Buoy Observations of Turbulent Mixing in the northwestern subtropical Pacific Ocean

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ABSTRACT

Strong winds from typhoons decrease sea surface temperatures through turbulent mixing, Ekman pumping, and air-sea heat fluxes. To better understand the physical process of mixing and improve numerical models, more observations of turbulent mixing are required, but observing the upper ocean in such an extreme environment is challenging. In addition, the mesoscale eddy affects the background conditions and turbulent mixing.

In 2022, we deployed two buoys and one ADCP in the northwestern subtropical Pacific Ocean, an area frequently affected by typhoons and eddies. Our study found that within the 34-knot wind radius of Typhoon Hinnamnor, the peak value of the probability distribution of Richardson number (*Ri*) was less than 0.25 at 20-m depth. Additionally, during the cold eddy period, the upwelling made the stratification more stable, resulting in a significant increase in *Ri* at 20-m depth.

DATA and METHOD

In 2022, the buoys and ADCP observed a mesoscale cold eddy and category-5 Typhoon Hinnamnor in the northwestern subtropical Pacific Ocean (Fig. 1). We estimated the Richardson number (*Ri*), which is the ratio of buoyancy frequency squared (N^2) to velocity shear squared (S^2).

$$Ri = \frac{N^2}{S^2} = \frac{-\frac{g}{\rho_0}\frac{\partial \rho}{\partial z}}{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2}$$

ρ_0 : reference density

$\frac{\partial \rho}{\partial z}$: vertical density gradient

$\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z}$: vertical shear of current velocity

Besides estimating N^2 from two adjacent thermistors, we also used single thermistor data and performed a linear fit of temperature and depth to estimate N^2 (Fig. 2).

