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IN THIS ISSUE

NEWS IN THIS QUARTER

NRL Science Highlights and Perspectives on the JCSDA

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The Joint Center for Satellite Data Assimilation (JCSDA) was established by NASA and NOAA in July 2001, and the Department of the Navy and the Department of the Air Force were subsequently added as full partners by 2002. I was the technical liaison for the Navy from 2002–2014, and I am now part of the Executive Team as the Associate Director for the Navy. Although the JCSDA has evolved considerably since its inception nearly two decades ago, its core mission, *"To accelerate and improve the quantitative use of research and operational satellite data in weather, ocean, climate, and environmental analysis and prediction systems"* has not changed. In this article, we highlight Navy science, research, and development that project onto and benefit from this core JCSDA mission.

During its formative years, the JCSDA established an ongoing series of meetings to share our satellite data assimilation science development and results. These include the annual JCSDA sessions at the American Meteorological Society (AMS), the Annual Science Workshops, the Workshop on the Assimilation of Satellite Cloud and Precipitation Observations in NWP Models, and the Summer Colloquium on Data Assimilation. These meetings help to foster intra- and inter-agency collaborations, and the summer colloquiums provide opportunities to engage with graduate students and scientists who are new to the community.

However, truly collaborative work was often elusive, in part due to the different agencies' software differences, and this made it challenging to define and gain full benefit of "in-kind" contributions. Today, the Joint Effort for Data assimilation Integration (JEDI) seeks to unify the underlying data assimilation infrastructure, and this should facilitate collaborations in the future. More recently, the JCSDA has clarified how it operates as an interagency coordination mechanism. Collaborative R&D goals are defined in advance through the

Annual Operational Plan (AOP) and coordination and accountability supported by Executive Team and project leads.

While there is currently significant focus on the development of software and DA infrastructure (e.g., CRTM and JEDI), my hope is that we do not lose sight of the underlying science, and that the JCSDA remains an interagency forum to encourage and support the scientific exchange of information, *"To accelerate and improve the quantitative use of research and operational satellite data in weather, ocean, climate, and environmental analysis and prediction systems."* In that spirit, we highlight a number of specific satellite and data assimilation related efforts at NRL in the following sections.

NRL COSMIC-2 Implementation

After developing the assimilation capability for COSMIC-2, NRL delivered it to the Fleet Numerical Meteorology and Oceanography Center (FNMOC), and operational assimilation began on 18 December 2019. The COSMIC-2 observations for this early adoption follow the same assimilation procedures as the other currently assimilated GNSS-RO missions: GRAS from the MetOp series (-A, -B and -C), Terra SAR-X and TanDEM-X, KOMPSAT-5, and PAZ ROHPP. These are all assimilated using a one-dimensional (1D) bending angle operator from the Radio Occultation Processing Package (ROPP), developed under the EUMETSAT ROM-SAF (Burrows et al., 2014; Culverwell et al., 2015). Although there have been recent efforts to better define the error characteristics between the different receivers (as the receivers view different transmitters), currently all the assimilated GNSS-RO data use the same observation error model. This includes a maximum percentage of uncertainty of 25% at the equator, which is then damped away from the equator by the cosine of latitude, resulting in a value of 16.5% at the Poles. The uncertainty percentage also decreases linearly with impact height to 1.5% at a "minimum error height;" this again varies with the cosine of latitude from 12 km at the equator to 5333.33 km at the Poles. The global innovation statistics for the COSMIC-2 receivers have been very consistent with the other assimilated GNSS-RO data, as shown in ***Figure 1***. The global statistics for the bending angle observation (O) minus simulated from background (B)

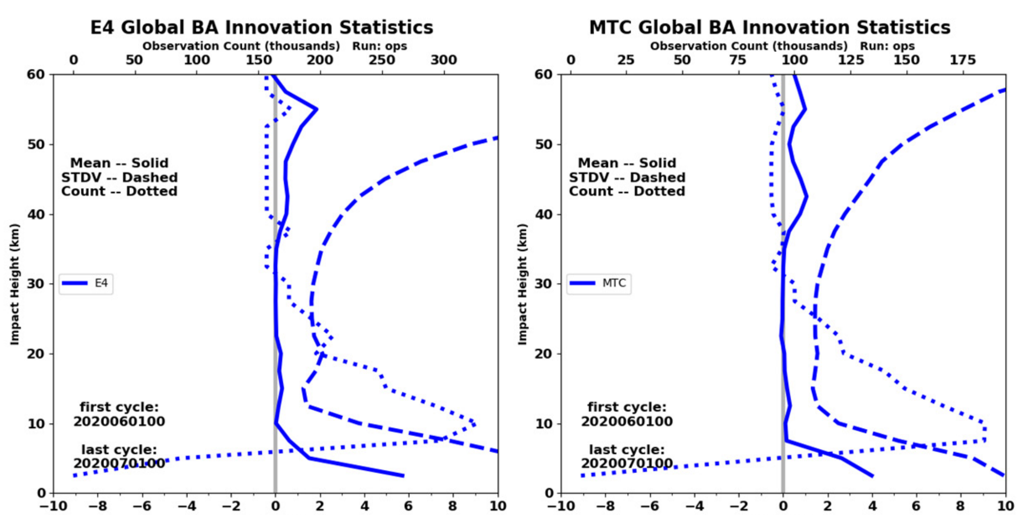

Figure 1. *The global statistics for the bending angle observation (O) minus simulated from background (B) normalized by background for the month of June 2020. Shown as a function of impact height are the mean O-B (solid), standard deviation (dashed) and the count (dotted) for COSMIC-2 E4 (left) and GRAS from MetOp-C (right).*

are then normalized by the background for the month of June 2020. In ***Figure 1***, the vertical axis of impact height and the three curves correspond to the mean O-B (solid), standard deviation (dashed) and the count (dotted) for COSMIC-2 E4 (left) and GRAS from MetOp-C (right). These plots highlight two characteristic and expected features in the standard deviation of the COSMIC-2 data that are due to the limited tropical latitude sampling of the COSMIC-2 mission. These features are the higher values near the surface and the slight increase at approximately 20 km, which for COSMIC-2 is just above the tropical tropopause. Both values correspond to the decreased fit of the forecast model to the GNSS-RO observation for the tropics.

The COSMIC-2 sensor observations have provided a nice addition to the global observing suite, with much-needed coverage from GNSS-RO observations in the tropical latitudes. This can be readily seen graphically in ***Figure 2***, which shows a zonal distribution of GNSS-RO occultation points in 5° latitude bins and 2.5 km vertical bins of impact height. The distribution from the COSMIC-2 E4 receiver is shown in the left panel, while the zonal distribution from GRAS onboard MetOp-C is shown in the right panel; both are for the month of June 2020. Note the change in the scales of the color bar, but the gap in coverage from the other program of record GRAS receiver is nicely covered by the COSMIC-2 mission.

Lastly, the addition of the COSMIC-2 data showed an immediate impact on the 24-hour error norm as determined by the Forecast Sensitivity to Observation Impact (FSOI) metric (Langland and Baker, 2004). The sensitivity of the observation to the 24-hour and 30-hour error norms can be traced backward using the adjoint of the data assimilation system to show the final FSOI value. The FSOI for the GNSS-RO sensors for the month of June 2020 is shown in ***Figure 3***, and the COSMIC-2 receivers are nearly the highest performer in both total accumulated impact and per observation. Since the incorporation of the COSMIC-2 data into the FNMOC operational suite, these data have shown consistent high performance per observation, and we plan to continue to explore ways to optimize their use in the data assimilation methodology. Also note, that the figures shown here are all publicly available through our monitoring page (https://www.nrlmry.navy.mil/metoc/ar_monitor/).

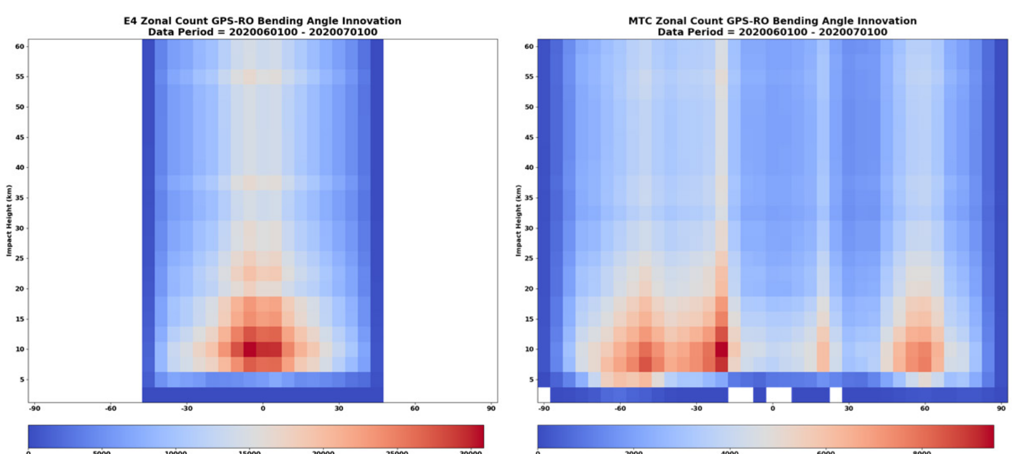

Figure 2. *The zonal distribution of GNSS-RO occultation points in 5° latitude bins and 2.5 km vertical impact height bins for COSMIC-2 E4 (left panel) and for GRAS from MetOp-C (right panel) for the month of June 2020.*

