Nonmigrating Tidal Variability on Planetary Wave-Scales in the Mesosphere and Lower Thermosphere Region from SABER

Komal Kumari, Jens Oberheide

Department of Physics and Astronomy , Clemson University

1. Abstract

The prominent eastward-propagating nonmigrating diurnal tide with zonal wave number 3 (DE3) can reach into the mesosphere and lower thermosphere (80-100 km), introducing longitudinal and large day-to-day variability in temperature, wind and density. In this paper, we discuss the physical reasons for the observed tidal variability on a ~10-day planetary wave (Q10DW) timescale from 16 years of SABER (onboard the TIMED satellite) short-term tidal diagnostics. Our analysis uses an information-theoretic approach based on Bayesian statistics, time dependent probability density functions and Kullback-Leibler divergence. We also discuss the interannual statistical characteristics of the DE3 variability on a 10-day time scale associated with the quasi-biennial oscillation (QBO), El Niño-Southern Oscillation (ENSO), and solar cycle.

Objective: **To understand the causes of short-term tidal variability on ~10-30 day time-scales and how it responds to the QBO, ENSO, and solar cycle.**

2. Short term tidal variability from SABER

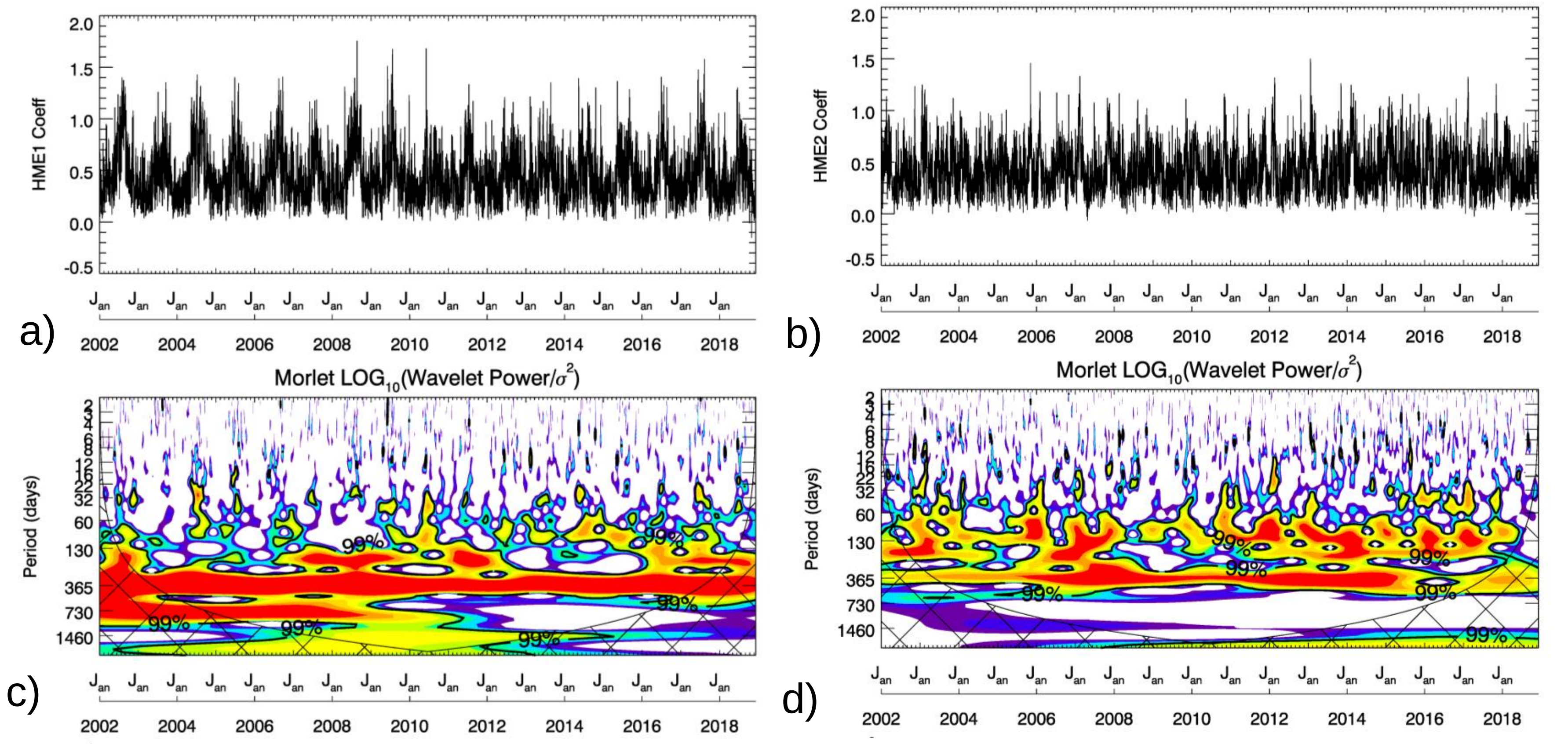
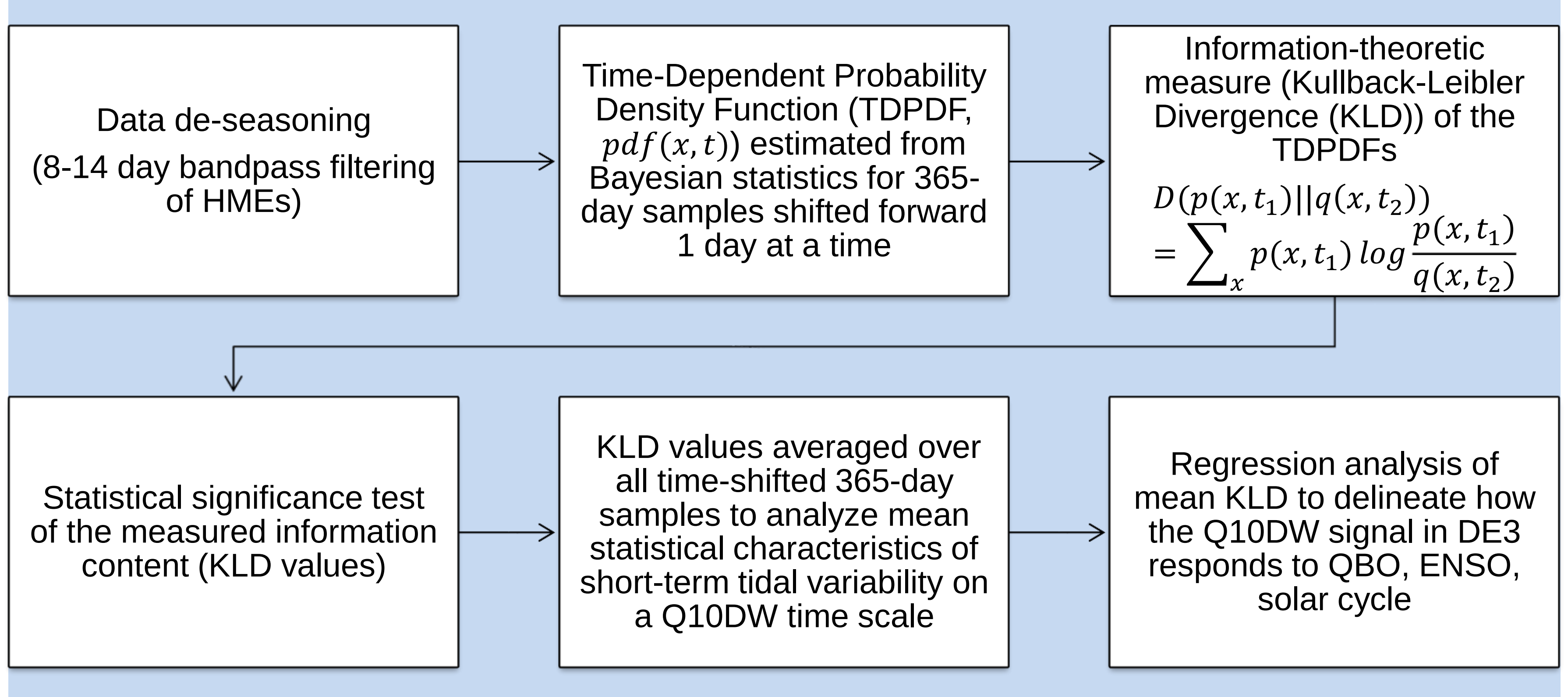


Figure 1: DE3 temperature tide from SABER (1-day resolution) decomposed into a) symmetric and b) anti-symmetric modes (Hough Mode Extensions, HMEs) [*Oberheide and Forbes* 2008]. Note that both modes have a different seasonal variation. Wavelet analyses of the symmetric timeseries HME1 and the antisymmetric timeseries HME2 are shown in c) and d), respectively. Long- and and short-term variability is observed. While wavelets allow us to estimate multi-scale temporal variations, they do not allow us to gain physical insight in the causes of short-term tidal variability. Therefore, we apply an information-theoretic approach to study 10-30 day tidal variability.

