Total Ozone Analysis from Stratospheric and Tropospheric (TOAST) Satellite Sources

Presented by L. Flynn

with contributions from J. Niu and the rest of the TOAST Team

Date: 2018/08/30

Outline

- Team Members and Affiliations
- Blended Product Development
  - Inputs needed for the Blended Product Algorithm
  - Technical Approach
  - Product Examples/Outputs
  - Product Evaluation/Validation/Tools
- Identified Issues/Risks/Mitigations
- Future Algorithm Improvements
- Documentation/website links

TOAST Blended Product Team

Algorithm Team Members

Role	Name	Organization	Task
Lead	Lawrence Flynn	NOAA/NESDIS/STAR	Manage development resources
PAL	Vaishali Kapoor	NOAA/NESDIS/OSPO	Manage implementation resources
Developer	Jianguo Niu	STAR/IMSG	Algorithm development and validation
Implementer	Venkata Rao Anne	OSPO/PSGS	Operational processing and monitoring
Support	Eric Beach	STAR/IMSG	Data management

Input Needs for the TOAST Algorithm

Required Satellite Data Products

	Data Product Name (Inputs)	Input Data Type (Satellite/Model Forecasts/*In-situ*)	Temporal/ Spatial Resolution, Format	Source(s)
1	V8Pro or V2Limb	NOAA-19 SBUV/2 PMF S-NPP/NOAA-20 OMPS EDRs S-NPP OMPS EDRs	Daily PMF Daily NetCDF Daily NetCDF	OSPO NDE NDE
2	NUCAPS Ozone	S-NPP/NOAA-20 CrIS EDRs MetOP-A,-B,-C IASI EDRs	Daily NetCDF Daily NetCDF	NDE NDE
3	TOVS Ozone	Metop-A HIRS EDRs	Daily	NDE

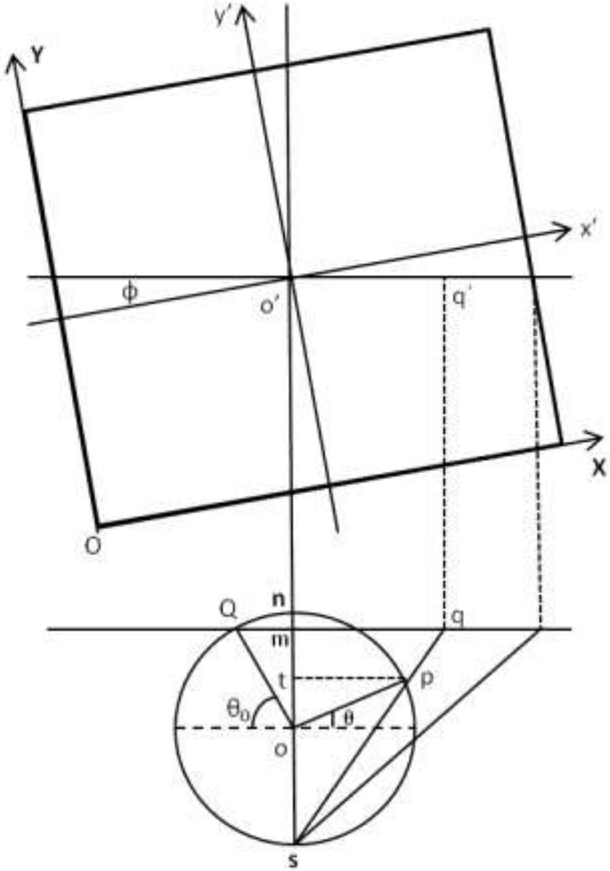
NDE products are in granules with approximately 1100 per day for OMPS

{Product Name} Technical Approach

1. Blended Product Algorithm Description
2. Technical Approach
    - Methods of Bracketing – daily data from 180 E to 180 W
    - Quality Control Methods – need for improvements
    - Calibration – single input for each piece
    - Geo-location Tests – from input product Geolocation
    - Gap Handling – persistence with distance weighting
    - Handling Duplicates – infrequent, duplicates are double weighted

TOAST objective analysis

- **Basic consideration:**
  1. IR obs. possess higher sensitivity to tropospheric ozone.
  2. UV obs. possess higher sensitivity to stratospheric ozone
  3. Combining the IR and UV retrieved O_3 may increase the total column O_3 accuracy.
  4. Use analysis to fill in the UV observation gaps.
- **Basic procedures:**
  1. Convert IR and UV O_3 pressure scale into same pressure scales.
  2. Transform coordinate from geographic into stereographic.
  3. Objective analysis.
  4. Analyzed global ozone data are transformed back to the geographic coordinate with $1^\circ \times 1^\circ$ resolution.



$$X = \cos\theta \cdot \cos\phi \cdot \frac{\sin\theta_0 + 1}{\sin\theta + 1} \cdot \frac{\mathrm{Re}}{mesh} + \frac{N-1}{2} \qquad (1)$$

$$Y = \cos\theta \cdot \sin\phi \cdot \frac{\sin\theta_0 + 1}{\sin\theta + 1} \cdot \frac{\mathrm{Re}}{mesh} + \frac{N-1}{2} \qquad (2)$$

mesh=24,384/(N-1) km, θ_0=60˚; N is mesh grid number;
For CrIS N=245; for OMPS N=65

Fig 1. Coordinate transformation from geographic to Stereographic.

$$C = WE \qquad (3)$$

$$W = \frac{R^2 - d^2}{R^2 + d^2} \qquad (4)$$

Any initial value on the grid within radius R of a measurement point A will be corrected by a weighted sum, where E is the difference between the observation and the initial value and W is the weighting factor.

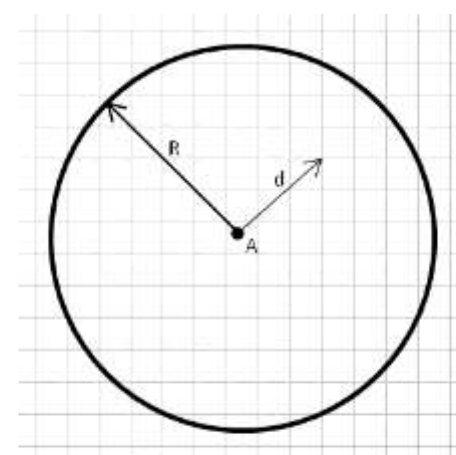
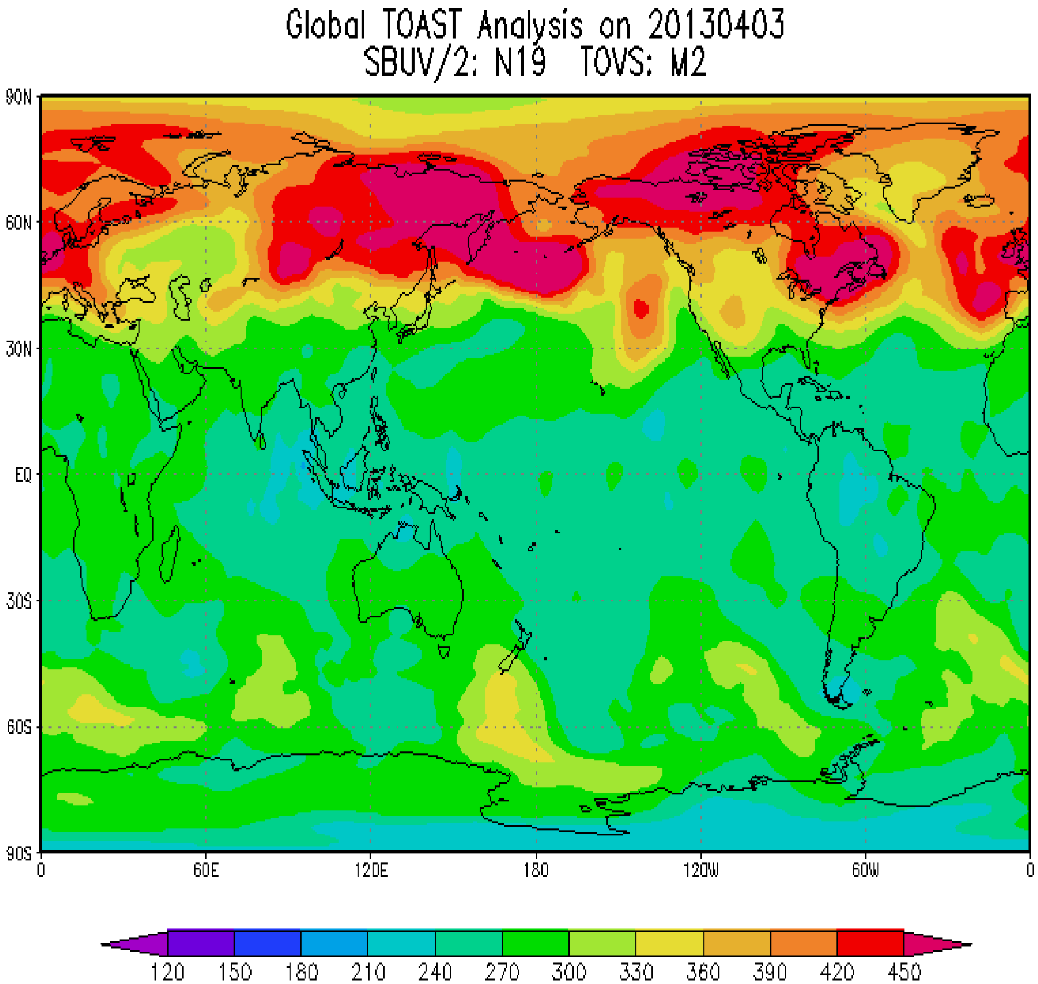


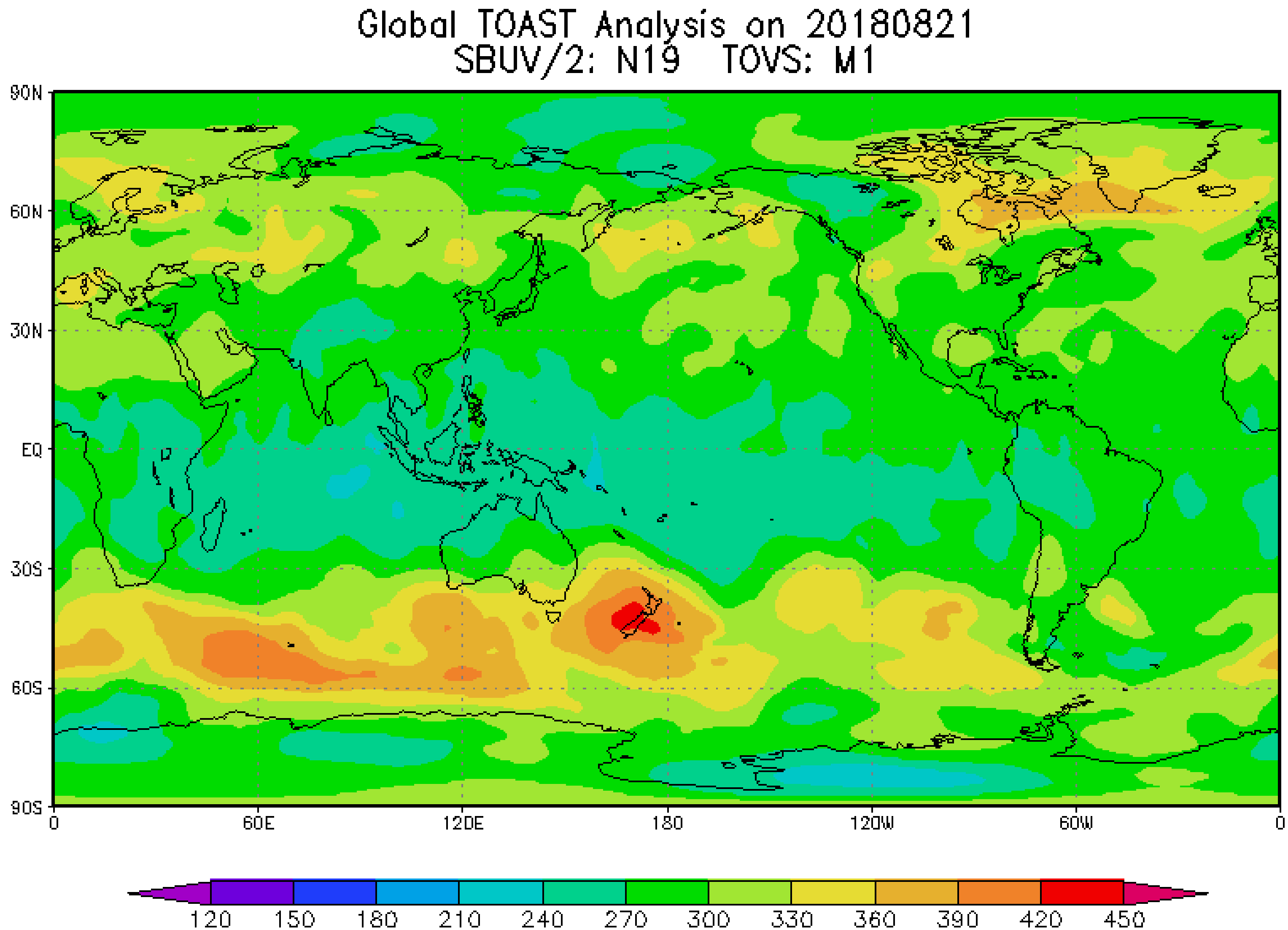
Fig 2. scheme of objective analysis

TOAST Description

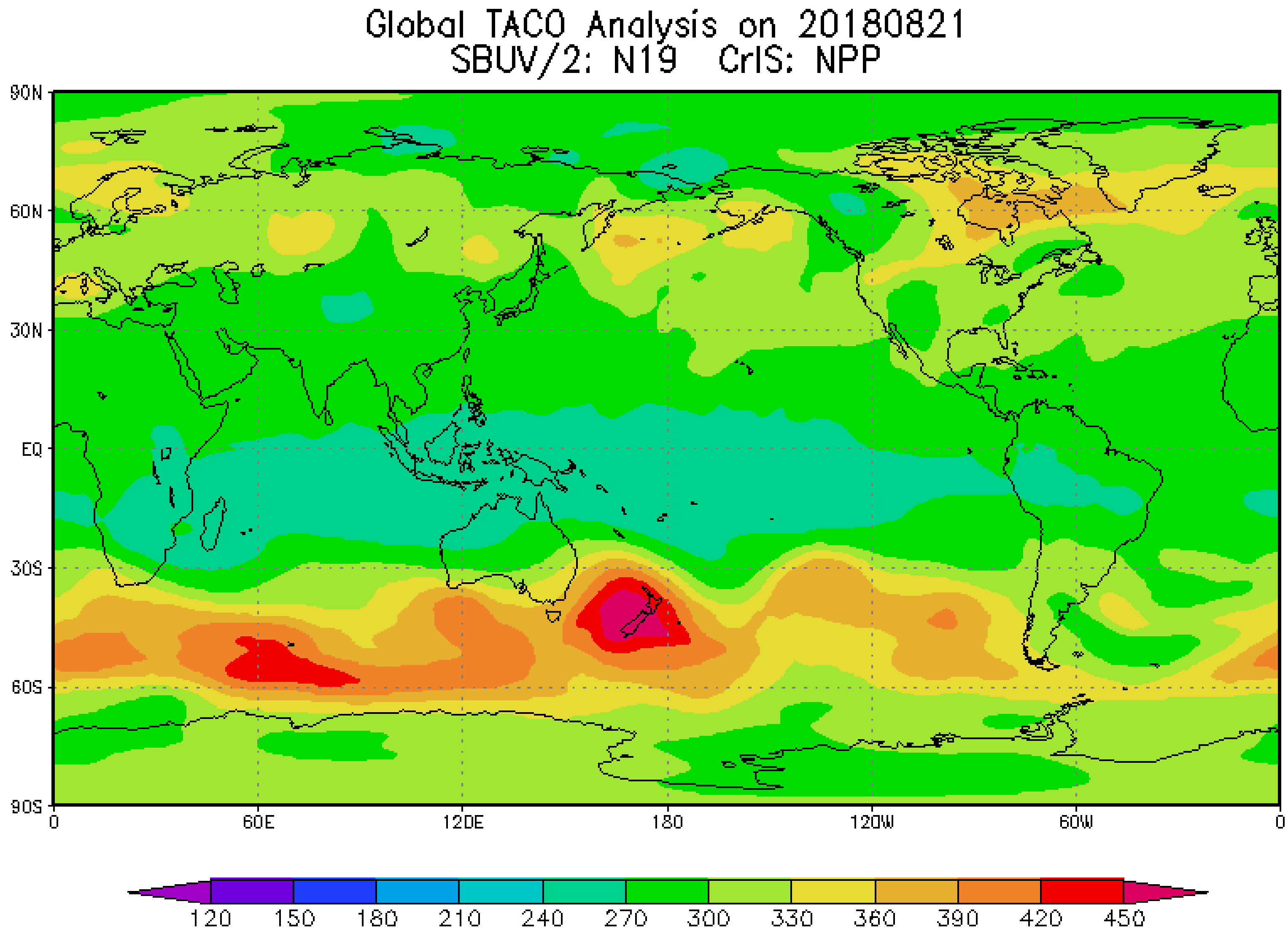


The original TOAST is a total column ozone map generated by combining TOVS tropospheric and lower stratospheric (4 to 23 km) ozone retrievals with SBUV/2 spatially smoothed mid-to-upper stratospheric (24 to 54 km) layer ozone retrievals. In essence, we are replacing TOVS climatology with real-time SBUV/2 measurements in the mid-to-upper stratosphere.

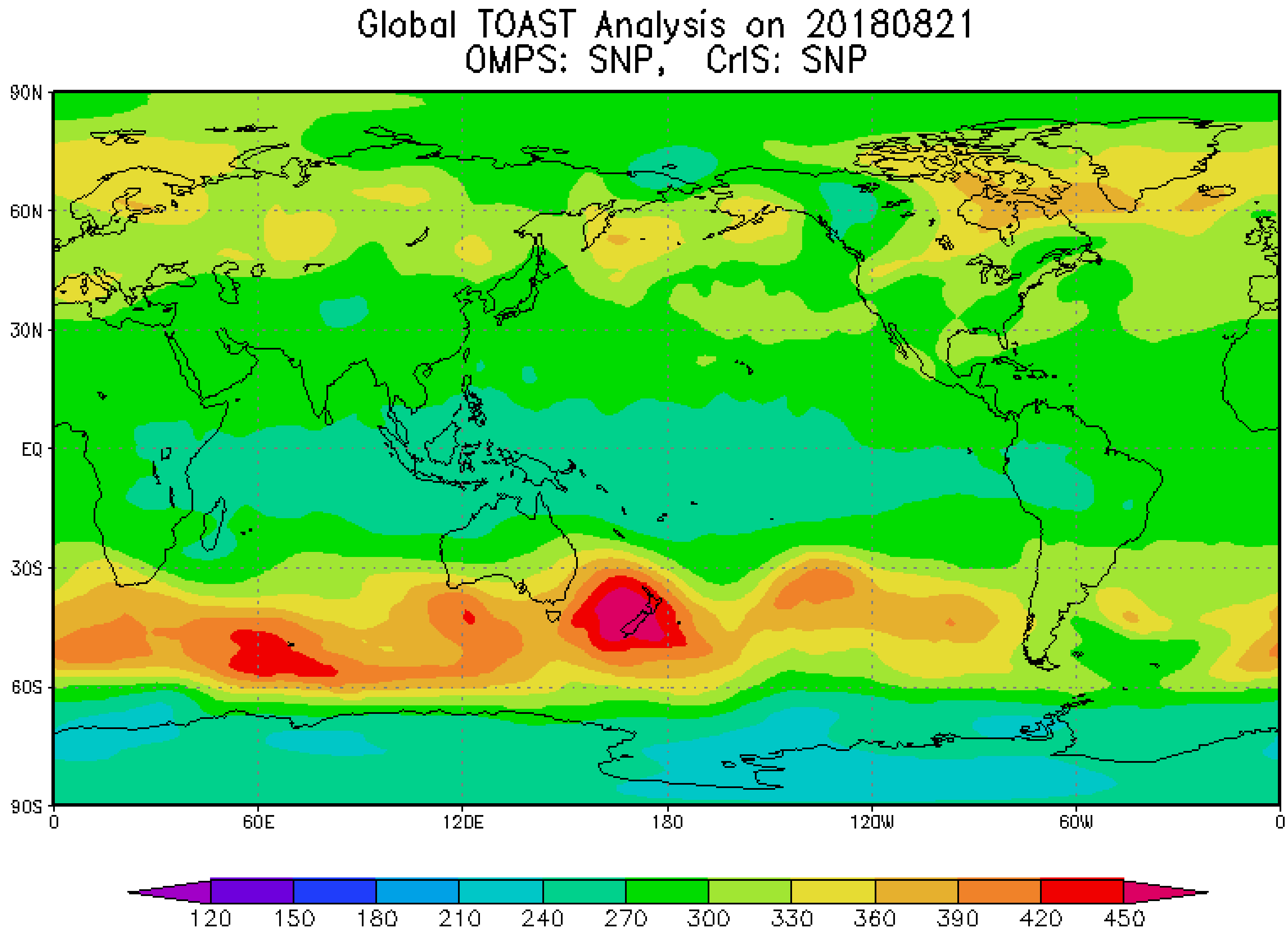
TOAST (SBUV/2 + HIRS)



eTOAST (SBUV/2 + CrIS)



nTOAST (OMPS NP + CrIS)

