Southern Ocean air-sea buoyancy flux estimates

with application to Subantarctic Mode Water formation

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Outline of the talk

•Water mass formation in the Southern Ocean estimated from air-sea heat and freshwater flux

•*SAMW formation*, important because it ventilates large areas of lower thermocline in all three southern hemisphere oceans (Schmitz 1996)

•Impetus for the work came from a recently developed air-sea heat and freshwater flux estimate from a data assimilating ocean model *"Southern Ocean State Estimate" (SOSE)* by Mazloff et al. (2009)

•Evaluate accuracy of SOSE air-sea flux estimates for years 2005-2007, in particular in SAMW formation region

•Compare SOSE air-sea fluxes with fluxes from NCEP1 (Kalnay et al., 1996), ECMWF operational model, Large and Yeager (2009)

•Goal *WAS NOT* to carry out a systematic flux comparison

•Evaluate SOSE fluxes suitability for use as input in SAMW formation calculation using Walin analysis (1982) which quantifies the along isopycnal transport ("formation of water") in each density layer from air-sea fluxes and mixed layer density distribution

•*Why SOSE?*

•SOSE is an ocean model, unlike the NWP models it provides not only air-sea fluxes but it provides dynamically consistent, time evolving 3-D global ocean state estimate

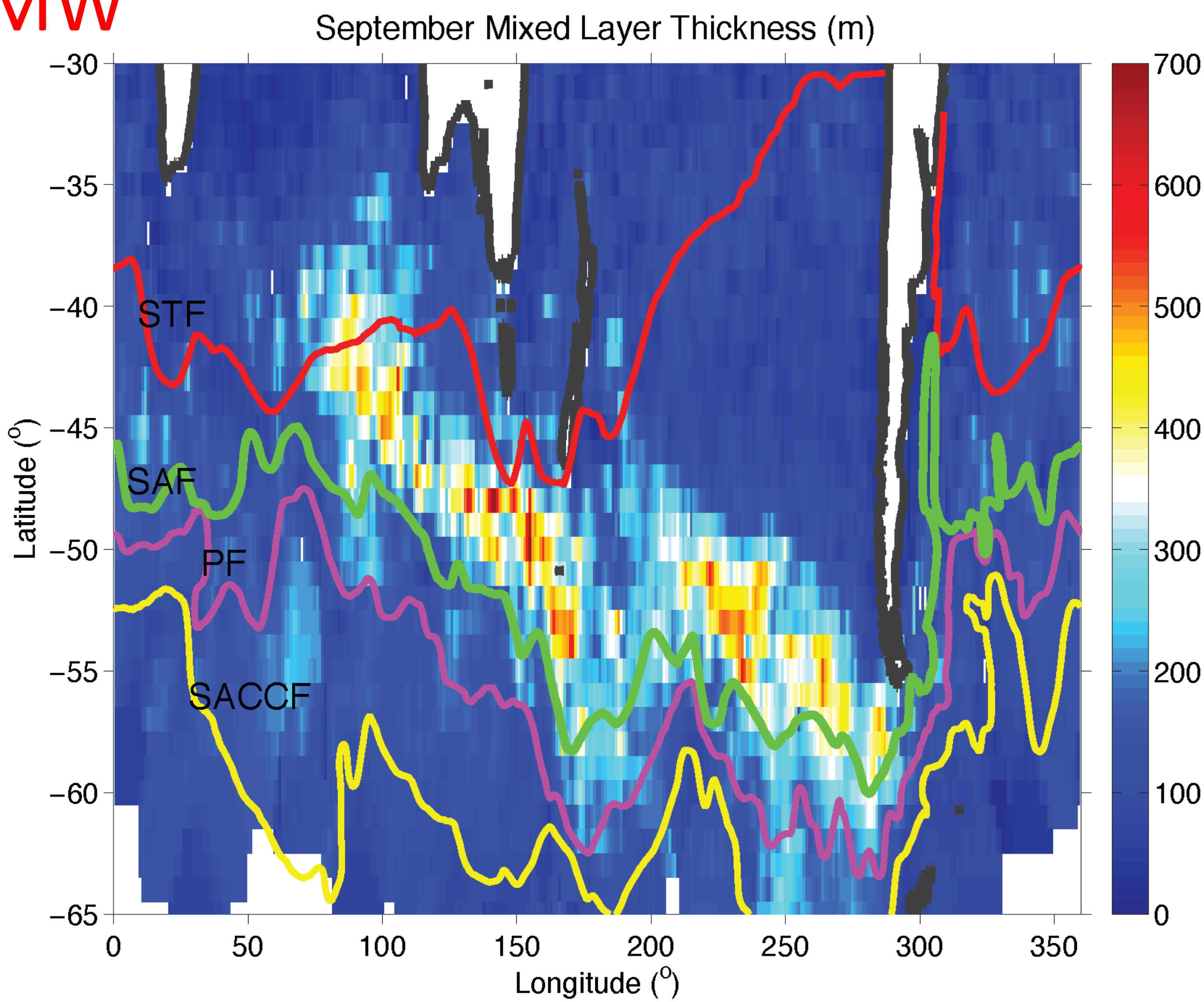
•Results of Walin analysis using SOSE input, compare with them with the results using NCEP1, ECMWF and LY09

•Which air-sea heat and freshwater flux accuracy do we wish to have?

•Conclusions

Mixed layer thickness from Argo floats for September: Dong et al., 2007

SAMW



•The Southern Ocean State Estimate (SOSE)

by Matt Mazloff, Wunsch and Heimbach (2009)

•An alternative way to estimate the air-sea heat and freshwater flux.

•A data-assimilating ocean circulation model that includes atmospheric forcing. The initial guess for the atmospheric state, together with the ocean's T and S initial conditions, is then systematically adjusted in order to best fit the oceanic observations.

•SOSE uses NCEP1 (Kalnay et al., 1996) for an initial guess for the atmospheric state (air temperature, specific humidity, zonal and meridional wind speed, precipitation, and downward radiation).

- Do SOSE adjustments of the NCEP1 atmospheric state, made as part of SOSE optimization procedure represent a true improvement of the NCEP1?

