Recent Observation Assimilation Advancement for U.S. Navy's Numerical Weather Prediction Systems

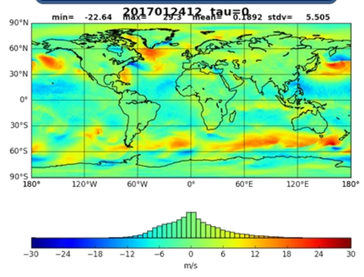
[1]H. Christophersen (hui.christophersen@nrlmry.navy.mil)

[1]N. L. Baker, [1]P. M. Pauley, [1]W. Campbell, [1]D. Tyndall, [1]S. Swadley, [1]E. Satterfield, [1]W. Crawford, [1]A. Zhao, [2]E. Simon

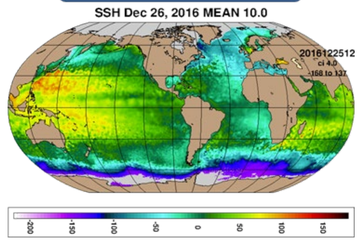
[1]Naval Research Laboratory, Monterey, CA [2]SAIC, Monterey, CA

U.S. Navy's NWP Models and Data Assimilation Capabilities

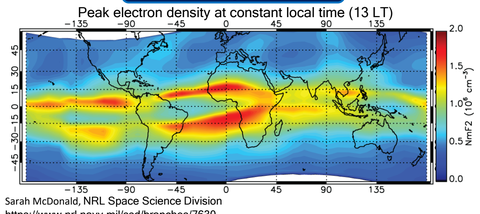
Atmosphere



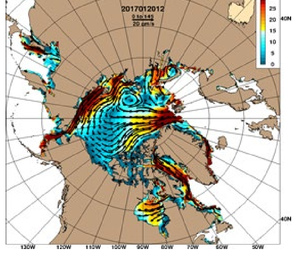
Ocean



Ionosphere



Sea Ice



The Naval Research Laboratory (NRL) develops, delivers and maintains operational environmental analysis, forecasting and satellite ground processing systems to Fleet Numerical Meteorology and Oceanography Center (FNMOC).

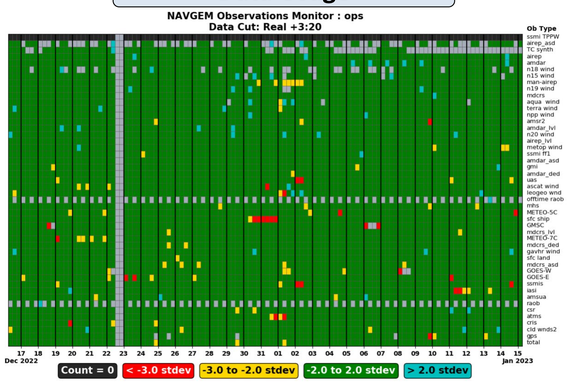
Global Atmospheric Data Assimilation: NAVDAS-AR (Hybrid 4DVar) for NAVGEM and NEPTUNE (in development)

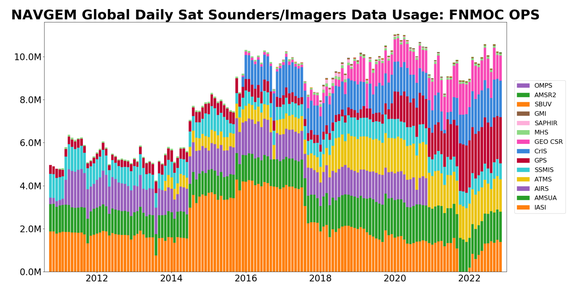
Regional Atmospheric Data Assimilation: 3DVar & 4DVar (research mode) for COAMPS ; EnKF for COAMPS-TC; Radar DA: hourly 3DVar; All-Sky DA EnKF

Navy ESPC Coupled Global Atmosphere /Ocean Data Assimilation

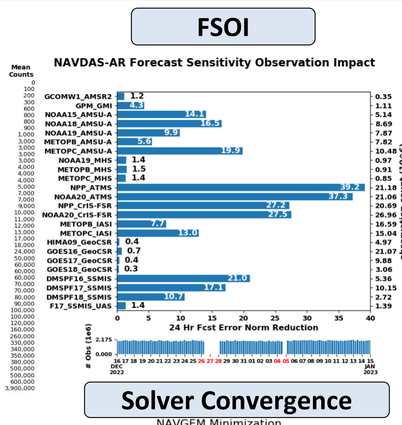
Aerosol Data Assimilation: 2DVar, 3DVar (research mode), EnKF

