Satellite Ocean Color Remote Sensing for Ocean Coastal and Inland Waters

Menghua Wang
NOAA/NESDIS/STAR
E/RA3, Room 102, 5200 Auth Rd.
Camp Springs, MD 20746, USA
Menghua.Wang@noaa.gov

NESDIS-CREST Technical Meeting
SSMC3, RM 4527, Silver Spring, Maryland, December 7-8, 2009


Open ocean
7/03/2006


Coastal/Near Shore
07/05/2006


Lake Taihu


XINHUANET


Chesapeake Bay

Ocean Color Remote Sensing: Derive the ocean water-leaving radiance spectra by accurately removing the atmospheric and surface effects.

Ocean properties can be derived from the ocean water-leaving radiance spectra.

At satellite altitude ~**90%** of sensor-measured signal over ocean comes from the **atmosphere & surface**!

- It is crucial to have accurate **atmospheric correction** and **sensor calibrations**.
- **0.5%** error in atmospheric correction or calibration corresponds to possible of ~**5%** error in the derived ocean water-leaving radiance.
- We need **~0.1%** sensor calibration accuracy.

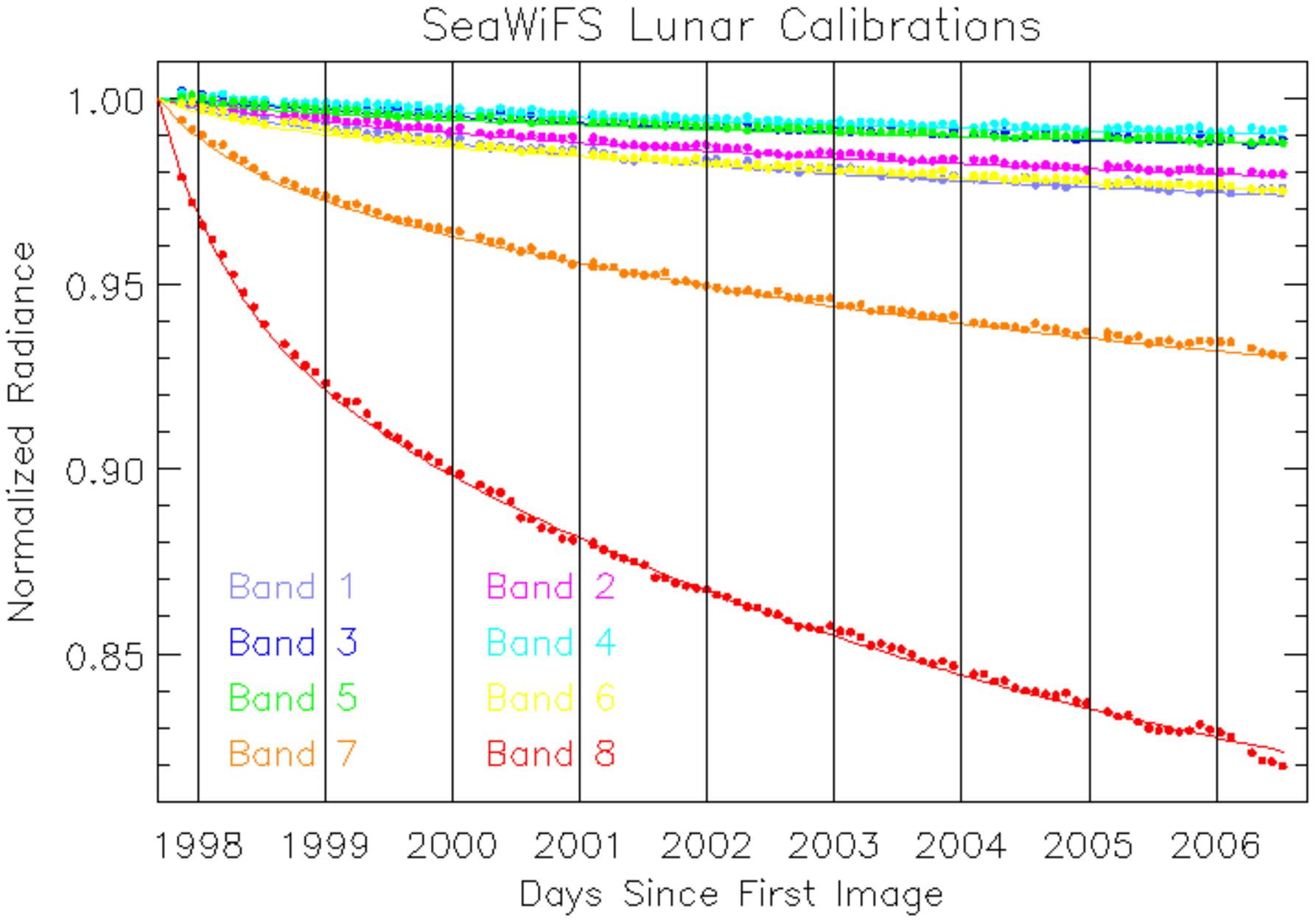
The Ocean Color and Other Useful Spectral Bands for VIIRS, MODIS, and SeaWiFS

