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SATELLITE DATA UTILIZATION BY U.S. NAVY METEOROLOGY AND OCEANOGRAPHY

Don T. Conlee and Richard L. Crout*

Naval Meteorology and Oceanography Command
Stennis Space Center, MS 39529

1. INTRODUCTION

Meteorology and Oceanography (METOC) professionals of the U.S. Navy and Marine Corps face a daunting task: characterize the operating environment globally, and more specifically, in the vast oceans and littoral regions, to enhance the safety and efficacy of forces. However, this operating environment is typically the very definition of "data sparse". Remote Sensing from satellites has become an integral part of Naval operational analysis and forecasting. This has been accomplished though extensive and focused research and operational transition efforts, both Navy-sponsored and leveraged from the scientific community at large.

This paper offers an overview of current satellite usage and those research areas which hold the promise of transition to operations in the near term. Technologies include passive microwave, visual and infrared imaging applications, multispectral applications, scatterometry, altimetry, SAR and feature analysis from high-resolution commercial imagery. Applications of these technologies to real-world Naval operations are detailed.

2. VIS/IR APPLICATIONS

Like all of those charged with operational meteorology, visible and infrared imagery remain primary tools in weather analysis and forecasting. We therefore share the common requirements of increased spatial resolution and refresh for this type of data from both geostationary and polar-orbiting platforms.

The VIS/IR data are also used extensively in more quantitative ways. The Naval Oceanographic Office (NAVO) produces Sea Surface Temperature analyses from multi-channel IR sensors using the 11-12 micron split-window technique for operational Navy usage and for general use under the auspices of the Shared Processing Program (SPP) (Rigney et al., 1997).

Geostationary VIS/IR and water vapor channels are used to derive high-density feature-tracked winds for use in Numerical Weather Prediction (NWP) models run at Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, CA (Figure 1). This operational capability is the culmination of a collaborative research effort between the Naval Research Laboratory (NRL) Monterey and U. of Wisconsin/CIMMS (Velden et al., 1997). Expansion of this program is underway to include data from the Japan Meteorological Agency GMS and EUMETSAT Meteosat processed by another SPP partner, the Air Force Weather Agency (AFWA) in Omaha, NE with FNMOC background fields.

Data from IR Sounders are also important inputs to NWP efforts. Through SPP, the Navy leverages NESDIS expertise in soundings, using the NESDIS-supplied POES soundings delivered via SPP communications operationally. In addition, research is progressing on direct radiance assimilation into Navy numerical models.

Recent transitions into operational usage include a low cloud product using a bispectral IR technique, which gives forecasters a nighttime capability for fog/stratus determination. A new capability to stitch together multiple geostationary data has also been developed, offering military planners with global purview (and the METOC professionals supporting them) a virtually seamless global satellite depiction. These capabilities were part of a Cooperative Research and Development Agreement (CRADA) between NRL Monterey and SeaSpace, Inc. described in Hawkins, et al., 2000.

Corresponding author address: Dr. Richard L. Crout, N543, COMNAVMETOCCOM, 1100 Balch Blvd., Stennis Space Center, MS 29529-5005; email: croutr@cnmoc.navy.mil
Online paper link: https://www.cnmoc.navy.mil/nmosw/handbk.htm#articles

