JOINT CENTER FOR SATELLITE DATA ASSIMILATION

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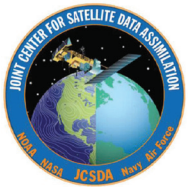

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NEWS IN THIS QUARTER

SCIENCE UPDATE

Optimizing the CRTM for Improved Performance of All-Sky Radiance Data Assimilation

One of the most important aspects of an all-sky radiance data assimilation system is the speed and accuracy of the observation operator, which converts 3D Numerical Weather Prediction model variables into equivalent radiances as measured by satellites (Bennartz and Greenwald 2011). For clouds, precipitation, and aerosols, the most relevant components of observation operators like the Community Radiative Transfer Model (CRTM) are the particle absorption and scattering properties (see Yang et al. article in spring 2018 JCSDA newsletter) and the methods used to solve the radiative transfer (RT) equation in scattering atmospheres. In data assimilation applications, the latter is by far the most time consuming calculation and is the topic of this article.

Typically, the approach taken in selecting a multiple scattering RT solver for data assimilation applications has been to rely on a single computationally efficient method that provides good overall accuracy (Bauer et al. 2006). However, because no one RT solver can provide both high accuracy and speed in all conditions, there is a need to better utilize existing RT solution methods in data assimilation, particularly in operational environments where severe time constraints often exist and in the prediction of severe weather where significant scattering can occur at higher microwave frequencies.

A move toward addressing this need was made in the development of the CRTM in which the aim was to offer flexibility in the speed and accuracy of infrared and microwave RT calculations through the use of multi-stream solvers – the Advanced Doubling Adding (ADA) model (Liu and Weng, 2006) and the Successive Order of Interaction (SOI) model

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(Heidinger et al., 2006). Taking the next step of actually making optimal use of these solvers, that is, predicting the minimum number of streams (i.e., angular resolution) needed to achieve a desired accuracy in the solution and determining whether scattering even needs to be considered was accomplished in our previous JCSDA project. This was done objectively through the use of a scattering indicator (SI) to provide a measure of the degree of scattering since the number of streams required for a desired accuracy tends to increase with the amount of scattering, which can significantly slow down RT calculations (Bennartz and Greenwald, 2011).

Figure 1 illustrates how well the method performs using a high-resolution (1.5 km horizontal grid spacing) Weather Research and Forecasting (WRF) model simulation of Hurricane Katrina for selected Global Precipitation Mission Microwave Imager (GMI) channels representing conditions of weak, moderate, and strong scattering. A simulation at high-spatial resolution that included 5 types of hydrometeors was required to realistically capture the full range of scattering conditions. Results show that the SI method correctly predicts the optimum number of streams 94% of the time (assuming a solution accuracy of 0.5 K) for all 13 channels of the GMI over the model domain. On the other hand, the current release of the CRTM (v2.3.0) in its default configuration uses more streams than are necessary in the vast majority of cases and uses too few streams near the inner core of the hurricane at high microwave frequencies (i.e., 165 GHz) where significant scattering occurs. The time savings of using an optimized version of the CRTM v2.3.0 over the current release is a factor of 2.5, at least for this severe weather case. Even greater speeds are anticipated globally where non-scattering situations will dominate at microwave frequencies.

Our current project takes this approach a step further by taking advantage of ultra-fast analytic RT solvers to achieve even greater efficiency of forward/adjoint infrared and microwave RT calculations in scattering atmospheres while maintaining accuracy. In the first year of our project, we have integrated a polarized two-stream model (Liu and Weng, 2002) and an Eddington model (Smith et al., 2002) into the CRTM v2.3.0. The tangent linear and adjoint models of the Eddington model are currently under development.

Results show the Eddington model is exceptionally fast, being just 33% slower than the emission-only (i.e., non-scattering) model and 2.8x faster than the ADA 2-stream model. In addition, the Eddington model has significantly smaller errors for strongly scattering conditions than the 2-stream model (Figure 2). However, for conditions of weak scattering, the Eddington is slightly less accurate than the ADA 2-stream model and is more useful if the assumed solution accuracy is relaxed to 1 K. Pairing the emission-only model with the Eddington model can provide a nearly 4x speedup over CRTM v2.3.0, while achieving an accuracy of 1 K in over 90% of the cases. It is also worth noting that 1 K accuracy can be achieved in 75% of the cases using emission-only calculations.

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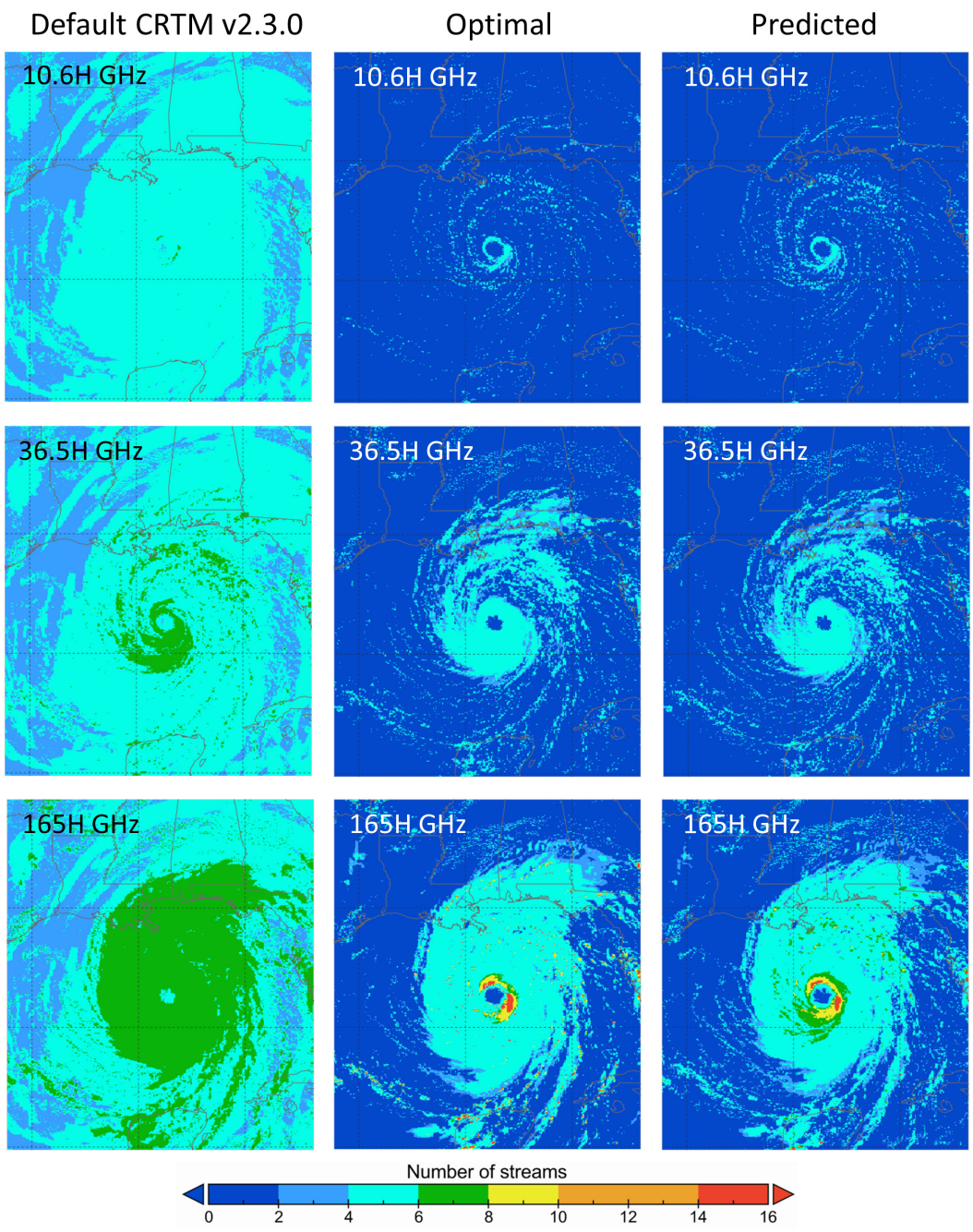

