DOI: 10.25923/xs16-ad39

JPSS BLENDED PRODUCTS WORKSHOP

August 30, 2018 College Park, MD

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Workshop Report – JPSS Blended Products

30 August 2018

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1. Introduction

The Joint Polar Satellite System (JPSS) Blended Products Workshop was held on the fourth day of the 2018 JPSS Science Teams Annual Conference, on August 30th, 2018, at the University of Maryland Earth System Science Interdisciplinary Center (ESSIC) in College Park, Maryland. The full agenda can be found in Appendix A. The workshop was attended by experts across agencies of satellite research and applications, such as the National Oceanic and Atmospheric Administration (NOAA)/the National Environmental Satellite, Data, and Information Service (NESDIS)/JPSS, Center for Satellite Applications and Research (STAR), Office of Satellite and Product Operations (OSPO), the National Center for Environmental Information (NCEI), the Naval Research Laboratory (NRL), Climate Prediction Center (CPC), Environmental Modeling Center (EMC), and European Centre for Medium-Range Weather Forecasts (ECMWF), and the NOAA-cooperative Institutes and industry partners (Appendix B).

The objective of the workshop was to determine the status of various algorithm approaches used to blend operational products; the emerging, new techniques being tested through developing products from the JPSS Proving Ground Risk Reduction (PGRR) initiatives; and to identify common tools and their potential use in NESDIS enterprise systems. The workshop was organized into six sessions and covered topics including the status of the blending products and methods, the strategy for improving future blended products; and the common tools that would be useful for future blended products and ripe for the enterprise system. A special lunch time brown bag seminar was presented featuring data fusion through synergy of data assimilation and remote sensing techniques. The workshop concluded with the discussions about the future improvements to meet end users' needs (data formats, metadata, latency, resolution, etc.).

2. Summary of the Sessions

Session 1 *Opening Remarks*

This introductory session laid the groundwork for the one-day workshop. Opening remarks were provided by Lihang Zhou (STAR, JPSS ADP lead), Mitch Goldberg (JPSS Program Scientist) and Ralph Ferraro (STAR, Hydrology Initiative). Then, Limin Zhao (OSPO, blended and microwave Products Area Lead), provided a detailed overview of the current operational blended products (see Appendix C and D). There is considerable diversity among the various blended products in terms of parameters, methodologies and sensors used.

Session 2 *Blending Methods*

An overview of blending methods was given by Tom Smith (STAR) followed by a gap-filling methodology presentation by Xiaoming Liu (CIRA).

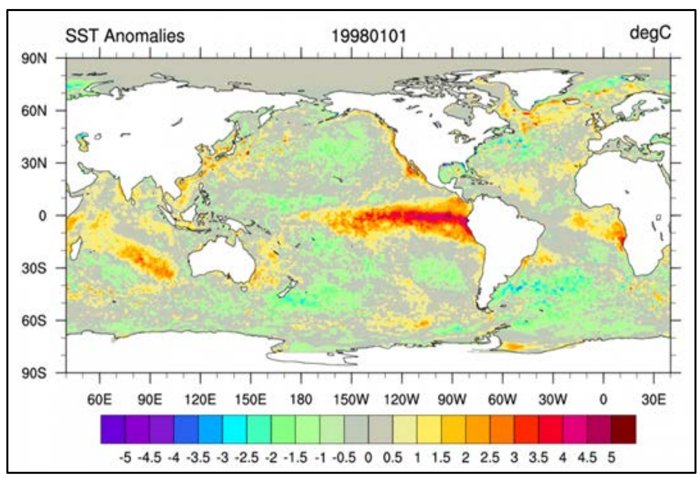


Figure 1- The OISST dataset, a 0.25-deg daily analysis of sea-surface temperature (SST) using optimal interpolation (OI) for climate users and applications. Blending the data required sensor bias estimates, noise/signal variance and knowledge of the different spatial scales. The inputs include AVHRR (changing to VIIRS), MW (for part of period), Ships (more important early) and Buoys (more important later).

Tom Smith described a number of common methods to blend products and used examples to illustrate the relative strengths and weaknesses. The different methods involve **Merging**: combining data within a grid square and/or **Interpolation**: filling gaps between data (examples: linear interpolation is used when data is dense and with comparable quality, Optimum Interpolation and statistics are used when sparser data of different quality is being combined, Variation Methods (nD-Var, for assimilation) are used to simplify OI statistics and process faster when data are dense, Morphing Methods are used to morph between high-quality observations using supplemental data, and Machine

Learning is used for tuning and adjusting on the fly). A sample blended dataset is in Figure 1.

Some key points discussed during this talk included:

- With dense-enough data almost any method will work
- Most methods require a non-satellite-based measurement to provide confidence in the accuracy of the blend
- Inter-satellite biases should be removed in analyses intended for climate studies
- The attributes of the datasets, assumptions made and how they may or may not complement each other need to be analyzed prior to blending
- Users wants and needs are important to consider when blending and significant work is needed for verifying what requirements are important to avoid overly complicated or overly simplified end products

The second presentation by Xiaoming Liu (CIRA) described an application using a Data INterpolating Empirical Orthogonal Function (DINEOF) method to fill in data voids in ocean color satellite products. The DINEOF was applied to VIIRS-derived global level-3 9km EDRs to generate daily, 8-day, monthly global level-3 binned ocean color data. To validate and evaluate the gap-filled data, a set of pixels in the VIIRS images were selected randomly and withheld from the DINEOF process, so that the reconstructed pixels could then be compared with the original withheld data.

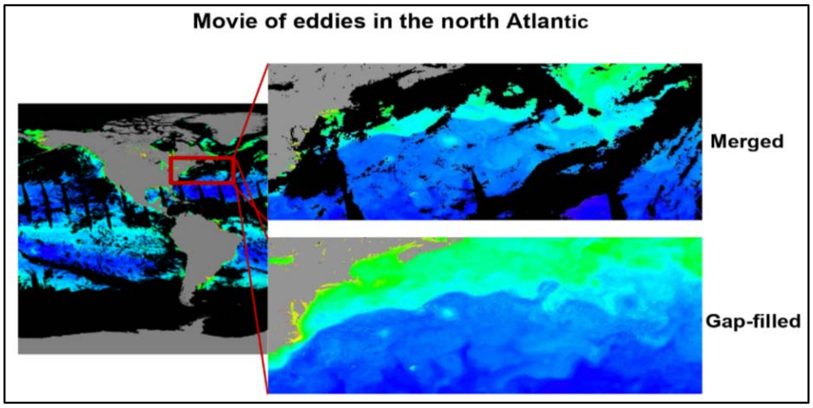


Figure 2-- Snapshot of Ocean Color movie showing merged product and gap-filled DINEOF product at the same time.

A few notes on the results include:

- Oligotrophic areas, where there are very low values of chlorophyll, did not have as high a correlation with the withheld data as did non-oligotrophic areas (to be expected)
- 16 zonal sections were reviewed for correlations.
- Overall, the method produced gap-filled meso-scale and large-scale spatial ocean features and captured interesting temporal variations of the features. There was

some discussion on how the method worked and ways to possibly improve it, depending on the intended use of the results, as well as whether the methodology should be different between gap-filling (no-data) and filling in areas where there are bad data due to sun-glint.

- The DINEOF method keeps the number of pixels used for weighting.
- The presentation included helpful side-by-side animated comparisons of the input data that was being merged with the resulting gap-filled product. One topic of discussion was that many technical users would rather not have a gap-filled product because they are concerned that blending will provide misleading information depending on how the gaps are filled. The animated side-by-side comparisons are particularly helpful for those users.

Some key takeaways from this session were:

- A single methodology for blending is not suitable for all applications, and the best method for an application depends on data density and other data qualities
- Blended animations can be powerful tool for showing the quality of a blended product, and it can be a helpful for technical users to include on the same page the individual datasets being merged. That way if they have questions about where some feature came from they can easily determine the answer. Also important is to have metadata (age of pixels, number of pixels that contributed to weighting, sensor contributions, quality flags of input data, etc.) available and easy to find.

Session 3 *Composite Products*

This session focused on composite products, total ozone, blended biomass burning, and multi-platform tropical cyclone surface winds.

Larry Flynn described the attributes of the Total Ozone Analysis from Stratospheric and Tropospheric (TOAST) Satellite product (Figure 3), which include:

- The TOAST algorithm is used for total ozone (including the troposphere), NUCAPS has replaced inputs formerly from TOVS.
- TOAST uses Ozone derived from various sensor types; some are used from hyperspectral IR sensors such as CrIS while others use the SBUV.

