Gravity waves and mixing around tropical cyclone Hinnamnor

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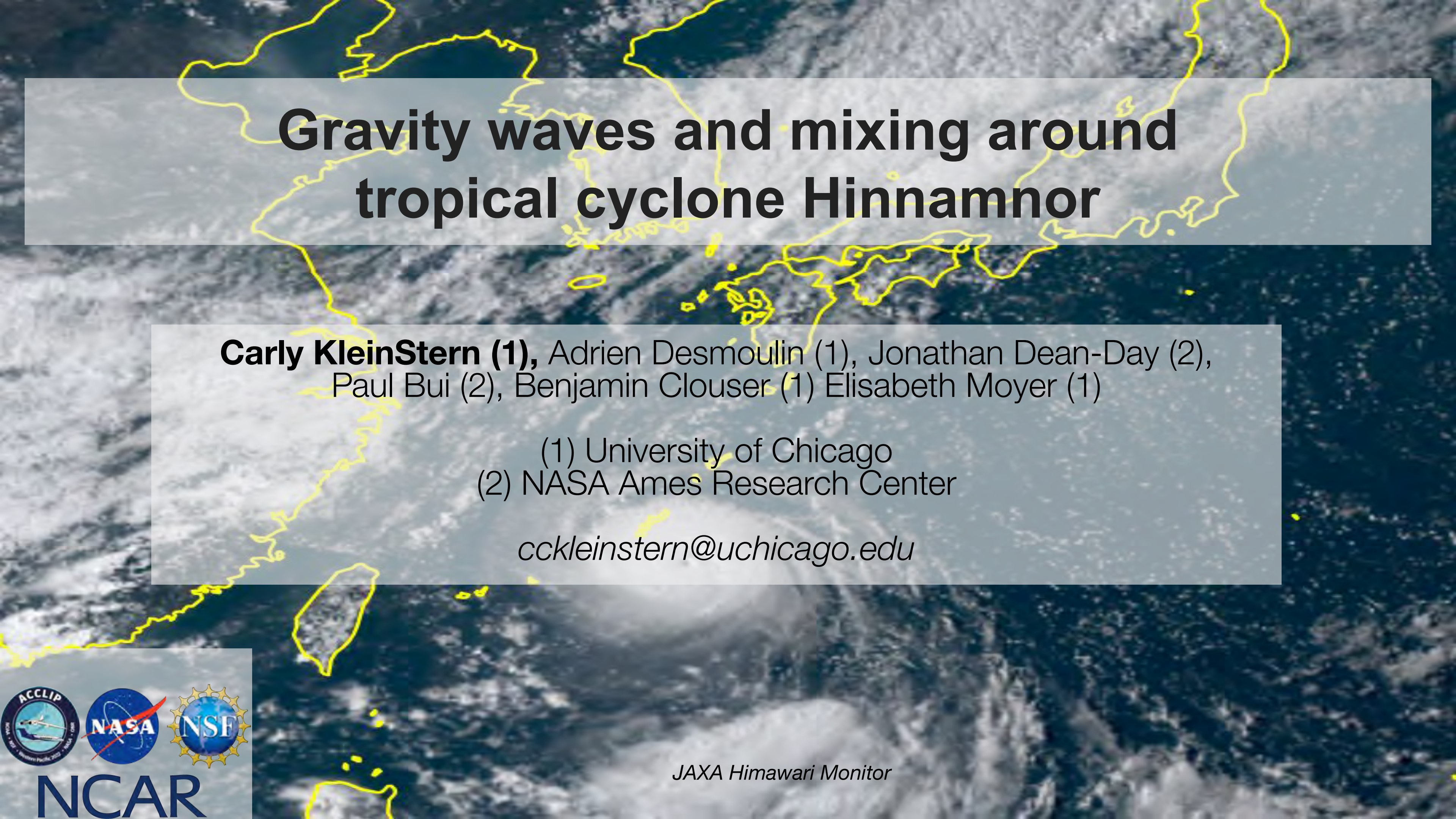
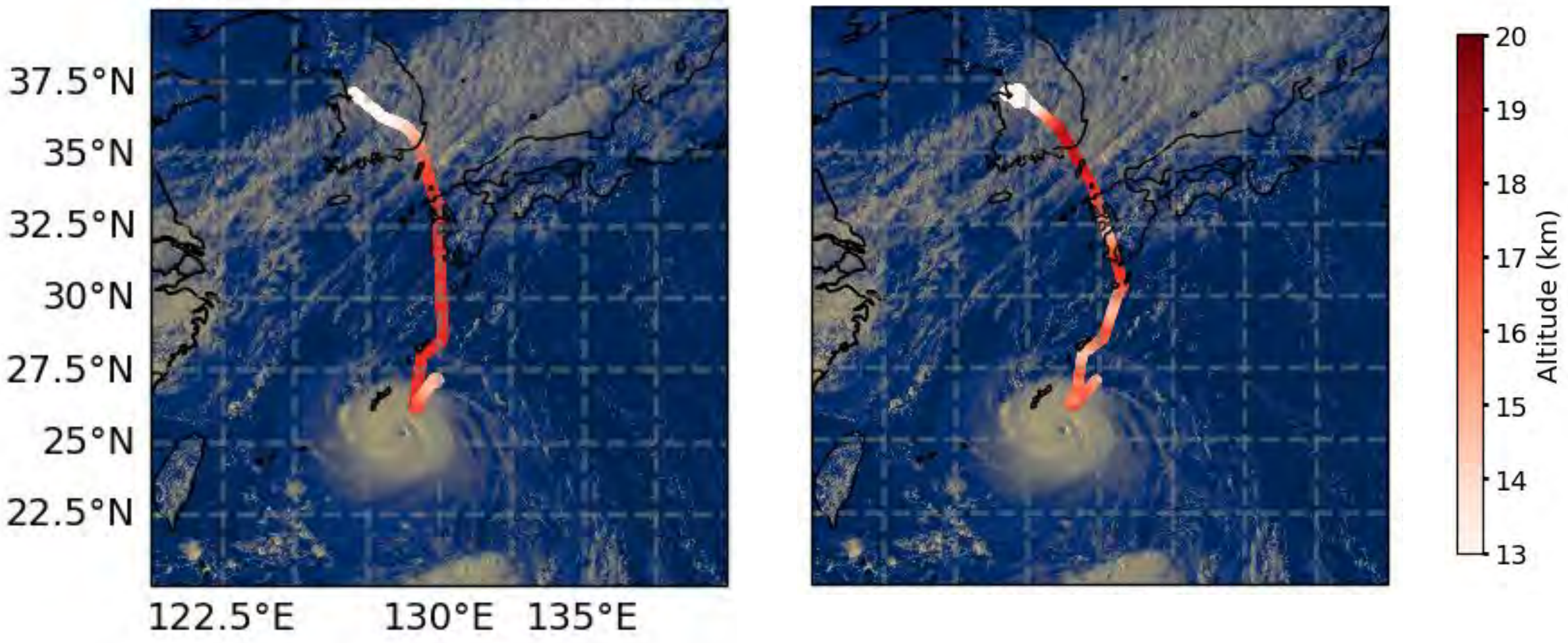


JAXA Himawari Monitor

ACCLIP NASA NSF NCAR

TC encounter; edges and near center



Himawari data from 7:00 UTC on 8/31

3 lessons from TC Hinnamnor

TC effect on STRATOSPHERE:

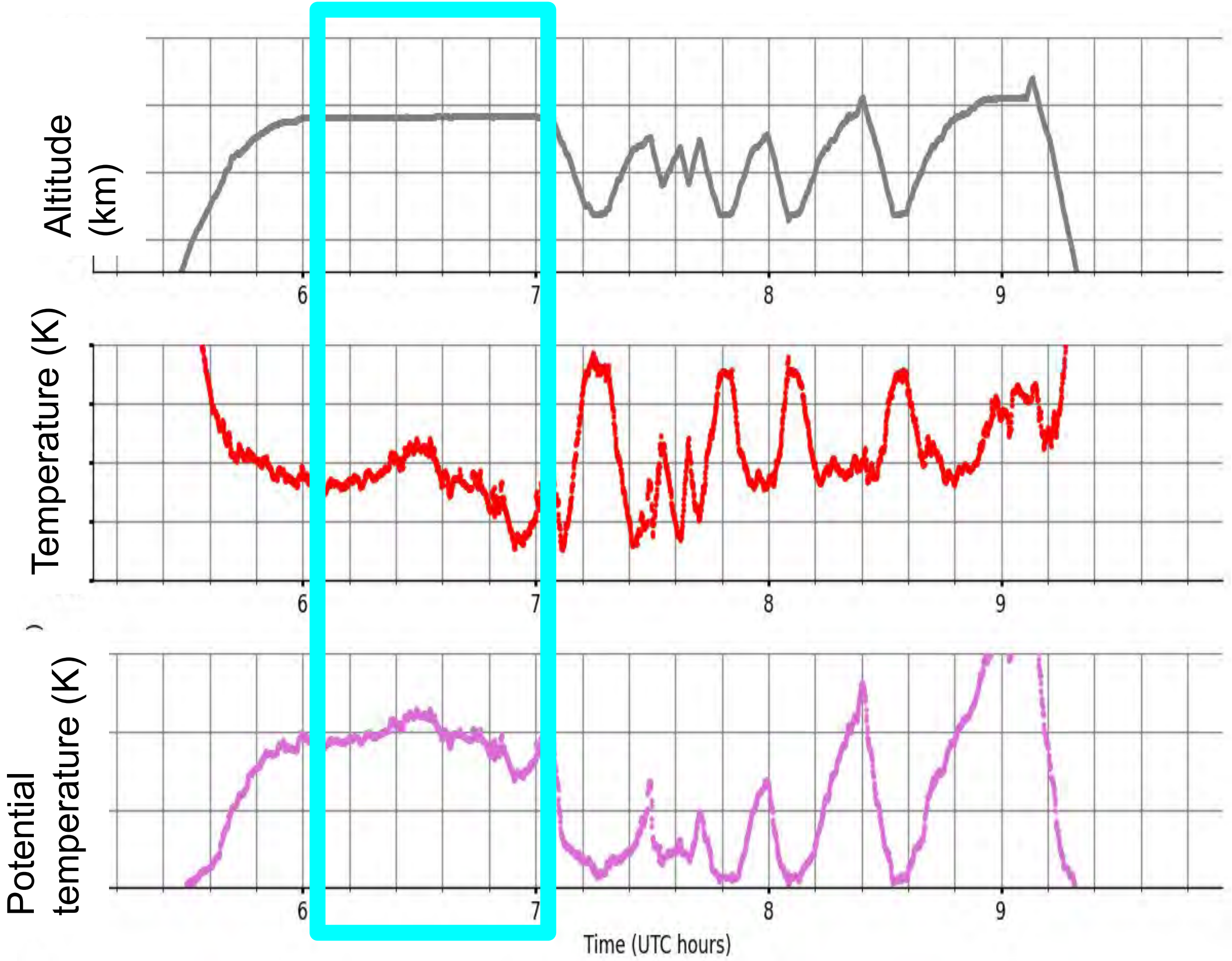
- Compared to in-situ data gravity wave amplitudes are underestimated by ~3x in ERA5
- There is no evidence that the TC is strongly sucking down stratospheric air

