Geocorrection of HICO data

Marcos Montes (Naval Research Laboratory)

HICO Users Group

Contributors

Parts of this work were made possible by:

- Tae Lim (formerly NRL Code 8231)
- William Snyder (formerly NRL Code 7231)
- Dan Korwan (NRL Code 7234)
- Susan Gomez (NASA Johnson Space Center)
- Jeff Bowles (NRL Code 7231)
- Gia Lamela (NRL Code 7231)
- Jasmine Nahorniak (OSU/COAS)
- Joe Rhea (NRL Code 7234)
- NASA for continued funding

Bottom Line Up Front

- Two geometric files available
  - The only good one is *LonLatViewAngles.bil
    - Created at NASA, is a part of HDF file
    - Good version includes ODRC time offset in calculations
    - Don't use*_rad_geom.bil unless it is the only one available – much larger errors
- For *LonLatViewAngles.bil (w/ODRC offset)
  - Uncertainties are limited by ISS attitude knowledge at HICO of $\lesssim 1°$/axis (3σ)
  - Users will need to manually adjust to obtain better geocorrection

Recipe for geocorrection

- Position: ISS data stream with GPS position
  - Where is the sensor?
  - Changes with time
- Attitude: ISS data stream with GPS-derived attitude
  - How is the sensor (ISS/HICO) oriented in space?
