Surface fluxes and transports from Global Ocean Reanalyses

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Context

- Part of **the Ocean Reanalysis Intercomparison Project (ORA-IP)** under the GOV and CLIVAR-GSOP *(see Balmaseda et al. 2015 for details).*

- Contributing to **the ESA activity "Towards Improved Estimates of Ocean Heat Flux" (TIE-OHF)** *(PI: A. Bentamy, IFREMER)*

Results

1. M. Valdivieso et al. (2014): **Heat fluxes from ocean and coupled reanalyses.** *CLIVAR Exchanges Issue no. 64, 28-31, February 2014.*
2. M. Valdivieso et al. (2015): **An assessment of air-sea heat fluxes from ocean and coupled reanalyses.** *Climate Dynamics, Special Issue: Ocean Reanalyses, In Press.*

Objectives

- Global heat budgets and the ocean transports implied by ocean reanalysis heat fluxes
- Ensemble consistency of flux variability on seasonal to interannual time scales
- Comparisons with available surface heat flux datasets (primarily ship, satellite, atmospheric reanalysis or hybrid products)
- Documenting errors against in situ flux measurements at a number of OceanSITES moorings

ORA-IP Datasets

	ORA-IP Data Sets	Model	Forcing	Assimilation	Period	Reference
1	BOM PEODAS	MOM2, 2°	ERA40/NCEP-R2	EnKF (T, S, SST)	1980-2012	Yin et al. (2011)
2	ECMWF ORAS4	NEMO, 1°	ERA40/ERAi Flux Forcing	3DVAR (T, S, SLA)	1960-2009	Balmaseda et al. (2013)
3	MRI/JMA MOVEG2	MRI.COM, 1°	CORE.2 with CORE Bulk Fluxes	3DVAR (T, S, SST, SLA)	1948-2007	Fujii et al. (2015)
4	MRI/JMA MOVECORE	MRI.COM, 1°	JRA-25 with Bulk Fluxes	3DVAR (T, S, SST, SLA)	1993-2012	Toyoda et al. (2013)
5	U. Hamburg GECCO2	MIT, 1°	NCEP-R1 with Bulk Fluxes	4DVAR (T, S, SST, SLA)	1948-2010	Köhl (2014)
6	JPL ECCOv4	MIT, 1°	ERAi with CORE Bulk Forcing	4DVAR (T, S, SLA)	1993-2010	Wunsch & Heimbach (2013)
7	NCEP GODAS	MOM3, 1°	NCEP-R2 Flux Forcing	3DVAR (T, SLA)	1980-2011	Behringer (2007)
8	CMCC C-GLORS05v3	NEMO, ½°	ERAi corr + CORE Bulk Forcing	3DVAR (T, S, SST, SLA)	1990-2011	Storto et al. (2014)
9	U. Reading UR025.3	NEMO, ¼°	ERAi with CORE Bulk Forcing	OI (T, S)	1989-2010	Haines et al. (2012)
10	U. Reading UR025.4	NEMO, ¼°	ERAi with CORE Bulk Forcing	OI (T, S, SST, SLA, IC)	1989-2010	Valdivieso et al. (2014)
11	Met Office GloSea5	NEMO, ¼°	ERAi with CORE Bulk Forcing	3DVAR (T, S, SST, SLA)	1993-2010	Blockley et al. (2013)
12	Mercator GLORYS2v1	NEMO, ¼°	ERAi corr + CORE Bulk Forcing	KF (T, S, SST, SLA)	1993-2009	Ferry et al. (2012)
13	Mercator GLORYS2v3	NEMO, ¼°	ERAi corr + CORE Bulk Forcing	KF (T, S, SST, SLA, IC)	1993-2011	Ferry et al. (2012)
14	MRI/JMA MOVE-C	MRI.COM, 1°	Coupled Model Fluxes	3DVAR (T, S, SST, SLA)	1993-2011	Fujii et al. (2009)
15	NCEP CSFR	CSFRv2/MOM4, ½°	Coupled Model Fluxes	3DVAR (T)	1980-2011	Xue et al. (2011)
16	GFDL ECDA	CM2.1/MOM4, 1°	Coupled Model Fluxes	EnKF (T, S, SST)	1993-2011	Chang et al. (2013)

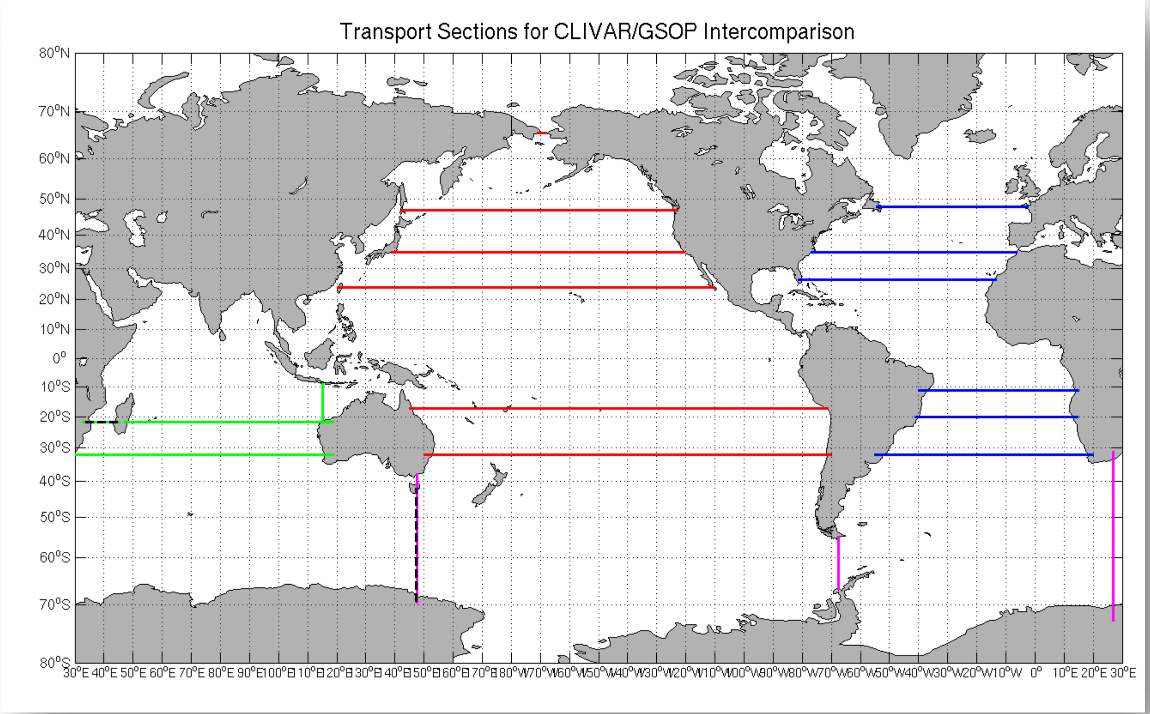
Low Resolution (1–7); My Ocean (8–13); Coupled (14–16)

- **Most reanalyses are forced with bulk formula using an atmospheric reanalysis product**

