Current & Near Future LEO Microwave Satellite Sensors

Jeff Hawkins[1]

[Derrick Herndon, Chris Velden, Tony Wimmers, Tim Olander][1], Bill Blackwell[2], Joe Munchak[3] Christopher Jackson[4], Shannon Brown[5], Thomas Meissner[6], Paul Chang[7], Mark Bourassa[8]

[1] U. of Wisconsin/CIMSS, [2]MIT-LL, [3]Tomorrow.io, [4]Global Science and Technology Inc., [5]NASA/JPL, [6]Remote Sensing Systems, [7]NOAA NESDIS, [8]FSU-COAPS

Interdepartmental Hurricane Conference

March 8, 2023

Near Future Satellite Missions Relevant to TC Analysis

Thanks:

- **WMO OSCAR satellite data base, excellent resource: https://space.oscar.wmo.int/spacecapabilities**
- **Fly-out charts: graphically see the continuity or lack thereof for each set of TC monitoring sensors**
- **All charts can be outdated the moment they are created!!**

Operational
Ceased ops

Expected Ops
Planned Ops

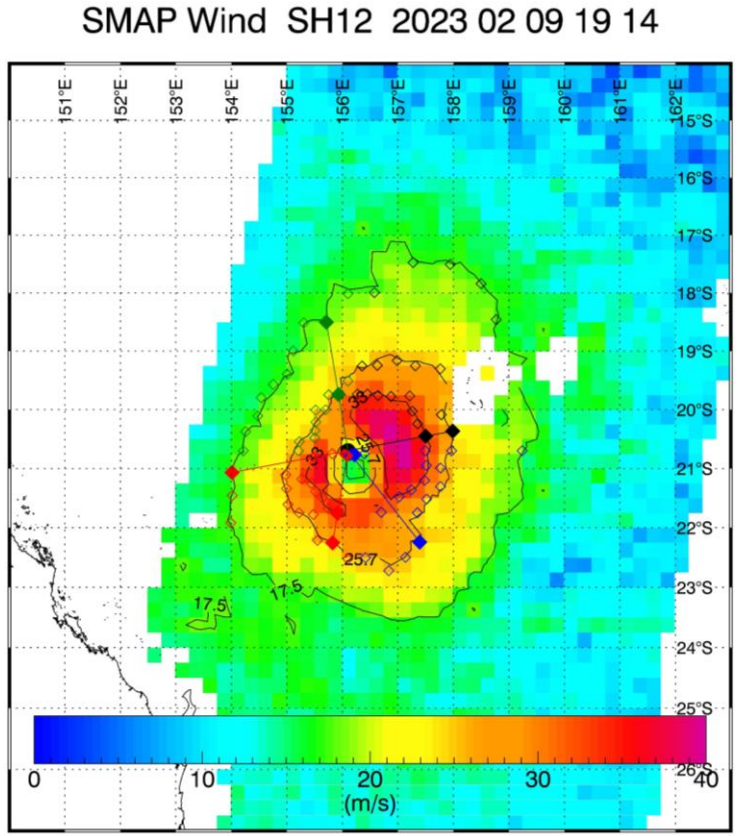
SMAP/SMOS Passive Microwave Imagers

L-band (1.4 GHz) microwave imagers on LEO sats with huge antenna

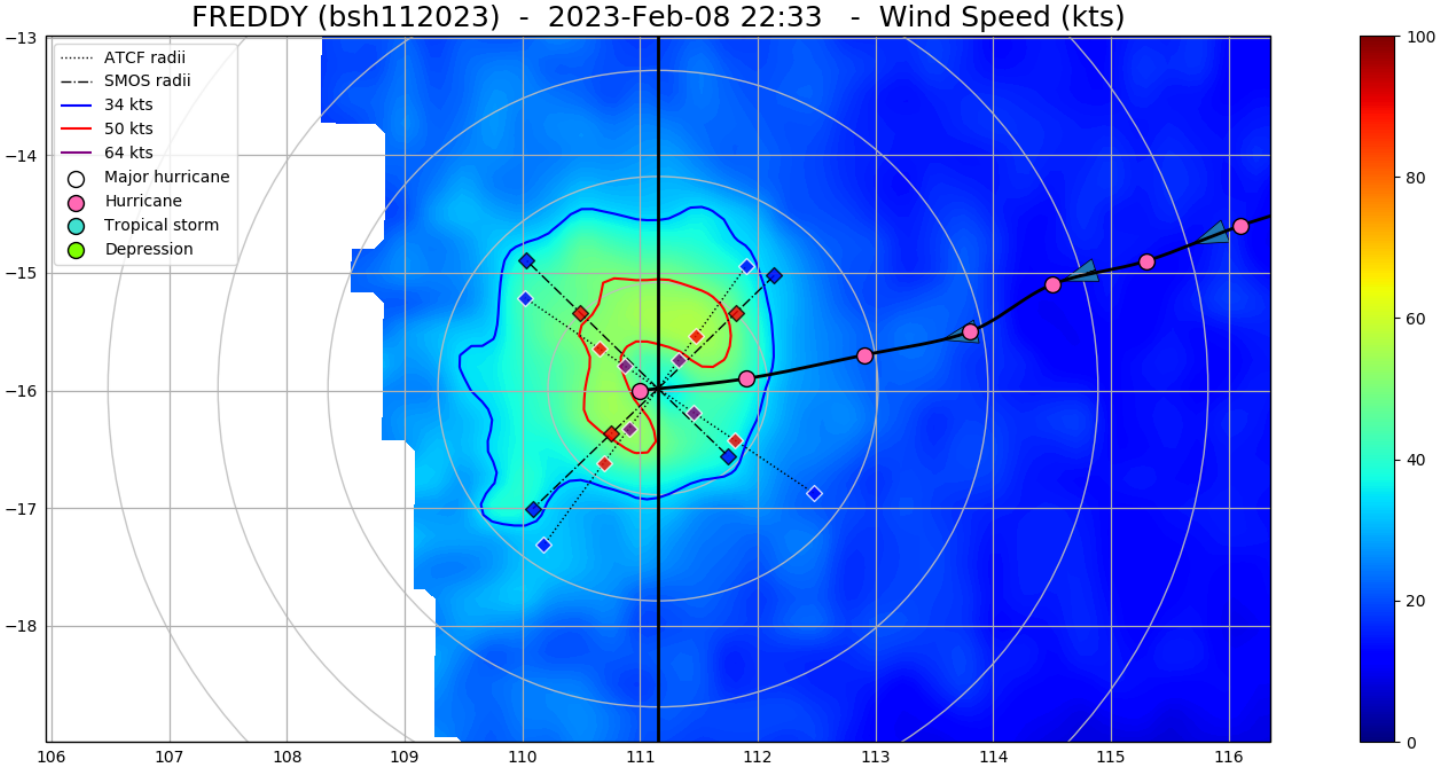
SMAP: Soil Moisture Active Passive sensor

