Kamodo – an Adaptable Tool to Obtain and Compare Observations and Modeling Results.

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What is Kamodo?

- Official NASA open-source project written in Python
- Built upon the functionalization of datasets.
  - It is a CCMC developed and maintained software tool for access, interpolation, and visualization of space weather models and data.
  - It allows model developers to represent simulation results as mathematical functions which may be manipulated directly by end users.
  - It handles unit conversion transparently and supports interactive science discovery through jupyter notebooks with minimal coding.
- All Kamodo tools are accessible through Python, and all source code is publicly available on the Kamodo NASA GitHub repositories.
- Kamodo does not generate model outputs. Users need to acquire the desired model outputs before they can be functionalized by Kamodo.

What can Kamodo do?

- Kamodo supports
  - Function composition
  - Automatic unit conversions
  - Coordinate transformations
  - Interpolation
  - Interactive plotting
  - Access to APIs such as HAPI
- These features then enable
  - Satellite flythrough with automatic coordinate conversions
  - Constellation mission planning tools
  - Data/Model comparison analysis
  - Model driver swapping

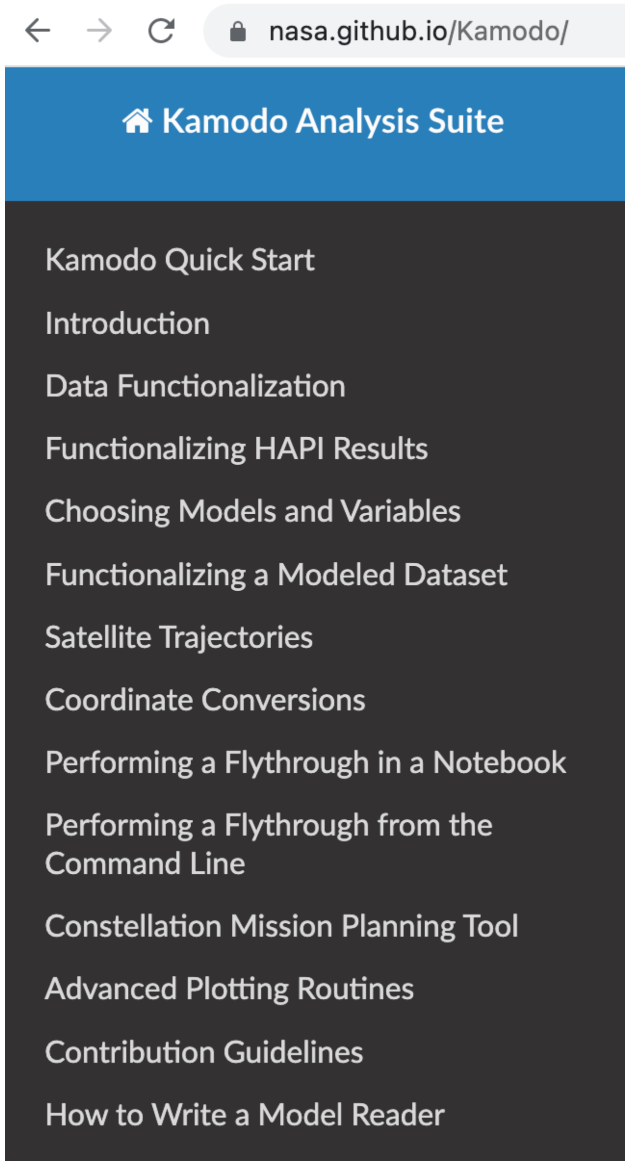
Models in Kamodo

- Current models supported in Kamodo:
  - **2D Ionosphere electrodynamics:** ADELPHI, AMGeO, SuperDARN, SWMF-IE, Weimer
  - **3D Ionosphere-Thermosphere:** CTIPe, DTM, GITM, IRI, TIE-GCM, WACCM-X, WAM-IPE
  - **3D Magnetosphere:** SWMF-GM, OpenGGCM,
- Models coming soon:
  - **3D Heliosphere:** ENLIL, GAMERA-IH,
  - **3D Magnetosphere**: GUMICS-GM, GAMERA-GM, LFM-GM, MARBLE (a GSFC Hall MHD model)
  - **3D Ionosphere-Thermosphere/Plasmasphere:** SAMI3
  - **2D Ionosphere electrodynamics:** (Re)MIX, OpenGGCM-IE, GUMICS-IE
  - **4D Ring Current/Radiation Belt:** CIMI, RAM-SCB, VERB
- SWMF-GM is the first model with a custom interpolator written in C
  - GAMERA-GM, CIMI, RAM-SCB will follow with custom interpolators
- In addition, several APIs are supported to ingest data (including HAPI)

Kamodo support

- The full package is on github, it is well documented and includes quick start guides
- Upgraded documentation
  - Thorough description of what Kamodo can do, how to do it, and how to extend it to new models and datasets
- New testing notebooks
  - Not yet automated, but the notebooks are a quick test to make sure changes don't break existing functionality
- New tutorial notebooks
  - Many how-to's and examples available
- Sample Data:
  - Simulation runs for each model on CCMC web site

https://ccmc.gsfc.nasa.gov/tools/Kamodo
https://nasa.github.io/Kamodo/



Kamodo plotting:

- Fully generalized and automated:
  - Type of plot returned is function of the dimensionality of the input/output arguments:
    - 1D line plot for 1D array of input of size N and output is also a 1D array of size N,
    - 2D Color Contour for 2D arrays of inputs/outputs
  - Any combination of 1D/2D/3D with line/scatter/vector/contour/etc. can be automatically created.
- Plotly for dynamic interactive visualizations
- Customized Plots:

  Example: 1D array of values extracted along a satellite trajectory can also be viewed as 2D and 3D visualizations. (example on next slides)

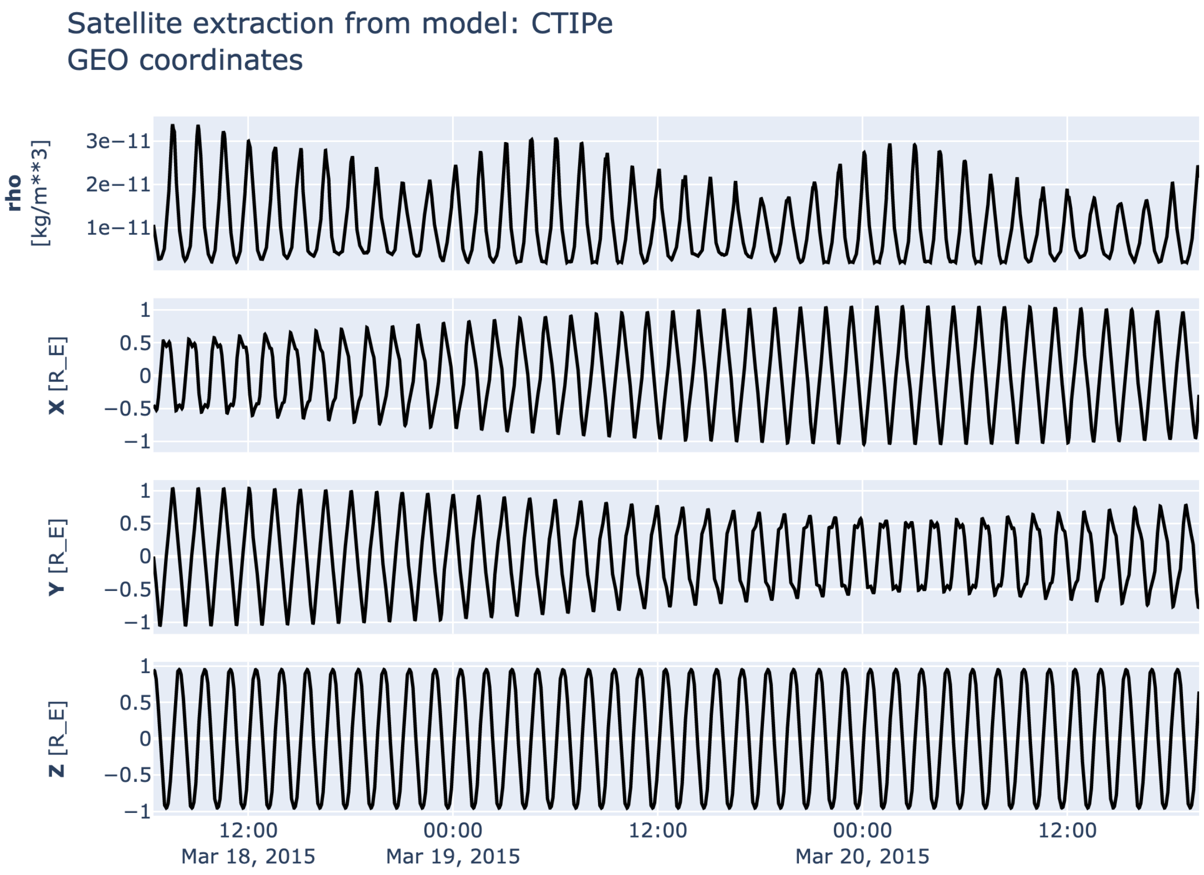
Plot Example: 1D satellite track

```python
# Stacked 1D plot
SatPlot4D(var, cdf_dict['utc_time']['data'], cdf_dict['c1']['data'],
          cdf_dict['c2']['data'], cdf_dict['c3']['data'],
          cdf_dict[var]['data'], cdf_dict[var]['units'],
          'GDZ', 'sph', 'GEO', 'all', 'CTIPe', type = '1D')
```

Density (Rho) along satellite track [X, Y, Z]

