Fast, large-scale waves in the MLT observed by TIMED/SABER

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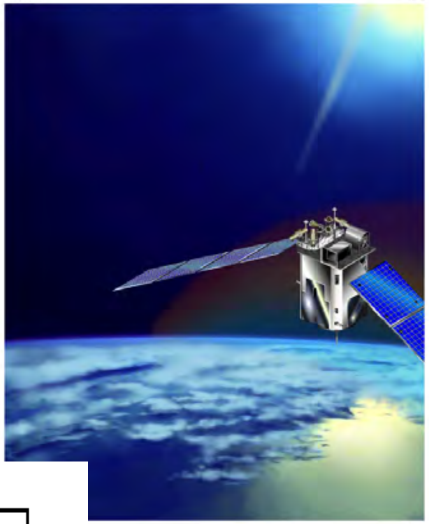
outline

- SABER instrument and sampling
- Fast-Fourier Synoptic Mapping
- waves observed by SABER
  1. diurnal migrating tide
  2. diurnal non-migrating tides
  3. fast Kelvin waves
  4. the 2-day wave
- conclusions

SABER instrument

TIMED satellite: Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (polar orbiter)

SABER : Sounding of the Atmosphere Using Broadband Emission (broadband radiometer)



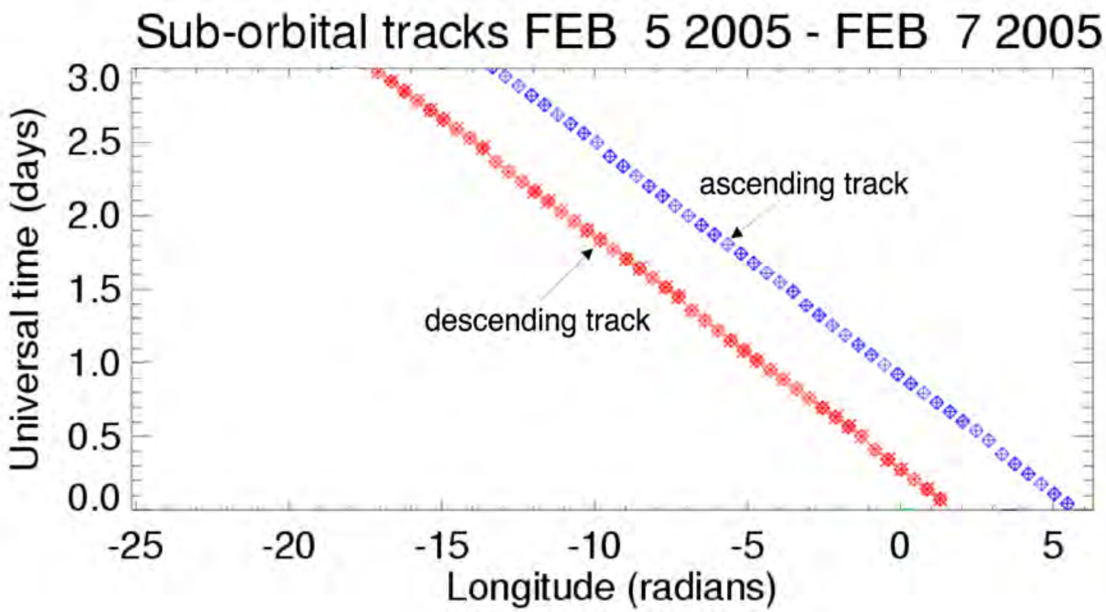
SABER Measurements and Applications			
Parameter	Wavelength (μm)	Application	Altitude Range (km)
CO_2	14.9 & 15.2	T, density, IR cooling rates, P(z), non-LTE	10–130
O_3	9.6	O_3 conc., cooling rates, solar heating, chemistry and dynamics studies	15–100
$O_2(^1\Delta)$	1.27	O_3 conc. (day), inferred [O] at night, energy loss for solar heating efficiency	50–105
CO_2	4.3	CO_2 conc., mesosphere solar heating, tracer	85–150
OH (v)	2.0 & 1.6	HO_y chem., chemical heat source, dynamics, inference of [O] and [H], PMC studies	80–100
NO	5.3	Thermosphere cooling, NO_x chemistry	90–180
H_2O	6.9	HO_y source gas, dynamical tracer	15–80

The Johns Hopkins University   Applied Physics Laboratory

- analyses here use data from version 2.0 retrievals in the range ~17-110 km
- geopotential height is also available
- data spans the period 2002-2016

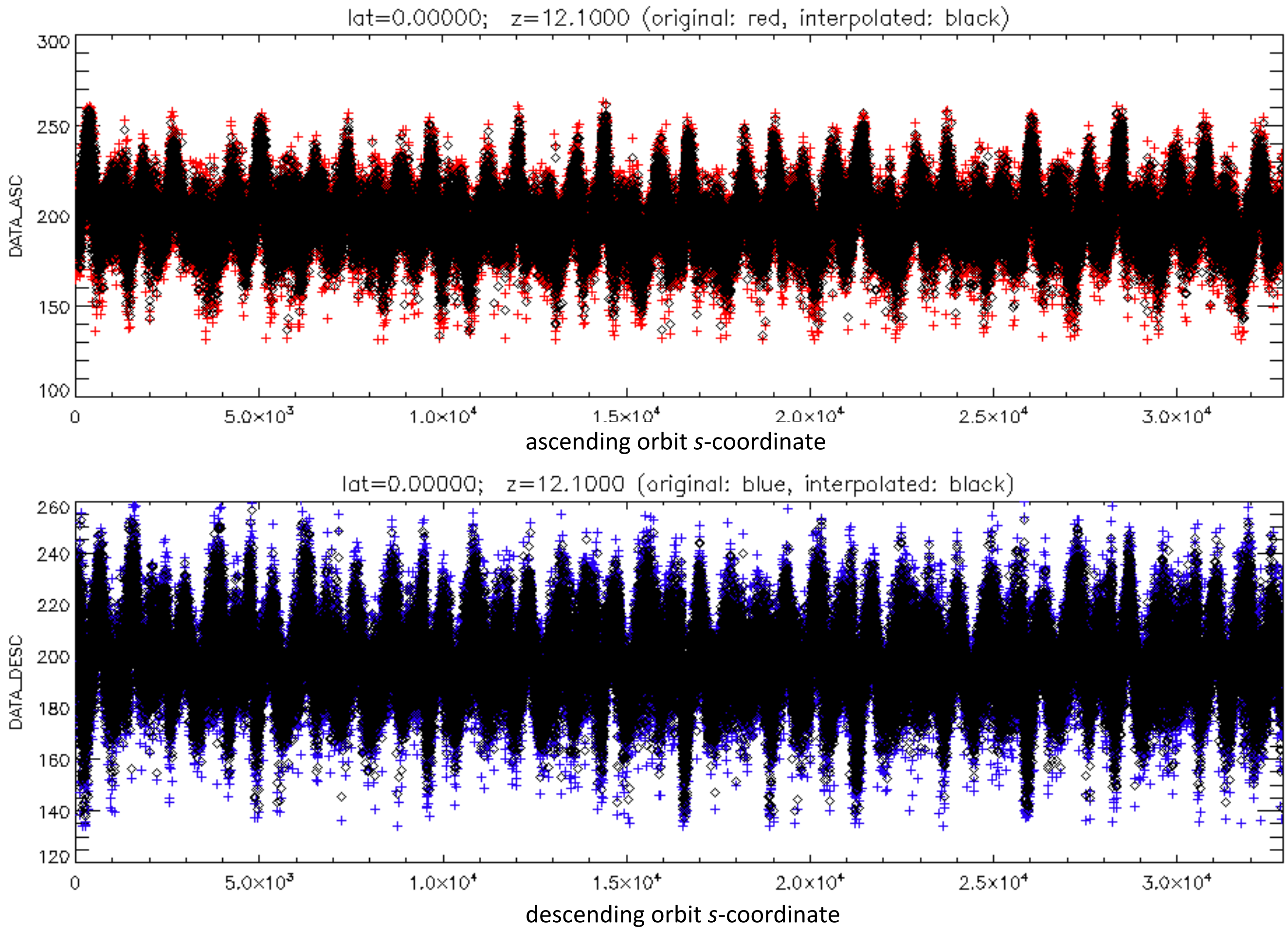
SABER sampling and data processing

SABER observations are *asynoptic*:



- Use the Fast-Fourier Synoptic Mapping algorithm (Salby, *JAS*, 1982)
- Obtain spectrum of observations along SABER's hybrid space-time observing coordinate
- Map the asynoptic spectrum into the synoptic wavenumber-frequency (m, ω) domain
- Apply to observations in the range ±52° latitude, which is *observed continuously* (14 yrs: 2002-2016)

