Tutorial on volume, heat, and freshwater budgets

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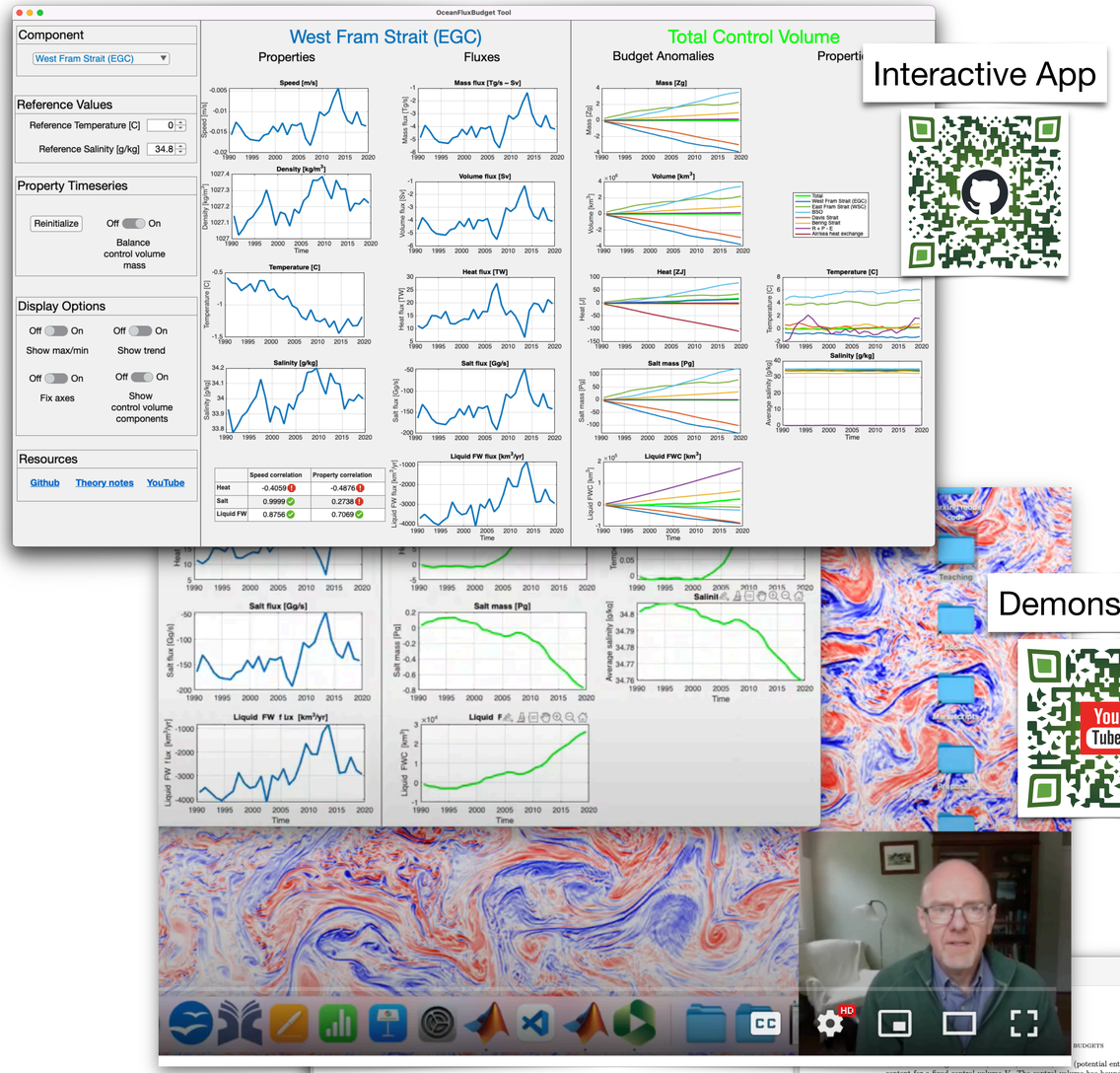
Abstract

An essential task in physical oceanography is to construct budgets of conserved quantities, like heat, salt and seawater mass, and the masses of trace chemicals. In the Arctic and subArctic oceans, for example, such budgets are routinely used to diagnose and understand the effects of natural variations and anthropogenic climate change on temperature and salinity. Traditionally, temperature variability is analyzed using a budget of heat fluxes relative to a reference temperature. Similarly, salinity variability is analyzed using so-called freshwater fluxes relative to a reference salinity. Well-documented pitfalls exist in the interpretation of these heat and freshwater fluxes, however. Yet, despite being well-documented, these pitfalls are not universally understood or accepted.