SMOS: Soil Moisture and Ocean Salinity sensor

- 1.4 GHz not impacted by rain even within TC conditions

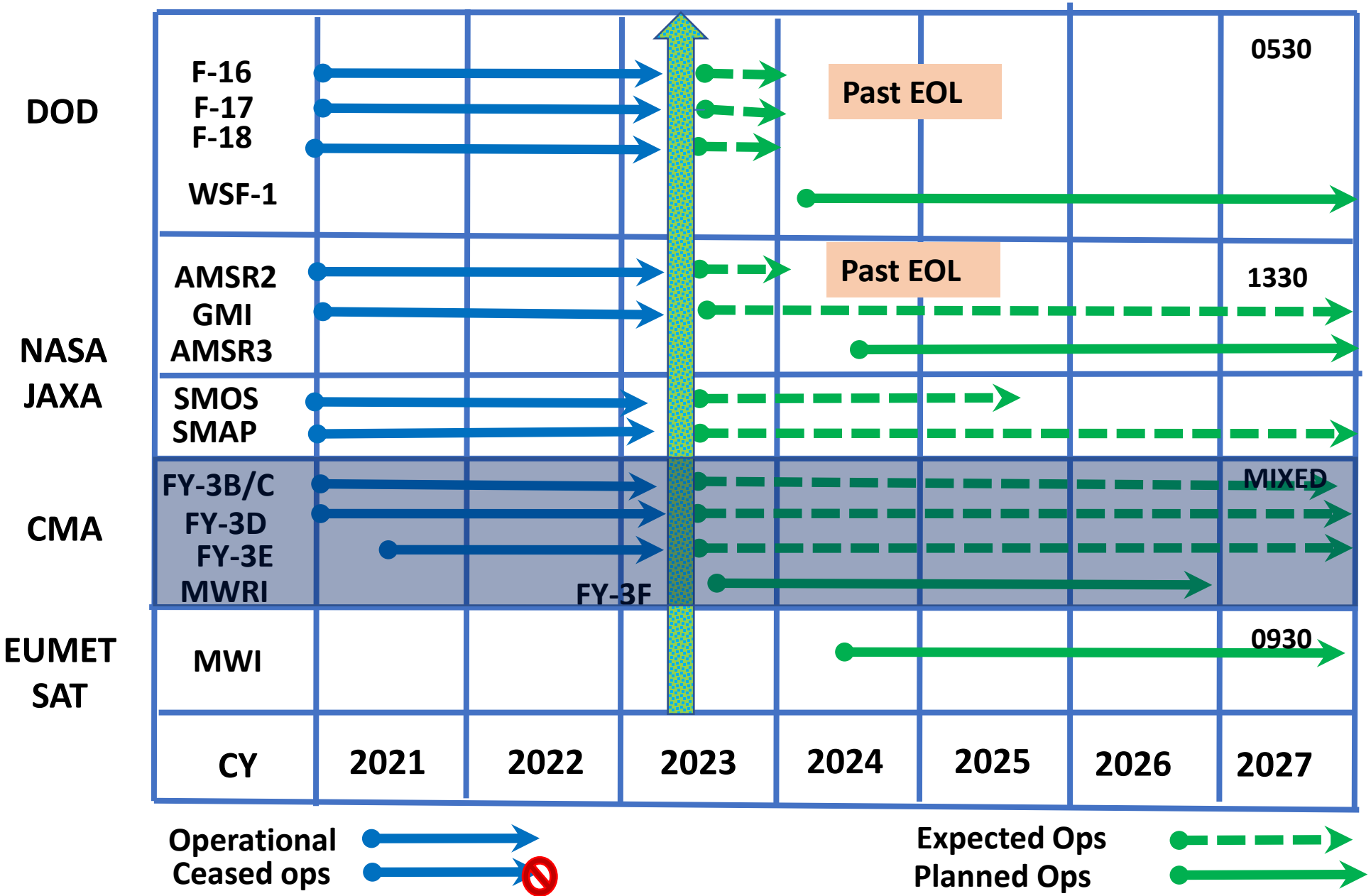


Courtesy: Remote Sensing Systems



Courtesy: ESA Data Portal

Current/Future Satellite Passive Microwave Imagers



Polarimetric, but lacks 6 GHz

Two C and X-band freq., both dual pol

Unreliable for NRT ops

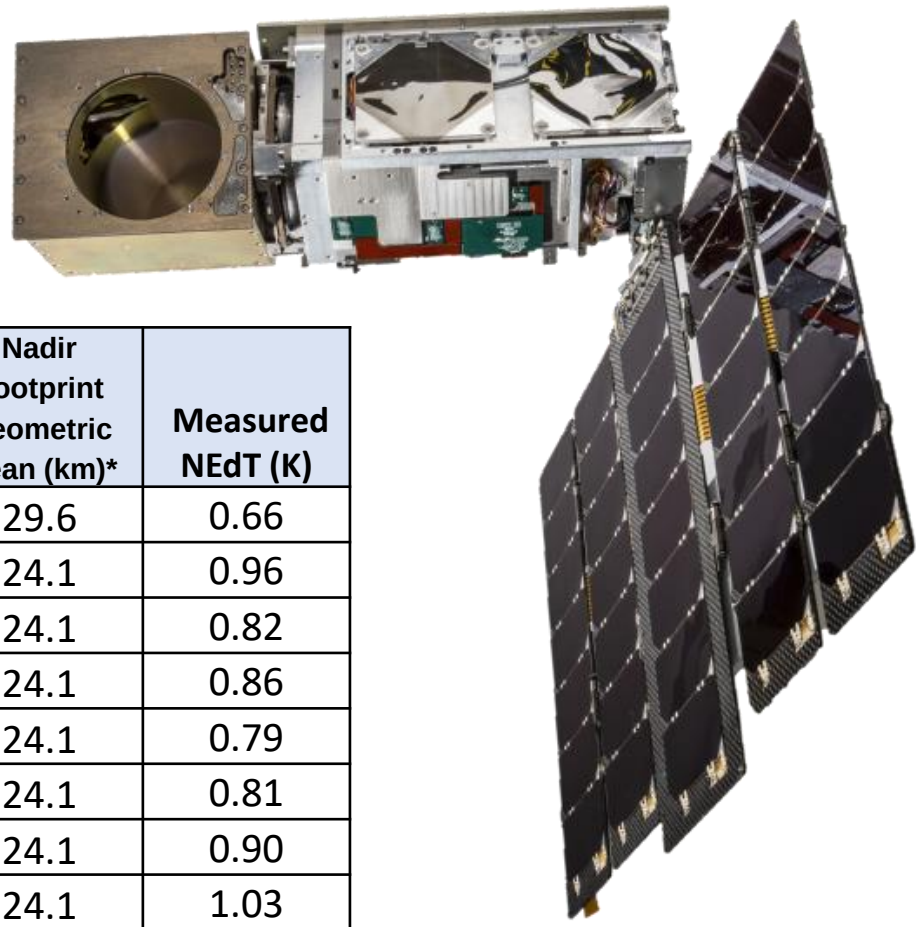
Lacks 6 & 10 GHz

TROPICS Satellite ("CubeSat") (TROPICS Millimeter-wave Sounder = TMS)

- 3U CubeSat: 10 cm x 10 cm x 36 cm
- Mass: 5.4 kg; Power: 15 W (payload is 3W)
- Blue Canyon Technologies bus
- LL passive millimeter-wave payload
- Innoflight SCR-100 S-band radio

TMS Channel	Central frequency	ATMS Channel	MHS Channel	*MWHS-2 Channel*
1	91.655±1.4 GHz	88.2 GHz	89.0 GHz	*89.0 GHz*
2	114.50 GHz	-	-	*118.75±5.0*
3	115.95 GHz	-	-	*118.75±3.0*
4	116.65 GHz	-	-	*118.75±2.5*
5	117.25 GHz	-	-	*118.75±1.1*
6	117.80 GHz	-	-	*118.75±0.8*
7	118.24 GHz	-	-	*118.75±0.3*
8	118.58 GHz	-	-	*118.75±0.2*
9	184.41 GHz	183.31±1.0	183.31±1.0	*183±1.0*
10	186.51 GHz	183.31±3.0	183.31±3.0	*183±3.0*
11	190.31 GHz	183.31±7.0	190.31	*183±7.0*
12	204.8 GHz	-	-	-

Beamwidth (degrees) Down/Cross	Nadir Footprint Geometric Mean (km)*	Measured NEdT (K)
3.0/3.17	29.6	0.66
2.4/2.62	24.1	0.96
2.4/2.62	24.1	0.82
2.4/2.62	24.1	0.86
2.4/2.62	24.1	0.79
2.4/2.62	24.1	0.81
2.4/2.62	24.1	0.90
2.4/2.62	24.1	1.03
1.5/1.87	16.9	0.58
1.5/1.87	16.9	0.55
1.5/1.87	16.9	0.53
1.35/1.76	15.2	0.52

