demonstrate that when the particles are massless, or, equivalently, when the particles are extremely energetic, the cross section reduces to

Gravity waves and horizontal mixing within supertyphoon Hinnamnor

EGU24-13410 **X5.52**

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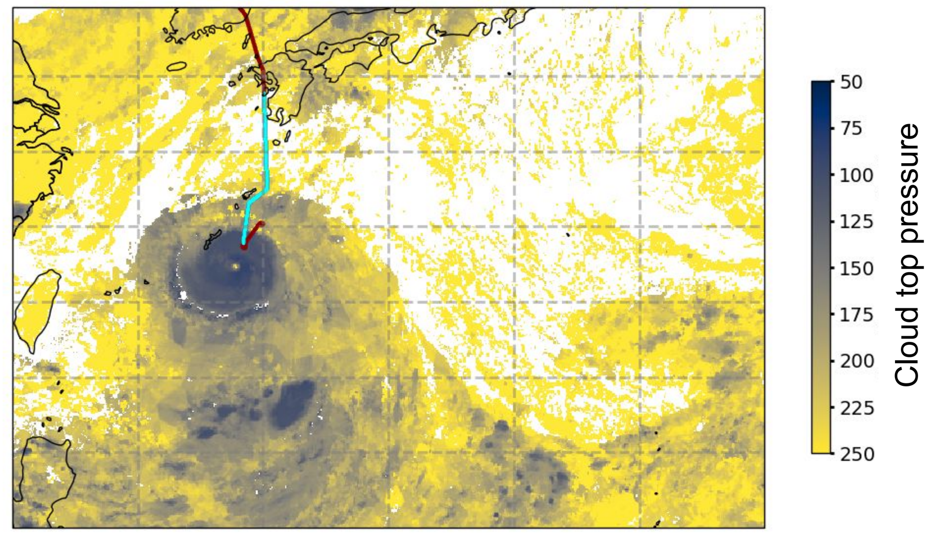
Introduction: On 31 August 2022, one flight of the Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP), out of South Korea, included an overflight of supertyphoon Hinnamnor. The aircraft (NASA WB-57) flew within ~140 km of the core of the typhoon. We show that the gravity waves are produced during periods of the typhoon, and that wave amplitude is underestimated in ERA5 compared with in-situ data. Although the cold phase of the wave could produce temperatures conducive for in-situ cirrus, we do not see an example of this cirrus below the flight level. We conclude with a characterization of the length scale of horizontal mixing between typhoon and environmental air, and show that sublimated lofted ice leaves behind the expected enriched isotopic signal..

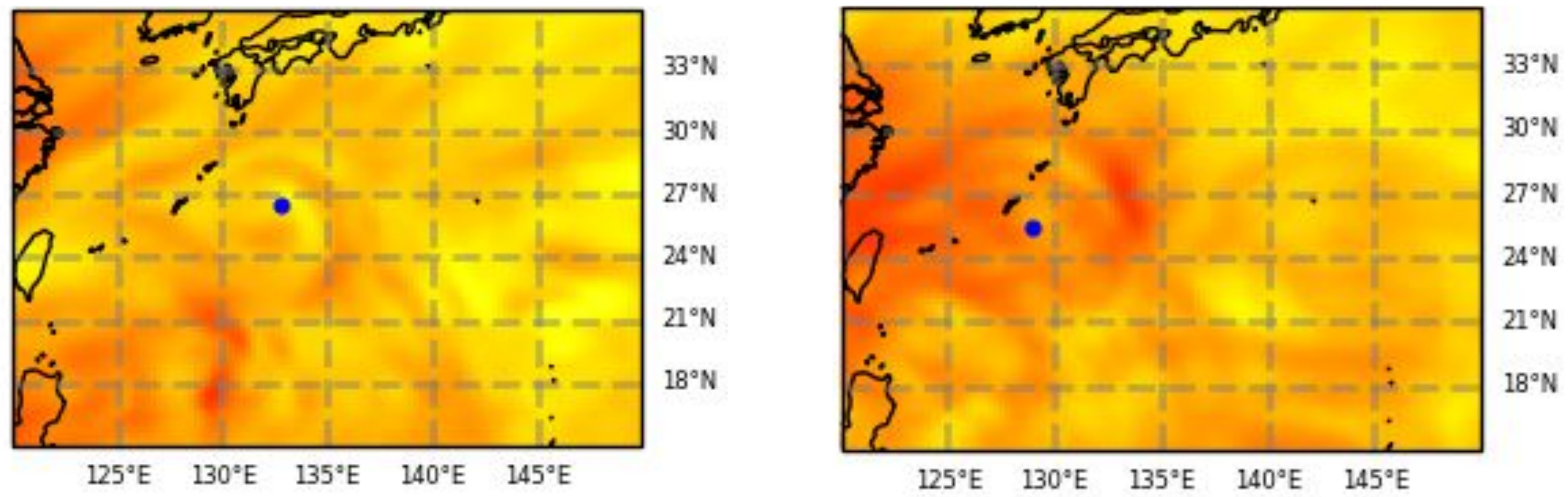
Overflight of cloud band, edges of TC center

