Estimates of the oceanic heat budget in the North Atlantic: the role of heat transport convergence

LuAnne Thompson

Kathryn A. Kelly

Suzanne Dickinson

University of Washington

Julie McClean

Scripps Institution of Oceanography

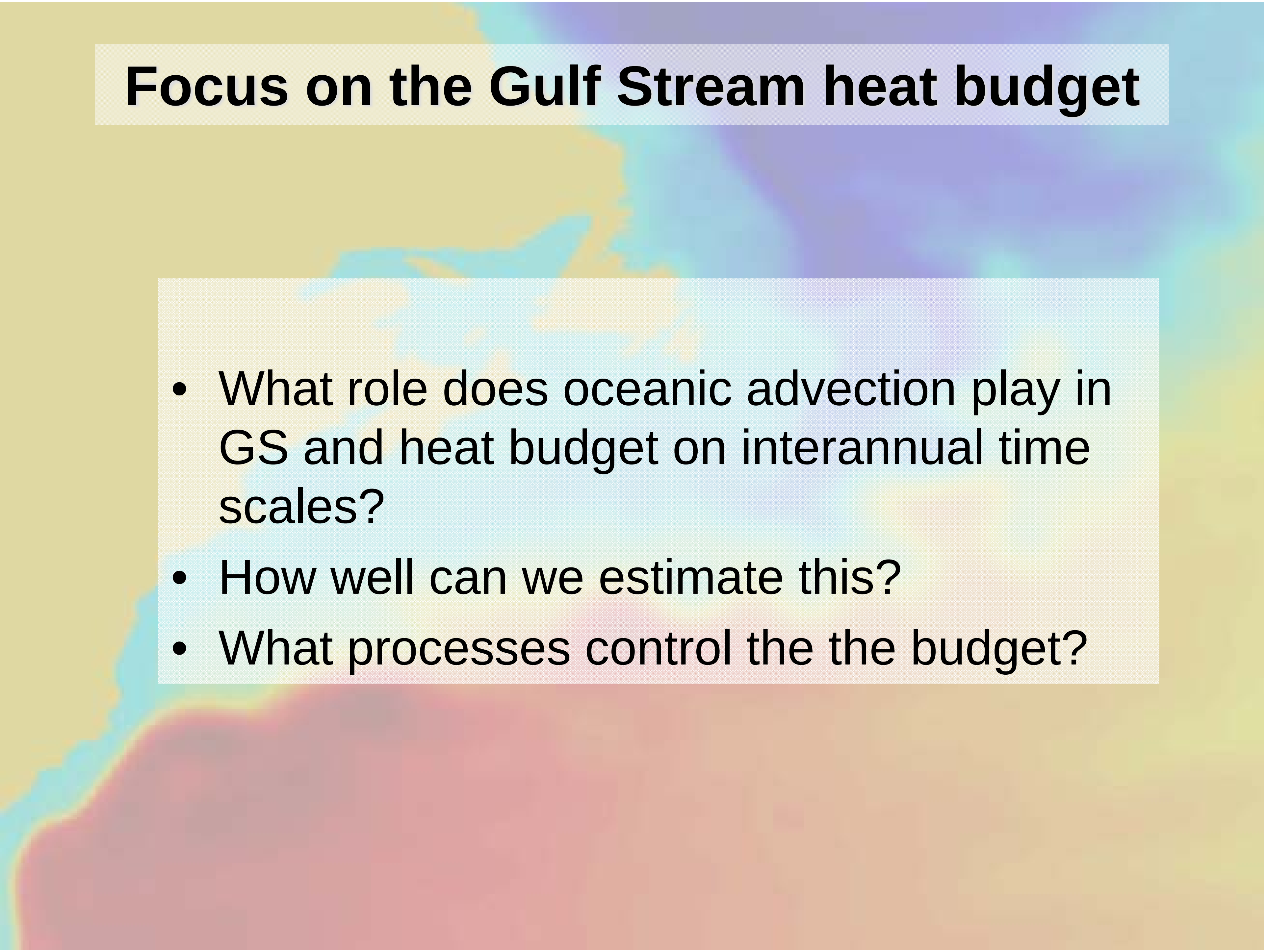
Eric Greiner

Mercator Ocean

