Fidelity in the present-day simulation and projected changes to the Southern Hemisphere extratropical ocean/sea-ice system in the AR4 coupled climate models

Alexander **Sen Gupta**, Agus Santoso, Andrea Taschetto, Caroline Ummenhofer and Matthew H. England

Climate Change Research Centre

Faculty of Science, University of New South Wales, Sydney, NSW 2052, Australia

E-mail: *a.sengupta@unsw.edu.au*

CMIP3 Coupled Models from IPCC - AR4 Project

Model	Institution, Country	Oceanic Model	Oceanic Resolution	Vertical Coord	Mixing Parameterization	Flux Correction
BCCR BCM2.0	Norway	MICOM2.8	1.5°x1.5°(0.5°) L35	RHO	KT, KPP	none
CGCM3 T47	Canadian Centre for Climate Modeling & Analysis, Canada	MOM1.1	1.85°x1.85° L29	Z	GM, EVD	heat & freshwater
CGCM3 T63	Canadian Centre for Climate Modeling & Analysis, Canada	MOM1.1	1.85°x1.85° L29	Z	GM, EVD	heat & freshwater
CNRM CM3	Météo-France/Centre National de Recherches Météorologiques, France	OPA8.1	2°(0.5°)x2° L31	Z	GM, TKE	none
CSIRO Mk3.0	CSIRO Atmospheric Research, Australia	MOM2.2	0.84°x1.875° L31	Z	GM*, BL, PP	none
CSIRO Mk3.5	CSIRO Atmospheric Research, Australia	MOM2.2	0.84°x1.875° L31	Z	GM*, BL, PP, V, KT	none
GFDL CM2.0	U.S. Dept. of Commerce/NOAA/ Geophysical Fluid Dynamics Laboratory, USA	OM3P4	1°(1/3°) x1° L50	Z	GM*, BL, BBL-BD, KPP	none
GFDL CM2.1	U.S. Dept. of Commerce/NOAA/ Geophysical Fluid Dynamics Laboratory, USA	OM3.1P4	1°(1/3°) x1° L50	Z	GM*, BL, BBL-BD, KPP	none
GISS AOM	NASA/Goddard Institute for Space Studies, USA	AOM	3°x4° L16	S	KPP	none
GISS-EH	NASA/Goddard Institute for Space Studies, USA	HYCOM	2°x2° L16	H	KT	none
GISS-ER	NASA/Goddard Institute for Space Studies, USA	Russell et al (1995)	4°x5° L13	Z-M	GM*, KPP	none
IAP FGOALS	LASG/Institute of Atmospheric Physics, China	LICOM1.0	1°x1° L33	ETA	GM, PP	none
INGV ECHAM4	National Institute of Geophysics and Volcanology, Italy	OPA8.2	2°x2°(1°) L31	Z	BBL-BD, TKE	none
INM CM3.0	Institute for Numerical Mathematics, Russia	INMCM3	2°x2.5° L33	S	PP	water flux
IPSL CM4	Institut Pierre Simon Laplace, France	OPA	2°x2° (1°) L31	Z	GM, BBL-BD, EVD, TKE	none
MIROC Hires	(JAMSTEC) Japan	COCO3.3	0.19°x0.28° L47	H	GM, NK, BBL-NS, EVD	none
MIROC Medres	(JAMSTEC) Japan	COCO3.3	1.4°(0.5°) x1.4° L43	H	GM, NK, BBL-NS, EVD	none
MIUB ECHO-G	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model & Data Group, Germany/Korea	HOPE-G	2.8°x2.8° (0.5°) L20	Z	PP, EVD	heat, water
MPI ECHAM5	Max Planck Institute for Meteorology, Germany	MPI-OM	1.5°x1.5° L40	Z	GM*, PP, BBL-BD	none
MRI CGCM2.3	Meteorological Research Institute, Japan	Bryan-Cox	2.0°(0.5°)x2.5° L23	Z	GM	heat, freshwater, momentum
NCAR CCSM3	National Center of Atmospheric Research, USA	POP	1.1°(0.27°)x1.1° L40	Z	GM, KPP, NO-BBL	none
NCAR PCM1	National Center of Atmospheric Research, USA	POP	2/3°(0.5°)x2/3° L32	Z	GM, KPP, NO-BBL	none
UKMet HadCM3	Hadley Centre for Climate Prediction and Research/Met Office, UK	Bryan-Cox	1.25°x1.25° L20	Z	GM*, V, KT, PP	none
UKMet HadGem1	Hadley Centre for Climate Prediction and Research/Met Office, UK	Bryan-Cox	1°(1/3°) x1° L40	Z	GM*, V, KT, PP	none

***Vertical Coordinate**: Ocean: **Z** denotes that the vertical coordinate is depth, **P** that it is pressure, **M** that it is mass per unit area (~ pressure under constant gravity), **ETA** that it is a topography-weighted depth (cf. Mesinger and Janjic 1975), and **RHO** that it is density (i.e., isopycnal coordinates), S – sigma, H – hybrid (S+Z). Atmosphere: S is sigma, P is pressure, S-P is hybrid sigma-pressure, S-M is hybrid sigma-mass.*

Parameterization:

GM: Eddy-induced transport via Gent and McWilliams (1990) scheme

GM: Adiabatic eddy-induced transport via the Griffies (1998) implementation of the Gent and McWilliams (1990) scheme.*

BL: Vertical mixing of tracers by Bryan and Lewis (1979) – constant mixing coefficients everywhere.

PP: Richardson number–dependent scheme of Pacanowski and Philander (1981) for vertical eddy viscosity and diffusion

NK: Noh and Kim (1999) parameterisation for vertical diffusion and viscosity with Richardson number dependence.

EVD: Enhanced vertical diffusion in the presence of static instability to parameterize convective mixing.

TKE: TKE scheme (Blanke and Delecluse,1993)

V: Visbeck et al. (1997) scheme to control the strength of the ocean eddy-induced transport coefficient κ.

KT: Kraus-Turner used for mixing due to wind-generated turbulent kinetic energy.

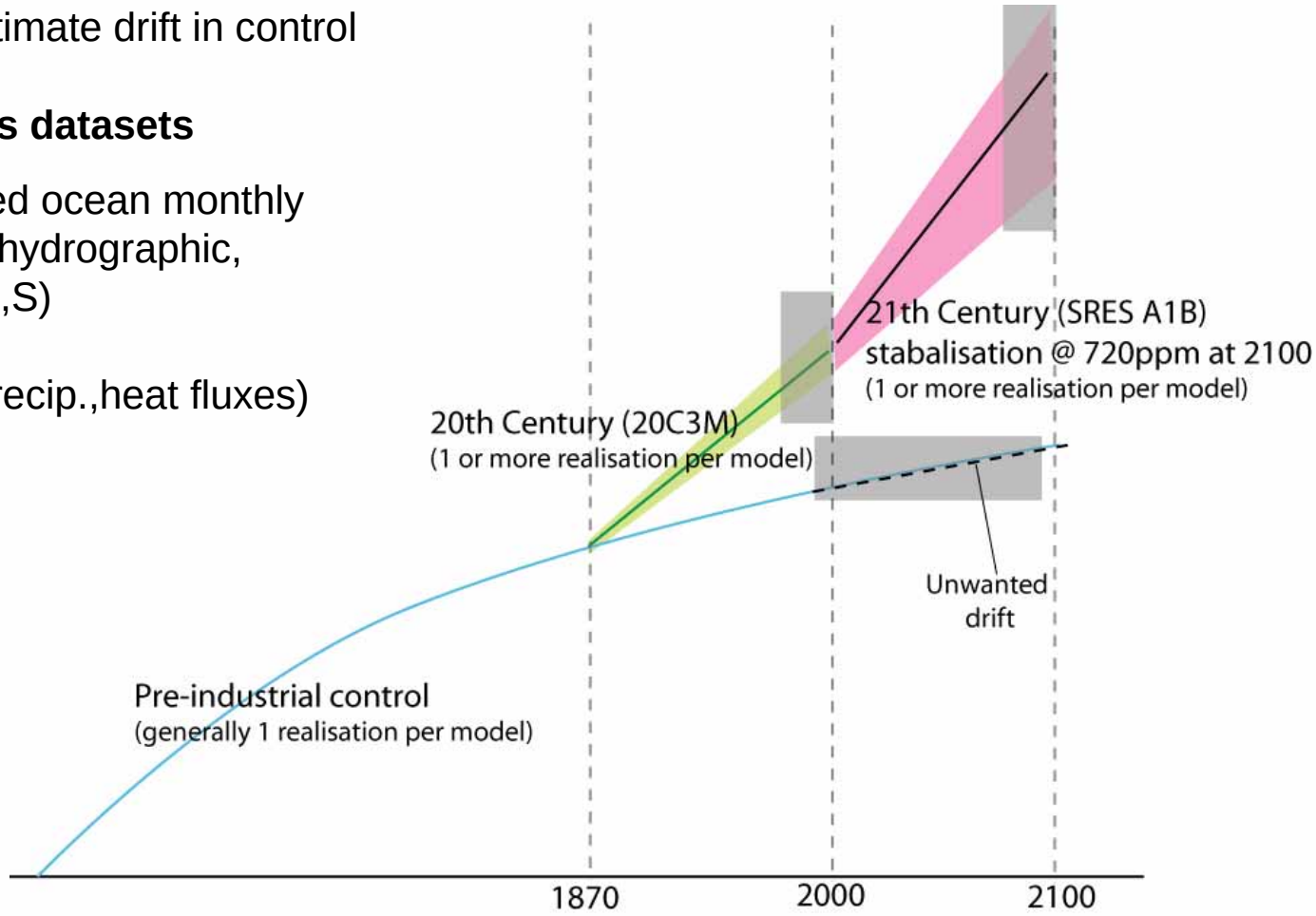
KPP: KPP scheme for mixed-layer treatment. Large et al., (1994)

Model Data (*www-pcmdi.llnl.gov/projects/cmip/)*

All available realisations for the different models are considered
Use is made of pre-industrial, 20th century and SRES A1B integrations
(SRES A1B – contain the largest number of relevant variables for the most models)
Comparison with observation uses end of 20C
Differences are calculated based on the last 10 years of the 20th and 21st centuries
Full 100yrs are used to estimate drift in control

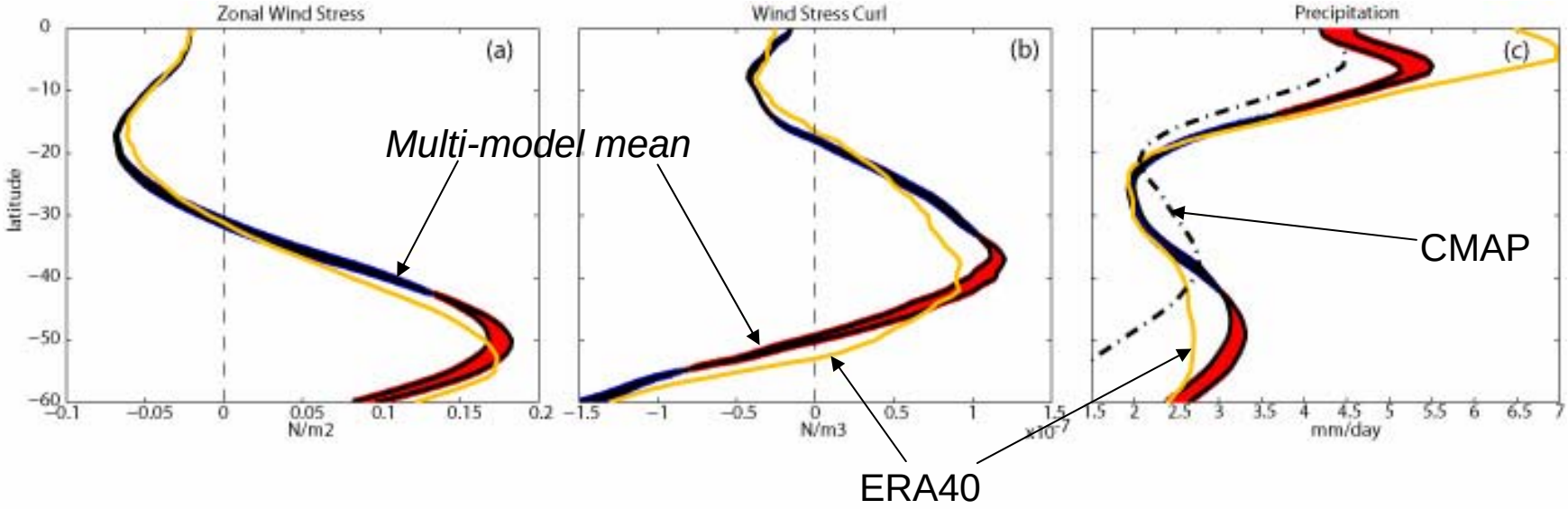
Observational/Reanalysis datasets

- CARS 2006 – SH gridded ocean monthly climatology based on all hydrographic, satellite & ARGO data (T,S)
- SODA (ocean u,v)
- ECMWF-ERA40 (tau, precip.,heat fluxes)
- CMAP (precip.)
- SOC (heat fluxes)
- HadISST (sea-ice)



Ocean Forcing

Multi-model mean for zonally averaged surface fields. Red (blue) indicates a positive (negative) change over 21st century. Black or yellow line shows observed long-term-mean. Yellow – ERA40, dashed precip: CMAP