3. Methodology



Data de-seasoning (8-14 day bandpass filtering of HMEs)

Time-Dependent Probability Density Function (TDPDF, $pdf(x,t)$) estimated from Bayesian statistics for 365-day samples shifted forward 1 day at a time

Information-theoretic measure (Kullback-Leibler Divergence (KLD)) of the TDPDFs

$$D(p(x,t_1)||q(x,t_2)) = \sum_x p(x,t_1)\, log\frac{p(x,t_1)}{q(x,t_2)}$$

Statistical significance test of the measured information content (KLD values)

KLD values averaged over all time-shifted 365-day samples to analyze mean statistical characteristics of short-term tidal variability on a Q10DW time scale

Regression analysis of mean KLD to delineate how the Q10DW signal in DE3 responds to QBO, ENSO, solar cycle

4. Results: DE3 short-term variability on quasi 10-day planetary wave timescale

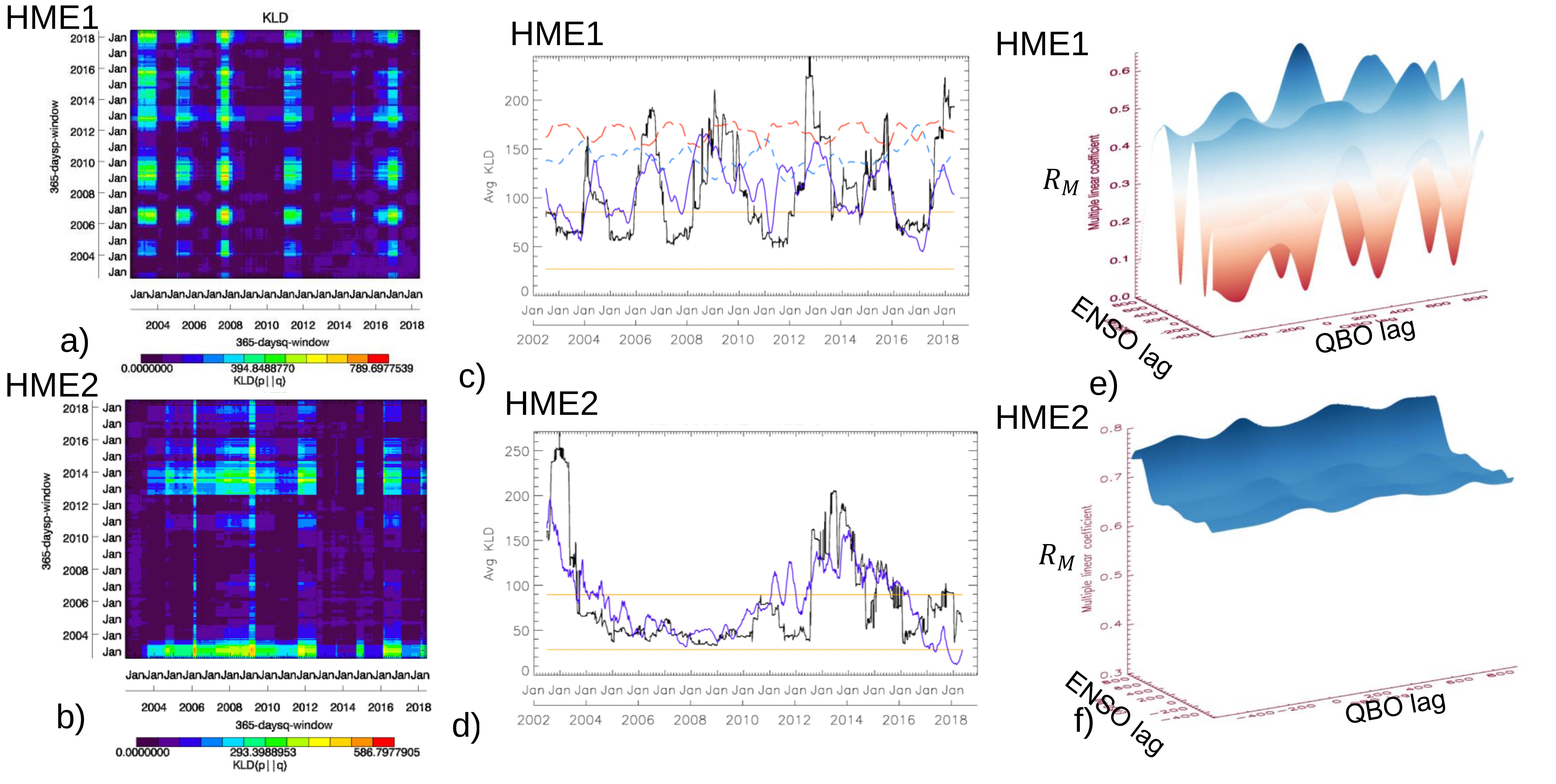


Figure 2: The contour plots show KLD values after bandpass filtering (8-14 days) the SABER DE3. a) HME1 (symmetric) and, b) HME2 (anti-symmetric). KLD values are a measure for the divergence of two time-shifted PDFs ($p(x,t_1)$ on $y-axis$, $q\,(x,t_2)$ on $x-axis$) drawn from the TDPDF ($pdf(x,t)$) of the given timeseries x. As such, high (low) KLD values signify high (low) variability of time-shifted samples. The black curve in c) and d) are the mean KLD values averaged along the $x-axis$ of the contour plots in a) and b), respectively. They are the mean statistical characteristics of DE3 HME1 and HME2 variability on a 10-day planetary wave timescale. Orange lines are the confidence interval for 95% significance. Blue solid lines show the multiple linear regression fit using the model $Y = A0 + A1 * QBO + A2 * ENSO + A3 * F10.7$. To ensure the best regression fit, the QBO (red) and ENSO (light blue) timeseries are shifted left (negative) and right (positive) with respect to the mean KLD values (black curve). Multiple linear regression coefficients (R_M) corresponding to each lag are shown in e) for HME1 and f) for HME2. For HME1, the