



Protocol Landsat 9 Cross Calibration Under-Fly of Landsat 8: Planning, and Execution

Edward Kaita ^{1,*}, Brian Markham ², Md Obaidul Haque ³, Donald Dichmann ⁴, Aaron Gerace ⁵, Lawrence Leigh ⁶, Susan Good ⁷, Michael Schmidt ⁷ and Christopher J. Crawford ⁸

- ¹ Science Systems Applications Inc@NASA GSFC, Code 618, Greenbelt, MD 20771, USA
- NASA GSFC, Code 618, Greenbelt, MD 20771, USA
 KBR, Contractor to the U.S. Ceological Survey Earth
 - KBR, Contractor to the U.S. Geological Survey Earth Resources Observation and Science Center, Sioux Falls, SD 57198, USA
- ⁴ NASA GSFC, Code 595, Greenbelt, MD 20771, USA
- ⁵ Chester F. Carlson Center for Imaging Science, Digital Imaging and Remote Sensing Laboratory, 54 Lomb Memorial Drive, Rochester Institute of Technology, Rochester, NY 14623, USA
- ⁶ Office of Engineering Research, College of Engineering, South Dakota State University, Brookings, SD 57007, USA
- ⁷ A.I. Solutions@NASA GSFC, Code 595, Greenbelt, MD 20771, USA
- ⁸ U.S. Geological Survey Earth Resources Observation and Science Center, Sioux Falls, SD 57198, USA
- * Correspondence: edward.kaita@nasa.gov; Tel.: +1-301-332-2798

Abstract: During the early post-launch phase of the Landsat 9 mission, the Landsat 8 and 9 mission teams conducted a successful under-fly of Landsat 8 by Landsat 9, allowing for the near-simultaneous data collection of common Earth targets by the on-board sensors for cross-calibration. This effort, coordinated by the Landsat Calibration and Validation team, required contributions from various entities across National Aeronautics and Space Administration and U.S. Geological Survey such as Flight Dynamics, Systems, Mission Planning, and Flight Operations teams, beginning about 18 months prior to launch. Plans existed to allow this under-fly for any possible launch date of Landsat 9. This included 16 ascent plans and 16 data acquisition plans, one for every day of the Landsat orbital repeat period, with a minimum of 5 days of useful coverage overlap between the sensors. After the Landsat 9 launch, the plan executed, and led to the acquisition of over 2000 partial to full overlapping scene pairs. Although containing less than the expected number of scenes, this dataset was larger than previous Landsat mission under-fly efforts and more than sufficient for performing cross-calibration of the Landsat 8 and Landsat 9 sensors. The details of the planning process and execution of this under-fly are presented.

Keywords: Landsat 9; under-fly; cross-calibration

1. Background

The Landsat program now has a 50-year history of documenting the Earth's land surface conditions through multispectral imaging. One of the key recent goals of the Landsat program is to provide a consistent record of radiometrically and geometrically calibrated data over its full mission history. One useful tool in providing radiometric calibration consistency between concurrently operating satellites is near-simultaneous acquisition of image data over common ground reference targets. In their nominal 705 km operational World Reference System Two (WRS-2) orbits, Landsat 8 and 9 satellites are phased to provide 8-day repeat coverage, and thus, near-simultaneous imaging of common ground reference targets is essentially non-existent. However, an opportunity that does exist for providing near-simultaneous coverage is during the commissioning phase of each newly launched satellite. (Note, "commissioning" begins with post-launch satellite deployment, and lasts for several months prior to the declaration of normal operations). The insertion orbit for the Landsat satellites is always lower than the final desired operational



Citation: Kaita, E.; Markham, B.; Haque, M.O.; Dichmann, D.; Gerace, A.; Leigh, L.; Good, S.; Schmidt, M.; Crawford, C.J. Landsat 9 Cross Calibration Under-Fly of Landsat 8: Planning, and Execution. *Remote Sens.* 2022, *14*, 5414. https://doi.org/ 10.3390/rs14215414

Academic Editor: David M Johnson

Received: 23 September 2022 Accepted: 25 October 2022 Published: 28 October 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). altitude, in part, to ensure that the final orbit can be reached without performing retrograde orbit adjustments (orbit lowering adjustments), which for the Landsat satellites, involve a non-nominal attitude. When in a lower altitude orbit during commissioning, the Landsat satellite is off its WRS-2 [1,2] ground tracks that are maintained during nominal operations. As such, the ground track of the newly launched satellite (Landsat 9, by example) will shift in and out of phase with its nominal WRS-2 orbital track, and for certain periods of time will be highly overlapping with the path of the existing satellite (Landsat 8, by example) that results in short-term near-simultaneous (if the equatorial crossing times are the same) imaging. The timing and length of these near-simultaneous "tandem flying" or "under-fly" periods are a function, in part, of altitude difference between the two satellites. The closer in altitude, the slower the drift and thus the longer the period of high imaging overlap and near-simultaneity.

Previous Landsat Missions

Dating back to the commissioning phase for Landsat 2 in 1975, data were collected with both the Landsat 1 and Landsat 2 Multi-Spectral Scanners (MSS) and used to adjust the calibration coefficients to provide visually comparable data products, as the focus at that time was visual interpretation. Similarly for each new satellite, under-fly data were collected. Note that Landsat 4 (and all later Landsat satellites through at least Landsat 9) operated at a lower altitude with a new WRS-2. As such, Landsat 4 was regularly underflying Landsat 3 and multiple near-simultaneous data collects could be performed if Landsat 3 was still operating.

Another factor considered for an under-fly is the equatorial crossing times of the two satellites being compared. The Landsat satellites were historically allowed to deviate up to 15 min from their nominal mean local crossing times. As thruster fuel ran low, they often were allowed to drift even farther apart. Landsat satellites 1–3 had a nominal equatorial crossing time of 9:30 a.m.; Landsat satellites 4–5 were at 9:45 a.m., and Landsat satellites 7–9 were at 10:00 a.m. For example, by November 2021, Landsat 7, being low on fuel, had been allowed to drift to 8:45 a.m. while still collecting data. So, at the time of launch of Landsat 9, Landsat 7 was at about 9 a.m. mean local crossing time at the equator, and Landsat 9 was at about 10:12 a.m. This resulted in a more than one hour time difference when imaging the same ground area on the same day. By contrast Landsat 8 was at about 10:13 a.m., resulting in only a few minutes difference in imaging the same areas when Landsat 9 was in phase with the operational Landsat 8.

The extent of planning conducted for the early Landsat program under-fly periods is unknown, at least to these authors. Of the references cited, Teillet et al. [3] focus on the cross-calibration process of Landsat 5 to Landsat 7 using under-fly data and provide some information about the under-fly data collections. Mishra et al. [4] likewise discuss cross calibration between Landsat 8 Operational Land Imager (OLI) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) but do not discuss the planning process in any detail. These historical datasets were extremely valuable in performing cross calibration, although a recurrent challenge was obtaining sufficient cloud free imagery over desirable targets. So, for Landsat 9, substantial effort was put into planning for its under-fly of Landsat 8. As such, the intent of this paper is to document (1) the planning process used to maximize the acquisition and useability of simultaneous and near-simultaneous overlapping imaging during commissioning, (2) the successes and failures, and (3) lessons learned for the future so that users of Landsat 8 and Landsat 9 under-fly datasets can understand what they have and why, and future mission planning can benefit from a documented process.

2. Planning Goals and Strategy

2.1. Goals

Two main radiometric goals that the Landsat calibration/validation team wanted to achieve with near-simultaneous imaging during the Landsat 8 and Landsat 9 underfly campaign were (1) obtain sufficient coincident to near-coincident datasets to perform radiometric cross calibration of Landsat 8 OLI and Landsat 9 OLI-2 data and (2) obtain sufficient coincident to near-coincident datasets to perform radiometric cross calibration of Landsat 8 Thermal Infrared Sensor (TIRS) and Landsat 9 TIRS-2 data. The guidelines in Table 1 were used to help schedule the datasets for acquisitions.

Instrument	Guidelines for Acquiring Data
	1. Uniform targets of sufficient size (~300 \times 300 m). (10 IFOV (Instantaneous Field of View) \times 10 IFOV).
OLI	 Cloud free At a range of brightness levels from typical vegetated target radiances to near saturation radiances Instrumented sites, as available Routinely used sites, as available
	 Acquisition time differences of less than 15 min View zenith angle differences of less than 5 degrees.
TIRS	 Uniform targets of sufficient size (~1 × 1 km). (10 IFOV × 10 IFOV). Cloud free At a range of water surface temperatures from approximately 4 °C to 30 °C; land surface from -40 °C to 50 °C Instrumented sites, as available Routinely used sites, as available
	 Acquisition time differences of less than 15 min (water) and 5 min (land) View zenith angle differences of less than 20 degrees.

Defining how much data need to be planned and acquired to meet these crosscalibration needs is difficult given the unknown cloud cover contamination during imaging. This is further complicated by the one-shot nature of the under-fly opportunity, in addition to the challenges encountered during operations early in the mission. As such, the flight operations strategy adopted was to acquire as many near-simultaneous Landsat 8 and Landsat 9 scenes with as much overlap in ground coverage as possible, within the constraints of the multi-mission planning system. The scenes with the most overlap and smallest time and angular differences were given the highest priority.

2.2. Strategy

2.2.1. Planning Constraints

Several technical constraints dictated how the under-fly was conducted as part of the Landsat 9 commissioning, how many scenes could be acquired, and the types of ground sites that could be imaged. The under-fly constraints are detailed in Table 2.

Туре	Constraints and Guidelines
Science	 Maximize the number of scenes with >50% overlap that were within 10 min of Landsat 8 imaging Allocate the final ~30 days of commissioning at the operational altitude to allow the geometry calibration team to complete their work Limit Landsat 8 off-nadir pointing to nighttime (ascending node orbit) acquisitions to preserve its long-term acquisition plan Match final orbit with 8-day phasing between Landsat 9 and Landsat 8 (same location as Landsat 7) at a 10:12 a.m. mean local equatorial crossing time

 Table 2. Cont.

Туре	Constraints and Guidelines									
	 Do not extend the commissioning period (nominally 90 days) more than a few days to complete the under-fly; i.e., all under-fly and orbit raising activities need to occur between instrument activation and approximately 60 days after launch Place no restrictions on the launch date or time Perform engineering thruster burns on mission days 4 and 6 									
Operational	 Perform no non-nominal maneuvers (e.g., retrograde or orbit-lowering) Consume no significant extra fuel Fully activate both instruments and complete their initial checkouts (about 35 days from launch) Do not acquire more than the maximum number of scenes of 740 scenes acros a 3-day running average Ramp up to full scene acquisitions after instrument activation (required 5+ days) Limit off-nadir pointing to ±15°, equivalent to one WRS-2 path difference; limit number of off-nadir acquisitions allowed each day, and have no off-nadir pointing in sun direction Require the following for ascent burns: minimum of 3 days between ascent burns; perform no ascent burns before mission day 9; perform ascent burns during day shifts, if possible; achieve 50% of ascent in first two burns; achiev 50% in two-second burns (post under-fly) Obtain Tracking Data Relay Satellite (TDRS) coverage during ascent burns, which limits where burns can be performed Allow for early inclination maneuver if launch dispersion is large 									
Coordination with other missions	 Require initial orbit of 24 km below the 705 km equatorial altitude constellation to permit phasing into final orbit Maximize separation between full constellation fleet envelope during ascent, i.e., under-fly orbit is chosen to be a frozen orbit with same eccentricity as 705 km constellation Avoid close conjunctions with C-train satellites (CALIPSO and Cloudsat) via launch window cutouts 									
Collision Avoidance	 Screen all ascent plan for close conjunctions Perform avoidance maneuvers as necessary Require maneuver plans from flight dynamics as well as no burn and special one burn ephemerides (if more than 2 burns in 7-day screening period) 									

2.2.2. Ascent Planning

To achieve the goals within the bounds of these constraints, the flight dynamics team developed detailed ascent plans. The initial design of the Landsat 9 under-fly of Landsat 8 was based upon the Landsat 8 under-fly of Landsat 7 in 2013 [5]. All these ascent plans achieved ~5-day under-fly intervals (defined as where the two satellites were within 1 WRS-2 path and within 10 min of each other) centered on 47.5 days after launch for all possible launch dates (one for each day of the WRS-2 cycle) (Figure 1).

2.2.3. Scene Acquisition Ramp up to Tandem Flying

As mentioned previously, to maximize the number of scene pairs acquired during the tandem flying, a plan was devised to ramp up the Landsat 9 scene acquisitions to its maximum 740 scenes per day. Starting on the first day of earth imaging on Day 34 (D34) since launch, the ramp up schedule was as follows:

- D34–36: 200 scenes;
- D37–38: 500 scenes;
- D39–40: 700 scenes;
- D41-onwards: 740 scenes.

