Taking Advantage of the SmallSat Revolution to Address the Orbital Debris Problem: Data of Opportunity for a new Assimilative Satellite Drag Model

❖Science ❖ Technology ❖ Applications
Bringing It All Together

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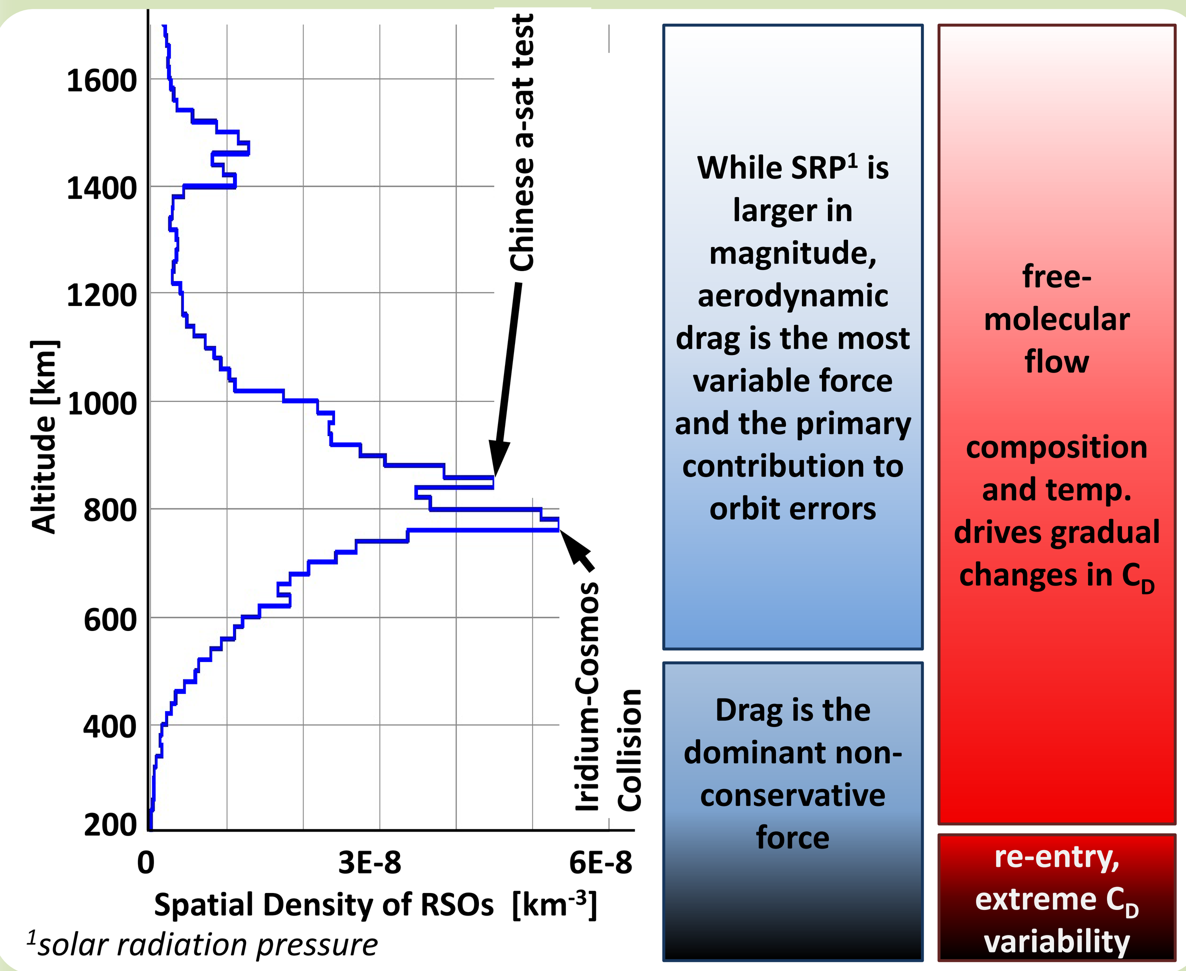
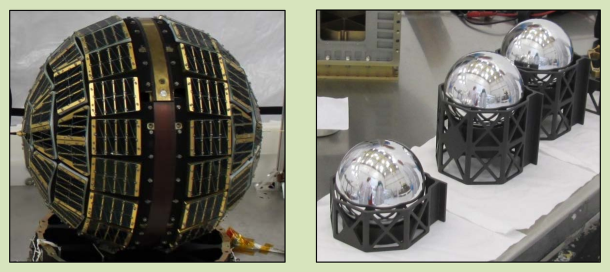
Dragster is an assimilative tool designed to provide drag specification for the majority of resident space objects (see altitude distribution below) in the region where drag is the most relevant non-conservative orbital perturbation. This region is also populated with critical space assets (A-train, DMSP, Iridium, ISS, etc.).



