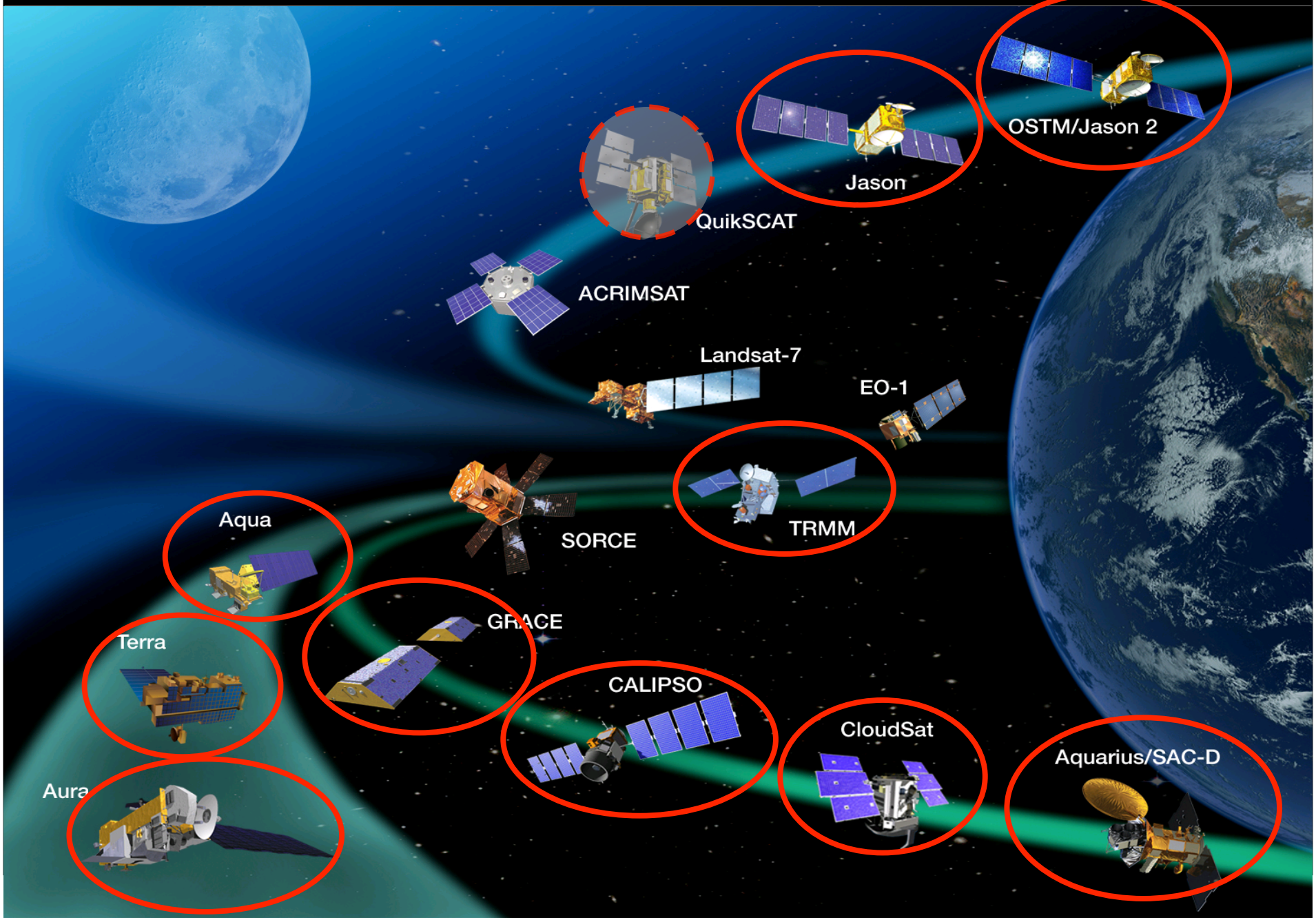
NASA PMM Program Status

Ramesh Kakar
TRMM, Aqua and GPM Program Scientist
NASA Headquarters

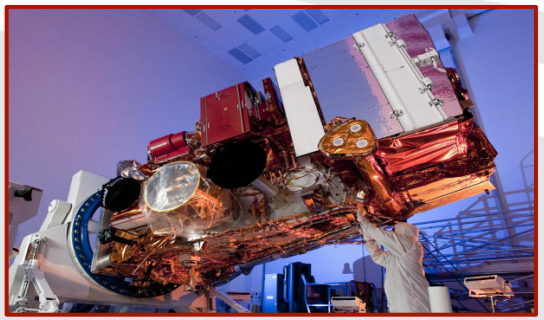
November 7, 2011

NASA Operating Missions (International Collaboration)

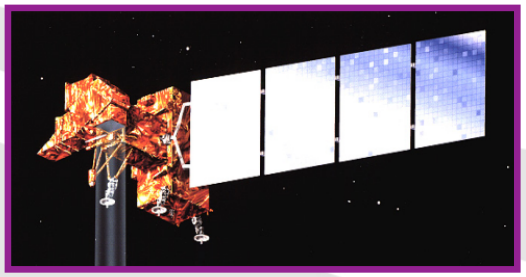


Missions in Formulation and Implementation – 11/2011

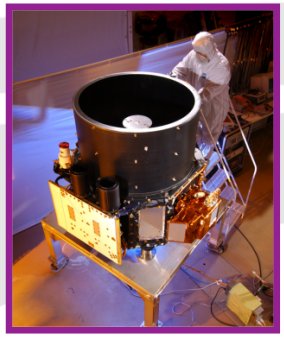
AQUARIUS
6/10/2011
w/CONAE; SSS



NPP
10/28/2011
w/NOAA
EOS cont., Op Met.



