Predicting surface heat flux with ocean heat content anomalies in the North Atlantic

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Question:

Can the heat content be used to predict surface heat flux in the North Atlantic? Where and when?

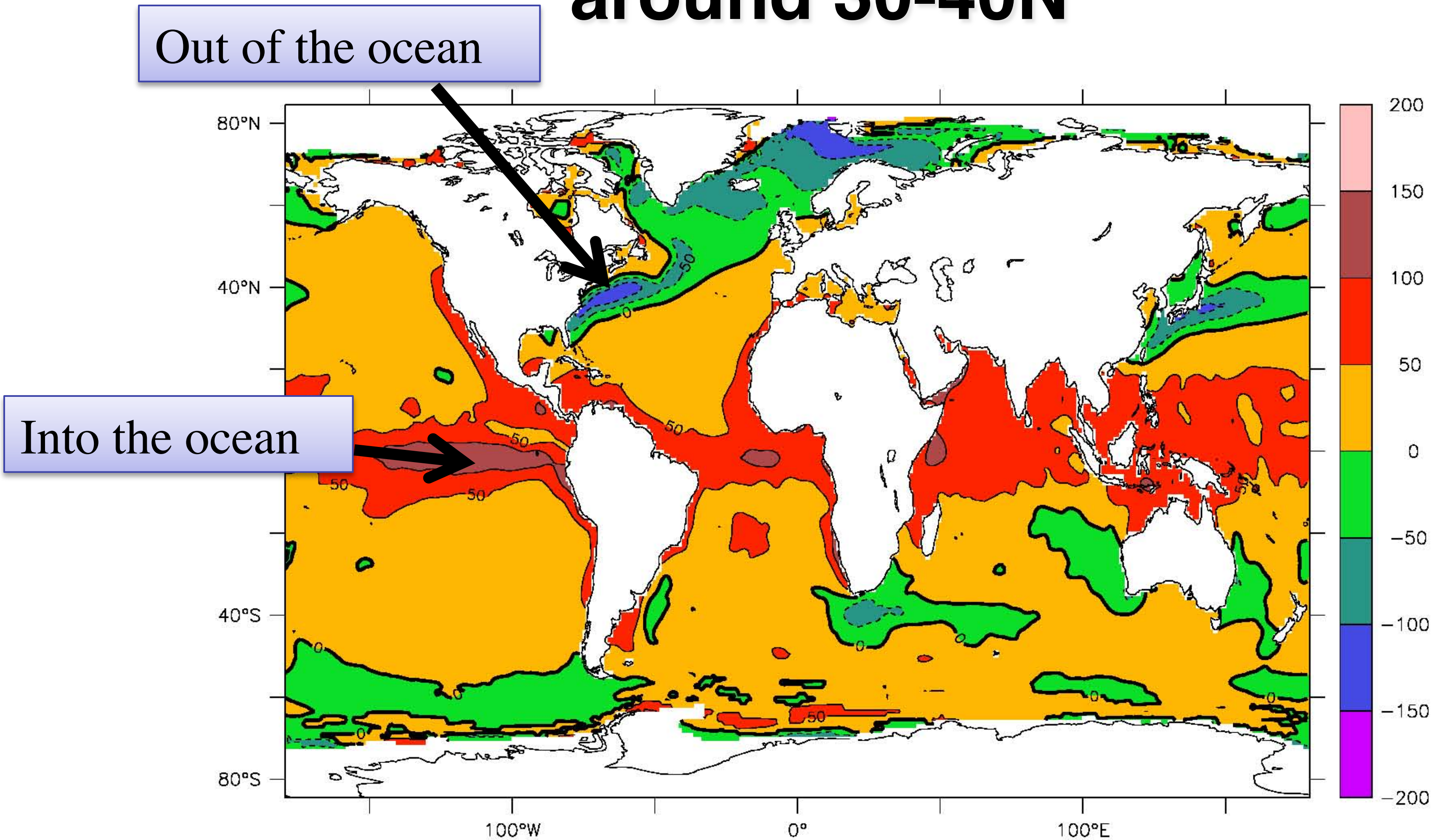
Answer

Use sea level as a proxy for upper ocean heat content to find:

Basin wide interannual relationships

Basin wide seasonal relationships

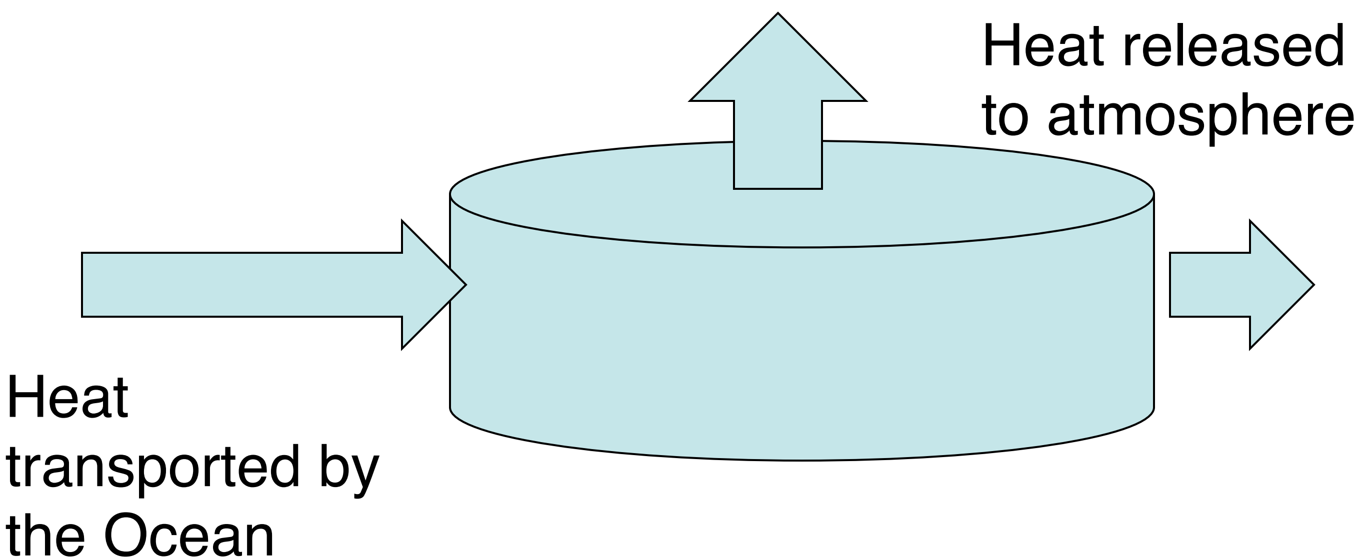
Net surface flux from the atmosphere to the oceans Watt/m^2: implied ocean heat transport convergence, maximum around 30-40N



Role of heat transport: mean balance

Heat is lost from the Gulf Stream to the atmosphere (about 0.2 PWatts)