- The stratosphere total is assumed to be good to get the troposphere, SBUV/2 is used in the stratosphere. Figure 3 shows the SBUV 12-layer input vs. ToAST SBUV-2 analyzed images on September 3, 2013.
- There are four versions of TOAST: TOAST, eTOAST, nTOAST, ITOAST, each is derived from different satellite and input data.
- The blending method transforms data to a common scheme, they are combined and they transformed back to a common grid.
- In the future TOAST will be used, with a confidence map.

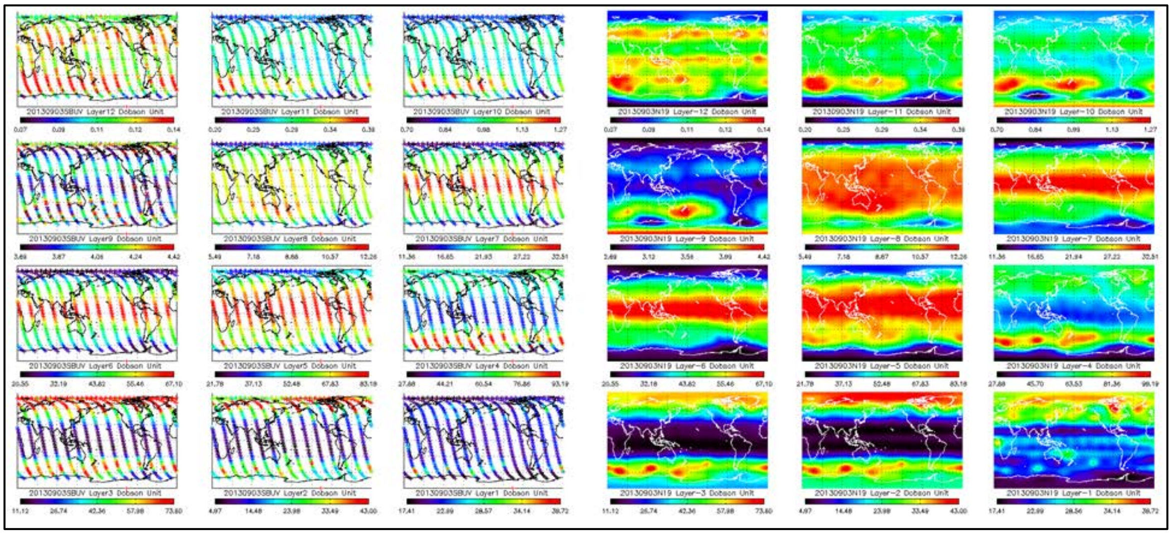


Figure 3 - SBUV 12-layer input (left panel) vs. TOAST SBUV-2 analyzed (right panel) on September 3, 2013.

Shobha Kondragunta summarized the Global Biomass Burning Emissions Product:

- The Global Biomass Burning Emissions Product (GBBEPx) is an operational product used by NCEP NGAC v2 aerosol model
- It uses measurements from various geostationary satellites and different low earth orbiting satellites. The data are combined to develop the diurnal cycle which is then used to generate the various emission products.
- GBBEPx categorizes emissions from fires, which are estimated to cause 250,000 excess deaths / year.
- The five types of fires are peat/forest/savanna/trash and agricultural.
- MODIS is used as the truth; the NASA algorithm has been ported to OSPO.
- Fire location, radiative power and duration are brought into models via satellite measurements. Other parameters such as plume injection and aerosol composition are also needed but are not currently used.

A key discussion topic was related to the funding of blended products. Despite the clear operational users there is still no funding to include GOES-16, GOES-17, Himawari-8 and

Himawari-9 inputs. There needs to be a way to fund this type of work for blended products. Potentially the NESDIS budget line reorganization (to change funding to be based upon “LEO” or “GEO” rather than for specific satellites) will help.

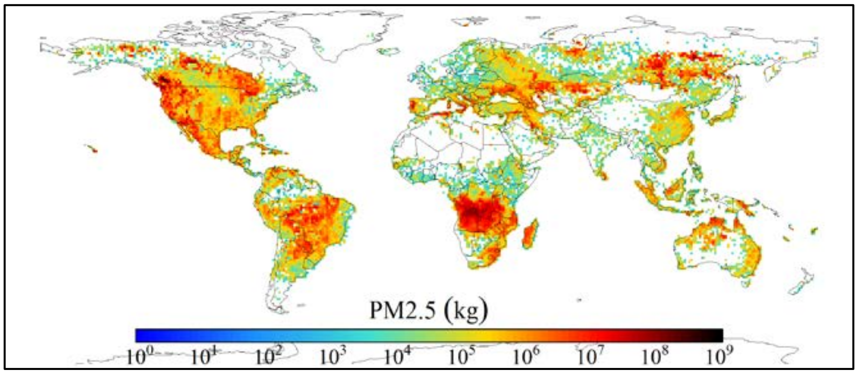


Figure 4 – Example of the GBBEPx Total PM2.5 for 15 June to 15 August 2017.

The final speaker of the session, John Knaff, described the characteristics of the Multi-Platform Tropical Cyclone Surface Wind Analysis (MTCSWA) Blended Product as:

- The MTCSWA product blends four types of winds (AMVs, microwave sounding-based winds, scatterometer, and IR-based flight-level proxy winds) to create a wind field product around tropical storms.
- Winds are adjusted to a common pressure level
- The variational analysis scheme is based on oceanography work (sparse data) and employs a cost function for speed and direction.
- The algorithm will be migrated to run on NDE.

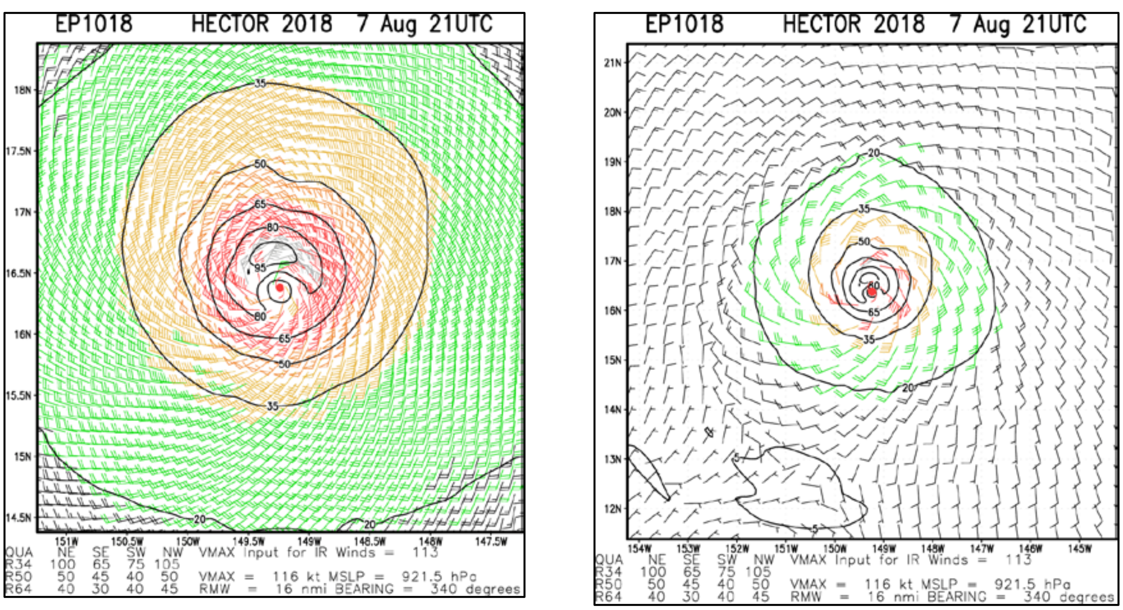


Figure 5 - Example of the MTCSWA Blended Product for Hurricane Hector at 2100 UTC on 7 August 2018.

The three diverse products shown in the composite section illustrate the importance of temporal sampling from polar orbiting spacecraft. Changes in satellite constellations and availability can impact the algorithm approach.

Session 4 *PDF Matching and OI Methods*

This session focused on PDF (Probability Distribution Function) Matching and OI (Optimal Interpolation) Products. Three primary products were highlighted in this session and are described below.