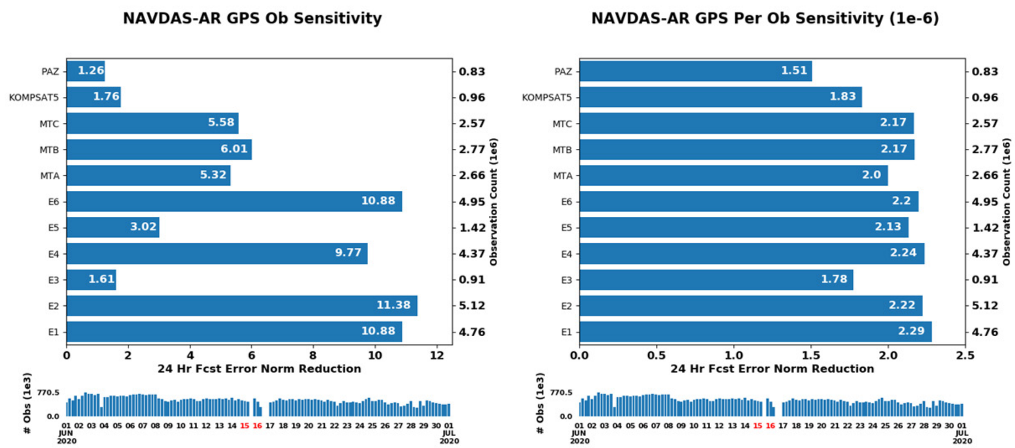

Figure 3. *The forecast sensitivity to observation impact (FSOI) for the GNSS-RO sensors for the month of June 2020 showing both the total accumulated impact (left) and per observation (right).*

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Revisions to Metop-B SST Processing Algorithms

The 27 May 2020 failure of the High-Resolution Infrared Radiation Sounder (HIRS) on Metop-B interrupted the feed of global Metop-B sea surface temperature (SST) from U.S. Naval Oceanographic Office (NAVOCEANO) to Navy operational models and the Group for High Resolution Sea Surface Temperature (GHRSST) community. Efforts to restore functionality of Metop-B HIRS have thus far been unsuccessful. An anomaly review board among EUMETSAT/NASA/manufacturing partners identified potential factors that might have led to the failure and noted that the HIRS aboard Metop-A, while presently functional, faced similar risks.

Fortunately, NRL had been developing a new SST algorithm for Metop-C, a next-generation Metop that omits the HIRS instrument and relies solely on the AVHRR/3 instrument common to all Metop satellites in this series. NRL quickly extended application of its new software to the other Metop platforms, enabling NAVOCEANO to restore the operational SST feed from Metop-B on 17 June 2020.

The NAVOCEANO Metop-A, -B, and -C retrievals are provided in real time to the global community in the GHRSST L2P format through the Physical Oceanography Distributed Active Archive Center (PODAAC) at https://podaac.jpl.nasa.gov/GHRSST.

GHRSST-affiliated centers requesting restoration of the NAVOCEANO Metop-B SST data feed included the Australian Bureau of Meteorology, the Canadian Centre for Meteorological and Environmental Prediction, and the U.S. National Ocean and Atmospheric Administration National Center for Environmental Information (NOAA NCEI). The SST data also directly support U.S. Navy applications including assimilative atmospheric and ocean model products generated by Fleet Numerical Meteorology and Oceanography Center (FNMOC). NAVOCEANO has confirmed in a series of operational acceptance tests the performance of the new retrieval software for the Metop series satellites, switching to or introducing the new software for the real-time data releases on 17 June for Metop-B, 24 June for Metop-C, and 6 July for Metop-A. The new data feeds are in place to the PODAAC in the latest GHRSTT L2-P format with additional details in the documentation available on that site.

The new algorithm increases the number and accuracy of retrievals from the Metop satellites relative to retrievals from the prior software version. Metop-C provided the primary motivation for developing new SST software code that eliminates dependencies on HIRS, because Metop-C does not include HIRS in its instrument package. In addition, new methodologies to more precisely distinguish reliable retrievals in regions of oceanic SST variability from those affected significantly by clouds or aerosols enable the new software to increase the number of SST retrievals while reducing the RMS error relative to independent measurements of SST from drifting buoys.

Plots associated with matchups between SST retrievals and coincident buoy SST observations are shown in ***Figure 4***. Each pair of satellite and buoy SST measurements coincides in location and time within 10 km and 1 hour. The real-time statistics prepared by NAVOCEANO are shown since the start of 2020. Note the anomaly in 30-day count of Metop-B matchups in the time between failure of the HIRS sensor and introduction of the new retrieval software. The number of matchups increases and RMS errors decrease for Metop-A and Metop-B following introduction of the new SST software. Each satellite typically provides similar numbers of daytime and nighttime retrievals each day, typically between 9 and 10 million of each type. The lower number of matchups associated with Metop-C relative to Metop-A and -B is a consequence of relatively lower

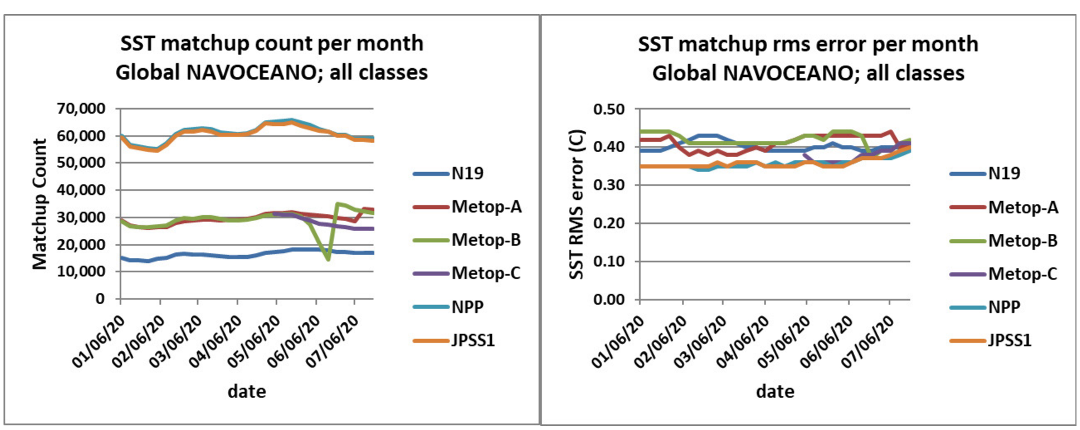

Figure 4. *Count of average number of matchups (left) and average root-mean square error of these matchups (right) over the prior 30 days between satellite SST observations and independent in-situ measurements from moored or drifting buoys.*

numbers of daytime retrievals generated using Metop-C; this discrepancy is unexpected and under review.

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JEDI Integration with NEPTUNE

The Navy Environmental Prediction sysTem Using the NUMA corE (NEPTUNE) is the upcoming atmospheric model under development at Naval Research Laboratory (NRL). The dynamical core is based on the Nonhydrostatic Unified Model of the Atmosphere (NUMA) (Giraldo, 2013). It uses three-dimensional spectral elements on a cubed-sphere grid. The development pace of the NEPTUNE is accelerating, and in the next year will see the creation of a linearized model and ensemble, as well as physics suite selection.

An interface between NEPTUNE and JEDI is under development at NRL. Currently, this interface enables the use of the JEDI 3D-Var with the BUMP (Background error on Unstructured Mesh Package) univariate covariance for data assimilation with radiosonde and satellite observations. ***Figure 5*** represents the difference between a 24-hour NEPTUNE forecast (starting from 3/14/2018 18Z) and a cycled 6-hour forecast produced using 3D-Var with a 6-hour update cycle assimilating radiosonde air temperatures. Both forecasts are valid at 3/15/2018 18Z. The effective model resolution was approximately one degree, and the BUMP covariance length scales were prescribed.

