# Temperature Control of Variability of Tropical Tropopause Layer Cirrus Clouds

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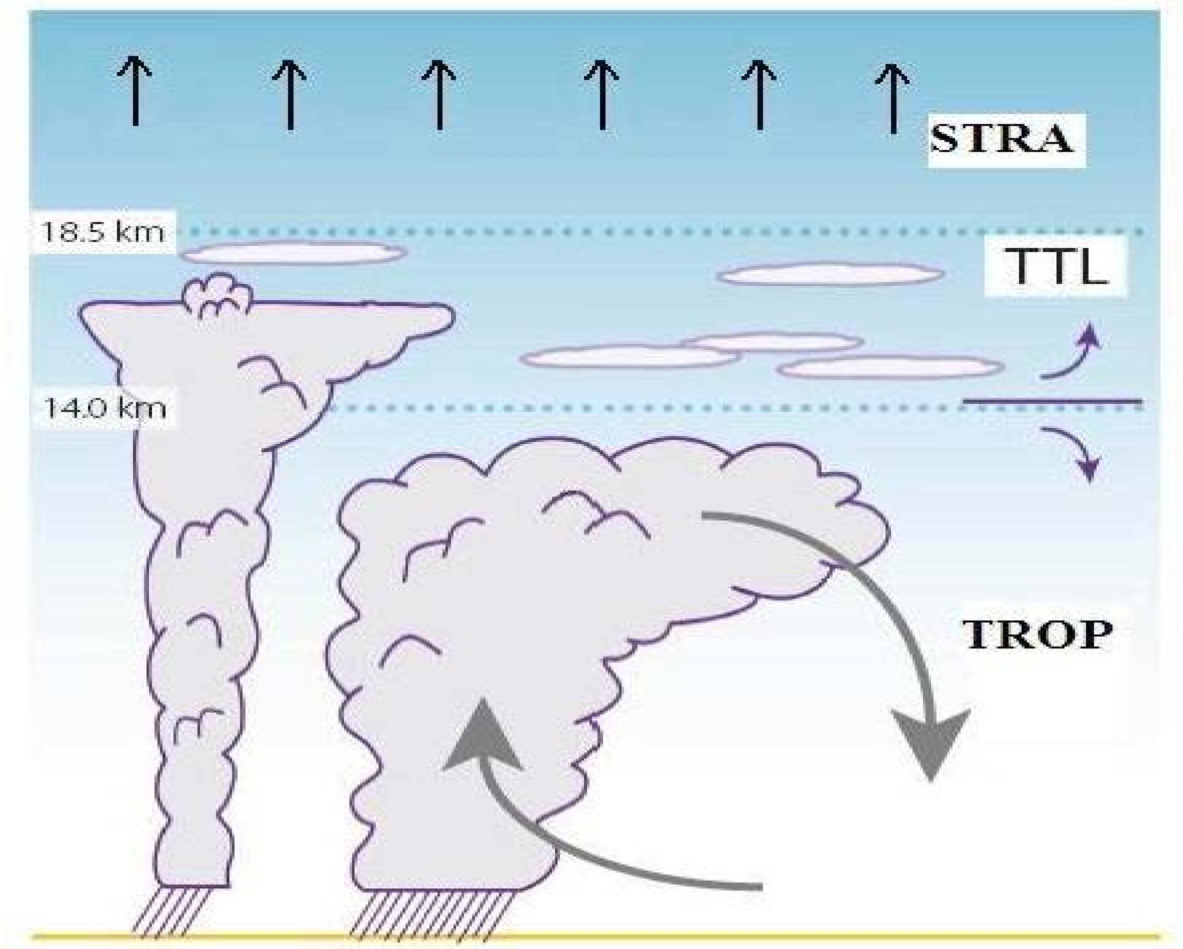
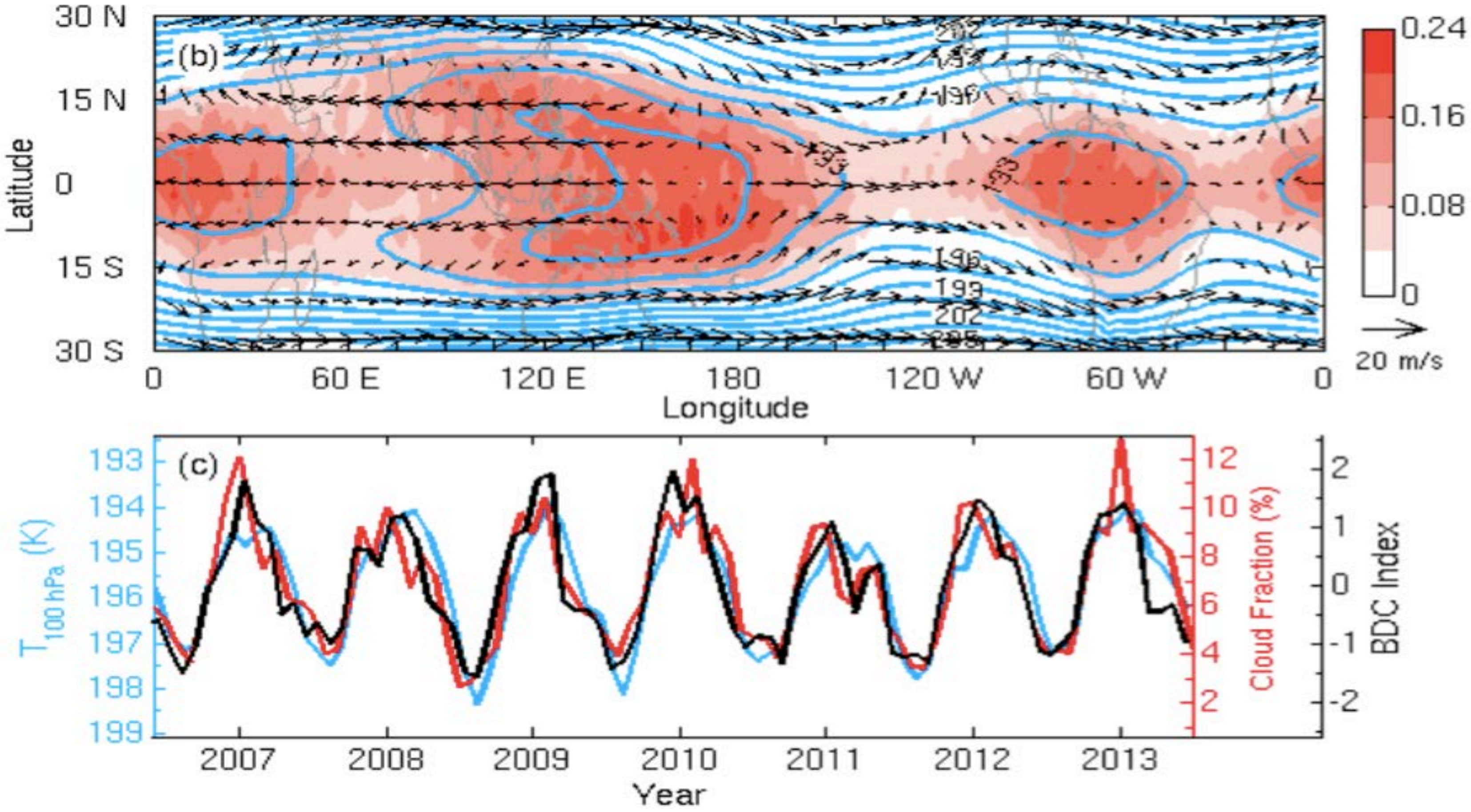



# Tropical Tropopause Layer (TTL)

Fueglistaler et al. (2009)

- Temperatures in the TTL govern stratospheric $H_2O$ (e.g., Fueglistaler et al. 2009) and TTL thin cirrus clouds are often associated with the $H_2O$ dehydration (e.g., Jensen et al. 1996).

- TTL cirrus clouds: Clouds with bases higher than 14.5 km




Fu (2013, NCC)

- To what extent do the TTL temperatures control the variability of the TTL cirrus clouds in both seasonal and interannual time scales?
- How are the TTL temperatures and cirrus clouds related to the large scale dynamic variability such as the El Niño Southern Oscillation (ENSO), quasi-biennial oscillation (QBO), and the Brewer–Dobson circulation (BDC)?

