Field measurements for GOES-R post-launch validation

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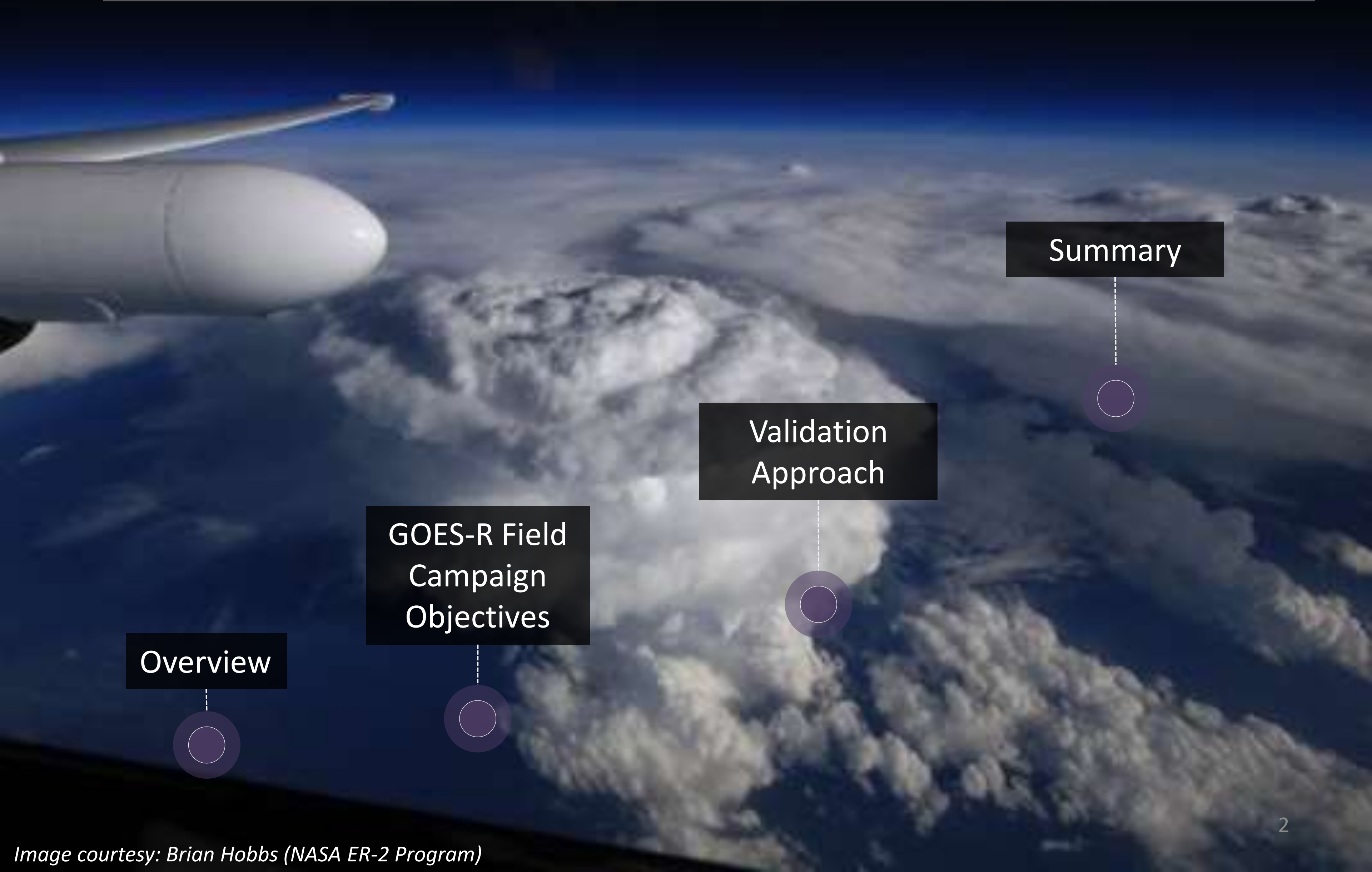
NOAA/NESDIS/GOES-R Program Office

41th CEOS Working Group on Calibration and Validation Plenary (WGCV-41)
Tokyo, Japan, September 5-7, 2016

Outline



- Overview
- GOES-R Field Campaign Objectives
- Validation Approach
- Summary

Image courtesy: Brian Hobbs (NASA ER-2 Program)

NOAA Science Participation in All Phases of GOES-R Calibration Life-Cycle

» **NOAA has placed a great amount of support in the pre-launch calibration of the next generation GOES-R era instruments, in reference to the heritage instruments**

- Ensured the SI traceability of the ABI instrument calibration was established pre-launch

» **Leveraging this in-depth knowledge of pre-launch system performance, a dedicated GOES-R validation field campaign was planned to independently validate ABI's performance post-launch:**

- Field campaigns are essential for collecting reference data that can be directly related to satellite observations
- Committee on Earth Observation Satellites (CEOS) and Global Space-based Inter-Calibration System (GSICS) recognized best practice

ABI Performance Metrics:

- Reflective Solar Bands (RSB)
  - 5 % radiometric uncertainty
- Thermal Emissive Bands (TEB)
  - 1 K radiometric uncertainty

GLM Performance Metrics:

- 70 % flash detection efficiency
- 5 % false alarm rate

GOES-R Field Campaign Overview

The purpose of the GOES-R field campaign is to support post-launch validation of L1b & L2+ products:

- **Advanced Baseline Imager (ABI) & Geostationary Lighting Mapper (GLM):**
  - Planning ~6 week field campaign (~100 flight hours) with the high-altitude NASA ER-2 platform coordinated with ground based and near surface observations over several Earth targets
  - An official flight request has been submitted to the NASA ER-2 Program:
    - April – June 2017

GOES-R Field Campaign Overview

GOES-R Field Campaign Workshop – April 8-9, 2015:

Established a baseline consensus of the GOES-R field campaign validation plan for L1b & L2+ products - *http://www.goes-r.gov/users/2015-Campaign-Workshop.html*

Two Phased Approach

April – June 2017

Phase 1 (2 weeks)

- ER-2 Based at Palmdale, CA (U.S. West Coast)

Phase 2 (4 weeks)

- ER-2 Based at Warner Robins AFB, GA (U.S. East Coast)

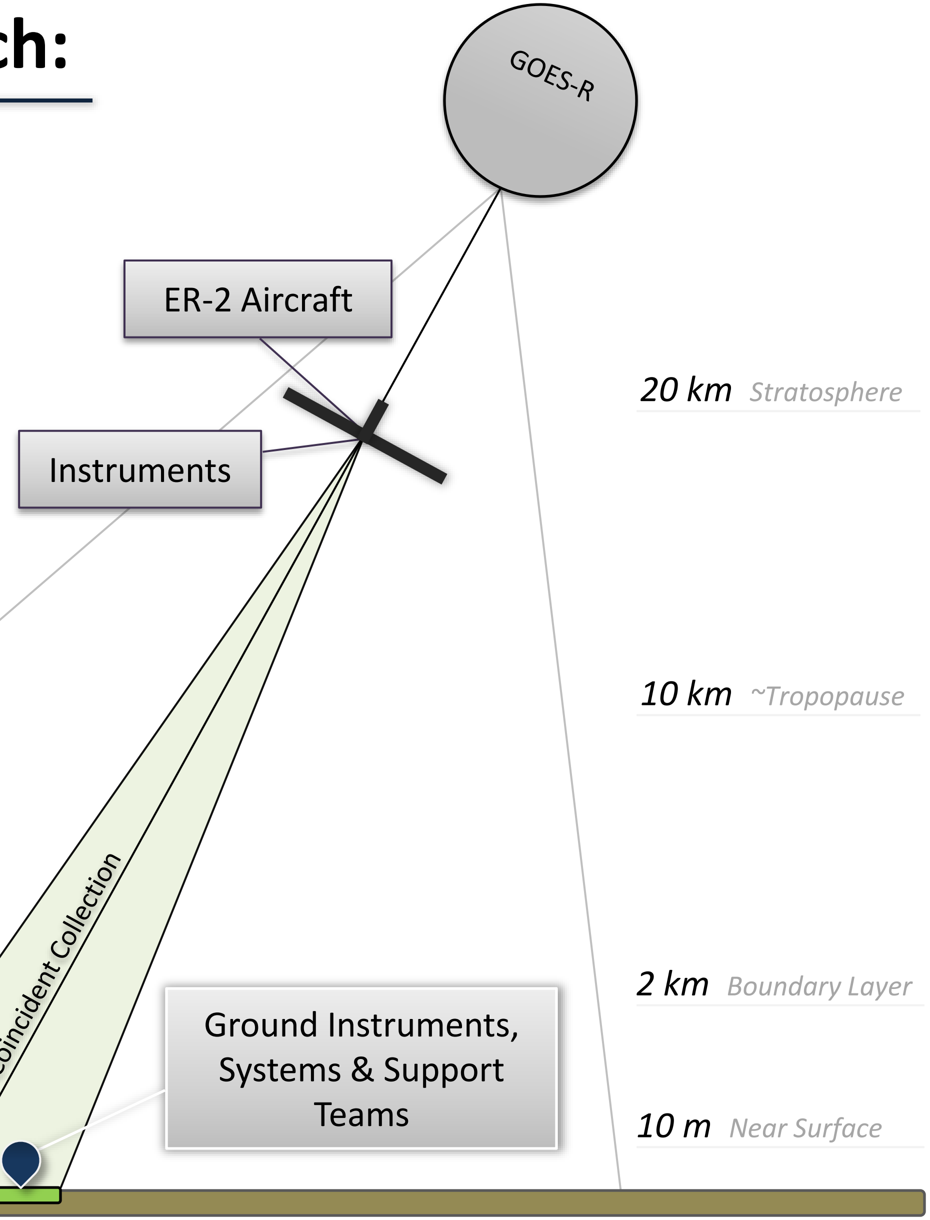
- Underflights to be collected, when possible, with low Earth orbit environmental satellites which may include S-NPP, Terra/Aqua, METOP, Landsat, ISS & GPM
- We plan to have an open data access policy

ABI Field Campaign Approach:

Primary Objective: provide validation of ABI L1b spectral radiance observations to validate SI traceability

Secondary objective: provide surface and atmospheric geo-physical measurements to support L1b & L2+ product validation

Targets of Interest:

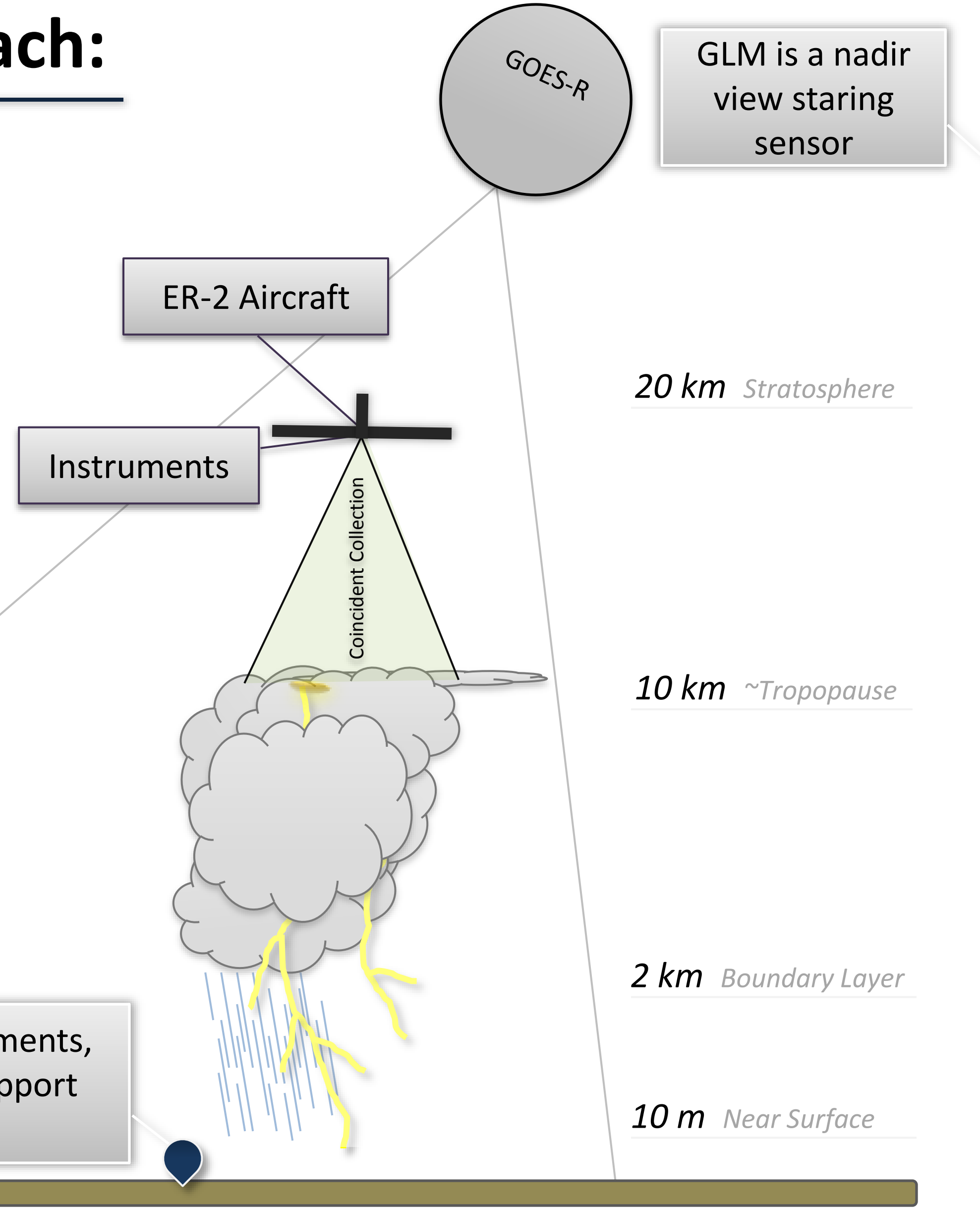


GLM Field Campaign Approach:

Primary Objective: provide validation of GLM flash detection efficiency day through night over land at well characterized total lightning supersites: Northern AL, Norman OK, Lubbock TX, KSC FL, and Wallops/DC area, as well as other LMAs