Himawari cloud top pressure data: 2022-08-31 6:00:00, with flight track overlaid (cyan denotes level leg)

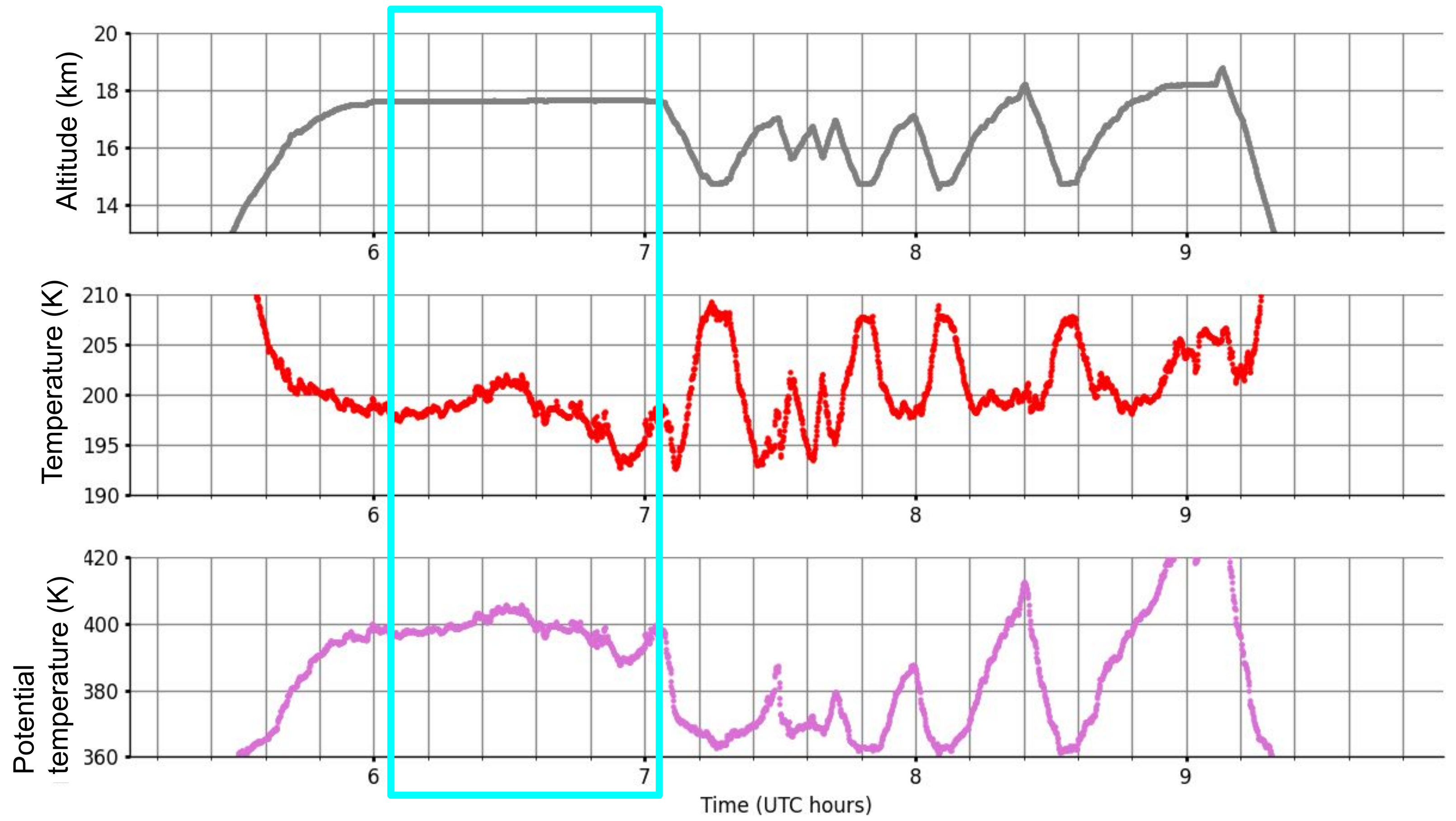


ERA5 shows rings in temperature field; variations are asymmetric [1]

ERA5: left - 2022-08-30 15:00:00, right - 2022-08-31 6:00:00, level=70mb. Blue dot denotes center of TC, from IBTrACS

