



## Design Overview of the Thermal Control System for the SMAP Mission

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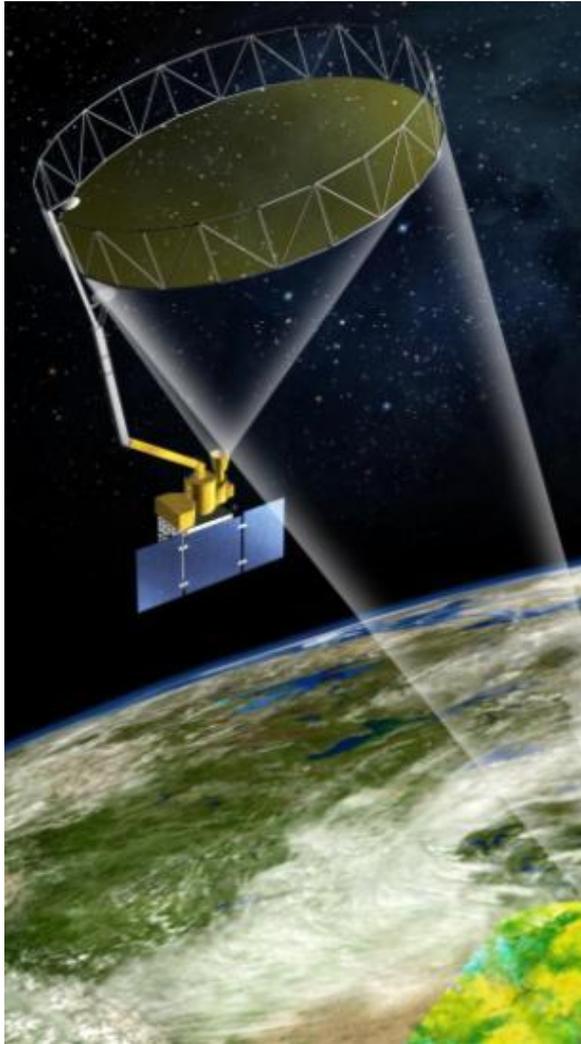


Presented By  
Nick Emis

Thermal & Fluids Analysis Workshop  
TFAWS 2012  
August 13-17, 2012  
Jet Propulsion Laboratory  
Pasadena, CA



# SMAP Project Overview



<http://smap.jpl.nasa.gov/>

*SMAP is a first-tier mission recommended by 2007 NRC Earth Science Decadal Survey*

## *Primary Science Objectives :*

**Global, high-resolution mapping of soil moisture and its freeze/thaw state to:**

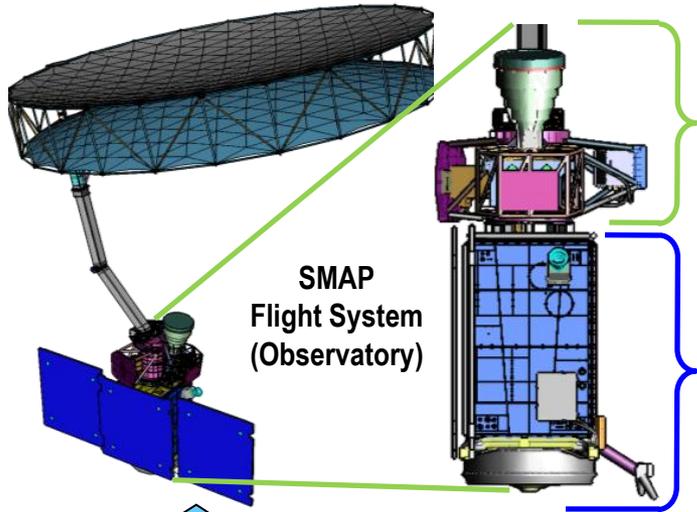
- Link terrestrial water, energy and carbon cycle processes
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Extend weather and climate forecast skill
- Develop improved flood and drought prediction capability

## *Mission Implementation:*

<b>Partners</b>	<ul style="list-style-type: none"><li>• JPL (project &amp; payload mgmt., science, spacecraft, radar, mission operations, science processing)</li><li>• GSFC (science, radiometer, science processing)</li></ul>
<b>Risk</b>	<ul style="list-style-type: none"><li>• 7120.5D Category 2; 8705.4 Payload Risk Class C</li></ul>
<b>Launch</b>	<ul style="list-style-type: none"><li>• Oct. 2014, Delta II LV</li></ul>
<b>Orbit</b>	<ul style="list-style-type: none"><li>• Polar sun synchronous; 685 km (equatorial) altitude, 98 minute orbit</li></ul>
<b>Duration</b>	<ul style="list-style-type: none"><li>• 3 years</li></ul>
<b>Payload</b>	<ul style="list-style-type: none"><li>• L-band (non-imaging) synthetic aperture radar (JPL)</li><li>• L-band radiometer (GSFC)</li><li>• Shared 6m rotating (14 rpm) antenna (JPL)</li></ul>



# Mission Overview

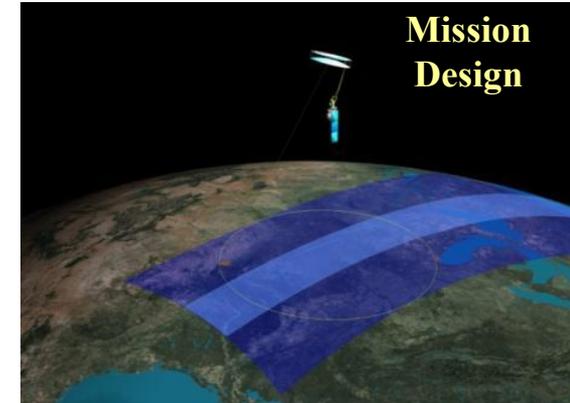


## INSTRUMENT

- L-band (1.3-GHz) Radar (JPL)
- L-band (1.4-GHz) Radiometer (GSFC)
- Shared antenna (6 m diameter)
- Conical scan: 13–14.6 rpm; 40 incidence
- Contiguous 1,000-km swath width