  - Changes with time (oscillations about the TEA)
- Time
  - What time is it when the line of data is obtained?
  - How is sensor time determined? How does it relate to GPS time?
- Position of each pixel of HICO in the sensor frame
  - Measured in laboratory
  - Does not change with time
  - Well understood, no need to discuss here

Position

- Measured by USGNC system
  - ISS GPS Position
  - In Health & Status 1 Hz data stream
  - Available as ECI position
  - Not correcting for position difference between ISS and HICO, but this is $\ll 1$ pixel

Attitude

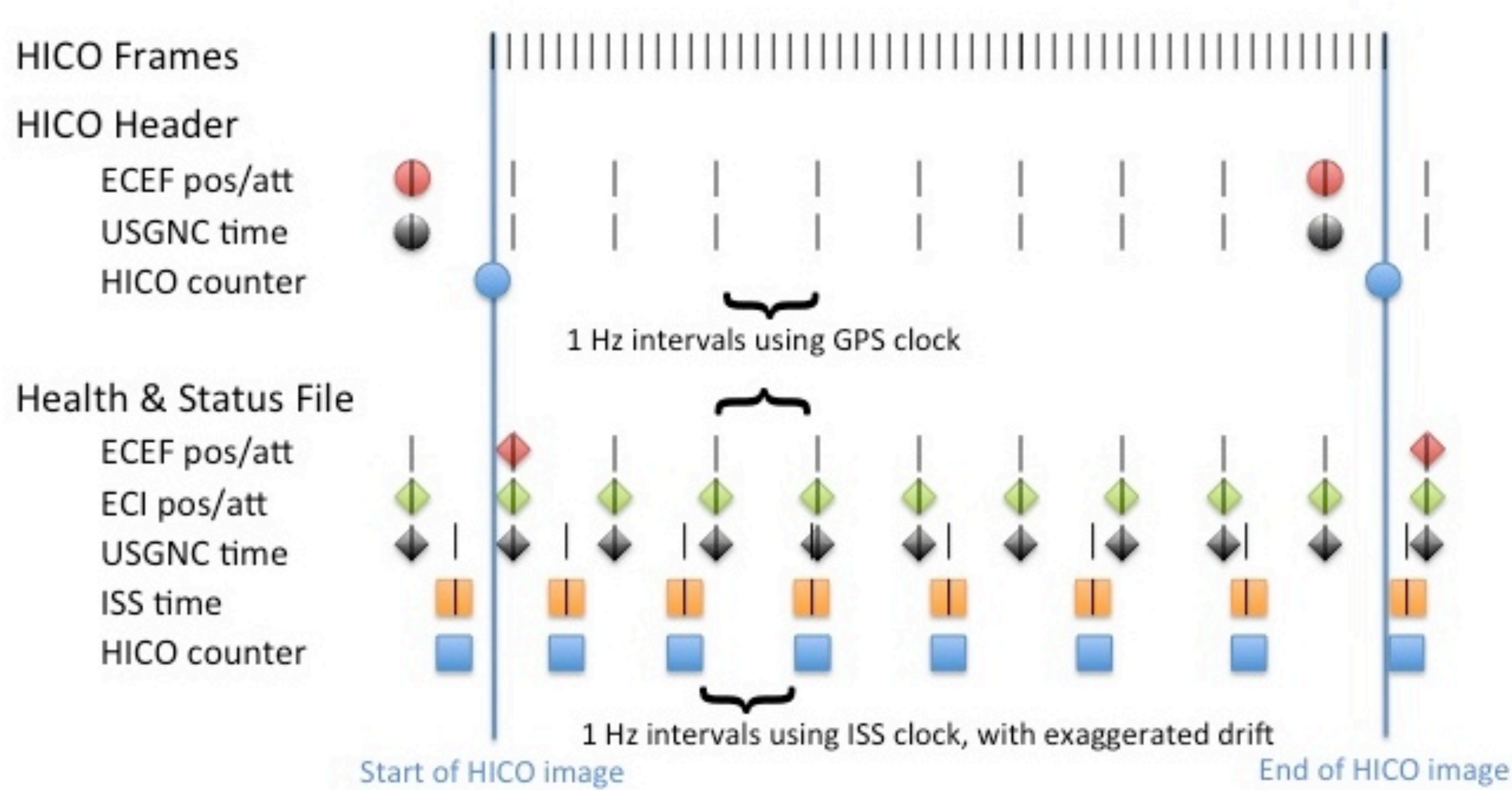
- Star Tracker
  - Not used due to data issues
  - Even if we used it, there would be many times when it wasn't available due to sun or glints in FoV
- ISS Attitudes
  - Determined from GPS array
  - Attitude knowledge at S0 truss $\lesssim$ 0.25° /axis (3σ)
    - Elsewhere $\lesssim$ 1° /axis (3σ) (Flexing, etc.)
    - Source: Susan Gomez (Memorandum, Nov. 19, 2010)
  - ISS ECI attitude quaternions available at 1 Hz
- HICO pixel subtends ≈0.013° = 0.22mrad
  - Uncertainty even at S0 truss is ~20 pixels

