The Atmosphere Variability Cluster concerns the analysis, modeling and prediction of variations in the thermosphere at all spatial and temporal scales, but particularly regarding the impact on satellite atmospheric drag.

Key questions:

1. What are the driver-response relationships, the temporal and spatial scales of the density and wind variability due to EUV/UV radiation and geomagnetic disturbances, radiative cooling, and, to a lesser degree, forcing due to disturbances propagating up from lower altitudes?
2. Which observations/proxies/indices are most representative of upper atmosphere heating due to solar EUV/UV emissions and geomagnetic activity?
3. What is the accuracy and precision of upper atmosphere density and wind models? The result of this activity will be a standard assessment procedure, which requires appropriate metrics as well as high-quality and high-resolution data over many years.
4. Which density and temperature datasets are available, or critically needed, to deal with items 1-3? Are the datasets coherent and appropriately edited?
5. How should atmospheric drag be computed in a consistent and standard manner?

The Atmosphere Variability Cluster concerns the analysis, modeling and prediction of variations in the thermosphere at all spatial and temporal scales, but particularly regarding the impact on satellite atmospheric drag.

Key questions:

Paper 1

1. What are the driver-response relationships, the temporal and spatial scales of the density and wind **variability** due to EUV/UV radiation and geomagnetic disturbances, radiative cooling, and, to a lesser degree, forcing **due to disturbances propagating up from lower altitudes?**

2. Which observations/proxies/indices are most representative of upper atmosphere heating due to solar EUV/UV emissions and geomagnetic activity? New geomagnetic index Hpo developed by GFZ; EUV still a problem

3. What is the accuracy and precision of upper atmosphere density and wind models? The result of this activity will be a standard assessment procedure, which requires appropriate metrics as well as high-quality and high-resolution data over many years. Metrics and procedures for model assessment published

Paper 2

4. **Which density and temperature datasets are available, or critically needed**, to deal with items 1-3? Are the datasets coherent and appropriately edited?

Paper 3

5. **How should atmospheric drag be computed in a consistent and standard manner?**

Papers for topical issue 1:

Title	Authors	Working abstract
Lower atmosphere impact on thermosphere density	Jia Yue, Nick Pedatella, Wandi Yu, Sean Bruinsma	Using two sets of WACCM-X runs with and without solar and geomagnetic disturbances but with lower atmosphere processes, we can quantify how much the lower atmosphere processes may contribute to the thermosphere density variability.
Description and comparison of 21st century thermosphere data	Sean Bruinsma, John Emmert, Christian Siemes, Kent Tobiska, Marty Mlynczak	The main upper atmosphere density datasets of this century as well as TIMED lower thermosphere data are reviewed, evaluated and compared. Total mass densities used in this study include all high-resolution CHAMP, GRACE and GOCE data, SwarmA, Stella, Starlette, global daily mean TLE densities, and the SET HASDM density database.
Drag Coefficient Modeling and its Impact on Density Estimation	Piyush Mehta, Christian Siemes, Gunther March, Nicholas Crisp, Logan Sheridan, Smriti Paul, ???	Drag coefficient play a critical role in deriving state-of-the-art density estimates for scientific investigation. However, the physics of drag coefficient can induce significant uncertainties. We will investigate and compare the different methods and models for drag coefficient in an attempt to characterize this uncertainty.

Papers for topical issue 1

Paper 1: Lower atmosphere impact on thermosphere density

1. **Comparing lower atmosphere impact on thermosphere density to geomagnetic forcing**
2. **WACCM-X runs with realistic Ap/F10.7 and constant Ap/F10.7**
3. **Separate geomagnetic storm times and quiet times**
4. **Lower atmosphere impact is one order smaller than geomagnetic forcing during stormtimes.**
5. **During quiet times (Kp<3), the influences from above and below are comparable.**
6. **Lower atmosphere contributes to the AO and SAO of the density.**
7. **FFT shows multiple day oscillations in the thermosphere density induced by lower atmosphere waves.**

First rough draft:	**August**
Complete draft:	**November**
Submission:	**December**

Papers for topical issue 1

Paper 2: Description and comparison of 21st century thermosphere data

Review 21st century thermosphere data:

1. **CHAMP density**
2. **GRACE density**
3. **GOCE density**
4. **Swarm density**
5. **TLE global-mean densities**
6. **Stella and Starlette mean densities**
7. **SET HASDM density database**
8. **TIMED**

First rough draft:	**August**
Splinter meeting:	**16 September**
Complete draft:	**xx November**
Submission:	**December**

Papers for topical issue 1

Paper 3: Drag Coefficient Modeling and its Impact on Density Estimation

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Paper for topical issue 2: Neutrals and satellite drag pathways

Review sources of uncertainty in drag calculation and forecasting:

1. **Upper atmosphere models**
2. **Upper atmosphere data**
3. **Solar activity: measurements and forecasts**
4. **Geomagnetic activity: measurements and forecasts**
5. **Satellite shape and aerodynamic coefficient modeling**
6. **Orbit extrapolation and uncertainty propagation**
7. **Operational concerns**

Tentative planning

Outline:	**16 September 2021**
Complete draft:	**December 2021**
ISWAT internal review:	***January 2022****
Updated version:	**March 2022**
Submission:	**April 2022**

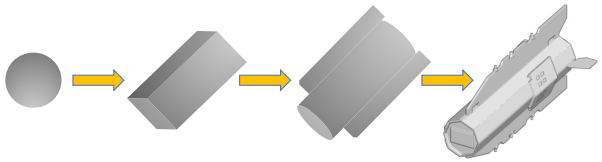
*** We propose an internal review of the pathway papers by moderators & team leads**

Satellite drag computation and forecasting requires expertise in several domains

Main contributors to paper sections

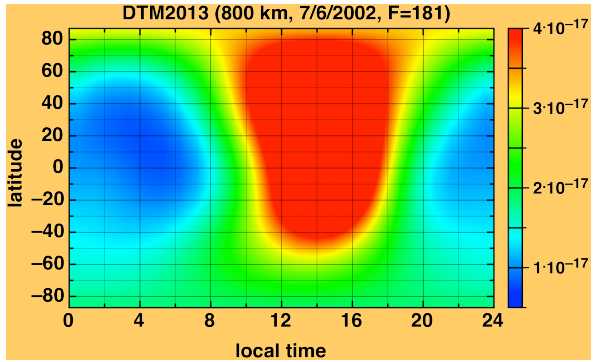
Mehta
Bruinsma

- ✓ Satellite shape and characteristics



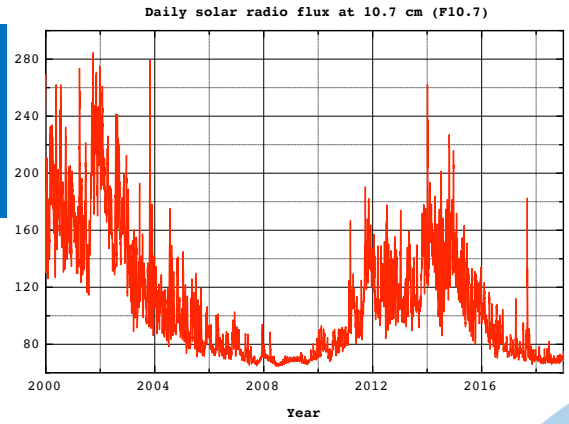
Satellite aerodynamic model

- ✓ Upper atmosphere models & data



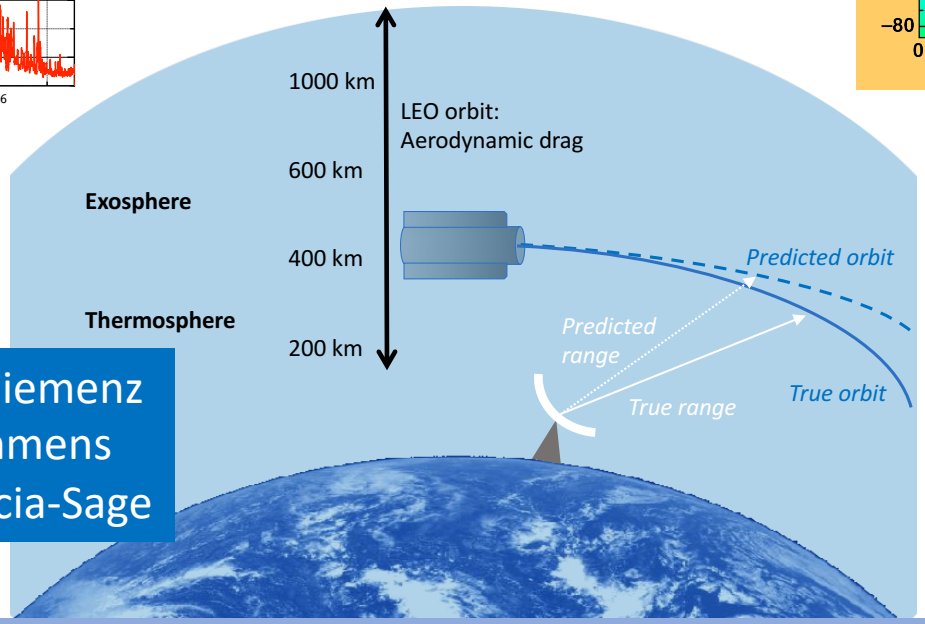
Dudok de Wit
Shprits
Fuller-Rowell

- ➢ Drivers (solar and geomagnetic)
- ➢ Forecasts (day-year-cycle)



Satellite drag

Solar activity ***Thermosphere model***



Fuller-Rowell
Yue
Bruinsma

Schiemenz
Lemmens
Garcia-Sage

- ✓ Orbit computation