



Overview of Navy's Future Ionospheric/Thermospheric DA

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Objectives and Goals

Goal:

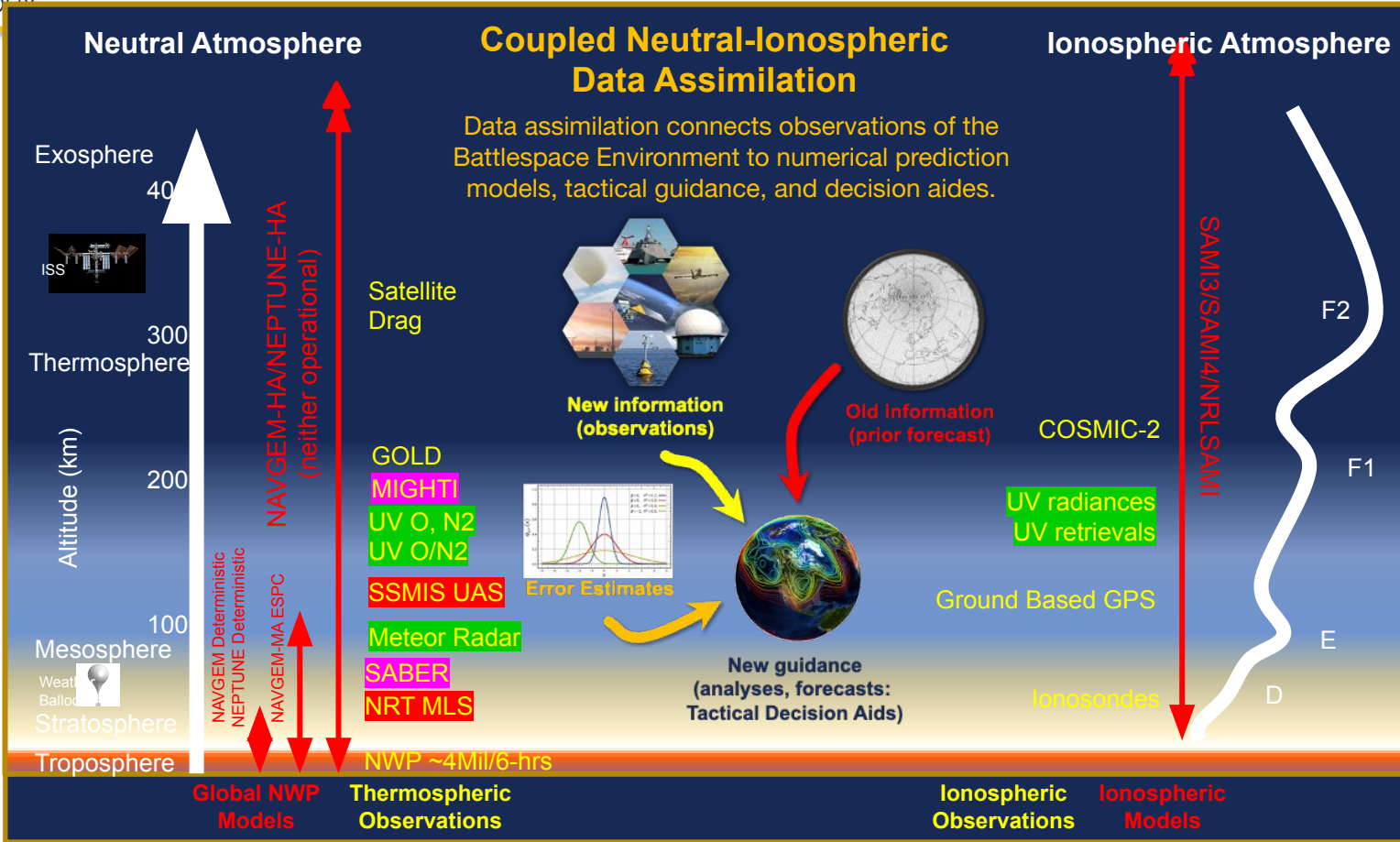
Improved operational analysis and forecasts
of ionosphere and thermosphere

Objective:

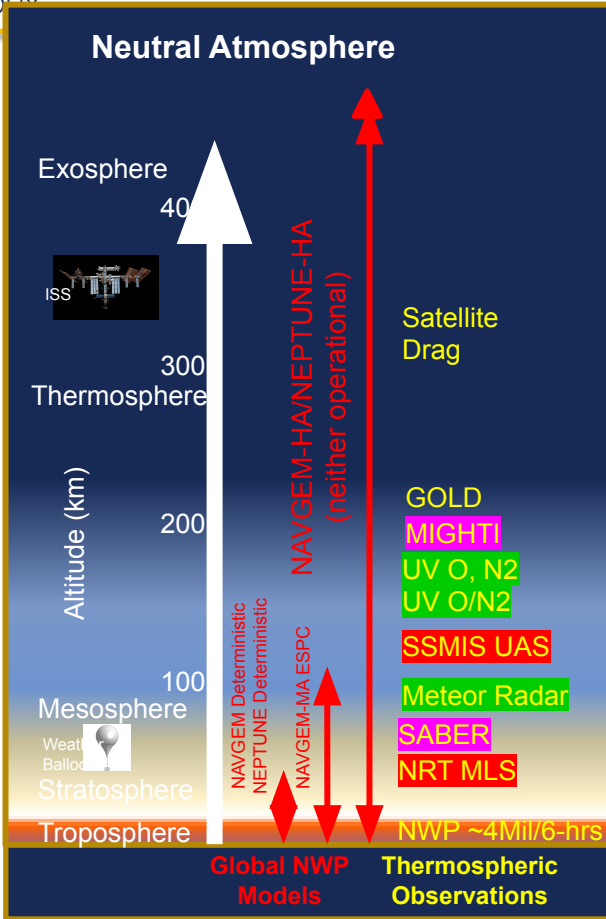
Fully coupled ionospheric-thermospheric
data assimilation system

