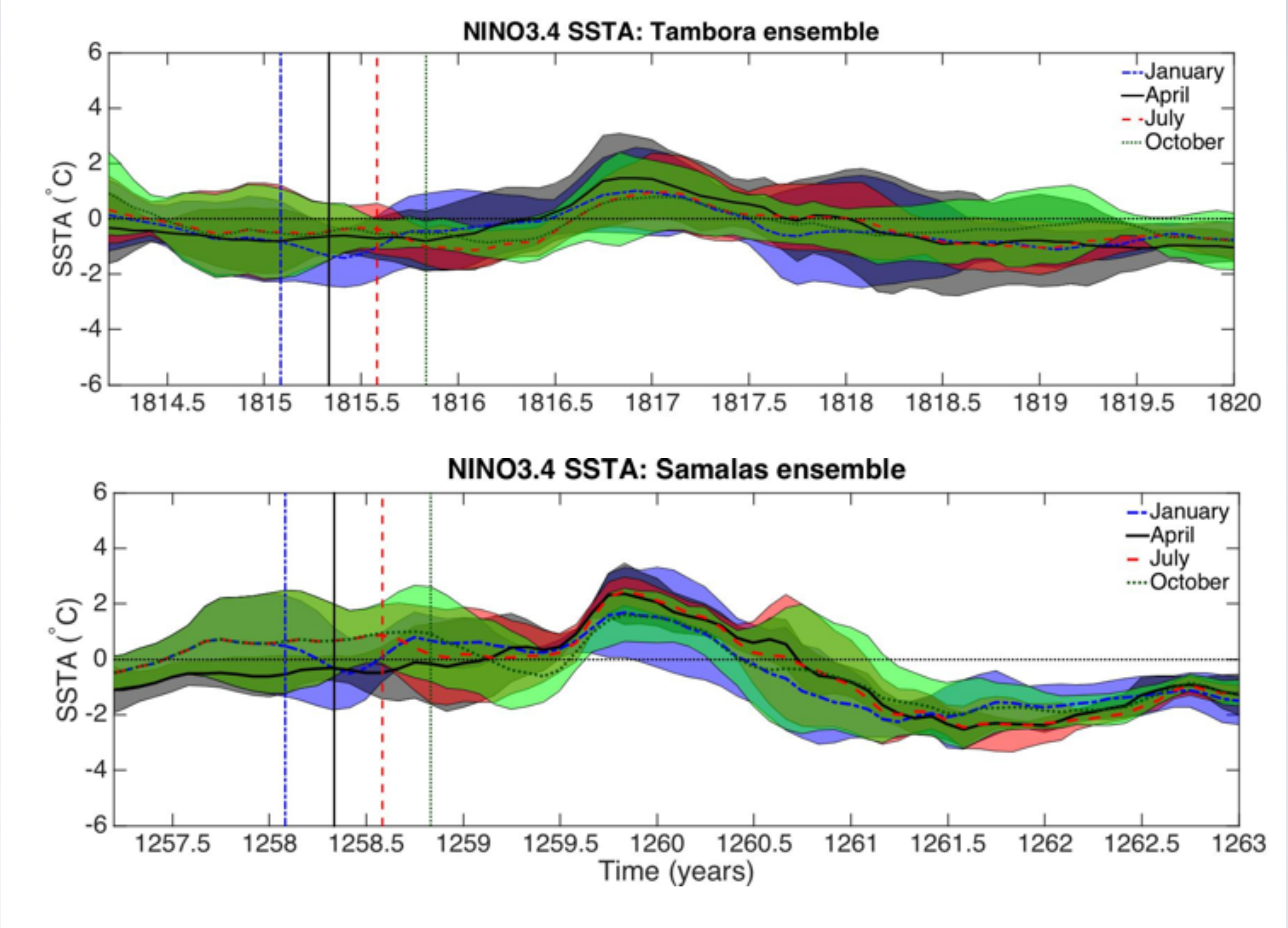


Primary contributor to vertical heating: anomalous advection of mean
(i.e. shutdown of equatorial upwelling)
Distinct from "ocean dynamical thermostat"

El Niño enhancement following eruptions occurs regardless of season

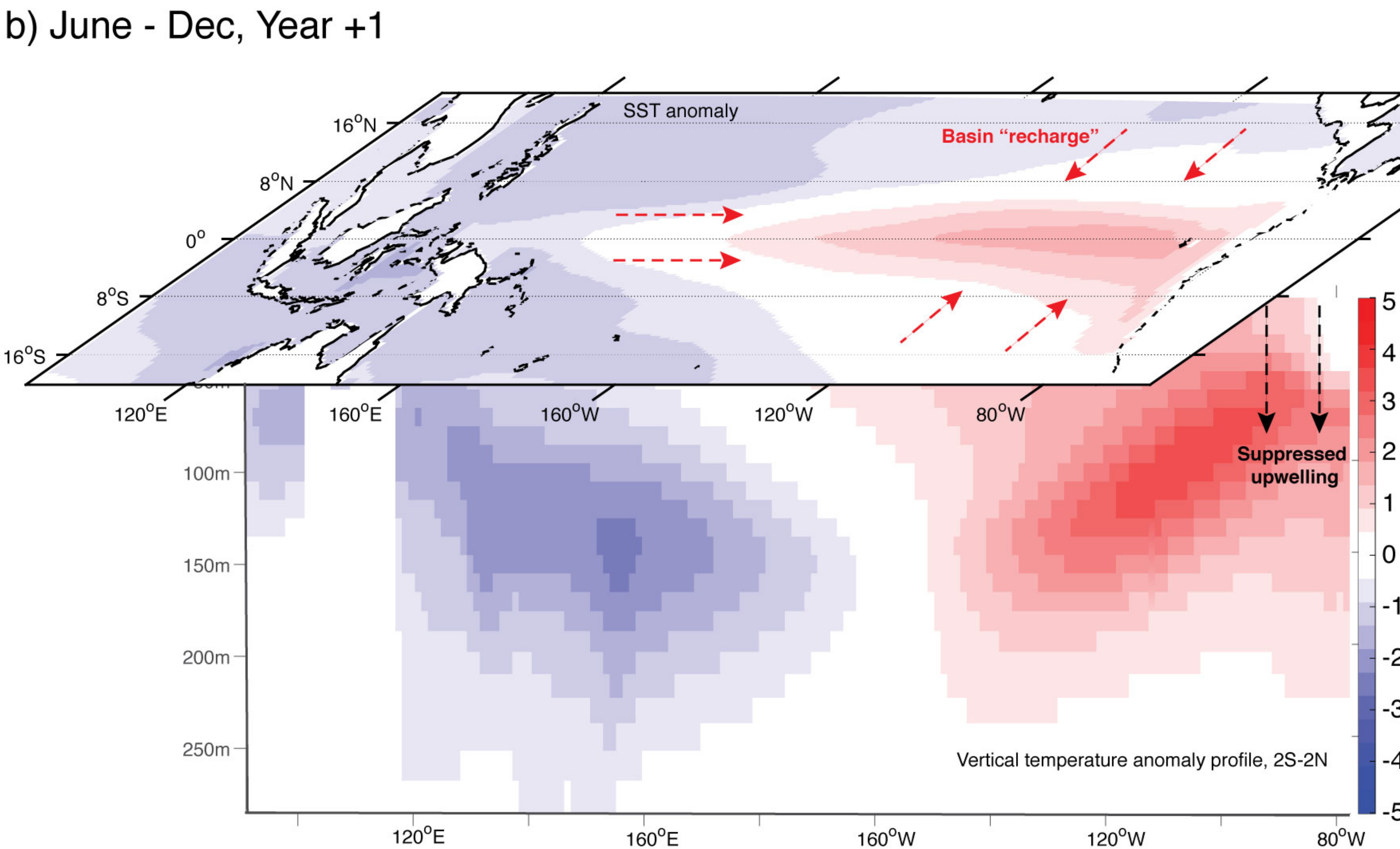
Tambora: 1815
Samalas: 1258
(both Indonesian volcanoes)

