17. On-Orbit Mission Operations

The GOES-NOP spacecraft are designed for a 10 year on-orbit lifetime: 8 years of in-service environmental data collection, and up to 2 years of on-orbit storage. When in-service, on-orbit operations consist of daily (routine) and periodic operations, both of which are planned in advance and executed as per the operations schedule. Routine operations driven by the on-board schedule include instrument commanding and one housekeeping period (for clock adjustments and momentum dumping) with the spacecraft on-board systems controlling the spacecraft attitude, systems monitoring, and maintaining general operations and health monitoring. Periodic operations entail infrequent events such as stationkeeping, space environment monitoring (SEM), X-ray sensor/extreme ultra violet (XRS/EUV) instruments, Solar X-ray Imager (SXI), precision sun sensor (PSS), and magnetometer instrument calibrations; eclipse operations, yaw flip (if necessary), and station relocation, which occur over the spacecraft's life.

Typical Daily Operations

Daily operations for the Imager and the Sounder are structured to primarily satisfy the meteorological needs of the NOAA National Weather Service. Figures 17-1 and 17-2 show typical daily schedules for the two operational spacecraft which support these needs – actual event times may vary.

Operational scenarios for the Imager and Sounder also must comply with spacecraft state-of-health requirements and operational constraints. The initial, "Day l" operational scenarios feature one of three modes for the Imager: routine, rapid, and super-rapid scan. The Sounder has three modes that operate concurrently with the three Imager modes. The mode being used at any given time is related to the severity of the meteorological activity being observed.

Full Disk Scenario

The Imager full disk scenario consists of a full disk scan of the earth followed by star looks and a blackbody calibration. This sequence is repeated every half-hour. The full disk scan is changed to an extended northern hemisphere scan once every 6 hours. This allows sufficient time to perform the 10 minute spacecraft housekeeping activities.

The corresponding Sounder operations follow a summer scenario (June to November) or winter scenario (December to May) schedule. This schedule is 6 hours long and repeats itself immediately upon completion. The schedule starts with a full regional northern hemisphere sounding repeated three times at 1 hour intervals. Then, a full regional southern hemisphere sounding (winter mode) or a limited regional sounding and a mesoscale sounding (summer mode) is conducted followed by a limited regional sounding. Spacecraft housekeeping activities complete the 6 hour schedule. The soundings are interrupted for star looks each half-hour and for blackbody calibrations.

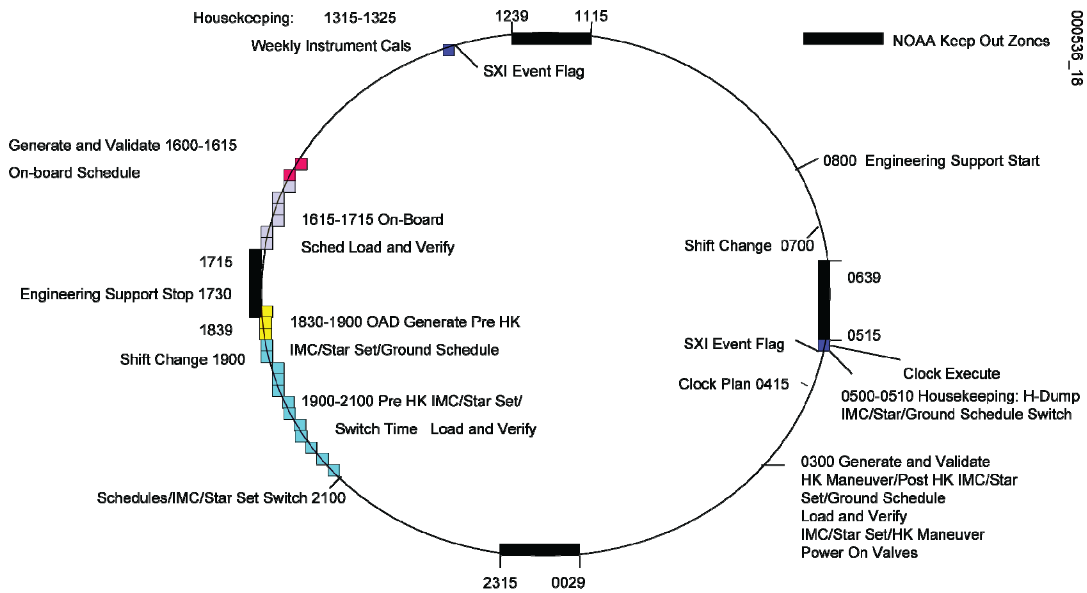

Figure 17-1. GOES-East Daily Timeline (SLT)