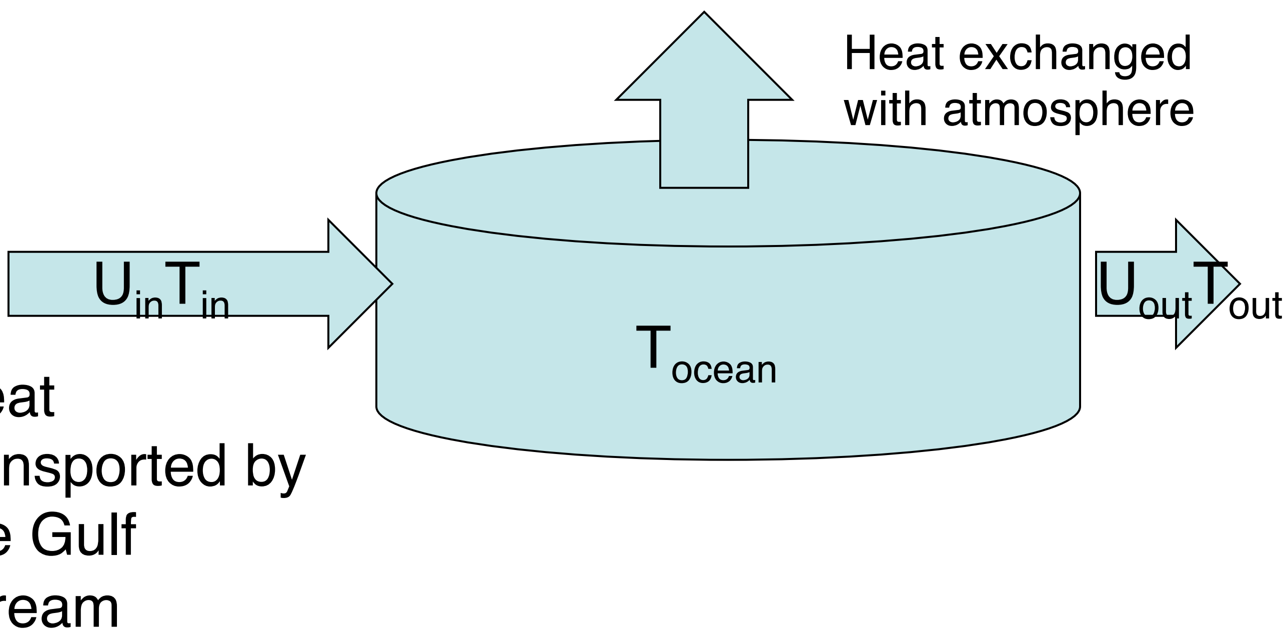
Maximum ocean meridional heat transport about 1 PW at about 20-25N



Heat Budget (temporally varying)

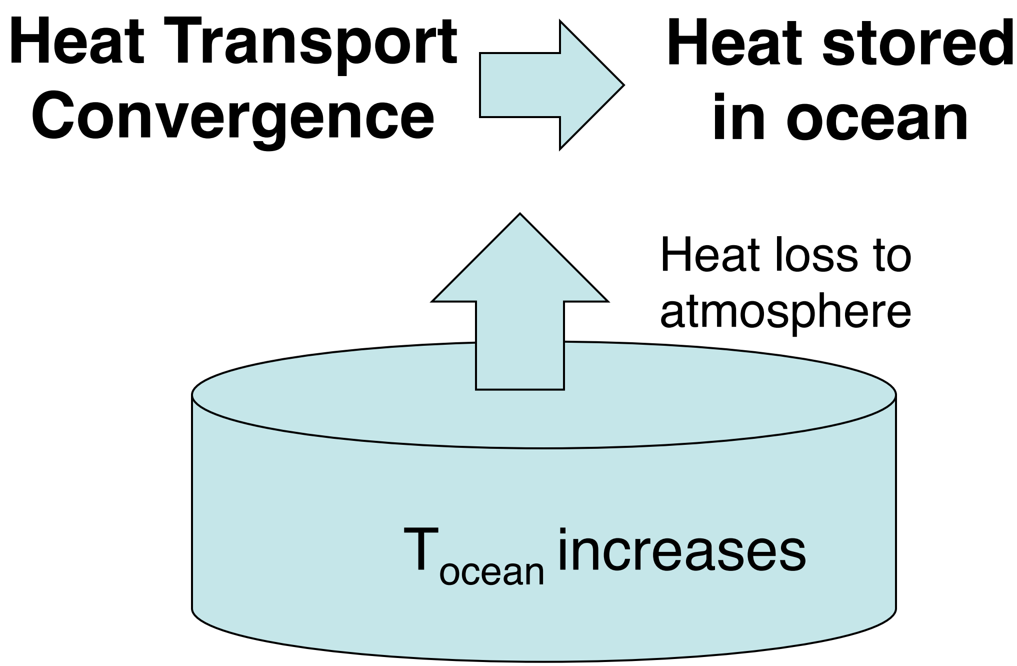
$$\rho_{ocean} H_{ocean} c_p \frac{dT_{ocean}}{dt} = \rho_{ocean} H_{ocean} c_p \nabla \bullet \vec{u} T + Q_{surface}$$

Heat storage rate in upper ocean = Heat Transport Convergence + Surface heat flux

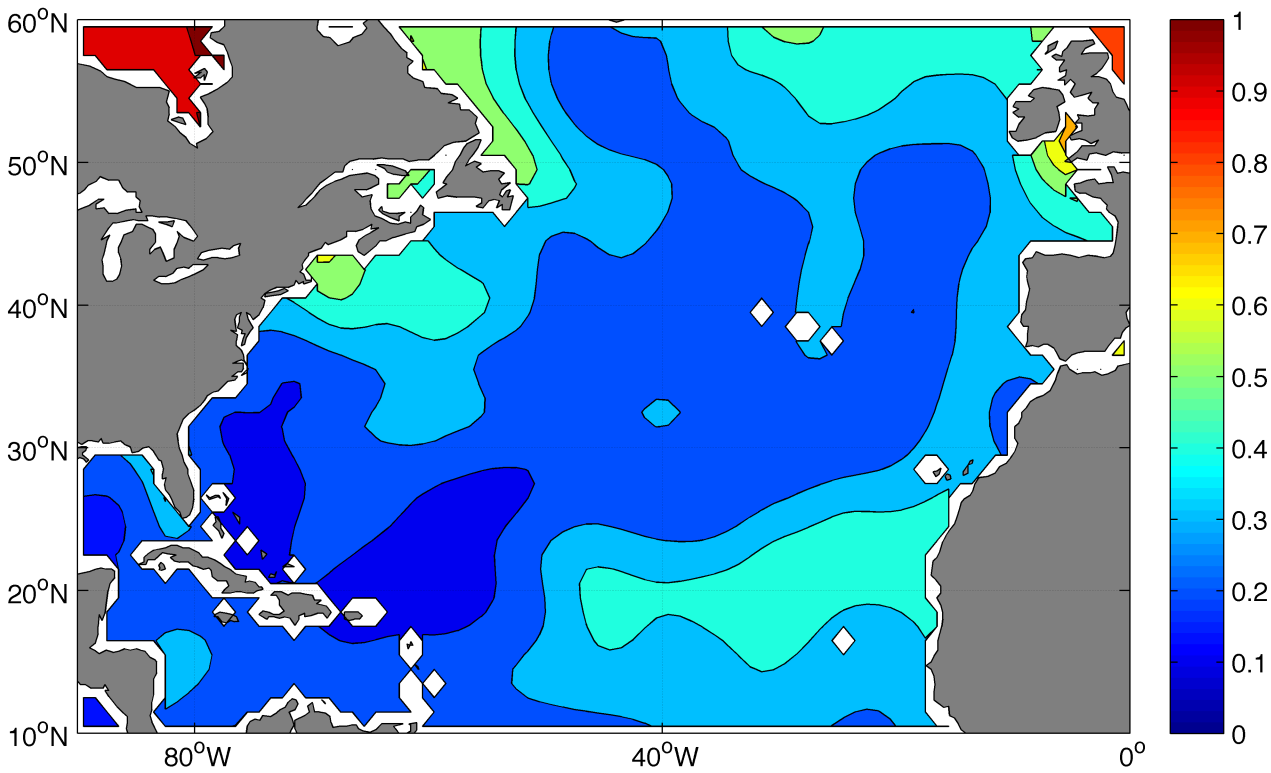


Local regional heat budget on interannual time scales behave similarly to the mean