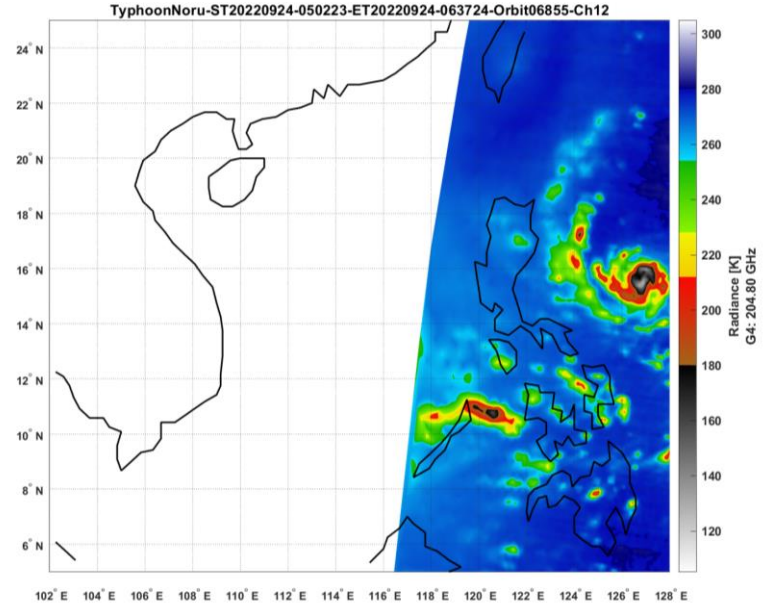


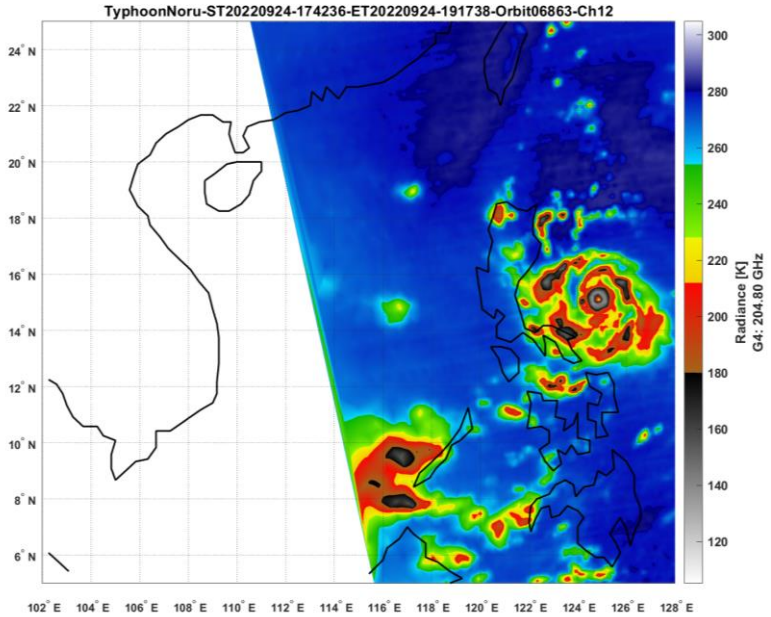
Courtesy: Blackwell MIT-LL

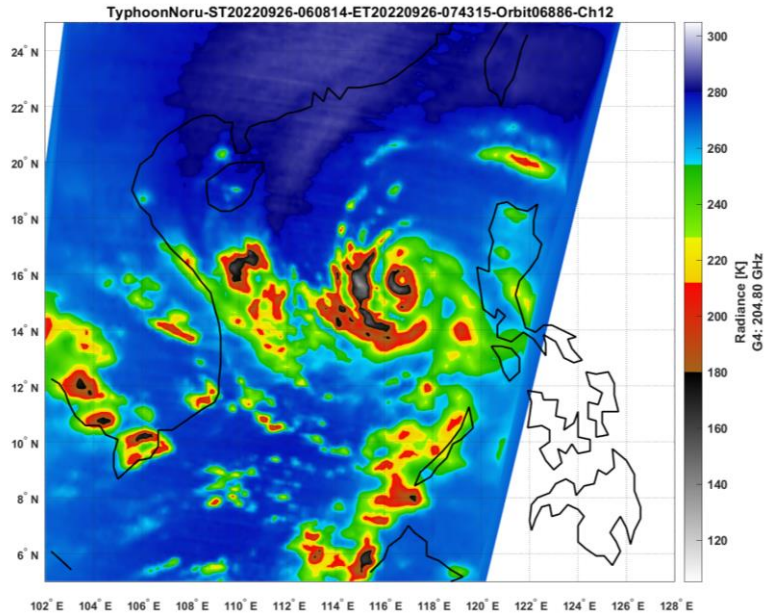
Typhoon Noru

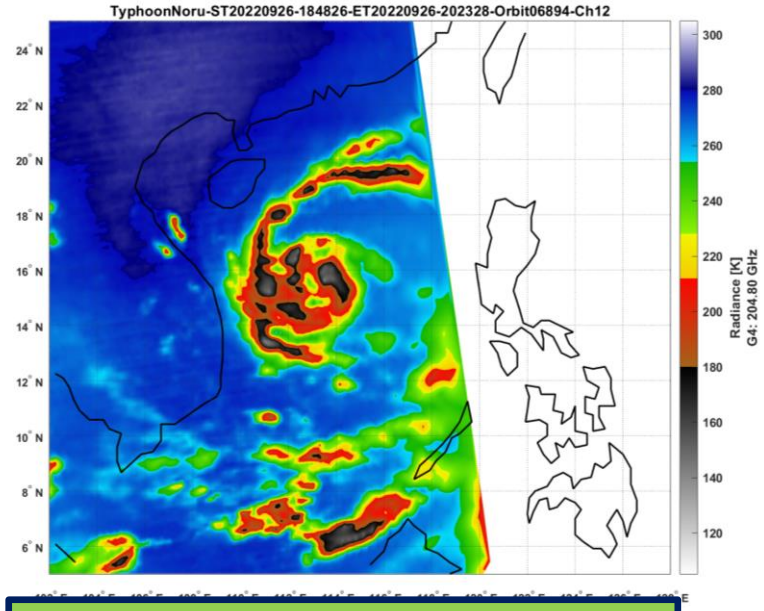
TROPICS PATHFINDER

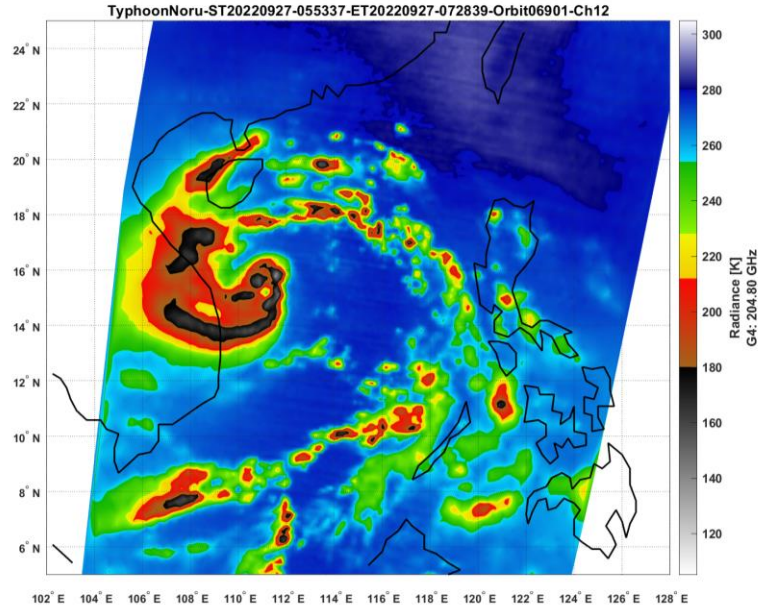
204 GHz

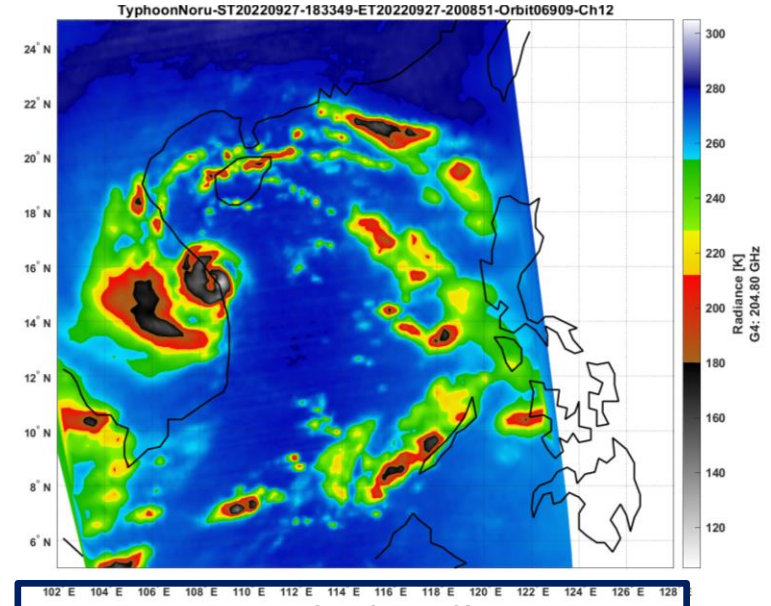












ARCHER available

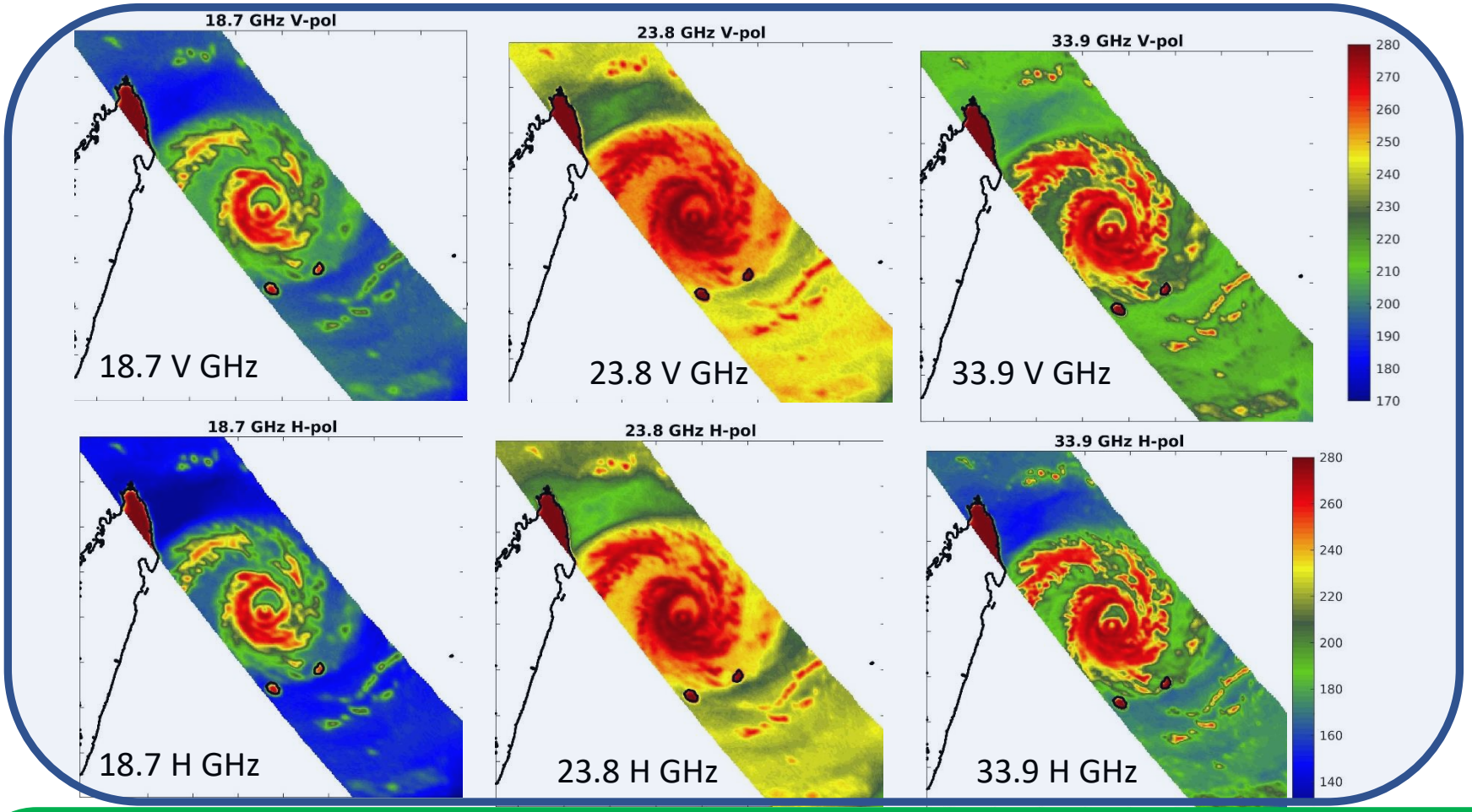
Courtesy: Blackwell MIT-LL

Tropical Cyclone Emnati

Feb 20, 2022

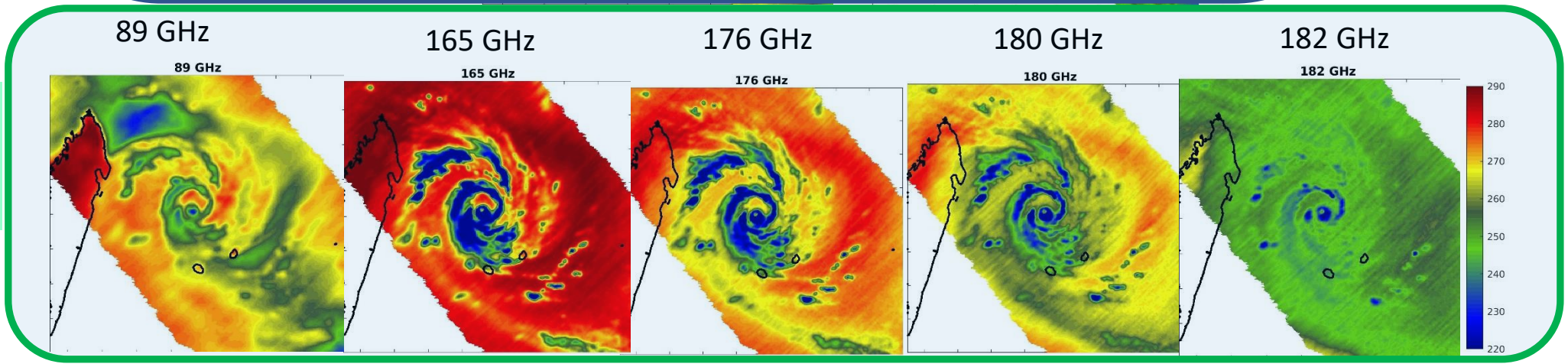
Off the coast of Madagascar

Compact Ocean Wind Vector Radiometer (COWVR)