Overview of Navy's Future Ionospheric/Thermospheric DA

Coupled Neutral-Ionospheric DA



NAVY Neutral Atmosphere Models/DA



Note: Model configuration differences between regular (low top), MA (Middle Atmosphere) and HA (High Altitude) are simply namelist flags, with same executable. System is designed that each vertical extension does not degrade forecast skill of the lower regions

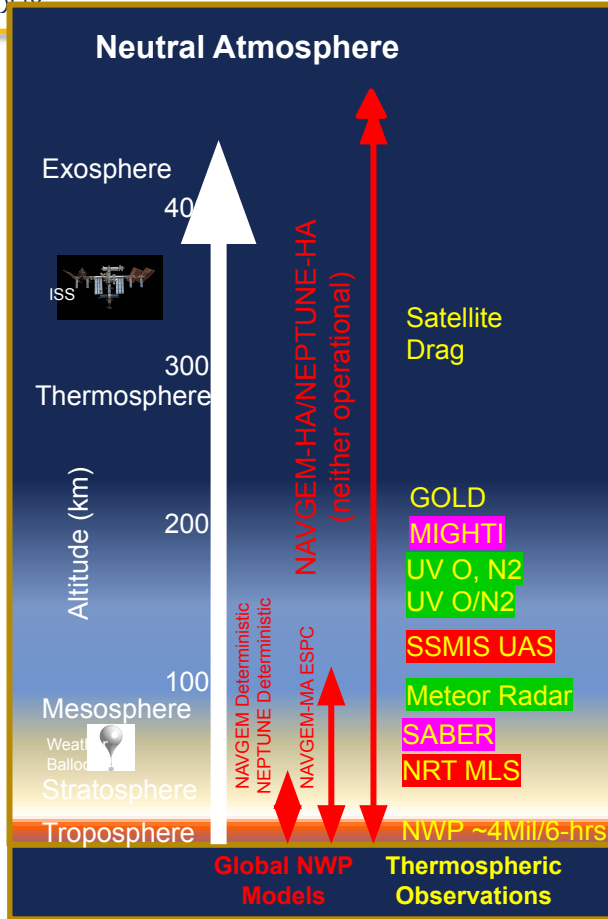
Current/Near future navy operational

- NAVGEM
 - Model 1: NAVGEM Deterministic (~65km top)
 - Model 2: NAVGEM-MA ESPC (~115km top)
 - DA: NAVDAS-AR (Hybrid 4D-Var)
- NEPTUNE
 - Model: NEPTUNE (~65km top)
 - DA: FALCON DA (4D-Var transition FY27)

Future:

- NEPTUNE-HA
 - Model: NEPTUNE-HA (~500km top)
 - DA: JEDI LETKF

NAVY Thermospheric Models/DA



1st Generation NAVGEM-HA LETKF

- Currently running in hindcast mode
- Built for DARPA SEE Project (concluded in 2023)
- Model: NAVGEM-HA
- DA: NAVDAS-AR reformulated to LETKF (NOT JEDI)
- Observations: NWP conventional and retrievals, NRT MLS, SABER, Meteor Radar, MIGHTI and GOLD

2nd Generation NEPTUNE-HA FALCON LETKF DA

- Currently being built for operations
- Model: NEPTUNE-HA
- DA: JEDI FALCON DA reformulated to LETKF (JEDI)
- Observations: NWP (trying for radiances as well), all mesospheric/thermospheric

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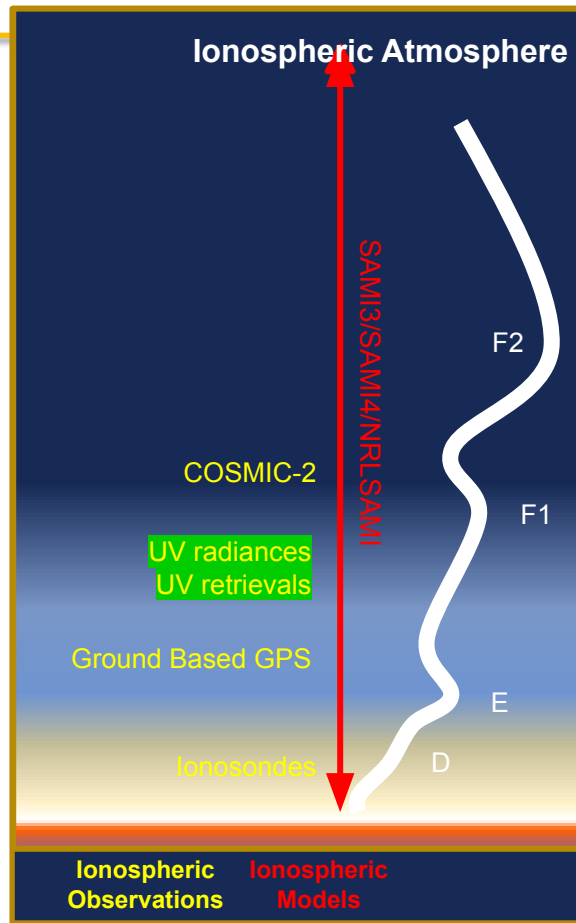
NAVY Ionospheric Atmosphere Models/DA