Dong and Kelly (2004) and Kelly and Dong (2004) for Gulf Stream



Heat transport convergence interannual variations on regional scales much larger than the surface heat flux



Ratio of interannual surface heat flux to heat storage rate from ECCO2 in North Atlantic (300 km Gaussian smoother)

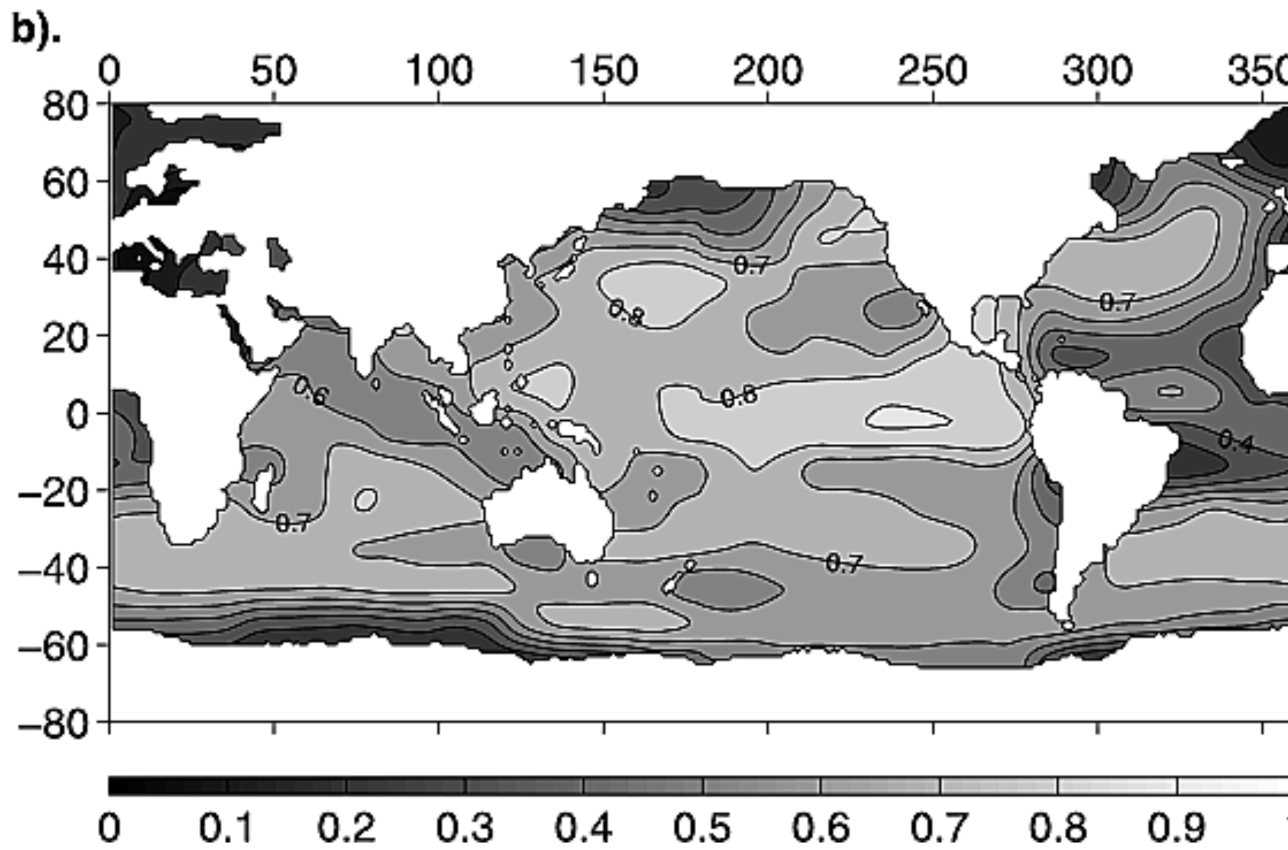
Using observations to look at the relationship between the heat content and surface flux smooth both with 500 km Gaussian smoother

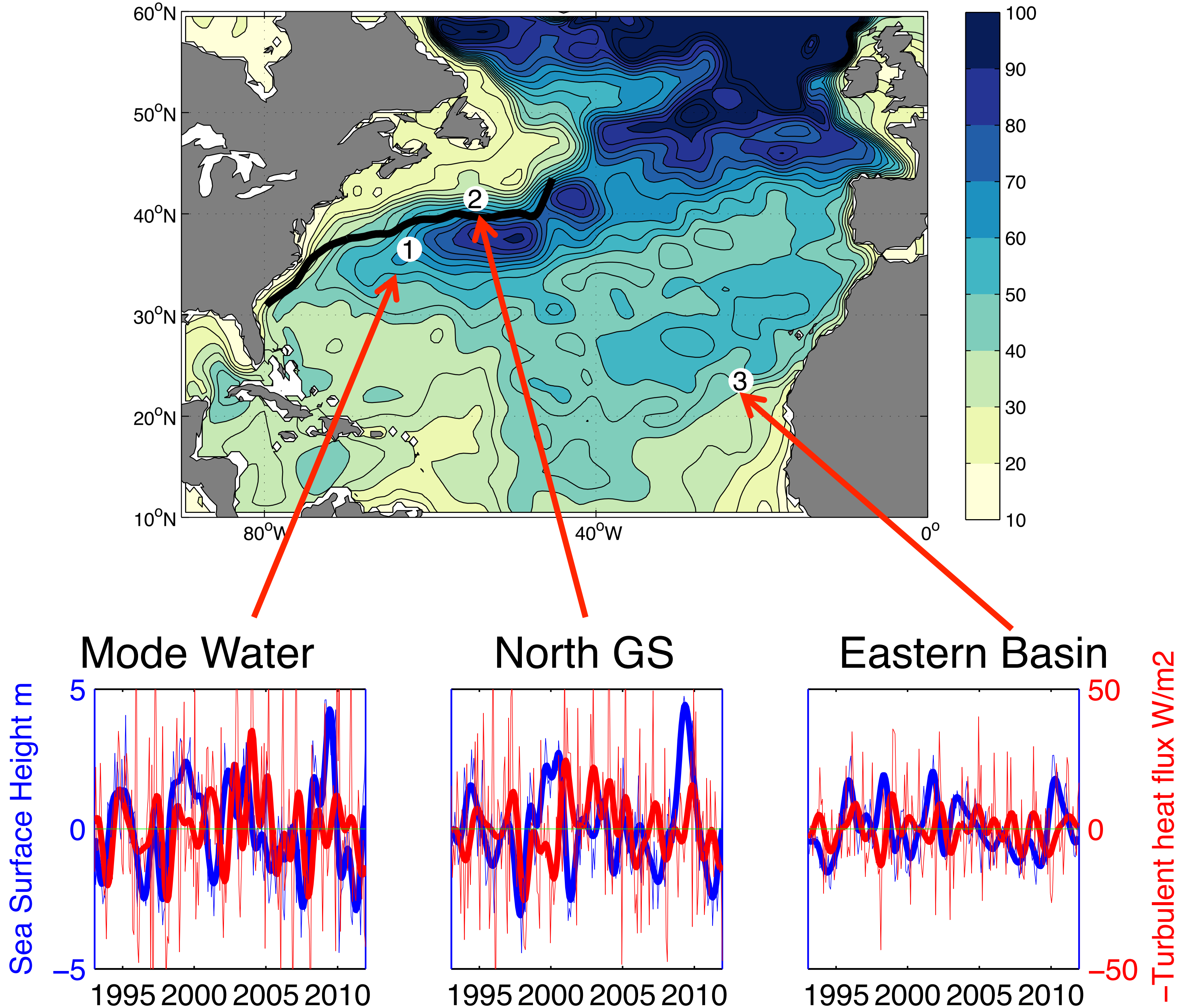
Observational Analysis variables	Source	Comment
Sea surface height (SSH)	Monthly maps of sea level anomaly from Ssalto/Duacs 1/3° x 1/3°, Mercator grid, Aviso	Used as proxy for upper ocean heat content
Turbulent heat flux Q_{turb} And net suface heat flux Q_{net}	OAflux: Objectively Analyzed air-sea fluxes for the Global Oceans (Yu and Weller, 2007) ISCCP for radiative fluxes	Fluxes are positive for warming the ocean.

