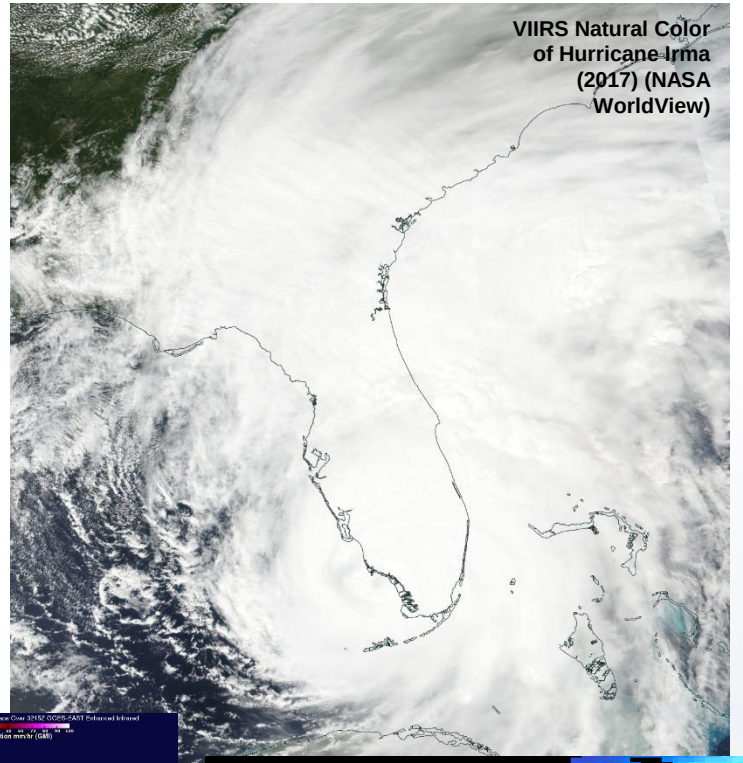
NASA Science Mission Directorate
Earth Science Division
Applied Sciences Program

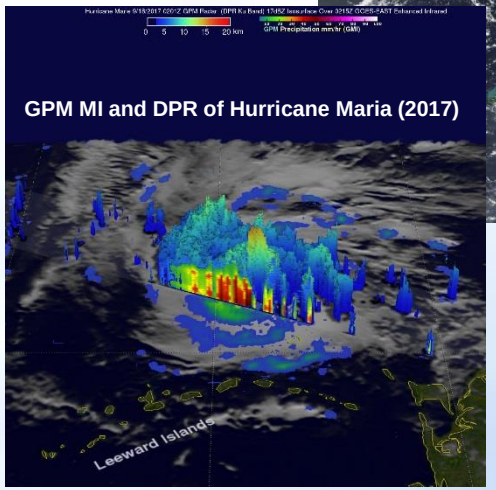
Summary and Recommendations from the Second TROPICS Applications Workshop

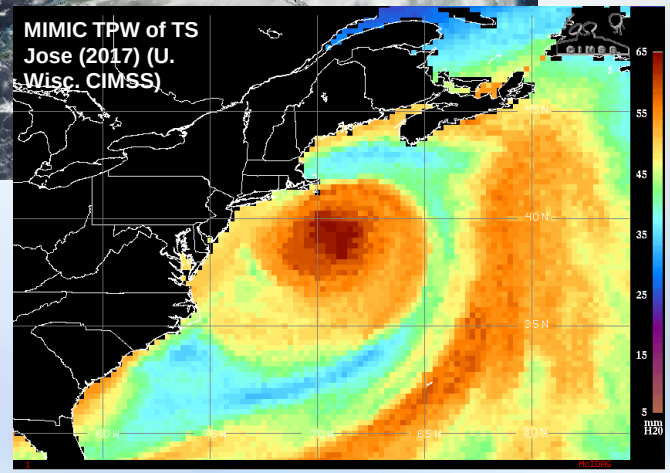
Initial points for discussion by Emily Berndt (NASA/MSFC/SPoRT), Jason Dunion (UM/NOAA/AOML), Patrick Duran (NASA/MSFC/SPoRT), Erika Duran (UAH/SPoRT)

Workshop Purpose & Objectives

- Introduce end-users to expected value of TROPICS by reviewing mission specifications and status
- Engage the end-user community to learn how TROPICS observations could be used by their organizations and barriers to data use
- Provide an opportunity for the early adopter community to share results with current and/or proxy data, communicate challenges, successes, and future needs to the Science Team
- Identify technical and visualization needs that can be addressed by the science and applications community (e.g., data assimilation, Level 3/Level 4 products, visualization tools) to accelerate broad utilization of TROPICS data post launch