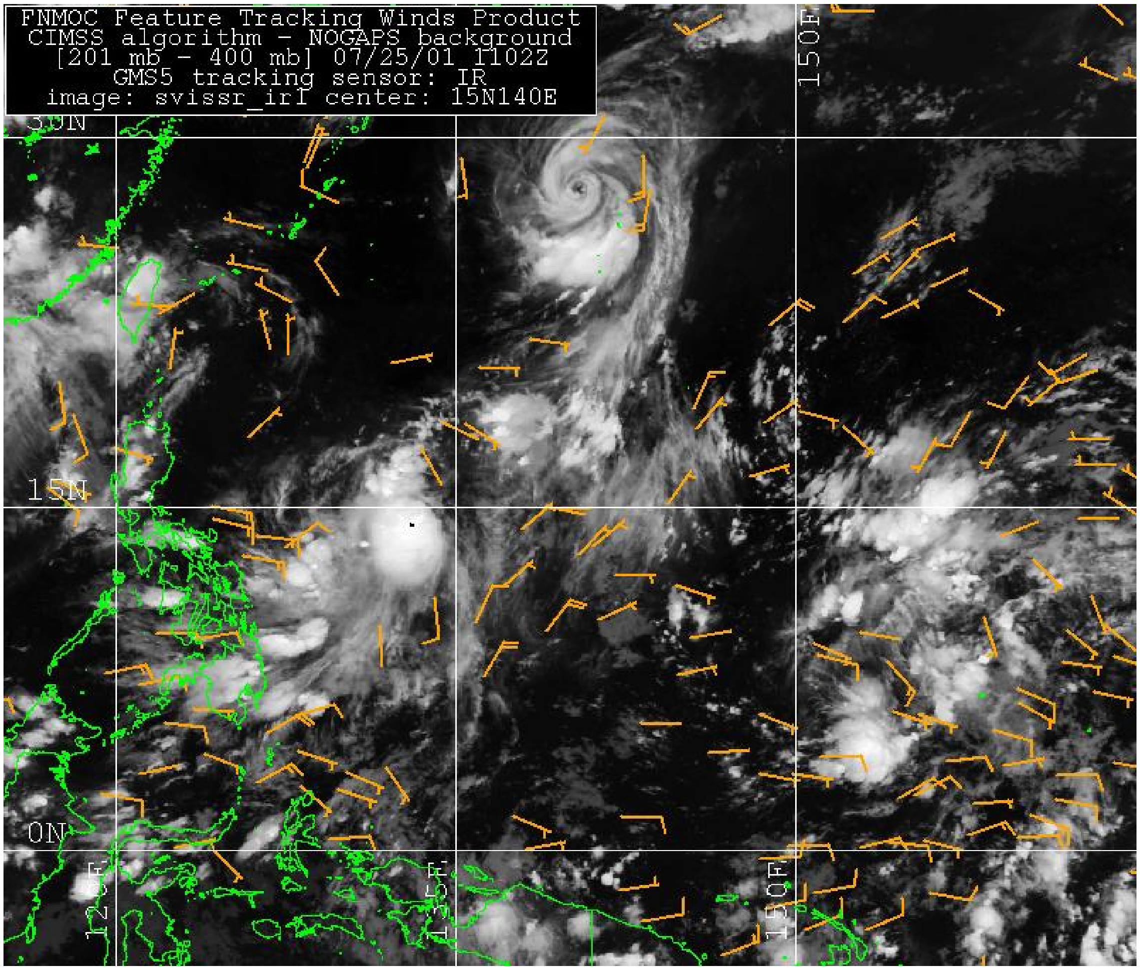

FIG. 1. High density feature tracked winds product. The typhoon near 28N, 140E is Kong-Rey (9W).

3. PASSIVE MICROWAVE

Exploitation of passive microwave imagery, particularly that from the Special Sensor Microwave Imager (SSM/I), has long been a primary emphasis of Navy remote sensing. The passive microwave ability to sense surface wind speed over the vast data-sparse oceans is fundamental to Navy METOC efforts to assess and predict high winds and seas. FNMOC is the SPP Core Processing Center (CPC) for passive microwave imagery, providing the parameters of wind speed, rain rate, integrated water vapor, cloud water content, soil moisture and ice concentration for SPP and operational Navy usage (Cornelius, et al., 2000). The algorithms for these parameters are those approved by the SPP Algorithm Research Panel (ARP) process, co-chaired by FNMOC and the Naval Research Laboratory (Colton and Poe, 1994). FNMOC also partners with NRL as lead agents for Calibration/Validation of newly-flown passive microwave sensors.

A less quantitative but operationally useful technique of using microwave imagery is that of using SSM/I 85 GHz imagery to locate tropical cyclone centers and convective structure. This is used extensively at centers such as the Joint Typhoon Warning Center in Pearl Harbor, Hawaii which obtains the data from the Navy's Tropical Cyclone Web Page, currently in transition from NRL Monterey to FNMOC (Hawkins et al., 2001). Figure 2 is an example of SSM/I 85 GHz imagery of TC Bilis and shows how clearly passive microwave can locate a circulation center via the convective organization. The most valuable application of this is in cases when no clear eye is apparent in traditional VIS/IR imagery.

