Tropical Tropopause Transition Layer Cirrus as Represented by CALIPSO Lidar Observations

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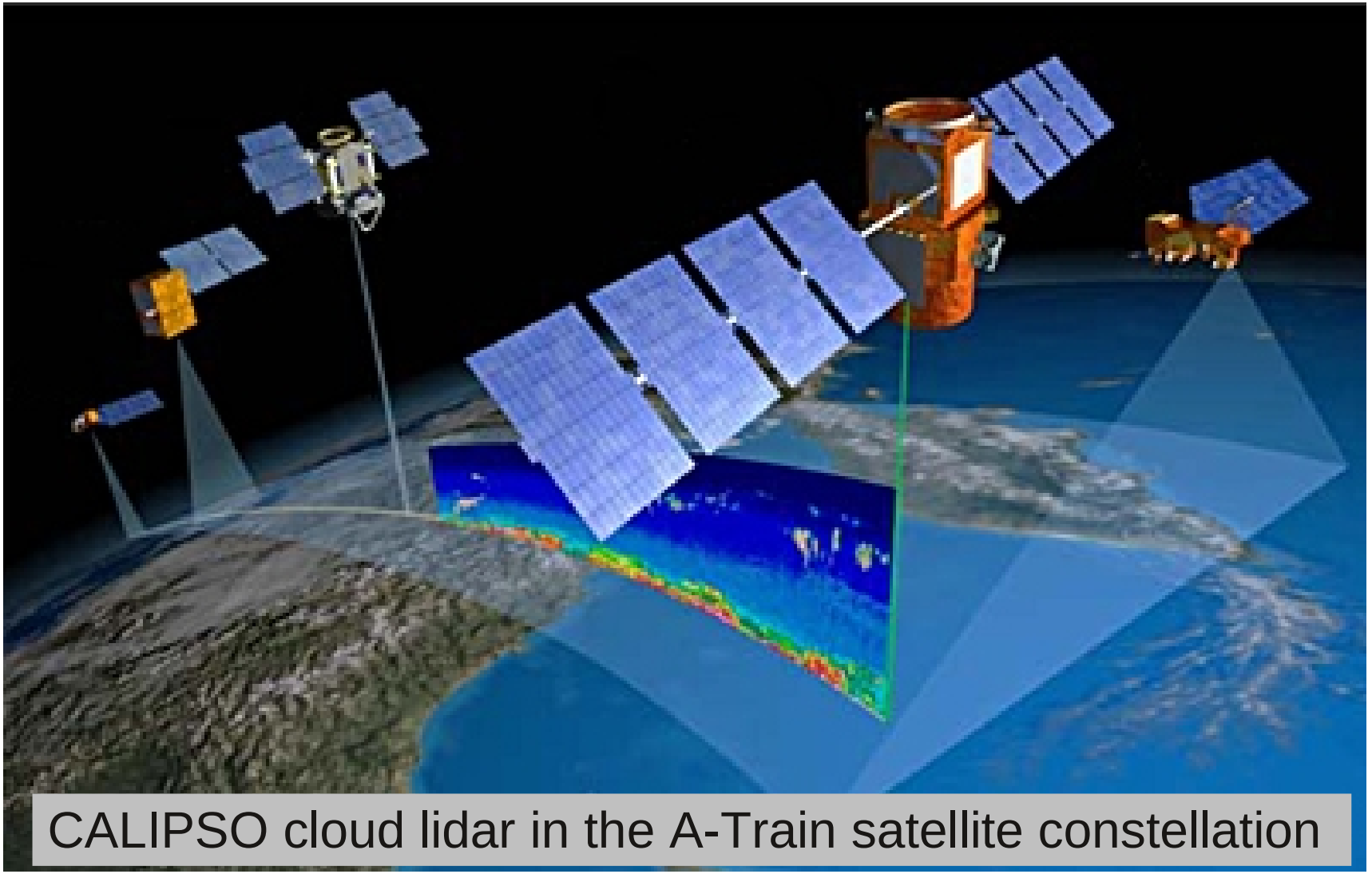
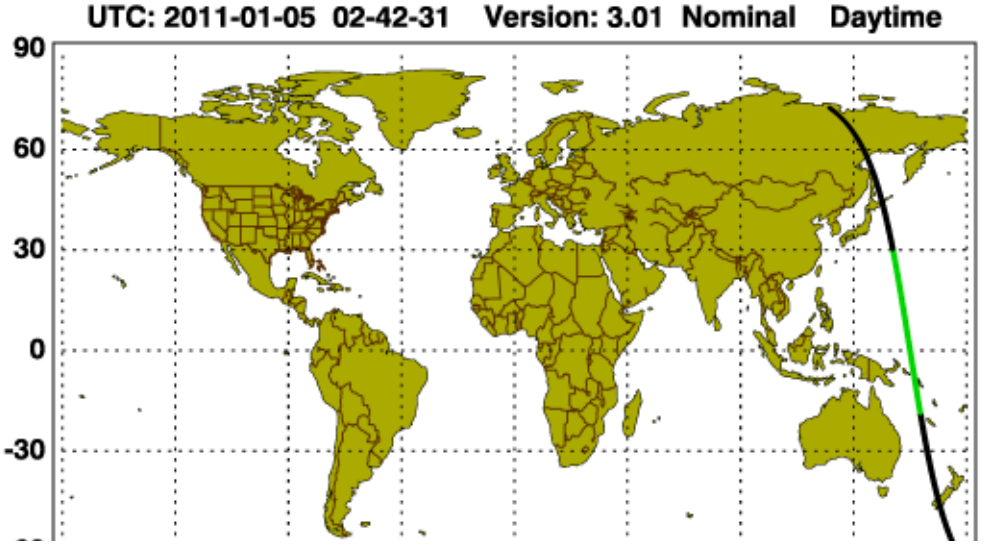


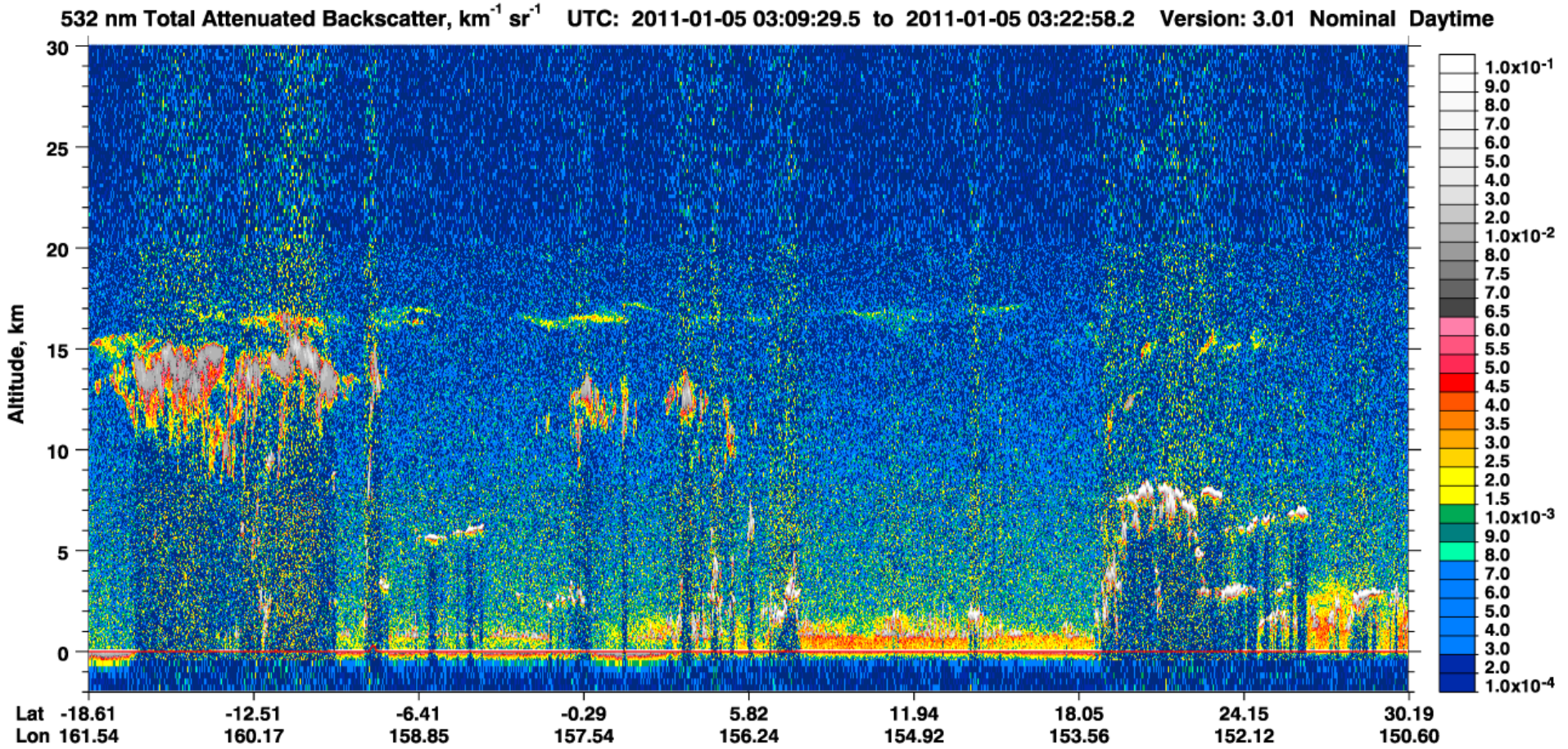
CALIPSO cloud lidar in the A-Train satellite constellation