Figure 1. *Simulation of the default number of streams obtained from CRTM v2.3.0 (left column), optimal number of streams (middle column) and predicted number of streams (right column) for the 10.65 GHz (top row), 36.5 GHz (middle row) and 165.5 GHz (bottom row) horizontally polarized channels of the GMI for a high-resolution WRF model run of Hurricane Katrina at 1800 UTC 28 August 2005. The valid number of streams is 2, 4, 6, 8, and 16. A stream number of 0 represents the emission-only model.*

For the second year of our project, we are currently linking an optimized version of CRTM v2.3.0 into the Community Gridpoint Statistical Interpolation (GSI) system to Hybrid 4D EnVar all-sky radiance data assimilation experiments using the NASA Goddard Earth Observing System Model, Version 5 (GEOS-5) Data Assimilation System (DAS) and GMI observations. Additional plans include applying the SI method to optimize RT calculations for clouds and aerosols in the infrared, as well as extending the Eddington method, which assumes a 2-term truncation of the radiance

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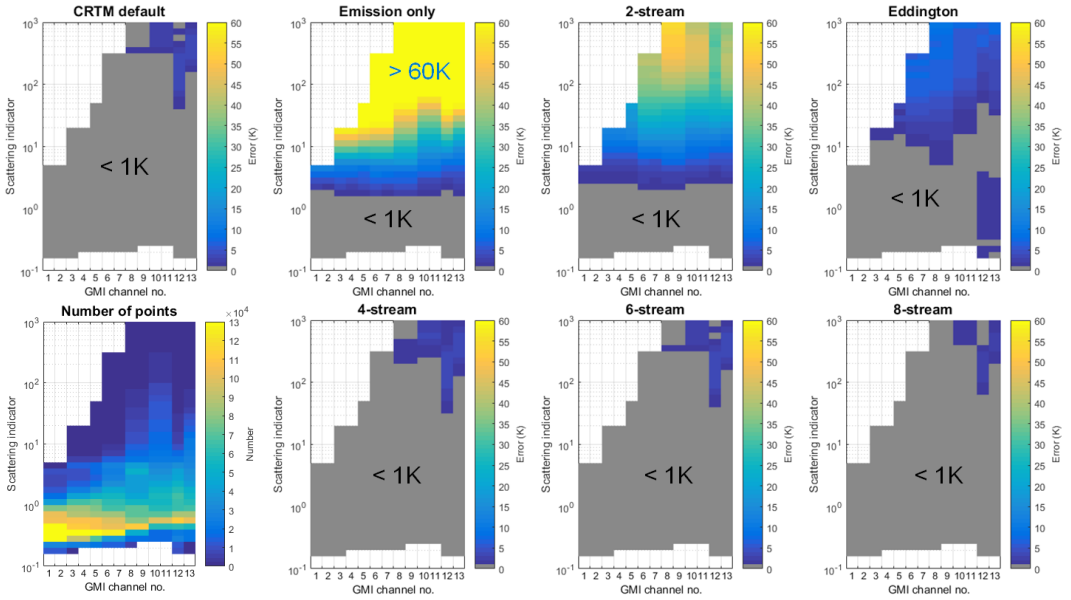

Figure 2. *Scattering indicator versus GMI channel histograms of the brightness temperature errors in the default CRTM v2.3.0, emission-only model, Eddington model, ADA 2-, 4-, 6-, and 8-stream models for the WRF model simulation. Gray areas denote errors of less than or equal to 1 K. The ADA 16-stream solution was used as the reference for computing errors. Also shown is the number of model grid points used in the analysis.*

field in a spherical harmonics expansion, to a 4-term truncation that is expected to yield better accuracy and maintain high speed (Li and Ramaswamy, 1996; Zhang and Li, 2013). Because of renewed interest in accounting for sources of polarization in the CRTM from the surface and atmospheric ice particles, we also plan to add a polarized delta-4-stream model (Liou et al., 2005).

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Assimilation of Hyperspectral Infrared Observations with Optimal Spectral Sampling

Current hyperspectral infrared sounders have thousands of channels. The number of channels is much higher than the number of independent elements of information regarding profiles of temperature, water vapor, and trace gases, but the redundancy is useful for reducing the effective noise of the channel set as a whole, and variational data assimilation methods are capable of extracting the information while exploiting the noise reduction. It is impractical, however, to assimilate data from full channel sets due to the high computational costs of the variational solution and of the radiative transfer calculations. Weather centers commonly reduce the volume of data from hyperspectral infrared sensors by excluding a large fraction of the channels from assimilation. The Infrared Atmospheric Sounding Interferometer (IASI), for example, has 8,461 channels, and only 150 selected channels have routinely been assimilated in the Global Data Assimilation System (GDAS) at the National Centers for Environmental Prediction (NCEP). Channel selection is typically done with an approach that seeks to retain information that is valuable for the forecast and eliminate channels that cannot be well modeled or assimilated, but inherently there is some loss of profile information and loss of channel redundancy for noise suppression. We have implemented and tested an alternative to channel selection, based on optimal spectral sampling (OSS), which has the potential for achieving about the same computational efficiency as channel selection while retaining the same information content as full channel sets.

