Wintertime Gulf Stream-Atmosphere Interactions: Effects of Model Resolution & Climate

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"How will global warming change the storm track"
Some ancient history...

From an unfunded 2005 proposal (Colle, Peng, Robinson, & Thompson)

Is this – strong local atmospheric forcing of the ocean and weak ocean feedback on the atmosphere – the whole story in midlatitude atmosphere-ocean interaction? Ample evidence suggests that the answer is “No.” First, the extratropical ocean is not entirely passive. In some regions, particularly where western boundary currents separate from their coasts and turn towards the middle of their basins, oceans dynamically generate SST anomalies in association with meanders in these currents or with shifts in where they separate from their coasts (e.g. Frankignoul et al. 2001; Seager et al. 2001). These ocean anomalies are responses to variations in wind stress that can be remote both in space and in time. Because the SST gradients near western boundary currents are strong, small displacements of these currents can lead to large anomalies in the SST. Second, recent observational evidence reveals that SST anomalies in the vicinity of the Gulf Stream tend to precede anomalies in the large scale atmospheric circulation on a timescale of ~two weeks (Ciasto and Thompson 2004). The atmospheric response to North Atlantic ocean forcing, combined with the delayed response of the Gulf Stream position to variations in wind stress may, in turn, lead to coupled atmosphere-ocean variability on interdecadal timescales (Czaja and Marshall 2001).

The relevant ocean features associated with displacements of western boundary currents and their mid-ocean extensions, however, occur on spatial scales that are small – gradients of 10 °C/100 km are common – in comparison with the distances between gridpoints – typically hundreds of kilometers – in the atmospheric models used to conduct GCM experiments.

The questions for our proposed study are first, how is the influence of these sharp ocean thermal fronts, and in particular, their displacement by ocean dynamical processes, conveyed to the atmosphere? Second, how well are the dynamics of this ocean-atmosphere interaction represented in GCMs, which have long been the primary tools for studying the atmospheric response to SST anomalies in climate research?
Five years later...

- Move to NC State
- Begin collaboration with Gary Lackmann focusing on the role of diabatic potential vorticity (PV) in the stormtrack
- Realize that diabatic PV generation is a way to think about SST influence, but don’t do anything about it (until now)
Current project...

• Since diabatic processes that reinforce cyclones are on storm (meso) scales, and diabatic processes should (all else equal) be enhanced in a warmer climate, we hypothesize that:
  
  - Storm track response to global warming will increase with resolution
  
  - Resolution sensitivity of the storm track depiction will increase with warming
300 hPa EKE (7-day highpass)

Resolution effect

Climate effect

Willison et al., in prep.
How calculations are done

- **Weather Research and Forecasting (WRF) model**
  - WRF-ARW 3.2.1
  - 27 levels, top at 50 hPa
  - Mercator projection
  - WSM6 microphysics: single moment, 6 classes
  - Kain-Fritsch convective parameterization
  - Yonsei University boundary layer parameterization
  - Community Atmosphere Model (CAM) radiation
  - Gravity-wave drag included

- **Years 2001-2010**
  - Driven at boundaries by Global Forecast System final analysis (GFS-FNL)
  - Real-time Global SST updated each time step by linearly interpolating from weekly values

- **Two grid scales: 120 and 20 km**

- **Climate change: “Pseudo global warming”**
  - Apply position and calendar date dependent changes to GHGs, lateral boundary T and SST; relative humidity fixed at present values,
  - 2090-2100 average of 5 CMIP3 GCMs, A2 scenario
Pros & Cons

• Pros:
  - Realistic climate & upstream disturbances
  - Computationally tractable

• Cons:
  - Boundary issues in regional domain
  - Inconsistencies of GCM climate change with resolved limited-area dynamics*

*Global WRF experiments underway with 2-way nest to latitude band spanning NH storm tracks
Air-sea interaction results

- **Means**
- **Regressions**

### Mean 2 m T (K)

### Δ 2 m T (K)
Surface (10 m) wind speed (m/s)

Resolution effect

Climate effect

20 km grid current climate
Curl of surface wind stress (Pa/m)

20 km grid current climate

Climate effect

Stronger wind driven Gulfstream in future?
Precipitation (mm/day)

Resolution effect

Climate effect

20 km grid current climate
Sensible heat flux: + upward (W/m²)

Resolution effect

Climate effect

20 km grid current climate
Latent heat flux: + upward (W/m²)

Resolution effect

Climate effect
Regressions against SST

- A complication
  - In a global AMIP run, SSTs at some time are unaffected by and uncorrelated with atmospheric conditions at earlier times.
  - In a regional AMIP run, observed SSTs are the product, in part, of large-scale conditions retained in the lateral boundary conditions.
  - Following Ciasto & Thompson (2004), we remove seasonal means, and regress atmospheric tendencies on SST
Energy flux (sensible + latent) tendency on SST - point by point

\[ \text{flux}'(t+14d) - \text{flux}'(t-14d) \]

Results change little with resolution or climate

\((\text{W/m}^2/\text{K})\)
500 hPa $z'$ tendency on SST

$[z'(t+14d)-z'(t-14d)]$

Strong resolution dependence, but results change little with climate

Ciaсто & Thompson 2004
Energy flux tendency on SST
\[ \text{flux}'(t+14d) - \text{flux}'(t-14d) \]

Possible positive feedback with flow response

120 km grid

20 km grid
Summary

• Strong climate and resolution dependence of N. Atlantic air-sea interactions
  - Resolution dependence greater in a warmer climate
  - Climate dependence greater at higher resolution
  - Implies current GCM resolutions are insufficient

• In warmer climate, stronger mean air-sea interactions in mean but no stronger coupling of variability.

• Atmospheric response to SST variability is sensitive to resolution