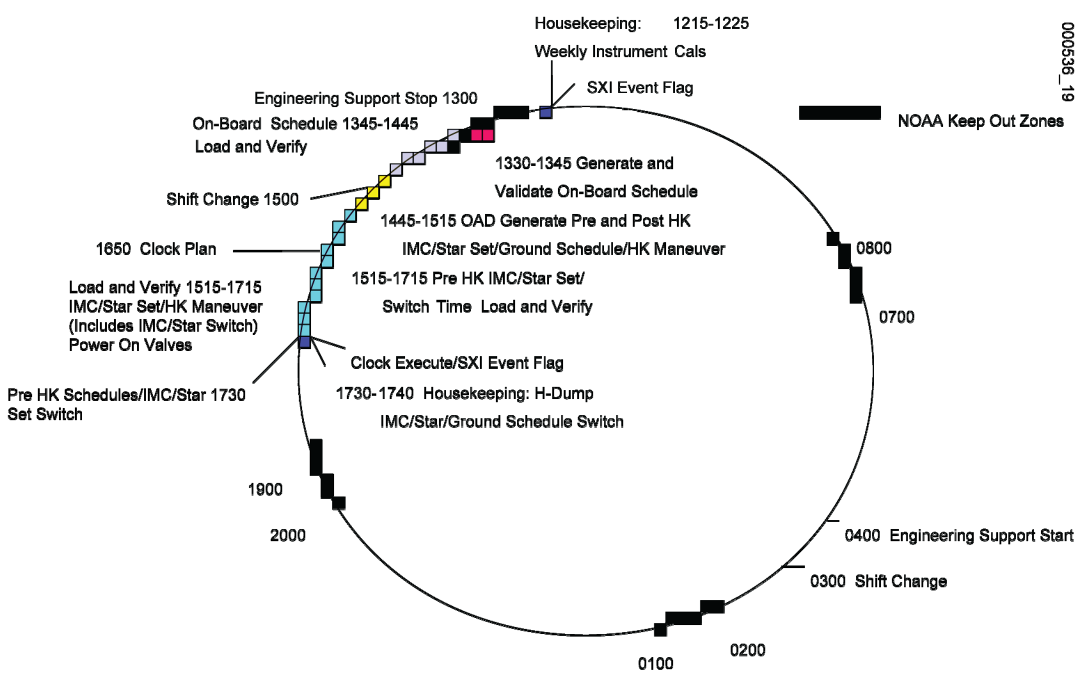

Figure 17-2. GOES-West Daily Timeline (SLT)

Routine Mode

The Imager routine mode is a 3 hour sequence that repeats itself immediately upon completion. The sequence begins with a full disk scan, followed by the half-hour sequence of an extended northern hemisphere scan, a continental U.S. (CONUS) scan, and a southern hemisphere-south scan. This sequence is repeated five times. The last southern hemisphere-south scan is omitted every 6 hours to allow for spacecraft housekeeping. Star looks and blackbody calibrations are performed every half-hour.

The Sounder performs the same summer mode or winter mode schedule as the Imager full disk mode.

Rapid Scan Mode

This mode modifies the routine mode in order to focus on providing additional 1 minute duration sectors of severe storm regions.

The Sounder warning mode is performed in conjunction with the Imager rapid scan mode. This is a 6 hour sequence that repeats itself immediately upon completion. The schedule starts with a limited regional sounding then nine repeated mesoscale soundings. Then another limited regional sounding is performed, followed by eight mesoscale soundings and spacecraft housekeeping activities. The soundings are interrupted for star looks each half-hour and for blackbody calibrations.

