Prospects for High-Resolution to Improve Small-Scale Ocean Processes and Ocean-Atmosphere Interactions

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Outline

• What constitutes a “high-resolution” ocean model?

• Small-scale features/processes newly resolved
  – SST coupling with low-level winds
  – Intrinsic variability in upper ocean heat content & surface fluxes

• Interactions small-scale/large-scale
  – Modulation of the N. Pacific storm track
  – Initiation of tropical convection
  – Sea ice polynas and water mass formation

• Large-scale features: bias reduction/amplification
  – Eastern boundary current SST biases
Resolving The Synoptic Scale: Atmosphere vs. Ocean

Mean Sea Level Pressure: $O(1000 \text{ km})$

Troposphere

\[ R_1 = \frac{NH}{f} \approx \left( 10^{-2} \frac{s}{s} \right) \left( 10 \text{ km} \right) \frac{10^{-4}}{s^{-1}} = 1000 \text{ km} \]

Open Ocean

\[ R_1 = \frac{NH}{f} \approx \left( 10^{-3} \frac{s}{s} \right) \left( 4 \text{ km} \right) \frac{10^{-4}}{s^{-1}} = 40 \text{ km} \]

Sea Surface Height Anomaly: $O(100 \text{ km})$
Ocean grid-spacing (deg. lat)

Atmosphere grid-spacing (deg. lat.)

1deg.

1deg.

1/4deg.

Not to scale. Grid spacing in km varies in many global grids.

1/2deg.

1/10deg.

HR

LR

1deg.

1/4deg.

1/3deg.

1/10deg.

Ocean grid-spacing (deg. lat.)

CCSM3.5->CESM
Hack et al. T341

McClean et al. FV
Small et al 2014

CM2.6
Delworth at al.
CCSM3.5
Kirtman et al.

CM2.5
Delworth at al.
MIROC4h
Sakamoto et al.
CFES Komori et al.

HiGEM
Shaffrey et al.

CCSM3.5
Gent et al.

CESM “standard resolution”
1. Response of Low-level Winds to SST

Basin Scale
(-ve Corr.)

High Winds ➔
High latent and sensible heat flux, entrainment ➔
Cool SST

Frontal Scale
(+vs Corr.)

High SST ➔
High Winds

Mantua (1998)

Chelton and Xie (2010)
Correlation High-Pass SST w/ $|U_{srf}|$

QuickScat + AMSR

CCSM 0.5° atm / 1° ocn

CCSM 0.5° atm / 0.1° ocn

CAM5 0.5° w/ 0.25° Observ. SST
Resolution Dependence of Wind-SST Coupling Coefficient

Experiments w/ CAM5

• Stronger Dependence
  • Atm. VERT. Res. (#1 vs #2 or #5 vs #6)
  • HORIZ. Res. of SST (#3 vs #6)

• Weaker Dependence
  • Atm HORIZ. Res. (1° vs. 0.25°) (#2 vs. #3)

Provided by R. Tomas
2. Coupled Variability in Surface Heat Fluxes

Correlation of Surface Turbulent Heat Flux and SSH

HR Model

LR Model

OBS (JOFURO+ AVISO)
Correlations between HC & THF, $d(HC)/dt$ & THF in Coupled Simulations

von Storch (2000)
Wu and Kirtman (2006)
Scale Dependence of Lagged Correlation

HC and THF

$d(HC)/dt$ & THF

Ocean Weather

Atmosphere Weather

(Agulhas Region)
Transition Scale: Ocean Dominance to Atmosphere Dominance

HC vs. HFLX

|d(HC)/dt| vs. HFLX

[d]
Does Intrinsic Ocean Variability Influence the Free Troposphere?

Correlation Annual SSH and Convective Precipitation
3. Decadal variability in the Kuroshio Extension

KE Path Identified as SSH Contour at Mid-Jet

After Qiu and Chen (2005)
Observed Changes in Northward Ocean Heat Transport Between Stable and Unstable KE Regimes

Mean SSH


MHT

Bishop (2013) JPO
Simulated KE Path Length Variability

Year 0015

Year 0037

CESM-H

AVISO Altimetry Observations

Atmospheric Response: Poleward Heat Flux

Vertically-Integrated Transient Eddy Heat Flux

\[
\frac{1}{g} \int_{p_0}^{p_s} \left( C_p \overline{v' T'} + L \overline{v' q'} \right) dp
\]

Pacific Sector Integrated MEHT
Schematic Summary: “Local Bjerknes Compensation”

- Lower Ocean Heat Poleward Transport
- Strong SST Front
- Strong low-level baroclinicity
- High Ocean-Atmos. Surface Heat Flux S. of KE Axis
- High Atmos Transient Eddy Poleward Heat Transport

- Higher Ocean Heat Poleward Transport
- Weak SST Front
- Weak Low-level Baroclinicity
- Low Ocean-Atmos. Surface Heat Flux S. of KE Axis
- Low Atmos Transient Eddy Poleward Heat Transport
Onset of Tropical Convection
Li and Carbone, JAS (2012, 2015)

\[ \left( \nabla_h \cdot \hat{u}_h \right)_t \propto \nabla^2 p \propto \nabla^2 \text{SST} \]

- Track \( O(10,000) \) precipitation events over 4 year period
- For 75% of events precipitation events onset co-located with convergent LSST
- Infer a Lindzen-Nigam type response on scales \( O(100 \text{ km}) \)
Better sea ice resolution allows for more concentrated heat loss, increasing the drive of surface waters to densify, and forming more, and colder, AABW

Newsom et al J. Clim. (in review)
The Lower Cell is stronger, deeper, and extends more northward at fine resolution.
Heat loss though sea ice

0.1° resolution (HR)

1.0° resolution (HR)

0.1° resolution (HR)

1.0° resolution (HR)

Fraction of grid cells

Ice area fraction

Surface heat flux

W/m²
Eastern Boundary SST Biases

LOW-RES ATMOSPHERE BIAS

LOW-RES OCEAN BIAS

CHANGE DUE TO HIGH-RES ATMOSPHERE

CHANGE DUE TO HIGH-RES OCEAN
Resolution Dependence of Benguela Current Bias

Conclusions

• Qualitative difference in mechanisms involved in ocean-atmosphere interaction when ocean eddies resolved
• Strong observational and computational evidence for role of intrinsic ocean variability as an important source of variability in air-sea interaction at scales below about 1000km
• Current high-resolution coupled models do a credible job of capturing this class of variability and ocean-atmos. Interaction. **PROSPECTS GOOD for improvement with increased resolution.**
• *Suggestive* of source of sub-seasonal to seasonal predictability, but as yet not demonstrated. Challenges for initialization of ocean mesoscale and hence improved predictions.
• Weak signatures of impact on larger-scale atmospheric state
  – Eastern boundary current/marine stratus deck systems
  – Some response in storm track statistics
• Improvement with resolution is non-uniform/non-monotonic especially when resolution of ocean and atmosphere are not increased in concert.
Postscript: Still to Be Explored

- Atmospheric Coupling/Interaction with the Oceanic Sub-mesoscale
  - Inertial wave generation
  - TC cold wake restratification
  - ... ?