Warm Deep Water and OHC changes in the Weddell Sea - 20th and 21st C

CMIP5 and Ocean-reanalysis

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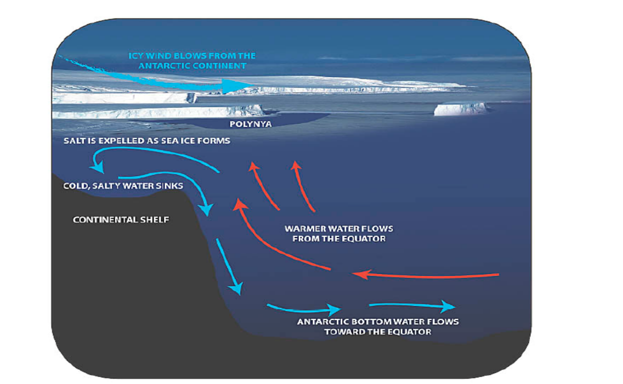
OMWG meeting 01-2015

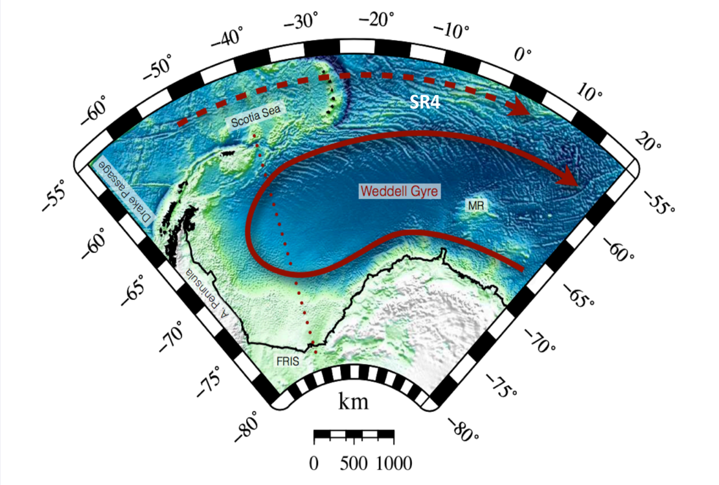
Southern Ocean = large uncertainties in climate models

Region of dense water mass formation



Focus on the Atlantic sector of the Southern Ocean

Weddell Sea



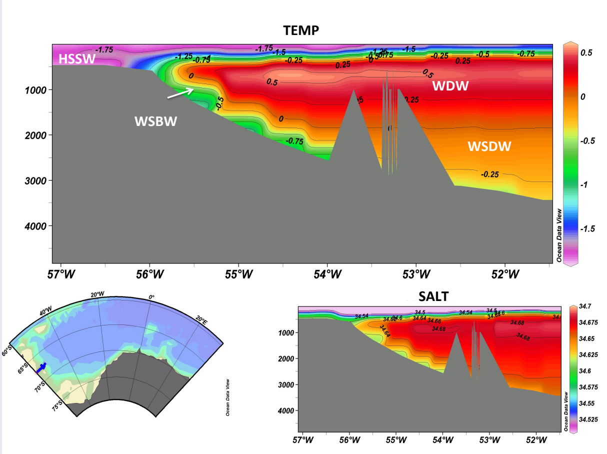
Southern Ocean

Climate Hotspot

- Source (and export) region for Antarctic Bottom Water (AABW);
- AABW becoming fresher and lighter (*Schmidkto et al., 2014*)
- Processes such as ice shelves desintegration; shelf Water Freshening (*Van Wijk & Rintoul, 2014*);
- We want to know how Weddell Sea water masses are represented in large-scale climate models.

