Vertically fine structure of the stationary circulation in the upper troposphere over the Indian Ocean

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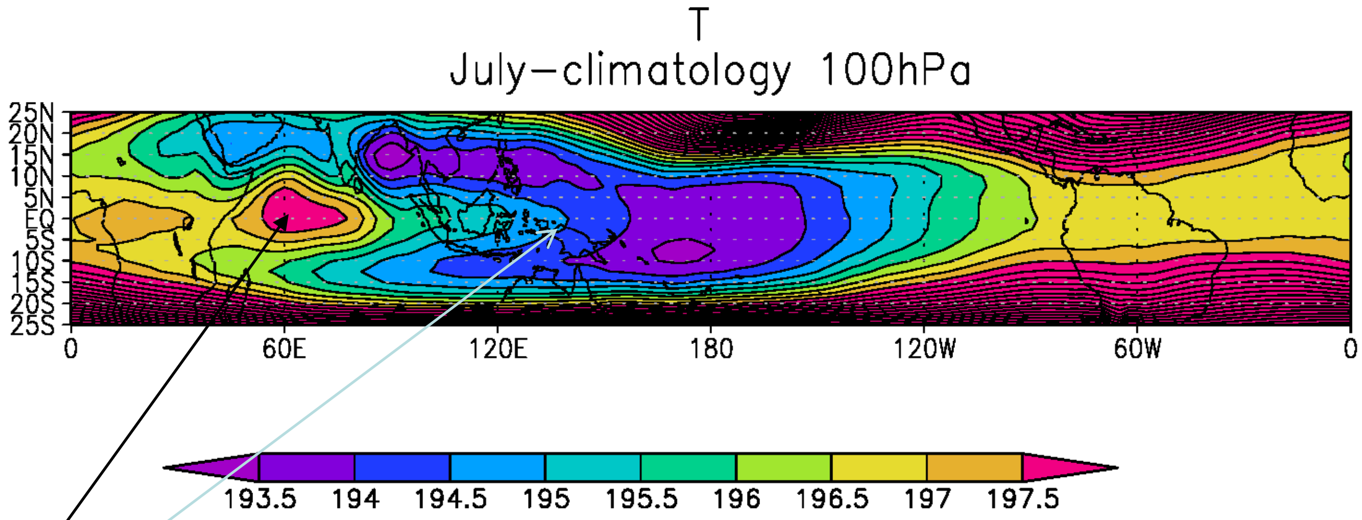
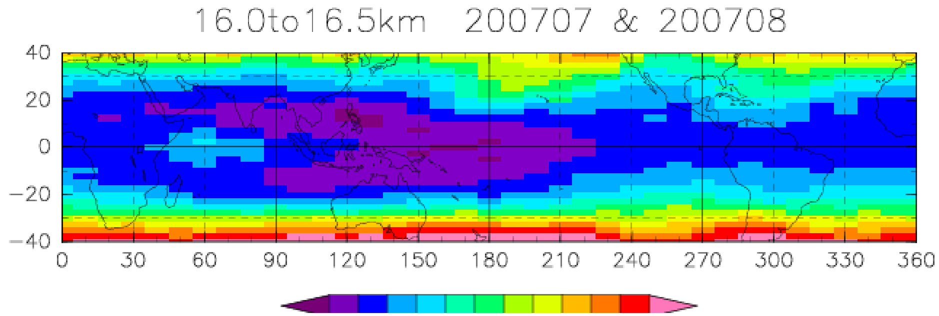
Warm anomaly: ERA-40 (1979-2001)



- The horseshoe pattern – Recognized as so-called ‘Gill pattern’
  - (e.g. Randel and Park 2006, JGR)
- Zonally and meridionally compact **warm** anomaly – 60E, 100hPa, June-September

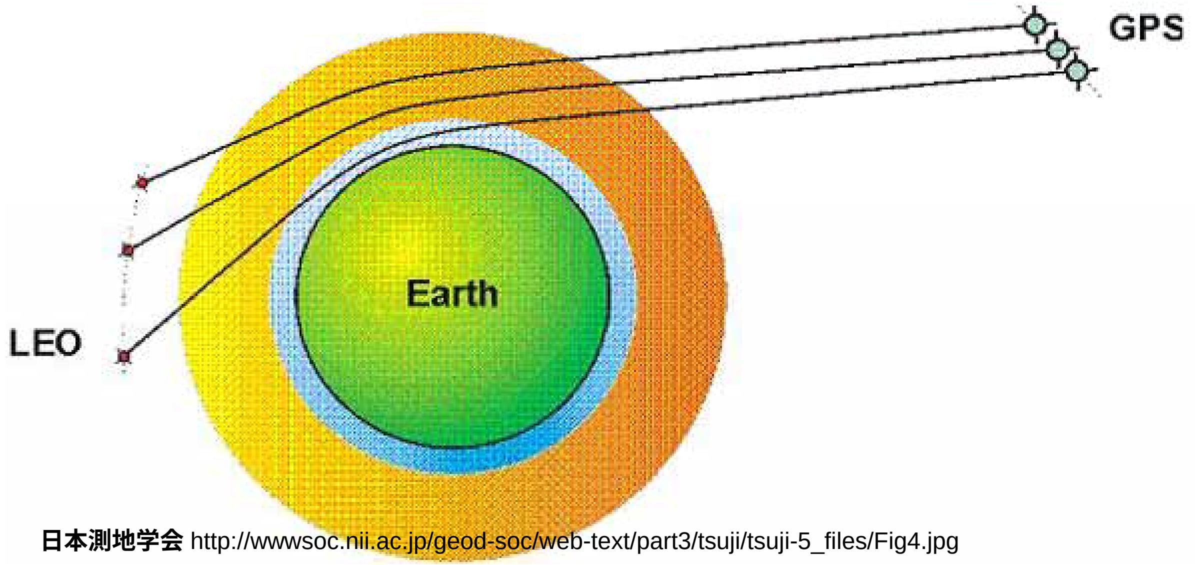
  The quasi-stationary structure -- Good target of COSMIC dry temperature data
  - ***Interesting vertically fine structure → shown soon later***
  - ***Rather large horizontal and temporal scale***
    - ***A large number of profiles by COSMIC – OK!***

Of course, in COSMIC data (July-August average 2007) →



GPS Radio Occultation

- Dry temperature data – obtained with the hypothesis that refractivity depends only on the temperature
  - This is reasonable in the upper troposphere / lower stratosphere
  - High accuracy and vertical resolution
- COSMIC
  - Since 2006
  - Large number of the observation by 6 LEO (low orbital) satellites.



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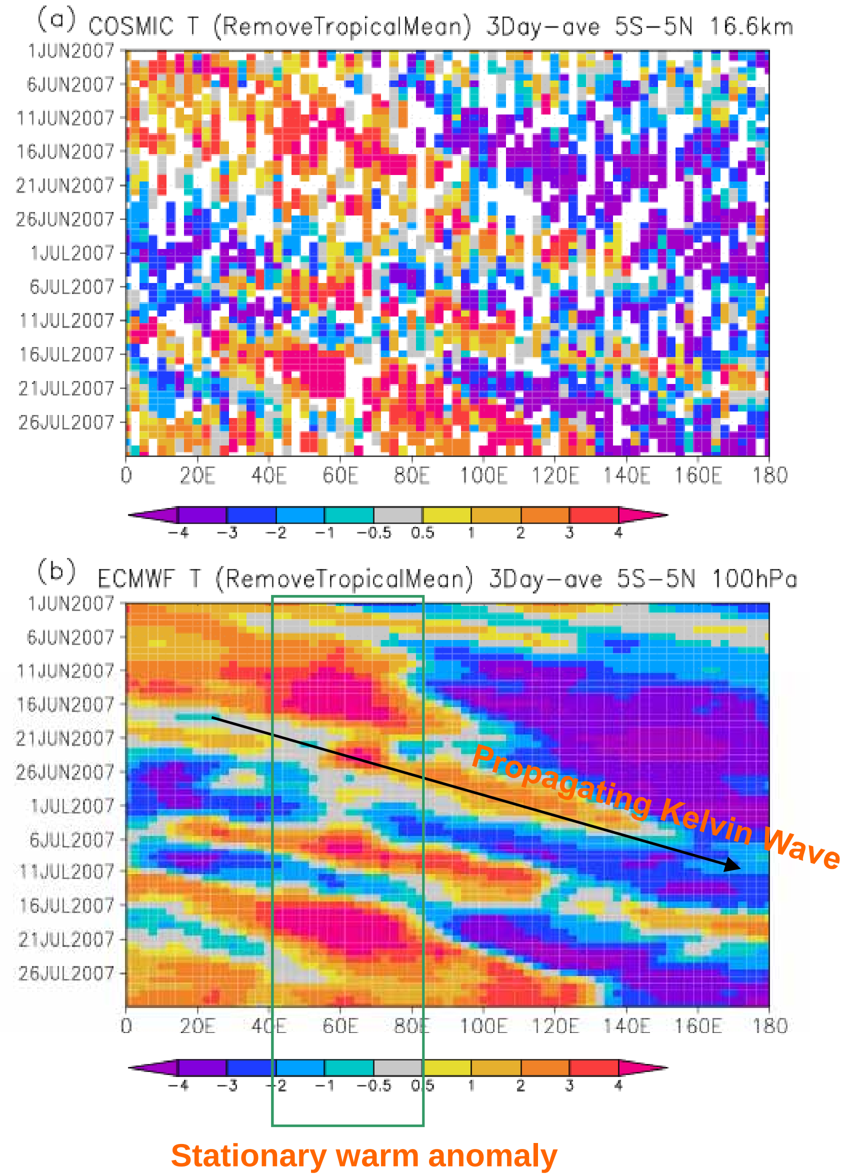
Comparison: COSMIC RO and Objective analysis