VIIRS		MODIS		SeaWiFS
Ocean Bands (nm)	Other Bands (nm)	Ocean Bands (nm)	Other Bands (nm)	Ocean Band (nm)
412		412	645	412
445		443	859	443
488		488	469	490
Ń		531	555	510
555	*SWIR Bands*	551	*SWIR Bands*	555
672	1240	667	1240	670
746	1610	748	1640	765
865	2250	869	2130	865

VIIRS has similar SWIR bands as **MODIS**

SeaWiFS

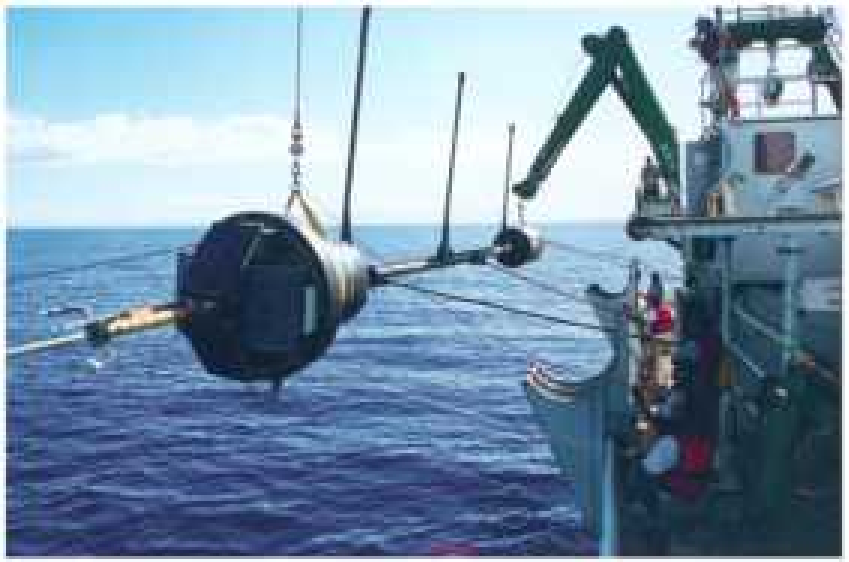
Sea-Viewing **Wi**de-**F**ield-of-view **S**ensor