largest R_M is 0.63 for a QBO lag of ~5 months with corresponding *linear* correlation coefficient R_{QBO} ~ -0.27. and an ENSO lag of ~1 year with R_{ENSO} ~ -0.43. The solar cycle lag is currently taken as zero with $R_{F10.7}$ ~ -0.14. In contrast, R_M for HME2 does not vary significantly for different QBO lags and only somewhat for ENSO. The best regression fit in this case is (R_M ~ 0.71) which is predominantly due to solar cycle F10.7 variability (of zero lag and $R_{F10.7}$ ~ 0.67) and ENSO (of lag ~ 2 years and R_{ENSO} ~ -0.40), as shown by the solid blue curve in d).

5. Discussion and Conclusions

The lacking Q10DW variability response to QBO in the antisymmetric DE3 (HME2) can be explained by the anti-symmetric behavior of the mode. HME2 peaks in the winter hemispheres when the Q10DW is most active at middle latitudes during winter and equinoxes [*Forbes and Zhang* 2015]. **The prominent solar cycle response signifies a DE3 tidal-Q10DW interaction modulation due to the solar cycle.**

The negative linear correlation coefficients corresponding to QBO and ENSO for the symmetric DE3 mode (HME1) indicate a **high short-term tidal variability on a Q10DW time scale during the easterly phase of the QBO and La Niña conditions.** This can be tentatively explained because the planetary wave propagation is more equatorward and upward in mid-latitudes during easterly QBO phase than during the westerly phase [*Naoe and Shibata* 2010]. Also, DE3 variability is larger during the La Niña phase [*Warner and Oberheide* 2014], consistent with our findings.

The statistical characteristics of the tidal variability can in principle be extended to forecast the variability features in different propagation and forcing conditions, once the physical causes are fully understood. DE3 tidal variability on 16-day, and 23-day planetary wave timescales is also significant and is currently being investigated.

6. References

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kkumari@g.clemson.edu