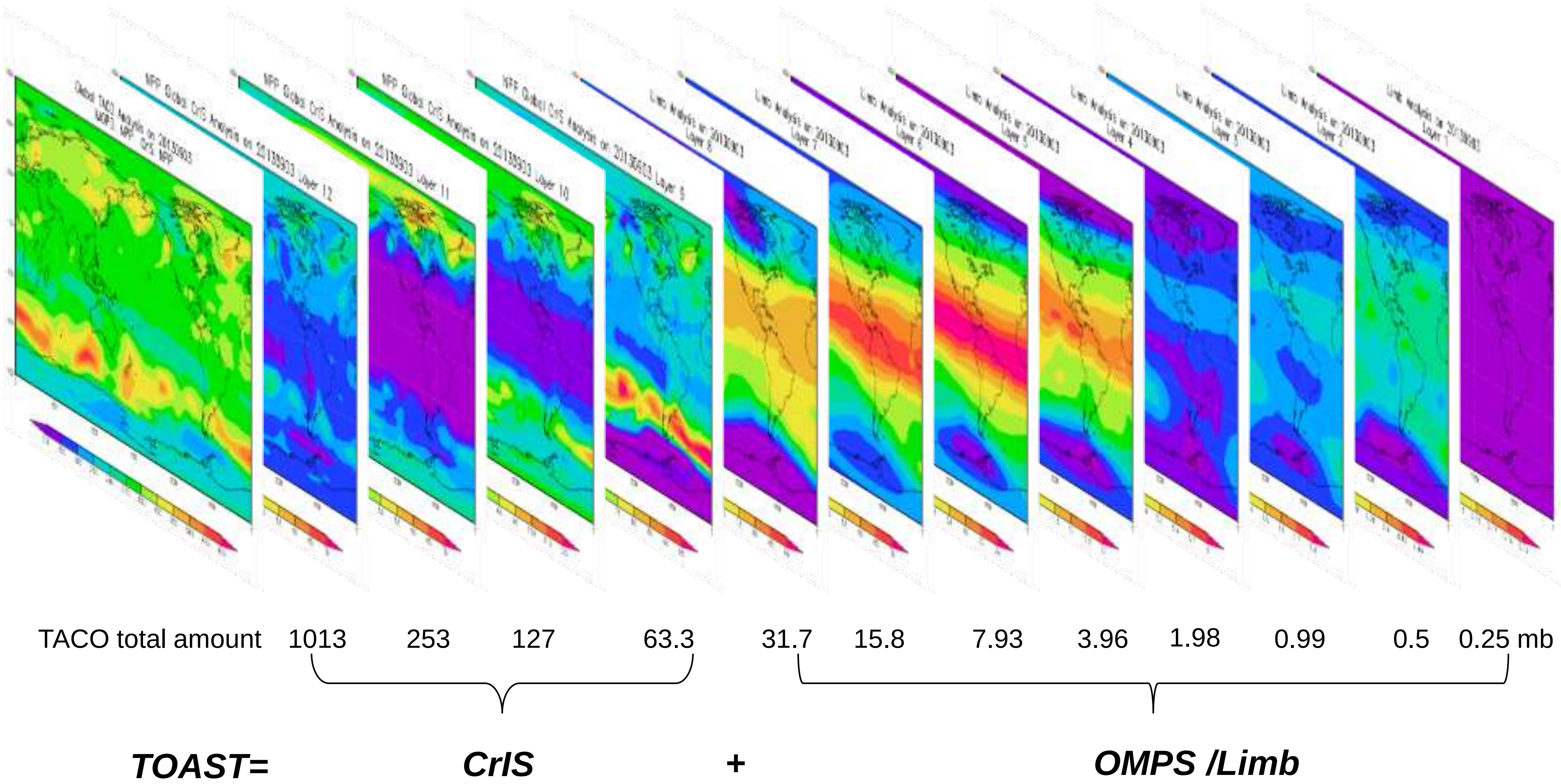


Product(s) Examples/Outputs

Output Data Products

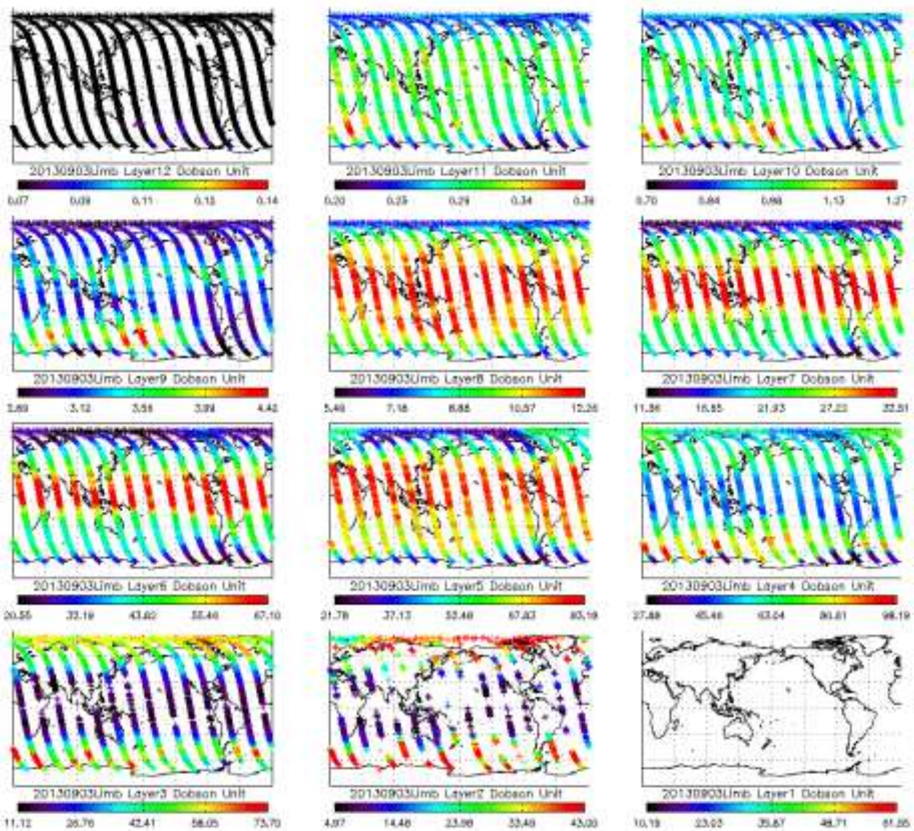
	TOAST (Outputs)	Output Data Type Daily maps of Total Ozone and Ozone Profiles	Spatial, Temporal Resolution, Format
1	TOAST	Total ozone and NOAA-19 SBUV/2 and HIRS layers	1° x 1° Grib, Binary and png
2	eTOAST	Total ozone and NOAA-19 SBUV/2 and NUCAPS	1° x 1° etc.
3	nTOAST	Total ozone and S-NPP/NOAA-20 OMPS-NP and NUCAPS	1° x 1° etc.
4	lTOAST	Total ozone and S-NPP OMPS-LP and NUCAPS	1° x 1° etc.

TOAST using CrIS and OMPS LP (09-03-2013)

