Status of the NOAA Unique Combined Atmospheric Processing System (NUCAPS)

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Presented by Lihang Zhou

2017 ATOVS Working Group Meeting
Friday, December 1st, 2017

N as in NUCAPS

NOAA
NOAA's mandate: ensuring state of art inversion methods and highest computational efficiency in order to maximize utilization of large volumes of hyperspectral data for a weather ready nation

Unique
A globally applicable yet mathematically sound (land/ocean, day/night, all season, all sky, TOA-surface) hyperspectral sounding retrieval code

Combined
… that can fully exploit all assets currently available on operational polar sounders: infrared, microwave, visible

Atmospheric
… to generate a full suite of retrieval products: cloud cleared radiances, skin temperature, vertical profiles of temperature, water vapor, O_3, CO, CH_4, HNO_3, N_2O, SO_2, CO_2 (future: NH_3)
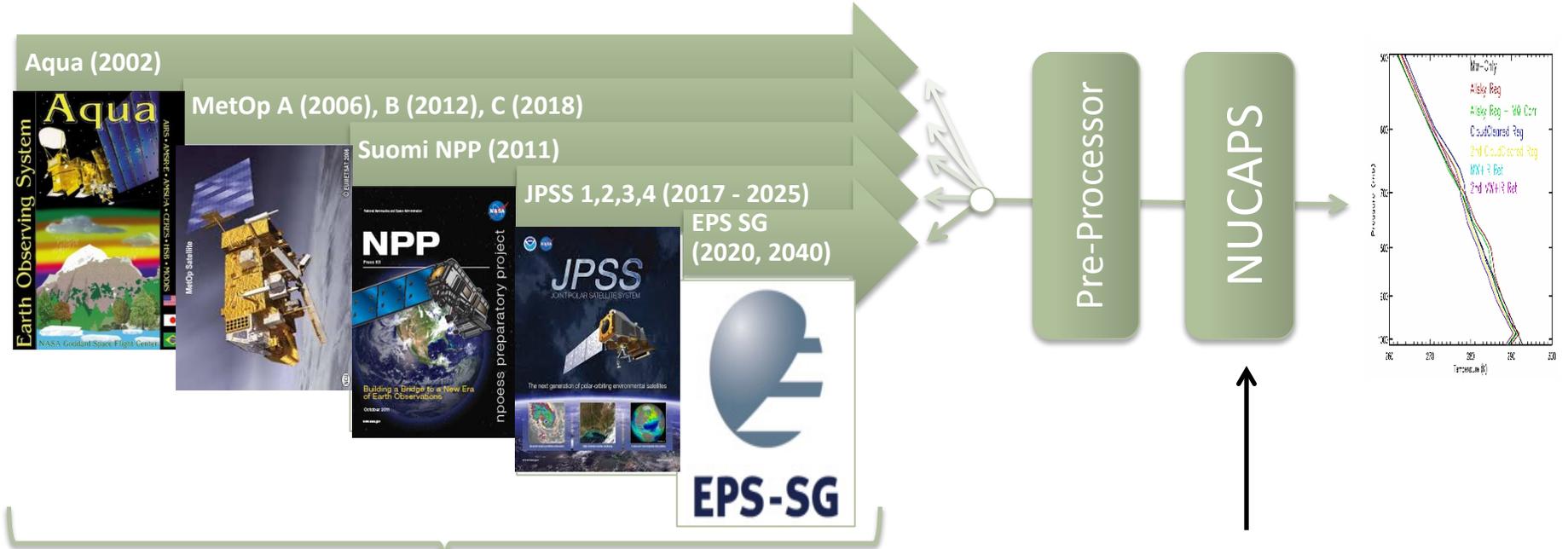
Processing
… by the use of a modular design compatible with multiple platforms: Aqua, MetOp, SNPP, JPSS, EPS-SG

System
NUCAPS has been running operationally at NOAA since 2004. It is now in AWIPS II and has been installed in CSPP DB.

# NOAA Long term strategy of hyperspectral sounding

Aqua (2002)

MetOp A (2006), B (2012), C (2018)

Suomi NPP (2011)

JPSS 1,2,3,4 (2017 - 2025)

EPS SG (2020, 2040)

Earth Observing System

MetOp Satellite

npoess preparatory project

EPS-SG

Joint Polar System Agreement, December 2, 2015:
Twenty More Years of Full, Free and Open Data

Pre-Processor

NUCAPS

Same exact executable
Same underlying Spectroscopy
Same look up table methodology
for all platforms

November 18th 2017:
JPSS 1 successfully launched!

VIIRS

CrIS

ATMS

OMPS

https://www.youtube.com/watch?v=WZITzp2on9w
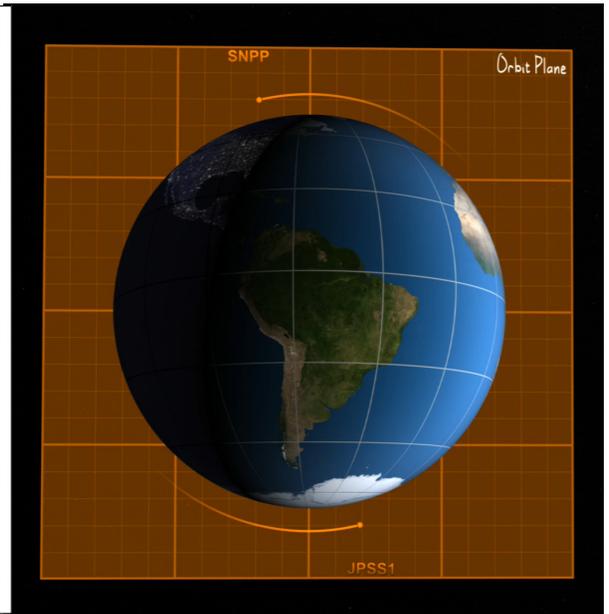
NUCAPS Retrieval Algorithm Flow Chart
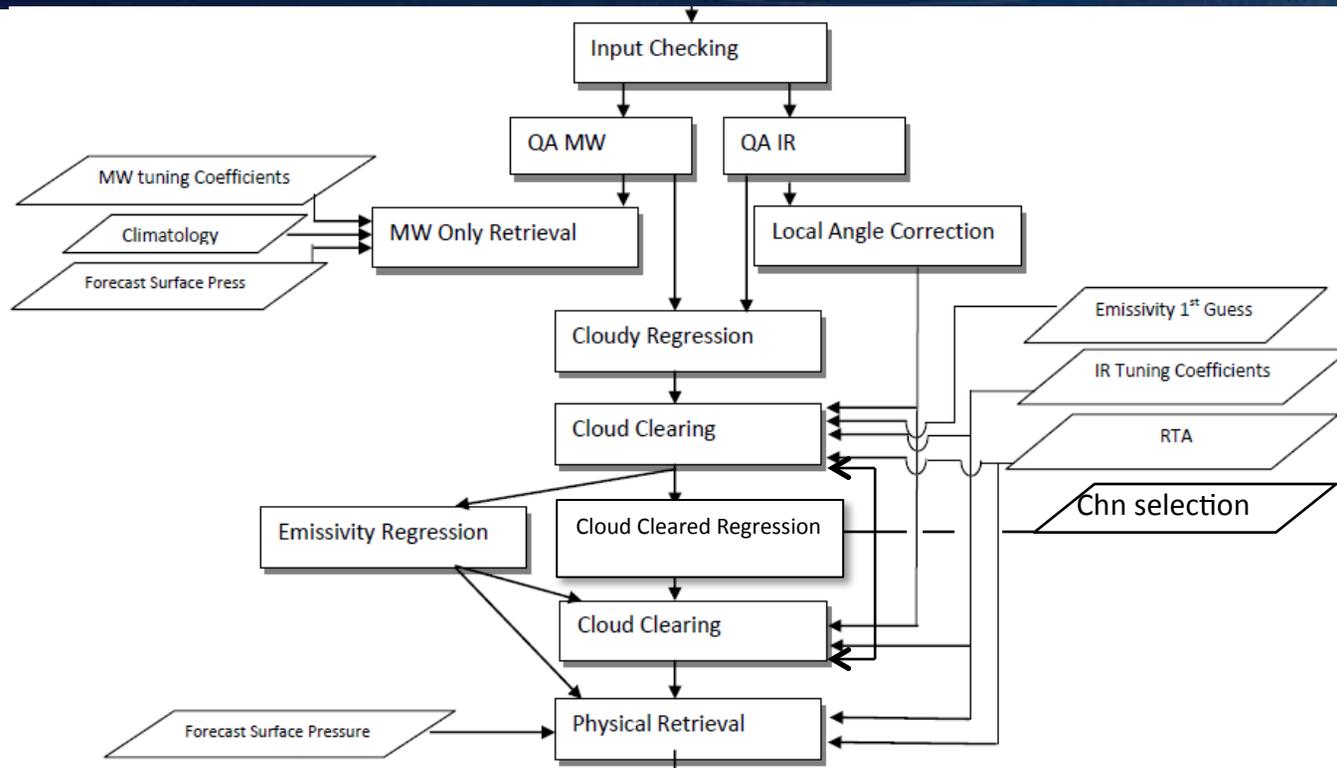
- **I. A microwave retrieval module** which computes Temperature, water vapor and cloud liquid water (Rosenkranz, 2000)
- **II. A fast eigenvector regression** retrieval that is trained against ECMWF and all sky radiances which computes temperature and water vapor (Goldberg et al., 2003)
- **III. A cloud clearing module** (Chahine, 1974)
- **IV. A second fast eigenvector regression** retrieval that is trained against ECMWF analysis and cloud cleared radiances
- **V. The final infrared physical retrieval** based on a regularized iterated least square minimization: temperature, water vapor, trace gases (O3, CO, CH4, CO2, SO2, HNO3, N2O) (Susskind, Barnet, Blaisdell, 2003)
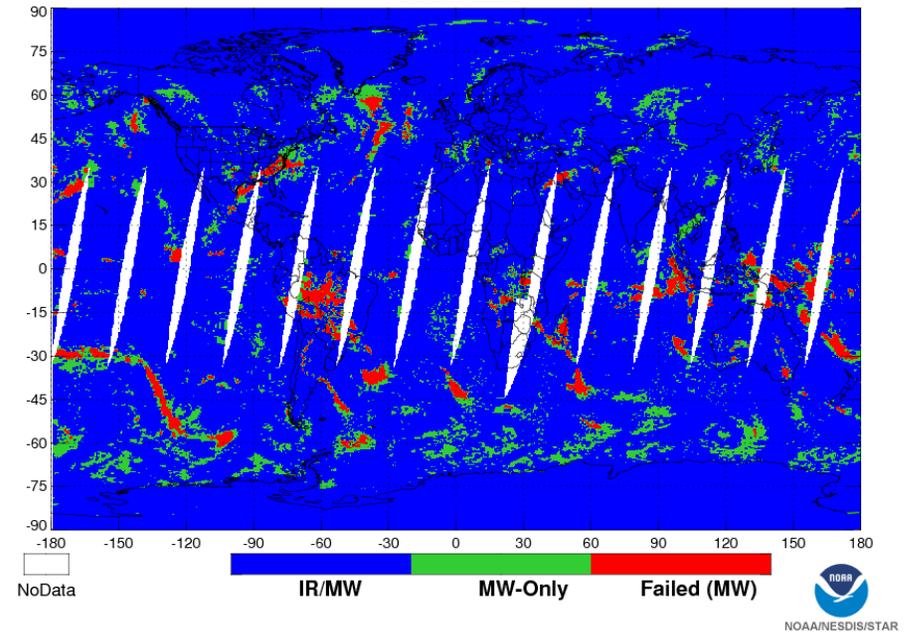
NUCAPS Acceptance Yield Upon Cloud Clearing

