Climate Goal Impacts & Possible Mitigations with a Certified NPOESS

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Outline

- Climate Program Needs from Space-based Sensors
- NPOESS & Nunn-McCurdy Certification
- Joint NASA-NOAA Climate Goals and NPOESS
  - Collaboration between NASA / NOAA
  - Joint Climate Goal Priorities
  - Summary of Recommendations
    - NPOESS Climate Sensor and Mitigation priorities

Climate Change Study Requires Long Time Series

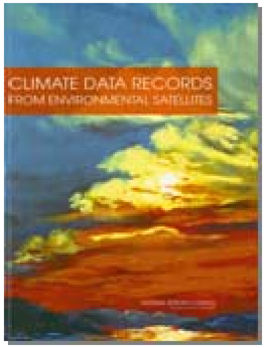
- Climate Change patterns are likely occurring in many variables
  - Establishing a ‘reference’ climate requires data series extending beyond natural, cyclical or spurious events (e.g., solar cycle)
  - Relating variables can help in attribution and prediction
  - Data ‘environments’ are needed to inform models on current state and current trends

- Interannual change can be very small and masked by noise or natural variability
  - Changes are persistent trends
  - Scientific search requires both well-established climatic reference values and long time series which allow decomposition of signal and noise

Climate Data Records

Formalizing CDR Concept

- A climate data record is a "time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change"



NAP, 2004

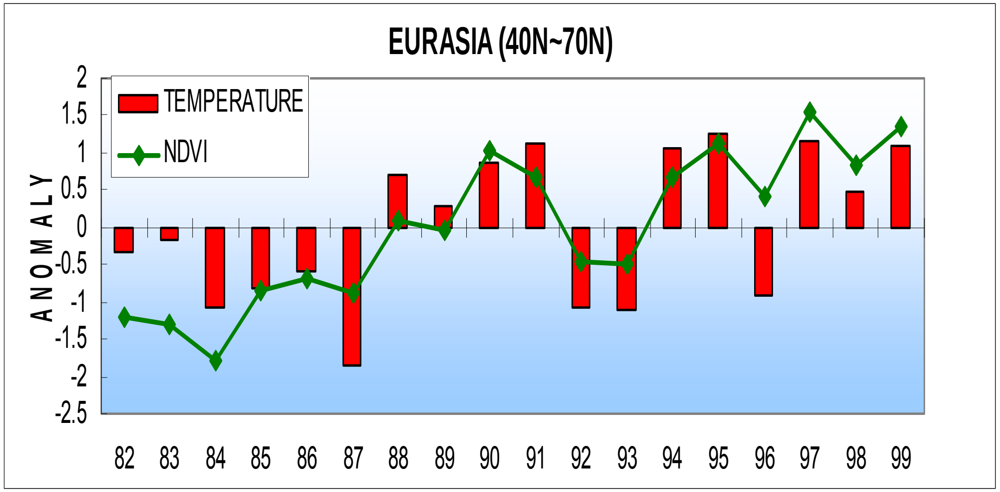
- Characteristics include:
  - Long-term (multi-decadal)
  - Multi-satellite/multi-sensor (possibly 'fused' data sources)
  - Seamless, unified and coherent
    - Normalized (absent of observatory and sampling artifacts)
  - Peer-reviewed, "best practice" or "community" algorithms
  - Validated (uncertainty well-characterized)
  - Well documented (incl. peer-reviewed literature)
  - Comprehensive metadata and QA information
  - Active data stewardship (planned reprocessings, refreshed storage media, "known issues" publicly posted)