Ensembles with eruptions in different seasons (colored lines = eruption start)

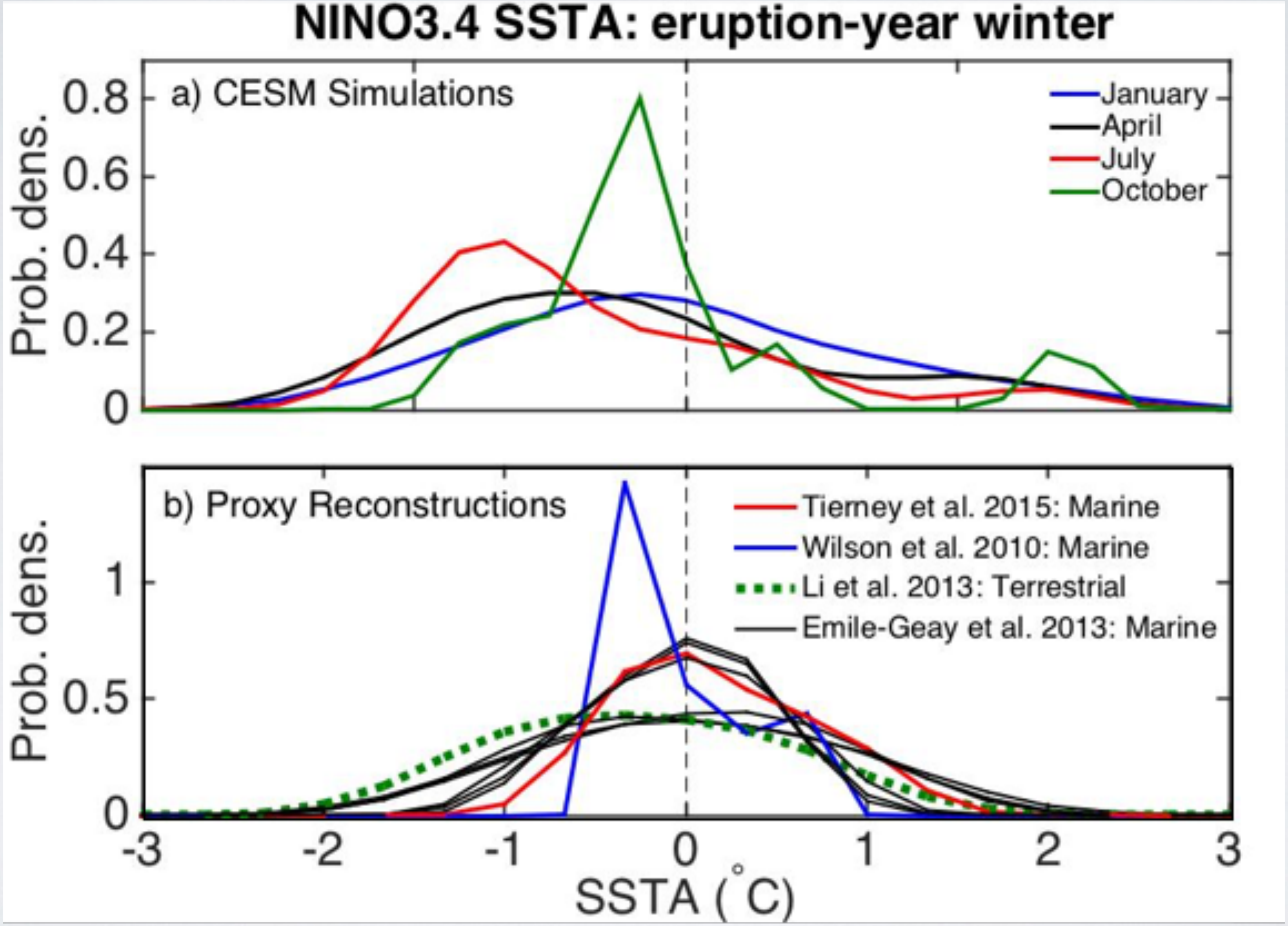


Stevenson et al. (2016b)

El Niño enhancement following eruptions occurs regardless of season



CESM actually does fairly well at capturing SSTA after eruptions



Stevenson et al. (2016b)

