Short-term Tidal Variability From SABER as a Function of Geophysical Conditions Using Bayesian Statistics and Information Theory

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1. Abstract

Atmospheric tides significantly impact the dynamics of the upper atmosphere (i.e. mesosphere and lower thermosphere [MLT]) and are the key to understanding how tropospheric weather influences space weather. Seasonal tidal variability and their impact on the Earth's atmosphere have been extensively studied, but very little is known about variability on shorter, e.g., daily or weather time scales. Therefore, we are developing a statistical empirical model of the short-term tidal variability observed in SABER temperatures using Information Theory and Bayesian statistics. In this paper, we will present initial results of how the short-term tidal variability changes as a function of geophysical conditions such as the Quasi-Biennial Oscillation (QBO), El Niño-Southern Oscillation (ENSO), etc., using SABER and WACCMX-2.0 DE3 data. The statistical significance test of the methodology will also be discussed.

2. Short term tidal variability from SABER

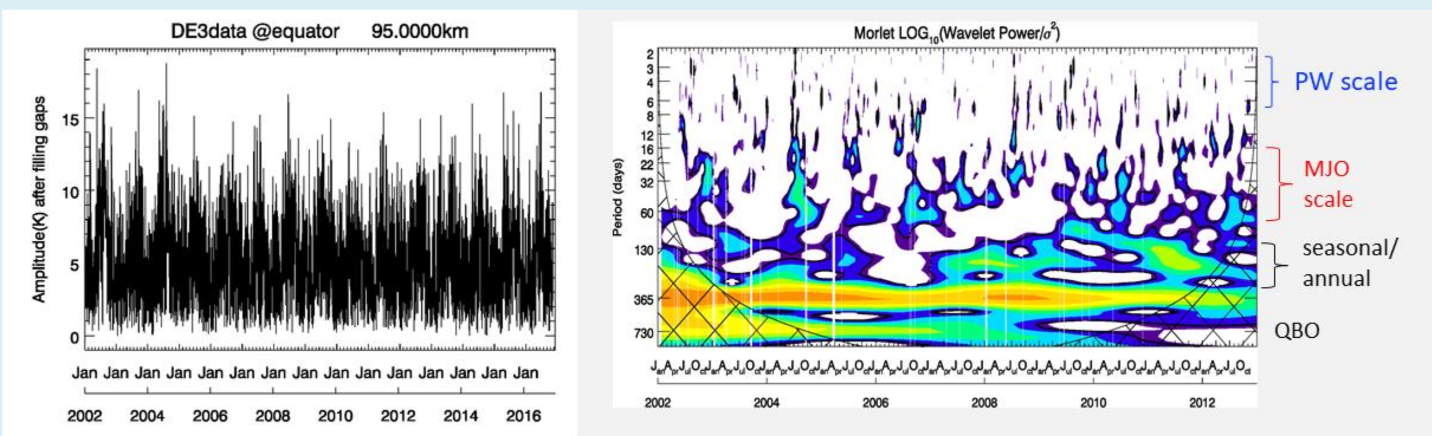
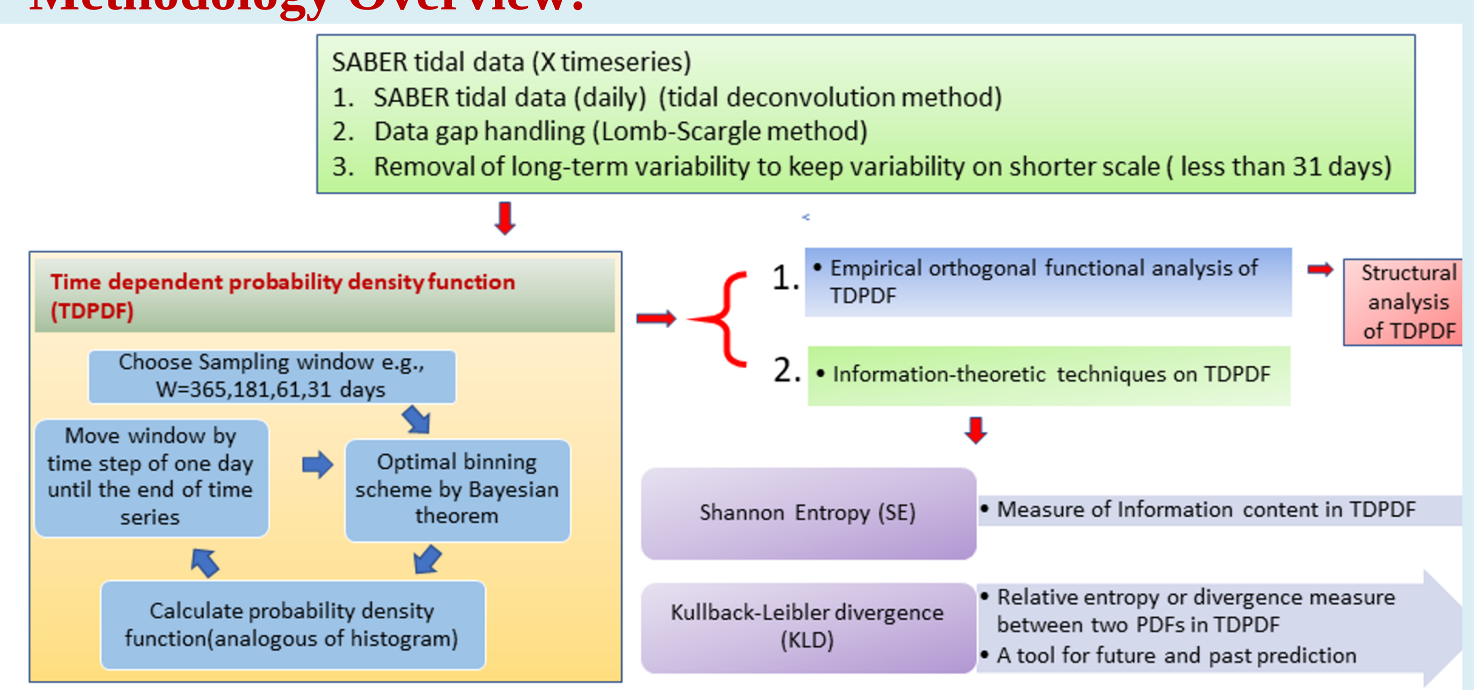


