# Space & time variability of pan-Arctic estimates of internal wave-driven dissipation, mixing, and heat fluxes inferred from the Ice-Tethered Profiler network

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**Abstract**

Quantifying mixing rates in the Arctic Ocean is critical to our ability to predict heat flux, freshwater distribution, and circulation. However, turbulence measurements in the Arctic are sparse, and cannot characterize the high spatiotemporal variability typical of ocean mixing. Using year-round temperature and salinity data from Ice-Tethered Profiler (ITP) instruments between 2004 and 2018, we apply a finescale parameterization to obtain pan-Arctic estimates of turbulent dissipation and mixing rates at unprecedented space-time resolution. Building on previous work that used ITP data to identify double-diffusive staircases and analyze the associated convective mixing, we apply the finescale parameterization only where these step-like thermohaline structures are not present and mixing is expected to be internal wave-dominated. We find that the inferred wave-driven dissipation and mixing rates are generally low, but highly variable in both space and time, displaying significant regional differences between the shelves and central basins, as well as a small seasonal cycle. We detect no statistically significant interannual trend in mixing rate estimates over the period examined, with the exception of a small increase in the Canada Basin immediately below the mixed layer. The joint consideration of turbulent dissipation rates and stratification imply varied Arctic Ocean mixing regimes, which are most often not appropriately characterized as isotropic turbulence. Where justified, we infer turbulent heat fluxes out of the Atlantic Water layer that are mostly small, but also exhibit a distinct regional dependence.

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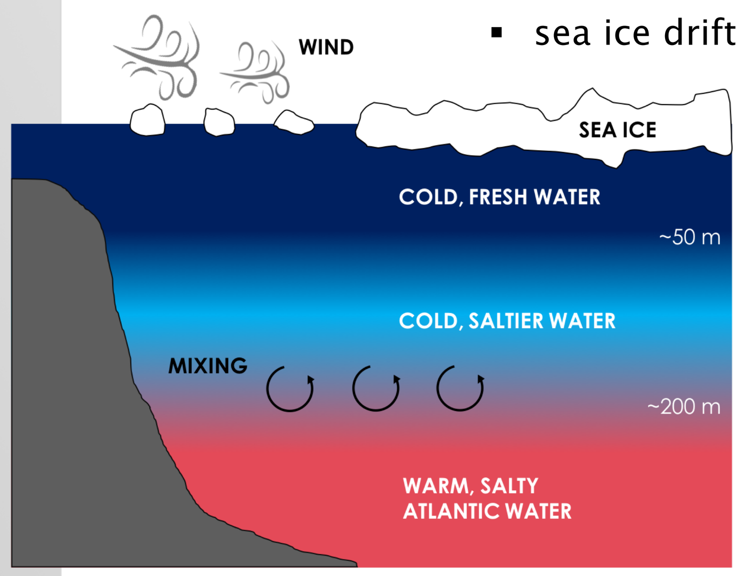
## I. Turbulent Ocean Mixing in the Arctic Ocean

- the Arctic Ocean is a diverse and rapidly changing environment that is tightly linked to changes in the Earth's climate
  - multiyear and summer ice have decreased dramatically… [1]
  - storms have intensified… [2]
  - sea ice drift speeds have increased… [3]




- these changes => a potential increase in mixing rates due to increased forcing of internal waves that generate turbulence[4]
- such a scenario could have important consequences, e.g., on ice melt due to increased heat fluxes[5]
- however, sampling challenges that limit the space–time scope of observations => our understanding of the dynamics and space–time variability of mixing is incomplete

**➔ STUDY OBJECTIVE:**
to characterize Arctic Ocean mixing metrics on a broad range of space and time scales by exploiting a turbulence parameterization and a compilation of existing finescale measurements of density structure

## II. Methods & Data

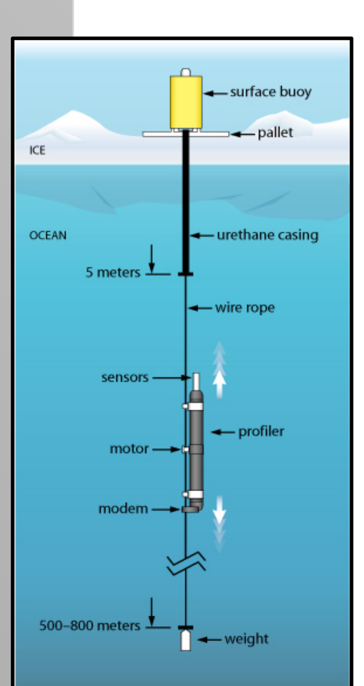
### ➔ Finescale Parameterization of Turbulent Dissipation [6]

