On the sensitivity of net heat flux into the tropical Indian Ocean to storminess, in the OFES ocean model

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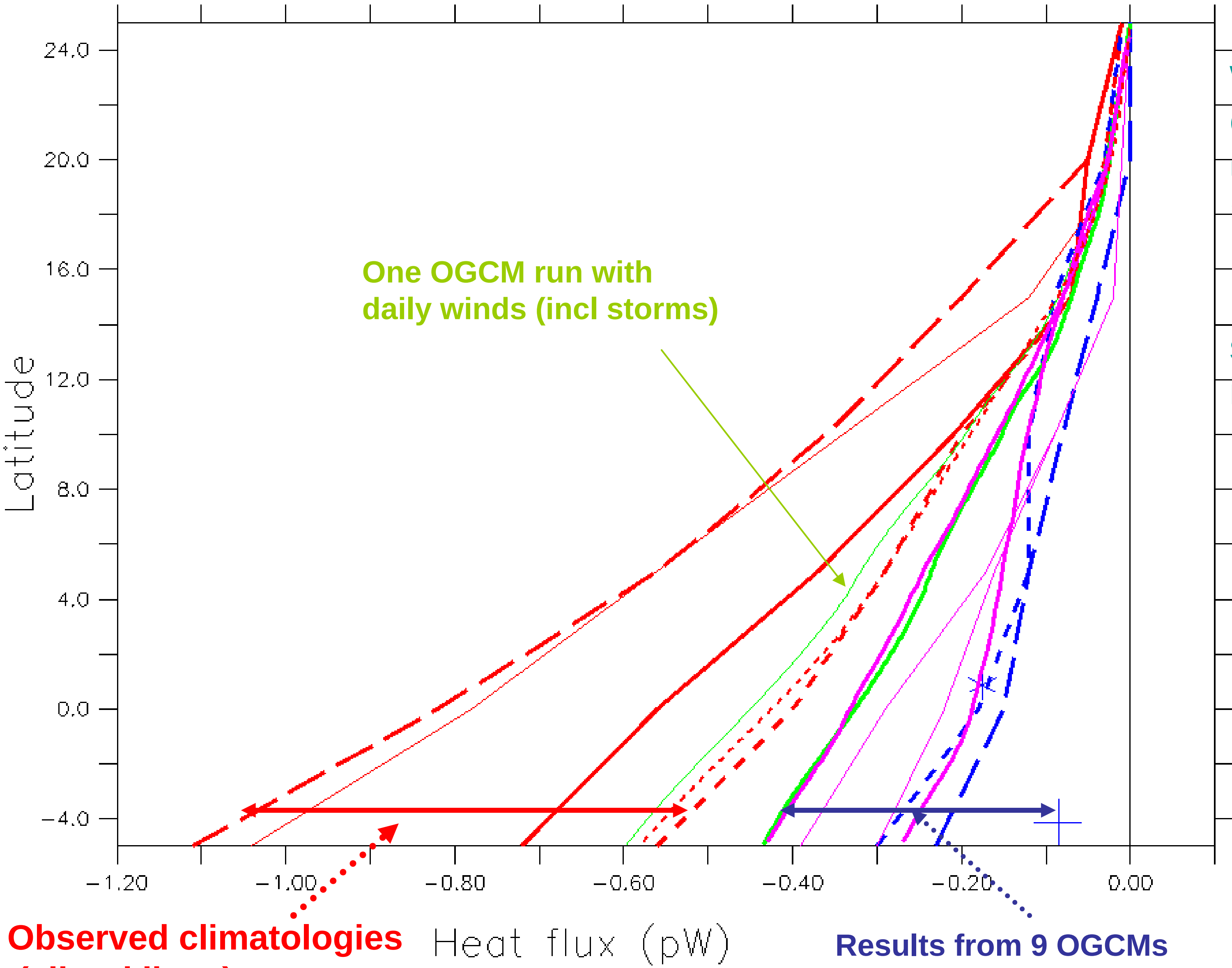
A literature-based survey of annual mean net heat fluxes, into the tropical Indian ocean (Hu and Godfrey 2007)



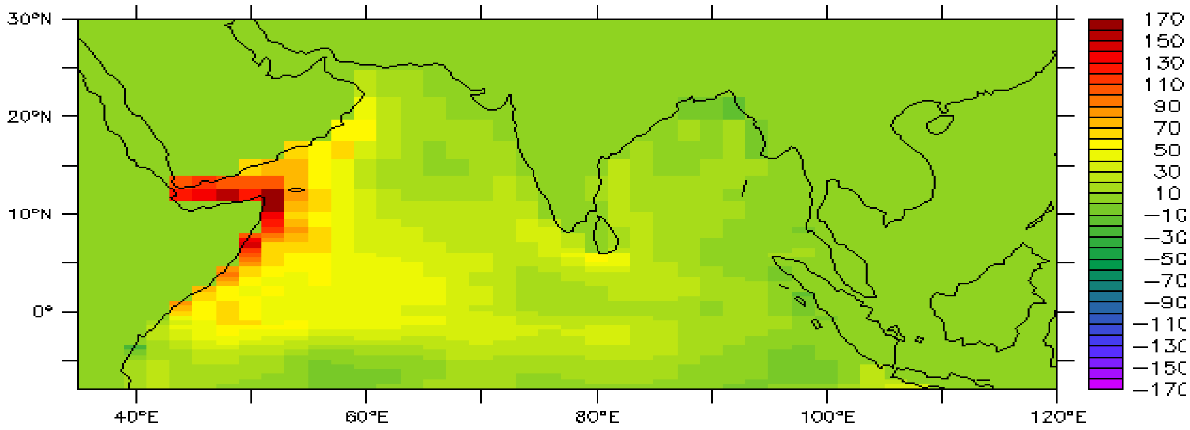
Why do OGCMs underestimate net heat flux?

Is inclusion of storminess important?

Observed climatologies (all red lines)

Results from 9 OGCMs (monthly or annual mean winds only)

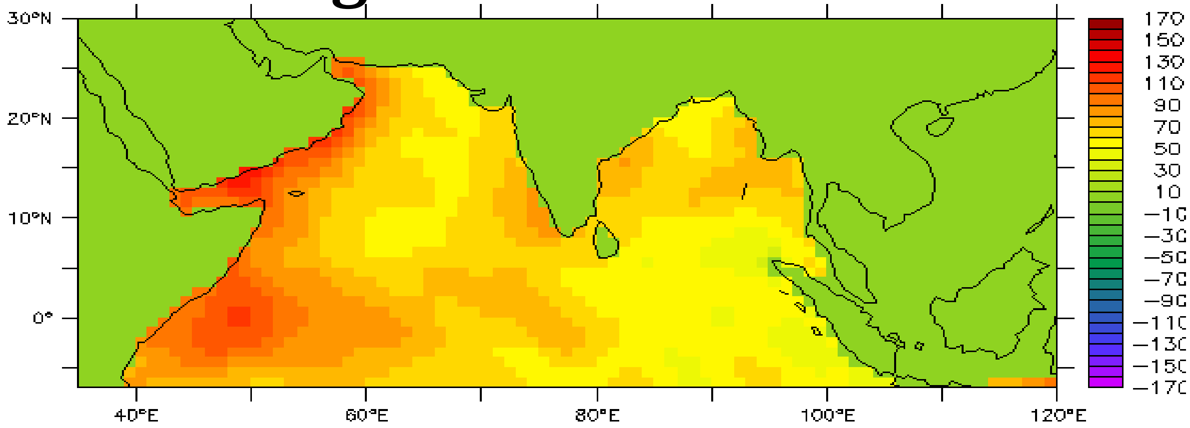
Strongest model flux compared to strongest observed product



