Real-Time ERS Altimetry at NOAA

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The Laboratory for Satellite Altimetry (LSA) is a division within NODC which processes and analyzes data from all current altimetry missions (Topex/Poseidon, ERS-2, Geosat Follow-On) as well as historical ones (GEOS-3, Seasat, Geosat, ERS-1). The data obtained from the European Space Agency's satellites, ERS-1 and ERS-2 (Figure 1), are unique in that ESA's ground system makes the data available to NOAA and other agencies within 6 hours of acquisition. This makes it possible for NOAA to generate near real-time altimetry products which can be used in oceanographic analyses and model assimilation.

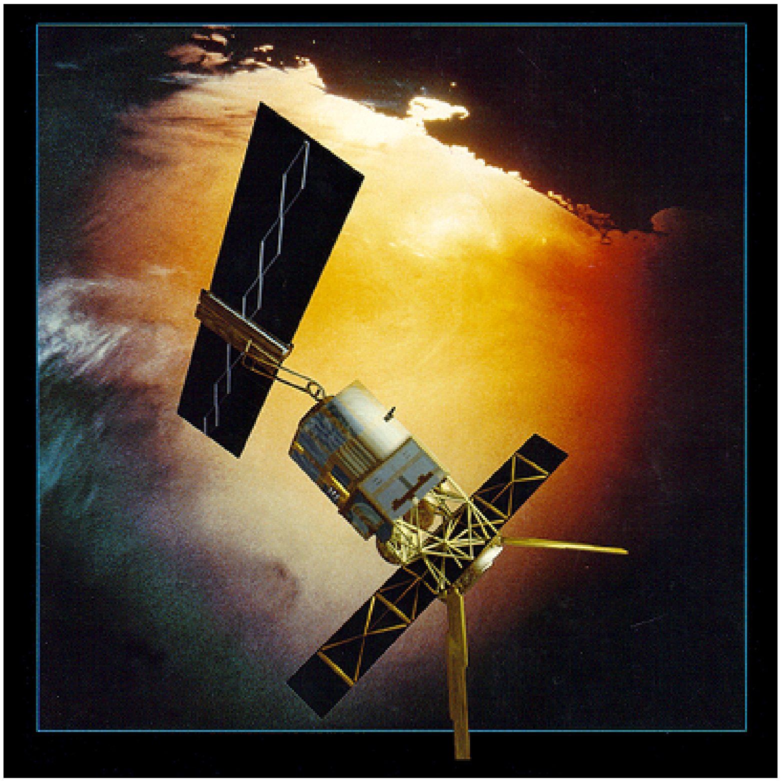

Figure 1. Artist's Rendering of the European Space Agency's ERS-2 satellite.

ERS-1 (the first European Remote Sensing satellite) was launched in August 1991, and LSA began routine processing of the altimeter data six months later. The fast-delivery altimeter data received from ESA contain the range measurements between the satellite and sea surface, but in order to compute changes in sea surface topography, it is necessary to also have accurate satellite orbit information. The altimetry group at the Delft University of Technology has been providing "quick-look" orbits for both ERS satellites, through a cooperative effort with NOAA. LSA combines the altimeter range data with these orbits, adds corrections for travel time delays of the radar pulse through the troposphere and ionosphere, and removes the tidal components of sea level since these are not related to large scale ocean circulation. The flow chart in Figure 2 describes the LSA processing system. (The most important media correction, which accounts for path delays due to water vapor, can be measured by ERS's onboard microwave radiometer. However, those corrections did not become available in ESA's fast-delivery data until late 1998.)

