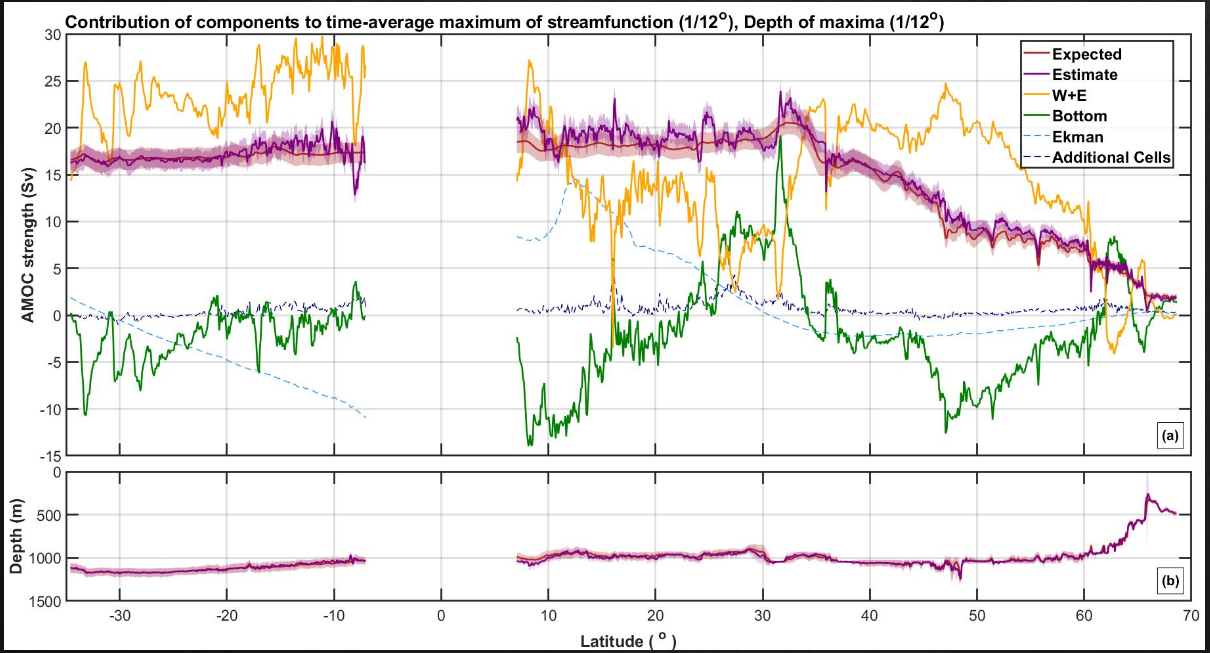
Decomposing the time-mean Atlantic Meridional Overturning Circulation and its variability with latitude

Maximum overturning streamfunction with latitude



$1/12^{\circ}$ **HadGEM-GC3.1 data**

- ➔ Decompose AMOC transport using:
  - ◆ West/East boundary densities.
  - ◆ Bottom velocities, Wind stress.

$$\tilde{T}_{Est} = T_W + T_E + T_{bot} + T_{Ekm} + T_{AC}$$

- ➔ Stability of estimate
- ➔ Significant latitude dependence of contributing components
  - ◆ Boundary currents
  - ◆ Gulf / Carribean densities significant
  - ◆ Decoupling W / E difficult
- ➔ Resolution impacts:
  - ◆ Greater max strm with resolution
  - ◆ Depth coords. (horizontal mixing)
  - ◆ Bottom cont. weakens significantly in 1° at high northern latitudes, weak DWBC
  - ◆ Bathymetry

@tjmor95

tomas.jonathan@earth.ox.ac.uk

Tomas Jonathan, *Helen Johnson, David Marshall, Mike Bell*

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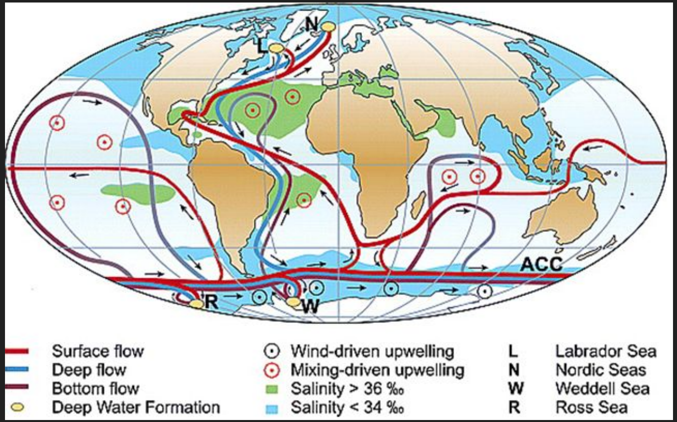


Kuhlbrodt et al. 2007

Tomas Jonathan [1], Mike Bell [2], Helen Johnson [1] & David Marshall [1]

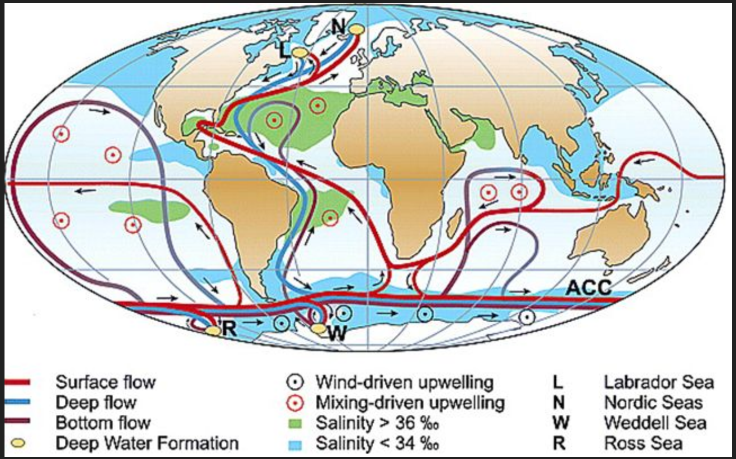
April 26th 2021

University of Oxford [1], Met Office [2]

Meridional Overturning Circulations (MOCs)

MOCs:

- ➔ System of surface and deep currents
- ➔ Transport heat, salt, carbon, nutrients etc.
- ➔ Connect ocean's surface and atmosphere with deep sea
- ➔ Critical to global climate system



Kuhlbrodt et al. 2007

Mathematically:

- ➔ Zonally - and depth - integrated northward volume transport

$$T(z;y) \equiv \int_W^E \int_{-H}^{z} v_N \, dz' \, dx$$

Atlantic MOC Variability

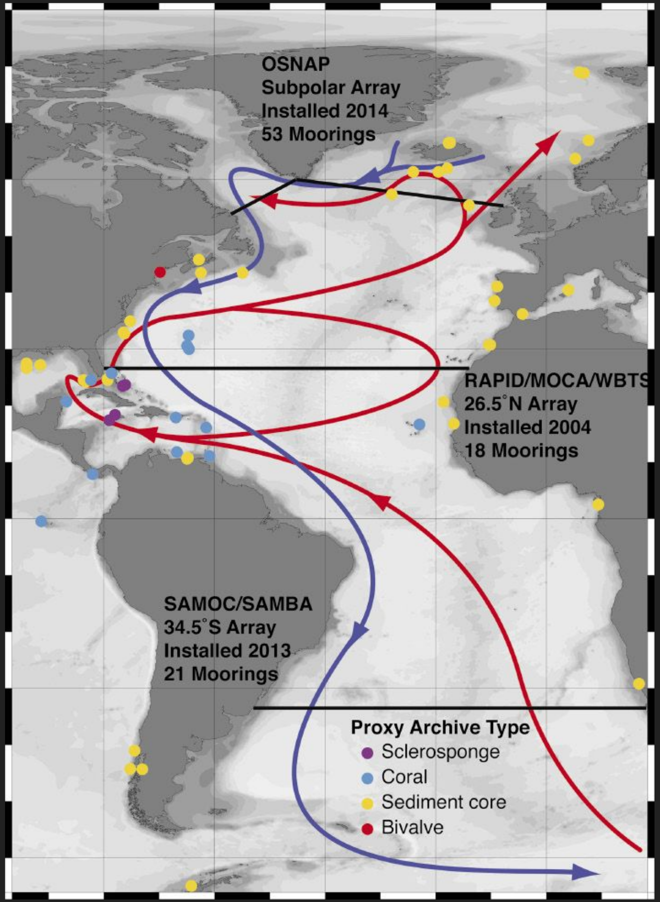
Temporal:

- ➔ Varies on all timescales
- ➔ Intra-annual and seasonal: Wind stress
- ➔ Inter-annual and decadal: Geostrophic component
- ➔ Centennial: convective mixing in Labrador Sea and NAO - (Vellinga, HadCM3)

Other:

- ➔ Atlantic multidecadal variability (AMO index)
- ➔ Possible AMOC slowdown
- ➔ Coherence throughout basin
  - ◆ Gyres vary at different timescales

Need to distinguish between natural MOC variability and climate change driven variability