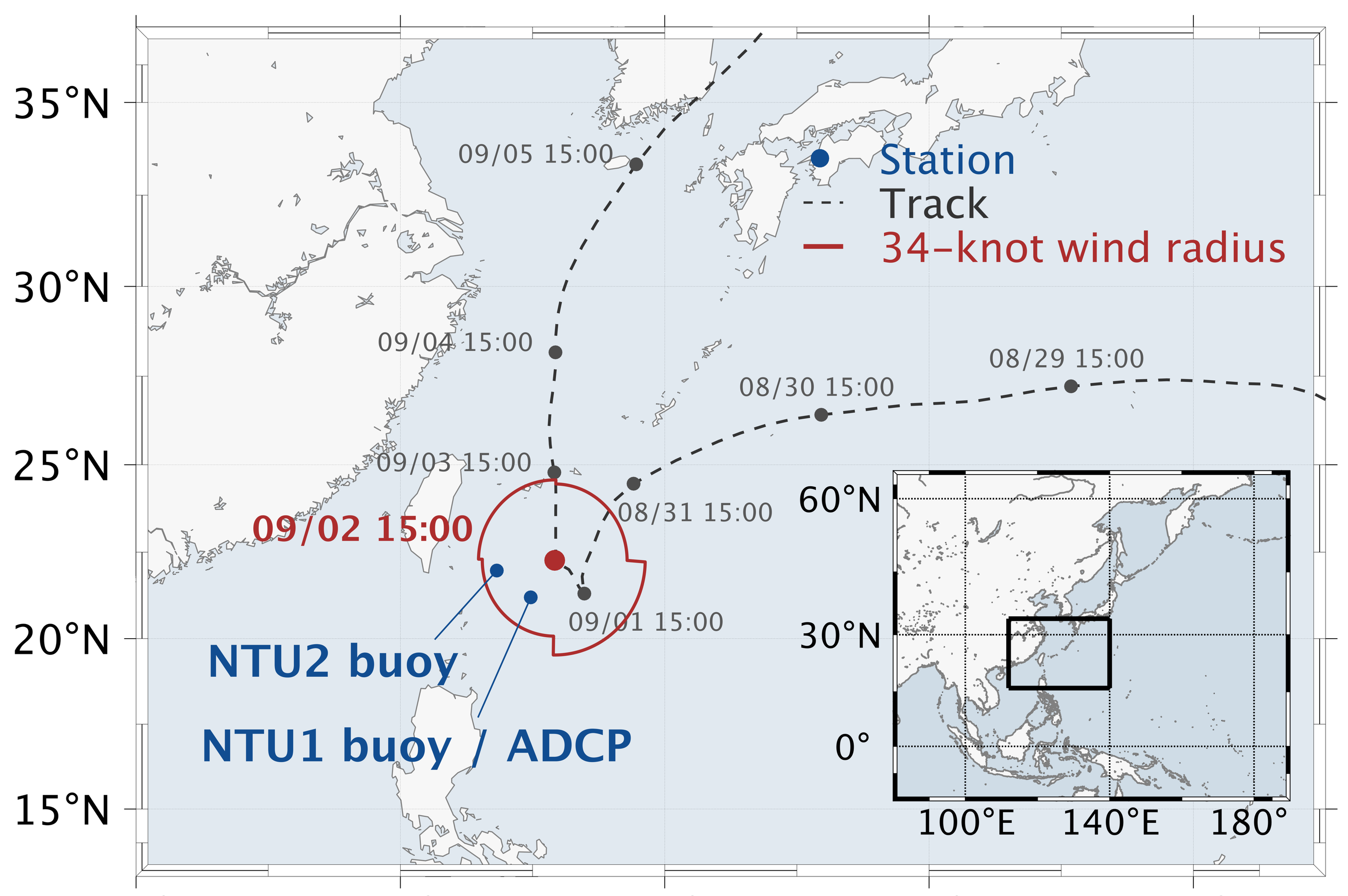

Fig.1. Two buoy station locations and the track of Typhoon Hinnamnor.

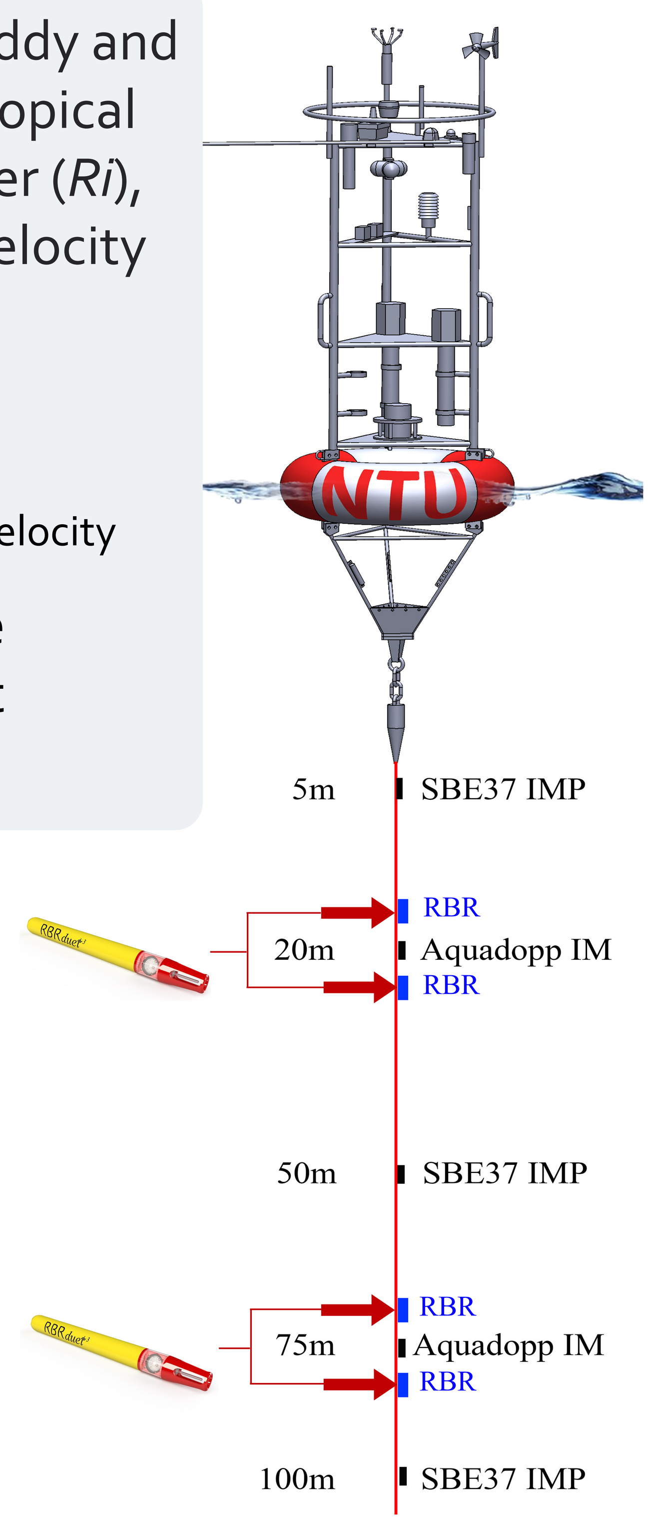

Fig. 2. Buoy diagram. Red arrows indicate logger locations for high-frequency temperature and depth sampling.