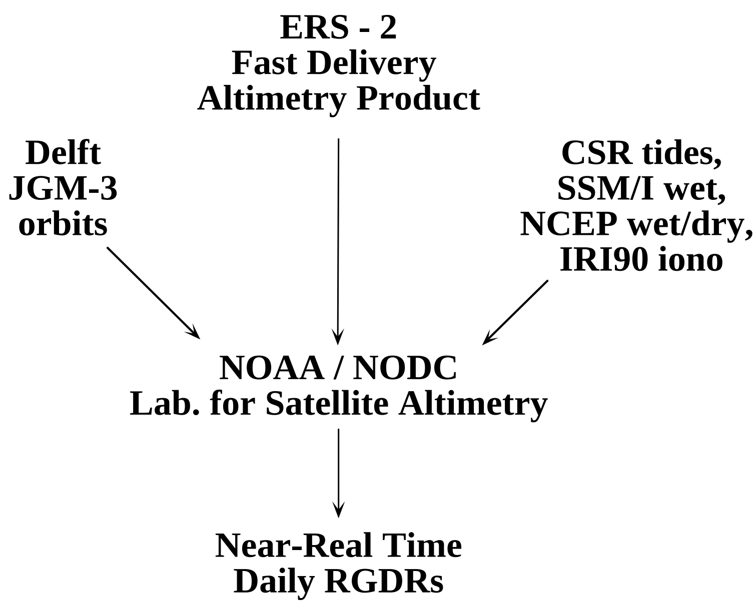

Figure 2. Flow chart of the real-time altimetry system at NOAA.The fast-delivery altimeter data from ESA lack an orbit and (until 1998) a measured wet troposphere correction. Orbits are provided by the Delft University of Technology, and media and tidal corrections are supplied at NOAA. The final "Real-time Geophysical Data Records" (RGDRs) are distributed via the internet.

During the first years of the ERS-1 mission, the Delft orbits had radial orbit errors on the order of 1-2 meters. To accommodate delays in receiving all the laser tracking data for generation of the final orbit, there was a latency of nearly two weeks between reception of the altimetry data from ESA and production of the NOAA sea surface height data. Over the course of the ERS-1 mission enhancements were made, most notably the utilization of orbits based on better gravity models, which reduced the radial orbit error to the 10-20 cm level.

In November 1995 LSA began a new method of data production which allowed generation of daily data with a latency of only 13 - 14 hours. Since the orbits were still the time-limiting factor, it was necessary to use "predicted" orbits in order to operate in near real-time. The Delft group modified their orbit production scheme to extend the orbit beyond that part of the solution which is based on actual laser tracking data. The gain in timeliness, however, exacted a price in terms of orbit error: data based on predictions of a few days typically had uncertainties of 30-50 cm, despite further improvements in the gravity model.

ERS-2 (which differs only slightly from ERS-1) was launched on April 20, 1995, and after a year of calibration/validation activities, replaced ERS-1 as the operational satellite. For the next two years the ERS processing at LSA was very stable, and data sets were automatically generated with little manual intervention. In the last half of 1998, however, several significant improvements were made:

1) The Delft orbits incorporated a new gravity model optimized for ERS-2. These state-of-the-art orbits reduced the orbit error in the NOAA products.

2) In order to further reduce orbit error, a "feedback" scheme was developed which minimizes the lack of laser-tracking data in the orbit prediction. A first-cut RGDR is generated using the previous day's orbit; the resulting height data are then utilized by Delft to compute a better constrained orbit for the current day; and NOAA then incorporates this improved orbit into the final data set.

3) ESA began providing the measured wet troposphere correction from the radiometer onboard ERS-2.

The net effect of these improvements in late 1998 can be readily seen in Figure 3.

