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How diabatic is the observed Mesoscale ?

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Summary

SST and SSH Anomalies from high resolution satellite observations suggest that :

- **observed SST anomalies are firmly associated to mesoscale eddies in regions of high mesoscale variability like the gulf stream (fig. 5) or the ACC (fig. 6),**
- **eddies' SST signals are strongly damped over the gulf stream (fig. 8) and most of the Southern Ocean, however damping strength reaches a minimum over the core of the ACC (fig. 9),**
- **thermodynamic feedback alone cannot account for the observed damping strength in WBC regions (figures 3-4 versus 8-9).**

Motivation

The negative feedback between air-sea heat fluxes and SST is believed to increase towards smaller scales. Therefore mesoscale SST anomalies will be quickly damped. **The knowledge of the observed damping strength on the mesoscale is crucial to understand**

1) Mesoscale Ocean-Atmosphere Coupling

As damping becomes stronger on the mesoscale, SST anomalies at the origin of coupling are quickly attenuated and the importance of high-resolution ocean-atmosphere coupling decreases.

2) Mesoscale Eddy Heat Transports

In steady state the mesoscale only contributes to the poleward heat transport if diabatic forces damp SST anomalies. Otherwise eddies move back and forth across fronts transporting heat reversibly in both ways (**fig.1**).

However if SST anomalies decay much quicker than the time eddies need to cross the front, eddy heat transport will also be limited.

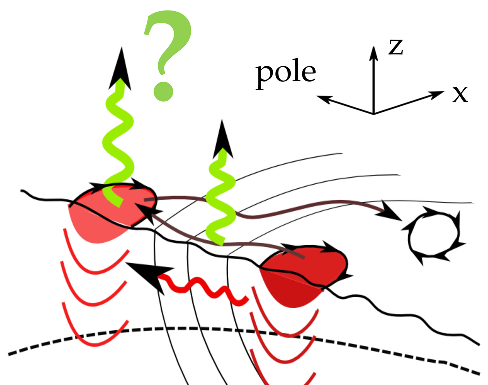
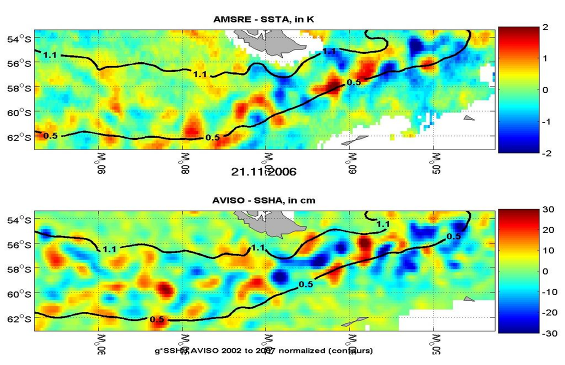


Fig.1: Eddy Heat Flux (red) and Damping Strength (green) – example of a warm eddy

High-resolution satellite observations for SSH and SST

Fig. 2:



Anomalies of SST (top, in K) and SSH (bottom, in cm) on the 21th november 2006 show warm anticyclones (red) and cold cyclones (blue) moving along the path of the ACC through Drake passage. Contours show the average streamfunction gη/f.

Through-cloud MW SST from AMSR-E are available daily since June 2002 on a 1/4° grid with an effective resolution of 50km[1].

AVISO provides an SSH dataset from merged altimeter missions on a 1/3° Mercator grid every 3-4 days[2].

Anomaly datasets for North Atlantic and Southern Ocean are built for **2002 – 07** by subtracting climatologies of Reynolds SST[3] and Aviso SSH.