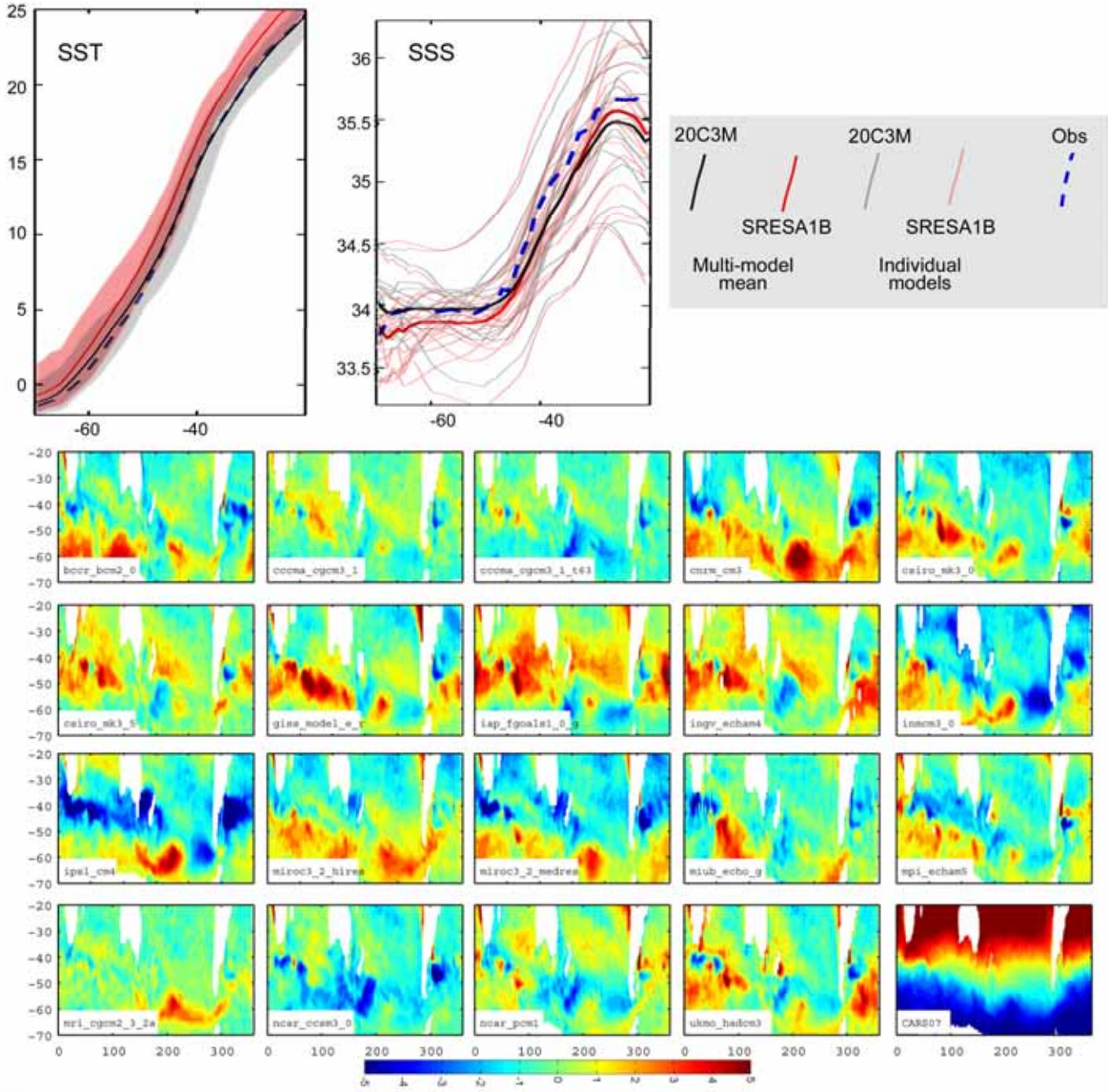


- Maximum wind stress generally farther north and weaker than observed
- 21C – shifts southwards and intensifies
- Maximum wind stress curl farther north and stronger than observed
- 21C – shifts southwards and intensifies
- Large biases in hydrological cycle
- 21C –cycle intensifies

SST (and SSS) Bias

Zonal multi-model mean SST & SSS

Difference between 20C3M model mean and observations (Bottom left – observed mean field)

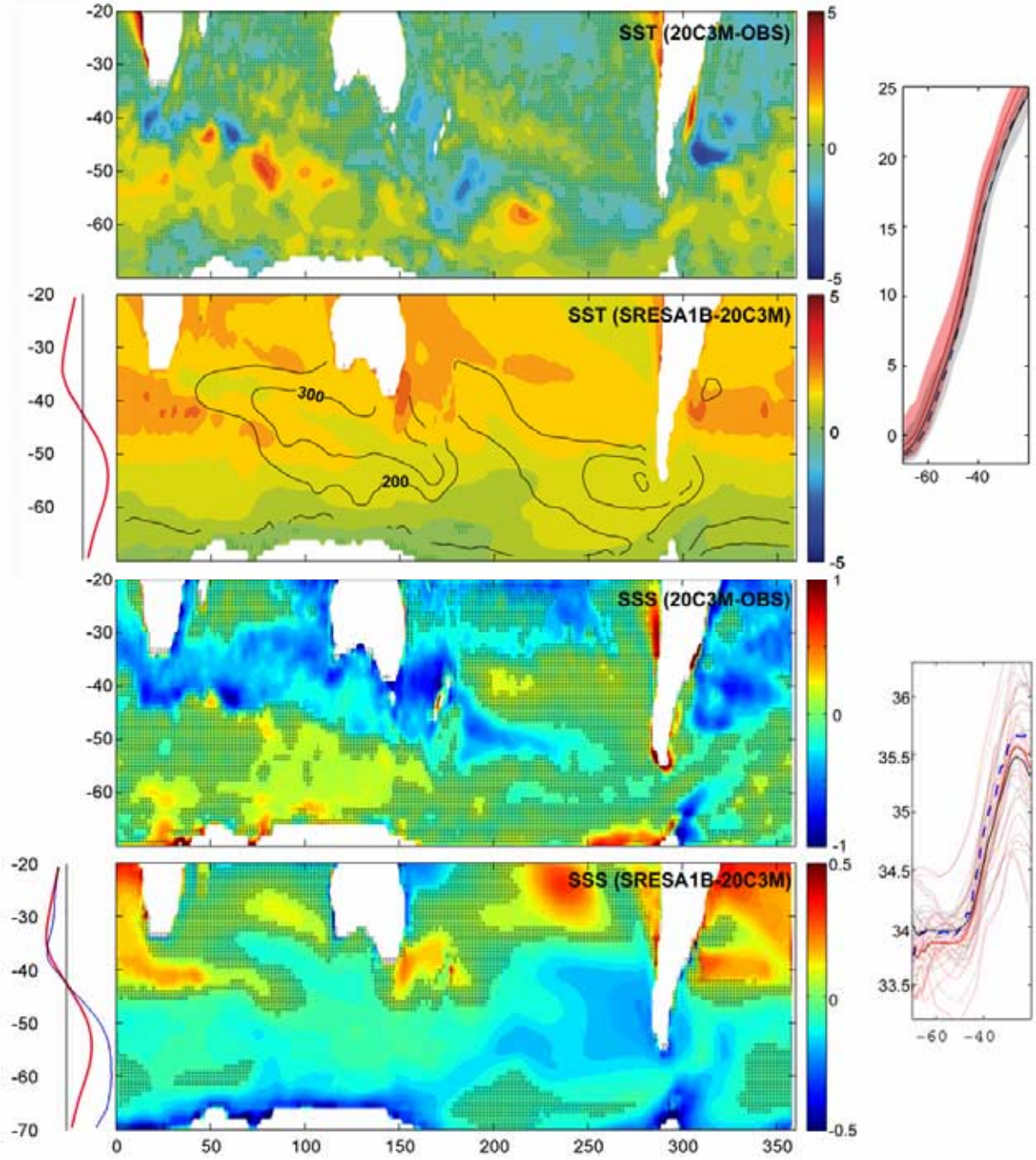


SST / SSS Multi-Model Bias and Change

SST & SSS changes modulated by change in Ekman transport

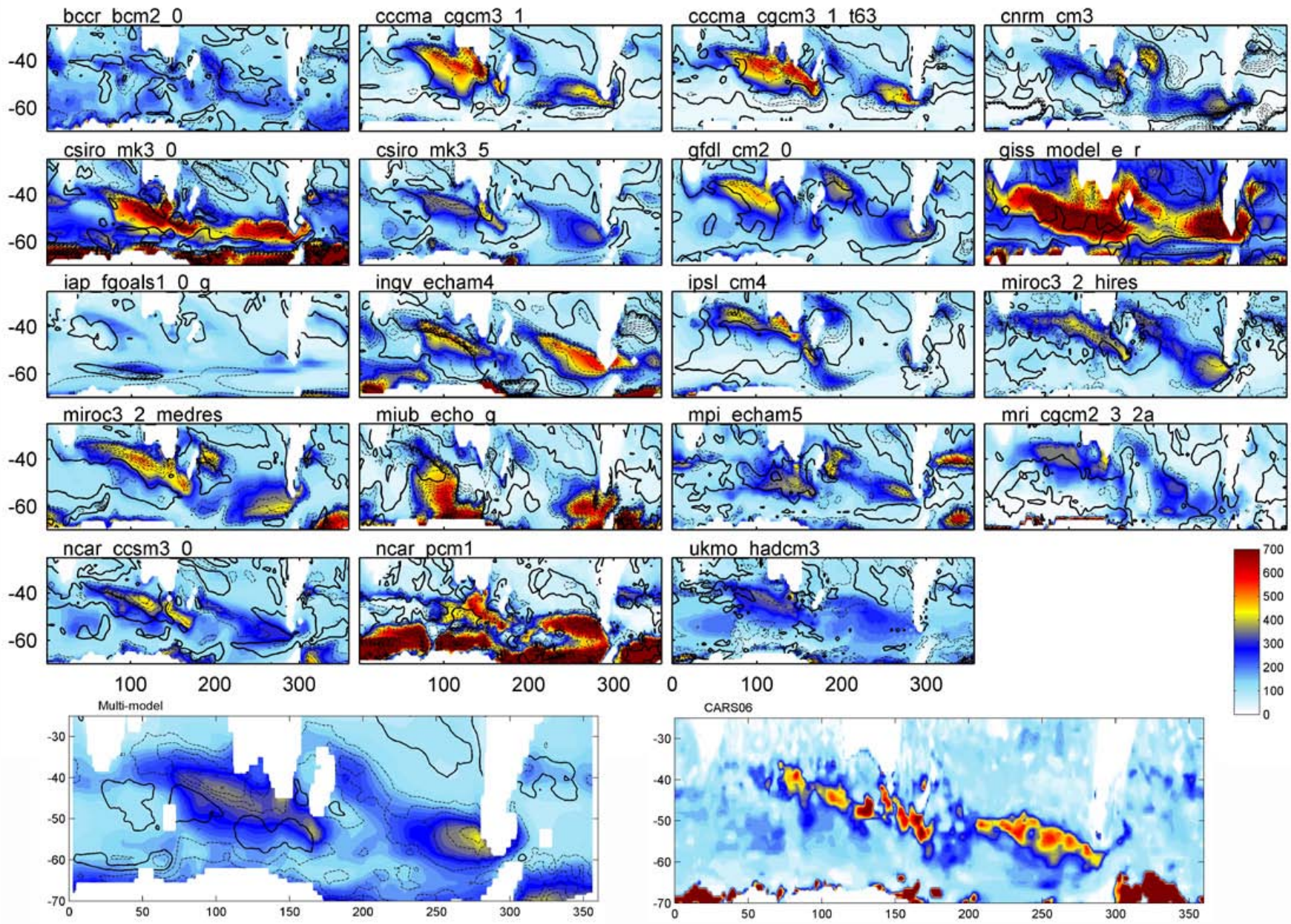
Spatial pattern of SST change affected by MLD

SSS change consistent with change in hydrological cycle

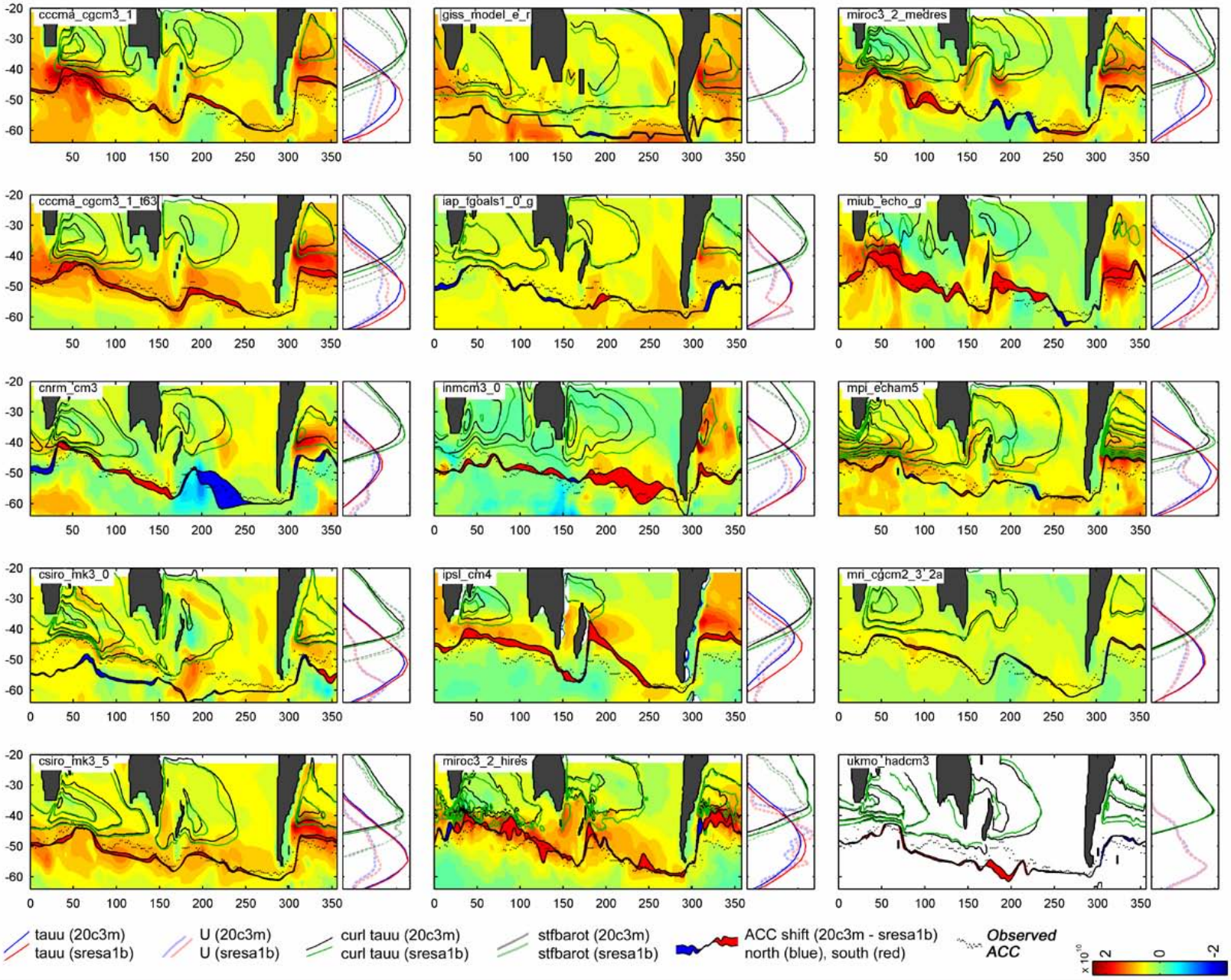


Side panel:
Red – Ekman transport
Black - Precipitation

Mixed Layer Depth Envelope (long term mean and 21st Century Change)