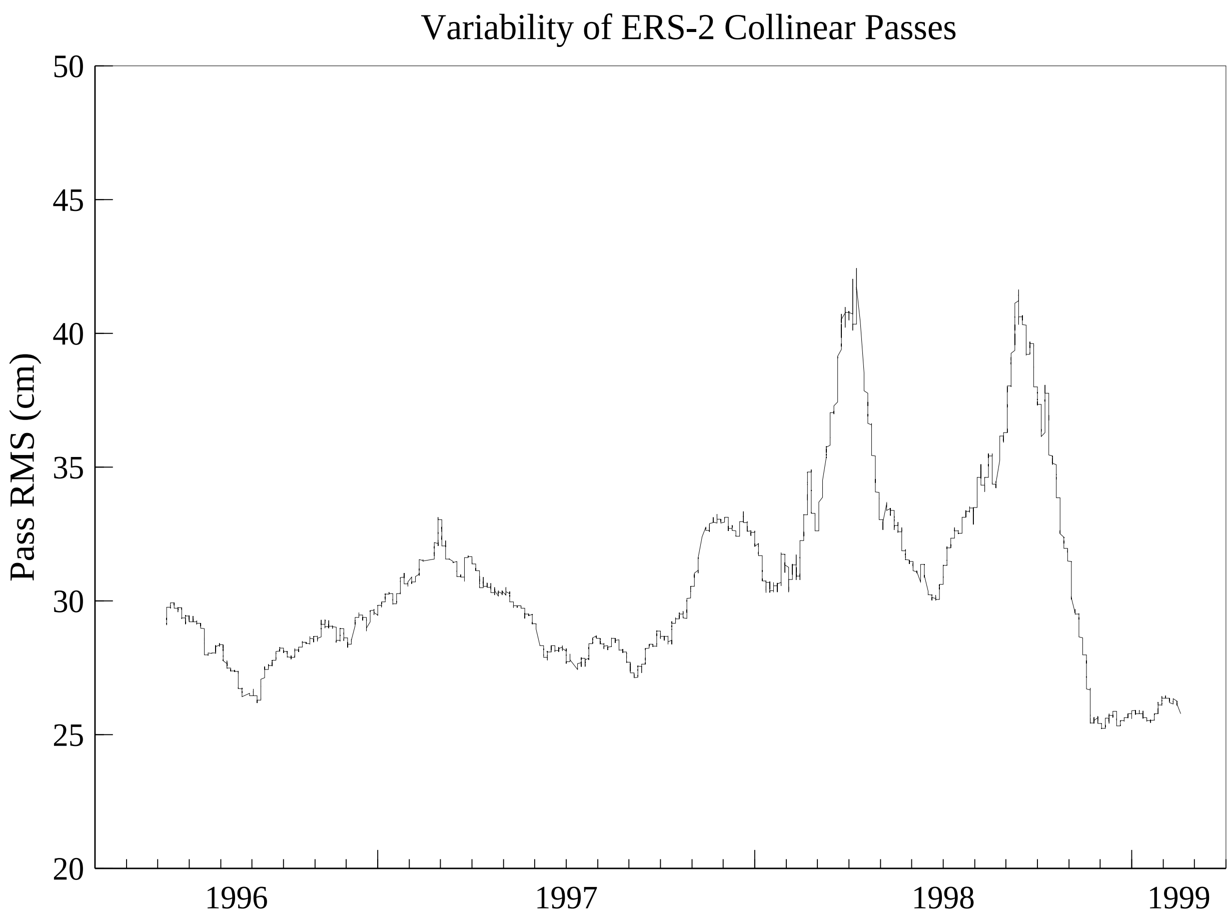

Figure 3. Global sea surface height variability from ERS-2 altimeter collinear differences. This plot provides an estimate of the change in uncertainty in the real-time data. "Perfect" observations of sea level would yield rms values of 15-20 cm, due to actual variations in currents and the effects of seasonal and interannual signals. Since late 1998, improvements in ERS-2 processing have reduced the global value to 25 cm rms, or only 5-10 cm higher than the true variability.

This plot is based on a collinear analysis of the real-time data for ERS-2. Every 35 days ERS-2 repeats its ground track, and each “pole-to-pole” pass (between 81.5° N and 81.5° S) can be compared to the other passes along the same ground track. The rms variability of each pass, relative to its reference pass, is plotted at the equator crossing time of the pass. To highlight the changes over time a 70-day (two repeat-cycle) median filter was applied to the original time series. The large drop in variability, indicative of a large decrease in orbit and media errors, can be seen in the fall of 1998. After these improvements were made, the rms variability of each pass is stable at about 25 cm. This variability includes the true oceanic variability as well as orbit and media correction errors. Similar pass statistics for Topex/Poseidon are at the 15-20 cm level, indicating that the errors in the real-time ERS-2 data are only 5-10 cm higher.

The NOAA real-time products are utilized by altimetric specialists at a number of institutions. LSA currently supplies ERS-2 data to the University of Delft, the University of Colorado, the Naval Research Laboratory, the Naval Oceanographic Office, and the Southampton Oceanography Center in the United Kingdom. Each of these institutions regularly retrieves ERS-2 data via ftp, resulting in network traffic of several hundred megabytes per month (Figure 4).

