Upper Atmosphere Data Assimilation and Dataset Quality Importance

Matthew Brown & Sean Elvidge

PITHIA Third Innovation Day,
June 12, 2024

Requirement for Upper Atmosphere DA Modelling

- Thermosphere:
  - Collision avoidance among orbiting satellites has become a routine task in space operations
  - In Low Earth Orbit (LEO; < 2,000 km) the largest unknown in orbit determination is atmospheric drag
  - Impacts on
    - Orbital propagation
    - Collision avoidance
    - Re-entry prediction
    - Lifetime estimation
- Ionosphere:
  - Many communication and navigation systems are affected by the ionosphere
    - Global Navigation Satellite Systems: GPS, Galileo, … (PNT)
    - Precise Point Positioning (PPP), e.g. convergence times
    - HF (comms / radar)

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- Median models are useful for planning
- But high-fidelity environmental specification, coupled with real time forecasting, is required to provide new functionality

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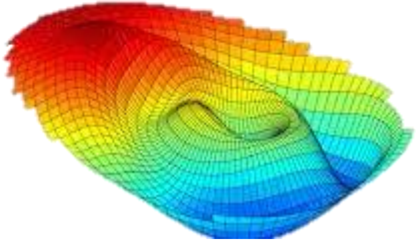
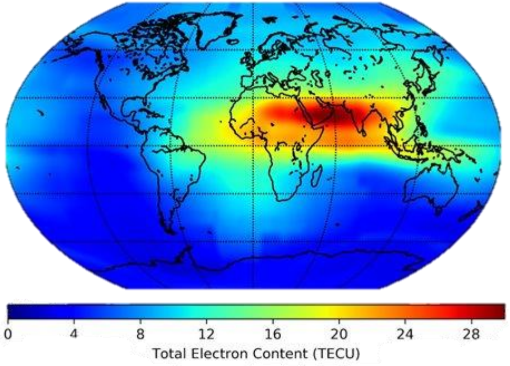
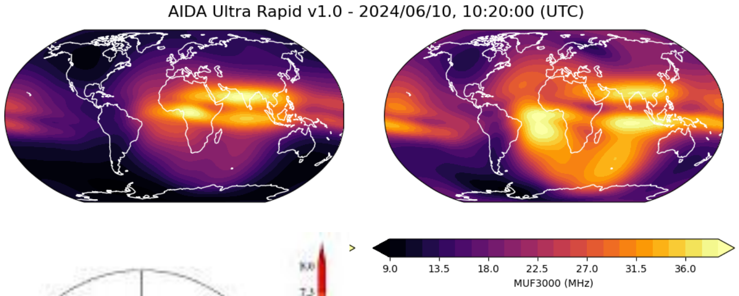
SERENE’s Upper Atmosphere Models

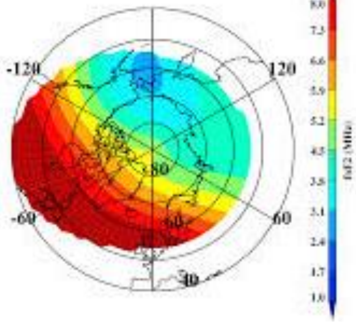


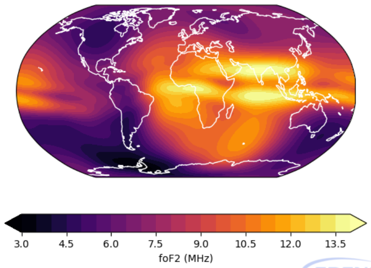


- AENeAS
  - The **A**dvanced **E**nsemble **Ne**tworked **A**ssimilation **S**ystem



- E-/A-CHAIM
  - The **E**mpirical/**A**ssimilation – **C**anadian **H**igh **A**rctic **I**onospheric **M**odel





