UNDERSTANDING THE SYSTEMATIC ERRORS OF CHAMP ACCELEROMETER-DERIVED NEUTRAL MASS DENSITY DATA USING DATA ASSIMILATION

Timothy **Kodikara**[1*], Isabel Fernandez-Gomez[1], Ehsan Forootan[2], W. Kent Tobiska[3], Claudia Borries[1]

Accelerometer-derived neutral mass density (NMD) is an important quantity that describes the variability of the upper atmosphere. NMD is widely used to calibrate and validate some models used for satellite orbit determination and prediction. Quantifying the true NMD is nearly impossible due to, among others, the lack of simultaneous in-situ measurements to cross-validate and the incomplete characterization of the uncertainties of these NMD products. Using multiple data assimilation (DA) experiments and robust statistical techniques, this study investigates the error distribution of three different accelerometer-derived NMD products from the CHAMP satellite mission during a time period of low solar and geomagnetic activities. The strategies applied here may be useful and applicable to other space missions spanning over longer time periods. The results indicate considerable differences among the three CHAMP data sets and also show a pronounced latitudinal dependency for the estimated error distributions. On average, the error estimates for NMD vary in the range 6.5–15.6% of the signal. The results further demonstrate that DA considerably enhances the capability of the physical model as well as an excellent tool to assess data uncertainties.

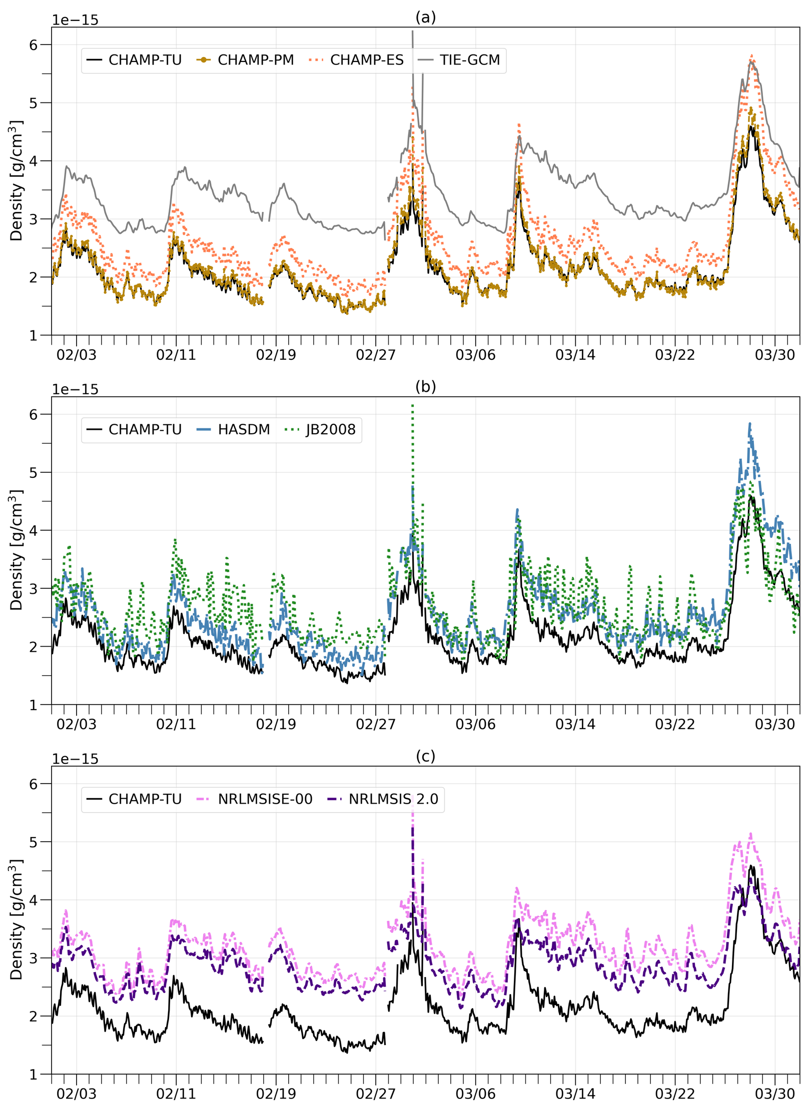

Figure 1: Orbit-averaged NMDs from CHAMP as estimated by *Doornbos* [2012] (TU), *Mehta* [2017] (PM), and *Sutton* [2011] (ES) during 1 February–31 March 2008. The estimates from the HASDM, JB2008, NRLMSISE-00, NRLMSIS 2.0, and TIE-GCM are along the orbit corresponding to CHAMP-TU.

