Tracing the thermohaline Conveyor Belt circulation;

from the Drake Passage to the Pacific Ocean

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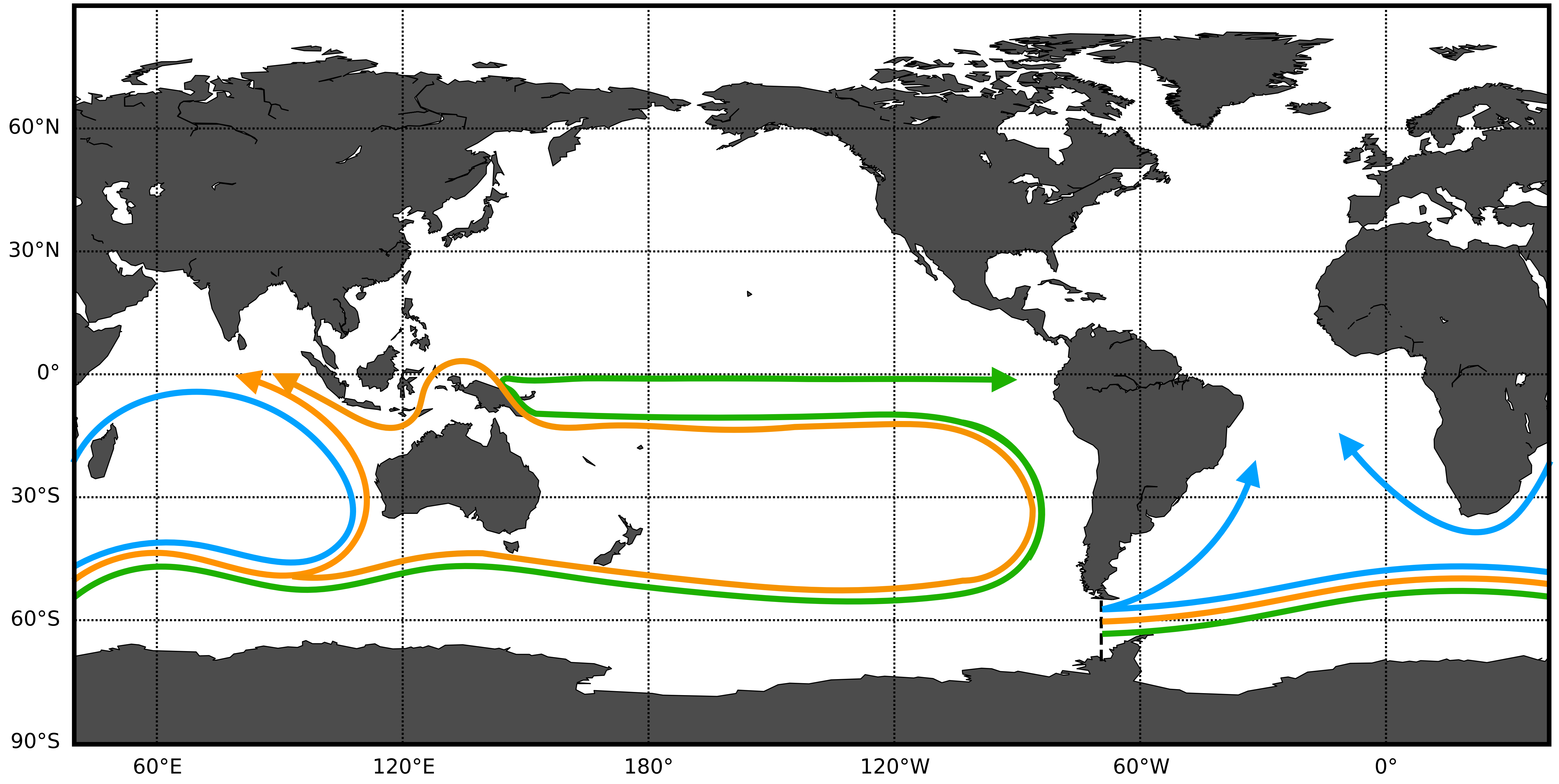
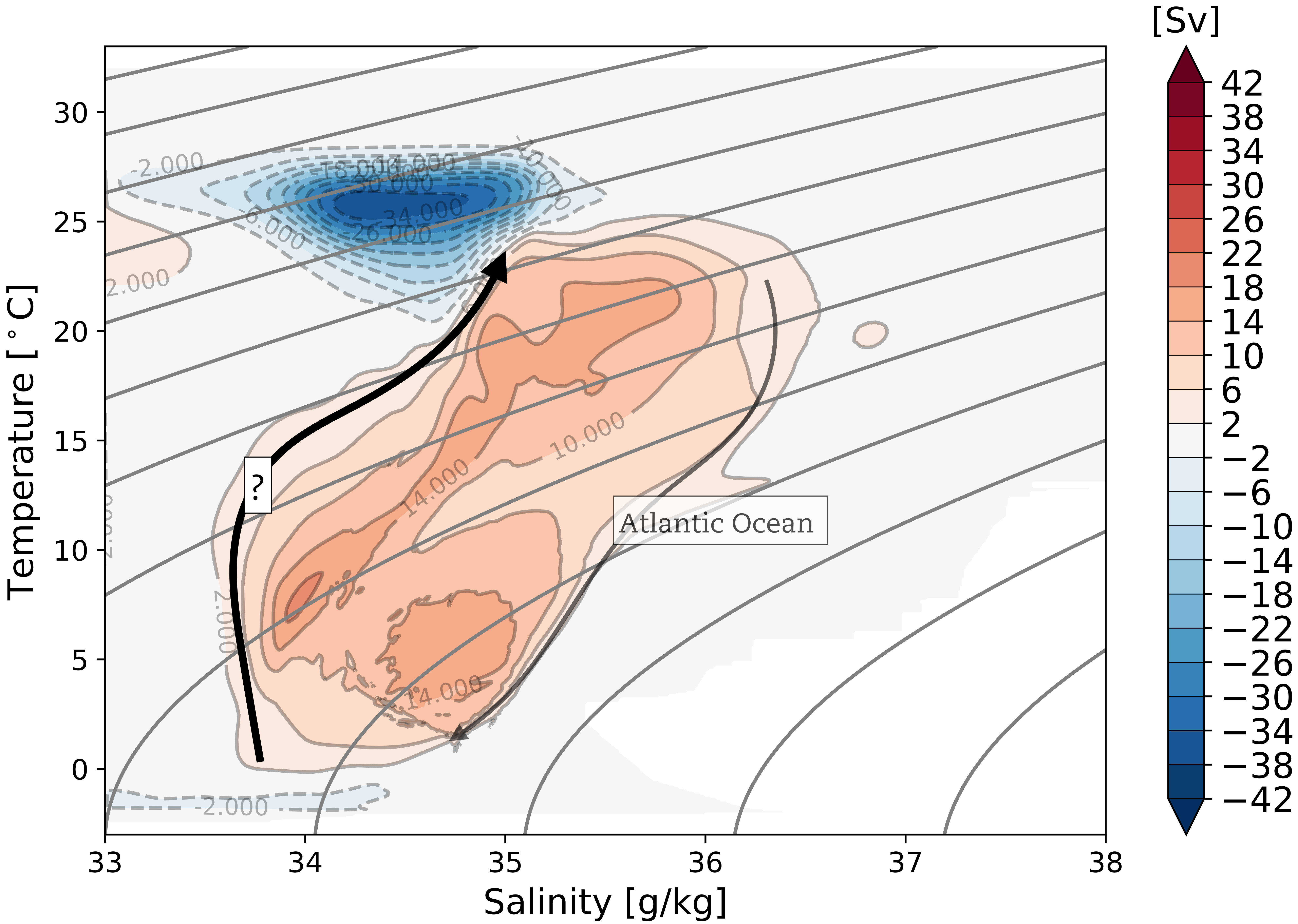


Thermohaline stream function



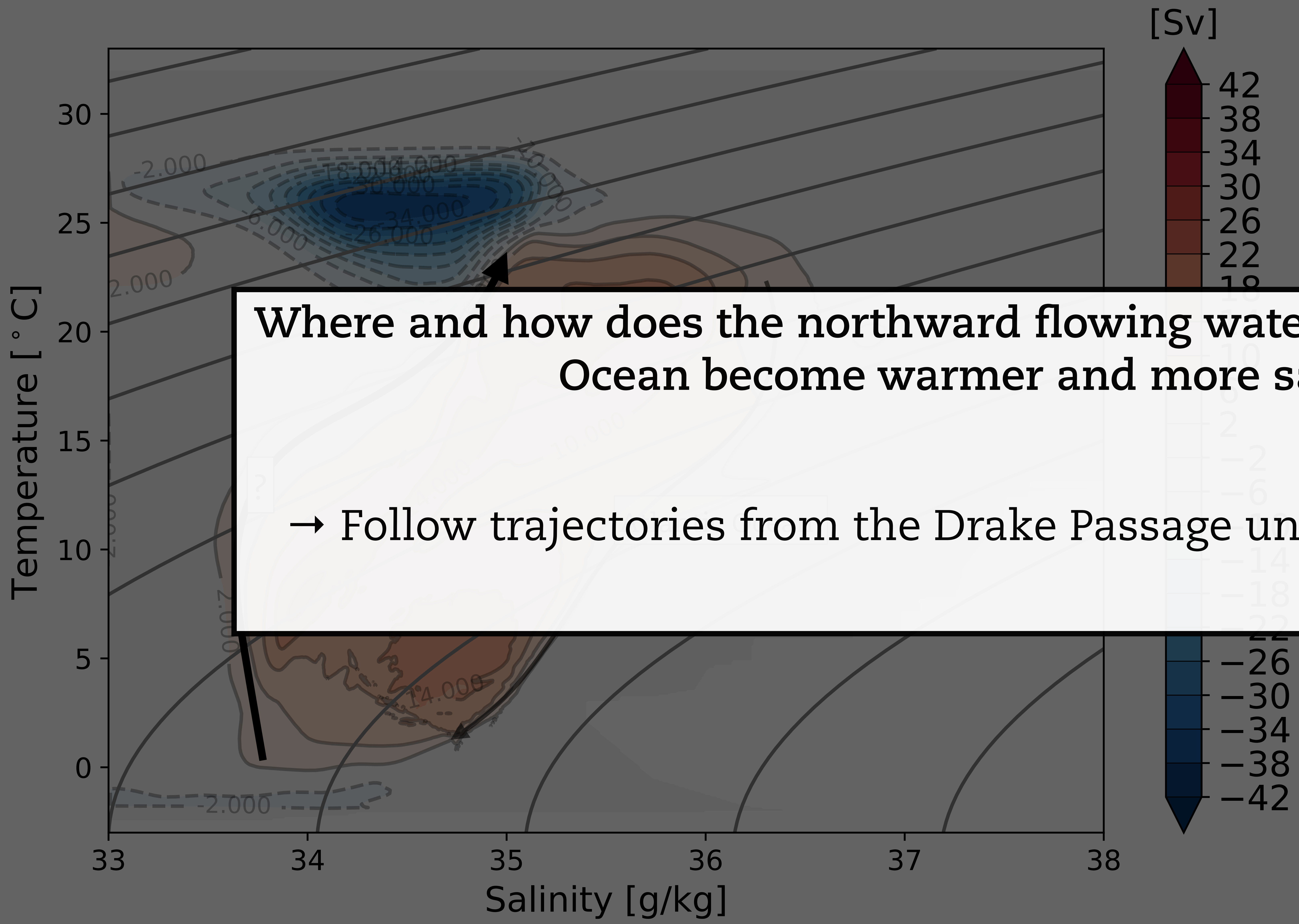
To read more about the thermohaline stream function check out Döös et al. (2012), Zika et al. (2012), Berglund et al. (2017), Groeskamp et al. (2019)

The thermohaline stream function describes the oceanic overturning circulation in a temperature and salinity space. The red cell describes the Conveyor Belt circulation, whereas the blue cell at higher temperature describes the surface waters in the tropics.

The right-hand-side of the red cell represents water travelling northward in the Atlantic Ocean. As going from the Southern Atlantic to the Northern parts water becomes colder and fresher. Berglund et al. (2017) used Lagrangian trajectories to identify this water and where the changes are happening. They showed that a large part of the decrees in temperature and salinity occurs in the North Atlantic Subtropical Gyre as the water spirals downward.

In this presentation, the focus is on the left-hand-side of the red cell. This part describes the pathway of waters that are cold and fresh and become warm and saline. These cold and fresh water masses are expected to be found in the Southern Ocean.

