Cirrus and Wave-induced Temperature Anomaly Relationships in ATTREX Measurements

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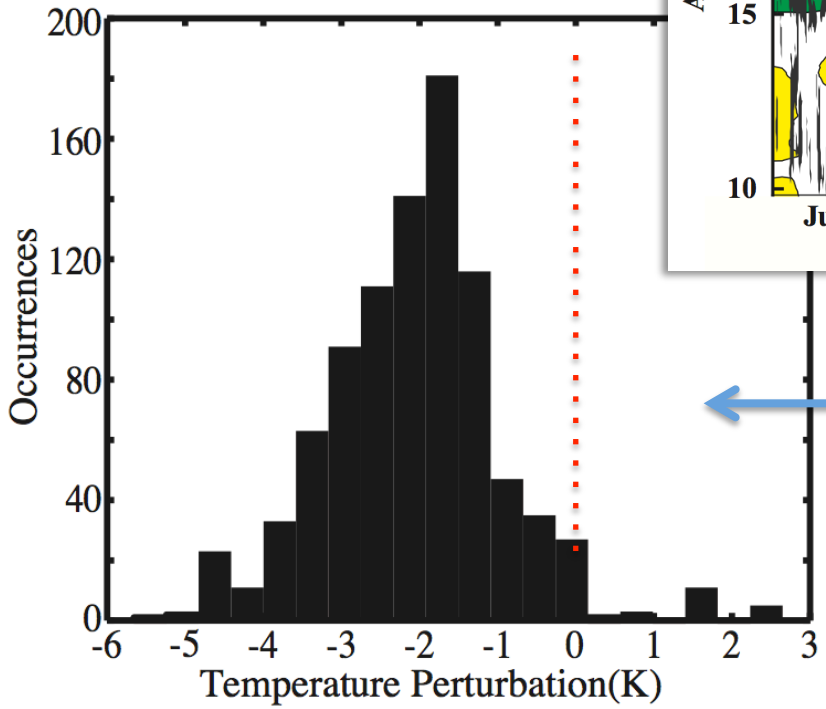
TTL Wave Effects on Cirrus

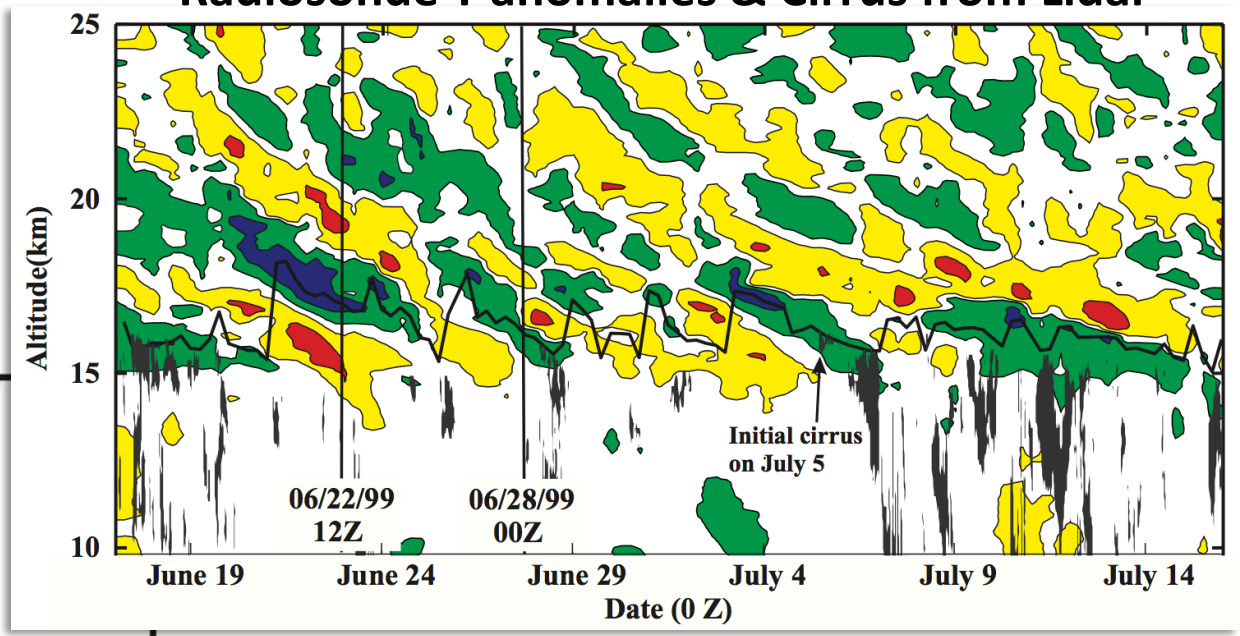
Boehm & Verlinde [2000]

Observations at Nauru (0.5°S,167°E) showed Kelvin wave modulation of cirrus.



30-day Intensive Observation Period

Radiosonde T anomalies & Cirrus from Lidar

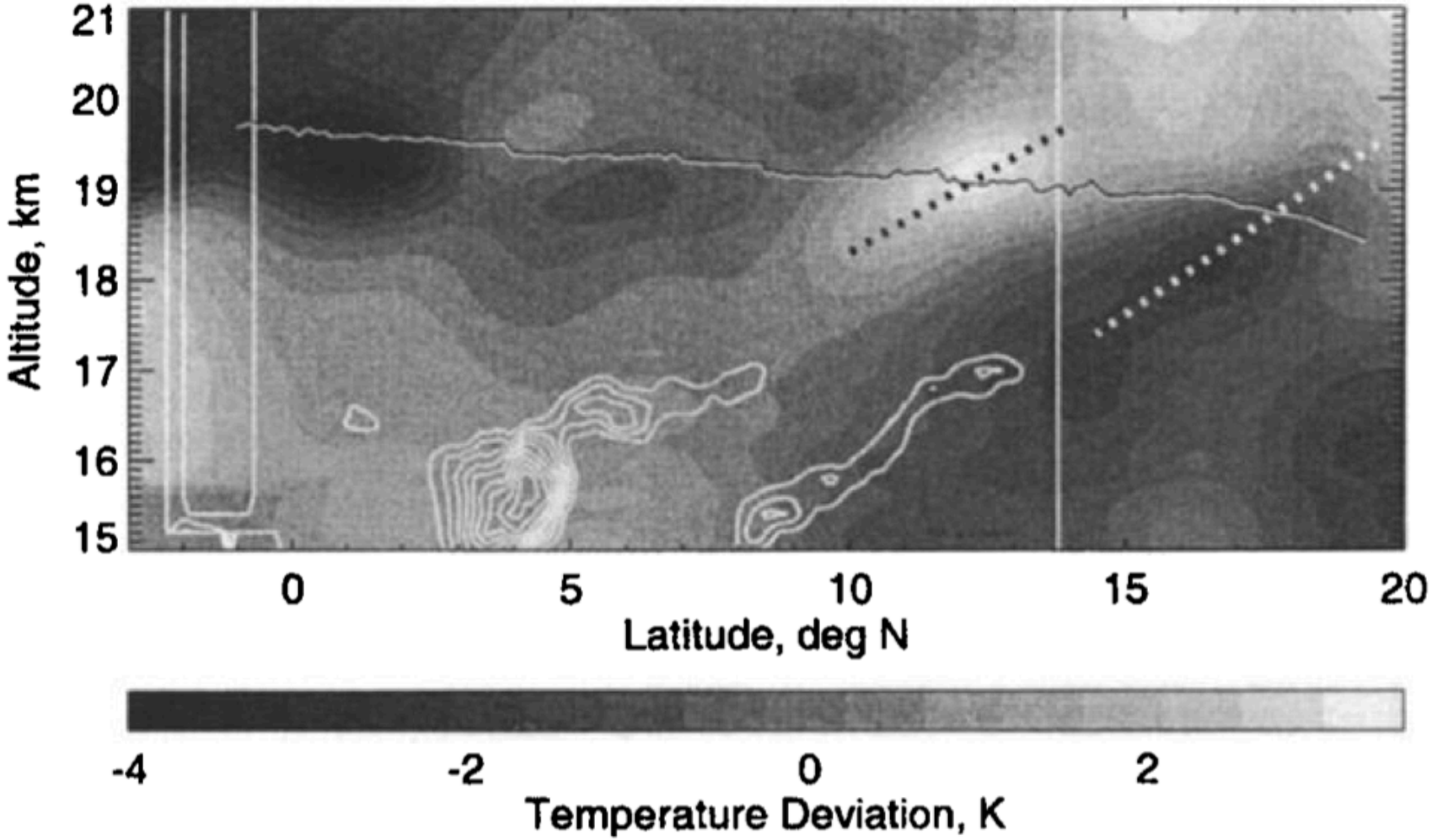


Cirrus occurrence above 15 km… almost exclusively in cold phases of tropical waves