[1]solar radiation pressure



DANDE POPACS 1, 2, 3

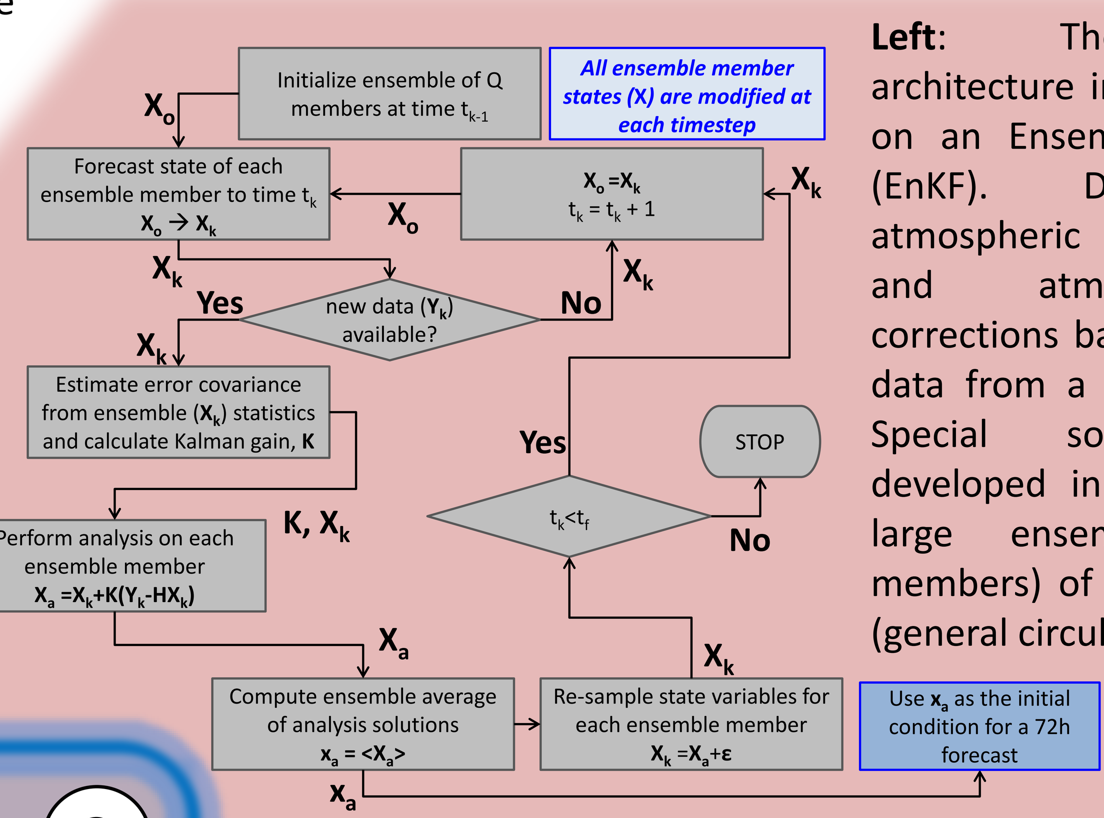
Dragster assimilates orbital data from a cross-calibrated database of resident space objects. Examples of a few are illustrated on the left.

ABSTRACT: **1.** Satellite drag variability caused by the dynamics of the upper atmosphere is a major cause of orbit specification and prediction errors in Low Earth Orbit. The problem is particularly severe during geomagnetic storms. These storms can severely degrade the accuracy of conjunction analysis between debris and spacecraft with LEO perigees and all other resident space objects.

2. We describe an assimilative upper atmosphere model (**Dragster**) capable of taking advantage of the increasing quantity of orbital data-of-opportunity represented by Smallsats.

