Using Data Assimilation to Understand the Systematic Errors of CHAMP Accelerometer-Derived Neutral Mass Density Data

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Abstract

Accelerometer-derived neutral mass density (NMD) is an important measurement of the variability in upper atmosphere and one of the widely used measurements to calibrate and validate models used for satellite orbit determination and prediction. Providing precise estimates of the true uncertainty of these NMD products is a challenging task but essential for the space weather and geodetic communities. Using multiple data assimilation (DA) experiments and robust statistical techniques, we investigate the uncertainty distribution of three different accelerometer-derived NMD products from the CHAMP satellite mission. Here, in three different DA experiments, we use an ensemble Kalman filter to drive a physics-based model with CHAMP in-situ electron density and temperature data as well as neutral wind estimates from an empirical model. Using a multi-model ensemble comprised of both physical and empirical models, we characterize the error variances among the different NMD products. Our results indicate considerable differences among the 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. Our experiments demonstrate that DA considerably enhances the capability of the physical model. We note that the generic strategies applied here may be useful and applicable to other space missions spanning over longer time periods.

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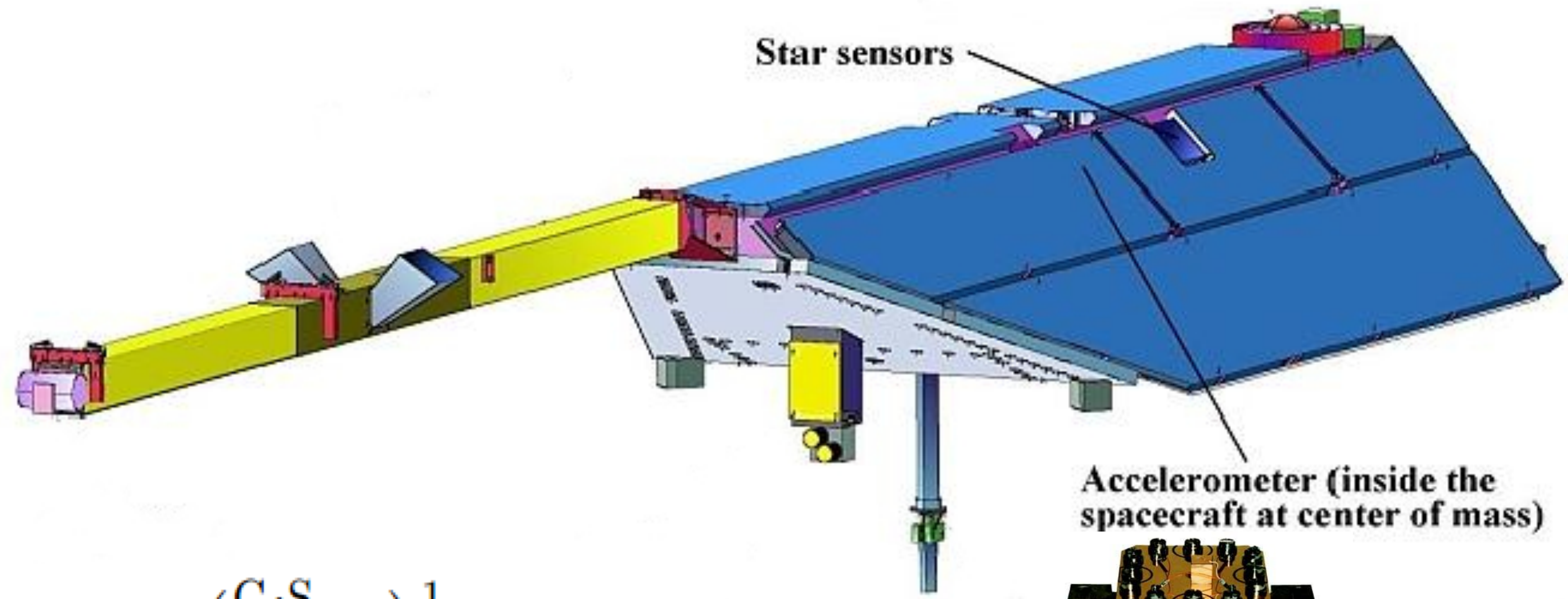
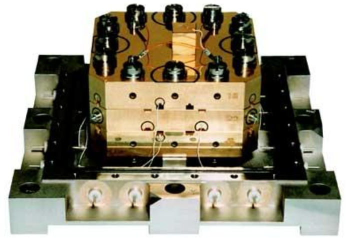
Neutral mass density can be derived from accelerometer measurements onboard CHAMP