NUCAPS Quality Control Flag Asc (v2.0.5.4HR)
17 Feb 2015
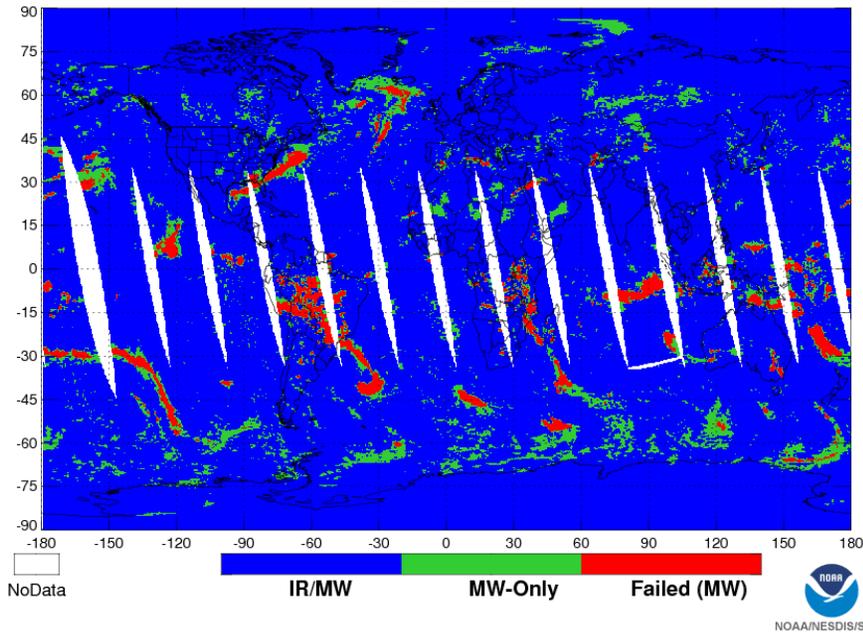
NUCAPS Quality Control Flag Des (v2.0.5.4HR)
17 Feb 2015

NoData   IR/MW   MW-Only   Failed (MW)

NOAA/NESDIS/STAR

NUCAPS global yield = 83 %
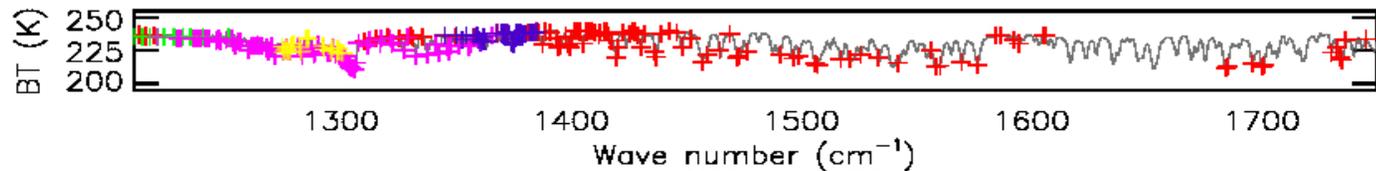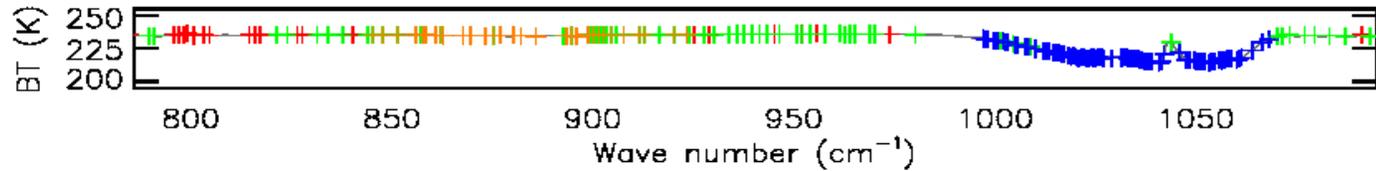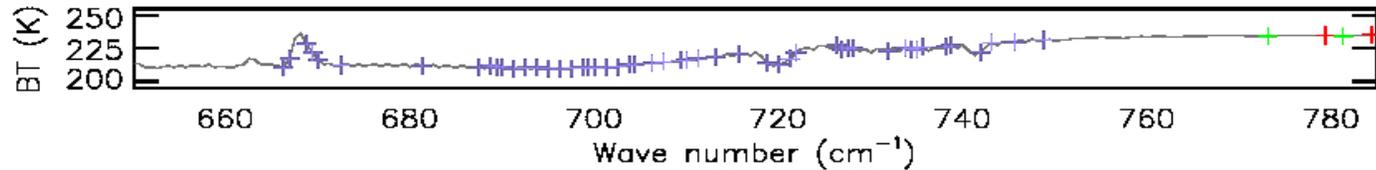
- **The Cross-Track Infrared Sounder (CrIS)** is a Fourier spectrometer covering the longwave (655-1095 cm^{-1}, "LW"), midwave (1210-1750 cm^{-1}, "MW"), and shortwave (2155-2550 cm^{-1}, "SW") infrared spectral regions.

