Ocean Exploration and Research

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MAPPING DATA ACQUISITION AND PROCESSING SUMMARY REPORT

CRUISE EX-16-01: Transit and Mission Patch Test (Mapping)

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1. Introduction

The NOAA Office of Ocean Exploration and Research is the only federal program dedicated to exploring our deep ocean, closing the prominent gap in our basic understanding of U.S. deep waters and seafloor and delivering the ocean information needed to strengthen the economy, health, and security of our nation.

Using the latest tools and technology, OER **explores** previously unknown areas of our deep ocean, making discoveries of scientific, economic, and cultural value. Through live video streams, online coverage, training opportunities, and real-time events, OER allows scientists, resource managers, students, members of the general public, and others to actively **experience** ocean exploration, expanding available expertise, cultivating the next generation of ocean explorers, and engaging the public in exploration activities. From this exploration, OER makes the collected data needed to **understand** our ocean publicly available, so we can maintain the health of our ocean, sustainably manage our marine resources, accelerate our national economy, and build a better appreciation of the value and importance of the ocean in our everyday lives.

Contents

2. Report Purpose

The purpose of this report is to briefly describe the acoustic seafloor and water-column mapping data collection and processing methods utilized during the transit and mission patch test expedition EX-16-01, and to present a summary of the overall mapping results and mapping related cruise activities. A detailed description of the *Okeanos Explorer's* mapping capabilities is available in the 2016 NOAA Ship *Okeanos Explorer* Mapping Systems Readiness Report, available in the NOAA Central Library.

3. Cruise Objectives

EX-16-01 was conducted in support of the **C**ampaign to **A**ddress **P**acific Monument **S**cience, **T**echnology, and **O**cean **NE**eds (CAPSTONE), a multi-year effort focused on the systematic collection of baseline information in support of scientific and management needs within and in the vicinity of monuments and marine protected areas in the central and western Pacific. This cruise focused on conducting shakedown, testing, and calibration of the existing and newly installed mapping systems onboard the Okeanos Explorer in preparation for the 2016 field season. The expedition commenced on January 12th from Alameda, CA and concluded on February 7th in Honolulu, HI.

During the preceding drydock period a number of new systems were installed or upgraded on the ship, including a new Very Small Aperture Terminal (VSAT) antenna, a Keyboard-Video-Monitor (KVM) system, a Doppler speed log, a POSMV inertial measurement and positioning system, four EK 60 split-beam sonars, two ADCPs, a digital file storage system, and an UnderwayCTD.

The complete objectives for this cruise are detailed in the EX-16-01 Project Instructions, which are archived in the NOAA Central Library at http://dx.doi.org/10.7289/v5513w71.

4. Summary of Mapping Results

EX-16-01 mapped 22,784 square kilometers of seafloor during the 19 days-at-sea (Figure 1 and Table 1).