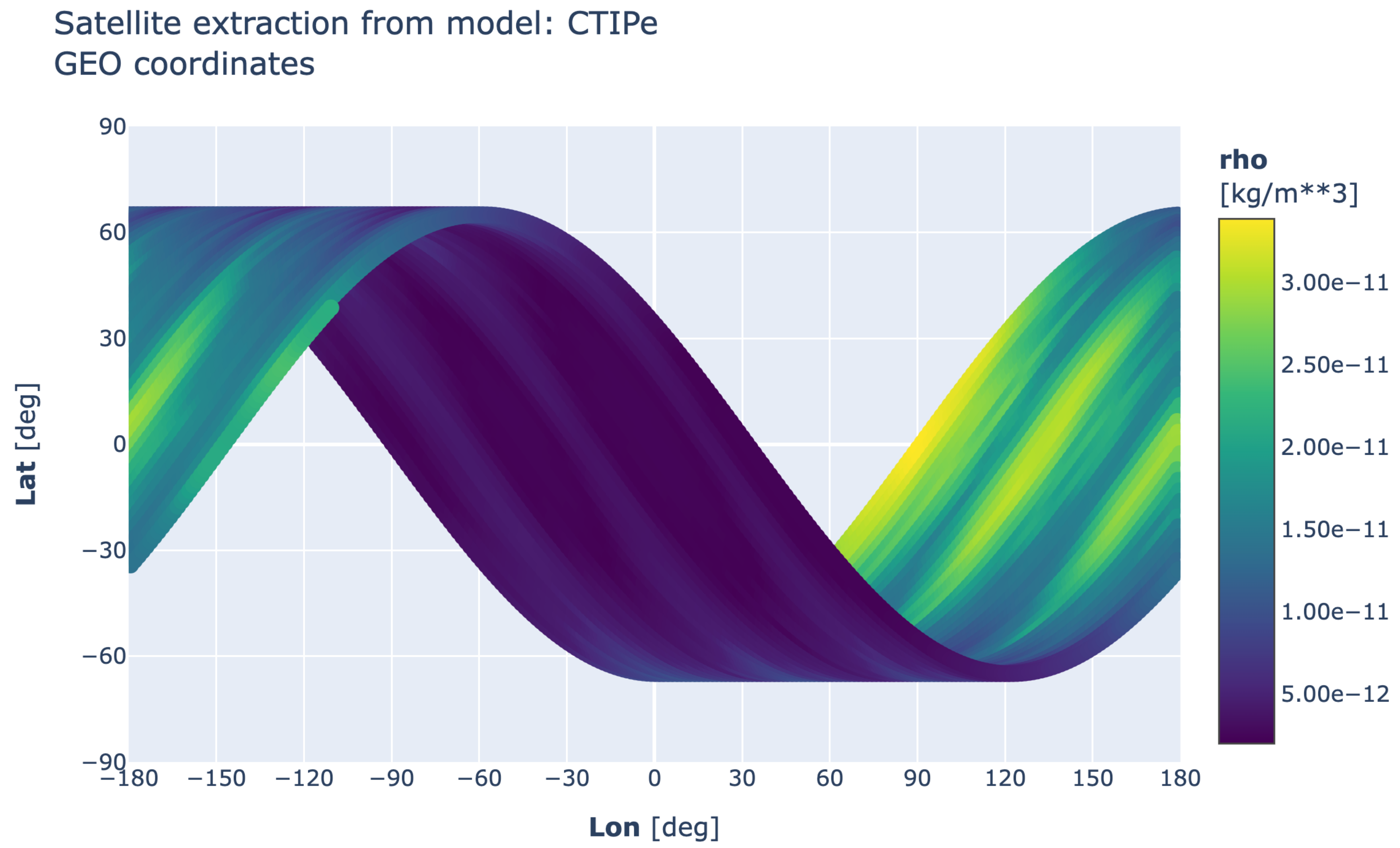
through

CTIPe ionosphere thermosphere

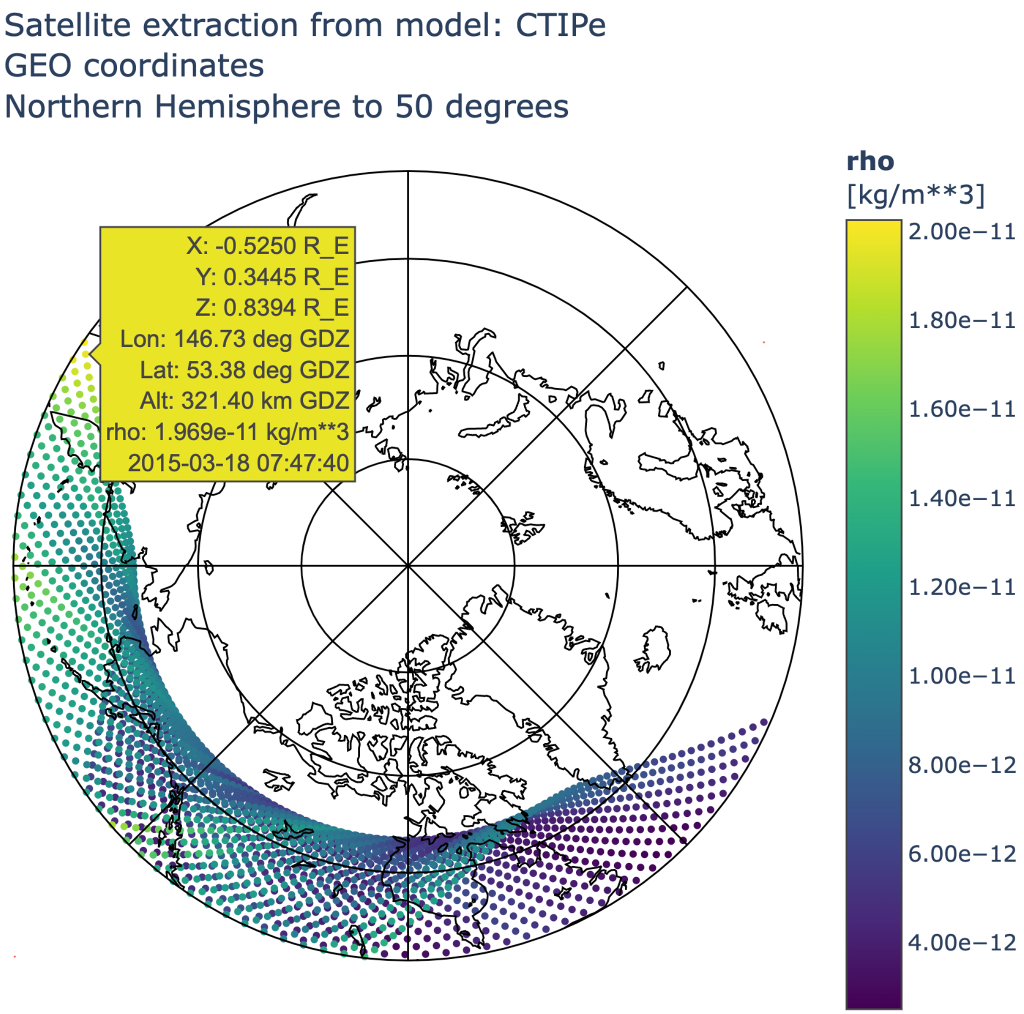


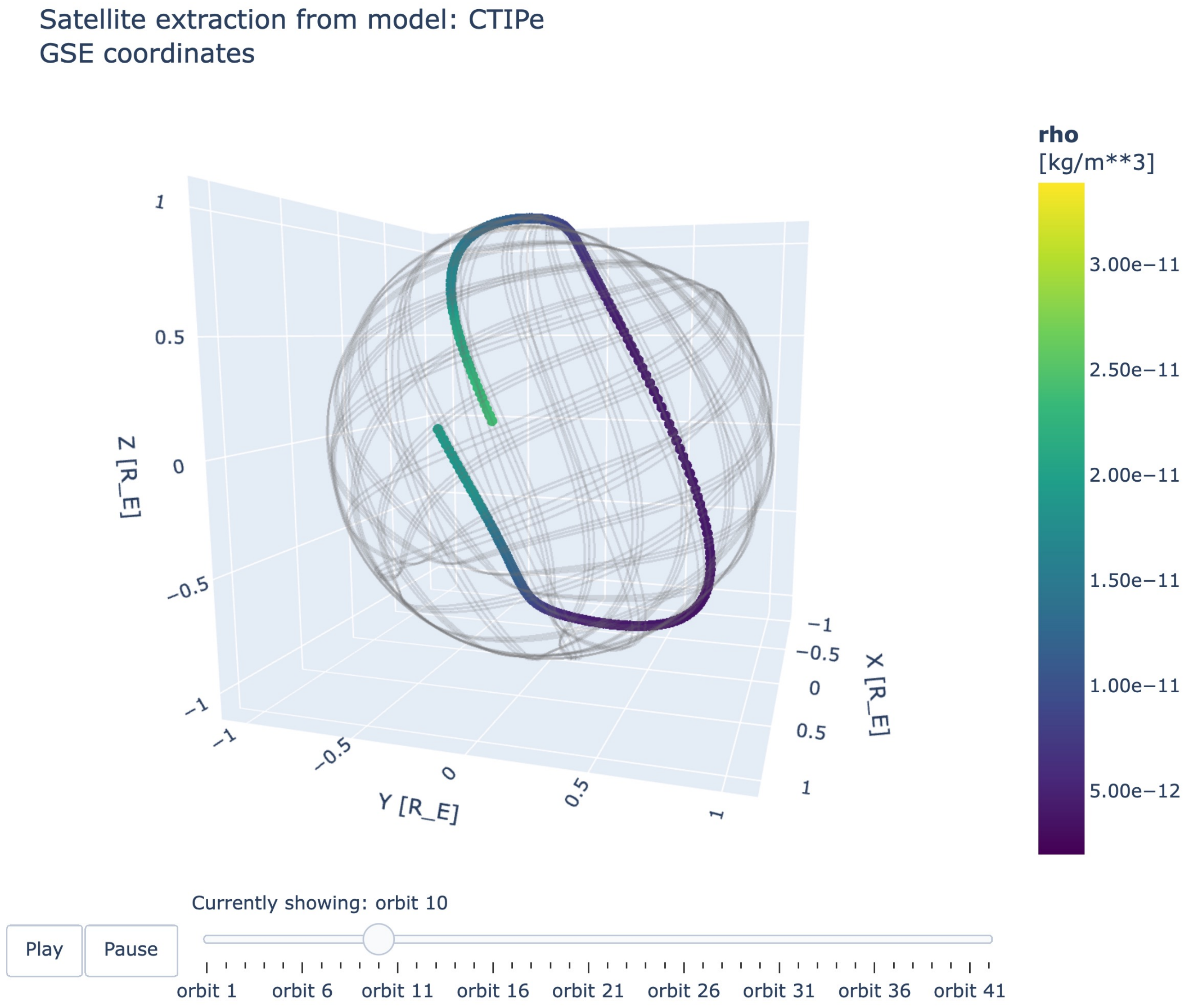
Track viewed in 2D longitude-latitude

