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

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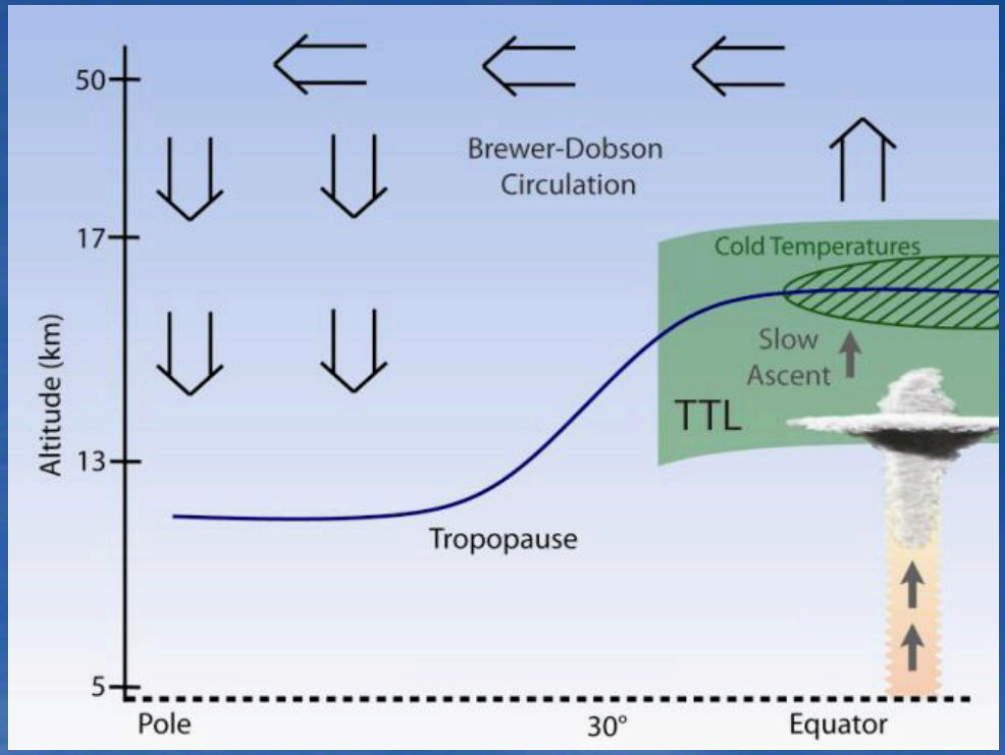
Why do we care about TTL & cirrus clouds?

TTL: Tropical Tropopause Layer

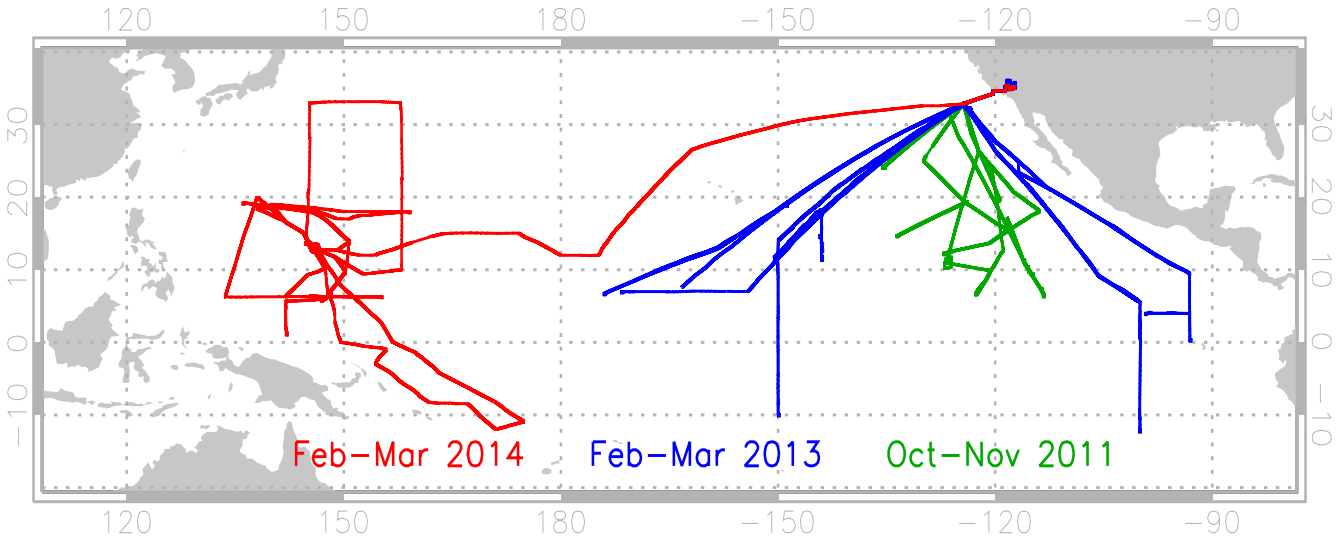


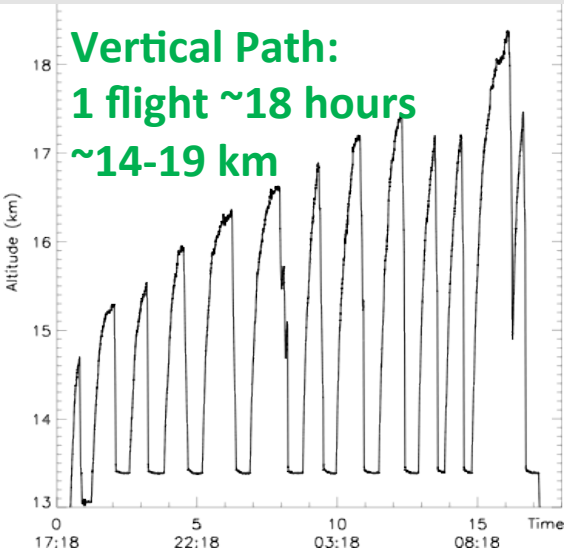
Courtesy of Eric Jensen

- 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?

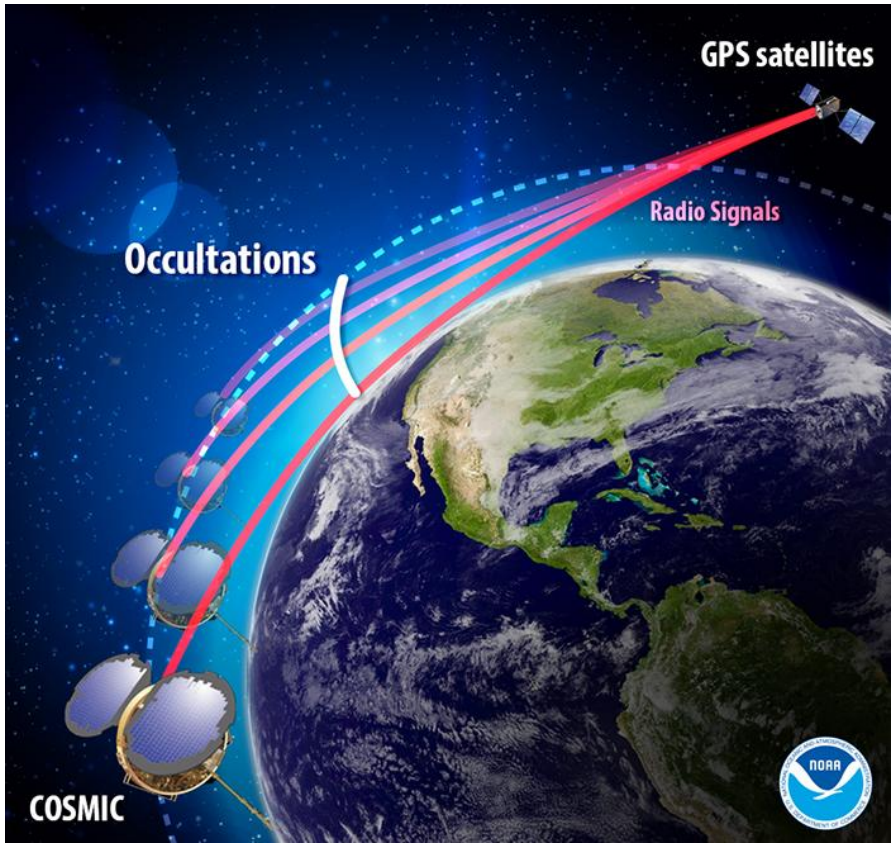
T’ = Aircraft temperature – Mean (?)