Courtesy: Shannon Brown: JPL

TEMPTEST-D2 W & G-Band

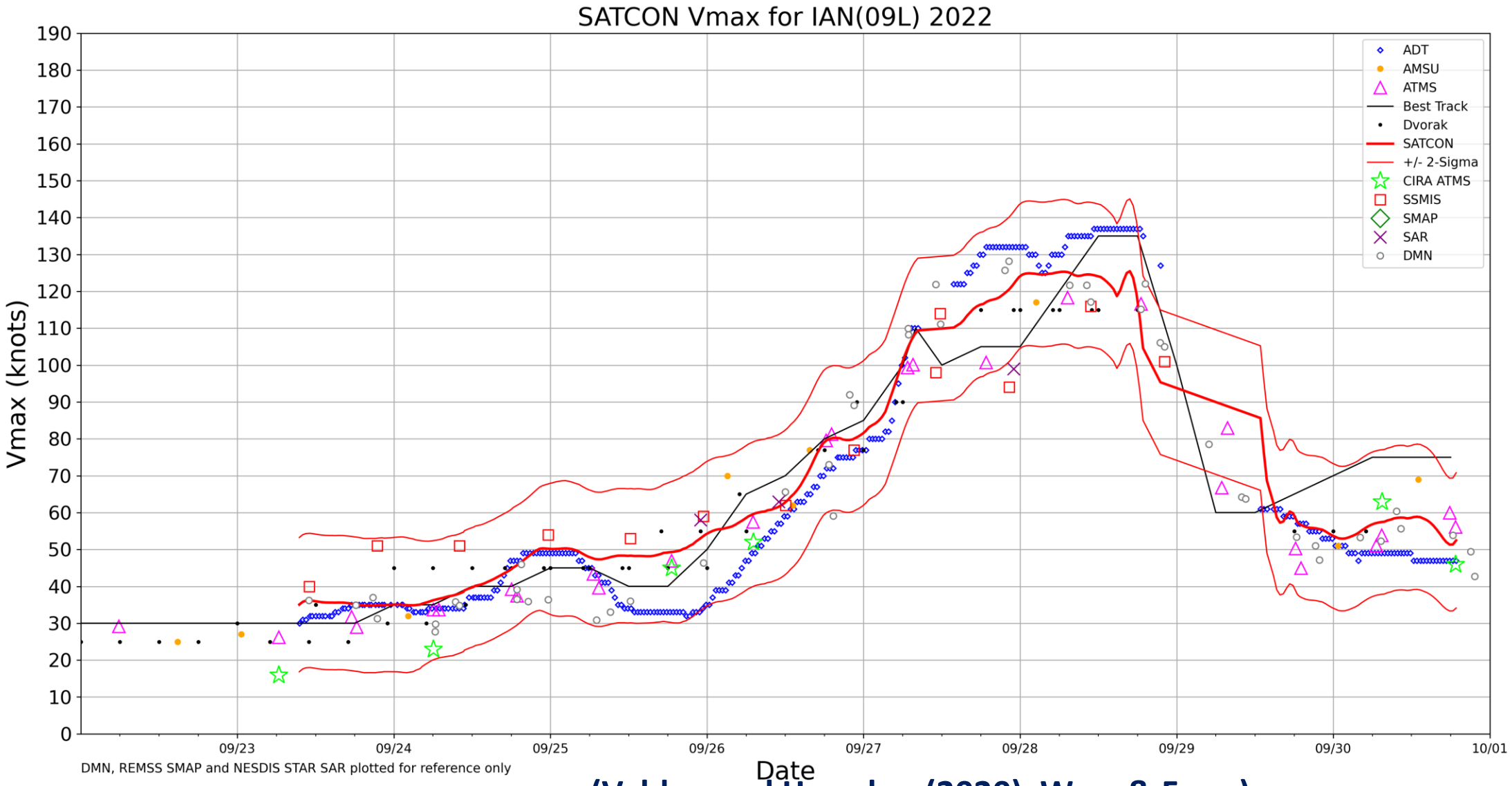


Current/Future Satellite Passive Microwave Imagers

Summary:

- Many legacy sensors (DMSP) past expected operational life, thus very poor coverage is possible in short term (1-2 years)
- EUMETSAT SG-B1 MWI welcome addition, but no 6 & 10 GHz
- AMSR3 will enable improved TC surface wind speeds (dual pol X & C)
- WSF-1/2: wind vectors, but not as good as WindSat's in TCs
- Future highly dependent on capabilities/cost of SmallSats/CubeSats
  - TROPICS, COWVR, and TEMPEST follow-ons like Tomorrow.io?

