Seasonal Coupling in the Gulf Stream Region between the Atmosphere and the Ocean

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Introduction

Seasonal coupling in the Gulf Stream region between the atmosphere and ocean is investigated using a model and observations. Dong and Kelly (2004) showed, using a diagnostic model constrained by observations, that on interannual time scales, the upper ocean heat content leads surface heat flux out of the ocean by approximately 3 months, with a warmer ocean leading to heat flux out of the ocean. Here, we examine the seasonality of the relationship between upper ocean heat content and surface flux. We use turbulent surface heat flux and upper ocean heat content from ECCO2 (Estimating the Circulation and Climate of the Oceans, Phase II), and observations of sea surface height (SSH) from AVISO as a proxy for upper ocean heat content, and surface turbulent heat flux from the OAFlux project. We focus on the period between 1992 and 2007, in a region encompassing the separated Gulf Stream between 33°N and 45°N, and 74°W and 52°W.

Data for analysis

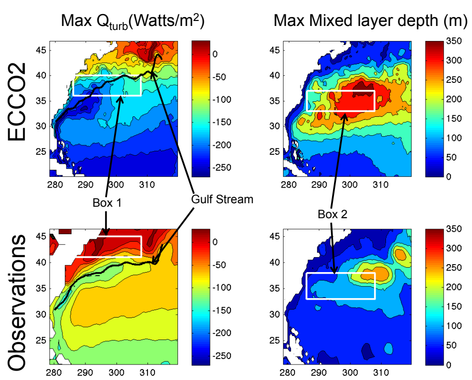
ECCO2: Estimating the Circulation and Climate of the Ocean, Phase II
18 km resolution, monthly averages, model constrained by SSH, sea surface temperature etc. with 50 simulations for parameter choices

ECCO2 Analysis variables	Derivation
Heat Content	Vertically integrated temperature in top 800 m
Turbulent heat flux	Difference between net surface heat flux, short wave flux, and long wave flux taken from ISCCP
Mixed-layer depth	Model defined

Observations: monthly averages of all quantities

Observational Analysis variables	Source	Comment
Sea surface height (SSH)	Monthly maps of sea level anomaly from Ssalto/Duacs 1/3° x 1/3°, Mercator grid	Used as proxy for upper ocean heat content
Turbulent heat flux Q_{turb}	OAflux: Objectively Analyzed air-sea fluxes for the Global Oceans (Yu and Weller, 2007)	Sum of sensible and latent heat flux
Mixed-layer depth	1 degree monthly mixed-layer climatology from Johnson et al (2012)	

Regional context: comparison of ECCO2 and observations

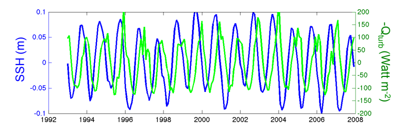


- ECCO2 reproduces the path of the Gulf Stream determined from SSH (black line in left hand panels)
- Maximum mixed layer depth in ECCO2 is further to the west, over a broader region, and deeper than observations
- Region of positive (warming the ocean) maximum turbulent heat flux (Q_{turb} sensible plus latent) is larger in observations, with the positive region located just to the North of the Gulf Stream, but is limited to a region further to the North in ECCO2.
- Because of the differences between the model and observations, the analysis was done over different boxes.

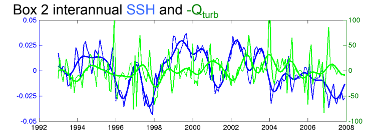
Analysis regions: 74°W to 58°W	ECCO2	Observations
Box 1 North of the Gulf Stream	36°N to 40°N	41°N to 45°N
Box 2 South of the Gulf Stream	33°N to 37°N	33°N to 38°N

Box 2 observations: the relationship between surface flux and heat content

Box 2 monthly SSH and negative of Q_{turb}

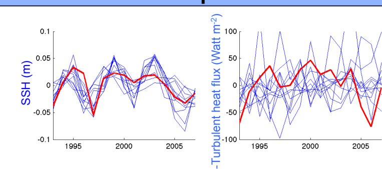


Box 2 interannual SSH and $-Q_{turb}$



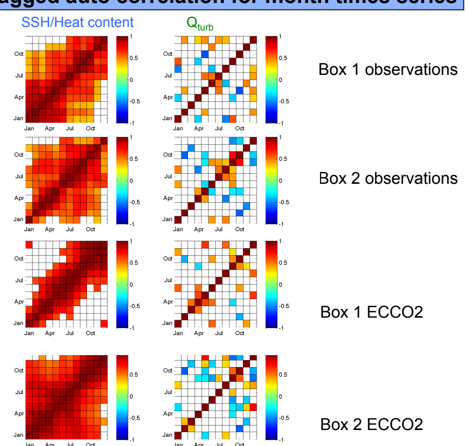
SSH leads Q_{turb} by 5 months with a correlation of 0.53,significant at the 95% confidence level.