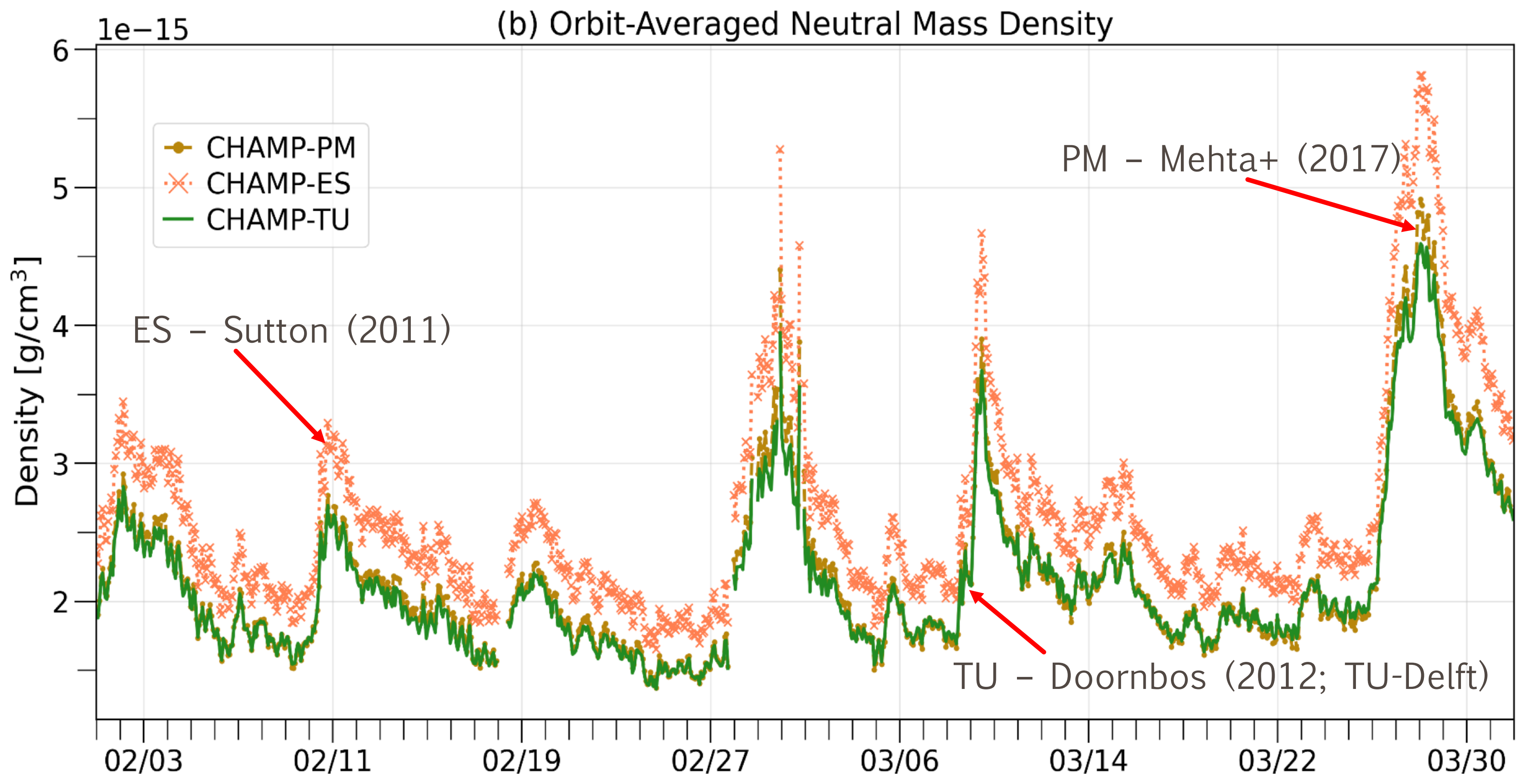


$$a_{drag} = -\left(\frac{C_d S_{area}}{S_{mass}}\right)\frac{1}{2}\rho V_{rel}^2$$