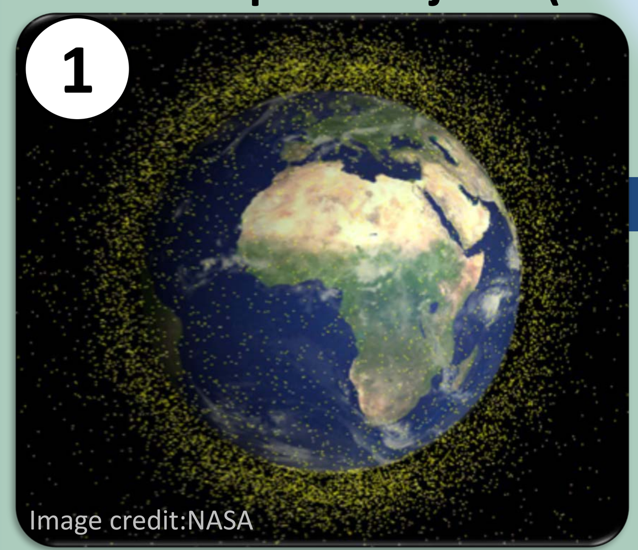
3. We show that many CubeSats and Smallsats can be used to calibrate the state of the atmosphere.

4. This calibrated data can be used to improve global atmospheric modeling and orbital predictions for both space debris and active satellites.



Left: The assimilation architecture in Dragster is based on an Ensemble Kalman Filter (EnKF). Dragster estimates atmospheric forcing parameters and atmospheric state corrections based on assimilated data from a variety of sources. Special software has been developed in order to manage large ensembles (50-100 members) of full-physics models (general circulation models)

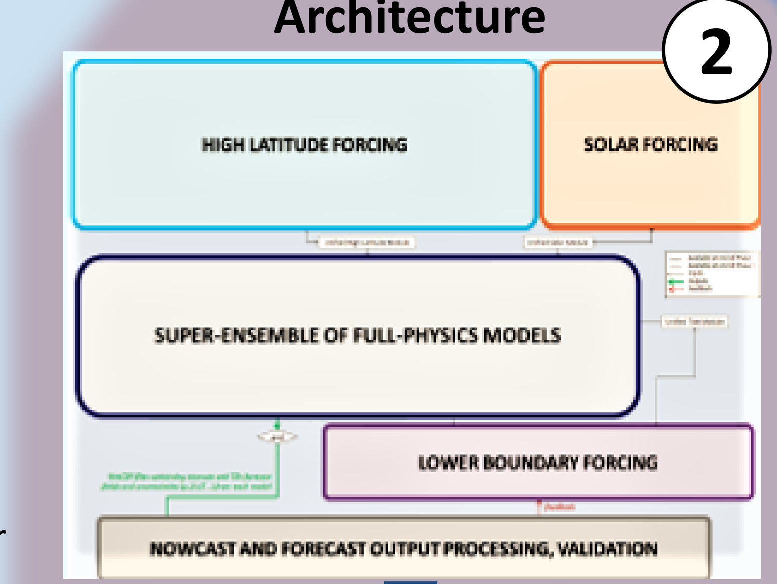
Resident Space Objects (LEO)



satellite drag and density observations

- ***Orbit observations***
- *GPS*
- *Accelerometers*
- *O/N_2*
- *Mass Spectrometer*