TC effect on TROPOSPHERE:

- There is a small region (~15km) around the TC where air from within mixes with dry, environmental air

TC induced gravity waves

In-situ data shows temperature variations at level altitude

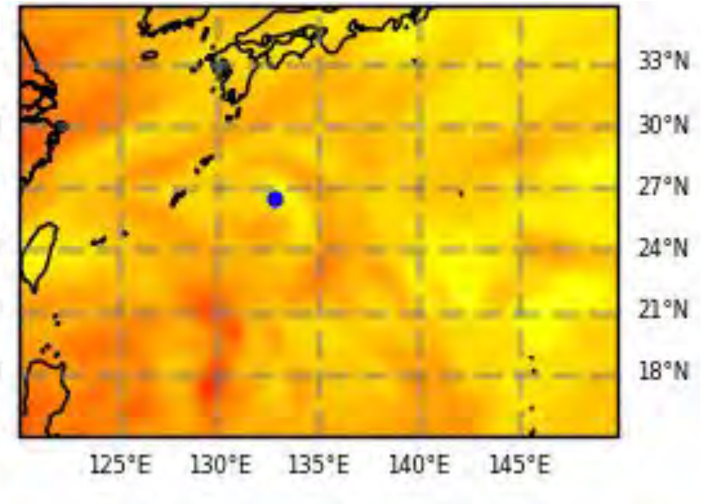


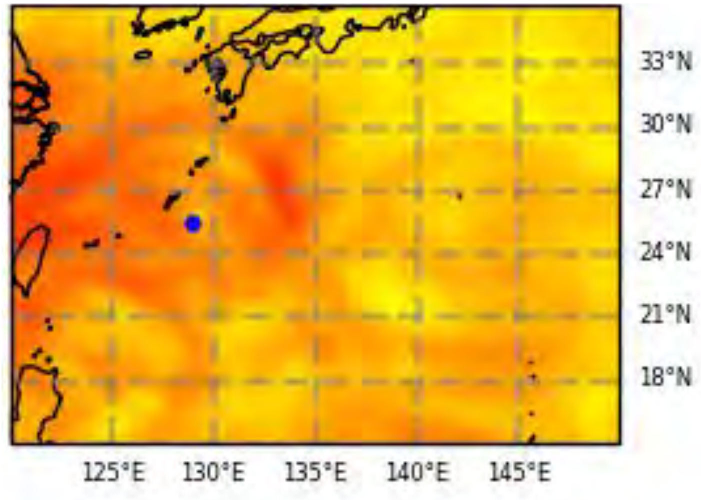
Flight data from 2022-08-31, level leg is highlighted in cyan (avg 87 mb).

Typhoons regularly produce gravity waves

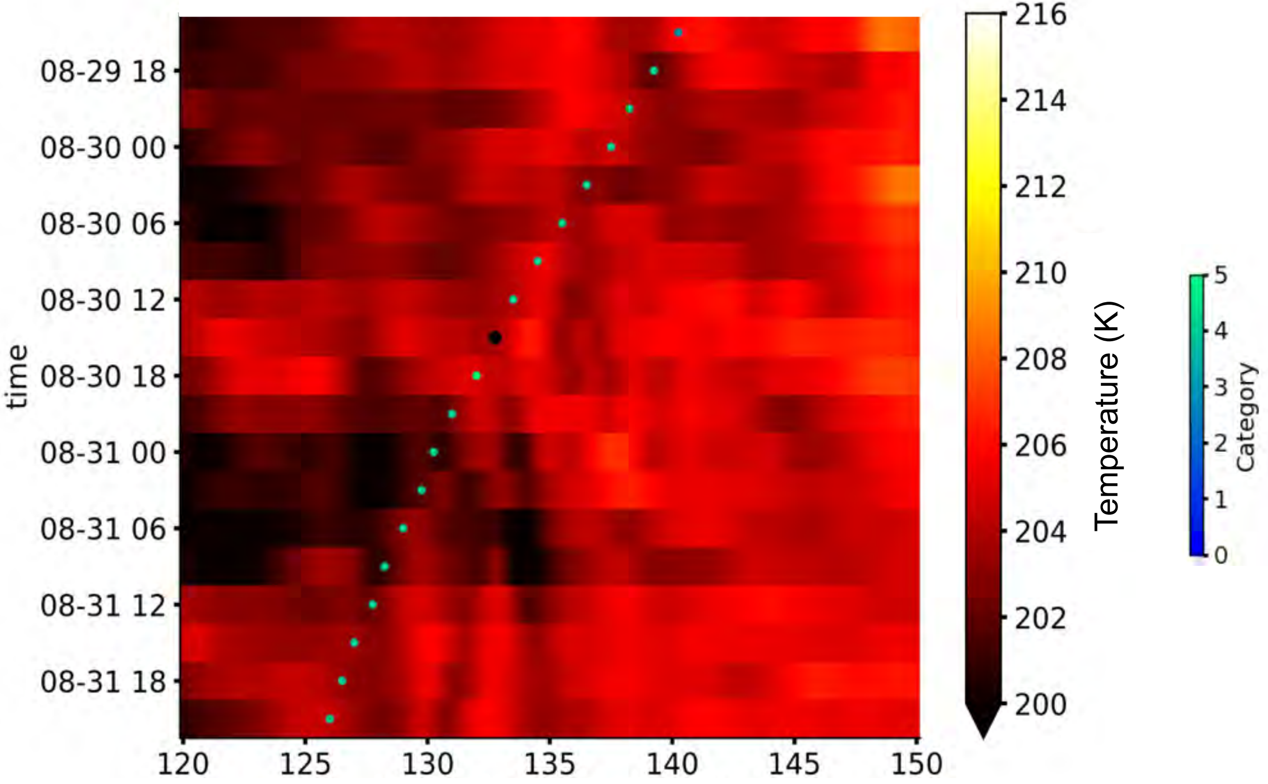
ERA5 shows rings in temperature field; variations are asymmetric