Cruise Overview Map

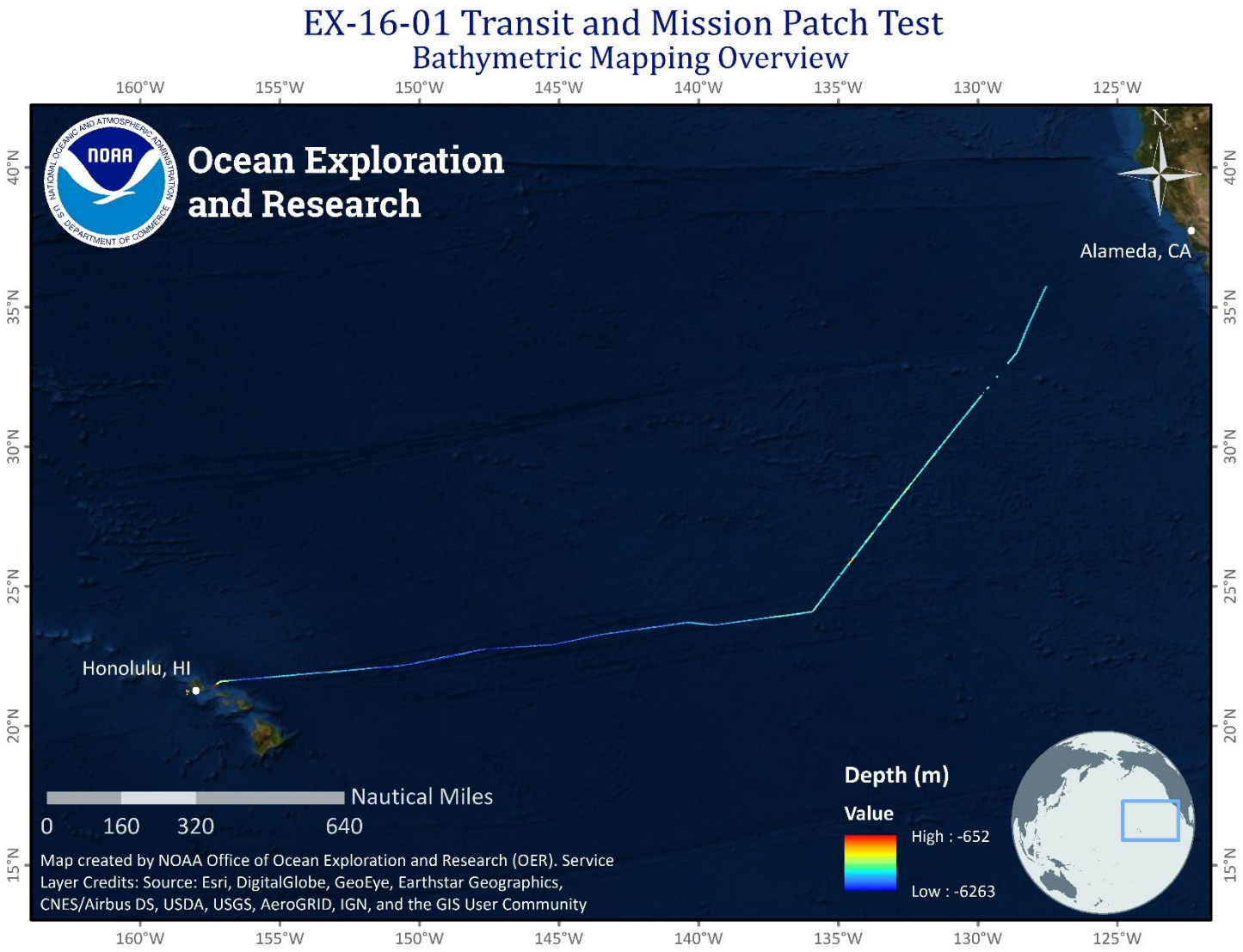

Figure 1. Overview of bathymetric mapping coverage completed during EX-16-01. Map generated in ArcMap.

5. Mapping Statistics

Table 1. Summary statistics of ocean mapping work completed during EX-16-01.

Dates of cruise	January 20 – February 7, 2016
Ship's draft: Start of cruise (01/19/2016) End of cruise (02/07/2016)	 Fore: 15' 0'', Aft STBD: 14' 8" Fore: 15' 3"; Aft STBD: 14' 2"
Linear kilometers of survey with EM 302	3,834.5
Square kilometers mapped with EM 302	22,784
Number / Data Volume of EM 302 raw bathymetric / bottom backscatter multibeam files (.all)	234 files/ 13.1 GB
Number / Data Volume of EM 302 water column multibeam files	234 files / 48.4 GB
Number / Data Volume of EK 60 water column split beam files (.raw)	120 / 22.6 GB
Number / Data Volume of sub-bottom sonar files (.segy, .kea, .keb)	318 / 2.93 GB
Number of XBT casts	34
Number of CTD casts (including test casts)	7

6. Mapping Sonar Setup

Kongsberg EM 302 Multibeam Sonar

NOAA Ship *Okeanos Explorer* is equipped with a 30 kilohertz (kHz) Kongsberg EM 302 multibeam sonar capable of detecting the seafloor in up to 10,000 meters of water and conducting productive mapping operations in 8,000 meters of water. The system generates a 150° beam fan containing up to 432 soundings per ping in waters deeper than 3300 meters. In waters shoaler than 3300 meters the system is operated in dual swath mode, and obtains up to 864 soundings per ping by generating two swaths per ping cycle. The multibeam sonar is used to collect seafloor bathymetry, seafloor backscatter, and water column backscatter data. Backscatter represents the strength of the acoustic signal reflected from a target, such as the seafloor or bubbles in the water column. The system is patch tested annually and the results are reported in the annual readiness report. The 2016 NOAA Ship *Okeanos Explorer* Mapping Systems Readiness Report is available in the NOAA Central Library.

Simrad EK 60 Split-beam Sonars

The ship operated five Simrad EK 60 split-beam fisheries sonars: 18 kHz, 38 kHz, 70 kHz, 120 kHz, and 200 kHz. These sonars are quantitative scientific echosounders calibrated to identify the target strength of water column acoustic reflectors - typically biological scattering layers, fish, or gas bubbles – providing additional information about water column characteristics and anomalies.

Knudsen 3260 Sub-bottom Profiler

The ship is equipped with a Knudsen 3260 sub-bottom profiler that produces a frequency-modulated chirp signal with a central frequency of 3.5 kHz. This sonar is used to provide echogram images of shallow geological layers underneath the seafloor to a maximum depth of approximately 80 meters below the seafloor. The sub-bottom profiler is normally operated to provide information about sub-seafloor stratigraphy and features. The data generated by this sonar are fundamental to helping geologists interpret the shallow geology of the seafloor.