Annual mean net heat flux, "Control" run

Ocean Model

Area average north of 7° S = 28 W/m2



Annual mean net heat flux, Southampton climatology

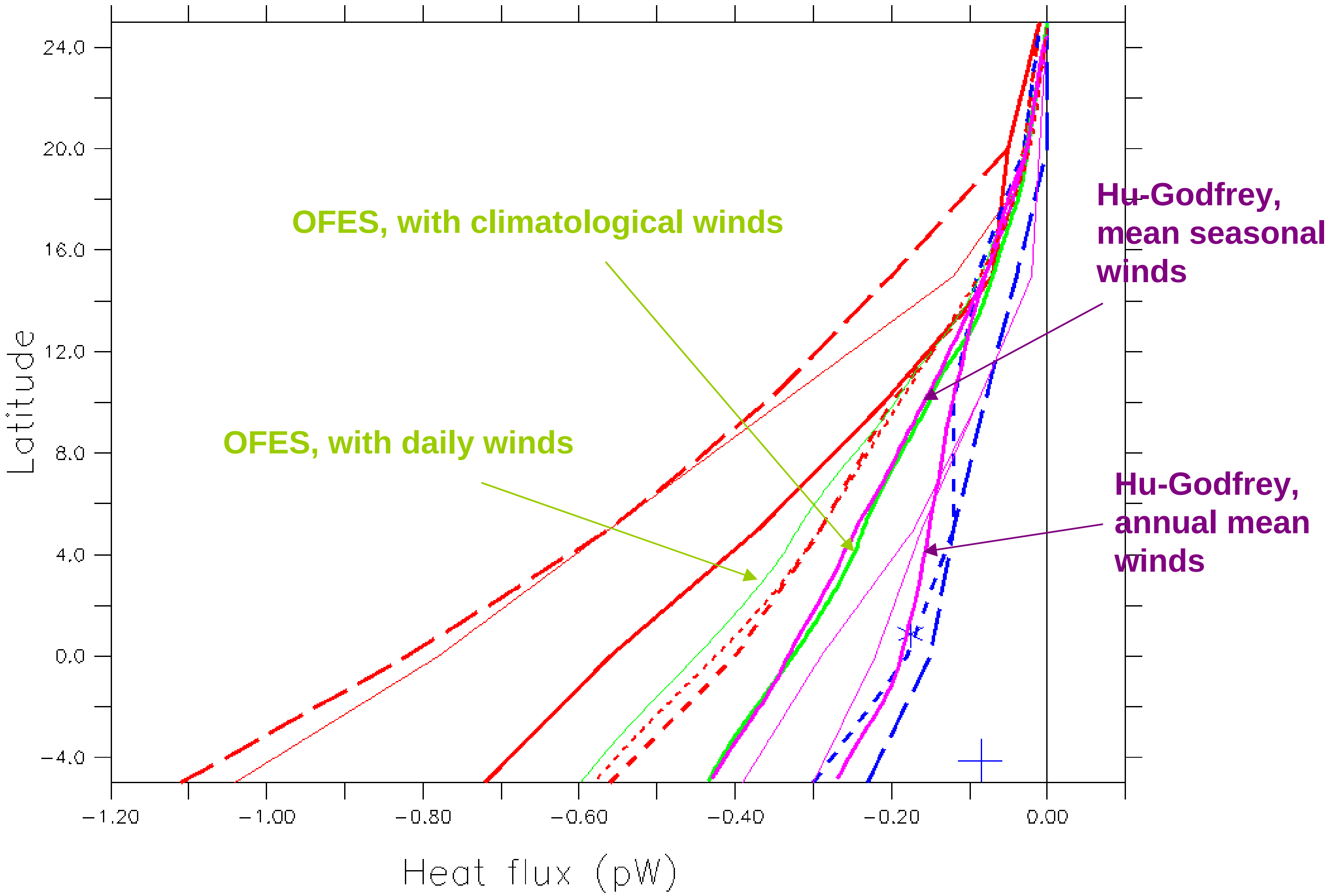
Observed flux

Area average north of 7° S = 74 W/m2

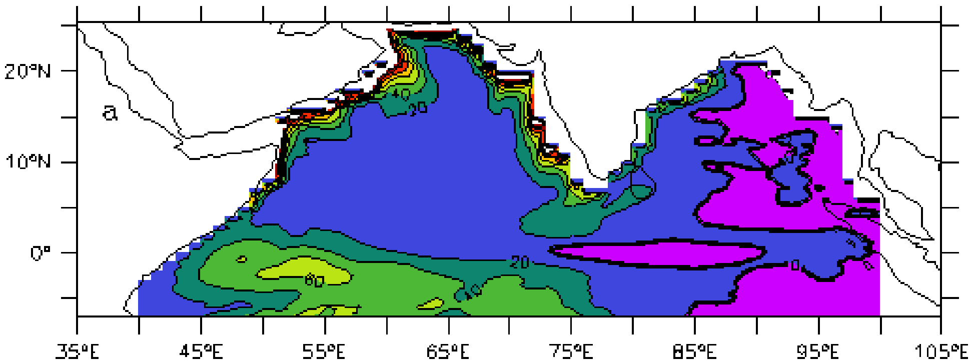
Climatologies say heat is absorbed all over the Indian Ocean.
OGCMs (except OFES2) say it is absorbed only in western ocean.

We have two pairs of runs, each with identical annual mean Ekman transports and the same model. What can we learn?

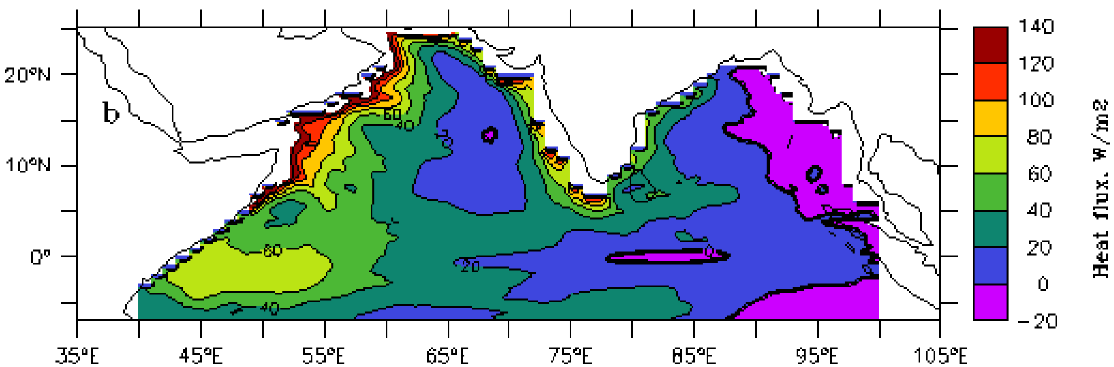
The stronger the rms wind stress, the greater the heat flux magnitude (due to wind mixing)(??)