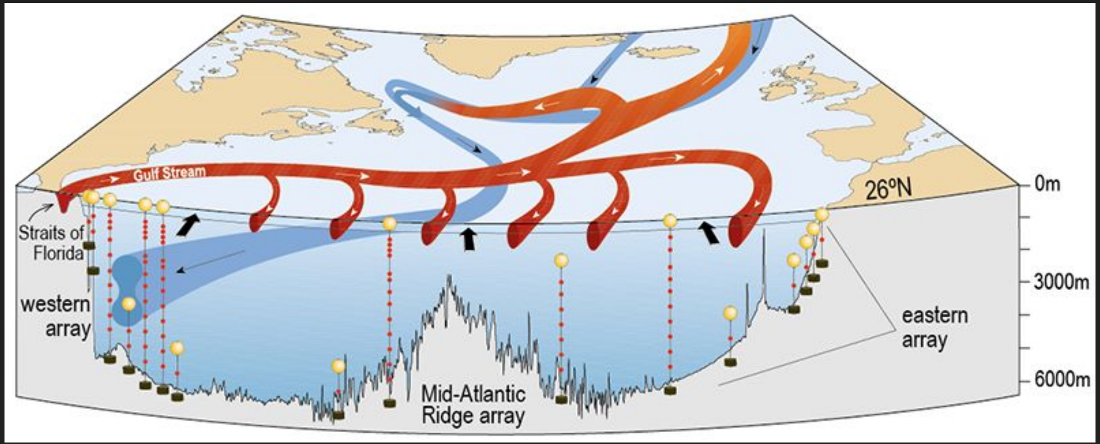


https://doi.org/10.22498/pages.24.1.51

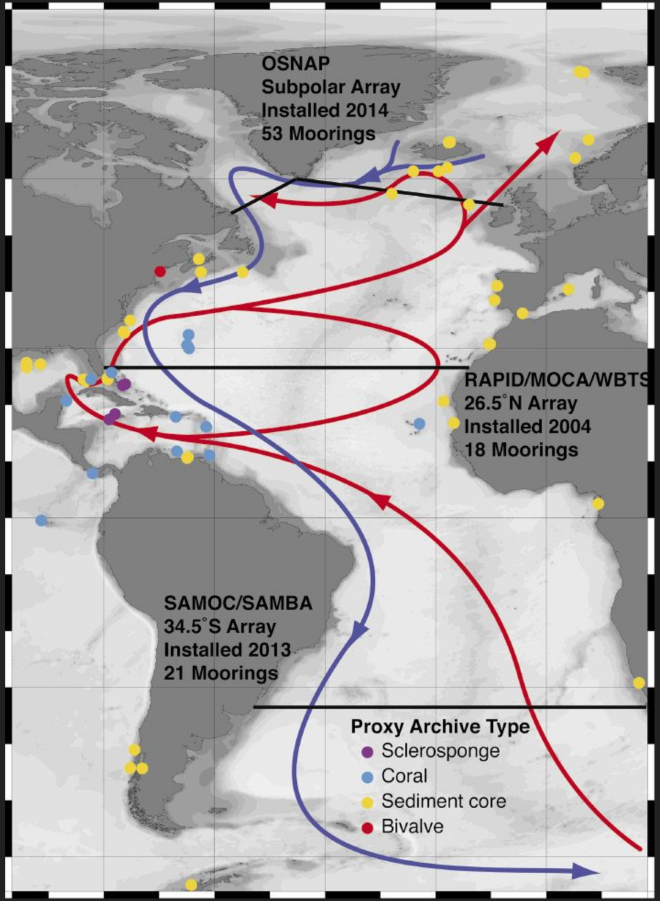
Foundation

- Densities and thermal wind used before to reconstruct transport
  - Lee and Marotzke (1998) in the Indian Ocean
  - Geostrophic RAPID methodology
  - Reducing a complex 3D system down to 2D

$$\frac{\partial v}{\partial z} = -\frac{g}{\rho_0 f}\frac{\partial \rho}{\partial x}$$



https://www.rapid.ac.uk/research/tenyearsofrapid.php

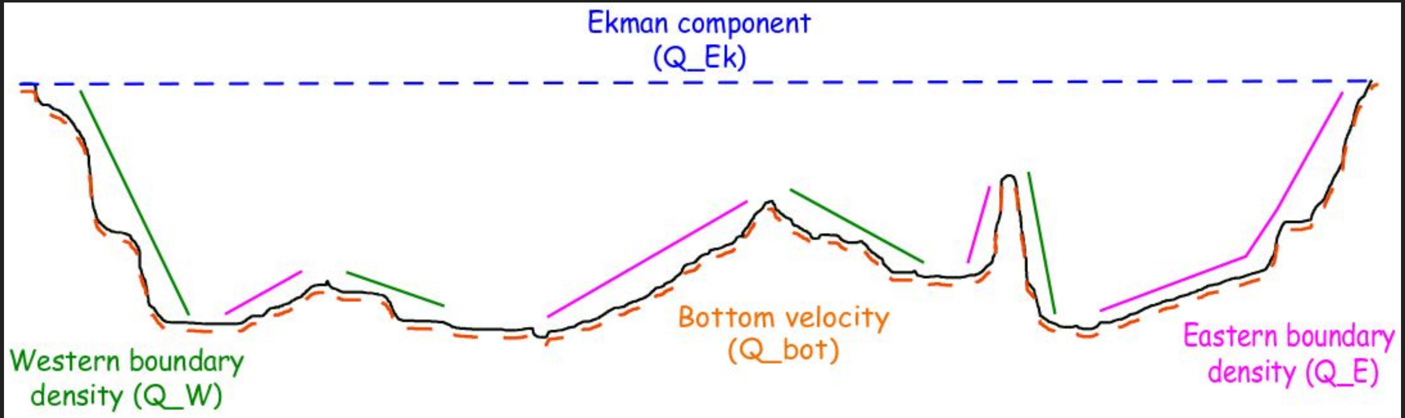


https://doi.org/10.22498/pages.24.1.51

Decomposition

Describing AMOC in terms of boundary conditions:

- ➔ Eastern and Western boundary densities
- ➔ Bottom component
- ➔ Ekman transport
- ➔ No need to know about conditions on the interior of the domain
- ➔ Multiple pairs of eastern and western boundaries possible at depth



$$\tilde{T}_F(z_k; y_j) = T_W(z_k; y_j) + T_E(z_k, y_j) + T_{bot}(z_k; y_j) + T_{Ekm}(z_k; y_j)$$

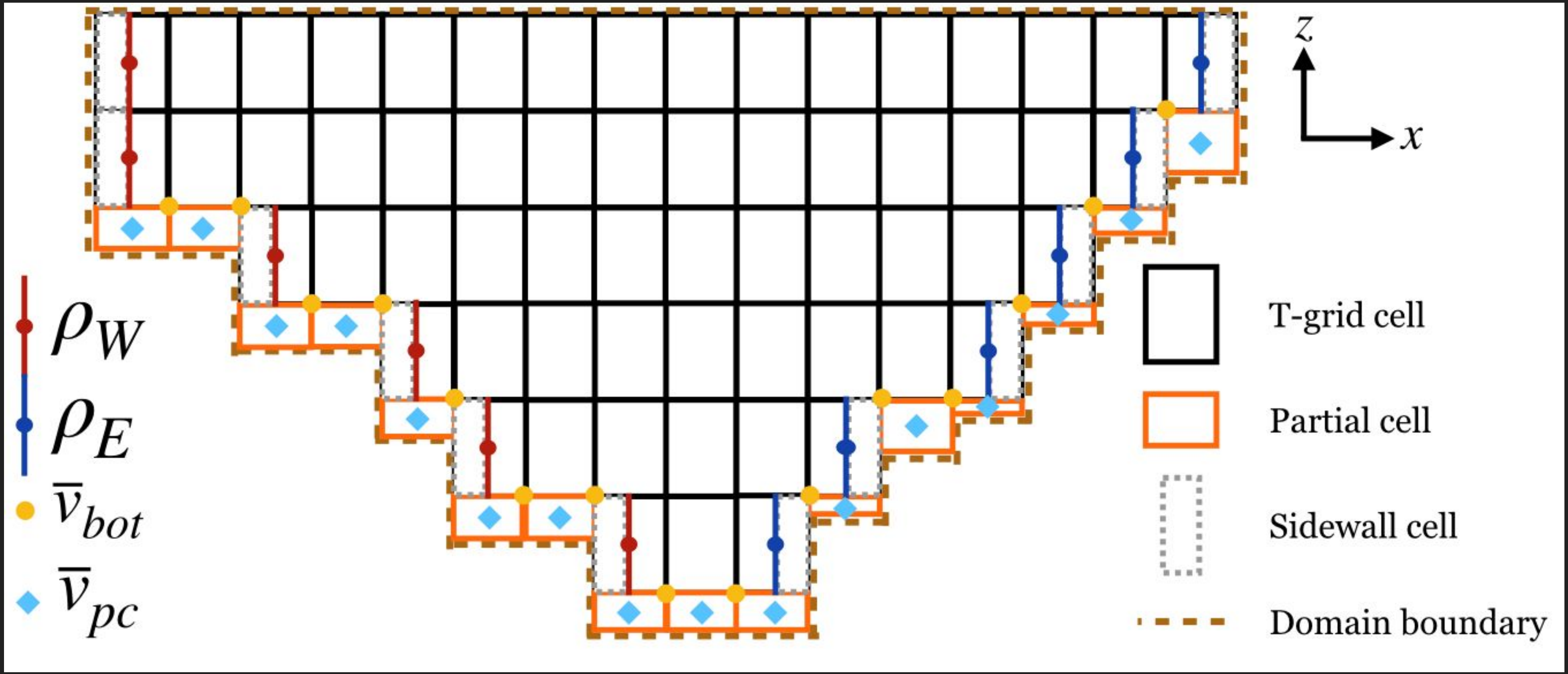
Decomposition allows us to quantify physical processes driving AMOC variability

Calculation

$$\tilde{T}(z;y) = \frac{g}{\rho_0 f(y)} \int_{-H_{\max}(y)}^{z} (z-z')\rho_W(z';y)\mathrm{d}z' - \frac{g}{f(y)\rho_0} \int_{-H_{\max}(y)}^{z} (z-z')\rho_E(z';y)\mathrm{d}z' + \int_{W(z;y)}^{E(z;y)} Z_{bot}(x,z;y)v_{bot}(x;y)dx - \frac{1}{\rho_0 f(y)} \int_{W(z;y)}^{E(z;y)} \int_{-h(x;y)}^{z} \frac{\tau_S^x(x;y)}{h(x;y)} \mathrm{d}z'\mathrm{d}x. \quad (1.$$

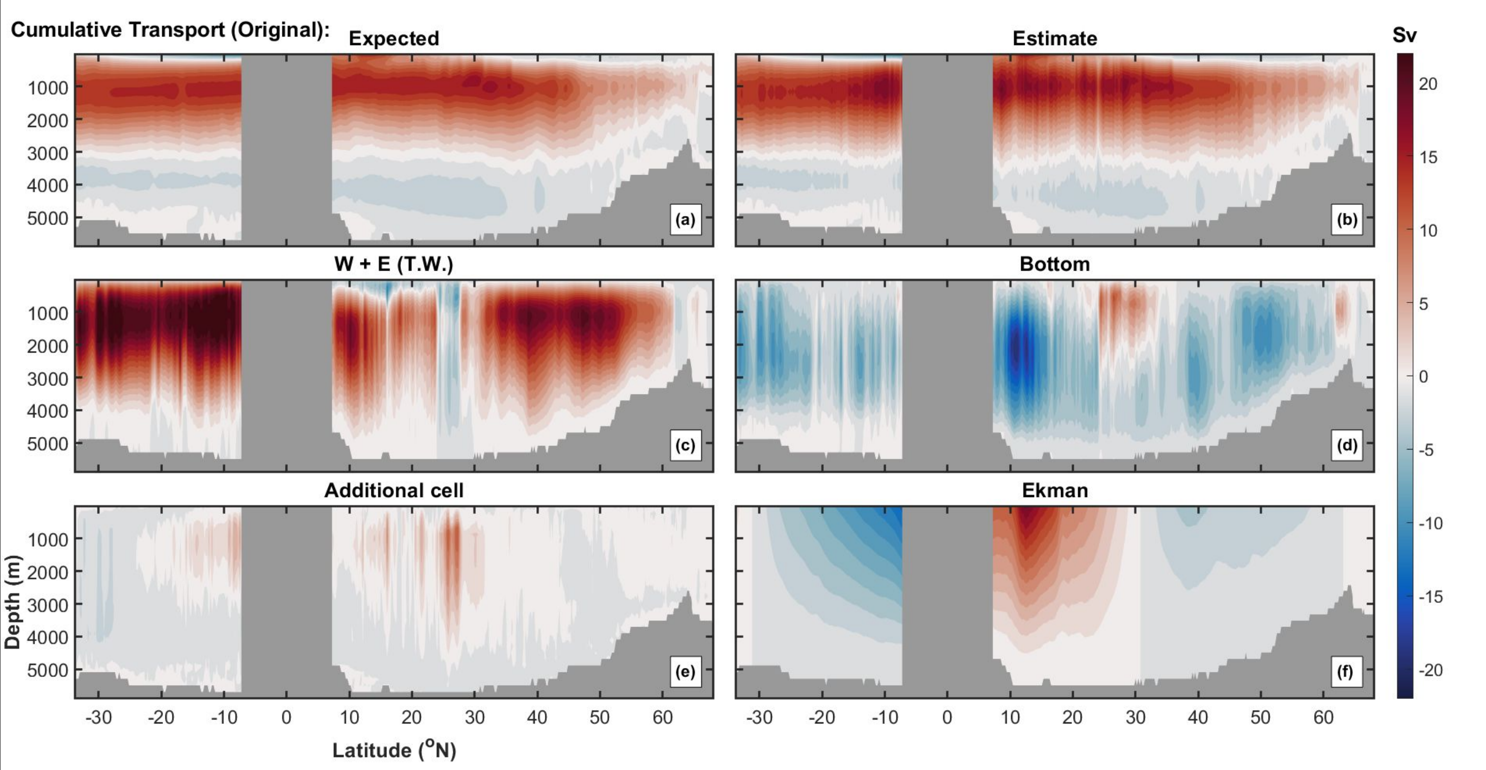
- ➔ We reference the boundary densities to basin average density
- ➔ Application within HadGEM-GC3.1 HighResMIP annual data

