Microwave Satellite Retrievals and Applications

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Microwave Basics

- Microwave Instruments are on many Polar Orbiter Meteorological Satellites
  - Sounders
    - ATMS on the JPSS series (SNPP, NOAA-20, NOAA-21)
    - AMSU/MHS on the earlier series of NOAA satellites along with ESA’s Metop series (Metop-A, Metop-B)
    - Many others
  - Imagers
    - Such as AMSR2 on JAXA GCOM-W1

- Slido Question
  - What is the main purpose of having Microwave Instruments on Polar Orbiting Satellites?

Microwave Data Impact on Numerical Weather Prediction (NW)

European Center for Medium-Range Weather Forecasts (ECMWF)

Bands	Instruments used	Usage
Temperature-sounding *(52-57 GHz)*	6 AMSU-A; 2 ATMS	Clear channels only; AMSU-A to be moved to all-sky in Oct 2021
Temperature-sounding *(118 GHz)*	2 MWHS-2	All-sky
Humidity-sounding *(183 GHz)*	4 MHS; 2 ATMS; 2 MWHS-2; 2 SSMI/S; GMI	Mostly all-sky (except ATMS)
Window/imager channels *(19, 24, 37, 89/91, 150/166 GHz)*	1 SSMI/S; AMSR2; GMI; MWRI	All-sky

Table 2: Current use of passive MW instruments at ECMWF

Bormann, N., Lawrence, H., & Farnan,J., 2019: Global observing system experiments in the ECMWF assimilation system. ECMWF Technical Memorandum 839, doi: 10.21957/sr184iyz

MW sounding data currently have the strongest impact among all satellite data (Bormann et al 2019). Forecast Sensitivity Observation Impact (FSOI) analysis of ECMWF models shows the growing impact of humidity-sensitive MW radiances, making it comparable in impact to temperature-sensitive MW radiances (Figure 5).

MWMV – Microwave Water Vapor

MWT – Microwave Temperature

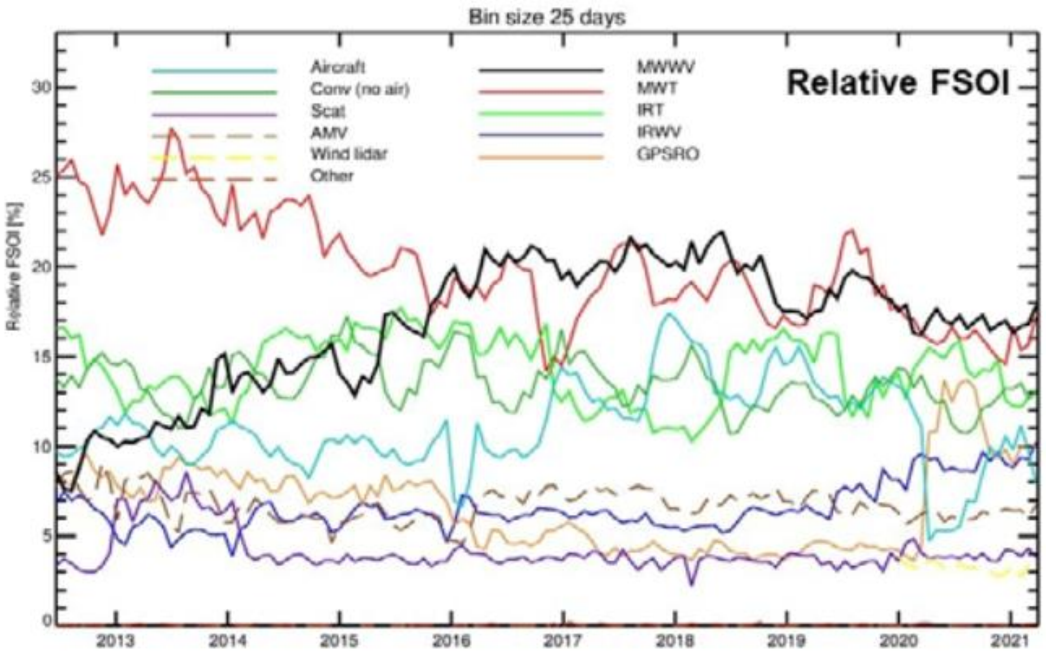
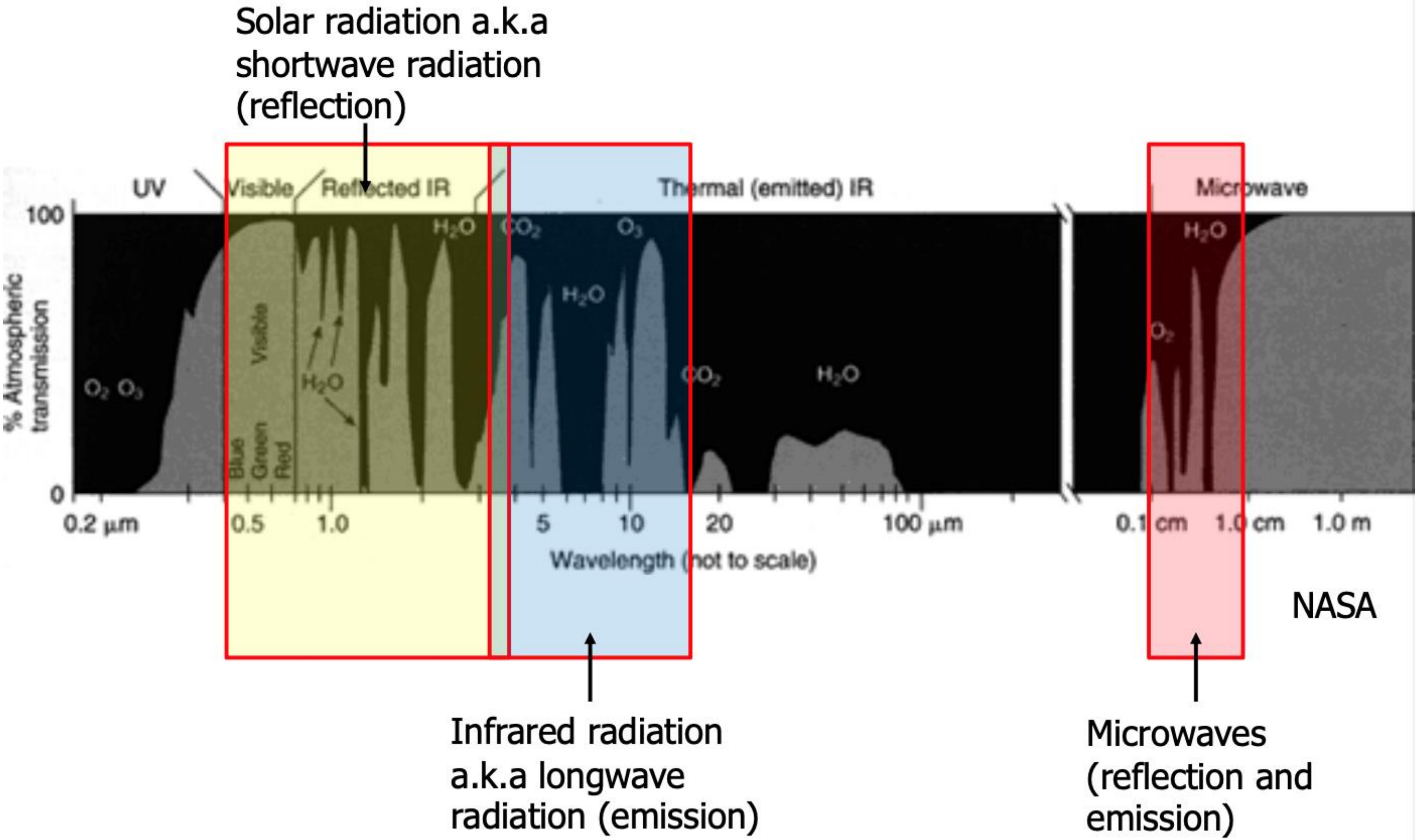


Figure 5: Growing impact of humidity-sensitive MW radiances.

Source: Bormann

Atmospheric Absorption Spectra



Microwave Basics

- Satellites detect emitted and reflected microwave energy from the earth/ocean atmosphere at wavelengths between 1 to 300 GHz (30 to .1 cm) (passive microwave instruments)
- Compared to visible and infrared satellite instruments, microwave radiation can penetrate clouds, air molecules, aerosols, vegetation, and limited layers of liquid water (like the sea surface), and soil (especially dry soil).

Why can microwave instruments see through clouds?

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Why can microwave instruments see through clouds?

Because cloud drops are typically 5-50 microns in diameter.

Microwave Basics Continued

Slido Question

Why aren’t there any Microwave Instruments on Geostationary Satellites?

Microwave Basics

- Earth emitted energy peaks at about 11 micron (Terrestrial temperatures - Planck function). We are sensing small amounts of energy in the microwave (longer wavelengths). Because of this, you need a large aperture, collection region, in order to get enough signal to measure. LEO satellites fly much closer to the earth than GEO satellites. Since GEO are so much farther away, you would need a very big energy collector which has not been practical to put in orbit yet.

What is the Value of Microwave Observations?

Advantages

- Global observations (Polar Satellite).
- Aerosols and cloud drops are too small to attenuate the signal (energy at these wavelengths pass through). Non-precipitating clouds are transparent.
- Precipitation can attenuate signal.
- Day and night observations.
- Take advantage of emissivity differences in these wavelengths.
- Large variety of available products.

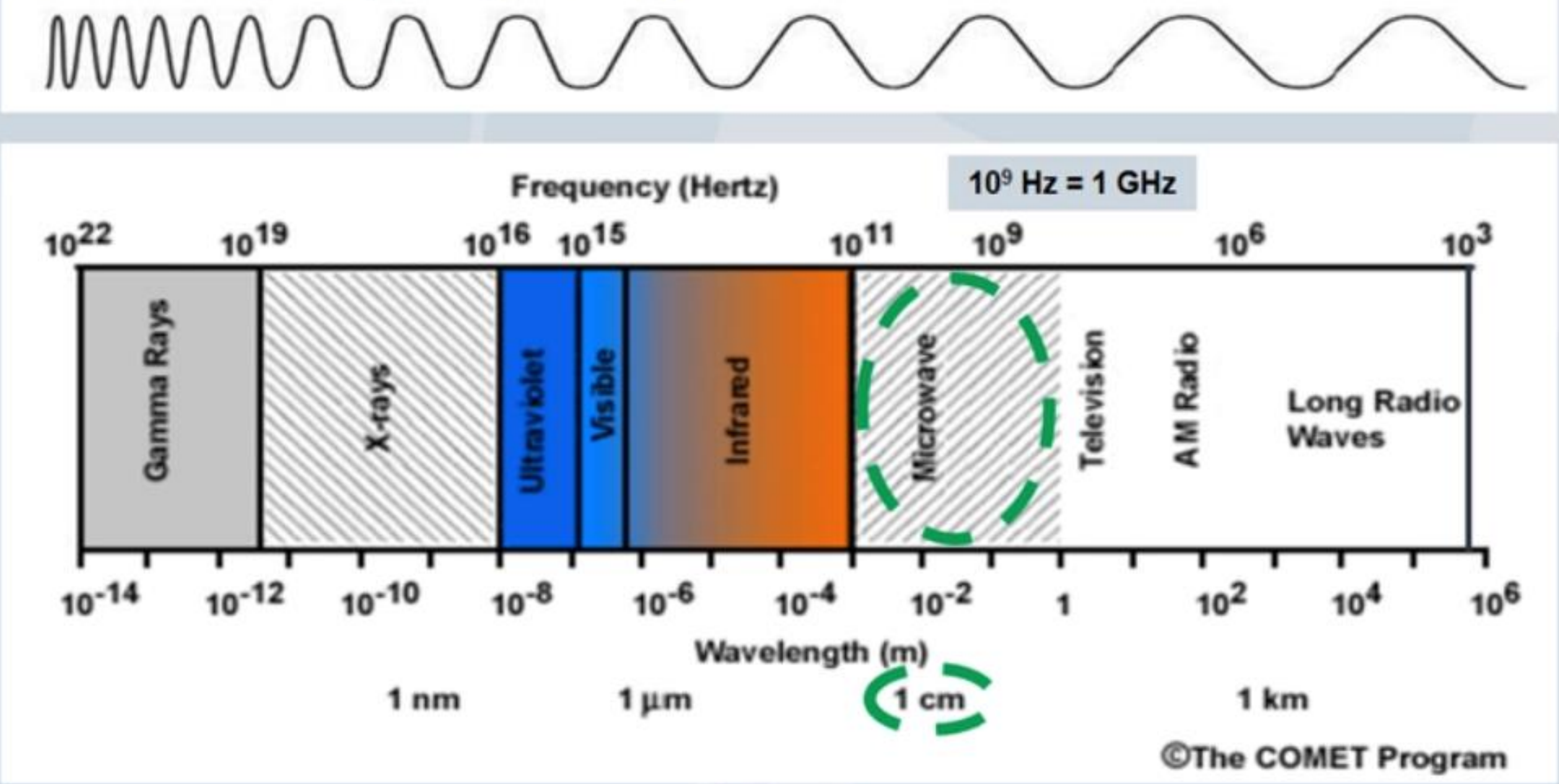
Disadvantages

- Spatial resolution (need large FOV to get a large enough signal to detect).
- Polar Orbit means lowered temporal resolution.
- Takes getting used to in order to use correctly. That is what makes products so useful.

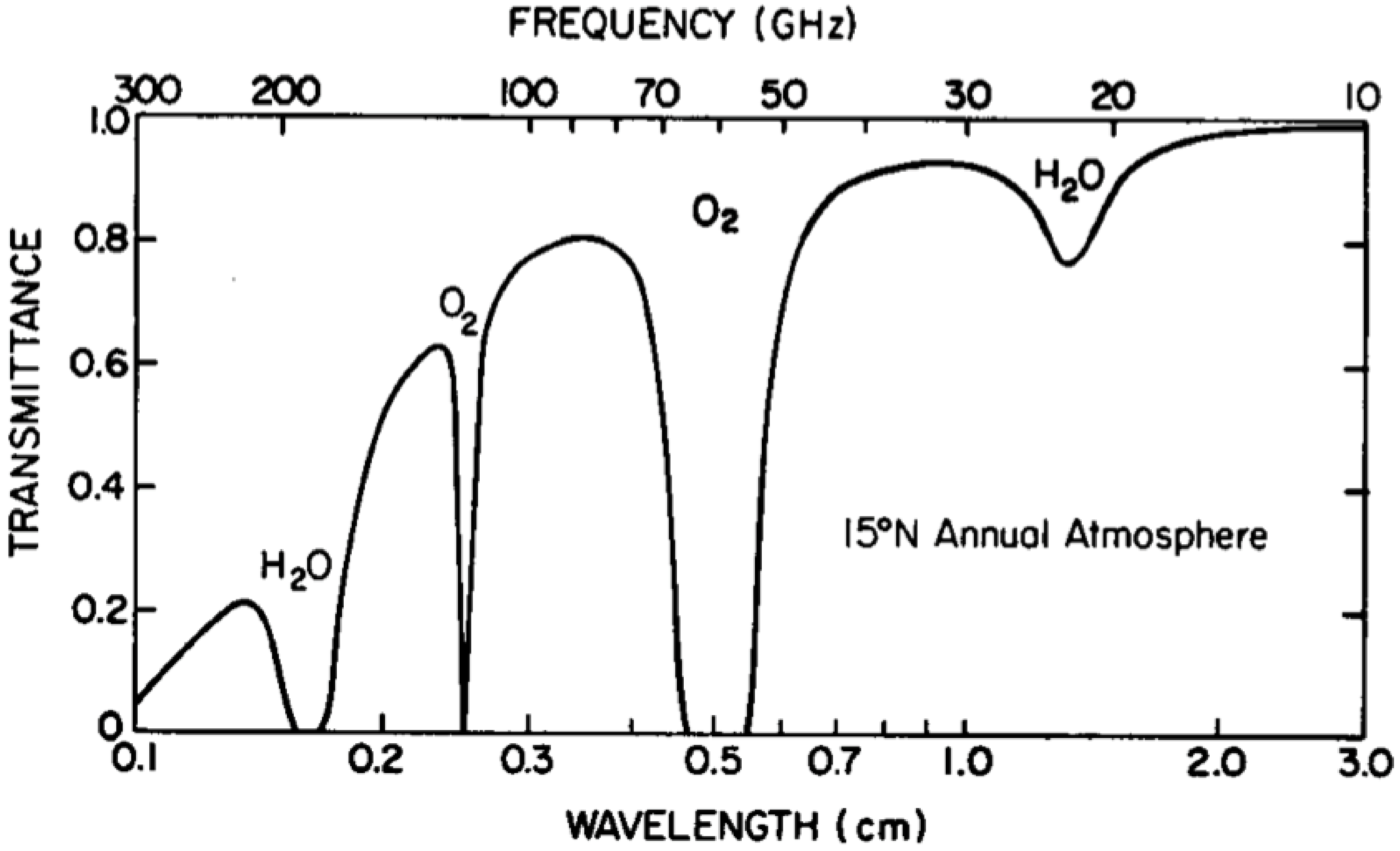
Microwave Basics Continued

Microwave wavelength = 0.1-30 cm (300-1 GHz)

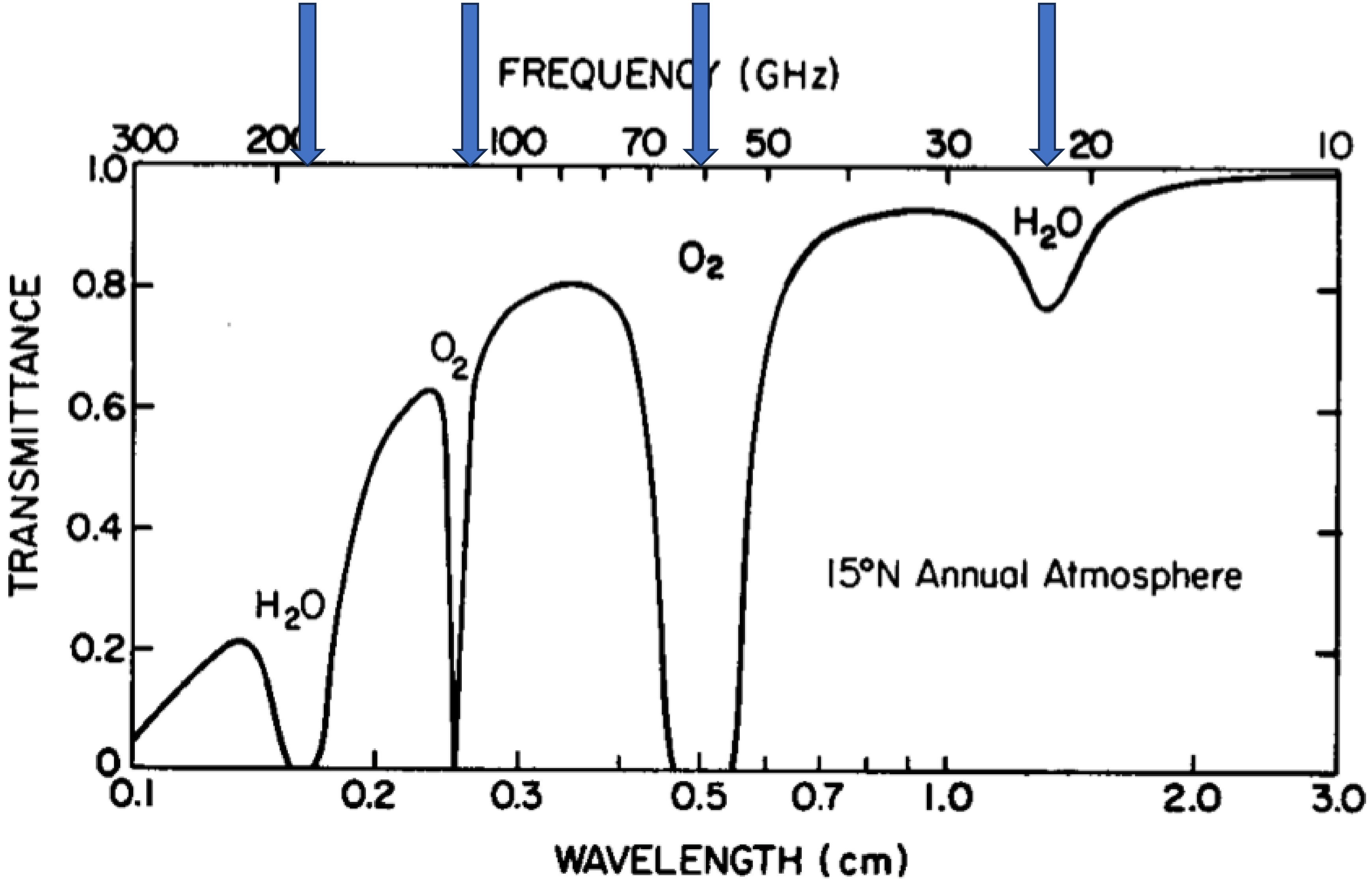
Increasing: wavelength, sensor footprint
Decreasing: frequency, energy



Microwave Basics Continued



Absorption Regions
(Centered at ~22 GHz, 60 GHz, 118 GHz, 183 GHz)



Advanced Technology Microwave Sounder(ATMS) Specifications (NOAA)