TTL Wave Effects on Cirrus

Gravity Wave influencing TTL cirrus formation [Pfister et al. 2001]

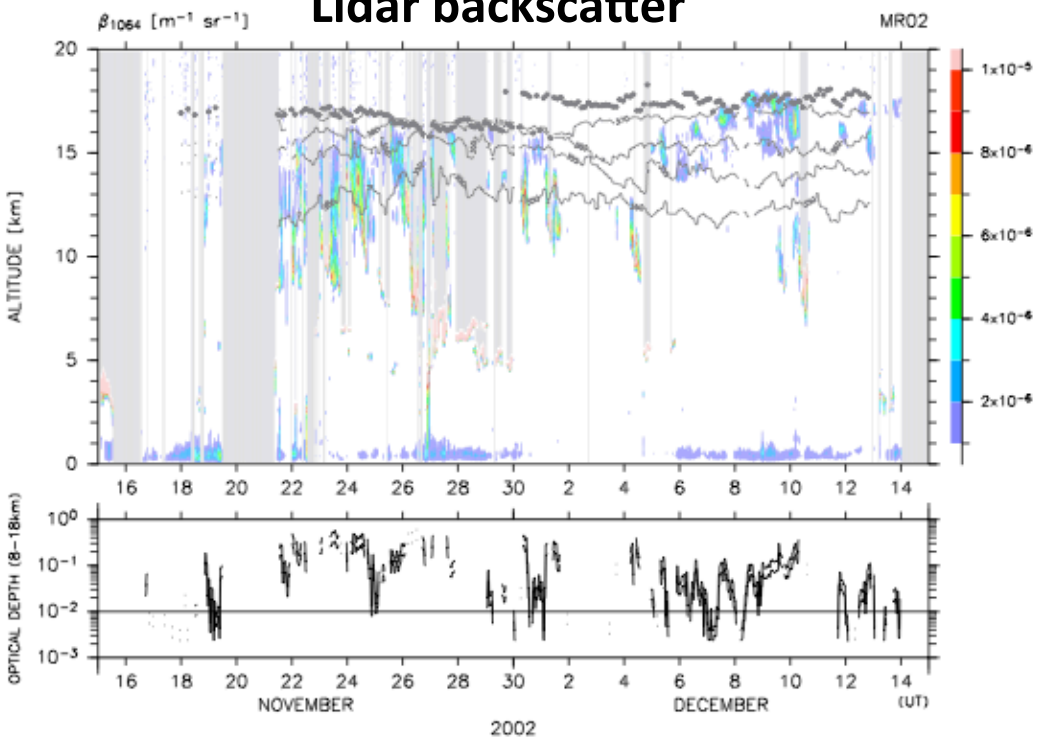
TOTE/VOTE DC-8 and ER-2: Cirrus and Temperature anomalies



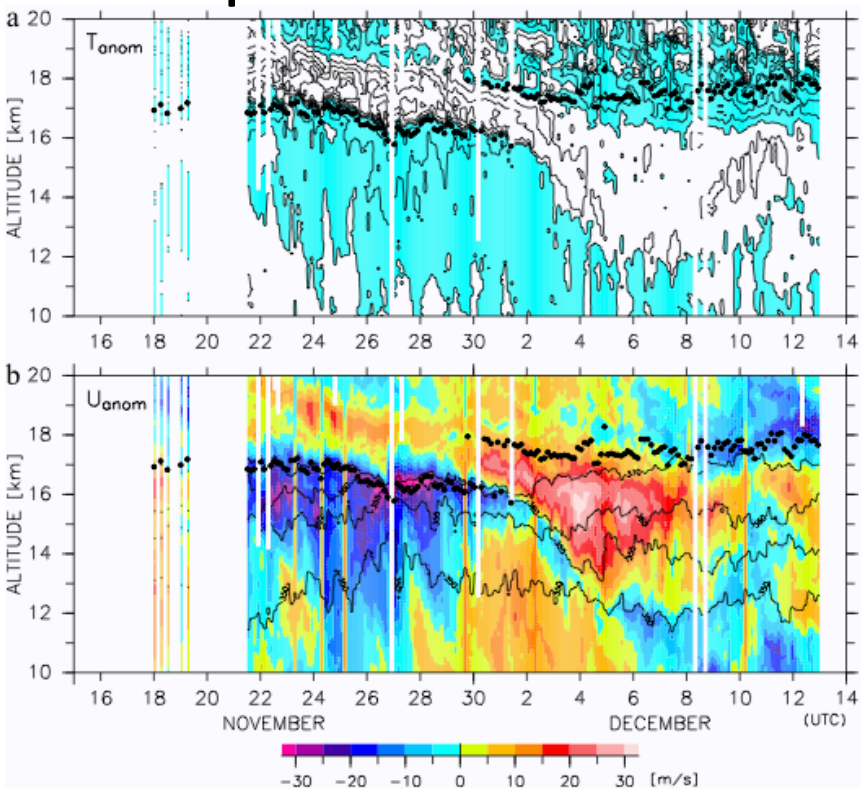
TTL Wave Effects on Cirrus

Kelvin Wave modulation of the tropopause and cirrus (2°N,138°E) [Fujiwara et al. 2009]

Lidar backscatter



Temperature and Zonal Wind



TTL Wave Effects on Cirrus

- Jensen et al. 1996 – waves & microphysics
- Jensen and Pfister, 2004 – wave parameterization for cirrus cloud studies
- Kim and Alexander, 2013 – new wave scheme for wave periods > diurnal in reanalyses.
- Wave effects on cirrus examined in many model studies, e.g. Wang et al. 2015, Schoeberl et al. 2014, Ueyama et al. 2015
- Higher frequencies and shorter vertical wave structures still missing in analyses, so parameterizations for unresolved waves are still needed. [e.g. Ji-Eun Kim's previous talk]
- Kim and Alexander, 2015 – wave effects on cold point T =1.6K → 1 ppmv decrease.

TTL Wave Effects on Cirrus

- *How common and widespread are these wave dynamical influences on cirrus occurrence?*

- We investigate wave influences on cirrus occurrence with measurements from the ATTREX campaign.

TTL Wave Effects on Cirrus

- Study uses all ATTREX data at 25N-12S
  - 2011 E-Pacific Oct-Nov
  - 2013 E-Pacific Feb-Mar
  - 2014 W-Pacific Feb-Mar