## SPACECRAFT (& RADAR ELECTRONICS)

- JPL-developed & built
- JPL's MSAP/MSL avionics, power assys with a small number of new mission-unique card designs
- 1160 kg wet mass (Observatory-level)
- 1100 W capacity (Observatory-level)
- 80 kg propellant capacity
- Commercial space electronics elsewhere



- 685-km polar orbit (Sun-sync)
- 8-day repeat ground track
- Continuous instrument operation
- 2- to 3-day global coverage
- 3-year mission duration



- SMAP recently selected Delta II launch vehicle in July '12
- Planned launch date: Oct 31, 2014

Near-Earth Network



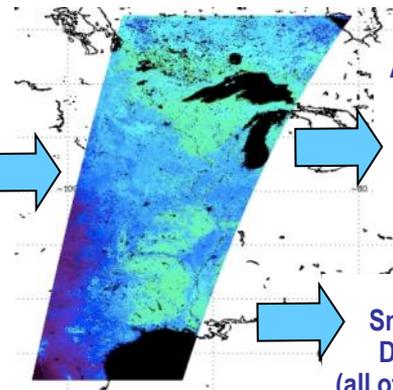
Surface Validation



SMAP Mission Operations & Data Processing (JPL, GSFC)

## SCIENCE DATA PRODUCTS

Soil Moisture & Freeze/Thaw State Data Products



Alaska Satellite Facility Data Center (Radar L1 Products)

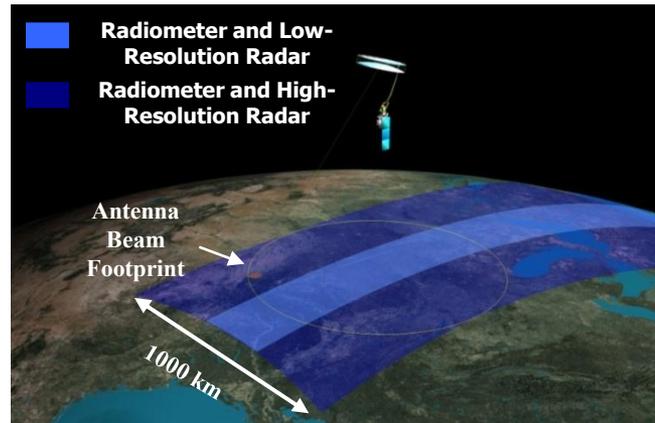
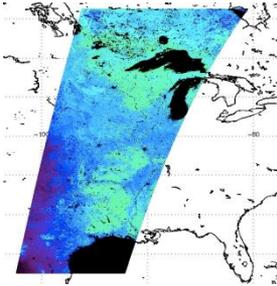
National Snow and Ice Data Center (all other Products)



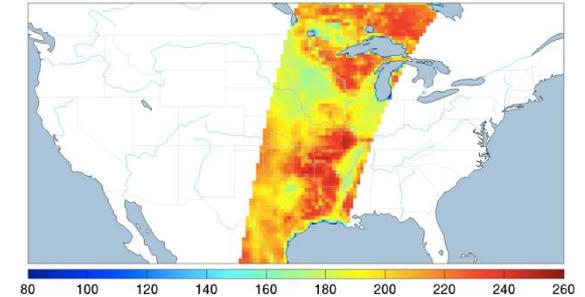
# Mission/Science Driving Requirements



HI-RES RADAR BACKSCATTER PRODUCT (1-3 KM)



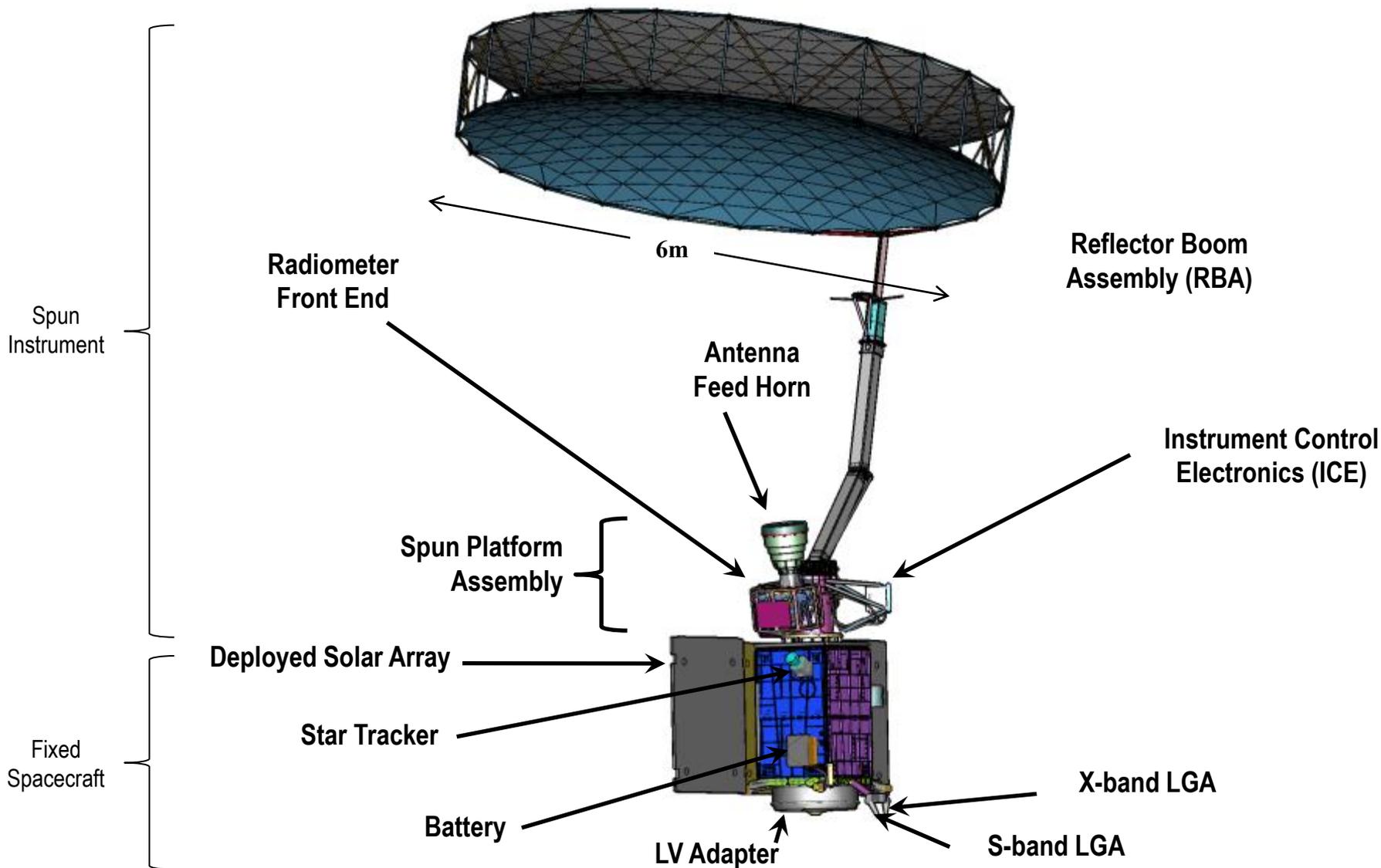
RADIOMETER BRIGHTNESS TEMPERATURE PRODUCT (40KM)