Current/Near future navy operational

- NIMO 1.1.3 (now)
 - Model: SAMI3
 - DA: IDA-4D DA system (3DVar with FGAT)
- NIMO 2.0 (FY26)
 - Model: SAMI4
 - DA: ANCHOR (Kalman Filter)

Future

- NIMO
 - Model: NRLSAMI
 - DA: JEDI-ETKF (possibly ANCHOR informed solver)

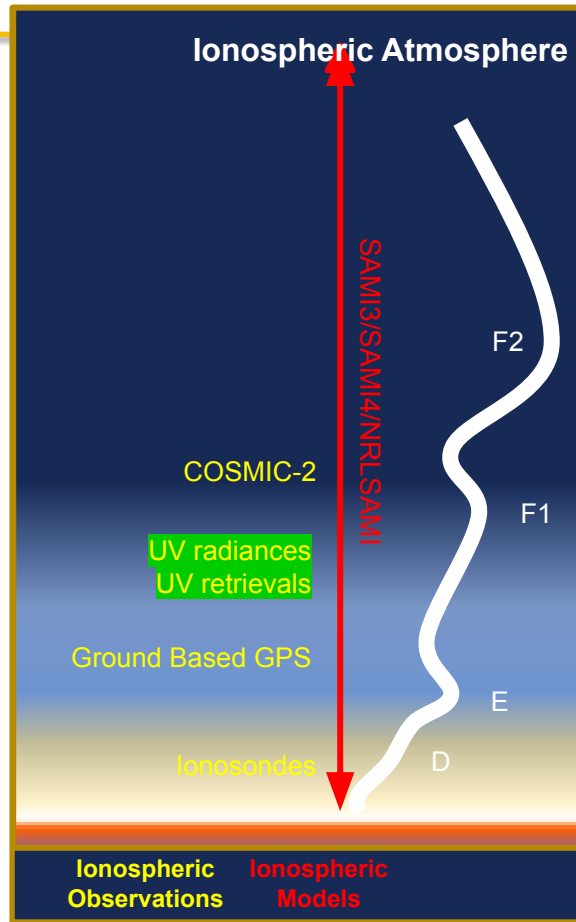


Overview of Navy's Future Ionospheric/Thermospheric DA

NAVY Ionospheric Atmosphere Models/DA

1st Generation JEDI-ETKF

- State Space: Ion Densities in Geomagnetic Coordinates plus driving parameters (such as F10.7)
- Observations: EDP and TEC
- ETKF: Ensemble global solve of state space



Overview of Navy's Future Ionospheric/Thermospheric DA

NAVY Ionospheric Atmosphere Models/DA

1st Generation JEDI-ETKF

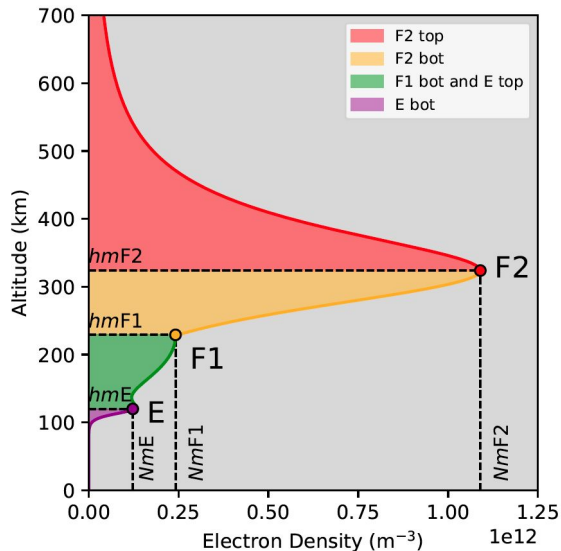
- State Space: Ion Densities in Geomagnetic Coordinates plus driving parameters (such as F10.7)
- Observations: EDP and TEC
- ETKF: Ensemble global solve of state space

2nd Generation JEDI-ANCHOR

- State Space: ANCHOR points and driving parameters
- Observations: ANCHOR points
- LETKF: Ensemble localized solve of state space

- V. Forsythe Presentation Thursday 2025 CSWMDAW (2025 Community Space Weather Modeling and Data Assimilation Workshop)
- V. Forsythe et. al "ANCHOR: Global Parametrized Ionospheric Data Assimilation," Space Weather, <https://doi.org/10.1029/2023SW003803>

ANCHOR Parameter Space (Victoriya Forsythe)



EDP Decomposed into 6 ANCHOR parameters:
 $hmF2$, $NmF2$, $hmF1$, $NmF1$, hmE , NmE

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NAVY Ionospheric Atmosphere Models/DA

