Two flavors of Atmospheric variability associated with mesoscale ocean features

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Thank you also to Bunmei Taguchi
Outline

• Investigation of atmospheric variability in coupled model with and without a highly resolved ocean
• Part 1: Storm track response (sub-weekly variability)
• Part 2: Interannual variability of atmosphere
Community Earth System Model (CESM)

CAM5 includes aerosols

Simulation set up from present day (~year 2000) conditions.

Land-ice model not used here
Simulations were performed in 2012 and 2013 including the early use period of Yellowstone — “Accelerated Scientific Discovery” thanks to CISL.
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Climatological mean SST: sensitivity to high resolution ocean

• 80 year segments
• HR or high-res- coupled run with high-resolution ocean
• LR or low-res– with low-res ocean
SST bias, CESM with 0.25deg atmosphere, 1deg ocean. Relative to Reynolds (2007). Annual mean

SST difference, CESM with 0.25deg atmosphere: 1deg. Ocean minus 0.1deg ocean.

Sign convention – matching colors (top and bottom) implies improvement with resolution.
N-W PACIFIC
LOW-RES OCEAN BIAS

Surface temperature (radiative)

CHANGE DUE TO HIGH-RES OCEAN

Surface temperature (radiative)
Antarctic Circumpolar Current

LOW-RES OCEAN BIAS

CHANGE DUE TO HIGH-RES OCEAN
Surface temperature difference HR-LR

Surface temperature (radiative) DJF K

Temperature range: -3 to 2.6 K
Surface temperature Gradients

HR has stronger gradients over ocean but LR has very strong gradients at coastline.

Fig. 4. Surface temperature gradient. Note weaker gradient along ocean front but stronger gradient along coastline, in left plot.
Part 1: Storm Track Response

• Storm track activity **amplified** by SST gradients

• Storm track location governed by SST gradients and air-sea stability i.e. “anchored”
  – Nakamura 2004, Booth et al 2010,

• **Very little sensitivity** of storm track to including high resolution ocean model
  – (Msadek 2014, Ocean Sciences)

• How do we reconcile these views?
Surface (10m) storm track (V)

DJF. Storm track is defined using 1-day difference filter of Wallace et al 1988. Similar results for more traditional band-pass.

Here we use meridional wind at 10m as a measure of surface storm track. Later show 850hPa winds.
Surface (10m) storm track (V) difference HR minus LR.

Difference between run with HR-OCN minus LR-OCN, showing 95% significant values, based on 30 winters.
Surface (10m) storm track (V) difference HR minus LR.

Difference between run with HR-OCN minus LR-OCN, showing 95% significant values, based on 30 winters.

Responses to warmer SST or to stronger SST gradient are weak or not significant.

*Possibly because changes to stability (Ts-Ta) are only large off US East coast, east of Japan. Ref: Booth et al 2010.*
N. Atlantic Storm Track
Surface storm track is closer to coast in run with low res ocean (right panel) than with high-res ocean (left), because SST is warmer near coast in former case, and storm track follows Gulf Stream in latter case.

Note: land-sea temperature contrast much larger in LR – due to warmer ocean at coast and colder land.

Left: close up of differences (left panel) and statistically significant differences(right), highlighting ~20% reduction near US East coast in high-res run.
Now compare against a high-resolution atmosphere AMIP run with Reynold’s et al (2007) 0.25deg SST.

Differences reduced with high-res ocean
N. Pacific storm track

Left: close up of statistically significant differences between HR and LR, highlighting ~20% reduction east of Japan.

Storm track too strong off coast

Storm track slightly too weak
Lower Free Troposphere storm track

(850 hPa) storm track (V) in DJF

Left: close up of statistically significant differences, highlighting ~10% reduction off US East coast and Japan in high-res run.