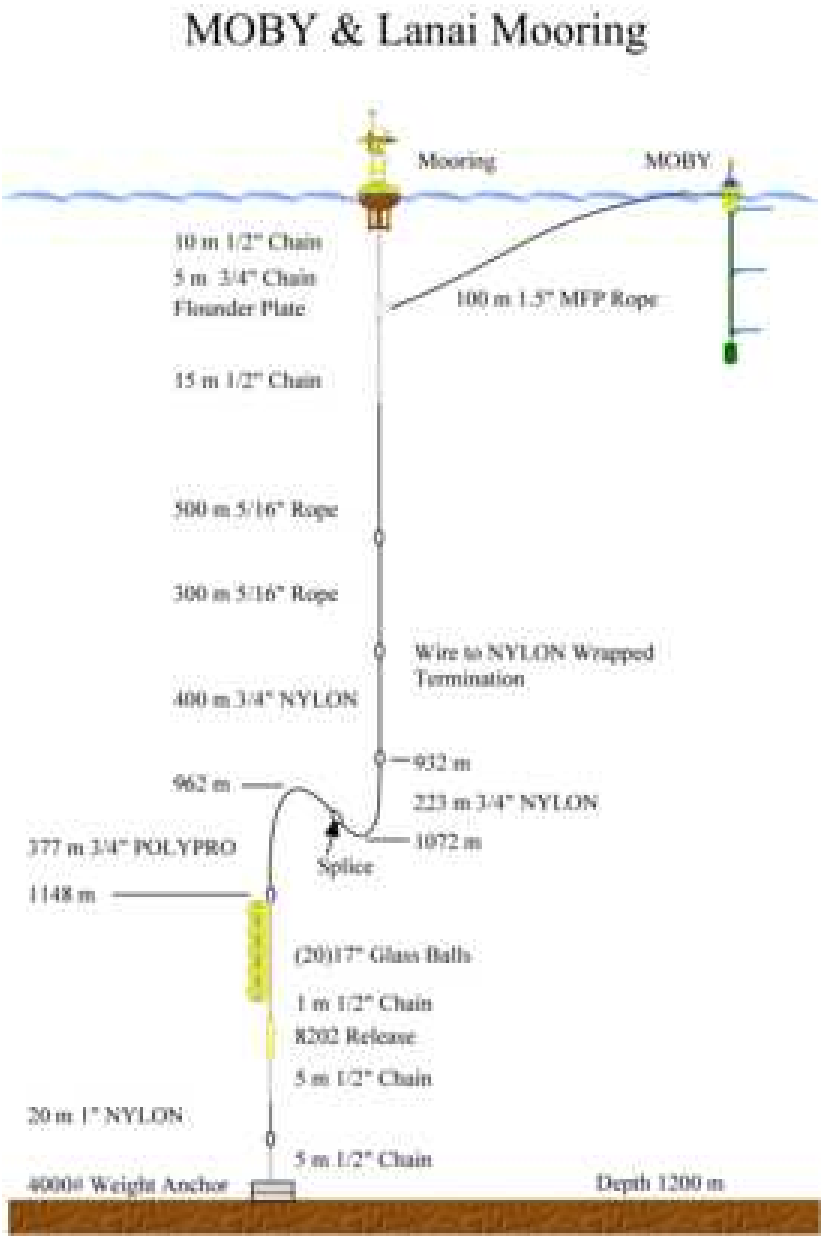
Menghua Wang, NOAA/NESDIS/STAR

From http://oceancolor.gsfc.nasa.gov

MOBY--Vicarious Calibration Facility for Ocean Color Satellite Sensors