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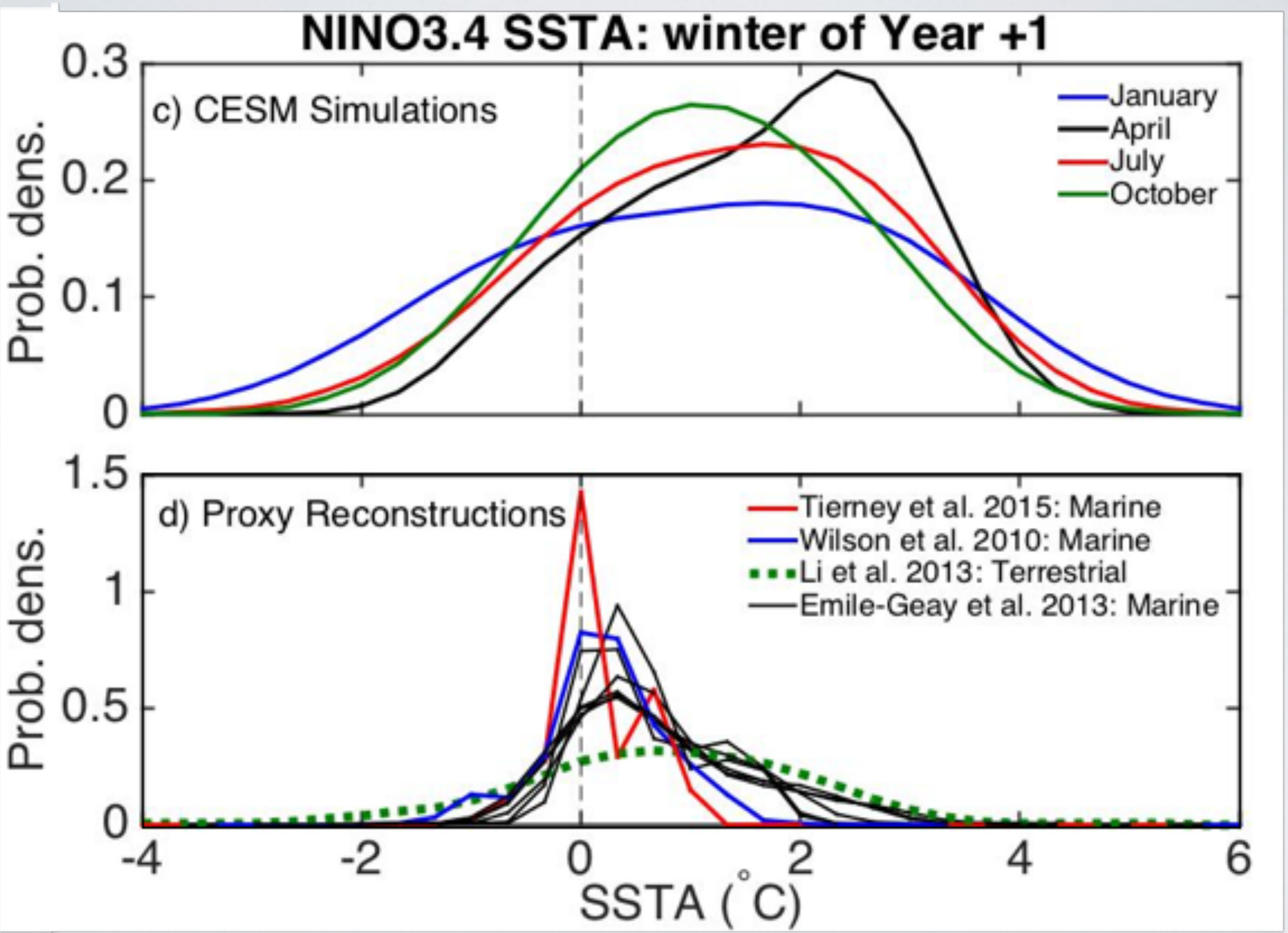


Stevenson et al. (2016b)

Conclusions

"Year 0" eruption response: NOT La Niña-like!

- Primarily a response to radiative cooling; amount of net cooling depends on season
- Hydroclimate patterns also vary strongly with eruption season, competition between "El Nino-like" and "La Nina-like" circulation anomalies; little correspondence with tropical Pacific SST

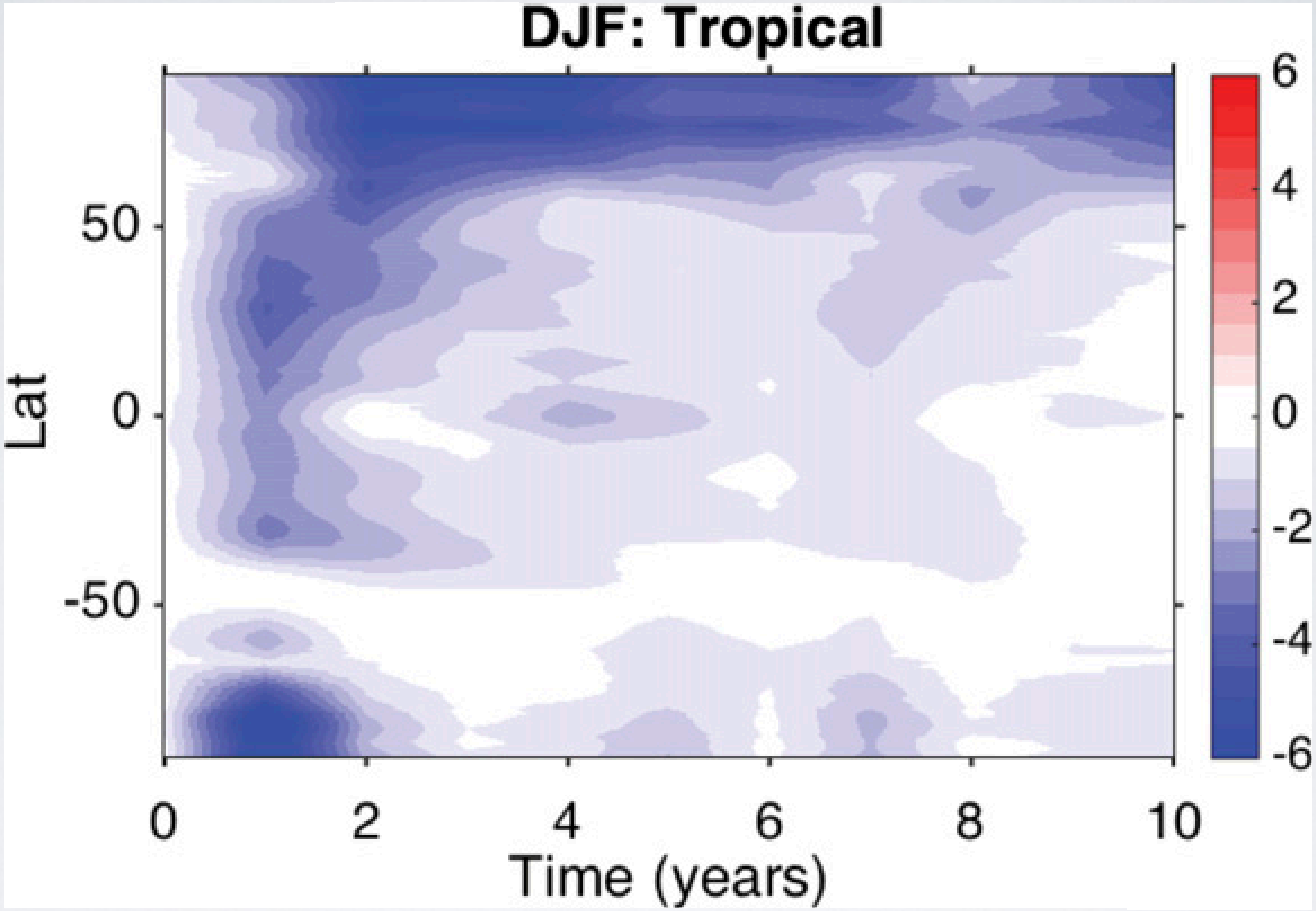
"Year 1" eruption response: El Niño-like (in both SST and hydroclimate)

