The Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Program was established to provide a long-term ocean color data set which encompasses the measurements from several satellite instruments. The program aims to create a bridge between previous, current, and future ocean color missions. Both the SIMBIOS Science Team and the Project are working on optimal procedures for combining Ocean Color and Temperature Scanner (OCTS), Polarization and Dimensionality of the Earth's Reflectances (POLDER), Modular Optoelectronic Scanner (MOS), Moderate Resolution Imaging Spectroradiometer (MODIS), and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) measurements into a single, global ocean color data set. This comprehensive data set will be later expanded to incorporate other current and future satellite missions. Leading to the data merger goal, the SIMBIOS Project has established a thorough ocean color validation program. Additionally, an effort has been made to MOS estimate relative accuracies of the products from each mission, involving bio-optical matchups with *in situ* measurements, and to improve the compatibility among the products, which includes sensor crosscalibrations, such as for MOS and SeaWiFS. The objectives of data merger are:

Improvement in ocean color spatial and temporal coverage.

- Definition of a variety of ocean color products, including
- · climatological data and long-term time series,
- daily global product maps at the highest feasible spatial resolution,
- · regional and local products for a variety of local applications at the highest feasible spatial resolution.

• Support for specialized ocean color applications by taking advantage of sensor-varying spectral, spatial, temporal, and ground coverage characteristics.

Selected Levels for Ocean Color Data Merger

• Merger of optical parameters, such as normalized water-leaving radiances, at sensor-dependent spectral bands. The eventual biological parameters, like chlorophyll concentration, are then obtained using more (empirical) or less (semi-analytical) standard algorithms. This type of merger can be performed on level-2 or level-3 ocean color data. Level-2 products are images which pixel geophysical values are derived from level-1 radiance counts by applying sensor calibration, atmospheric correction, and bio-optical algorithms. Level-3 consists of level-2 products binned spatially within an equal-area grid and then, optionally, binned temporally within a specified time interval.

• Merger of biological parameters, such as chlorophyll concentration, where the parameters are individually obtained from each sensor's processing chain. This type of merger is most suitably performed on retrieved water-leaving radiances and aerosol models, level-3 ocean color binned data.

SIMBIOS Project Achievements and Activities in FY2001

This poster describes a part of research and development work undertaken by the SIMBIOS Project Office to gain expertise in the merger of ocean color data. A number of image processing and data fusion methodologies and algorithms have been developed to meet the goals of the Project. Multisensor ocean color measurements are merged using the relative accuracies of the products from each mission.

1) Definition of daily global products merged from different ocean color missions. For sensors with different calibration and data processing characteristics, data mining techniques are investigated to define a set of optimal level-3 binned ocean color and data quality parameters. These parameters are mapped from one sensor to another using a back-propagation neural network. Mapped products can then be added from a number of sensors to produce extended ocean color coverage at a uniform range of geophysical values and



2) Definition of local ocean color products at the highest feasible spatial resolution. For cases where there is overlapping coverage from sensors of different spatial resolutions, merger of ocean color measurements is developed which results in the highest resolution product. The merger is based on an image processing approach — the wavelet multiresolution analysis. The algorithm enables enhancement of

oceanic features in lower resolution imagery through the use of higher resolution data. The method extracts lowscale spatial variation in higher resolution scenes and assigns it to the lower resolution imagery without SeaWiFS level-2 chlor a & CalCOFI especially useful when the quality date from 1 of the ocean color values. The application is



& CalCOFI especially useful when the quality data from both sensors is different. This method is the subject of the current poster.

3) Support for specialized ocean color applications.

A general approach is developed to merge level-2 ocean color satellite and in situ data for local applications. Results have been analyzed for SeaWiFS and California Cooperative Oceanic Fisheries Investigation (CalCOFI) measurements.



laily average normalized water-leaving reflectance band 2 Level-2 MOS and SeaWiFS Comparison.

SIMBIOS destriping of MOS imagery and calibration of MOS level-1B radiances based on SeaWiFSsee Franz et al., OS52A-0513.



SIMBIOS Merger of Ocean Color Information of Different Spatial Resolution: SeaWiFS and MOS

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Atlantic Ocear Mediterranean Sea (28 Feb 1998) Adriatic Sea



NASA

(24 Sept 1997)

Examine the feasibility of merging chlorophyll concentration products from ocean color sensors of different spatial resolutions and also the prospect of enhancing oceanic features in lower resolution imagery through the use of higher resolution data.

patial binning of level-2 imagery to level-3 products. SeaWiFS is binned at 1km and MOS at 0.5km resolution. SIMBIOS Project receives data from both sensors. MOS data are de-striped and calibrated to SeaWiFS measurements. Uniform processing is available for both sensors.



Level-2 MOS chl oc2 product.