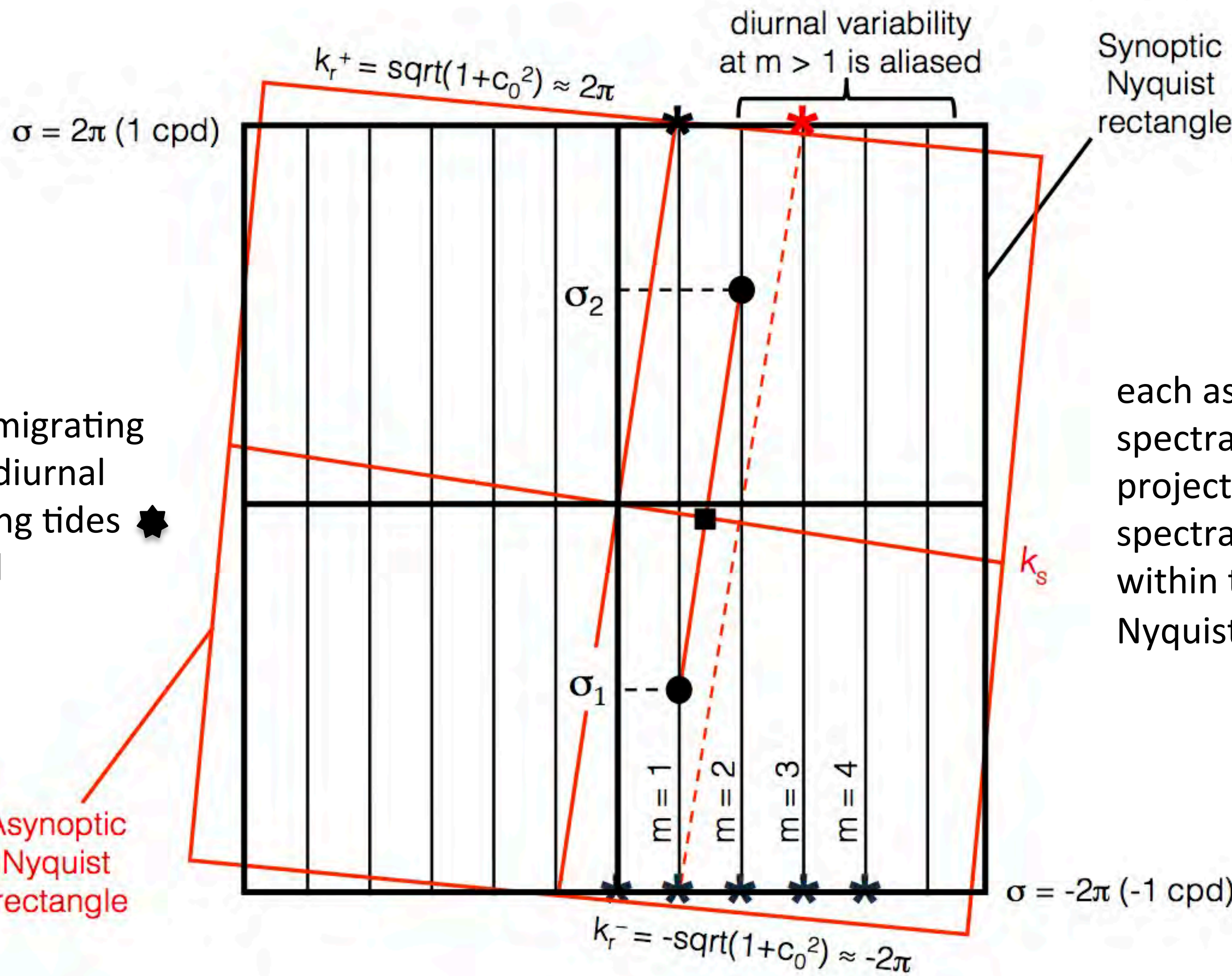
continuously sampled data at equator



temperature at Equator, 85 km

- length of sequence is 14 years

synoptic vs. asynoptic spectra



the diurnal migrating tide and all diurnal non-migrating tides ✸ are resolved

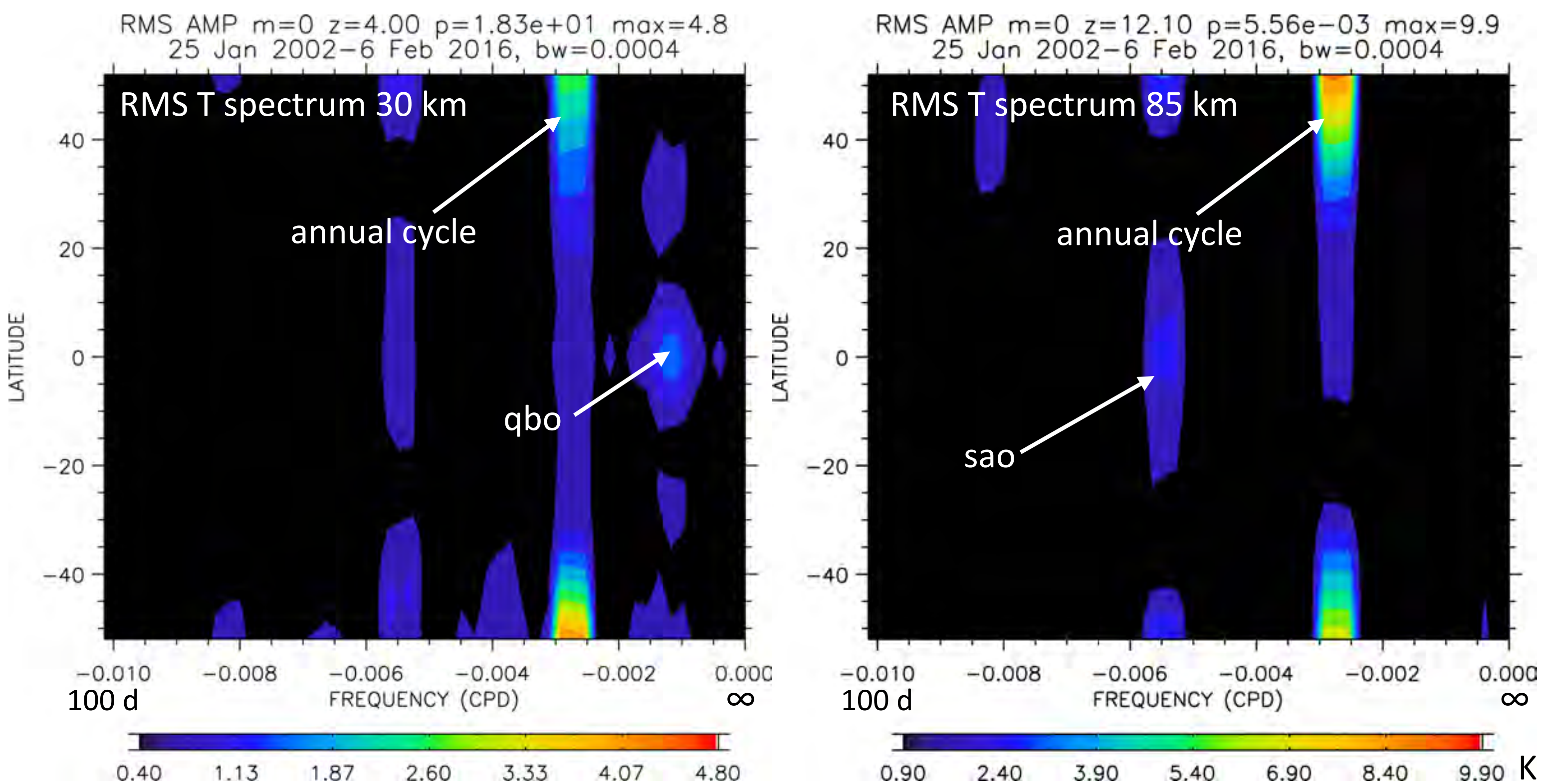
each asynoptic spectral component ■ projects on 2 synoptic spectral components ● within the synoptic Nyquist reactangle

Salby, *JAS*, 1982

so, what can SABER observe?

