Diagnosing Water Mass Transformation Budgets in Finite-Volume Generalized Vertical Coordinate Ocean Models

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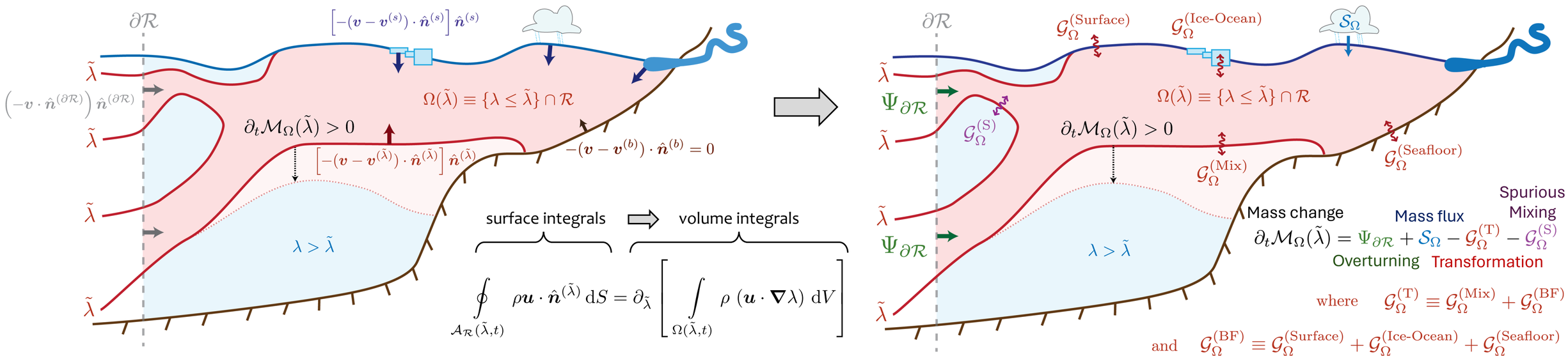
Introduction

Water Mass Transformation (WMT) theory provides quantitative relationships that relate changes in integral water mass properties to overturning circulations and processes that modify tracer concentrations along material trajectories. At equilibrium, this framework directly attributes overturning circulations to the transformation processes that drive them. We explain how to diagnose full WMT budgets from finite-volume generalized vertical coordinate models such as MOM6 and demonstrate the utility of these diagnostics for both science and model development.

Key Takeaways

1. WMT budgets provide insights into the processes transforming material water mass properties and how they relate to circulation.
2. Spurious WMT due to advection scheme errors can be quantified by combining readily available mass and tracer budget diagnostics.
3. We develop a set of best practices for model analysis and present a novel stack of Python packages for model-agnostic and out-of-memory calculations for arbitrarily shaped regions.

Water Mass Budget | **Water Mass *Transformation* Budget**



Proof of concept: application to a regional Baltic Sea test configuration in MOM6, sensitivity/robustness tests, and software development

We illustrate the method by analyzing a Baltic Sea test simulation configured as follows:

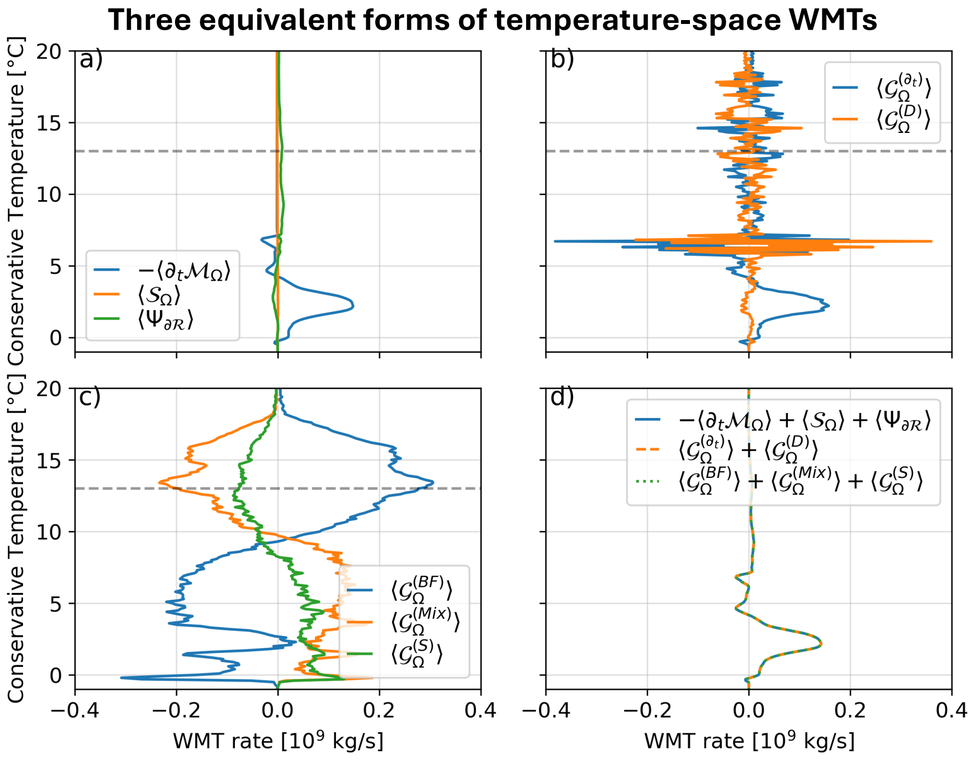
- Year-long JRA-forced simulation 0.25º resolution with all parameterizations present in OM4
- Extensive properties binned online in native vertical layers as well as depth and density layers
- Save closed layer-integrated budget diagnostics (for mass, heat, and salt) at three temporal resolutions: monthly-mean, daily-mean, hourly (timestep)-mean