Thermohaline stream function



Where and how does the northward flowing water from the Southern Ocean become warmer and more saline?

→ Follow trajectories from the Drake Passage until they reach 25°C.

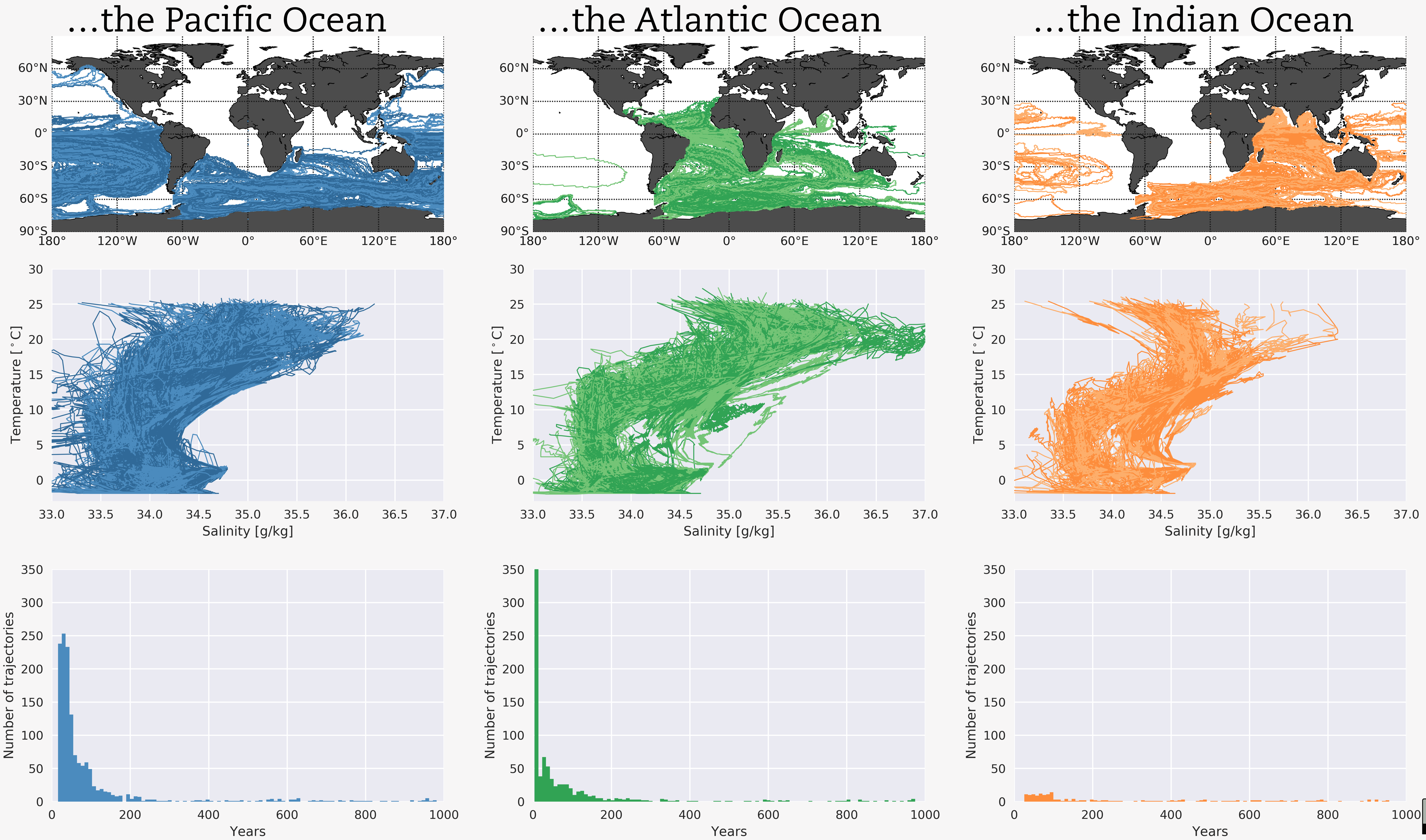
The thermohaline stream function describes the oceanic overturning circulation in a temperature and salinity space. Imagine the stream lines to be the mean pathways of the entire oceans water in temperature and salinity coordinates. The red cell describes the Conveyor Belt circulation, whereas the blue cell at higher temperature describes the surface waters in the tropics.

The right-hand-side of the red cell represents water travelling northward in the Atlantic Ocean. As going from the Southern Atlantic to the Northern parts water becomes colder and fresher. Berglund et al. (2017) used Lagrangian trajectories to identify this water and where the changes are ... part of the decrees in temperature and freshening occurs in the North Atlantic tropical Gyre as the water spirals downward.

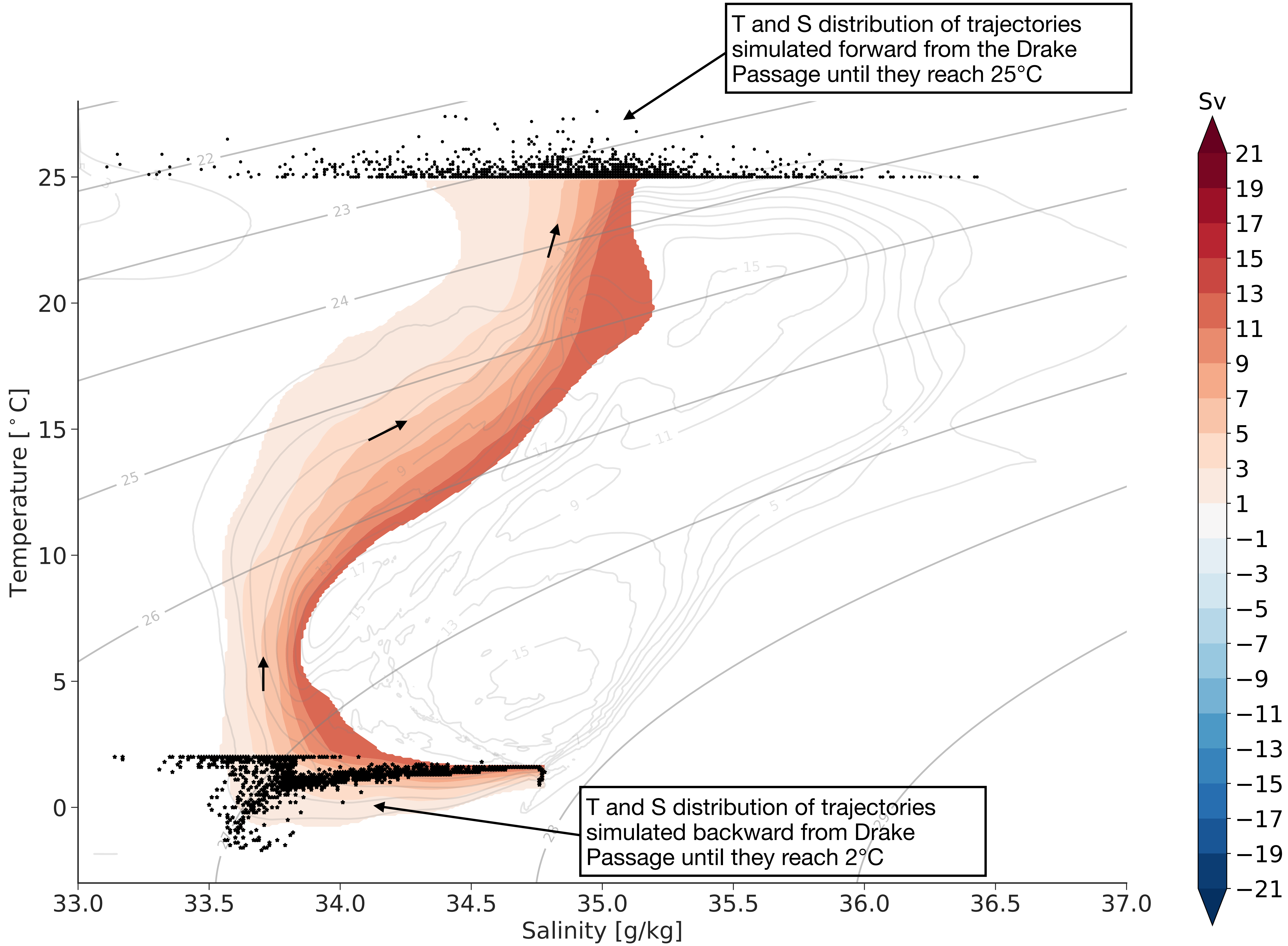
In this presentation, the focus is on the left-hand-side of the red cell. This part describes the pathway of warming and salinification for waters that are cold and fresh. These waters ... Southern Ocean.

To read more about the thermohaline stream function check out Döös et al. (2012), Zika et al. (2012), Berglund et al. (2017), Groeskamp et al. (2019)

Distribution of waters from the Drake Passage to...



Water mass transformation from 2°C to 25°C



Total water mass transformation	
Temperature	23.7°C | 1578 MW
Salinity	0.7 g/kg | 11.38 Mkg/s
Density	-4.2 kg/m³

To read more about the Lagrangian thermohaline stream function check out Berglund et al. (2017)

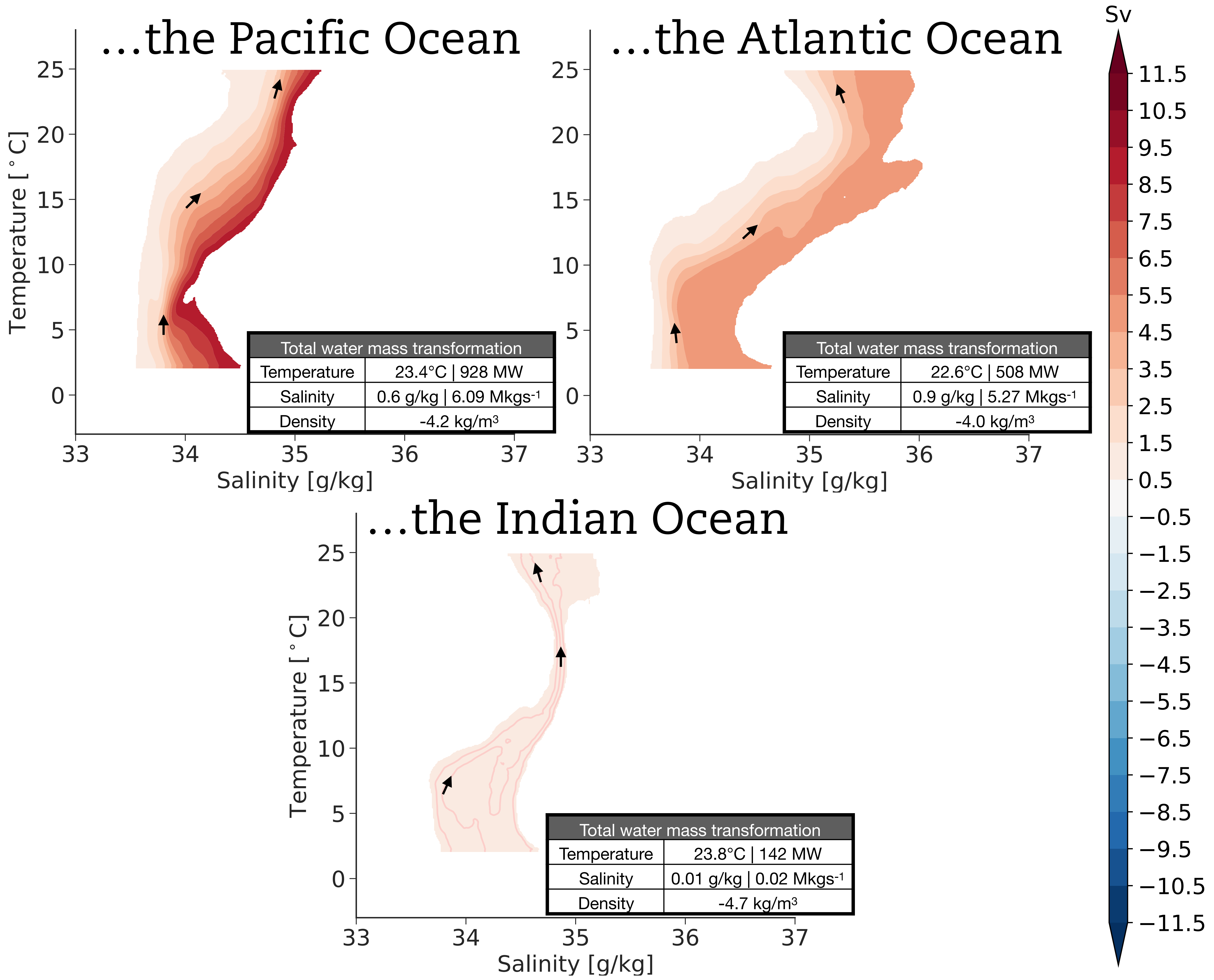
The Lagrangian thermohaline stream function describes the mean pathway of the trajectories going from Drake Passage to 25°C. The TS distribution in Drake Passage are spred over a large range of temperatures, going from -2°C to 10°C. The trajectories started in Drake Passage are simulated backward until they reach 2°C, by doing so, the sources in TS space are limited to smaller temperature range.