Dimitris Menemenlis

JPL

Funded by NASA OSTST



Focus on the Gulf Stream heat budget

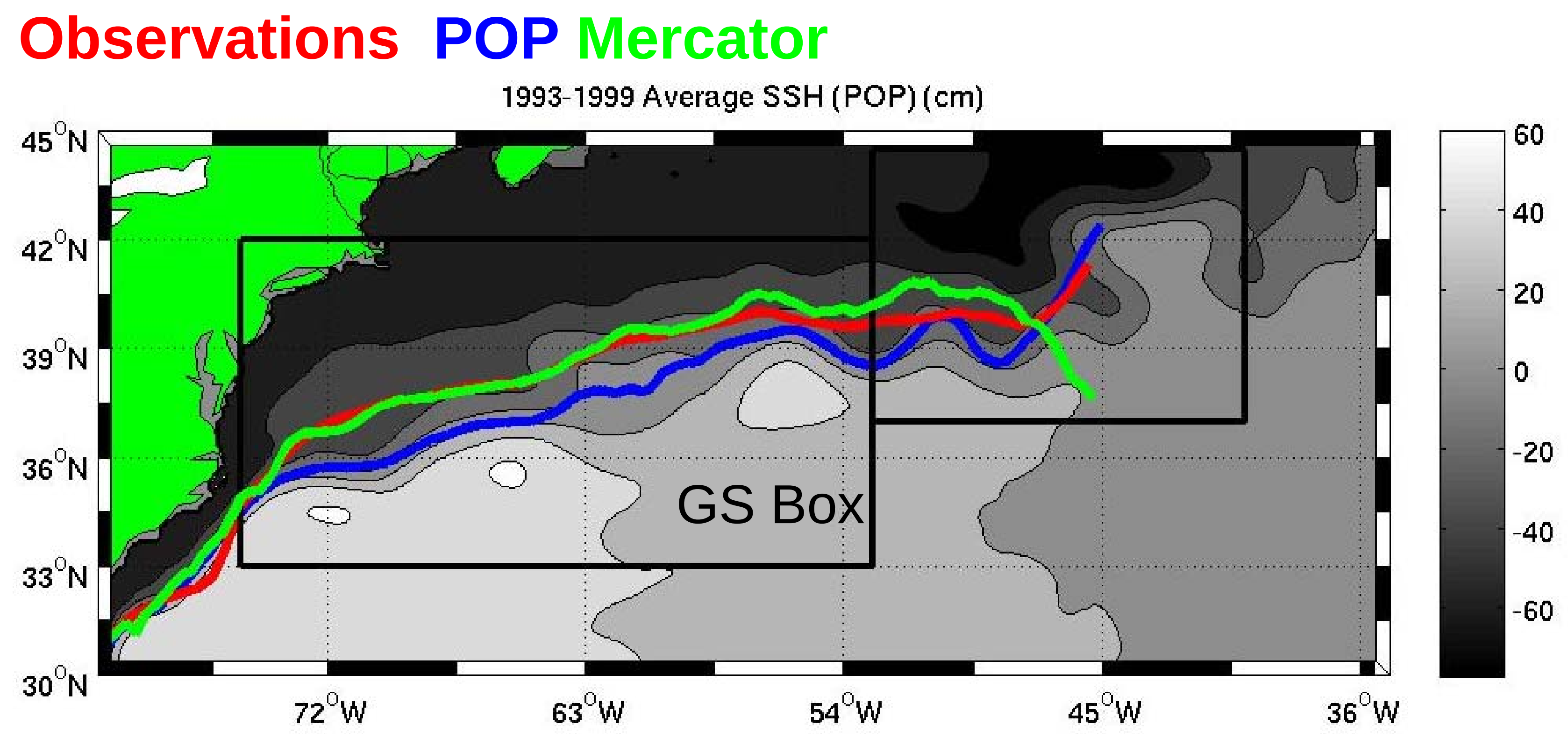
- What role does oceanic advection play in GS and heat budget on interannual time scales?
- How well can we estimate this?
- What processes control the the budget?