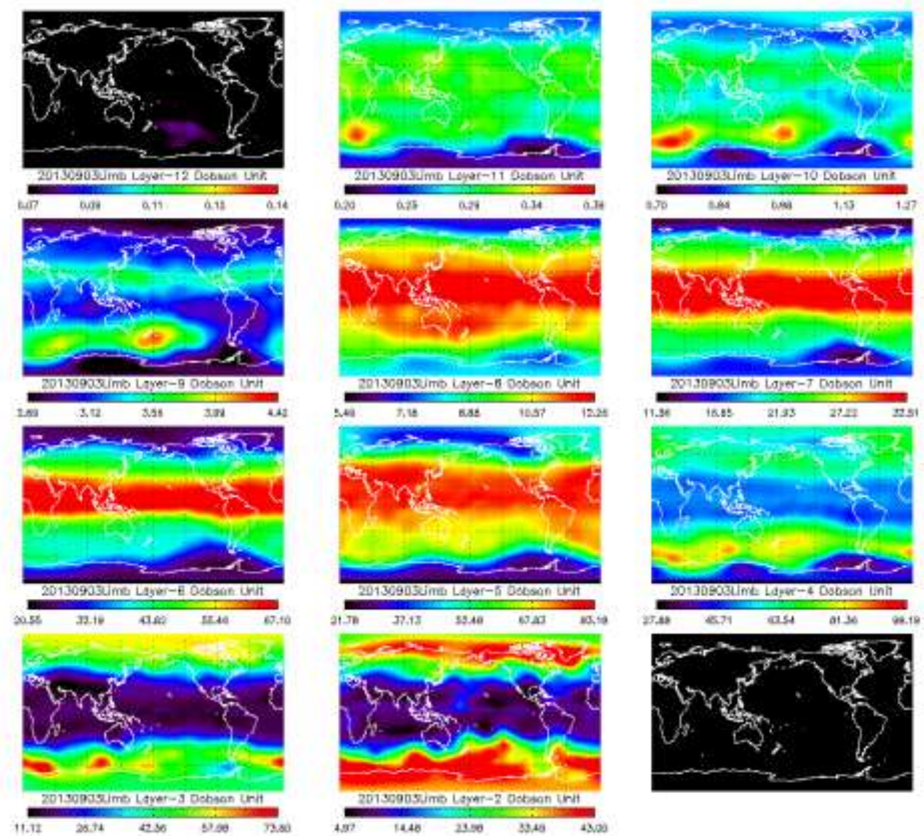


Limb Layer reformed vs. analyzed 09-03-2013

- Layer reformed Limb input

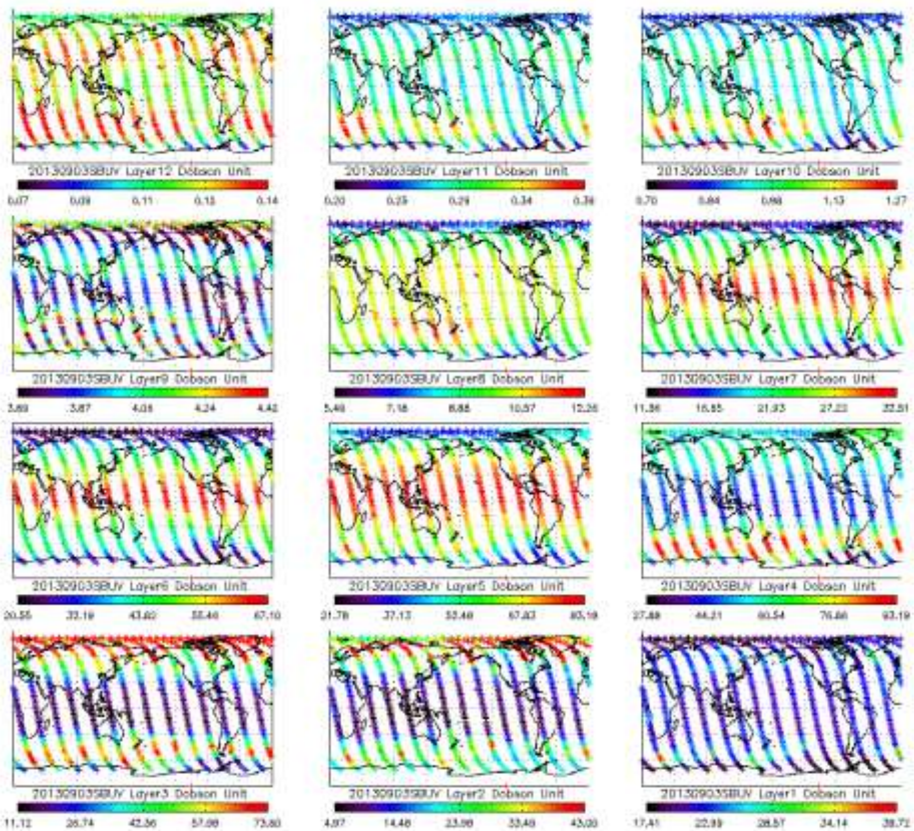


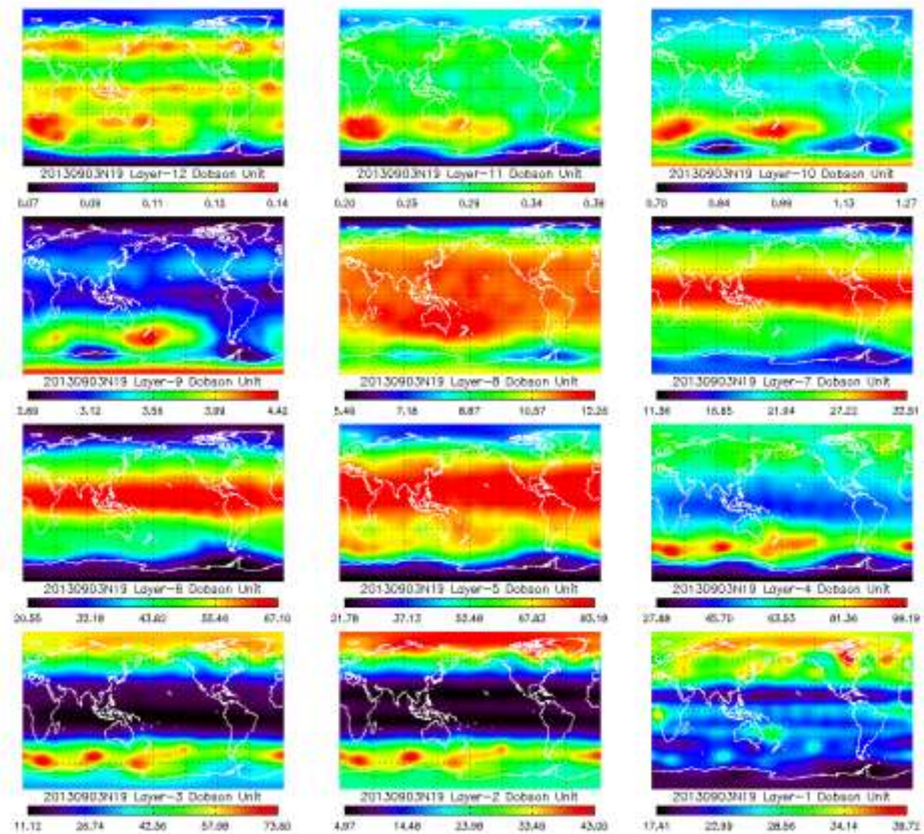
- Limb TOAST analyzed



SBUV 12-layer vs. analyzed 09-03-2013

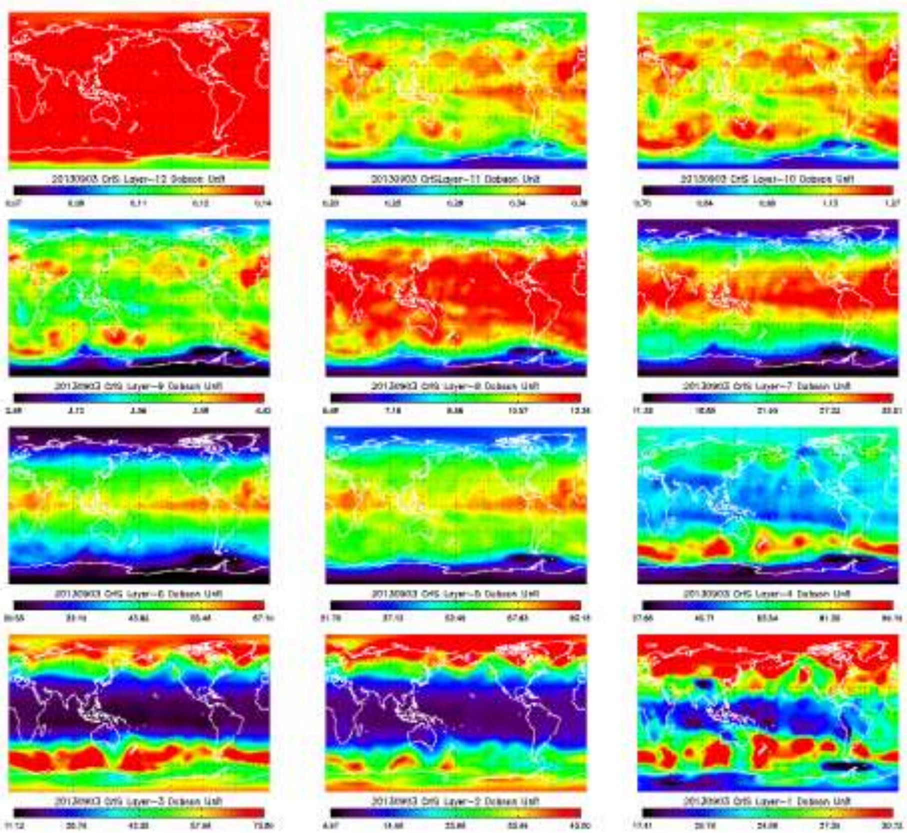
- SBUV-2 input
- TOAST SBUV-2 analyzed



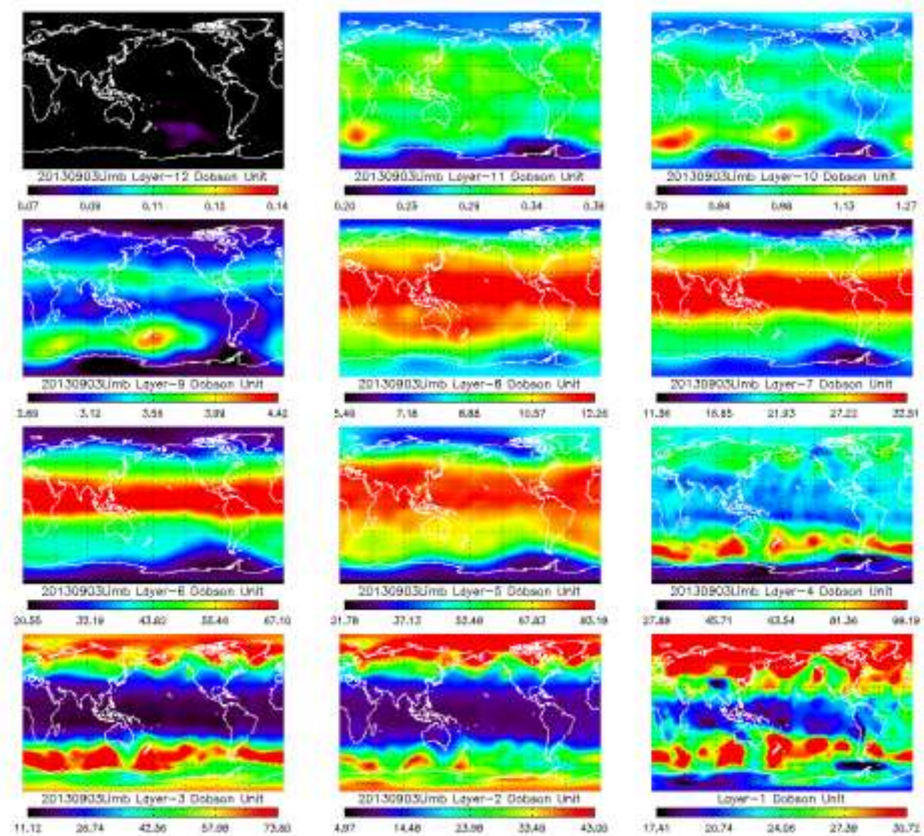


Analyzed 12 Umkehr O_3 layers 09-03-2013

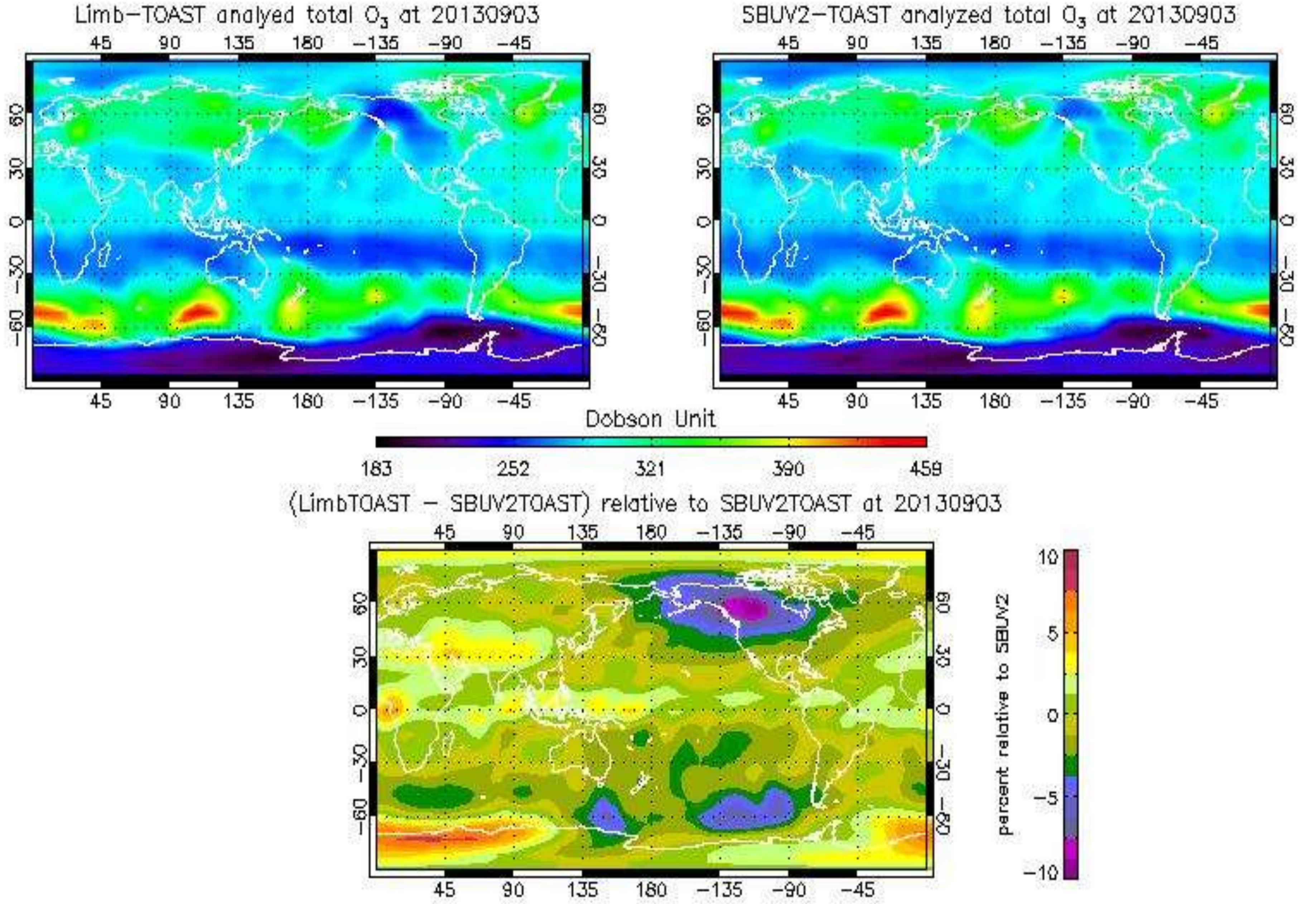
- CrIS



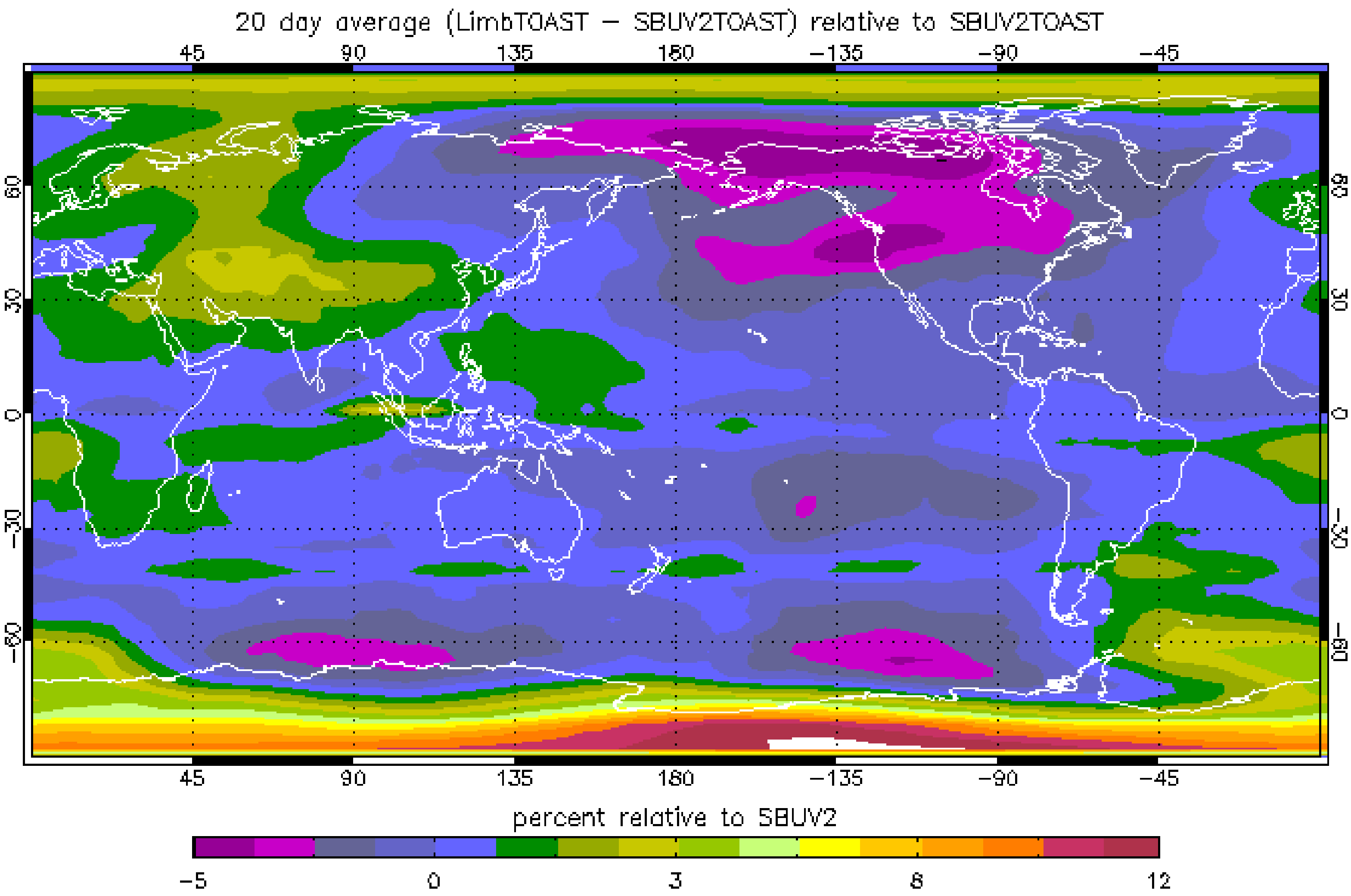
- CrIS + Limb



Comparison of Limb and SBUV/2



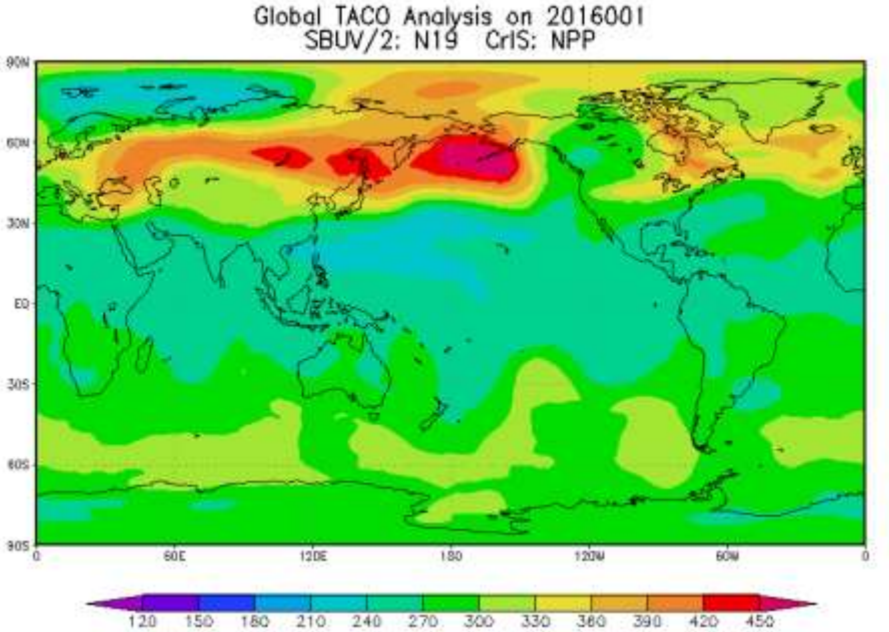
20-day average of the relative differences to current version from 09-03-2013 to 09-22-2013

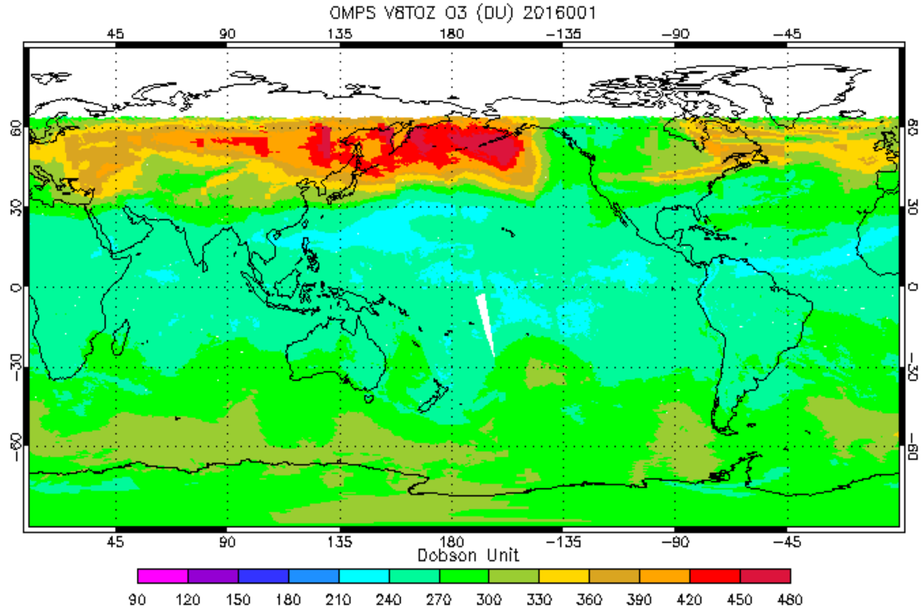


Product Evaluation/Validation/Tools

- Product Evaluation/Validation
  - Compared to individual components and their validation.
  - Compared to sunlit Earth from Daily UV Mappers.
- Defined Quality Flags
  - Need to determine how to show where data was updated.

eTOAST versus S-NPP OMPS V8TOz for January 1, 2016





Identified Issues/Risks/Mitigations

- Provide a list of identified risks/issues/mitigations and any examples identifying artifacts.

Identified Risk/Issues	Action/Mitigation
NOAA-19's Drifting orbit limits SH coverage for TOAST and eTOAST.	Switch to lTOAST and nTOAST using S-NPP and NOAA-20 OMPS products.
Final products do not have flags to show where recent data was available for analysis.	Consider creating maps showing where components were updated.
Product screening for OMPS products does not use error flag information.	Modify code to screen input to only use error flag values of 0, 1, and 10, 11.

Recent and Future Algorithm Improvements

- Provided code with better handling of Equatorial “boundary”.
- Deliver code with better error flag handling for OMPS.
- Deliver code to read in NetCDF version of Limb Profile products.
- Future Validation Plans for ITOAST
  - Comparisons to MLS and SAGE III
  - Comparisons to OMPS NM and TropoMI
  - Provide code with better error flag handling.
- Use stratospheric ozone analysis fields as A Priori to NUCAPS

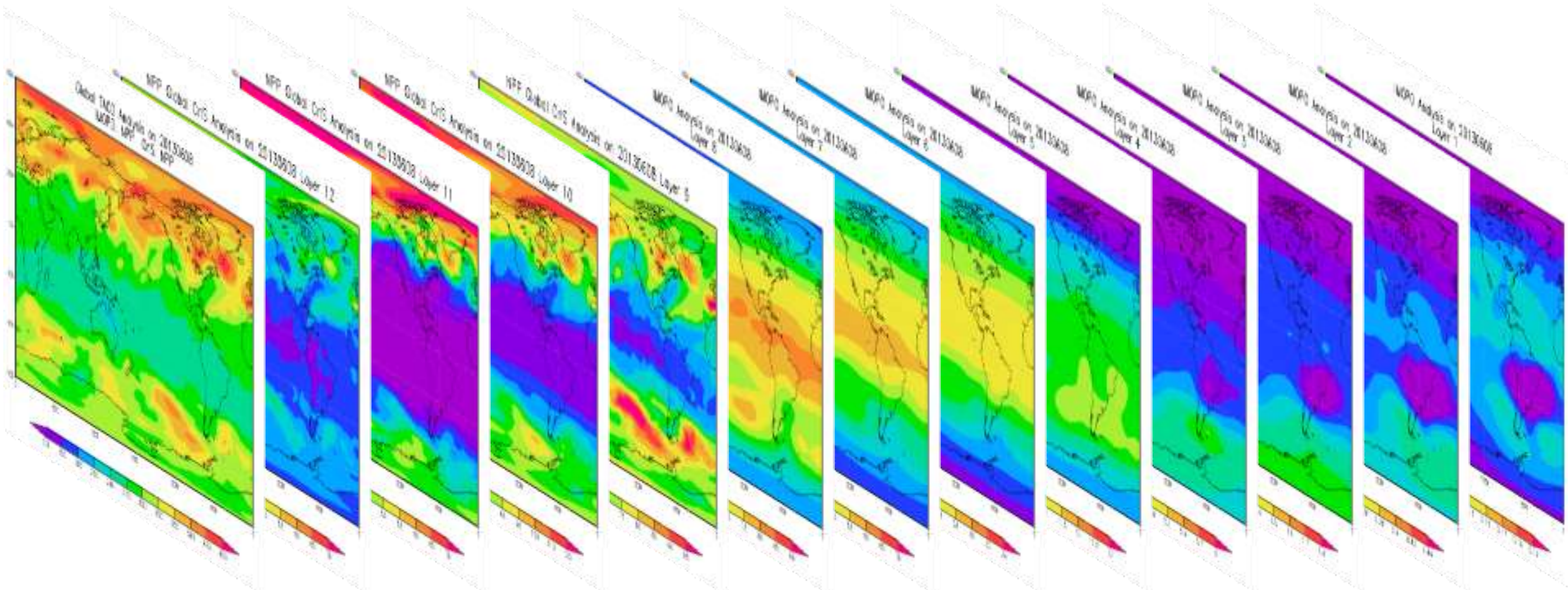
Documentation/website links

Toast products can be accessed at the following pages

- https://www.ospo.noaa.gov/Products/atmosphere/toast/index.html
- https://www.ospo.noaa.gov/Products/atmosphere/etoast/index.html
  https://www.ospo.noaa.gov/Products/atmosphere/ntoast/index.html
- https://www.ospo.noaa.gov/Products/atmosphere/ltoast/index.html

Backup Slides

Current operational eTOAST using CrIS and SBUV-2 for June 8, 2013



1013 253 127 63.3 31.7 15.8 7.93 3.96 1.98 0.99 0.5 0.25 mb

TOAST = ***CrIS*** **+** ***SBUV***

Implementation Status

- eTOAST is operational
- nTOAST will be soon
- lTOAST is awaiting a new delivery and the start of operational processing at NDE.

Input Product(s) Requirements

Identify satellite and ancillary data Inputs

(use additional slides as needed)

Input Data	Resolution	Source
e.g. GFS – T(p), q(p)	0.5 x 0.5 deg; 31 levels	NCEP
e.g. Annual Surface Type	1 km Global	JPSS-VIIRS
e.g. SST	5 km Global	ACSPO

Output Product(s) Specifications

- Blended Product Name: **{SST}**
- Output Data Type(s): {S-NPP/NOAA-20/GOES-16}
- If your blended product algorithm produces more than one output product, use additional slides as required.

Output Product(s) Attributes	Threshold	Observed/validated
Latency		
Geographic coverage		
Vertical Coverage		
Vertical Cell Size		
Horizontal Cell Size		
Mapping Uncertainty		
Measurement Range		
Measurement Accuracy		
Measurement Precision		
Measurement Uncertainty		

Quality Flags

- Defined Quality Flag(s)
  - Variable, description, value, verification

Quality Flag	Description	Value

Implementation Status

- Discuss current status of implementation including the availability in AWIPS or alternatives.
- Algorithm version/LUTs
- Processing environment and resources required for implementation or porting.
- Future plans on implementations including AWIPS or alternatives

Importance/Benefits/Users

- Product Importance/Benefits/Users
- PGRR/PGI Activities

Name	Organization	Application	User Feedback - User readiness dates for ingest of data and bringing data to operations

Documentation/website links

- Provide website links for documentation, down-load instructions, etc.

TOAST TOTAL OZONE MAPS USING CRIS AND OMPS LP PROFILES

Jianguo Niu
System Research Group@NOAA/NESDIS/STAR

Larry Flynn,
NOAA/NESDIS/STAR

STAR JPSS Annual Science Team Meeting
August 9, 2016

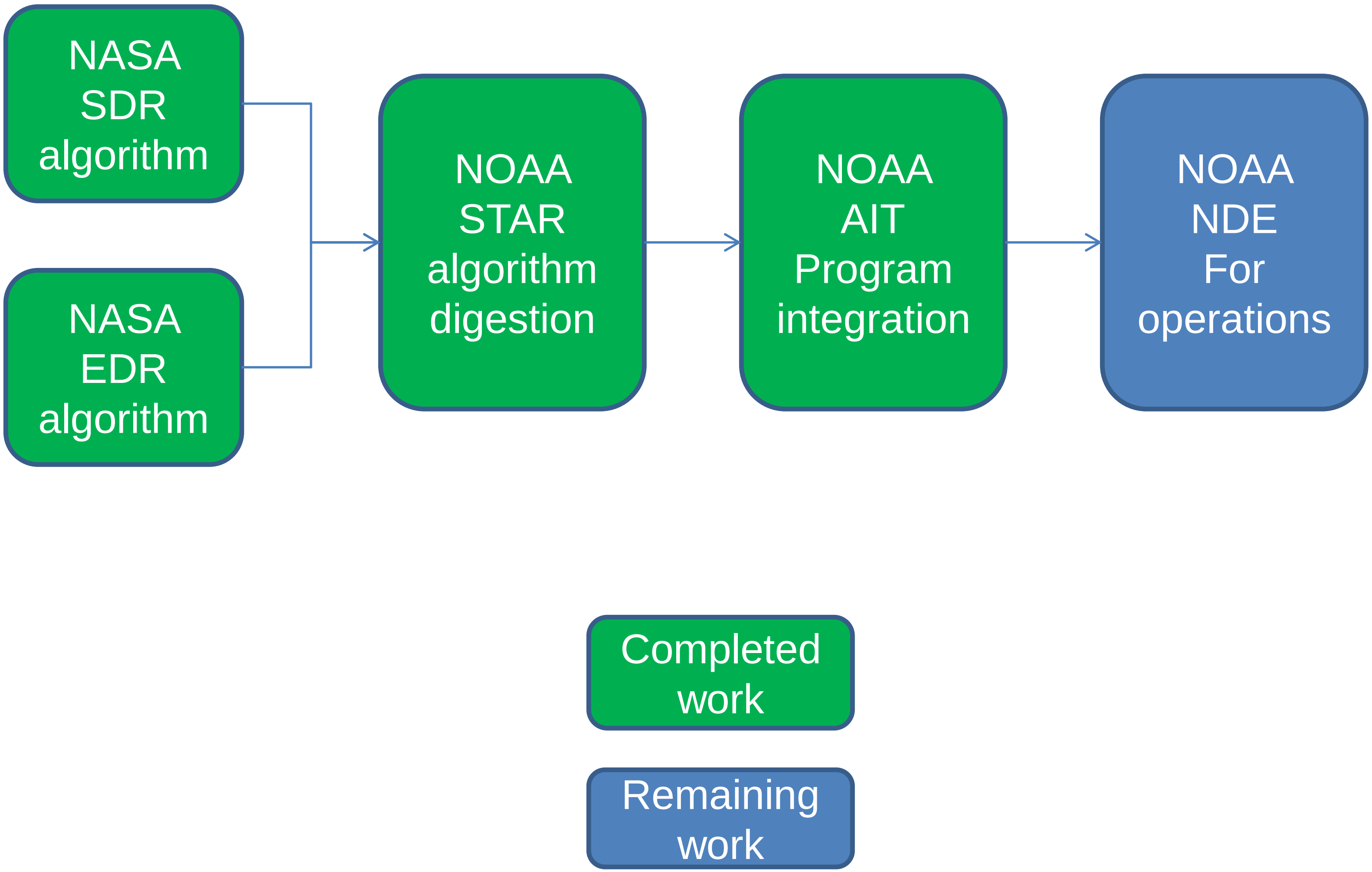
S-NPP provides following ozone sensors

- CrIS IR full global day and night profiles
- OMPS NP nadir view vertical profiler
- OMPS NM full daily total ozone for sunlit Earth
- OMPS LP limb view vertical profiles

The current TOAST was developed in 2014

- **T**otal **O**zone from **A**nalysis of CrIS and SBUV2 in **S**tratosphere and **T**roposphere
- ***TOAST*** will use CrIS + OMPS NP when OMPS NP is at NDE.
- ***TOAST*** will use CrIS + OMPS LP when OMPS LP is at NDE.