Teledyne ADCPs

The ship utilizes a 38 kHz Teledyne RDI Ocean Surveyor Acoustic Doppler Current Profiler (ADCP), with a ~1000 meter range; and a 300 kHz Teledyne RDI Workhorse Mariner ADCP, with a ~70 meter range. The ADCPs gather data prior to ROV deployments in order to assess currents at the dive site in support of safe operations. They are kept running throughout the ROV dives. The ADCPs are typically not run concurrently with the other sonars during mapping operations due to interference issues.

7. Data Acquisition Summary

Mapping operations included data collection via the EM 302 multibeam sonar, EK 60 split-beam (18, 38, 70, 122, and 200 kHz) sonars, and Knudsen 3260 sub-bottom profiler. Data were collected by each sonar concurrently during the transits.

Survey lines were planned to either maximize edge matching of existing bathymetric data, or to fill data gaps in areas with existing bathymetric coverage. In regions with no existing data, lines were planned to optimize potential exploration discoveries.

Throughout the cruise multibeam data quality was monitored in real time by acquisition watchstanders. Ship speed was adjusted to maintain data quality as necessary, and line spacing was planned to ensure at least ¼ swath width overlap between lines. Cutoff angles in the multibeam acquisition software Seafloor Acquisition System (SIS) were generally left wide open for maximum exploration data collection and routinely adjusted on both the port and starboard side to ensure the best data quality and coverage.

Multibeam data received real time surface sound velocity corrections via the RESON SVP-70 at the sonar head, as well as through profiles generated from Expendable Bathythermographs (XBTs) conducted at intervals no greater than 6 hours, as dictated by local oceanographic conditions. RESON sound velocity values were constantly compared against secondary derived sound speed values from the ship's onboard thermosalinograph flow-through system as a quality assurance measure.

Simrad EK 60 split-beam water column sonar data were collected throughout the majority of the cruise (Figure 2). Data were monitored in real time for quality but were not post-processed.

Knudsen 3260 sub-bottom profiler data were also collected during the majority of the cruise (Figure 3). Data were monitored in real time for quality but were not post-processed.