RESULT and DISCUSSION

Estimation of N^2

Fig. 3 shows that the estimation of N^2 with a single or dual thermistor was about the same, but slightly smaller with a single thermistor. And weaker stratification led to more differences.

The instrument accuracy, the sampling frequency, and the background environment are the main factors causing the difference.

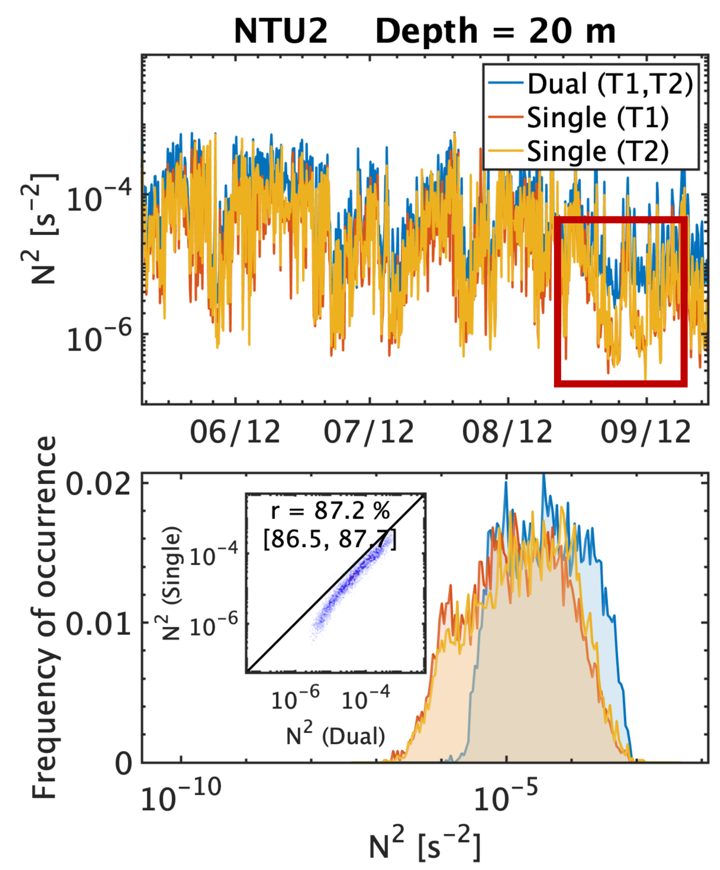

Fig. 3. Comparison of N^2 estimation methods.

Ri of Typhoon Hinnamnor (2022)

Before the typhoon passed, the probability distribution of *Ri* peaked at about 3-4 with a 12% probability of being less than 0.25 at 20-m depth (dashed curves in the top pannel of Fig. 4). When the buoy was within the 34-knot wind radius of a typhoon, the peak value of the probability distribution of *Ri* decreased to slightly below 0.25, with a 62% probability of being less than 0.25 (solid curves in the top pannel of Fig. 4). Fig. 5 shows the deepening of the mixed layer and SST cooling. The lower value of *Ri* suggests that vertical mixing was a crucial factor.

At a depth of 75 m, *Ri* did not significantly change during the typhoon period. It shows that typhoon-induced turbulent mixing occurred above 75-m depth (bottom pannel of Figs. 4 and 5).