Figure 1: (Left) DE3 from SABER at equator and 95 km, (Right) Wavelet spectrum, which shows that Atmospheric tides observed in MLT (~100 km) exhibit both long and short-term variability.

Objective: To understand the causes and impact of the tidal variability on the scales ~10-30 days and how it responds to the QBO, MJO, etc.

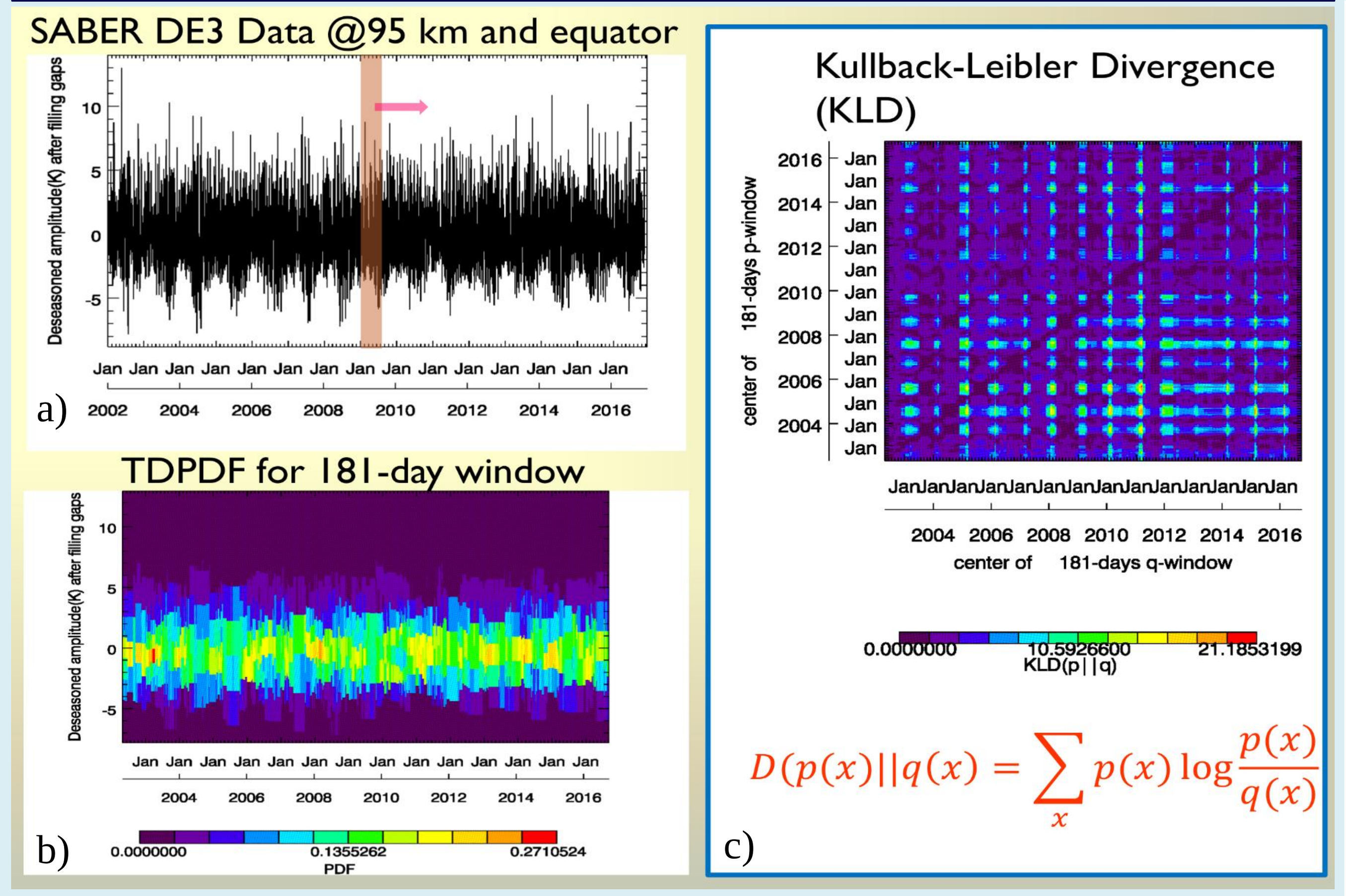
Methodology Overview:



How is short-term tidal variability studied using a sample of such large window length (e.g. 181 days)?

The key point is that I am considering here the ***'variability over variability'*** in TDPDF. The TDPDF using 181-day window is utilized to study inter-annual changes of the short-term tidal variability. These changes represent how short-term variability responds to other forcing factors in the atmosphere on inter-annual or larger scales. Identifying changes in short-term tidal variability related to intra-seasonal effects (such as MJO, a ~60-day periodic atmospheric event) would require a shorter window length sample selection.

3. Summary of the results



$$D(p(x)||q(x)) = \sum_x p(x) \log \frac{p(x)}{q(x)}$$

Figure 2: Overview of the results for SABER DE3 data at 95 km & equator: The TDPDF (b) of the de-seasoned data (a) is obtained using a sample of 181-day window length and then advancing the window in steps of one day until the end of the time series. Bayesian optimal binning scheme provides best optimization between information vs noise in the data. The annual variation in the KLD values (c) indicates the seasonal variations of PDF structures of the short-term tidal variability. KLD gives insight into the relative stable short-term tidal variabilities (low KLD values) and rapid changes (large KLD values).