Time

- ISS Attitude and Position
  - 1 Hz USGNC records are tagged with GPS time
- HICO Sensor
  - Latched counter available at first and last frame
  - Associated Broadcast Ancillary Data time is also recorded
  - Time for each frame calculated using known frame time interval (13.7 ms) offset from initial frame time
- Health & Status file
  - Record of HICO counter and Broadcast Ancillary Data time at 1 Hz
  - Broadcast Ancillary Data time is not GPS time
    - Varies by ±1s from GPS time, the ODRC Time Offset
    - Currently value is available in real time
    - Previously, needed to obtain it by accessing NASA computers
    - New method of availability, but not automated yet at NRL

- Need to interpolate ISS Attitude and Position to HICO sensor times

Relations Between Data Streams



This is just an example: there are really 2000 lines of data in about 27.5 seconds.

Boresight offsets

- Need to account for slight mounting offsets between HICO frame and ISS frame
- Determine ground control points for several data sets, and use the group to determine a “best” parameter set
  - Find features in image (pixel coordinates) and obtain true position (latitude, longitude) from a trusted map

Bore sight results

(HICO pixel subtends ~0.013° ~0.22mrad)

	1689 (CCNY)	2042 (E Falkland)	2170 (Con. CL)	3797 (E. Falkland)	2881 (Han R)	2141 (SB Channel)	3079 (Bahrain)
date	20100118	20100227	20100315	20100826	20101527	20100311	20100615
Lat	40° 49' 9.623"	-51° 53' 17.997"	-36° 36' 2.357"	-51° 53' 46.369"	37° 44' 42.916"	34° 8' 41.535"	26° 18' 27.951"
Long	-73° 44' 31.051	-58° 37' 58.029"	-72° 50' 37.033"	-58° 59' 34.406"	125° 49' 1.946"	-119° 45' 45.978"	50° 33' 45.783"
Angle (°)	57.7	67.9	21.8	88.6	64.9	71.7	57.6
Orient	+XVV	+XVV	+XVV	+XVV	+XVV	+XVV	+XVV
direct	ascend	ascend	ascend	ascend	descen	ascend	descen
Alt (km)	345	365	361	367	352	345	361
D_thx(°)	-0.8901	-0.9957	-1.0030	-1.0067	-0.9139	-1.2067	-0.8039
D_thy(°)	-0.1132	0.0268	0.0149	0.0349	-0.0701	-0.1008	-1.9442
D_thz(°)	0.0063	-0.0128	0.0966	-0.1821	-0.2211	0.1090	1.7290
RMS (m)	66	61	72	98	192	2744	5808

Boresight Bootstrap Results

(HICO pixel subtends ~0.013° ~0.22mrad)

1689 Units are degrees

	L99.7	L95.4	L68.3	**MEDIAN**	U68.3	U95.4	U99.7
θ_X offset	-0.894791	-0.893145	-0.891788	**-0.890253**	-0.888835	-0.887374	-0.886594
θ_Y offset	-0.122228	-0.119685	-0.115388	**-0.11215**	-0.109435	-0.107328	-0.103717
θ_Z offset	-0.22833	-0.132769	-0.055151	**0.023085**	0.083473	0.145064	0.240528

2042 Units are degrees

	L99.7	L95.4	L68.3	**MEDIAN**	U68.3	U95.4	U99.7
θ_X offset	-0.998893	-0.997919	-0.996601	**-0.995058**	-0.993414	-0.991801	-0.990034
θ_Y offset	0.020577	0.026159	0.031275	**0.035664**	0.040474	0.045286	0.050686
θ_Z offset	-0.178608	-0.140297	-0.104165	**-0.064913**	-0.029829	0.007816	0.042313

100000 bootstrap trials were run for each file, and a boresight parameter retrieval was made for each trial.

Given these two files, the results are not consistent. X & Y offsets are extremely inconsistent. These correspond to “roll-like” and “pitch-like” offsets, respectively.

Conclusions:

After checking code, timing, the lens file, GCP image coordinates, and GCP ground coordinates, the ISS attitude knowledge uncertainty at HICO is consistent with these results.

Boresight parameter selection

	Original Method: HICO Header				New Method: CCNY boresight correction		
	Errors in meters				Errors in meters		
Image	Along Track	Across Track	RMS		Along Track	Across Track	RMS
1	232	94	250		912	296	959
2	133	840	6643		0	0	0
3	6381	1240	6500		528	754	920
4	6307	1572	6500		588	51	590
5	6700	0	6700		622	580	850
Mean	3950	749	4160		530	336	664
St Dev	3443	692	3303		331	328	398

For these 5 scenes, the CCNY boresight parameter selection produces a mean error of ~7 pixels, consistent with NASA estimates of attitude knowledge at HICO.

Bringing it all together

- Obtain sequence of HICO frame times
  - Interpolate initial counter to Broadcast Time
  - Add frame intervals
  - Add current ODRC time offset to obtain corrected HICO frame times
- Interpolate ECI positions and attitudes to HICO times
- Calculate ECI to ECEF rotation matrix as a function of time (position and attitude)
- Calculate HICO to ISS/ECI rotation matrix (attitude)
  - Include estimate of boresight parameters
- Use ECEF position and attitude to shoot a ray to the WGS-84 surface
- Calculate latitude and longitude from ECEF intercept

Current calculations

- Implemented in Fortran 2003
  - ECI to ECEF calculations use Vallado's subroutines
  - Portions come from Tafkaa library (solar calculations and header preparation)
  - Translations from IDL of earlier HICO code for quaternions and other rotation/geometry calculations
  - Runs quickly, does not crash
- Running at NASA
  - Initial NASA GSFC calculations do not include ODRC time offset
  - When NASA GSFC receives ODRC offset from NRL, recalculated
  - Distributed in HDF5 files
  - Includes latitude, longitude, view zenith, view azimuth, solar zenith, and solar azimuth angles

Conclusion

- Positions for HICO images are available
  - Knowledge of ISS attitude at HICO limits ability to provide better pixel coordinates
  - Attitude uncertainty may lead to ground position uncertainty of hundreds of meters to several kilometers
  - In general, simple translations should suffice to re-align the images to the ground
  - Positions in the *LonLatViewAngles.bil files are better than positions in the *_rad_geom.bil files.