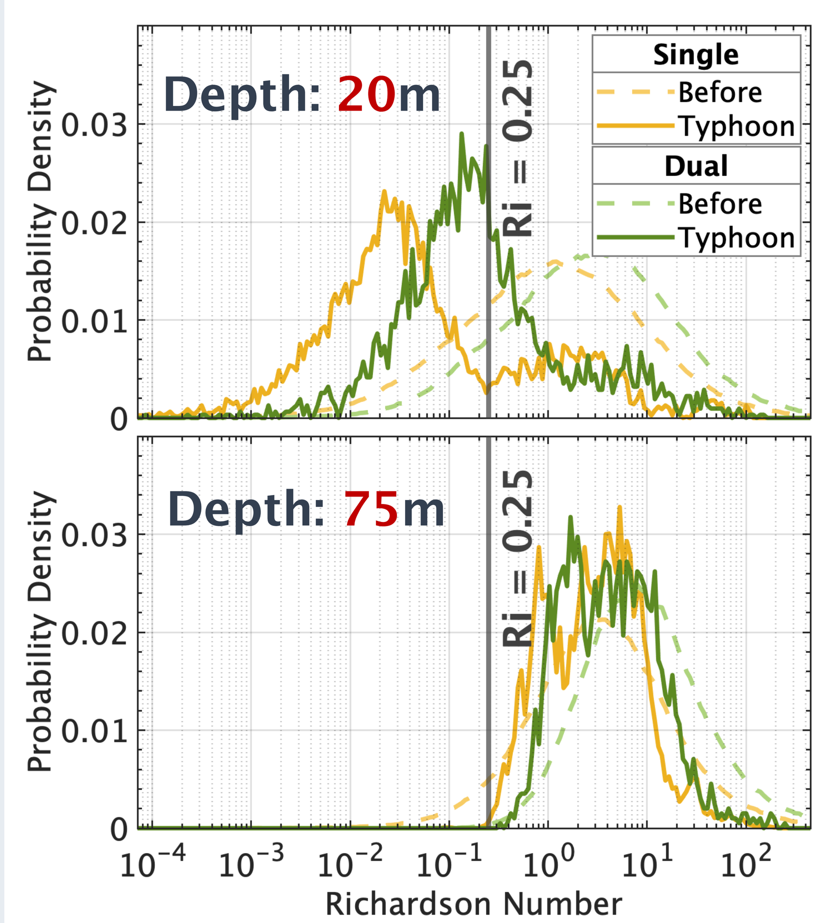

Fig. 4. PDF of *Ri* during typhoon period.

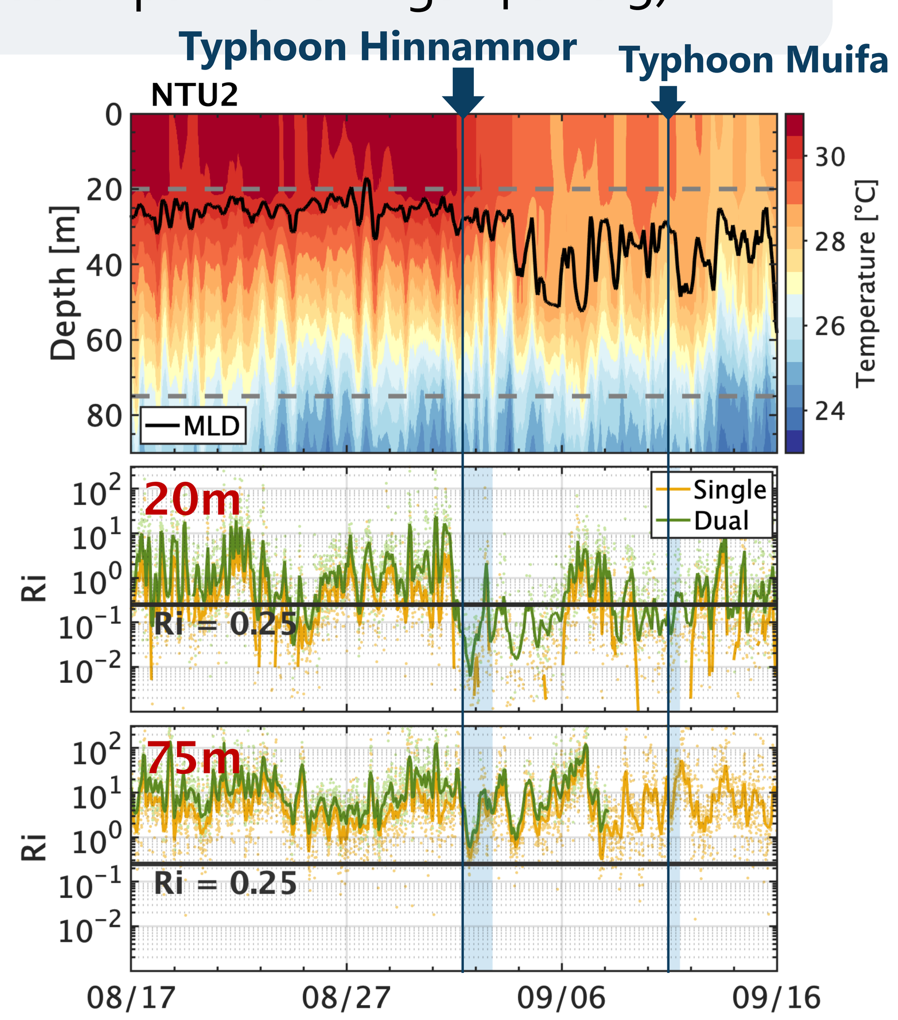

Fig. 5. Time series of temperature profile and *Ri*.