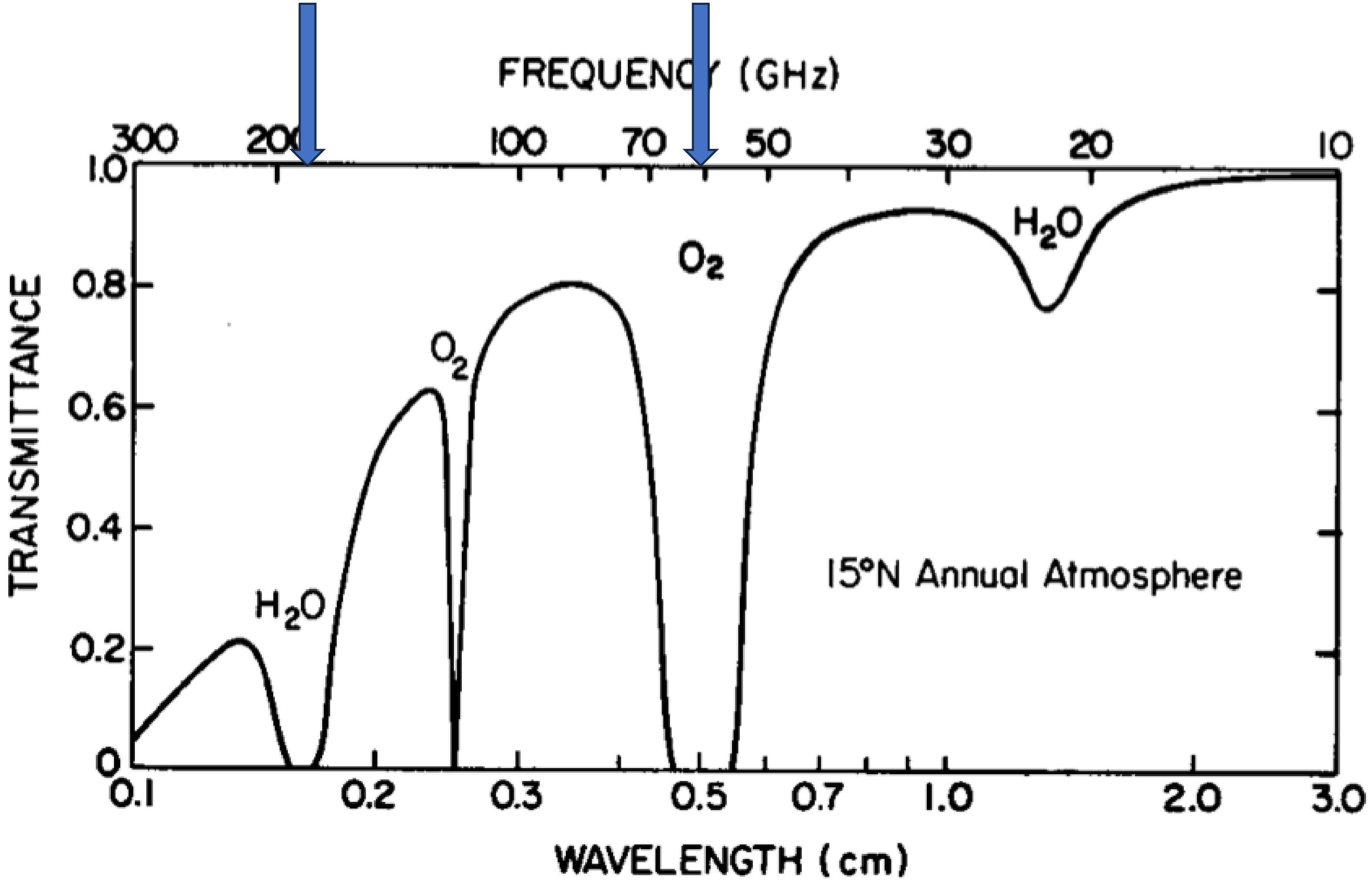
Channel Number	Passband Center Frequency (GHz)	Polarization near nadir	Number of Passbands	Radiometric Resolution NEDT (K)	Primary Function
1	23.8	vertical	1	0.25	Water Vapor Burden
2	31.4	vertical	1	0.31	Water Vapor Burden
3	50.3	horizontal	1	0.37	Surface Emissivity, Precipitation
4	51.76	horizontal	1	0.28	Tropospheric Temperature
5	52.8	horizontal	1	0.28	Tropospheric Temperature
6	53.596 ± 0.115	horizontal	2	0.29	Tropospheric Temperature
7	54.4	horizontal	1	0.27	Tropospheric Temperature
8	54.94	horizontal	1	0.27	Temperature Near Tropopause
9	55.5	horizontal	1	0.29	Temperature Near Tropopause
10	57.290344	horizontal	1	0.43	Stratospheric Temperature
11	57.290344 ± 0.217	horizontal	2	0.56	Stratospheric Temperature
12	57.290344 ± 0.3222 ± 0.048	horizontal	4	0.59	Stratospheric Temperature
13	57.290344 ± 0.3222 ± 0.022	horizontal	4	0.86	Stratospheric Temperature
14	57.290344 ± 0.3222 ± 0.010	horizontal	4	1.23	Stratospheric Temperature
15	57.290344 ± 0.3222 ± 0.0045	horizontal	4	1.95	Stratospheric Temperature
16	88.2	vertical	1	0.29	Clouds/Snow
17	165.5	horizontal	1	0.46	Water Vapor
18	183.31 ± 7.0	horizontal	2	0.38	Water Vapor
19	183.31 ± 4.5	horizontal	2	0.46	Water Vapor
20	183.31 ± 3.0	horizontal	2	0.54	Water Vapor
21	183.31 ± 1.8	horizontal	2	0.59	Water Vapor
22	183.31 ± 1.0	horizontal	2	0.73	Water Vapor

75 km (channels 1–2)

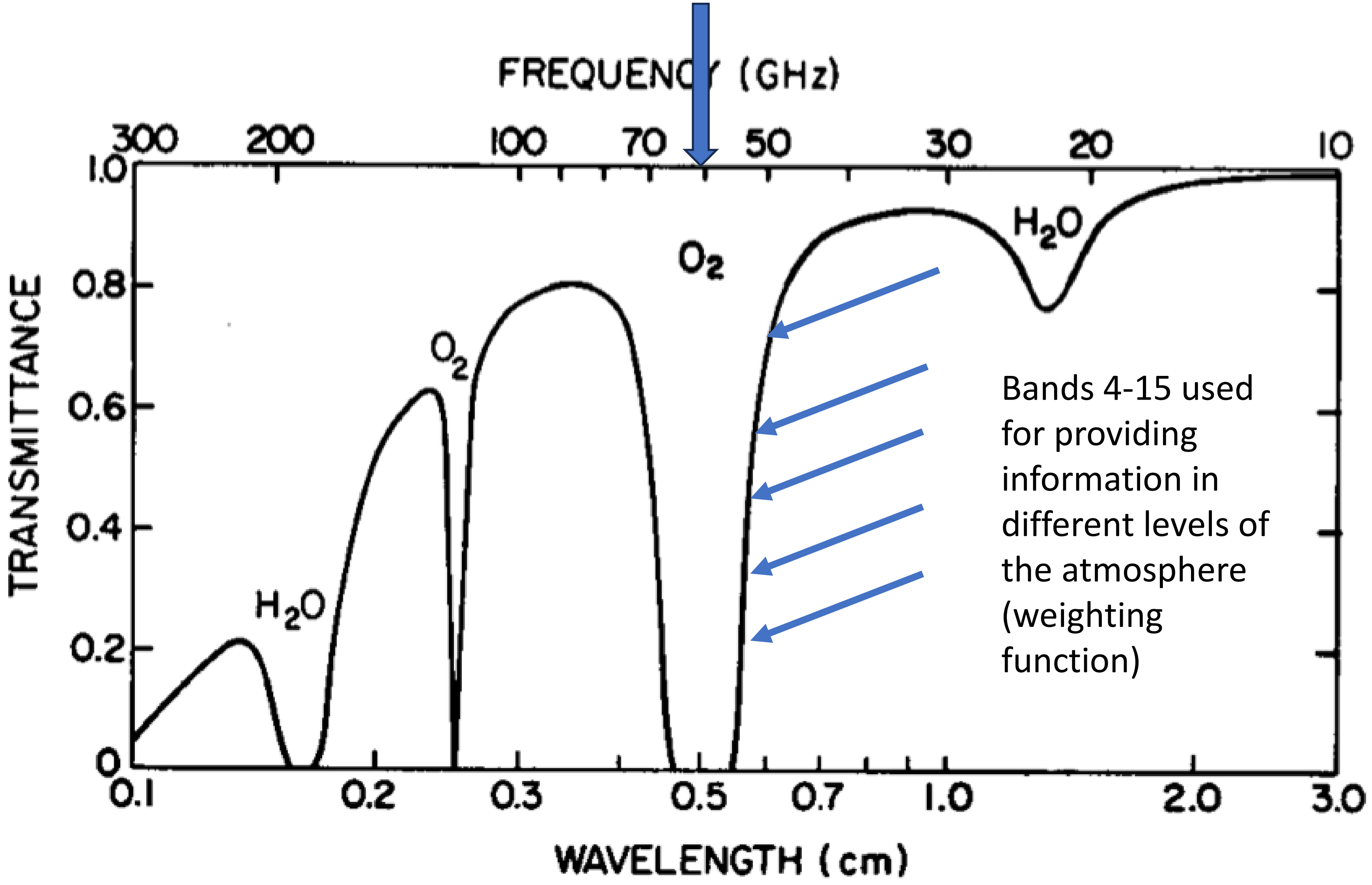
32 km (channels 3–16)

16 km (channels 17–22)

Absorption Regions
(Centered at ~22 GHz, 60 GHz, 118 GHz, 183 GHz)



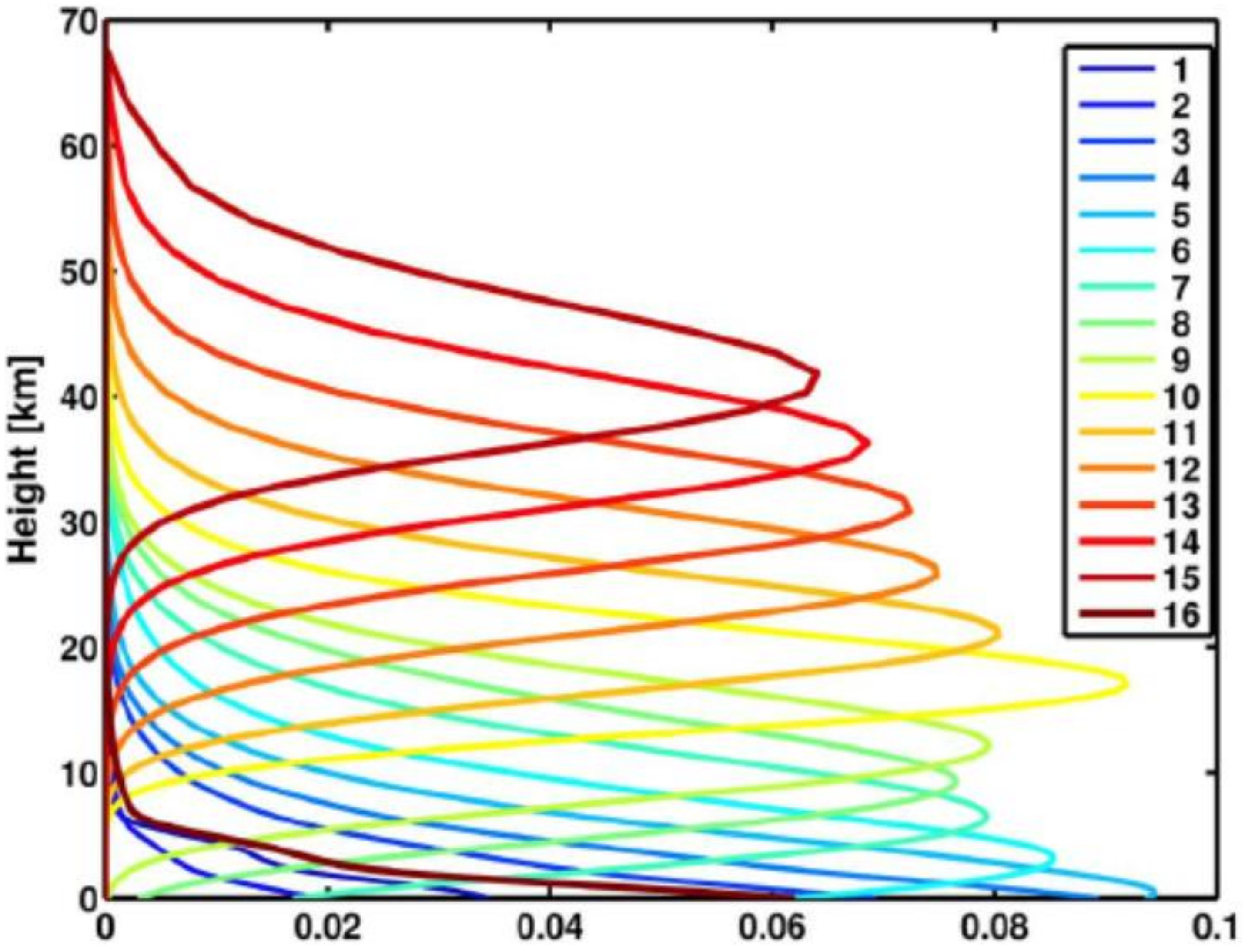
Oxygen Absorption Region Used for Temperature Profile (Centered at 60 GHz)



Bands 4-15 used for providing information in different levels of the atmosphere (weighting function)

ATMS Band Weighting Functions

- Moradi, Isaac & Ferraro, R. & Eriksson, Patrick & Weng, Fuzhong. (2015). Intercalibration and Validation of Observations from ATMS and SAPHIR Microwave Sounders. IEEE Transactions on Geoscience and Remote Sensing. 53. 1-1. 10.1109/TGRS.2015.2427165.



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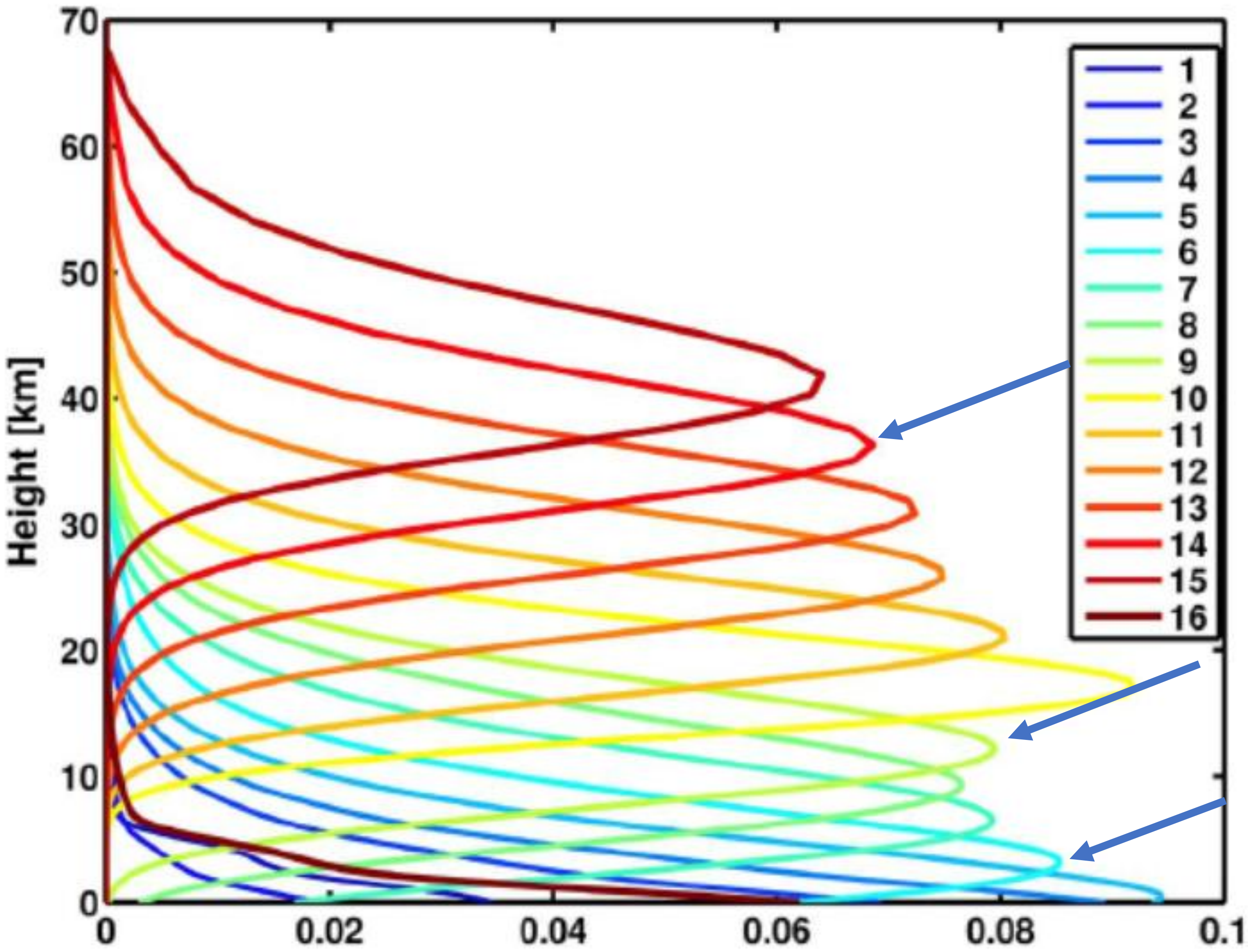
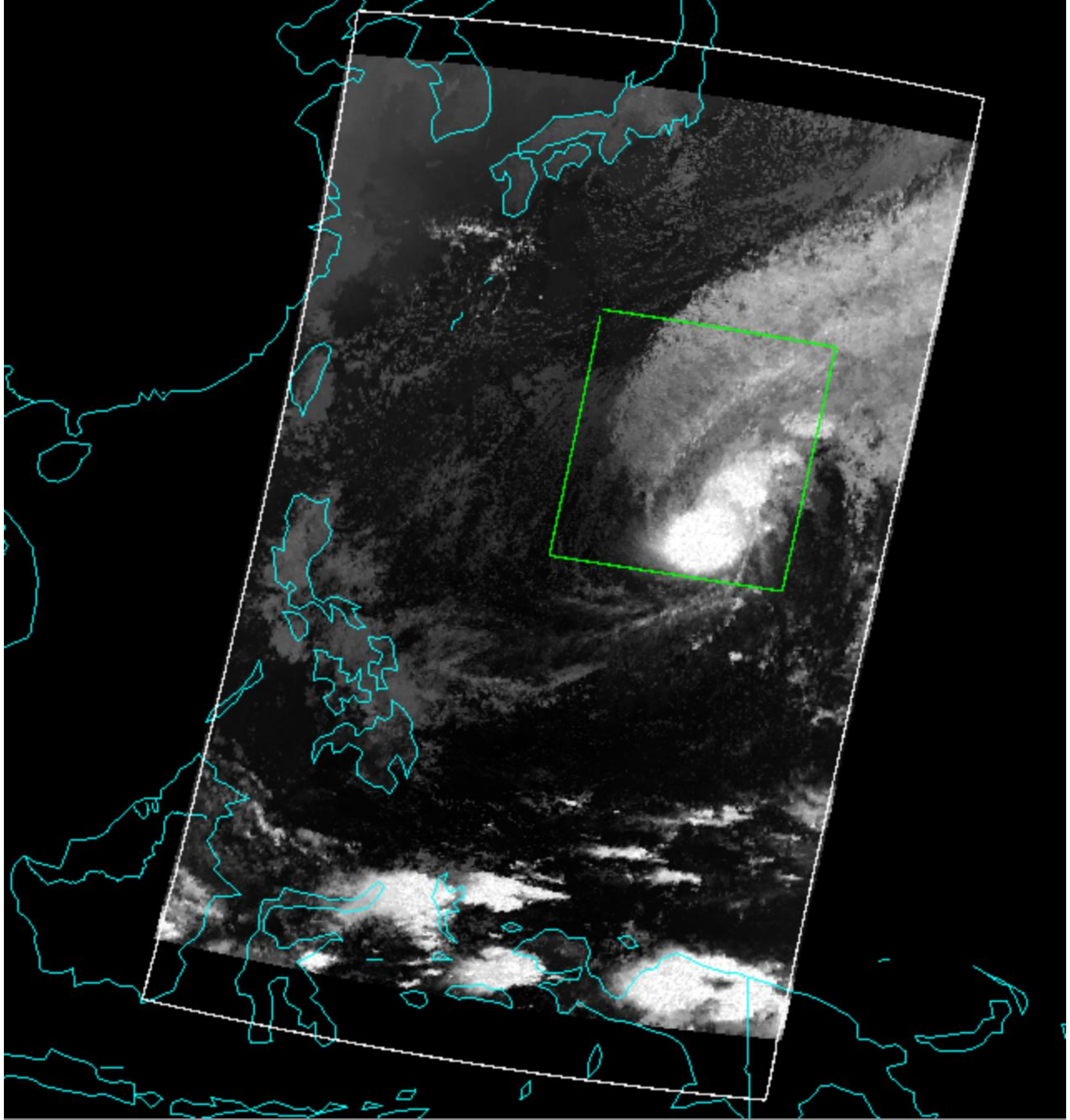
- Moradi, Isaac & Ferraro, R. & Eriksson, Patrick & Weng, Fuzhong. (2015). Intercalibration and Validation of Observations from ATMS and SAPHIR Microwave Sounders. IEEE Transactions on Geoscience and Remote Sensing. 53. 1-1. 10.1109/TGRS.2015.2427165.



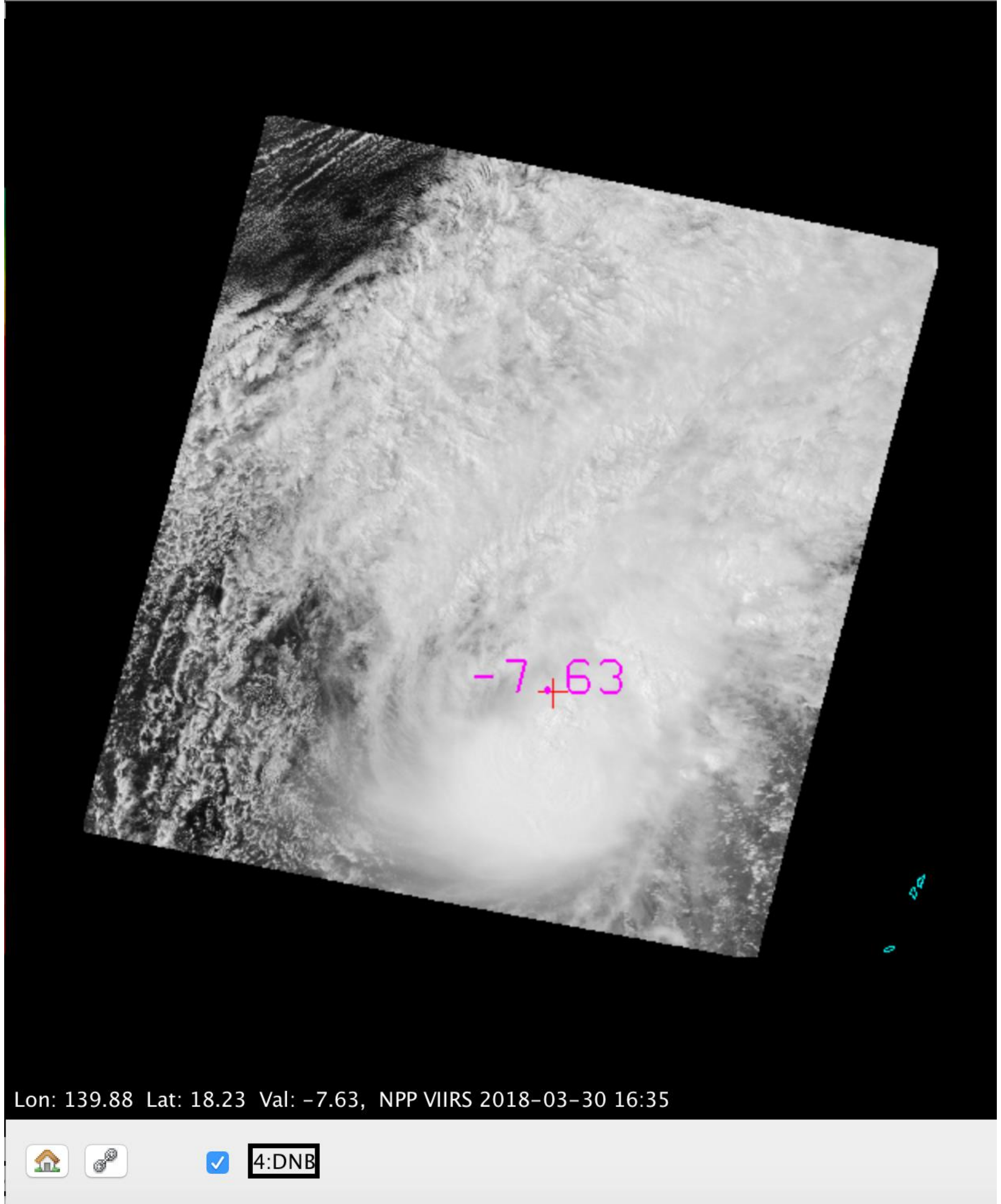
Examples from Typhoon Jelawat, 30 March 2018