Backups

HICO Data Flow: Collection to Distribution

HICO/ISS

NASA/HOSC

NRL-DC/POCC
HREP Server

NRL-DC/RSD
HICO Server

Level 0 + scene metadata + health & status
Merge retransmits (dropped packets)
Dark correction
Smear correction
Second order correction
Apply calibrations w/ vicarious adjustments
Basic QC: zero invalid values
Level 1B: calibrated radiances, RGB, NDVI, flags, geolocation*, JPEG

*NRL: initially crude based on L0 header then replaced with more refined when ISS time offset value available
NASA: initially more refined algorithm with 0 ISS time offset then reprocessed with actual ISS time offset when available

NASA/GSFC
L0+meta+H&S
Process to L1B
Oceancolor web

OSU
Tar of ENVI L1B files
Distribute to registered users

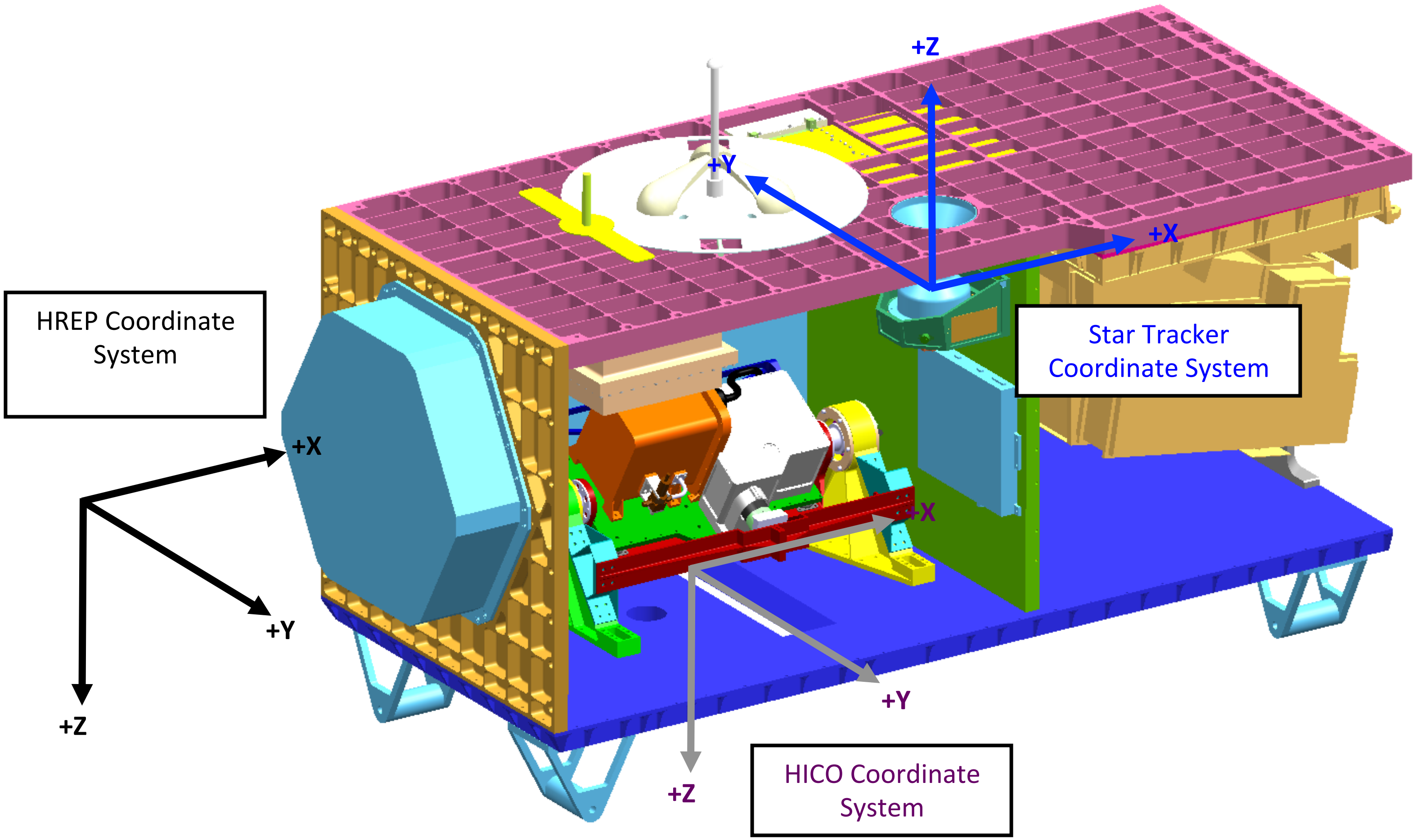
NRL-Stennis
HDF5 L1B files
APS processing