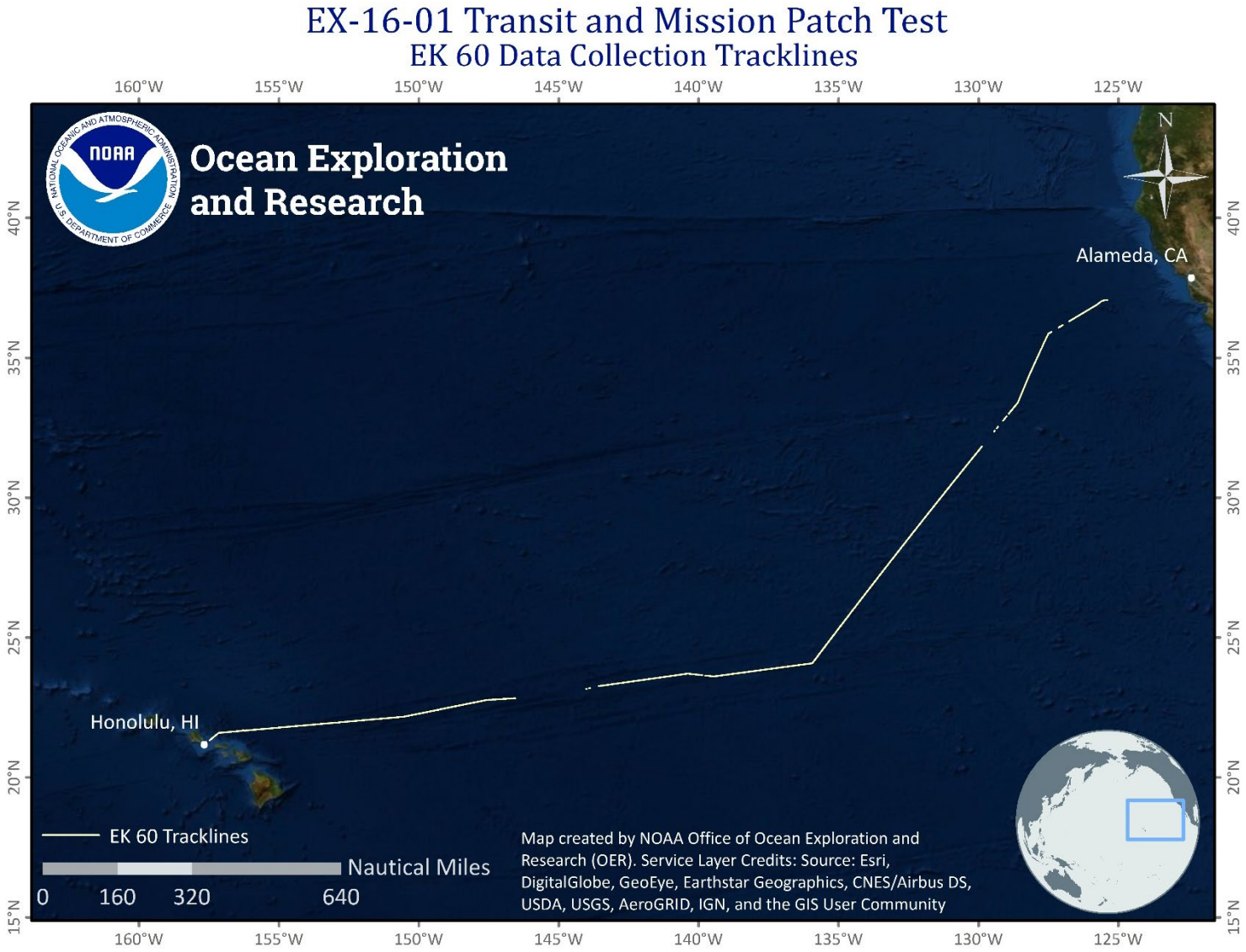

Figure 2. Simrad EK 60 split-beam sonar data tracklines (in yellow) collected during EX-16-01. Map generated in ArcGIS.

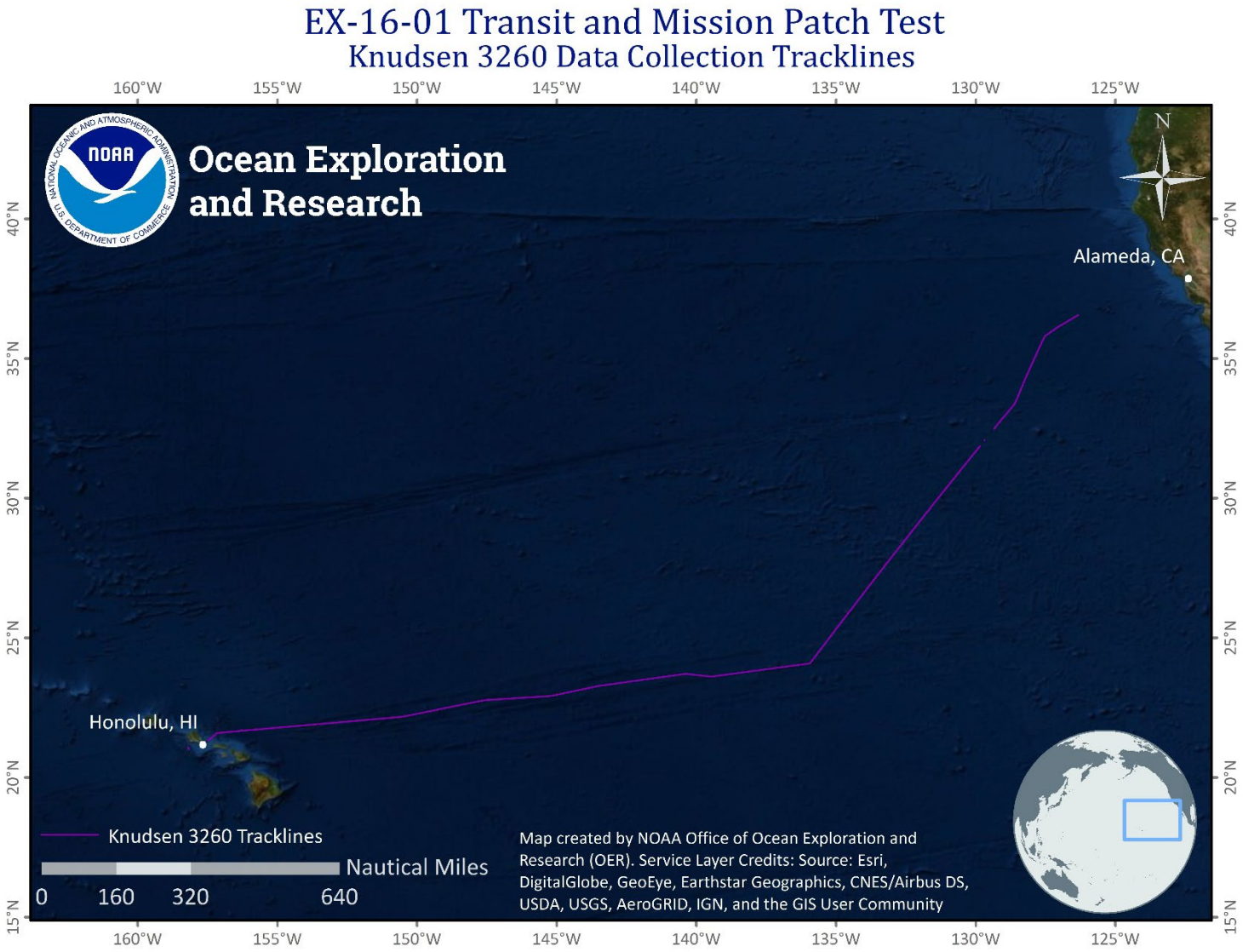

Figure 3. Knudsen 3260 sub-bottom profiler data tracklines (in purple) collected during EX-16-01. Map generated in ArcGIS.