- **Past operations (NUCAPS Phase 1-3):**
  - Maximum geometrical path L of 0.8 cm (LW), 0.4 cm (MW) and 0.2 cm (SW)
  - Nyquist spectral sampling ($1/2L$): 0.625 cm^{-1}, 1.25 cm^{-1} and 2.5 cm^{-1}

- **Operational in August 2017 (NUCAPS Phase 4):**
  - Maximum geometrical path L of 0.8 cm in all three bands
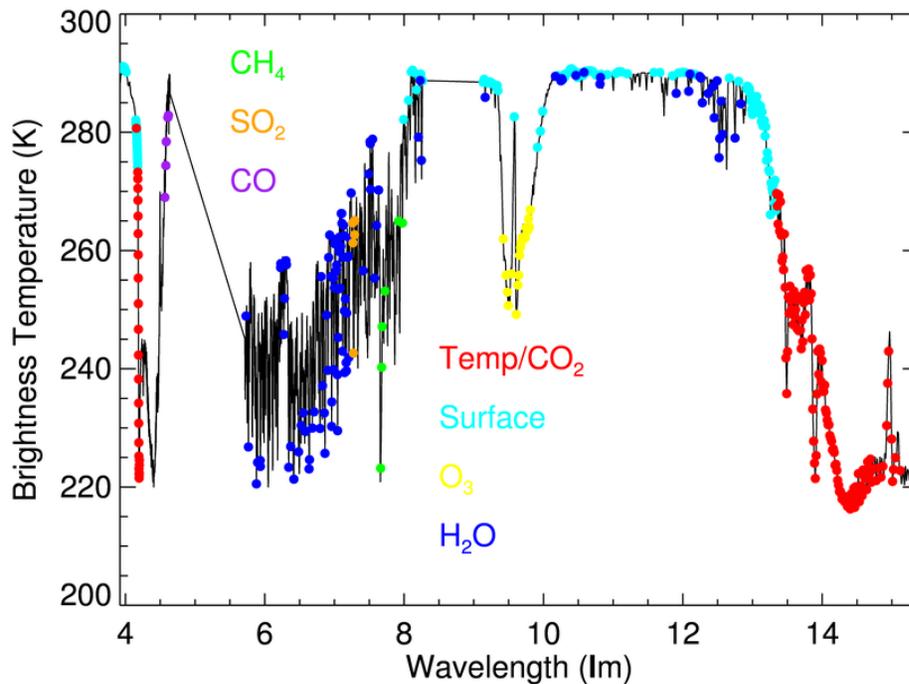 - Nyquist spectral sampling ($1/2L$): 0.625 cm^{-1} in all three bands

EDR	#chns
Temp	116
Surf	136 (62)
HO2	123 (62)
O3	77
CO	52
CH4	84
N2O	21
SO2	31
HNO3	30
CO2 (& Temp)	50 (T LW)
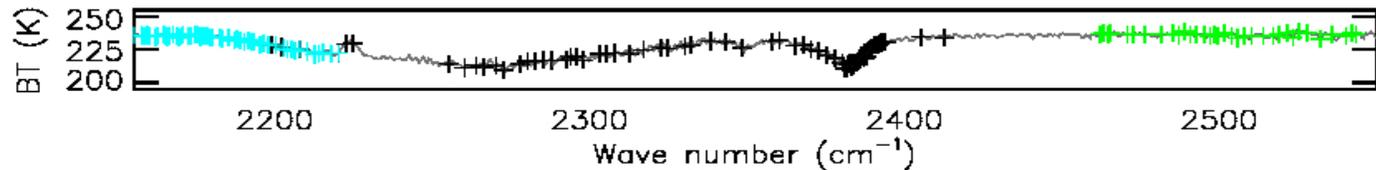
REF: A. Gambacorta and C. Barnet., Methodology and information content of the NOAA NESDIS operational channel selection for the Cross-Track Infrared Sounder (CrIS), IEEE, Vol. 51, Issue 6, 2013

Channels chosen:
LW Temp/CO$_2$ 125
Surface (LW+SW) 139
O$_3$ 19
H$_2$O 108
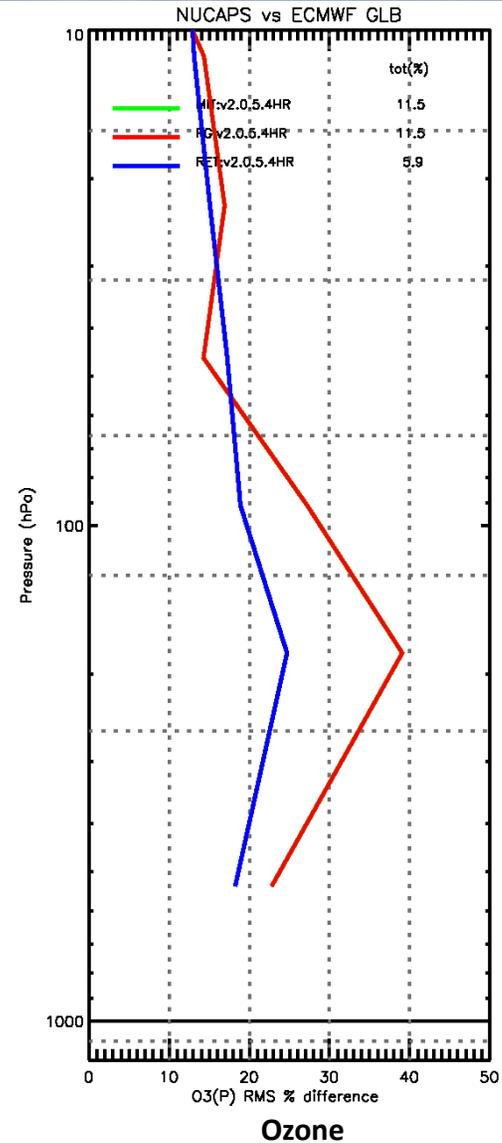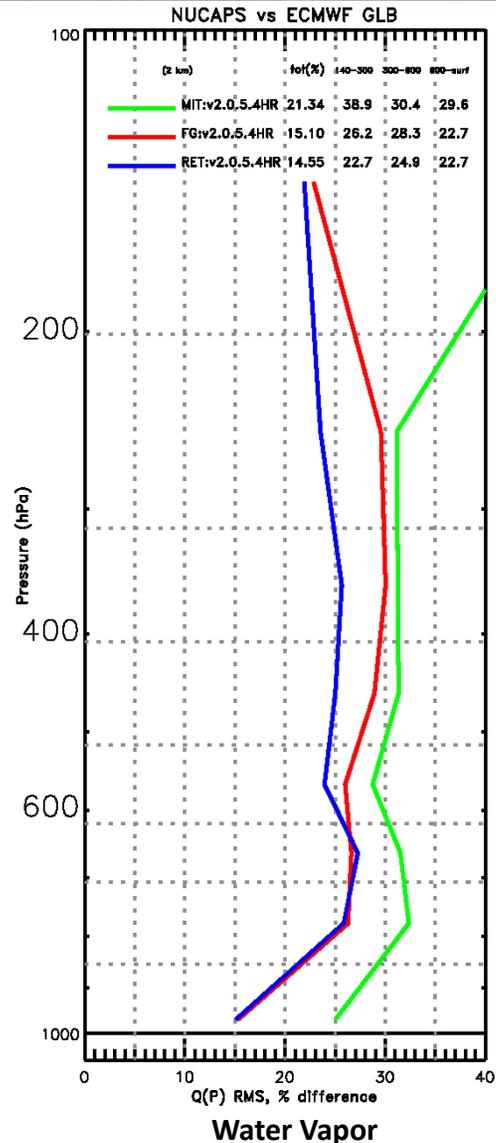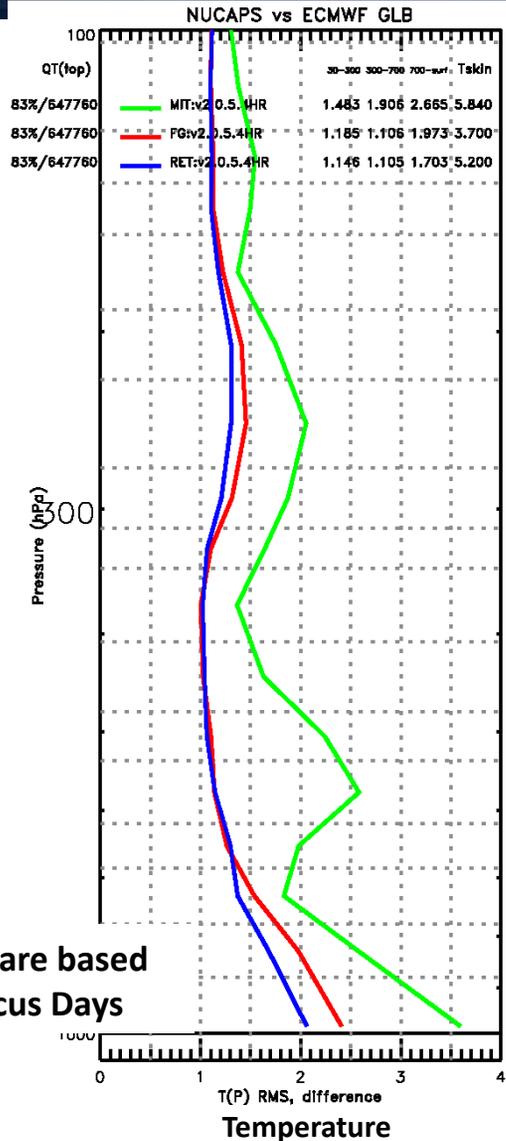SW Temp 24
SO$_2$ 5
CO   5
CH$_4$ 6

Excerpt from Andrew Collard's poster: "Plans for the use of JPSS and GOES-R satellite systems at NCEP"