Limb processing algorithm status



What have we achieved?

- OMPS Limb TOAST and SBUV/2 TOAST show similar global patterns and values in the upper layers (comparison need to introduce retrieval averaging kernels).
- Limb analysis algorithm functions well from the comparison of the EDR input and analyzed figures.
- 20 days of total column Ozone analysis have been tested.
- The averaged relative differences show Limb TOAST total analysis has ±5% differences relative to the current operational version (SBUV/2 TOAST).

The upcoming TOAST (CrIS + OMPS/Limb)

Baseline products:

- 12 layers global 1˚ × 1˚ layer VCD O_3 maps
- Eight layers of Limb global 1˚ × 1˚ layer VCD maps at pressure level of 31.7, 15.8, 7.93, 3.96, 1.98, 0.99, 0.50, 0.25 mb
- Four layers of CrIS global 1˚ × 1˚ layer VCD maps at pressure level of 1013, 253, 127, 63.3 mb.

Based on operational request we could:

- Provide 21 layer (V8 layers ~3km) the same analyzed maps
- Provide 61 Limb layers of analyzed maps

Summary

- The TOAST algorithm for CrIS + Limb has been developed and tested using NUCAPS and NASA Limb Profiler daily data products.
- The OMSP Limb Profiler SDR and EDR processing algorithms have been successfully transferred from NASA to NOAA, and have completed code and security review, they are ready for implementation the next builds at NDE.

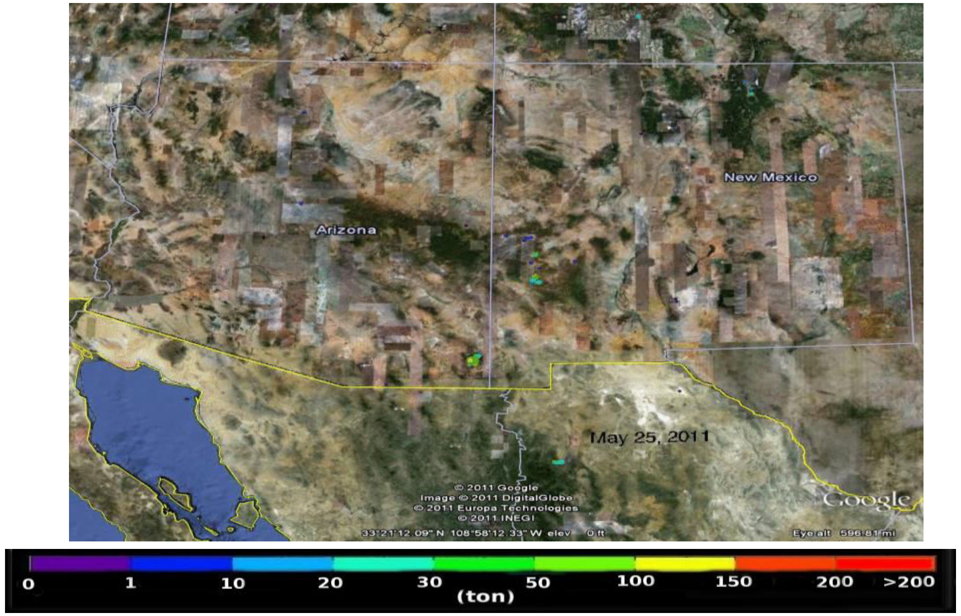
Global Biomass Burning Emissions Product (GBBEPx)

Shobha Kondragunta
NOAA/NESDIS STAR

Xiaoyang Zhang
South Dakota State University

Hanjun Ding
NOAA/NESDIS OSPO

Funded by JCSDA, G-PSDI, and J-PSDI



Biomass Burning

- Fires release large amounts of aerosols into the atmosphere that have adverse affects on human health and economy
  - Long range transport of smoke from fires impacts air quality in downwind regions. Worldwide 250,000 premature deaths per year (Jacobson, JGR, 2014).
  - Impacts national parks, monuments, and transportation due to reduced visibility.

Ft. McMurray Fire, Canada, May 2016

Types of Fires

Air Quality Predictions

- Numerical models that predict air quality (ozone and PM2.5) need to know where the fires are located, how high is the aerosol loading being emitted, at what height is the plume injection, and the duration of the fire.
- Near real time information from satellites that models need
  - Fire location - ***yes***
  - Fire Radiative Power (a proxy to calculate emissions) - ***yes***
  - Fire duration (if satellite is in geostationary orbit) - ***yes***
  - Plume injection – ***no***
  - Aerosol composition - ***no***

Emissions Calculation

$$E_x = FRP \times \beta \times F$$

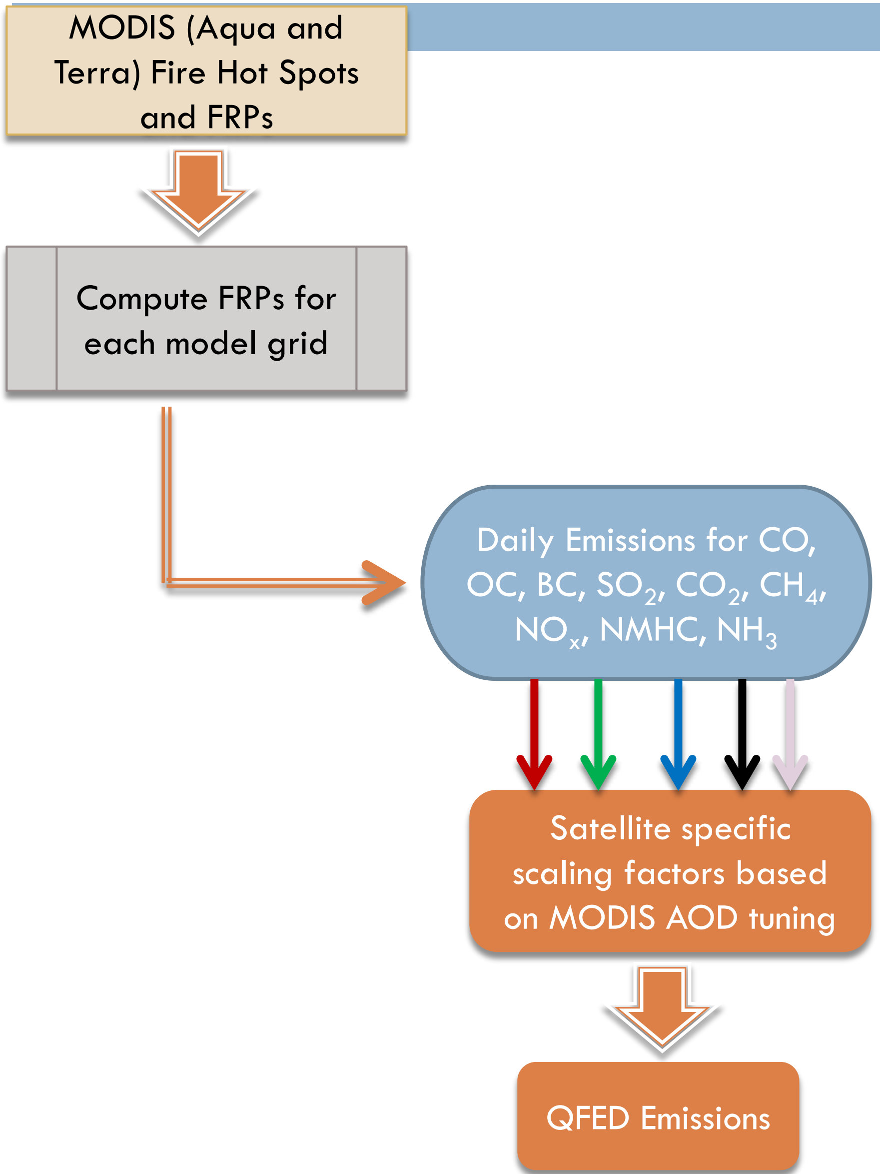
$$E_{fx} = \beta \, . \, \frac{FRP}{A} \, . \, F$$

Emission Factors (g/kg) in computing GBBEP-Geo. LC1-forests, LC2-savanna, LC3-shrublands, LC4-grasslands, LC5-croplands.

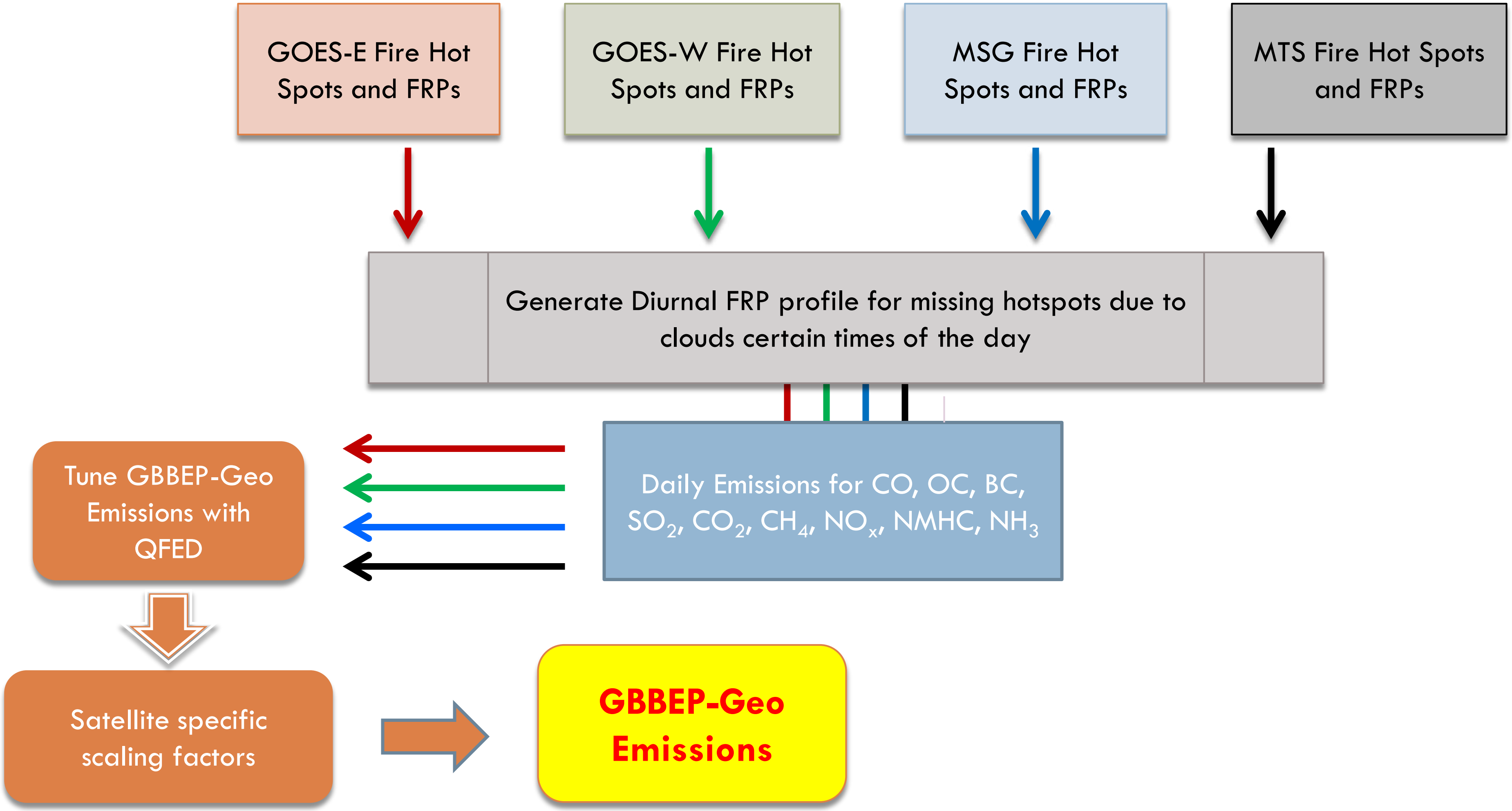
	LC1	LC2	LC3	LC4	LC5	Average
PM2.5	12.3	7.35	9.3	5.4	5.8	8.04
CO	106.4	63.5	68	59	111	81.58
OC	7.74	4.6	6.6	2.6	3.3	4.97
BC	0.408	0.435	0.5	0.37	0.69	0.481
SO2	0.89	0.58	0.68	0.48	0.4	0.606
CO2	1586	1704	1716	1692	1537	1647.04
CH4	5.42	2.05	2.6	1.5	6	3.514
NOX	2	3.35	3.9	2.8	3.5	3.11
NMHC	4.9	3.4	3.4	3.4	7	4.42
NH3	2.152	0.845	1.2	0.49	2.3	1.3974

E_x: biomass burning emissions (kg) of species x
S: burned area (km^2)
F: emission factors (g/Kg)
β: a combustion rate per unit energy (KgC/Joules)
A: area of the pixel

GBBEPx(1)


MODIS (Aqua and Terra) Fire Hot Spots and FRPs
Compute FRPs for each model grid
Daily Emissions for CO, OC, BC, SO_2, CO_2, CH_4, NO_x, NMHC, NH_3
Satellite specific scaling factors based on MODIS AOD tuning
QFED Emissions

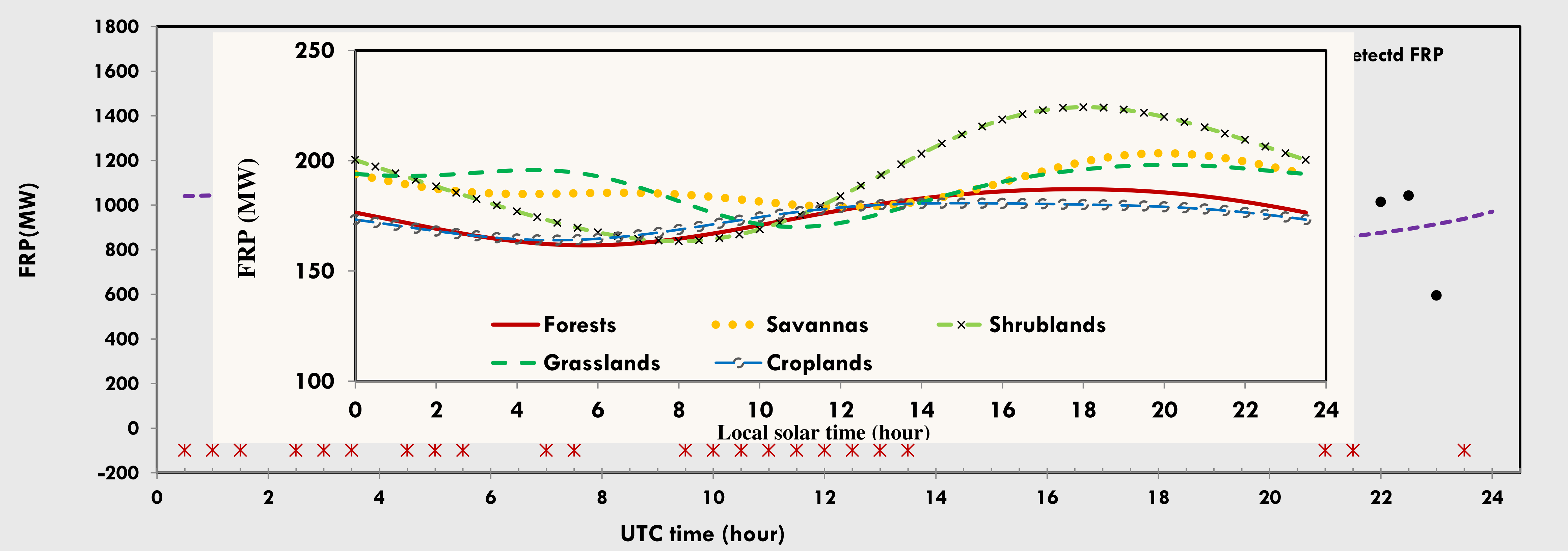
GBBEPx(2)


GOES-E Fire Hot Spots and FRPs
GOES-W Fire Hot Spots and FRPs
MSG Fire Hot Spots and FRPs
MTS Fire Hot Spots and FRPs
Generate Diurnal FRP profile for missing hotspots due to clouds certain times of the day
Daily Emissions for CO, OC, BC, SO_2, CO_2, CH_4, NO_x, NMHC, NH_3
Tune GBBEP-Geo Emissions with QFED
Satellite specific scaling factors
GBBEP-Geo Emissions

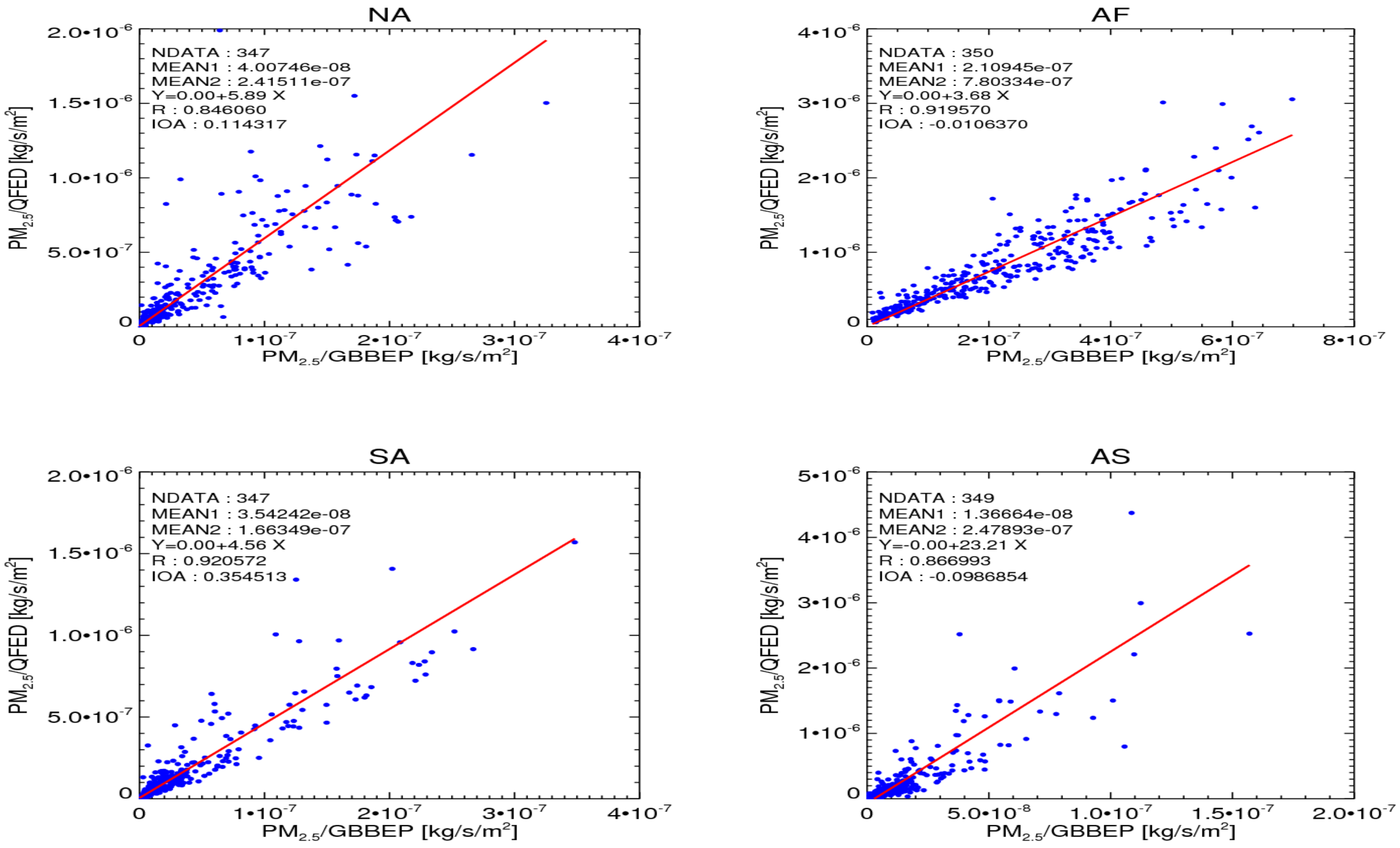
GBBEPx(2)