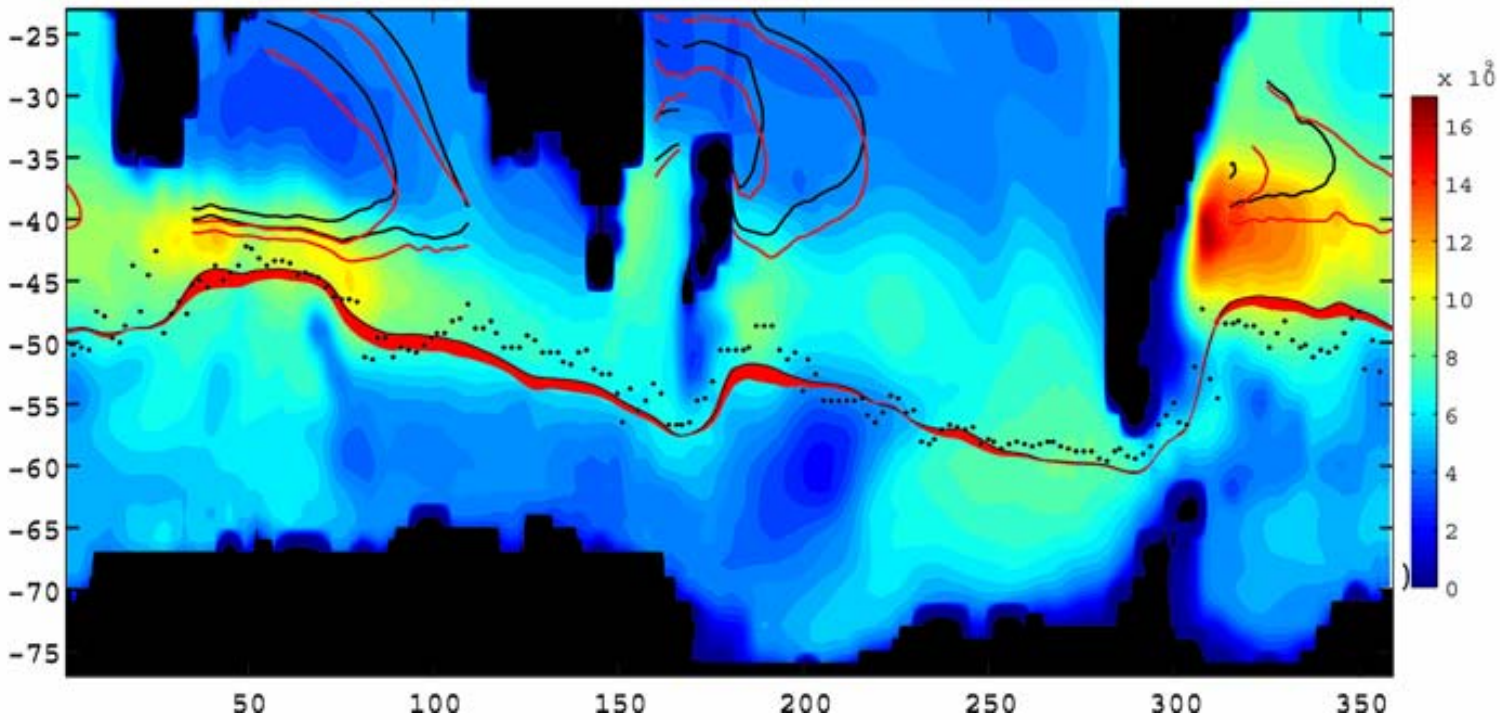


Changes in the lateral circulation and depth integrated heat content



Changes in the lateral circulation and depth integrated heat content

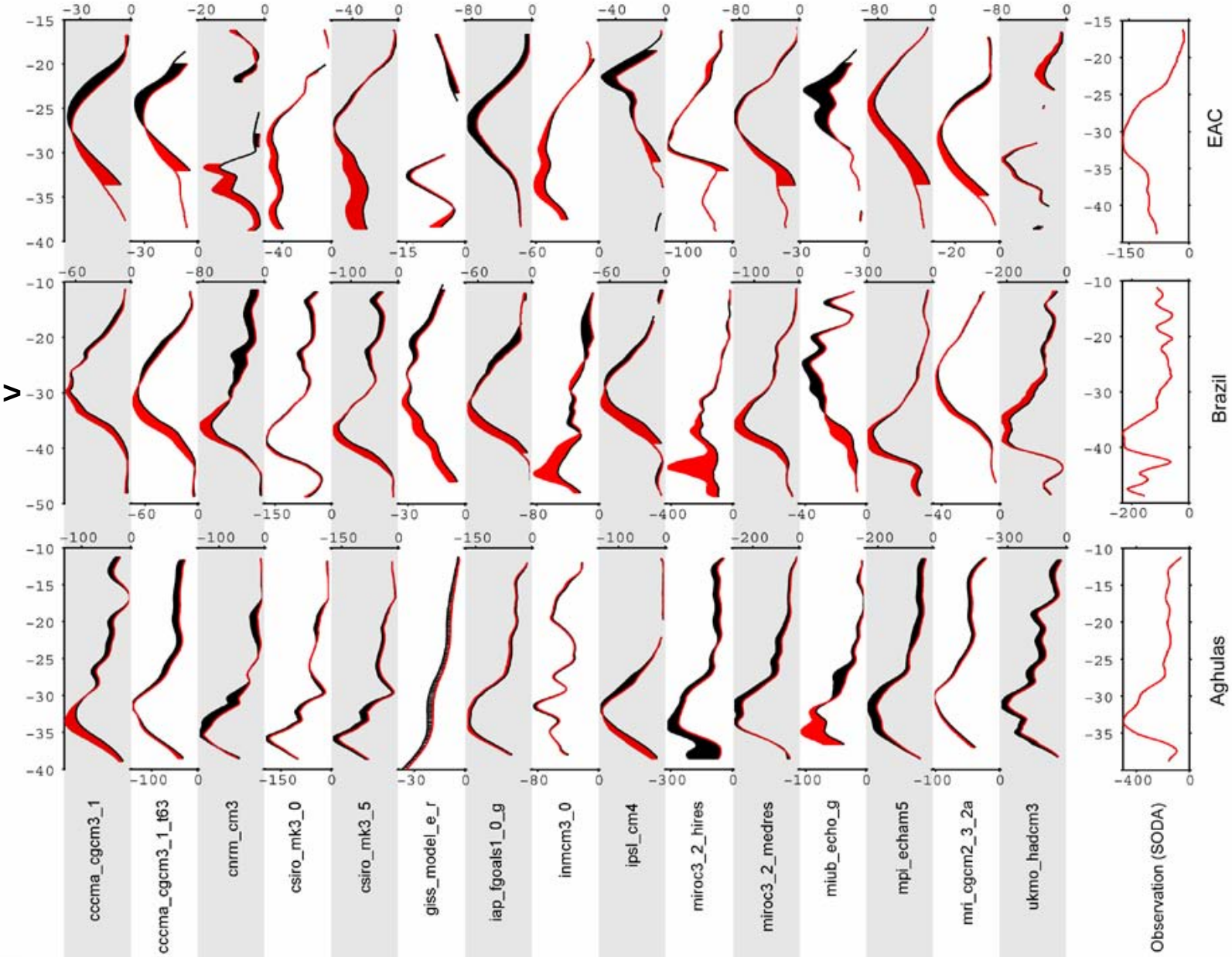
Poleward shift of wind stress curl > southward shift of gyres
Poleward intensification of wind stress > southward intensification of ACC
Increased depth integrated heat content – intensified at mid-latitudes



Multi-model mean

Changes in the core strength of the Western Boundary Currents

Spin up of Atlantic STG



Meridional Overturning Circulation

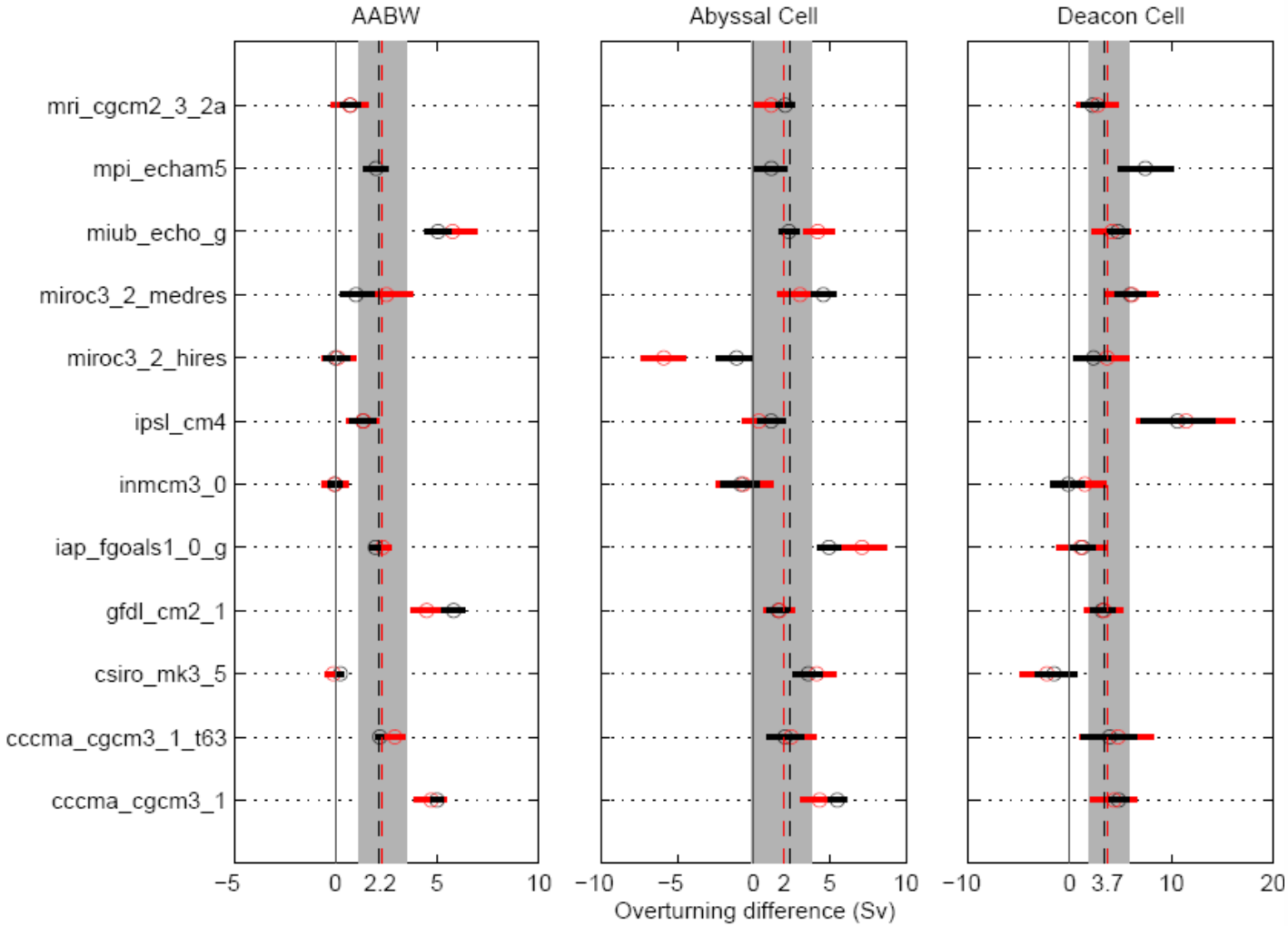
20th C

Antarctic Cell
-6.9±6.3 Sv

Abyssal Cell
-11.0±6.7 Sv

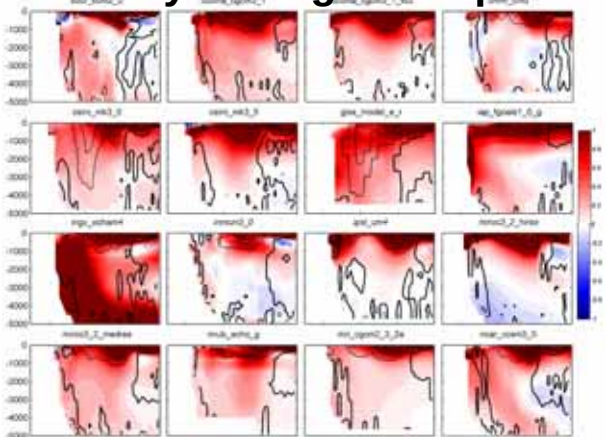
Deacon Cell
26.4±9.4 Sv

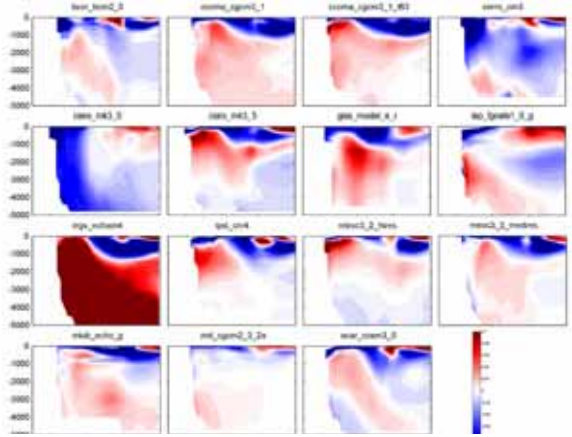
- Spin down of Bottom water formation
- Spin up of deep water upwelling
- Consideration of model drift affects magnitude of change