Inclusion of “Additional Cells”



$$\tilde{T}_F(z_k; y_j) = T_W(z_k; y_j) + T_E(z_k, y_j) + T_{bot}(z_k; y_j) + T_{Ekm}(z_k; y_j) + T_{AC}(z_k; y_j)$$

Time-mean view (Latitude - depth)

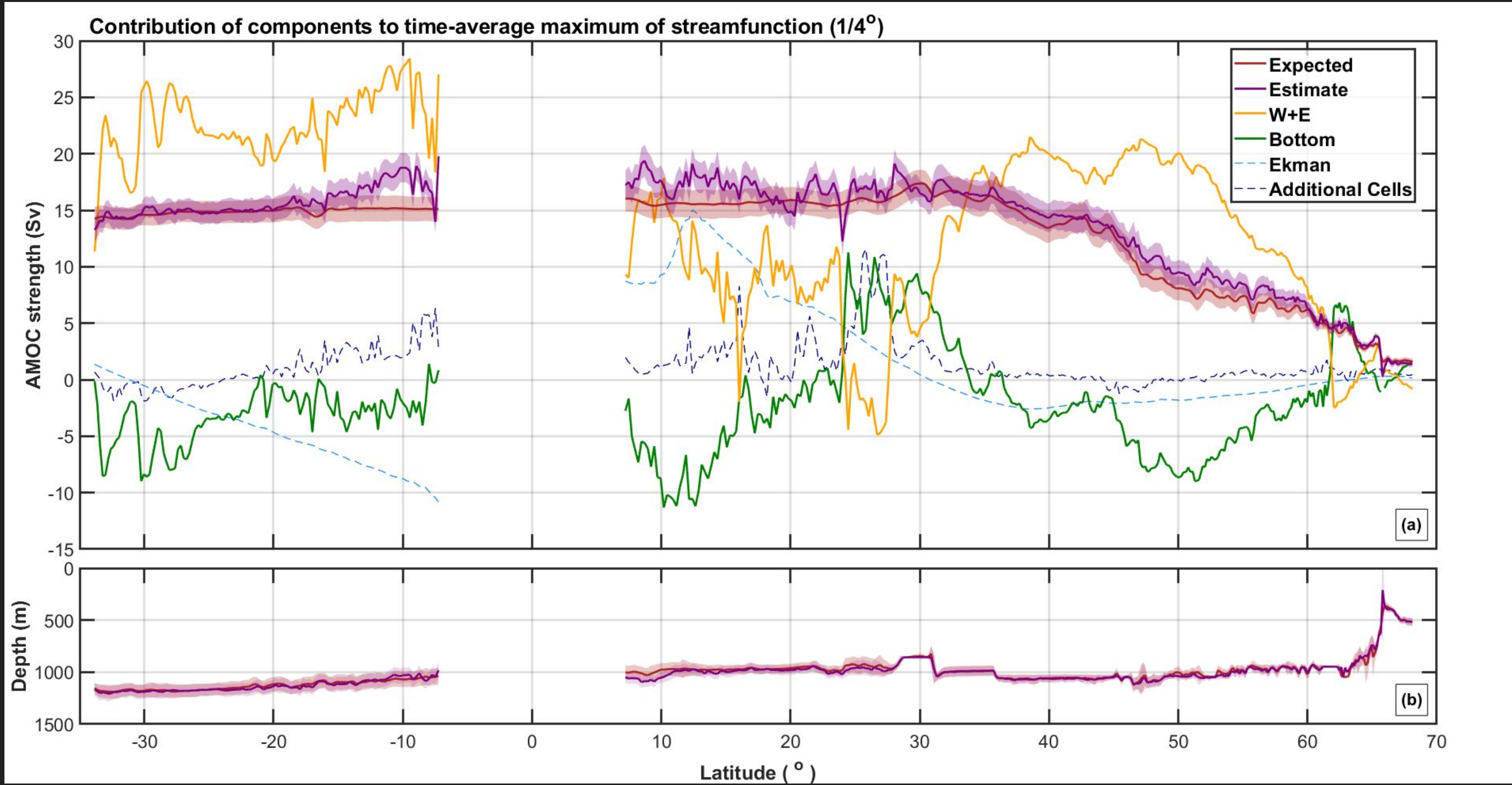


- ➔ Apply compensation to each term to conserve basin volume
- ➔ Annual-means, HighResMIP project
- ➔ Bottom cmpt. Near 26N similar to Sime (06)

$$\tilde{T}^c_F(z_k;y_j) = T^c_W(z_k;y_j) + T^c_E(z_k,y_j) + T^c_{bot}(z_k;y_j) + T^c_{Ekm}(z_k;y_j) + T^c_{AC}(z_k;y_j)$$

TM

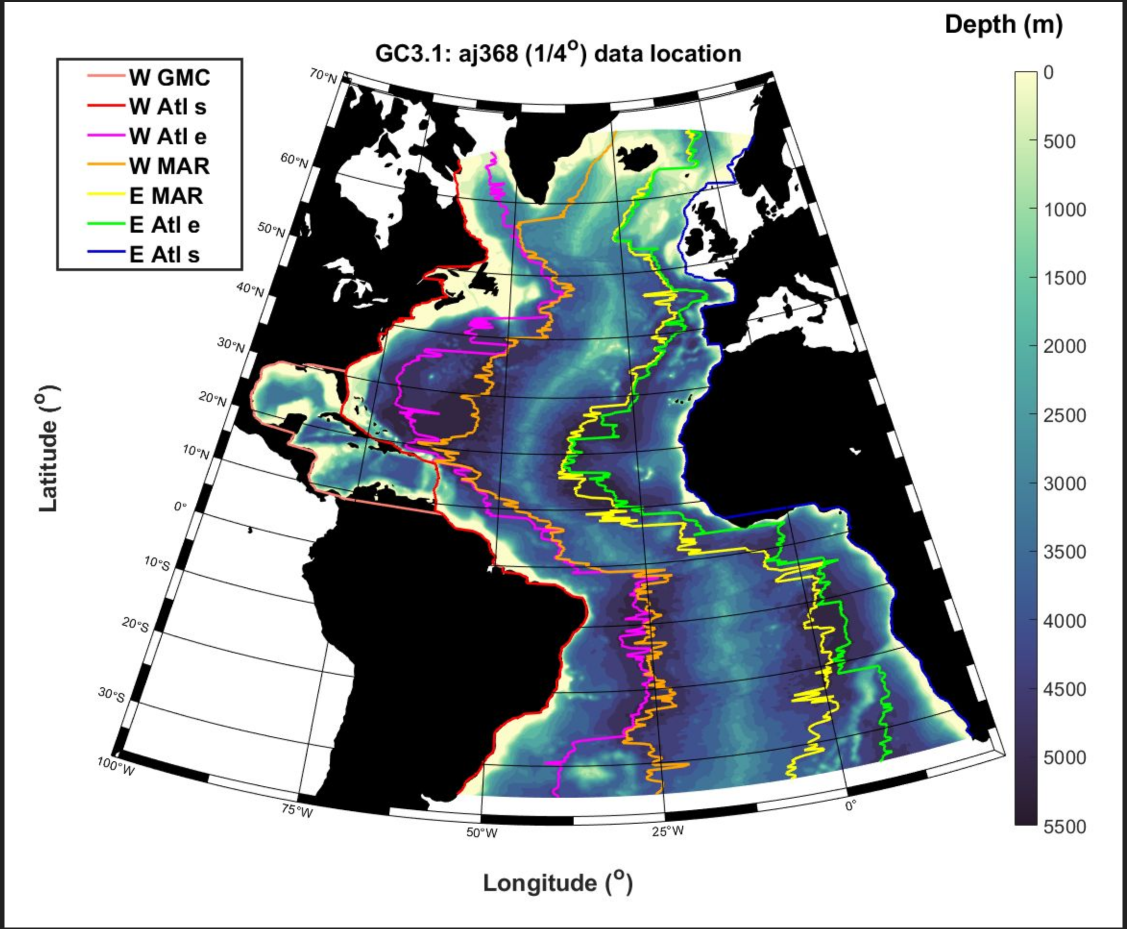
Overturning with latitude (e.g. 1/4°)



- ➔ Interesting interplay between boundary density component and bottom component