Results:
From the trajectories started as 2°C, crossing the Drake Passage and becoming 25°C a Lagrangian thermohaline stream function is computed. It reflects the left-hand-side of the thermohaline stream function well. However, at higher temperatures the stream lines are differing from each other This can either be due to overlapping cells in the Eulerian view, or seasonality in the Lagrangian case.

The waters transported from 2°C to 25°C gain a total of 1578MW heat during the transit, and 11.38Mkgs^{-1} salt. The total change in temperature is 23.7°C and for salinity 0.7g/kg. which gives rise to a decrease in density of 4.2 kg/m^3.

The gain of heat and salt can be separated between occurring inside the mixed layer and below the mixed layer. Doing so shows that the gain of heat is mostly confined to below the mixed layer, and there is actually a loss of heat in the mixed layer.

Water mass transformation in…



Pacific Ocean:

Total water mass transformation	
Temperature	23.4°C | 928 MW
Salinity	0.6 g/kg | 6.09 Mkgs^{-1}
Density	-4.2 kg/m^3

Atlantic Ocean:

Total water mass transformation	
Temperature	22.6°C | 508 MW
Salinity	0.9 g/kg | 5.27 Mkgs^{-1}
Density	-4.0 kg/m^3

Indian Ocean:

Total water mass transformation	
Temperature	23.8°C | 142 MW
Salinity	0.01 g/kg | 0.02 Mkgs^{-1}
Density	-4.7 kg/m^3

The Lagrangian thermohaline stream function can be computed depending on which basin the trajectories end in.

Pacific Ocean: 59% of the total mass transport started at the Drake Passage becomes 25°C in the Pacific Ocean. These waters gain a total of 928 MW heat during the transit from Drake Passage until they reach 25°C.

Atlantic Ocean: 32% of the total mass transport started at the Drake Passage becomes 25°C in the Atlantic Ocean. These waters can further be separated into two different paths, one reaching the Atlantic Ocean directly from the Drake Passage and one through the Agulas system. However, in this presentation only the total contribution from the Atlantic Ocean is considered. Totally these water gain 508MW heat from the Drake Passage until they reach 25°C in the Atlantic Ocean.

Indian Ocean: 9% of the total mass transport becomes 25°C in the Indian Ocean. These waters gain a total of 142 MW heat during the transit from the Drake Passage to 25°C in the Indian Ocean.

Comparison:
Heat: The trajectories reaching the Pacific Ocean gain 59% of the total heat gain for all trajectories, whereas the ones reaching the Atlantic ocean and the Indian ocean gain 33% and 9% respectively. This reflects the amount of mass transport ending in each basin since the change in temperature is the same for all basins.

Salt: The trajectories ending in the Pacific Ocean and the Atlantic Ocean gain 53% and 46% respectively. Thus the gain in salt is similar for the basins in comparison to heat. This is because the change in salinity is greater for the trajectories ending in the Atlantic Ocean, but the transport is much less compared to those ending in the Pacific Ocean.

Water mass transformation in the Pacific Ocean

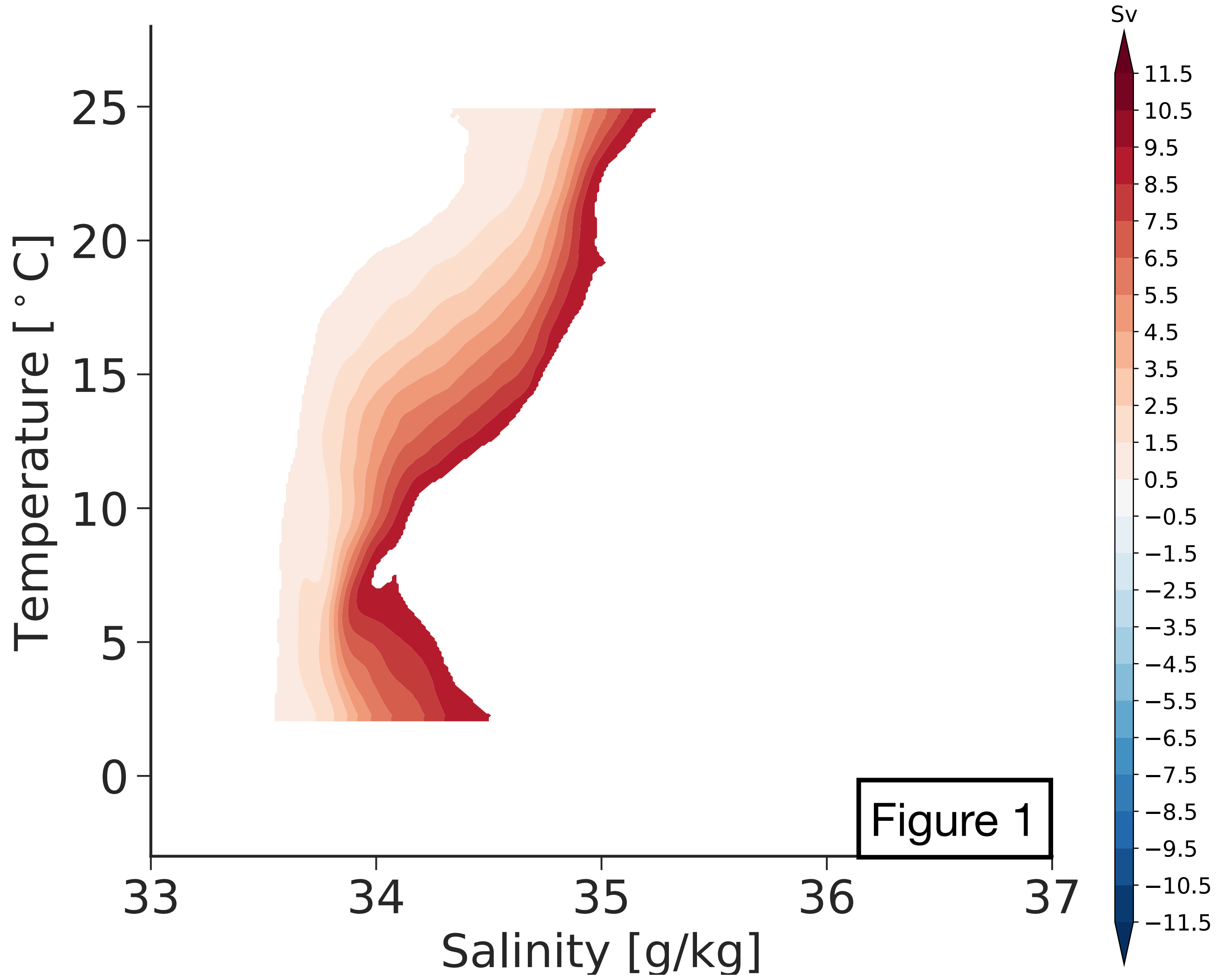


Figure 1

Total water mass transformation	
Temperature	23.4°C | 928 MW
Salinity	0.6 g/kg | 6.09 Mkgs^{-1}
Density	-4.2 kg/m^3

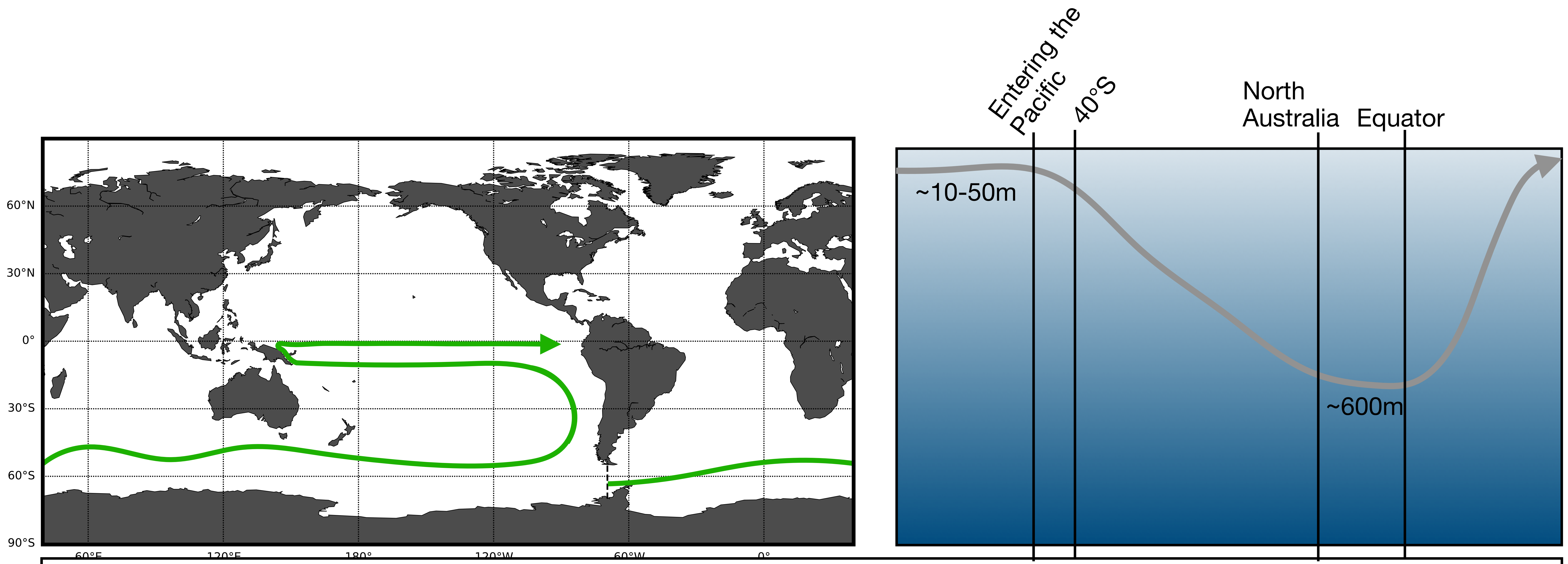
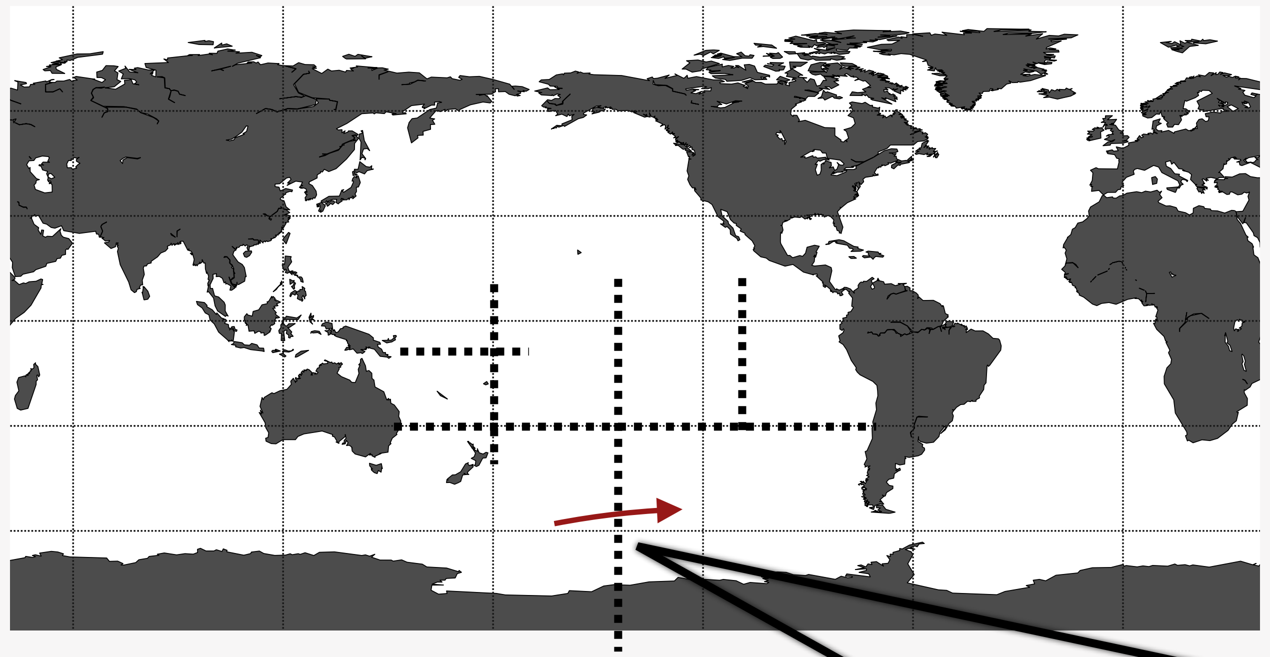


Figure 2 Schematic view of the pathway from Drake Passage to 25°C in the Pacific Ocean. a) shows a latitude-longitude view. b) shows a schematic view with depth on the y-axis and the whole pathway stretch at the x-asis (thus both latitude and longitud.

