# Data Assimilation of Thermosphere Neutral Densities in WAM

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## Abstract

The thermosphere neutral density during the November 2003 storm has been simulated by Whole Atmosphere Model (WAM). The Iterative Driver Estimation and Assimilation (IDEA) data assimilation ingests the thermosphere neutral density measurements from Challenging Mini-Satellite Payload (CHAMP) satellite, which is further employed to quantify the uncertainties of measurements from the Global Ultraviolet Imager (GUVI) on board the Thermosphere Ionosphere Mesosphere Energy and Dynamics (TIMED) satellite in various locations and altitudes during the November 2003 storm. Results show that the improved WAM neutral densities well agree with CHAMP observations (root-mean-square error < 5%). Meanwhile, TIMED-GUVI neutral densities are in accordance with the improved WAM at the altitude of 250-300km, which shows that these datasets are useful to improve WAM in the IDEA data assimilation scheme.

### Whole Atmosphere Model (WAM)

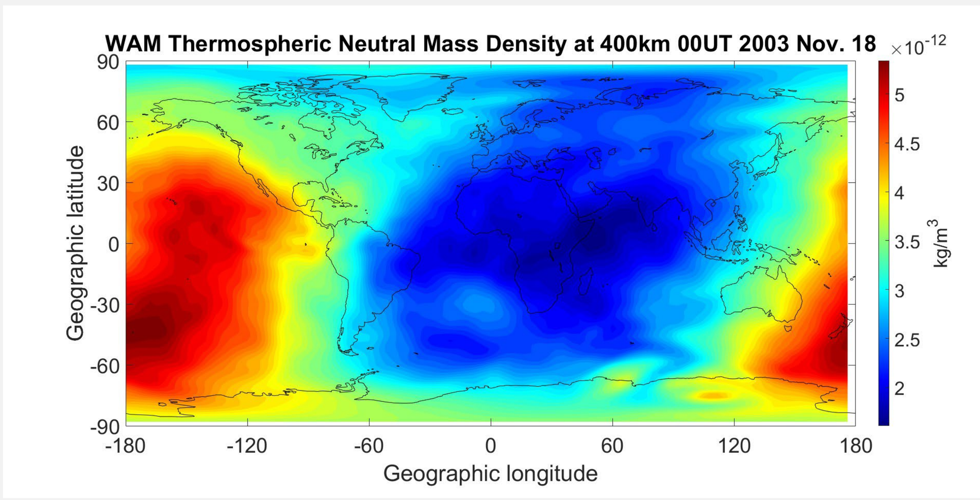
- Extended Global Forecast System (GFS) upper boundary from 64 km to 600 km
- Resolution 2°×2° in latitude-longitude, H/4 in altitude
- Free or forecast runs
- Horizontal & vertical mixing
- Radiative heating (EUV & UV) and cooling
- Ion drag & Joule heating
- Major species composition

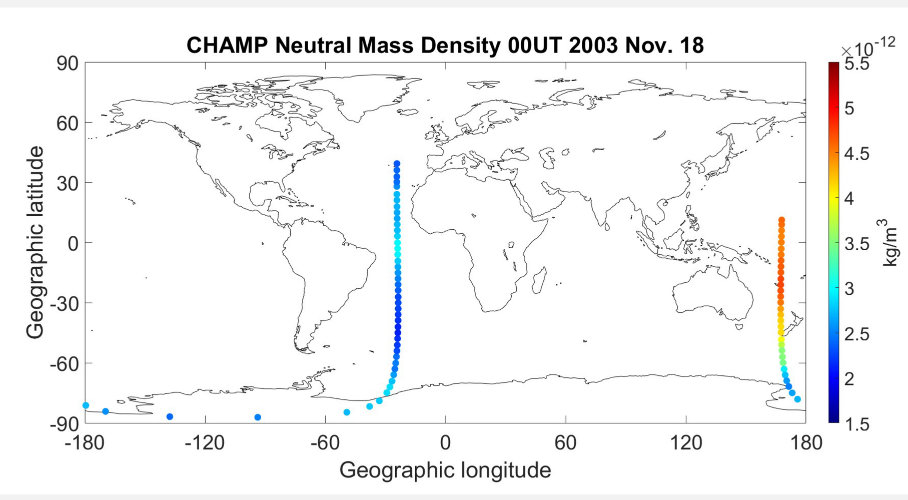
### CHAMP satellite and accelerometer

- Launch date: 15 July 2000
- Decay date : 19 September 2010
- Altitude: 400 km
- Period: 93.55 minutes
- Inclination: 87.18°
- The atmospheric density, $\rho$, can be obtained from corrected drag acceleration, $a_D$:

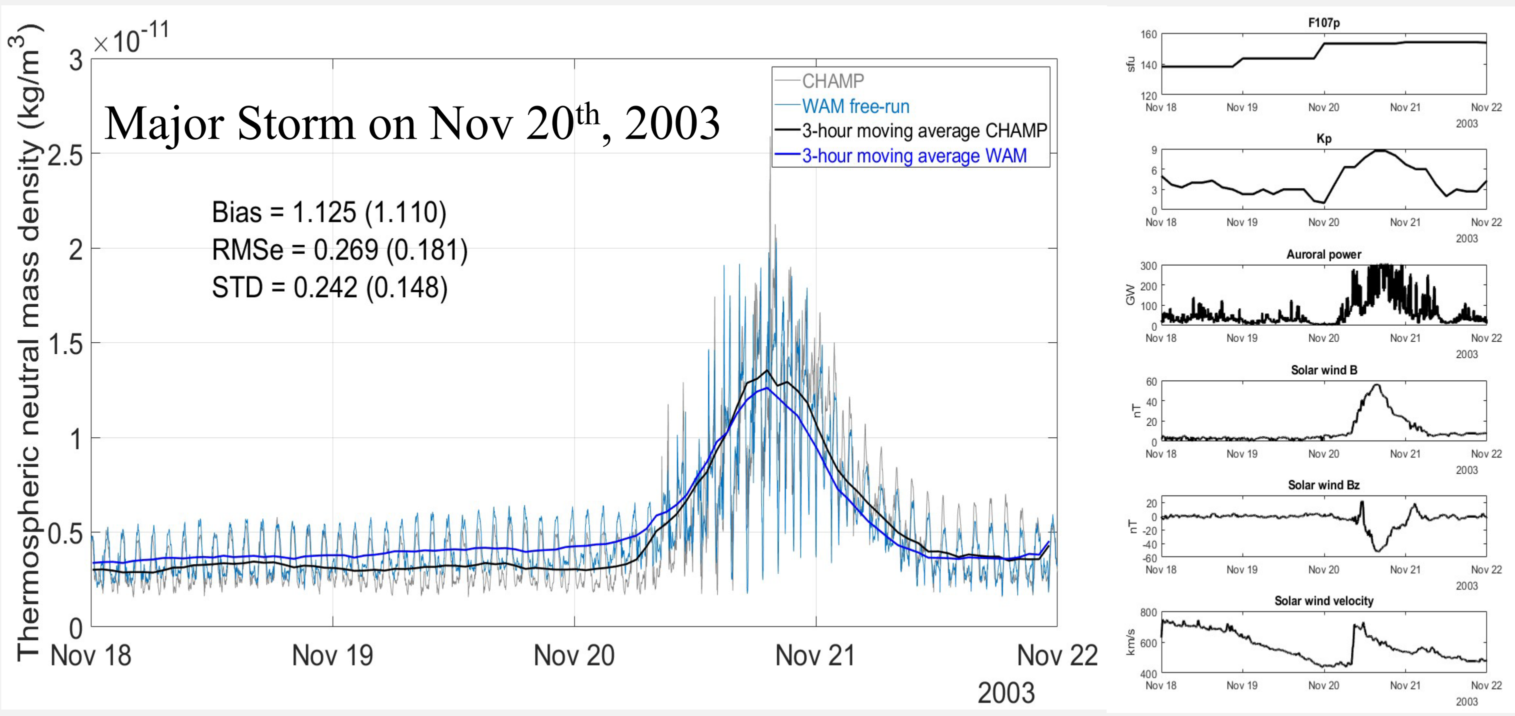
$$a_D = -\frac{1}{2}\rho C_D A_{ref} |\bar{v}|^2$$

where $C_D$ is the coefficient of drag, $A_{ref}$ is the reference area of the satellite, and $\bar{v}$ is the direction of the satellite velocity with respect to the atmosphere