COSMIC RO data
Applied 3-day, 5S-5N avegage 2.5˚ longitude grid

•We made a grid-point data, by simply average all the profiles in a day and 2.5 ° grid in each height range

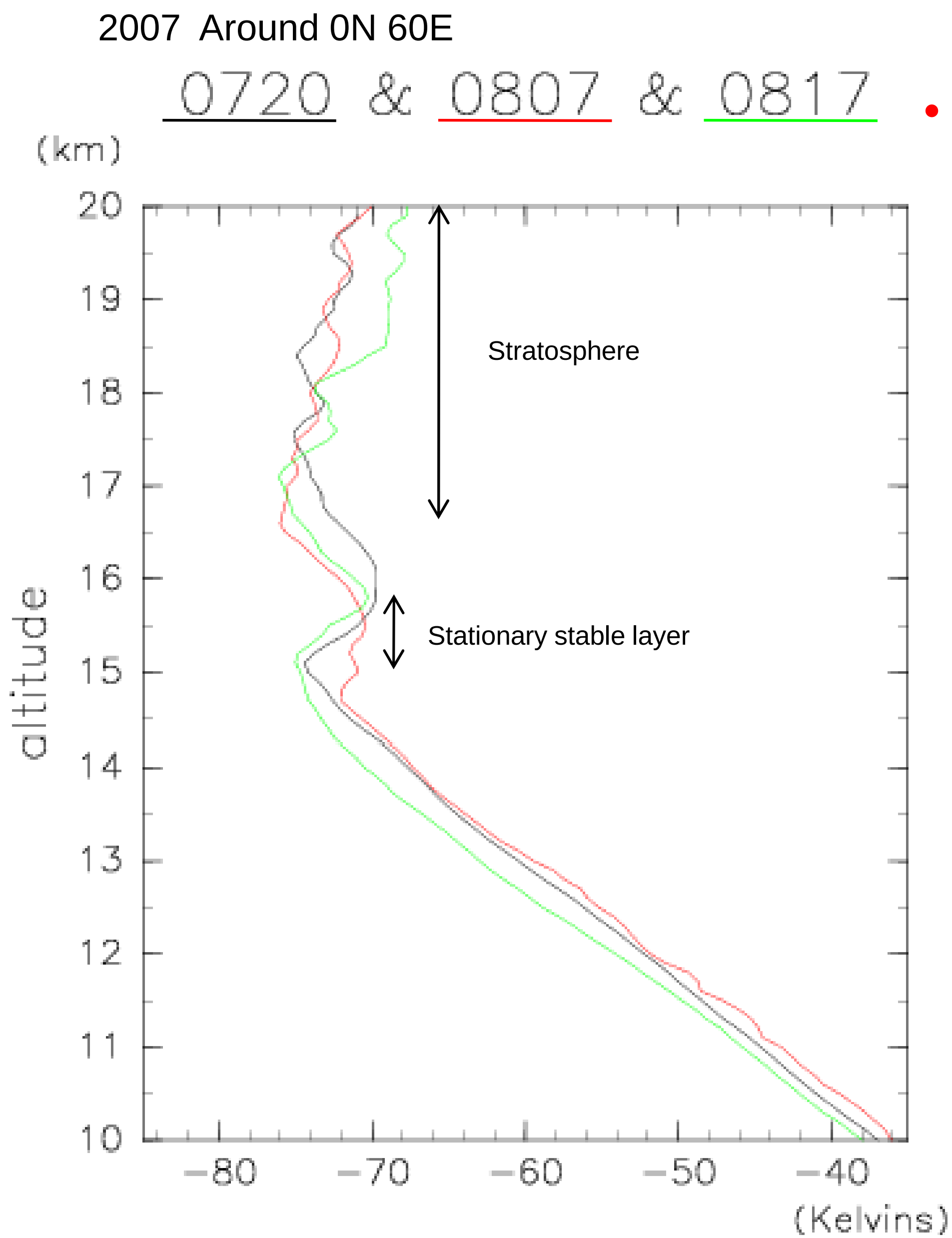
ECMWF operational analysis
Applied 3-day, 5S-5N avegage 2.5˚ longitude grid

- Superposed on the propagating waves, stationary warm anomaly is detected around 60E
- COSMIC RO dataset has enough profiles to describe the warm anomaly.



Three-day average (K), anomaly from the tropical mean (10S-10N)