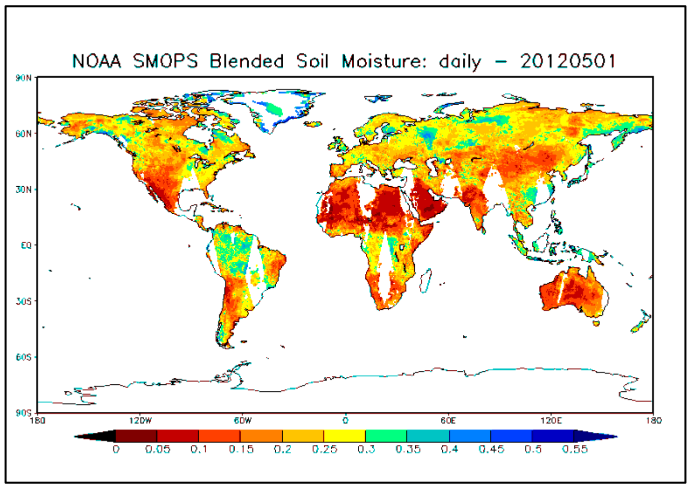


Figure 6 - SMOPS Blended Global product for 01 May 2012.

Xiwu Zhan described the blending approaches for Soil Moisture Operational Products System (SMOPS) – See Figure 6. SMOPS first performs a gap fill for spatial coverage since there is not daily global coverage from a single sensor. Knowing the error characteristics for each source are important. Then, SMOPS applies CDF (PDF) matching that currently is done with average weighting. Testing indicates that weighted averaging using the TCEM-based relative RMSE of individual sensor retrievals may generate better blended products. Testing for a Triple Collocation Weighing (TCW) Error Model is ongoing and is being compared to USDA SCAN sites. Most sites show a marked improvement in Soil Moisture performance but there are sites that have lower performance with the TCW.

Sean Helfrich spoke about a series of blended Snow and Ice Products. This included three specific products described below:

- Interactive Multi-Sensor Snow and Ice Mapping System (IMS) uses humans to determine the ice and snow extent, with the analysts selecting to either use automated data where performance is high or using imagery or surface reports where automated performance is low. Data sources have varied greatly over time. Replacement with automated products includes VIIRS snow and ice cover, NOHRSC map, GMASI, Blended Ice Concentrations (IMS internal files, and SAR ice classification)

- Global Multisensor Automated Snow and Ice Mapping System (GMASI) uses optical and microwave snow and ice data to gap fill snow and ice extent for a cloud free estimate of the snow and ice conditions. Currently does not use VIIRS, ATMS, or AMSR 2, but needs to continue production for customers
- IMS Blended Snow Depth uses 3 techniques for blending IMS/GMASI snow cover, passive microwave, and surface reports to generate a 4km global snow depth. Techniques include OI, downscale kriging, and fixed weighting. New ASMR 2 snow depth using surface report adjustments is in development.

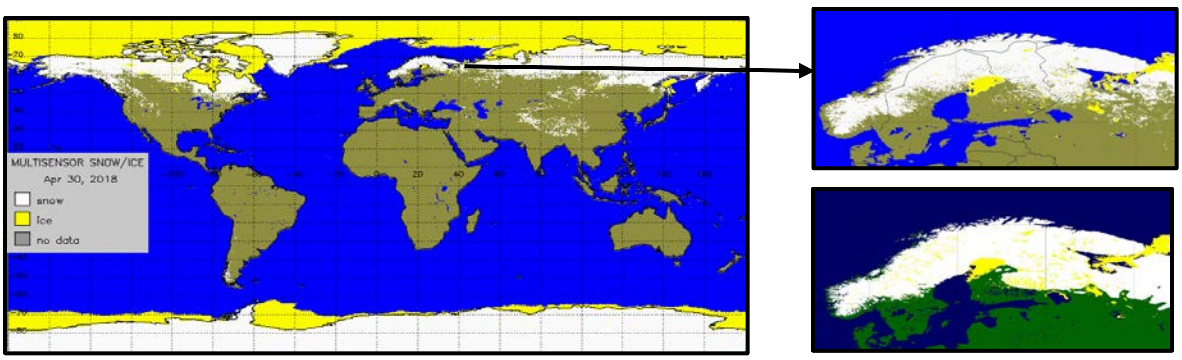


Figure 7 - The GMASI daily product for 30 April 2018. The right figures show a zoomed in region over Europe and compares the GMASI (top) to the IMS (bottom).

IMS will be migrating to NWS as part of NIC realignment in 2020. This means that the product will no longer be a NESDIS product. However, the NWS will be a customer for the NESDIS blended products. GMASI improvements (add SNPP/NOAA-20 VIIRS and GCOM-W1 snow and ice products, 1km resolution, and new formats (netCDF, HDF, geotiff) will be implemented during FY 2019-2020. Greater integration of Passive Microwave (ATMS, AMSR) + VIIRS + SAR + Scatterometry + GEO + Altimetry products is planned to improve accuracy and customer support.

The last speaker of the session was Eileen Maturi, who spoke on the Geo-Polar Blended Sea Surface Temperature (SST) Analysis – See Figure 8. Characteristics of the product include:

- Uses Geo and Polar platforms to generate a more spatially and temporally SST analysis, then is possible with a single sensor.
- The method employs a recursive estimator which emulates the Kalman Filter and uses data-adaptive correlation length scales to provide a reasonable balance between noise reduction and detail preservation

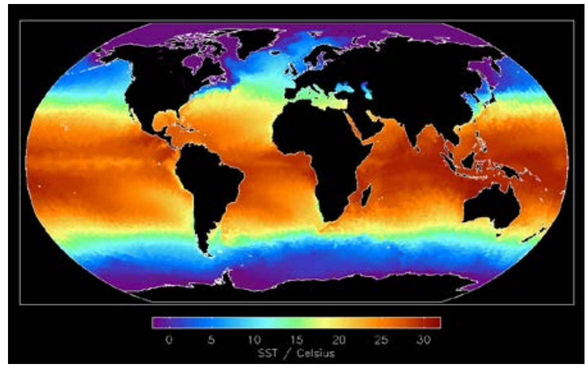
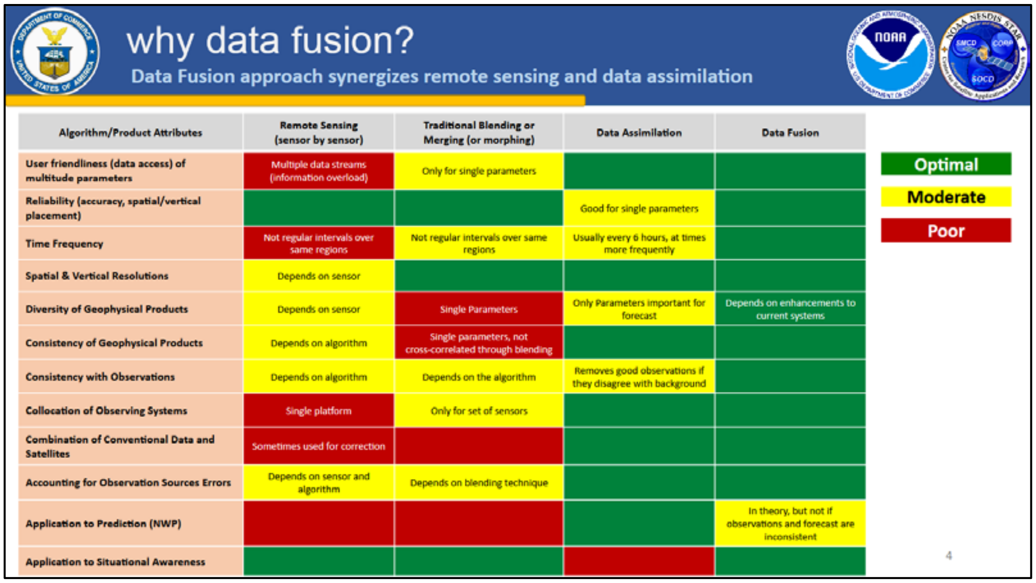


Figure 8 - Example of the global Blended SST product.

- There are 3 operational (24/7) products generated, a Blended Day/Night, Blended Night only, and Blended Diurnally Corrected.
- They use STAR SQUAM web site to evaluate the performance of the products
- Future products involve Improvement of the diurnal warning model, regional analyses, Arctic SST, an overhaul of bias correction methodology, and the reprocessing of historical data.