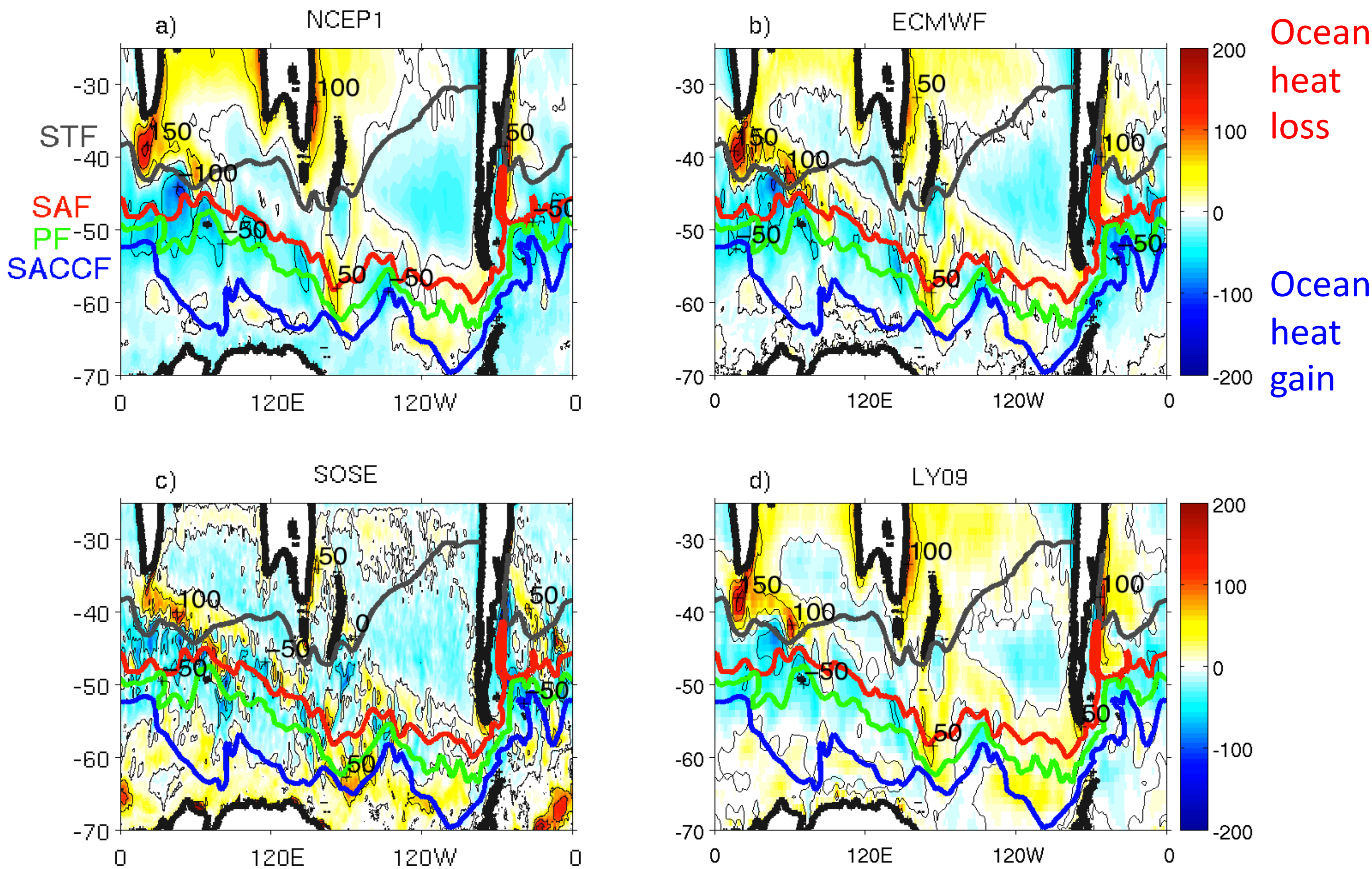
- **Inter-comparison** of annually-averaged air-sea buoyancy fluxes in the SO for years **2005-2007**

•Assess the quality of the SOSE air-sea buoyancy fluxes by verifying

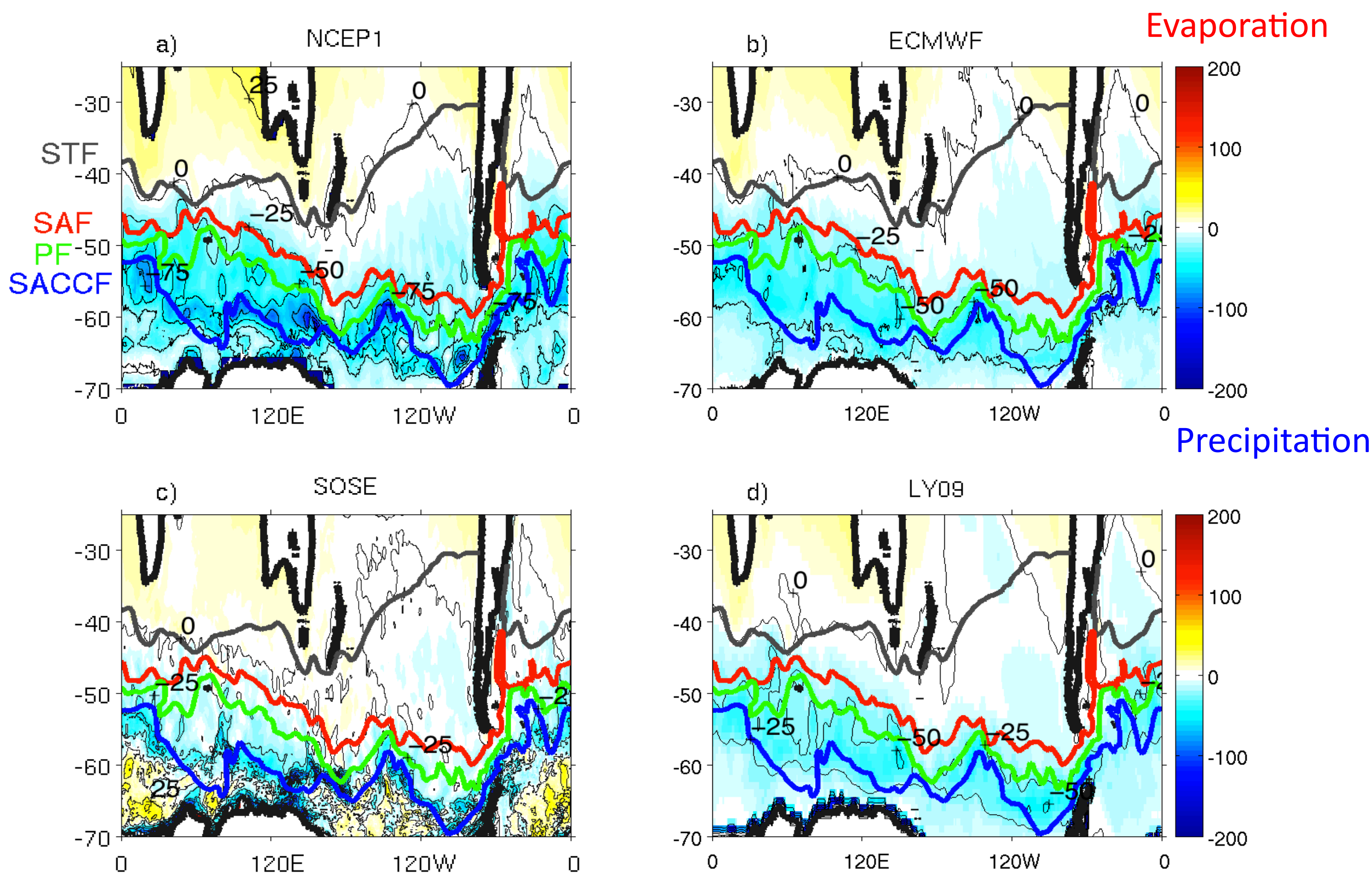
• that the SOSE adjustments of NCEP1 forcing fields largely correct the NCEP1 biases reported by WGASF (Taylor et al., 2000),

