Localtime-dependent structures in the Venusian atmosphere revealed by Akatsuki radio occultation measurements

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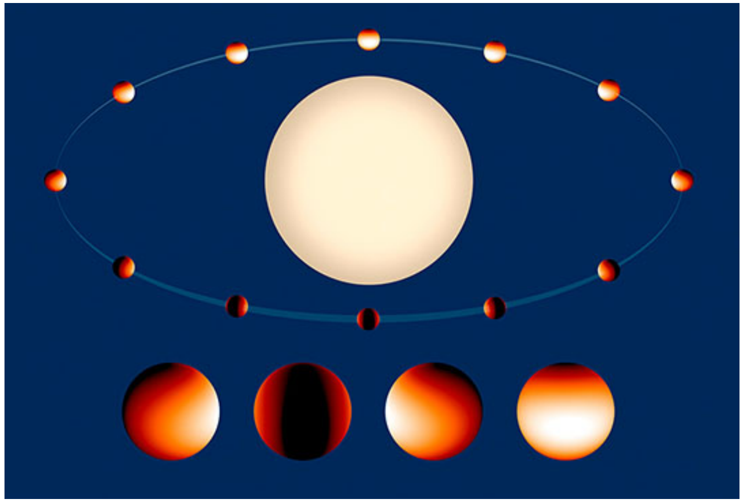
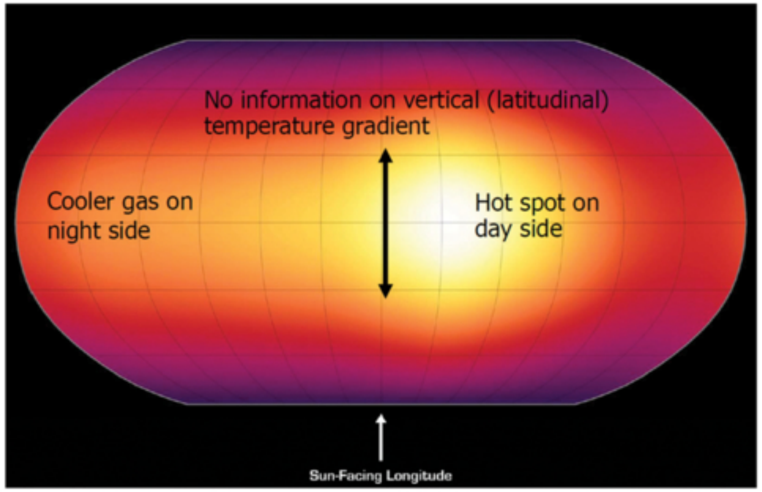
Diurnal variation on slow rotators

- Tidally-locked exoplanets are mostly slow rotators. Super-rotation can redistribute heat along the local time on such planets.
- Occurrence of superrotation is suggested for several exoplanets from the location of the temperature maximum.
- For constraining the climates of exoplanets, understanding of the response of a superrotating atmosphere to stellar radiation is crucial.





Knutson et al. (2007)

Diurnal variation on Venus

- Surface level:

  One solar day $\sim$ 0.3 year

  Radiative relaxation time $\sim$ 30 years

- Cloud level:

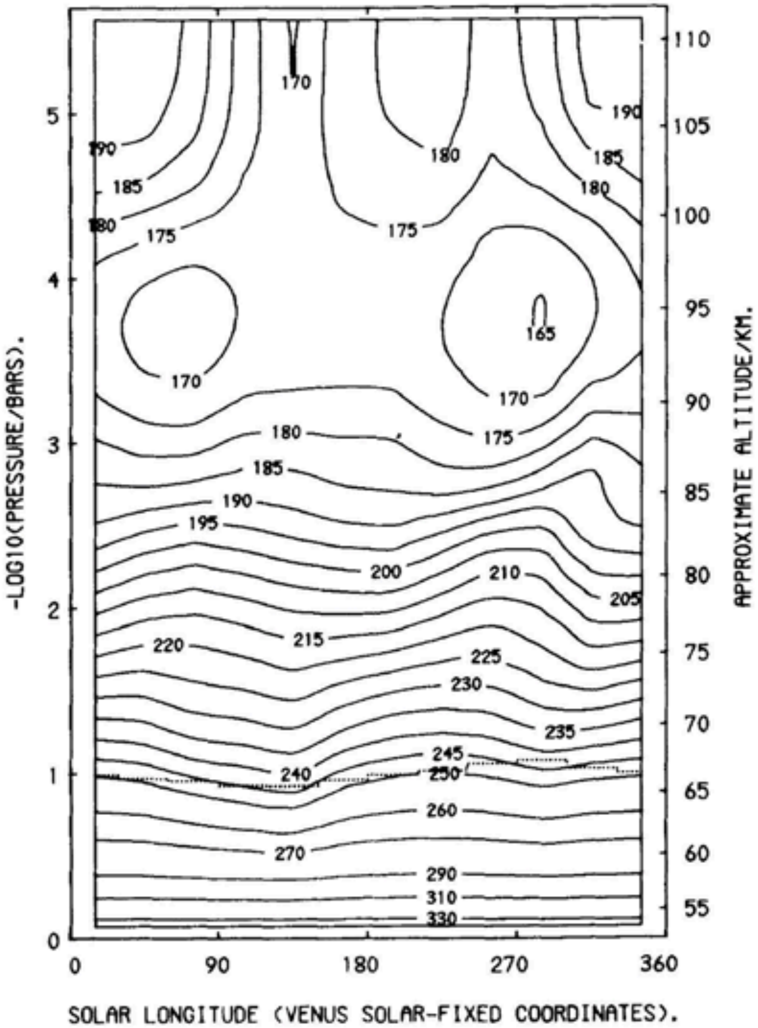
  One solar day (for atmosphere) $\sim$ 4 days

  Radiative relaxation time $\sim$ 100 days

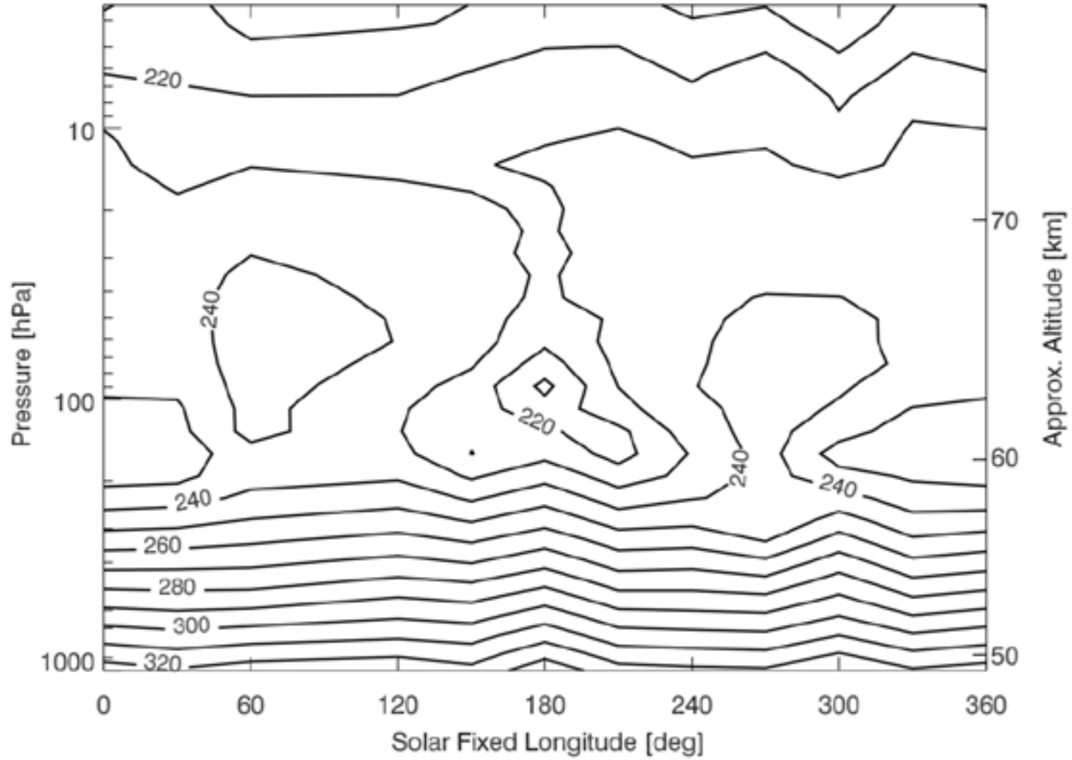
Temperature variation of 1-10 K is expected