Launch Date	1	2	3	4 5	6	7 17	18	19	20	21	22 23	24	25	26	27 2	8 29	30	31	32	33	34	35 36	37	38	39	40 4	1 42	43	44	45	46	47	48	49 5	0 51	52	5360	61	62	63	64	65	66	67 (68 E	69 70
16-Sep				E1	E2		A1			A2																							UF					A3		Т	A4					
17-Sep				E1	E2																	A1		A2									UF					A3			A4					
18-Sep				E1	E2						A1		A2																				UF					A3			A4					
19-Sep				E1	E2																			A1		A	2						UF					A3			A4					
20-Sep				E1	E2								A1		A	2																	UF						A3		A4					
21-Sep				E1	E2												_									A	1		A2				UF					A3			A4					
22-Sep				E1	E2											A	L		A2														UF					A3			A4					
23-Sep				E1	E2																							A1			A2			UF					A3			A4				
24-Sep				E1	E2														A1			A2											UF					A3 A3			A4					
25-Sep				E1	E2				A1		A	2																					UF					A3			A4					
26-Sep				E1	E2																	A1			A2								UF						A3			A4				
27-Sep				E1	E2							A1			A2																		UF					A3			A4					
28-Sep				E1	E2												_									A1		A2					UF					A3			A4					
29-Sep				E1 E1 E1 E1 E1 E1 E1 E1 E1 E1 E1 E1 E1 E	E2 E2 E2 E2 E2 E2 E2 E2 E2 E2 E2 E2 E2 E										A1		A2																UF					A3 A3 A3 A3 A3			A4					
30-Sep				E1	E2																						A:	L		A2			UF					A3			A4					
1-Oct				E1	E2												A1			A2													UF		_			A3	1		A4					

Figure 1. Table of Ascent Plans for a 16-day Launch Cycle. For each prospective launch date for Landsat 9, Landsat 8 can be in a different position in its orbit, requiring a different Ascent Plan. Because Landsat 8 has a 16-day Repeat Ground Track, the Flight Dynamics team created 16 Ascent Plans. This figure begins on 16 September 2021 because that was the planned launch date, until circumstances forced a skip until 27 September 2021. This figure indicates possible Engineering Burns (E1–2), Ascent Burns (A1–4) and Under-fly periods (UF) to meet mission constraints and guidelines in Table 2.

2.2.4. Calibration Site Identification

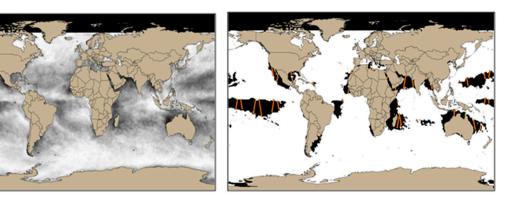
Landsat Calibration and Validation (CalVal) team colleagues from South Dakota State University (SDSU) and the Rochester Institute of Technology (RIT) provided candidate sites for under-fly acquisition for OLI-2 and TIRS-2, respectively. General guidelines included providing candidates that would increase the likelihood of acquiring 'cloud-free' scenes, prioritizing them to facilitate building scheduling requests and increasing the likelihood of acquiring the most desirable targets. Given the range of launch dates allowed, a set of targets needed to be identified for all possible launch days within the 16-day cycle. Additional planning details are discussed below.

1. OLI-2

Acquisition priority was given to cover three different approaches for radiometric evaluation; simulations of the under-fly period for cross calibration, various Pseudo Invariant Calibration Sites (PICS) based approaches for trending and cross calibration, and vicarious calibration team field measurements for absolute and cross calibration. For the under-fly, the following criteria were met; acquire all images within +/ – 45 degrees latitude (excluding 0 and -10 degrees), for all land cover types classes derived by SDSU [2] that exhibited less than 1% uncertainty impacts due to spectral and angular corrections, and for similar view angles and solar angles. "Sand" classification targets included PICS and Extended PICS sites (EPICS), e.g., North Africa desert, given their temporal and spectral stability characteristics and broad coverage providing worldwide trending information. Sites were also identified and measured by CalVal members from the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, and international collaborators. USGS EROS coordinated this effort that included Australia and South Africa sites.

2. TIRS-2

Considering the utility of the open-ocean and near-shore data acquired during the Landsat 8/Landsat 7 under-flight (i.e., these data were critical for the development of the TIRS stray-light mitigation algorithm), an emphasis was placed on identifying similar scenes for the Landsat 9/Landsat 8 under flight. Roughly 75% of the image data acquired by TIRS during the Landsat 8/Landsat 7 under flight were contaminated with clouds. As such, a simple geographic information system (GIS) tool was developed here to better identify potential cloud-free scenes for acquisition, see Figure 2.



Temporal average of MODIS monthly cloud product. Thresholded MODIS monthly cloud product.

Figure 2. (Left) Temporal average of the MODIS monthly cloud product for November (right), and thresholded (50%) image of temporal average (left) with an orbital model overlaid for scene identification.

A 20-year temporal average of the Moderate Resolution Imaging Spectroradiometer (MODIS) monthly cloud product (MODIS Standard Atmosphere Level-3 MCD06COSP product) for November was obtained (Figure 2, left) and a threshold of 50% set to identify areas where cloud coverage would be less likely. Figure 2 (right) shows the thresholded image where black represents areas with less than 50% cloud probability based on the MODIS product. (Note that a 25% threshold nearly eliminates all the favorable (black) regions in Figure 2, right). The orbital model "WRS2DATA" file developed by Flight Dynamics System (discussed later) was used to predict where Landsat 9 would be during commissioning and, for this study, the under-flight period from ~13 November 2021 to 17 November 2021. The orange dotted lines in Figure 2 (right) shows where the orbital model and low cloud regions intersect for the first day of the under flight.

Recommendations for favorable intervals were made based on this analysis with a 'highest' priority given to nearshore continental United States (CONUS) path/rows due to the availability of reference data. (Note that the National Oceanic and Atmospheric Administration (NOAA) nearshore buoy network is extensive, and a ground campaign was conducted across the United States by RIT using Tidbit temperature sensors to expand the availability of reference data to support TIRS-2 calibration efforts.) 'High' priority was given to world-wide nearshore scenes as the contrast between hot land and cooler water provides potential scenarios where effects due to stray light can be observed in the image data. Near-shore image data acquired with TIRS during the Landsat 8/Landsat 7 under-fly were critical to the development of its stray light correction algorithm. Finally, open ocean scenes were assigned a 'medium' priority because reference data are typically not available, and land-geometries are not present to inform on the presence of stray light. In the context of calibration, open ocean scenes also have significant utility for flat-field assessment.

3. Execution

3.1. Launch and Ascent

On 27 September 2021, at one minute into the launch window (18:12 UTC), an Atlas V 401 inserted Landsat 9 into a circular orbit with an altitude of 685 km, in nearly the same orbit plane as Landsat 8. Following a sequence of six maneuvers, Landsat 9 reached its mission orbit of 705 km in equatorial latitude, Mean Local Time-Descending Node crossing of 10:12 (same as Landsat 8). Landsat 9 is 180 deg away from Landsat 8, so that the two observatories image the globe from -81 deg to +81 deg latitude every 8 days.

A pair of Engineering Maneuvers to calibrate thrusters, followed by two pairs of Ascent Maneuvers preceding the under-fly, followed by two additional ascent maneuvers, achieved the ascent goals. The Semi-major Axis history during the Landsat 9 ascent is shown in Figure 3, with the calibration under-fly period highlighted. The first pair of Ascent Maneuvers (ASC-1 and ASC-2) raised Landsat 9 from the insertion orbit to the intermediate orbit, about 10 km below mission orbit. Maneuvers ASC-1 and ASC-2 were

timed so that Landsat 9 would be under Landsat 8, in the center of the tandem flying interval, on day 47.5. The timing of ASC-1 and ASC-2 depended on where Landsat 8 was located relative to Landsat 9 at launch. For the launch date on 27 September 2021, at 18:14, ASC-1 was performed on day 25, and ASC-2 was performed on day 28. During mission planning in the years before launch, the day-of-launch was unknown. To be prepared for all possibilities, an ascent was planned at the start of the Launch Window for each day in a 16-day repeat cycle for Landsat 8.

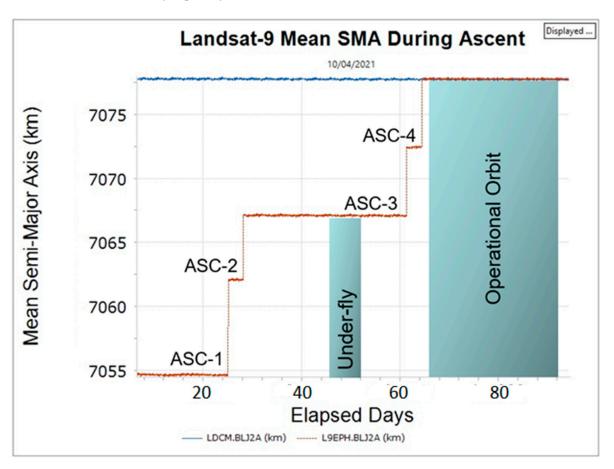


Figure 3. Landsat 9 Semi-major Axis versus Elapsed Days for launch.

Figure 4 shows the location of Landsat 9 in terms of WRS-2 paths from Landsat 8 during the ascent. The calibration under-fly, from days 45 to 51, is highlighted by a green rectangle. This selection is also highlighted in green in Figure 5. Note that there were two earlier under-fly opportunities, starting near Day of Year (DOY) 277 or L-day (day since Launch) 7 and DOY 291 or L-day 21. The first two under-fly opportunities occurred before the Landsat 9 observatory was ready to perform cross-calibration with Landsat 8. The first two under-fly opportunities were used to prepare for days when Landsat 8 and Landsat 9 would be competing for the same ground station resources. Note also that the first two under-fly opportunity periods were shorter, the altitude difference were larger, and the drift rates were faster than the third.

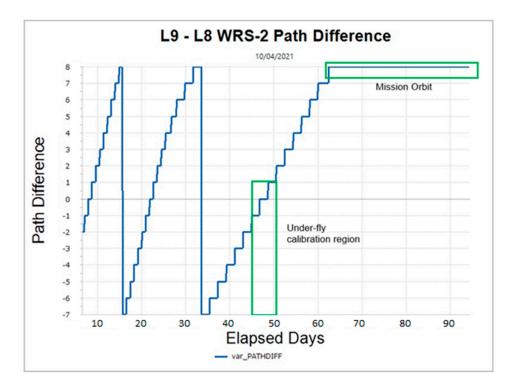


Figure 4. Landsat 9 offset from Landsat 8 in WRS-2 path difference.

#	Entry Epoch	DOY	Exit Epoch	DOY	L-Days at Entry	L-Days at Exit	Duration
1	Oct 04 2021 21:01:26	277	Oct 07 2021 11:20:43	280	7.062	9.658	2.597
2	Oct 18 2021 19:35:27	291	Oct 21 2021 09:54:43	294	21.002	23.599	2.597
3	Nov 11 2021 18:46:57	315	Nov 17 2021 09:37:11	321	44.968	50.586	5.618

Figure 5. Under-fly epoch options with final selection highlighted in green.

After the under-fly, the second pair of Ascent Maneuvers, ASC-3, and ASC-4, were performed to reach mission orbit. This second pair of maneuvers was timed to occur when Landsat 9 had drifted from being under Landsat 8 on day 47.5 to being 180 degrees from Landsat 8. The synodic period between the intermediate orbit and the mission orbit was about 32 days, so this drift of 180 degrees took 16 days. Maneuvers ASC-3 and ASC-4 were performed on days 61 and 64 respectively.

3.2. Acquisition Scheduling

The process of scene selection and scheduling was performed manually. This process required using Flight Dynamic predictions of the orbit for each day and selecting calibration sites from predefined lists to populate the acquisition request. After calibration sites were identified, priority was given to CONUS intervals, and scenes from the Land Collection Request (LCR) also known as Long Term Acquisition Plan (LTAP). With a mix of ascending and descending scenes, a file of corresponding path/rows was generated daily and submitted as a "Special Collection Request" (SCR) to the User Portal System (UPE). The Landsat calibration validation team worked closely with Flight Dynamics and Mission Planning & Scheduling teams within the Landsat Multi-Satellite Operations Center (LMOC) system during and after the submission of any acquisition requests. Further details of the scheduling process are described below.

3.2.1. Scheduling Constraints

The SCR constructed for each under-fly day considered a list of scheduling constraints whose main objectives were to mitigate instrument safety concerns and to not compromise science image acquisitions. These constraints were as follows:

- Maximum number of night acquisitions per orbit is limited to 24 scenes;
- Maximum off-nadir angle is limited to +/− 15 degrees;
- Maximum number of scenes within an off-nadir collect is limited to 18 scenes;
- Maximum number of off-nadir acquisitions per orbit is limited to two;
- For simultaneous day earth collects, point Landsat 9 off-nadir keeping Landsat 8 nadir to minimize the loss of science acquisitions of the operational satellite;
- For simultaneous day ocean collects, point Landsat 9 off-nadir keeping Landsat 8 nadir, or point Landsat 8 off-nadir keeping Landsat 9 nadir, whichever is desired depending on the target;
- For simultaneous night collects, point Landsat 9 off-nadir keeping Landsat 8 nadir, or point Landsat 8 off-nadir keeping Landsat 9 nadir, whichever is desired depending on the target.

3.2.2. Flight Dynamics Products

During the building of special collection requests, flight dynamic products like "WRS2TTT" and "WRSData" files were used extensively. These files were generated based on the orbital prediction of both Landsat 8 and Landsat 9 satellites and provided predicted WRS-2 Path and Rows along with their acquisition times. The WRS2TTT records also provided a corresponding sun elevation angle for each path/row.

The WRS2DATA file proved particularly useful during the tandem flying and provided the time of each descending node, the current longitude, the desired longitude (for the WRS-2), the error, the path number, and the Landsat 8 path number. An example is shown in Figure 6 below. The inputs for this file were the Landsat 9 predicted ephemeris and Landsat 8 ephemeris file, from which the spacecraft orbit positions were determined. For each step in the orbit towards the descending node crossing, an offset was computed from the defined longitude center in degrees (based upon the WRS-2 center) for each satellite. Finally, a corresponding path/row was derived for each step, as well as a path difference and spacecraft separation (SC_SEP) in minutes. These files were routinely updated after each Landsat 9 ascension burn.

AscendingLandsa	t.EpochText	AscendingLandsat.Longitude	DesiredLong	ErrorKm	PATH (L9)	PATH2 (L8)	PATHDIFF	SC_SEP
Nov 15 2021	14:03.2	314.5663302	313.940768	69.6372417	222	222	0	2.85605
Nov 15 2021	52:43.0	289.9007638	289.219748	75.8103391	5	5	0	3.07561667
Nov 15 2021	31:23.0	265.2341972	264.49871	81.8740808	21	21	0	3.29515
Nov 15 2021	10:03.0	240.5675973	241.322742	-84.062269	36	37	-1	3.51458334
Nov 15 2021	48:42.9	215.9015695	216.601716	-77.939936	52	53	-1	3.73405
Nov 15 2021	27:22.7	191.2362747	191.880692	-71.736163	68	69	-1	3.95353334

Figure 6. Example from WRS2DATA file.