SNPP VIIRS M-Band 15
11 micron
16:35 UTC



Examples from Typhoon Jelawat, 30 March 2018

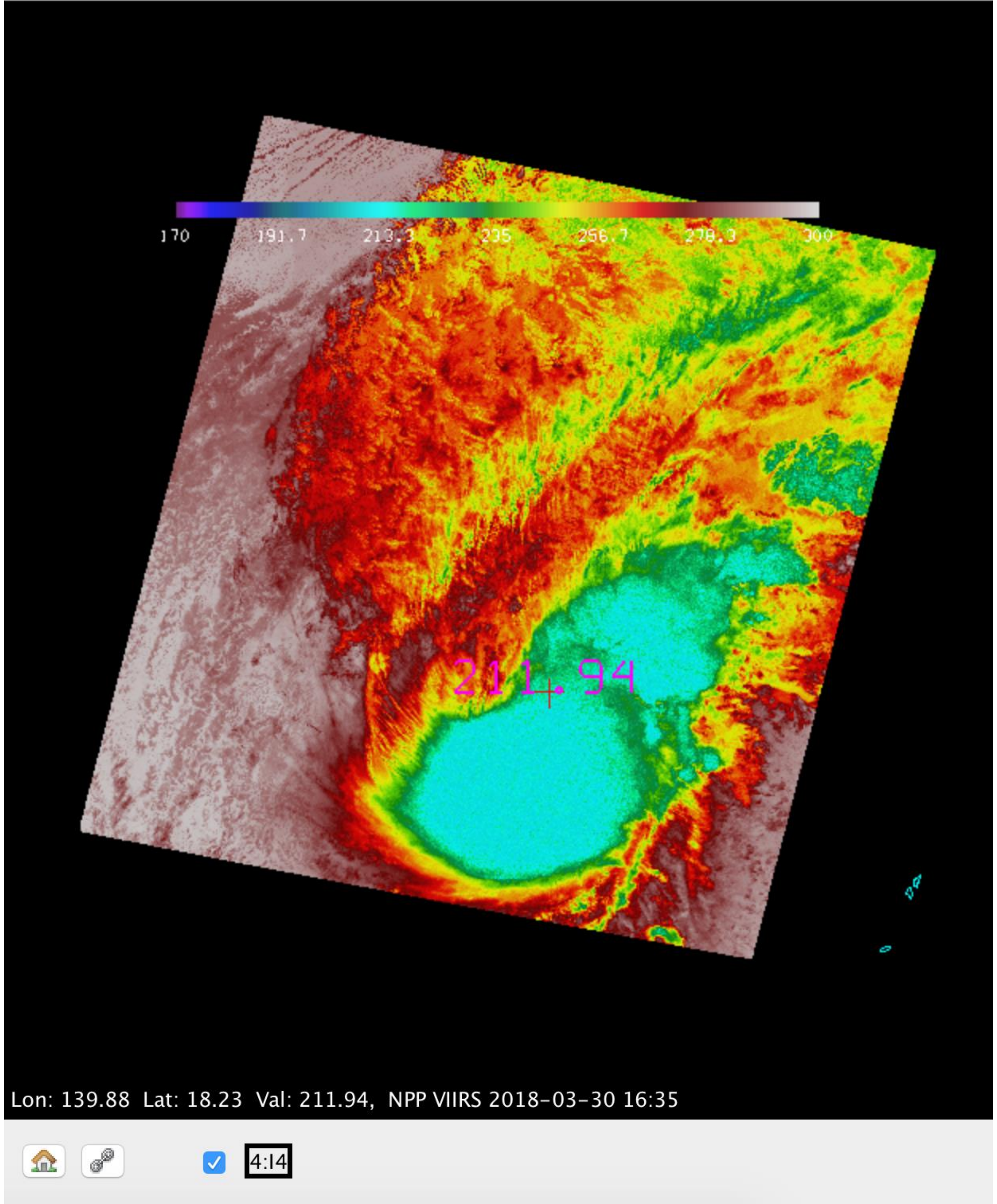
SNPP VIIRS Day/Night Band 16:35 UTC



Examples from Typhoon Jelawat, 30 March 2018

SNPP VIIRS I-Band 4
11 micron
16:35 UTC

Temperature Range:
170 K to 300 K
-103 C to 26.8 C

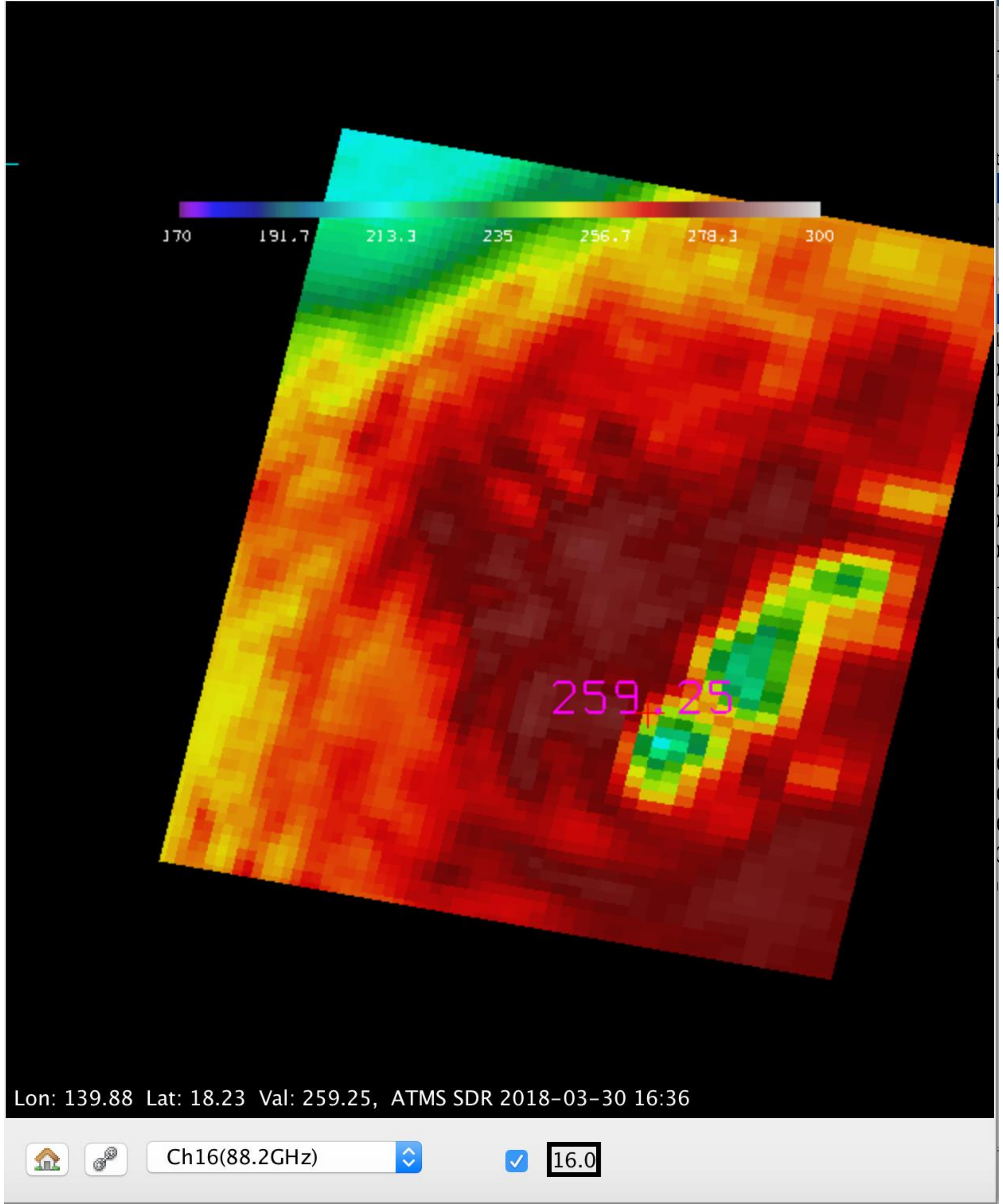


Examples from Typhoon Jelawat, 30 March 2018

SNPP ATMS Band 16
88 GHz
16:35 UTC

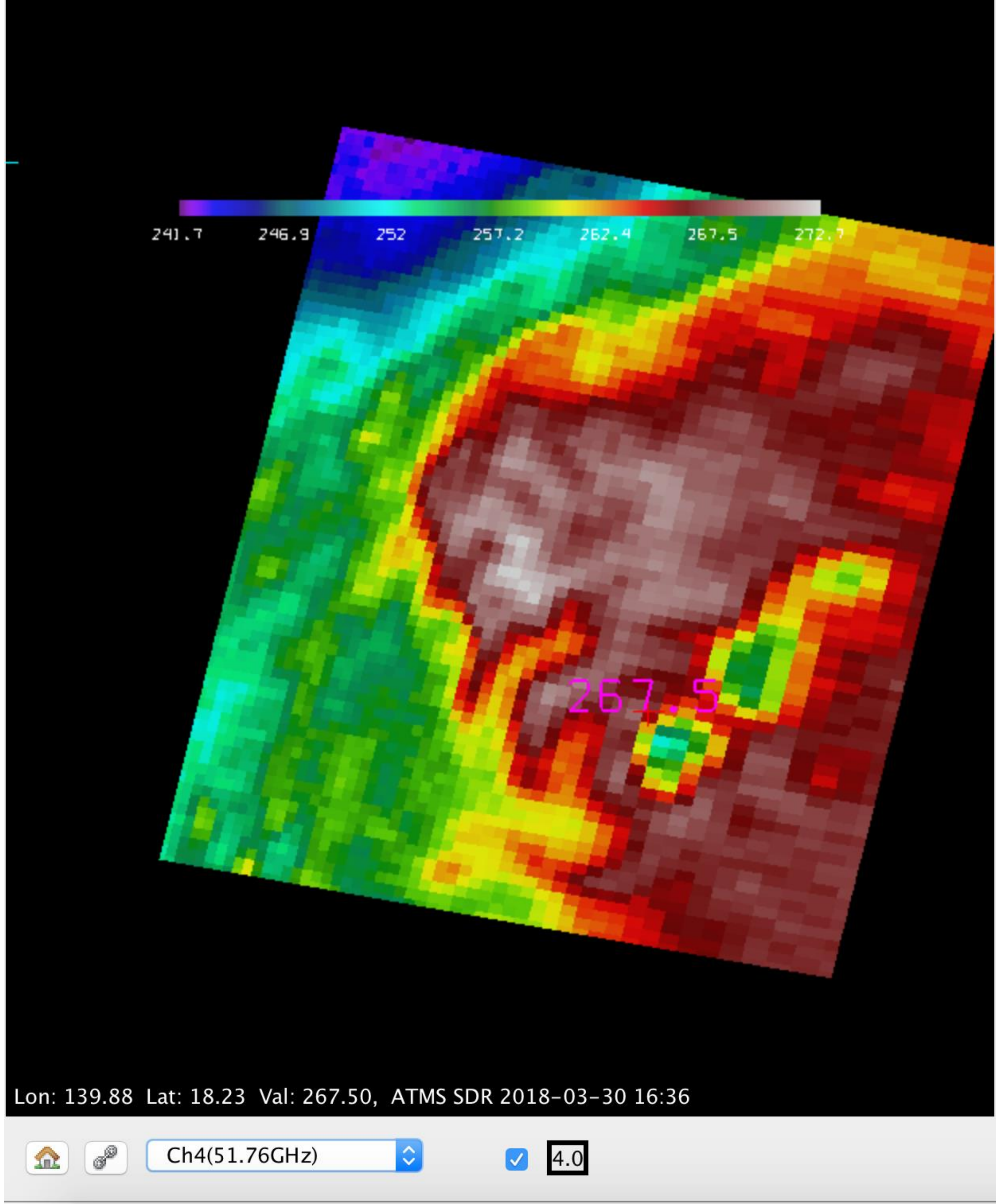
Temperature Range:
170 K to 300 K
-103 C to 26.8 C

Some surface information



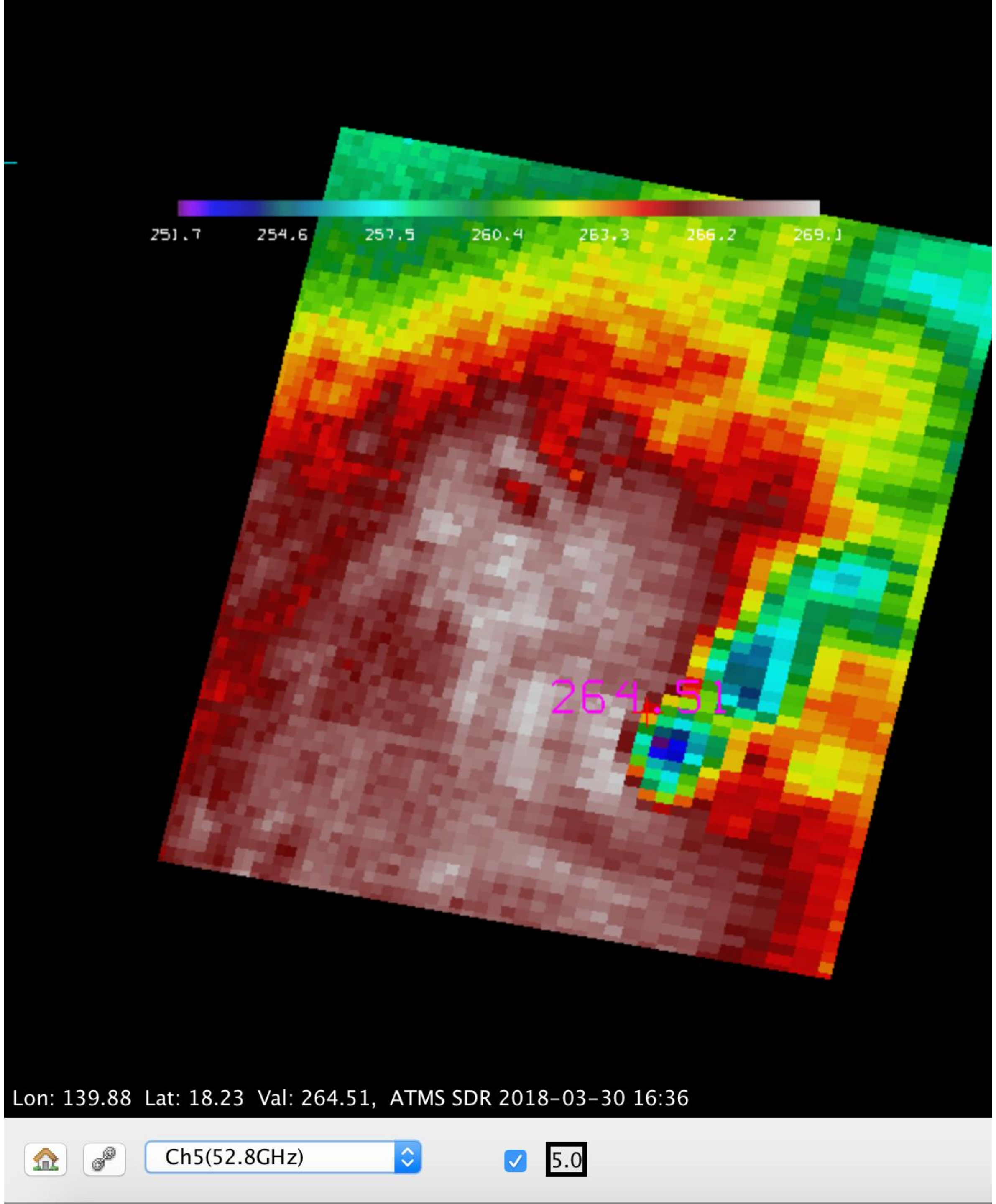
Examples from Typhoon Jelawat, 30 March 2018

SNPP VIIRS M-Band 15
11 micron
16:35 UTC



Examples from Typhoon Jelawat, 30 March 2018

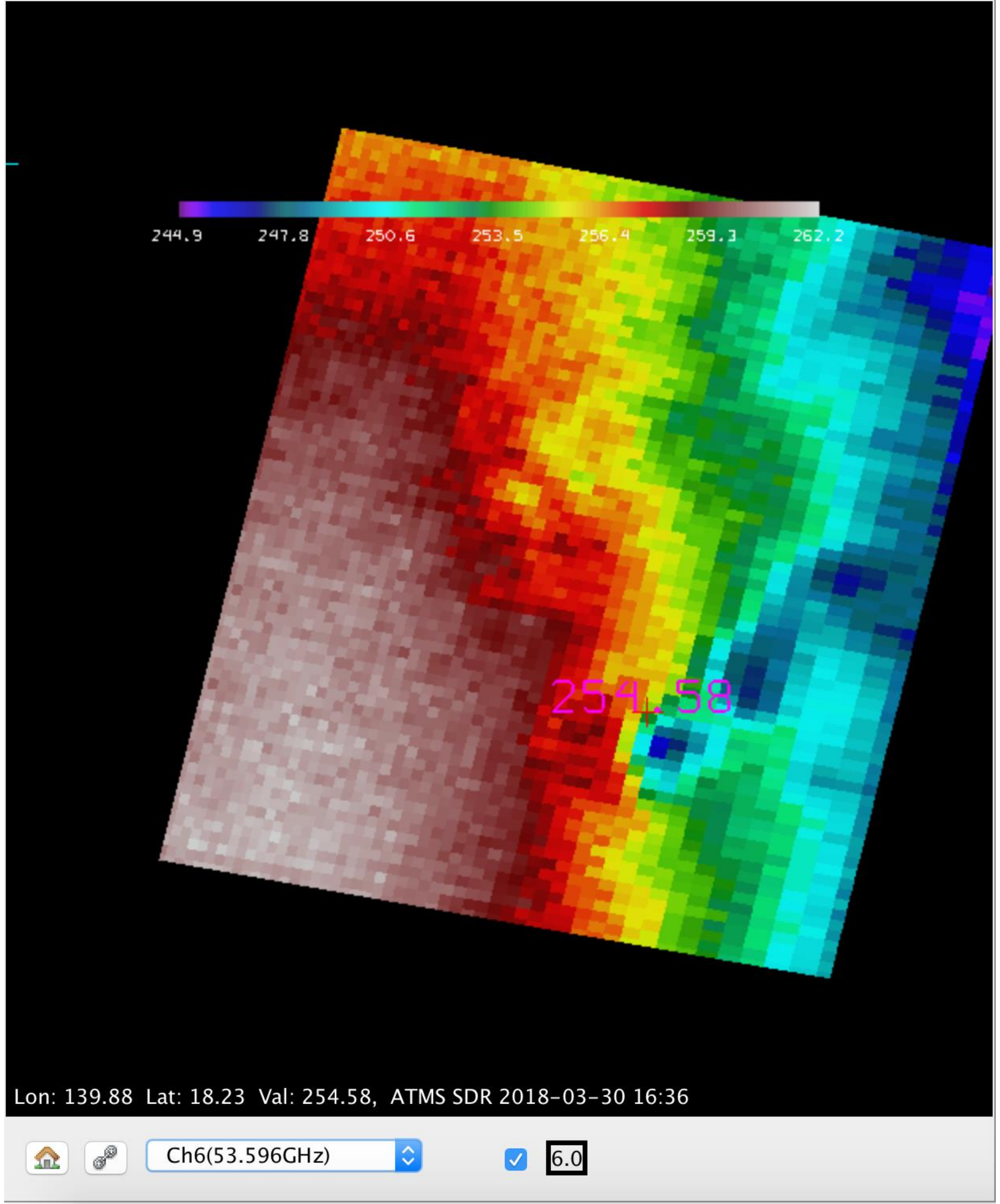
SNPP VIIRS M-Band 15
11 micron
16:35 UTC



Examples from Typhoon Jelawat, 30 March 2018

SNPP ATMS Band 6
53.6 GHz
16:35 UTC

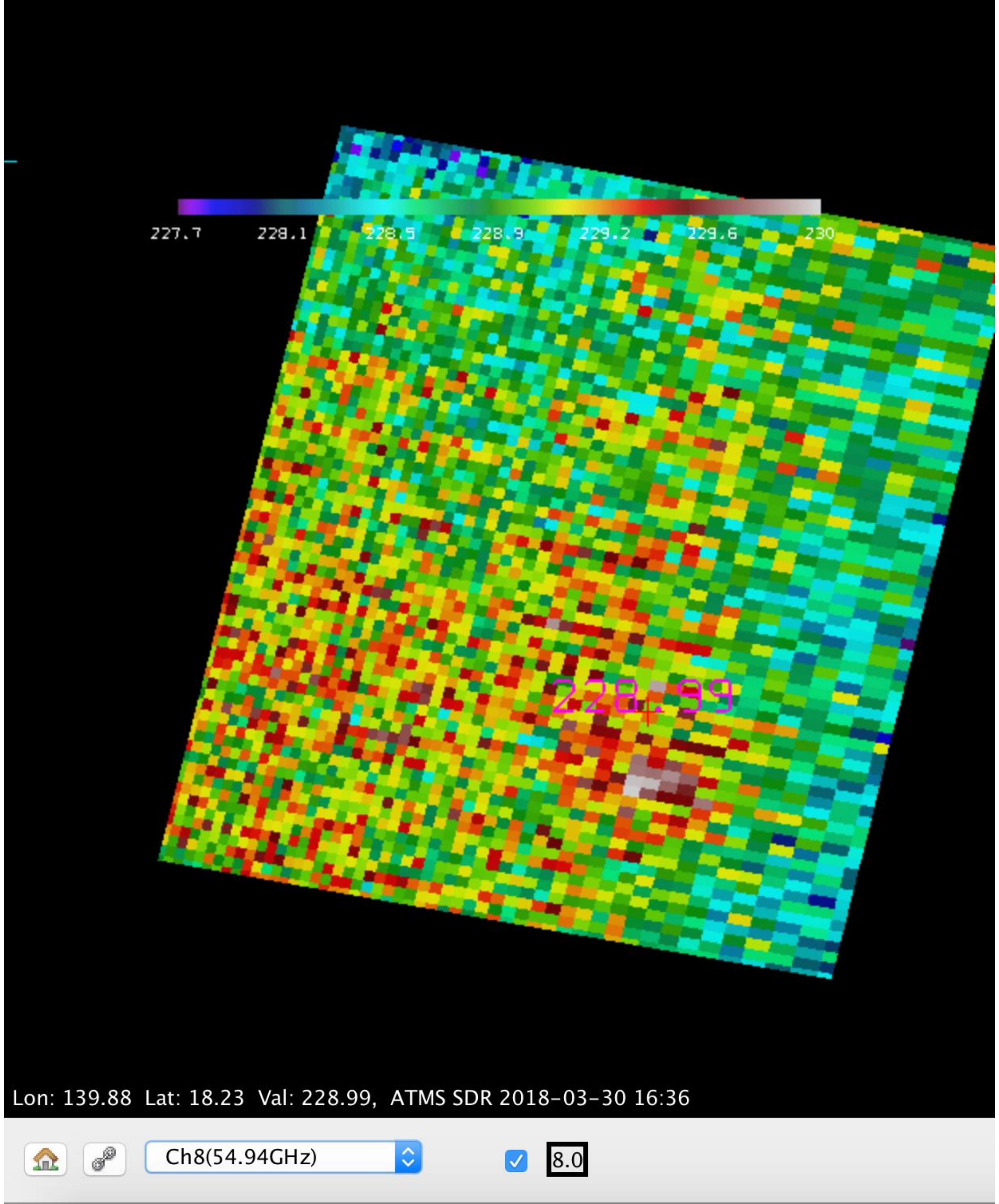
Temperature Range:
245 K to 262 K
-28 C to -11 C