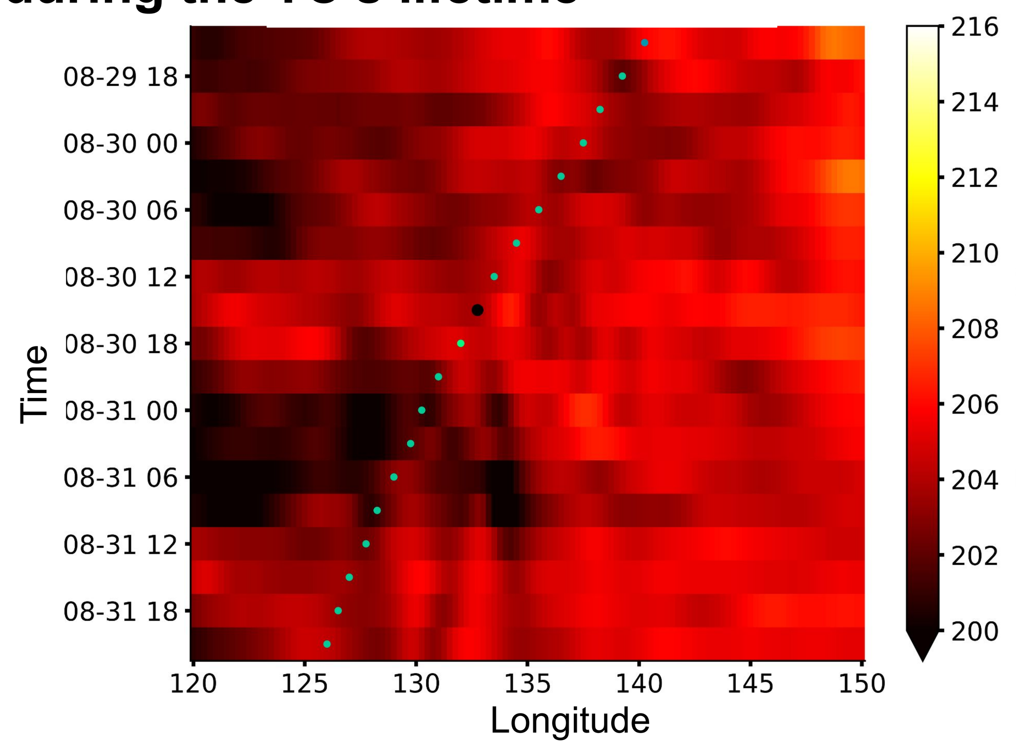


Flight data shows temperature variations at constant altitude



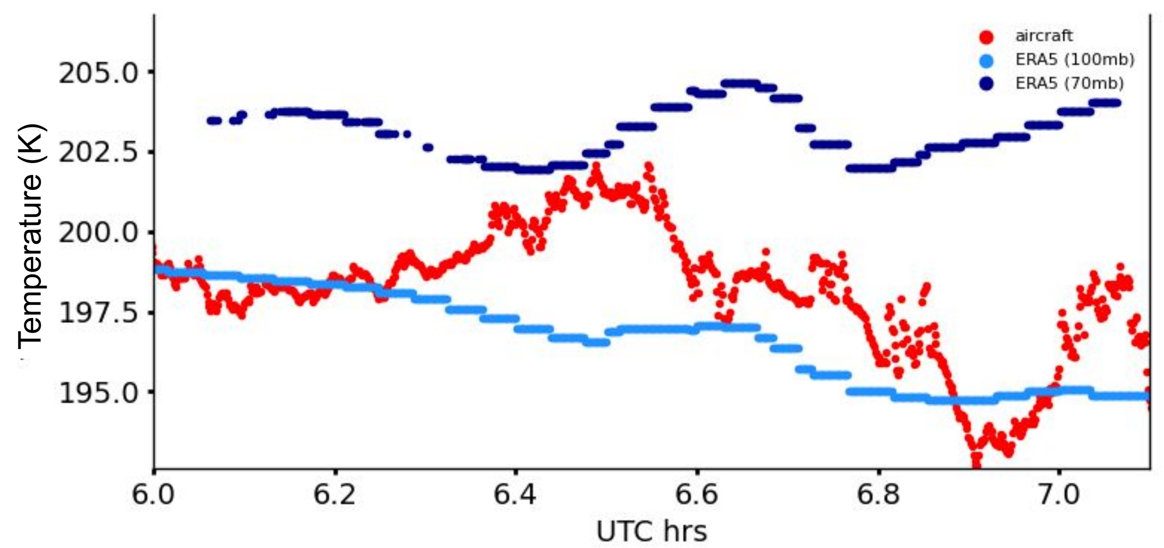
Flight data from 2022-08-31, level leg is highlighted in cyan (avg 87 mb).

GWs are pumped out unequally during the TC's lifetime



Hovmöller diagram of ERA5 temperatures at 70mb and latitude=26.5 deg. GW activity mainly starts at 15:00 on 8/30; strongest wave activity does not begin with strongest surface winds. Secondary colorbar shows category of storm at given time step.

