

# Operational Application of Composit MODIS Chlorophyll-a

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**Abstract-** WorldWinds, Inc. and NASA MSFC SPoRT developed a daily Chlorophyll-a composite product from NASA's MODIS satellite data to aid in the development of a system to track favorable conditions of certain pelagic fish species. This data has been applied in the XMWX commercial weather product which provides live, site specific atmospheric and oceanographic information to motorists, boaters, outdoorsmen, commercial mariners, and emergency personnel. Graphical user data is continuously transmitted over the XM satellite radio constellation in GIS format overlaid on a GPS enabled 3D relief map.

## I. INTRODUCTION

To provide mariners with all of the needed aspects of pertinent meteorological and oceanographic data, WorldWinds and partners WxWorx and XM Satellite Weather, developed a suite of data products, dubbed XMWX, that includes: current in-situ measurements; sea surface temperature; significant wave height, period, and direction; current and forecasted wind, sea level pressure, and visibility; cloud cover mosaic; marine zone forecasts, additional in-house proprietary data, including FishBytes™, and other germane information.

As part of the XMWX partnership, WorldWinds, Inc. recently developed a method of locating favorable conditions for certain fish populations. The FishBytes™ product is a system that guides fishermen to areas most likely to contain certain species, thus making more informed decisions while saving time and fuel. While developing FishBytes™, WorldWinds sought public sources of operational satellite data and discovered a reliable source for sea surface temperature (SST) composites from the National Aeronautics and Space Administration (NASA) Short-term Prediction Research and Transition Center (SPoRT) at the Marshall Space Flight Center. SPoRT had previously developed an algorithm that compensates for holes in SST data caused by cloud cover that interferes with satellite readings. This was important to WorldWinds ability to utilize NASA SST data into the FishBytes™ product as commercial requirements dictate that the product must be operational 24/7. Even if clouds should cover most of the East Coast for multiple consecutive satellite passes, FishBytes™ must continue to function.

## II. NEAR-REALTIME CHLOROPHYLL-A

Building on the SST composite data algorithm, WorldWinds and SPoRT teamed up to build a similar product for the MODerate resolution Imaging Spectroradiometer (MODIS) Chlorophyll-a products (hereafter simply chlorophyll). WorldWinds entered into a NASA Cooperative Agreement with the SPoRT group in January 2008 to develop a daily chlorophyll composite product from MODIS data, with a project entitled "Daily Chlorophyll Products for Ecosystem and Fishery Applications". The goal of this project was to provide MODIS value-added chlorophyll products to the scientific and operational marine user communities. MODIS data is the most accurate daily source of SST and chlorophyll concentrations available. It is high-resolution (approximately 1-km near coastal regions) and spatially continuous. Daily, cloud-free chlorophyll composites will aid in many marine applications by monitoring the spatial variability of chlorophyll, track daily changes in distribution due to river outflow and interaction with ocean currents, and will develop a robust data set for field campaigns.

### A. Realtime Data Access

We would like to acknowledge the funding and support this project has received from the NASA SPoRT group at Marshall Space Flight Center; specifically PI Dr. Gary Jedlovec.

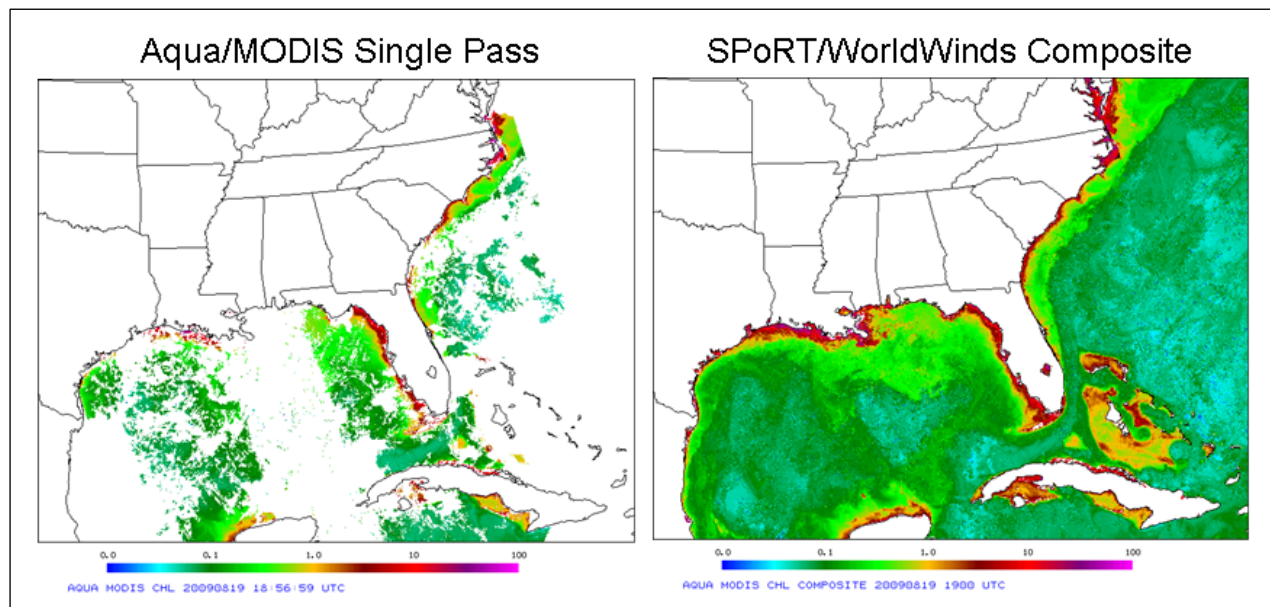
The WorldWinds and SPoRT teams developed server capabilities to allow real time access to MODIS data collected at the University of South Florida (USF) Institute for Marine Remote Sensing (IMaRS) MODIS Direct-Broadcast data station- <http://modis.marine.usf.edu>. This included writing shell scripts in Linux and installing McIDAS (Man computer Interactive Data Access System) software on the dedicated server that WorldWinds purchased for chlorophyll processing as its part of the NASA cost sharing agreement.