4. Statistical significance test

KLD significance test:

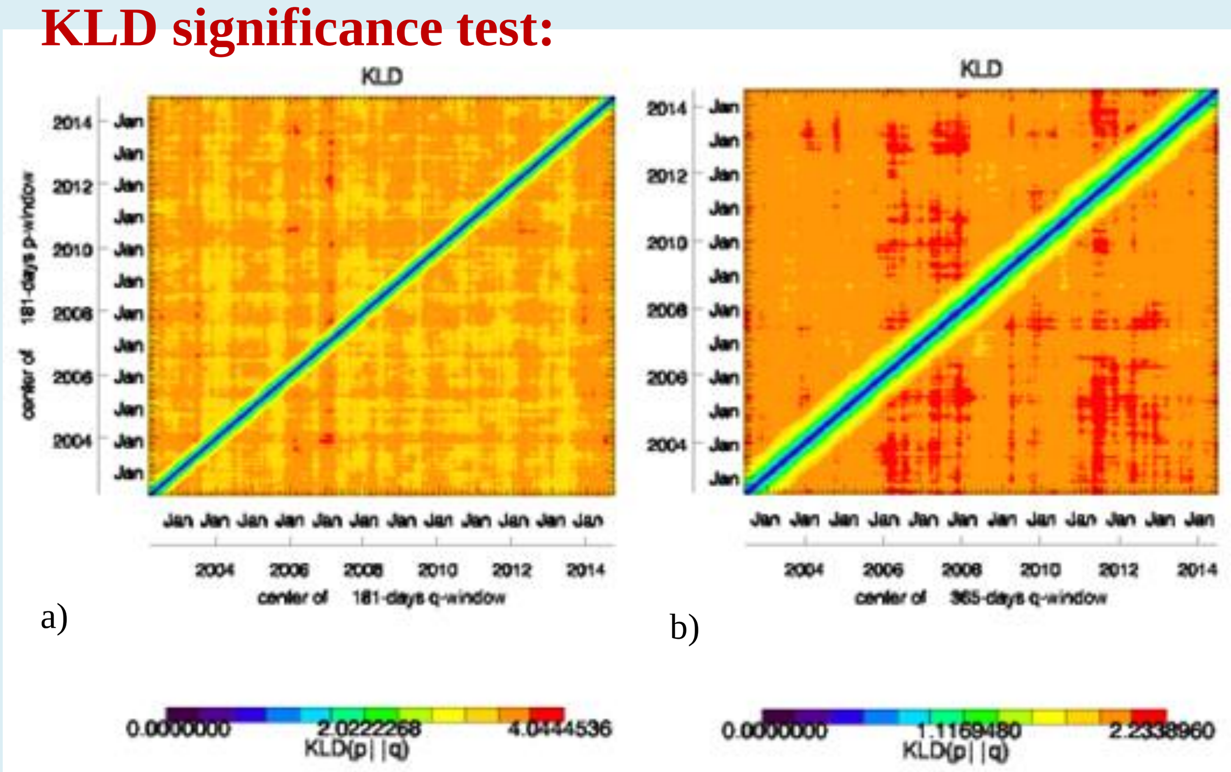


Figure 3: The averaged KLD values for 200 random normal distribution datasets (i.e. random draw from normal distribution (gaussian PDF) data which has standard deviation same as real observations SABER data (i.e. similar variability but with no physical information)) gives a) the range of KLD values (2,4) using 181-day window analysis, and b) the range (1,2) using 365-day analysis.

Bin sensitivity test:

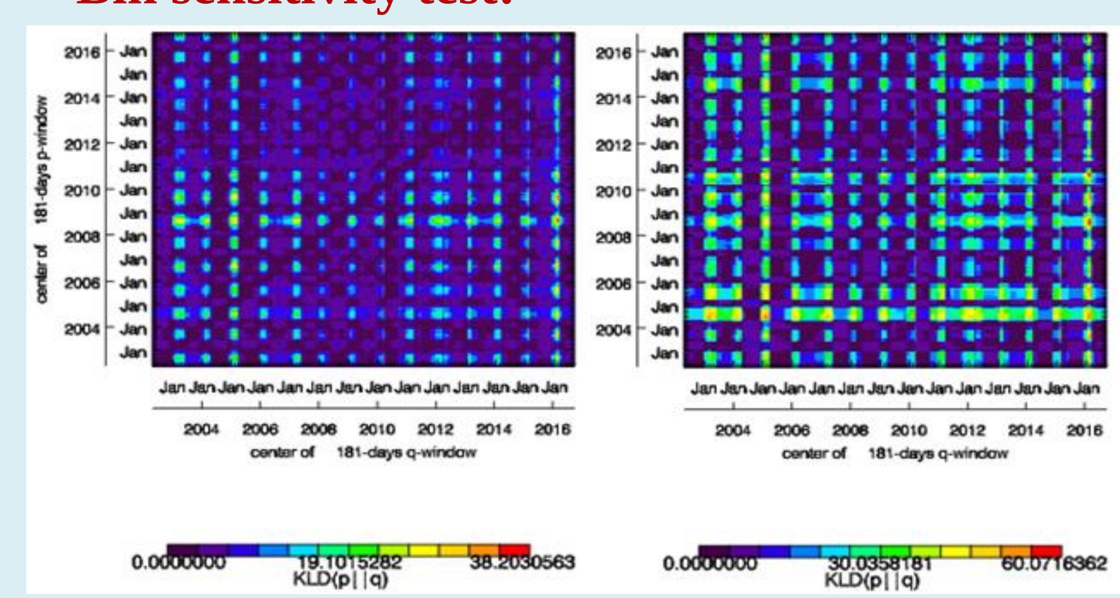


Figure 4: The KLD plot using constant bin 20 (Left) and 5 (Right) for SABER DE3 at 90 km and equator.

The annual feature of the short-term tidal variability persists for both the variable and the constant binning choice which needs further testing right now; this allows me to further analyze using constant bins for shorter windows, as Bayesian statistics doesn't give reliable bin number for sample size smaller than 181-day.

Here, the KLD-values range (2,4) is significantly smaller than that of the short-term tidal variability from SABER data using 181-day window as explained in the previous Figure 2. Therefore, any KLD value <2 and >4 will be statistically significant in the 181-day windowed samples TDPDF analysis. This gives us confidence that the annual variations in KLD values for SABER-DE3 data is statistically significant.