Super Rapid Scan Mode

The Imager super rapid scan operation (SRSO) is a special schedule requested by the research community under the auspices of the NWS to study weather phenomena. The SRSO schedule is currently limited to one 6 hour period of the day and is activated on the spacecraft within one to two hours of the NWS request. The SRSO is a 6-hour schedule that combines northern hemisphere and 1-minute frames with a full disk frame every three hours and normal sounder frames. The 1-minute frames cover an area approximately 1500 km by 1500 km, and are repeated eight or nine times during a 30-minute period. Upon receipt of the SRSO request, the GOES scheduler enters the frame latitude and longitude center point and sends the schedule to OATS for conversion of the frame coordinates to instrument coordinates. The updated schedule is then uplinked to the spacecraft and activated when appropriate.

Scan Sector Boundaries and Durations

The typical Imager and Sounder scan sector boundaries and scan durations are for the operational scenarios described above (Tables 17-1 through 17-4). The boundaries assume that the GOES East satellite subpoint will be located at 75° West longitude.

Imager/Sounder

Imaging and sounding are performed at predefined scan coordinates. When scan frame coordinates are required, the GOES telemetry and command system (GTACS) requests the orbit and attitude tracking system (OATS) to provide scan frame conversion from scan lines and pixel number (or longitude and latitude) to cycles and increments for use by the Imager and Sounder. GTACS also specifies the stepping mode of the Imager and Sounder as part of the request. In response, OATS converts scan coordinates to cycles and increments for the Imager and Sounder and sends scan start and stop coordinates and scan start and stop times. These data are then used by GTACS in the command message to the Imager and Sounder.

Table 17-1. GOES East Imager Scan Sectors: Boundaries and Duration for Day 1 Scenarios (Subsatellite Longitude: 75° West)

Frame Name	Boundaries (Latitude/Longitude)			
	North	South	West	East
Full Disk	Earth edge			
Northern Hemisphere	60°N	0°N	112°W	30°W
Northern Hemisphere—Extended	65°N	20°S	112°W	30°W
Southern Hemisphere—South	20°S	55°S	116°W	23°W
CONUS	60°N	14°N	112°W	64°W
Southern Hemisphere—Small Sector	0°	20°S	100°W	80°W
Northern Hemisphere—North	65°N	14°N	113°W	30°W
Northern Hemisphere—South	14°N	0°	113°W	30°W
Northern Hemisphere—Storm Sector	48°N	30°N	98°W	76°W
Southern Hemisphere—Abbreviated	0°	20°S	113°W	65°W

Table 17–2. GOES East Imager Scan Sectors Timing Scenario

Mode	Half-hour	Sector	Start Time	Duration, min
Full Disk	1-11	Full Disk	00:00:00	26:16
	12	Northern Hemisphere—Extended	00:00:00	14:19
Routine	1, 7	Full Disk	00:00:00	26:16
	2-6, 8-11	Northern Hemisphere—Extended	00:00:00	14:19
		CONUS	00:15:00	4:45
		Southern Hemisphere—South	00:23:00	5:37
	12	Northern Hemisphere	00:00:00	9:52
		CONUS	00:15:00	4:45
Rapid Scan	1,7	Full Disk	00:00:00	26:16
	2-6, 8-11	Northern Hemisphere	00:00:00	9:52
		CONUS	00:10:06	4:45
		Southern Hemisphere—Small Sector	00:15:05	1:51
		CONUS	00:17:11	4:45
		CONUS	00:25:00	4:45
	12	Northern Hemisphere	00:00:00	9:52
		CONUS	00:10:06	4:45
		Southern Hemisphere—Small Sector	00:15:05	1:51

The sector scan start times are referenced at the start of each half-hour. The last 10 minutes of half-hour #12 are reserved for spacecraft housekeeping activities.