### B. Refine and Implement Compositing Scheme

The SST compositing scheme developed in 2007 by Haines et al. [1] to produce a high resolution, spatially continuous SST composite product was analyzed to determine its appropriateness for chlorophyll applications. The SST compositing algorithm generates a detailed and spatially continuous SST field while minimizing cloud contamination and data latency effects. The SST algorithm conducts a mean of the highest two values of the last three clear pixels based on the expectation that any cloud contamination acts to reduce the SST value. Since this approach works so well for the MODIS SST data, the team began development of the chlorophyll compositing algorithm from this point. This algorithm was modified and applied to the MODIS chlorophyll data. Initially, the single highest of the most recent two clear pixels was used for chlorophyll compositing under the expectation that the visible wavelengths would be attenuated by thin clouds not detected by the cloud masking algorithm but with the temporal variability of oceanic chlorophyll it was foreseeable that the additional latency introduced by considering the three most recent clear pixels would affect the product's validity.

Through the validation work, discussed below, the team discovered that use of the higher of the last two clear pixels approach in the chlorophyll compositing algorithm caused the composite to inaccurately reflect seasonal basin scale increases and decreases of chlorophyll, especially during mid-spring along the Atlantic seaboard. Further study indicated that using anything older than the latest pixel would likely misrepresent feature transport and transformation; furthermore, the Level 2 MODIS data was effectively cloud masked by the University of South Florida before it was transmitted to the WorldWinds chlorophyll server, so any blending, averaging, or use of older pixels was not needed to handle cloud contamination.

Based on these findings, the WorldWinds/SPoRT team agreed to refine the SPoRT-developed McIDAS programs to discontinue use of the “warmest” of the last two clear pixels approach and instead rewrite the scripts to employ only the latest available chlorophyll pixel for use in the composite. Fig. 1 depicts a recent chlorophyll composite and corresponding latency values generated by the latest available pixel algorithm.



**Fig. 1: One day-time pass cloud-free chlorophyll data (left) and composited chlorophyll data (right). Both plots in  $\text{mg/m}^3$ .**

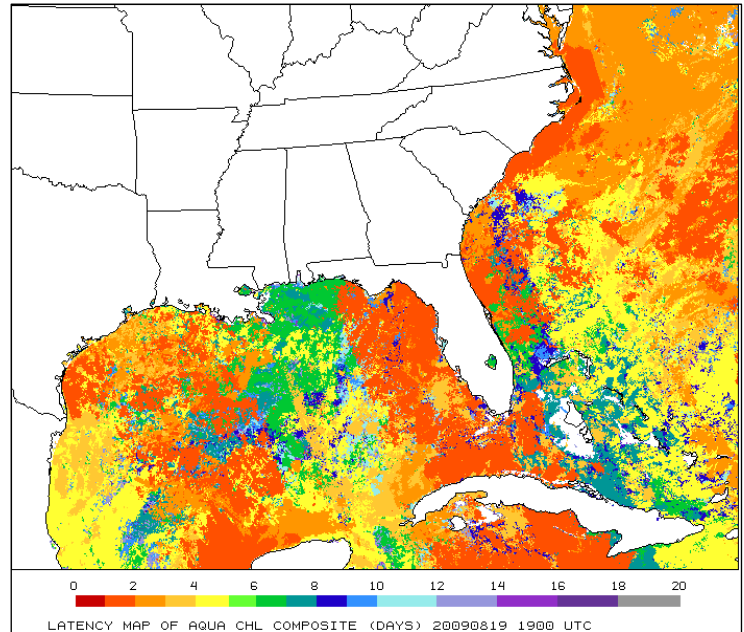
Once the scripts were completed and implemented at the WorldWinds facility in Slidell, LA, Aqua/MODIS chlorophyll Level 2 data from the USF Direct Broadcast site was retrieved and tested visually against plots of single passes obtained from NASA SPoRT.

Fig. 2 shows the latency, in days, associated with each pixel present in the composite shown in Fig. 1, right panel. With the realtime data downloading and processing successfully an in-depth analysis of the data was begun by testing the archived Aqua/MODIS data in McIDAS.