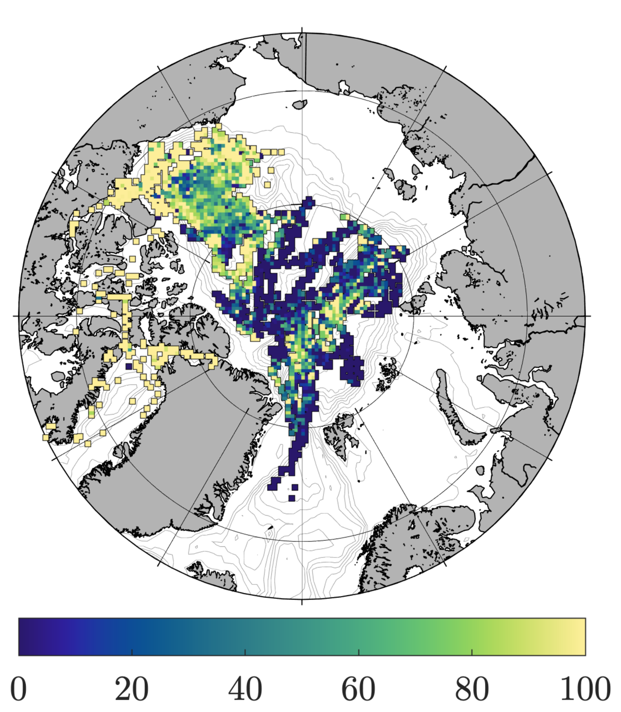
$$\varepsilon_{IW[\mathrm{strain}]}(z) = \varepsilon_0 \frac{\overline{N^2}}{N_0^2} \frac{\langle \xi_z^2 \rangle^2}{\langle \xi_{zGM}^2 \rangle^2} h(R_\omega) L(f,N)$$

strain variance integrated over internal wave scales; background stratification; empirical correction factors

equates the rate of spectral energy transfer due to non-linear internal wave–wave interactions at intermediate scales (O(10) to O(100) m) to the rate of TKE dissipation, offering a key opportunity to exploit a wealth of existing CTD measurements that span space and time much more extensively than current microstructure datasets

### ➔ Ice-Tethered Profiler Network [7] + Ship-Lowered CTDs [8]




- 32,158 vertical density profiles (1m-resolved) spanning the central Arctic Ocean and Canadian Arctic shelf over an 18-year period (2002–2019)
- since the parameterization is not appropriate in double-diffusive (DD) regimes where turbulence is not wave-driven, we reject $\varepsilon_{IW}$ estimates in profile segments identified to contain DD steps[9]
- in the O(100) m water column layer immediately below the mixed layer (ML), 58% of profiles segments are staircase-free

where DD staircases are not present, we obtain 16,849 $\varepsilon_{IW}$ estimates below the ML

## III. Results: Map of Wave-Driven Dissipation Rates

**➔ estimates of inferred internal-wave driven dissipation rates, $\varepsilon_{IW}$, span 4 orders of magnitude and exhibit distinct regional differences; the average dissipation rate found in Canadian Arctic shelf waters is a factor of 7 larger than the average value found in the central basins**