CLIVAR/GSOP Intercomparison of Ocean Reanalysis Transports

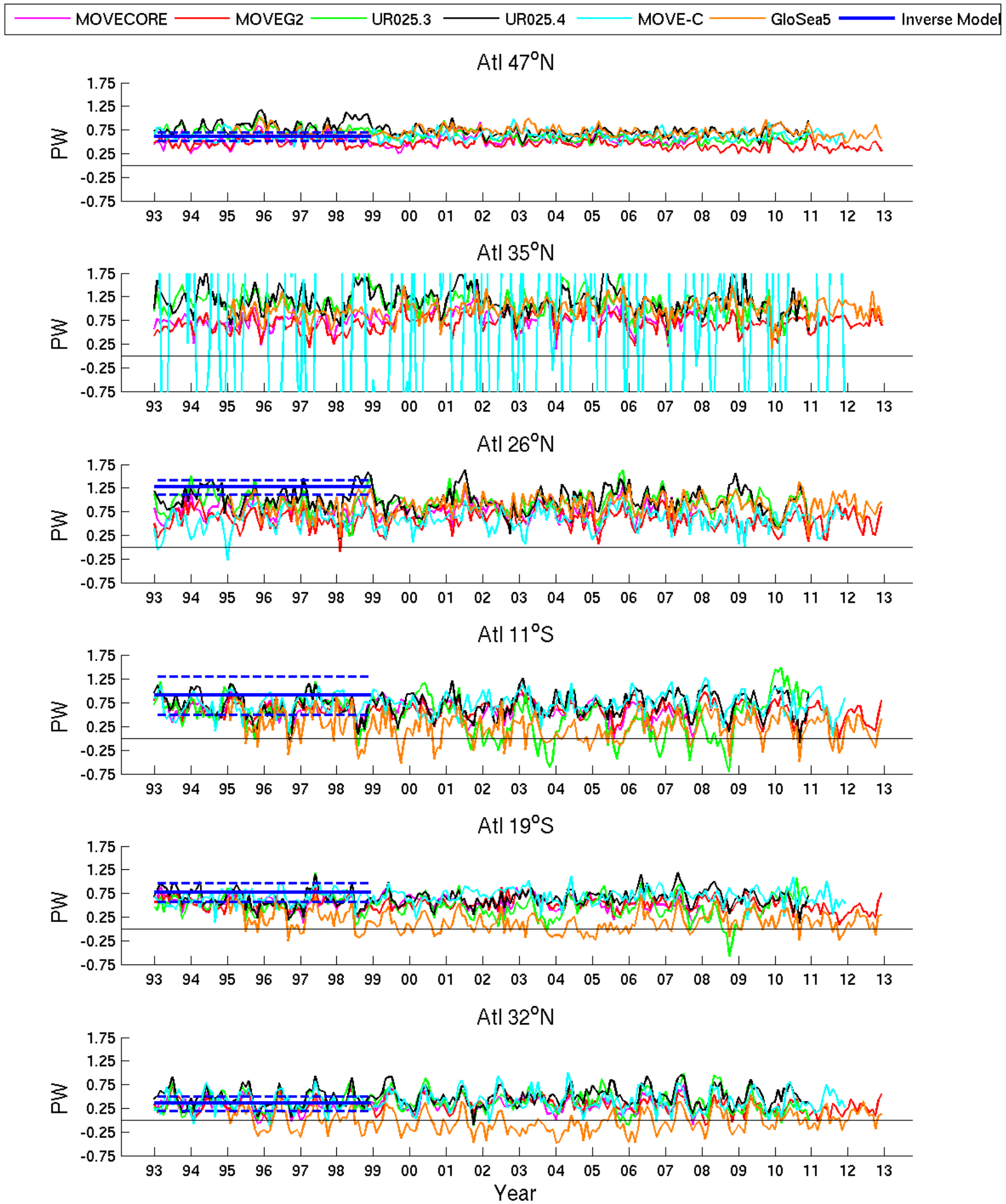
Maria Valdivieso and Keith Haines – U. Reading, UK

- Horizontal, depth-integrated transports (volume, heat and salt) by basin
- Ht transports only included. Freshwater also done
- Divergences v surface fluxes underway