### C. Validation Study

In addition to composite/analysis visual and numeric comparisons, validation of the chlorophyll composites were made by comparing them with SeaBASS (SeaWiFS Bio-optical Archive and Storage System) in-situ records. High quality in-situ measurements are a prerequisite for satellite data product validation and algorithm development. The NASA Goddard Space Flight Center (GSFC) [Ocean Biology Processing Group](http://oceanbiology.gsfc.nasa.gov) (OBPG) maintains SeaBASS (<http://seabass.gsfc.nasa.gov>) a local repository to catalog radiometric and phytoplankton pigment data and other measured quantities used in satellite calibration and validation activities.

WorldWinds obtained a full set of SeaBASS in-situ records coinciding with available archived Aqua/MODIS chlorophyll data. The corresponding in-situ records were searched for three chlorophyll SeaBASS field names compatible with the Earth Observing System (EOS) Ocean Color Generation 3 – MODIS (OC3M) algorithm results (as referenced in OBPG documentation [http://seabass.gsfc.nasa.gov/docs/seabass\\_std\\_fields.lst](http://seabass.gsfc.nasa.gov/docs/seabass_std_fields.lst)).



**Fig. 2: Latency in days for each pixel in composited data shown in Fig. 1, right panel.**

The three compatible field names were:

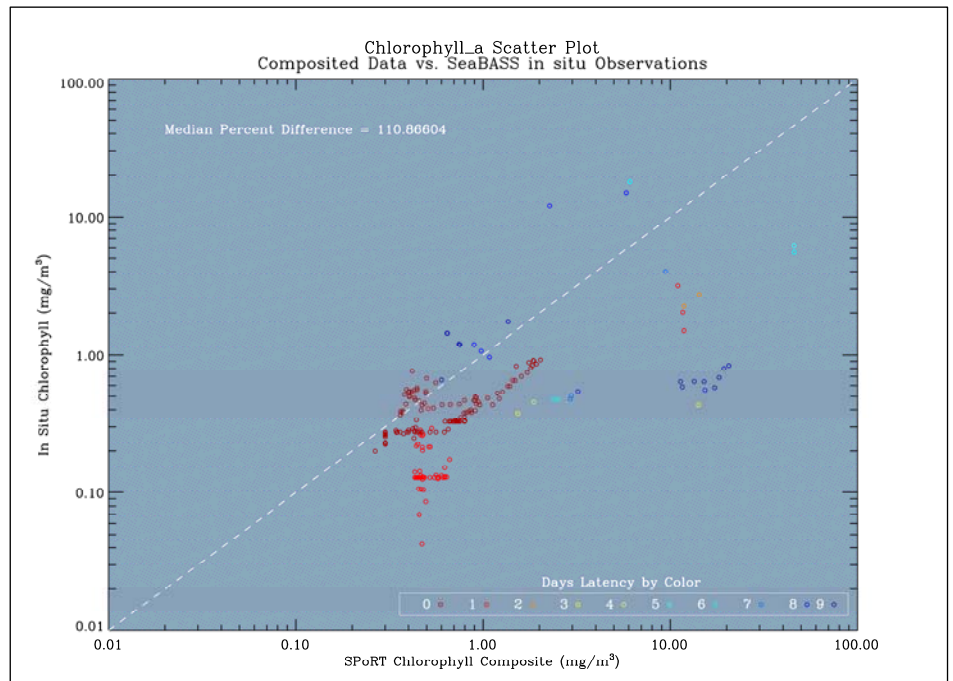
- 1) **Tot\_Ch1\_a:** HPLC DV\_Ch1\_a + MV\_Ch1\_a + Chlide\_a + Chl\_a\_allom + Chl\_a\_prime (HPLC– High Performance Liquid Chromatography)
- 2) **Ch1\_a:** HPLC Chlorophyll\_a
- 3) **CHL:** Fluorometrically/spectrophotometrically derived chlorophyll\_a

The pertinent data records were then chronologically sorted and organized to determine the spatial and temporal diversity of the observations. Data coincident within  $\pm 3$  hours of the daytime Aqua/MODIS satellite collection for the Eastern US (19:00 UTC) were chosen [2]. Also sought were time periods, on the order of about one month, for the largest available sample size for validation with archived satellite data. The resulting subset contained 1,358 observations from a total of 34,000 available.

- 1) Of 34,000 total available observations, 6,993 were found contain at least one of the three needed variables and be temporally coincident within  $\pm 3$  hours of 19:00 UTC.
- 2) This subset of 6,993 was sorted chronologically to seek the largest number of observations over a month long period.
- 3) The top five periods returned were compared with records of Aqua/MODIS monthly climatology from the GSFC's Distributed Active Archive Center (DAAC) to determine the biological diversity of the ocean within the study area.
- 4) Based on all criteria, the period from March 21 to April 11, 2005 was chosen for validation; it contained 1,358 along track in-situ cruise observations for chlorophyll.

Once the validation time period was determined Level 2 archive data for all Aqua/MODIS passes were retrieved for March 8 through April 11, 2005. A March 8 start date was chosen to allow the cloud-free composite to “spin-up” before the first in-situ observation comparison on March 21. This spin-up time allowed for the best comparison conditions for multiple scenarios, including those with up to 10 days latency. The March/April comparison period represents a time in the northeast Atlantic continental shelf waters known as the “spring bloom” or transition. This is likely one of the most challenging time periods for a composite product to adequately represent ground truths. During this time the chlorophyll measurements change frequently as the increased spring sunlight causes phytoplankton blooms to explode; the bloom continues to grow until surface nutrients are depleted, then the bloom declines rapidly until it reaches a steady-state condition [3].

