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.
HyspIRI’s VSWIR swath (cyan), nested within TIR swath (red)
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.

25 March 2009 11:21:30 UTC

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

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

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.

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).

Annual TIR imaging opportunities in a 19/5-day repeat HyspIRI reference orbit
Swath: 50.92°, symmetric about nadir. Sampled using a 1 by 1 deg. coverage.

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).

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).
Annual VSWIR Imaging Opportunities by Latitude in a 19-day repeat HyspIRI Reference Orbit
Swath: 13.62°, pointed 4° off-nadir; Local solar elevation angles > 20°; 56 km sample spacing
(Hi-res sampling was a 90-by-90 degree region, sampled at 1/8 degree.)

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).
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).

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

**US-Brw: Moist Tundra, Barrow, Alaska (71.32 N)**

**CA-Ca1: Campbell River, Maturing Douglas-fir, British Columbia, Canada (49.87 N)**

**US-SO2: Sky Oaks Old Stand, Chaparral regrowing from 2003 fire, California (33.37 N)**

**CR-Sro: Santa Rosa, Mosaic of pasture & secondary forest, Costa Rica (10.81 N)**

**BR-Sa1: Santarem km 67 (LBA), Primary forest, Brazil (2.86 S)**
VSWIR accesses for 1 simulated year

US-Bar: Bartlett Experimental Forest, Deciduous broadleaf, New Hampshire (44.06 N)

US-SP1: Sao Paulo Cerrado, Savannah vegetation, Brazil (21.62 S)

AR-Lac: La Ciguena Santa Fe, Croplands, Argentina (29.26 S)

AU-Tum: Tumbarumba, Wet temperate sclerophyll forest, Australia (35.66 S)

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.

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°

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.

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

<table>
<thead>
<tr>
<th>Flux Site</th>
<th>Latitude</th>
<th>Mean SZA</th>
<th>Std. Dev.</th>
<th>n</th>
<th>Mean SZA</th>
<th>Std. Dev.</th>
<th>n</th>
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</thead>
<tbody>
<tr>
<td>US-Brw</td>
<td>71.3 N</td>
<td>56.0</td>
<td>6.9</td>
<td>38</td>
<td>70.5</td>
<td>14.1</td>
<td>322</td>
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<td>CA-Ca1</td>
<td>49.9 N</td>
<td>46.7</td>
<td>14.3</td>
<td>32</td>
<td>50.9</td>
<td>16.1</td>
<td>135</td>
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<tr>
<td>US-Bar</td>
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<td>46.0</td>
<td>16.0</td>
<td>38</td>
<td>47.3</td>
<td>16.0</td>
<td>104</td>
</tr>
<tr>
<td>US-SO2</td>
<td>33.4 N</td>
<td>37.8</td>
<td>14.7</td>
<td>38</td>
<td>37.5</td>
<td>14.6</td>
<td>96</td>
</tr>
<tr>
<td>CR-Sro</td>
<td>10.8 N</td>
<td>28.1</td>
<td>6.9</td>
<td>19</td>
<td>27.6</td>
<td>6.9</td>
<td>77</td>
</tr>
<tr>
<td>BR-Sa1</td>
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<td>28.3</td>
<td>4.3</td>
<td>19</td>
<td>27.8</td>
<td>4.4</td>
<td>77</td>
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<tr>
<td>BR-Sp1</td>
<td>21.6 S</td>
<td>35.9</td>
<td>10.6</td>
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<td>35.5</td>
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<td>AR-Lac</td>
<td>29.3 S</td>
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<td>12.8</td>
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<td>12.7</td>
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<tr>
<td>AU-Tum</td>
<td>35.7 S</td>
<td>45.7</td>
<td>13.8</td>
<td>38</td>
<td>45.4</td>
<td>13.8</td>
<td>95</td>
</tr>
</tbody>
</table>
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.
TIR accesses for 1 simulated year

BR-Sa1, Primary Forest tower, Santarem, Brazil (2.86 S)

US-Skr, Mangrove tower, Shark River Slough, Florida (25.36 N)

US-ARM, main tower, ARM-SGP, Croplands, Oklahoma (36.61 N)

CA-Obs, SSA Old Black Spruce, Saskatchewan, Canada (53.99 N)

US-Brw, Moist tundra flux site, Barrow, Alaska (71.32 N)
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).

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).