LDCM
12/2012
w/USGS; TIRS



ICESat-II
Likely 2016
Ice Dynamics

SMAP
Early CY2015
w/CSA
Soil Moist., Frz/Thaw

GPM
2/2014
w/ JAXA; Precip

OCO-2
2013
Global CO_2

2011 Senior Review Findings

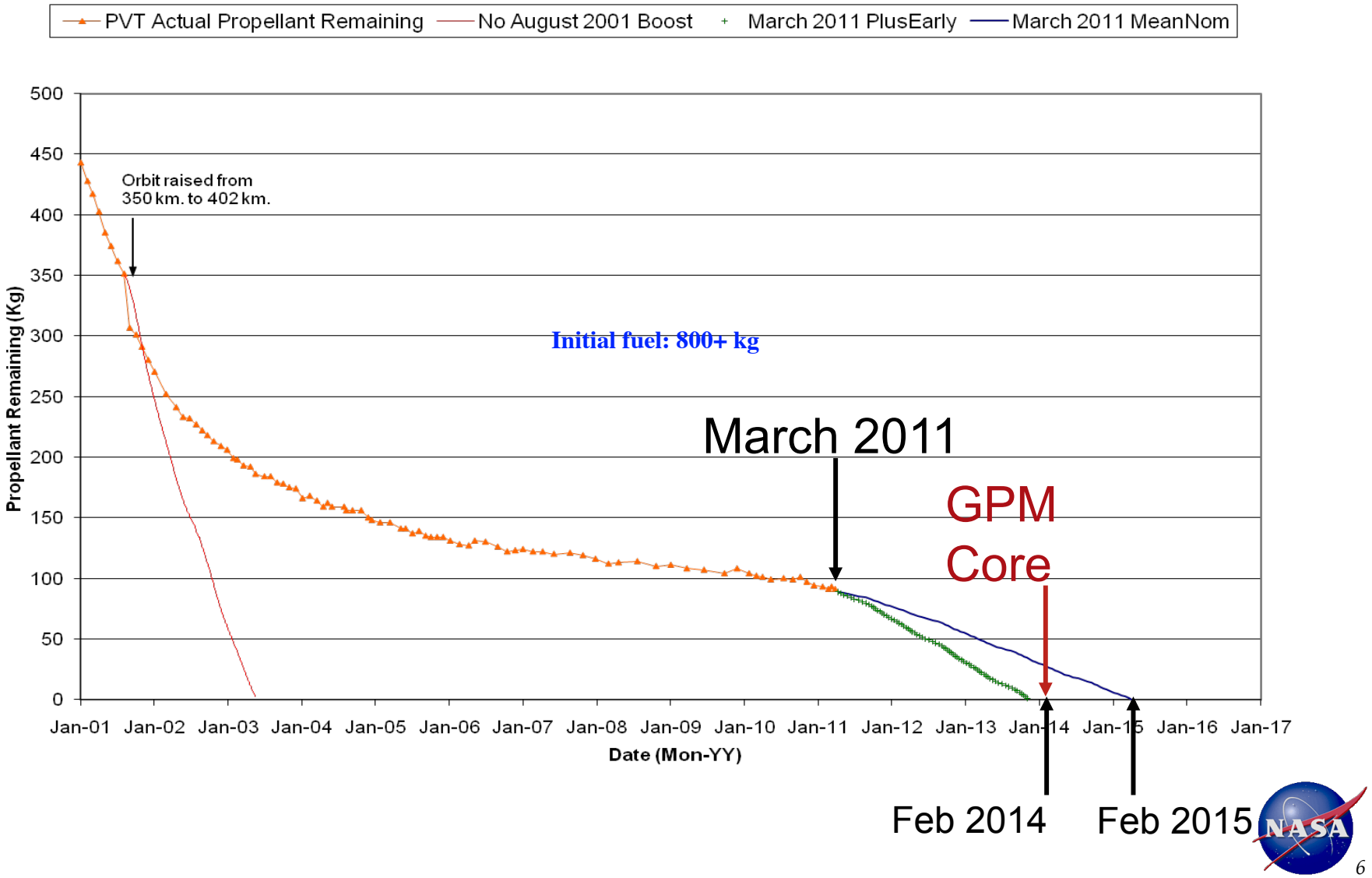
Mission	Science Scores			Summary Science Adjectival Score	Utility Score	Technical Risk	Cost Risk	Conclusion	
	Merit	Relevance	Product Maturity					FY12-13	FY14-15
Aqua	5.0	5.0	5.0	Outstanding	Very High	Medium	Medium	Baseline*	Baseline
Aura	5.0	5.0	5.0	Outstanding	High	Medium-High	Low	Reduce	Reduce
CALIPSO	4.1	5.0	3.8	Very Good +	High	Medium-Low	Low	Baseline	Baseline
CloudSat	5.0	5.0	5.0	Outstanding	High	Medium*	Low	Baseline*	Baseline*
EO-1	4.0	4.4	3.4	Very Good -	High	High*	High	Baseline	Baseline
GRACE	5.0	5.0	4.7	Outstanding -	High	Medium-High	Medium	Augment*	Augment*
Jason-1	5.0	5.0	5.0	Outstanding	High	Medium-High	High	Baseline	Augment
OSTM	5.0	5.0	5.0	Outstanding	Very High	Low	Low	Baseline	Baseline
QuikSCAT	5.0	5.0	5.0	Outstanding	High	High*	Medium	Baseline	Augment
SORCE	5.0	5.0	5.0	Outstanding	High	Medium-High	Medium	Augment*	Augment*
Terra	5.0	5.0	5.0	Outstanding	Very High	Medium	Low	Baseline	Baseline
TRMM	5.0	5.0	5.0	Outstanding	High	High*	Low	Baseline	Baseline

