Team Member Report

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Integrated Residual Analysis Inputs and Products

3° and 5° Ocean Scan Operational Plan

Profile and Waveform Matching Status

Puget Lowland Operational Plan

Inland Water, Vegetation Height, and Alpine Glacier Activities

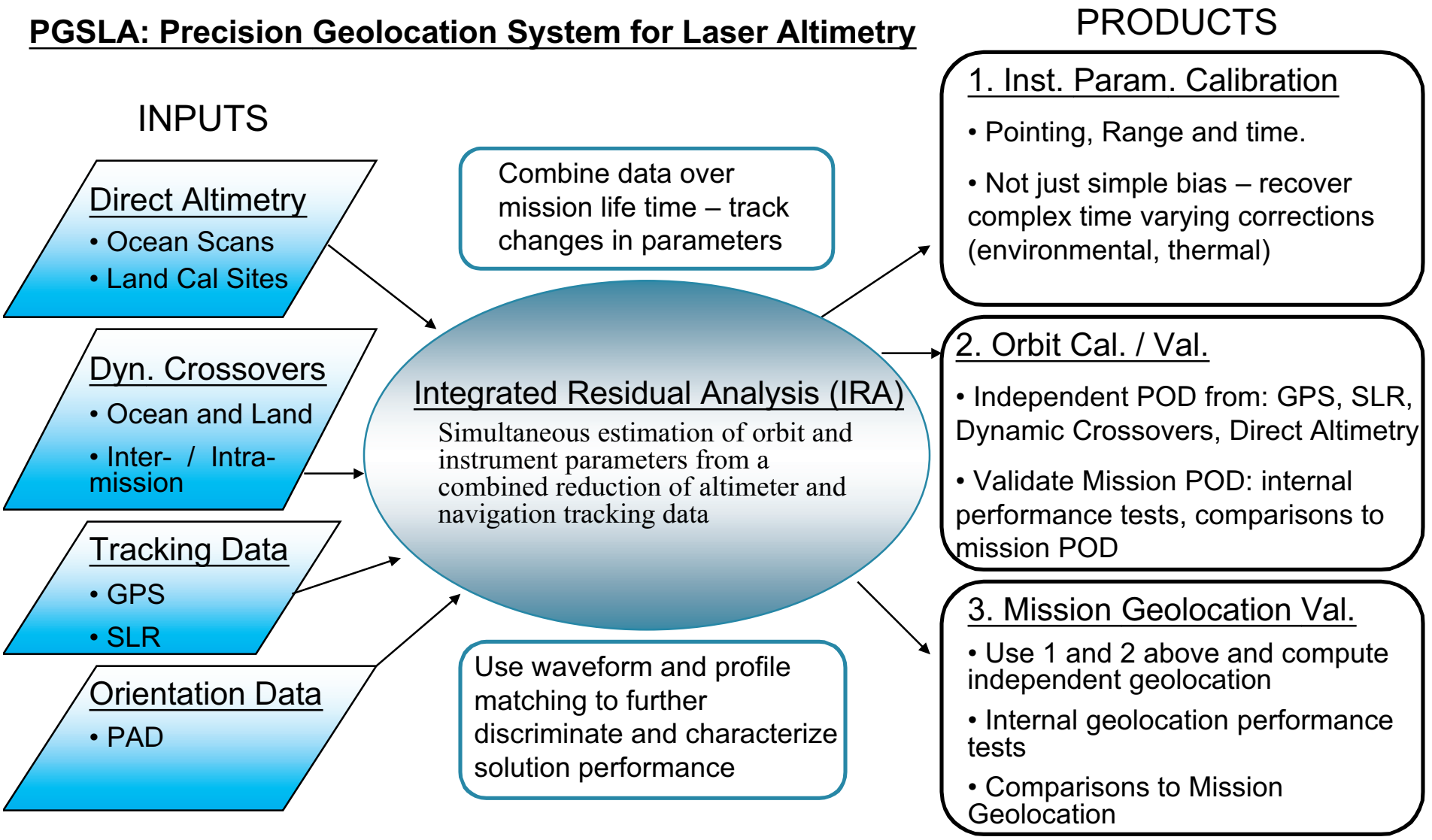
Multi-angle Ocean Scans

ICESat Science Team Meeting

November 12, 2002

Integrated Residual Analysis (IRA)

PGSLA: Precision Geolocation System for Laser Altimetry



PGSLA Input Data

Table 1. PGSLA/IRA required input data

Description	Source	GLAS ID
Pulse round trip time of flight 1. Range and waveform parameters to compute range to "surface" 2. Time tags and flags	SCF	GLA06, GLA12-15
Spacecraft and Laser orientation data 1.0 Parameters to compute body orientation (time tag and quaternion time series of Bench to ICRF rotations), 1/40 sec 2.0 Parameters to compute laser pointing orientation (time tag and quaternion time series of laser to Bench rotations), 1/40 sec	CSR	Special File from CSR
Spacecraft GPS receiver data Observation data in RINEX2 format	SCF	ANC39
Precision Orbit Ephemeris To CG, in SP3 format	CSR	Special File from CSR
Geolocated surface returns • Time and geodetic coordinates of each laser spot	SCF	GLA06, GLA12-15
Laser range corrections Troposphere delay, body tide, ocean tide, loading, etc…	SCF	GLA06, GLA12-15
Laser temperature, pressure and houskeeping data	SCF	???
Other Laser and Spacecraft Information Mass, CG, maneuver history Instrument operation details Laser reference CG Offsets GPS Phase Center and SLR LRR CG offsets	 CSR/Ball CSR/Ball SCF CSR ?	 GLA SUP 08 GLA SUP 01 ANC37 ???
GPS ground network data	CDDIS	
GPS constellation and station information	IGS	
IGS GPS precise orbits	CDDIS	
SLR tracking data	CDDIS	
SLR station information	CDDIS	
Polar motion, A1-UT1	USNO	
Solar activity	NOAA	
Ocean surface and met. data	GSFC/ NOAA	

PGSLA Products (1)

Table 2. PGSLA products summary

PGSLA ID	Type	Description
PGSLA-PO	Data	Precision Orbit solution 1. File contains: 2. Time, position and velocity of cg 3. In SP3 format 4. Provided for each orbit solution necessary to support calibration
PGSLA-GLR	Data	Geolocated Laser Return 1.0 File contains: 2.0 Time 3.0 Geodetic coordinates with respect to reference ellipsoid with time varying surface effects removed 4.0 Range and geophysical corrections (trop. delay, body tides, ocean tides, loading) 5.0 Intend to format similar to GLA geolocated surface return parameters 6.0 Provided for each calibration solution arc
PGSLA-IPCS	Data	Instrument Parameter Calibration Solution File contains: Calibration solution for the following parameter types: pointing, range, observation and attitude time tag (timing only if necessary) For each type of parameter contains: epoch, and parameters of applied function (eg. bias, drift, quadratic and sine and cosine amplitudes of periodic terms) This file will be cumulative over the entire mission and provide the necessary parameter correction modeling throughout the mission. The parameters for individual calibration solutions along with overall mission solutions will be provided.

PGSLA Products (2)

PGSLA-CAR	Report	Calibration Analysis Report •Provided for each calibration solution •Report contains: **Precision Orbit Determination Analysis**: Orbit overlap statistics for each solution (rms, min., max, mean) Radial, cross-track, along-track, total position Plots of overlap differences Residual statistics for each solution and each tracking type (number of points, rms) Plots of tracking data residuals Orbit difference statistics between PGSLA solution and nominal ICESat POD product (rms, min., max., mean) Radial , cross-track, along-track, total position Plots of orbit differences **Geolocation Analysis:** Geolocation overlap statistics for each solution: Differences in geodetic coordinates Done for pre and post calibration geolocation solution Residual statistics for each solution and each altimeter data type (number of points, rms) Direct altimetry: ocean, land calibration sites

Products Summary (1)

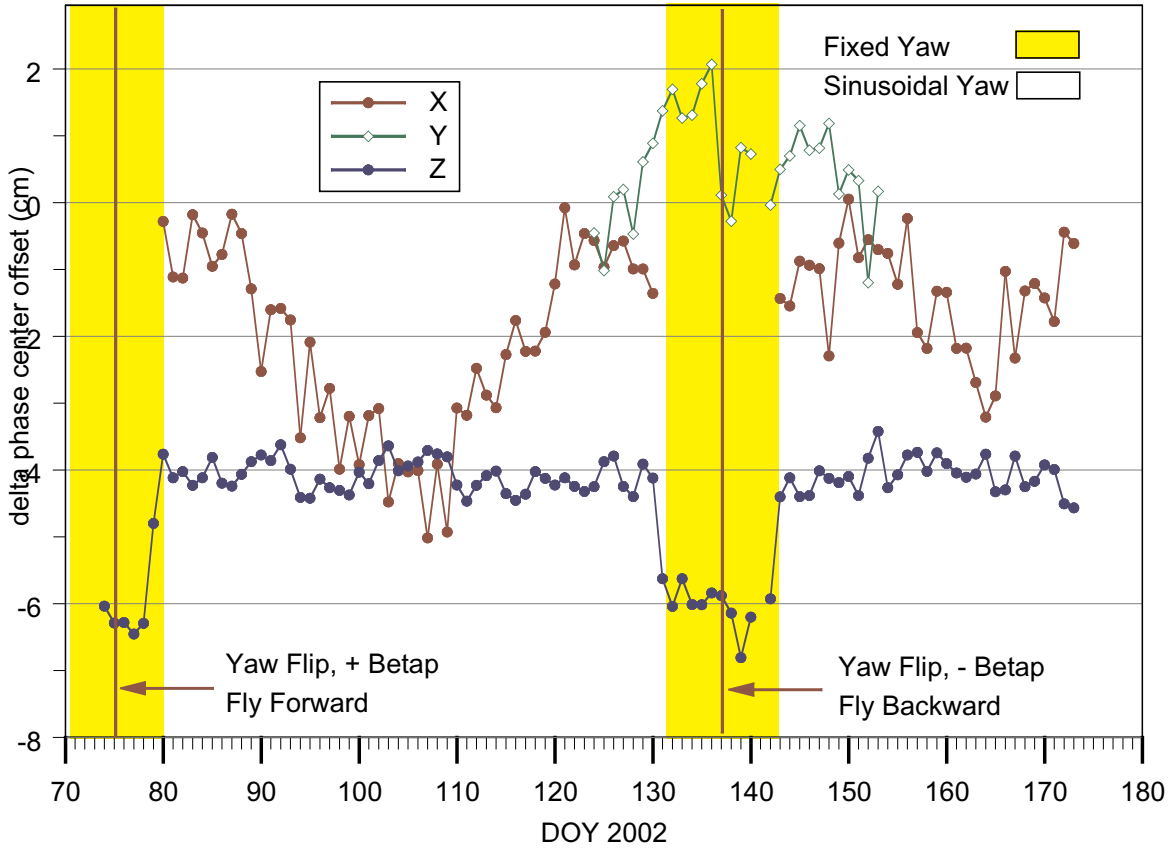
- Calibration of pointing parameters for Roll and Pitch:
  - Biases and higher order time dependences (e.g. rate, quadratic, periodic).
  - Track over mission lifetime.
  - Use data from ocean scans, dynamic crossovers and land DEM sites.
  - Single Ocean Scan, worst case < 1 arc-sec, RSS roll and pitch
    - *From Luthcke et al., 2000, consider covariance analysis*
  - Single Ocean Scan, Noise only < 0.1 arc-sec, RSS roll and pitch
  - Performance < 0.4 arc-sec, RSS roll and pitch expected from combining all data types and multiple ocean scans
- Calibration of range bias:
  - Use data from ocean scans (corrected for EM bias) and land DEM sites.
  - Expected accuracy is on the order of ~ 2- 4 cm.