1st Generation JEDI-ETKF

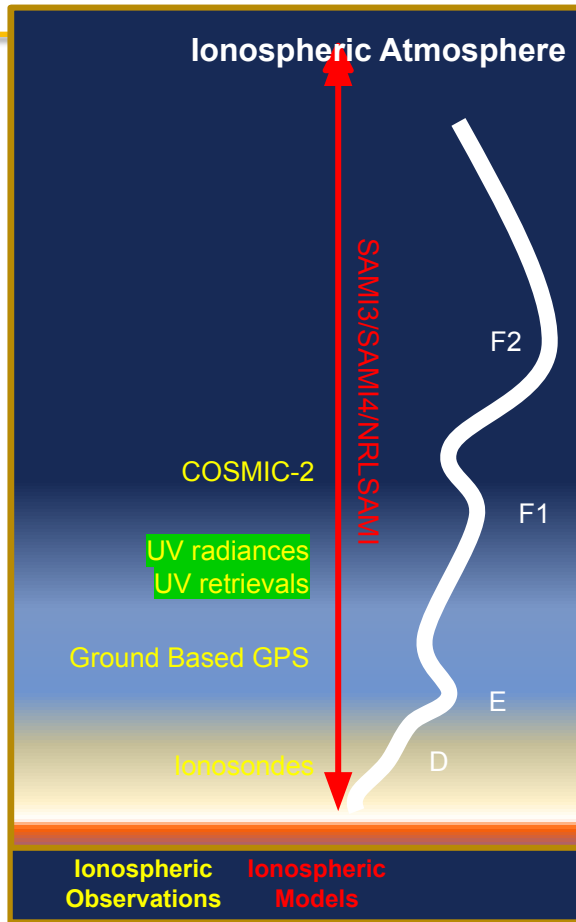
- State Space: Ion Densities in Geomagnetic Coordinates plus driving parameters (such as F10.7)
- Observations: EDP and TEC
- ETKF: Ensemble global solve of state space

2nd Generation JEDI-ANCHOR

- State Space: ANCHOR points and driving parameters
- Observations: ANCHOR points
- LETKF: Ensemble localized solve of state space

3rd Generation JEDI-Hybrid?

- State Space: Combination of Ion Densities ANCHOR points and driving parameters (?)
- Observations: Mixed TEC and ANCHOR points (?)
- (L)ETKF: Ensemble solve of state space?



❖ 1A) Implement JEDI thermospheric DA

- Raising the top of the FALCON DA system and turning it into LETKF assimilation
- Add in thermospheric observations. . .