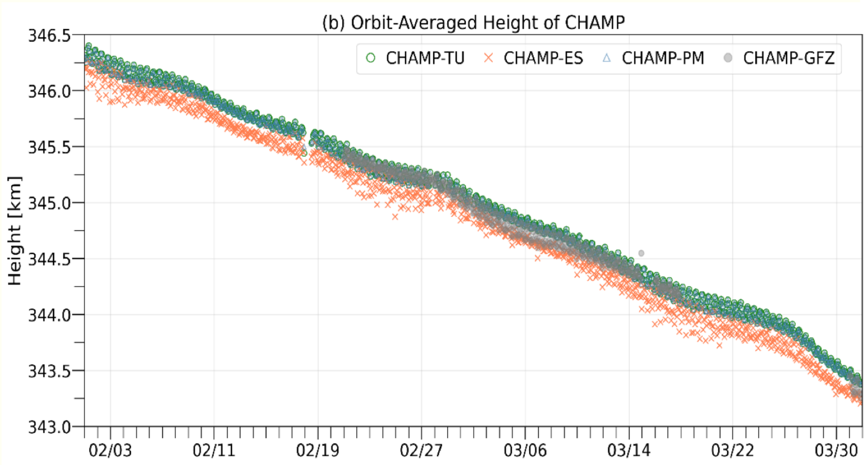
Density

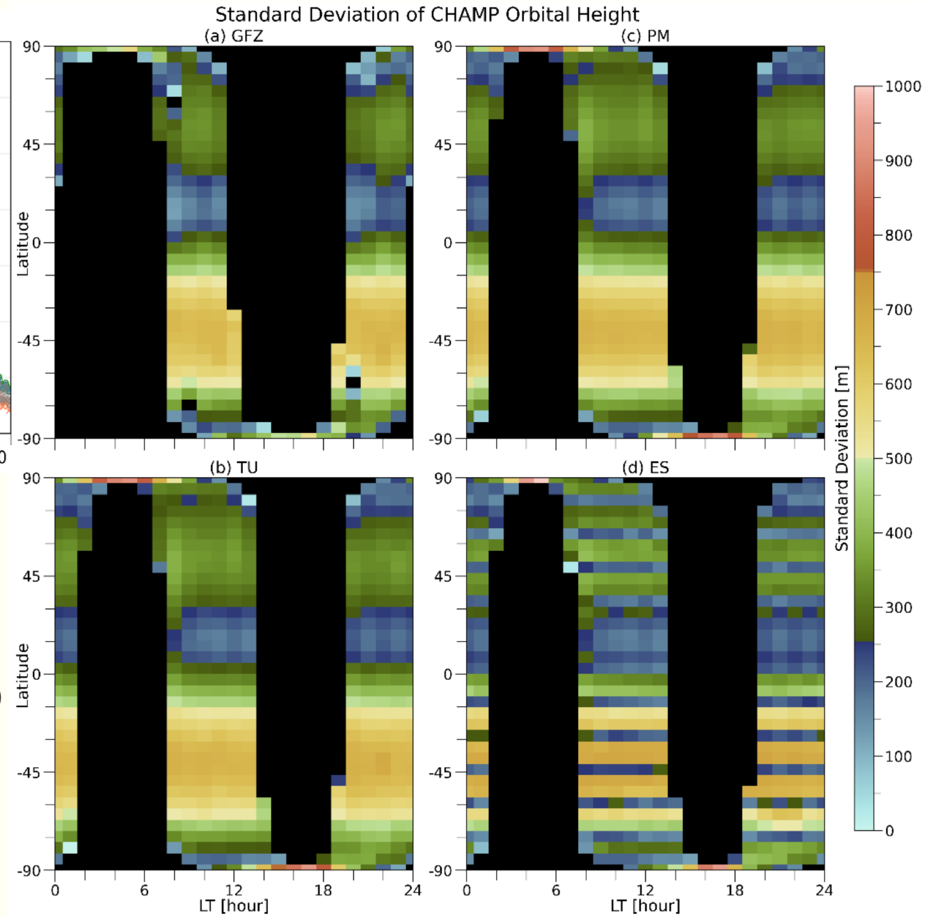
GFZ Helmholtz-Zentrum POTSDAM

The uncertainties of accelerometer-derived NMD are not fully understood



Some discrepancies exist in the published CHAMP height





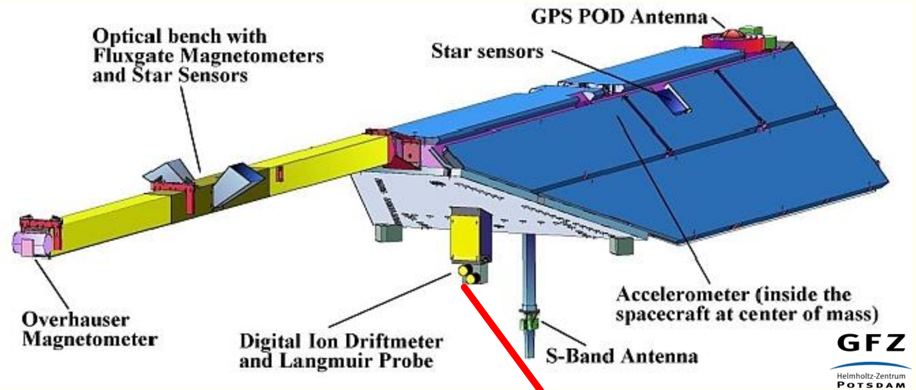