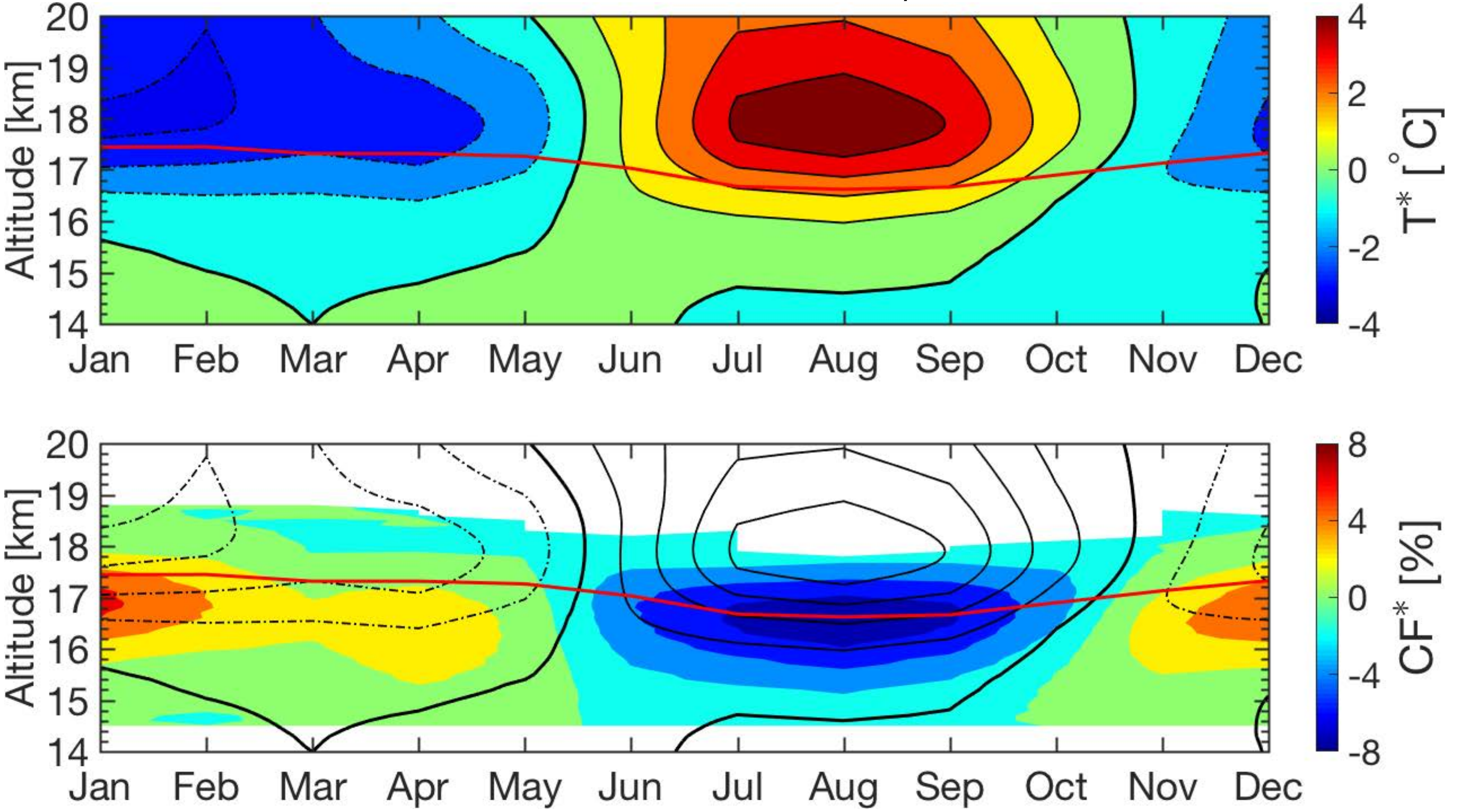
- Observational Data

The CALIPSO cloud data (version 3) for 06/2006-04/2016 (Winker et al. 2009) with the consideration of clouds included in the "stratospheric features" (Tseng and Fu 2017).

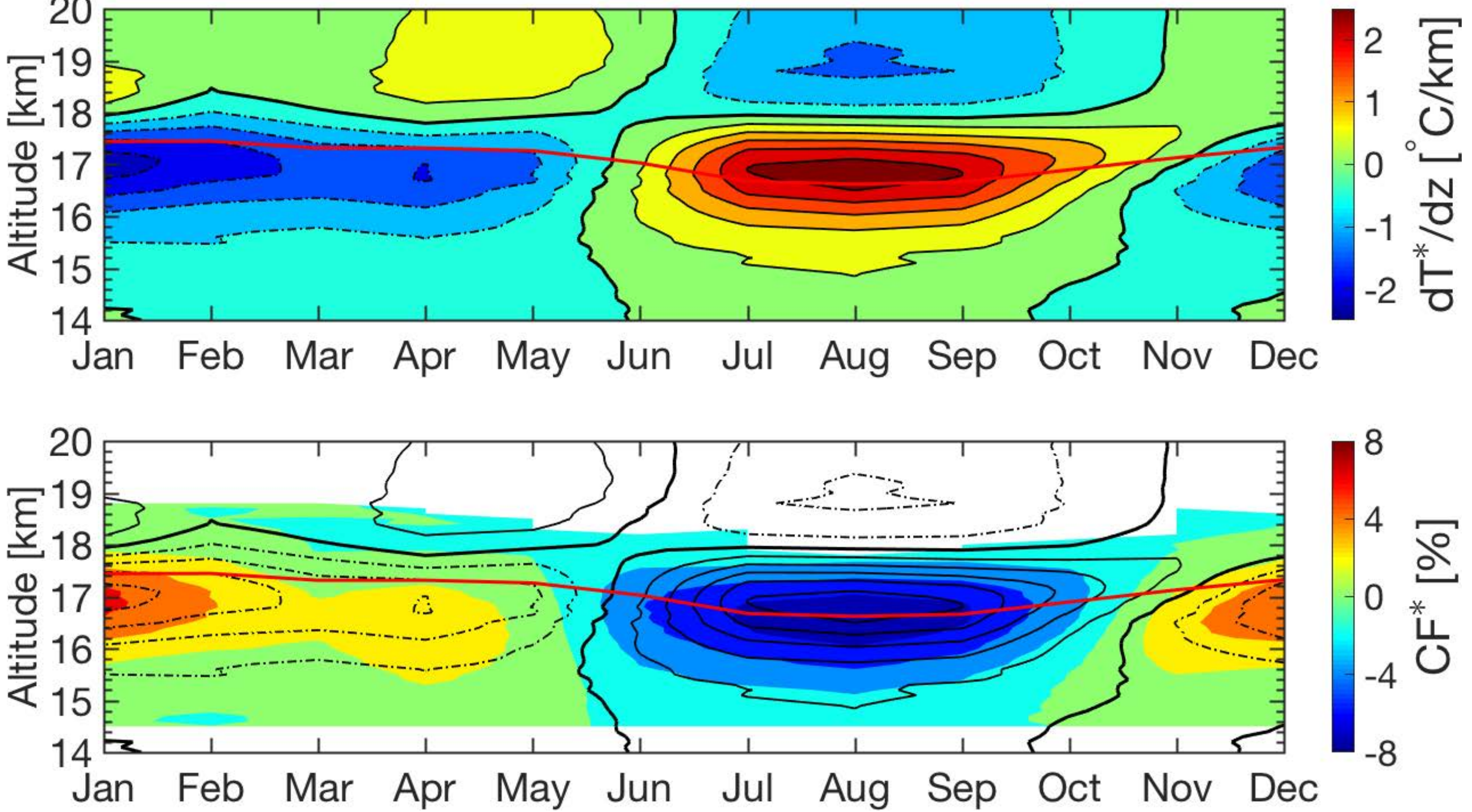
The COSMIC level 2 temperature profiles from the COSMIC satellite mission GPS retrievals for 06/2006-04/2014 (Kuo et al. 2004).

Temporal and vertical variability of the TTL cloud and temperature averaged over 15$^\circ$N–15$^\circ$S