Data Usage

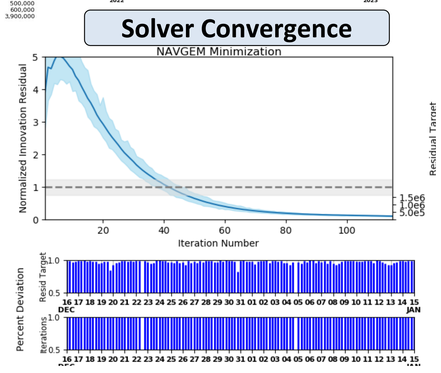




FSOI



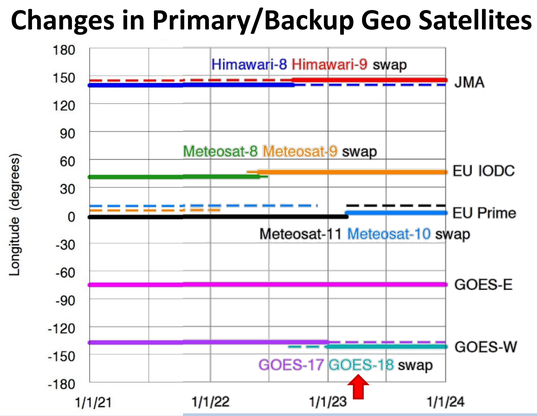
Solver Convergence



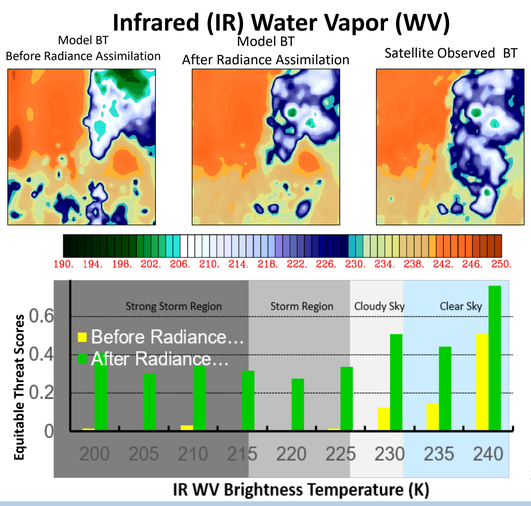
New Additions to the Data Assimilation Capabilities

- **Infrastructure**
  - Radiance and GNSS-RO preprocessing refactored
  - Radiosonde and surface observation quality control upgraded
- **Observations (from FY21 – present)**
  - **GPS-RO:** Commercial data from GeoOptics, Spire Global, NOAA Delivery Order 1-3), GNSS-RO data from GRACE-C and Sentinel-6A
  - **GNSS ground-based:** Zenith Total Delay (Christophersen et al. (2023))
  - **GeoCSR**: Himiwari-09, Meteosat-9 & 10, GOES 18
  - **Ozone:** OMPS V8
  - **MW** : N21 ATMS (In progress w/ Ka Band transmitter issues)
  - **IR radiances:** AIRS/Aqua
  - Revised the **correlated ob errors** for ATMS, CrIS, and IASI
  - IR water-vapor all-sky radiances: Zhao et al. (2021)
  - MODE-S aircraft: Blaylock et al. (2023)
  - **AMVs:** Operational use of Himawari-9, GOES-18, Meteosat-11, KOMPSAT-2A, MODISS SWIR winds
- **Diagnostics**
  - Fit-to-observation capability upgraded to use new observation API
  - New monitoring capabilities for GNSS-RO
  - METplus suite for verification

Changes in Primary/Backup Geo Satellites

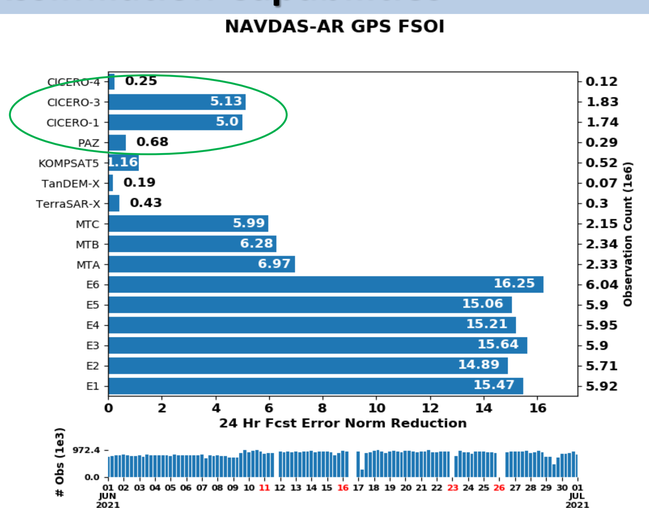


Infrared (IR) Water Vapor (WV)