- All band 1 channels in the previous 399 subset (as band 1 has not changed when going to FSR) except those designated as sensitive to HNO$_3$ and HCl.
- All channels between channels 50 and 200 (i.e., total coverage for the 15μm CO$_2$ band tropospheric sounding channels)
- 48 channels in the band head of the 4.3μm CO$_2$ band (this band has the sharpest CO$_2$ Jacobians in the spectrum).
- A very reduced number of channels sensitive to trace gases (less of a priority for NWP).
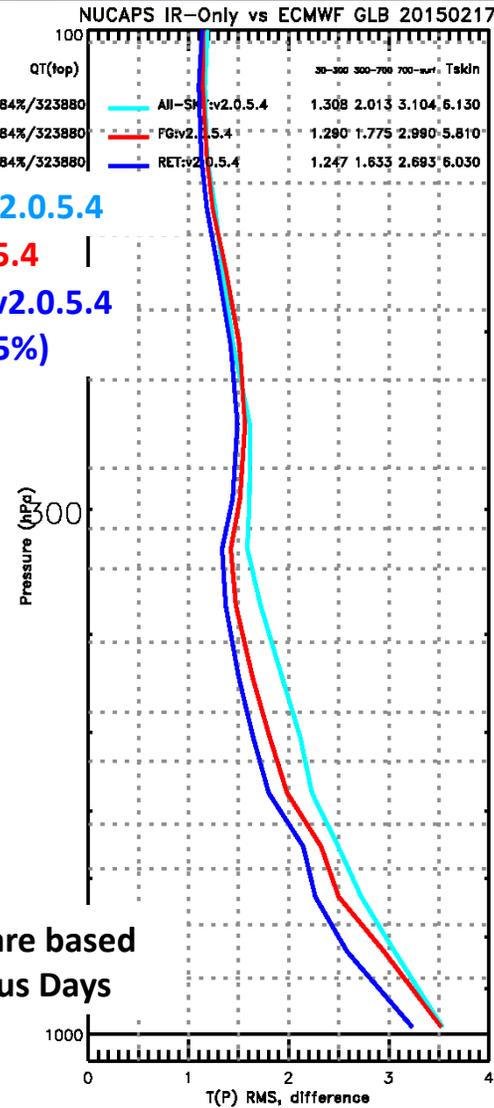
Results are based on 2 Focus Days

Temperature   **Water Vapor**   **Ozone**

NUCAPS IR-Only vs ECMWF GLB 20150217

All-Sky v2.0.5.4
FG v2.0.5.4
IR-Only v2.0.5.4 (Yield=85%)

Results are based on 2 Focus Days
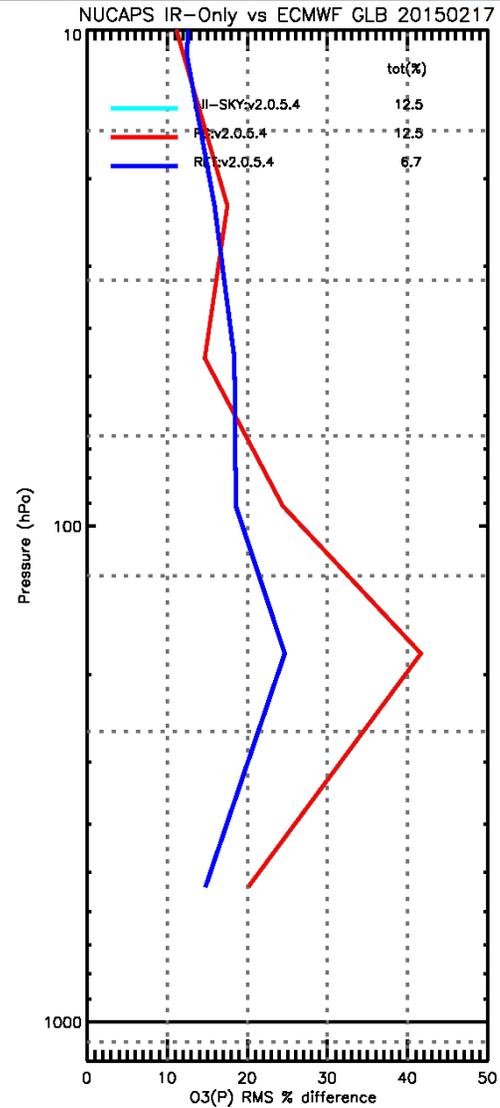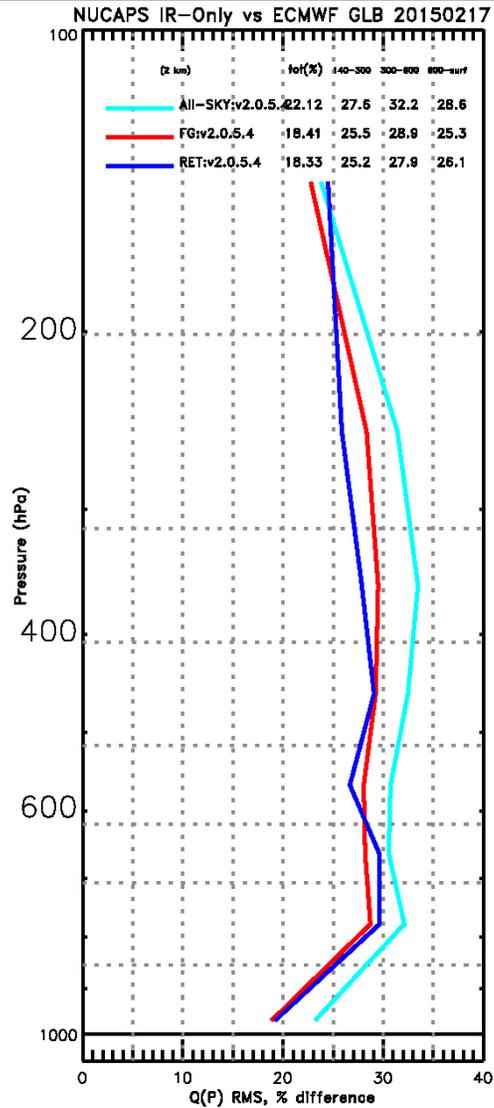
Sensitivity Analysis to 1% CO perturbation

2.5cm^{-1} (CrIS NSR)   0.625 cm^{-1} (CrIS FSR)   0.25cm^{-1} (IASI)
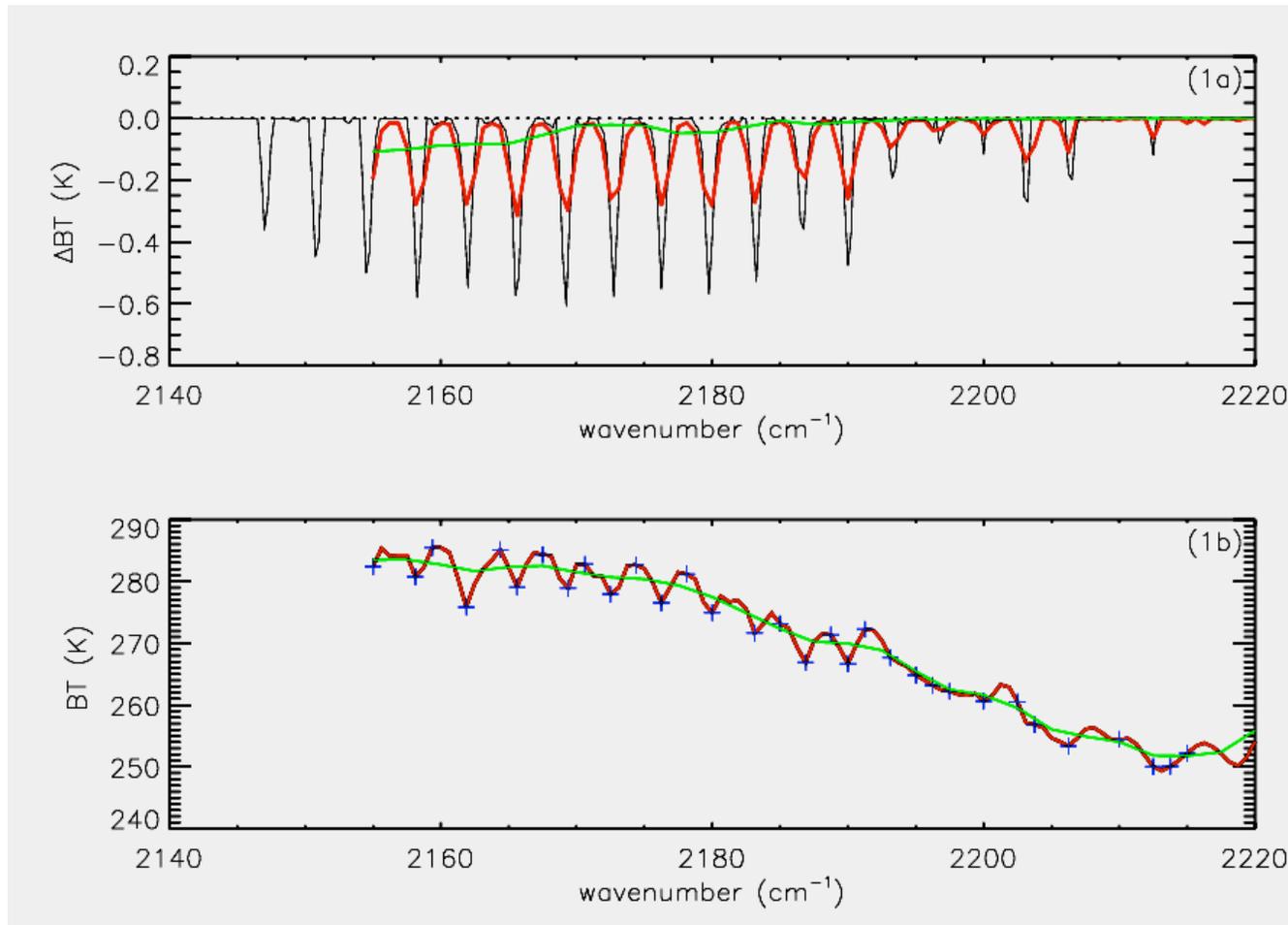
Ref.: Gambacorta et al., "An experiment using CrIS high spectral resolution measurement for trace gas retrievals: CO retrieval impact study", IEEE Transactions on Geoscience and Remote Sensing Letters, 2014.