Examples from Typhoon Jelawat, 30 March 2018

SNPP ATMS Band 8
54.94 GHz
16:35 UTC

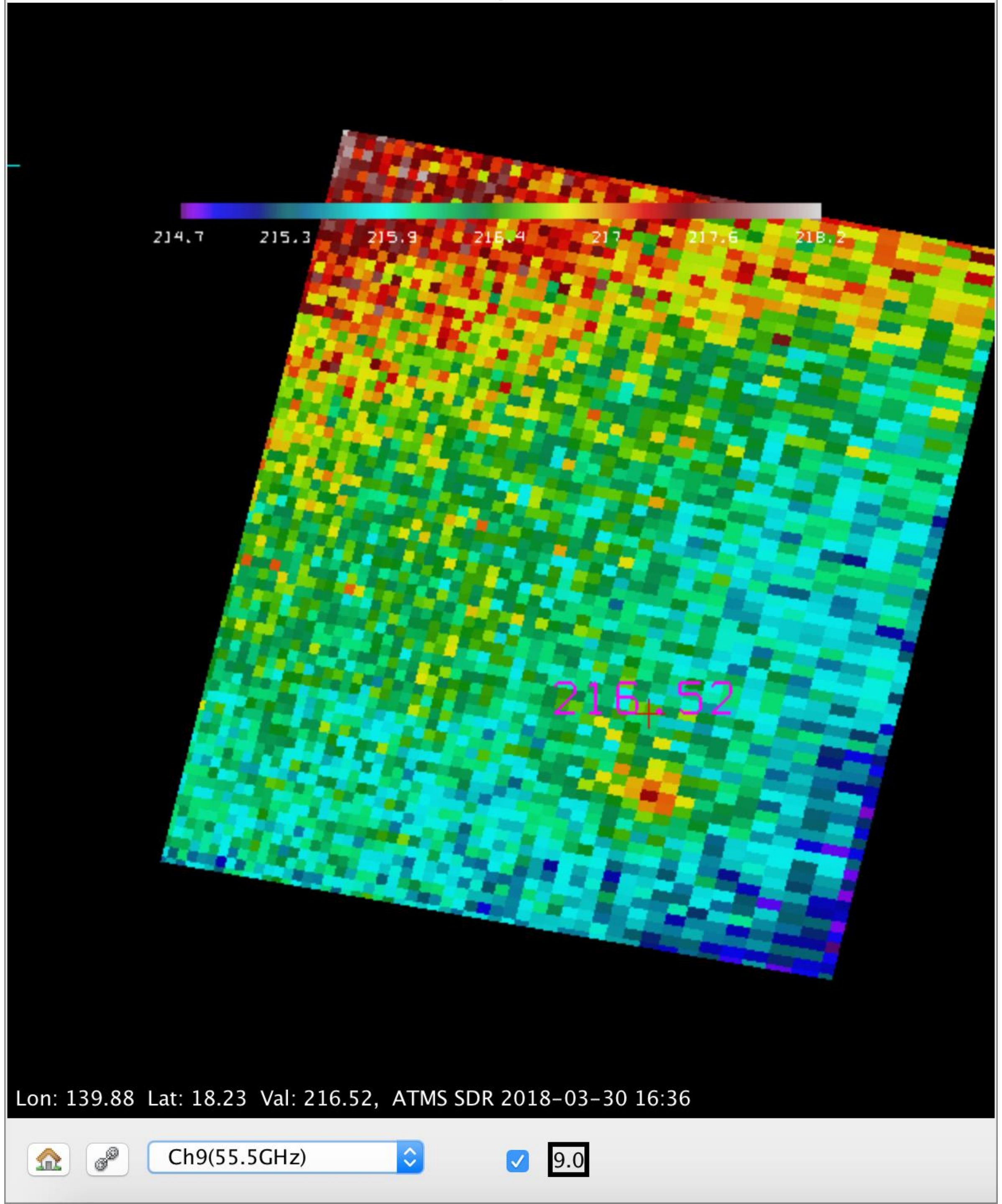
Temperature Range:
227 K to 230 K
-46 C to -43 C



Examples from Typhoon Jelawat, 30 March 2018

SNPP ATMS Band 9
55.5 GHz
16:35 UTC

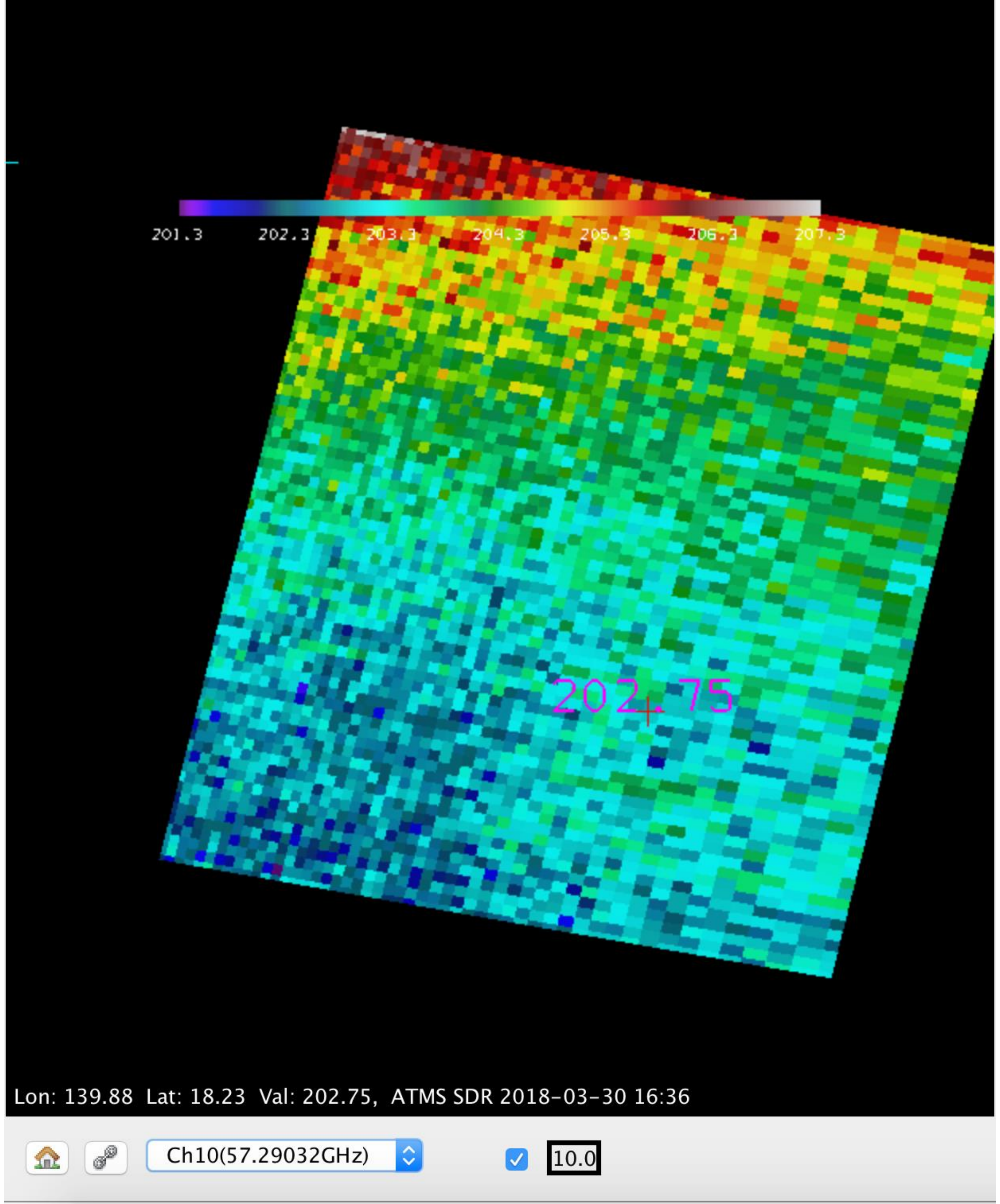
Temperature Range:
215 K to 218 K
-58 C to -55 C



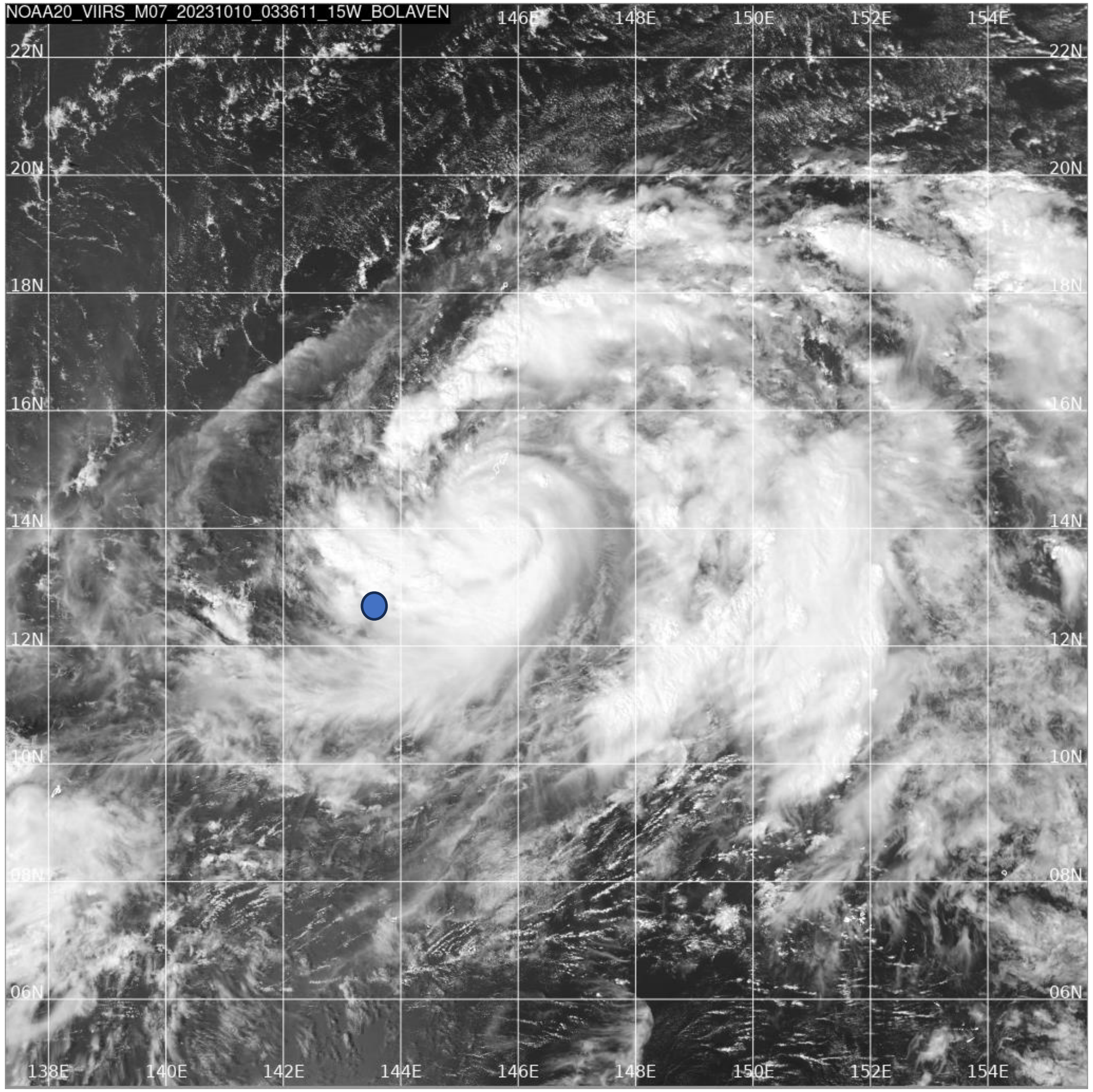
Examples from Typhoon Jelawat, 30 March 2018

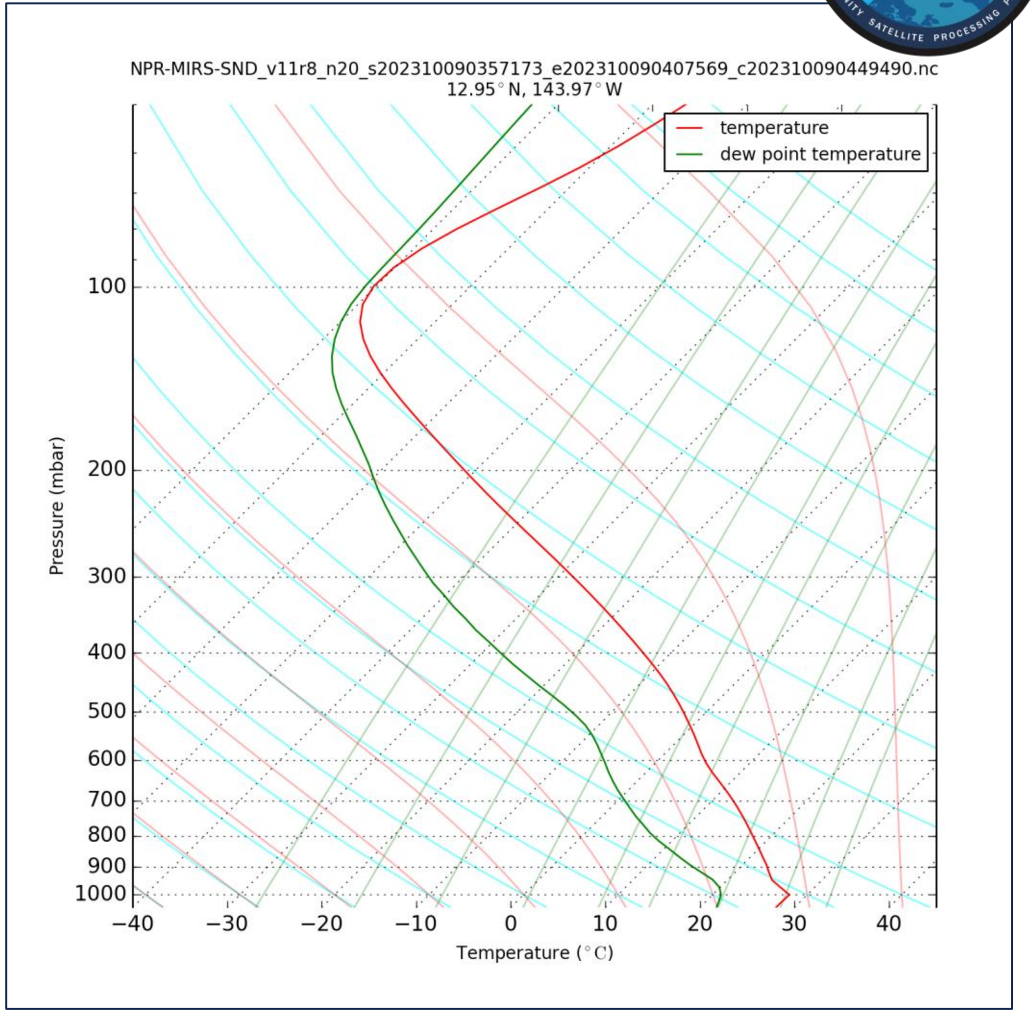
SNPP ATMS Band 10
57.29 GHz
16:35 UTC

Temperature Range:
201 K to 207 K
-72 C to -66 C



Temperature and Moisture Retrievals





Example ATMS Microwave Integrated Retrieval System MiRS profile retrieval Skew-T diagram
Typhoon Bolaven, 9 October 2023

Slido question

- Why is the Skew-T retrieval so smooth?
    - Not much activity going on in the atmosphere.
    - Bad data or bad retrieval.
    - Limited number of bands means limited information at different levels.

Slido question

- Why is the Skew-T retrieval so smooth?
  - Not much activity going on in the atmosphere.
  - Bad data or bad retrieval.
  - Limited number of bands means limited information at different levels.
    - NUCAPS retrievals combine IR bands (1000s) with microwave ability to penetrate the clouds.

CSPP NOAA MiRS Products

https://cimss.ssec.wisc.edu/cspp/

Official Validated Products for Suomi-NPP, NOAA-20/21, NOAA-18/19, Metop-B/C

- Temperature profile over open water ocean
- Humidity profile over open water ocean
- Humidity Profile over non-coastal Land
- Total Precipitable Water (TPW) over open water ocean
- Total Precipitable Water over non-coastal land
- Land surface temperature
- Surface Emissivity over land and snow
- Surface Type Classification
- Snow Water Equivalent (SWE)
- Sea Ice Concentration (SIC)
- Snow Cover Extent (SCE), based on the SWE
- Vertically-Integrated Non-precipitating Cloud Liquid Water (CLW) over open water ocean
- Vertically-Integrated Ice Water Path (IWP)
- Vertically-Integrated Rain Water Path (RWP)
- Rainfall Rate (RR) over open water ocean and non-coastal, non-snow-covered land surface types
- Effective grain size of snow (over snow-covered land surface)*
- Multi-Year (MY) Type Sea Ice Concentration*
- First-Year (FY) Type Sea Ice Concentration*
- Snow fall rate (SFR)***

*Note that FY and MY Sea Ice Concentration, as well as Snow Grain Size are not officially operational, but preliminary products, which is a higher maturity level than experimental status.
**Note that all retrieval products from NOAA-20 are at full validated maturity level.
***Note that snowfall rate is not produced for Metop-A and NOAA-18.

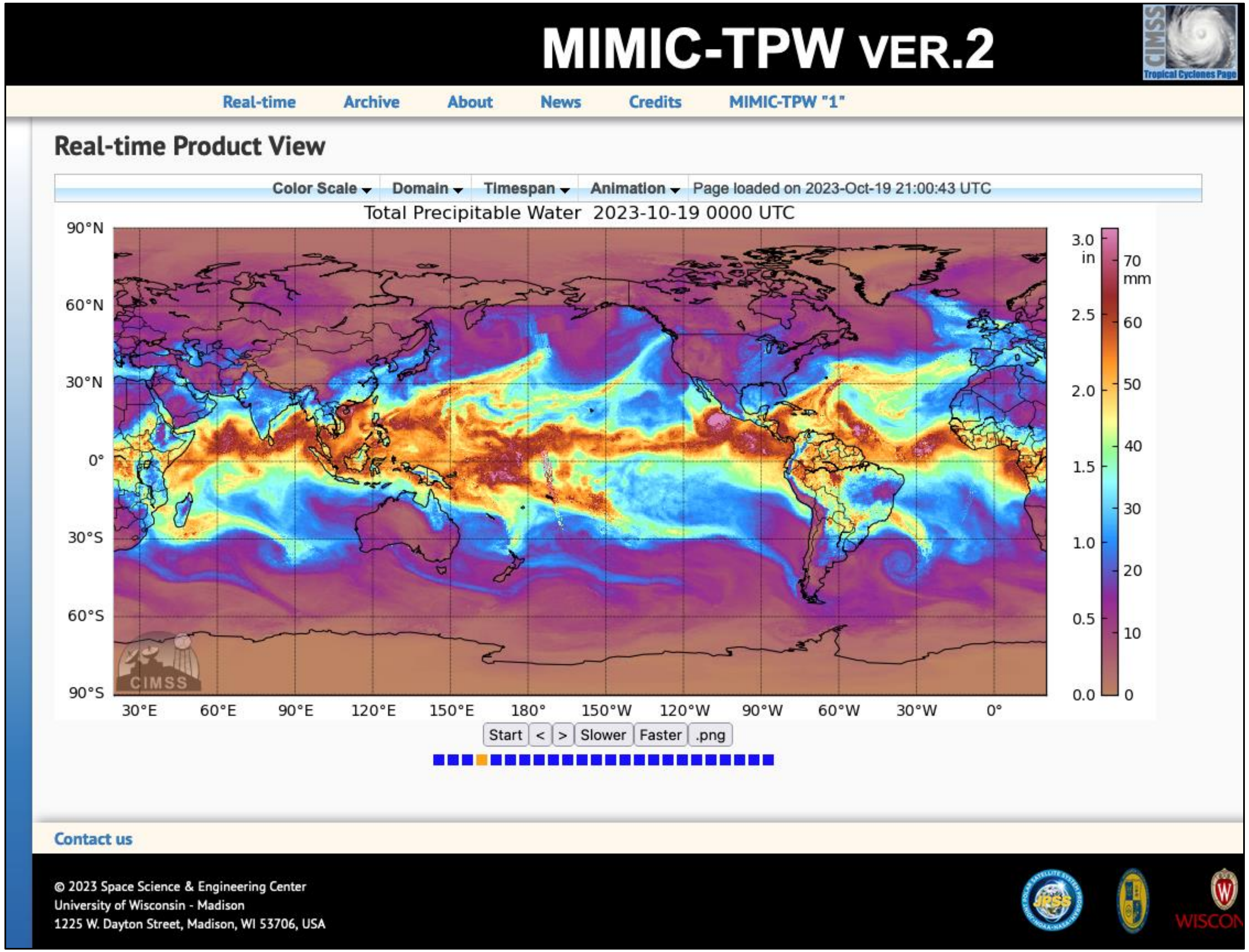
Morphed integrated microwave imagery (MIMIC)

- Wimmers, A. J., and C. S. Velden, 2007: MIMIC: A New Approach to Visualizing Satellite Microwave Imagery of Tropical Cyclones. *Bull. Amer. Meteor. Soc.*, **88**, 1187–1196, https://doi.org/10.1175/BAMS-88-8-1187.
- https://tropic.ssec.wisc.edu/real-time/mtpw2/product.php?color_type=tpw_nrl_colors&prod=global2&timespan=24hrs&anim=html5

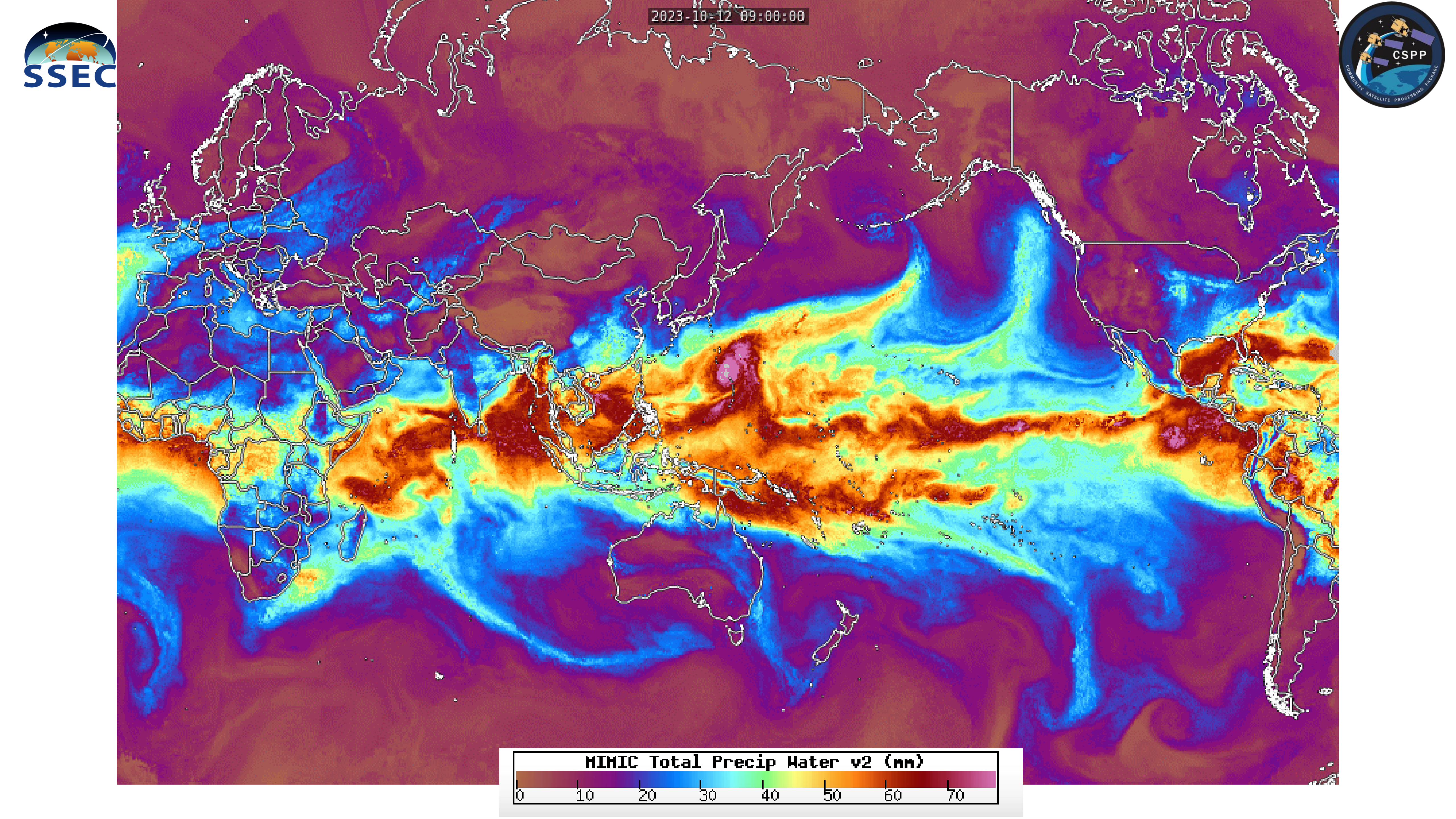
MIMIC Total Precipitable Water (TPW)

- The composite product is made from TPW retrievals using SNPP and NOAA-20 ATMS and NOAA-18, NOAA-19, Metop-B and Metop-C AMSU-A/MHS retrievals (6 satellites).
- The MIMIC algorithm "advects" the data backward and forward in time using a vertically-averaged wind field. This new advected dataset then can be used in a full sequence of composite images valid exactly on the hour (or at any desired timestep).
- How accurate is the morphed TPW fields? The authors demonstrated that the morphological compositing process added a mean average error of only 1-2 mm TPW in a multi-satellite composite over the ocean, which is usually negligible. We assume that the error over land is somewhat larger, but this will have to be investigated sometime later.
    - Wimmers, A. J., and C. S. Velden, 2011: Seamless Advective Blending of Total Precipitable Water Retrievals from Polar-Orbiting Satellites. *J. Appl. Meteor. Climatol.*, **50**, 1024–1036, https://doi.org/10.1175/2010JAMC2589.1.