- Response does not depend on eruption starting month
- El Nino initiation is more likely but ***not guaranteed***
- Mechanism for El Nino initiation tied more closely to basin recharge dynamics than the ocean dynamical thermostat

CESM does a reasonable job capturing both Year 0 and Year 1 responses

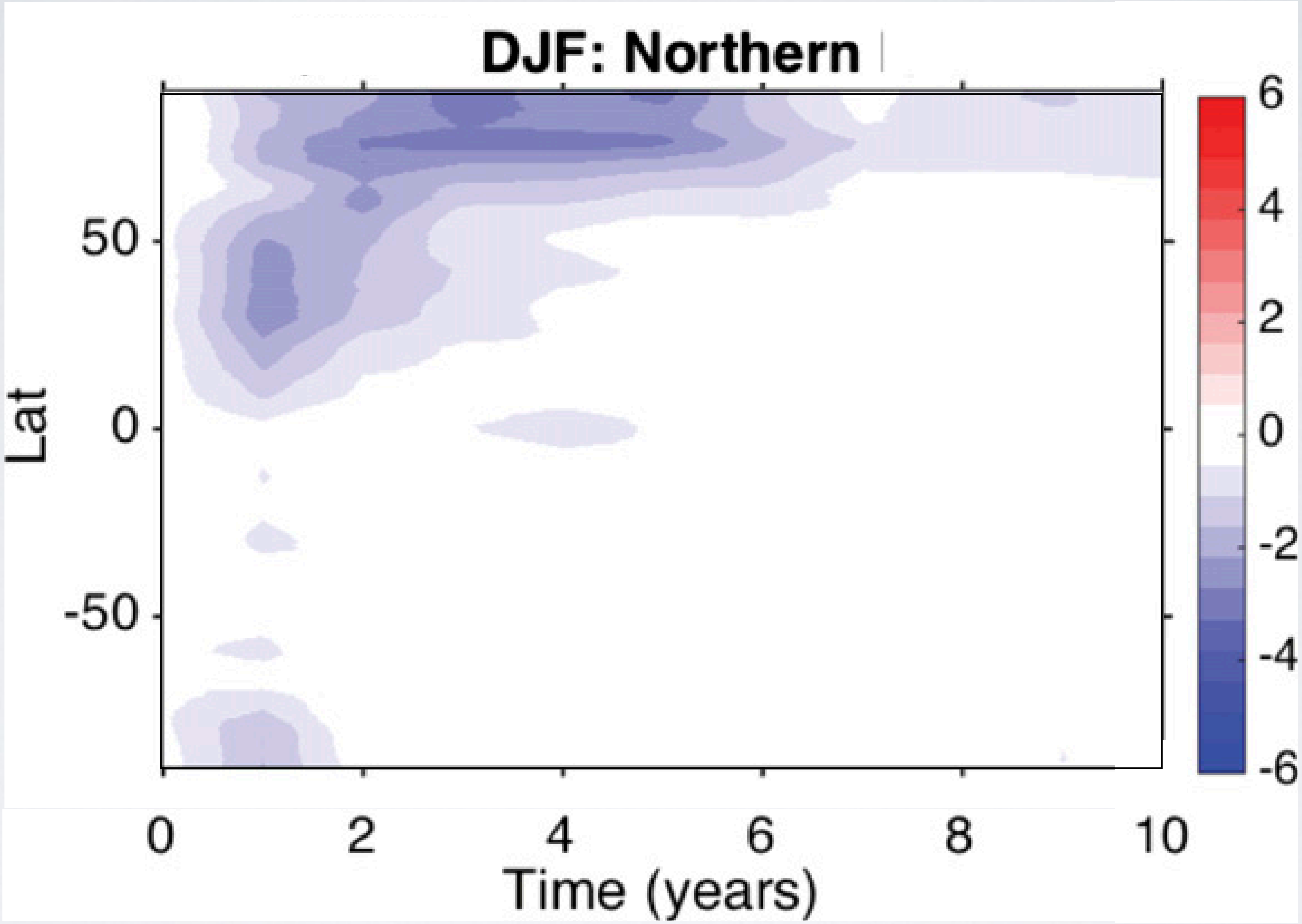
- More attention to forcing uncertainties in the context of model/proxy disagreements is critical