Secondary Objective: provide validation of GLM flash detection efficiency day through night at other land locations and over ocean

Tertiary Objective: provide validation of GLM flash location & time stamp accuracy, and GLM image navigation and registration (INR) accuracy



Target of Interest:

Storms

GOES-R Field Campaign ER-2 Based Instruments

Candidate Instruments	
AVIRISng	Next-Generation Airborne Visible/Infrared Imaging Spectrometer
S-HIS	Scanning High-resolution Interferometer Sounder
FEGS	Fly's Eye GLM Simulator
LIP	Lightning Instrument Package
CPL	Cloud Physics Lidar
CRS	94-GHz (W-band) Cloud Radar System (CRS)
GCAS	GeoCAPE Airborne Simulator (GCAS)

Instrument	Type	Spectral Range	Spectral Res.	GSD	FOV	Swath Width
AVIRISng	HSI	380 – 2510 nm	5 nm	0.3 m to 20 m	34 deg	~11 km
S-HIS	Hyperspectral	3.3 - 18 µm	$0.5cm^{-1}$	2 km	40 deg	40 km
FEGS	Passive EO	near-infrared (777.4 nm)	10 nm			~10 km
LIP	Passive Electrical					
CPL	Lidar	1064, 532, & 355 nm		30x200 m		
CRS	Doppler Radar	94 GHz (W-band; 3 mm wavelength)		na		
GCAS	Hyperspectral	300 – 490 nm; 480 -900 nm	0.6 nm; 2.8 nm	350 x 1000 m; 250 x 250 m	45 deg; 70 deg	

ABI & GLM combined campaign provides an opportunity for data collection with broad suite of instruments

Critical Set of Instruments

Add-on Capability

GOES-R Field Campaign: Critical Components

Satellite

ABI

GLM

Desert

Open Ocean

Primary ABI Validation »

High-Altitude Aircraft — **Primary Validation Approach (Direct)**

Near Surface UAS — **Secondary Validation Approach (Earth as Ref.)**

ABI SNO Special Collection — **Secondary Validation Approach (Direct)**

Two Main Paths to Validate SI Traceability

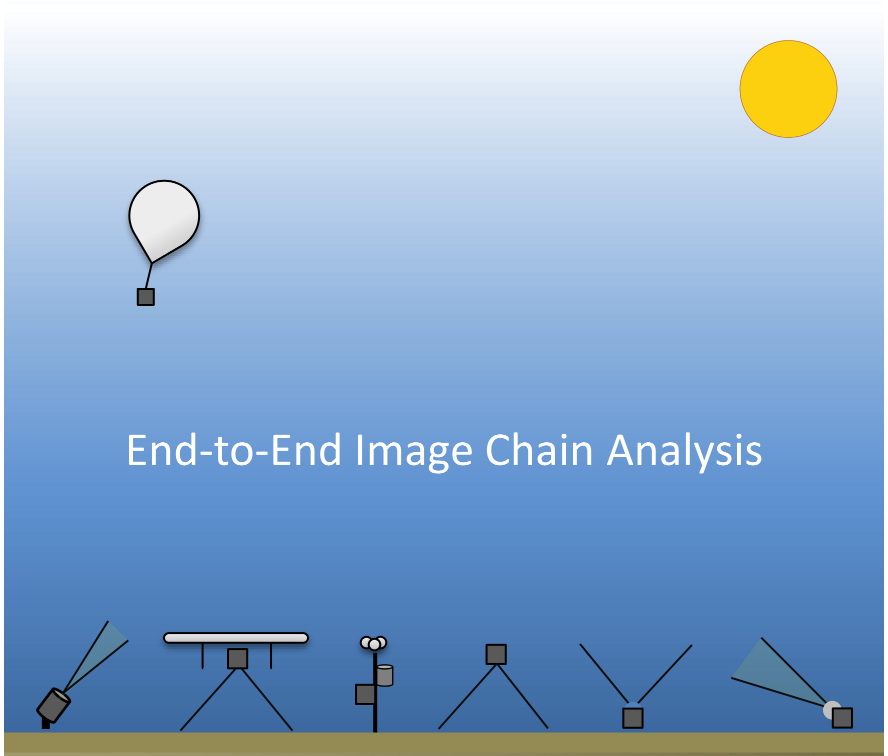
Direct Comparison of Observations from SI Traceable Reference Sensor(s)

- Well calibrated reference sensor(s)
- Match the reference sensor and satellite sensor view geometry

Radiance to Radiance Comparison (L1b)

SI Traceability through Earth Surface Reference Observations

- Measurement of the primary physical state variables at the time of satellite image acquisition over a uniform target
- Radiative Transfer Modeling



Comparison conducted through modeling (L1b & L2+)

GOES-R THE FUTURE OF FORECASTING

3X MORE CHANNELS

Improves every product from current GOES Imager and will offer new products for severe weather forecasting, fire and smoke monitoring, volcanic ash advisories, and more.

4X BETTER RESOLUTION

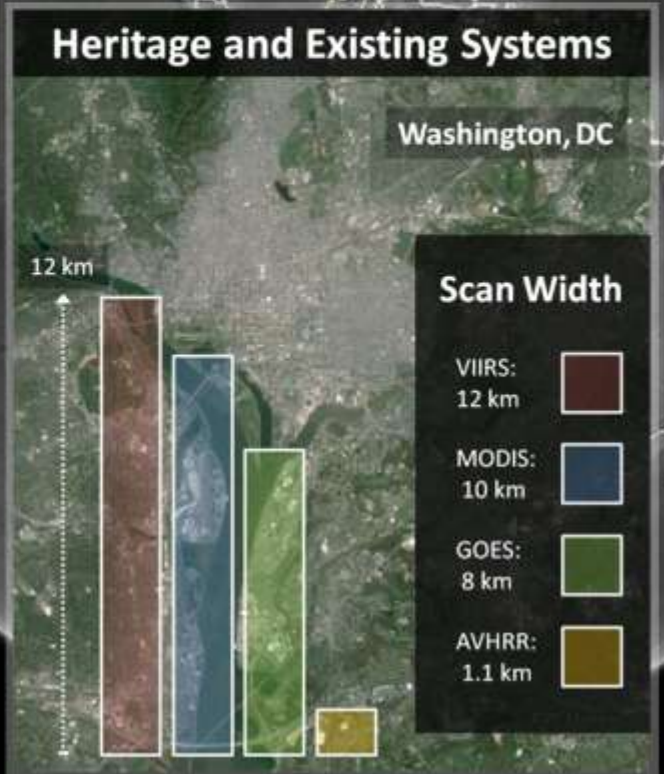
The GOES-R series of satellites will offer images with greater clarity and 4x better resolution than earlier GOES satellites.

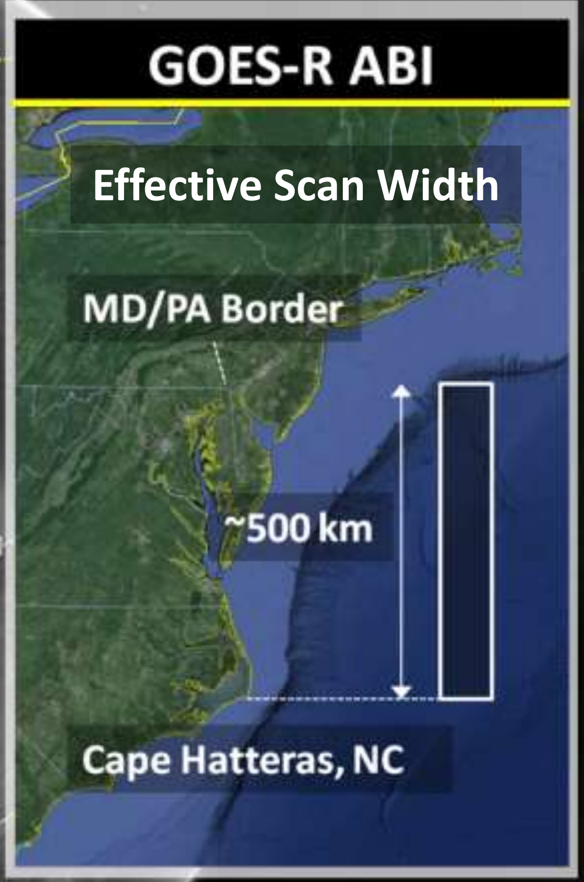
5X FASTER SCANS

Faster scans every 30 seconds of severe weather events and can scan the entire full disk of the Earth 5x faster than before.

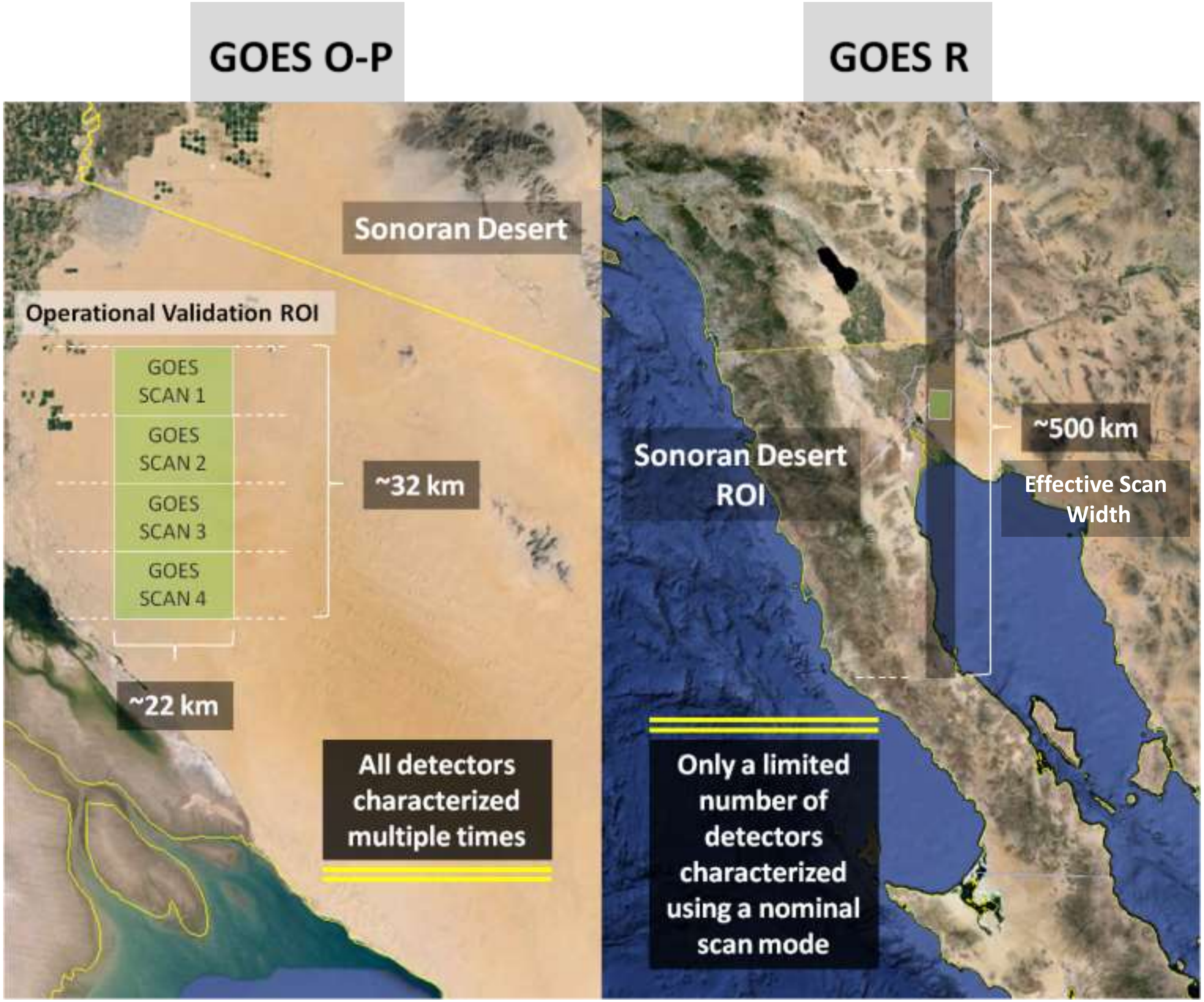
New Validation Challenges Due to FPA Size Increase

Imaging System	Number of Detectors/ Ch.
GOES R	**332, 372, 408, 676, 1460**
GOES O-P	8, 2
MODIS	10, 20, 40
VIIRS	16, 32
AVHRR	1

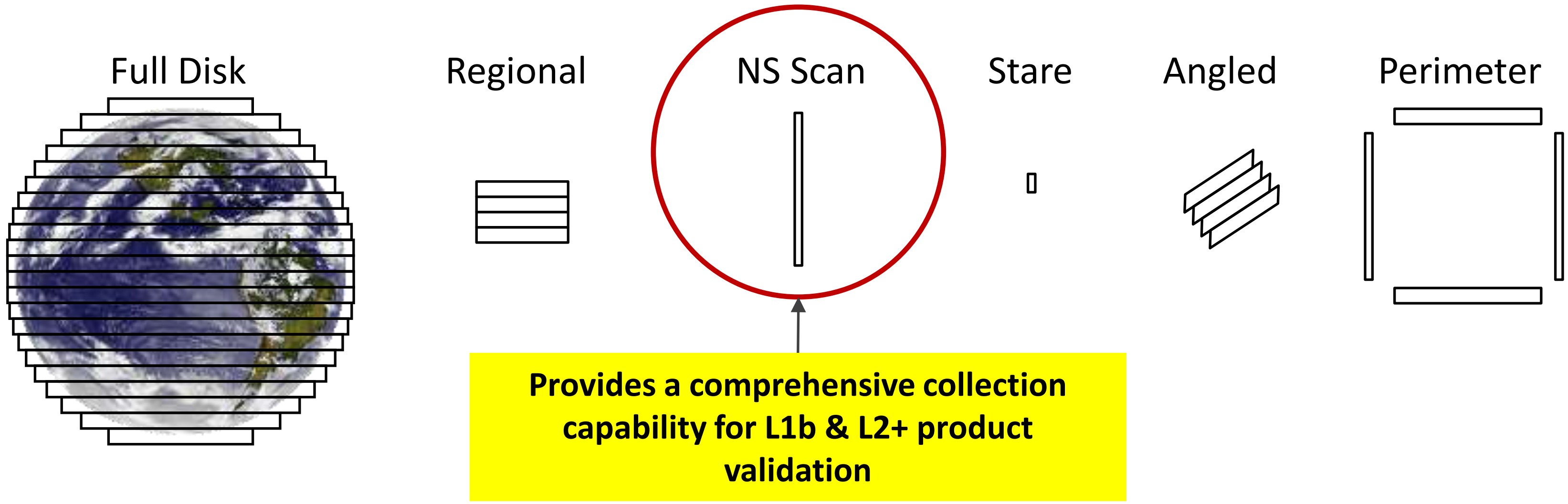




GOES-R ABI Post-Launch Validation Challenges



ABI Scan Flexibility



North South Scan (NSS):