Architecture



conjunction analysis

Dragster

orbital analysis

Super-Ensemble Approach

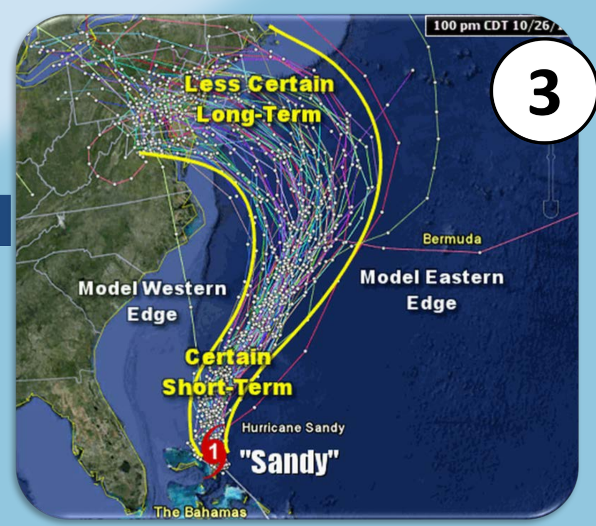
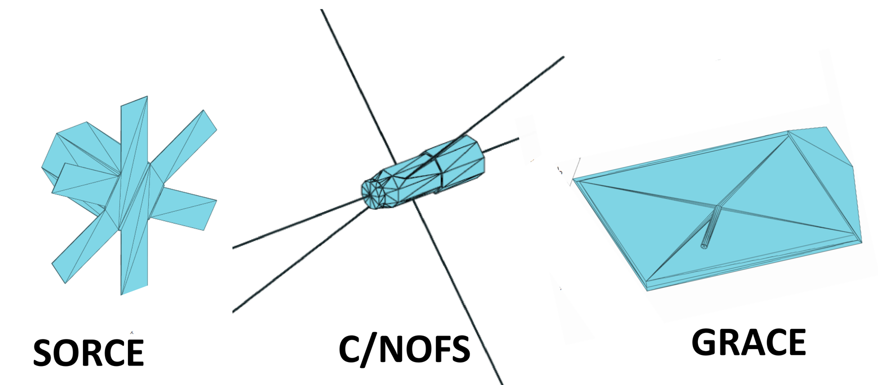


Image credit: TerraMetrics, Google

Output information feeds into existing orbit prediction and determination tools

4 Results

- Improved satellite orbit nowcast and 72h forecast
  - Improvements over HASDM and JB08
  - Up to three-fold improvement during storms and solar minimum
- Densities, winds and composition outputs
- Covers altitudes from 30 km to 1500 km
- Improved performance during geomagnetic storms