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The OSS method has been demonstrated to be a fast and accurate way to model radiometric observations and their Jacobians as linear combinations of monochromatic radiative transfer calculations (Saunders et al., 2007, Calbet et al., 2011). A set of channel radiances ($\mathbf{y}$) is thus modeled as $\mathbf{y} = \mathbf{W}\tilde{\mathbf{y}}$, where $\tilde{\mathbf{y}}$ represents the radiances at a set of monochromatic spectral points we call "nodes," $\mathbf{W}$ is a matrix of weights, and the nodes and weights are defined through an optimization process. Jacobians ($\mathbf{K}$) are transformed similarly as $\mathbf{K} = \mathbf{W}\tilde{\mathbf{K}}$. The radiative transfer computations are done monochromatically, and then the matrix multiplications can be viewed as projections from node space to channel space. The number of nodes required depends on the amount of independent information in the modeled channel set, including the number of variable gases modeled, and the required accuracy of the approximation, which is selectable when the optimization is performed. We typically impose an accuracy requirement of 20% of the sensor noise standard deviation, and the accuracy is measured in terms of root mean square (rms) error for sets of training profiles that span the range of conditions that occur globally. With this requirement and with six variable gases modeled, the entire IASI 8,461 set of channels can be modeled with about 400 OSS nodes.

With the method we call node-based assimilation, the assimilation system operates on nodes (i.e. $\tilde{\mathbf{y}}$, and $\tilde{\mathbf{K}}$) instead of on channels (i.e. $\mathbf{y}$, and $\mathbf{K}$), and we thus avoid the transformation $\mathbf{K} = \mathbf{W}\tilde{\mathbf{K}}$ that can be computationally costly when there are large numbers of channels and large numbers of atmospheric state variables on which radiances depend: that is, when both dimensions of $\mathbf{K}$ are large. Prior to assimilation, the observations are projected from channel space to node space by a linear operation $\tilde{\mathbf{y}}^{obs} = \mathbf{A}\mathbf{y}^{obs}$, where $\mathbf{A}$ is determined by least squares: $\mathbf{A} = (\mathbf{W}^T\mathbf{R}^{-1}\mathbf{W})^{-1}\mathbf{W}^T\mathbf{R}^{-1}$, with observation error covariance $\mathbf{R}$. Mathematical equivalence between assimilation in channel space and node space is assured if the observation error covariance in node space is defined as $\tilde{\mathbf{R}} = (\mathbf{W}^T\mathbf{R}^{-1}\mathbf{W})^{-1}$. This node-based method is the only practical way to assimilate unapodized interferometric spectra, enabling assimilation systems to use data from interferometric sensors, such as IASI and the Cross-track Infrared Sounder (CrIS), without the loss of spectral resolution (and vertical profiling resolution) associated with apodization. In particular, the monochromaticity of nodes circumvents the spectral blending inherent in unapodized channel radiances (which have extensive side-lobes) and in principal-component representations of radiances. Avoiding spectral blending means avoiding spectrally non-localized effects of clouds, the Earth surface, and trace gases, whereby a trace gas signal in one part of the spectrum can, for example, affect radiances in channels whose primary responses are elsewhere in the spectrum.

We implemented the node-based method in the NCEP Gridpoint Statistical Interpolation (GSI) assimilation system and conducted a set of experiments to analyze the performance of the method. In this endeavor, our approach was for the node-based process to be as consistent as possible with a baseline channel-based process, apart from differences necessary to use node

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data rather than channel data. The baseline configuration was three-dimensional variational (3Dvar) assimilation, rather than the newer 4D hybrid ensemble variational system, to allow sufficient throughput with the available S4 computer system (Boukabara et al., 2016). In particular, we used GSI release 5.0.0, along with version 2.2.0 of the Community Radiative Transfer Model (CRTM), which has an option to use the OSS method for radiative transfer calculations.

The test case for our experiments was the two-month period June-July 2015. To facilitate implementation and interpretation, we made a baseline assimilation sequence in which the only satellite data assimilated were from IASI, along with the standard non-satellite observations.

To prepare for node-based experiments, there were several practical aspects of the GSI and associated data processing that needed to be addressed. The main aspects are discussed below, omitting significant details for brevity.

1. CRTM-OSS was modified to give it the option to provide $\tilde{\mathbf{y}}$ and $\tilde{\mathbf{K}}$ as outputs, without transforming to channels. In addition, the layer optical depth, emissivity, and emissivity Jacobians were made available as outputs, as these are needed by the IASI data quality control (QC) process of the GSI.
2. The IASI data stream available at NCEP consists of apodized data and contains only 616 of the 8,461 IASI channels. To get access to the full channel set, we obtained IASI L1c data from the Comprehensive Large Array-data Stewardship System (CLASS) and converted the data into Binary Universal Form for the Representation (BUFR) files.
3. In an off-line process, we created BUFR files of IASI observations projected onto OSS nodes using the formula described above. In this conversion, we used a version of $\mathbf{R}$ in which the diagonal terms were the measurement error variances (D. Tobin, personal communication) and the off-diagonals were zeros. We will refer to this version as $\mathbf{R}_m$ hereafter. The measurement error covariance of the node radiances, $\tilde{\mathbf{R}}_m$, was computed by applying the OSS weights as shown above.
4. The baseline GSI processes 465 IASI channels through radiative transfer and QC, all of which are in IASI bands 1 or 2, and assimilates data from 150 of those channels, while the other 315 channels are just monitored. There are several criteria by which the IASI channel set was reduced to 150, the first of which is semi-subjective analysis based on information content (Collard, 2007; Gambacorta and Barnet, 2013). Then additional subjective processes have been applied at NCEP, toward eliminating channels in parts of the spectrum where radiative transfer models perform relatively poorly (e.g., strong non-LTE effects) and channels where the radiative transfer is strongly non-linear (including some water vapor channels) that have been found to interfere with convergence of the process that minimizes the variational cost function. One mechanism by which the criteria had been applied was analysis of observation-minus-background (O–B)

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statistics. To account for these practical considerations while still allowing experiments with node data and with an IASI channel set that had not had severe channel reduction, we first eliminated IASI band 3, thus avoiding non-LTE effects. Then we relied on O−B statistics that we generated for the full channel set and for node data (as a by-product of an experiment that assimilated only the baseline 150 channels), eliminating channels and nodes for which the rms O−B was exceptionally high in relation to nearby channels. This process resulted in 5,014 channels passed and 265 nodes passed.