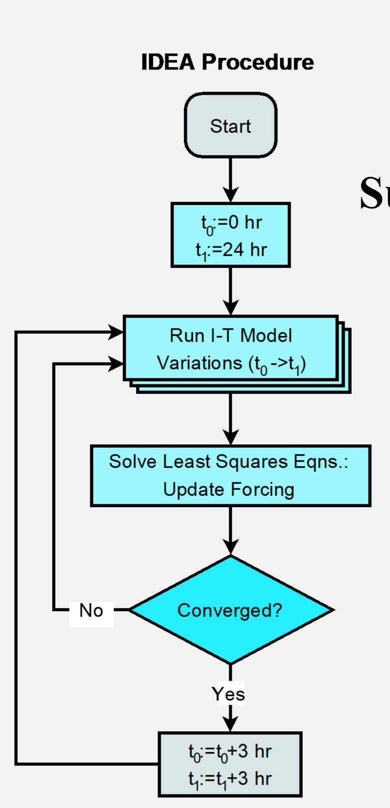

## 1. WAM neutral density and CHAMP accelerometer



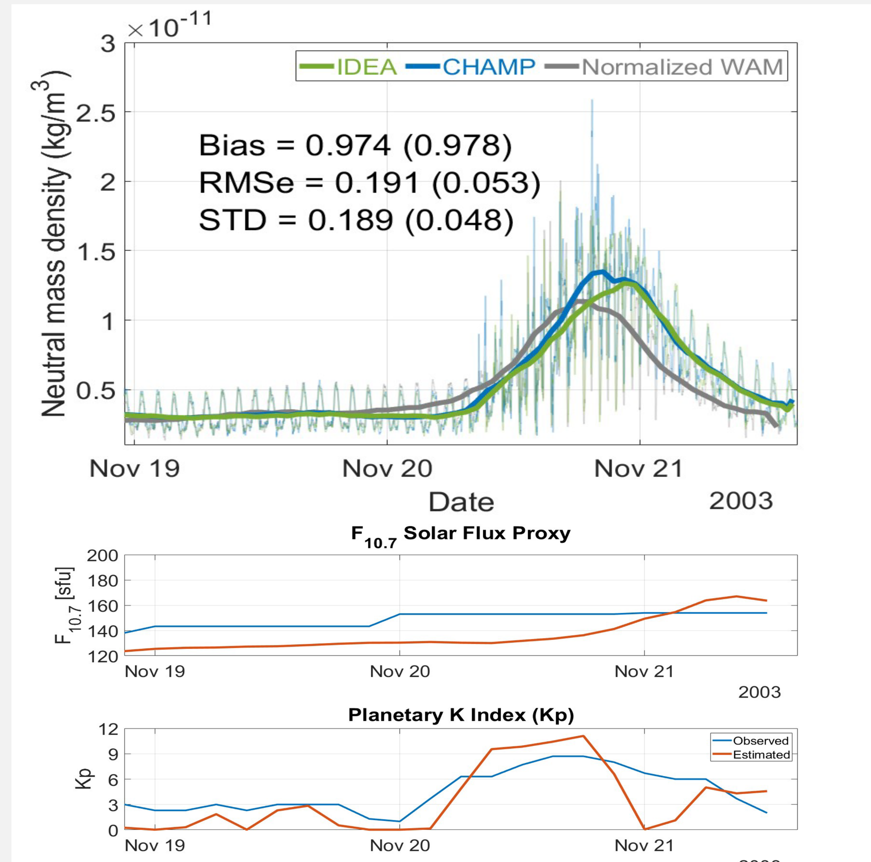

- WAM density is higher than CHAMP density on November 19, while it becomes lower during the storm time (November 20th)
- WAM density dips sampled over high latitude regions (geographic latitude > 70°) appear at 12-24UT on the 20th.

**Figure 1.** WAM free run and CHAMP accelerometer neutral densities during major storm in November, 2003. WAM free run uses observed solar wind velocity and IMF B and $B_z$ to drive the Weimer model in WAM. Light blue solid line stands for the free-run WAM density sampled along the CHAMP satellite orbit. Blue and black solid lines represent 3-hour moving average of CHAMP and WAM densities with 1-hour resolution.

