

# GEMS2-Amethyst: Current Status, Data Products, and Future Directions at Weather Stream

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# Presentation Overview

- Weather Stream Timeline
- GEMS2-Amethyst
- PyGEMS
- Calibration-Validation and Retrieval activities
- Future efforts at Weather Stream

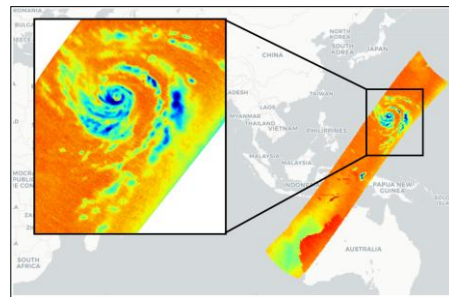
# Weather Stream is a decade in the making with a long track record of success

OMS Founded to deploy  
GEMS mission



2015

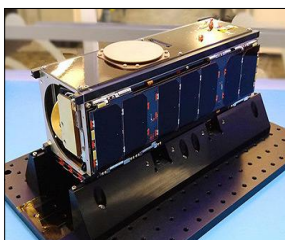
IOD-1 GEMS1 mission  
launches – on orbit for 2 years



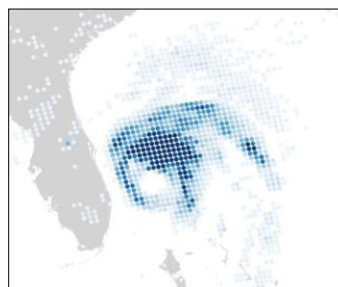
2019 - 2021

2018

IOD-1 GEMS1 instrument  
developed and integrated  
to 3U CubeSat



2022



GEMS2 development begins  
with US Air Force CWDP

GEMS2 first article  
completed



2023

2024

GEMS-PEARL, GEMS-CZ, GEMS-  
CUBIC development started

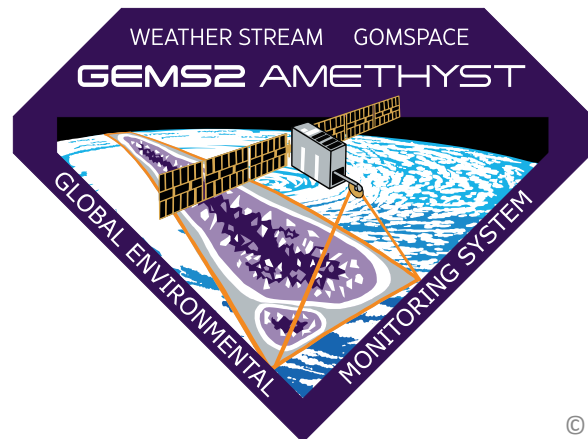
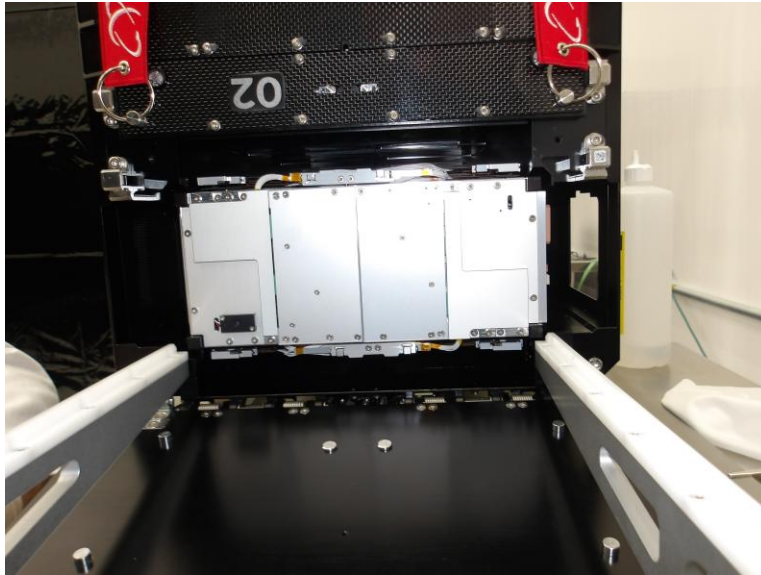
Preparations for GEMS2 launch

GEMS2-A launch, data  
delivery to federal  
partners

GEMS2-B in 2027  
GEMS3? GEMS-PEARL?