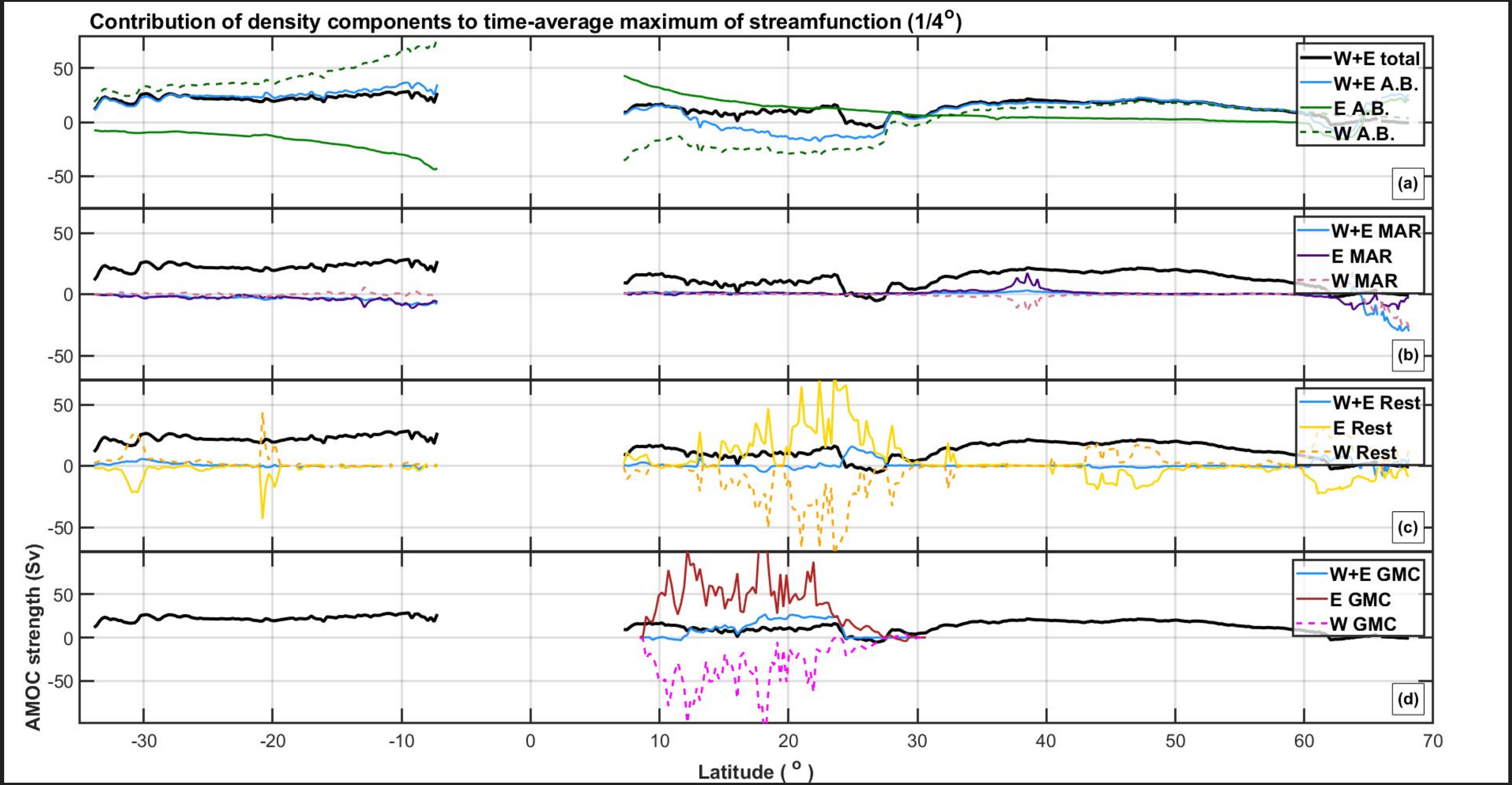
- ➔ Estimate (purple) and Expected (red) are stable throughout basin (conserve volume)
- ➔ Underlying boundary components evaluated at depth of maximum streamfucntion show significant variation

Decomposing density (W+E) contribution (1/4°)

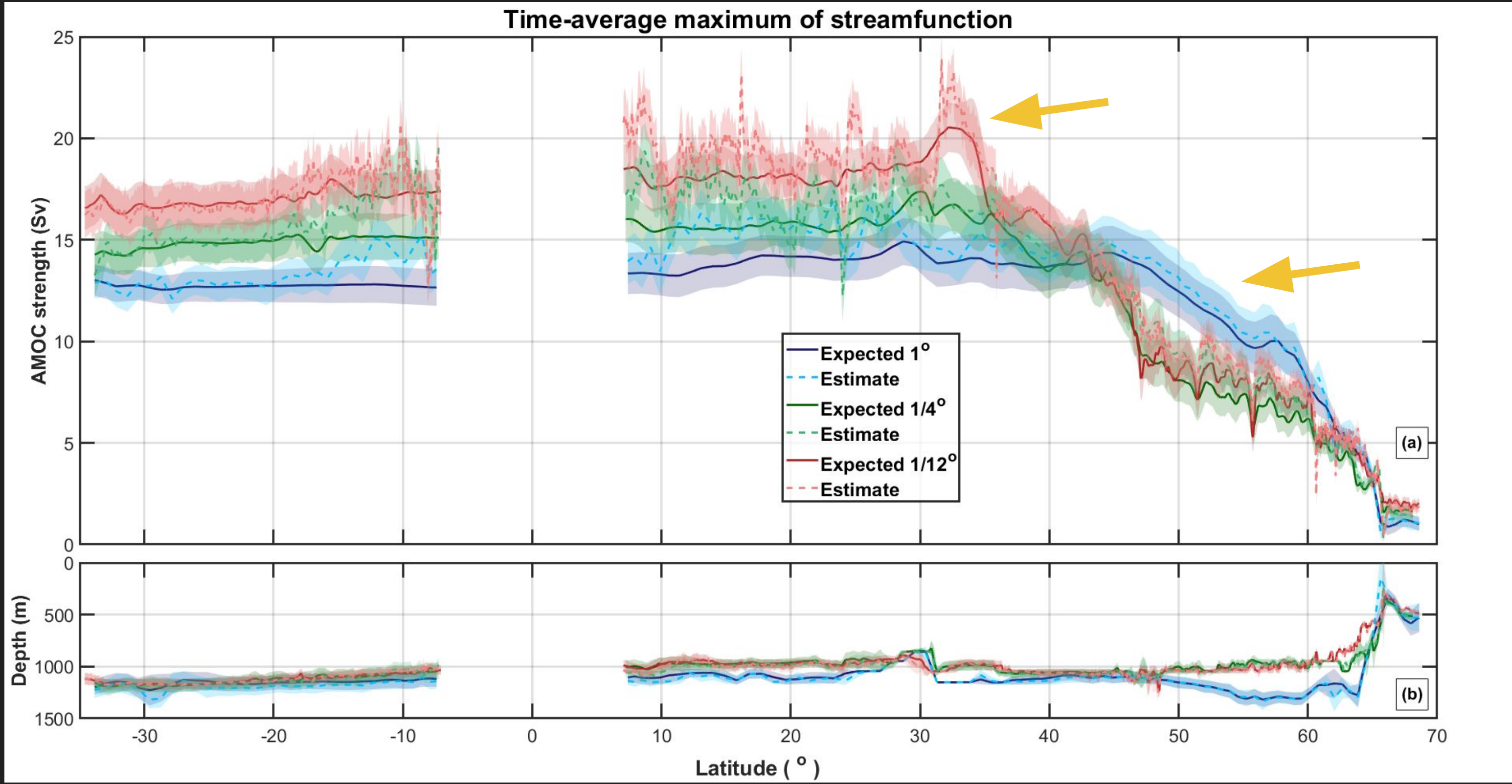


- ➔ Split density contributions to regions within basin
- ➔ MAR W / E (orange - yellow)
- ➔ West Atlantic (red - pink)
- ➔ East Atlantic (green - blue)
- ➔ Gulf / Caribbean (salmon - red)
- ➔ Remainder

Decomposing density (W+E) contribution (1/4°)

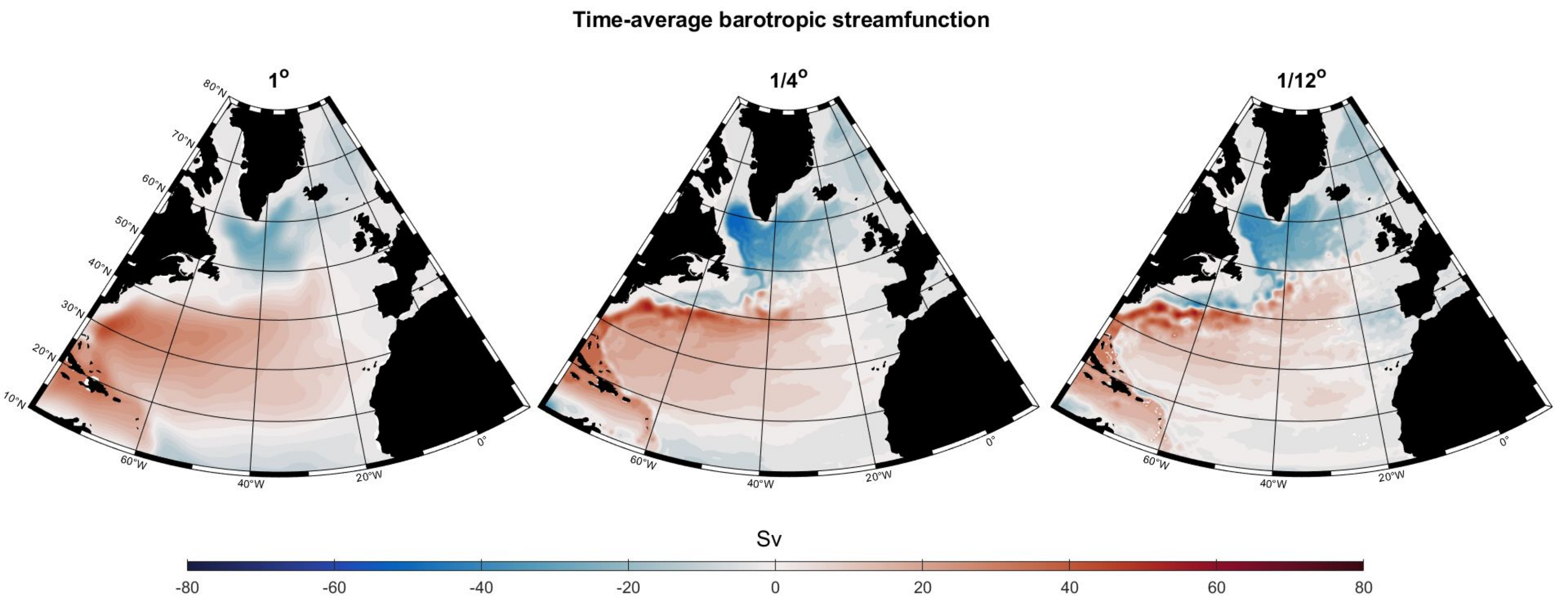


Overturning with latitude (resolution comparison)