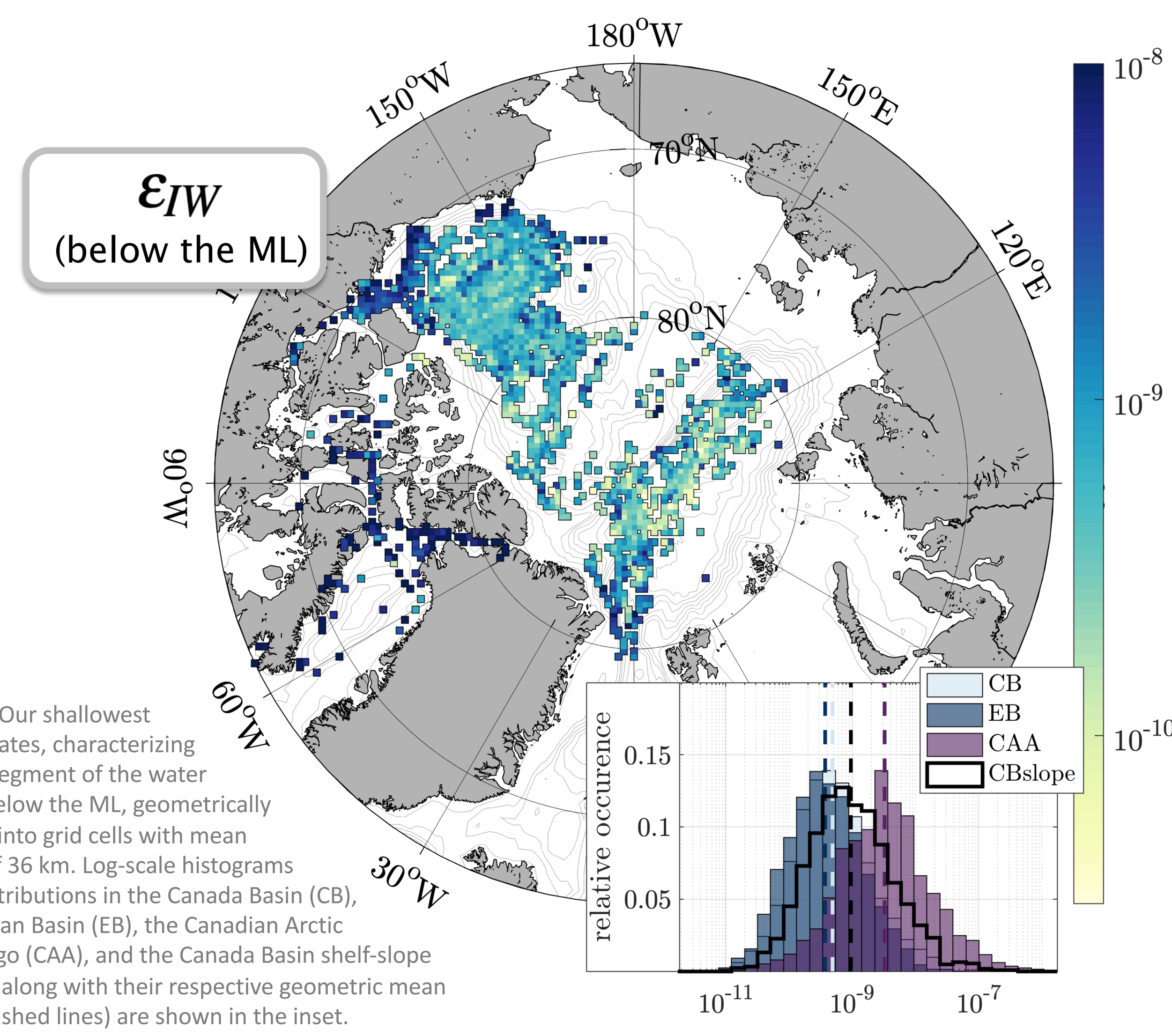