Mean profiles from analysis data always have biases.

GPS mean temperatures are very accurate!

- Temperature perturbation?

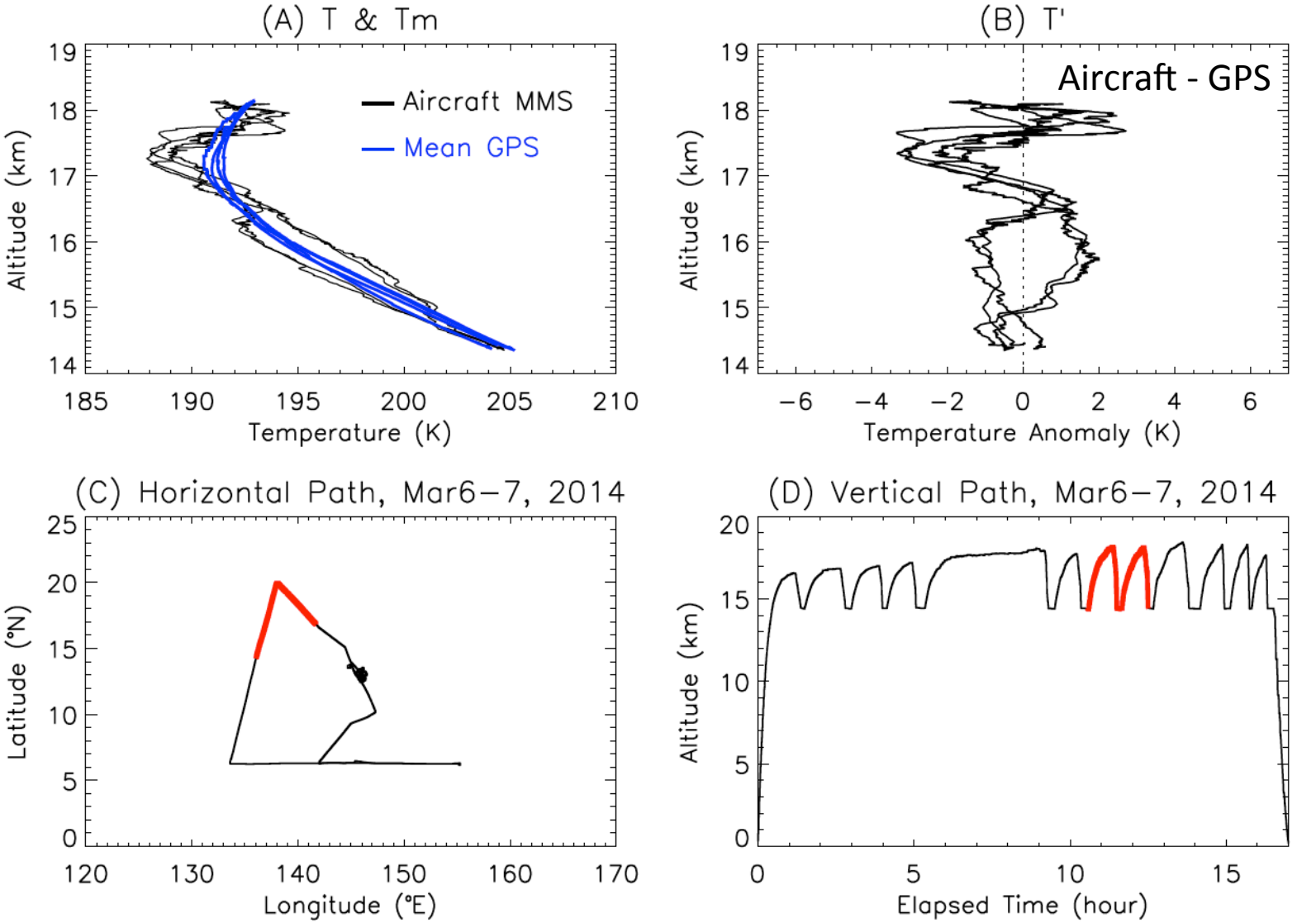
  T’ = Aircraft temperature – GPS Mean



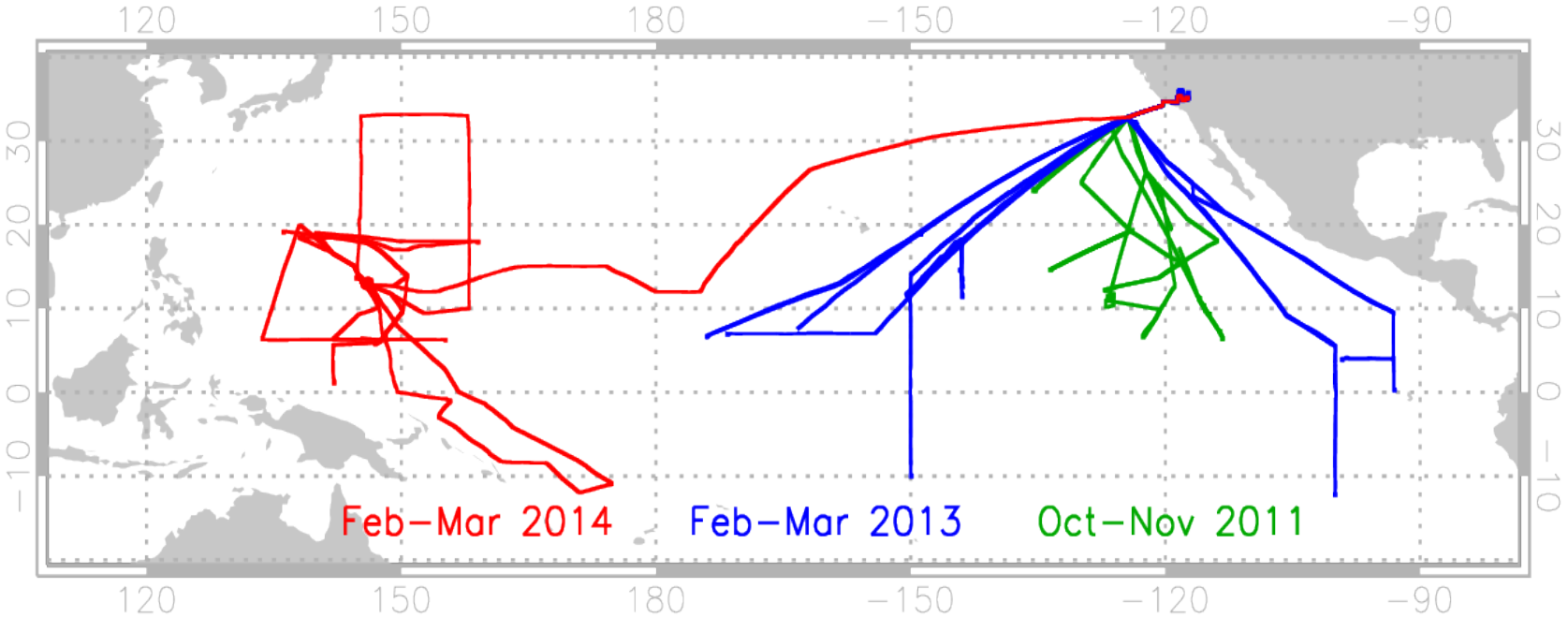
GPS Mean

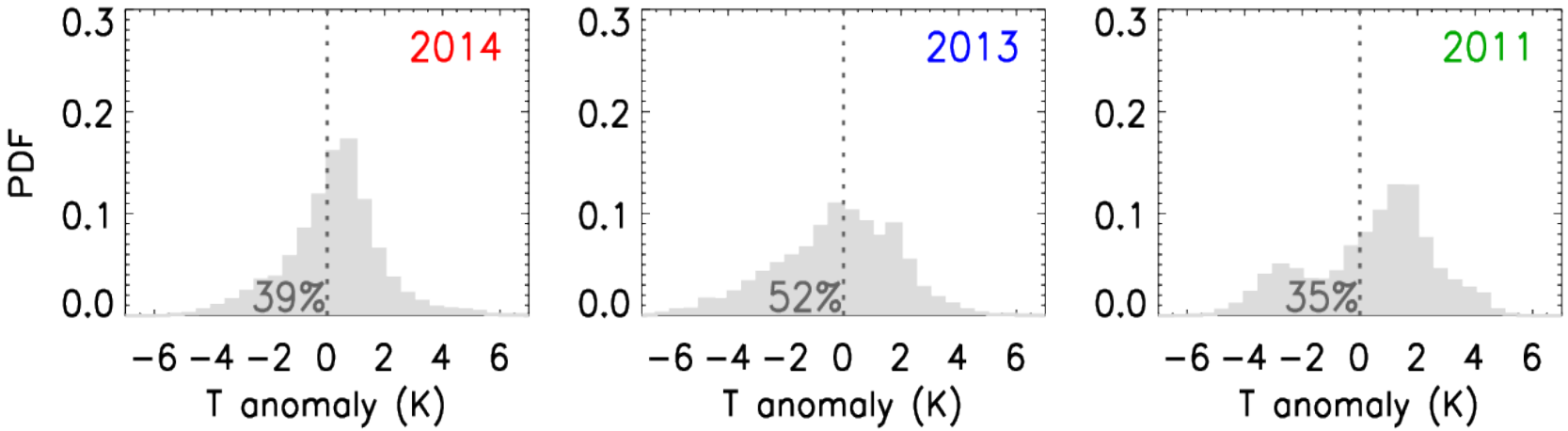
- 30 days centered on each flight date
- 10x5 degrees centered on each flight location
- Result is T’ due to waves with periods<30days

How do means and anomalies look like?