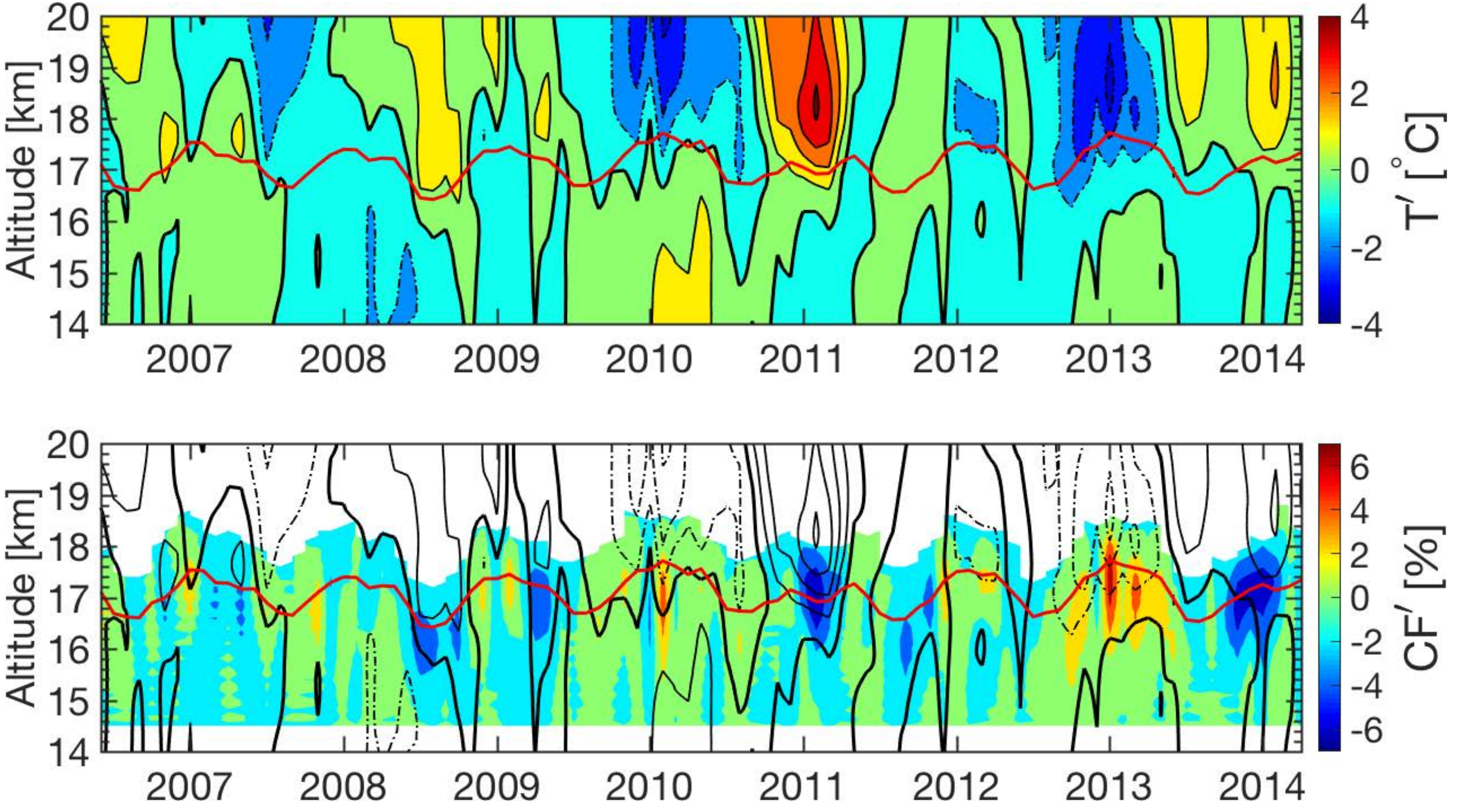
# Seasonal variability



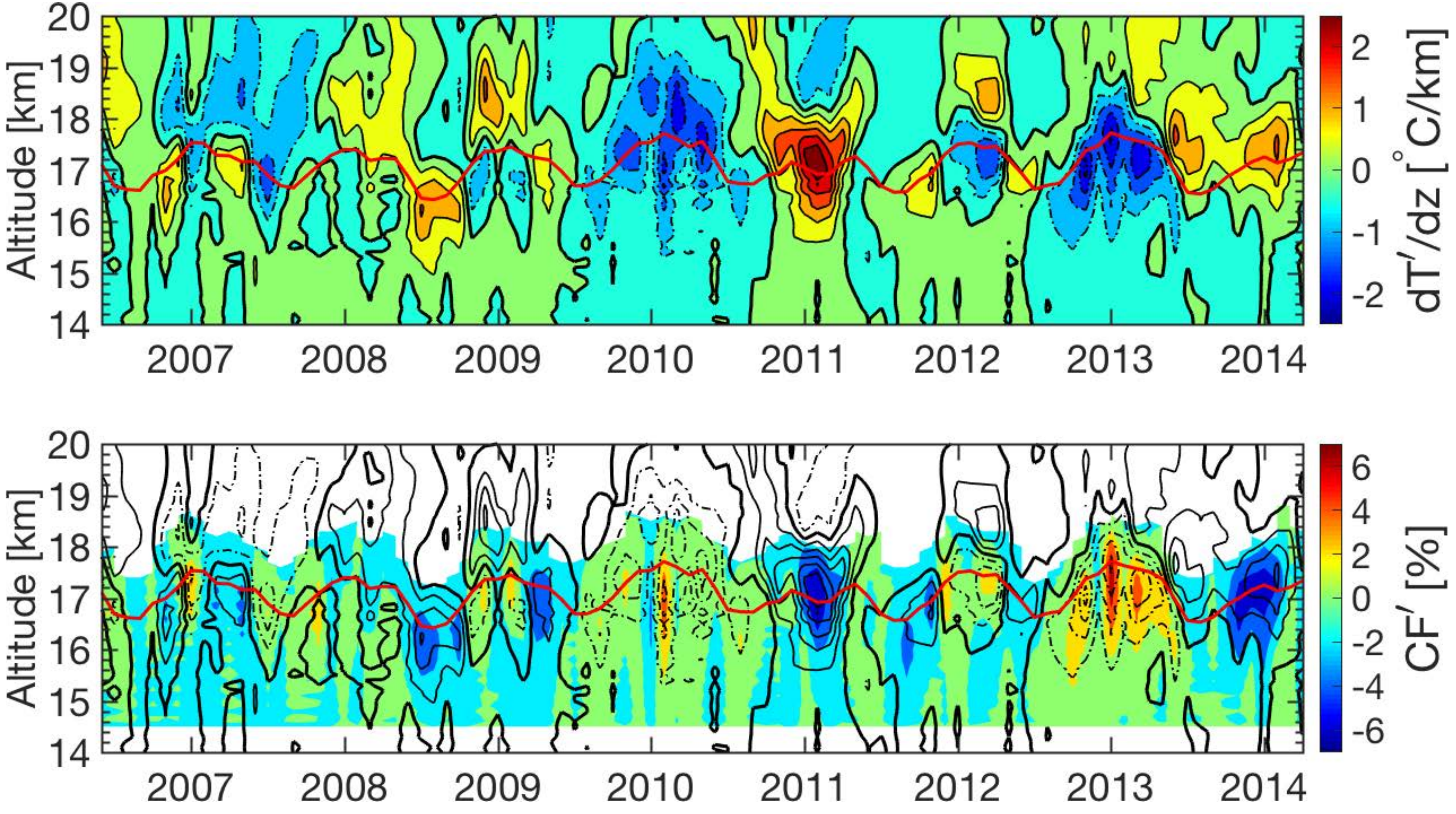
# Seasonal variability



# Interannual variability



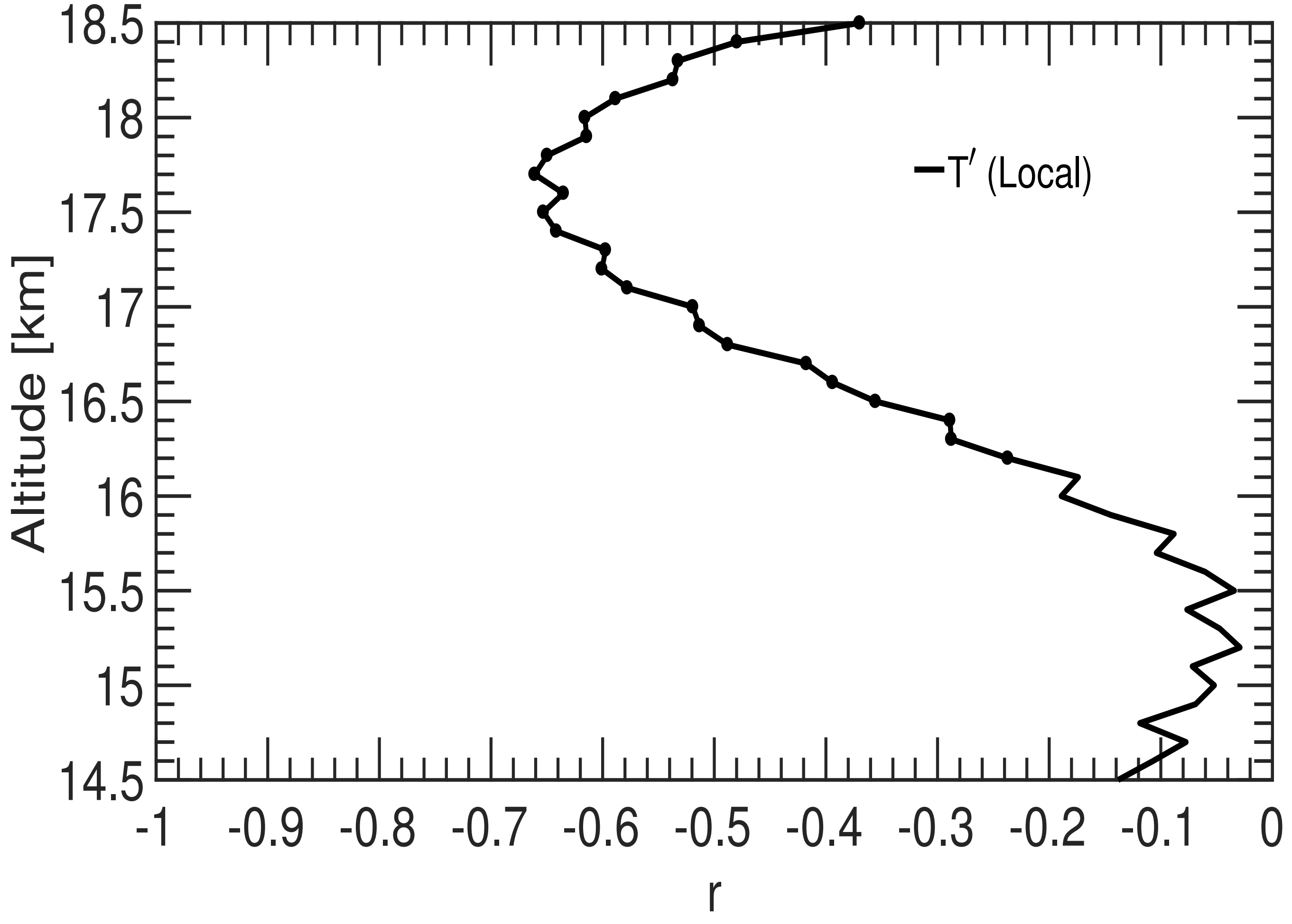
# Interannual variability



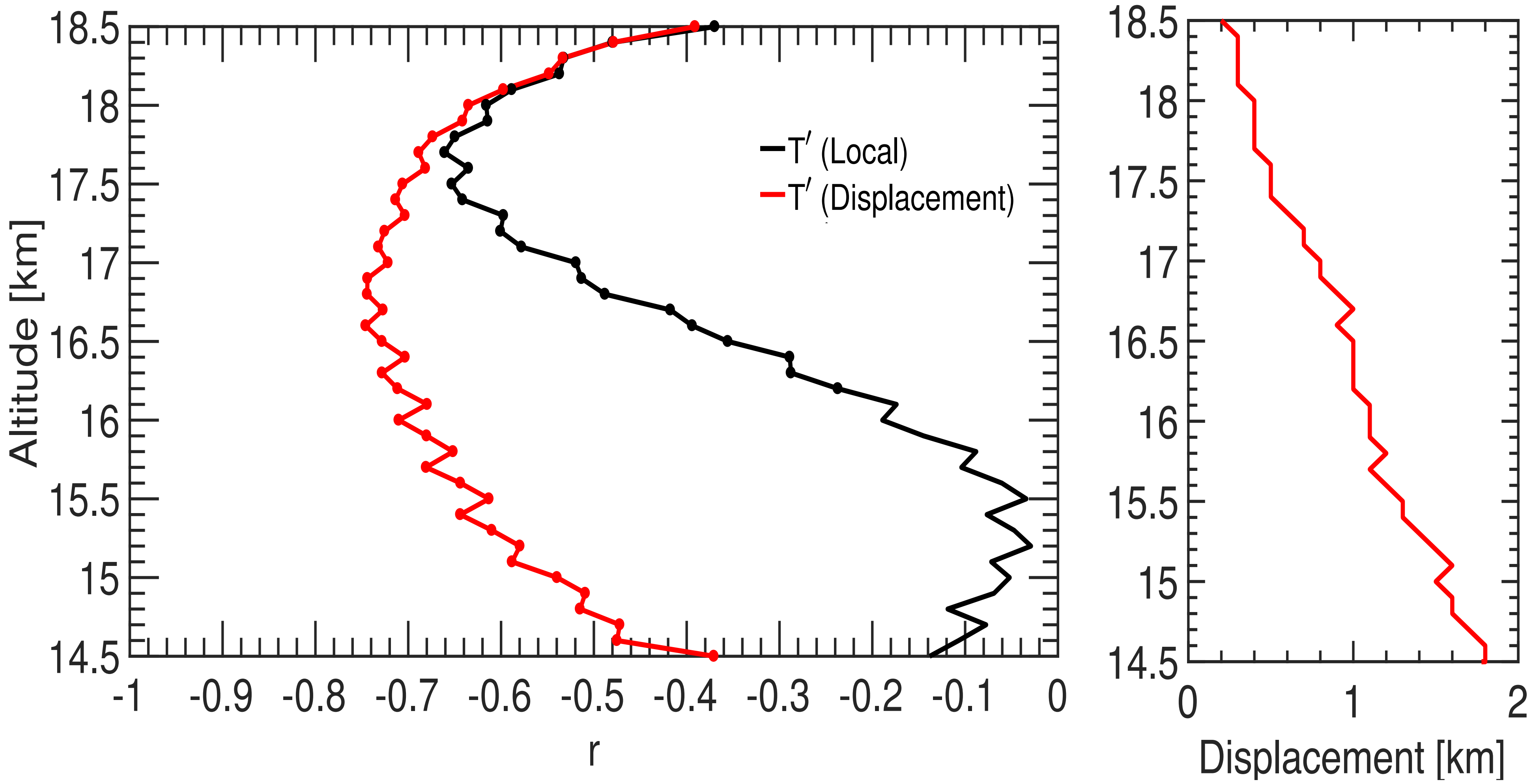

- The CF$*^{(')}$ and dT$*^{(')}$/dz coincide well with each other both temporally and vertically: A positive dT$*^{(')}$/dz corresponds a negative CF$*^{(')}$ and vice versa.