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



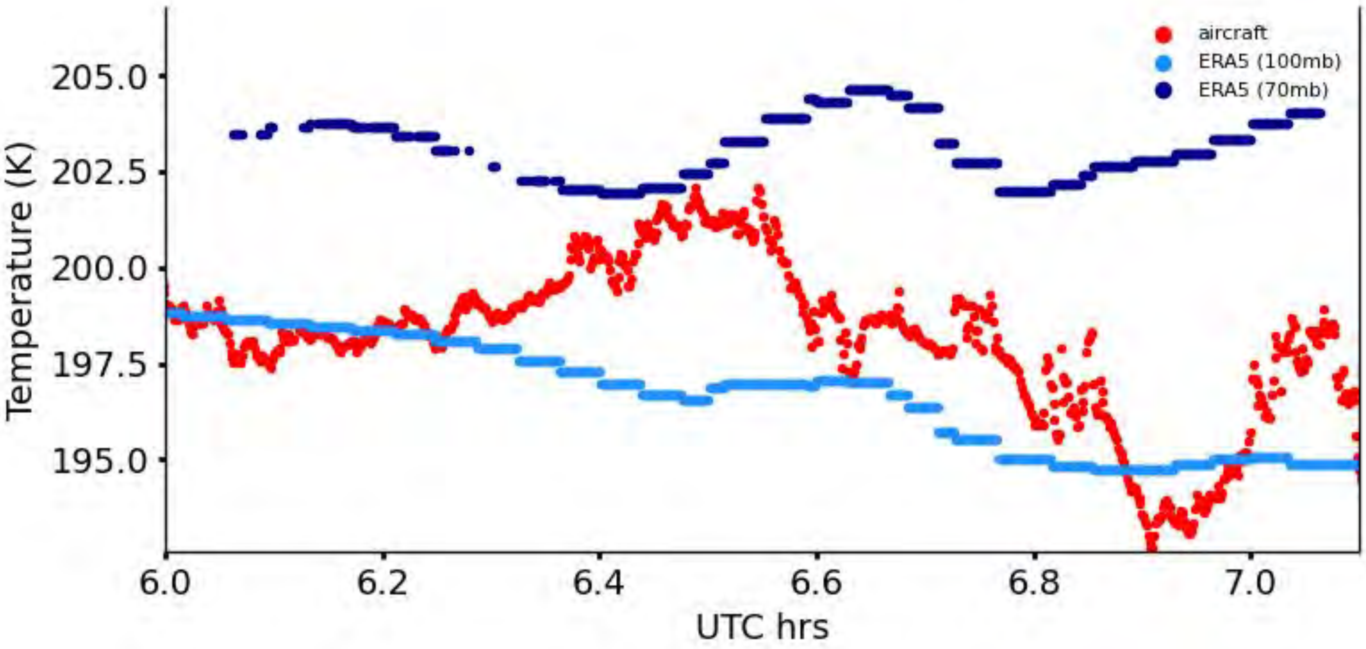


GWs are pumped out unequally during the TC's lifetime



ERA5 underestimates TC amplitude by ~3x

ERA5 often compared to satellites, rarely in-situ data above the TC



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

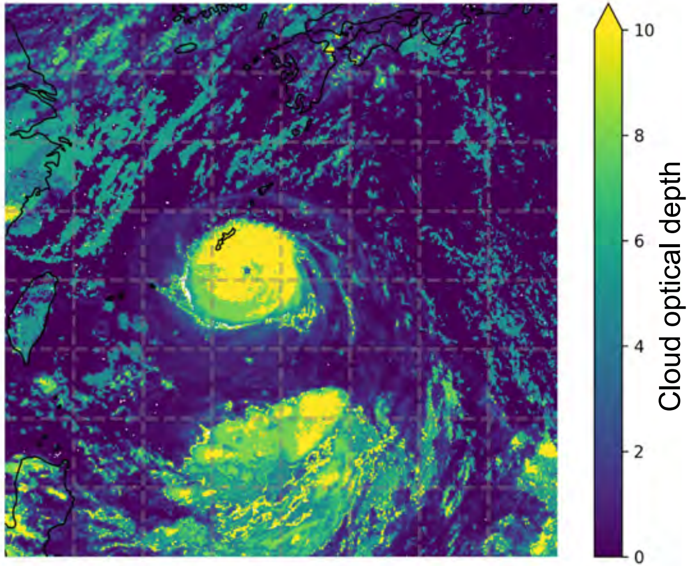
TC characteristics:

- **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)**

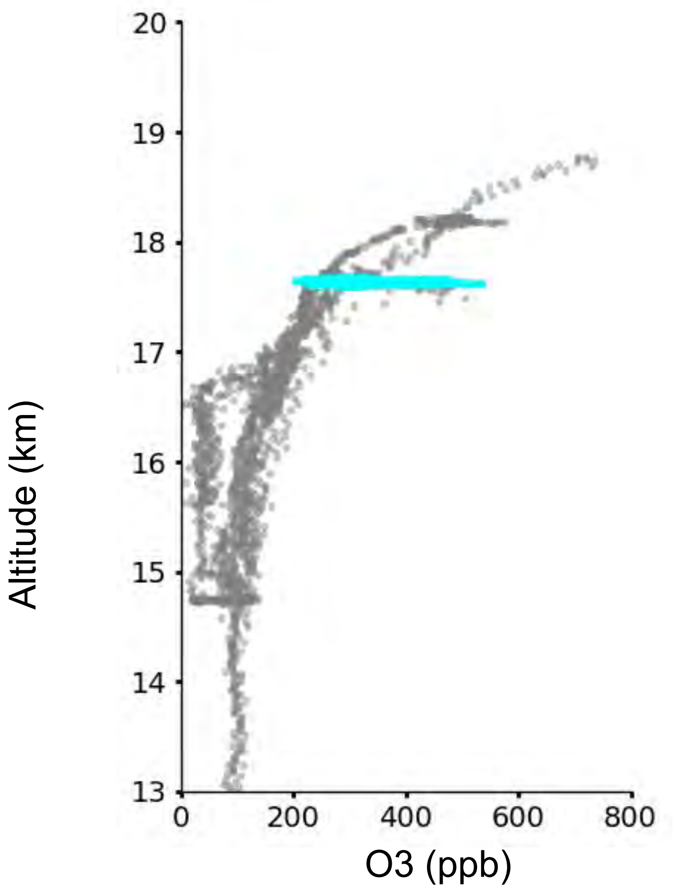
Implication for cirrus formation

- Assuming 7% change in RH per degree of cooling
- 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.

- **<u>Case study:</u>** the plane flew over cirrus at ~120mb, but it is likely blow-off from convection, not in-situ formed cirrus



Also, TC does not strongly suck down stratospheric air

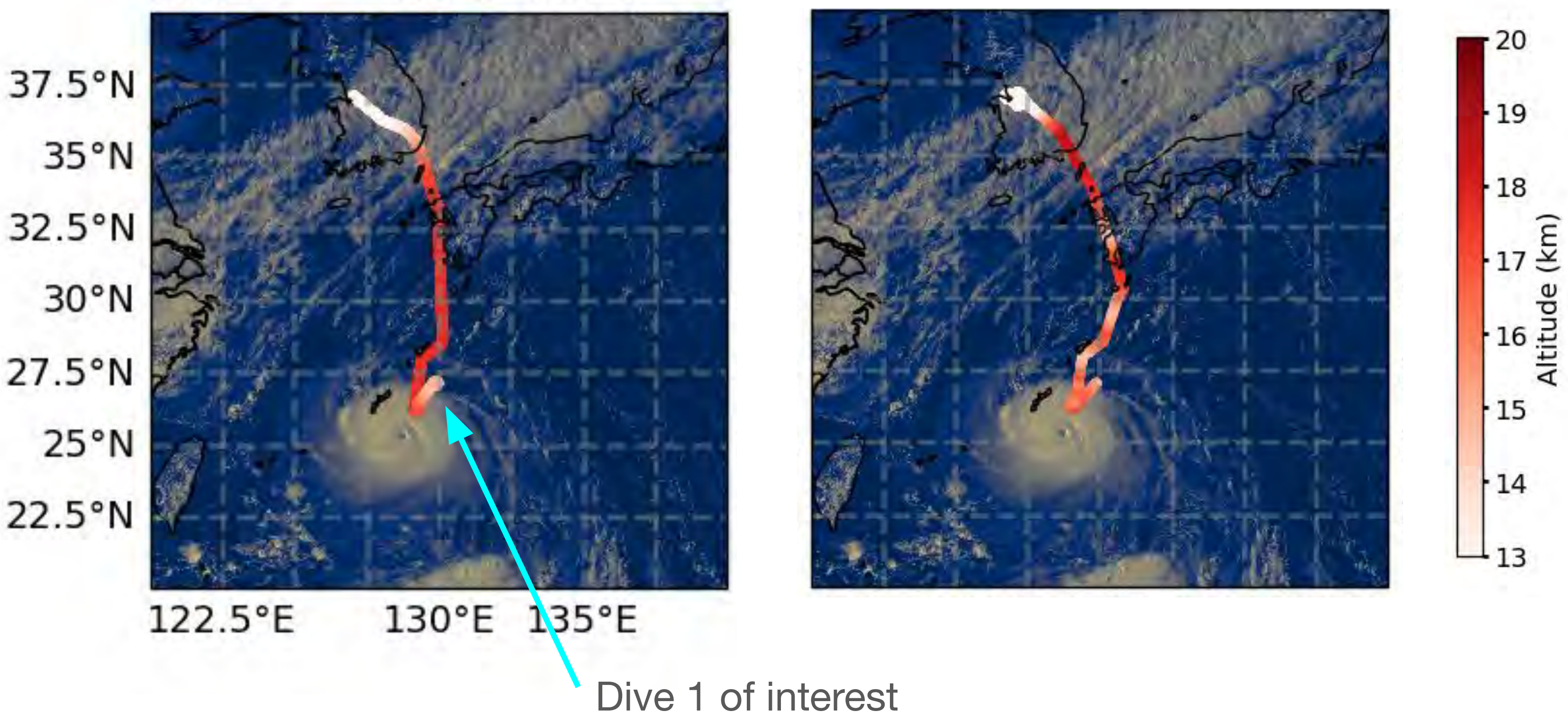


If due to motion besides the gravity wave, would expect higher ozone values during the level leg