Localtime-dependent structures

Thermal tides seen by PVO OIR (Schofield & Taylor 1983)

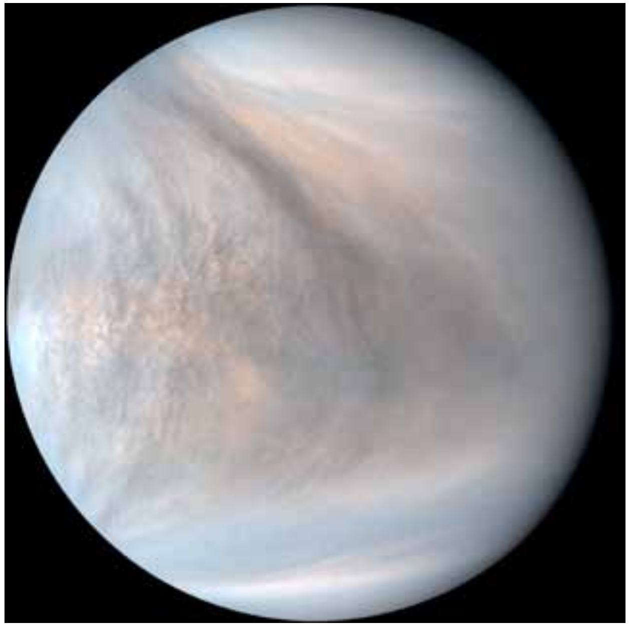


Thermal tides seen by VEx radio occultation (Tellmann et al. 2009)

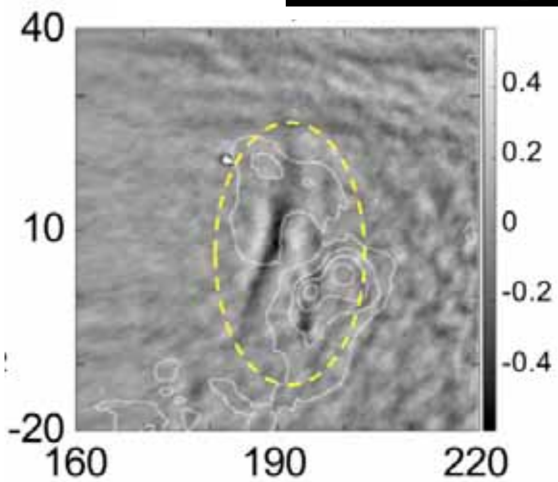


Localtime-dependent structures

Turbulent cloud features in UV from noon to afternoon



Topographic gravity waves in the afternoon

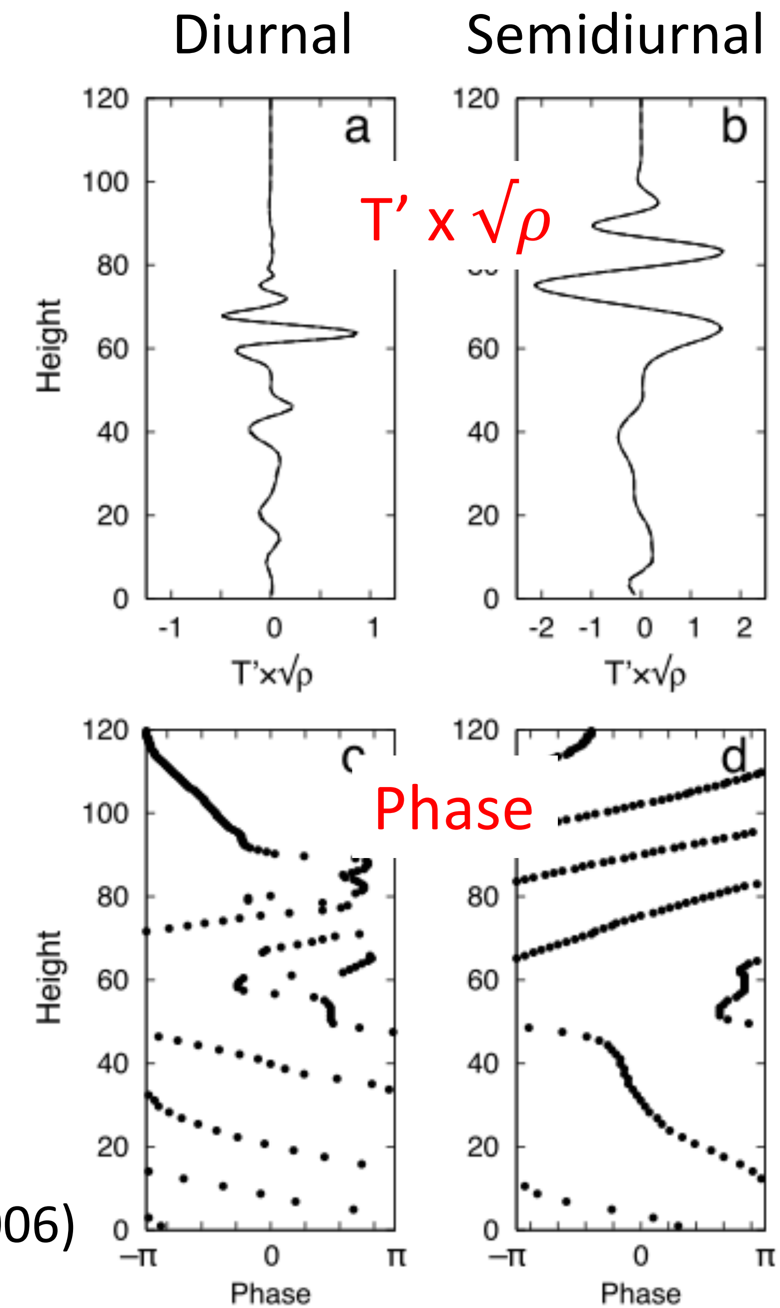


Akatsuki UVI: 283 nm
(Kitahara et al. JGR, 2019)

Unresolved issues

Propagation of thermal tides from the cloud level to the lower atmosphere may induce vertical transport of angular momentum between the upper atmosphere and the surface to maintain the superrotation (Takagi et al. 2007).

Are thermal tides exist also below the clouds ?