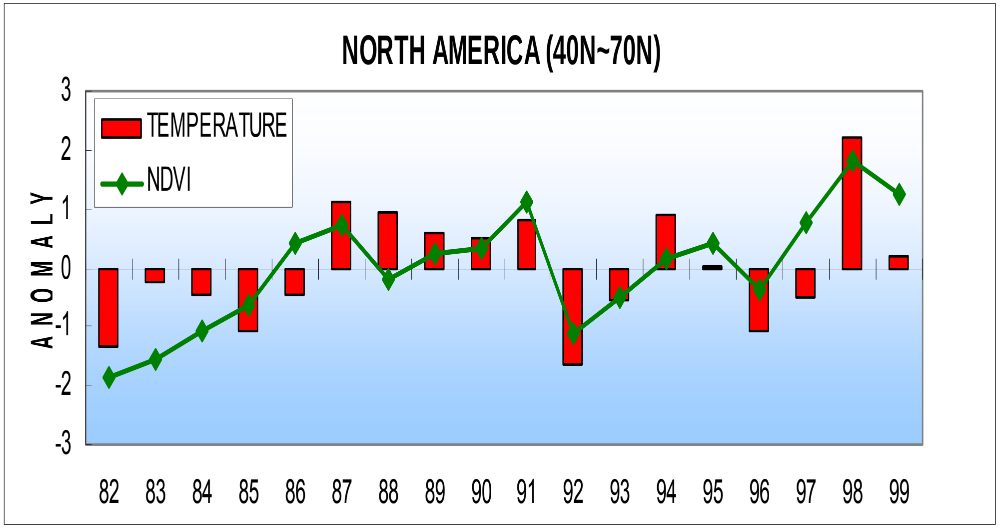
Example of Change Detected from AVHRR "CDR"

Northern latitude "greening" found from AVHRR vegetation index

Culprit: Longer growing seasons due to warming temperatures

- "Anomaly" is determined relative to reference climate information (statistics) derived from long time series of well-calibrated products





Courtesy Ranga Myneni

Climate Program Driving Variables

Essential Global Climate Variables *(from CCSP & GCOS)*

1. *Atmospheric Variables*

The following essential atmospheric variables are required over land, sea and ice:

1.1 Surface

- ***a.*** Air temperature
- ***b.*** Precipitation
- ***c.*** Air pressure
- ***d.*** Surface radiation budget
- ***e.*** Wind speed and direction
- ***f.*** Water vapor
- ***g.*** Evaporation & evapotranspiration

1.2 Upper-air

- ***a.*** Earth radiation budget (including solar irradiance)
- ***b.*** Upper-air temperature (including MSU radiances)
- ***c.*** Wind speed and direction
- ***d.*** Water vapor
- ***e.*** Cloud properties

1.3 Composition

- ***a.*** Carbon dioxide
- ***b.*** Methane
- ***c.*** Ozone
- ***d.*** Other long-lived greenhouse gases *
- ***e.*** Aerosol properties

Climate Program Driving Variables

Essential Global Climate Variables *(from CCSP & GCOS)*

2. *Ocean Variables*

2.1 Surface

- ***a.*** Sea-surface temperature
- ***b.*** Sea-surface salinity
- ***c.*** Sea level
- ***d.*** Sea state
- ***e.*** Sea ice
- ***f.*** Current
- ***g.*** Ocean color (for biological activity)
- ***h.*** Carbon dioxide partial pressure
- ***i.*** ocean surface wind & wind stress
- ***j.*** Surface air temp/humidity
- ***k.*** Precip (fresh water/salinity flux)
- ***l.*** Evaporation
- ***m.*** Fresh water flux from rivers & ice melt
- ***n.*** CO_2 flux across the air sea interface
- ***o.*** Geothermal heat flux – ocean bottom

2.2 Sub-surface

- ***a.*** Temperature
- ***b.*** Salinity
- ***c.*** Current
- ***d.*** Nutrients
- ***e.*** Carbon
- ***f.*** Ocean tracers
- ***g.*** Phytoplankton

3. *Terrestrial Variables*

- ***a.*** Snow cover
- ***b.*** Glaciers and ice caps
- ***c.*** Permafrost and seasonally-frozen ground
- ***d.*** Albedo
- ***e.*** Land cover (including vegetation type)
- ***f.*** Fraction of absorbed photosynthetically active radiation (FAPAR)
- ***g.*** Leaf area index (LAI)
- ***h.*** Biomass
- ***i.*** Land surface temp

Overview of Nunn-McCurdy Certification

Climate Goal Impacts

- **Nunn-McCurdy certified NPOESS**
  - Priority placed on continuity of operational weather measurements
  - Pre Nunn-McCurdy: 3 orbits and 6 spacecraft
  - Post Nunn-McCurdy: 2 orbits and 4 spacecraft