A benchmark estimate for damping on the large-scale

An estimate for the damping of SST anomalies by turbulent heat fluxes can be derived from bulk formulae[4]. Assuming no dynamic coupling ($\partial u^a/\partial T \sim 0$, $\partial c_d/\partial T \sim 0$) and no thermal atmospheric adjustment to SST anomalies ($\partial T^a/\partial T \sim 0$):

$$\alpha_{\substack{large\\scale}} = \partial(Q'_{sens}+Q'_{lat})/\partial T\Big|_{SST} = \rho^a|u|^a\left(c_s c_p^{\,a} + c_l L\frac{dq_{sat}}{dT}\Big|_{SST}\right)$$

This constitutes the **upper bound** for the damping by **purely thermodynamic** processes and sets the large-scale background damping experienced by mesoscale eddies. Towards larger scales thermal adjustment reduces damping (to a radiative limit of ~3 W/m²K on global scales[5]), whereas an increase towards smaller scales is only possible through dynamic coupling.

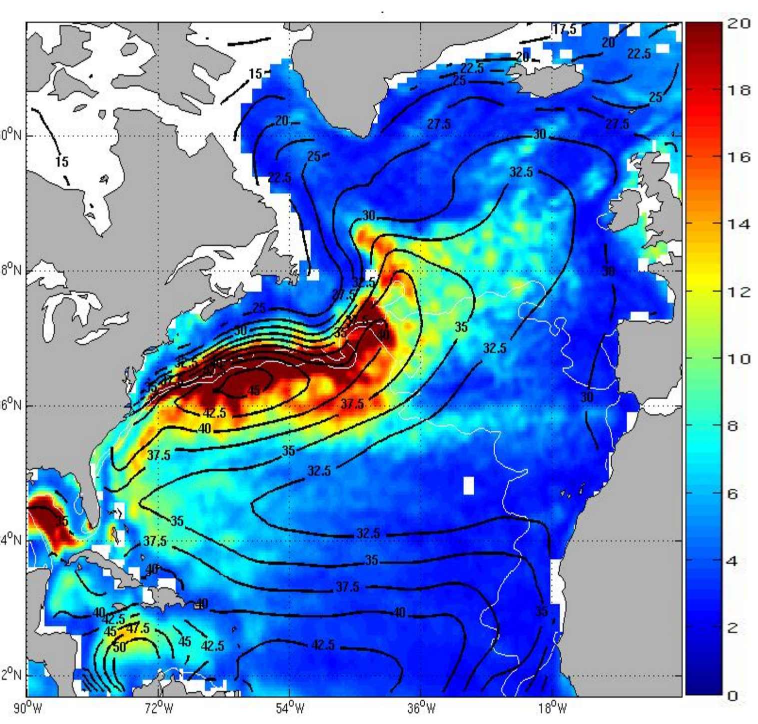


Fig.3: $\alpha_{largescale}$ **(contours, in W/m²K)**
Std of SSH Anomalies (colour, in cm)

Contours in **figures 3 and 4** show $\alpha_{largescale}$ estimated from large-scale wind-speed[6] and SST[3].

Minima occur in cold high latitudes (~25 W/m²K along the ACC) and along the westerly-trade winds boundary in the STG.

Damping peaks along the warm Gulf Stream, coincident with strong mesoscale variability (colours), but values never exceed ~45 W/m²K.