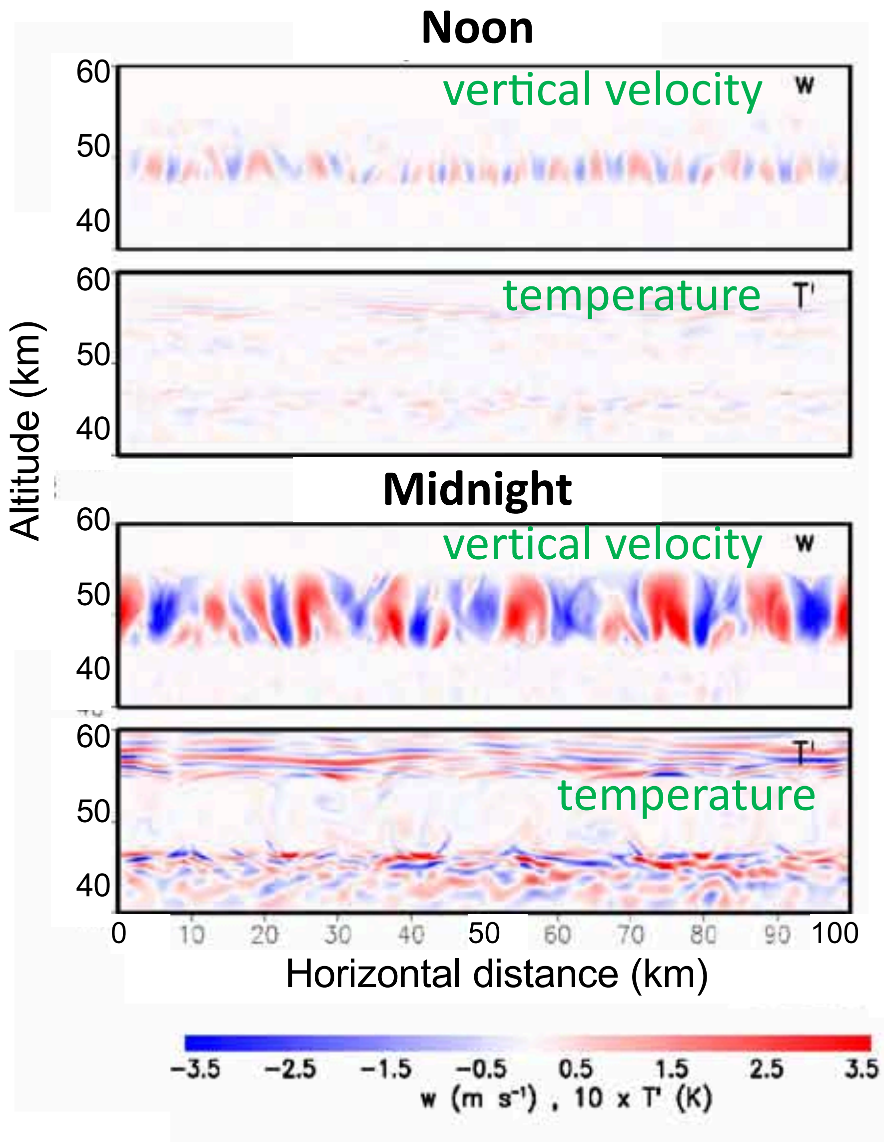
Takagi & Matsuda (2006)

Unresolved issues

Is the turbulent feature around noon a manifestation of intensified cloud-level convection?

Mesoscale models suggest that stronger convection occurs on the *nightside* due to stronger radiative cooling of the upper cloud. (Imamura et al. 2014; Lefèvre et al. 2017)

How does the convective layer respond to solar heating?

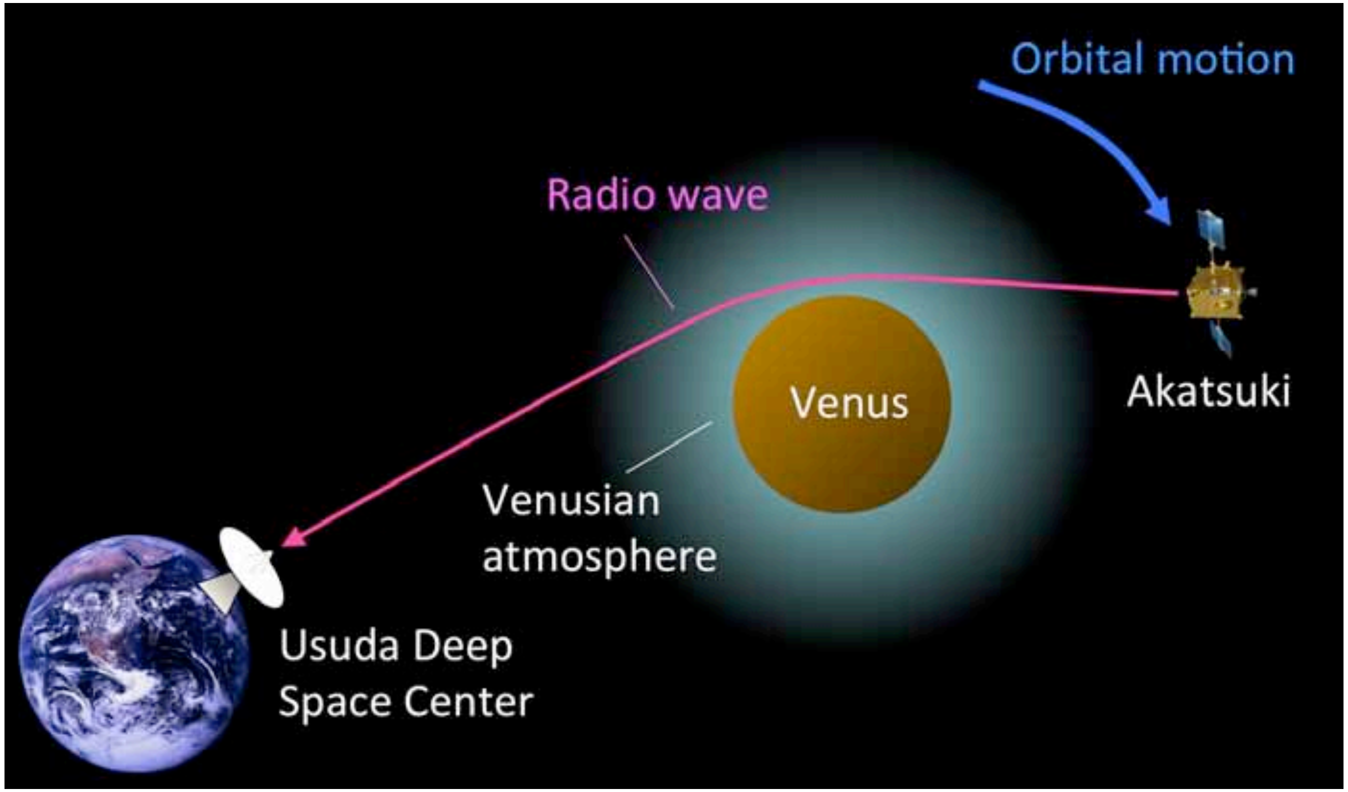


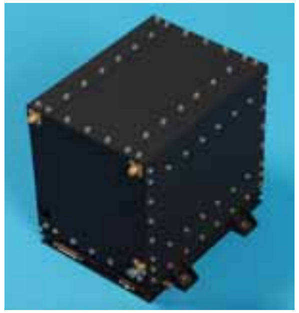
Imamura et al. (Icarus, 2014)