Reduced storm track activity in HR where warm SST bias is reduced.
Part 2: Interannual atmospheric Variability

- On interannual timescales, a new type of atmosphere-ocean covariability identified with high-resolution ocean models
- Sea surface height (SSH) and turbulent surface heat flux co-vary,
  - with heat out of ocean over high SSH/warm SST.
  - For scales of ~1000km or less
  - This is a local air-sea analysis
- Does this lead to enhanced atmosphere variability on this timescale?
• Following slides courtesy of Frank Bryan, Bob Tomas (NCAR)
• All data annual averages, linear trend removed.
• Pointwise correlations shown
• Observations are J-OFURO2 -AVISO, similar to OAFLUX-AVISO
• HR- run with high resolution ocean
• LR – low resolution ocean
THF = LHFLX + SHFLX > 0 upward; out of ocean, into the atmosphere

- In the extra-tropics, HR and OBS are more similar to each other than the LR
- + correlations suggest ocean forcing atmosphere in mid-latitudes, HR and OBS
- All are similar in the tropics
An Analysis Framework: Atmosphere drives SST variability

\[ \frac{dT_a}{dt} = \alpha(T_o - T_a) - \gamma_a T_a + N_a \]

\[ \frac{dT_o}{dt} = \beta(T_a - T_o) - \gamma_o T_o \]

- Barsugli and Battisti (1998), Wu et al (2006): \( \beta \sim \alpha/20, \gamma_a \sim 6 \text{ day}^{-1}, \gamma_o \sim 3 \text{ years}^{-1} \)
An Alternative Model: Oceanic Driven Variability

\[
\frac{dT_a}{dt} = \alpha (T_o - T_a) - \gamma_a T_a
\]

\[
\frac{dT_o}{dt} = \beta (T_a - T_o) - \gamma_o T_o + N_o
\]

Oceanic Weather Noise

Influence of ocean variability on the atmosphere extends beyond the vicinity of air-sea interface

Possible mechanism where internally generated ocean variability may influence atmospheric circulation patterns
• How much does this affect magnitude of atmospheric variability?
• Following results from CESM experiments
Variability: SSH

LR – Sea surface height

HR – Sea surface height

Plots show standard deviation of interannual variability.
Variability: SSH and latent heat flux

Plots show standard deviation of interannual variability. Linear trend removed.
Kuroshio extension close-up

LR – Latent heat flux

LR – Sea surface height

HR – Latent heat flux

HR – Sea surface height

cm

Wm$^{-2}$

Wm$^{-2}$
Variability: SSH and 10m wind speed

LR – 10m wind speed

LR – Sea surface height

HR – 10m wind speed

HR – Sea surface height
Wind speed fluctuations are a major contributor to latent heat flux variability.
Variability: SSH and convective precipitation: Kuroshio Extension

LR – Convective precipitation
LR – Sea surface height

HR – Convective precipitation
HR – Sea surface height
Conclusions

• Part 1:
  – Storm track not stronger in case with high-res ocean (using $v$ wind metric). Consistent with Msadek (2014).
  – However it is anchored in the correct location (as in Nakamura 2008, Ogawa 2012)
  – Low-res too strong near US East coast and east of Japan due to SST bias

• Part 2:
  – Enhanced co-variability in mid-latitudes between SSH, turbulent heat flux
  – Gives rise to enhanced variance of atmosphere thermodynamic quantities on interannual timescales
Discussion

• Part 1:
  • Likely that change in SST gradients between run with 1deg ocean and with 0.1deg ocean not sufficient to enhance storm track
  • Nakamura et al 2008, Sampe et al 2010 made much larger change to SST gradient, see Small et al 2014
  • Possibly a bigger influence on eddy heat fluxes due to downgradient effects.
  • Lagrangian storm track analysis planned (path change vs intensity change vs frequency change)
Discussion

• Part 2.
• Other timescales between daily and interannual need to be explored
• Influence of mean SST bias on atmosphere variability
• Are dynamic quantities affected (other than SLP) e.g. divergence, vorticity at low and upper level? Also SLP Laplacian?