8. Multibeam Sonar Data Quality Assessment and Data Processing

Figure 4 shows the multibeam data processing workflow for this cruise. EM 302 Built-in Self Tests (BISTs) were run throughout the cruise to monitor multibeam sonar system status and are available as ancillary files in the sonar data archives. Raw multibeam bathymetry data files were acquired by SIS, and were imported into CARIS. In CARIS, attitude and navigation data stored in each file were checked, and erroneous soundings were manually removed using CARIS Swath Editor and Subset Editor. With the vast majority of surveying completed in deep water, depth measurements were not adjusted for tides, as they are an essentially insignificant percent of the overall water depth. Data cleaning projects were in UTM zone projections for the operations area. Final data products were exported and archived as field geographic WGS84 coordinate reference frame (i.e., unprojected).

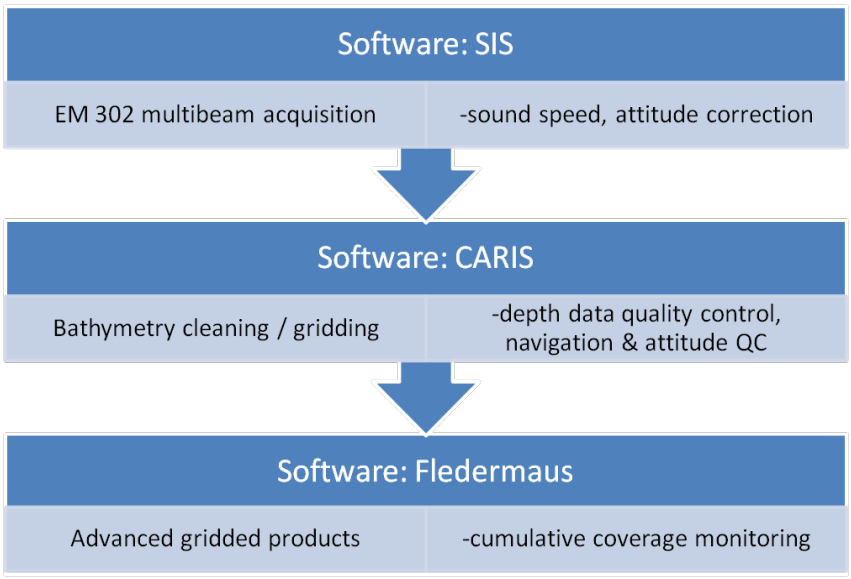

Figure 4. Shipboard multibeam data processing workflow.

9. Data Archival Procedures

All mapping data collected by the NOAA Ship *Okeanos Explorer* are archived and publicly available within 90 days of the end of each cruise via the National Centers for Environmental Information (NCEI) online archives. The complete data management plan (which describes the raw and processed data formats produced for this cruise) is available as an appendix in the EX-16-01 project instructions, available in the NOAA Central Library. Ancillary and supporting files are archived with the sonar datasets. These include:

EM 302 Multibeam bathymetry and bottom backscatter dataset:

- Mapping watch stander log
- Weather log
- Sound velocity profile log
- Multibeam acquisition and processing log
- Built-In-System-Tests (BISTs)
- Processor Unit Parameters
- Text files of telnet sessions on the EM 302 transceiver unit (TRU)

Simrad EK split-beam water column dataset:

- Mapping watch stander log
- Weather log
- EK data log

Knudsen 3260 Sub-bottom Profiler dataset:

- Mapping watch stander log
- Weather log
- Sub-bottom data log

EM 302 Multibeam water column dataset:

- Mapping watch stander log
- Weather log
- Sound velocity profile log
- Multibeam acquisition and processing log
- Built-In-System-Tests (BISTs)
- Processor Unit Parameters

- Text files of telnet sessions on the EM 302 transceiver unit (TRU)
- Multibeam water column data review log if data were reviewed for presence of seeps in Fledermaus MidWater

EM 302 and EK 60 water column data are available in the NCEI Water Column Sonar Archives: https://www.ngdc.noaa.gov/maps/water_column_sonar/index.html (last accessed 01/15/20). EM 302 http://doi.org/10.7289/V5PN93VQ and EK 60 http://doi.org/10.7289/V5TD9VJM.

Sub-bottom data, supporting data, and informational logs are available in the NCEI Data Archives accessible at https://maps.ngdc.noaa.gov/viewers/geophysics/ (last accessed 01/15/20).

EM 302 bathymetry data, supporting informational logs, and ancillary files are available in the NCEI Data Archives accessible at https://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html (last accessed 01/15/20).

10. Cruise Calendar

All times listed are local ship time, which was UTC -8 hours at the beginning of the cruise. Gradual changes to shift to Hawaii time throughout the cruise are noted in bold below.