NRL-DC/RSD
Additional diagnostics
Archive L0 & L1B
Backup L0+meta+H&S

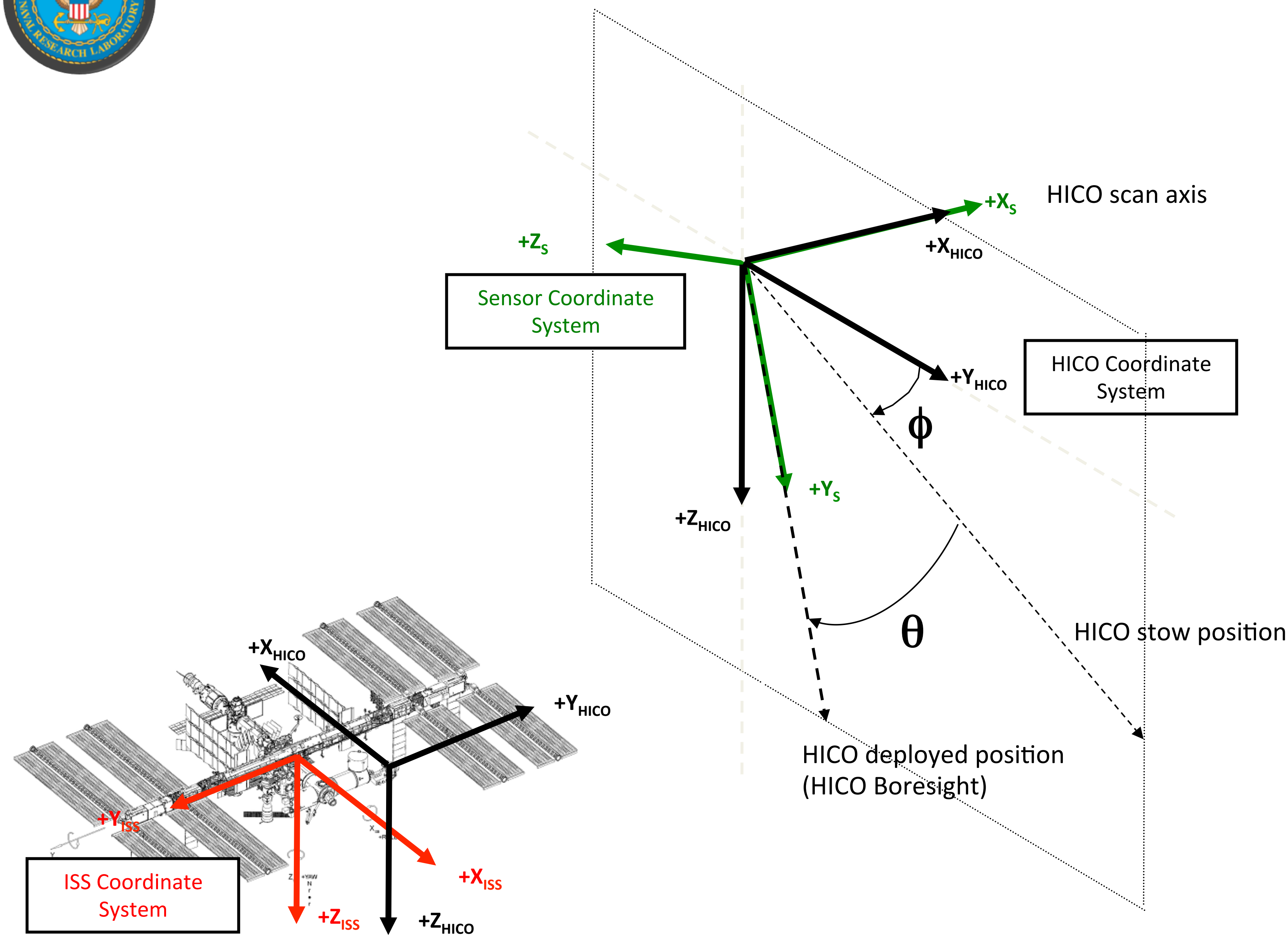
Green items are automated on NRL-DC HICO server