Changes in El Niño initiation relate to zonal-mean heating anomalies



DJF zonal-mean surface temperature anomaly

Changes in El Niño initiation relate to zonal-mean heating anomalies



DJF zonal-mean surface temperature anomaly

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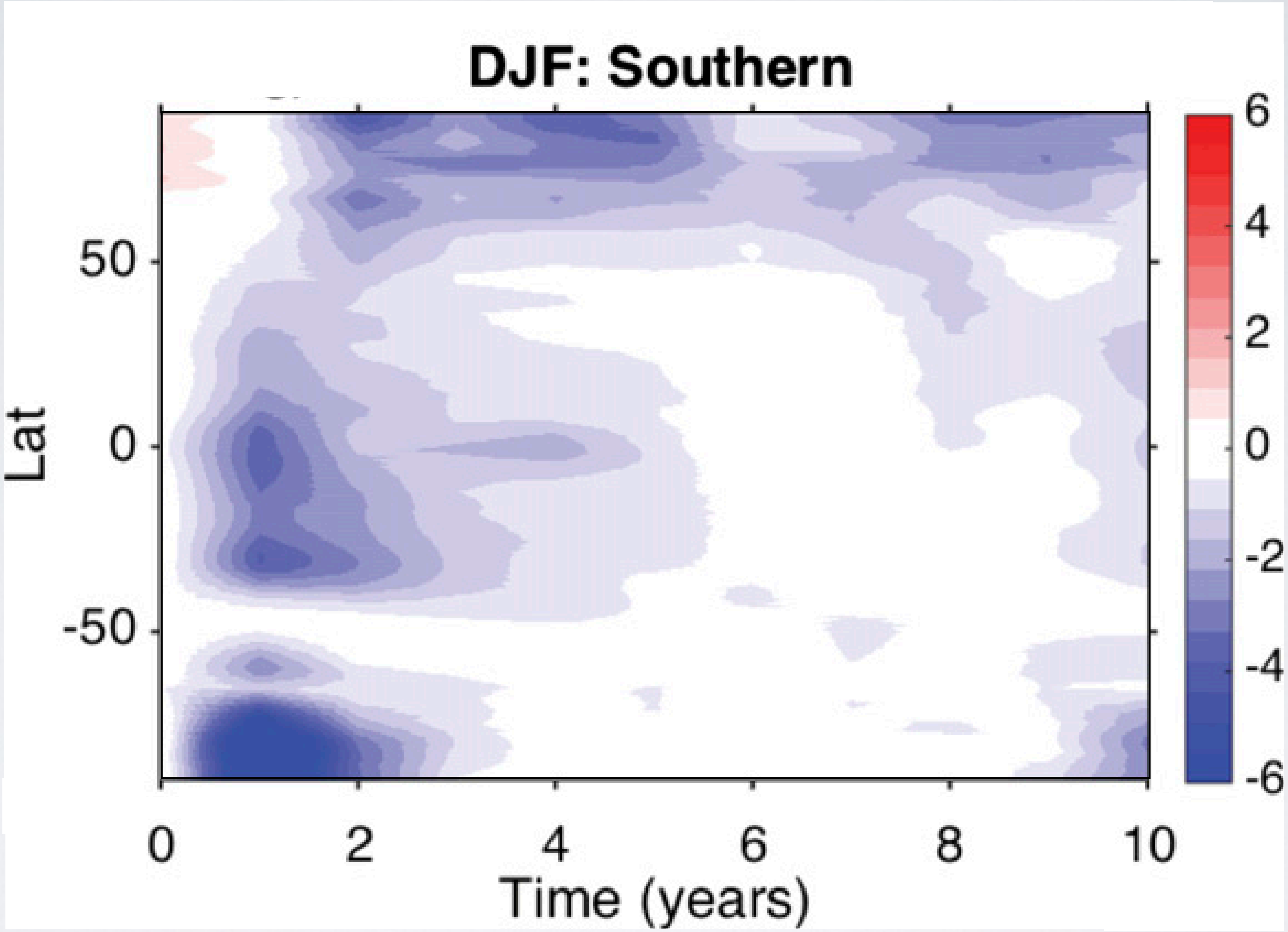
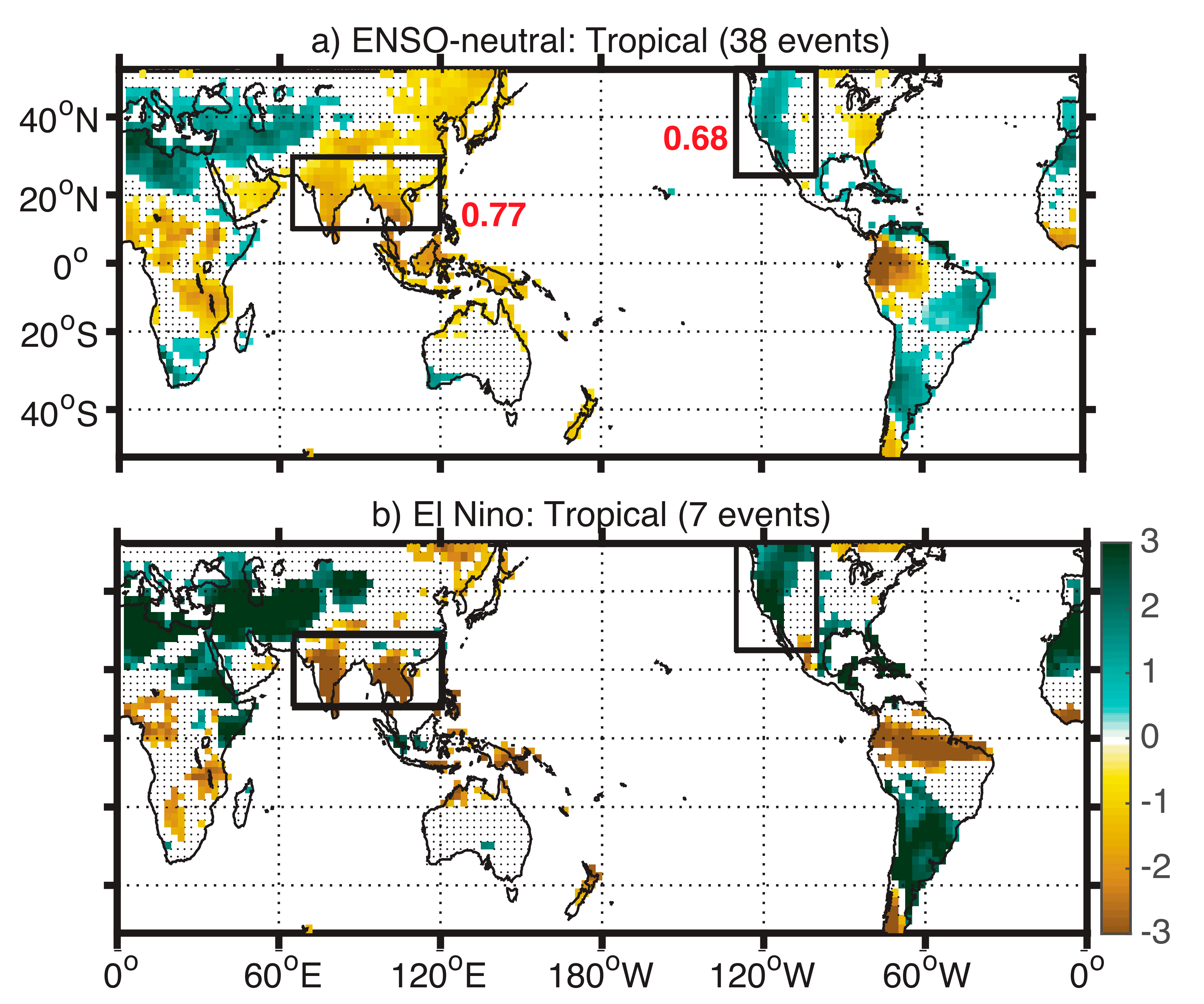