Seasonal relationship between SSH and Q_{turb}



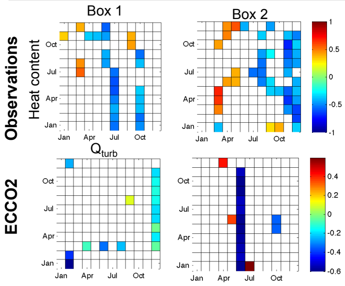
The blue lines show time series of SSH and $-Q_{turb}$, for each month of the year. SSH has long persistence with similar time series for each month. $-Q_{turb}$ shows very little persistence. The red lines show October SSH, and October and November $-Q_{turb}$. The correlation between SSH and Q_{turb} for these month is -0.43 and is significant at the 95% confidence level.

Persistence of SSH/heat content and Q_{turb}: lagged auto correlation for month times series



White areas have insignificant correlations. SSH/Heat content is more persistent than Q_{turb}. ECCO2 shows more persistence in Box 1 with increasing persistence late in the year. Observations show more persistence in Box 2, with persistence larger at the beginning of the year.

Can heat content predict surface flux? Lagged correlations between SSH/heat content and Q_{turb}

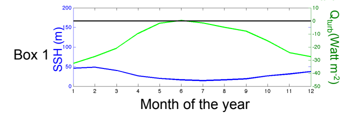


Box 1: winter/spring SSH/heat content predicts July Q_{turb}
Box 2: spring/ summer heat content predicts November/ December Q_{turb}

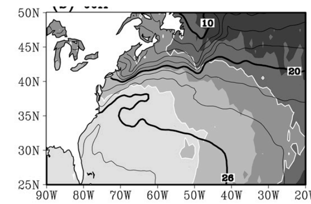
Box 1: fall heat content predicts December Q_{turb}
Box 2: spring/ summer heat content predicts June Q_{turb}

What causes the seasonal correlation? Box 1

Seasonal cycle of mixed layer depth and Q_{turb} for observations

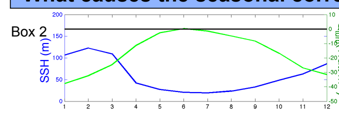


Satellite derived Low level cloud fraction

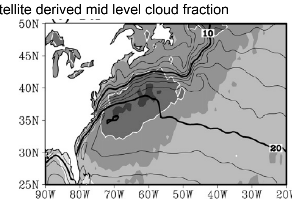


In **Box 1**, the mixed layer is shallow throughout the year, and the turbulent heat flux is into the ocean in July. Atmospheric variability is also at a minimum.
Low cloud fraction is at a maximum in June/June/August (Minobe et al. 2010, Fig. 8b).

What causes the seasonal correlation? Box 2



Satellite derived mid level cloud fraction



In **Box 2**, the mixed layer depth is nearing its maximum in November and is accessing heat stored the previous winter (reemergence, Timlin et al. 2002). Mid-level cloud fraction is at a maximum and is associated with increased convergence and precipitation (Minobe et al. 2010, Fig. 8c).

Conclusions

By examining correlations between individual times series for each month of the year, for Q_{turb} and SSH/upper ocean heat content, we find that: Q_{turb} has no persistence beyond a month for both ECCO2 and OAFlux, but SSH/upper ocean heat content persists for up to a year. July and December Q_{turb} can be predicted from upper ocean heat content from the previous 3–6 months.

ECCO2: Summer to fall SSH/ocean heat content leads Q_{turb} south of the Gulf Stream. Spring ocean heat content leads July surface flux north of the Gulf Stream.
Observations: Summer to fall SSH/ocean heat content leads December Q_{turb} south of the Gulf Stream. Spring SSH/ocean heat content leads July Q_{turb} north of the Gulf Stream

Despite the good representation of the Gulf Stream, differences between ECCO2 and observations are likely owing to adjustment of Q_{turb} to biased model sea surface temperature and mixed layer depth.

Coupling in summer:
Q_{turb} is into the ocean in June/July, the mixed layer is shallow, and the atmosphere is warmer than the ocean, leading to a shallow planetary boundary layer, weak surface winds, atmospheric temperature inversion, and stratocumulus clouds. The impact of the ocean may be limited to the boundary layer, but could have a larger scale impact by forcing changes in stratocumulus cloud distribution.

Coupling in winter:
During late fall, the Q_{turb} is out of the ocean as the mixed layer nears its maximum depth; the atmosphere then has access to the heat stored in deeper ocean. Later in the winter, the deep heat content loses its memory of the previous year, as it is more directly affected by the atmosphere. Impact in the atmosphere may be felt in the mid-troposphere, through changes in near surface wind convergence.

Future analyses include evaluation of the seasonal correlations throughout the North Atlantic and the rest of the world's oceans, and examination of these relationships in coupled climate models.

References

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