5. WACCMX-2.0 vs SABER

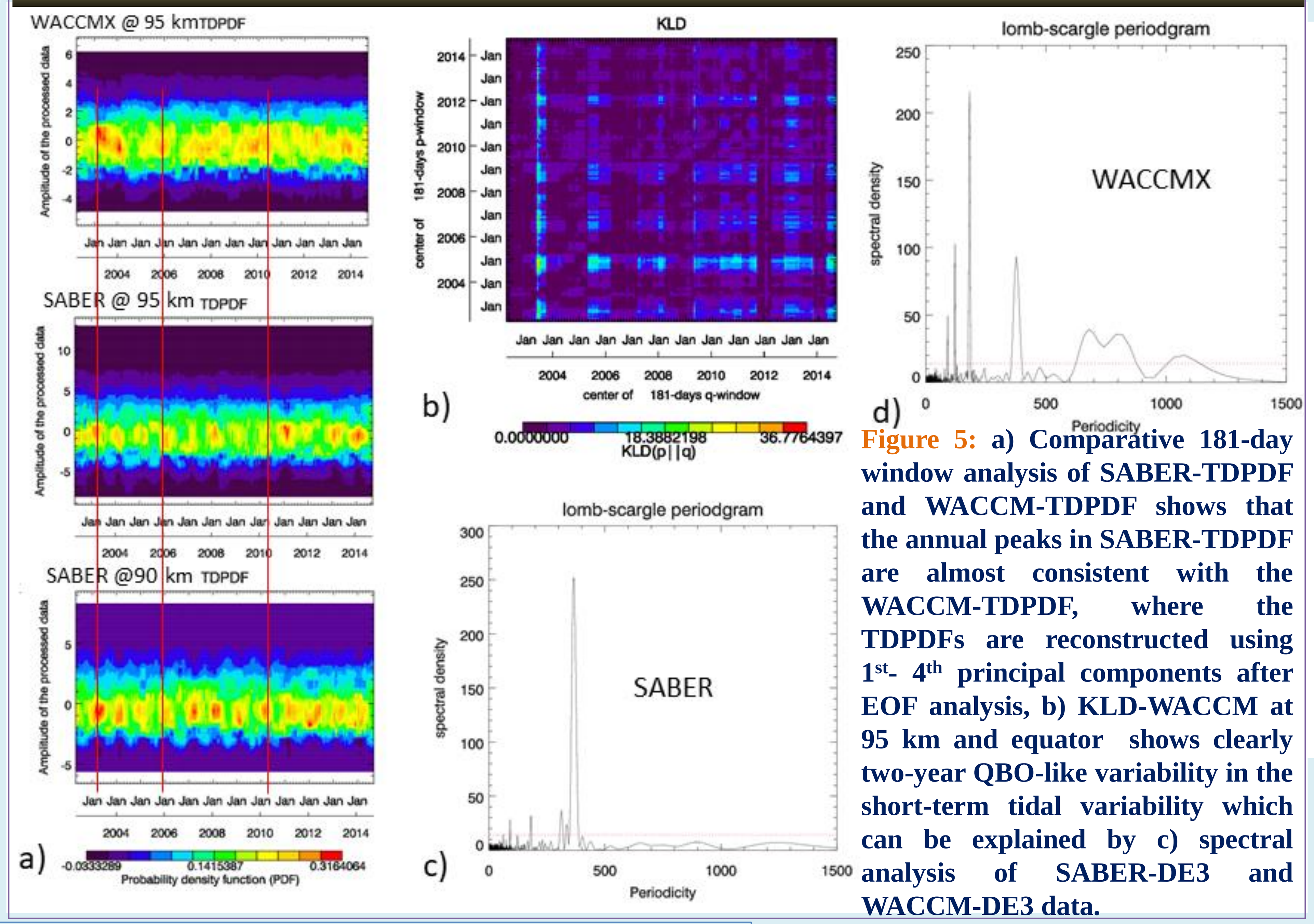


Figure 5: a) Comparative 181-day window analysis of SABER-TDPDF and WACCM-TDPDF shows that the annual peaks in SABER-TDPDF are almost consistent with the WACCM-TDPDF, where the TDPDFs are reconstructed using 1st- 4th principal components after EOF analysis, b) KLD-WACCM at 95 km and equator shows clearly two-year QBO-like variability in the short-term tidal variability which can be explained by c) spectral analysis of SABER-DE3 and WACCM-DE3 data.