GFZ - Rother and Michaelis (2019)

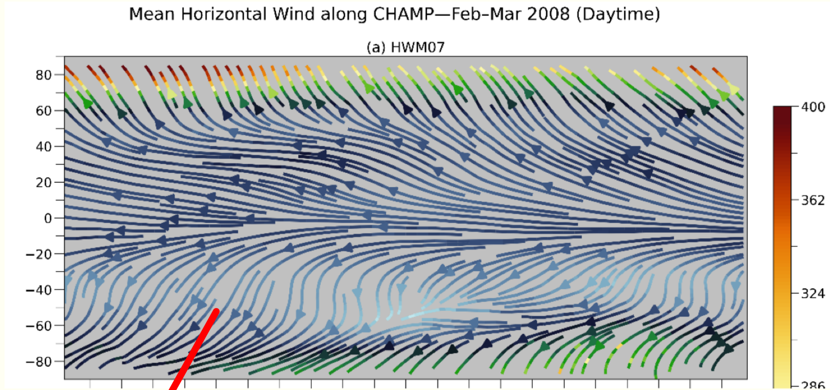
PM – Mehta+ (2017)

ES – Sutton (2011)

TU – Doornbos (2012; TU-Delft)

Assimilate observations along CHAMP to understand the impact on NMD





electron density +
electron temperature
Rother and Michaelis (2019)

Horizontal wind model 2007
Drob+ (2008)

