Strengthening trade winds and an enhanced Equatorial Pacific carbon source

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1. Question

“Dangerous” length of observational records, mixture of anthropogenic and natural forcings.

How can the newly available Earth System Model Initial Condition Large Ensemble experiments and data-based carbon flux products inform each other about natural variability in the strength of the ocean carbon sink?
Outline

1. Question

2. Tools

3. Findings
   a. Global Picture
   b. Equatorial Pacific
Schematic: Sources of Uncertainty

Scenario

Model

Internal/Natural (Large Ensembles)

Ensemble mean

Ensemble members 1-30

Historical Forcing

1860 control: >1000yrs

Future

Past

RCP2.6

RCP8.5

CMIP5

GESGLES2M

CESM1-BGC


0°C 1°C 2°C 3°C 4°C

RCP8.5

THIS PRESENTATION ---
1. Two initial condition large ensemble experiments (GFDL-ESM2M, CESM1-BGC)

2. CMIP5 Earth System Models, multi-model ensemble

Fig. 1. Global Annual Air-to-Sea Carbon Flux
2. Tools

1. Two ICLE’s (GFDL-ESM2M, CESM1-BGC)
2. CMIP5 multi-model ensemble
3. Observational data-based products of Air-Sea carbon fluxes over the period 1990-2009

Fig. 1. Global Annual Air-to-Sea Carbon Flux
Sidebar: Why is ocean carbon uptake sensitive to atmospheric initial conditions?

- Winds and climate modes change upwelling strength/patterns
- Freshwater fluxes change carbon concentrations
- Winds change gas exchange rate between ocean and atmosphere
- Temperatures changes solubility
- Buoyancy fluxes change mixing
- Biology – Nutrients, temperature, light, etc.
Outline

1. Motivation
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3a. Global Picture

Returning to the main question, how do the ESM ensembles and data-based ensembles compare?

(1<sup>st</sup>) Mean & (2<sup>nd</sup>) Natural Variability
3a. Observational Period 1990-2009

Fig. 3. 20-Year Trends: Individual GFDL-ESM2M Ensemble Members

Differences in ensemble members due *only* to background climate.

Appreciate the contribution of internal variability to setting decadal trends in the ocean carbon sink.

1 gC/m²/yr *ocean.area = 0.33 PgC/yr
Current annual uptake ~2 PgC/yr

source  gC/m²/yr/yr  sink
Fig. 3. 20-Year Trends: Individual GFDL-ESM2M Ensemble Members

3a. Observational Period 1990-2009

1 gC/m²/yr * ocean.area = 0.33 PgC/yr, Current annual uptake ∼2 PgC/yr

El Nino

La Nina
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Data-Based Trends
Mean OBS trends in Pacific Air-Sea carbon flux outside the range of the ensembles.
Why are the observed trends in Air-Sea carbon exchange over the Equatorial Pacific outside the range of the ensembles?

*Hypothesis:* Model bias in wind stress
Model bias in Eq. Pacific wind stress lead to model bias in hindcasting 1980’s-2010’s Pacific Basin SST’s. To what extent is this true for carbon fluxes?

England et al. (2014), McGregor et al. (2014)
Support for Wind-stress hypothesis:
Consistent model bias in

(1) Wind-stress
(2) East-West SSH gradient
(3) Air-Sea carbon fluxes
(1) **Wind-stress**

(2) **East-West SSH gradient**

(3) **Air-Sea carbon fluxes**

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**PDF of Zonal Wind Stress Trends**

- **Slope**: $5.312 \text{PgC/yr/N/m}$
- $R^2$: 0.331, $p$: ~0

**SSH Trends: GFDL vs. OBS**

**Wind vs. Carbon Trends**

- **Source**
  - **GFDL-ESM2M**
- **Slope**: $5.312 \text{PgC/yr/N/m}^2$
- $R^2$: 0.331, $p$: ~0

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3b. Observational Period 1990-2009, Pacific
Currently Underway: wind-substitution experiments, using Delworth et. al., (2014) method, but with ESM2M, testing ocean-carbon response to observed decadal trends in Equatorial Pacific winds.
Currently Underway: wind-substitution experiments
First 2 years (1979-1980) of simulations complete:
Conclusions

1. Initial Condition Large Ensemble and Multi-model experiments with ESM’s indicate natural variability produced much of data-based regional trends in the ocean carbon sink over past 2 decades.

2. Model bias in decadal variability of Equatorial Pacific wind stress is candidate cause of disagreement between data-based estimates and modeled trends in the ocean carbon sink in this region.