- AIDA
  - The **A**dvanced **I**onospheric **D**ata **A**ssimilation model

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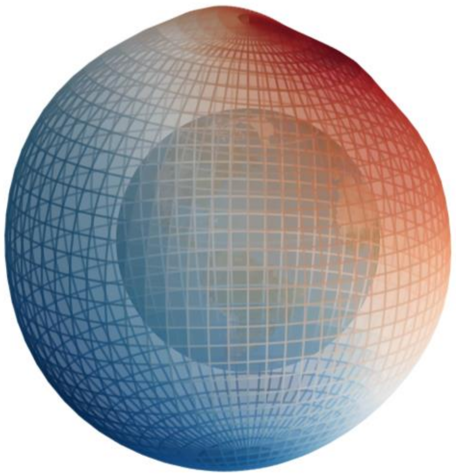
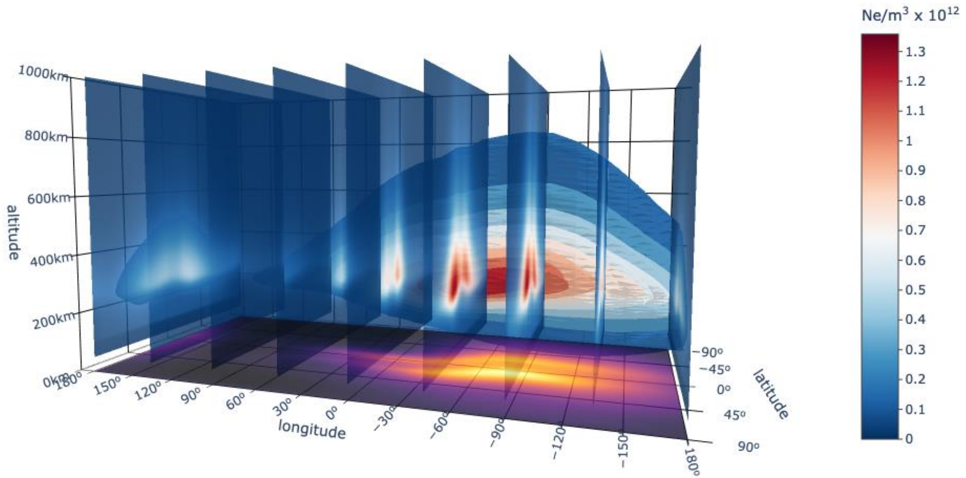
Neutral temperature at model “lid”



AENeAS

- A realtime upper atmosphere data assimilation model
    - Based on solving the underlying physics of the system and fusing with observations
    - Variant of the ensemble Kalman filter (LETKF)
- Provides:
    - Probabilistic nowcasts and forecasts (with uncertainties)
        - Not necessarily Gaussian
    - Runs operationally at UK Met Office (output available from Q4 2024)



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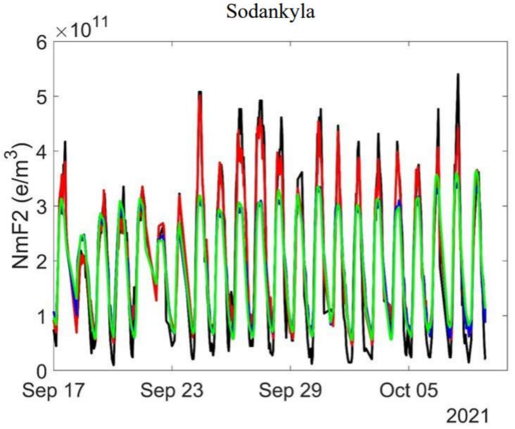
E-/A-CHAIM

- E-CHAIM:
  - Empirical model of high latitude (> 50˚N geomagnetic latitude) ionospheric electron density
  - Primarily climatology, but also includes intermediate timescale variability (1 to 30 day-timescale variations)
  - Includes electron precipitation, D-Region, Solar Energetic Protons (PCA)
  - Openly available source code: http://e-chaim.chain-project.net/
  - Designed to support Over-the-Horizon Radar (OTHR) and HF radio propagation operations at high latitudes.

- A-CHAIM:
  - Auxiliary particle filter data assimilation scheme that uses E-CHAIM as its background model.
  - Freely available output: https://a-chaim.chain-project.net/
  - System run every hour. Reanalysis of last three hours and two hour forecast.