## 2. Iterative Driver Estimation & Assimilation (IDEA)




Sutton (2018)




- The IDEA technique is used to improve data-model agreement.
- The IDEA data assimilation technique adjusts Kp and F10.7 inputs to optimizing RMSe between modeled log density with the corresponding observational data.

**Figure 2.** Green line stands for neutral densities assimilated with CHAMP using IDEA technique (IDEA-WAM density). Blue line is CHAMP observations. Grey line represents free-run WAM densities normalized by CHAMP observations on November 19. Bias, RMSe, and STD shown in the figure are calculated using IDEA-WAM and CHAMP densities. The IDEA-estimated solar and geomagnetic indices are those required to drive the model given the uncertainties in the empirical relationships between the indices and the real energy input to the upper atmosphere.

**Acknowledgements**

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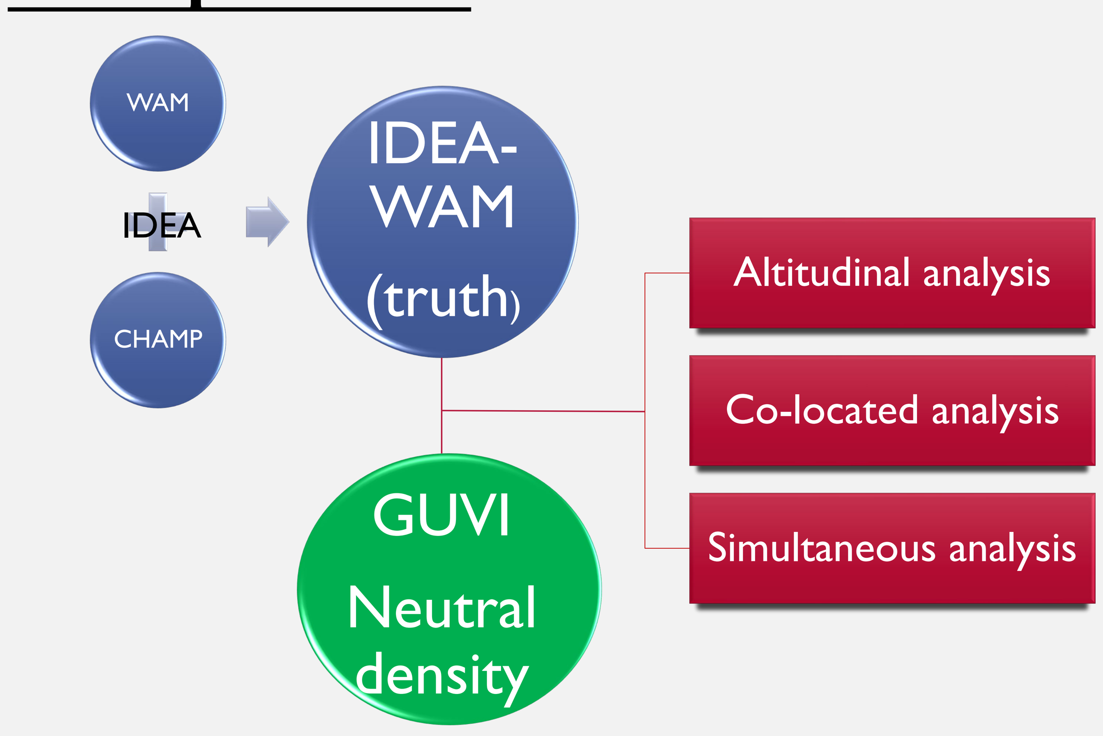
**Reference**

Sutton, E. K. (2018). A new method of physics-based data assimilation for the quiet and disturbed thermosphere. *Space Weather*, *16*, 736–753. https://doi.org/10.1002/2017SW001785

## 3. Experiment




A possible real-time data source is available from an instrument similar to the TIMED-GUVI observations. This part of the study is designed to evaluate the usefulness of this data-stream in the IDEA data assimilation scheme to improve the WAM neutral thermospheric density. IDEA-WAM is generated by the combination of WAM and CHAMP neutral densities, to serve as the 3-D truth density structure, which can be used to quantify the uncertainties of GUVI neutral density profiles and to perform altitudinal, co-located, and simultaneous analyses.