Same density rho along track shown in geographic coordinates

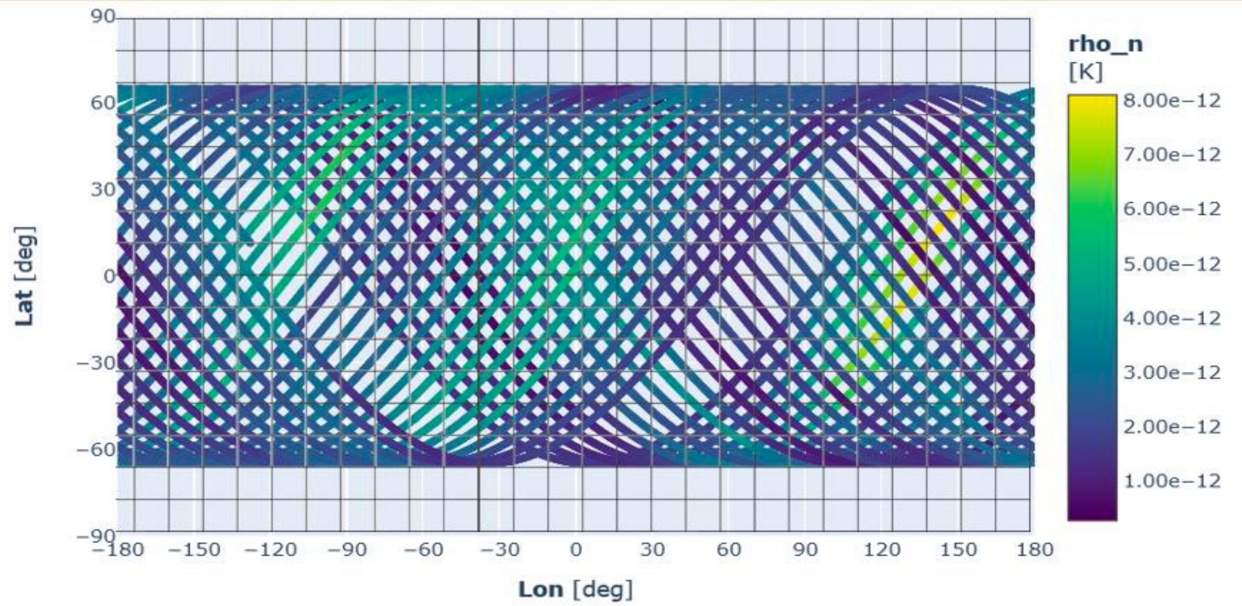


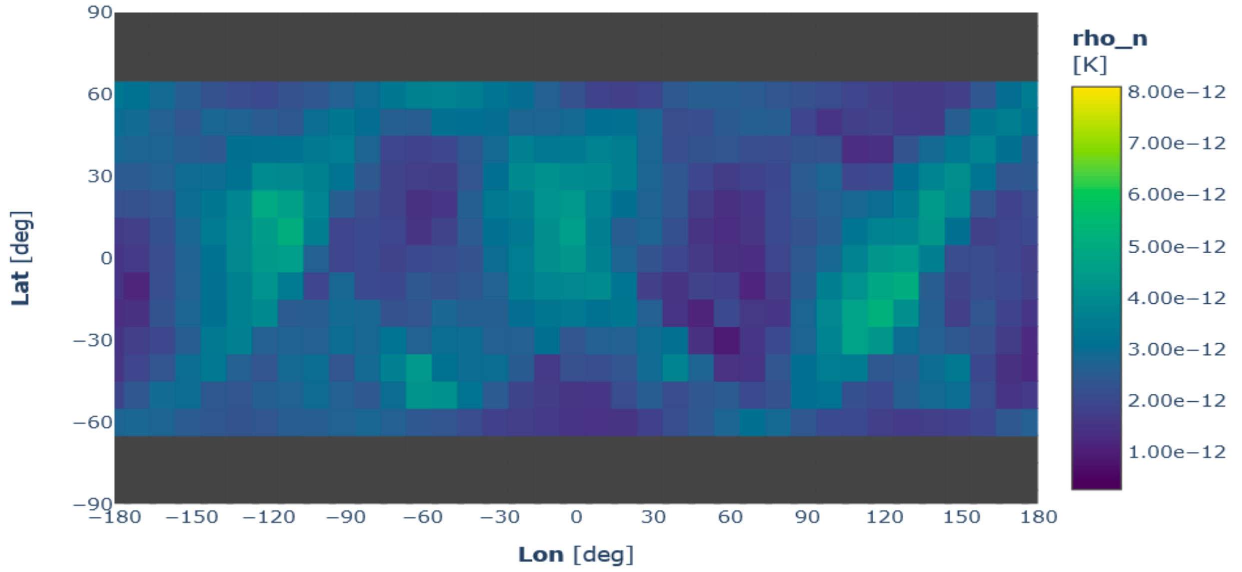
Polar Plot, 3D Sphere





