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Surface Water Mass Transformation: the role of eddies revisited

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Water Mass Transformation

- Transformation of sea water from one density class to another
  - Due to the action of air-sea buoyancy fluxes and interior diabatic processes (mixing)
- Walin 1982, Tziperman 1986, Speer and Tziperman 1992, Large and Nurser 2001 , Cerovecki et al. 2013, 2016, Groeskamp et al. 2019, many others
- Surface effect: integrate air-sea buoyancy flux between isopycnals (i.e. density classes)

Role of eddies
Review: Cerovecki and Marshall 2008

Cerovecki and Marshall identify two roles of eddies

i) By altering the air-sea buoyancy flux and isopycnal area
ii) By interior eddy buoyancy fluxes altering the interior diabatic flux
iii) They found these effects partially cancel
iv) We'll start by looking at effect i)

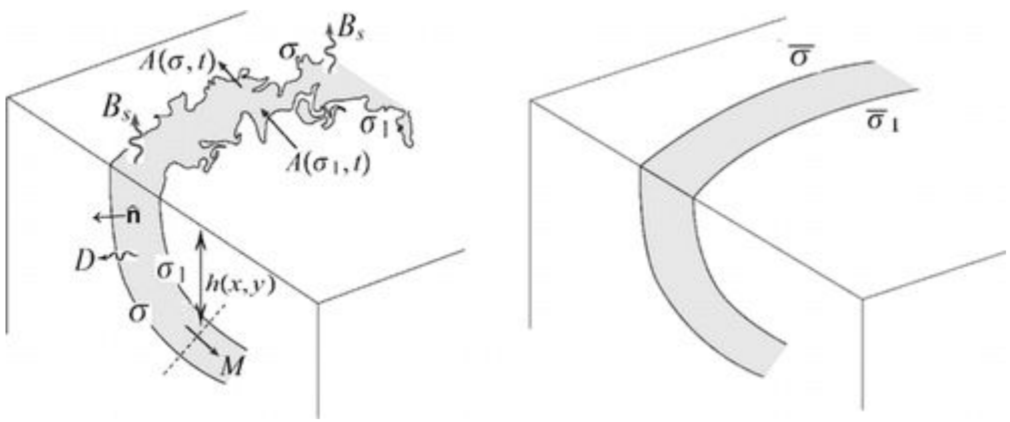
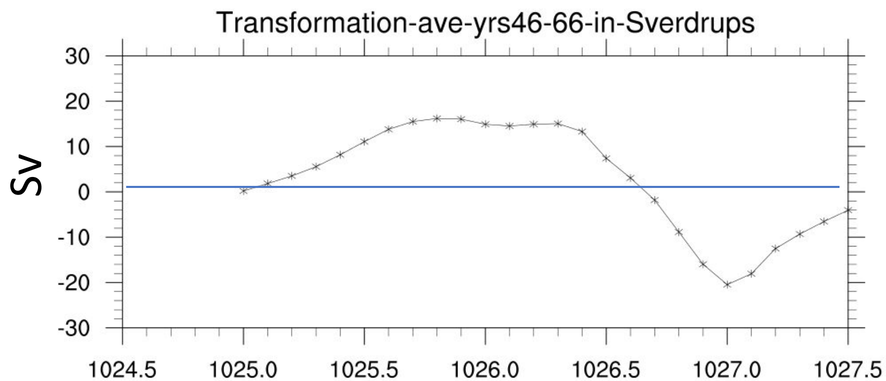


Fig. 8. Schematic showing application of the formalism due to Walin (1982): (left) Sketch of the outcrop in the presence of the eddies. The shaded region $R(\sigma, t)$ is bounded laterally by two outcropping isopycnals with density σ and reference density σ_1 (less than σ), and vertically by the sea surface and a control surface $z = -h(x, y)$. Lateral volume flow $A(\sigma, t)$ across the isopycnals, whose convergence drives net subduction M across the control surface $h(x, y)$ in the ocean interior, is induced by air–sea density flux B_S acting across the sea surface and the interior density flux D acting across the lateral isotherms: $\mathbf{n}_\sigma$ is the unit vector perpendicular to the isopycnals. (right) The corresponding picture after coarse graining, which spatially smooths isopycnals and the outcropping window bounded by σ and σ_1.

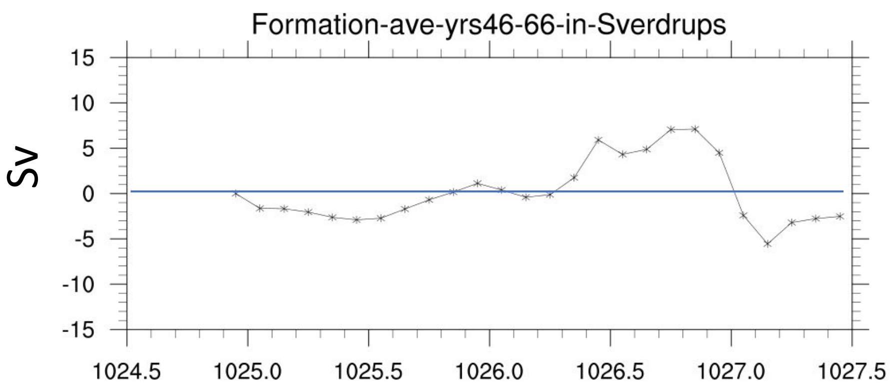
Water-mass transformation in high-res CESM

- Focus on Southern Ocean
  - Especially SubAntarctic Mode Water (SAMW) region
- CESM-HR
  - 0.1deg ocn, 0.25deg. Atm
  - Quite realistic MLD and SST variability in Southern Ocean
  - Small et al 2014 JAMES, 2019 JCLI, 2020 Cli. Dyn.
- Method:
  - Start with daily data of SST, SSS, surface heat flux, surface freshwater flux
  - Compute potential density using POP EOS
  - Compute air-sea buoyancy flux from heat+freshwater flux (e.g. Cerovecki et al 2011)
  - Compute water-mass transformation in predefined density bins of 0.1kgm^{-3} from 1025 to 1028 kgm^{-3} (e.g. Cerovecki et al 2013, 2016)
  - Time-average over 20 years
- Sensitivity to spatial scale: repeat above but spatially smooth daily density and buoyancy flux to remove eddies