Using sea level as a proxy for heat content. 1993-1999 (see also Jayne et al 2003)

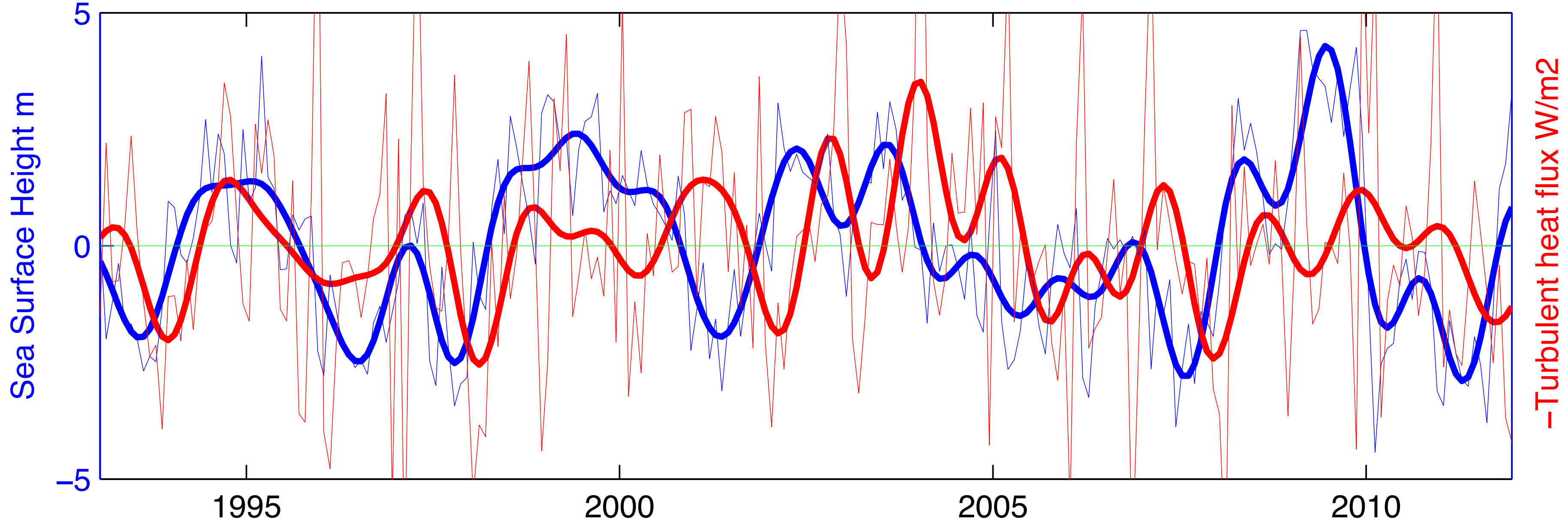
Local sea level determined by thermosteric (thermal expansion), and halosteric (haline contraction). Thermosteric dominates in tropics and subtropics

Willis and Roemmich (2004). Seasonal correlations between upper 700 m ocean heat content (mostly XBTs) and sea level, 1993-1999



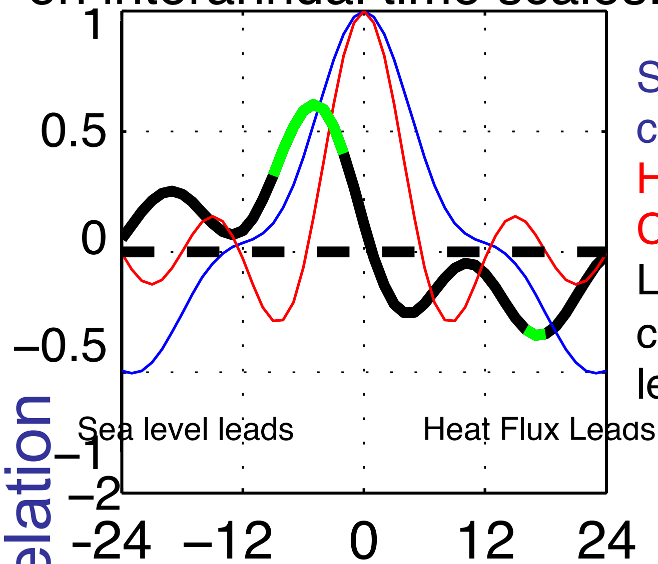

60°N
50°N
40°N
30°N
20°N
10°N
80°W
40°W
0°
100
90
80
70
60
50
40
30
20
10
1
2
3
Mode Water
North GS
Eastern Basin
Sea Surface Height m
5
0
−5
−Turbulent heat flux W/m2
50
0
−50
1995
2000
2005
2010

