



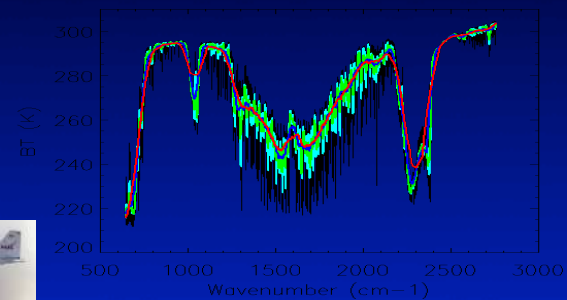
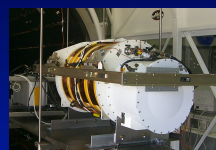
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NAST-I and SNPP Field Campaign Experience



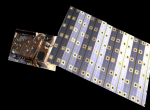
Allen Larar
Science Directorate
NASA Langley Research Center

GOES-R Field Campaign Workshop
College Park, MD, 8-9 April, 2015

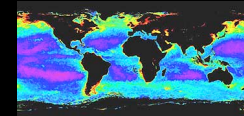
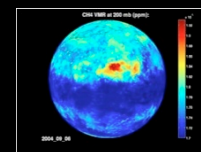
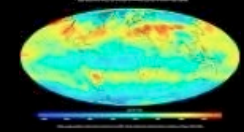
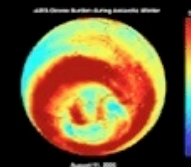
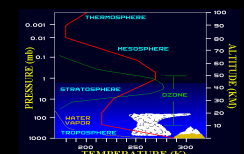
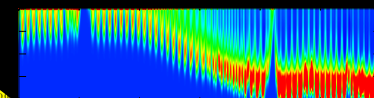
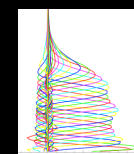
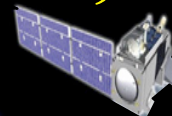


*Aqua
(AIRS)*

*Metop
(IASI)*



*SNPP
(CrIS)*





Topics

- **Airborne Campaigns**
 - Cal/Val benefits
 - NAST-I contributions
- **SNPP-1 Field Campaign**
 - Palmdale, CA (May 2013)
- **SNPP-2 Field Campaign**
 - Keflavik, Iceland (March 2015)
- **Key planning thoughts**



Key Cal/Val benefits from airborne campaigns

- Simultaneous independent, SI-traceable high spectral resolution radiance measurements for absolute **radiometric and spectral cal/val** of satellite sensors (i.e. provides absolute truth without relying on models)
- Space/time coincident observations enable **best method of inter-comparisons** with spaceborne measurements **in the presence of geophysical field spatial/temporal variability**
- **Transfer standard for cross-validation** of sensors in different orbits at more than a very limited range of polar latitudes (i.e., as provided by SNO approaches)
- Simultaneous independent in-situ and remotely sensed geophysical variables within the footprint of the satellite sounder to enable **validation of satellite direct/derived products and forward radiative transfer models** used for their derivation
- Higher spatial, spectral, and temporal resolution radiance measurements useful for **assessing impact of satellite sensor measurement characteristics on derived product accuracy**
- Redundancy of most critical measurements among campaign observation platforms (e.g., airborne IR FTS) ensures campaign success; **enables rapid internal-verification of satellite sensor and processing system performance**

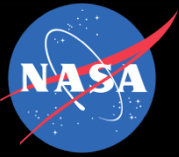




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NAST-I Program Overview

- **NAST-I is an airborne, x-track scanning IR FTS sounding system**
 - IR spectral radiance direct product; profiles of temperature, water vapor, trace species, surface and cloud properties for derived products
- **Significant campaign heritage in satellite measurement system cal/val (i.e., sensor, algorithms, and data products)**
 - High-altitude, airborne FTS systems (e.g. NAST-I, S-HIS) play a vital role by enabling traceable high-spectral-resolution comparisons with space/time coincident spaceborne measurements (validation & cross-validation)
- **LaRC NAST-I team is airborne cal-val centric, but impact is much broader**
 - Algorithm advancements & geophysical product retrievals infused into global programs (e.g., AIRS, IASI, & CrIS) and operational processing (e.g. NWP)
- **LaRC NAST-I team has end-to-end capability (measurement concept through results dissemination)**
 - Passive radiance measurements
 - Forward radiative transfer modelling
 - Geophysical product retrievals
 - Analysis & science studies
- **NAST-I is qualified and has had past missions on NASA ER-2, Proteus, and WB-57; DC-8 integration efforts underway in preparation for PECAN**
 - NADIR port 7 I&T in-progress



NASA / NOAA Airborne Sounder Testbed - Interferometer (NAST-I) Overview

~ 180 mission sorties accumulating ~ 1000 hours of flight data in 20 field experiments
[e.g., CAMEX, C-IOP, WV-IOP, TRACE-P, IHOP, CRYSTAL-FACE, INTEX, EAQUATE, JAIVEX, SNPP, SNPP-2]