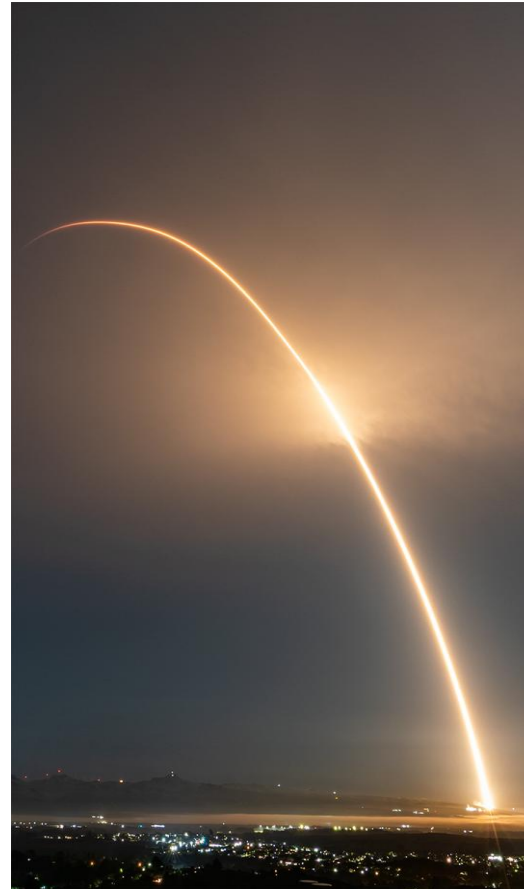
2026+

# GEMS2-Amethyst successfully launched March 30, 2026 on Transporter 16



## GEMS2-A commissioning is underway

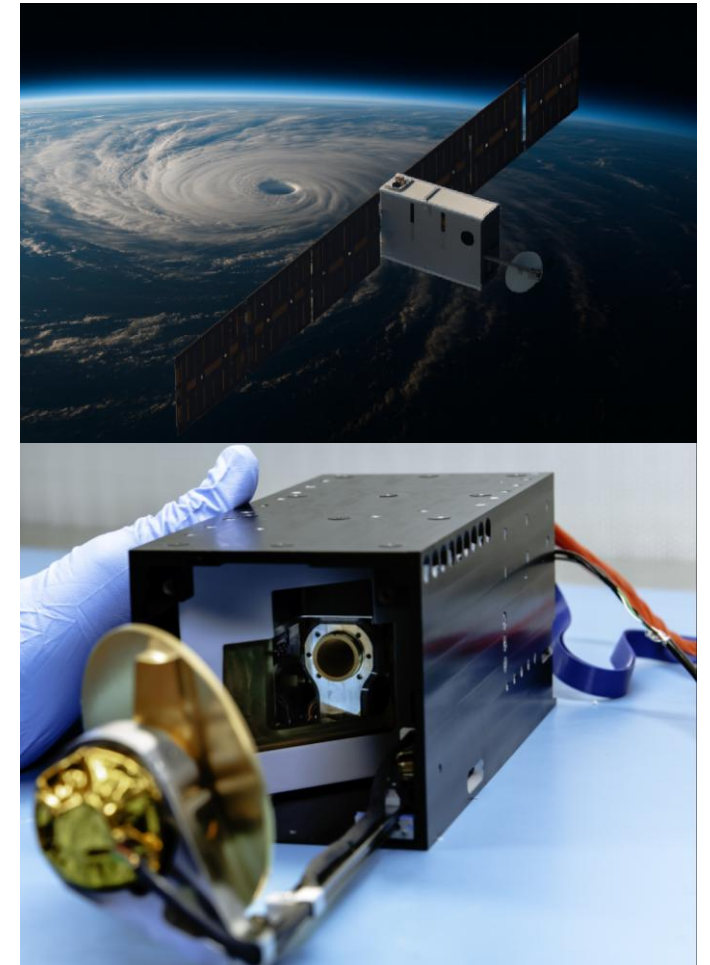
- Verified positive power generation
- Deployed solar panels
- Verified 2-way communications at 4 different ground stations
- Bus and payload commissioning ongoing



# GEMS2A is our 2<sup>nd</sup> generation payload providing improved all-sky sounding capabilities

- **Payload:**
  - Microwave radiometer with 15 channels between 104-125 GHz (22km nadir) and 9 channels between 155-190 GHz (16km nadir)
  - Cross track scanning instrument with ~1 Hz scan rate for a ~2200km swath width
  - 15 W of power for 3 kg mass
- **Spacecraft:** 6U CubeSat built by GOMSpace.
- **Ground segment:** KSAT ~70% < 1 hour latency with 95% target
- **Design life:** 3 to 5 years
- **WMO OSCAR Entry:**

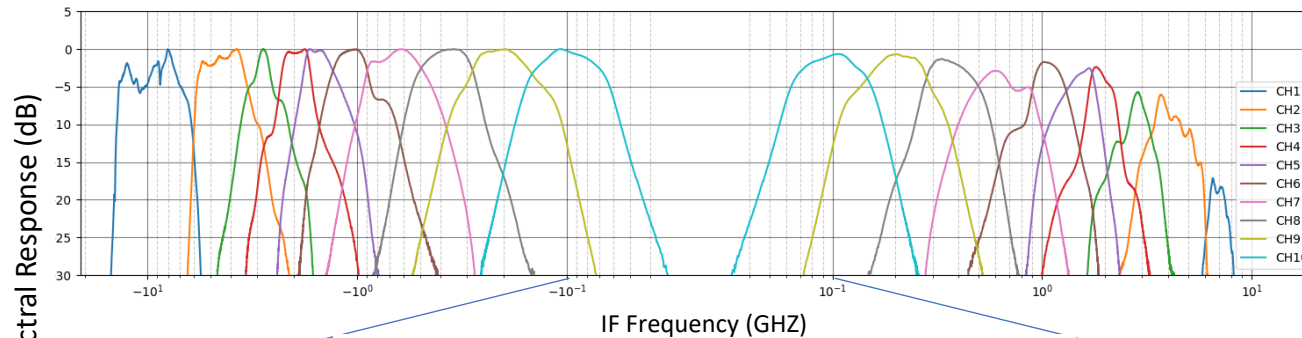
[https://space.oscar.wmo.int/satellites/view/gems2\\_amethyst](https://space.oscar.wmo.int/satellites/view/gems2_amethyst)