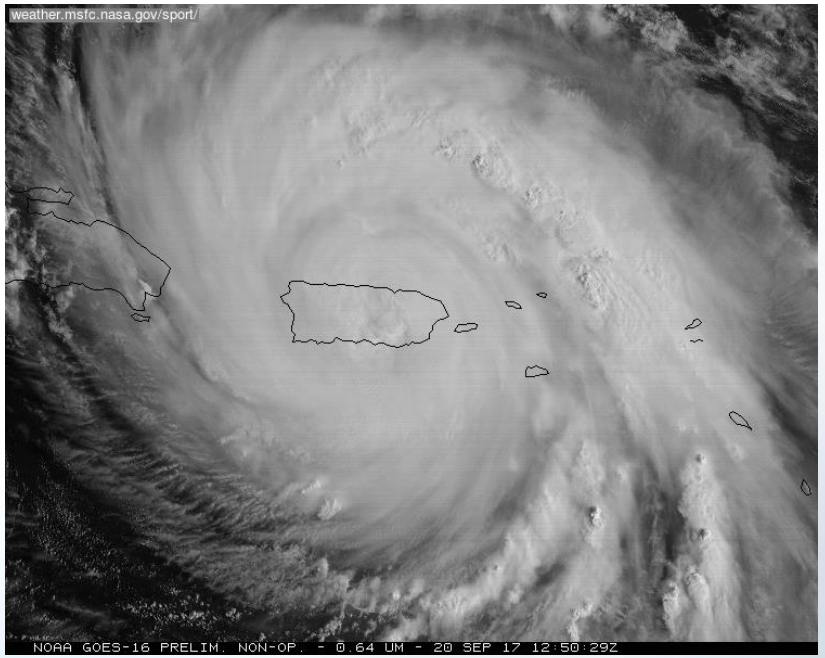




†Source: Charles Watson Jr. of Enki Holdings, LLC and Mark Johnson of JISC, Inc.

Meeting Organization

- 40 registered attendees
- A comprehensive 1.5-day workshop agenda was assembled by the organizing committee that encompassed five sessions and two breakout sessions.
  - Sessions
    - Introductory
    - Proxy Data
    - Applications 1: TC Analysis & Forecasting
    - Applications 2: Terrestrial/Disasters/Severe Weather
    - Applications 3: TC Modeling & Data Assimilation
    - Synergy with other Missions
  - Breakouts
    - Latency
    - Community Needs
    - Advantages/Limitations of SmallSats

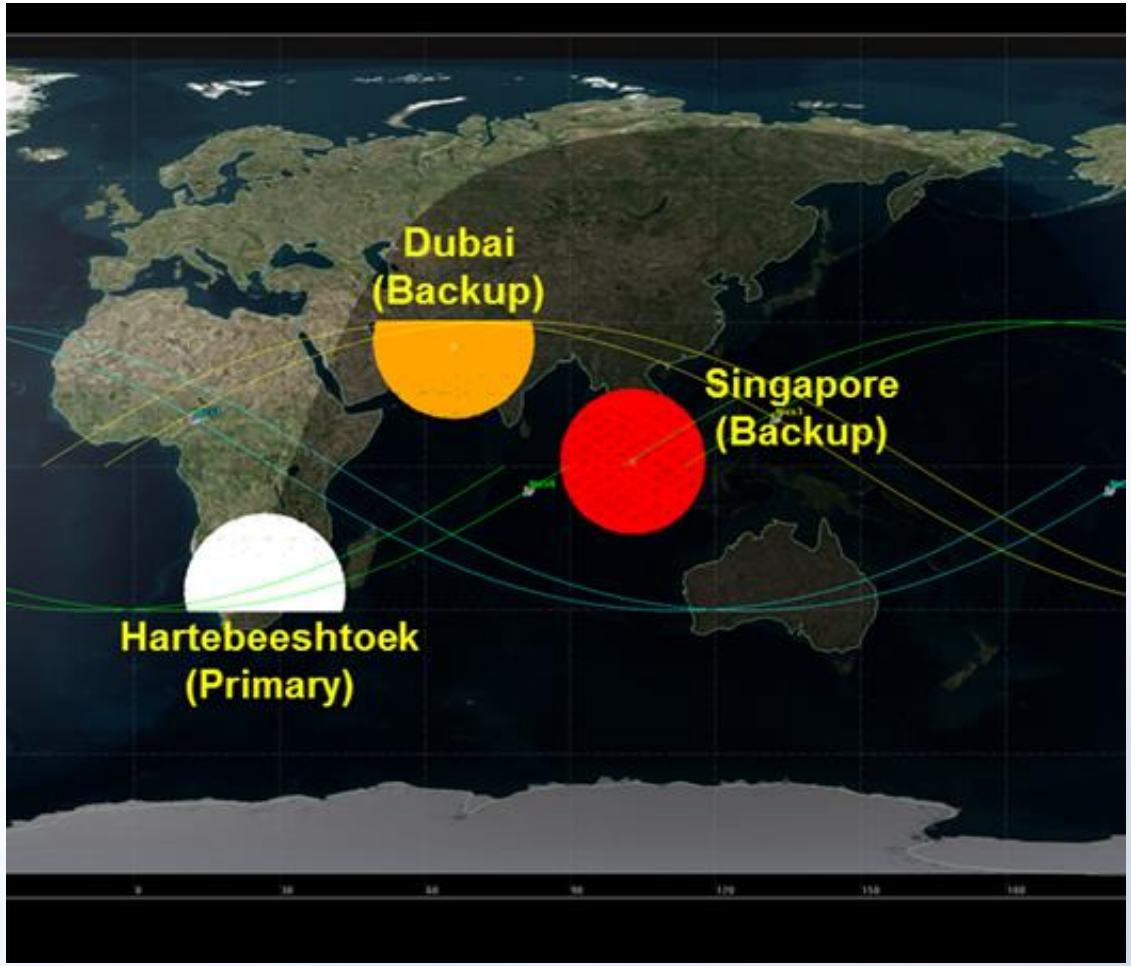


Hurricane Maria (2017) from GOES-16 ABI (SPoRT)