CALIPSO Data

Example from the Western Pacific

Backscatter shows thin layers in the TTL

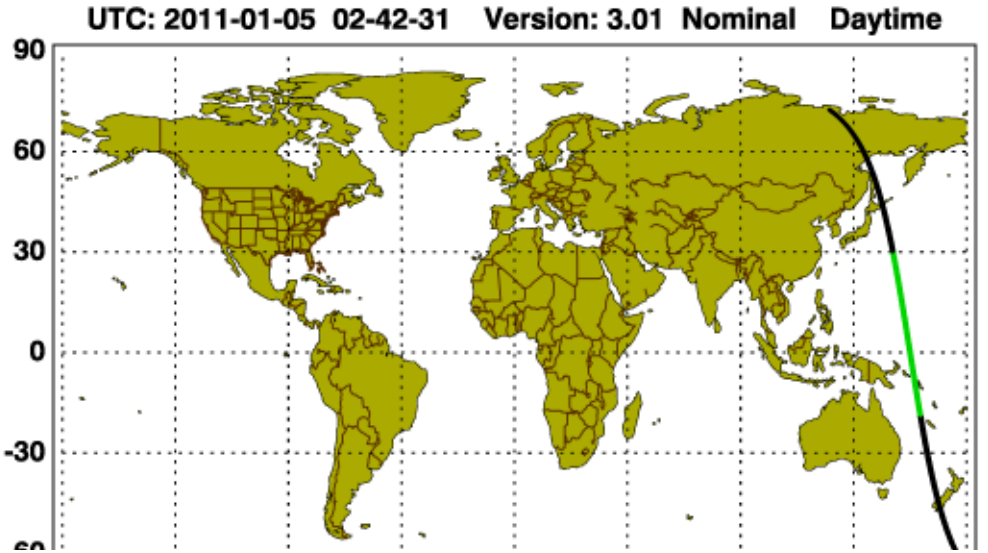


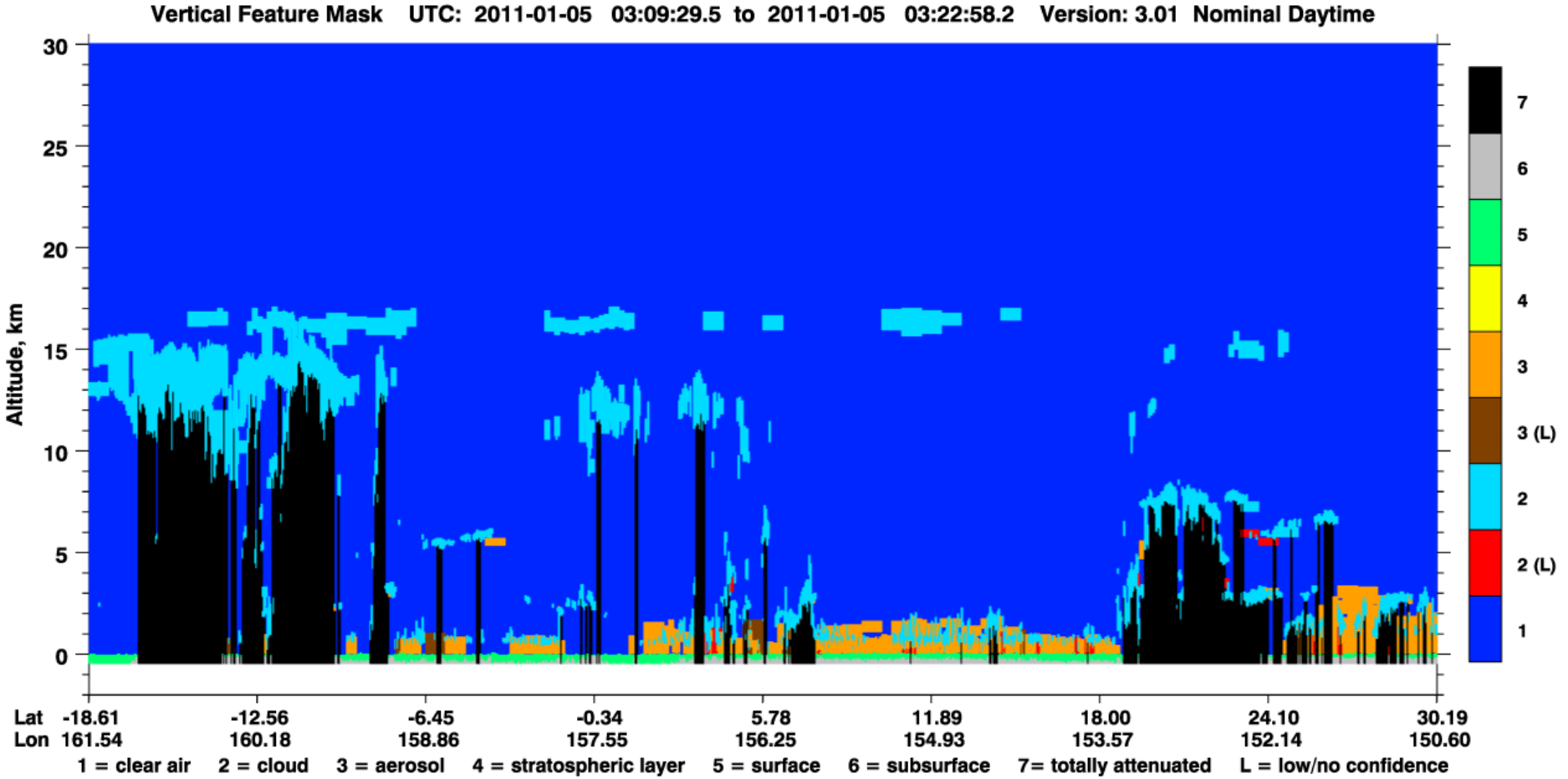


CALIPSO Data

Example from the Western Pacific

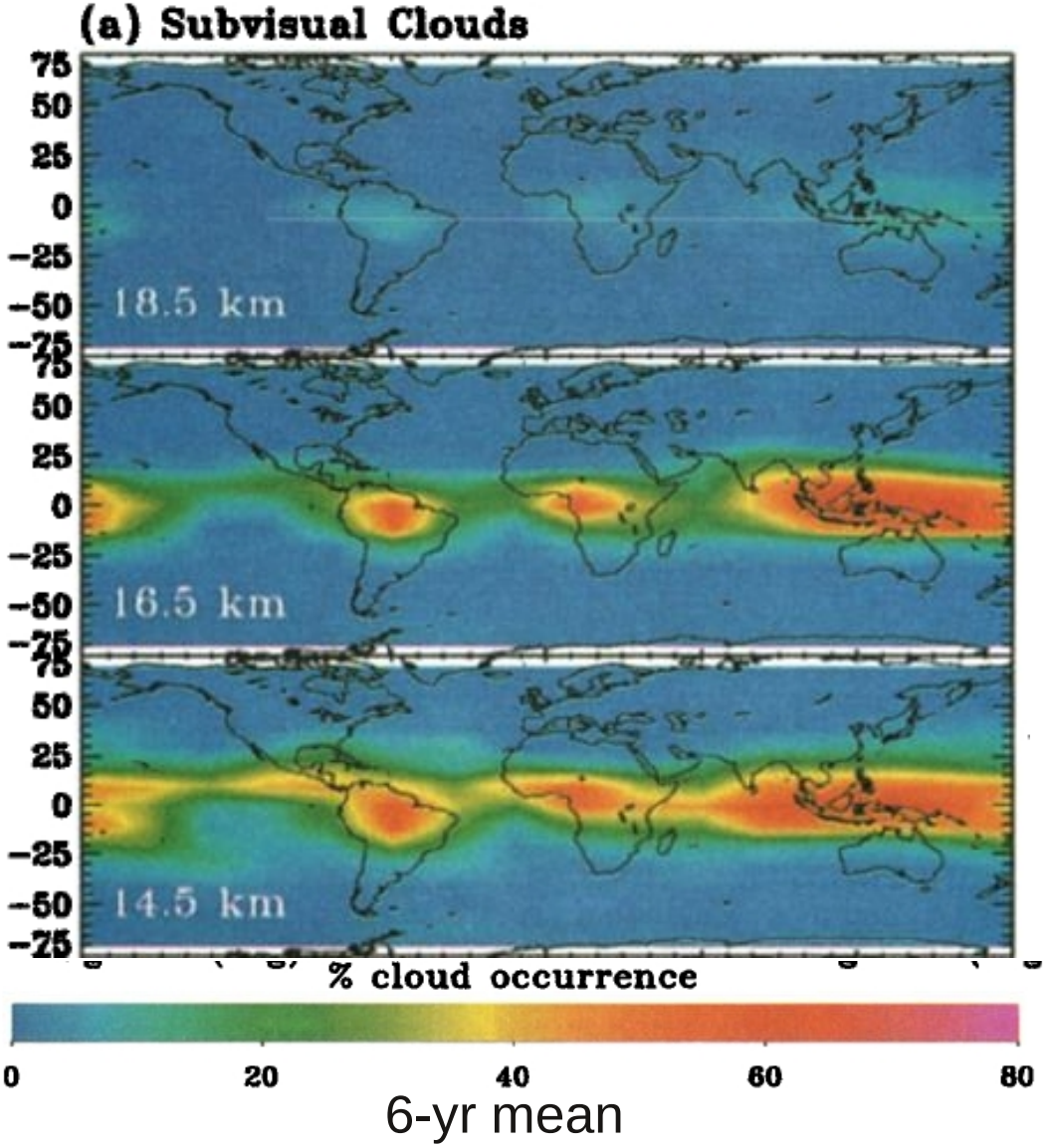
Other products identify features as ice clouds, etc.