Brown Bag Seminar *Environmental Data Fusion*

Kevin Garrett (STAR) provided a summary of current work as part of STAR's Environmental Data Fusion (EDF) project, which offers a unique approach to blending of geophysical parameters derived from satellite observations. The approach synergizes existing remote sensing algorithms and global data assimilation applications, to create a completely unified, observation-weighted analysis. Figure 9 illustrates the benefits from the EDF and key attributes improved over traditional remote sensing and blending approaches. These include timely global analyses based on observations from the global observing system (at hourly or sub-hourly intervals), the physical consistency between parameters horizontally and vertically (e.g. mass-wind), the physical consistency with the observations (e.g. convergence), and the consistency of error characteristics and quality control information provided to the users. Case studies involving severe weather events were used to demonstrate the utility of the EDF analysis through the AWIPS2 interface. Future effort on EDF involves increasing user engagement and exploring Artificial Intelligence/Machine Learning applications to improve the global analysis and the user experience.



why data fusion?

Data Fusion approach synergizes remote sensing and data assimilation

Algorithm/Product Attributes	Remote Sensing (sensor by sensor)	Traditional Blending or Merging (or morphing)	Data Assimilation	Data Fusion
User friendliness (data access) of multitude parameters	Multiple data streams (information overload)	Only for single parameters		
Reliability (accuracy, spatial/vertical placement)			Good for single parameters	
Time Frequency	Not regular intervals over same regions	Not regular intervals over same regions	Usually every 6 hours, at times more frequently	
Spatial & Vertical Resolutions	Depends on sensor			
Diversity of Geophysical Products	Depends on sensor	Single Parameters	Only Parameters important for forecast	Depends on enhancements to current systems
Consistency of Geophysical Products	Depends on algorithm	Single parameters, not cross-correlated through blending		
Consistency with Observations	Depends on algorithm	Depends on the algorithm	Removes good observations if they disagree with background	
Collocation of Observing Systems	Single platform	Only for set of sensors		
Combination of Conventional Data and Satellites	Sometimes used for correction			
Accounting for Observation Sources Errors	Depends on sensor and algorithm	Depends on blending technique		
Application to Prediction (NWP)				In theory, but not if observations and forecast are inconsistent
Application to Situational Awareness				

Figure 9 - Attributes of remote sensing and DA products and the rationale for data fusion.

Session 5 *Advanced Methods*

The Session focused on the advanced blended algorithms that are under development through JPSS Proving Ground, including the blended algorithms for Sea Ice Concentration and Sea Ice Motion, MIMC TPW, Multisensor Blended Hydrometeorological Products, CMORPH, JPSS VIIRS Flood Map.

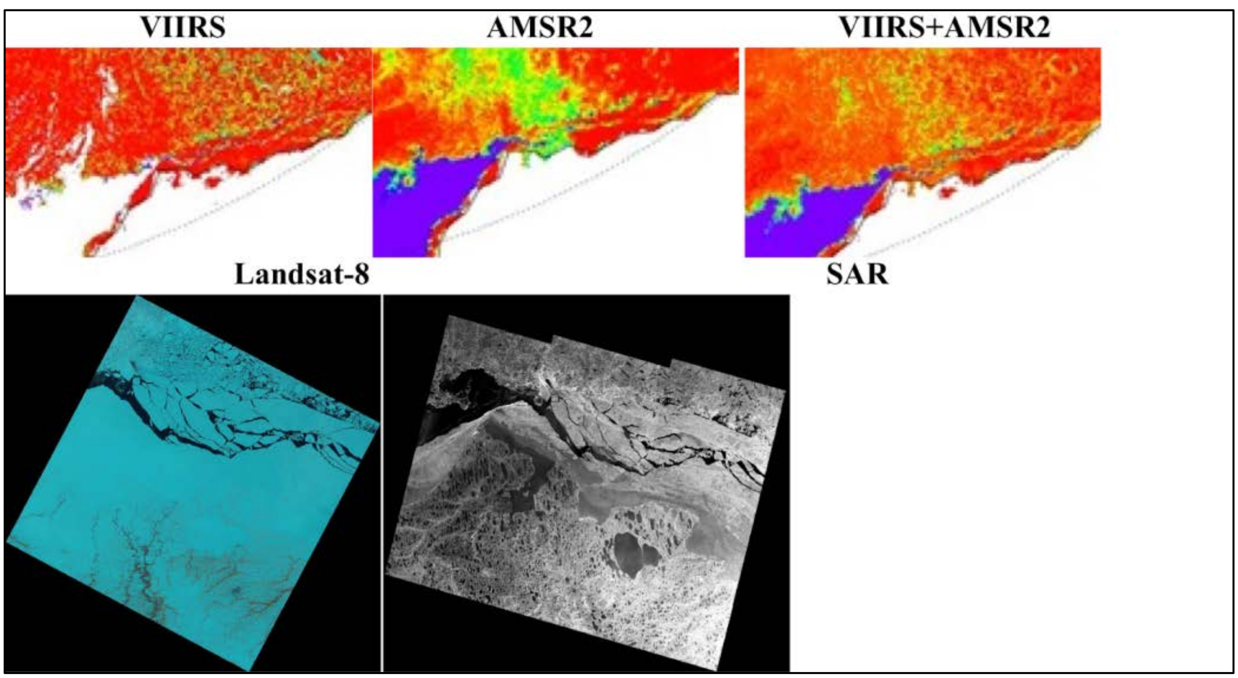


Figure 10 – Example of the blended VIIRS and AMSR ice concentration product (upper right) for 27 May 2017. The region is the Alaskan Beaufort Sea. The VIIRS and AMSR2 individual components are also show on the top. Landsat-8 (left) and SAR Sentinel-1A are shown on the bottom.

Yinghui Liu (CIMSS) discussed the blended Sea Ice Concentration product (**Blended VIIRS+Microwave Ice Concentration**), which takes the advance of high spatial resolution of visible and infrared (VIIRS) and all-weather capability of microwave (AMSR2) – see Figure 10. He described the Best Linear Unbiased Estimator (BLUE) that is applied to derive the blended ice concentration product from VIIRS and AMSR2, while taking their measurements precision accuracy into consideration. He noted that blended ice concentration from VIIRS and passive microwave provides high spatial resolution ice concentration under all-weather condition. Further improvement and evaluation is needed with new ice concentration products from sensors with very high spatial resolution, e.g. SAR.

Aaron Letterly (CIMSS) discussed the blended ice motion product that derived from VIIRS and AMSR2 (**Blended AMSR2+VIIRS Sea Ice Motion**) – See Figure 11. The sea ice motion uses a pair of satellite images to determine the displacement of ice features under clear sky conditions. The challenge is to track advection with multiple resolutions. The solution was to use a common intermediate resolution, and this also results in better coverage than with one sensor only. Both VIIRS and AMSR2 swath data are remapped onto a polar stereographic grid with a shared resolution (~1km). Ice motion is calculated, then combined with the arithmetic mean. Blended ice motion from VIIRS and AMSR2 provides high spatial resolution ice motion under all-weather conditions.

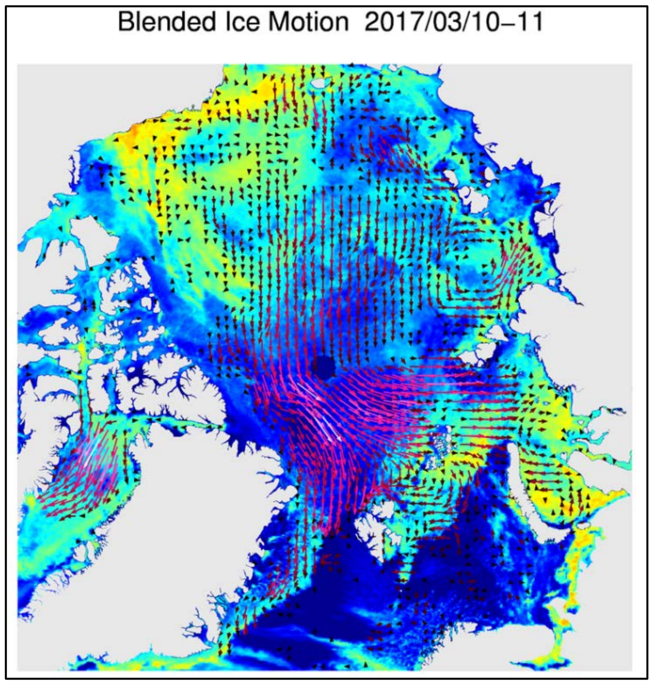


Figure 11 - Example AMSR-2 and VIIRS sea-ice motion for March 10-11, 2017.