Mode Water: sea level leads turbulent heat flux by about 5 months

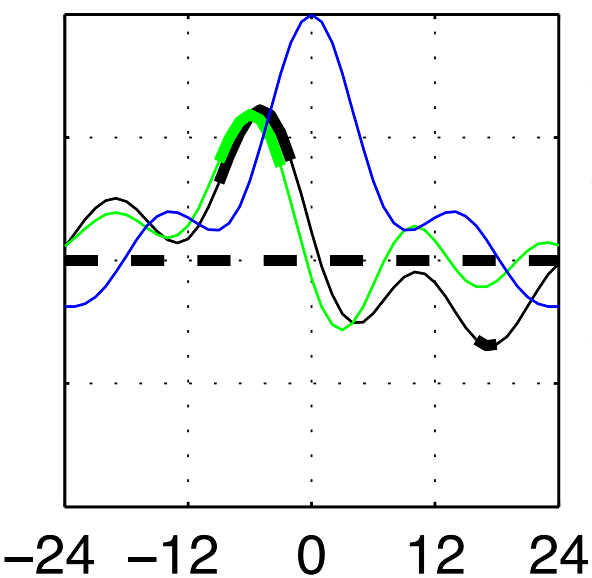


Lag Correlations between sea level (SST) and surface flux in mode water:
both lead the surface flux by a few months on interannual time scales. (mode water)

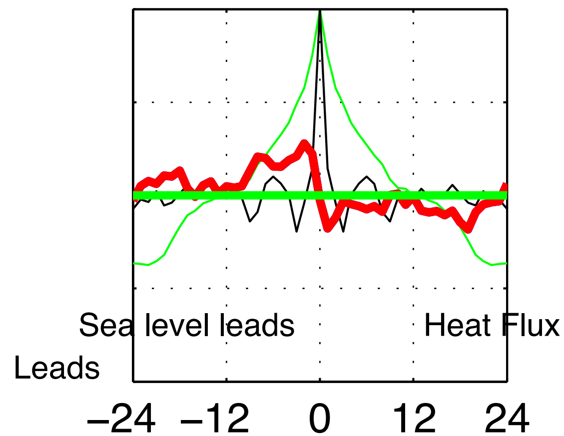
On monthly time scales, SSH has longer persistence and shows more predictive skill than SST.



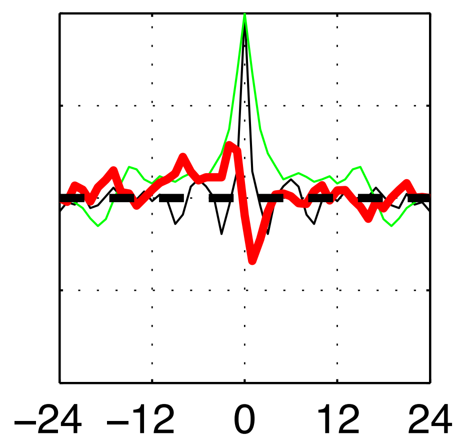
Sea Level auto correlation
Heat flux auto Correlation
Lagged correlation: sea level heat flux



SST auto correlation
Lagged correlation: SSH heat flux
Lagged correlation: SST heat flux



Sea Level auto correlation
Heat flux auto Correlation
Lagged correlation: sea level heat flux

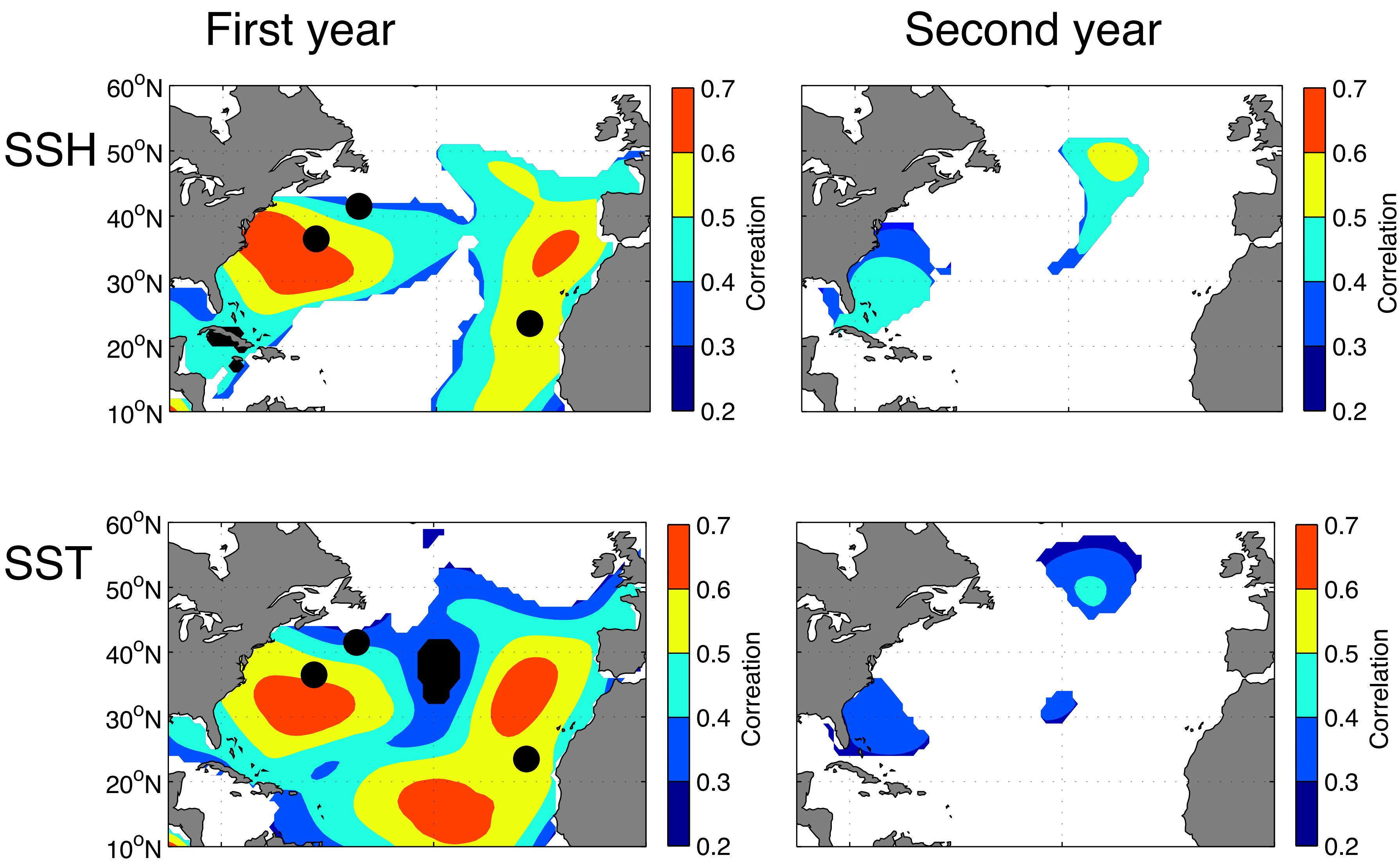


SST auto correlation
Heat flux auto correlation
Lagged correlation: SST heat flux

Correlation of low frequency turbulent heat flux: typically SSH leadsby 3-5 months