Net surface heat flux , Hu-Godfrey:

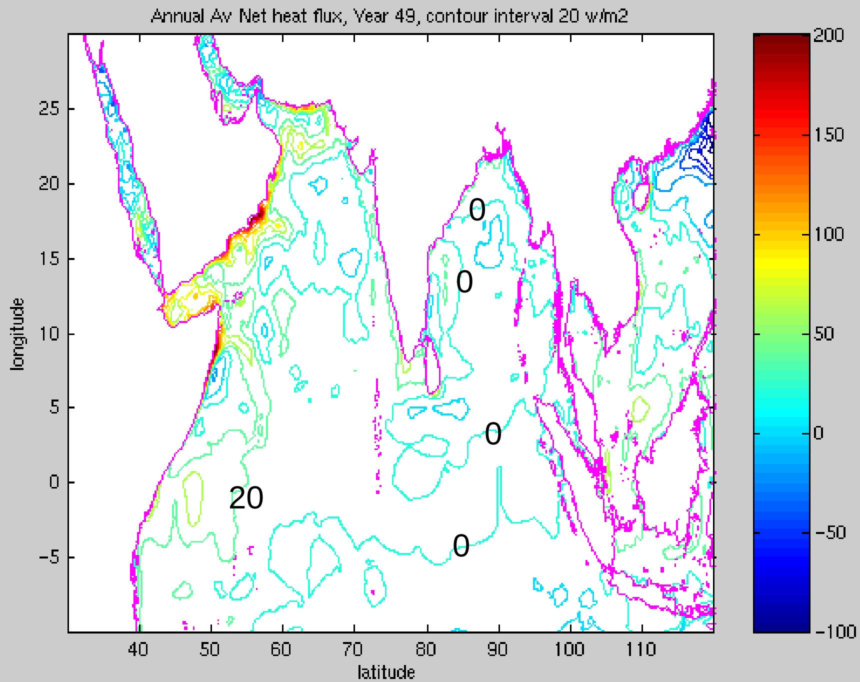


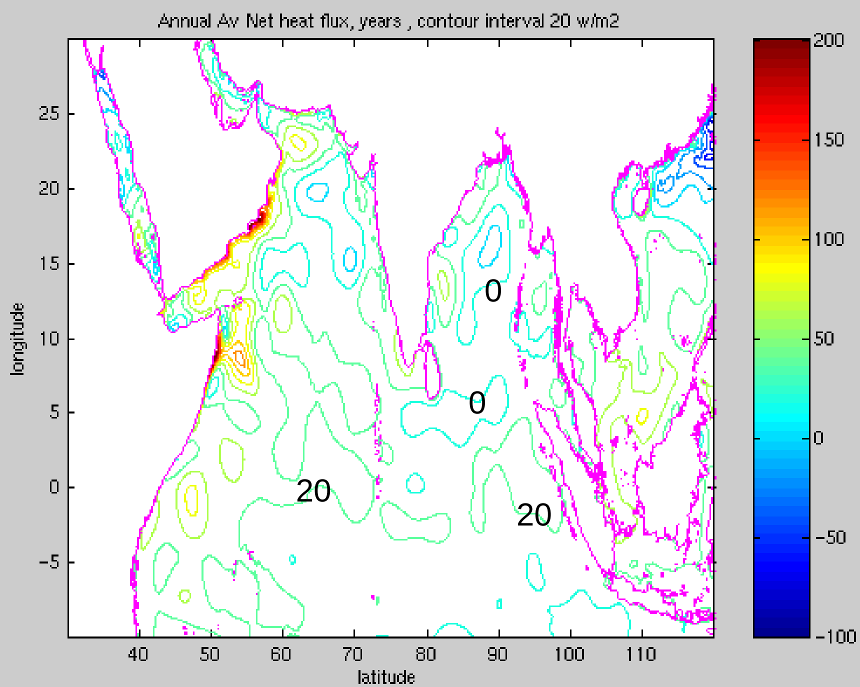
Run with annual mean winds



Run with seasonal winds

The heat flux maps are similar, but stronger opposite the western boundary current in the case of seasonal winds -- and in western equatorial strip





In the OFES2 model,

for the first time we

get significant positive heat

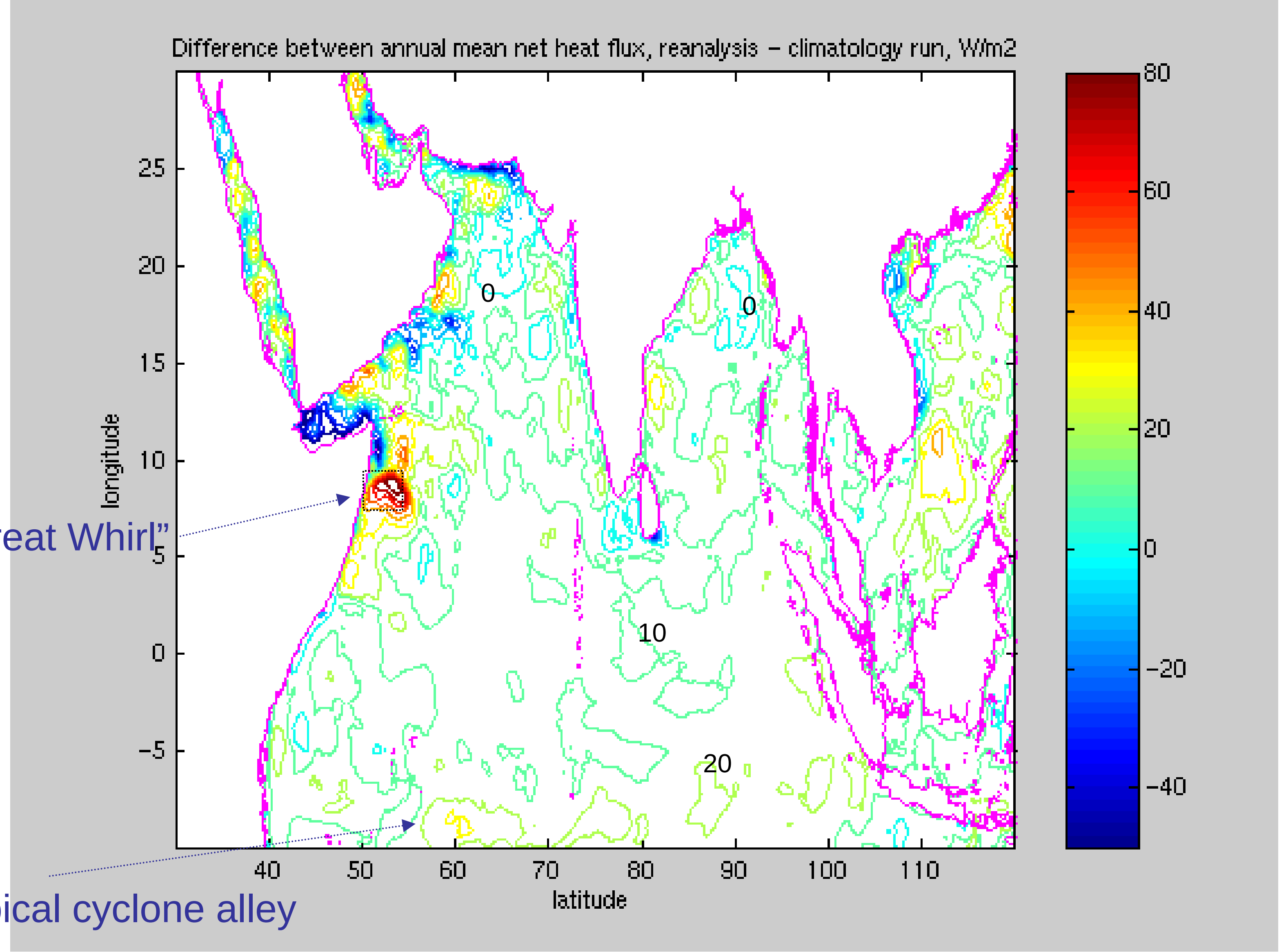
fluxes in the east Indian

Ocean -- and big

heat absorption near

Great Whirl

OFES2-OFES1 -- Contour interval 10 W/m2



“Great Whirl”

