Modeling Carbon Cycle in the Pacific Ocean

Prof. Fei CHAI (柴扉)
University of Maine

Dr. Peng XIU
University of Maine/South China Sea Institute of Oceanology

• Ocean Carbon Cycle and Climate Variability
• Physical and Biogeochemical Models (two models)
• pCO₂ (increasing) & pH (decreasing) Trends
• A Twin Experiments - Anthropogenic CO₂
• Air-Sea CO₂ Flux, ENSO and PDO
The dominant factors controlling the temporal variability of carbon cycle?

The role of anthropogenic signal in modulating the carbon response to natural variability?
Regional Ocean Model System (ROMS)
1/8 deg. (~7-12km) (1991 to 2014)
or 1/2 deg. (~50km) (1958 to 2010)

Model Simulations

Initial conditions of TCO$_2$ and TALK are from GLODAP climatology

- Atmospheric pCO$_2$:
  - 280 ppm
  - 100 years

- Preindustrial level

- 1948, 1958, 2010

- Fixed Air pCO$_2$

- Anthropogenic CO$_2$
Sea Surface pCO$_2$

Seasonal cycle is largest
Anthropogenic trend is 1-2 ppm/year

Xiu & Chai, JGR-Oceans, 2014
Model Simulations

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

Normal

Fixed Air CO₂ Case

Control: atmospheric pCO₂ increases due to anthropogenic CO₂ emission

Fixed: atmospheric pCO₂ fixed at 1958 values

Sea Surface pCO₂ at SEATS

Xiu and Chai, JGR-Oceans, 2014
Two Model Sets

Anthropogenic CO2 (µmol/kg)

1958 to 2010
(0-1000m)

Control

Fixed

Anthrop

From Dai et al.

1958
Anthropogenic CO$_2$ along 30N
Anthropogenic CO$_2$ Distribution in the Pacific Ocean (along 30N, 2004-1994)

Modeled Results

Observational Estimates

Sabine et al., 2004
Sea-to-Air CO$_2$ flux

SEATS: $-0.14$ g C m$^{-2}$ yr$^{-1}$
MB: $4.6$ g C m$^{-2}$ yr$^{-1}$
HOT: $-5$ g C m$^{-2}$ yr$^{-1}$

Integrated North PACIFIC (ocean sink): $-0.57$ Pg C yr$^{-1}$

$R=0.72$
Seasonal pattern in \( p\text{CO}_2 \) and sea-to-air \( \text{CO}_2 \) flux
Interannual and decadal variability

CO₂ flux

1st

57%

PDO, MEI, NGPO

2nd

17.5%

PDO, MEI, NGPO

Normal Run
# Sea-to-Air CO₂ flux and correlations with climate indices

<table>
<thead>
<tr>
<th>Correlation/Lags</th>
<th>PC1 normal run</th>
<th>PC2 normal run</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDO</td>
<td>0.77/0</td>
<td>0.62/12</td>
</tr>
<tr>
<td>MEI</td>
<td>0.53/0</td>
<td>0.59/15</td>
</tr>
<tr>
<td>NPGO</td>
<td>-0.51/15</td>
<td></td>
</tr>
</tbody>
</table>

(57% variance) (18% variance)

Xiu & Chai, JGR-Oceans, 2014
Model resolution matters!

Fiechter, Chai, Curchister, et al., GBC, 2014
Regional Ocean Model System (ROMS) and CoSiNE (~10 km) (1993 to 2013)

Mean surface pCO$_2$ during 1993-2013
Regional Ocean Model System (ROMS) and CoSiNE (~10 km) (1993 to 2013)

Linear increasing trend of surface pCO$_2$ during 1993-2013
Coral Triangle

Surface Trends

$pCO2 = 1.1 \text{ ppm/year}$

$pH = -0.0007 /\text{year}$

$\Omega = 0.002 /\text{year}$
pH decreasing trend

Monterey Bay

-0.0017/y

Feely, 2008

HOT

-0.0022/y

-0.0017/y
Surface pH decreasing trends (1958 to 2010)
California Current System (upwelling vs. offshore)

Upwelling pH: -0.0007/year
Offshore pH: -0.0015/year
Modeling Carbon Cycle in the Pacific Ocean

Prof. Fei CHAI (柴扉)

University of Maine

• Physical and Biogeochemical Models (ROMS-CoSiNE)

• pCO₂, CO₂ flux, pH Trends (regional dynamics, nonlinear processes, ENSO, NGPO, & PDO)

• A Twin Experiments (separating natural and anth.)

• Model Resolution Matters (global, basin-wide, regional and local; impacts on ecosystems)