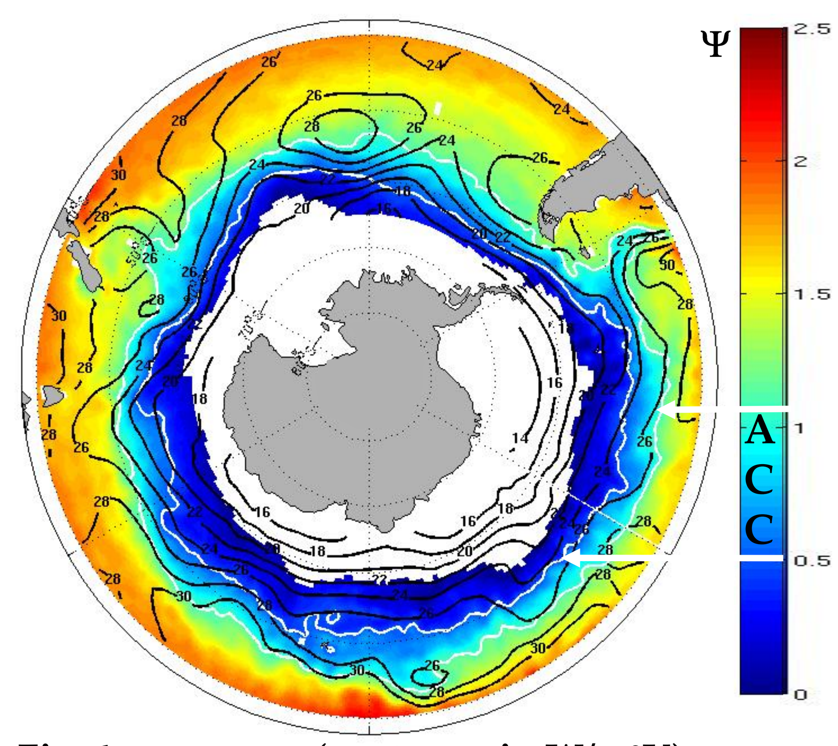
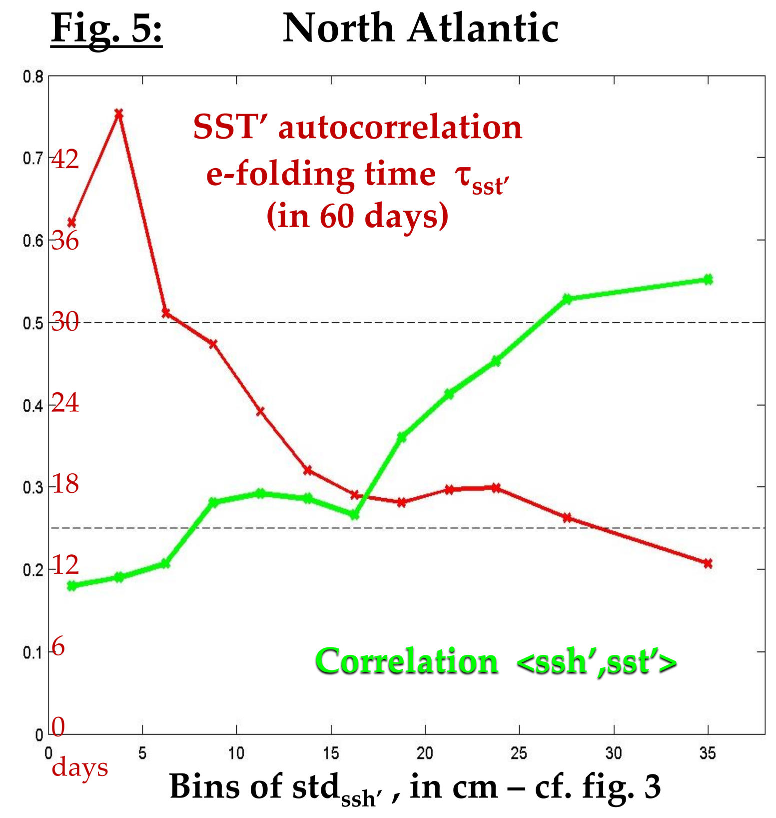


Fig. 4: $\alpha_{largescale}$ **(contours, in W/m²K)**
Streamfunction Ψ gη/f (colour, normalized)

Eddies' SST signals

North Atlantic's mesoscale variability peaks around the Gulf stream (std_{ssha} exceeds 35cm – **fig. 3**). Here SST anomalies are firmly associated to mesoscale eddies (green) and persist much shorter (~10 days) than in quieter regions (~30 days, red). This suggests increased damping on the mesoscale.