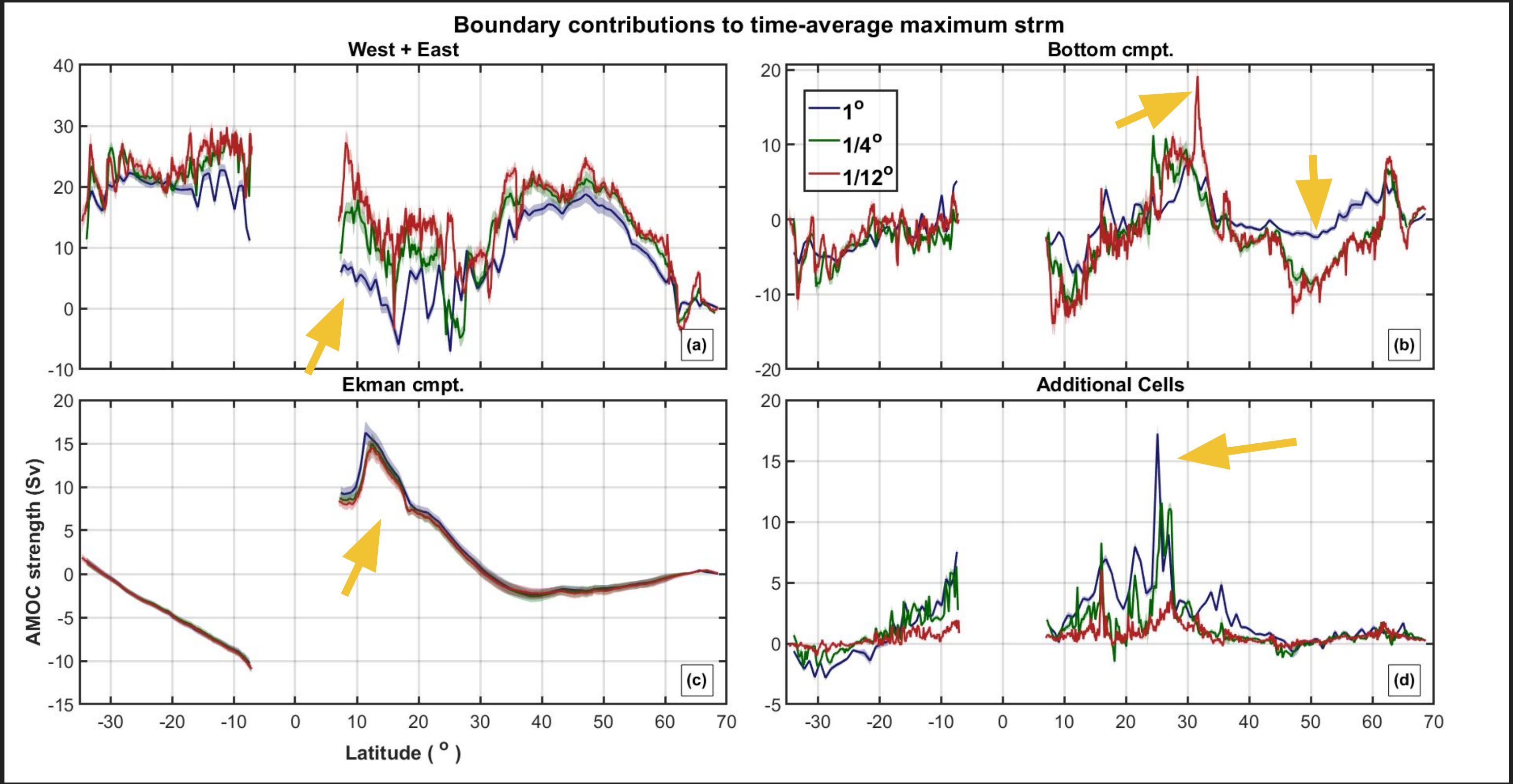
➔ Maximum streamfunction for expected and estimated transports

Subpolar gyre



- ➔ Stronger gyre at higher resolutions
- ➔ Greater horizontal circulation (steeper decline of max strm.)
- ➔ Weakness of depth coordinates at high latitudes

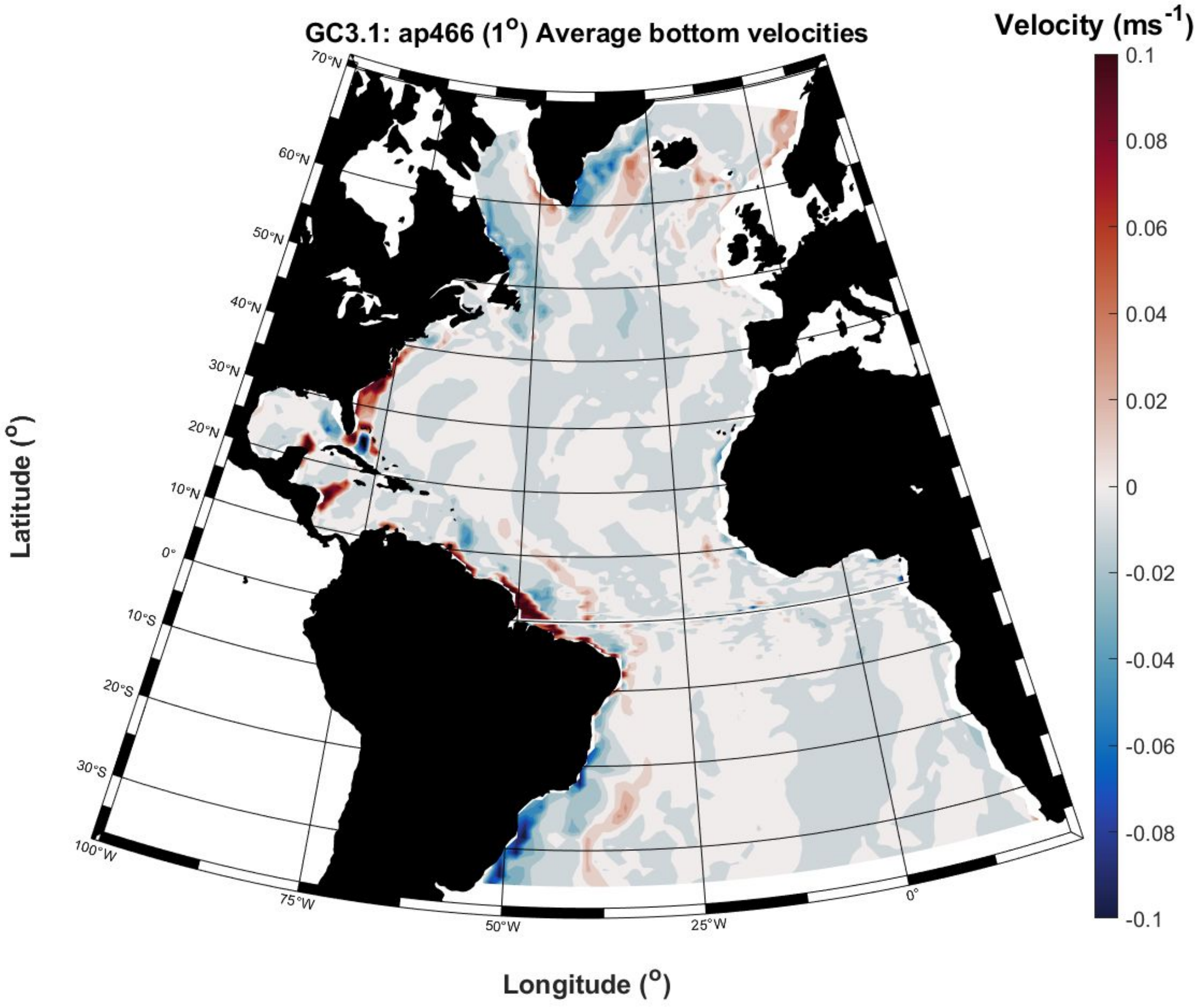
Boundary components with resolution



- ➔ Ekman cmpt. stable
- ➔ Greater resolution improves density resolution on (especially) eastern boundary of Caribbean islands

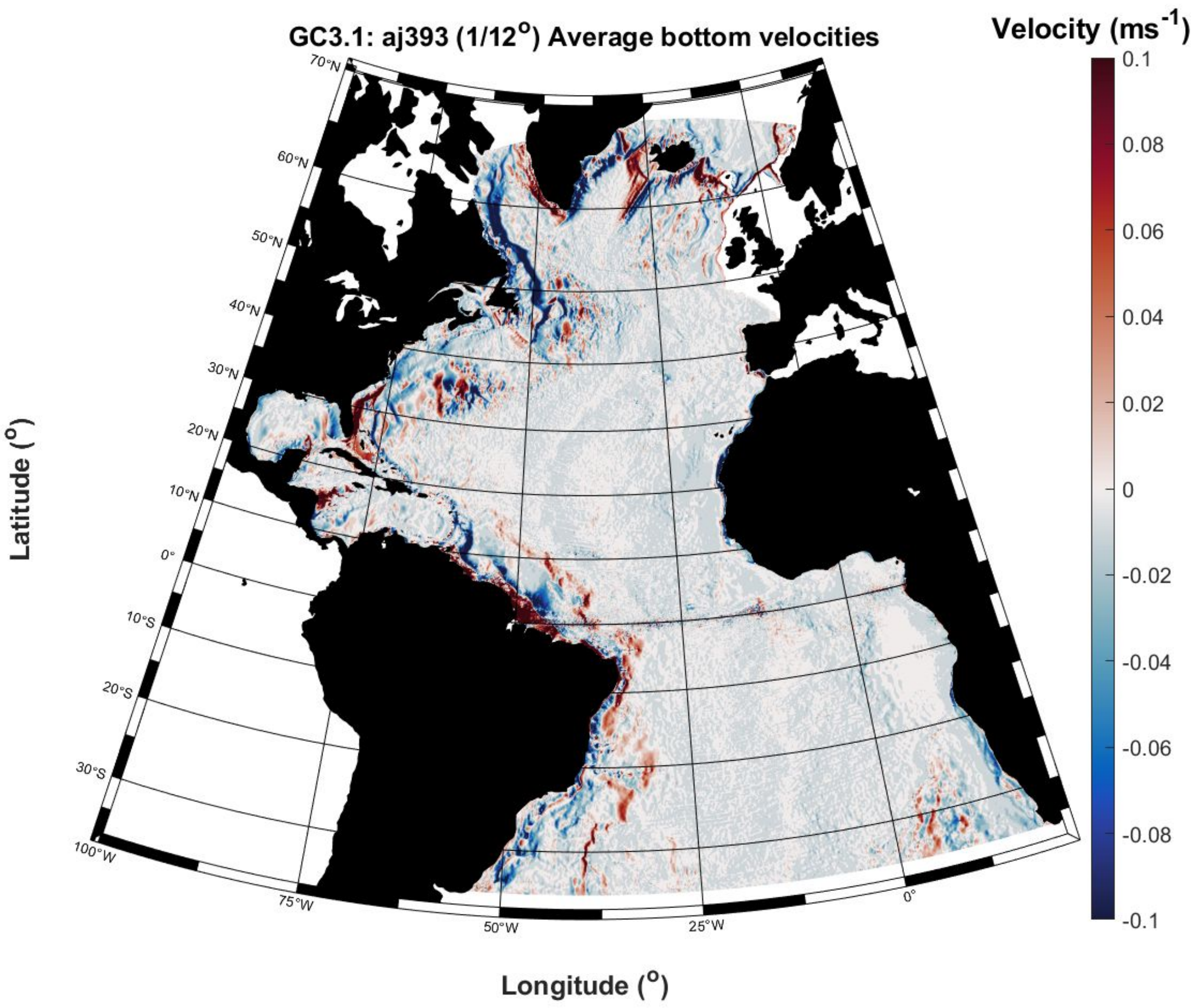
- ➔ Additional cell contribution peak in 1° (25°N), narrow shallow channel near Florida

