P1.21 DEMONSTRATING NPOESS/VIIRS IMAGING CAPABILITIES OVER THE CONTINENTAL UNITED STATES WITH MODIS

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1. INTRODUCTION

Under the auspices of the National Polar Orbiting Environmental Satellite System (NPOESS) Integrated Program Office (IPO), the Naval Research Laboratory's (NRL) Marine Meteorology Division has implemented "NexSat"—an internet-based public-access web page demonstrating next-generation satellite products (http://www.nrlmry.navy.mil/nexsat_pages/nexsat_home.html). The purpose of NexSat is three-fold: 1) inform the general public on selected capabilities of the future NPOESS program, with emphasis placed on imagery applications from the Visible/Infrared Imaging Spectrometer (VIIRS), 2) to make available examples of domestic near real-time applications to resource managers, emergency response teams, planners, the aviation community, and various government agencies, including the Department of Homeland Security, and 3) provide a research test-bed for robust algorithm development and opportunities for participation in various atmospheric research field programs.

To this end NexSat features a suite of value-added environmental products and physically based enhancements (e.g., detection of snow, low clouds, cirrus, convection, and dust) over the CONtinental United States (CONUS) based on a number of real time and near real-time satellite telemetries, numerical weather prediction (NWP) fields, and data from the National Lightning Detection Network (NLDN). Satellite data include the National Aeronautics and Space Administration (NASA) Earth Observing Mission (EOS) Terra and Aqua satellites, the National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellites (GOES) and Polar Orbiting Environmental Satellite (POES) program, and the Defense Meteorological Satellite Program (DMSP) operated by the United States Air Force Space and Missile Systems Command (SMC).

The purpose of NexSat is to compare contemporary operational capabilities (i.e., DMSP and POES sensors) with the next-generation polar orbiting satellite in NPOESS. In addition, we foresee VIIRS leveraging algorithms developed based on EOS MODerate-resolution Imaging Spectroradiometer (MODIS; aboard Terra and Aqua) data. Presenting this comparison in the context of near real-time data, NexSat adds a new dimension to this assessment, adding relevance to an expanded audience. This paper outlines the derivation, development, and implementation of NexSat utility, provides selected examples of available products, and concludes with a general discussion of potential applications.

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2. HERITAGE

NexSat brings to the public forum and the CONUS domain a resource developed by NRL in support of military assets during Operations Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) over the Middle East and southwest Asia. This section provides a brief overview of this previous wartime support effort, its scope and impact, and the logical extension to the current application.

2.1 *The Satellite Focus Web Page*

Miller *et al.* (2003) describe in detail the Satellite Focus webpage (hereafter referred to as "Satellite Focus"), developed by NRL and hosted operationally on secure Internet bandwidth by the Fleet Numerical Meteorology and Oceanography Center (FNMOC). Created during the post 9/11 military mobilization leading into the "War on Terrorism," the development of Satellite Focus centered on consolidation of all available near real-time satellite telemetries to a common framework (co-registered products enabling rapid comparisons for time-critical decision making). With telescoping spatial domains to provide synoptic and mesoscale meteorological context to the theater of operations, the dynamic Satellite Focus web interface features satellite pass prediction, online training modules, and a user-friendly navigation scheme. A number of satellite sensors contributed to a myriad of environmental products ranging from rainfall intensity, deep convective cloud top altitudes, low cloud detection at night, and snow/cloud discriminators to aerosol optical properties and desert dust storm enhancements. These sensors include: Terra/Aqua MODIS, the POES Advanced Very High Resolution Radiometers (AVHRR) and Advanced Microwave Sounding Unit-B (AMSU-B), the Sea-viewing Wide Field-of-View Sensor (SeaWiFS), Meteosat-5, DMSP Operational Linescan System (OLS) and Special Sensor Microwave Imager (SSM/I), and the Tropical Rainfall Measuring Mission (TRMM) microwave imager (TMI) and precipitation radar (PR).

NPOESS-VIIRS	DMSP-OLS	POES-AVHRR	NASA-MODIS	GOES-10	GOES-12
0.412 (M1)	---	---	0.412 (8)	---	---
0.445 (M2)	---	---	0.442 (9)	---	---
---	---	---	0.465 (3)	---	---
0.488 (M3)	---	---	0.486 (10)	---	---
---	---	---	0.529 (11)	---	---
---	---	---	0.547 (12)	---	---
0.555 (M4)	---	---	0.553 (4)	---	---
0.640 (I1)	---	0.63 (1)	0.646 (1)	0.65 (1)	0.65 (1)
---	---	---	0.665 (13)	---	---
0.672 (M5)	---	---	0.677 (14)	---	---
0.700 Day/Night	0.7 Day/Night	---	---	---	---
0.746 (M6)	0.75	---	0.746 (15)	---	---
			0.856 (2)	---	---
0.865 (I2, M7)	---	0.863 (2)	0.866 (16)	---	---
---	---	---	0.904 (17)	---	---
---	---	---	0.935 (18)	---	---
---	---	---	0.936 (19)	---	---
1.24 (M8)	---	---	1.24 (5)	---	---
1.378 (M9)	---	---	1.38 (26)	---	---
1.61 (I3, M10)	---	1.61 (3A)	1.69 (6)	---	---
2.25 (M11)	---	---	2.11 (7)	---	---
3.70 (M4)	---	---	---	---	---
3.74 (I4)	---	3.74 (3B)	3.79 (20)	---	---
---	---	---	3.99 (21)	3.9 (2)	3.9 (2)
---	---	---	3.97 (22)	---	---
4.05 (M13)	---	---	4.06 (23)	---	---
---	---	---	6.76 (27)	6.7 (3)	6.7 (3)
---	---	---	7.33 (28)	---	---
8.55 (M14)	---	---	8.52 (29)	---	---
---	---	---	9.72 (30)	---	---
10.763 (M15)	---	10.8 (4)	11.0 (31)	10.7 (4)	10.7 (4)
11.45 (I5)	11.6	12.0 (5)	12.0 (32)	12.0 (5)	
12.013 (M16)	---	---	13.4 (33)	---	13.3 (6)
---	---	---	13.7 (34)	---	---
---	---	---	13.9 (35)	---	---
---	---	---	14.2 (36)	---	---

Table 1: Spectral coverage of VIIRS as compared with OLS, AVHRR, and MODIS sensors. Instrument band indices provided in parentheses where applicable. Also shown are GOES-10/12 channels provided on NexSat. Note: GOES-12 13.3 micron channel is indexed as "6" to avoid confusion with contemporary GOES (9/10/11) imagers.

These products assisted the U.S. and Coalition forces in aircraft strike planning, ship routing, and weapons selection during the recent conflicts in the Middle East. Of particular utility for this domain were the significant dust enhancements derived from MODIS, described by Miller [2003], which when combined with near surface wind overlays from the Coupled Ocean/Atmosphere Mesoscale Prediction System COAMPS™; Hodur (1997)) provided unambiguous identification and short-term tracking of dust storms over low-contrast land backgrounds.

