Supporting Information for "A state estimate of the routes of the upper branch of the Atlantic Meridional Overturning Circulation"

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Contents of this file

1. Text S1 to S4
2. Figure S1

Additional Supporting Information (Files uploaded separately)

1. Captions for Movies S1 to S2

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Introduction

A description of the algorithm and software used for the Lagrangian trajectories is provided, together with two animations of four typical particle trajectories.

Particle-trajectory calculation

ECCOv4 provides the three-dimensional velocity field on a gridded mesh in latitude, longitude and depth for the 24 years of the assimilated period. We use the monthly climatological average repeated for 2011 years over the annual period. In order to preserve the conservation properties of the gridded ECCOv4 fields, and in particular the incompressibility of the velocity, it is important to use the fields on the native curvilinear grid. The global domain of ECCOv4 is decomposed in 13 tiles, and particle trajectories must be exchanged across the tiles' boundaries (Forget et al., 2015). To our knowledge, the only code that is capable of seamlessly exchanging particles across tiles on the three dimensional ECCOv4 curvilinear grid is the FLT package within the MITgcm suite and this is what we used (Campin et al., 2019). Additionally, the FLT package is computationally efficient on the multi-processor, multi-node supercomputer available to us.

The spatial interpolation algorithm for the velocity field was modified according to Döös (1995) , to *linearly* interpolate the *transport* associated with each velocity component on the staggered grid used by ECCOv4: in this way incompressibility of the velocity is guaranteed at every point along the particle trajectory. With velocity incompressibility satisfied exactly, particles never reach the land points where the velocity vanishes. Unlike Döös (1995), we use a 4th order Runga-Kutta scheme to time-step the trajectories; this introduces a small error in the time-integration, without violating incompressibility.

Particle-trajectory animations

In figure S1 and in the associated animations, four particles are tracked from their initial entry in one of the sections to the exit section at 6°S in the Atlantic. The particles are chosen as they best represent: (i) the average temperature and salinity at each entry section (i.e. $\pm$ 0.2 from mean T°C and $\pm$ 0.1PSU from mean salinity); (ii) the median transit times shown in Figure 2 (i.e. $\pm$ 15 years from T50%). Particle entering through Tasman Leakage and Indonesian Throughflow are shown respectively with a diamond and a circle. Both ”direct” and ”indirect” cold routes from Drake Passage are shown by two different trajectories (stars). In addition to the position, which is shown every 3 months, the color of the particle denotes its temperature or salinity at that position, allowing to visualize the thermodynamic transformations occurring along each trajectory. The temperature and salinity variations over time (along trajectories) are also displayed in the bottom right inset. The bottom left legend indicates the arrival time of each particle at 6°S.

Movie S1. Positions of four particles along typical trajectories from the entry sections are shown every 3 months with different symbols: stars denote particles entering at DP, diamonds are for entry at TL, and dots are for entry at IT. The color of the symbols denotes salinity (in PSU). The salinityevolution for each particle is shown in the bottom right inset. The bottom left legend indicates the arrival time of each particle at 6°S.

Movie S2. Positions of four particles along typical trajectories from the entry sections are shown every 3 months with different symbols: stars denote particles entering at DP, diamonds are for entry at TL, and dots are for entry at IT. The color of the symbols denotes potential temperature (in ° C). The temperature evolution for each particle is shown in the bottom right inset. The bottom left legend indicates the arrival time of each particle at 6°S.