- Science scores based on intrinsic science value of dataset, relevance to ESD science goals, and data product maturity.
- Utility scores based on intrinsic value of data products, frequency and timeliness of use.
- Technical Risks were based on: Redundancy, Age, Design(e.g. mechanical components), Heritage (long-lived predecessor), power and propellant margins, performance to date.
- Cost Risk based on whether an optimal request was submitted, and if the optimal was needed to maintain spacecraft health & safety.

Spacecraft & Instruments Summary

Subsystem/Instrument	Functionality	Notes
Electrical Power (EPS)	Fully Functional	Battery-1: Fully Functional Battery-2: Cells sensitive to overcharge PSIB-A erratic clock
Flight Data (FDS) / Command and Data Handling (C&DH)	Fully Functional	Frequency Standard B in use since launch FS-A exhibited anomaly on pad U/L Card B used due to problem in SAA
Radio Frequency (RF) / Communications (Comm)	Fully Functional	No Issues
Attitude and Control (ACS)	Fully Functional	ESAs not used at current altitude.
Reaction Control (RCS)	Fully Functional	
Propulsion	Fully Functional	
Thermal	Fully Functional	
Deployables [HGA, S/A Drive Assemblies]	Degraded	HGA: Fully Functional SADA –Y: Parked at 0° SADA +Y: Fully Functional
Clouds, & the Earths Radiant Energy System (CERES)	Failed	Powered Off on 05/29/2001 due to excessive noise & Terra/CERES launch. No longer operational
Lightning Imaging Sensor (LIS)	Fully Functional	
Precipitation Radar (PR)	Fully Functional	Frequency Converter and Intermediate Interface (FCIF) & System, Control and Processing (SCDF) on B-Side due to low anomalous values (05/2009)
TRMM Microwave Imager (TMI)	Fully Functional	
Visible and Infrared Scanner (VIRS)	Fully Functional	

TRMM Lifetime – March 2011 Schatten Update



TRMM Status

- *TRMM completed 13 years of on-orbit operations on November 27, 2010 (with 9+ years at 402 km and 3+ years at 350 km)*
- *TRMM began as an experimental mission, but has become a standard reference for a global set of satellites used to study precipitation characteristics and variability, and is being used in near real-time applications*
- *This year completed the Senior Review process for the fourth time*
- *Instruments (LIS, PR, TMI, VIRS) and spacecraft remain in excellent operating shape with some minor degradations*
- *Based on current fuel consumption expectations, TRMM data could be available into 2013-2015, providing the potential for overlap with GPM*

Replan Background

- **Directed Earth Science Systematic Mission**
- **Formulation authorized in July 2002**
  - Extends globally the measurement of precipitation initiated by the Tropical Rainfall Measuring Mission (TRMM) with increased temporal and spatial sampling and increased measurement sensitivity and accuracy
  - Lead Implementation Center – GSFC
  - Major Partnership with JAXA
- **Mission Confirmed December 2009 (KDP-C)**
  - External LRD July 2013; Internal Level 1 Requirement July 2013
- **HQ PPBE2013 (Feb 2011) guideline de-scoped GMI#2 development and accommodation on the Low Inclination Observatory (LIO) consistent with 2012 President's Budget Request;**

Replan Background (cont'd)

- **Replan became necessary due to depleted schedule reserve**
  - Spacecraft hardware technical issues/rework (including GIDEP)
  - GMI delivery slip; RF subsystem development issues
  - Late DPR delivery; Earthquake and required hardware rework
  - To incorporate 2012 President's Budget Request directed descope (GMI-2 deletion)
- **Received approval from APMC for the GPM Replan October 2011**
  - Establish new internal/external LRD commitments
    - Internal LRD of February 2014 (was July 2013)
  - Development Cost/LCC remain within KDP-C commitments