HICO Times

- Interpolate start counter value with 1 Hz sequence of Counter Values, ISS Time to get HICO start time in ISS Time frame
- Add ODRC offset to get HICO start time in GPS frame
- For each line, add frame time increment
- At this point, each line number is assocaited with a GPS time
  - This is used to interpolate the 1 Hz attitudes and positions in order to obtain values at each HICO frame time.

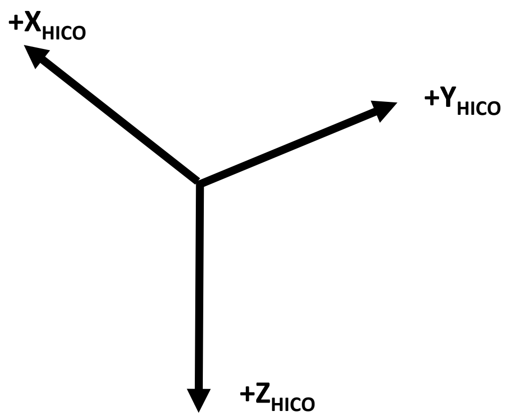

+Z
+Y
+X
Star Tracker Coordinate System
HREP Coordinate System
+X
+Y
+Z
+X
+Y
+Z
HICO Coordinate System

Definition of ISS, HICO, and Sensor Coordinates



Coordinate Transformations Among ISS, HICO, and Sensor Coordinates (1 of 2)

HICO Coordinate System



ISS to HICO

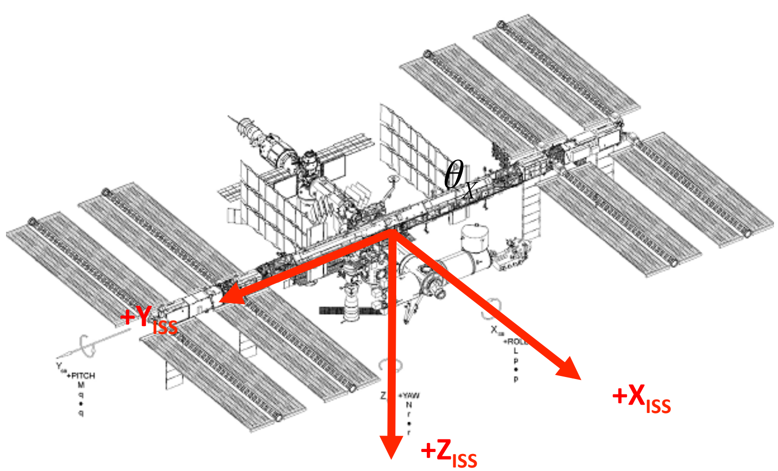
$$\begin{Bmatrix} X_{HICO} \\ Y_{HICO} \\ Z_{HICO} \end{Bmatrix} = \begin{bmatrix} 1 & \theta_z & -\theta_Y \\ -\theta_z & 1 & \theta_X \\ \theta_Y & -\theta_X & 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} X_{ISS} \\ Y_{ISS} \\ Z_{ISS} \end{Bmatrix}$$

or

$$\begin{Bmatrix} X_{HICO} \\ Y_{HICO} \\ Z_{HICO} \end{Bmatrix} = \begin{bmatrix} -1 & -\theta_z & -\theta_Y \\ \theta_z & -1 & \theta_X \\ -\theta_Y & \theta_X & 1 \end{bmatrix} \begin{Bmatrix} X_{ISS} \\ Y_{ISS} \\ Z_{ISS} \end{Bmatrix} = {}^{HICO}C_{ISS} \begin{Bmatrix} X_{ISS} \\ Y_{ISS} \\ Z_{ISS} \end{Bmatrix}$$

Where $\theta_X, \theta_Y, \theta_z$ represent small angle misalignment between the Nominal HICO Coordinates and Actual HICO Coordinates about X, Y, Z axis, respectively.