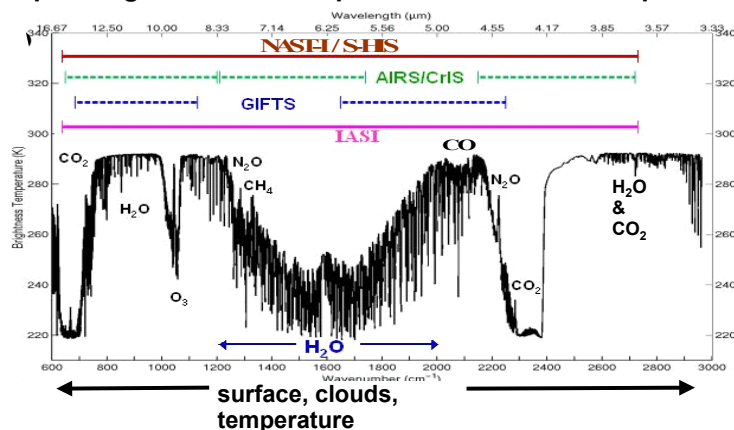
- ✓ Validation tool
- ✓ AQUA/SNPP/JPSS risk mitigation
- ✓ Airborne science
- ✓ Engineering testbed

IR Michelson Interferometer

Spectral range: 3.5 - 16 μ (630 – 2700 cm^{-1})
 Spectral res.: 0.25 cm^{-1} ($\nu/\nu\delta > 2000$)
 Spatial res.: 130m/km flight alt. (2.6 km @ 20 km)
 A/C platforms: ER-2, Proteus, WB-57, DC-8 (FY15)

Radiometric Measurement Capability
 Radiances <0.5 K absolute accuracy, ~ 0.1 K precision

“Upwelling” IR Radiance Spectrum: Earth + Atmosphere



FY15 Campaigns

Main Objectives

- Cal/Val for SNPP sensors (CrIS, ATMS, VIIRS), algorithms, and data products
- Inter-platform comparisons between SNPP and legacy systems on MetOp and Aqua
- Advanced sounder science studies

Purpose: continue SNPP validation with a specific focus on cold scene radiance spectra assessment and retrieval evaluation.

Aircraft: ER-2

Payload: NAST-I (LaRC), S-HIS (UW-Madison), NAST-M (MIT-LL), MASTER (AMES)

S/C under-flights: SNPP, Aqua, Metop-A, Metop-B

SNPP-2

Base location: Keflavik, Iceland

Time period: ~ 7-31 March, 2015

Key Mission Objectives: Satellite under-flights over Greenland, over-flight of ground sites, collaborate with UK Met Office who will be basing their BAe 146 (fully instrumented with remote and in-situ sensors) flights out of Prestwick, UK and are also interested in some joint sorties over Greenland. Collaborate with ICECAPS (Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit) team.

PECAN (Plains Elevated Convection at Night)

- NAST-I & LASE on the NASA DC-8
- ~ 3 weeks within June 1 - July 15, 2015
- US Southern Great Plains

PECAN

Project Description:

Multi-agency project (NSF, NOAA, NASA, DOE) designed to advance the understanding of continental, nocturnal, warm-season precipitation.



NAST-I Field Campaign Contributions

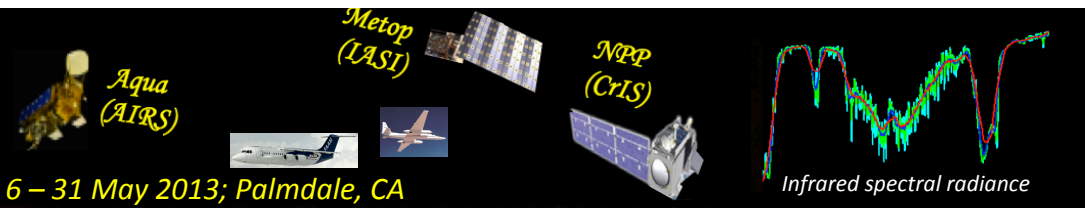
NAST-I DATA PRODUCT	CAMPAIGN RELEVANCE
<p><u>Radiance</u></p> <ul style="list-style-type: none"> Infrared spectrum (3.5 – 16 μm) with 0.25 cm^{-1} spectral resolution. Infrared spectral radiative heating/cooling information during aircraft ascents and descents. 	<p><u>Science</u></p> <ul style="list-style-type: none"> Temperature and trace species information helpful to characterize the boundary layer and free troposphere; contributes to weather, climate, air quality and biogeochemistry studies Information on water vapor, ozone, cirrus clouds, and vertical profiles of infrared spectral radiance in the upper troposphere and lower stratosphere region beneficial for better understanding the radiative forcing of this region on climate system Information on local meteorology, infrared heat budget, and trace gas evolution <p><u>Validation</u></p> <ul style="list-style-type: none"> Contributes toward radiance and geophysical product validation, e.g., AIRS, IASI, CrIS Inter-comparisons by spectral and spatial convolution to common resolution and coverage High spatial resolution enables the effects of scene variability to be assessed <p><u>Future sensor studies</u></p> <ul style="list-style-type: none"> Direct and derived NAST-I products contribute toward instrument specification and retrieval studies for future sensors, e.g., missions defined within the National Research Council Earth Science Decadal Survey (NRC DS)
<p><u>Atmospheric Thermodynamics</u></p> <ul style="list-style-type: none"> 3-d characterization of atmospheric state (temperature & moisture). Profiles with vertical resolution of ~1-2 km for clear air or above clouds, vertical region dependent; horizontal resolution of < 130 m per km flight altitude 	
<p><u>Atmospheric Composition</u></p> <ul style="list-style-type: none"> Profiles in clear air or above clouds with vertical resolution of 2 – 10 km, depending on altitude and atmospheric constituent Tropospheric CO and O₃ (PBL and free troposphere) from nominal flight altitude; other trace species (e.g., CO₂, CH₄, N₂O, and SO₂) also possible during platform ascents / descents. 	
<p><u>Cloud Microphysical & Radiative Properties</u></p> <ul style="list-style-type: none"> Effective top height, temperature, & spatial extent Effective particle size & optical depth Spectral emissivity 	
<p><u>Surface Properties</u></p> <ul style="list-style-type: none"> Temperature and spectral emissivity 	