This path information along with LTAP and CalVal site lists were the basis of SCR scene selections. During the early days of the imaging ramp up period when only a few scenes were selected for acquisition, CalVal requests and CONUS scenes received higher priority. With the ramp up of the number of acquired scenes, better coverage around the globe was possible.

3.2.3. UPE (User Portal Elements)

Both Landsat 8 and Landsat 9 acquisition requests were submitted through User Portal Element (UPE) interfaces. Figure 7 below shows the Landsat 9 interfaces among various ground subsystems including the UPE (highlighted). Note that Landsat 8 had its own Mission Operations Center (MOC) and planning system until the Spring 2022, when it was

merged with Landsat 9 into a single Landsat Multi-Satellite Operations Center (LMOC). Until the merge, separate UPE systems had to be used with slight differences; e.g., acquisition requests were submitted as "ground look calibrations" or "off-nadir calibrations" for Landsat 8, whereas requests were submitted only as "ground look calibrations" for Landsat 9. The inputs for individual nadir requests were the WRS-2 path/row or latitude/longitude and acquisition date. Both UPE's also provided the option to upload a list containing WRS-2 path row information. Off-nadir acquisition requests required latitude/longitude information for each corresponding path/row of interest. Other criteria for acquisition requests included start date, end date, cloud cover, and priority level. Each SCR submission was assigned a unique ID and flagged by the Mission Planners, Flight Operations Team and/or Flight Dynamics Team. Some SCRs, like off-nadir requests, were evaluated by the Flight Dynamics/Mission Planners to ensure that no instrument constraints would be violated. Final approval of each submission was provided by the Data Acquisition Manager (DAM). Upon approval from the DAM, LMOC mission planners-built acquisition loads to upload to the satellite for execution. Figure 8 below shows the Landsat 9 UPE interface for nadir and off-nadir acquisition requests.

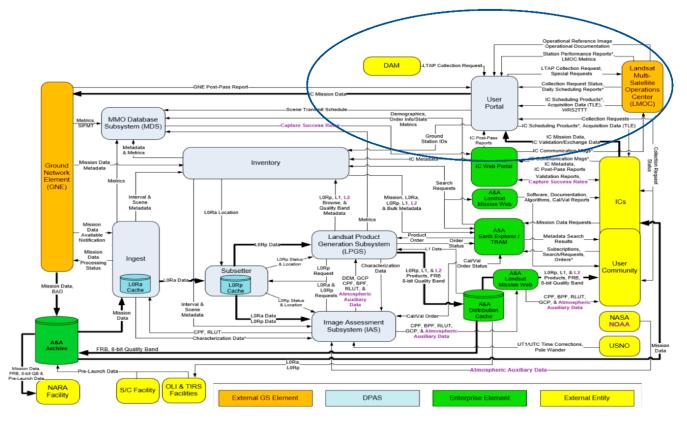


Figure 7. Landsat 9 User Portal Elements Release 7.0.0 Test Subsystems and Interfaces (GNE-Ground Network Element, IC-International Cooperator, DAM-Data Acquisition Manager, SIFMT-Scene to Interval to File Mapping System, L0Ra-Level 0 Reformatted Archive, L0Rp-Level 0 Reformatted Product, A&A-Archive and Access, TRAM-Tracking, Routing and Metrics, FRB-Full Resolution Browser, CPF-Calibration Parameter File, BPF-Bias Parameter File, RLUT-Response Linearization Look Up Table, GCP-Ground Control Point, USNO-U.S. Naval Observatory, TLE-Two Line Element, L1-Level 1, L2-Level 2, S/C-Spacecraft, GS-Ground Systems, DPAS-Data Processing and Archive System).

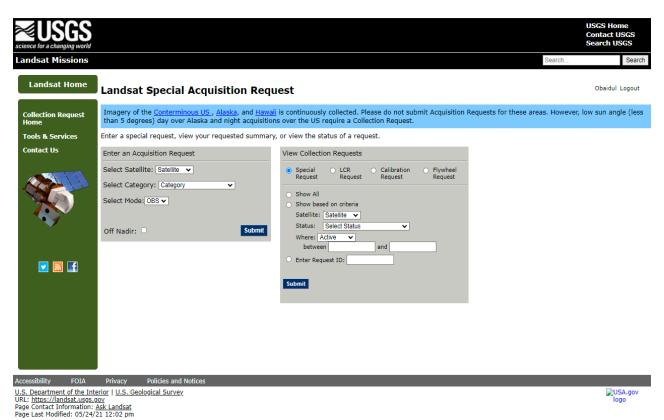


Figure 8. Landsat 9 User Portal Element (UPE) User Interface.

4. Data Collection

A well-coordinated effort with the Flight Dynamics Systems, Flight Operations, and Mission Planning Teams led to achieving the most desirable tandem flying acquisitions, starting on Day of Year 316 (DOY 316 or 12 November 2021). As mentioned previously, to avoid potential disruptions to this acquisition, the CalVal strategy included foregoing any spacecraft maneuvers about one week prior to the heart of the under-fly with 0-path separation. This resulted in nadir (pointing) partial to full overlap collects on DOY 316–317, full overlap collects on DOY 318–319, and off-nadir collects on DOY 320–321.

Scenes scheduled for each day of the tandem flying were derived from the various lists of TIRS ocean, "near-shore" intervals transiting near land, "off-shore" intervals crossing land and water, and buoy sites, as discussed in Section 2. The land calibration sites were identified from lists assembled for Landsat 8 with the remainder of the daily scene acquisitions scheduled from the LTAP. Figure 9 illustrates the path/rows acquired for both Landsat 8 and Landsat 9 within and up to 1 path of each other. The first 3 overlays illustrate the DAY scene acquisitions separated out by periods of the under-fly; i.e., "Early" (DOY 316–317 or 12 November 2021–13 November 2021), "Mid" (DOY 317–319 or 13 November 2021–15 November 2021), "Late" (DOY 319–321 or 15 November 2021–17 November 2021), to better illustrate the overlap between Landsat 9 and Landsat 8. The last overlay illustrates the NIGHT scene acquisitions over the entire under-fly period (i.e., DOY 316–321).

Figure A1 (in Appendix A) provides details on the scene pairs acquired from the SCRs and LTAP. The POINTING column for each satellite indicates its acquisition orientation; i.e., nadir or off-nadir where Landsat 9 off-nadir implies that Landsat 9 was pointing to the Landsat 8 path and vice versa. Additional information includes the scene counts for each PATH interval, as well as LOCATION information for the calibration sites only. Note, these sites were identified using the International Geosphere Biosphere Programme (IGBP) Land Classification to fall with 14 categories, i.e., Dark Soil, Deciduous Needleleaf, Mixed Forest, Open Shrublands, Woody Savanna, Savanna, Grasslands, Croplands, Natural Vegetation/Croplands, Snow, Evergreen Broadleaf, Light Soil, Sand, and Water (TIRS Only).

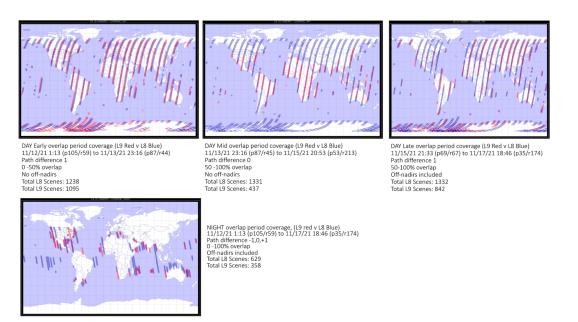


Figure 9. Landsat 9 and Landsat 8 Path(P)/Rows(R) Acquired During the Tandem flying (Day and Night).

From all scene pairs, approximately 1000 provided useful data for Landsat 9/Landsat 8 radiometric cross-calibration evaluations [6], approximately 930 scenes were used for geometric calibration assessments [7], and approximately 10 scenes for thermal vicarious calibration.

5. Lessons Learned

It should be noted that Figure A1 lists and Figure 9 shows all the scenes downlinked, but not all that were requested and/or scheduled by SCR or LTAP. In particular, during the center of the under-fly period, Landsat 8 scenes outnumber Landsat 9 scenes by about 3:1. If the under-fly had gone as proposed, about 1300 coincident scenes would have been acquired during the center of this period. The actual number was about 400 and although yielding a valuable dataset for characterization, a post under-fly investigation revealed several factors that contributed to the acquisition shortfall. These shortfalls are outlined below:

- The SCR scene rejection criteria differed based upon the solar zenith angle. As noted previously, there were two scheduling systems (i.e., Landsat 8 MOC and Landsat 8 and Landsat 9 LMOC) that required inputs and SCR evaluations. As such, each system was found to calculate the solar angle zenith angle differently with Landsat 9 derived from earth-center, and Landsat 8 derived from the earth-surface. This resulted in the loss of some coincident images.
- Landsat 9 scenes were not acquired due to the overriding priority given to calibration collects (scheduled by SCR) over routine earth collects (scheduled by the Landsat 9 LTAP). Due to a flaw in the Landsat 9 scheduling process, the SCR calibration collects for a given path were scheduled while routine LTAP Earth collects were rejected. Note in Figure 9, in particular, the lack of coverage over Europe and Canada due to the large number of calibration-collects requested over the United States and Africa. By contrast, in the Landsat 8 scheduling system, calibration collects were automatically scheduled based upon a list of predefined acquisition constraints including instrument and/or calibrator configuration, cadence, and location defined to avoid affecting Earth collects.
- Landsat 9 scenes were missed due to a different (smaller) scene gap size between intervals versus Landsat 8.
- Incorrect scene PATH reporting information derived for SCR versus LCR acquisitions attributed to an error in the LMOC system. Note that this did not lead to a loss of scenes but rather, a skewed reporting of scenes acquired.

All these issues were addressed after the Landsat 9 commissioning period and point to one of the challenges in conducting a calibration campaign early in a flight mission while still transitioning to "nominal operations."

6. Conclusions

A radiometric cross-calibration campaign was successfully conducted between the Landsat 8 sensors and the Landsat 9 sensors during the commissioning phase of Landsat 9 when Landsat 9 was under-flying Landsat 8. Close coordination between the Flight Dynamics team, mission operations, data scheduling and acquisition planning, data processing, and the Calibration and Validation team provided the burn planning and execution to achieve about 5 days of useful overlap between the two satellites sensors coverage. Although a few challenges were encountered in the end-to-end MOC and LMOC systems, a valuable dataset was obtained for both OLI and TIRS instruments. Initial results of the cross calibration for OLI [7] has been published, attesting to the value of the Landsat 8 and Landsat 9 under-fly dataset.

Author Contributions: All the authors were involved in the various aspects of the under-fly planning and execution. B.M., the Landsat CalVal Manager, led and coordinated the planning effort. D.D., S.G. and M.S. provided the Flight Dynamics modeling inputs. A.G. and L.L. performed the calibration site assessments for acquisition. M.O.H. and E.K. developed the calibration acquisition plan and generated the special calibration requests for each day of the under-fly, and C.J.C. reviewed and provided final approval for all acquisition requests submitted. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Conflicts of Interest: The authors declare no conflict of interest.

Underfly Tin	ne		Underfly Information												
			Landsat-9					Landsat-8							
DOY	DSL	MM-DD-YYY	Pointing	WRS-2 Path	WRS-2 Row	Path Scene Count	Pointing	WRS-2 Path	WRS-2 Row	Path Scene Count	Location Description (Cal Sites only)				
316	46	11/12/21	NADIR	106	60-64,67-83	21	NADIR	105	60-64,67-83	21	Western Australia				
				122	29-44,64-65	18		121	29-44,64-65	18					
					158-159	2			158-159	2					
					200-204	5			200-204	5					
				138	25-49	25		137	25-49	25	Tibet, Dunhuang China				
				154		38		153	15-52		Indian Ocean				
					69-79	11			69-79	11					
						3			108-110	3					
				170	15-38,42-43,46-83	64		169	15-38,42-43,46-83	64					
				[109-110	2			109-110	2					
				[118-122	5			118-122	5					
				186	15-63	49		185	15-63	49	Libya				
	[1	109-117, 120-121	11	1	1	109-117, 120-121	11					
	[202	16-55	40	1	201	16-55	40	Mauritania				
	[1	104-115,118-119	14	1		104-115,118-119	14					
	[1	164-171	8	1		164-171	8					
	[218	15	1	1	217	15	1					
	[1	62-76	15	1		62-76	15					
				1	103-116	14	1		103-116	14					
	[17	15-52	38	1	16	15-52	38	Lake Erie NY, Tampa Bay Bridge FL				
	[1	110-119	10	1	1	110-119	10					
				1	168-170	3	1		168-170	3					
	[33	15-45	31	1	32	15-45	31	White Sands N.MEXICO, Van Horn TX, Custer SD				
				1	109-116,121	9	1		109-116,121	9					
				1	167-172	6	1		167-172	6					
				1	191-195,203-205	8	1		191-195,203-205	8					
				49	15-26	12	1	48	15-26	12					
				[58-73,79	17	[58-73,79	17					
	1				110-120	11	1	1	110-120	11					
[1	210-213	4	1	1	210-213	4					
	[[65	15-18	4	ľ	64	15-18	4					
	[[1	45	1	ľ		45	1					
	[[1		6	l	[109-114	6					
	[[1	208-209	2	[[208-209	2					
	[1	[81	16,23-24	3	1		16,23-24	3	l				
	[1	[1	59,68	2	1	1	59,68	2	l				
	1			1	73-76	4	1		73-76	4	Coral Sea (near Australia)				
	[[1	107-108	2	ľ		107-108	2					
	[[1	116	1	ľ	[116	1	Antarctica Dome 1				
	[[1	191-195	5	ľ	[191-195	5					

Appendix A

Figure A1. Cont.