ISS Coordinate System



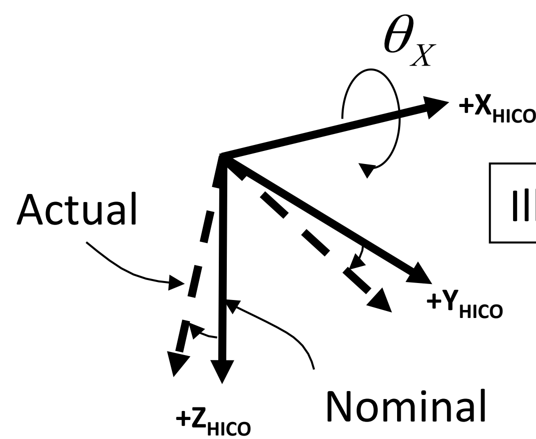
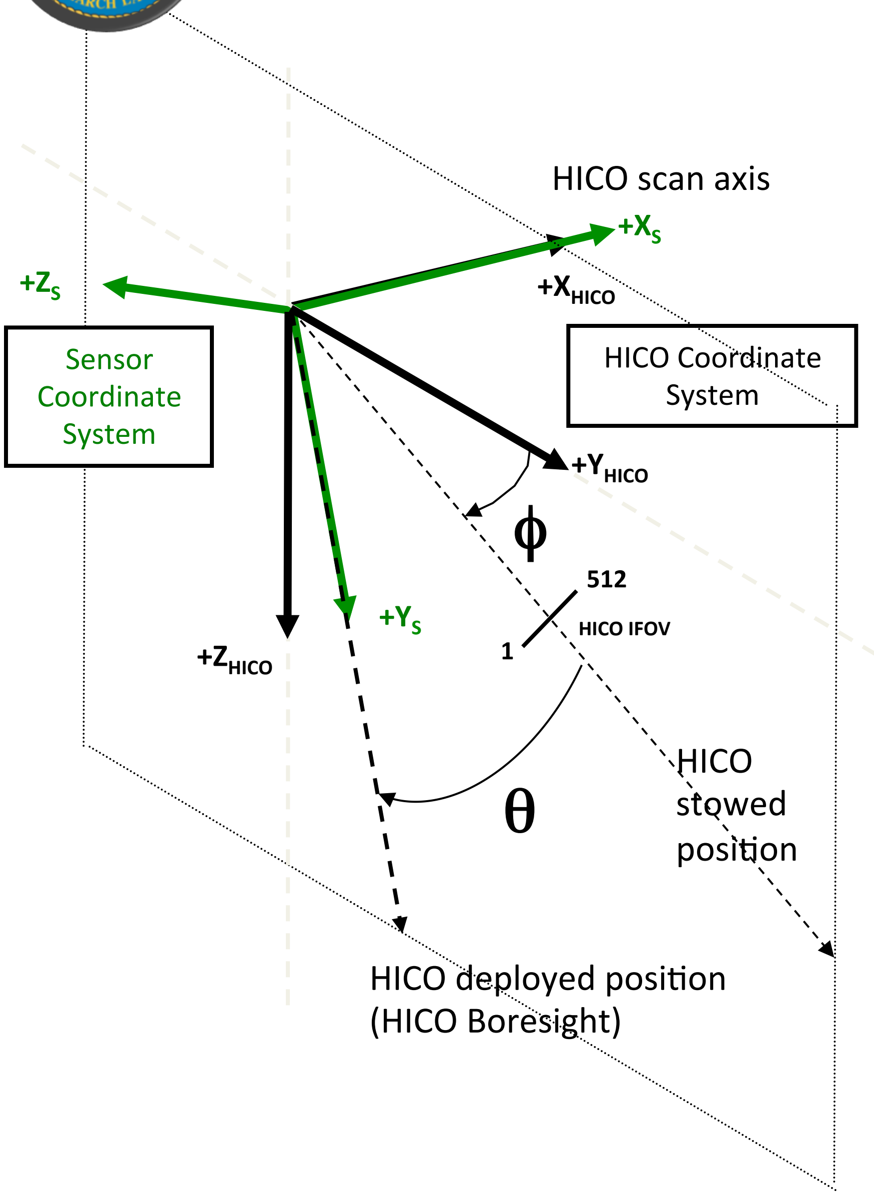