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(NAST-I examples to follow from this campaign...)

Joint NASA / NOAA airborne field campaign in support of Suomi NPP (SNPP) cal/val (May 2013)



6 – 31 May 2013; Palmdale, CA

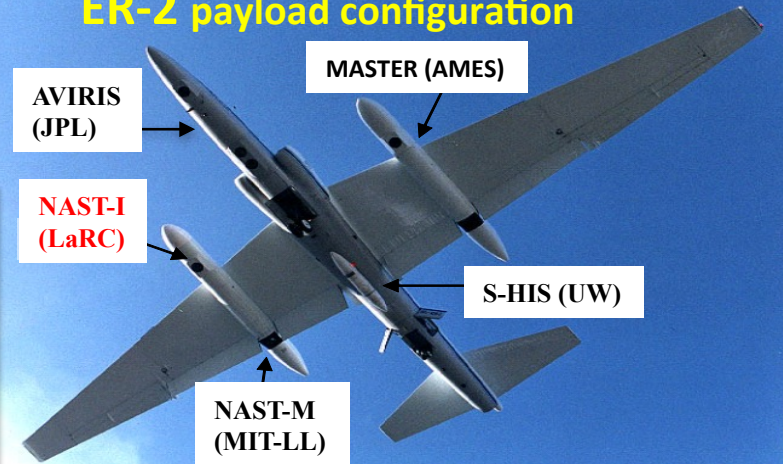
Purpose:

- Cal/Val for SNPP sensors (CrIS, ATMS, VIIRS), algorithms, and data products (SDRs & EDRs)
- Inter-platform comparisons between SNPP sensors and legacy systems on MetOp and Aqua (e.g. CrIS vs IASI vs AIRS)
- Advanced sounder science studies (e.g. convective tendencies, surface characterization, retrievals and radiative transfer modeling)

Approach:

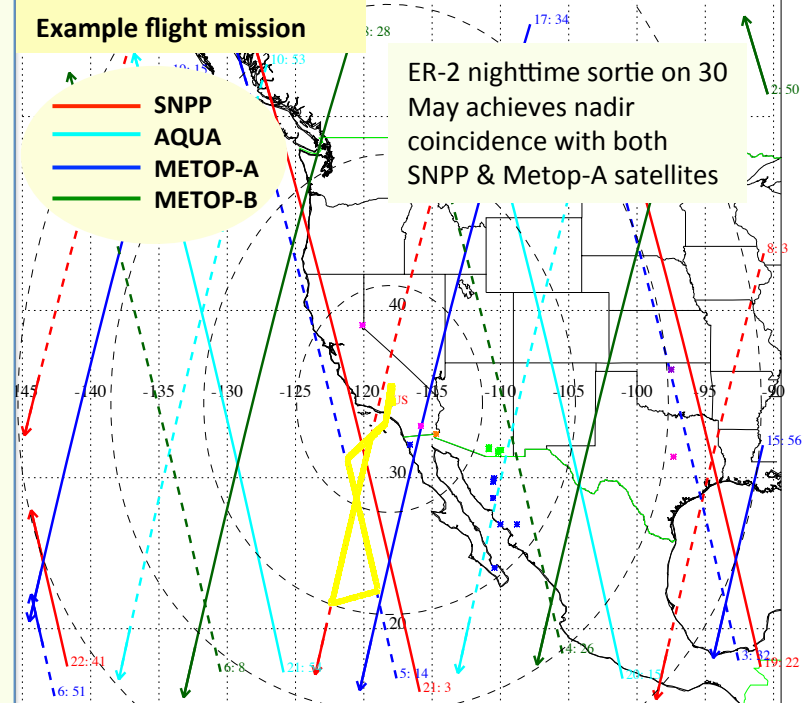
- ER-2 aircraft under-flights of SNPP, Aqua, MetOP-A, and MetOP-B satellites
- Over-flight of several instrumented calibration ground sites (i.e. Salton Sea water site, DOE mobile site in Yuma, AZ; DOE CART site in Lamont, OK; NOAA, DOE, NGA measurements at the CarbonTracker tower in Moody, TX) including ground-based FTIR and radiosonde measurements
- Joint sorties with UK Met Office BAe146 aircraft based out of Tucson, AZ (fully instrumented with remote / in-situ sensors and dropsondes)