## 4. Data assimilation in November 2003 storm

To improve the data-model agreement, we employ IDEA technique, and several changes have been applied.

- Update F10.7 every 24 hours and Kp every 90 min
- Remove the upper boundary of Kp=9 while estimating Kp (Kp>9 is allowed in WAM simulation)
- Replace the Kp-based solar wind velocity formula with a new one to make the solar wind velocity increase when Kp>9
- Filter the CHAMP observation using its uncertainty data.

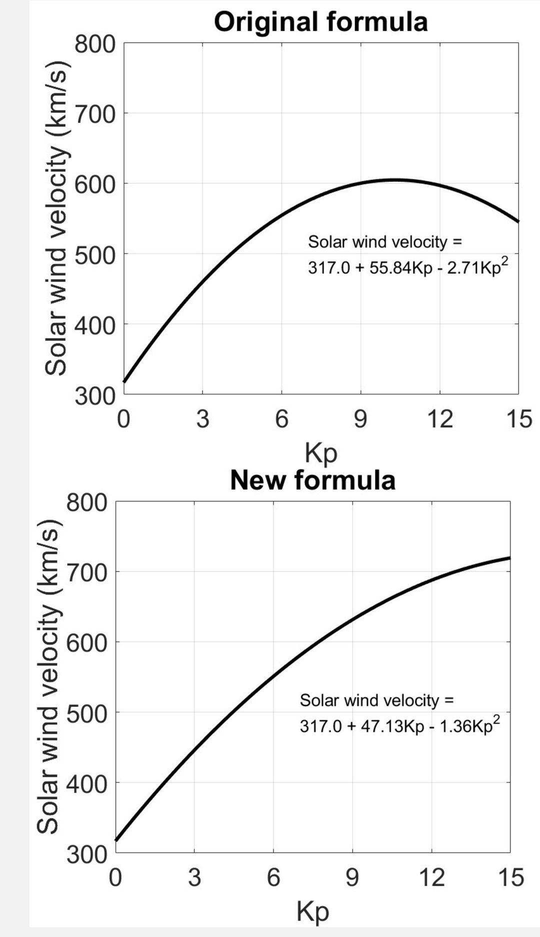



**Figure 3.** The 2nd and 3rd coefficients in the solar wind velocity formula have been adjusted to remain the relation between Kp and the velocity similar and allow the velocity increase while Kp>9

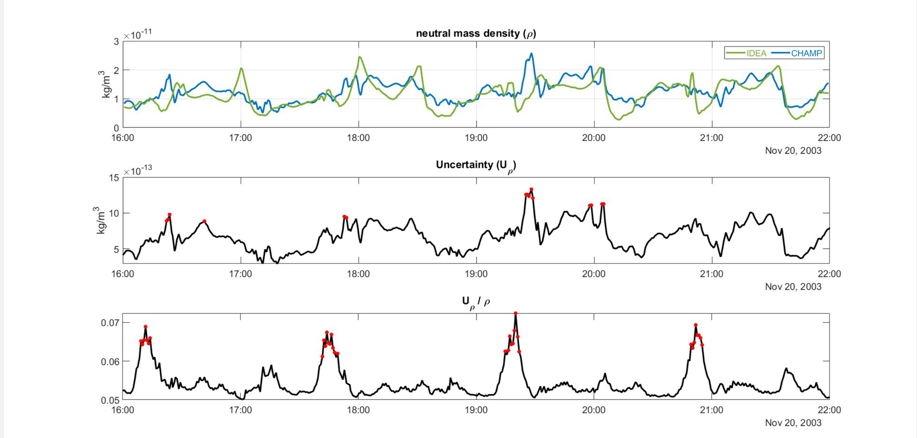


**Figure 4.** Neutral mass density, uncertainty and normalized uncertainty (uncertainty divided by density) in 16-22UT November 20, 2003. Red dots in the middle and bottom panels stand for the associated outliers. The variation of uncertainty is nearly the same as that of CHAMP density, while the normalized uncertainty shows a clear period of ~90 minutes which corresponds to CHAMP orbital period.