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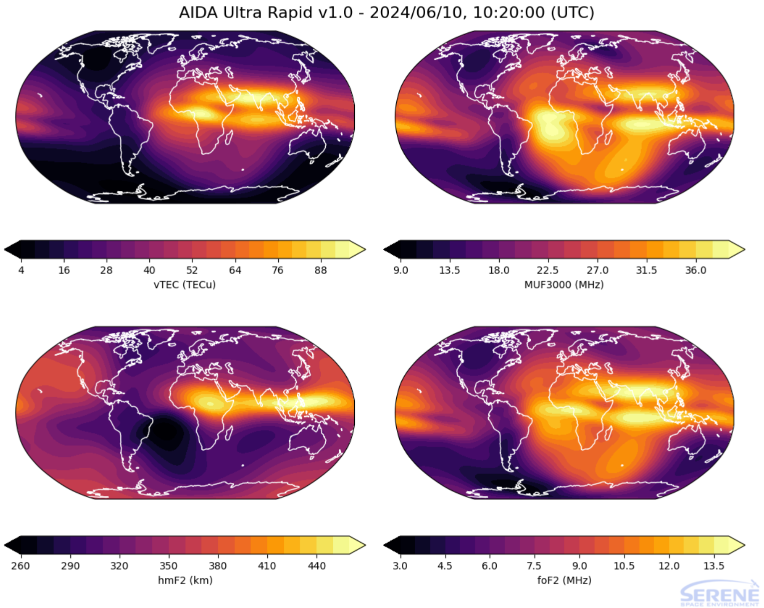
AIDA

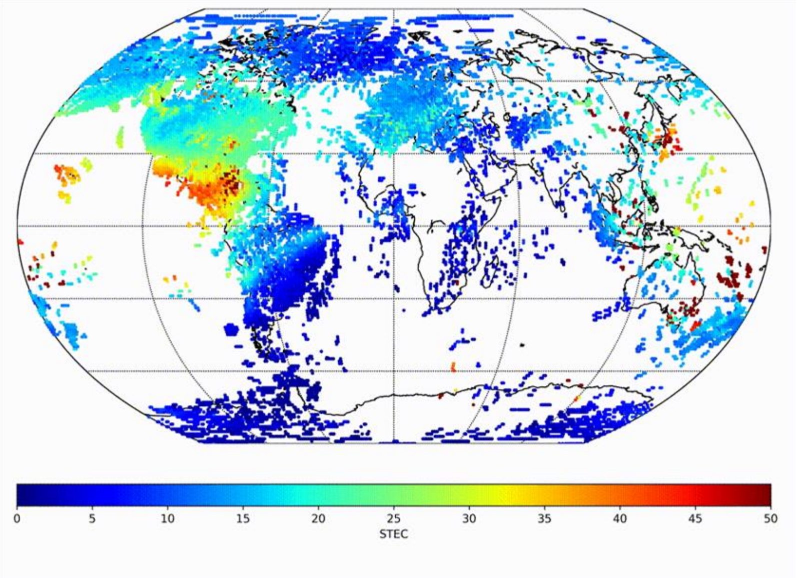
- Global particle filter which uses NeQuick as its background model
    - Model state space built using the parameterized vertical structure, with spherical harmonics for the horizontal perturbations makes it relatively small

Name	**Time resolution**	**Latency**	**Expected assimilated observations**
Ultra-Rapid	5 min	5 min	NTRIP GNSS
Rapid	5 min	90 min	GNSS (partial), Ionosonde (partial)
Final	5 min	Daily	GNSS, Ionosonde, RO



Observations Used by the Models

- Electron density
    - Slant TEC (STEC) from GNSS satellites
    - Vertical TEC (VTEC) from altimeter satellites
    - Vertical profiles from ionosondes (true heights)
        - [Over 30 million observations used to build empirical model]
    - Radio Occultation
        - Bending angle assimilation
        - [Over 1 million observations used for empirical model]
- Total neutral density
    - From CHAMP/GRACE/Swarm (processed)
    - Two-line elements (derived)



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Importance of Data Quality & Uncertainties

- Empirical Models
  - Require large sets of clean data with well characterized errors to build models

- Data assimilation
  - Uncertainties of data critical for assimilation algorithms
  - Some data more “noisy” than others (e.g. TLEs)

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- Enabling novel data assimilation (“non-diagonal R”)
  - Many values clearly have correlated errors, using a diagonal R artificially reduces observation errors
  - Using the correct off-diagonal terms completely removes this problem

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- Model validation

Conclusions

- SERENE run a range of upper atmosphere models:
  - Empirical, physics-based and data assimilation

- Quantified and calibrated data is critical for:
  - Building empirical models
  - Assimilating data fusion schemes
  - Enabling novel data fusion techniques
  - Validating upper atmosphere models