MIMIC-TPW Version 2



https://tropic.ssec.wisc.edu/real-time/mtpw2/


2023-10-12 09:00:00
SSEC
CSPP
COMMUNITY SATELLITE PROCESSING PACKAGE
MIMIC Total Precip Water v2 (mm)
0
10
20
30
40
50
60
70

How Can MIMIC Product be Useful

- Example from Typhoon Saola

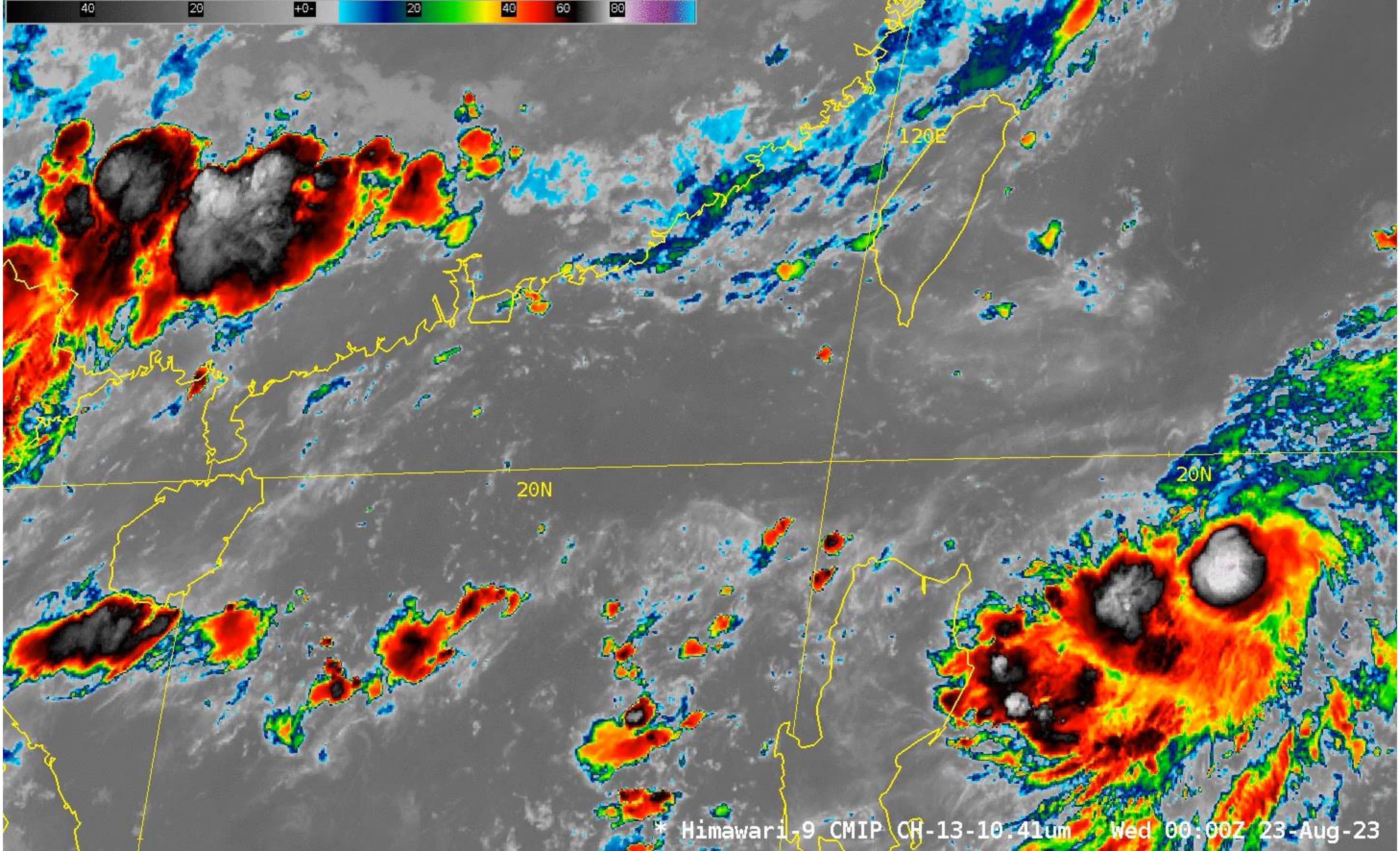
  23 August – 3 September 2023

  AHI Band 13 Infrared Loop (10.4 micron)

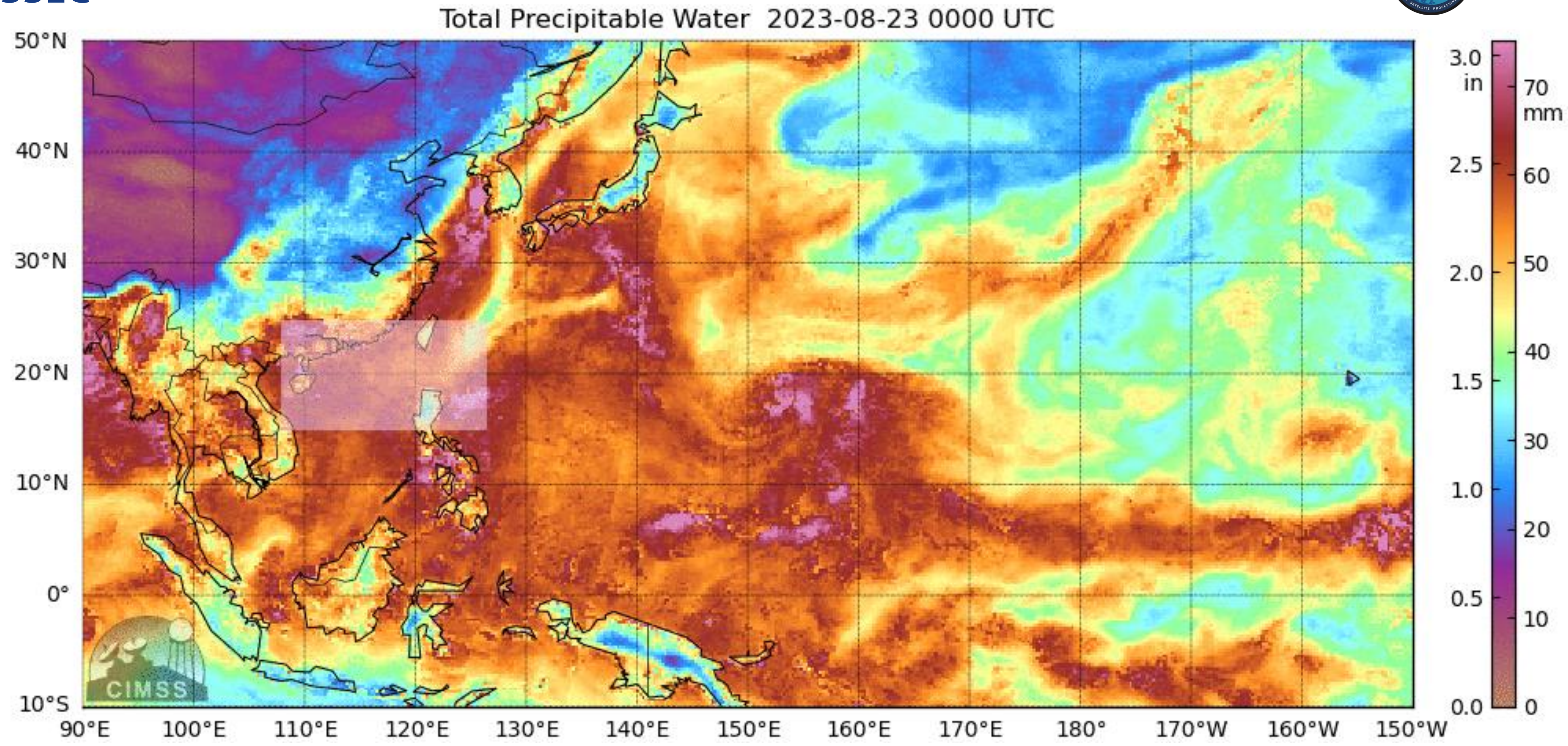
  every 30 minutes

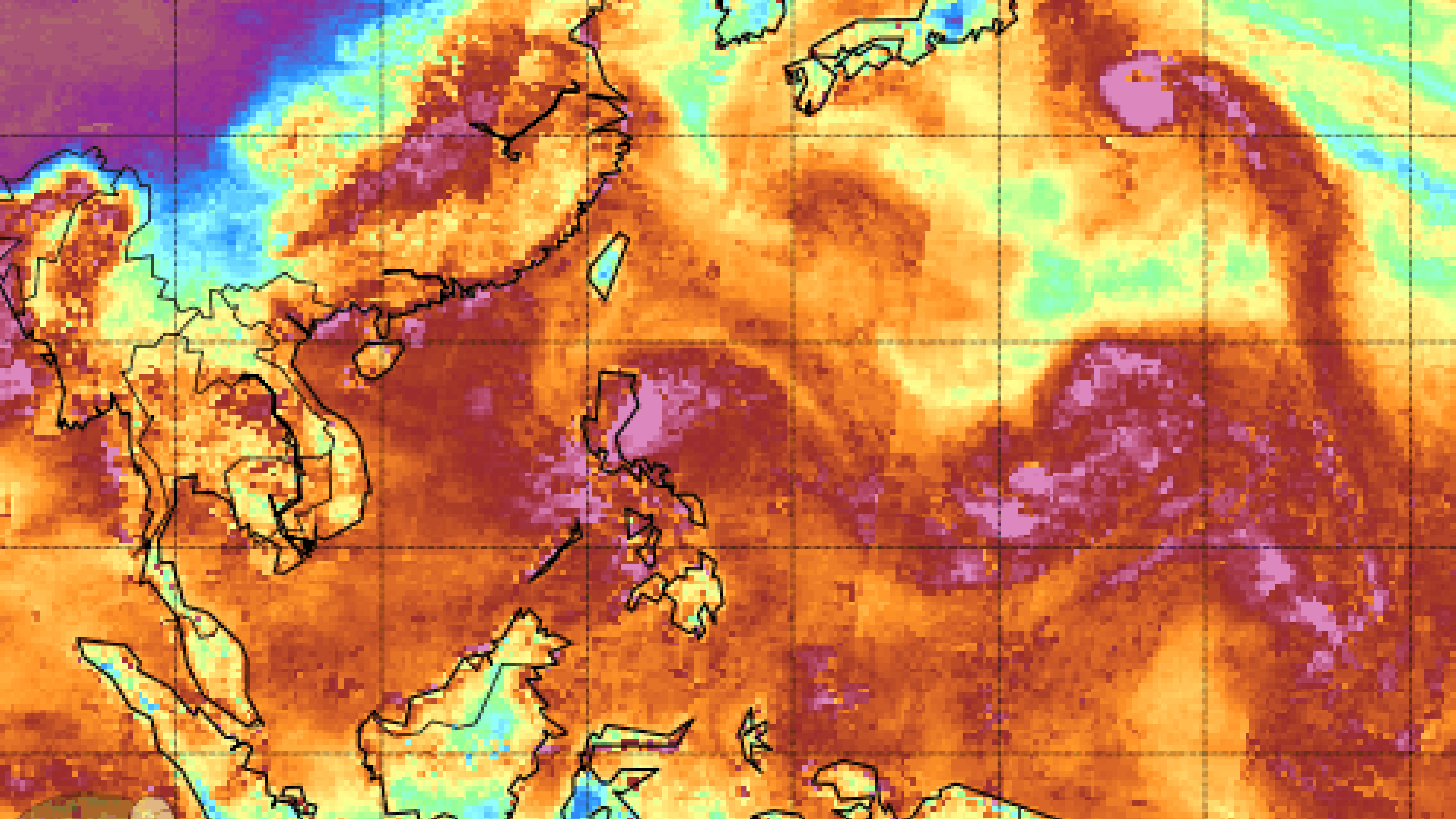
- Slido Question: Some weakening occurred on 27-28 August

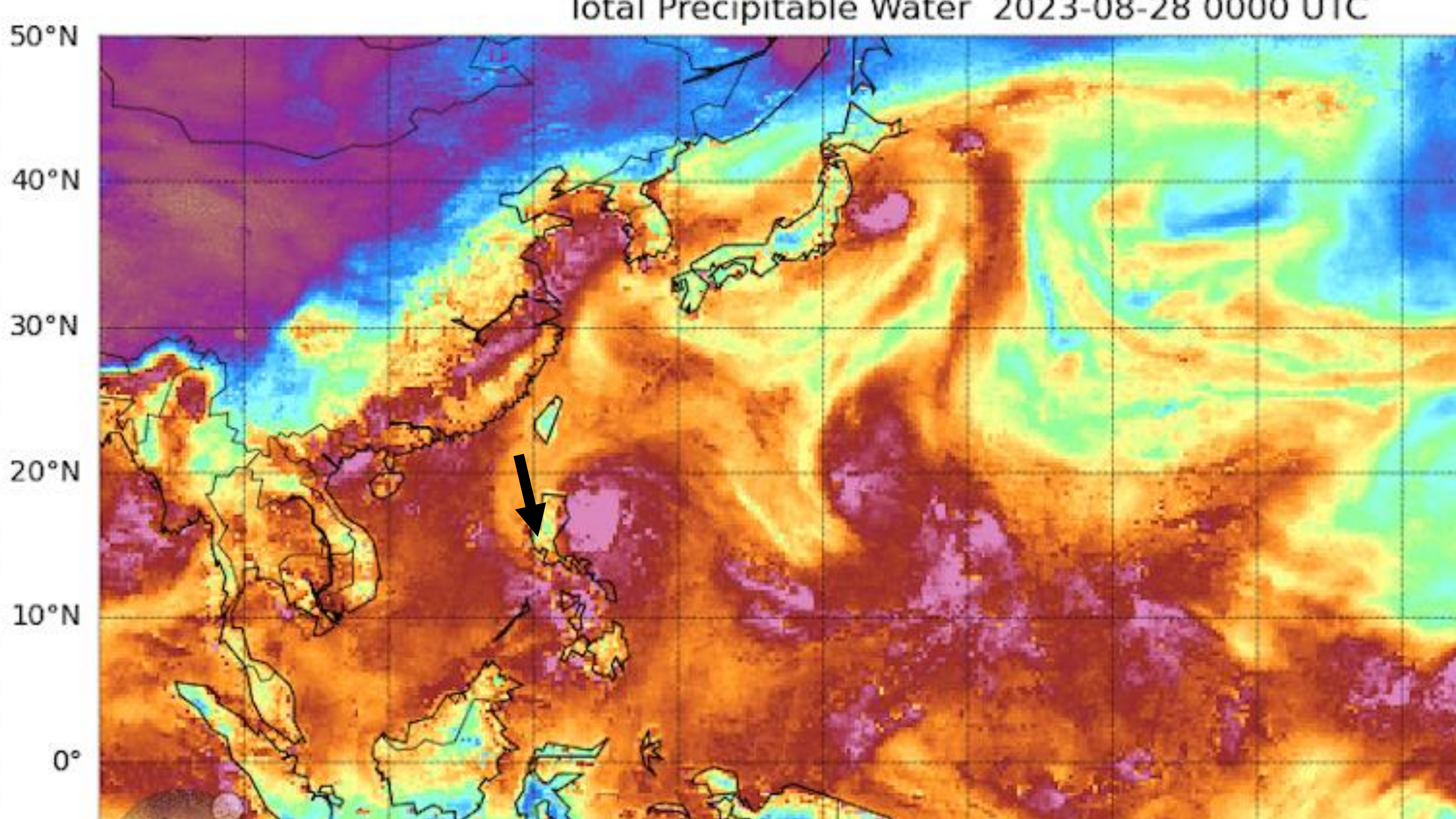
  Why?


40
20
+0-
20
40
60
80
120E
20N
20N
* Himawari-9 CMIP CH-13-10.41um   Wed 00:00Z 23-Aug-23

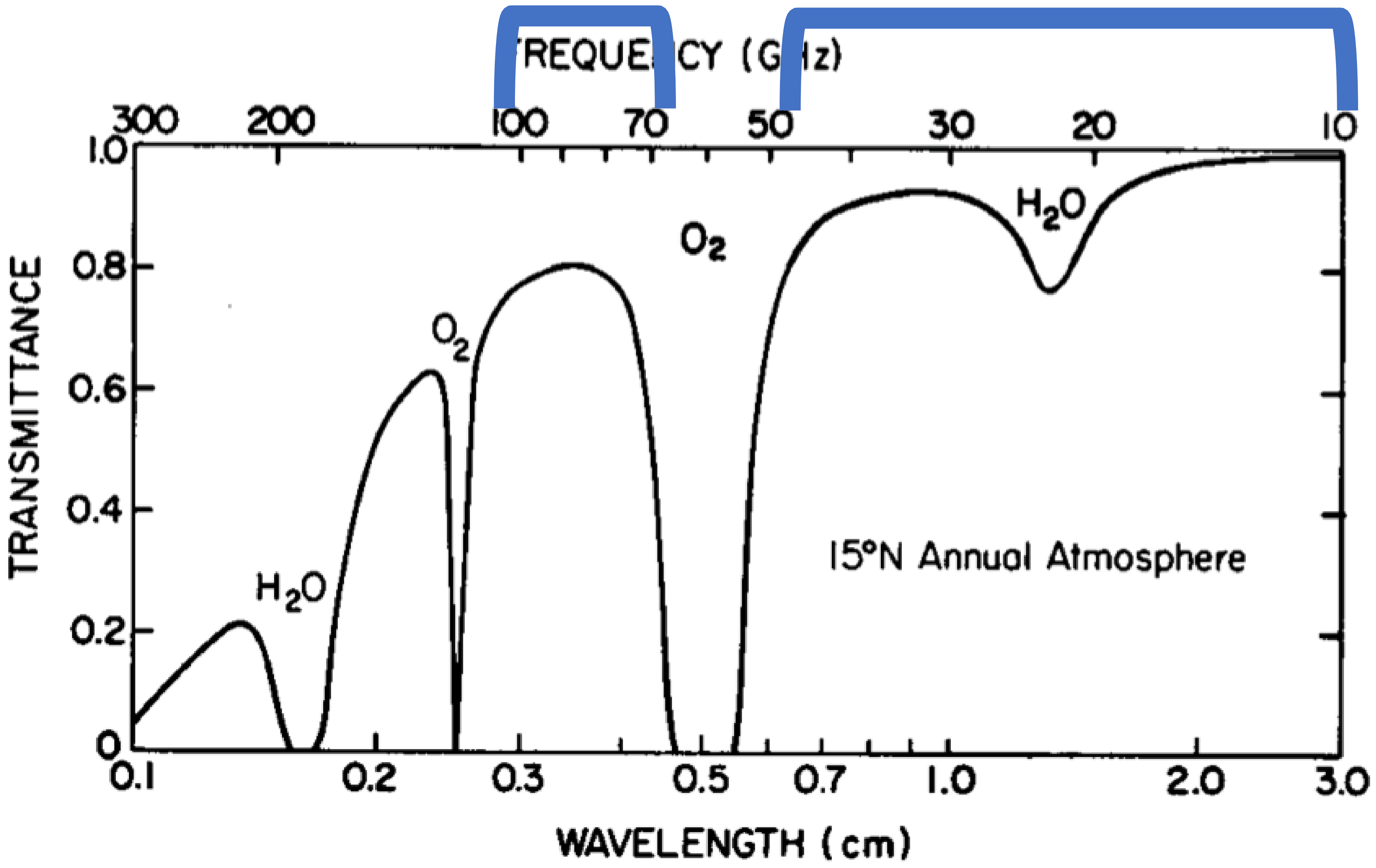
MIMIC-TPW Version 2






Total Precipitable Water 2023-08-28 0000 UTC
50°N
40°N
30°N
20°N
10°N
0°

Window Regions Approximately Below 50 GHz, And 65-100 GHz (some H_2O absortion)