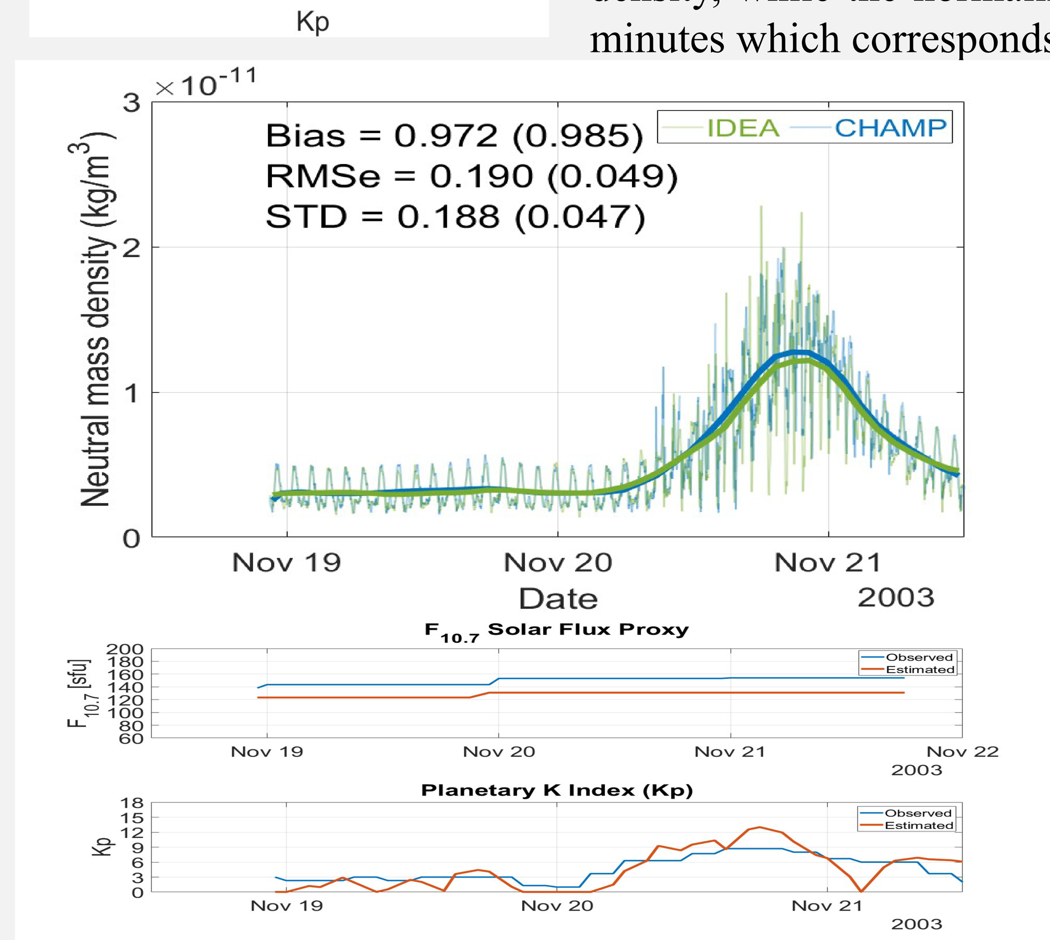
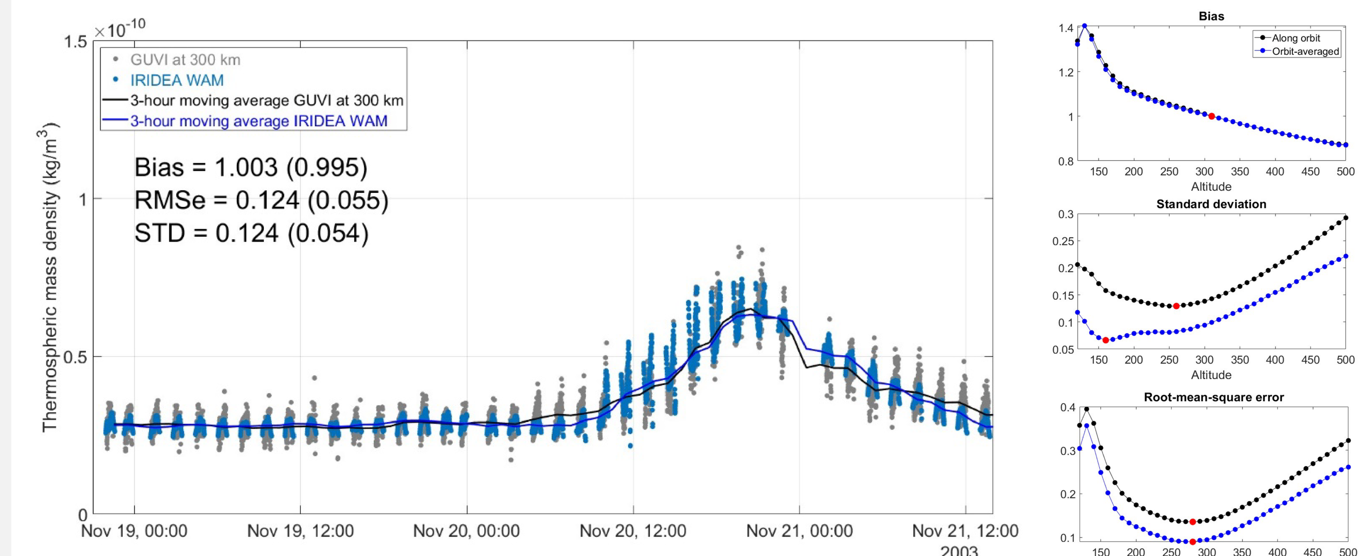