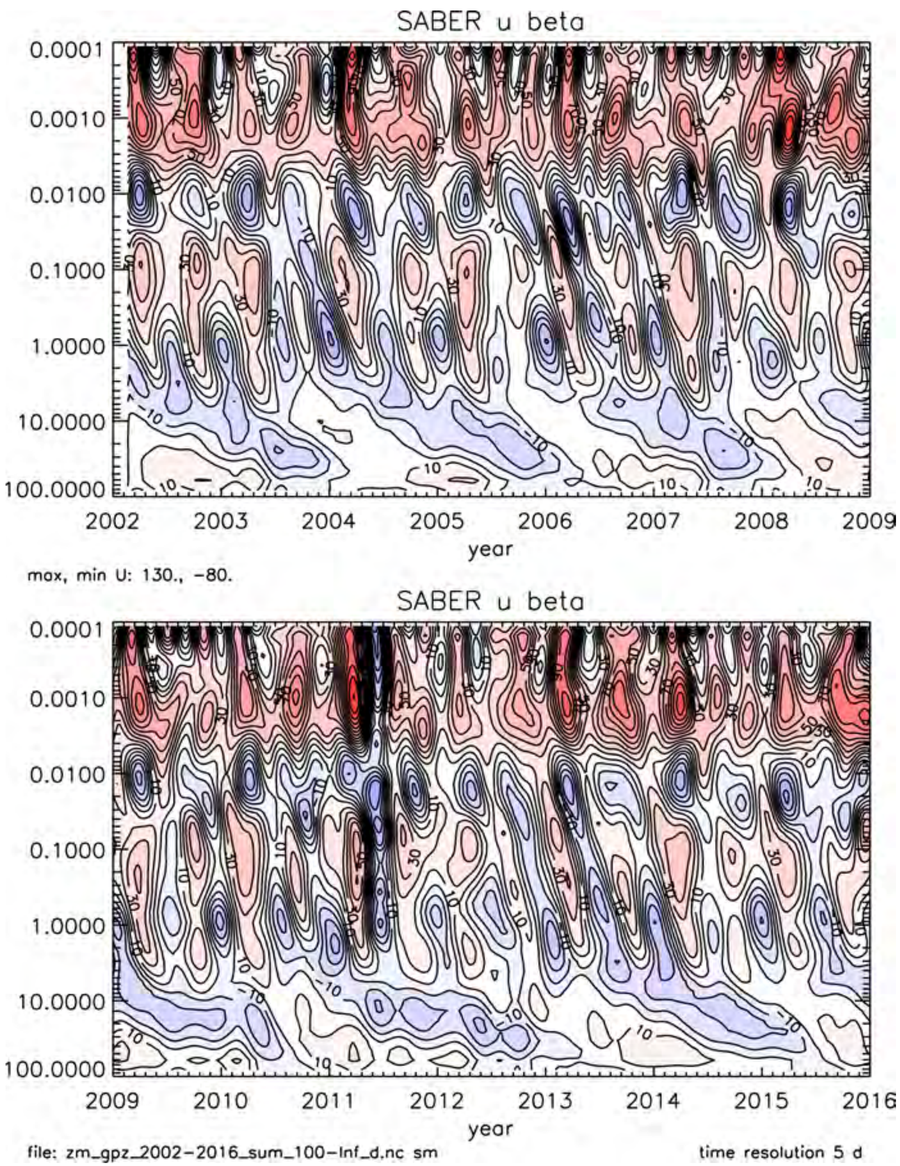
- any signal whose variance falls within the *asynoptic* Nyquist rectangle (~ ±1 cpd, and m = 0 – 6)
- the very long data series analyzed here (14 years) yields spectra with extremely fine bandwidth (~0.0002 cpd); this allows discrimination of waves narrowly separated in frequency
- can also discriminate spectrally between annual, semi-annual and quasi-biennial signals

low frequency spectra for *m* = 0



- equatorial spectra of zonal mean (*m* = 0) temperature in mid-stratosphere and upper mesosphere
- low-frequency variability is well resolved by the fine bandwidth of the long SABER time series
- QBO dominates non-annual low frequency variability at 30 km, SAO at 80 km

synthesized low-frequency <U> evolution

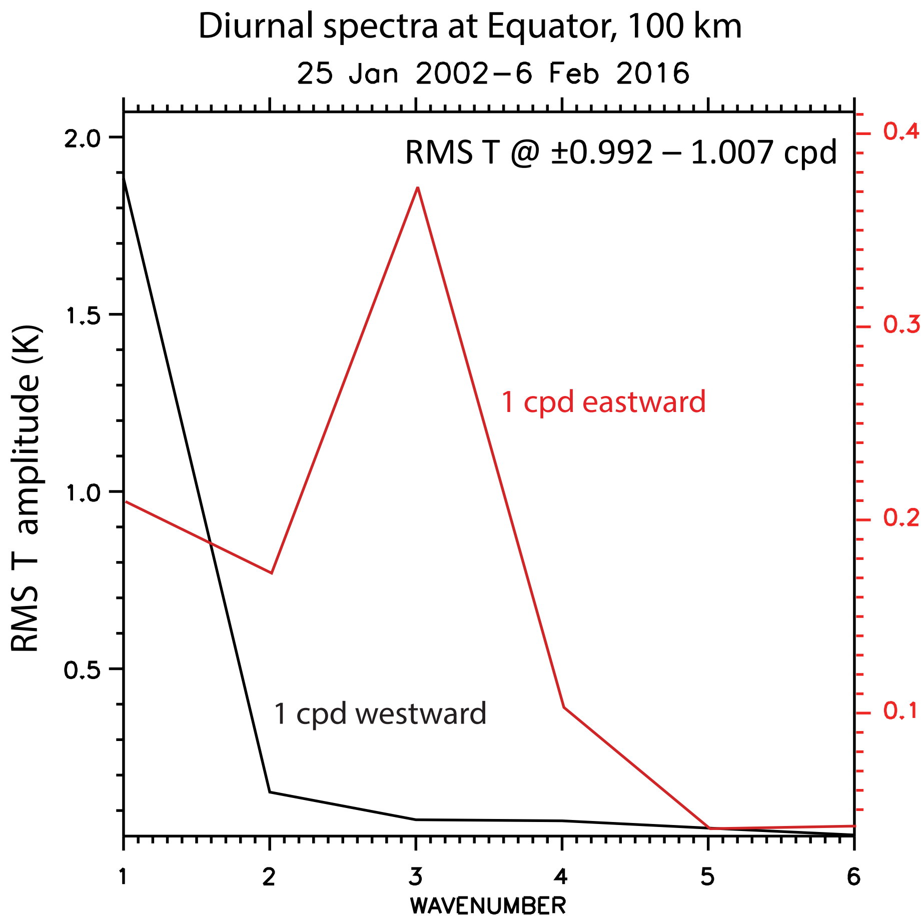


- obtained from the geopotential, ϕ, via the equatorial beta-plane approximation:

$$U_{eq} = -\frac{1}{\beta}\frac{\partial^2 \phi}{\partial y^2}$$

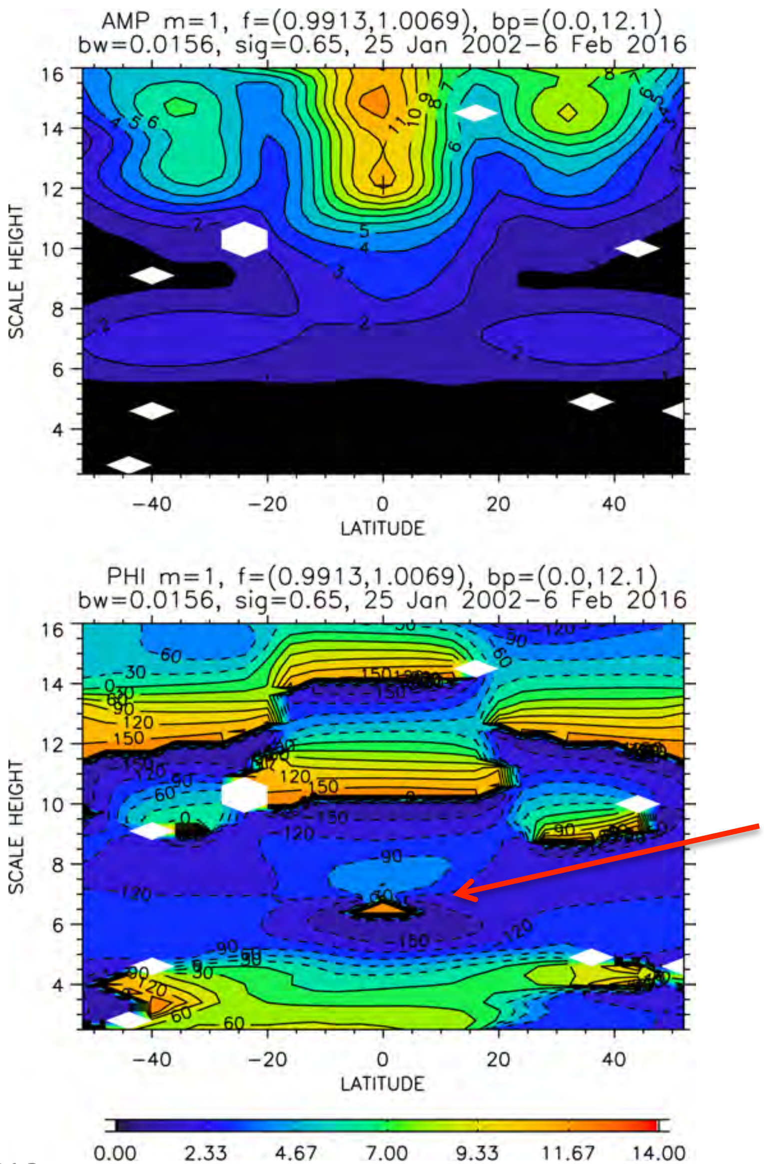
- here ϕ was synthesized over frequencies of 0 to 0.01 cpd (periods 100 days to ∞)
- continuous reconstruction of the QBO and SAO in zonal-mean zonal wind from 100 to 0.0001 hPa (~ 17-110 km)
- the QBO period over 2002-2016 is about 28 months (~ 6 cycles in 14 yr)

wavenumber spectra at ±1cpd: tides



- T spectra as functions of zonal wavenumber *m* at the Equator, 100 km
- westward diurnal spectrum is dominated by *m* = 1 (the migrating diurnal tide)
- eastward diurnal spectrum has significant power at *m* = 1 – 4, with *m* = 3 dominant