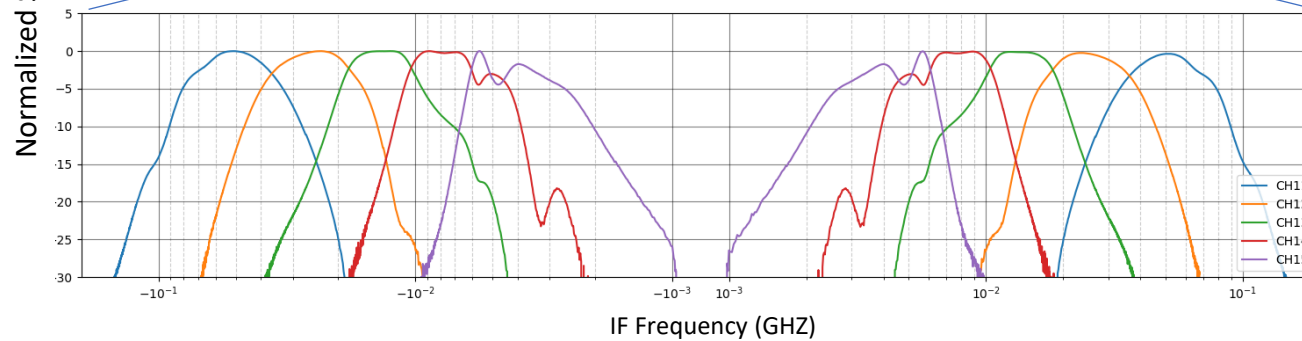
# 118 GHz observations extend from the surface to well into the stratosphere

Modeled using ARTS with measured passband responses, clear sky over ocean with a typical tropical atmosphere profile