Latency

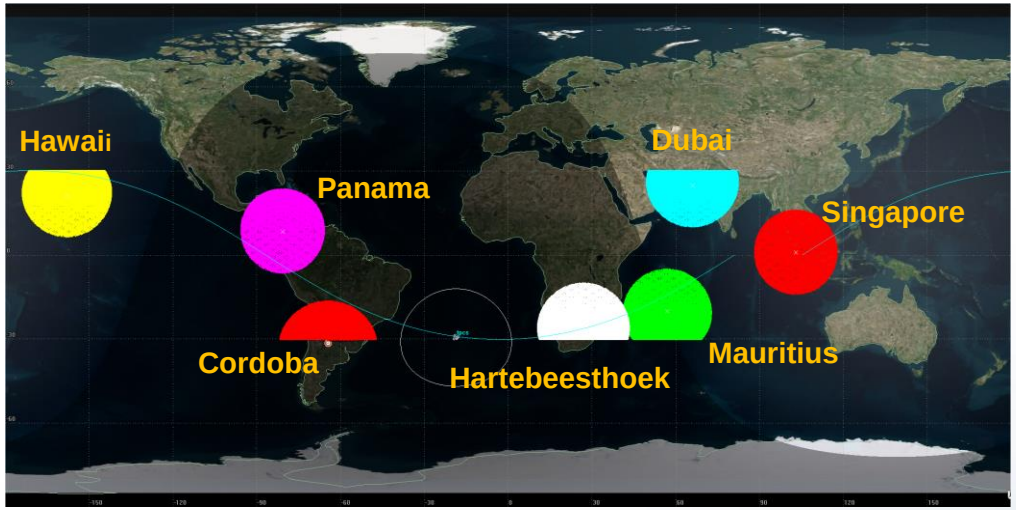
- The mission latency requirements (e.g., four days from downlink time) for TROPICS in the original mission proposal were not designed for use by the operational community.
  - Average latency over a 1 month period with two contacts per day at the primary ground station is about 6.5 hours.
  - TROPICS will pass over the South Africa ground station immediately after traversing the Atlantic.

- Any optimization of data latency is performed on a best-effort basis or with external funding, given the constraints of the fixed-price mission.



Proposed Latency Reduction Options

- CONOP 1: **+, $**
  - Leverage existing low-latency passes coming in over the Atlantic
  - Use the currently planned stations
- CONOP 2: **+**, **++, $$**
  - Reduce latency 8 months of the year to: ~120 min
  - Reduce latency 4 months of the year to: ~90 min
  - Use a total of 7 KSAT-Lite stations
- CONOP 3: **+, ++, $$$**
  - Reduce latency 12 months of the year to: 60-90 min
  - Use a total of 7 KSAT-Lite stations

