ENSO sensitivity to radiative forcing

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Motivation

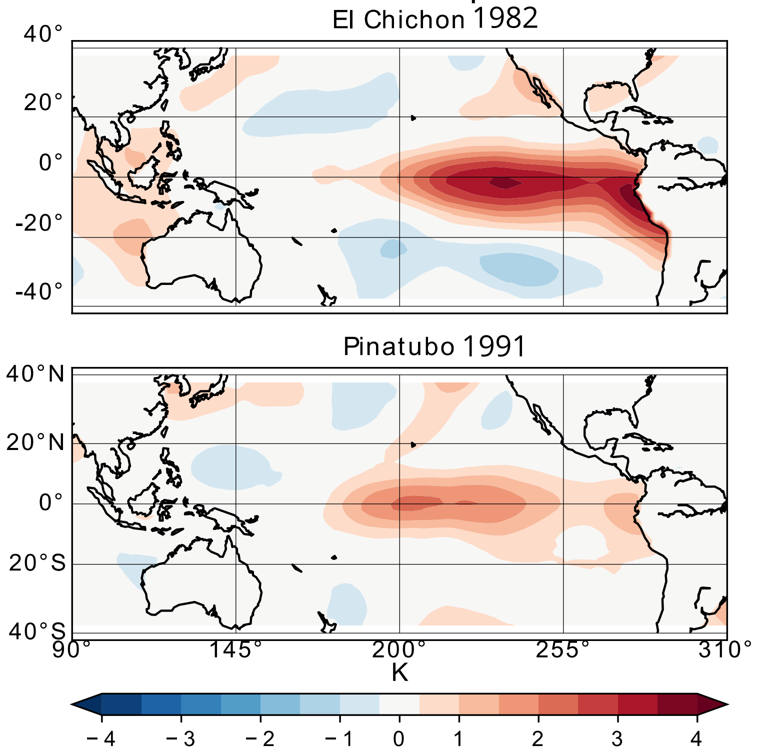
Paleo data suggest that the El Niño probability doubles after the volcanic eruption (Adams et.al, 2003, etc.).

The aerosols, formed after stratospheric volcanic eruptions, scatter considerable amount of incoming solar radiation decreasing the surface temperature around the globe.

Such volcanic eruptions serve as a natural experiment, which could help us to uncover the hidden features of ENSO.

There were many modelling studies on the ENSO response to volcanic eruptions, but no consensus has been reached yet.

December sea surface temperature anomaly



Predybaylo, E., Stenchikov, G. L., Wittenberg, A. T., and Zeng, F. (2017), Impacts of a Pinatubo-Size Volcanic Eruption on ENSO, *J. Geophys. Res. Atmos.*, 122, 925– 947, doi:10.1002/2016JD025796

Objective

Classify ENSO responses to volcanic eruptions taking into account:

1. Ocean preconditioning (Ohba et.al, 2013; Pausata et.al, 2016, etc)
2. Seasonal timing of the eruption (Stevenson et.al, 2017, etc)
3. Magnitude of the volcanic eruption (McGregor and Timmermann, 2011; Li et al., 2013; Stevenson et al., 2017; Ohba et al., 2013, Emile-Geay et.al, 2008)
4. Location of the volcano (Pausata et.al, 2015, 2016; Stevenson et.al, 2016, Sun et.al, 2019, etc)

Methods

Click on the links to see the details

Using GFDL CM2.1 coupled climate model, we built grand-ensemble simulations **to break the ENSO response to volcanic eruptions into two components:**

Stochastic	**Deterministic**
response to Butterfly perturbations (Butterfly ~ 0.001xPinatubo)	pure response to volcanic perturbations

Contribution of these components defines 1) the predictability of the response and 2) the deterministic response mechanisms.

To simulate the responses of each ENSO preconditioning to Butterfly perturbations and volcanic perturbations, we perform sets of control and perturbed experiments. The perturbed simulations are performed using perturbed forcing technique and result in grand-ensemble simulations with Butterfly, Pinatubo-size, and Tambora-size perturbations in three different seasons.