Tony Wimmers (CIMSS) discussed the uniqueness of the **MIMIC TPW2** product (Figure 12), with emphasis on the importance of temporal continuity in using the morphing technologies. The MIMIC retrieval is pushed and pulled with a weighted average, while the weighting function comes from a climatology of specific humidity. They have advanced MIMIC-TPW to a multi-level real-time product that is compatible with CIRA's design. The multi-level advection terms come from a climatologically weighted average of GFS wind. The differences between a climate average weight and an actual weighting function is of a lower-order significance, so it allows for a simple treatment of wind to make blended advection possible. Tony Wimmers pointed out the importance of temporal continuity in blended products. This is an important feature when the end users want to study a product for transport and local changes in value with time. It is also a major reason to avoid multisensor compositing (e.g. microwave and infrared retrievals) in some situations. On the other hand, if end users are looking for an "ensemble" range of retrievals, then it is better to use multisensor compositing at the cost of less temporal continuity.

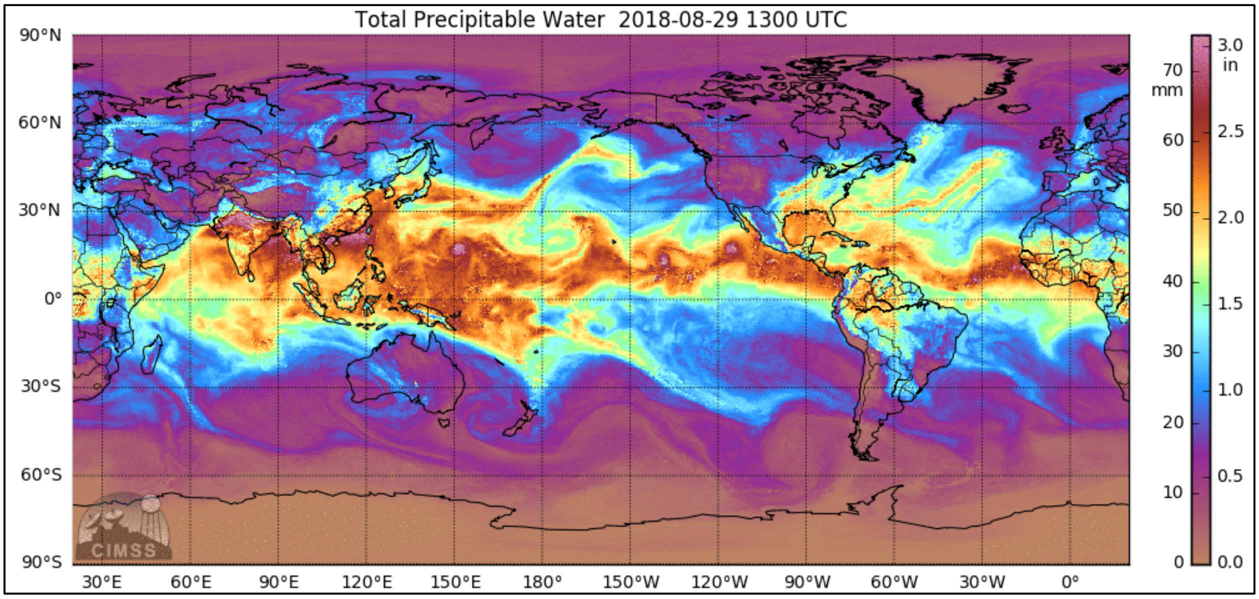


Figure 12 - Example of the MIMIC2 product for 1300 UTC 29 August 2018.

John Forsythe (CIRA) discussed the algorithm for the current operational blended TPW and RR products, and the layered PW products that are under development at CIRA (**Multisatellite Water Vapor and Rain Rates**). In the blended TPW product, a PDF matching method is used to adjust the retrievals from each satellite to the reference satellite. The histogram is dynamically derived using the latest five-day worth of data. The GFS wind field is also used for advecting the PW for the layered PW products. The data are composited together using either overlay (latest observation in operational) or average (development). The product runs on the Data Product and Error Analysis System (DPEAS) processing environment, which enables high-level functionality for real-time processing. This includes data retrievals and remapping.

The advected Layer Precipitable Water product (see Figure 13) is available on the layers Sfc-850, 850-700, 700-500 and 500-300 hPa, demonstrating with an example that it is can be used in NWS forecasts to show water vapor transports and Saharan Air Layer location. The product is now widely used and evaluated in over 16 NWS forecast offices as well as WPC and NHC.

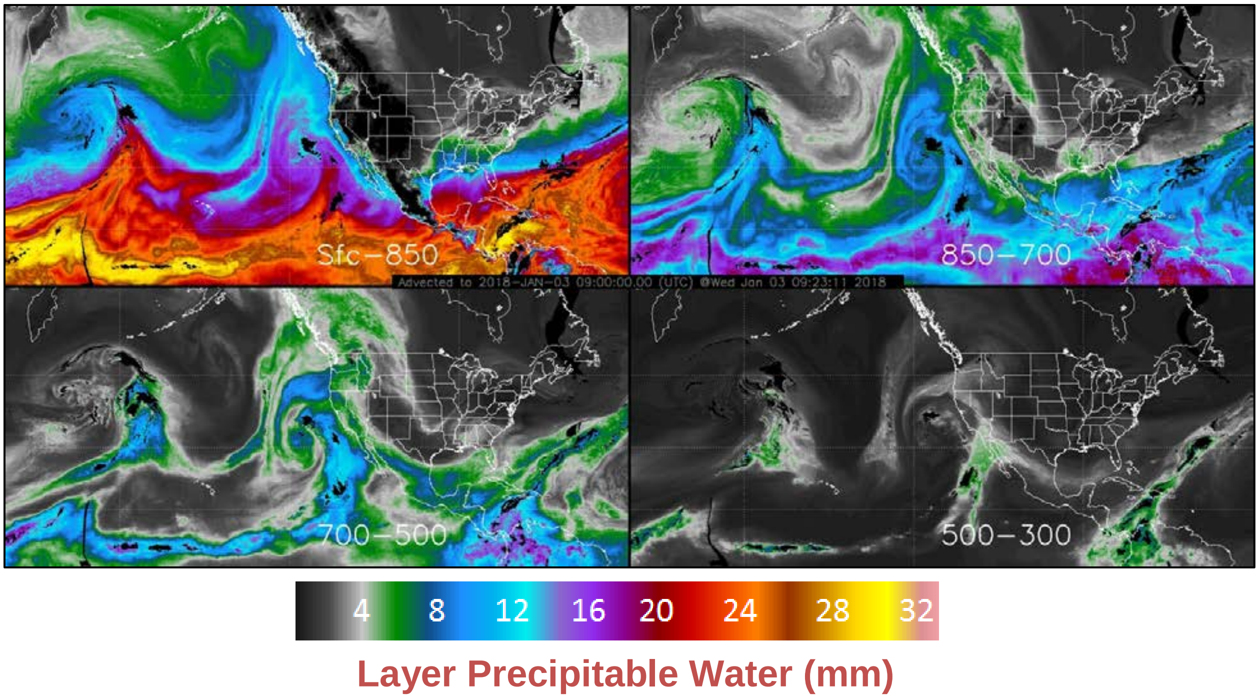


Figure 13 - Example of the advected layered precipitable water (ALPW) product from 09 UTC 3 January 2018.

Moving forward, the current JPSS PGRR project with CIMSS will integrate MIMIC advection approach into CIRA's DPEAS to generate next-generation advected TPW products (merger of MIMIC and operational blended TPW). An effort is also underway to integrate the enhanced temporal / spatial sampling of GOES-R into blended TPW under the GOES-R Risk Reduction project.

Pingping Xie (NCEP/CPC) presented the latest developments with CMORPH. These include improved quality control and quality assessment and the addition of snow fall rate to cover the solid precipitation (**CMORPH Blended Global Precipitation Products**) – See Figure 14. CMORPH's key elements are: satellite-retrieved instantaneous precipitation rates; cloud motion vectors to propagate the field of instantaneous rates; and in situ / long-term data perform bias correction. In CMORPH, PMW retrievals are propagated in both forward and backward directions along the motion vectors from their respective measurement times to the target analysis time. Precipitation rate inter-calibration is achieved with PDF matching: all microwave rates are PDF matched against reference L2 retrievals (TMI/GMI); IR based estimates defined through PDF matching against the inter-calibrated PMW retrievals. Accuracy is improved with a bias correction to rain gauge data, which has significant effects on the distribution of rainfall. User requirements led the development of three versions: a 45-minute, 2-hour and 24-hour latency product, to balance the needs for timeliness and accuracy. They are now developing a 2nd generation product that is global and works with all phases of precipitation.