Akatsuki radio occultation experiment

- To determine the vertical distributions of the temperature, pressure, H_2SO_4 vapor and electrons
- An ultra-stable oscillator is onboard as a stable frequency source

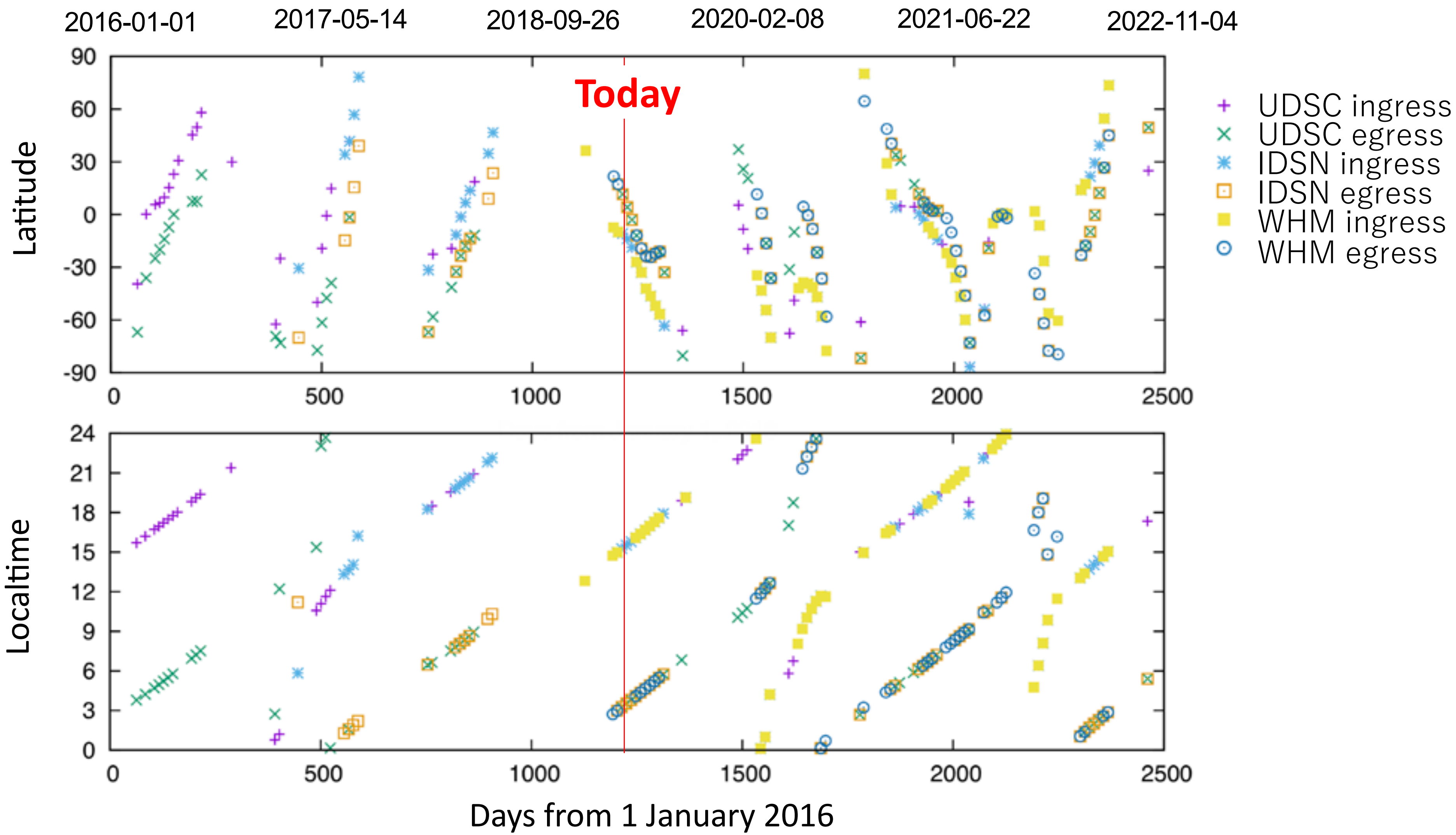
UDSC (JAXA)
IDSN (ISRO)
WHM (Germany)





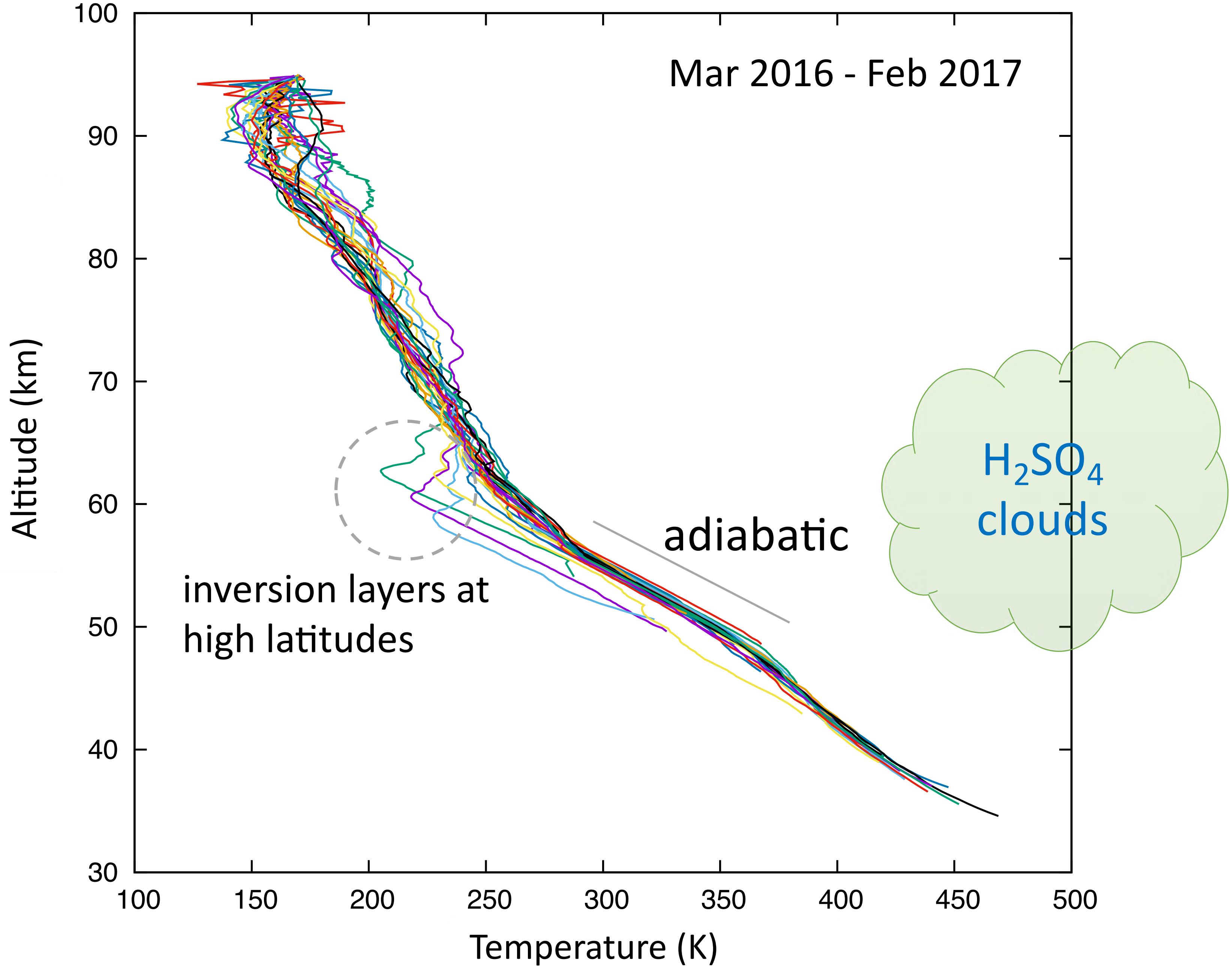
Ultra-stable oscillator (Timetech)