- Forces each detector to pass over the same ground target (i.e. all detectors view the same total radiance)
- Collection achieved by holding the EW scan mirror fixed and moving the NS scan mirror

Note: To collect the same Earth location with each ABI band using NS swaths:

- A shift in the EW scan mirror is required to position a given band's array over the desired region of interest before each NS swath (i.e. each band is collected separately)

Graphics Courtesy: Harris

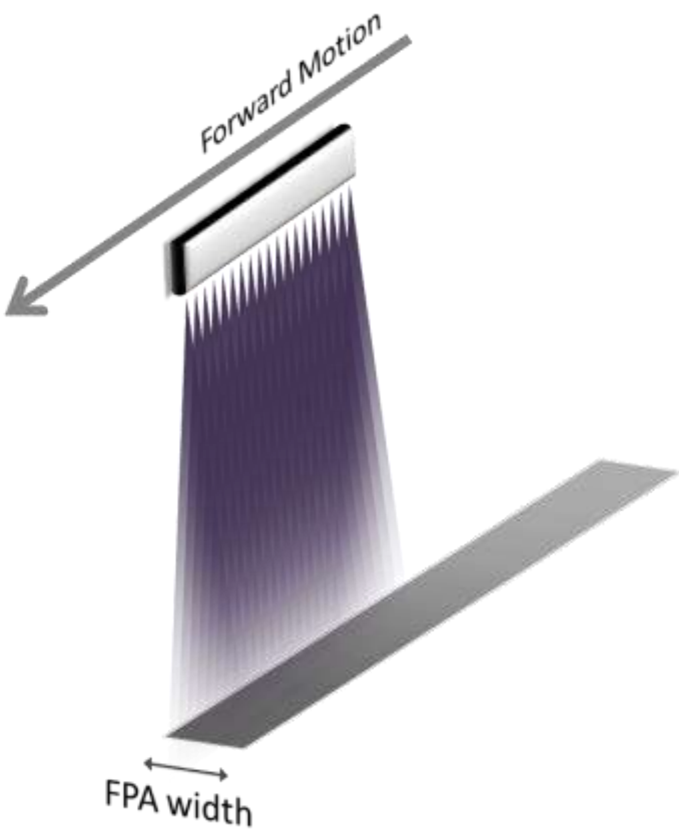
Leveraging Lessons Learned from Previous & Existing Large Array Systems

Pushbroom Sensor
Side-Slither Collection

Spacecraft Maneuver Required
(90º Yaw Maneuver)

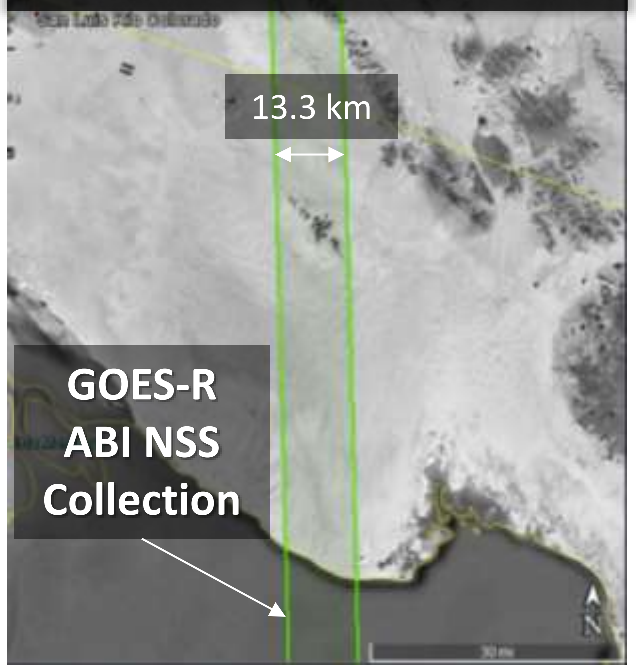
GOES-R ABI
North South Scan

NO Spacecraft Maneuver Required



GOES-R Field Campaign Plan:

ABI NSS Will Provide the Opportunity to Validate All ABI Detectors Over a Single Earth Target

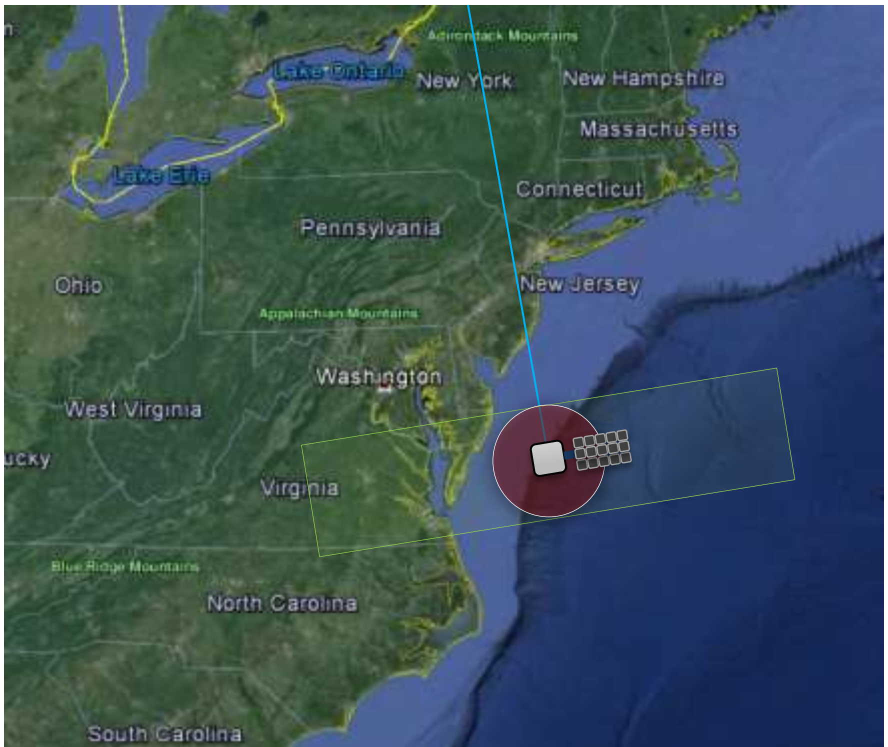


Aircraft Field Campaign Validation of Space-Based Sensors

Aircraft Sensor Footprint

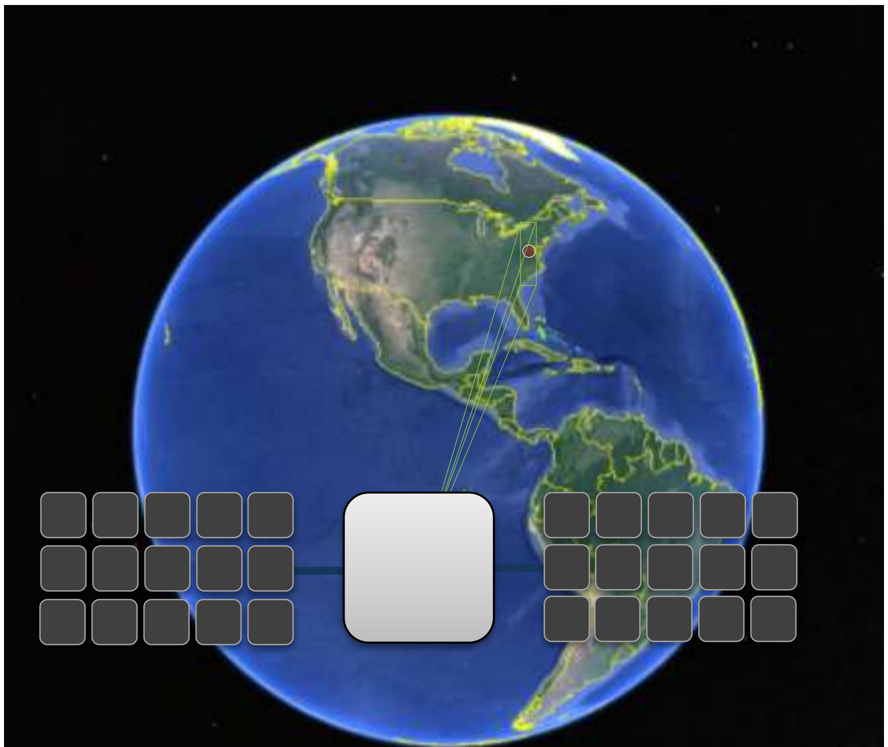
Geostationary Orbit presents unique validation challenges with Aircraft sensors due to view geometry

Low Earth Orbit



Aircraft validation is more established for Low Earth Orbit validation efforts

Geostationary Orbit

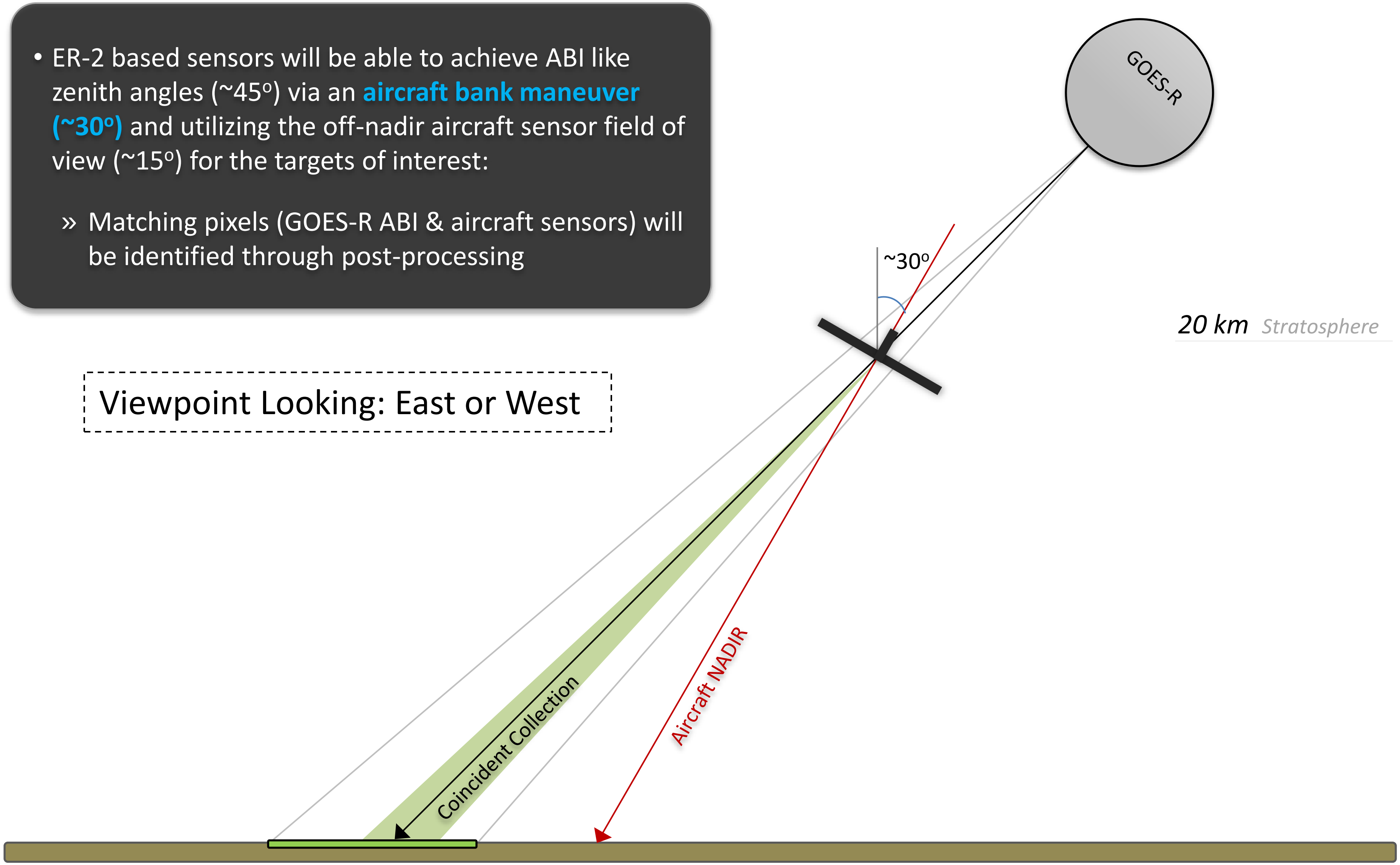


Aircraft validation efforts are more challenging for Geostationary validation

Address the Challenges of Geostationary Field Campaign Validation: Aircraft Collection Strategy

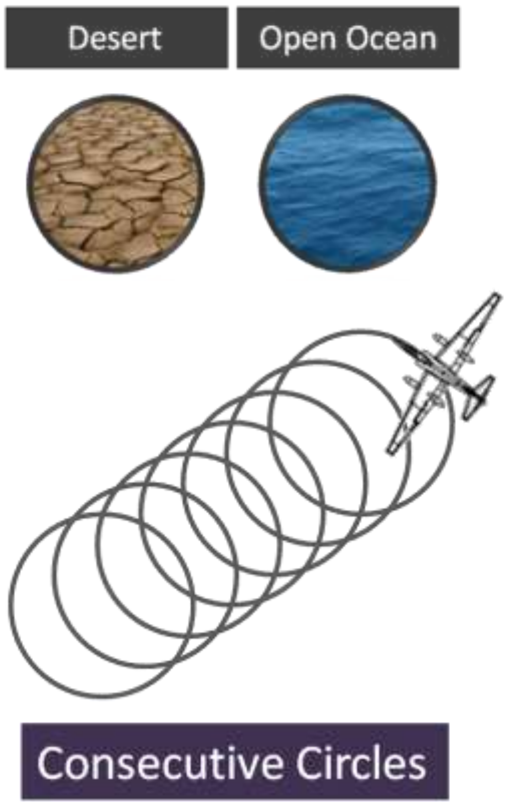
- ER-2 based sensors will be able to achieve ABI like zenith angles (~45º) via an **aircraft bank maneuver (~30º)** and utilizing the off-nadir aircraft sensor field of view (~15º) for the targets of interest:
  - » Matching pixels (GOES-R ABI & aircraft sensors) will be identified through post-processing