❖ 2A) Implement JEDI thermospheric-coupled JEDI Ionospheric DA

- Add in Ionospheric observations

❖ 3) Implement JEDI Fully coupled thermosphere/ionosphere DA

- Couple the ensemble ionospheric and thermospheric DA systems together

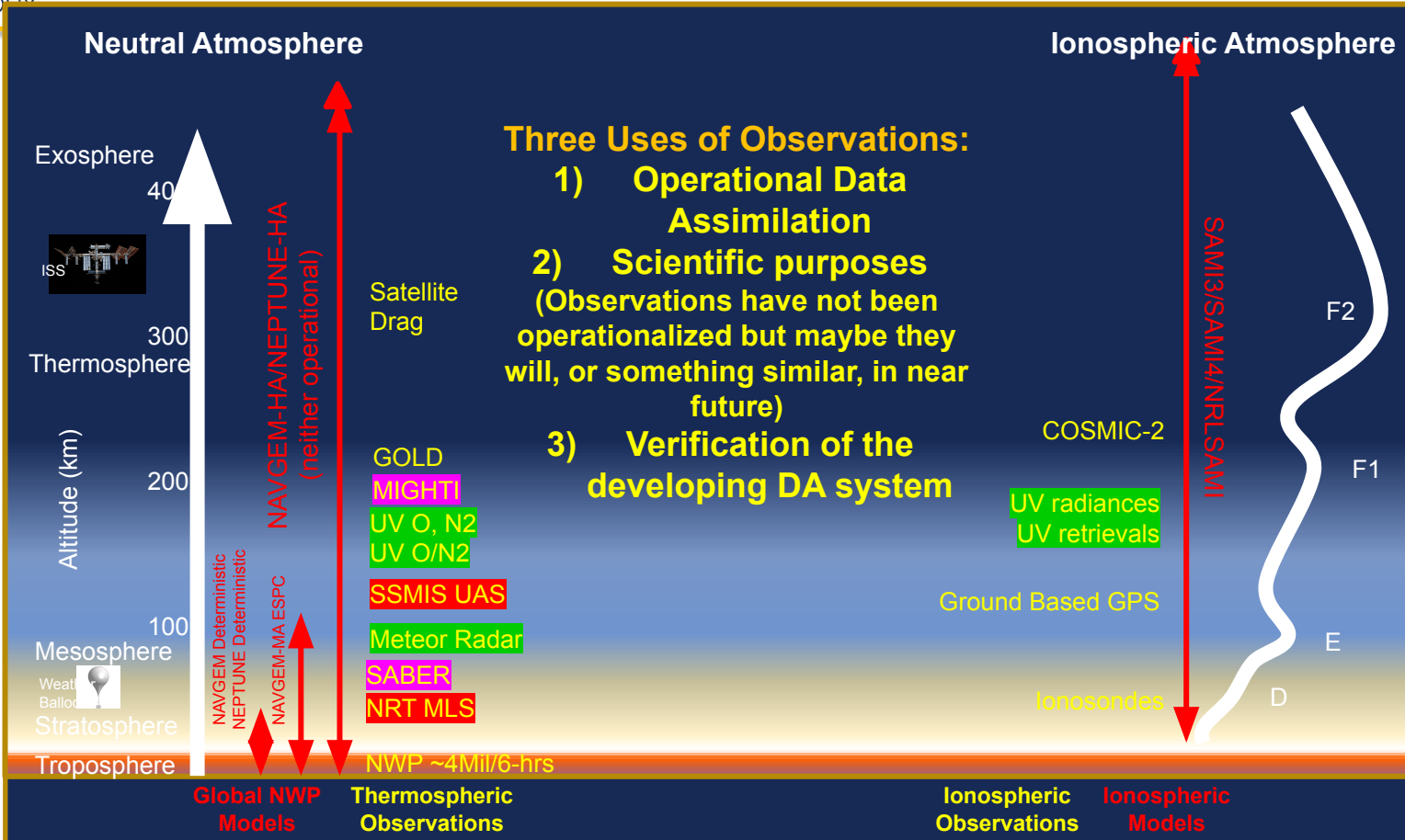
❖ 1B) Implement JEDI Ionospheric DA

- Test time windowing size
- Test ANCHOR point vs. other assimilations
- Add in ionospheric observations