- ➔ Weak bottom cmpt 45°N to 55°N
- ➔ DWBC weak in 1° model

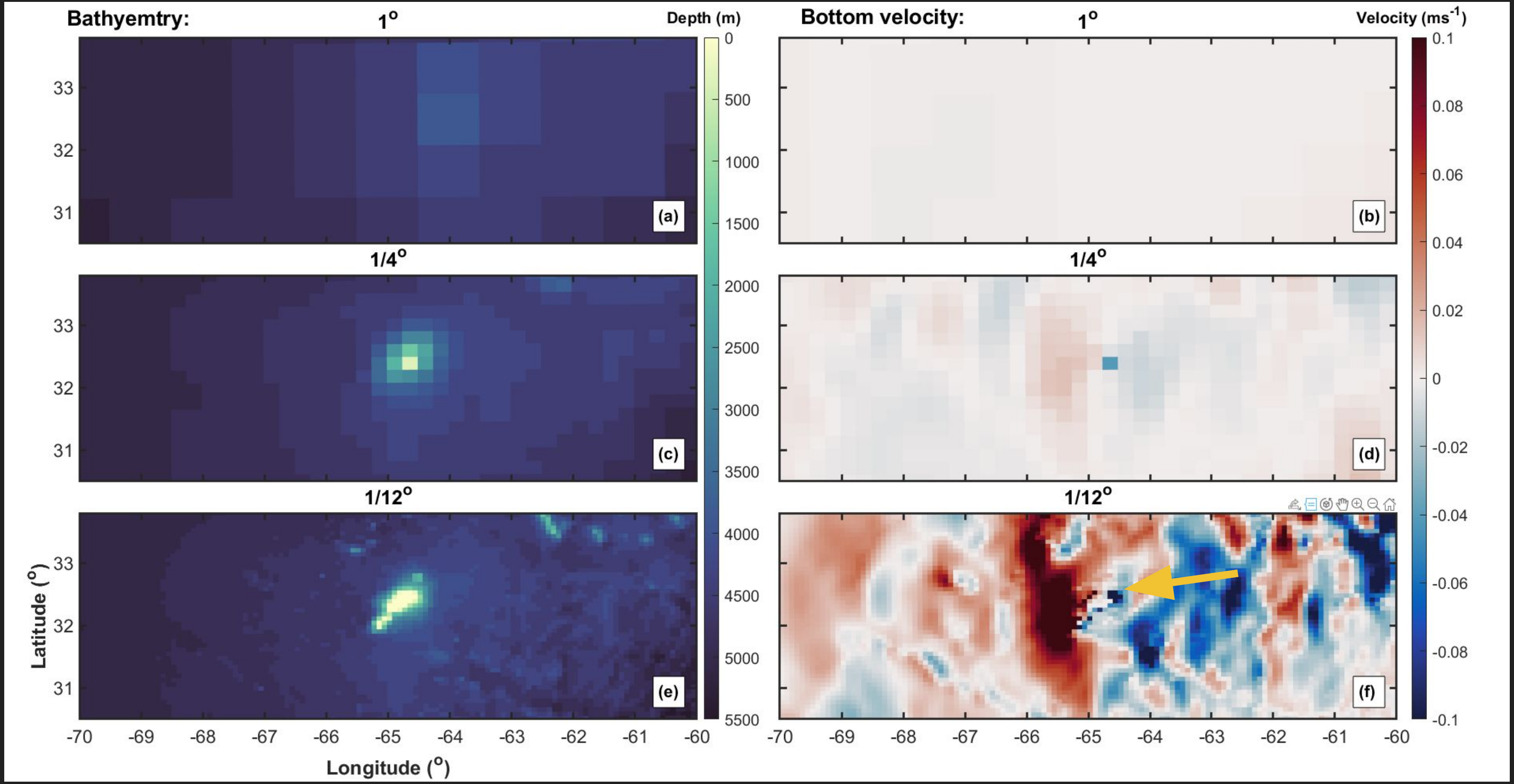


- Weak bottom cmpt 45°N to 55°N
- DWBC weak in 1° model

- Peak in 1/12° (31.66°) - just off Bermuda
- Significant differences in bottom velocities
- Bermuda poor in 1/4°, 1° models



Local bathymetry and time-average bottom velocities (northward)



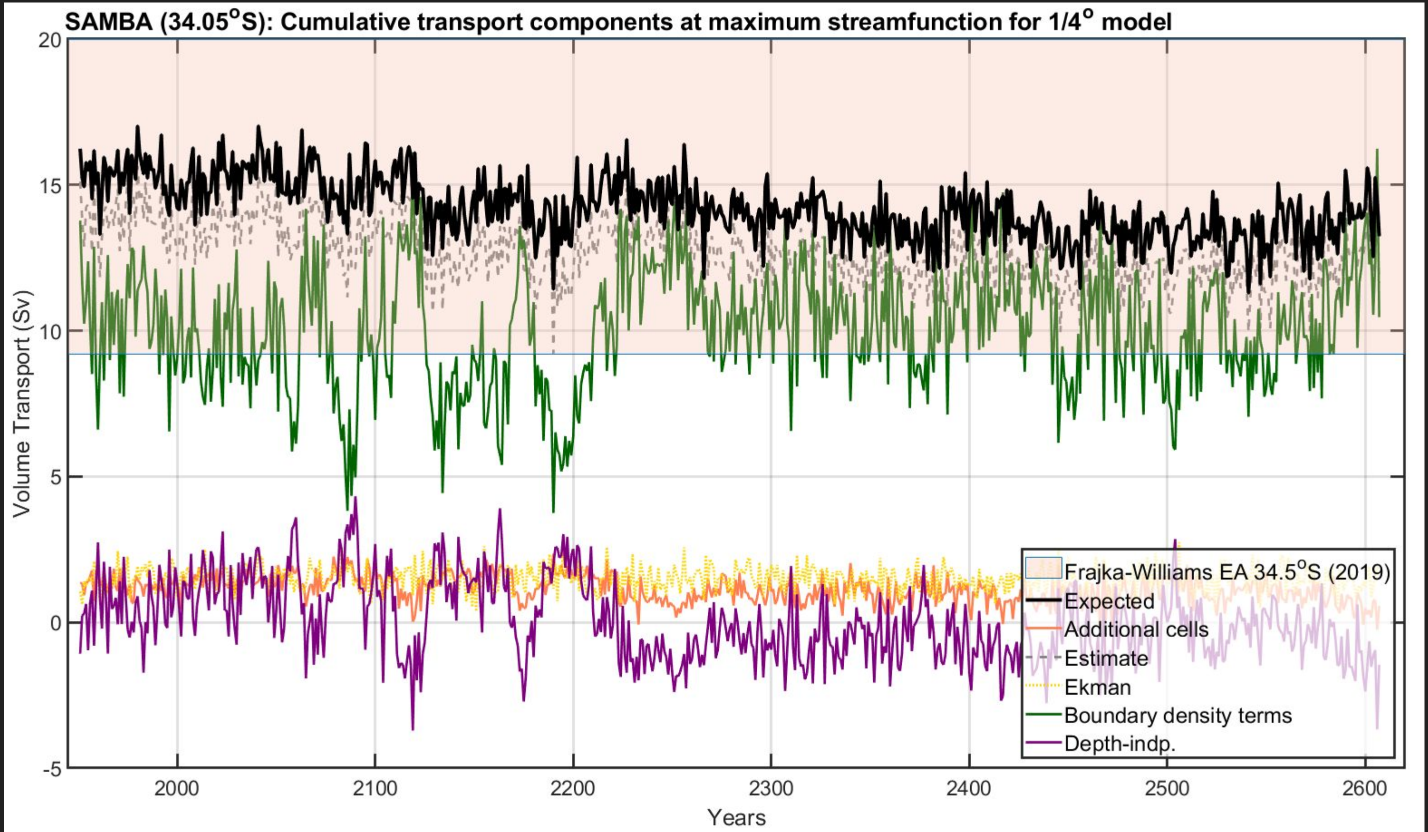
➔ 1/12° the only resolution with Bermuda as an island

➔ Superior resolution has dramatic effect on regions bottom velocities

Maximum streamfunction with latitude summary

- Stable nature of maximum streamfunction with latitude
  - Estimate performs well
  - Conservation of volume possibly? (Ideas??)
- Less coherence with latitude for boundary contributions
  - Impact of boundary currents
  - Density contribution of GMC and Atlantic boundary
- Model resolution impact
  - Higher resolution are more competent (gyre circulation)
  - DWBC
  - Boundary densities

Temporal variability at SAMBA array (1/4°)



➔ Maximum streamfunction through time at SAMBA array (components evaluated at depth of estimate maxima)

Correlation of components with time (at SAMBA)

$$\tilde{T}_F(z_k;y_j) = T_W(z_k;y_j) + T_E(z_k,y_j) + T_{bot}(z_k;y_j) + T_{Ekm}(z_k;y_j)$$

Correlation between components at SAMBA (34.5°S)			
	1°	1/4°	1/12°
T^c vs. T^c_F	1.00	0.96	0.96
$\tilde{T}^c_F$ vs. T^c_{th}	0.58	0.45	0.62
$\tilde{T}^c_F$ vs. T^c_{bot}	0.32	0.01	−0.15
T^c_{th} vs. T^c_{bot}	−0.46	−0.86	−0.84
T^c_{th} vs. T^c_W	0.17	0.65	0.39
T^c_{th} vs. T^c_E	0.68	−0.03	−0.16

Table 1.3: Correlation between components at SAMBA array (34.5°S, depth of maximum estimated overturning streamfunction)