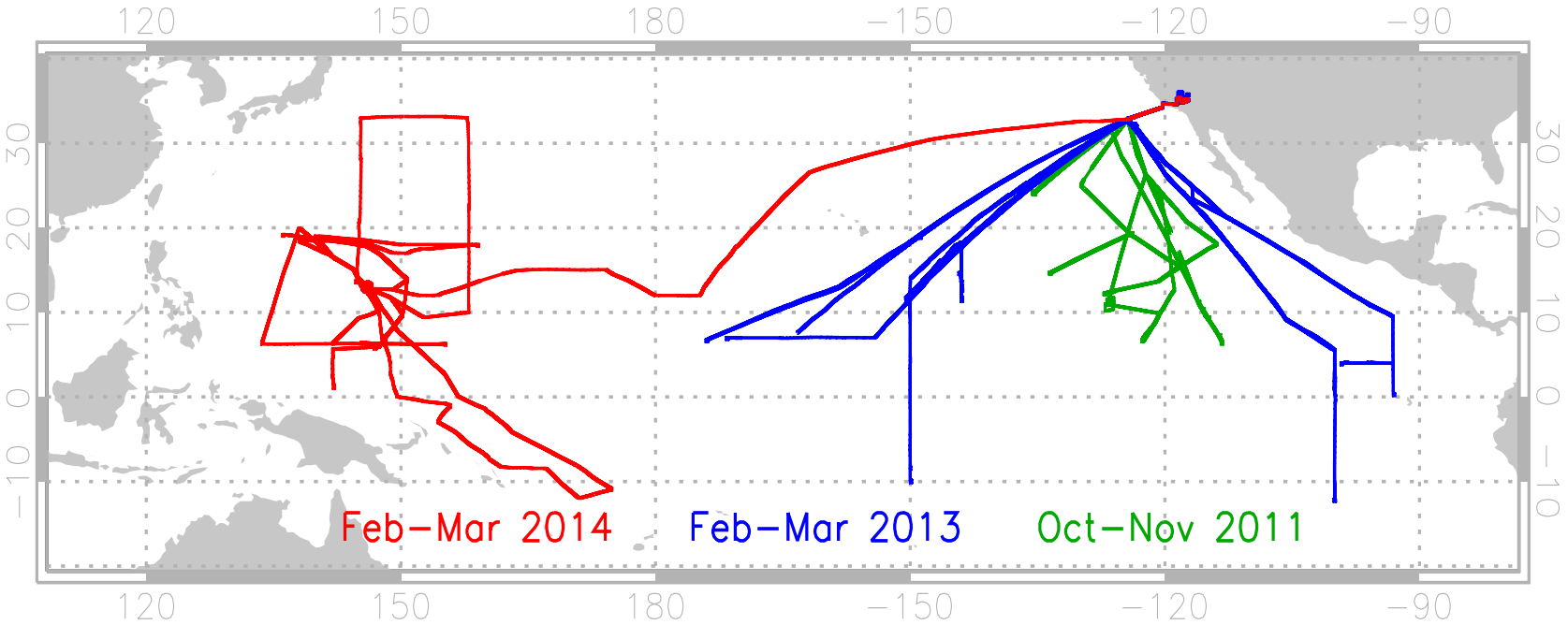


Total sampling (=all sky) distribution of temperature anomalies

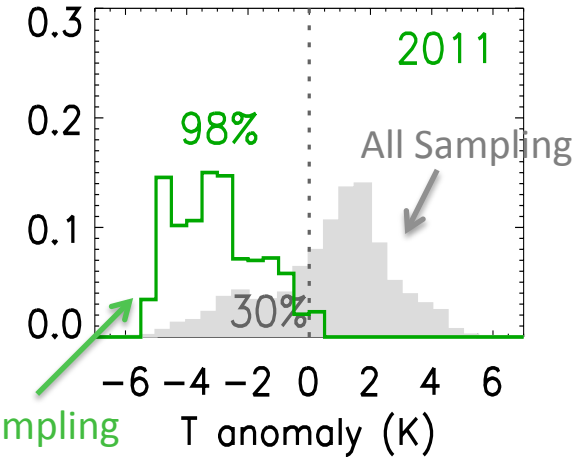




Cirrus clouds are dominantly observed at negative temperature anomalies

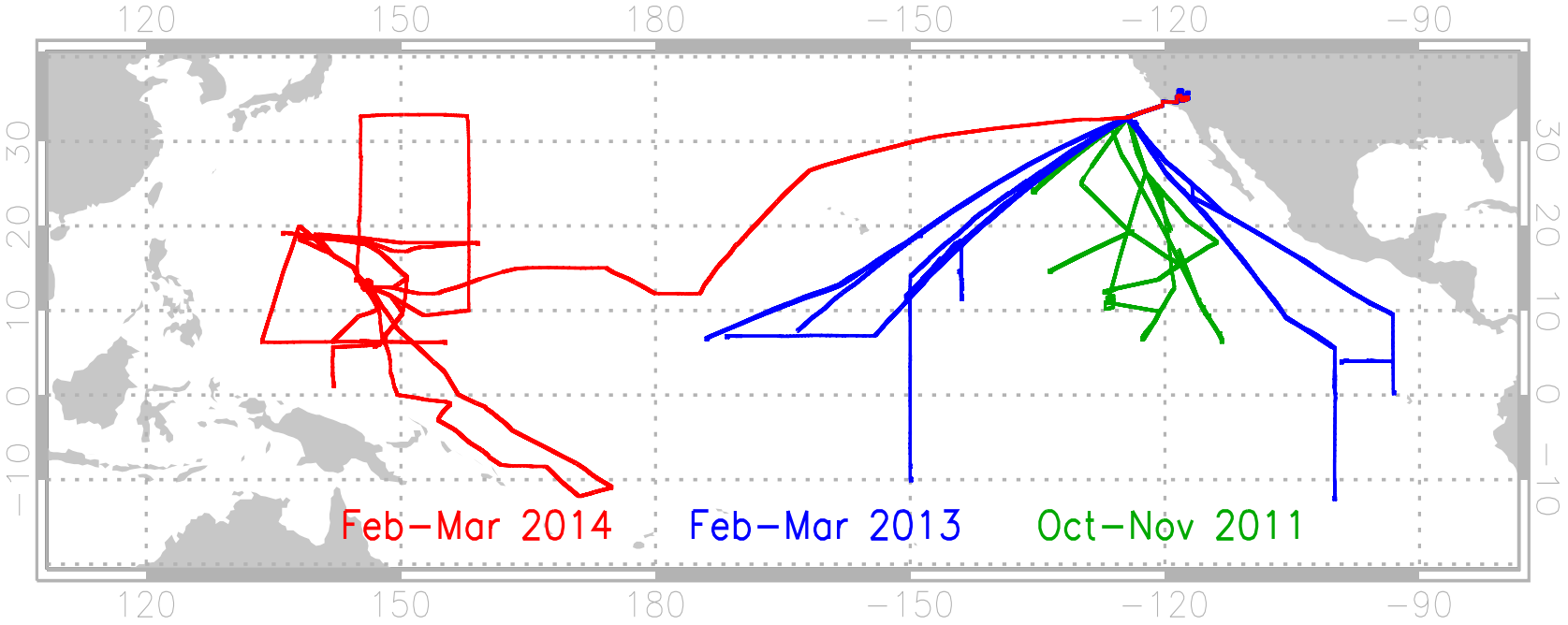