5. In the GSI, the net combination of the components of IASI observation error (measurement, radiative transfer, representativeness) is derived from tabulated base observation error standard deviations (here called BOESDs) in brightness temperature units. BOESD data are provided for 150 assimilated IASI channels and 315 monitored IASI channels (465 channels in total) in IASI bands 1 and 2, but are not provided for the full channel set, as are needed for experiments with the full set of IASI channels and for node-based assimilation. Considering that the BOESD data were produced through a partly subjective process that could not be quickly replicated for the full channel set, we developed a regression equation to predict the BOESDs for any given channel or OSS node, where the predictors are the first 13 principal components of the channel or node brightness temperatures, and the PC transformation is based on the global *spatial*, location-to-location covariance matrix (i.e., not the more commonly used spectral covariance). This approach essentially extrapolates BOESDs from the 465 channels, using spatial variation of a channel's brightness temperature as a proxy for the channel's radiometric response to varying atmospheric temperature and water vapor.
6. The error variance for each specific measurement is obtained by multiplying the BOESD by an inflation factor, through the QC process, and the squared result can be represented as a diagonal error variance matrix $\mathbf{V}$. In channel space, the minimization of the variational cost function uses $\mathbf{R} = \mathbf{V}$. When running GSI with data on nodes, we use BOESDs for nodes (obtained as discussed above), and the QC process yields inflated errors $\tilde{\mathbf{V}}$. To obtain $\tilde{\mathbf{R}}$ (node space), one option is to scale $\tilde{\mathbf{R}}_m$ to obtain a matrix that has diagonal terms the same as $\tilde{\mathbf{V}}$ and has the same correlation as $\tilde{\mathbf{R}}_m$. A second option is to compose $\tilde{\mathbf{R}}$ by replacing the diagonal elements of $\tilde{\mathbf{R}}_m$ with the diagonal elements of $\tilde{\mathbf{V}}$. We tested both options, referenced below as methods 1 and 2, respectively. In either case, the mathematical equivalence between channel-based and node-based assimilation is compromised by the fact that the transformation $\tilde{\mathbf{y}}^{obs} = \mathbf{A}\mathbf{y}^{obs}$ (where $\mathbf{A}$ is a function of $\mathbf{R}$) must be performed before QC (because $\tilde{\mathbf{y}}^{obs}$ are inputs to QC), while QC then filters out some channels or nodes on an observation-by-observation basis.
7. The cost function minimization algorithm of the GSI operates on the inverse of the observation error covariance matrix. With the default, diagonal $\mathbf{R}$ in channel space, the

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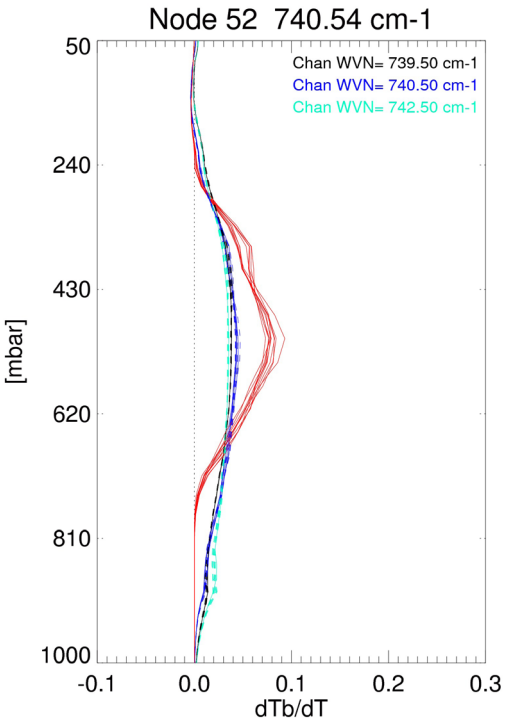

Figure 1. *Temperature Jacobians for an OSS node at 740.54 cm^{-1} (red) and for three nearby channels (black, blue, and cyan) for which the Jacobians peak at about the same pressure level. The 11 curves are for observations in the subtropical South Pacific on July 28, 2015.*

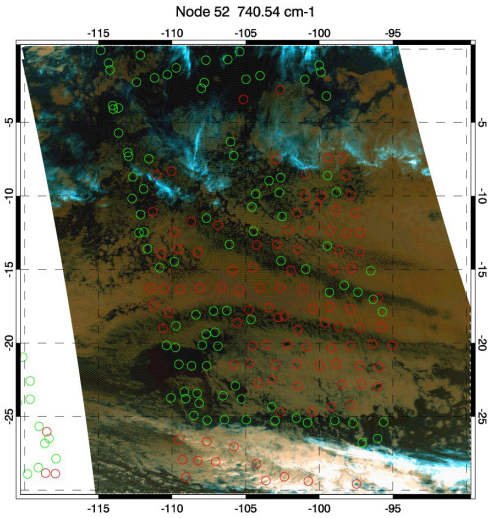

Figure 2. *July 28, 2015 image composite of Advanced Very-High-Resolution Radiometer (AVHRR) channels centered near 3.7 μm (red), 10.8 μm (green), and 12.0 μm (blue), whereby high, thin clouds appear cyan, low clouds appear reddish brown, and thick clouds appear white. IASI observation sites where the QC process passed the node at 740.54 cm^{-1} and also passed the associated channels (see Figure 1) are marked green, and sites where the node passed but the channels did not pass are marked red.*

inversion operation is computationally trivial. For processing the non-diagonal $\tilde{\mathbf{R}}$ in node space, a full matrix inversion step was introduced.

Aside from the revisions discussed above, the GSI treats observations on OSS nodes exactly as it treats observations on channels. For example, the adaptive variational bias correction (Zhu et al., 2014) and the QC processes operate without regard to whether the radiances represent channels or nodes.

With respect to making use of measurements above opaque clouds, we had found through prior one-dimensional variational (1Dvar) experiments that node-based retrieval was more robust than channel-based retrieval, because weighting functions (Jacobians) are more sharply peaked for monochromatic nodes than for channels. There are thus instances where there are nodes that provide upper-tropospheric information uncontaminated by low-level clouds, but there are no such uncontaminated channels. We found that such circumstances occurred within our assimilation experiments. For example, Figure 1 shows an instance where a node has peak sensitivity near 520 mb and virtually no sensitivity below 760 mb, while the spectrally nearby channels with similar peak pressures have significant sensitivity down to almost 1000 mb. Figure 2 shows many locations where the QC process filtered out these channels over low clouds while the QC passed (accepted) the node data for use in assimilation.