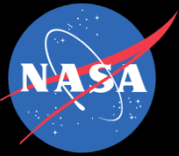
ER-2 payload configuration



SNPP cal/val campaign sub-satellite tracks & ground sites: 5 / 30 (Thu)

Example flight mission

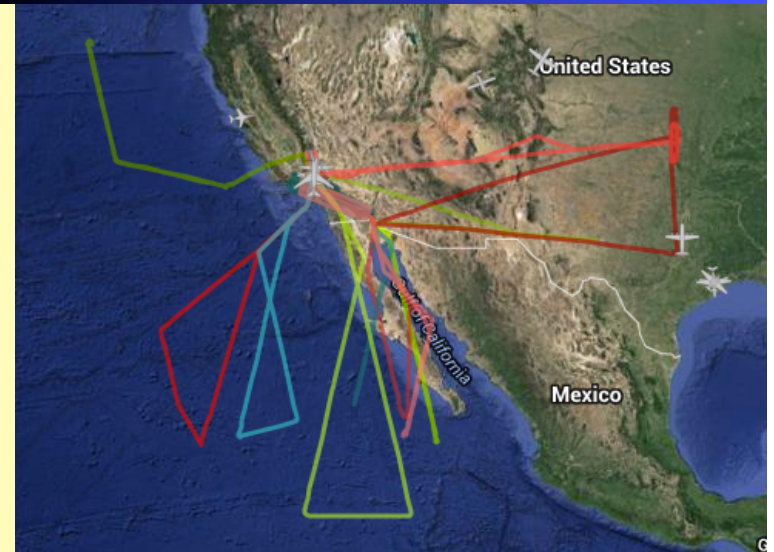




Suomi NPP (SNPP) 2013 cal/val campaign summary

Summary:

- Implemented 11 science flights, ~ 70 flight hours, over varying surfaces and meteorological scenes (i.e. water, land, clear, cloudy,...)
- All flights achieved satellite coincidence (8 at s/c nadir); 9 days had coincidence with multiple s/c in single flight; 3 night flights implemented
- Diplomatic clearance enabled flights over Mexican airspace (i.e. Gulf of California and Baja California)
- Convective stability tendency flight captured Moore, OK tornado on 20 May



Mission flights capture summary: Aircraft flight profile and key measurement asset coincidence

GMT Date	Day / Night	S/C				A/C	GROUND				Primary capture
		SNPP	AQUA	METOPA	METOPB	BAE146	Yuma	Salton Sea	Moody	CART	
5/7/13	Day	x	x								pacific ocean; S/C nadir tracks
5/10/13	Day	x									Clear over GOC & Pacific; SNPP nadir
5/15/13	Day	x	x								Clear over GOC; S/C nadir Pacific
5/16/13	Day			x							Pacific & GOC; Metop-A nadir
5/18/13	Day										Moody site overflight; SNPP & Aqua near nadir
5/20/13	Day										CART and MOODY sites; Moore Tornado!
5/23/13	Day	x	x								Pacific; SNPP & Aqua nadir
5/24/13	Day										CART site; precip in transit; SNPP near nadir
5/30/13	Night	x		x							Pacific, clear air at night; SNPP & Metop-A nadir
5/31/13	Night	x		x							Pacific and Baja CA at night; some clouds
6/1/13	Night	x									GOC & Pacific at night; clear regions

Aircraft flight coincidence with measurement asset

S/C nadir track coincidence



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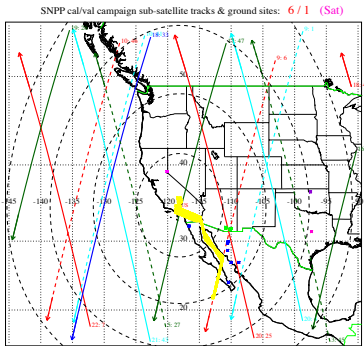
Example NAST-I products from SNPP campaign (2013)