317	47	11/13/21	NADIR	97	15-18	4	NADIR	96	15-18	E 4	1
····· ^{31/} ·····	·····				15-18 54-55	2	1.1.1.1.1.1		54-55	2	
			1		61-74,78-86	23	1		61-74,78-86	23	Queensland, Tinga Tingana Australia
			[106-107	2			106-107	2	
			ļ		17-30,35-41	21	ļ	112	17-30,35-41	21	
	·		 		52-74,78-84	30	<u> </u>	ļ	52-74,78-84	30	
			}		106 207-208	2			106 207-208	2	Buoys
			<u> </u>		18-42,45-60	41		128	18-42,45-60	41	Mongolia
			1		109,112	2	1		109,112	2	1
			[145	15-42,45-55	39		144	15-42,45-55	39	Tibet, Tarim Basin China
			ļ		106	1			106	1	
			 		15-48,53-57	36	ļ	160	15-48,53-57 67-77	36	<u> </u>
			}		67-77 16-41	26	<u> </u>	176	16-41	26	
			1		44-75,79-81	35			44-75,79-81	35	<u> </u>
					109,112-114	4	1		109,112-114	4	
			[193	18-40	23		192	18-40	23	Algeria-3,-4
			ļ		43-57	15			43-57	15	
			 		88 117	1	<u> </u>		88 117	1	
			}		117 19-24	6		208	117	1	
			t		103,112-114,117	5	†		103,112-114,117	5	
					59-80,85-87	25		224	59-80,85-87	25	1
			[109-114	6			109-114	6	
			ļ	8	24-29	6	ļ	7	24-29	6	
			<u> </u>		46-48,51-69 22-41	22 20	<u> </u>	22	46-48,51-69 22-41	22	Alevandria Loluciana
			t		22-41 47-48	2	<u> </u>	<u></u>	47-48	2	Alexandria Loiusiana
			t		24-35,38-41	16	1	39	24-35,38-41	16	RRValley Playa NV, Lunar Lake Playa, Barstow CA
			<u> </u>	56	71	1	<u> </u>	55	71	1	[
			ļ		48,69,87	3	ļ		48,69,87	3	
			ļ			957	 		<u> </u>	957	Early Overlap Total
			<u> </u>	87	46,51-56 65-70,73-74,79-82	7 12	<u> </u>	87	46,51-56 65-70,73-74,79-82	7 12	Philipine Sea Corral Sea , Australia (Near-shore)
318	48	11/14/21	NADIR		65-70,73-74,79-82 44-49,54	7	NADIR	103	44-49,54	7	Corrai Sea , Australia (Near-shore) Sea of Japan
	<u>~</u>		1		61	1	1		61	1	Papua New Guinea
			[66-68,73,76-81	10	[66-68,73,76-81	10	South Australia
	ļ	ļ	ļ	119	25-42	18	ļ	119	25-42	18	South Korea
			ļ		53-54,57-64,69	11	 		53-54,57-64,69 160-161	11	South China Sea , Indonesia (Near-shore)
			<u> </u>	}	160-161 203-204,209	2		}	160-161 203-204,209	2	South Argentina (Night) Gulf of Mexico, Gulf States (Off-Shore, Night)
			ł	135	38-42,45-50	s 11	<u> </u>	135	38-42,45-50	5 11	Bangladesh, Bay of Bengal (Off-shore)
			t		73-75	3	†		73-75	3	Bay of Bengal
					195-202,207	9			195-202,207	9	North Pacific Ocean, Mexico (Off-shore, Night)
			ļ		44-50	7		151	44-50	7	Pakistan
			ļ	167	42-45,48-50,55-79	32		167	42-45,48-50,55-79	32	South Africa
			<u> </u>		42-65 185	24	<u> </u>	183	42-65 185	1	Libya, Chad, Cameroon Africa Coral Sea (Night)
			ł		201-204	4	<u> </u>	}	201-204	4	Philipine Sea (night)
			1		34-36	3	†	199	34-36	3	Valencia, Spain
			1		44-57		***************				
			£			14			44-57	14	Spain, Morocco
					163-170	14 8			163-170	14 8	Coral Sea (night)
					163-170 194-201	8 8			163-170 194-201	14 8 8	Coral Sea (night) Philipine Sea (night)
				215	163-170 194-201 59-61,65-75	8 8 14		215	163-170 194-201 59-61,65-75	14 8 8 14	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia)
				215	163-170 194-201 59-61,65-75 55-69,	8 8		215 231	163-170 194-201 59-61,65-75 55-69,	14 8 14 15 8	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E.Australia) South America
				215	163-170 194-201 59-61,65-75 55-69, 163-170	8 8 14			163-170 194-201 59-61,65-75 55-69, 163-170	14 8 14 15 8 14	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E.Australia) South America Indian Ocean (Near-shore W.Australia, night) Buoys (Cape FL) (cheaspeake Basy Tunnel. MD
				215 231 14	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170	8 8 14 15 8		231	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170	14 8 8 14 15 8 14 4	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South America Indian Ocean (Near-shore W.Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean
				215 231 14 30	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49	8 8 14 15 8		231	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49	14 8 8 14 15 8 14 14 14 4 14	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South America Indian Ocean (Near-shore W Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TX, W.Kansas, Mexico
				215 231 14 30	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195	8 8 14 15 8 14 4		231 14 30	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195	14 8 8 14 15 8 14 14 14 4 14 3	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South America Indian Ocean (Near-shore W Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TX, W.Kansas, Mexico
				215 231 14 30	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195 201-204	8 8 14 15 8 14 4		231 14 30	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195 201-204	14 8 14 15 8 14 14 14 14 14 3 3 4 5	Coral Sea (, night) Phillipine Sea (, night) South Atantic (, Near-shore, E. Australia) South America Indian Ocean (Near-shore W. Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean, Arington, TK, W. Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Persian Gulf, Iran (Off-shore, night)
				215 231 14 30 46	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195 201-204 30-34	8 8 14 15 8 14 4		231 14 30	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195	14 8 8 14 15 8 14 14 14 3 4 4 5 5 2 2	Coral Sea (, night) Phillipine Sea (, night) South Atantic (, Near-shore, E. Australia) South America Indian Ocean (Near-shore W. Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean, Arington, TK, W. Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Persian Gulf, Iran (Off-shore, night)
				215 231 14 30 46	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195 201-204	8 8 14 15 8 14 4		231 14 30 46	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195 201-204 30-34 73-74 164-168	14 8 14 15 14 14 14 14 14 3 3 4 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South America Indian Ocean (Near-shore W Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TX, W.Kansas, Mexico
				215 231 14 30 46	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195 201-204 30-34 30-34 37-74 154-168 206-208	8 8 14 15 8 14 4		231 14 30 46	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,94-50 167-170 33-41,45-49 193-195 201-204 30-34 73-74 164-168 206-208	14 8 8 14 15 8 15 14 14 14 3 4 5 2 2 2 3 3	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, E Australia) Bidan Ocean (Near-shore W. Australia, night) Bidan Ocean (Near-shore W. Australia, night) Bidan Ocean Arilington, TX, W. Kansas, Mexico Arabian Sea (Nama) Arabian Sea (Nama) Persian Gulf, Iran (Off-shore, night) Bidan Cean South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night)
				215 231 14 30 46 62	163-170 194-201 195-201 195-105-75 55-69 163-170 254-0,49-50 167-170 133-41,45-49 193-195 201-204 30-34 30-34 103-195 201-204 30-34 164-168 206-208 161-168	8 8 14 15 8 14 4		231 14 30 46 62	163-170 194-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 103-195 201-204 30-34 133-195 201-204 30-34 154-168 206-208 165-168	14 8 8 14 15 8 4 14 4 3 4 4 5 5 2 2 5 5 3 8	Coral Sea (, night) Phillipine Sea (, night) South Atantic (, Near-shore, E.Australia) South Atantic (, Near-shore, W.Australia, night) Indian Ocean (, Near-shore W. Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arabian Sea, Oman (Off-shore, night) Persian Gulf, ran (Off-shore, night) Buoys (Eel River CA) South Atantic Cocean South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night)
				215 231 14 30 46 62 78	163-170 194-201 396-1.65-75 55-69, 163-170 29-40,49-50 167-170 29-40,49-50 167-170 29-34,49-50 201-204 201-20	8 8 14 15 8 14 4		231 14 30 46 62	163-170 194-201 194-201 196-105-75 55-69. 183-170 183-170 183-170 183-170 183-170 183-170 183-170 193-195 201-204 193-195 201-204 193-195 201-204 193-34 193-195 201-204 203-34 193-195 201-204 203-34 193-195 201-204 203-34 205-208	14 8 14 15 8 14 4 4 4 4 5 5 5 5 3 3 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, E.Australia, night) Biuoya (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TK, W.Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Arabian Sea, Oman (Off-shore, night) Persian Gulf, Iran (Off-shore, night) Buoya (Ed River CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea
310	49	11/15/21		215 231 14 30 46 62 78	163-170 194-201 39-61.65-75 55-69 163-170 29-40.49-50 167-170 31-41.45-49 193-195 201-204 30-34 103-195 201-204 201-204 205-208 161-168 206-208 161-168 206-208 161-168	8 8 14 15 8 14 4	NADIR	231 14 30 46 62 78	163-170 194-201 59-61,65-75 55-69, 163-170 163-170 163-170 133-41,45-49 133-41,45-49 133-135 201-204 30-34 73-74 164-168 206-208 161-168 62 100-198	14 8 8 14 15 8 14 14 4 4 4 4 5 5 5 5 5 8 8 1 9 9 1 1 8 8 1 1 4 4 1 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (night) Phillipine Sea (night) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, E.Australia) Indian Ocean (Near-shore W.Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arabian Sea, Oman (Off-shore, night) Persian Gulf, Aran (Off-shore, night) Buoys (Eel River CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) Coral Sea
	49	11/15/21	NADIR	215 231 14 30 46 62 78 94	163-170 194-201 294-105-75 55-69, 163-170 163-170 163-170 163-170 163-170 133-195 201-204 133-195 201-204 2	8 8 14 15 8 14 4	NADIR	231 14 30 46 62	163-170 194-201 59-61.65-75 55-69. 163-170 163-170 163-170 163-170 163-170 163-170 163-170 103-195 201-204	14 8 14 15 8 14 14 14 14 14 14 3 2 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (, night) Phillipine Sea (, night) South Atlantic (, Near-shore, E.Australia) South Atlantic (, Near-shore, W.Australia, night) Indian Ocean (, Near-shore, W.Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean, Near-shore, Night) Persian Gulf, Nathan (Off-shore, night) Persian Gulf, Nath (Off-shore, night) Buoys (Eel River CA) South Pacific Ocean South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Coral Sea (Doesen Sea) North Atlantic, West Africa (Near-shore, night) Coral Sea (Doe-ocean)
319	49	11/15/21	NADIR	215 231 14 30 46 62 78 94	163-170 194-201 39-61.65-75 55-69 163-170 29-40.49-50 167-170 31-41.45-49 193-195 201-204 30-34 103-195 201-204 201-204 205-208 161-168 206-208 161-168 206-208 161-168	8 8 114 15 8 8 14 4 4 4 5 5 5 5 5 3 8 8 1 1 9 9 3	NADIR	231 14 30 46 62 78	183-170 194-201 59-61.65-75 55-66 183-170 183-170 183-170 193-195 201-204 193-195 201-205 2	14 8 14 15 8 14 15 14 4 4 4 5 2 2 3 3 3 4 1 5 2 2 3 3 3 4 1 5 2 2 3 3 3 4 1 5 2 2 5 3 3 1 5 3 3 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (, night) Phillipine Sea (, night) South Atlantic (, Near-shore, E.Australia) South Atlantic (, Near-shore, W.Australia, night) Indian Ocean (, Near-shore, W.Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean, Arabian Sea, Oman (Off-shore, night) Persian Gulf, rain (Off-shore, night) Persian Gulf, rain (Off-shore, night) Buoys (Eel River CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) Coral Sea North Altantic, West Africa (Near-shore, night) Cureral Sea (Dper-ocean) Gueensland, Dunrobin, New South Wales Australia Papua New Guinea
319	49	11/15/21	NADIR	215 221 14 30 46 62 78 94 110	163-170 194-201 59-61,65-75 53-69 163-170 294-60,49-50 167-170 33-41,45-49 193-195 201-204 30-34 103-168 202 206-208 103-168 62 109.198 54-56 64 166,71-72,76-83 65-66,70-74 155-161	8 8 114 15 8 8 14 4 4 4 5 5 5 5 5 3 8 8 1 1 9 9 3	NADIR	231 14 30 46 46 47 48 48 49 49 49 49 49 49 49 49 49 49 49 49 49	183-170 194-201 194-201 195-61.65-75 155-69 153-170 224-0.04-50 167-170 133-145-49 133-195 201-204 133-195 201-204 133-195 201-204 133-195 206-208 161-168 206-208 161-168 206-208 161-67 155-161 155-161	14 8 8 14 15 8 4 4 4 3 4 4 5 5 5 8 8 8 8 8 9 9 9 7 7	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, E Australia) Indian Ocean (Near-shore W. Australia) Buoys (Cape FL); Chesapeake Bay Tunnel. MD Indian Ocean Arlington, TX, W. Kansas, Mexico Arabian Sea (Nama) Arlington, TX, W. Kansas, Mexico Arabian Sea (Nama) Buoys (Sei Niver GA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, West Africa (Near-shore, night) Coral Sea (North Allantic, West Africa (Near-shore, night) Coral Sea (North Allantic, South Africa (off-shore, night) Coral Sea (North Allantic, South Africa (Near-shore, night) Coral Sea (North Allantic, South Africa (Near-shore, night) Coral Sea (North Allantic, South Africa (Near-shore, night) Coral Sea (North Allantic, South Africa (off-shore, night) Allantic, South Africa (off-shore, night) Allantic, South Africa (off-shore, night) Allantic, South Africa (off-shore, night)
	49	11/15/21	NADIR	215 231 14 30 46 	163-170 194-201 194-201 194-201 195-201 195-201 195-170 193-170 193-141,45-49 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 195-161 190-198 54-56 01-66,21-72,76-83 54-56 01-66,21-72,76-83 54-56 195-161 209-215 2	8 8 114 15 8 8 14 4 4 4 5 5 5 5 5 3 8 8 1 1 9 9 3	NADIR	231 14 30 46 62 78 94 110	183-170 194-201 194-201 195-61,65-75 55-66, 163-170 193-170 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 195-168 54-56 61-66,71-72,76-83 55-66,70-74 155-161 209-215 209-215	14 8 8 14 15 5 14 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (, night) Phillipine Sea (, night) South Atlantic, (Near-shore, E.Australia) South Atlantic, (Near-shore, E.Australia) South Atlantic, (Sanger Shore, E.Australia) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arilington, TX, W.Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Persian Gulf, Aran (Off-shore, night) Buoys (Eel River CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (Off-shore, night) Mediterranean Sea (Off-shore, night) Mediterranean Sea (Off-shore, night) Coral Sea South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, West Africa (Near-shore, night) Cueenaland, Durobin, New South Wales Australia Papua New Guinea South Atlantic, South America (off-shore, night) South Stantic, South America (off-shore, night) Buoys (Night)
319	49	11/15/21	NADIR	215 231 14 30 46 62 78 94 110 126	163-170 164-201 59-61,65-75 53-69, 163-170 29-40,49-50 167-170 33-41,45-49 30-34 201-204 30-34 201-204 30-34 164-168 206-208 161-168 62 162 168 62 169-62 169-62 169-168 65 164-51 266-72 155-161 209-215 205	8 8 114 15 8 8 14 4 4 4 5 5 5 5 5 3 8 8 1 1 9 9 3	NADIR	231 14 30 46 46 47 48 48 49 49 49 49 49 49 49 49 49 49 49 49 49	183-170 194-201 194-201 194-201 194-204 194-204 194-204 193-195 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 164-168 206-208 161-168 206-208 164-168 206-208 164-168 206-208 164-168 206-208 165-165 165-167 195-168 165-167 195-168 165-172 165-168 165	14 3 3 14 15 3 3 4 4 4 4 4 5 2 2 3 3 3 3 4 5 2 2 3 3 4 4 5 5 2 2 5 3 3 4 4 7 7 7 7 5 6 6 6 7 7 7 7 7 7 7 7 7 7 7 7 7	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, E Australia) Indian Ocean (Near-shore W. Australia), night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TK, W. Kansas, Mexico Arabian Sea. Oman (Off-shore, night) Persian Gulf, Iran (Off-shore, night) Buoys (Eel Niver CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Ocrail Sea (Open-ocean) Deterniand, Dumobin, New South Wales Australia Papaa New Guinea South Atlantic, South America (off-shore, night) Deterniand, Dumobin, New South Wales Australia Papaa New Guinea
	49	11/15/21	NADIR	215 231 14 30 46 62 78 94 110 126	163-170 194-201 194-201 194-201 195-201 195-201 195-170 193-170 193-141,45-49 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 195-161 190-198 54-56 01-66,21-72,76-83 54-56 01-66,21-72,76-83 54-56 195-161 209-215 2	8 8 114 15 8 8 14 4 4 4 5 5 5 5 5 3 8 8 1 1 9 9 3	NADIR	231 14 30 46 62 78 94 110	183-170 194-201 194-201 195-61,65-75 55-66, 163-170 193-170 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 195-168 54-56 61-66,71-72,76-83 55-66,70-74 155-161 209-215 209-215	14 8 8 14 15 8 14 14 14 14 14 5 5 8 8 8 8 8 8 9 9 7 7 7 7 7 15 8 8 8 8 8 8 8 8 8 8 8 8 8	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, E Australia) Indian Ocean (Near-shore W. Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arabian Sea, Oman (Off-shore, night) Bersian Gul, Iran (Off-shore, night) Buoys (Eel River CA) South Atlantic, Coean South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Meenco, Gulf of Mesico, Teesas (night)
319	49	11/15/21	NADIR	215 231 14 30 46 62 78 94 110 126	163-170 164-201 59-61,65-75 53-69, 163-170 29-40,49-50 167-170 33-41,45-49 30-34 201-204 30-34 201-204 30-34 164-168 206-208 161-168 62 162 168 62 169-62 169-62 169-168 65 164-51 266-72 155-161 209-215 205	8 8 114 15 8 8 14 4 4 4 5 5 5 5 5 3 8 8 1 1 9 9 3	NADIR	231 14 30 46 62 78 94 110	183-170 194-201 194-201 194-201 194-204 194-204 194-204 193-195 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 164-168 206-208 161-168 206-208 164-168 206-208 164-168 206-208 164-168 206-208 165-165 165-167 195-168 165-167 195-168 165-172 165-168 165	14 3 3 14 15 5 8 14 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, E Australia) Indian Ocean (Near-shore W Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TX, W Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Persian Guif, Iran (Off-shore, night) Buoys (Ed Biver CA) South Atlantic, South Africa (off-shore, night) Metiterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Carel Sea South Atlantic, South Africa (off-shore, night) Carel Sea South Atlantic, South Africa (off-shore, night) Buoys Guinea South Atlantic, South America (off-shore, night) Buoys (Night) Thailand, Guif of Thailand, Malaysia Mexico, Guif of Mexico, Teexas (night)
