NOAA-NASA R2O2R Quick Win - Neutral Density Validation

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1. Introduction

During the NOAA-NASA Summit on May 25-26th, 2022, three R2O2R Quick Wins were identified in the focus areas of Proving Grounds/Testbed, O2R Grants Program, and Neutral Density. "Quick Wins" are defined as something that can be fully completed within the next year (by July 2023), demonstrates the progression in the R2O2R process to a higher RL, and has a concrete benefit to space weather operations. The Neutral Density R2O2R Quick Win is described as follows:

"Develop a neutral density scoreboard/warning product where WAM-IPE outputs can be used in support of orbital drag and Space Traffic Coordination (Ending RL 5)."

The purpose of this project is to validate the neutral density product from the operational WAM-IPE forecast system v1.0 (WFS.v1) against the high-fidelity space-based accelerometer-derived neutral density from the GRACE-FO (Gravity Recovery And Climate Experiment Follow-On mission; doi: 10.1051/swsc/2023014). The project is performed in close collaboration between the NOAA/SWPC and the NASA/CCMC.

2. Achievement

To support this R2O2R Quick Win, four major milestones are achieved during June 2022-July 2023, which are provided as follows:

- NOAA SWPC delivered the achieved WAM-IPE operational outputs of July 2021-July 2022 as well as a software package for extracting neutral density and extending altitude range to the NASA CCMC.
- The data is digested by the NASA CCMC for validation and for establishing a neutral density validation over three geomagnetic storms (https://webserver1.ccmc.gsfc.nasa.gov/camel/NeutralDensity/).
- One year of Historical raw WFS.v1 outputs and converted neutral density products are archived at the NASA CCMC, and they are publicly available to users hosted by the NASA/CCMC (https://ccmc.gsfc.nasa.gov/external-runs/swpc/ionosphere/WAM-IPE/WAM-IPE-July2021-22/index.html).
- An open-source Python-based visualization tool for the WAM-IPE output is built upon the NASA CCMC Kamodo Analysis Suite, and is publicly available at the NASA GitHub Kamodo repository (https://nasa.github.io/Kamodo/).
- An interactive web-based visualization service of the continuous real-time WAM-IPE output originally downloaded from NOAA/SWPC is being developed, and it is expected to be publicly available by late August 2023 on the NASA CCMC website.

3. Neutral Density Validation

The R2O2R Quick Win neutral density validation is built upon the CAMEL (Comprehensive Assessment of Models and Events Using Library Tools) framework developed and hosted by the NASA CCMC, and it has been incorporated within the CAMEL Web Application for the NASA/CCMC-CNES/Space Geodesy Office joint neutral density validation project (Figure 1). The CAMEL framework is a flexible and public framework allowing users to seamlessly compare and visualize modeled neutral density with observational data sets.