* Grey : PDF of all T'
* Color: PDF of T' with clouds

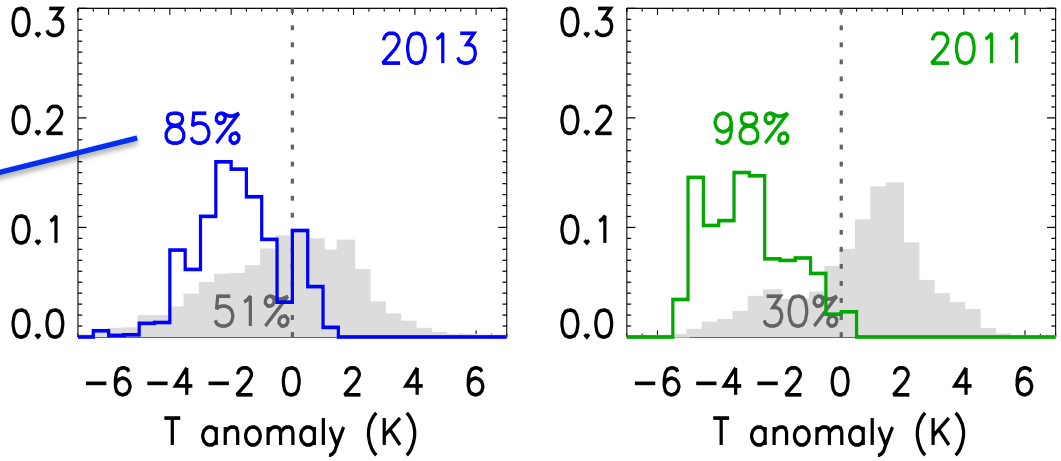


98% cirrus occurred in T'<0 !

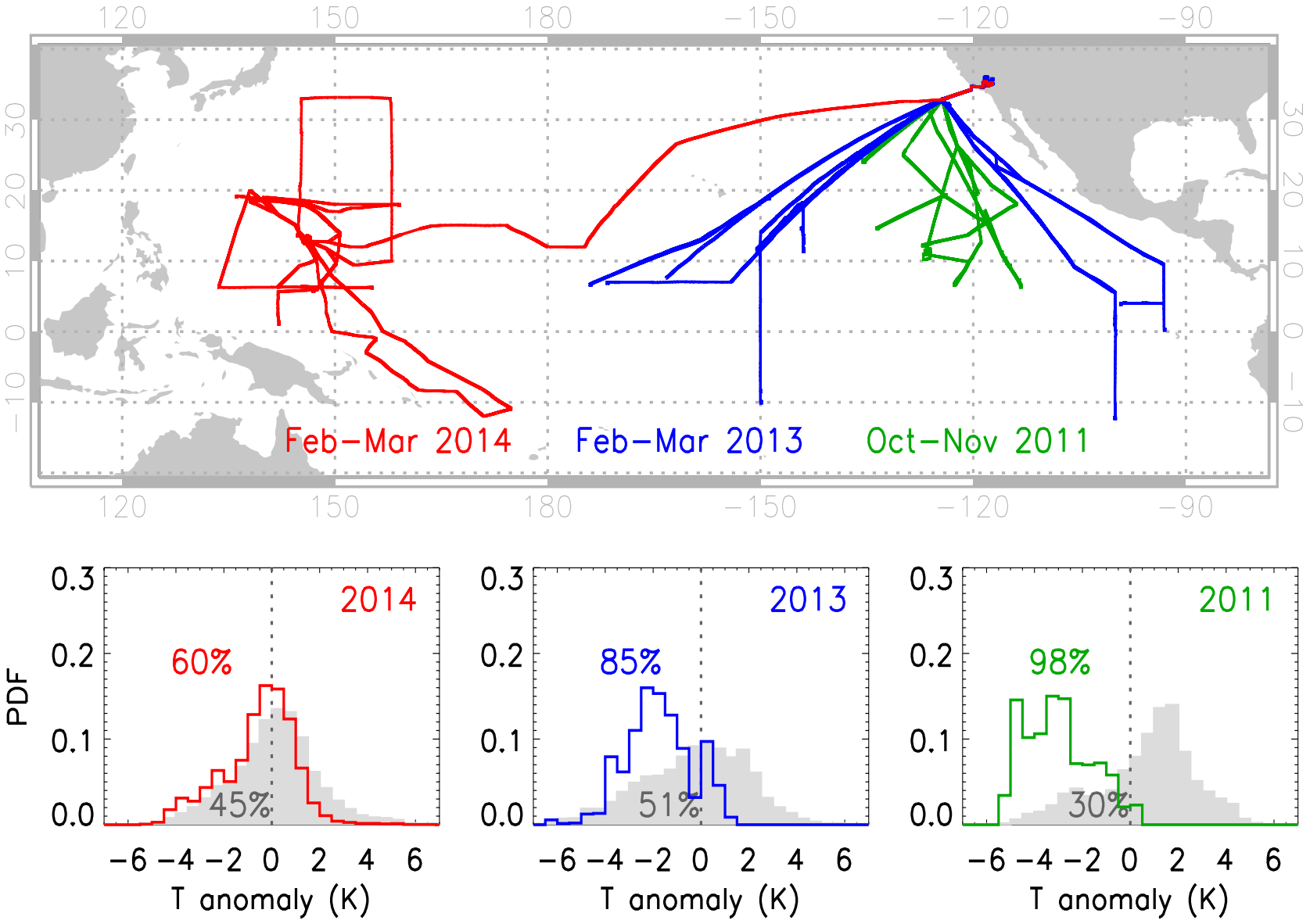
Cirrus clouds are dominantly observed at negative temperature anomalies