- Two to three day global coverage
  - Drives requirement for conically scanning antenna
- Spatial resolution at 10 km and 3 km for soil moisture and freeze-thaw products
  - Drives 6 meter antenna size, synthetic aperture radar design
- Soil moisture measurement accuracy, including through moderate vegetation
  - Drives requirements for combined active and passive instrument combination
  - Drives the thermal stability requirements for both radiometer and radar
  - Drives requirement for dual polarizations
- Dynamics and control of the scanning antenna to ensure pointing requirements are met while spinning at 14.6 rpm
  - Drives mass properties, antenna optics, spin rate stability/accuracy requirements of the spun instrument
- Characterizing/bounding the terrestrial RFI environment early and ensuring that mitigations are adequate to prevent unacceptable degradation to science data
  - Drives radiometer and radar electronics designs
- Compatibility with existing FAA Radars in shared L-band spectrum allocation
  - Drives radar duty cycle and peak power requirements



# Observatory Configuration

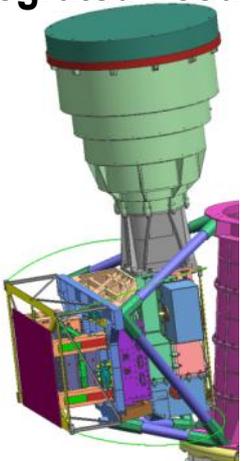




# Spun Instrument Configuration



## Integrated Feed Assy

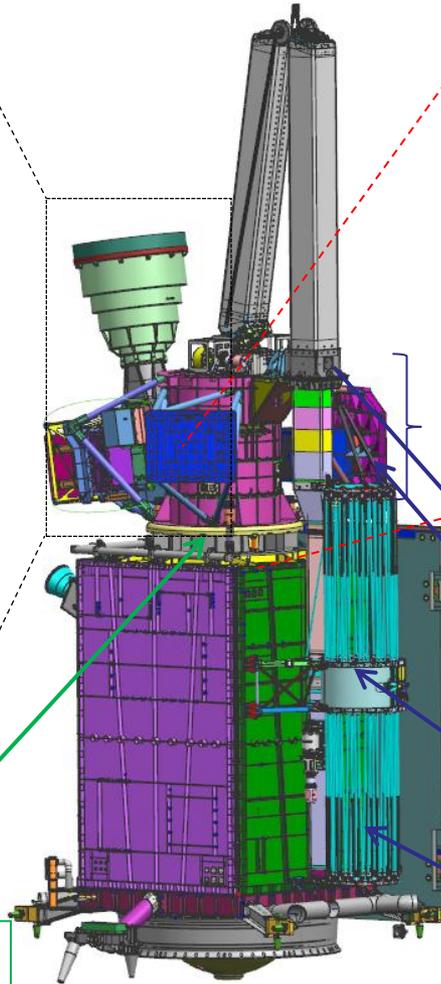


RFE & Passive RF components mounted to "stacked plate" structure

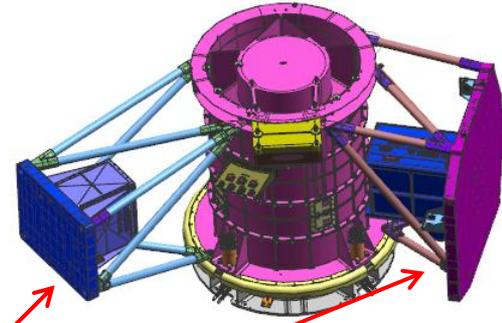
Feed Assembly mounted to RFE Plate

Assembly mounted to core structure using 3 bi-pods

## Cone-Clutch Assembly



## Radiometer Electronics



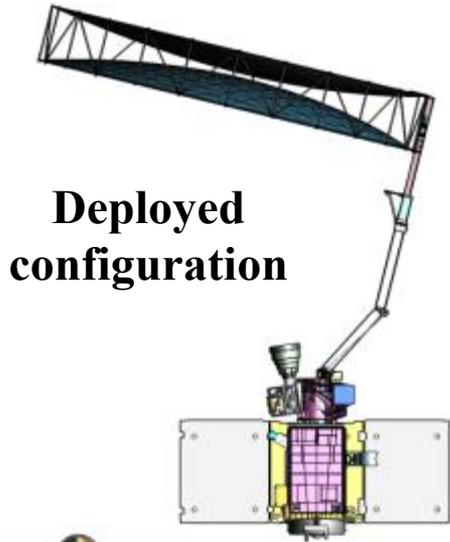
ICE and RDE/RBE mounted to separable structures with mounting surface used as radiators

## RBA Launch Restraints

- Boom Restraint
- Upper Hoop Restraint
- Cradle
- Lower Hoop Restraint



# Observatory Overview



**Deployed configuration**



**Stowed configuration**

## Mission Overview

- 2- to 3-day global coverage
- 685-km Sun-sync orbit, 6 p.m.

