Orbit dynamics, overpass times and repeated sensor coverage: implications for seasonal measurements and change detection

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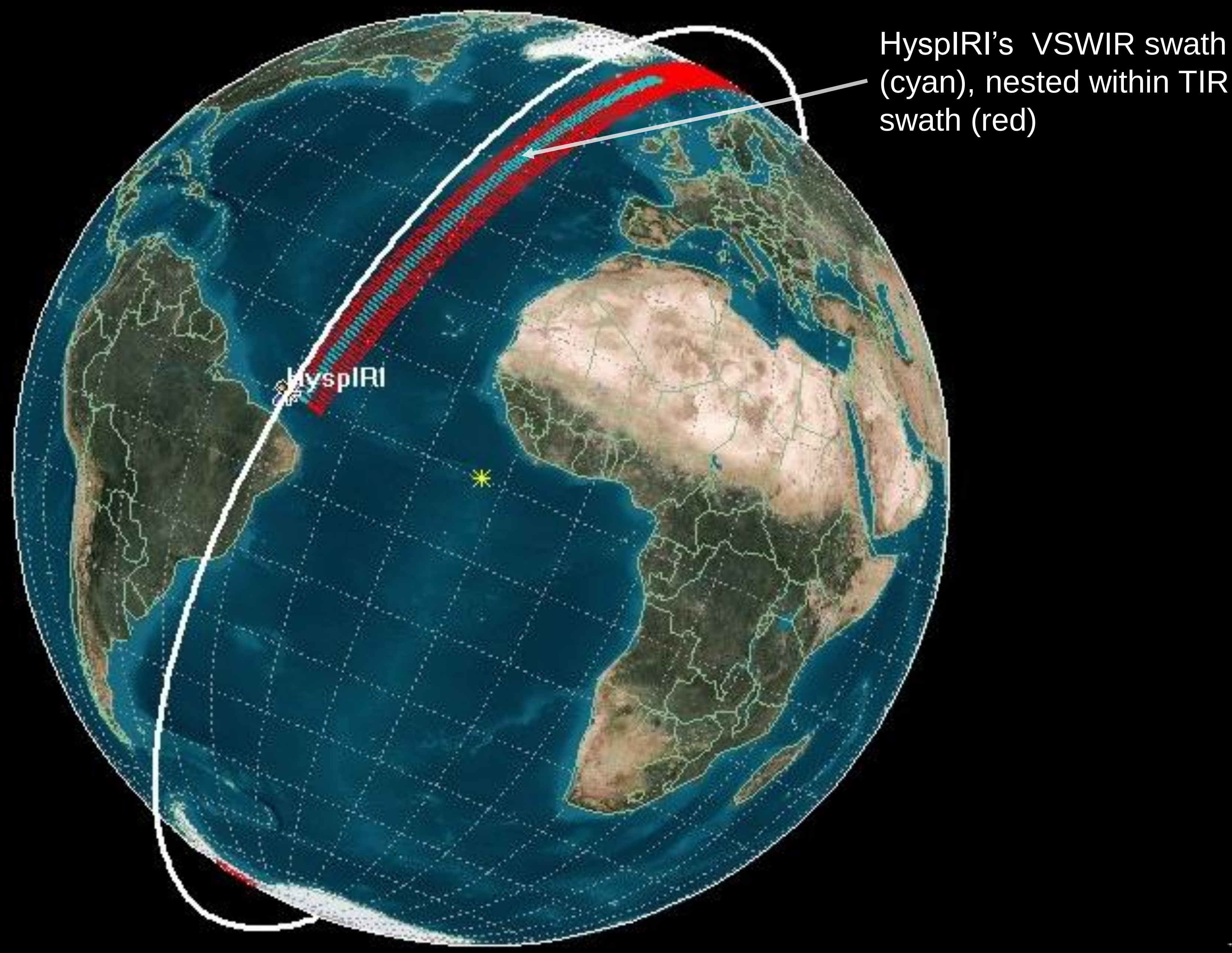
Introduction

Context

- Mission requirements for 5-day and <20 day repeat overpasses.
- Sun-synchronous, repeating, low Earth orbit (LEO).
- Family of LEO reference concepts.
- HyspIRI concept was adjusted to reduce sun-glint in the VSWIR swath: Nominal mid-morning crossing time (10:30 AM) and 4° off-nadir pointing.

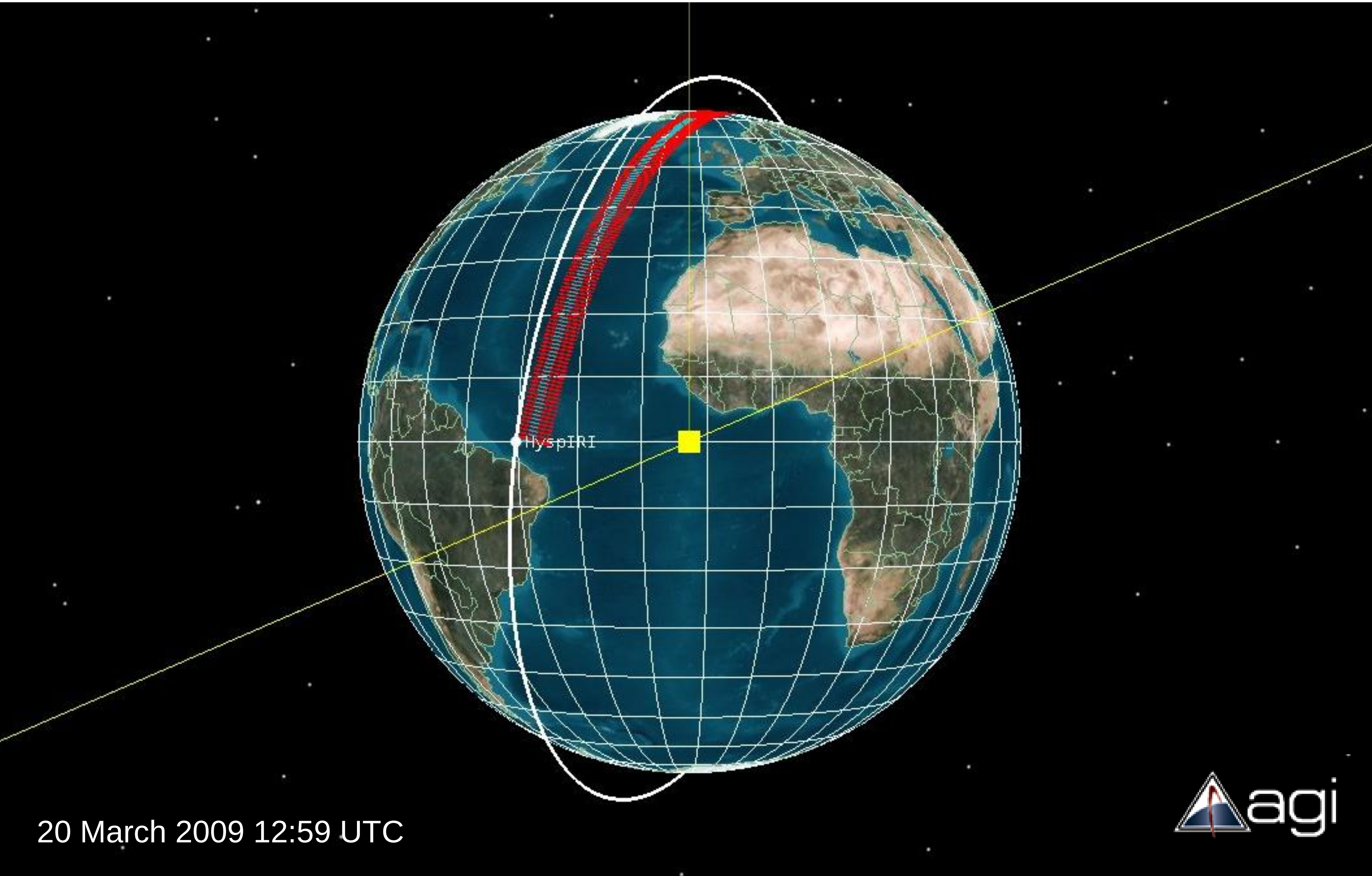
Outline

- Orbital geometry and repeat cycles for some suitable reference orbits.
- Imaging opportunities for each sensor (TIR & VSWIR)
  - Overpass times/dates for example sites
  - Variation in frequency with latitude
- View-illumination geometry variation and constraints.
- Observations at intervals shorter than 5-day or <20 day repeats.