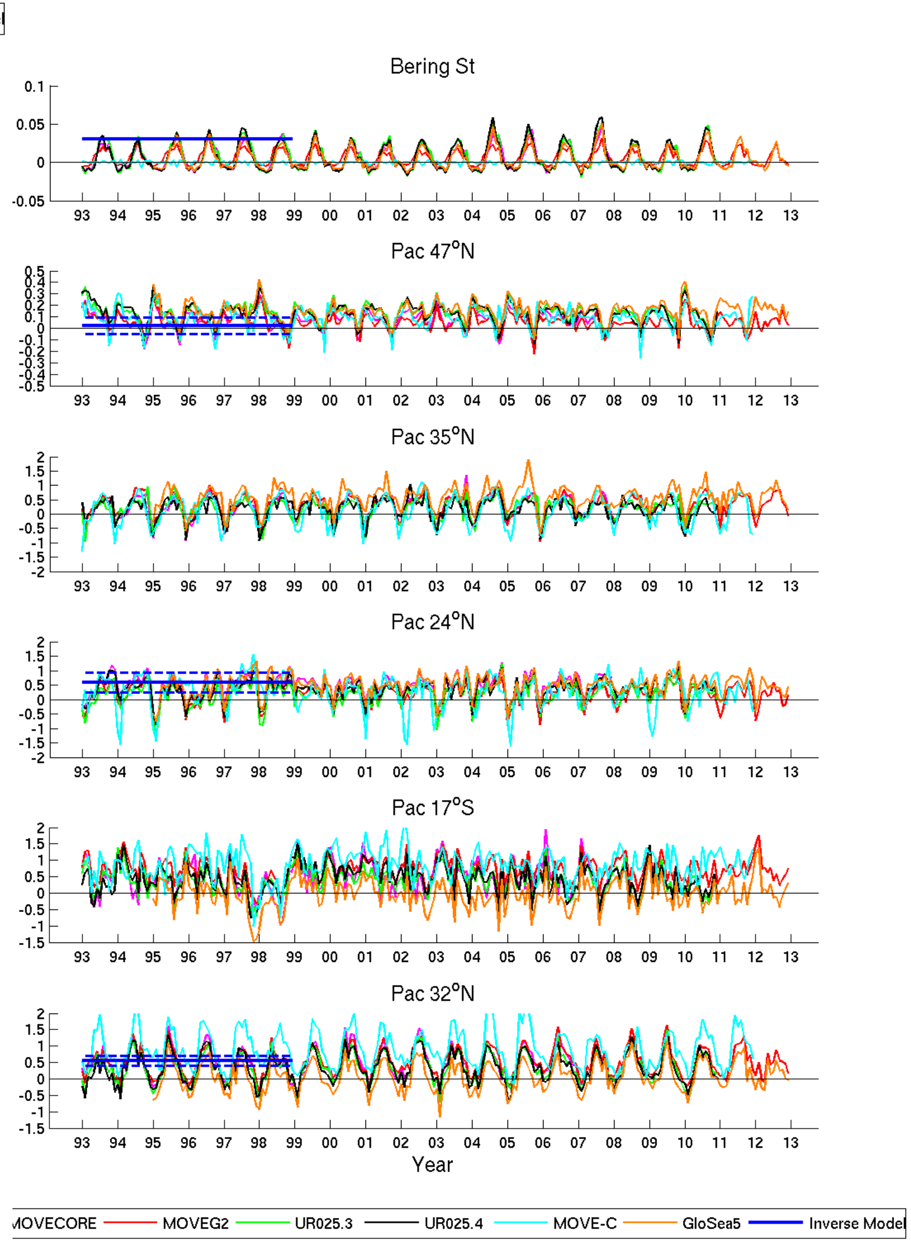


Meridional heat transports by basin

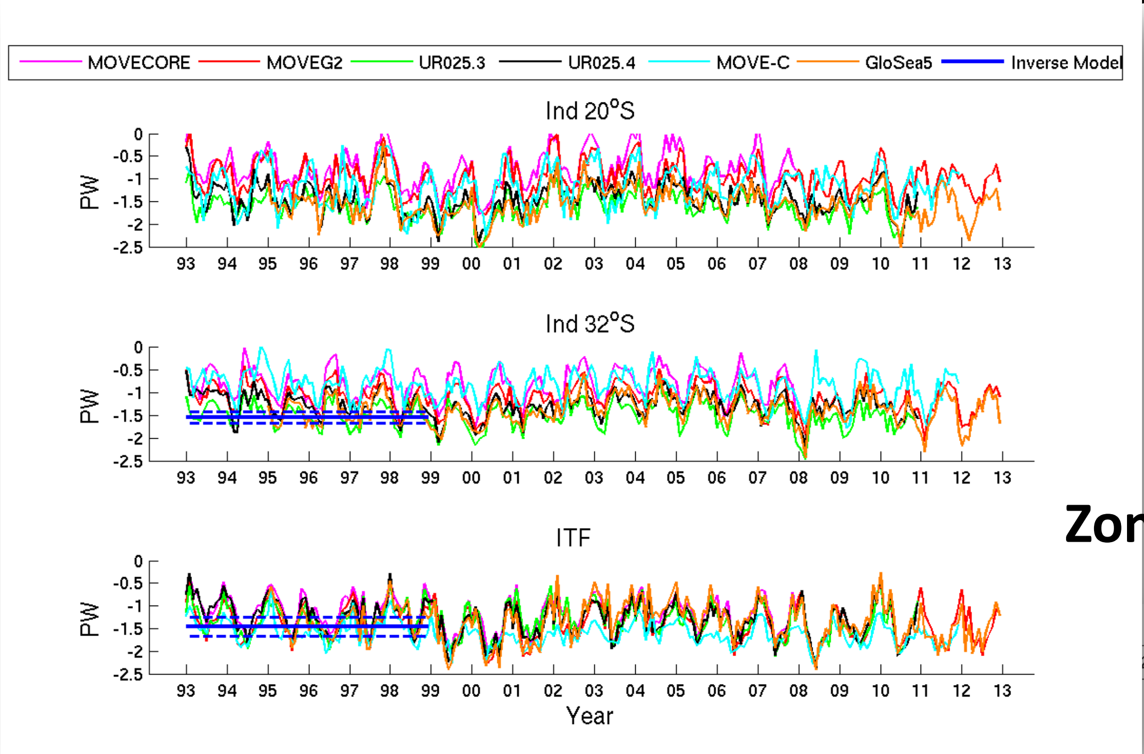
Atlantic



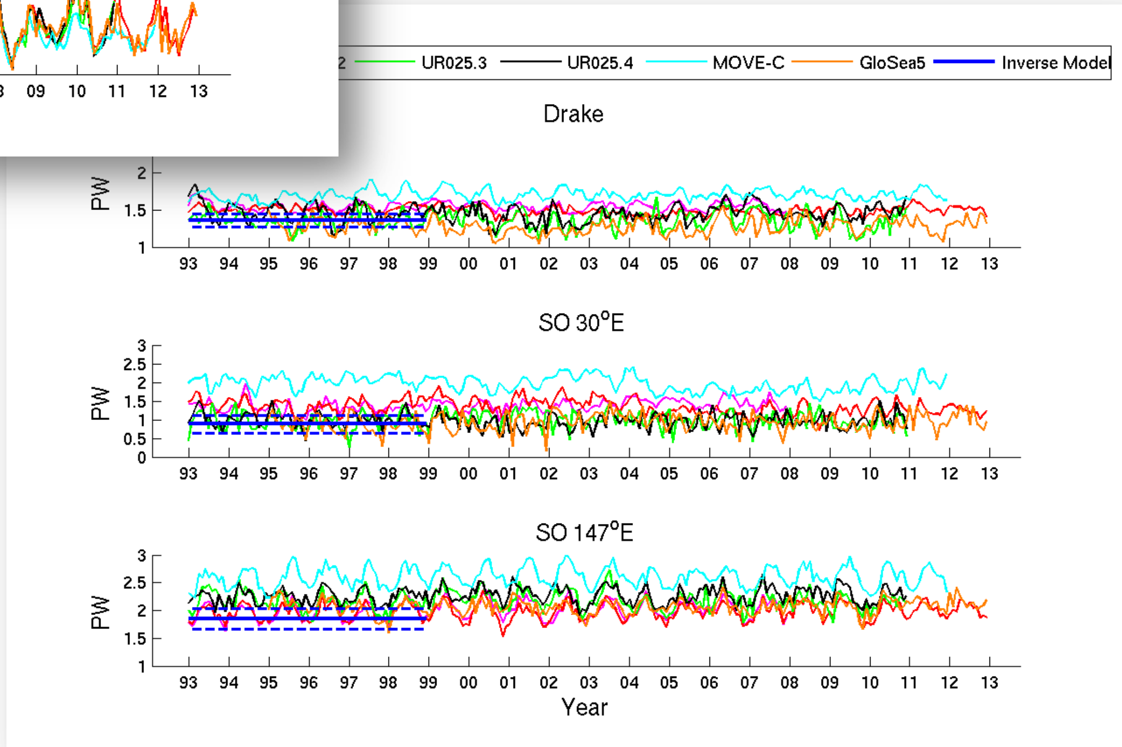
Pacific



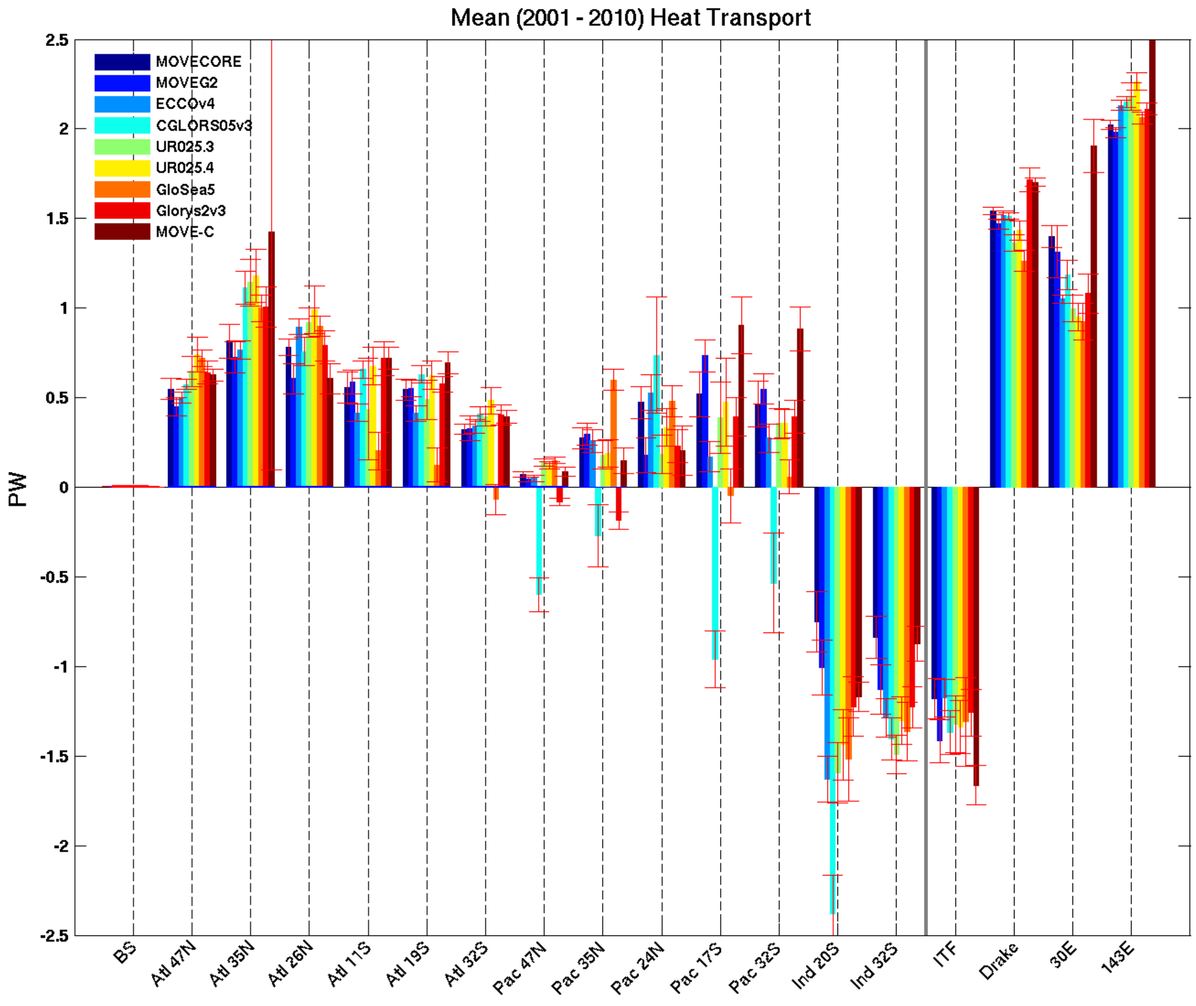
Heat transports (cont.)