Tropical cyclone alley

Heat flux difference >0 nearly everywhere

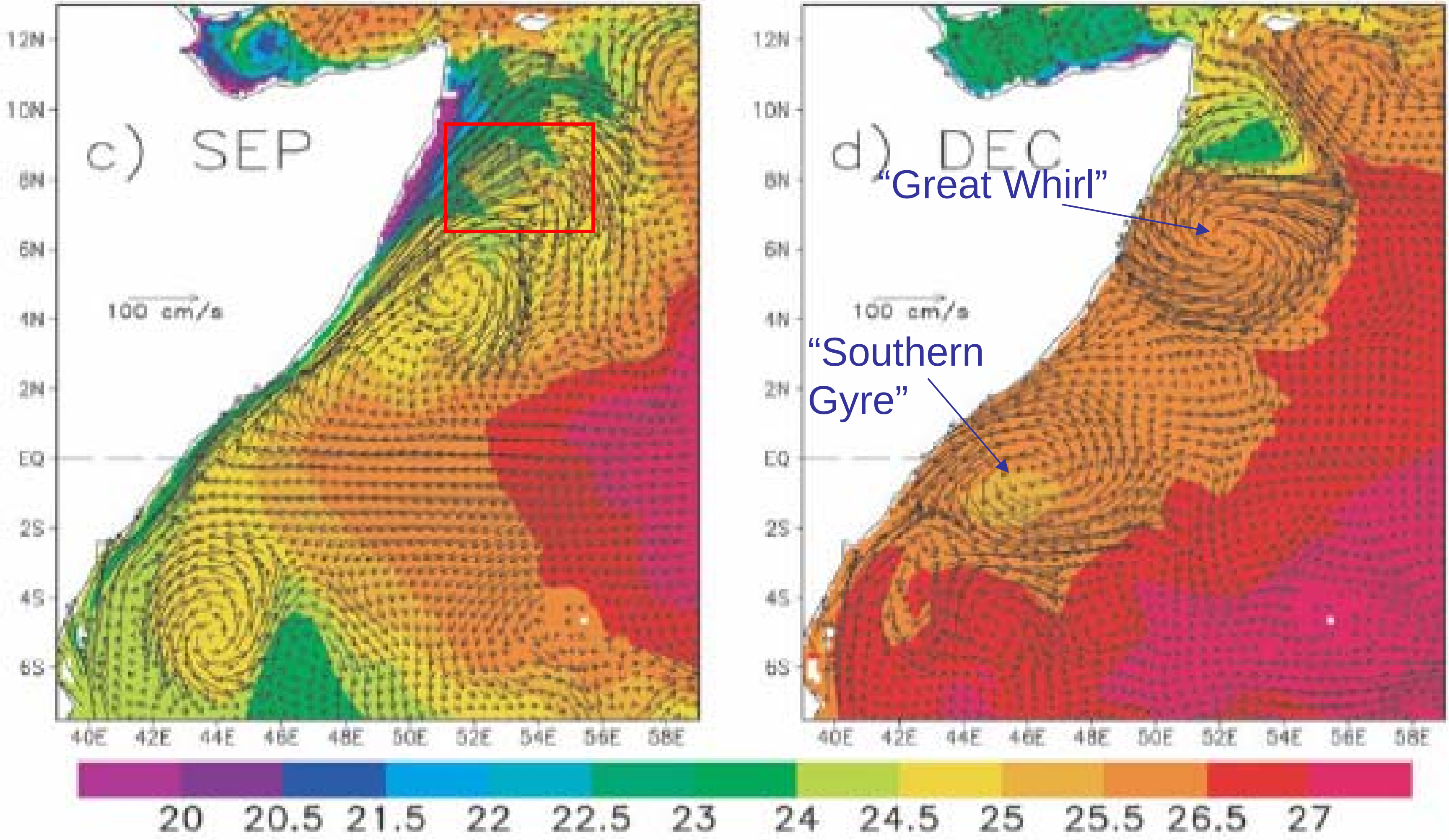
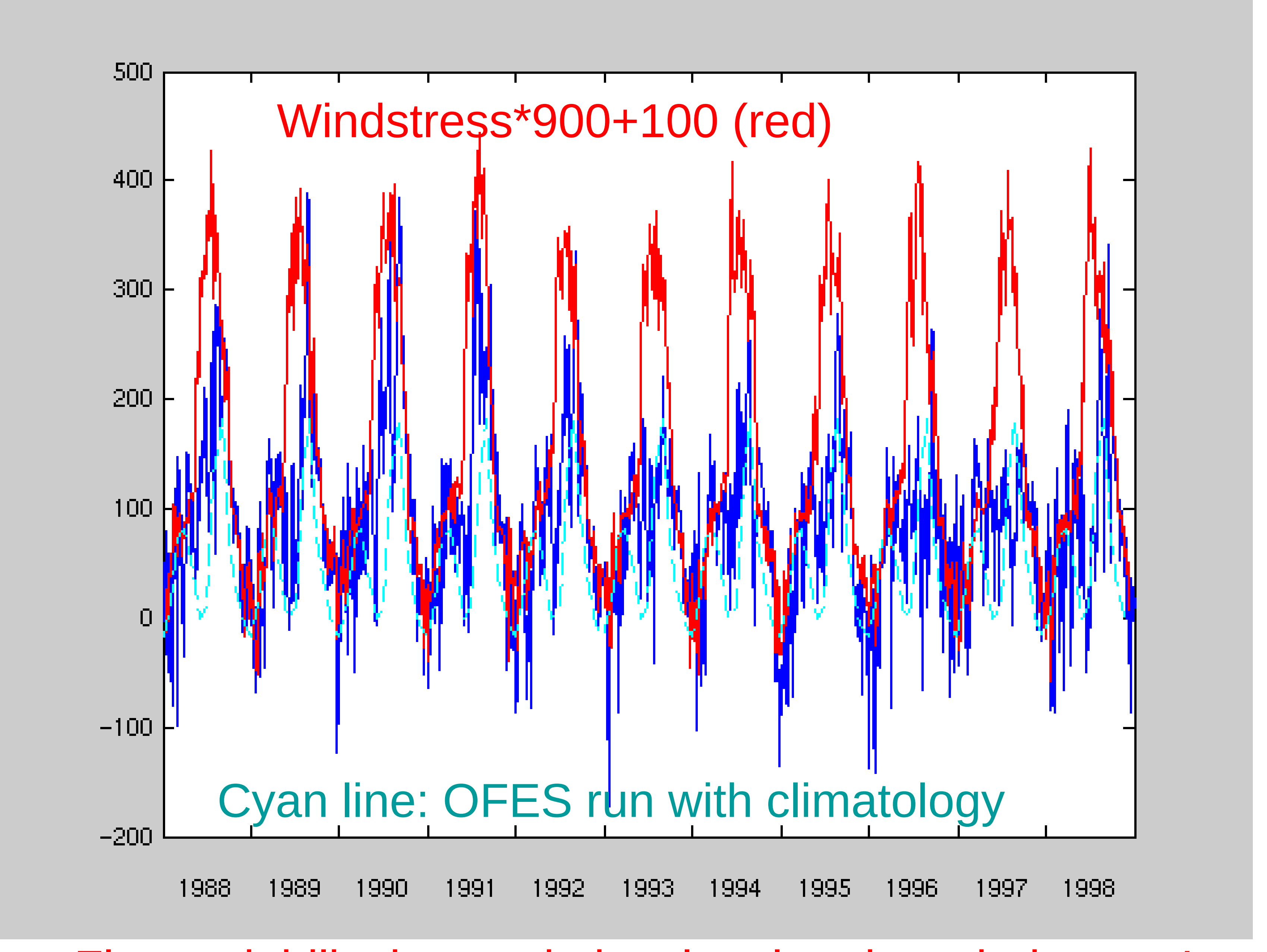


Fig. 16 Seasonal sequence of the Somali Current system in a) March b) June c) September d) December. Vectors are zonal velocities at 25 m depth. Contour is for the sea surface temperature. Data are from the monthly averages.