Transformation & Formation in CESM-HR



Formation-ave-yrs46-66-in-Sverdrups



Potential density kgm^{-3}

20 year average in domain shown below: does not include Antarctic margin

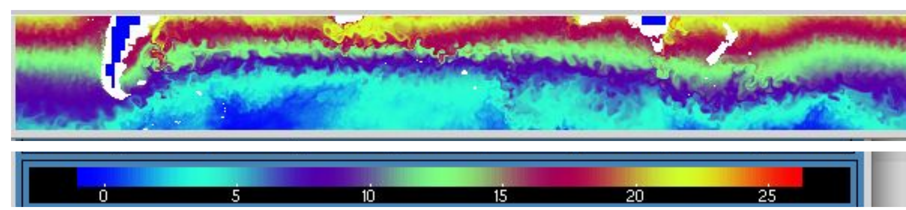


Fig. shows a daily average SST

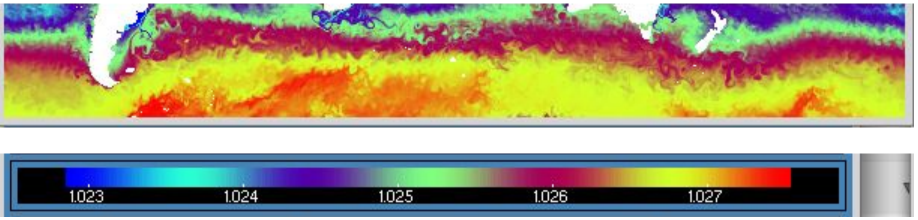
Note strong formation in 1026.45 to 1026.95 kgm^{-3} range of pden, the SAMW range in model

Part 1: Investigate role of eddies, small scales

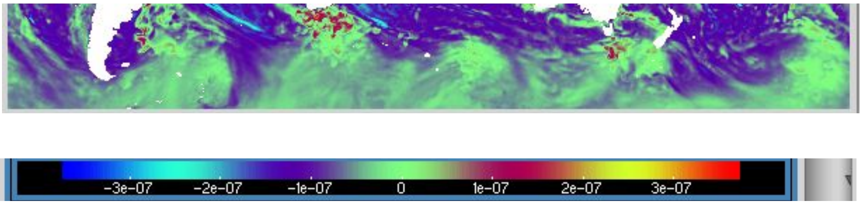
- Apply same analysis but the daily potential density and air-sea buoyancy flux are spatially smoothed to remove eddies

Illustration of smoothing: 3-5deg boxcar smoothing. One day of full and smoothed data.

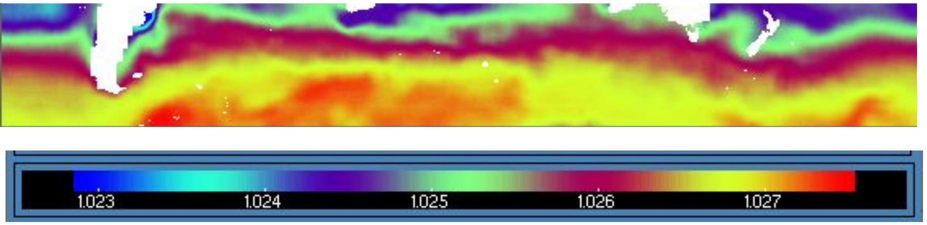
1 day potential density



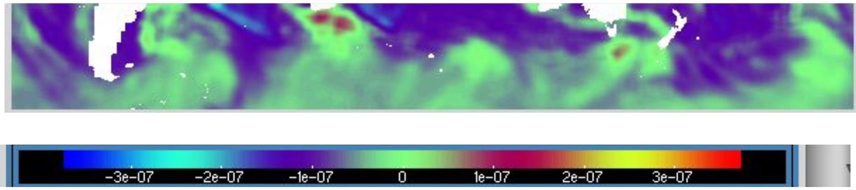
1 day air-sea buoyancy flux



1 day potential density, smoothed



1 day air-sea buoyancy flux, smoothed



Comparison of Full and Smoothed case

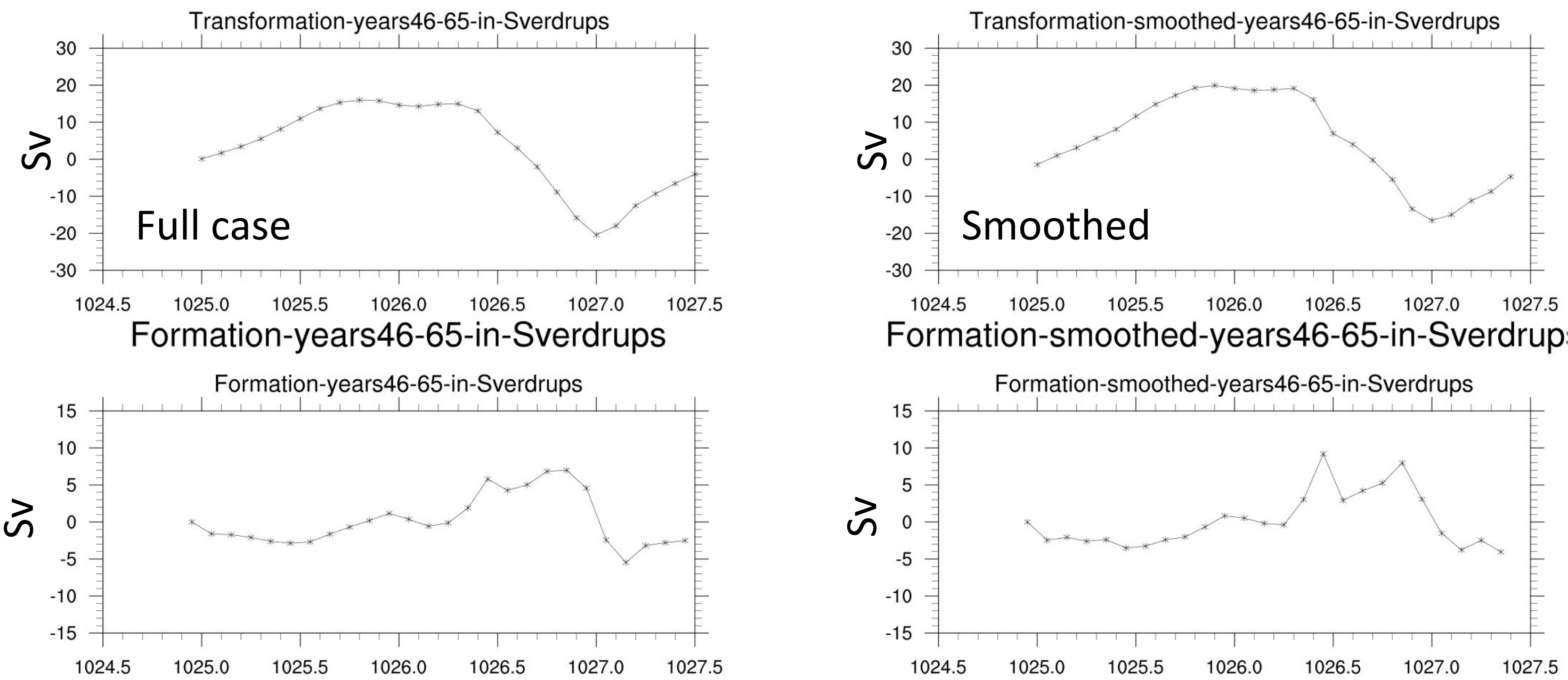
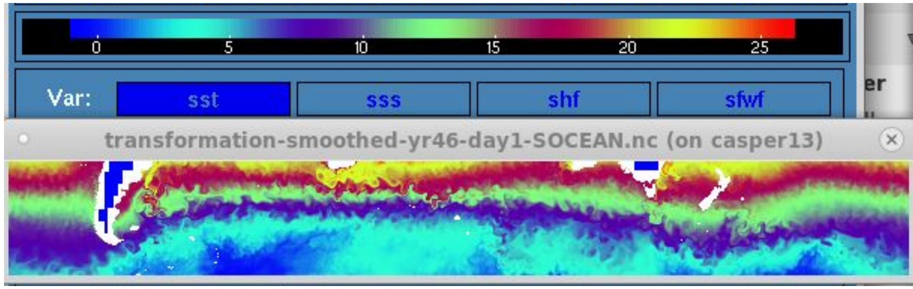