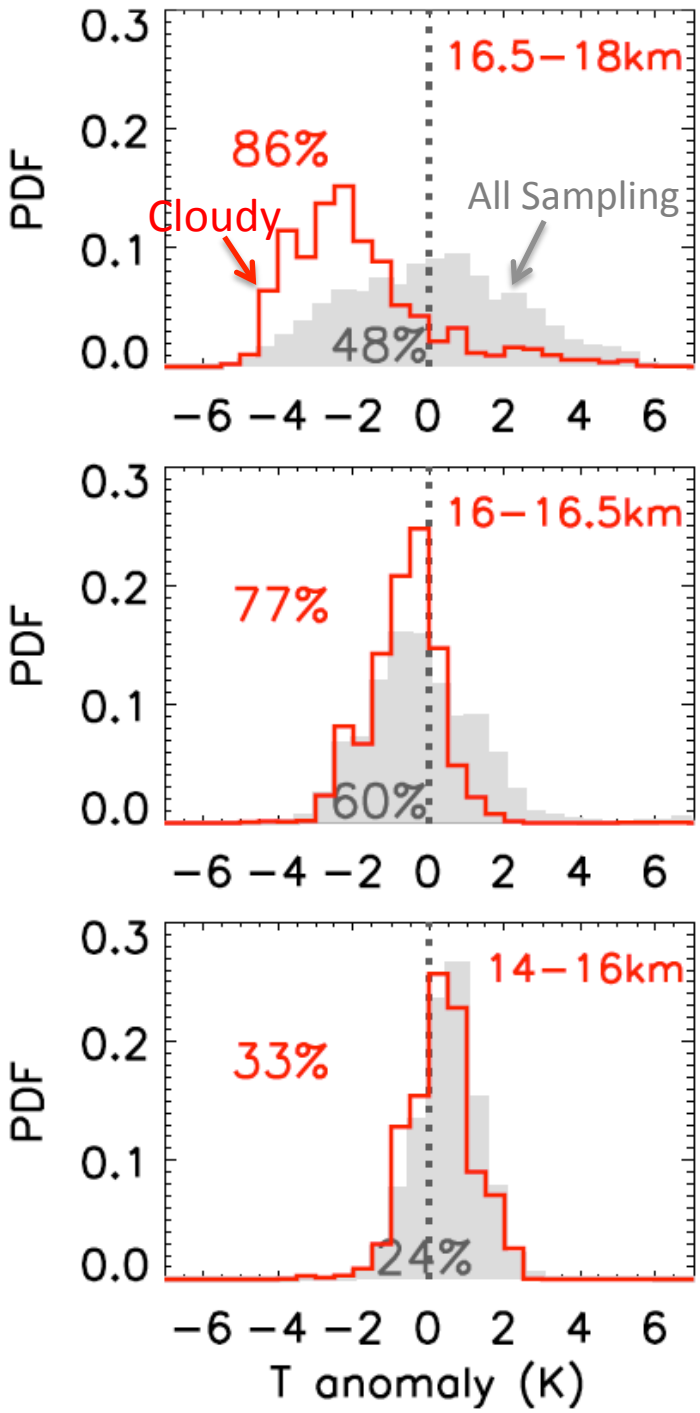


85% cirrus occurred in T'<0 !