Viewpoint Looking: East or West



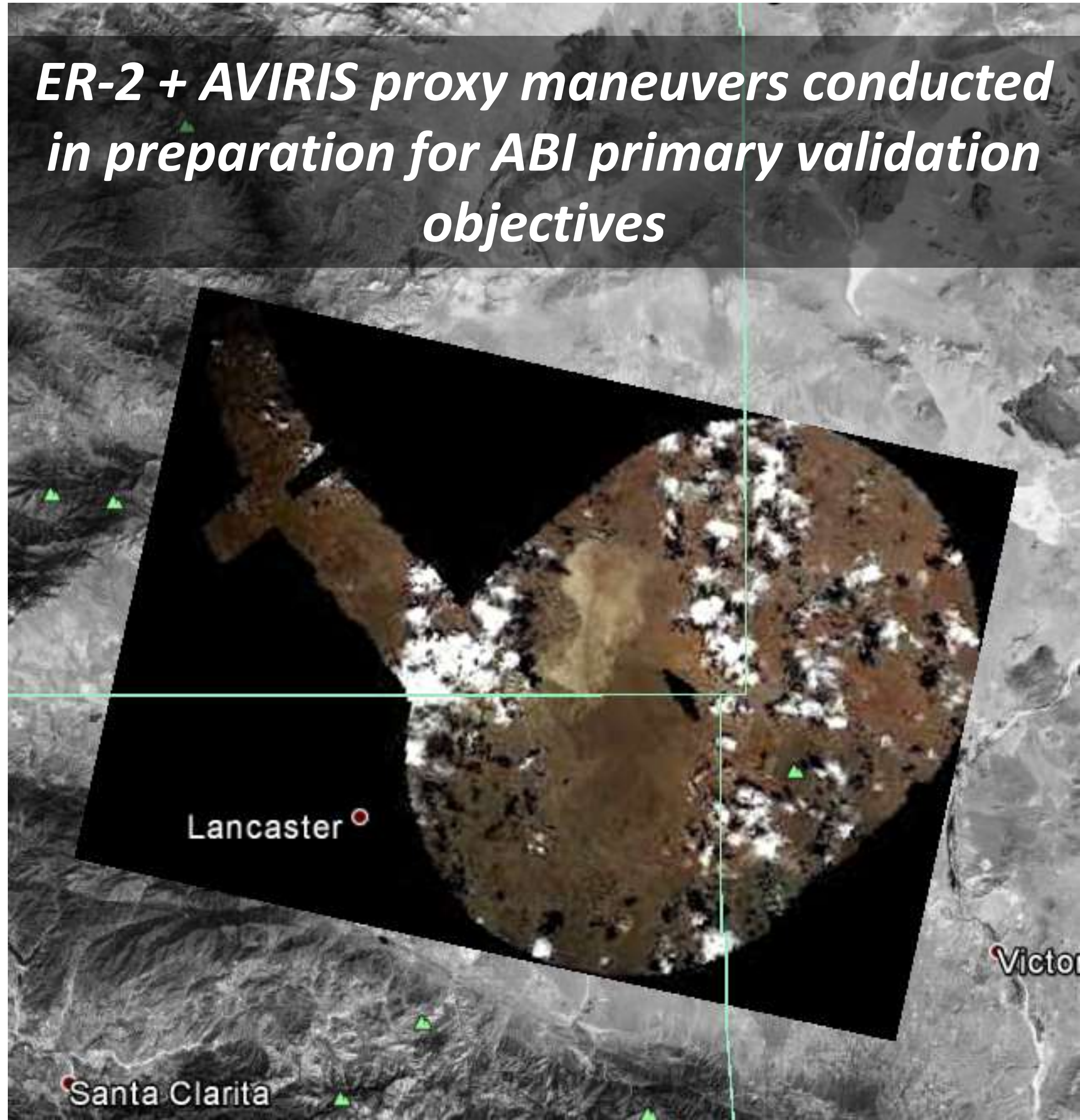
ER-2 Collection Strategy

ABI ER-2 Validation Pattern:



ER-2 maneuvers conducted in Spring 2016:

(Special thanks to Timothy Williams NASA AFRC and Ian Mccubbin NASA JPL)



ABI Primary Validation Objective Activities

ABI NSS Collections + ER-2 Continuous Circle Maneuvers

Summary:

- **Collection provides an absolute validation capability of ALL ABI detectors and is the primary pathway to validate SI traceability**
- Planned Collection:
  - Desert (daylight)

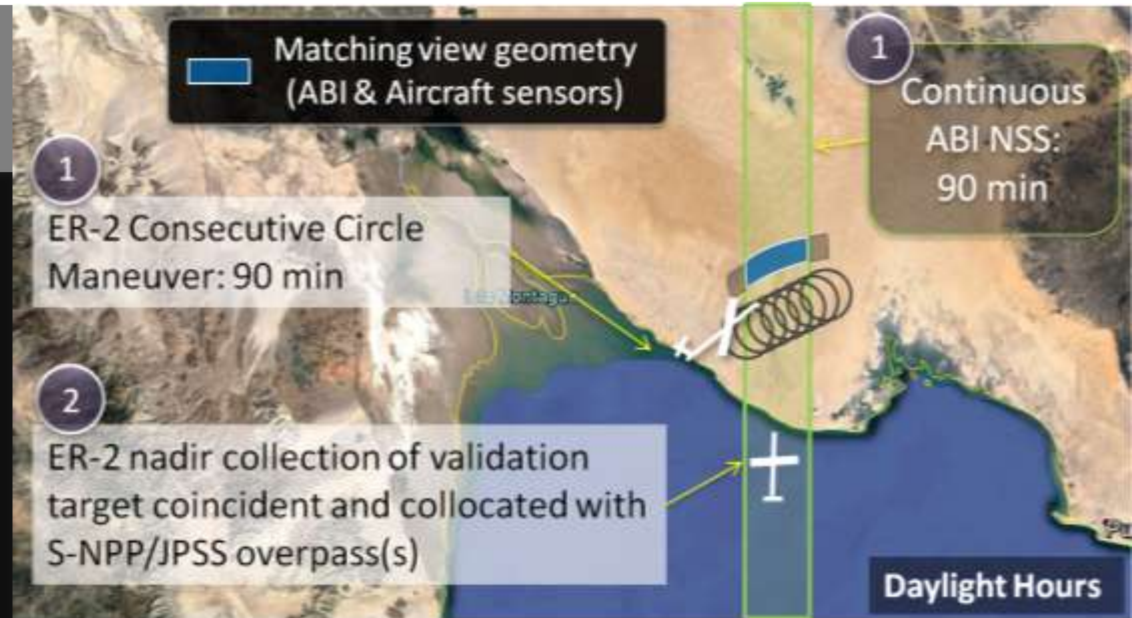
    - Zenith: ~45°
    - Azimuth: ~41° (counter-clockwise from north)
  - Water (night)

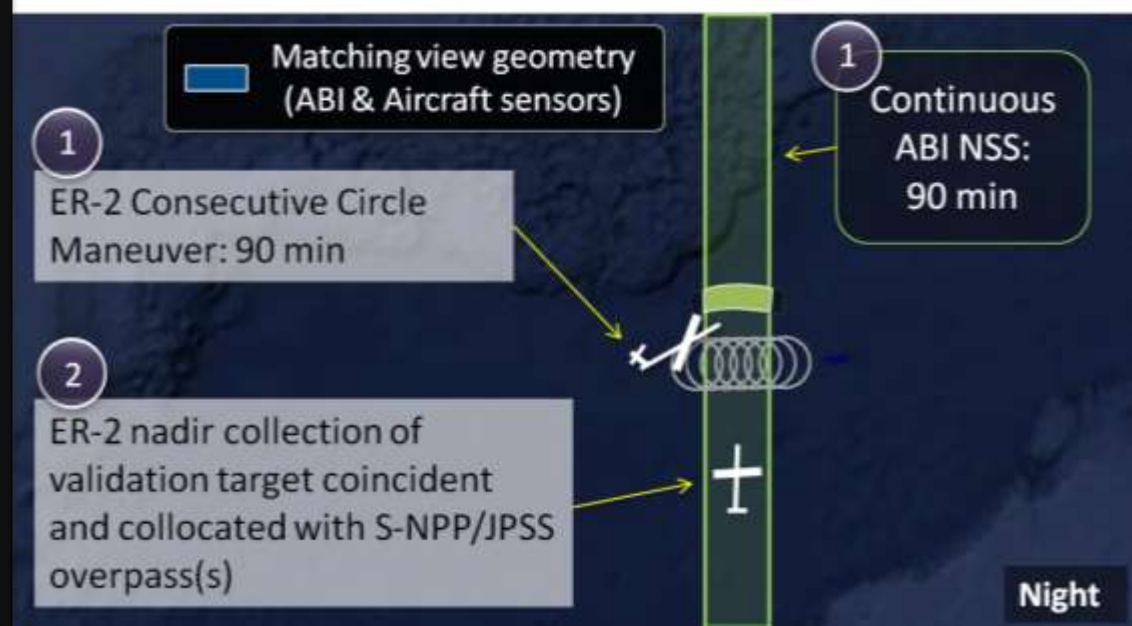
    - Zenith: ~30°
    - Azimuth: ~0° (counter-clockwise from north)

  **ABI view geometries from 89.5 W*

  (Coincident with S-NPP/JPSS instruments)

- ABI N-S scan collection of ~90 min for each target collection
  - provides an opportunity to acquire large sample sizes for each detector





ABI Field Campaign Approach:

Primary Objective: provide validation of ABI L1b spectral radiance observations to validate SI traceability

Validation Through Direction Comparison:

» **Thermal Emissive Band (TEB) Post-Launch Validation:**
- S-HIS (uncertainties are well documented)
- Previous work has demonstrated validation of better than ~0.2 K
- **Heritage approach** – *direct comparison with well calibrated high altitude sensor*

» **Reflective Solar Band (RSB) Post-Launch Validation**:
- **Direct comparison methodologies in the RSB are less mature (NOT the heritage approach)**

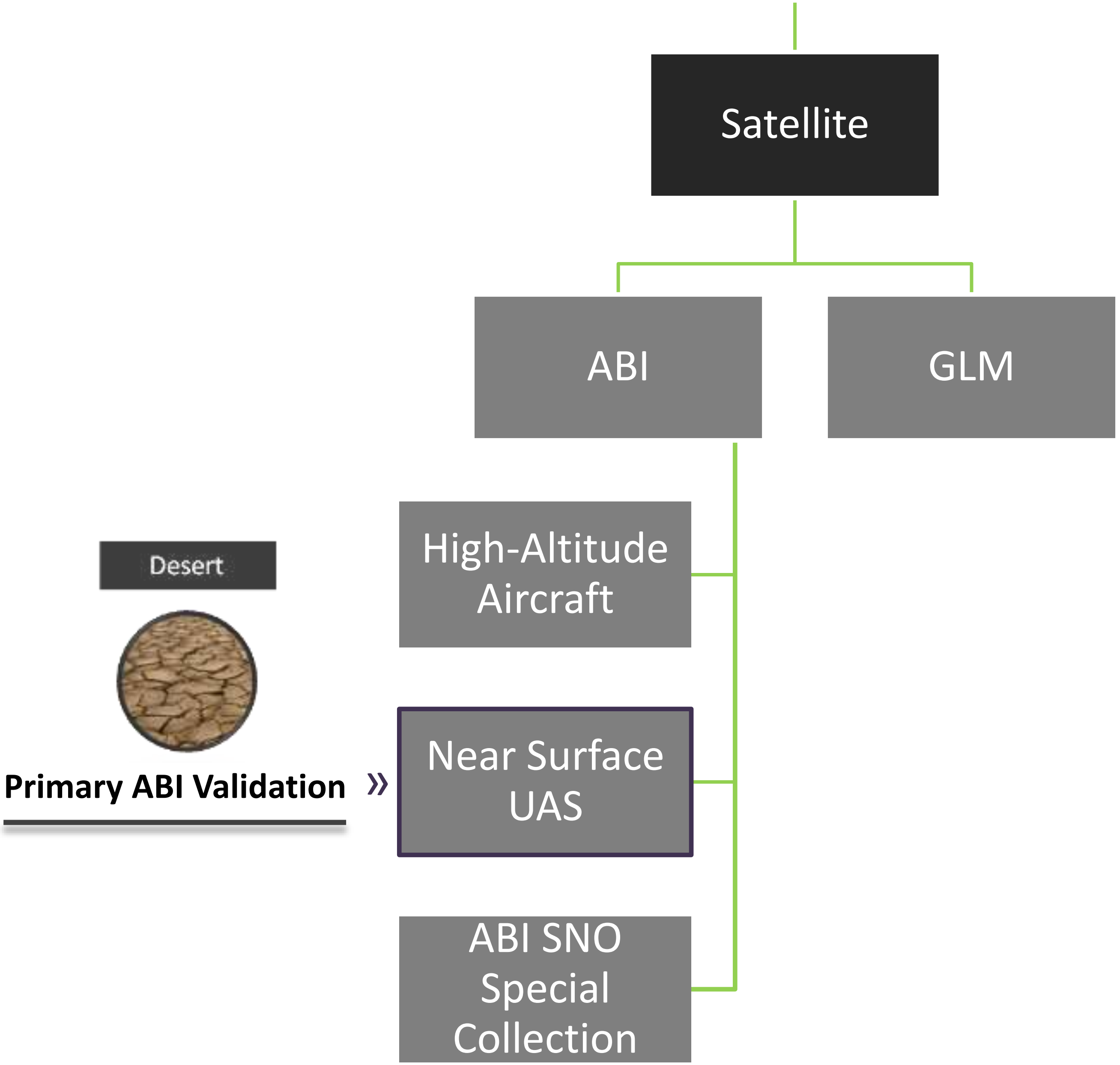
AVIRIS provides:

» ALL detector validation methodology

» Funded the Remote Sensing Group at the College of Optical Sciences, University of Arizona to provide an independent calibration of AVIRIS during test execution (heritage approach ~3-5 %)

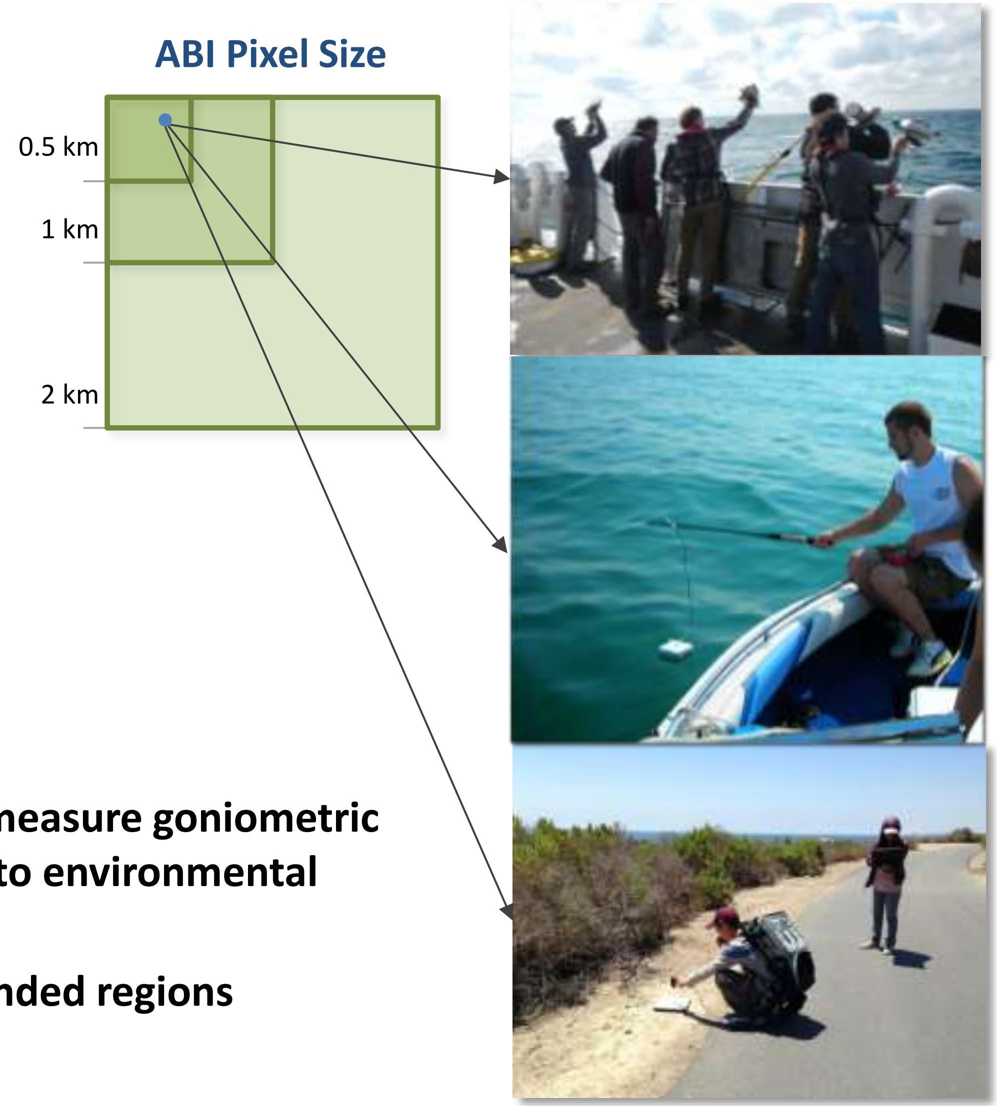
Heritage Approach:

GOES-R Field Campaign: Critical Components



Environmental Remote Sensing Ground Measurement Validation Challenges & Gaps

- **Challenging to provide high quality data that can be directly compared to satellite observations without gross assumptions (i.e. uniformity):**
  - Ground validation measurements are typically point-based measurements
  - Often need to disturb the collection environment to make the measurements
  - Labor intensive
  - Costly (typically involves a large team)
  - Repeatability can be challenging
  - Limited collection geometry
- **Currently no operational capability to measure goniometric observations over regions comparable to environmental satellite observations**
- **Difficult to collect observations of extended regions**



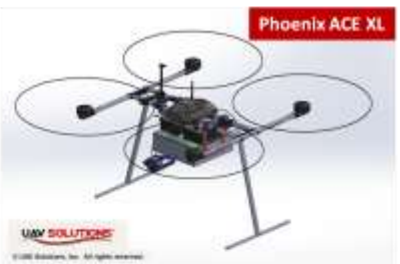
Development of Advanced Post-Launch Validation Capabilities: Near Surface UAS Measurements

GOES-R Funded: "GOES-R Near Surface UAS Feasibility Demonstration Study" - NOAA Cooperative Institute Partnership with the University of Maryland (UMD) in collaboration with the NOAA UAS Program

Scope: Develop prototype UAS & assess the feasibility of near surface validation reference measurement capabilities in support of GOES-R Field Campaign validation efforts (L1b/L2+)

Phase 1: Procurement/Development & Integration of Prototype Systems:

Rotary UAS



Phoenix ACE XL Specifications
Endurance: 30 minutes
Fully autonomous system
Take-off weight: 10 lbs.

Customized electronic enclosure and autonomous 2 axis gimbal

Fixed-Wing UAS

Talon120 Specifications
Length: 6' Wingspan: 12.5' MGTOW: 20 lbs.
Payload capacity: 2.5 lbs.
Range: 8 miles LOS
Endurance: 2.0 – 2.5 hours
Fully autonomous system
Typical operating alt.: 50-500 ft. AGL; MSL up to 10,000 ft

Customized nose cone for high resolution georeferenced imagery

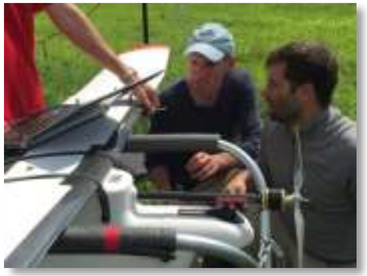
Collection Reference Data:

1) **Rotary UAS -** Goniometric observations & area collection

2) **Fixed-wing UAS** – area collection

Phase 2: Capability & CONOPS Optimization

Phase 3: Intensive Field Campaign Deployment



GOES-R UAS Feasibility Demonstration Study:

Successful Fixed-Wing UAS functional & operational performance demonstrations

Completed 2 successful test flights at the:

- University of Maryland (UMD) UAS test site in Bushwood, MD on August 3, 2016
- NOAA National Estuary Research Reserve (NERR) in Jug Bay, MD on August 8, 2016 – UAS test data provided to NOAA NERR as operational data
- Resulting products: 2D & 3D geo-referenced maps

NADIR Imagery

Oblique Imagery

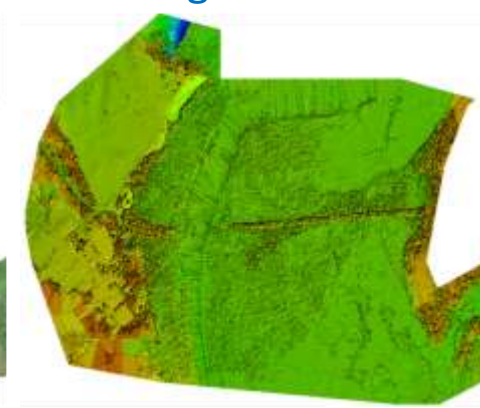
2D Geo-Referenced Orthomosaic

3D Digital Surface Model

UMD UAS Test Site (subset – 2 flight lines of data collection)

2D Geo-Referenced Orthomosaic

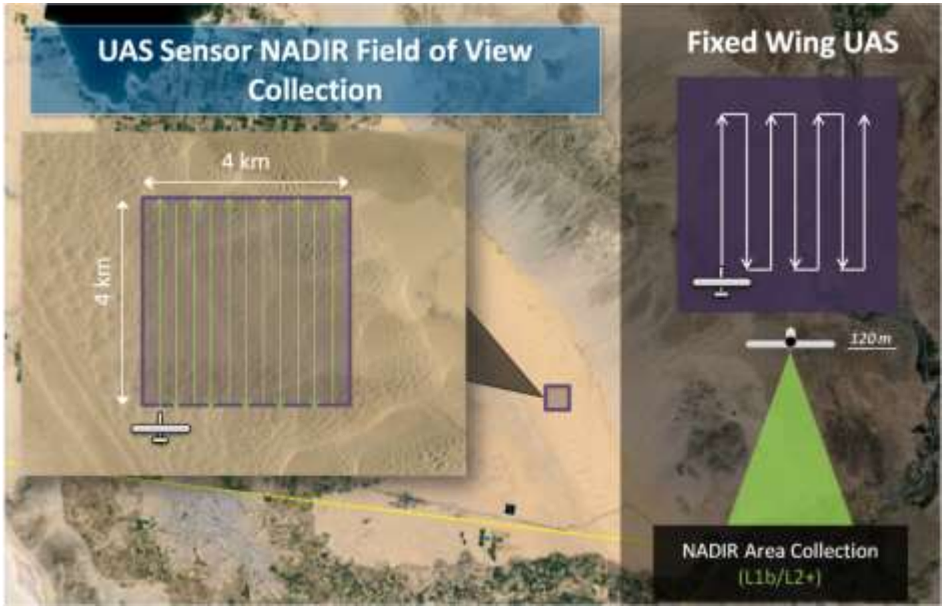
3D Digital Surface

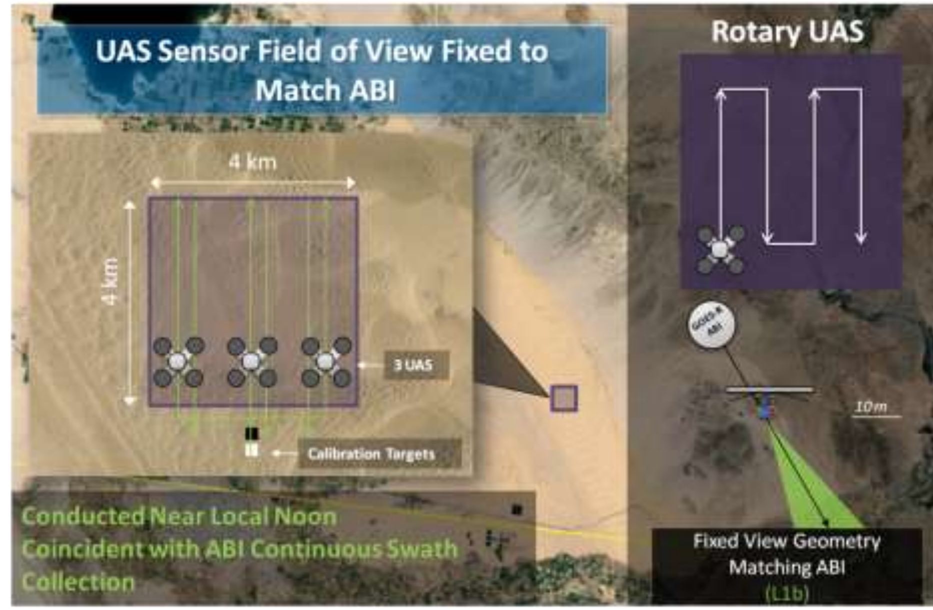


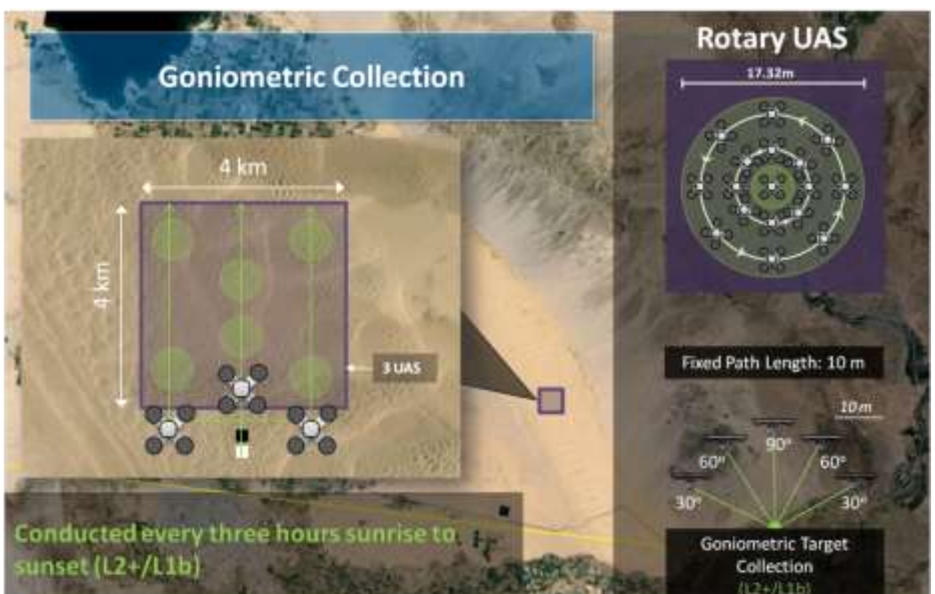
NOAA NERR – Jug Bay, MD

Near Surface UAS Initial CONOP for Post-Launch Validation:

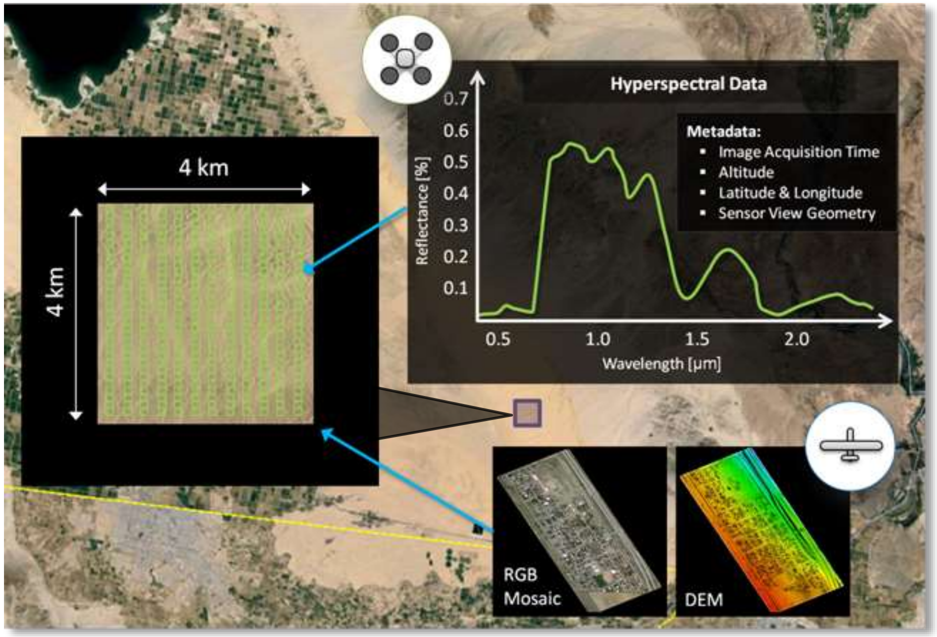
Validation of L1b Data & Support of L2+ Product Uncertainty







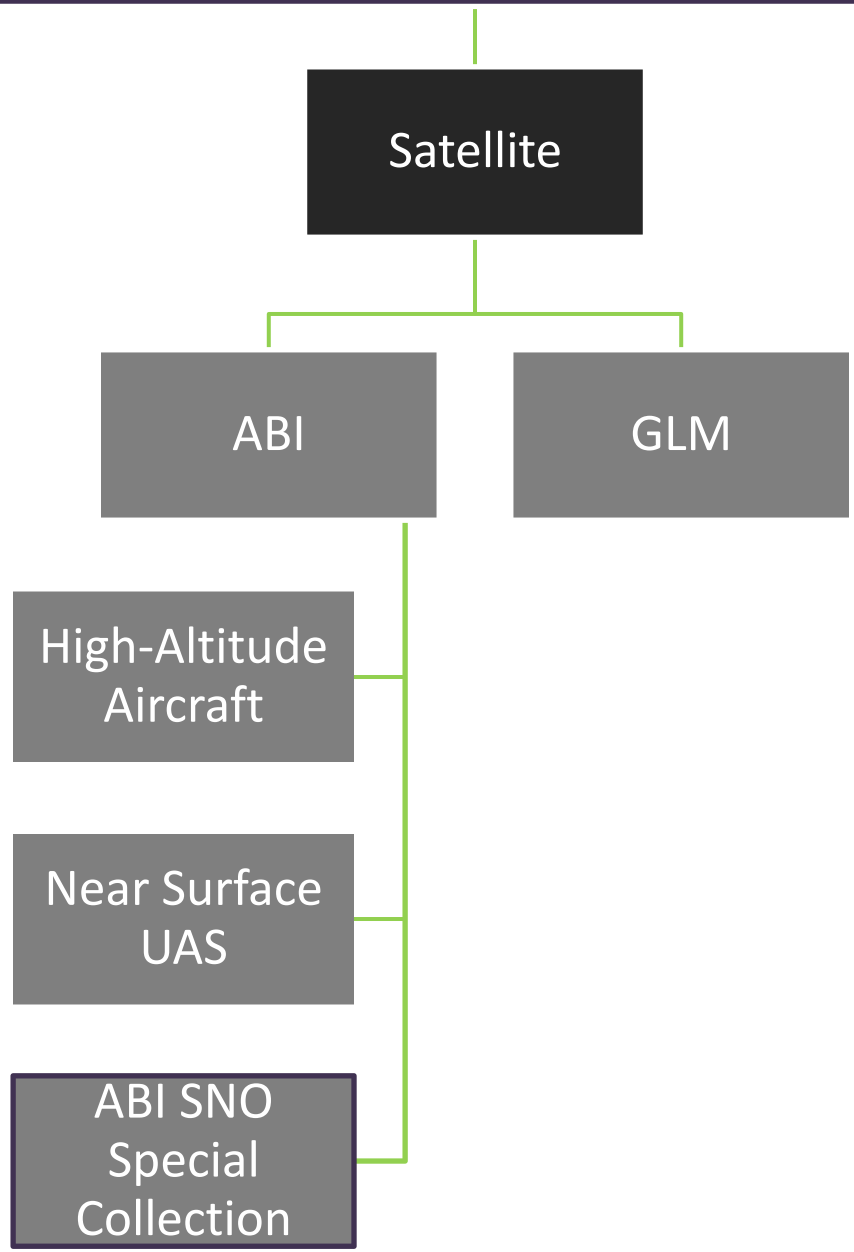
Near Surface UAS Measurements Provide Improved Validation Capabilities:
Validation of L1b Data & Support of L2+ Product Uncertainty



UAS Capability Can Enhance GOES-R Post-launch Validation Capabilities:

- Provides an absolute validation capability, a secondary pathway to validate SI traceability (RSB & TEB surface channels), and L2+ product performance uncertainties
- UAS deployments can support long-term monitoring of ABI performance
- Enduring capability for Cal/Val scientist:
  - Near surface UAS campaigns can be replicated numerous times throughout the year at significantly reduced costs in comparison to heritage approaches
  - UAS deployments can support characterization of the degree of uniformity within the given satellite footprint (Ideally, for all reference Cal/Val sites (i.e. fixed ground instruments) in different seasons
- Goniometric surface measurements can be used to check components of model values used in retrieval algorithms

GOES-R Field Campaign: Critical Components



Open Ocean

Primary ABI Validation »

ABI NSS during GEO/LEO Simultaneous Nadir Overpass (SNO) Events Provides All Detector Validation of ABI

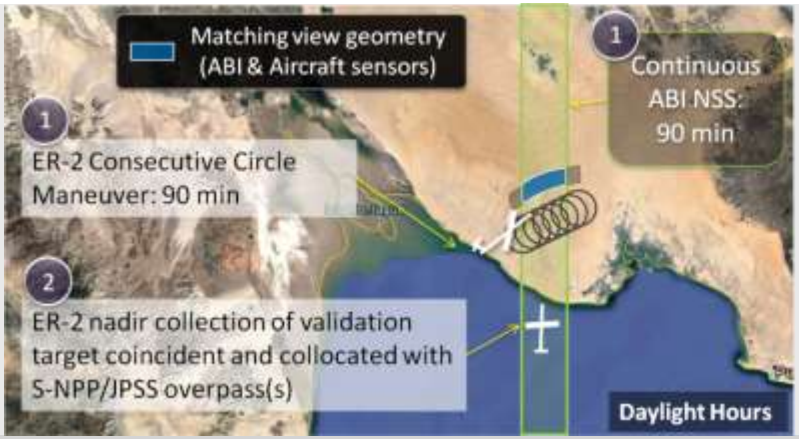
ABI NSS + LEO SNO Collection:

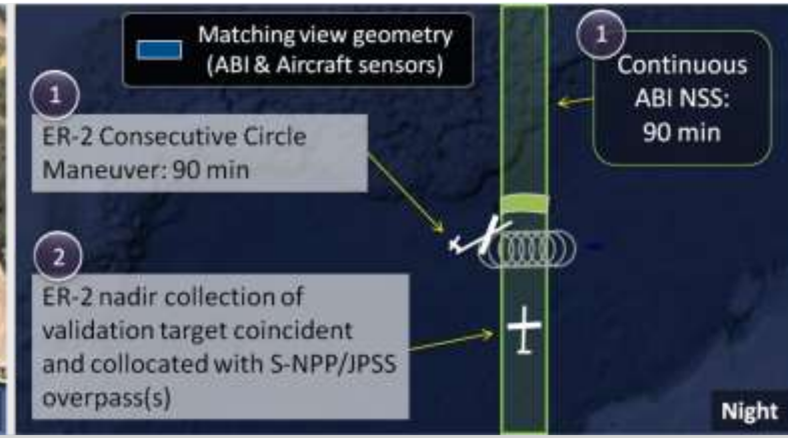
- Provides an ALL ABI detector validation methodology through reference LEO instruments (reduced uncertainties compared to heritage inter-comparison methodologies)
- Our focus will be to collect a single optimal inter-compare between ABI & S-NPP VIIRS (day), S-NPP CrIS (night), & MeTOP IASI (night) under clear sky conditions

GOES-R Field Campaign ABI Primary Validation Summary

Provides independent validation of the SI traceability of L1b spectral radiance observations & leverages lessons learned from extensive pre-launch analysis

(1) Aircraft Validation





(2) UAS Validation

(3) SNO Validation

1) **NSS Collections + High-Altitude Aircraft:** provides an absolute validation capability of ALL ABI detectors and is the primary pathway to validate SI traceability

2) **Near Surface UAS Collection:** provides an absolute validation capability, a secondary pathway to validate SI traceability (RSB surface channels), and product performance uncertainties

3) **NSS + SNO Collection:** a secondary pathway to validate SI traceability of ALL ABI detectors through reference instrument(s)

Absolute independent validation of ALL ABI detectors using hyperspectral sensors over ideal cal/val Earth targets

GOES-R Field Campaign Summary: Phase 1 & 2

Timeframe: April – June 2017
Duration: ~6 weeks
Flight hours: ~100 hrs

Phase 1 Summary:

- Focus: achieve ABI primary validation objective (L1b)
- Opportunity for ABI UAS collection in Desert region
- Opportunity for GLM validation targets:
  - GLM LMAs within range:
    - Socorro, NM
    - Ft. Collins, CO
    - Lubbock, TX
    - Norman, OK
- Collections of opportunity for ABI & GLM

Phase 2 Summary:

- Focus: GLM primary and ABI secondary objectives
- GLM LMAs within range:
  - Huntsville, AL
  - Washington, DC
  - Kennedy Space Center, FL
  - Houston, TX
  - Wallops Island, VA
  - Atlanta, GA
  - Toronto, Canada
  - Lubbock, TX
  - Norman, OK
- Opportunity for ABI UAS collection in the Gulf of Mexico & at the DOE ARM site or similar sites
- Collections of opportunity for ABI & GLM

ER-2 Loiter Time (based on an 8 hr mission)

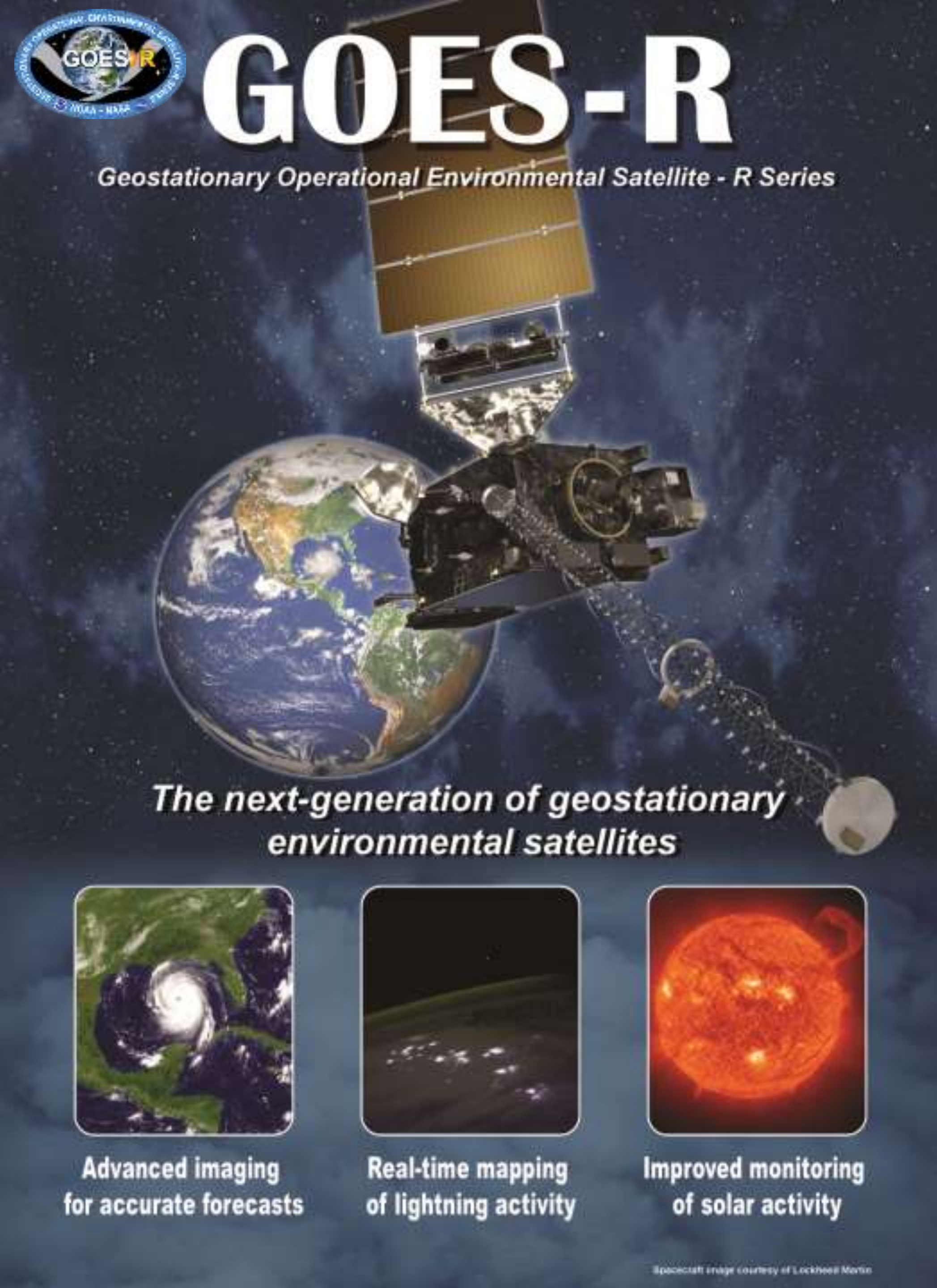
Summary

The purpose of the GOES-R field campaign is to support post-launch validation of L1b & L2+ products

Underflights to be collected, when possible, with low Earth orbit environmental satellites which may include S-NPP, Terra/Aqua, METOP, Landsat, ISS & GPM

Field Campaign Data Portal with ALL Coincident Data

Open data access policy



Thank you!