For each day in the validation period, the compositing processes were run to include all passes within  $\pm 3$  hours of 19:00 UTC and to capture plots, McIDAS AREA files, and GRIBed Binary (GRIB) output. Interactive Data Language (IDL) programs were written to seek spatially and temporally coincident pixels in the composite results for each in-situ observation. Some averaging of the in-situ observations was performed when 50 or more observations were collected along a track within the same 2 km by 2 km pixel area on the same day by a single cruise. Initially, the chlorophyll composite was generated using the highest of the last two clear pixel approach and each SeaBASS measurement was compared to a composite image pixel using the 'nearest neighbor' approach. Scatter plots were generated showing the nearest neighbor composite data vs. in-situ observations; results exhibited an order of magnitude high bias in the composited chlorophyll data, in the range of 1.0 to 10.0  $\text{mg}/\text{m}^3$  (with in-situ data ranging from 0.1 to 1.0  $\text{mg}/\text{m}^3$ ).



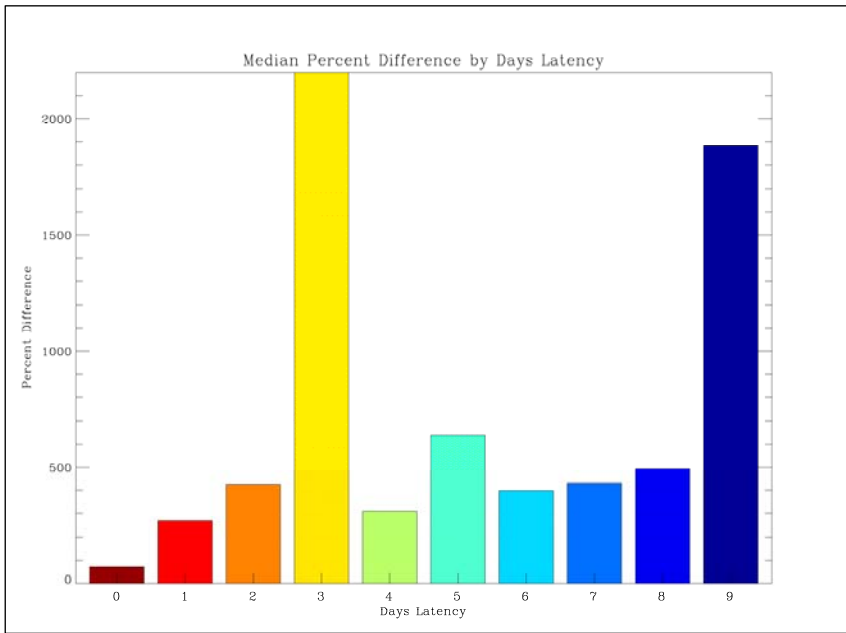
**Fig. 3: Scatter plot of in-situ and composited chlorophyll color coded red to blue to show zero to nine days latency, respectively.**

Not satisfied with these results, WorldWinds/SPoRT team members agreed to apply similar validation methods to those used by the OBPg at GSFC. Additional IDL code was developed to conduct a 5 pixel by 5 pixel filtered mean of the composited Aqua/MODIS data as per Bailey and Werdell [2]. A new scatter plot, based on the filtered mean, resulted in an improvement over the nearest neighbor method.

Given the changing nature of chlorophyll over time, especially during the spring transition, the team then decided to make changes to the algorithms to conduct these compositing techniques using only the latest available pixel (as discussed above). This method substantially improved the scatter plot results over both the nearest neighbor and 5 x 5 filtered mean methods.

WorldWinds/ SPoRT team members then analyzed the latency of each pixel included in the scatter plots to determine if the latency introduced by the compositing of satellite passes over multiple days was the cause of the seemingly high bias exhibited by the composited data. Color coded scatter plots were generated to more easily distinguish the age of each data point, an example is shown in Fig. 3.

Clearly, there are outliers with latencies in the range of eight or nine days, yet there are rather extreme outliers with latencies of zero and one day as well. More importantly, there appears to be a systematic high bias in the composited satellite data with many of the zero day latency data points falling parallel to a 1.0 correlation. Single passes from the GSFC Distributed Active Archive Center (DAAC) were examined and determined to agree well with the zero day latency areas in the composite data for the same day. In an attempt to further investigate this issue, two of the principle investigators that collected the chlorophyll in-situ data by research cruise were contacted. Both made reference to their missions sampling riverine waters high in colored dissolved organic matter and that satellite algorithm results are known to have a high bias under these circumstances [4].



**Fig. 4: Median percent difference of all data points in scatter plot shown in Fig. 3 sorted by days latency zero through nine.**

Given the high bias (even in the zero-day latency pixels) the validation was reevaluated, reaching a conclusion that the objective should be to ascertain if latency of the pixels substantially affects error. To this end, the scatter plot points were sorted by days of latency and the median percent difference for each was calculated with the results shown in Fig. 4. Initially, it appears that the latency does have an influence in error, as to be expected, from latency days one – eight is encouraging, outside that for three days latency. Once nine days of latency occurs, it appears that a threshold has been passed and the values may not be representative, at least in the waters sampled by these research cruises. The number of coincident measurements for each day of latency must be examined and shows only a few measurements per latency

days two – eight. A more even distribution would be preferred, as only a few erroneous population members could largely affect the

calculated statistics when fewer than 20 population members are present. Further study with many more in-situ observations, as well more diverse observations, is highly desired.