Mission Planning for Constellations



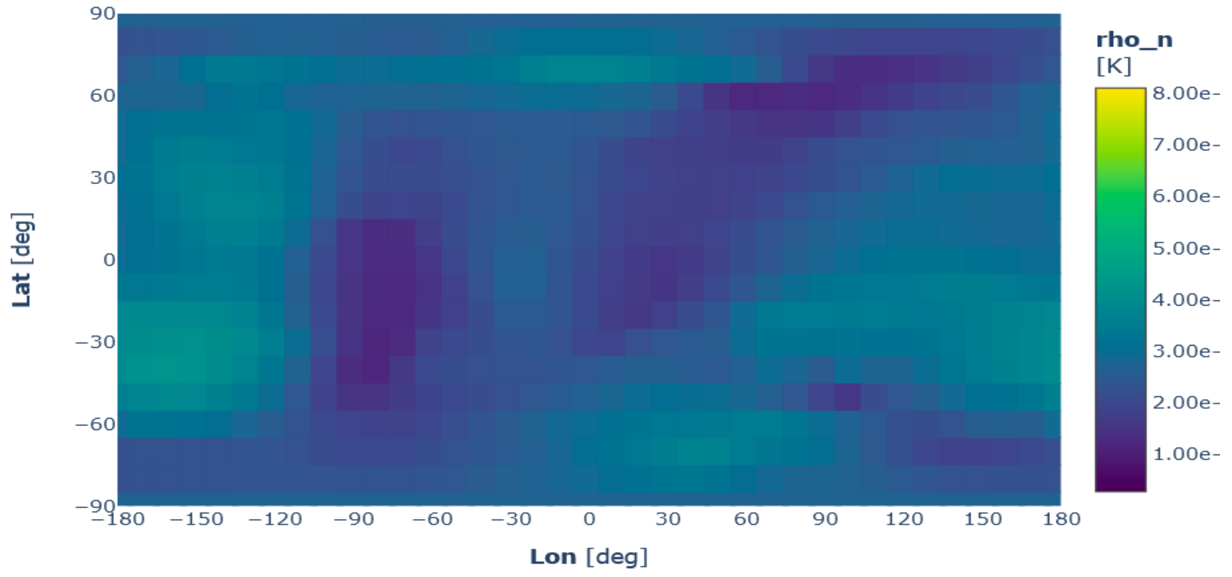


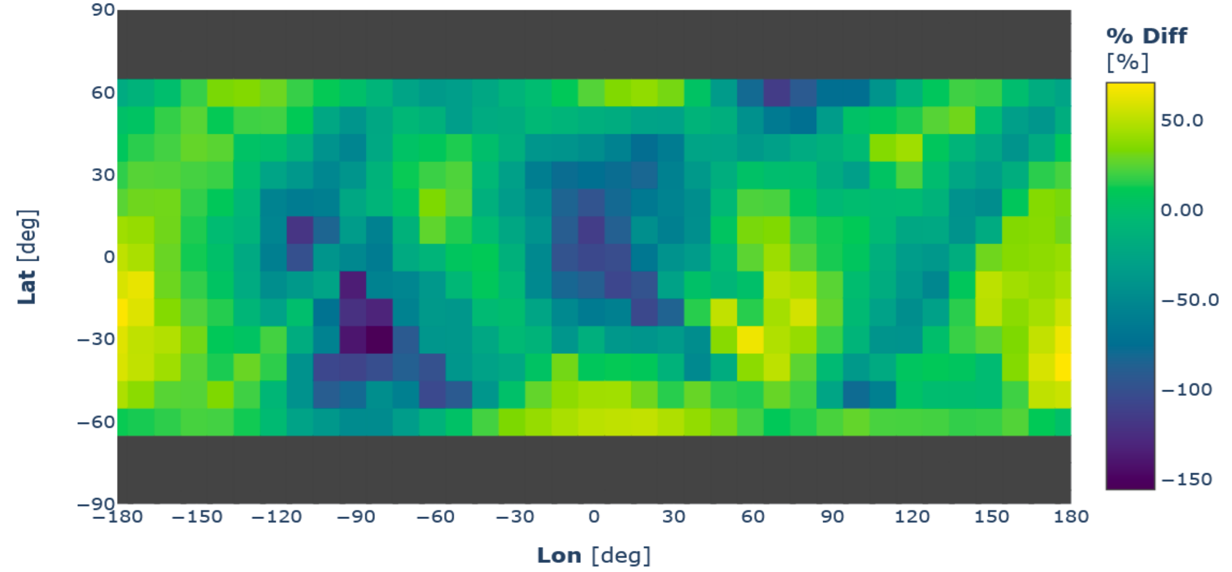
1. Fly the given trajectory through the chosen model data
GITM model data shown here.

2. Sort the resulting values into a grid of longitude-latitude cells.
Resolution of the grid is chosen by the user.
Here: 10-degree by 10-degree cells.