❖ 2B) Implement JEDI ionospheric-coupled JEDI Thermospheric DA

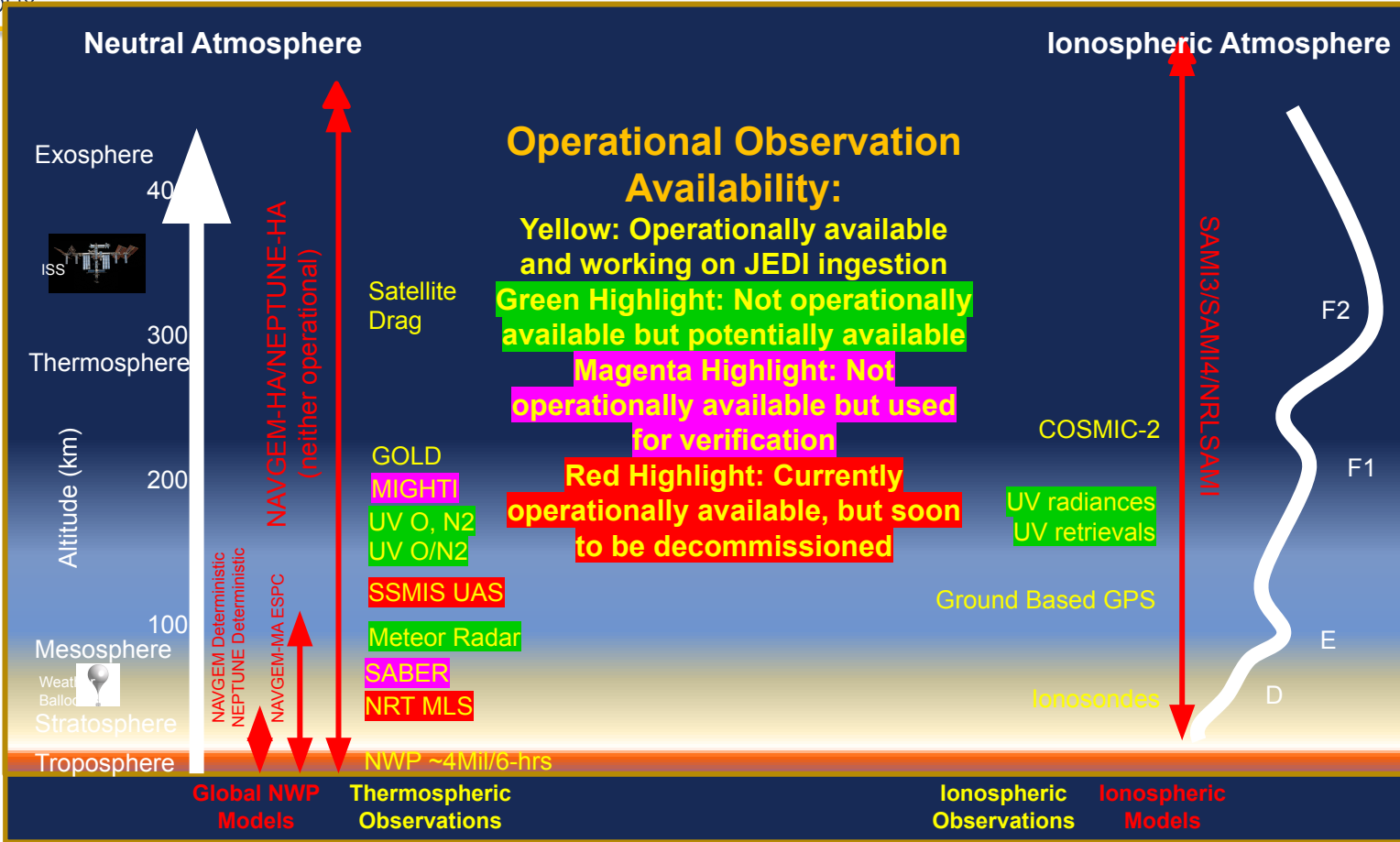
- Add in thermospheric observations

Neutral-Ionospheric DA: Observations



Overview of Navy's Future Ionospheric/Thermospheric DA

Neutral-Ionospheric DA: Observations



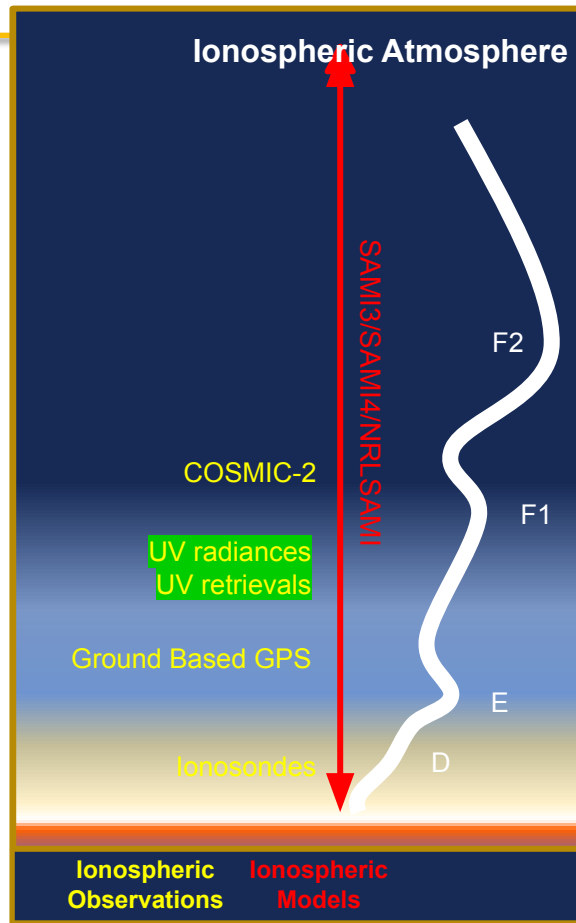
Ionospheric ETKF JEDI Modes

We Use JEDI in two modes:

1. Data assimilation Mode
2. Observation Verification Mode

Observation Verification mode

- Uses JEDI IODA observation read into IODA
- Uses JEDI Forward operators for model analysis/forecasts $H(x)$ into IODA
- ❖ Pass IODA files directly into MET software
- ❖ This way, as observations are added to the DA, verification is instantly available as well for those observations (with the same forward operators as DA)



JEDI ETKF

JEDI:

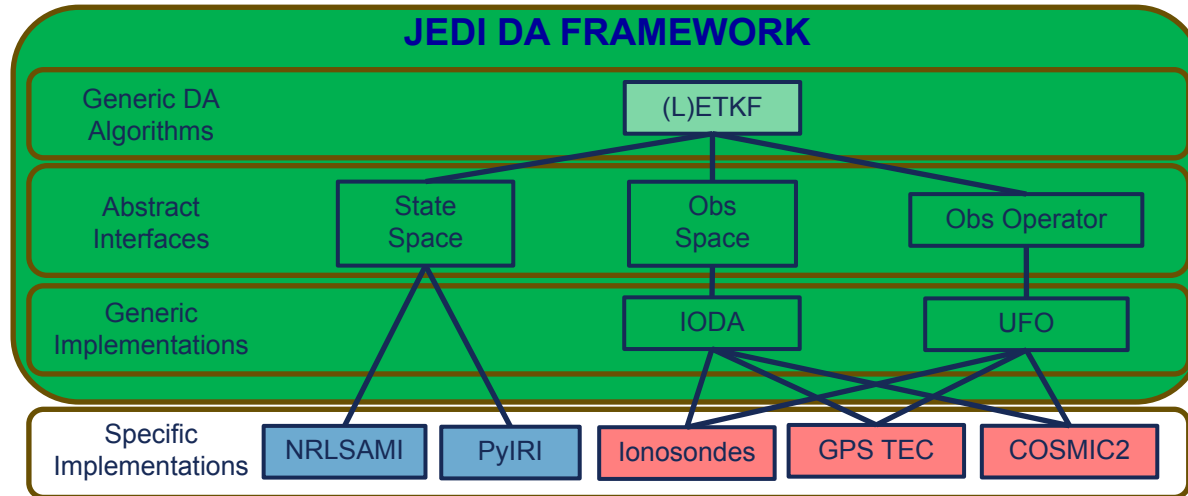
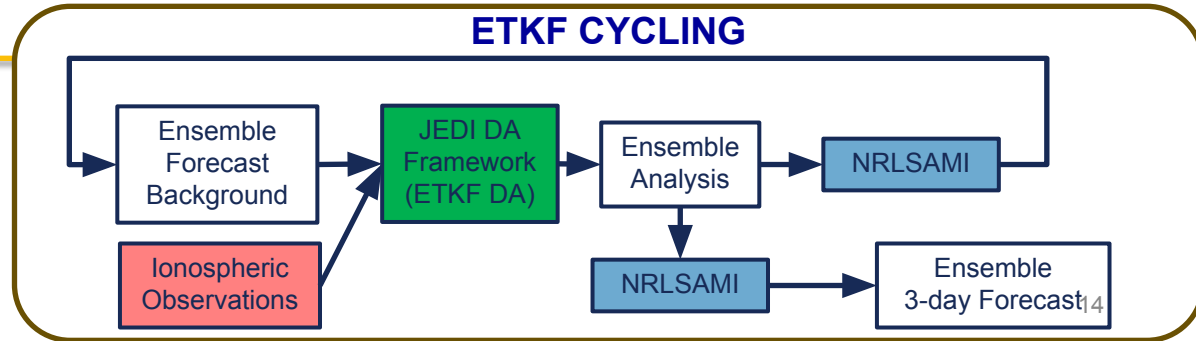
Joint effort for data assimilation integration