- **Impacts to Climate Sensors**
  - **Five climate oriented sensors de-manifested**
    - APS (aerosols), TSIS (solar irrad.), OMPS-Limb (ozone), ERBS (radiation budget), ALT (ocean altimetry)
    - Instruments flown only if developed outside of NPOESS program
  - **Three climate oriented sensors have reduced coverage**
    - VIIRS (imagery), CrIS (thermal sounder), ADCS (data relay)
    - One less flight per day
  - **One climate oriented sensor will have reduced capability**
    - CMIS (μwave sounder)
    - Build a less expensive, less capable instrument of the same type

Specific Deficits

- Science
  - Some work on climate change detection, understanding, prediction, and attribution will be curtailed or not possible (e.g., ALT is needed to monitor ocean level rise)
- Data Continuity
  - Some critical Climate Data Records will cease (e.g., solar irradiance monitoring started in 1979; now slated to end in ~2014)
- Measurement Overlap
  - Some sensors will not be able to achieve the required accuracy since they require on-orbit co-calibration with predecessor (e.g., CERES-to-"ERBS-like-sensor" transition)

METOP Lessens Some Impacts

- EUMETSAT's METOP program can provide some capabilities lost due to elimination of the the mid-AM orbit
  - Sensor Substitutions
    - IASI/AMSU for CrIS/ATMS (thermal & µwave sounding)
    - AVHRR for VIIRS (imagery)
  - Substitutions are not necessarily replacements
    - AVHRR/3: advancements, climate data records and studies from EOS MODIS-Terra stop, especially for frequent PM cloud areas or ocean areas with "PM glint"
  - Use of data from non-NPOESS sources leads to additional costs to climate program
  - Planned METOP flights current extend only through 2020 (vs. 2026+ for NPOESS)

Climate Goals & NPOESS

Collaboration between NASA & NOAA

NASA and NOAA are partnering on a joint response on the climate impacts with a certified NPOESS

- **Phase 1: A NASA-NOAA team developing a joint document on Climate Impacts and potential mitigation strategy for OSTP**
  - Caveats
    - Only Climate goal priorities considered;
      - *the wider mandates beyond climate for either agency not considered*
    - Cost estimate for mitigations not yet available for consideration
- **Phase 2: Follow-up with costs of various mitigation strategies will be forthcoming**

NOAA/NASA Climate Priorities

Response to NPOESS Certification

Emphasis on Two Climate Priorities

1. Those sensors that continue NASA's EOS capabilities into the NPOESS program

2. Those sensors that represent a fundamental contribution to NOAA's Climate Observation Program

For NOAA and NASA, NPOESS (and NPP) represents the cornerstone of the Nation's future climate research mission

Summary of Recommendations

Priority Order Ranking

1. Total Solar Irradiance Sensor (TSIS) De-manifested Sensor

- **Mitigation 1:** NASA builds 2 additional TSIS instruments for C2 (2016) & C4 (2022) to continue measurements collected on NASA Glory (2008-2013)
- **Mitigation 2:** Do Mitigation 1 plus solicit a joint partner geostationary satellite platform with launches to overlap instrument in space for 6-12 months

2. Earth Radiation Budget Sensor (ERBS) De-manifested Sensor

- **Mitigation 1:** Fly CERES instrument on NPP; Develop ERBS for C1 & C3 flights; NPOESS to support integration of ERBS onto C1 & C3. If not possible for C1, build another CERES for C1

3. RADAR Altimeter (ALT) De-manifested Sensor

- **Near-term Mitigation:** OSTM JASON-2 to fly 2008-11; Support planning of either an operational OSTM follow-on mission (i.e., JASON-3) as a NOAA-Eumetsat effort, or the development of a next generation altimeter (i.e., wide swath, higher resolution) as a research and development mission between NASA and the Navy.
- **Longer-term Mitigation:** After the planning period, select the best option in a time frame that allows the required overlap with OSTM. Implement successive flights of missions of comparable characteristics at an interval to provide the required overlap.