•that they are largely in agreement with "the adjustments" of LY09. The methods and input data sets used by the LY09 and the SOSE to estimate the air-sea fluxes are very different. The agreement between the estimates at least partially validates the products and procedures used in developing each.

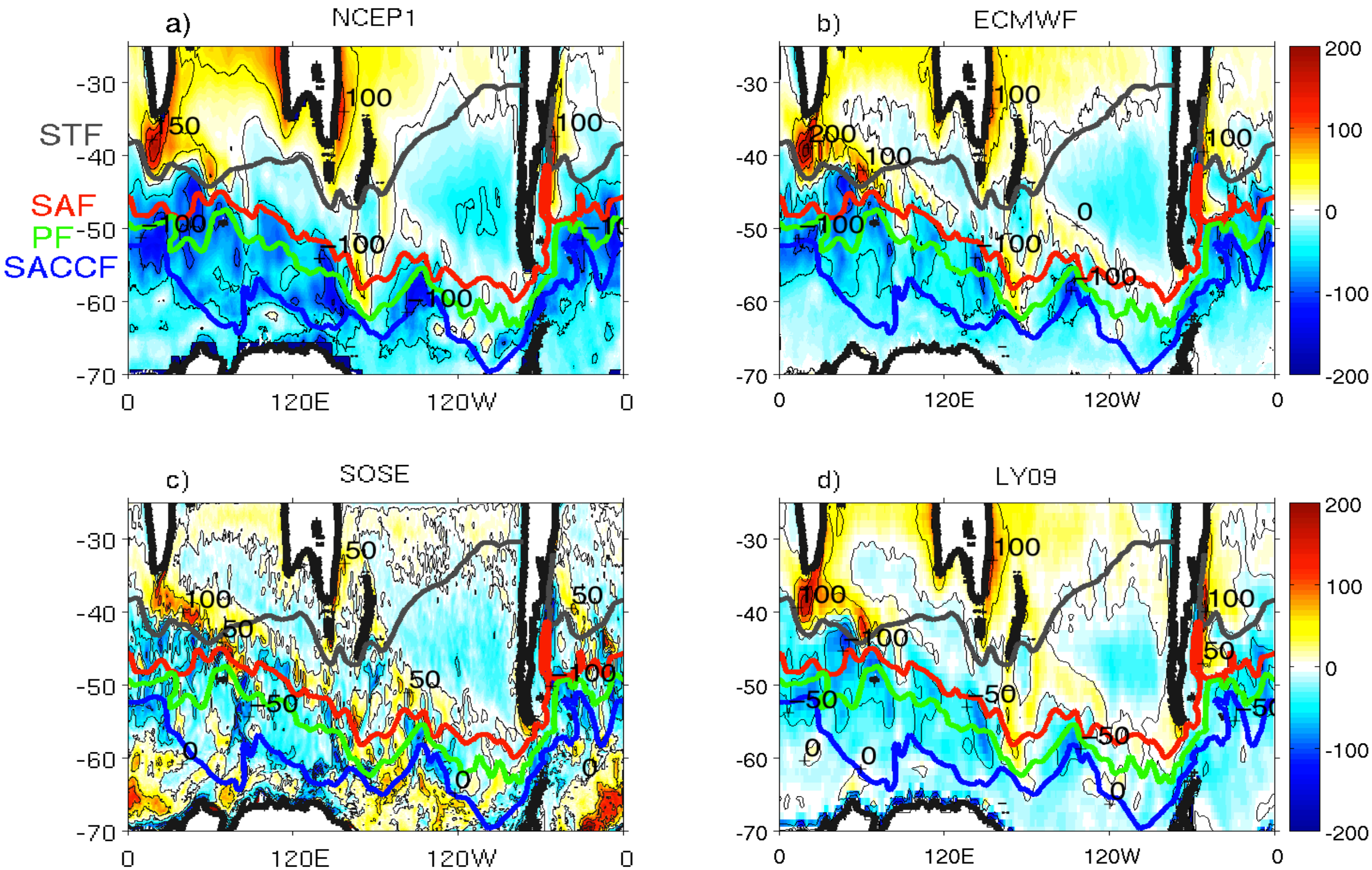
Net air-sea heat flux [W/m^2] averaged 2005-2007



Freshwater heat equivalent flux [W/m^2]