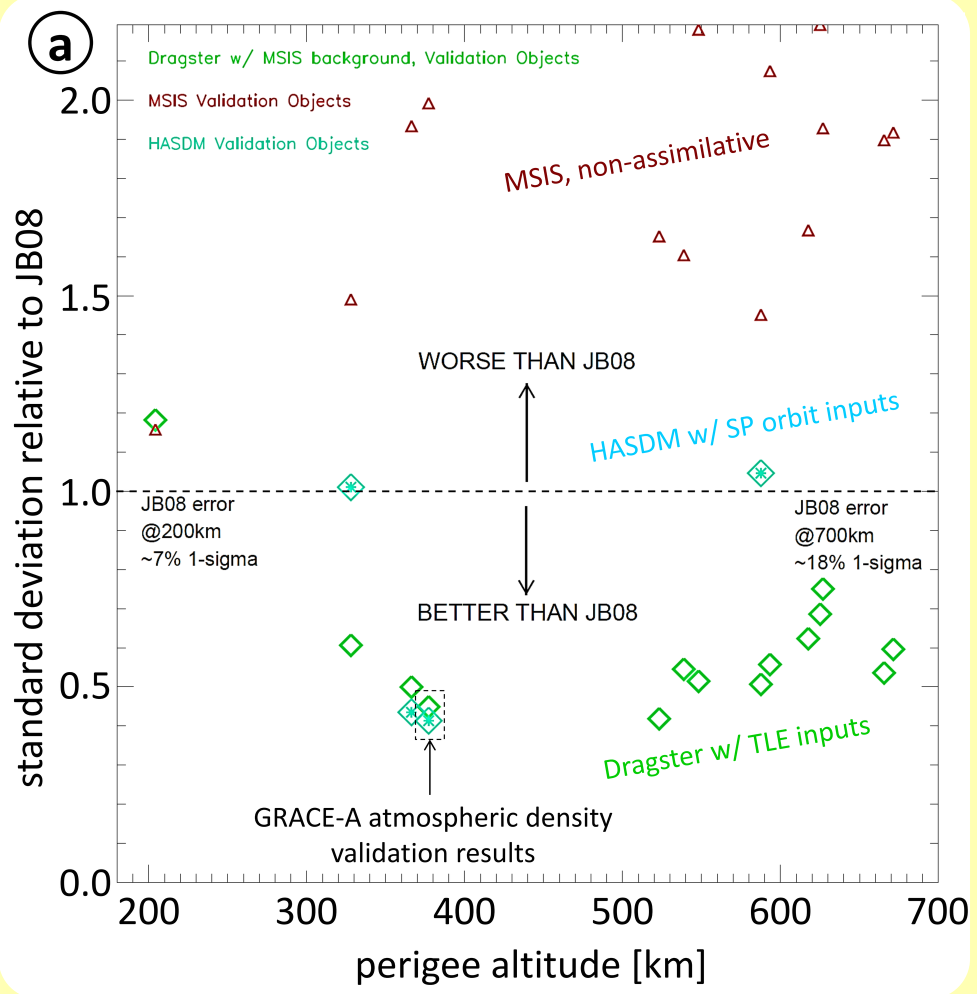


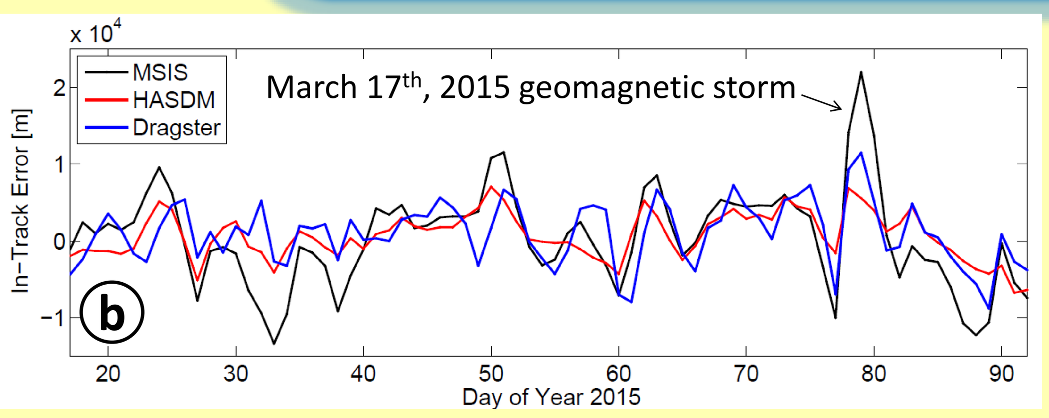
Dragster software includes detailed aerodynamic models. This allows assimilation of data from objects whose A/m ratios are not constant but vary in a predictable way. <u>This means Dragster can ingest more data than previous atmospheric-calibration tools.</u>

Dragster consists of several ensemble model backgrounds (CTIPe, TIME-GCM, TIE-GCM, MSIS, JB08). Models are in turn driven by ensemble assimilation. Much like hurricane predictions, Dragster will propagate each model forward to predict the most probable trajectory of the thermospheric state and its uncertainty. Unlike tropospheric weather, the thermosphere is strongly driven by external inputs. <u>Therefore, forecast of the input will play an important role in reducing satellite drag errors. ASTRA is teaming with SET to include their state-of-the-art forcing and index forecasts.</u>

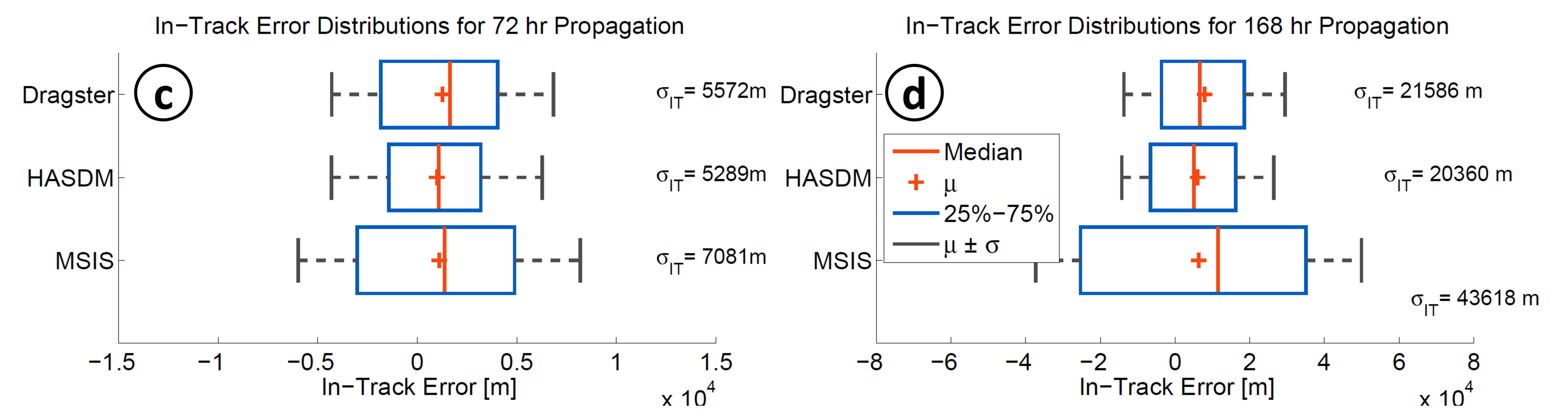
The plot below **(a) shows density errors relative to the JB08 model** for all validation satellites as a function of perigee altitude