319	49	11/15/21	NADIR	215 231 14 30 46 46 78 94 110 126 142	163-170 194-201 194-201 194-201 194-201 195-201 195-170 193-170 193-170 193-141,45-49 193-195 101-204 193-195 101-204 103-141 103-195 103-105 103-10	8 8 114 15 8 8 14 4 4 4 5 5 5 5 5 3 8 8 1 1 9 9 3	NADIR	231 14 30 46 62 78 94 110	183-170 194-201 194-201 195-61,65-75 55-66, 163-170 193-170 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 195-168 54-56 54-56 61-66,71-72,76-83 55-66 65-66,70-74 155-161 190-198 54-56 61-66,71-72,76-83 55-55 206-212 206-215 206	14 3 3 14 15 3 3 4 4 4 4 4 5 2 2 3 3 3 3 4 5 2 2 3 3 4 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South America Indan Ocean (Near-shore W. Australia, night) Buoys (Cape FL): Chesapeake Bay Tunnel, MD Indan Ocean (Near-shore W. Australia, night) Buoys (Cape FL): Chesapeake Bay Tunnel, MD Indan Ocean Arlington, TK, W. Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Persian Guif, Iran (Off-shore, night) Buoys (Eel River CA) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Coral Sea (Deno-Cean) Queensiand, Dunrobin, New South Wales Australia Papua New Guinea South Atlantic, South America (off-shore, night) Dunys (Night) Thailand, Guif of Thailand, Majaysia Mexico, Guif of Mexico, Teexas (night) India, Bay of Benjal (off-shore)
	49	11/15/21	NADIR	215 231 14 30 46 	163-170 164-201 59-61,65-75 53-69 163-170 29-40,49-50 167-170 33-41,45-49 133-41,45-49 130-34 201-204 30-34 161-168 206-208 161-168 206-208 161-168 262 190-198 54-56 66.71-72,76-83 65-66,70-74 155-161 209-215 45-53,58-63 197-204 45-53,58-63 197-204 45-55	8 8 114 15 8 8 14 4 4 4 5 5 5 5 5 3 8 8 1 1 9 9 3	NADIR	231 14 30 46 62 78 94 110 126 142	183-170 194-201 194-201 195-61.65-75 195-69 163-170 224-60.49-50 163-170 133-41.45-49 133-195 1201-204 133-195 1201-204 133-195 1202-120 133-195 1202-120 135-168 162-108 162-108 162-108 163-168 163-168 164-671-72.76-83 165-667 139-139 155-161 1209-215 165-657 137-204 165-358-63 137-204 155-55 107-204 155-55 155-	14 8 8 14 15 8 14 14 14 14 14 5 5 14 4 5 5 1 3 8 1 1 7 7 7 7 15 8 8 1 1 7 7 7 7 7 7	Coral Sea (night) Philipine Sea (night) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, E Australia) Buoya (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean (Near-shore W. Australia) Arlington, TX, W. Kansas, Mexico Arabian Sea (night) Buoya (Sea (Near-Shore, night)) Bersian Gulf, Iran (Off-shore, night) Buoya (Sea Nier CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Coral Sea (Dueronion, New South Wales Australia Papua New Guinea South Atlantic, South Africa (off-shore, night) Coral Sea (Duerobin, New South Wales Australia Papua New Guinea South Atlantic, South Africa (off-shore, night) Buoya (Night) India, Bay of Bengal (off-shore) Buoya (Night) India, Bay of Bengal (off-shore) Mexico, Sea (night) Iran
319	49	11/15/21	NADIR	215 231 14 30 46 62 78 94 110 126 142 158	163-170 194-201 194-201 194-201 194-201 194-201 195-201 195-170 192-40,49-50 107-170 193-41,45-49 193-195 101-204 103-314 104-108 105 105 105 105 105 105 105 105 105 105	8 8 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	NADIR	231 14 30 46 46 46 47 84 48 49 44 110 126 126 138	183-170 194-201 194-201 195-201 195-205 195-205 195-170 195-170 195-170 195-170 195-170 195-170 195-195 195	14 3 8 14 15 8 14 3 4 5 2 5 3 3 4 5 5 3 3 3 4 5 5 3 3 3 3 4 5 5 3 3 3 3 4 5 5 3 3 3 4 5 5 5 3 6 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	Coral Sea (.night) Philipine Sea (.night) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, W.Australia), Buoys (Cape FL); Chesapeake Bay Tunnel. MD Indian Ocean Arlington, TX, W.Kanasa, Mexico Arabian Sea, Oman (Off-shore, night) Persian Gul; Iran (Off-shore, night) Buoys (Tel River CA) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Coral Sea Ouerosiand, Durrobin, New South Wales Australia Papua New Guinea South Atlantic, South America (off-shore, night) Thailand, Guif of Thailand, Malaysia Mexico, Gulf of Mexico, Teesex (night) India, Bay of Bengai (off-shore) Buoys (Night) Itan Arabian Sea, Iran (Off-shore) Buoys (Night)
319	49	11/15/21	NADIR	215 231 14 30 30 46 	163-170 164-201 59-61,65-75 53-69 163-170 29-40,49-50 167-170 33-41,45-49 30-34 201-204 30-34 164-168 206-208 161-168 206-208 161-168 206-208 162-168 162-168 163-168 164-55 165-161 209-215 45-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 209-215 209 200 200 200 200 200 200 200 200 200	8 8 14 15 15 14 14 14 14 3 3 4 4 5 5 5 5 5 5 5 5 5 5 5 7 7 7 7 7 7 7	NADIR	231 14 30 46 46 52 78 54 54 54 54 54 54 55 55 55 55	183-170 193-201 194-201 195-61.65-75 195-69 163-170 194-049-50 165-170 133-41.45-49 133-41.45-49 130-34 164-168 105-168 165-16	14 38 14 15 15 14 15 14 14 14 14 15 25 25 25 25 26 27 77 77 77 77 77 77 77 75 10 29 20 20 20 20 20 20 20 20 20 20	Coral Sea (night) Filipine Sea (night) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore W.Australia), night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TK, W.Kansas, Mexico Arlington, TK, W.Kansas, Mexico Manaba Sea, Nama (Off-shore, night) Persian Gulf, Iran (Off-shore, night) Buoys (Eel River CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (Near-shore, night) Oral Sea(Den-ocean) Queensland, Dunrobin, New South Wales Australia Papaa New Guinea South Atlantic, South America (off-shore, night) Buoys (Night) Thailand, Gulf of Thailand, Malaysia Mexico, Gulf of Mexico, Texas (night) India, Bayod Benaja (off-shore) Buoys (Night) Iran Arabian Sea, Iran (Off-shore) Buoys (Night) Iran Botwana, Stou Africa
319		11/15/21	NADIR	215 231 14 30 46 46 46 46 46 46 46 46 46 46 46 46 46	163-170 163-170 154-201 154-201 155-61,65-75 155-69, 163-170 152-40,49-50 167-170 133-41,45-49 193-195 103-195 103-195 103-195 103-195 104-168 105,102 105,103 105,168 105,102 105,103 105,168 105,102 105,103	8 8 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	NADIR	231 14 30 46 	183-170 194-201 194-201 195-201 195-205 195-205 195-170 195-170 195-170 195-170 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 195-120 197-204 195-120 197-204 195-120 197-204 195-120 197-204 195-120 197-204 197-205 197-204 197-205 197-204 197-205 197-204 197-205 197-204 197-205 197-204 197-205 197-204 197-205 197-204 197-205 197-204 197-205 197-204 197-205 197	14 8 8 14 15 14 15 14 15 14 3 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5	Coral Sea (.night) Philipine Sea (.night) South Atlantic (.Near-shore, E.Australia) South Atlantic (.Near-shore, E.Australia) South Atlantic (.Near-shore, W.Australia, .night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arabian Sea, Oman (Off-shore, .night) Persian Gul; tran (Off-shore, .night) Buoys (Tele River CA) South Atlantic, Coean South Atlantic, Coean South Atlantic, Coean South Atlantic, South Africa (off-shore, .night) South Atlantic, South Africa (off-shore, .night) Coral Sea (Deensian), Durnobin, New South Wales Australia Papua New Guinea South Atlantic, South Africa (off-shore, .night) Coral Sea (Deensian), Durnobin, New South Wales Australia Papua New Guinea South Atlantic, South Africa (off-shore, .night) Thailand, Guif of Thailand, .Malaysia Mexico, Gulf of Holes(o, Teesea (.night)) Thailand, Guif of Thailand, .Malaysia Mexico, Suth Africa (.night) India, Bay of Bengal (off-shore) Buoys (Night) Iran. Arabian Sea, Iran (Off-shore) Botswana, South Africa
319	49	11/15/21	NADIR	215 231 14 30 46 46 46 46 46 46 46 46 46 46 46 46 46	163-170 164-201 59-61,65-75 53-69 163-170 29-40,49-50 167-170 33-41,45-49 30-34 201-204 30-34 164-168 206-208 161-168 206-208 161-168 206-208 162-168 162-168 163-168 164-55 165-161 209-215 45-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 30-31 209-215 34-55 206-212 209-215 209 200 200 200 200 200 200 200 200 200	8 8 14 15 15 14 14 14 14 3 3 4 4 5 5 5 5 5 5 5 5 5 5 5 7 7 7 7 7 7 7	NADIR	231 14 30 46 46 46 46 46 46 46 46 46 46	183-170 193-201 194-201 194-201 195-61.65-75 195-69 163-170 194-049-50 165-170 133-41.45-49 133-195 201-204 130-34 164-168 206-208 165-168 165-161 120-215 165-161 120-215 165-161 120-215 165-55 107-204 145-53.58-63 107-204 145-53 206-212 209-31 24-43.37-51 63-79 127-76-83 34-43.350-56	8 14 14 3 4 5 3 4 5 5 3 4 5 5 3 1 9 3 16 7 7 15 8 11 7 7 7 7 7 7 15 8 11 22 7 7 22 23 14 7 7 7 7 7 7 7 12 13 14 15 15 16 17	Coral Sea (night) Filipine Sea (night) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, E.Australia) South Atlantic (Oape FL), Chesapeake Bay Tunnel, MD Indian Ocean (Near-shore W.Australia, night) Buoys (Cape FL), Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TK, W.Kansas, Mexico Mathana, Sama (Off-shore, night) Persian Gulf, Iran (Off-shore, night) Buoys (Eel River CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (Near-shore, night) Coral Sea (Deno-cean) Cueensland, Durrobin, New South Wales Australia Papaa New Guinea South Atlantic, South America (off-shore, night) Dueensland, Durrobin, New South Wales Australia Papaa New Guinea South Atlantic, South America (off-shore, night) Mexico, Guif of Thailand, Malaysia Mexico, Guif of Mexico, Texas (night) Iran Arabian Sea, Iran (Off-shore) Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) (Mexico) Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) Iran Boyson (Night) (Mexico) Boyson (Night) Iran Boyson (Night) Iran Ira
319		11/15/21	NADIR	215 231 14 30 46 62 78 94 110 126 142 158 158 174 158	183-170 184-201 59-61,65-75 55-69, 163-170 29-40,49-50 167-170 33-41,45-49 193-195 201-204 30-34 72-74 184-168 206-208 161-168 62 100-198 54-56 62-66,70-74 155-161 129-198 54-56 164-55 155-161 129-215 164-55 164-55 164-55 165-161 172.76-83 65-55 206-212 203-215 204 24-53 205-72,76-81 24-53 205-72,76-81 24-53 205-72,76-81 24-53 205-72,76-81 24-53 205-72,76-81 24-53 205-72,76-81 24-53 205-72,76-81 24-53 205-72,76-81 24-53 205 212 235 24-23 255 265 275 275 275 275 275 275 275 275 275 27	8 8 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	NADIR	233 14 30 30 46 46 46 46 47 84 48 49 49 49 49 40 40 40 40 40 40 40 40 40 40	183-170 193-201 29-61.65-75 55-69 163-170 29-60.49-50 163-170 29-40.49-50 163-170 29-40.49-50 163-170 20-204 20-208 161-168 20-208 161-168 20-208 161-168 20-208 161-168 20-215 209-21	8 14 14 3 4 5 3 4 5 5 3 4 5 5 3 1 9 3 16 7 7 15 8 11 7 7 7 7 7 7 15 8 11 22 7 7 22 23 14 7 7 7 7 7 7 7 12 13 14 15 15 16 17	Coral Sea (njeth) Philipine Sea (njeth) South Atlantic (Near-shore, E.Australia, South Atlantic (Near-shore, E.Australia, Ilidan Ocean (Near-shore W.Australia, njeth) Buoys (Cape FL); Chesapeake Bay Tunnel, MD indian Ocean Arlington, TX, W.Kansas, Mexico Arlington, TX, W.Kansas, Mexico Mayos (Ed Biver CA) South Atlantic, South Africa (off-shore, njeth) Metiterranean Sea (njeth) South Atlantic, South Africa (off-shore, njeth) Metiterranean Sea (njeth) South Atlantic, South Africa (off-shore, njeth) Metiterranean Sea (njeth) South Atlantic, South Africa (off-shore, njeth) South Atlantic, South Africa (off-shore, njeth) South Atlantic, South Africa (off-shore, njeth) Coral Sea North Atlantic, South Africa (off-shore, njeth) Buoys (Ilight) Buoys (Njeth) Buoys (Njeth) Iraniand, Guif of Thailand, Malaysia Mexico, Guif of Mexico, Teexas (njeth) Iraniand, Bayo Bengal (off-shore) Buoys (Njeth) Iran Arabian Sea, Iran (Off-shore) Betovana, South Africa Niger 3 North Atlantic, West Africa (Near-shore) Betovana, South Africa Near Africa (Near-shore) Betovana, South Africa Niger 3 North Atlantic, West Africa (Near-shore) Coral Sea, W.Australia (Near-shore) Brauti, South Africa Near Alantic, West Africa (Near-shore) Coral Sea, W.Australia (Near-shore) Betzel, South Africa Near Africa (Near-shore) South Atlantic, West Africa (Near-shore) Coral Sea, W.Australia (Near-shore) South Atlantic, West Africa (Nea
319 339	49	11/15/21	NADIR	215 231 14 30 46 62 78 78 94 110 126 142 158 158 158 174 190 206 222 5	163-170 164-201 29-61,65-75 25-69 163-170 29-40,49-50 167-170 33-41,45-49 133-41,45-49 130-34 201-204 30-34 161-168 206 208 161-168 206 208 161-168 162 109.188 155 161 105.161 209-215 45-53 266-62 107.204 45-53 266-21 200-12 203-31 197.204 45-55 206-212 203-31 197.204 45-55 206-212 203-31 207.204 25-55 206-212 203-31 207.204 25-55 206-212 203-31 203-215 24-54 25-5 206-212 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-31 203-215 205-21 203-2	8 8 8 14 15 15 14 14 14 14 14 3 1 4 4 14 2 5 5 5 5 5 5 5 5 5 5 6 1 1 9 9 1 1 1 1 7 7 7 1 5 8 1 1 1 5 7 7 7 7 7 1 5 8 1 1 1 5 7 7 7 7 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 5 8 1 1 1 1	NADIR	2231 14 30 46 46 46 46 46 46 46 46 46 46	183-170 194-201 194-201 194-201 195-61,65-75 195-69 195-195 195-69 193-195 193-195 193-195 193-195 193-195 193-195 193-195 103-198 105-168 102 105-198 105-168 105-161 107-204 105-161 107-204 105-33,86-63 107-204 105-33,86-63 107-204 105-33,86-63 107-204 105-33,86-63 107-204 105-33,86-63 107-204 105-33,86-63 107-204 105-33,86-63 107-204 105-33,85-63 107-204 105-35,85 107-207-20 105-35,85 105	8 14 14 3 4 5 3 4 5 5 3 4 5 5 3 1 9 3 16 7 7 15 8 11 7 7 7 7 7 7 15 8 11 22 7 7 22 23 14 7 7 7 7 7 7 7 12 13 14 15 15 16 17	Coral Sea (, night) Fillipine Sea (, night) South Atlantic (Near-shore, E. Australia) South Atlantic (Near-shore, E. Australia) South Atlantic (Near-shore, K. Australia) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TX, W. Kansas, Mexico Marbian Sea (night) Buoys (Edi Niver GA) South Atlantic, South Africa (off-shore, night) Buoys (Edi Niver GA) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Desensiand, Dumobin, New South Wales Australia Papua New Guinea South Atlantic, South Africa (off-shore, night) Buoys (Night) Thalland, Suff of Thalland, Malaysia Mexico, Guilf of Mexico, Teexas (night) India, Bay of Bengal (off-shore) Botsman, South Africa North Albantic, West Africa (Near-shore) Botsman, South Africa Network (Night) India, Bay of Bengal (off-shore) Indian Cean, Madagasar (Off-shore) Botsman, South Africa Night, South Africa Night, South Africa Night, South Africa, Night) Brazil, South Atlantic, Garribean Sea, South Africa, South Africa, Night) Brazil, South Atlantic, Brazil, South Atlantic, Brazil, South Atlantic, South Atlantic, South Africa, South Pacific,
		11/15/21	NADIR	215 231 14 30 46 46 46 46 46 46 46 46 46 46 46 46 46	163-170 194-201 194-201 194-201 194-201 195-61,65-75 195-69, 163-170 192-40,49-50 105-170 193-195 105-120 103-34 193-195 103-195 103-195 103-195 104-168 105 105-161 105-16 105-16 105-16 105-16 105-16 105-16 105-16 105-16 105-16 105-16 105	8 8 8 14 15 14 15 14 14 14 14 14 14 14 15 15 14 4 1 14 14 14 14 14 14 14 14 14 14 14	NADIR	231 14 30 30 46 	183-170 194-201 194-201 195-201 195-201 195-205 195-205 195-170 195-170 195-170 195-170 195-170 195-195 195-195 195-195 195-195 195-195 195-195 195-195 195-195 195-195 195-195 195-195 195-195 195-195 195-195 195-195 197-204 195-195 197-204 195-195 197-204 195-195 197-204 195-195 197-204 197-204 195-195 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-205 197-204 197-204 197-204 197-204 197-204 197-204 197-204 197-205 197-204 197-205 197	5 14 14 14 14 3 3 4 5 5 5 8 8 9 9 9 10 9 9 11 16 7 7 7 7 7 7 7 7 7 7 7 7 7	Coral Sea (night) Fullipine Sea (night) South Atlantic (Near-shore, E Australia, South America South America South America South America South America Buoys (Cape FL); Chesapeake Bay Tunnel, MD indian Ocean Arlington, TK, W. Kansas, Mexico Arlington, TK, W. Kansas, Mexico Manager (Sea State State State State State Arlington, TK, W. Kansas, Mexico Mexico State State State South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Coral Sea South Atlantic, South America (off-shore, night) Buoys (Night) Thalland, Guif of Thalland, Malaysia Mexico, Suif of Mexico, Teexas (night)) Biola, Bay of Bergal (off-shore) Biosys (Night) Trailand, Sea, Jr Australia (Near-shore) Botswana, South Africa Night Atlantic, West Africa (Near-shore) Botswana, South Africa Night Atlantic, South Africa (Mear-shore) Botswana, South Africa Night Atlantic, South Africa Night Atlantic, South Africa Night Atlantic, West Africa (Near-shore) Botswana, South Africa Night Atlantic, South Africa (Mear-shore) Coral Sae, South Africa South Atlantic, South Africa South Atlantic, South Africa Night Atlantic, South Africa Night Atlantic, South Africa Night Atlantic, South Africa South Atlantic, South Africa South Atlantic, South Africa Night Atlantic, South Africa South Atlantic
