Wave Influence on Tropical High Cirrus Clouds as Observed by the NASA Global Hawk

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Why do we care about TTL & cirrus clouds?

- Stratospheric air is mainly controlled by TTL processes.
- Stratospheric water vapor and TTL clouds have significant impacts on surface climate – temperature & circulation.
Search for TTL Wave-Cirrus relation

- NASA’s unmanned aircraft Global Hawk had 15 science + 2 transit flights over the tropical Pacific.
- Measurements include $T$, winds, water vapor, cloud ice particles, radiation, and various trace gases.
- Vertical dives give dropsonde-like profiles.
Definition of the mean temperature is critical to isolating wave anomalies

• Temperature perturbation?

\[ T' = \text{Aircraft temperature} - \text{Mean (?)} \]

Mean profiles from analysis data always have biases.
GPS mean temperatures are very accurate!

- Temperature perturbation?
  \[ T' = \text{Aircraft temperature} - \text{GPS Mean} \]

**GPS Mean**
- 30 days centered on each flight date
- 10x5 degrees centered on each flight location
- Result is \( T' \) due to waves with periods \(<30\text{days}\)
How do means and anomalies look like?

(A) $T$ & $T_m$

(B) $T'$

(C) Horizontal Path, Mar6–7, 2014

(D) Vertical Path, Mar6–7, 2014
Total sampling (=all sky) distribution of temperature anomalies
Cirrus clouds are dominantly observed at negative temperature anomalies.

98% cirrus occurred in $T' < 0$!
Cirrus clouds are dominantly observed at negative temperature anomalies.

85% cirrus occurred in $T' < 0$!
But, the relation over W-Pacific seems weaker
Upper W-Pacific

Strong wave influence (suggesting impact on stratospheric water transport)

Mid W-Pacific

Transitional behavior

Lower W-Pacific

Weaker wave influence due to convective hydration
Examples of aircraft T anomaly profiles:

- Range of vertical scales (~4 to <1 km) is evident.
- Multiple layers of clouds are associated with shallow waves.
- Clouds are often detected where $T' < 0$ & $dT'/dz < 0$. 

**Red: Cloud Occurrence (measured by FCDP)**
Why more clouds at \( \frac{dT'}{dz} < 0 \) ?

Wave-induced temperature anomaly pattern has downward propagation
Why more clouds at $dT'/dz < 0$?
$dT'/dz < 0$ corresponds to $dT'/dt < 0$ (cooling of air)

The most favorable condition for cirrus is cold air with ongoing cooling
Cirrus clouds with $T' < 0$ & $dT'/dz < 0$
Conclusion

- Unprecedented airborne measurements reveal that waves are strong modulators of cirrus clouds away from deep convection. A favorable condition is cold anomalies (T’<0) with ongoing cooling (dT’/dt<0).

- Final dehydration before entering the stratosphere is dominantly affected by wave temperature anomalies.

- Various vertical scales of cloud layers are associated with various scales of waves (even < 1km).

- Our results suggest that representation of waves in models is important for cirrus cloud processes thus for stratospheric water vapor and the feedback on surface climate.
Wave Flight

Thicker persistent cirrus with colder Kelvin waves & Thinner broken clouds with weaker Kelvin waves

Radiosonde temperature perturbations by Kelvin waves
Cirrus occurrence over the central and eastern Pacific is small but governed by cold anomalies.

Final dehydration will be strongly affected by wave motions over the western Pacific.

Western Pacific low cirrus shows two types: convective-influenced & wave-induced.