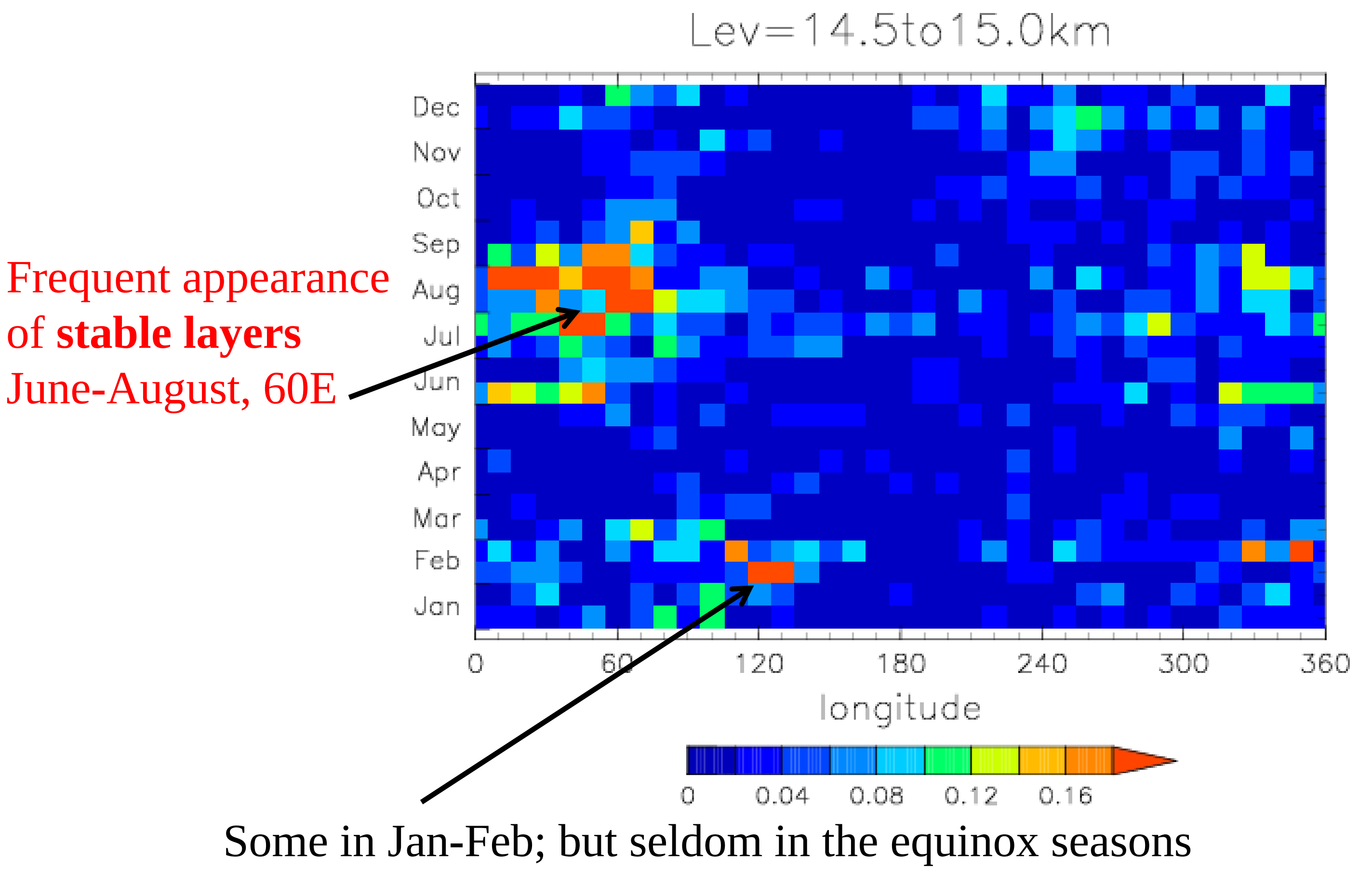
Examples of vertical profile by RO



- Quasi stationary stable (inversion) layer is frequently observed around 15-15.5 km over the equatorial western Indian Ocean.

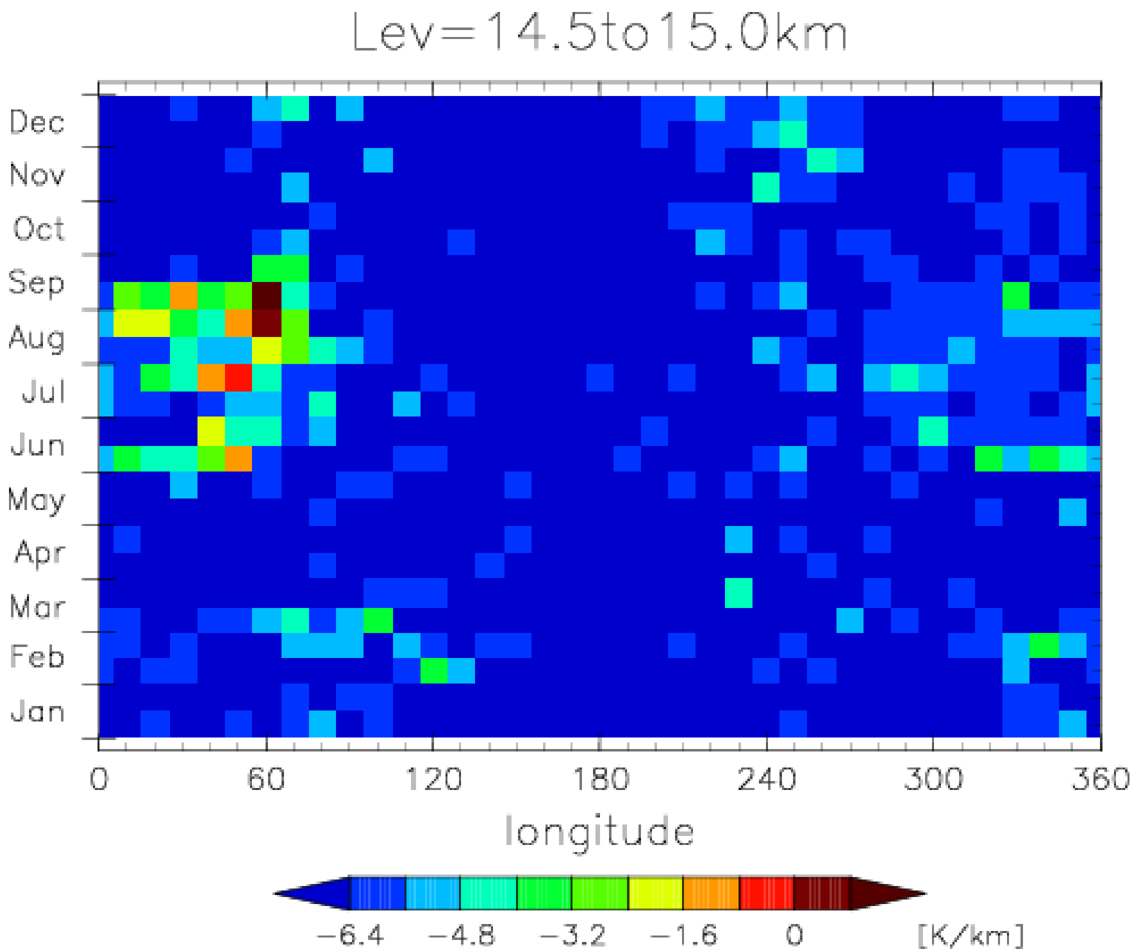
Seasonal/longitudinal distribution of the inversion layer

- To detect zonally confined temperature anomaly, we count the frequency of inversion layer (defined dT/dz > 0) within the upper troposphere
  - COSMIC RO observation, 2007, 2.5S-2.5N, 14.5-16.5 km altitude