We quantify the convergence of errors in WMT calculations by testing all permutations of diagnostics.
Main result: offline remapping of monthly-mean output into tracer coordinates results in O(1) errors.

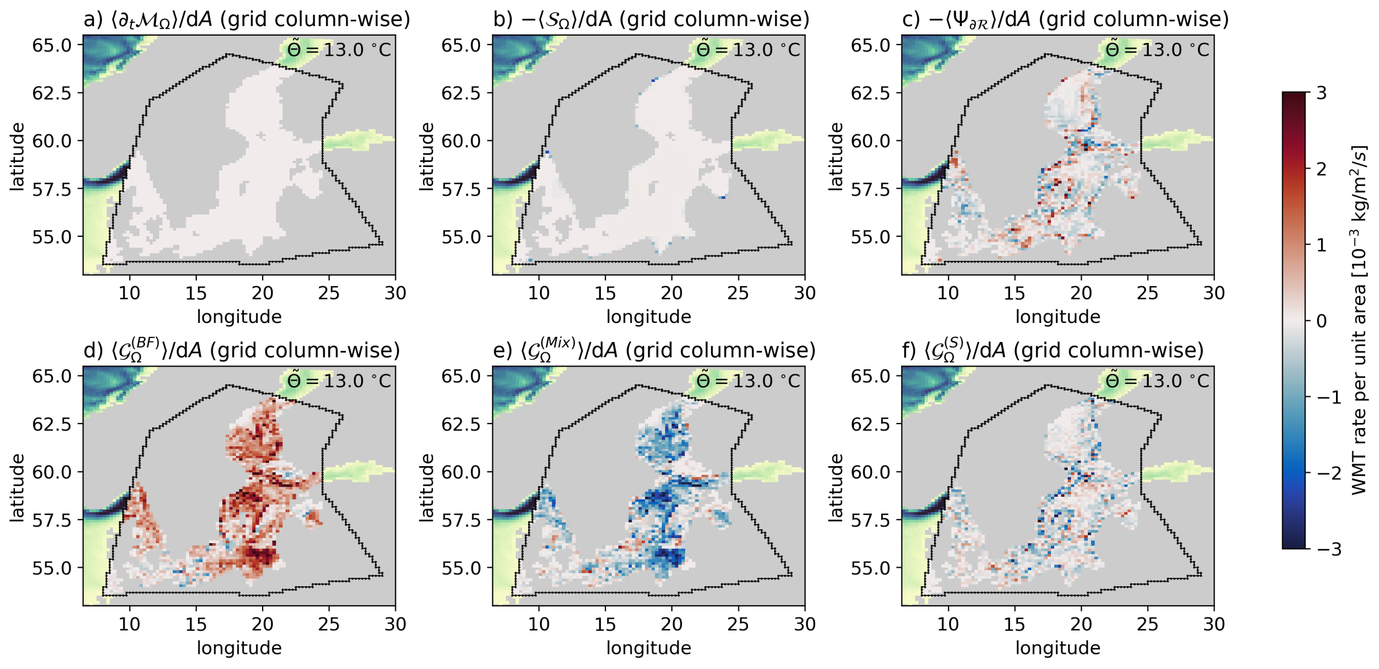
We diagnose time-averaged WMT budgets for the region $\mathcal{R}$ bounded by the black polygon in the figure below, as follows:

- **Mass change:** from finite difference of snapshots bounding the time-averaging interval
- **Overturning:** from the convergent transport across the region's boundary (and within the tracer bounds)
- **Mass flux:** area-integrated cross-boundary mass fluxes
- **Transformations:** by finite-differencing volume integrals of density-weighted tracer tendencies
- **Spurious Mixing:** as the remainder of the other terms.