Figure 4. Water Mass Transformation in S. Ocean from 20 years of daily data, CESM-HR. Left panels: from full data. Right panels: daily data of air-sea buoyancy flux and sea surface density is smoothed spatially. Inset shows the domain of analysis (a snapshot of SST is shaded).



Significant Differences

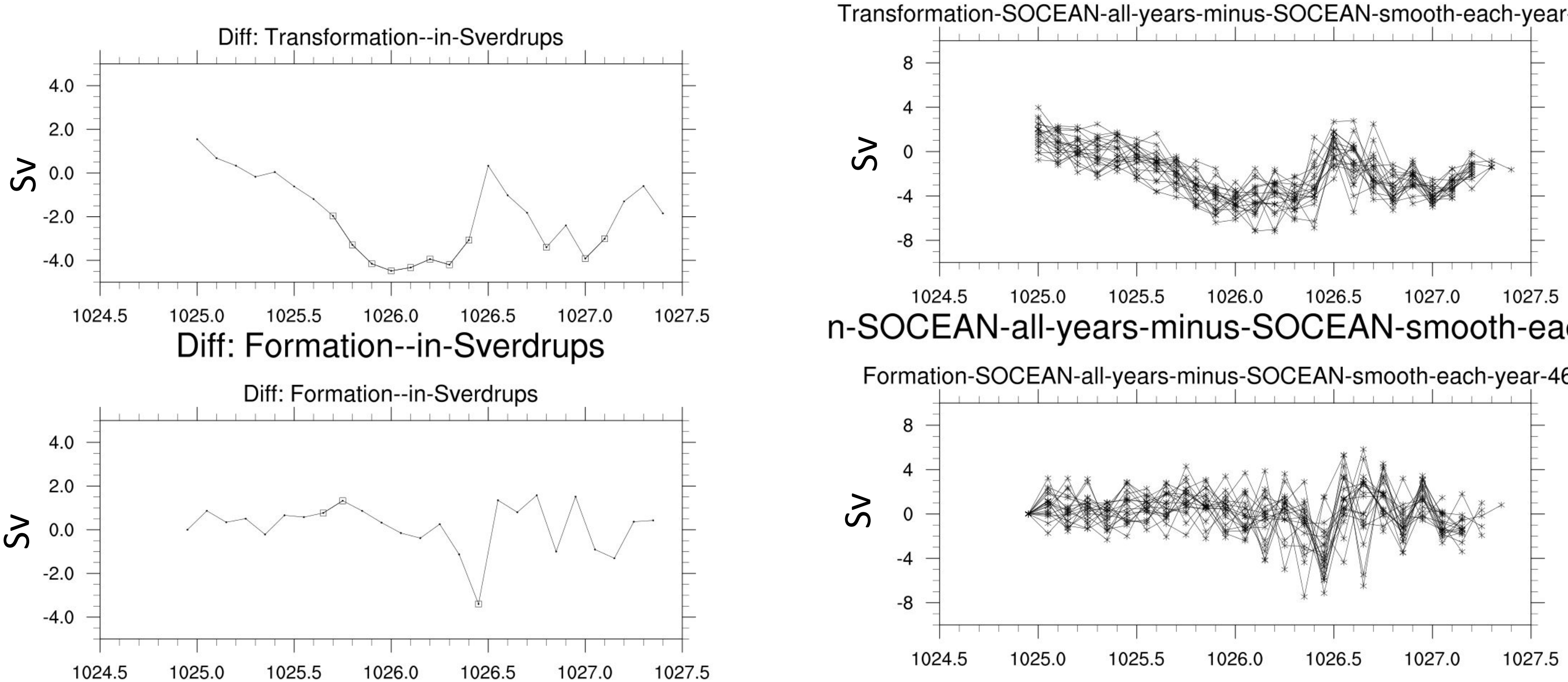
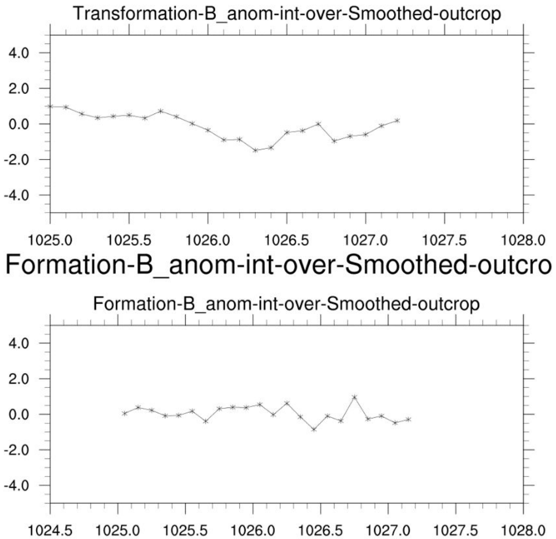