DIFFERENCES IN CHAMP DATA

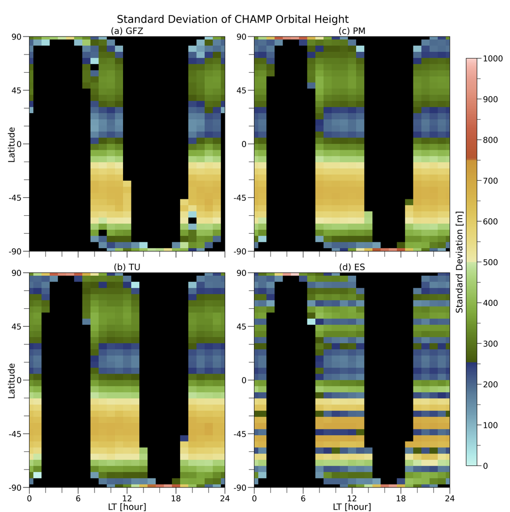

Figure 2: The standard deviation of the CHAMP satellite height as a function of geographic latitude and local time. The data correspond to the time period of Figure 1 as reported in (a–d) *Rother and Michaelis* [2019] (GFZ), CHAMP-TU, -PM, and -ES, respectively.

DATA ASSIMILATION EXPERIMENTS

E1-10% Assimilate CHAMP-*Ne*-*Te* with 10% measurement uncertainty;

E2-100% Assimilate CHAMP-*Ne*-*Te* with 100% measurement uncertainty; and

H7-10% Assimilate neutral winds from the HWM07 with 10% uncertainty along CHAMP.