#### D. Disseminate Data to the Public

WorldWinds has made this data available to the public through their Department of Defense hardened facility with redundant power and cooling resources appropriate for operational processing and data dissemination. Data is posted to the public web site within one hour of the daytime MODIS/Aqua collection at: <http://www.worldwindsinc.com/Chlorophyll.htm>.

### III. OPERATIONAL DISTRIBUTION OF PRODUCTS TO END USERS

Mariners are among those most in need of reliably available, quality meteorological and oceanographic information. The difference between reliable, quality data and otherwise can have a huge impact on completing a job, having a successful research cruise, the efficient use of fuel, safety, or enjoyable recreation. The equipment needed to receive and display the data, a small antenna, with embedded receiver, and a display device, can be installed in any type of home or vehicle. This weather data is available anywhere in the continental United States and up to 600 miles offshore in coastal US waters. An accompanying GPS option also makes it possible for users to plot their own position on the interface map, showing their movements in relation to storms and other features. The Graphical User Interface (GUI) is visualized on the user's choice of hardened displays.

### IV. OPERATIONAL FORECAST MODELS OF THE ATMOSPHERE AND OCEAN

In order to capture the best quality possible in forecasted winds, pressure, and visibility over water, WorldWinds has applied the US Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) model in the North American domain. The model is run every six hours, generates a 48 hour forecast, and outputs variables for each simulated hour. The model simulations are conducted on three servers in three geographically separated locations for the sake of reliability. The users are provided a current condition graphic of each of the three variables as well as the 12, 24, and 36 hour forecasts. Constant research and sensitivity studies are conducted to improve model performance [6].

Wave height, period, and direction are obtained from National Oceanic and Atmospheric Administration (NOAA)'s National Centers for Environmental Prediction (NCEP) WaveWatch III wave model. The model is operationally run every 6 hours. The data is retrieved and supplemented by wind-driven wave information generated in-house by WorldWinds to fill in shoaling wave information near the coasts and in bays. The users are presented with current condition wave height, period, and direction and forecast information for all three at forecast intervals of 12, 24, and 36 hours.

## V. OPERATIONAL CURRENT SEA STATE AND ATMOSPHERIC CONDITIONS

### A. Current in-situ Observations

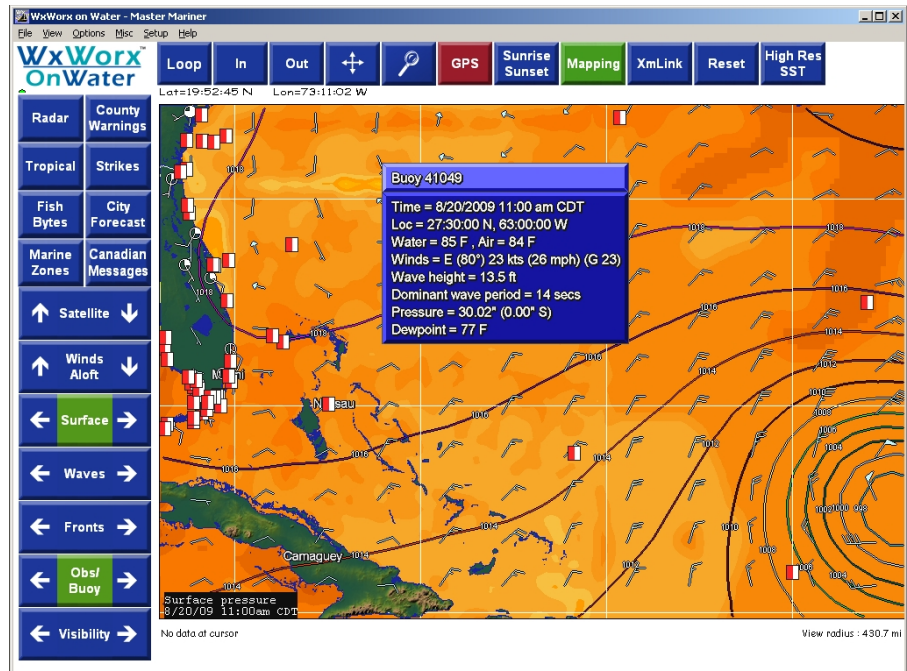
WorldWinds obtains all available surface observations from NOAA's National Data Buoy Center (NDBC) multiple times per hour, discards data more than two hours old, normalizes all observations to the World Meteorological Organization standard of ten meters above surface level, and reformats the remaining data for satellite transmission. This data stream is inclusive of moored buoys, drifting buoys, and Coastal-Marine Automated Network (C-MAN) stations. The data includes observations of air temperature, water temperature, wind speed, wind direction, gust speed, atmospheric pressure, pressure tendency, dew point temperature, wave height, wave period, and wave direction. An example screen capture showing the buoy observations, as well as the current wind, pressure, and SST fields, is shown in Fig. 5. WorldWinds' system automatically handles changing data availability by accounting for buoys that are drifting, including formerly moored buoys, buoys that cease functioning and new buoys and C-MAN stations added to the database. When buoys are added to the NDBC database, or buoys retrieved for winter are redeployed, they will automatically appear in the WorldWinds data stream. The users are also provided with decoded versions of all available Aviation Routine Weather Reports, also known as METARs.