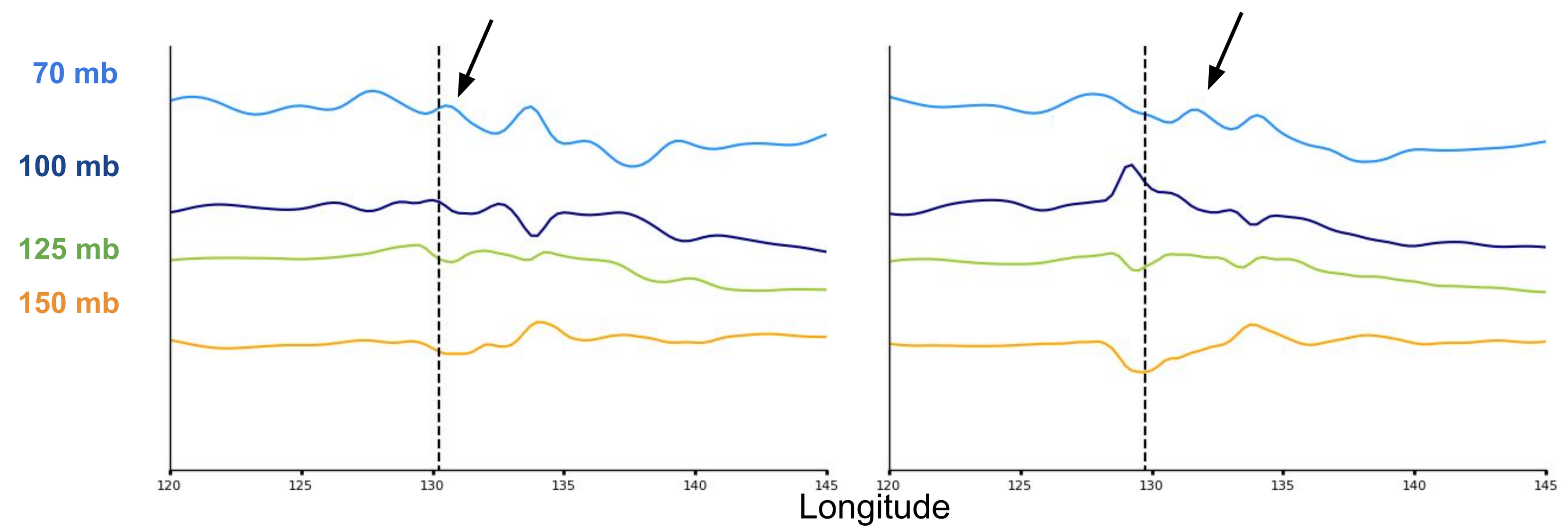
ERA5 underestimates amplitude (~3x smaller)



Flight data (red) plotted with ERA5 profiles at 70, 100 mb.

TC characteristics:

- **Horiz. wavelength: ~320 km (aircraft) vs. ~200 km (ERA-5)**
- **Horiz. propagation: ~70 km / hr (ERA-5, about twice TC speed of ~30 km/ hour)**
- **|amp|/2: ~4.7 K (aircraft) vs. 1.3 K (ERA-5)**