migrating diurnal T tide: mean structure

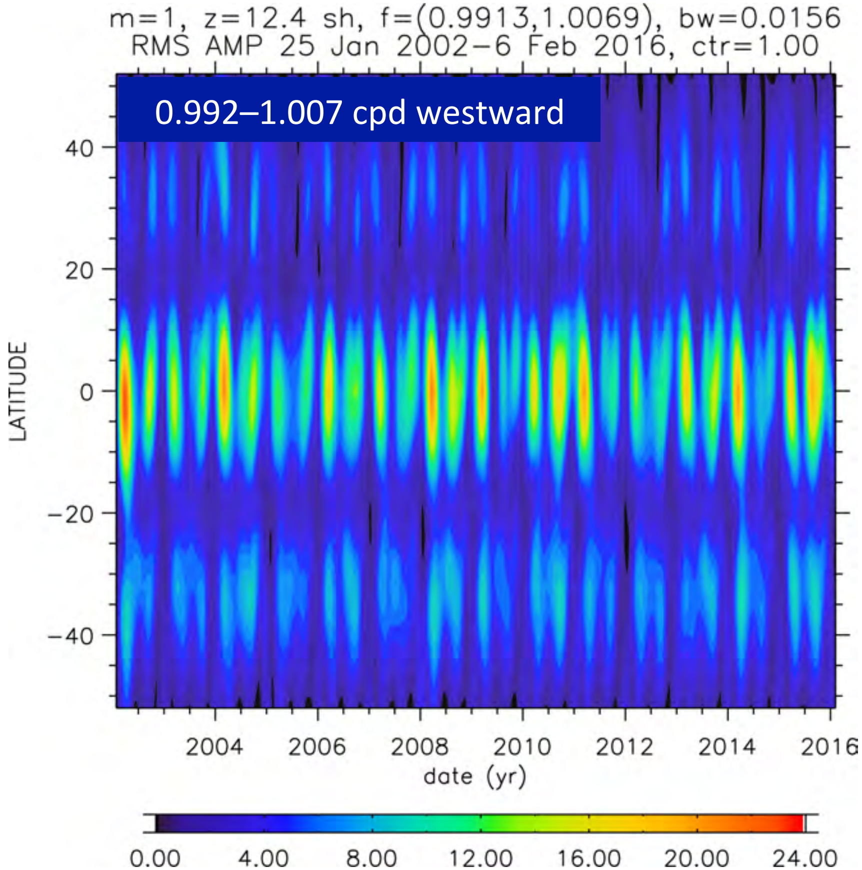


Coh² analysis for the period 2002-2016
over frequencies 0.992 – 1.007 cpd westward

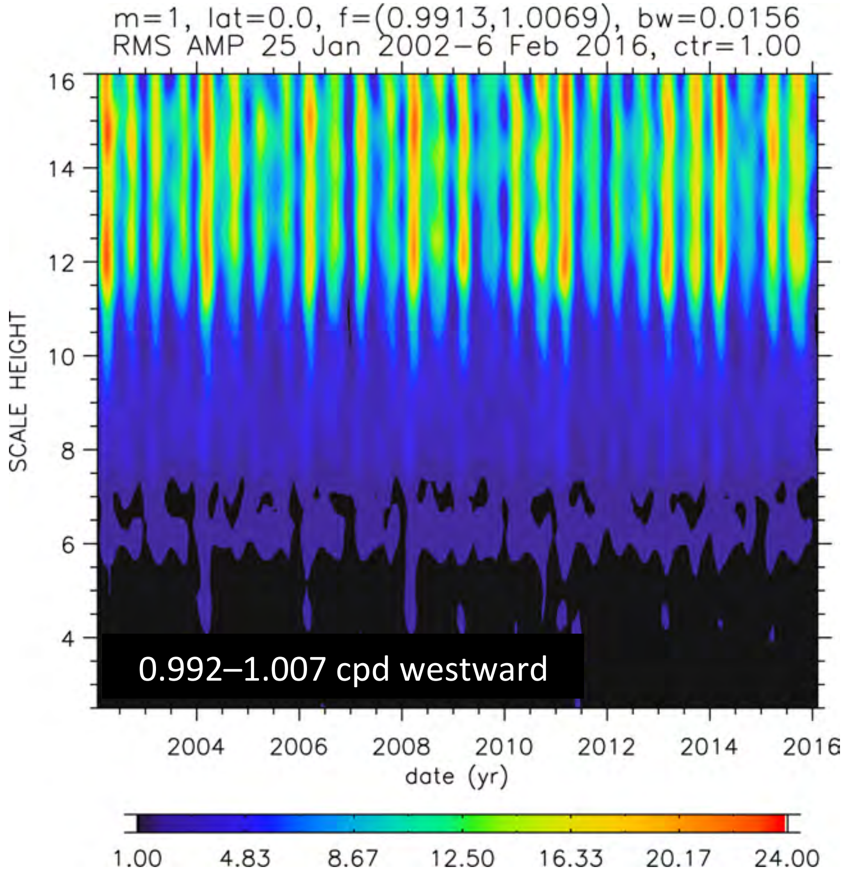
- the only westward tide resolved explicitly by SABER
- amplitude reaches ~12 K; this may be considered the long-term mean over the period 2002-2016
- instantaneous amplitude can be much larger
- note non-propagating character in upper stratosphere (O_3 heating projects onto non-propagating modes)