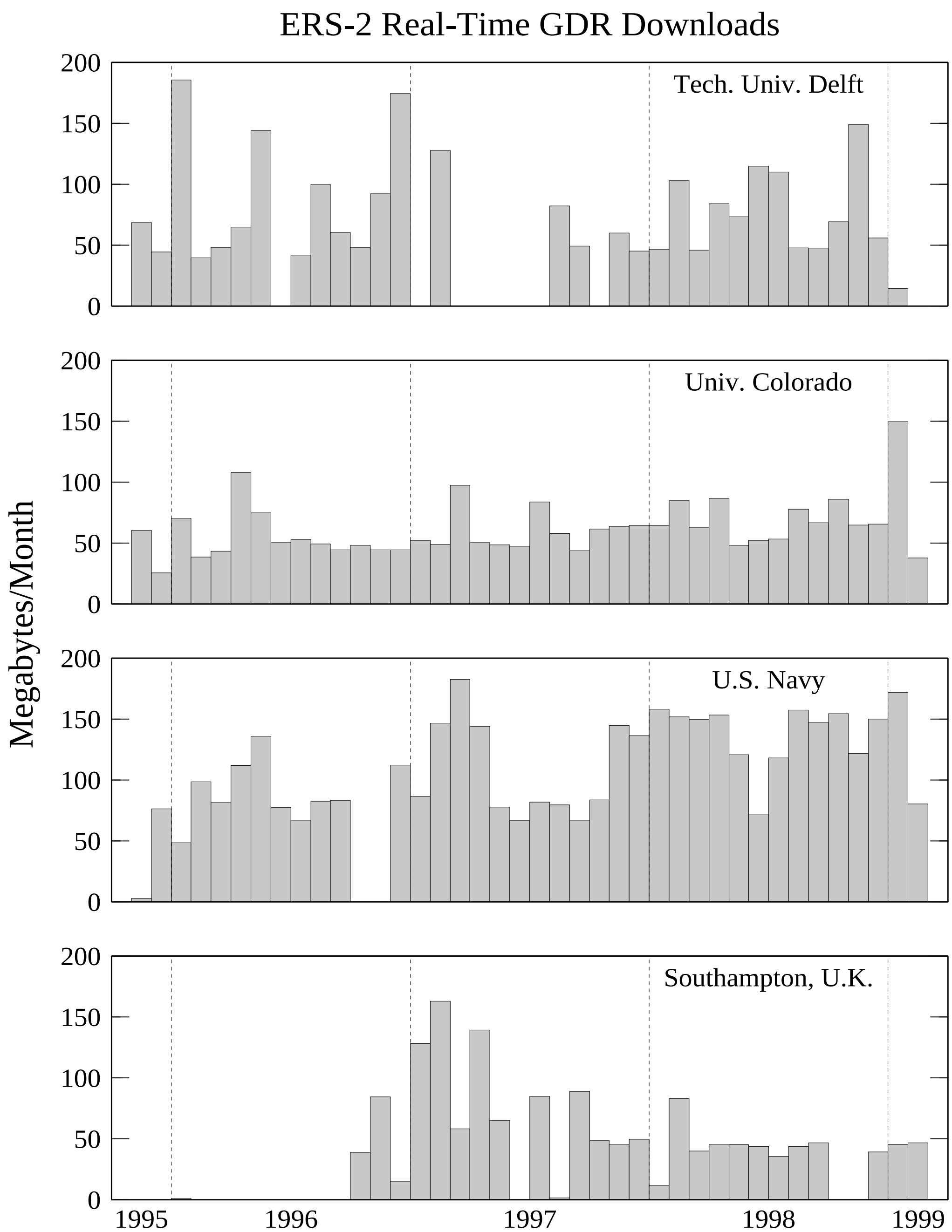

Figure 4. Network traffic between the NOAA Laboratory for Satellite Altimetry and its primary customers. Each group routinely downloads at a rate of 50 Mb/month, with peak traffic of nearly 200 Mb/month.