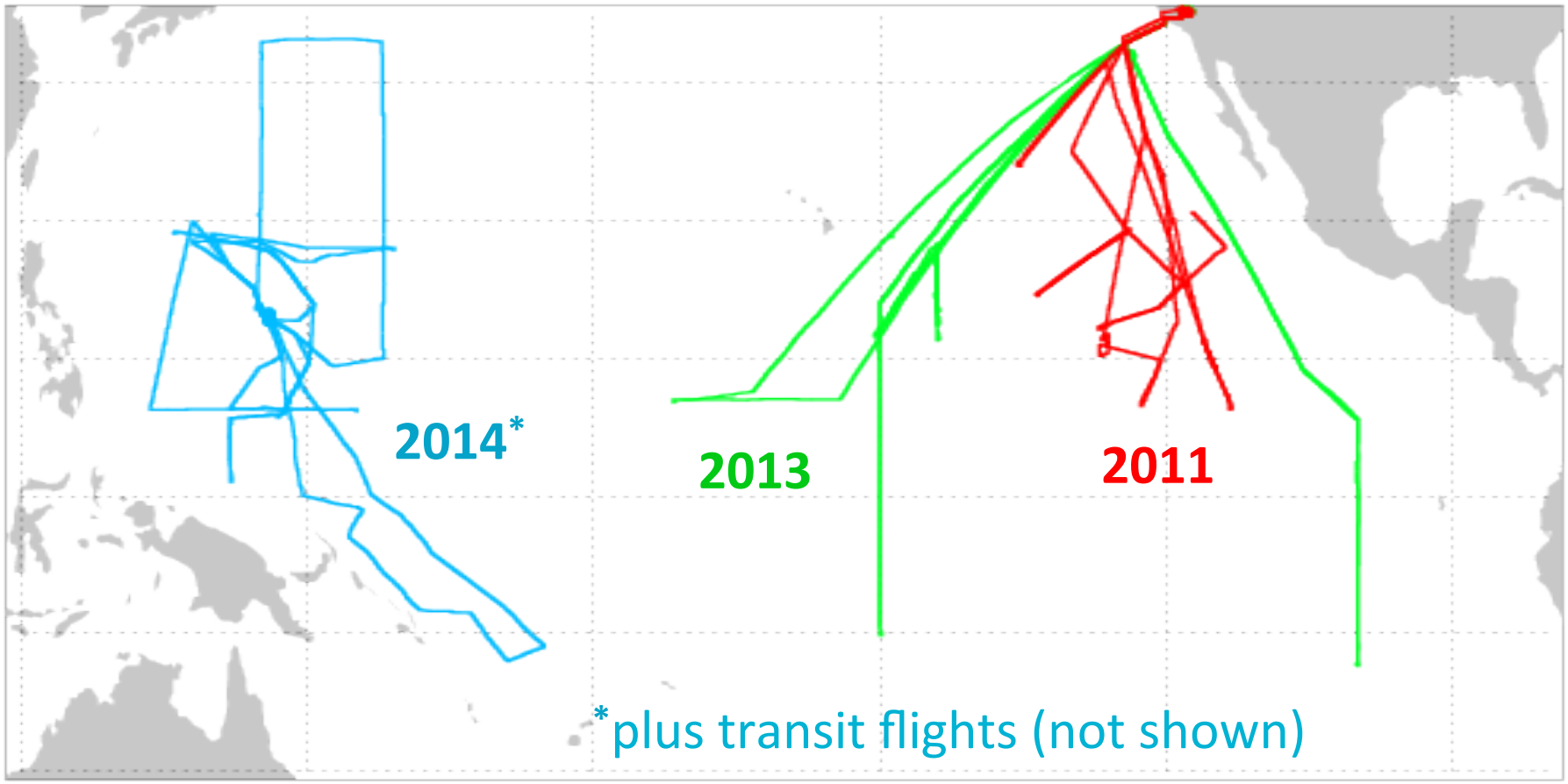
- Wave temperature perturbations (Tp) defined as residual after subtracting mean derived from GPS (Tp = GH MMS – GPS mean)
  - 30 days centered on each flight date
  - 10^{o}x5^{o} centered on each measurement location

  Tp anomalies are waves with periods < 30 days

TTL Wave Effects on Cirrus

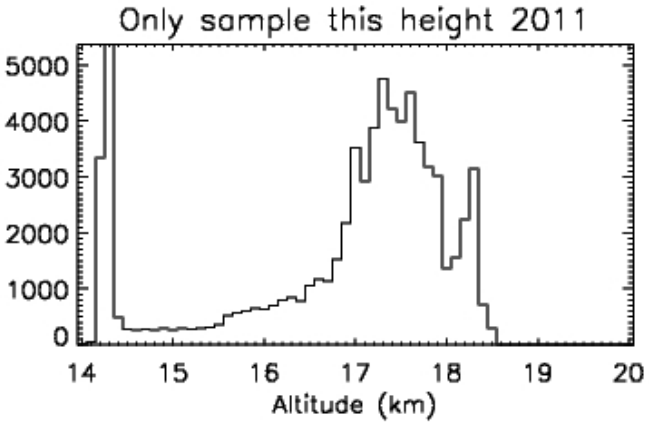
ATTREX measurements:

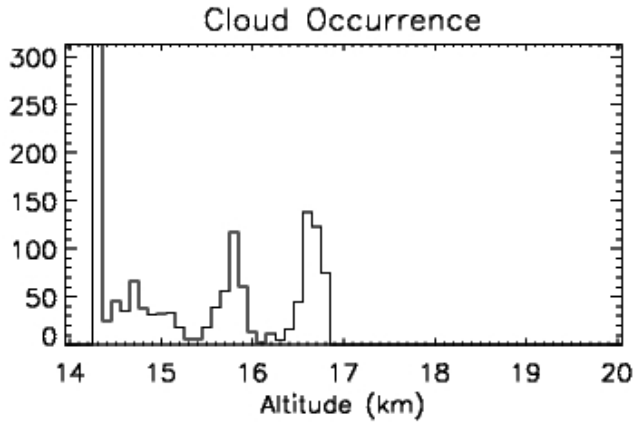
3 deployments of the Global Hawk aircraft



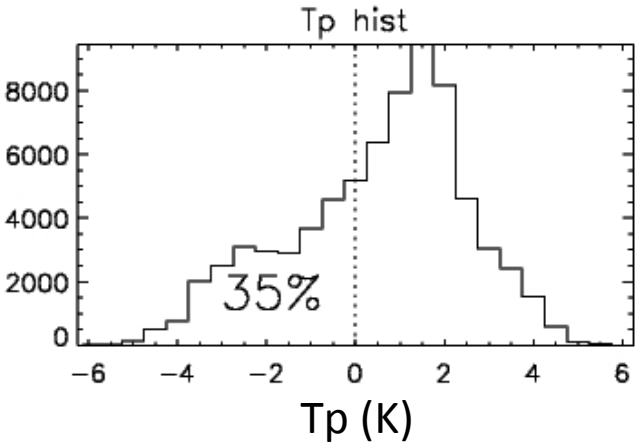
Oct-Nov 2011:

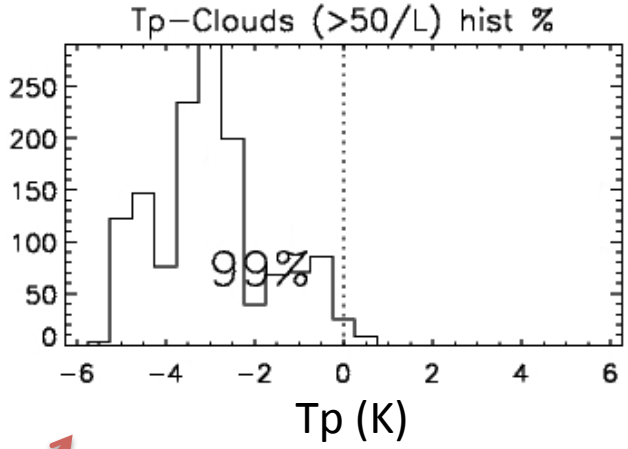
Measurements and # Cloud detections vs Altitude





Histograms:
Left: Tp Occurrence
Right: Cloud occurrence vs Tp

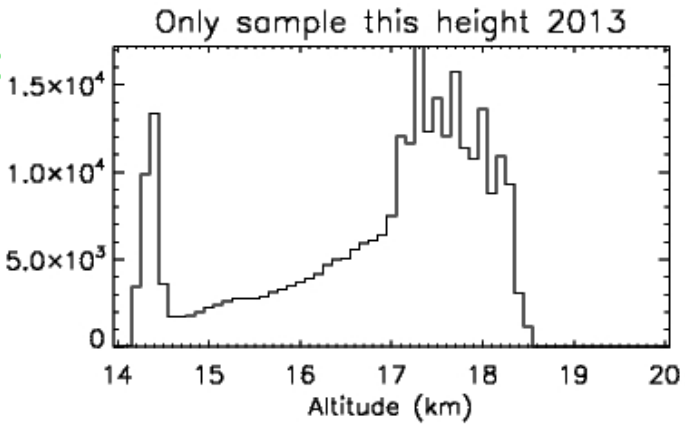


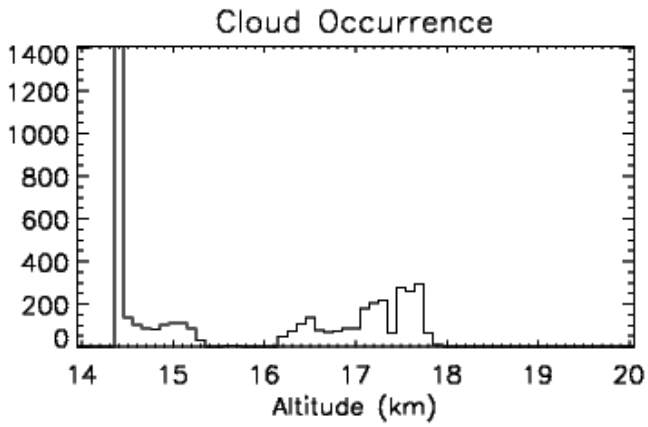


99% of clouds occur in cold wave anomalies!