IMPACT OF DATA ASSIMILATION ON NEUTRAL MASS DENSITY

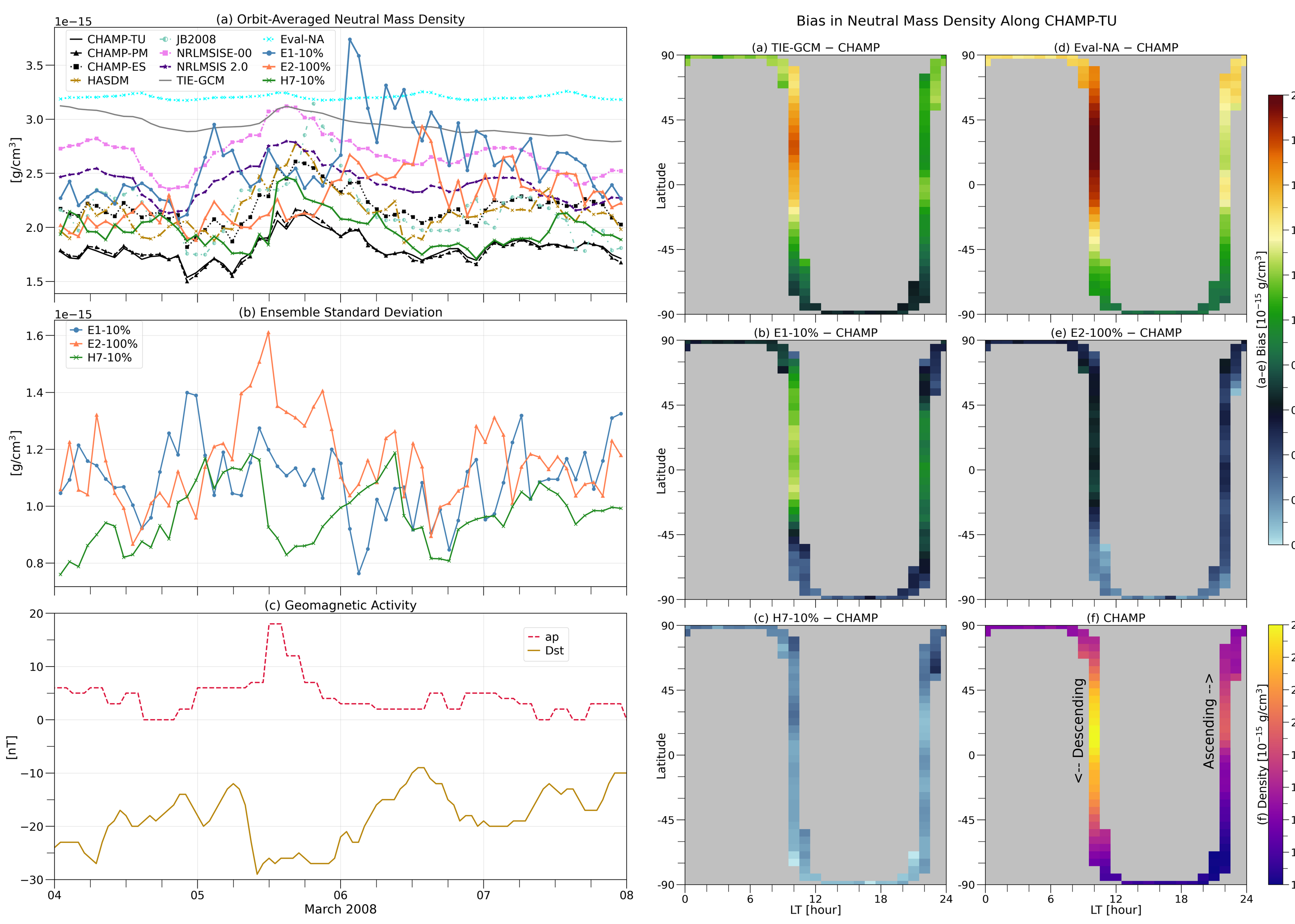

Figure 3: (left-a) The orbit-averaged NMDs from CHAMP-TU, -PM, and -ES. The estimates from HASDM, JB2008, NRLMSISE-00, NRLMSIS 2.0, physics-based TIE-GCM, Eval-NA (evaluation-no assimilation), and the three DA experiments—E1-10%, E2-100%, and H7-10% are along CHAMP-TU. (left-b) The standard deviation among the 90-member ensemble for each DA experiment. (left-c) Space weather conditions for the time period 4–7 March 2008 demonstrated via 3-hour *ap* and *Dst* indices as reported on omniweb.gsfc.nasa.gov. (right) The bias between model and CHAMP-TU NMDs as a function of geographic latitude and local time.

CONCLUSIONS

1. Validation results with ISR data show that assimilation of neutral winds (H7-10%) not only improves TIE-GCM's neutral states but also the electron density state;
2. Experiment H7-10% yields the overall best agreement with CHAMP NMD data;
3. Experiments E1-10% and E2-100% yield some improvement in the specification of NMD but they also introduce large uncertainties;
4. The differences between the three CHAMP data sets are systematic and persistent during the entire study period;
5. We describe a method to estimate the uncertainty of CHAMP NMD—$\sigma(\mathrm{E_A})$ for CHAMP-TU -PM, and -ES approximately varies in the range 6.5–12.1, 7.8–14.2, and 9.9–15.6%, respectively;
6. The results demonstrated a latitudinal dependency of $\sigma(\mathrm{E_A})$ for both CHAMP data and mode estimates. These $\sigma(\mathrm{E_A})$ values are generally large in the middle-low latitudes.