TCCON Stations (17-Feb-15 17-Jul-15 Focus Days)

TCCON (*Wunch et al.* 2011)

NUCAPS v2.0.5.4 acc (17–Feb–15 17–Jul–15)

All FOR within threshold radius (100 km)

Time window (±6 hours) versus mean TCCON

Carbon Monoxide — $n = 128$

Methane — $n = 128$

Carbon Dioxide

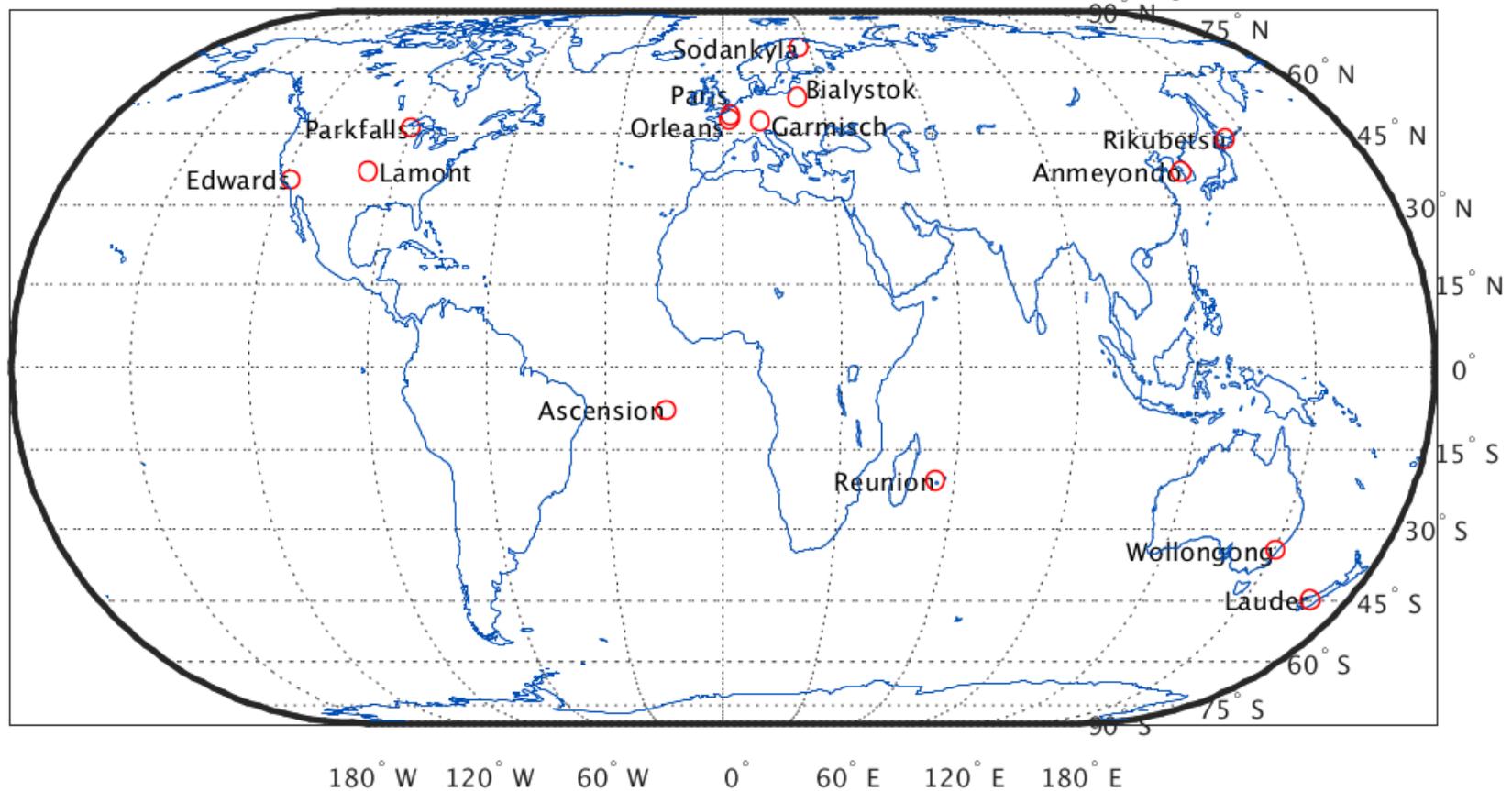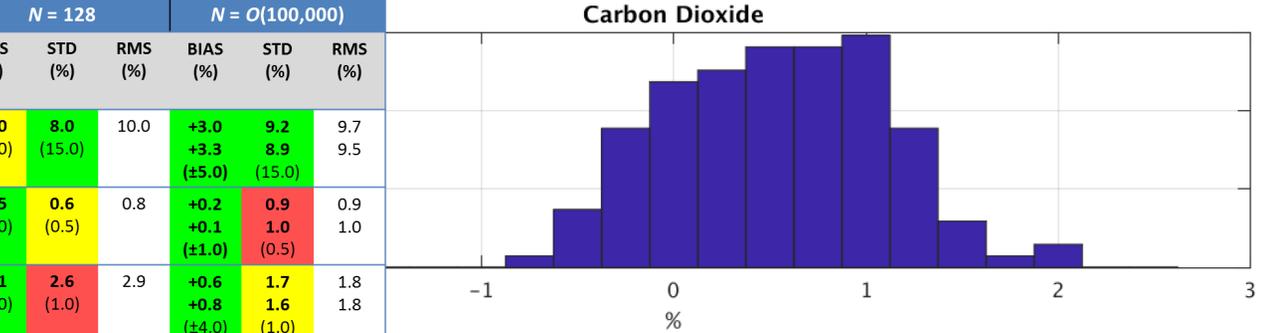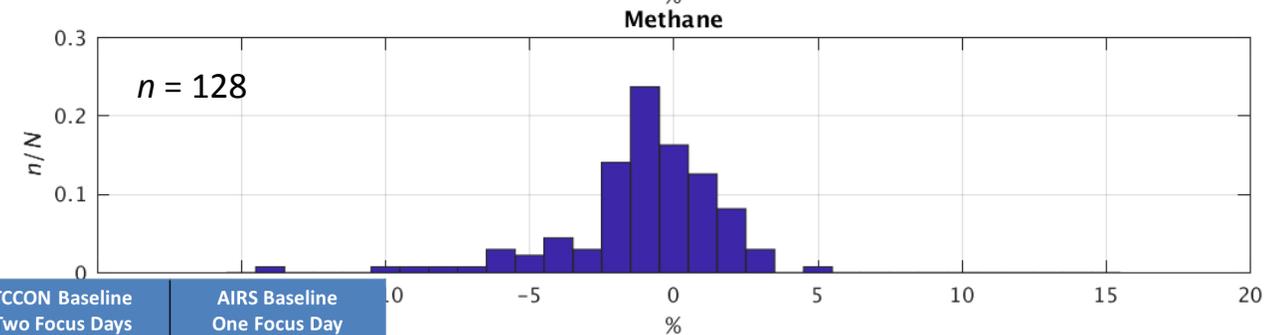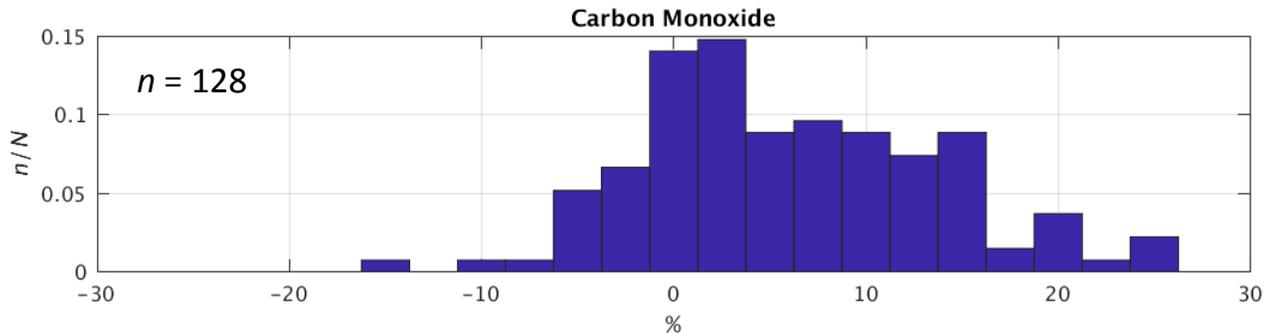| Trace Gas EDR	TCCON Baseline One Focus Day N = 151			TCCON Baseline Two Focus Days N = 128			AIRS Baseline One Focus Day N = O(100,000)		
	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)
CO	+2.1 (±5.0)	12.9 (15.0)	13.1	+6.0 (±5.0)	8.0 (15.0)	10.0	+3.0 +3.3 (±5.0)	9.2 8.9 (15.0)	9.7 9.5
CO_2	−0.3 (±1.0)	0.6 (0.5)	0.7	+0.5 (±1.0)	0.6 (0.5)	0.8	+0.2 +0.1 (±1.0)	0.9 1.0 (0.5)	0.9 1.0
CH_4	−3.0 (±4.0)	4.4 (1.0)	5.3	−1.1 (±4.0)	2.6 (1.0)	2.9	+0.6 +0.8 (±4.0)	1.7 1.6 (1.0)	1.8 1.8