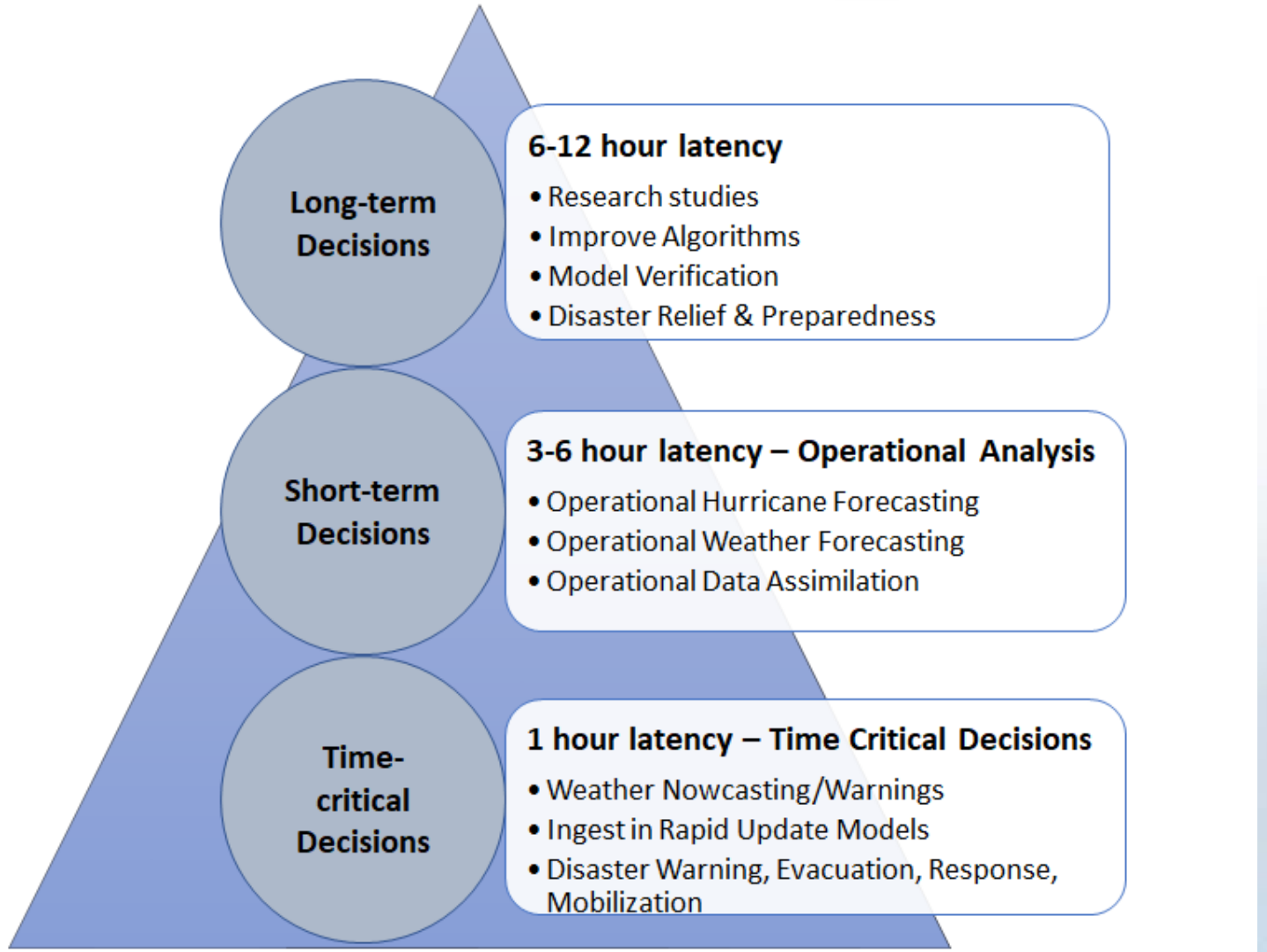


+ Requires additional data processing optimization

++ Requires additional ground station time/priority and data processing optimization

Benefits of Reduced Latency

- Current mission latency specifications enable end user analysis and decisions that are time-independent
- There is a high interest in latency to enable time-critical analysis and decisions
- 1-hour latency and increased spatial coverage (Atlantic, West Pacific, East Pacific) enables use for time-critical decisions that have the potential to mitigate devastating socio-economic impacts



Attendee Ideas to Mitigate Latency

- Continue discussions to partner with NOAA, leveraging existing direct broadcast network
- Prioritize processing and release of Level 1B at low latency
- Consider an “intermediate” data release with minimal processing (e.g., Integrated Multi-satelliE Retrievals for GPM Early and Late products)
- Increase processing centers beyond Wisconsin
- Streamline processing (e.g., current plan for data to go to Colorado then Wisconsin)
- Install a receiver and/or data process at operational centers/locations (e.g., National Hurricane Center, Joint Typhoon Warning Center, Brazil’s National Institute for Space Research)
- Conduct a cost-benefit analysis to demonstrate the funds for optimal latency may be small relative to the benefit of preparedness and disaster mitigation and improvements to NWP and forecasting
- Request international support to cover the extra costs; leverage international data sharing agreements
- Engage with the Tropical Cyclone Operations and Research Forum
- Partner with the military branches for support and funding
- Demonstrate value with launching the 7th Qualification Unit

Latency Summary

Meeting Take Away: Seek external funding and/or partnership with NOAA or International organizations to optimize mission latency to the greatest extent possible to facilitate operational application of data for time-sensitive decisions.

- There is a strong preference to increase the coverage and availability of TROPICS observations.
- While current mission specifications are suitable for applied research and time-independent end user decisions, optimal latency would expand the utility for operational decision making related to weather forecasting, NWP, and disaster response, increasing the societal benefit.
- Without augments to existing mission specifications, there could be a missed opportunity to maximize the potential of NASA data and prepare the community for future missions of value that are likely to be comprised of SmallSat technology.

Proxy Data Summary

- **Meeting Take Away:** There is a need for refinement and expansion of the HNR proxy data or additional datasets
  - Correct for limb-effects and underestimation of brightness temperatures. This caused difficulty in TC analysis with proxy data and suggestions were made to improve the data through tuning of parameters in CRTM.
  - Precipitation proxy data isn't widely available
  - Additional proxy data over land and outside TCs for use in other applications was also of interest, indicating the need for more nature runs with a variety of phenomena/structures.

- **Meeting Take Away:** Participants expressed the importance of pre-launch instrument characterization and stable in-orbit performance, as well as quality control and bias correction and request these metrics from the Science Team.

Proxy Data Summary

- **Meeting Take Away:** Launch the 7th TROPICS unit to prepare for full mission capabilities before launch.
  - Given the short-comings of existing proxy datasets and restricted access to the FY-3C data, the pathfinder would provide a more encompassing proxy dataset without the identified short-comings
  - Launch of a pathfinder mission would provide rich opportunities for applied research, development of training, preparation of algorithms, understanding error characteristics, bias, on-orbit performance prior to launch of the full mission.
  - In addition, development of the infrastructure and preparing observations of operations prior to launch would accelerate use of the full TROPICS mission quickly after launch, maximizing the short mission life and benefit to society.