Feb-Mar 2013:

Measurements and # Cloud detections vs Altitude





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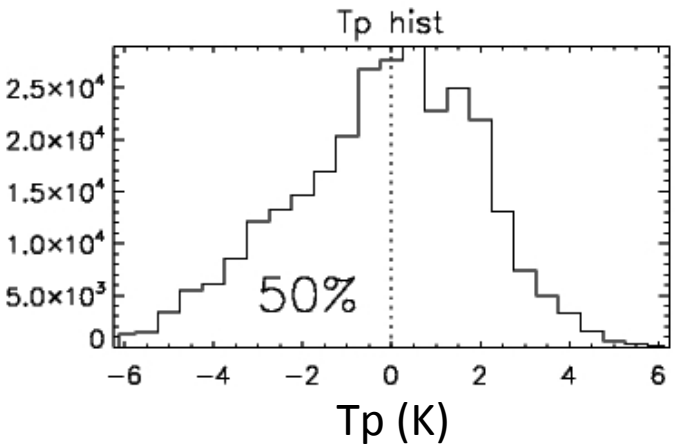
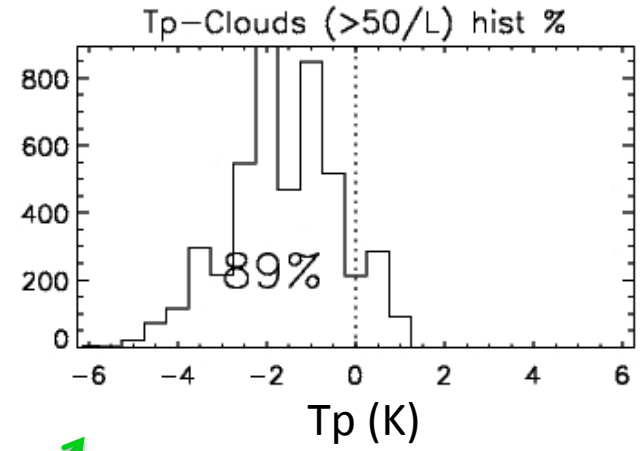
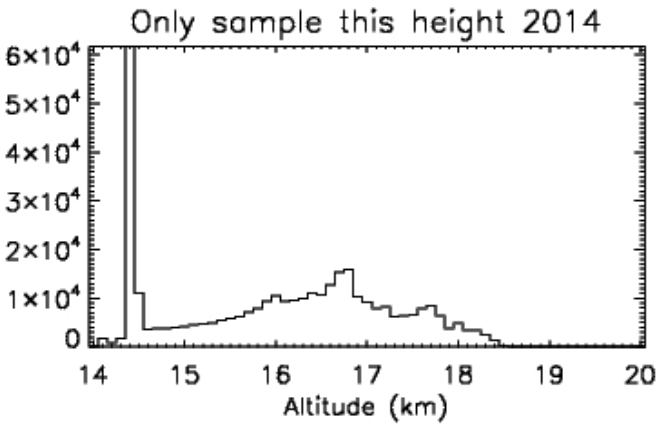


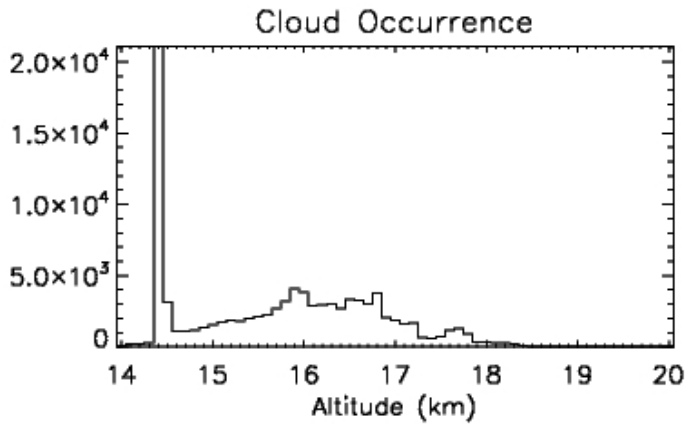


89% of clouds occur in cold wave anomalies!

Feb-Mar 2014:

Measurements and # Cloud detections vs Altitude





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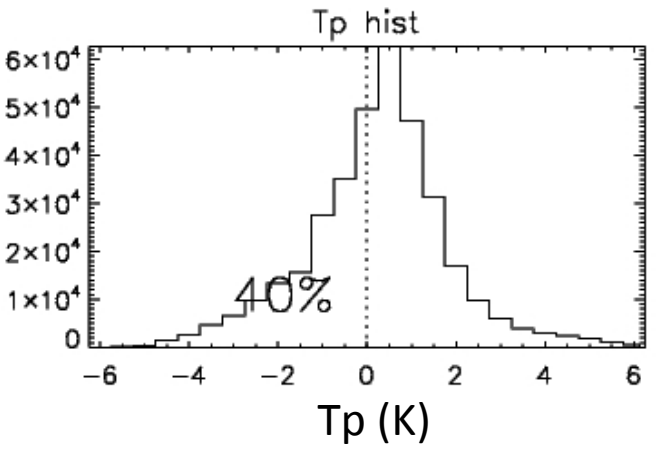
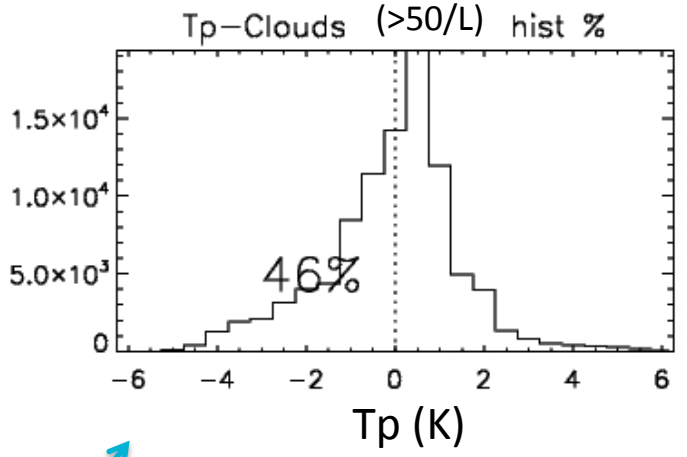
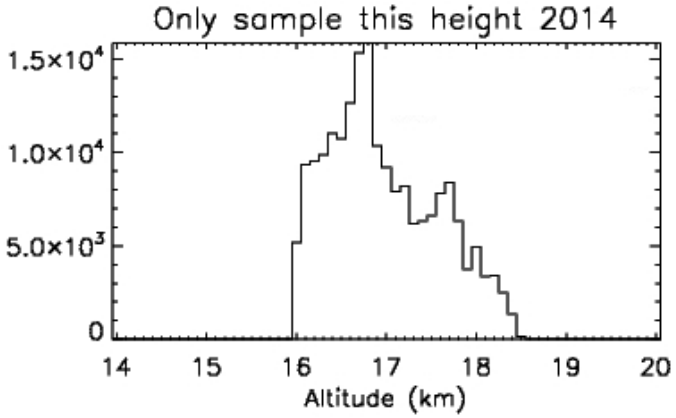


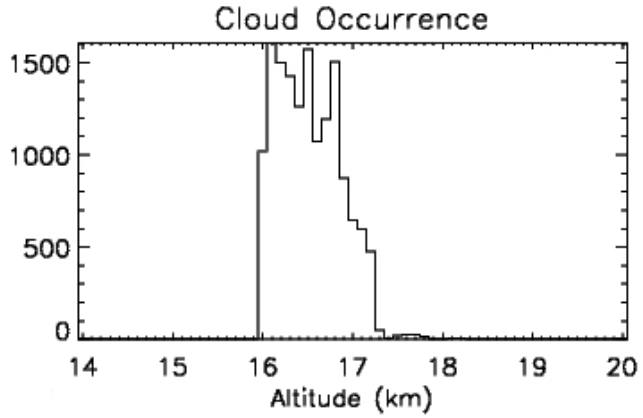


46% of clouds occur in cold wave anomalies – no influence of wave temperature anomalies evident