(From Japanese OFES model, climatological winds)

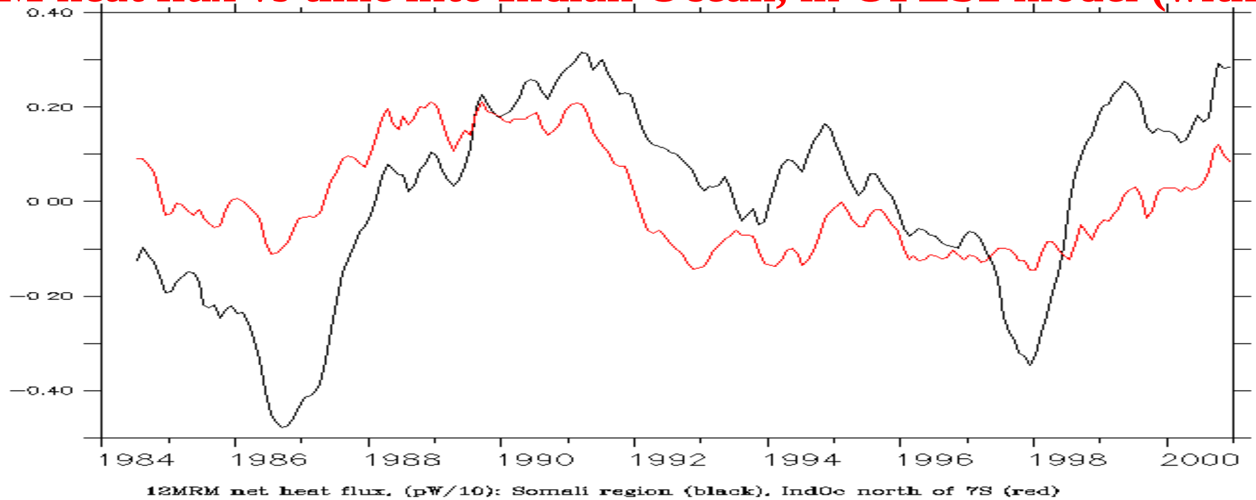
What happens when <u>strong intraseasonal winds</u> blow over the red box?

Area average flux over red box, vs time (blue):

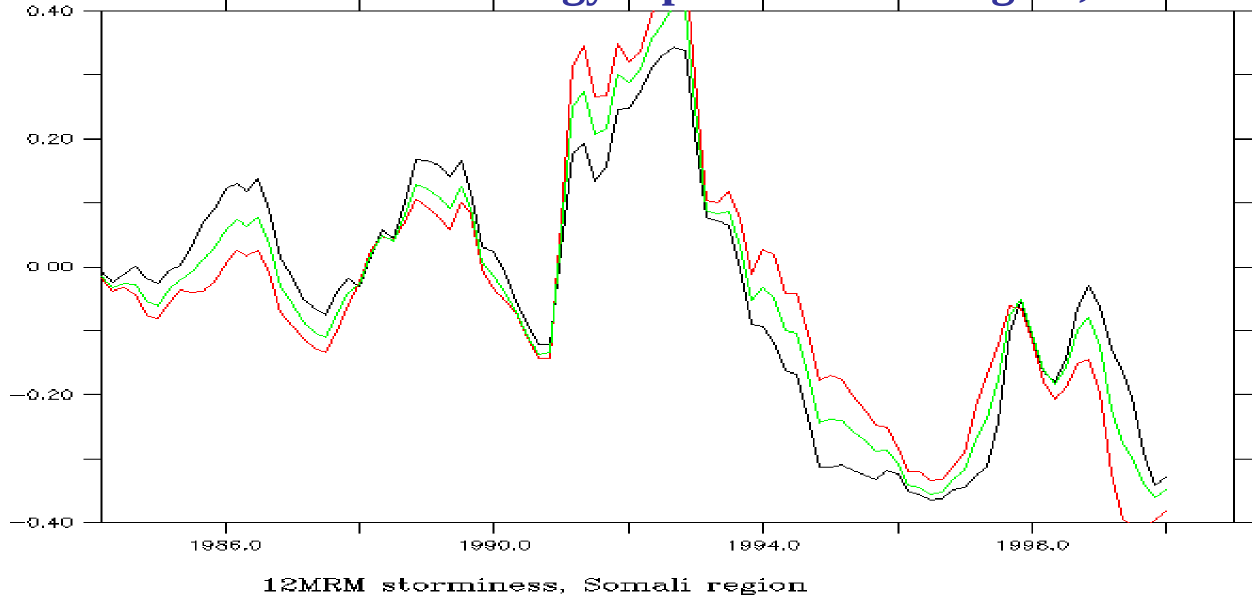


Flux variability is not obviously related to wind stress!

12MRM heat flux vs time into Indian Ocean, in OFES2 model (with daily winds)



12MRM index of sub-inertial wind energy input to Somali region, a la Alford (GRL, 2003)



I have not (yet) seen indications that storminess correlates with OFES heat flux.

Could lack of correlation be due to interannual eddy details?

TIME FOR SOME BASIC OCEANOGRAPHY.

Some principles of ocean heat transport, from Hu-Godfrey work.

- The Levitus (1988) heat transport mechanism

- Use of “overturning streamfunction in temperature coordinates” (OSTC), to simplify annual mean heat budget calculations

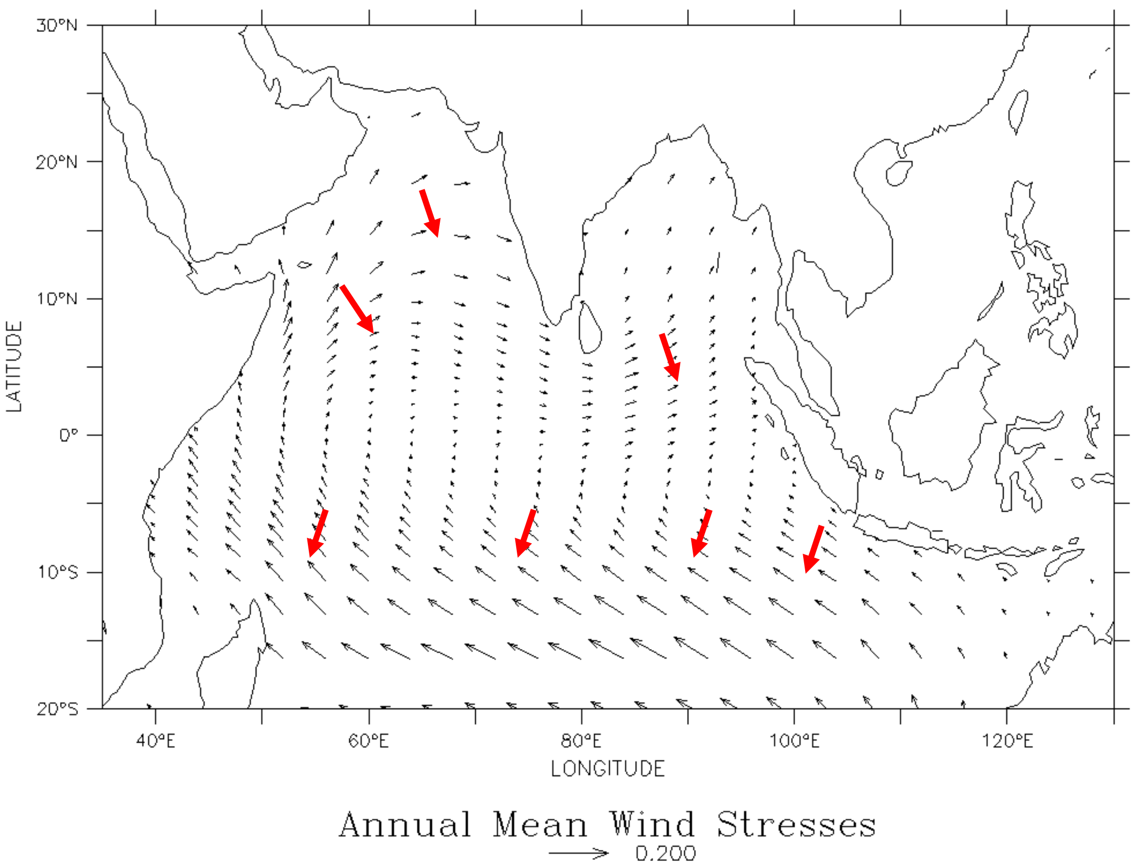
- Inference from OSTC that vertical mixing (to substantial depths) plays an essential role in setting surface heat flux

The Levitus (1988) mechanism of IO heat fluxes north of Indo gap :

Annual mean Ekman transports are southward everywhere, so colder geostrophic flow must go north to replace them, thus carrying heat southward.