319	49	11/15/21	NADIR	215 231 14 30 46 	163-170 164-201 159-61,65-75 15-69 163-170 129-40,49-50 167-170 133-41,45-49 130-34 103-195 201-204 103-195 201-204 103-195 201-204 103-195 10	8 8 8 14 15 14 15 14 14 14 14 14 14 14 15 15 14 4 1 14 14 14 14 14 14 14 14 14 14 14	NADIR	2231 14 30 46 46 46 46 46 46 46 46 46 46	183-170 193-201 194-201 194-201 195-20 195-25 195-69 163-170 29-40,49-50 167-170 133-41,45-49 133-41,45-49 133-34 201-204 133-34 134-168 206-208 135-168 120-206 208 135-168 120-206 120 130-198 155-161 120-215 155-161 120-215 155-161 120-215 130-31 137-204 45-55 206-212 130-31 137-204 45-55 206-212 130-31 137-204 45-55 206-212 130-31 137-30 44-35 205-212 130-31 139-139 137-30 44-47 138-170 133-199 137-39,44-47	5 14 14 14 14 3 3 4 5 5 5 8 8 9 9 9 10 9 9 11 16 7 7 7 7 7 7 7 7 7 7 7 7 7	Grail Sea (night) South Atlantic, (Near-shore, E.Australia, night) South Atlantic, (Near-shore, E.Australia, night) Iodian Ocean (Near-shore W.Australia, night) Buoy, (Cape FL), Chesapeake Bay Tunnel, MD Iidian Ocean Arlington, TX, W.Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Buoy, Elei River, CA) South Atlantic, South Africa (off-shore, night) Buoys (Eel River, CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea (night) South Atlantic, South Africa (off-shore, night) Coral Sea (Open ocean) Cuensiand, Durobin, New South Wales Australia Papua New Guinea South Atlantic, South America (off-shore, night) Coral Sea (Open ocean) Queensiand, Durobin, New South Wales Australia Papua New Guinea South Atlantic, South America (off-shore, night) Coral Sea (Open ocean) Queensiand, Curi of Thailand, Malaysia Mesico, Guif of Mexico, Teexas (night) Tina Arabian Sea, Iran (Off-shore) Buoys (Night) Tina Bouy, (Night) Tina Braul, Guith Africa Niger-3 North Atlantic, West Africa (Near-shore) Coral Sea, Madagascar (Off-shore) Braul, South Africa South Africa South Africa Sauth
319 319			NADIR	215 231 14 30 46 47 78 94 94 110 126 138 158 158 158 174 190 206 205 222 5	163-170 163-170 164-201 163-170 163-170 163-170 163-170 163-170 163-170 163-168 163-170 163-168 163-172 164-168 165 168 165 168 165 172 164-168 166 172 164-168 165 165 172 164-168 165 165 172 164-168 165 165 172 164-168 165 165 172 164-168 165 172 164-168 165 172 164-168 175 164 165 172 173 174 174 175 175 175 175 175 175 175 175 175 175	8 8 8 14 15 14 15 14 14 14 14 14 14 14 15 15 14 4 1 14 14 14 14 14 14 14 14 14 14 14	NADIR	231 14 30 30 62 78 62 78 94 110 110 1126 1126 1126 1126 128 128 129 129 129 120 120 120 120 120 120 120 120	183-170 194-201 194-201 194-201 194-201 195-201 195-20 195-170 193-145-49 193-195 193-195 193-195 193-195 193-195 195 195 195 195 195 195 195 195 195	5 14 14 14 14 3 3 4 5 5 5 8 8 9 9 9 10 9 9 11 16 7 7 7 7 7 7 7 7 7 7 7 7 7	Coral Sea (.night) Fillipine Sea (.night) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, K.Australia) South Atlantic (Near-shore, W.Australia, night) Buoys (Cape FL); Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TX, W.Kanasa, Mexico Arabian Sea, Oman (Off-shore, night) Buoys (Eel River CA) South Atlantic, Coean South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Coral Sea North Atlantic, South Africa (off-shore, night) Buoys (Night) Thailand, Guif of Thailand, Malaysia Mexico, Guir of Mexico, Teexas (night) Iradia, Bay of Bengal (off-shore) Buoys (Night) Iradian Ocean, Madagascar (Off-shore) Botswana, South Africa (Off-shore) Botswana, South Africa (Off-shore) Botswana, South Africa (Natsralia) South Atlantic, West Africa (Near-shore) Coral Sea, Y.Australia (Near-shore) Botswana, South Africa North Atlantic, West Africa (Near-shore) Botswana, South Africa North Atlantic, West Africa (Near-shore) Botswana, South Africa North Atlantic, South Africa South South Africa South Atlantic, South
		11/15/21	NADIR	215 231 14 30 46 47 78 94 94 110 126 138 158 158 158 174 190 206 205 222 5	163-170 164-201 59-61,65-75 53-63 163-170 29-40,49-50 167-170 33-41,45-49 103-195 201-204 30-34 103-195 201-204 30-34 164-168 206 208 161-168 206 208 161-168 206 208 161-168 206 21 209-115 205-216 209-215 205-212 209-215 205-516 129-215 206-212 209-215 205-516 129-204 45-55 206-212 209-215 209 209 209 209 209 209 209 209 209 209	8 8 8 14 15 14 15 14 14 14 14 14 14 14 15 15 14 4 1 14 14 14 14 14 14 14 14 14 14 14	NADIR	231 14 30 30 46 	183-170 193-201 194-201 194-201 195-61.65-75 195-69 163-170 194-049-50 165-170 133-41.45-49 133-195 201-204 130-34 164-168 206-208 165-168 165-161 169-120 164-168 206-208 165-168 165-161 165-161 165-161 165-161 165-161 165-161 165-162 165-161 165-163 177-204 45-53 206-212 20-31 144-43 175-10 188-170 163-79 47.55 163-79 47.55 163-79 47.55 163-79 47.55 163-79 175-204 155-161 188-170 163-199 175-26 175-20 136-41 195-102 195-102 195-102 195-105 1	5 14 14 14 14 3 3 4 5 5 5 8 8 9 9 9 10 9 9 11 16 7 7 7 7 7 7 7 7 7 7 7 7 7	Coral Sea (night) Filipine Sea (night) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, E.Australia, night) Buoya (Cape FL), Chesapeake Bay Tunnel, MD Indian Ocean (Near-shore W.Australia, night) Buoya (Cape FL), Chesapeake Bay Tunnel, MD Indian Ocean Arlington, TK, W.Kansas, Mexico Mathematical (Sea (Near-shore, night)) Persian Gulf, Iran (Off-shore, night) Buoya (Eel River CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (Near-shore, night) South Atlantic, South Africa (Near-shore, night) Coral Sea North Atlantic, South Africa (Near-shore, night) Coral Sea (Den-ocean) Cueenaland, Durrobin, New South Wales Australia Papaa New Guinea South Atlantic, South America (off-shore, night) Buoya (Night) Trailand, Guif of Thailand, Malaysia Mexico, Guif of Mexico, Texas (night) Iran Arabian Sea, Iran (Off-shore) Botwana, Scouth Africa North Atlantic, West Africa (Near-shore) Botwana, South Africa Narbia Alantic, West Africa (Near-shore) Botwana, South Africa North Atlantic, West Africa (Near-shore) Botwana, South Africa Arabian Sea, South Africa South Atlantic, West Africa (Near-shore) Botwana, South Africa Arabian Sea, Iran (Off-shore) Botwana, South Africa South Atlantic, South Africa South Atlantic, South Africa South Atlantic, South Africa South Sea, South America, South Pacific Bay of Bergal, Bangladesh (near-shore, night) Buoya
319	49		NADIR	215 231 14 30 46 62 78 94 94 110 126 138 142 158 158 158 158 158 158 158 158 158 158	183-170 184-201 59-61,65-75 53-69, 163-170 29-40,49-50 167-170 29-40,49-50 167-170 29-40,49-50 201-204 39-34 20-204 39-34 193-195 201-204 39-34 161-168 161-168 162 162 162 163 163 164-168 165-55 164-67 190-198 55-56 164-57 197-204 45-53 197-204 45-53 197-204 45-53 197-204 45-53 197-204 45-55 206-212 209-215 45-55 206-212 209 209 209 209 209 209 209 209 209 20	8 8 8 14 15 14 15 14 14 14 14 14 14 15 15 14 4 4 5 5 5 5	NADIR	231 14 30 30 62 78 62 78 94 110 110 1126 1126 1126 1126 128 128 129 129 129 120 120 120 120 120 120 120 120	183-170 193-201 194-201 194-201 194-201 194-201 195-170 29-40.49-50 165-170 29-40.49-50 165-170 20-30 20-30 201-204 20-34 20-34 164-168 206-208 161-168 206-208 161-168 206-208 161-168 206-208 162 190-198 554-56 164-671-72,76-83 265-66,70-74 155-161 209-215 206-212 209-215 206-212 209-215 24-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-55,58 206-212 209-215 24-43,47-51 26-47 197-204 45-55,58 206-212 209-215 24-43,47-51 26-47 195-202 26-44 158-170 159-202 26-41 166-173 192-193 26-30	5 14 14 14 14 3 3 4 5 5 5 8 8 9 9 9 10 9 9 11 16 7 7 7 7 7 7 7 7 7 7 7 7 7	Grail Sea (night) South Atlantic, (Near-shore, E.Australia, night) South Atlantic, (Near-shore, E.Australia, night) South Atlantic, (Near-shore, M.Australia, night) Buoy, (Cape FL); Chesapeak Bay Tunnel. MD indian Ocean (Near-shore, Neares) Arlington, TX, W.Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Buoy, ISel River, CA) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (Near-shore, night) Coral Sea (Deno Canal) Papua New Guinea Papua New Guinea North Atlantic, South America (off-shore, night) Buoy, (Night) Thailand, Guif of Thailand, Malaysia Mexico, Guif of Mexico, Teexas (night) Arabian Sea, Iran (Off-shore) Buoys (Night) Thailand, South Africa Niger-3 North Atlantic, West Africa (Near-shore) Grail Sea, W.Australia (Near-shore, night) Coral Sea, W.Australia (Near-shore, night) Boys (Night) Bauys (Night) Arabian Sea, India (Off-shore) Buoys (Night) Buoys (Night) Arabian Sea, India (Off-shore), Night) Buoys Arabian Sea, India (Off-shore), Night) Buoys Arabian Sea, India (Off-shore, night) Az Indian Cocan, Madagascar (Near-shore, night) Az
319 319			NADIR	215 231 14 30 46 46 46 46 46 46 46 46 46 46 46 46 46	183-170 184-201 194-201 194-201 194-201 194-201 192-61,65-75 193-61,65-75 193-193 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 201-204 193-195 101-108 101-108 102 103-198 103-108	8 8 8 14 15 14 15 14 14 14 14 14 14 15 15 14 4 4 5 5 5 5	NADIR	231 14 30 46 47 46 48 49 48 49 44 49 44 49 44 40 44 44 45 44 44 44 45 44 44 44	183-170 194-201 194-201 194-201 195-61,65-75 195-69 163-170 194-049-50 197-170 193-145-49 193-195 193-195 193-195 193-195 102-1204 103-34 164-168 1200-208 161-168 1200-208 161-168 1200-215 162-108 162-108 162-108 162-108 162-108 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-73,50-72,76-81 164-173 195-202 164-173 192-192 192-193 192-192	5 14 14 14 14 3 3 4 5 5 5 8 8 9 9 9 10 9 9 11 16 7 7 7 7 7 7 7 7 7 7 7 7 7	Coral Sea (night) Filipine Sea (night) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, Mustralia, night) Buoys (Cape FL); Chesapeake Bay Tunnel. MD Indian Ocean Arlington, TX, W.Kansas, Mexico Mabla Sea (Namas, Mexico Mabla Sea (Namas, Mexico South Atlantic, South Africa (off-shore, night) Buoys (Eel Kiver CA) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Mexico, Guife of Thailand, Malaysia Mexico, Guife of Mexico, Teexas (night) India, Bay of Bergal (off-shore) Boyos (Night) India, Matantic, West Africa (Near-shore) Boyos (Night) India, Bay of Bergal (off-shore) Botswana, South Africa North Atlantic, West Africa (Near-shore) Botswana, South Africa North Atlantic, West Africa (Near-shore) Botswana, South Africa North Atlantic, West Africa (Near-shore) Botswana, South Africa Boyos Arabian Sea, India (Off-shore, night) Arabian Sea, South Africa Boyos Arabian Sea, India (Off-shore, night) Arabian Sea, South Africa Boyos Arabian Sea, India (Off-shore, night) Boyos Arabian Sea, India (Off-shore, night) Boyos Arabian Sea, India (Off-shore, night) Botswana, South Africa Boyos Arabian Sea, India (Off-shore, night) Boyos Arabian Sea, India (Off-shore, night) Boyos Arabian Sea, India (Off-shore, night) Boyos Arabian Sea, India (Off-shore, night) Boyos Arabian Sea, India (Off-shore, night) Boyos Boyos Arabian Sea, India (Off-shore, night) Boyos Boyos Boyos Boyos Boyos Boyos Boyos Boyos Boyos Boyos Boyo
		11/15/21	NADIR	215 231 14 30 46 46 46 46 46 46 46 46 46 46 46 46 46	163-170 164-201 59-61,65-75 55-69, 163-170 29-40,49-50 163-170 29-40,49-50 167-170 33-41,45-49 103-195 201-204 30-34 72-74 164-168 206-208 161-168 206-208 161-168 206-208 161-168 206-208 163-168 206-207 190-198 55-51 206-212 205-215 206-212 205-21 205-212 205-21	8 8 8 14 15 15 8 14 14 14 14 3 3 3 5 5 5 3 3 8 8 3 3 8 8 3 3 8 8 10 9 9 9 3 3 8 8 10 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	NADIR	231 14 30 46 47 46 48 49 48 49 44 49 44 49 44 40 44 44 45 44 44 44 45 44 44 44	183-170 193-201 194-201 194-201 194-201 194-201 195-170 29-40.49-50 165-170 29-40.49-50 165-170 20-30 20-30 201-204 20-34 20-34 164-168 206-208 161-168 206-208 161-168 206-208 161-168 206-208 162 190-198 554-56 164-671-72,76-83 265-66,70-74 155-161 209-215 206-212 209-215 206-212 209-215 24-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-53,58-63 197-204 45-55,58 206-212 209-215 24-43,47-51 26-47 197-204 45-55,58 206-212 209-215 24-43,47-51 26-47 195-202 26-44 158-170 159-202 26-41 166-173 192-193 26-30	B 14 14 14 14 14 14 14 14 14 3 4 5 2 5 1 9 1 16 7 7 7 7 7 7 11 2 2 11 7 2 2 11 7 2 11 7 2 11 7 2 20 7 8 6 2 3	Coral Sea (night) Filipine Sea (night) South Atlantic (Near-shore, E Australia, South Atlantic (Near-shore, E Australia, South Atlantic (Near-shore, W. Australia, Buoys (Cape FL); Chesapeake Bay Tunnel, MD indian Ocean Arlington, TX, W. Kansas, Mexico Arlington, TX, W. Kansas, Mexico South Atlantic, South Africa (off-shore, night) Persian Guif, Iran (Off-shore, night) Buoys (Edi Biver CA) South Pacific Ocean South Atlantic, South Africa (off-shore, night) Metiterranean Sea (night) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (Near-shore, night) Coral Sea North Atlantic, South Africa (Near-shore, night) Coral Sea South Atlantic, South Africa (off-shore, night) Coral Sea South Atlantic, South Africa (Near-shore, night) Buoys (Itil Biver) South Atlantic, South Africa (Near-shore, night) Buoys (Night) Tantand, Guif of Thailand, Malaysia Mexico, Guif of Mexico, Teexas (night) Iran Arabian Sea, Iran (Off-shore) Botswana, South Africa Night) Broth Atlantic, West Africa (Near-shore) Coral Sea (Dengal (Near-shore) Coral Sea, W. Australia (Near-shore) Coral Sea, W. Australia (Near-shore) Coral Sea, South Africa Night) Buoys Arabian Sea, India (Off-shore) Arabian Sea, India (Off-shore, night) Buoys Arabian Sea, India (Off-shore, night) Buoys
				215 231 14 30 46 	163-170 164-201 59-61,65-75 53-69 163-170 29-40,49-50 167-170 33-41,45-49 133-41,45-49 130-34 201-204 203-24 204 205 201-204 205 201-204 205 206-208 206-208 206-208 206-208 206-208 206-208 207 207 207 207 207 207 207 207 207 207	8 8 8 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	NADIR	233. 14 30 30 46 46 46 46 46 46 46 46 46 46	183-170 184-201 184-201 184-201 185-175 185-69 163-170 184-170 184-170 184-170 184-170 183-145 183-195 183-195 183-195 183-195 183-195 183-195 184-195 185-161 185-161 185-161 185-161 185-161 185-161 185-163 197-204 45-55 197-207 45-50 197-207 45-50 197-207 45-50 197-207 45-50 197-207 197-107	5 14 14 14 14 3 3 4 5 5 5 8 8 9 9 9 10 9 9 11 16 7 7 7 7 7 7 7 7 7 7 7 7 7	Coral Sea (night) Filipine Sea (night) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, E Australia) South Atlantic (Near-shore, Mustralia, night) Buoys (Cape FL); Chesapeake Bay Tunnel. MD Indian Ocean Arlington, TX, W.Kansas, Mexico Mabla Sea (Namas, Mexico Mabla Sea (Namas, Mexico South Atlantic, South Africa (off-shore, night) Buoys (Eel Kiver CA) South Atlantic, South Africa (off-shore, night) South Atlantic, South Africa (off-shore, night) Mediterranean Sea (night) South Atlantic, South Africa (off-shore, night) Mexico, Guife of Thailand, Malaysia Mexico, Guife of Mexico, Teexas (night) India, Bay of Bergal (off-shore) Boyos (Night) India, Matantic, West Africa (Near-shore) Boyos (Night) India, Bay of Bergal (off-shore) Botswana, South Africa North Atlantic, West Africa (Near-shore) Botswana, South Africa North Atlantic, West Africa (Near-shore) Botswana, South Africa North Atlantic, West Africa (Near-shore) Botswana, South Africa Boyos Arabian Sea, India (Off-shore, night) Arabian Sea, South Africa Boyos Arabian Sea, South Africa (Near-shore, night) Boyos Arabian Sea, India (Off-shore, night) Boyos Arabian Sea, India (Off-s
				215 221 221 231 30 30 62 62 78 94 126 126 126 126 122 222 266 222 25 37 37	163-170 163-170 164-201 163-170 163-170 163-170 163-170 163-170 163-170 163-170 163-168 163-170 163-168 173-168 163-173 163-168 173-168 163-173 163-168 173-168 163-173 163-168 173-168 163-173 163-168 173-168 163-173 163-17	8 8 8 14 15 15 8 14 14 14 14 3 3 3 5 5 5 3 3 8 8 3 3 8 8 3 3 8 8 10 9 9 9 3 3 8 8 10 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	NADIR	233. 14 30 30 62 78 62 78 63 94 110 126 110 126 110 126 127 137 138 174 190 206 21 1 37 5 33 5 5 5 5 5 5 5 5 5 5 5 5 5	183-170 194-201 194-201 194-201 195-61,65-75 195-69 163-170 194-049-50 197-170 193-145-49 193-195 193-195 193-195 193-195 102-1204 103-34 164-168 1200-208 161-168 1200-208 161-168 1200-215 162-108 162-108 162-108 162-108 162-108 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-53,58-63 197-204 164-73,50-72,76-81 164-173 195-202 164-173 192-192 192-193 192-192	B 14 14 14 14 14 14 14 14 14 3 4 5 2 5 1 9 1 16 7 7 7 7 7 7 11 2 2 11 7 2 2 11 7 2 11 7 2 11 7 2 20 7 8 6 2 3	Coral Sea (night) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, E.Australia) South Atlantic (Near-shore, E.Australia) Boyo (Cape FL) (Chesapeake Bay Tunnel, MD Boyo (Cape FL) (Chesapeake Bay Tunnel, MD Atlington, TX, W.Kansas, Mexico Arabian Sea, Oman (Off-shore, night) Persian Guid, Iran (Off-shore, night) Boyos (Ed River CA) South Atlantic, South Africa (off-shore, night) Metiterranean Sea (night) South Atlantic, South Africa (Off-shore, night) Metiterranean Sea (night) South Atlantic, South Africa (Inf-shore, night) South Atlantic, South Africa (Inf-shore, night) Caral Sea (Den-ocean) Causensland, Durrobin, New South Wales Australia South Atlantic, South America (off-shore, night) Boyos (Night) Thailand, Guid of Thailand, Malaysia Mexico, Guif of Mexico, Feexas (night) South Atlantic, West Africa (Near-shore) Boyos (Night) Trainand, Sea, Iran (Off-shore) Boyos (Night) Boyos South Atlantic, West Africa (Near-shore) Rorris, South Africa Niger-3 South Atlantic, West Africa (Near-shore) Rorris, South Africa Niger-3 Boyos Mathatic, West Africa (Near-shore) Rorris, South Africa Niger-3 Boyos (Night) Boyos Arabian Sea, India (Off-shore, night) Boyos Arabian Sea, India (Off-shore, night) Boyos Boyos Boyos Boyos Boyos Boyos Boyos Boyos Boyos Boyos Boyos