Zonal sections at "chokepoints" of the ACC



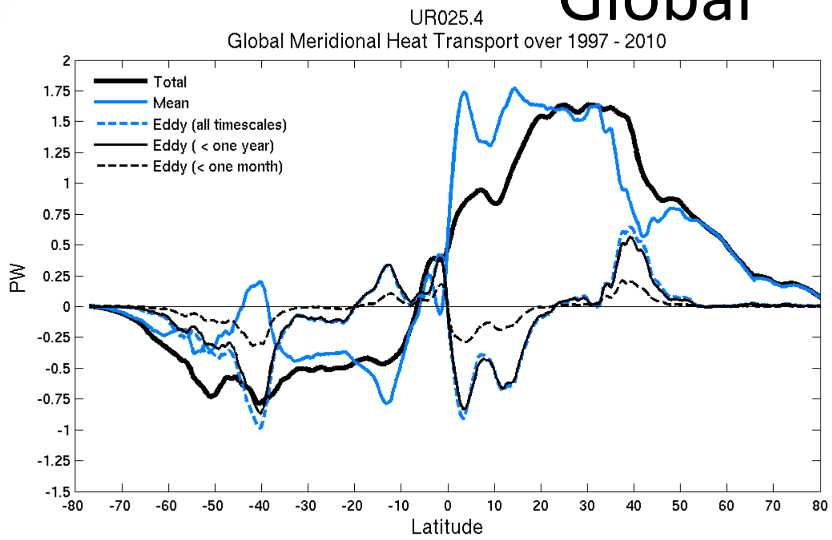
Time-mean (2001-10) heat transport estimates from ocean reanalyses



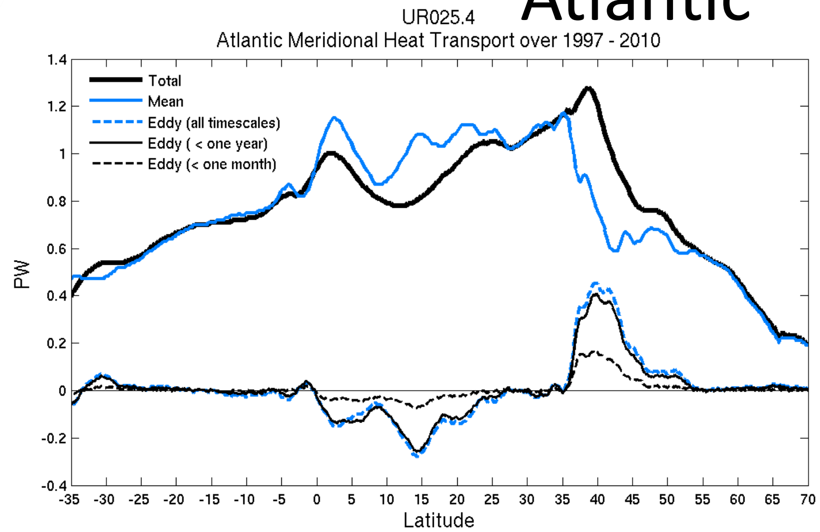
Error bars representing the STD of the annual mean estimates over the years 2001-2010

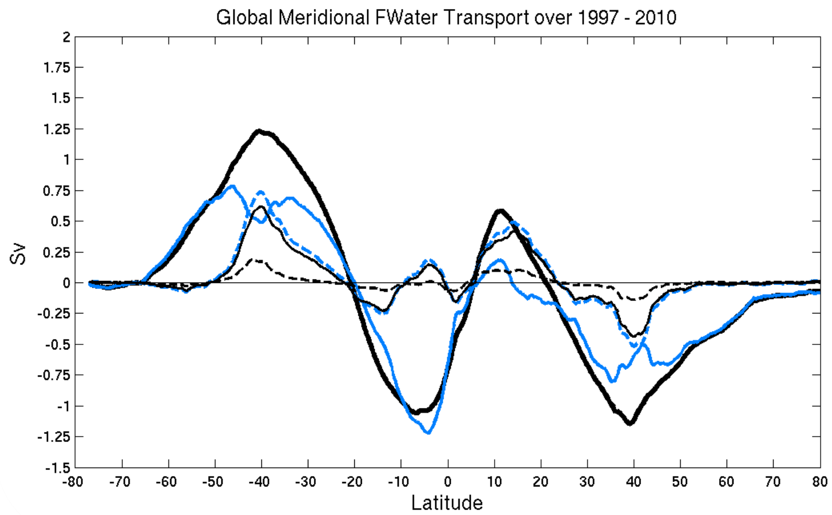
MHT and MFWT (>0, northward)