TC Satellite-Derived Intensity Estimates

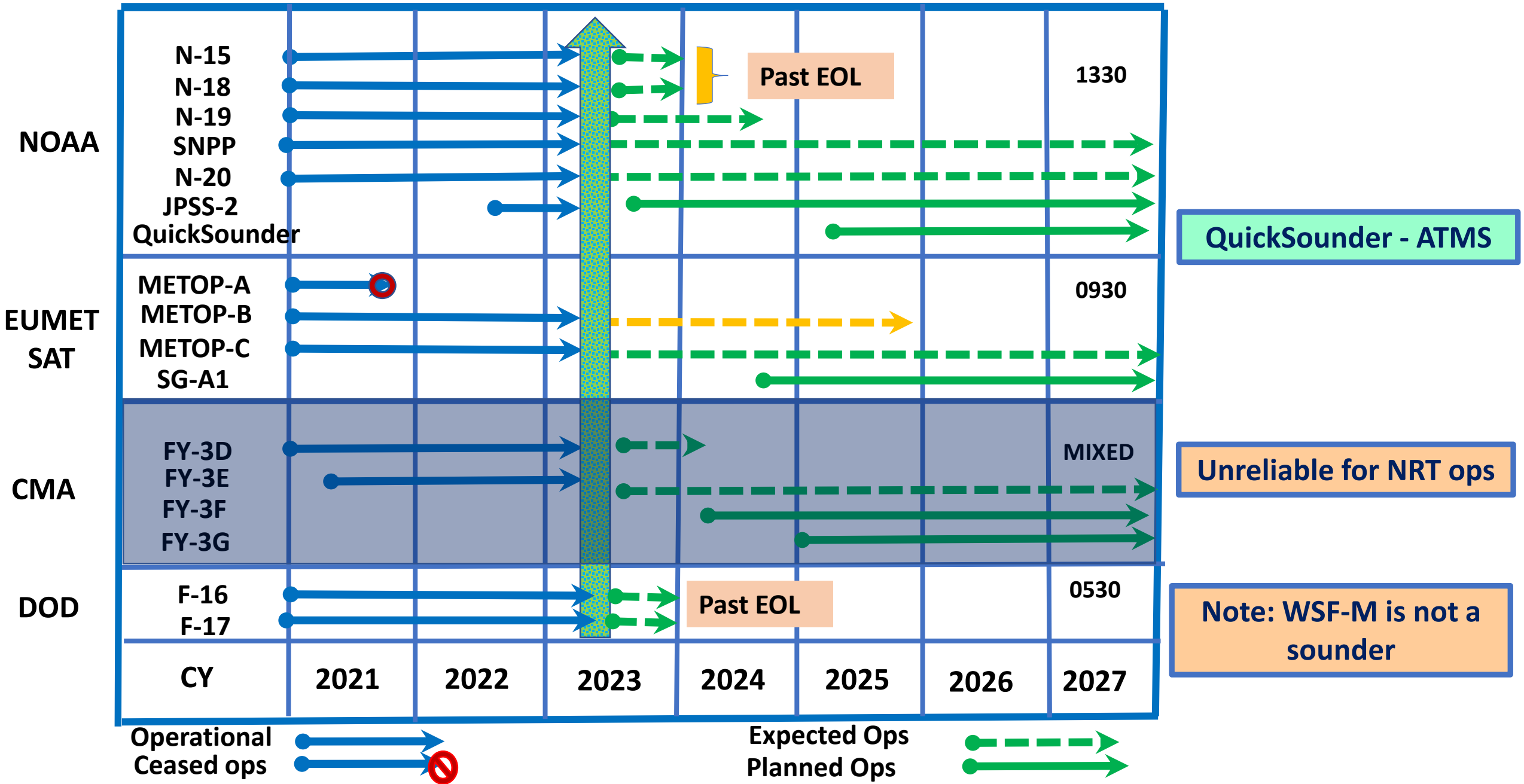


(Velden and Herndon (2020), Wea. & Fore.)

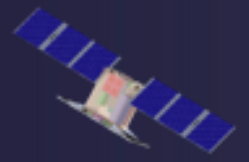
https://tropic.ssec.wisc.edu/real-time/satcon/202209L.html

Courtesy: UW/CIMSS

Current/Future Satellite Microwave Sounders



Tomorrow.io Factsheet Summary

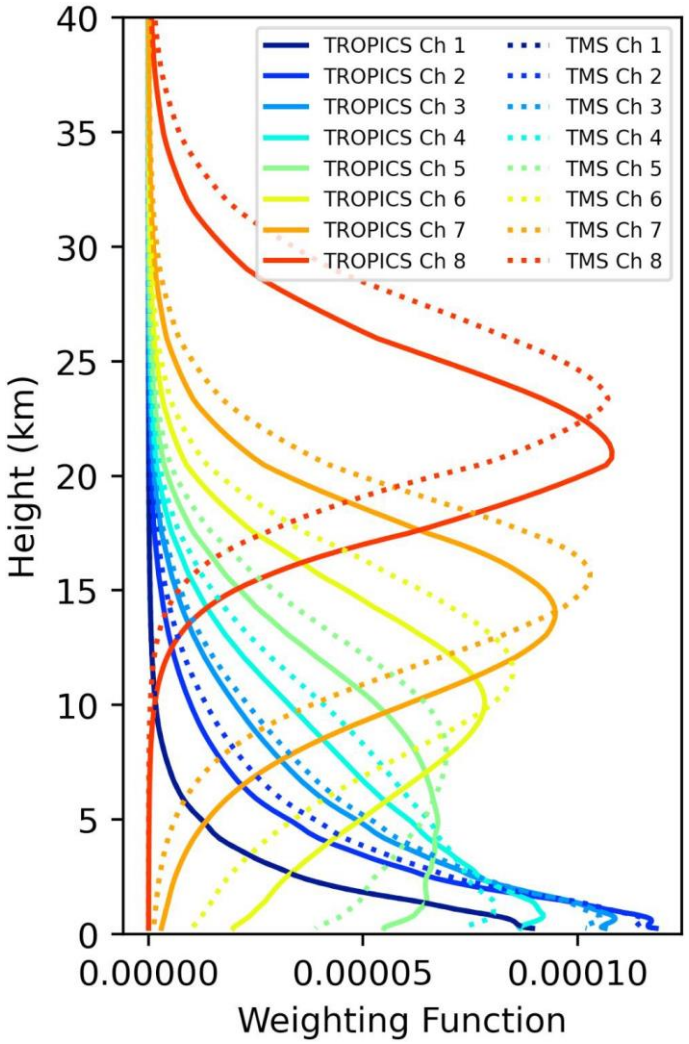
	MW Sounder	Radar
		
# of Satellites	18	8
Naming	Tomorrow S1-S18	Tomorrow R3-10
Size	6U, 12kg	ESPA Grande, 200 kg
Orbits	550 km / SSO+Mid-incl.	550 km / SSO+Mid-incl.
Design Lifespan	3yrs	5yrs
Instrument Type	Passive MW Radiometer	Ka-Band Software Defined Radar
Frequency	91-204 GHz	35.5-36 GHz
Horizontal Resolution	14 x 17 km @ nadir (204 GHz) 26 x 28 km @ nadir (91 GHz)	5 km x 5 km
Vertical Resolution	N/A	250 m
Swath	2200 km (120° scan)	400 km (40° scan)
Channels/Beams	12+ Channels	~130 Beams
Antenna Size (Area)	78 cm^2	~1.7 m^2
Antenna Type	Cross-track scanning	Cross-track scanning
Sensitivity	N/A	12 dBz
Revisit Rate and Data Latency	Combined Average Revisit Rate of 1 hour over most latitudes, Data Latency <20min	

Courtesy: Joe Munchak – Tomorrow.io

Passband Changes: TROPICS vs Tomorrow Microwave Sounder (TMS)

