ENSO amplitude asymmetry in Met Office Hadley Centre climate models

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1. Introduction

Extreme El Niño events can severely disrupt global weather patterns and are associated with worldwide environmental impacts. Typical regional impacts include severe drought and reduced food production, flooding and mudslides, poor air quality due to forest fires, and coral bleaching.

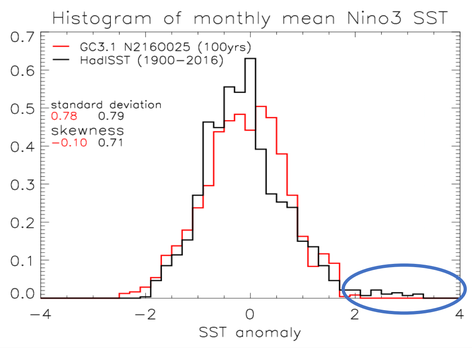
It is important that climate models are able to simulate these infrequent but large events, as this may impact on our ability to evaluate the risk of extreme regional events.

However, many models have an ENSO cycle which is too symmetric i.e. El Niño events and La Niña events are of similar magnitude

A measure of asymmetry is skewness.

$$\text{skewness} = \frac{m_3}{(m_2)^{3/2}},$$

$$m_k = \sum_{i=1}^{N} \frac{(x_i - \overline{X})^k}{N}$$



No strong El Niño events

2. Method

Here we explore possible reasons for the weak amplitude asymmetry in Met Office Hadley Centre climate models through the framework of a perturbed parameter experiment (PPE) climate model, HadGEM3-GC3.05 (Yamazaki et al.,2021)

- 19 members, 200 years
- N216, 60km atmosphere, ORCA025 1/4° ocean (MM)
- range of perturbations applied to the atmosphere

We also analyse low (LL) and high (HH) resolution versions of HadGEM3.

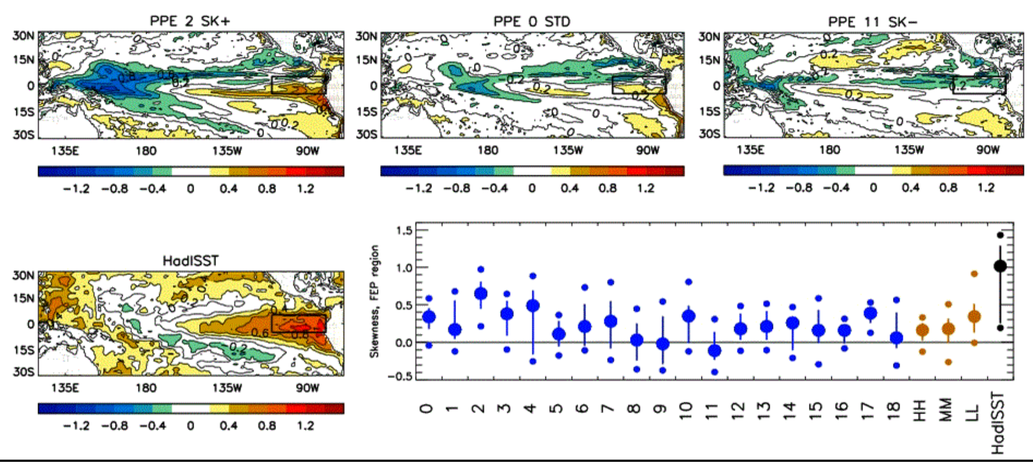
We focus on two key hypotheses relating to ENSO asymmetry; the roles of:

(**A**) Westerly wind bursts (e.g. Lengaigne et al., 2004, Levine et al., 2016)

(**B**) Warming due to ocean nonlinear advection (NDW) (e.g. An and Jin, 2004, Su et al., 2010, Hayashi et al., 2020, Chen et al., 2021)

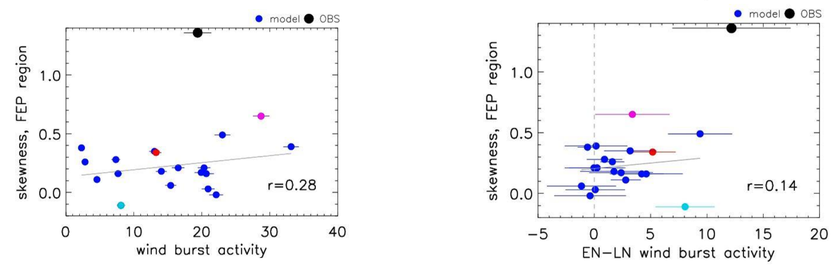
3. Skewness in the PPE

- There is diversity in skewness in the PPE, with a range of multidecadal variability
- No member has a mean skewness (or 50yr max) as high as the mean observed skewness
- Skewness is not dependent on resolution in this model