Distribution of observations

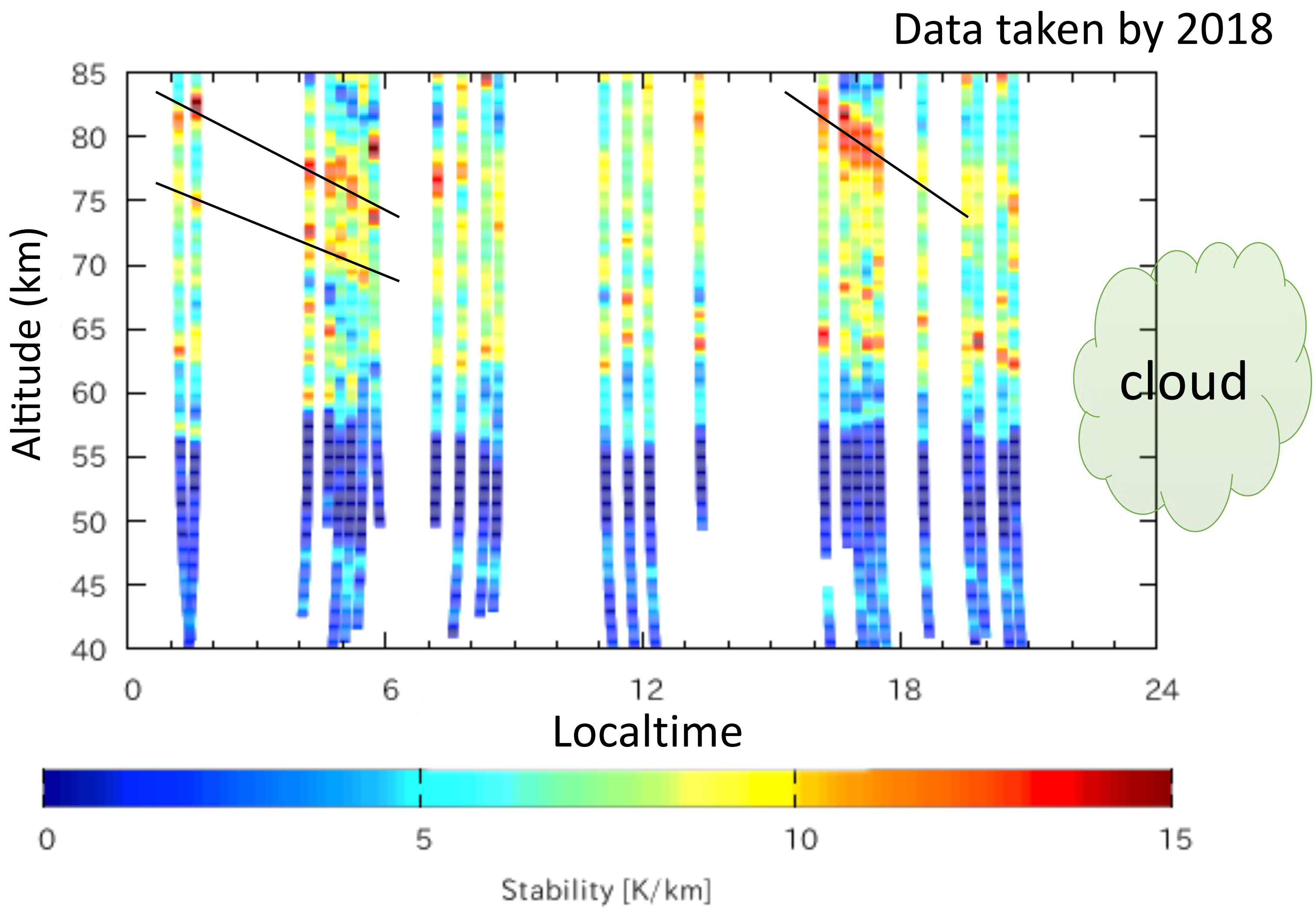


The equatorial orbit allows a relatively dense sampling in the low latitude

Examples of the temperature profile

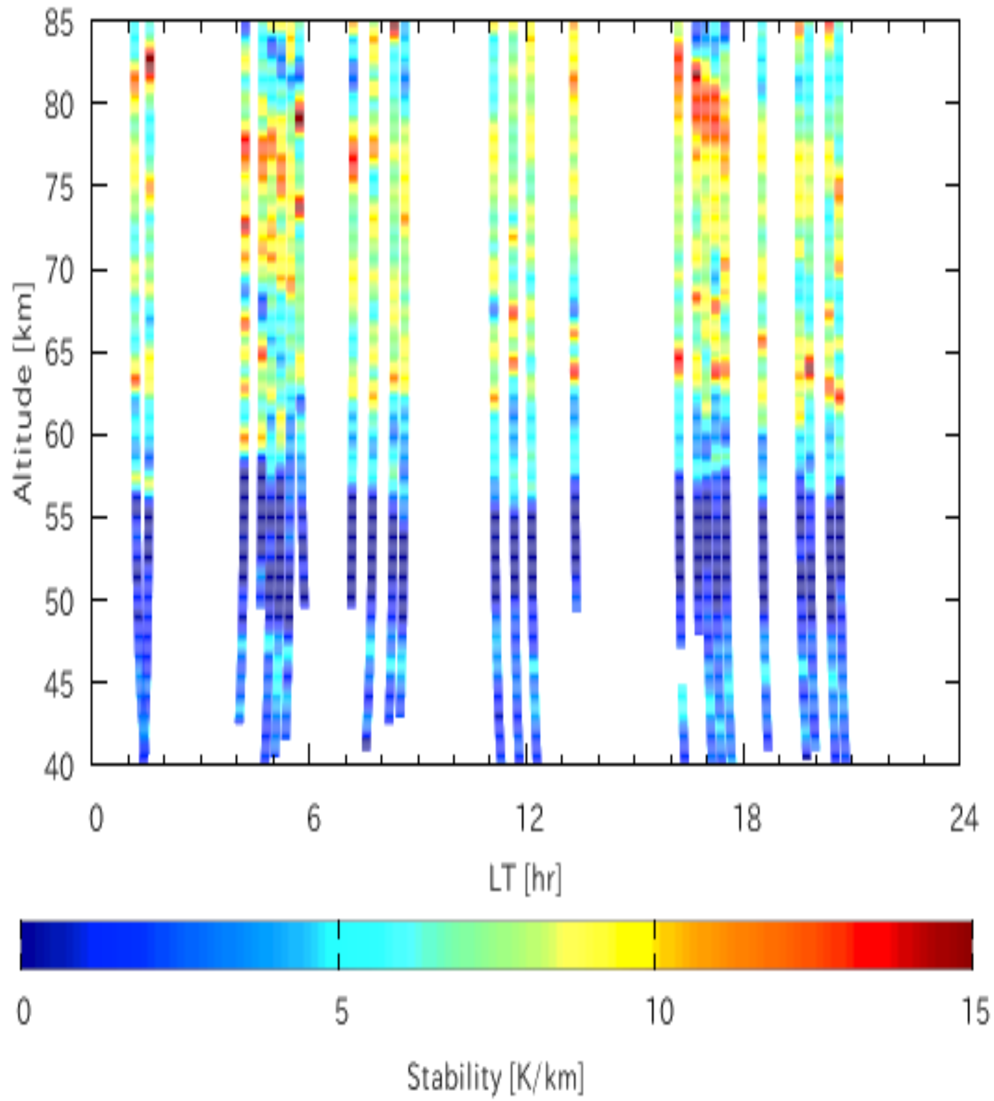


Localtime dependence of static stability (< 40°)