Generate Diurnal FRP profile for missing hotspots due to clouds certain times of the day

115.4°W , 44.49°N



GBBEPx(2)



Tune GBBEP-Geo Emissions with QFED

↓

Satellite specific scaling factors

GBBEPx(3)

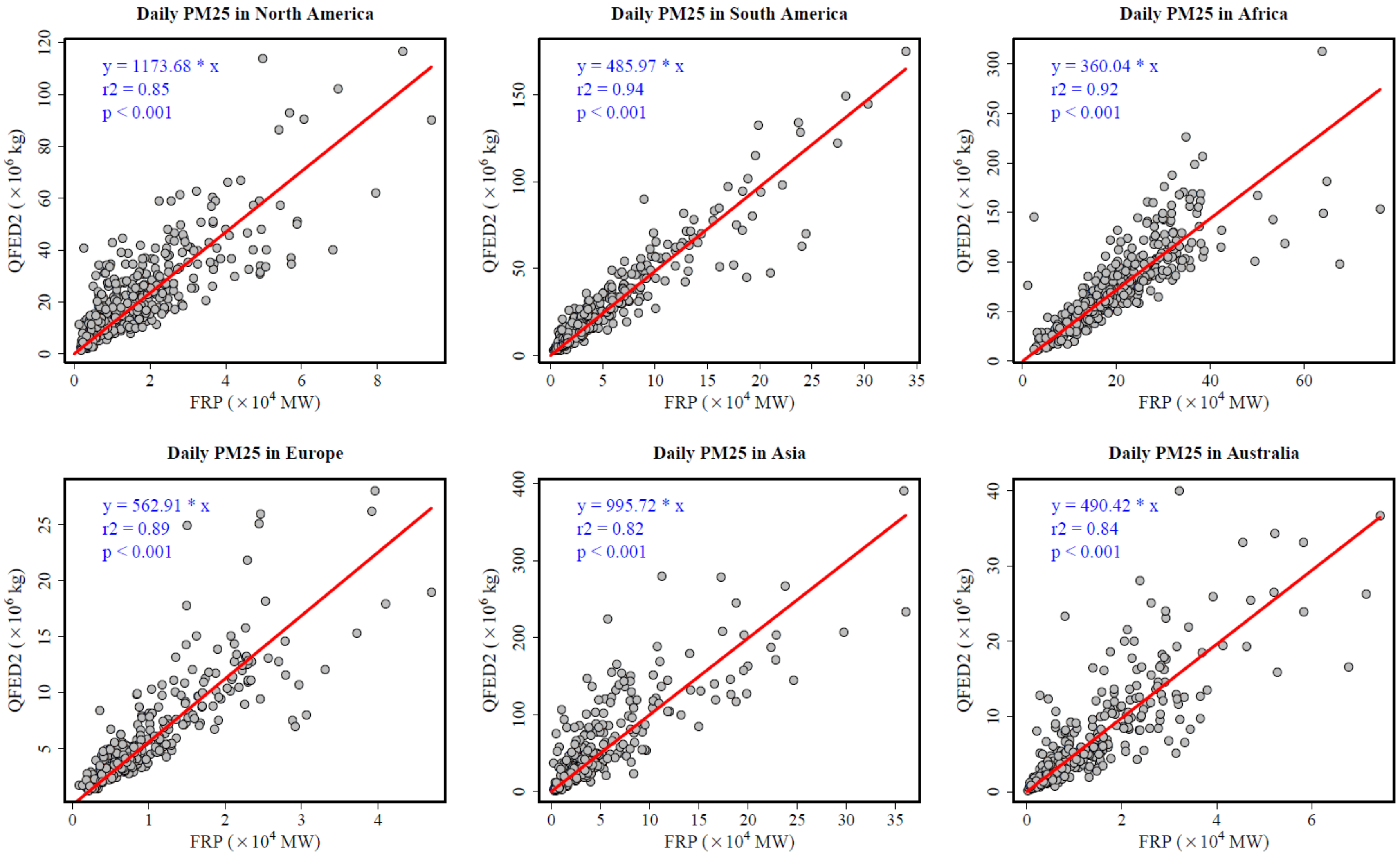
VIIRS Hot Spots and FRPs

↓

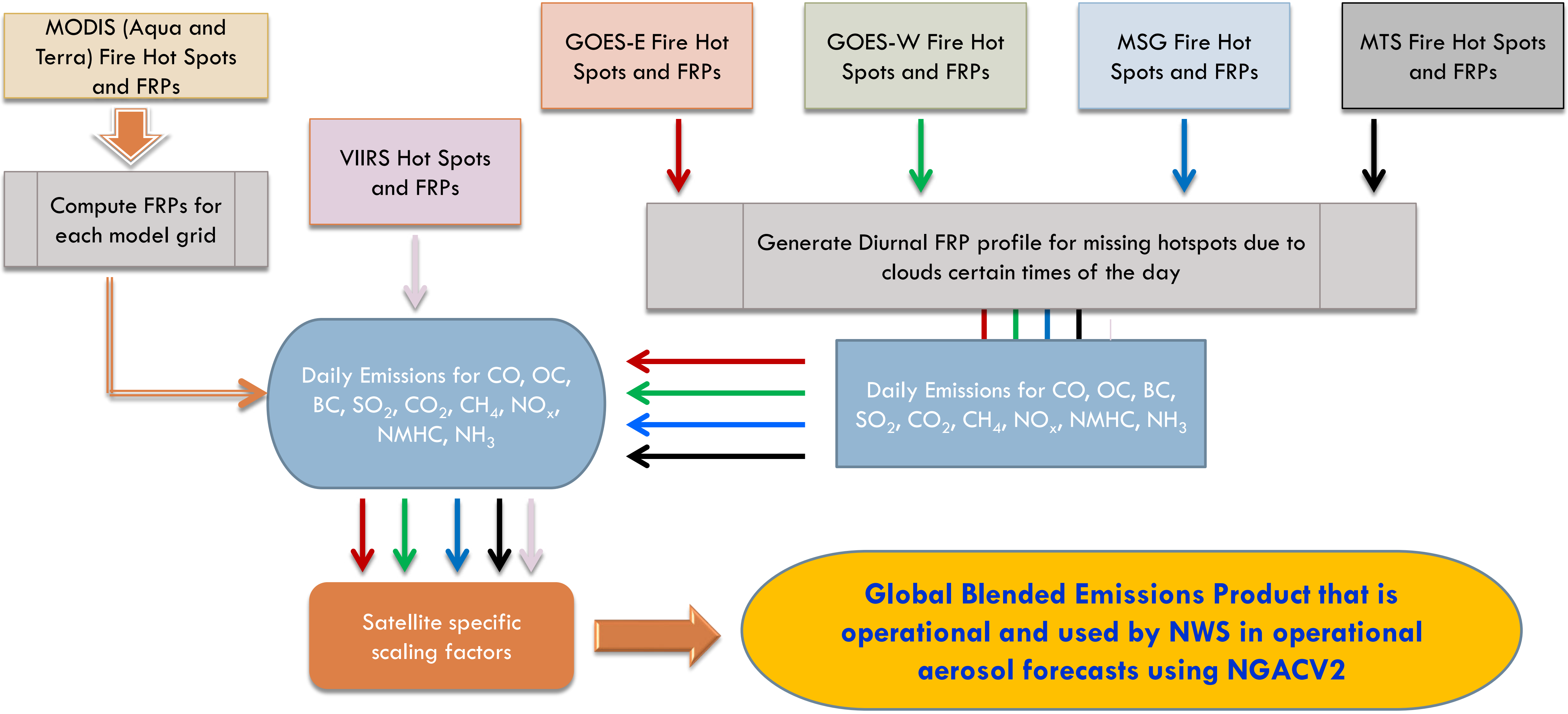
Regress VIIRS FRPs with QFED Emissions

↓

Daily Emissions for CO, OC, BC, SO_2, CO_2, CH_4, NO_x, NMHC, NH_3



GBBEPx


MODIS (Aqua and Terra) Fire Hot Spots and FRPs
Compute FRPs for each model grid
VIIRS Hot Spots and FRPs
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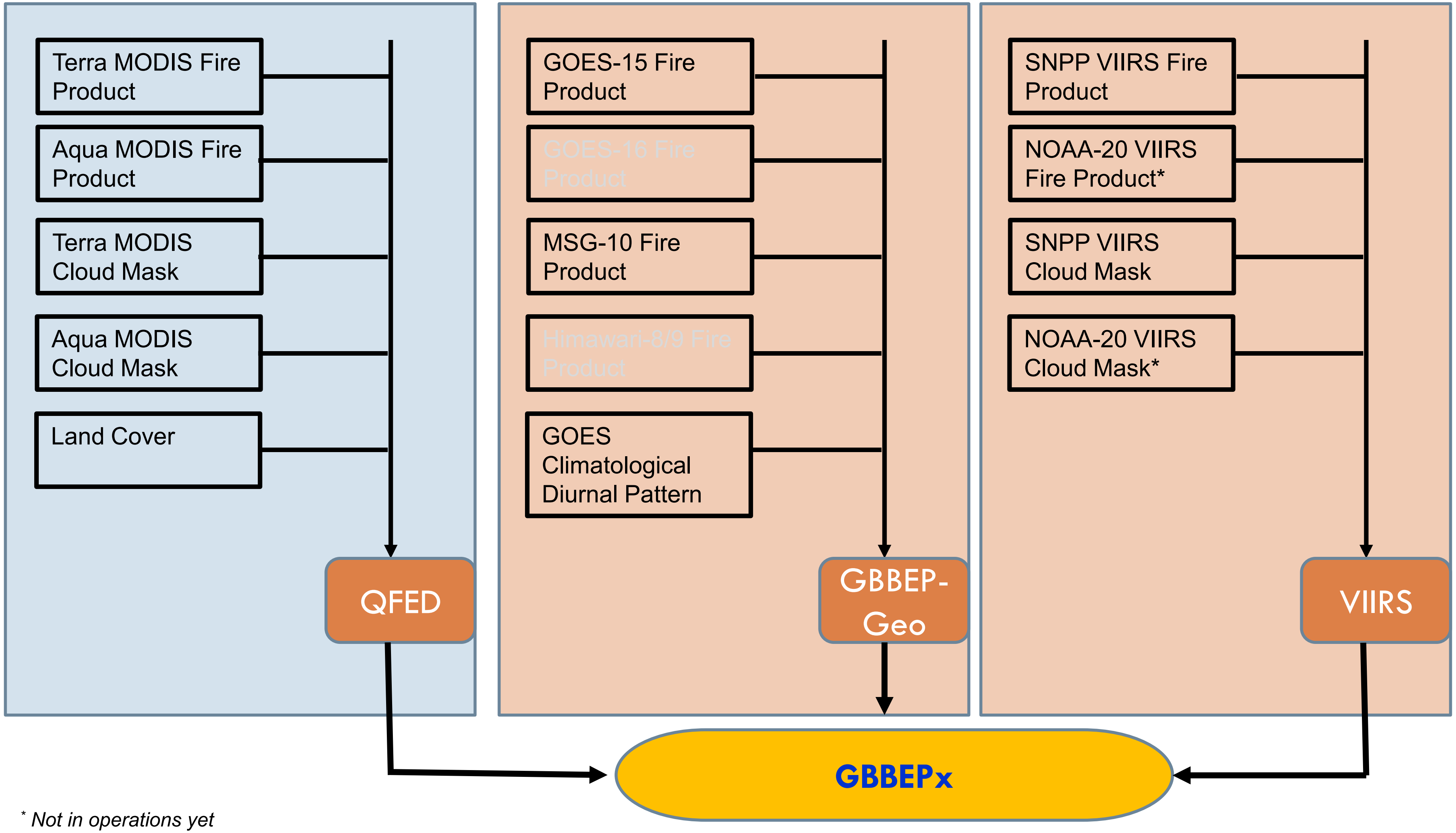
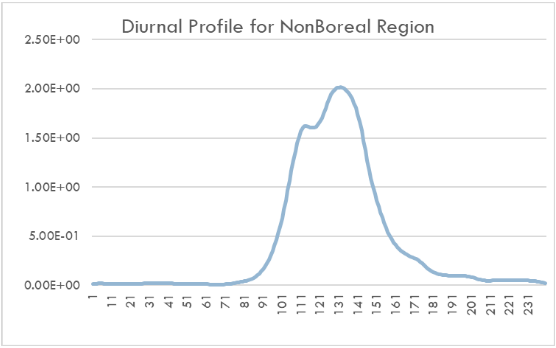
Daily Emissions for CO, OC, BC, SO_2, CO_2, CH_4, NO_x, NMHC, NH_3
Satellite specific scaling factors
Global Blended Emissions Product that is operational and used by NWS in operational aerosol forecasts using NGACV2

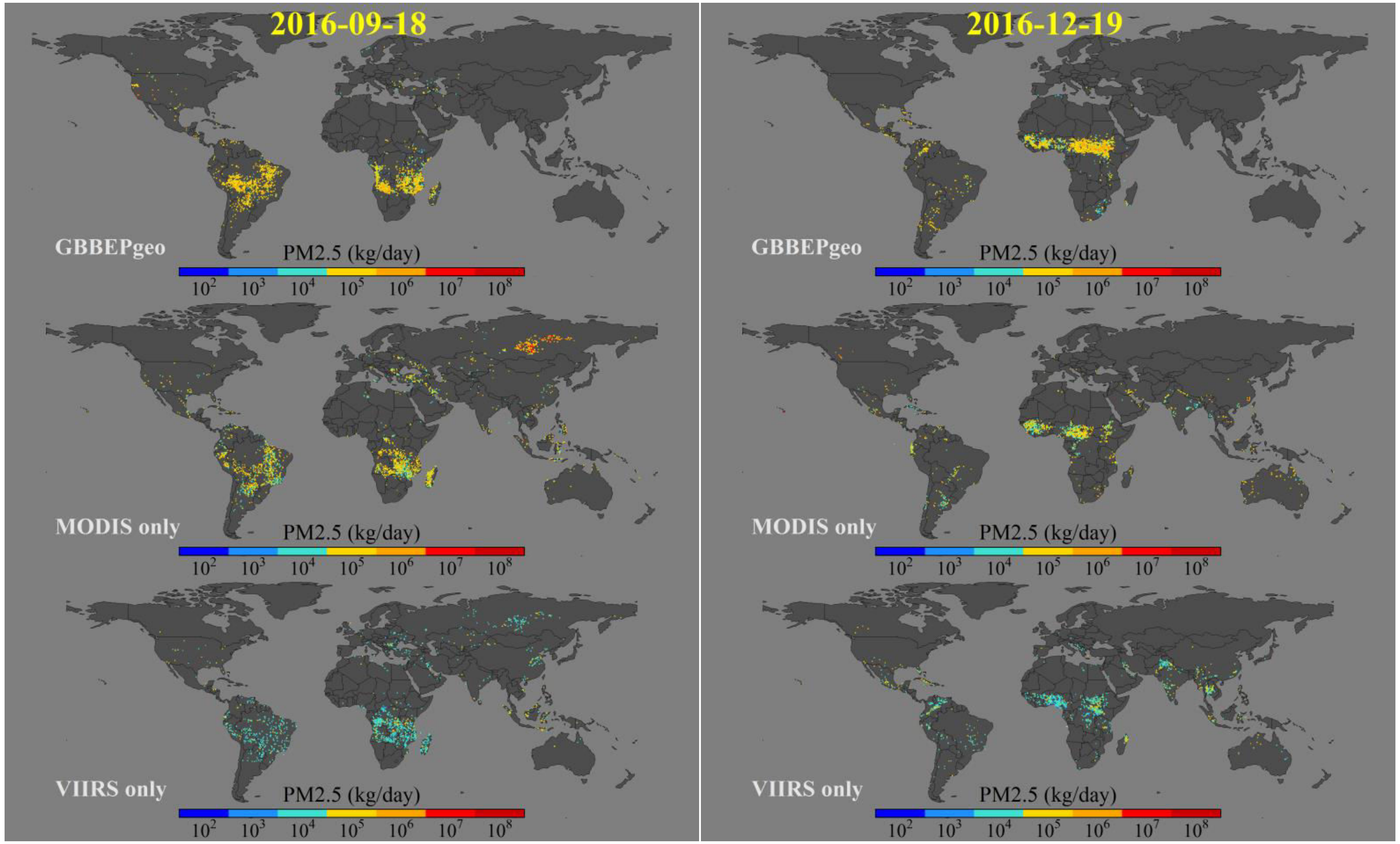
GBBEPx



GBBEPx is an output of daily emissions, an average of QFED, GBBEP-Geo, VIIRS.