seasonal and interannual variability

T amplitude (t, θ) at 85 km

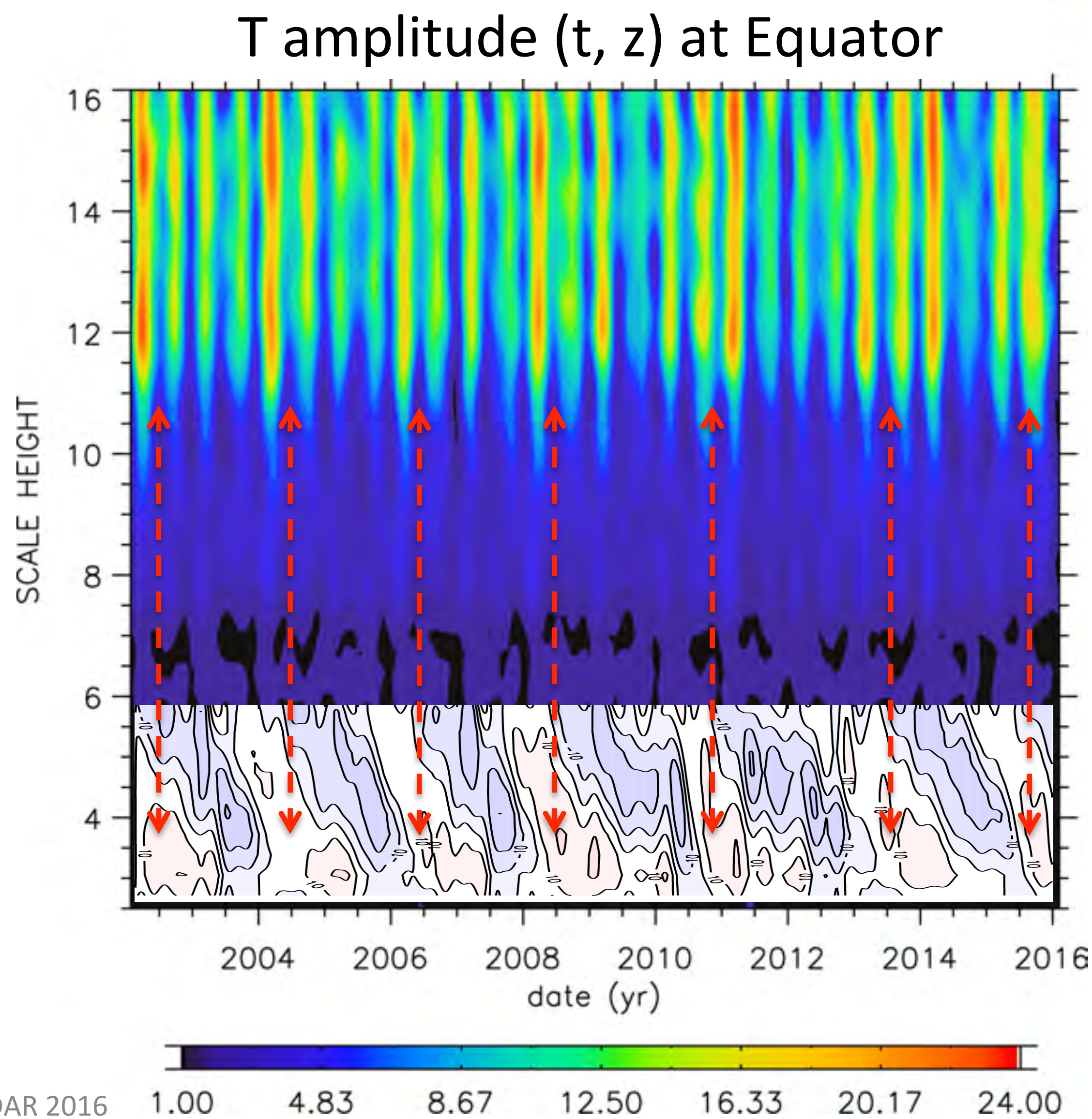


T amplitude (t, z) at Equator



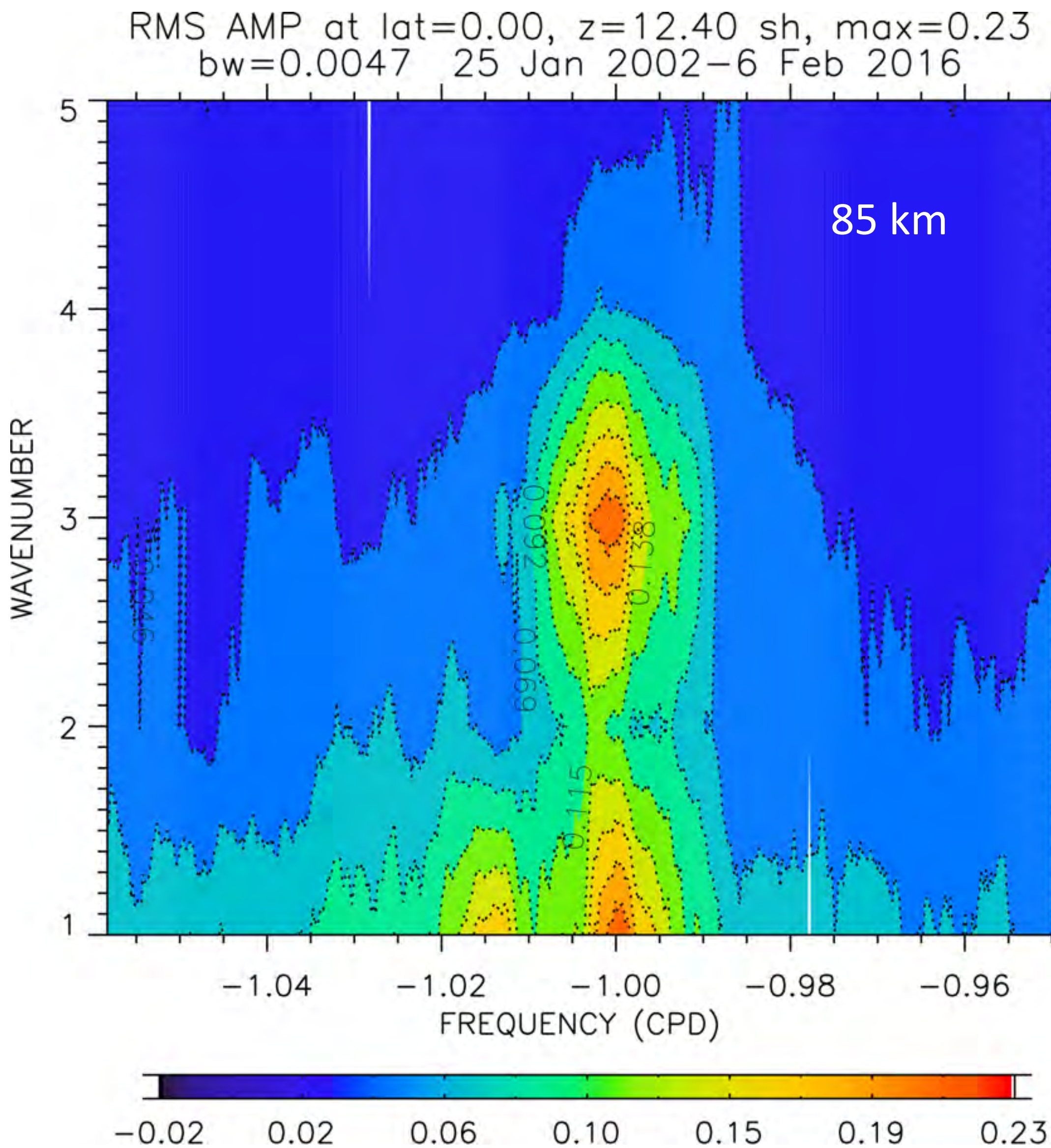
- amplitude is very large at the equinoxes: ~20-24 K at 85 km
- amplitude displays striking, repeatable semiannual and quasi-biennial variability

tidal amplitude vs. QBO



- periods of large amplitude coincide with westerly QBO phases in the stratosphere
- QBO wind obtained from SABER geopotential at the Equator