COMPARISONS WITH ISR MEASUREMENTS

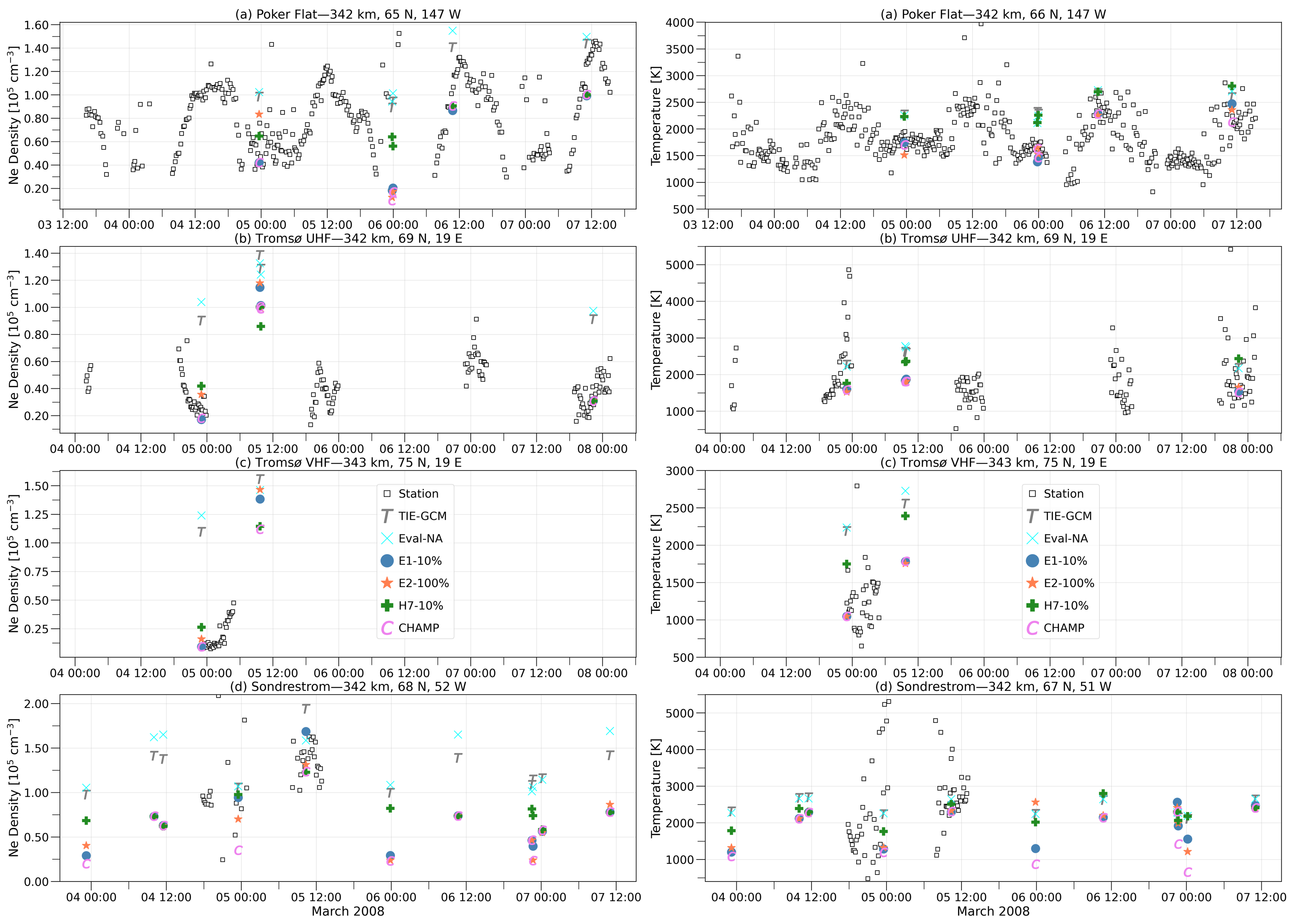

Figure 4: A comparison with co-located incoherent scatter radar (ISR) measurements of (left) electron density *Ne* and (right) electron temperature *Te*. The co-located measurements exist within ±5 km in altitude, and ±2.5° in latitude and longitude of the specified mean coordinates at each ground station. Each panel has a different vertical scale. The ordinate gives the local time corresponding to each ground station.