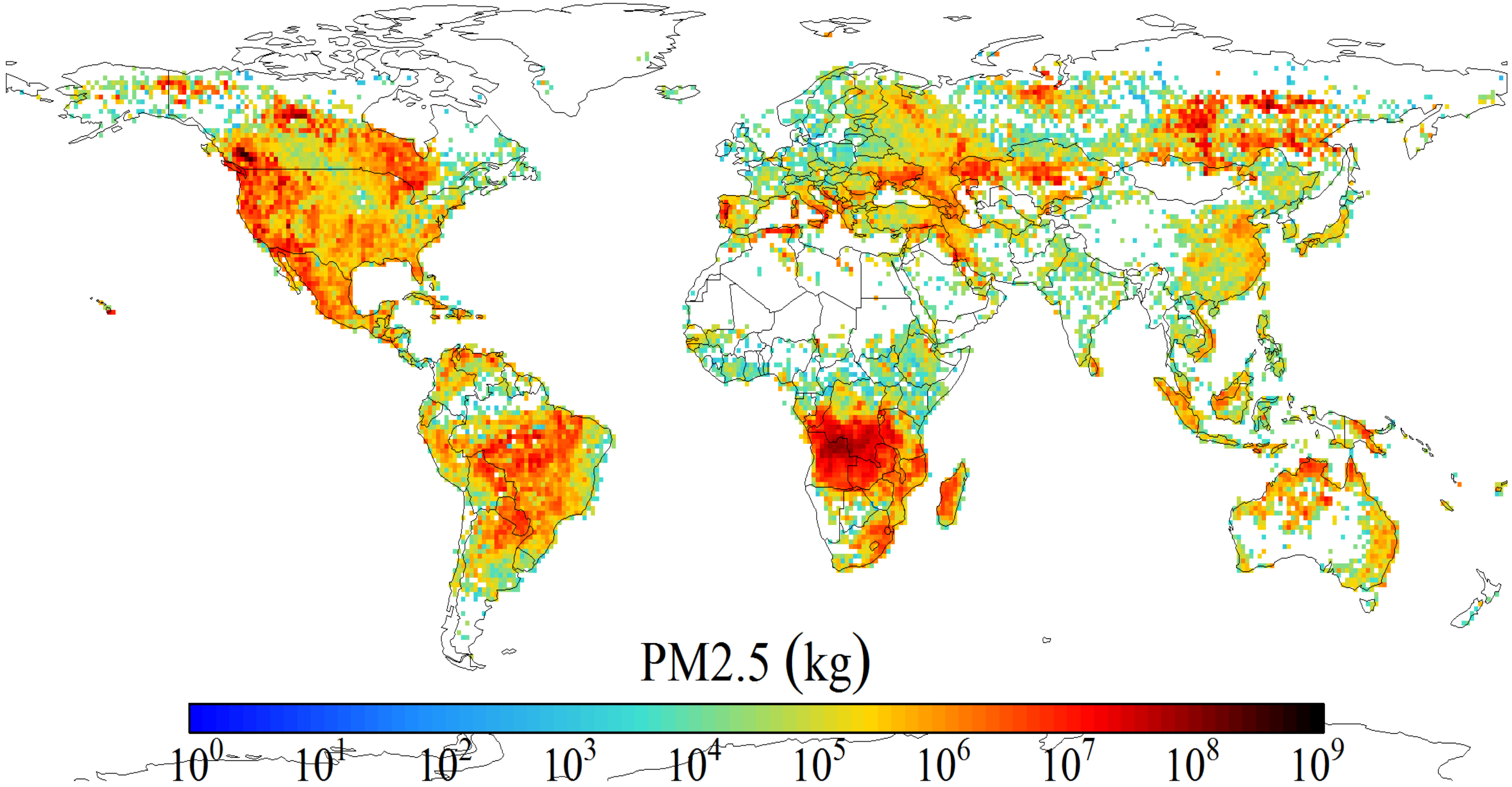
* *Not in operations yet*



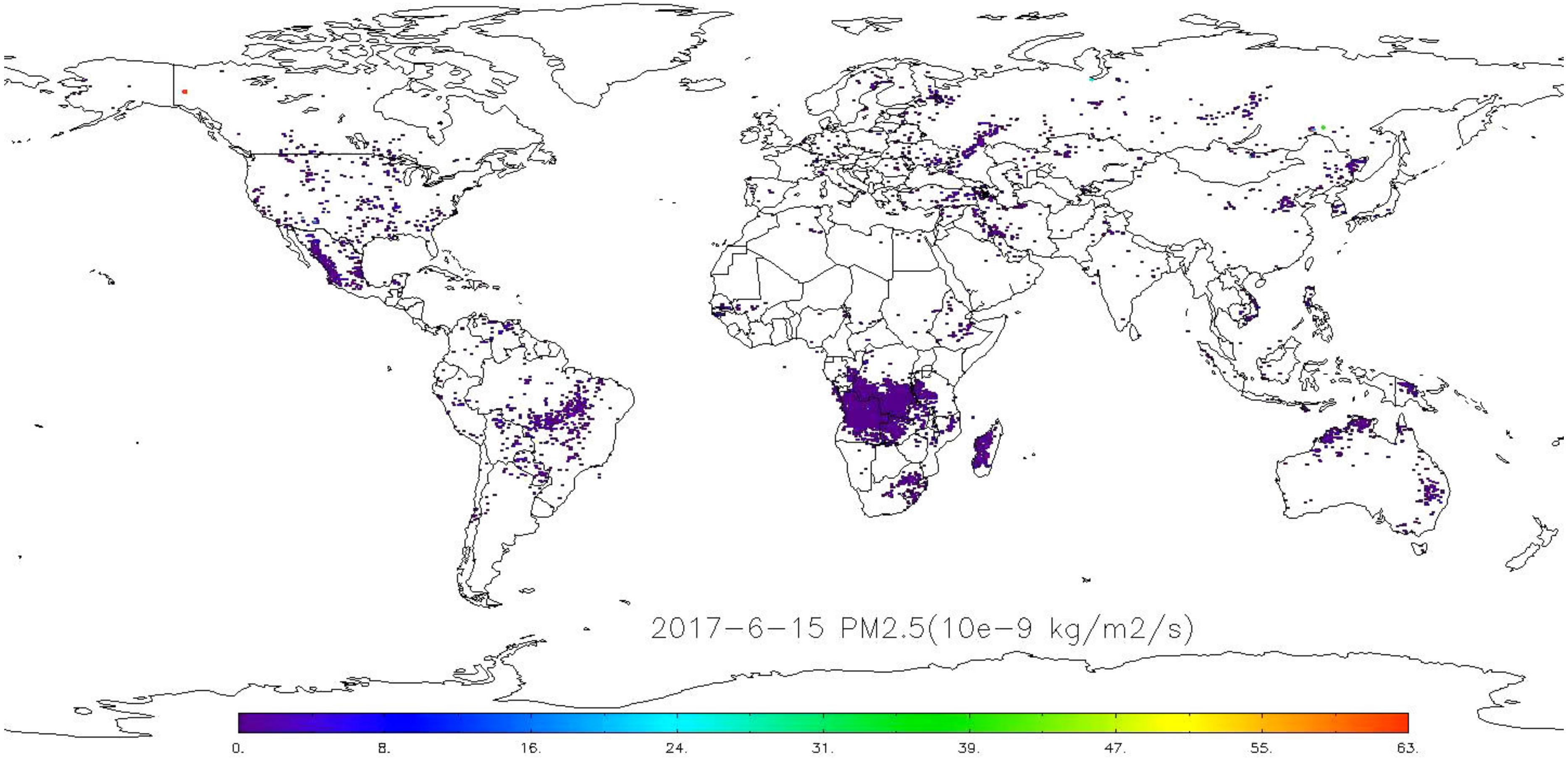
Two examples of fire emissions:

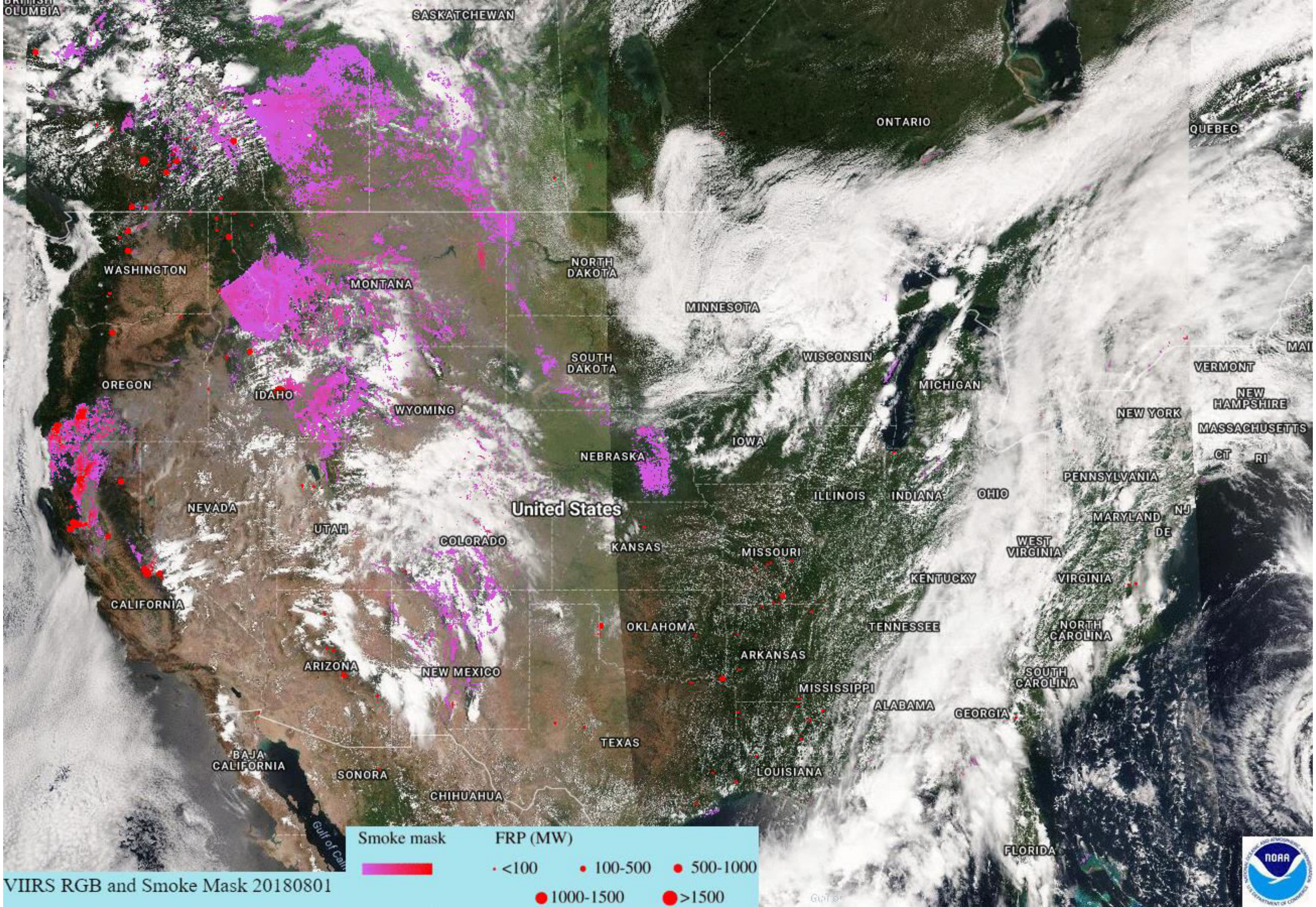
- geostationary satellites only
- MODIS only
- VIIRS only

Total PM2.5 (June 15 – August 15 2017

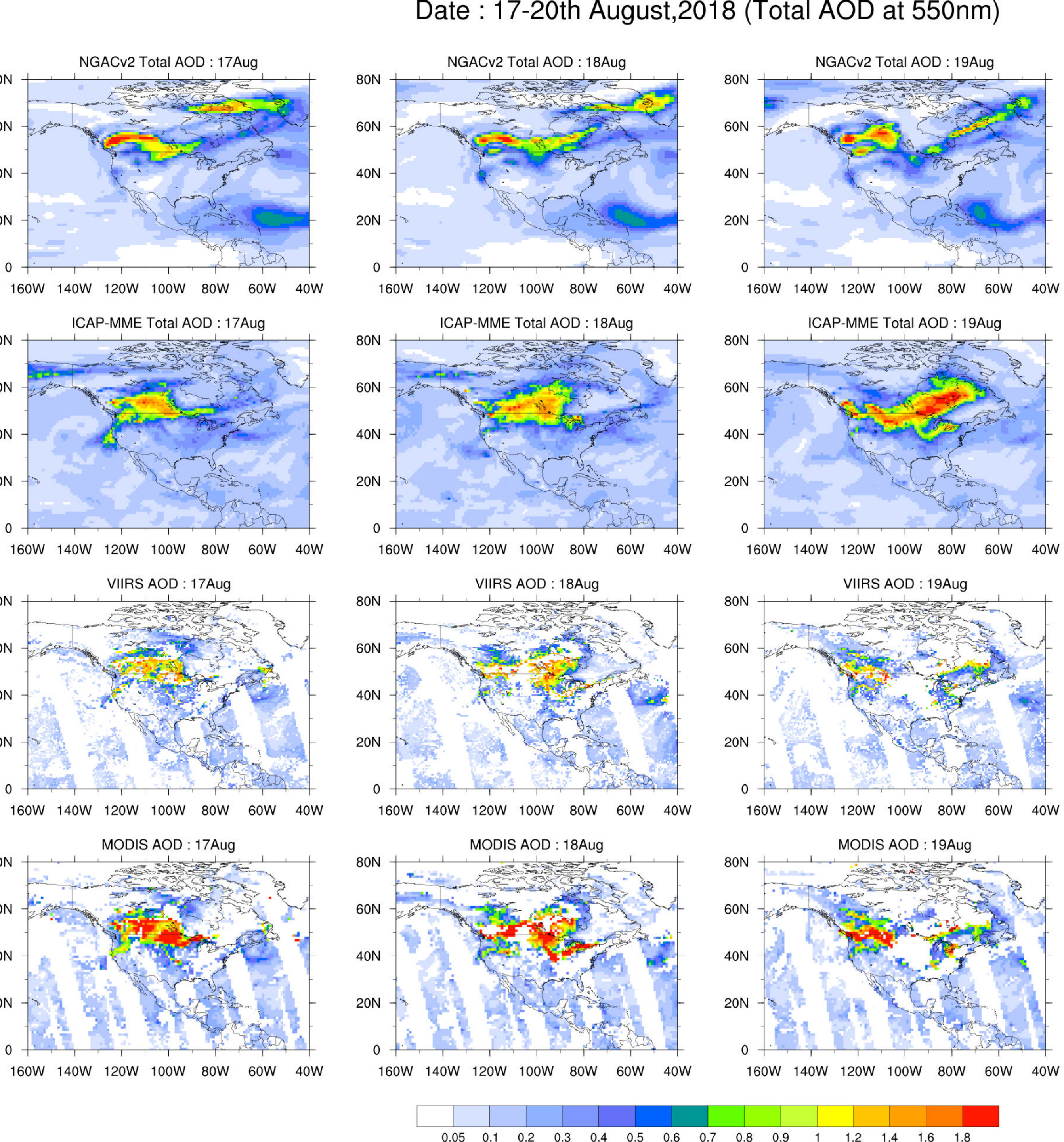


Daily PM2.5 (June 15 – August 15 2017



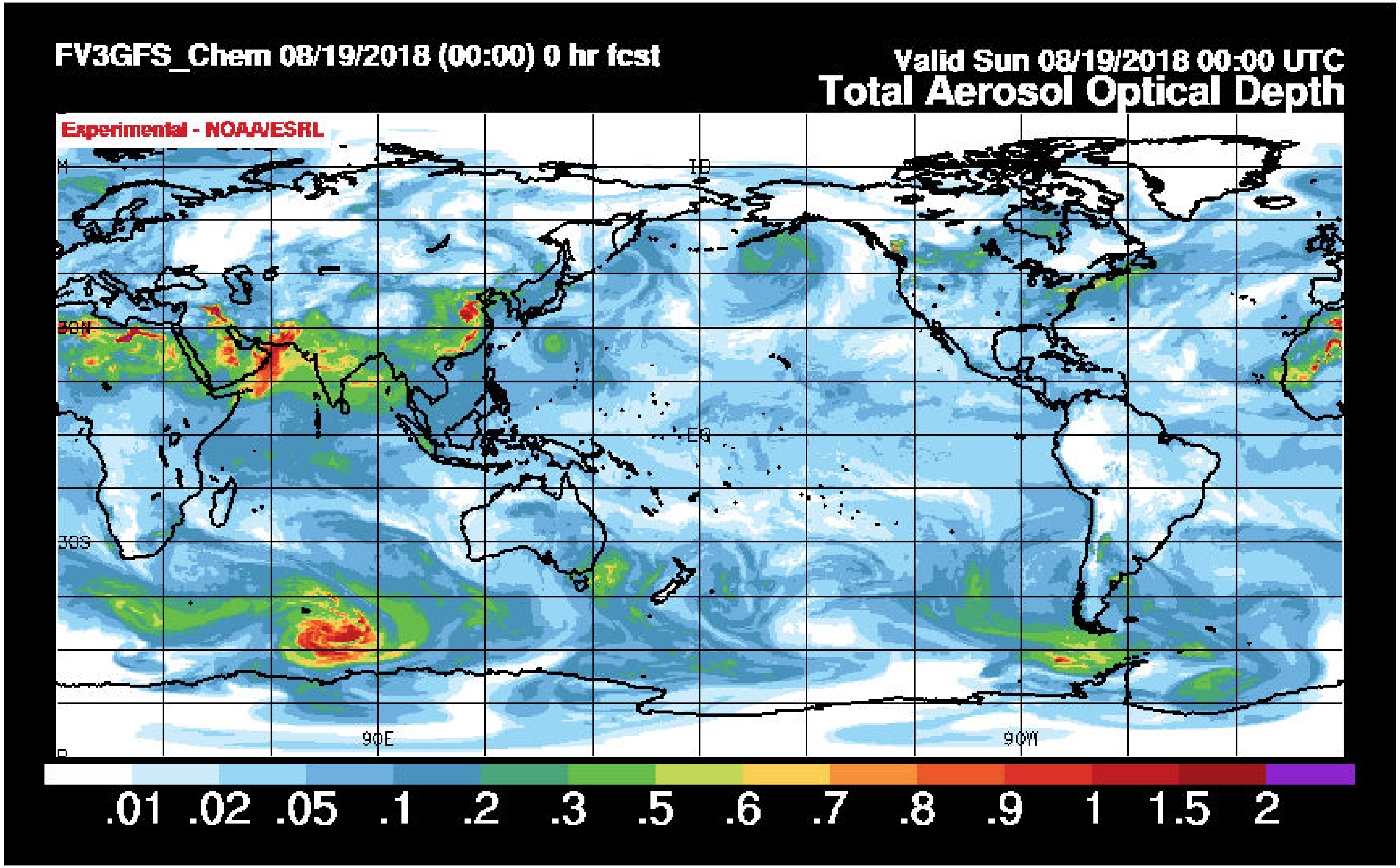


VIIRS RGB and Smoke Mask 20180801



NWS/NCEP operational model run with GBBEPx V2

FV3GFS-Chem Simulated AOD



Courtesy of NOAA/ESRL

- FV3GFS_Chem is the Next Generation Global Prediction System (NGGPS) for aerosols
- We are currently adapting GBBEPx file format to FV3 grid so it can be tested

Conclusions

- GBBEPx is an operational product currently being used by operational NGAC v2 aerosol model at NCEP
- Plans underway to add NOAA-20 fire emissions to GBBEPx
- Despite repeated proposal submissions to PSDI to replace legacy GOES and MTSAT with GOES-16/17 and Himawari-8/9 fire emissions, no funding
- GBBEPx sample data were provided to HRRR-smoke model for testing
- GBBEPx output is being adapted for FV3 grid for testing purposes
- Algorithm/product has been published in multiple journal articles

1. Li, F., Zhang, X., Kondragunta, S., Csiszar, I., 2018, Comparison of fire radiative power estimates from VIIRS and MODIS observations. *Journal of Geophysical Research-Atmosphere*, https://doi.org/10.1029/2017JD027823.
2. Li, F., Zhang, X., Kondragunta, S., Roy, D.P., 2018, Investigation of the fire radiative energy biomass combustion coefficient - a comparison of polar and geostationary satellite retrievals over the Conterminous United States. *Journal of Geophysical Research-Biogeoscience*, 132, 722-739. https://doi.org/10.1002/2017JG004279.
3. Huang, R., Zhang, X., Chan, D., Kondragunta, S., Russell, A.G., Odman, M.T., 2018, urned Area Comparisons between Prescribed Burning Permits in Southeastern USA and two Satellite-derived Products. *Journal of Geophysical Research-Atmosphere*, https://doi.org/10.1029/2017JD028217
4. Zhang, X., Kondragunta, S., and Roy, D.P., 2014. Interannual variation in biomass burning and fire seasonality derived from geostationary satellite data across the contiguous United States from 1995 to 2011. *Journal of Geophysical Research-Biogeosciences*, http://dx.doi.org/10.1002/2013JG002518.
5. Zhang, F., Wang, J. Ichoku, C., Hyer, E., Yang, Z., Ge, C., Su, S., Zhang, X., Kondragunta, S., Kaiser, J., Wiedinmyer, C., and da Silva, A., 2014. Sensitivity of mesoscale modeling of smoke direct radiative effect to the emission inventory: A case study in northern sub-Saharan African region. *Environmental Research Letters*, **9,** 075002, http://dx.doi.org/10.1088/1748-9326/9/7/075002.
6. Zhang, X., Kondragunta, S., Ram, J., Schmidt, C., Huang,H-C, 2012. Near Real Time Global Biomass Burning Emissions Product from Geostationary Satellite Constellation. *Journal of Geophysical Research-Atmosphere,* http://dx.doi.org/10.1029/2012JD017459.