Feb-Mar 2014:

Measurements and # Cloud detections vs **Altitudes > 16km**





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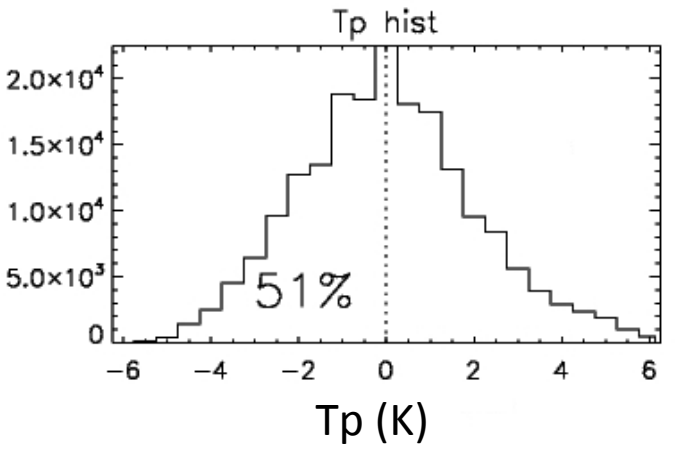
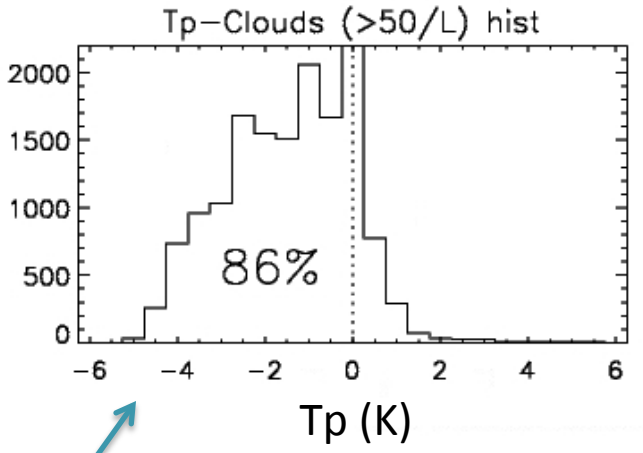




86% of clouds occur in cold wave anomalies – different effect above/below 16km

TTL Wave Effects on Cirrus

Question: Why is the 2014 data different? Why do the clouds below 16 km exhibit no clear association with wave temperature anomalies?

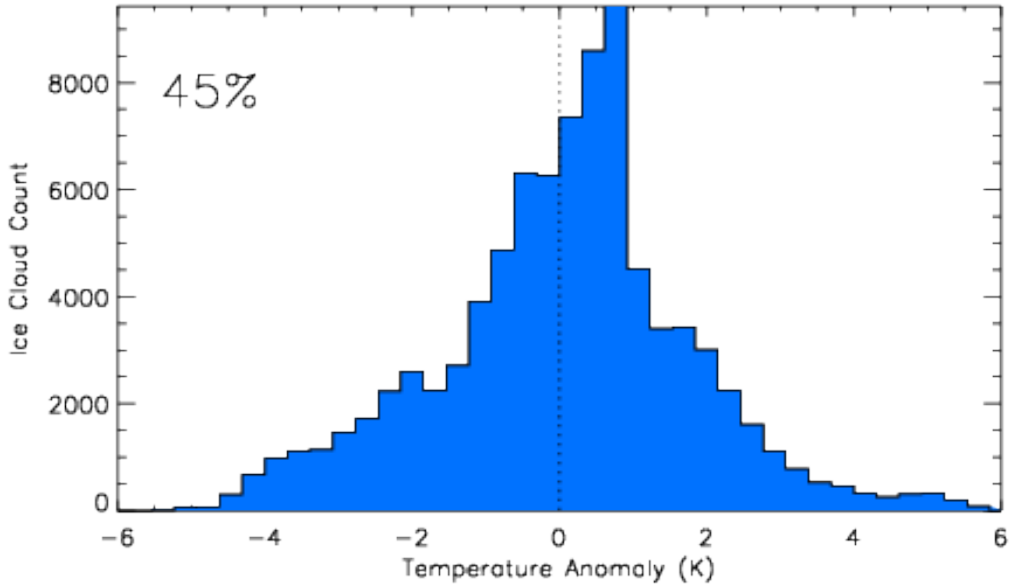
- Role of sedimentation?
- Role of convective moistening?
- Other effects?

Feb-Mar 2014:

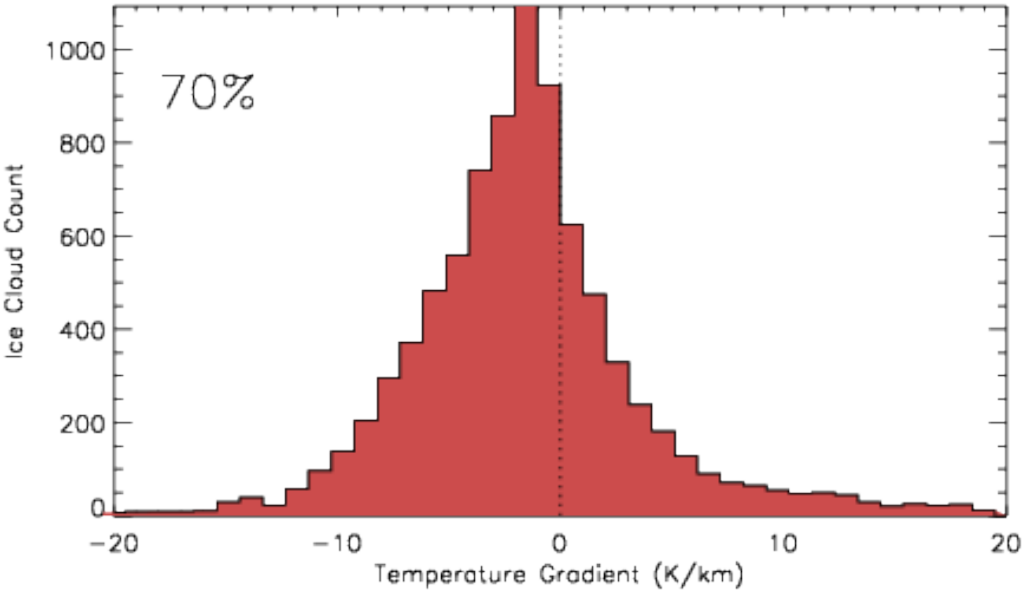
All TTL Altitudes

Dives only

Wave temperature **anomaly** influence on cloud occurrence



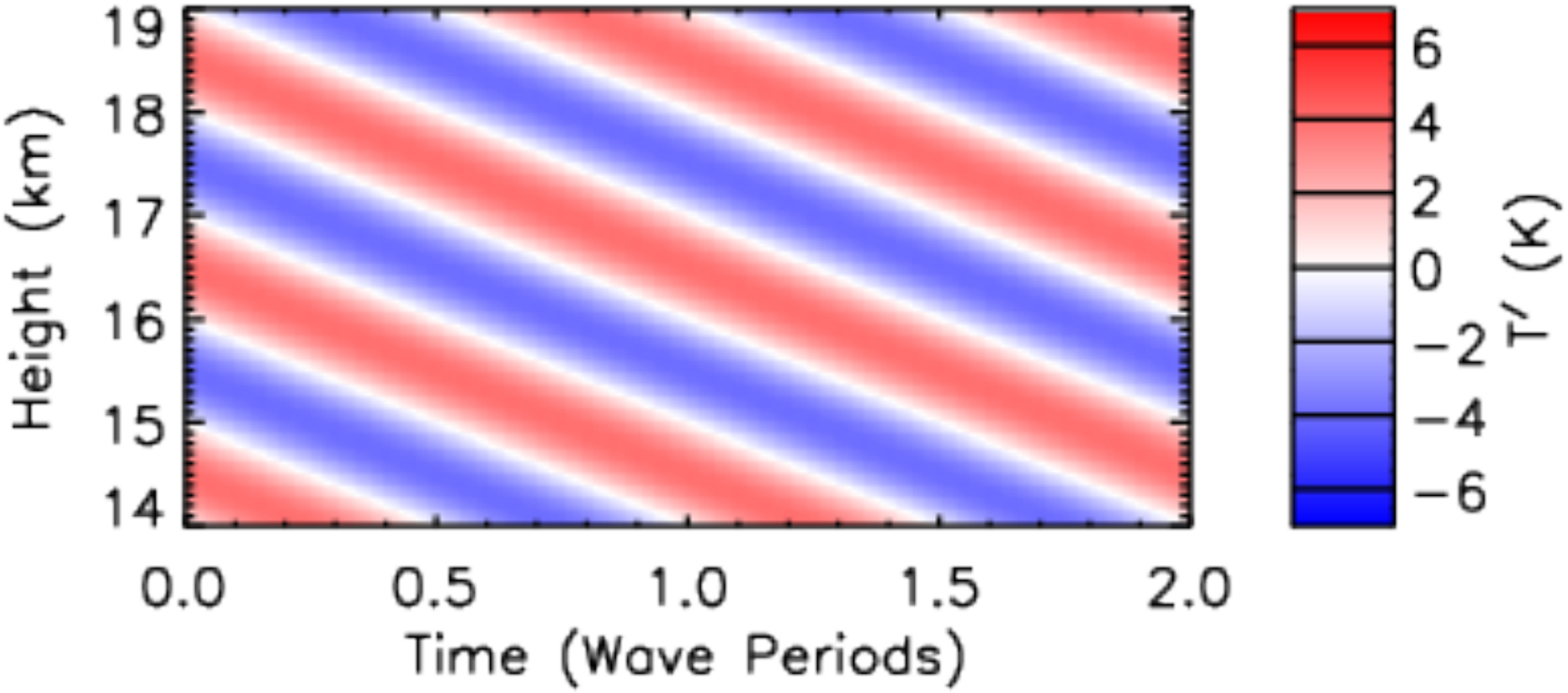
Wave temperature **gradient** influence on cloud occurrence



Most TTL cirrus (70%) occur where wave temperature *gradients* dT/dz < 0

TTL Wave Effects on Cirrus

Example Wave: 2-km vertical wavelength



TTL Wave Effects on Cirrus

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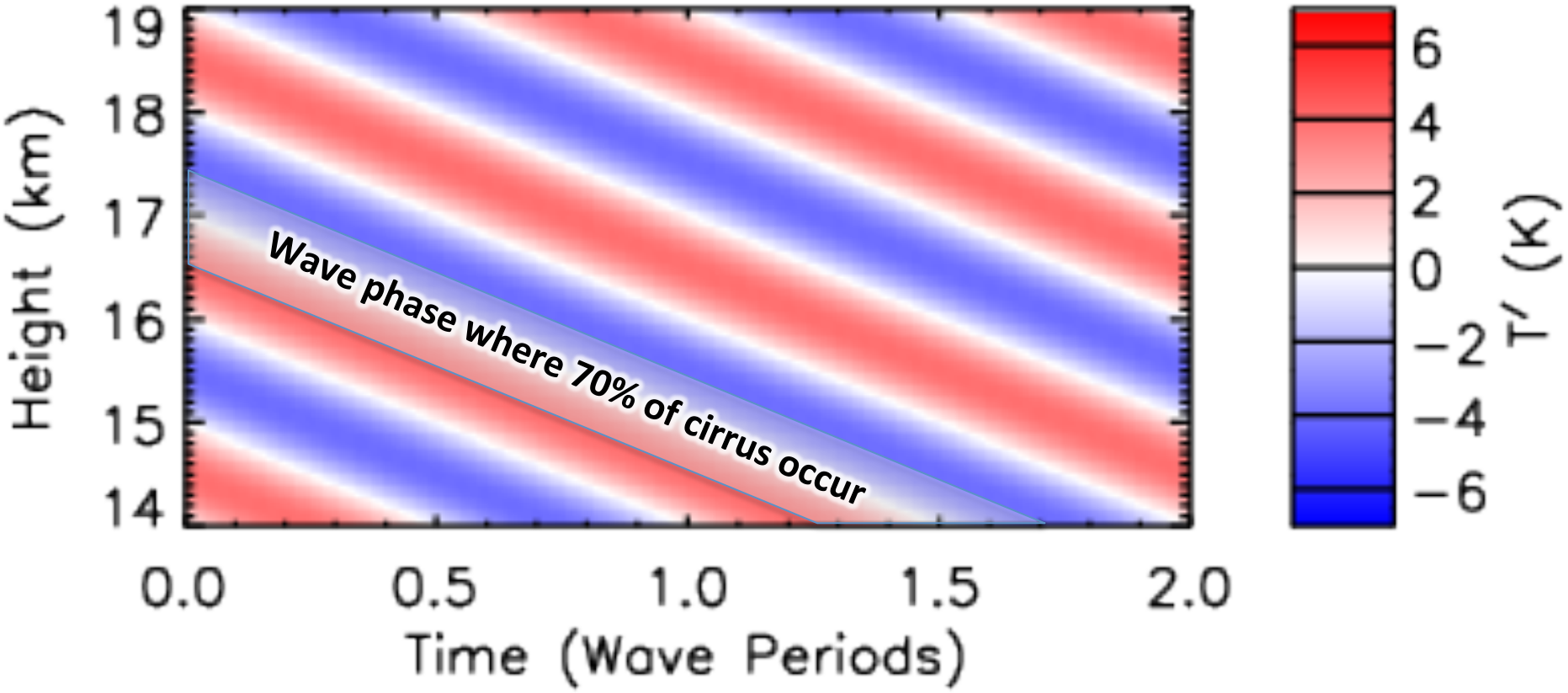

TTL Wave Effects on Cirrus

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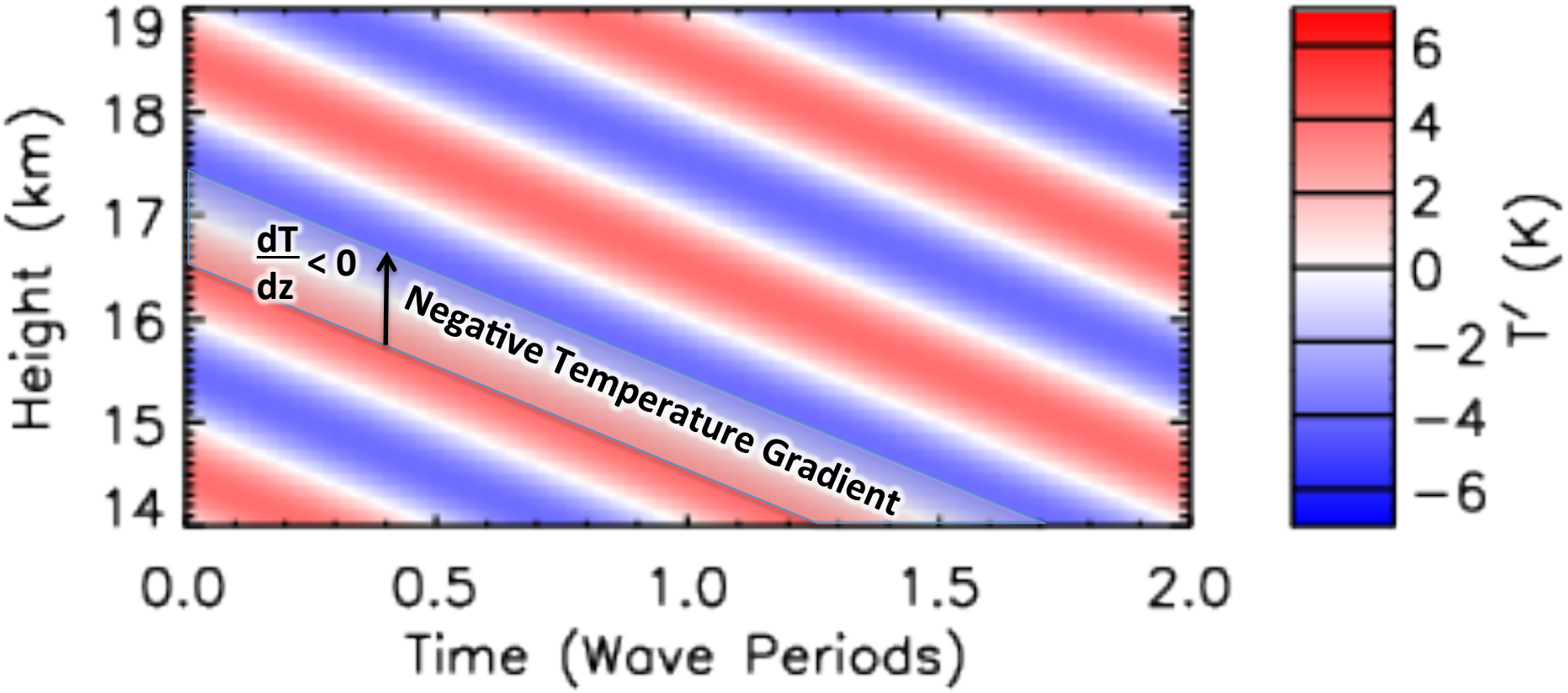