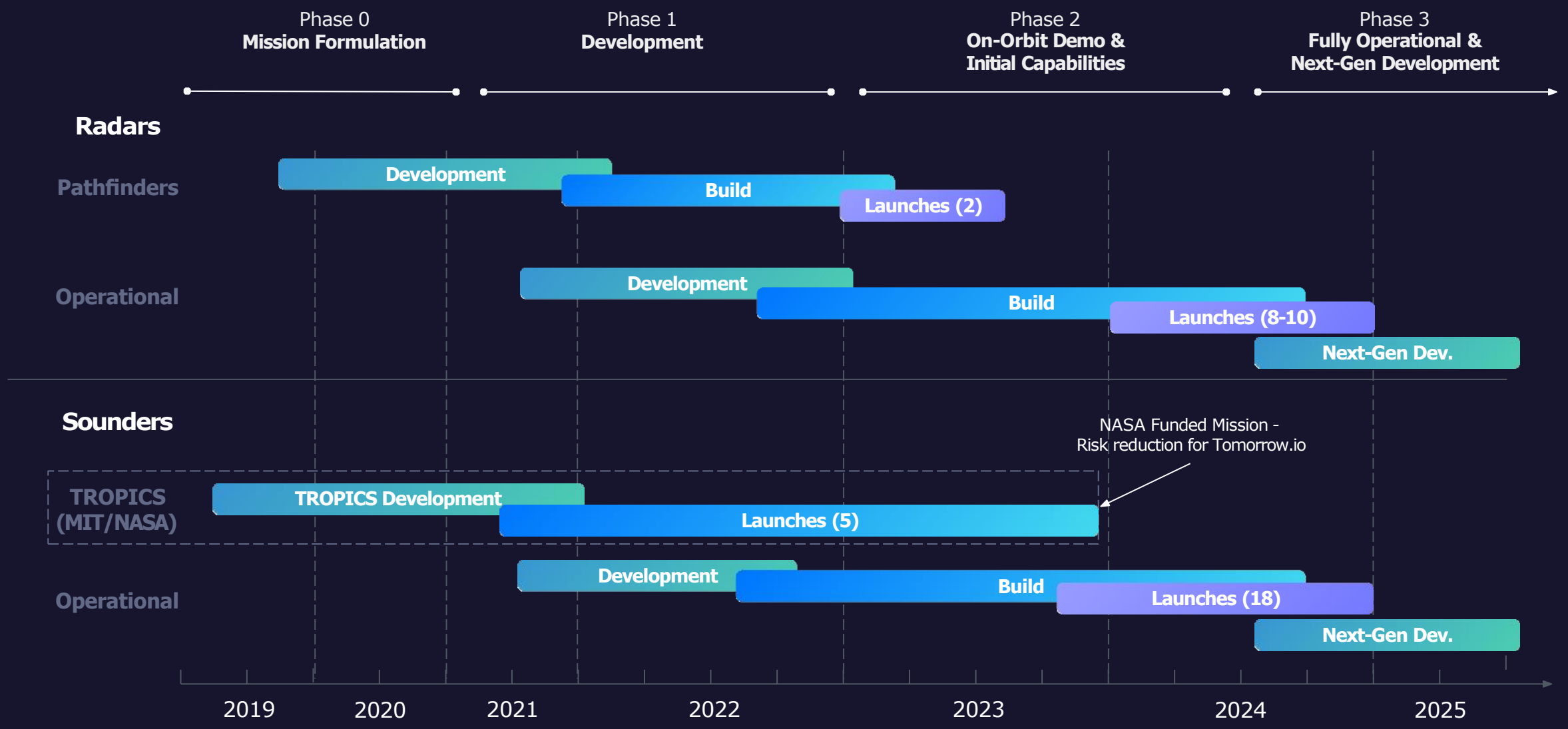
tomorrow.io

Channel	TROPICS Center Freq. (GHz)	TROPICS Bandwidth (GHz)	TROPICS NEDT (K)	TMS Center Freq. (GHz)	TMS Bandwidth (GHz)	TMS NEDT (K)
1	91.65 +/- 1.4	1	0.66	91.65	2	0.27
2	114.5	1	0.96	118.75±3.5	1	0.39
3	115.95	0.8	0.82	118.75±2.625	0.75	0.45
4	116.65	0.6	0.86	118.75±1.875	0.75	0.45
5	117.25	0.6	0.79	118.75±1.25	0.5	0.55
6	117.8	0.5	0.81	118.75±0.75	0.5	0.55
7	118.24	0.38	0.9	118.75±0.375	0.25	0.78
8	118.58	0.3	1.03	118.75±0.125	0.25	0.78
9	184.41	2	0.58	184.41	2	0.45
10	186.51	2	0.55	186.51	2	0.45
11	190.31	2	0.53	190.31	2	0.45
12	204.8	2	0.52	204.8	2	0.45



Courtesy: Joe Munchak – Tomorrow.io

Development and Launch Timeline



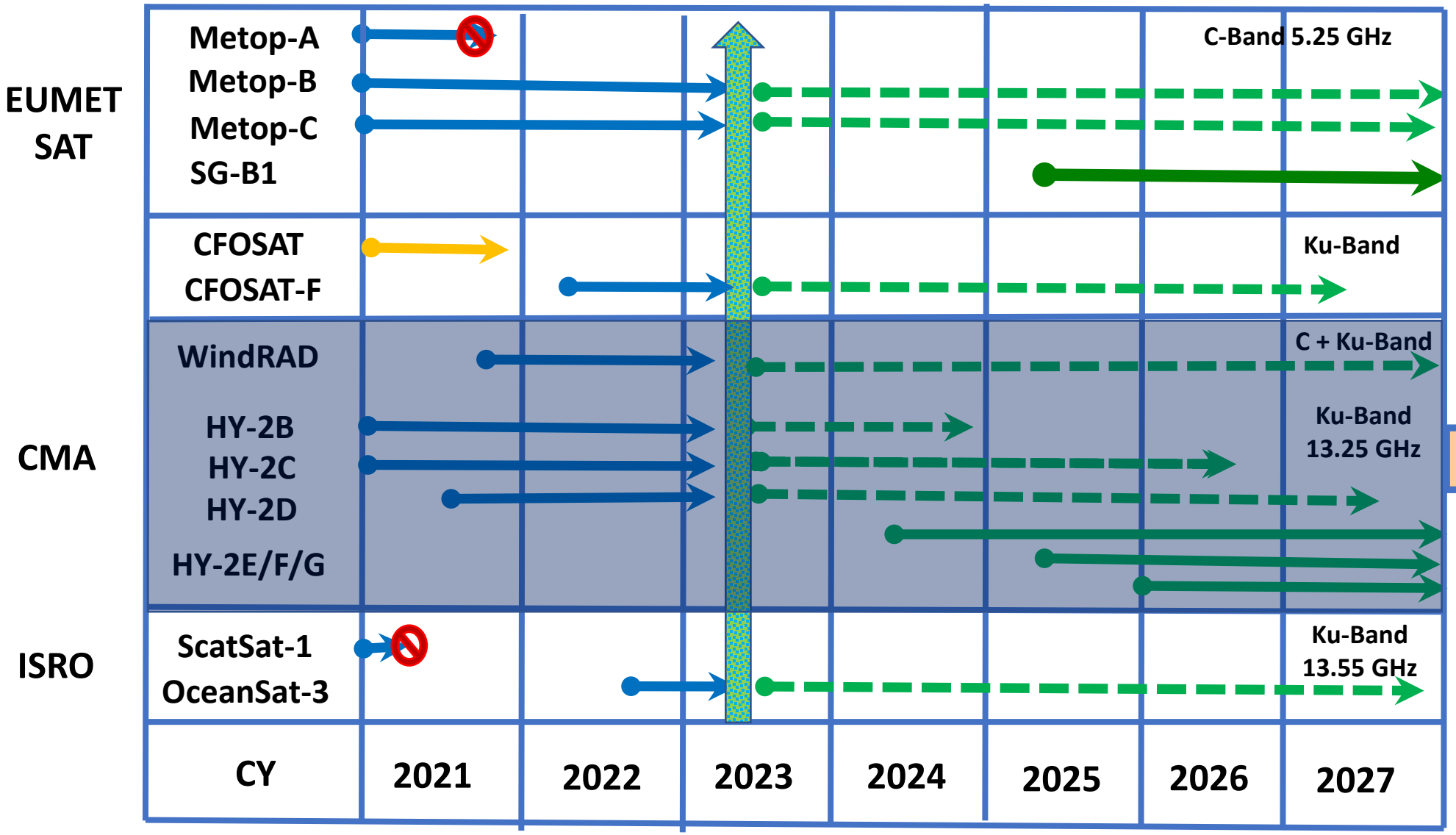
Courtesy: Joe Munchak – Tomorrow.io

Current/Future Satellite Passive Microwave Sounders

Summary:

- SSMIS sounders limping along well past lifespan, WSF-M1 not a sounder
- NOAA's QuickSounder a welcome addition (ATMS-EDU)
- Good continuity with SG-A1
- What will be the role of SmallSats, CubeSats, and DATA BUYS?
    - TROPICS
    - Tomorrow.io [TROPICS 1.1]
    - HYMS [Hyperspectral Microwave Sounder, Spire]