The Pacific Ocean stands for the largest contribution of the warming shown by the thermohaline stream function.
The gain of heat is separated between occurring in the mixed layer and below the mixed layer and it clearly shows that a large part of the heat gain is confined below the mixed layer.

In the Pacific Ocean the trajectories are all following a clear pathway:
Waters enter the Pacific Ocean in the most eastern parts, as reaching 40°S the water subducts and turn towards the western parts of the basin, with the aim north of Australia. During the transit to the western parts the waters continue to sink. As reading the western parts, it again turns northward until reaching the equator where is turns eastward and continues in the equatorial undercurrent. This is shown schematically in Figure 2a and b.

Density distributions of trajectories in the Pacific Ocean



Blue shading - Eastward/Southward

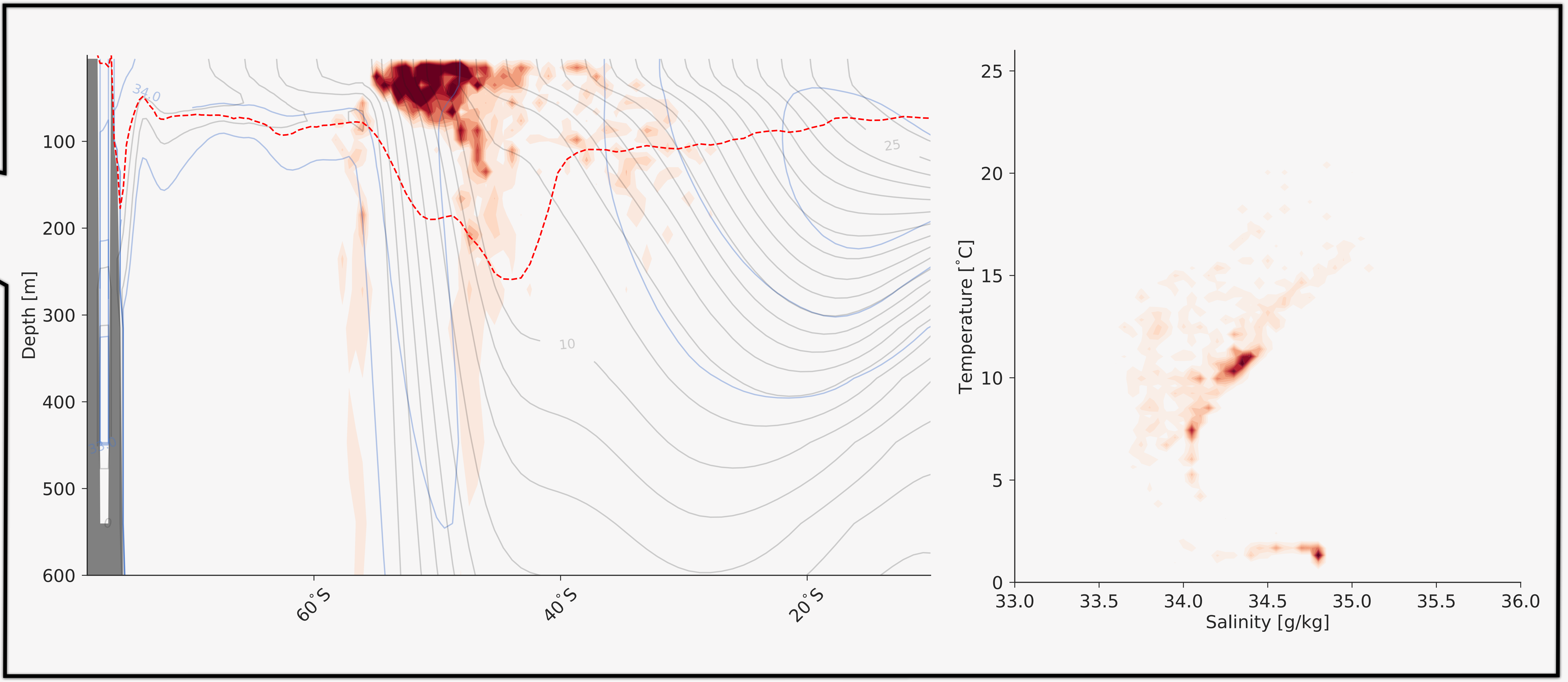
Red shading - Westward/Northward

Grey area - topography

- Max. mixed layer

- Mean temperature

- Mean salinity



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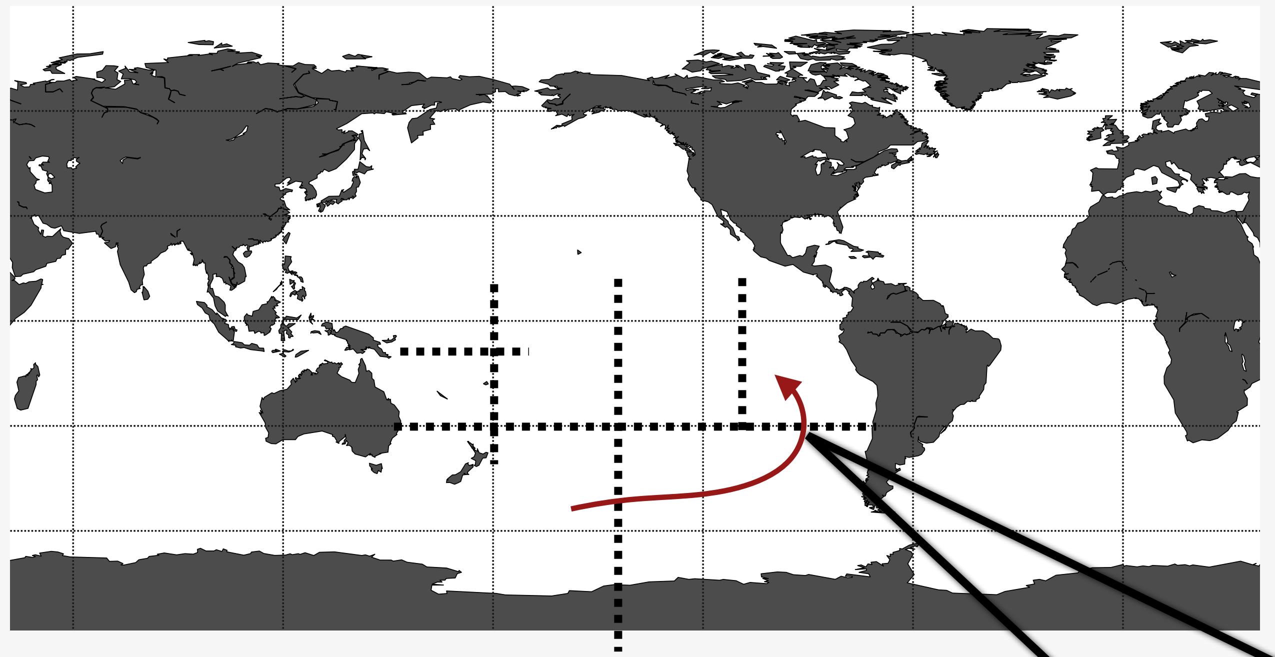

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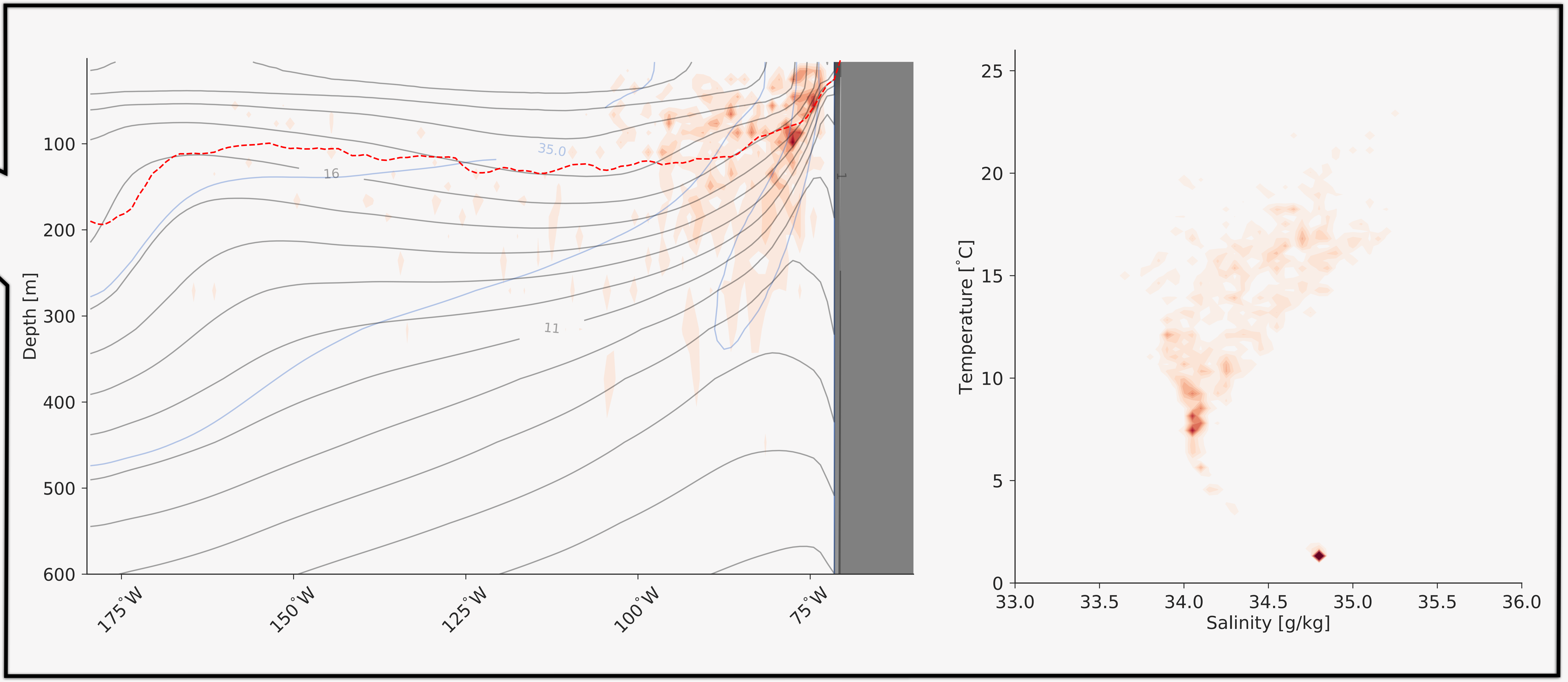