Community Needs

- Product ideas
  - Monthly aggregated products of rainfall, moisture, and temperature. These aggregates could be compared to those provided by the existing GPM constellation, especially Integrated Multi-satelliE Retrievals for GPM (IMERG).
  - Multiple attendees expressed a desire for the creation of a 37-GHz channel proxy, which is particularly valuable in tropical cyclone analysis.
- Visualization
  - For operational forecasters at the National Weather Service (NWS) and the National Hurricane Center (NHC), distribution of products through the Local Data Manager (LDM) feed for visualization in the Advanced Weather Interactive Processing System (AWIPS) is preferred.
  - Open-source tools for product visualization
  - Capability for display in NASA's Mission Tools Suite (MTS)
  - NASA's Earth Observing System Data and Information System (EOSDIS) Worldview online tool

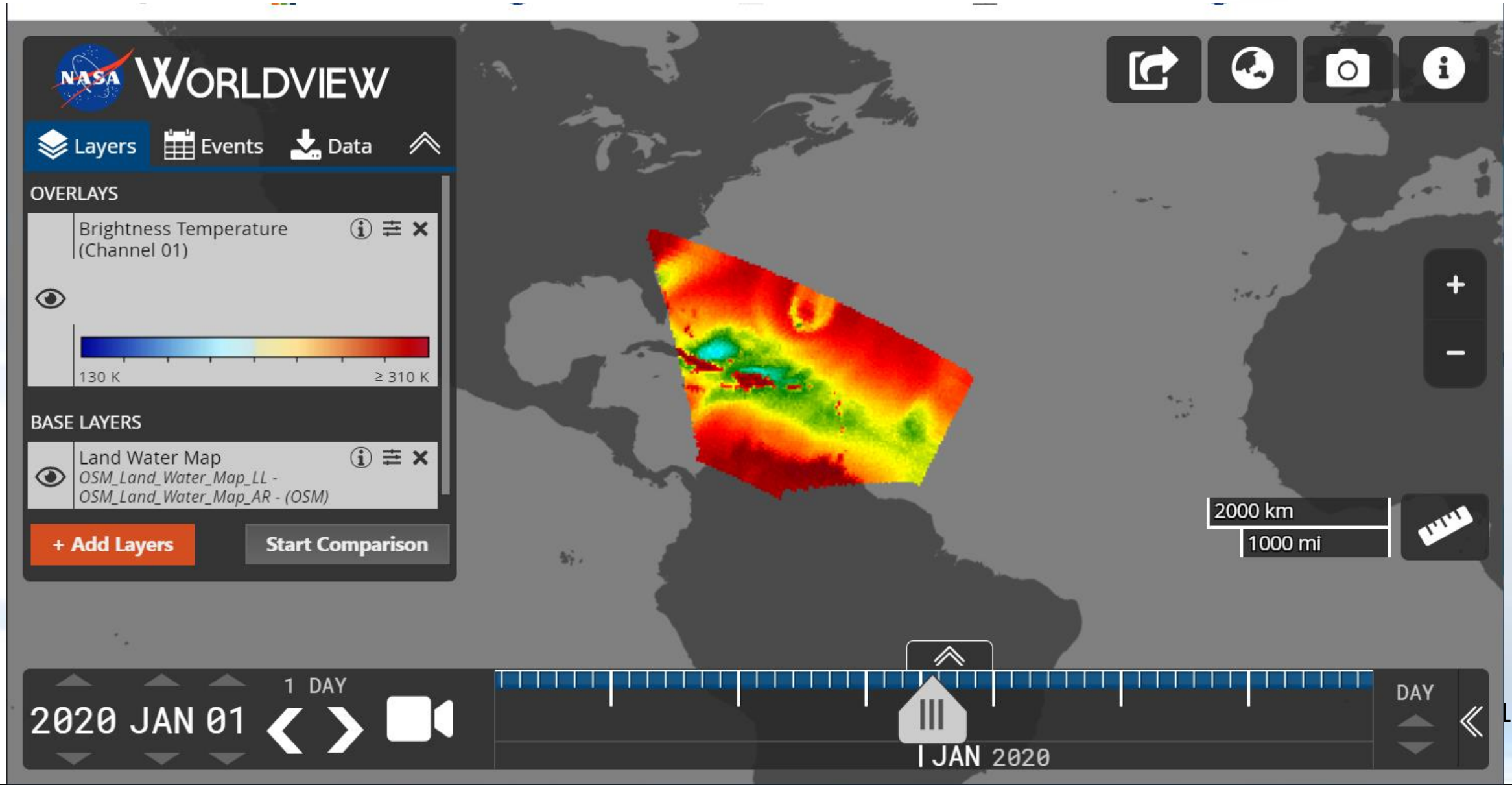
Community Needs

- Tools
  - Orbital navigation tool to view upcoming TROPICS overpasses
  - TROPICS overpasses with other satellite overpasses to track the lifecycle of convective systems (or even individual precipitation features) would be highly valuable
- Formats
  - BUFR format with metadata
  - netCDF4 was preferred for research purposes
- Training
  - Individual channels and derived products, especially 118, 183, 205 GHz channels
  - Highly focused, short-training available online to quickly garner the information
  - Trainings to describe how to use TROPICS imagery and examples
  - Seminars geared toward operational users
  - Launch of a pathfinder vehicle could facilitate the development of these trainings by providing an initial view of how these products behave