Ann mean heat flux N of y = Ann mean heat transport thru y

$= \rho C_p$ *ann mean Ekman transport*$(\bar{T}_{ekman} - \bar{T}_{geostrophic})$



1) Can we quantify

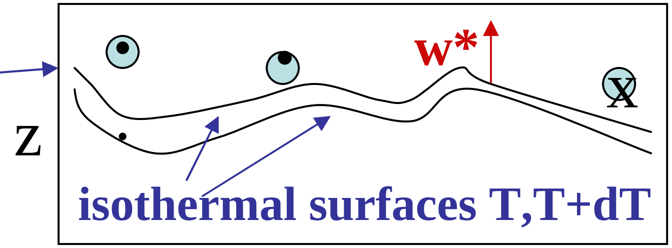
"$(\bar{T}_{ekman} - \bar{T}_{geostrophic})$" ?

2) In our model pairs: Why is $\bar{T}_{geostrophic}$ colder, when rms winds/transports increase?

1)Can we quantify "(T_{ekman} -$T_{geostrophic}$)"?

Define the "overturning streamfunction in temperature coordinates"
ψ (y,T,t) to be the total flow through latitude y, above the T isotherm, at time t.

Then $(\partial\psi/\partial T)dT$ is the increment of volume transport with temperature between T and T+dT.



Thus the instantaneous heat transport Q must be:
$Q = \rho C_p \int [T \partial\psi(y ,T,t)/\partial T] dT$

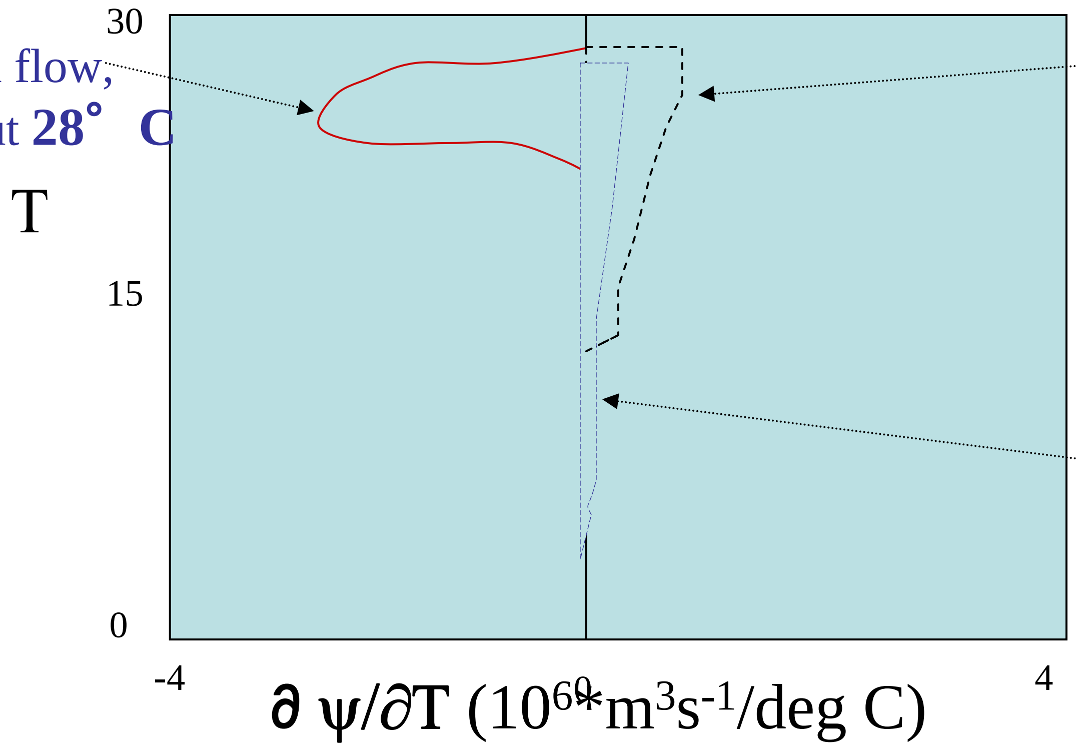
Its time average must be just:

$\overline{Q} = \rho C_p \int [T \partial\overline{\psi}(y ,T)/\partial T] dT$

-- <u>no bar over T, i.e. no eddy fluxes!</u> (because T is the variable of integration). But $\overline{\psi}$ is set by annual mean Ekman transport -- the same in each pair of runs. So, split $\overline{\psi}$ into Ekman and geostrophic pieces, in this integral.

Split $\overline{\psi}(y, T)$ into an Ekman piece, $\overline{\psi_E}$ =(11-13 Sv, at 5S) on annual mean;and equal-opposite geostrophic flow. What should the "transport-weighted temps. (T_E,T_G)" of these two parts be, to give $\rho\, C_p \psi_E\, (T_E - T_G) = 0.3$ pW (models); 0.7 pW (climatologies)?

Ekman flow, at about **28° C**



Geostrophic flow: needs to have transport-weighted temperature of about **22° C**, to give 0.3 pW heat transport across 7S (as per models)

Geostrophic flow must be about **14° C**, to give transport of 0.7 pW (as per climatologies)

2) Why is $T_{geostrophic}$ colder, when rms winds increase?

Mass conservation takes the form:

$$\partial V(y,T,t)/\partial t=\psi(y,T,t)+\int w^*(x',y',T,t)dx'dy'$$

V(y,T,t) = volume above temperature T;

ψ(y,T,t) = streamfunction;

w* is the "diathermal entrainment velocity"

(i.e. water warms as it upwells -- by sunlight or, below minimum SST, by mixing).

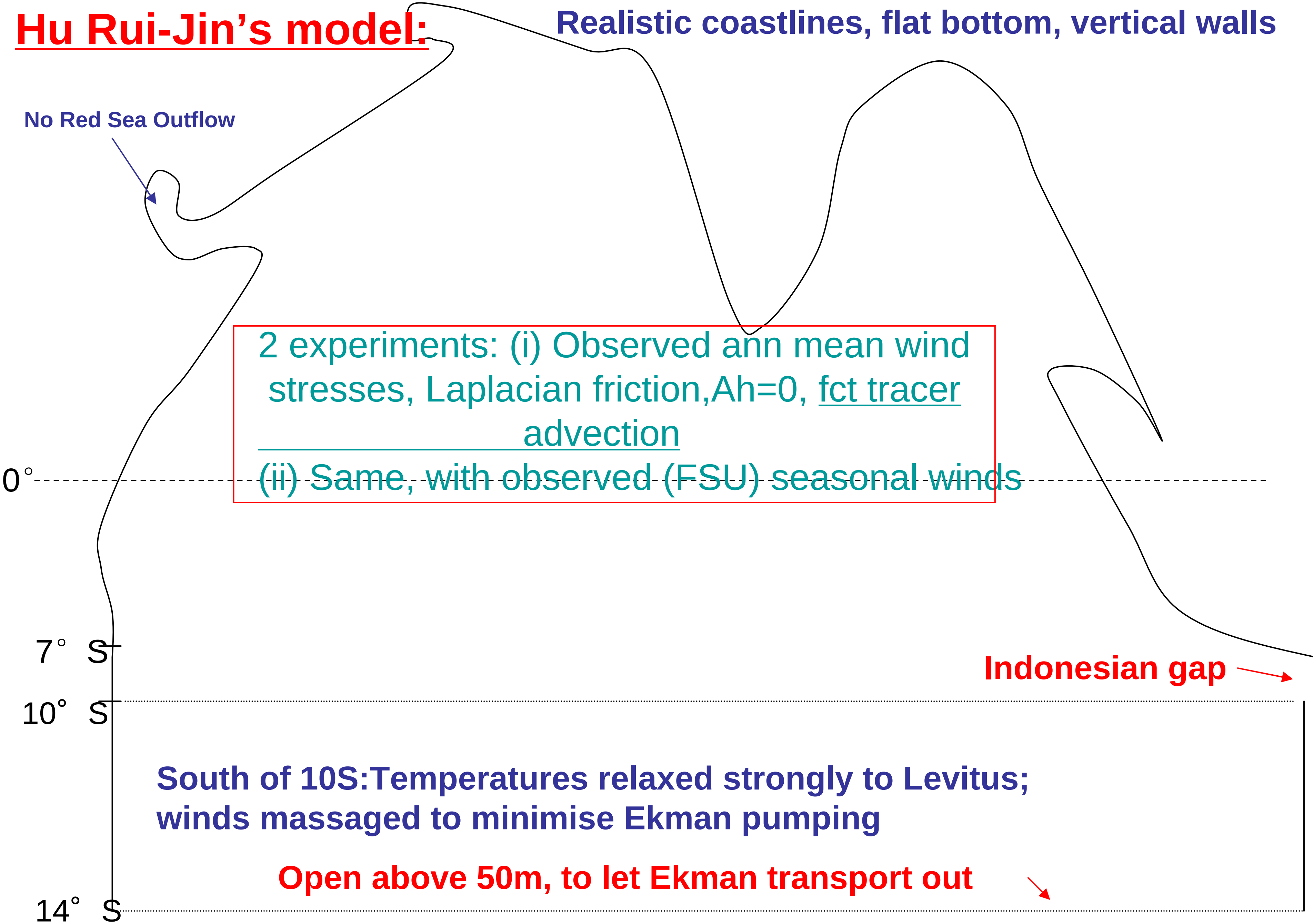
In steady state V is constant, so that:

$$\underline{\psi}(y,T) = -\int \underline{w}^*(x',y',T)dx'dy'$$

But vertical diffusion is needed to warm water as it rises through temperature T< min SST ; and diffusion needs kinetic energy dissipation. More wind/current means more diffusion.

Hu Rui-Jin's model:

Realistic coastlines, flat bottom, vertical walls



2 experiments: (i) Observed ann mean wind stresses, Laplacian friction,Ah=0, fct tracer advection

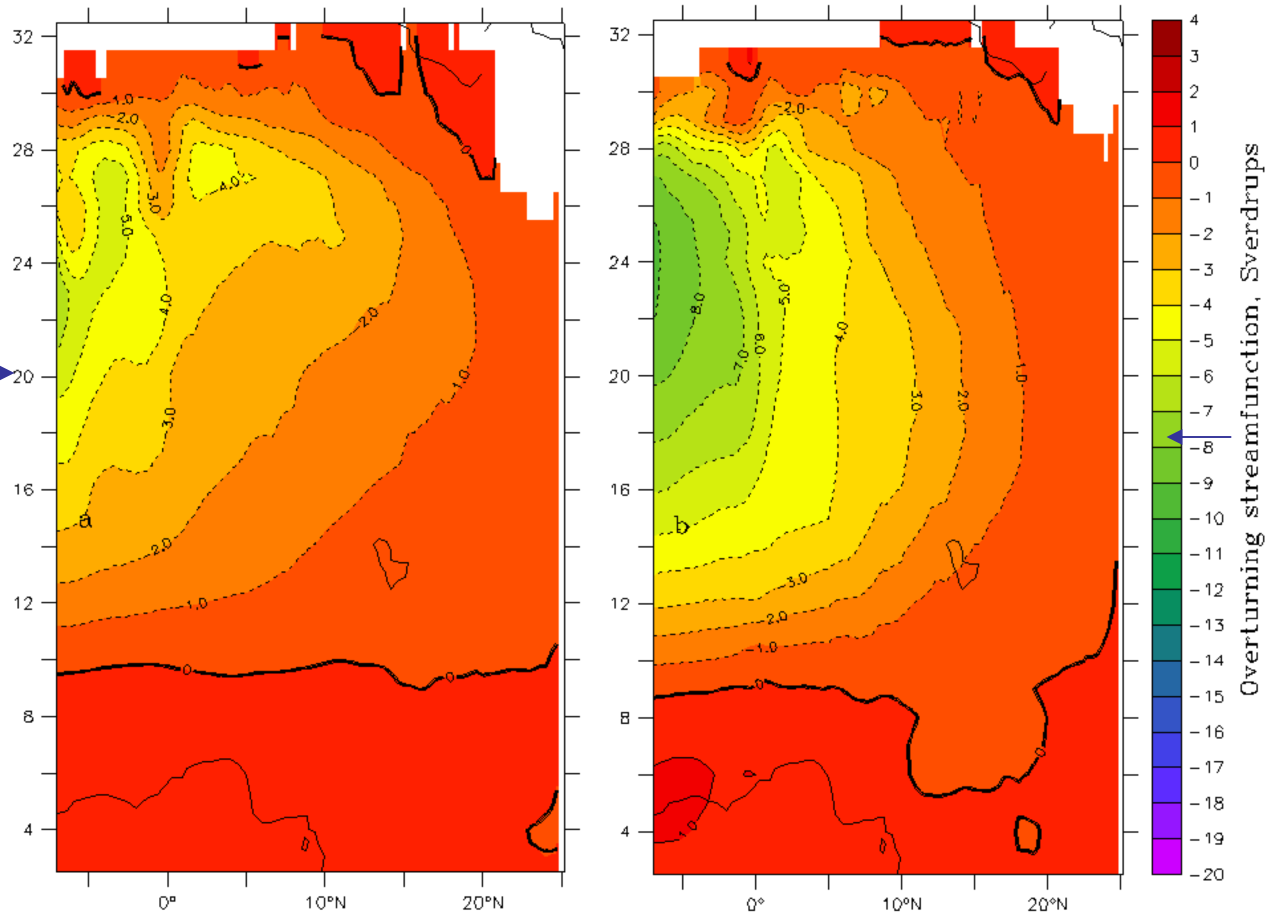
(ii) Same, with observed (FSU) seasonal winds

South of 10S:Temperatures relaxed strongly to Levitus; winds massaged to minimise Ekman pumping

Open above 50m, to let Ekman transport out

Annual mean overturning streamfunctions in temp. co-ords, H-G runs, year 6. Steady (left) and seasonal (right) winds respectively. Contour interval 1 Sv.