Four model estimates

- **POP North Atlantic (Parallel Ocean Program)**
  - Daily Navy forecast winds, prognostic
  - 1/10^{o} resolution, 21 day
  - Relaxation to climatology at northern (72N) and southern boundaries (20S)
  - 1980-2000
- **Mercator North Atlantic**
  - Daily ECMWF ERA 40 winds
  - 1/3^{o} resolution, monthly
  - Nudges to in situ, SSH and SST
  - 1992-2003
- **ECCO2 Global**
  - NCEP daily forcing
  - 18km resolution, monthly
  - Green's function assimilation
  - 50 simulations for parameter choices
  - 1992-2007
- **Diagnostic GS and NAC**
  - Daily NCEP/ISCCP forcing
  - 1^{o} by .5^{o}, 5 day
  - Velocity from SSH and prescribed vertical structure
  - 1993-2004

Observed SSH

Analysis region, focus on GS



Heat Budget

Calculate contribution to heat content from Horizontal advection and surface heat flux

- –Average over boxes
- –Remove seasonal cycle
- –Low (high) pass for interannual (monthly) signal
- –Positive indicates ocean heating

$$\frac{dH}{dt} = \frac{d}{dt}\iiint \rho c_p T \, dx \, dy \, dz \, / \, Area$$

Heat content tendency

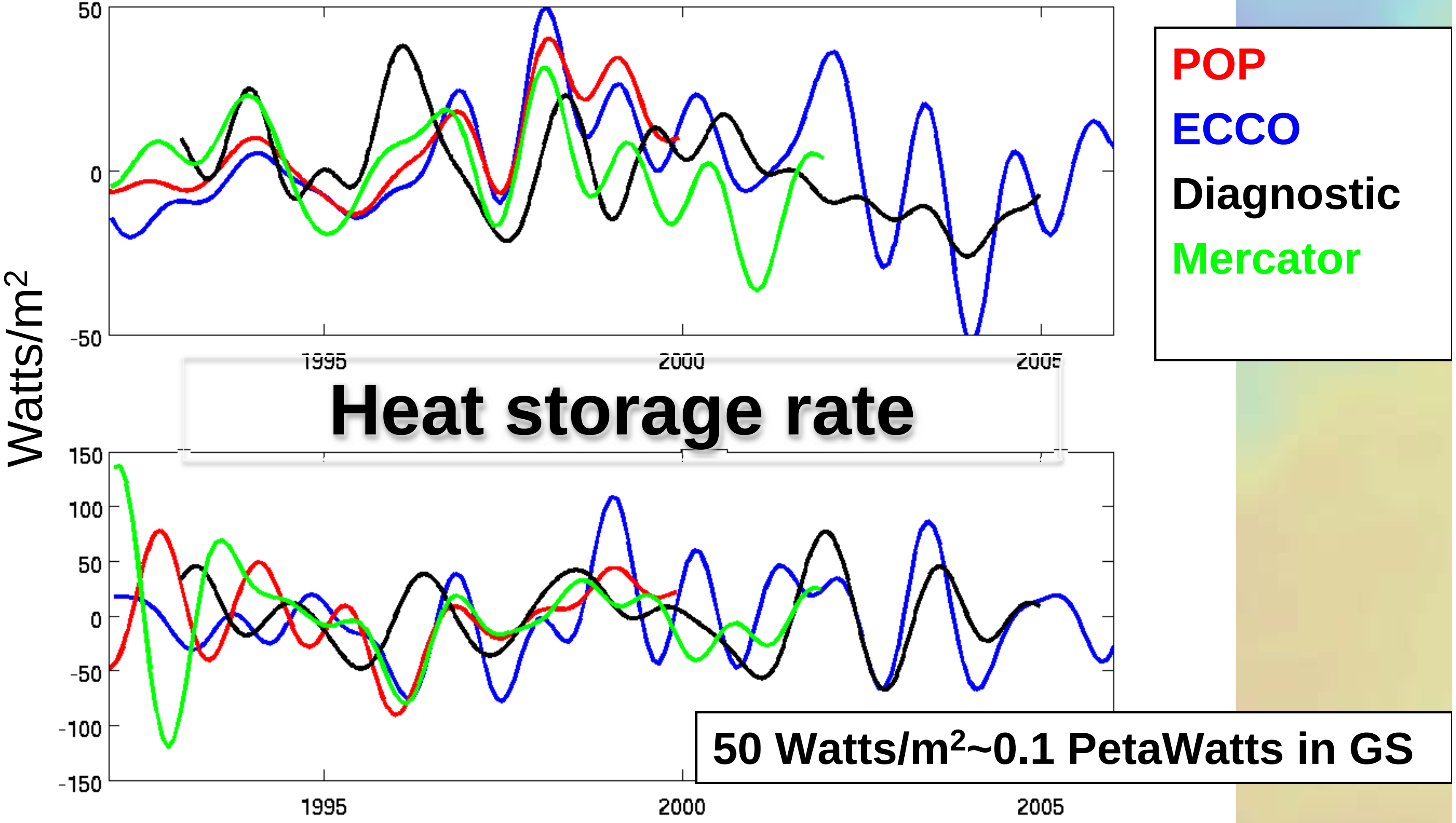
$$\rho c_p \nabla \cdot \mathbf{u}_h T = \rho c_p \iint \mathbf{u}_h (T - T_{ave}) \cdot \hat{n} \, \mathbf{dl} \, dz \, / \, Area$$