ENSO response diagram

1. The stochastic response to February perturbations **(a)** is large for all ENSO types compared to June perturbations **(b)**

2. The ENSO response to February and April (not shown) perturbations is difficult to detect even for Tambora-size eruptions (response to Butterfly perts ~= response to volcanic perts), except for the neutral onset

3. Butterfly perturbations may significantly change the trajectories of moderate, strong, and-extreme El Niños

4. There is a strong robust cooling after June Tambora-size eruptions in the first year

5. The strongest El Niño-like responses are observed for weak and moderate El Niños

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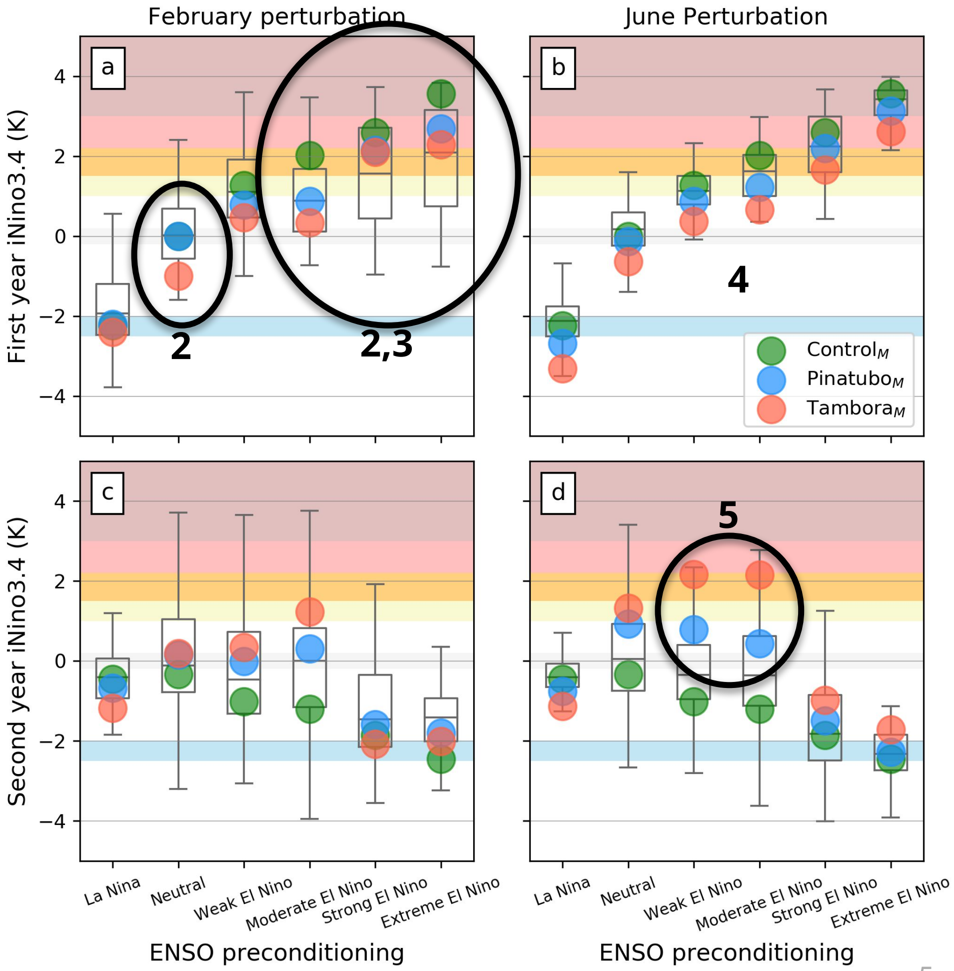

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What is in the response diagram?

Niño3.4 (K) averaged over the first year boreal winter (October-December 1991) after the (a) February, or (b) June perturbations.