Community Needs Summary

- **Meeting Take Away:** A recommendation for the Science Team and Applications Community to develop a variety of data types and visualization tools to facilitate use of TROPICS data by diverse communities and ease of integration within operational systems to accelerate use, given the short duration mission.
  - Given the experience of the UW/SSEC DPC the recommendation was made for them to create and distribute BUFR-formatted data
  - The experience of NASA SPoRT can be leveraged to develop formats and display capabilities for NWS display systems (AWIPS)
  - GES DISC has experience with development of geoTIFF-formatted files and necessary experience with Common Metadata Repository (CMR) requirements to enable integration of TROPIC in NASA's Worldview display and GIS
  - Other frameworks of interest include NASA's Mission Tool Suite, commonly used during Field Campaigns and the Jet Propulsion Laboratory's Tropical Cyclone Information System.

TROPICS in WorldView



Community Needs Summary

- **Meeting Take Away:** Establish a working group on requirements for operational data assimilation to discuss and develop requirements for BUFR format, forward operators, data assimilation tools, pre-launch testing and error/anomaly characterization, and best practices for data assimilation of SmallSat data and assessing the impact on forecasts. A recommendation for interested data assimilation centers to assign a point of contact for TROPICS data assimilation and interaction with the Science Team on pre-launch activities, questions, and feedback. In addition, the NWP community can easily uncover anomalies and relay finding to the mission calibration/validation team.

Community Needs Summary

- Users request short-targeted training and seminars to understand TROPICS basics and new capabilities such as the value of the 205 GHz channel

- **Meeting Take Away:** Applied research or “proof of concept” studies are necessary to discover the advantages and limitations of new TROPICS channels and the benefit to science and applications.
  - Understanding the thermodynamic and microphysics features these channels detect and the relationship to TC structure, intensity, and evolution is integral to use in operations.
  - Although a mission with a focus on TC’s, how do these features relate to thunderstorm structure, intensity, and resulting hazards?
  - Understanding the relationship of the remote sensing, detected features, and associated phenomena can be used to create targeted training material for the community of end users to demonstrate capabilities relevant to the operational environment and decision making.

Strengths/Limitations of SmallSats

- As SmallSat technology is developed, demonstrated, and matures it presents new opportunities for satellite observations but also presents strengths and limitations that will be uncovered as users integrate this new technology into applied research and applications.
  - SmallSats present advantages for more agile, cost effective solutions to complement existing satellite architectures
  - But introduce challenges related to maturity, design life, stability, reliability, and data quality
- During the breakout, workshop attendees gave their perspective on strengths and limitations of integrating SmallSats into their research or application as well as an opportunity to comment on the enabling aspects of TROPICS.
  - Coverage and temporal frequency of TROPICS are exciting attributes of the mission
  - The advantage of some familiar frequencies
  - The ability to use the data for validation of NWP output, physics, or other satellite products such as IMERG.

Strengths/Limitations of SmallSats

- The temporal resolution is the greatest strength that users foresee as an advantage of integrating a constellation of SmallSats in their research and/or application,
  - allowing for rapid updating for data assimilation systems and
  - improved vortex initialization
  - and the fidelity for cloud tracking and winds,
  - assessing the tropical environment, TC genesis and TC evolution.
- Overall, the greatest limitations that users foresee with integrating a constellation of SmallSats in applied research and applications are the challenges related to
  - calibration, short mission life and
  - limited longevity of hardware, and
  - the amount of time to ingest new data into data assimilation and user applications.
- To mitigate the challenges with the short mission life and the time it takes to integrate data into assimilation systems and user applications, the attendees strongly recommended launching the 7th TROPICS unit as an early pathfinder mission to allow preliminary integration into algorithms, end user applications, and data assimilation systems as an opportunity to create the needed infrastructure for the full mission.

Summary

- The inputs from the Second TROPICS Application Workshop will be considered by the Science Team and NASA Applications as possible actions to continue to build capacity for utilization of TROPICS data in applications and to maximize the benefit to society, but much of the effort will require community involvement

- Similar to the first workshop, the desire for improved data latency (e.g., less than 3 hours; optimally <1 hour) beyond mission requirements is strongly desired and viewed as attainable given the required cost and high potential return on investment.

- Launch of the 7th TROPICS qualification unit as an early pathfinder mission will enable
  - Initial steps to deal with complexities of integrating SmallSats in existing systems, and the need to characterize error and bias
  - A more robust proxy dataset to overcome deficiencies with current proxy datasets
  - Preliminary integration into algorithms, end user applications, and data assimilation systems as an opportunity to create the needed infrastructure for the full mission and accelerate post-launch activities.