Products Summary (2)

- Calibrate POD Parameters to Validate Mission Orbits
  - POD solutions for days of interest (where instrument parameter calibration performed)
  - Our own internal orbit test statistics
  - Comparisons to CSR mission Precision Orbits
  - < 5 cm radial RMS over 30-day arc.
    - Experience with Jason and CHAMP POD suggests performance will be even better
- Use the calibration of all of the above parameters to validate mission geolocation
  - Our own internal geolocation tests statistics
  - Differences with mission geolocation
- Software and algorithms have ability to calibrate time tag biases for laser fire and attitude data.
  - Will perform further analysis

Example POD Calibration

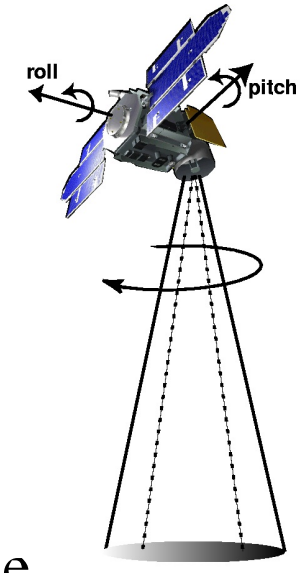
Jason-1 Recovered GPS LC Phase Center Offset Adjustment



Phase Center:
Must calibrate post-launch
Must test for temporal variability

Ocean Scan

- Single Ocean Scan:
  - Composed of two maneuvers
  - Each maneuver is an octagon
  - Each maneuver has a 10 minute period
  - Both 3 and 5 degree amplitudes are available
  - Total time to complete scan is 20 minutes



Ocean Scan CAL/VAL Operations Plan

Ascending and Descending Intersecting Ocean Scan Pair

- Done every day starting as early as possible
- For tracking any long period variations (e.g., beta prime dependence)
- Will process as needed

Preliminary Solution

- Based on ascending/descending scan pair repeated "back-to-back"
- Done once as early as possible
- "Back-to-back" repeat on consecutive orbits to double data sample close in time
- Exercise PGSLA functionality and provide preliminary instrument parameter calibration

Initial Solution

- Based on an 8-day ocean scan campaign done as early as possible
- Single instrument configuration (GPS, laser, detector, digitizer/oscillator)
- Assess affect of operating conditions on quality of solutions
  - 5° vs 3°, solar array articulation (SA) on vs off, short arc vs full orbit revolution, day vs night

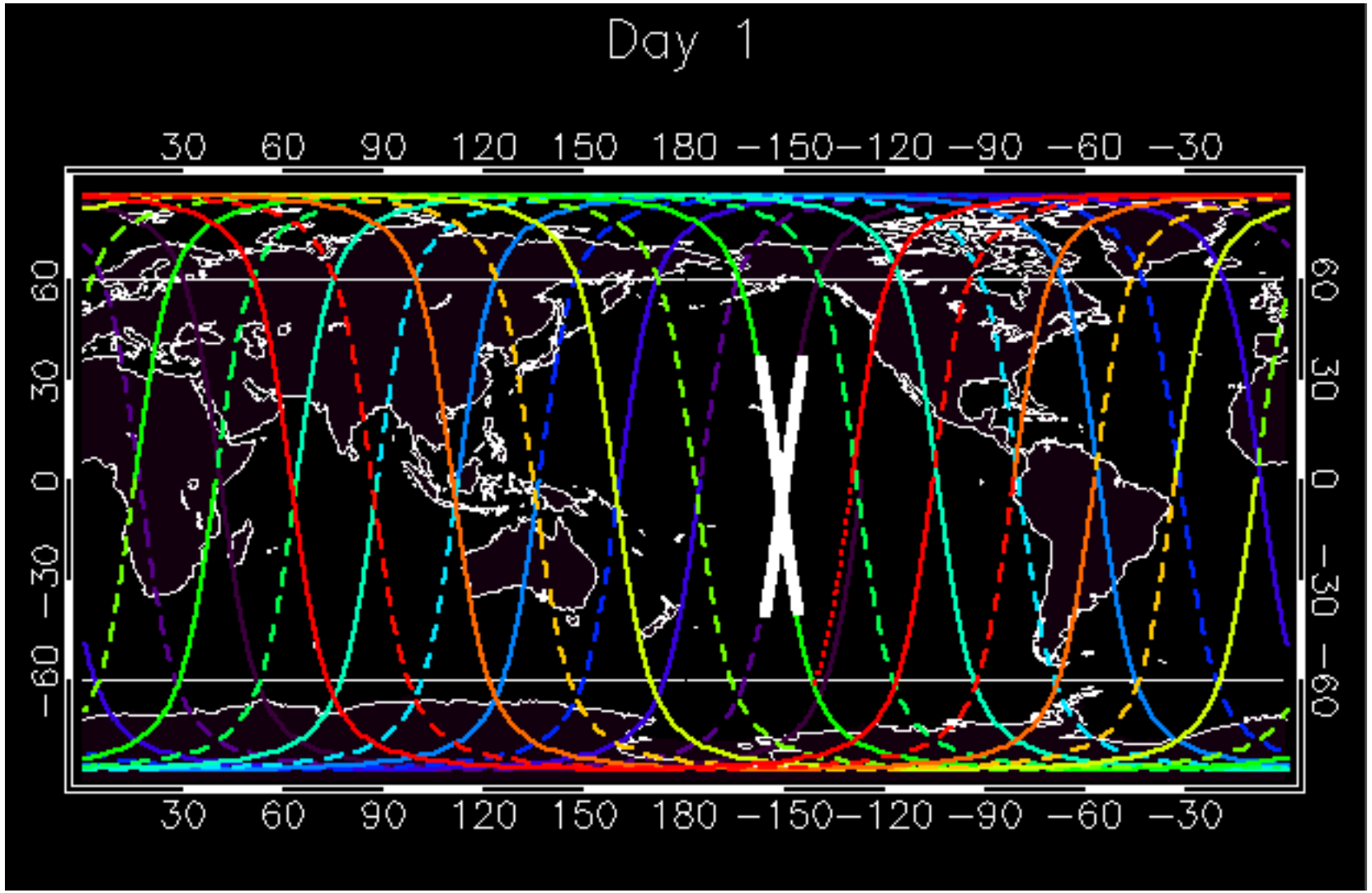
Full Solution

- Combined reduction of:
  - Three 8-day campaigns - at beginning, middle and end of cal/val phase
  - Ocean and land dynamic crossovers
  - GPS and SLR navigation tracking data
  - Land cal/val site(s) direct altimetry
- Could evaluate multiple instrument configurations (GPS, laser, detector, digitizer/oscillator)

Initial 8-day Ocean Scan Campaign

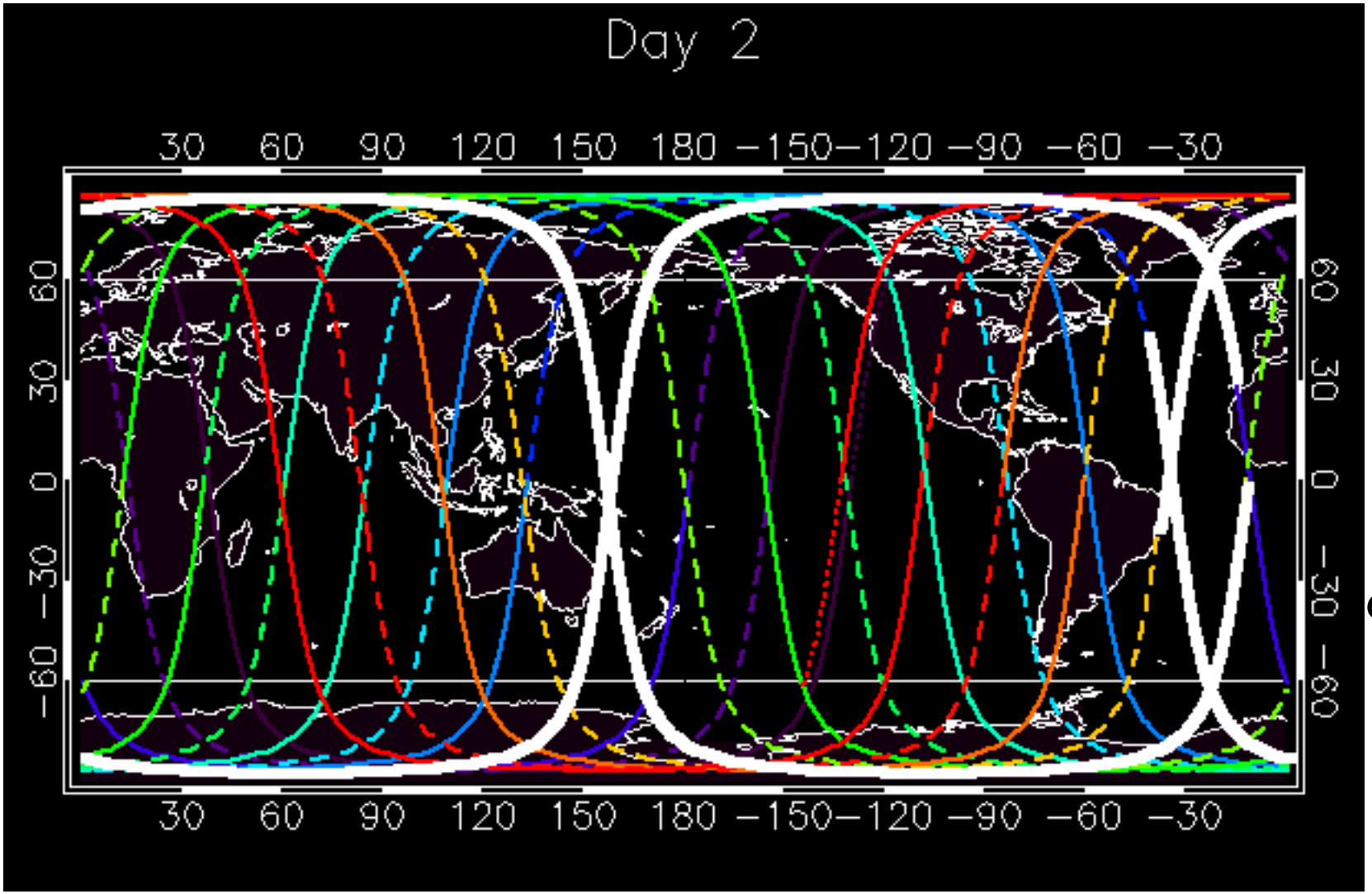
- Day 1: Single ascending (SA off) and descending (SA on) pair, 5 deg scan amplitude
  - Ascending and descending passes that intersect in the Pacific Ocean
- Day 2: Two revolution samples, ascending: SA off, descending: SA on, 5 deg
  - Each composed of 5 continuous scans such that they sample an orbit revolution
  - Selected to maximize ocean coverage in Atlantic and Pacific
  - Used to assess any once-per-revolution temporal variability in biases
- Day 3: Back-to-back ascending and descending pairs, 5 deg vs. 3 deg
  - A scan on ascending Pacific pass with 5 deg amplitude. Then a scan on the very next orbit's ascending Pacific pass with 3 deg amplitude. Repeat this for back-to-back descending Pacific passes.
- Day 4: Back-to-back ascending and descending pairs, 5 deg, SA off vs. SA on
  - Same as Day 3, except the scan amplitude is held fixed at 5 deg and the back-to-back ascending Pacific passes are done with SA off vs. SA on.
- Day 5: Same as Day 1 with 3 deg scan amplitude.
- Day 6: Same as Day 5 with SA on when ascending
- Day 7: Atlantic and Indian ascending and descending pairs, 5 deg
  - Scan pairs in Atlantic Ocean and Indian Ocean
- Day 8: Same as Day 2, but with 3 deg scan amplitude.