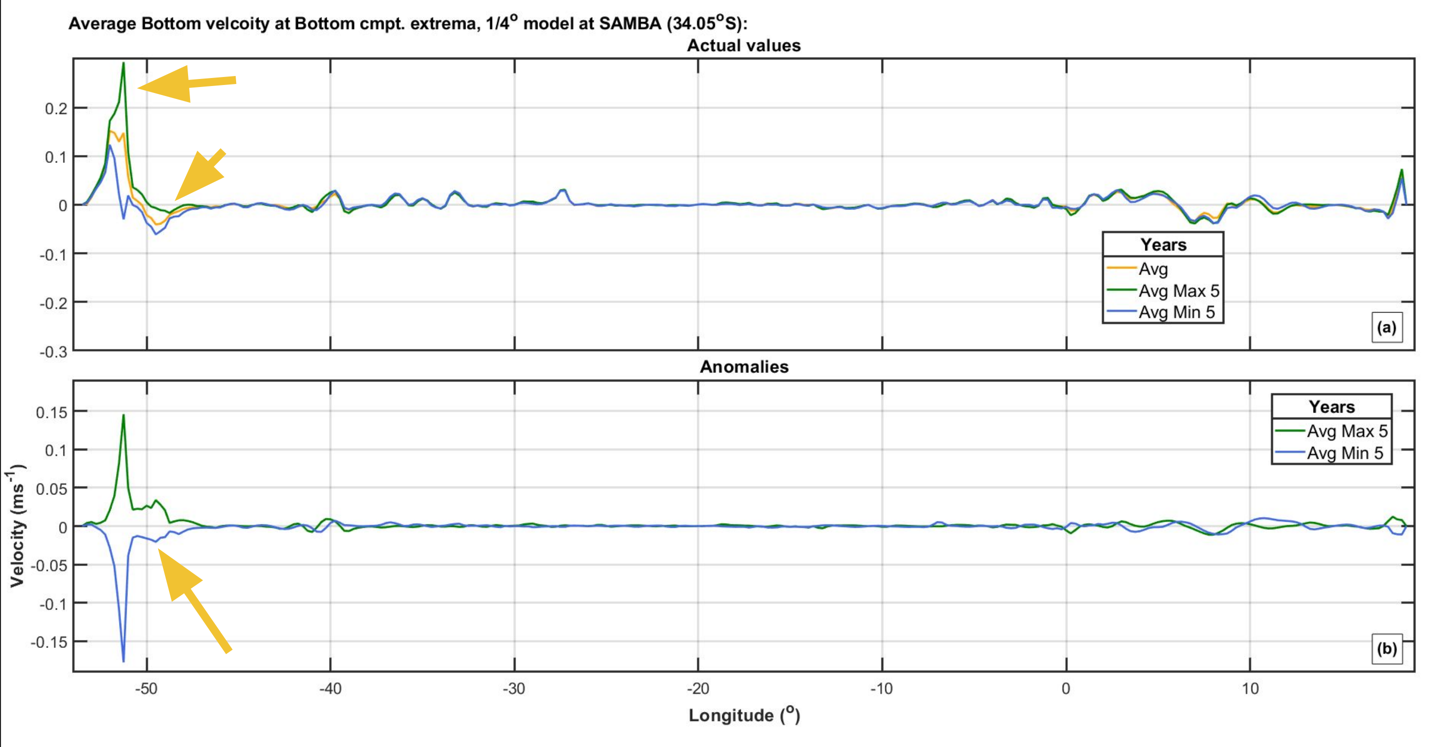
- ➔ Expected (T^c) and Estimate (T^c_F) good agreement
- ➔ Density terms seem to dominate temporal variability
- ➔ Close correlation between bottom and density terms (at higher resolution)
  - Density component leads by a few years
  - Previous work - eddies in eastern part of section

Maxima and minima years of bottom component

Taking the 5 maximum and minimum years of the bottom component

We analyse:

- ➔ Bottom velocities
- ➔ SSH
- ➔ Bottom densities

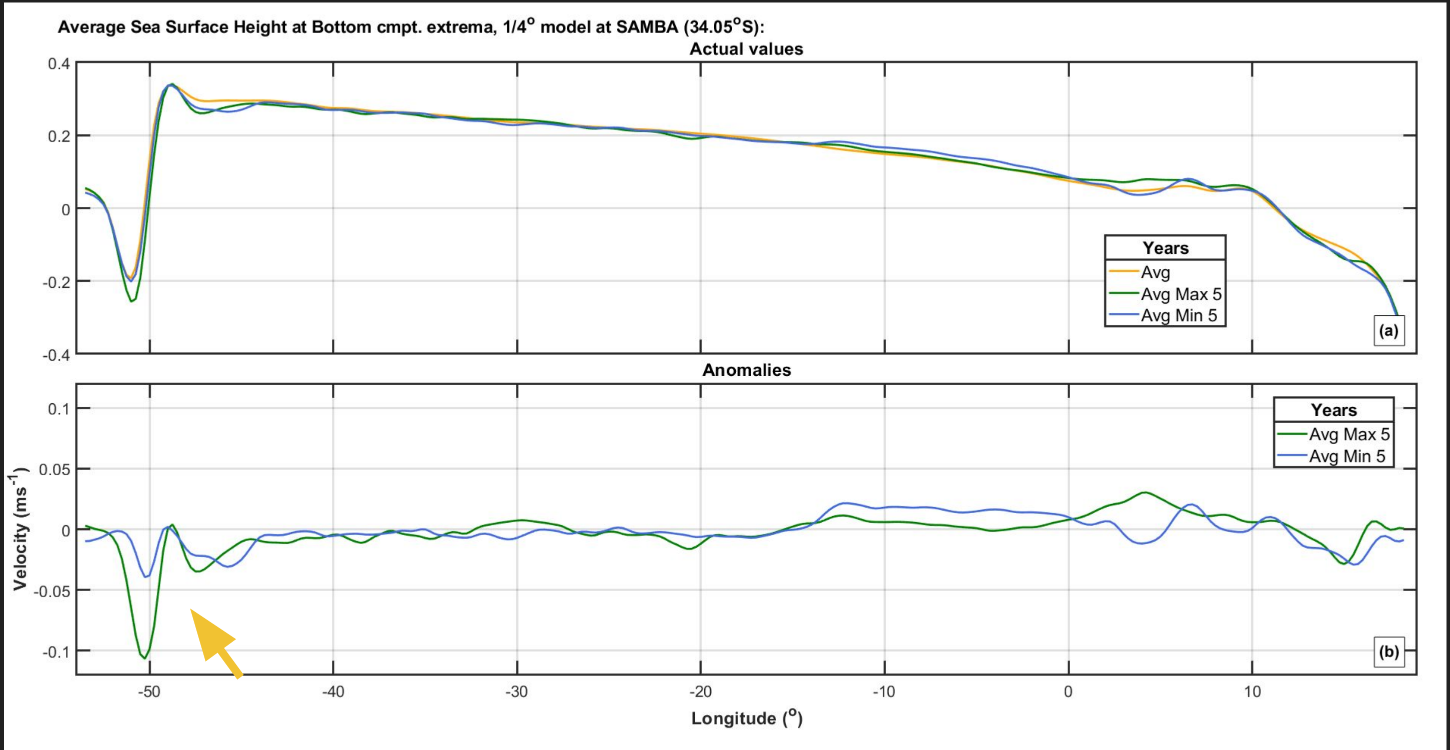


➔ Stronger northward and weaker southward for max 5yrs

Maxima and minima years of bottom component

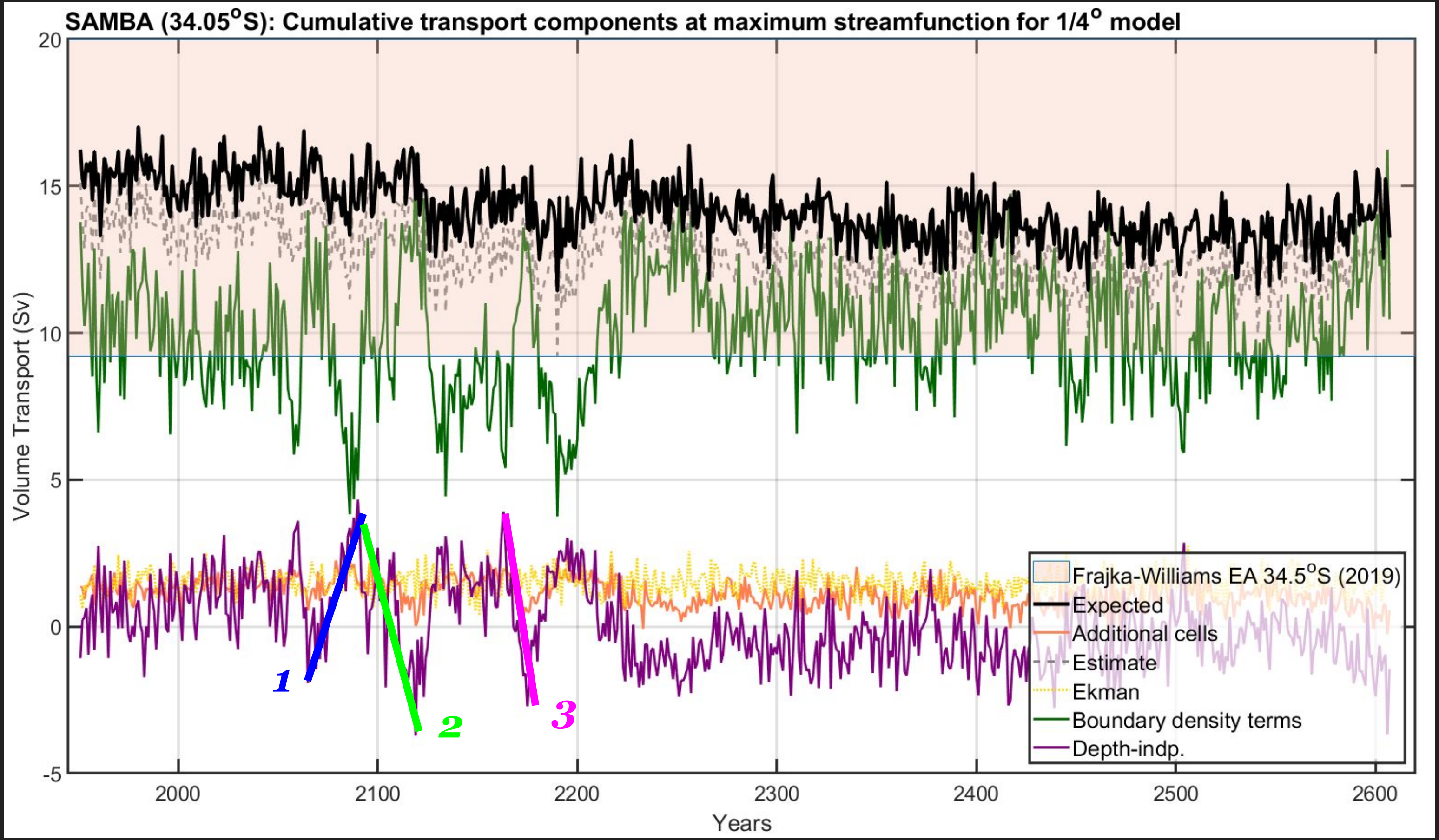
Analyse:

- ➔ Bottom velocities
- ➔ SSH
- ➔ Bottom densities



➔ Contracted sea surface in max 5yrs

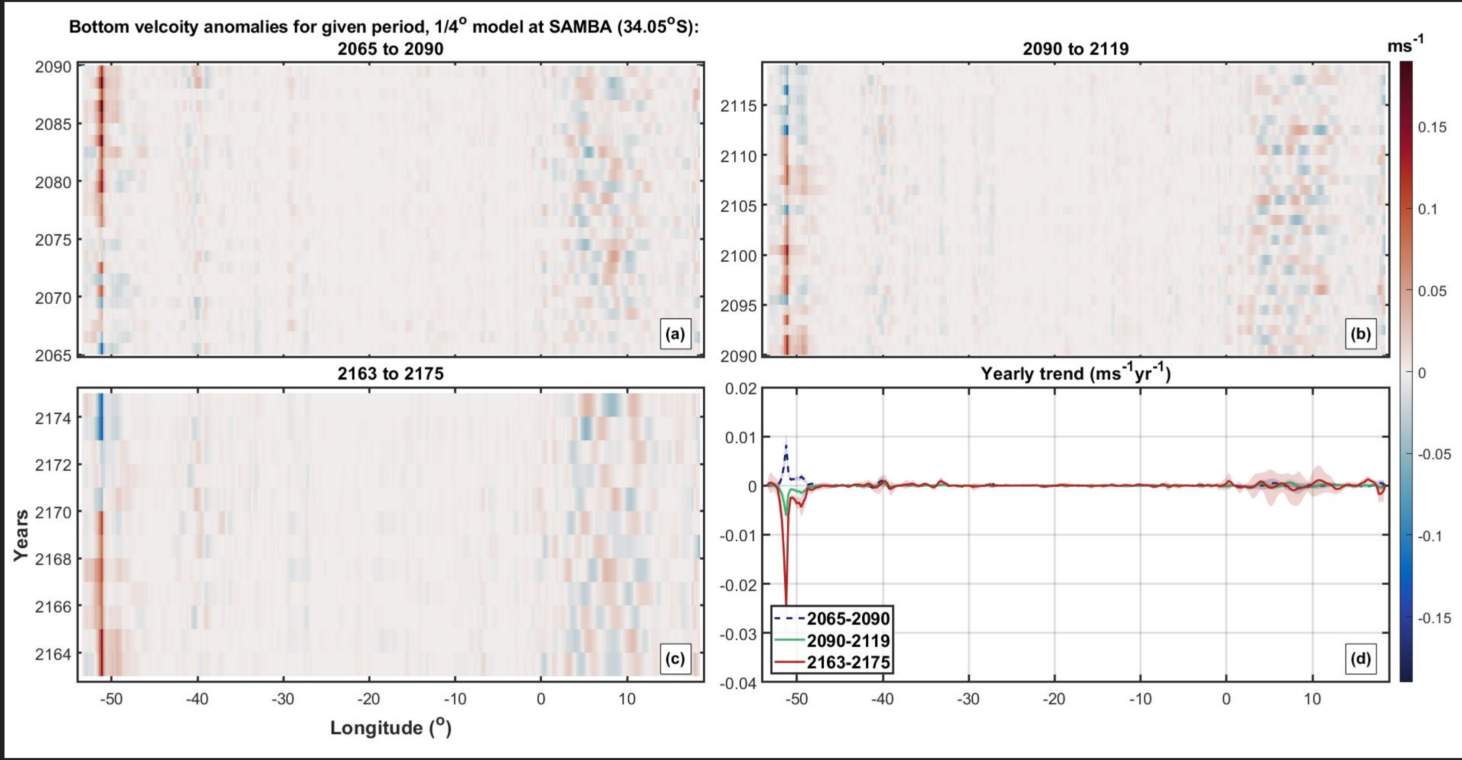
Choose time intervals to investigate



Investigate specific periods of time

Analyse anomalies:

- ➔ Bottom velocities
- ➔ SSH
- ➔ Bottom densities

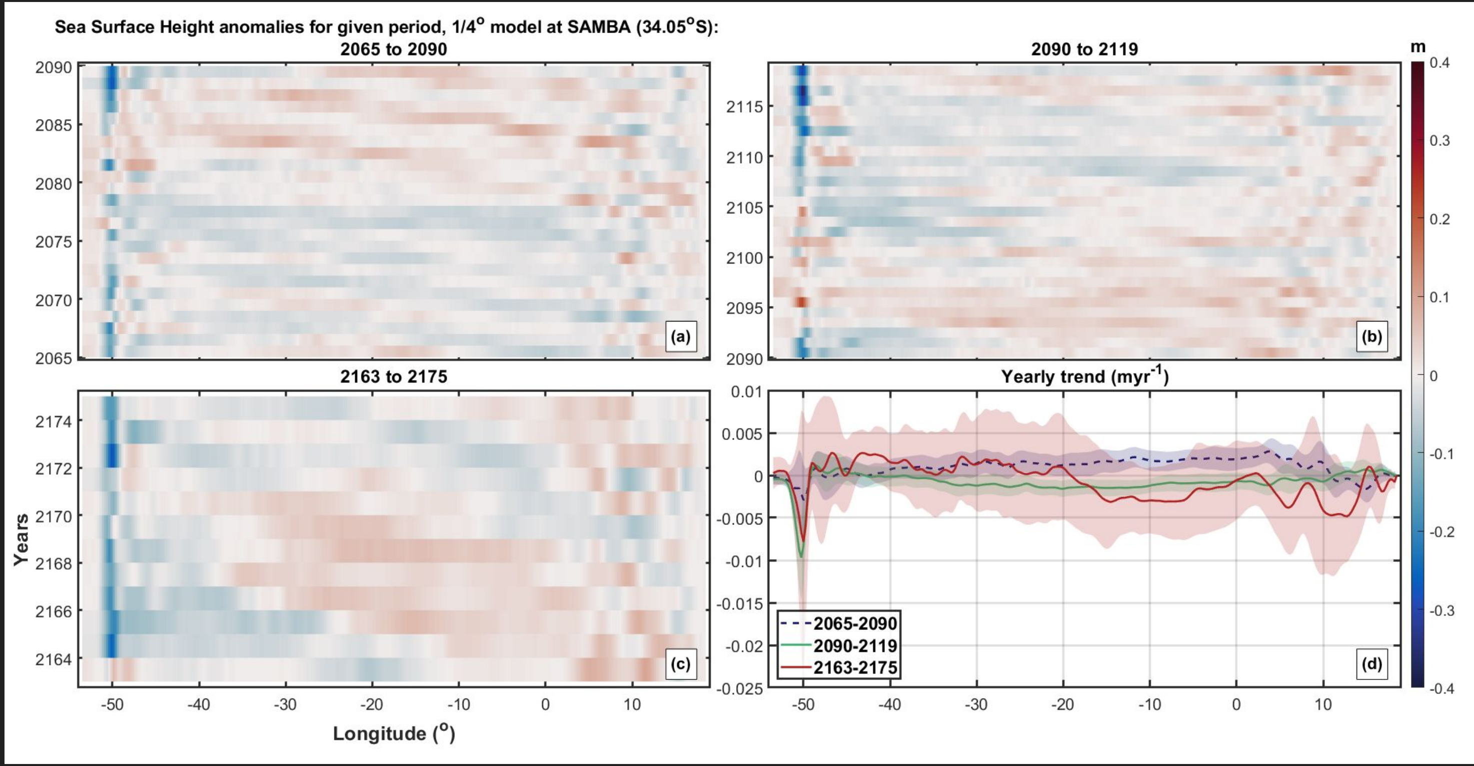


- ➔ (b), (c) are max to min periods
  - Significant weakening in western section
  - (a) shows opposite trend

Investigate specific periods of time

Analyse anomalies:

- ➔ Bottom velocities
- ➔ SSH
- ➔ Bottom densities

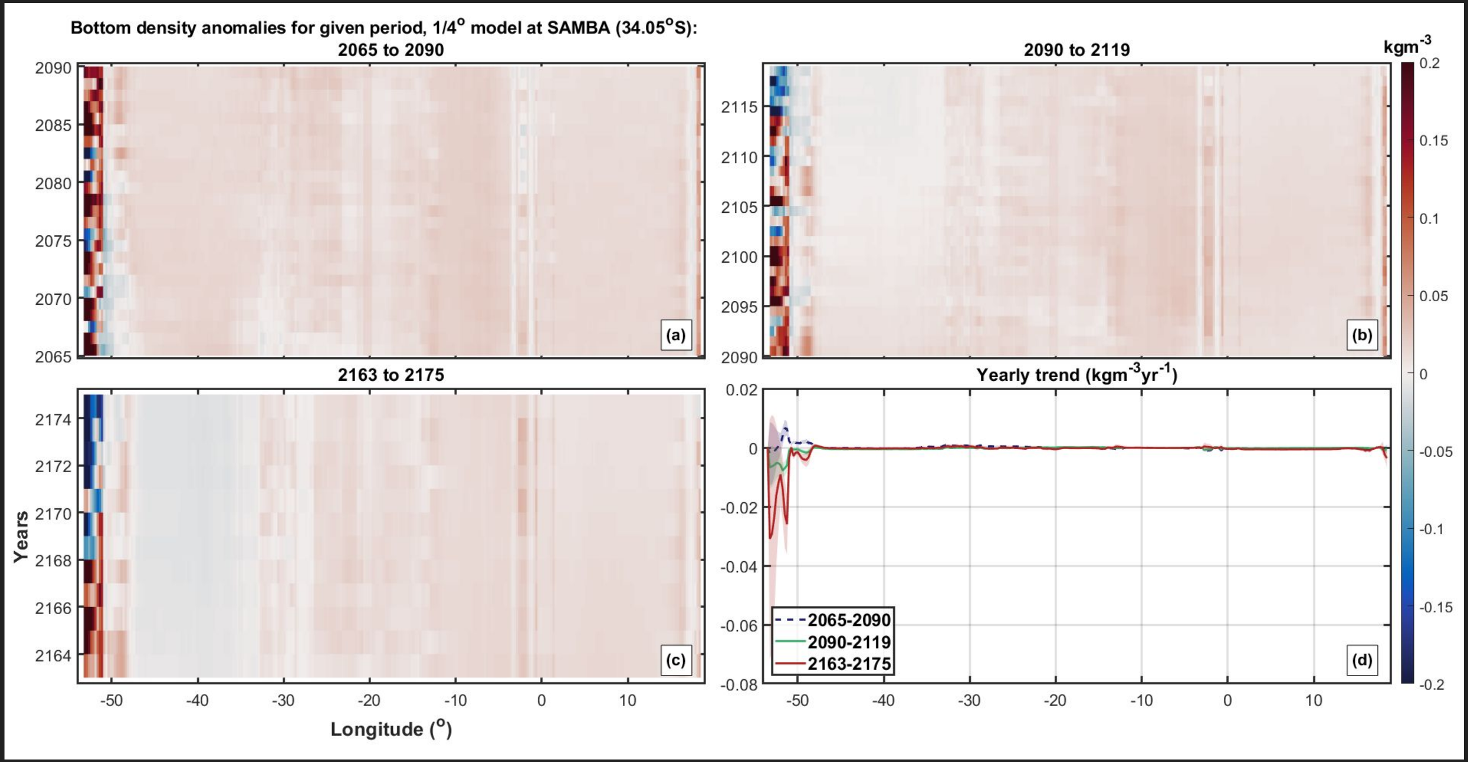


- ➔ (b), (c) are max to min periods
  - ◆ Greater weakening in western section
  - ◆ More weakening within interior section

Investigate specific periods of time

Analyse anomalies:

- ➔ Bottom velocities
- ➔ SSH
- ➔ Bottom densities



➔ (b), (c) are max to min periods
- ◆ Greater weakening (lightening) in western section
- ◆ (a) positive (heavier) in western section

Summary

- ➔ Close correlation between bottom cmpt.(purple) and density cmpt. (green)
- ➔ Max to min sections:
  - ◆ Weakening of bottom velocities in western part of section
  - ◆ Greater contraction of SSH
  - ◆ Lightening of densities
- ➔ These changes are mainly tied to western part of section near Brazil - Malvinas confluence
  - ◆ Max Bot years = strong northward Malvinas current, weaker Brazil current
  - ◆ Weak Bot years = weak northward Malvinas current, stronger Brazil current


End.
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