Weddell Sea Water Masses

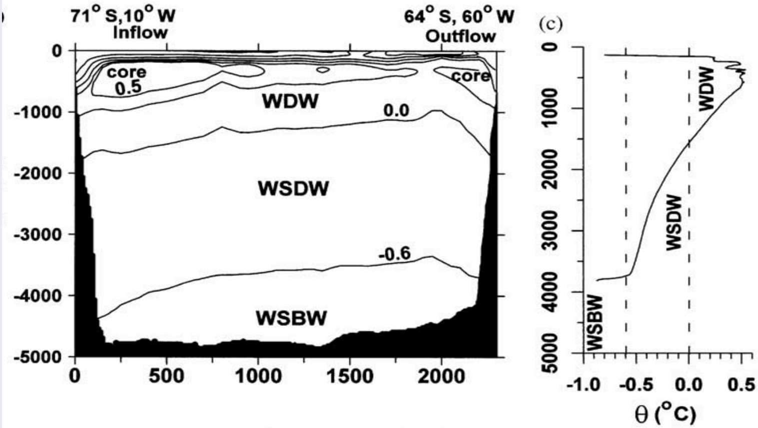
Observations



Weddell Sea Water Masses

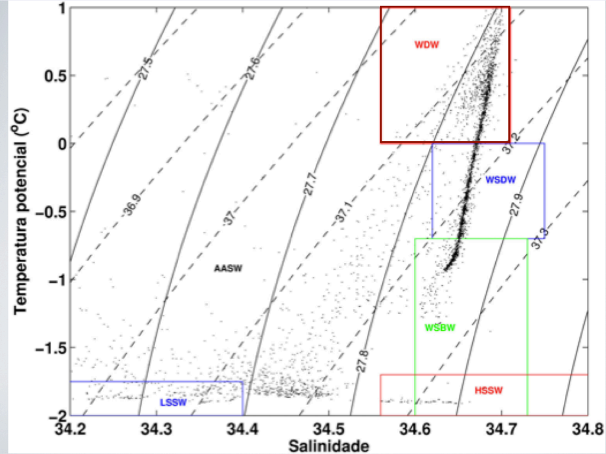
Interest is in the Warm Deep Water (WDW)

Robertson et al., 2002



Water masses are excellent indicators for climate change

Warm Deep Water along SR4 - WOCE data



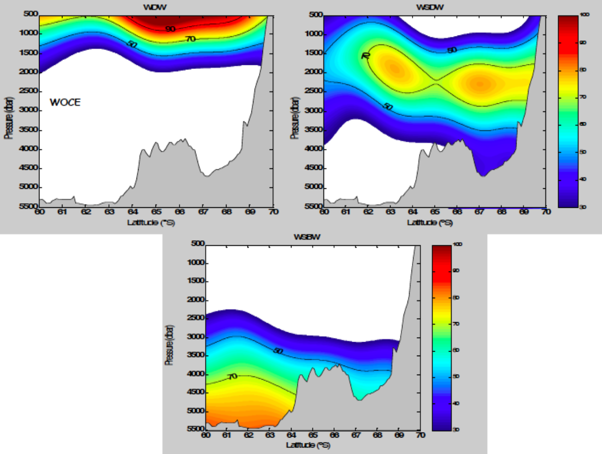
Evaluate the dense water masses in climate models.

Separation of water masses using OMP (optimal multiparameter) method

- OMP is based on simple linear mixing, starting from observed values of water mass parameters.
- Determine the contributions (in percentage) from predefined source water types (SWT).

OMP results

Weddell Sea - WOCE data



Weddell Sea Water Masses

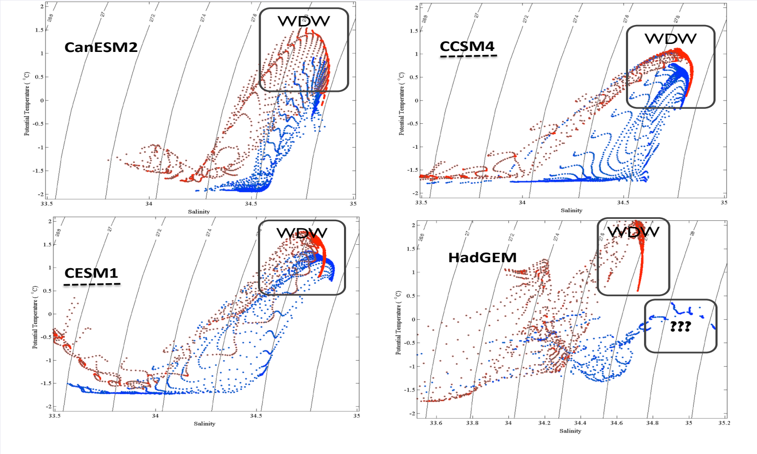
CMIP5 models intercomparison

CanESM, CCSM4, CESM1-CAM5, GFDL-CM3, Hadgem2-ES, IPSL-CM5A-MR,MIROC5, MIROC-ESM, MPI-ESM-MR

- Locate WDW highest percentage and track:
  - temperature changes
  - salinity changes
  - core depth changes