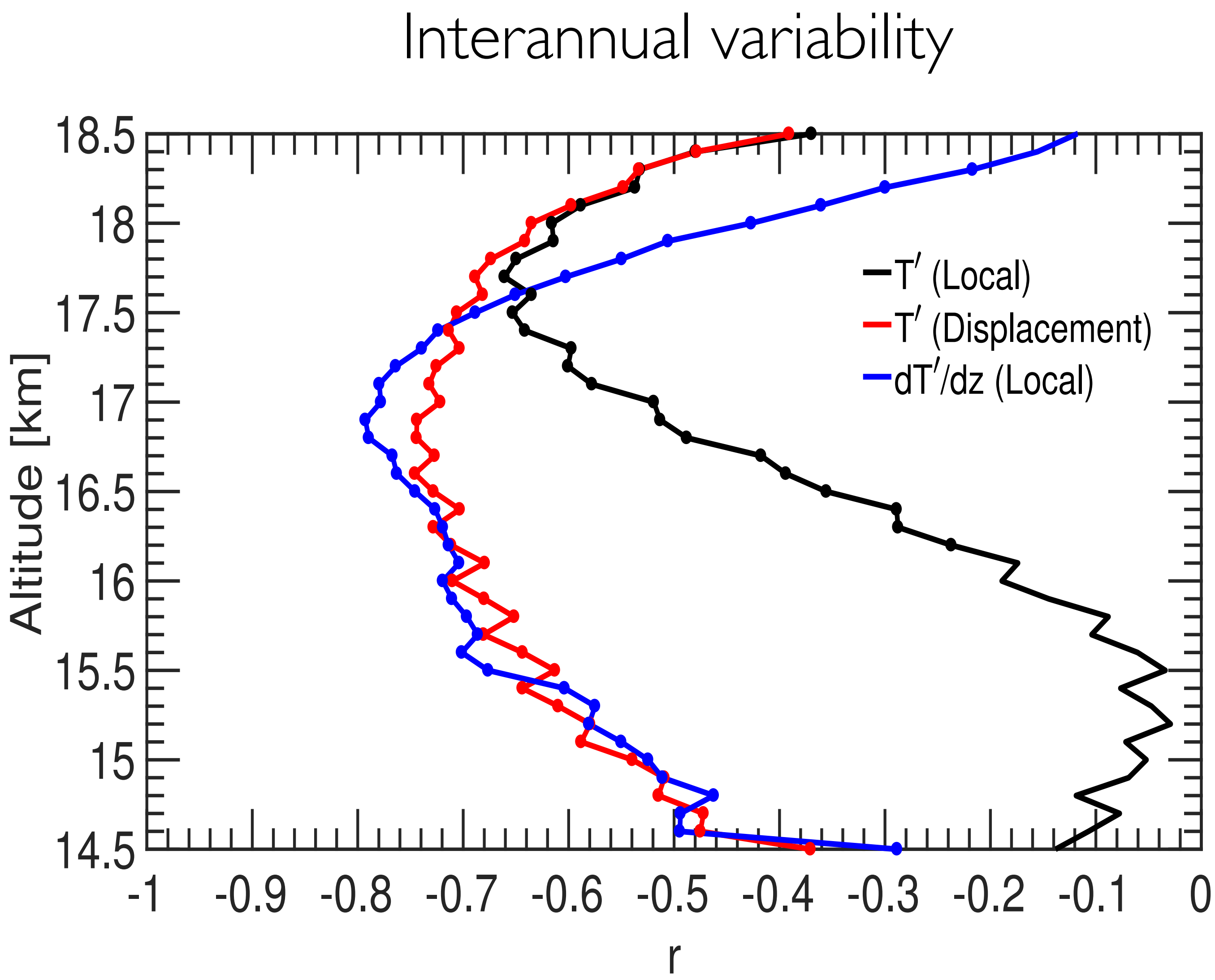
# Vertical profiles of correlation between TTL cloud and temperature-based variables

# Interannual variability



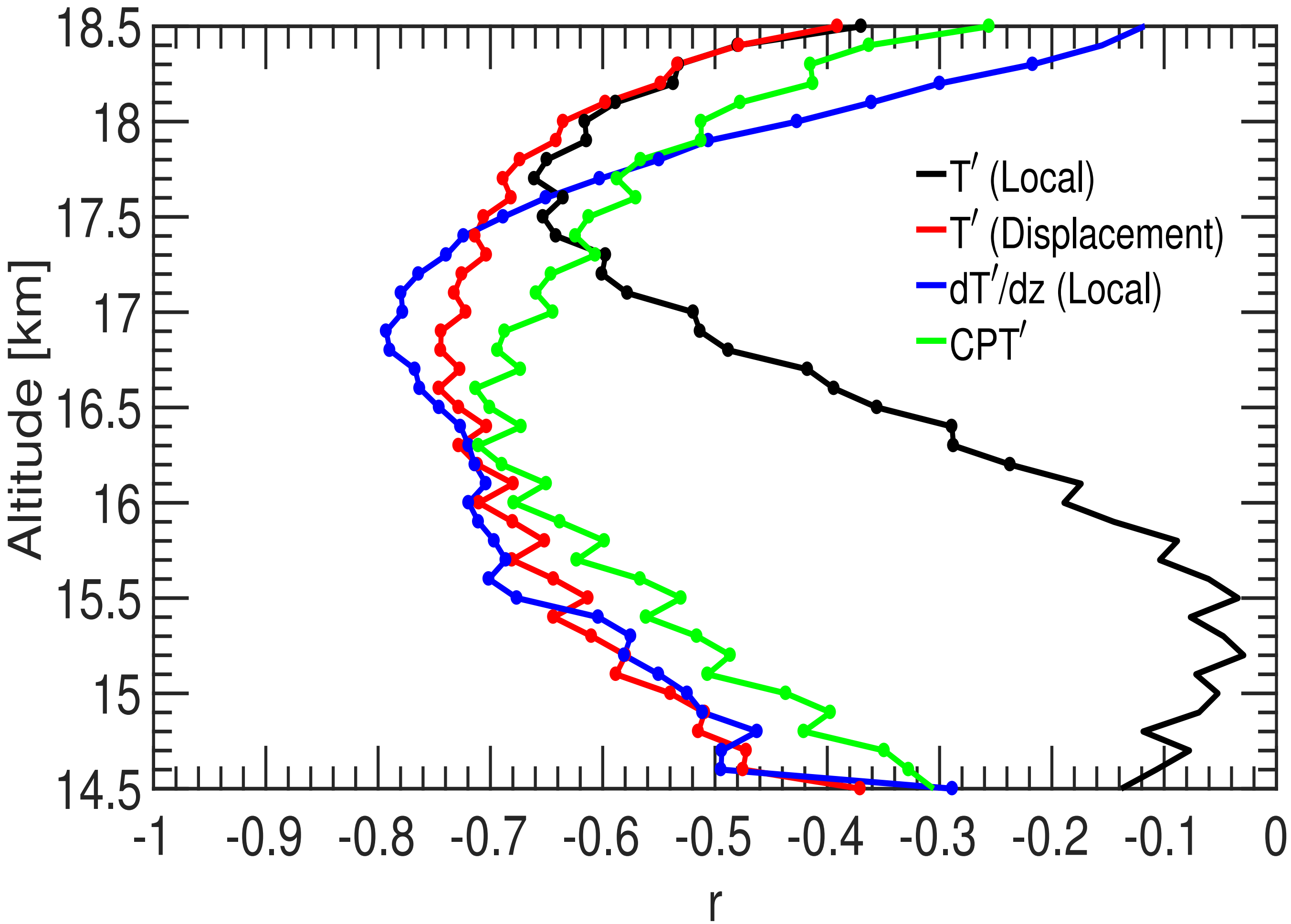
# Interannual variability

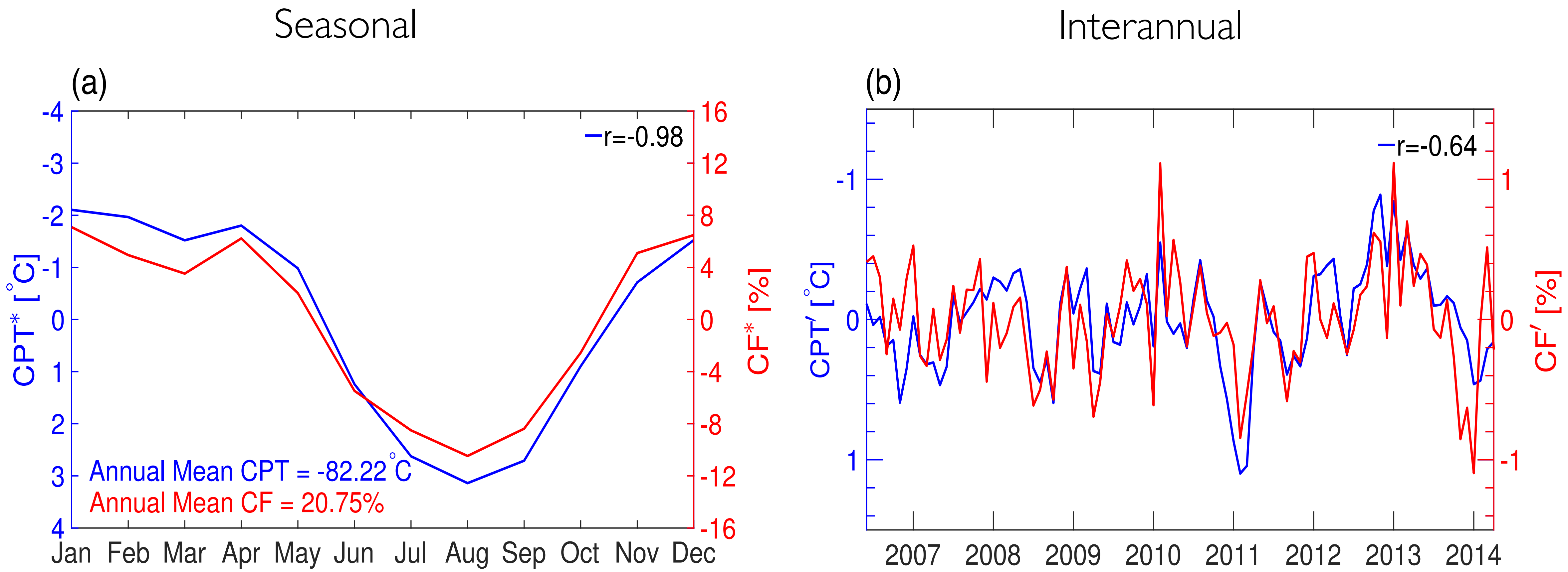




Interannual variability
Altitude [km]
r
18.5
18
17.5
17
16.5
16
15.5
15
14.5
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
T′ (Local)
T′ (Displacement)
dT′/dz (Local)