SST has more skill than SSH up to one year ahead

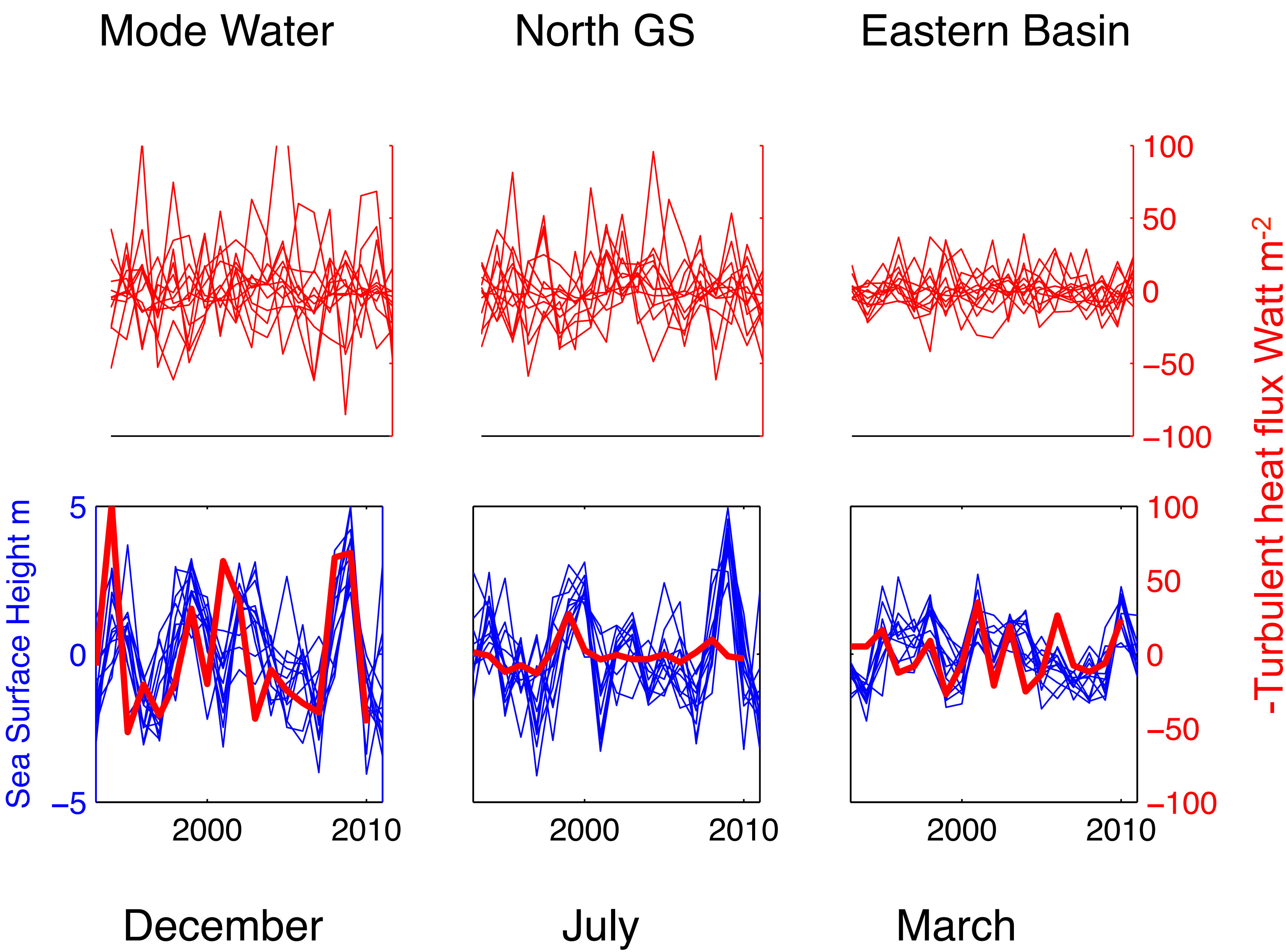
SSH has more skill more than a year ahead



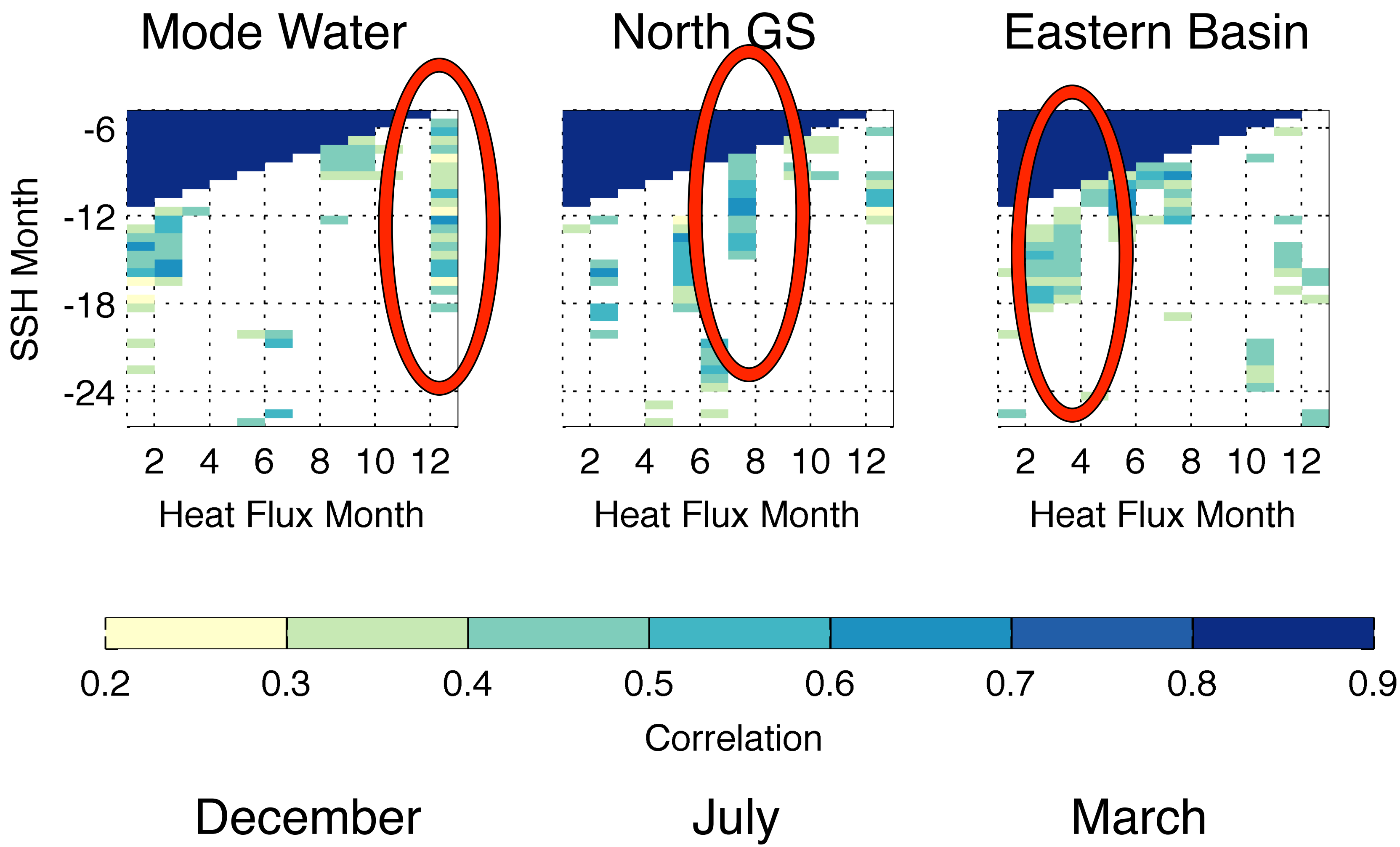
Question: where does the 3-5 month lead come from? Could it be seasonality in the relationship?