Partners: Models

- NOAA: FV3, MPAS and MOM6
- NASA: GEOS
- NAVY: NEPTUNE (FALCON), NRLSAMI
- UK-MET: UM
- AIR FORCE

Space Weather Moving to JEDI:

- NAVY: NRLSAMI/PyIRI
- SWPC: WAM-IPE and then FV3
- UCAR: WACCM-X
- UK Met:
- U Colorado:



IODA: Interface for Observation Data Access, UFO: Unified Forward Operator

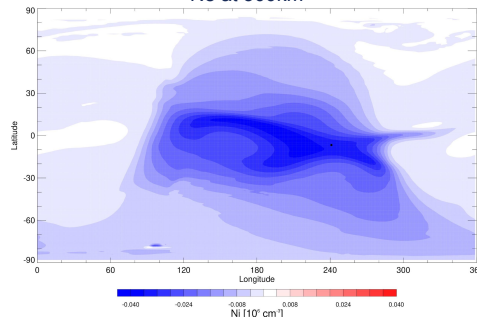
Blue: Models Red: Observations Green: Data Assimilation

Overview of Navy's Future Ionospheric/Thermospheric DA Ionospheric Multi-Observation Assimilation with Parameters Estimation

- Hodyss ETKF is a non-operational DA system written up in: Hodyss et. al 2023
- First "sanity" check of the JEDI ETKF code is to replicate the results of his system.
- Assimilated are 84 TEC observations (scattered over the globe) with the F10.7 value included in the state variable.