January – February 2016

Sun	Mon	Tues	Wed	Thur	Fri	Sat
			20 Ship underway for sea trials in San Francisco Bay. GAMs calibration conducted. ADCP testing conducted.	21 Ship moved from Pier 19 to the Exploratorium. Sailing delayed due to weather.	22 Sailing delayed due to weather. Sonars tested alongside.	23 Ship underway at 1700.
24 Transit mapping.	25 Transit mapping.	26 Transit mapping. **-1hr time change to UTC -9**	27 Transit mapping.	28 Transit mapping.	29 Transit mapping. **-1hr time change to UTC -10**	30 Transit mapping.
31 Transit mapping.	1 Transit mapping.	2 Transit mapping. Deployed EX1 for personnel transfer in Maunalua Bay.	3 ADCP and EK 60 calibrations.	4 ADCP survey acceptance testing. EK 60 calibrations.	5 EM 302 patch test conducted. EK 60 noise level testing conducted.	6 EK 60 noise level testing. Patch test continued. ADCP testing.
7 Ship moored at pier F10 in Pearl Harbor at 0830.						

11. Daily Cruise Log Entries

Generated from the daily expedition situation reports. All times listed are in local ship time with ship time changes noted in bold.

January 20 (ship time UTC -8 hrs)
The ship got underway for sea trial work in San Francisco Bay. ADCPs successfully collected data, with dedicated testing lines run inside the bay. The GAMS calibration went smoothly and antenna offsets were adjusted by several millimeters. The EM 302 TRU did not boot cleanly. Several BISTs failed. The sonar may have to get pinging before successful BIST results can be obtained, but this was deferred given shallow water depths and so as not to interfere with the higher priority ADCP testing work. KVM installation is ongoing, with several user stations and mission computers now on the new KVM. Spare EM 302 parts, mosaic computer/monitor, UnderwayCTD, and Sun Photometer are all onboard.

Following completion of tests, the ship docked at Pier 19 in San Francisco.

January 21
The Navy contacted EX and advised the ship not to leave San Francisco earlier than 1900 Saturday, given the forecasted seas of 13-17', which exceeds the ship's highest operational limits. The ship command was not comfortable with the under keel clearance at low tide at the Pier 19 location and moved the ship mid-day to the pier at the Exploratorium.

The Netapps server is being decommissioned. Mapping Expedition Coordinators determined new server file structure for mapping data, and data is being migrated to the new OER_NAS server.

January 22
A new transit plan was completed today to Hawaii. The transit must be completed in 9.5 days. Given this limited time, mapping of even relatively small sections of the Murray or Molokai Fracture Zones is not possible. The transit has been planned to map areas that mostly lack multibeam sonar data.

The EM 302 sonar was tested today at the dock and had a clean boot with all BIST tests green. All of the EK 60 sonars (except the 333kHz which lacks a transceiver unit) were pinged at the dock and are functional. Both ADCPs were pinged and appeared to be functioning normally.

The UnderwayCTD (UCTD) was set up on the stern today.

January 23
The ship departed the pier at 1700. Mission spaces were further organized and secured for sea. HYPACK projects were created to cover the transit to Hawaii. National Marine

Sanctuaries contacts in CA were notified to let them know a patch test could not be completed within their boundaries due to weather constraints.

Just prior to leaving the pier, a problem with the new KVM developed that prevented access to all of the computers already transferred to it (including all of the sonar acquisition computers). The SCS computer and ADCP Logging computer were temporarily moved back to the old KVM to enable data acquisition during transit through the bay. The problem on the new KVM switch was fixed within several hours.

The ADCPs were run upon departing the pier and during the transit through the bay. The percent good pings quickly dropped to zero percent once the ship hit rough seas, and the ADCPs were secured. Bubble sweepdown was frequent and ship motion was substantial, so no other sonars were turned on since the data would not have been usable. Given the conditions, the mapping watch for the night was released from duty and most mission personnel went to bed to try to prevent seasickness.

January 24
After several failed attempts in the early morning, the multibeam successfully found bottom and was run for approximately 1.5 hours but then suddenly stopped working. Troubleshooting this issue took most of the day. The attitude/velocity data feed from the POSMV to the EM 302 was not being received, even though the POSMV heave, pitch, and roll data were being received. The problem was eventually isolated to a damaged cable between the EM 302 operator computer and the transceiver unit (TRU). Multibeam data in the evening has appeared to be good quality even though there has not been an opportunity to do a patch test.

An extensive effort was made today to set up the live stream for the multibeam display. The first several attempts did not work, but after persistent troubleshooting a solution was implemented and the multibeam live stream is now up.

All of the available EK 60 frequencies were run and appeared to be operating normally (albeit as yet uncalibrated). Initial interference testing of the new EK 60 frequencies, sub-bottom, and ADCPs, were conducted. Initial results indicate:

ADCP 38 kHz:
No interference observed in Knudsen.
Possible minor interference observed in EK 60: 18, 38, 70, 120, 200 kHz

ADCP 300 kHz:
No interference observed in Knudsen.
Possible interference with EK 60: 38 kHz.