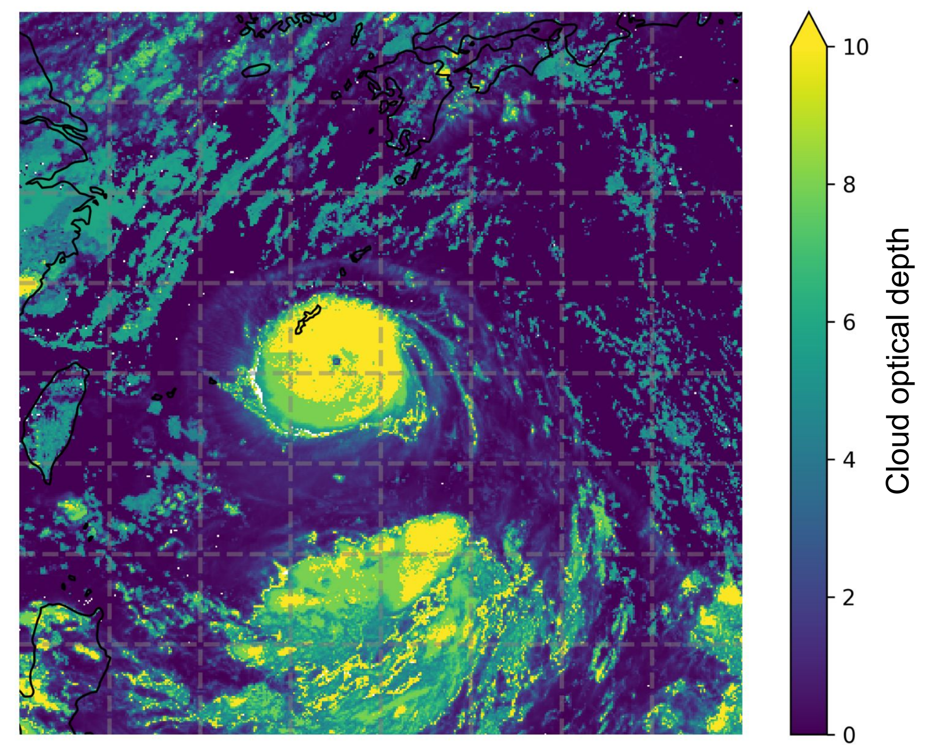


ERA5 temperature profiles (latitude=26.5 deg as in Hovmöller diagram) for pressure level = 70, 100, 125, and 150 mb. Dashed line denotes longitude of TC center. Arrows follow a wave crest over 3 hrs (2022-08-31 12:00 to 3:00).

Implications for cirrus formation

Assuming 7% change in RH per degree of cooling (from the Clausius-Clapeyron equation), the conditions at 70mb above the typhoon are too dry