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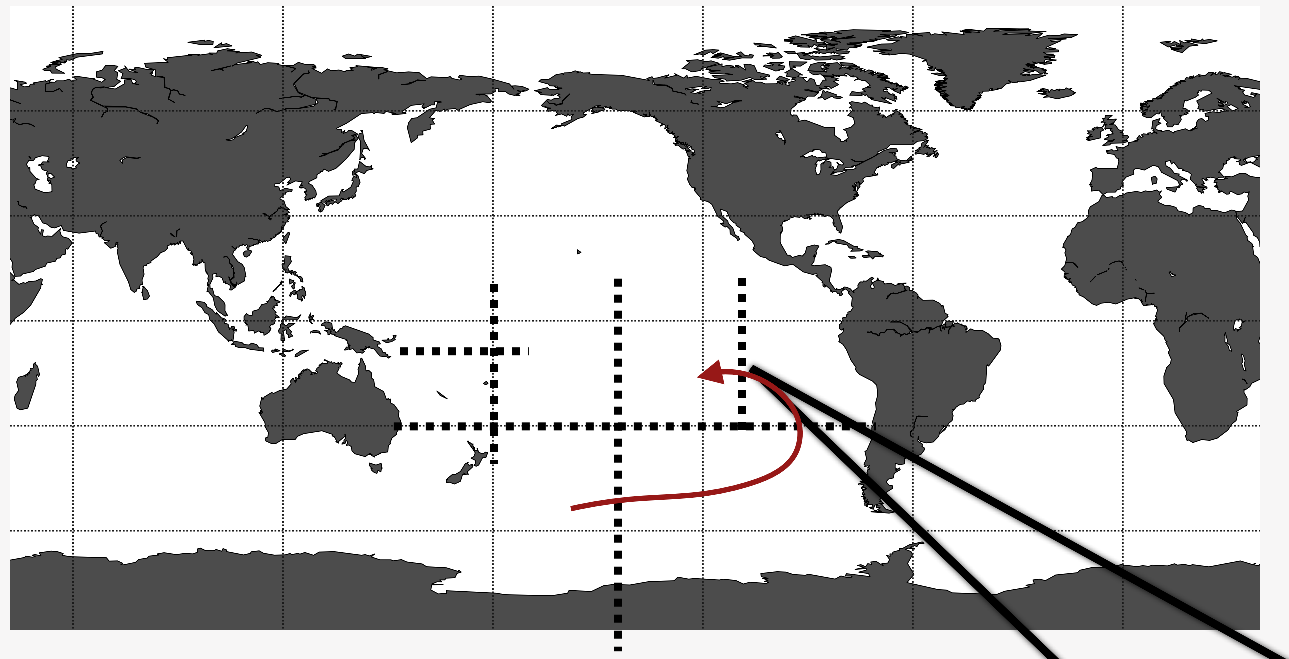

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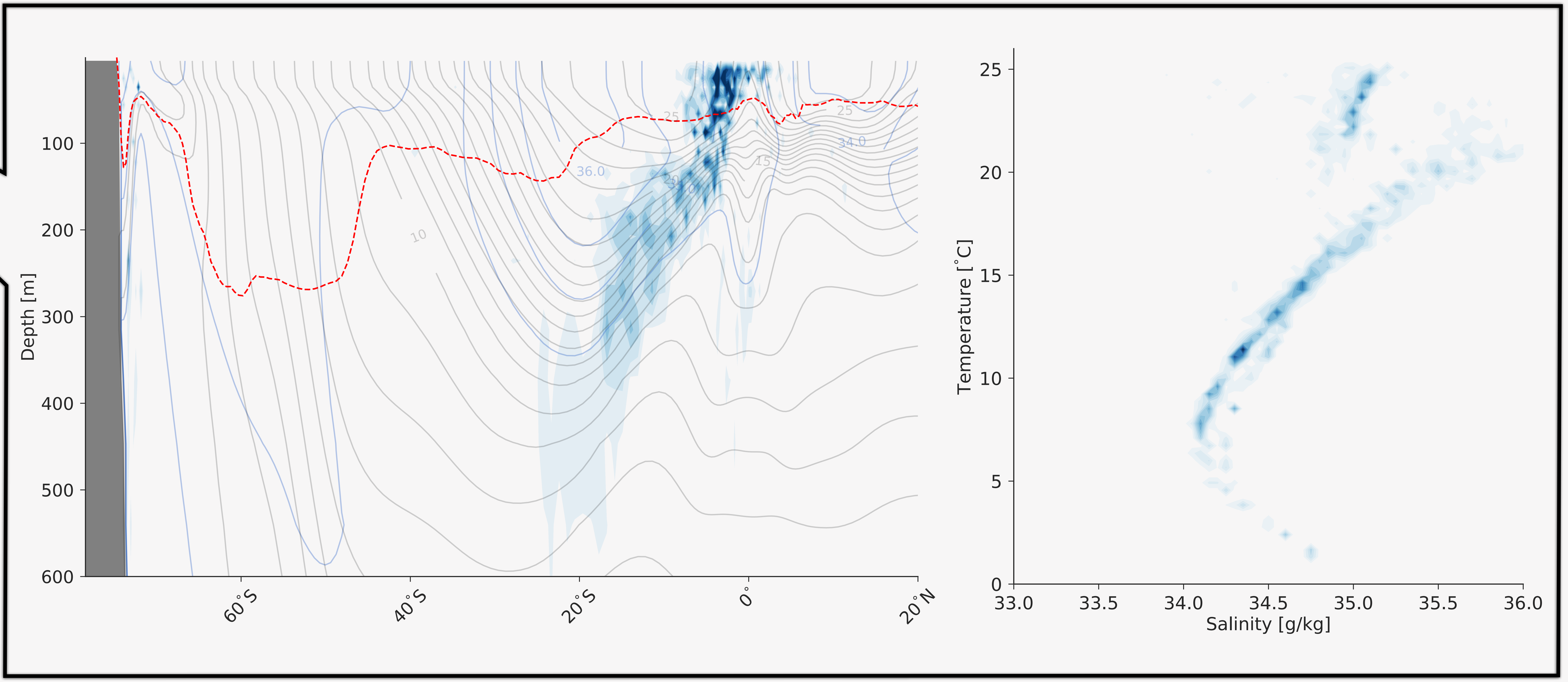

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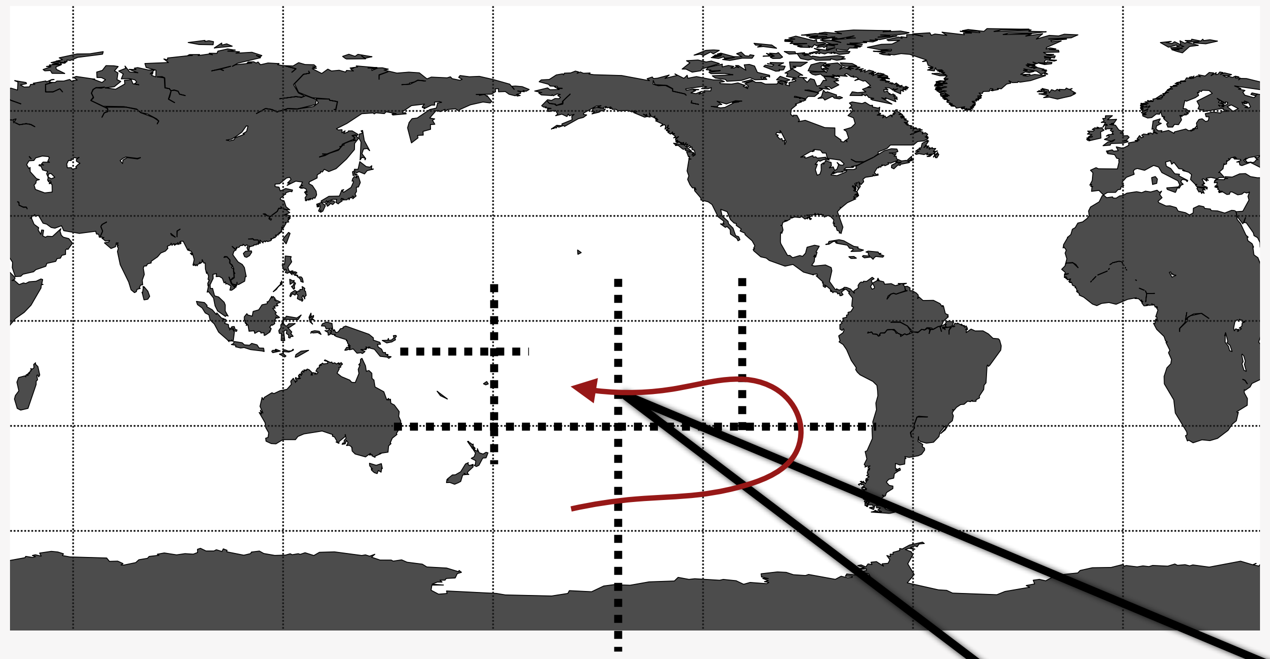

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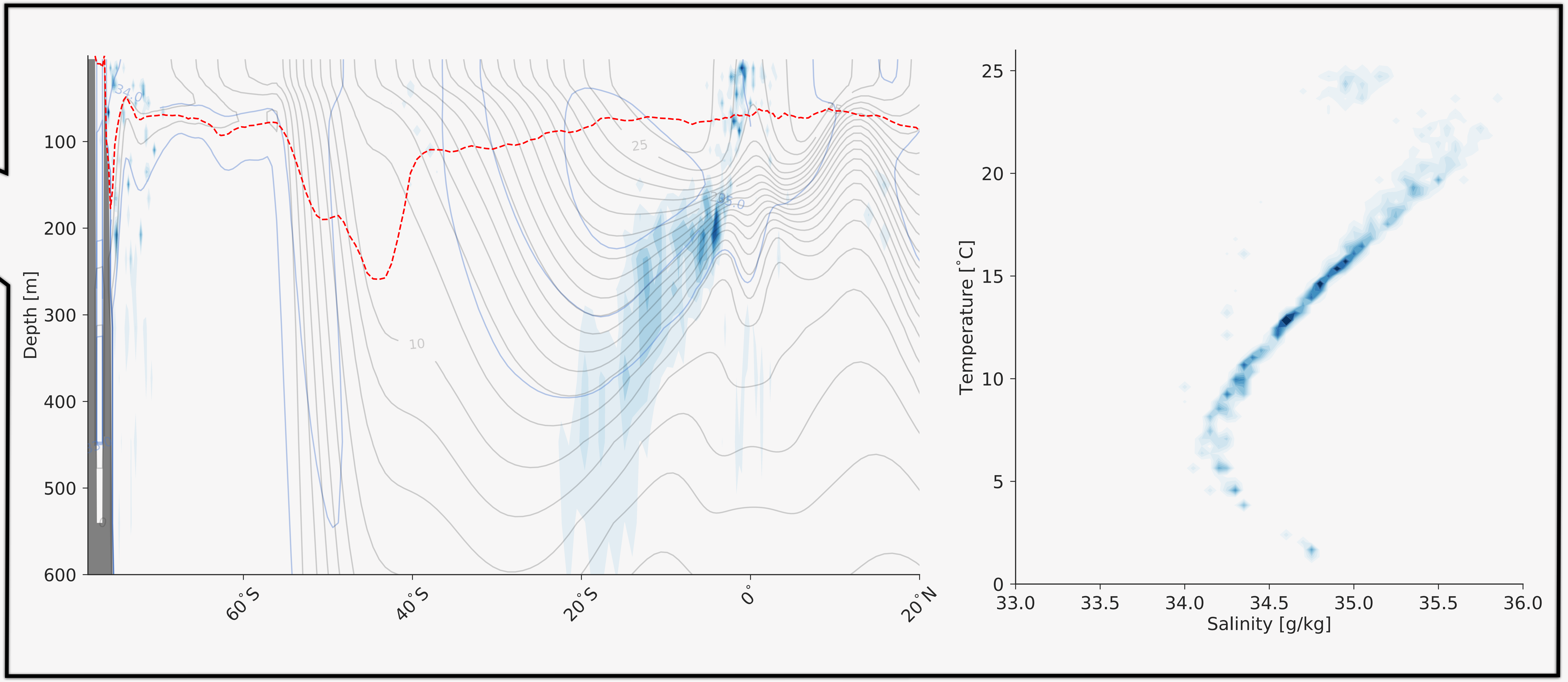