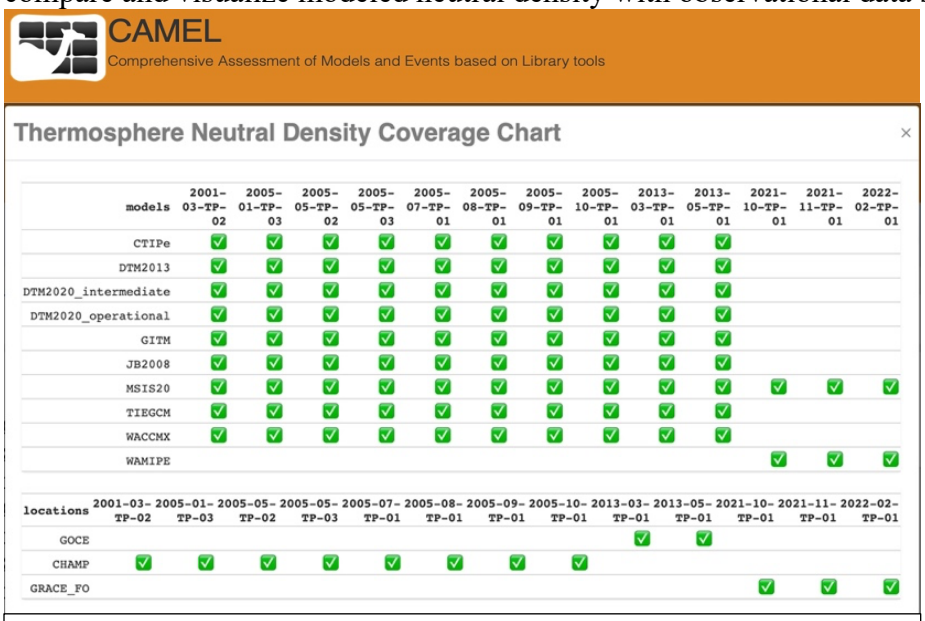

Figure 1: Neutral density model and observation availability chart.

The front-end interactive web tool allows users to select interested models and time periods (Figure 2). The user-selected model-data pairs are then used for selected skill score calculations (Bruinsma et al., 2021; doi: 10.1051/swsc/2021002).

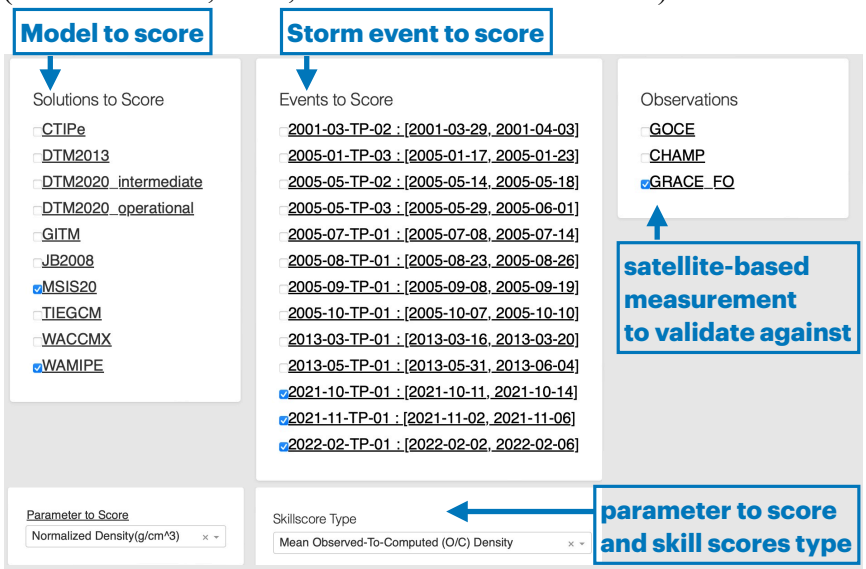

Figure 2: CAMEL user interface offers choice of events, models, observations, and skillscore type.

- In the current project, 3 unique time periods of the model assessment during geomagnetically disturbed times are selected (Table 1). An empirical model NRLMSIS 2.0 (Emmert et al., 2021; doi: 10.1029/2020EA001321) are also utilized in this project. The neutral density outputs from NRLMSIS 2.0 and WAM-IPE are validated against the GRACE-FO observations (Siemes et al., 2023; doi: 10.1051/swsc/2023014). Note that the solar and geomagnetic drivers in NRLMSIS 2.0 are identical to that in WFS.v1, so discrepancy in the modeled neutral density output between NRLMSIS 2.0 and WAM-IPE should be subject to the model physics or formulation schemes. The result of the skill score is shown in Figure 3, which is the mean observed-to-computed neutral density ratio among the 3 selected periods using the time series of de-biased neutral density. Skill score=1 is the best score for validation. As Figure 3 demonstrates, **WAM-IPE outperforms NRLMSIS2.0 over those three magnetic storms.**

Start/end date	Min Dst (nT)	Max Kp	Observation LT at the equator
2021/10/11-2021/10/14	-65	6.3	04 LT/16 LT
2021/11/02-2021/11/06	-105	7.6	02 LT/14 LT
2022/02/02-2022/02/06	-66	5.3	07 LT/19 LT

Table 1: Selected time periods for model assessment in the study.