TTL Cirrus

"TTL cirrus clouds have been detected throughout the tropics but are especially prevalent above the western Pacific"



6-yr mean

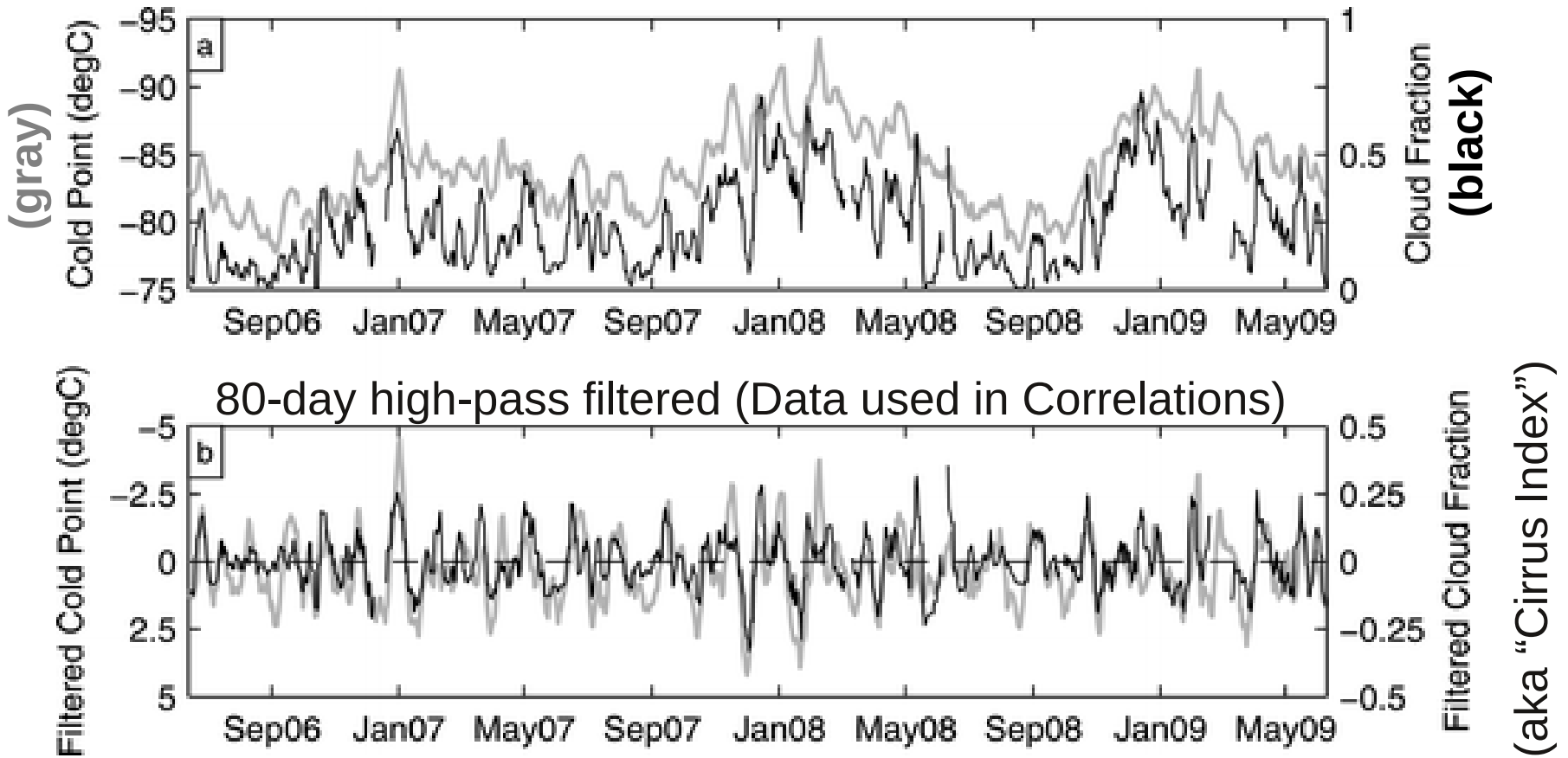
Example from Wang et al. (1996) derived from SAGE II satellite measurements.

SAGE II views the limb and should be more sensitive to thinner clouds than the nadir-viewing CALIPSO.

The Virts et al. study... "focuses on the relationship between TTL cirrus and the surrounding environment on the intraseasonal time scale."

Virts et al. (2010): Fig. 1

7-day running means at Manus Island, Papua New Guinea (2S, 147E)



Cold point temperature = lowest T above 15 km in radiosonde profiles

Cloud fraction = fraction of CALIPSO profiles within 10^{o}x10^{o} box with cloud base >15km

Virts et al. (2010): Fig. 3

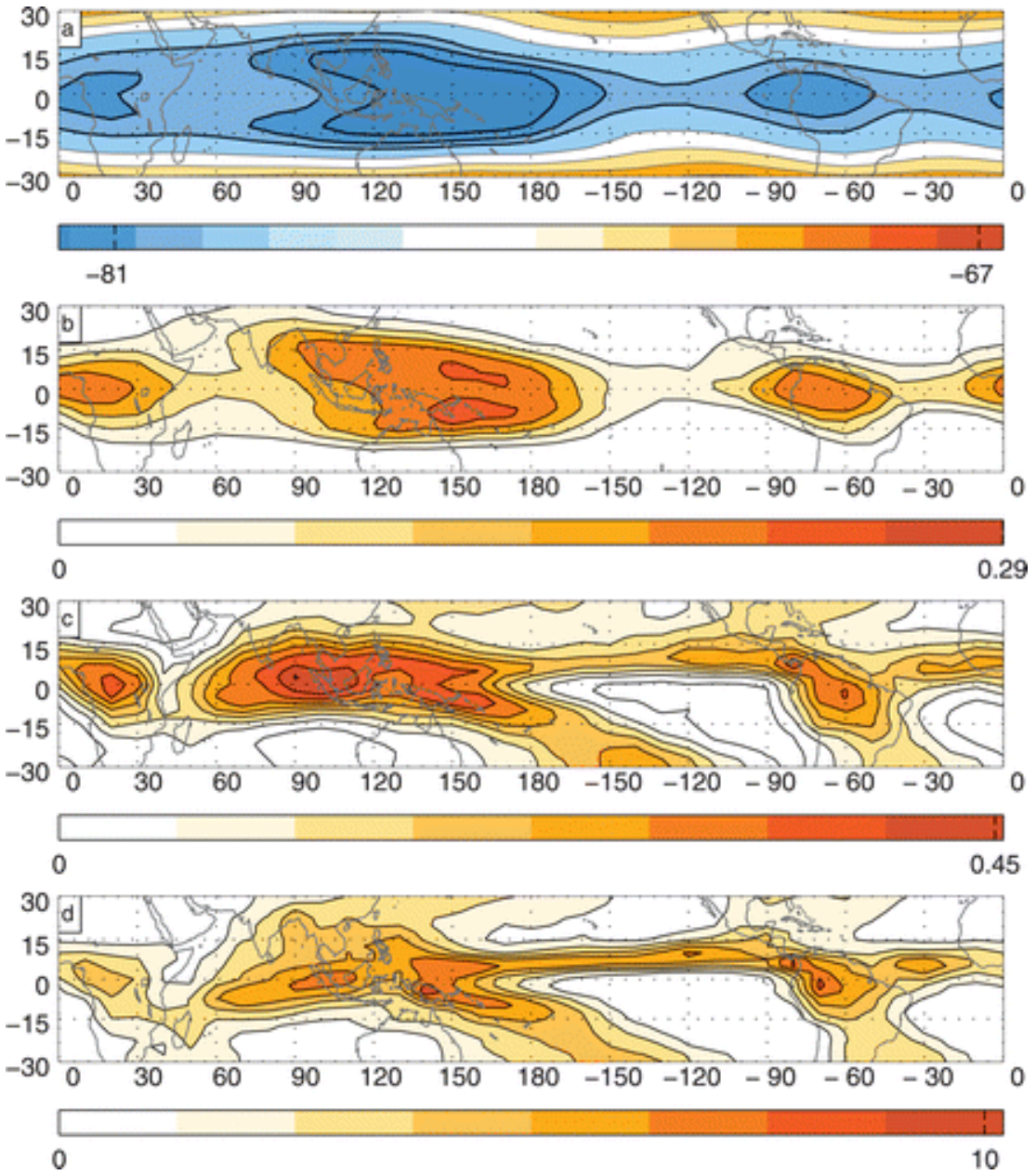
Annual Means

100 hPa Temperature

Cloud Fraction with base z >15km

Cloud Fraction z = 11-12 km

GPCP Rain Rates



"If TTL cirrus formed primarily by the spreading of anvils from deep convective clouds, then one might expect the TTL and convective cloud distributions to look broadly similar."