2.2 *Shifting the "Focus" to CONUS*

The successful implementation of Satellite Focus, particularly with regard to state-of-the-art MODIS-derived products, paved the way toward development of NexSat. Whereas the timeliness of data over a domain of active conflict was the primary sensitivity precluding public access of Satellite Focus, shifting the domain to the CONUS has eliminated this point of concern. Most of the meteorological phenomena characterizing the climate of southwest Asia, for which the science algorithms originally were developed, occur with regularity within the CONUS domain. Cloud and snow detection products over the mountainous terrain of the Rockies, Cascades, Wasatch, and Sierra Nevada, low clouds and fog off the west coast, dust storms in the desert southwest, and deep convection over the Midwestern states provide ample opportunity to demonstrate the full scope of Satellite Focus products.

In this way NexSat provides an overview of future operational environmental remote sensing capabilities through the looking glass of a contemporary operational and research-grade observing systems. The following sections detail i) the attributes of the observing systems to be consolidated within the NPOESS Visible/Infrared Imager/Radiometer Suite (VIIRS), ii) the production system responsible for rapid product turnaround based on near real-time acquisition of these telemetries, iii) the design and functionality of the NexSat interface, and iv) examples selected to illustrate the wide scope of potential applications emerging from this new consolidated resource.

3. CONTEMPORARY ANALOGS TO VIIRS

In 2009, the first in a series of sun-synchronous operational environmental satellites comprising the NPOESS program will mark the official consolidation of the DMSP and POES operational satellite programs. This section describes the salient features of the NPOESS-VIIRS sensor (which will actually fly first upon the NPOESS Preparatory Project (NPP) in 2006) and its legacy instruments (OLS, AHVRR, and MODIS).

3.1 *NPOESS-VIIRS Characteristics*

With 9 spectral bands in the visible/near infrared, a day/night visible band, 8 in the short/mid-wave infrared, and 4 in the long wave infrared, VIIRS is an ambitious sensor chartered to address multiple science challenges pertaining to interactions between multiple components of the atmosphere (e.g., clouds, smoke, volcanic ash), lithosphere (e.g., fire detection, high resolution imagery, vegetation), and hydrosphere (e.g., sea surface temperature, ocean color). Table 1 compares the proposed VIIRS instrument against the heritage OLS, AVHRR, and MODIS sensors. VIIRS provides five high-resolution (~370m spatial resolution at nadir and ~800m at edge of scan) imager channels similar to POES, 16 moderate resolution (~740m spatial resolution and ~1.6km at edge of scan) channels (including many from MODIS), and a day/night visible band similar and in several ways superior to the OLS day/night band (Lee *et al.*, 2004). With superior spatial, spectral and radiometric resolution, VIIRS will be in a much better position than current observing systems to meet future environmental data requirements.

The only science shortcoming of the initial VIIRS design is in its lack of a 6.7 micron (water vapor) channel, valuable for polar wind-vector estimates via feature tracking algorithms (e.g., Key *et al.*, 2002); made tractable due to the high temporal sampling frequency achieved by the polar orbiting constellation at high latitudes). A provision for evolving instrument requirements during the NPOESS program may allow for inclusion of a vapor channel on follow-on VIIRS sensors (i.e., those scheduled to fly follow on members of the constellation).

The data acquisition (ground segment) of NPOESS will implement a "Safety Net" system comprising fifteen globally distributed unmanned downlink stations connected through public fiber optic communication lines to four weather central (data processing) facilities. Through use of this network, 75% of VIIRS data will be available within 15 minutes of observation and the remainder within 30 minutes—unprecedented timeliness for global polar orbiter data. The NPOESS constellation will entail three operational satellites with ascending node local-time equatorial crossings of 0930, 1330, and 1730.

3.2 *DMSP-OLS Characteristics*

The DMSP is a Department of Defense (DoD) satellite program operated by the Air Force. The satellites follow sun-synchronous orbits at 830 km altitude and 101 minute periods. At the time of this writing, two primary (F13 and F16) and two secondary (F14 and F15) DMSP satellites provide operational global data (two additional satellites, F8 and F12, operate in test and tactical modes exclusively). With the exception of F15, the DMSP satellite orbits are situated near the terminator for "first light" observations. The OLS comprises two telescopes for visible (~0.7 micron, uncalibrated) and infrared window (~11 micron, 8-bit linear calibration across 190 to 310 kelvins) bands, and a photomultiplier tube for the broad nighttime visible band with photomultiplier tube signal amplification for the primary purpose of day/night cloud imaging over a 3000 km swath. An important feature of the OLS is its pendulum-motion (i.e., slowing at scan edge) "whisk-broom" scanning and constant sample rate, which when combined with a variable detector size with scan angle (see Elvidge, 1997) achieves equidistant pixels in the cross track direction with minimal degradation of spatial resolution toward the edge of the swath.

NRL receives its global DMSP-OLS smooth (2.7 km resolution) format data from FNMOC via the Air Force Weather Agency (AFWA). Owing to restrictions in the release of these DoD data to the public domain, OLS products typically are made available no sooner than three hours after satellite observation time.

3.3 *POES-AVHRR Characteristics*

The POES series features a constellation of sun-synchronous satellites having orbital altitudes of 833 km and periods of 102 minutes. Currently the primary satellites are NOAA-16 (afternoon pass) and NOAA-17 (morning pass), with NOAA-15 as backup for NOAA-17. The primary instrument aboard contemporary POES platforms, the AVHRR/3 radiometer, provides six spectral bands: visible (band 1; 0.65 micron), near-infrared (band 2; 0.86 micron), shortwave-infrared (band 3A; 1.6 and band 3B; 3.7 micron), and thermal infrared (band 4; 11.0 and band 5; 12.0 micron). To avoid thermal contamination in band 3B during the day NOAA-17 switches between band 3A (daytime) and 3B (nighttime). NOAA-16 maintains band 3B during both day and night. The superior spectral capabilities of AVHRR/3 to OLS enable additional hydrologic, oceanographic, and meteorological applications, including surface characterization, snow detection, cloud property determination, and fire detection. AVHRR/3 does not contain a day/night visible band, and due to its constant scan rate and fixed field of view lacks the superior swath-edge resolution and pixel spacing achieved by the OLS instrument.

NRL currently receives CONUS-domain AVHRR through a combination of local and remotely captured high-resolution picture transmission (HRPT; 1.1 km pixels at center of swath) reception. Global data are provided via subscriptions to the NOAA Satellite Active Archive (SAA). Latencies on POES data range from only minutes for HRPT, to 2.0-2.5 hours for the SAA datasets.