Most of the current development with the NEPTUNE-JEDI interface involves incorporating more observation types and cycling 3D-Var. As additional IODA-converters for the NRL preprocessed data

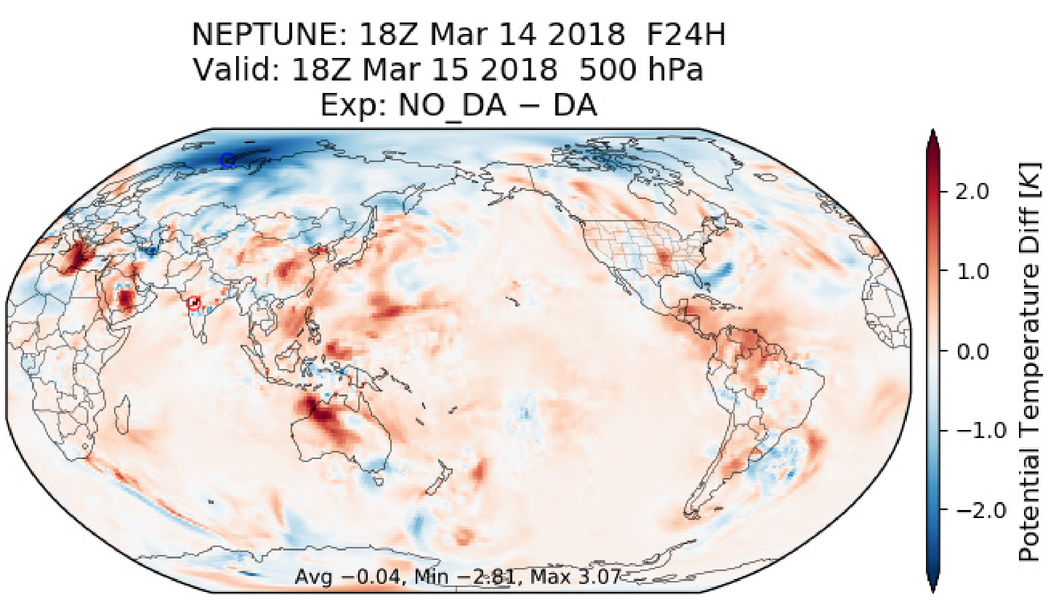

Figure 5. *Difference between 24-hour NEPTUNE forecast valid at 3/15/2018 18Z with no data assimilation and the 6-hour forecast valid at 3/15/2018 18Z produced from the 3D-Var analysis after 6-hour update cycling.*

stream become available, these observation types are added to the NEPTUNE-JEDI interface. At NRL, we are use the Cylc workflow engine (Oliver et al., 2018) to manage and run the complex suites of inter-dependent jobs that characterize cycling data assimilation. A Cylc suite has been developed to manage the workflow for cycling the NEPTUNE-JEDI data assimilation. NEPTUNE currently does not have an ensemble component, which limits the use of BUMP for a multivariate covariance for cycling DA. The NRL static B (Daley, 1991; Daley and Barker, 2001) is being refactored to work within JEDI to provide a multivariate background error covariance for the cycling 3D-Var.

As the NEPTUNE matures, additional features will be added to the NEPTUNE-JEDI interface. In the upcoming year, the tangent linear and adjoint models will be sufficiently developed to be incorporated within the NEPTUNE-JEDI interface, and this will enable cycling 4D-Var with the NRL multivariate background error covariance. The recent NEPTUNE model refactoring efforts will be a key enabler for EDA and other ensemble techniques, and development for the ensemble components of the NEPTUNE-JEDI interface will begin in early FY21.

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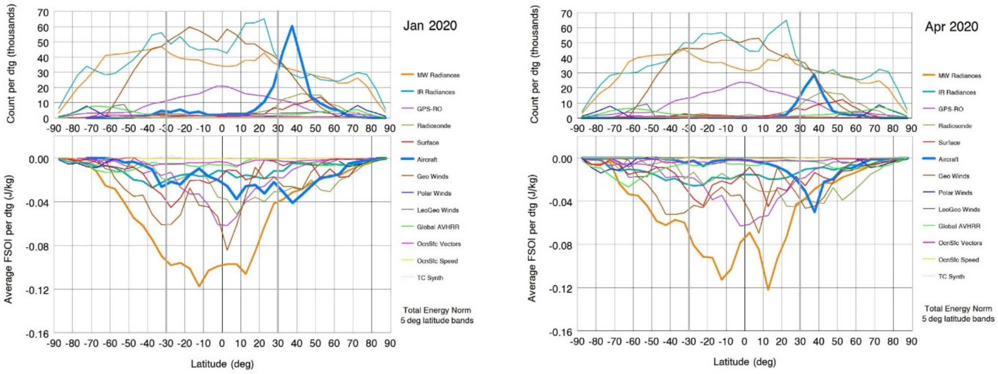
Impact of COVID-19-related Decreases in Aircraft Data

As countries closed their borders to mitigate the spread of COVID-19, some airlines canceled flights while others stopped flying altogether. A loss of aircraft-based observations resulted from the decrease in flights, with the greatest decrease in observations occurring in the latter half of March. The average number of aircraft observations per day used in NAVGEM was 1.031 million for January 2020, before the COVID-19 decrease, and 0.371 million for April 2020, after the bulk of the COVID-19 decrease. ***Figure 6*** shows both the decrease in counts as a function of 5° latitude band and the reduction in Forecast Sensitivity Observation Impact (FSOI; Langland and Baker, 2004). Note that negative values for FSOI indicate that the observations are reducing the error in 24-hour forecasts and so having a beneficial impact. This figure shows that the most dramatic change in FSOI does not occur in the northern mid-latitudes

Figure 6. Counts (top) and FSOI (bottom) for January 2020 (left) and April 2020 (right) as a function of instrument type and 5° latitude band. Aircraft data are indicated by the thick blue line.



where the peak counts are present, but rather in the tropics and southern hemisphere where a relatively small number of observations were having a large impact. The relatively few radiosonde and surface observations also have an outsized impact for their numbers in the tropics and southern hemisphere. Even so, radiosonde and surface observations and geostationary satellite winds have enhanced FSOI in the northern mid-latitudes in April 2020, compensating at least to some extent for the reduction in aircraft observations.

To at least partially counter the COVID-19-related decrease in aircraft observations, FLYHT Aerospace Solutions Ltd. made their Automated Flight Information Reporting System (AFIRS) AMDAR and TAMDAR data available to meteorological agencies during the COVID-19 crisis. NRL and FNMOC scientists worked together to implement the AFIRS AMDAR data in the operational NAVGEM system in less than ten days after first receipt of the data. While the AFIRS AMDAR data only provide roughly 10,000 observations per day, some of these are in relative data sparse regions (such as the Arabian Peninsula, Papua New Guinea, and western Canada) and so provide significant beneficial impact.

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All-Sky IR Radiance Assimilation for TC Prediction

An all-sky radiance assimilation system has been developed at the Naval Research Laboratory (NRL) Marine Meteorology Division to add new data assimilation (DA) capabilities for the US Navy's COAMPS-TC to improve tropical cyclone (TC) prediction. Through collaboration with scientists at Penn State University (PSU), the advanced all-sky radiance assimilation techniques developed at PSU were adapted and integrated into the NRL Ensemble Kalman Filter (EnKF). Several additional new cloud and TC data assimilation techniques have been developed recently at NRL to further advance NRL all-sky DA capabilities.

Several challenging TC storms were selected to study the impact of the new DA system and all-sky radiance assimilation for COAMPS-TC track and intensity forecasts. Results from our recent experiments show that all-sky radiance assimilation has substantially improved TC intensity and track forecasts, in addition to better capturing the trend for storm development. ***Figure 7*** gives the forecasts of minimum sea level pressure (SLP) and maximum surface wind speed for Hurricane Patricia (2015) from experiments without (Control Run) and with (All-Sky DA) radiance assimilation. The impact of all-sky radiance assimilation on TC rapid intensification (RI) looks promising. The results also suggest that All-Sky DA has improved the dynamical and physical structures of the TC inner core and made them more consistent with the large-scale environment during the storm development. Analysis for the Patricia case indicated that the radius of the initial vortex is reduced from ~24 km in the Control Run to ~7 km with All-Sky DA. The smaller eye makes for a better comparison with the tight inner core observed. A much deeper layer of convection is present in the thin eyewall in the All-Sky DA experiment and this well-organized convective activity within the eyewall persists over the 72-h forecast. The impact from assimilating the all-sky radiance is being assessed for thermodynamic processes to improve understanding the RI.

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Analysis Correction-based Additive Inflation (ACAI)

Following the works of Piccolo and Cullen (2016) and Bowler et al., (2017), we have begun exploring the use of analysis corrections drawn from our atmospheric hybrid 4D-Var data assimilation system (NAVDAS-AR; Kuhl et al., 2013; Rosmond and Xu, 2006; Xu et al., 2005) as a representation of model error in our ensemble and deterministic forecasting systems using the Navy Global Environmental Model (NAVGEM; Hogan et al., 2014). We refer to this method as Analysis Correction-based Additive Inflation (ACAI, Crawford et al., 2020). The