University of Hawaii Data Acquisition System (UHDAS) ADCP experts let us know that the ADCP data we were able to collect while leaving SF Bay yesterday was not enough to determine the

initial transducer angle offsets for the 38 kHz ADCP. This requires bottom tracking data from 1000 meters or less, and will thus have to wait until Hawaii.

January 25
The multibeam and Knudsen are both performing very well. ADCP data collection today enabled UH to generate initial first order calibration on the OS38 (38 kHz ADCP).

Interference testing to gather data on how other sonars impact the ADCP data was accomplished by running the ADCP alone for 12 minutes, running the ADCP concurrently with another sonar for 12 minutes, and repeating until 5 segments are completed for each sonar pairing. The following interference pairing tests were completed, and the data is workings its way to shore for evaluation by the UHDAS team:

- WH300 (300 kHz ADCP) versus the multibeam
- OS38 (30 kHz ADCP) versus the multibeam
- OS38 versus the EK 60 18 kHz
- OS38 versus the EK 60 38 kHz (partial test)

January 26 ***(UTC -9hrs)***
The multibeam and Knudsen are both performing very well, despite the fast transit speeds. This speed does reduce our along-track data density, so the multibeam bathymetry surfaces are being gridded to a 100 meter (m) resolution instead of 50 m.

All EK 60's other than the 18 kHz are secured. During interference testing water column interference was observed in the multibeam, although bottom tracking was not affected significantly.

January 27
The multibeam, Knudsen, and EK 60 18 kHz are all performing very well, despite the fast transit speeds. This speed does reduce our alongtrack data density, so we are gridding the multibeam bathymetry surfaces to 100 m resolution instead of 50 m.

The latest version of Caris processing software (9.0) is now being used to process multibeam data, and SOPs are being updated accordingly.

January 28
The multibeam, Knudsen, and EK 60 18 kHz are all performing very well, despite the fast transit speeds. This speed does reduce our along-track data density, so we are gridding the multibeam bathymetry surfaces to 100 m resolution instead of 50 m. A long section of the Molokai Fracture Zone that lacked previously-collected multibeam coverage was successfully mapped today, revealing a distinct linear ridge with complex rugged topography. The subbottom data over this feature should also be of high interest to marine geologists.

The EK 60 70 kHz is now also being run along with the regular 18 kHz transducer, as testing revealed no interference with EM 302 water column data. The EK 60 120 kHz and 200 kHz transducers were tested today – they clearly showed periodic noise spikes of unknown origin. Analysis of the multibeam backscatter data in Fledermaus Mid-Water software does not seem to show increased noise in the backscatter with the new frequency EK 60s running as compared to when the EK 60s are all secured. We will continue to monitor this to ensure that the ability to detect water column anomalies of interest in the MB data is not compromised by running additional EK 60 frequencies.

January 29 ***(UTC -10 hrs)***
The multibeam, Knudsen, and EK 60 18 & 70 kHz are all performing well. A long section of the Molokai Fracture Zone that lacked previously-collected multibeam coverage was successfully mapped today, but lacked a distinct ridge feature in this area. EM 302 water column data are reviewed daily with no detected anomalies thus far.

Transient interference is observed in all EK frequencies, and most severely in the higher frequencies 120 and 200 kHz. The interference is not at regular intervals and occurs 24 hrs/day, so is not due to needle gunning or other ship force activities. Current theories being explored are the spikes are from irregularly cycling equipment, such as air compressors. Survey is working with the engineering department to temporarily secure various pieces of equipment and see if the interference disappears.

January 30
The multibeam, Knudsen, and EK 60 18 kHz are all performing very well. EM 302 water column data is reviewed daily with no detected anomalies thus far.

A seamount was discovered along a seam of the Molokai Fracture Zone.

EK 60 intermittent interference (70, 120, 200 kHz) testing was conducted with engineering. Several engineering systems were cycled off to observe if interference ceased. The source of the interference has not yet been determined.

The XBT system was down for several hours today and remains inoperable. Probes are detected by the launchers, the data collection software indicates to launch the probe, but once launched, the launch is not detected. All wire connections have been checked. Probes from different batches were tested, including the test probe. The software was re-installed and port communications tested. Troubleshooting continues. The next step is to switch to the spare rack unit, which will be configured tomorrow. Although the ship's CTD was terminated before leaving port, it was mounted on the winch incorrectly and had to be cut to get free from the winch. The UnderwayCTD is partially set up, but not ready for profiling yet.

January 31
The multibeam, Knudsen, and EK 60 18 and 70 kHz are all performing very well. EM 302 water column data is reviewed daily with no detected anomalies thus far.

EK 60 intermittent interference (70, 120, 200 kHz) testing was conducted with engineering. Several engineering systems were cycled off to observe if interference ceased. The source of the interference has not yet been determined.

The XBT system continued to be troubleshot. Manufacturer has been contacted support. A probe was bucket tested, the launch was detected, but no data stream was received.

February 1
The multibeam, Knudsen, and EK 60 18 and 70 kHz are all performing very well. EM 302 water column data is reviewed daily with no detected anomalies thus far.