### B. Hourly Surface Wind Analysis

To provide users with an accurate depiction of the current state of ocean and atmosphere conditions, WorldWinds has implemented a series of analysis algorithms that ingest the COAMPS forecast fields for background, all METARs, an average of 3000 currently, and an average of 600 active buoy and C-MAN observations. The analysis is conducted hourly and includes all available observations from within the preceding hour. As tropical cyclones do not always fall where observation platforms are present and the in-situ observation platforms do not always adequately measure tropical cyclone conditions, the current condition winds are supplemented by the Multiplatform Tropical Cyclone Surface Wind Analysis generated by the NOAA Cooperative Institute for Research in the Atmosphere (CIRA) when a tropical cyclone is present in the domain. The CIRA analysis is generated every six hours by including information from NASA's QuikSCAT scatterometer, the European Space Agency's Advanced Scatterometer (ASCAT), feature track winds from NOAA's operational satellite centers, flight-level

winds estimated from NOAA infrared imagery, and winds created from NASA's Advanced Microwave Sounding Unit (AMSU) [5]. The difference between inclusion of the tropical cyclone analysis and depending only on models and surface observations is impressive, even in the Florida Straits where there is a relative abundance of surface observations. Fig. 6 (next page) shows the original COAMPS background field, an eight hour forecast (back), and the current condition analysis (front), inclusive of the tropical cyclone wind analysis from CIRA, of Tropical Storm Fay's winds in the Florida Straits valid for 20:00 UTC August 18, 2008. The improvement is that the winds are correctly oriented about Fay's center and magnitude and direction reflect measurements by both in-situ platforms and remote sensing systems.

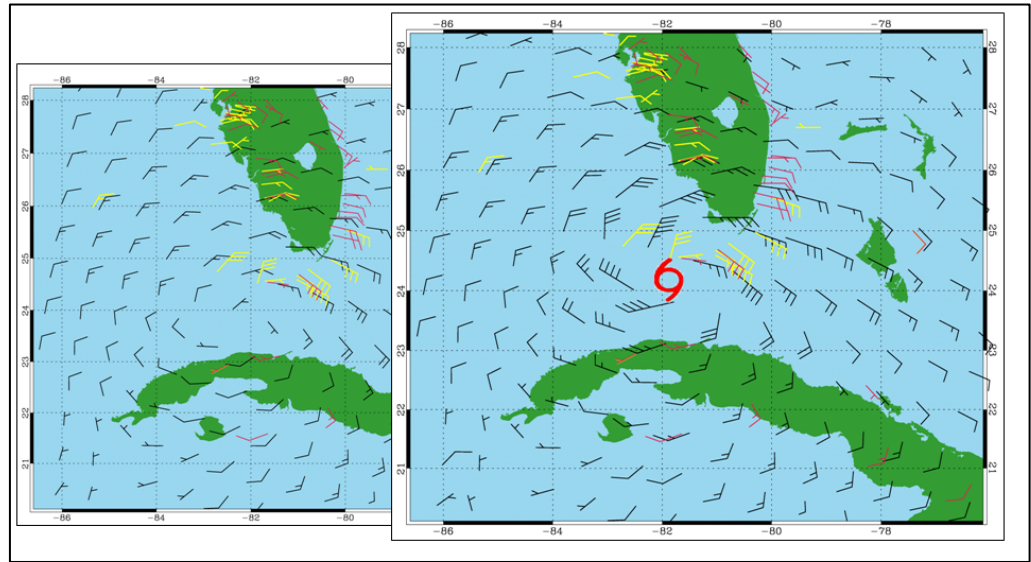
**Fig. 5: GUI example from 11:00 AM CDT August 20, 2009 showing buoy information from north of Hurricane Bill and wind, pressure, and SST**



### C. Hourly Wave Analysis

Sea State current conditions are also updated hourly by a WorldWinds analysis algorithm that uses the Wave Watch III for background and adjusts the wave fields based on buoy measurements.

The algorithm applies the in-situ wave measurements to a dynamic area of influence in all directions that is dependent on the bathymetry gradient. This is done to avoid applying wave information from moored buoys in a bay or on the continental shelf to deep water areas and vice versa.



**Fig. 6: Original forecast and analysis results for the Florida Straits during Tropical Storm Fay 20:00 UTC August 18, 2008. Barbs depict wind in knots (full flag for 10 knots, half for 5). Black barbs for current wind field, red for METARs, yellow for buoys and C-MAN stations.**

### VI. SEA SURFACE TEMPERATURES

The users of the XMWX data expressed a desire to have sea surface temperature (SST) data regardless of persistent cloudiness, which interferes with most of the operational methods of remotely measuring SST. To make their desires a reality, WorldWinds obtains near-realtime, cloud free, composited SST data from NASA SPoRT group. The data is a composite of cloud free pixels from the MODIS instrument aboard the Aqua and Terra polar orbiting satellites. It is available four times daily coincident with the twice daily over flights of the two satellites within one hour of the over flight. The data has a cloud mask applied and is then merged into the previous composite for that particular time of day. The resulting data is a cloud free map of the SST for the northwest Atlantic basin containing the latest available measurements with latencies of 0 days up to 21 days. Normally, without certain special atmospheric conditions, the data usually contains only pixels from within the previous 10 days. Validation studies have been conducted to confirm that SST values have so little daily variability for the same time of day that the latencies present in the SST composite do not introduce much error and are an improvement over other cloud free SST products [1].