Examples of the ways in which the NOAA RGDRs are being utilized can be found on the web sites of LSA's primary customers. The altimetry group at the Naval Research Laboratory assimilates ERS-2 data (along with Topex/Poseidon and Geosat Follow-On altimetry) into a global ocean model and produces daily maps of sea surface dynamic topography. By assimilating the data into a dynamical ocean model, it is possible to generate synoptic pictures of the sea surface in spite of the variable space/time sampling of the original data. Figure 5 shows an example of their real-time global model output. Refer to the NRL web site for further information: http://www7300.nrlssc.navy.mil/altimetry.

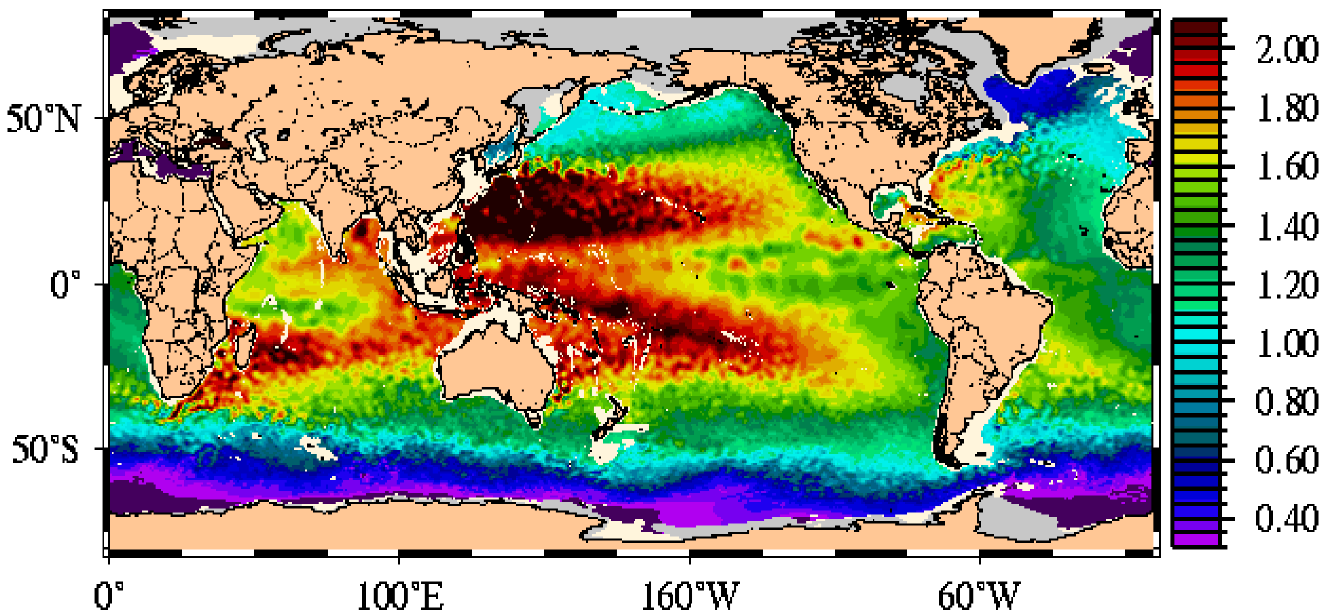

Figure 5. Global sea surface dynamic topography from the Modular Ocean Data Assimilation System model (courtesy of the Naval Research Laboratory). Altimetric data from ERS-2, Topex/Poseidon, and GFO are assimilated into the ocean model and daily global grids are generated. The dynamic heights, scaled by the color bar on the right, are in dynamic meters - roughly equivalent to meters of sea surface elevation.

Another example of the use of RGDR data in real-time altimetry can be found at the University of Colorado's Gulf of Mexico web site: http://www-ccar.colorado.edu/~realtime/gom/gom_nrt.html. This group has been using real-time ERS-2 data in conjunction with the higher precision (but more widely spaced) Topex/Poseidon data to generate sea surface topography maps in the Gulf of Mexico. The Loop Current in the Gulf, which feeds into the Gulf Stream south of Florida, can be monitored in this way along with eddy features that have broken off the main current. Figure 6 shows an example from the summer of 1996, when surface drifters were deployed in the Loop Current during a research cruise. The flow of the drifters along the contours of sea surface topography illustrates how well the altimetry system performs.