But, the relation over W-Pacific seems weaker





Upper W-Pacific

→ **Strong wave influence (suggesting impact on stratospheric water transport)**

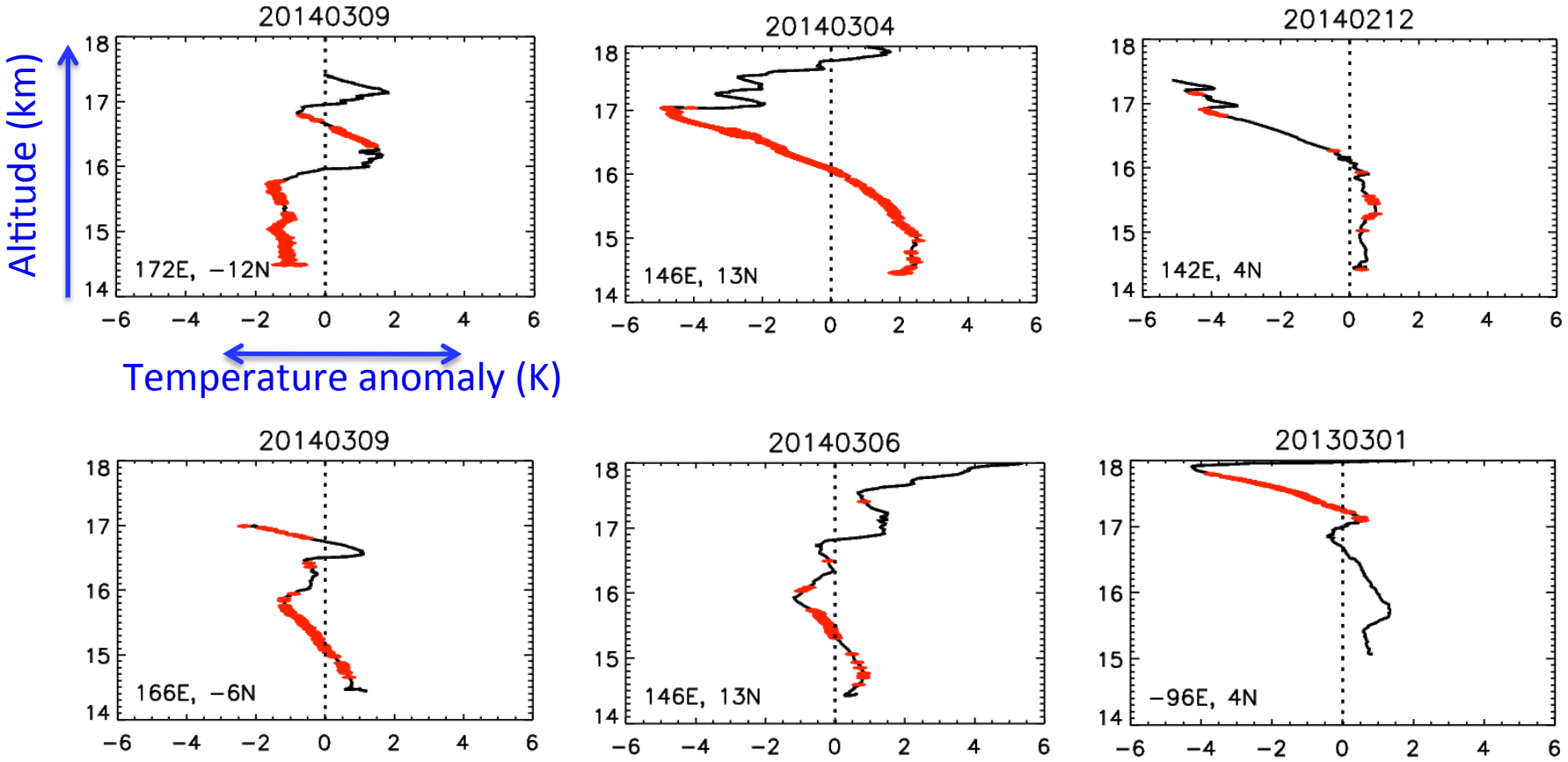
Mid W-Pacific

→ **Transitional behavior**

Lower W-Pacific

→ **Weaker wave influence due to convective hydration**

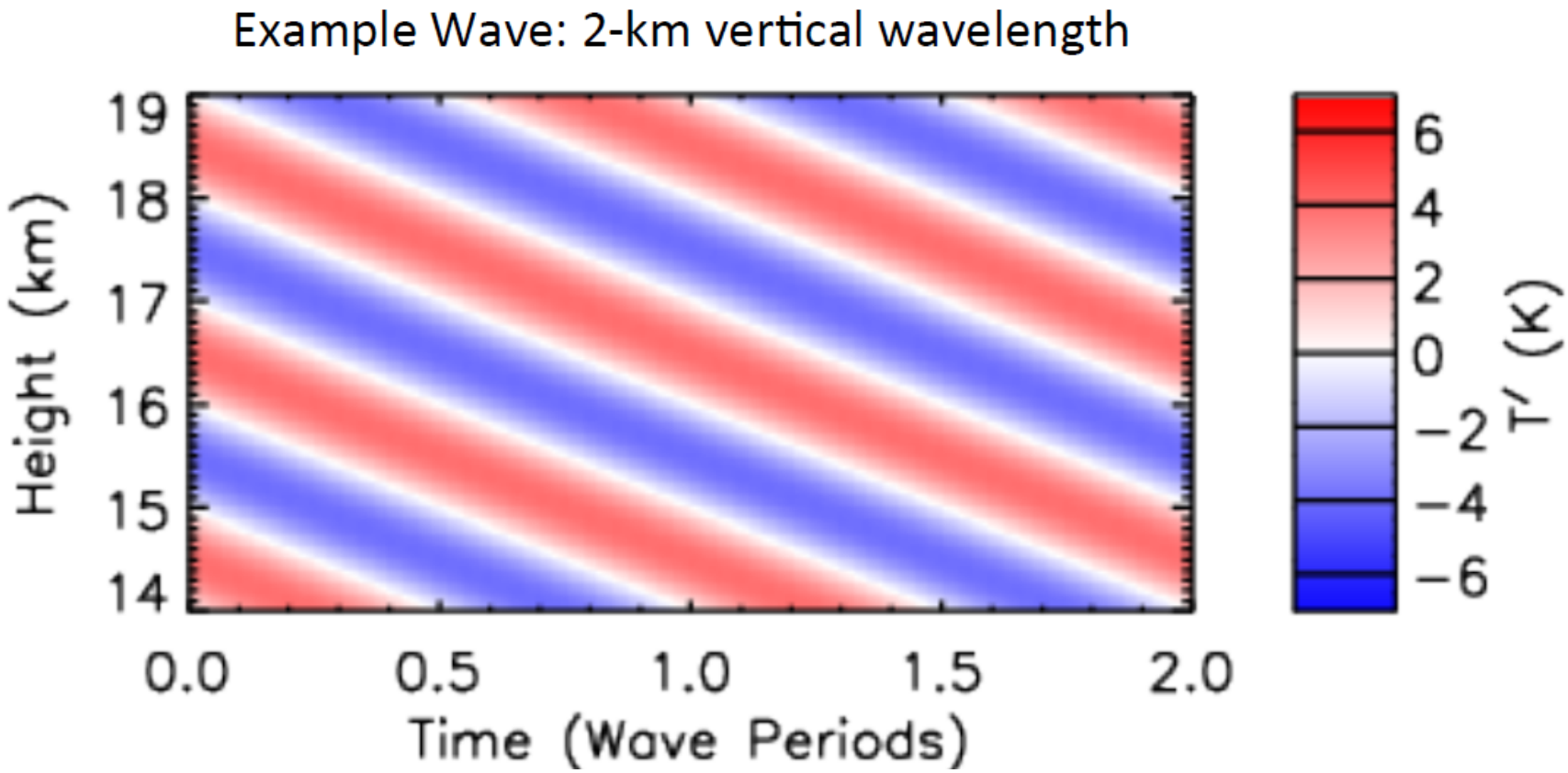
Examples of aircraft T anomaly profiles:



Red: Cloud Occurrence (measured by FCDP)

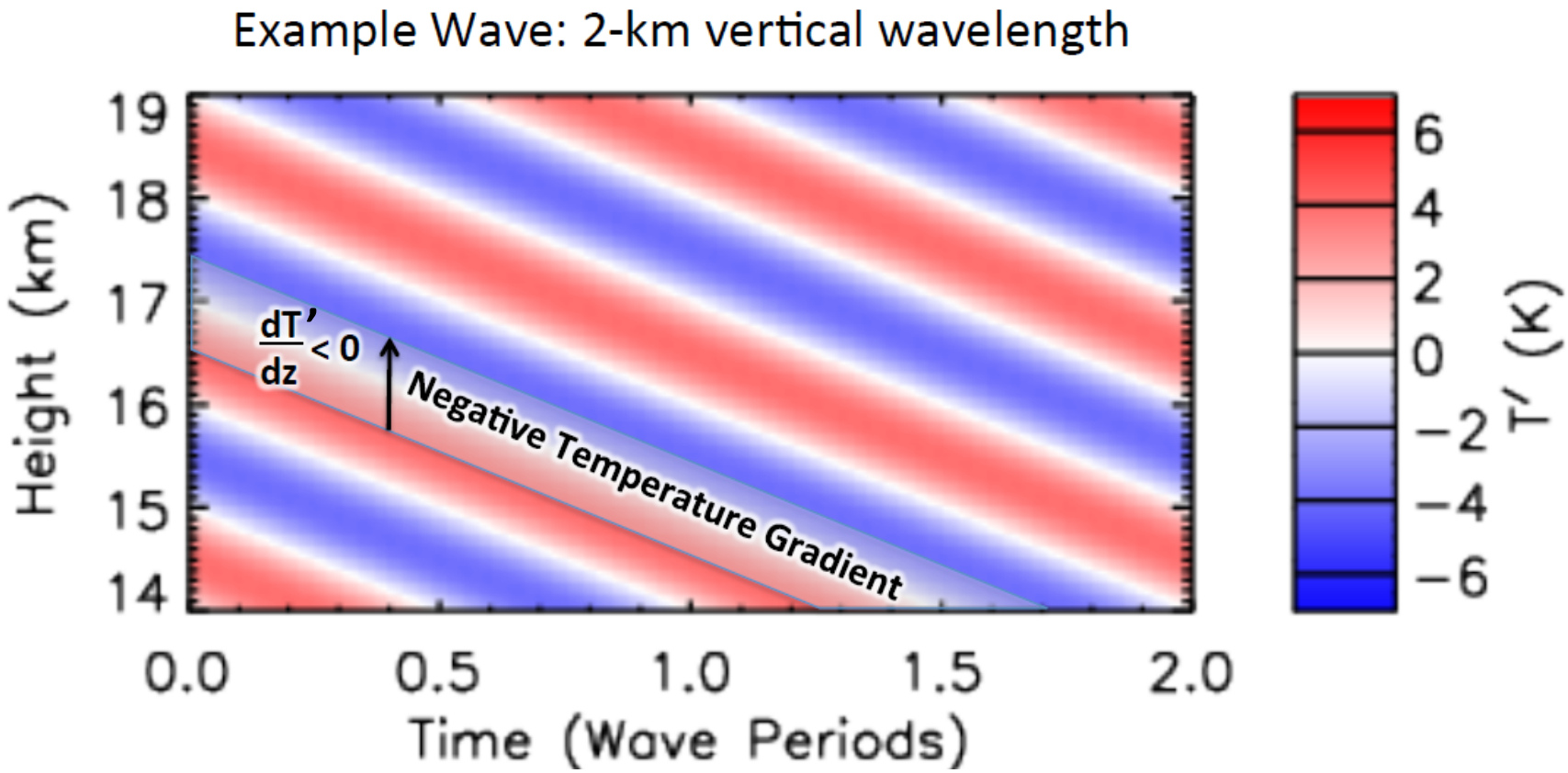
- Range of vertical scales (~ 4 to <1 km) is evident.
- Multiple layers of clouds are associated with shallow waves.
- Clouds are often detected where **T'<0 & dT'/dz < 0**.

Why more clouds at dT'/dz < 0 ?