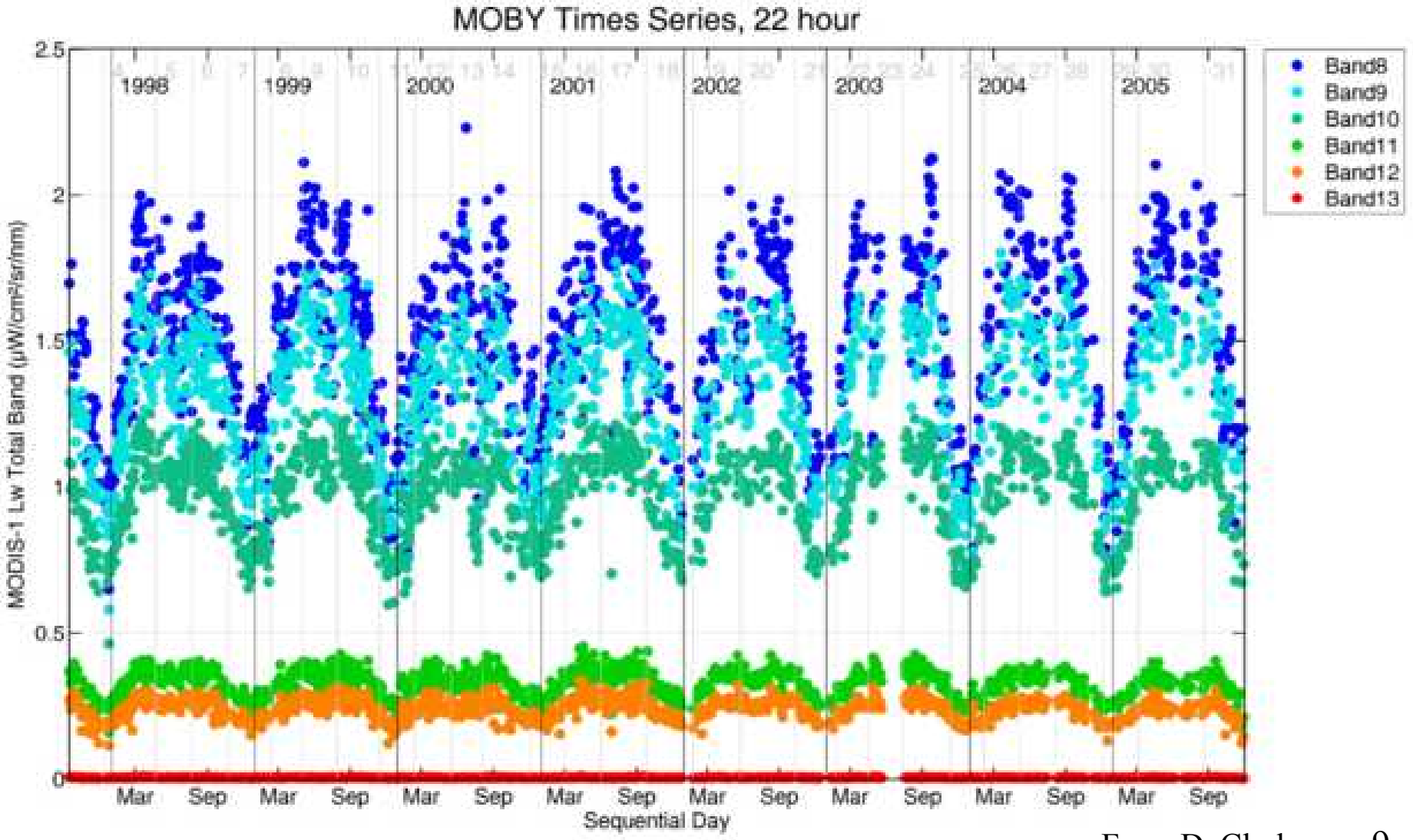


From D. Clark



Time Series of MODIS ocean color bands

Uncertainty ~ 5%



From D. Clark

Algorithms for Various Ocean Color Sensors

(Routine Global Ocean Color Data Processing)