6. Future work

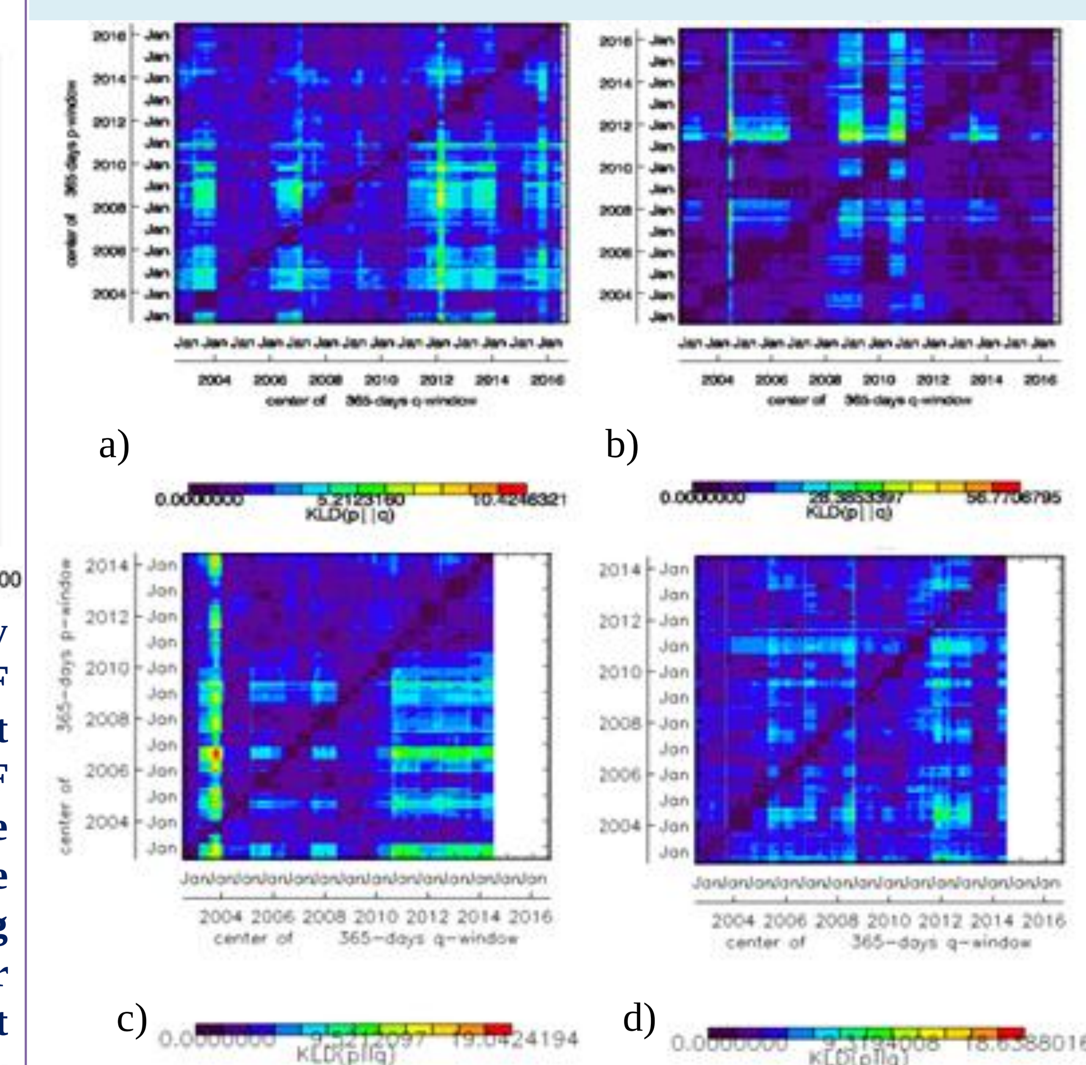


Figure 6: KLD using 365-day window analysis of the short-term tidal variability for the de-seasoned a) symmetric SABER-DE3 at equator & 95 km, b) antisymmetric SABER-DE3 at 10 N & 95 km, c) symmetric WACCM-DE3 at 10 N & 95 km, d) antisymmetric WACCM-DE3 at 10 N & 95 km (all KLDs statistically significant as shown in Fig. 3 (b)).

365-day window analysis is used to remove the annual feature and to investigate the QBO, ENSO-like effects in SABER and WACCM short-term tidal variability. Since, QBO and ENSO has similar periodicities and relative phase between QBO-ENSO could result superposed impact on tides, the symmetric and anti-symmetric analysis includes DE3 amplitudes and phases. The ongoing effort is to understand the 2-4 year features in Figure 6 (a, b, c), while no such feature in (d).

7. Conclusions

- ✓ The KLD values are statistically significant for SABER and WACCM-DE3 data.
- ✓ The annual feature in SABER-TDPDF reasonably follow the WACCM-TDPDF but it's clouded by two years feature in WACCM-TDPDF which can be seen from WACCM-KLD as well. This can be explained from spectral analysis of WACCM-DE3 tidal data, as the annual feature looks weaker than SABER and very comparable to QBO.
- ✓ The 365-day analysis shows the potential to investigate further the QBO, ENSO-like response in the short-term tidal variability.
- ✓ The preliminary bin sensitivity test results allow to do analysis using shorter (< 181-day) windows with constant binning to further investigate MJO-like response in the short-term tidal variability.

8. References

1. Larson, J. Walter (2012), "Visualizing Climate Variability with Time-Dependent Probability Density Functions, detecting It Using Information Theory", Procedia Computer Science 9 917-926
2. Knuth, K. H. (2006), Optimal data-based binning for histograms, https://arxiv.org/pdf/physics/0605197.pdf
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