Partnering with the NPOESS Integrated Program Office and the Space Test Program, NRL is developing the WindSat instrument (St. Germain and Gaiser, 2000). This effort is designed to demonstrate the ability of polarimetric methods to

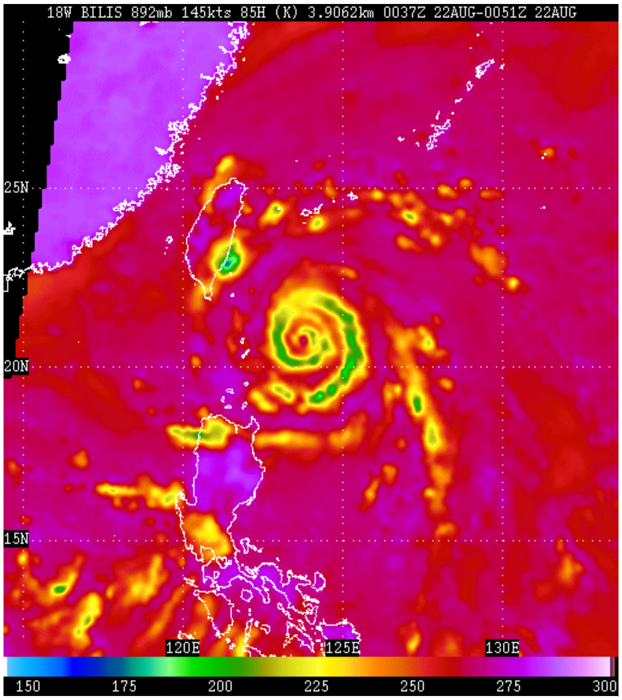

FIG. 2 85 GHz (Horiz. Pol.) imagery from FNMOC.

retrieve wind direction as well as speed from a passive microwave instrument. FNMOC will be the Payload Operations Center (POC) for WindSat. The Navy also makes use of other R&D passive sensors such as the TRMM TMI in much the same fashion as SSM/I.

As in the case of IR sounders, microwave sounders play an important role in NWP. Again leveraging SPP partnerships, NESDIS SSM/T-1 and T-2 soundings are used operationally in Navy models. The integrated microwave imager and sounder, SSMIS, to be launched on the next DMSP satellite, will be exploited similarly to SSM/I and SSM/T-1/2, with some improvements likely to be derived from the co-located conically scanning configuration.

4. SCATTEROMETRY

The scatterometer provides an important supplement to passive microwave methods for retrieval of ocean surface wind in providing wind direction and supplementing coverage. At FNMOC, Navy model data is applied to the backscatter from the QuikSCAT and ERS-2 scatterometers to remove directional ambiguity in a product-line consistent fashion. Figure 3 is an example of a web-based, interactive surface wind speed product that combines both scatterometry and passive microwave.

5. ALTIMETRY

The radar altimeter provides a function for the ocean similar to that of a barometer for the atmosphere. The sea surface height, determined by processing the altimeter range measurement with a full set of corrections, is a function of the density of the water mass beneath it. Cold (dense) and warm (less dense) water masses are represented by differences in the sea surface height of the column of water. Narrow geostrophic currents generated at the boundaries of water masses are represented by rapid (10 to 100 centimeters) changes in sea surfaces over a relatively short spatial scale (50 to 100 kilometers). These features are revealed in the sea surface heights generated by the radar altimeter (Figure 4). Mesoscale features are gleaned from a combination of altimeter sea surface height and sea surface temperature measurements.

NRL Stennis Space Center devised a method to assimilate sea surface height and sea surface temperature measurements to resolve a three-dimensional cube of the temperature, salinity, and density of the water column. The Modular Ocean Data Assimilation System (MODAS) was developed and transitioned to NAVO to assimilate GEOSAT Follow-On (GFO), Topex/Poseidon, and ERS-2 altimeter data at the Altimeter Data Fusion Center. In a majority of ocean areas MODAS provides information that is superior to climatology or climatology plus sea surface temperature measurements alone. The Navy Layered Ocean Model (NLOM) is a global/regional ocean model capable of assimilating sea surface heights. Model evaluations indicate that in order to properly represent the mesoscale oceanic variability, an altimeter in a 17- or 35-day exact repeat orbit is adequate, although model improvements continue with additional satellites up to a maximum of three altimeters (Hurlburt, 2000). An altimeter ARP is being formed under the SPP to continue investigating improvements in altimeter research and transitioning those efforts to operations.