Table 17-3. GOES East Sounder Scan Sectors: Boundaries and Duration for Day 1 Scenarios (Subsatellite Longitude: 75° West)

Frame Name	Boundaries (Latitude/Longitude)				Scan Duration, min
	North	South	West	East	
Full Regional—Northern Hemisphere	51.5°N	23.3°N	120°W	63.6°W	52.1
Full Regional—Southern Hemisphere	20°S	50°S	130°W	75°W	52.0
Limited Regional	50°N	26°N	118°W	66°W	39.8
Mesoscale—CONUS	43.6°N	26.8°N	106.2°W	87.9°W	12.2
Mesoscale—Tropics	24.7°N	15.0°N	70.2°W	44.5°W	12.1

Table 17–4. GOES East Sounder Scan Sectors Timing Scenario

Mode	Hour	Sector	Start Time	Duration, min
Summer	1-4	Full Regional—Northern Hemisphere	00:05:00	52:06
(June- November)	5	Limited Regional	00:05:00	39:48
		Mesoscale—Tropics	00:50:00	12:06
Winter	1-4	Full Regional— Northern Hemisphere	00:05:00	52:06
(December – May)	5	Full Regional— Southern Hemisphere	00:05:00	52:00
	6	Limited Regional— Southern Hemisphere	00:05:00	39:48
Warning	1, 4	Limited Regional	00:05:00	39:48
		Mesoscale	00:49:30	12:12
	2, 3, 5	Mesoscale	00:05:00	12:12
			00:20:00	
			00:35:00	
			00:49:30	
	6	Mesoscale	00:05:00	12:12
			00:20:00	
			00:35:00	

The sector scan start times are referenced at the start of each hour. The last 10 minutes of hour #6 are reserved for spacecraft housekeeping activities.

For its daily schedule, GTACS requests from OATS star sense command parameters of a specified duration. OATS responds with star sense coordinates in cycles and increments, dwell times, and look start time for each instrument. Start time is the time at which the pulse command, star-sense start is received at the instrument.

Spacecraft

The daily operational procedure for spacecraft subsystems are controlled by the attitude control electronics (ACE), which control the attitude, image motion compensation (IMC), and dynamic motion compensation (DMC) in support of instrument operations. It also controls bus systems monitoring via parameter checking. Attitude determination is achieved through the use of stellar inertial attitude determination (SIAD), which uses two of three star trackers. These star trackers, along with the hemispherical inertial reference unit (HIRU) continuously supply data to the ACE for attitude calculations. Attitude control is supplied by four reaction wheels, with thrusters being used for momentum dumping and delta velocity operations (stationkeeping, station change, deorbit). Up to two 10 minute housekeeping opportunities occur daily, one of which is used for momentum dumping and on-board clock adjustments and the other for the weekly instrument and PSS calibrations. Other activities can be placed into the second housekeeping period as needed for east-west stationkeeping. The momentum dumping is planned to occur at an SLT which does not disturb the frequency of east-west stationkeeping maneuvers. Other spacecraft activities that do not affect image navigation and registration (INR) operations are planned as necessary for spacecraft maintenance and include battery bias calibrations during eclipse season, magnetometer internal calibrations, and SEM calibrations not involving pointing changes.

Space Environment Monitor and Sun Pointed Instruments

The SEM is on and operational once the spacecraft reaches station. Sun pointed instruments are activated and calibrated after the solar array and instrument mounting platform (IMP) are deployed. Sun pointing for the solar array and all sun pointed instruments is maintained by the ACE using PSS inputs.

Image Navigation and Registration

To support INR, a parent image motion compensation (IMC) coefficient set and star set are generated every day and uploaded to the spacecraft. These are included along with the daily schedule uplink, and a new set is generated and uplinked for eclipse operations before any orbit perturbing maneuver (momentum dumps, east-west stationkeeping). OATS provides GTACS with the new IMC coefficient data set to be uploaded approximately 2 hours before the planned upload to the spacecraft. IMC operation for GOES East and GOES West is performed separately.