TTL Wave Effects on Cirrus

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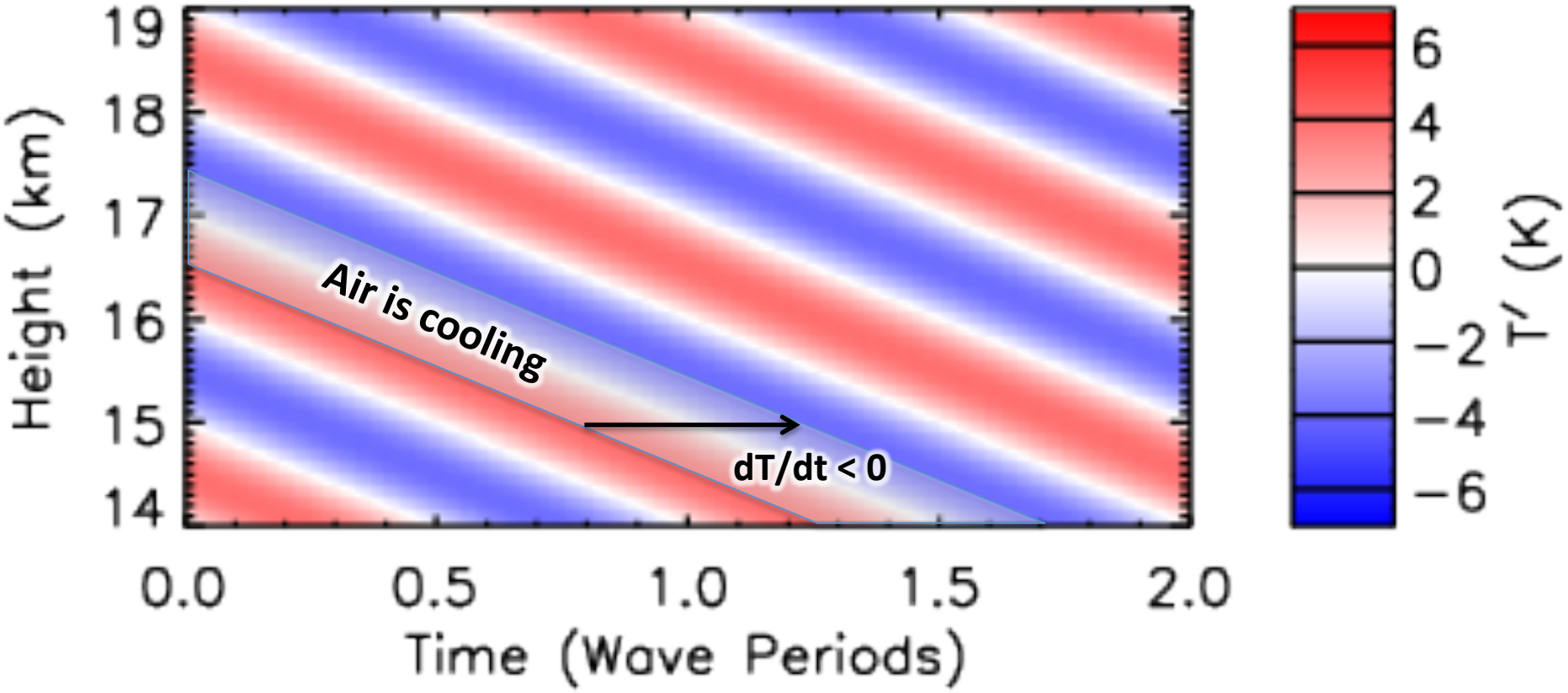
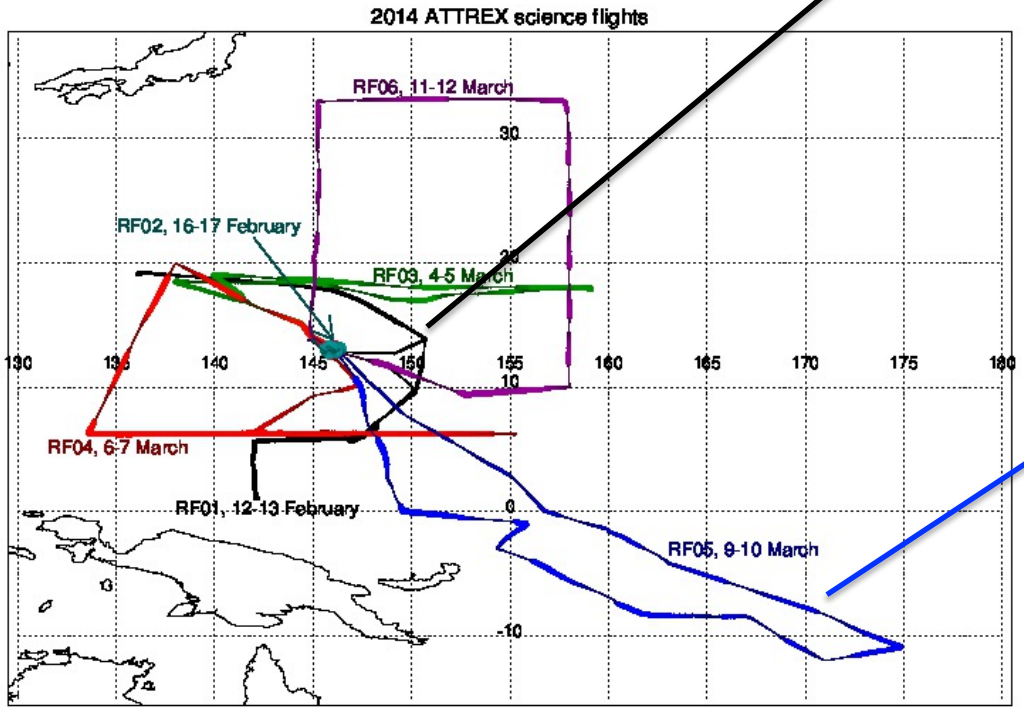


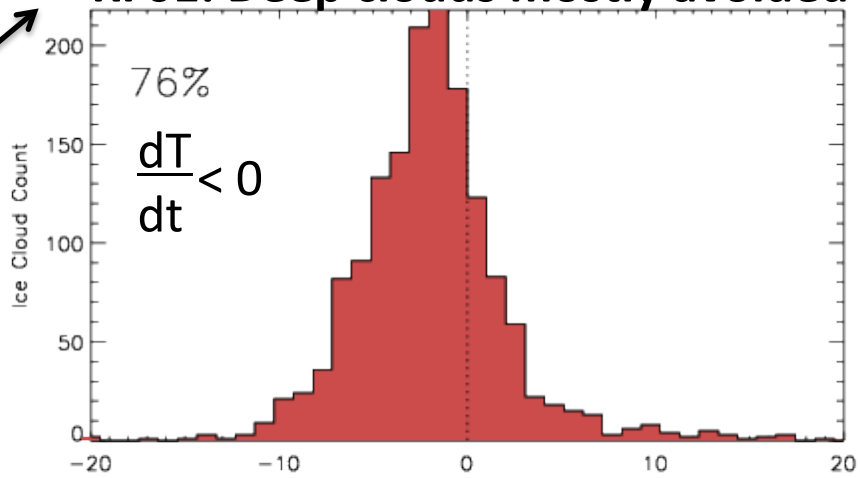
Most TTL cirrus occur where waves are cooling air parcels: dT/dt < 0

Effects of recent convection?