Figure A1. Cont.

320	50	11/16/21	NADIR	100	21-25	5	NADIR	101	21-25	5	
	1				47,50	2				2	
	******	~~~~~	****			23				23	No.Australia
·····				116		26			17-42	26	No.Australia
				110							
						20				20	
	Į				107	1				1	
	1		NADIR		191-204	14	OFF NADIR			14	Buoy (Night)
	1			132	15-49	35	NADIR	133	15-49	35	Pacific Ocean, Mexico (Off-shore, Night)
					106-110	5			106-110	5	
	1		NADIR		194-199	6	OFF NADIR		194-199	6	
	******			148		34	NADIR			34	
*****	*******	****			107109					3	*****
)										
	ļ			164		46	J			46	Yemen, Arabia
						4				4	
					109-110,119-122	6			109-110,119-122	6	
	1		OFF-NADIR	180	15-55	41	NADIR	181	15-55	41	Libya 2
	1	(74-77,98	5			74-77,98	5	
	******				109-117,120-121	11				11	
	<u> </u>			196		44				44	La Crau, Algeria
	******	*****		190	108-113,118-119	444 0					La Ciau, Aigena
						8	ļ			8	
			OFF-NADIR	212	65-67	3	NADIR		65-67	3	South Atlantic, Brazil (Near-shore)
	1					14				14	
	1		OFF-NADIR	228	67-72	6	NADIR	229	67-72	6	Brazil
	1	r	NADIR		91-98	8	r		91-98	8	
	1		****			10				10	
	1		NADIR		169-170	2	OFF-NADIR		169-170	2	Indian Ocean Austrialia (Off-shore night)
******	ł	}	OFF-NADIR	11	28-44	17	NADIR	12	28-44	2 17	Indian Ocean, Austrialia (Off-shore, night) Buoys (Portand ME, Montauk NY)
),			11		1/	NADIK			1/	Budys (Portand IVIE, Montauk IVY)
	J	ļ	NADIR		110-114,119-120	7	ļ		110-114,119-120	7	
			OFF-NADIR	27	33-49	17		28	33-49	17	
	1		NADIR		109-117,121-122	11			109-117,121-122	11	
	1		NADIR		193-196	4	OFF-NADIR		193-196	4	Indian Ocean, Yemen (Off-shore, night)
	******		OFF-NADIR	43			NADIR	44		10	MN, Mineral Wells TX
	\$~~~~~~~~~~~~~	*****	NADIR		76,110-116	8				8	
	ļ		NADIK	59		0				0	
				59	15-19	5			15-19	5	
	1		OFF-NADIR		59-65	7	NADIR			7	South Pacific Ocean
			NADIR		111-118	8			111-118	8	
	1	(75	15-22	8		76	15-22	8	
	1				42,67-71	6			42,67-71	6	
	******				84,90-95,108-109	0				9	
	f~~~~~~~~~~~	*****	ALA DID			17	OFF-NADIR				South Atlantic West Africa (Near shore Night)
	}		NADIR			17				17	South Atlantic, West Africa (Near-shore, Night)
				91	15-17	3				3	
			OFF-NADIR		71-76	6	NADIR			6	Australia
321	51	11/17/21	NADIR		106-107	2			106-107	2	
	1			107	15-19,25-36	17		108	15-19,25-36	17	
	1		OFF-NADIR		66-69		NADIR			4	Australia
	1		NADIR		106-107	2			106-107	2	
*****	******	*****			157-159	2	OFF-NADIR		157-159	2	South Atlantic, Uraguay (Off-shore, Night)
	<u> </u>	ŀ					*****				
)		OFF-NADIR		201-217	17	NADIR		eren eren eren er er er er er er	17	North Altantic (Night)
	1		NADIR	123		33				33	
L	1	I			106-109	4	L		106-109	4	
[1		OFF-NADIR		190-206	17	NADIR		190-206	17	Buoys, North Pacific (Night)
	1		NADIR	139	Tererenerererererererere	31		140	erenererererererererererer	31	
h	1					5	}		94,106-109	5	
)çını en en en en en en										Durun (Laba Takan CA, Davidia Ossan L'
	<u> </u>	ļ	NADIR			14	OFF-NADIR		205-218	14	Buoys (Lake Tahoe CA, Pacific Ocean; Night)
)			155	anaranananananananananana	8		156	16-23	8	
	1		OFF-NADIR		43-50	8	NADIR		43-50	8	Arabian Sea (Off-shore)
1	1		NADIR			10			70-79	10	
Г	T	r	[r		4	r		108-110,122	4	
*****	1		OFF-NADIR	171		15	NADIR	172	29-43	15	Saudi Arabia
	f		NADIR			14			63-75.84	14	
	}		INAUIK						******	******	
	1	ļ		J		8				8	
1			OFF-NADIR	187	30-46	17	NADIR		30-46	17	Niger (Niger-2)
	[109-111	3	
	<u> </u>		NADIR		109-111	3					
••••••					109-111 116	3 1			116	1	
·····			NADIR		116	1	NADIR		116	1	Mauritania-N Atlantic
			NADIR OFF-NADIR	203	116 38-54	3 1 17 7	NADIR		116 38-54	1 17 7	Mauritania-N.Atlantic
••••••••••••••••••••••••••••••••••••••			NADIR	203	116 38-54 164-170	1 17 7	NADIR OFF-NADIR	204	116 38-54 164-170	7	Mauritania-N.Atlantic Tasmanian Sea, Australia (Near-shore, Night)
			NADIR OFF-NADIR		116 38-54 164-170 62-76	1 17 7 15		204	116 38-54 164-170 62-76	7 15	
			NADIR OFF-NADIR NADIR	203 219 2	116 38-54 164-170 62-76 27-28,48-71	1 17 7 15 26	OFF-NADIR	204 220 3	116 38-54 164-170 62-76 27-28,48-71	7 15 26	Tasmanian Sea, Australia (Near-shore, Night)
			NADIR OFF-NADIR NADIR OFF-NADIR	203 219 2	116 38-54 164-170 62-76 27-28,48-71 28-44	1 17 7 15 26 17	OFF-NADIR NADIR	204	116 38-54 164-170 62-76 27-28,48-71 28-44	7 15	Tasmanian Sea, Australia (Near-shore, Night) Buoys (Guif, Lake Erie, Penacola)
			NADIR OFF-NADIR NADIR	203 219 2	116 38-54 164-170 62-76 27-28,48-71 28-44 195	1 17 7 15 26	OFF-NADIR	204 220 3	116 38-54 164-170 62-76 27-28,48-71 28-44 195	7 15 26 17 1	Tasmanian Sea, Australia (Near-shore, Night)