Green dots show the 10-member medians of the unperturbed control ensembles, for various types of ENSO preconditioning identified in the control run (abscissa) and shown in horizontal shaded bands: La Niña (blue), Neutral (light gray), weak El Niño (yellow), moderate El Niño (orange), strong El Niño (red), and extreme El Niño (dark red).

Gray box-and-whiskers show the distribution (median, quartiles, extrema) of the 100-member Butterfly grand-ensemble;

Blue dots show the median of the 100-member Pinatubo grand-ensemble;

Red dots show the median of the 100-member Tambora grand-ensemble.

(**c** and **d**) as in (**a** and **b**), but for the Niño3.4 averaged over September-November 1992.

Conclusions

1. A unique experimental framework was built to separate the stochastic and deterministic components of ENSO response.
2. The partial contribution of these components depends on the timing of the eruption.
3. ENSO response to all stratospheric volcanic eruptions strongly depends on the ocean preconditioning.
4. The robust deterministic response scales with the magnitude of the eruption.
5. The results help explaining the inconsistencies between the previous modeling and observational studies: time-composite and ensemble design.

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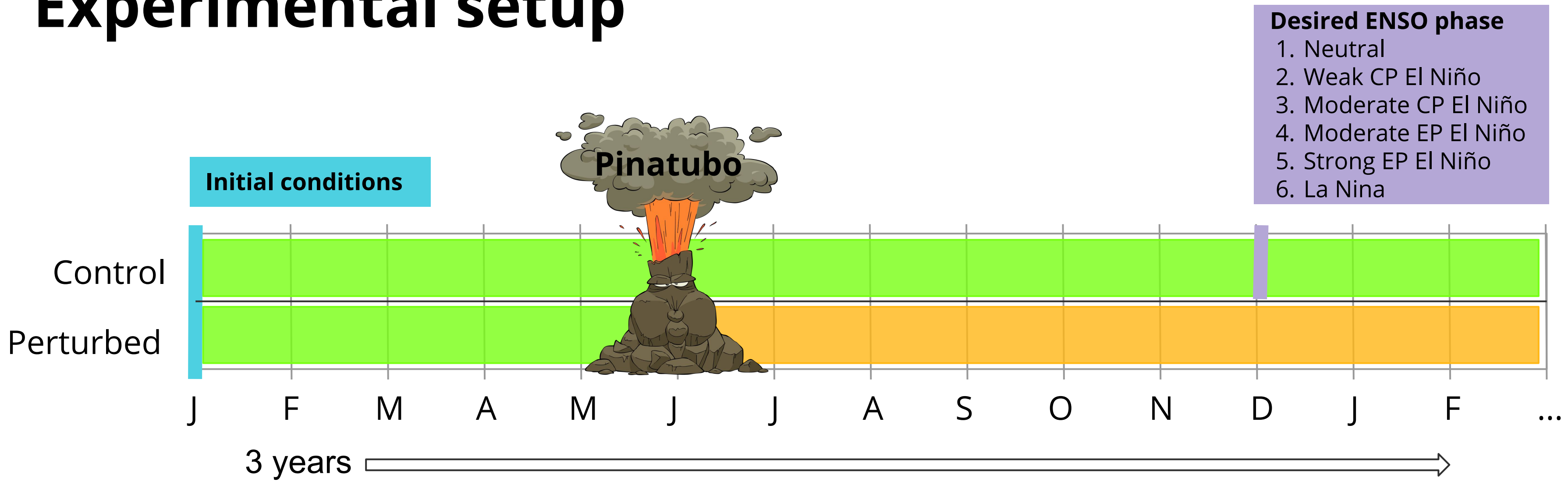
Experimental setup



Perturbed experiments **with volcano** — Control experiments **without volcano** = ENSO **response** to volcano

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Coupled atmosphere-ocean general circulation model CM2.1



Stenchikov et.al, 2009

Atmosphere:

- 2^0 (latitude) x 2.5^0 (longitude)
- 24 vertical levels

Ocean:

- 1^ox1^o -> equator 0.3^ox0.3^o)
- 50 vertical levels

Used in:

- Intergovernmental Panel for Climate Change (IPCC) AR4
- Coupled Model Inter-comparison Project (CMIP3)

ENSO phase frequencies

	Neutral	CP El Niño	EP El Niño	La Niña
Observations	0.43	0.23	0.11	0.23
CM2.1	0.49	0.16	0.08	0.27

This cartoon is made using the icons by Smashicons, Freepik, and fjstudio from www.flaticon.com/

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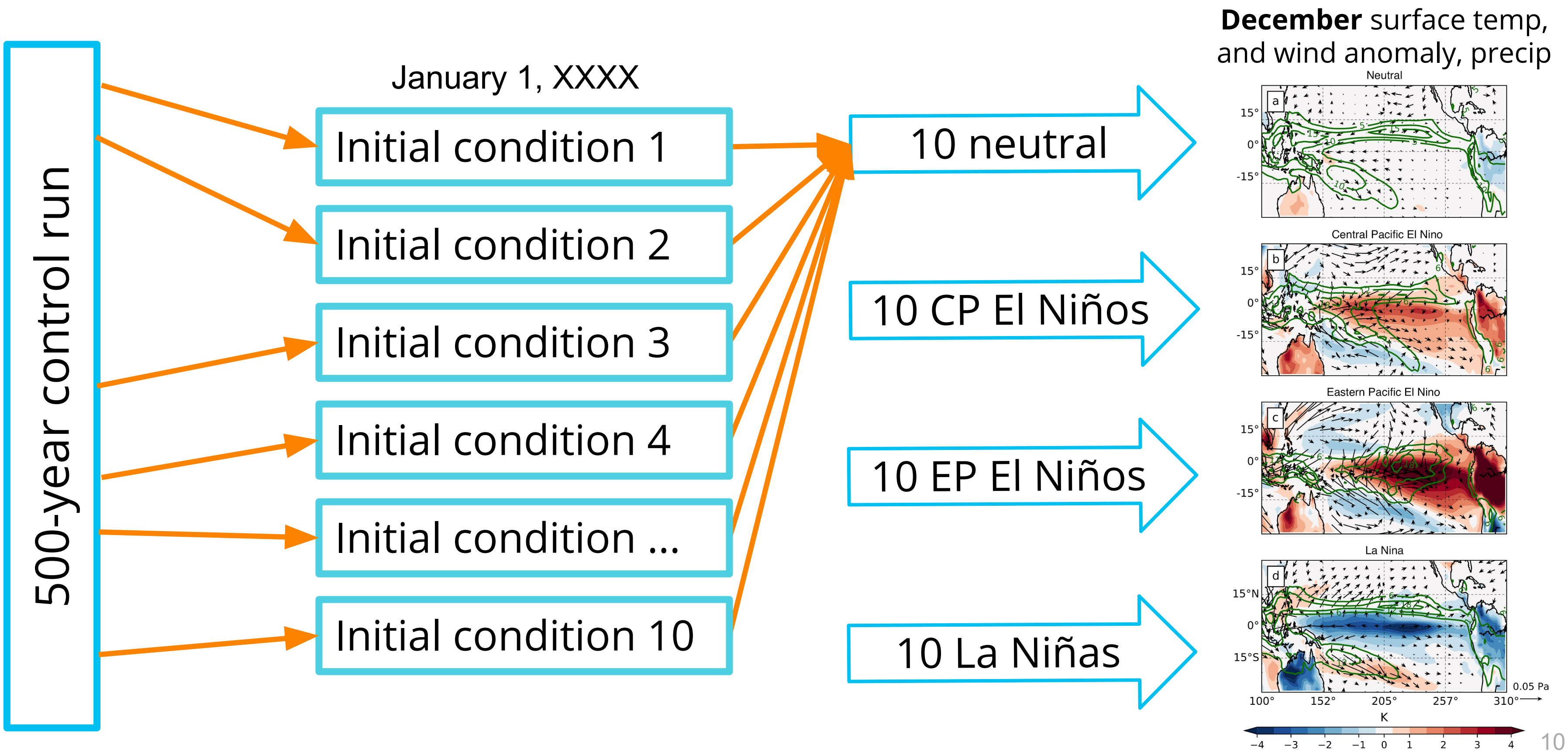
Control 10-member initial condition ensembles