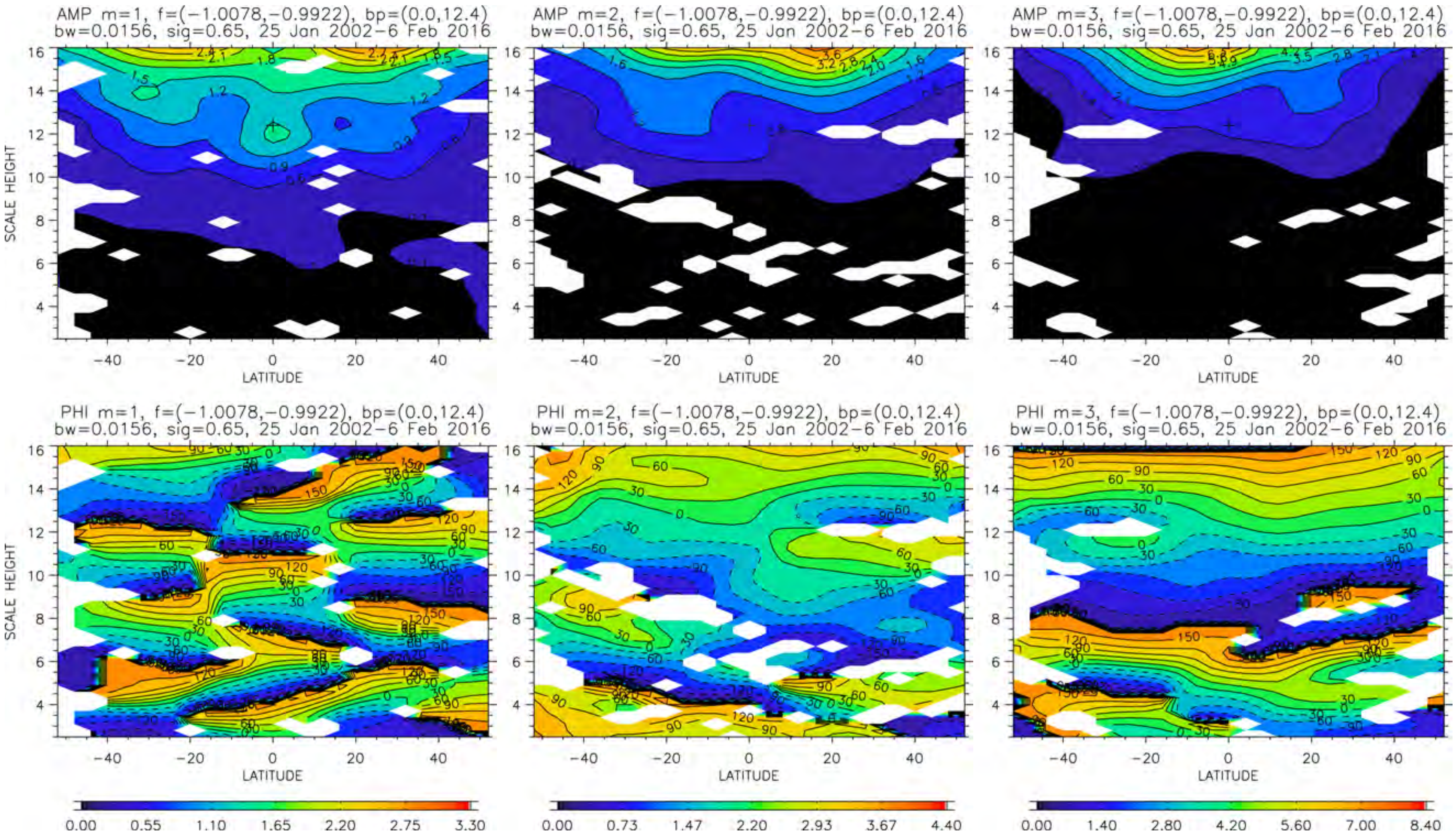
non-migrating tides: *ω,m* spectrum



- spectrum at Equator, 85 km
- power at *m* = 1 – 4
- *m* = 3 dominant

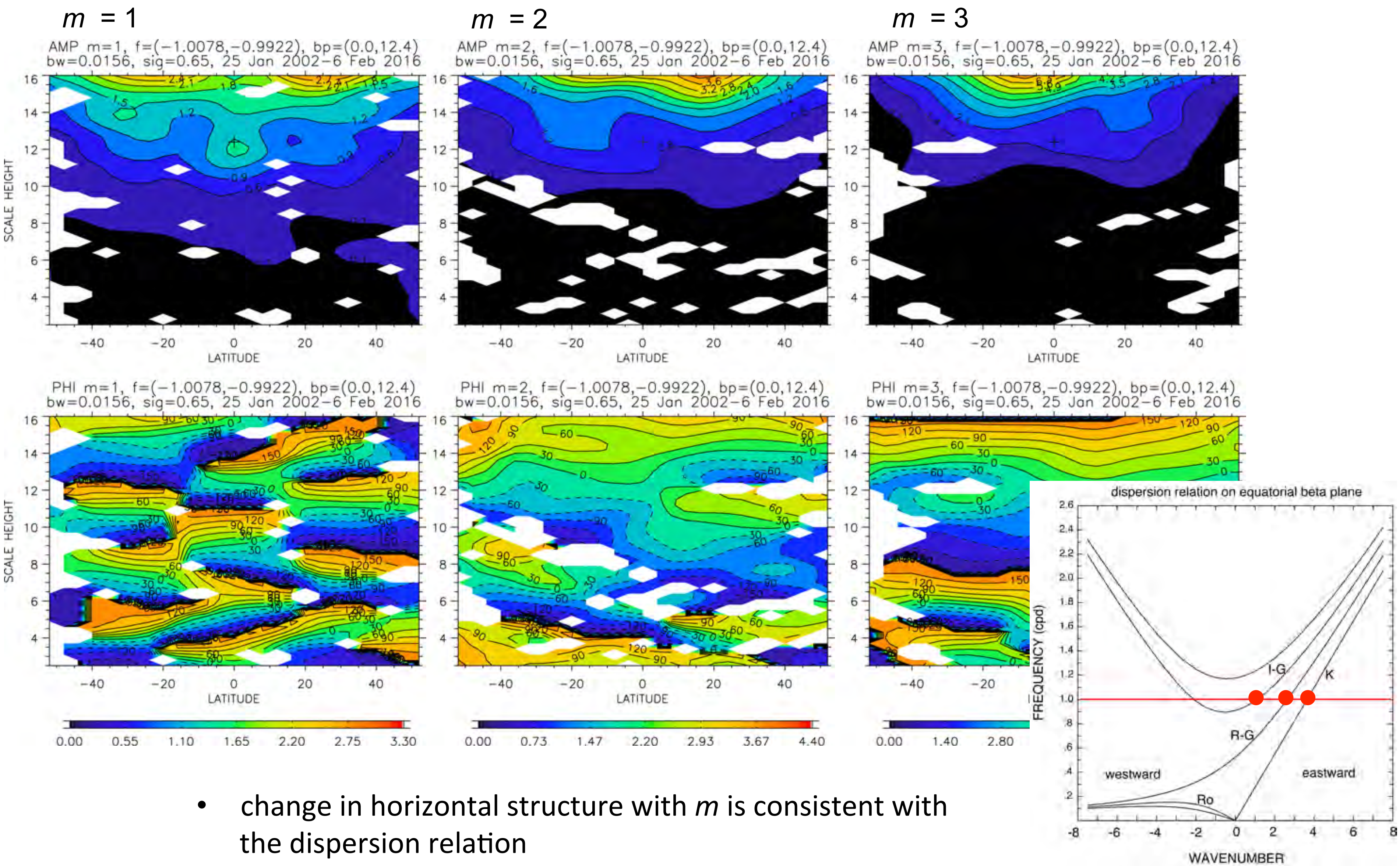
non-migrating diurnal T tide structures

m = 1 *m* = 2 *m* = 3



- *m* = 1 has IG wave structure (like the migrating tide—but vertically propagating everywhere); *m* = 2 has mainly antisymmetric RG wave structure; *m* = 3 has mainly symmetric Kelvin wave structure

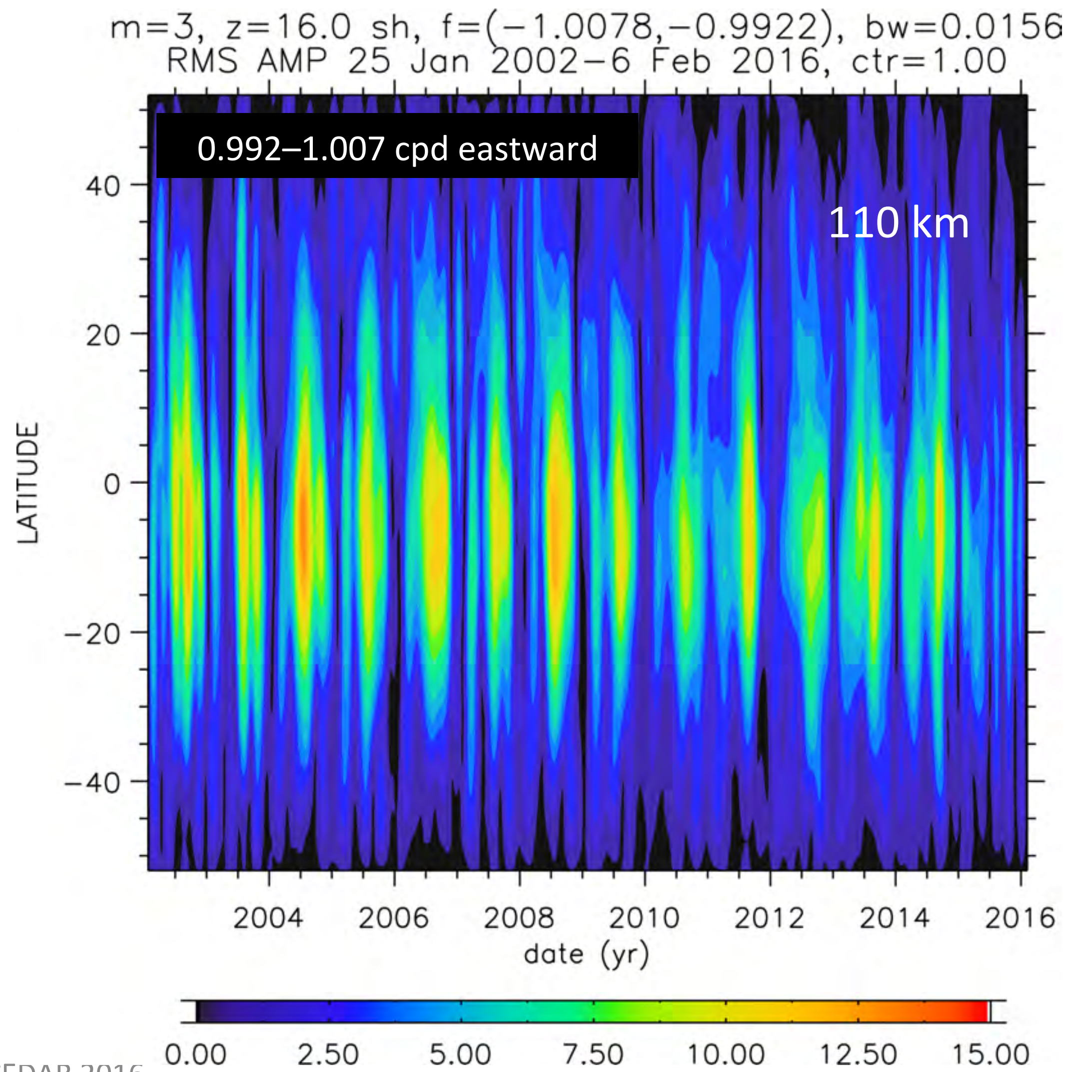
non-migrating diurnal T tide structures



- change in horizontal structure with *m* is consistent with the dispersion relation