Advanced Microwave Scanning Radiometer 2 (AMSR-2) Specfications - JAXA

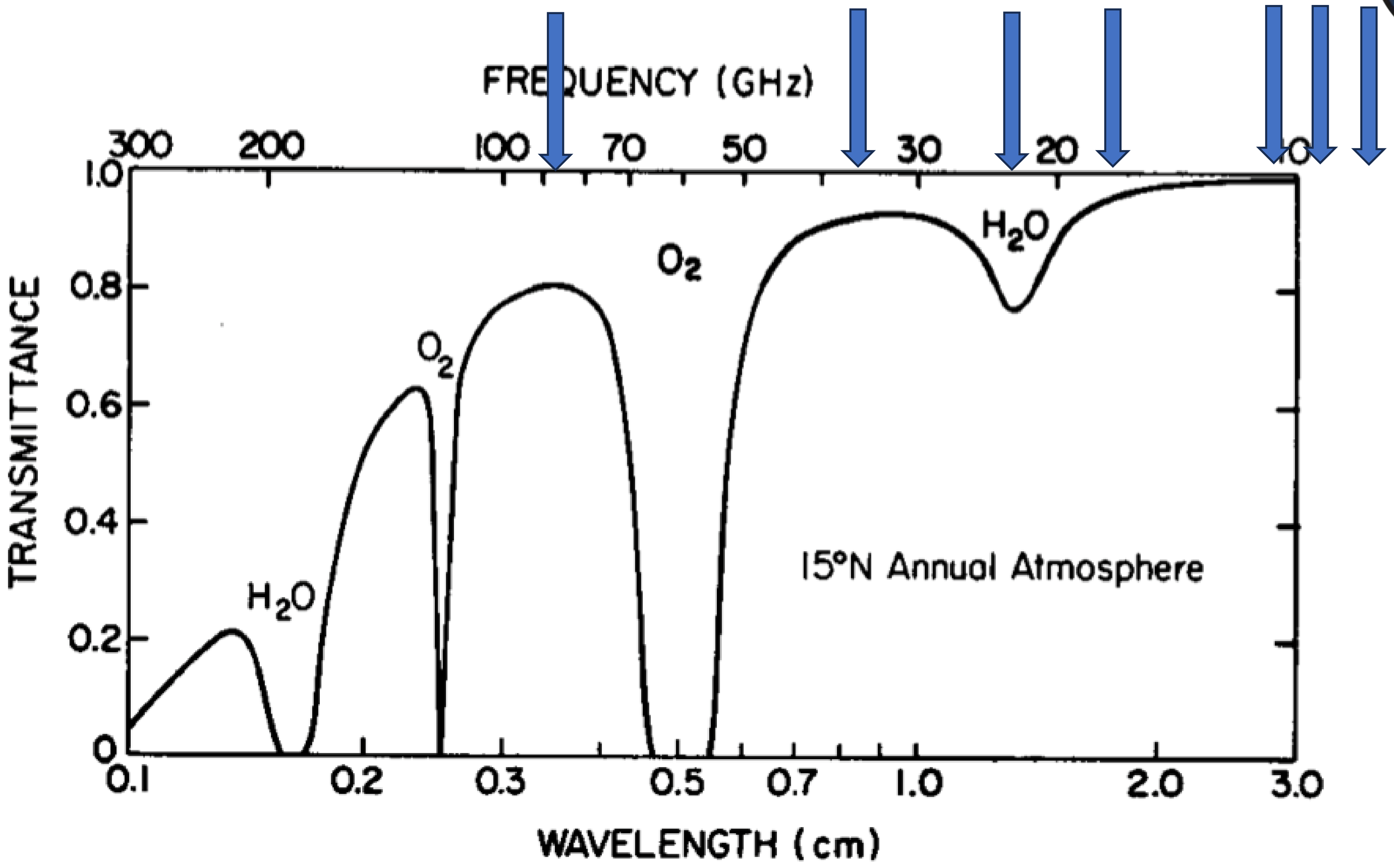
GCOM-W / Main Specifications of AMSR2

Scan and Rate:	Conical Scan at 40 rpm
Antenna:	Offset parabola with 2.0m diameter
Swath Width:	1450km
Incidence Angle:	Nominal 55 degrees
Digitization:	12 bits
Dynamic Range:	2.7 - 340K
Polarization:	Vertical and horizontal

AMSR2 Channel Set

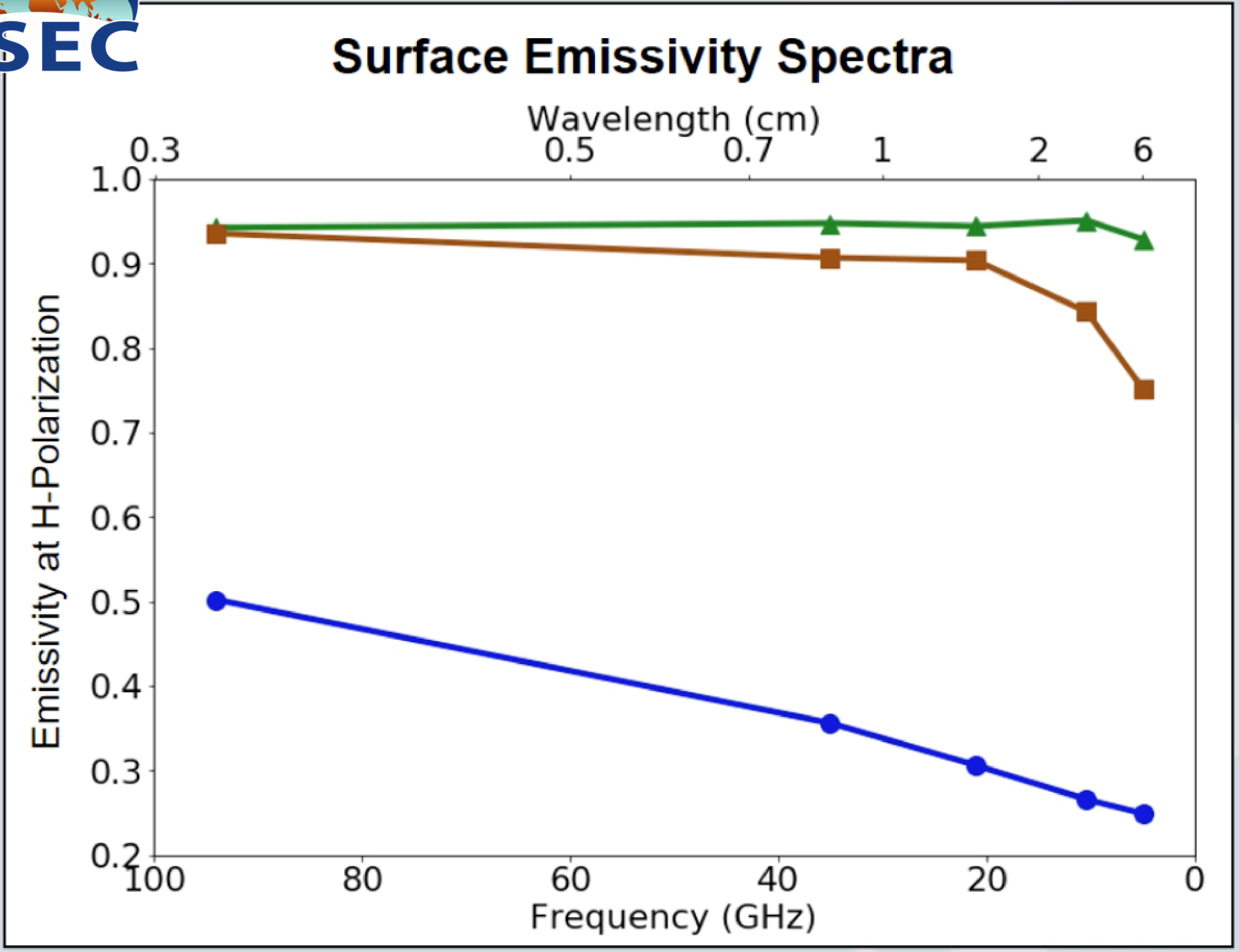
Center Frequency (GHz)	Band Width (MHz)	Pol.	Beam Width (degree)	Ground Resolution (km)	Sampling Interval (km)
6.925/7.3	350	V / H	1.8	35 x 62	10
10.65	100		1.2	24 x 42	
18.7	200		0.65	14 x 22	
23.8	400		0.75	15 x 26	
36.5	1000		0.35	7 x 12	
89.0	3000		0.15	3 x 5	5

AMSR-2 Imager Bands



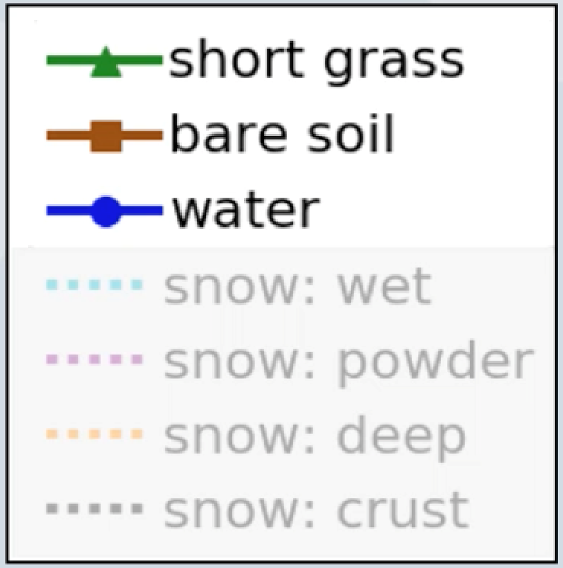
Window Channel Products

- High Transmittances – See deep into the atmosphere
- Complications
  - Emissivity – How much of the energy is emitted for the given surface?
  - Scattering properties of ice and water at different wavelengths
  - Polarization
  - Limb effects



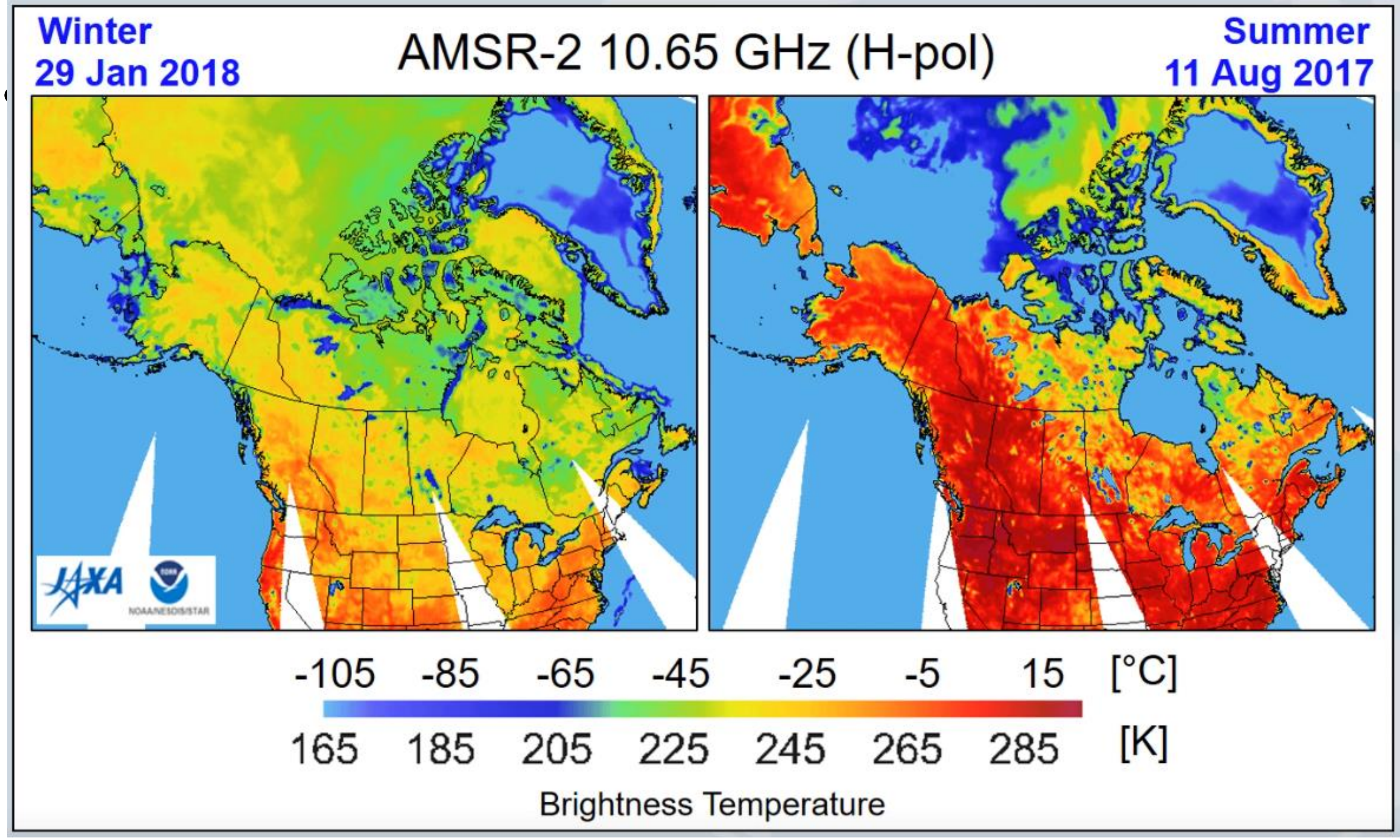
Parameters:

- wavelength
- material characteristics
- polarization
- surface roughness
- viewing angle



Data Source: C. Matzler, "Passive Microwave Signatures of Landscapes in Winter", *Meteorol. Atmos. Phys.* (1994)

Window Channel Retrievals



10 GHz is a window Channel.

- No clouds
- water cold!
- Emissivity

  at 10 GHz the water emissivity is about .3

Characteristic of 36 and 89 GHz Window Channels

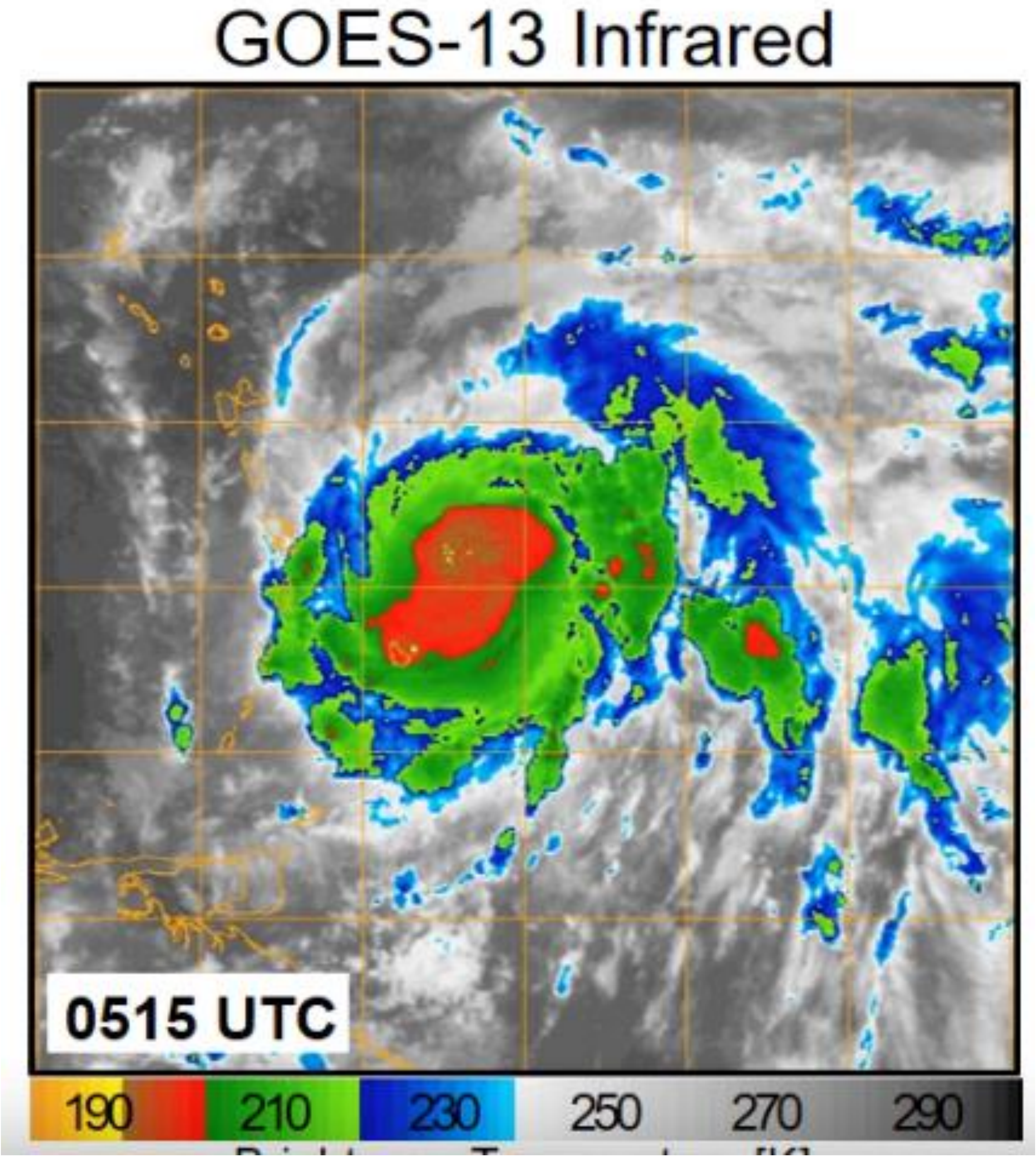
- 36 GHz
  - Warm emission from precipitating clouds provides good differentiation between that and cold ocean. Transmittance over water is .3 so very cold temperatures. Retrieving precipitation over land is harder. Not as much of a contrast.
  - Ice (snow) is mainly transparent at this frequency. So precipitation detected is emission from rain.
  - Rain rates are more accurate from microwave retrievals because you are measuring the direct observations of emissions from the precipitation.
- 88 GHz
  - Water transmittance is higher, so warmer water temperatures.
  - Ice scattering affects this wavelength, so can see more mature glaciated convective clouds.

- Parallax effects mean that it will affect bands differently.

GOES Infrared

Improved Spatial and Temporal Resolution

Nighttime 11 micron infrared

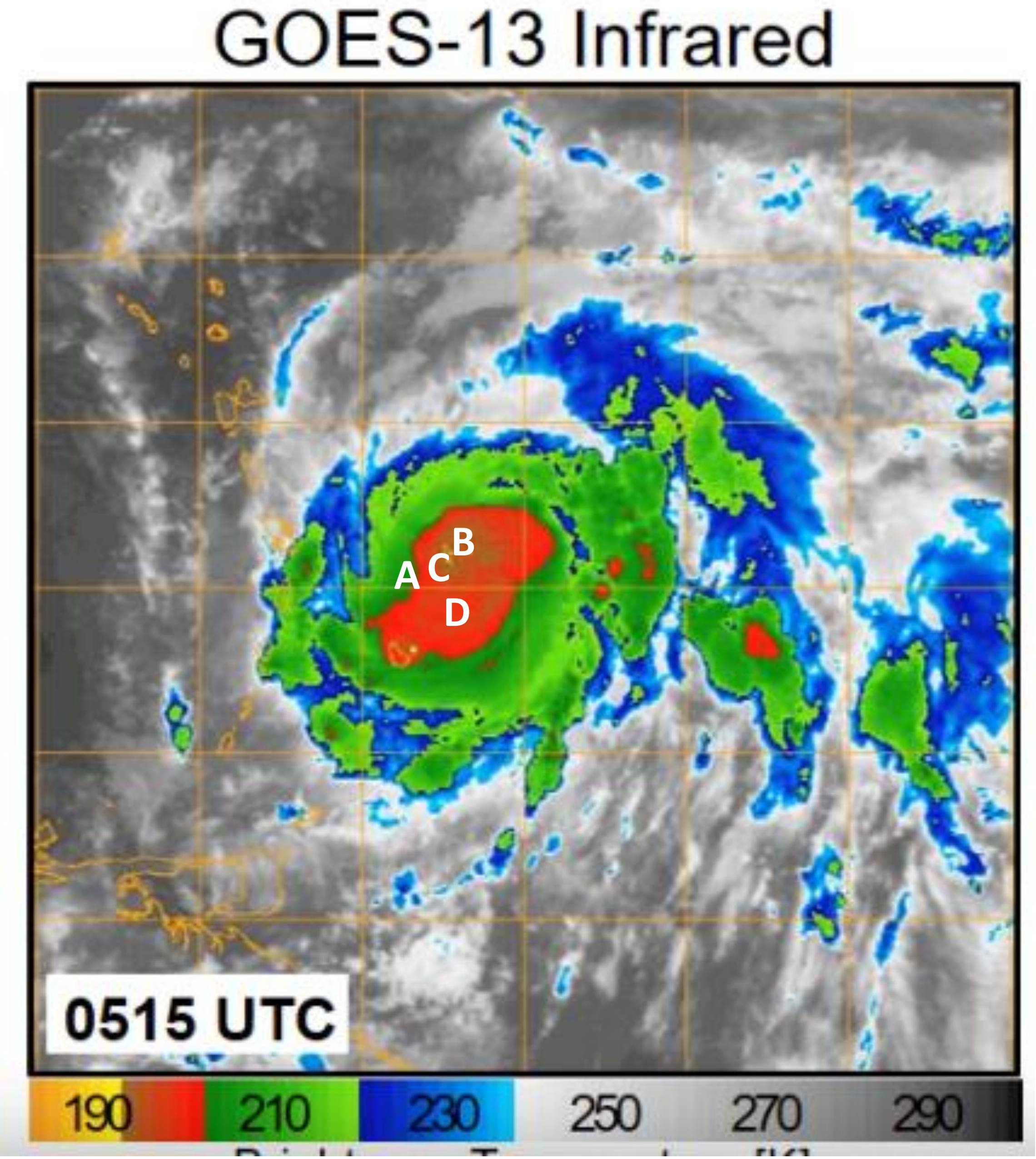


Taken from RAMMB SHyMet: Satellite Foundational Course for JPSS (SatFC-J)
https://rammb2.cira.colostate.edu/training/shymet/satfc-j_intro/

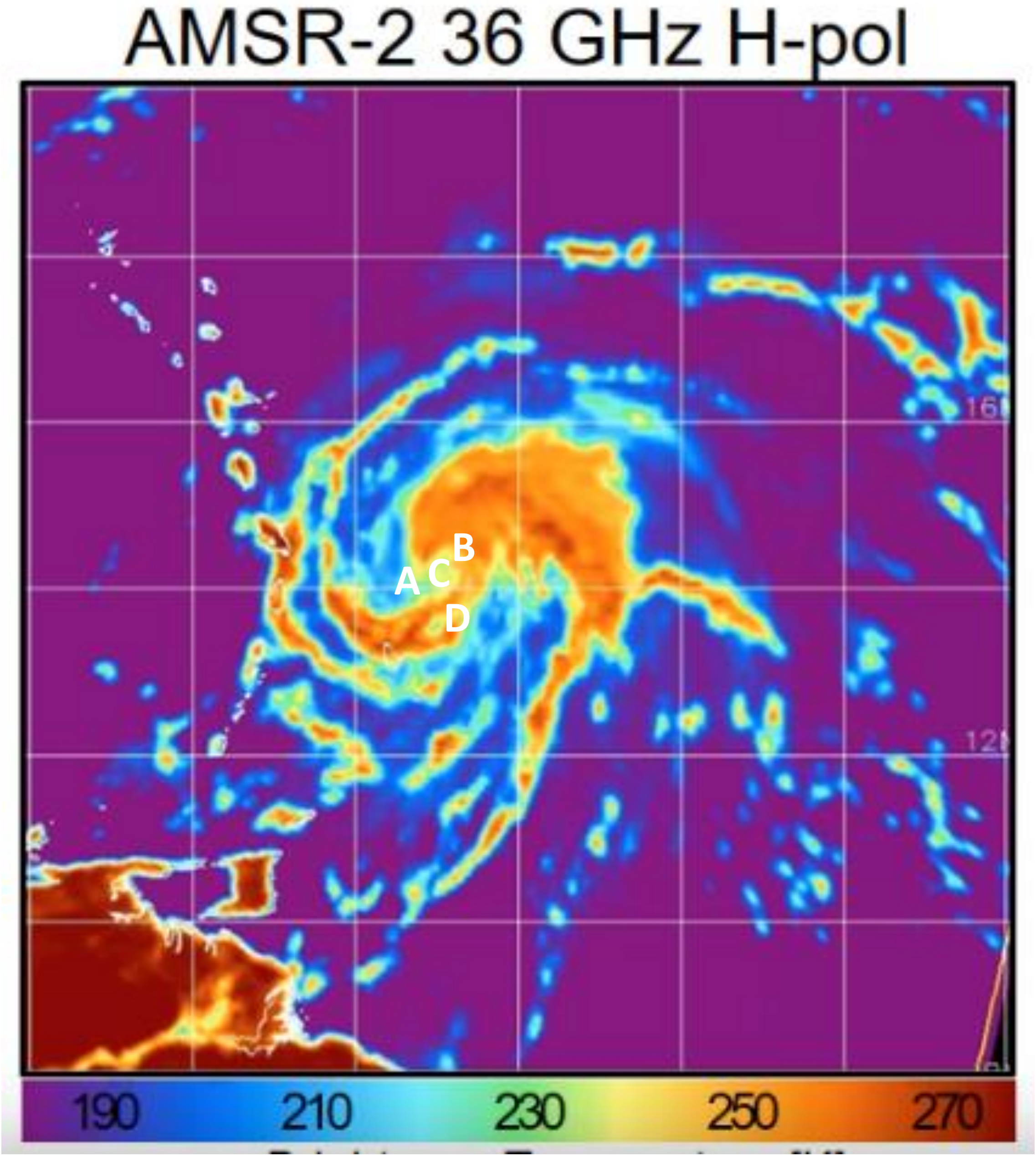
GOES Infrared

Improved Spatial and Temporal Resolution

Slido Question: Where is the the Center of the Tropical Cyclone?