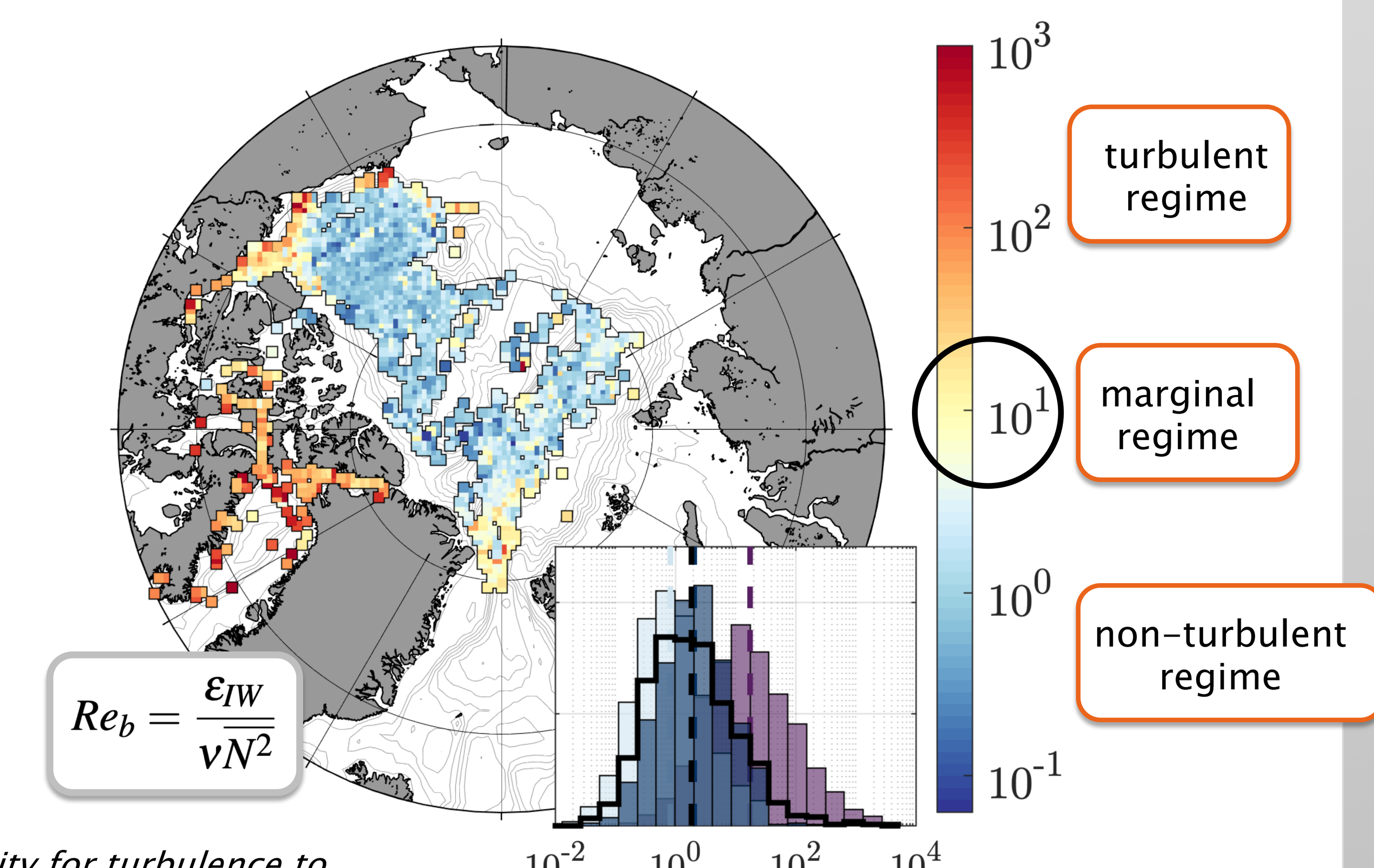