Figure 5. The difference between full field and spatially smoothed fields, for the same 20 years. Left: mean difference. Points with squares are significant at 95% according to the student t-test. The dip in transformation between 1025.7 and 1026.4 then around 1027.0, is significant, as is the negative spike in formation difference at 1026.45. Right: individual years

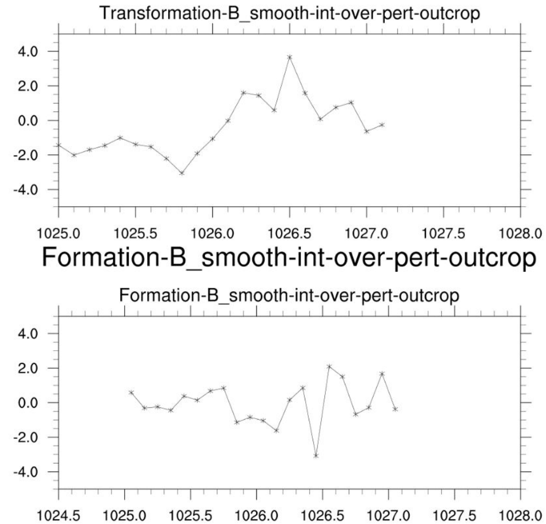
Decomposition of Full minus Smoothed WMT

Effect of small-scale buoyancy flux



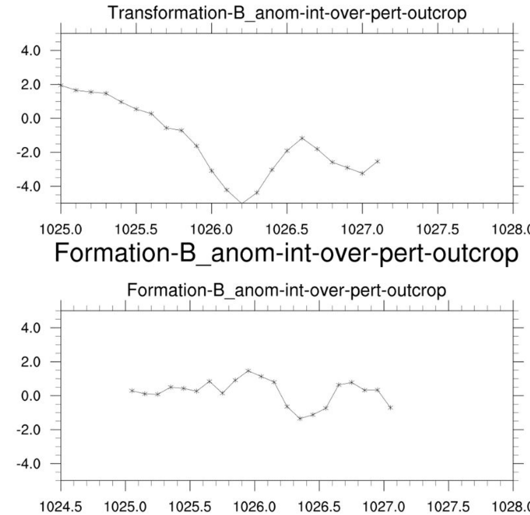
Term i) Buoyancy flux anomaly integrated over smooth outcrop

Effect of small-scale surface density outcrop



Term ii) Buoyancy flux smoothed integrated over anomalous outcrop

Effect of co-variability of small-scale surface density outcrop and buoyancy flux



Term iii) Buoyancy flux anomaly integrated over anomalous outcrop

Total difference

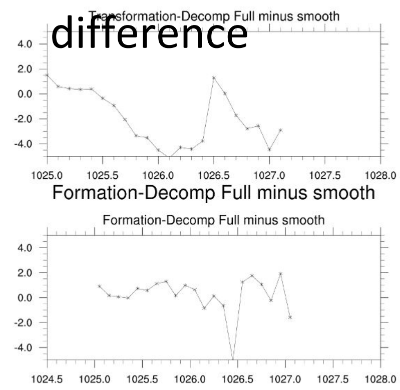


Fig. 7. Years 46-50. Here we decompose into 3 terms as labelled above. For reference the total difference (Full-Smooth) is shown at bottom right.

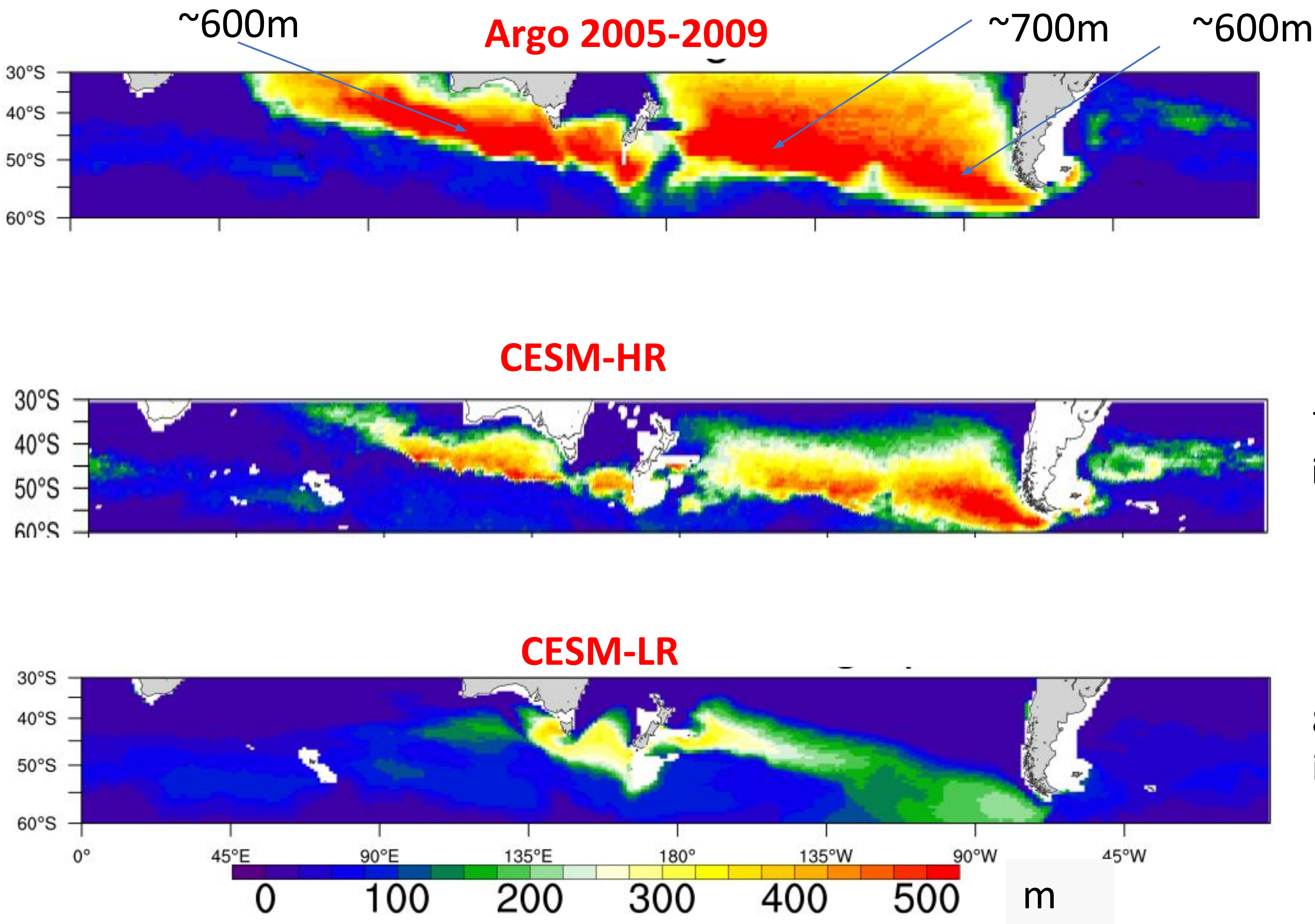
"Buoyancy flux smoothed integrated over anomalous outcrop" has an interesting role and appears to determine the spikes in **formation** difference.