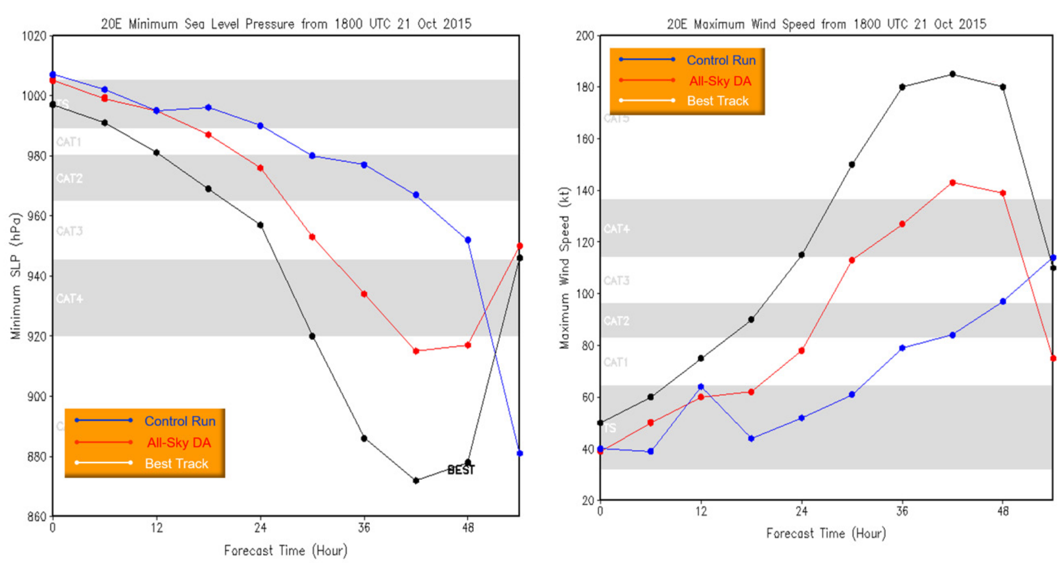

Figure 7. *Minimum sea level pressure (1a, hPa) and maximum surface wind speed (1b, kt) forecasts from experiments without (Control Run) and with all-sky radiance assimilation (All-Sky DA) compared with NHC Best Track data for Hurricane Patricia in 2015. The forecast start time is 1800 UTC 21 October 2015.*

analysis corrections are used to produce perturbations that are added as tendencies to the model solution at each time step of the integration. In the ensemble-based system, the ACAI perturbations are comprised of a mean analysis correction and a random sample drawn from an archive of analysis corrections. The mean analysis correction is a 3-month, seasonal average of analysis corrections centered on the month of the forecast and is aimed at correcting model bias. The randomly-sampled analysis correction is intended to be an added source of stochastic perturbation during the forecast. For each ensemble member, a random sample is drawn from the same 3-month time period used to compute the seasonal average. In the deterministic system, only the seasonal average analysis correction is used to correct model biases during the forecast. In both systems, the perturbations are added to surface pressure, temperature, humidity, zonal wind speed, and meridional wind speed at each model grid point. The use of ACAI in both the ensemble and deterministic settings has resulted in the reduction of systematic biases and RMSE for many atmospheric variables, as well as an improvement of the spread-skill performance of our ensemble of data assimilations (EDA)-based system. ***Figure 8*** shows the 500hPa geopotential height bias in a deterministic control experiment compared to an experiment using ACAI to reduce model bias. The figure shows that ACAI is effective at reducing bias throughout the entire 5-day forecast with a reduction of up to ~15 meters.

We have also begun exploring the use of ACAI in extended-range global coupled ensemble forecasts using the Navy ESPC (Earth System Prediction Capability) model, and initial tests indicate significant improvement to many forecast skill metrics. Furthermore, we plan to expand our use of the ACAI method in an upcoming project aimed at exploring the correction of stratospheric biases using a version of NAVGEM with an expanded model top.

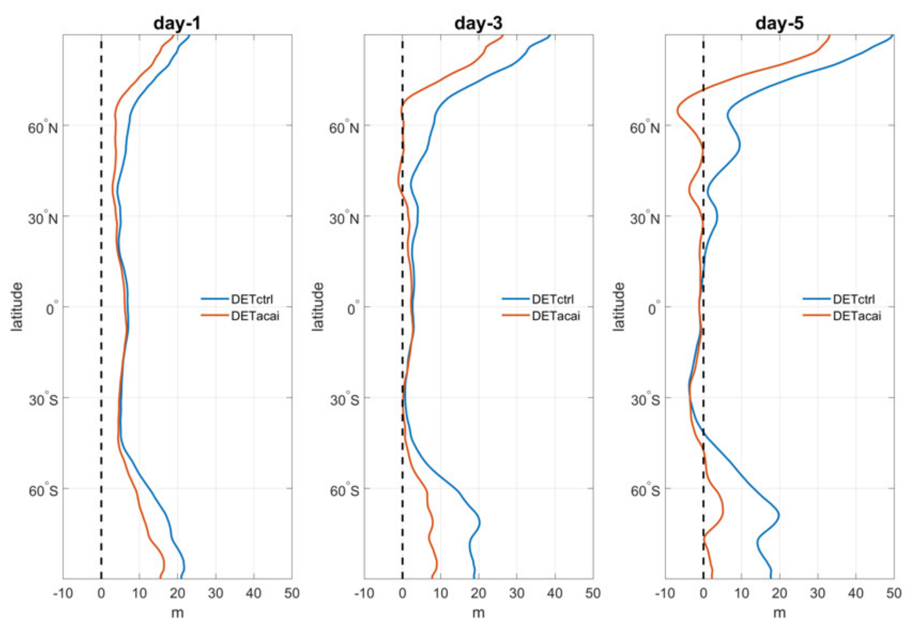

Figure 8. *Zonal averages of 500hPa geopotential height bias (meters) in a deterministic control (DETctrl; blue) and ACAI-based (DETacai; red) experiment at days 1, 3 and 5.*

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Land Data Assimilation at the JCSDA: Plans and Progress

Background

The land surface determines the lower boundary conditions of the atmosphere and interacts with weather and climate through regulation of energy and mass fluxes over a range of temporal and spatial scales. Much of the complexity in these interactions stems from heterogeneity in land use, soil type, vegetation type, soil moisture, and the presence of snowpack. In NWP and climate models, it is the role of coupled land surface models (LSMs) to accurately represent this heterogeneity and simulate the exchanges of energy, water, and carbon through the soil-plant-atmosphere continuum. ***[Figure 1]***

Given these interactions with the atmosphere, land surface initialization can influence forecast performance when this land-atmosphere coupling is strong and when there is sufficient variability, but also significant memory, in land surface states

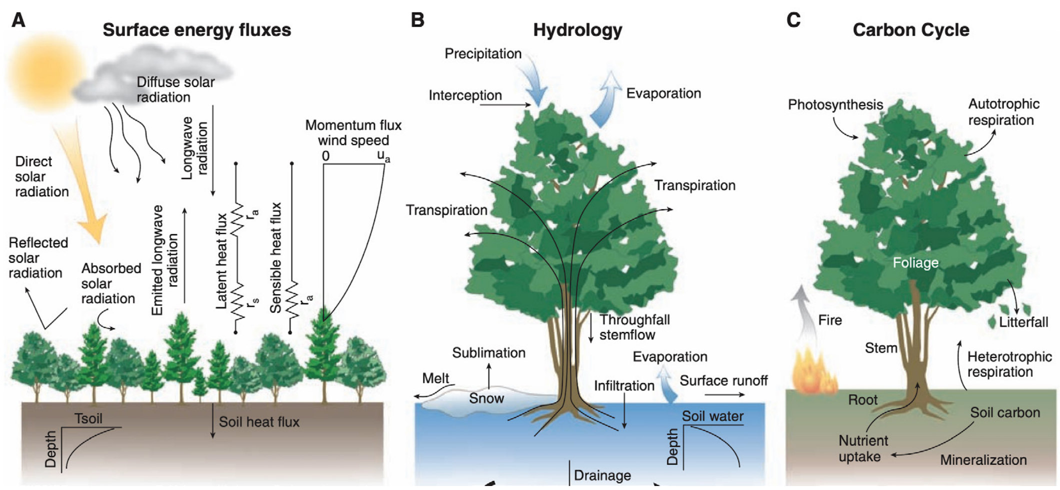

Figure 1. *Land surface models treat the biosphere and atmosphere as coupled systems and simulate (A) surface energy fluxes and (B) the hydrological cycle. Earth System Models also simulate (C) the carbon cycle. (Figure from Bonan, 2008)*

(Koster et al., 2010, 2004). Soil moisture conditions have been shown to impact temperature and precipitation forecast skill when the forecast model properly represents processes linking land anomalies, surface fluxes, and atmospheric physics. Although earlier work focused on sub-seasonal to seasonal timescales, more recent studies have shown the influence of antecedent soil moisture from day one, with peak impact on skill during week 2 (Dirmeyer et al., 2018; Dirmeyer and Halder, 2016). In particular, models with incorrect land initialization and/or poor land-atmosphere coupling behavior will have biases in temperature, humidity, and precipitation forecasts during periods of drought. ***[Figure 2]***

Snow cover with its high albedo and low thermal conductivity also can have large impacts on the atmospheric forecast accuracy, as well as being a key determinant of the magnitude and timing of river runoff over large portions of the globe. This highlights another important role for LSMs in hydrological forecasting. When driven by atmospheric forecasts, and coupled with hillslope and channel runoff schemes, they form a critical tool for flood prediction and water resource planning, which again benefit greatly from accurate initialization through data assimilation. The most complex land surface schemes, particularly those used in fully-coupled Earth System Models, now incorporate many processes that simulate the biosphere and, as such, have emerged as useful for making "ecological forecasts" of diverse model outputs, such as agricultural productivity or wildfire risk (Bonan and Doney, 2018).