Seen by Roux et. al. 2020, Roy et. al. 2023
Not seen by Cairo et. al. 2008

Mixing region around the TC

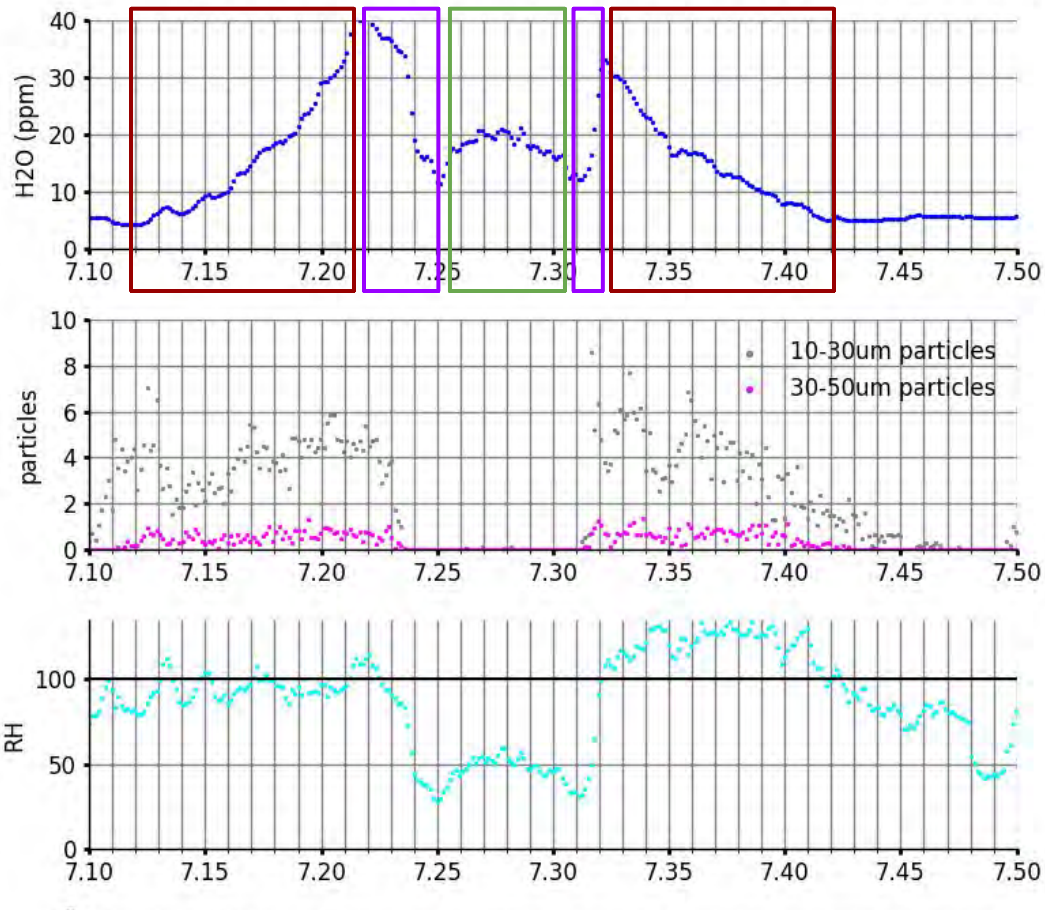
TC encounter; edges and near center



Himawari data from 7:00 UTC on 8/31

3 distinct types of air sampled during this dive

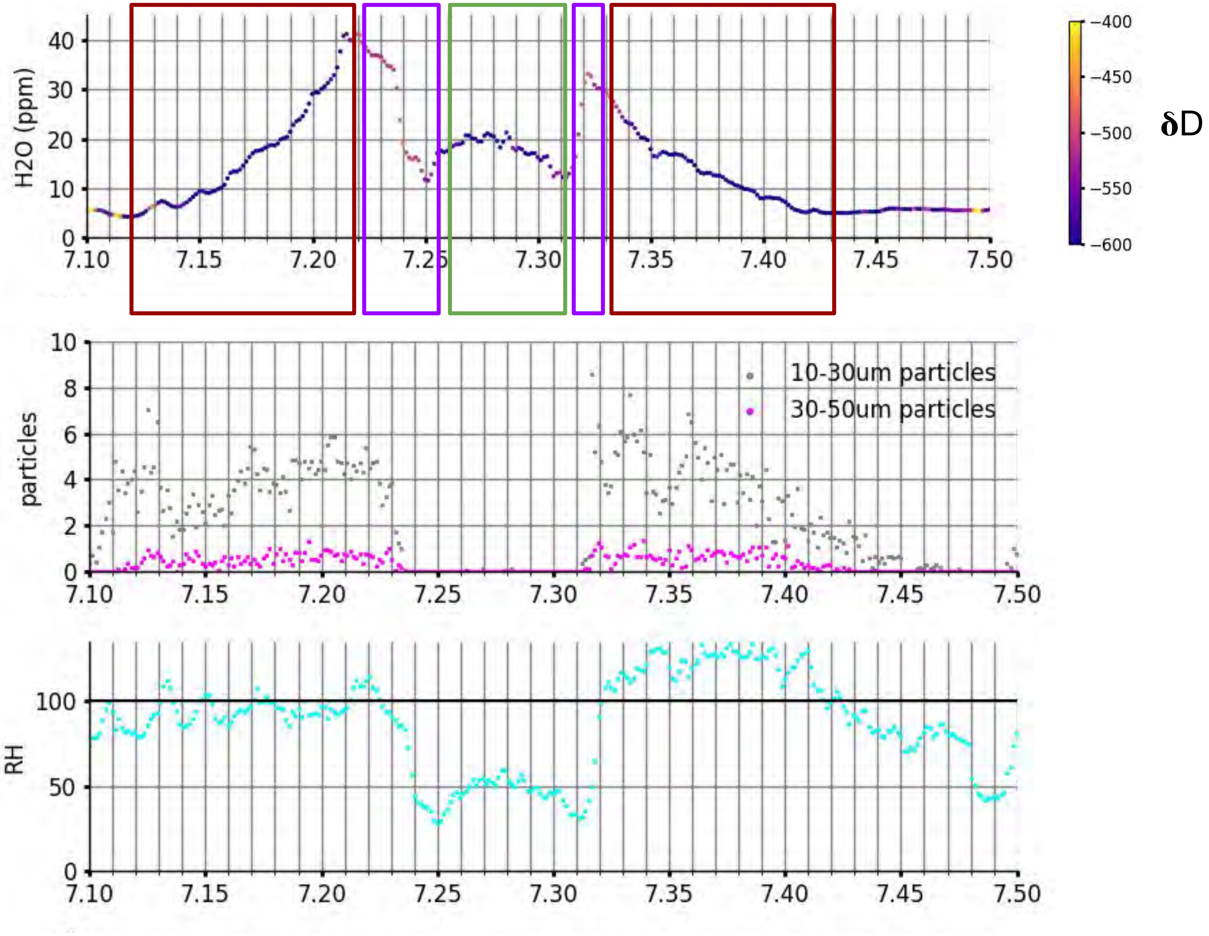
1. TC
2. Mixing zone
3. Dry air



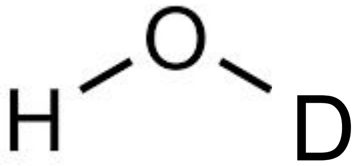
3 distinct types of air sampled during this dive

1. **TC**
2. **Mixing zone**
3. **Dry air**

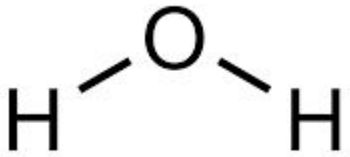
Water vapor isotopes can help us understand



Reminder about isotopes



semi-heavy water

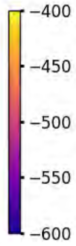


water

$$\delta \mathrm{D} = \frac{R_{samp} - R_{VSMOW,D/H}}{R_{VSMOW,D/H}} \times 1000$$

Typical scale:

Enriched



δD

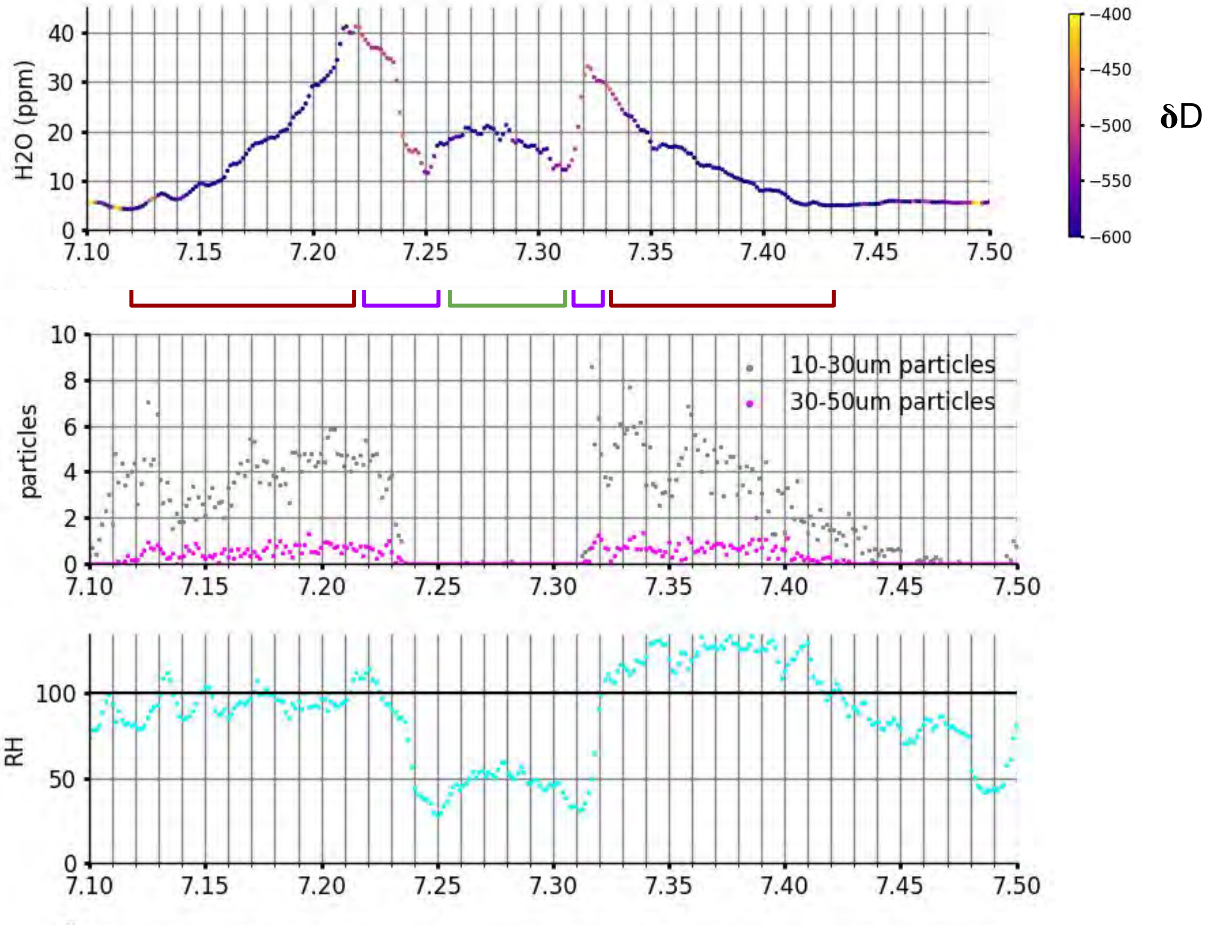
Depleted

Read: “how much does my sample differ from ‘standard’ water with regards to isotopic composition?”