We have run a series of experiments to test the impacts of expanding the use of IASI data from 150 channels to the full information content of IASI bands 1 and

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2, apart from the O–B filtering (aspect 4, above), in the forms of and: 1) baseline 150 channels, 2) 5,014 channels, 3) 265 nodes with observation error method 1, and 4) 265 nodes with observation error method 2. A 7-day forecast was initiated once per day over the two-month experimental period. For analysis of results, we excluded the first two weeks, to ensure complete spin-up of the adaptive bias correction. The forecast error is based on comparing each forecast to the subsequent analysis that has the same valid time.

In plots of 500-mb geopotential height anomaly correlations (AC; Figure 3) and other metrics, the most prominent finding is that the assimilation with the "full" channel set (5,015 channels) performed worst (i.e., lowest ACs and highest errors). A likely explanation is that the assumption that the observation errors for channels are uncorrelated is significantly problematic when using many channels over this spectrum. Campbell et al. (2017) found that there were significant differences in forecast error (up to about 3%) depending on whether correlations were taken into account while assimilating 73 channels from IASI and 17 channels from the Advanced Technology Microwave Sounder (ATMS). Bormann et al., (2016) also found substantial benefits of accounting for correlations, by various metrics, while assimilating data from 191 IASI channels. We would expect the impact of correlations to be much higher with 5,015 channels. There is currently an effort underway at NCEP to implement a capability to account for observation error correlations (Bathmann, et al., 2017), as has been done at other forecast centers.

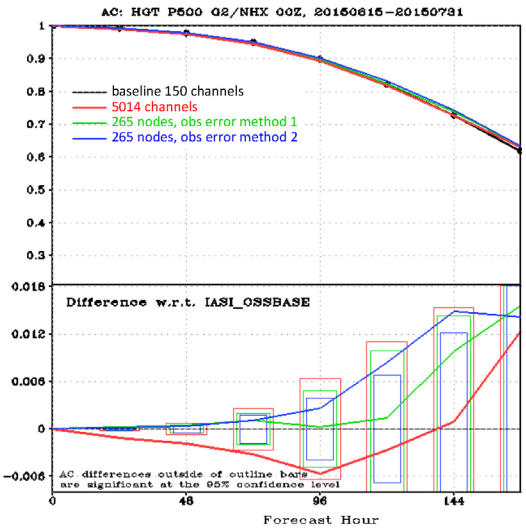

Figure 3. *Anomaly correlations for 500-mb geopotential height for the northern hemisphere for four experiments, as labeled. The lower frames show the differences of three experiments relative to the baseline 150-channel experiment.*

Among the metrics we analyzed for several model variables (geopotential height, temperature, relative humidity, and wind), there was variability among the relative performances of the 150-channel baseline and the two node-based assimilation methods. For example, node-based method 2 performed best with respect to northern hemisphere AC in 1-day to 6-day forecasts (Figure 3), while the baseline and node-based method 1 performed best with respect to relative humidity (RH; Figure 4). To get a broad view of performance, we prepared summary assessment metrics (SAMs; Figure 5) following the approach of Hoffman et al. (2017). Overall, method 1 for composing $\tilde{\mathbf{R}}$ for node-based assimilation performed better than method 2, and the baseline did relatively well for RH and for the southern hemisphere.

The finding that, for RH, the node-based methods were generally outperformed by the baseline may relate to a criterion of the channel reduction that was imposed on the baseline channel set but not on the node-

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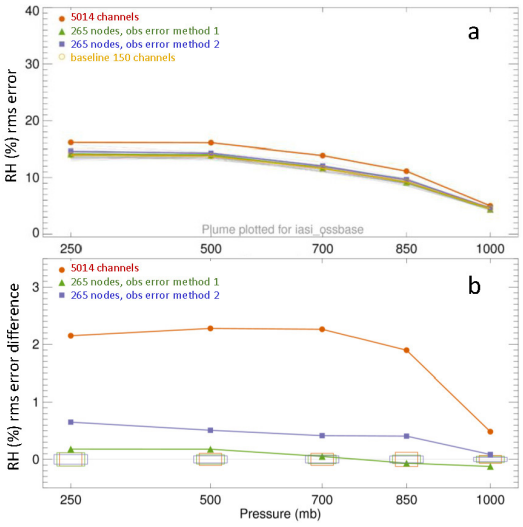

Figure 4. *Global RMS error of RH (%) at forecast hour 24, as a function of pressure, with plot b showing the differences, relative to the baseline, for the other three cases. In plot a, the gray lines represent all of the instances that went into the statistics for the baseline case. In plot b, the boxes indicate an estimate of the 90% confidence interval for significance of differences from the baseline.*

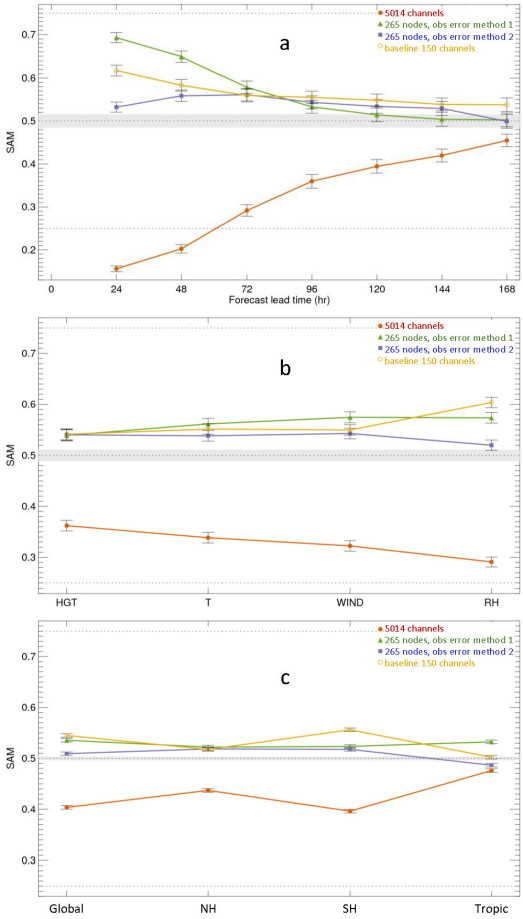

Figure 5. *SAM scores (normalized performance relative to the average of all cases) a) as a function of forecast lead time, b) by variable, and c) by domain. The data represented are pooled over all forecast cycles, lead times, variables, and atmospheric levels, except where an aspect is broken out across the horizontal axis. Higher SAM scores correspond to better forecast performance.*

based methods: elimination of instances with strongly non-linear radiative transfer, as mentioned above. Ultimately, the best solution would be to advance the cost function minimization algorithm so that highly non-linear channels or nodes do not degrade convergence. As an interim measure, a similar reduction criterion could be applied to nodes.