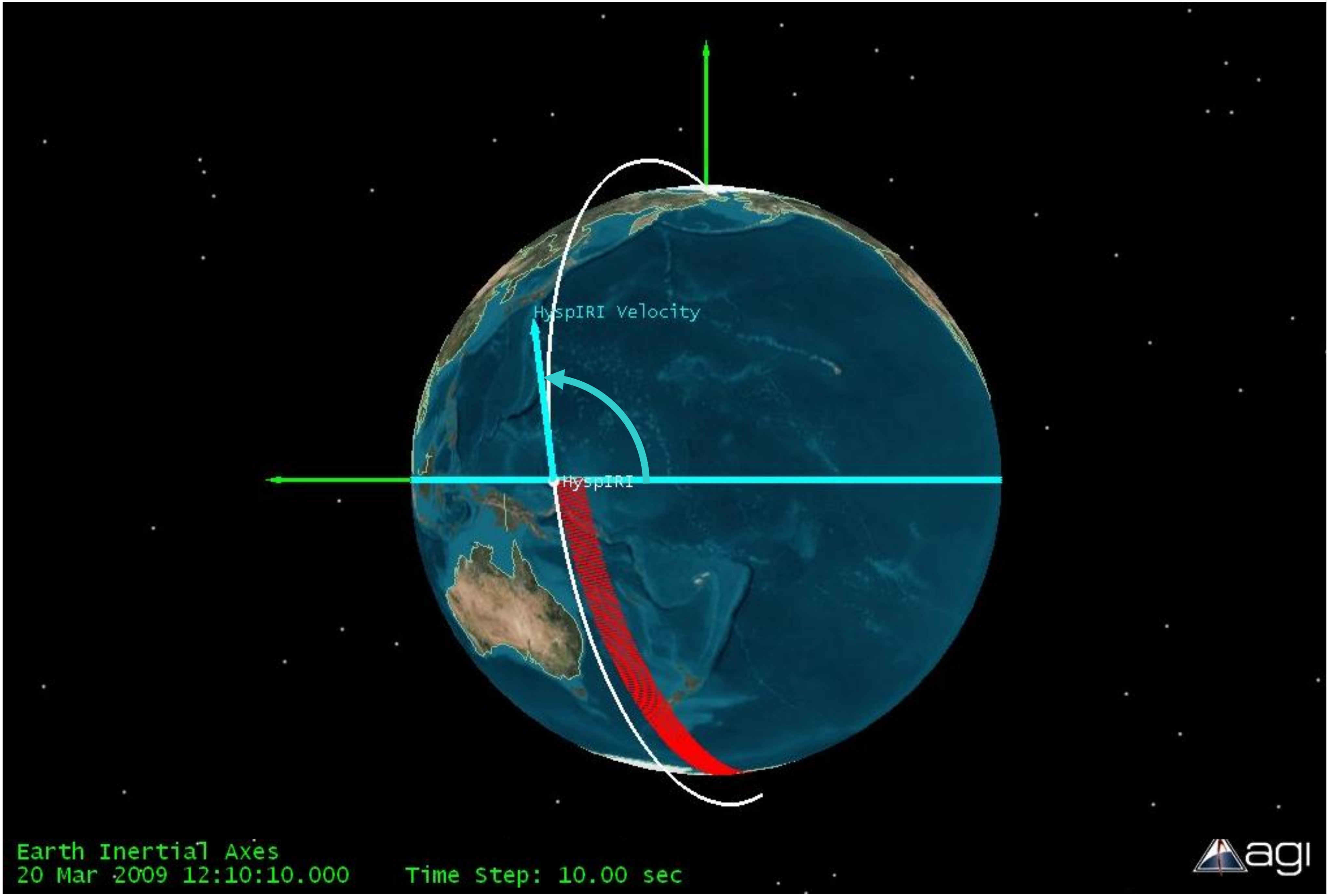


20 March 2009

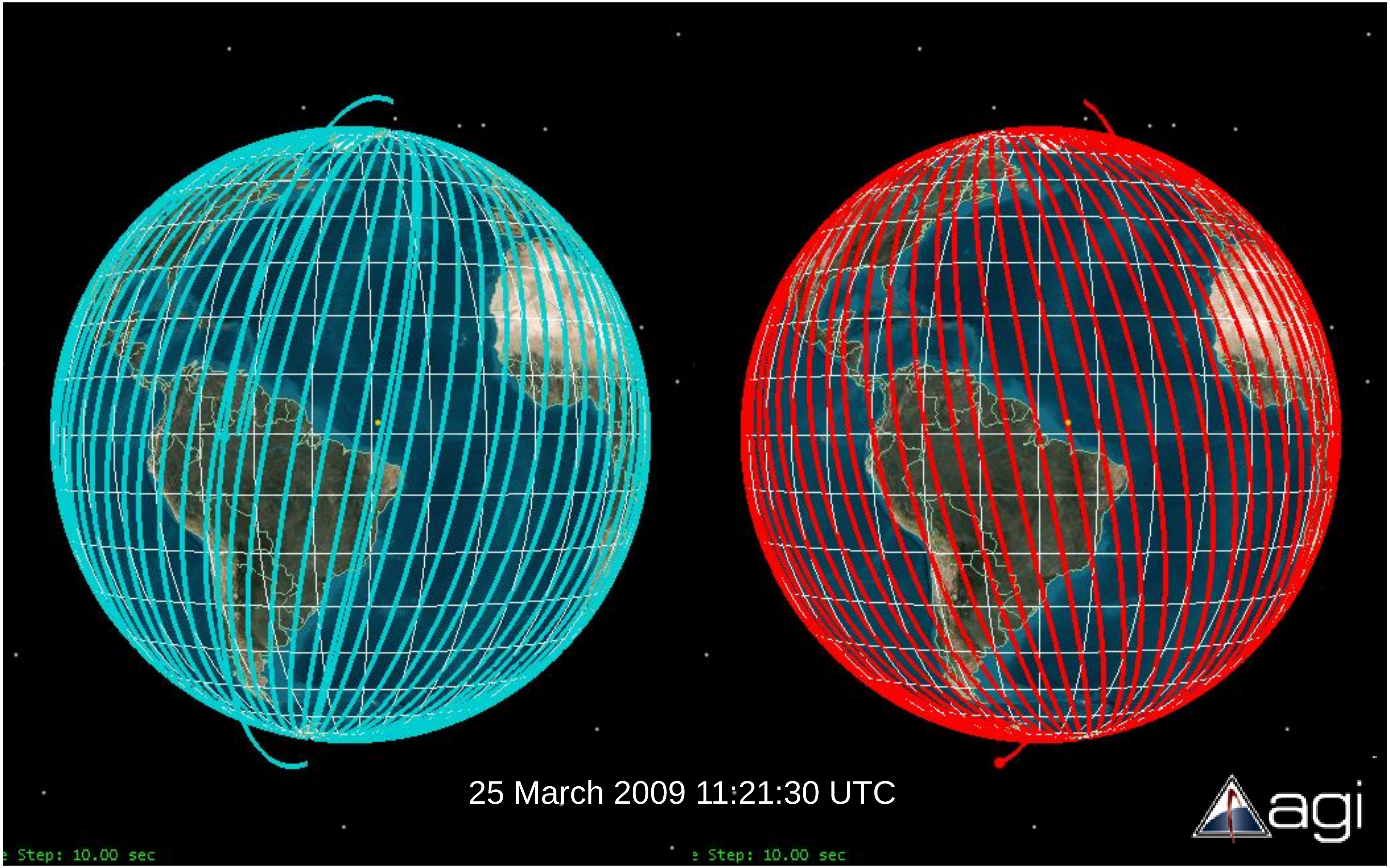
Daylight side of a sun-synchronous reference orbit, with 10:30 AM equatorial crossing (mean local time) at a descending orbit node. The sub-solar point (yellow) shows the location on Earth where the Sun is directly overhead, east of the ground track. Green line shows the plane of the ecliptic. 3-D view shown in Earth Inertial Axes.



Orbital inclination (97.9) represents the angle between the Earth's equatorial plane, and the orbit plane, measured (by convention) at an ascending node.

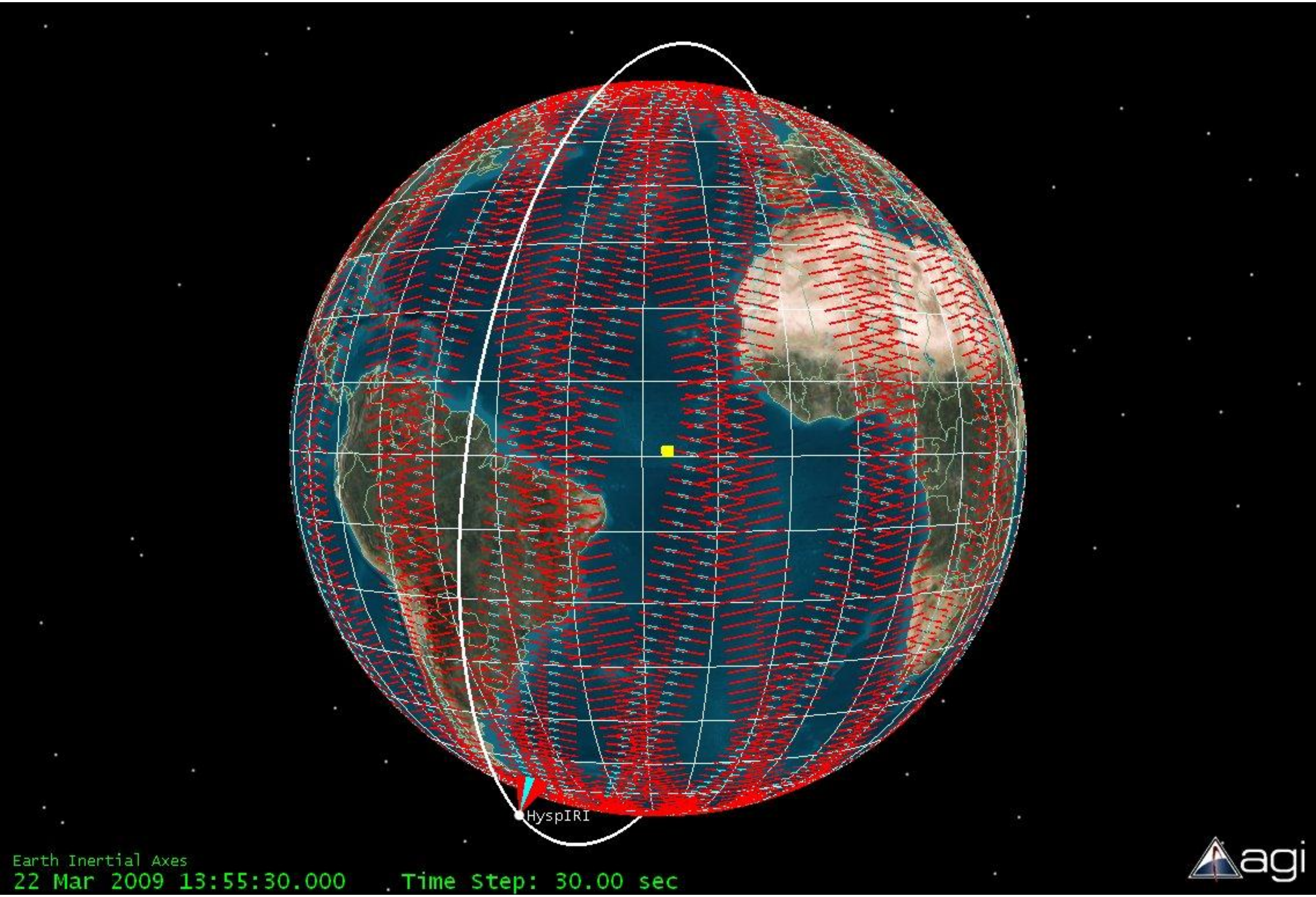


HyspIRI ground tracks shortly after completing a 5-day near repeat pattern:
(a) blue – descending (day) passes and orbit track;
(b) red – ascending (night) passes and orbit track.



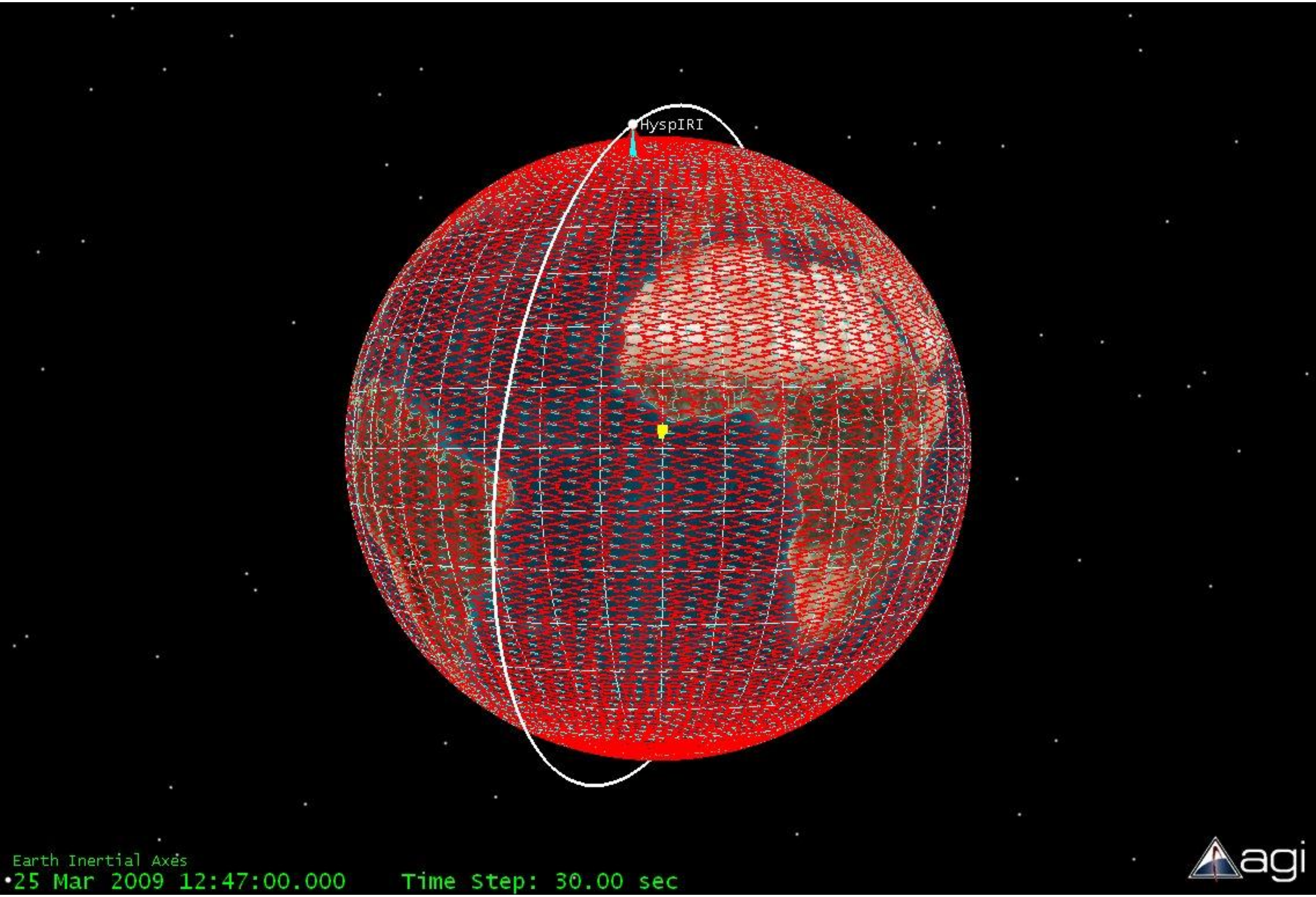
R.G. Knox simulation with STK v8.1.3. Orbit: alt. 626.8 km, inclination: 97.8°. Earth graphics courtesy of Analytical Graphics Inc.