Summary of Recommendations

Priority Order Ranking (continued)

4. Ozone Mapping & Profiler Suite (OMPS) Limb Subsystem: De-manifested Sensor

- **Mitigation 1:** OMPS Limb for NPP is already built; Fund calibration, testing, & integration of OMPS on NPP; Build and fly additional OMPS Limb for all NPOESS flying OMPS nadir

5. Conical Scanning Microwave Imager (CMIS): Reduced Sensor Capability:

- **Mitigation 1:** Fly SSMIS on C2; continue development of an advanced microwav imager with AMSR-E like capabilities for C3 and C4
- **Mitigation 2:** NASA builds for C3 an instrument complementary to re-competed CMIS which together equal or exceed original CMIS requirements

6. Aerosol Polarimeter Sensor (APS): De-manifested Sensor

- **Mitigation 1:** Fly APS instrument on the NASA Glory Mission; If successful, include APS on C4;
- **Mitigation 2:** Do Mitigation 1 plus enhance research program to utilize VIIRS for aerosols in combination with advanced geostationary imagers

Summary of Recommendations

Priority Order Ranking (continued)

7. Visible Infrared Imaging Radiometer Suite (VIIRS): *Reduced Coverage Sensor*

- **Mitigation 1:** Use another spacecraft with VIIRS-like capabilities for mid AM orbit; Work with Eumetsat to define requirements for a VIIRS-like imager to fly on future METOP platforms

8. Cross-track Infrared Sounder (CrIS): (*Reduced Coverage Sensor)*

- No additional mitigation proposed.

9. Advanced Data Collection System (ADCS): (*No Change)*

- No action proposed.

NPOESS Climate Relevant Sensors

Need for Co-located Sensors

Co-locating Some Sensors (same platform or orbit) improves the quality and interpretation of sensor records

If flying:	ALT	APS	CMIS	CrIS/ ATMS	ERBS	OMPS-Limb	TSIS	VIIRS
ALT								
APS								■
CMIS				■				■
CrIS/ ATMS								■
ERBS		■	■	■				■
OMPS-Limb				■				■
TSIS								
VIIRS								

■ *= Sensors should be located on same platform or constellation*

□ *= No requirement for measurement simultaneity*

NPOESS Impacts & Mitigation Team

NOAA Participants

- Chet Koblinsky - NOAA Climate Lead
- Tom Karl - NOAA COA Lead
- Mike Tanner – NESDIS
- John Bates – Editor
- Jeff Privette – Editor
- Stan Wilson – ALT
- Laury Miller – ALT
- A.R. Ravishankara - APS/OMPS
- Dan Murphy - APS/OMPS
- John Janowiak - CMIS (Precip)
- Dick Reynolds - CMIS (SST)
- Ted Strub - CMIS (Winds)
- Mitch Goldberg - CrIS/ATMS
- Steve Ackerman - CrIS/ATMS
- Dave Hofman – Sondes
- Bruce Barkstrom – TSIS/ERBS
- Bill Rossow - TSIS/ERBS
- Paul Menzel – VIIRS
- Mark Abbott – VIIRS

Questions

Back-up

Instrument: Total Solar Irradiance Sensor (TSIS)

Essential Climate Variable: Total Solar Irradiance

Societal applications and impacts: Required to determine changes in UV solar output which effects stratospheric temperature, structure, composition, and dynamics impacting climate, ozone, & human health

Mitigation Options	Pros	Cons	Pro--jected Costs
Re-certified program •NPOESS will fly if TSIS sensors are provided from outside program	• Cost savings for NPOESS • Program now concentrates on non-climate impact EDR sensors.	• Ends 20-year climate record • Total solar output essential to determining natural variability in climate change	$ 0
Mitigation scenario 1 • TSIS flies on NASA Glory mission; 2008-13 • NASA builds 2 additional TSIS instruments: C2 (2016) & C4 (2022)	• Continues 20-year record through 2013 in a Joint Agency program using planned ground segment and processing	• Significant risk that Glory TSIS will not survive to overlap with 2016 C2 launch	$??
Mitigation scenario 2 • Same as scenario 1 • Solicit a joint NASA/ NOAA/ Commercial geostationary satellite platform with launches to overlap instrument in space for 6-12 months	• Greater likelihood of continuing 20 year record • Includes required overlap periods for intersatellite calibration through 2022.	• Entire communications, ground systems, and processing costs borne by this Mitigation.	$??