3.4 *NASA-MODIS Characteristics*

The Moderate Resolution Imaging Spectroradiometer (MODIS; e.g., King *et al.*, 1992) instruments feature 36 narrow bands across the optical spectrum between 0.4 to 14.4 μm. Spatial resolution among these bands varies from 1km in the thermal infrared (bands 8-36), 500m in the blue/green-visible and shortwave infrared (channels 3-7) and 250m in the red-visible and near infrared (bands 1-2, respectively). The MODIS instrument is onboard two sun-synchronous EOS satellites (with 705 km orbit altitudes and 99 minute periods). The first satellite, Terra (launched December 1999), provides a local ~1030 AM daytime equatorial crossing on a descending node). The second satellite, Aqua (launched May 2002), crosses the equator roughly 3 hours later at 1330 on an ascending node. The two-satellite EOS constellation therefore suffers a 7-hour gap (on average) between daytime and nighttime passes—a problem that will be overcome in the NPOESS era by a 3-satellite constellation with local crossing times spaced by 4 hours (and thereby providing 4 hour temporal resolution with sample frequency improving with increasing latitude).

NRL receives global Terra and Aqua MODIS data (all resolutions of calibrated Level-1B data and a subset of Level-2 environmental data records including aerosol and cloud properties) in near real time (typically on the order of 2 hours after observation) through a Near Real Time Processing Effort (NRTPE) coordinated between (NOAA, NASA the United States Navy and Air Force. The NRTPE allows NRL to provide a suite of MODIS-derived products (including high resolution true color imagery, fire detection, dust enhancements, cloud and snow discrimination, and nocturnal low cloud and fog detection) meeting the timeliness requirements for utility in military applications during OIF. In the context of NexSat, the NRTPE will facilitate the incorporation of multiple streaming ancillary datasets (e.g., NWP fields, National Lightning Detection Network, and METAR observations) in the production system described further along in Section 4.

3.5 *Geostationary Datasets*

To fill in temporal gaps arising from the polar orbiter sampling of the CONUS domain, real-time observations from the NOAA Geostationary Operational Environmental Satellites (GOES) supplement NexSat. These data, available to NRL in real-time via the GOES-10 (135 W) and GOES-12 (75 W) rebroadcast, provide a valuable time series and dynamic context to the AVHRR/OLS/MODIS snap-shots. In addition, the high temporal refresh of GOES offers opportunities for a limited subset of multi-sensor demonstrations based on channels shared among GOES/AVHRR/OLS with the additional spectral information available upon MODIS. In this case, co-registered datasets over domains where sensor scan line times match within some specified criteria are selected for analysis.

The comparisons are limited further by the capabilities and compatibilities of the independent sensor datasets. For example, applications involving the nighttime visible channel are limited by the fact that the OLS equivalent day/night band is uncalibrated. NexSat emphasizes concepts that will become realities in the VIIRS era, illustrating them with current satellite products when possible.

3.6 *The Ensemble Observing System*

Using heritage sensors, the overarching strategy for NexSat is to illustrate via intra-sensor comparisons, multi-sensor and sensor/model-fusion products, and stand-alone sensor demonstrations (where applicable) the anticipated “combined” sensor capability to become available with NPOESS-VIIRS. For example, improvements due to increased spatial resolution can be demonstrated with MODIS 250 m visible data (sub-sampled to VIIRS 370 m pixels) versus 1.1 km AVHRR imagery. At swath edge, OLS may be compared against AVHRR or MODIS to demonstrate additional spatial resolution improvements of VIIRS over AVHRR due to adoption of the DMSP-OLS scanning technique. Spectrally, MODIS provides many opportunities to demonstrate improved environmental characterization beyond OLS/AVHRR. Multi-sensor products can be addressed on spatially and temporally matched data. In addition to matches between the polar orbiters with co-registered geostationary data, potential matches exist for example between the following pairs: NOAA-15 (1826 Local Time Ascending Node (LTAN)) with F-13 (1828 LTAN), NOAA-17 (2223 LTAN) with Terra (2230 LTAN) or F-15 (2112 LTAN), and NOAA-16 (1420 LTAN) with Aqua (1330 LTAN). The likelihood of finding good spatial and temporal matches among the various polar orbiters increases with increasing latitude.

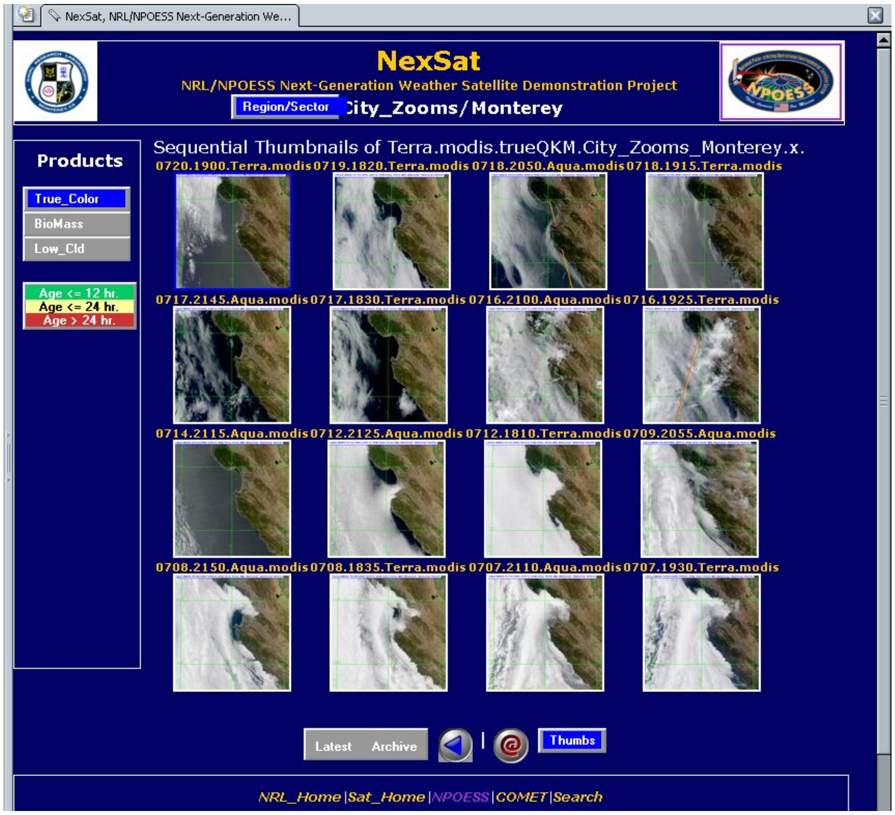

Figure 1: Example screen capture of the NexSat webpage. Sector navigation, product selection, and product display options are located at top, left, and bottom, respectively.

4. PRODUCTION SYSTEM

Processing of the large (> 50 Gigabyte/day) CONUS dataset is tasked to a multi-processor cluster running an portable batch system (PBS) queuing architecture with onboard 300 GB raid. The system is essentially a collection of Linux machines (each having dual 2.8 GHz processors with 4 GB memory cards) operating serially and tasked by a server according to its current load. To minimize input/output (I/O) delays and network file system (NFS) mount points, caching of satellite and numerical model fields to local disks. Mirrored system disks, dual power supplies, a backup generator, and stand-alone configuration provide additional fail-safes and system stability. The generic system is configured to readily accept additional processing nodes as computational demands increase with time.