References

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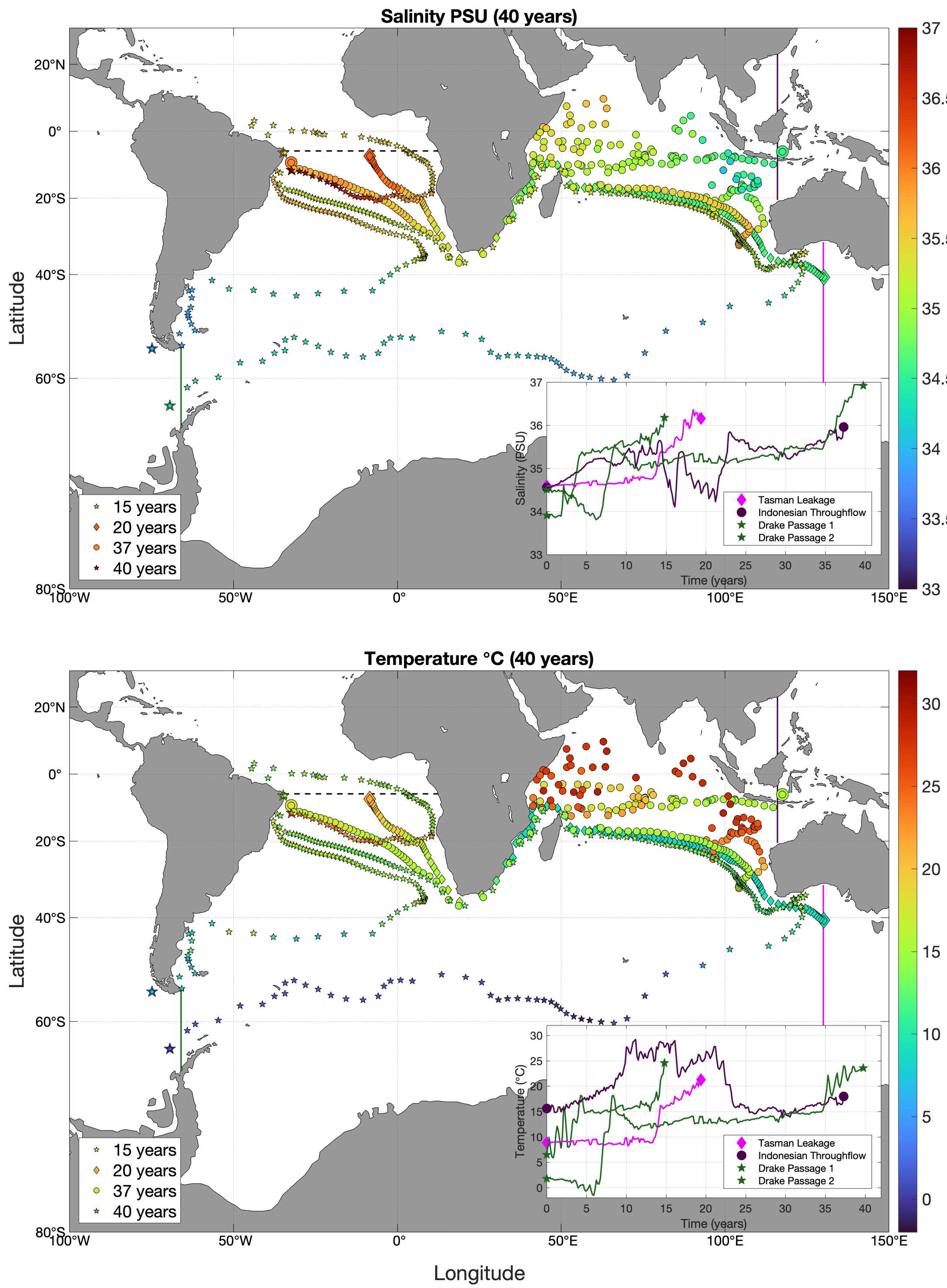

Figure S1. Positions of four particles along typical trajectories from the entry sections are shown every 3 months with different symbols: stars denote particles entering at DP, diamonds are for entry at TL, and dots are for entry at IT. The color or the symbols denote salinity (in PSU) in the top panel and potential temperature in the bottom panel (in ° C). The salinity and temperature evolution for each particle is shown in the bottom right inset. The bottom left legend indicates the arrival time of each particle at 6°S.