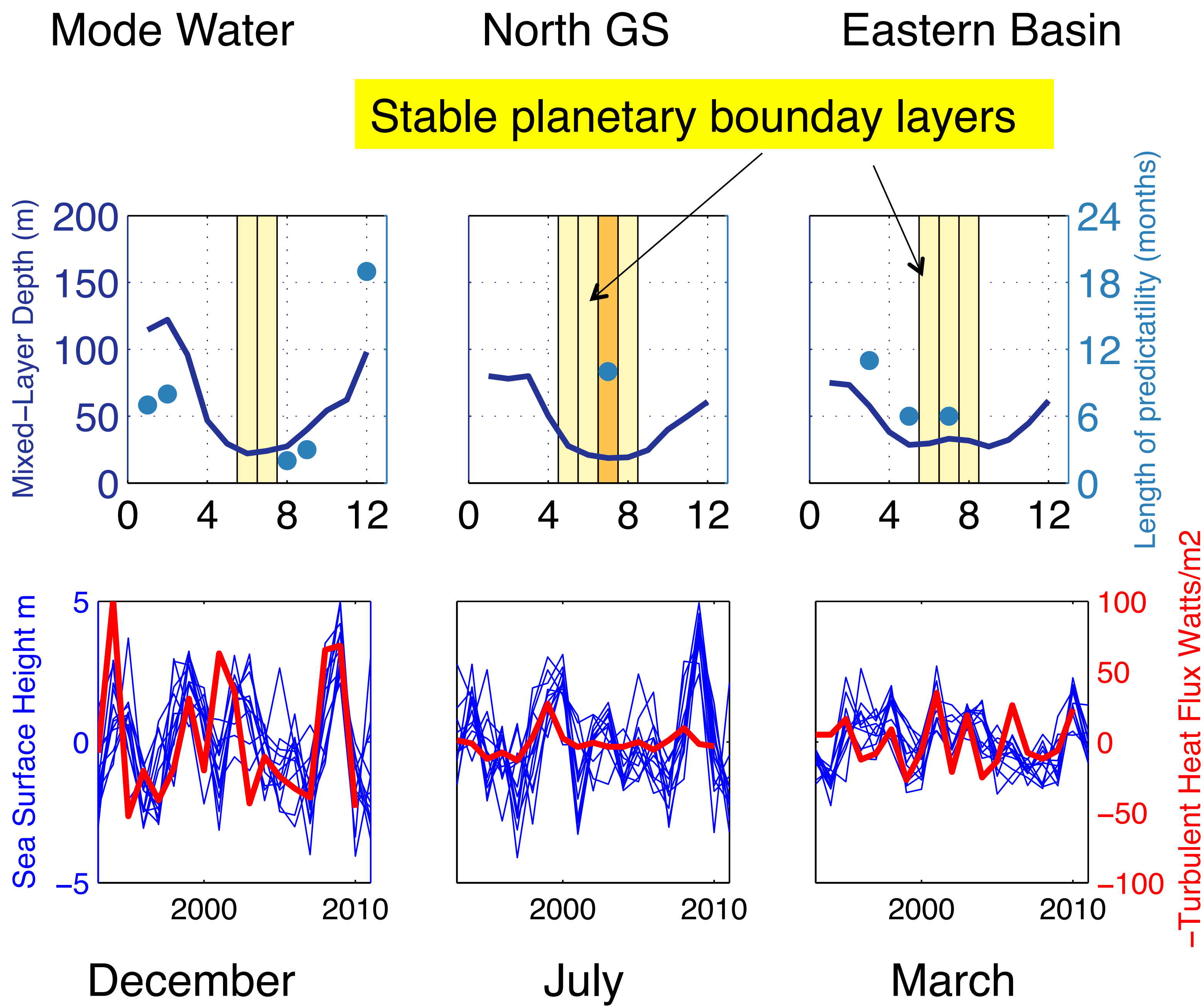
Investigate the seasonal relationships between heat content and surface flux

1. **Make 12 times series, one for each month, of anomalous heat content and surface flux**
2. **Investigate heat content and surface flux persistence**
3. **Investigate correlations between heat content and surface flux between different seasons**


Mode Water
North GS
Eastern Basin
100
50
0
−50
−100
-Turbulent heat flux Watt m-2
Sea Surface Height m
5
0
−5
2000
2010
December
July
March

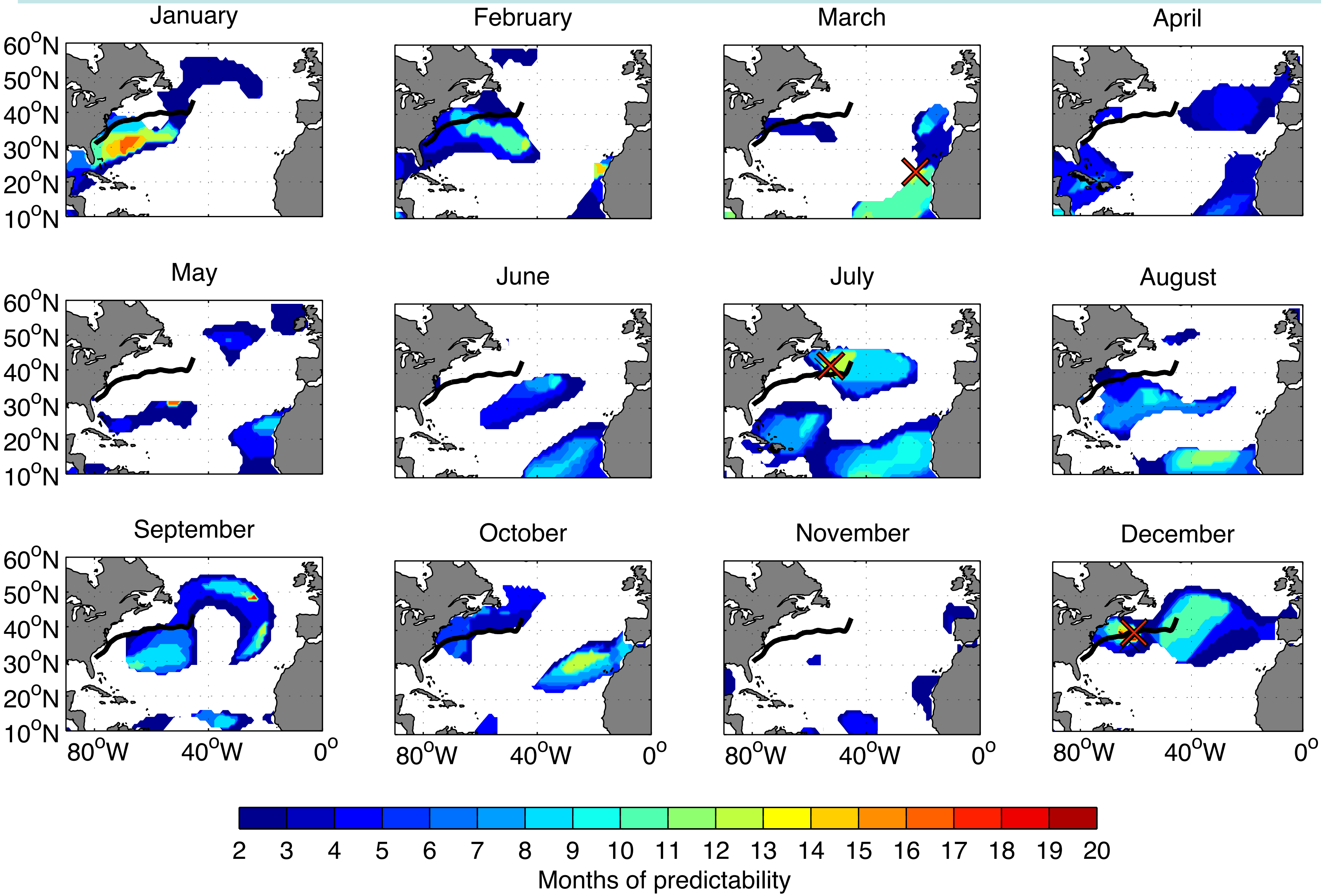
Perform the lagged correlations between surface flux and heat content and look for the places where SSH predicts surface flux (warmer ocean predicts heat flux out of the ocean)