This contribution aims to improve understanding of, and to promote best-practices in, the interpretation of heat and freshwater fluxes, and the construction of their budgets. The contribution consists of:

1. A free, open-source, interactive, pedagogical software application called the Ocean-Flux-Budget tool.
2. A tutorial YouTube video demonstrating the Ocean-Flux-Budget tool, the pitfalls mentioned above, and suggested workarounds.
3. A document explaining the issues, with references to the original literature, and proposed best practices.

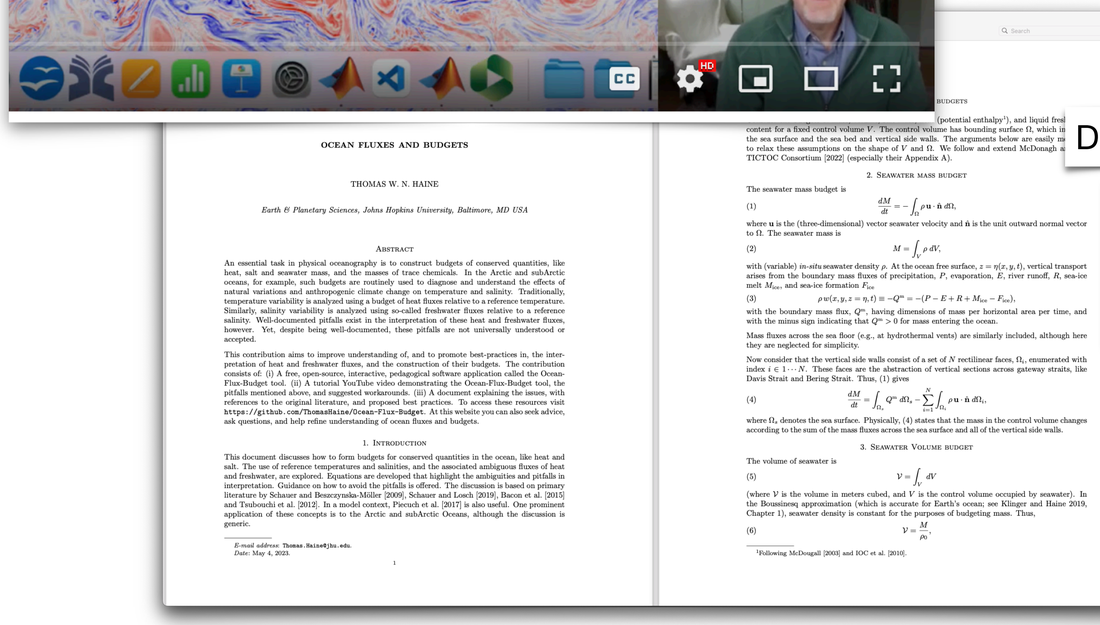
To access these resources visit github.com/ThomasHaine/Ocean-Flux-Budget or scan the QR codes. At this website you can also seek advice, ask questions, and help refine understanding of ocean fluxes and budgets.



Interactive App

Demonstration

Documentation



OCEAN FLUXES AND BUDGETS

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ABSTRACT

An essential task in physical oceanography is to construct budgets of conserved quantities, like heat, salt and seawater mass, and the masses of trace chemicals. In the Arctic and subArctic oceans, for example, such budgets are routinely used to diagnose and understand the effects of natural variations and anthropogenic climate change on temperature and salinity. Traditionally, temperature variability is analyzed using a budget of heat fluxes relative to a reference temperature. Similarly, salinity variability is analyzed using so-called freshwater fluxes relative to a reference salinity. Well-documented pitfalls exist in the interpretation of these heat and freshwater fluxes, however. Yet, despite being well-documented, these pitfalls are not universally understood or accepted.

This contribution aims to improve understanding of, and to promote best-practices in, the interpretation of heat and freshwater fluxes, and the construction of their budgets. The contribution consists of: (i) A free, open-source, interactive, pedagogical software application called the Ocean-Flux-Budget tool. (ii) A tutorial YouTube video demonstrating the Ocean-Flux-Budget tool, the pitfalls mentioned above, and suggested workarounds. (iii) A document explaining the issues, with references to the original literature, and proposed best practices. To access these resources visit `https://github.com/ThomasHaine/Ocean-Flux-Budget`. At this website you can also seek advice, ask questions, and help refine understanding of ocean fluxes and budgets.