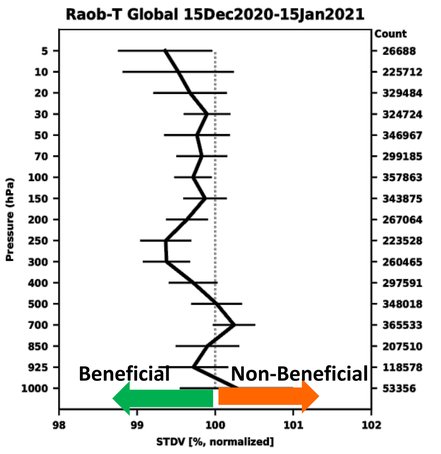
Zhao et al. (2021)

NAVDAS-AR GPS FSOI



The accumulated Forecast Sensitivity to Observation Impact (FSOI) for the GNSS-RO sensor assimilated operational by FNMOC from 01Jun – 01Jul, 2021. The counts are shown in the time series of bars at the bottom of the figure, note the jump which occurs at 09Jun2021 (12Z) where the NOAA commercial data program delivery order 2 (DO2) data was added. These are the "CICERO" receivers from GeoOptics

Raob-T Global 15Dec2020-15Jan2021



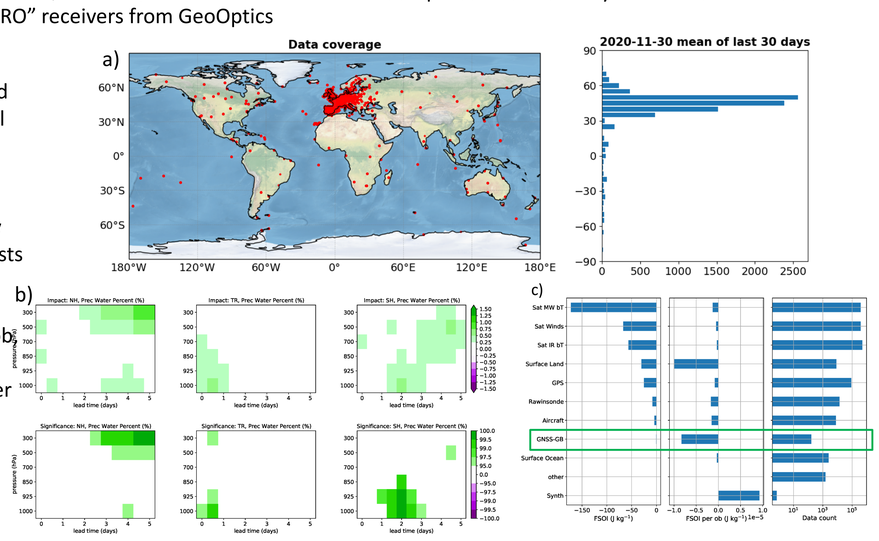
Impact of the NOAA commercial weather data purchase delivery order 1 (DO1) data on 1 month of radiosonde temperature statistics. Those values less than 100, show improvement in the fit to radiosonde using the commercial data. Statistical significance for the 95th percentile shown by the horizontal bars.

a) Spatial map of assimilated ground-based zenith total delay (ZTD) and its latitudinal count

b) The ground-based ZTD's impact on model five-day precipitable water forecasts as verified against the ECMWF analyses

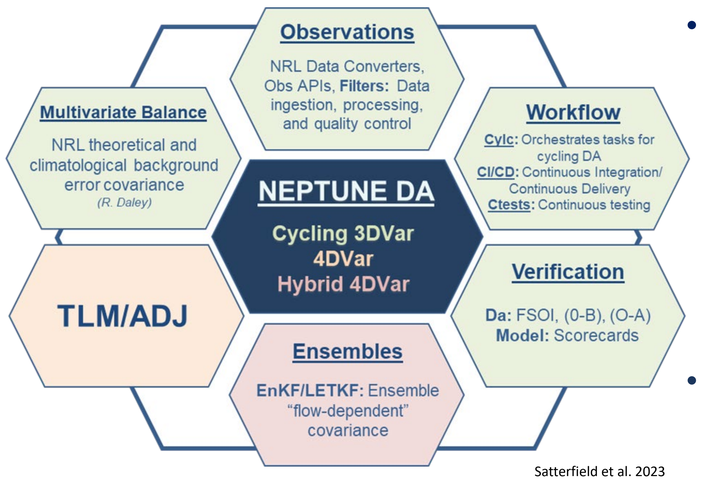
c) The total FSOI, FSOI per ob and its data count normalized by the number of cycles for Southern Hemisphere only.