Ri of cold eddy

The upwelling of cold water during the cold eddy period thinned the mixed layer and intensified stratification (before June 2 in Fig. 6). The increase in *Ri* values suggests that the presence of a cold eddy would suppress turbulent mixing at 20-m depth (solid curves in Fig. 7).

Without a cold eddy, the mixed layer depth was over 20 m (after June 2 in Fig. 6). The probability distribution of *Ri* oscillated around 0.25 within the mixed layer, indicating marginal instability (dashed curves in Fig. 7).

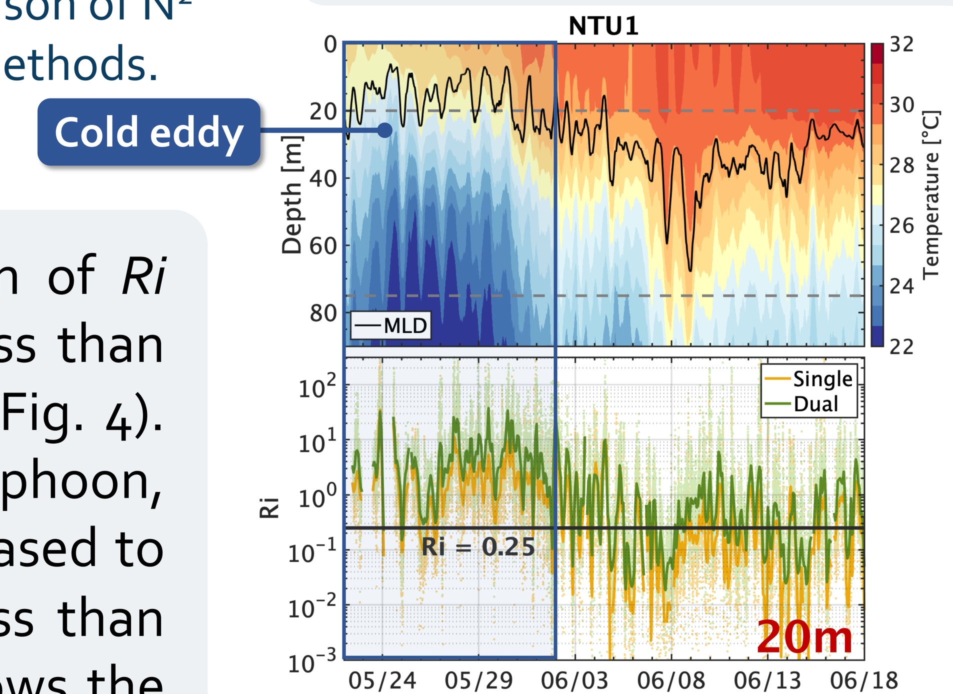

Fig. 6. Time series of temperature profile and *Ri*.

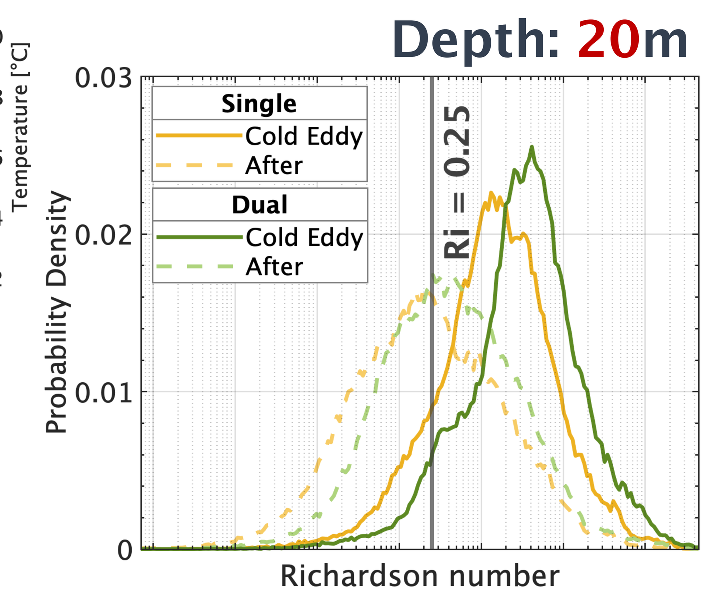

Fig. 7. PDF of *Ri* during the cold eddy period.

SUMMARY

- N^2 estimation using single or dual thermistors was consistent in stratified environments but varied slightly with weak stratification.
- Typhoon Hinnamnor caused the peak value of *Ri* to decrease to below 0.25 in PDF at 20-m depth, indicating strong turbulent mixing, which occurred at depths shallower than 75-m.
- During the cold eddy period, stratification intensified and turbulent mixing was suppressed at 20-m depth.

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