4. (A) Westerly wind bursts

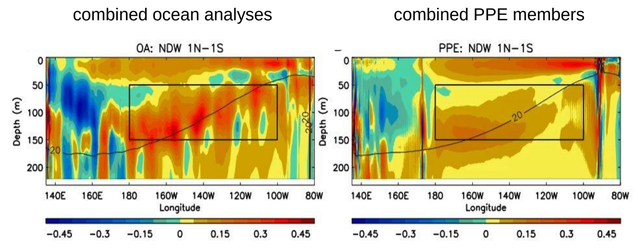
- There is a range of wind burst activity in the PPE
- Observations (ERAI) lie within this range
- Observations show state dependence
- The PPE tends to underestimate the observed modulation by ENSO



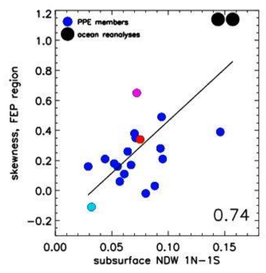
5. (B) Nonlinear Dynamic Warming (NDW)

$$\frac{\partial T'}{\partial t} = -\left(\begin{array}{l} u'\frac{\partial \overline{T}}{\partial x} + v'\frac{\partial \overline{T}}{\partial y} + w'\frac{\partial \overline{T}}{\partial z} \\ + \overline{u}\frac{\partial T'}{\partial x} + \overline{v}\frac{\partial T'}{\partial y} + \overline{w}\frac{\partial T'}{\partial z} \end{array}\right)$$

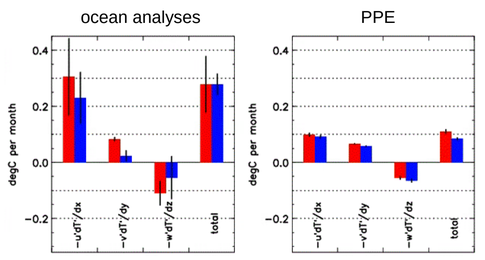
$$-\left(u'\frac{\partial T'}{\partial x} + v'\frac{\partial T'}{\partial y} + w'\frac{\partial T'}{\partial z}\right) + R'$$

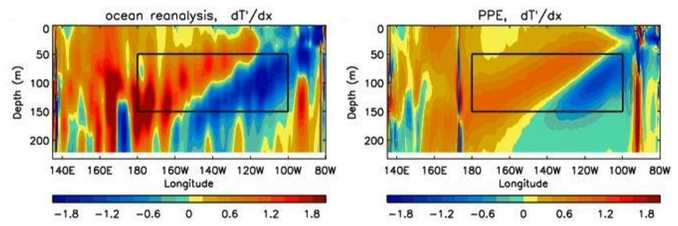


- Nonlinear advection terms contribute warming in the region of thermocline and in the mixed layer
- Weaker in the PPE than observations
- Significantly correlated with skewness in the PPE

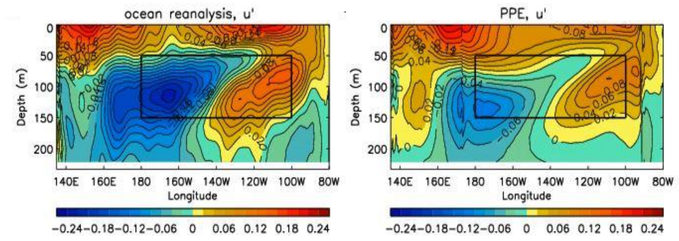


NDW during growth phase of El Niño and La Niña





- Both El Niño and La Niña make a positive contribution to NDW
- u′ ∂T′/∂x is small in PPE compared to the ocean reanalysis



- u′ is underestimated in the PPE

6. Summary

- ENSO amplitude asymmetry is weak in HadGEM3-GC3 compared with observations
- Modulation of westerly wind bursts by ENSO may be underestimated
- Contribution to NDW from ocean zonal nonlinear advection is too small
  - anomalous zonal currents are too weak in the region of the equatorial undercurrent

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