DATA-DRIVEN MODEL PERFORMANCE

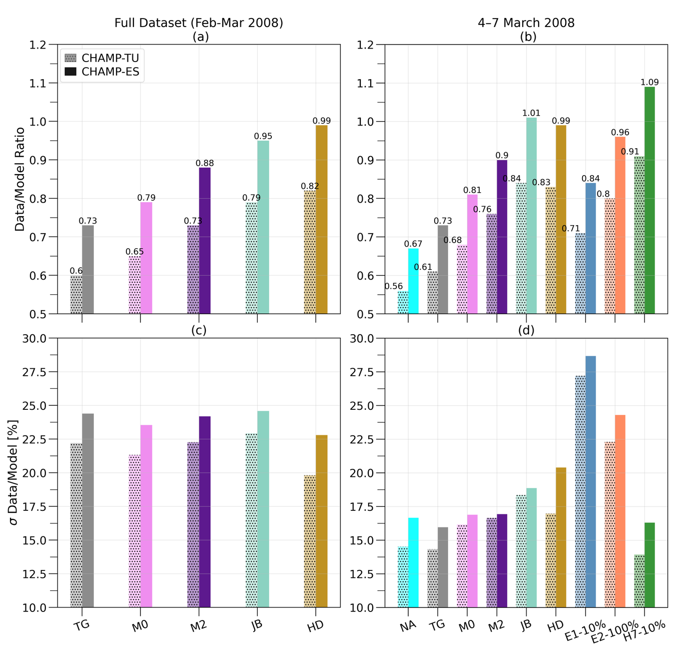

Figure 5: (a–b) The mean NMD log-ratio $\exp(\langle \ln(\mathrm{Data}/\mathrm{Model})\rangle)$ relative to CHAMP-TU (dotted-bar) and CHAMP-ES (plain bar). (c–d) The standard deviation (σ) of the data-to-model log-ratio as a percentage. NA = Eval-NA, TG = TIE-GCM, M0 = NRLMSISE-00, M2 = NRLMSIS 2.0, JB = JB2008, and HD = HASDM.

ESTIMATING THE ERROR IN CHAMP NEUTRAL MASS DENSITY

Following *Grubbs* [1948], consider four different instruments A, B, C, and D taking the same measurement whose recorded values consists of the truth T and some error E (e.g., $\mathrm{A = T + E_A; B = T + E_B}$, and so forth). The variance of the difference between A and B:

$$\mathrm{Var(A-B)} = \frac{1}{\mathrm{n}}\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{A_i - B_i})^2 - \langle \mathrm{A - B}\rangle^2. \tag{1}$$

Error standard deviation σ of $\mathrm{E_A}$ is,

$$\sigma(\mathrm{E_A}) = \sqrt{\mathrm{Var(E_A)}} = \Big\{\frac{1}{3}(\mathrm{Var(A-B) + Var(A-C) + Var(A-D)}) - \frac{1}{6}(\mathrm{Var(B-C) + Var(B-D) + Var(C-D)})\Big\}^{\frac{1}{2}}. \tag{2}$$