Instrument: Earth Radiation Budget Sensor (ERBS) / CERES

Essential Climate Variable: Net shortwave and longwave radiation at the top of the atmosphere

Societal applications and impacts: Required to determine Earth-atmosphere system equilibrium temperature (balance shortwave & longwave radiation as regulated by clouds & greenhouse gases)

Mitigation Options	Pros	Cons	Pro-- jected Costs
Re-certified program • NPOESS will fly if instruments are provided from outside program • NPOESS asks NASA to fly remaining CERES instrument on C1	• Cost saving for NPOESS • ERB budget record continued thru life cycle of C1	• Gap in earth radiation likely – Last CERES: AQUA 2002 – CERES C1 Launch: 2013 • No long-term plans to fly CERES beyond C1	$ 0
Mitigation scenario 1 • Fly CERES instrument on NPP • Develop ERBS for C1 & C3 flights • NPOESS to support integration of ERBS onto C1 & C3	• Continuity of Earth radiation budget observations • Flights on NPOESS provide synergy with VIRRS high resolution cloud data	•Integrating CERES on NPP may be prohibitive • Funding required outside of NPOESS for new ERBS & for transition to operations	$??

Instrument: RADAR Altimeter (ALT)

Essential Climate Variable: Sea level height, ocean currents, basin-scale variability (El Niño)

Societal applications and impacts: Required to monitor changes in global/regional sea level, basin-scale and regional ocean circulations. Sea level rise is of increasing concern in the coastal zone and air-sea interactions are responsible for persistent climate flood & drought anomalies such as El Niño and the Pacific Decadal Oscillation.

Mitigation Options	Pros	Cons	Pro--jected Costs
Re-certified Program • Contains no Altimeter • NPOESS will fly if instruments are provided from outside program	• Cost savings for NPOESS	•No ability to globally monitor sea level rise • Inability to provide validation of ocean climate models.	$0
Mitigation scenario 1a • OSTM JASON-3 to fly 2008-11 • Cost sharing between NOAA and Eumetsat	• Continuity of sea level rise monitoring and seasonal to interannual forecasting and validation	• Long-term, stable funding required. • 2nd mission to meet NASA development and NAVY operations required (funds for both option 1a and 1b)	?
Mitigation scenario 1b • Advanced altimeter mission as a NASA research mission with rapid transition to NAVY operations.	•High resolution/swath scan altimeter for the Navy (high temporal resolution) and NASA (monitoring mesoscale ocean variability)	• Navy requirement conflicts with NASA / NOAA requirement for exact repeat orbit backward compatible. •Technology is higher risk and Navy use will be experimental	?

Instrument: Ozone Mapping and Profiler Suite (OMPS Limb)

Essential Climate Variable: Global ozone observations at high vertical resolution

Societal applications and impacts: Stratospheric ozone absorbs incoming solar ultraviolet radiation that can be harmful to humans and other organisms. The Montreal Protocol, ratified by the U.S., requires ongoing monitoring of ozone recovery.

Mitigation Options	Pros	Cons	Pro--jected Costs
Re-certified Program • Contains no ozone limb sounder • NPOESS will fly if instruments are provided from outside program	• Cost savings for NPOESS	• Inability to observe / predict ozone changes required by the Montreal Protocol	$0
Mitigation scenario 1 • OMPS Limb for NPP is already built • Fund calibration, testing, & integration of OMPS on NPP • Build and fly additional OMPS Limb for all NPOESS flying OMPS nadir	• May be more cost effective to fund the currently built OMPS instrument than to cancel it. •Ozone limb soundings critical to monitoring ozone recovery & climate modeling maintained	• Funding required	?

Instrument: Conical Scanning Microwave Imager (CMIS)

Essential Climate Variable: sea sfc. temps., sea ice & snow cover extents, vegetation, ocean sfc. wind speed (& more recently wind direction), integrated atmospheric liquid water, water vapor, precip. rates, & other surface variables to be analyzed even in the presence of heavy cloud cover

Societal applications and impacts: The ability to observe many ECVs even in the presence of heavy cloud cover; important in monitoring polar regions where rapid climate change is taking place

Mitigation Options	Pros	Cons	Pro-- jected Costs
Re-certified Program • Develop a downscoped replacement for CMIS likely based on the SSMIS. • No microwave instrument on C1and the mid morning orbit; but METOP will fly a narrow width scatterometer	• Cost savings for NPOESS	• No microwave imager on C1 means a loss of continuity of products from AMSR-E and other potential losses, such as soil moisture and all-weather sea surface temperature.	$0
Mitigation scenario 1 • Fly SSMIS on C2; continue develop advanced microwave imager(AMSR-E capabilities) for C3 & C4 based with continued NASA development	•Continues development of microwave technology begun with the AMSR-E on AQUA & planned flights of a microwave soil moisture mission	• Contingent upon continued reduction of costs in application of these new technologies and transfer to an operational environment.	?
Mitigation scenario 2 • NASA builds for C3 an instrument complementary to re-competed CMIS which together= or >original CMIS req	• Fully restores lost capability •SSMI & later records extended	• Operational program relies on research sensor depending upon variance of new design from heritage designs	?