### VII. GOES CLOUD MOSAIC

XMWX users are provided continuous cloud mosaic updates from NOAA's Geostationary Operational Environmental Satellite (GOES) platforms. Users can display the clouds that exceed certain levels to gauge the amount of convection present, which can help determine the severity of a storm when away from the coverage area of the ground based National Weather Service Radars. The users can display the data at 5,000 foot intervals - from 5,000 feet to 40,000 feet above sea level. Most any experienced mariner knows well that 35,000 and 40,000 foot cloud tops at sea are a good indication of torrential rain, lightning, and strong wind gusts.

### VIII. FISHBYTES

FishBytes™ is a system that checks all available measurements of oceanic conditions and compares the conditions for the entire domain to a database of known preferences of pelagic sportfish species. FishBytes™ begins with a database of known preferences for 18 fish species popular with sport fishermen, including yellowfin tuna, mahi-mahi, sailfish, blue marlin, swordfish, bluefin tuna, albacore tuna, blackfin tuna, white marlin, king mackerel, Crevalle Jack, African Pompano, bigeye tuna, cobia, amberjack, permit, wahoo, and tarpon. This database includes known SST preferences, salinity preferences, affinity for frontal conditions also known as blue-green breaks, and a number of others. Data was compiled from numerous sources, such as NOAA National Marine Fisheries, catch reports, multiple tag and release programs, and state natural resource agencies.

### A. Operational Data

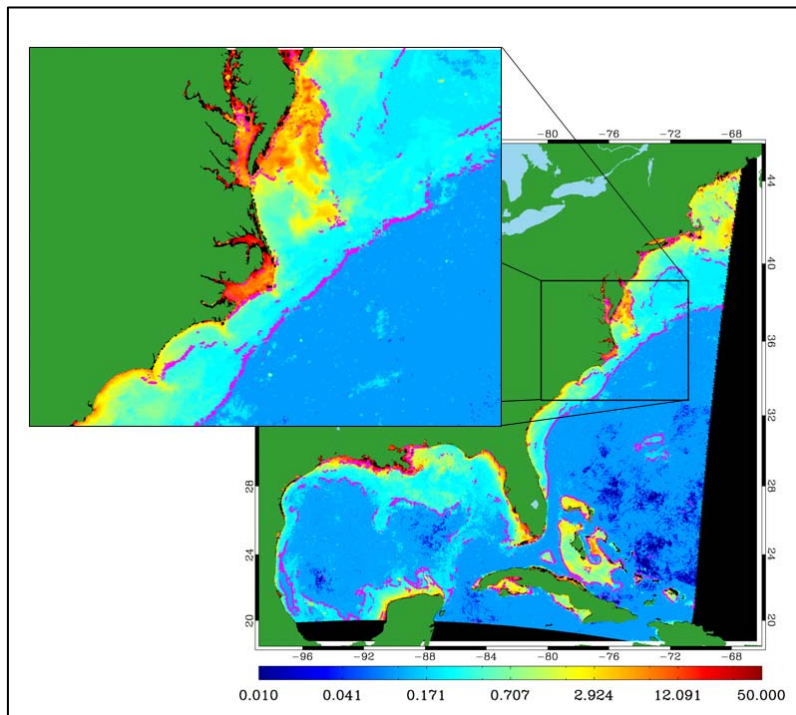
The system operationally collects data to compare to the species' known preferences. This includes the SST from the SPoRT group at NASA Marshall Space Flight Center, salinity from Real-Time Ocean Forecast System run by the Marine Modeling and Analysis Branch of NCEP's Environmental Modeling Center, and high resolution bathymetry data from NOAA's National Geophysical Data Center. All of these data sets are interpolated to a common two kilometer grid. There are a few other proprietary data sets included as well.

### B. Edge Detection

FishBytes™ runs a WorldWinds' proprietary edge detection algorithm built to seek frontal locations within the chlorophyll data set. This is proprietary software developed in-house. An example result of the edge-detection software is shown Fig. 7.

### C. Pass/Fail Species Preferences

Each species' individual preferences are then compared to all of the collected data and a simple pass or fail criteria is applied for each of the data parameters. The final result of the system is a tool that communicates to fishermen where the conditions are favorable for any one of the 18 identified species. It is not a forecast system, nor does it detail that the fish are present or feeding, but simply where their known preferences exist. The results of this twice-daily process are ultimately transmitted by XM satellite to end users to make more informed decisions concerning locations where desired fish may be present.