Sampling pattern after 2 days, with instrument footprints at 30 second intervals



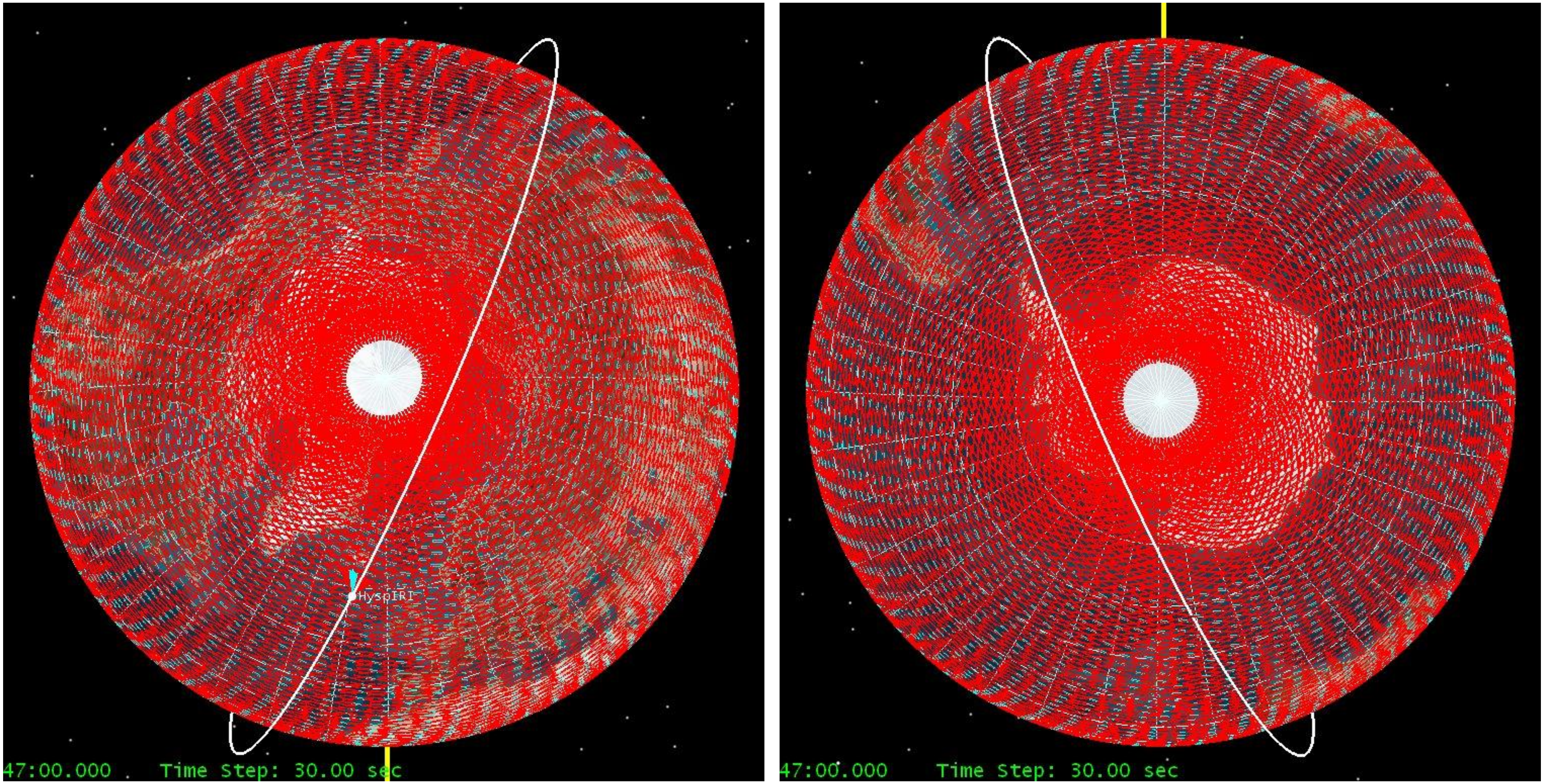
R.G. Knox simulation with STK v9.2. Orbit: alt. 626.8 km, inclination: 97.8°. Earth graphics courtesy of Analytical Graphics Inc.

Sampling pattern after 5 days, with instrument footprints at 30 second intervals



R.G. Knox simulation with STK v9.2. Orbit: alt. 626.8 km, inclination: 97.8°. Earth graphics courtesy of Analytical Graphics Inc.

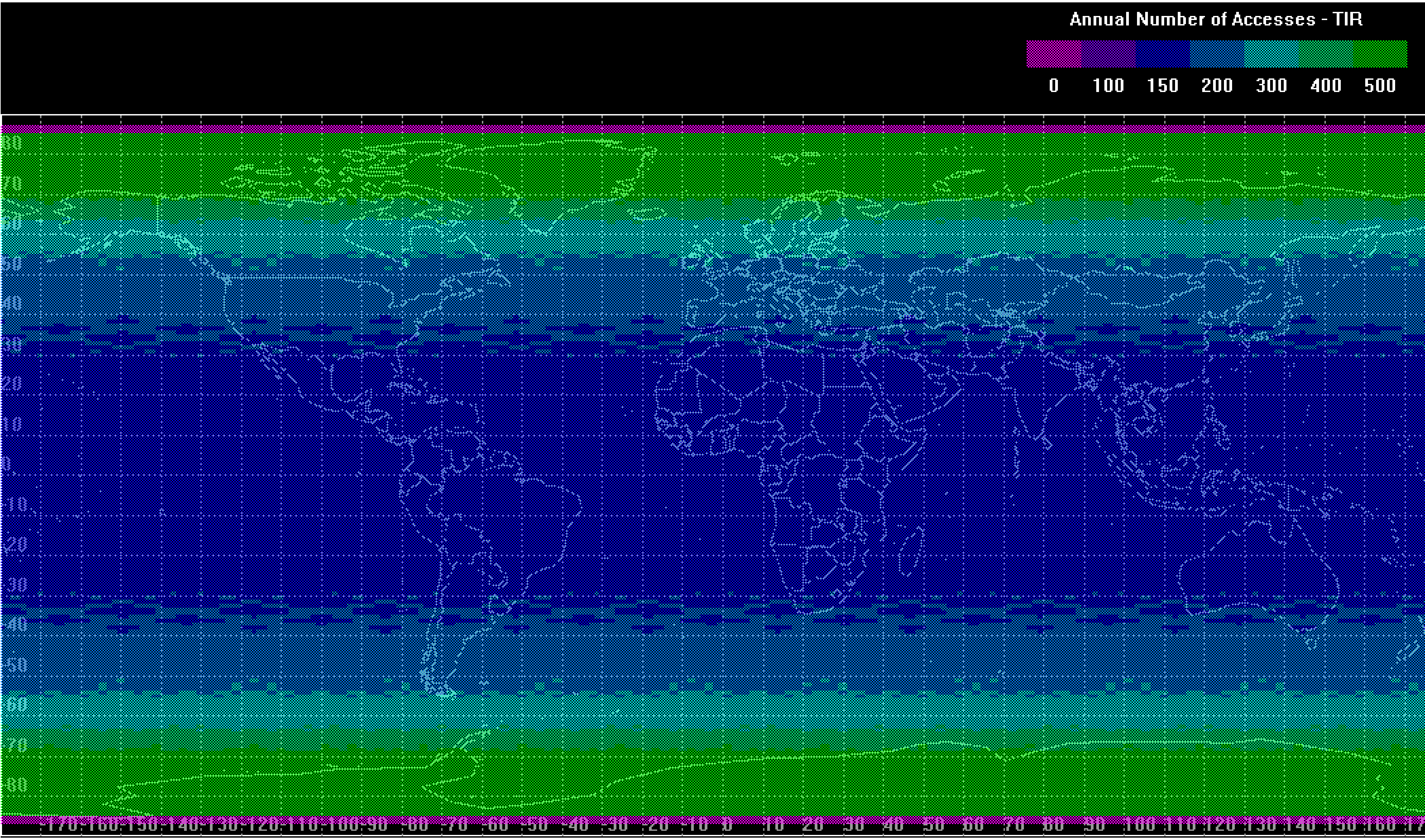
HyspIRI sampling pattern after 5 days: Holes at N and S poles



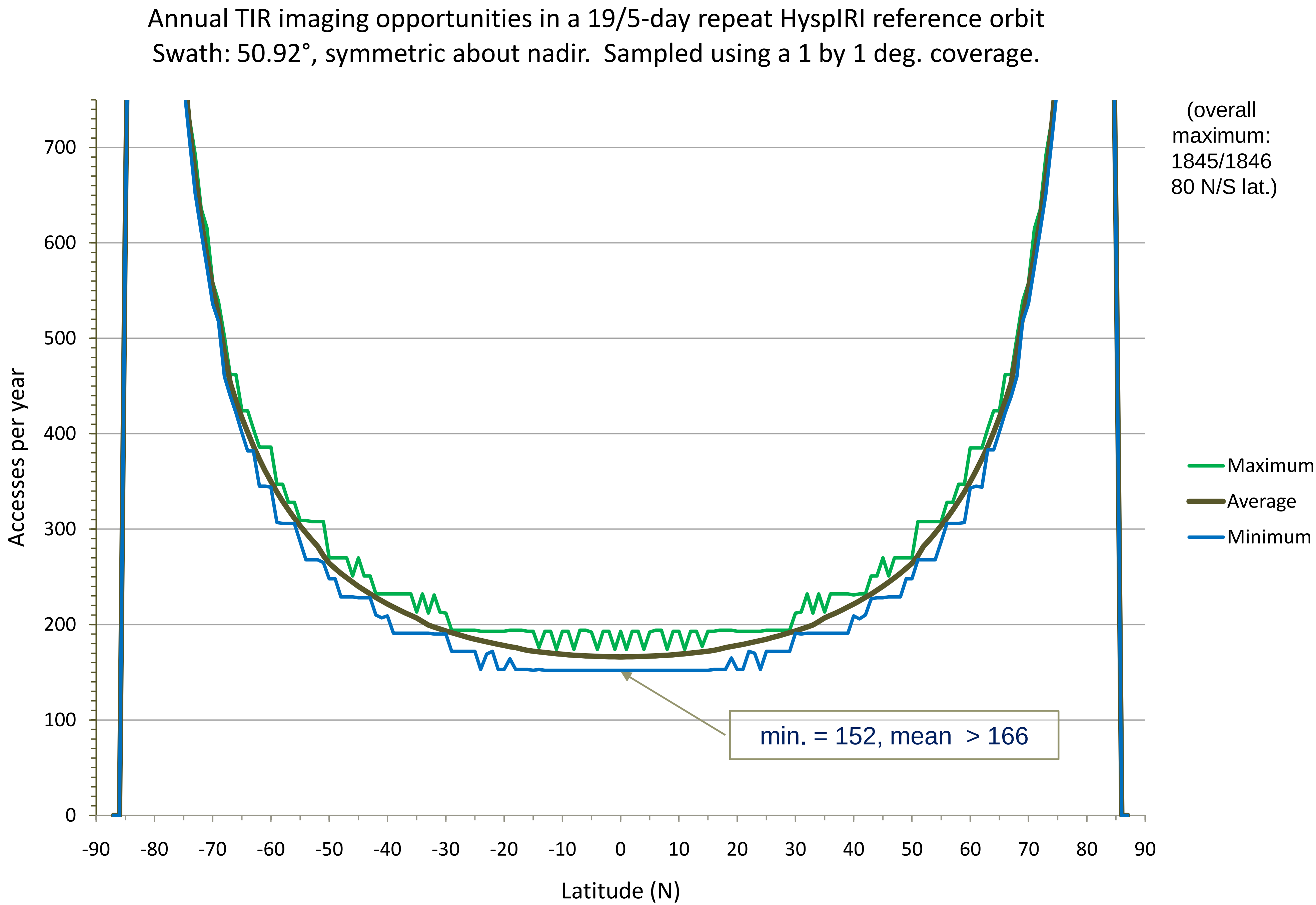
HyspIRI's nominal mid-morning (10:30 AM) crossing time is on a descending orbit (N-to-S) pass. Hence the observatory passes over sunlit terrain while descending east of the North Pole and while approaching west of the South Pole. TIR coverage is similar at both poles. (Ground tracks of sun-synch. orbits cannot pass directly over the poles.) Because the VSWIR sensor relies on reflected illumination, it can collect data from well-illuminated surfaces at higher latitudes in the north.

R.G. Knox simulation with STK v9.2. Orbit: alt. 626.8 km, inclination: 97.8°. Simulated mission days March 20-25, 2009. Nominal TIR & VSWIR FOV marked at 30 second intervals. Earth graphics courtesy of Analytical Graphics Inc.