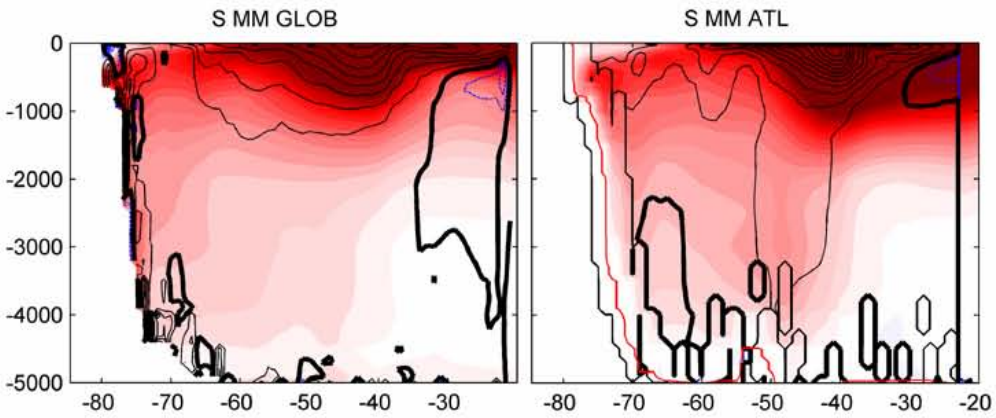


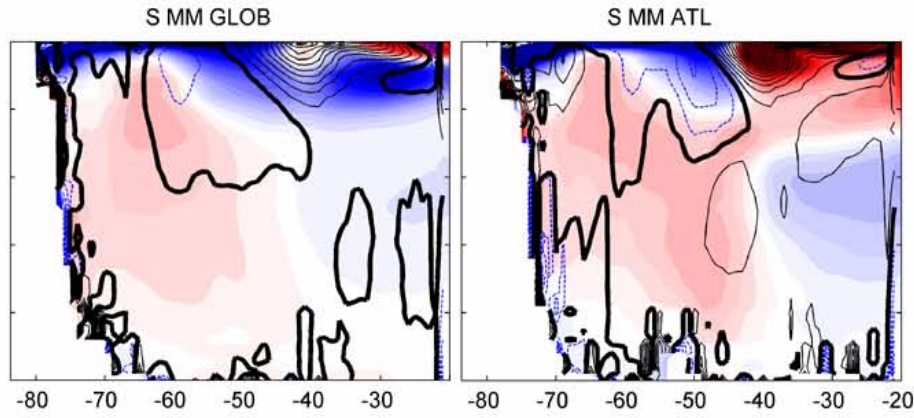
Red: drift removed, black: drift not removed

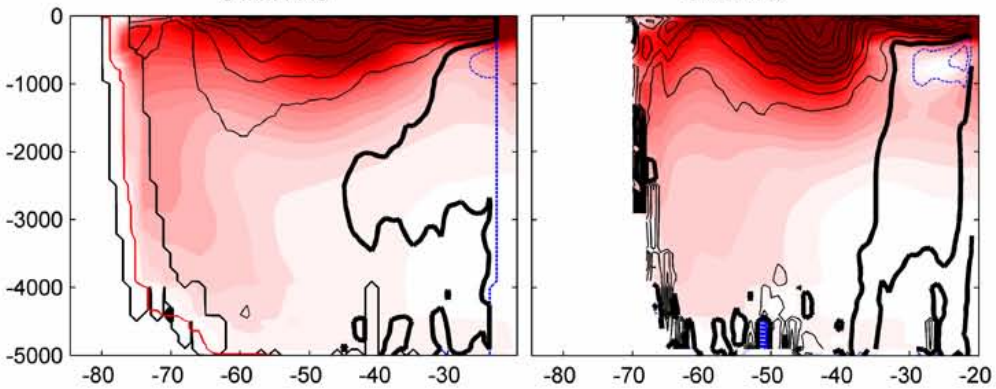
Changes in zonally averaged temperature & salinity, by basin for multi-model mean

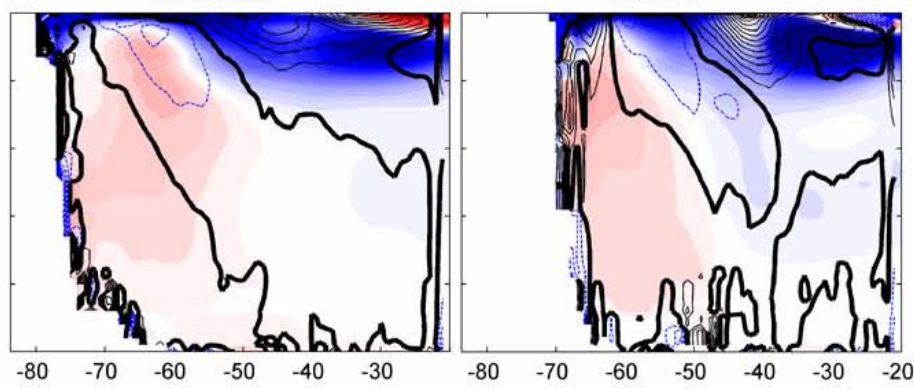




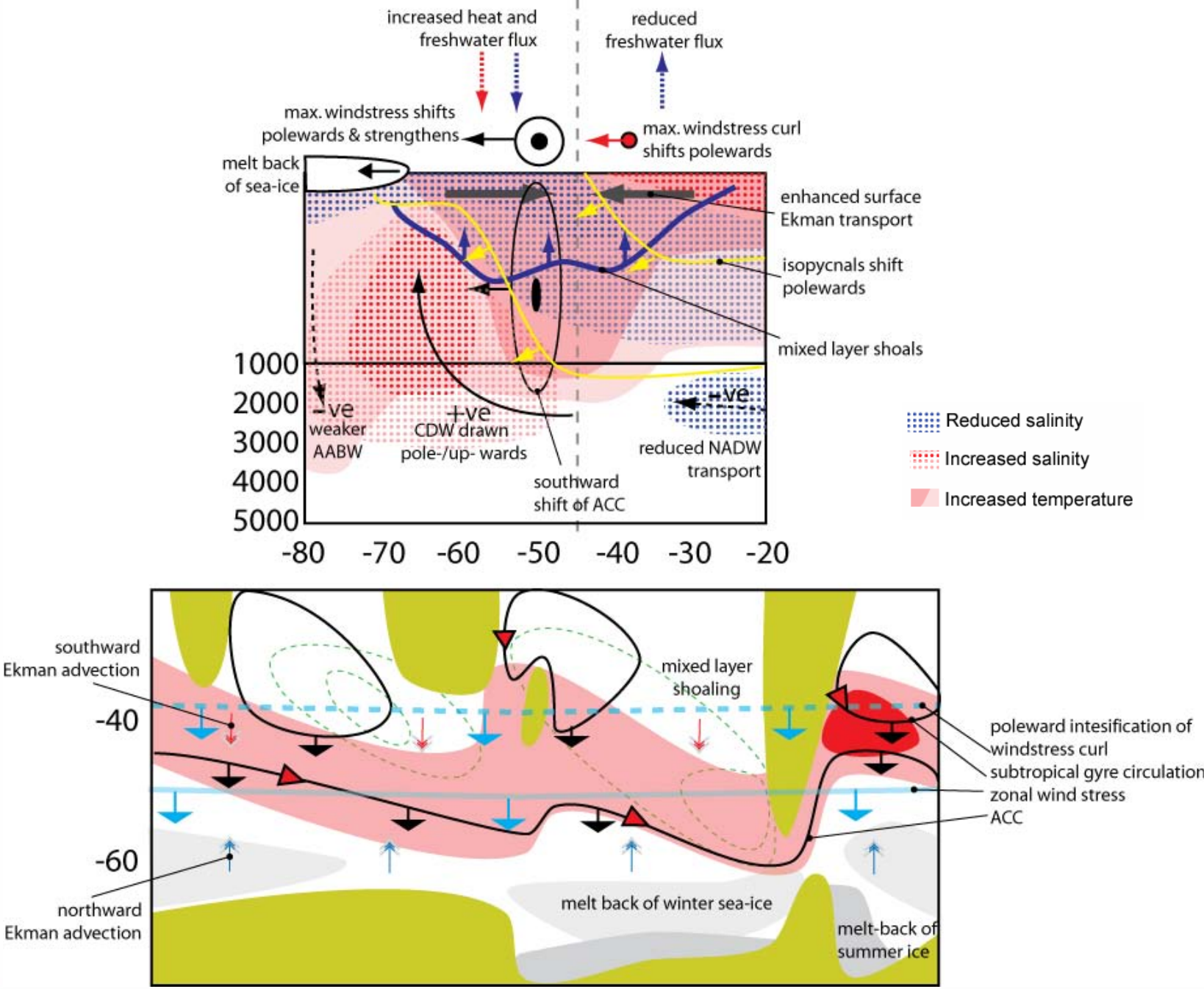








Summary


increased heat and freshwater flux
reduced freshwater flux
max. windstress shifts polewards & strengthens
max. windstress curl shifts polewards
melt back of sea-ice
enhanced surface Ekman transport
isopycnals shift polewards
mixed layer shoals
1000
2000
3000
4000
5000
-ve weaker AABW
+ve CDW drawn pole-/up- wards
+ve reduced NADW transport
southward shift of ACC
-80 -70 -60 -50 -40 -30 -20
Reduced salinity
Increased salinity
Increased temperature
southward Ekman advection
-40
-60
northward Ekman advection
mixed layer shoaling
poleward intesification of windstress curl
subtropical gyre circulation
zonal wind stress
ACC
melt back of winter sea-ice
melt-back of summer ice

Fidelity in the present-day simulation and projected changes to the Southern Hemisphere extratropical ocean/sea-ice system in the AR4 coupled climate models

Alexander **Sen Gupta**, Agus Santoso, Andrea Taschetto, Caroline Ummenhofer and Matthew H. England

Climate Change Research Centre

Faculty of Science, University of New South Wales, Sydney, NSW 2052, Australia

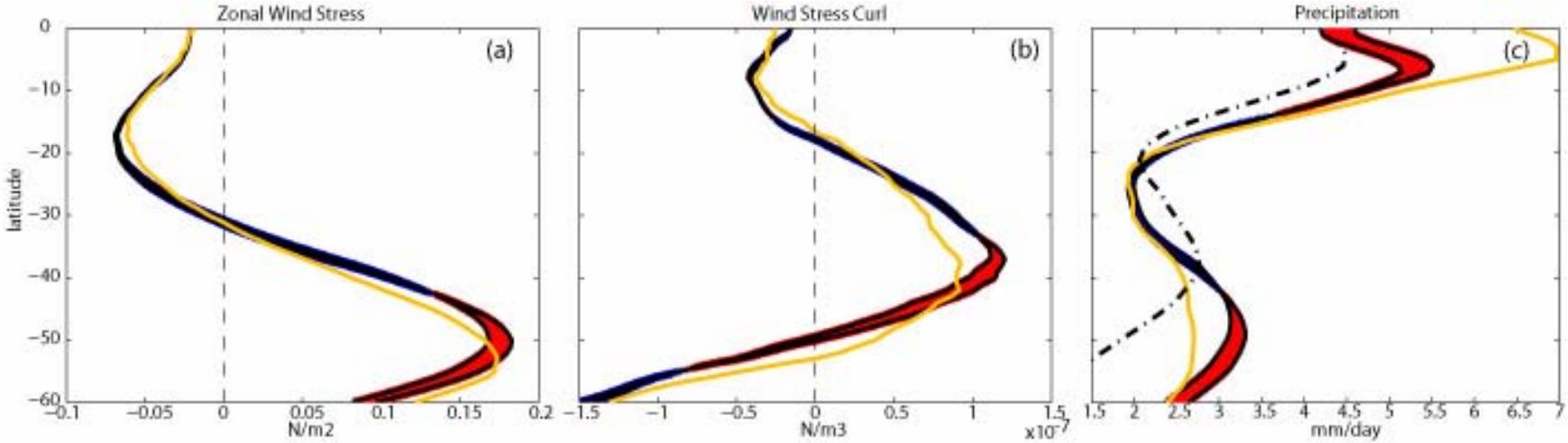
E-mail: *a.sengupta@unsw.edu.au*

Thank You

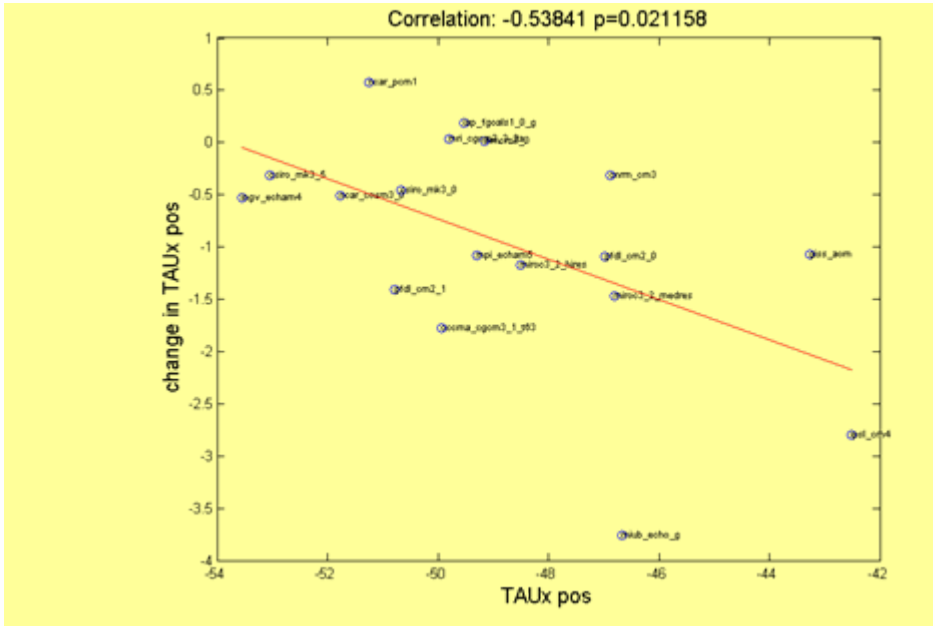
"*We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.*"

Ocean Forcing

Multi-model mean for zonally averaged surface fields. Red (blue) indicates a positive (negative) change over 21st century. Black or yellow line shows observed long-term-mean. Yellow – ERA40, dashed precip: CMAP, heat fluxes: SOC