Periodic Operations

Periodic operations are infrequent but recurring events that are scheduled periodically through the spacecraft's on-orbit lifetime (Figure 17-3). These operations can be inserted into the daily operations schedule as needed and performed during one of the housekeeping intervals, the other scheduled functions being altered accordingly. Major periodic operations are:

- East-west stationkeeping (EWSK)
- North-south stationkeeping (NSSK)
- SEM and sun pointed instrument calibration
- Sun/moon intrusion
- Station relocation
- Eclipse operations
- Yaw flip
- On-board star catalog (OSC) update
- Leap second adjustments

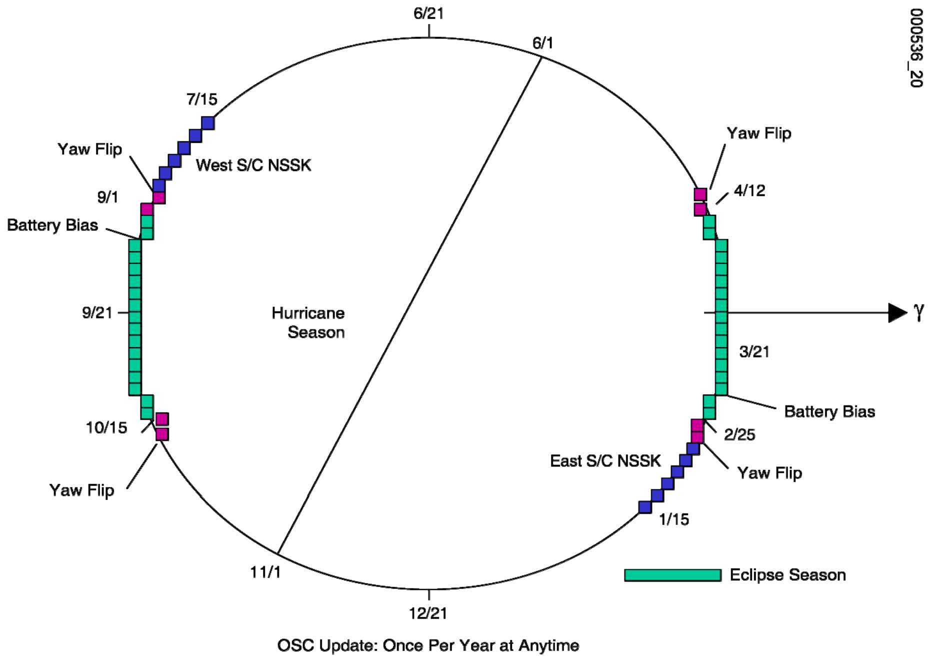

Figure 17-3. Yearly Operations

East-West Stationkeeping

East-West stationkeeping is required once every 2 to 4 months to counteract the effects of earth's triaxiality on spacecraft drift and solar radiation pressure on orbital eccentricity. The maneuver strategy is to start the stationkeeping cycle with the spacecraft at one edge of the longitude deadband (±0.5°), drifting across the deadband with negative perturbing acceleration. With an initial drift rate of just the right magnitude, the spacecraft drifts to the desired longitude, where an EWSK maneuver is applied to reverse the spacecraft drift and keep it within the deadband at the assigned station longitude (either 75° or 135° West). OATS software performs the necessary calculation for determining when to perform the maneuver and the corresponding command data for thruster selection and required duration. An east-west stationkeeping maneuver will be planned prior to entering eclipse season to avoid having to perform a thruster maneuver during eclipse season. East-west stationkeeping maneuvers will be performed during a second housekeeping period, with full INR operations recovery at the end of the housekeeping period.

North-South Stationkeeping

Once a year, a north-south stationkeeping maneuver is required to counteract the gravitational forces exerted by the sun and moon on the spacecraft. The maneuver strategy is to start the stationkeeping cycle with the spacecraft at one edge of the inclination deadband (±0.5° of the equator) at the optimum node, allowing it to drift to zero inclination and then back to 0.5°. The maneuver is again performed to bring the spacecraft back to the beginning of the deadband (optimum node). This minimizes the velocity increment required and, hence, propellant used. OATS software performs the calculation for determining when to perform the maneuver and the corresponding command data.