Annual TIR imaging opportunities in a 5-day near-repeating orbit, 1 yr. simulation

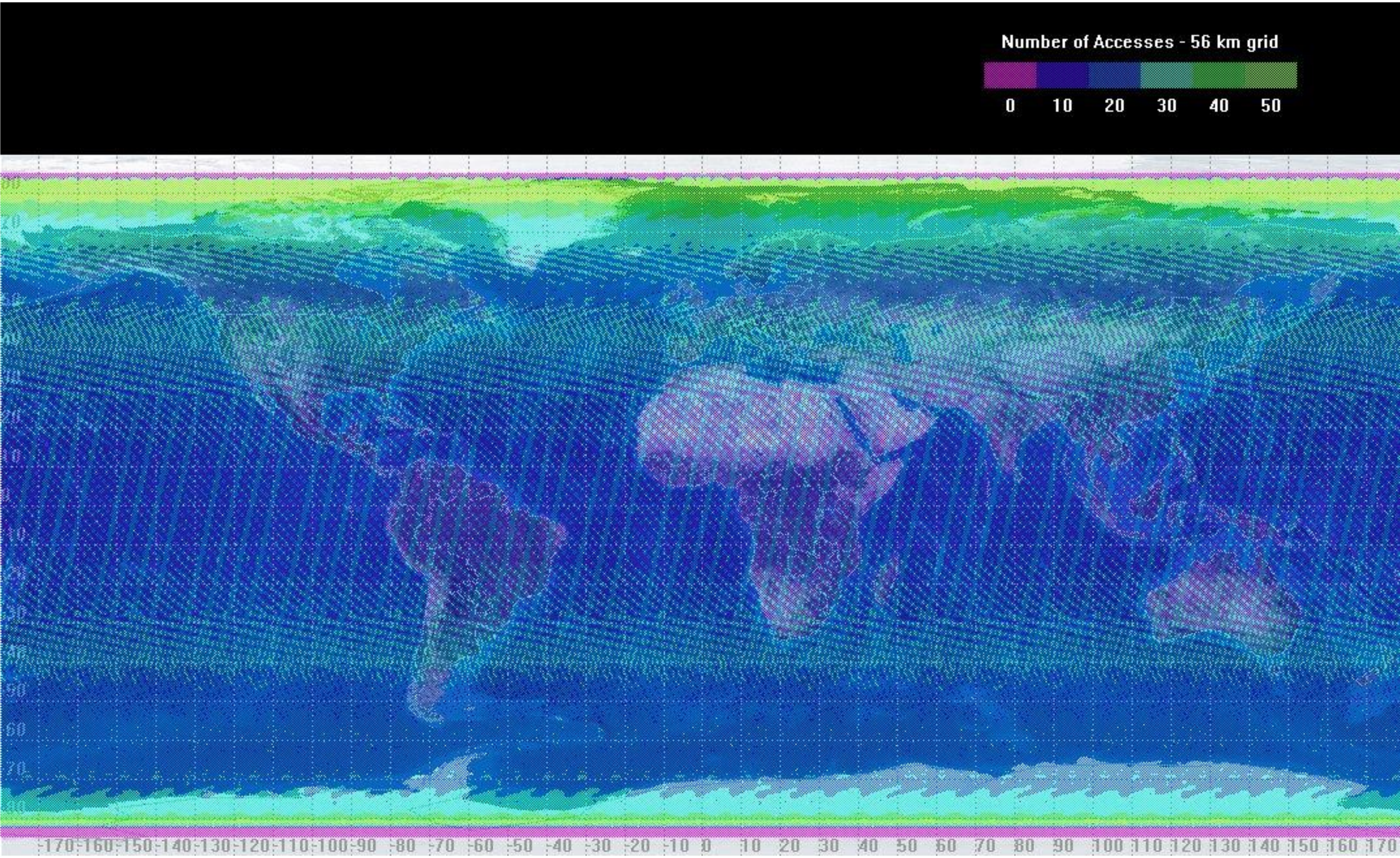


Nominal orbit: average alt. 626.8 km, inclination 97.8°. TIR imager FOV: +/- 25.46° (60 m pixel GSD at nadir, 9272 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 7, 2010. Plotted May 3, 2010.

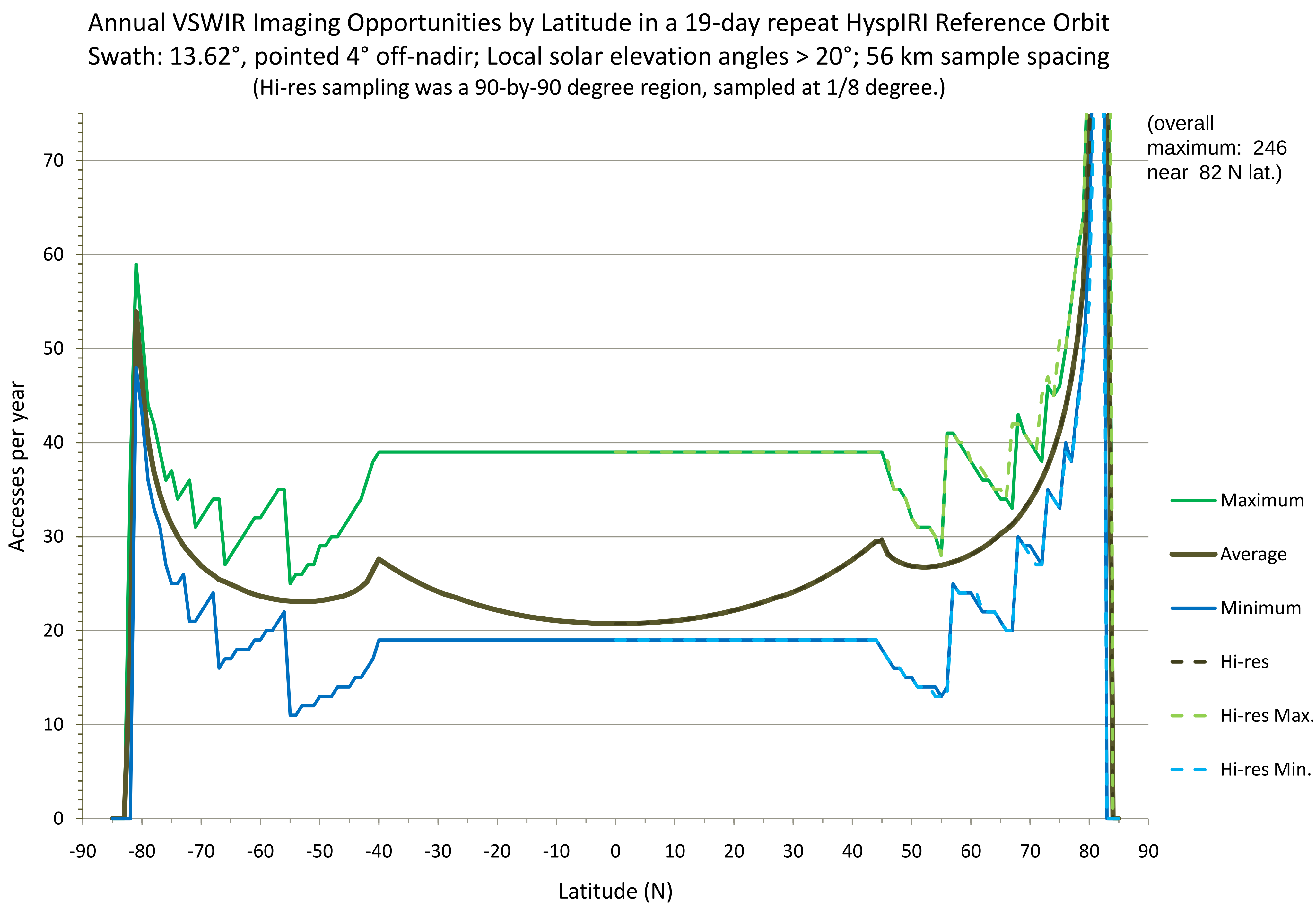


Nominal orbit: average alt. 626.8 km, inclination 97.8°. TIR imager FOV: +/- 25.46° (60 m pixel GSD at nadir, 9272 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 7, 2010.

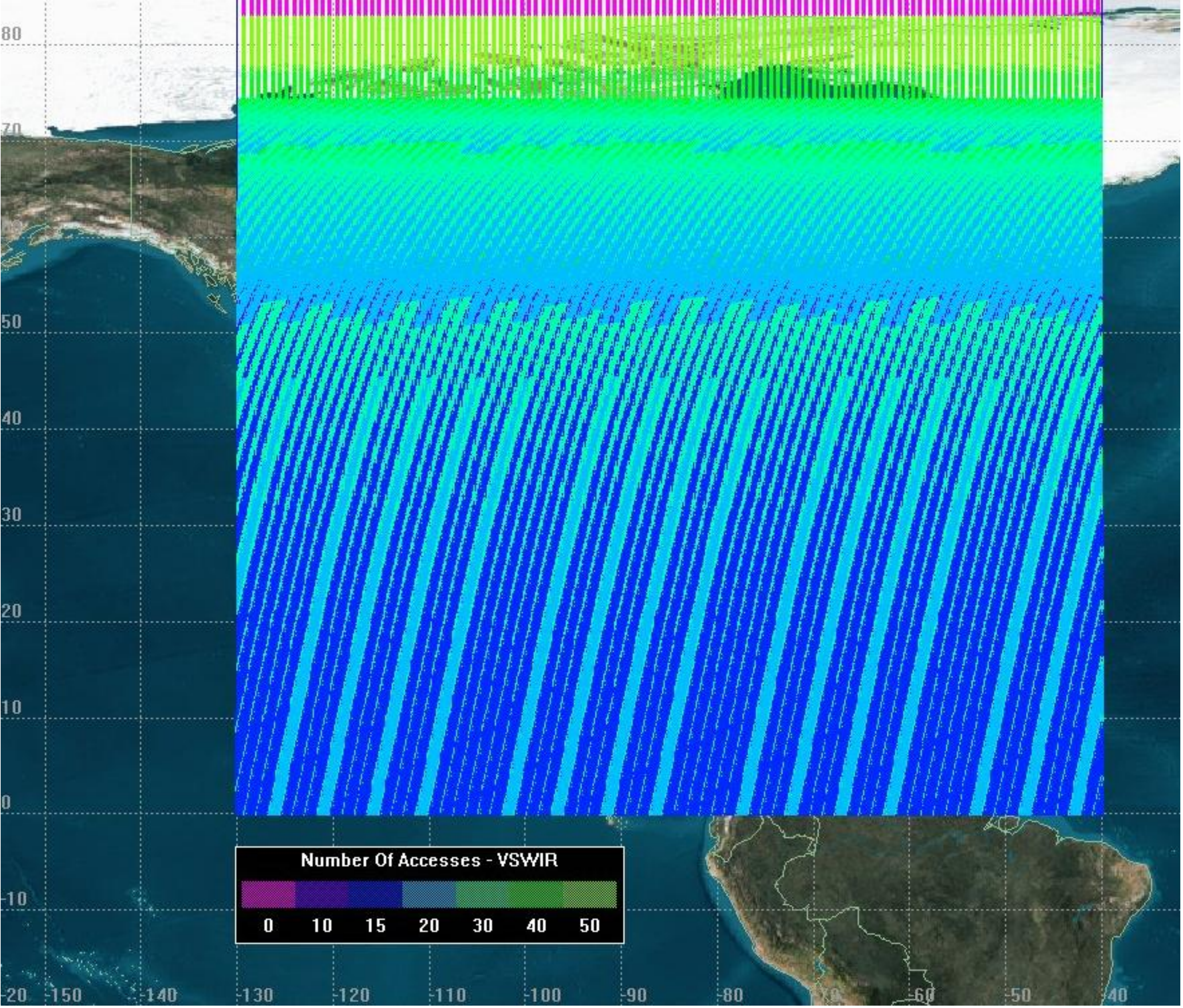
Annual VSWIR imaging opportunities in a 19-day repeating orbit, 1 yr. simulation, with a minimum solar elevation of 20°



Nominal orbit: av. alt. 626.8 km, incl. 97.8°. VSWIR spectrometer FOV: 2.8° E, 10.8° W (60 m pixel GSD at nadir, 2480 cross-track pixels). R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v9.2, August 20, 2010. Note aliasing with sample grid.