NAST-I vs SNPP CrIS: 1 June 2013 Flight

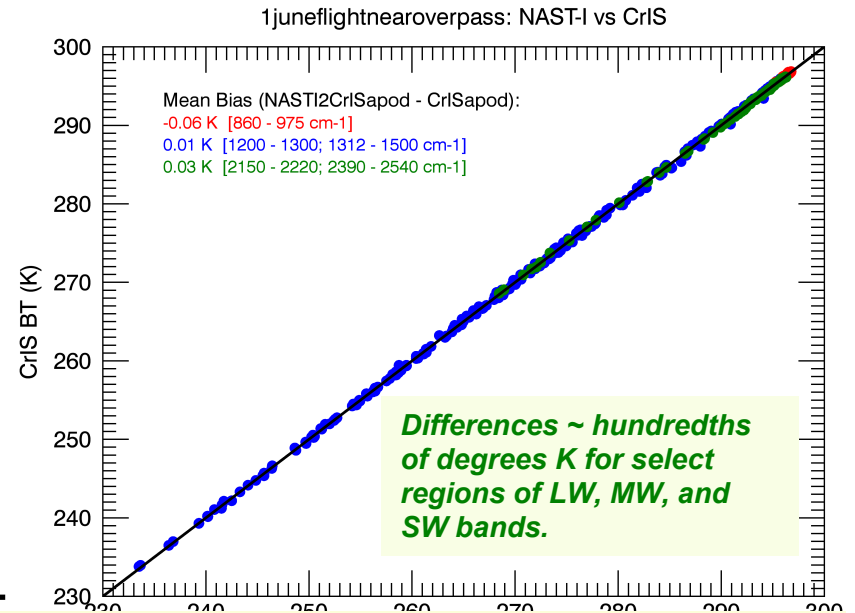
ER-2 nighttime sortie on 1 June achieves nadir coincidence with SNPP (0908 GMT); observes clear air over Pacific & GOC

Spectra compared for over water, near overpass time

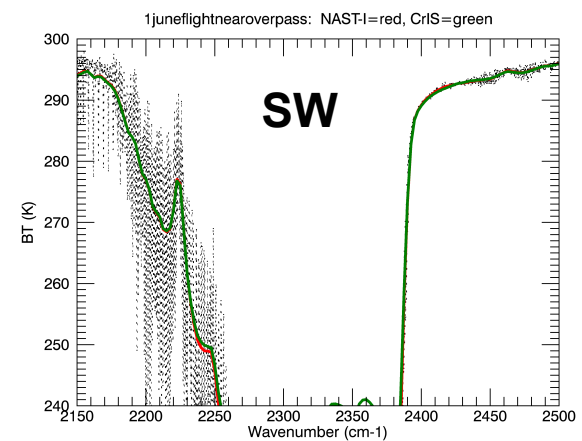
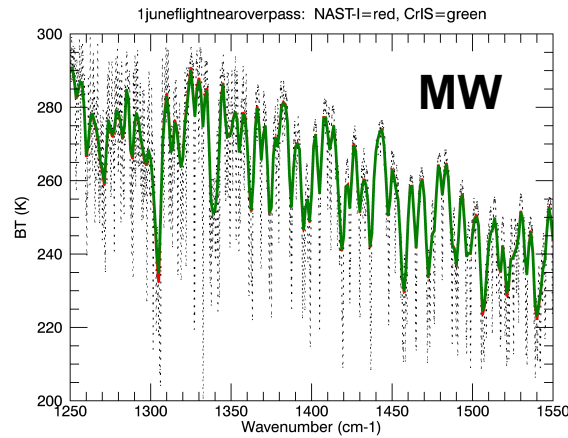
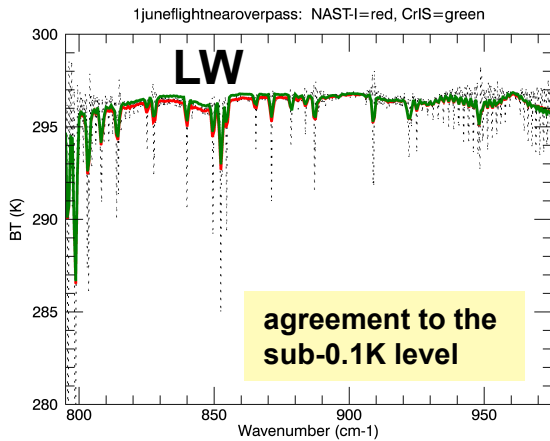
Key: spectra intercomparisons



- NAST-I (original)
- NAST-I (degraded to apodized CrIS)
- CrIS (apodized)



CrIS versus NAST-I average spectra. The higher-resolution NAST-I data have been reduced to the CrIS spectral resolution and spectra have been (Hamming) apodized to better facilitate radiometric calibration intercomparison.





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SNPP-2 Arctic Validation Campaign



Purpose: continue SNPP validation with a specific focus on cold scene radiance spectra assessment and retrieval evaluation.