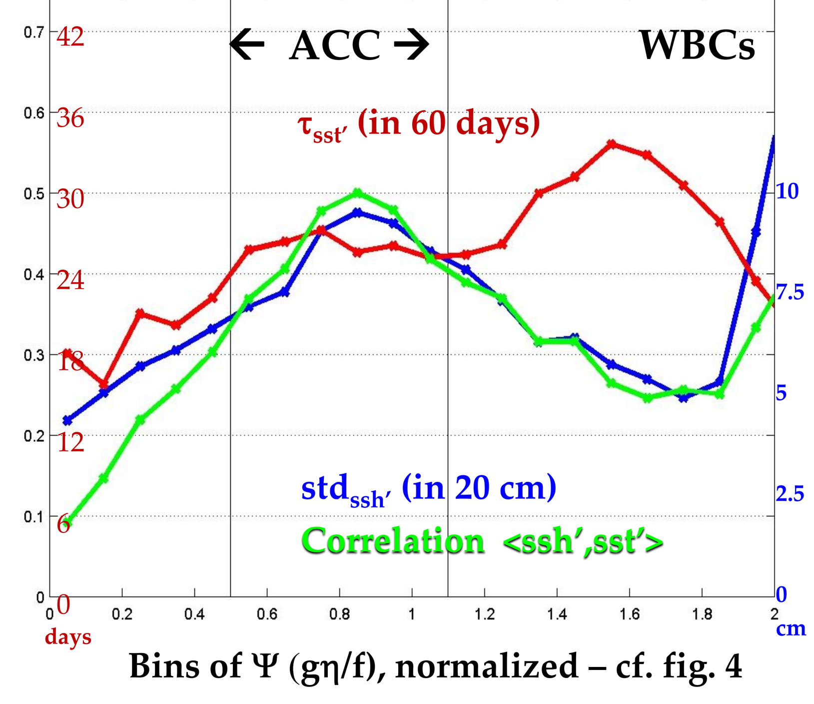
Fig. 5: North Atlantic



In the **Southern Ocean** mesoscale variability (blue) peaks along the path of the ACC and in WBC regions.

Along the ACC, SST anomalies are more closely linked to mesoscale eddies than to the north and south (zero-lag correlations locally exceed 0.75 and reach 0.5 when averaged along streamlines – green curve), but nevertheless persist quite long (~25 days).

Fig. 6: Southern Ocean



How strongly damped are observed eddies ?

Assuming the SST' are mainly damped by turbulent air-sea heat fluxes:

$$\partial sst'/\partial t \sim -Q'/\rho c_p h \sim -\alpha\ sst'/\rho c_p h,$$

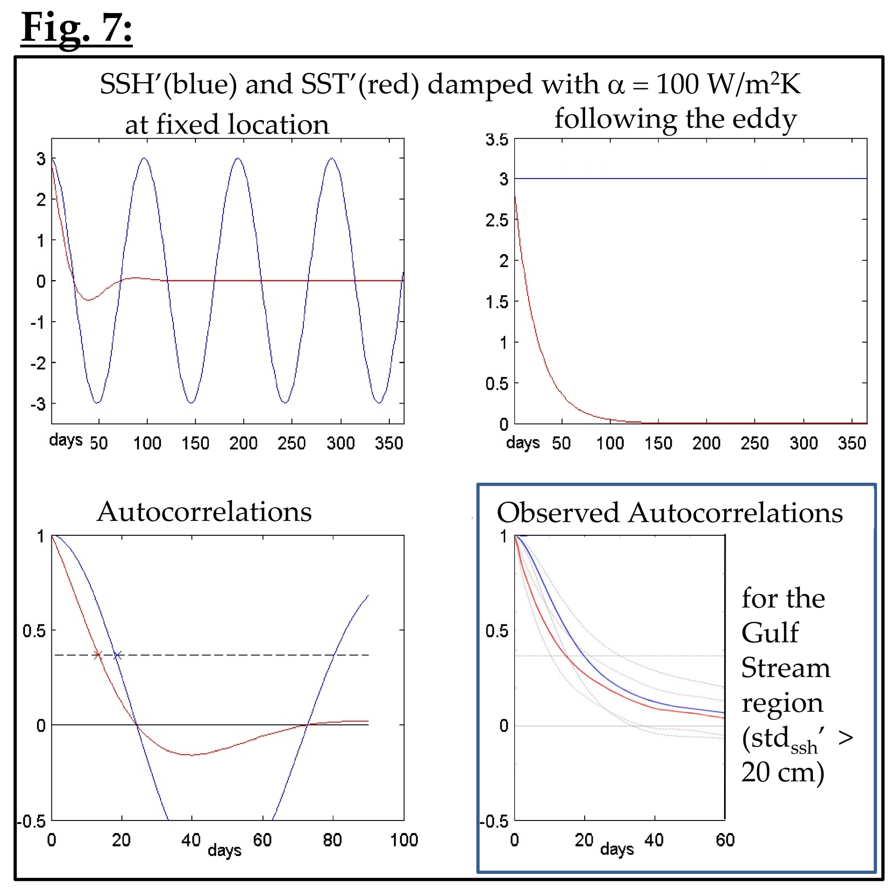
SST' persistence (measured by the their autocorrelation e-folding time $\tau_{sst'}$), combined with a mixed depth dataset[7], yields an estimate of the damping strength α **(red curves in fig.8 and 9)**.