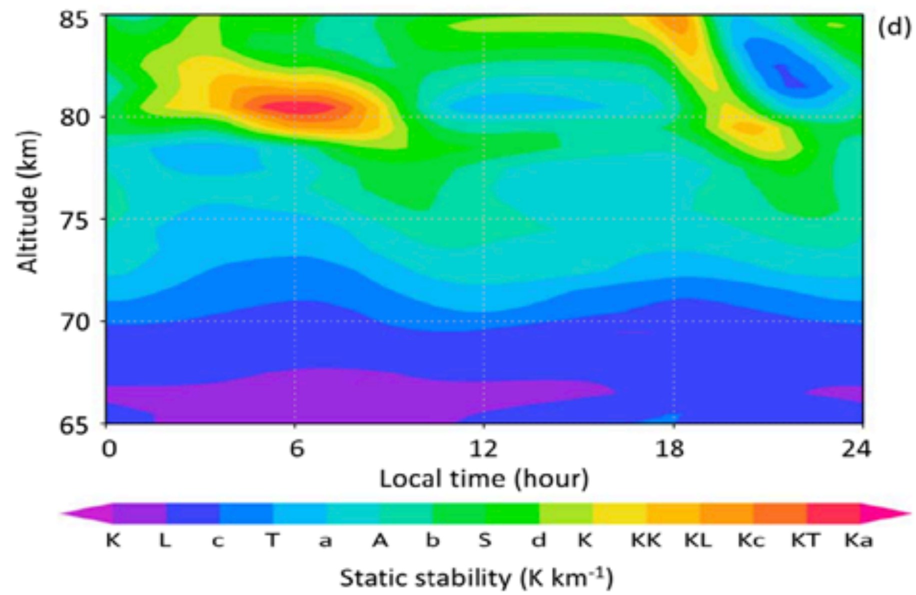


Phase tilt indicative of thermal tides is seen

Localtime dependence of static stability (< 40°)



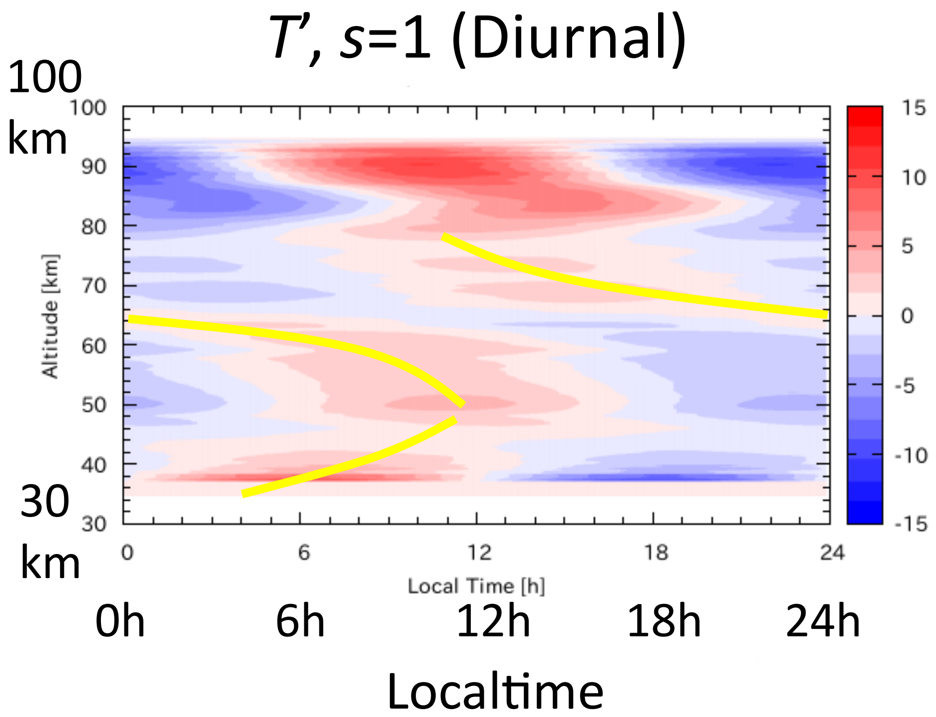
Static stability in Venus GCM

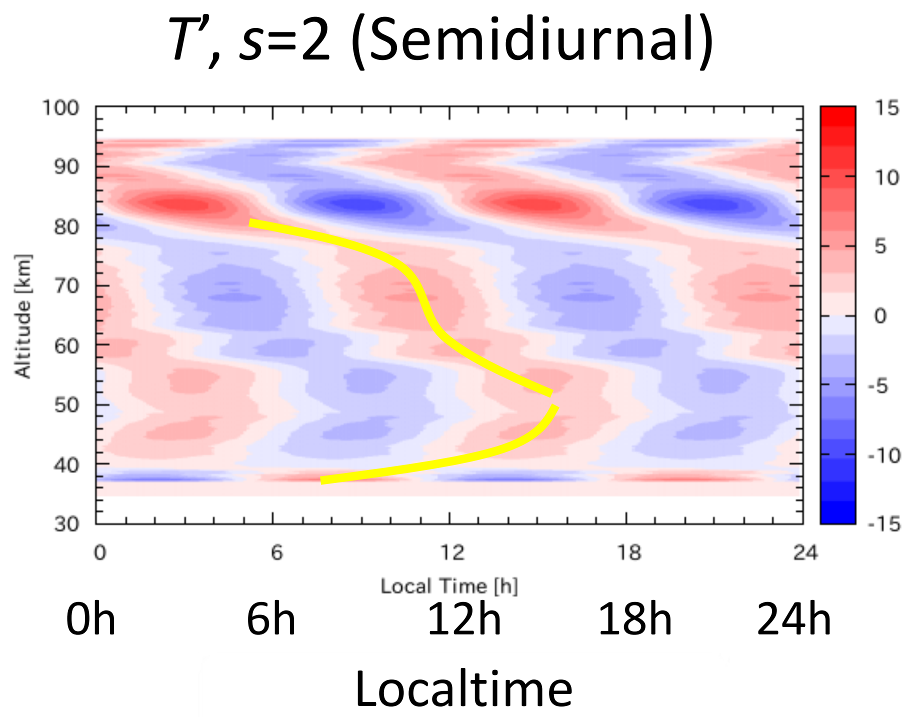


Ando, Takagi, et al. (JGR, 2018)

Finer structures are seen in the observation than the model.