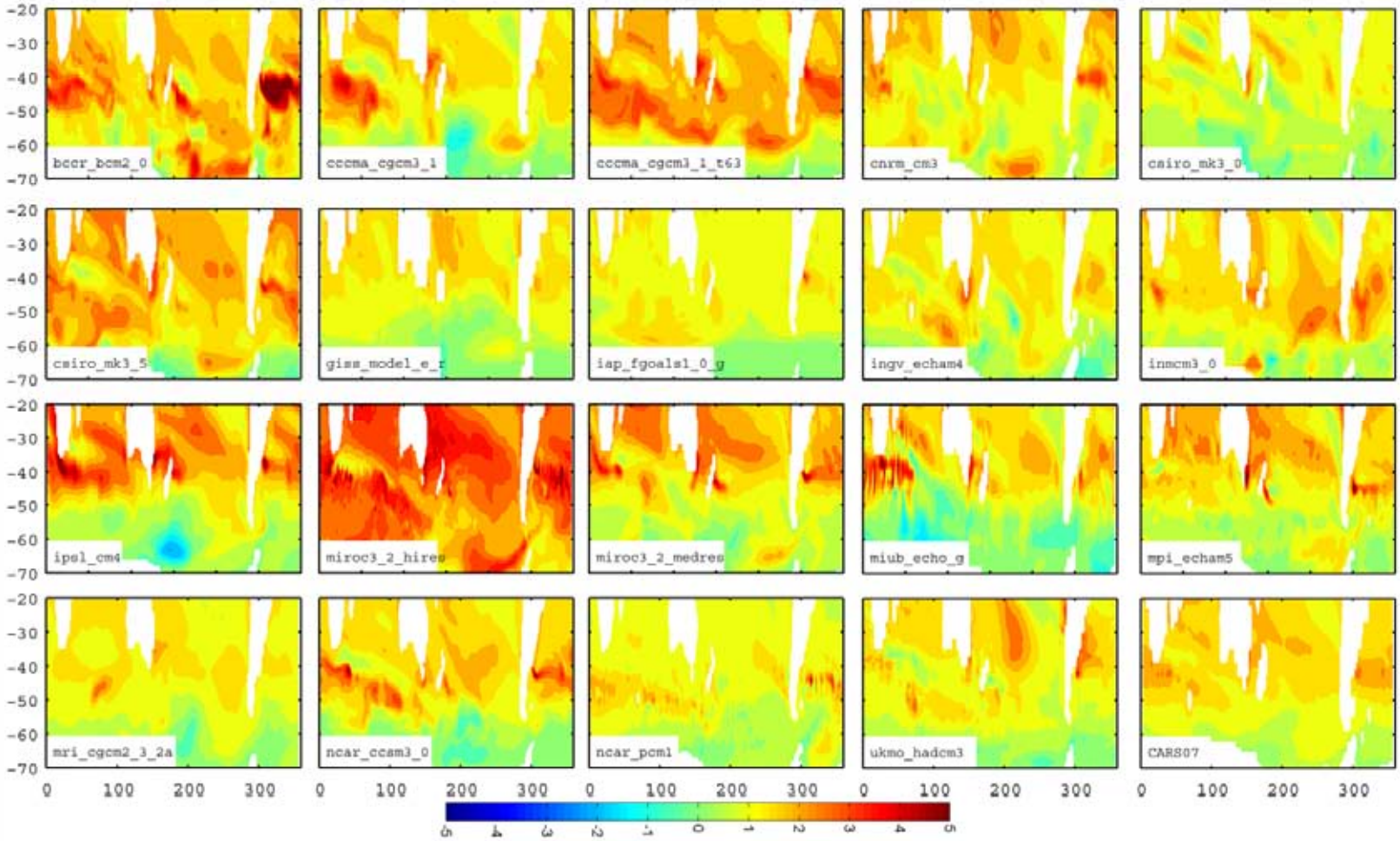


Maximum wind stress generally farther north and weaker than observed
21C – shifts southwards and intensifies
Maximum wind stress curl farther north and stronger than observed
21C – shifts southwards and intensifies
Hydrological cycle too strong and displaced
21C –cycle intensifies



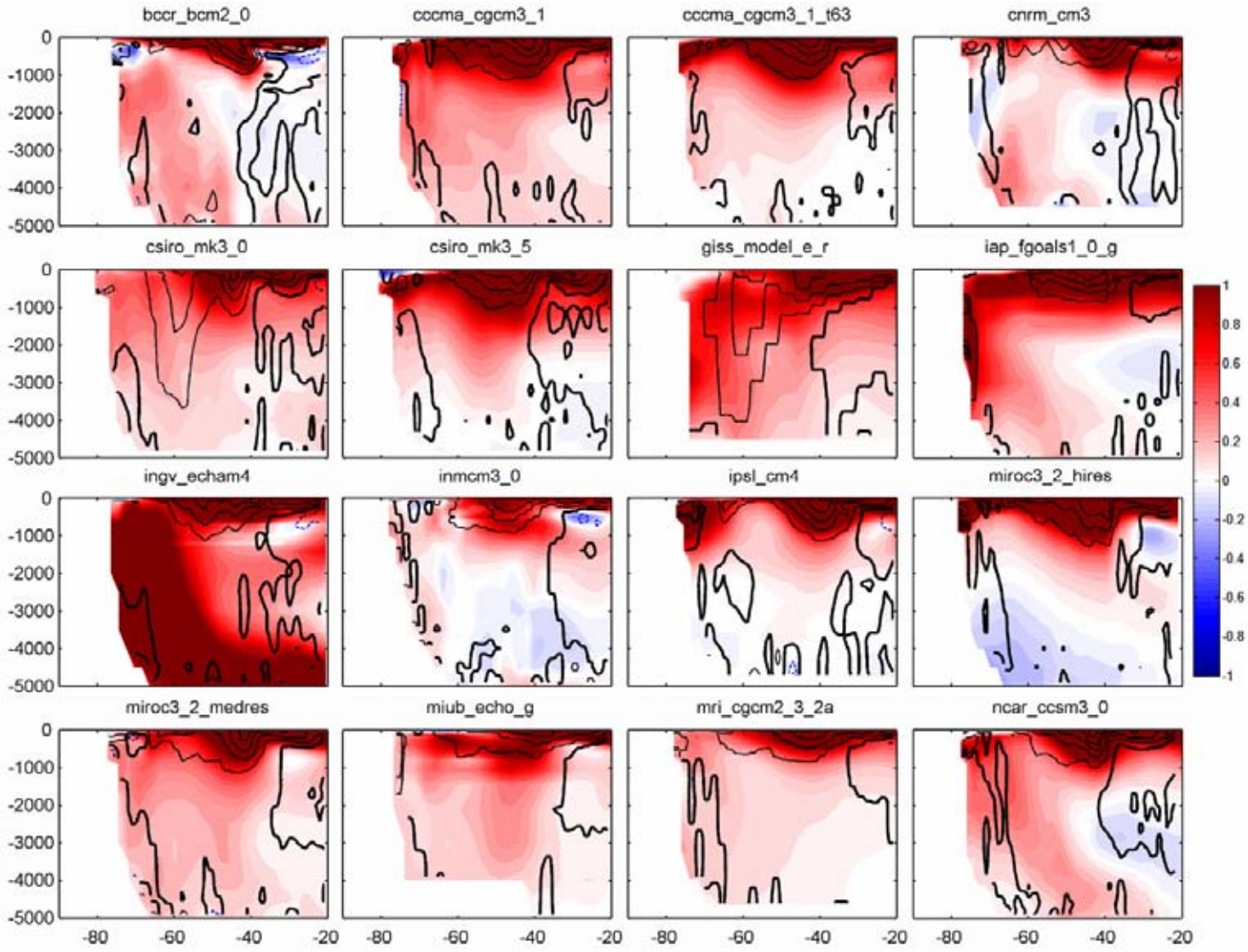
SST Change

Projected change in SST over 100 yrs

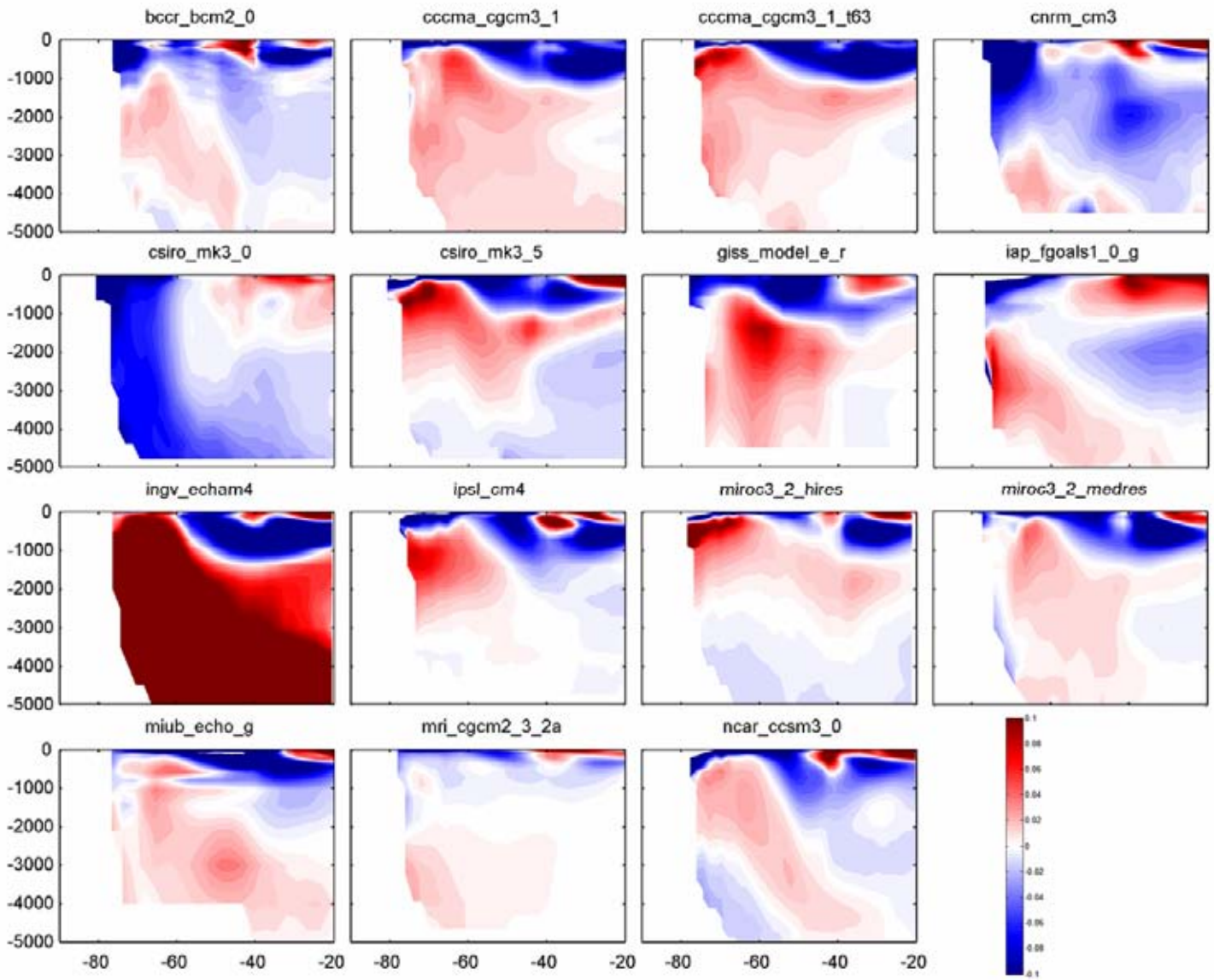


Robust warming across all models
Minimum warming at high latitudes

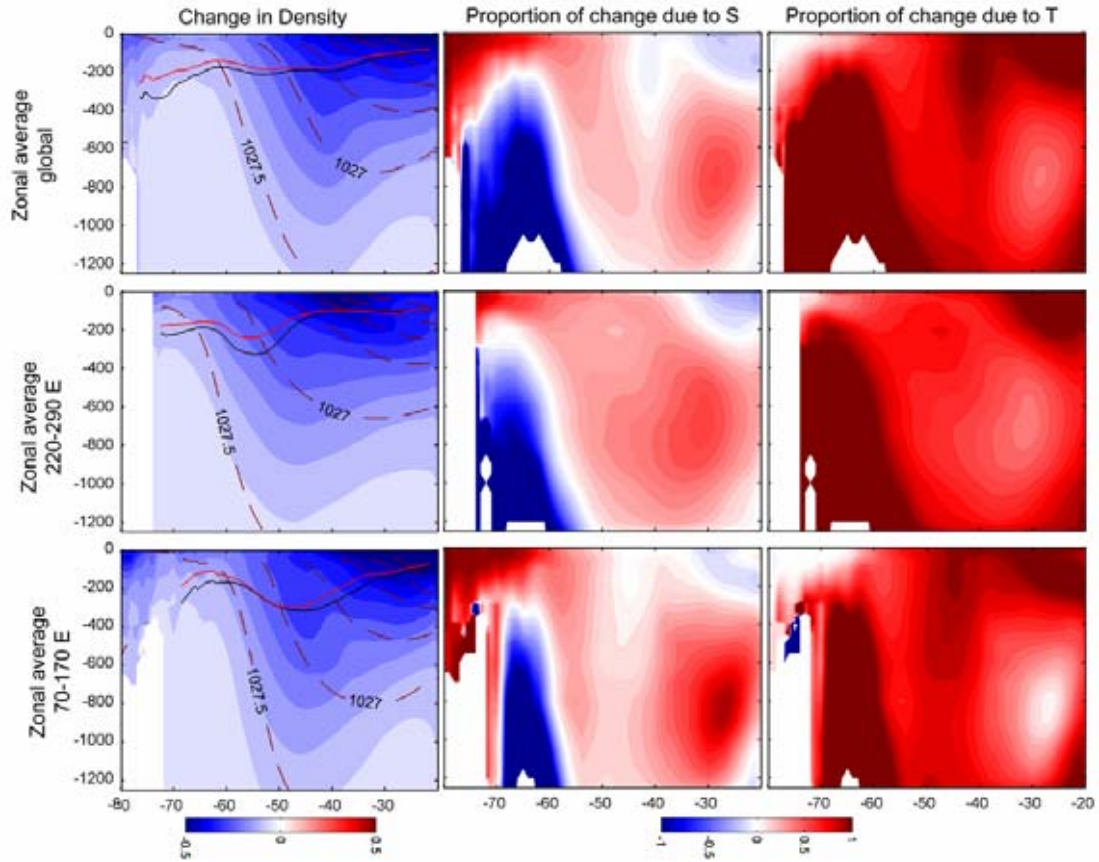
Changes in zonally averaged temperature , by model