## Observatory Summary

- 3-axis-stabilized spacecraft, providing momentum compensation for spinning antenna
- Single-string avionics and power control/distribution electronics
- Limited redundancy in ACS sensors and actuators, and telecom radios
- S-band telecom and 130 Mbps science data return via X-band link
- Deployable, fixed solar array
- Hydrazine blow down propulsion system
- Passive and heater-based thermal control with bus structure serving as radiators

## Propellant

- 80.0 kg usable capacity
- Delta-V: 112.6 m/s (includes contingency)
- Propellant budget: 74.2 kg (includes contingency)

## Combined Instruments

- L-band (1.26 GHz) Radar
- L-band (1.41 GHz) Radiometer
- Shared antenna (6 m diameter) rotating fixed rate 13 to 14.6 rpm

## Mass

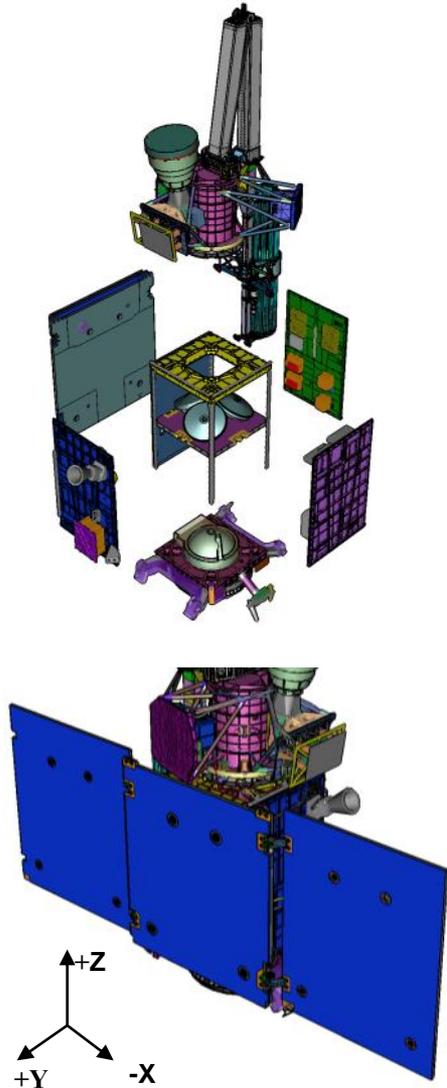
- Spacecraft: 527 kg (CBE)
- Instrument: 312 kg (CBE)
- JPL DP mass margin: 22%

## Power

- 1023 W (science mode load), via 3-panel deployable solar array
- 59-Ah BOL battery for launch, eclipse, and other off-Sun modes
- JPL DP power margin: 22%
- Nominal bus voltage: 29.4 – 32.8 V
- Fault bus voltage: 24–29.4 V and 32.8–34 V



# Spacecraft Overview



## External Configuration

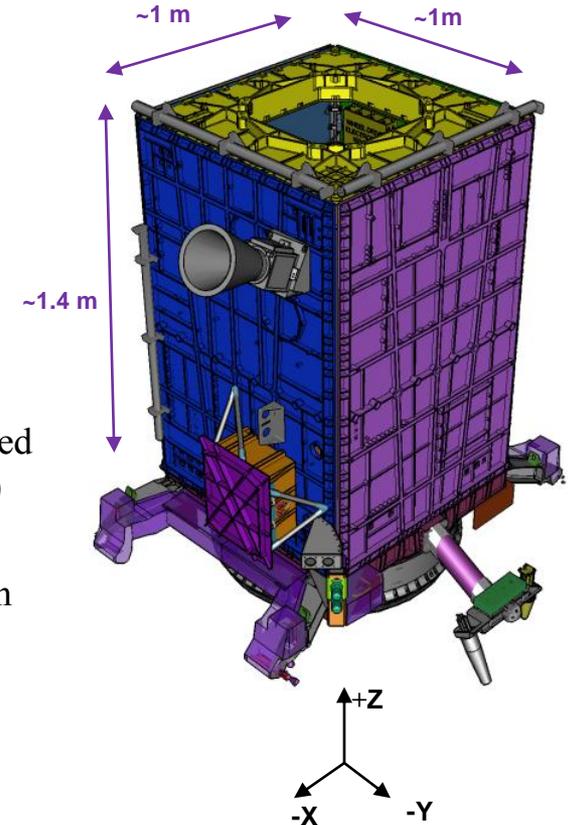
- Solar arrays are  $\sim 8.0 \text{ m}^2$ 
  - ❖ Single stage deployment
  - ❖ Cell type are triple junction,  $\eta = 28\%$
- 59 A-hr battery outside of  $-X$  panel
- Thruster clusters at corners of  $-Z$  deck
- Telecom antennas located on outrigger

## Internal Configuration

- Highest power instrument radar H/W mounted on  $-Y$  panel (anti-sun side, thermally stable)
- Four reaction wheels on mid-deck
- Propulsion tank protrudes into LV separation plane by  $\sim 4$  inches

## Spacecraft is 3-axis stabilized

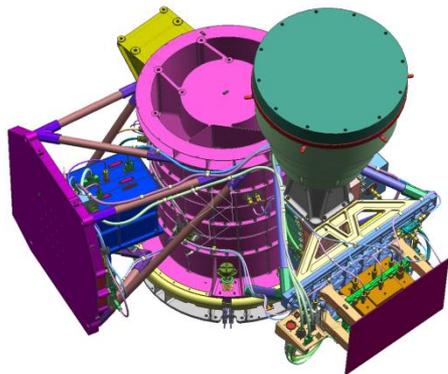
- $+X$  (direction SC is traveling)
- $+Y$  (direction of sun)
- $-Z$  (direction of earth, nadir)