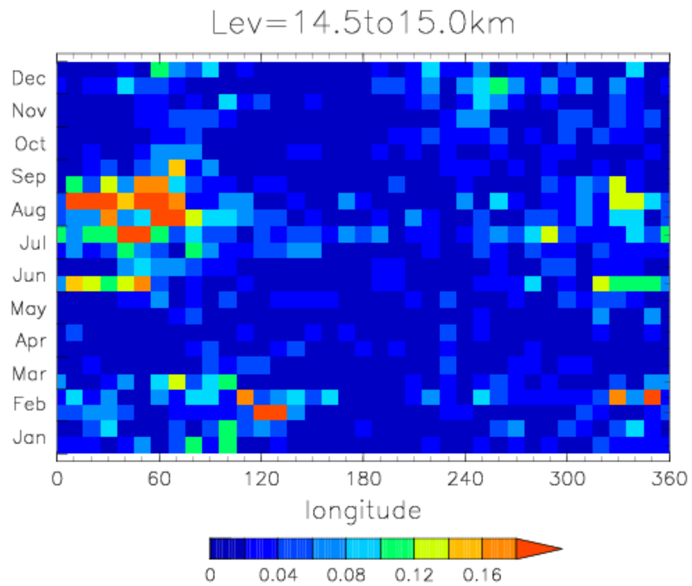


Stability averaged in half month

Average of dT/dz in each half month



Frequency of inversion layer

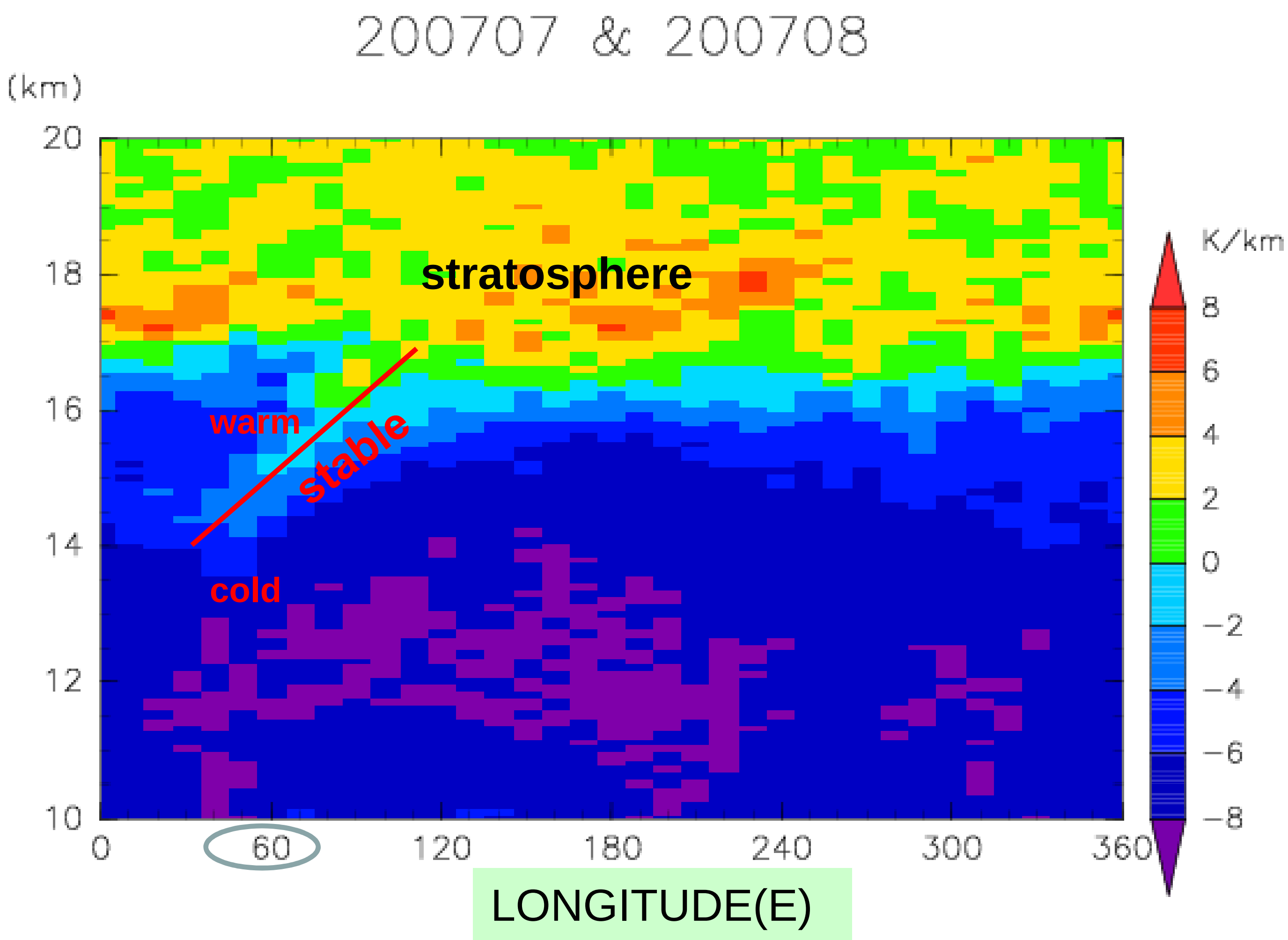


2.5S-2.5N during 2007
by COSMIC RO

- Stable period continues from June to September around 20-60E.
- It suggests that not traveling disturbances but quasi stationary structure makes this stable region.

dT/dz

Equator
Jul- Aug2007
(COSMIC RO)

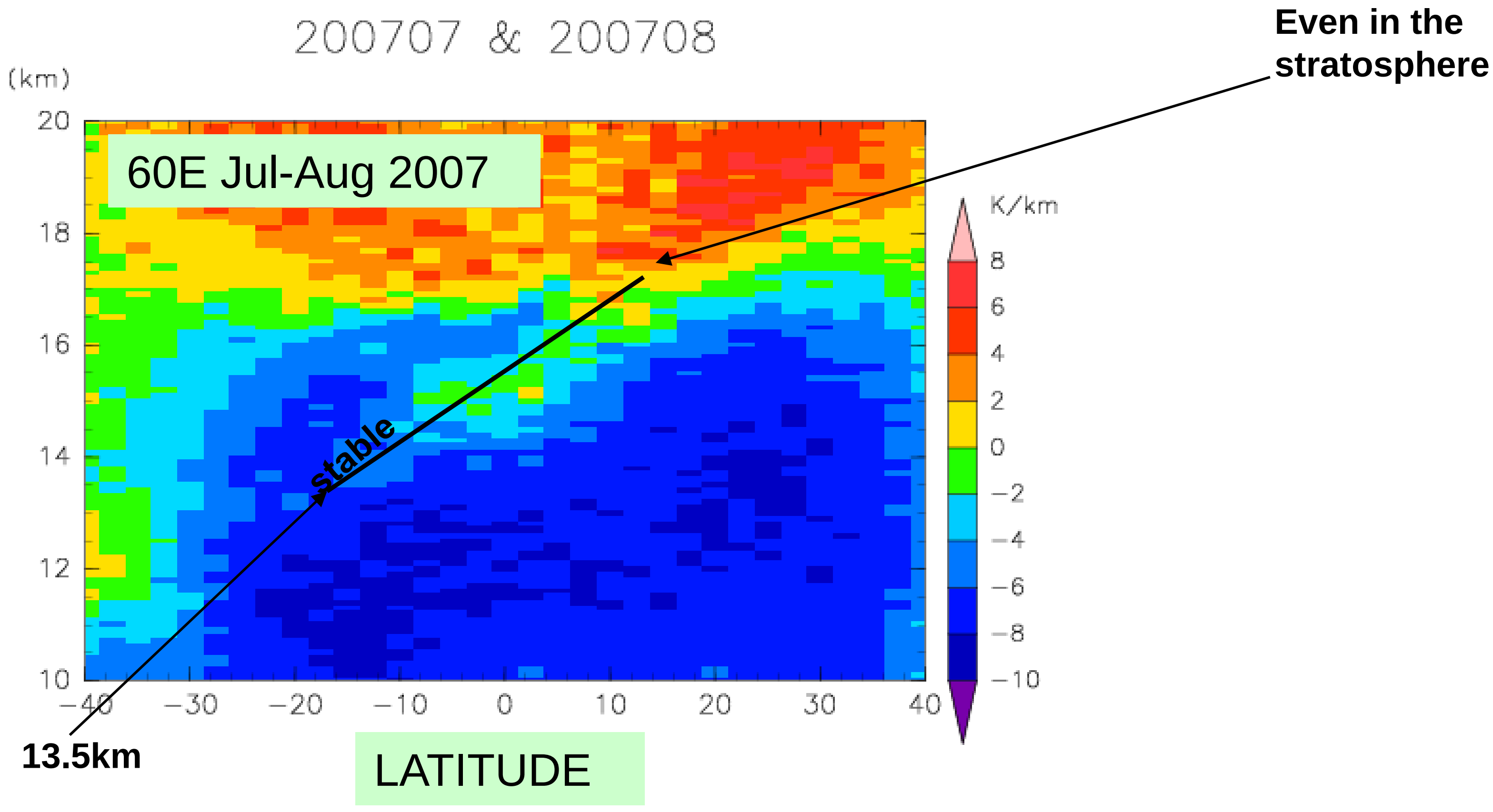


- COSMIC RO dry temperature data (calculated with the hypothesis that the relrection rate depends only on the temperature) can obtain the fine structure of quasi-stationary warm anomaly
- Stable layer (Large postitive dT/dz) penetrates down into the troposphere
- The axis of the stable layer: west in the low altitude and east in the high altitude