Buoyancy anomaly integrated over anomalous outcrop (i.e. covariance-like term) governs **Transformation difference**.

Part 2- Resolution Comparison

- Do eddy effects on WMT explain the differences of SAMW between low and high resolution models?
- Community Earth System Model High Resolution (CESM-HR)
  - 0.1deg. Ocean, 0.25deg. Atmosphere (Small et al. 2014)
- Community Earth System Model Low Resolution (CESM-LR)
  - 1deg. Ocean, 0.25deg. Atmosphere
  - Note: atmosphere resolution the same
- ~100 year runs initialized from obs

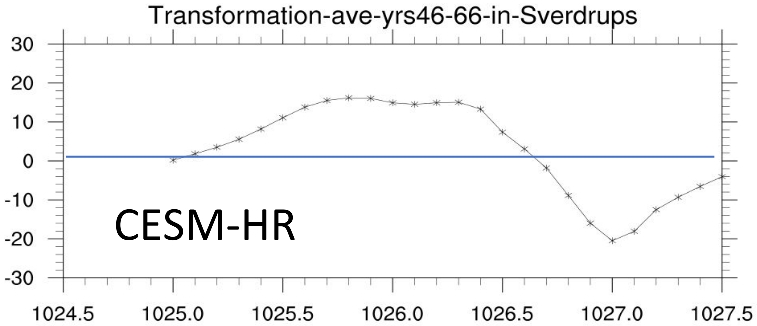
SAMW thickness – annual mean

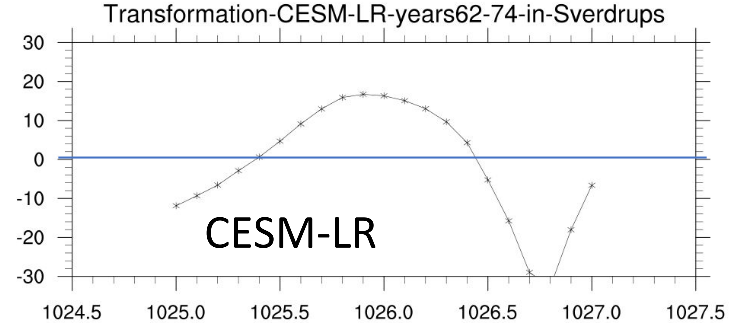


70-80 years after initialization from obs

80-90 years after initialization from obs

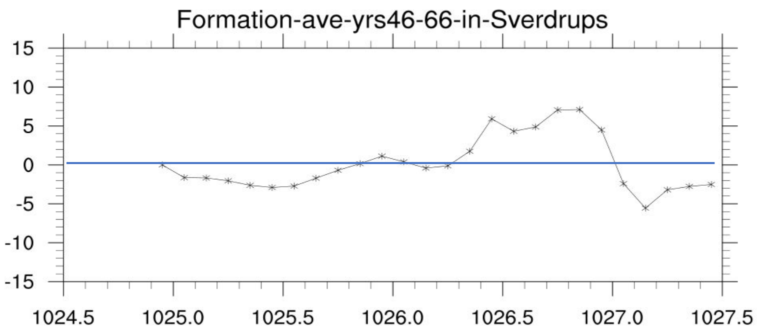
Potential densities between *1026.5* and 1027.1kgm^{-3}, and PV less than *5010^{-12}m^{-1}s^{-1}**

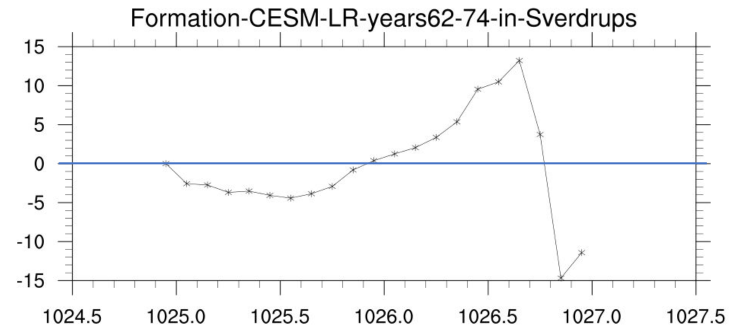


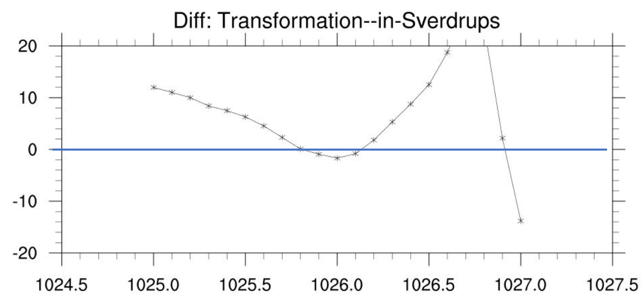


Formation-ave-yrs46-66-in-Sverdrups

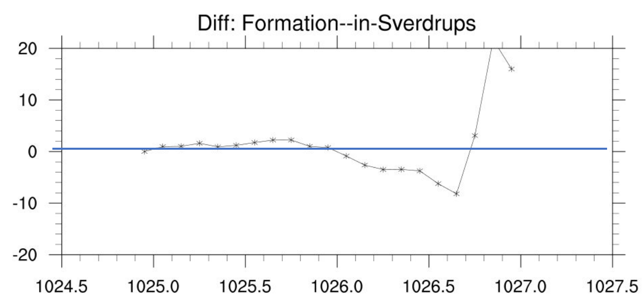
Formation-CESM-LR-years62-74-in-Sverdrup