**E Configuration**  
(as of 2/19/2012)

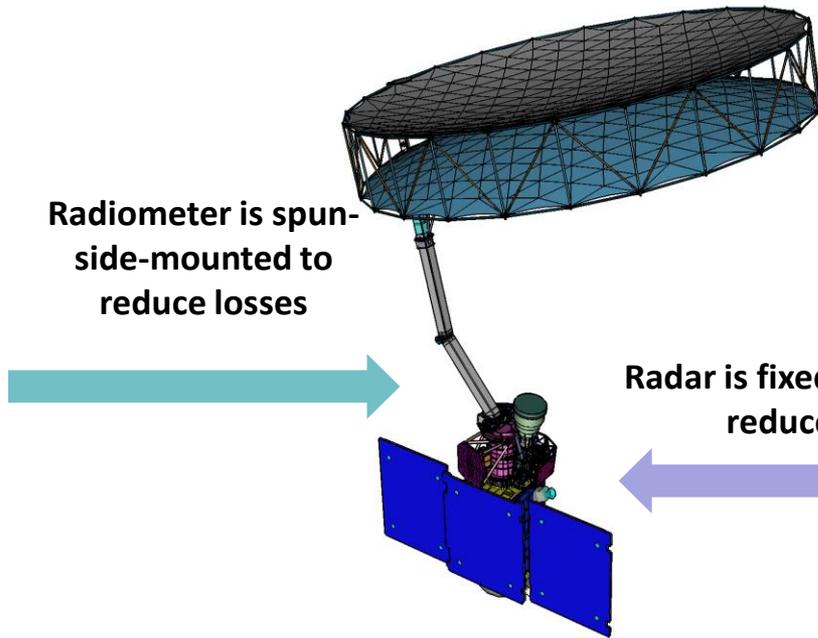


# Instrument Overview



## Radiometer

- Provided by GSFC
- Leverages off Aquarius radiometer design
- Includes RFI mitigation (spectral filtering)
- 1400–1427 MHz
- Polarizations: V, H, 3<sup>rd</sup> & 4<sup>th</sup> stokes
- 1.3-K accuracy
- 40-km resolution
- 4.3-Mbps data rate

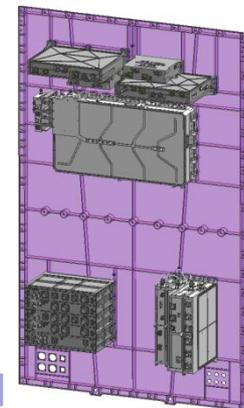


Radiometer is spun-side-mounted to reduce losses

Radar is fixed-mounted to reduce spun inertia

## Common 6-m Spinning Reflector

- Spin Assembly and Reflector/Boom Assembly derived from heritage designs
  - RBA provided by NGAS-Astro
  - BAPTA provided by Boeing
- Spun structure & thermal from JPL
- Conically scanning at 13–14.6 rpm
- Constant incidence angle of 40-deg



## Radar

- Provided by JPL
- Leverages off past JPL L-band science radar designs
- 1-MHz chirps tunable over 1217–1298 MHz
- Polarizations: VV, HH, HV
- 500-W SSPA (9% duty cycle)
- 3-km spatial resolution
- 35-Mbps data rate



- **Maintain a simple, reliable, inexpensive thermal design**
  - Primarily passive design (use radiator/MLI as thermal control surfaces)
  - Most active heaters use mechanical thermostat control for replacement heat
  - Flight software controls external propellant line heaters and RFE heaters
- **Each electronics box conductively coupled to structural panel (doubles as a radiator)**
  - Contact conductances results in 2-5°C gradients between elec boxes and panels
  - Instrument subassemblies each have their own dedicated radiators and replacement heaters
- Must maintain components within Allowable Flight Temperatures (AFTs) per ERD
  - Initial goal was to size radiators to give ~5°C hot-case margin to AFT
  - Thermostat-controlled heaters sized to keep 2°C (redundant heaters) to 5°C (primary heater) margin against cold Op/Non-op AFTs during cold/safe cases
- **MLI blanketing (15 layer) used to block off panel area** to provide required radiator area
  - MLI blanket properties:  $\varepsilon^*_{\text{hot}} = 0.02$  and  $\varepsilon^*_{\text{cold}} = 0.05$
- Optical properties
  - **End-of-life (EOL) for hot cases, beginning-of-life (BOL) for cold cases**



# Power/Mass Inputs to Thermal Model



- Component power dissipations
  - Hot Science: “Science and Telecom” CBE + Contingency from PEL (10-30% contingency for most components)
  - Cold/Safe Mode: 90% of “Science” or “Safe” CBE
    - For Safe Mode - spacecraft is nadir pointed, similar to science orbit
      - Fixed attitude is conservative compared with safe mode rotisserie roll
  - Transient cases analyzed for commissioning phases, transitions, and special operational cases (maneuvers, cold sky calibration)
- Component Mass
  - Use CBE from MEL (less mass is conservative for any stability calculations)



# Spacecraft Thermal Overview



Spacecraft Thermal Design

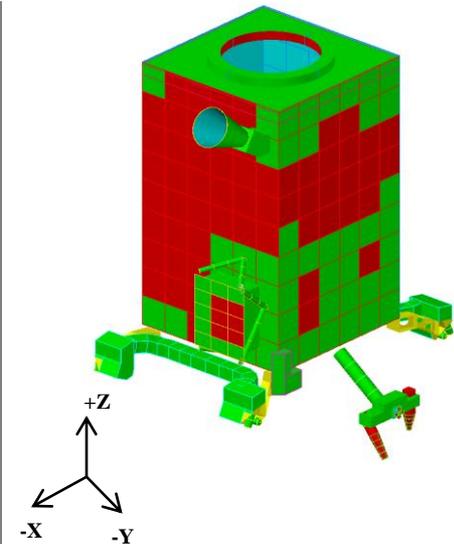
- Simple, inexpensive, low-risk thermal design
  - Mostly passive design features (MLI, radiators supply cold biasing)
  - Electronics conductively coupled to radiator panels
    - CDH / Power panel (-X) = 162 W (CBE)
    - Radar panel (-Y) = 220 W (CBE)
    - GNC / Telecom panel (+X) = 111 W (CBE)
  - MLI coverage optimized to reject electronic heat and conserve survival heater power
  - Some active design features (primary and redundant heater circuits)
    - Most Kapton film heaters controlled via mechanical thermostats
    - FSW controlled propellant line heaters
  - Battery temperature controlled via dedicated radiator/MLI/heaters
    - Externally mounted battery is thermally isolated from SC -X panel
  - Graphite heat spreaders on CDH (-X) panel under high powered H/W
    - K-Core (APG) thermal doubler from Thermacore