Given the apparent importance of land-atmosphere coupling to NWP, it is perhaps surprising that development of LSMs, and in particular land-focused DA activities, have been such a low priority in the past. In a 2018 editorial piece in the American Geophysical Union's (AGU) newsletter, EOS Paul Dirmeyer addressed this question directly, suggesting that a lack of observations of land surface states or land-atmosphere fluxes meant "schemes were developed to adjust land surface states to ameliorate systematic atmospheric model errors … addressing one error by introducing additional ones" (Dirmeyer, 2018), but the latest generation of satellite and in-situ observations of soil moisture and snow now allows for more rigorous verification of process-model improvements and initialization of forecasts.

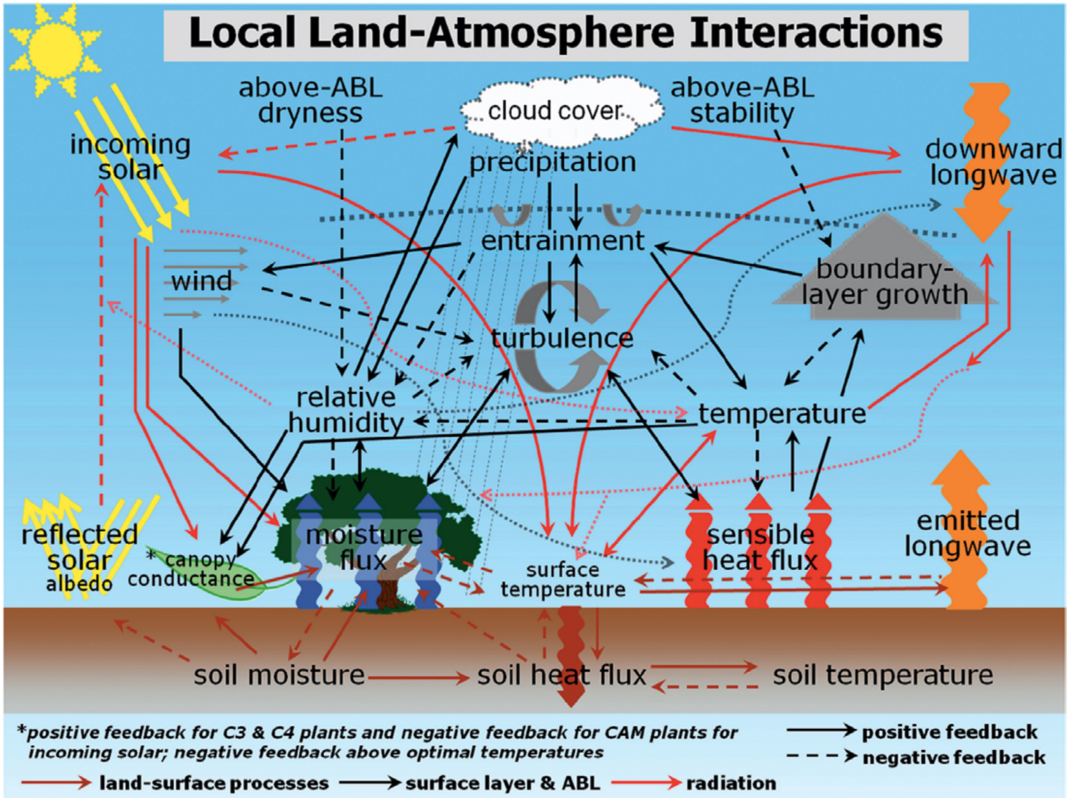

Figure 2. *A schematic of local L-A interactions in a quiescent synoptic regime, including the SM–P feedback pathways. Solid arrows indicate a positive feedback pathway and large dashed arrows represent a negative feedback, while red indicates radiative, black indicates surface layer and PBL, and brown indicates land surface processes. Thin red and gray dashed lines with arrows represent positive feedbacks. The single horizontal gray dotted line (no arrows) indicates the top of the PBL, and the seven small vertical dashed lines (no arrows) represent precipitation. (Figure from Santanello et al., 2018)*

This means that when combined with on-going coupled model developments proper initialization of land states in operational models has become a realistic goal. A review by (de Rosnay et al., 2014) captures the range of techniques used to initialize soil moisture and snow at different operational centers. Whilst there have been some minor changes since then and the United Kingdom Meteorological Office (UKMO) approach now more closely follows European Centre for Medium-Range Weather Forecasts' (ECMWF) lead, it is still correct to say that simple approaches are used. Snow and soil moisture analyses are produced by basic updating, optimal interpolation, and simplified extended kalman filters.

Motivation

Compared to atmospheric data assimilation, only a relatively small number of individuals across government agencies, national laboratories, and universities are actively involved in developing approaches to land surface data assimilation. Therefore, the Joint Center for Satellite Data Assimilation (JCSDA) will play a pivotal role in leveraging these activities so that everyone derives maximum benefit from these diverse efforts. For example, across JCSDA partner organizations teams are focused on numerical weather prediction (NOAA/NCEP/EMC; NOAA/ESRL/PSD; USAF 557th Wing), hydrological prediction (National Water Model teams at NOAA/OWP and NCAR), soil moisture data product generation and reanalysis (NASA/GMAO) and surface reanalysis (NASA/HSB). We are working in close collaboration with all these efforts.

At the JCSDA, we are focused on improving capacity to assimilate observations into the Noah-Multiparameterization (MP) land surface model (LSM), with the overarching goal of improving skill in coupled models. Initially, we are targeting the National Water Model (NWM) and the Unified Forecast System (UFS), the Weather Research and Forecasting Model (WRF) that all use this LSM. It should also be noted that the Model for Prediction Across Scale (MPAS) and the Navy's NEPTUNE system rely upon Weather Research Forecast (WRF)-based land physics, and the general applicability of our approach to land DA should also apply with these models. It is a characteristic of Noah-MP that it operates either within an atmospheric model as part of its physics package or is coupled with another modeling system. Therefore, we have to think about developing interface strategies that work with both approaches and also how to provide offline (uncoupled) capabilities and setup tools for local, regional, and continental scale experiments. During the JCSDA's 2020 Annual Operating Plan cycle, we are working on three land projects:

1. Developing initial land DA capabilities for the UFS;
2. Adding snow DA capabilities to the National Water Model (NWM); and
3. Establishing working relationships with JCSDA partners with operational land DA capabilities, specifically NASA Land Information System (LIS) and UKMO.

Unified Forecast System

Reflecting the "Data Assimilation" sub-project of the UFS research-to-operations plan, our focus is on enhancing existing stand-alone, uncoupled land DA capabilities. Working with scientists from NOAA/NCEP/EMC, we are investigating how to improve existing GLDAS-based operations through Joint Effort for Data assimilation Integration (JEDI) development and integration for land surface initialization. Given known limited baseline capabilities, we are working with the land modeling team at EMC to map out future directions and establish basic requirements, encompassing both scientific need in terms of control variables to be updated and observations used, technical workflow requirements that define how the stand-alone offline LSM is used in forecast initialization, and how DA cycles will fit into this. However, conceptually we will leverage the work already underway with the NWM to expedite the offline LSM interface and utilize the Interface for Observation Data Access (IODA) and Unified Forward Operator (UFO) components developed for that project, with a focus on snow cover data that NCEP currently receives from the NESDIS Interactive Multisensor Snow and Ice Mapping System (IMS). It will be important to coordinate closely with those involved in strongly-coupled DA to ensure the offline work best informs them and vice-versa.

National Water Model

Currently, one of our main projects is coupling the National Water Model (also known as WRF-Hydro) with JEDI. ***[Figure 3]*** This work is in conjunction with NCAR Research Applications Laboratory, NOAA Office of Water Prediction (OWP), and University of Alabama partners. Work is scheduled through 2023 to deliver a system that demonstrates capability to improve runoff forecasts ***[Figure 4a]*** and snowpack analyses. ***[Figure 4b]***

During the first six months of 2020, we have built an interface to the model and have implemented H(x) capabilities with the goal of having a working DA solver in place to begin testing by early Fall. Initially, we are

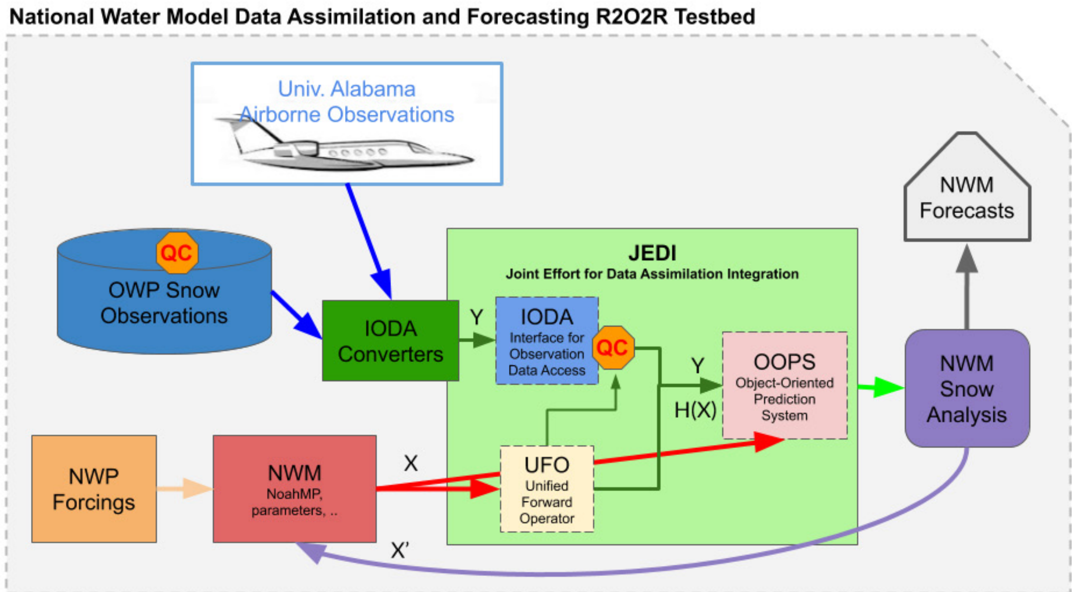

Figure 3. *Schematic of the main components of the NWM DA system.*

Figure 4a. *Visualization of National Water Model streamflow analysis. Screenshot taken from* https://water.noaa.gov/map.