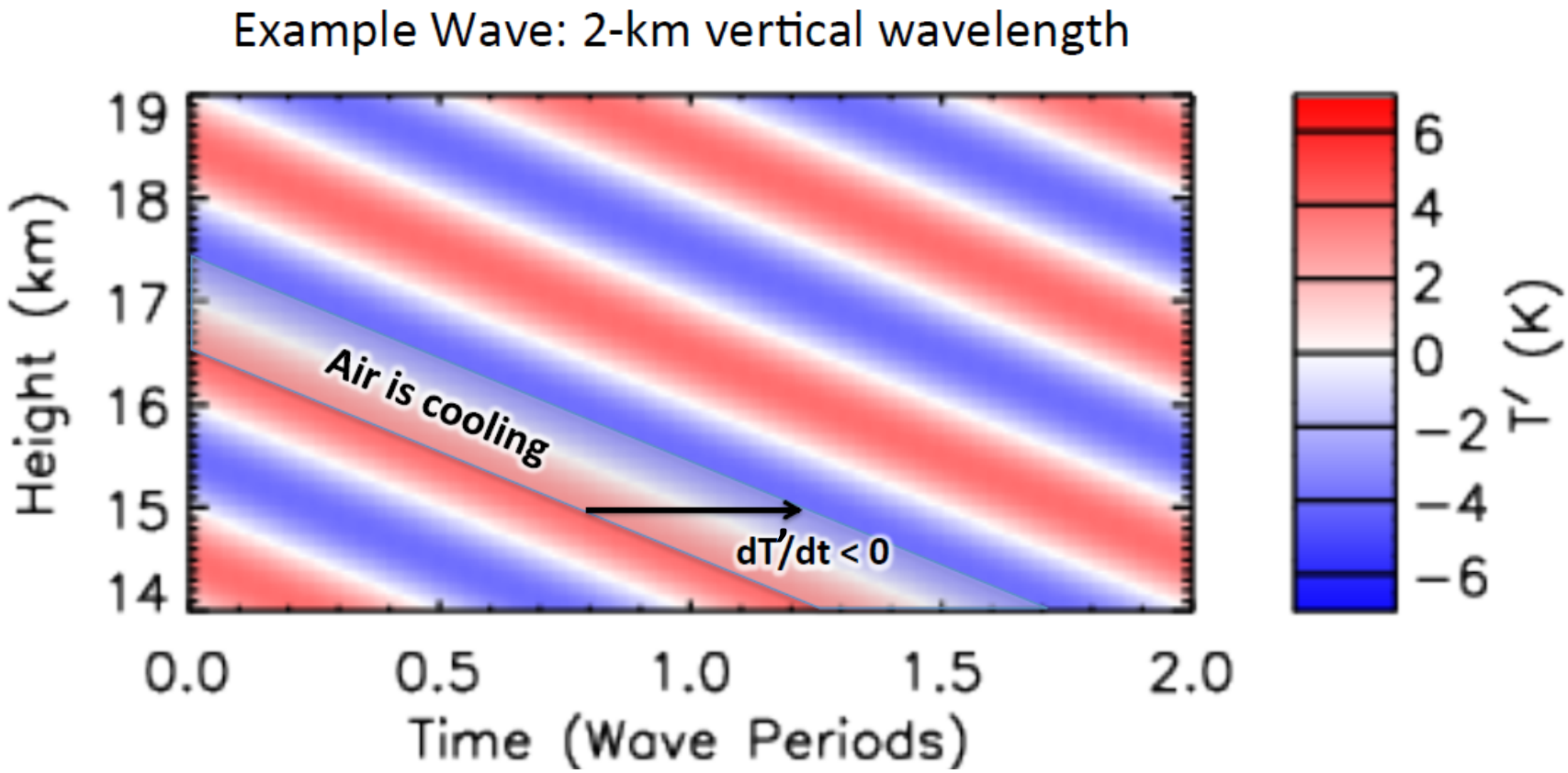


Wave-induced temperature anomaly pattern has downward propagation

Why more clouds at dT'/dz < 0 ?

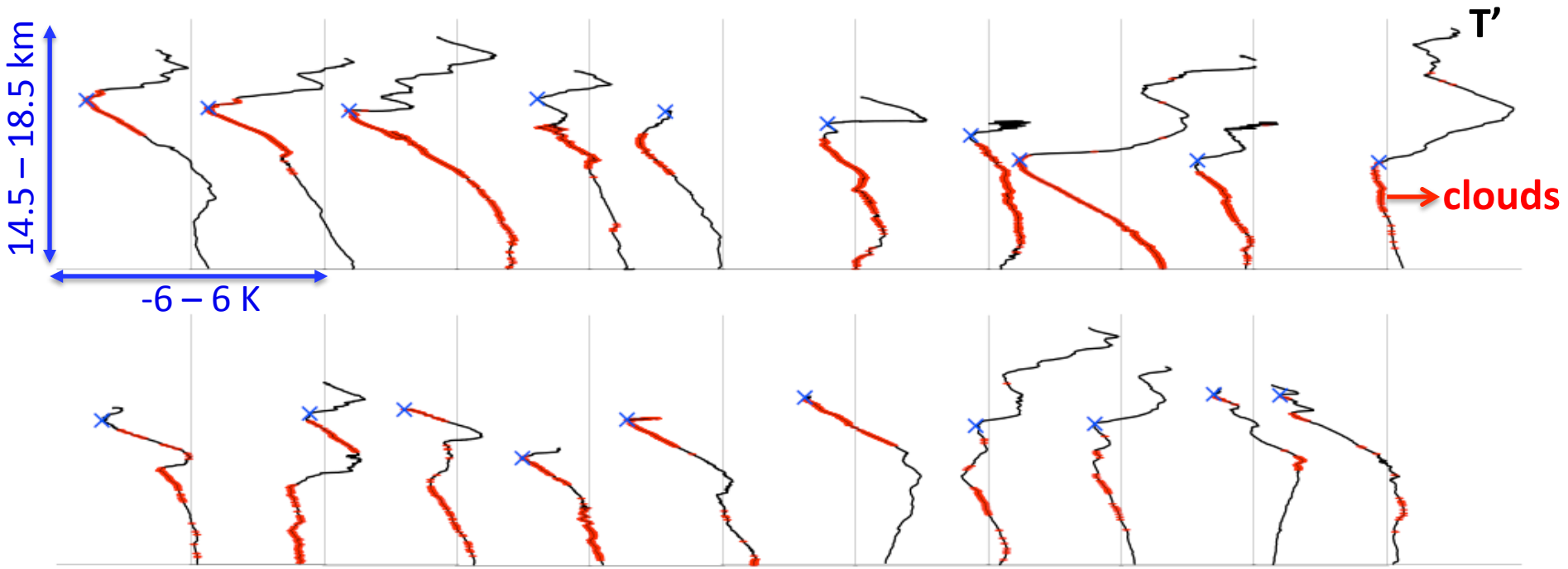


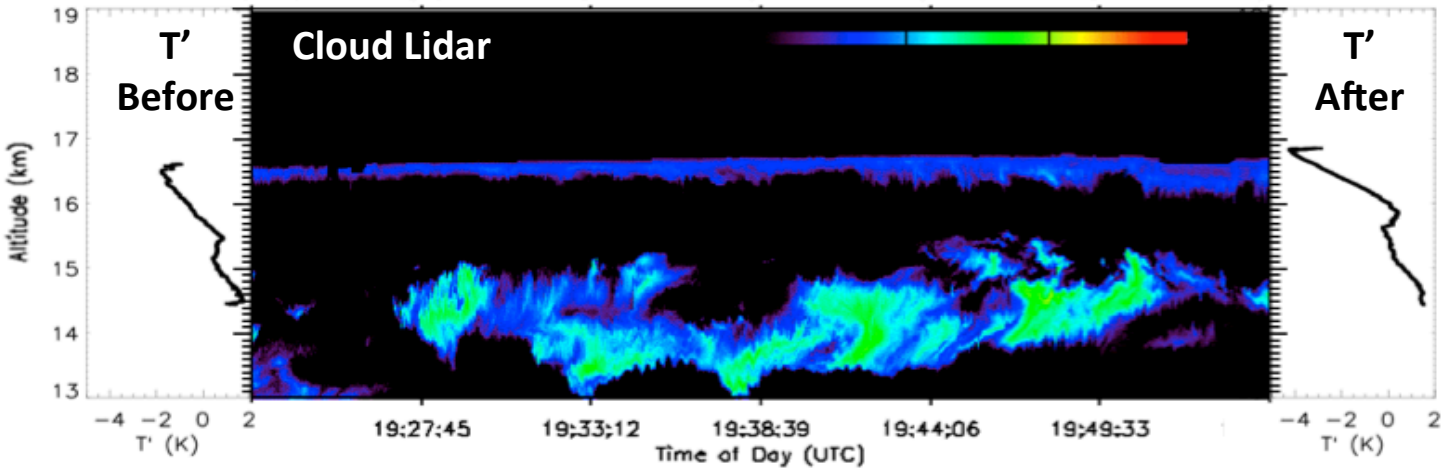
dT’/dz < 0 corresponds to dT’/dt < 0 (cooling of air)