Three equivalent forms of temperature-space WMTs

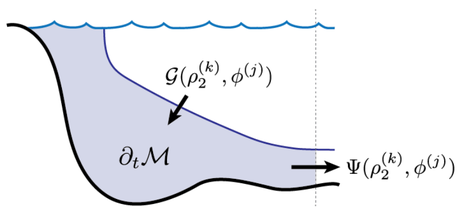


Temperature-space WMTs per unit area within $\mathcal{R}$ for waters colder than 13ºC

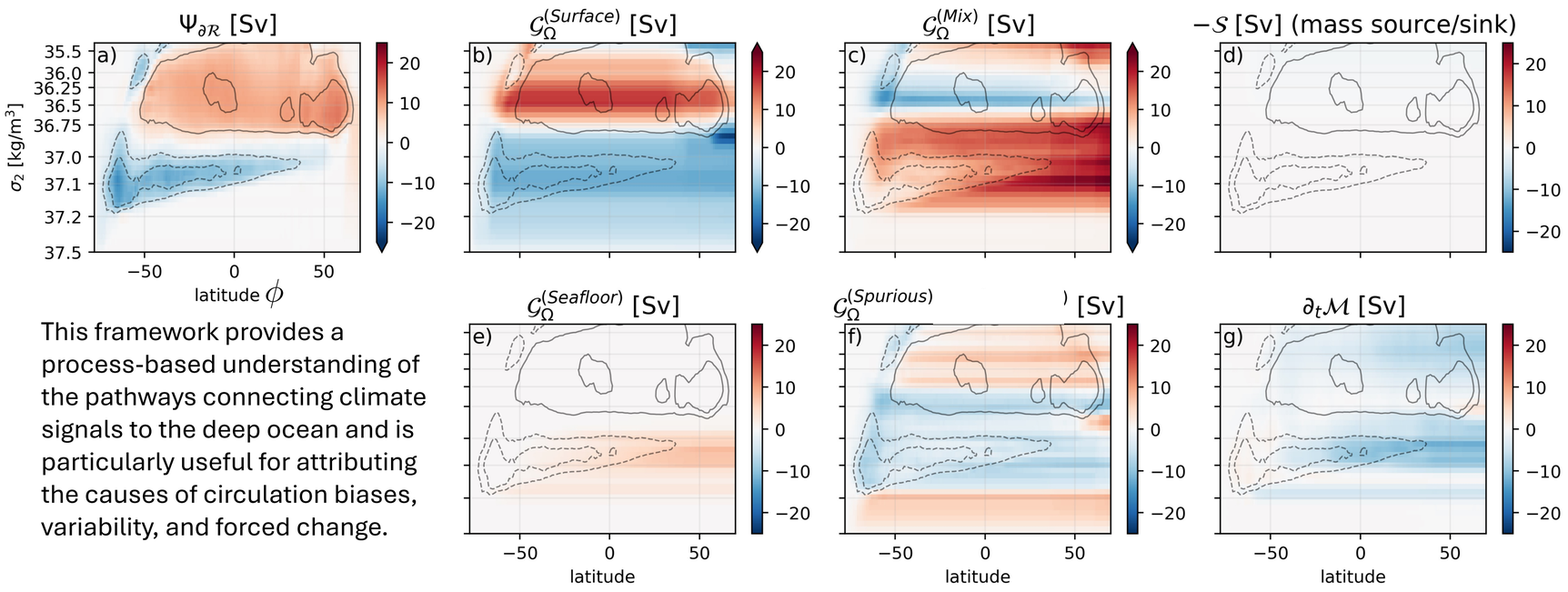


Applied to deep ocean pathways: a process-based decomposition of the Meridional Overturning Circulation's residual streamfunction

When $\lambda = \sigma_2$ and the region $\mathcal{R}$ is defined as southward of a given latitude ϕ, we identify the overturning term in the WMT budget as the zonally-integrated meridional transport integrated below a given σ_2 surface.



By repeating the calculation for a grid of (ϕ, σ_2) values, the transport term becomes the Meridional Overturning Circulation's full residual streamfunction. Then, rearranging the WMT budget, we can thus decompose the circulation in terms of its thermohaline drivers and unbalanced water mass trends.



This framework provides a process-based understanding of the pathways connecting climate signals to the deep ocean and is particularly useful for attributing the causes of circulation biases, variability, and forced change.

Example notebooks: `github.com/hdrake/xwmb`
Group website: `faculty.sites.uci.edu/drakelab/`

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