Ocean Scan 8-day Campaign



5° SA asc off desc on

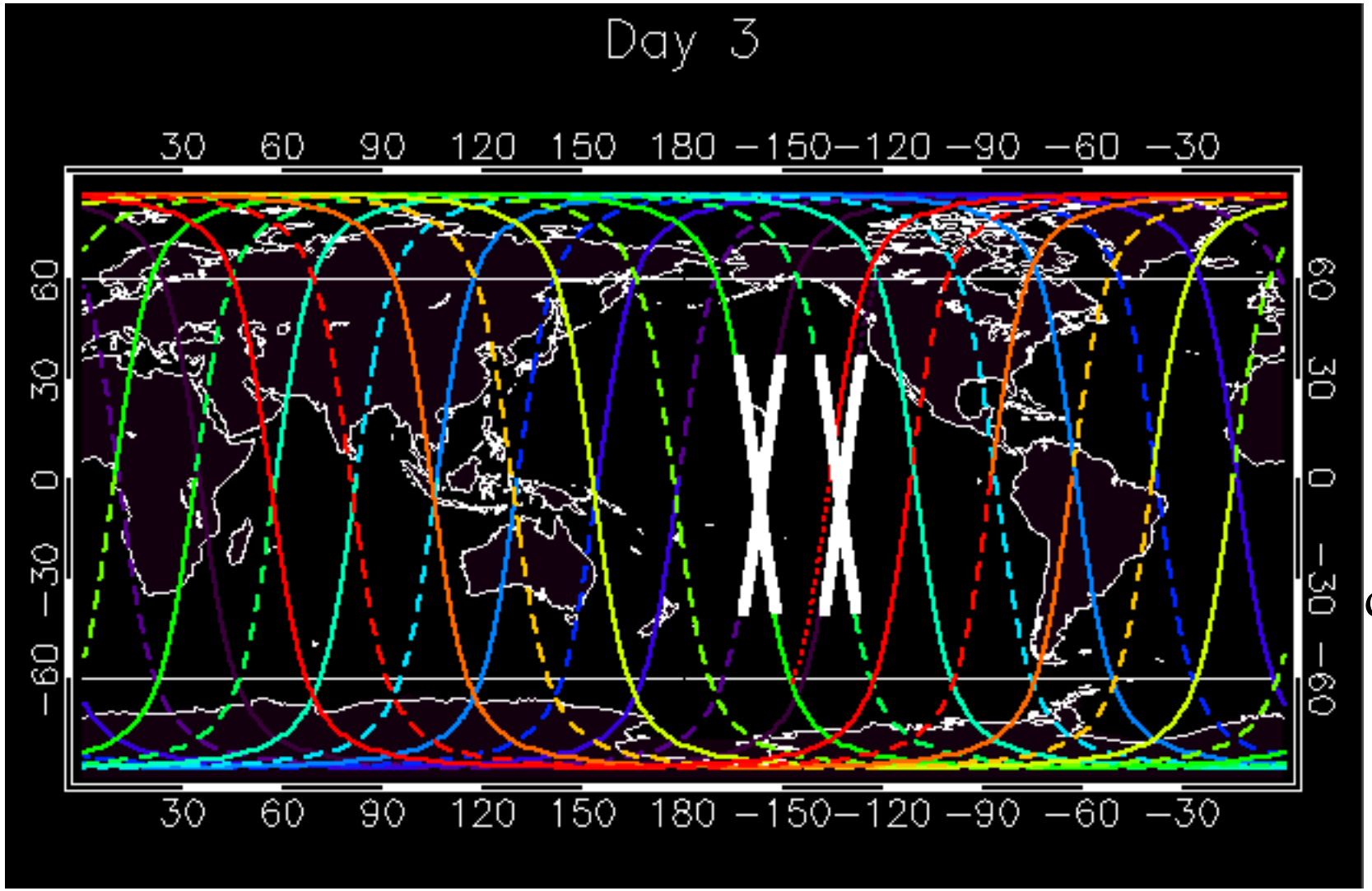
Ocean Scan 8-day Campaign



5° SA asc off desc on

Ocean Scan 8-day Campaign

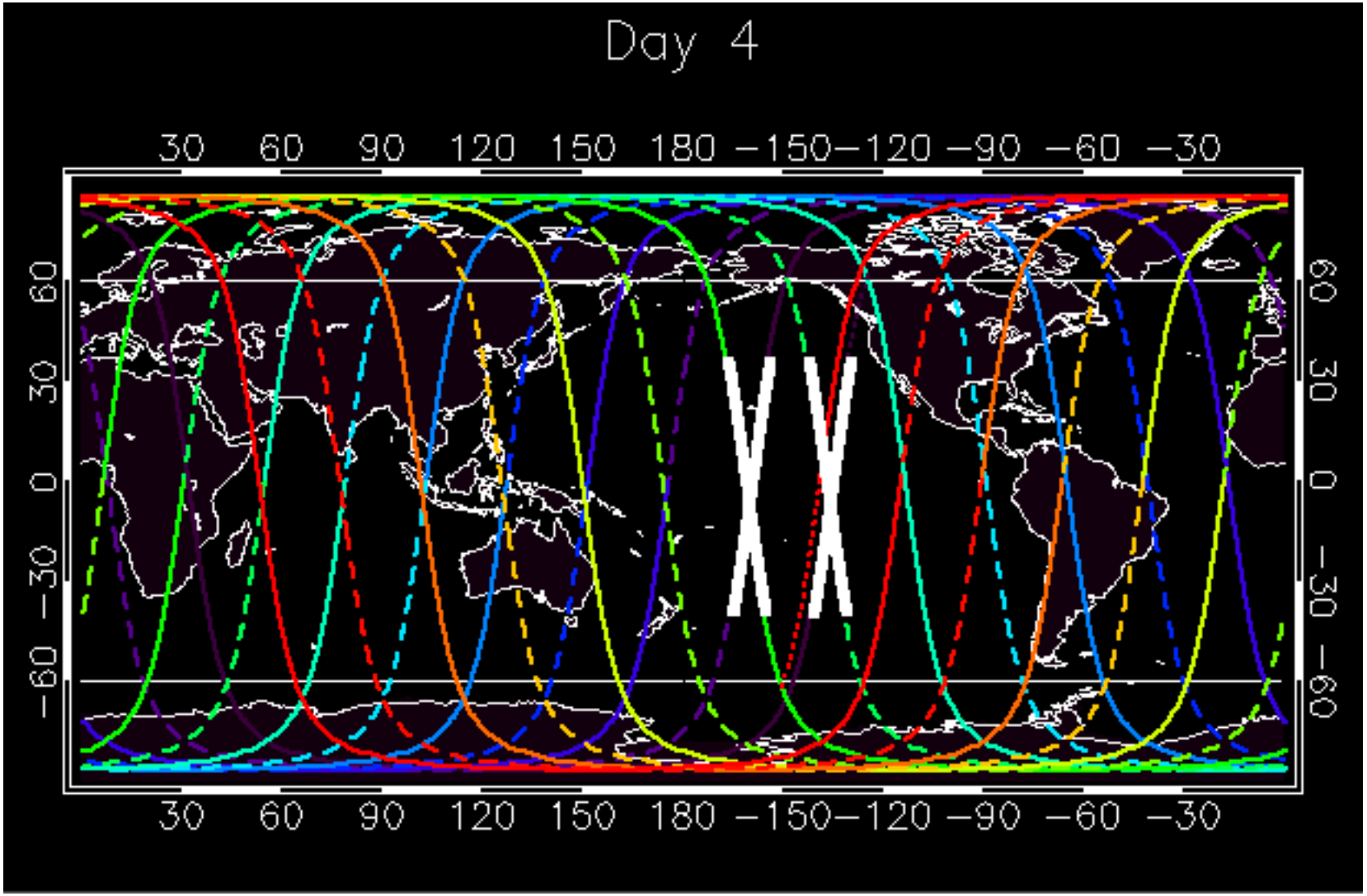
3° SA asc off desc on



5° SA asc off desc on

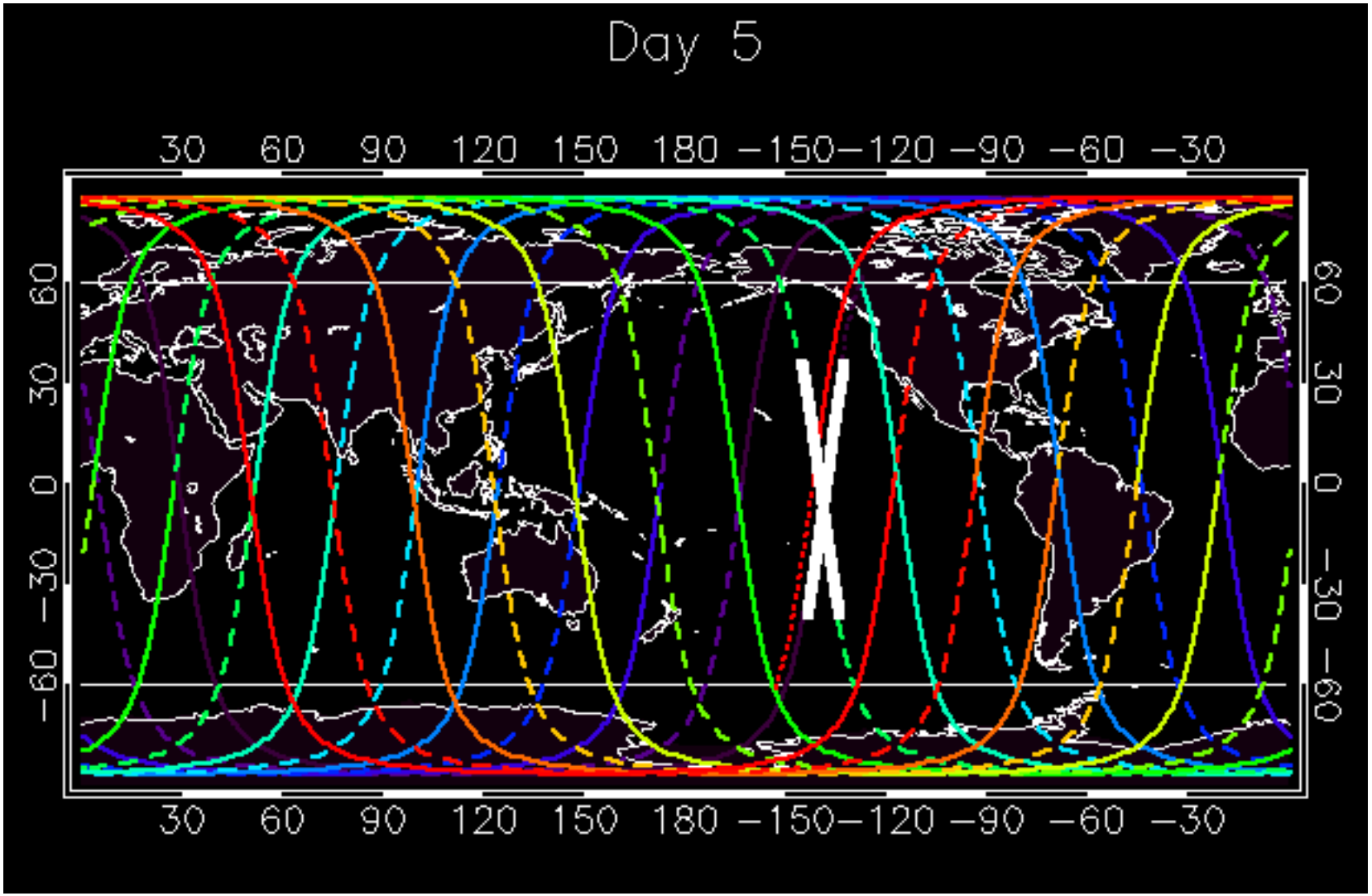
Ocean Scan 8-day Campaign

5° SA asc on desc on



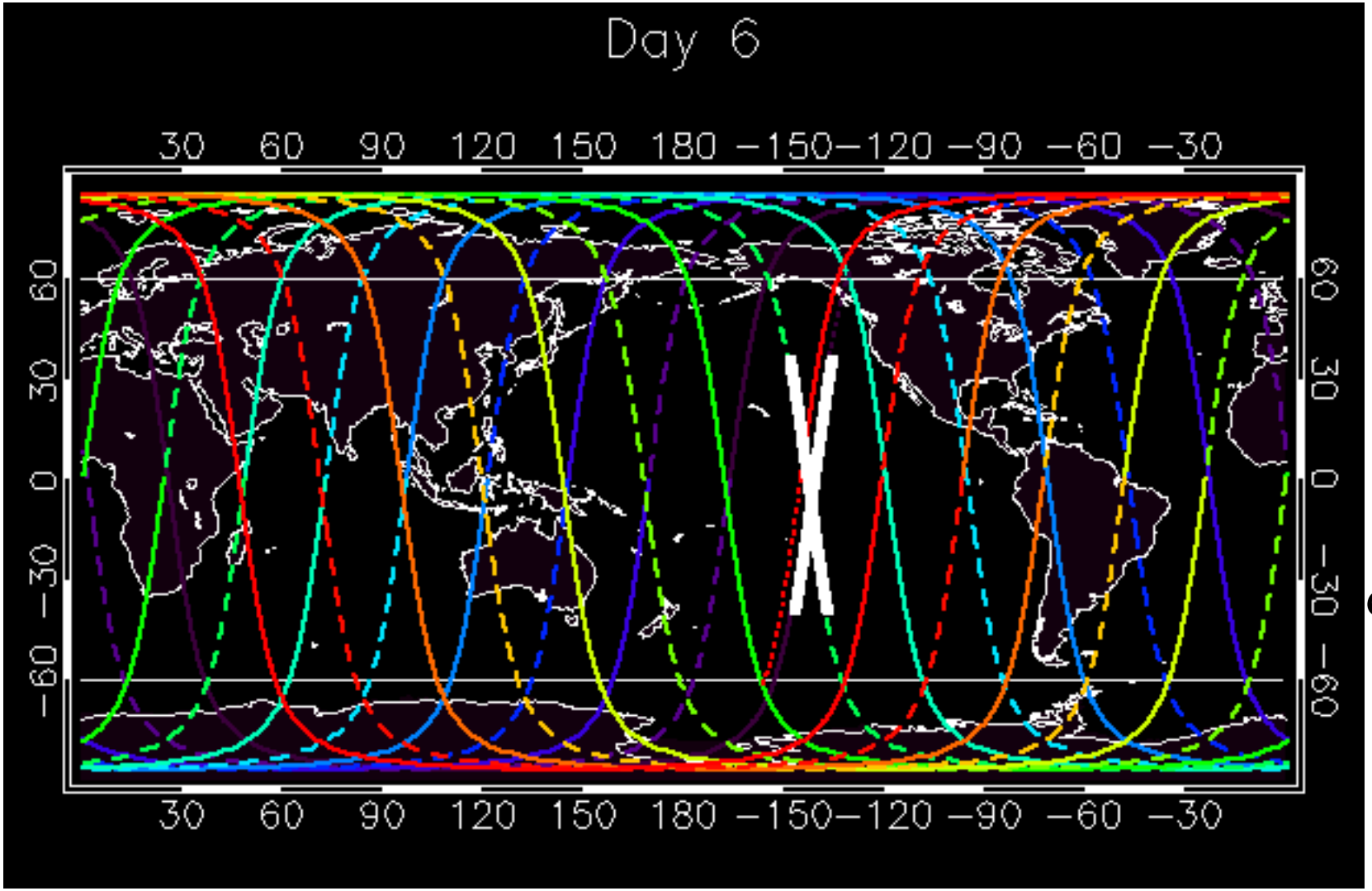
5° SA asc off desc on

Ocean Scan 8-day Campaign



3° SA asc off desc on

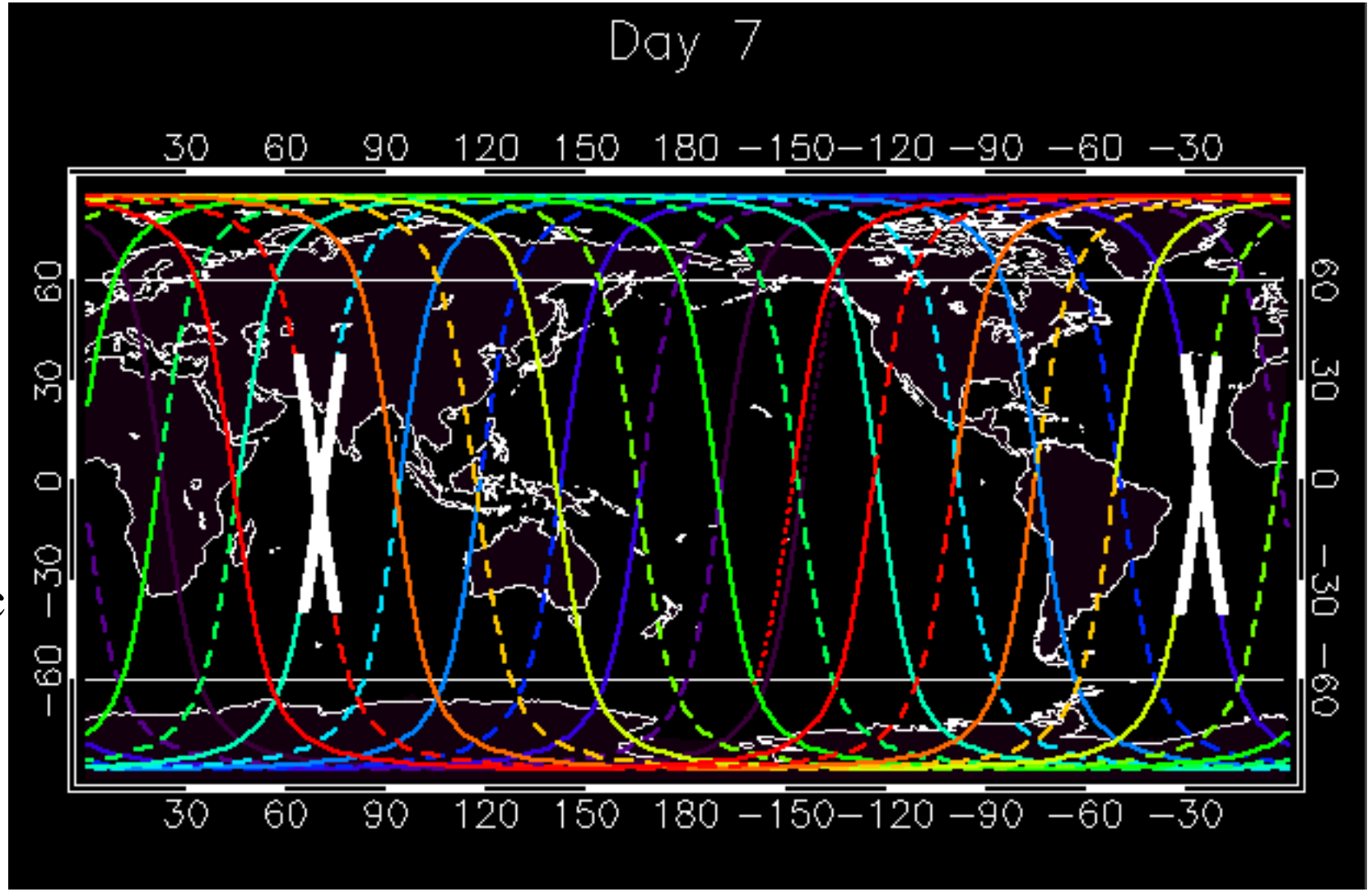
Ocean Scan 8-day Campaign



3° SA asc on desc on

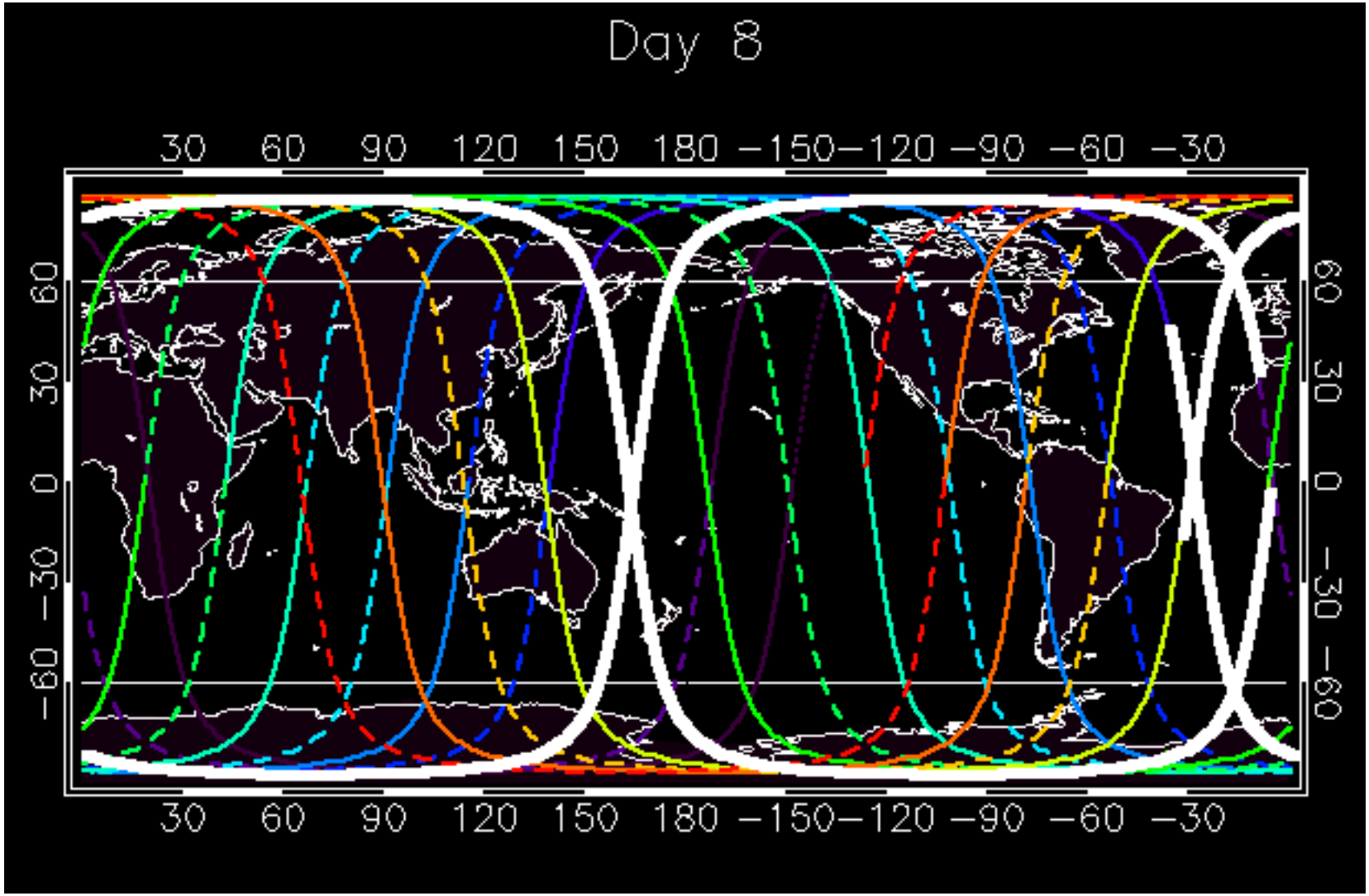
Ocean Scan 8-day Campaign

5° SA asc off desc on



5° SA asc off desc on

Ocean Scan 8-day Campaign



3° SA asc off desc on

Ocean Scan 8-day Campaign

```
Ocean Scan Start and End for 8-day Repeat Orbit
Day, Secs from 8-day Start, Lat, Lon, Orbit #, Asc/Desc, Angle, SA Artic.

Start:
   1     5210  36.768131 213.919067    1 D    5 off
End:
   1     6410 -37.844471 202.835236    2
Number of scans (composed of 2 octagon maneuvers): 1

Start:
   1    48710 -37.328228 212.492020    9 A    5 off
End:
   1    49910  37.285370 201.409241    9
Number of scans (composed of 2 octagon maneuvers): 1

Start:
   2   102030  31.935513 344.502899   18 O    5 off
End:
   2   108030  44.297665 318.062805   19
Number of scans (composed of 2 octagon maneuvers): 5

Start:
   2   145030  -0.789542 347.529114   26 O    5 off
End:
   2   151030 -13.205745 321.615540   27
Number of scans (composed of 2 octagon maneuvers): 5
```

Land Calibration Site DEMs

- PGSLA requires DEM grid as input (not x,y,z vector points)
  - Will use grids made available for cal/val sites
    - Ideally with a grid resolution of 10 to 20 m
    - Will resample if provided as a higher resolution
  - Puget Lowland bare-earth & canopy-top are in-hand (1.8 m grid for 9,000 sq km)
  - Evaluating gridding methods and resolutions for ATM data
    - Multi-year Greenland data for Jakobshaven as analog for alpine glaciers
    - Discussions underway for ATM flight on southern Alaska 8-day track in March, '03
  - Is there a plan to generate grids for western U.S. ATM 8-day reference tracks?
  - Are ATM Antarctica Dry Valley and UT Lake Bonneville grids available?

- Need for common ellipsoid and reference frame
  - ICESat geolocation will be in Topex ellipsoid and ITRF 2000 reference frame