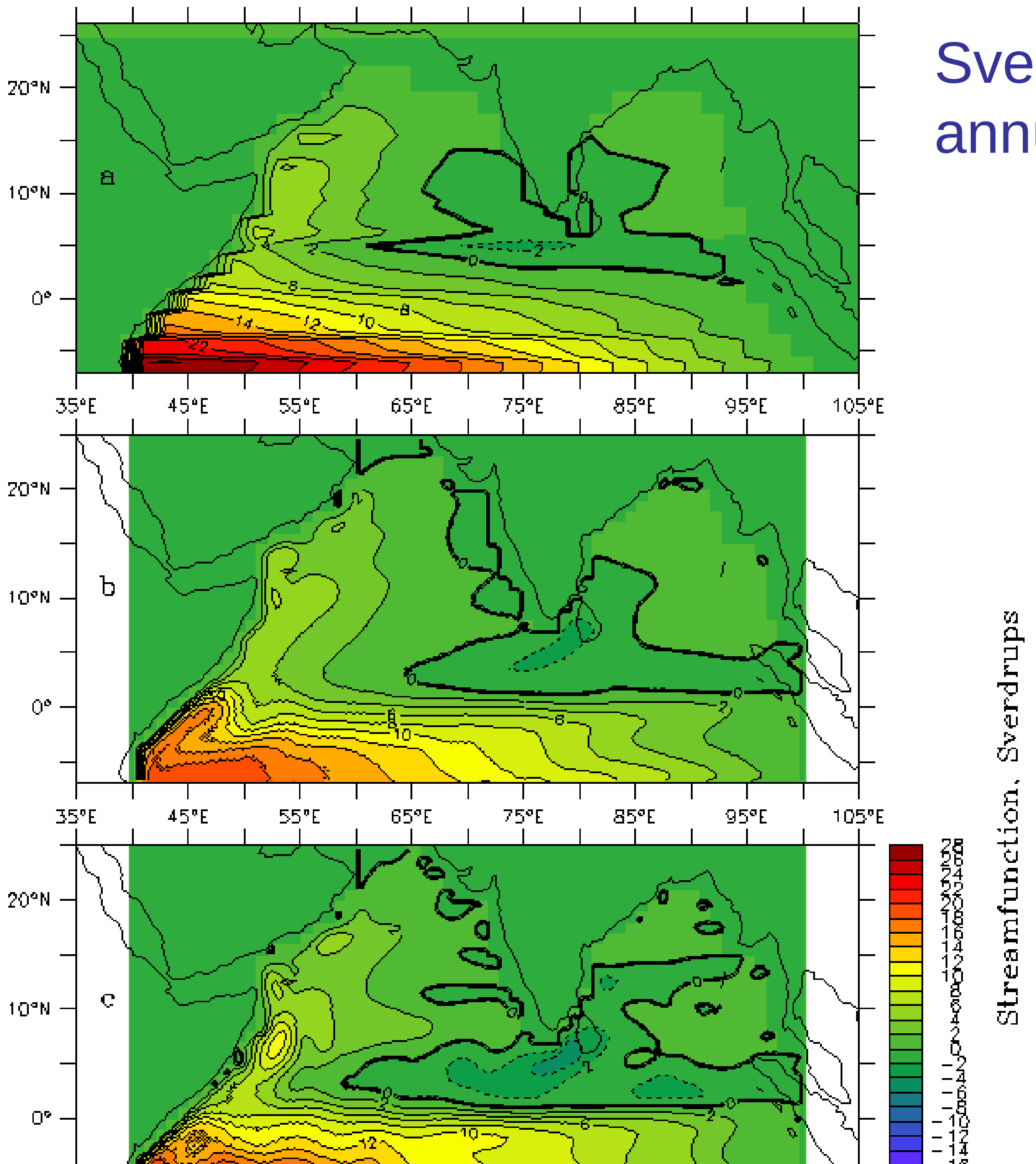
Minimum SST =20°



Minimum SST =18°

Both have 12 Sv of Ekman transport. Max overturning is 6 Sv (9 Sv) in left (right) panels. Upwelling below min SST is due to mixing, inshore from Somali Current (faster in right panel).

Horizontal streamfunctions, Hu-Godfrey model:



Sverdrup streamfunction, annual mean winds

Streamfunction from model, annual mean winds

Streamfunction from model, mean seasonal winds

The "Great Whirl" is stronger, with seasonal winds. Does water warm in it

Conclusions:

We (Hu Rui-Jin and I) feel we are ready to explore these ideas within the OFES2 model output.

Tasks:

i) Calculate the annual mean overturning streamfunction, and the horizontal streamfunction, in OFES1 and OFES2. Is the former deeper/stronger in OFES2? Is the Great Whirl bigger?

ii) How do wind and eddy variability combine to give interannual heat flux variability, in OFES2?

iii) Use OFES2 to test easily measurable oceanic indices of interannual flux variability.

A Stommel inertial solution, applied to the Somali Current:

Assume top layer of 1.5 layer model obeys:

-fv = -gÕ¶h/¶x **(1)**

u(f+¶v/¶x)=-¶(gÕh +v^2/2)/¶y (=0, at western boundary -- Bernoulli) **(2)**

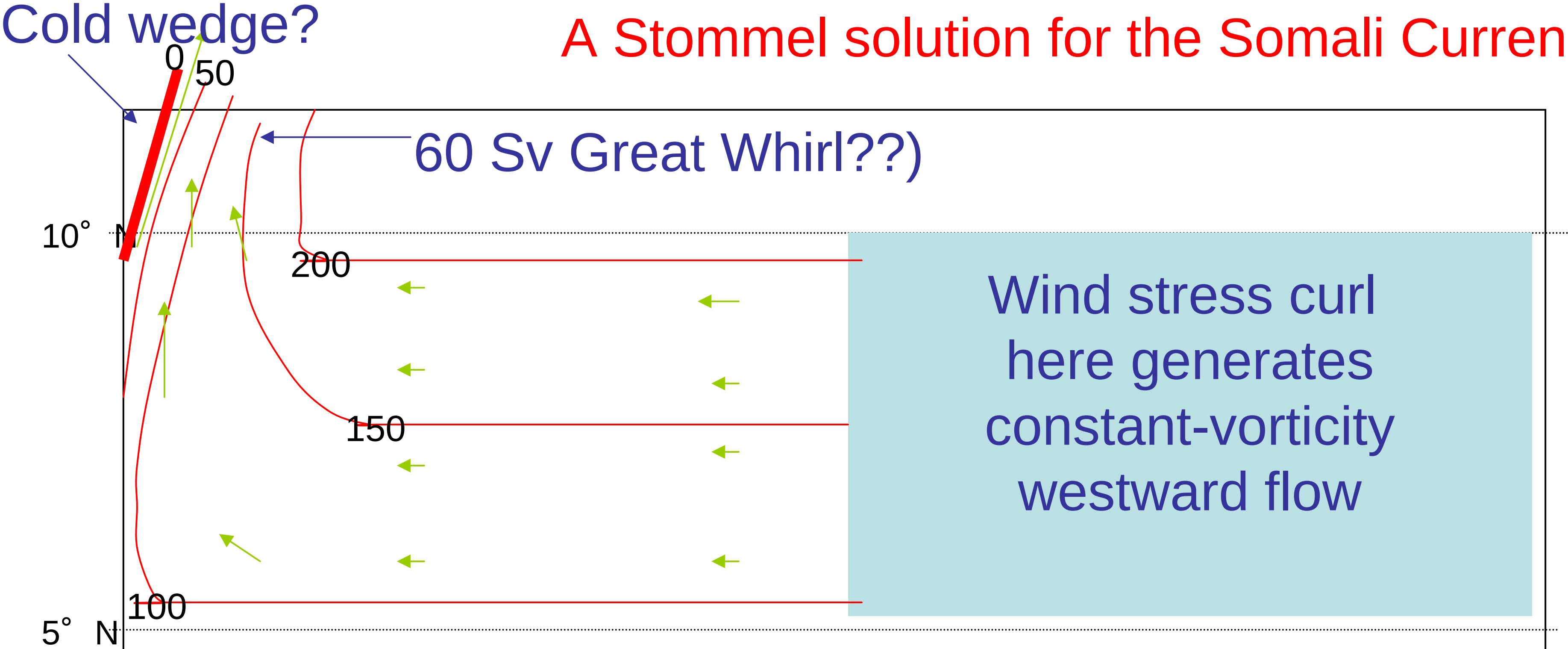
¶(uh)/¶x + ¶(vh)/¶y = 0 **(3)**

Vorticity ζ is conserved, so Stommel chose:
(f+¶v/¶x)/h = ζ = constant everywhere. A solution is:

h(x,y)=
(h(0,y)-f(y)/ζ)exp (-x/L) +f(y)/ ζ

((2) is the boundary condition at shore)

A Stommel solution for the Somali Current



i) Flow follows h contours, open ocean (geostrophic)

ii) Flow “falls down” h contours, near bdy (Bernoulli); i.e. flow arrows cross h contours

iii) h surfaces near 10° N (strong flows -- cold wedge?)

WHAT WILL HAPPEN IF WE BLOW A NORTH WIND?

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TIFF (Uncompressed) decompressor
are needed to see this picture.

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