Current/Future Satellite Scatterometers



Cross pol channels raise wind speed saturation from 30 to 50 m/s

Unreliable for NRT ops

NOAA hopes to have NRT winds by summer TC season

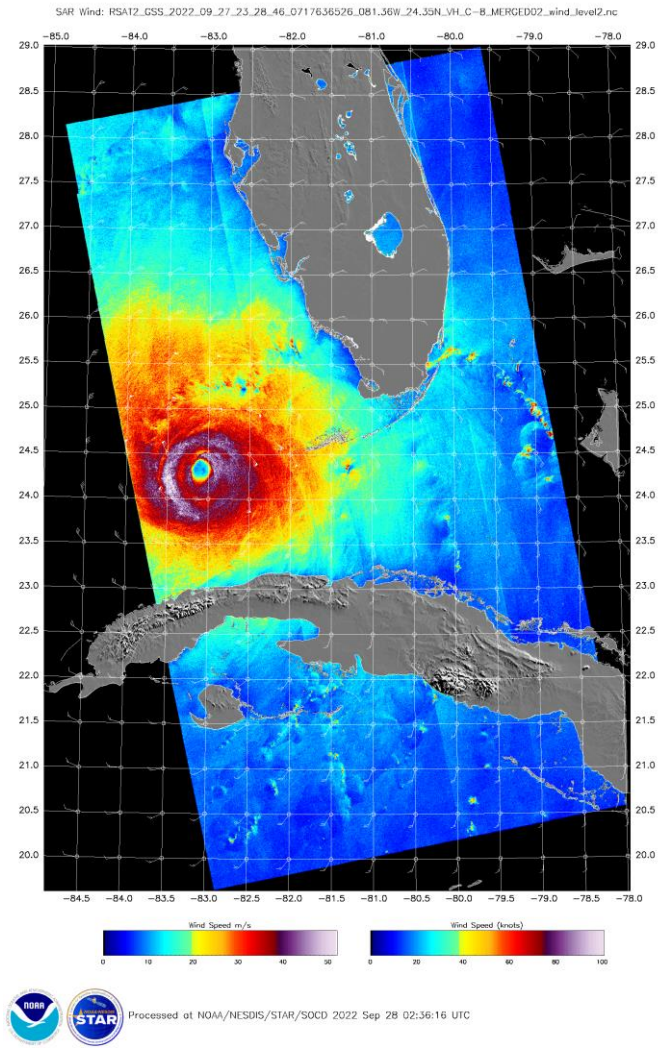
Operational
Ceased ops
Degraded
Expected Ops
Planned Ops

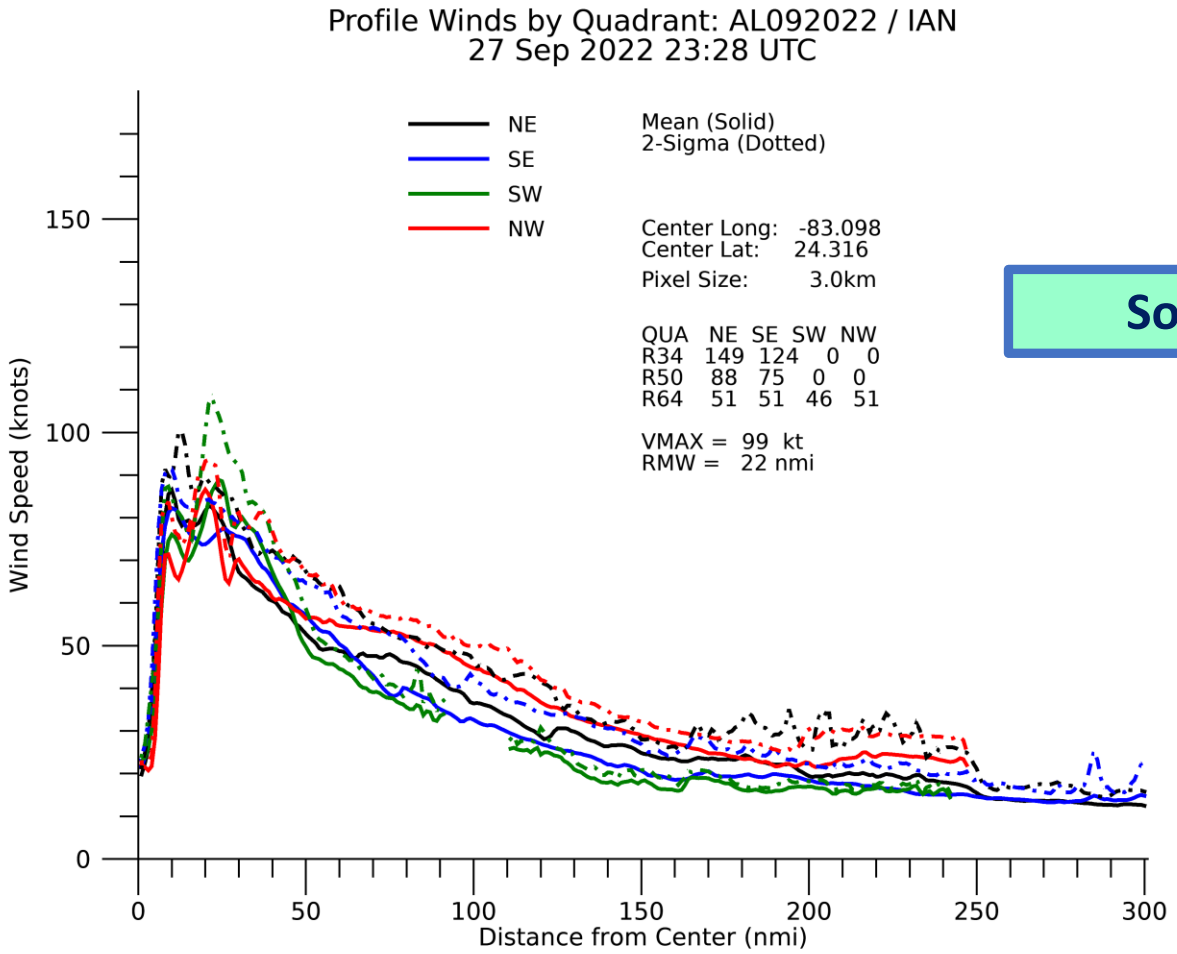
Current/Future Satellite Scatterometers

Summary:

- Poor global TC coverage currently
- Improved EUMETSAT SCA capabilities
- Hope to have Oceansat-3 in time for summer 2023 (Chang)
- Interesting future: SmallSat/CubeSat scatt constellations
  - Care Weather: CubeSat scatt (2025 demo)

Synthetic Aperture Radar (SAR)





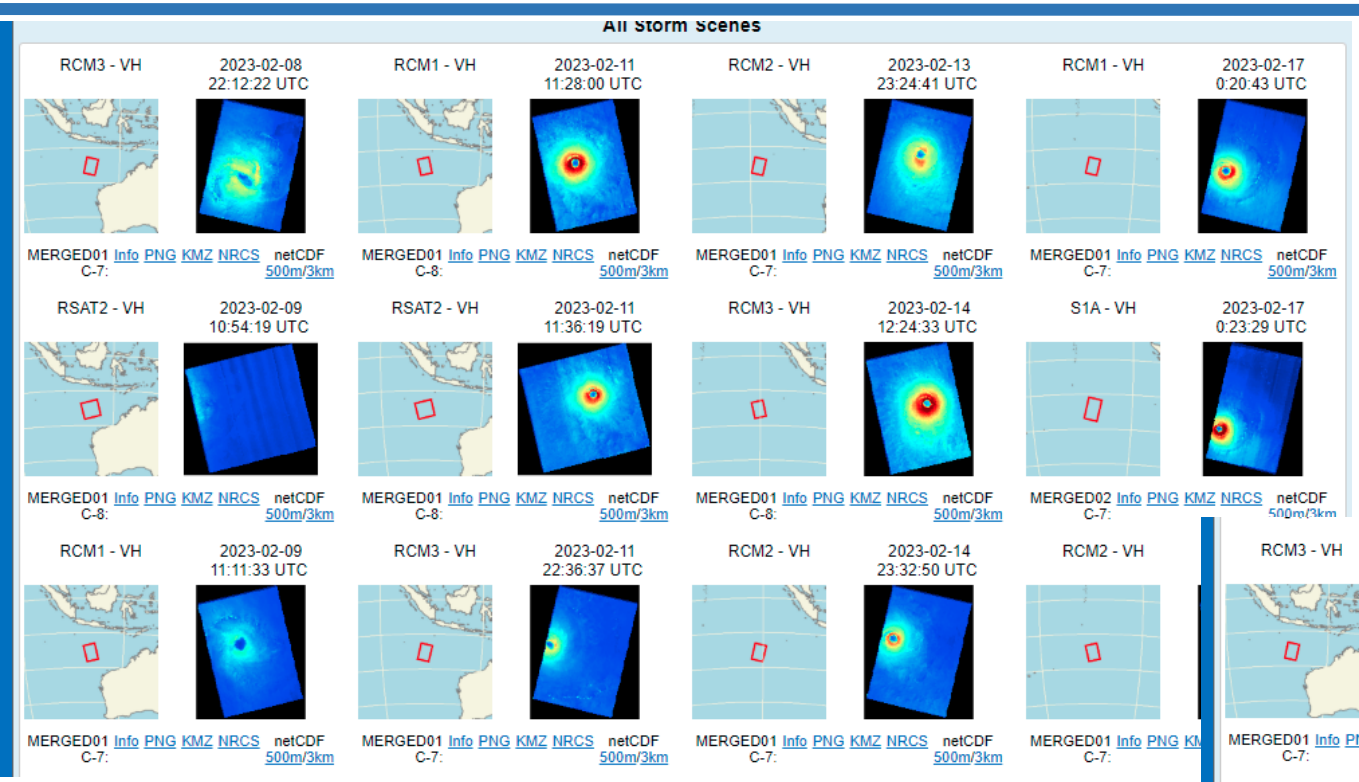
Some Vmax ?