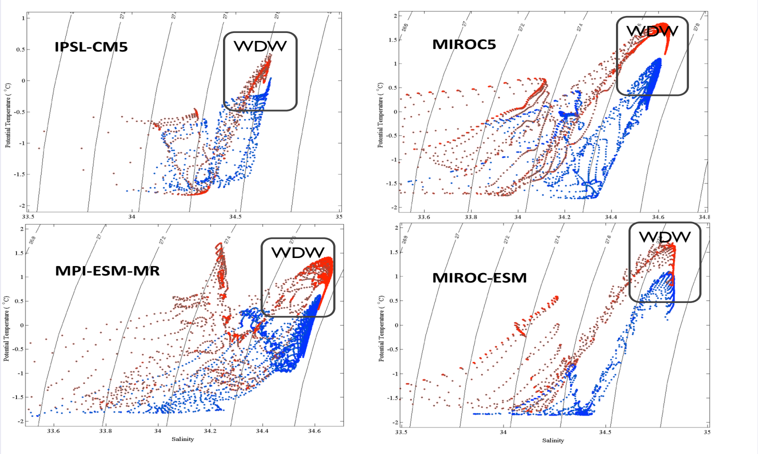
RESULTS: Weddell Sea Water Masses

T-S for historical (blue) and RCP8.5 (red)



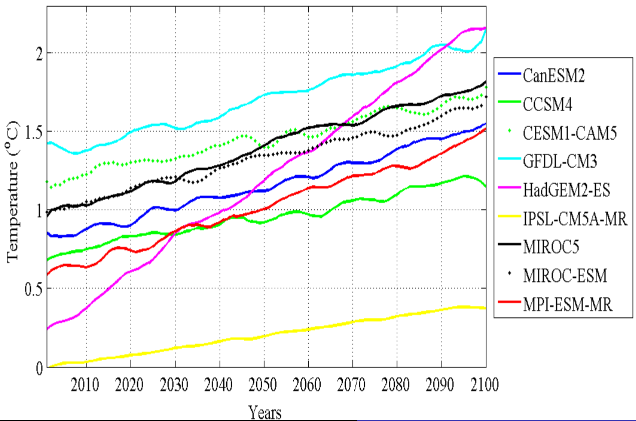
Weddell Sea Water Masses - RESULTS

T-S for historical (blue) and RCP8.5 (red)



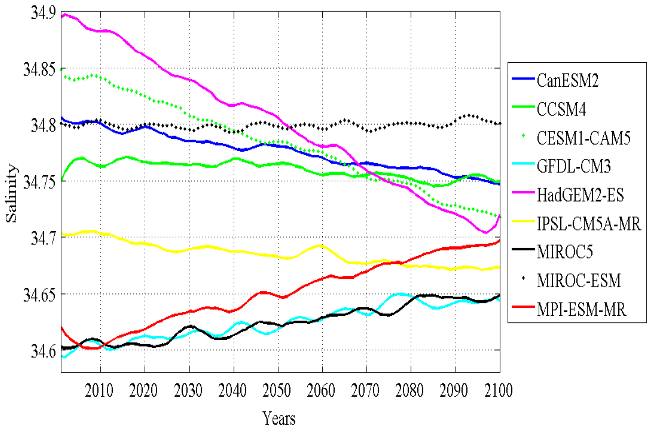
Weddell Sea Water Masses - RESULTS

All models show warming, however, their representation of the water masses is very different