DATA FUSION: NUCAPS + NOAA MADIS Surface Observations

Surface-Based Convective Available Potential Energy (SB-CAPE)
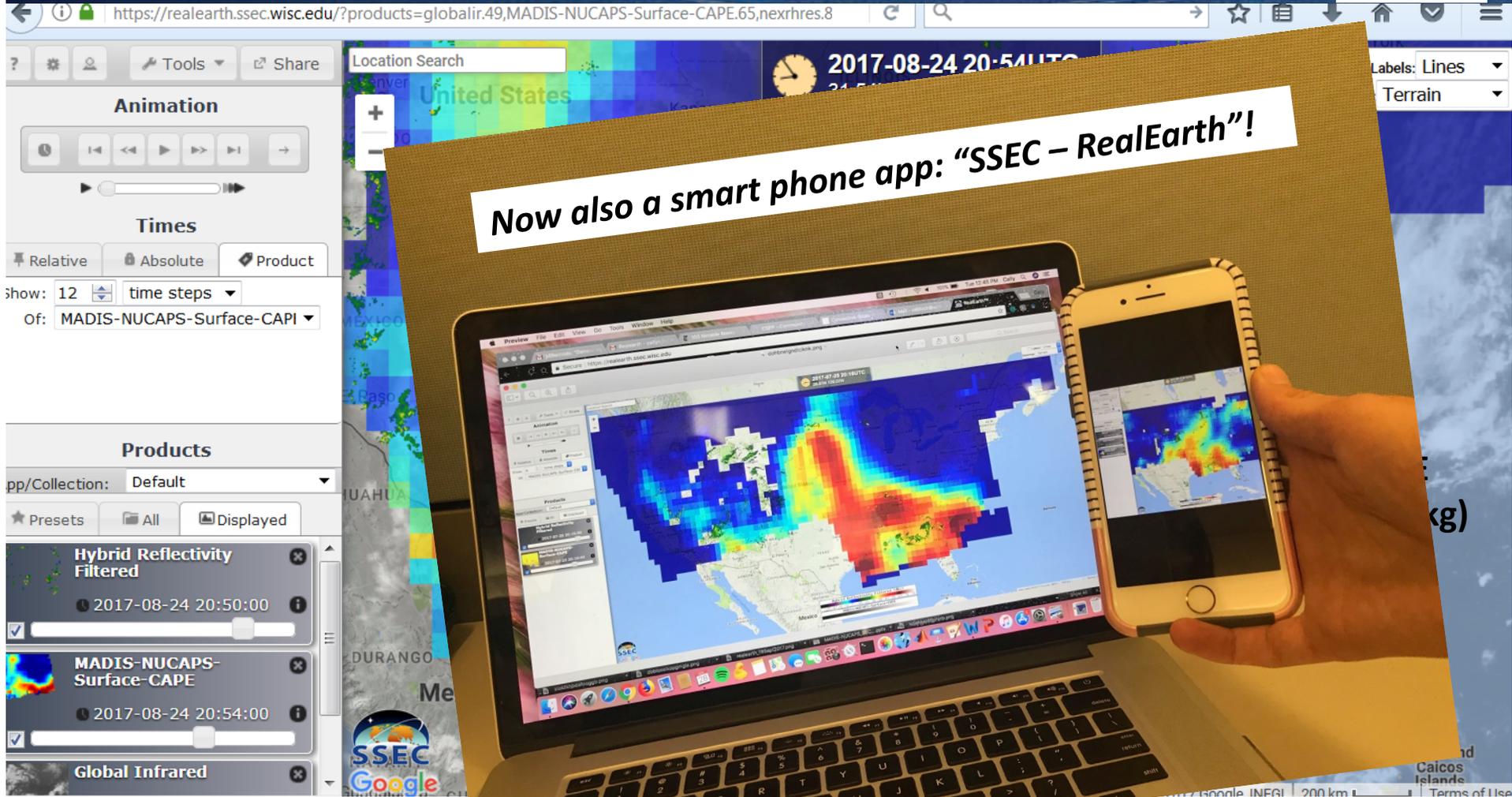
Now also a smart phone app: "SSEC – RealEarth"!

- Experimental near-real time pro... ...by Cailyn Bloch, now at NOAA/NESDIS/STAR.
- Substitutes NUCAPS surface T, T... ...NOAA MADIS surface observations to compute CAPE.
- SSEC Real-Earth updates automatically for DB overpasses with CSPP NUCAPS EDRs.
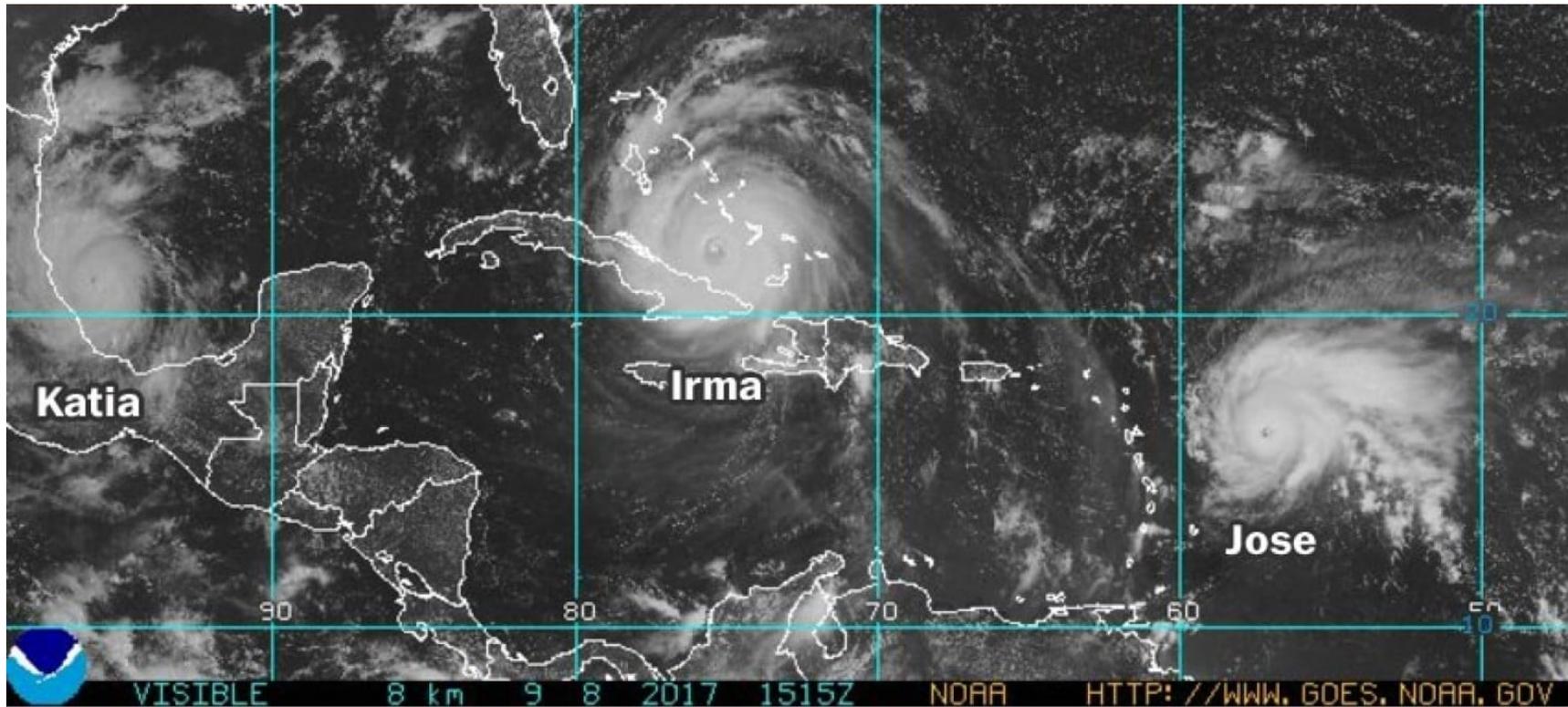
September 8th, 2017