## IX. SUMMARY

FishBytes™ now incorporates MODIS Sea Surface Temperature and Chlorophyll data from NASA's Short-term Prediction Research and Transition Center (SPoRT) into its daily operational analysis. WorldWinds sends the FishBytes™ data to Baron Services' WxWorx division, which then broadcasts the service as part of XMWX Satellite Weather's Master Mariner package. The Master Mariner package currently has several thousand subscribers, with a satellite footprint that reaches nearly 600 miles offshore into the Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea.

WorldWinds takes basic scientific information that NASA, NOAA, and the Navy provide and creates tailored products for specific end users in the government and commercial sectors. WorldWinds has had excellent feedback from users who state that FishBytes™ works even better than they expected. With this unique product, mariners are able to maximize their time on the water. An example of the user interface presenting two species of interest is shown in Fig. 8 below. In the fall of 2009, WorldWinds plans to expand its database of fish species and its geographic coverage into the Pacific Ocean and Gulf of Alaska. Upgrades may include ocean current data, mixed layer depth, net primary productivity, turbidity, and further research with billfish/pelagic tagging groups to gain a better understanding of species' preferences.

## ACKNOWLEDGMENTS

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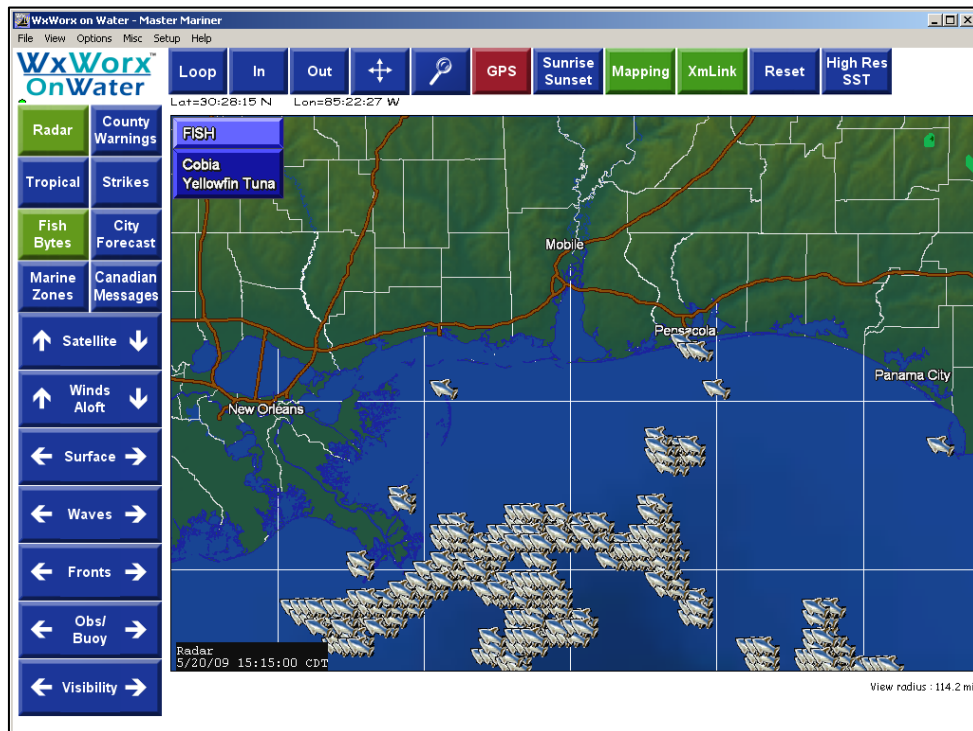


Fig. 8: Example screen capture of users' interface showing two species.

## REFERENCES

- [1] S.L. Haines, G.J. Jedlovec, and S.M. Lazarus, "A MODIS Sea Surface Temperature Composite for Regional Applications," *IEEE Transl. on Geoscience and Remote Sensing*, vol. 45, pp. 2919–2917, September 2007.
- [2] Werdell, P., Bailey, S., 2006: Recent Advances in the Operational Vicarious Calibration of Visible and Near-infrared Ocean Color Satellite Radiometry. NASA Goddard Space Flight Center ~ <http://oceancolor.gsfc.nasa.gov>.
- [3] O'Reilly, J. E., and C. Zetlin. 1998. Monograph on the seasonal, horizontal, and vertical distribution of phytoplankton chlorophyll\_a in the northeast U.S. continental shelf ecosystem. NOAA Technical Rep. 139, Fishery Bulletin, National Marine Fisheries Service.
- [5] Del Castillo, C., P. Coble, R. Conmy, F. Müller-Karger, L. Vanderbloemen, and G. Vargo, 2001: Multispectral in situ measurements of organic matter and chlorophyll fluorescence in seawater: Documenting the intrusion of the Mississippi River plume in the West Florida Shelf. *Limnol. Oceanography*. 46(7), 2001, 1836–1843.
- [5] J.A. Knaff, and M. DeMaria, A *Multi-platform Satellite Tropical Cyclone Wind Analysis System*. AMS 14th Conference on Satellite Meteorology and Oceanography. Atlanta, GA, 29 January–3 February, 2006.
- [6] V.G. Anantharaj, P. Fitzpatrick, R. L. King, L. Wasson, 2004. *Incorporation of MODIS landcover data to improve land surface parameterization in the COAMPS numerical weather prediction model*. Geoscience and Remote Sensing Symposium, 2004, available from: <http://www.worldwindsinc.com/publications.htm>.