Cirrus and Wave-induced Temperature Anomaly Relationships in ATTREX Measurements

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Boehm & Verlinde [2000]
Observations at Nauru (0.5°S,167°E) showed Kelvin wave modulation of cirrus.

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]
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• 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.
• 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.
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• 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 ($T_p$) defined as residual after subtracting mean derived from GPS
  ($T_p = GH \text{ MMS} - \text{GPS mean}$)
  ➢ 30 days centered on each flight date
  ➢ $10^\circ \times 5^\circ$ centered on each measurement location

$T_p$ anomalies are waves with periods $< 30$ days
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ATTREX measurements:
3 deployments of the Global Hawk aircraft

*plus transit flights (not shown)
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

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

89% of clouds occur in cold wave anomalies!
Feb-Mar 2014:  
# Measurements and # Cloud detections vs Altitude

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

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

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

86% of clouds occur in cold wave anomalies – different effect above/below 16km
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 \( dT/dz < 0 \)
Example Wave: 2-km vertical wavelength
Example Wave: 2-km vertical wavelength

Wave phase where 70% of cirrus occur
TTL Wave Effects on Cirrus

Example Wave: 2-km vertical wavelength

\( \frac{dT}{dz} < 0 \)  
Negative Temperature Gradient
Example Wave: 2-km vertical wavelength

Most TTL cirrus occur where waves are cooling air parcels: \( \frac{dT}{dt} < 0 \)
Effects of recent convection? 
Compare two Guam flights

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

RF01: Deep clouds mostly avoided
76%
dT < 0
dt

Temperature Gradient (K/km)

RF05: Skirting deep convection
64%
dT < 0
dt

Temperature Gradient (K/km)
• Wave **cooling** layer \((dT/dz < 0)\) marks upper cirrus layer
• Wave **warming** layer \((dT/dz > 0)\) indicates the gap region
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- Effect of wave cooling or warming on mean size distribution from FCDP
- Shows enhancement of smaller particles < 20 \( \mu m \) in air undergoing wave cooling.
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).