6. SYNTHETIC APERATURE RADAR

Synthetic Aperture Radar (SAR) technology takes advantage of the forward motion of the spacecraft carrying the active microwave radar to synthetically increase the antenna size and acquire more information from the signal, thus allowing a higher spatial resolution to be extracted from the signal. The U.S. National/Naval Ice Center (NIC) has the responsibility of mapping sea ice conditions over all ocean regions of the world. In addition to visible and infrared imagery and ice imagery from the Special Sensor Microwave Imager on the DMSP satellite, the Navy uses SAR data from the Canadian RADARSAT-1. The synthetic aperture radar (SAR) imagery is extensively used in the production of sea ice analyses in U.S. waters and the Arctic. SAR data allow an all-weather, day/night capability that determines ice edge, ice coverage, and ice concentration.

Much of the analysis of the SAR data is manual, but Navy and NOAA funded research is underway to automate the processes to distinguish between first year and multiyear ice. Gineris et al. (2000) describe an operational evaluation of ARKTOS, a knowledge-based sea ice classification system. ARKTOS is in use at NIC to aid in the mapping of ice covered oceans.

7. SPECTRAL APPLICATIONS

The utilization of multi-spectral data is increasing in Naval METOC. Although the utility of satellite-sensed ocean color data for Naval operations has been known for some time, the availability of real-time data has been the limiting factor. The SeaWiFS sensor on Orbview-2 has provided the consistent data to implement ocean color into operations. Recently transitioned from R&D by NRL Stennis Space Center to NAVO, Figure 5 shows a chlorophyll product, which along with water clarity/visibility is now available for METOC support of Naval expeditionary, special, and mine warfare operations.

SeaWiFS is also showing promise in Meteorology in detecting sand/dust/aerosols. In regions prone to major sand/dust events, the impact on Naval operations is severe, and forecasting is challenging. Although the once per day frequency is insufficient, the clarity with which multi-spectral data depicts these events makes it a useful supplement to other analytical and forecasting tools. The cover of this volume depicts a sand/dust event which is about to accompany frontal passage on the Iberian peninsula. The sand/dust was entrained into the mid-latitude system beginning with easterly surface winds off of North Africa.

8. COMMERCIAL/HIGH-RES APPLICATIONS

The arrival of commercial high-resolution imagery has brought new capability to efforts by NAVO's Warfighting Support Center (WSC) to support DoD customers in describing the ocean environment, particularly in the littorals. The latest generation of commercial satellites with a resolution of 1 m add to the existing usage of sensors such as Landsat. Figure 6 is a product of the WSC which uses imagery as an "anchor" for providing littoral oceanographic data pertinent to Navy and USMC operations.

9. SUMMARY

The Navy and Marine Corps extensively use satellite data in operational METOC analysis and forecasting efforts, and are increasingly reliant upon satellites for gains in forecasting accuracy and quality of METOC support. We are engaged in strong partnerships, leveraging the expertise areas of our SPP partners, acedemia and industry.

Although the Navy maintains a focused R&D capability in critical areas of remote sensing, opportunities do exist for other researchers to contribute and participate in areas which can eventually lead to operational usage. Collaboration by other government, academic and commercial scientists with Navy labs such as NRL Monterey and with the Naval Postgraduate School have lead to many of the recent advancements in operational remote sensing. NRL's sponsor, the Office of Naval Research, solicits proposals from the research community in specific areas of interest, information available from the ONR homepage at http://www.onr.navy.mil. The CRADA process provides a path for commercial developers and vendors to partner with Navy. Finally, the Shared Processing Program maintains Algorithm Research Panels (ARP) in Passive Microwave, Altimetry, Satellite Soundings and Multi-Channel Sea Surface Temperature. Proposed algorithms or improvements in these areas may be submitted to the appropriate ARP chair.