The time period to perform the north-south stationkeeping maneuver is at solstice ±30 days. This allows for at least 6 hours of lit earth observations following the maneuver while maintaining spacecraft requirements for solar array stay out zones for north thruster firings. It is recommended that one GOES (East or West) spacecraft north-south stationkeeping maneuver be performed in winter and the other spacecraft's maneuver be performed in the summer to eliminate schedule congestion and to ensure at least one fully operational spacecraft is available at all times.

SEM and Sun Pointed Instrument Calibration

The operation of the SEM and sun pointed instruments involve weekly in-flight calibrations of the magnetometer, XRS/EUV, SXI, and EPS/HEPAD. The magnetometer and EPS/HEPAD calibrations do not affect INR operations and can be performed at any time. XRS/EUV and SXI calibrations require the offset pointing of either the solar array or IMP from the sun and are scheduled to occur during a second housekeeping period. The XRS/EUV calibration is combined with the spacecraft PSS weekly calibration, which also requires offset pointing the solar array or IMP.

The XRS/EUV requires offset pointing from the sun, which includes the PSS requirement of a short span offset.

The SXI requires an offset, which will be performed separately from the XRS/EUV and PSS calibration in order to ensure INR recovery following that calibration.

An in-flight calibration of the EPS/HEPAD is initiated by ground command to verify proper operation of the instrument and to adjust the photomultiplier tube high voltage for optimum performance. Once calibration is initiated, the IFC circuitry provides a series of calibration signals to the dome, telescope, and HEPAD amplification channels. The calibration sequence is self-terminating.

Magnetometer Calibration

A non-recurring bias and alignment calibration is performed for the magnetometer during PLT. This calibration requires the spacecraft to execute a series of slews. During the maneuver, attitude and sensor data is collected. The data is processed offline with a batch least square estimator to yield magnetometer axes alignment and biases.

Sun/Moon Intrusion

The sun, and to a lesser extent the moon, periodically interferes with spacecraft operations, affecting the Imager and Sounder radiometric reference, and degrading the INR accuracy. The sun affects telecommunications between the spacecraft and ground. The sun and moon at low declination can interfere with the Imager and Sounder. For the sun, this occurs during the eclipse season centered on the equinoxes (22 March and 22 September). Moon intrusion can occur at any time during the year, especially during eclipse season when the moon is full or nearly full as it reaches low declinations. The sun is also expected to approach the command and data acquisition (CDA) antenna beam and degrade spacecraft communications during eclipse season.

Upon request from GTACS, OATS computes the orbital events and sensor intrusions given a future time span and provides the intrusion start and end times, the sensor(s) being impaired (Imager, Sounder), and the edge (east or west for the Imager and Sounder). With these data, the GTACS scheduler determines when operations of a particular sensor are impaired and formulates commands to switch operating modes to account for the interference. The space clamp (radiometric cold reference) is disabled for the Imager/Sounder on the side of the scan line that is experiencing interference.

Image Interaction Diagnostics

Several periodic operations relate to the INR process: dynamic interaction diagnostics, mirror motion compensation tuning, and image motion compensation calibration.

- *Dynamic Motion Compensation* (DMC) is provided to adjust for excessive interaction due to mechanical motion events (such as reaction wheel, solar array drive assembly, and Imager/Sounder mirror motion). Measurement data consist of three-axis angular displacement from the HIRU, Imager and Sounder servo errors, and discrete event information related to solar array drive assembly and X-ray platform

(XRP) motor stepping and Imager/Sounder mirror motion. The ACE continuously calculates DMC values and adds them to the IMC for INR pointing determination.

- *Image Motion Compensation Calibration*. A set of baseline in-flight IMC scale factors is established during initial on-orbit startup operations. This baseline, updated yearly, compensates for errors introduced by the digital/analog converters in the ACE. The updated baseline provides the best agreement between commanded IMC offsets and actual instrument line-of-sight offsets. IMC calibration can be performed at any time if imaging and sounding operations are suspended during the IMC calibration period and the instruments are specifically configured to support the calibration process. IMC calibration involves performing a series of star sightings with different IMC offsets as defined by OATS. The resulting Imager and Sounder wideband data are used by OATS to update the east-west and north-south compensation scale factors, which are then transmitted to the spacecraft via GTACS.