A series of pre-processing steps (quality checks, format/units conversions, and corrections initiates upon first receipt of new data in preparation for calls to the science algorithms. Each science algorithm, wrapped within a generic driver script for rapid application to new domains, is called automatically upon completion of data preprocessing. These algorithms were developed in a variety of high-level languages including C++, Fortran-90, the Interactive Data Language (IDL), and TeraScan (SeaSpace Corp.). The drivers loop over a list of “sector files” containing all information relevant to a given coverage sector (position, pixel size, map projection, coastline/grid/text annotation specification, product-dependent variables, destination directory, etc.). Value-added products are distributed public and secure (dependent on domain and application) network area storage (NAS) systems, each having Terabyte capacity (allowing for online storage of a large product archive). TeraScan/IDL also provided the primary visualization packages.

5. THE NEXSAT DEVELOPMENT

5.1 *Philosophy*

The goal of NexSat is to communicate many of the advantages anticipated from the forthcoming NPOESS-VIIRS sensor, while at the same time serving as a weather resource to various operational users within the DoD, government, academia, private, and general public domains. With a strong emphasis on visualization of the current weather situation, the purpose of NexSat is to simultaneously inform, educate, and capture the imaginations of potential future atmospheric scientists.

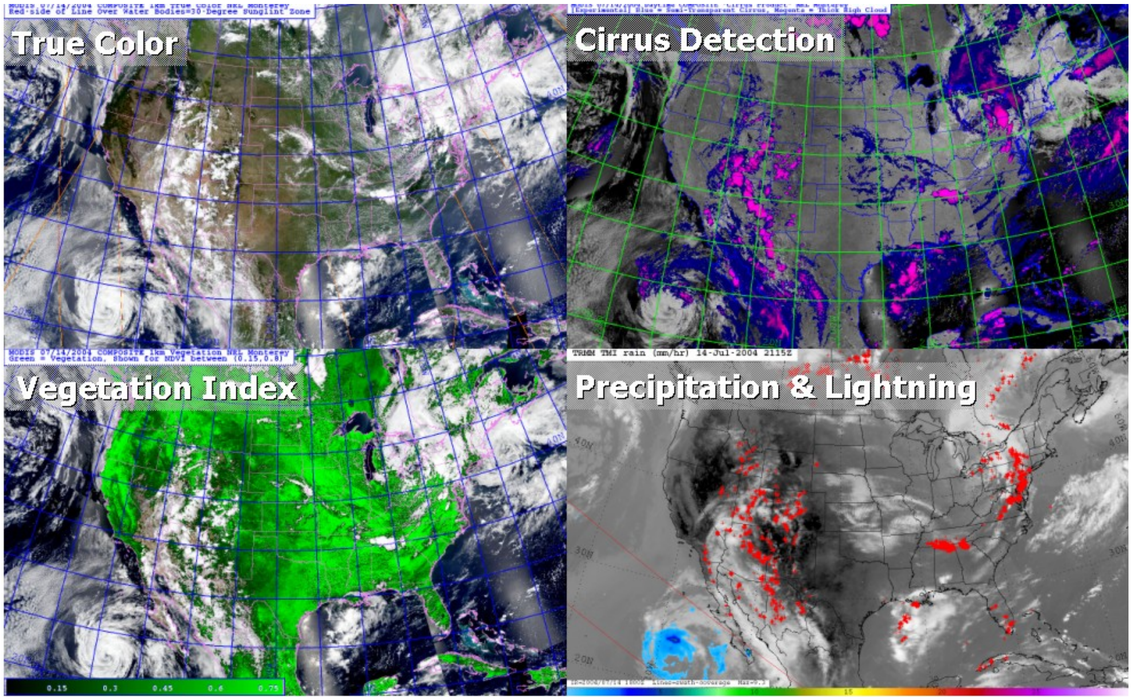

Figure 2: The NexSat CONUS domain with co-registered true color, cirrus, vegetation index, and precipitation/lightning.

The push toward next generation optical-spectrum radiometers (research sensors; e.g., MODIS, SeaWiFS) began in 2002 with Satellite Focus (Miller *et al.*, 2003), but access to this resource was limited to the DoD. Building on the design heritage of its predecessors, the current NexSat effort provides the "public analog" to Satellite Focus. From the Navy perspective, NexSat forms a functional bridge between DMSP/POES/MODIS and the NPOESS Preparatory Project (NPP) in the short term. In the long term, NexSat provides a formal transition into the operational NPOESS era.

5.2 *Form*

As mentioned above, NexSat draws heavily upon constructs established for Satellite Focus (and, in turn, the TC Webpage). The high spatial resolution sensors highlighted on NexSat lend themselves to a telescoping (toward increasing spatial resolution, e.g., from coarse-scale "Domains" to medium-scale "Regions" and finally to fine-scale "Sectors") directory structure for product display. These definitions intentionally are left general, since scale is relative to the sensors in question (e.g., visible data for MODIS is fine compared to GOES but coarse compared to LandSat). Within the Sectors of the NexSat architecture, environmental product categories rank above satellite sensors pertaining to them, since various sensors may be able to create the same product at various levels of detail and accuracy and it is the comparison of these capabilities that we wish display. The single Domain for NexSat is the CONUS, Regions include the Western, Central, and Eastern U.S., and a number of sectors reside within each of these regions. The current production system allows for population of new areas of interest with a full complement of available satellite products only in a matter of minutes. In terms of processing, in many instances the same software populates both pages, with domain flags determining the posting destination for various products.

5.3 *Functionality*

NexSat is a graphical user interface run upon an Internet browser (e.g., Netscape or Microsoft Explorer). An example of this display is shown in Figure 1. Operation of the page is largely self explanatory, with drop-down menus and highlighted buttons controlling sector, product, and sensor selection. Products are presented as a collection of the most recent quick-look thumbnail images, whereby the user may scan for scenes of interest and select higher quality versions. Configurable interfaces for animation and interrogation of the online archive (typically spanning from several days for GOES to several weeks for polar orbiter datasets) simplify exploration of the page. Users may toggle between temporally matched products from individual products or multiple-pass composites, view satellite pass prediction, and access online training. The training element is germane to new users (especially members of the general public) who may not be familiar with the wide variety of NRL satellite applications, their interpretation, utility, and any caveats. All product buttons are color coded (green < 12 hr, yellow < 24 hr, red ≥ 24 hr) according to the most recent observations available.