-1000 means no heavy water compared to standard, 0 means all heavy water compared to standard

3 distinct types of air sampled during this dive

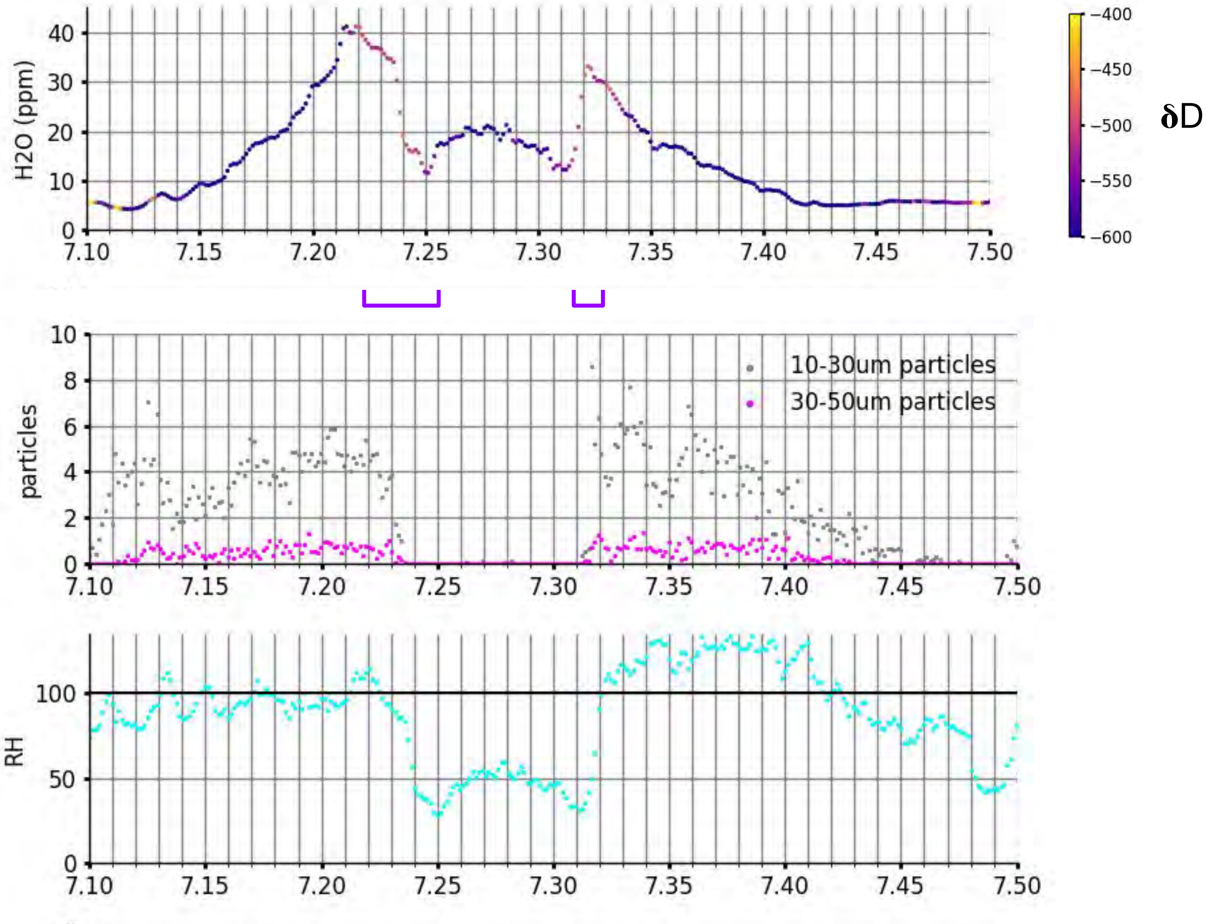
1. TC
2. Mixing zone
3. Dry air



Small zone where TC communicates with environment

2. Mixing zone

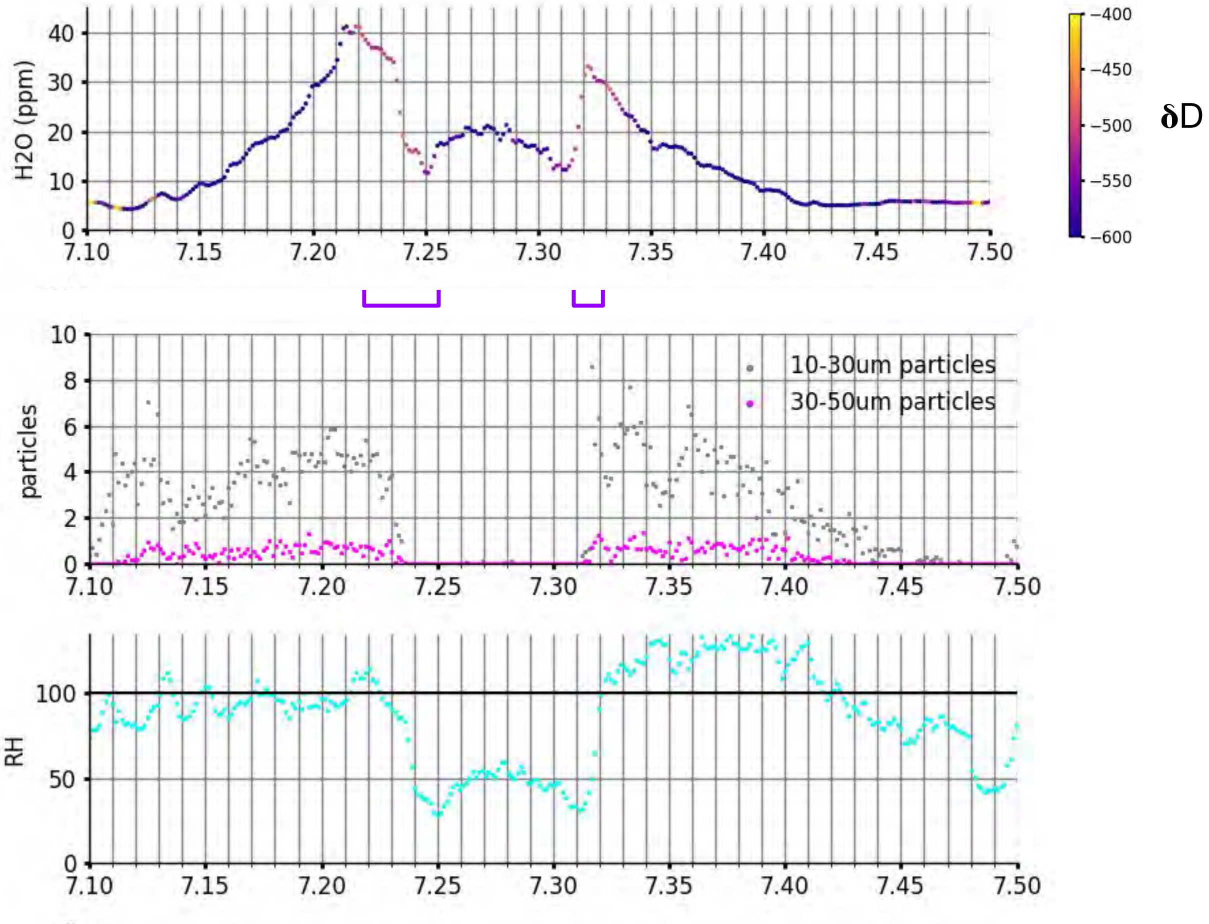
Regions in and out of the TC are more depleted than mixing zone, as expected



Small zone where TC communicates with environment

2. Mixing zone

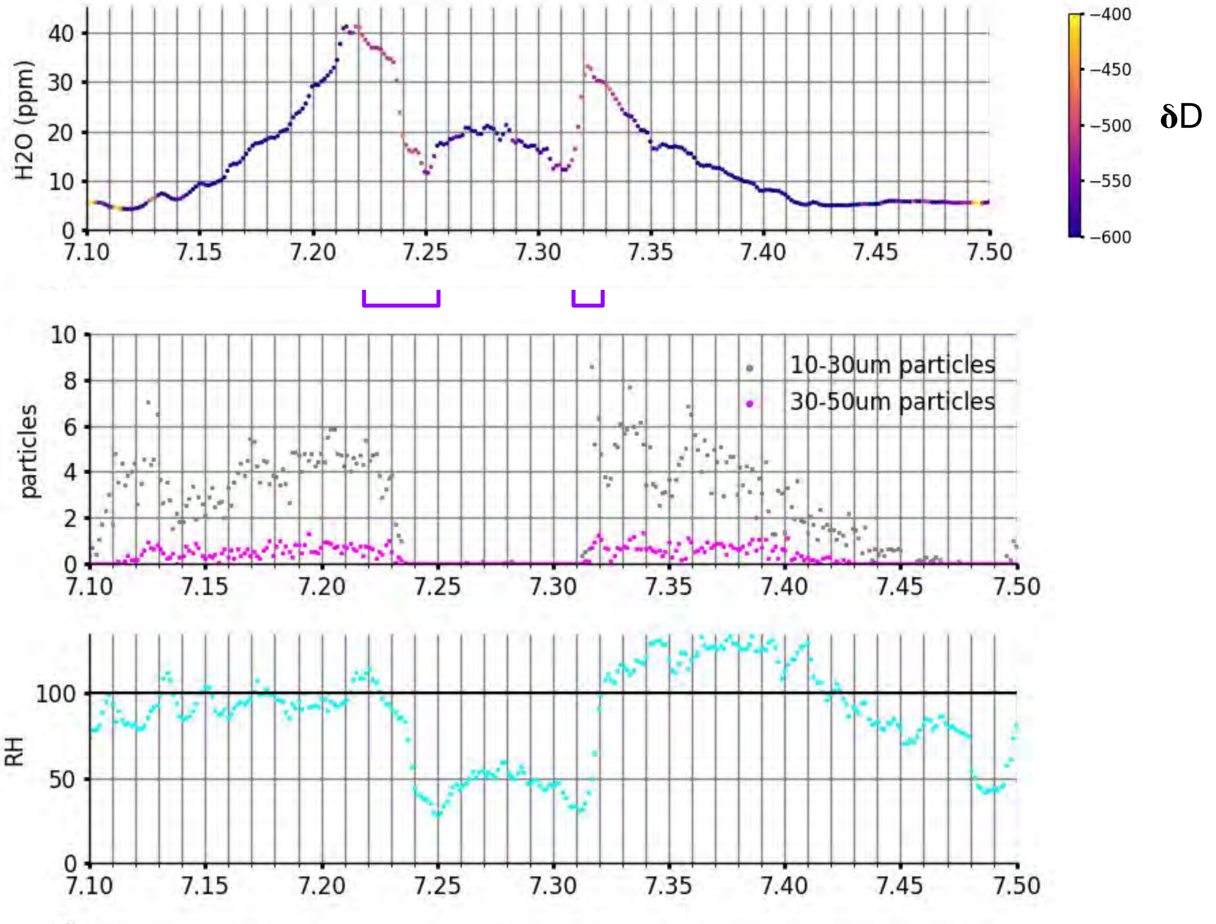
~100‰ enhancement as ice sublimates and releases heavy isotopes to vapor phase