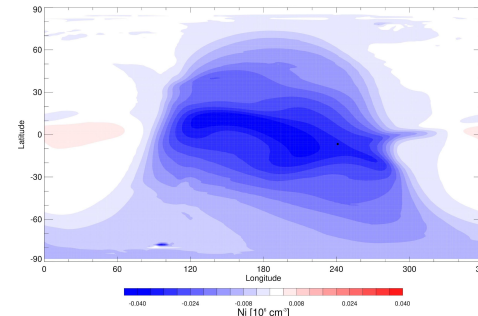
Hodyss ETKF

Ne at 300km

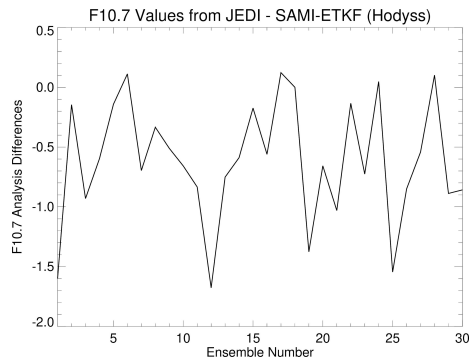


JEDI ETKF

Ne at 300km

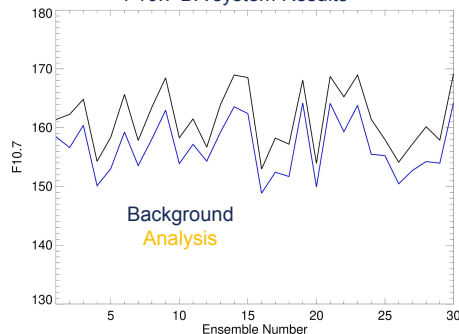


Difference F10.7 Values JEDI ETKF - Hodyss ETKF



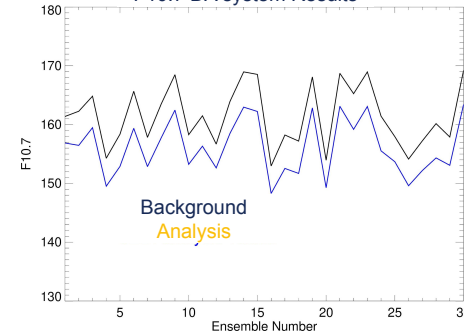
Hodyss ETKF

F10.7 DA system Results



JEDI ETKF

F10.7 DA system Results

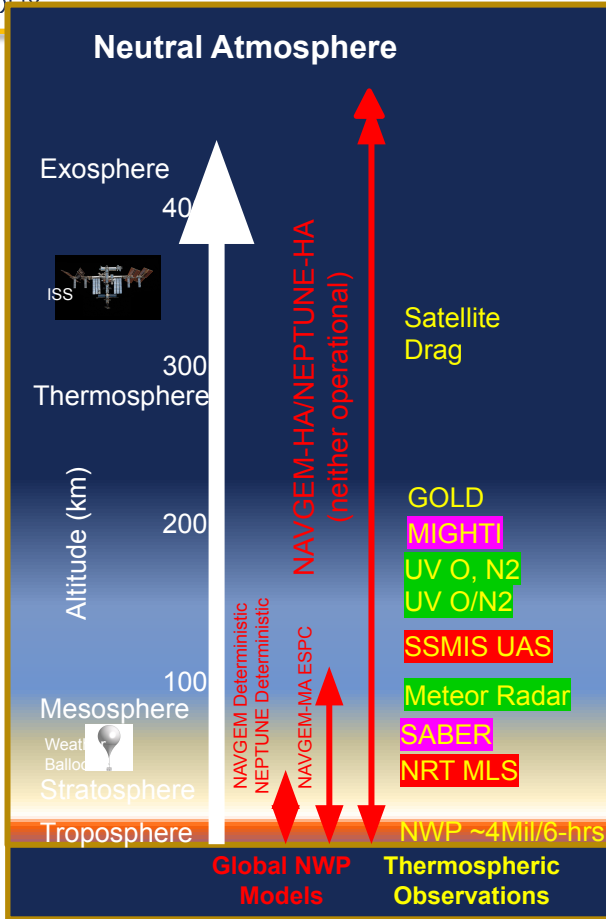


Ionospheric JEDI ETKF system

- The JEDI ETKF system is to be used to not only give an analysis state but it is also for creating an ensemble which accurately estimates the uncertainty of the model (SAMI) forecasts
- **Next Steps:**
 - Experimentation with real ionosonde assimilation
 - Add in COSMIC2 and Ground based GPS observations
 - Formulation of the system into ANCHOR state space solve
 - Bake off between ANCHOR state space and Ion Density state space solvers
 - Possibly design hybrid ANCHOR/Ion Density system
- **Future Work:**
 - JEDI (ATLAS?) compatibility with geomagnetic grid
 - Discussions ongoing with JEDI developers and ECMWF ATLAS group
 - Ionospheric LETKF working with geomagnetic grid

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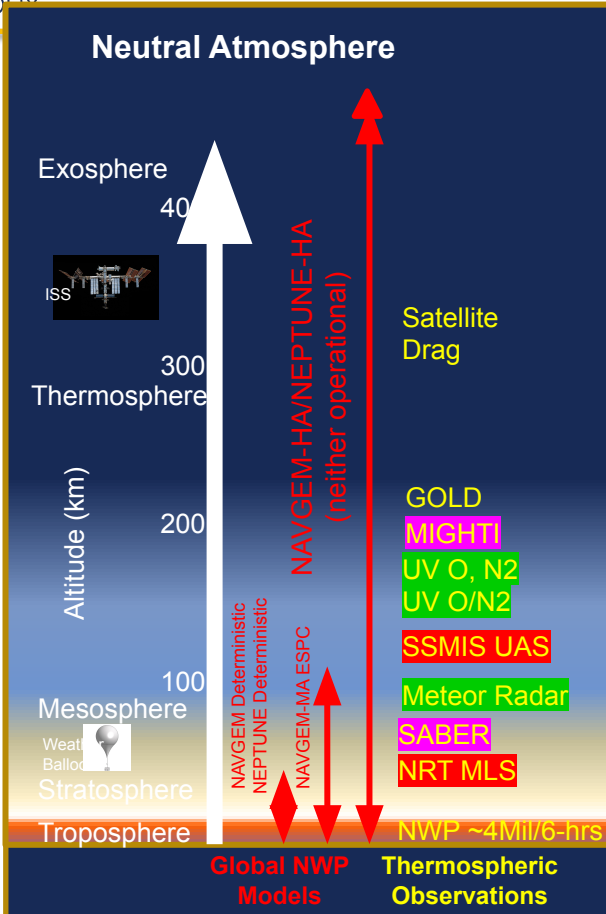
Navy Tropospheric to Thermospheric DA



- NEPTUNE FALCON DA has been in development since 2020 and it uses a JEDI 4D-Var solver (transition FY27)
 - They are assimilating all the current NWP operational observations ~4Mil/6-hours
- NEPTUNE-MA will be run with ESPC coupled system and will use a similar FALCON JEDI 4D-Var DA system (or Ens-4D-Var) when it transitions
 - It will run with all the current NWP operational observations plus Meteor Radar and SSMIS UAS (if it's still collecting data)
- NEPTUNE-HA will be using a JEDI LETKF solver
 - It also will run with all the current NWP operational observation plus Meteor Radar and SSMIS UAS (if it's still collecting data) and as many operational thermospheric observations as we can setup

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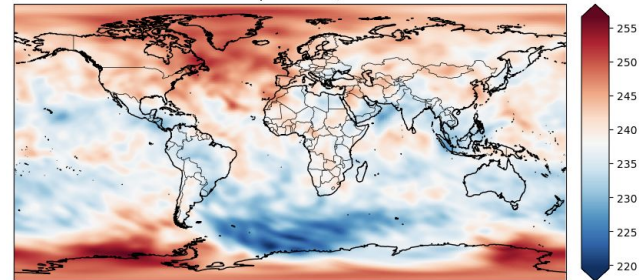
Thermospheric DA Status/Next Steps



• Status

- The NEPTUNE-HA model is running but not cycling with DA
- We have been testing the NEPTUNE FALCON DA system in LETKF mode
- We use our DARPA/SEPHIR NAVGEM-HA LETKF system to compare and validate results

**NEPTUNE FALCON LETKF assimilation
Temperature Analysis at 61km**



• Next Steps:

- Raise top to NEPTUNE-MA for NEPTUNE FALCON DA
- Stabilize and cycling in LETKF mode
- Raise the top to NEPTUNE-HA in LETKF mode and start filling in the HA observations



Thank you for your time and attention!