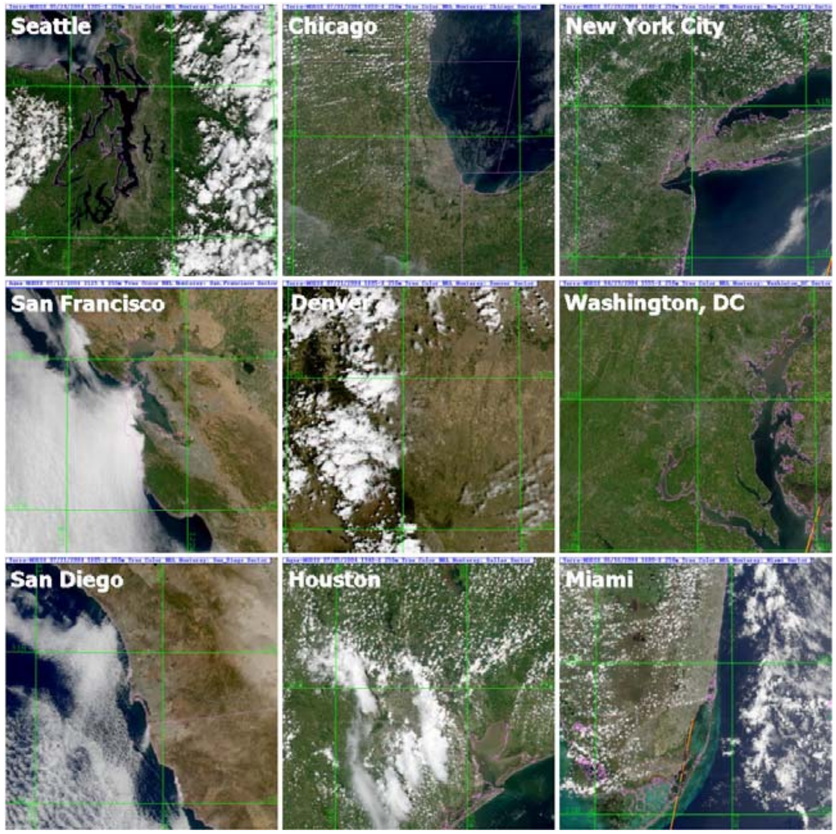

Figure 3: Examples of MODIS 250m resolution "City Zoom" true color zoom imagery for selected CONUS cities.

6. SELECTED EXAMPLES

The examples to follow help to illustrate the wide and growing scope of applications included on the NexSat Web Page. Unless otherwise specified, the retrieval algorithms and enhancement techniques feeding NexSat are organic to NRL, developed in connection with concurrent internally and externally sponsored satellite research and development programs.

6.1 *Multi-Scale Products*

Figure 2 depicts the NexSat "Full" Region with true color composite, cirrus detection (e.g., Turk and Miller, 2004), normalized-difference vegetation index (NDVI), and satellite-derived precipitation (Turk *et al.*, 1999). As indicated, the domain encompasses the CONUS and extends outward 10-15 degrees in all directions for the purposes of tracking land-falling storms. Although depicting spatial resolution advantages at these scales is prohibitive, such "big picture" views are useful for gaining a synoptic context of the current meteorological situation. In the current example, a user may key-in on the tropical depression southwest of Baja California, the monsoonal convection over the southwestern deserts, or the convective line traversing the east coast. In each case, the user has the option to zoom in to the areas of interest simply by selecting the most appropriate Region/Sector via the top-frame navigation button.

At the other extreme, NexSat displays high resolution (here, 250m pixels) MODIS true color products over selected major cities throughout the CONUS. Figure 3 shows examples of these sectors (each frame is centered on a Global Positioning System (GPS) specified location), which are produced by encoding the observed variance in the red band (at native 250m resolution) in the blue and green bands (both at 500m native resolution. A similar technique will be applied to VIIRS bands to produce 370m spatial resolution true color imagery.

6.2 *Dust Enhancements*

Another key product developed for applications over southwest Asia but readily translated to the CONUS is a dust enhancement (Miller, 2003) developed for MODIS, which enlists multiple channels across the optical spectrum to decouple dust from other components of the scene while drastically enhancing its contrast against bright backgrounds. A digital mask of dust coverage is then readily produced for application in other algorithms. The southwestern desert regions of the CONUS occasionally provide impressive outbreaks of dust that are reminiscent of those observed across the Middle East. While most dust storms over the

CONUS originate from thunderstorm outflows (called "Haboobs" in the Middle East) and are often obscured on MODIS images by overlying cirrus anvils, synoptic scale forcing (e.g., strong pre and post frontal winds) will lift substantial dust where the soil conditions permit. Figure 4 reveals such an event that occurred during the spring of 2004 over southwestern Nevada. The diffuse region noted in the upper (true color) panel is revealed to be a substantial area of dust (optical thickness greater than 0.5) propagating southward along the California border. NPOESS-VIIRS will supply the requisite channels to implement this technique globally, and the late afternoon (1730 local time) satellite pass will be particularly useful in tracking events tied strongly to the diurnal heating cycle.

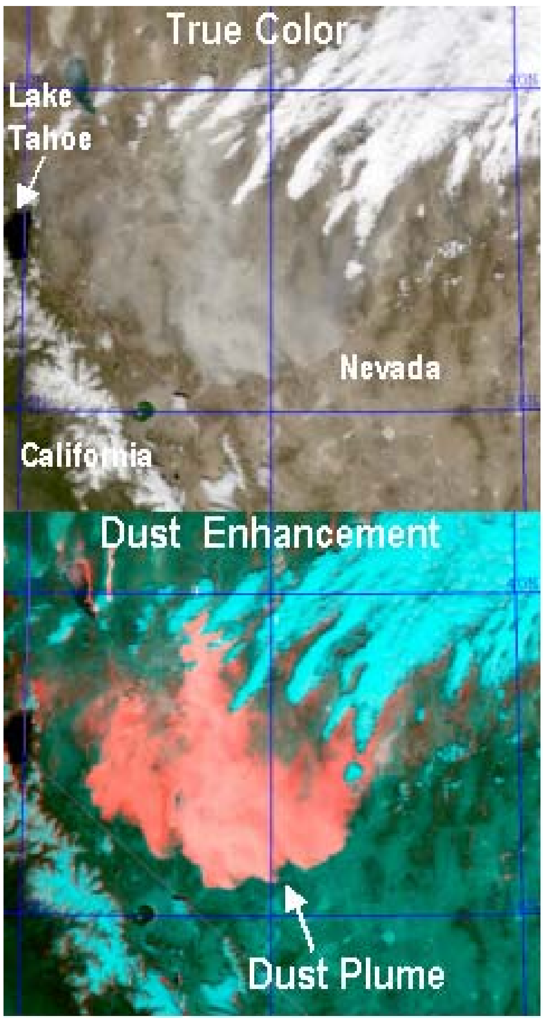

Figure 4: True color (top) and dust-enhanced imagery (bottom) of a large dust plume drifting across the Great Basin and Mohave Deserts of southern Nevada.