Christophersen et al. (2023)



Upcoming Data Assimilation Capabilities

NEPTUNE DA: Next generation data assimilation capabilities utilizing JEDI infrastructure



Satterfield et al. 2023

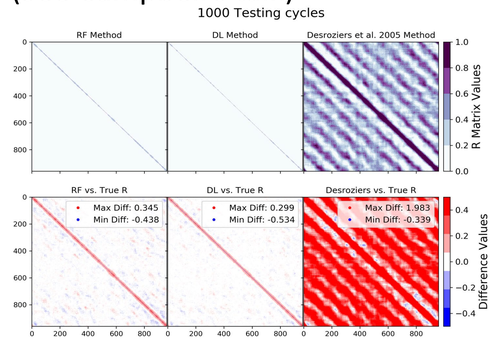
Objective: Develop a flexible and modular system for future NEPTUNE applications – coupled, ensembles, limited area, high altitude…

- **Build a flexible observation API to provide system portability**
  - This model agnostic preprocessor will feed into four models: COAMPS®, NAVGEM, NEPTUNE, Navy ESPC
  - Observation decoding, QC, thinning/super obs, etc.
  - Expected delivery by the end of FY24
- **Diagnostics**
  - Based on NAVGEM (https://www.nrlmry.navy.mil/metoc/ar_monitor/), JEDI Skylab, and METplus
  - Forecast verification and scorecards

Leveraging SmallSats in Navy's Global Model

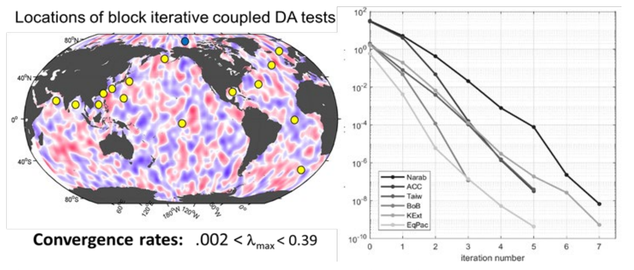
- COWVR and TEMPEST onboard ISS
- TROPICS pathfinder
- **Approach**: develop adaptive data sampling and error estimation

(See Campbell's talk)



Predicted R matrix of a random forest, deep learning model and Desroziers with inclusion of model error (Burke et al. 2021)

Towards Strongly Coupled DA in ESPC



(left) Locations of block iterative tests and (right) solution convergence.

- Developed method to conduct pointwise tests of the block iterative approximation (Yaremchuk et al. 2021) to strongly coupled Data Assimilation (DA).
- The strongly coupled DA increments were determined using the observation innovations in the real time run.
- Estimates of the fully coupled covariances were determined from the 16 ensemble members at the coincident time and localized in the vicinity of the observations.

References:

Blaylock B., Tyndall D.P., and Pauley P.M. (2023). Assimilating EMADDC MODE-S aircraft observations in the Navy's numerical weather models. . The 103rd AMS Annual Meeting, Denver, CO.

Burke, A., E. Satterfield, and A. McGovern,)2021). Approximating Observation Error Statistics Using Two Machine Learning. Joint Center for Satellite Data Assimilation (JCSDA) Quarterly. Number 69, Spring 2021, pages 12-17.

Christophersen, H., Ruston, B., & Baker, N. L. (2023). Assimilation of GNSS Zenith Total Delay in NAVGEM Journal of Geophysical Research : Atmospheres. *Journal of Geophysical Research: Atmospheres*, 1–17. https://doi.org/10.1029/2022JD037502

Satterfield, E.A. Sarah A. King, Nancy L. Baker, *et al*., (2023). An Update on the Navy's JEDI-enabled NEPTUNE Data Assimilation System. The 103rd AMS Annual Meeting, Denver, CO.

Yaremchuk, M., C. Beattie, and Frolov S. (2021). Block iterative correction in strongly coupled data assimilation. Quarterly Journal of the Royal Meteorological Society, 147, 2729-2740, doi: 10.1002/qj.4047.

Zhao, Q., N. L. Baker, Y. Jin, and R. G. Nystrom. (2021). Scale analysis of infrared water vapor brightness temperature for tropical cyclone all-sky radiance assimilation. Geophysical Research Letters, **48**, e2021GL095458. https://doi.org/10.1029/2021GL095458.