NUCAPS IR/MW Total Precipitable Water Des v2.1
7 Sep 2017
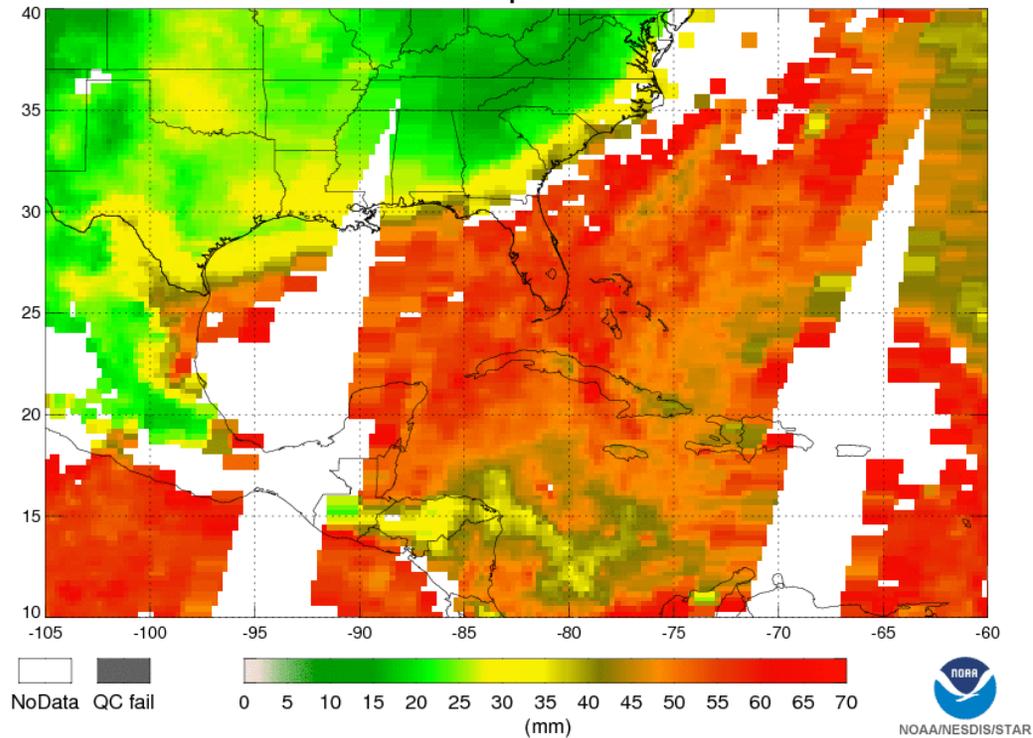
- NUCAPS combines MW and IR measurements to retrieve the atmospheric state.
- Rejection occurs under precipitation (MW only QC) and overcast scenes (IR QC).

Exploring an innovative data fusion product:
MW+IR and MW-only

NUCAPS IR/MW Total Precipitable Water Composite Des v2.1
7 Sep 2017
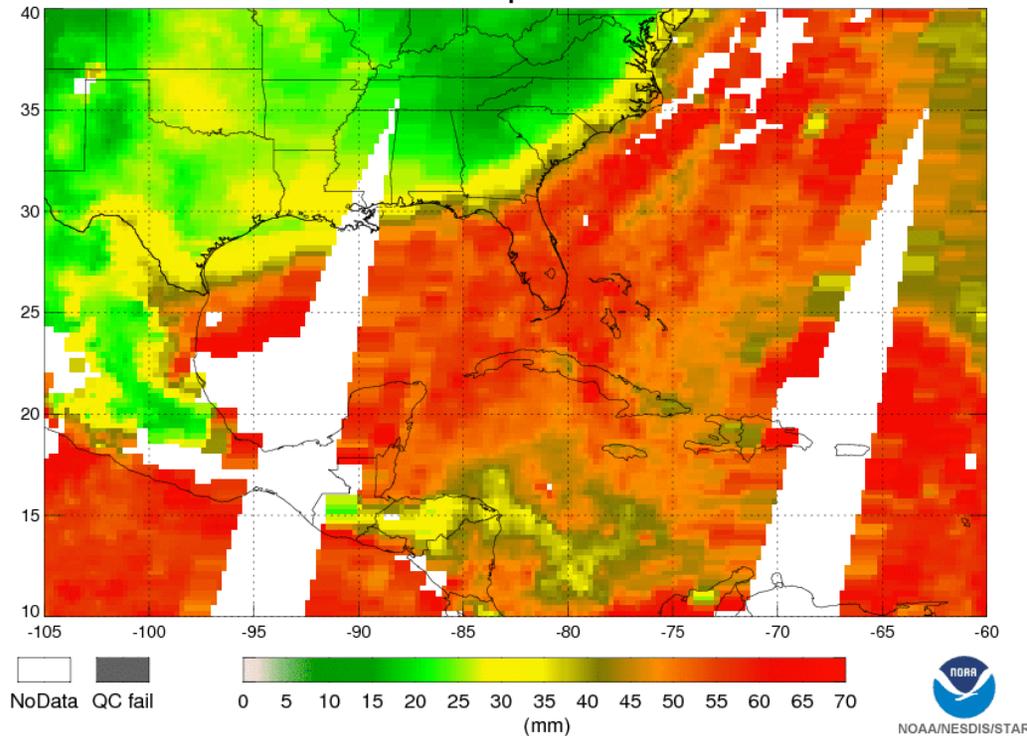
- Using accepted NUCAPS MW+IR retrievals & NUCAPS MW only retrievals when MW+IR retrievals fail.
- Composite yield increases to ~95%
- Validation is underway. Challenges: ensure stability when transitioning from MW+IR to MW-only retrievals.
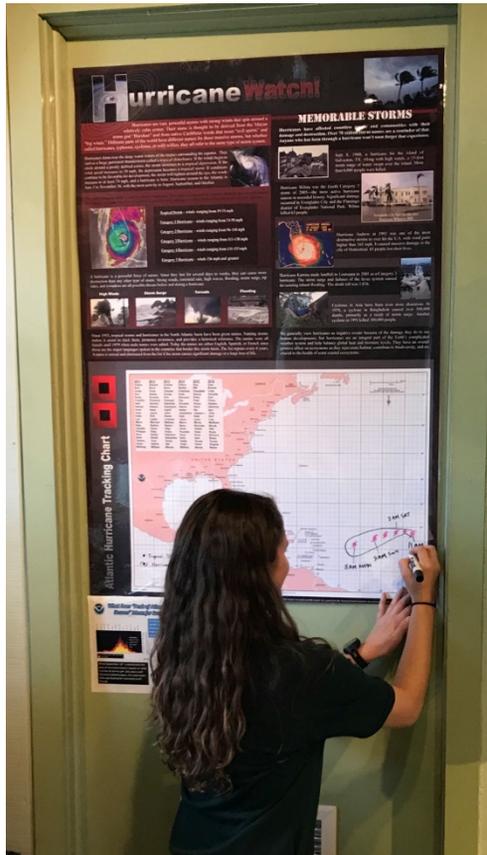
NUCAPS Total Precipitable Water Des
4 Sep 2017
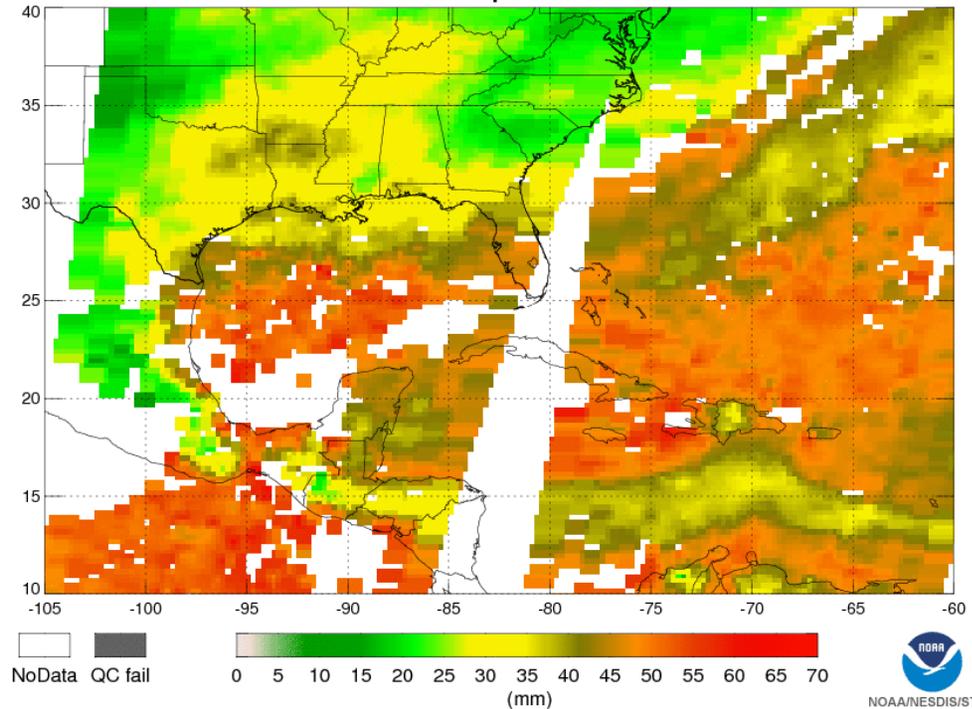
"We are expecting a 15 feet storm surge, wherever hurricane Irma makes landfall. I am glad that this year the US and the European models are in agreement. This means that the investment made in the aftermath of hurricane Sandy in 2012 is paying off. We will soon start preparing for the evacuation of the state of Florida".
Everglades National Park Visitors Center, September 1st, 2017