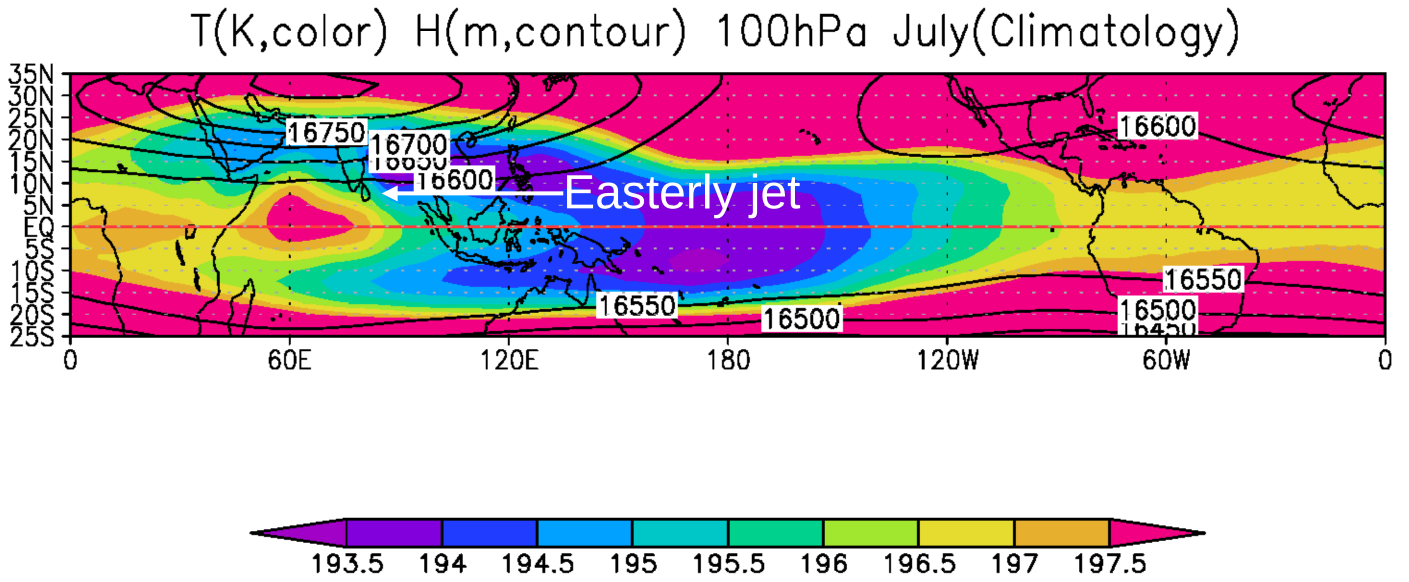
Asymmetric structure about the equator

- Shallow stable layer – not horizontal
  - 15S, 13.5km --15N, 17km, (further 30N, 19km)
- If this asymmetric structure is essential to the stationary pattern, monsoon circulation is probably more important than Kelvin wave, which is symmetric about the equator.

dT/dz (K/km) 60E by COSMIC RO

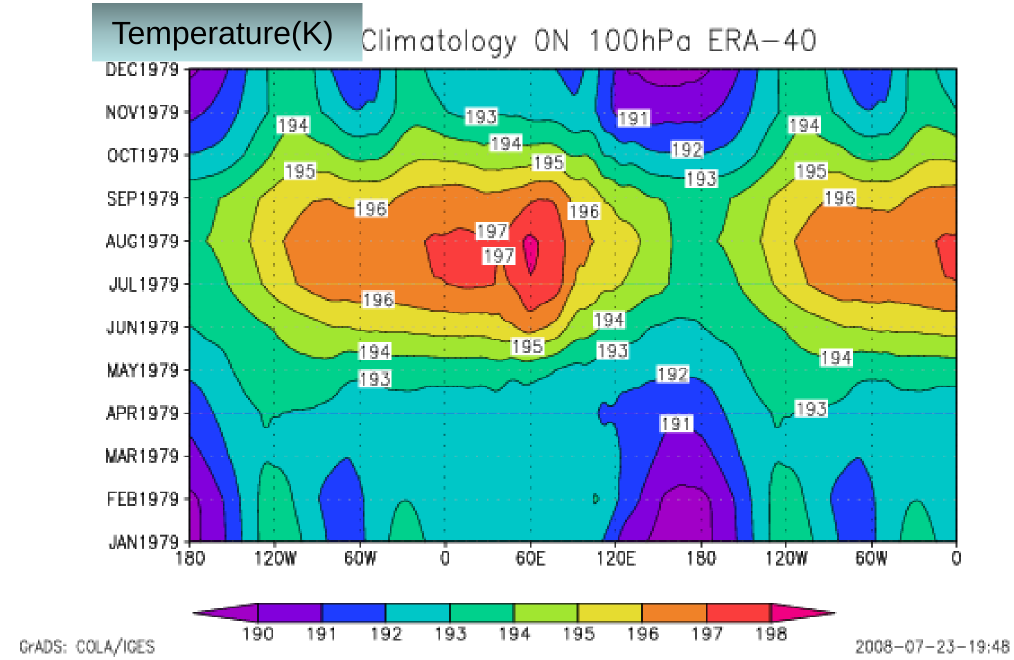


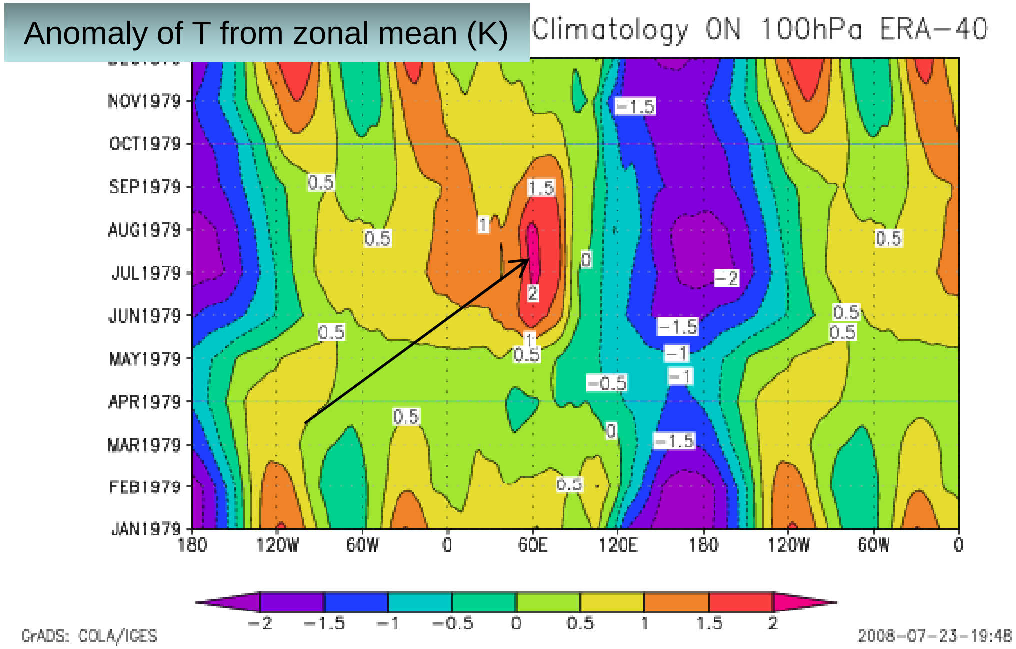
Two factors: quasi-stationary warm anomaly



- 1. Tibetan high system and monsoon circulation (as modified form of 'Gill-mode)
  - Center of Tibetan high – a little north
  - Wide monsoonal easterly jet
- 2. Equatorial-trapped waves
  - Eastward-propagating waves (probably Kelvin wave) in the basic easterly

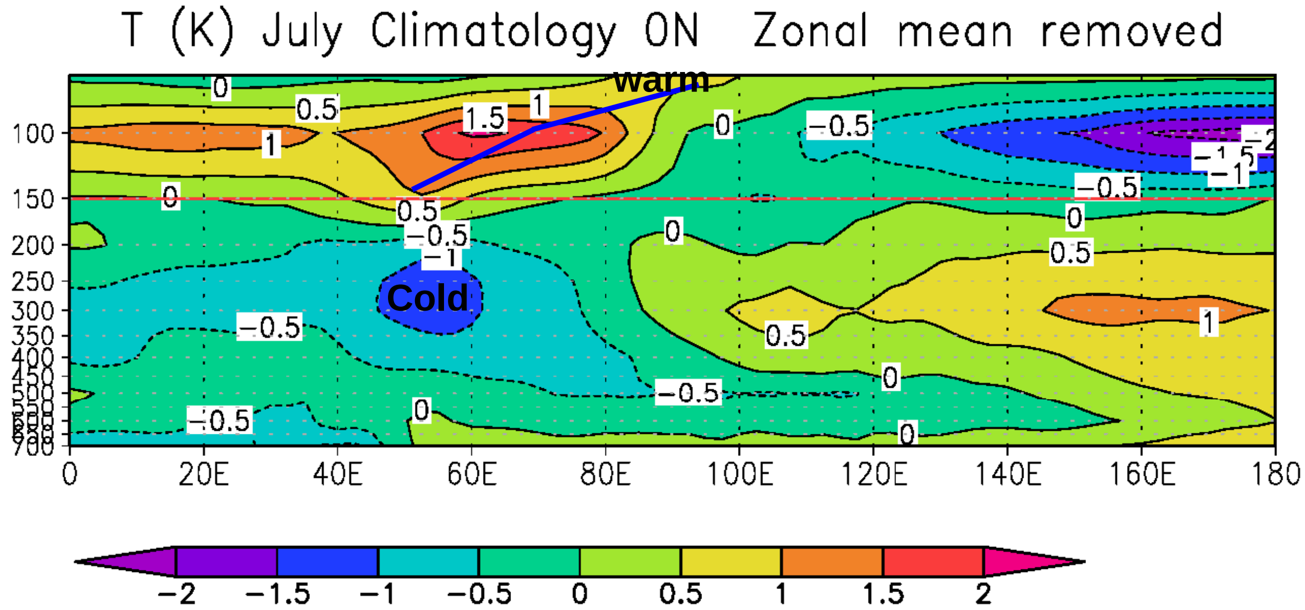
ERA-40: Seasonal distribution of T at 100 hPa (16.5 km) at the Equator