Taken from RAMMB SHyMet: Satellite Foundational Course for JPSS (SatFC-J)
https://rammb2.cira.colostate.edu/training/shymet/satfc-j_intro/



Taken from RAMMB SHyMet: Satellite Foundational Course for JPSS (SatFC-J)
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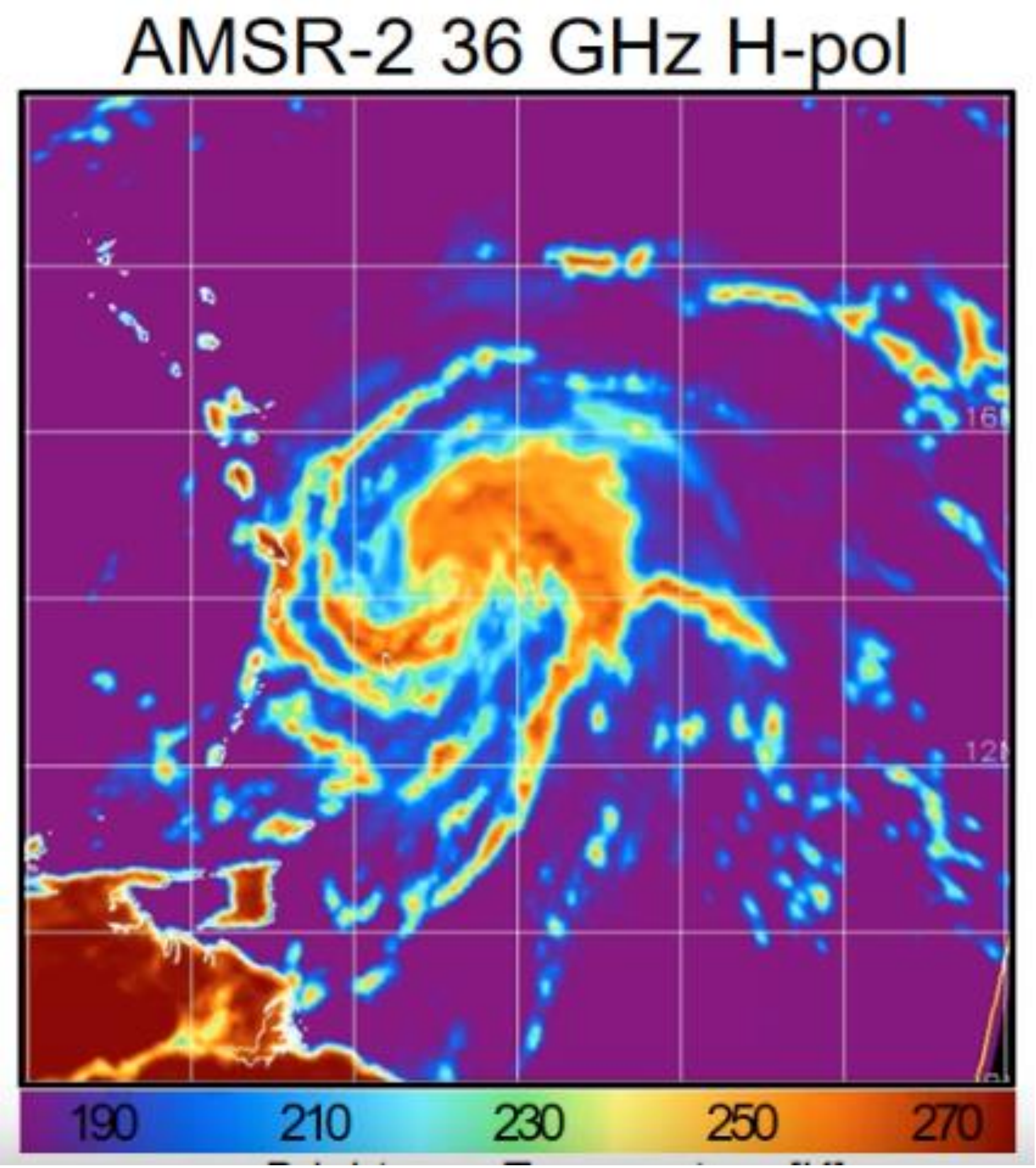
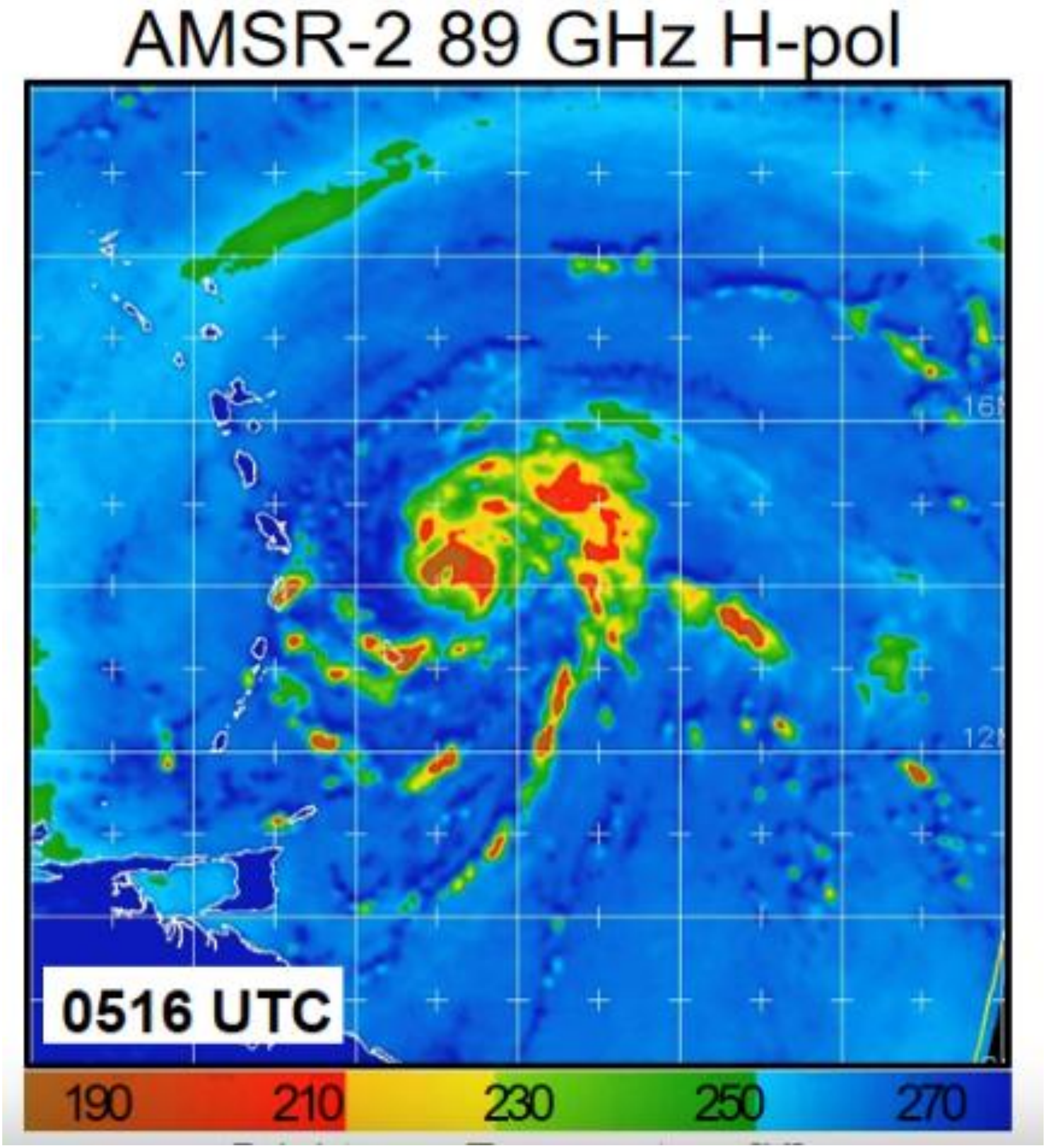


Taken from RAMMB SHyMet: Satellite Foundational Course for JPSS (SatFC-J) **https://rammb2.cira.colostate.edu/training/shymet/satfc-j_intro/**

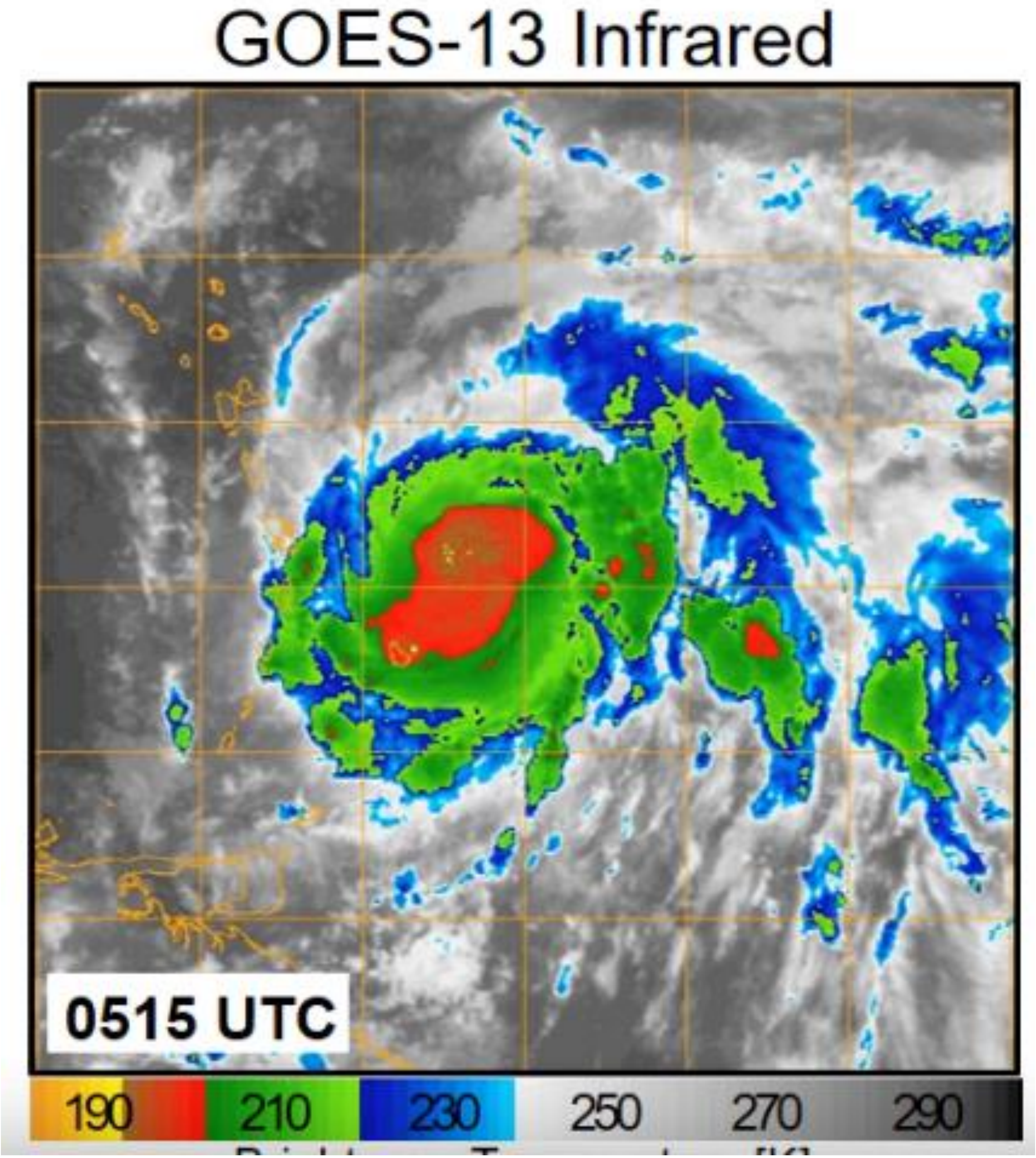


Taken from RAMMB SHyMet: Satellite Foundational Course for JPSS (SatFC-J)
https://rammb2.cira.colostate.edu/training/shymet/satfc-j_intro/

GOES Infrared

Improved Spatial and Temporal Resolution

Nighttime 11 micron infrared



Taken from RAMMB SHyMet: Satellite Foundational Course for JPSS (SatFC-J)
https://rammb2.cira.colostate.edu/training/shymet/satfc-j_intro/

CSPP NOAA AMSR-2 GCOM-W1 AMSR2 Algorithm Software Package (GAASP)
https://cimss.ssec.wisc.edu/cspp/

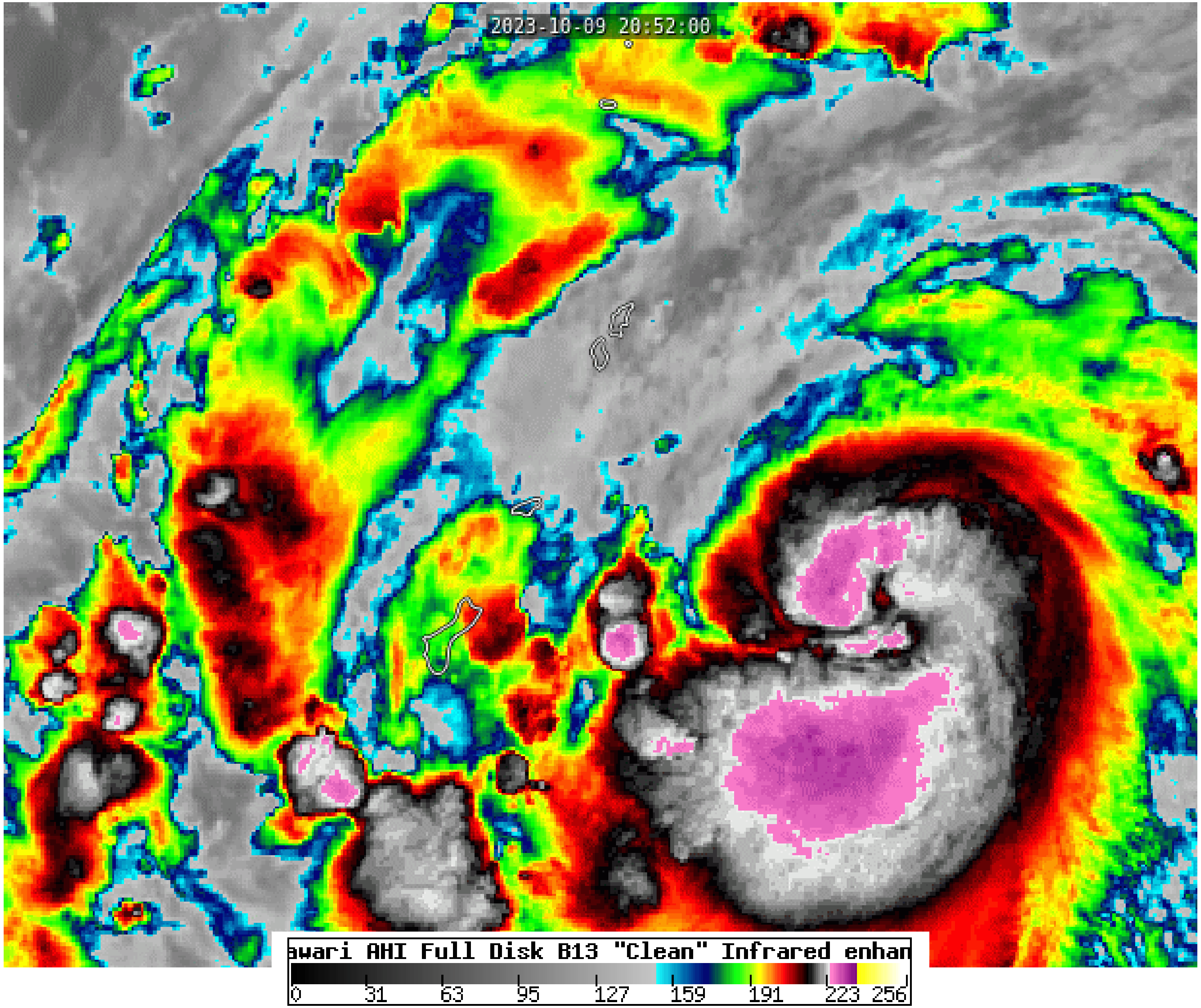
Products

- **Ocean** Sea Surface Temperatures, Sea Surface Winds, Cloud Liquid Water, Total Precipitable Water.
- **Precipitation:** Convective Precipitation, Surface Rain Rate.
- **Soil Moisture:** Land Cover Type, Soil Moisture.
- **Snow:** Snow Cover, Snow Depth.
- **Sea Ice:** Ice Concentration, Multiyear Ice, Range of Ice Concentration.

Operation Use of Polar Orbiter Data

- Example from Typhoon Bolaven

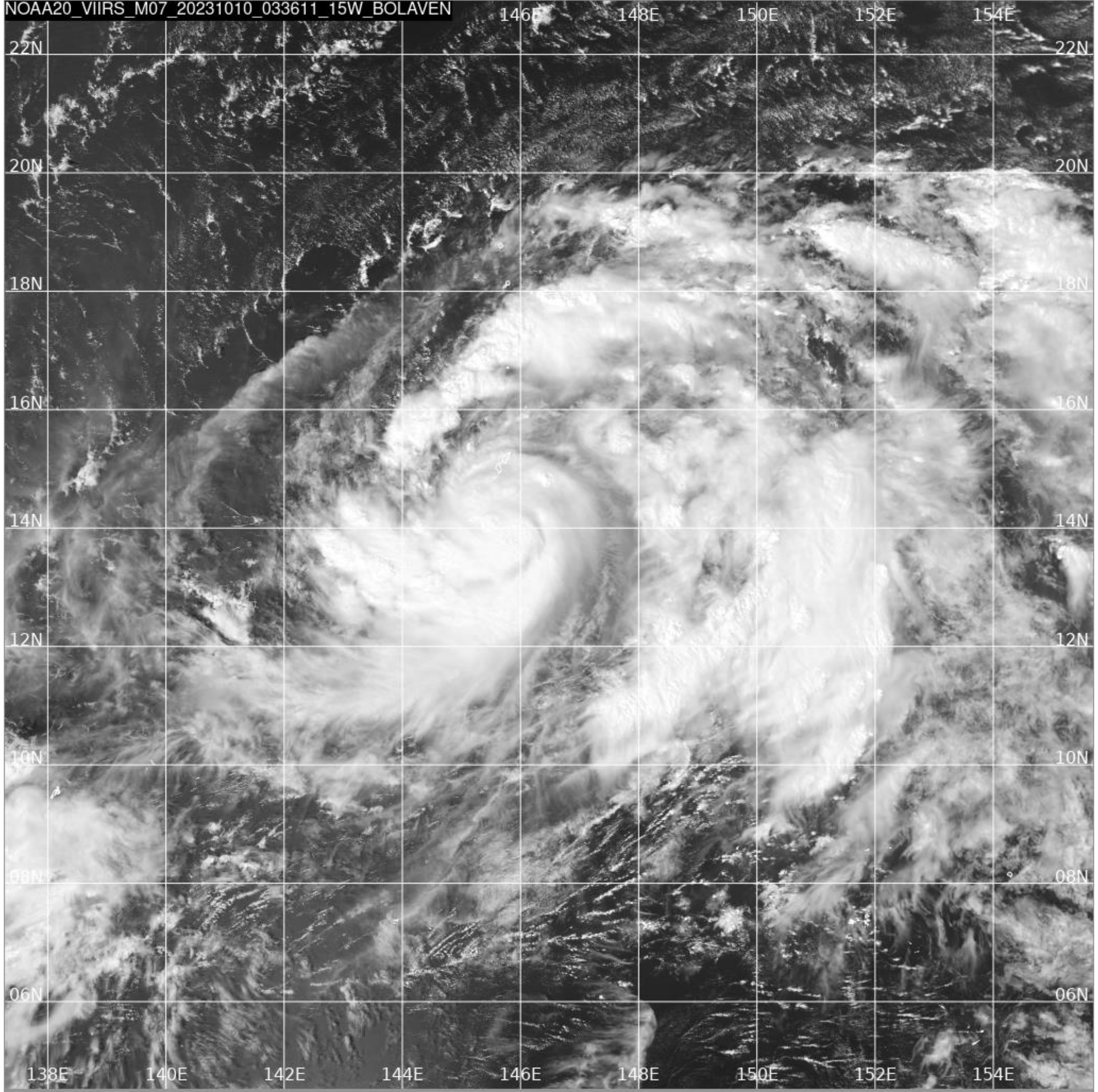
  9-10 October 2023


2023-10-09 20:52:00
awari AHI Full Disk B13 "Clean" Infrared enhan
0 31 63 95 127 159 191 223 256