Profile & Waveform Matching CAL/VAL Objectives

- Establish optimal matches by minimizing residuals using iterative spatial search
  - Observed profiles vs. moderate resolution DEMs (10-90 m)
  - Observed waveforms vs. simulated waveforms from high resolution DEMs (1-5 m)
    - utilize complex waveforms created by vegetation cover & building edges to enhance precision
- Validation
  - Geolocation solutions
    - Pointing Control
  - Waveform-derived land parameters
    - Highest, centroid, and lowest within-footprint elevations

Profile & Waveform Matching CAL/VAL Objectives (cont.)

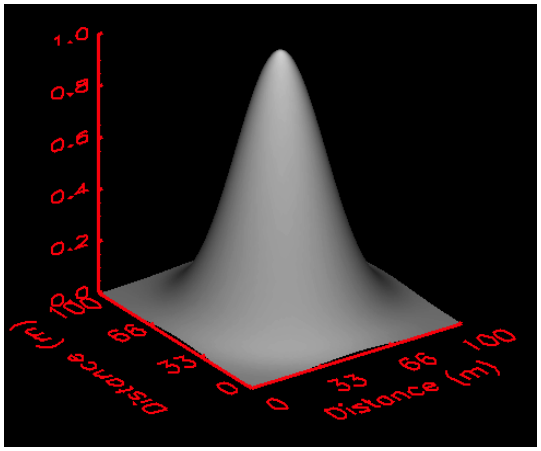
- Calibration
  - Attitude time bias ?
  - FOV boresight ?
  - Caveats
    - with premise that POD is accurate and laser pointing bias and laser fire time bias are accurately determined using other techniques
    - Accuracies are TBD, depending on sensitivity to local uniqueness of the terrain
- Data Needs
  - Mostly GLA-xx and PGSLA-GLR standard products
  - Not currently in GLA products:
    - Laser vector in topocentric coordinates (off-nadir angle and azimuth)
    - Alternate definition for start and end of signal (waveform extent)
      - Standard threshold start and end sensitive to day/night noise differences
      - Use more robust 2% and 98% of cumulative distribution

Profile & Waveform Matching Status

- Methodologies described in:
  - Section 6.7.7 of the GLAS Altimeter Post Launch Cal/Val Plan
  - Rowlands, et al, 2001, Satellite laser altimetry: on-orbit calibration techniques for precise geolocation, The Review of Laser Engineering, 28: 796-803.
- Profile matching
  - x,y optimal match methodology demonstrated with SLA vs 90 m and 30 m DEMs
    - Luthcke, Carabajal and Rowlands, D.D., 2002, J. Geodynamics (DTED & NED)
    - Carabajal and Harding, 2002, Spring AGU (SRTM)
- Waveform matching
  - "Essentials only" grid-based waveform simulation (normalized signal; no noise)
    - Agreement with FOV range error & signal loss analytic curves demonstrated
    - Adding "slope" grid to account for off-nadir pointing and time-domain convolution to account for transmit pulse impulse response
  - Procedures for generating and mosaicing highest, random, and lowest elevation and surface type grids at 1.8 m resolution from Puget Lowland airborne, discrete-return, laser point clouds being finalized