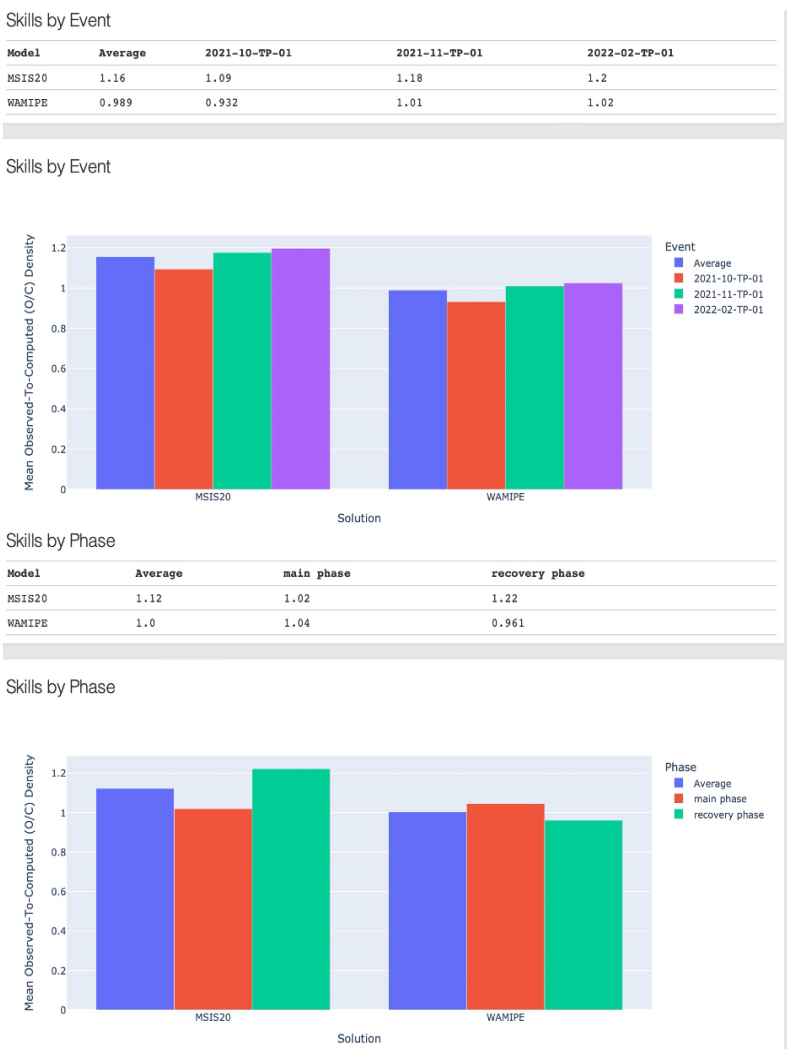

Figure 3: Mean observed-to-computed neutral density ratio for WAM-IPE and NRLMSIS 2.0 at all selected time periods. Skill scores are tabulated by time period or event (top) and storm phase (bottom), respectively. Note that the computed neutral density is de-biased with respect to the observations by computing a scaling factor during the geomagnetically quiet times.

- The time series of the observed and computed neutral density can also be graphed interactively and dynamically with panning, point picking, and zooming capabilities (Figure 4).

Figure 4: (top) Normalized neutral density during 2021/10/11-2021/10/14 from GRACE-FO, WAM-IPE, and NRLMSIS 2.0. (Bottom) Corresponding Dst values.

4. Future outlook

A follow-on study will upload the year-long WAM-IPE neutral density dataset into CAMEL, along with the neutral density simulated by other state-of-art physics-based models (e.g., TIE-GCM v2.5) and empirical models (e.g., DTM2020, NRLMSIS 2.0, JB2008, and HASDM). Such modeled neutral density will be validated against the GRACE-FO neutral density throughout the whole year, which will cover both geomagnetically quiet and disturbed times. New storm events or time periods in 2023 and 2024 (Heliophysics Big Year) will also be added in the campaign. It is expected that the CAMEL front-end will also be upgraded in the next fiscal year after feedback from the community are received. Additional features for the neutral density campaign in CAMEL are currently in the planning stage and should be included in the next upgrade. Particularly, the CAMEL webapp will allow users to dynamically select their desired time period and the duration of each phase in both skill scores calculation and plotting of results.