Diff: Formation--in-Sverdrups



CESM-LR has very different WMT and WMF:
Positive WMT over smaller range of densities
Larger negative WMT at lower density than CESM-HR
WMF over a more restrictive range of densities

Summary

- Explicit Influence of eddies on WMT is small but significant and non-negligible-
  - removing the effect of eddies on the surface calculations leads to larger transformation
  - Eddying surface density has bigger impact than eddying surface buoyancy flux, but the combination of the two is important
- Differences between low-resolution and high-resolution CESM are much greater than the explicit eddy effects discussed above
  - Mean flow is also different (implicit eddy effect?-CPT?)
  - Mean surface buoyancy flux and surface density are different
  - Winter Mixed layer Depth very different Small et al. 2020 Clim. Dyn.
  - See also Bryan, Gent, Tomas, 2014 –differences between HR and LR are not just due to eddies, parameterizations
- Higher volume SAMW found in high resolution CESM experiments
  - consistent with deeper winter MLD, and subduction and consequent advection

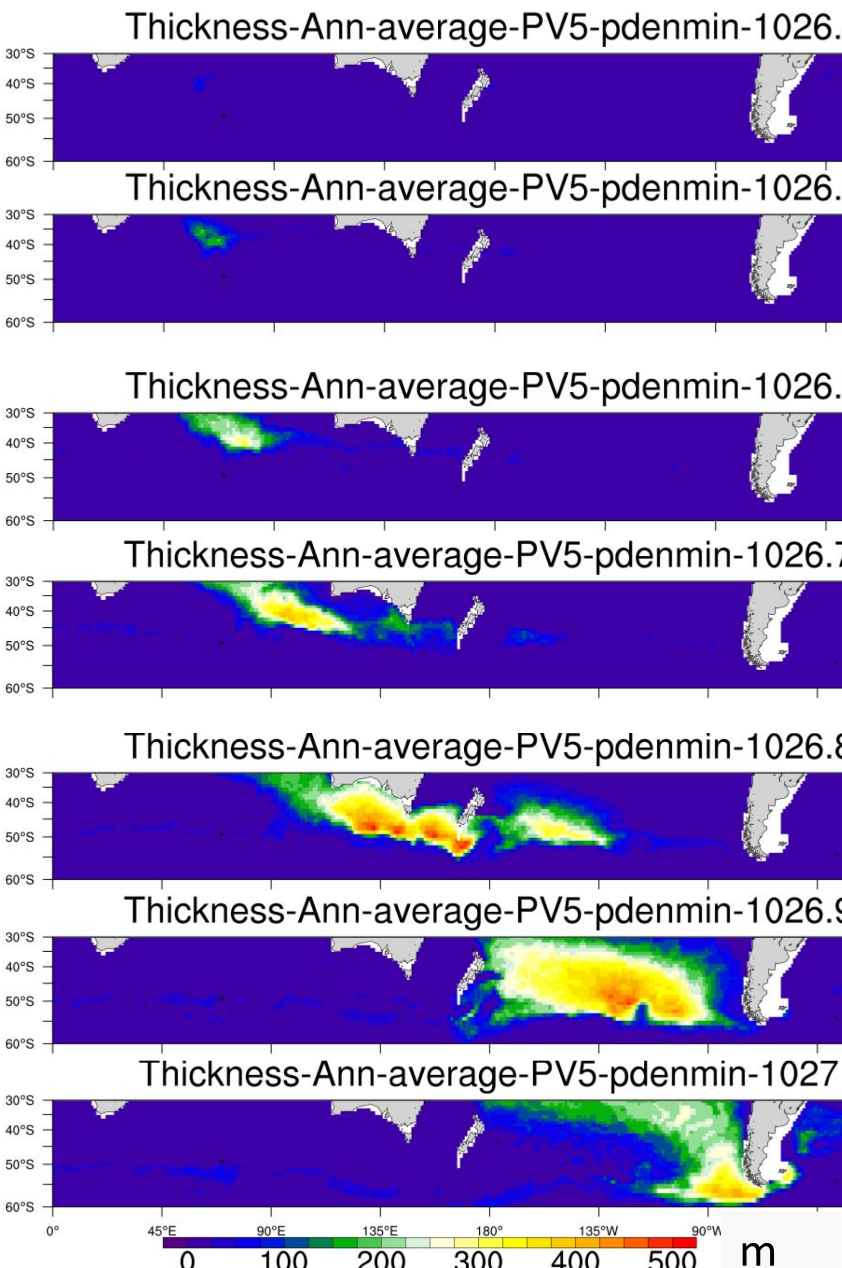
Way forward

- Investigation of role of salinity transport in SAMW variability
- Water Mass Transformation (WMT) analysis using state of the art observations including satellite salinity
- WMT analysis to understand the SAMW differences between models
- Full volume budgets for SAMW
- Using Surface Flux products, Southern Ocean State Estimate, CESM, Argo and satellite observations