Grid-based Simulation of FOV Offset

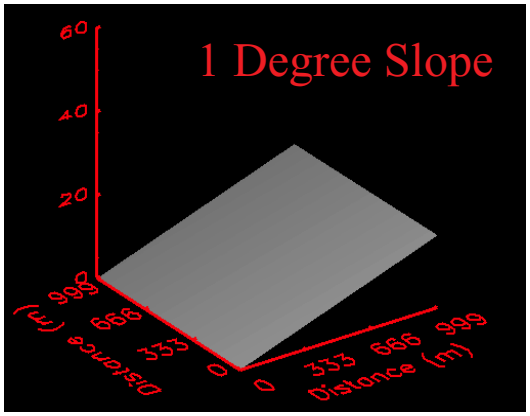
Gaussian Transmit Pulse normalized to 1

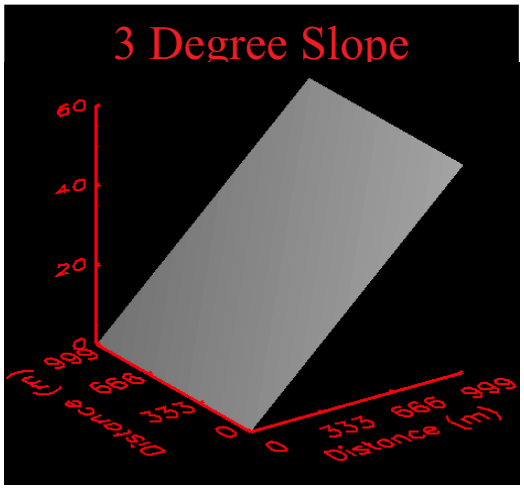


100 x 100 m grid

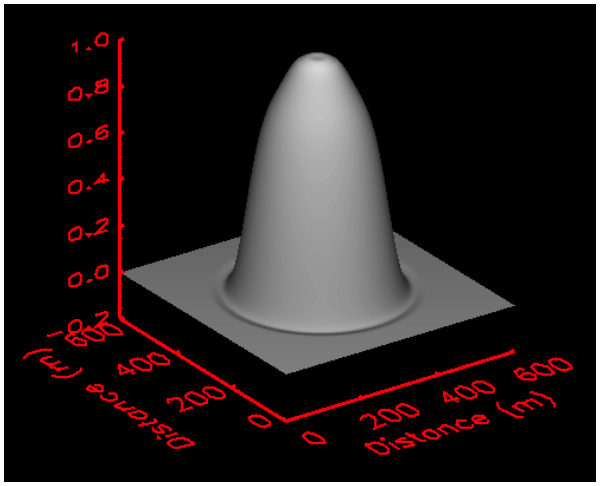
operationally we will use LPA image of transmit pulse far-field energy pattern

Targets





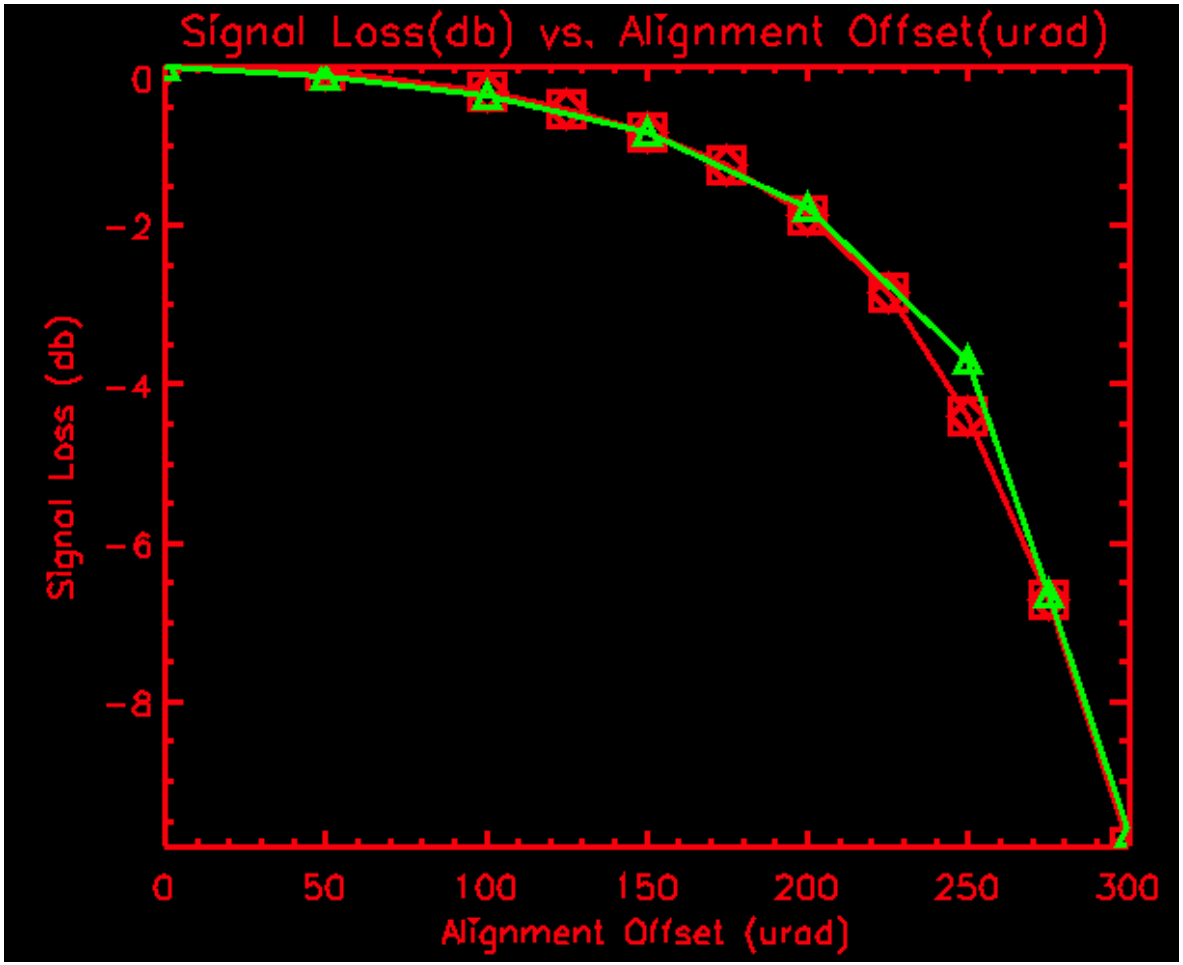
Measured FOV Response (smoothed) normalized to 1



600 x 600 m grid

All surfaces gridded at 1 m spacing; Waveforms binned at 0.15 m vertical sampling

Signal Loss (db) vs. Alignment Offset



IT

Up-slope offset

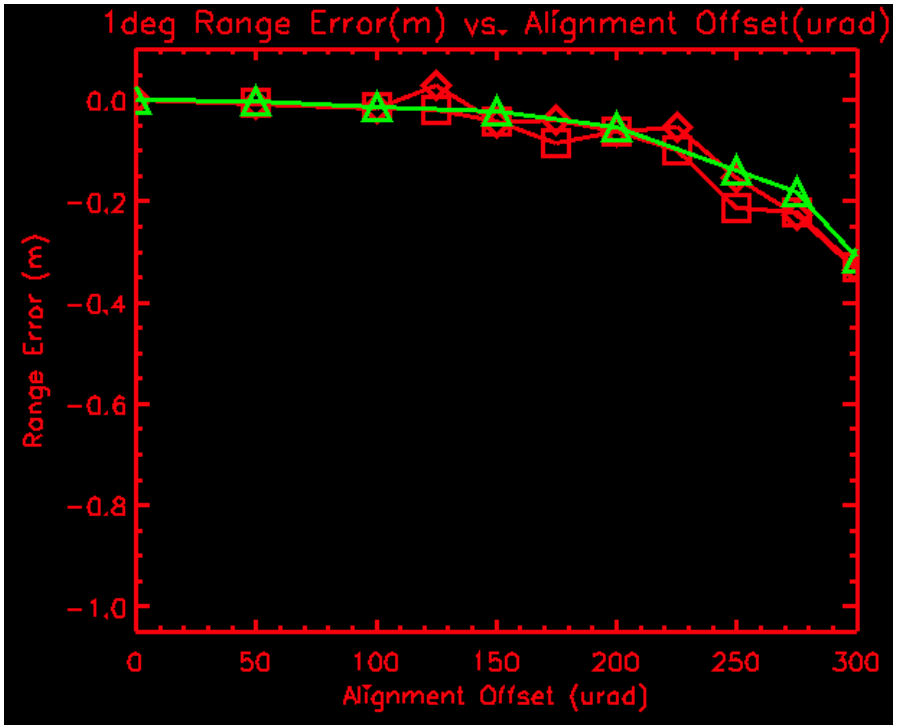
S

Down-slope offset

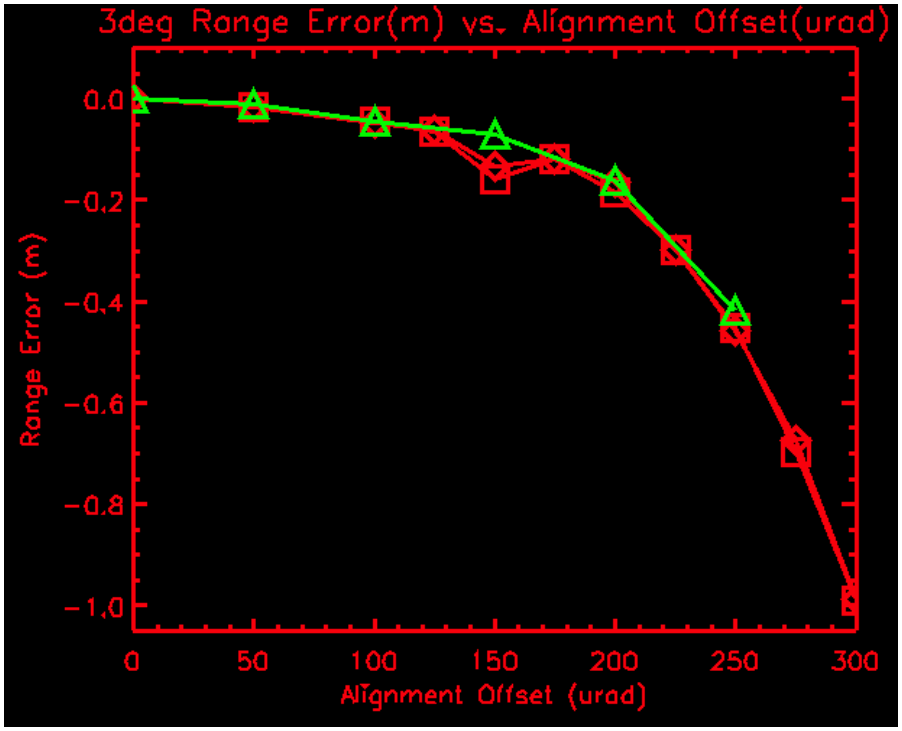
Grid Resolution = 1 m, Waveform binning = 0.15 m

Range Error vs. Alignment Offset

1 Degree Slopping Surface



3 Degree Slopping Surface



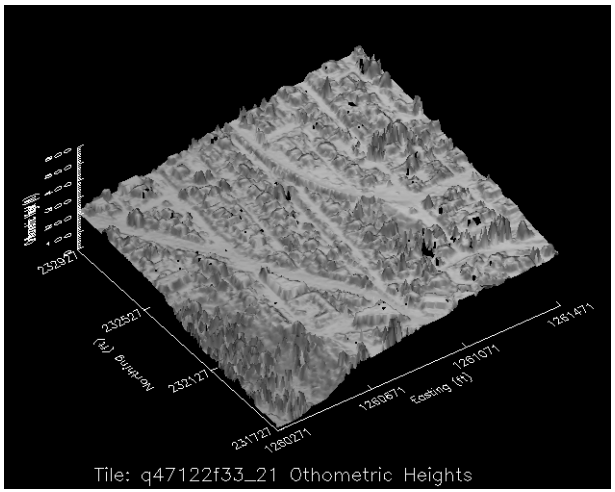
Up-slope offset Down-slope offset S IT

Grid Resolution = 1 m, Waveform binning = 0.15 m

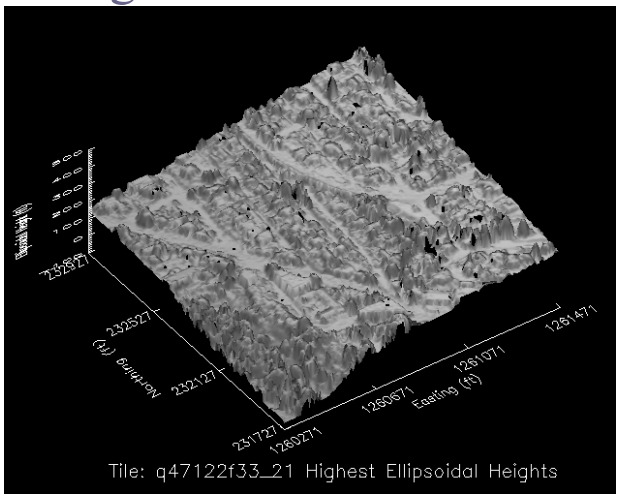
Puget Lowland Laser Return 1.8 m Grids

(~ 2 returns per m^2, classified as ground vs. not ground)