E1-10%: CHAMP-Ne-Te
with 10% uncertainty

E2-100%: CHAMP-Ne-Te
with 100% uncertainty

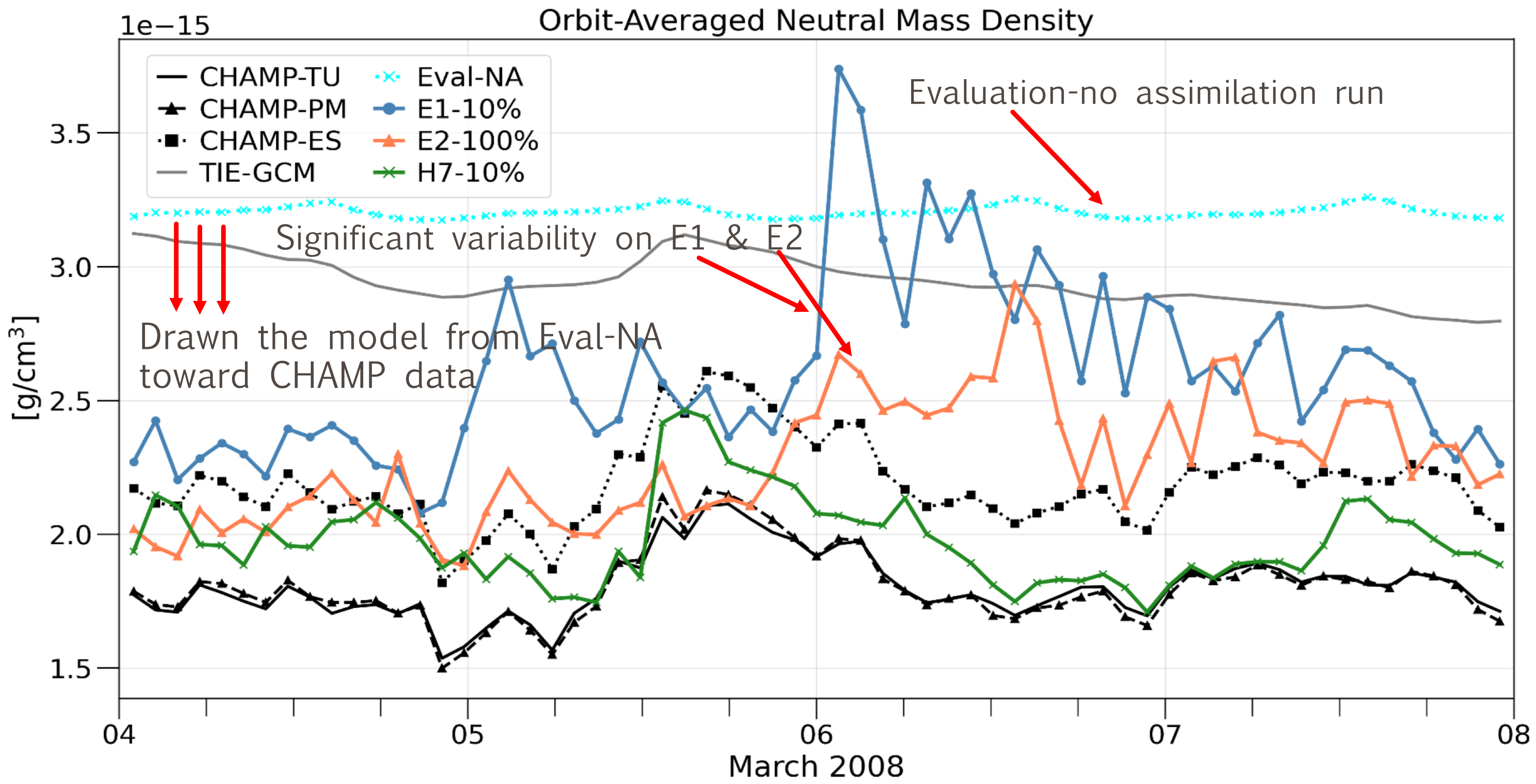
TIE-GCM
+
DART

H7-10%: HWM07
with 10% uncertainty

HWM07 was partly used to derive CHAMP-TU

ncar.ucar.edu

Assimilation of HWM07 neutral winds greatly improves TIE-GCM's agreement with CHAMP neutral mass density



Using Data Assimilation to Understand the Systematic Errors of CHAMP Accelerometer-Derived Neutral Mass Density Data, Kodikara et al., AGU Fall Meeting 2021

Estimating the Error Variance using the Grubbs' method

Grubbs (1948) "On Estimating Precision of Measuring Instruments and Product Variability", Journal of the American Statistical Association