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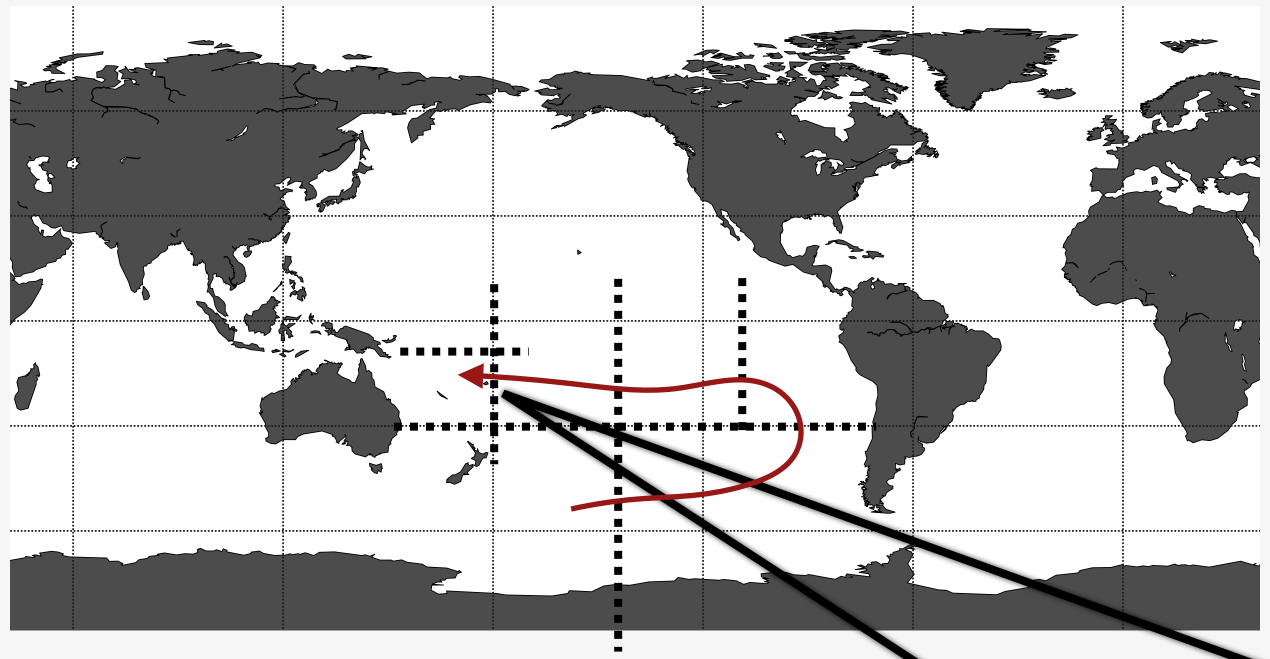

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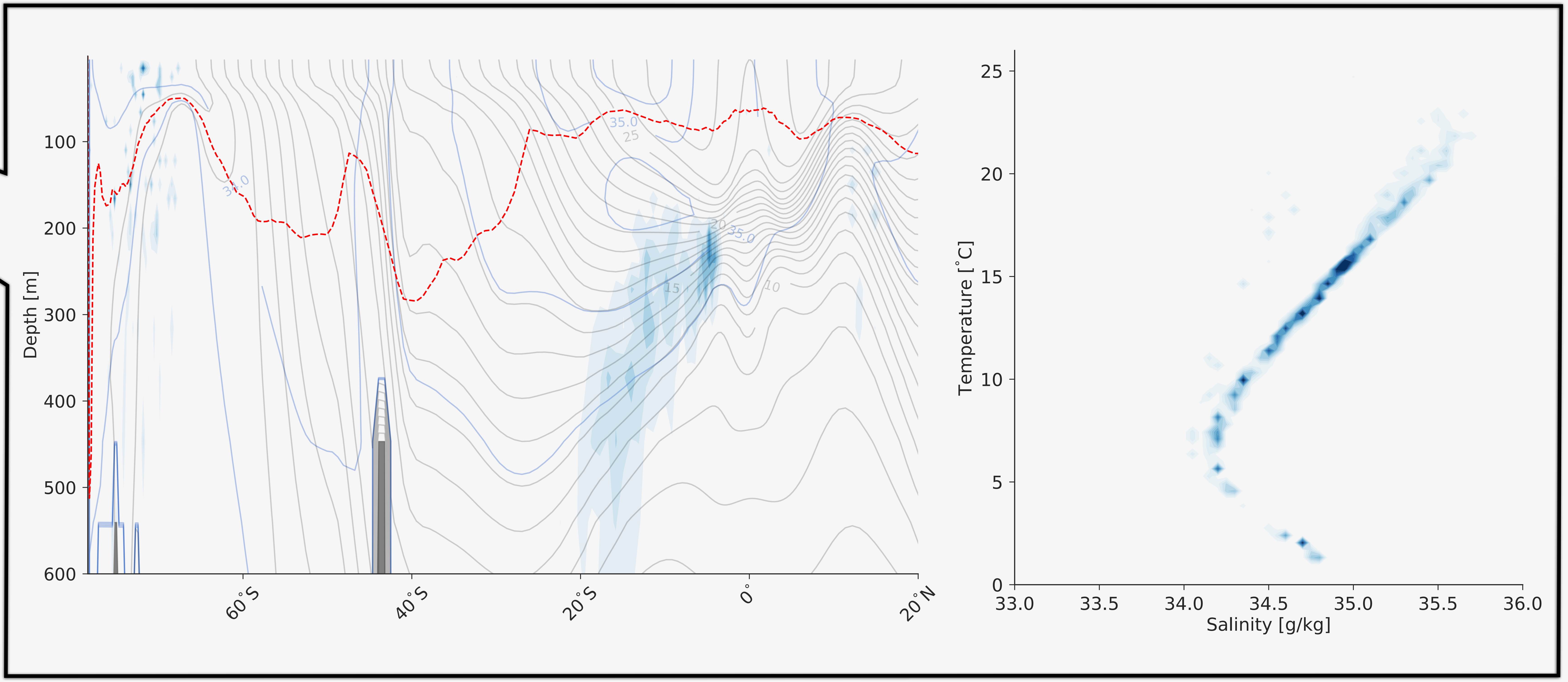

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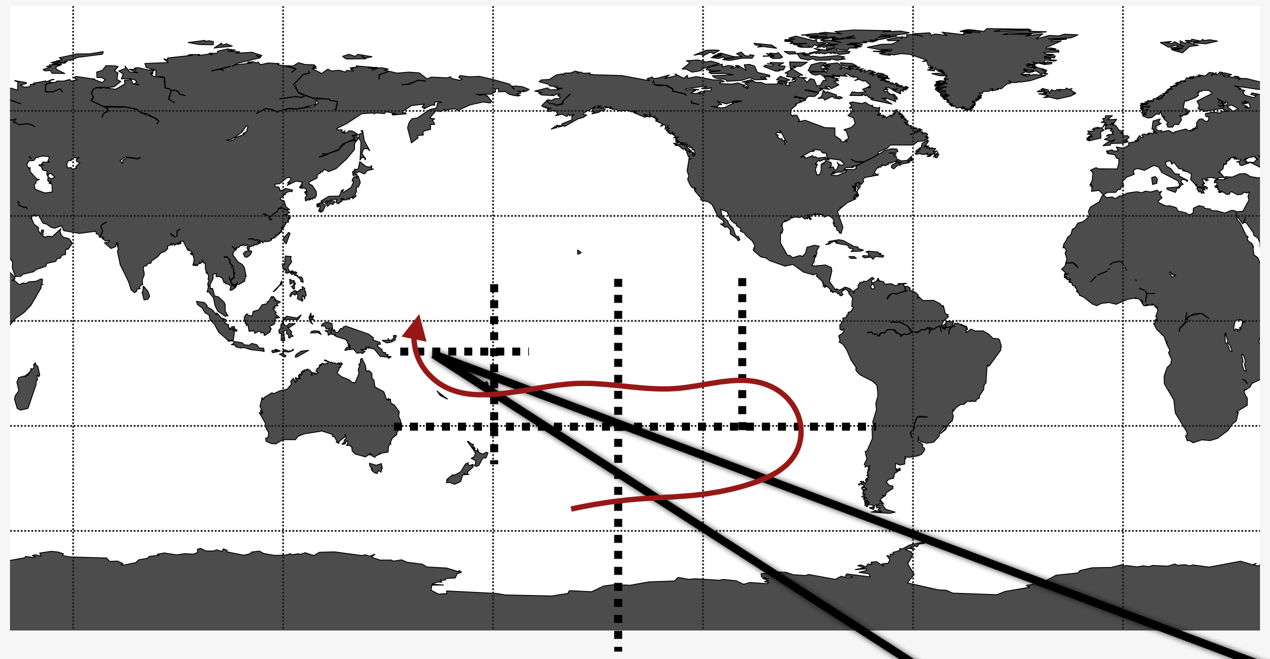

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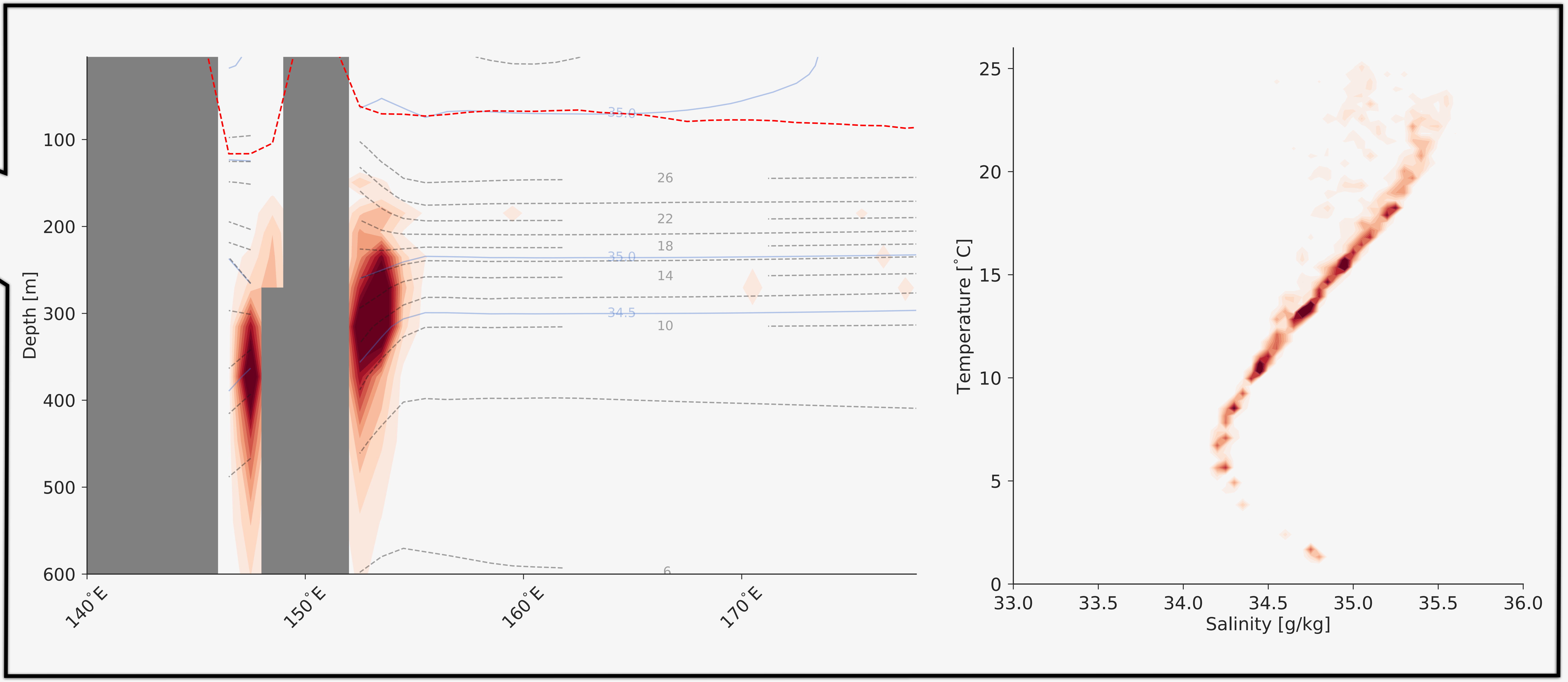