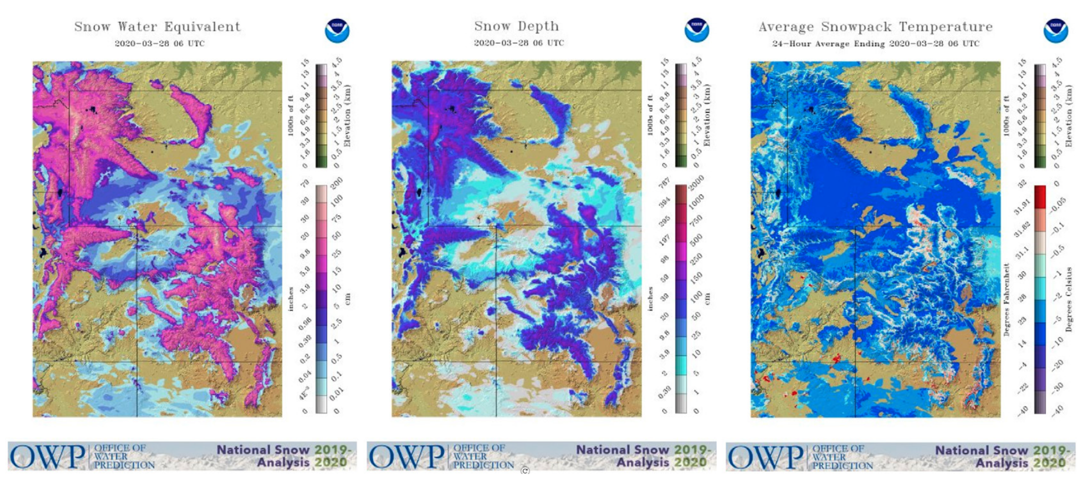

Figure 4b. *Visualization of snow water equivalent, snow depth, and snow temperature from the National Snow Analysis. Screenshots taken from* https://www.nohrsc.noaa.gov/nsa/index.html?region=Central_Rockies&year=2020&month=3&day=27&units=e

utilizing existing WRF-Hydro capability for workflow control and use a pseudo-model, or file-based, approach with JEDI. We are also developing observation operators within the UFO for targeted snow observations of snow depth, snow water equivalent, and snow covered area, which may include simple, linear aggregation of variables. We will have to assess requirements for interpolation and test accuracy and performance. The OWP team is implementing sophisticated quality controls specifically developed for operational systems that will then be implemented into UFO. By the end of 2020, we will be conducting initial OSSEs in the small Taylor Park river catchment.

LIS and Next Generation Land DA

It is important that as we build up capacity to support land DA within the JCSDA, we work constructively with all our partners. An example of this is how we are working to establish strong interactions between JEDI and NASA's Land Information System (LIS), and subsequently with the land DA component of the UKMO's Next Generation Modeling System (NGMS). These two entities already interact through the Air Force's use of LIS and the Unified Model. Our goal is to leverage the existing financial and intellectual investment in LIS and work together to produce optimized, operational land DA systems. NASA LIS scientists/software engineers attended the JEDI Academy training in February 2020, and in conjunction with the UKMO, NASA, and USAF scientists, there is an exciting opportunity to develop a strategy for land DA in the NGMS, further strengthening existing ties between JEDI and this next generation system. We are currently conducting a comprehensive review of existing capabilities, which will be followed by a gap analysis and requirements gathering exercise for future development.

Future Directions

Once basic JEDI applications are functional with the UFS and NWM, we anticipate an extended period of experimentation, scientific exploration, testing and verification as we develop and test these new state-of-the-science systems. Additional functionality, such as enhanced QC filters, will need to be added to meet operational requirements. Over a longer timeframe, these projects will also benefit from a number of additional technical and scientific goals we have for land DA at the JCSDA over the next five years.

Validation Activities

An important step in transitioning new land DA capabilities into operations is a clear demonstration of the benefits this will bring. We need to consider verification in two different contexts, both in terms of the land surface analysis and the coupled model forecast. As discussed above, there might be tension between these two objectives given inadequacies in model physics and coupling and their existing "tuning." We might even expect improvement in land surface analysis to initially degrade coupled model skill (weather in the UFS, runoff in the NWM). Therefore, it will be important that we work with others on validation activities outlined in the UFS R2O plan that can both assess the adequacy of the land surface analysis, and then capture its impact on coupled model skill in an informed manner that will ultimately lead to increased skill in weather/hydrological forecasts.

Soil Moisture

Updates to soil moisture has been shown to improve weather forecast skill on short, medium, and S2S timescales and represent one of two key model variables (the other being snow) currently analysed operationally. Historically, DA approaches have been limited by a lack of in-situ or remotely sensed observation, so soil moisture has been updated by assimilating 2-m temperature and relative humidity. Updates and advances to this approach will be facilitated through our partner agencies focused on coupled systems. The advent of new data mean several NWP centers have started to investigate the use of satellite-derived soil moisture observations for assimilation using a range of approaches. Building upon existing expertise at both NASA and USAF and our experience with snow data assimilation, we will develop soil moisture DA capability into the UFS and explore its use in the NWM. We will develop converters for data ingest and forward operators for a range of soil moisture retrievals, initially targeting those from SMAP, SMOS, and ASCAT sensors.

Advanced Observation Operators

To date, most land DA systems have concentrated on assimilating remotely sensed data products/retrievals, rather than reflectances or radiances. However, this can of course introduce considerable error when there are inconsistencies between auxiliary data used in generating the retrievals and LSMs. We anticipate that the JCSDA will play an important future role in leading development and application of advanced observation operators that will enable the assimilation of land surface reflectance, brightness temperatures, and backscatter directly. We are strongly positioned to do this given many years of involvement and expertise with the Community Radiative Transfer Model (CRTM) and the development and use of complex observations operators in DA systems. We will make connections with ongoing and future CRTM/CSEM tasks and look for synergies in this regard across the center as a whole, and believe this is an important area in which we are uniquely positioned to make substantial contributions to land DA science.

Other Observations

In addition to snow and soil moisture, a large number of additional satellite data products are currently being actively investigated in the context of land DA. A subset seems particularly promising for improving land model performance in the context of NWP. This includes leaf area index (LAI), land surface and snow albedo, and snow and land surface temperature (LST), which is intrinsically tied to land surface emissivity. The value of all these can be assessed through using JEDI with Noah-MP in this context. Additionally, there are a large number of additional types of remote sensing observations that potentially offer powerful constraints on LSMs, particularly if the requirement for near-real time availability is relaxed. These include observation of solar induced fluorescence as a proxy for photosynthesis (e.g., OCO2/3), river discharge (e.g., SWOT), surface roughness and vegetation height and biomass (e.g., GEDI/IceSAT2) and high resolution thermal/evapotranspiration retrievals (e.g., ECOSTRESS). Research into how to optimally use these new observations will form a core component of JCSDA Land DA activities.

Advancing Algorithms

A wide variety of different approaches have been applied to land DA in research settings, but in operational scenarios mainly simple algorithms—optimal interpolation and simplified EKF/2Dvar—have been used. For reanalysis and data product generation, ensemble kalman filters have been a popular choice, and this is true across the research community. This is because a large part of land surface model error comes from inaccuracy in atmospheric forcings, which can be accounted for using ensemble techniques to some extent. It is also partially due to the difficulties in developing and maintaining adjoints of LSMs, which contain lots of nonlinear processes and exhibit many types of threshold and "on-off" behaviors, and also the community as a whole has little experience in generating background error covariances outside of an ensemble framework. Therefore, there is an expectation in the JEDI user community that our system will offer some EnKF capabilities. We will leverage the considerable work at the Joint Center that is going into LETKF and Ensemble of Data Assimilations and Block methods implementation and investigate how to best use this algorithm with LSMs, drawing on expertise at partner agencies. In addition to forcing/boundary conditions error, another key source of uncertainty comes from choice of parameter values, making parameter optimization an important aspect of land DA. We anticipate that considerable research effort will concentrate on this, with several emerging techniques, in particular 4DEnVar (e.g., Pinnington et al., 2020), looking like a promising approach to this long standing, complex problem.