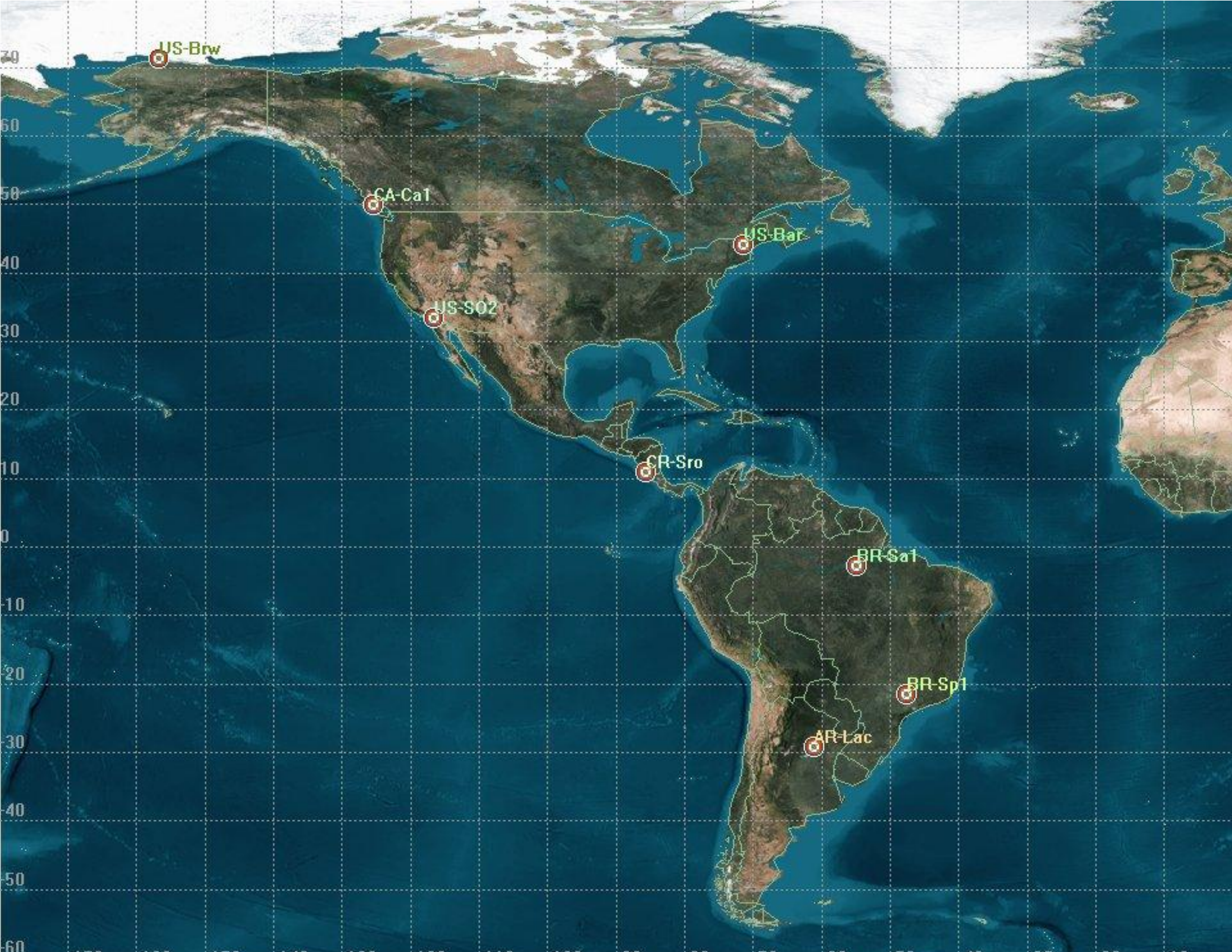


Nominal orbit: av. alt. 626.8 km, incl. 97.8°. VSWIR spectrometer FOV: 2.8° E, 10.8° W (60 m pixel GSD at nadir, 2480 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v9.2, Aug. 20, 2010.; hi-res subset Aug. 17.

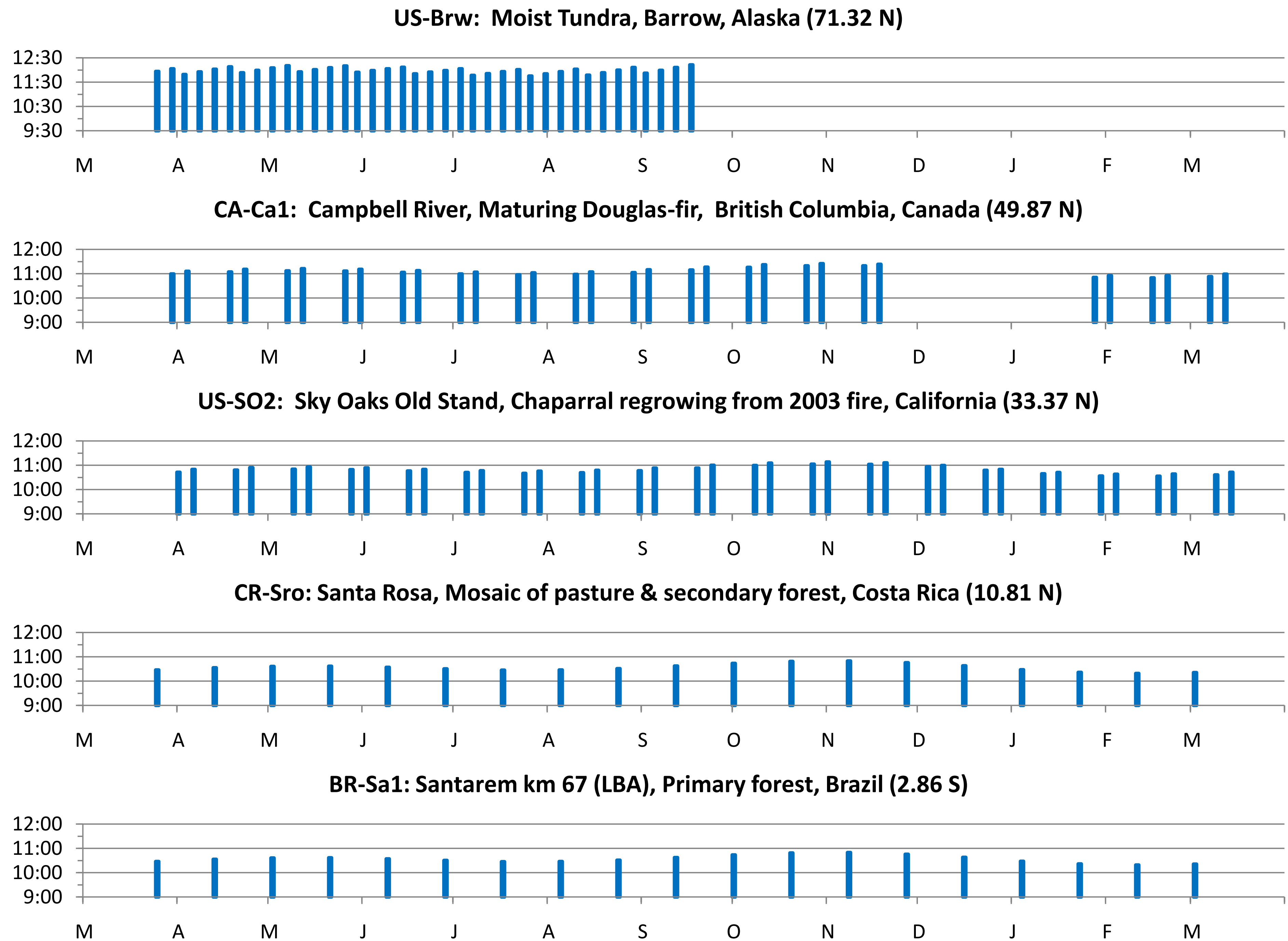


High resolution (1/8 degree) simulation of annual VSWIR coverage, 90 x 90 degree (lat, lon) region

Nominal orbit: av. alt. 626.8 km, incl. 97.8°. VSWIR spectrometer FOV: 2.8° E, 10.8° W (60 m pixel GSD at nadir, 2480 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v9.2, August 17, 2010. Note aliasing at high latitudes.

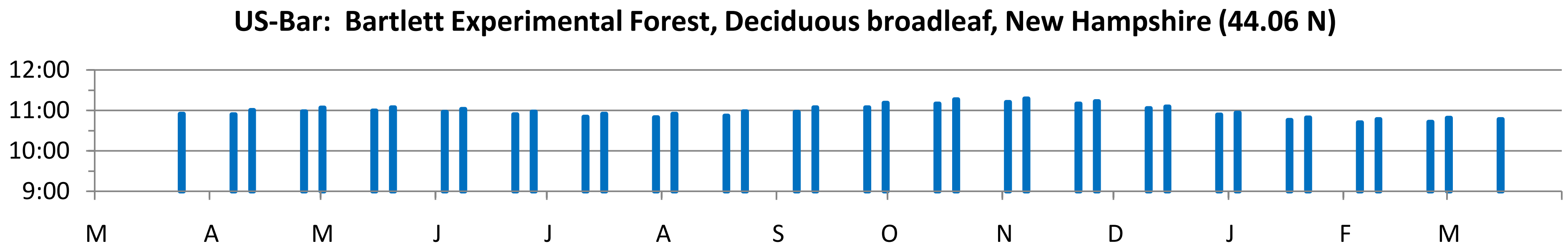

US-Brw
CA-Ca1
US-Bar
US-SO2
CR-Sro
BR-Sa1
BR-Sp1
AR-Lac
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60

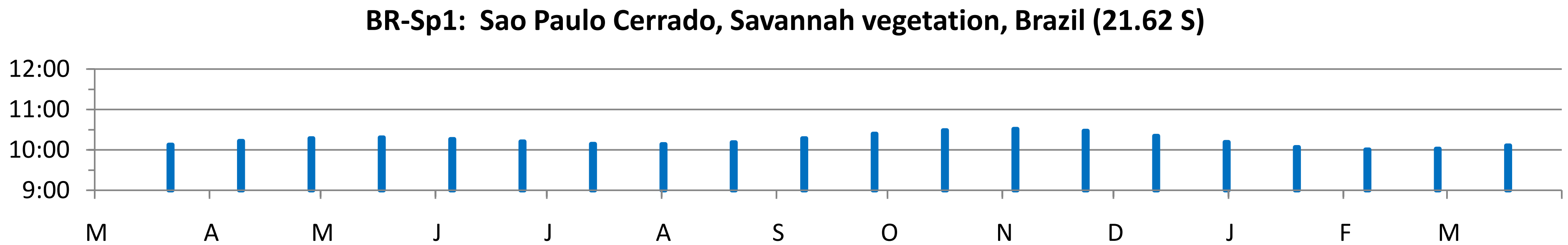
VSWIR accesses (SZA < 70°) for 1 simulated year

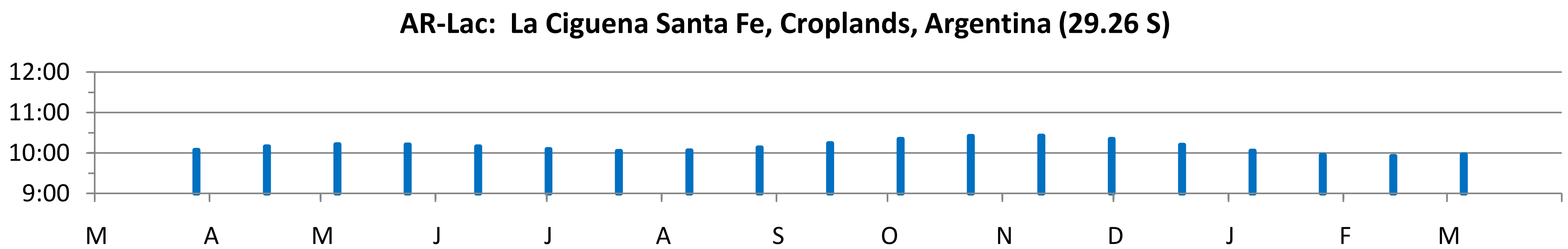


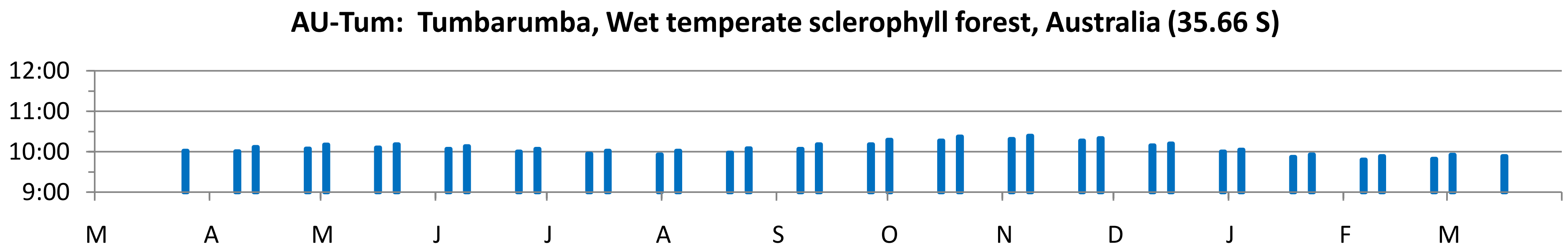
R.G. Knox & E.M. Middleton, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v9.2