1. INTRODUCTION

This document discusses how to form budgets for conserved quantities in the ocean, like heat and salt. The use of reference temperatures and salinities, and the associated ambiguous fluxes of heat and freshwater, are explored. Equations are developed that highlight the ambiguities and pitfalls in interpretation. Guidance on how to avoid the pitfalls is offered. The discussion is based on primary literature by Schauer and Beszczynska-Möller [2009], Schauer and Losch [2019], Bacon et al. [2015] and Tsubouchi et al. [2012]. In a model context, Piecuch et al. [2017] is also useful. One prominent application of these concepts is to the Arctic and subArctic Oceans, although the discussion is generic.

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Date: May 4, 2023.

2. SEAWATER MASS BUDGET

The seawater mass budget is

$$\frac{dM}{dt} = -\int_\Omega \rho\,\mathbf{u}\cdot\hat{\mathbf{n}}\,d\Omega, \tag{1}$$

where $\mathbf{u}$ is the (three-dimensional) vector seawater velocity and $\hat{\mathbf{n}}$ is the unit outward normal vector to Ω. The seawater mass is

$$M = \int_V \rho\,dV, \tag{2}$$

with (variable) *in-situ* seawater density ρ. At the ocean free surface, $z = \eta(x, y, t)$, vertical transport arises from the boundary mass fluxes of precipitation, P, evaporation, E, river runoff, R, sea-ice melt M_{ice}, and sea-ice formation F_{ice}

$$\rho\,w(x, y, z = \eta, t) \equiv -Q^m = -(P - E + R + M_{\text{ice}} - F_{\text{ice}}), \tag{3}$$

with the boundary mass flux, Q^m, having dimensions of mass per horizontal area per time, and with the minus sign indicating that $Q^m > 0$ for mass entering the ocean.

Mass fluxes across the sea floor (e.g., at hydrothermal vents) are similarly included, although here they are neglected for simplicity.

Now consider that the vertical side walls consist of a set of N rectilinear faces, Ω_i, enumerated with index $i \in 1 \cdots N$. These faces are the abstraction of vertical sections across gateway straits, like Davis Strait and Bering Strait. Thus, (1) gives

$$\frac{dM}{dt} = \int_{\Omega_s} Q^m\,d\Omega_s - \sum_{i=1}^{N}\int_{\Omega_i} \rho\,\mathbf{u}\cdot\hat{\mathbf{n}}\,d\Omega_i, \tag{4}$$

where Ω_s denotes the sea surface. Physically, (4) states that the mass in the control volume changes according to the sum of the mass fluxes across the sea surface and all of the vertical side walls.

3. SEAWATER VOLUME BUDGET

The volume of seawater is

$$\mathcal{V} = \int_V dV \tag{5}$$

(where $\mathcal{V}$ is the volume in meters cubed, and V is the control volume occupied by seawater). In the Boussinesq approximation (which is accurate for Earth's ocean; see Klinger and Haine 2019, Chapter 1), seawater density is constant for the purposes of budgeting mass. Thus,

$$\mathcal{V} = \frac{M}{\rho_0}. \tag{6}$$

[1]Following McDougall [2003] and IOC et al. [2010].

Proposed Best Practices

For **fluxes across individual straits**, state:

- The face-averaged conservative temperature, absolute salinity, and seawater density timeseries.
- The mass flux timeseries and salt flux timeseries.
- The advective relative heat flux timeseries using at least two reference temperatures.
- Any tacit assumptions, such as a closed mass budget or the Boussinesq approximation.

Also, optionally, state:

- The seawater volume flux timeseries.
- The advective liquid freshwater content flux (LFC) timeseries, as long as at least two reference salinities are used.

For **control volumes**, state:

- The volume-averaged seawater mass, conservative temperature, absolute salinity, and seawater density timeseries.
- Any tacit assumptions, such as a closed mass budget or the Boussinesq approximation.

Also, optionally, state:

- The seawater volume timeseries.
- The relative heat content and LFC timeseries, as long as at least two reference temperatures and salinities are used.

In all cases,

- Provide access to the original data and the data-processing pipeline.
- Fluxes and budgets of trace chemicals are treated analogously to salt mass and salinity.

ASOF
Arctic-Subarctic Ocean Fluxes

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