Horizontal Heat transport convergence

$$Q_{net} = \iint Q \, dx \, dy \, / \, Area$$

Surface heat flux

Net surface heat flux



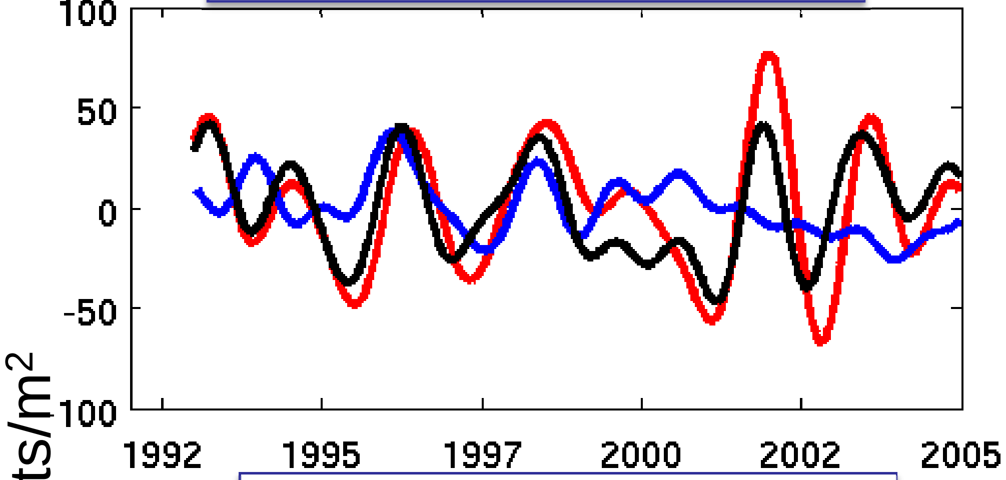
Heat storage rate

50 Watts/m^2~0.1 PetaWatts in GS

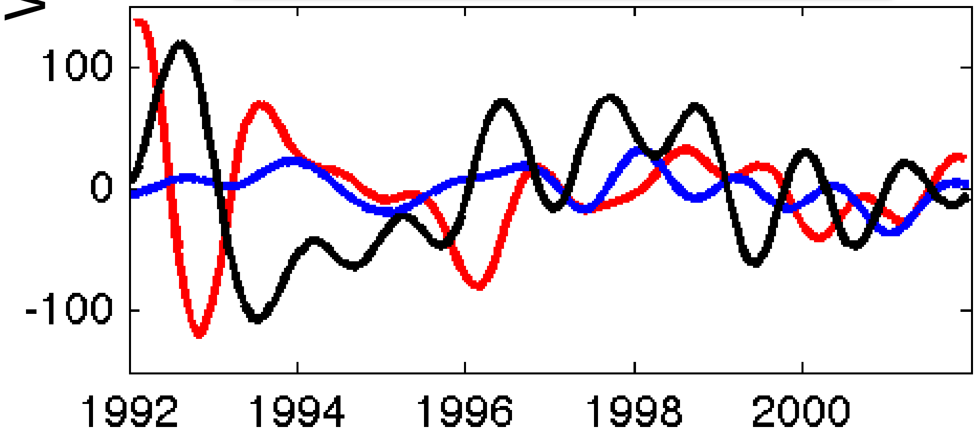
Surface fluxes and heat storage rates differ
Atmospheric specifications are similar in all models,
But, turbulent surface fluxes are determined partially by model SST