The XBT ethernet rack unit is configured and collecting data. The old USB rack unit for this system will be phased out.

February 2
Ship secured mapping data collection as the ship entered more shallow waters. Arrived to Maunalua Bay, fast rescue boat *EX2* deployed, began overheating shortly after deployment. Recovered *EX2* and deployed fast rescue boat *EX1*. Dropped visiting marine technician Johna Winters (Oregon State University) ashore and retrieved Scott Idle (Teledyne), Gregg Juergens (Kongsberg), and Toby Martin (UHDAS). Began ADCP calibrations overnight.

February 3
Ship is underway near Lana'i conducting ADCP and EK 60 calibrations. Conducted a 70 m CTD prior to EK 60 calibrations. ADCP calibrations commenced after sunset.

February 4
ADCP initial sea acceptance testing by Teledyne technician continued into the morning. Remaining shallow water testing (~50 m) will be conducted near Honolulu, as all water of that depth is within the Penguin Bank Sanctuary, or too close to shore.

A CTD to 50 m was conducted and used for the EK 60 calibration.

EK 60 calibrations on the new transducers recommenced in the morning. The 333 kHz was calibrated at a pulse length of 1 millisecond (ms), and the 18 kHz was calibrated at 2ms and 4ms. The RMS values for the 333 kHz calibration were higher than expected, but putting more separation between line knots and the calibration sphere provided slightly better results. Three independent calibration runs were completed with the best one being applied. The Kongsberg technician thinks the higher RMS values are being caused by the knots in the monofilament line in the cradle that holds the calibration sphere, resulting in an unsmooth sphere surface. The ship does not carry a 333 kHz topside unit, so this is not much of a concern. The 38 kHz has not been calibrated because only 1 of 4 quadrants was

detecting the calibration sphere and there is clearly something wrong with it. The Kongsberg technician believes the GPT is not working properly and is troubleshooting. The calibration corrections have been applied to all of the working EK 60 sonars onboard.

UHDAS ADCP testing with commenced in the evening in ~2500 m water. Overnight, the ship conducted zig zag UHDAS testing on the way to the patch test site southwest of Oahu.

February 5
Overnight, the ship conducted a zig zag transit on the way to the patch test site west of Oahu, during which UHDAS ADCP testing was conducted. Testing re-commenced in the evening in ~2500 m water.

EK 60 noise level testing was conducted.

A 2000m CTD was conducted and applied for the EM 302 patch test. The CTD wire was greased and integrity looked good with minimal surface rust on outer layers of the spool. An XBT was also conducted for comparison and results are under analysis.

The multibeam patch test was conducted on the western side of Oahu and data is under analysis.

February 6
EK 60 noise level testing continued. The Kongsberg technician will produce a report with full testing results from the cruise.

The roll lines of the multibeam patch test were rerun to obtain data over a flatter seabed. The full patch test resulted in no changes to last year's offsets.

EM 302 speed test lines were attempted to determine swath coverage and receive (RX) noise levels at speeds from 4-12 kts in~2000 m water. However, the weather picked up quickly to gusts > 35 kts, and the tests were not completed.

ADCP UHDAS interference testing continued through the morning and recommenced in the evening.

Shallow water ADCP VmDAS, which is the Teledyne manufacturer provided software, testing occurred in 50 m water. The WH300 ADCP is showing pronounced ringing in the first few bins at the top of the water column. The technician thinks this is due to the design of the acoustic window. This is not a major problem and can be accounted for by increasing the blanking distance just under the transducers. UHDAS will provide specific configuration numbers to adjust this once they have looked more thoroughly at the data.

Both ADCP technicians are in agreement that the ADCPs are underpowered since they are both on the same 15 amp circuit breaker. Ideally they should be on different breakers. Both ADCPS were run this cruise together without issue. Since the ADCPs draw a lot of power when they are first energized, it is highly recommended to turn one on, wait 10 minutes, then turn the other on.

February 7

The ship tied up at pier F10 in Pearl Harbor at 0830. The physical scientists assembled the cruise data package. Cabins and common mission areas were cleaned by survey personnel.

12. References

The 2016 NOAA Ship *Okeanos Explorer* Survey Readiness Report can be obtained in the NOAA Central Library at doi:10.7289/VSFT8J2Z or by contacting the NOAA OER mapping team at oar.oer.exmappingteam@noaa.gov.

The EX-16-01 Project Instructions are available at the NOAA Central Library at doi:10.7289/v5513w71. The EX-16-01 Data Management Plan is an appendix of the project instructions.

EX-16-01 EK 60 Calibration Report can be obtained in the NOAA Central Library or by contacting the NOAA OER mapping team at oar.oer.exmappingteam@noaa.gov.

The following were used for reference throughout the cruise:

Sandwell, D. T., and W. H. F. Smith, Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge Segmentation versus spreading rate, J. Geophys. Res., 114, B01411, doi:10.1029/2008JB006008, 2009.

NOAA Nautical Charts