"...advection by the horizontal winds could distort the shapes of anvils as they spread, but it is not obvious why it should simplify the pattern and make it more symmetric about the equator..."

Virts et al. (2010): Fig. 4

Cirrus Index correlated with ERA 100hPa T in the box

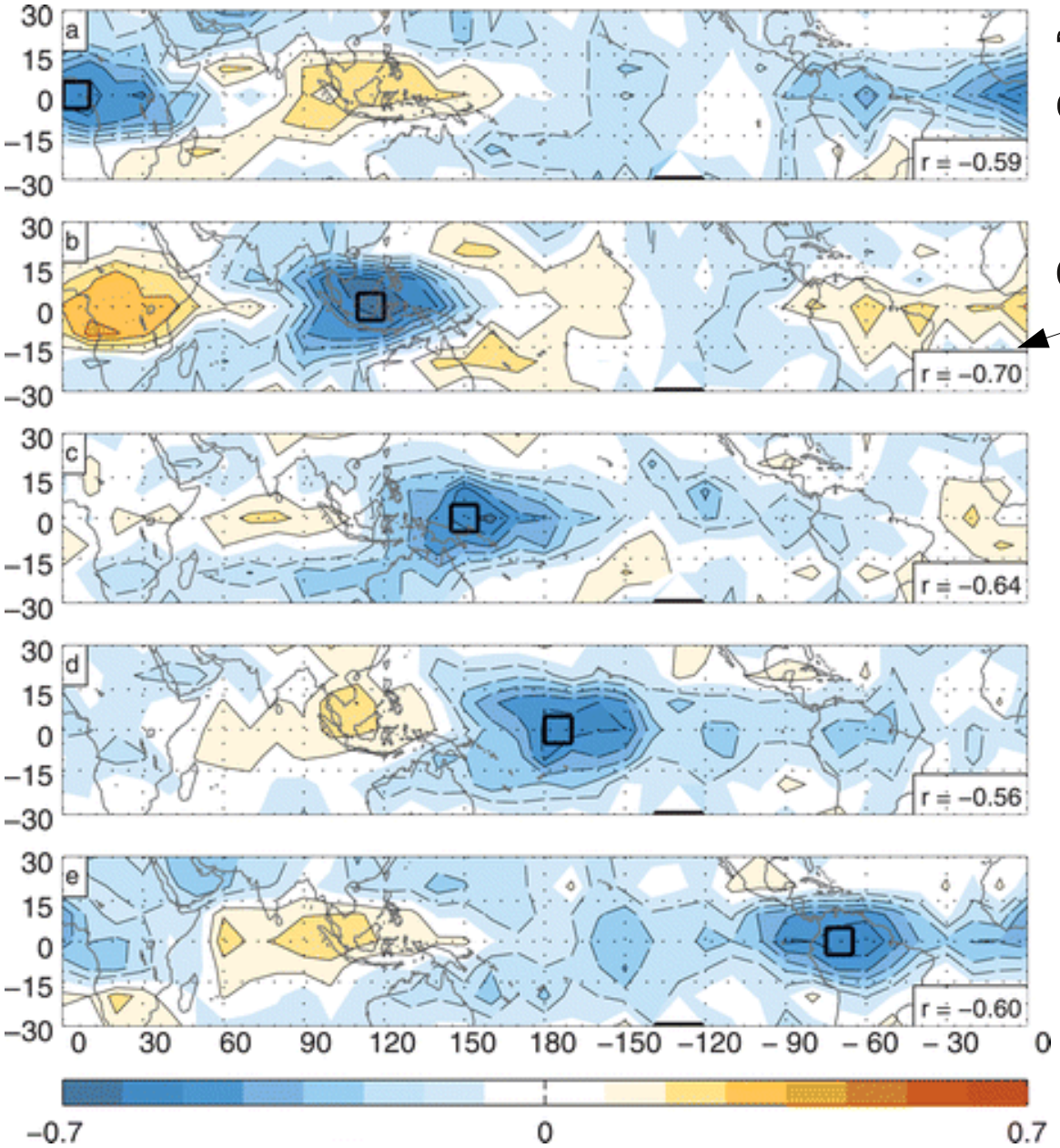
Africa

Maritime Continent

Western Pacific 1

Western Pacific 2

South America



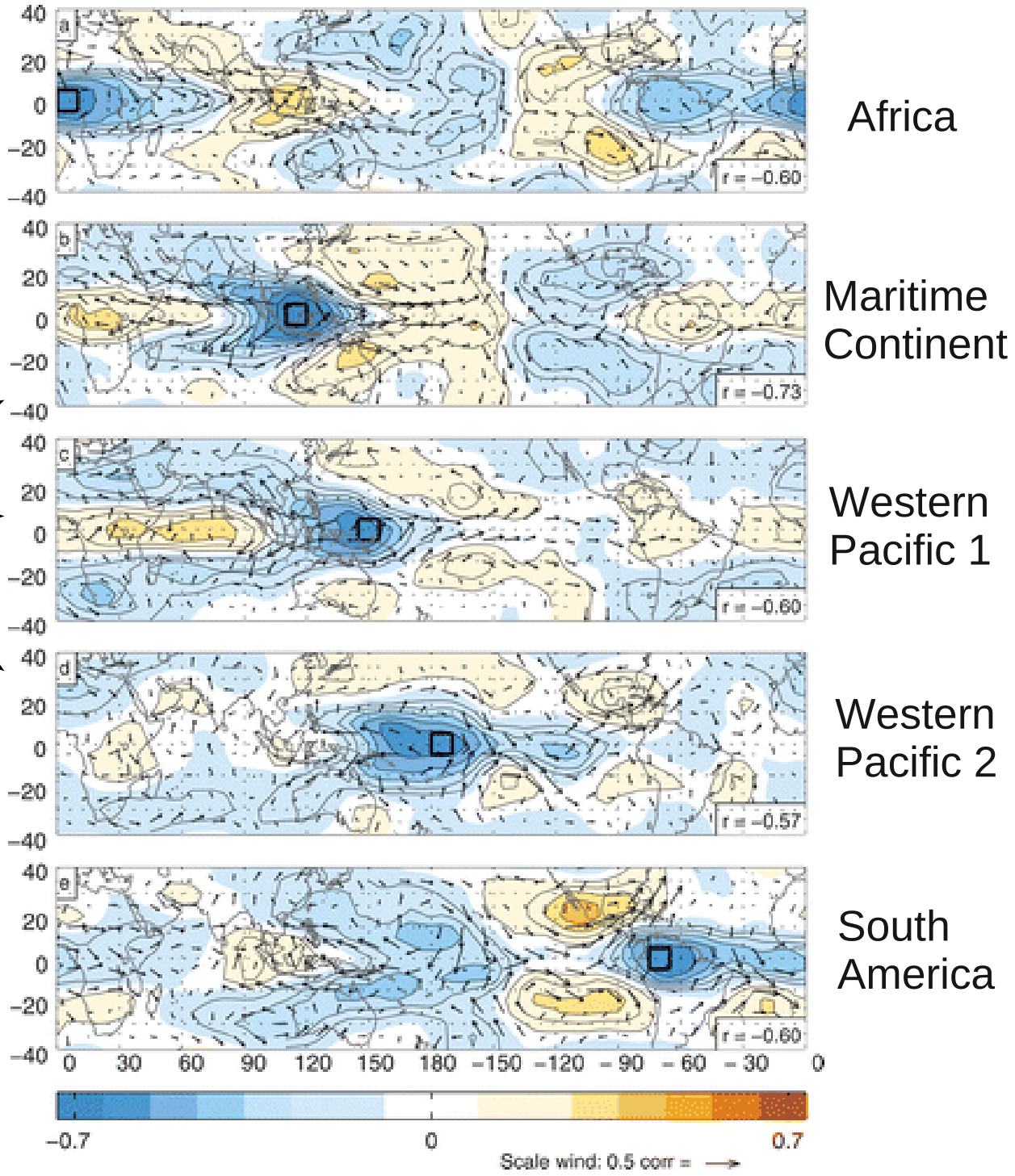
"100 hPa is significantly correlated with TTL cirrus"