DJF zonal-mean surface temperature anomaly

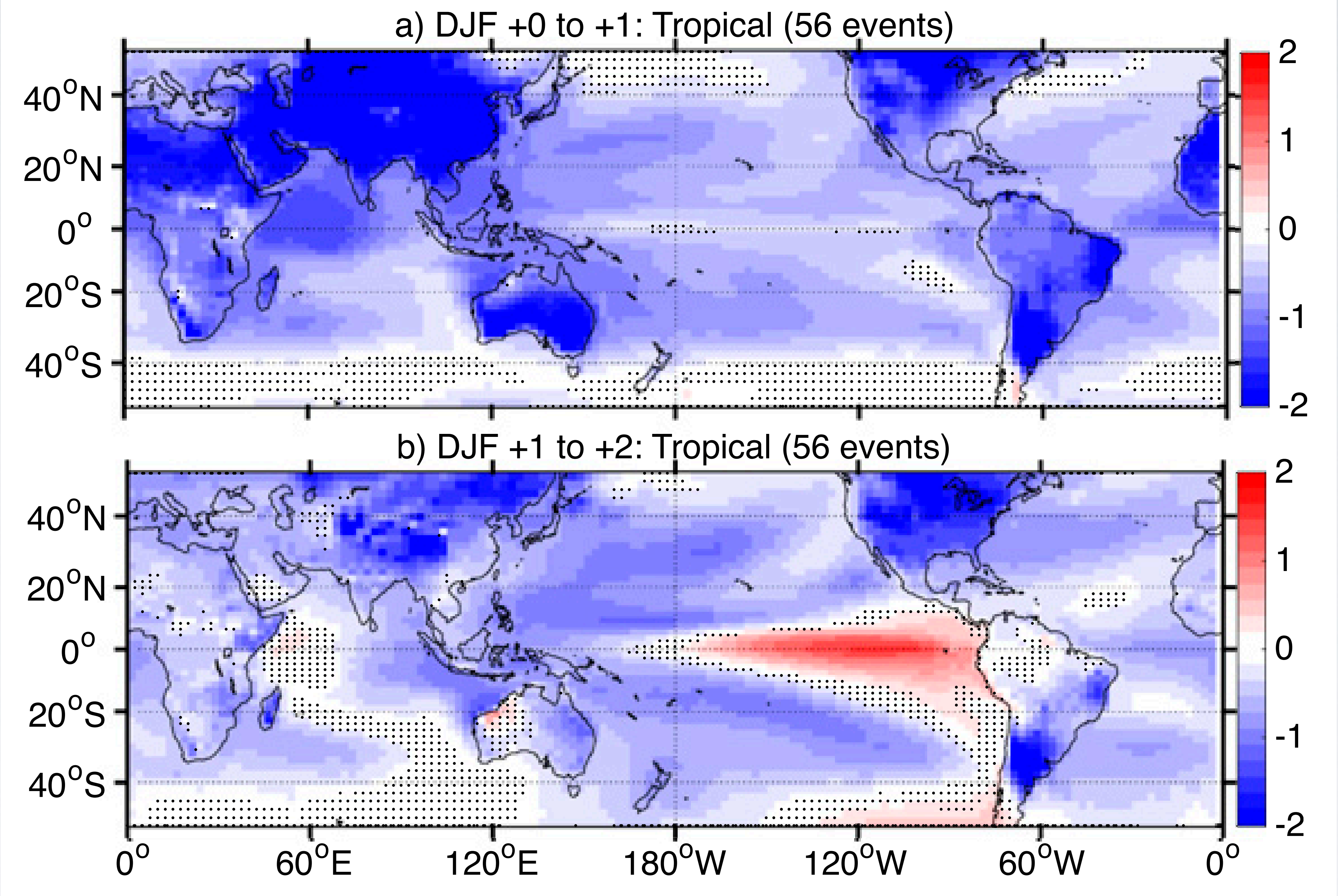
Post-eruption El Nino: amplifies (some) hydroclimate signatures



PDSI for LME full-forcing and volcanic-only simulations
Red values = pattern correlations between 'ENSO-neutral' and El Nino-driven hydroclimate changes

Stevenson et al. (2016a)