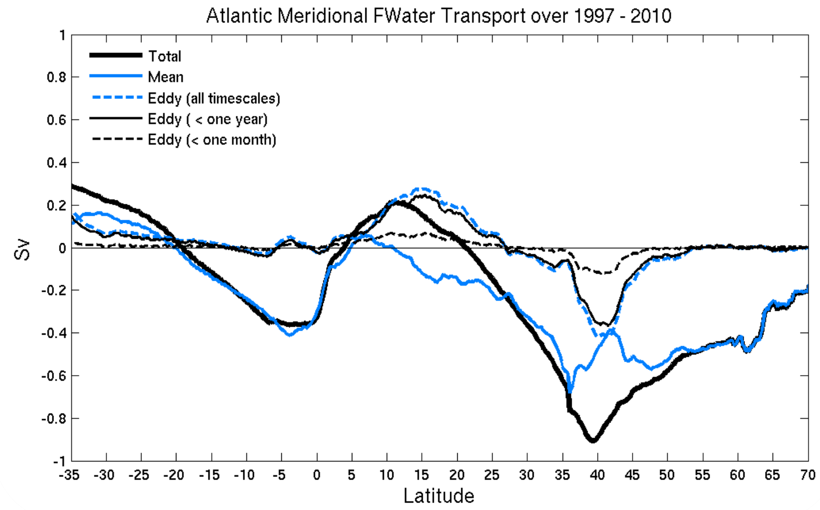
Global



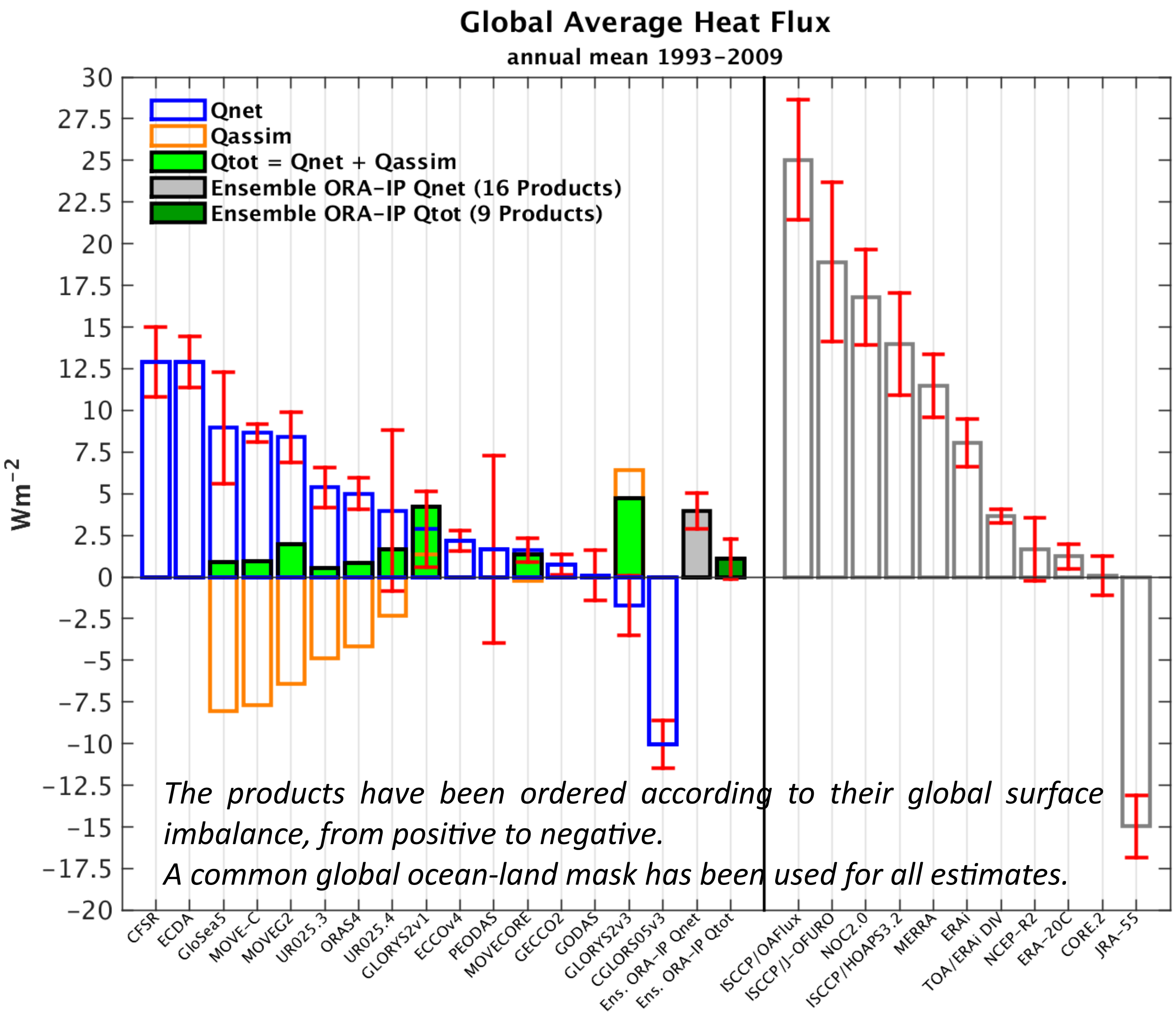
Atlantic





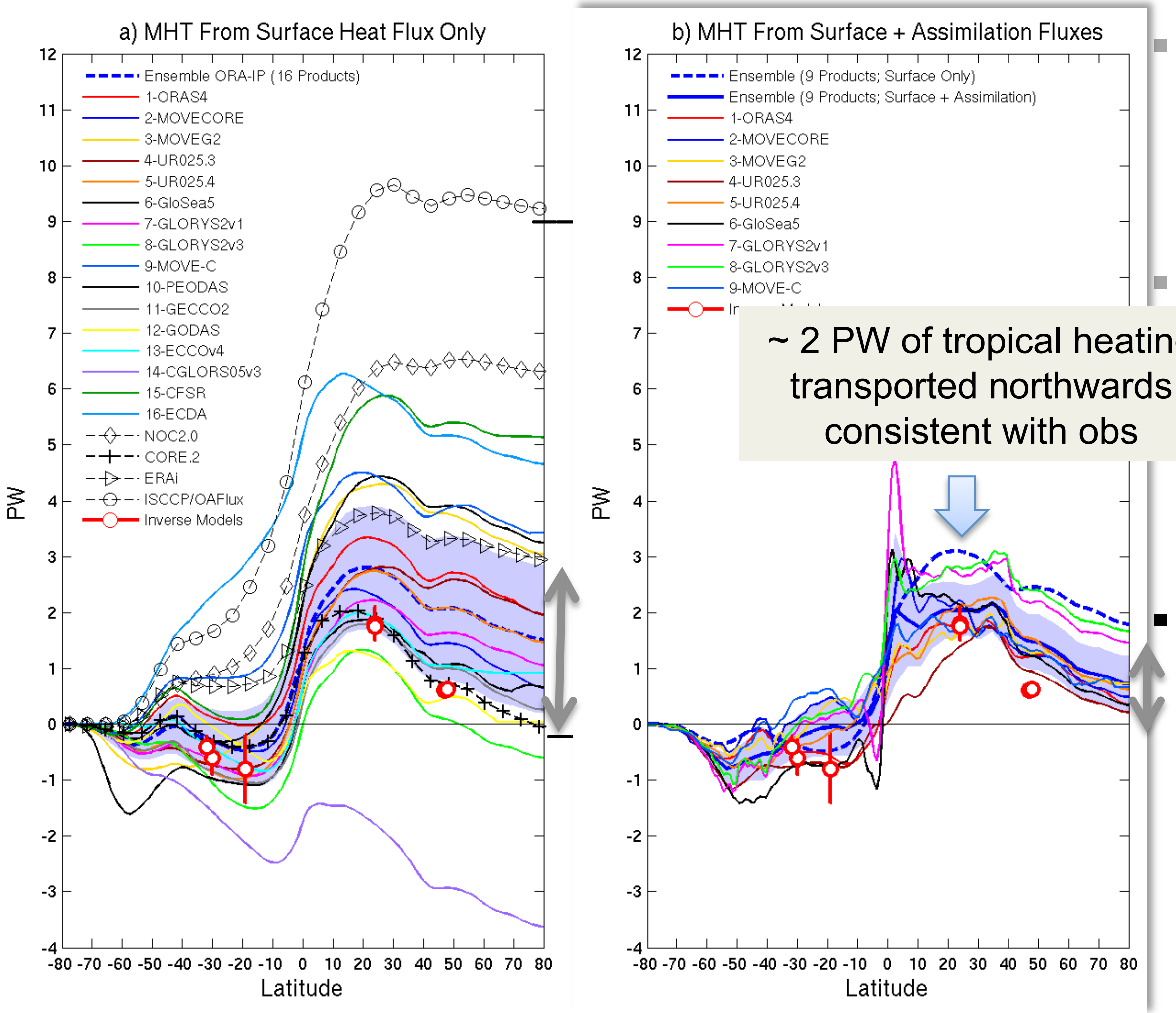


Global Heat Budget



- Most ORA-IP surface fluxes (blue bars) have global positive biases (i.e., net heat flux into the ocean) over 1993–2009
- The 16-member ensemble mean ~4 Wm^{-2} (grey bar)
- Interannual variability ~1 Wm^{-2} related to ENSO (red error bars)
- Assimilation of ocean observations removes heat from the ocean on a global basis (orange bars)
- Total heat flux applied (surface fluxes + assimilation sources) are reduced to small positive imbalances, typically ~1-2 Wm^{-2} (green bars)
- These are generally smaller than for observational-based products – ***Bulk Formulae estimates applied to ship/satellite obs have typical overall bias in the range +15-25 Wm^{-2}***

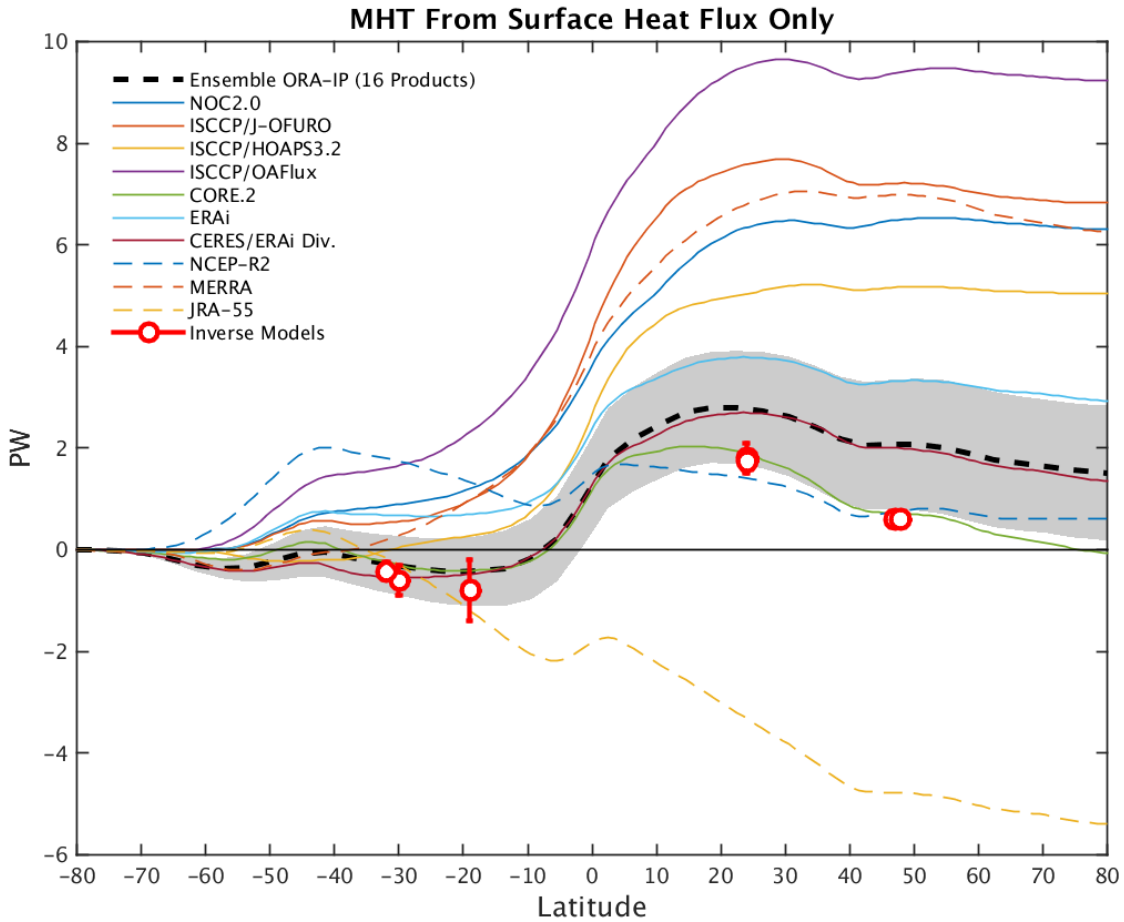
Implied Ocean Heat Transports



Global meridional net surface heat transport inferred from integrated heat fluxes, starting in the south (i.e., the Antarctic continent) in comparison with WOCE-based inverse model estimates at control sections from Ganachaud and Wunsch (2003) and Lumpkin and Speer (2007)