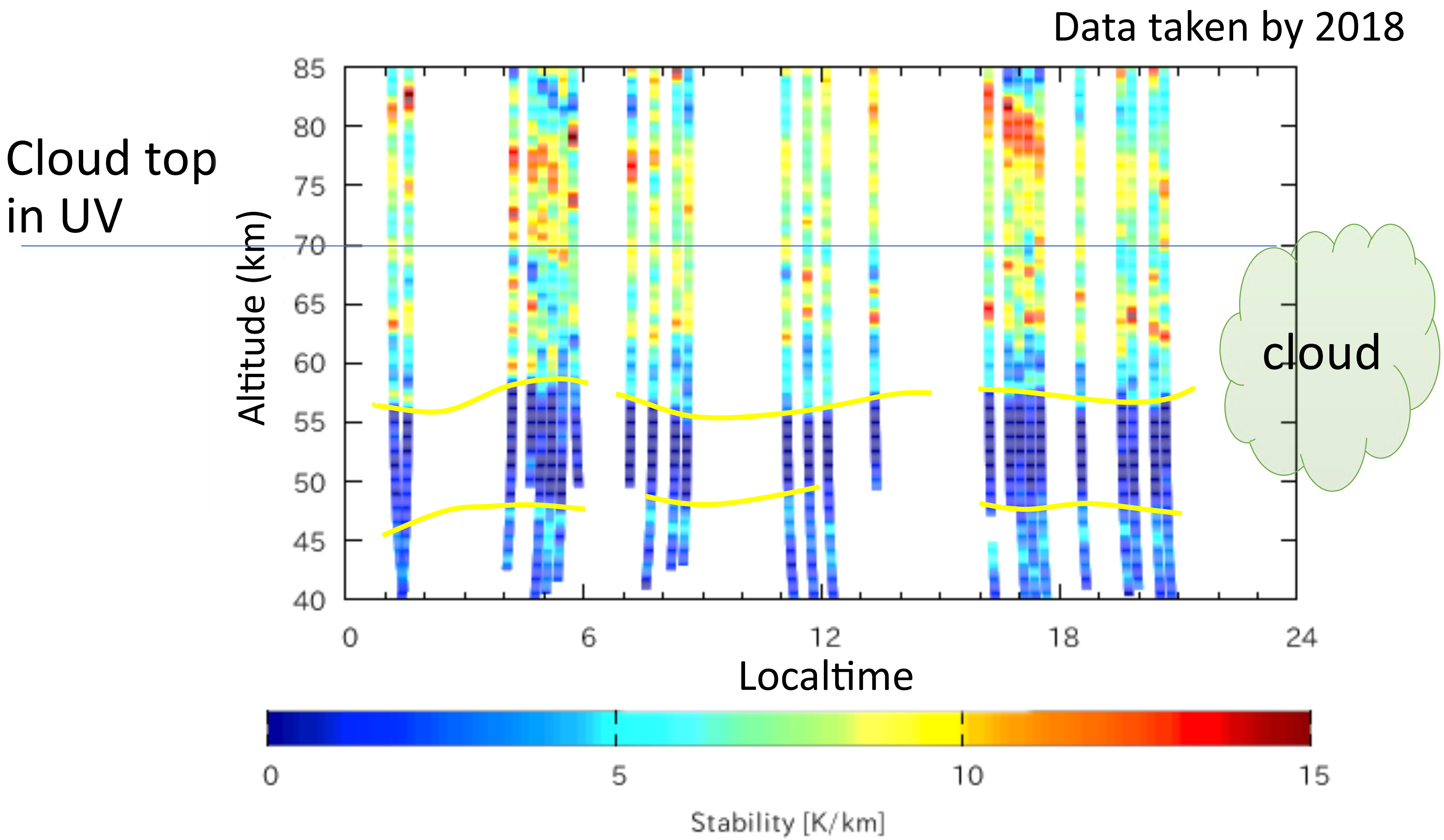
s = 1 and 2 harmonics (*Preliminary*)





Downward propagation below the clouds is suggested.
(More data filling the localtime gaps will be obtained soon)

Localtime dependence of static stability (< 40°)



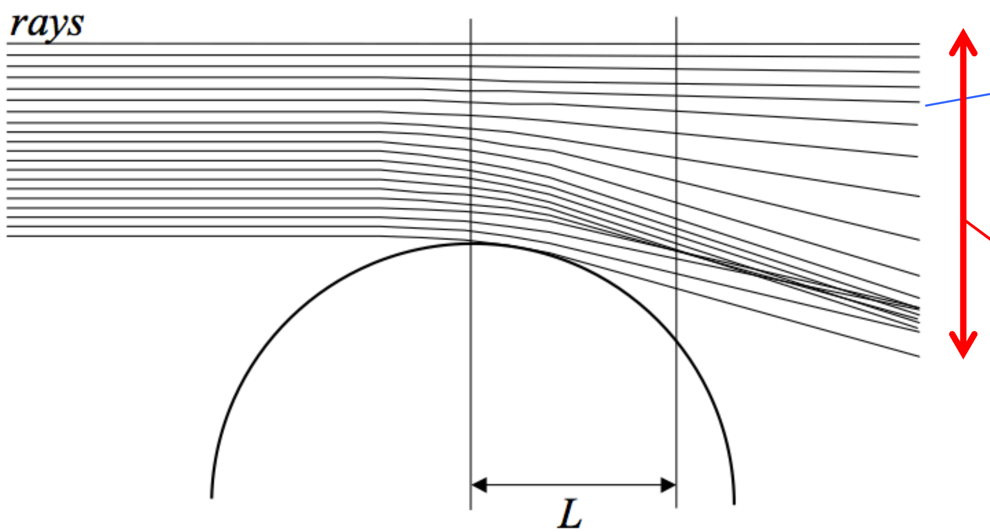
The neutral layer is even thinner on the dayside.

Extension to the cloud top is not seen.

Radio holographic analysis of Venus Express and Akatsuki radio occultation data (Imamura et al., JGR, 2018)

- One of the radio holographic methods, FSI ("Full Spectrum Inversion" Jensen et al. 2003) is applied to RS data.
- Spectral analysis is applied to the entire signal at once instead of applying it to successive short time blocks.