With regard to the fact that the baseline performed relatively well in the southern hemisphere, interpretation of the performance statistics is not straight forward because of a peculiarity of the analysis. In the southern hemisphere, a large majority of the assimilated data are from IASI, considering that no other infrared or microwave satellite sounder data were included. The forecast performance metrics are based on comparing an analysis of IASI data valid at one time with a forecast produced by starting from an analysis of IASI data at a prior valid time. In the hypothetical case where the method of using IASI data causes all channels to be excluded, the analysis step leaves the prior forecast unchanged and so forecast–analysis differences are zero. A method of using IASI data that introduces more information to the analysis can result in higher forecast–analysis differences, particularly if the forecast model has shortcomings that lead to systematic errors. In regions where the analysis is constrained by more diverse data sources, such as the northern hemisphere, forecast–analysis differences would generally be more indicative of analysis errors and their growth over time.

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A factor in the performance of the baseline relative to the "full" channel set and the node-based methods was that the channel filtering and the BOESD have been optimized (to some degree) for the 150-channel baseline but not yet for the other cases.

To get insight into how the assimilation computation time is affected by using the node-based approach, we gathered CPU time data from portions of the software that depend heavily on the radiative transfer model or otherwise depend on the number of channels. In particular, setuprad runs the CRTM-OSS forward model and performs QC on the observation data and intrad computes the gradient of the radiance observation terms, as part of the cost function minimization. For a batch of 10,748 IASI observations from one ±3-hr analysis time window, the setuprad time was 39,600 s for the "full" channel set run and 1,800 s for the node-based runs (rounded to nearest 100). The processes of setuprad operate on assimilated and monitored channels, of which there were 404 in the node-based runs, for which each node is treated as if it were one channel. The "full" channel set runs applied setuprad to 5,420 channels. The radiative transfer component of the processing was the same for all of these runs, because CRTM-OSS modeled the 5,420 channels from calculations at the same 404 nodes. The extra time for the channel-based runs included projecting radiances and Jacobians from nodes to channels, which depends on the numbers of nodes and channels and other factors (Eq. 3 of Moncet et al., 2015) and included performing QC on 5,420 channels versus 404 nodes. The ratio of the computation times (39,600/1,800=22.0) is considerably higher than the ratio of channels to nodes (5,420/404=13.4), due to the nodes-to-channels projection step that is not needed when the whole process happens in node space. The intrad time per batch was 2,900 s for the "full" channel set run and 82,300 s for the node-based runs, while intrad operates only on the assimilated channels or nodes. The vast majority of the intrad time for the node-based runs was used for the inversion of $\tilde{\mathbf{R}}$, as shown with another test where we treated $\tilde{\mathbf{R}}$ as diagonal, for which the intrad time was 160 s. In both cases where inversion operated on a diagonal matrix, intrad took 1.2 s per channel or node. When the GSI implementation of correlated observation errors is complete, the inversion distinction between channel-based and node-based approaches will be eliminated, and the intrad time will scale with the number of channels or nodes to first order (if Cholesky decomposition is employed to avoid explicit matrix inversion) or higher. While the time for the "full" channel set runs is inherently higher than for the node-based runs, the information content from the observations is virtually identical.

Overall, the results are encouraging, from the standpoint that the node-based approach provides positive impacts on the forecast for some metrics, regions, and lead times, despite the fact that there are aspects of the node-based processing that have not yet been optimized. Investigations of some of the performance issues discussed above could be subjects of follow-on work.

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MEETING REPORT

Marine Code Sprint Report

Eleven scientists and engineers gathered in the NCWCP building for 2 weeks of intense coding in the Joint Effort for Data assimilation Integration (JEDI) software framework, with the goal of populating the Unified Forward Operator (UFO) repository with additional operators to simulate ocean observations.

The team represented the Navy, NASA, NOAA, JCSDA core and the University of Maryland. At the end of the code sprint, five observation operators were added to the marine UFO repository: In-situ temperature, practical salinity, significant wave height, non-diurnal sea surface temperature (SST), diurnal SST operator and absolute dynamic topography.

Three of the newly added UFO's have all the functionalities needed to be used in the JEDI-based prototype 3DVAR currently in development for MOM6-SIS2 coupled ocean sea-ice model. With two previously developed observation operators, this code sprint brings the total list of marine UFO's to seven, five of which are in advanced prototype stage and integrated within the JEDI 3DVAR.

Summary of the 16th Annual JCSDA Science and Technical Workshop

The 16th Annual Science and Technical Workshop was conducted at NOAA's David Skaggs Research Center in Boulder, CO May 30 – June 1, 2018. Over seventy persons registered and took part in this year's workshop, which featured 30 oral presentations and 12 posters. Boulder proved to be a location with excellent facilities and inspiring scenery - as evidenced

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in the group photo - as well as one which spread the effort of traveling quite equitably among the participants.

Director Tom Auligne opened the Workshop with a presentation reviewing the mission, vision, and operation of the JCSDA, a summary of the accomplishments of the previous year, and a high-level review of the Annual Operating Plan (AOP) for 2018, which began to be executed on April 1. The importance of including only those activities that are truly joint and collaboratively pursued to be included in the AOP was re-emphasized. This was followed by a series of six shorter (15 minute) talks from the Executive Team members (or their delegates) describing the plans and anticipated issues for each of the JCSDA partners in 2018, and how these influenced their respective contributions to the Joint Center projects in the AOP.

Subsequent oral sessions were arranged based on JCSDA projects (Community Radiative Transfer Modeling and New and Improved Observations) or science priorities and similar topical themes, including assimilation of observations impacted by clouds and aerosols, diagnostics, advances in data assimilation methodologies (including but not limited to the JEDI project), all-sky and all-surface radiance assimilation, one devoted to the assimilation and impact of GNSSRO observations. All of these presentations were allotted 25 minutes to facilitate more detailed descriptions of processes, analyses, and results, and still have adequate time for questions and comments. The twelve posters generally mapped into the same categories, and thus were ideal for provoking extended conversations on the afternoon of Wednesday, May 30.