3. Take the average of the values in each grid cell.
Here: 10-degree by 10-degree cells

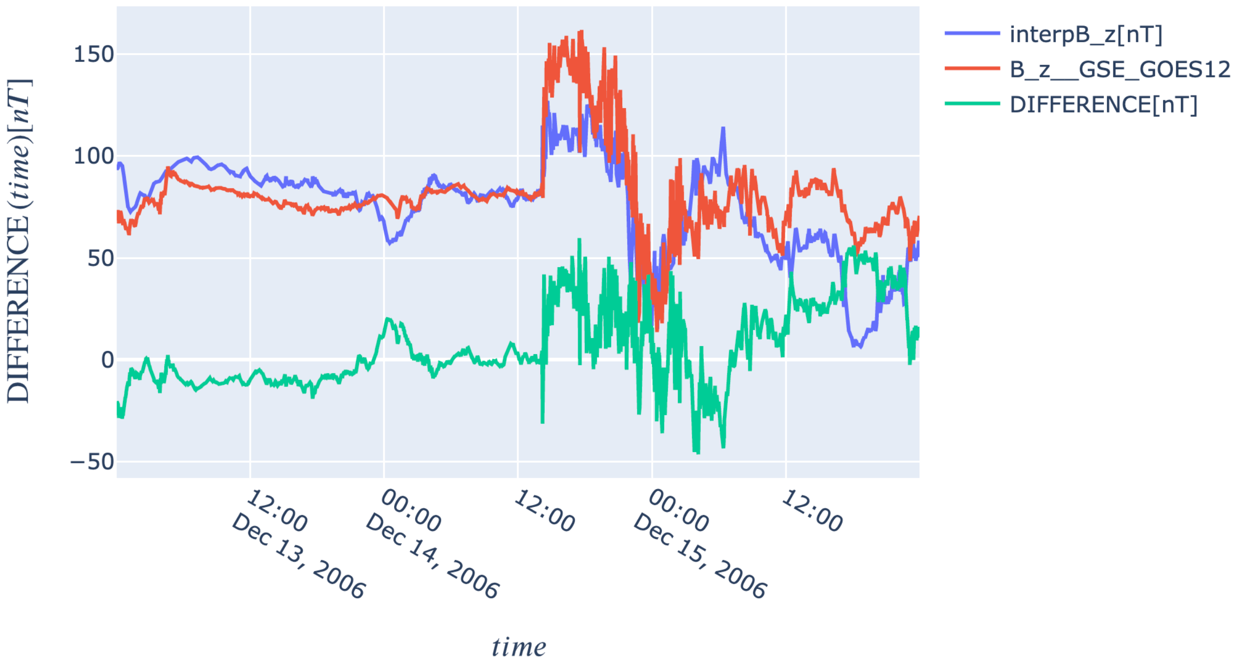
Mission Planning (cont.)





4. Prepare Ground Truth.

$\mathrm{DIFFERENCE}(time)[nT] = \lambda(time)$



Identify unresolved spatial structures.