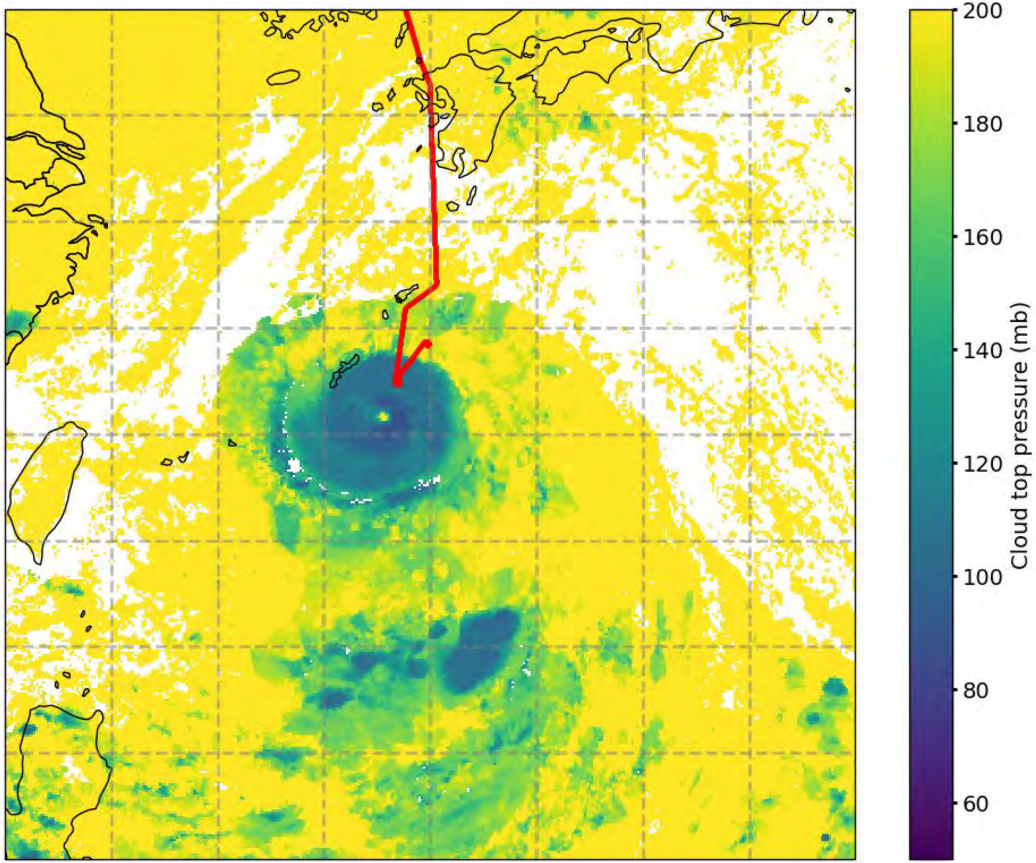
Small zone where TC communicates with environment

2. Mixing zone

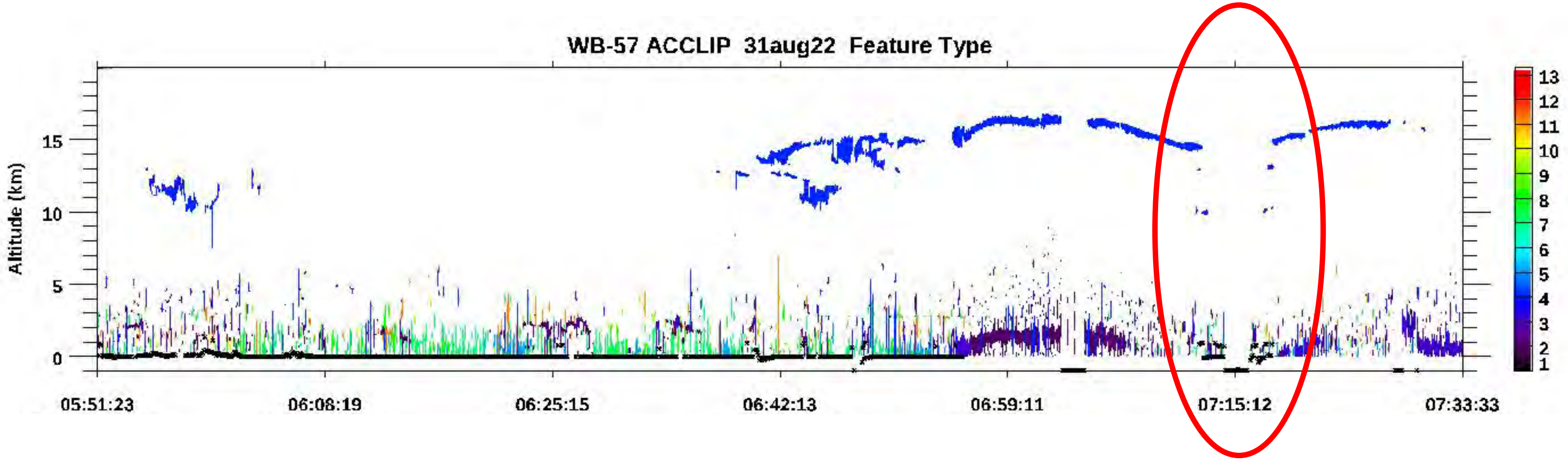
No strong updrafts (low RH), clear air below



Dive does not occur in center or rain band of TC



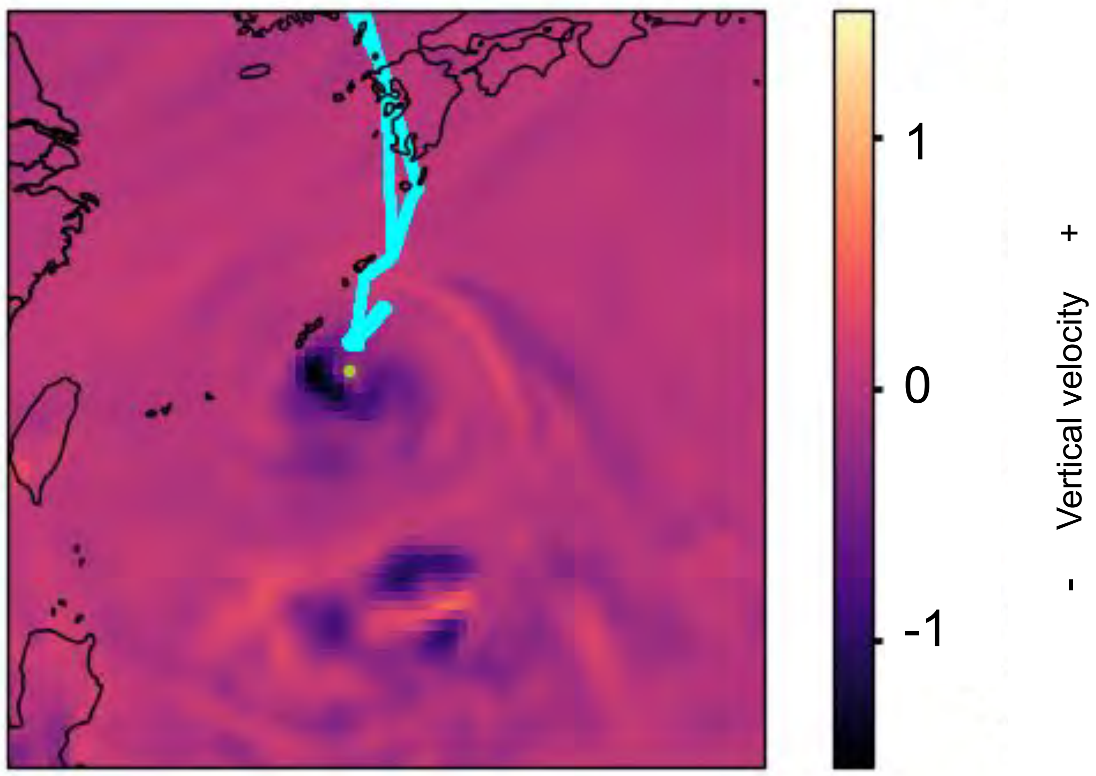
Lidar shows no clouds below plane at bottom of dive; cirrus elsewhere



Highlighted region shows there are no clouds below the aircraft at the bottom of the dive. Particle and RH values are characteristic of non-cyclone air sampled during the rest of the campaign (dry, no particles).