- Inst. SIA is mechanically coupled to S/C deck (by design, there is a poor thermal path from instrument to SC)
  - Integrated model assesses SC and instrument thermal performance

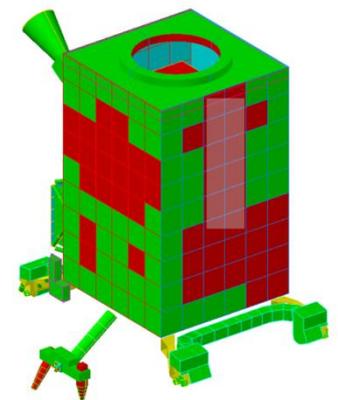
- Earth orbiter
  - 685 km altitude
  - 98° inclination (Beta angle = 58° to 89° , max eclipse = 19 min)

Observ. Design

Mission Design



MLI/Radiator coverage (Green = MLI) (Red = radiator)

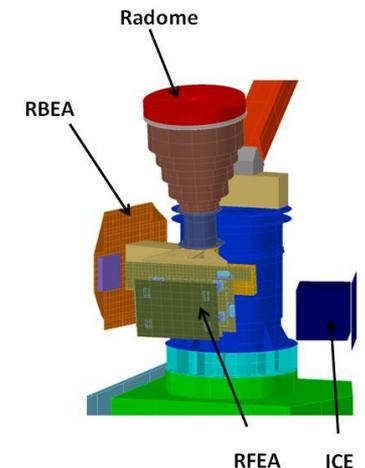
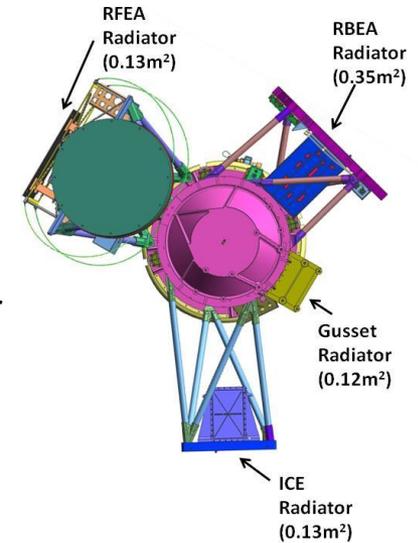




# Spun Instrument Thermal Overview



- SMAP instrument thermal design is challenging and requires frequent interaction with the mechanical team to implement
  - Highly variable thermal environment results from fast spinning platform
  - Tight thermal stability is critical to success of radiometer
  - BAPTA bearing gradient is coupled to the SC top deck temperature
- 4 thermal enclosures are part of the spun platform; each has a dedicated radiator for proper thermal management
  - RFEA (Radiometer Front End Assembly) = 11.0 W (CBE+unc)
  - RBEA (Radiometer Back End Assembly) = 62.9 W (CBE+unc)
  - ICE = 35.7 W (CBE+unc)
  - BAPTA/RJA = 8.24W (CBE+unc)
- Silvered teflon used for radiators to meet temporal stabilities
- RFEA and OMT enclosed within an MLI cocoon for better short term stabilities
- Active control for RFEA to address gain glitches (control authority range of 15°C )
- Feedhorn closed by EPS radome to eliminate sun illumination
- Single string survival heater architecture to minimize slip ring usage



\* RFEA cocoon and RBEA MLI tent removed



# Summary of Thermal Control Hardware



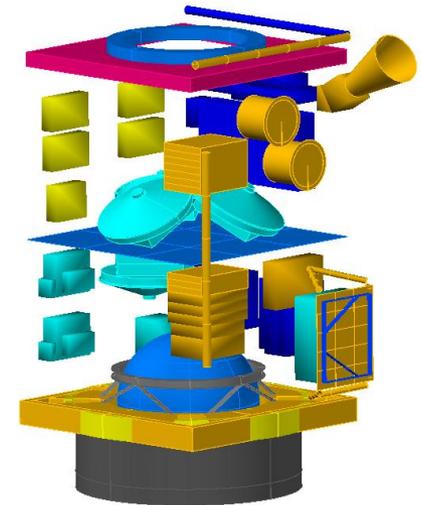
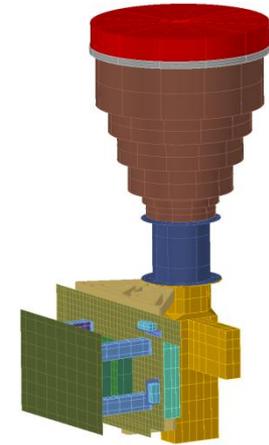
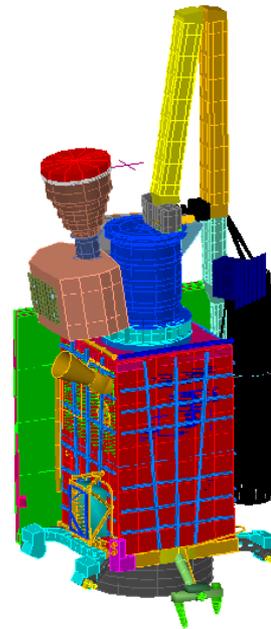
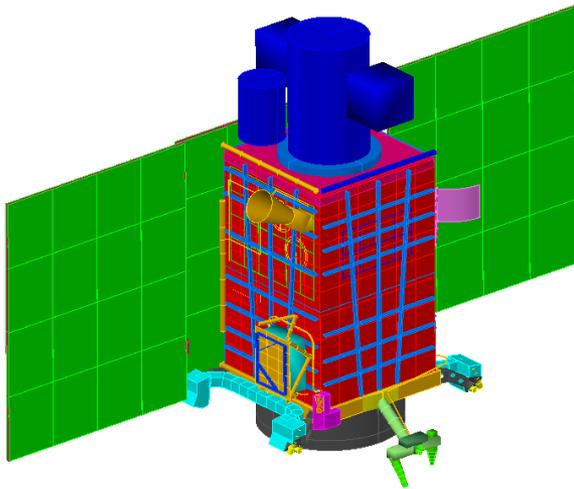
- **Kapton film heaters (Tayco/Translogic)**
  - SC uses primary and back-up circuits, with 2 thermostats per heater
    - Flight software controlled heaters on the external propellant line
  - Instrument uses single string survival heaters, with 4 thermostats per heater, except RBA heaters
    - SIA operational heaters are powered by ICE
- **Thermostats (Honeywell)**
  - Thermostats primary turn-on temperature is 2-5C above AFT (with 7C dead-band)
- **Thermal sensors (Honeywell/Goodrich PRT or Boeing Thermistor)**
  - Use 500, 1000, or 2000 ohm PRT or Boeing thermistor for health & status and active heater control
- **APG Doubler/Bracket (Thermacore/K-Core)**
  - High conductivity APG used to transfer heat along SC panel
  - Instrument uses it as a highly conductive structural member to support RFEA radiator
- **Passive thermal control elements**
  - Thermal paints, coating, and isolators use typical JPL parts/processes
  - MLI provides passive isolation from external environment. Typical JPL blankets will be used throughout SMAP