for cirrus formation, but at 100mb and RH above 79%, the cold phase of the GW could cause temperature conditions conducive for cirrus.

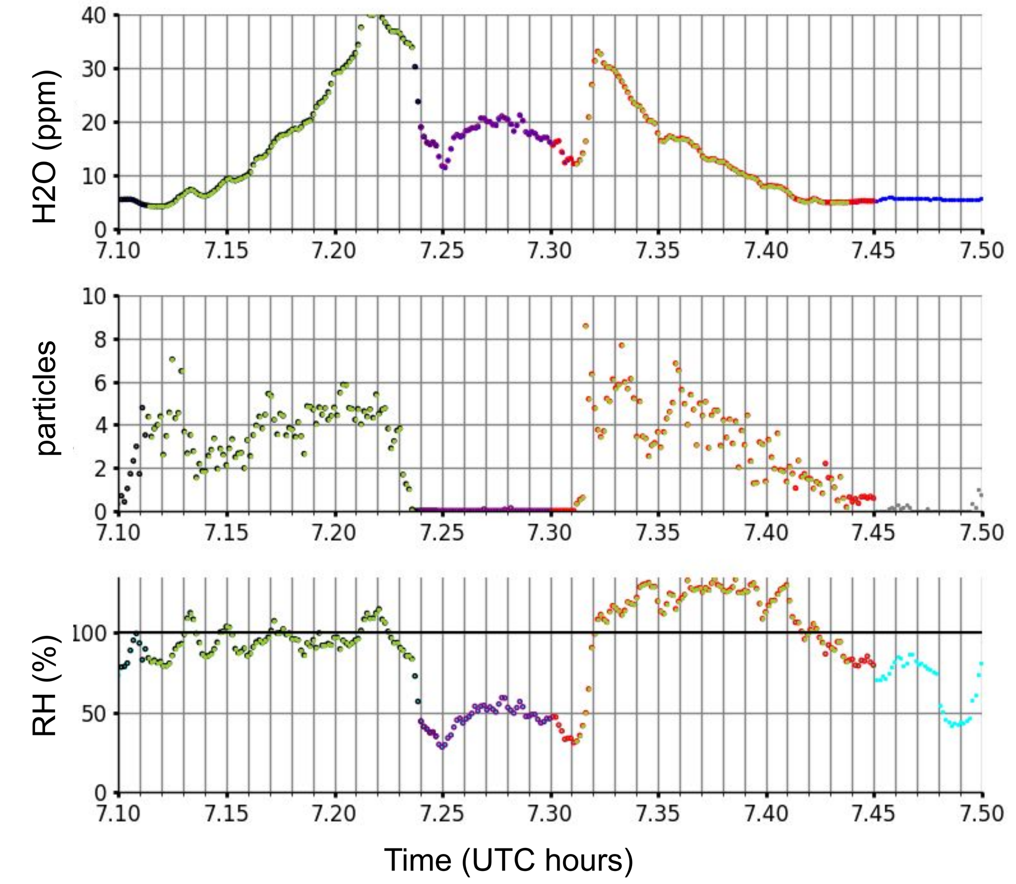
Looking specifically at Hinnamnor, we see the plane flew over cirrus at ~120mb, but tracing the cloud band in satellite imagery shows it is blow-off from convection, not in-situ formed cirrus. Previous studies have shown cirrus formation in the cold phase of waves [2].