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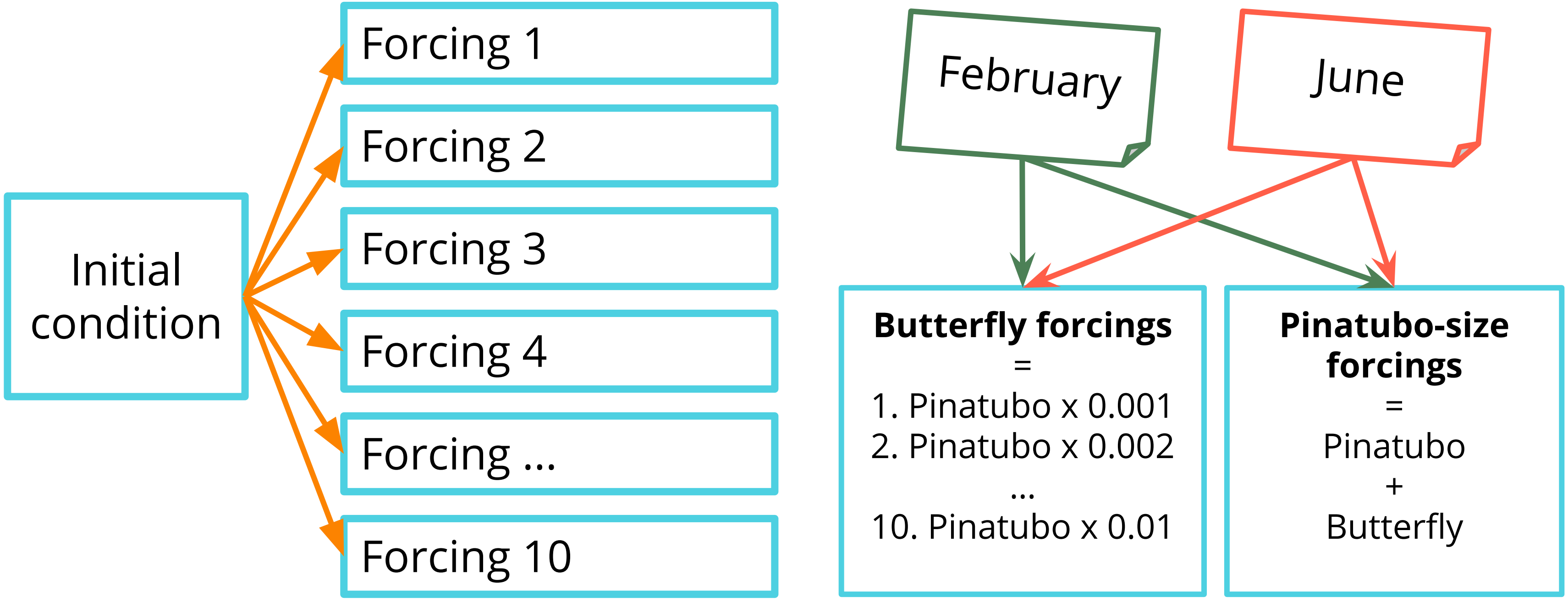
Perturbed forcing 10-member ensembles