GPM Project Level 1 Requirements Overview

Science Requirements
- Measurements of the same geophysical scenes using both active and passive technique from 65N to 65S latitude with mean sampling time of 24 hours
- DPR, Ku/Ka bands
  - Quantify rain rates between 0.22 {0.3} and 110 mm/hr
  - Detection of snowfall at effective resolution of 5 km
- GMI, multi-channel wide-band
  - Quantify rain rates between 0.2 {0.3} and 60 mm/hr
  - Detection of snowfall at effective resolution of 15 km
- Estimate precipitation particle size distribution
- Rain rate biases at 50 km resolution <50% at 1 mm/hr; <25% at 10 mm/hr {within the tropics}
- {Outside the tropics: Rain rate biases at 50 km resolution <100% at 1 mm/hr; <50% at 10 mm/hr}
- Rain rate random error at 50 km resolution <50% at 1 mm/hr; <25% at 10 mm/hr {within the tropics}
- {Outside the tropics: Rain rate random error at 50 km resolution <100% at 1 mm/hr; <50% at 10 mm/hr}
- Standard data products (level 1, 2, 3), metadata and documentation available to all users
- Combined radar/radiometer swath products available within 3 hours of observation time, 90% of the time
- Radiometer precipitation products available within 1 hour of observation time, 90% of the time

Full Mission Success
- Meet the Baseline Performance Requirements for a minimum of three years.

Minimum Mission Success
- Meet the Threshold Performance Requirements for a minimum of three years.

Core Observatory Space Segment
- Design life of 3 years, with propellant sized for 5 years
- Orbit maintained to within +- 1 km of operational orbital attitude
- LRD February 2014 [internal commitment]
- Meet NPR 8715.6A and NSS 1740.14 requirements for limiting orbital debris

~~**Low-Inclination Observatory (LIO) Payloads**~~
- ~~TDRS communication subsystem integrated, tested and stored~~
- ~~GMI instrument integrated, tested and stored~~

Budget Requirement:

Ground Segment
- Core observatory monitoring and control (8x5 staffing, with automation at other times, after PLAR)
- Precipitation Processing System operations
- ~~LIO GMI instrument monitoring and control~~
- Ground validation

Core Observatory Launch Segment
- JAXA-provided H-IIA ELV
- Launch from Tanegashima, Japan
- 407 km, 65 degree inclination orbit

De-scope/Re-plan changes
Threshold Performance/Minimum Success

GPM Spacecraft I&T Status

- **Began I&T in Dec 2010 with the delivery of Flight Structure and Flight Harness**
- **Flight-like ETUs integrated on spacecraft where flight hardware not available**
  - Power System Electronics; Flight Unit delivery 12/12/11
  - Command and Data handling (C&DH); Flight Unit delivery #1 12/15/11, #2 2/13/12
  - Mechanisms Attitude Control Electronics (MACE); Flight Unit delivery #1 11/9/11, #2 12/2/11
  - Scalable Space Inertial Reference Unit (SSIRU); Flight Unit delivery 10/29/11
  - Test battery; I&T Battery delivery date 2/2012
- **The following flight hardware have been delivered and integrated on the Core Observatory:**
  - Propulsion subsystem
  - Transponder #1 (#1 requires some rework; Transponder #2 delivery 12/15/11)
  - +Y Solar Array Drive Assembly (SADA #1); SADA #2 integration in progress
  - Propulsion Interface Electronics (PIE)
  - Deployment Firing Unit (DFU)
  - Star trackers, magnetic torquer bars, structure-mounted Coarse Sun Sensors, Three-Axis Magnetometer
  - Reaction Wheel #4 (integrated and removed for rework)
    - All 5 Reactions wheels completed rework, in vibration testing, on track for delivery to I&T on Dec 19, 2011
    - Lunar Reconnaissance Orbiter (LRO) reaction wheel anomaly could impact GPM; proceeding with reaction wheel development pending resolution
  - GPS NAV-A (integrated and removed to complete qualification)
- **High Gain Antenna System completing environmental testing and scheduled for delivery to I&T on 10/23/11**
- **Both Solar Array wings delivered, integration and test in progress**

TRMM Overlap With GPM

- ***Optimal—One year, to include seasonal cycle and compare coincident precipitation***
- ***Minimum for TMI is ~3 months***
- ***Minimum for PR < 3 months–compare surface signals in non-raining areas***
- ***If no overlap***
  - *Compare surface signals over specific land masses (e.g. Sahara, Amazon)*
  - *Active Radar Calibration (JAXA)*
  - *Compare statistics of differences from GV data sets*
- ***Comparison to other satellites***
  - *Megha-Tropiques (French-Indian, launch late 2011)*
  - *GCOM-W (Japanese, launch Feb. 2012)*

Precipitation Algorithms History and Future

- ***V1-V2 changed during launch and instrument checkout–never publically released***
- ***V3 and V4 released within first 6 months***
- ***V5 lasted for ~5 years, V6 for 7 years***
- ***V7 expected to last for at least 5 years, after which new version will use consistent algorithms to merge TRMM and GPM records***
- ***GPM ATBD's, reviewed, approved and in place***
- ***Precipitation Processing System (PPS) Build 3 reviewed in August 2011***