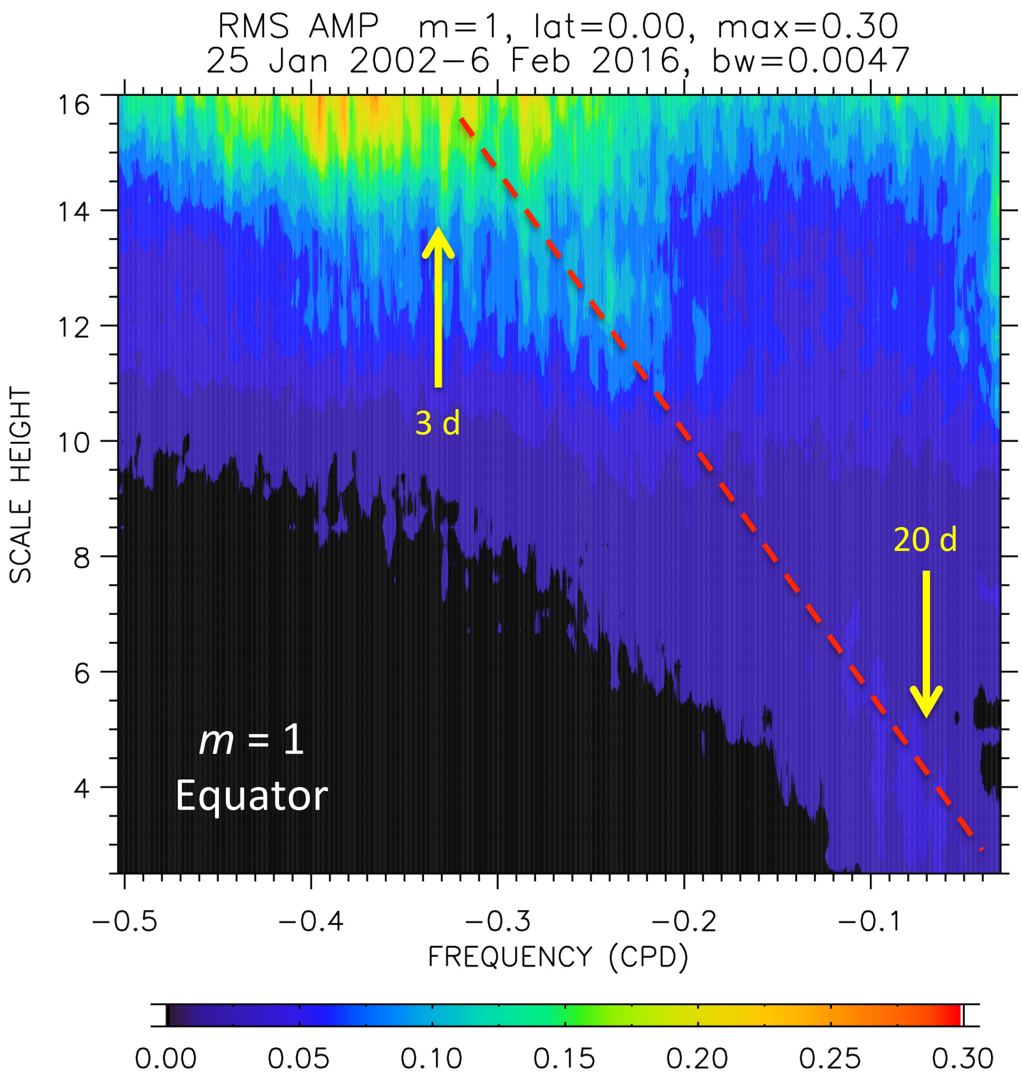
m = 3 non-migrating tide variability

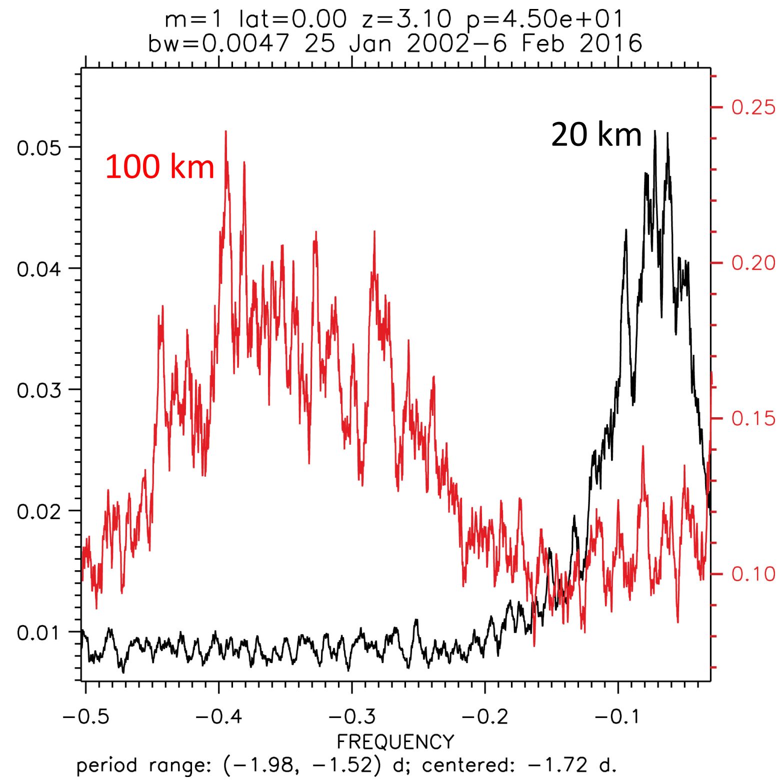
amplitude (t, θ) at 100 km



- RMS amplitude integarted over the band 0.992 – 1.007 cpd eastward
- largest amplitude in NH summer
- structure not precisely symmetric about the Equator → mix of Kelvin wave and an anti-symmetric mode (RG?)
- amplitude is large (~ 12 K) and still growing at 110 km, the highest altitude considered in this analysis–comparable to the migrating diurnal tide

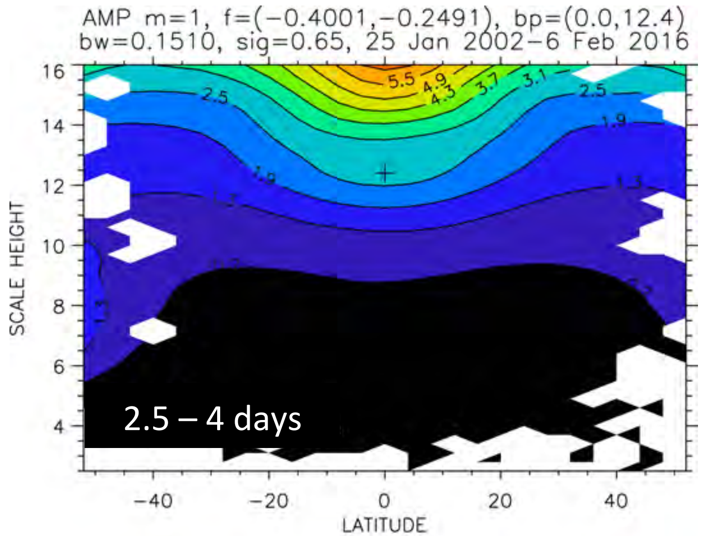
equatorial Kelvin wave T spectrum



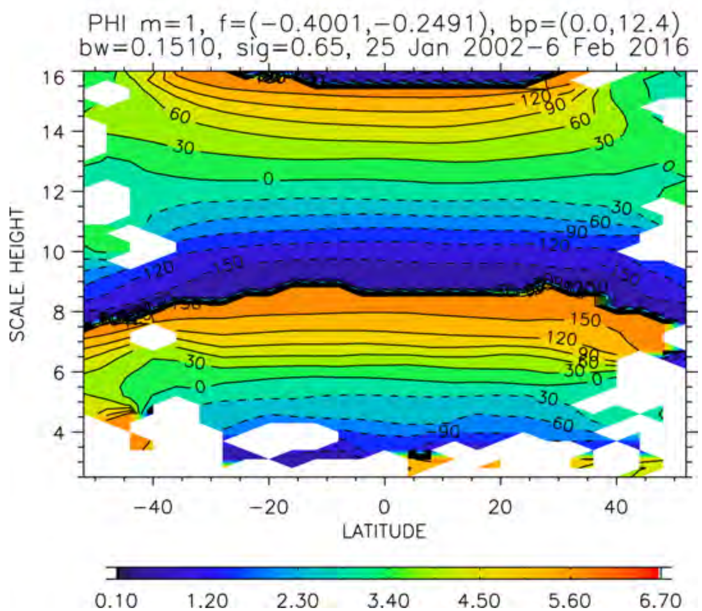


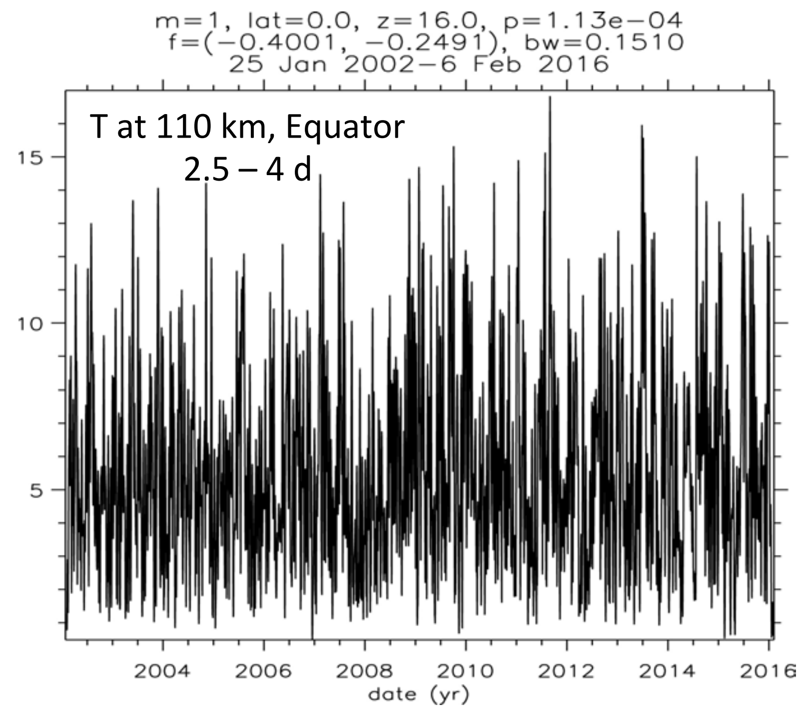
- spectrum at 15 km centered at ~ 20 days
- spectrum at 100 km centered at ~ 3 days
- slower waves absorbed/dissipated at lower altitudes

fast Kelvin waves



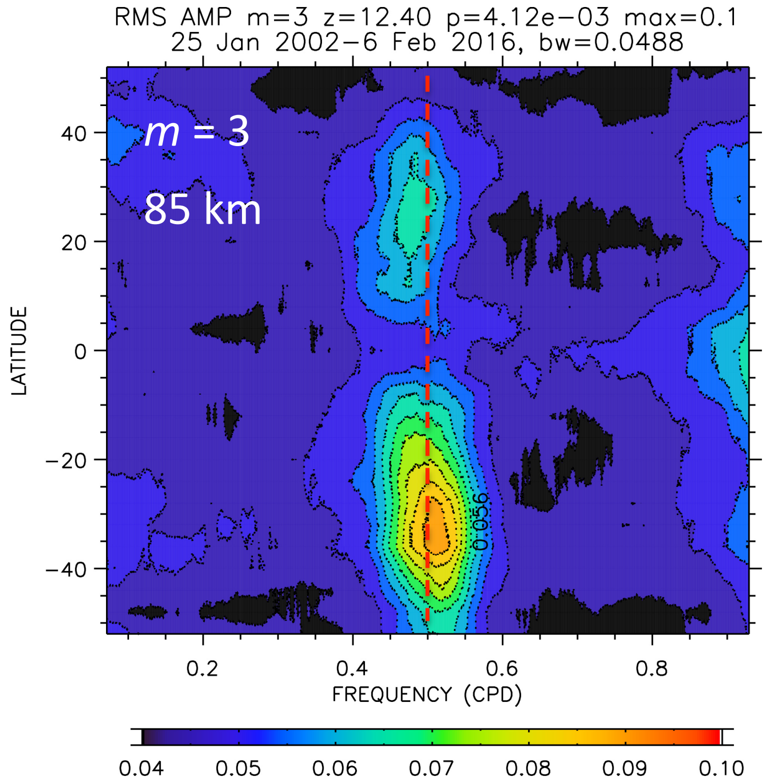
- synthesized in band 0.25-0.4 cpd eastward (period 2.5-4 d)
- RMS amplitude for the entire period of analysis (left) is large in the lower thermosphere (~ 6 K at 110 km)
- instantaneous amplitude (below) can be much larger (10-15 K), with no regular seasonal variability