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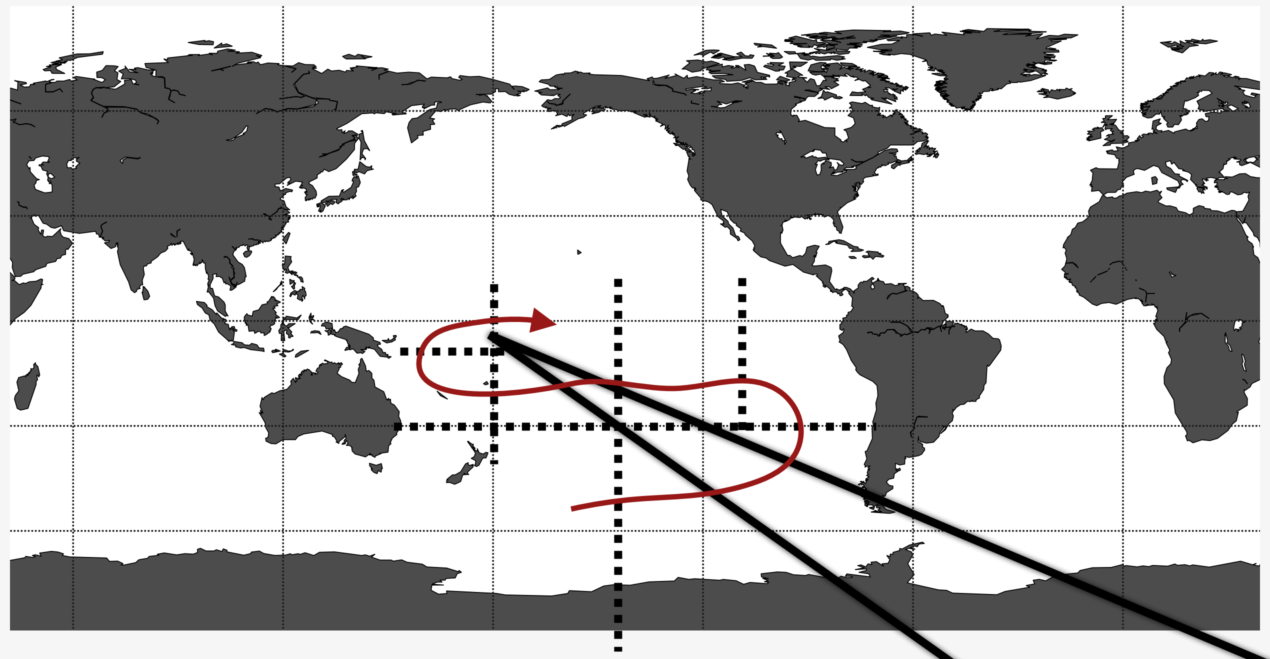

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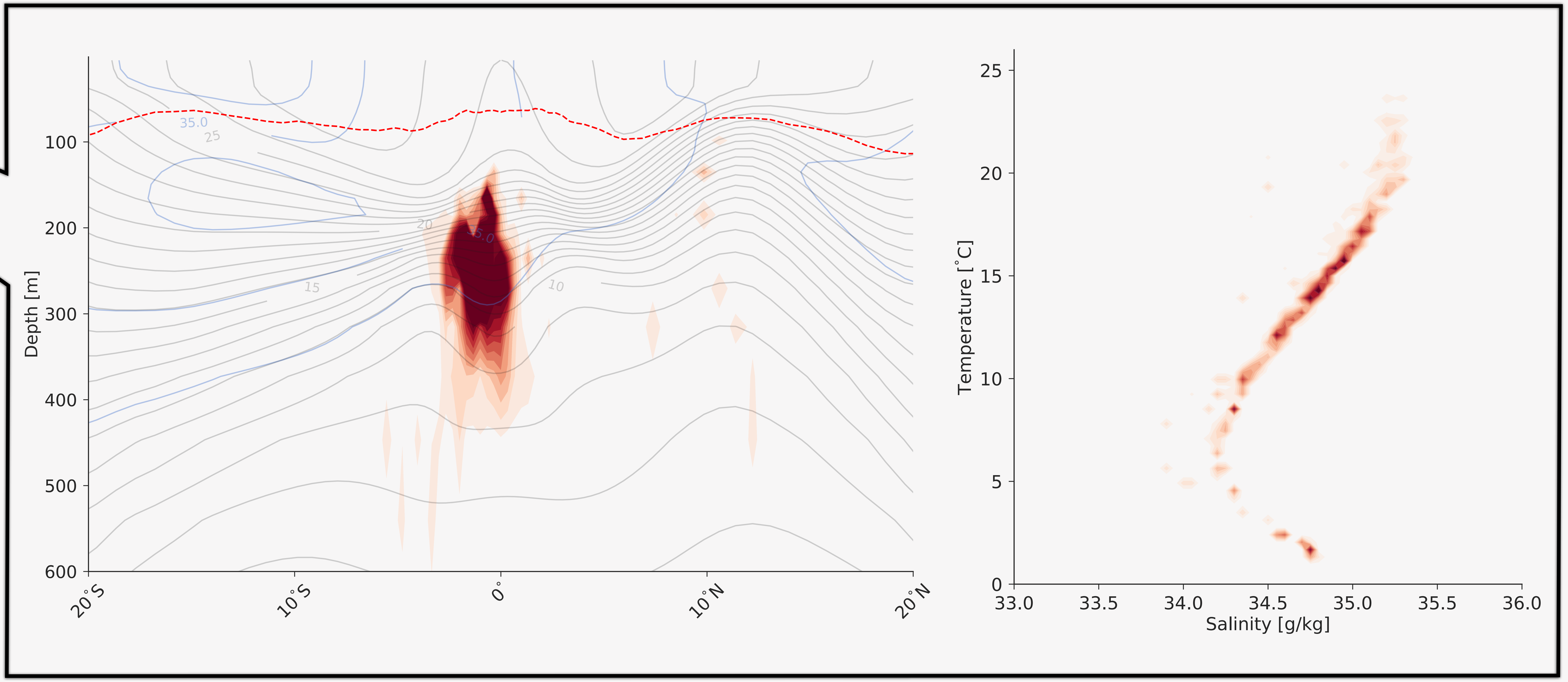

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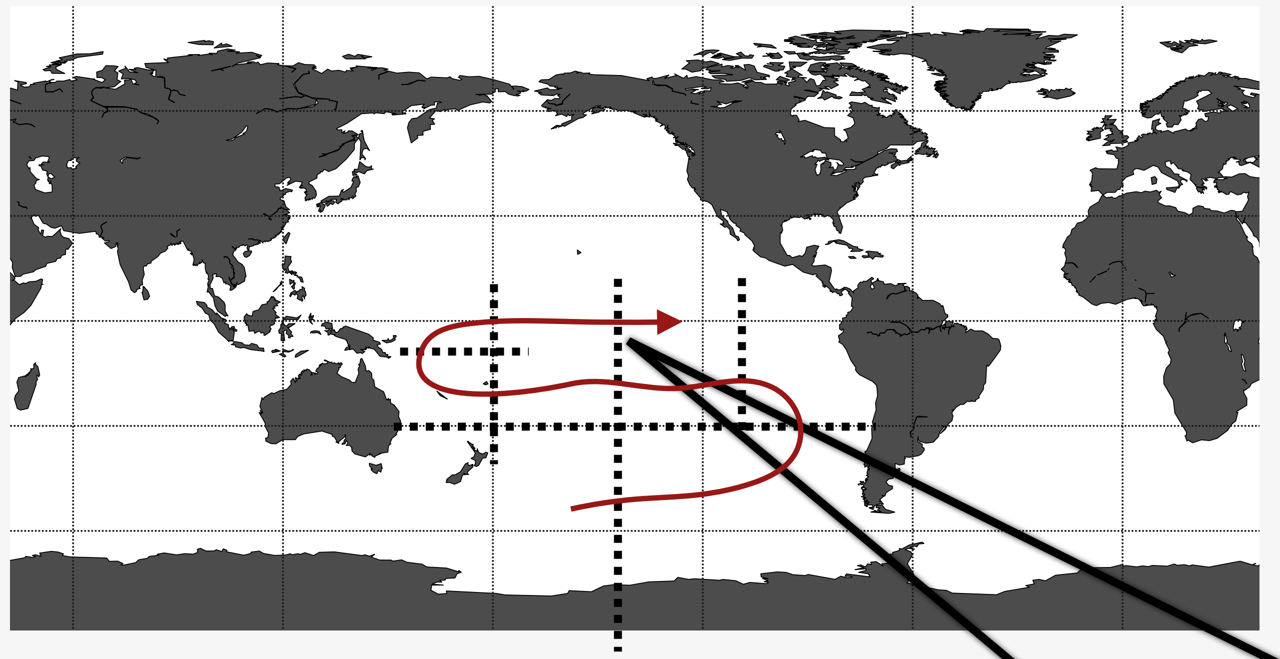

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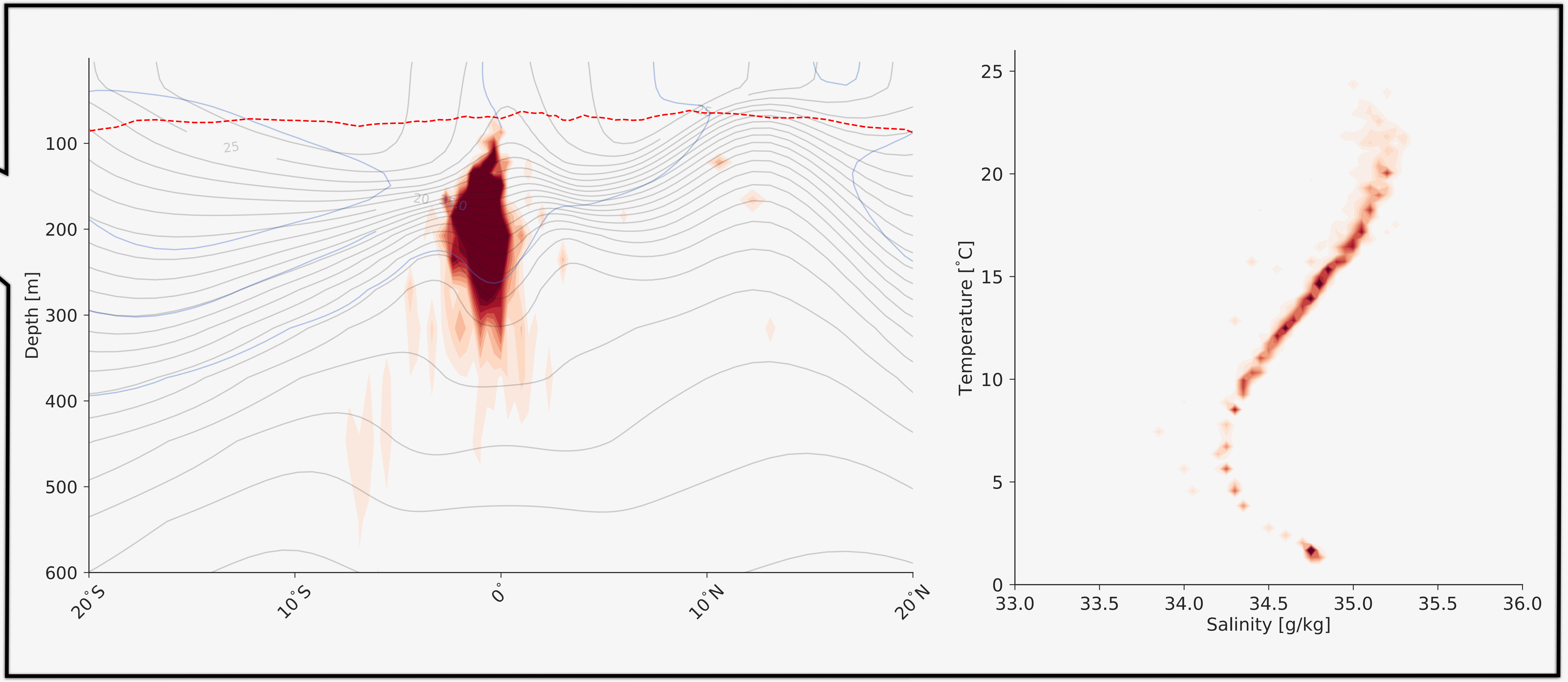

