Strengthening of the East Australian Current and weakening of the Leeuwin Current in a warming climate: Results from dynamical downscaling

Chaojiao Sun
CSIRO Marine and Atmospheric Research
Acknowledgement

- Ming Feng
- Richard Matear
- Matthew Chamberlain
- Peter Craig
- Ken Ridgway
- Andreas Schiller
- Graham Symonds
- Stuart Godfrey
- Jay McCreary

Outline

• Motivation
  • To model the changes in ocean boundary currents around Australia 50 years from now

• Approach:
  • Use climate model projections of large-scale atmospheric fluxes as forcing and ocean state as initial condition
  • Downscale with a high-resolution ocean model

• Results:
  • The Leeuwin Current & Indonesian Throughflow weaken
  • The East Australian Current strengthens
Models

- the CSIRO Mk3.5 climate model
  - capable of simulating large-scale circulation patterns
  - cannot adequately resolve narrow boundary currents
  - could provide forcing fields and initial condition

- the BLUELink’s Ocean Forecasting Australia Model (OFAM)
  - 10-km resolution around Australia
  - global domain: no need for open-boundary or nesting
MK3.5 and OFAM simulated current speed in 1990s (averaged over 0-200m)
Downscaling experiments

Current observed climate

Future climate SRES A1B

Mk3.5 Climate forcing

SRES A1B (2060s)

20C3M (1990s)

ERA40 fluxes

Current climate experiment (CTRL)

Future climate experiment (FUTR)

SRES A1B (2060s) + climate forcing
Example of biases in climate models: Zonal wind stress $\tau^x$ bias in four models:

Bias averaged over 1981-2000, using ERA40 reanalysis as benchmark.
Daily snapshots of speed over 0-200m, 2060s
Mk3.5 LC simulations
OFAM LC simulations, zoomed view 28°S – 35.5°S, 110°E – 116°E
Daily SST (color) and streamfunction (contours)

\[ \Psi = \text{depth integrated steric height, relative to 200 m} \]
EAC changes: Mk3.5 (left); OFAM (right)
Daily current fields in the 2060s (averaged 0-200m)
Table 2: Annual volume transports of the Indonesian Throughflow (ITF), Leeuwin Current (LC), and the EAC. Note the numbers after ± are standard deviations of annual volume transports calculated over the 10-year time period. The LC transport is averaged over a latitude band between 32°S and 34°S. BRAN is the Bluelink ReAnalysis from 1992 to 2006 (Oke et al., 2008, Schiller et al. 2008). INSTANT estimate is from a 3-year field program from January 2003 to December 2006 (Spintall et al., 2009; Gordon et al., 2010).

<table>
<thead>
<tr>
<th></th>
<th>OBS (1990s)</th>
<th>Mk3.5 (1990s)</th>
<th>OFAM (1990s)</th>
<th>Mk3.5 (2060s)</th>
<th>OFAM (2060s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITF</td>
<td>15 Sv (INSTANT)</td>
<td>9.7±4.4 (BRAN)</td>
<td>14.5 ± 0.8</td>
<td>9.6±2.1</td>
<td>13.0 ± 0.9</td>
</tr>
<tr>
<td>LC</td>
<td>3.4 Sv at 32°S (Feng et al. 2003)</td>
<td>2.2±0.4</td>
<td>3.6±0.2</td>
<td>1.6 ±0.3</td>
<td>3.1±0.2</td>
</tr>
<tr>
<td>EAC core 28°-32°S</td>
<td>20-30 Sv (Mata et al., 2000, Ridgway and Dunn, 2003)</td>
<td>19.3 ± 1.3</td>
<td>34.4 ±3.1</td>
<td>18.0 ± 1.3</td>
<td>37.9 ±3.3</td>
</tr>
<tr>
<td>EAC Ext. 38°-42°S</td>
<td>9.4 Sv (Ridgway and Godfrey, 1994)</td>
<td>7.1± 0.7</td>
<td>18.5 ± 2.2</td>
<td>10.1 ± 1.0</td>
<td>25.0± 3.2</td>
</tr>
</tbody>
</table>
Discussion: long-term trends vs decadal variability

- The changes from our downscaling study agree with the **long-term trend** simulated by the Mk3.5 climate model.
- These changes are not necessarily in agreement with trends over a **shorter** time period.
- The LC transport is shown to have a strengthening trend over the past 15 years (Feng et al., 2011).
- The EAC transport, however, has continually strengthened over the past decades (e.g., Ridgway, 2007; Hill et al., 2008).
weakened equatorial Pacific zonal wind stress

GFDL CM2.1 and observed anomaly
Over 1850-2000
(Vecchi et al. 2006)
EAC long-term trends in the Mk3.5 climate model
Conclusions (1)

- In the 2060s, compared to the 1990s, from downscaling
  - EAC strengthens by about 20%
  - Leeuwin Current weakens by about 15%
  - mainly due to changes in Mk3.5 large-scale wind forcing
  - Consistent with observed trends over the past 50 years, but opposite to the trend over the past 15 years or so
- The eddy-resolving downscaling provides *regional details* that are lacking in climate model projections, which can significantly impact the marine ecosystems.
Conclusions (2)

- We have developed the capability to downscale climate model projections for ocean circulations using eddy-resolving ocean models.
- This is a first step towards producing robust high-resolution marine projections by downscaling an ensemble of global climate models and scenarios.
CSIRO Marine and Atmospheric Research
Chaojiao Sun
Research Scientist

Phone: +61 8 9333 6583
Email: chaojiao.sun@csiro.au
Web: www.csiro.au/cmar

Thank you

Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: Enquiries@csiro.au Web: www.csiro.au
## Model configurations

<table>
<thead>
<tr>
<th></th>
<th>Mk3.5</th>
<th>OFAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>~ 200 km</td>
<td>~ 10 km around Australia</td>
</tr>
<tr>
<td>Ocean model</td>
<td>MOM2</td>
<td>MOM4</td>
</tr>
<tr>
<td>Coupled model</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Domain</td>
<td>Global</td>
<td>Global</td>
</tr>
<tr>
<td>Forcing</td>
<td>SRES A1B</td>
<td>Wind stress, radiative fluxes, fresh water fluxes</td>
</tr>
</tbody>
</table>
**Downscaling forcings**

CTRL forcing $\rightarrow$ ERA40 1990s fluxes $\rightarrow$ CTRL

- Mk3.5 20C3M (1990s)
- Mk3.5 SRES A1B (2060s)

Climate forcing

FUTR forcing $\rightarrow$ CTRL forcing $+$ Climate forcing $\rightarrow$ FUTR

repeat-year forcing (including daily variability from 1995)

Initial condition = present climate + climate forcing
Results:

1. The Indonesian Throughflow (ITF)
2. LC (the Leeuwin Current)
3. EAC (the East Australian Current)
ITF sections and velocity profiles from Mk3.5 and OFAM
Weakened ITF -> weakened LC

(Godfrey and Ridgway, 1985, Fig. 3)
Mk3.5 and OFAM LC transport: black (1990s), red (2060s)
EAC transport

OFAM 2060s

OFAM 1990s