Multi-platform Tropical Cyclone Surface Wind Analysis (MTCSWA) Blended Product

Presented by John Knaff

J. Dostalek (CIRA), L. Ma (OSPO)

August 30, 2018

Outline

- Team Members and Affiliations
- Blended Product Development
- Identified Issues/Risks/Mitigations
- Future Algorithm Improvements
- Product Outreach
- Summary and Path Forward

MTCSWA Blended Product Team

Algorithm Team Members

Name	Organization	Major Task
John Knaff	STAR	Lead Developer
Liqun Ma	OSPO	Lead OSPO
Jack Dostalek	CIRA	Software/implementation support
ASSISTT	STAR	NDE implementation

Input Needs for the Blended Product Algorithm

- Blended Product Name: **MTCSWA**

Required Satellite and Ancillary Input Data Products

	Data Product Name (Inputs)	Input Data Type (Satellite/Model Forecasts/*In-situ*)	Temporal/ Spatial Resolution, Format	Source(s)
1	Wind Scatterometry	METOP-A/B	12-hrly/25 km	OSPO
2	Wind (850, 700 hPa) AMSU	MIRS Retrievals METOP-A/B, NOAA-18/19	12-hrly/50 km	OSPO
3	Wind (850, 700 hPa) ATMS	MIRS Retrievals SNPP	12-hrly/25 km	OSPO
4	IR-proxy-wind (700 hPa)	GOES-15/16, Metosat-8/11, Himawari-8	3-hrly/4 km x 10^{o}	OSPO
5	AMV winds	GOES -15/16	3-hrly/variable	OSPO
6	AMV winds	Himawari-8/Metosat	3-hrly/variable	Navy/OSPO
7	TC location/intensity	ATCF (text)	6-hrly	JTWC/NHC

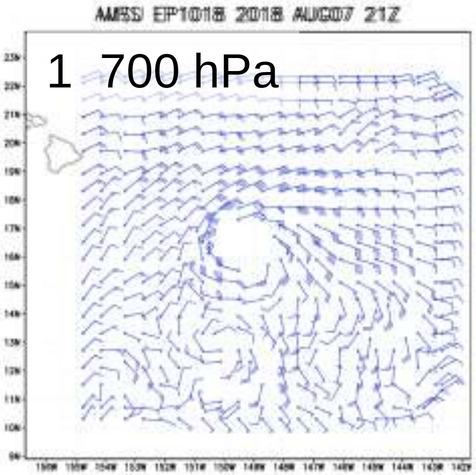
Blended Product Development

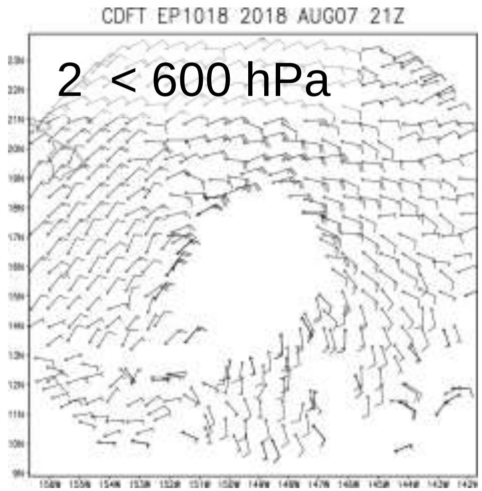
MTCSWA Technical Approach

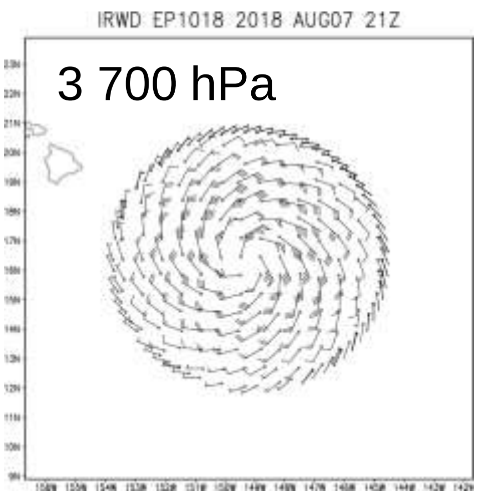
1. MTCSWA **blends four satellite-based wind estimates** compiled over 9 hours
   - **AMVs** below 600 hPa (NESDIS, EUMETSAT, JMA)
   - **AMSU/ATMS** – sounding based **winds** (solves the balance equations on pressure levels) (Bessho et al. 2007)
   - **Advanced Scatterometer**
   - **IR-Based flight-level proxy winds** (given intensity, motion and location estimates the 2-D wind field at 700 hPa) (Knaff et al. 2015, Mueller et al. 2006)

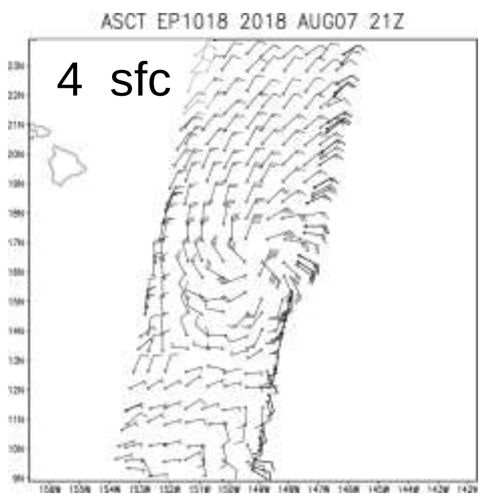
2. Technical Approach
   - Moves wind data to a **storm-motion-relative framework** valid at analysis time.
   - Adjust winds to a **common pressure level** (Franklin et al. 2003)
   - **Adjust for lack of frictional inflow** for surface winds (Zhang and Ehlhorn 2012)
   - A variational **data fitting** approach in polar coordinates
   - **Adjusts winds** to 10-m oceanic exposure or land (Franklin et al. 2003)
   - **Applies** appropriate frictional **inflow angles** (Zhang and Ehlhorn 2012).

Input data









1. Microwave Sounder – based winds (Bessho et al. 2006)
2. Atmospheric Motion Vectors
3. IR-based flight-level proxy winds (Knaff et al. 2015)
4. Scatterometery

Special treatment of A-SCAT wind speeds

A hurricane specific bias correction is applied to A-SCAT data based on Chou et al (2013).

Results based on collocated dropwindsonde observations

Increases observed winds, especially above 17.5 ms^{-1} (35 kt)

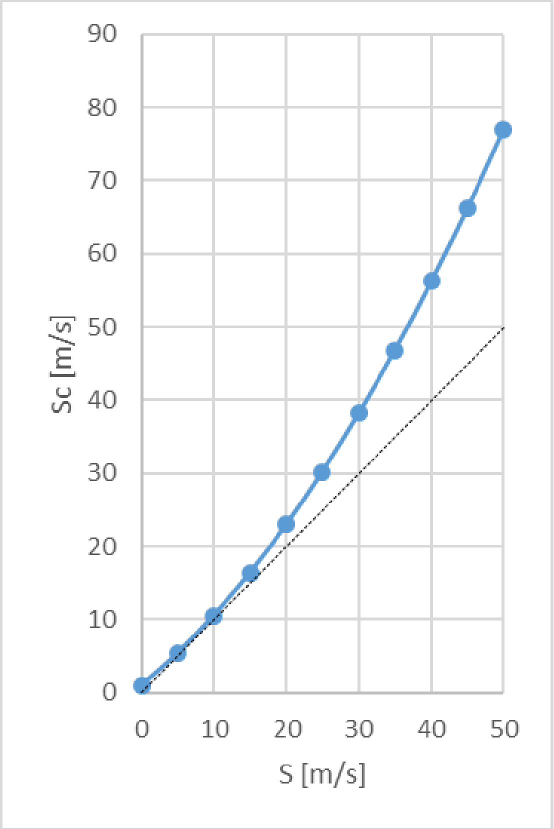
Form of the bias correction

S ≡ observed A-SCAT wind speed

S_c ≡ bias corrected A-SCAT wind speed,

Where S has units of ms^{-1}

$$S_c = 0.014S^2 + 0.821S + 0.961$$



A motion-relative/common level framework

INPUTS:

1. Current position and intensity (ATCF)
2. Past position and intensity (ATCF)
3. Forecast Position/Intensity, if available
4. Observed and Proxy winds (last 9 hours)

PROCEEDURE:

1. Spline Latitude (t)
2. Spline Longitude (t)
3. Move observations from their observed time to the analysis time using these estimates for positions
4. Calculate r, ϴ coordinates based on the analysis center
5. Bias correct ASCT
6. Adjust winds/inflow angles to a common analysis level (700 hPa)

RESULT:

Observations (9h worth) are in a motion relative framework
Observations on a polar grid
Observations at a common level (gradient level/ 700 hPa)

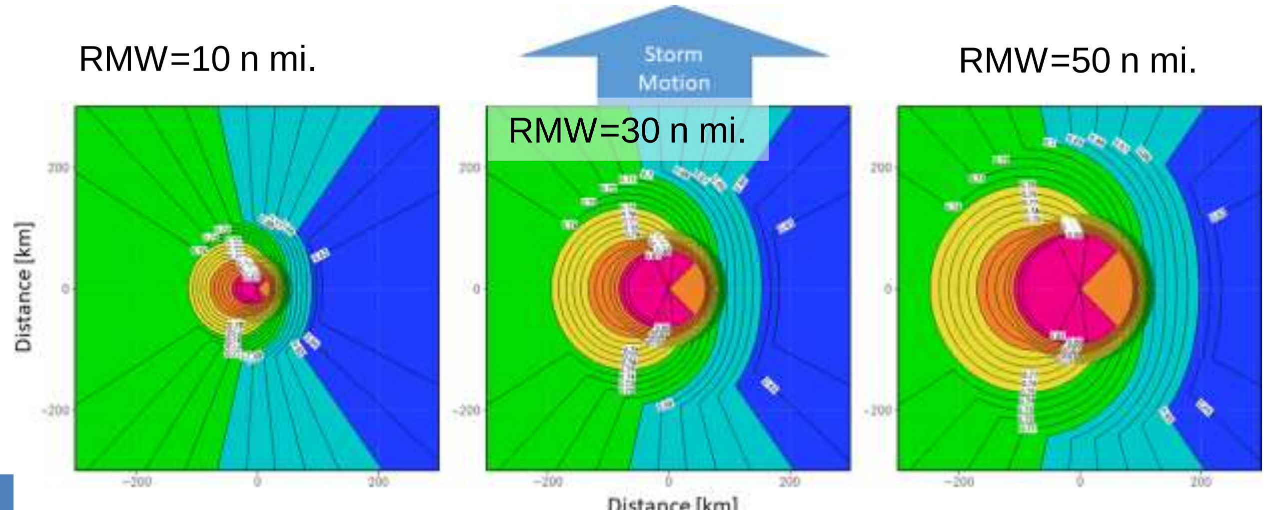
These are ready for blending in the analysis

Adjusting winds to common levels (speed)

- Algorithm is based on the findings of Franklin et al. (2003) who defined reductions to the surface in two regions and four pressure layers.
  1. Eyewall (within 2 * RMW)
  2. Outer vortex
  3. There is also 4% and 17% differences as a function of azimuth in Eyewall and outer regions

Level (hPa)	Eyewall	Outer Vortex
600-800	0.88	0.83
800-900	0.78	0.78
900-990	0.73	0.73
990-Sfc	0.77	0.77

Examples: Reduction Factors (R) from 700 hPa

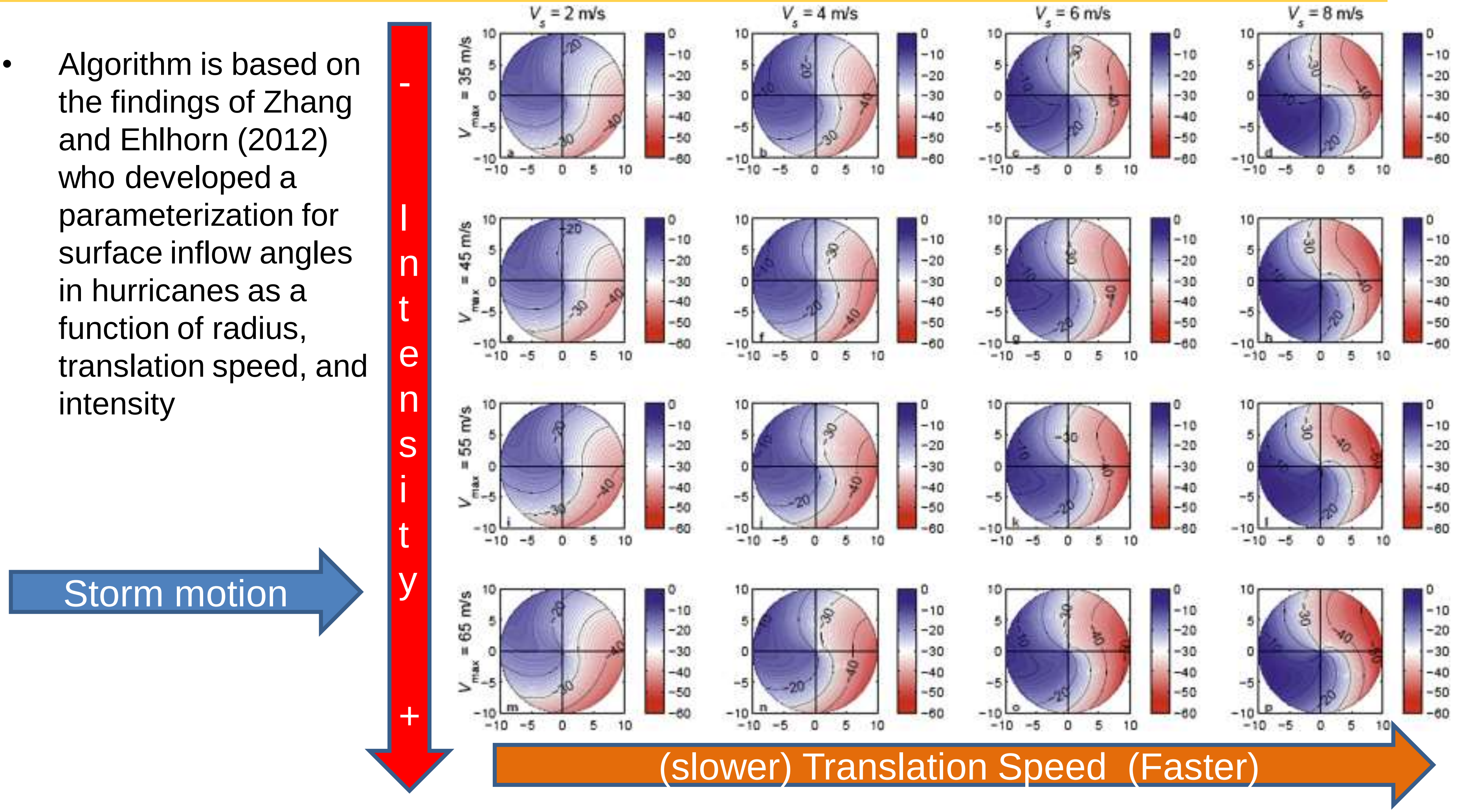


R < 0.65 | 0.75≤ R< 0.80
0.65≤ R <0.70 | 0.80≤ R <0.85
0.70≤ R <0.75 | R > 0.85

This algorithm allows for
1. **Adjustment of the wind speeds to a common level**
2. **Adjustment from the analysis level to the surface following analysis**

Adjusting winds to common levels (angles)

- Algorithm is based on the findings of Zhang and Ehlhorn (2012) who developed a parameterization for surface inflow angles in hurricanes as a function of radius, translation speed, and intensity



This algorithm allows for
1. **Adjustment of the inflow angles from the surface to a common level**
2. **Estimation of surface inflow angles for analyzed wind speeds adjusted to the surface**

The Analysis Scheme

- Based on Thacker (1988) – a data fitting method
- Variational (Minimize *C*)
- Data fitting
- Allows for scalar wind estimates
- Allows for weighting of observation types
- Has adjustable filter weights (r, Ө)
- On a polar grid 4.5 km x 10º (i.e., Makes circles rather than squares)
- Solved iteratively via steepest decent

$$C = \frac{1}{2}\sum_{k=1}^{K} w_k\left[(u_k - U_k)^2 + (v_k - V_k)^2 \right]$$

Wind vectors
Measures misfit

$$+\sum_{m=1}^{M} w_m (s_m - S_m)^2$$

Wind speeds
Measures misfit

$$+\sum_{i=1}^{I}\sum_{j=1}^{J}\left\{ \begin{array}{l} \alpha\left[(\delta_{xx}U_{ij})^2 + (\delta_{xx}V_{ij})^2\right] \\ +\beta\left[(\delta_{yy}U_{ij})^2 + (\delta_{yy}V_{ij})^2\right] \end{array} \right\}$$

Penalty term
Acts as a filter

$$\delta_{xx}U_{ij} = (U_{i+1,j} + U_{i-1,j} - 2U_{ij}) / \Delta x^2$$

$$\delta_{yy}V_{ij} = (V_{i+1,j} + V_{i-1,j} - 2V_{ij}) / \Delta y^2$$

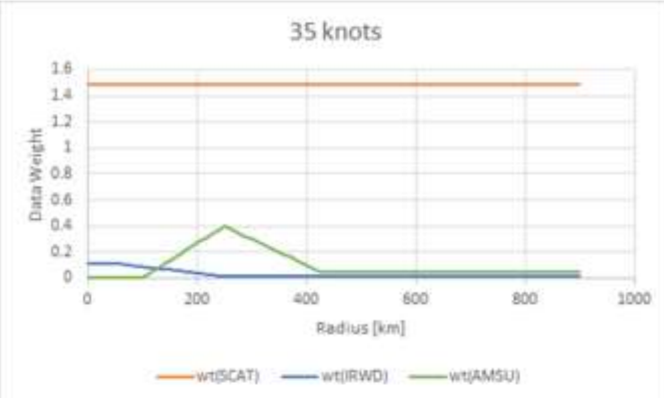
Filter weights	Data weights
α	w_k
β	w_m

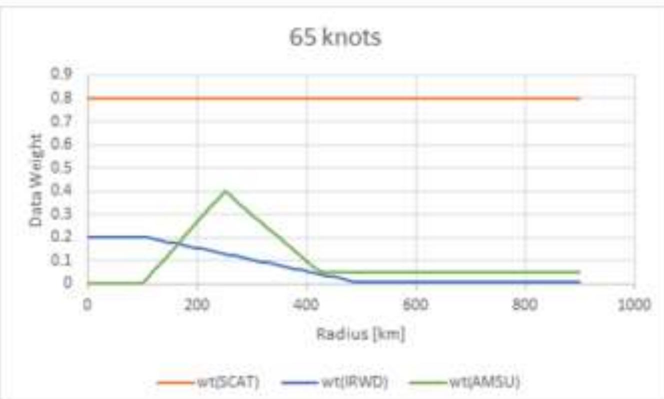
response function F (k) of the filter weights

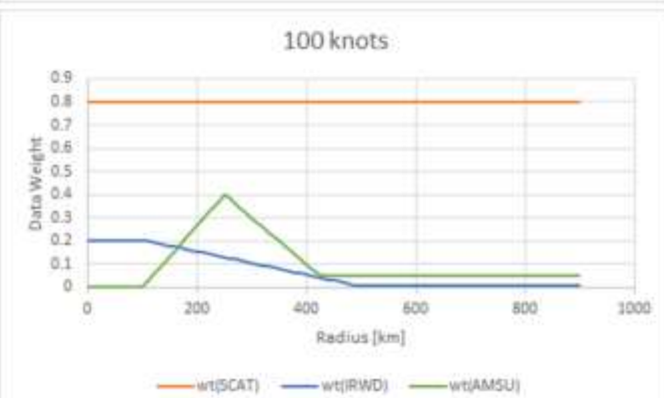
$$F(k) = 1/\{1 + 8\alpha[1 - \cos(k\Delta x)]^2\}$$

Where x can be r or θ and α = β

Data weights







To help overcome the shortcomings of each input data weights are used to weight data selectively as a function of radius, current intensity and data type.

- Weights were tuned using aircraft-based analyses
- Weights are a function of intensity
- Weights are a function of the number of points in the analysis.

AMVs weights = 5.0 for all intensities

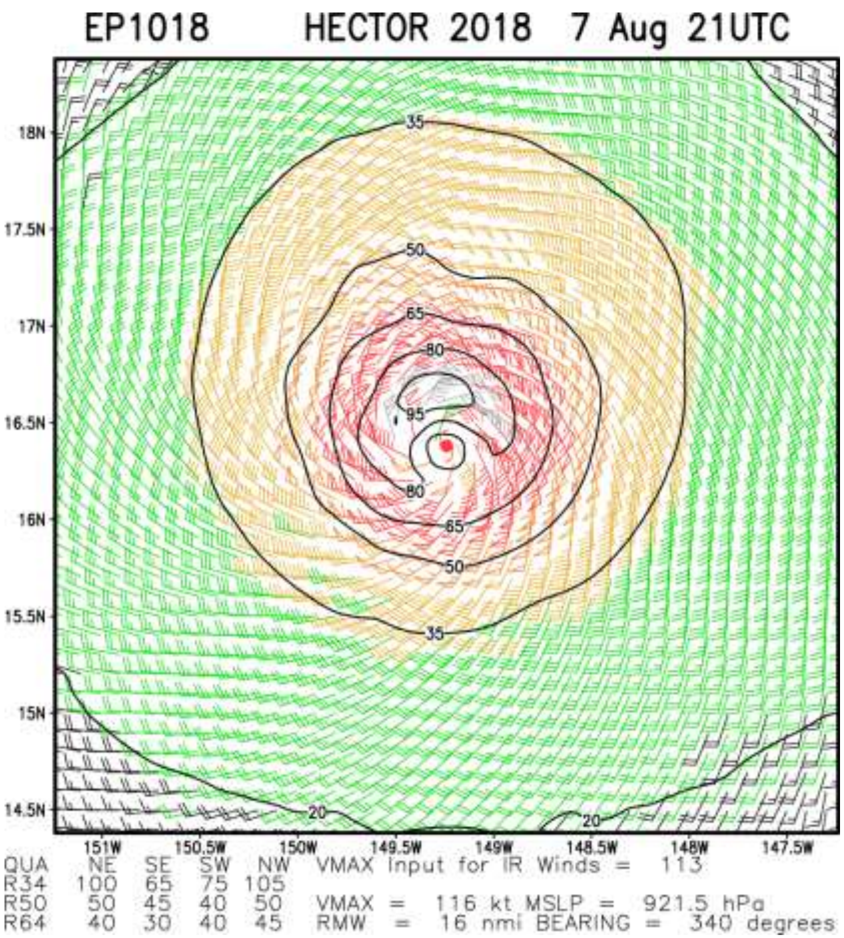
MTCSWA Examples/Outputs

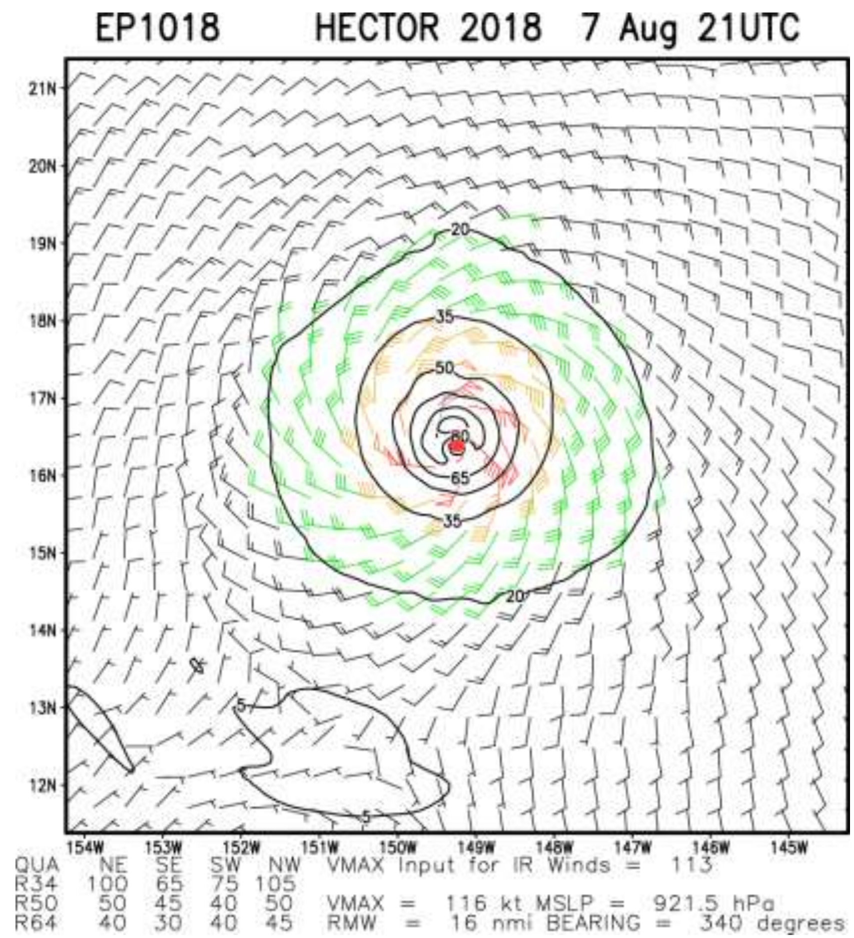
Output Data Products

	Blended Data Product Name (Outputs)	Output Data Type (Satellite; Model Forecasts; In-situ)	Spatial, Temporal Resolution, Format	Source(s)
1	TC Surface Wind Analysis	GOES/Met-op/Metosat/POES/SNPP/H8	10km, 3-hourly, NETCDF	STAR Enterprise NDE
2	TC ATCF-Fix	GOES/Met-op/Metosat/POES/SNPP/H8	Wind Radii, RMW, MSLP, 3-hourly, ASCII	STAR Enterprise NDE