The most favorable condition for cirrus is cold air with ongoing cooling

Cirrus clouds with T'<0 & dT'/dz<0





Conclusion

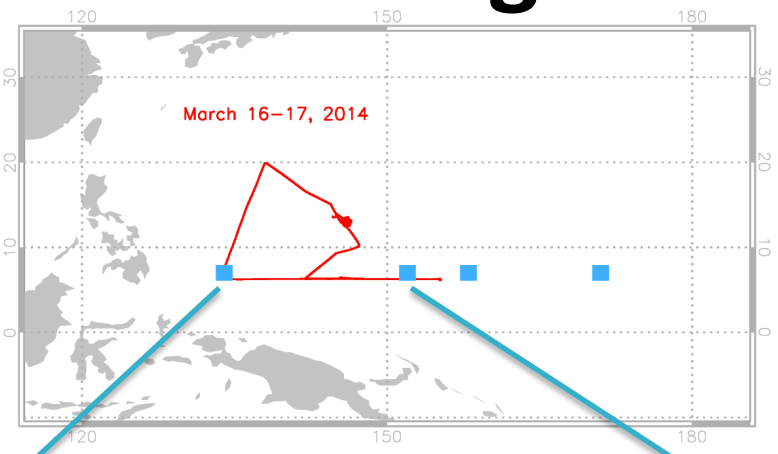
- Unprecedented airborne measurements reveal that waves are strong modulators of cirrus clouds away from deep convection. → A favorable condition is cold anomalies ($T'<0$) with ongoing cooling ($dT'/dt<0$).

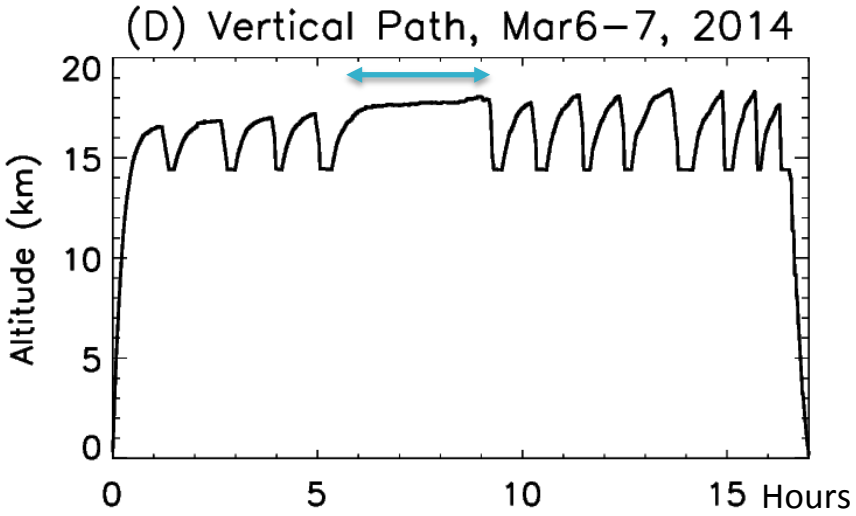
- Final dehydration before entering the stratosphere is dominantly affected by wave temperature anomalies.

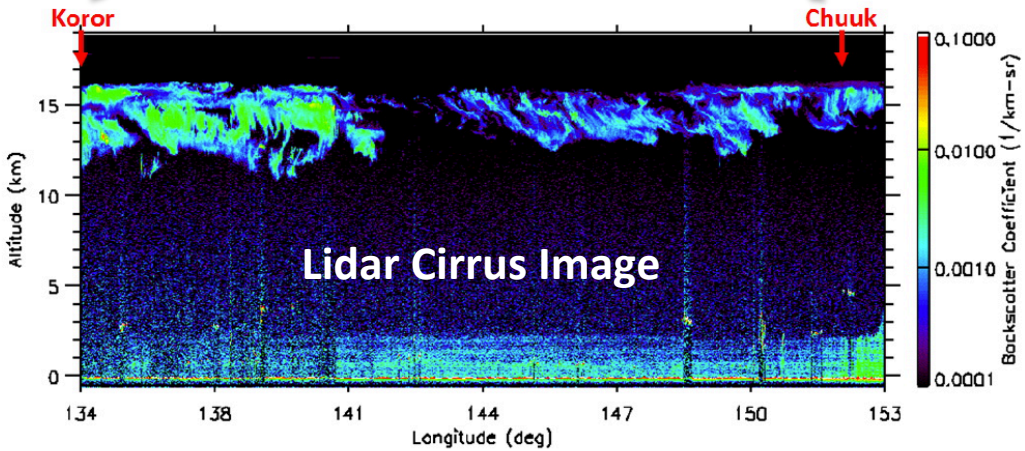
- Various vertical scales of cloud layers are associated with various scales of waves (even < 1km).

- 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.

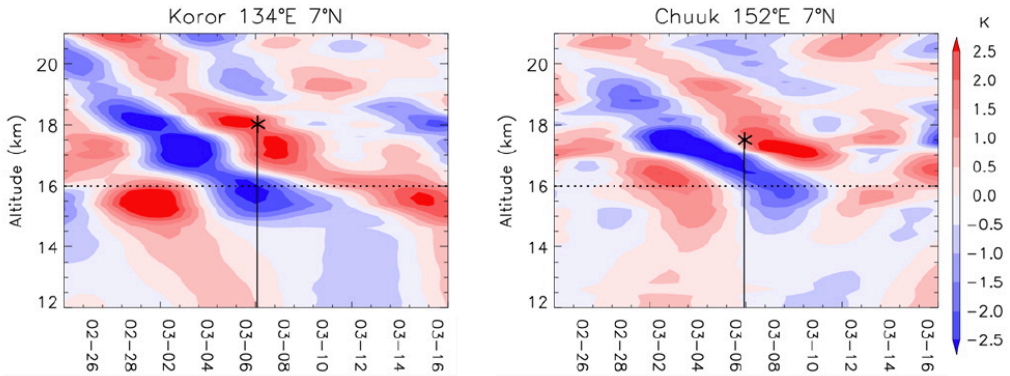
Wave Flight





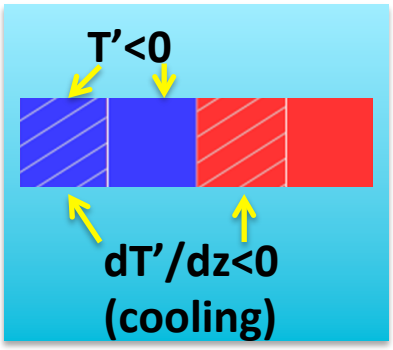


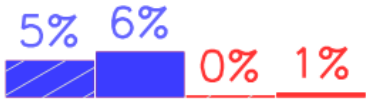
Thicker persistent cirrus with colder Kelvin waves & Thinner broken clouds with weaker Kelvin waves



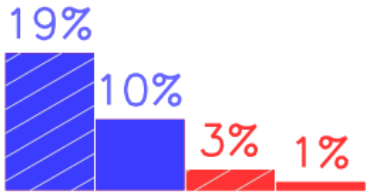
Radiosonde temperature perturbations by Kelvin waves

Statistics of ATTREX wave-cirrus relation

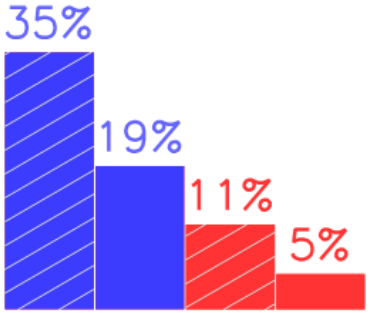




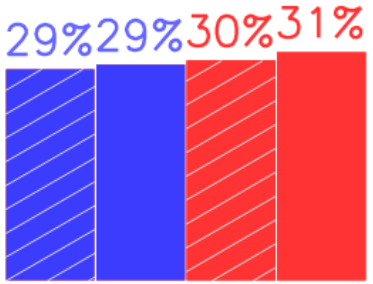
Central & Eastern



Western Upper



Western Lower (non-convective)



Western Lower (convective)

- 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.