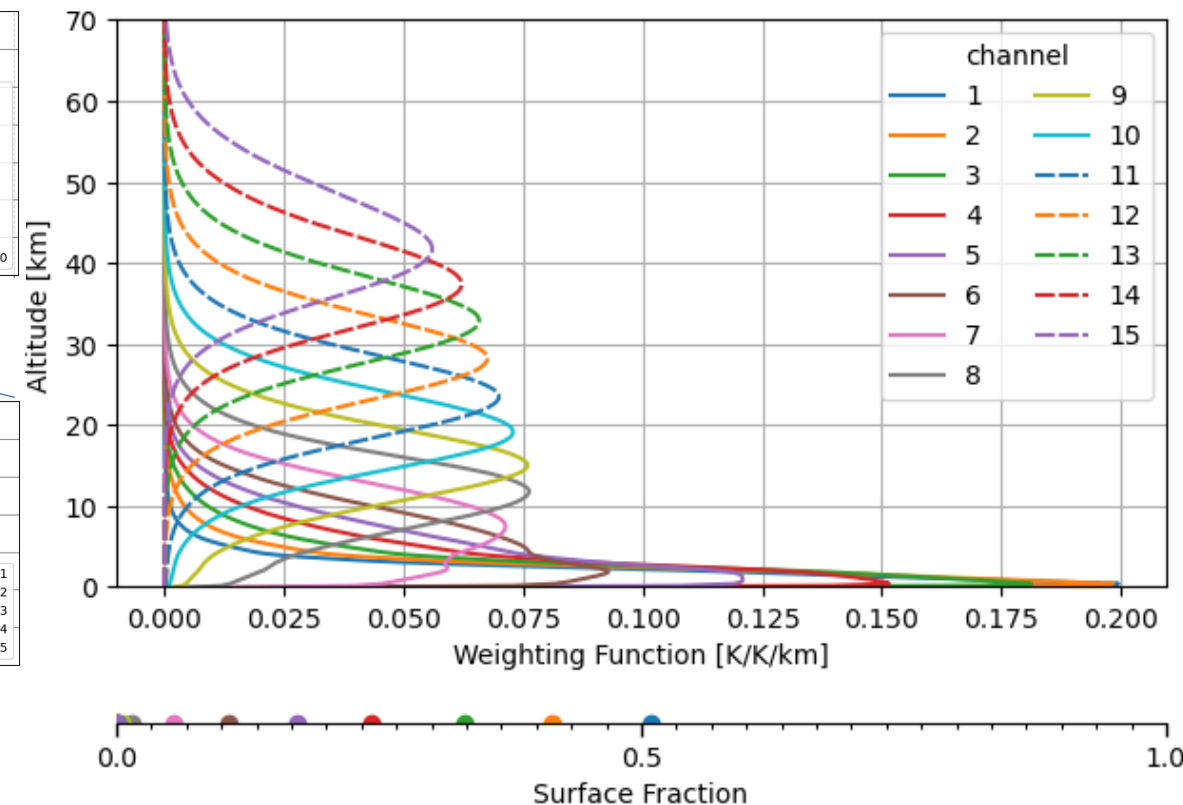
Measured Wide F-Band Channel Responses



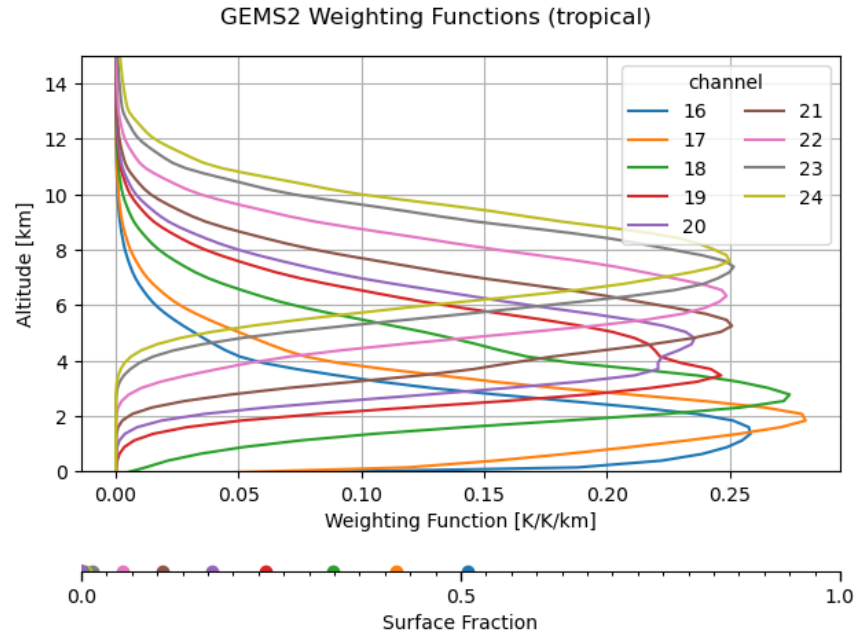
Measured Narrow F-Band Channel Responses



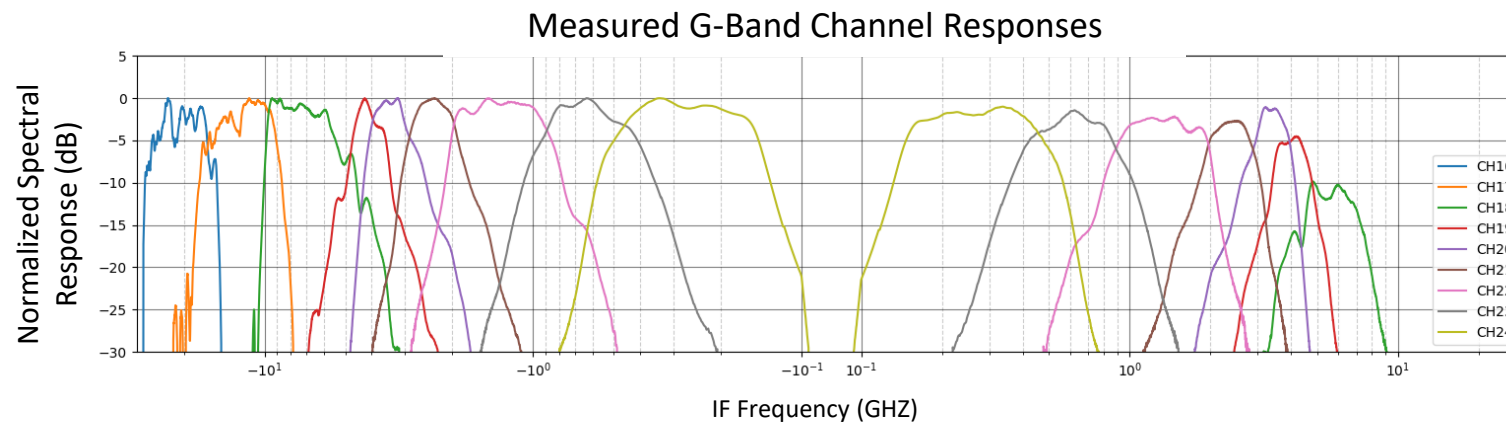
GEMS2 Weighting Functions (tropical)