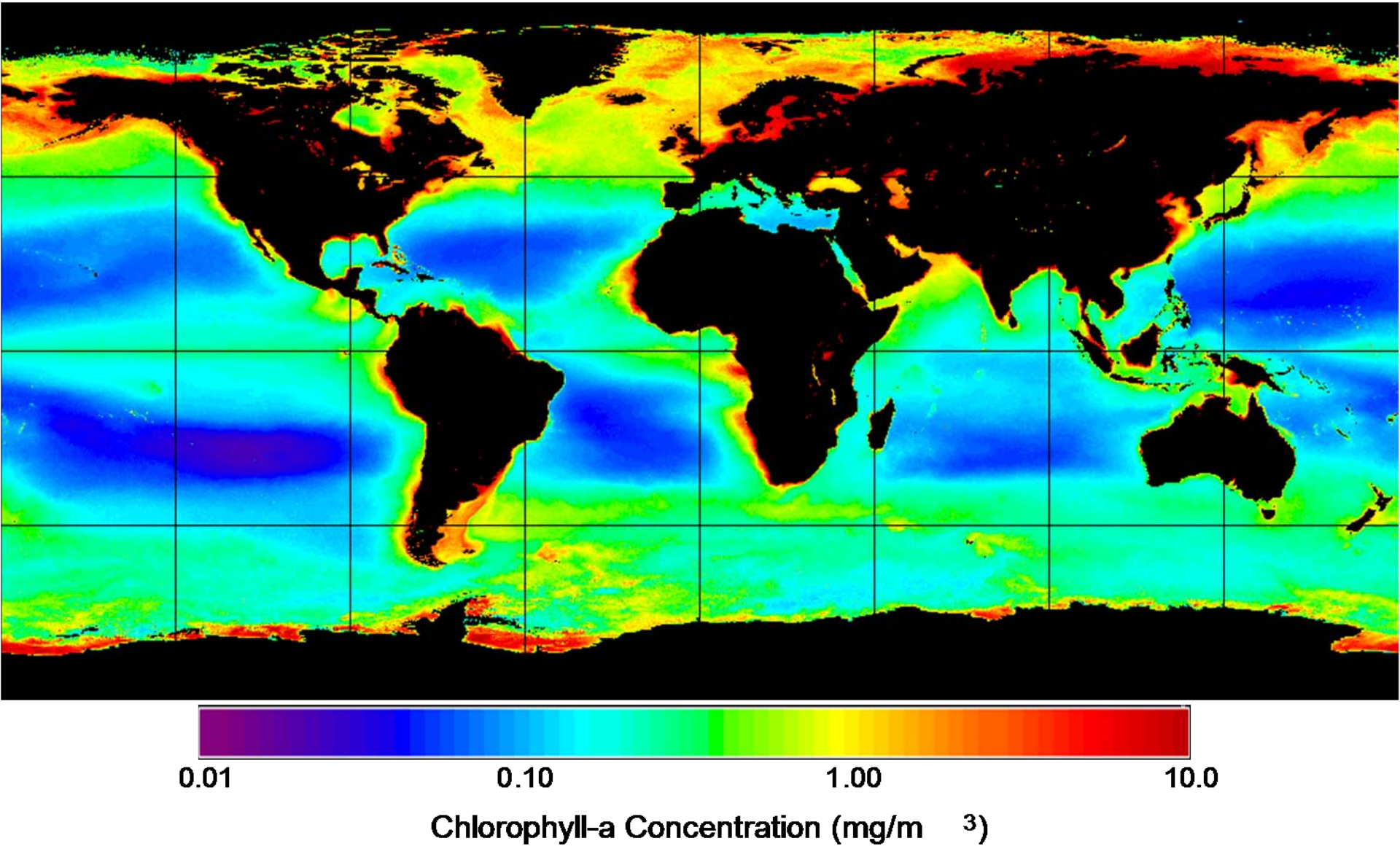
- **Gordon and Wang** (1994) for **SeaWiFS** and **MODIS** ocean color products.
- **Fukushima** et al. (1998) for **OCTS** and **GLI** ocean color products.
- **Antoine and Morel** (1999) for **MERIS** ocean color products.
- **Deschamps** et al. (1999) for **POLDER** ocean color products.

Assumptions:

- **Ocean is black at the NIR wavelengths.**
- **Aerosols are non- or weakly absorbing.**

Wang, M. (ed.), Atmospheric Correction for Remotely-Sensed Ocean-Color Products, *Reports of International Ocean-Color Coordinating Group*, No. 10, IOCCG, Dartmouth, Canada, 2010 (In press).