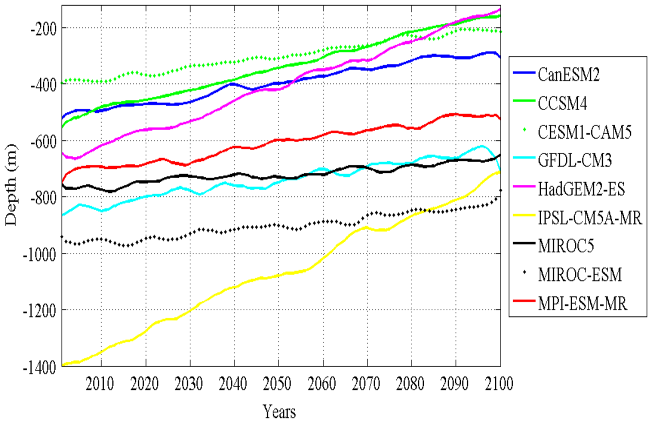
Weddell Sea Water Masses

WDW salinity: some models show freshening

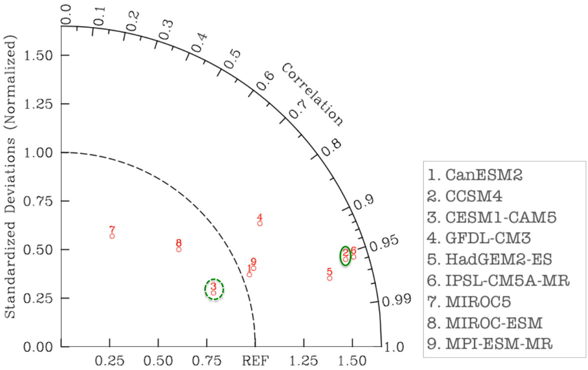


Weddell Sea Water Masses

WDW core depth changes



How well are CMIP5 models doing w/r WDW core depth?



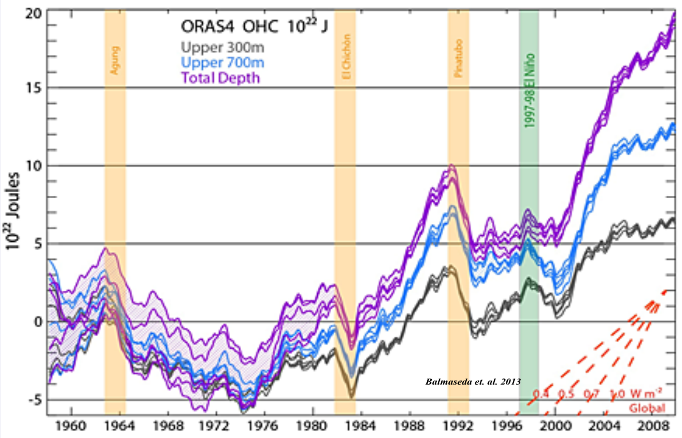
Weddell Sea Water Masses

Changes in CMIP5 models - Conclusions

- all models show warming
- most models show freshening 0.2 decrease (max)
- all models show WDW core is moving up (less dense)
- note: GFDL and HadGEM - poor WDW representation (historical)

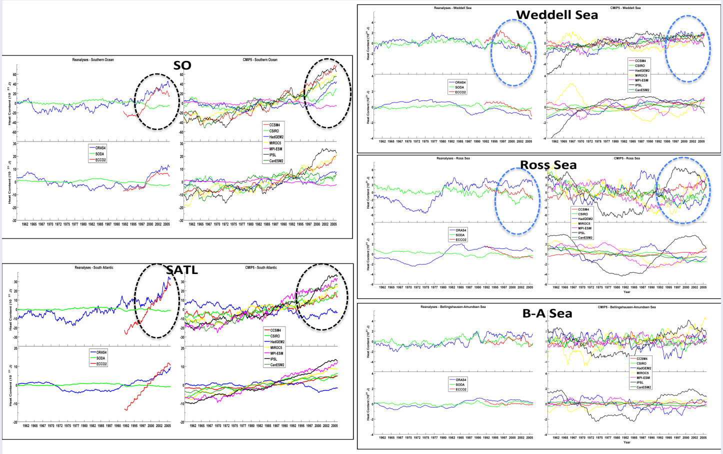
Ocean Heat Content

(Global OHC) ORAS4 Reanalysis *Balmaseda et al., 2013*



Time series of OHC

Reanalysis vs. CMIP5 for SO, SATL and Regional Seas



OHC trends

	Southern Ocean [W/m2]	
	0-2000m	700-2000m
ORAS4	1.23	0.03
SODA	-0.17	-0.09
ECCO2	7.54	1.95
CCSM4	3.49	0.84
CSIRO	0.73	0.26
HadGEM2	0.69	0.17
MIROC5	2.93	1.00
MPI-ESM	-0.17	-0.09
IPSL	3.70	1.19
CanESM2	2.75	0.49