NASA Field Experiments

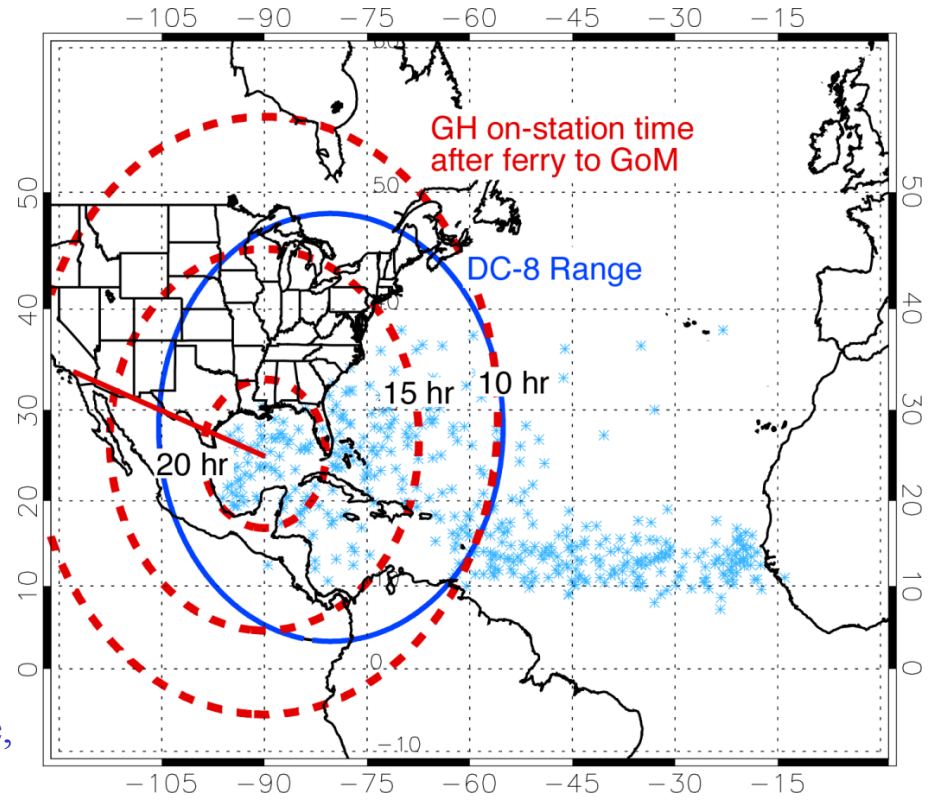
- We do field experiments to accomplish:
- - calibration/validation of satellite sensors
- - evaluation of new sensor concepts
- - process studies

- Since 1998 we have carried out major field experiments in support of hurricane research and precipitation algorithm development

GRIP: (Hurricane) Genesis and Rapid Intensification Processes Field Experiment

- Global Hawk (UAV) (240 hours)
  - Radar (Heymsfield/GSFC), Microwave Radiometers (Lambrigtsen/JPL), Dropsondes (NOAA), Electric Field (Blakeslee/MSFC)
  - Geosynchronous Orbit Simulation
- DC-8 four engine jet (120 hours)
  - Dual frequency precipitation radar (Durden/JPL)
  - Dropsondes (Halverson/UMBC), Variety of microphysics probes (Heymsfield/NCAR)
  - Lidars for 3-D Winds (Kavaya/ LaRC) and for high vertical resolution measurements of aerosols and water vapor (Ismail/LaRC)
  - In-situ measurements of temperature, moisture and aerosols (Bui/ARC)
- WB-57 (60 hours, funded by NOAA)
  - Hurricane Imaging Radiometer
- Six week deployment centered on September 5, 2010

RED= IIP, GREEN= IIP+AITT



Blue line: DC-8 range for 12-h flight, 6 h on station

Red lines: GH range for 30-h flight with 10, 15 and 20 h on station

Light blue X: Genesis locations for 1940-2006

Hurricane and Severe Storm Sentinel (HS3)

Application of the Global Hawk for Hurricane Studies

PI: Scott A. Braun (GSFC)

Science Goal:

To understand hurricane genesis and intensification.

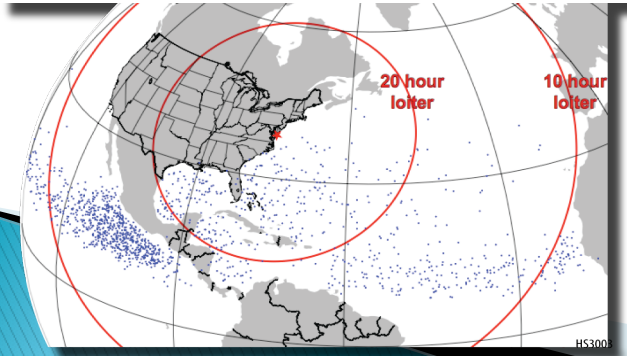
Key Science Questions:

- How do hurricanes form?
- What causes rapid intensity changes?
- How are intensity changes after formation related to upper-tropospheric flow features?
- What's the role of the Saharan Air Layer?