Aircraft / Payload: ER-2/ NAST-I (LaRC), S-HIS (UW), NAST-M (LL), MASTER (AMES)

S/C under-flights: SNPP, Aqua, Metop-A, Metop-B

Base location / schedule: Keflavik, Iceland, **7-31 March, 2015**

Flight hours: ~ 52 hrs science, 75 hrs total; 6-10 mission flights

Key Mission Objectives: Satellite under-flights over Greenland, over-flight of Summit station ground site, collaborate with UK Met Office who based their BAe146 (fully instrumented with remote and in-situ sensors) flights out of Prestwick, UK and were also interested in some joint sorties over Greenland (conducted jointly from Keflavik). Collaborate with ICECAPS (Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit) team with over-flight of Summit Station, Greenland ground site.

Specific mission goals include:

Cold scene satellite radiance assessment and retrieval evaluation.

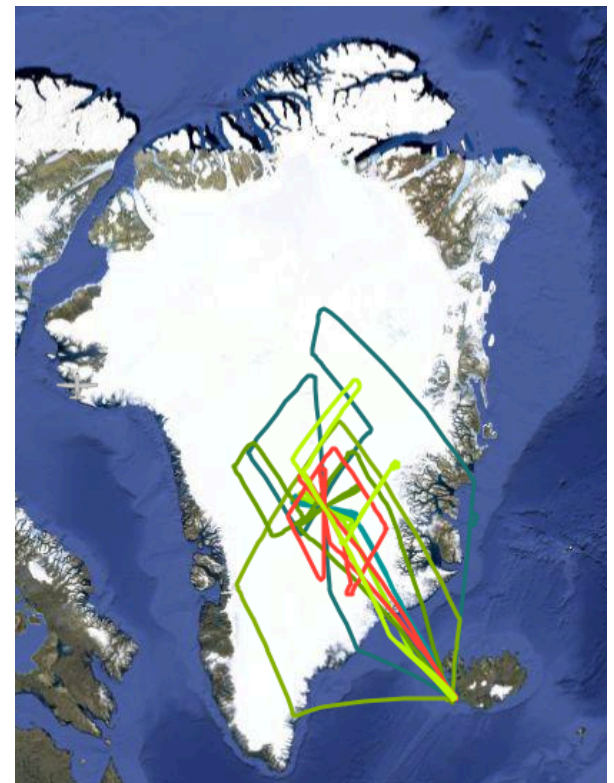
Assess CrIS and IASI radiance observations for very cold scenes (i.e. ~ 230K).

EDR retrievals for such cold SDR spectra are quite challenging (e.g., complex snow, ice, cloud surface spatial distribution / emissivity non-uniformities and regions of limited vertical thermal contrast).

To provide "anchor points" for NWP data assimilation studies.

Aircraft observations coincident with spacecraft sounder (CrIS, IASI, AIRS) overpasses and ground-based measurement assets (e.g. radiosondes) can provide closure datasets important for NWP data assimilation studies (i.e., independent SDRs, EDRs, and retrieved EDRs, for improving assimilation studies and corresponding error characterization).

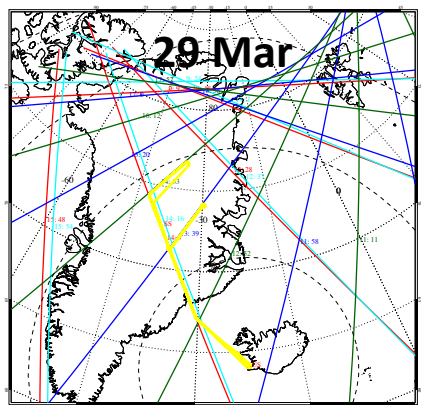
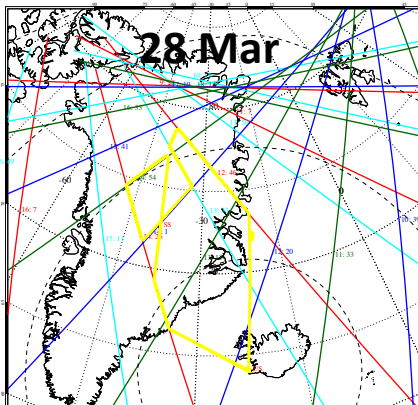
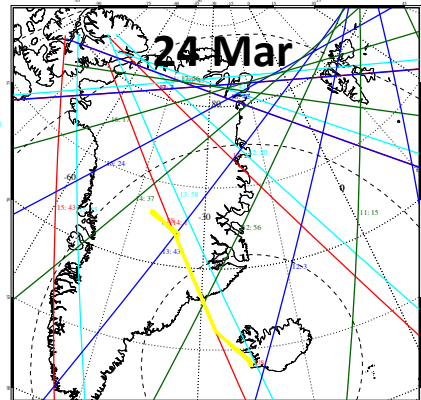
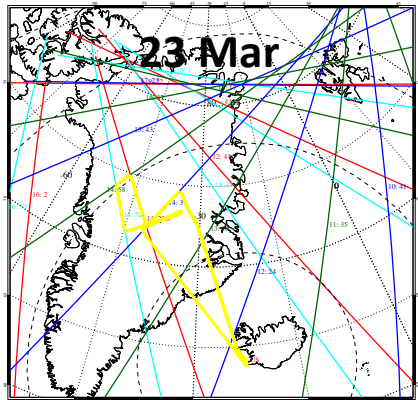
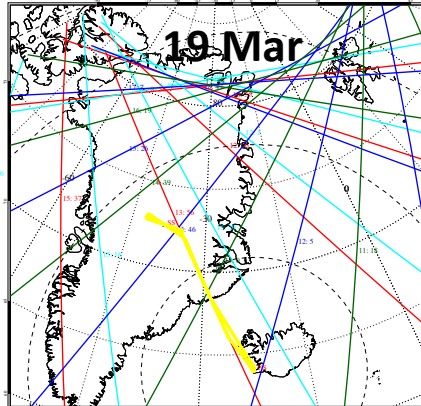
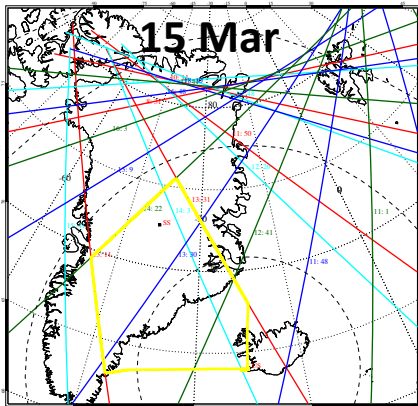
ER-2 payload configuration