# 183 GHz channels also capture surface information, but mainly focus on the troposphere

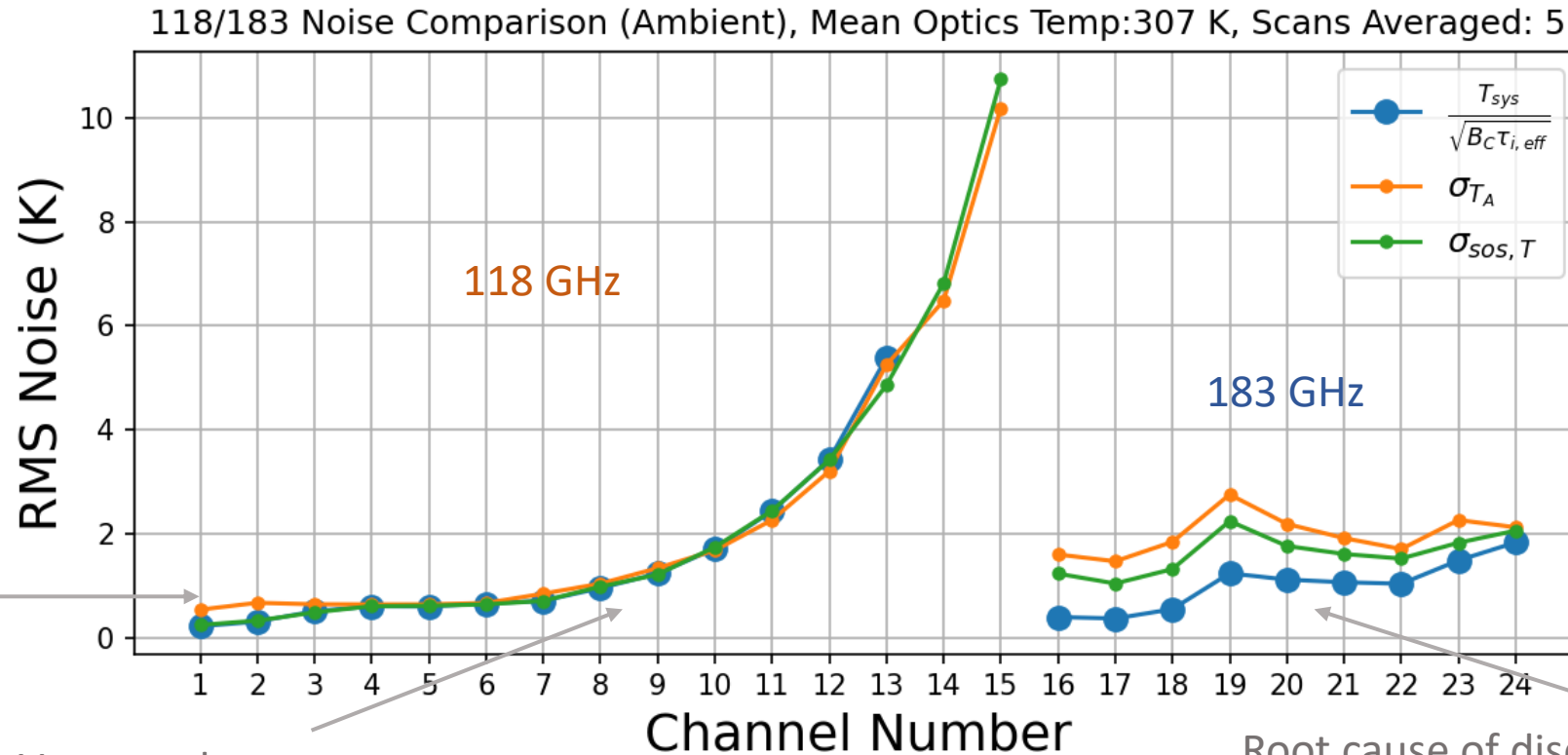


Modeled using ARTS with measured passband responses, clear sky over ocean with a typical tropical atmosphere profile



Pre-flight test campaign showed good agreement in noise comparisons at F-band with understood discrepancy at G-band

Wide-band channels show some increase in inter-sample noise measurement, indicating possible 1/f noise