Horizontal heat transport convergence dominates heat storage rate

Diagnostic to 800 m



Mercator to bottom



Heat Storage Rate

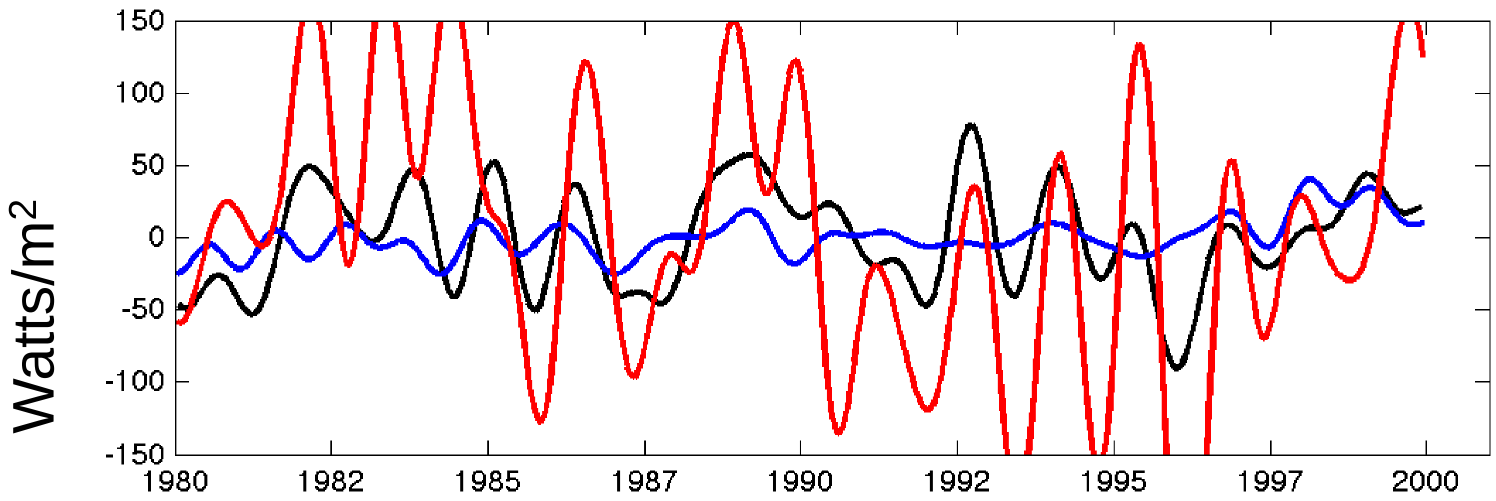
Net surface heat flux

Heat Transport Convergence

Extension of
Dong and Kelly (2004)