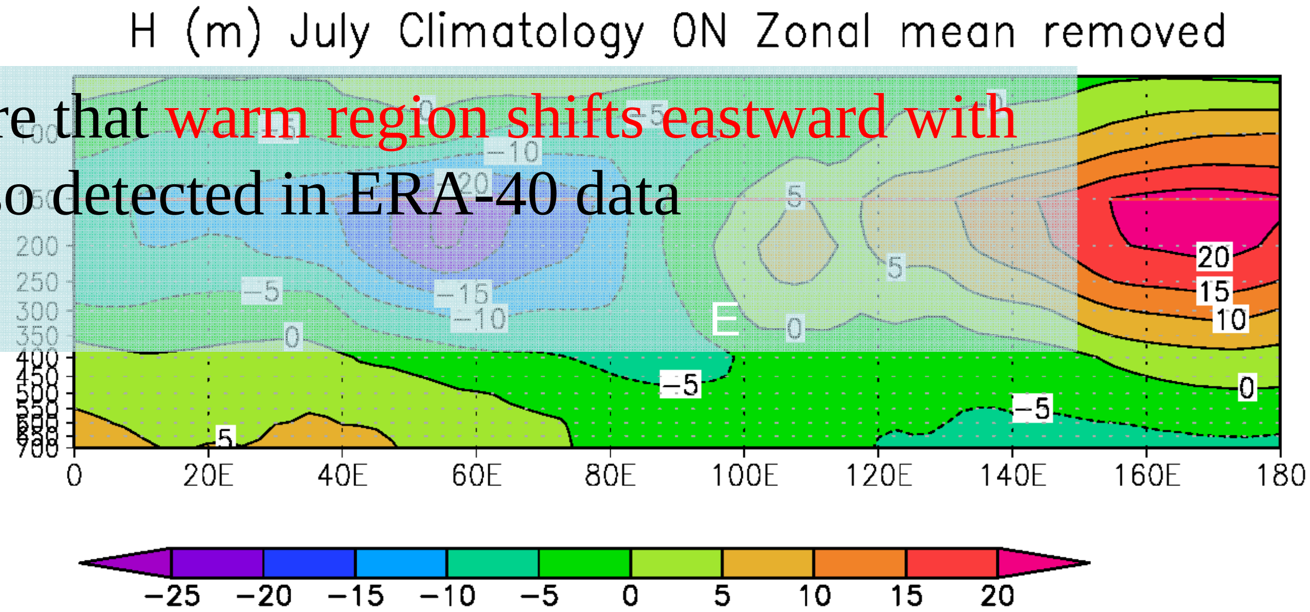




- Perpetual presence of the cold anomaly around 180E
- Compact warm anomaly around 60E
  - June—September
  - (Peak July, August)

Zonal/vertical structure of stationary pattern





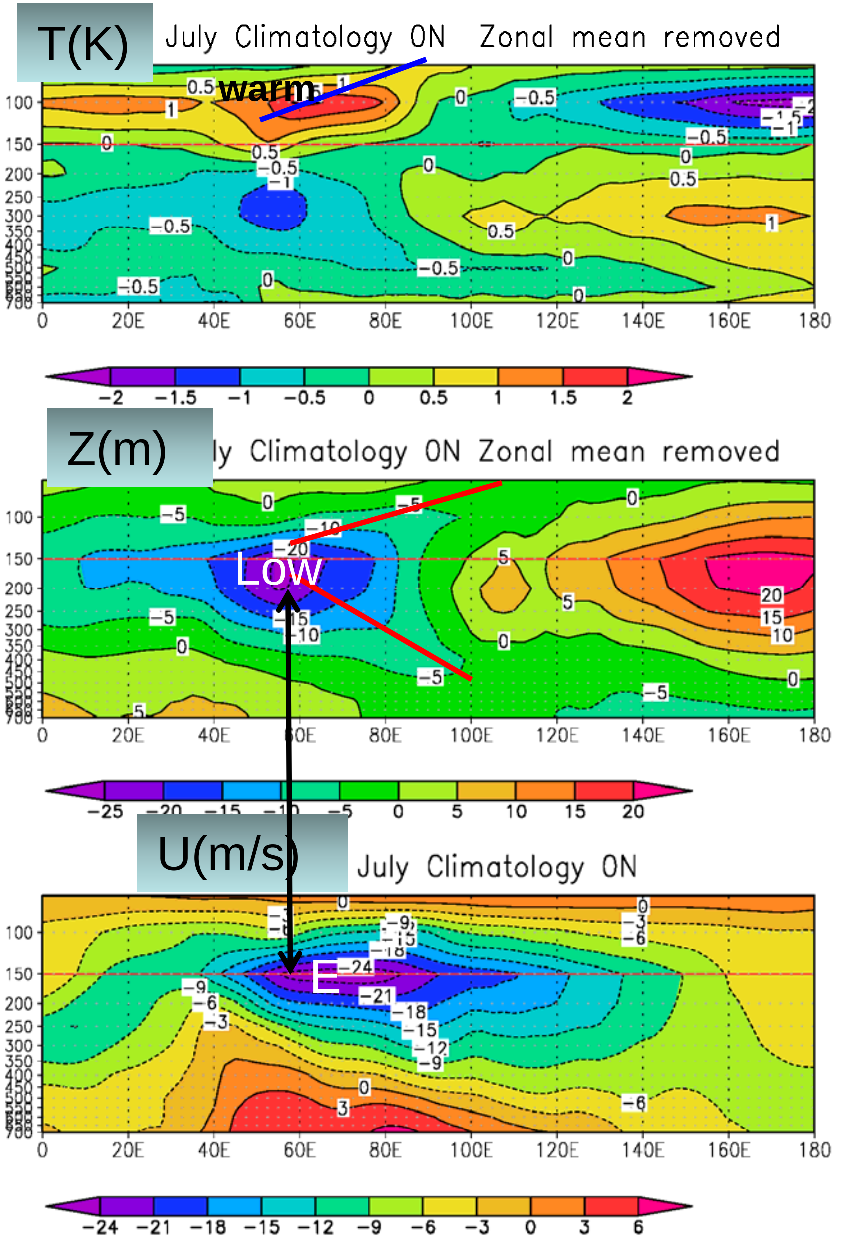
- The structure that warm region shifts eastward with height is also detected in ERA-40 data