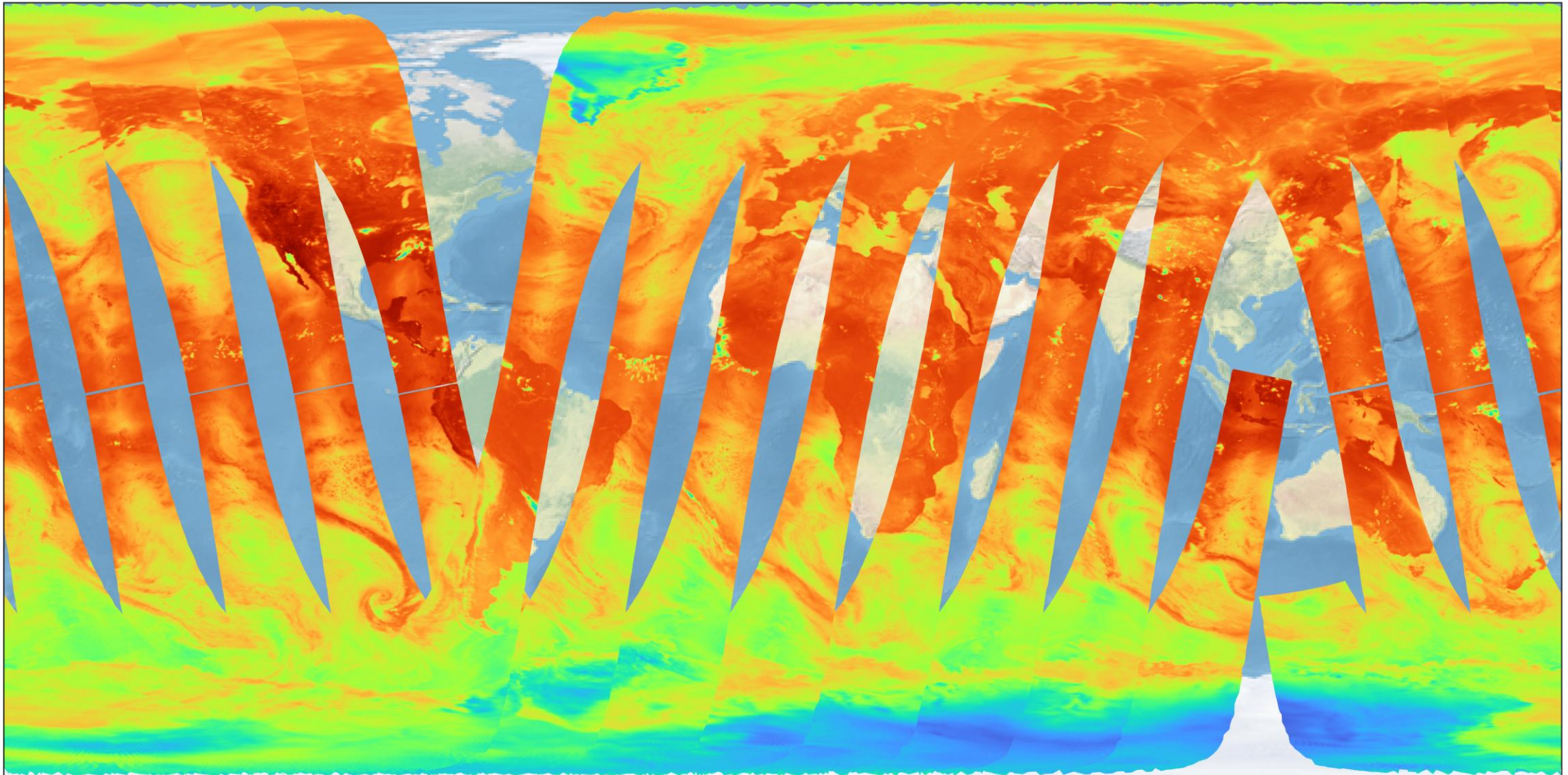


Very good agreement between predicted fundamental noise and intra-sample (4ms) / inter-sample (5s) noise measurements for F-Band

Root cause of discrepancy between predicted and measured noise identified in partnership with our vendor. Will be working towards a solution for GEMS-2B.

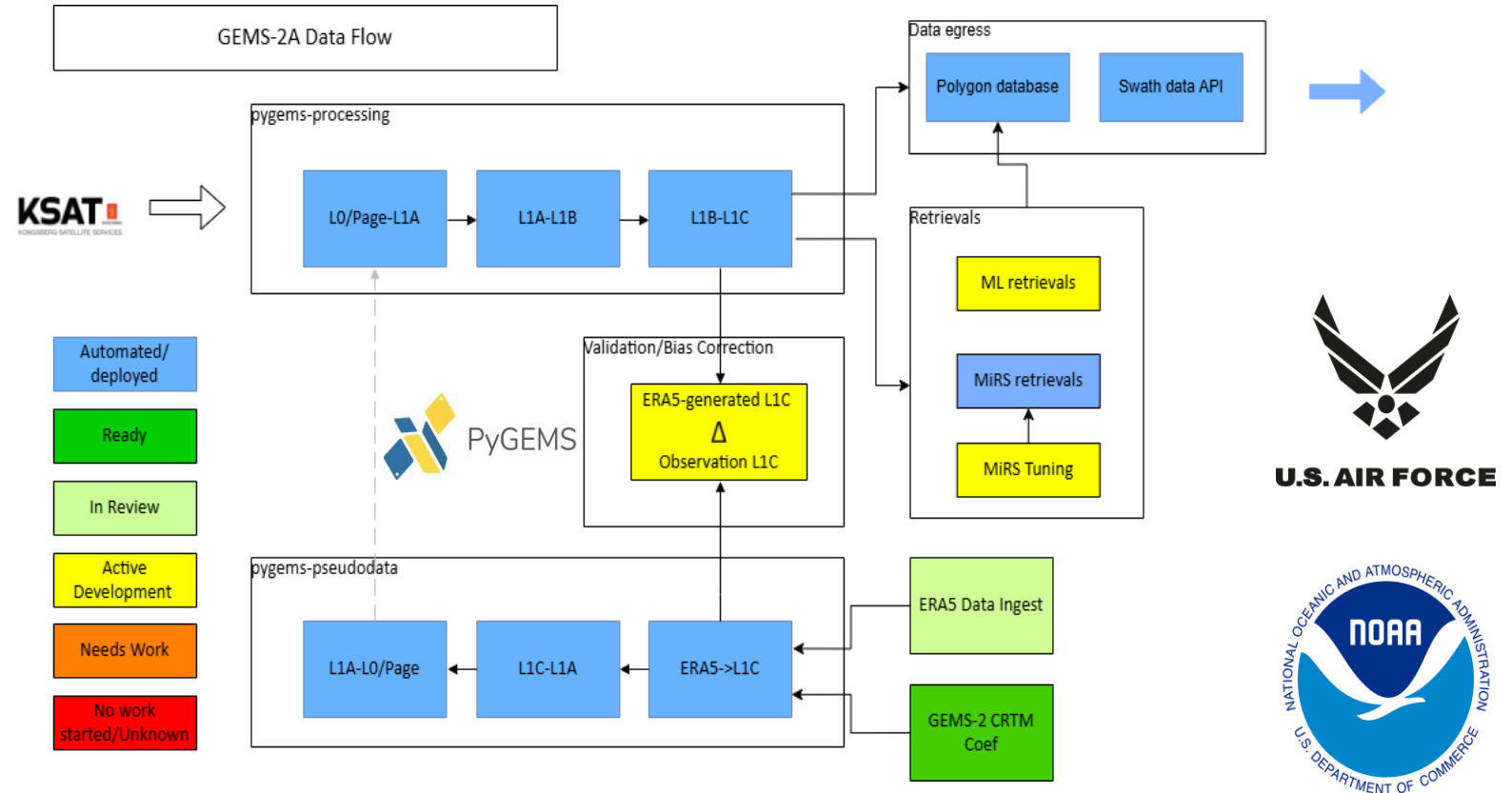
# GEMS2-Amethyst First Light Data (Uncalibrated)