MTCSWA Examples/Outputs

Output Data Products





MTCSWA Examples/Outputs

Output Data Products

ATCF Fix

EP, 10, 201808072100, 70, ANAL, PR, , **1638N, 14924W**, 10 , 2, , 2, **922**, 2, MEAS, **34, NEQ, 100, 65, 75, 105**, , , , , 2, 16, , E, CIRA, MPS, MPS, 201808070900, 201808080046, , , AMSU CD WV IR ASCT , CIRA Combined Multi-Platform Satellite Analysis

EP, 10, 201808072100, 70, ANAL, PR, , **1638N, 14924W**, 10 , 2, , 2, **922,** 2, MEAS, **50, NEQ, 50, 45, 40, 50**, , , , , 2, 16, , E, CIRA, MPS, MPS, 201808070900, 201808080046, , , AMSU CD WV IR ASCT , CIRA Combined Multi-Platform Satellite Analysis

EP, 10, 201808072100, 70, ANAL, PR, , **1638N, 14924W**, 10 , 2, , 2**, 922**, 2, MEAS, **64, NEQ, 40, 30, 40, 45**, , , , , 2, 16, , E, CIRA, MPS, MPS, 201808070900, 201808080046, , , AMSU CD WV IR ASCT , CIRA Combined Multi-Platform Satellite Analysis

Product Evaluation/Validation/Tools

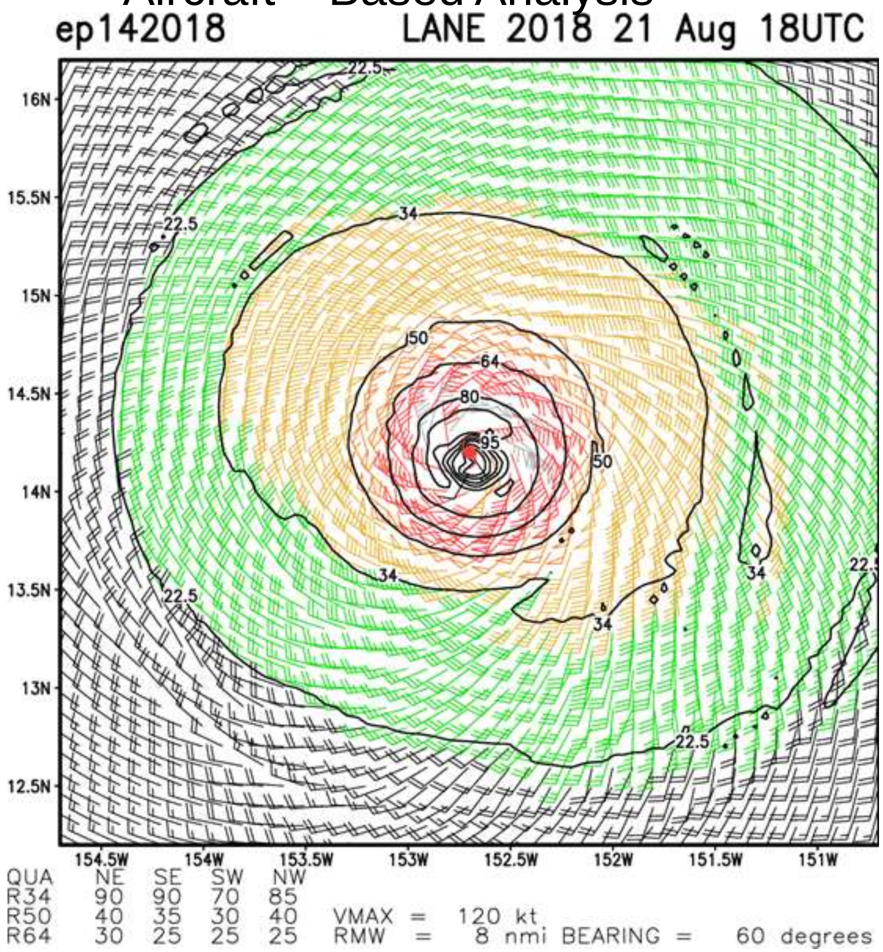
- Product Evaluation/Validation
  - Initial validation and training was based on aircraft-based H*Wind (Powell et al. 1998) surface wind analyses
  - Current evaluation is based on an in-house aircraft-based surface wind analysis developed for the Joint Hurricane Testbed and final best track estimates or 34-, 50- and 64-kt winds.

- Validation show that the largest errors (~ 5 ms-1) are in the vicinity the radius of maximum winds. Elsewhere errors are typically less than 2 ms^{-1}

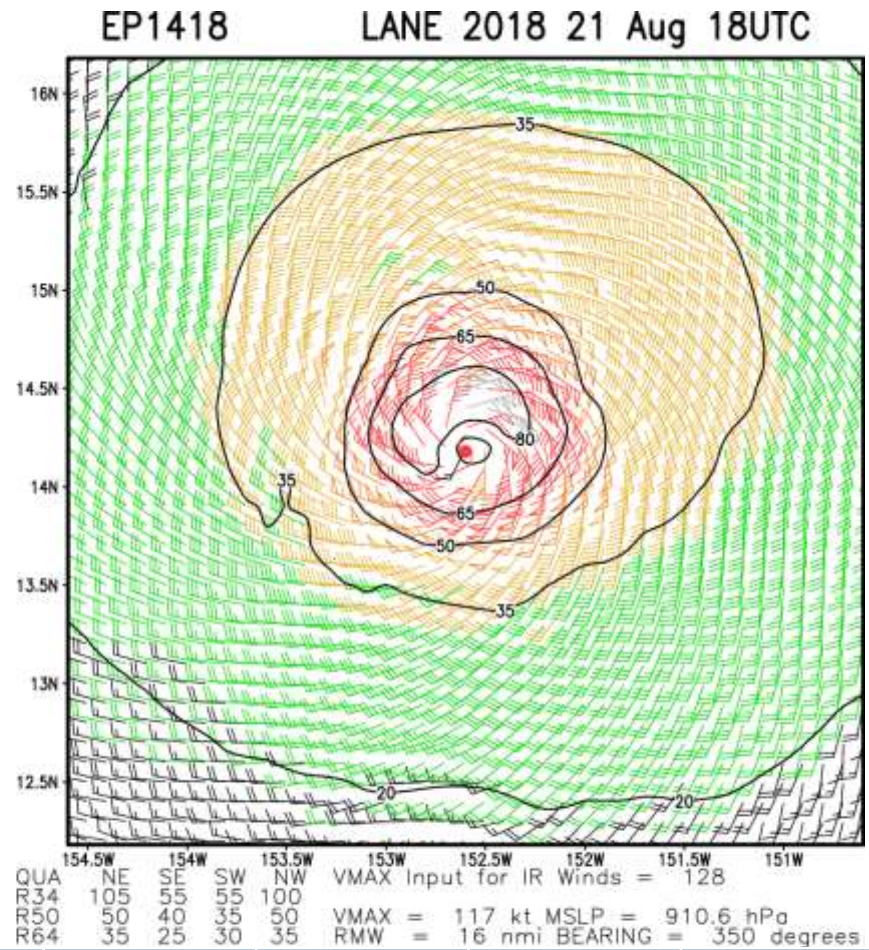
Recent example Hurricane Lane (next slide)

Hurricane Lane (small, compact, and intense)

Aircraft – Based Analysis



MTCSWA



Working Best Track

Vmax = 135 kt

CP = 941 hPa

RMW = 20 nmi.

	NE	SE	SW	NW
R34	110	95	50	120
R50	70	40	30	80
R64	35	25	25	30

MTCSWA Implementation Status

- Implementation
  - Previous version running at NSOF (degraded)
  - This version is running experimentally at CIRA
  - Planned in late 2018.
  - ATCF fix files are already getting to NHC, CPHC and JTWC
  - NetCDF output should help with use on AWIPS-II, ATCF
- Will be run on NDE
- Help coming from ASSISTT

Identified Issues/Risks/Mitigations

Identified Risk/Issues	Action/Mitigation
Transition to operations (NDE)	Working with ASSISTT personnel
Himawari access	Plans for moving to operations
Failure of ASCAT	None
Metop-C products replacing A	Plans for moving to operations

Future Algorithm Improvements

- Improvements
  - Incorporation of ASCAT from Metop-C
  - Possible use of SMAP and SMOS winds (experimental)
  - Improved estimation of radius of maximum winds from satellite (ongoing work)
  - Work to improve central pressure estimates in intense storms.
- Future Validation Plans
  - Continue to use aircraft-based data for inner core
  - SMAP and SMOS wind speeds and TROPICS non-linear balance winds as independent assessment of outer winds

Summary and Path Forward

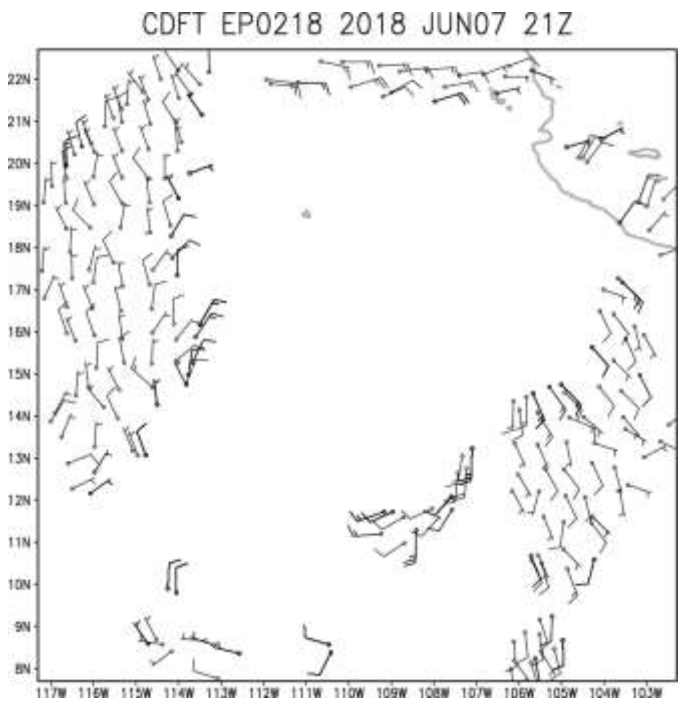
- MTCSWA provides **unique** and important information regarding the **real-time surface wind structure** in **global** tropical cyclone
- The **satellite-only-based** information provides key information in regions where routine aircraft reconnaissance is not performed
- Surface wind structure estimates support NWP (e.g., Bender et al. 2017), wind probabilities, watch/warnings, and wave forecasts (various methods) and thus impact TC impacts and forecasts.

Path Forward:

1. Get these updates in operations
   - mitigate the GOES-16 and soon GOES-17 degradation
   - Improved known shortcomings of the legacy analyses.
2. Continue to improve the inputs and methodology as part of StAR base or other funding opportunities

Backup Slides

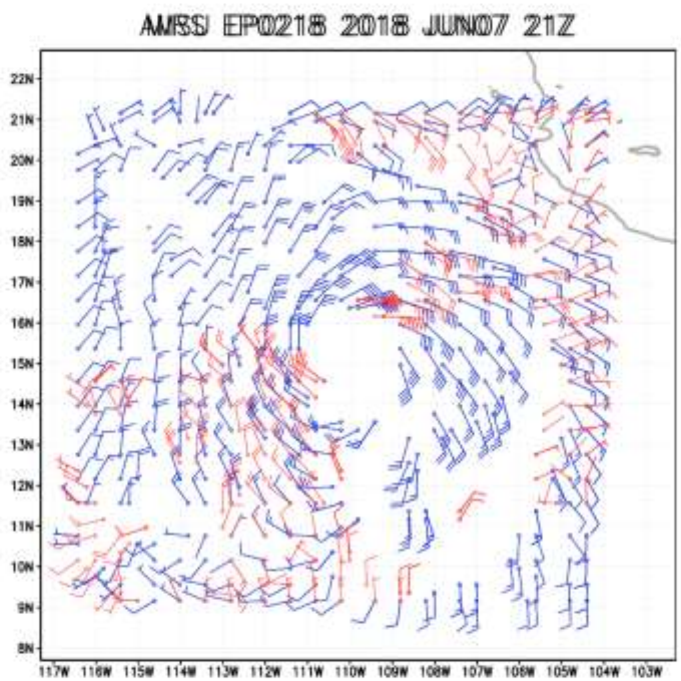
Input 1: AMVs



- Source (NESDIS & US Navy)
- All AMVs below 600 hPa (IR, Vis,WV)
- Each data point is compiled in a storm-motion relative framework valid at the analysis time
- Each are adjusted to 700 hPa as a function of pressure, azimuth and radius
- Provides environmental winds

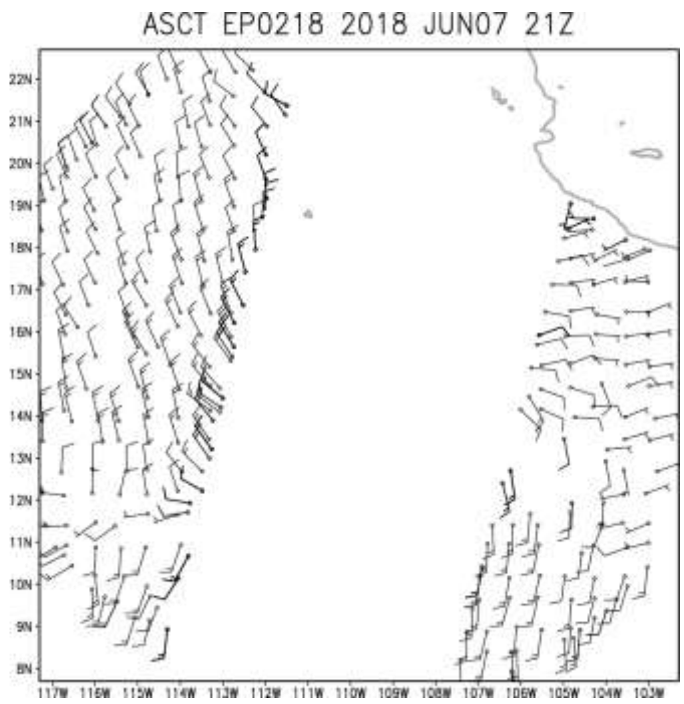
Input 2: AMSU/ATMS Sounder-based winds

Statistical
MIRS



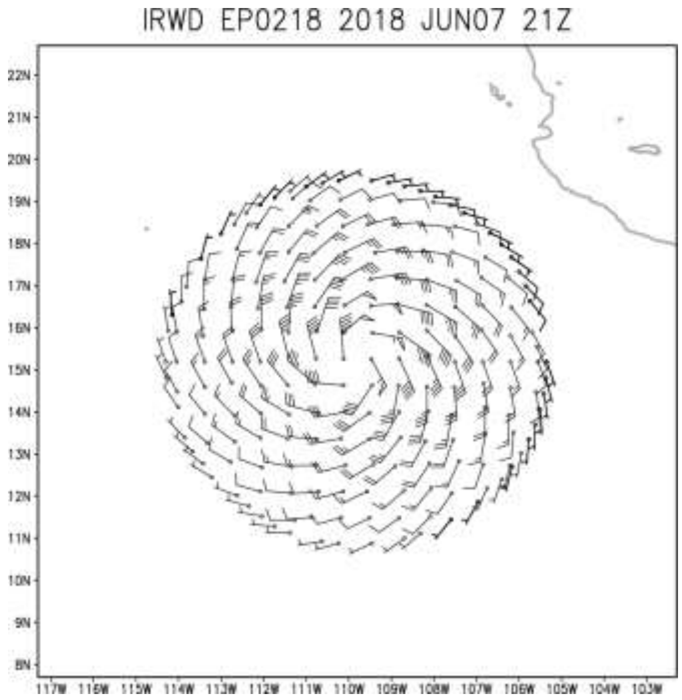
- Method of Bessho et al. (2006) that solves the non-linear balance equations on pressure surfaces
- Winds are compiled in a motion relative framework
- Winds are adjusted to 700 hPa
- By product of the Hurricane Intensity and Structure Algorithm (HISA)
- Statistical (NCEP) and MIRS (OSPO) based inputs
- Provides asymmetries r=200 - 400

Input 3: A-Scat



- Source: OSPO MCADDE server
- Winds are compiled in a motion relative framework
- Winds are adjusted to 700 hPa, speed (Franklin et al. 2003), angles (Zhang and Uhlhorn 2012), bias (Chou et al. 2013)
- Provides environmental and near core winds, when availalbe

Input 4: IR-based flight-level proxy winds



- Winds are based on the algorithm discussed in Knaff et al. (2015) that related intensity, motion and IR patterns to the flight level winds (wavenumbers 0-2)
- Winds are compiled in a motion relative framework
- Winds are adjusted to 700 hPa as a function of pressure, azimuth and radius
- Provides winds near the core and the radius of maximum winds

References used in this talk

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Importance/Benefits/Users

- In tropical cyclone regions without routine aircraft reconnaissance the surface wind estimates efficiently provide critical information about the surface wind structure associated with TCs.
  - Initial wind structure estimates influence watch/warning, TC conditions of readiness
  - Initial wind structure estimates are provided to NWP
  - Initial wind structure influence output of the wind speed probability product, which are inputs to watch/warning and significant wave height guidance
- No current funding for maintenance or future development (out of hide)

Name	Organization	Application	User Feedback
Mark Demaria	NHC	Wind Radii Estimation	Experimental and older operational versions fixes in ATCF Viewed on web-site
Brian Strahl	JTWC	Wind Radii Estimation	Older operational versions in fixes at JTWC Technical exchange occurring this week. Viewed on web-site

Documentation/website links

(Provide this information in your back-up slides)

- For experimental products
  http://rammb.cira.colostate.edu/products/tc_realtime/
- For legacy/operational product (degraded)
  http://www.ssd.noaa.gov/PS/TROP/mtcswa.html

Output Product(s) Specifications

- Blended Product Name: **MTCSWA**
- Output Data Type(s): Wind (netCDF), ATCF-fix (ASCII)

Output Product(s) Attributes	Threshold	Observed/validated
Latency	1h	35m
Geographic coverage	Global	Global
Vertical Coverage	N/A	N/A
Vertical Cell Size	N/A	N/A
Horizontal Cell Size	10 km	10 km
Mapping Uncertainty	50km	~20 km
Measurement Range	0-100 m/s	0-75 m/s
Measurement Accuracy	5 m/s	5 m/s
Measurement Precision	5 m/s	5 m/s
Measurement Uncertainty	5 m/s	5 m/s