	South Atlantic [W/m2]	
	0-2000m	700-2000m
ORAS4	0.42	0.07
SODA	-0.01	-0.01
ECCO2	2.69	1.32
CCSM4	0.31	0.10
CSIRO	0.33	0.14
HadGEM2	-0.21	-0.03
MIROC5	0.53	0.23
MPI-ESM	0.83	0.32
IPSL	0.73	0.34
CanESM2	0.72	0.15

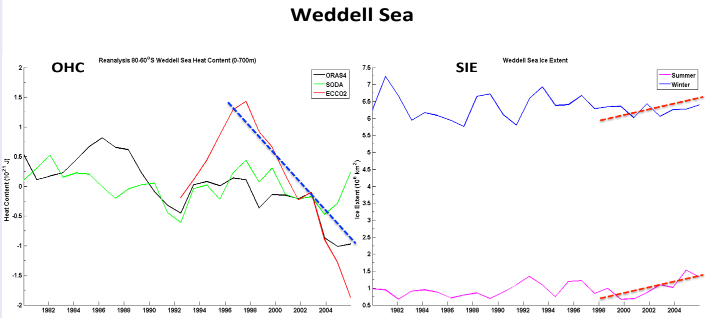
	Weddell [W/m2]	
	0-2000m	700-2000m
ORAS4	-0.20	-0.22
SODA	-0.00	-0.00
ECCO2	-1.47	-0.62
CCSM4	0.24	0.14
CSIRO	0.30	0.15
HadGEM2	0.46	0.31
MIROC5	-0.13	-0.28
MPI-ESM	0.13	0.03
IPSL	0.66	0.41
CanESM2	0.32	0.04

	Ross [W/m2]	
	0-2000m	700-2000m
ORAS4	0.80	0.38
SODA	-0.25	-0.13
ECCO2	-0.69	-0.85
CCSM4	0.30	0.05
CSIRO	-0.59	-0.27
HadGEM2	-0.25	-0.10
MIROC5	-0.47	-0.36
MPI-ESM	-0.38	-0.40
IPSL	0.31	0.06
CanESM2	-0.27	-0.23

	Bellingshausen-A. [W/m2]	
	0-2000m	700-2000m
ORAS4	0.80	0.31
SODA	0.13	0.02
ECCO2	0.31	-0.2
CCSM4	0.54	0.06
CSIRO	0.01	-0.03
HadGEM2	-0.55	-0.33
MIROC5	1.23	0.36
MPI-ESM	-0.04	-0.22
IPSL	0.67	0.34
CanESM2	-0.10	-0.15

Is OHC and SIE correlated?

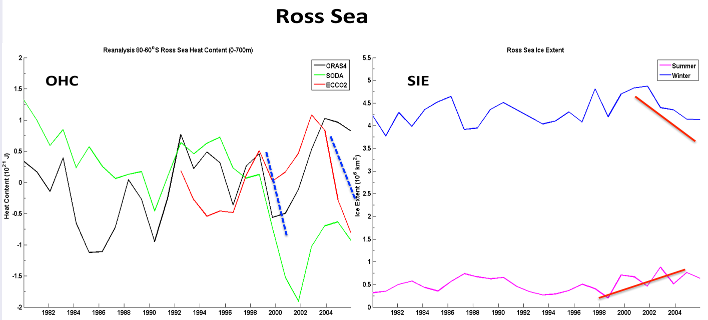
Annual avg - Weddell Sea from 1982



ORAS4 and summer SIE: r = -0.60 (99% confidence interval)
SODA and summer SIE: r = -0.42 (95% confidence interval)
ECCO2 and summer SIE: r = -0.48 (90% confidence interval)

Correlation of reanalysis OHC and satellite SIE

Annual avg - Ross Sea from 1982



ORAS4 and **winter** SIE: r = -0.37 (90% confidence interval)
SODA and **summer/winter** SIE: r = -0.56 (99% confidence interval)
ECCO2 and SIE: no significant correlation