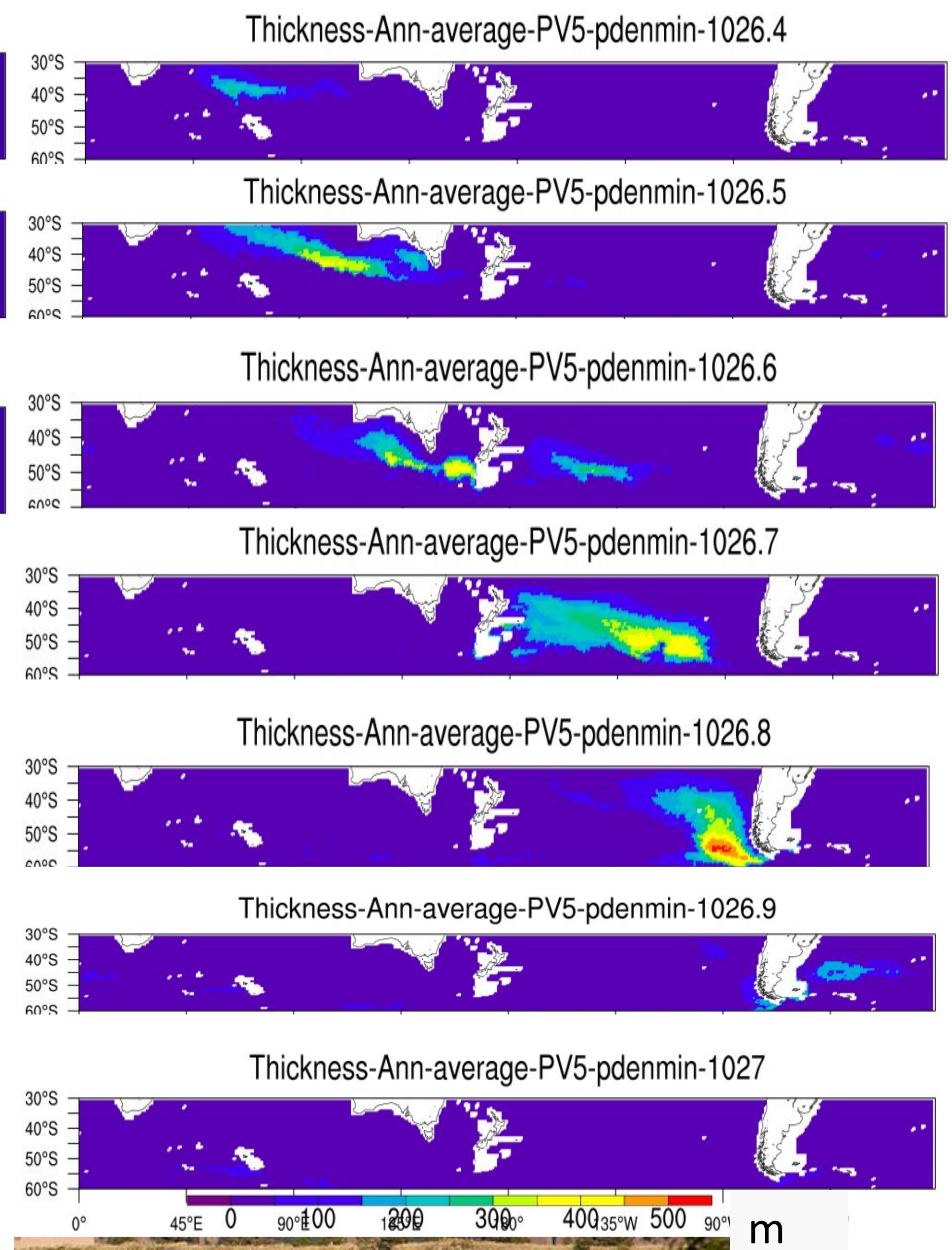
Extra slides

Thicknesses in pden classes:PV<5E-11

Argo

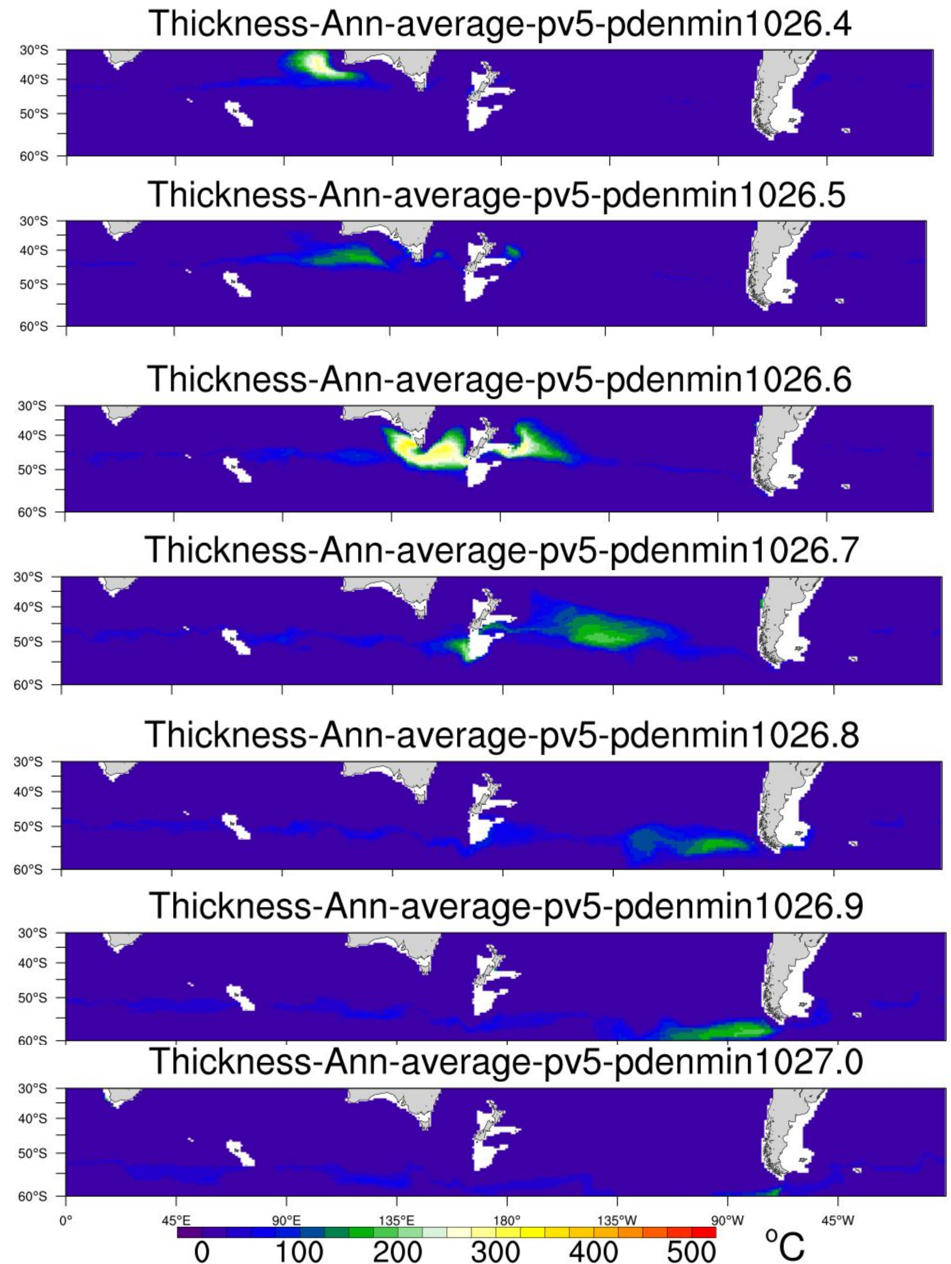


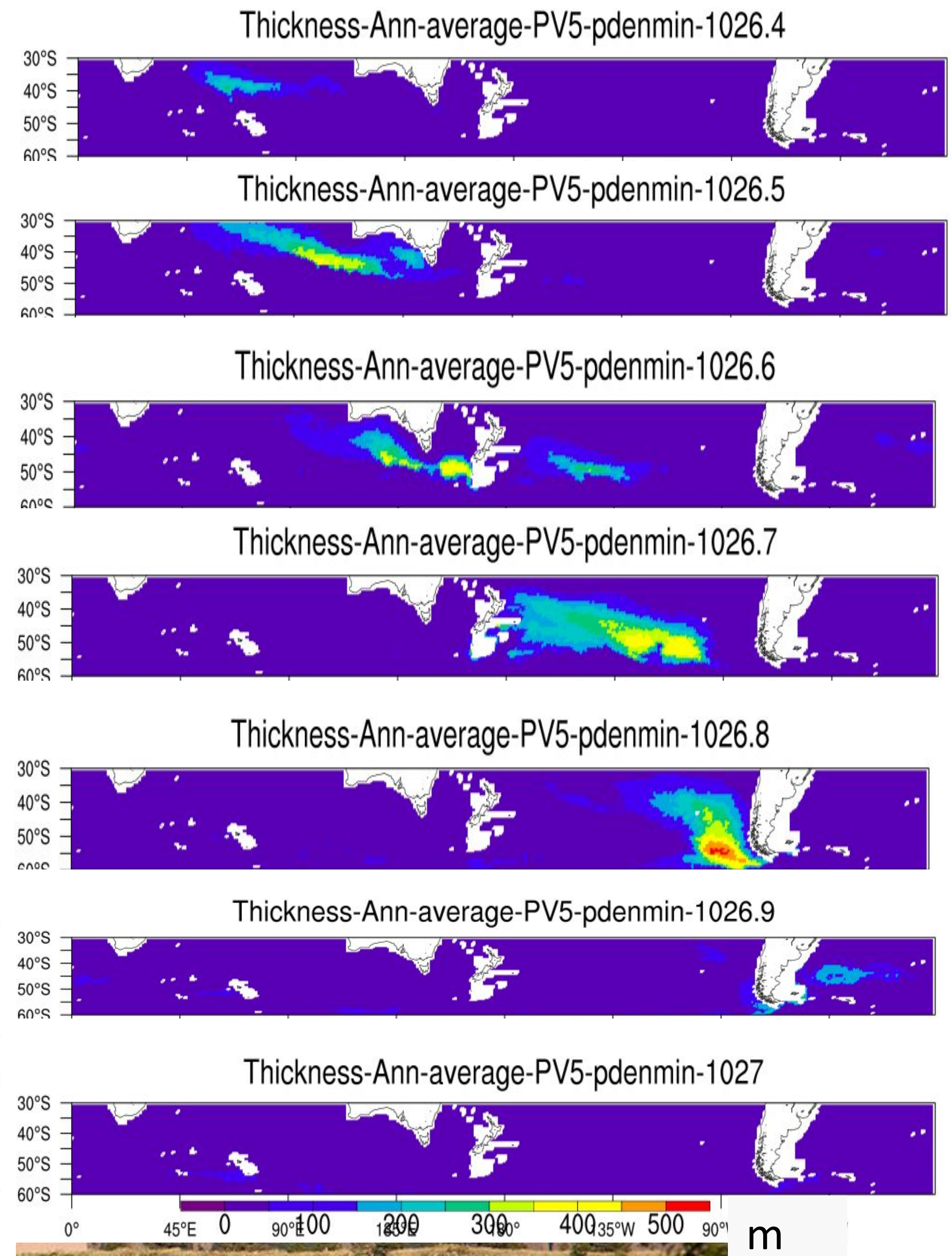
CESM-HR



Thicknesses in pden classes:PV<5E-11

CESM-MR | CESM-HR





SubAntarctic Mode Waters (SAMW) and Deep Mixing Band (DMB)

(a)

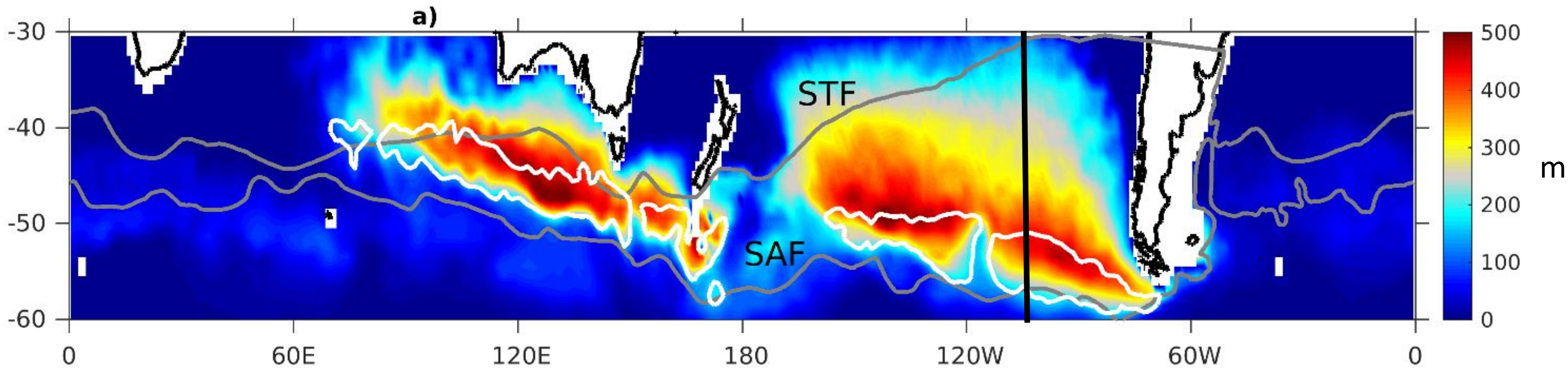


Fig. 2. a). Annual mean thickness of SAMW from ARGO (Roemmich and Gilson product), defined as a water mass with densities between 1026.6 and 1027.1kgm^{-3}, and PV less than 40*10^{-12}m^{-1}s^{-1}. Overlaid thick white contour is 300m mixed layer depth in September in ARGO. The thick grey contours are climatological positions of the fronts given by Orsi et al. (1995): STF, and SAF as labelled.

Courtesy Ivana Cerovecki, Dan Whitt