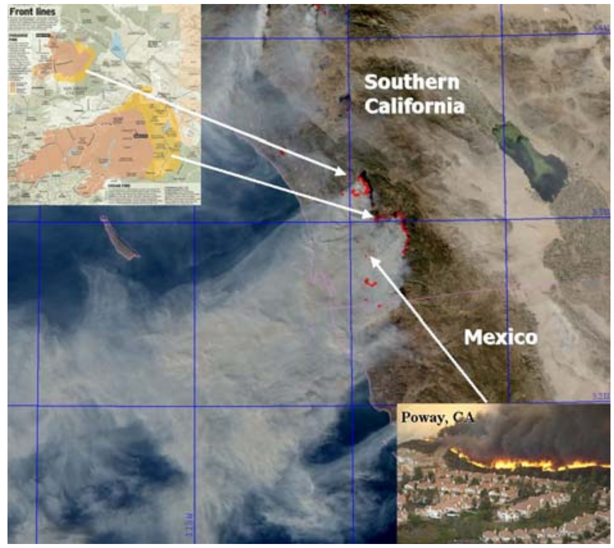

Figure 5: MODIS fire/hot-spot overlay (red) depicts active fire lines from the San Diego County Paradise and Cedar wildfires during October, 2003.

6.3 *Fires and Hot Spots*

Kaufman et al. (1998) and Prins et al. (1998) demonstrate the utility of the 4.0 micron band (available upon MODIS, GOES, and AVHRR) for detection of fires and hot-spots. Owing to the non-linear response of the Planck function, 4.0 micron offers exceedingly higher sensitivity to hot sources (even when present only at sub-pixel scales) compared to the IR window channel situated at ~11.0 microns. The OLS does not include a 4.0-micron channel, but its nighttime visible channel provides an alternative method of detection via sub-pixel scale light emissions from active fires. This adds a level of discrimination not directly available to the heat-signature technique, and provides an example of the improvements anticipated by VIIRS, which will contain all requisite bands.

In October 2003, wildfires fueled by years of drought and strong Santa Ana winds ravaged Southern California. Figure 5 depicts the scene of chaos as observed by MODIS, with fires detected by the algorithm highlighted in red. Even with the conservative daytime thresholds (due to contributions to 4.0 micron observations from solar reflection; nighttime scenes allow for more aggressive detection thresholds), the fire lines are defined clearly and correspond closely with surface depictions. The same fire products were used during the early stages of OIF to monitor the oil fields of southern Iraq, which the military feared would be set ablaze (and causing potentially severe visibility hazards for pilots) by the Iraqi Republican Guard as in the 1991 Gulf War. NPOESS-VIIRS will provide both detection methods mentioned above on the same platform and at higher spatial resolution than contemporary platform.

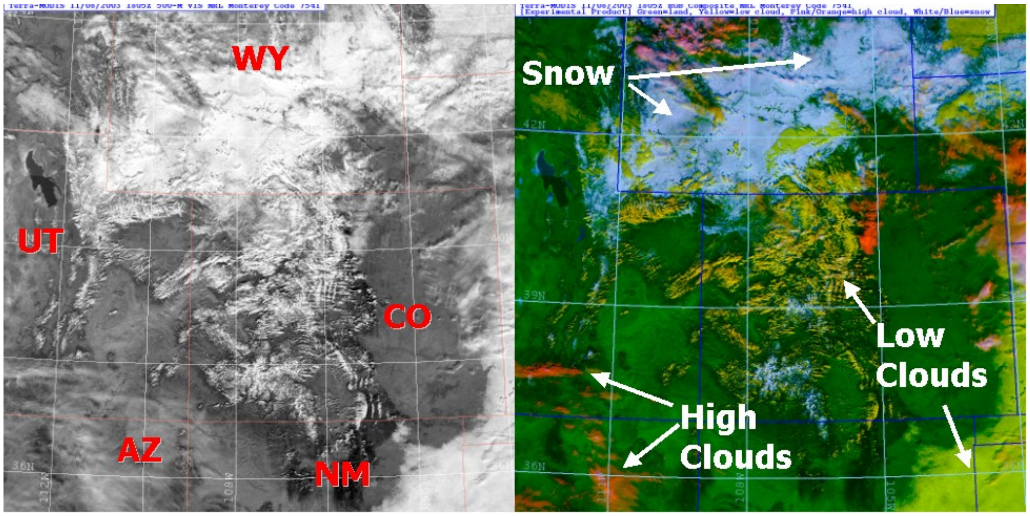

Figure 6: Conventional visible imagery (left) for a complicated cloud/snow scene over the Rocky Mountains. The Cloud Layer/Snow enhancement (right) discriminates low clouds and fog from upper level cirrus, while clearly decoupling the snowfield in southern Wyoming.

6.4 *Cloud/Snow Discrimination*

Discriminating between cloud and snow cover over complex terrain with visible (both are bright) and infrared (can have similar temperatures) imagery is extremely challenging. Even in the shortwave infrared channels (e.g., 1.6 and 3.9 micron), which provide improved discrimination of snow from liquid clouds due to enhanced snow absorption, suffer ambiguity with certain forms of cirrus. Miller *et al.* (2004) discuss multi-spectral techniques, combining the bands mentioned above with additional bands available on MODIS to improve discrimination, that yield improved delineation of cloud and snow. An example of this technique is shown in Figure 6 for a complex cloud/snow scene over the Rocky Mountains. The visible image in the left panel of this example provides little insight on the snow distribution, and particularly any differences between the bright regions over southern Wyoming and western New Mexico. In the right panel, the snow/cloud enhancement reveals an extensive snowfield in Wyoming and a low cloud deck in New Mexico. The 1.38-micron near infrared vapor channel on MODIS enables discrimination between cirrus clouds (pink/magenta) and lower tropospheric clouds, giving some indication of regions where multi-layered clouds exist. In NexSat, the cloud/snow product will be highlighted during the winter months throughout the CONUS. The improved detection of snow cover from VIIRS (with similar capabilities to MODIS, in addition to the day/night band for detecting snow cover at night) will provide improved snow depiction over POES for use by resource managers, search and rescue, the DoD, and climate research.

6.5 *Deep Convection and Lightning*

The heavy rain, hail, turbulence, microbursts, and lightning often associated with deep convection pose high risk to aviation. At the surface, these same elements have the potential to cause severe damage and loss to property and life. The NRL deep convective cloud top height products combine a convective identification based on the 11.0-6.7 micron brightness temperature difference (e.g., Schmetz *et al., 1*997) with a simple temperature/height interpolation based on the 11.0 micron brightness temperature and a model temperature sounding. The assumptions are that any clouds analyzed are sufficiently opaque such that satellite-measured temperatures represent the ambient atmospheric temperature at cloud-top altitude. In addressing the needs of the aviation community, the retrieved cloud top heights are expressed as equivalent altimeter heights (by converting the retrieved altitude to an equivalent model pressure, and interpolating height based on a standard atmosphere profile). The results may differ by as much as 1 to 4 thousand feet from the temperature/height retrieval.

Figure 7 shows the GOES deep convective cloud height product in the top panel, along with lightning data overlaid upon GOES imagery in the central panel, and a nighttime visible/infrared product based on OLS observations. The deepest convective cells in the scene, over West Virginia and North Carolina, exhibit 50-55 Kft tops and are electrically active. The OLS nighttime visible channel detected several of these strikes even over the extremely short period during which the detector scanned across over these storms (evident in the OLS image as white streaks). Used together, the cloud heights and lightning data may provide researchers with additional insight on the evolutionary behavior of convection.