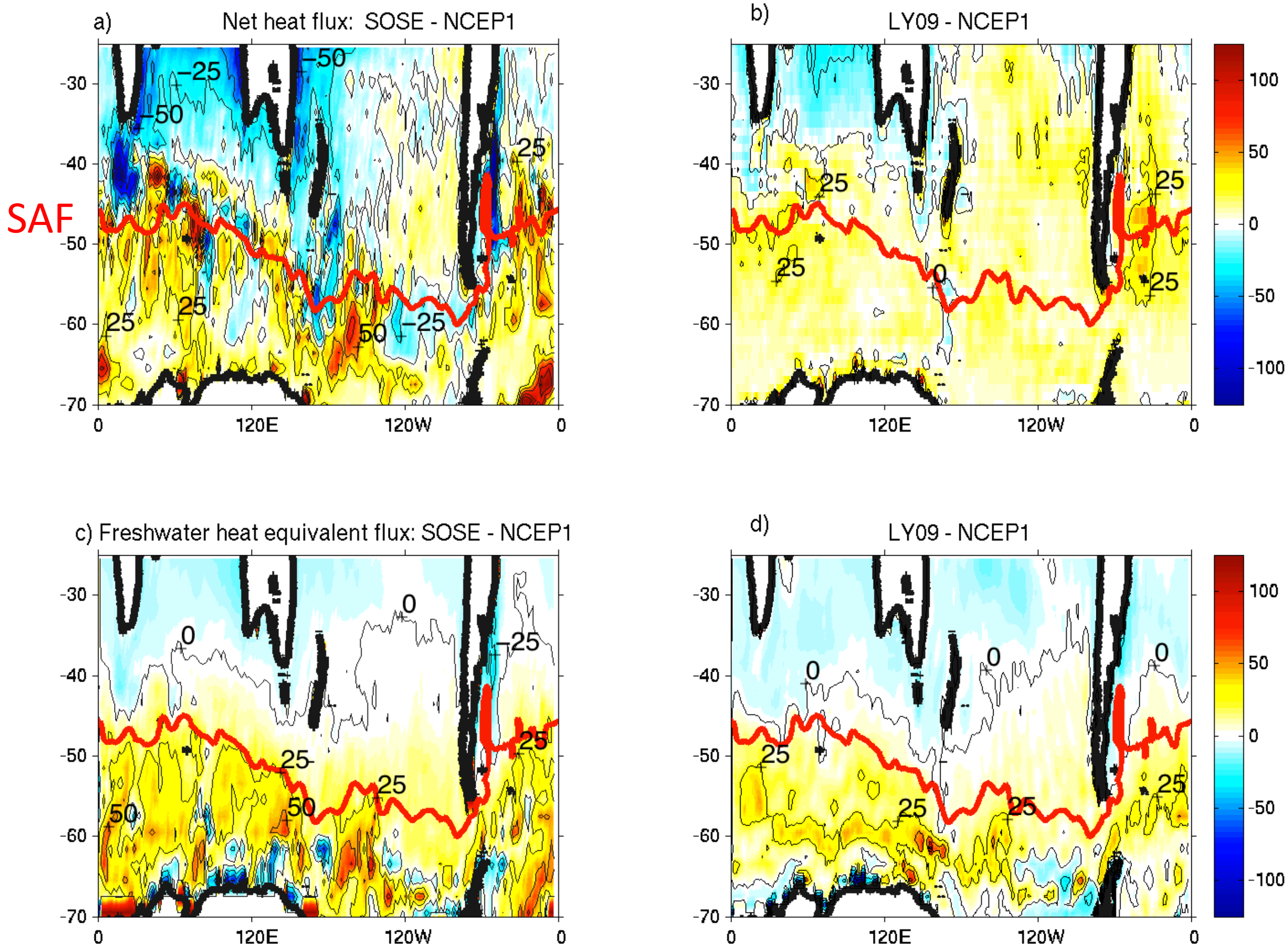
Buoyancy heat equivalent flux [W/m^2]