# Interannual variability



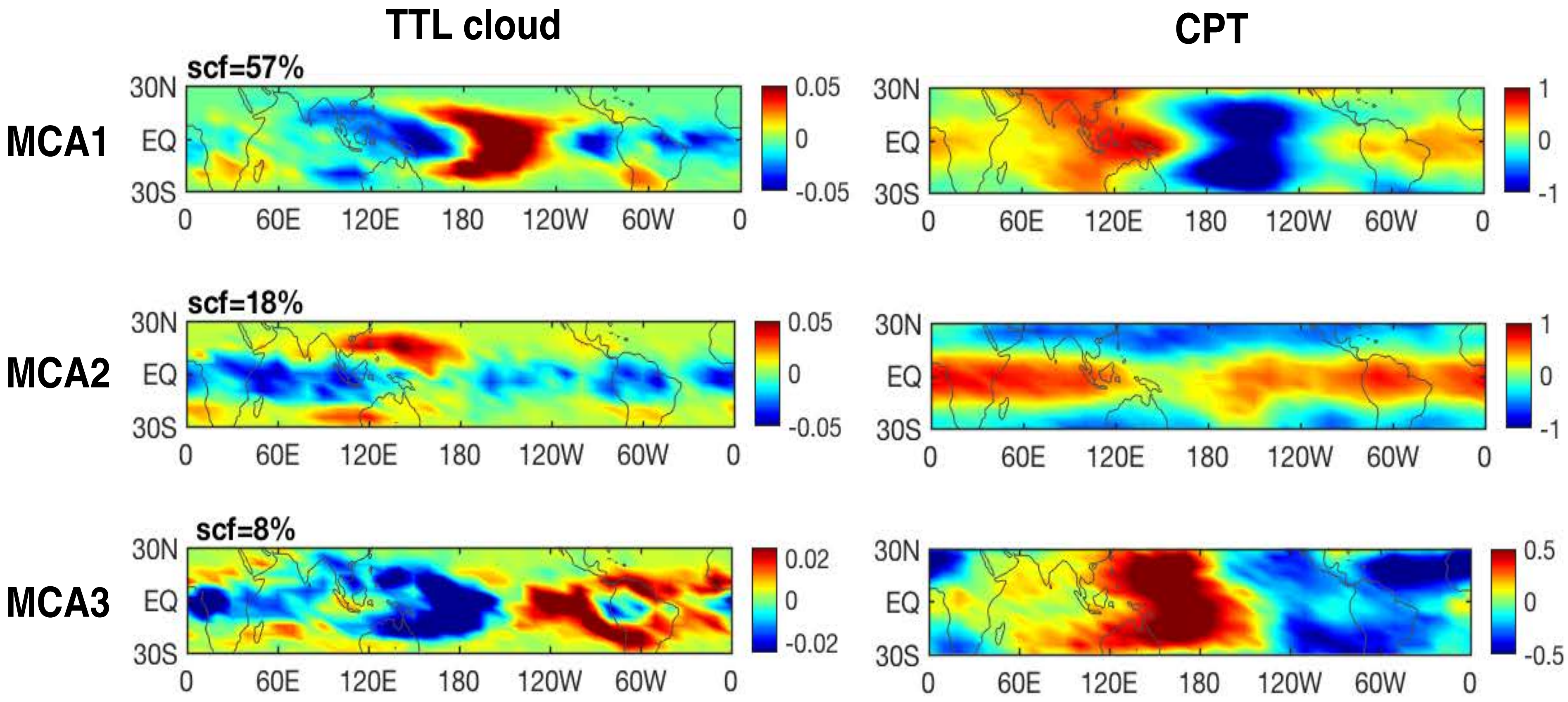

Seasonal
Interannual
(a)
r=-0.98
CPT* [°C]
CF* [%]
Annual Mean CPT = -82.22 °C
Annual Mean CF = 20.75%
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
(b)
r=-0.64
CPT′ [°C]
CF′ [%]
2007 2008 2009 2010 2011 2012 2013 2014

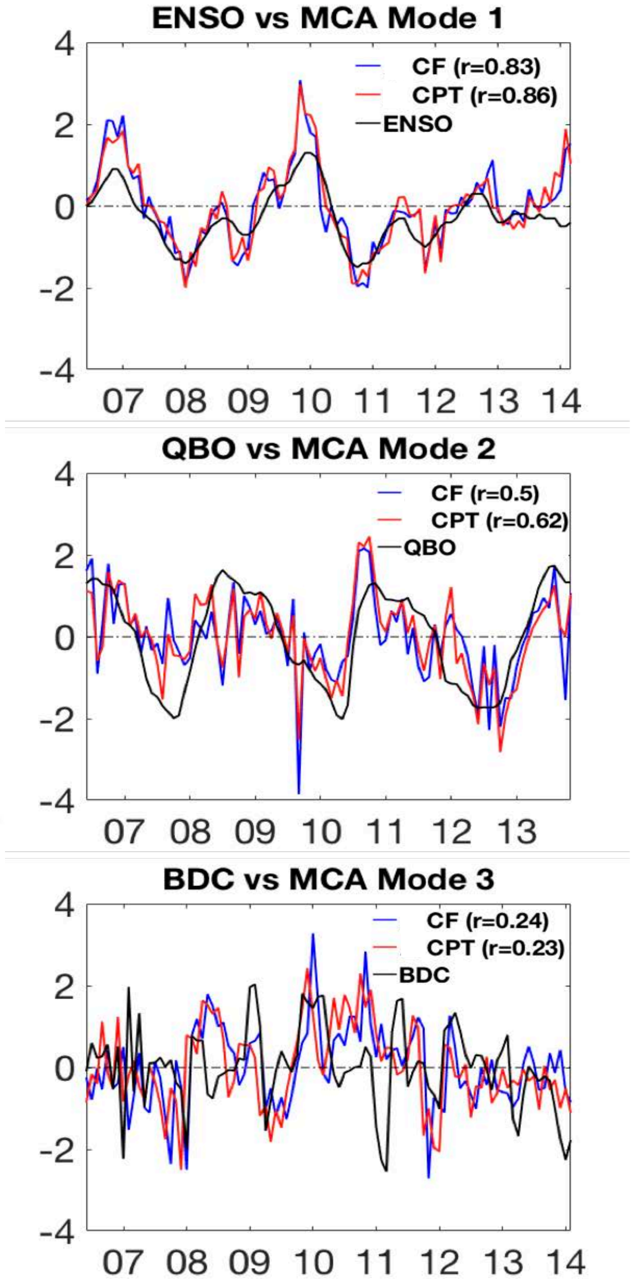
# Plausible Mechanisms

- Ice particle sedimentation
- Cooling associated with wave activities: dT'/dt have the same sign as dT'/dz, thus dT'/dz< 0 implies that a local air parcel experiences cooling (Kim et al. 2016).
- Change of atmospheric instability
- Vertical gradient of water vapor mixing ratio: dT/dz< 0 leads to larger vertical gradient of water vapor mixing ratio that favor the TTL cloud maintenance (Dinh et al. 2010).

# Spatial co-variability between the TTL clouds and tropopause temperature from MCA* and their relations to the large-scale dynamic variability

*Maximum covariance analysis (MCA) looks for patterns in two space-time datasets which explain a maximum fraction of the covariance between them (Wallace et al. 1992).




- The ENSO and QBO are the leading factors that control the spatial variability of temperature and cirrus clouds in the TTL while the BDC plays a secondary role.