→High vertical resolution + Disentanglement of multipath

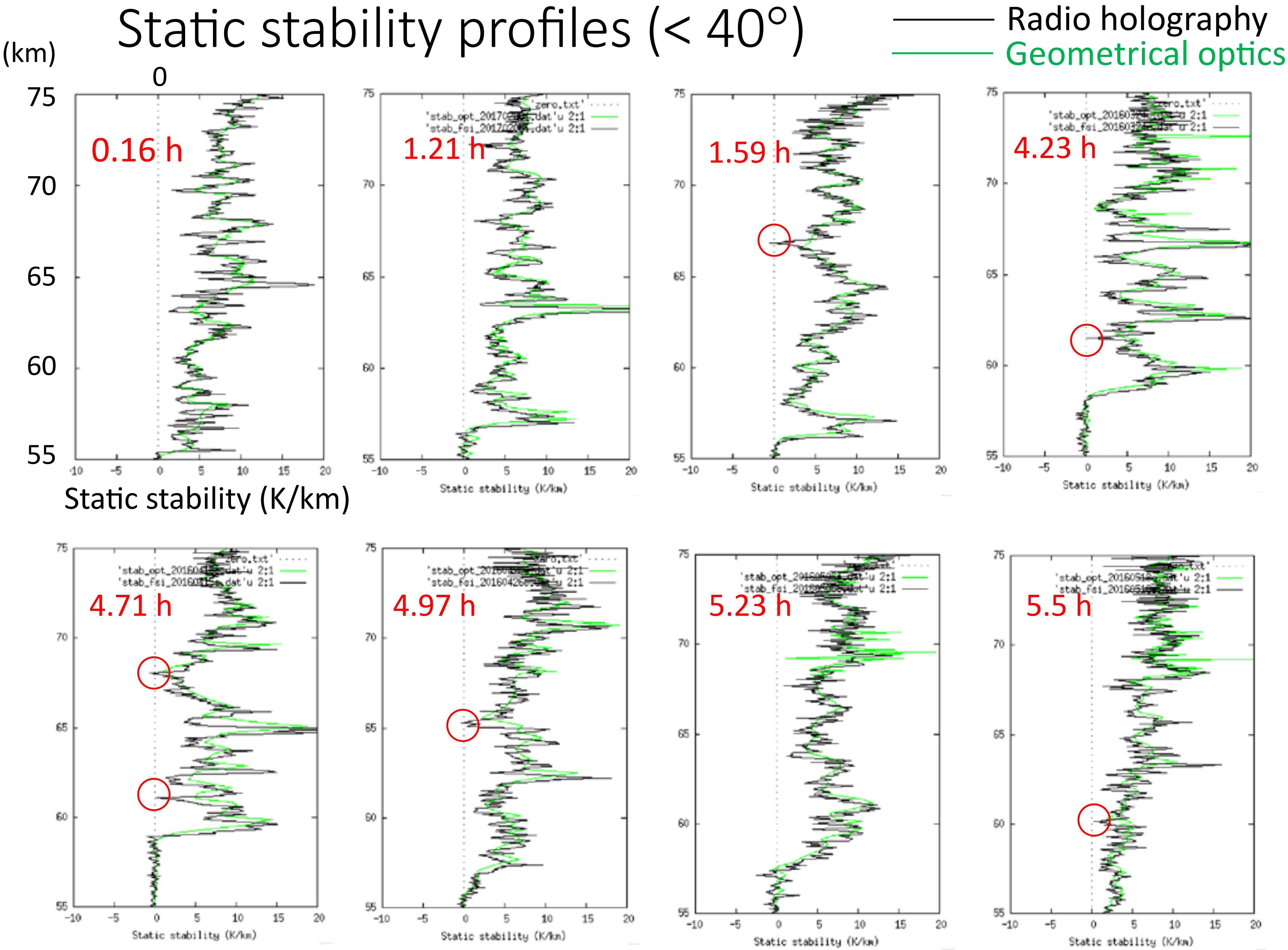


Geometrical optics solves the instantaneous ray path at each time step

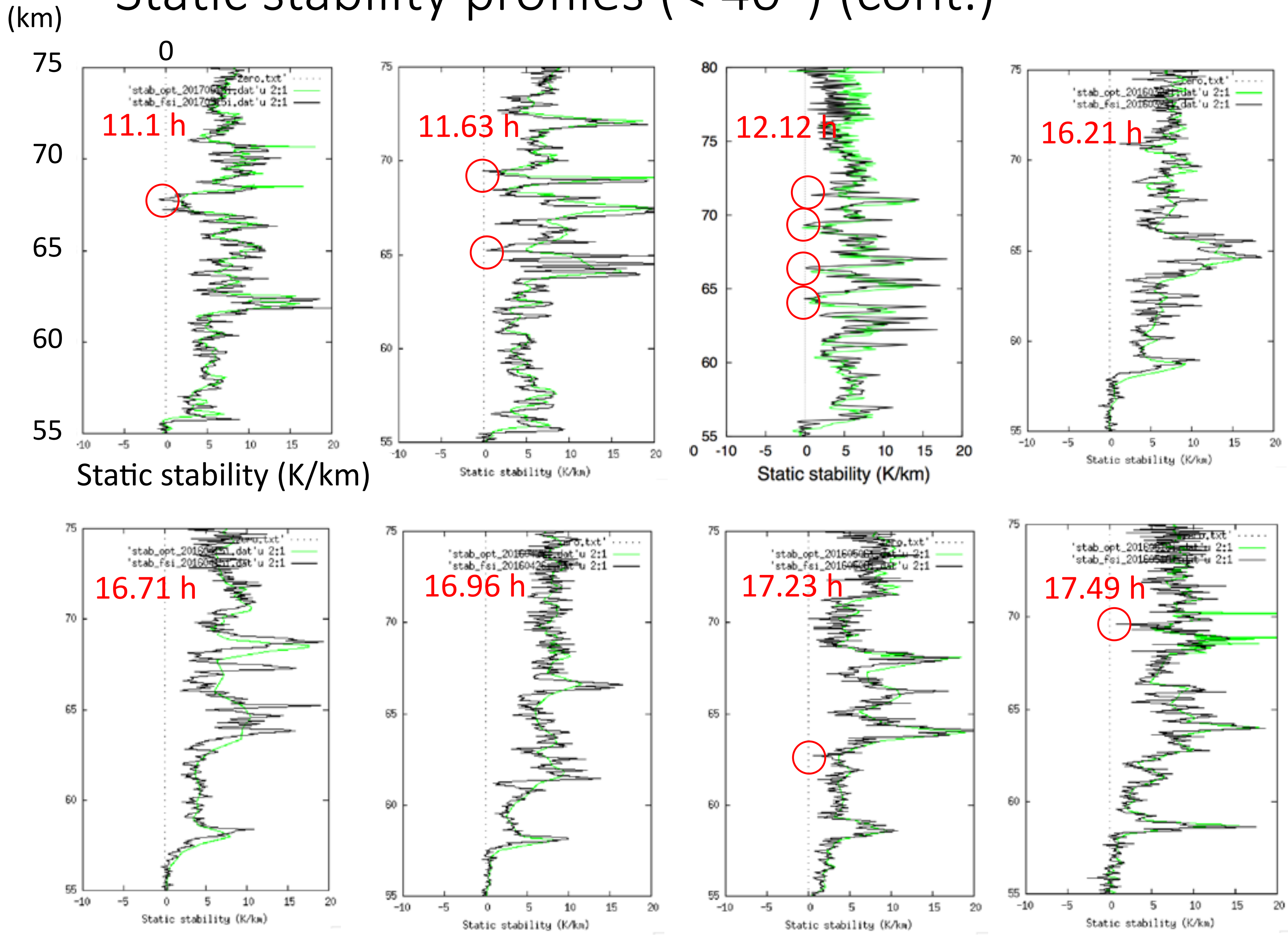
FSI solves the whole time series of the signal phase at once

Schematic of multipath (Sokolovskiy, 2004)

Static stability profiles (< 40°)



Static stability profiles (< 40°) (cont.)



Summary

- Propagation of thermal tides was observed both above and below the clouds. The downward-propagating component may contribute to the maintenance of the superrotation.
- Localtime dependence of the thickness of the neutral layer in the cloud was revealed. The convection seems to be relatively suppressed on the dayside; the turbulent cloud feature around noon cannot be explained by deep vertical convection.
- Thin neutral layers detected by radio holographic analysis may suggest some unknown mesoscale processes related to the cloud-top turbulent feature.