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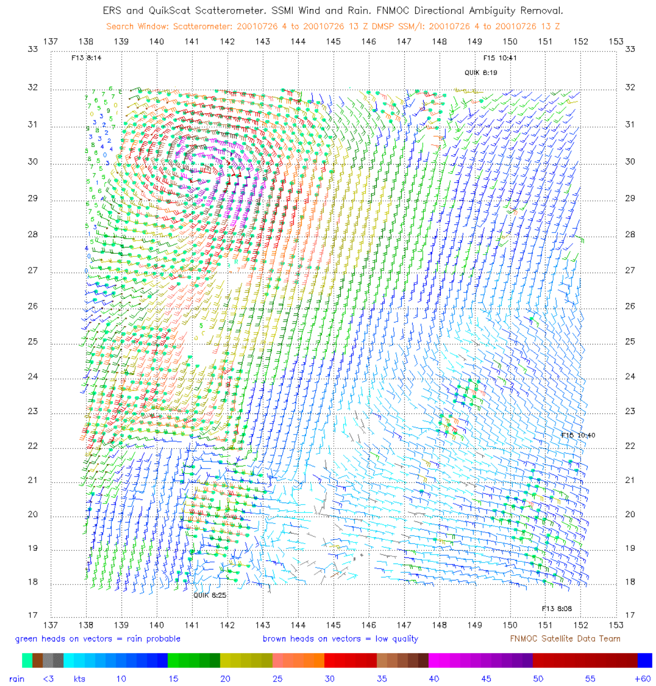

FIG. 3. Web-based, interactive surface wind product from FNMOC, zoomed to reveal full resolution data.

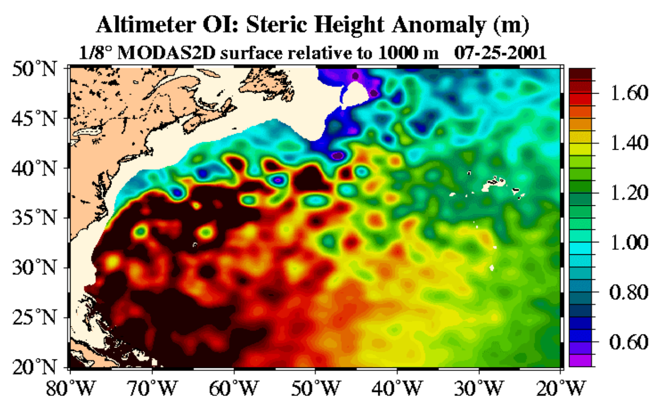

FIG. 4. MODAS Sea Surface Height (SSH) residuals product derived from altimetry.

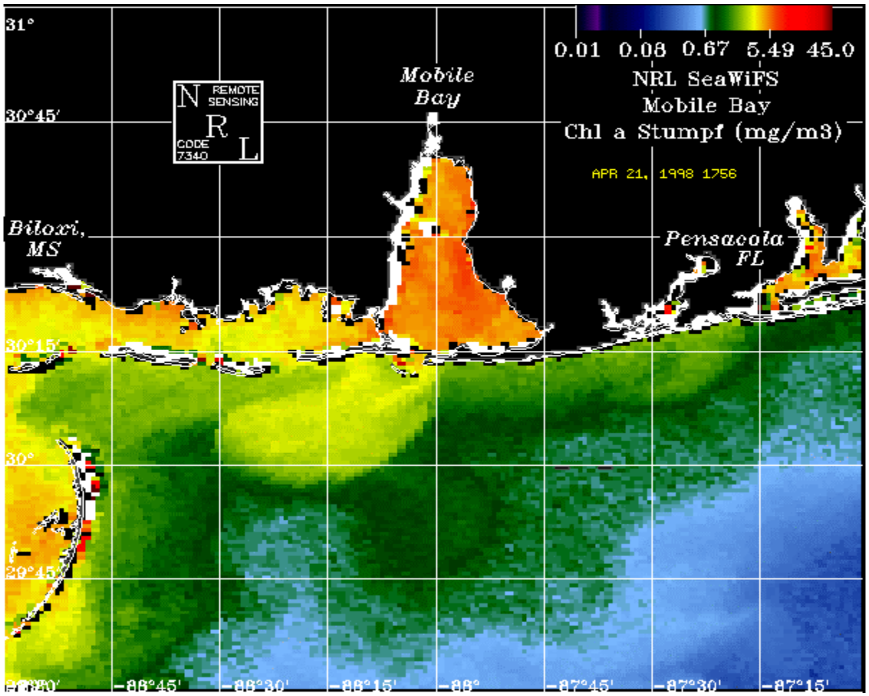

FIG. 5. SeaWiFS-derived Chlorophyll Concentration product from NRL/NAVO. SeaWiFS data used with permission of ORBIMAGE.