One of the challenges of conducting an annual workshop is devising ways to keep the program fresh from one year to the next. Taking into account the adoption a year ago by the JCSDA Management Oversight Board of a new concept of operations built around the core-managed projects, it was timely to reconsider how to measure success in the JCSDA. A five-person panel was convened to lead a 1-hour discussion on this topic, with ET member Kevin Garrett serving as moderator. The panel consisted of two JCSDA "internal" representatives, T. Auligne and H. Shao, an academic contributor, Z. Pu, and two individuals providing industrial/private sector perspectives, S. Tucker and R. Kursinski. A number of themes emerged, including the need to make better use of the academic sector (and to foster that collaboration by re-newing federally funded opportunities (FFOs) for universities by the Joint Center in the future). The need for metrics to be tangible, and thus reasonably straight-forward for assessment, was also raised, and it was noted that this would be more in-line with a European approach emphasizing requirements, rather than an approach based on goals and objectives. One example of a tangible, readily quantifiable metric raised is speed - that, tracking and reducing the time it takes new observations or methodologies to move from research to operations.

Thanks are due to all of those who contributed talks, posters, questions, and comments to make this a successful and forward-looking forum. Likewise, the JCSDA executive team

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members and project leaders are to be thanked for chairing sessions during the Workshop, keeping the program on schedule and facilitating productive discussions. Special gratitude is reserved for those who worked unstintingly to ensure that preparations for every logistic aspect were made in advance, including registration, access coordination with NOAA security, meals, audio-visual support, poster mounting, and evening gatherings. For this, recognition goes to Heidi Allen of UCAR/CPAESS, Sandra Claar and Suryakanti Dutta of the JCSDA, and Mike Mascola, Dale Perry, Andre McClain, and Zachary Wilson of NOAA/ESRL.

PEOPLE

Welcome Stephen Herbener

Stephen Herbener joined the JCSDA in Boulder in December 2017. He is a software engineer on the core team for the Joint Effort for Data assimilation Integration (JEDI) project. Stephen is responsible for the development of the Interface for Observation Data Access (IODA) subsystem of JEDI. The IODA subsystem handles the storage, both file and in-memory, of observation data, as well as access to those data within the JEDI system.

Stephen has a Bachelor's Degree in Computer Science from the University of Nebraska, a Master's Degree in Electrical Engineering from the University of Illinois, and has completed forty-five hours of doctoral studies in Atmospheric Science at Colorado State University (CSU). Stephen worked in the electronics industry for twenty-five years primarily as a software engineer developing tools to assist engineers performing circuit design and then made a switch to the atmospheric science community seven years ago. Prior to joining JCSDA, he was a research associate at CSU performing research on Saharan dust interactions with tropical cyclones and developing the Regional Atmospheric Modeling System, which is CSU's cloud resolving model.

Stephen is an avid amateur musician in his spare time. He plays the trumpet and has, over the years, been a member of concert bands, jazz bands, marching bands, brass ensembles, and orchestras. Currently, Stephen plays with the Foothills Community Orchestra. In addition to trumpeting, Stephen enjoys many outdoor activities including skiing, hiking, and camping.

Meet Dr. Mark Miesch

Dr. Mark Miesch joined the JCSDA in January 2018. As a core member of the JEDI (Joint Effort in Data assimilation Integration) team, he is helping to build a unified, next-generation software infrastructure for assimilating observational data into numerical weather models. The JEDI system will serve JCSDA partners, as well as the broader atmospheric science community, and will support both research and operations. The innovative, high-level C++ framework provides maximal flexibility for integrating new observations and models while maintaining optimal computational efficiency.

Mark is delighted to join the JCSDA team and is excited about this new direction for his career. His professional background is in solar physics, astrophysics, space weather, and computational fluid dynamics. Before joining JCSDA, he worked for over twenty-five years as a research scientist, seventeen of them at NCAR's High Altitude Observatory (HAO). After receiving his PhD in Astrophysical, Planetary, and Atmospheric Sciences (APAS) from the University of Colorado in Boulder, he did postdoctoral work at NASA GSFC (Greenbelt, MD) and the University of Cambridge (UK) before returning to Boulder and joining NCAR in 2001. Mark's research focused on developing global numerical models of solar internal dynamics that are in many ways analogous to global weather and climate models. He used these models to explore the origins of solar magnetism and large-scale meridional and zonal flows (differential rotation). In particular, Mark is the lead developer of the STABLE (Surface flux Transport And Babcock-LEighton) solar dynamo model that captures both the eleven-year solar cycle and the observed evolution of magnetic flux in the solar photosphere with high fidelity. Along the way, Mark acquired a diverse and valuable set of software engineering skills that are now serving him well as a member of the JEDI team.

Like many of us, Mark became interested in science out of curiosity. Why is the sky blue; why do stars shine... But as time passes, science in the service of society has become an increasingly compelling motivation for his work. Exploring the inner workings of stars is fascinating, but so is exploring the atmospheric dynamics of our own planet, and the latter has more bearing on peoples' daily lives. This is one reason why he feels fortunate and grateful to be a part of JCSDA and JEDI. But the wonder is still there. In addition to his research work, Mark has devoted countless hours over the years to education and public outreach (EPO). Active projects include serving as one of the lead organizers of the Boulder Space Weather Summer School, as a Space Sciences Department Associate at the Denver Museum of Nature and Science, and as a member of the Board of Directors for the educational non-profit National Space Science and Technology Institute (NSSTI). One of NSSTI's flagship projects is the Mobile Earth and Space Observatory (MESO), a "science center on wheels" equipped with scientific instrumentation and museum-grade exhibits that visits

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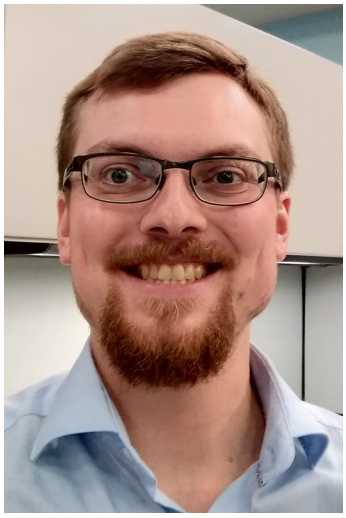
underserved schools and science festivals to engage students and the public in scientific exploration (http://gomeso.org). MESO's first deployment was to Nebraska in August 2017, to take measurements of the 2017 Great American Solar Eclipse.

Mark's passions outside of work are for family, travel, and wilderness. His wife is a solar physicist at NCAR/HAO, and he has two sons (ages 15 and 18) who are also fascinated by science. His older son will be enrolling in the Physics Department at the University of Colorado in fall 2018. Memorable travel experiences include safaris in Masai Mara, Kenya, communing with dolphins and albatrosses in New Zealand, approaching Machu Picchu from the Inca trail in Peru, snorkeling in Hawaii and Australia, bear encounters in Alaska, a solar eclipse in western China, sole occupancy of a French castle, libations to the Gods in Santorini and Delphi, St Matthew's passion in Salisbury Cathedral and, most recently, leaving his mark on the Arabian desert with a "sand angel."