Zonal/vertical structure of stationary structure

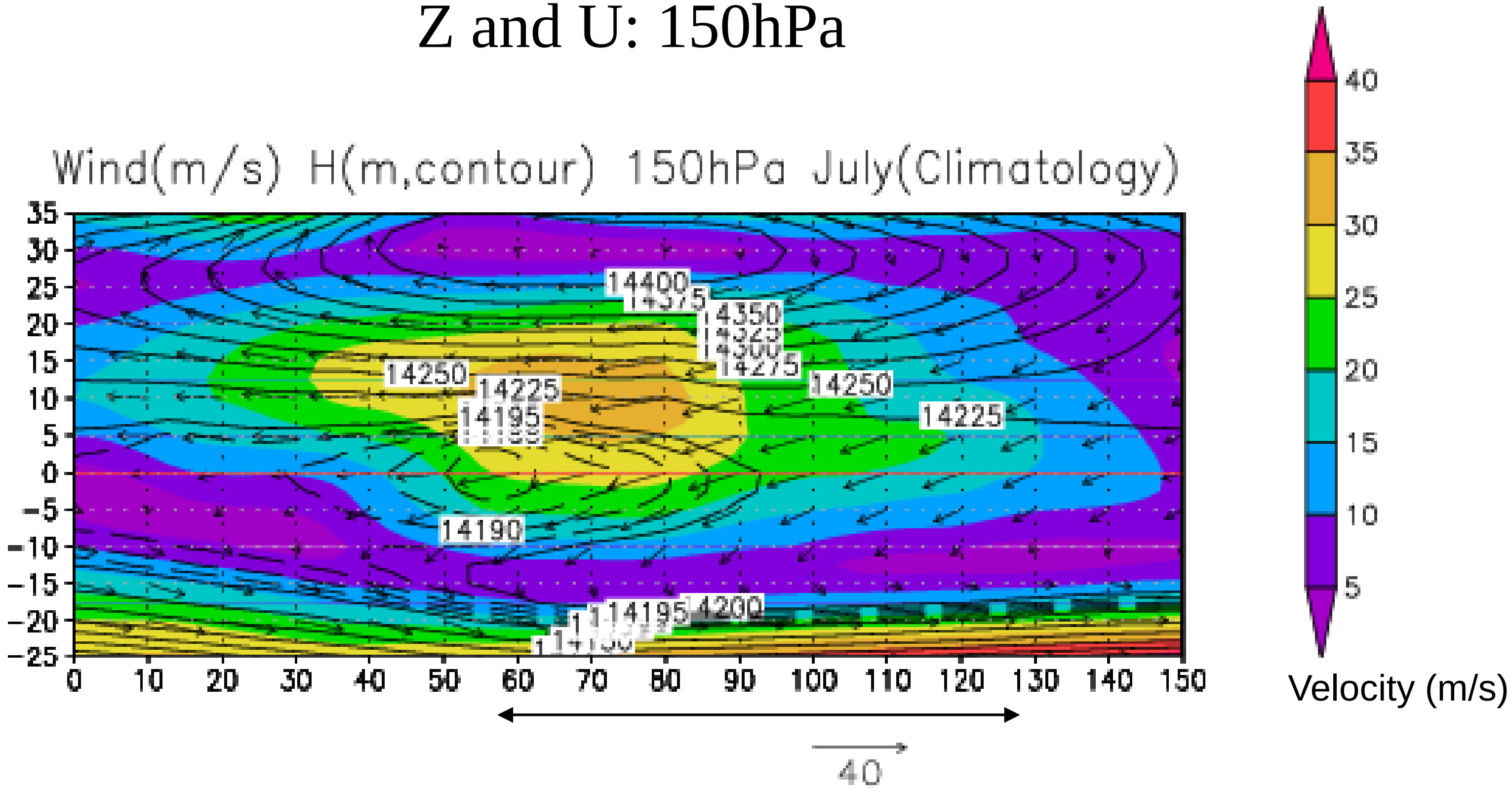
- Warm anomaly at 100 hPa is correspondent with the low height anomaly at 150 hPa
  - 150 hPa is a jet-height
- T, Z have "boomerang" shape in the figures

- From here, we discuss the dynamics at 150 hPa, using Z instead of T with U

- Low-height anomaly is located at the western edge of the strong easterly.



Z and U: 150hPa

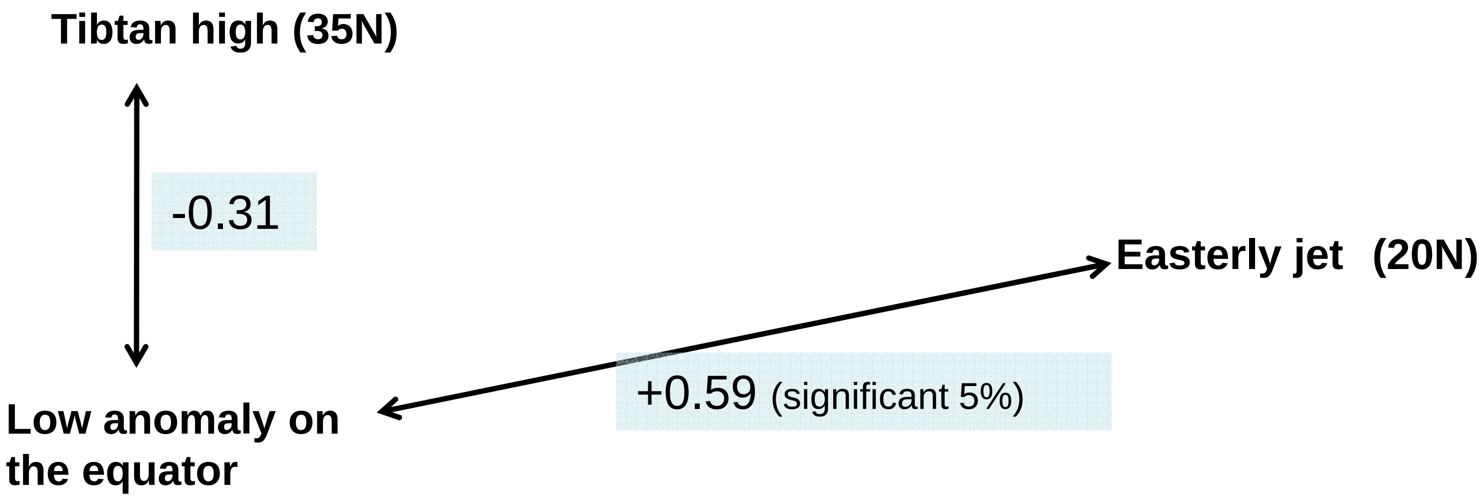


- Monsoon easterly jet (ENE wind at the equator, 150 hPa) is observed between 30-90 E at the center latitude.
- However, the zonal extent is samll at the equator; the western edge is around 55 E.
- The low-height anomaly is around the western edge of equatorial easterly.

Relationship with Tibetan high and monsoon jet

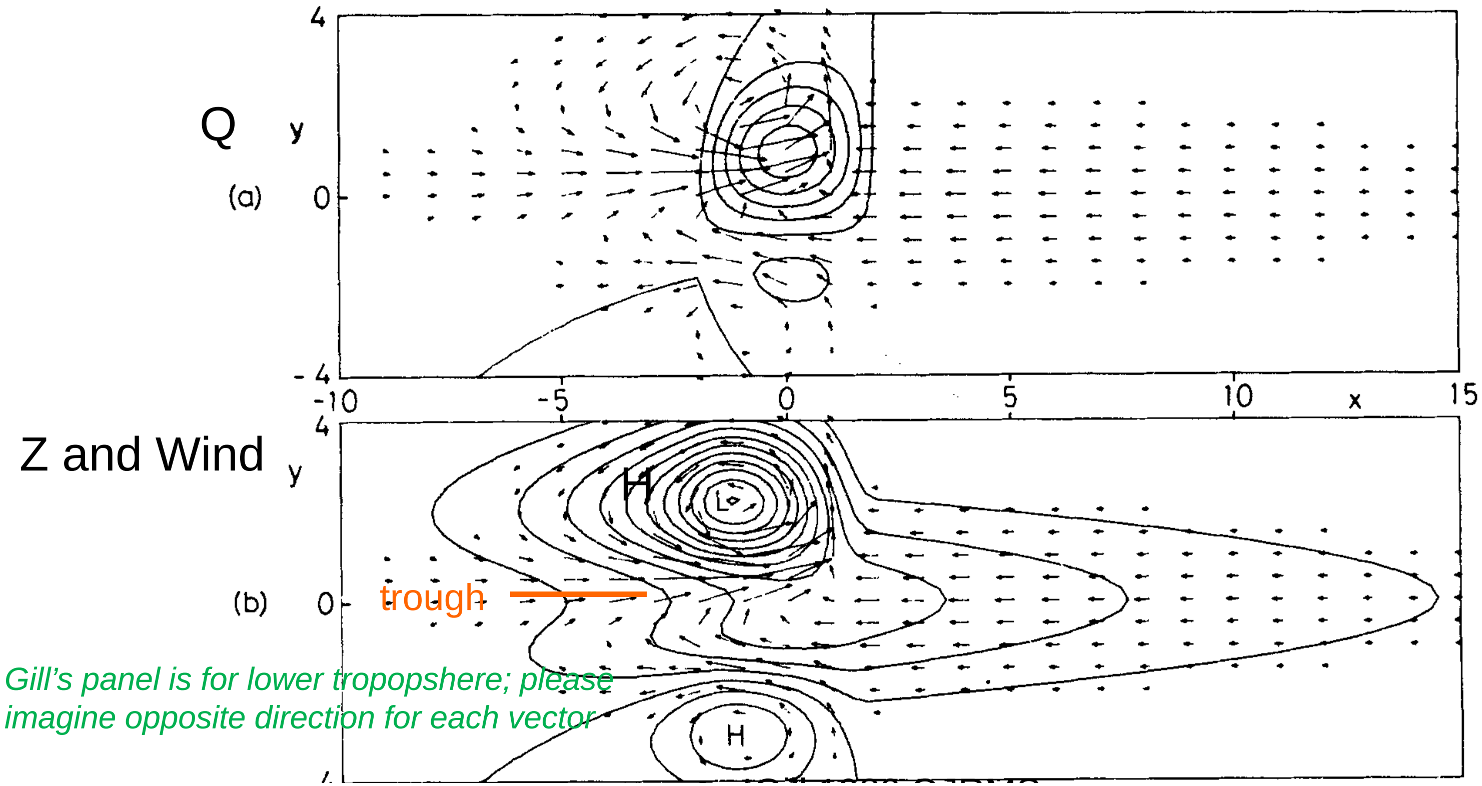
- Tibetan high (35N) and monsoon jet (20N) have correlation with low height anomaly at 0N, 60E.
  - In the years with strong Tibetan high and easterly jet, the low-height anomaly at 0N, 60E is also well-developed