Additional Land Models

Due to its key role in the NWM, the UFS, and the WRF, Noah-MP was chosen as the LSM for initial work at the Joint Center. However, currently it is only undergoing moderate development, and over a 3–5 year timescale all such activity is envisioned to switch to the Community Terrestrial System Model (CTSM), which represents efforts within NCAR to unify land model developments between Noah-MP and the Community Land Model (CLM). This highly configurable model will be suitable for a variety of weather and climate model uses and, as such, represents state-of-the-science capability. Therefore, it represents a possible next target for an interface with JEDI initially in offline mode. As a future step, it would represent a path to working with fully coupled Earth System models, such as CESM.

Final Remarks

It has been an interesting and very illuminating first year working at the JCSDA for me personally. Although I have worked on land DA for many years, this has been in using climate models in university-based research settings, so my introduction to the world of operational NWP has involved a very steep learning curve! I have been delighted how supportive JCSDA partners have been towards land DA efforts, and I am sure that over the coming years our work will evolve into cutting edge DA systems, with capabilities that rival the world's best.

Author

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NEWS ANNOUNCEMENTS

The Joint Center for Satellite Data Assimilation (JCSDA) is pleased to announce that we are planning the first public, open-source release of the Joint Effort for Data assimilation Integration (JEDI) system this fall.

The proposed initial release of JEDI intends to feature:

- Source code on publicly accessible JCSDA Github repository under open-source license.
- Code needed to run observation operators (aka, H(x)) as shown in our near-real-time monitoring application) with GFS and GEOS model backgrounds.
- Code required for the JEDI Academy tutorials.
- A container equipped with the environment to pull JEDI source code from GitHub, build necessary executables, and run data through H(x) for a single data assimilation cycle.
- Documentation and self-paced tutorials posted on the JCSDA website.
- Limited user support will be provided via a dedicated forum monitored by the JEDI users and developers community.

Future JEDI Academy training sessions will take advantage of the publicly posted code for practical sessions, allowing users to apply what they learn at the Academy to their own JEDI pursuits with ease. The target release date is October 28, 2020. The JCSDA also plans to release the latest version (Version 2.4) of the Community Radiative Transfer Model (CRTM) this Fall.

PEOPLE

Welcome Rick Grubin

Rick Grubin joined the JCSDA in April, 2020, as a software engineer working with the JEDI core team. He will focus on developing infrastructure for JEDI-based near-real time environments and application suites, workflows and cycling systems in cloud computing and HPC environments, and support of HPC systems in general.

Rick worked at NCAR in the Research Applications Program on the Terminal Doppler Weather Radar (TDWR) project. He was responsible for developing the Geographic Situation Display (GSD) used by air traffic controllers to provide aircraft arrival and departure decision-making information to commercial aviation interests. The highlight of this work was flying through microbursts and gust fronts on NASA's instrument-laden test aircraft to validate the data provided by the GSD. He also developed TDWR's end-to-end system monitoring software for research scientists "observing" aviation weather from RAP's operations center in Boulder, CO. He continued this work at the MIT Lincoln Laboratory on the Integrated Terminal Weather System (ITWS, the successor to TDWR), which is the basis for similar systems installed in airport control towers and regional terminal radar control centers around the U.S.

Later, he helped develop the NCAR Command Language (NCL) and similar tools for post-processing of model output data. He also worked at Sun Microsystems on Lustre-based HPC tools and Solaris operating system installation software and at Lockheed Martin on embedded operating systems for small commercial satellites.

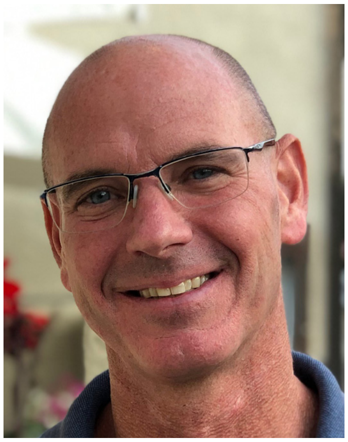
Rick graduated from the University of Colorado with a Bachelor's Degree in Electrical Engineering. He spent as much time as possible enrolled in literature and history courses, both to escape the engineering center and to satisfy interests in those areas. While at CU, he worked for the University's Academic Computing Services (ACS) as a Computing Advisor, acquiring skill with the paper tape-driven PDP-11 and punch card-driven Control Data Cyber computers. He and his colleagues were beyond thrilled when ACS's first VAX/VMS system arrived, along with an AT&T System V Unix 3B-20 "mainframe."

Outside of work, Rick's passions and interests revolve around his family, travel, and outdoor adventure and education in some form. His wife is a healthcare provider focusing on diagnostic echocardiography. Their kids are scattered about—a critical care flight nurse in Alaska, a public school curriculum developer in Denver, a plumber/longboarder/aspiring ski guide in Washington, and a public health researcher/field practitioner working with Indigenous peoples in New Mexico and Arizona.

Lured by oceans, rivers, and peaks, Rick's travels have taken him to 46 countries and six continents to float, hike, and ski. He has sea-kayaked from Alaska to New Zealand, run rivers in South America and Australia, skied in Gulmarg and the Atlas Mountains, and completed numerous "high route" ski tours in the EU and Scandinavia. Rick and his wife have enjoyed many hut walks in the EU, including the TMB, hiker's Haute Route, and most Alta Via routes in the Dolomites; next up will be the West Highlands Walk in Scotland, trekking in the Julian Alps, and back to the Tracks of New Zealand.

Rick has been an instructor (now effectively retired!) for the National Outdoor Leadership School since 1988, teaching skills for river running in Utah and Colorado, sea kayaking in Alaska and Patagonian Chile, and helping open the NOLS Yukon branch by reconnoitering remote river journeys via canoe in Canada. He has been a ski patroller at the Loveland Ski area since 1990, overseeing the snow safety education program there as a professional member of the American Avalanche Association.

He is very proud that all four of his kids share his passion for travel and adventure—together they've trekked the Atacama Desert and "O" circuit in Chile, circumnavigated Mt. Fitz Roy in Argentina and Chile, hiked Costa Rica's highest peak and surrounding national parks, and run rivers and backpacked and skied throughout the western U.S., Alaska, and Canada.



Introducing Dr. Greg Thompson

Dr. Greg Thompson has joined the JCSDA to bring to bear his cloud physics knowledge to improve satellite data assimilation for improvement of numerical weather prediction models. Greg is working as a member of the observations OBS team with Dick Dee to make the best possible usage of existing and new observation resources in the JEDI software.

Greg earned his B.S. in meteorology from Pennsylvania State University in 1990, his M.S. in atmospheric science from Colorado State University in 1993, and his Doctor of Philosophy in Atmospheric Science from the University of Colorado, for his dissertation "Advances in a microphysics parameterization to predict supercooled liquid water and application to aircraft icing" under advisor Katja Friedrich.

Dr. Thompson is internationally recognized for his research on numerical weather modeling, particularly the parameterization of cloud physics and precipitation processes. He developed a bulk microphysical parameterization that compares favorably against other two-moment bulk and more sophisticated spectral microphysics schemes. The latest version of the now aerosol-aware Thompson-Eidhammer microphysics scheme is operationally used in the Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR) models run at the National Center for Environmental Prediction (NCEP). The 2014 paper co-authored with Trude Eidhammer discussing the aerosol-aware microphysics scheme was recognized by RAL with its Publication Award in 2018 and nominated for the UCAR Outstanding Publication Award that same year.

Simultaneous to improving cloud physics parameterizations in weather models, Greg has greatly contributed towards the development of automated aircraft and ground icing forecast applications using model output and explicit prediction of super-cooled liquid water together with various surface, radar, and multispectral satellite data to create icing hazard guidance products that are now routinely generated by NCEP to serve the aviation industry.

In addition, Greg pioneered the automation and delivery of weather data and graphics to the web starting in 1994 with the RAP/RAL Real-Time Weather Data website. The immediate success of this site led to the Aviation Digital Data Service (ADDS) project. Under Greg’s leadership, the ADDS team successfully delivered the first ever NCAR technology transfer of operational systems to the National Weather Service, where it continues to run today. The ADDS team won the UCAR Outstanding Technical Achievement award in 1999, as well as a U.S. Government Technology Achievement award in 2000.

On a lighter note, Greg is not only a weather geek but also well known for his outstanding photography of weather phenomena and for making and drinking homebrew.

Say Hello to Dr. Hui Christophersen

Dr. Hui Christophersen joined the Marine Meteorology Division data assimilation section of the Naval Research Laboratory (NRL) in Monterey CA in June, 2020. Hui will conduct research and development to explore assimilation capabilities of new remotely sensed observations, observation assimilation upgrades, and the use of small-satellite platforms as well as calibration and validation of new and existing spaced-based microwave radiometer data.