Science Objectives:

- Observing the genesis of tropical cyclones and the intensification from a tropical storm to a hurricane over an extended period - surveillance rather than reconnaissance
- Providing 3-D observations of the wind field both within tropical cyclones and in the environment
- Measuring moisture fields, clouds, aerosols, and precipitation

Genesis Locations and Loiter Times



Two Global Hawk (GH) aircraft

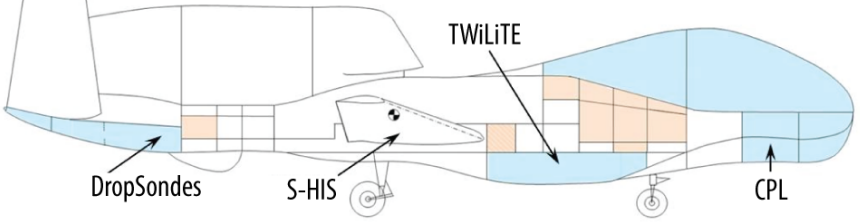
Environment GH instrumentation

- TWiLiTE (direct detection wind lidar)
- CPL (cloud & aerosol lidar)
- Scanning HIS (T, RH)
- Dropsondes (wind, T, RH)

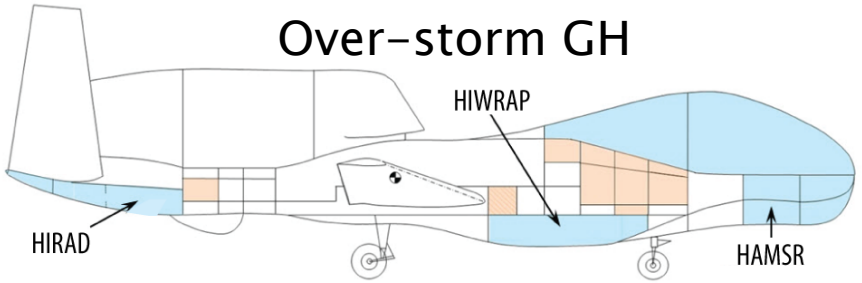
Over-storm GH instrumentation

- HIWRAP (3-D winds plus sfc winds)
- HIRAD (sfc winds and rain)
- HAMSR (T, RH)

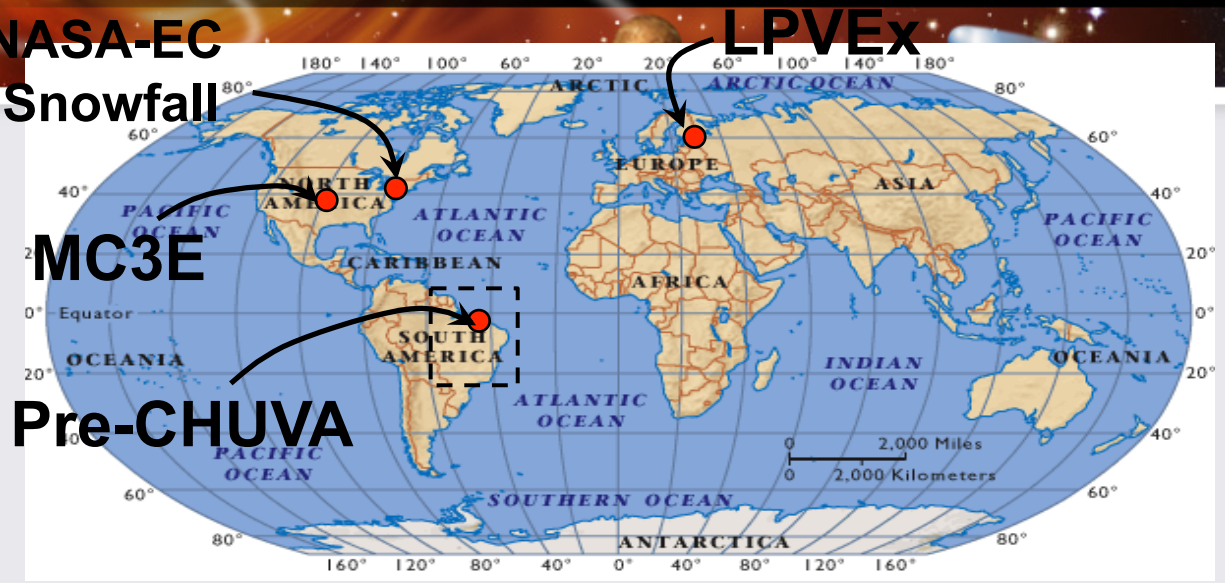
Environment GH



Over-storm GH



Physical Validation: Field Campaigns (2010-2012)



- Pre-CHUVA/CHUVA: GPM-Brazil/NASA GPM tropical rain (warm, ice) field campaign, March 2010
- LPVEX (Light Precipitation Validation Experiment): CloudSat-GPM cold latitude light rain in shallow melting layer situations. Fall 2010
- MC3E (Mid-Latitude Continental Clouds Experiment): GPM-DOE mid-latitude continental rainfall; spring/summer 2011
- NASA-EC Snowfall Campaign: GPM-Environment Canada snowfall research; early 2012

LPVEx Field Campaign (Sept. 15 – Oct. 24, 2010)