Summary

- Development of a variety of formats and visualizations will enable broad use of TROPICS observations. The greatest needs to consider pre-launch include BUFR format, AWIPS visualization, and NASA WorldView integration
- New product ideas include a monthly precipitation composite and 37GHz proxy
- Short, applications-based training on TROPICS basics and new capabilities will enable users to understand strengths/limitations of the data and adopt TROPICS observations into operations
- Understanding the relationship of the remote sensing, detected features, and associated phenomena can be used to understand new capabilities of TROPICS and to create targeted training material for the community of end users
- Pre-launch activities are integral for preparing users for TROPICS and enable use of TROPICS data quickly after launch

Backup

Proxy Data

- Workshop participants presented preliminary results using both the HNR and the FY-3C TROPICS proxy datasets.
  - Validation of the HNR TROPICS proxy data against the full HNR numerical simulation demonstrates that TROPICS proxy data capture similar TC structure, but underestimate precipitation amounts
  - Using Hövmoller diagrams and proxy data imagery (simulated Channel 10), TROPICS proxy data demonstrate similar TC convective structures, including eye/eyewall development, and diurnal variability.
  - Near the edge of the swath, however, data quality appears to deteriorate.
  - The spatial resolution of TROPICS may limit the ability to track individual convective cores; however, the HNR and other model simulations similar to the HNR suggest that the frequency of TROPICS overpasses can capture the evolution of the TC diurnal cycle.

Proxy Data

- Workshop participants presented preliminary results using both the HNR and the FY-3C TROPICS proxy datasets.
  - Analysis of the impact of PW sounding data in the European Centre for Medium-Range Weather Forecasts (ECMWF) system demonstrates that continued benefit is observed with the addition of each new PW sensor, and that this benefit is statistically significant.
  - There is also clear benefit for TC forecasting, showing improvement of track forecasts and short-term intensity when PW data is included.
  - Data from the FY-3C satellite have been assimilated in the ECMWF system since April 2019; results indicate that the clearest benefit is observed from the 183 GHz channels, and the main impact of the 118 GHz channels is through the improved short-range forecasts of clouds

TC Analysis & Forecasting

- For applications of TC analysis and forecasting, the TROPICS mission offers both promise and challenges. TROPICS will provide more frequent views of TC structure (e.g. warm core evolution and eyewall replacement cycle evolution), center finding, and intensity estimation than is available in the current constellation of PW satellites.
- However, data latency of more than 3 hour rapidly decreases the real-time utility of the data as forecasters are already moving into the next advisory cycle
- Regardless of latency, TROPICS data will still be useful for post-analysis and preparing final TC reports.
- It is anticipated that other Regional Specialized Meteorological Centers (RSMCs) such as Fiji, Darwin, La Reunion, Tokyo, and New Delhi) could also benefit from near real-time TROPICS data.

Time (HR:MIN)	Event
00:00	Issue Tropical Weather Outlook Issue Intermediate Public Advisory (if necessary) Synoptic time / cycle begins
00:45	Receive satellite fix data
01:00	Initialize models
01:10	Receive model guidance and *prepare forecast*
02:00	NWS / DoD hotline coordination
03:00	Advisory deadline
03:15	FEMA conference call
06:00	New cycle begins

TC Analysis & Forecasting

- The TC Analysis and Forecasting session also included presentations highlighting TROPICS related research with potential forecasting applications.
  - Simulated TROPICS radiances show positive impacts on Hurricane-WRF (v3.6) model initial conditions of moisture, TC position correction, short-term TC track forecasts, and TC track and intensity forecasts beyond 2 days.
  - UW/CIMSS research efforts have focused on using TROPICS data to improve the real-time estimation of TC intensity. The goal of this work is to develop a new TC intensity estimation algorithm that uses Tbs from the TROPICS satellite constellation.
  - NRL-Monterey plans to incorporate TROPICS data into machine learning analyses of TC structure to analyze and predict TC rapid intensification.

Community Needs Summary

- **Meeting Take Away Con't:** Applied research or "proof of concept" studies are necessary to discover the advantages and limitations of new TROPICS channels and the benefit to science and applications.
  - Considering NHC forecasters have relied on passive microwave 37 and 89 GHz observations, there is a need to understand how TROPICS observations provide similar or enhanced capabilities beyond the program of record.
  - Similarly, understanding and training regarding precipitation estimates and biases is critical for effective use by operational organizations.
  - Leveraging the experience of NASA SPoRT to create applications-based training to prepare users for satellite datasets, it is recommended the applications community and subject matter experts collaborate on proof of concept studies and development of training resources that describe the utility and interpretation of different products.
  - NASA ARSET is also a resource to leverage for training development and seminars.

Terrestrial/Disasters/Severe Weather

- Focus area seeks to use TROPICS data to improve the monitoring, modeling, and forecasting of atmospheric phenomena pertaining to the earth's surface.
  - The high temporal frequency of TROPICS will supplement precipitation data in tropical regions that lack ground-based radar coverage.
  - Preliminary results generated using the TROPICS HNR proxy data and the Precipitation Retrieval and Profiling Scheme (PRPS) demonstrate that the overall structure of precipitation is captured well, but the magnitudes tend to be underestimated
  - The use of TROPICS data in real time with low latency (< 30-60 minutes) would be valuable for monitoring and disaster response, in particular for flooding and for severe weather

Terrestrial/Disasters/Severe Weather

- Focus area seeks to use TROPICS data to improve the monitoring, modeling, and forecasting of atmospheric phenomena pertaining to the earth's surface.
  - TROPICS microwave data will provide additional information beyond geostationary infrared imagery, and low latencies would allow for monitoring and analysis with the combination of these two datasets.
  - The frequent data products available with TROPICS allow for the rapid detection of storms when combined with data from GPM; since the current constellation can have long gaps in coverage, many severe thunderstorms are entirely missed.

