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Improving CTIPe Neutral Density Specification by Assimilating Only SlantTEC

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INTRODUCTION

Neutral density measurements are difficult to make, limited in number and coverage, and often have large or unknown uncertainties. This makes the option to improve neutral density specification using plentiful ionospheric measurements very attractive.

We investigate whether it is possible to improve global thermosphere neutral density results by assimilating only slant TEC (sTEC) measurements from COSMIC-2. Our results demonstrate an improvement in neutral density during an 8 day period (January 31 - February 7, 2022) that includes the minor geomagnetic storm that lead to the loss of 38 SpaceX satellites.

1/ What is Data Assimilation?

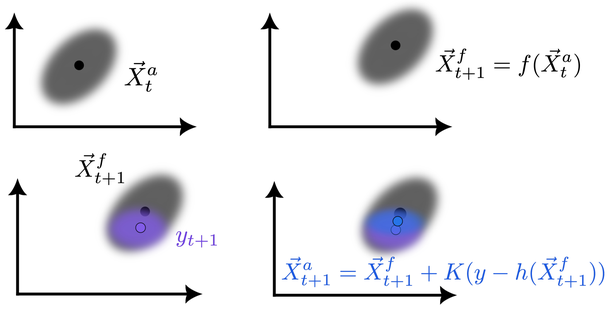
Data Assimilation (DA) is a technique to correct model results using observations. There are various forms of DA. We use an Ensemble Kalman Filter.

$$\vec{X}^f_{t+1} = f(\vec{X}^a_t)$$ model forecast step

$$\vec{X}^a_{t+1} = \vec{X}^f_{t+1} + K(y - h(\vec{X}^f_{t+1}))$$ analysis step (correct forecast)

where

- $\vec{X}_t$ is the model state, at time t
- f is the model itself, here CTIPe.
- y are measurements
- h is the measurement operator, gives the measurement as specified by the model



DATA ASSIMILATION in the Thermosphere-Ionosphere

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OVERVIEW

- Data assimilation is a *technique* to correct model results using measurements.
- The model used: CTIPe -- physics based.
- Assimilation code: TIDA -- Ensemble Kalman Filter.
- Observations assimilated: SlantTEC from COSMIC-2
- Results: Improved agreement between model and observed neutral density.

So What?

- Inaccurate neutral density modeling contributed to the loss of 38 SpaceX Starlink satellites in Feb 2022.
- Improved neutral density specification could improve orbit prediction -- ultimately saving resources.

5/ Results

The table below shows NRMSD% for Reference, Forecast, and Analysis over the 8 day period from January 31 - February 7, 2022.

$$\mathrm{NRMSD\%} = 100 * \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{\mathrm{meas}_i - \mathrm{model}_i}{\mathrm{meas}_i}\right)^2}$$

Satellite	n	**Reference** NRMSD%	**Forecast** NRMSD%	**Analysis** NRMSD%
COSMIC-2 sTEC	255872	80.56	88.17	78.44
GOLD ON2	15017	19.44	15.46	15.46
GOLD TDISK	15014	19.12	18.79	18.80
GRACE-FO	69119	33.24	32.53	32.15
SWARM-A	23807	32.34	31.41	30.96
SWARM-B	23807	35.09	34.72	34.32
SWARM-C	55817	32.48	31.11	30.65

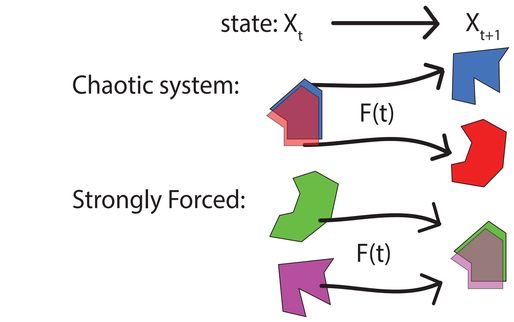
In these results:

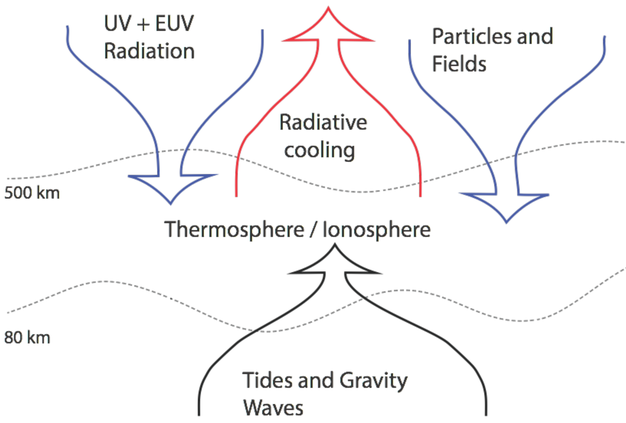
- **Reference**: is the model without assimilation.
- **Forecast**: is the model forecast from the pervious corrected state.
- **Analysis**: is the model forecast corrected using observations in the forecast period.

5/ Conclusion

- Assimilating exclusively sTEC measurements, it is possible to improve neutral density modeling, even during a geomagnetic storm.
- The possibility to improve neutral density, composition, and temperature by assimilating only ionosphere/plasmasphere measurements demonstrates the importance of coupling between the ionosphere and the thermosphere in physics based models.

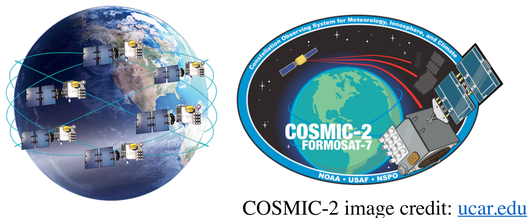
2/ System Types





3/ Observations

The data assimilated comes from 6 COSMIC-2 satellites observing radio occultation of GPS signals through the ionosphere. These observations are Slant Total Electron Content (sTEC), a measure of ionization along the signal path.



COSMIC-2 image credit: ucar.edu

Neutral density measurements used for comparison are derived from precise orbit determination (POD) for SWARM-A and B, and accelerometer for SWARM-C. The SWARM constellation orbits around ~460km altitude in a high inclination orbit

swarm

SWARM image credit: esa.int

4/ Experiment Configuration

We assimilate only sTEC from COSMIC-2. All others datasets are for comparison.

- Assimilation time step: 30 minutes
- Ensemble size: 75 members
- Kalman State:
  - neutral temperature
  - neutral winds
  - mixing ratios
  - plasmasphere parameters
  - forcing parameters via state augmentation.