Projection of bins onto a rectangular latitude/longitude grid map to facilitate image processing. The projection preserves spatial resolution of the bins in the mapped image.



Projected level-3 MOS chl_oc2 product.



Approximation of missing grid points using a wavelet-based iterative algorithm that minimizes image frequency anomalies associated with the missing data.



Interpolated-projected level-3 MOS chl oc2 product.



Vavelet coefficients for Step 1 decomposition of the interpolated-projected level-3 MOS chl_oc2 product.



Replacement of the original high resolution bins with merged data (MOS 0.5km bins).

Level-2 SeaWiFS chlor_a product.



Projected level-3 SeaWiFS chlor_a produ



Interpolated-projected level-3 SeaWiFS chlor_a product.

Weighted addition of the wavelet-transformed images and reversal of the transform. from the higher resolution scene enables the creation of the merged result at the high spatial resolution.

Merged 30%MOS chl oc2 and 70%SeaWiFS chlor a prod Reverse wavelet transform: 30% MOS LL coefficients +/ SeaWiFS preprocessed image + 100% MOS H coefficie





Contracted and dilated Daubechies wavelets in the time and frequency domain.



Original Image

Advantages of Wavelet-Based Merger • To validate the wavelet algorithm, merger products were • The method enables enhancement of marine features compared against the results of weighted additions of MOS in lower-resolution ocean color imagery through the use images and SeaWiFS scenes which were bi-linearly of higher resolution data. interpolated to the MOS resolution.

• Weighted addition of wavelet coefficients can use • The bi-linear interpolation merger does not provide the different ratios between the two sensors depending on benefits of the higher resolution feature extraction and the the established relative accuracies of the products from data quality transfer from the lower resolution image.

both instruments. • Quantitatively, the correlation of the • The highest frequency coefficients from the higher interpolation-based merger results with resolution image remain unscaled and add the desired MOS original scenes can be considerably detail to the lower resolution image. smaller than the correlation for the • The algorithm allows the increase in quality of higher wavelet merger for low weight values of resolution imagery to the level of well-calibrated and the addition. Qualitatively, the gain in produce a lower resolution image expanded to the size approach is consequential and unique.

validated lower resolution data. The approach can spatial detail obtained by the wavelet of the higher resolution image with only high frequency • Although the wavelet-merged scenes detail being added. This results when low frequency appear sharper, there is a lot of high coefficients from the higher resolution scene are fully frequency noise introduced from MOS replaced by the lower resolution preprocessed image. which is peculiar to this sensor's data.



• High frequency features in an image cause undesirable ringing effects which arise during the manipulation of wavelet coefficients. To limit the ringing, a selected De-noised interpolated-projected level 3 number of transformed solutions, based on different wavelet functions, is averaged. MOS chl oc2 product • Flags and masks of the ocean color products from both sensors are also merged in the final product.

sensor observations comparable to ensure the quality of fused products. • Emphasis will be put on global missions, such as MODIS and SeaWiFS.

Analysis and Machine Intelligence, vol. 11, no. 7, Jul. 1989.

Introduction to the Wavelet Transform

• Wavelets are used to analyze non-stationary signals, i.e., signals with time-varying frequency components. They provide a simultaneous time and frequency representation of a signal.



L-Low H-High horizontal-vertical frequencies

Step 1 wavelet coefficients

Step 3 wavelet coefficients Step 2 wavelet coefficients Validation of Wavelet-Based Merger



Interpolation merger: 20% MOS

Wavelet Application Details

• Wavelets provide means for de-noising speckled imagery. The soft-thresholding of wavelet coefficients is equivalent to removing Gaussian noise from an arbitrary image. The figure on the left shows the original MOS chl_oc2 scene which was de-noised by ^{10.10} reducing its high frequency coefficients by the value of their standard deviation.

• Magnitude of the low frequency pixel values change with each step of the wavelet decomposition. To ensure the proper magnitude of values in the merged ocean color product, the lower resolution image is preprocessed by passing it through a wavelet transform without subsampling.

Concluding Remarks

Can be preceded by an optional de-noising of either of the scenes. Addition of the high frequency coefficients • This poster has introduced an image processing methodology for merging multiresolution ocean color data to create local products at a higher spatial resolution. It has shown that with the application of novel wavelet techniques, it is possible to transfer spatial detail in high resolution imagery to low resolution images and, at the same time, preserve relative magnitudes of low resolution bio-optical values. The method was useful in increasing spatial detail in quality SeaWiFS images using MOS high-resolution data. In the future, MODIS and SeaWiFS data will be applied.

> • Research will continue to generate daily global products merged from different ocean color missions. Statistical and artificial intelligence methods will be used to extract a set of data products and sensor parameters which will define a mission's bio-optical retrievals. Methods, including neural networks, will continue being developed to make cross-

- <mark>References</mark> /

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