For more information visit www.goes-r.gov

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Questions?

GOES Imaging

GOES-1

1st image October 25, 1975

Over 4 Decades of Earth Observation

» [Primarily qualitative imagery products]

[Broad set of qualitative & quantitative imagery products] «

Essential support in weather forecasting & environmental monitoring

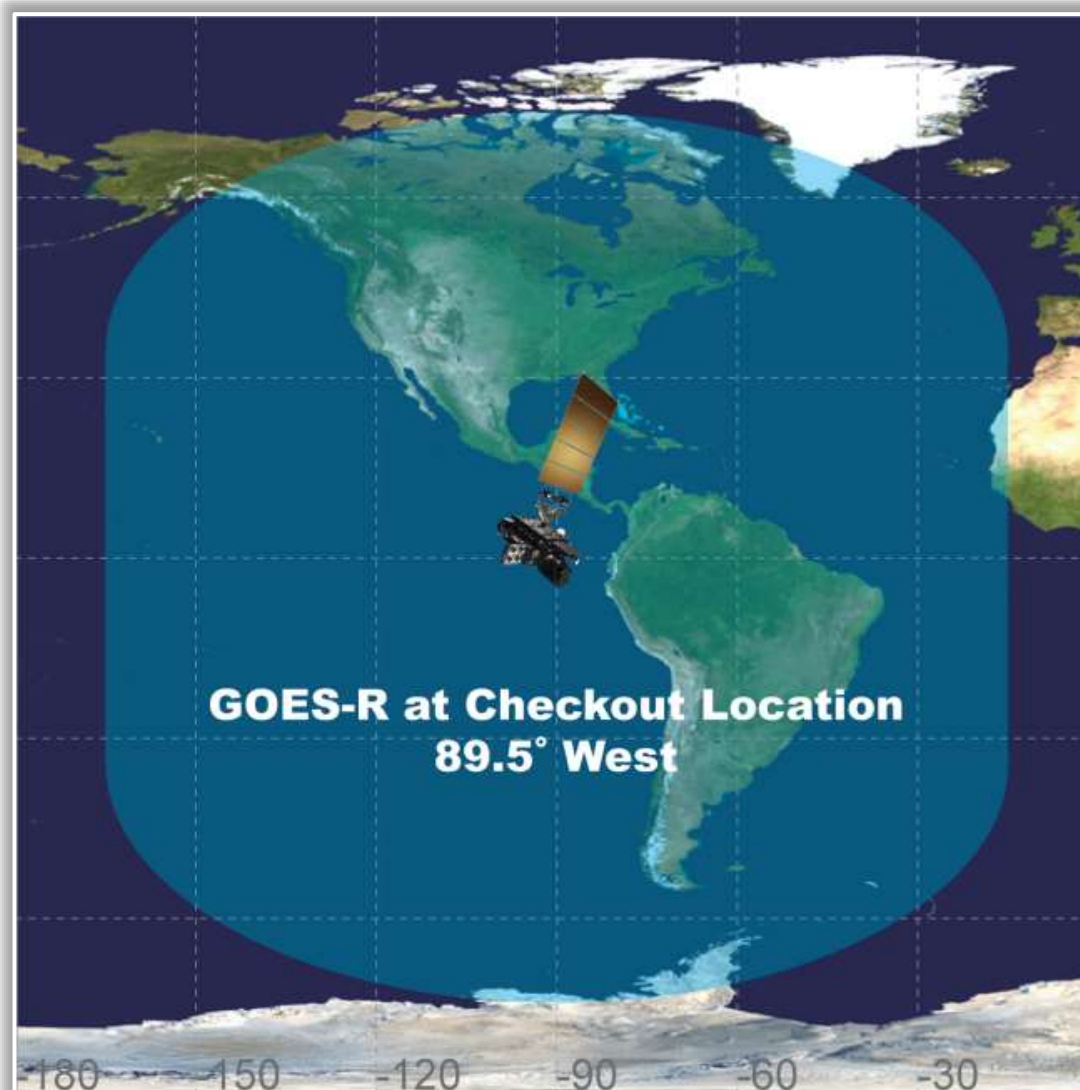
GOES-R
Advanced Baseline Imager

16 Band Imager

Spectral Region	Spatial Resolution
6 VNIR/SWIR	0.5,1 & 2 km
10 Infrared	2 km

Images courtesy: www.goes-r.gov & www.nesdis.noaa.gov/news_archives/40_years_of_goes_the_anniversary_of_goes1.html

GOES-R Located at 89.5 W During GOES-R Field Campaign Activities: Post Launch Product Test (PLPT)



ER-2 Loiter Time (based on an 8 hr mission)

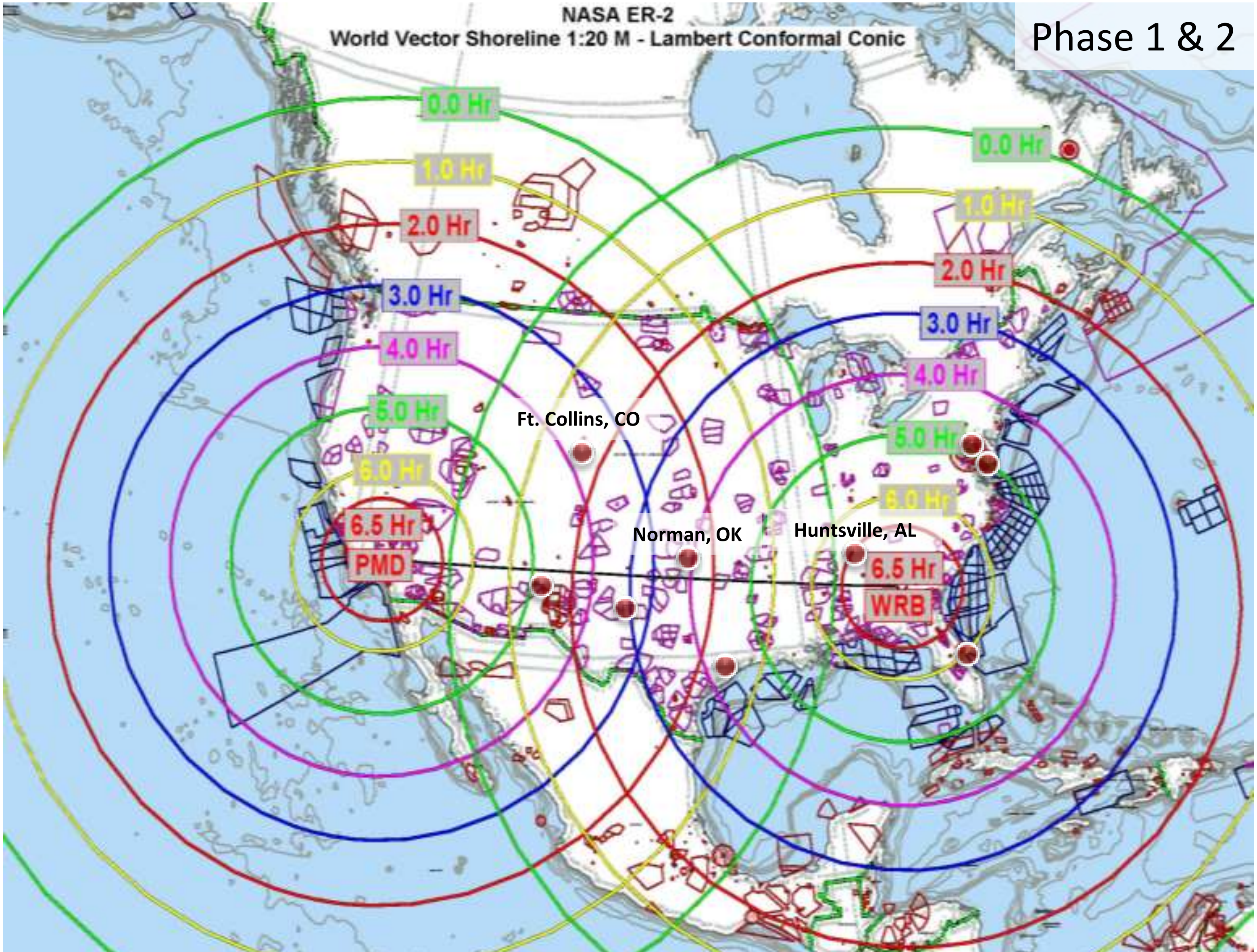


Image courtesy: Brian Hobbs (NASA ER-2 Program)

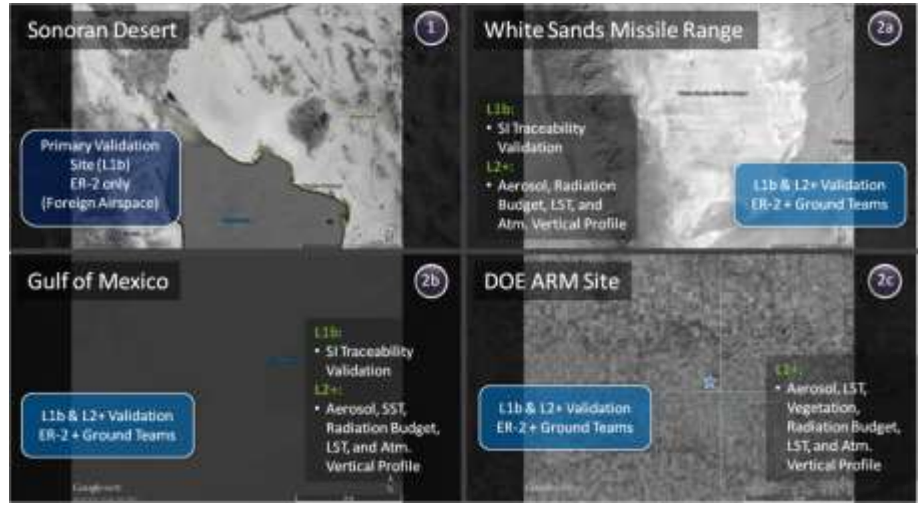
ABI Collection Priorities - 3 Components

1) **Direct Comparison - ABI Observations vs. ER-2 Based AVIRIS & S-HIS Observations:**
   - » AVIRIS vs. ABI Ch. 1-6
     - ▪ Radiance & TOA Reflectance
   - » S-HIS ABI Ch. 7-16
     - ▪ Radiance & Brightness Temperature

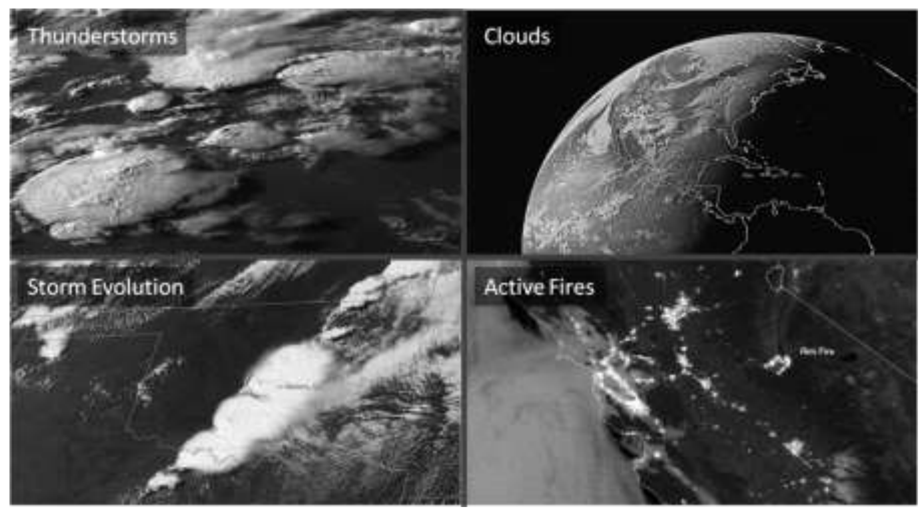
2) **Intensive Ground Campaign – Near Surface UAS Collections:**
   - » Desert (L1b & L2+):
     - ○ Candidate Site:
       - ▪ White Sands, NM or similar site
   - » Open Ocean (L1b & L2+)
     - ○ Candidate Site: 100 km off the coast of the Gulf of Mexico or US East coast in the Atlantic (pending available funding)
   - » Vegetation (L2+):
     - ○ Candidate Site:
       - ▪ ARM Site or similar site

3) **Collection of Opportunity**
   - » Primarily targets coincident with GLM validation collections, large wild fires, Chesapeake Bay, Salton Sea/Lake Tahoe