VIIRS Day/Night Band
10 October 2023
03:36 UTC

Guam US National Weather Service Direct Broadcast Antenna

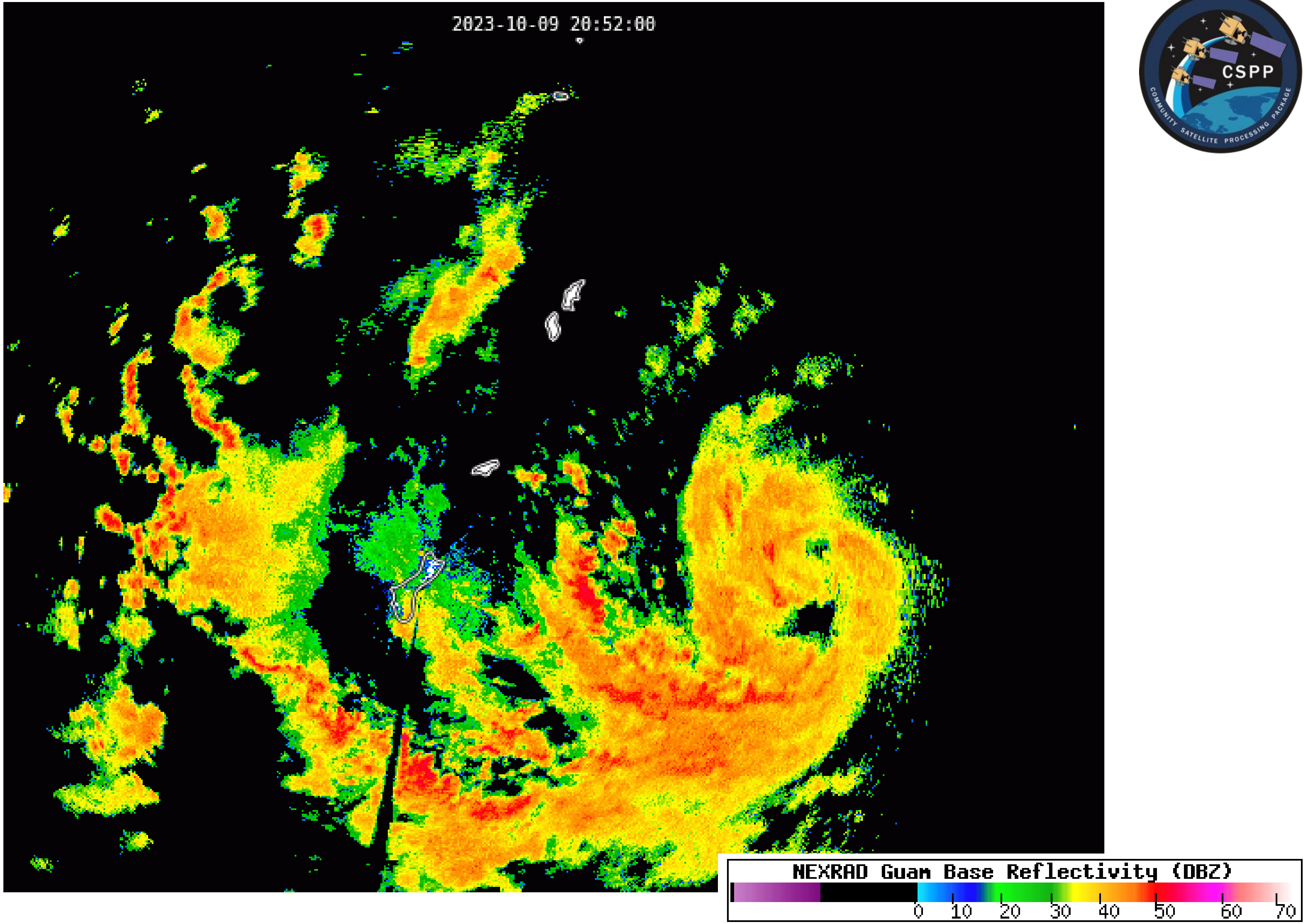
Typhoon Bolaven



Guam
US National
Weather Service
Radar

9-10 October 2023

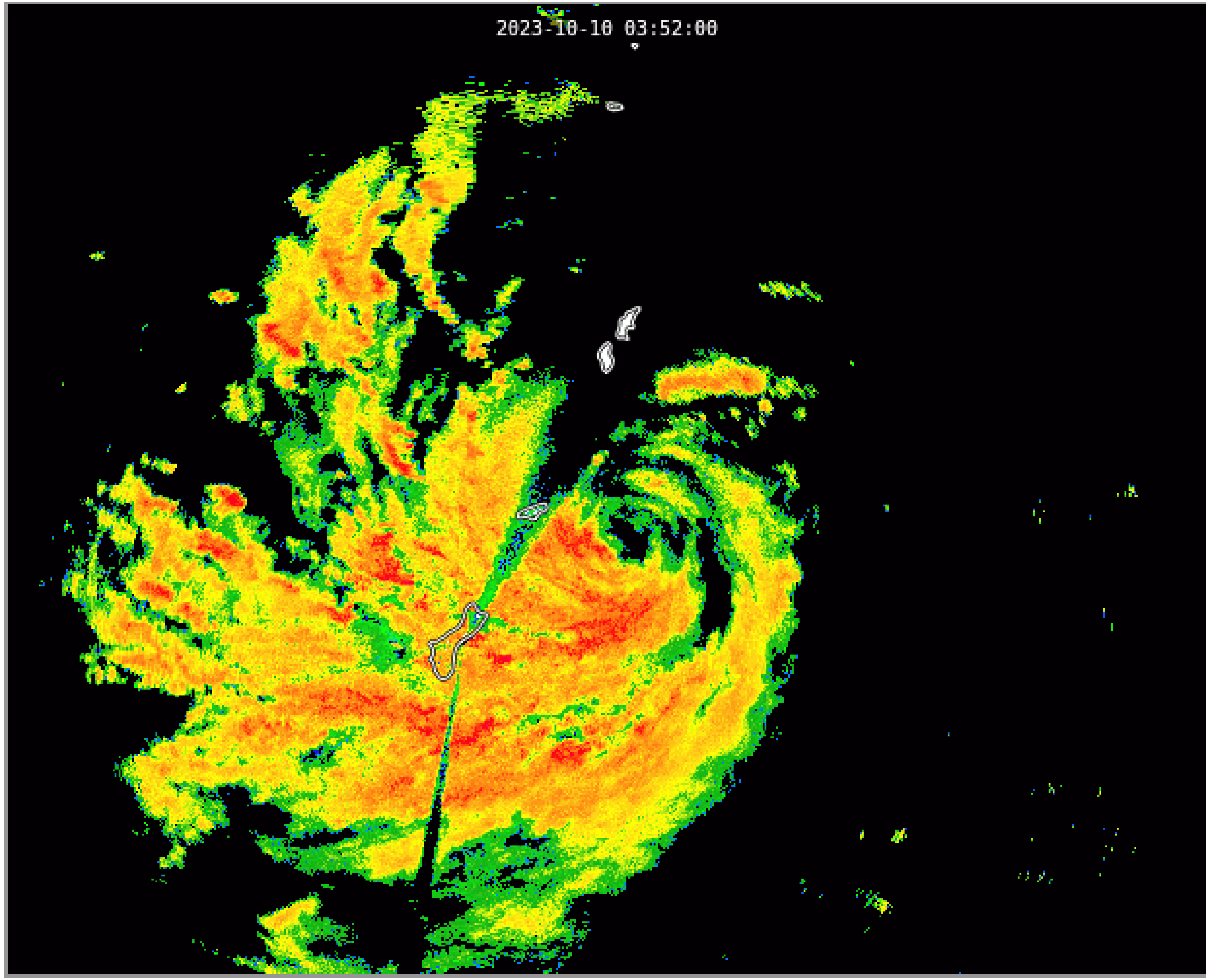
Typhoon Bolaven



Guam
US National
Weather Service
Radar

03:52 UTC
10 October 2023

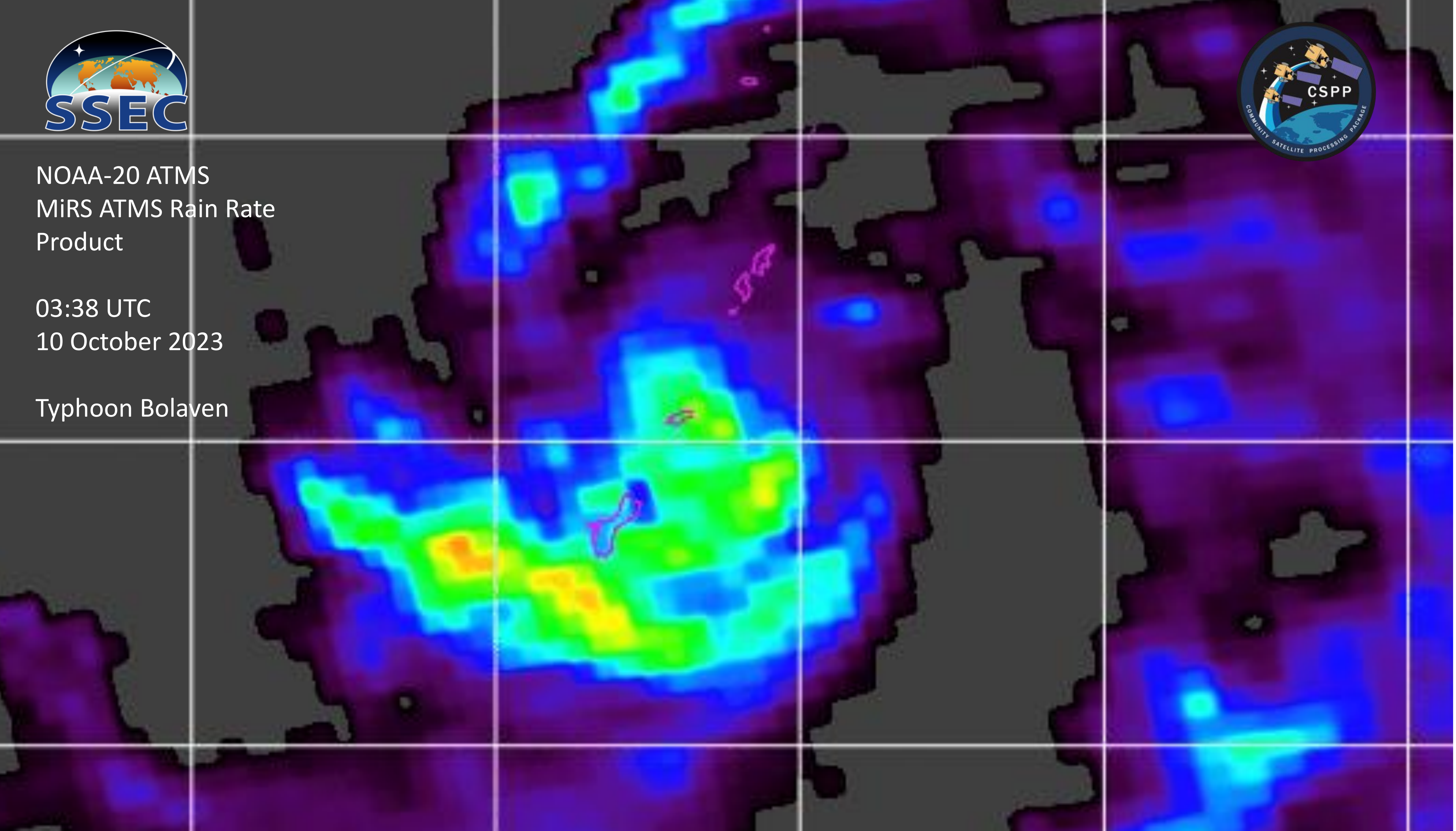
Typhoon Bolaven

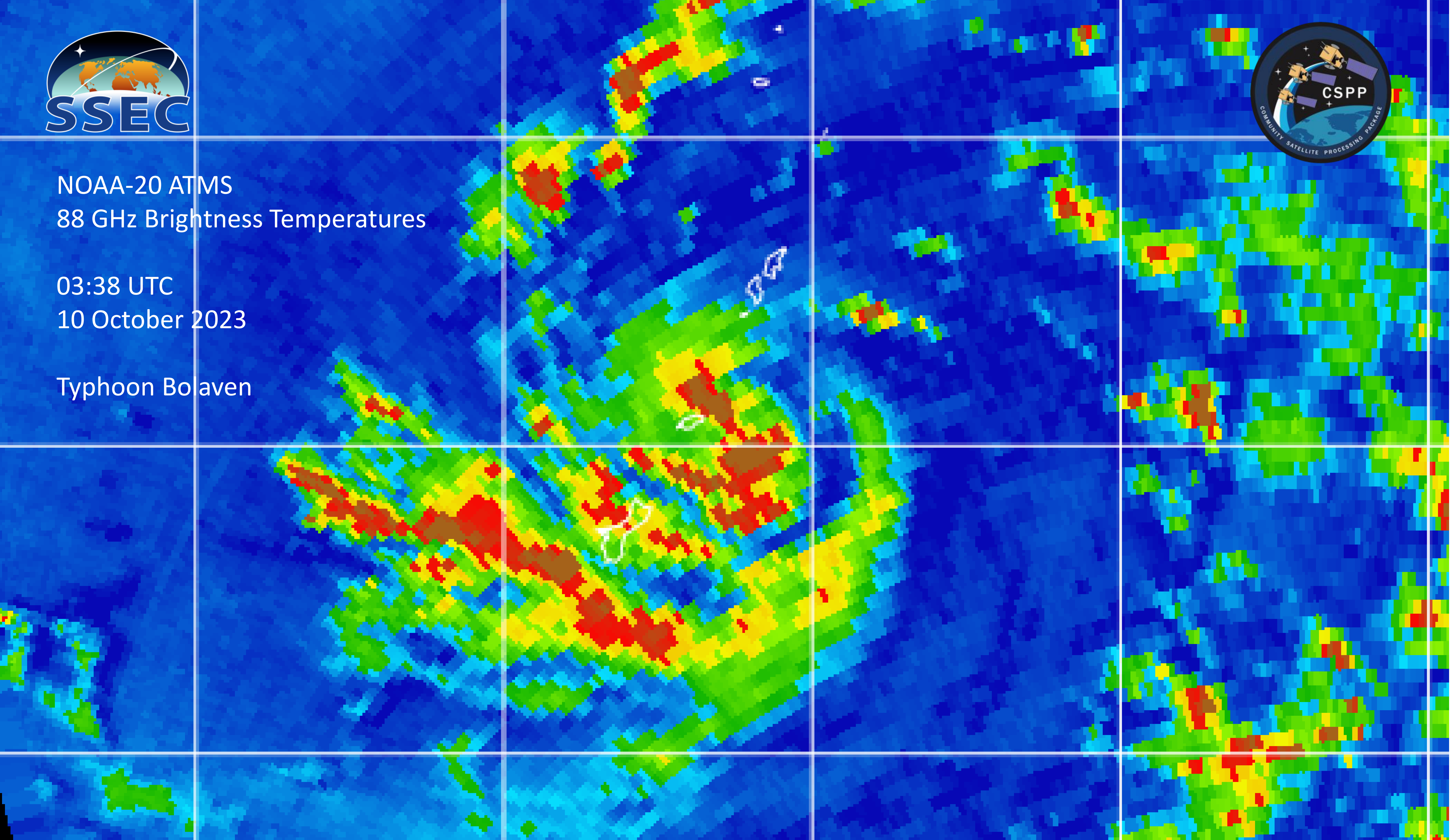


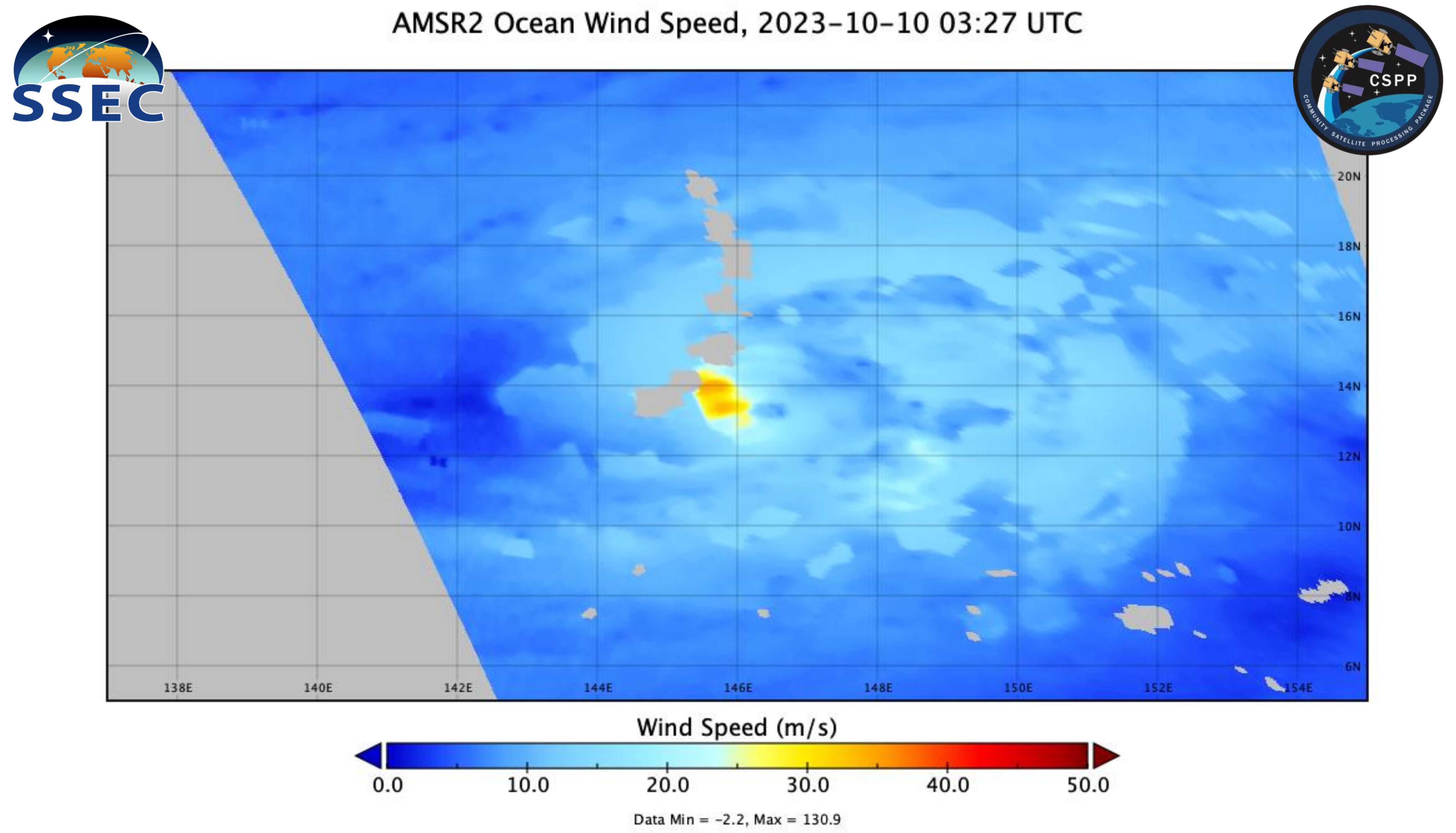
NOAA-20 ATMS
MiRS ATMS Rain Rate Product

03:38 UTC
10 October 2023

Typhoon Bolaven

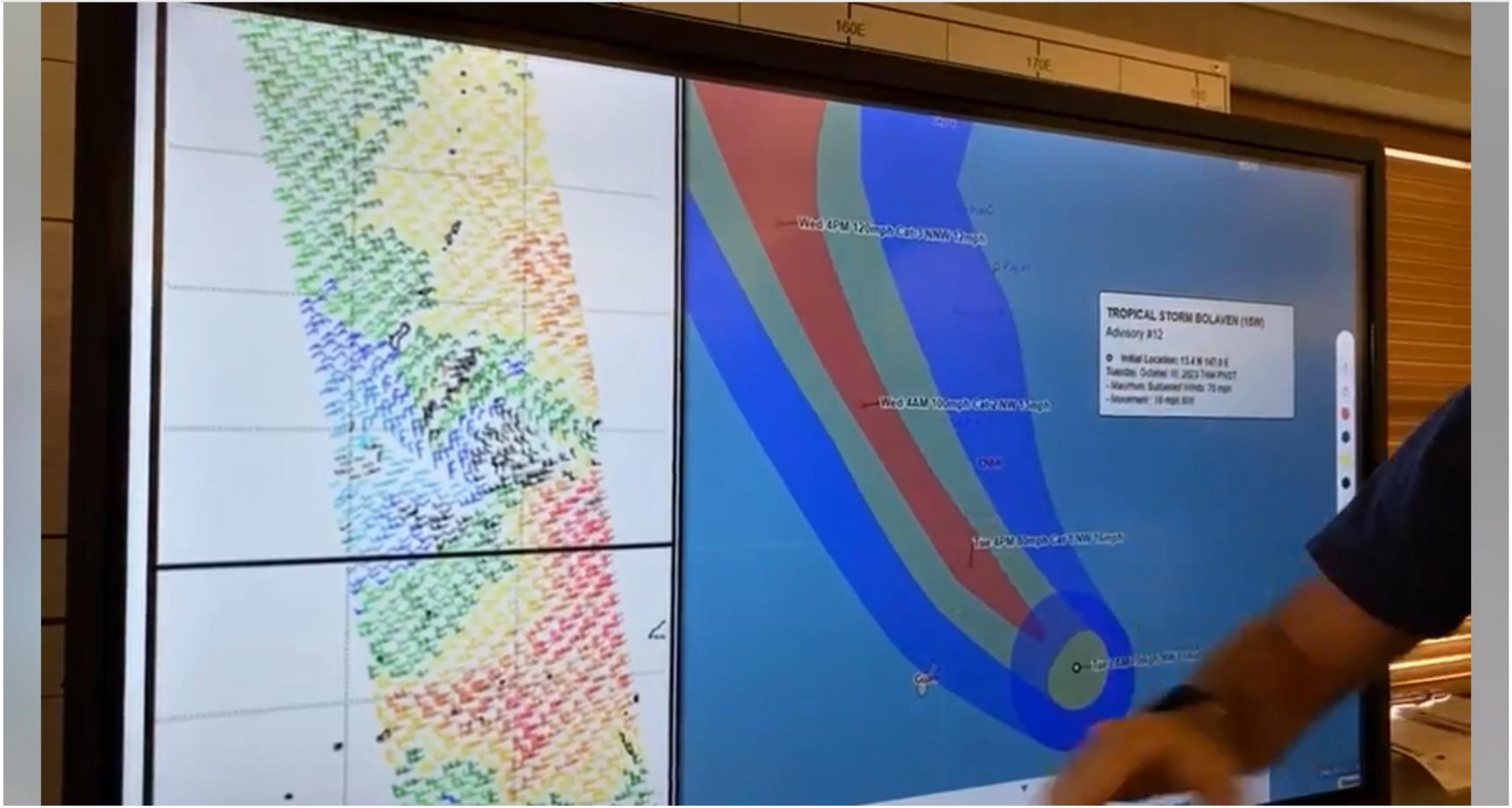



SSEC
CSPP
COMMUNITY SATELLITE PROCESSING PACKAGE
NOAA-20 ATMS
88 GHz Brightness Temperatures
03:38 UTC
10 October 2023
Typhoon Bolaven



AMSR2 Ocean Wind Speed, 2023-10-10 03:27 UTC
SSEC
CSPP
COMMUNITY SATELLITE PROCESSING PACKAGE
20N
18N
16N
14N
12N
10N
8N
6N
138E
140E
142E
144E
146E
148E
150E
152E
154E
Wind Speed (m/s)
0.0
10.0
20.0
30.0
40.0
50.0
Data Min = -2.2, Max = 130.9

Can Polar Orbiter Data Be Useful to Operational Forecasters?



LIVE from NWS Guam 8:30 am ChST - 10 October 2023 Tropical Storm within radar range of the Marianas. Likely to pass through the CNMI as a typhoon late...

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Questions?

kathy.strabala@ssec.wisc.edu