Correlations exceed 0.7

"Temperature fields exhibit a high degree of equatorial symmetry throughout the tropics"

Virts et al. (2010): Fig. 5

ERA T_{100hPa} & Winds correlated with Cirrus Index in box



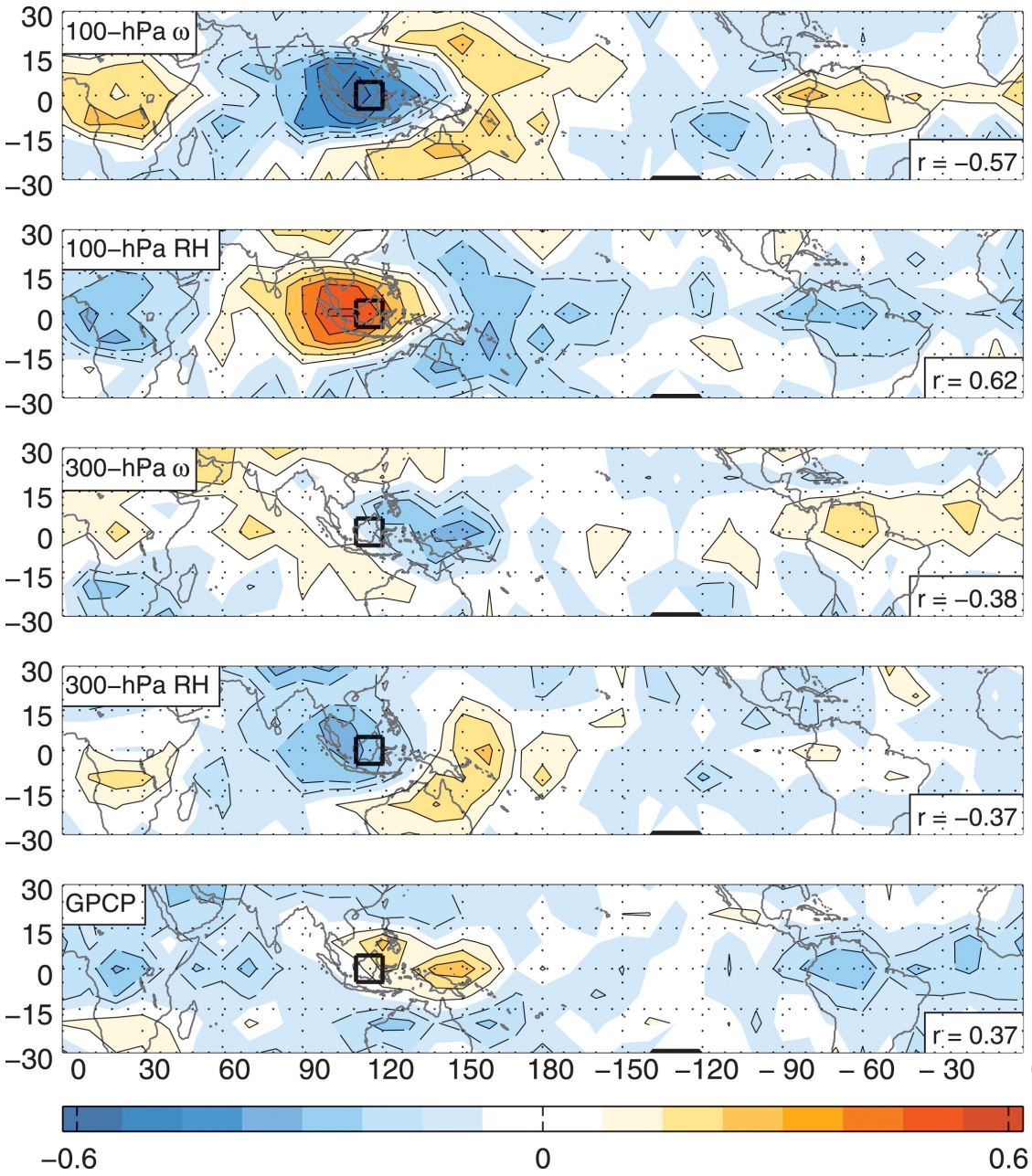
"Planetary wave temperature signatures are apparent"

"Suggestion of a wave train in all panels"

"a, b, e suggest an out-of-phase relationship between Maritime Cont. T and equatorial Aftrica and South America T"

Virts et al. (2010): Fig. 6

Cirrus Correlated with labeled variable within the box centered over the Maritime Continent



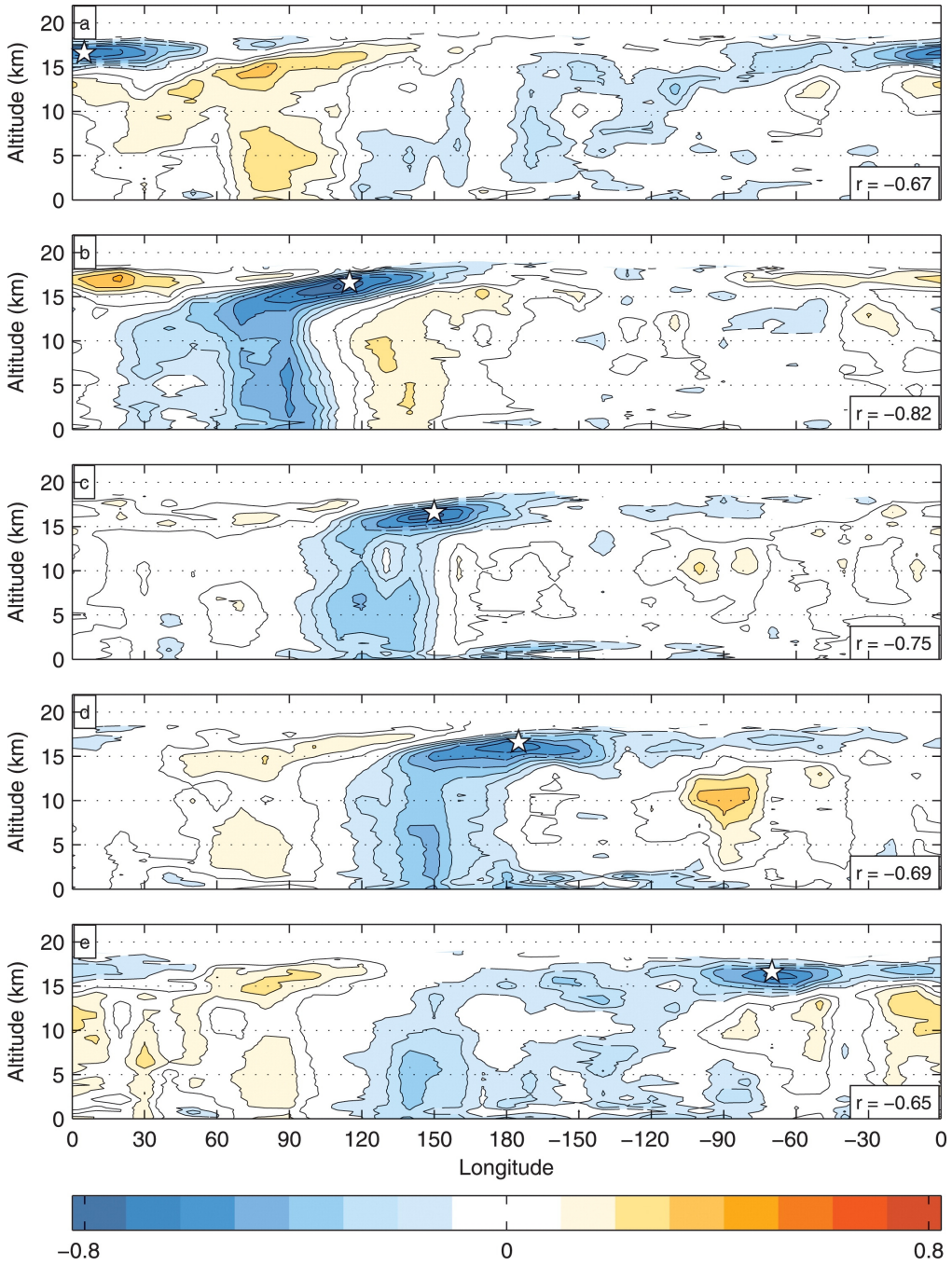
Cirrus high when air at 100hPa moves upward

Cirrus high when RH at 100hPa is high

For upward motion and high RH at 300hPa, cirrus enhancements are 30^{o} to the east