Target: Light rain in cold low altitude melting layer environment

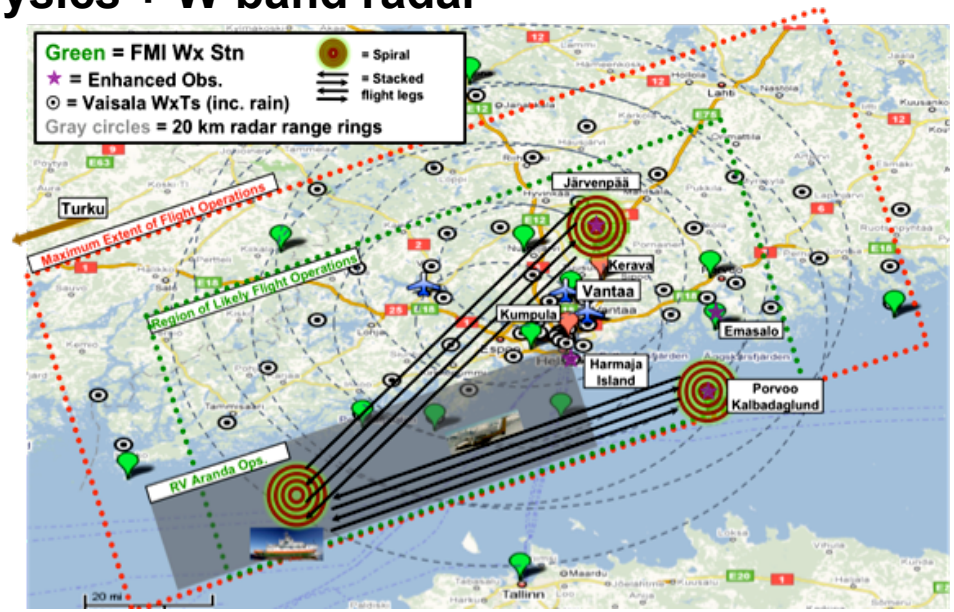
GV Science:

a) Quantify column DSD/precip variability over inland, coastal, sea regimes
b) Melting layer physics coupled to water below and ice above
c) Reconstructed Ka-Ku band (DPR) data for DFR algorithm testing
d) Observationally-validated model databases for radiometer algorithms

Approach:

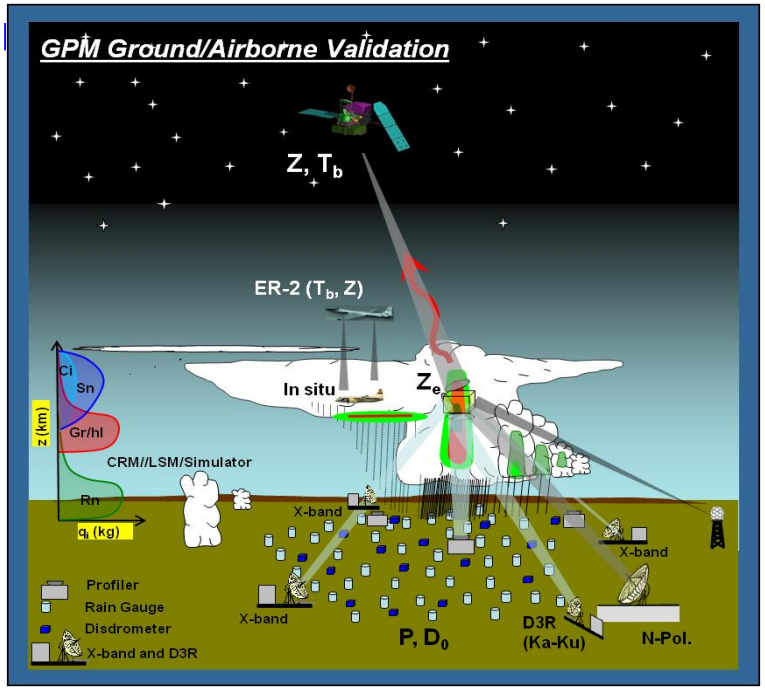
- Heavily instrument surface sites + 1 Ship under radar/aircraft/satellite coverage at Järvenpää (*inland*), Harmaja (*Island)*, Emasalo (*coast*), and R/V Aranda (*sea*)
- 3 Dual-pol radars, 6-8 disdrometers/4-MRRs/ADMIRARI radiometer/3 POSS U. Wyoming King Air Airborne microphysics + W-band radar

Sampling in Helsinki-Testbed
Gulf of Finland



MC3E Field Campaign (April 22 – June 2, 2011)