- One year Dragster run using NRLMSIS-00 as the background atmospheric model (9/2015 to 1/2016 results shown below)
- Public TLE's assimilated into Dragster
- Special perturbations orbit solutions from high-task tracking assimilated into HASDM. HASDM available for 4 satellites.
- Dragster state vector includes both solar and geomagnetic forcing
- <u>Test demonstrates reduction in errors over background model</u>
- <u>Preliminary test results demonstrate that Dragster can outperform or match JB08 and HASDM</u>



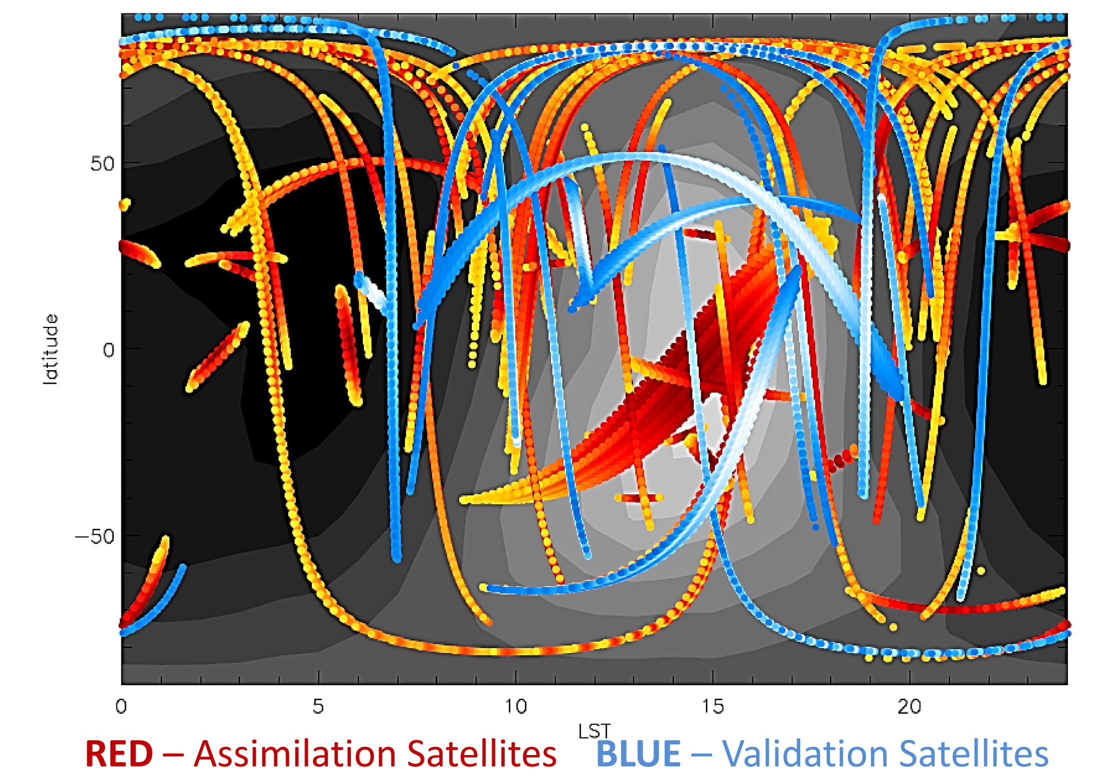


GRACE accelerometer measurements were used as a truth reference for orbit propagation. We compare in-track orbit errors associated with various atmospheric models by comparing to the GRACE reference. The plot above **(b) is a time series of 72-hr in-track orbit errors for the GRACE satellite** near 380-400 km altitudes. The larger errors near Day of Year 80 occur during a strong geomagnetic storm.