Channel 1 -- 108 GHz -- 12 hour collection

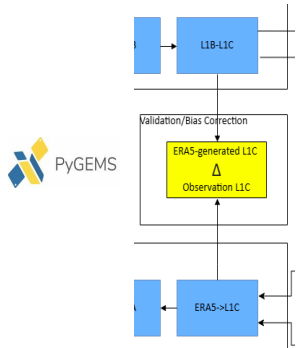


# PyGEMS is a fully automated ground segment for processing GEMS2-A data

- **L1B data will be freely available for evaluation and scientific research**
- Ground segment architecture deployed and in late-stage testing
- CRTM and RTTOV coefficients available
- Data buy in place with US Air Force under CWDP contract. NOAA data buy is currently pending



# Calibration-validation efforts are underway within the automated ground segment



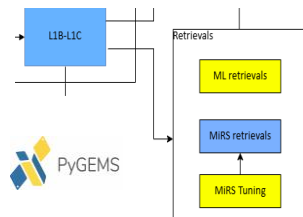
## Cal-Val efforts include:

- Observation minus Background (O-B)
  - **Implemented**
  - Monitors systematic sensor bias relative to NWP
- Radiosonde collocations
  - **In progress**
  - Provides independent, in-situ anchor
- Double difference
  - **Planned**
  - Cross calibration with heritage instruments (e.g. ATMS)

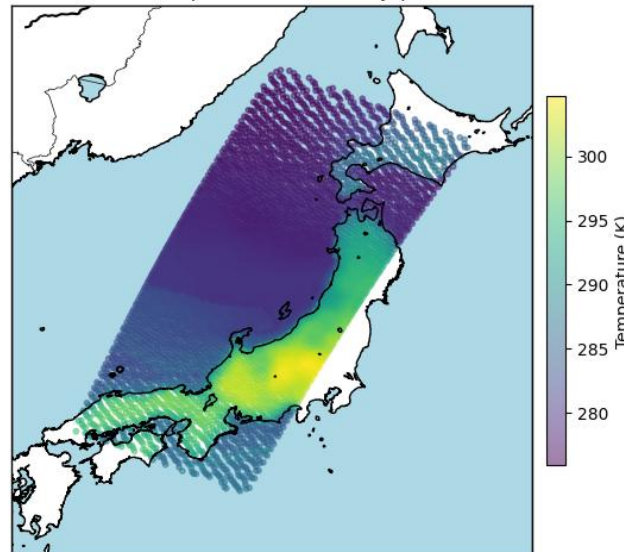
# MiRS and ML-based approaches are used for atmospheric retrievals

## MiRS

- Physical retrieval included in processing pipeline to meet NOAA L2 product requirements
- Serves as retrieval baseline for GEMS-MLR algorithm validation and comparison
- On-orbit tuning pending GEMS2-A observations



GEMS2A Surface Temperature Retrieval, Japan, 2023-04-01



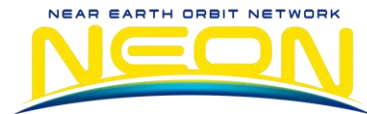
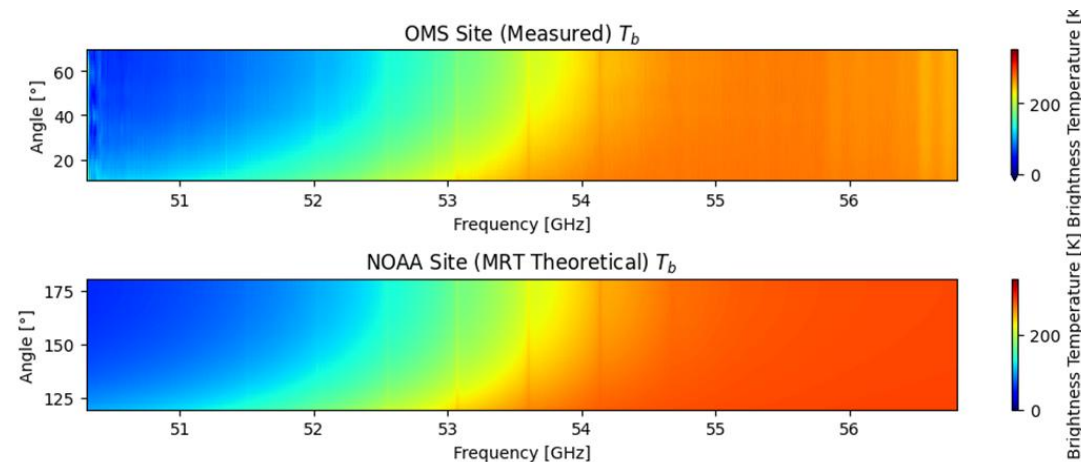
## GEMS-MLR

- GEMS-MLR package under active development for single pixel and CNN retrievals
- Retrieval algorithms designed for integration into the automated processing pipeline
- Developed/testing pre-launch retrieval algorithms
  - Temperature and humidity using MSE loss
  - Modular precipitation for precipitation classification using weighted BCE loss and precipitation rate retrieval using quantile regression loss

# Future efforts at Weather Stream include hyperspectral capabilities and deployable reflectors

## GEMS-CZ/3

- Hyperspectral radiometer backend developed under NASA SMBA Phase A
- 8000 channels @ 1 MHz resolution
- On-ground prototype demonstrated in upward-looking configuration.
- Targeting development towards integration on GEMS-3.



## GEMS-PEARL

- Prototype a family of modular, exchangeable sensors that can in aggregate produce microwave imagery based Environmental Data Record (EDR) products.
- Deployable reflector enabling large antenna aperture on a small satellite bus
- Target EDRs: Ocean Surface Vector Winds (OSVW), Tropical Cyclone Imagery (TCI), Temperature soundings (T), and Humidity soundings (q).