Instrument: Aerosol Polarimeter Sensor (APS)

Essential Climate Variable: Aerosol type and species

Societal applications and impacts: Aerosols have a major impact on climate and climate change. Since aerosols are relatively short lived, any change in aerosols will have major impacts in the next 10-20 years. Aerosols also have major health consequences.

Mitigation Options	Pros	Cons	Pro--jected Costs
Re-certified Program •Contains no aerosol sensor •NPOESS will fly if instruments are provided from outside program	• Cost savings for NPOESS	• Impact of aerosols on climate change remains highly uncertain	$0
Mitigation scenario 1 • Fly APS instrument on the NASA Glory Mission • If successful, include APS on C4	• Risk of new instrument is mitigated by flying it on Glory. • Leaves option open to fly on NPOESS C4 based upon performance and maturity	• Funding required to continue APS on NPOESS C4	?
Mitigation scenario 2 • Do Mitigation Scenario 1 • Enhance research program to utilize VIIRS for aerosols in combination with advanced geostationary imagers	• Same as Mitigation Scenario 1	• Budget required	?

Instrument: Visible Infrared Imaging Radiometer Suite (VIIRS)

Essential Climate Variable: Land cover type, snow cover, leaf area, land surface temperature, fires, cloud optical thickness, cloud top pressure, cloud top temperature, cloud effective radius, aerosol optical depth, precipitable water, ocean color, and sea surface temperature

Societal applications and impacts: VIIRS is critical for a variety of essential climate variables that directly contribute to monitoring and prediction of land and ocean interactions with the atmosphere, climate and ecosystem interactions, and cloud feedback processes and aerosols

Mitigation Options	Pros	Cons	Pro--jected Costs
Re-certified Program • VIIRS reduced coverage from 3 to 2 flights per day • METOP replaces mid AM orbit	• Cost savings for NPOESS	• Early morning orbit (5:30 am) not that useful for climate -- scene identification difficult due to large solar zenith angle •Loss of the mid-AM orbit will end the climate record begun by the TERRA MODIS	$0
Mitigation scenario 1 • Use another spacecraft with VIIRS-like capabilities for mid AM orbit • Work with Eumetsat to define requirements for a VIIRS-like imager to fly on the METOP follow-on series	• Continues the record of MODIS in the Mid AM orbit • Helps mitigate the loss of APS for aerosols	• VIIRS is a large instrument and flights of opportunity on another Earth remote sensing spacecraft are limited	$?

Instrument: Cross-track Infrared Sounder (CrIS) / ATMS

Essential Climate Variable: Vertical temperature and moisture profiles in clear (CrIS) and cloudy (ATMS) conditions, greenhouse gas amounts, cloud properties, precipitation (Scattering signature)

Mitigation Options	Pros	Cons	Pro--jected Costs
Re-certified Program •CrIS/ATMS reduced from 2 to 1 flight per day •Dropped from the early morning orbit	• The early morning orbit has only flown DMSP with the SSM (I, T, T2) and SSMIS microwave imager/sounder. • A reconfigured CMIS instrument should keep this continuity and so is acceptable	• Loss CrIS in the early morning will limit diurnal sampling of the atmosphere	?

Instrument: Advanced Data Collection System (ADCS)

Essential Climate Variables: Many meteorological and oceanographic variable (also biological variables) use the ADCS system for data transmission.

Societal applications and impacts: The ADCS relays meteorological and other data transmitted from in-situ based data collection platforms including buoys, free floating balloons, and remote weather stations.

Mitigation Options	Pros	Cons	Pro--jected Costs
Re-certified Program •NPOESS will no longer have a mid-AM flight • ADCS was not planned to fly on the mid-AM flight, so no ADCS impact due to fewer orbit planes	• None	• None	$0
None Needed			