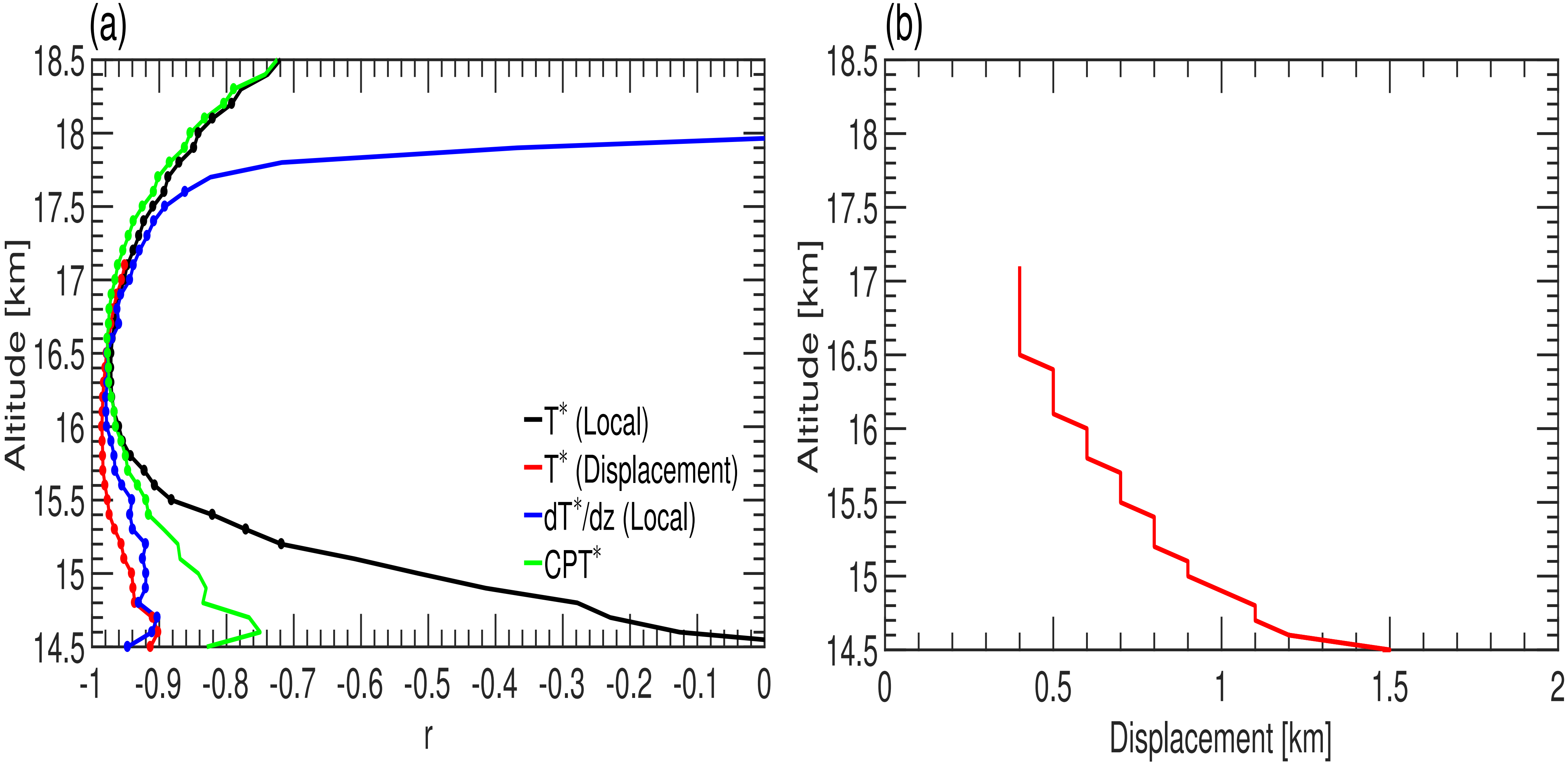
- For the TTL cloud fraction and cold point temperature averaged over 15°N-15°S, the QBO signal is dominant while the ENSO/BDC signal becomes secondary (Davis et al. 2013).

| Climate index | CF' | CPT' |
|---|---|---|
| ENSO | 5.5% | 1.1% |
| QBO | 12.7% | 28.5% |
| BDC | 4.4% | 0.1% |

# Conclusions

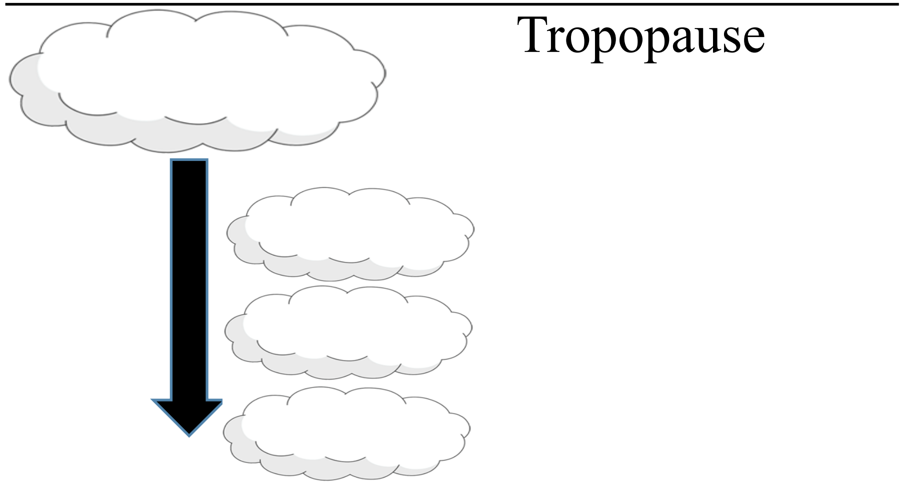
- The temporal variability of vertical structure of TTL cirrus cloud fraction can be well explained by the temperature vertical gradient variability for both the seasonal and interannual scales.
- The TTL cirrus cloud fraction at a given altitude is best correlated with the temperature at a higher altitude and this displacement decreases with height.
- The ENSO and QBO are the leading factors in controlling the spatial variability of the TTL cirrus clouds while the QBO becomes dominant in determining the variability of the zonal mean TTL cirrus cloud fraction.

