**Fast and Slow Responses of Equatorial SST Pattern to CO₂ Forcing**

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**Motivations**
- The long-term responses of equatorial Pacific sea surface temperature (SST) pattern to anthropogenic forcing has long been studied, but little is known about how much CO₂ effect contributes to these changes during a short time period.
- Abrupt 4xCO₂ experiment is used to emphasize the effect of CO₂ during a global warming process.
- This effect happens within the first few years, and the internal variability poses a big challenge in assessing the significance of CO₂ forced changes.
- The role of air-sea coupling during a short time period after imposing CO₂ needs to be better understood.

**Define fast and slow responses**

**Fast responses**
- First 2 years of fully coupled abrupt 4xCO₂ simulation is chosen because equatorial shows a rapid change in this period.
- Including both direct CO₂ forcing (important within the first month) and rapid land-sea contrast and air-sea coupling.

**Slow responses**
- Last 30 years of the simulation (89-119 years in this research).
- The earth system reaches equilibrium in this time period.

**Fast responses**

**Changes of surface temperature in the first 2 years normalized by global mean temperature changes (shadings) and equatorial surface wind anomalies (vectors) between 4xCO₂ and pre-industrial control simulation. Stippling indicate regions which are dominated by internal variability, based on Monte-Carlo simulation of the surface temperature (5).**

**Left column: Changes of precipitation between 4xCO₂ and industrial control simulation. Stippling indicates regions which are dominated by internal variability and pre-industrial control wind anomalies (vectors) averaged over 30 years of fully coupled large ensemble mean, and the bottom row shows results averaged over 30 years of slow (5659).**

**Time evolution of surface (horizontal) and subsurface (vertical, averaged from 79° to 2°N) temperature differences (shadings) and surface ocean current at 5m depth (vectors).**

**Important results:***
- An initial *cooling pattern* is found in Equatorial Pacific during *fast response* period.
- Strengthening in most of the equatorial atmospheric circulation in the first 2 years.
- Model and experiment setup (5).
- A very large initial ensemble abrupt 4xCO₂ experiment of CESM1 is used in order to eliminate internal variability.

**Goal**
- Explore the development of this fast cooling pattern and its evolution into an enhanced equatorial warming pattern.
- Compare the equatorial atmospheric circulation between fast and slow responses periods.

**Summary**
- Wind anomalies triggered by land-sea contrast together with ocean dynamics develop the fast cooling pattern.
- The weakening of anomalous easterlies and smoothing of vertical temperature gradient turn fast cooling to slow warming pattern.

**Pre-industrial Control**

120 ensemble members

**100 years**

**2 years**

**121 years**

**0… 30… 60… 150…**

**References**

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**Define Fast and Slow Responses Time Periods**

- **Fast responses:**
  - First 2 years of fully coupled abrupt 4xCO$_2$ simulation
  - Including both direct CO$_2$ forcing (important within the first month) and air-sea coupling

- **Slow responses:**
  - Last 30 years of the simulation (89-119 years in this research)

**Model and experiment setup:**

- A very large initial ensemble abrupt 4xCO$_2$ experiment of CESM1 is used, in order to eliminate internal variability.

**Important results:**

- A “La Niña-Like” initial cooling pattern is found in Equatorial Pacific during fast response period.
- Strengthening of Equatorial atmospheric circulation in the first 2 years.

**Goal**

Explore the development of this “La Niña-Like” fast cooling pattern and it’s evolution into an “El Niño-Like” slow warming pattern.

**Fast Responses**

- Changes of surface temperature normalized by global mean temperature changes (shadings) and equatorial SST denoted as “El Niño-Like” (regions boxed in red)
- Changes of vertical ocean temperature gradient (vertical) and thermodynamic temperature anomalies (horizontal and dynamical components)

**Slow Responses**

- Anomalous easterlies become almost zero
- Downwelling oceanic Kelvin wave transports warm water from west to east
- The magnitude of vertical ocean temperature gradient keeps decreasing
- Forms “El Niño-Like” warming pattern

**Summary**

- Wind anomalies triggered by land-sea contract together with ocean dynamics develop the fast cooling pattern.
- The weakening of anomalous easterlies and smoothing of vertical temperature gradient turn fast cooling to slow warming pattern.

**References:**