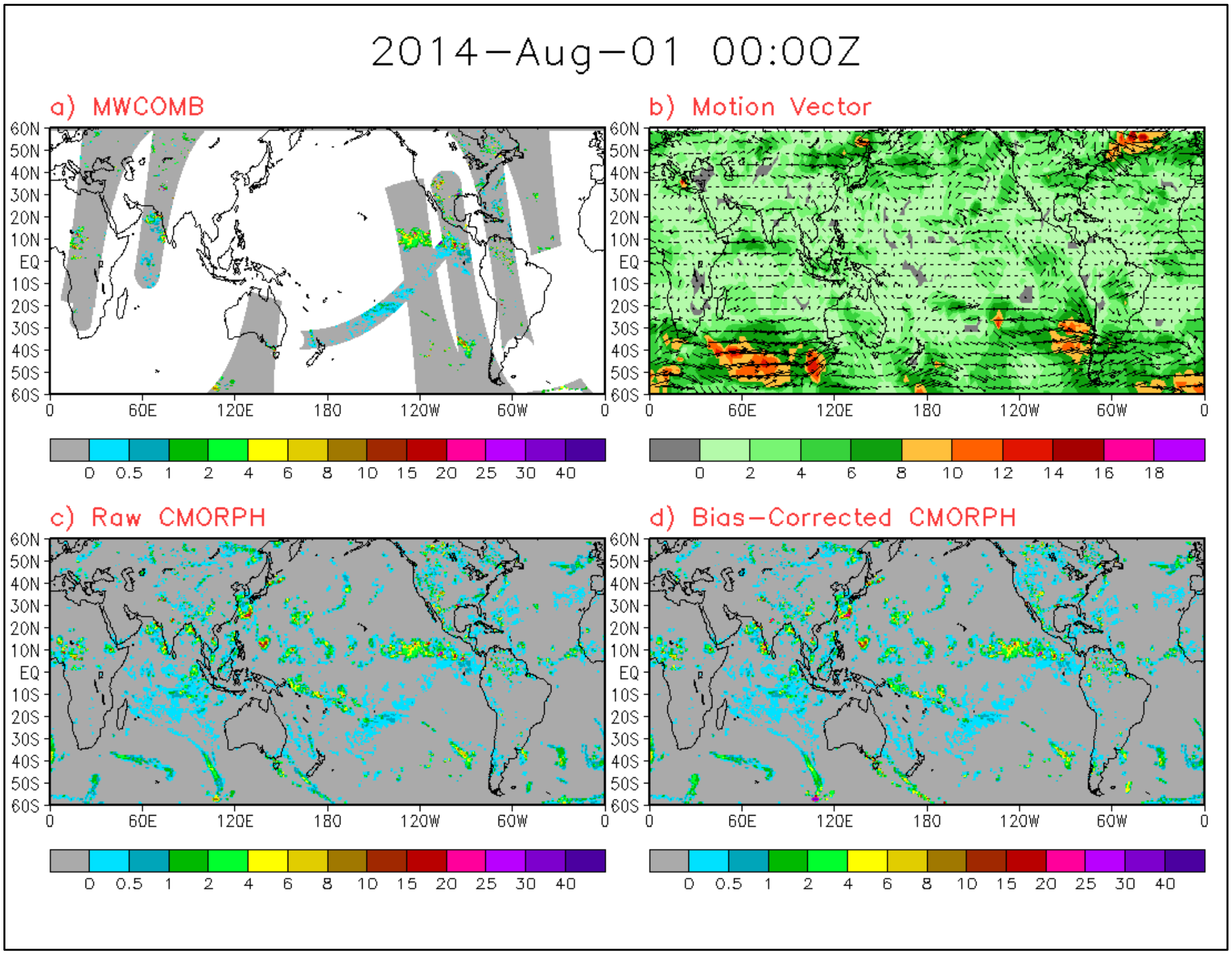


Figure 14 - Example of the various components used to generate the CMORPH product for 0000 UTC on 1 August 2014.

The last speaker of the session, Sanmei Liu (GMU) discussed the blended flood product from VIIRS and ABI and AHI, which takes advantage of high spatial resolution of VIIRS imagery, and high temporal resolution of ABI and AHI imagery (**Development of Geostationary-JPSS Flood Product for Flood Monitoring and Mitigation**). The product is based on the VIIRS global flood product, and gap-filled with geostationary satellite flood products from ABI and AHI over clouds/cloud shadows. There are five sources of data used for the flood mapping product, which allows the product to work at a higher resolution and a higher sampling rate. A simple nearest interpolation can blend the VIIRS, ABI and AHI flood products together, but does not produce smooth floodwater boundaries. The downscaling and upscaling process helps merge the floodwater fractions at different spatial resolution together and produce blended flood products with smooth floodwater boundaries. Efforts are ongoing to use the simplified downscaling /upscaling method instead of nearest interpolation to derive smoother floodwater boundaries from ABI/AHI in the blended products using high resolution DEM. Efforts are ongoing to improve the product quality by: (1) identification of sun-glint-contaminated water surface; (2) the use of more accurate techniques for cloud shadow removal.

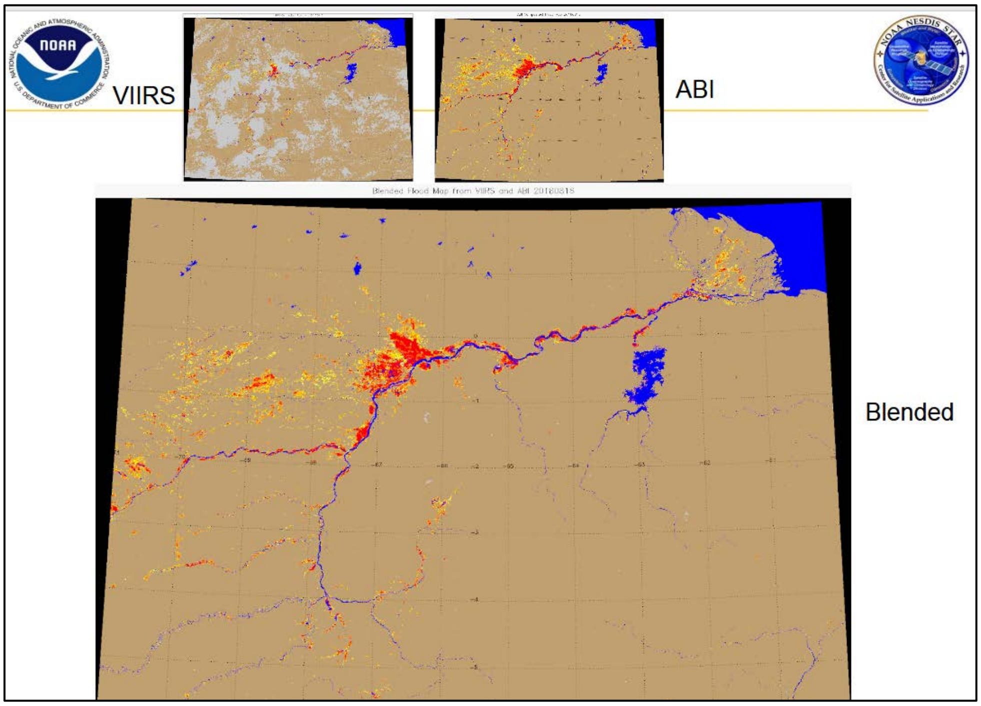


Figure 15 - Example of a merged VIIRS and ABI derived river flood product for 16 August 2018.

Session 6 *Open Discussion*

The workshop participants engaged in a discussion to determine some common threads and goals for current and future blended products at NESDIS. Some of the main points included:

- *Blending Methods and Tools:* Certain blending methods and tools are suitable for certain variables. A table showing all the EDR products along with (1) identification of the most suitable blending methods (geared toward areas where there is not already an official blended product) and (2) associated blending tools and output formats considering user recommendations. Attributes to include would be EDR, user requirements (e.g., time and space resolution, latency, etc.).
- *Baseline Products:* Develop or adapt baseline products for use in the generation of blended products. For example, the JPSS products now have reprocessing capability. NCEI has a climate record program that can provide a baseline for the blended products of interest. The goal is to ensure that if both input data streams and blended data are stored for climate applications then there is always a matching set (either they are updated at the same time or older versions of the input data are stored)

- *Transforming L2 into L3 products:* The sensitivities of the L3 products to input L2 products should be quantified (how drastic a change to L2 products can occur without disrupting the L3 users? What about latency – is there an improvement in blended products when receiving data from direct broadcast rather than orbitally?). These quantifications are useful for maintenance and sustainment activities as well as identifying the full benefit of operational upgrades to the L2 (or full pain of degradations) for resource identification.