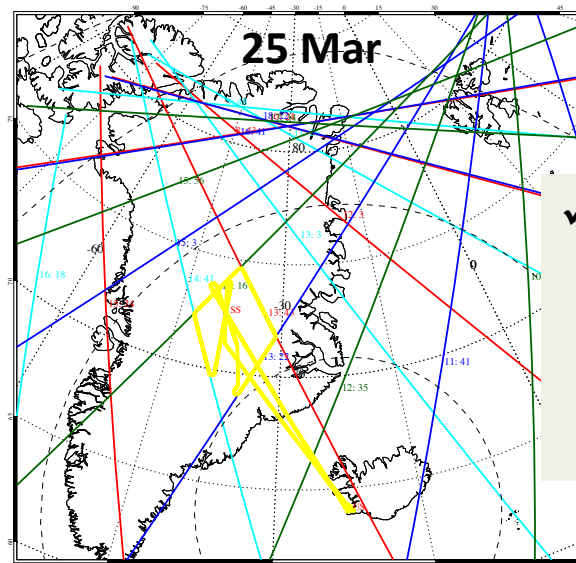
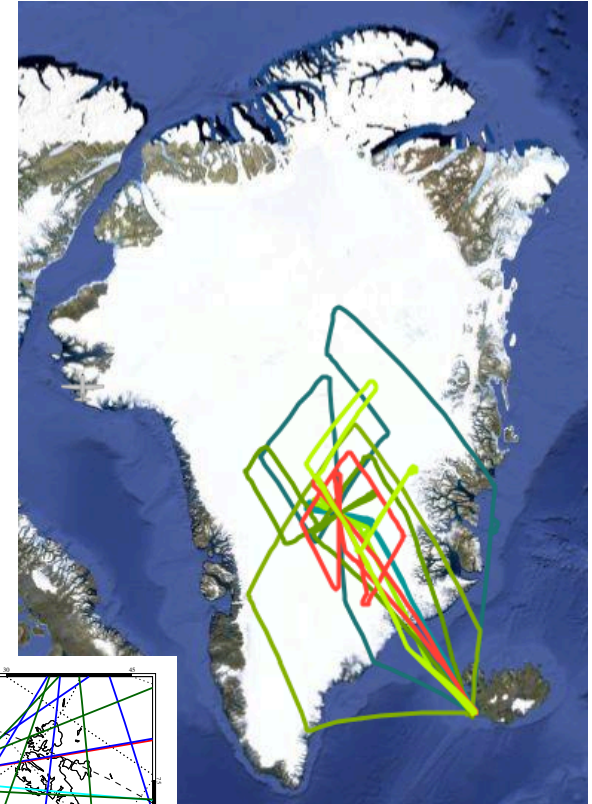
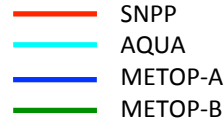


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SNPP-2 campaign flight summary



- ✓ 7 mission flights
- ✓ Repeated coincidence with SNPP, Aqua, Metop-A, Metop-B, Summit Station, BAe-146



- ✓ Some flights captured multiple assets for cross-validation



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Key elements for planning/costing (1/2)

Needed campaign measurements → payload sensors, A/C platform, campaign location(s) & frequency, seasonal dependence, specific target scenes, correlative measurements and ground truth (ground, balloon, other a/c, and s/c), etc.

Some elements to be sure to include and cost...