VSWIR accesses for 1 simulated year









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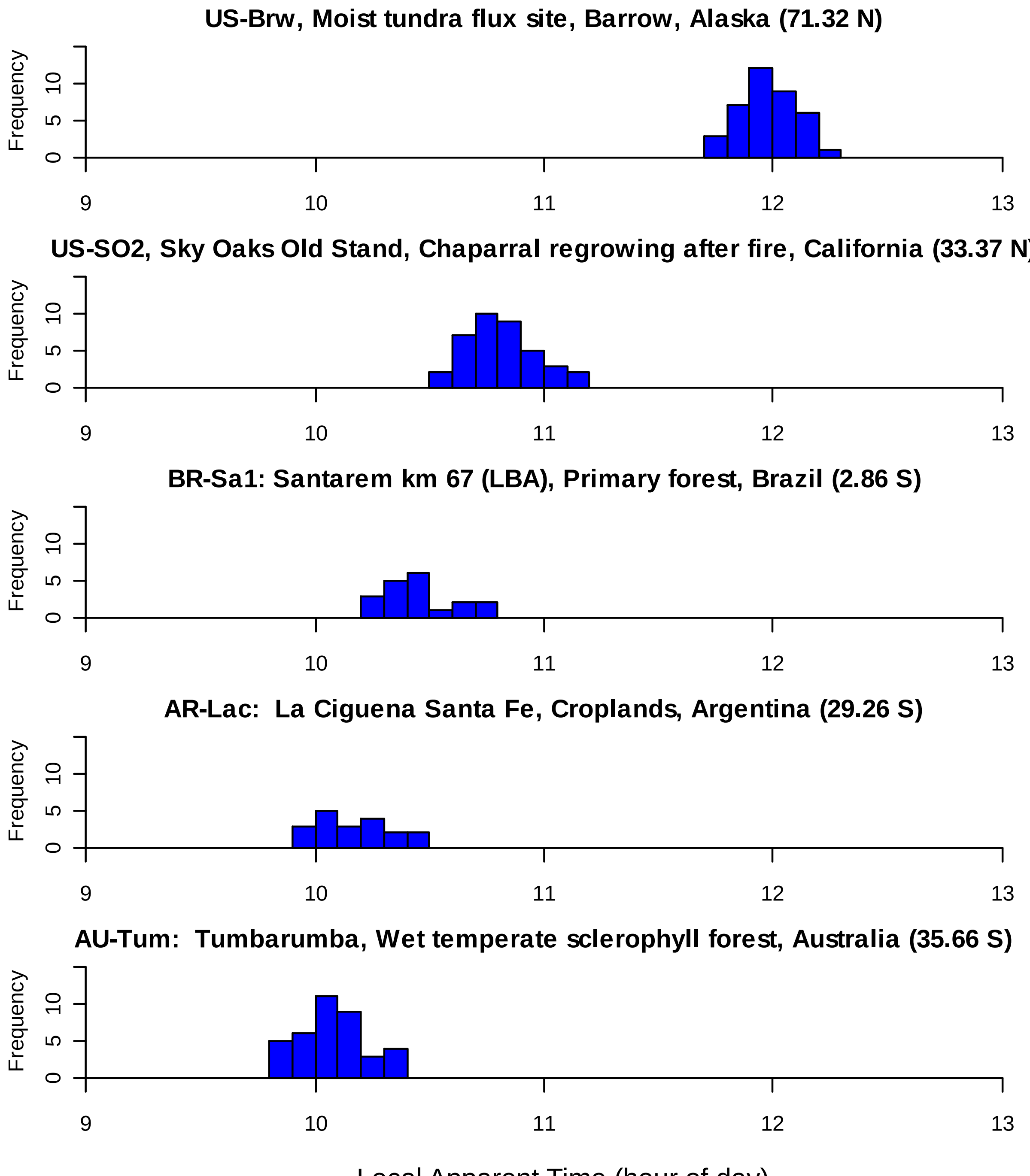
Local time of VSWIR overpasses of 5 FLUXNET sites, simulated for 1 year

Local apparent time, for a fixed mean local time, varies with the Earth's orbit. (Blue bars are 6 minutes wide.)

As the N latitude of the site increases, the local apparent times of potential VSWIR accesses also increase.

Near the north orbit pole (82.1 N) the local time of potential accesses may be nearly 6 hours later than when crossing the equator (not shown).

Moving toward the south orbit pole local times are progressively earlier in the morning.



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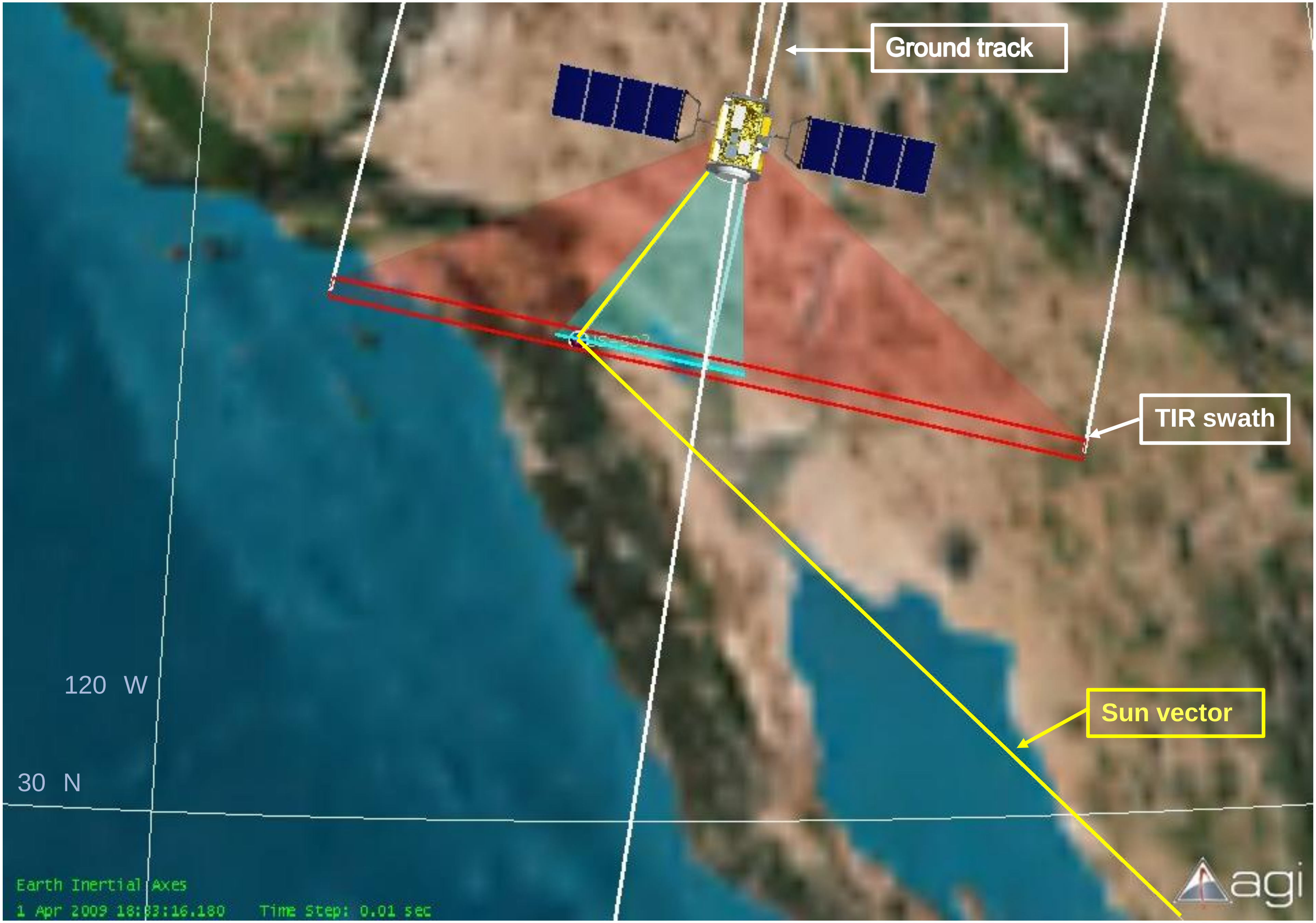
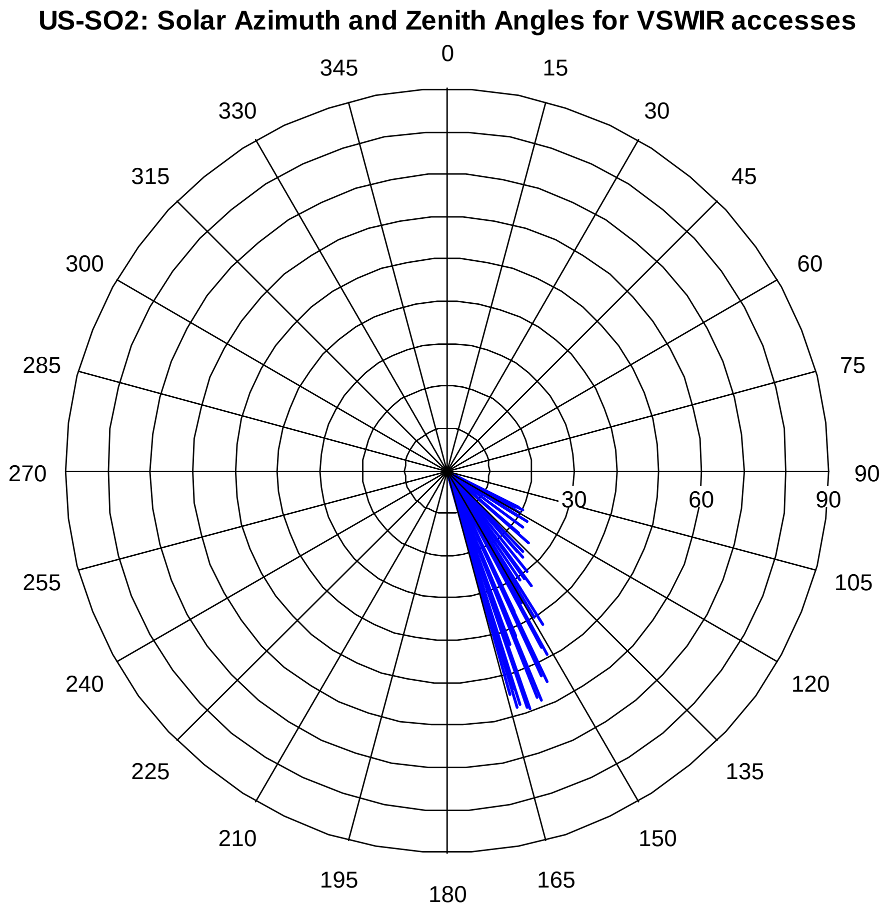
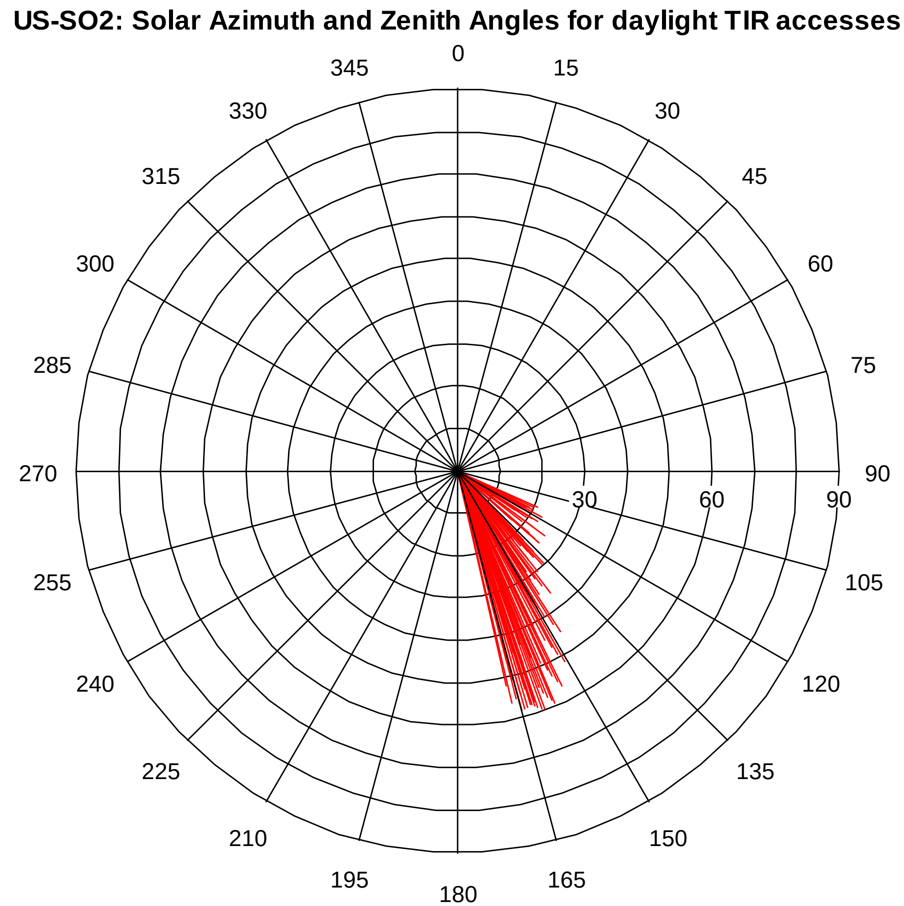
Example HyspIRI access to Sky Oaks (US-SO2, Old Stand) flux site in southern California