Illustration of θ_X

Coordinate Transformations Among ISS, HICO, and Sensor Coordinates (2 of 2)



HICO to Sensor (i.e., HICO Deployed)

$$\begin{Bmatrix} X_S \\ Y_S \\ Z_S \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Delta & \sin\Delta \\ 0 & -\sin\Delta & \cos\Delta \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{Bmatrix} X_{HICO} \\ Y_{HICO} \\ Z_{HICO} \end{Bmatrix}$$

$$\begin{Bmatrix} X_S \\ Y_S \\ Z_S \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Delta\cos\phi - \sin\Delta\sin\phi & \cos\Delta\sin\phi + \sin\Delta\cos\phi \\ 0 & -\sin\Delta\cos\phi - \cos\Delta\sin\phi & -\sin\Delta\sin\phi + \cos\Delta\cos\phi \end{bmatrix} \begin{Bmatrix} X_{HICO} \\ Y_{HICO} \\ Z_{HICO} \end{Bmatrix}$$

$$\begin{Bmatrix} X_S \\ Y_S \\ Z_S \end{Bmatrix} = {}^{S}C_{HICO} \begin{Bmatrix} X_{HICO} \\ Y_{HICO} \\ Z_{HICO} \end{Bmatrix}$$

Where ϕ represents stowed angle and $\Delta = \theta + \delta_{PIXEL}$, with θ and δ_{PIXEL} represent the HICO deployment angle from the stowed position and the angle to the pixel location from the center of the HICO FOV, respectively.

Assuming the HICO boresight is positioned at the center of the sensor 512 pixel CCD array, then

$$\delta_{PIXEL} = -3.487 \times f(p) + 0.035 \times f(p)^3 \text{ degrees,}$$

where $f(p) = (p - 256.5)/255.5$, and $1 \leq p \leq 512$ (see figure).

Sensor Attitude Determination

ISS ECI quaternion is converted to Direction Cosine Matrix (C) :

$$q_{ISS} \Rightarrow {}^{ECI}C_{ISS}$$

Sensor coordinate to ECI coordinate transformation

Function of cross-track index

ISS-HICO alignment

$$\begin{Bmatrix} X_{ECI} \\ Y_{ECI} \\ Z_{ECI} \end{Bmatrix} = {}^{ECI}C_{ISS}\,{}^{ISS}C_{HICO}\,{}^{HICO}C_{S} \begin{Bmatrix} X_{S} \\ Y_{S} \\ Z_{S} \end{Bmatrix} = {}^{ECI}C_{S} \begin{Bmatrix} X_{S} \\ Y_{S} \\ Z_{S} \end{Bmatrix}$$

ISS attitude quaternion (function of line number)

HICO deployment angle

ECI to ECF Transformation

Position or attitude vector in ECF

Position or attitude vector in ECI (function of line number)

$$\underline{r}_{ECF} = {}^{ECF}C_{TOD}\,{}^{TOD}C_{ECI}\,\underline{r}_{ECI} = {}^{ECF}C_{ECI}\,\underline{r}_{ECI}$$

Precession and Nutation (slow function of time)

Sidereal Time (GMST) to UTC (includes leap seconds) (function of line number)

Unneeded calculations

- Quantities we can ignore
  - Aberration of light:
    - Pixel size is too big to worry about this effect (~1/8 of a pixel)
  - Atmospheric refraction
    - Not big enough to consider at our view angles
  - Polar motion
    - Easy to include, but effect is only few meters
  - Earth and Ocean Tides displacement
    - Sub-meter