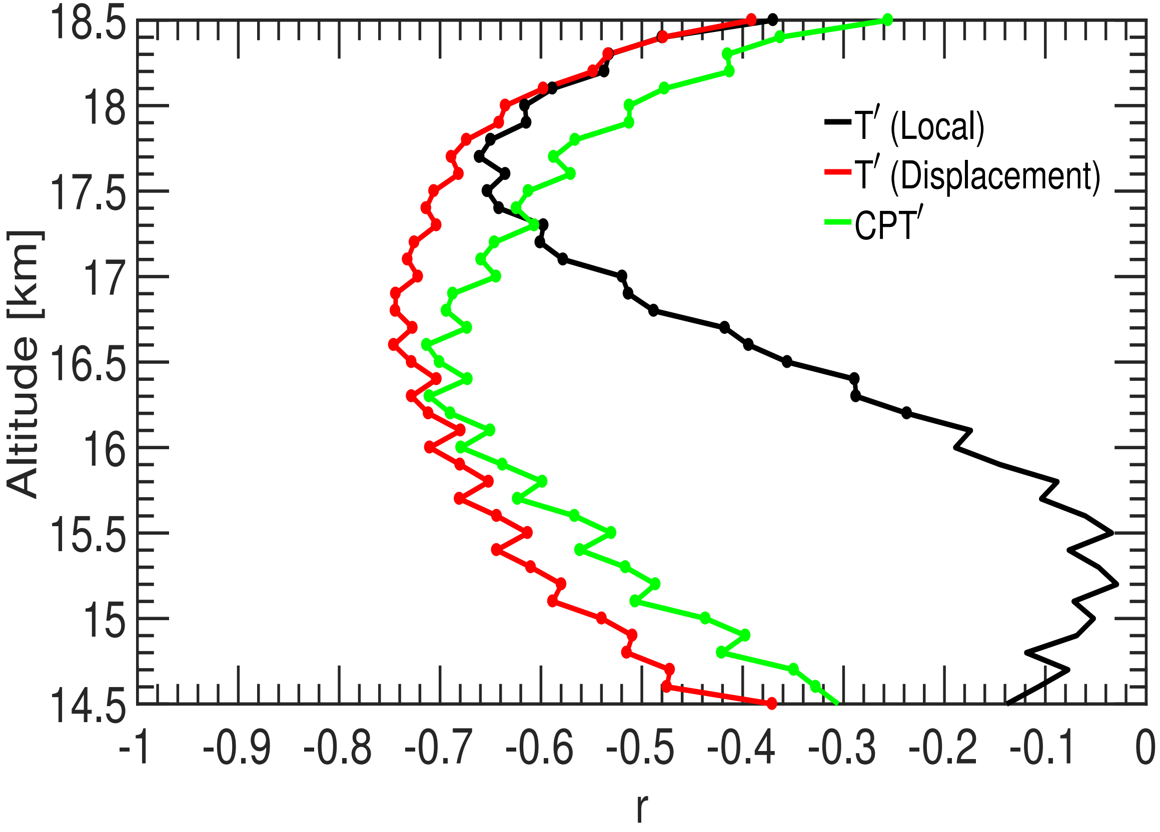
Seasonal variability



# Plausible Mechanisms

## 1. Sedimentation

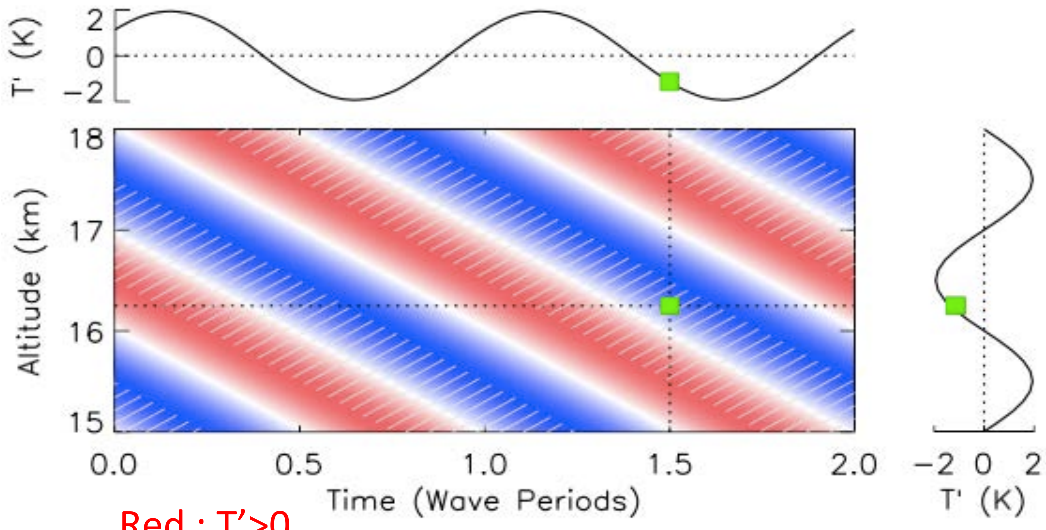


# Plausible Mechanisms

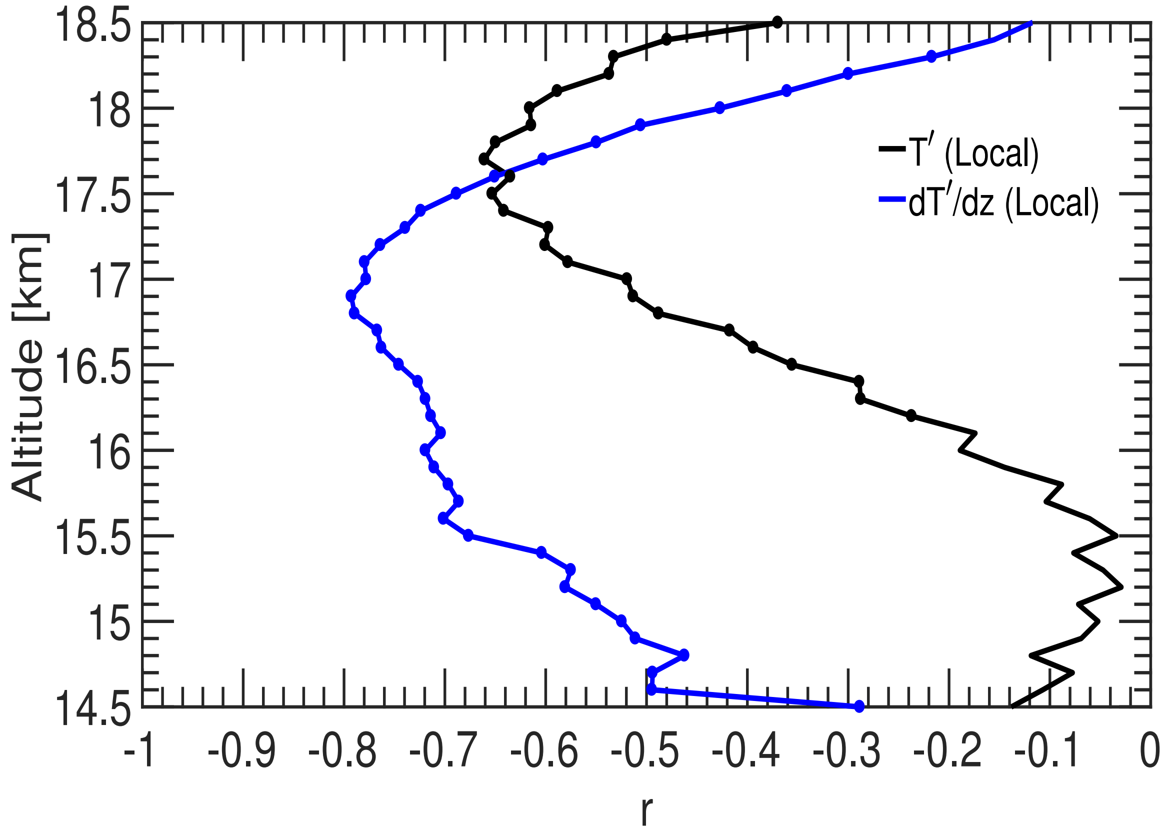
1. **Sedimentation**
2. **Cooling**

Typical wave anomaly structure in the TTL




Red : T’>0
Blue: T’<0
Hatching: dT’/dz<0

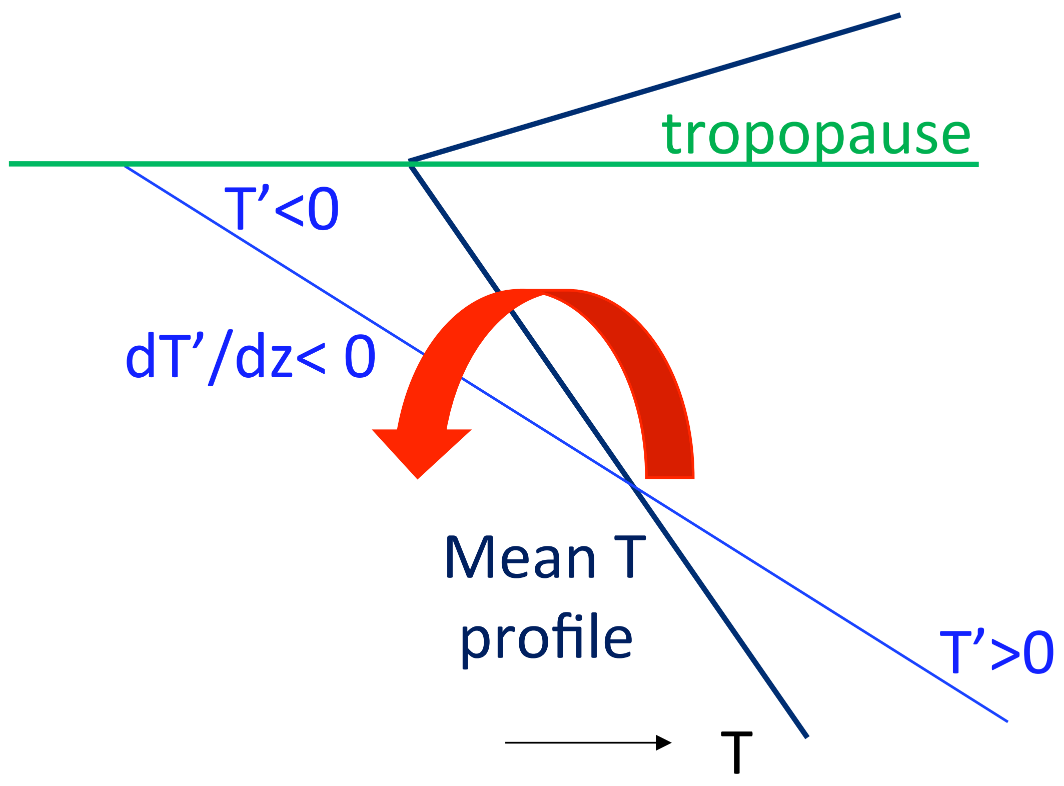
*Kim et al.* [2016]

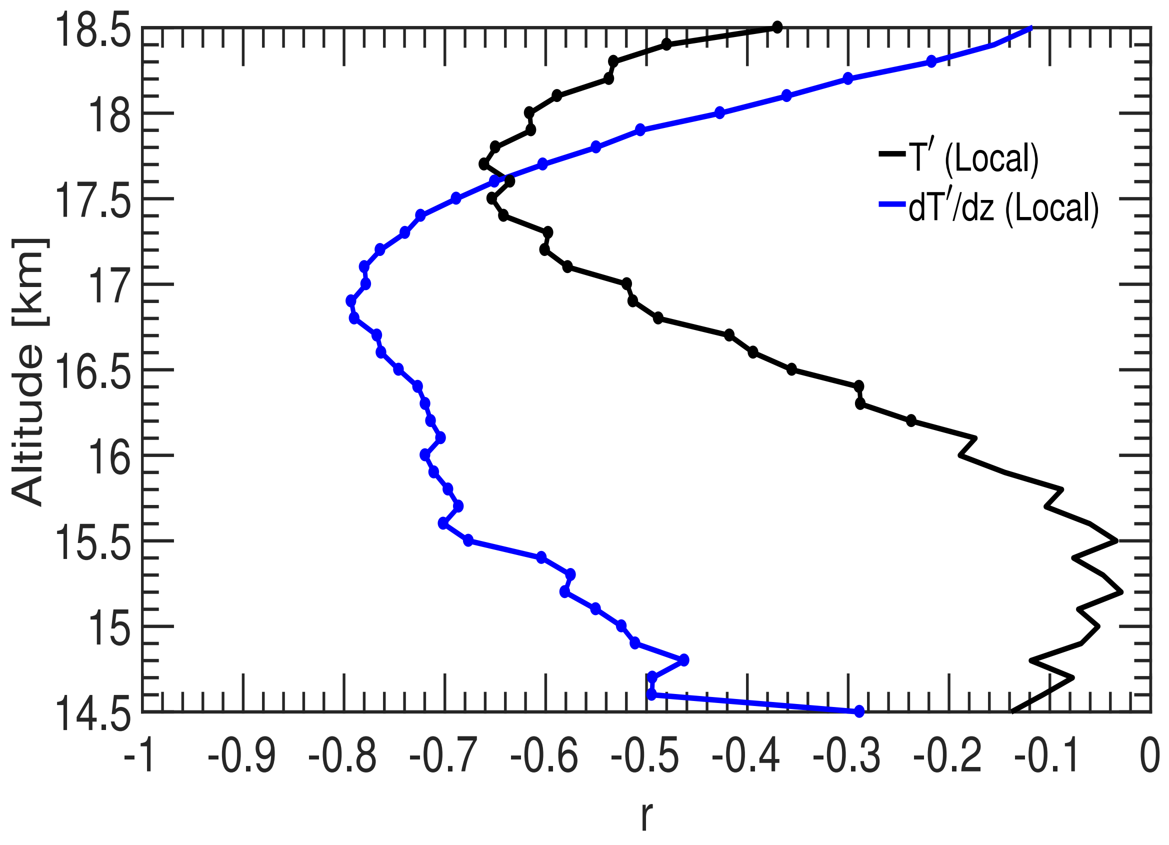



dT'/dt have the same sign as dT'/dz, thus dT’/dz< 0 implies that a local air parcel experiences cooling (Kim et al. 2016).

# Plausible Mechanisms

**1. Sedimentation**
**2. Cooling**
**3. Change of atmospheric instability**

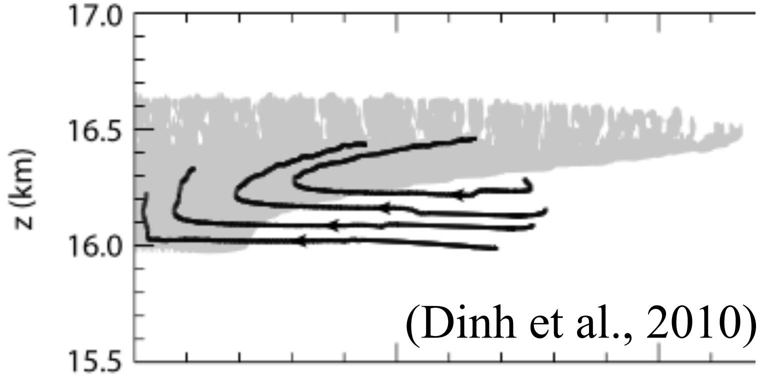



dT'/dz<0
-> Unstable
-> Upwelling
-> Cloud formation/maintainence

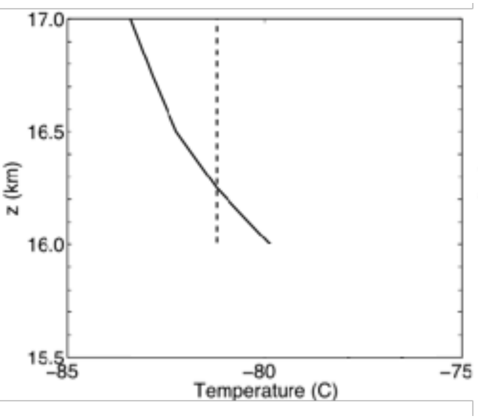
# Plausible Mechanisms

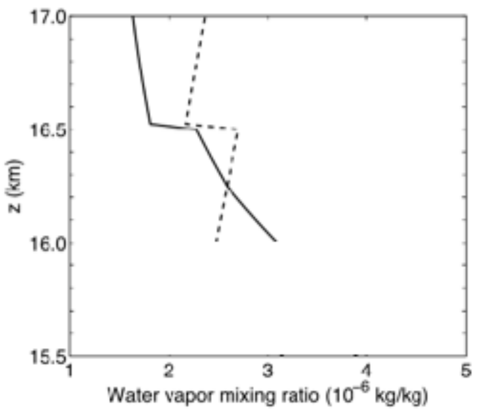
1. Sedimentation
2. Cooling
3. Change of atmospheric instability
4. Vertical gradient of water vapor mixing ratio (w)