Data: Roscoe

ERA5 provides additional support: no strong vertical velocities at 150 mb

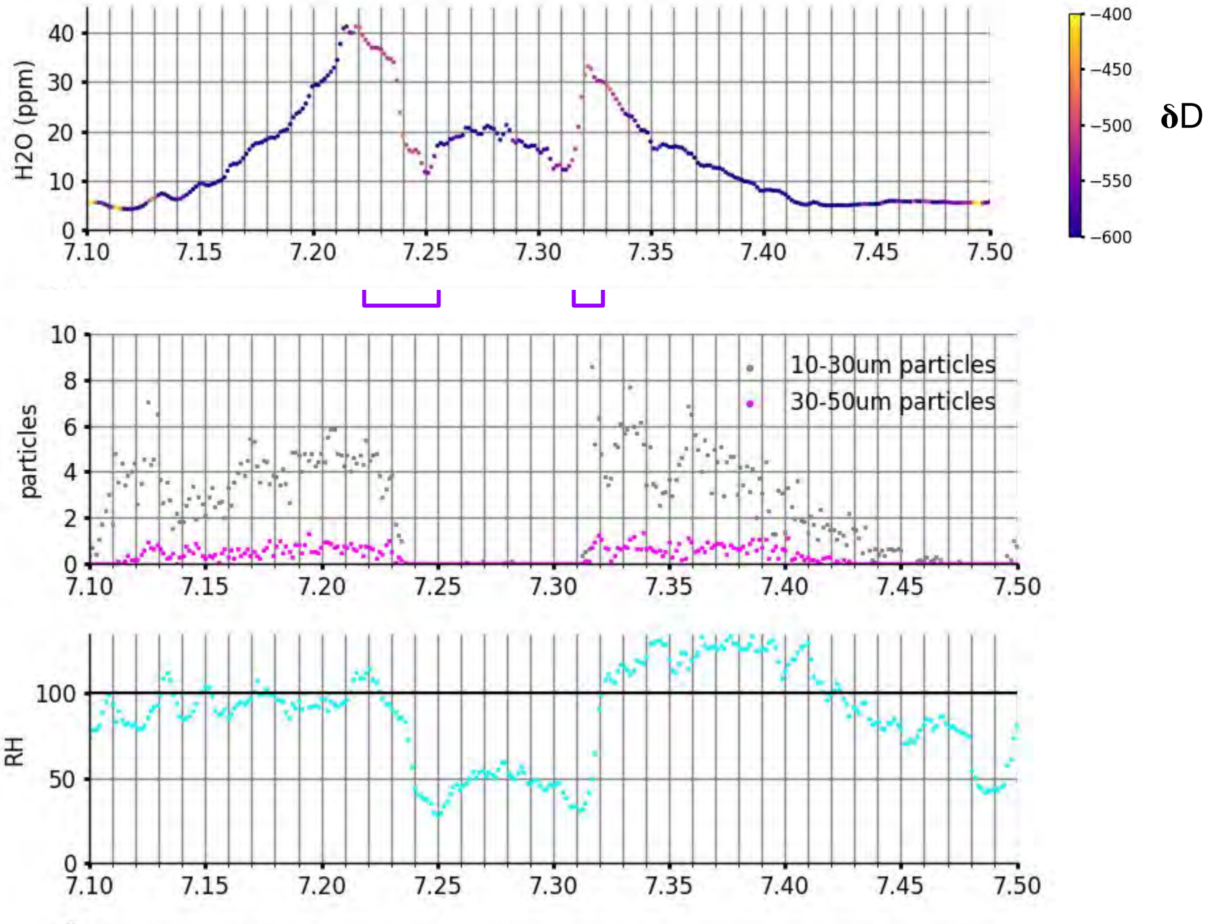


Small zone where TC communicates with environment

2. Mixing zone

~15km mixing zone - seems to be due to horizontal mixing between TC and environment, on the trailing edge of the TC

Limitation: only briefly sampled



Future work

- IWC and particle concentrations at larger bins will further confirm if sublimation is occurring

- Parcel at the bottom of the dive - would Lagrangian tracking be useful (due to proximity of strong convection and small scale)?

- What are the dynamical mechanisms that bring about this mixing phenomena? I'd love to discuss
    - How does the size of this region differ across TCs; also on the non-trailing edge?

Conclusions

<u>TC effect on STRATOSPHERE:</u>

- **Compared to in-situ data gravity wave amplitudes are underestimated by ~3x in ERA5**

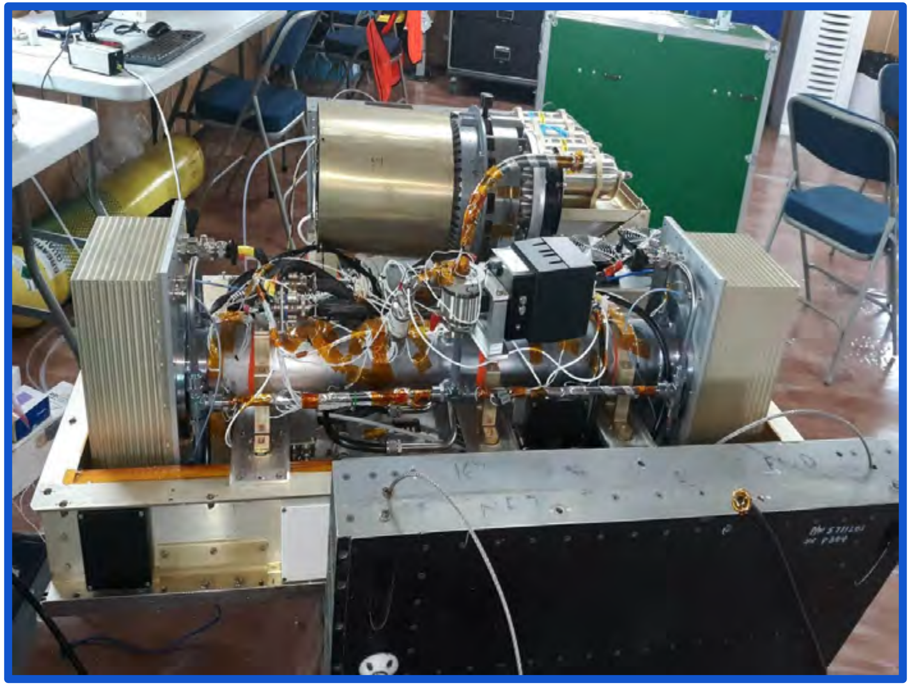
- **There is no evidence that the TC is strongly sucking down stratospheric air**

<u>TC effect on TROPOSPHERE:</u>

- **There is a small region (~15km) around the TC where air from within mixes with dry, environmental air**

Extra slides

ChiWIS instrument: how we measure water vapor and isotopes

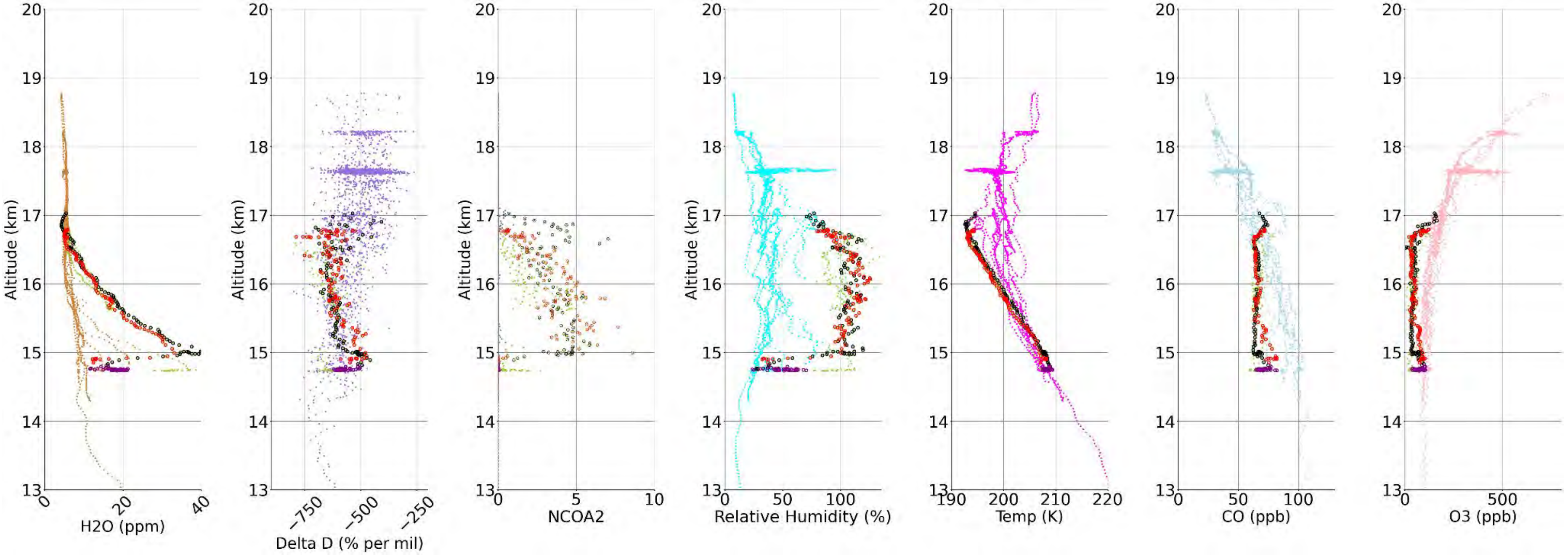


Integrated cavity output spectrometer, 2.65um laser

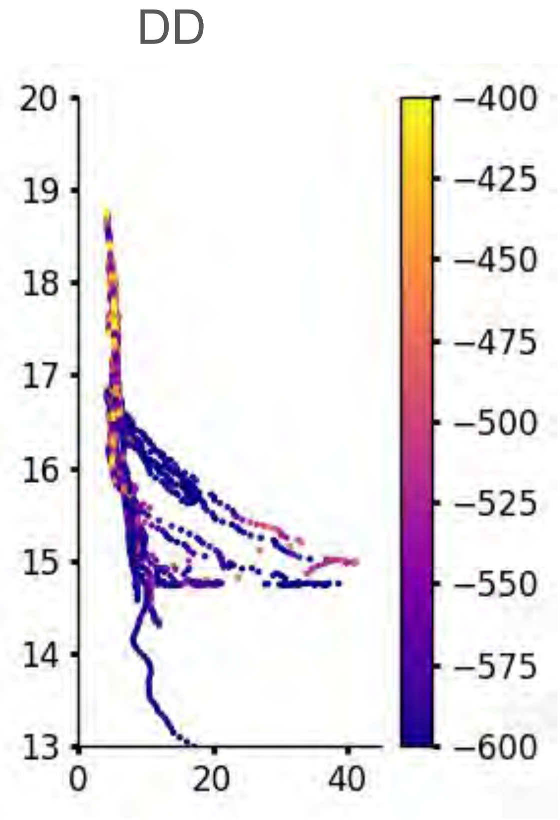
Specification	ChiWIS
Target molecule	water vapor (isotopes)
Weight	320 lbs
Cell length	.9 m
Cell diameter	4 inches
Flow rate	3.5 L/s
Inlet design	rear-facing
Noise, 1 σ, 5s	6e-4
HDO precision	10 ppbv
H2O precision	110 ppbt