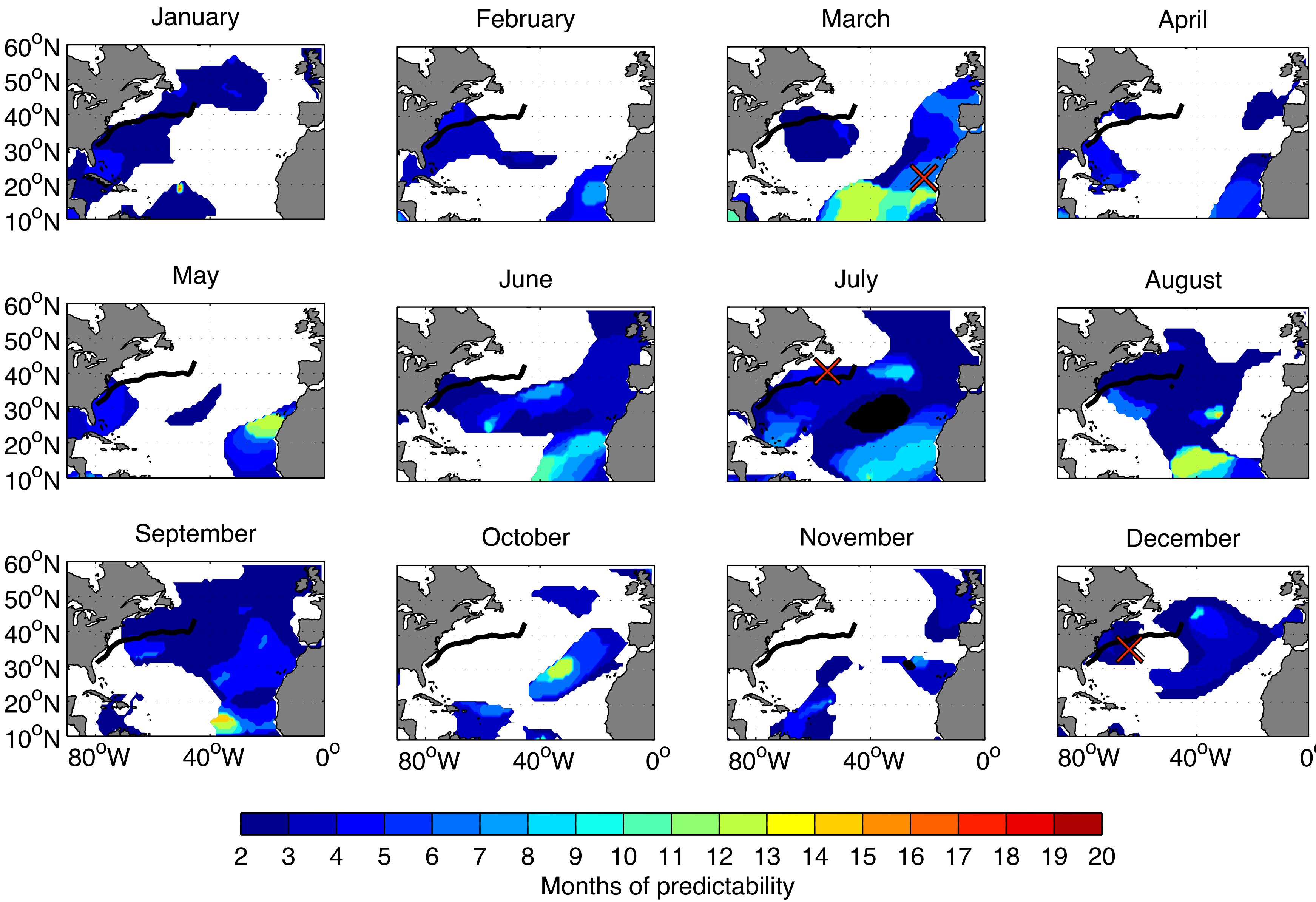


Mode Water
North GS
Eastern Basin
Stable planetary bounday layers
Mixed−Layer Depth (m)
Length of predictatility (months)
200
150
100
50
0
24
18
12
6
0
0
4
8
12
Sea Surface Height m
−Turbulent Heat Flux Watts/m2
5
0
−5
100
50
0
−50
−100
2000
2010
December
July
March

Regions and numbers of months of predictability for turbulent heat flux from sea level (heat content) for each month of the year



Regions and numbers of months of predictability for turbulent heat flux from SST for each month of the year



Conclusions

1. The 20 year satellite altimeter record allows investigation of the role of regional upper ocean heat content in ocean-atmosphere interactions.
2. The heat content (and SST) in the ocean is correlated with surface flux on interannual time scales in the Gulf Stream, both the heat flux by 3-5 months with a warmer ocean fluxing heat from the ocean to the atmosphere
3. The heat content has predictive skill for heat flux for up to 20 months local regions in the North Atlantic at specific times of the year. It has more skill than SST over many regions.
4. Most of the signal comes from latent heat flux, with the correlations also seen in net surface heat flux (not seen).
5. Regions of deep mixed layer have higher skill (away from large currents)
6. High predictive skill is found at the edges of regions of stable planetary boundary layers where sensible heat flux is into the ocean

What does this mean for understanding the influence of AMOC on the atmosphere?

1. Variations in AMOC are linked to local heat transport convergence
2. On interannual time scales heat transport convergence drives heat into or out of the ocean.
3. Local changes in AMOC may be linked to fluxes of heat into and out of the ocean
4. Heat content and the atmosphere are regionally and seasonally coupled allowing seasonal heat content (sea level) variations to be a key component of the link between AMOC and the atmosphere
5. Minobe et al (2008) suggest direct link between SST and climatological cloud cover (currently under investigation)
6. Ocean only models do not show the correlations found here: coupled model analysis is needed to investigate further (also underway)