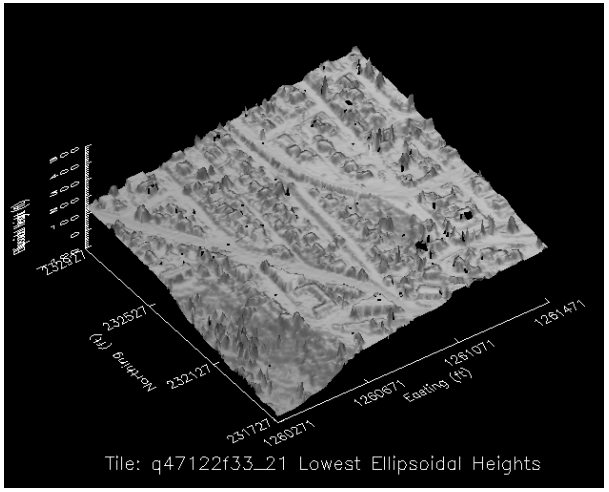
Random Returns Surface



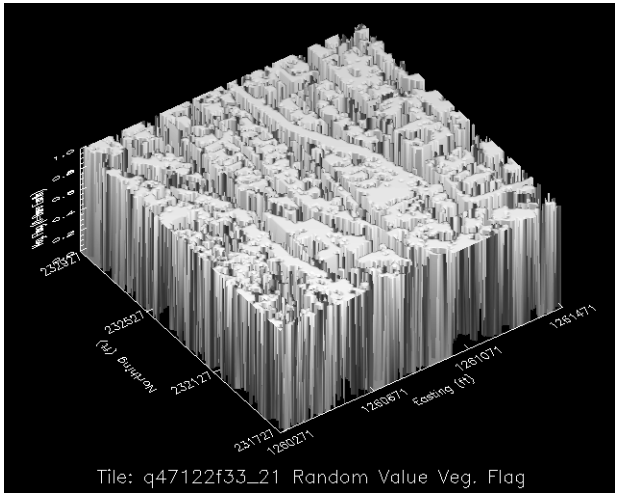
Highest Returns Surface

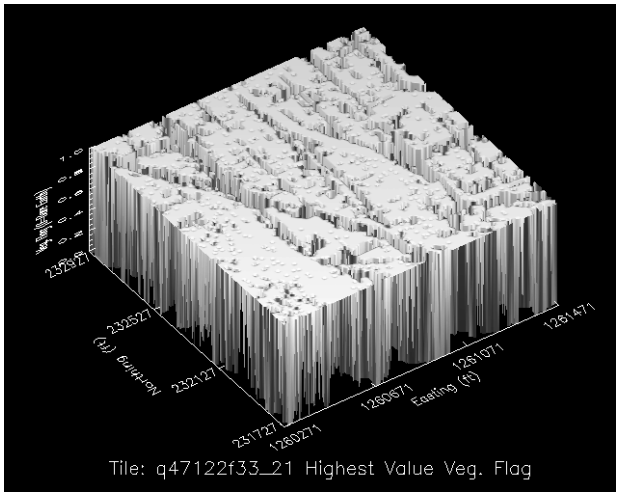


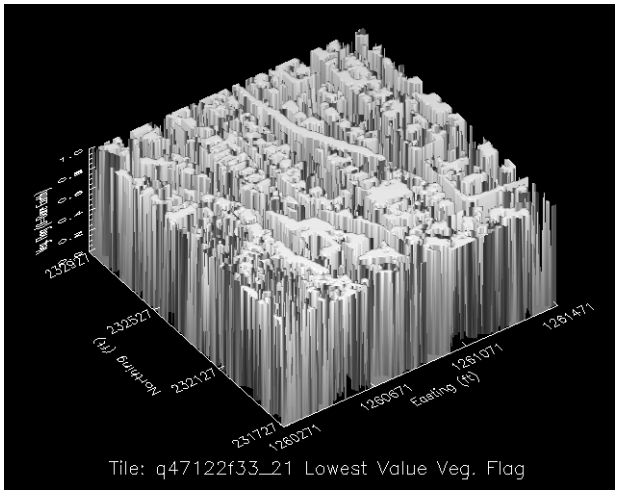
Lowest Returns Surface



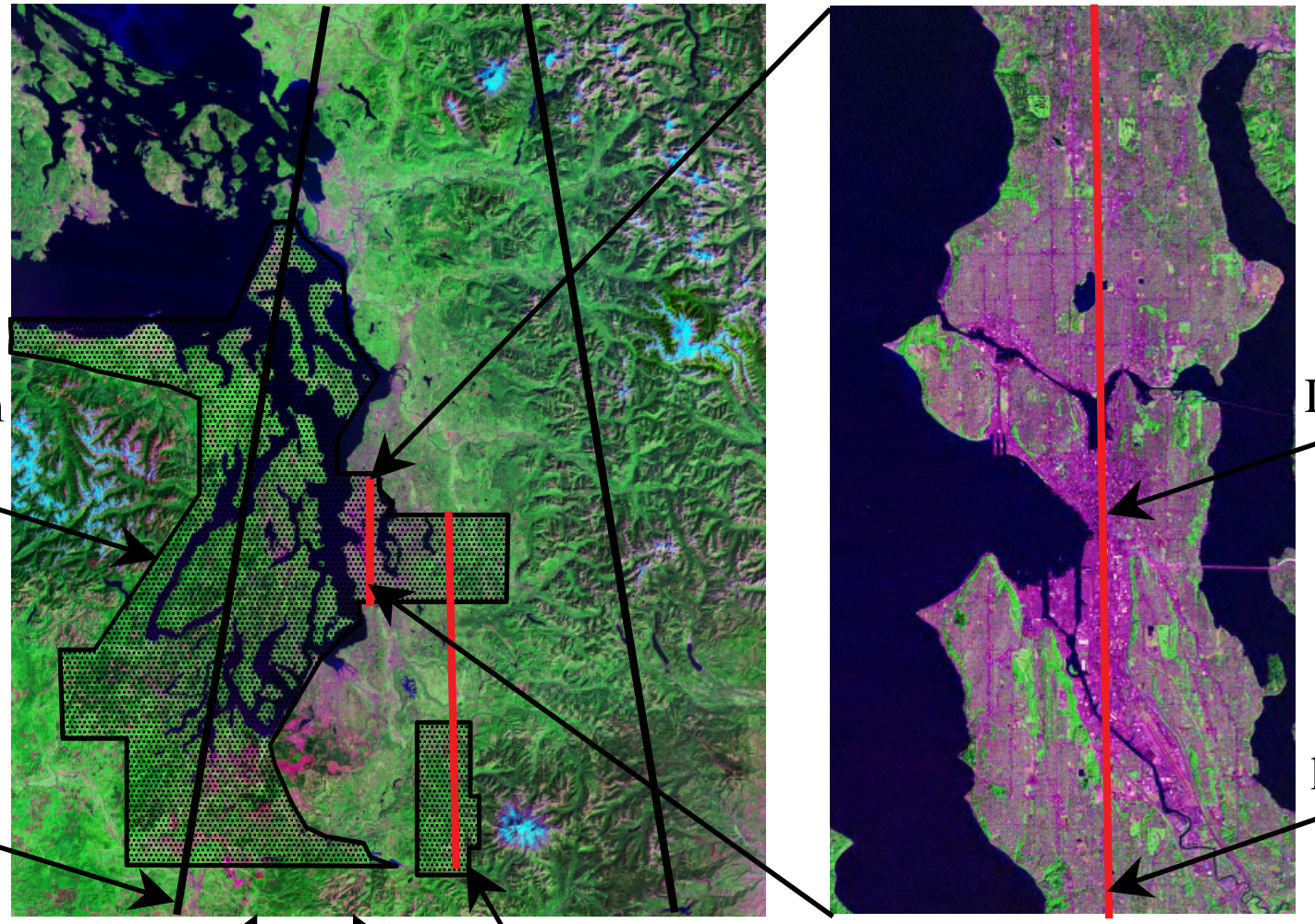
Corresponding Surface Type Grids (1 = vegetation or structure, 0 = ground)







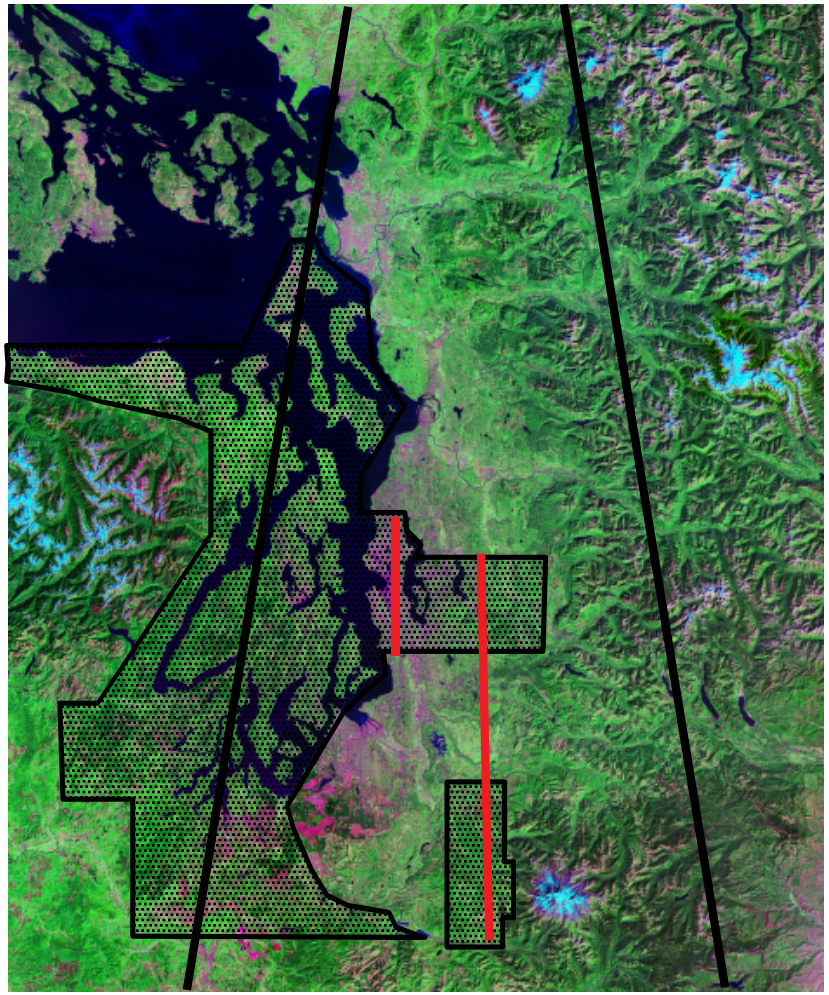
Puget Lowland, Washington



Puget Lowland, Washington

OPERATIONS PLAN:

- Western Descending Track
  - Alternate 8-day tracks between:
    - Precision pointing to reference track (low relief forest cover)
      - nadir
    - Path mode pointing to N-S Seattle line (urban cover)
      - 2.9° to 3.8°, 0.09°/sec roll
- Eastern Ascending Track
  - Alternate 8-day tracks between:
    - Path mode pointing to Rainier line (high relief forest cover)
      - 4.3° to 5.8°, 0.075°/sec roll
    - Path mode pointing to N-S Seattle line (urban cover)
      - 7.1° to 8.0°, 0.09°/sec roll



Inland Water Level CAL/VAL

Objectives:

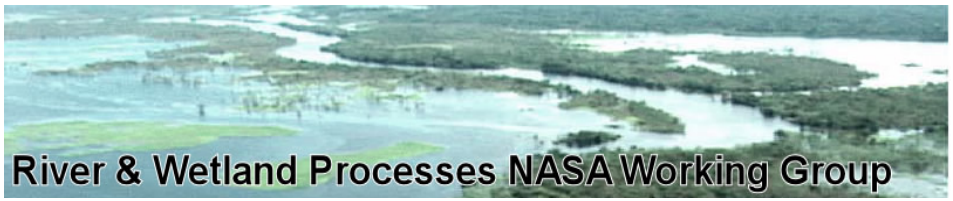
- Validate water level elevations in vicinity of river and lake gauges
- Assess signal quality as a function of water surface state & off-nadir angle
- Assess retrieval of along channel water slope