Observed SST' persistence is quite short (~15 days over the Gulf Stream, cf. **fig.5**), since locally advection wipes out its memory. For highly correlated SST and SSH anomalies a measure of the advective timescale can be obtained from e-folding times of SSH' autocorrelations $\tau_{ssh'}$:

$$\partial sst'/\partial t \sim -\alpha\ sst'/\rho c_p h - sst'/\tau_{ssh'}\ .$$

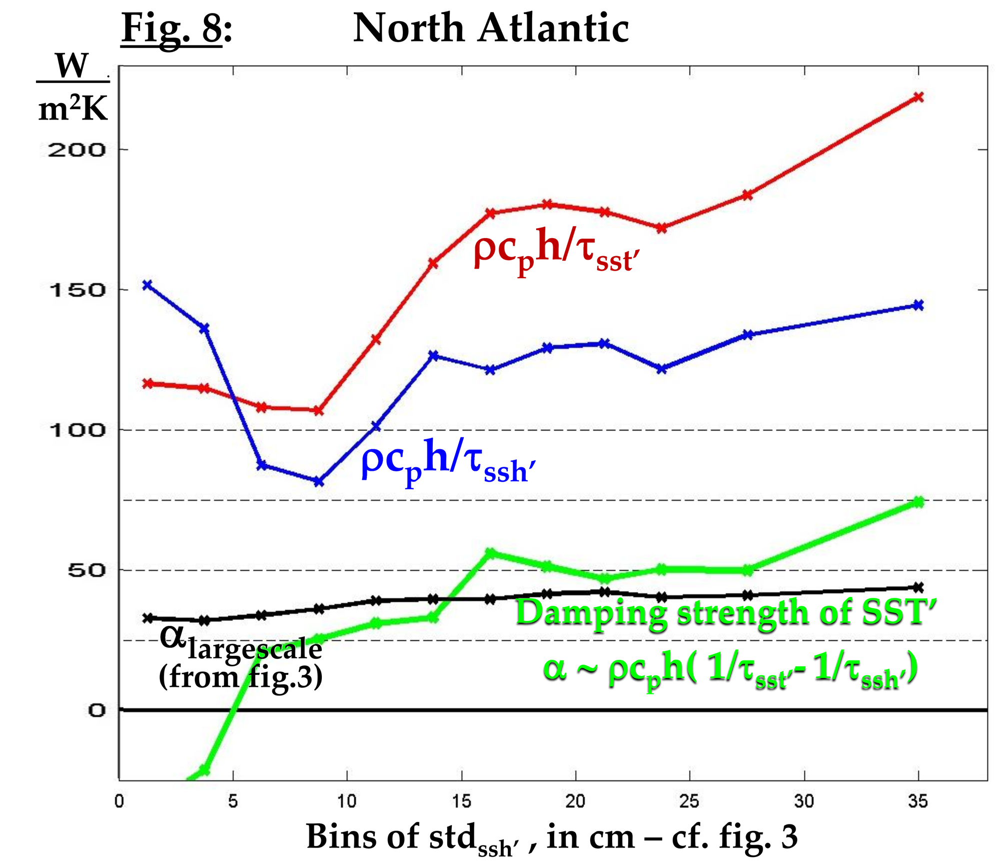
Subtracting this "apparent" damping by advection **(blue curves in fig. 8 and 9)** yields a crude estimate of the damping experienced by SST anomalies following the flow **(green curves in fig. 8 and 9)**.