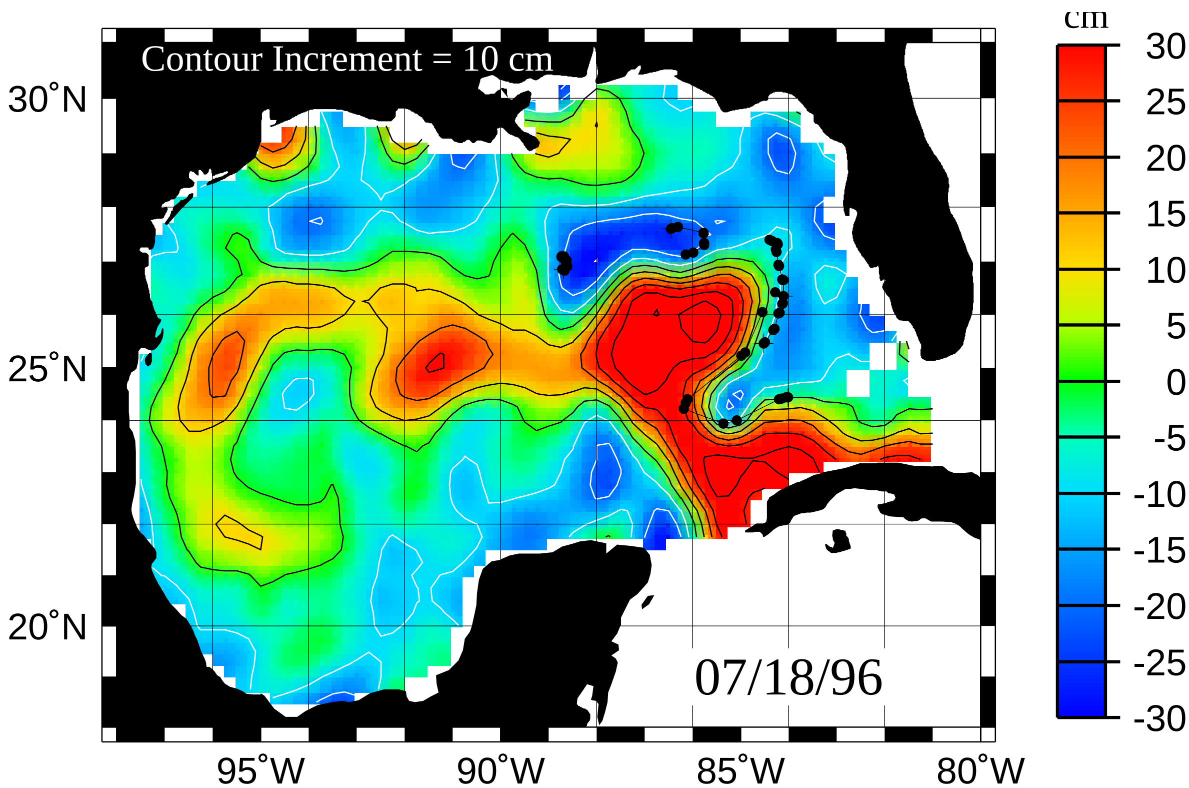

Figure 6. Sea surface topography in the Gulf of Mexico, based on ERS-2 and Topex/Poseidon altimetry (courtesy of the Colorado Center for Astrodynamics Research). The relative high in the sea surface (dark gray) delineates the Loop Current as it enters the Gulf between Cuba and the Yucatan and exits into the Gulf Stream between Florida and Cuba. The black dots show the tracks of surface drifters in the Loop Current, which follow the contours of sea surface topography.

In addition to supplying ERS-2 data to the altimetric community, LSA is providing weekly Topex/Poseidon analyses to the National Weather Service for El Niño forecasting and monitoring (see the article by Bob Cheney in the September, 1997 issue of the Earth System Monitor). In the future, other applications of the real-time data from ERS–2 as well as the Navy's Geosat Follow-On mission will be explored. There is potential for near-coastal applications (such as Gulf Stream monitoring) as well as open-ocean analyses to benefit from the timely production and delivery of altimetry data. NOAA will continue to play an important role in this operational activity.