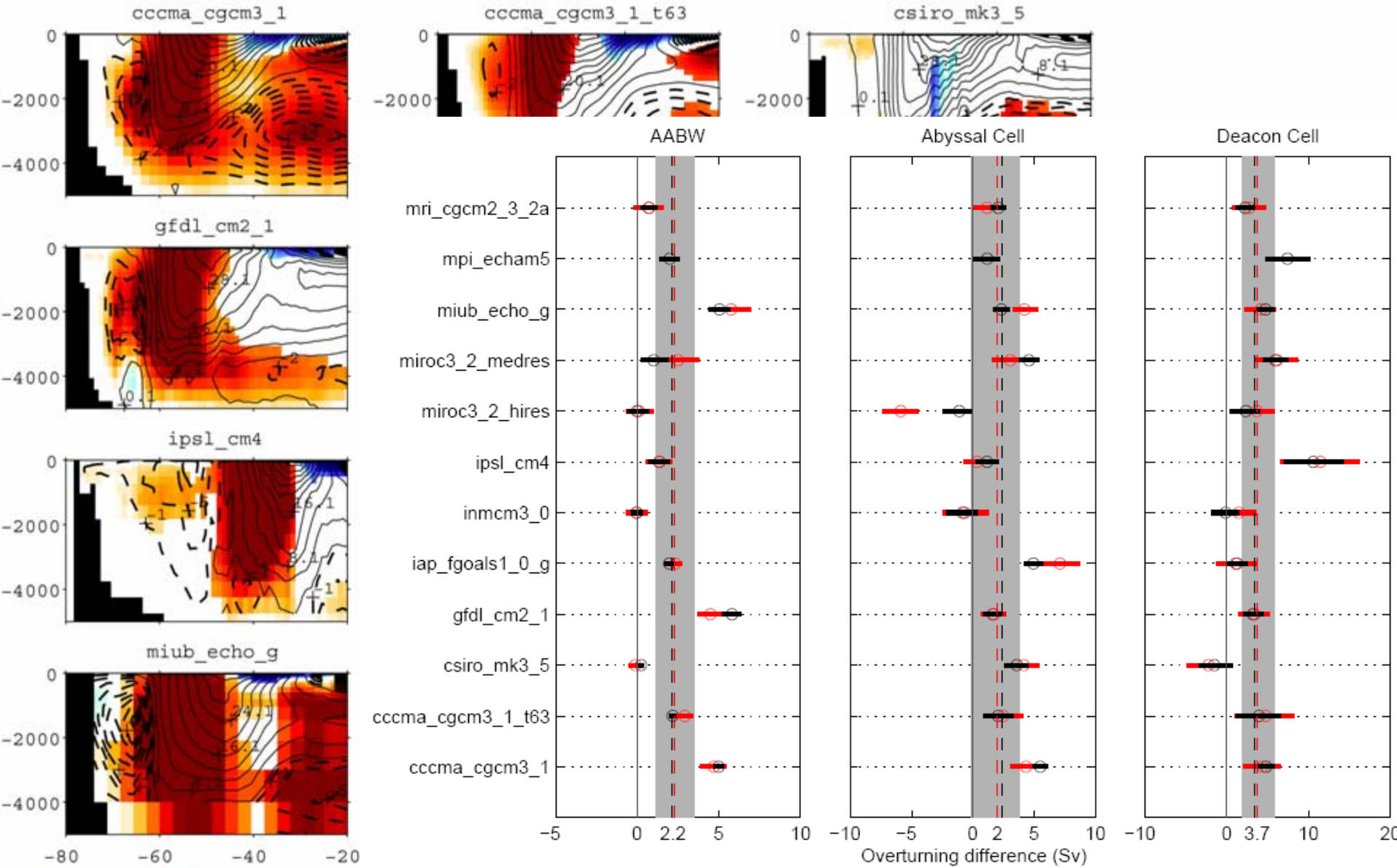
Changes in zonally averaged salinity, by model



Changes in zonally potential density (total, salinity component and temperature component)



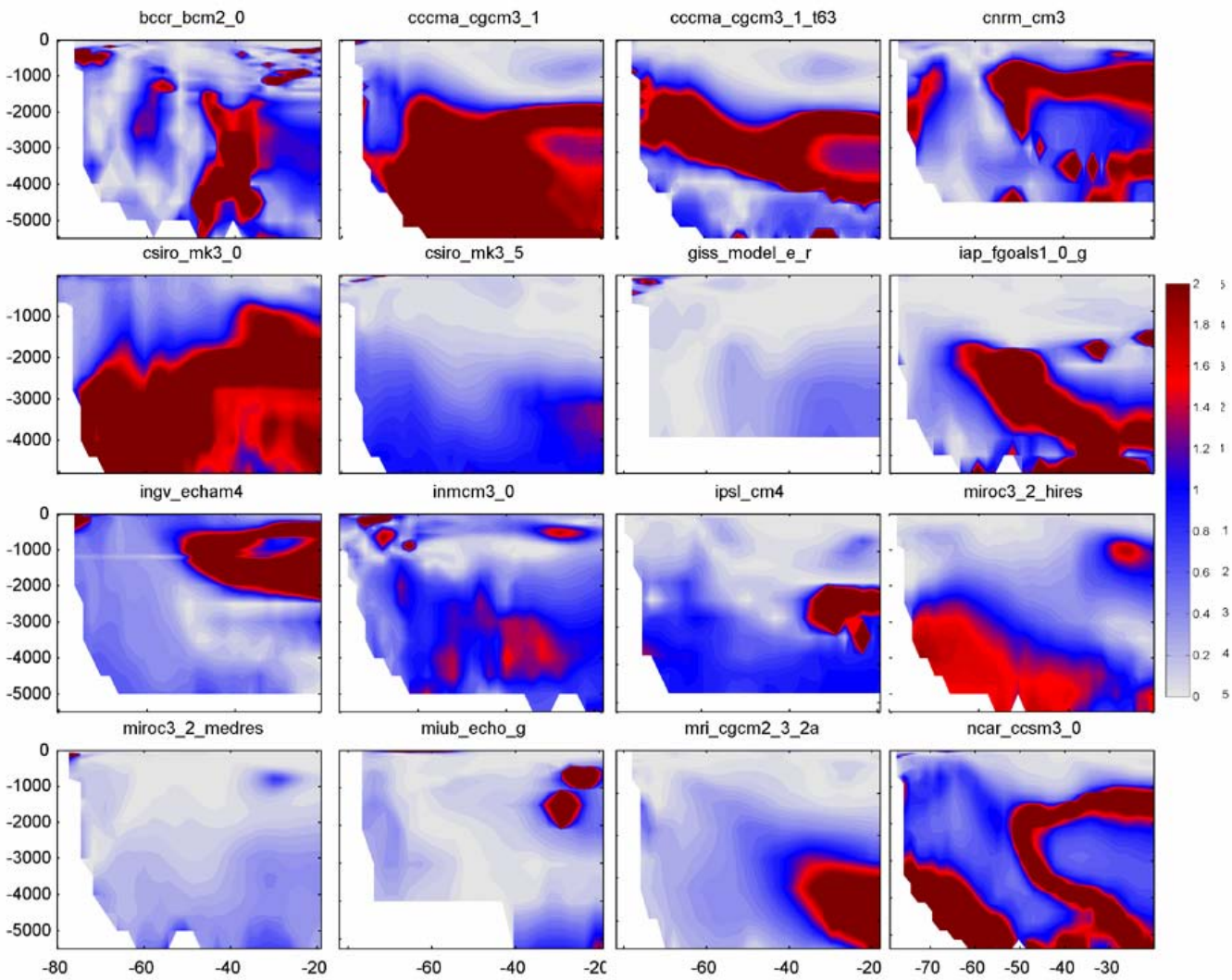
Meridional Overturning Circulation – projected changes (drift removed-red)



Model Drift

Relative size of drift over the 100yr period to temperature difference (calculated for each gridpoint))

•Particularly in deep ocean, drift is often of comparable magnitude to trend in forced run

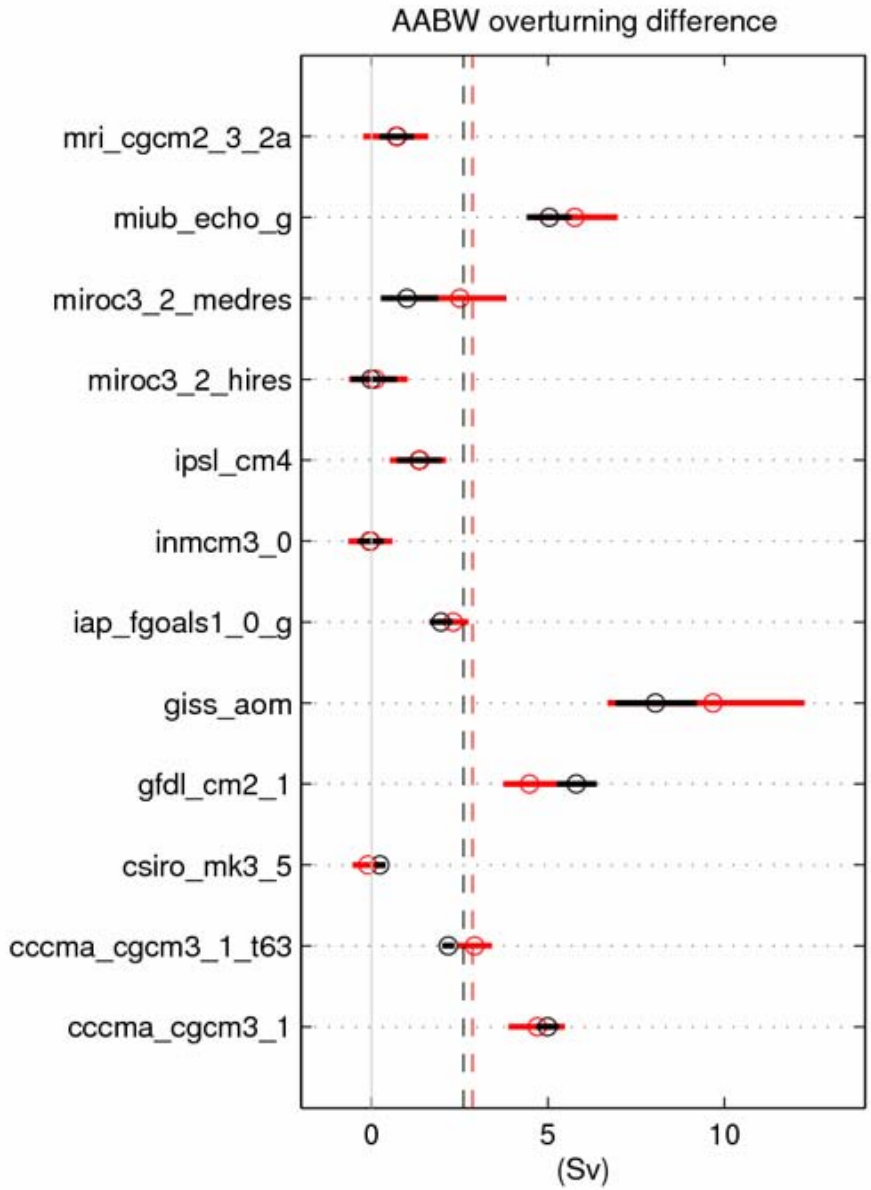


Model Drift

•Other fields also contain significant drifts

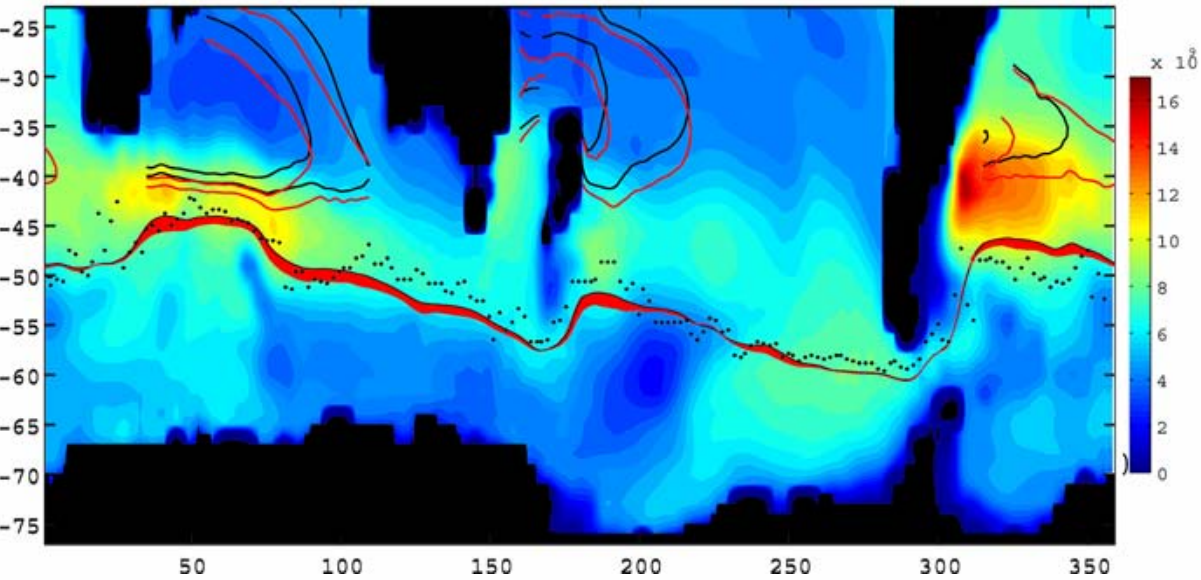
•Meridional overturning associated with bottom water formation show modified 21Century changes when drift is taken into account (red). Error bars – indication of errors associated with calculating 21C changes and model drift

•Temperature, salinity, MOT, baratropic stream function and all the subsequent derived variables have been corrected for drift – WHERE POSSIBLE



Changes in the lateral circulation and depth integrated heat content

Poleward shift of wind stress curl > southward shift of gyres
Poleward intensification of wind stress > southward intensification of ACC
Increased depth integrated heat content – intensified at mid-latitudes
Change in Drake Passage transport not as robust