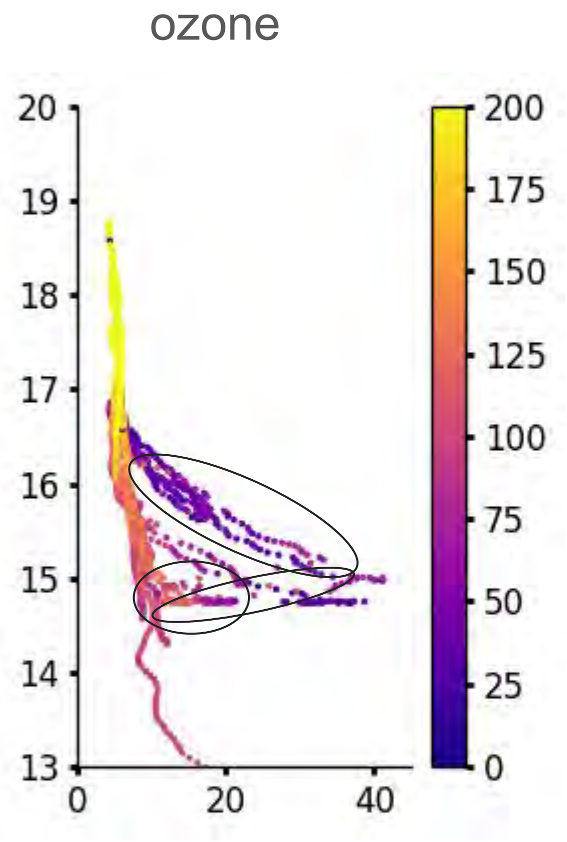
dD, 5s:
@ 80ppm: 3.5% per mil
@ 2.5ppm: 110% per mil

D1 vertical profiles



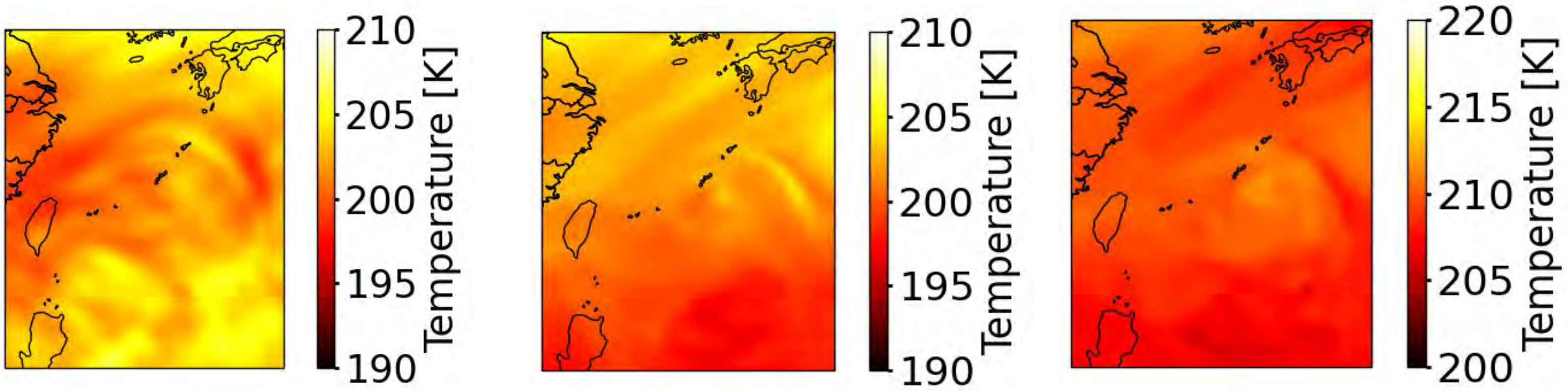
H2O colored by DD, Ozone

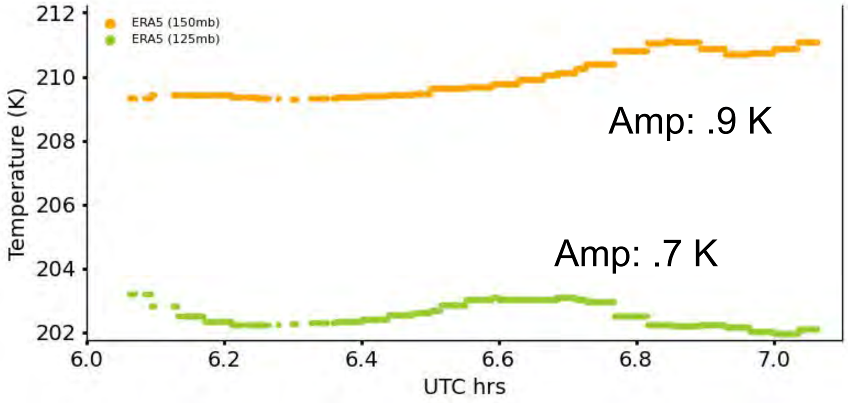


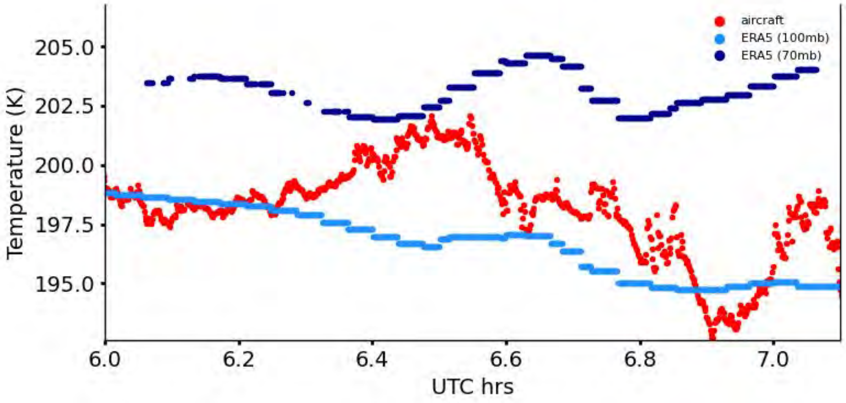


Waves penetrate down to at least 150mb, but with small amplitudes

70 mb **125 mb** **150 mb**

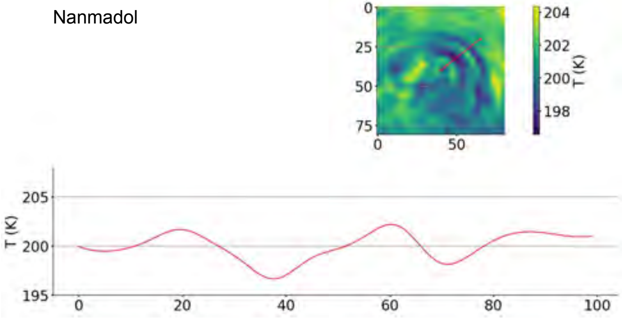




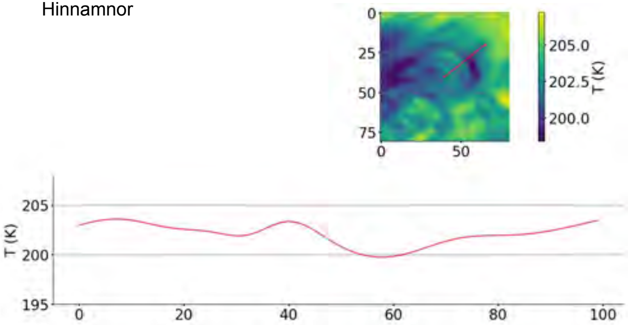


Temp variations are seen above other TCs – Hinnamnor's aircraft sampled anomalies are typical

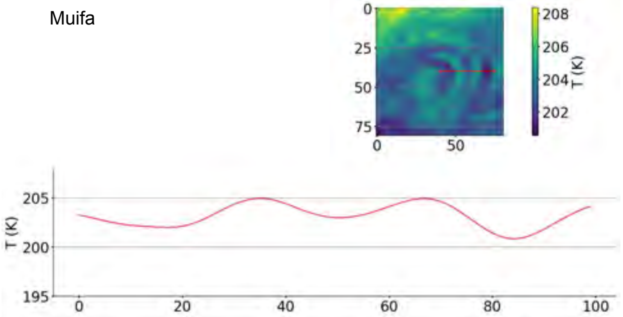
Nanmadol



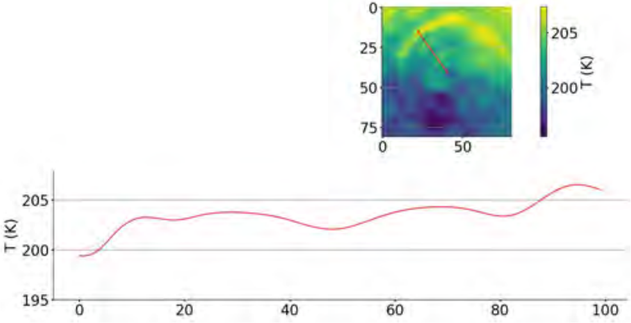
Hinnamnor



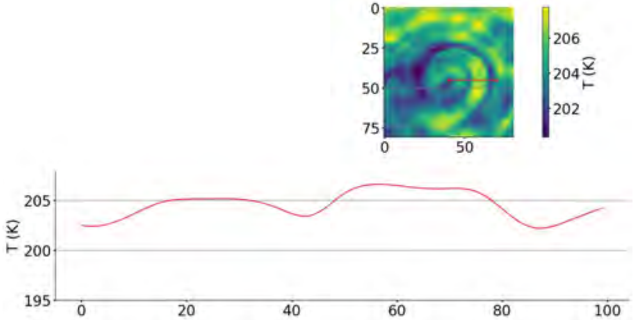
Muifa



Emily



Katrina



Kitchen & Shutts 1990 see 5K GW disturbances from balloon measurements

Alexander & Pfister 1995 show 3K disturbances