GRACE orbits were propagated for 72hr and 168hr timespans at one day intervals throughout 2015. The **in-track error distributions for each atmospheric model are summarized in figure (c) for 72hr timespans and (d) for 168hr timespans**. Assimilative models outperform the empirical model. HASDM and Dragster have equivalent performance in the case of GRACE.

Right: A snapshot of assimilation and validation data coverage in local-time and latitude coordinates. The image represents 75 assimilation satellites spanning perigee altitudes between 200-750 km. <u>Validation satellites are **not** assimilated into Dragster.</u>

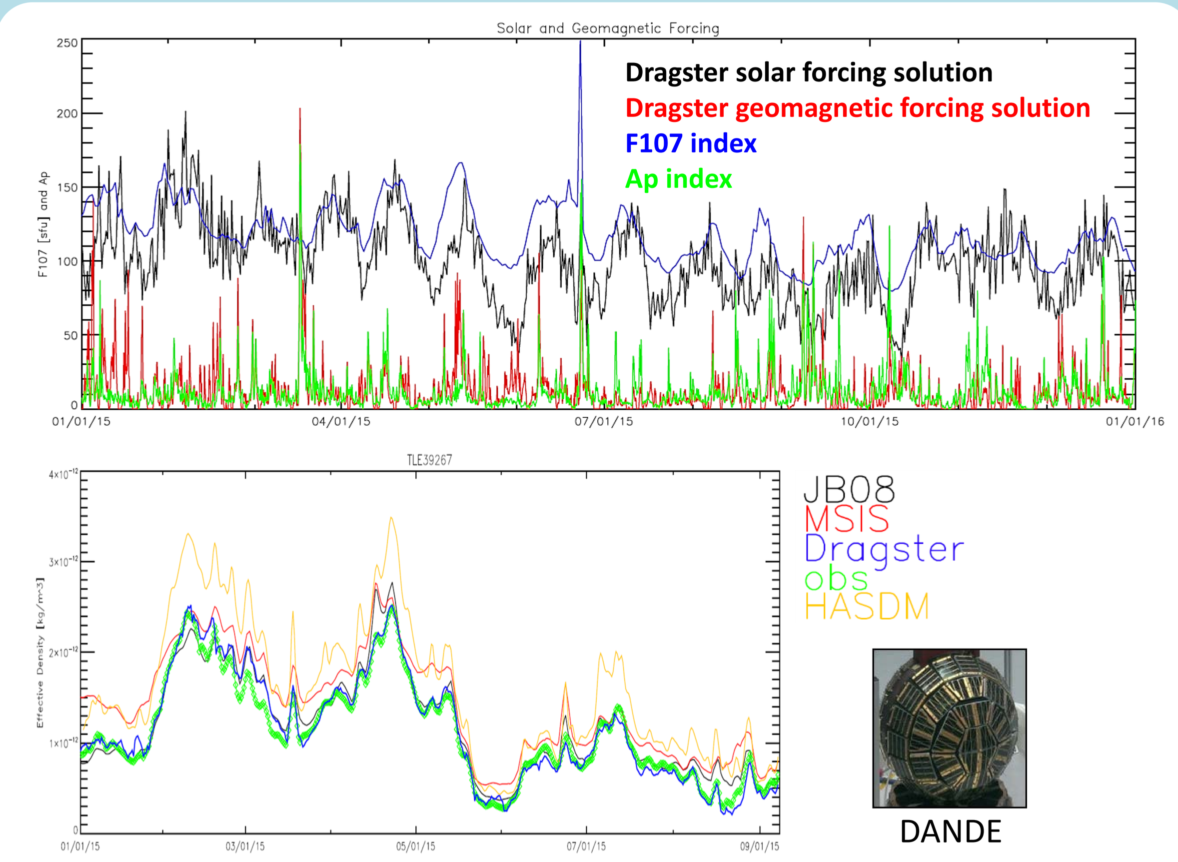


RED – Assimilation Satellites BLUE – Validation Satellites

Using DANDE as a validation object for assimilation results for 2015

Preliminary test runs are performed using publically available orbits (two line elements) and NRLMSISE-00 as the background model. Forcing solutions (F107 and Ap) are shown in the upper plot on the right along with the empirical indices.

The plot to the right shows the time-series of observed densities for the DANDE satellite along with the values specified by several models including HASDM*.



*HASDM – High Accuracy Satellite Drag Model used operationally at JSPoC. HASDM densities were provided by SET.

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