Four instruments A, B, C, D measuring the same physical qty

A = T + E_A

B = T + E_B

C = T + E_C

D = T + E_D

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

Error variance can be estimated independent of true value T

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

Estimating the Error Variance using the Grubbs' method

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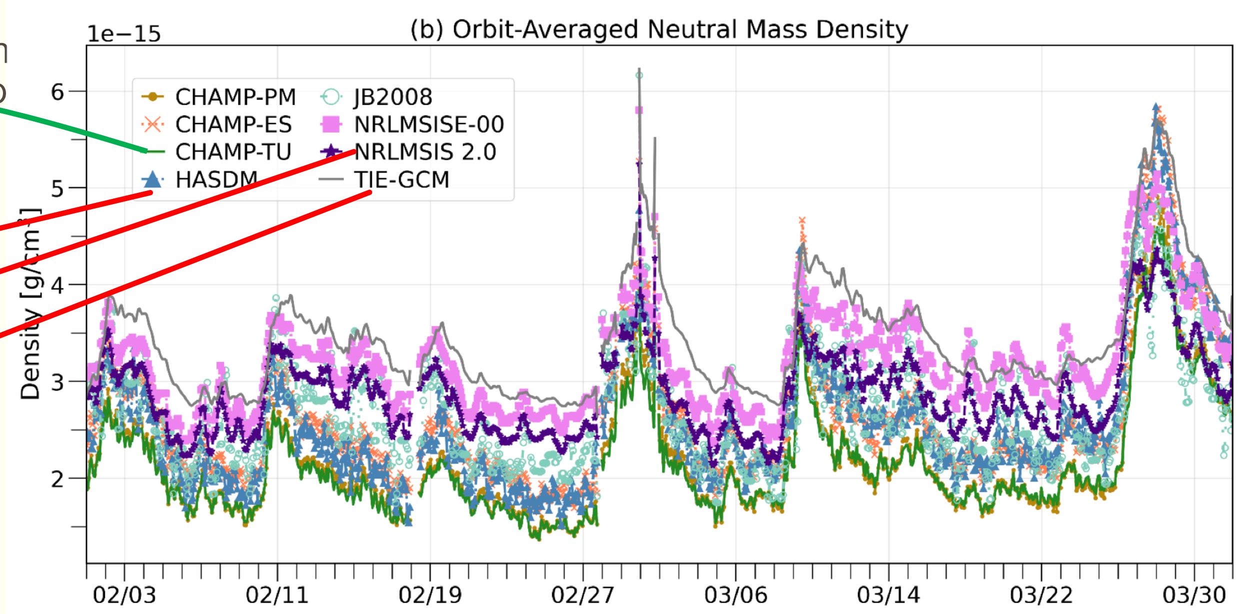

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Grubbs' method provide reliable estimates of the error