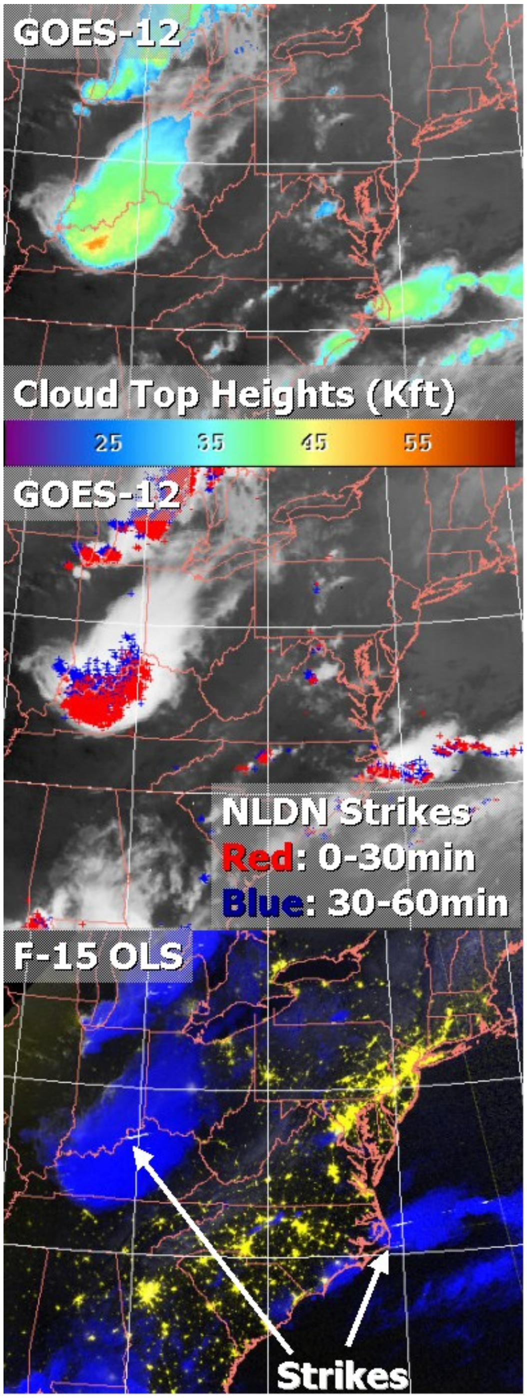

Figure 7: Deep convective cloud top heights (top) in kilo feet, National Lightning Detection Network cloud to ground strikes (center), and OLS nighttime visible product (bottom) depicting urban lights as yellow, cold cloud tops as blue, and detected lightning as white streaks atop the convective elements.

6.6 *Nocturnal Low Clouds*

Low clouds and fog also pose serious problems to aviation in terms of visibility impairment for landing aircraft and obscuration of low-altitude flight hazards. Their often wide spatial extent and disorienting effects in some regards make these seemingly benign cloud forms more dangerous than deep convection. At the surface, reduced visibility due to fog has claimed countless lives in automotive accidents (e.g., the so-called "Tule fog" of California's San Joaquin Valley has been responsible for numerous automobile fatalities on Interstate-5). The central challenge to satellite detection of low clouds at night arises from clouds having similar temperatures to surrounding cloud-free land and ocean surfaces. The 11.0 – 4.0-micron brightness temperature difference enables low cloud detection at night (taking advantage of cloud enhanced scattering at 4.0 micron; e.g., Kidder *et al.*, 1998). However, certain mineral-rich soils (particularly abundant in the deserts of the southwestern United States) possess similar spectral behavior to the "low cloud" signature, and may erroneously trigger the detection algorithm.

Lee and Miller (2003) explore the utility of additional spectral information surrounding 4.0 micron from MODIS (bands 20-23 in Table 1) to distinguish nocturnal low clouds from ambiguous surfaces, but find no single solution to the highly variant soil compositions of these backgrounds. They proceed to describe a fallback method whereby false low cloud regions are masked via low pass filtering of a scene (transient clouds removed and persistent false-detections due to mineral-rich land backgrounds retained). An example of this latter method, applied to the west coast of the United States, is shown in Figure 8. In the enhancement, low clouds appear red, high clouds appear cyan, and regions of potential false cloud (the land mask) appear green. Without the mask, many regions over the southwestern deserts would appear red, similar to the enhanced low clouds. Apparent low clouds overriding masked regions are considered "ambiguous," although in practice may be detected if their signal is substantial (producing a yellow tonality over the otherwise green mask zones). Note that in Figure 8, several areas along the immediate coast of California appear masked. These regions are most likely contaminated by persistent low cloud that occurred over the time frame of this mask's recent generation. Ongoing processing during the fall and winter seasons will gradually remove these artifacts.

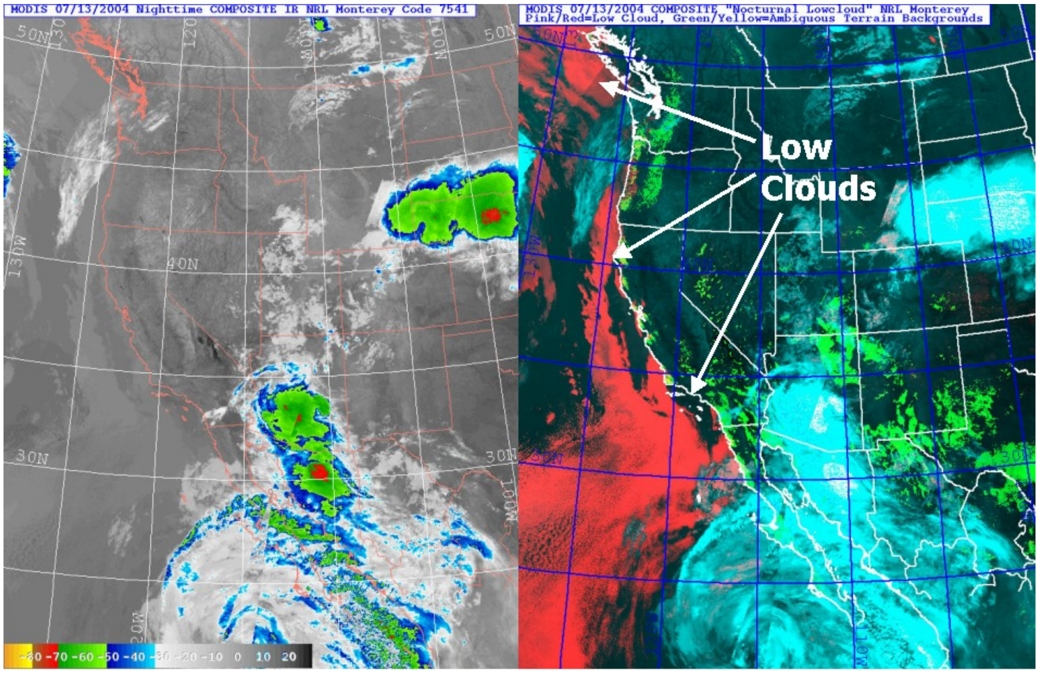

Figure 8: The detail of a marine stratocumulus deck residing off the California coast is difficult to discern in conventional infrared imagery (left) but readily apparent in the MODIS nighttime low cloud product (right).