Correlation (averaged in 50-80E, 23years)



Dynamical interpretation of the warm anomaly

- So-called 'Gill pattern' with linear response for very simple forcing explains a meridional height minimum (trough). However, the zonal minimum is hardly accounted for.
  - Additional factors like more practical forcing/ presence of basic wind/ finite amplitude will be needed?
  - One example by Norton (2006)



Simple GCM experiment (Norton 2006 JAS)

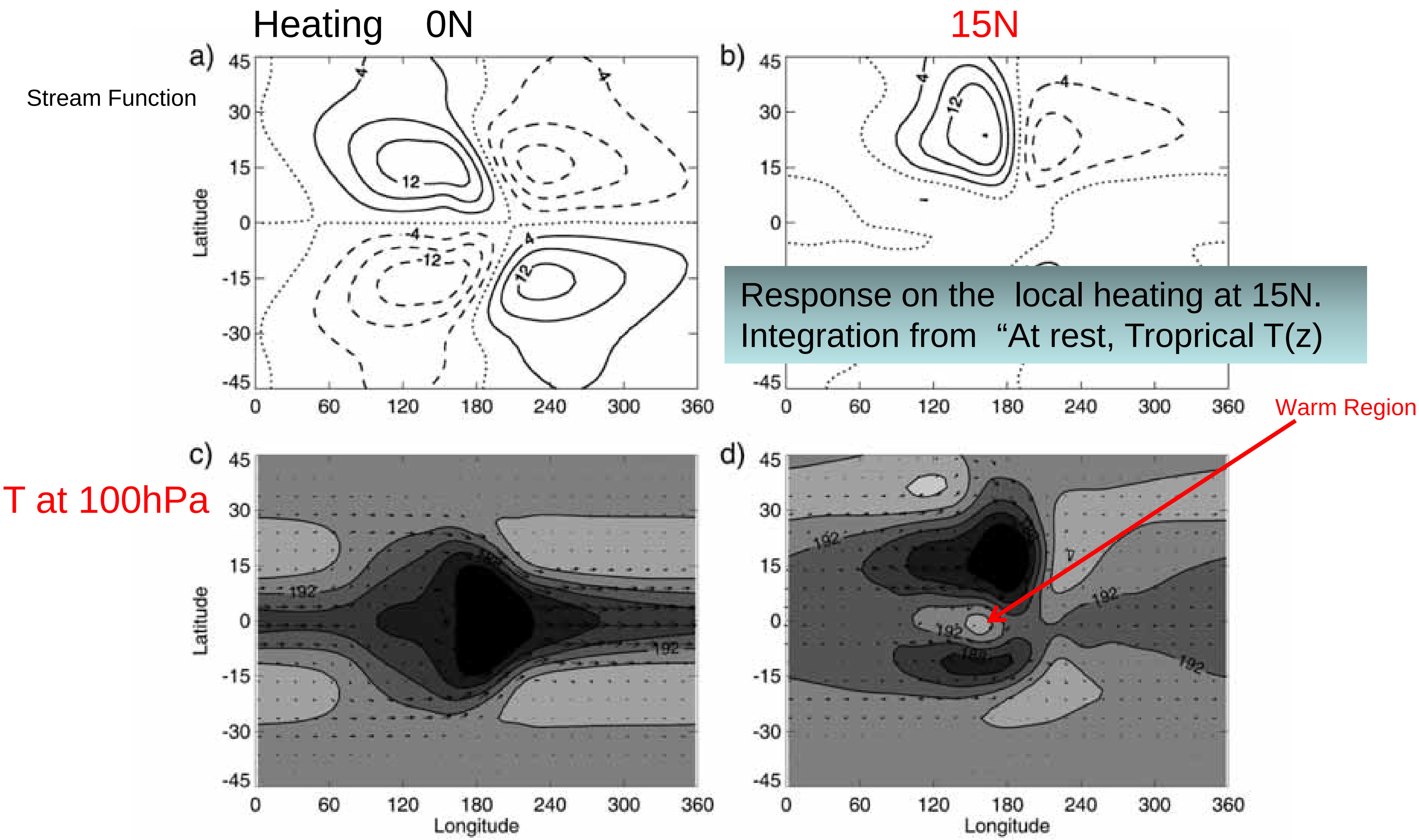
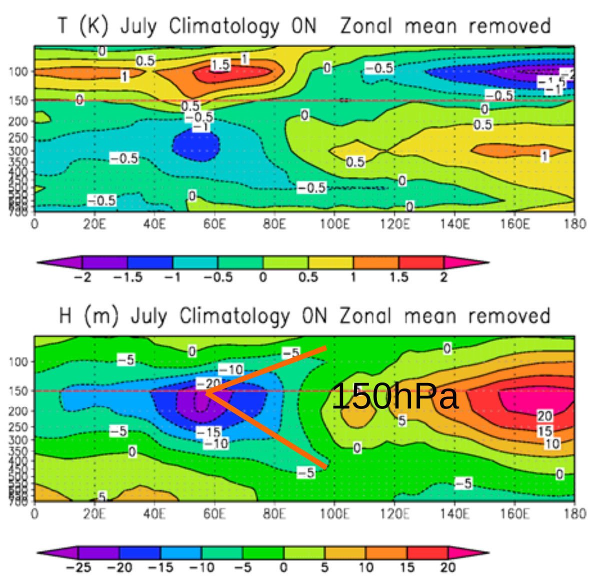


FIG. 6. Streamfunction at 100 hPa from the model with Gaussian heating centered at (a) the equator and (b) 15°N. Contour interval is 4×10^6 m^2 s^{-1}; solid contours indicate positive values, dashed contours negative values, dotted is the zero contour. Temperature and wind vectors at 100 hPa from the model with heating centered at (c) the equator and (d) 15°N. Contour interval is 2 K; darker shading indicates colder temperatures.

Dynamical interpretation of the warm anomaly

- Inclination of the stable layer
  - Not easily explained with the framework of stationary response for the simple heating
  - Equatorial Kelvin wave confined near the equator in the monsoonal basic easterly is needed?
    - In boreal winter, Randel and Wu (2005、JGR) proposed that the stationary Kelvin wave makes the tilted temerature structure in the W-Pacific.

If wave, Source may be at 150hPa?



Summary

- **Warm anomaly** (100 hPa) and low-height anomaly (150 hPa) are observed around **60E** around the equator during JJAS.
- Dry temperature by COSMIC RO has high vertical resolution and well describe the vertical fine structure in the stationary structure
  - Stable layer : eastward (and northward) shift with height in the upper troposphere
- Low-height anomaly at 150 hPa (~warm anomaly at 100 hPa) is at the western edge of the strong easterly. The magnitude of the anomaly has significant correlation with the monsoon easterly jet (center is around 20N).
  - (Hypothesis) Tibetan high system controls the position/extent of the equatorial easterly, which decides the position of the low-height (warm) anomaly
- *What decides the western edge of the* ***equatorial*** *easterly?*
- *Why the low-height (warm) anomaly is so* ***zonally compact****?*
- ***Kelvin*** *wave also has important contribution to explain the inclined stable layer?*