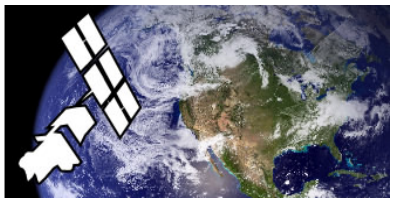
8-day Path Mode Targets:

- Lower Mississippi River
- Lower Missouri River
- Columbia River Reservoir
- Sacramento River
- Great Salt Lake
- Upper Nile River
- Lake Nasser/Aswan Dam

Standard Land Nadir Mode:

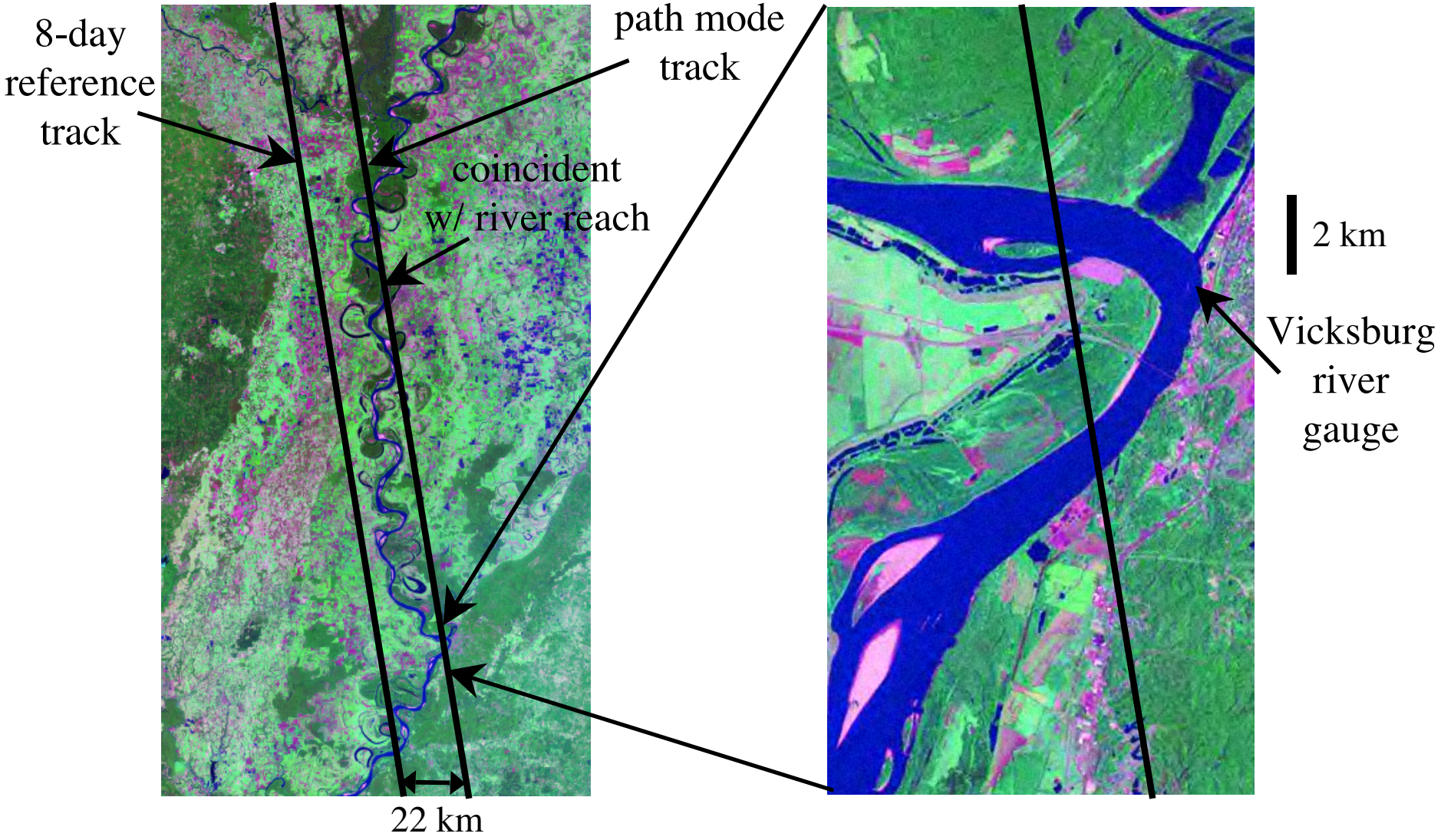
- Amazon River main stem
- Everglades
- Lake Ontario
- Lake Chad
- Paraguay River
- Yangtze River
  (filling of Three Gorges Reservoir)





Primary contacts: Charon Birkett, Doug Alsdorf, Dave Emmitt

Lower Mississippi River



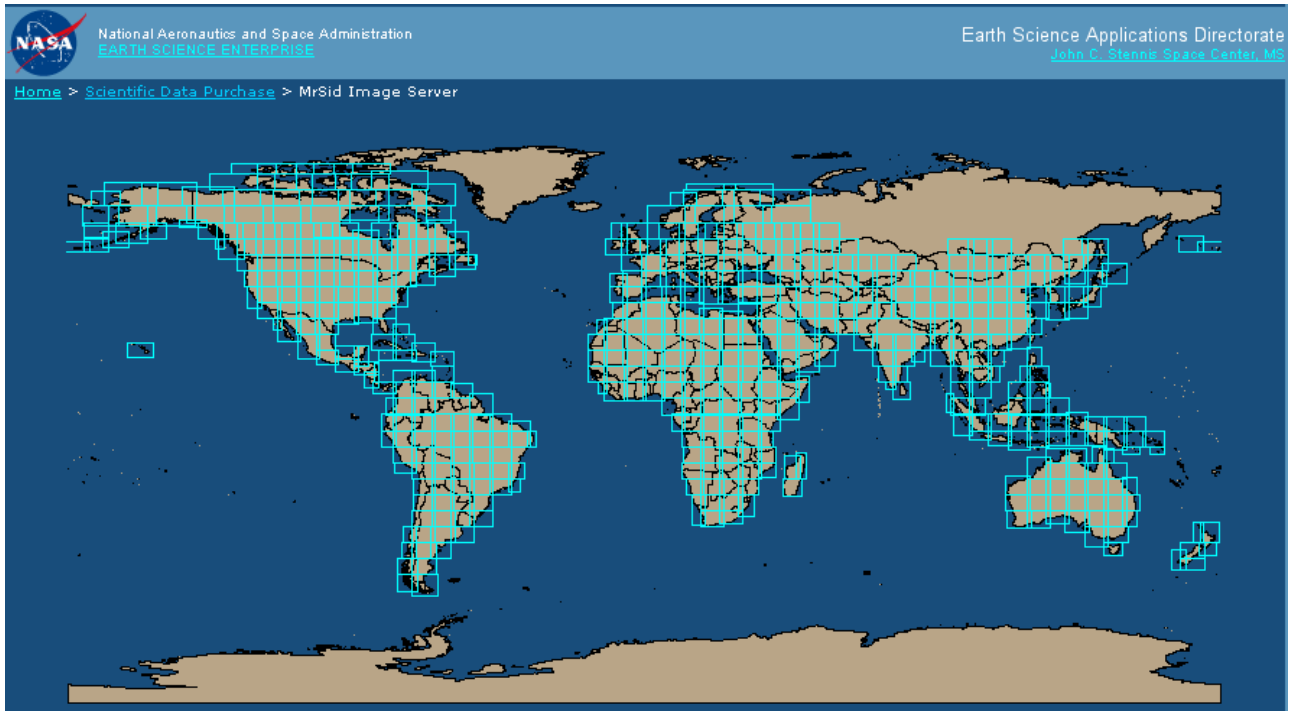
Global Landsat Mosaics

Earth Satellite Corp. Orthorectified GeoCover™ Product

Coverage:
Near-Global Land Areas

Data Rights:
Unrestricted
Download via WWW

Data Description:
TM Mosaics ~ 1990
Bands 7,4,2 Composites
R: Band 7 2.08-2.35 µm
G: Band 4 0.76-0.90 µm
B: Band 2 0.52-0.60 µm
Horiz. Resolution 28.5 m
Horiz. Accuracy ± 50 m
UTM Coordinates
WGS-84 Ellipsoid
MrSID Image Format
Nominal Mosaic Size 5° x 6°

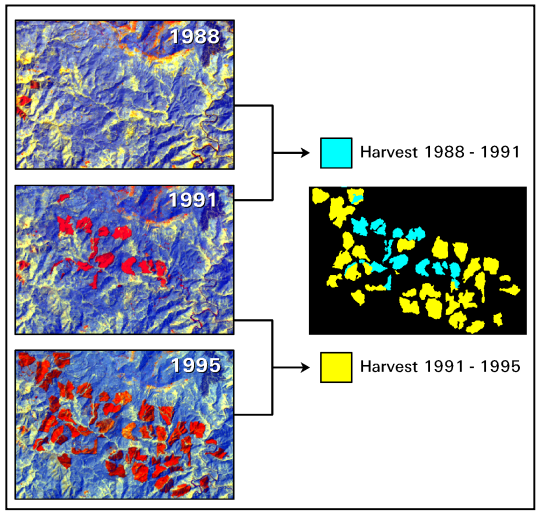


Stennis Space Center Earth Science Applications Directorate
http://www.esa.ssc.nasa.gov/datapurchase/default.asp

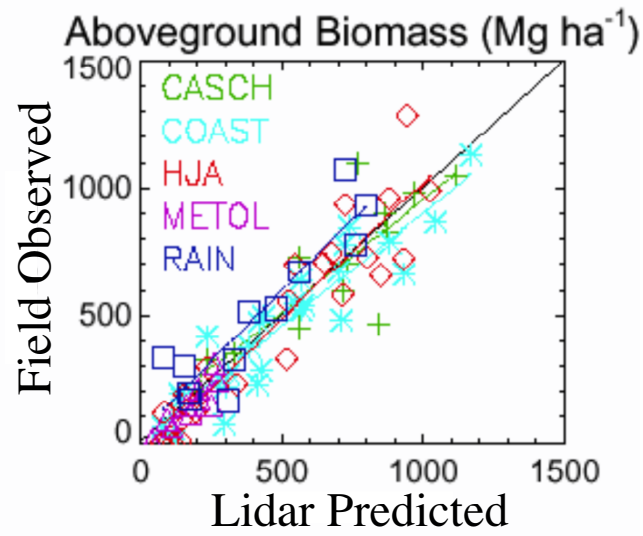
Canopy Height and Biomass CAL/VAL

Proposal submission to Earth Science REASoN CAN:

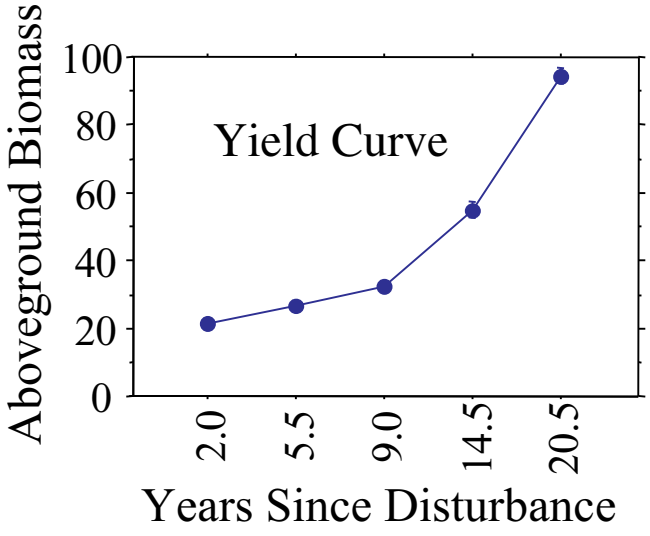
- Map North American mean canopy height, biomass and net primary productivity (biomass change vs. time) using ICESat waveforms and multi-date Landsat TM
- Integrate all North American waveforms with TM images in a GIS, making them more accessible and interpretable
- Forrest Hall & Jeff Masek (923), Mike Lefsky (CSU), Warren Cohen (NFS-OSU), David Harding (921), Ed Masuoka (922), Don Leckie (CFS-PFC)