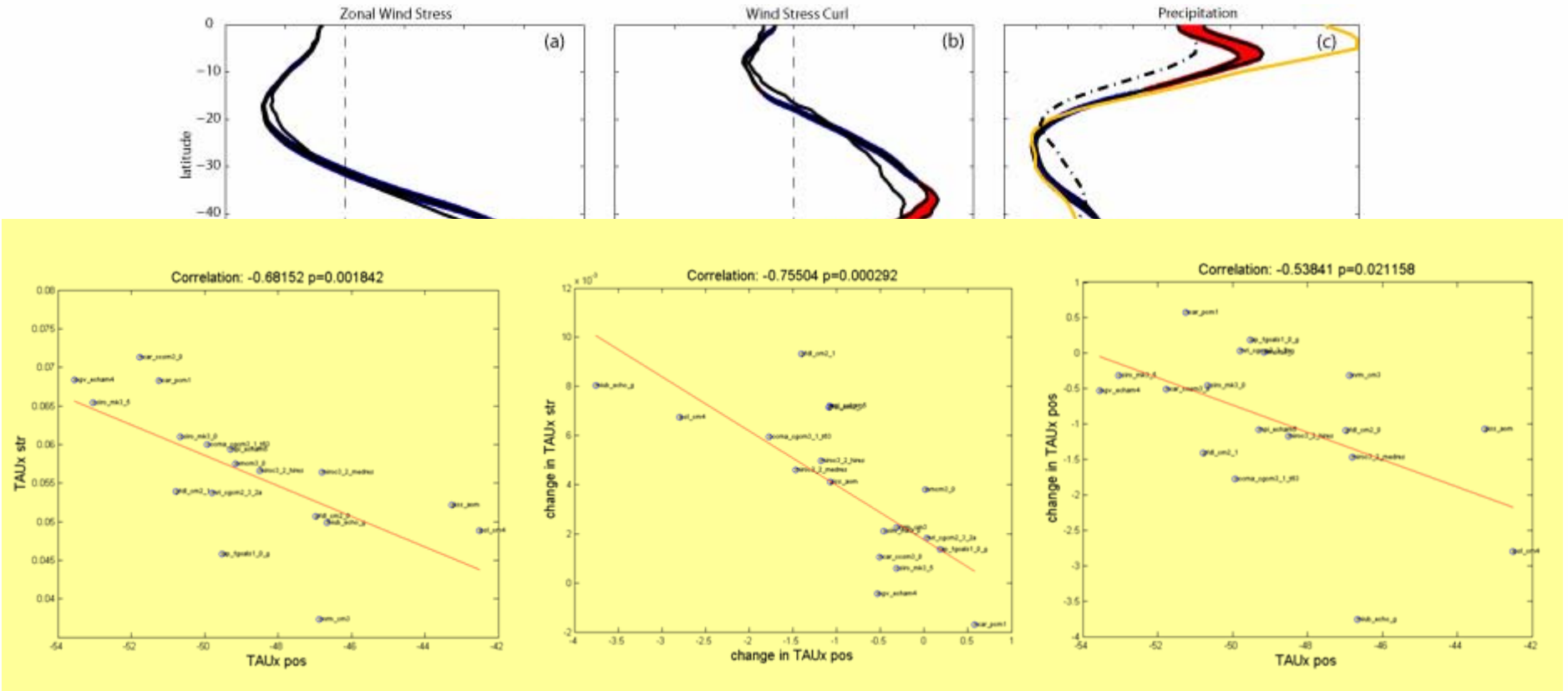
ACC Transport (drift removed)

bccr_bcm2_0	*95.9451*	*92.411*	**-3.7**
cccma_cgcm3_1	97.0	100.7	**3.9**
cccma_cgcm3_1_t63	110.3	122.5	**11.1**
cnrm_cm3	83.6	59.0	**-29.4**
csiro_mk3_0	317.6	295.8	**-6.9**
csiro_mk3_5	149.4	157.6	**5.5**
giss_model_e_r	225.8	223.4	**-1.1**
iap_fgoals1_0_g	71.8	66.5	**-7.3**
ingv_echam4	*139.0*	*131.0*	**-5.8**
inmcm3_0	71.5	91.7	**28.4**
ipsl_cm4	44.4	50.9	**14.6**
miroc3_2_hires	122.2	134.9	**10.4**
miroc3_2_medres	185.3	183.9	-0.7
miub_echo_g	71.2	73.5	**3.1**
mpi_echam5	155.1	161.8	**4.3**
mri_cgcm2_3_2a	93.6	95.4	**1.9**
ncar_ccsm3_0	*205.4*	*190.2*	**-7.4**
ncar_pcm1	*250.3*	*241.3*	**-3.6**
ukmo_hadcm3	217.6	218.4	0.4

Multi-model mean

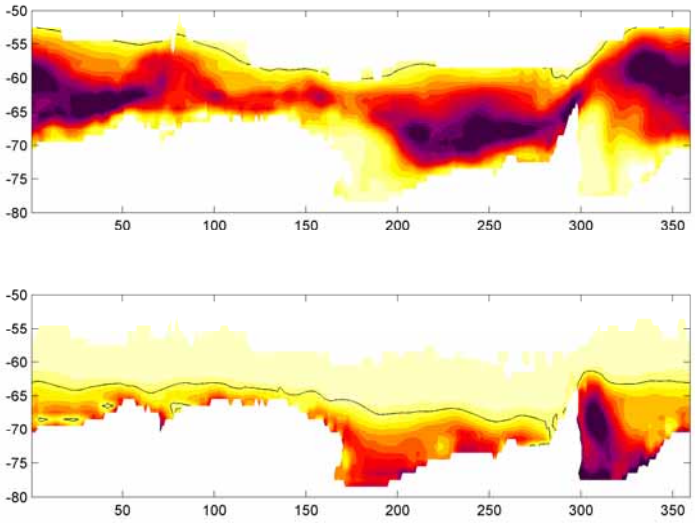
Ocean Forcing

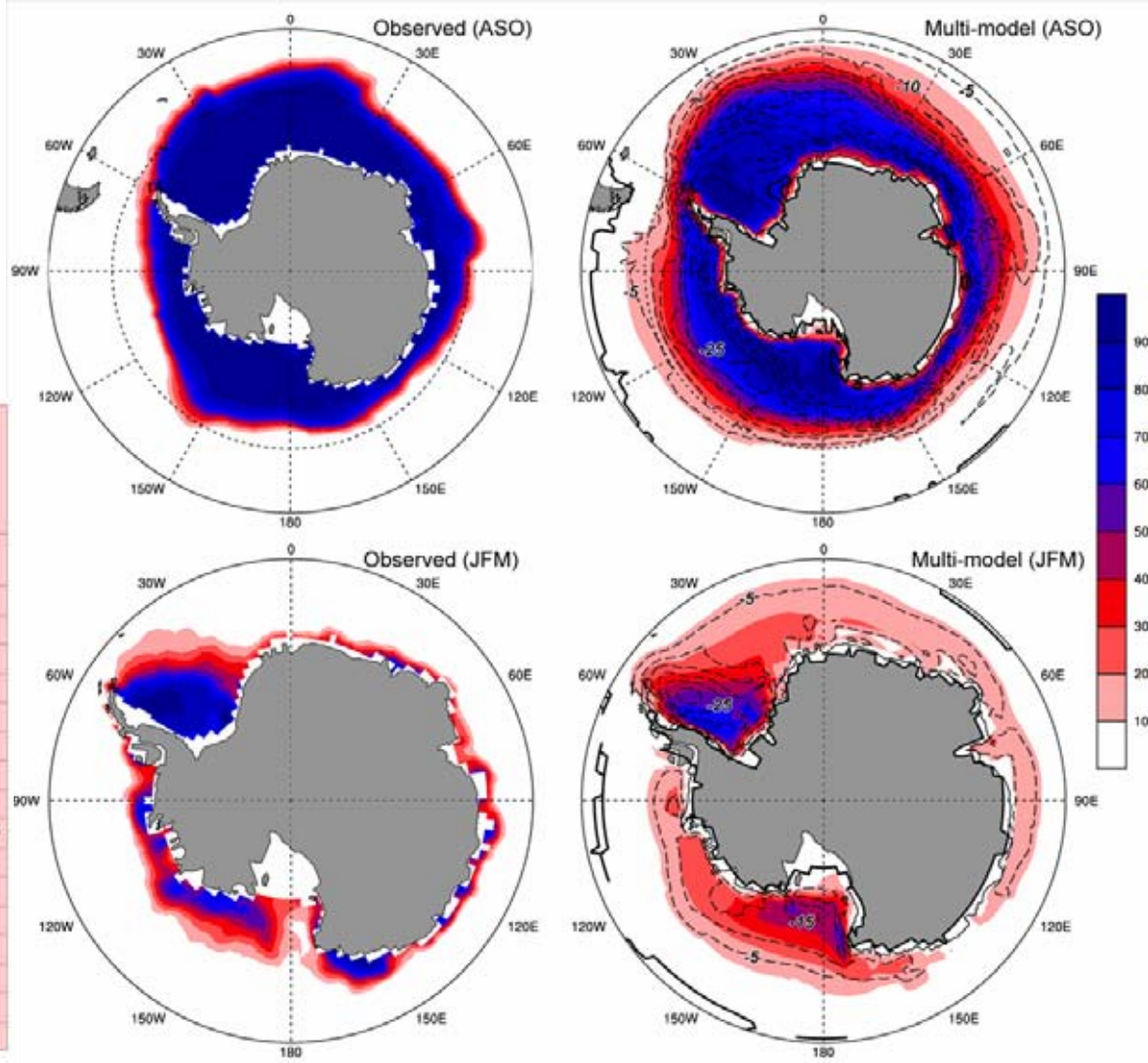
Maximum wind stress generally farther north and weaker than observed
21C – shifts southwards and intensifies
Maximum wind stress curl farther north and stronger than observed
21C – shifts southwards and intensifies
Hydrological cycle too strong and displaced
21C –cycle intensifies



Multi-model mean for zonally averaged surface fields. Red (blue) indicates a positive (negative) change over 21st century. Black or yellow line shows observed long-term-mean.

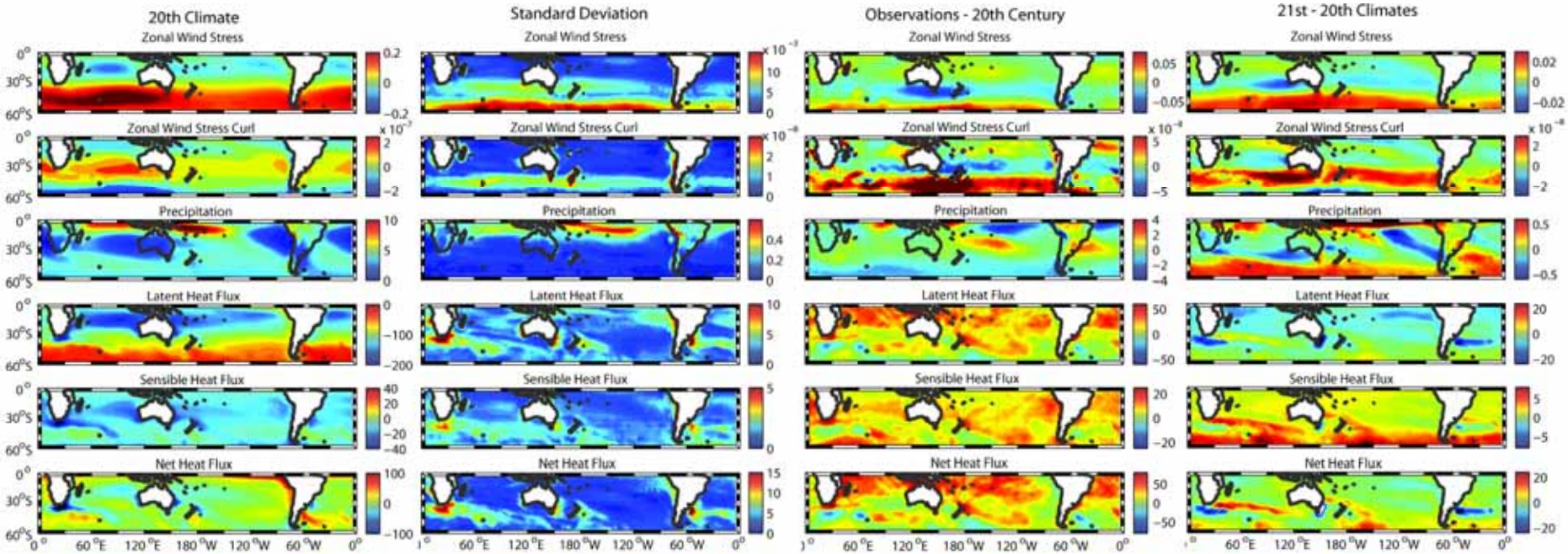
Multimodel change in sea-ice (at least 3 models)



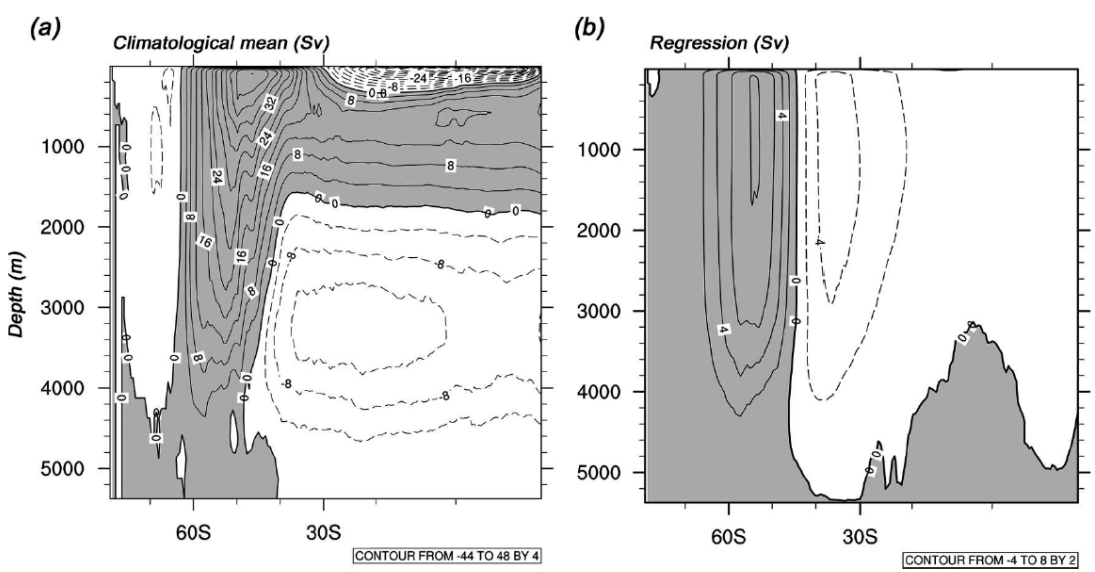


HadISST	20c3m	slice-2	20c3m	slice-2	20c3m	slice-2	20c3m	slice-2
	Area (JFM)		Area (ASO)		V (JFM)		V (ASO)	
Obs (CARS06)	16.0		3.1					
bccr_bcm2_0	13.6		2.2		13.7		2.2	
cccma_cgcm3_1	19.9	16.6	4.8	2.4	12.5	11.4	3.2	1.7
cccma_cgcm3_1_t63	24.1	15.4	6.7	1.8	13.9	9.4	4.1	0.8
cnrm_cm3	16.4	8.2	0.2	0.0	6.1	2.1	0.1	0.0
csiro_mk3_0	15.6	13.2	3.5	2.1	13.9	9.8	2.4	1.2
csiro_mk3_5	15.6		5.5		14.1		2.8	
giss_model_e_r	11.9	8.4	1.2	0.6	11.1	6.9	1.5	0.6
iap_fgoals1_0_g	37.5	29.6	34.1	27.2	39.0	26.6	21.3	10.3
ingv_echam4	12.3		1.8		7.8		1.5	
inmcm3_0	17.7	12.4	3.8	1.1	19.3	7.4	9.1	0.4
ipsl_cm4	14.5		0.9		9.9		1.7	
miroc3_2_hires	13.9		0.6		12.2		0.7	
miroc3_2_medres	11.5	6.5	0.8	0.2	5.9	3.1	0.5	0.1
miub_echo_g	14.4	10.7	1.1	0.4	5.1	3.1	0.5	0.1
mpi_echam5	12.9	4.5	2.6	0.3	9.4	2.3	2.3	0.1