- *Common Tools:* Identify any common tools that are applicable in the generation of blended products. What gap filling methods are available or considered? What are the scientific considerations (spatial distribution and temporal evolution of the retrieved products) in applying those methods? For example, gap filling using cloud motion vectors or simple advection models. What are the limitations on the use of the generated blended products (e.g. benefits are limited to qualitative applications and animations but not for quantitative use)?

- *Testbed:* An area is needed to test different blended algorithms (e.g. compare two gap filling methods) in generating a blended product. An environment with numerous software packages and tools is needed to promote data, tool and software discovery and reuse. There may be opportunities as the STAR environments migrate toward cloud environments in the future per NOAA goals.

- *Gap filling:* More work is needed to quantify the benefit of using overlapping orbits for gap filling (S-NPP and JPSS-1, GOES-E and GOES-W). For polar orbits such as S-NPP and JPSS-1 one satellite may be looking at a ground scene with a large scan angle (that makes the field of view (fov) resolution coarser) and the other satellite may be viewing the same ground scene at nadir (making the fov resolution finer); there is not a summary available describing the benefit of this to gap-filled blended products. Similarly, there is not a summary available for the benefits to blended products when GOES-E and GOES-W are able to view the same area at different angles. In both cases several blended products are taking advantage of overlapping orbits which would be inputs into a summary paper. Without a quantification of the benefits the proper allocation of effort to obtaining and using the data is not possible.

- *Validation and R2O:* It is hard to validate L3 blended products despite using validated L2 input data products for blended product generation. Blended products use the L2 input along with normalization or other techniques to bring the input data sets in conformity. For example, we may need to unravel radar composites to mimic ground truth in validating a blended rainfall product. Typically, the algorithm maturity levels and associated technical and programmatic oversight are not used to describe blended products. NESDIS and NWS have significant flexibility to determine if a blended product is mature enough for operations. There may be benefit to standardizing this process to ensure there are no gaps due to a diffusion of responsibility for the product.

- *Operational considerations:* The PGRR blended TPW products (e.g., CIRA/Forsythe and CIMSS/Wimmers) are now funded to merge their best attributes as opposed to funding both separately. The hypothesis is that NOAA/NESDIS should not be funding more than one blended product per environmental variable. This activity should be closely watched to see if it should be emulated in other areas where numerous research groups are blending.

3. Summary

A productive, informative and useful one-day workshop on JPSS Blended Products was held on August 30, 2018. Approximately 50 product developers and users participated. The workshop provided an opportunity to review the current and emerging methods that are used to combine multiple satellite data sources to provide improved L3 products to a variety of users. In some cases, different EDR use similar approaches.

The workshop achieved its goal of communicating the different current and emerging methods to the community creating merged data products. It's important for those developing merged methods to clearly understand the full range of tools available to use the best methods appropriate for a data-merging project. Differences and similarities of methods, along with their strengths and weaknesses were discussed in order to help data-set developers decide on the best method for a particular application.

The discussion period identified several topics that should be pursued to help blended algorithm teams potentially improve their product lines. Additionally, topics were identified that can lead to better products for end users. Several actions were identified and are summarized below. A follow-on workshop will take place in the next 1 to 2 years.

The next workshop should focus on progress made in data blending since this last meeting. Progress may include planning and testing different methods and new merged analyses. Any new analyses developed since this workshop should be discussed, with a focus on how knowledge from the workshop contributed to the analysis development.

4. Action Items

1. Develop a matrix that identifies various blending methods and which EDR's they can be used for. Information in Appendix C is a good start. Document best practices for blended product metadata (ex. provenance of input data, blending technique, age of input data, primary sensor used in input data, number of points used for grid data) and visual display that allows users to identify the locations where blending is occurring and how it compares to the input data (ex. side by side movie loops – one showing blended product and the other showing input data as it comes in).

2. Working with end users, identify more specific requirements for JPSS Blended products (time/space attributes) and develop appropriate validation plans for real-time users and archive users as appropriate. Consider if there is a need to add blended products to JSTAR science maintenance pages/tools. Determine if resources exist to enact the plans.

3. Identify requirements for blended products not covered by JPSS Blended product list (e.g. eTRaP, etc.), update if necessary, and develop appropriate validation plans for real-time users and archive users as appropriate. Consider if there is a need to add blended products to existing science maintenance pages/tools. Determine if resources exist to enact the plans.

4. Exploit existing computing resources and JPSS supported staff to identify a testbed or testbeds where various blending schemes can be applied for existing and emerging blended products. Determine if resources exist to develop at least two software packages based upon the methods described in Appendix C that are ripe for a "tool box" (i.e., OI, interpolation, etc.) that could be used for other EDRs ("Blend Swap") to document the difficulty and impact of moving to more standardized blending techniques which could save costs for development/maintenance.

5. Present results to JPSS, GOES-R, Legacy product managers and SPSRB. Determine resources that might be available to pursue highest priority actions.

Appendix A – Meeting Agenda

Time	Presentations / Topics	Speaker	Affiliation
0845 - 0920	*Session 1 - Introduction*	**CHAIR** - Ralph Ferraro, Lihang Zhou	NESDIS/STAR
0845 - 0855	*Introduction and Logistics*	Ralph Ferraro	STAR
0855 - 0905	*Objectives and Goals - PGRR funded merging products*	Mitch Goldberg	JPSS
0905 - 0920	*NESDIS Operational Blended Products*	Limin Zhao	OSPO
0920 - 1000	*Session 2 - Blending Tools*	**CHAIR** - Ingrid Guch, Tom Smith	Aerospace; NESDIS/STAR
0920 - 0940	*Commonly used Blending Techniques*	Tom Smith/STAR	STAR
0940 - 1000	*Gap filling methods - DIN EOF*	Xiaoming Liu	STAR
1000 - 1015	*Break*		
1015 - 1115	*Session 3 - Composite Products*	**CHAIR** - Huan Meng, John Forsythe	NESDIS/STAR; CIRA
1015 - 1035	*Blended Ozone*	Larry Flynn	STAR
1035 - 1055	*Blended Biomass Burning*	Shobha Kondragunta	STAR
1055 - 1115	*Multi-Platform TC surface winds*	John Knaff	STAR
1115 - 1215	*Session 4 - PDF matching and OI Products*	**CHAIR** - Nai-Yu Wang, Sean Helfrich	CICS; NESDIS/STAR
1115 - 1135	*Soil Moisture*	Jerry Zhan	STAR
1135 - 1155	*IMS*	Sean Helfrich	STAR
1155 - 1215	*Blended SST*	Eileen Maturi	STAR
1215 - 1330	*LUNCH BREAK*		

1300 - 1330	*Brown bag seminar: Data Fusion through Synergy of Data Assimilation and Remote Sensing Techniques*	Kevin Garrett	STAR
1330 - 1510	*Session 5 - Advanced Techniques*	**CHAIR** - Limin Zhao, Tony Wimmers	NESDIS/OSPO; CIMSS
1330 - 1350	*Multisensor Sea Ice Concentration and Motion*	Yinghui Liu and Aaron Letterly	CIMSS
1350 - 1410	*MIMIC*	Tony Wimmers	CIMSS
1410 - 1430	*CMORPH*	Pingping Xie	NWS/NCEP/CPC
1430 - 1450	*Multisatellite Water Vapor and Rain Rate Products for Forecasters*	John Forsythe	CIRA
1450 - 1510	*Development of Geostationary-JPSS Flood Product for Flood Monitoring and Mitigation*	Sanmei Li	GMU
1510 - 1530	*Break*		
1530 - 1700	*Session 6 - Topical Discussions/Common Threads*	**CHAIR** - Lihang Zhou, Ralph Ferraro	STAR
1530 - 1645	*Discussions*		
1645 - 1700	*Action Items, next steps, etc.*		
1700	*Workshop Ends*		

Appendix B – List of Participants:

First name	Last name	Email Address	Organization
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Appendix C - List of NESDIS Operational Blended Products