Figure 1: Our shallowest $\varepsilon_{IW}$ estimates, characterizing a 128-m segment of the water column below the ML, geometrically averaged into grid cells with mean spacing of 36 km. Log-scale histograms of $\varepsilon_{IW}$ distributions in the Canada Basin (CB), the Eurasian Basin (EB), the Canadian Arctic Archipelago (CAA), and the Canada Basin shelf-slope (CBslope) along with their respective geometric mean values (dashed lines) are shown in the inset.

## IV. Results: Characterization of Mixing Regimes

**➔ a map of the buoyancy Reynold's number, $Re_b$, suggests three mixing regimes that display large-scale spatial structure; non-turbulent conditions are most prevalent, but wide variability in $Re_b$ distributions implies turbulent mixing occurs in all regions at least some of the time**




*"capacity for turbulence to generate overturns"*

*$Re_b$ < O(10) ⟹ insufficient energy for turbulent overturns [10]*

Figure 2: As in Figure 1, but for the buoyancy Reynold's number, $Re_b$.

## V. Results: Implied Mixing Rates and Heat Fluxes

**➔ regional variability in mixing rates, $\kappa$, is most strongly influenced by the % of time that turbulent conditions dominate; associated vertical heat fluxes, $F_H$, are largest on the shelves (O(1) W m$^{-2}$), but rarely exceed O(0.01) W m$^{-2}$ in the basins, implying that turbulent wave-driven heat transport remains low where staircases are typically common, even where they are not actively present**

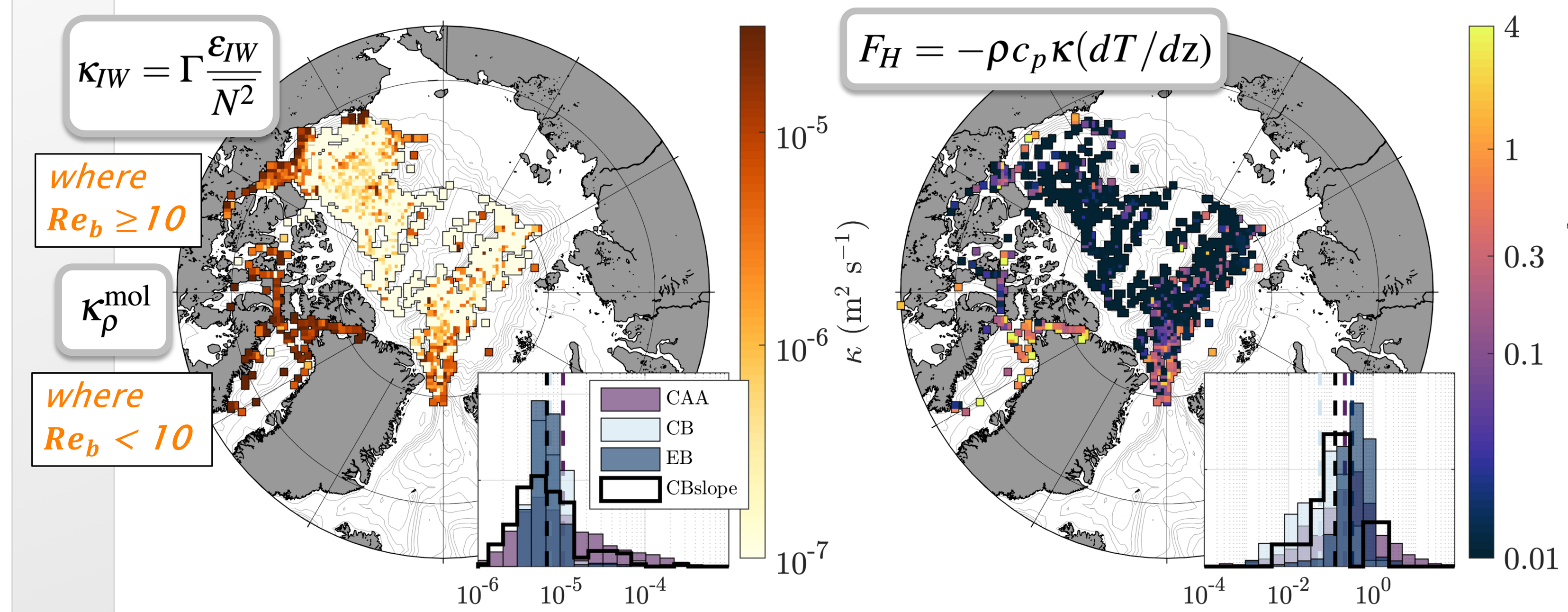



Figure 3: As in Figure 1, but for the arithmetically-averaged mixing rate, $\kappa$, and vertical heat flux, $F_H$. When $Re_b \geq 10$, we characterize the mixing rate by the internal-wave driven diffusivity, $\kappa_{IW}$, estimated via the Osborn Model[11]; otherwise, we estimate a molecular rate of density diffusivity, $\kappa_\rho^{\mathrm{mol}}$, based on the distinct molecular diffusivities of heat, $\kappa_T$, and salt, $\kappa_S$ and by assuming a linear approximation for the equation of state of seawater. Similarly, we compute $F_H$ by setting $\kappa = \kappa_{IW}$ when $Re_b \geq 10$ and $\kappa = \kappa_T$ when $Re_b < 10$. Inset histograms show the turbulent subset of estimates only.