- Some outstanding research questions raised by participants include:
  - Can TROPICS assess the rate of weakening or intensification of a storm?
  - Can retrievals of temperature and moisture profiles measure storm inflow thermodynamics?
  - A TROPICS proxy dataset of severe storms or over land could be valuable for exploring these questions

Modeling & Data Assimilation

- The high spatial and temporal resolution of TROPICS offers an opportunity to improve representations of TC structure and evolution in both the research and operational modeling environments.
  - Experiments using the Megha-Tropiques Sounder for Probing Vertical Profiles of Humidity (SAPHIR) cloudy radiances suggest that assimilation of these observations reduces ARPEGE TC track forecast errors by about six percent.
  - Impediments to operational assimilation include the time needed to test the impact of new observations after launch (about 7 months) combined with the short planned lifetime of the mission
  - latency is a primary limitation in the successful operational assimilation of TROPICS data, with a latency of less than 4 hours ideal for Météo-France.
- Overall, results presented by operational modeling groups show great promise that assimilation of all-sky radiances from TROPICS could further improve TC track and intensity forecasts.

Synergy with other Missions

- The TROPICS mission offers a unique capability for providing rapid refresh PW observations in the TC environment and has numerous potential synergies with existing satellite missions. Data from TROPICS has many potential applications that can provide enhanced capabilities for examining TC track (location), intensity change, and structure, as well as the larger scale environment surrounding storms.

- Potential overlap of the TROPICS and CYGNSS missions
  - will provide a unique opportunity to collect collocated thermal (TROPICS) and surface wind (CYGNSS) information in the inner core (R≤150 km), near environment (R=150-300 km), and peripheral environment (R≥300 km) of TCs at a relatively high temporal frequency.
  - will allow for detailed analyses of the evolution of TC structure over the complete lifecycle of a storm.
  - There are also opportunities for lessons learned from CYGNSS as this mission is also comprised of a constellation of SmallSats.

Synergy with other Missions

- Application synergies between GOES-R and TROPICS
  - TC center fixing: the TROPICS microwave imager (~90GHz) could improve TC center-fixing when the storm center is obscured by clouds in the IR.
  - TC Intensity Estimation: TROPICS TC intensity estimates could complement IR-based Advanced Dvorak Technique (ADT) and could also be entrained into the UW/CIMSS SATCON (Satellite Consensus) technique for estimating TC intensity.
  - Atmospheric Motion Vectors (AMVs): TROPICS PW imagery could be used to track convective cell motions with a relatively high temporal refresh rate, which could lead to improved 3-D winds in the TC inner core.
  - Saharan Air Layer (SAL): TROPICS moisture channels could aid in the detection of the SAL's low to mid-level dry air (~500-850 hPa), especially in the environment of TCs that are interacting with the SAL.
  - Geostationary Lightning Mapper (GLM): TROPICS rain-rate data could augment GOES-R GLM data and be used to diagnose and possibly predict TC rapid intensification events, relate precipitation structure evolution to the evolution of the TC upper-level warm core anomaly (intensity change), relate the occurrence of intense convective cores in the TC vortex (i.e., convective bursts) to TC intensity change, and examine the evolution of the TC diurnal cycle.

Synergy with other Missions

- Synergies between TROPICS and PW applications developed by UW-CIMSS that are currently being used for TC analysis around the globe:
  - Automated Rotational Center Hurricane Eye Retrieval (ARCHER): ARCHER is designed to aid TC forecasters in objectively identifying key TC characteristics such as center position, eye diameter, and presence of an eye. TROPICS data could be used to supplement the PW imagery that is currently used as input for the ARCHER algorithms.
  - Satellite Consensus (SATCON): the SATCON product blends TC intensity estimates derived from multiple objective algorithms to produce an ensemble estimate of TC intensity for storms worldwide. TROPICS data could be used to supplement the PW data that is currently used in SATCON (e.g., AMSU, SSMI/S, and ATMS).
  - Microwave-based Probability of Eyewall Replacement Cycle (M-PERC) Model: M-PERC is a statistical model for predicting the onset of TC eyewall replacement cycles (ERCs) that can affect storm intensity and structure. TROPICS data could be used to supplement the PW data that is currently used as input in M-PERC.

Strengths/Limitations of SmallSats

- Given a short mission life, in depth calibration isn't feasible, noting that calibration or instability between platforms will impact microwave intensity, precipitation retrieval, and noise will create undesired anomalies where errors of 1-5K impact applications.
- In addition, concerns were raised about ice scattering and the need to do training for the higher channels.
- Attendees noted the need to have good pre-launch data and documentation of bias corrections.
- Particularly the modeling and data assimilation attendees noted the need for covariance for instrument noise, antenna correction if applied, reflection and scan bias, quality flags including moon in view or whether a lower sample of calibration was used, and instrument temperature. Attendees noted the advantage of including any and all metadata to allow them to analyze and correlate attributes.
- Attendees noted, the need to begin planning a TROPICS mission follow-on. In the event, data is successfully transitioned to end users for disaster or forecasting applications, how will users deal with the sudden loss of data?