VSWIR swath (light blue) is nested within TIR cross-track scan pattern (red), with a swath center offset west of the satellite's ground track (white). Note view & illumination vectors (yellow). Access geometry simulated for 1 Apr 2009, 18:33:16.18 UTC, with STK v9.2.

Polar plots of illumination geometry for VSWIR and Daylight TIR accesses to Sky Oaks, Old stand, California (33.37 N)





Solar Zenith Angle

Mean	37.75°
Std.dev.	14.69°

Solar Zenith Angle (daylight)

Mean	37.47°
Std.dev.	14.62°

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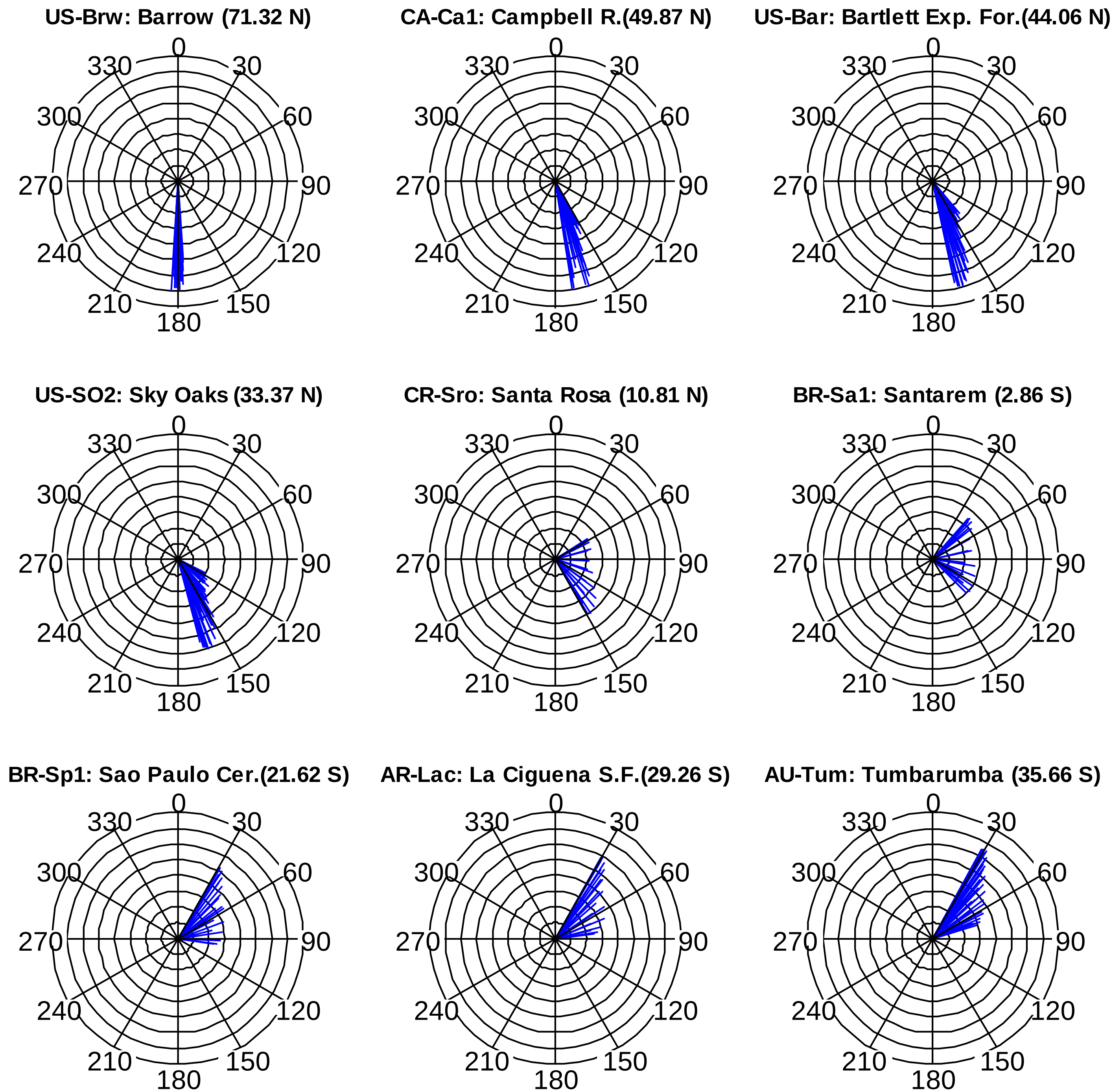
Polar plots of simulated illumination geometry for VSWIR accesses over 1 year, for 9 flux sites arranged by latitude.

Note that for clarity solar zenith angles were plotted from 0 to 80 degrees, and solar azimuths were marked in 30 degree increments.



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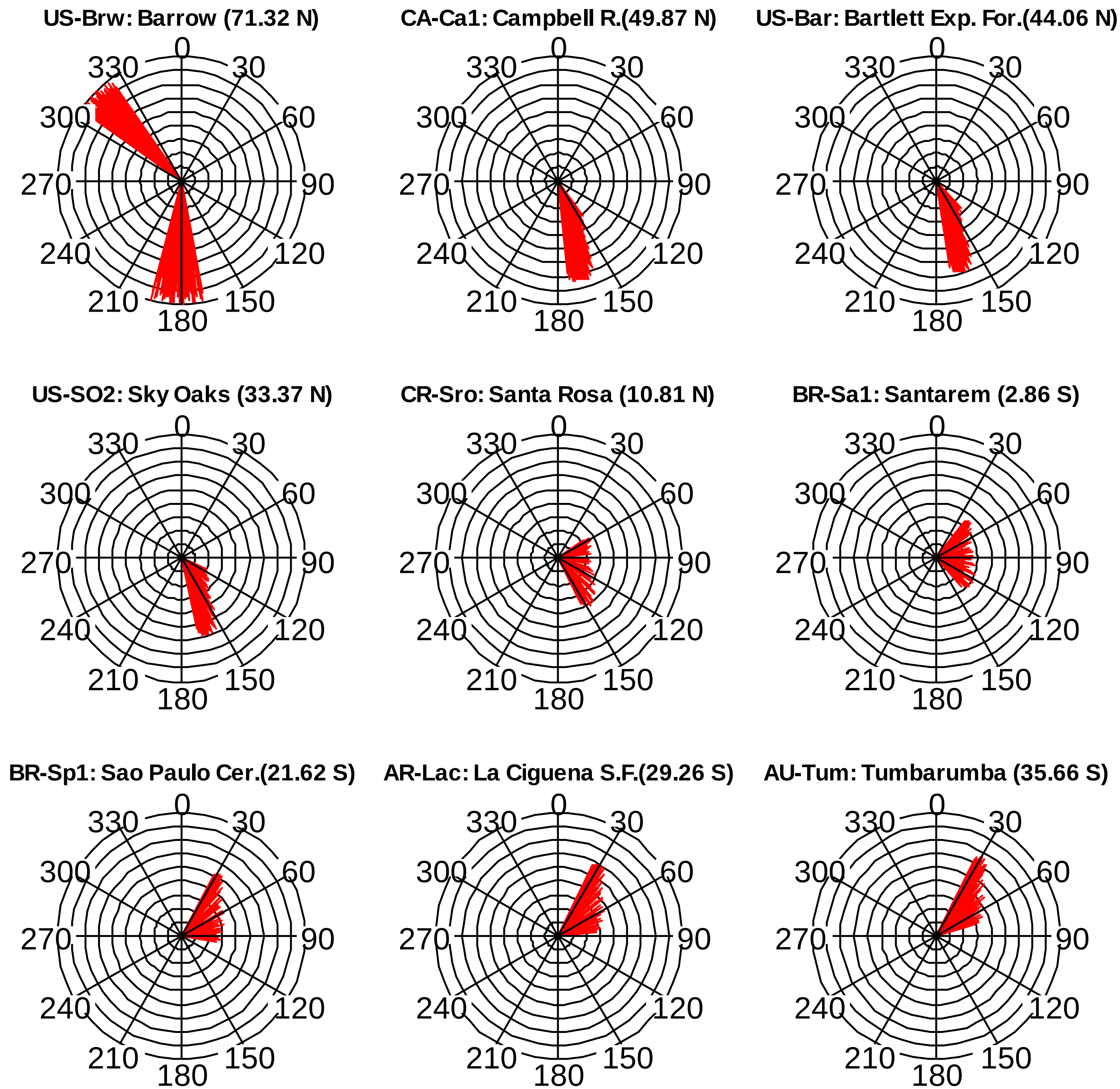
Polar plots of simulated illumination geometry for daylight TIR accesses over 1 year, for 9 flux sites arranged by latitude.

Unlike VSWIR simulations, solar zenith angles exceed 70°, and above the Arctic circle solar azimuths include daylight observations on ascending orbit passes.