Mercator heat budget
Does not close

POP: heat storage rate and transport convergence to 800 m



Heat storage rate

Net surface heat flux

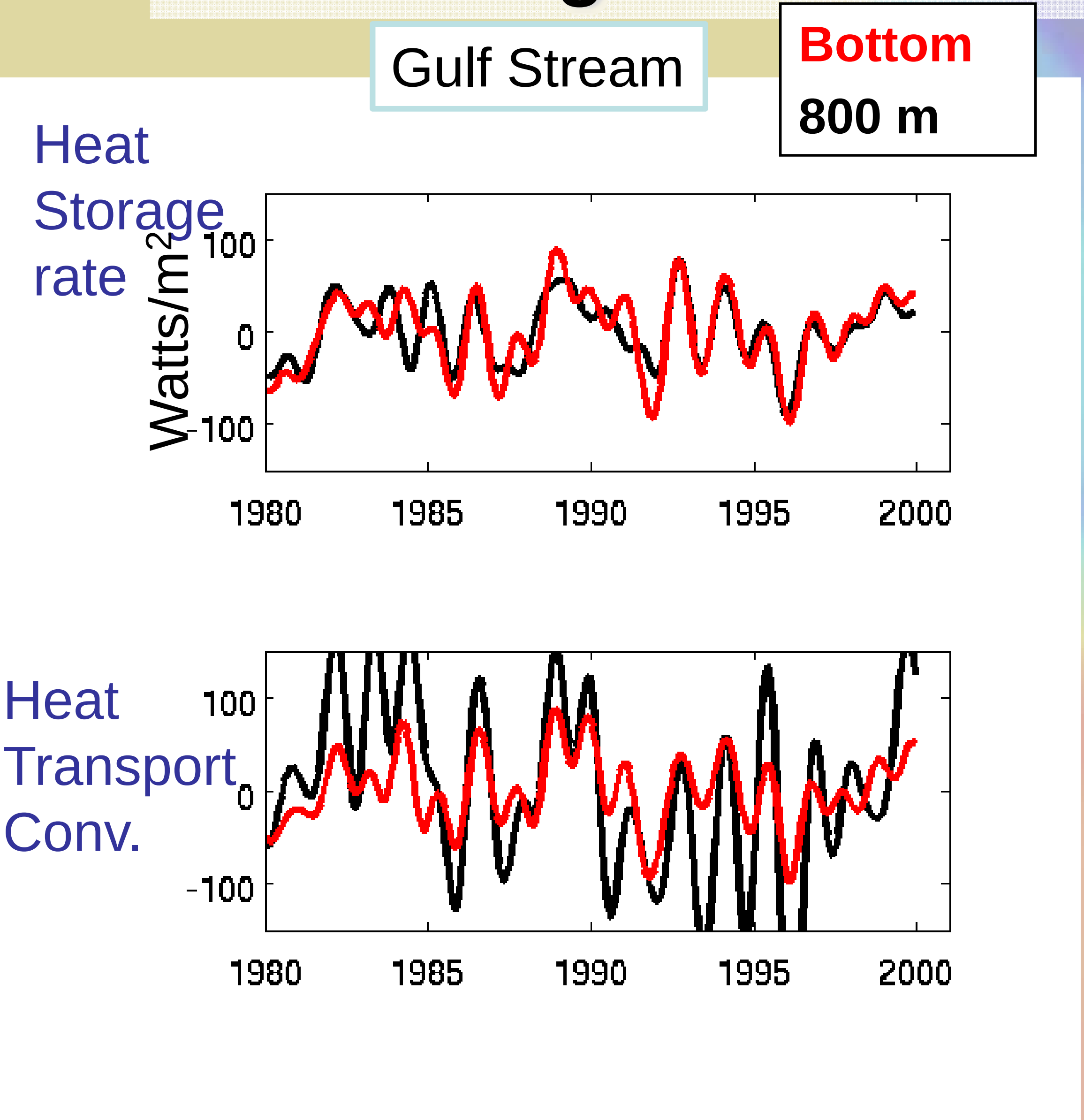
Heat Transport Convergence

Gulf Stream horizontal transport convergence

vertical processes important as well

Correlated with heat storage rate

POP: heat storage rate and transport convergence to bottom vs 800 m



Gulf Stream horizontal transport convergence balanced partially by vertical divergence at 800m

Most of heat content variability carried above 800m

Heat budget to the bottom closes

A simple model for heat content evolution: low frequency

At low frequencies, we find

$$\frac{dH}{dt} = advection + Q$$

with Q much smaller than advection
Dong and Kelly (2004) suggest that

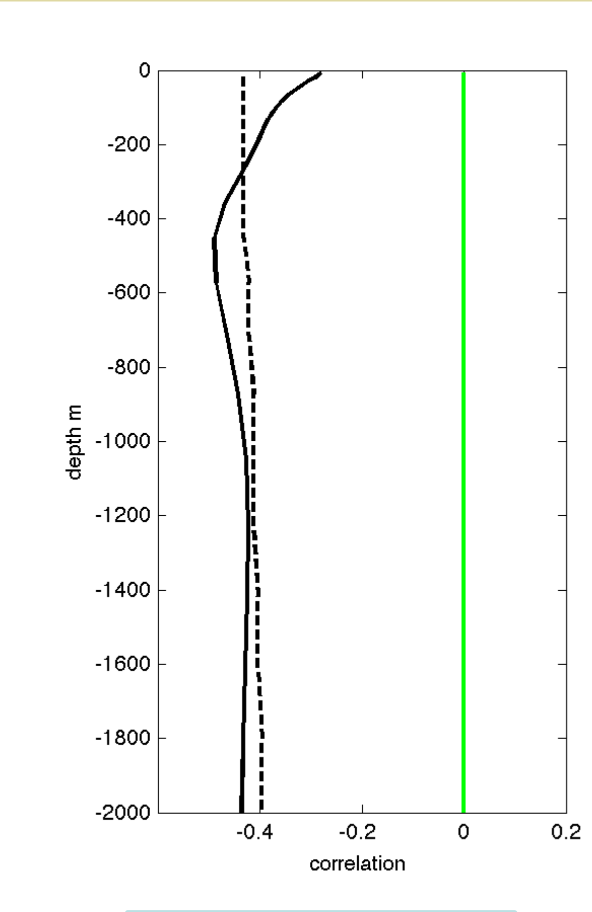
$$Q_{net} = Q' - \lambda H$$

With Q_{net} leading H by 3 months

Does this relationship hold in the full models?
To what depth does this apply?