Hui has a Bachelor's Degree in Information and Computing Science and a Master's Degree in the Applied Mathematics from the Nanjing University of Information Science and Technology (NUIST) in China. She received her PhD in Meteorology from Florida State University in 2015, where she worked on quality control of multiple satellite ozone datasets to improve hurricane vortex initialization. She developed an improved quality control scheme to better use AIRS cloud-cleared ozone data in and around hurricanes. She also worked on inter-calibration of the multi-datasets that are useful for climate research and simultaneous ingestion into the numerical weather prediction models.

Hui gained her postdoc training at the University of Miami through NOAA's Cooperative Institute for Marine and Atmospheric Studies (CIMAS) and NOAA Hurricane Research Division (HRD), where she mainly worked on evaluating the impact of a suite of datasets collected by the unmanned aircraft Global Hawk on tropical cyclone prediction. Her work demonstrated important value of the high-altitude dropsondes in improving tropical cyclone forecasts. She then became an assistant scientist at CIMAS working on small-satellite data assessment for tropical cyclone analyses and forecasting. She actively participated in HRD's annual hurricane field program, led experiment designs and science missions in the NOAA reconnaissance flights and had extensive experience with diverse reconnaissance data processing. She also actively engaged in mentoring students through NOAA's Hollings program.

Outside of work, she loves to spend time with her husband, Jon, and her two children to hike and travel. They are excited to explore the west coast and Sierra Nevada mountain range area. She also likes yoga and running to maintain physical and mental fitness.

Greetings to Dr. Eric Platt

Dr. Eric Platt is an applied mathematician and software engineer working at the Naval Research Laboratory (NRL) in Monterey, CA. He is a member of the data assimilation team where he currently works on building the JEDI-IODA interfaces to the NRL-specific observation stream with conventional and satellite data, linking it to the HofX framework, and optimizing the DA for hybrid 4DVar.

A native of Salt Lake City, Utah, he is the oldest of five siblings. After he graduated from Woods Cross High School in 2003, he studied at the University of Utah where he received a Bachelor's Degree in mathematics with an emphasis in scientific computing in 2007.

For several years, he worked as a software engineer, primarily in the video game development industry. He programmed physics, as well as game logic. In 2011, he resumed mathematics coursework at the University of Utah, then accepted a fellowship in the University of Houston mathematics department. From 2012 to 2017, he was a mathematics graduate student, as well as a teaching and research assistant.

Eric's doctoral research was on developing techniques for active manipulation of acoustic and electromagnetic fields with arrays of smart antennas or transducers. This work heavily involved functional analysis, inverse problem theory, boundary integral equations, and numerical methods, as well as the physics and electrical engineering associated with it. He continued working and publishing this research for a year and a half years after receiving the Ph.D.

Eric met Dr. Sarah King from the Monterey Naval Research Laboratory while she was visiting the University of Houston. This led to an interview, and shortly after, he began working with NRL while being hired by UCAR as a visiting scientist.

Eric's hobbies are broad and include studying mathematics, physics, and the other sciences, as well as history and philosophy, designing and playing board games, card games, and video games, hiking and bicycling, and writing answers to mathematics and science questions on the web service Quora, where he has over four-thousand followers. He is happy to be able to work with atmospheric scientists at NRL Monterey, UCAR, and other associates.

Introducing Francois Chabannes

I was lucky to join the SOCA team as a remote intern in May 2020. I am currently developing a Machine Learning based model to predict sea surface salinity using SMAP data with JPL processing under the supervision of Guillaume Vernieres. Fascinated by the oceans and their seafloors, I started studying in 2017 for a Master of Science in Hydrography and Oceanography at the École Nationale Supérieure des Techniques Avancées (ENSTA) Bretagne, Brest, France. Handling and processing bathymetric data gave me a taste for data analytics, and I therefore chose to pursue a dual Master of Science in Data Science the next year. I was able to combine both of these fields in a previous internship during the summer of 2019 in Durban, South Africa, applying Machine Learning for estuarine modelling purposes.

Data Science is a fascinating discipline and I would love to pursue a thesis combining both Machine Learning and Environmental Sciences once my internship is over. Because of the current quarantine situation, I am working from home in Brittany, France, close to the sea. Aside from work, I love spending time on—or in—the sea. At the end of a typical day, I will be on my kayak as the sun goes down or freediving and enjoying the absolute silence.

EDITOR'S NOTE

It gives me a great sense of satisfaction to present the Summer 2020 Issue of the JCSDA Quarterly Newsletter. Amid the continuing changes brought to bear on our working environments in response to the COVID-19 pandemic it seems more critical than ever not only to continue to work effectively but to share awareness of our efforts and accomplishments with one another and the broader community.

One tangible sign that we not only persevere but manage to thrive in the face of adversity is the on-boarding of new staff. In this issue are introductory biographical sketches of four new employees, Rick Grubin, Greg Thompson, Hui Christophersen, and Eric Platt, each of whom is working with the JCSDA either as core staff or with one of the sponsoring partner agencies. In addition there is a bio for an intern who has been collaborating remotely with us, Francois Charbannes. These pieces tell about the current and planned contributions of these new colleagues to the JCSDA mission, and provide summaries of their previous work as well as their personal interests. I know that you will appreciate the chance to learn a little bit about our new colleagues and their work, and like me, look forward to working with them.

A number of our recent issues have been built around single science or technical themes, with multiple articles devoted to a particular topic, such as assimilation of GNSSRO and aerosol observations, or the design and development of JEDI. This issue represents a departure from that motif, as we feature two very different articles. The first is contributed by Nancy Baker, Ben Ruston, Charlie Barron, Jean-Francois Cayula, Jackie May, Sarah King, Pat Pauley, Allen Zhao, and Will Crawford of the Naval Research Laboratory (NRL.) This piece provides an overview of the data assimilation research and development at NRL, and how that work connects to the JCSDA to the benefit of NRL and to the other partners. The other feature article is by Dr. Andy Fox, leader of the JCSDA Land Data Assimilation Project and outlining its objectives and associated activities.

While you're here be sure to check the calendar of upcoming events. The data assimilation community is remaining active, using creative means to share results and to work collaboratively. The meetings and conferences we will attend in the near future will be virtual, but the benefits will be real!

SCIENCE CALENDAR

UPCOMING EVENTS

Please note: All information about meetings and events are accurate as of the date of this publication. With the COVID19 situation being so fluid, please check status of the meetings and events to confirm.

MEETINGS OF INTEREST

DATE	LOCATIONS	WEBSITE	TITLE
Postponed. Date and other details To Be Determined.	Fort Collins, CO	http://www.isac.cnr.it/~ipwg/	IPWG
Postponed to June 6–10, 2021.	Fort Collins, CO	https://www.cira.colostate.edu/conferences/8th-international-symposium-on-data-assimilation/	8th International Symposium on Data Assimilation (ISDA)
Canceled due to COVID19.	Wurzburg, Germany	https://www.eumetsat.int/website/home/News/ConferencesandEvents/DAT_4635627.html	EUMETSAT Meteorological Satellite Conference 2020
Postponed to 2022. Date and other details To Be Determined.	Alberta, Canada	https://www.birs.ca/events/2020/5-day-workshops/20w5166	Mathematical Approaches for Data Assimilation of Atmospheric Constituents and Inverse Modeling
Novermber 16–20, 2020	Evian, France	https://www.eumetsat.int/website/home/News/ConferencesandEvents/DAT_4724240.html	5th Infrared Atmospheric Sounding Interferometer (IASI) Conference
December 1–17,2020	Virtual	https://www.agu.org/fall-meeting	American Geophysical Union (AGU) Fall Meeting: Shaping the Future of Science
January 10–14, 2021	Virtual	https://www.ametsoc.org/index.cfm/ams/	American Meteorological Society (AMS): 101st AMS Annual Meeting
May 25–28, 2021	Darmstadt, Germany	https://www.ghrsst.org/ghrsst-news/please-advertise-save-the-date-2nd-international-operational-satellite-oceanography-symposium/	2nd International Operational Satellite Oceanography Symposium

MEETINGS AND EVENTS SPONSORED BY JCSDA			
DATE	**LOCATIONS**	**WEBSITE**	**TITLE**
Week of November 16, 2020	Virtual	http://www.jcsda.org	Academy for the Community
Week of November 30, 2020	Virtual	http://www.jcsda.org	JEDI Academy for USAF and Met Office
January 10–14, 2021	Virtual	https://annual.ametsoc.org/2021	10th Symposium on the JCSDA conducted as part of the 101st AMS Annual Meeting
February, 2021	Virtual	http://www.jcsda.org	4th Annual JCSDA ET Retreat
May 17–20, 2021	Possibly Virtual	http://www.jcsda.org	18th Annual JCSDA Technical Review and Science Workshop
Summer, 2021	**TBD**	http://www.jcsda.org	JCSDA Summer Colloquium

CAREER OPPORTUNITIES

Opportunities in support of JCSDA may be found at https://www.jcsda.org/opportunities as they become available.