Fig. 7:



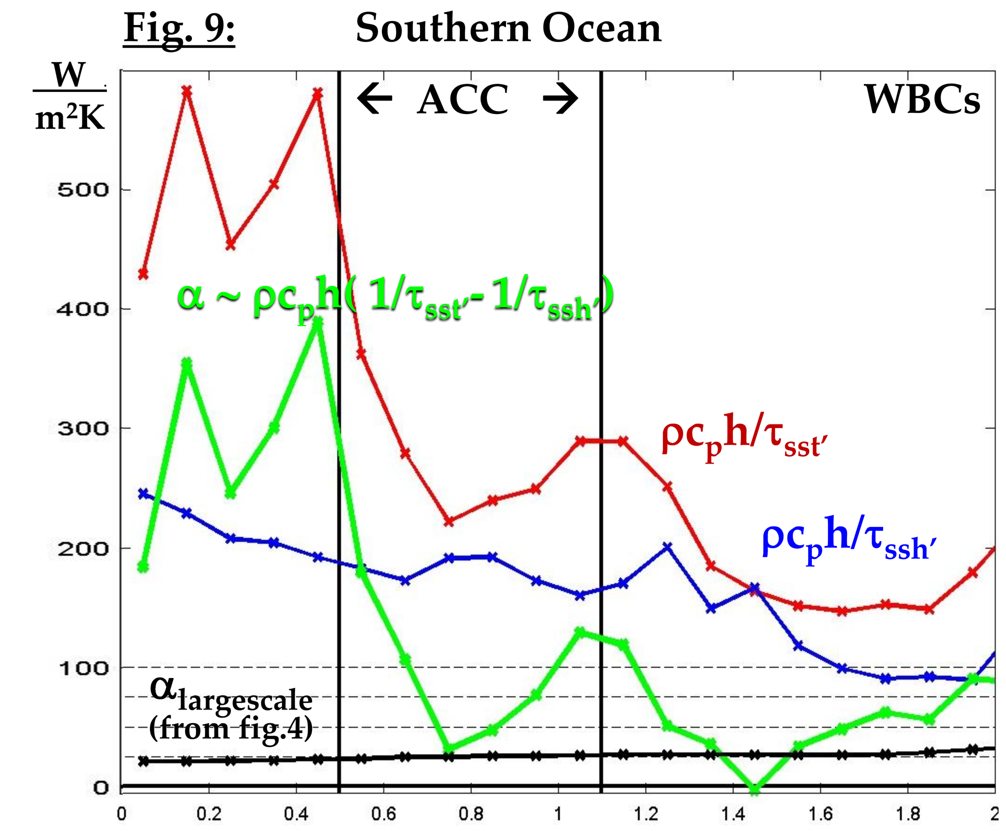
SSH' and SST' time-series and autocorrelations at a fixed location for an ideal wavelike eddy compared to observations in the Gulf stream region.

Fig. 8: North Atlantic



The damping of observed high resolution SST'**(green)** increases towards regions of strong mesoscale variability and reaches strengths (~ 75 W/m²K) that cannot be explained by large-scale thermodynamic damping **(black)** alone.

Fig. 9: Southern Ocean



In the WBC of the Southern Ocean damping of SST' **(green)** is comparable to the Gulf Stream region. However over the core of the ACC , where atmosphere and ocean equilibrate more far away from continents, damping is reduced and becomes comparable to the large scale upper bound **(black).**

References

1. AMSR-E data *are produced by* Remote Sensing *Systems and available at* www.remss.com.
2. *The altimeter products were produced by* Ssalto/Duacs *and distributed by* Aviso *with support from Cnes*.
3. Reynolds et. al., 2002, *J. Climate*, 15
4. Haney, 1971, *J. Phys. Oceanogr.*, 1
5. Bretherton, 1982, *Prog. Oceanogr.*, 11
6. da Silva et al., 1994, *Atlas of Surface Marine Data*, Vol. 1
7. de Boyer Montégut et al., 2004, *J. Geophys. Res.*, 109