Predybaylo et.al, 2017

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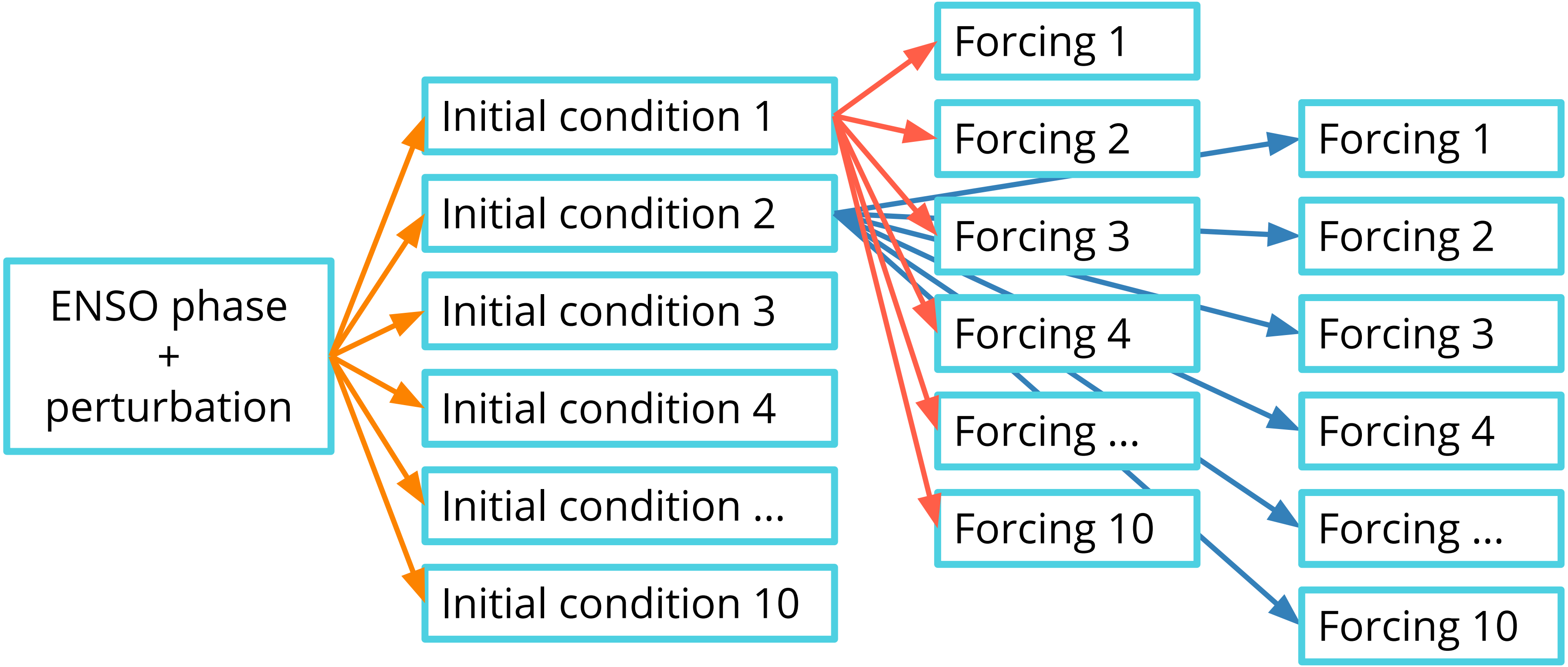
Perturbed 100-member grand-ensembles

(ensembles of ensembles)



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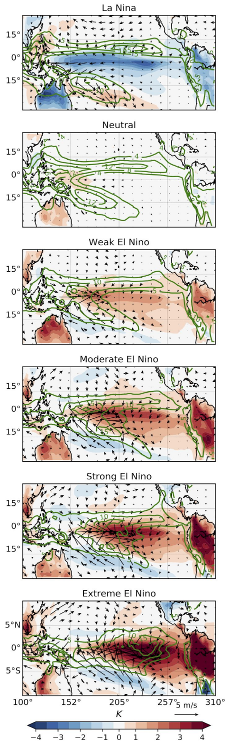
5400 perturbed simulations, >16000 years

6x10 IC



3x10 perturbations

Butterfly perturbations

Pinatubo+Butterfly
=
Pinatubo-size eruptions

3xPinatubo+Butterfly
=
Tambora-size eruptions

3 seasons