## VI. Results: Interannual Trends

**➔ despite expectations that climatic changes witnessed in the Arctic Ocean in recent decades could lead to an increase in turbulent mixing due to elevated internal wave energy levels, we find no evidence of interannual trends in the wave-driven dissipation rate in the ocean interior**

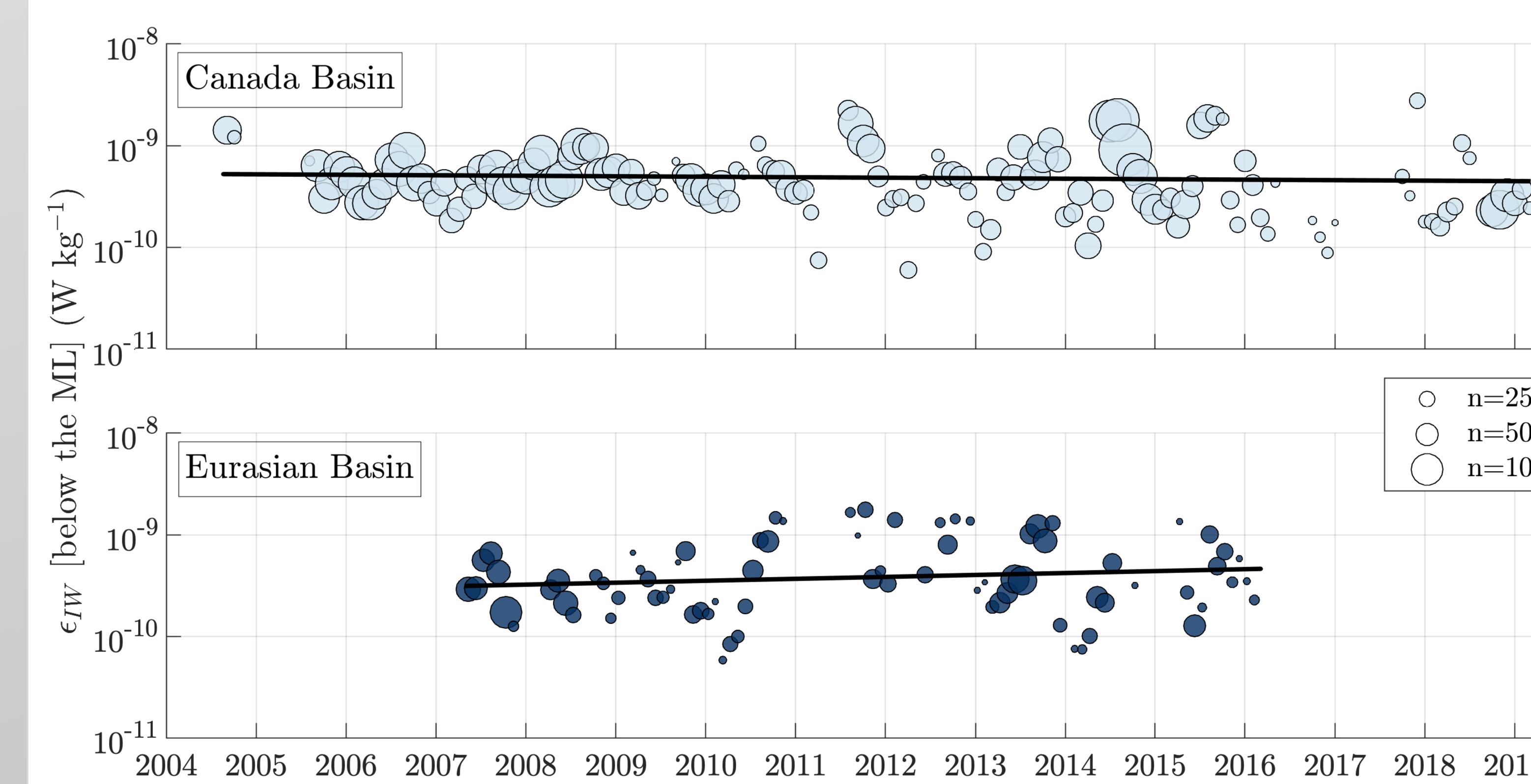



Figure 4: Monthly geometric averages of $\varepsilon_{IW}$ in the Canada and Eurasian Basins. Marker size is proportional to the number of estimates included in each average and solid lines indicate linear regression fits to the unaveraged data in each region.

## References & Acknowledgements

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