For lead institution

Mission scientist

- Overall campaign planning, management, implementation; leads in-field flight plan formulation activities and serves as a liason between the various groups (flight crew, ground crew, instrument teams, etc.) to ensure mission science accomplished.
- Should activate > 1 year prior

For each instrument team:

Pre-field-phase

- Instrument & algorithm readiness costs
 - For sensor to become and/or retain flight readiness (i.e. campaign series)
 - Sensor calibration & characterization testing
 - Shipping to/from deployment site
 - Algorithm development, testing, and validation

In-field costs

- Travel expenses (airfare, per diem for hotel/meals, rental car) for deploying
- Staffing
- Expendables
- In-field data processing, analysis, inter-comparisons, and mission planning support

[Better to not only gather data but also have sufficient support to produce preliminary data products and first-order comparisons in-field to ensure optimum instrument performance and better resultant dataset. Not all such support has to be in-field, but portions should to optimize 24x7 flight operations in a different time zone.]



Key elements for planning/costing (2/2)

For each instrument team: (cont.)

Post-field-phase

- Sensor calibration & characterization testing
- Data processing, final dataset preparation and dissemination
- **Data Analysis!**

Aircraft & infrastructure costs

Flight hour costs (platform/year dependent)

- ~ 50 – 80 mission flight hours per campaign, ~ 6-10 flights over ~ 3-4 week period is good baseline.
- Include 4+ hours for a checkout flight; even if all sensors are pre-qualified on platform, still needed for a system-level test before campaign.
- If deploying, must also add hours to enable round-trip ferry flights.

Mission peculiar costs (deployment of aircraft, flight and ground crew; overtime in support of non-standard duty day mission operations)

- ~ \$150K to several hundred \$K to deploy for a few weeks, depending on location and aircraft)

Facility costs (hangar, forklift, office/lab space, phone, internet, etc.—if deploying, base vs FBO differences)

Data archive & dissemination

- While instrument teams will likely have their data archived at their home institutions, it is helpful to have a single location (i.e. one stop shop) for team members (as well as others in the community) to obtain campaign data. This could be as simple as a single website with links to instrument team data, readers, and documentation to all data being archived locally.

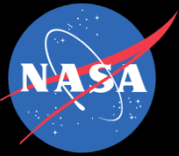
Meteorological product support

- Provides past observations and future model fields for campaign domain
 - Target measurement variables & scene conditions
- Greatly benefits flight option planning and Go / No-go decisions



Additional thoughts

- **Define what you can prior to in-field-phase**
 - Measurement objectives (prioritized), success criteria
 - Coincident observations (what, where, when?)
 - Ground sites, radiosondes, s/c tracks, other a/c & campaigns, ...
 - Draft a/c flight profiles, daily plan for coincidence (e.g. LEO s/c & other variable assets)
 - Go / no-go criteria (both target & payload), i.e. assuming local weather acceptable for a/c, define minimum science conditions and payload sensors required to warrant flight—usually based on many factors and varies as mission progresses, but good to consider in advance.



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Pursue campaign leveraging...

UK Met Office FAAM BAe146-301

Facility for Airborne Atmospheric Measurements (FAAM)

Complement of remote sensing and in-situ instruments

Dropsondes

In-situ CO, NO_x, O₃, CH₄ CO₂, SO₂, cloud & aerosol properties

Lidar (O₃, H₂O)

IR interferometer; Far-IR interferometer; Microwave Radiometer

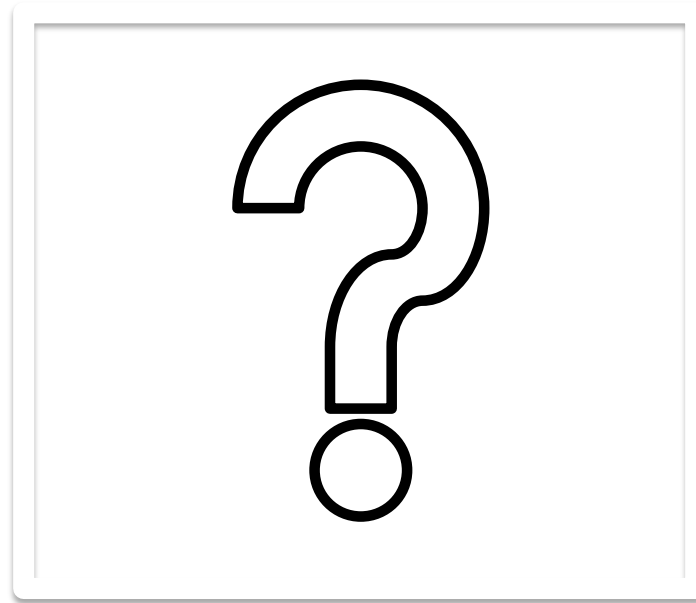
Short wave spectrometer; Infrared radiometer; Infrared imager

For the Suomi NPP campaigns, we have teamed with the UK Met Office to conduct joint sorties with their BAe-146 aircraft and our NASA ER-2





Questions



Acknowledgements. Thanks to Drs. J. Kaye (NASA SMD) and Mitch Goldberg (NOAA NESDIS/JPSS) for their continued, enabling support of the NAST-I program.