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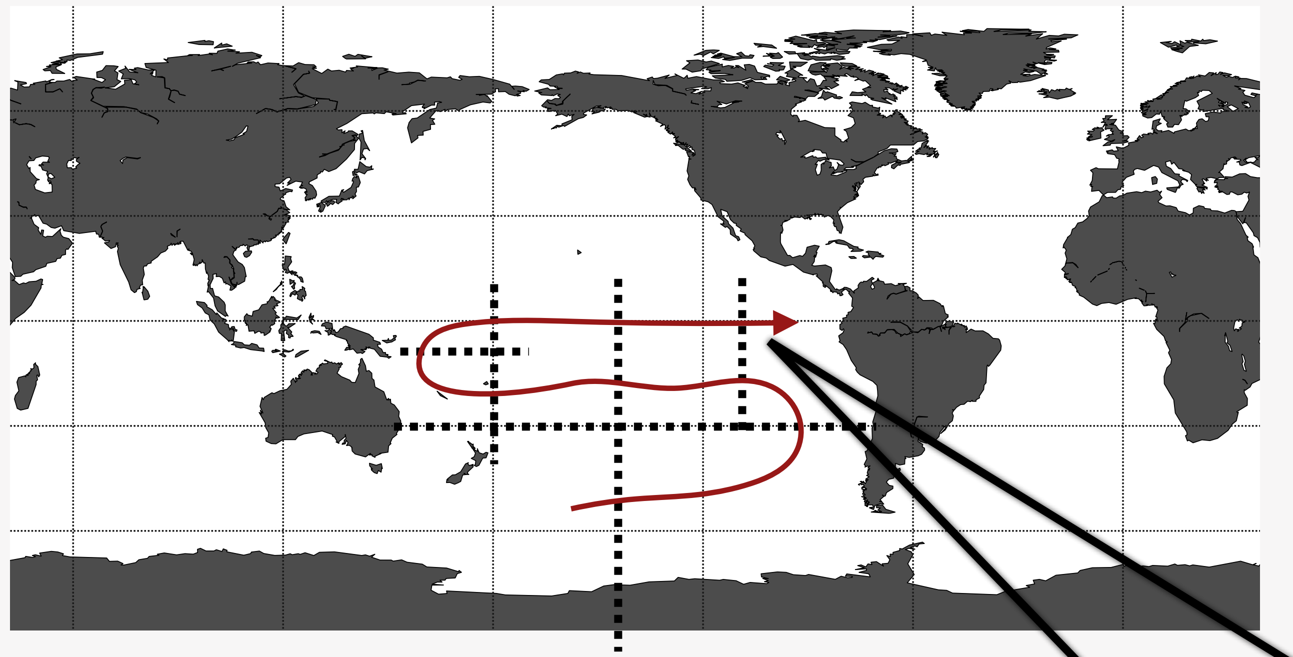

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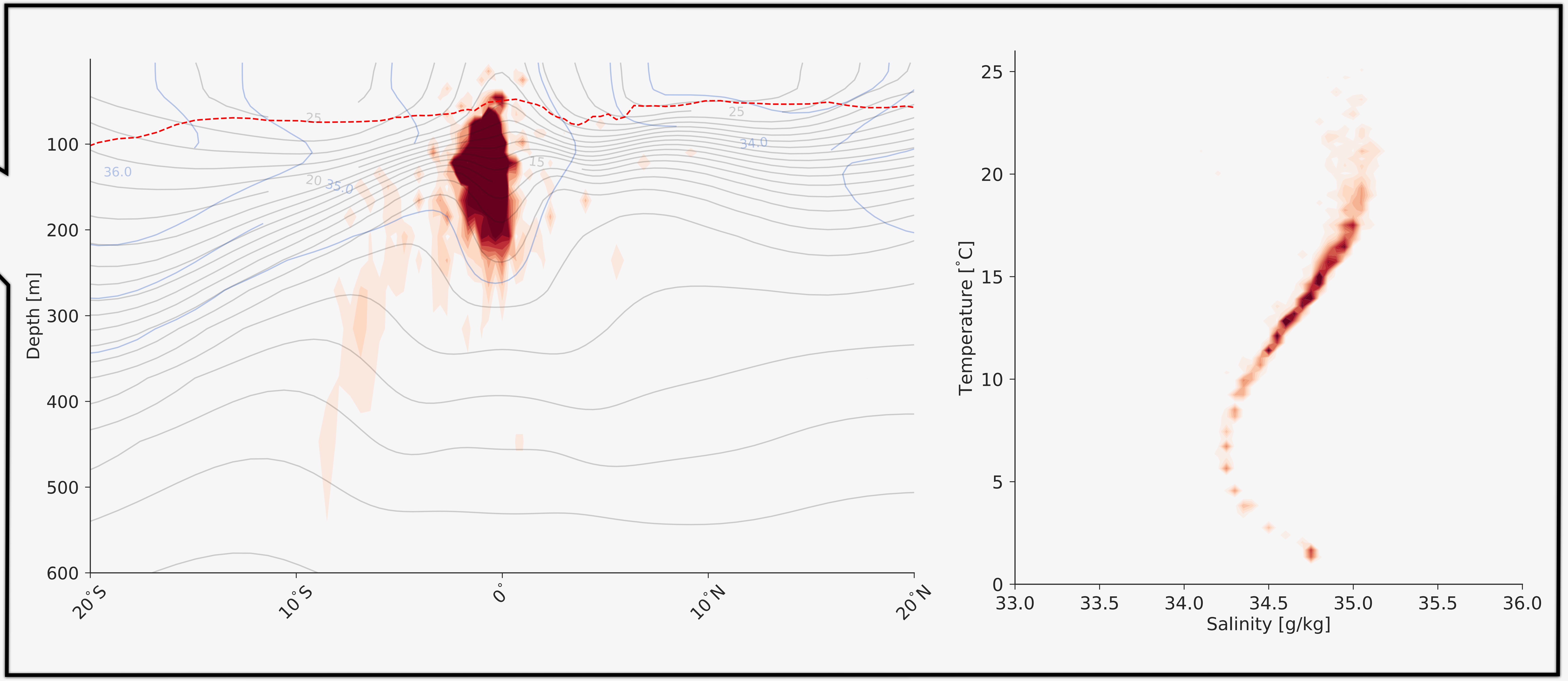
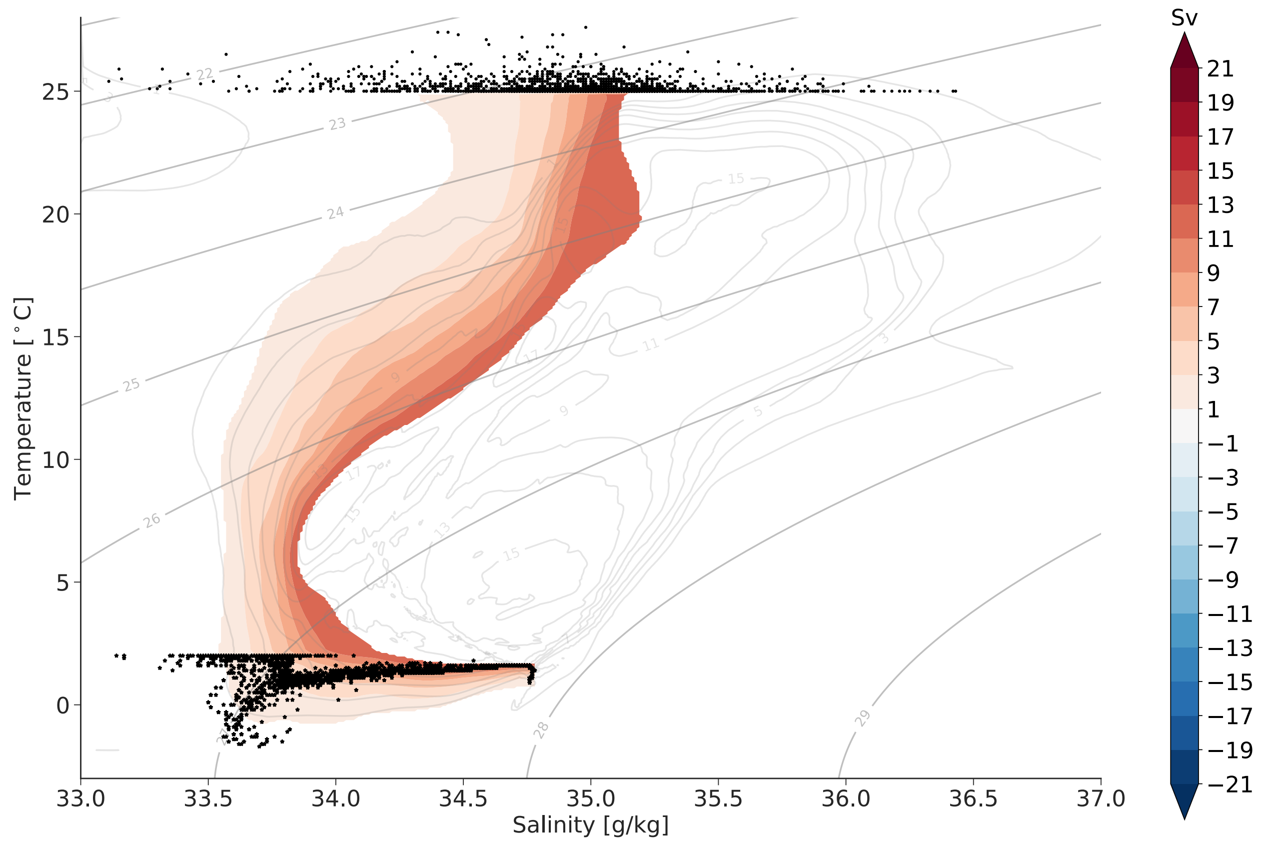
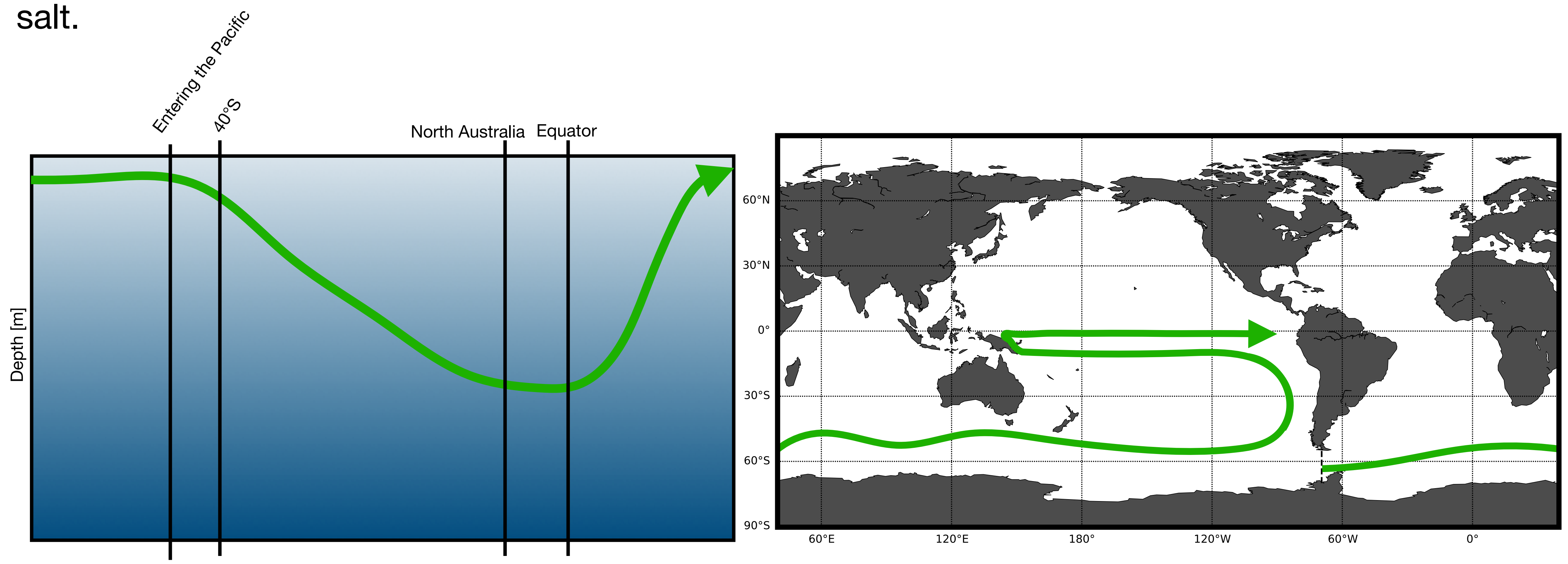


Take Home Messages

✻The waters travelling from 2°C to 25°C, crossing the Drake Passage, reflects the left-hand-side of the thermohaline stream function.



✻ A clear pathway in the Pacific Ocean reveals how the water is moving as it changes gains heat and salt.



Some more Home messages…

✻The gain of heat is mostly confined to below the mixed layer. Indicating that air-sea interactions do not contribute to a large part of the water mass transformation.

✻Separating trajectories depending on where they end show that the ones reaching the Pacific Ocean stands for 59% of the heat gain, while those ending in the Atlantic Ocean and the Indian Ocean stands for 32% and 9%, respectively.

✻The salt gain for trajectories ending in the Pacific Ocean is 53% of the total salt gain from 2°C to 25°C. Differently from heat, the trajectories ending in the Atlantic Ocean gain a similar amount, 46% of the total salt gain. The Indian Ocean only stands for 0.2% of the total gain.

Thank you!