Stand disturbance age: multi-date TM change

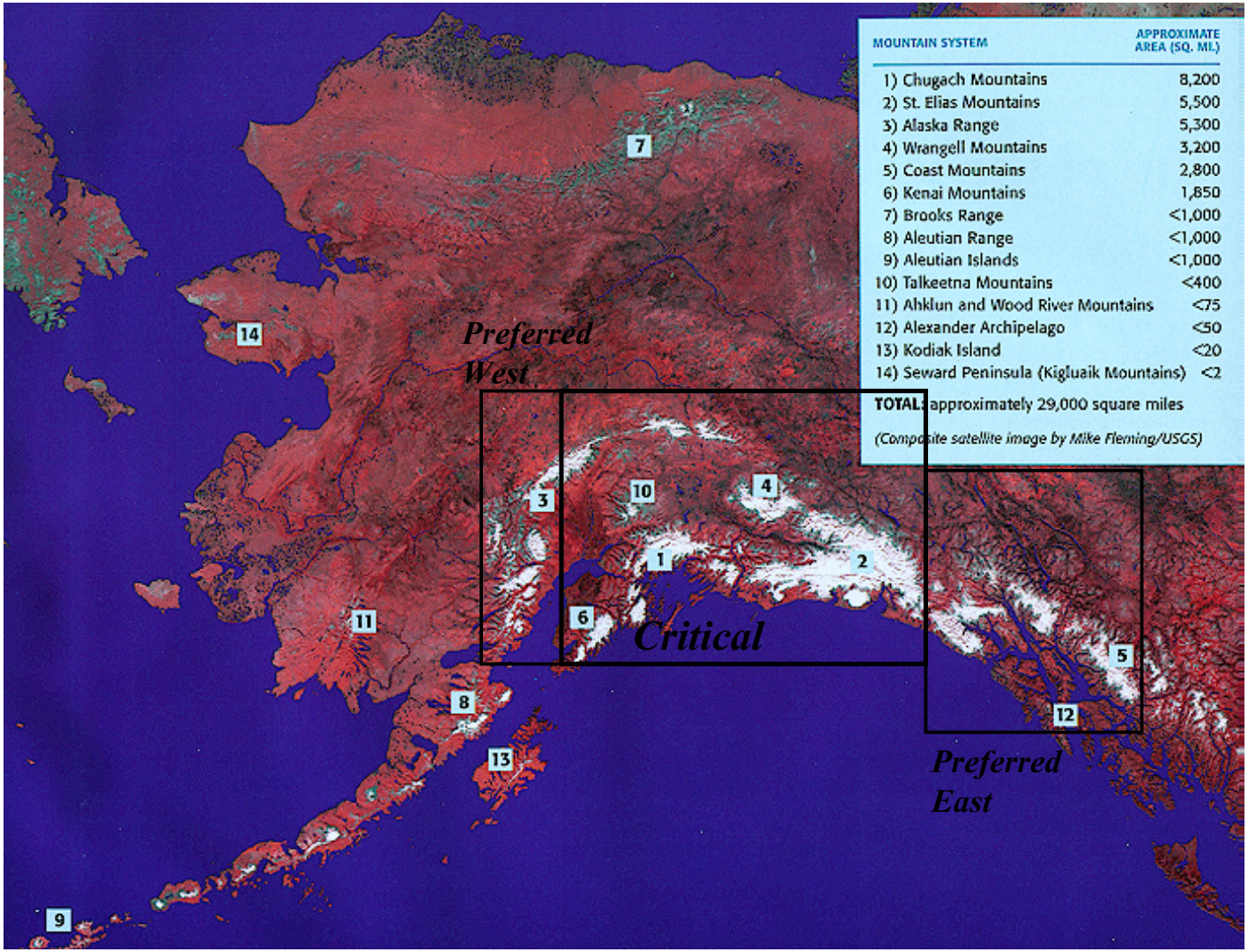


Above ground biomass: lidar mean stand height



Net primary productivity: biomass vs. age

Alaska Alpine Glacier Precision Repeats



Multi-Angle Off-Nadir Ocean CAL/VAL

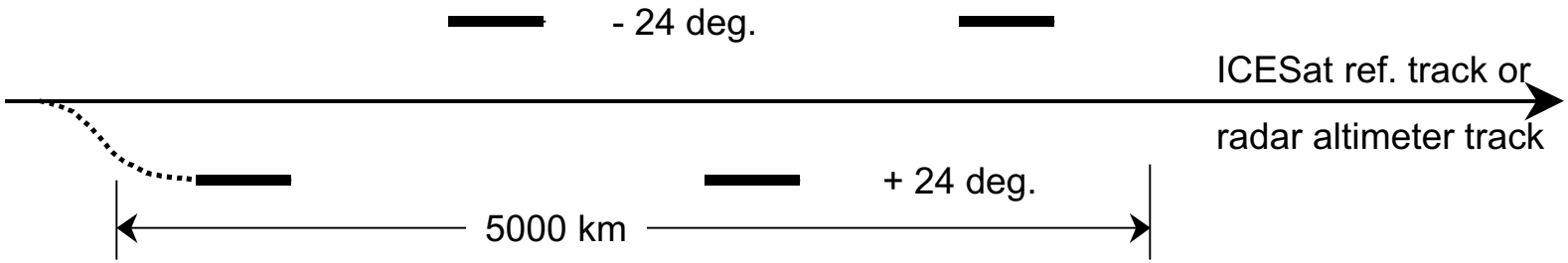
Objective: Collect and analyze multi-angle off-nadir ranging data to the open ocean surface as a means to establish the relationships between EM bias, pulse spreading, sea state and off-nadir pointing angle.

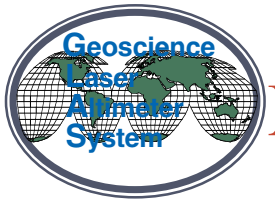
- Standard ocean scans are at a constant angle and were designed primarily to recover pointing biases
  - pointing biases are negligibly affected by systematic range errors (except for those at or near the maneuver frequency)
- However, in contrast, recovered range biases from ocean scans are directly affected by any systematic range errors such as EM bias
- Therefore, in order to obtain an instrument range bias from each ocean scan, the recovered range bias must be corrected for any EM bias dependent on sea state
- Also provides an assessment of range noise as a function of sea state and pointing angle
- Contributes to the inter-calibration of laser and radar altimeter observations for sea surface topography

Multi-Angle Off-Nadir Ocean CAL/VAL

OPERATIONS PLAN:

- Maneuver is 12 minutes in duration (5000 km long) and consists of four 20 sec dwells alternating between ±24 deg off-nadir connected by angular sweeps (at 0.3 deg/sec average rate)
- Coordinate with standard ocean scans during Ocean Scan 8-day Campaigns to select adjacent tracks with similar sea state
- If possible, adjust start and end points to follow near-contemporaneous radar altimeter tracks
- Pattern is defined by submitting 4 path targets for the ±24 deg dwells (solid lines)
- Sweeps (dashed lines) are conducted per spacecraft maneuver constraints





Multi-Angle Off-Nadir Ocean CAL/VAL

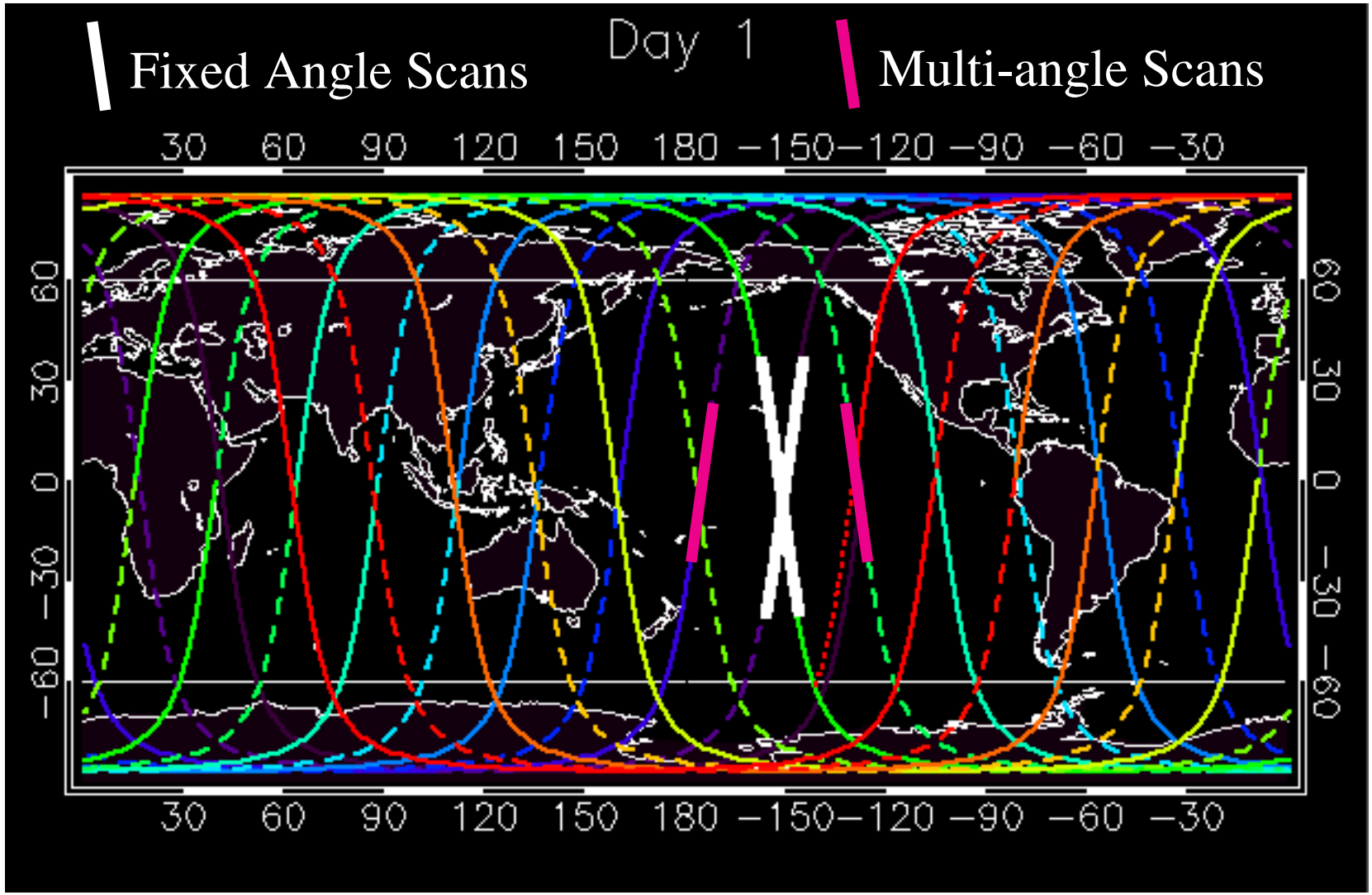
Data Analysis:

- Access relevant TOPEX, JASON, and QUICKSCAT data sets on ocean surface height, significant wave height, and surface wind field.

- Use PGSLA for simultaneous processing of laser and radar altimeter data sets.

- Compute ocean surface topography and waveform statistics, correlate data sets, determine bias sensitivities and report results vs. off-nadir angle, sea-state, and wind field.

Ocean Scan 8-day Campaign



Analysis/Simulation Review

Ocean Scans

- Comprehensive consider covariance analysis and simulation analysis performed - worse case estimate
- Includes noise and all systematic errors
- Manuever: Octagon, 620s of data (1000s arc, 40Hz data), 5 deg. amplitude, period of 460s, *data sigma 1m*

RSS Roll+Pitch Std. (noise only)
0.06" – single maneuver

8-Day Crossovers Simulations

- Simulation only: Included no errors other than noise, 14,996 crossovers in an 8-day repeat period (6,797 land, 8106 ocean, ~93 shoreline)
- Direct altimeter ranges simulated with following assumptions: 40 Hz data, 0.44 m range noise, no drop-outs, GTOPO-30 DEM used over land, ellipsoid used over ocean, Nadir pointing, ranges simulated with roll bias set to 363", pitch bias set to 54", *data sigma 1m*

RSS Roll+Pitch Std. (noise only)
0.34" – nadir pointing only

Land DEM Simulation

- Simulation only: nominal ICESat orbit, 0.44m noise, 0.50m slope on ~1600 km arc, small R+P biases, Nadir pointing, *data sigma 1m*
- DTED1 (90m) DEM – 106 W long., 32N to 48N
- More difficult to recover parameters, including time variation in pointing biases from short fly-overs (50km) when compared to long passes

RSS Roll+Pitch Std. (noise only)
0.16" – long pass

Land DEM Simulation S2

- Simulation only: included no errors other than noise, S/C pointing off up to 0.03 deg., 0.50m noise, *data sigma 1m*
- USGS (30m) DEM
- Used descending and ascending passes around S2 of 6.8 seconds (270 obs. each)

RSS Roll+Pitch Std. (noise only)
0.14"

Mission Phase CAL/VAL Activities

- Mission phase activity depends on results from initial CV activity
  - Short solutions
    - Centered on ocean scans or land DEM over-flights
    - Pair of 30-hour overlapping arcs
    - Nominally once per week
  - Full solutions (8-day arcs) if determined necessary during initial CV
  - Increase frequency of solutions
    - If there is a problem (e.g. GPS dropouts, suspect instrument parameter variation)
    - If determined necessary by initial CV analysis

- 3 / 5 year CV phase activity
  - Repeat initial CV analysis
  - Modified by initial and mission CV analysis