Also east of the rain

Virts et al. (2010): Fig. 7



Vertical Structure: Clouds Correlated with T_{100hPa} at indicated point (star symbol)

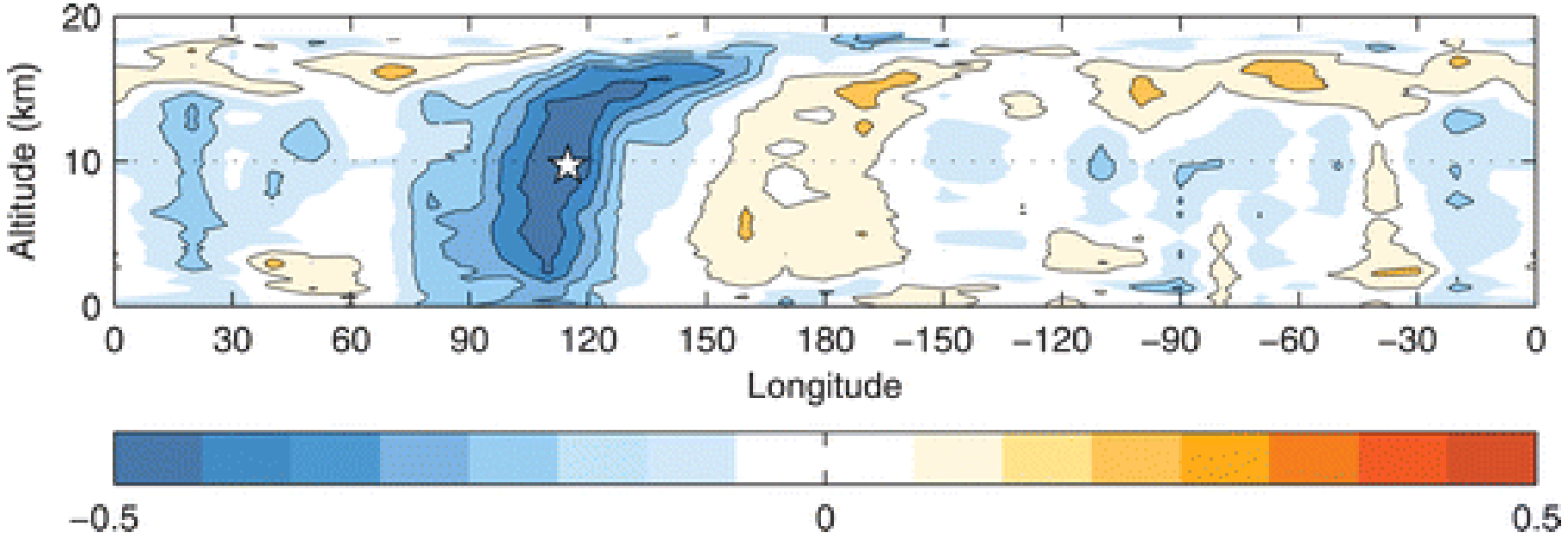
T in a 10ºx10º box on equator
Cirrus within 5ºS-5ºN

As before, cirrus are negatively correlated with T at 100hPa.

In the TTL, the cloud signature tilts eastward with altitude, and below and 30º to the east, a vertical cloud feature extends down to the surface.

Virts et al. (2010): Fig. 8

Vertical Structure: Clouds Correlated with ω_{300hPa} at indicated point (star symbol)

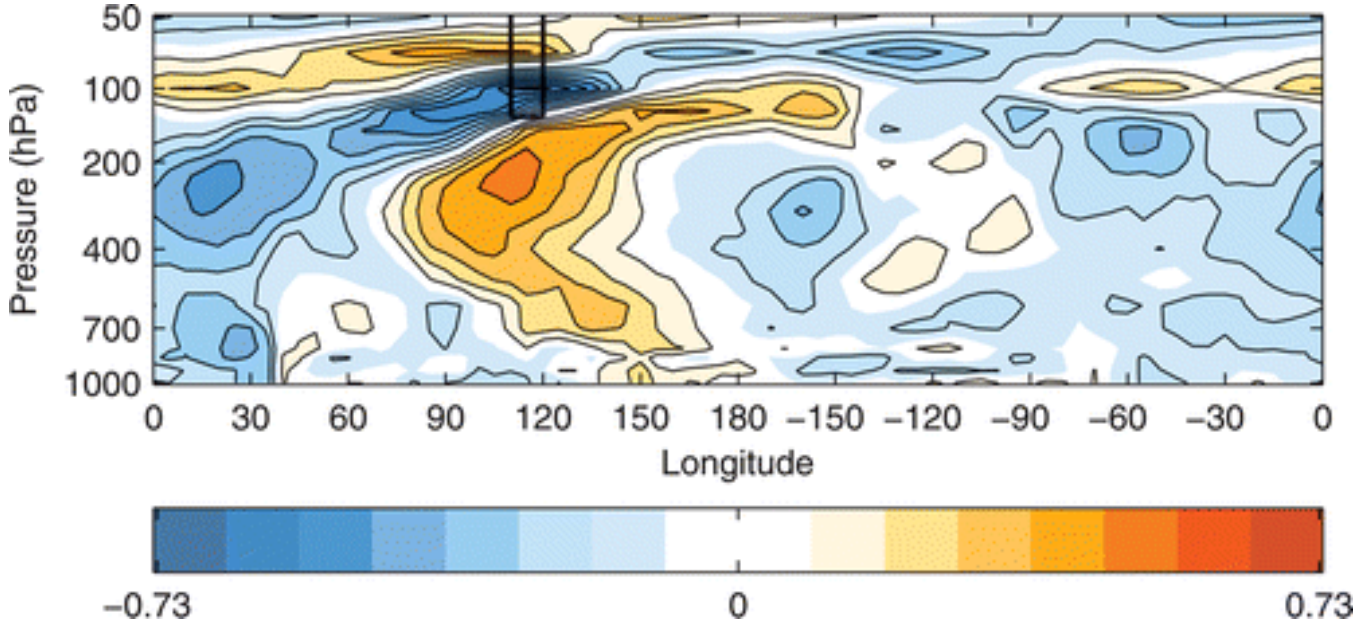


- Vertically aligned cloud feature at z<12km is correlated with upward motion.
- Eastward tilt with height of the cloud correlation above.

“The tilting bands of strong correlations should not be interpreted as indicating a continuous cloud emanating from the top of the convection and being advected eastward over an extent of several 1000 km... It seems more likely this band represents the region of planetary-scale ascent and low temperatures...”

Virts et al. (2010): Fig. 9

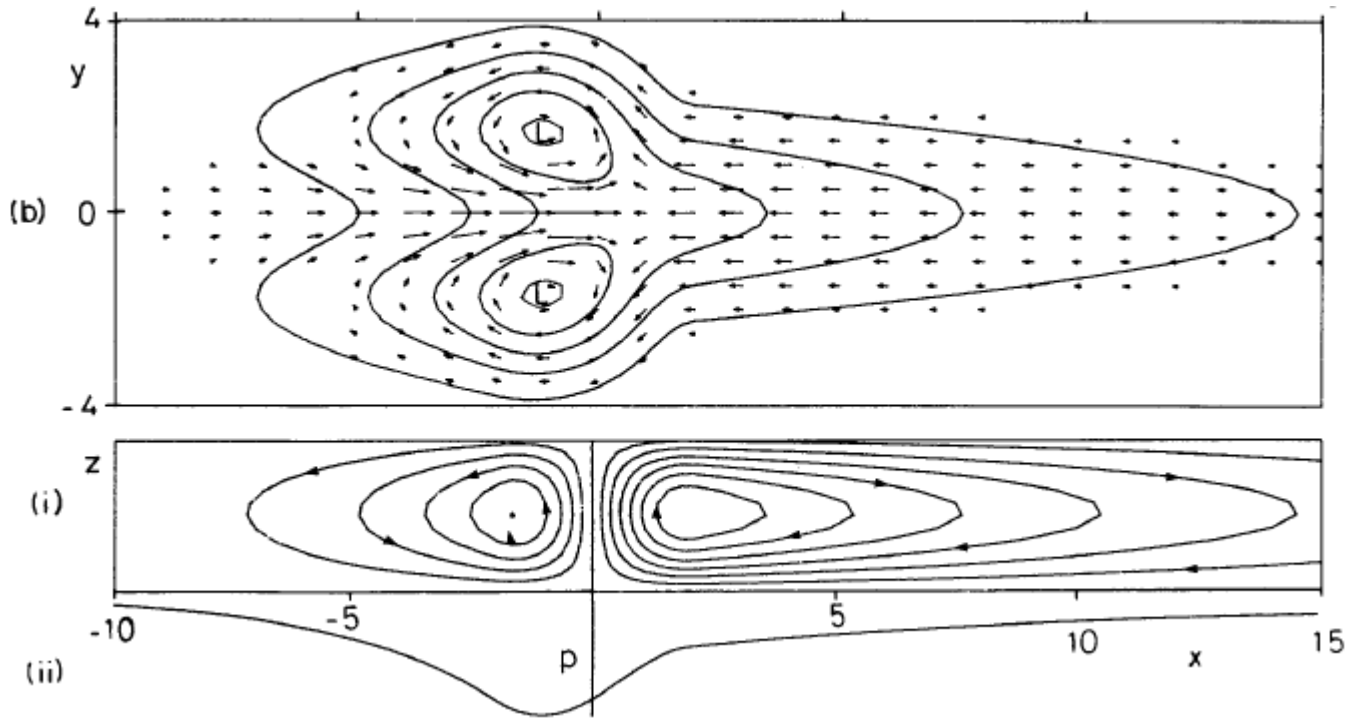
Vertical Structure: Temperature (2.5ºS-2.5ºN) Correlated with Cirrus (10ºS-10ºN) in the box



- Temperature correlations tilt eastward with altitude in the TTL
- Anomalous warm correlations below resemble convectively-coupled wave structures.