SOSE-NCEP1 **LY09-NCEP1**

Net air-sea heat flux

Freshwater heat equivalent flux

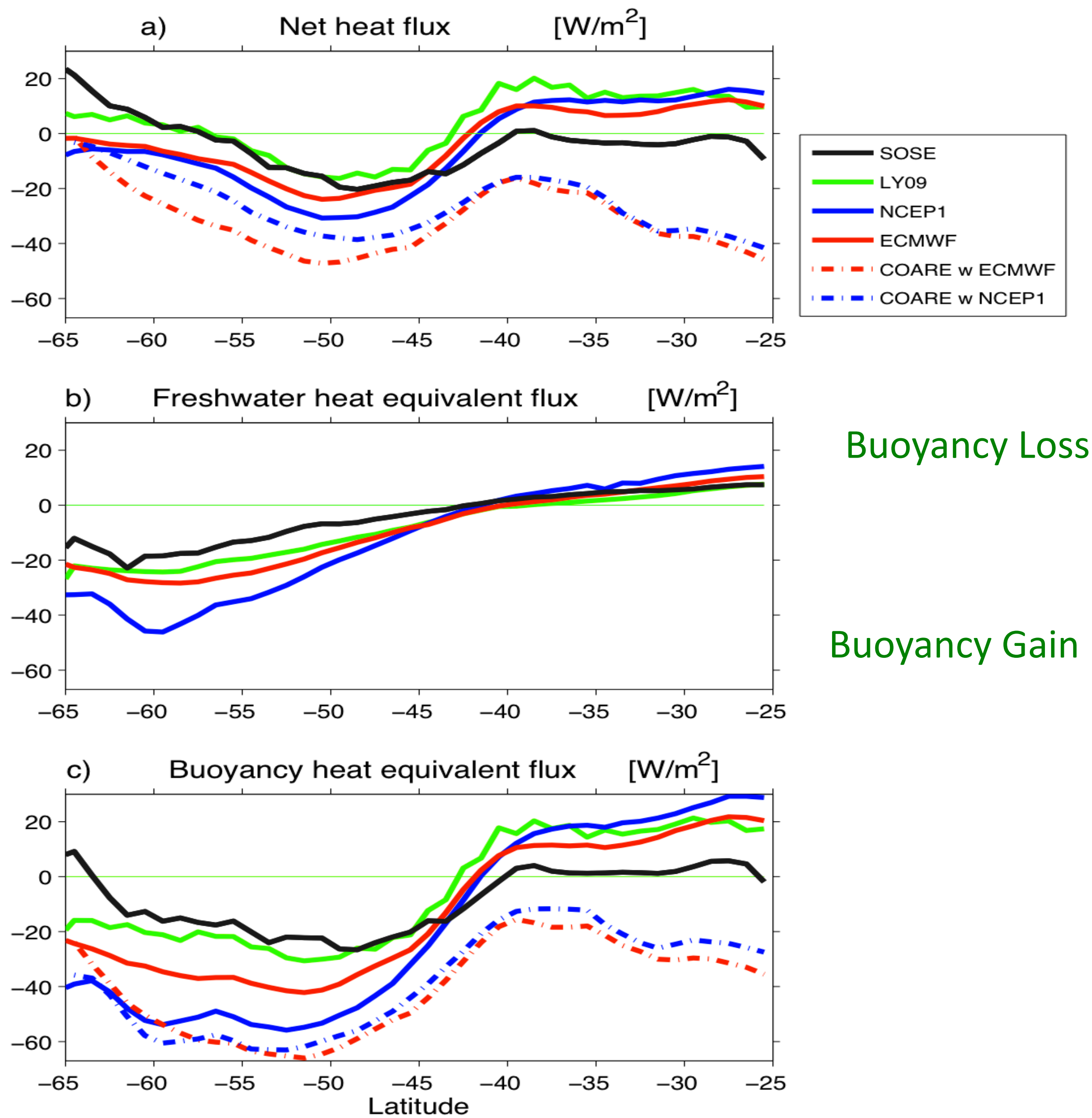


Zonal and time (2005-2007) average of:

HF

FWF

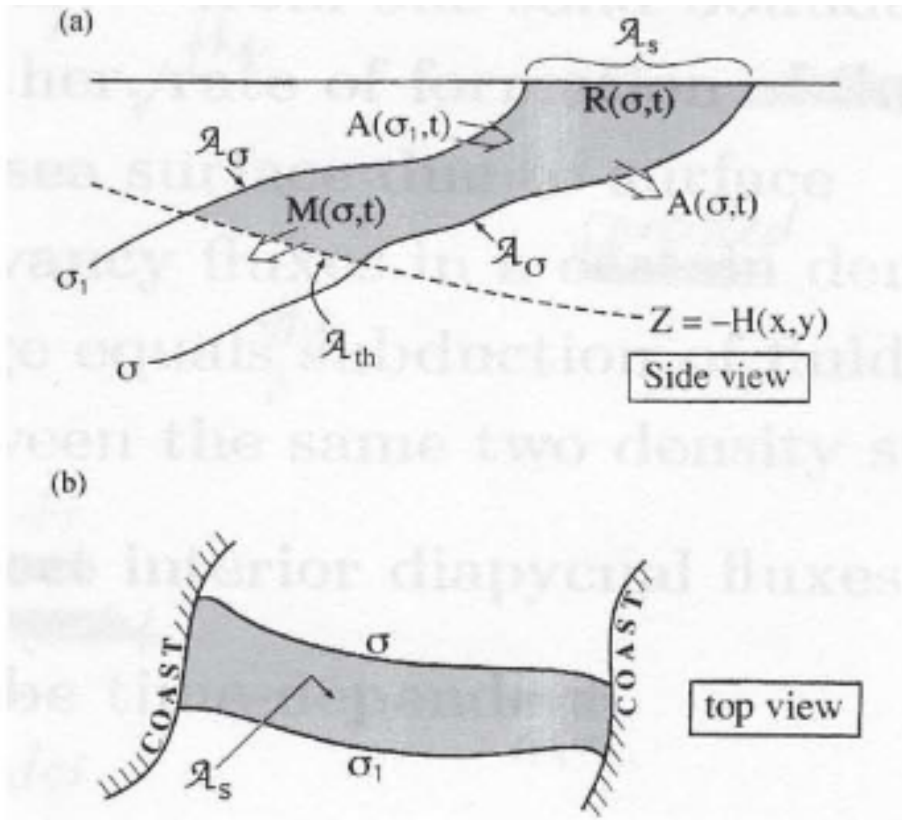
BF



Walin analysis (1982)

- combines conservation of heat and volume to estimate diapycnal volume flux (water mass transformation) by integrating surface buoyancy flux over outcrop windows