- Global surface imbalances have large implications for balancing heat transports (discrepancies in the north up to + 9 PW)
- The ensemble spread in ORA-IP (shaded around the mean) grows rapidly in the SO and crossing the tropics → largest uncertainties in net surface heat fluxes occurs in the SO and in the tropics.
- Better agreement in the implied MHT with obs at various sections by combining **'Surface + Assimilation'** fluxes, but not in the tropics *(due to lack of a pressure gradient bias correction in some of the DA systems; see Bell et al. 2004 for details).*

Global MHT



The ensemble of 16 ORA-IP products in comparison with other additional products .

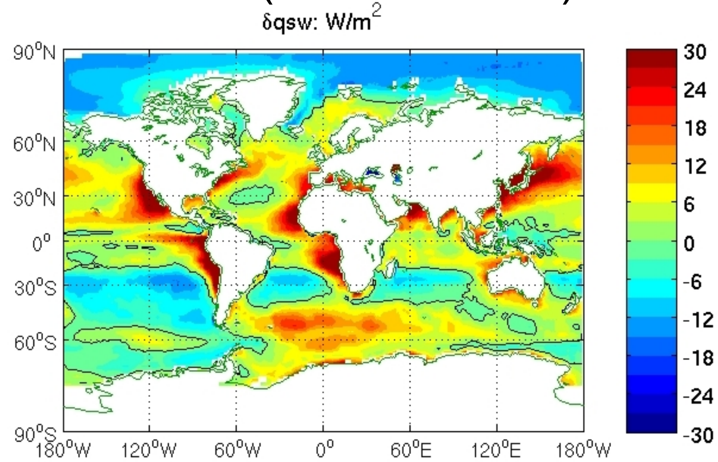
Role of Assimilation and Assimilation increments

i) Closing Reanalysis heat budgets
ii) Detecting process errors

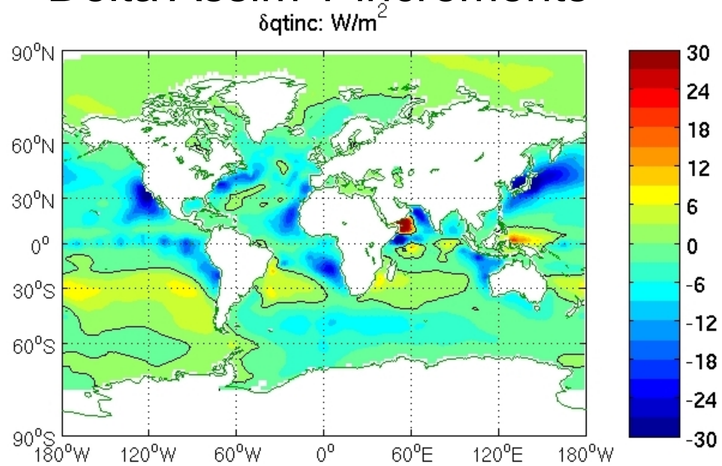
Ocean Reanalysis Twin Expt.

- Global NEMO 1° Ocean Assim and ERA-Interim Met 1989-2007
- 2 identical Assim runs with a small change in the SW radiation
- Ocean Assimilation controls
  - Ocean Advection of Ht.
  - SST and hence q_{LAT}, q_{SEN}, q_{LW}
  - Should be ~same in both runs
- Change in the SW can then be recovered from the change to **assimilation increments**
- **Demonstrates principle that Ocean data assimilation can give forcing error information without 4DVar approach**
- Assim increments do contain information on real heat flux errors which will show up on larger scales.
- Similarly with freshwater budget and S assimilation especially Argo

Delta SW (Interim-DFS4)