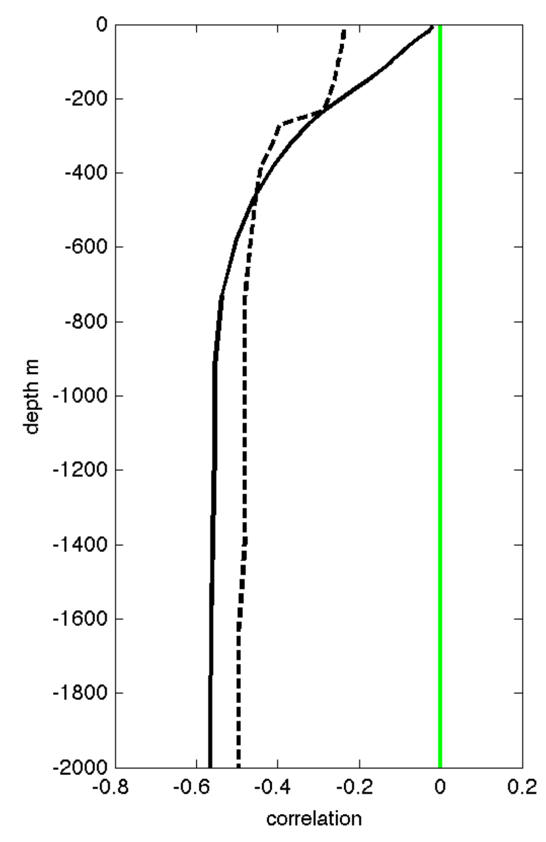
Correlation of low frequency H with Qnet: H leads Qnet and is negatively correlated

Mercator: lead 3 months



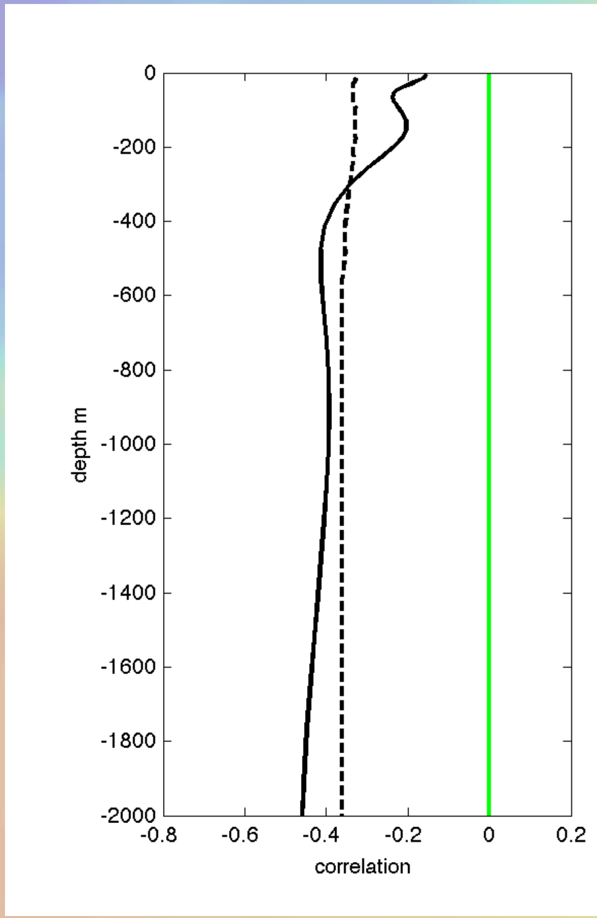
9.0 Watts/m^2

POP: lead 6 months?



7.5 Watts/m^2

ECCO2: lead 3 months



12.2 Watts/m^2

Correlation significant below 200-300m

Conclusion: Gulf Stream Heat Budget

The interannual upper ocean heat storage rate is controlled by advection

Interannual signal is model dependent

Variability in Qnet is a significant fraction of the mean (90 Watts/m^2 mean and 13-18 Watts/m^2 standard deviation). Heat storage rate can be as large as half of the mean heat flux.

The heat storage rate on interannual time scales is carried above 800m. Vertical divergences can be large if eddies are resolved.

At low frequencies, the surface heat flux is explained in a large part by upper ocean heat content, with flux negatively correlated and lagged by ~3 months. Heat content explains ~ 10Watts/m^2 of surface flux