Ocean Forcing



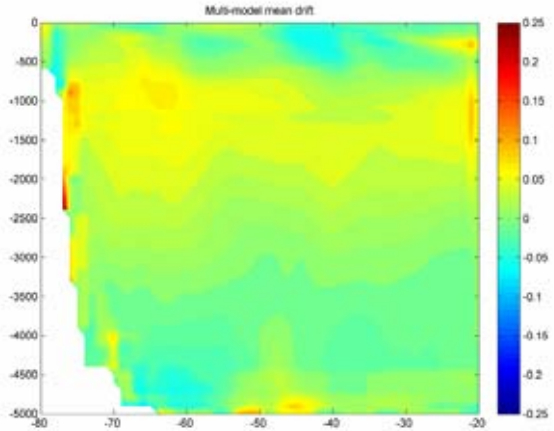
Multi-model mean for surface fields – 20thC, inter-model variability (std dev), bias from observation, change over 21stC


(a)
Climatological mean (Sv)
Depth (m)
1000
2000
3000
4000
5000
60S
30S
CONTOUR FROM -44 TO 48 BY 4
(b)
Regression (Sv)
1000
2000
3000
4000
5000
60S
30S
CONTOUR FROM -4 TO 8 BY 2

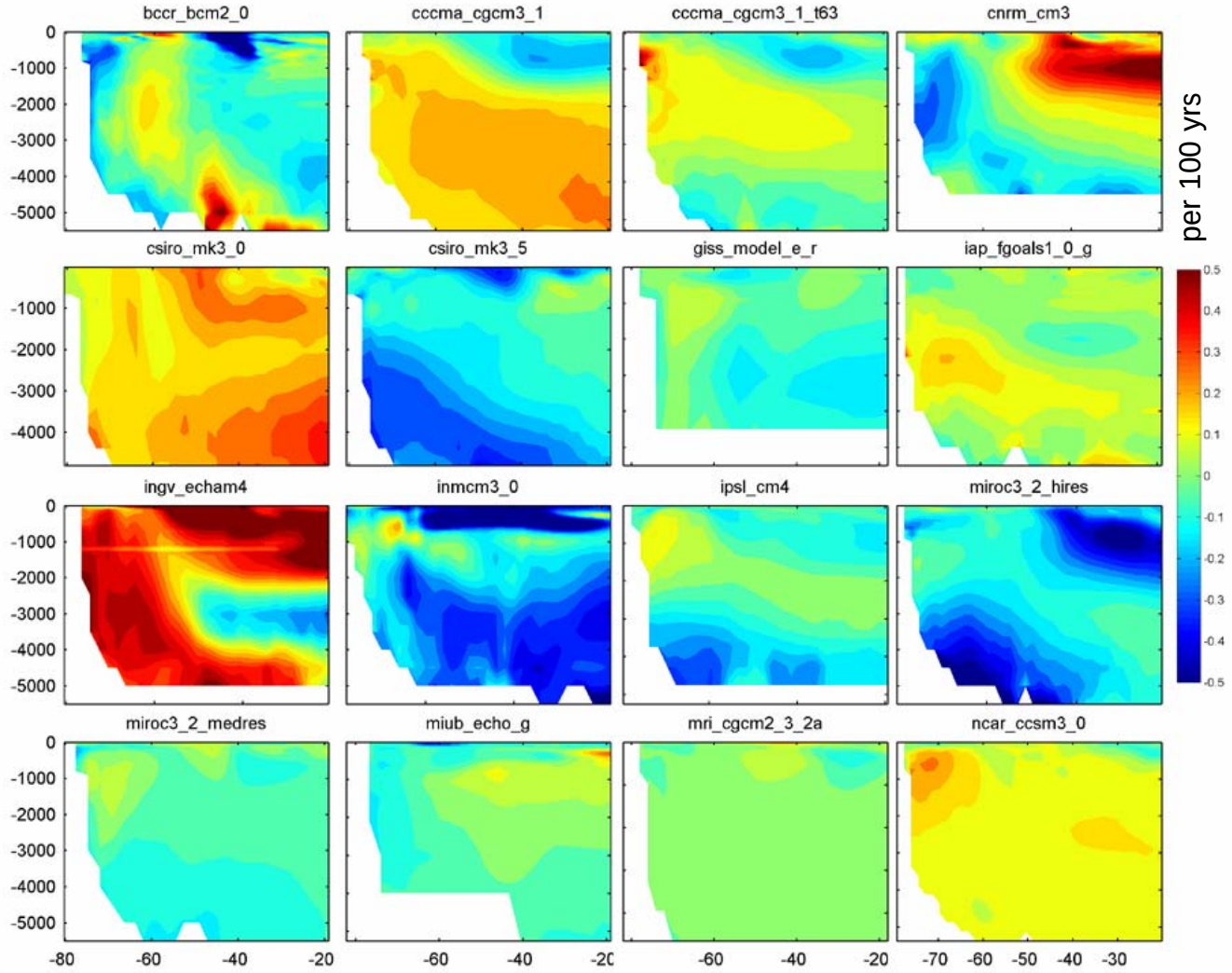
Model Drift

- Forced runs generally branch from control after few hundred years control integration
- Significant drift still evident in ocean fields
- Particularly in deep ocean natural variability may have low frequency
- Most models only have single realisation of control run

Drift in zonaly averaged temperature (calculated as linear trend over 100yr of 21st C)

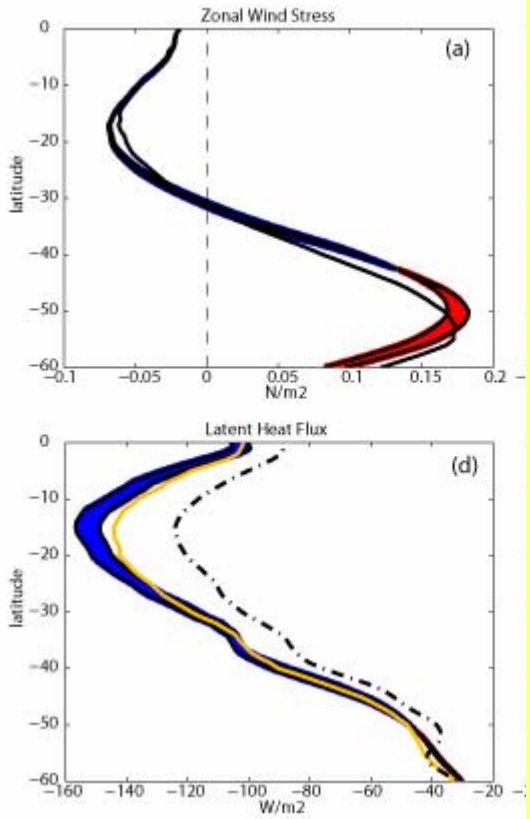


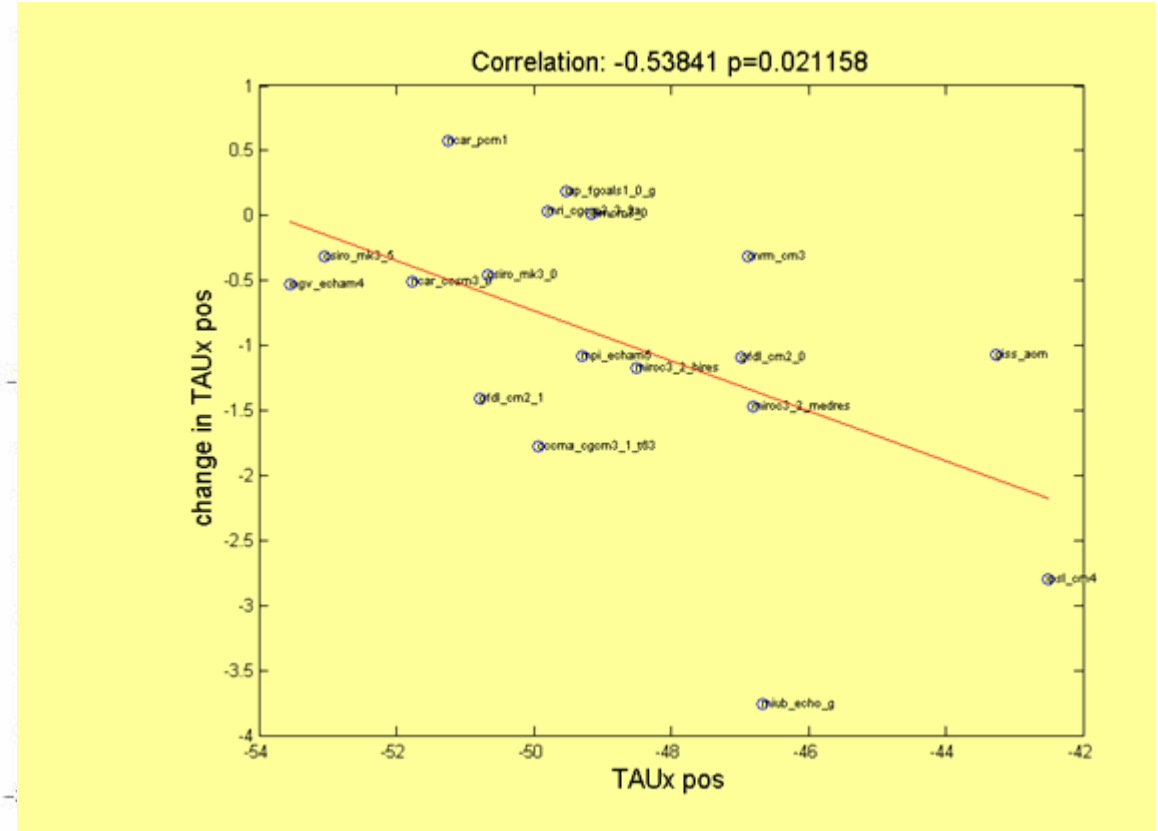
As above, for multi-model mean



Ocean Forcing

Maximum wind stress generally farther north and weaker than observed
21C – shifts southwards and intensifies
Maximum wind stress curl farther north and stronger than observed
21C – shifts southwards and intensifies
Hydrological cycle too strong and displaced
21C –cycle intensifies

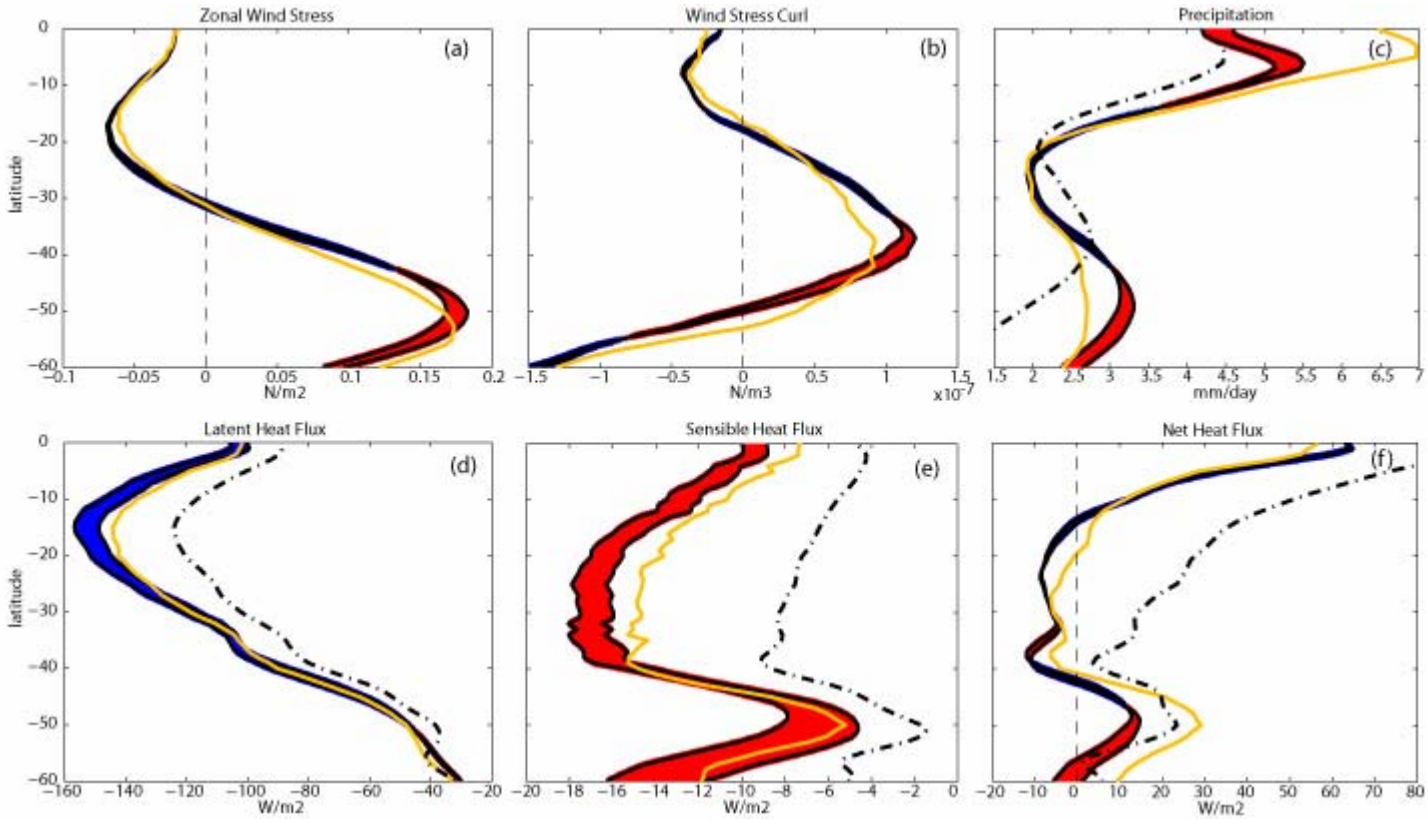




Multi-model mean for zonally averaged surface fields. Red (blue) indicates a positive (negative) change over 21st century. Black or yellow line shows observed long-term-mean.

Ocean Forcing

Maximum wind stress generally farther north and weaker than observed
21C – shifts southwards and intensifies
Maximum wind stress curl farther north and stronger than observed
21C – shifts southwards and intensifies
Hydrological cycle too strong and displaced
21C –cycle intensifies



Multi-model mean for zonally averaged surface fields. Red (blue) indicates a positive (negative) change over 21st century. Black or yellow line shows observed long-term-mean. Yellow – ERA-40; dashed precip – CMAP; dashed heat fluxes- SOC