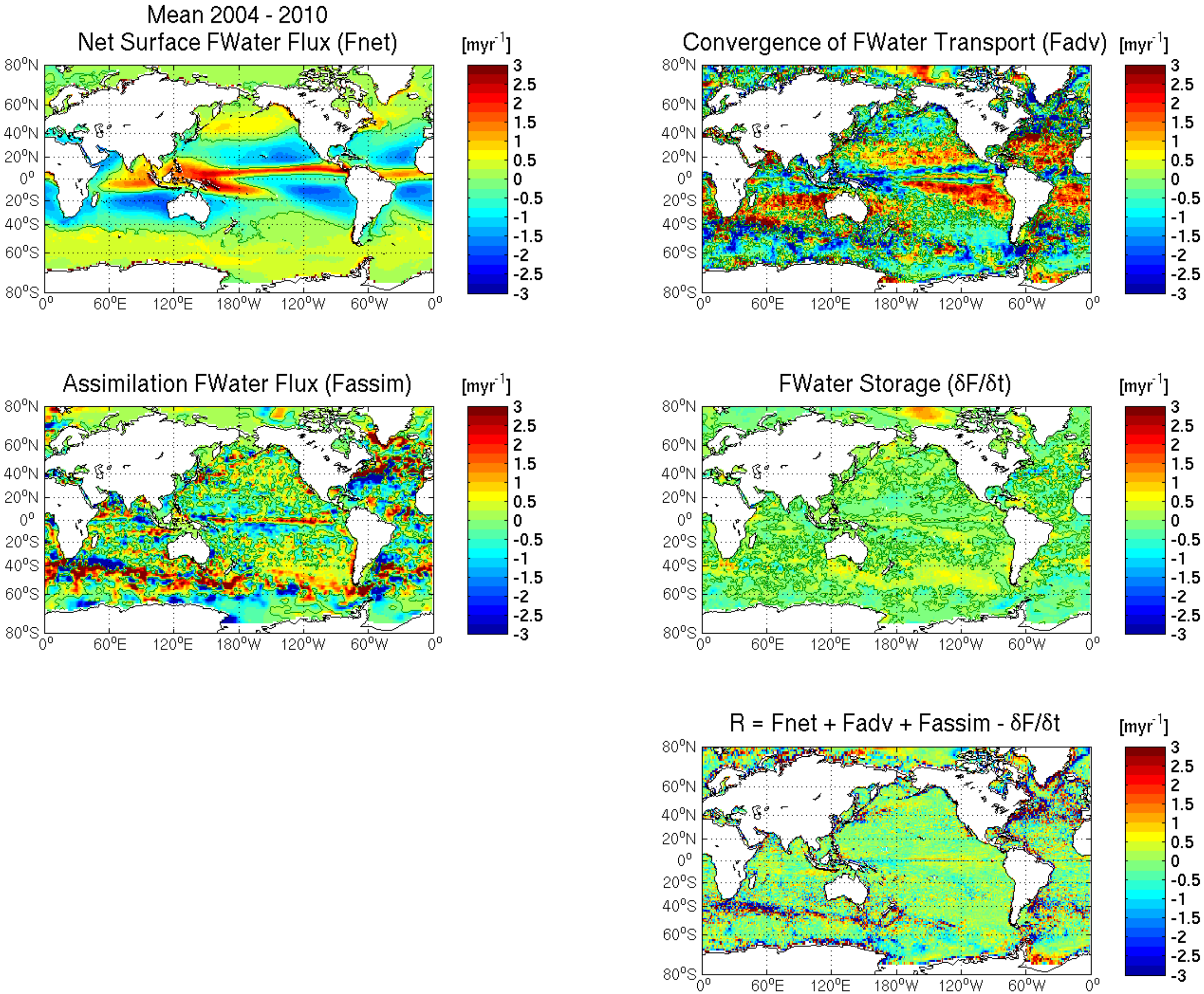


Delta Assim T increments

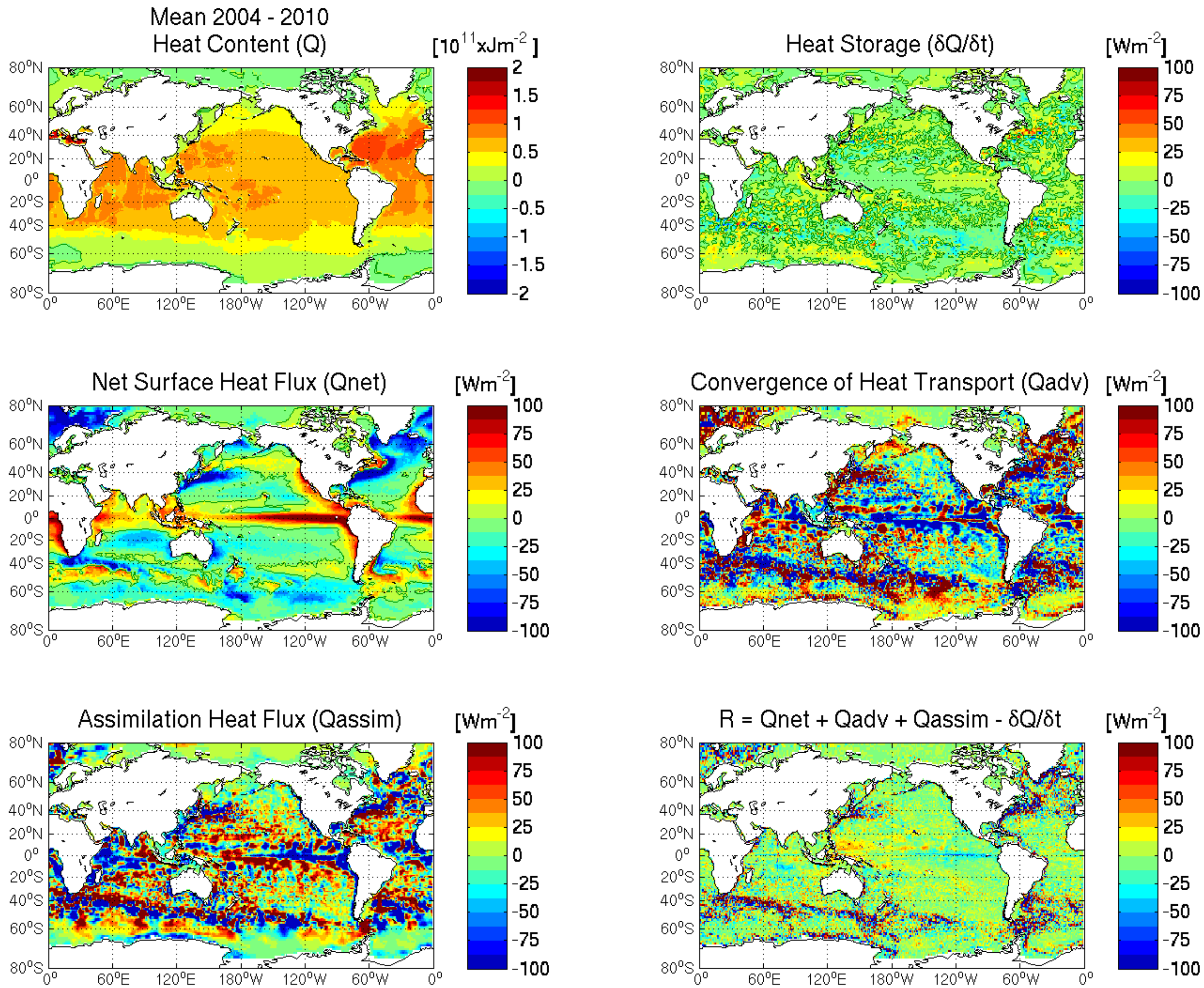


NCEO fellow Maria Valdivieso

Regional FW budget 2004 - 2010



Regional Heat budget 2004 - 2010

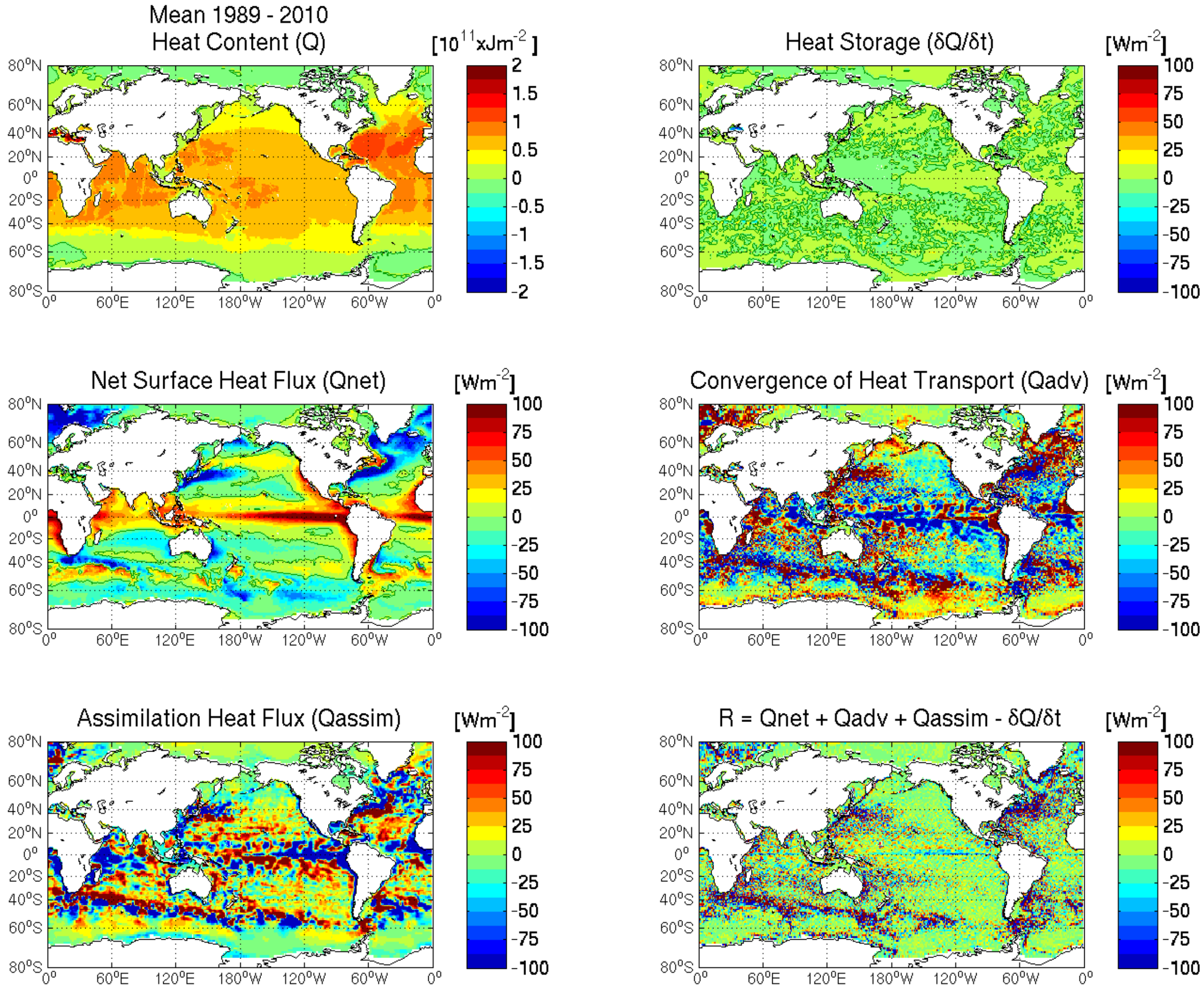


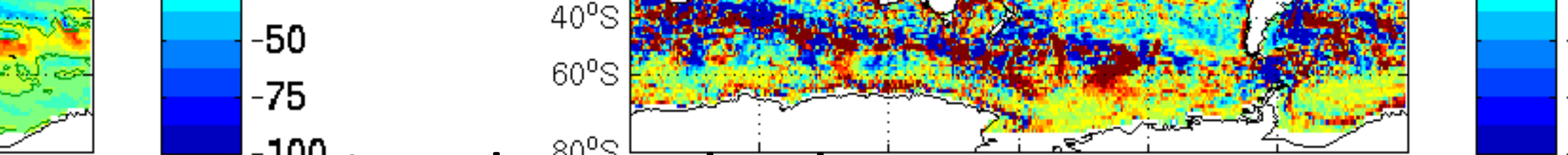
Further work

- Evaluate Reanalysis transports
  - Should be better than model only products
  - Role of assimilation in correcting transports
- Regional heat budget analyses (Cages)
  - Can assimilation increments be understood as corrections to surface fluxes?