# Thermal Desktop Model Description



- AutoCad Mechanical 2012 – Create geometry (based on mechanical NX CAD model)
- Thermal Desktop 5.4 – Calculate radiation exchange factors, describe orbits and calculate heat rates
  - Absorbed flux vs time arrays used for transients (orbital average for any steady state runs)
- Sinda Fluint 5.4 – Calculate temperatures/heat flows

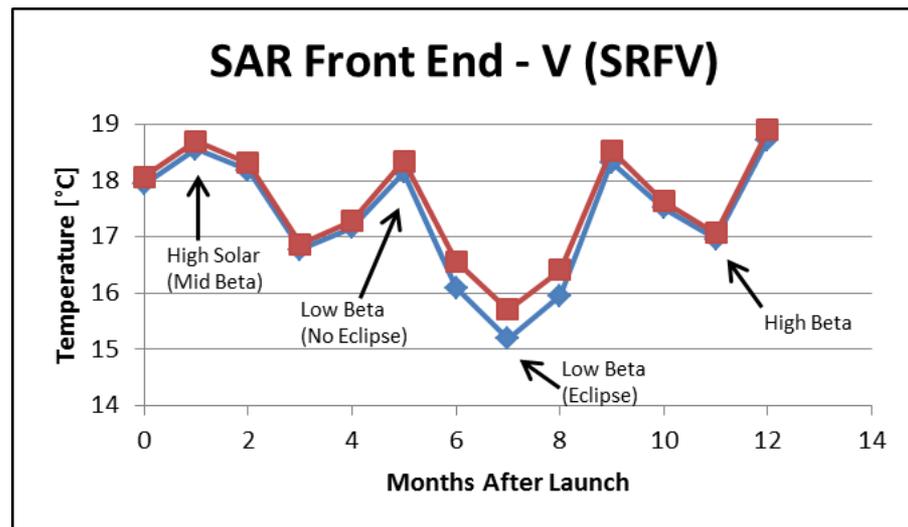
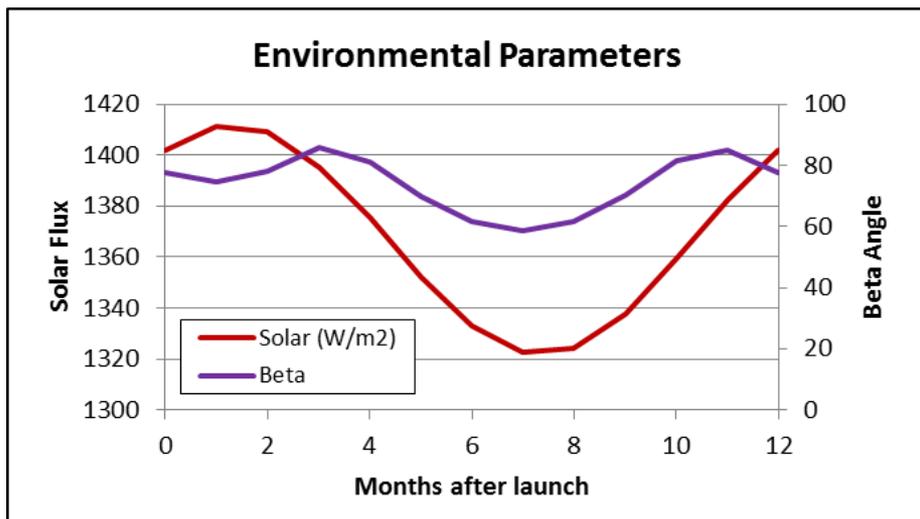
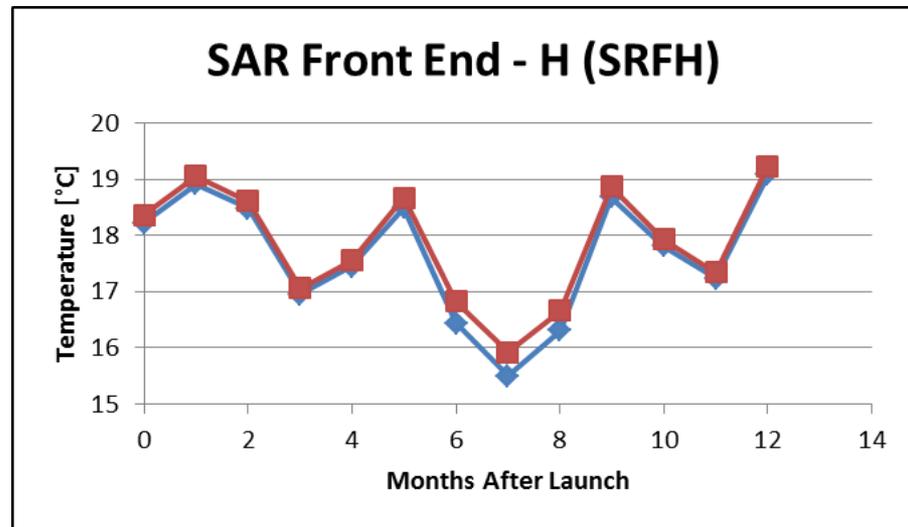