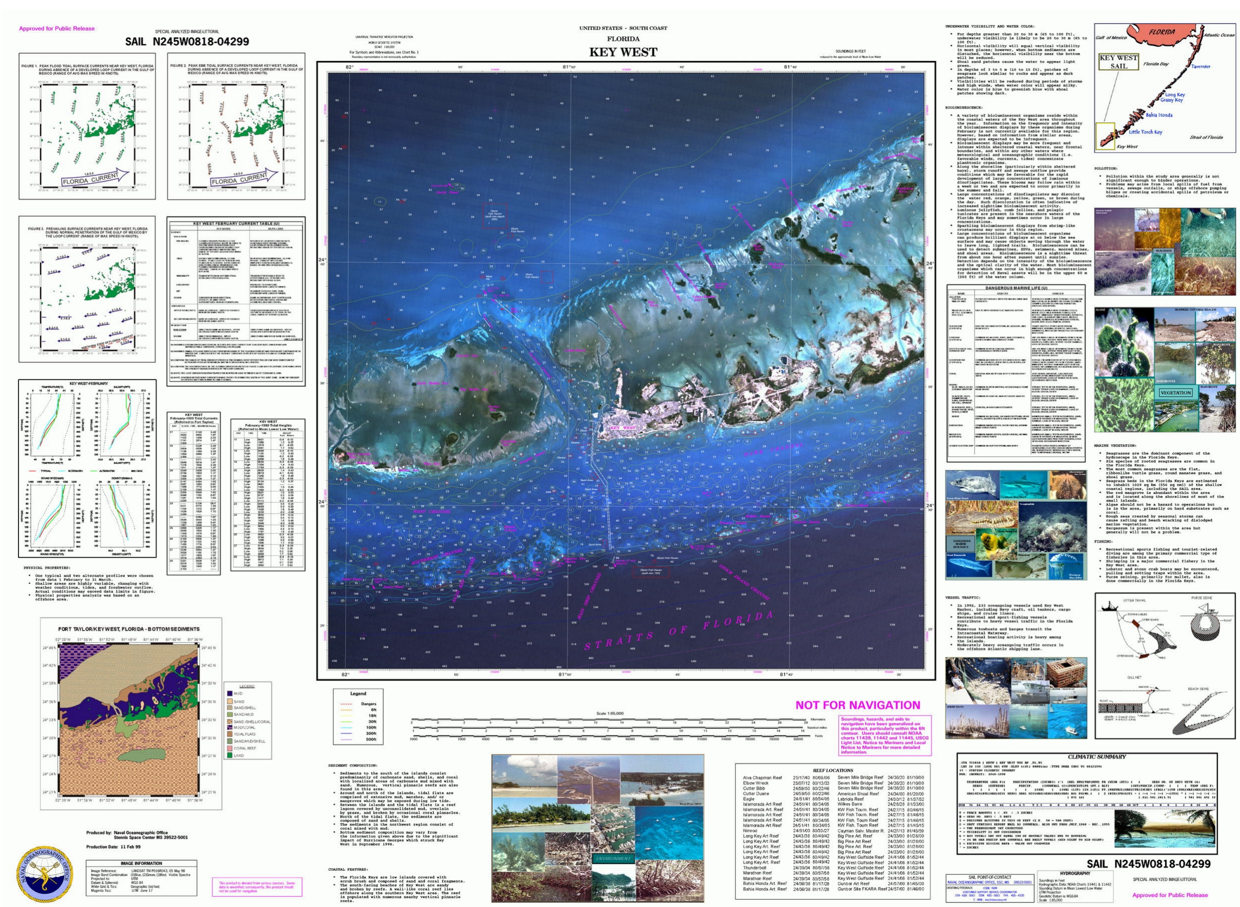

FIG. 6. NAVO High Resolution Commercial Imagery Product: Special Analyzed Image Littoral (SAIL)