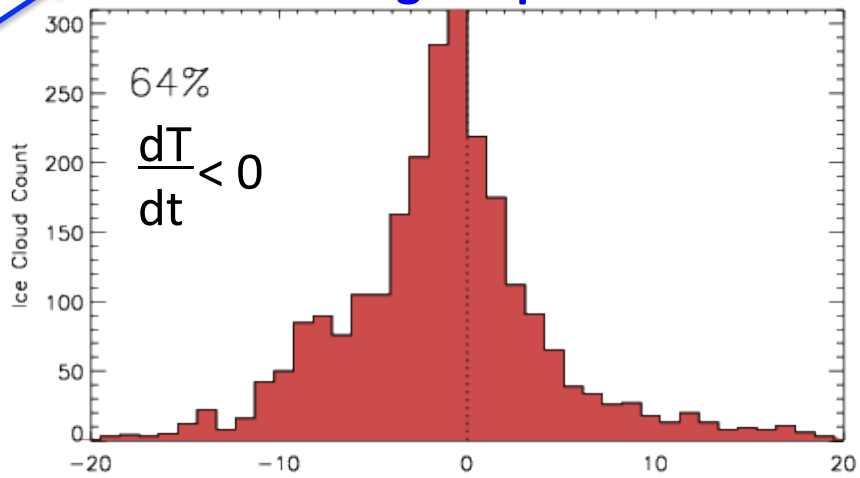
Compare two Guam flights



RF01: Deep clouds mostly avoided



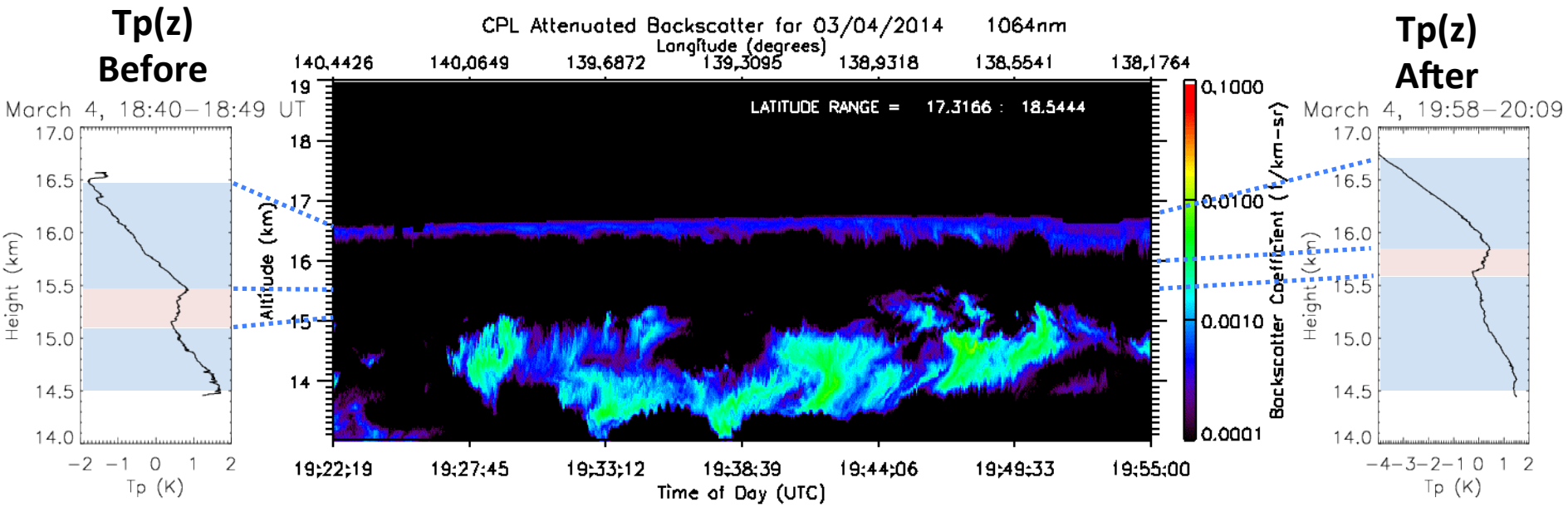
RF05: Skirting deep convection



Presence of recent convective moisture reduces influence of waves on high altitude cirrus.

TTL Wave Effects on Cirrus

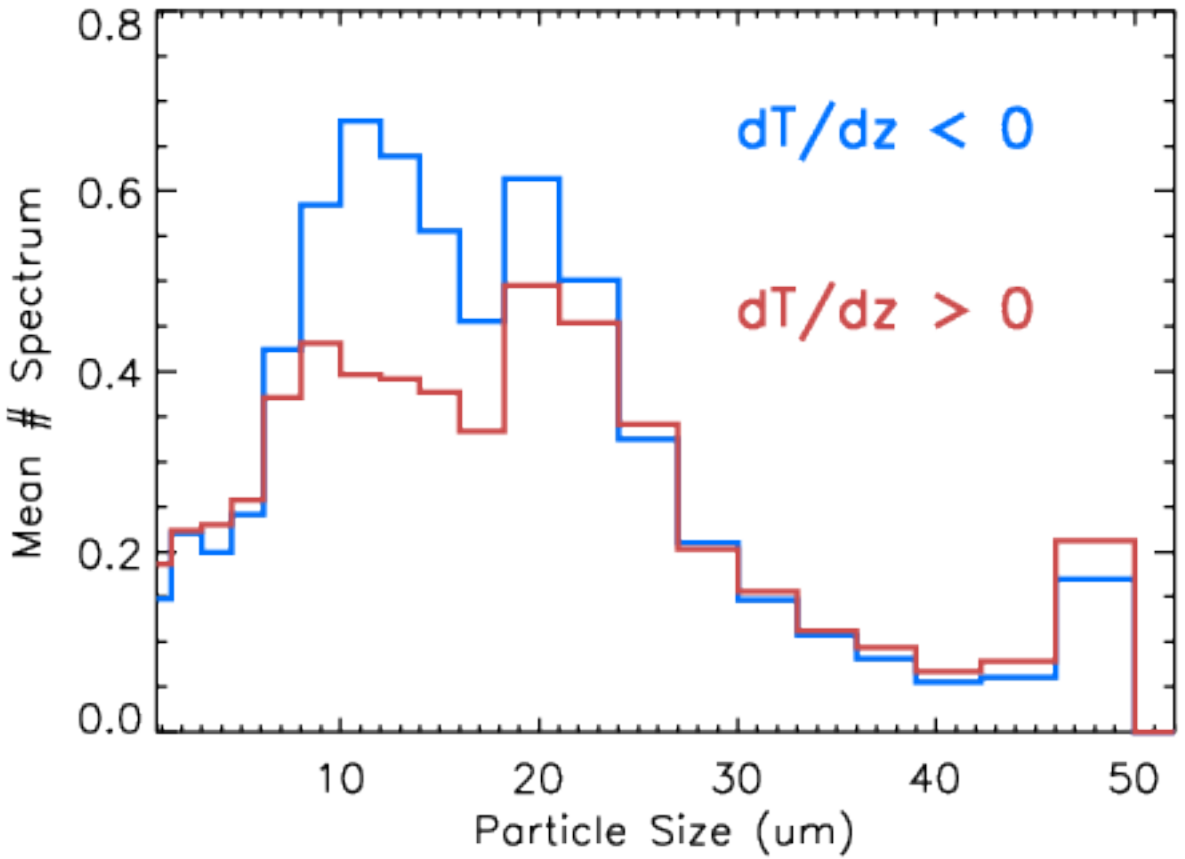
Wave cooling influence on cirrus layers in Cloud Physics Lidar



- Wave **cooling** layer (dT/dz < 0) marks upper cirrus layer
- Wave **warming** layer (dT/dz > 0) indicates the gap region

TTL Wave Effects on Cirrus

- Effect of wave **cooling** or **warming** on mean size distribution from FCDP
- Shows enhancement of smaller particles < 20 μm in air undergoing wave cooling.



TTL Wave Effects on Cirrus

Conclusions

- 2011 and 2013 ATTREX measurements show ubiquitous influence of waves on cirrus occurrence.
- 2014 measurements indicate 70% of cloud detections occur in the cooling phase of wave anomalies, where $dT'/dt < 0$.
- 2014 data indicate other influences are also important for explaining cirrus occurrence (convective moisture, sedimentation).