6.7 *Contrail Detection*

Contrails form when warm, moist jet exhaust mixes with the cold and dry upper troposphere environment. Depending on the upper tropospheric humidity (UTH), contrails may either dissipate rapidly or persist and spread over time (forming extensive cirrus shields). In the latter case these anthropogenically-forced cirrus impact the radiative profile by reflecting sunlight and absorbing and re-emitting terrestrial radiation, effectively reducing the diurnal range of surface temperature (Travis *et al.* 2002). In examining 25 years of satellite data under the assumptions of constant UTH and long-term trends in cirrus coverage being due entirely to aircraft activity (i.e., accounting for spread in favorable environments), Minnis *et al.* (2004) find that contrail formation can account for nearly all of the observed warming over the period.

Contrails are of interest from the military perspective from the standpoint of air traffic monitoring and stealth operations. Several papers (e.g., Lee, 1989, and Weis *et al.,* 1998) illustrate their detection from space, based on the 11.0 – 12.0 micron brightness temperature difference. Using additional information from the MODIS 8.5 micron channel, Figure 9 demonstrates a version of contrail detection where ice-phase clouds are depicted as red. The high spatial and spectral resolution of VIIRS will provide improved detection capabilities for fine-scale (e.g., recently created) contrails.

7. POTENTIAL APPLICATIONS

The examples above speak to a number of possible uses for the NexSat CONUS product suite when it is made available in near real time. The transportation industry, including aviation, maritime, and commercial vehicle drivers, benefits from real time depiction of strong convection and regions of developing fog. Additional users include natural resource and disaster management agencies (e.g., Federal Emergency Management Agency (FEMA), fire fighters, and the Environmental Protection Agency (EPA). The United States Border Patrol and Coast Guard may find NexSat products useful in assisting operations (e.g., supporting unmanned surveillance aircraft along the nation's borders). In a more general sense, NexSat products might address the many responsibilities of the Department of Homeland Security (e.g., high resolution city zooms with model wind overlay for now-casting of plume dispersion). Supporting domestic DoD activities, NexSat will dedicate several sectors over Naval and Air Force regions of interest.

Many practical weather forecasting applications require high temporal resolution, and as such will benefit most from NexSat products based on GOES and NWP data. The high-resolution polar orbiting imagery, while still very useful when available, is well suited to support scientific field programs and basic research of serendipitously observed phenomena. The extensive online archive of imagery allows users to search for case studies of interest, and the collection of co-registered products provides an enhanced

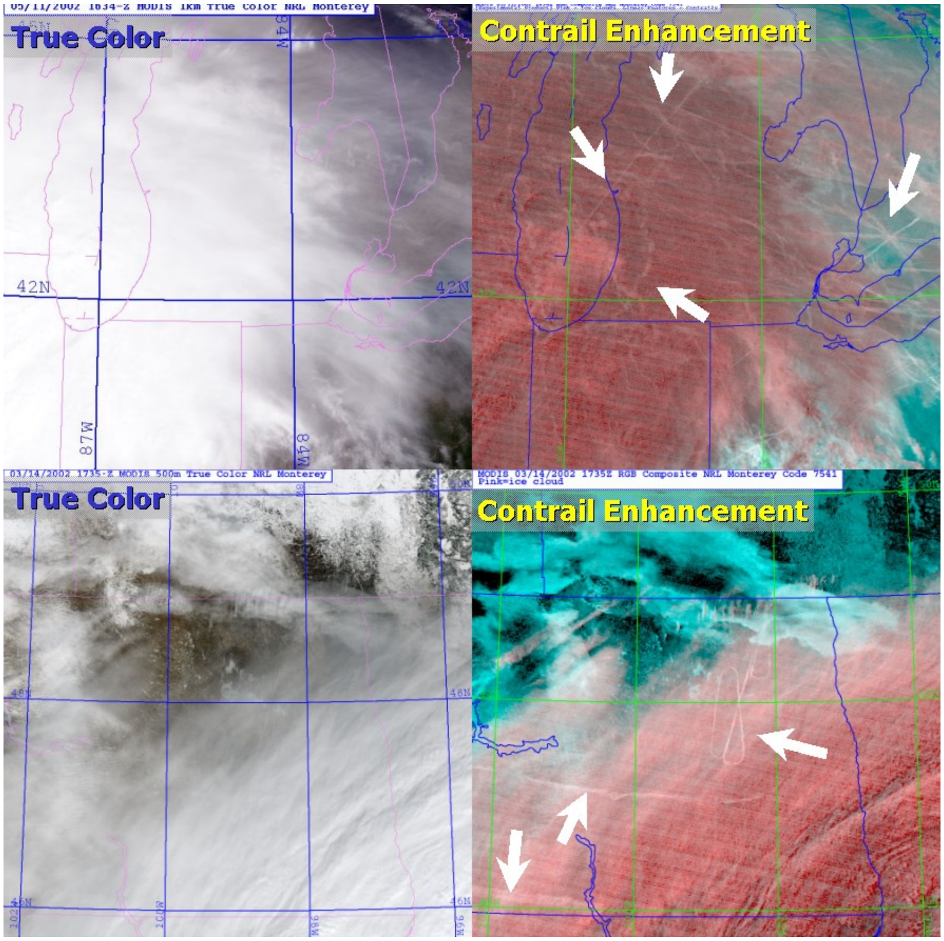

Figure 9: MODIS true color imagery (left) and the aircraft contrail enhancement (right) revealing numerous aircraft traclks in the proximity of cirrus shields.

meteorological context. NRL hosts research algorithms to NexSat only after considerable offline testing of algorithm performance under a large range of conditions. However, automated product generation occasionally reveals flaws in algorithm design that must be addressed. In this capacity NexSat is useful to NRL as a tool for development of a robust product suite as it paves a course for Navy applications of VIIRS in the NPOESS era.

8. CONCLUSION

This paper introduces a new public web page hosted by NRL Monterey featuring a broad collection of environmental products based on contemporary operational sensors generated by POES, DMSP, and GOES, as well as research-grade MODIS data. All NexSat applications fall under the general disclaimer of research and development. Data dropouts may occur, as NRL does not conduct 24/7 operations. Product artifacts, arising for example from departures of environmental conditions from implicit algorithmic assumptions or sensor-specific parameters, give rise to false alarms in the detection of a physical parameter. Uncertainties in retrieved properties originate from errors in measurements, approximations to the forward model, and nature inversion schemes applied. In the end, the nature of applications stemming from the near real-time product availability is at the full discretion of the user. Whether the pursuit be research, now-casting, or education, NRL encourages all users to provide feedback on the utility of the page for their applications, and suggestions for improving the interface and content when applying these products to assist in their various activities.

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