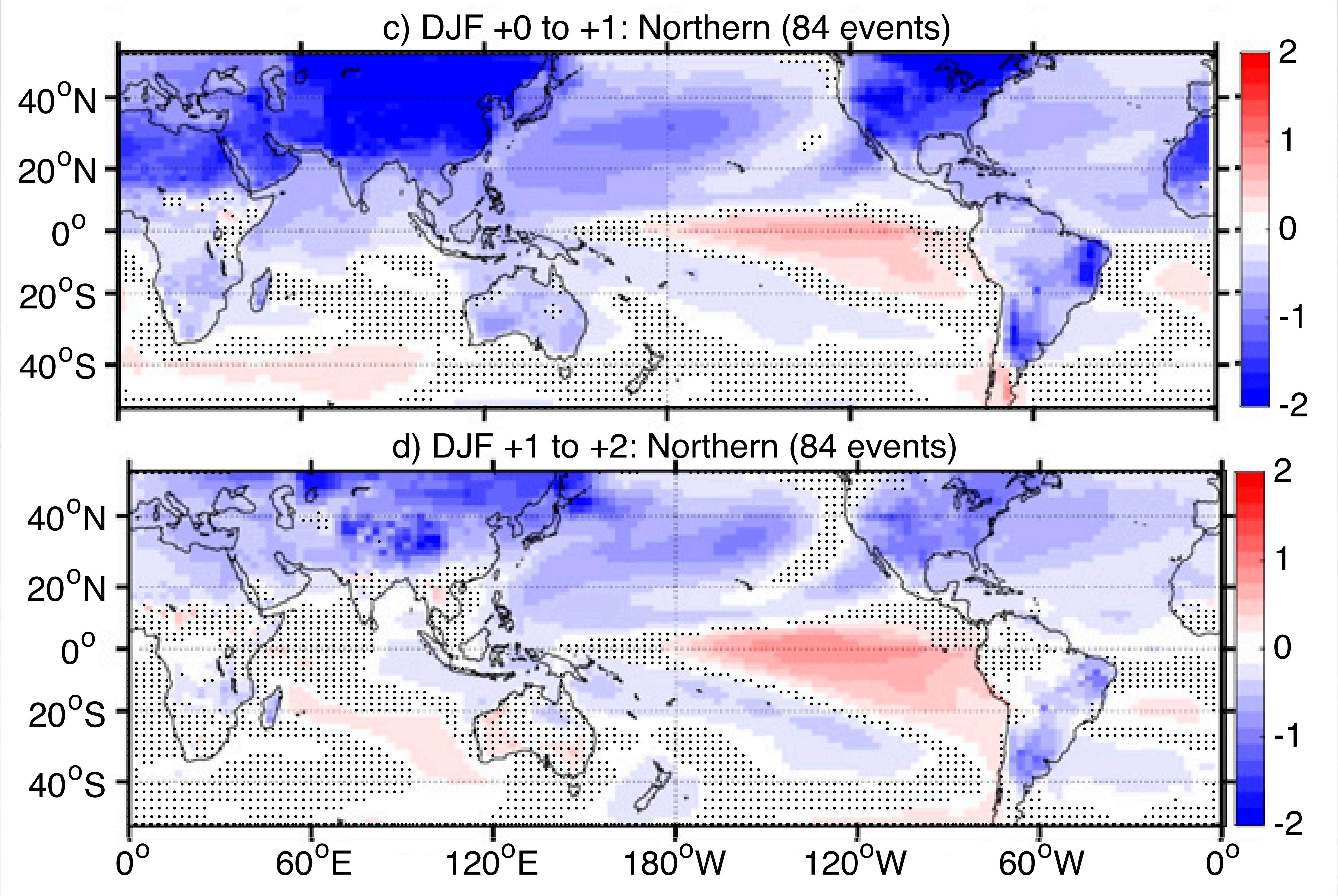
El Niño likelihood is enhanced following tropical eruptions



Stevenson et al. (2016a)

DJF SSTA for LME full-forcing and volcanic-only simulations
"Year 0" = year in which eruption occurs
"Tropical" eruptions = 1258, 1284, 1809, 1815

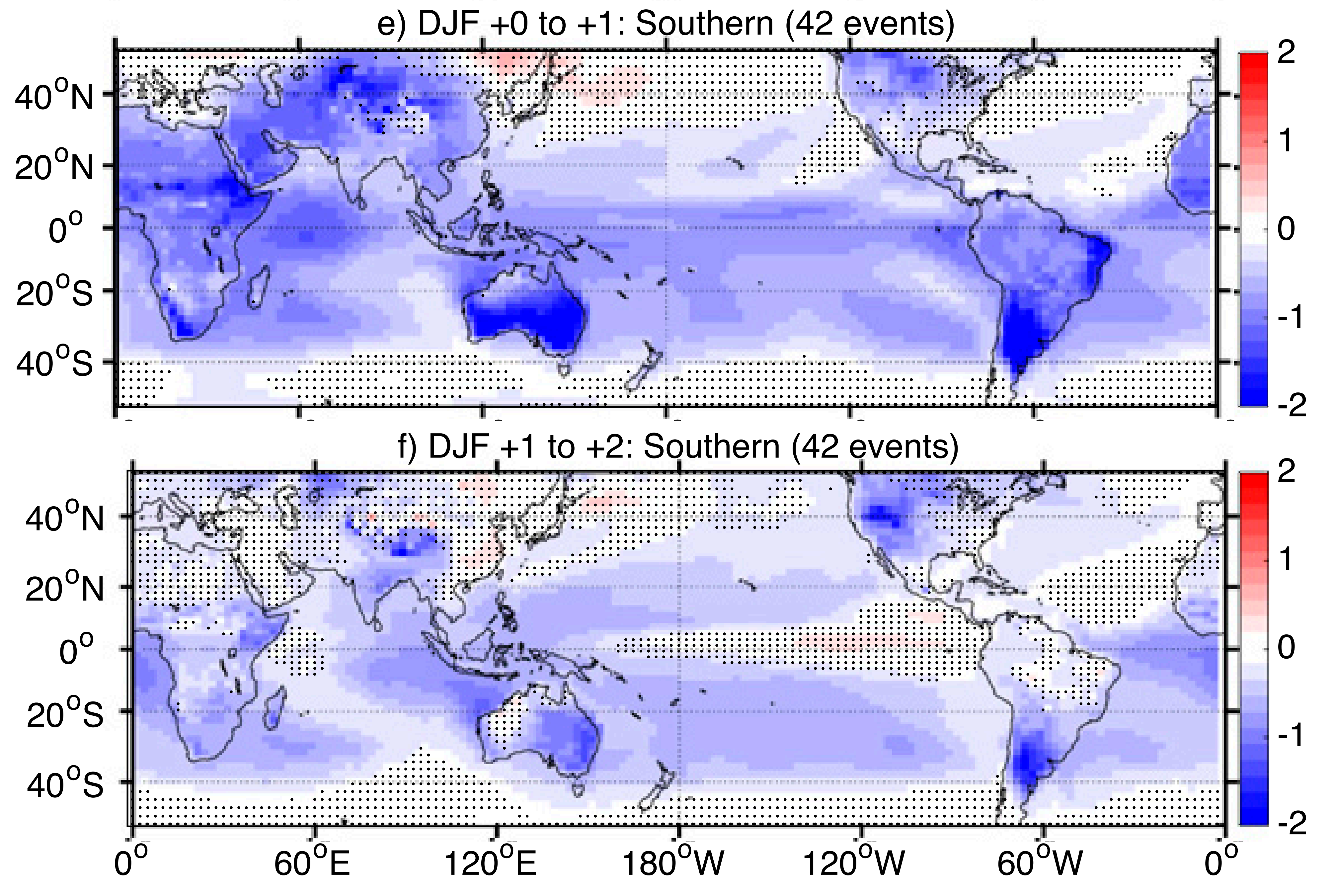
El Niño likelihood is enhanced following N. Hemisphere eruptions