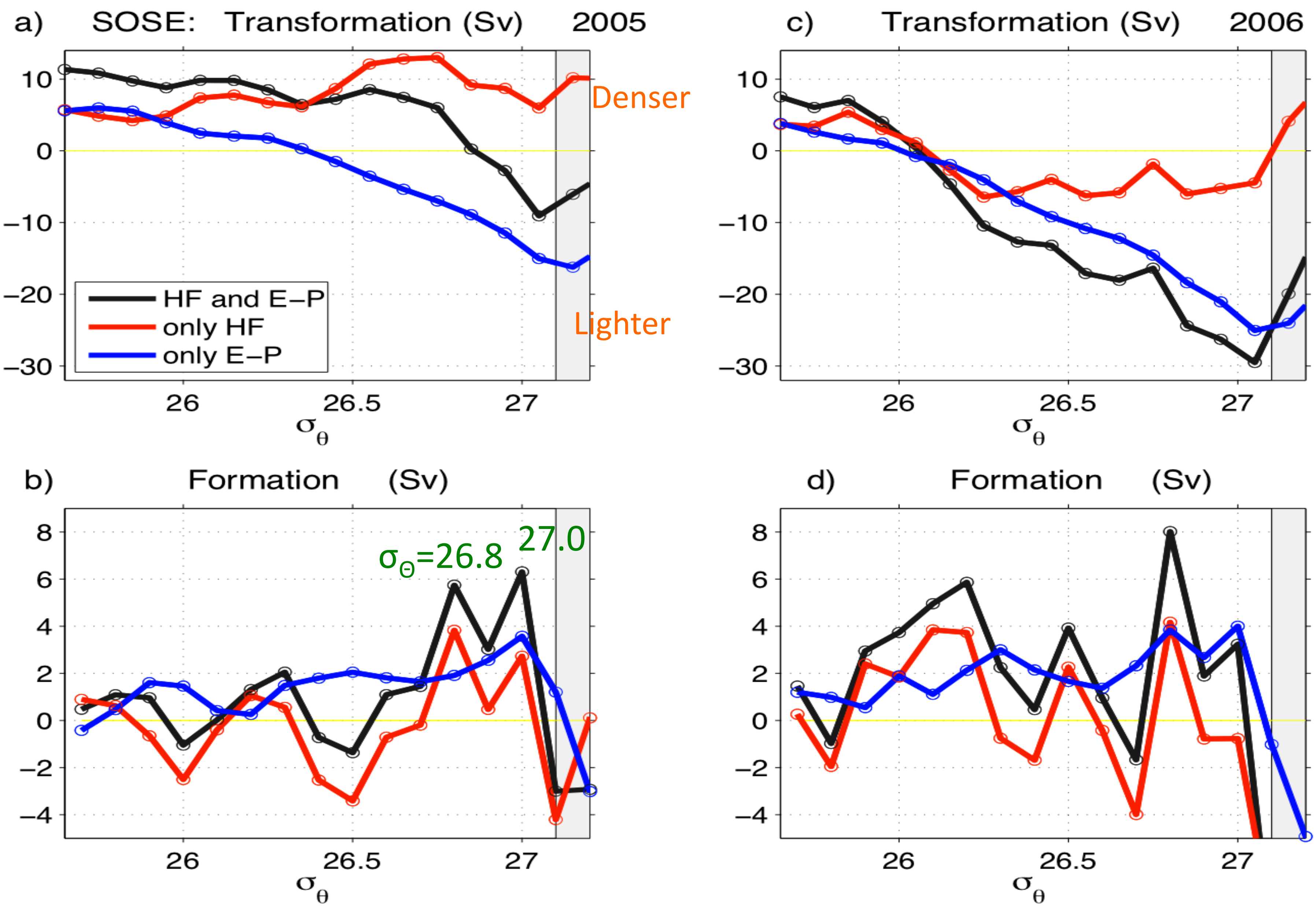
- the buoyancy flux integration on each density outcrop must be carried out from one solid boundary to another, the rate of formation of water at the sea surface due to surface buoyancy fluxes in a specified density range equals the subduction of fluid between the same two density surfaces