Station Relocation

The spacecraft is capable of at least nine station changes during its orbital lifetime:

- From checkout location to an on-orbit storage location
- From the on-orbit storage location to the operational station location
- Three changes of operational station location while maintaining INR specifications (≤1° shift/day)
- Two emergency relocations (≤3° shift/day)
- From operational station location to end-of-life longitude
- Boost from geosynchronous orbit to super synchronous altitude for deorbit

On-station longitude is changed by applying an incremental velocity, typically at an apse, to maintain eccentricity within acceptable limits and change the radius of the opposite apse. If the velocity increment is applied in the direction of motion, the orbit radius is increased and the spacecraft drifts westerly with respect to earth; if applied opposite to the direction of motion, orbit radius is decreased, and the spacecraft drifts easterly. When the desired on-station longitude is reached, an incremental velocity of equal magnitude, but opposite direction, is applied at the same apse as the first to arrest the drift. The total maneuver is essentially a pair of east-west stationkeeping maneuvers separated by a period for the spacecraft to drift to its new station. OATS software computes the maneuver sequences that place the spacecraft on a specified longitude at a specified time.

Eclipse Operations

The equinox seasons occur from about 28 February to 12 April for the vernal equinox and 31 August to 13 October for autumnal equinox. OATS determines the actual start times and duration of the solar eclipses that occur once a day during these seasons. Special IMC coefficient set and star set are generated and uplinked to the spacecraft for use during this period. During eclipse, the pre-eclipse IMC set is resurrected and renamed to allow for its use following the eclipse recovery period. The GOES-NOP power susbsytem is sized to allow all instrument and communications payload services to operate, uninterrupted, during eclipse.

Battery bias calibrations are performed at the beginning of eclipse season after the eclipse duration is greater than 30 minutes. This calibration ensures the full recharge of the batteries prior to re-entering eclipse.

Yaw Flip

In order to prevent possible sun intrusion into the Imager and Sounder radiant cooler's field of view (FOV), it is possible to operate the GOES-NOP spacecraft in either an upright or an inverted fashion. This maneuver entails a 180° yaw slew around noon SLT shortly before or after each eclipse season. The increased operational activities during eclipse season preclude the maneuver being performed during that period. The time of day (noon SLT) allows for both a stable thermal environment transition and eliminates large solar array motion during the maneuver.

It is recommended that one spacecraft be flipped before eclipse season entry and the other spacecraft flipped after eclipse season. Since estimates on the thermal recovery for resuming INR specifications are determined and updated each yaw flip, it is highly recommended that the same maneuver period (either pre- or post-eclipse season) be maintained for the same spacecraft for all future maneuvers in order to fine-tune these estimates and speed INR recovery.

On-board Star Catalog (OSC) Update

Once each year, the OSC is updated to compensate for proper motion. This can be performed at any time using a ground software tool that allows for the update and uplink of the entire OSC in individual 1° declination strips. The updates are epoched 6 months into the future to allow for the least impact of proper motion over the following year. This can be performed while SIAD is active and for declination strips currently in use by SAID.

Leap Second Adjustments

In the event that the UTC is adjusted for a leap second, both GOES spacecraft will be placed into a special housekeeping period at 0000 GMT on the day of the leap second. A clock adjustment will be performed to compensate for this change in UTC over the duration of the housekeeping period. Upon exit of the housekeeping period, the on-board clock will be synchronized with UTC within specifications.

Deorbit

At the end of its operational life, the spacecraft is raised 350 kilometers (217 statute miles) above synchronous altitude to allow other spacecraft to use the vacated orbital slot. In this deorbit maneuver, the thrusters impart an incremental velocity to the spacecraft, typically at an apse, in the direction of motion, producing an elliptical transfer orbit to the higher orbit radius and a westerly drift with respect to earth. The new orbit is circularized by a second velocity increment applied at the opposite apse in the direction of motion. After depleting stored energy sources to the maximum practical extent in order to minimize any subsequent debris generation due to micro-meteroid impact, the spacecraft subsystems and payloads are shut down to eliminate RF transmissions.

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