“The results... indicate that TTL cirrus is significantly correlated with Gill (1980)-like planetary wave perturbations within the TTL.”

Gill 1980: Shows response to localized heating



Low level
p', (u,v)

Meridionally
integrated
stream function
and pressure

The TTL lies above direct heating levels, so the patterns there will be freely propagating waves, not these convectively-coupled patterns.

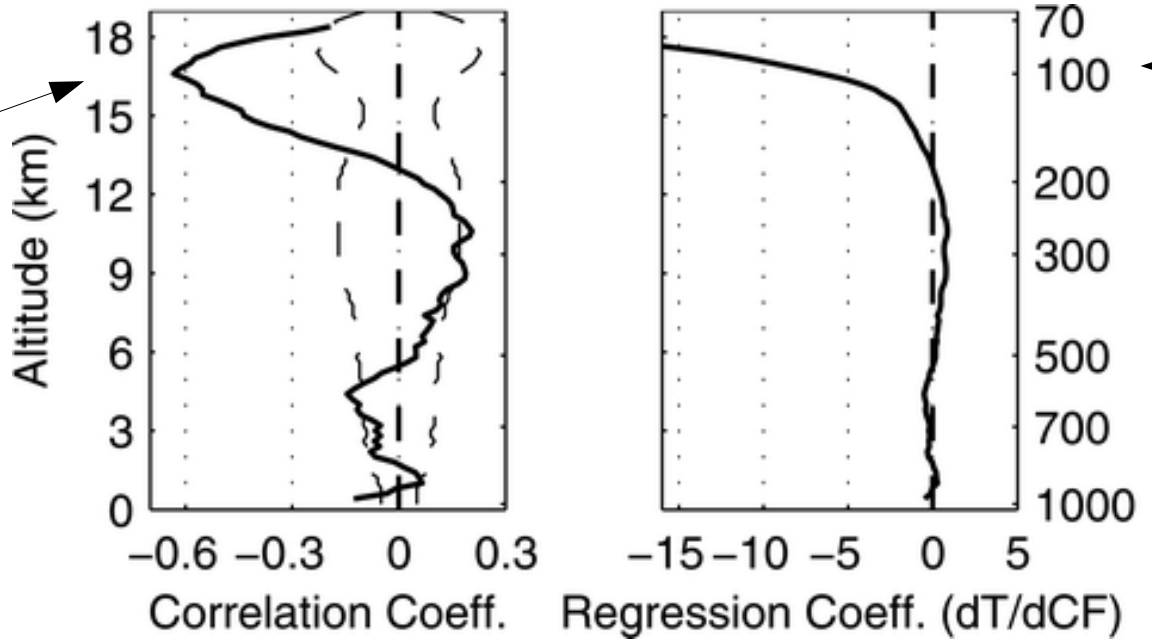
Virts et al. (2010): Fig. 10

Statistical relationship between Temperature and Cirrus in the TTL

"We view both variables as indicators of the air parcel's recent history of vertical velocity."

- Cloud fraction at Manus Island in 200m layers
- Closest radiosonde within 24 hrs of the CALIPSO overpass
- Correlation with height (left) and Regression of T onto Cloud fraction (right)

Significant correlations in the TTL.



At 17 km, regression coefficients =-9.4°C (a 0.94°C drop in T per 10% increase in cloud fraction)

At 6-13km, indicates a <1°C T difference between clear and cloudy sky.

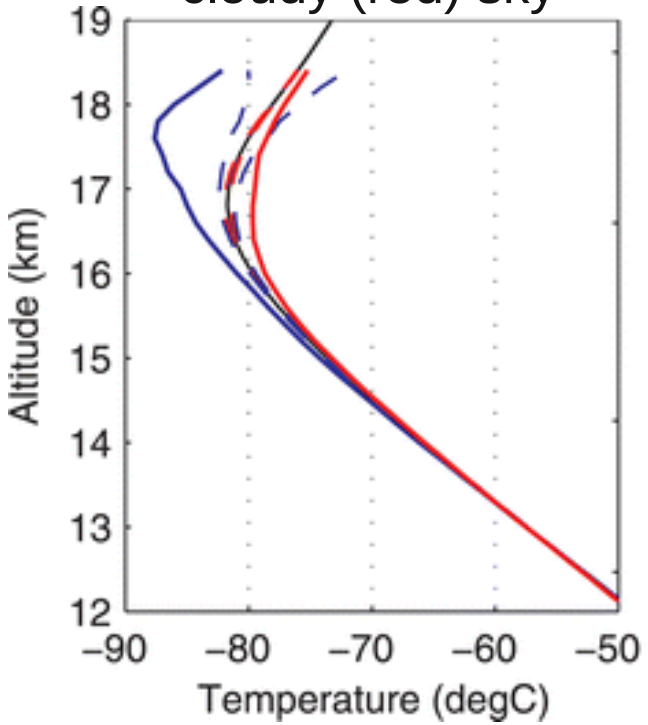
Virts et al. (2010): Fig. 11

Differences Clear and Cloudy

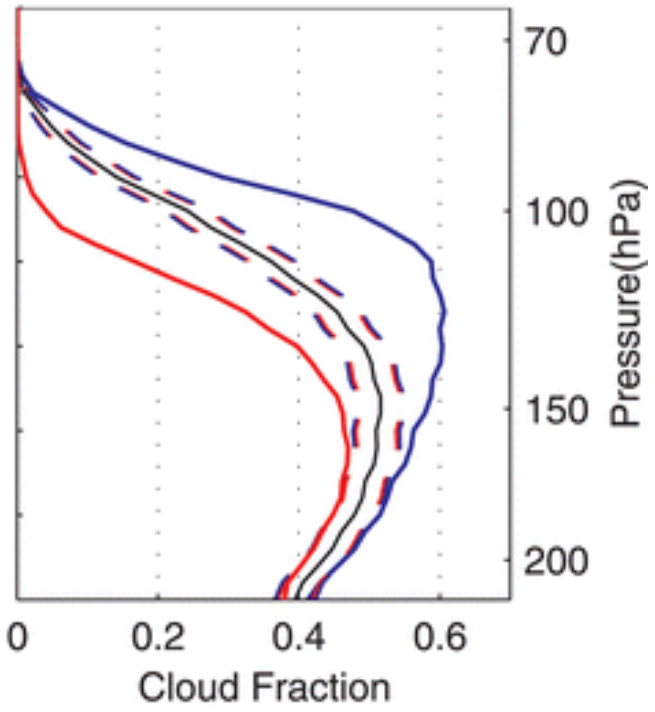
"Clear" = less cloudy than average
"Cloudy" = more cloudy than average

"Warm" = warmer than avg cold pt.
"Cold" = colder than avg cold pt.