Target: Mid-latitude variety of convective and stratiform rainfall over la



Location: DOE-ASR Central Facility, Oklahoma

GV Science Priorities

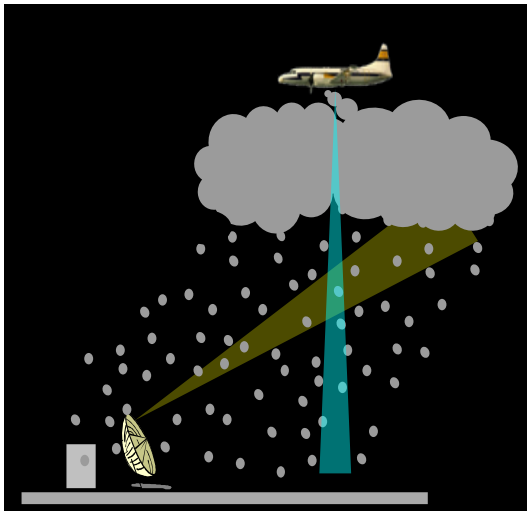
1. **Coordinated Airborne [high altitude/in situ]**
   a. High altitude Ka/Ku-band radar, multi-freq. radiometer with in-situ ice microphysics
   b. Pre/post storm surface properties
2. **3-D Mapping of *hydrometeor distribution/type***
   a. Unified framework for retrieving 3-D DSD
   b. Sub pixel scale DSD variability
   c. Cross validation/comparison of multi-frequency (Ka-Ku) and dual-pol. retrievals
3. **Satellite *simulator models (CRM/LSM/RT)***
   a. High quality sounding-based forcing data
   b. Microphysical and kinematic validation.
   c. Land surface impacts

Confirmed Instruments:

- Aircraft: ER-2, UND Citation (microphysics)
- Radars: NPOL, D3R, DOE X-band(s), C-band, Ka/W, S/UHF profiler
- Surface: Dense disdrometer/gauge net. ASR surface met, radiometer, flux and, aerosol instruments
- Soundings: ASR array 6 – 8 launches/day

International GV Science Collaboration

- *Direct statistical validation (surface)*
- *Precipitation physics validation (vertical column)*
- *Integrated science validation (4-dimensional)*



Active Projects

- Argentina (U. Buenos Aires)
- Australia (BOM)
- Brazil (INPE)
- Canada (EC)
- *Ethiopia (AAU)*
- Finland (FMI)
- France (CNRS)
- *India (ISRO)*
- Germany (U. Bonn)
- Israel (Hebrew U. Jerusalem)
- Italy (CNR-ISAC)
- *Italy (Sapienza U. Rome)*
- South Korea (KMA)
- Spain (UCLM)
- United Kingdom (U. Birmingham)

Proposals in Development

- Cyprus (CMS)
- Germany (MPI)
- Spain (Barcelona)
- Taiwan

Through No-Cost Proposals to NASA PMM Science Program

Finnish Meteorological Institute hosted the 4th International GPM GV Workshop and Environment Canada will host the 5th one in July 2012

Recent GPM Agreements

- - To formalize MT's participation in GPM, NASA & CNES have signed an implementation agreement and NASA & ISRO plan to sign one this month.

  - NASA-AEB have signed a Cooperative Agreement on GPM Scientific Collaboration.

  - NASA & NOAA are finalizing an Interagency Agreement on GPM cooperation.

  - NASA and EUMETSAT are in discussion to formalize EUMETSAT's contribution to GPM with a bi-lateral MOU.
  (Note that EUMETSAT already agreed to providing MetOp data to GPM through NOAA without a formal partnership.)

  - NASA & EC have signed an agreement to jointly conduct the GCPEX in Ontario, Canada, Jan-Feb 2012.

NASA Research Announcement

Science Mission Directorate
New NASA Research Announcement Expected
Precipitation Science Team
Solicitation: NNH12ZDA001N
Date Released February 2012
NOIs Due June 15, 2012
Proposals Due September 30, 2012
Funds likely to be available: ~ $7.5 M/year for 3 years
Number of Awards: 45-50 out of ~150 proposals

This solicitation will be for the selection of the 8th Precipitation Science Team

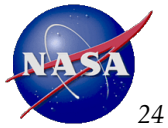
No-cost research proposals can be accepted from international investigators to complement existing science team activities

Some Recent and Upcoming Meetings of Interest

- JPST + JAXA PMM Science Team, Tokyo, Japan; April 2010
- 4th International GPM GV Workshop, Helsinki, Finland; June 2010
- Annual NASA PMM Science Team +JPST Meeting, Seattle, Washington; November 1-5, 2010
- Annual NASA PMM Science Team +JPST Meeting, Denver, Colorado; November 7-11, 2011
- CEOS Precipitation Constellation meeting, Denver, Colorado; November 10, 2011
- 5th International GPM GV Workshop, Toronto, Canada; July 10-12, 2012

Summary

- *TRMM easily passed the Senior Review*
- *Majority of the TRMM Spacecraft and Instruments are still in good shape*
- *GMI #2 has been descoped*
- *GPM replan has been approved by the NASA APMC and the launch of the core satellite is set for February 2014*
- *We expect some TRMM GPM overlap*
- *Considerable activity is ongoing to develop precipitation algorithms and the Precipitation Processing System*
- *A few field experiments have been carried out and more are planned to support algorithm development activities*
- *We plan to issue a ROSES call in February 2012 for the selection of the 8th PMM science team*



Impact of 2-3 more years of TRMM

- ***Comparison to other satellites***
  - *Megha-Tropiques (French-Indian, launch late 2011)*
  - *GCOM-W (Japanese, launch Feb. 2012)*
- ***Field campaigns***
  - *Hurricane and Severe Storm Sentinel (HS3) during hurricane seasons of 2012-14*
  - *Hydrometeorological Testbed-East*
    - *GPM and NOAA pre-launch field campaign in 2013 in southeast U.S.*