RadarSat2 SAR ocean surface wind speeds for Hurricane Ian on 9-27-2022 @ 23:38Z

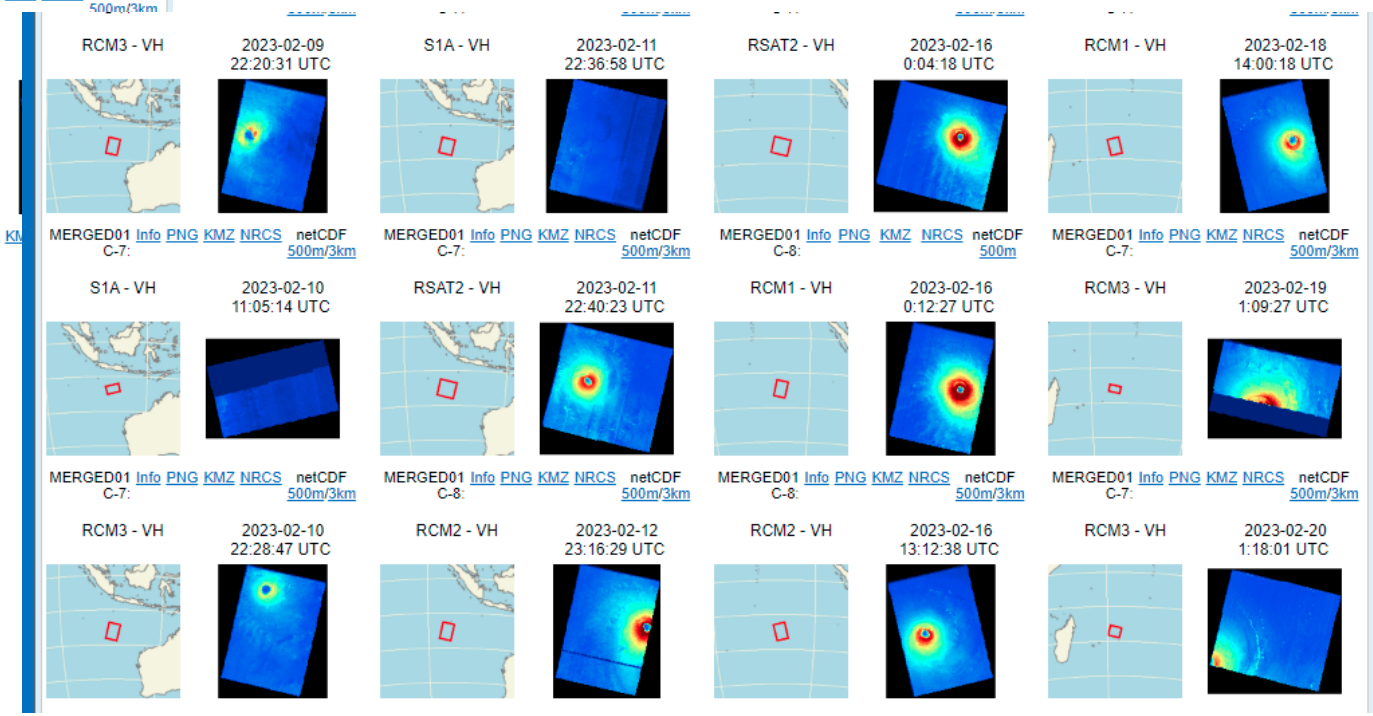
Courtesy: Chris Jackson, NOAA/STAR

https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/tropical/index.html

Synthetic Aperture Radar (SAR)

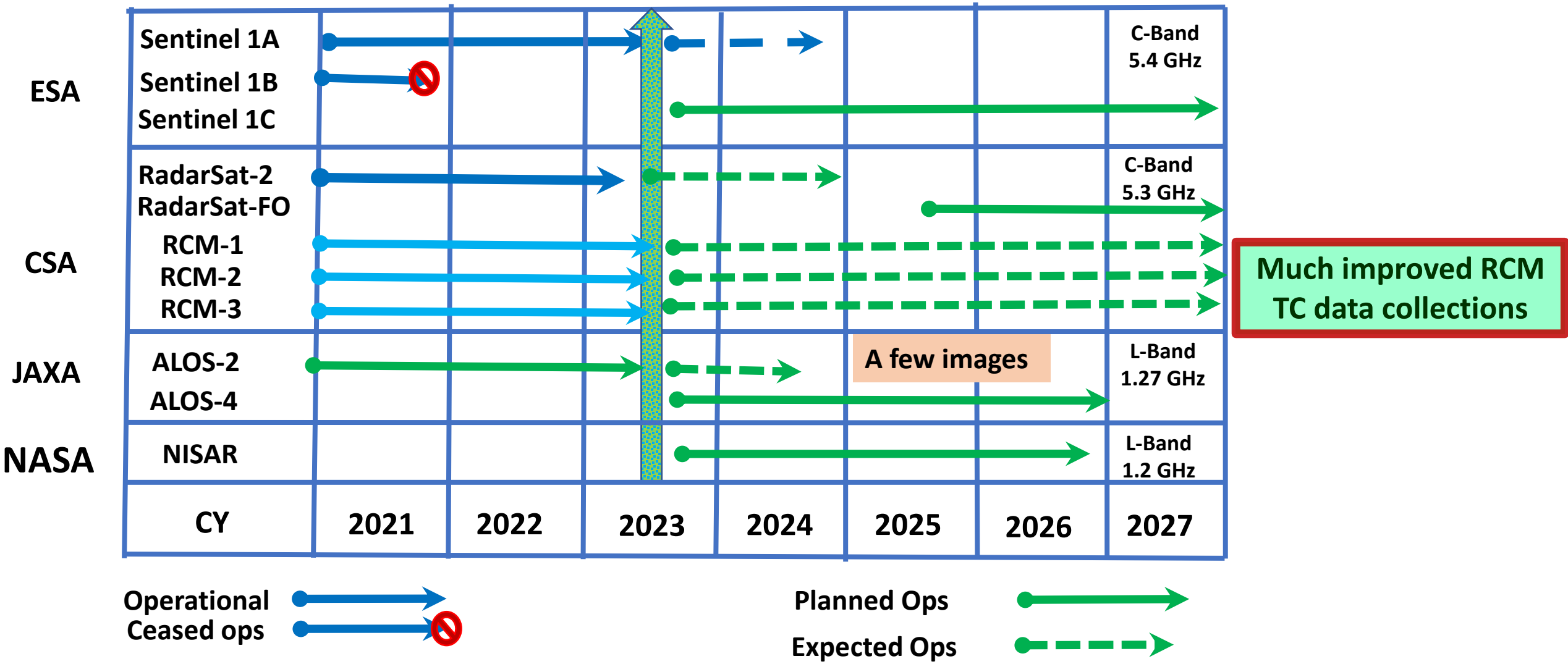


TC Freddy – SHEM 2023



RCM 1, 2, 3
17 out of 24 passes

Current/Future Synthetic Aperture Radars (SAR)



Sentinel 1C, 1D, and Sentinel 1 Next Gen will provide continuity > 2035

Current/Future Synthetic Aperture Radars (SAR)

Summary:

- Poor global TC spatial and temporal coverage currently
- Limited # of SAR data collects per year, but increasing in 2023 with tasking to RCM satellites
- RadarSat-FO will have 700 km swath
- Effort underway to overlap Sentinel 1A & 1C, and Radarsat-2/FO

Future Options

- Legacy sounder builders are designing lower SWaP sensors – Fewer $$

- The SmallSat/CubeSat arena is attracting HUGE $$ (private companies)
- They are on the verge of providing NRL TC remote sensing data sets?
- How will these “data buys” evolve for the global TC warning centers?

- Tomorrow.io plans to launch a constellation of CubeSat radars and microwave sounders [TROPICS 1.1]

- Spire plans to incorporate HYMS on its upgraded CubeSat platforms.

- Care Weather: SmallSat/CubeSat scatterometer (2025?)