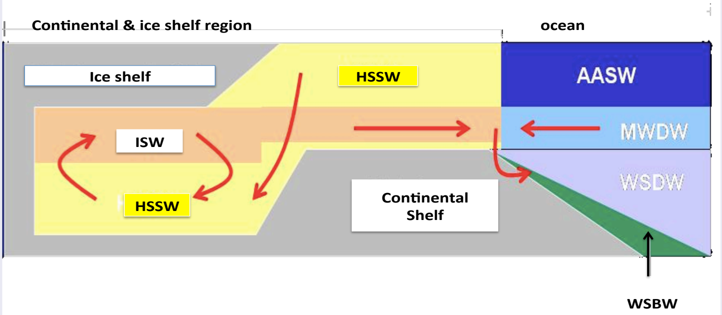
What is the *Bottom-line?*

Southern Ocean is Warming

- Warming of the deep water in the Weddell Sea has important implications for AABW formation, melting of pack ice, and the regional ocean–atmosphere heat transfer.
- Negative OHC trend in ice formation regions (WS and Ross) not captured by Cmip5 - How to explain the negative trend, is it real?
- Models missing important processes?

Ice shelves?

regional hydrography



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THANK YOU

OMP calculations

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\left\{
\begin{array}{ccccccccccccc}
x_1\theta_1 & + & x_2\theta_2 & + & x_3\theta_3 & + & x_4\theta_4 & + & 0 & = & \theta_{Obs} & + & R_\theta \\
x_1 S_1 & + & x_2 S_2 & + & x_3 S_3 & + & x_4 S_4 & + & 0 & = & S_{Obs} & + & R_S \\
x_1 O_1 & + & x_2 O_2 & + & x_3 O_3 & + & x_4 O_4 & - & \Delta O & = & O_{Obs} & + & R_O \\
x_1 N_1 & + & x_2 N_2 & + & x_3 N_3 & + & x_4 N_4 & + & \Delta N & = & N_{Obs} & + & R_N \\
x_1 P_1 & + & x_2 P_2 & + & x_3 P_3 & + & x_4 P_4 & + & \Delta P & = & P_{Obs} & + & R_P \\
x_1 Si_1 & + & x_2 Si_2 & + & x_3 Si_3 & + & x_4 Si_4 & + & \Delta Si & = & Si_{Obs} & + & R_{Si} \\
x_1 & + & x_2 & + & x_3 & + & x_4 & + & 0 & = & 1 & + & R_{CMass}
\end{array}
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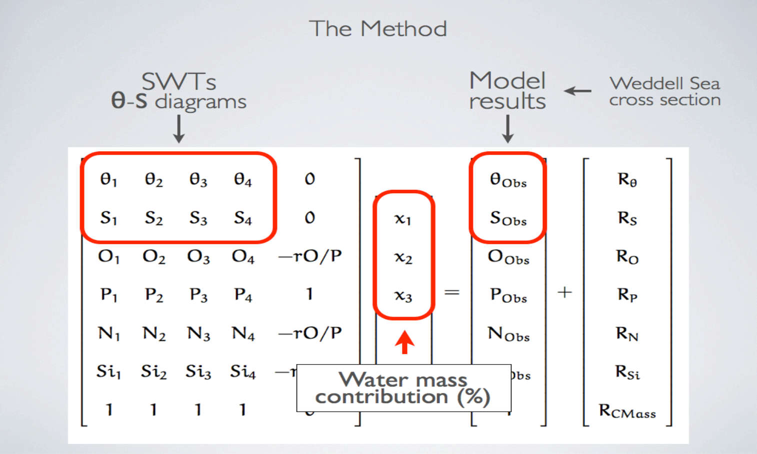
OMP calculations



OHC calculations

$$HC_m = \int_{z_1}^{z_2} \int_{y_1}^{y_2} \int_{x_1}^{x_2} \rho_0 c_p (T_m - T_c) \mathrm{d}x\mathrm{d}y\mathrm{d}z \qquad (1)$$

- HC_m is the monthly Ocean Heat Content value;
- ρ_0 the average density;
- c_p the specific heat of water;
- T_m the temperature at a given point (x,y,z,t);
- T_c, the climatological temperature for the specific month.