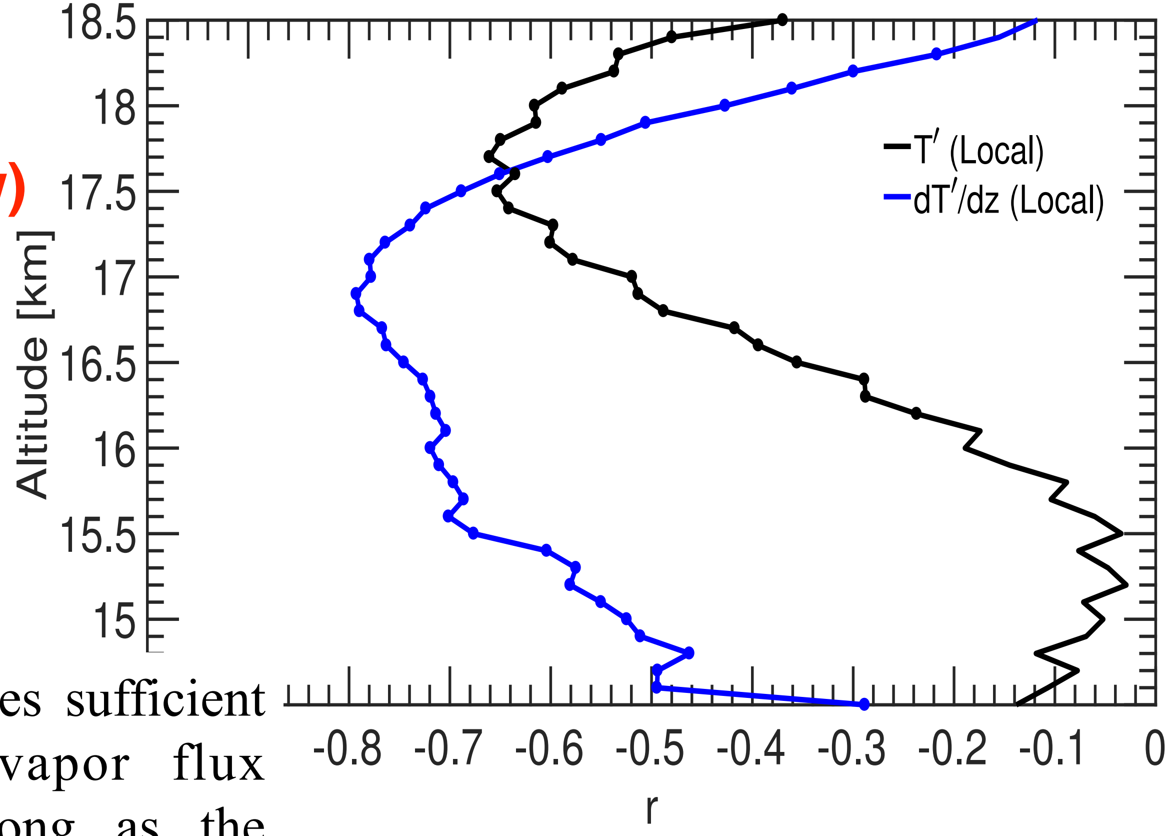

(Dinh et al., 2010)

The key to the maintenance of the TTL clouds is the circulation thermally forced by the cloud radiative heating.



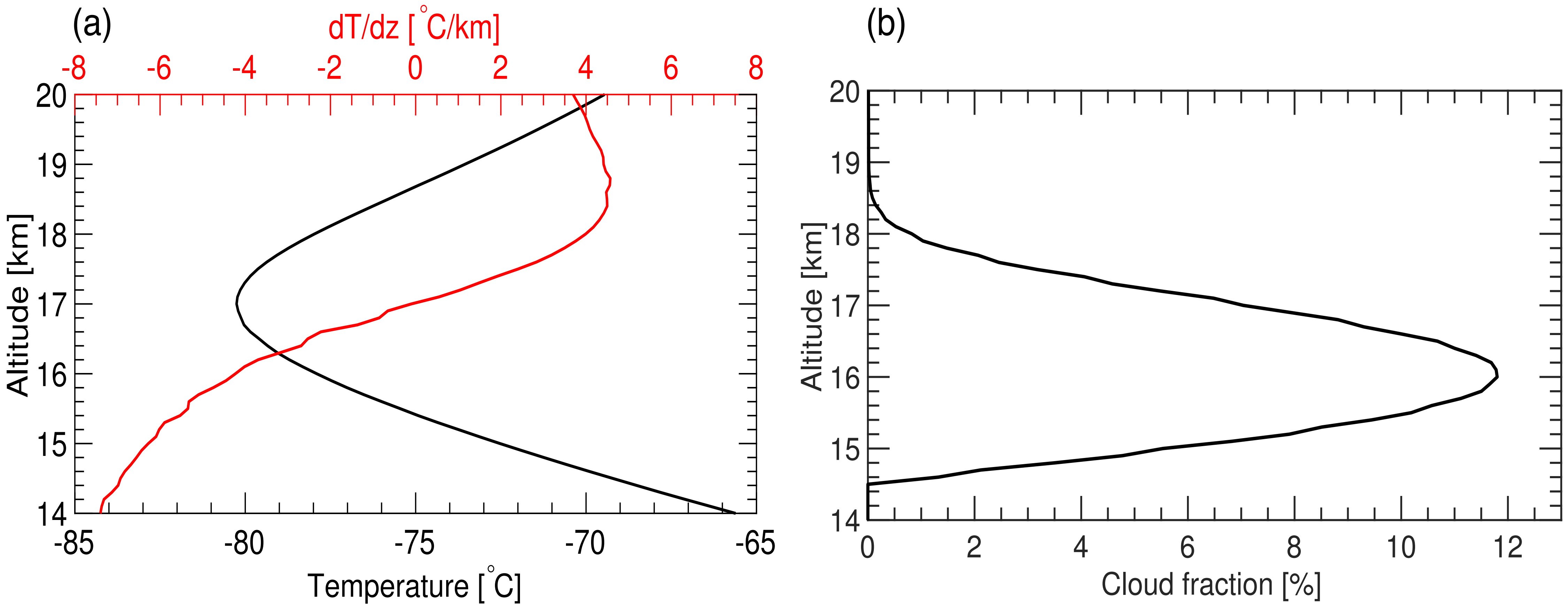




Circulation produces sufficient in-cloud water vapor flux convergence as long as the temperature decreases with height (water vapor mixing ratio decrease with height).

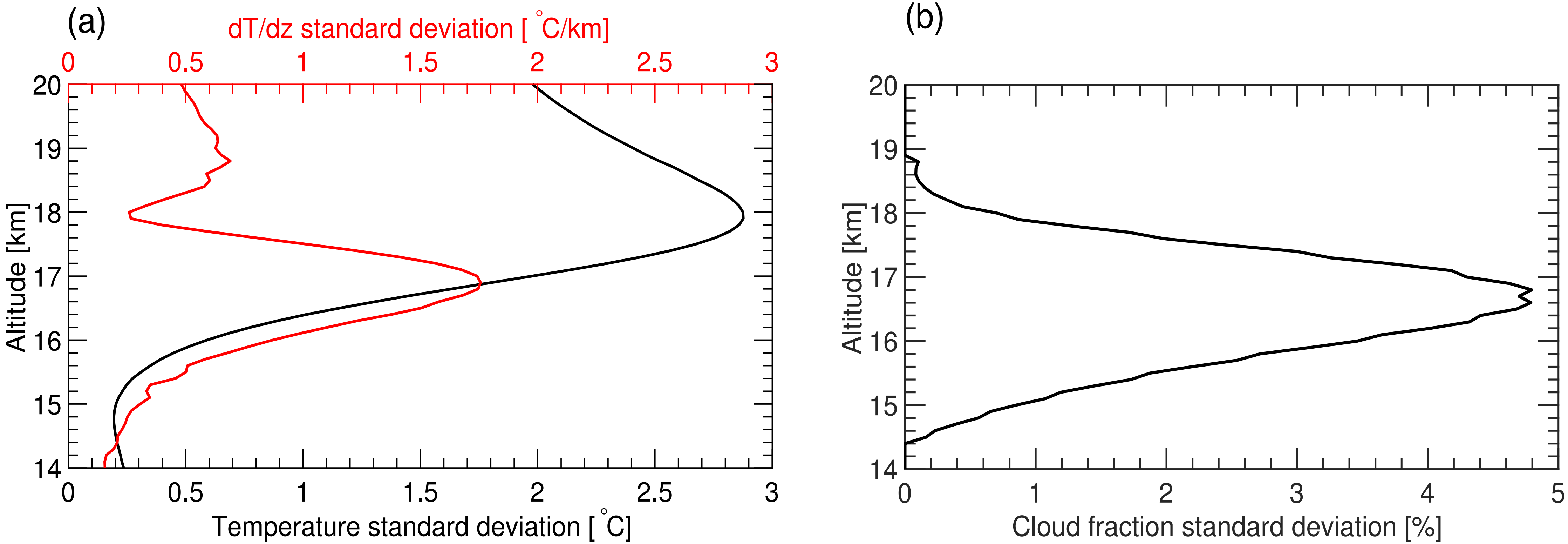



dT′/dz< 0 leads to larger vertical gradient of water vapor mixing ratio that favor the TTL cloud maintenance.

# Climatology mean



# Seasonal variability



# Interannual variability