Figure A1. Summary of Tandem flying pair acquisitions.

References

- 1. NASA Technical Memorandum (TM). *Landsat-4 World Reference System (WRS) Users Guide October 1982;* Doc ID:19830013208, NASA-TM-85284; NASA Technical Memorandum: Washington, DC, USA, 2013.
- 2. U.S. Geological Survey, WRS-2 Path/Row (Landsats 4, 5 and 7) and UTM Zones. Available online: https://landsat.usgs.gov/ sites/default/files/images/wrs2.gif (accessed on 1 October 2022).
- 3. Teillet, P.; Barker, J.; Markham, B.; Irish, R.; Fedosejevs, G.; Storey, J. Radiometric cross-calibration of the Landsat-7 ETM+ and Landsat-5 TM sensors based on tandem data sets. *Remote Sens. Environ.* **2001**, *78*, 39–54. [CrossRef]
- 4. Mishra, N.; Haque, M.O.; Leigh, L.; Aaron, D.; Helder, D.; Markham, B. Radiometric cross calibration of Landsat 8 Operational Land Imager (OLI) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+). *Can. J. Remote Sens.* **2014**, *6*, 12619–12638. [CrossRef]
- Mann, L.M.; Nicholson, A.M.; Good, S.M.; Woodard, M.A. Landsat Data Continuity Mission (LDCM) Ascent and Operational Orbit Design. In Proceedings of the 22nd AAS/AIAA Space Flight Mechanics Meeting, AAS 12-254, Charleston, SC, USA, 29 January–2 February 2012.
- 6. Gross, G.; Helder, D.; Begeman, C.; Leigh, L.; Kaewmanee, M.; Shah, R. Initial Cross-Calibration of Landsat 8, and Landsat 9 Using the Simultaneous Underfly Event. *Remote Sens.* **2022**, *14*, 2418. [CrossRef]
- Choate, M.J.; Rengarajan, R.; Storey, J.C.; Lubke, M. Landsat 9 Geometric Characteristics Using Underfly Data. *Remote Sens.* 2022, 14, 3781. [CrossRef]