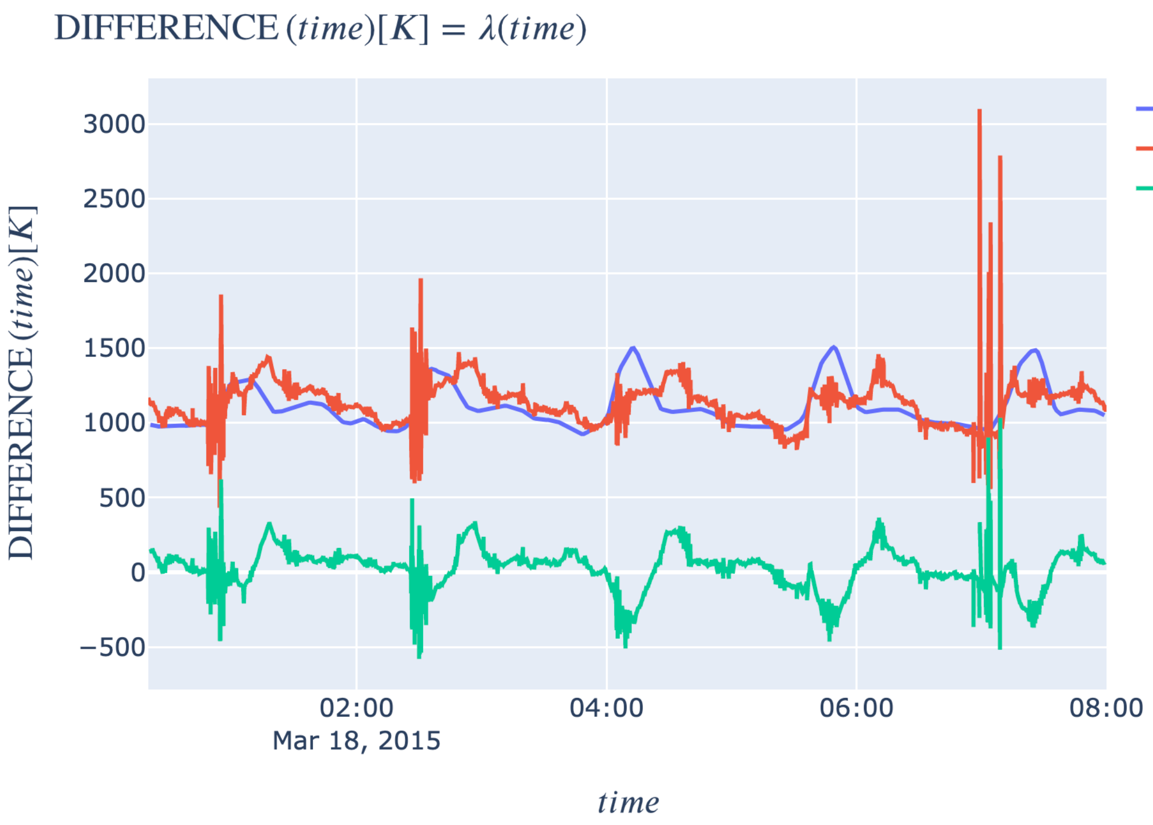
Mission Planning: Summary

Kamodo

- **Satellite Fly Through** was developed to formalize the steps taken to obtain trajectory data and interpolate them in time and space to sample *in-situ* model data.
- **Reconstruction Analysis Options** were modeled after steps taken during the definition process of the GDC mission.
- Options were added to support specific **use cases** and to anticipate **different approaches to averaging ground truth** (model) data for comparison.
- Software is **open source** and new missions are **invited to use it**.
    - Notebook: docs/notebooks/ConstellationMissionPlanningToolIntro.ipynb

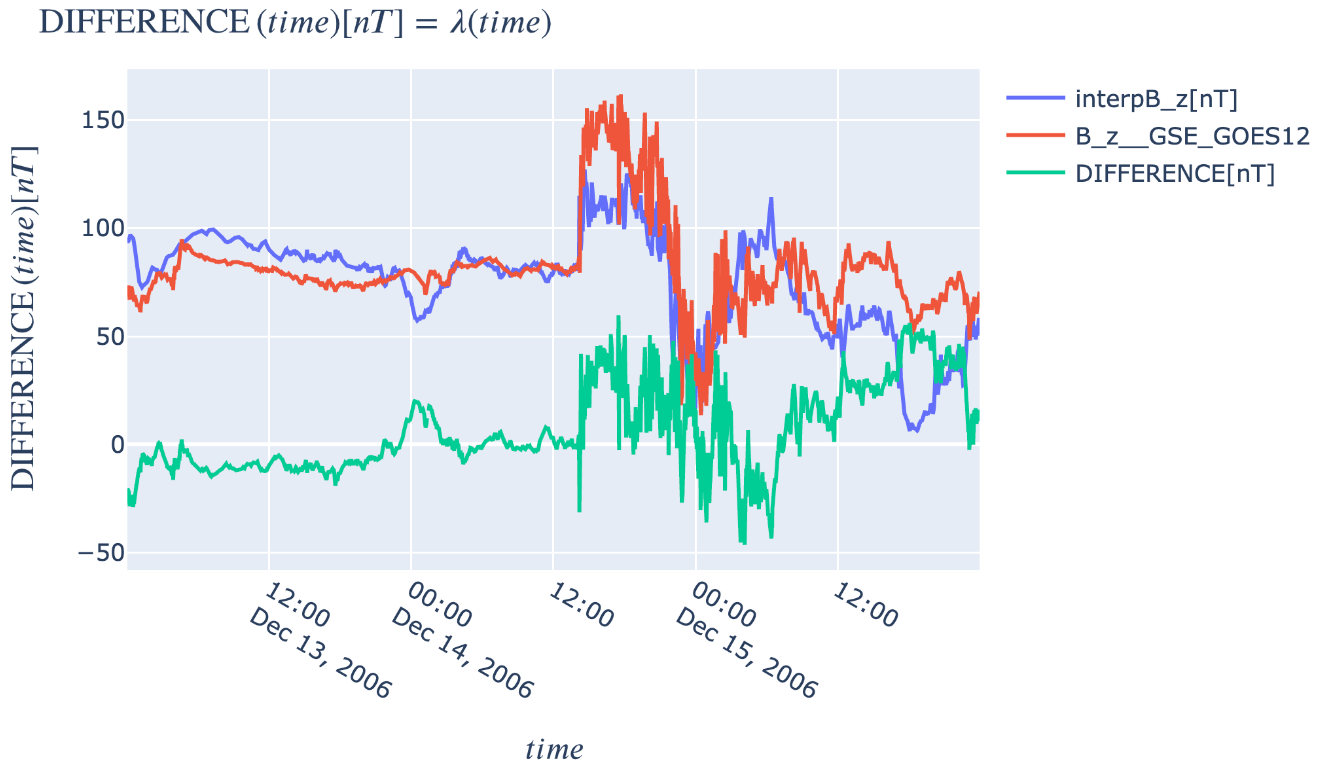
Data – Model Comparison

Kamodo



SWMF-GM and GOES-12

Magnetic Field B_Z



TIE-GCM – CINDI (via HAPI)

Ion Temperature

Current Projects:

Kamodo

- Orbit Propagation: improve tools over using statistical models.
- HAPI interface for Kamodo Fly-Through
- Interactive visualization to augment CCMC online analysis tools.
- Driver-Swapping: Prepare inputs from outputs of any other model.
- Cloud support: model and observation data in shared development spaces for CMCC collaborators, HDRL.
- Prepare data for model-data comparisons in analysis tools such as CAMEL.
- …

Collaboration:

- Github repository: https://github.com/nasa/kamodo
    - Example Notebooks
    - Fork, modify, contribute by submitting pull requests