Himawari cloud optical depth data from 2022-08-31 7:00 (close to time of aircraft overflight)

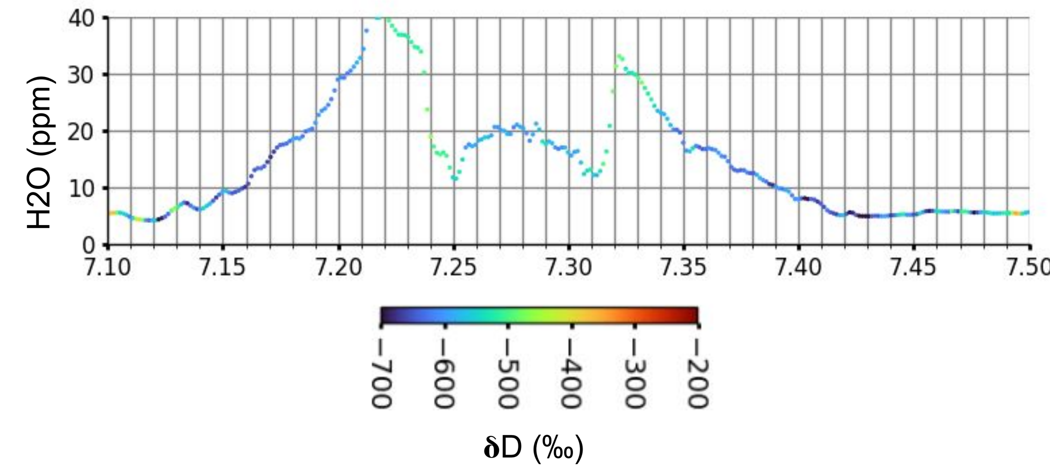
Horizontal mixing between TC and environmental air

Dive 1 consisted of punching through the TC and into dry, background air. Green dots denote presence of cirrus.



Black denotes descent, purple level leg at the bottom of the dive, and red denotes ascent

Assuming the speed of the plane to be 200 m/s and looking at the transition from high to low water vapor in the descent and ascent, we calculate the mixing length between the TC and dry air to be ~15km. This means the TC does not completely prevent air from mixing horizontally.



As the plane just leaves the TC, the high RH and presence of particles is maintained even as some dry air is mixed in. As we get further from the TC, the RH drops in the transition region and we see an enrichment in the isotopic ratio (~100 ‰). This is as expected: freshly convected ice particles are rich in heavy isotopes, and after sublimation in dry air and leave behind heavy isotopes in the vapor phase.

This mixed region is isotopically enriched compared to both inside the TC and the dry, environmental air.

The increase in water vapor at the bottom of the dive indicates air from a distinct origin, and can investigated with back trajectories.

Note: Temperature, H2O, and δD data is final particle data is not final

Conclusions

Gravity waves above a TC

- **TCs produce strong gravity waves (GWs) in *roughly* concentric rings**
- **GW activity is not uniform even during strongest phases of TC**
- **GW temperature amplitudes are strongly underestimated in reanalysis (1.3 K in ERA5 vs 4.7 K from in-situ measurements). This could result in underestimates of in-situ cirrus formation when using reanalysis.**

Horizontal mixing of TC air

- **Isotopic measurements show likely sublimation of ice particles at the TC edge after mixing with dry environmental air**
- **Horizontal mixing length scale is ~15km**

Future directions

- **Place into climatological context: what are the RH conditions of other TCs?**
- **How do ice concentrations vary within the horizontal mixing region between the TC and environmental air?**

References:

[1] Kim et. al. JGR, 114, 2009
[2] Atlas & Bretherton, ACP, 23, 4009–4030, 2023