Stevenson et al. (2016a)

DJF SSTA for LME full-forcing and volcanic-only simulations
"Year 0" = year in which eruption occurs
"Northern" eruptions = 1176, 1213, 1600, 1641, 1783, 1835

El Niño likelihood is reduced following S. Hemisphere eruptions



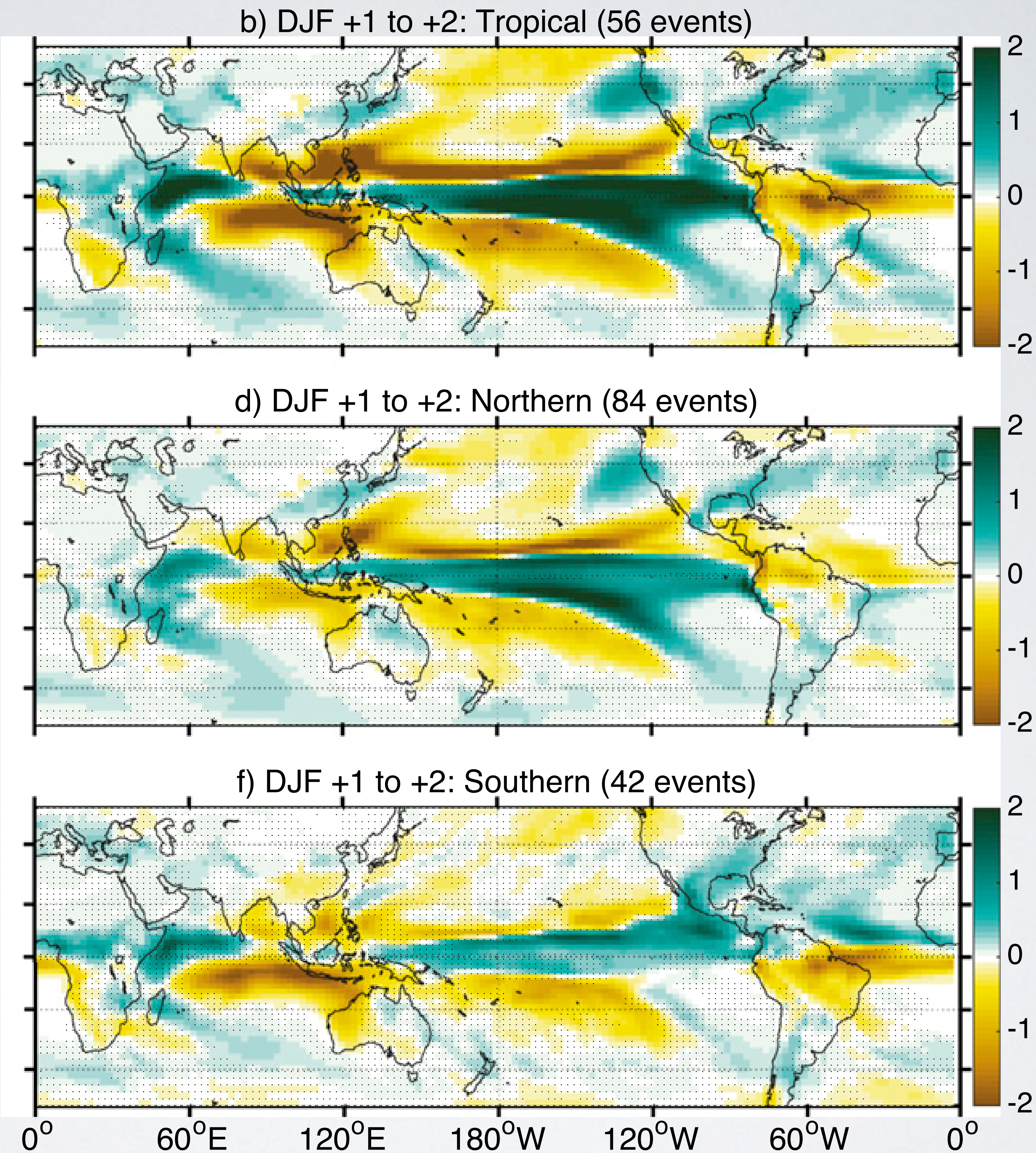
Stevenson et al. (2016a)

DJF SSTA for LME full-forcing and volcanic-only simulations
"Year 0" = year in which eruption occurs
"Southern" eruptions = 1275, 1341, 1452

Changes to El Niño likelihood: due to differing atmospheric responses?

DJF precipitation changes, boreal winter 1 year after eruption

Stippling indicates change insignificant relative to internal variability



Stevenson et al. (2016a)