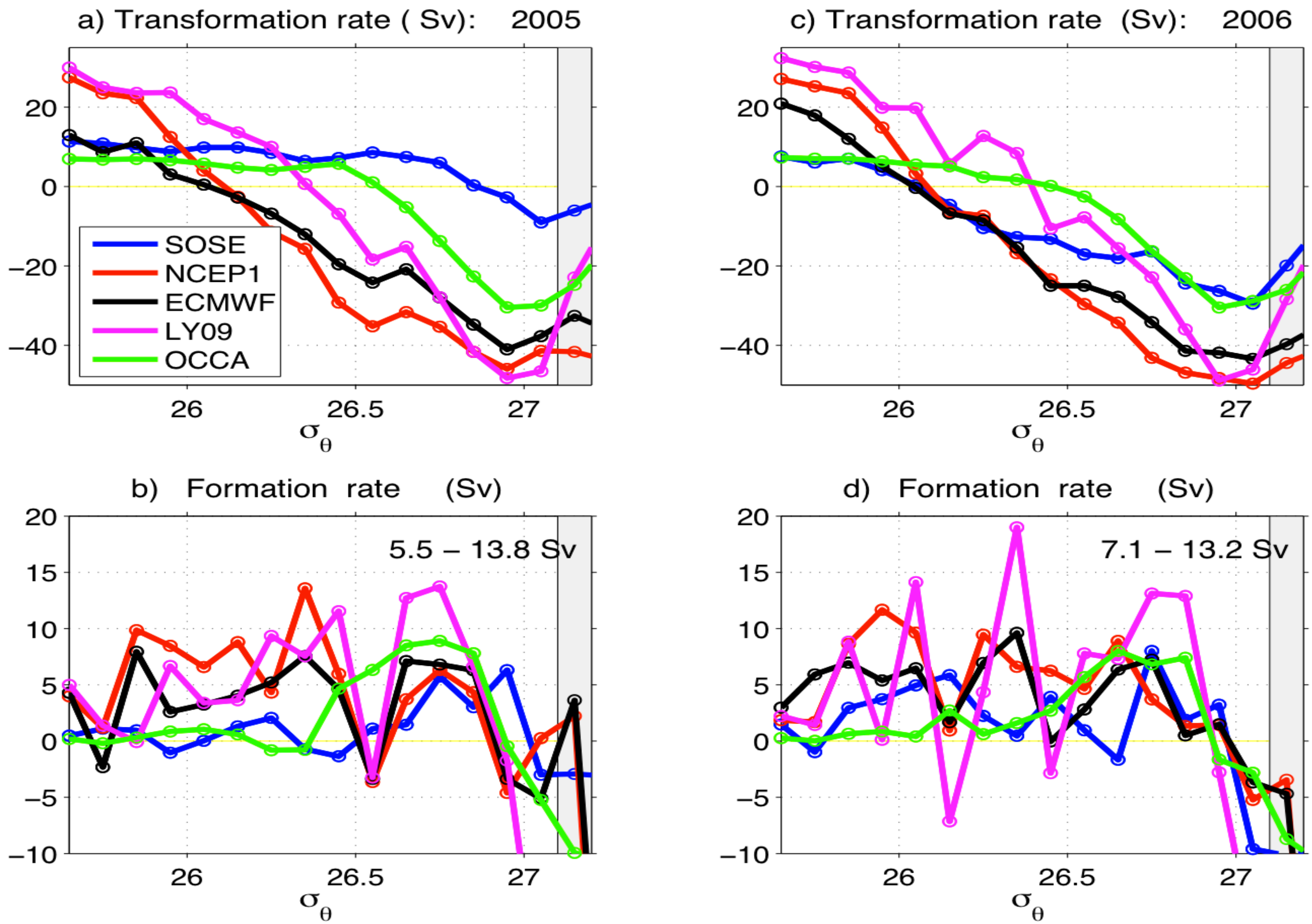
-neglects interior diapycnal fluxes

- includes time-dependance

Walin analysis: SOSE



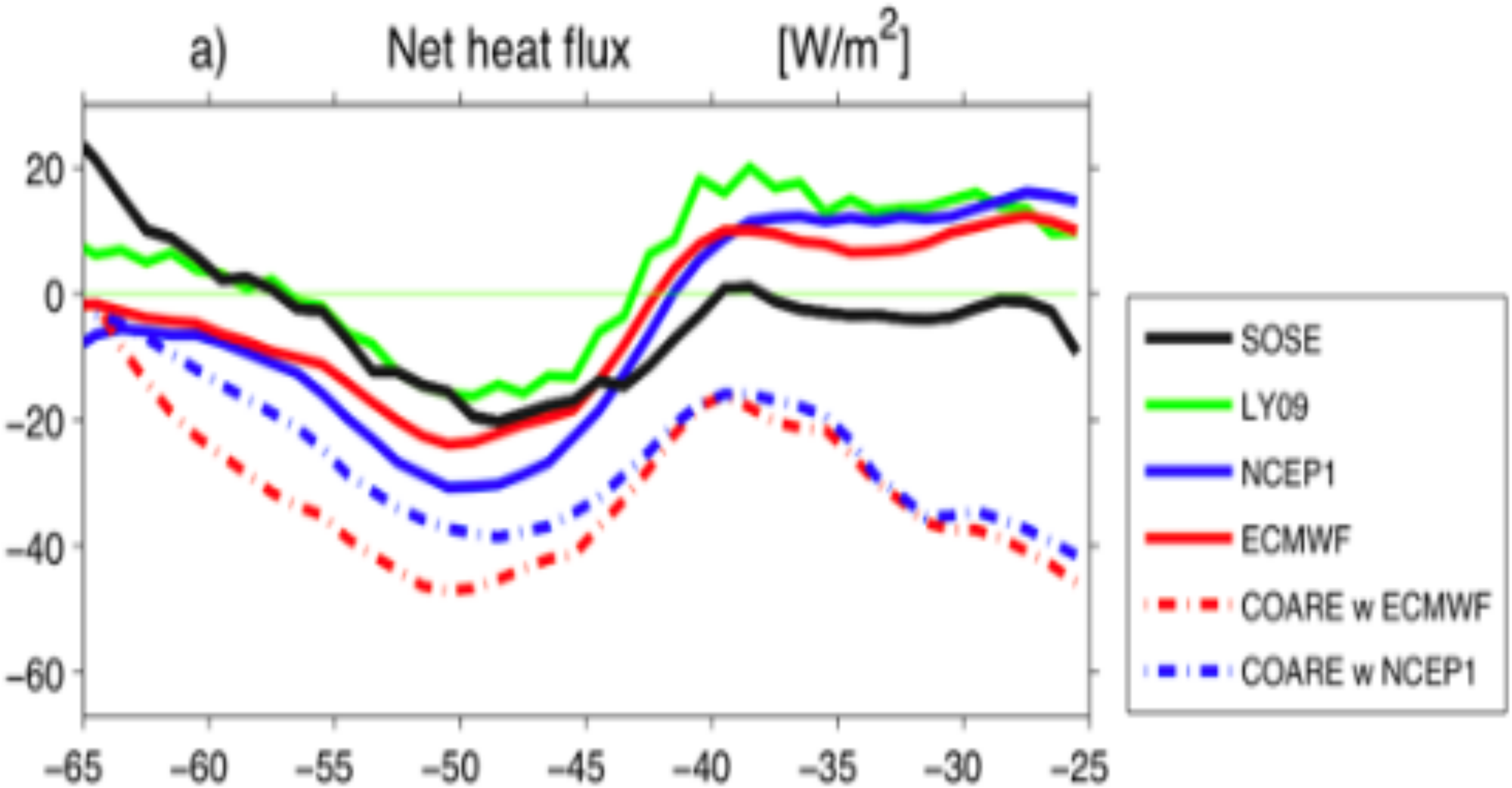
Walin analysis: intercomparison



Flux RMS differences

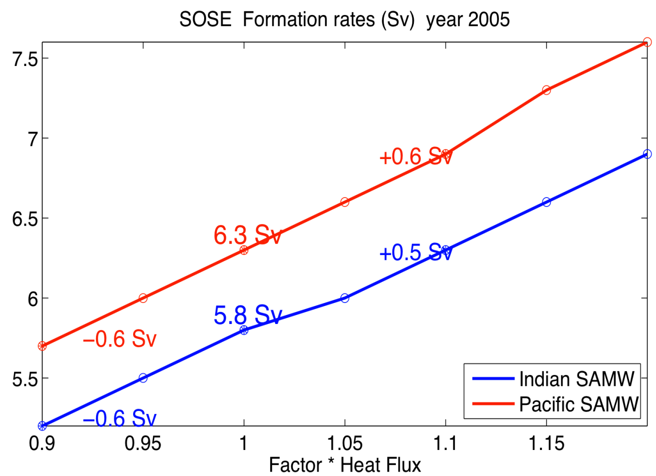
The root-mean square differences between monthly mean (years 2005-2007) net air-sea heat and freshwater equivalent heat flux estimates over the ocean south of 24.7°S in W/m^2. For the comparison all datasets are interpolated on a 1°x1° grid.

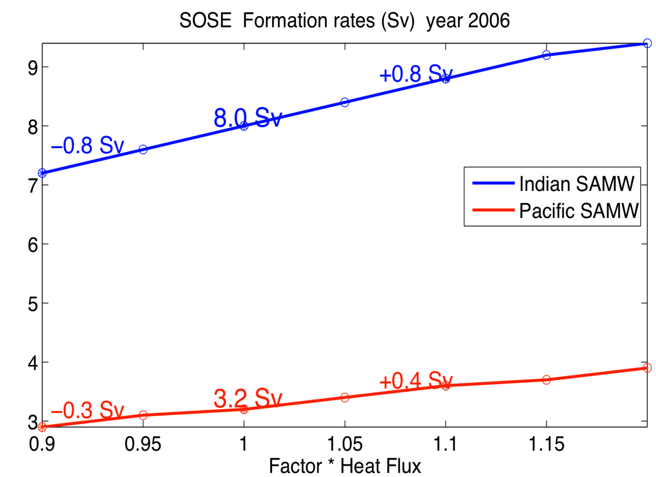
	NCEP1	ECMWF	NCEP1 with COARE	ECMWF with COARE	SOSE	LY09	
NCEP1	--	17.3±20.5	35.3±19.3	37.5±17.8	30.9±32.4	24.0±31.2	RMS heat flux difference (W/m^2)
ECMWF	9.8±7.4	--	40.0±20.7	37.0±14	33.9±32.1	25.7±29.5	
NCEP1 with COARE	No FW	No FW	--	31.0±27.2	40.4±50.9	43.3±66.4	
ECMWF with COARE	No FW	No FW	No FW	--	43.3±64.5	45.4±72.3	
SOSE	20.9±11.7	17.9±11.1	NoFW	NoFW	--	36.4±42.0	
LY09	14.6±12.0	9.6±9.4	NoFW	NoFW	19.5±26.0	--	
	RMS freshwater (equivalent heat flux) difference (W/m^2)						