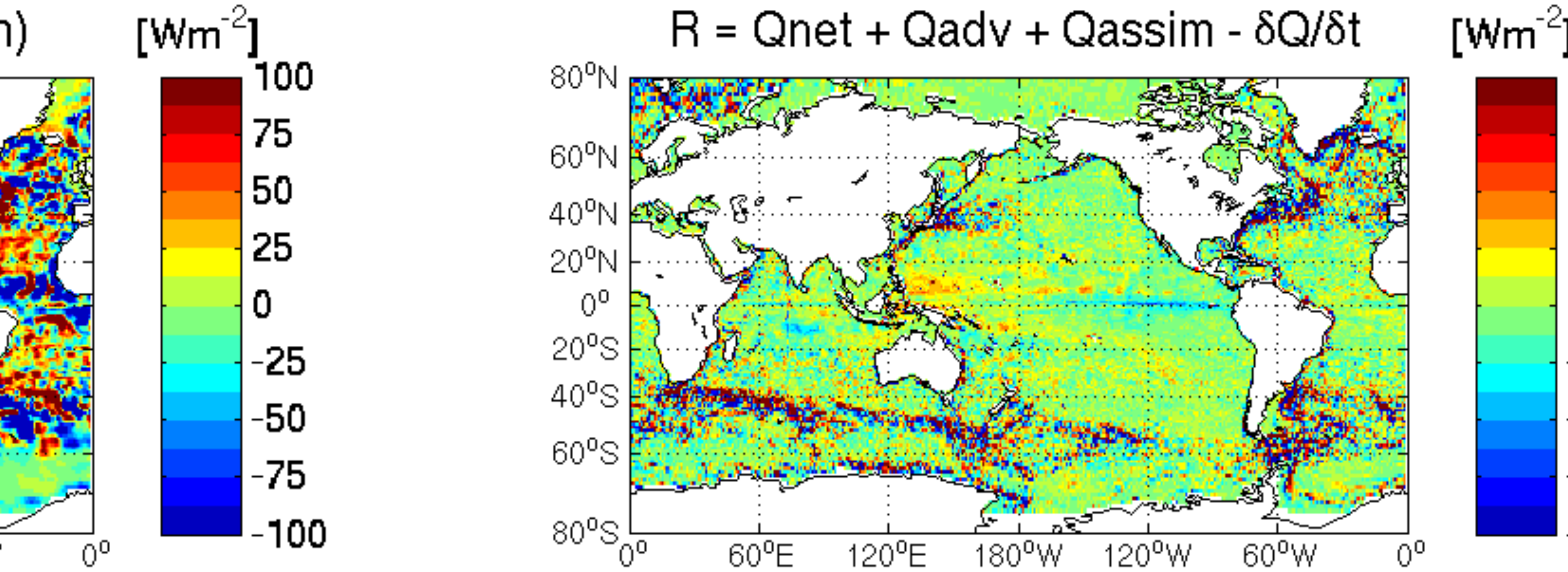
Finish

Regional Heat budget 1989 - 2010





Regional Heat budget 2004 - 2010

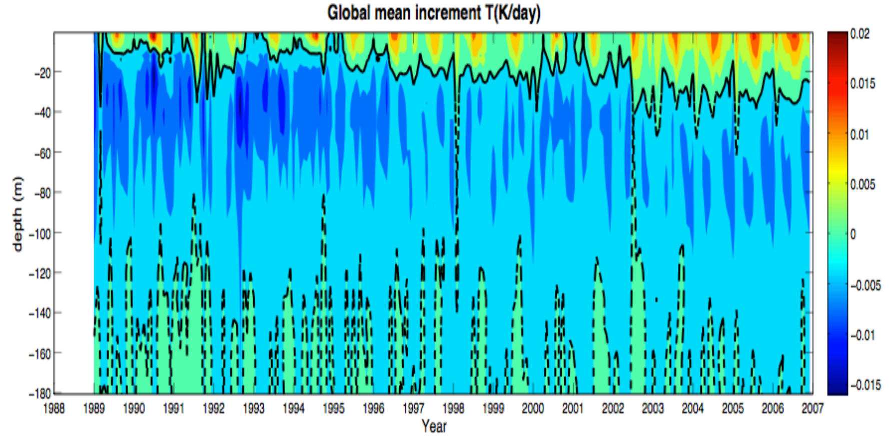


Assimilation increments near surface (Product UR025.4)

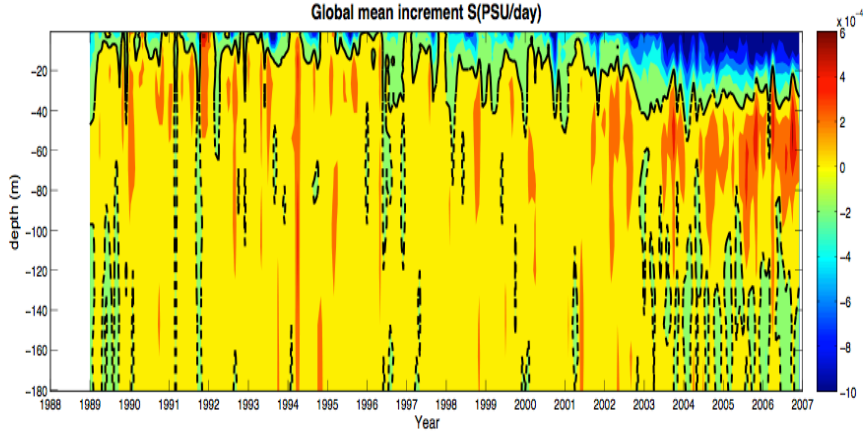
Increments show seasonal mixing errors
Top 30m always warmed, 30- 120m always cooled

Assimilation maintaining near surface thermocline against mixing

Global mean temperature increment (*K/day*)



Global mean Salinity increment (*PSU/day*)



Other Surface Heat Flux Data

Type	Data Sets	Resolution	Period	Reference
Ship-Based	NOC2.0	Monthly, 1°	1973-2009	Berry and Kent (2009)
Satellite-Based	CERES	Monthly, 1°	2000-	Loeb et al. (2009)
	ISCCP-FD	3 Hourly, 2.5°	1984-2009	Zhang et al. (2004)
	J-OFURO	Daily, 1°	1988-2008	Kubota et al. (2002)
	HOAPS	Monthly, 0.5°	1987-2008	Andersson et al. (2010)
NWP	ERA-Interim	6 Hourly, T255	1979-	Dee et al. (2011)
	JRA-55	Daily, 1.25°	1958-	Kobayashi et al. (2015)
	MERRA	Hourly, 0.5°	1979-	Rienecker et al. (2011)
	NCEP-R2	Hourly, T62	1979-	Kanamitsu et al. (2005)
Hybrid	CORE.2	Monthly, 1°	1948-2006	Large and Yeager (2009)
	TOA CERES/ERAi Divergence	Monthly, 1°	1984-	Liu et al. (2015)
	OAFlux	Daily, 1°	1983-	Yu et al. (2008)
Buoy	TAO/TRITON	Daily, Tropical Pac.	2007-09	McPhaden et al. (1998)
	RAMA	Daily, 15°N90°E	2007	McPhaden et al. (2009)
	PIRATA	Daily, Tropical Atl.	2007-09	Servain et al. (1998)
	WHOI Stratus	Daily, 20°S85°W	2001-09	Weller et al. (2015)

The ORA-IP heat flux products are compared with other global air-sea heat flux data based on **ship observations, satellite data, atmospheric reanalyses, or hybrid products** (a combination of atmospheric reanalysis and remote sensing products), and locally, with **buoy flux data** measured at moorings (limited in both time and space) – *details in Valdivieso et al. (2014, 2015).*