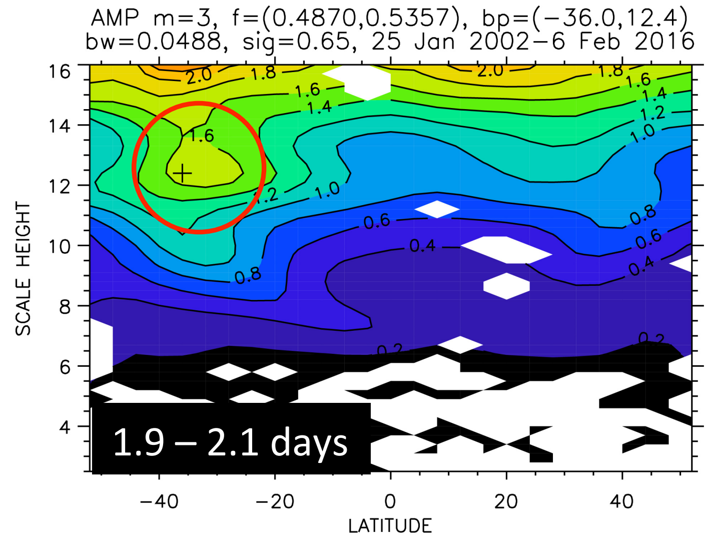


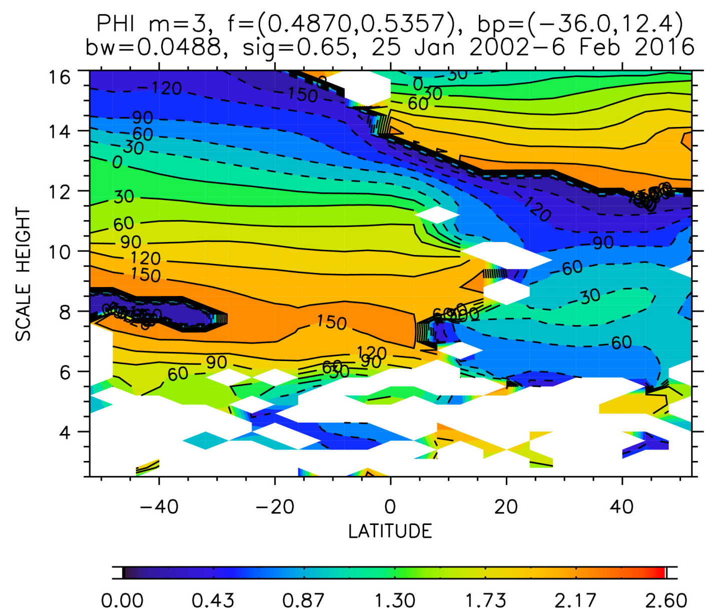


m = 3, 2-day wave in T

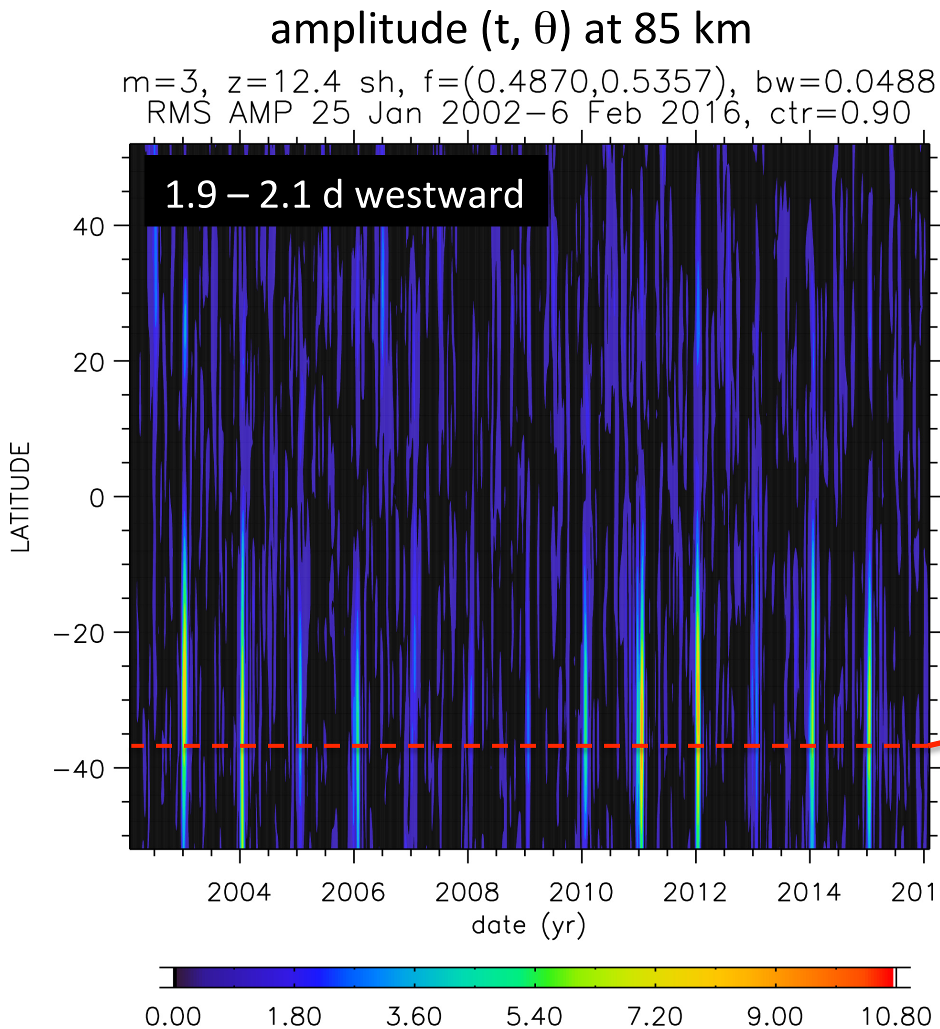
- m = 3 latitude vs. frequency spectrum (below) shows concentrated variance near 2 d
- structure in 1.9 – 2.1 d band (right) is consistent with RG mode excited by instability in SH (e.g., Plumb, 1983)

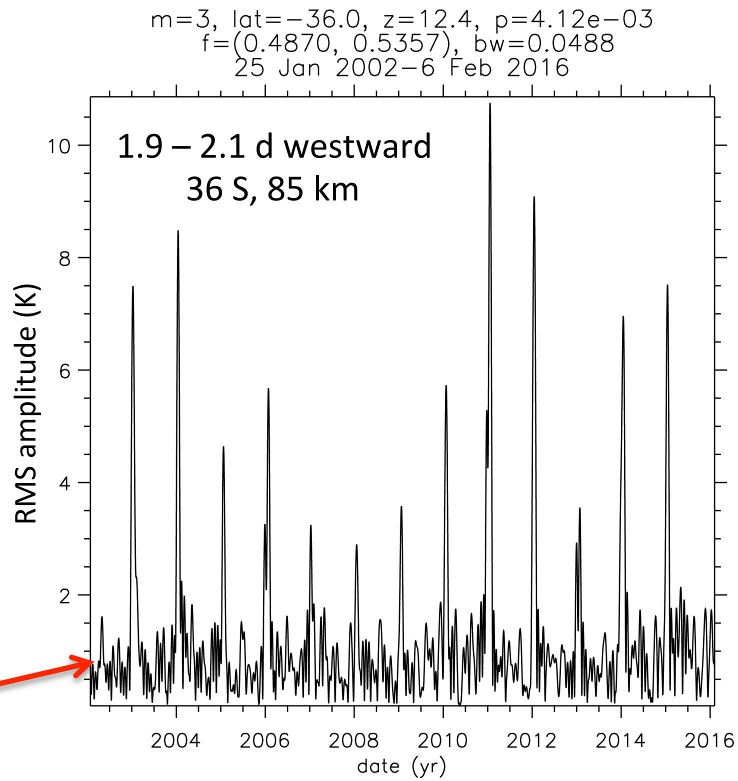






2-day wave variability





- strong summertime phenomenon in the SH
- instantaneous amplitudes are large, 6-10 K

conclusions

- SABER provides continuous data (2002-2016) over altitudes ~ 17–110 km
- observations resolve variability at ~ ±1 cpd and $m = 0 – 6$
- data is well suited for analysis using Salby's FFSM algorithm
- FFSM yields synoptic spectra; sampling theory can be applied to the interpretation of spectra, evaluation of information content, prediction of aliasing, etc.
- very long time series (14 yrs) yield extremely fine frequency resolution
- observations show the presence of most of the large-scale waves expected to dominate the variability in the middle atmosphere at periods down to 1 day
- ability to evaluate simultaneously the behavior of waves and the zonal-mean field is useful for assessing wave-mean flow interactions