a)
Net heat flux
[W/m2]
20
0
−20
−40
−60
−65
−60
−55
−50
−45
−40
−35
−30
−25
SOSE
LY09
NCEP1
ECMWF
COARE w ECMWF
COARE w NCEP1

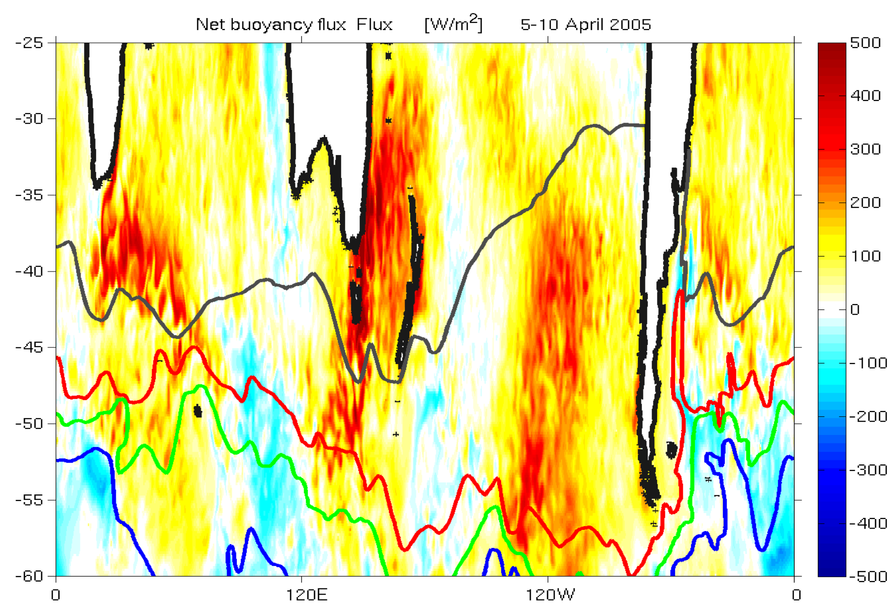
Which air-sea heat flux accuracy do we need?





Transformation=Integral (Buoyancy Flux* Outcrop Area)

Formation(ρ)= Transformation(ρ+Δρ)-Transformation(ρ)



Conclusions: general

•In SAMW formation region, especially in SE Pacific there is a near-cancellation of the contribution of the freshwater and heat flux to the buoyancy flux, which makes it especially difficult to obtain accurate buoyancy flux estimates in this region.

•The inter-comparison of NCEP1, ECMWF, LY09, and SOSE showed that in many polar regions the heat flux estimates are very different, and even of differing sign.

•In the sub-polar and polar oceans freshwater flux estimates tend to show too much precipitation, but they differ greatly in magnitude, so the resulting buoyancy flux estimates are of a different sign both in some regions of SAMW formation, and even more further poleward.

•The large differences between both heat and freshwater flux estimates from different products considered here clearly indicate that high quality in-situ meteorological and oceanic observations with high spatial and temporal resolution are needed to improve the flux estimates.

SOSE

•The SOSE air-sea heat and freshwater flux estimates agree better with NCEP1, ECMWF, and LY09 in the regions away from the model open boundary at 24.7°S and away from the southernmost part of the SO.

• In the subtropics the SOSE model domain does not include the whole subtropical gyre, but at 24.7°S the SOSE uses the results of coarser resolution state estimate by Forget (2009) as the open boundary condition.

•In the southernmost part of the domain the SOSE model is suspect due to a rather primitive sea-ice model and poor representation of shelf processes.

•However, in the middle of the domain, where the SOSE is well constrained by ARGO floats and also includes the regions of SAMW formation, cross-correlation coefficients estimated from monthly averaged data showed that SOSE heat and freshwater flux estimates were consistent with the other commonly used flux estimates (NCEP1, ECMWF, LY09).

SOSE

•SOSE estimates of SAMW formation reproduced very well both the density range and the magnitude of obtained from the hydrographic observation. SOSE assimilates oceanic observations (T,S from Argo floats), which helps to obtain an accurate estimate of the isopycnal outcrops, advantage for the this calculation. SOSE provides atmospheric forcing which is dynamically consistent with T and S data.

•Data assimilating ocean models may be a good tool to estimate SO air-sea fluxes since they take advantage of existing oceanic observations. It would be advantages if SOSE would assimilate atmospheric observations.

•SOSE shows insufficient ocean heat loss in the subtropics, it shows too strong ocean heat gain by net SW radiation. Using a more accurate radiative heat flux dataset, such as ISCCP-FD by Zhang et al. (2004), as in e.g. Yu and Weller (2007) and LY09, would like improve SOSE net air-sea heat flux estimate and increase SOSE net ocean heat loss thus bringing it closer to the other net air-sea heat flux estimates considered here.

Which air-sea flux accuracy is needed?

•More complicated than giving a number. This calculation illustrates that it is necessary to have air-sea heat flux estimates which are dynamically consistent with oceanic density fields. In the southern part of the SO density depends on salinity, so for calculation like Walin it would be important to have dynamically consistent air-sea fluxes, SST and Salinity; NWP models do not provide S.

•If 10% error in water mass formation is acceptable, error in air-sea buoyancy heat equivalent fluxes should be lower than 10%. For daily air-sea heat flux would imply an error < 50 W/m^2.

•In SAMW formation region 10% error in air-sea buoyancy heat equivalent fluxes would require even smaller error in individual flux contributions.

Walin analysis: SOSE