Radiosonde T in clear (blue) and cloudy (red) sky



Cloud fraction Warm vs Cold



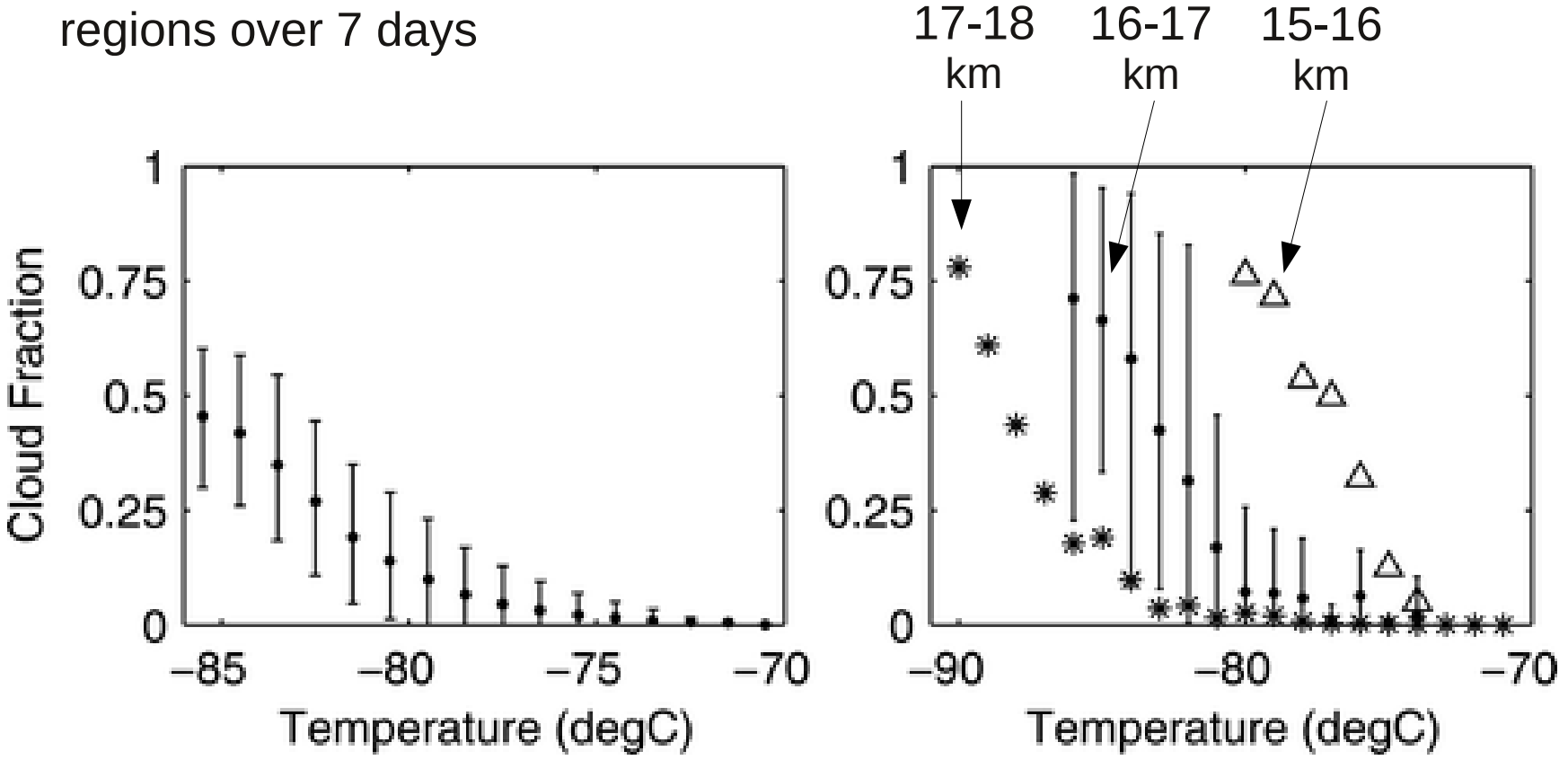
In the TTL, both clear and cloudy T are significantly different than the mean T (black)

At 16.5km, cloud occurrence is 7.5 times more likely when the cold pt T is below normal.

Virts et al. (2010): Fig. 12

Scatter-plots of TTL (z>15km)
Cirrus Index and Temperature

Within 30ºS-30ºN in 10ºx10º regions over 7 days

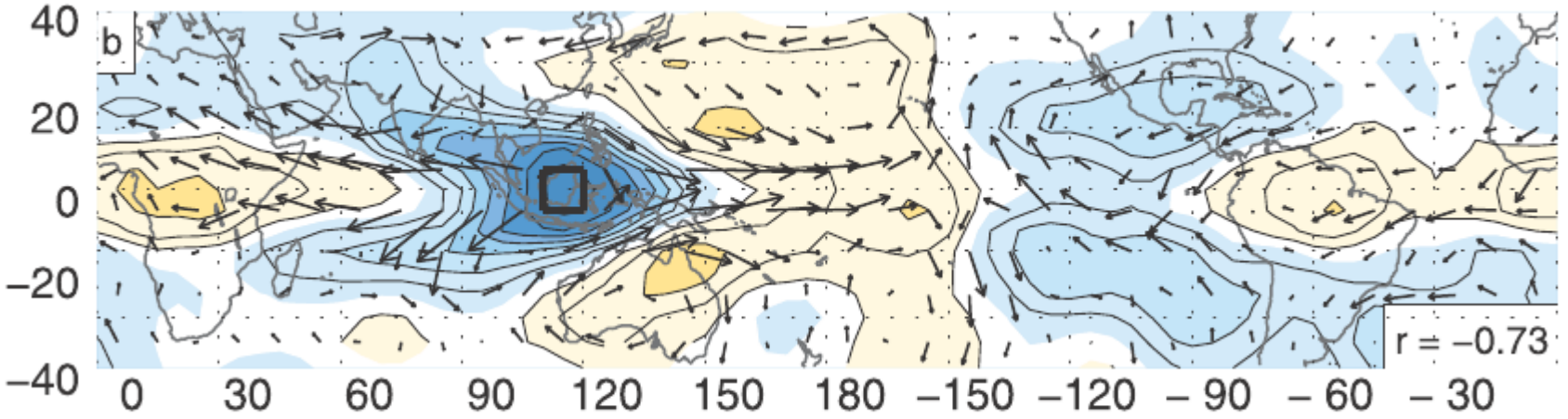


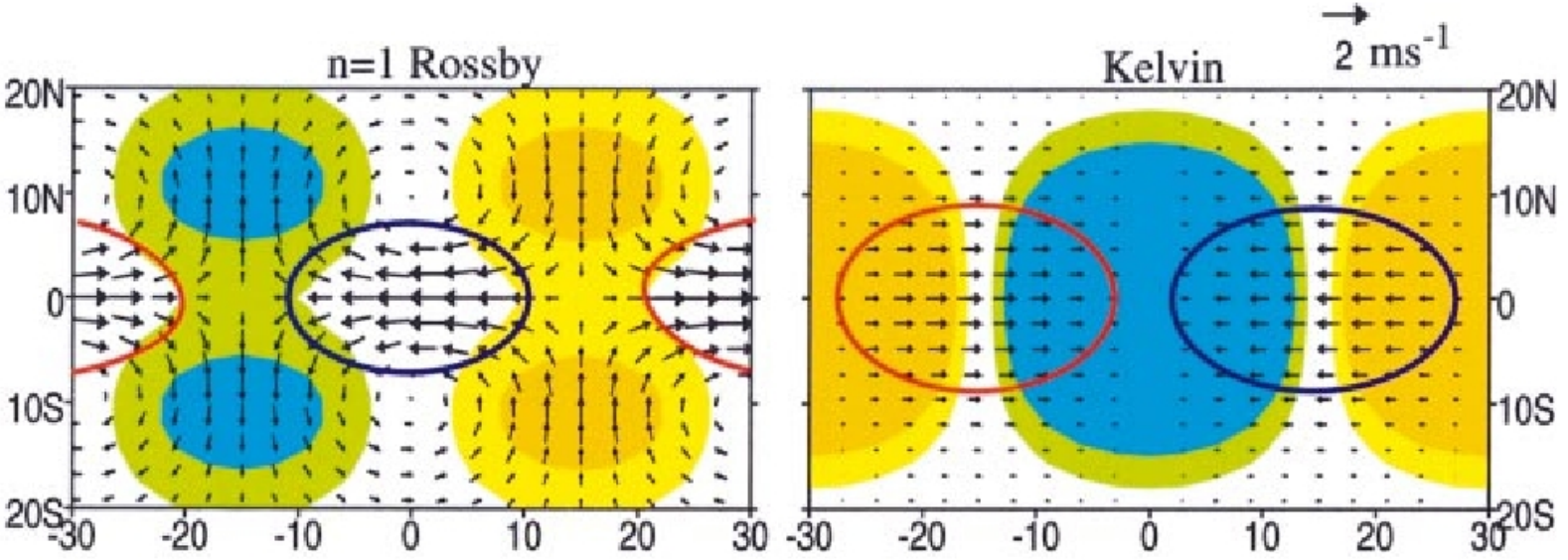
Clouds continue to increase below -84ºC (differs from a previous result at 100hPa).

At 17-18km observe existence of clouds as low as -90ºC

Main Conclusions

"The leading mode of variability in the TTL cirrus field on time scales less than 80 days includes a cirrus signature centered above the Maritime Continent that strongly resembles a convectively-induced Kelvin-Rossby wave couplet (Gill 1980)."





Yang et al. (2003):

Wind & Divergence in the Lower Troposphere (opposite of upper troposphere)

Main Conclusions

“The characteristics of TTL cirrus and the planetary-scale environments they are associated with are not uniform throughout the tropics... cirrus above equatorial Africa and S. America does not exhibit a Kelvin-Rossby wave signature... It does not exhibit an eastward tilt with height nor any obvious relation to convective activity... But it does appear to vary out of phase with deep convection cirrus over the Maritime Cont.

“TTL cirrus tends to be concentrated within planetary scale regions of anomalously low temperature... cirrus is more strongly correlated with temperature than any other variable.

“...Low temperature and high cloud fraction reflect a recent history of planetary-scale ascent.”

Main Conclusions