**Figure 5.** Adjusted IDEA data assimilation. Green lines stand for IDEA-WAM neutral density, and blue lines represent CHAMP neutral density. Light lines are densities sampled along CHAMP orbit. Solid lines are the associated running mean.

- IDEA-WAM and CHAMP densities reach their maximum at the same time (~22UT), while the IDEA-WAM density is slightly lower than CHAMP.
- Low density peaks at around 21-24UT on the 20th happened over high latitude regions in the midnight period

## 5. IDEA-WAM vs TIMED-GUVI neutral density




**TIMED-GUVI**

- Thermosphere Ionosphere Mesosphere Energetics and Dynamics Global Ultraviolet Imager
- Satellite altitude: 625 km (388 mi)
- Inclination: 74.1°
- Period: 97.3 minutes
- GUVI Observes thermospheric temperature, densities, auroral energy, solar EUV, and airglows.
- The 14 spatial imaging pixels across the entrance slit each generate a spectrum on the detector focal plane in 15 seconds. The scan mirror sweeps the slit across the limb and disk

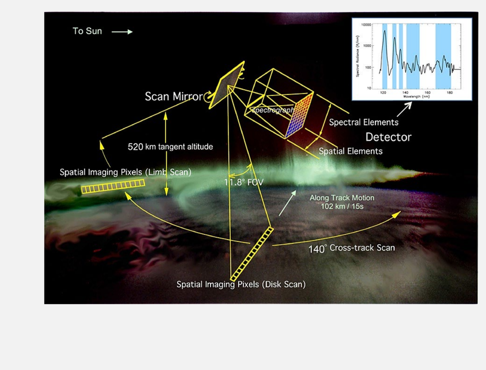


**Figure 6.** (left) Comparison of IDEA-WAM and GUVI neutral density at 300 km altitude. GUVI densities at around 00UT on November 21 are determined as outliers and discarded. (right) Bias, RMSe, and standard deviation between IDEA-WAM and CHAMP density in various altitudes. Red dots in the right figure represents the minimum value of RMSe and standard deviation as well as the value closest to bias=1. The optimized altitude is 250-300km.

## 6. Summary and Future work

- The WAM neutral density is well improved using IDEA technique which updates the solar and geomagnetic drivers. The new solar wind velocity formula and CHAMP uncertainty data also improve the neutral density result during the November 2003 major storm.
- The improved WAM neutral density is employed to quantify TIMED-GUVI neutral density. Results show that the optimal altitude is in the range of 250-300km
- A possible real-time data source available from an instrument similar to the TIME-GUVI will be employed to improve the WAM neutral density in the IDEA scheme.