Meet Dr. Patrick Stegmann

Dr. Patrick Stegmann joined the JCSDA in College Park, MD, in April 2018. He will support the continued development of the Community Radiative Transfer Model (CRTM) in the team of Dr. Benjamin Johnson and contribute to its seamless integration in the recent Joint Effort for Data assimilation Integration (JEDI) framework as a Unified Forward Operator (UFO) component.

Patrick began to work on the CRTM in his first year as a postdoc in the group of Dr. Ping Yang at Texas A&M University, where he calculated updated CRTM microwave scattering coefficients for snow and graupel using the Invariant Imbedding T-Matrix Method (IITM) and a Finite Difference Time Domain (FDTD) solver. The non-spherical particle model developed in this context featured a freely adjustable mass density and fractal dimension. Its scattering properties have been compared to common effective medium approaches for the particle refractive index, including Maxwell-Garnett and Bruggeman and the radiative transfer results computed using the CRTM have been compared against observations from the AMSU-A instrument aboard the Terra satellite.

Patrick holds a doctorate in the engineering sciences specific to Germany (Dr.-Ing.) and an M.Sc. and B.Sc. in Mechanical and Process Engineering from the TU Darmstadt. He was a member of the organizing committee for the joint ELS-XVII and LIP2018 conference in March and is a guest editor for the Journal of Quantitative Spectroscopy and Radiative Transfer. When he is not writing code, he is playing badminton and soccer.

Dr. Xin Zhang

Dr. Xin Zhang joined the JCSDA in Boulder in March 2017. He is one of the core team members of the Joint Effort for Data assimilation Integration (JEDI) project. The main objective of the project will be to define and implement the next-generation unified data assimilation framework for all JCSDA partners and the wider community. This framework will accommodate both operational and research needs through the use of modern software development techniques and tools. It will provide the infrastructure for exploring and addressing the grand scientific challenges for tomorrow's data assimilation and forecasting.

Xin has a Ph.D. in Atmospheric Sciences and almost 20 years' experience in data assimilation, NWP, and parallel computing. Before joining the JCSDA, he was a senior scientist at the IBM Research Laboratory-China and was responsible for the commercial NWP and air quality prediction operational system developments in IBM Great China Group. His main research interests are in data assimilation, and operational implementation of NWP system.

Dr. Zhang also spent seven years at MMM/NCAR, where he worked as the system manager of WRF Data Assimilation System (WRFDA). He oversaw the developments of 4D-Var in the WRFDA and led the efforts to development of an adjoint of the WRF model. Before joining NCAR, he spent three years at IPRC/University of Hawaii at Manoa, working on the data assimilation of tropical cyclone with MM5-4DVar.

Xin enjoys travels, watching movies, and playing soccer when he was young. Programming and exploring new technology are hobbies too.

EDITOR'S NOTE

Note from the Editor

Driving from Boulder to the Denver airport after the JCSDA Annual Science and Technical workshop, I found myself singing along to an old song on the (satellite) radio, "Roll out those lazy, hazy, crazy days of Summer." It's a catchy tune, of course, but it's likely that the coming months will be more crazy than lazy for people working in and with the Joint Center, some well-deserved vacations notwithstanding.

The Annual Operating Plan for 2018 has been completed and execution of tasks under all of the projects is underway. The Joint Effort for Data assimilation Integration (JEDI) and the Sea ice and Ocean Coupled Assimilation projects garner a great deal of attention as the newest efforts, and as new staff have been dedicated to them and considerable software developed during the past year, and for the promise they offer to provide community-wide tools and infrastructure to enhance satellite DA in the future.

Meanwhile, the results achieved through the older, "traditional" projects - the Community Radiative Transfer Model,

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Impact of Observation Systems, and New and Improved Observations, continue to be focused on supporting the accelerated and improved use of research and operational satellite data in the partners' operational model predictions. And indeed, there are numerous satellite launches looming in the near future, including COSMIC-2, Metop-C, and ESA's ADM/Aeolus Doppler Wind Lidar mission. In addition, GOES-17 observations are being evaluated and validated for operational testing and use. All of these points toward a busy and productive Summer.

Please remember, too, that from January 6-10, 2019, the JCSDA Symposium will be conducted once again during the 99th Annual Meeting of the American Meteorological Society (AMS) in Phoenix, AZ. Winter may seem far away, but in fact the call for abstracts is already open (https://annual.ametsoc.org/index.cfm/2019/call-for-papers/) and closes on August 1, 2018. I encourage you and your colleagues to consider submitting papers and posters for inclusion in the Symposium, which provides an invaluable opportunity to share your work with the JCSDA and the larger satellite, data assimilation, and modeling communities.

Finally, the triennial JCSDA Summer Colloquium will be held in Bozeman, Montana from July 22 - August 3. Scientists from all of the JCSDA partners and the broader community are preparing to deliver a program of lectures designed to introduce and connect the interdisciplinary building blocks of environmental modeling, satellites, remote sensing, and data assimilation for an audience of senior graduate students and early post-docs. The close interaction with students during this event has proved conducive to advancing their knowledge rapidly, and also to establishing relationships that consistently help the JCSDA partners identify top candidates to hire or to collaborate with in the near future.

SCIENCE CALENDAR

UPCOMING EVENTS

MEETINGS AND EVENTS SPONSORED BY JCSDA

DATE	LOCATION	TITLE
July 22-August 3, 2018	Bozeman, MT	JCSDA Annual Summer Colloquium 2018

MEETINGS OF INTEREST

DATE	LOCATION	WEBSITE	TITLE
September 17–21, 2018	Tallinn, Estonia	https://www.eumetsat.int/website/home/News/ConferencesandEvents/DAT_3647214.html	EUMETSAT Earth System Assimilation
November 5–9, 2018	Seoul, Korea	http://www.isac.cnr.it/~ipwg/	IPWG
December 10–14, 2018	Washington, D.C., USA	https://fallmeeting.agu.org/2018/	AGU fall meeting
January 6–10, 2019	Phoenix, AZ, USA	https://annual.ametsoc.org/2019/	99th AMS Annual Meeting

CAREER OPPORTUNITIES

Opportunities in support of JCSDA may also be found at http://www.jcsda.noaa.gov/careers.php as they become available.