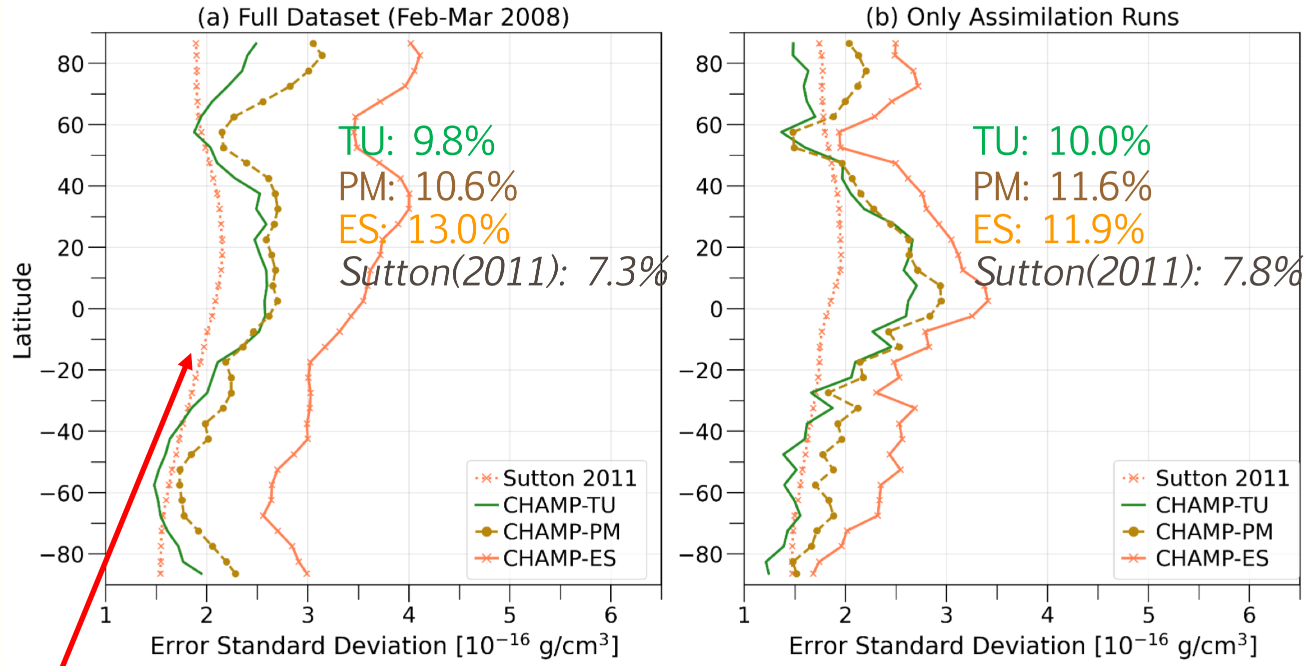
(b) uses only assim runs to estimate error (E1, E2, H7 as B, C, D instruments)

General agreement with previous estimates:

Bruinsma+(2004): 10-15%

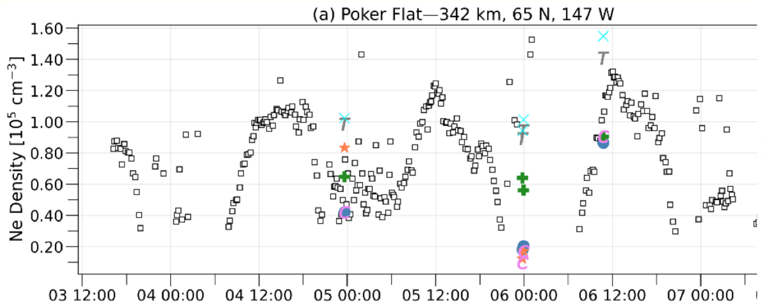
Sutton+(2007): 6-15.6%

Reveals latitudinal characteristics of error

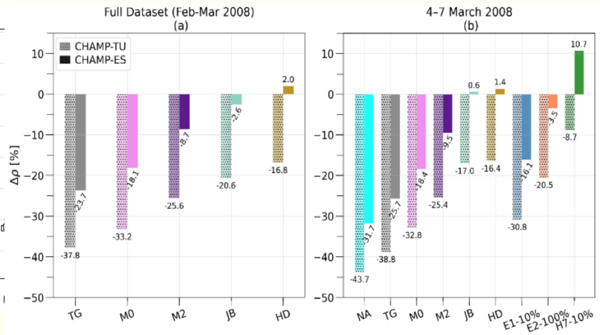


Error estimated by Sutton (2011) for CHAMP-ES data set

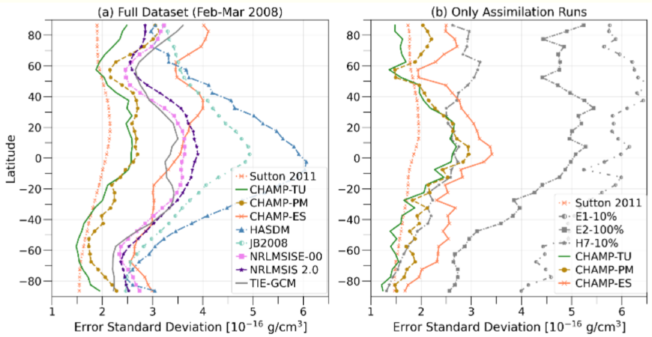
Validation with ISR data



Model Performance



Error Estimates



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