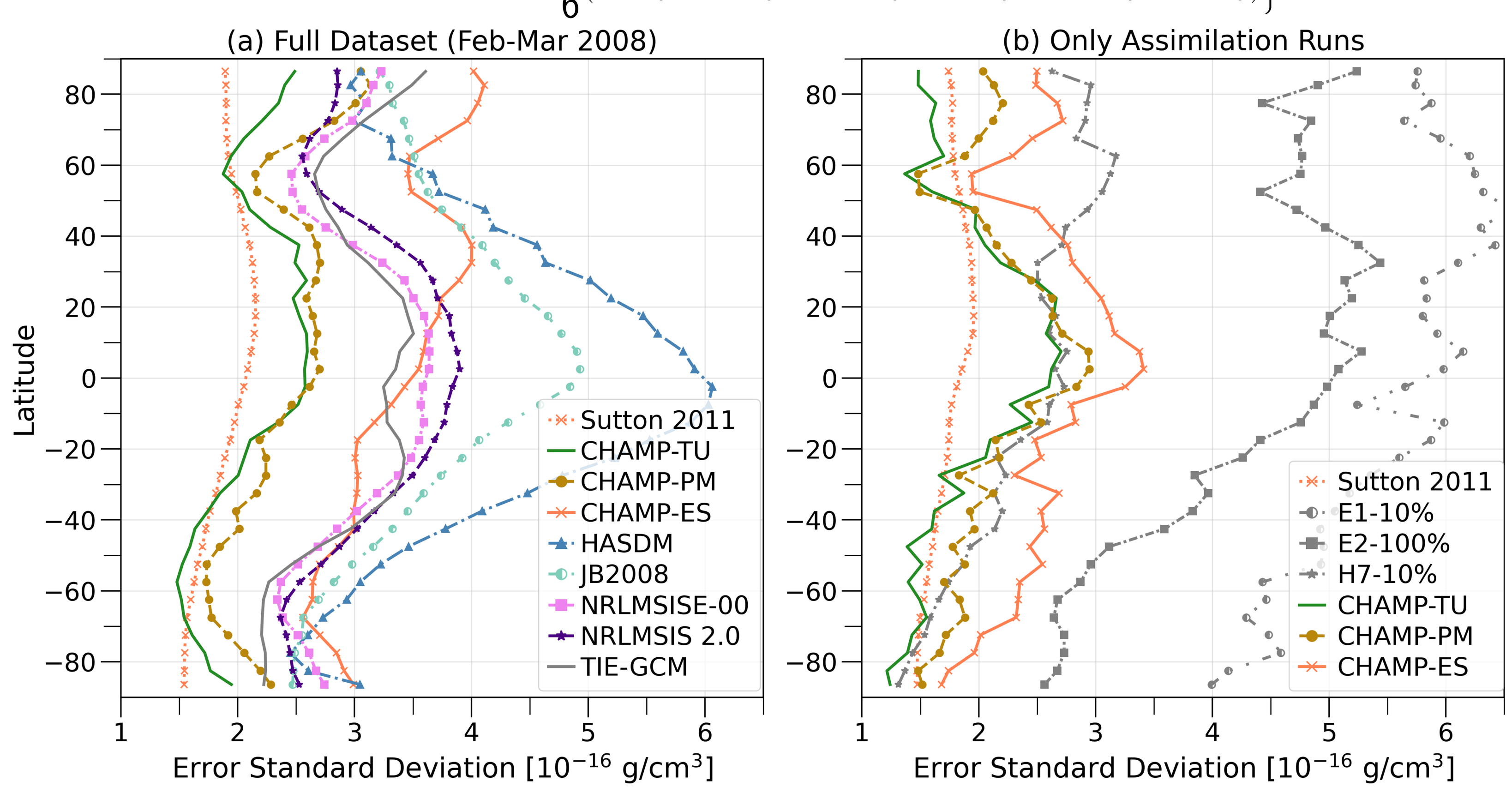

Figure 6: (a) Estimated error standard deviation $\sigma(\mathrm{E_A})$ as a function of geographic latitude for the specified eight different NMD data sets. Here, we treat each specified data set separately as A in Equation 2. The $\sigma(\mathrm{E_A})$ for a given data set is the mean of all possible 35 combinations with the other seven data sets as B, C, and D in Equation 2. (b) $\sigma(\mathrm{E_A})$ for CHAMP-TU, -PM, and -ES calculated using only the DA runs E1-10%, E2-100%, and H7-10% as B, C, and D in Equation 2. $\sigma(\mathrm{E_A})$ for E1-10%, E2-100%, and H7-10% calculated using multiple combinations of specified data sets. In both panels, *Sutton 2011* (orange-dotted) refers to the errors estimated by *Sutton* [2011] for the CHAMP-ES data set.

The promising results of this preliminary application of the *Grubbs* [1948]' method invite more work to investigate the applicability of the method to other data sets in the space weather and aeronomy community. For example, large data sets spanning over multiple years could be used to investigate the characteristics of error correlations between different measurements.

Main References

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1 Institute of Solar-Terrestrial Physics, German Aerospace Center, Neustrelitz, Germany; **2** Geodesy and Earth Observation Group, Department of Planning, Aalborg University, Rendburggade 14, 9000, Denmark; **3** Space Environment Technologies, Pacific Palisades, CA, USA. *** Correspondence:** timothy.kodikara@dlr.de

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