# Radar Seasonal Temperature Variations

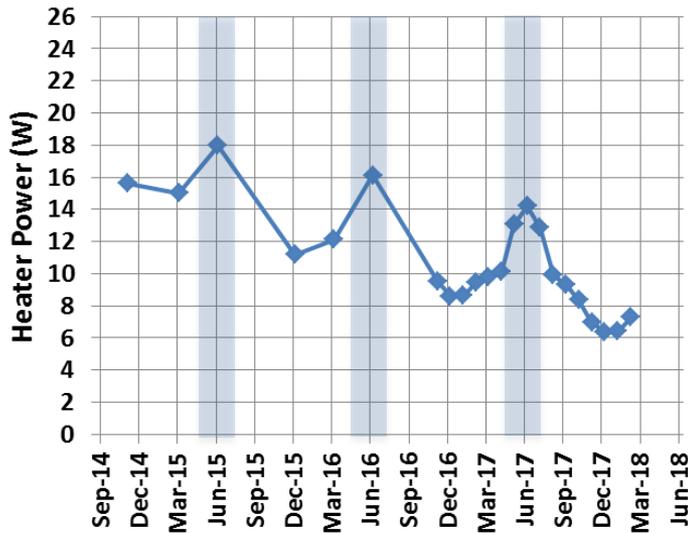
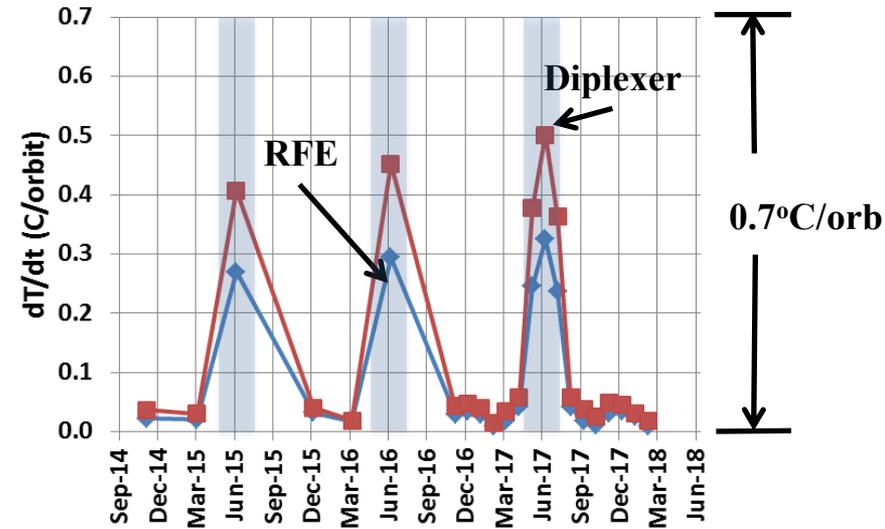
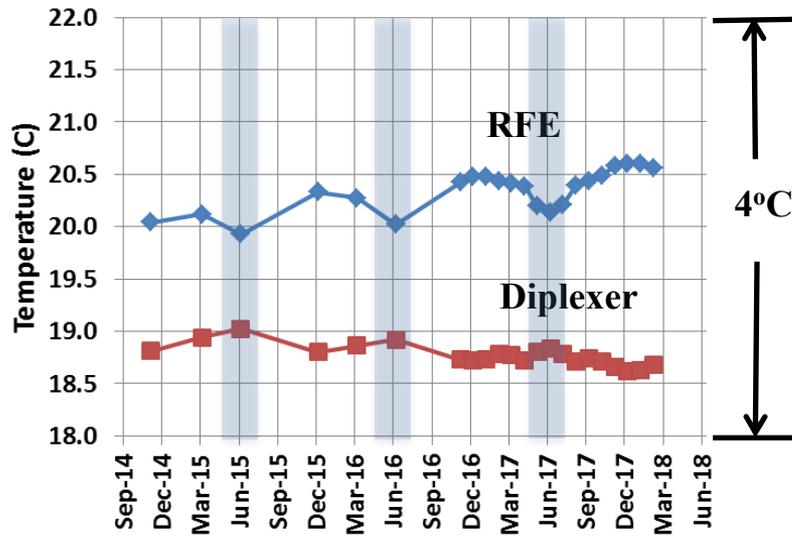


- Temperature trends follow the expected environmental loads (solar / beta inputs and optical property degradation)
- Low beta/long eclipse period results in largest orbital variation
  - Radar panel is most thermally stable (constantly viewing cold space)
- Yearly variations are small compared to 10°C requirement
- Orbital variations are small (1°C) compared to 4°C requirement





# Radiometer 3 Year Mission Life



- Modified P control is good enough to meet all stability requirements
  - The design meets stability requirements with passive thermal design
  - ATC used to correct for gain glitch temperature set point (which has been seen on previous radiometers)



# Conclusions



- Primarily passive thermal control (MLI/thermal control surfaces) provide simple/robust solution
  - Some active components (FSW and mechanical thermostatically controlled heaters) used for survival and operational heaters
- Current work demonstrates that the current thermal design is acceptable and will meet all thermal requirements
- Thermal stability requirements for radar and radiometer are met