Thank you!

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# GEMS2-A Channel Specifications

118 GHz

| Channel     | SSB/DSB | IF Passbands (MHz) | RF Passbands (GHz) |           |           |           | Quasi-pol | NEdT (K) [t_i] |             |
|-------------|---------|--------------------|--------------------|-----------|-----------|-----------|-----------|----------------|-------------|
|             |         | IF Bandwidth       | LSB Lower          | LSB Upper | USB Lower | USB Upper |           | GEMS2 [4ms]    | ATMS [18ms] |
| 118GHz Band |         |                    |                    |           |           |           |           |                |             |
| 1           | LSB     | 7700               | 104.7503           | 112.4503  | N/A       | N/A       | QH        | 0.3            | 0.1         |
| 2           | DSB     | 2600               | 112.4503           | 115.0503  | 122.4503  | 125.0503  | QH        | 0.4            | 0.2         |
| 3           | DSB     | 1200               | 115.0503           | 116.2503  | 121.2503  | 122.4503  | QH        | 0.5            | 0.2         |
| 4           | DSB     | 800                | 116.2503           | 117.0503  | 120.4503  | 121.2503  | QH        | 0.6            | 0.3         |
| 5           | DSB     | 400                | 117.0503           | 117.4503  | 120.0503  | 120.4503  | QH        | 0.6            | 0.3         |
| 6           | DSB     | 400                | 117.4503           | 117.8503  | 119.6503  | 120.0503  | QH        | 0.6            | 0.3         |
| 7           | DSB     | 400                | 117.8503           | 118.2503  | 119.2503  | 119.6503  | QH        | 0.7            | 0.3         |
| 8           | DSB     | 200                | 118.2503           | 118.4503  | 119.0503  | 119.2503  | QH        | 0.9            | 0.4         |
| 9           | DSB     | 100                | 118.5003           | 118.6003  | 118.9003  | 119.0003  | QH        | 1.2            | 0.6         |
| 10          | DSB     | 50                 | 118.6253           | 118.6753  | 118.8253  | 118.8753  | QH        | 1.6            | 0.7         |
| 11          | DSB     | 25                 | 118.6878           | 118.7128  | 118.7878  | 118.8128  | QH        | 2.3            | 1.1         |
| 12          | DSB     | 12.5               | 118.71905          | 118.73155 | 118.76905 | 118.78155 | QH        | 3.2            | 1.5         |
| 13          | DSB     | 6                  | 118.7348           | 118.7408  | 118.7598  | 118.7658  | QH        | 4.8            | 2.3         |
| 14          | DSB     | 3                  | 118.7428           | 118.7458  | 118.7548  | 118.7578  | QH        | 7.2            | 3.4         |
| 15          | DSB     | 1.5                | 118.74655          | 118.74805 | 118.75255 | 118.75405 | QH        | 10.7           | 5.1         |

183 GHz

| Channel     | SSB/DSB | IF Passbands (MHz) | RF Passbands (GHz) |           |           |           | Quasi-pol | NEdT (K) [t_i] |             |
|-------------|---------|--------------------|--------------------|-----------|-----------|-----------|-----------|----------------|-------------|
|             |         | IF Bandwidth       | LSB Lower          | LSB Upper | USB Lower | USB Upper |           | GEMS2 [4ms]    | ATMS [18ms] |
| 183GHz Band |         |                    |                    |           |           |           |           |                |             |
| 16          | LSB     | 10000              | 155.3100           | 165.3100  | N/A       | N/A       | QV        | 1.3            | 0.6         |
| 17          | LSB     | 8000               | 165.3100           | 173.3100  | N/A       | N/A       | QV        | 1.0            | 0.5         |
| 18          | LSB     | 4500               | 173.5600           | 178.0600  | N/A       | N/A       | QV        | 1.3            | 0.6         |
| 19          | LSB     | 1000               | 178.1100           | 179.1100  | N/A       | N/A       | QV        | 2.1            | 1.0         |
| 20          | LSB     | 1000               | 179.1100           | 180.1100  | N/A       | N/A       | QV        | 1.6            | 0.8         |
| 21          | LSB     | 1000               | 180.2100           | 181.2100  | N/A       | N/A       | QV        | 1.5            | 0.7         |
| 22          | DSB     | 1000               | 181.3100           | 182.3100  | 184.3100  | 185.3100  | QV        | 1.4            | 0.7         |
| 23          | DSB     | 500                | 182.3600           | 182.8600  | 183.7600  | 184.2600  | QV        | 1.8            | 0.9         |
| 24          | DSB     | 300                | 182.8600           | 183.1600  | 183.4600  | 183.7600  | QV        | 1.9            | 0.9         |



## History and Culture

Weather Stream's company **mission** is to stream real-time weather intelligence to the global community

Weather Stream's company **science objective** is to achieve Nyquist spatiotemporal sampling with passive microwave instruments

### Team and Culture:

- **World's first commercial passive microwave mission**
- Founded 2015 based on CU Boulder Research
- 30 Employees, 13 PhDs, 15 engineers
- **Civil servants trapped in a startup**
- Relationship and partnership driven
- Outdoor enthusiasts
- Community oriented, volunteers
- Driven to solve tough problems
- **"Every Photon is Sacred"**
- A global weather data supply chain partner