Thank you! Questions?

JPSS Instruments	Measurements
ATMS - Advanced Technology Microwave Sounder	ATMS and CrIS together provide high vertical resolution temperature and water vapor information needed to maintain and improve forecast skill out to 5 to 7 days in advance for extreme weather events, including hurricanes and severe weather outbreaks
CrIS - Cross-track Infrared Sounder	
VIIRS – Visible Infrared Imaging Radiometer Suite	VIIRS provides many critical imagery products including snow/ice cover, clouds, fog, aerosols, fire, smoke plumes, vegetation health, phytoplankton abundance/chlorophyll
OMPS - Ozone Mapping and Profiler Suite	Ozone spectrometers for monitoring ozone hole and recovery of stratospheric ozone and for UV index forecasts
CERES - Clouds and the Earth's Radiant Energy System	Scanning radiometer which supports studies of Earth Radiation Budget (ERB)

JPSS Program Data Products

VIIRS (28 EDRs) ●AP, ●RDR, ●SDR
EDRs:
Active Fires, Aerosol Detection, Aerosol Optical Depth, Aerosol Particle Size, Albedo (Surface), Annual Surface Type, Cloud Height (Top and Base), Cloud Cover/Layers, Cloud Mask, Cloud Optical Depth (D/N), Cloud Particle Size Distribution, Cloud Phase, Cloud Top Pres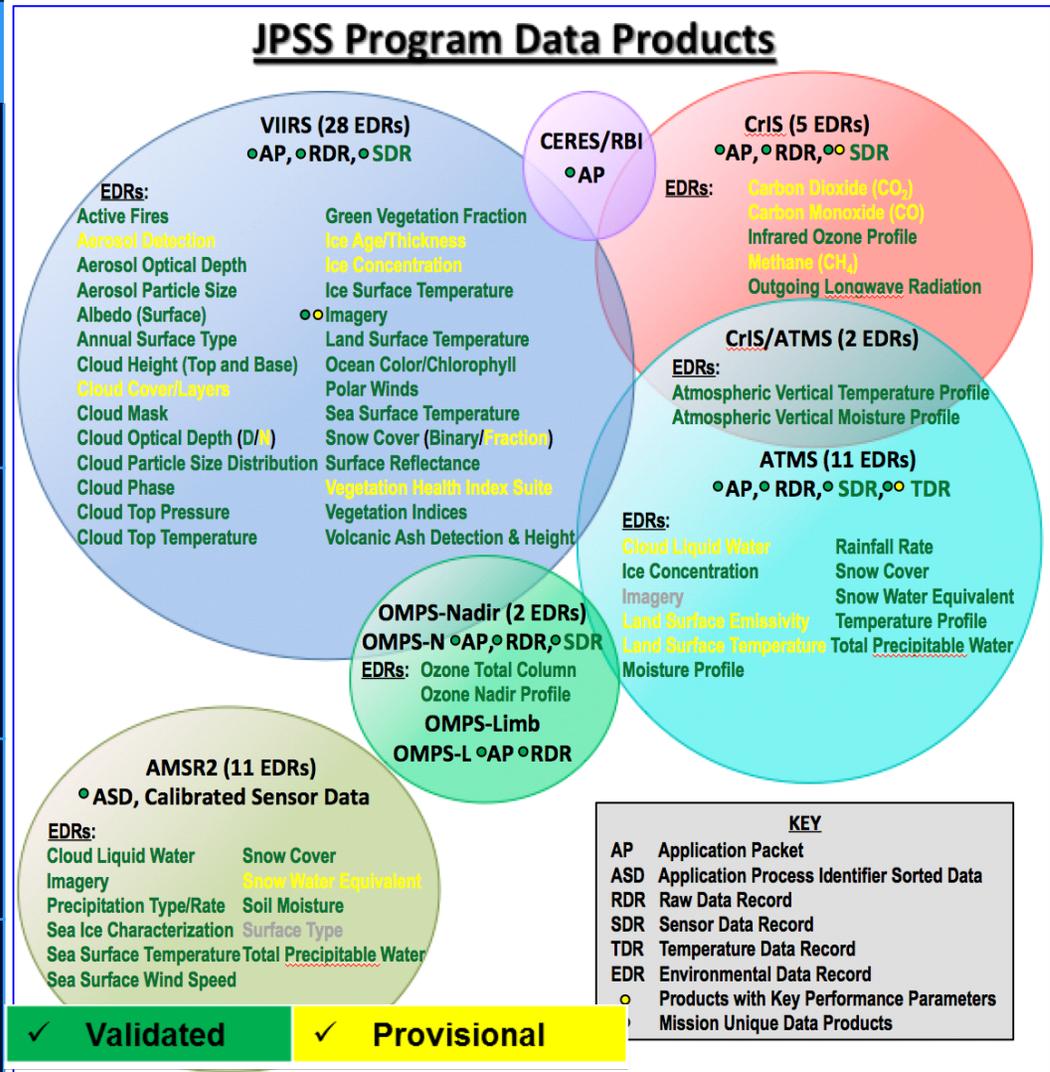sure, Cloud Top Temperature, Green Vegetation Fraction, Ice Age/Thickness, Ice Concentration, Ice Surface Temperature, ●●Imagery, Land Surface Temperature, Ocean Color/Chlorophyll, Polar Winds, Sea Surface Temperature, Snow Cover (Binary/Fraction), Surface Reflectance, Vegetation Health Index Suite, Vegetation Indices, Volcanic Ash Detection & Height

CERES/RBI ●AP

CrIS (5 EDRs) ●AP, ●RDR, ●●SDR
EDRs: Carbon Dioxide (CO_2), Carbon Monoxide (CO), Infrared Ozone Profile, Methane (CH_4), Outgoing Longwave Radiation

CrIS/ATMS (2 EDRs)
EDRs: Atmospheric Vertical Temperature Profile, Atmospheric Vertical Moisture Profile

ATMS (11 EDRs) ●AP, ●RDR, ●SDR, ●●TDR
EDRs: Cloud Liquid Water, Ice Concentration, Imagery, Land Surface Emissivity, Land Surface Temperature, Moisture Profile, Rainfall Rate, Snow Cover, Snow Water Equivalent, Temperature Profile, Total Precipitable Water

OMPS-Nadir (2 EDRs) OMPS-N ●AP, ●RDR, ●SDR
EDRs: Ozone Total Column, Ozone Nadir Profile
OMPS-Limb OMPS-L ●AP ●RDR

AMSR2 (11 EDRs) ●ASD, Calibrated Sensor Data
EDRs: Cloud Liquid Water, Imagery, Precipitation Type/Rate, Sea Ice Characterization, Sea Surface Temperature, Sea Surface Wind Speed, Snow Cover, Snow Water Equivalent, Soil Moisture, Surface Type, Total Precipitable Water

KEY
AP   Application Packet
ASD   Application Process Identifier Sorted Data
RDR   Raw Data Record
SDR   Sensor Data Record
TDR   Temperature Data Record
EDR   Environmental Data Record
○   Products with Key Performance Parameters
●   Mission Unique Data Products

✓ **Validated**   ✓ **Provisional**

Data available through PDA , CLASS, and Direct Readout