Name	Satellites	Sensors	Latency	Algorithm Notes	OSPO	STAR	URL
Biomass Burning Emissions Product Application (emissions, fire radiative power, burned area)	GOES-15	Imager	daily	The blended biomass burning emissions (GBBEPx V2) is produced by simply averaging QFED, VIIRS emissions, and scaled GBBEP-Geo in a grid cell (0.25 degreex0.315 degree).	Hanjun Ding	Shobha Kondragunta	https://www.ospo.noaa.gov/Products/land/bbep2/
	Meteosat-11	SEVIRI					
	Terra	MODIS					
	Aqua	MODIS					
	S-NPP	VIIRS					
Blended Hydrometeorological Products - Blended Rain Rate & Blended TPW	GOES-15	Imager	3 hours	PDF match to remove bias; overlay or averaged for composite	Limin Zhao	Ralph Ferraro	https://www.ospo.noaa.gov/Products/bTPW/index.html https://www.ospo.noaa.gov/Products/bRR/index.html
	NOAA-15	AMSU					
	NOAA-18	AMSU, MHS					
	NOAA-19	AMSU, MHS					
	MetOp-A	AMSU, MHS					
	MetOp-B	AMSU, MHS					
	F16	SSMIS					
	F17	SSMIS					
	F18	SSMIS					
	S-NPP	ATMS					
	GCOM-W1	AMSR2					
	GPM	GMI					
Blended Sea Surface Temperature	GOES-15	Imager	12 hours - daily product	OI- the observations are weighted according to statistical information regarding their errors. The optimal interpolation method attempts to minimize the total error of all the observations to come up with an "ideal" weighting for the observations.	John Sapper	Eileen Maturi	https://www.ospo.noaa.gov/Products/ocean/sst.html
	Himawari-8	AHI					
	GOES-16	ABI					
	Meteosat-11	SEVIRI					
	Meteosat-8	SEVIRI					
	MetOp-B	AVHRR					
	S-NPP	VIIRS					

Ensemble Tropical Rainfall Potential	NOAA-18	MHS	2.5 hours	Ensemble - Weights depend on the latency of the TRaP (greater weight for more recent input) and optionally for the sensor used. The TRaP members based on MSPPS, MiRS and GHE retrievals from multi-satellites/sensors	Liqun Ma	Bob Kuligowski	http://www.ssd.noaa.gov/PS/TROP/etrap.html
	NOAA-19	MHS					
	MetOp-B	MHS					
	GPM	GMI					
	F17	SSMIS					
	F18	SSMIS					
	GOES-15	Imager					
	Meteosat-8	SEVIRI					
	Meteosat-11	SEVIRI					
	S-NPP	ATMS					
	GCOM	AMSR					
Global Mosaic of Geostationary Satellite Imagery (GMGSI)	GOES-15	Imager	~ 30 mins	Mosaic Imagery of channel brightness temperatures from different satellites/sensors within 30 mins window; Using the latest and nearest retrievals	John Paquette	Ken Pryor	https://www.ospo.noaa.gov/Products/atmosphere/mirs/sat_mhs.html
	G-16	ABI					
	Meteosat-11	SEVIRI					
	Himawari-8	AHI					
GOES/POES Arctic Composites Imagery Products	GOES-15	Imager	2 ~ 3 hours	Mosaic Imagery of channel brightness temperatures from different satellites/sensors within one-hour window; Using the latest and nearest retrievals on each pixel.	Hanjun Ding	Jeff Key	https://www.ospo.noaa.gov/Products/imagery/arctic/
	Meteosat-11	SEVIRI					
	Himwari-8	AHI					
	NOAA-18	AVHRR					
	NOAA-19	AVHRR					
	MetOp-A	AVHRR					
	MetOp-B	AVHRR					
	Terra	MODIS					
	Aqua	MODIS					
Global Hydro-Estimator Satellite Rainfall Estimates	GOES-16	Imager	20 mins	Mosaic imagery of rainfall estimate from multiple geostationary satellites; Using the averaged retrievals on the overlaid pixels after parallax adjustment.	Limin Zhao	Bob Kuligowski	https://www.ospo.noaa.gov/Products/atmosphere/ghe/
	GOES-15	Imager					
	Meteosat-11	SEVIRI					
	Himawari-8	AHI					
	Metosat-8	IODC					

Interactive Multisensor Snow and Ice Mapping System	GOES-15	Imager		Weighted combination from multi-data resources; The highest weights are given to fast ice and no ice, and minimal weighting is provided to pack ice.	John Woods	Jeff Key	https://www.ospo.noaa.gov/Products/land/snow.html
	NOAA-18	AVHRR					
	NOAA-19	AVHRR					
	MetOp-A	AVHRR					
	MetOp-B	AVHRR					
	F18	SSMIS					
	S-NPP	VIIRS					
	Terra	MODIS					
	Aqua	MODIS					
	Himawari-8	AHI					
	Meteosat-11	SEVIRI					
Multi-Platform Tropical Cyclone Surface Wind Analysis (MTCSWA)	GOES-15	Imager	1 hour	Composites; the analysis is constructed from a variety of satellite-based surface and near-surface winds and wind proxies that have been developed	Liqun Ma	John Knaff	https://www.ssd.noaa.gov/PS/TROP/mtcswa.html
	GOES-R	ABI					
	Meteosat-11	SEVIRI					
	NOAA-15	AMSU-A					
	NOAA-18	AMSU-A					
	NOAA-19	AMSU-A					
	MetOp-A	ASCAT					
	MetOp-B	ASCAT					
	S-NPP	ATMS					
Total Ozone Analysis	NOAA-19	SBUV, HIRS	daily	Vertical composite with Cressman Analysis	Vaishali Kapoor	Larry Flynn	https://www.ospo.noaa.gov/Products/atmosphere/toast/index.html
	S-NPP	OMPS, CrIS					
Soil Moisture Operational Products System (SMOPS)	GCOM	AMSR2	2.5 hours	PDF Match; Composite with average	Limin Zhao	Xiwu Zhan	https://www.ospo.noaa.gov/Products/land/smops/
	SMOS	SMOS					
	GPM	GMI					
	SMAP	SMAP					
	NOAA/Metop	ASCAT					
	GOES-15	Imager			Liqun Ma	Jeff Key	

Advanced Dvorak Technique (tropical cyclone intensity and center location	GOES-16	ABI	30~60 mins	A computer-based objective algorithm to estimate tropical cyclone (TC) intensity			http://www.ssd.noaa.gov/PS/TROP/adt.html
	Meteosat-8	SEVERI					
	Meteosat-11	SEVERI					
	Himawari-8	AHI					
	GCOM	AMSR2					
	GPM	GMI					
	DMSP F15	SSMIS					
	DMSP F17	SSMIS					
	DMSP F118	SSMIS					
HMS	GOES-15	Imager	2 ~ 3 hours	A visualization and editing GUI system/tool that allows interactive human analysis on fire and smoke from multi-sensors/satellites	Hanjun Ding	Jeff Key	https://www.ospo.noaa.gov/Products/land/hms.html
	GOES-16	ABI					
	NOAA-15	AVHRR					
	NOAA-18	AVHRR					
	NOAA-19	AVHRR					
	MetOp-A	AVHRR					
	MetOp-B	AVHRR					
	Terra	MODIS					
	Aqua	MODIS					
	S-NPP	VIIRS					

Appendix D – JPSS ESPC Requirement (JERD) Vol II 3.33 Blended Products

Focal Points	Product	Priority
Maturi	Blended SST (w/VIIRS)	Critical
Maturi/Harris	Blended SST (w/AMSR2)	Critical
Kondragunta	Blended Biomass burning (w/VIIRS)	Supplemental High
Key	Blended snow cover (w/VIIRS)	Supplemental High
Key	Blended snow cover (w/AMSR2)	Supplemental High
Ferraro/Zhao	Blended rainfall rate (w/ATMS)	Supplemental High
Ferraro/Zhao	Blended rainfall rate (w/AMSR2)	Supplemental High
Ferraro/Zhao	Blended TPW (w/ATMS)	Supplemental High
Ferraro/Zhao	Blended TPW (w/AMSR2)	Supplemental High
Flynn	Blended Ozone (w/OMPS NP)	Supplemental High
Flynn	Blended Ozone (w/OMPS CrIS)	Supplemental High
Zhan/Zhao	Blended soil moisture (w/AMSR2)	Supplemental High
Yu	Blended land surface temp (w/VIIRS)	Supplemental Low
Knaff	Blended tropical cyclone surface wind analysis (w/ATMS)	Supplemental High
Knaff	Advanced Dvorak Technique (w/AMSR2)	Supplemental High