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Solar zenith angles (SZA) at times site viewed by HyspIRI instruments, over 1 simulated year

		VSWIR			Daylight TIR		
Flux Site	Latitude	Mean SZA	Std. Dev.	n	Mean SZA	Std. Dev.	n
US-Brw	71.3 N	56.0	6.9	38	70.5	14.1	322
CA-Ca1	49.9 N	46.7	14.3	32	50.9	16.1	135
US-Bar	44.1 N	46.0	16.0	38	47.3	16.0	104
US-SO2	33.4 N	37.8	14.7	38	37.5	14.6	96
CR-Sro	10.8 N	28.1	6.9	19	27.6	6.9	77
BR-Sa1	2.9 S	28.3	4.3	19	27.8	4.4	77
BR-Sp1	21.6 S	35.9	10.6	20	35.5	10.7	77
AR-Lac	29.3 S	41.0	12.8	19	40.2	12.7	96
AU-Tum	35.7 S	45.7	13.8	38	45.4	13.8	95

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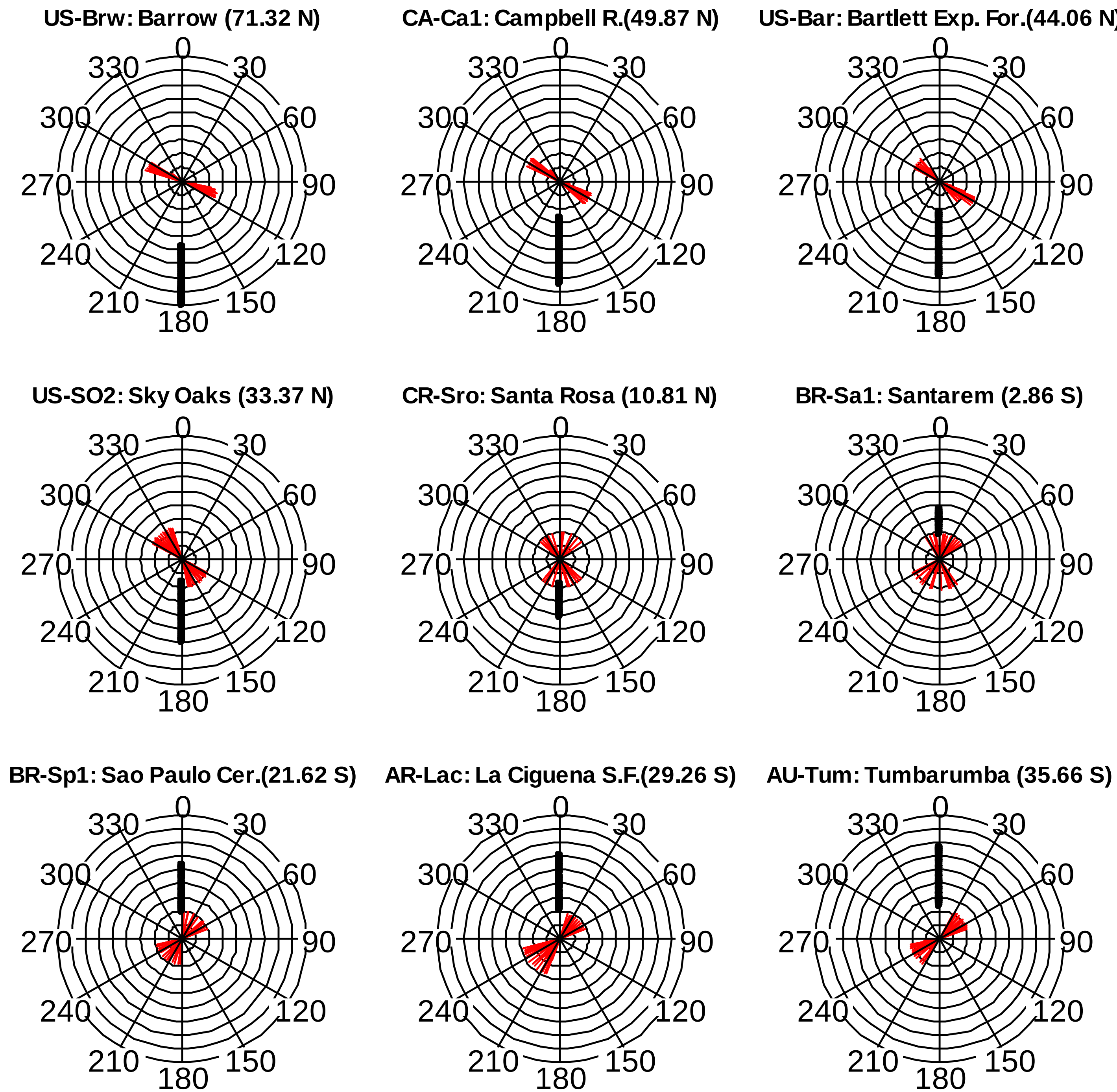
Polar plots of simulated view geometry (red) for daylight TIR accesses over 1 year, for 9 flux sites arranged by latitude. Solar zenith angles (black) plotted in the principal plane.

At higher latitudes views are well outside the principal plane. With a mid-morning crossing time, some data will be collected near the principal plane at subtropical and tropical latitudes.



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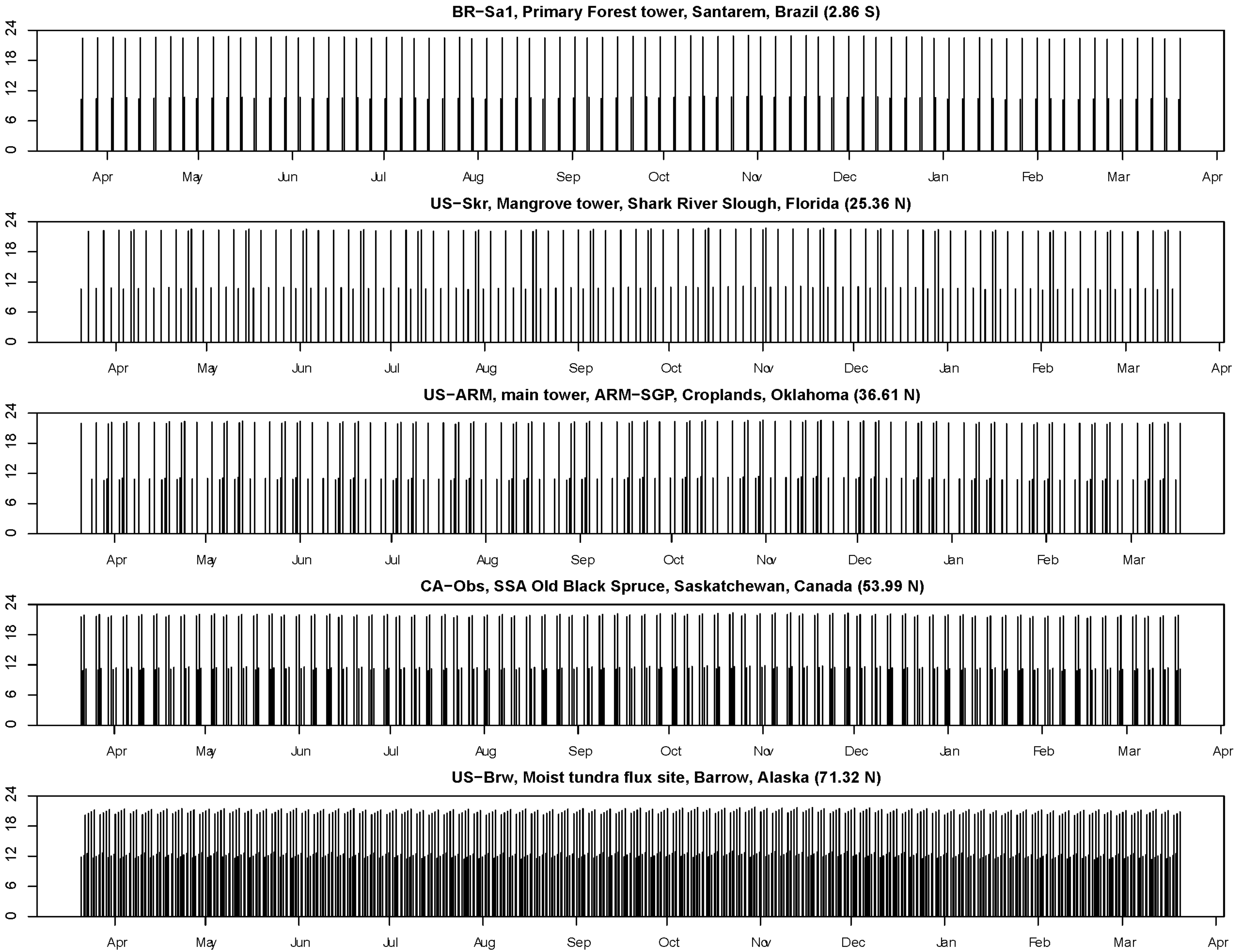
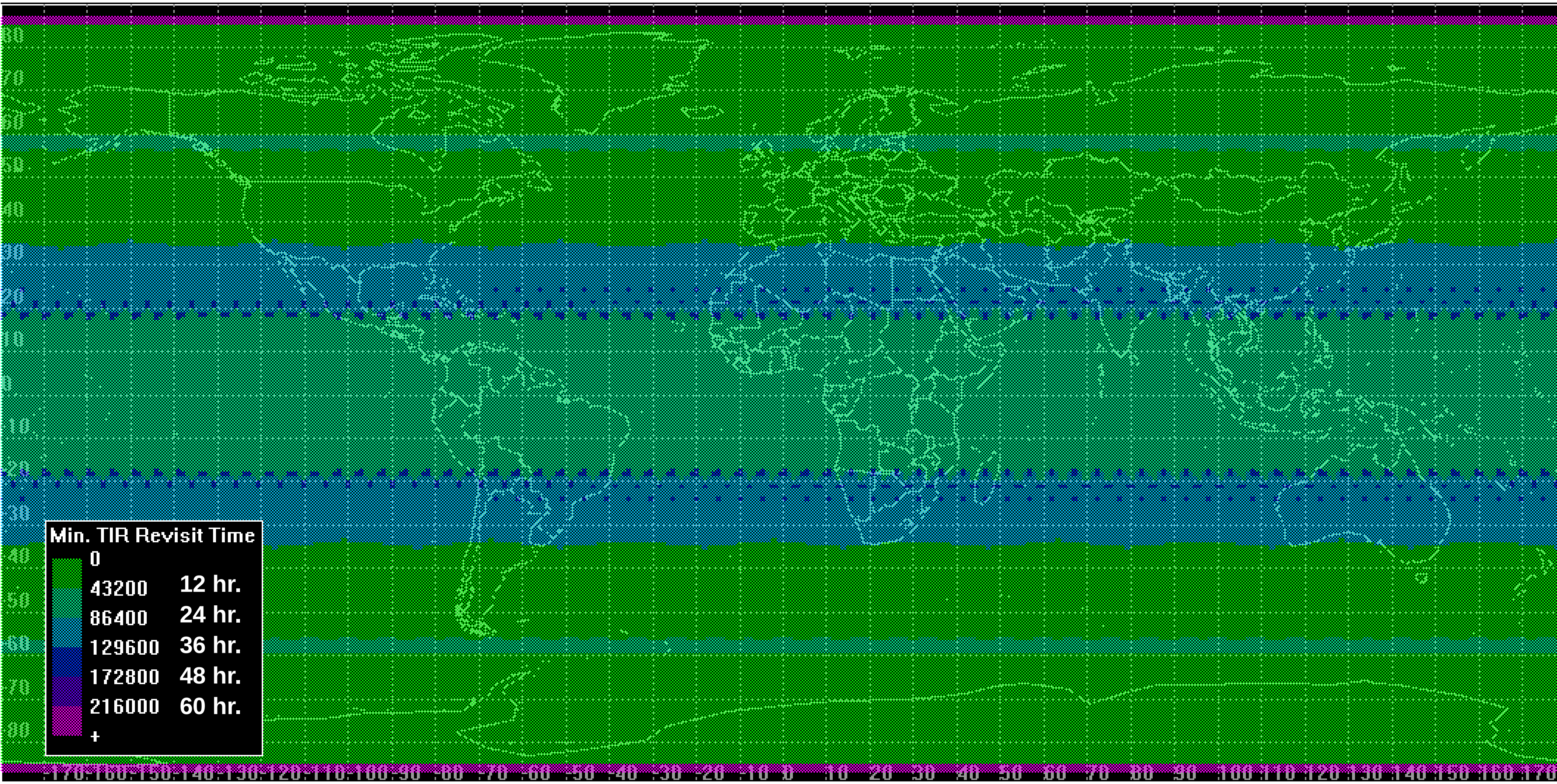
TIR accesses for 1 simulated year



Minimum times between Multispectral Thermal (TIR) Imager accesses

Potential accesses simulated for 1 year, sampled over a 1 by 1 deg. grid



Nominal orbit: alt. 626.8 km, incl.: 97.8. TIR sensor FOV: +/- 25.46 (60 m pixel GSD at nadir, 9272 cross-track pixels).

R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 20, 2010. Plotted May 3, 2010.

Some observations & conclusions

- The local apparent time for overpasses is usually **not** 10:30 AM.
- Viewing geometry is well-constrained in HyspIRI's reference design (*cf.* MODIS), but illumination geometry varies systematically with latitude. To produce consistent global data, algorithms will need to address this.
- A mid-morning orbit crossing time, for descending orbit passes, implies mid-day or later overpasses in the Arctic and progressively earlier morning overpasses in southern temperate to near-polar latitudes. This will reduce the quantity and/or quality of winter VSWIR data in the southern hemisphere. *(Glint reduction has trade-offs.)*
- A design concept to meet 5-day and < 20 day requirements (the reference orbit and instrument concepts) also provides highly sampled areas: e.g., high latitudes, overlapping swaths. (Longitudes with more frequent overlap might shift over the mission life—depending on specs. for maintaining orbit.)
- The reference orbit and TIR instrument swath provide day-night pairs—within 24 hours at most locations (not a mission requirement).

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