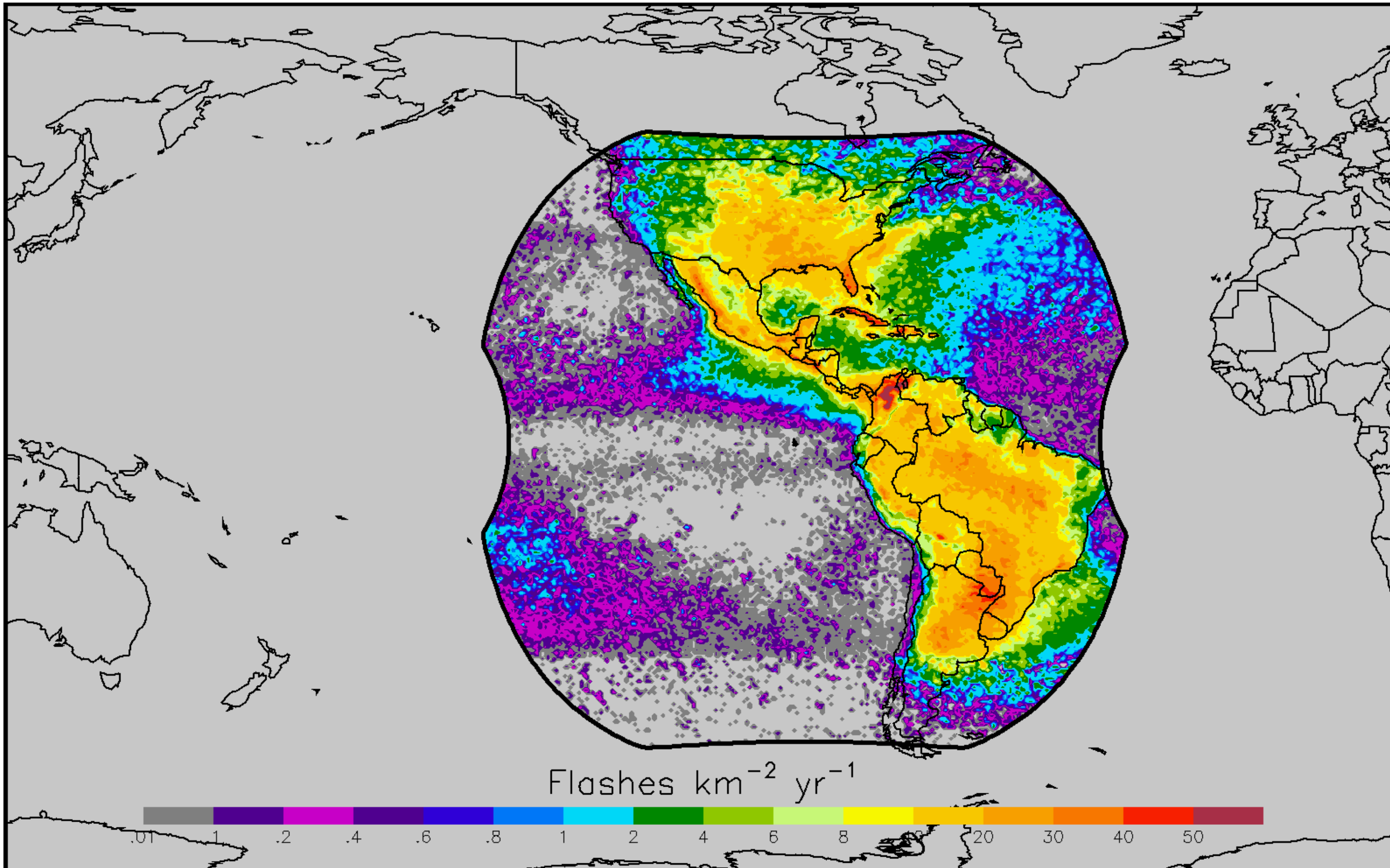
ABI Collection Priorities



ABI Collections of Opportunity



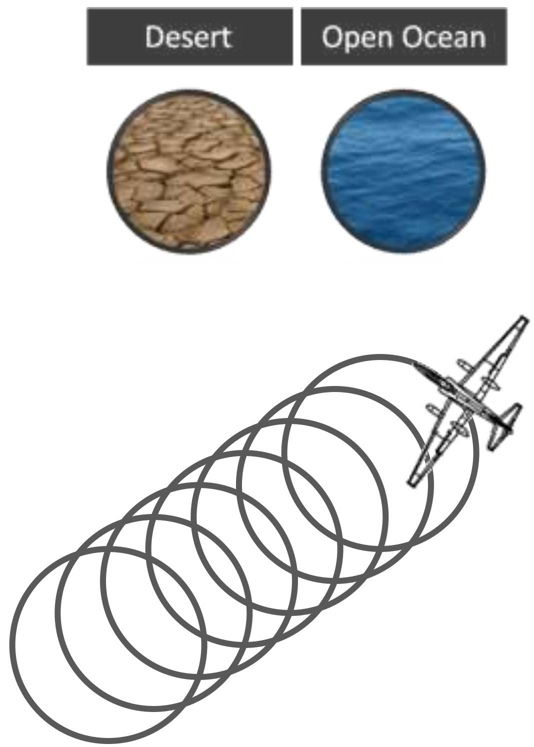
GLM FOV for PLPT (89.5°W longitude)



TRMM LIS Climatology

ER-2 Primary Validation Collection Strategies:

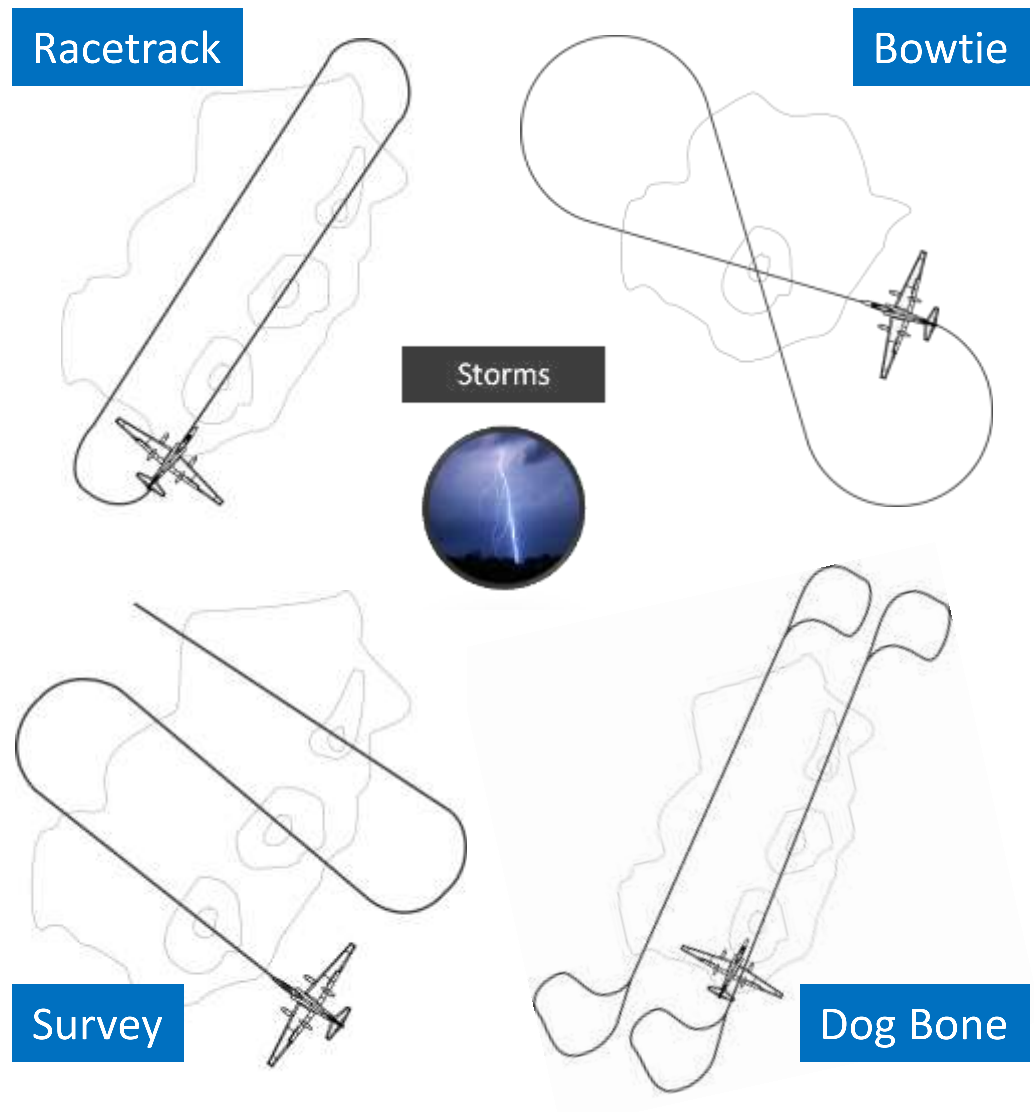
ABI Validation Pattern:



Consecutive Circles

ER-2 proxy maneuvers conducted in preparation for ABI primary validation objectives (AVIRIS Sierra Snowpack Campaign)

GLM Validation Patterns:



RSB Heritage Approach: Reflectance-Based

Inputs:

- Desert site (Ex. Landsat 7 [30 m pixels] – 480 m x 120 m)
  - Surface reflectance observations
    - User walked a backpack spectrometer 2 m height
    - 45 – 60 minutes to conduct collection
    - <2.5 % of total desert target area was sampled
  - Atmospheric observations
  - Radiative transfer code

Processing:

- Surface reflectance measurements are averaged to produce a single spectral reflectance for the entire site
- Determination of Gain

Uncertainty of the Method:

- 3-5 % radiometric uncertainty
- Well established for moderate/high spatial resolution space-based systems (Landsat/GeoEye)


calvalportal.ceos.org


Image Courtesy: SDSU


Image Courtesy: SDSU


Image Courtesy: Czapla-Myers et al. 2015

- K. Thome (2001) Absolute radiometric calibration of Landsat 7 ETM+ using the reflectance-based method, Remote Sensing of Env.
- Czapla-Myers, J., McCorkel, J., Anderson, N., Thome, K., Biggar, S., Helder, D., Aaron, D., Leigh, L., and Mishra, N., "The Ground-Based Absolute Radiometric Calibration of Landsat 8 OLI," Remote Sens. (7) 600-626 (2015).

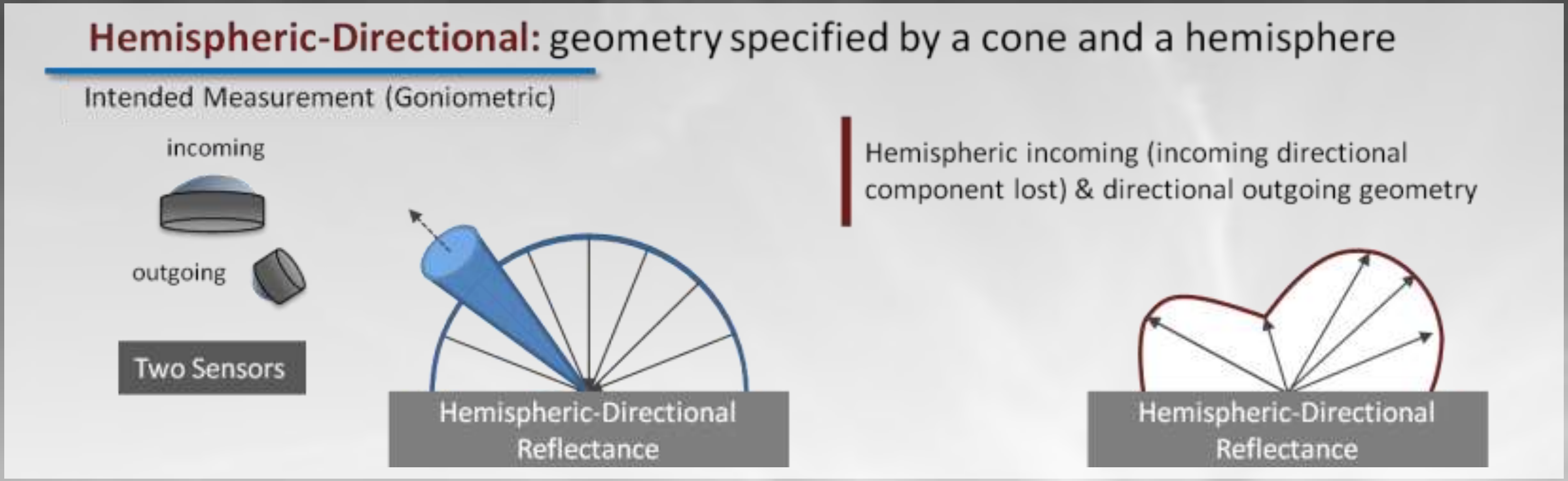
GOES-R Near Surface UAS Capability Priorities

1) Hyperspectral (0.35 – 2.5 µm) Reflective Solar Band (RSB) measurements are of highest priority

- **Upward Observation (total sky)**
- **Downward Observation (surface)**

  Ability to autonomously control the view geometry of the sensor payload(s) for oblique angle data collection of a fixed earth target: Range: 0° (nadir) to 90° (horizon) with a step size of 1° or less

  » Near surface ~10 m above ground level (i.e. assume atmosphere is negligible)



2) Broadband IR (8 – 14 µm) measurements

- **Directional Surface Observations (ideally filtered to match ABI spectral bands, initial focus ABI Bands 14-15)**

3) High resolution georeferenced imagery

- **Context imagery of calibration/validation targets & Digital Elevation Model (DEM) generation**

Common Requirements for Both Systems

- All sensor measurements have documented SI traceable paths
- All sensor measurement uncertainties are documented and reviewed
- System design shall be flexible to integrate on multiple UAS
- UAS capable of autonomous flight through pre-programmed flight planning
- Meta data to be collected & stored (image acquisition times, sensor look angles, GPS data)

Prototype Rotary System: UAS + Payloads

1. **Reflective Solar Band (RSB) Sensor Suite:**
   - Hyperspectral coverage from 0.35 to 2.5 µm
     - Downward (directional)
     - Upward (total hemispheric)
2. **IR Radiometer:**
   - Broadband IR – 8-14 µm/potentially filtered to match the ABI channels
3. **Context Imager:**
   - RGB HD video - context imager
4. **Atmospheric Sensor:**
   - T, RH, and Px profiles

Baseline Capabilities:

- Observations over extended regions matching ABI view geometry
- Goniometric observations over a given target (directional hemispheric)

Primary System – In Development

Rotary UAS

Phoenix ACE XL Specifications
Endurance: 30 minutes of collection
Fully autonomous system
Payload Capacity: 10-12 lbs

Customized electronic enclosure and autonomous 2 axis gimbal

Prototype Fixed-Wing System: UAS + Payloads

1. **High Resolution Camera:**
   – High resolution RGB camera
2. **Atmospheric Sensor:**
   – T, RH, & Px profiles

Baseline Capabilities:

- 2D high resolution georeferenced and orthorectified mosaics
- Digital Surface Model (± 1-5 m)
- Atmospheric profiles to maximum collection alt. (~400 ft or 121.9 m)

Secondary System

Fixed-Wing UAS

Talon120 Specifications

Length: 6’ Wingspan: 12.5’
Endurance: 2.0 -2.5 hours
Range: 8 mile LOS
Fully autonomous system
Payload Capacity: 2.5 lbs