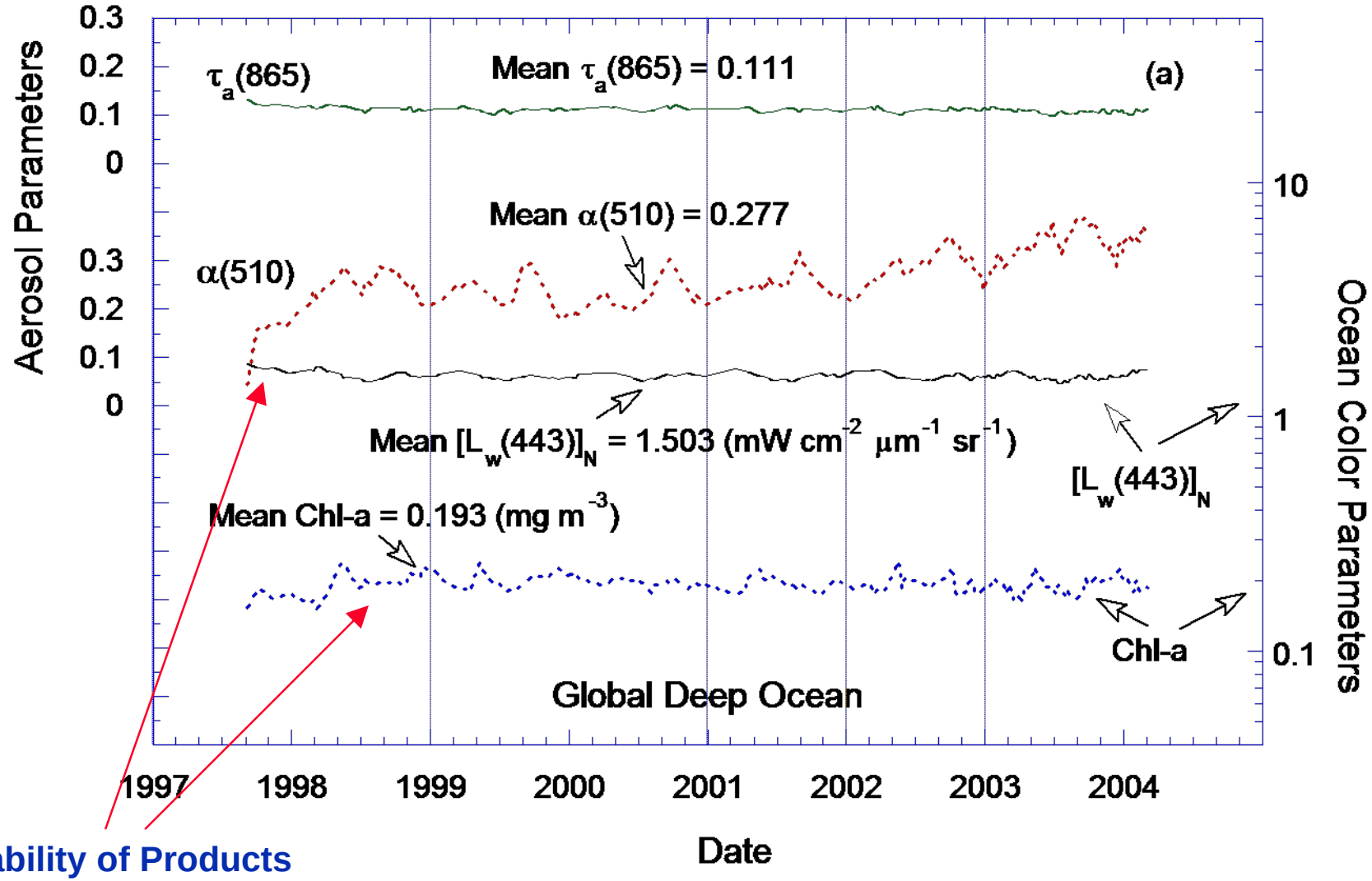
SeaWiFS Chlorophyll-a Concentration (October 1997-December 2003)



Menghua Wang, NOAA/NESDIS/STAR

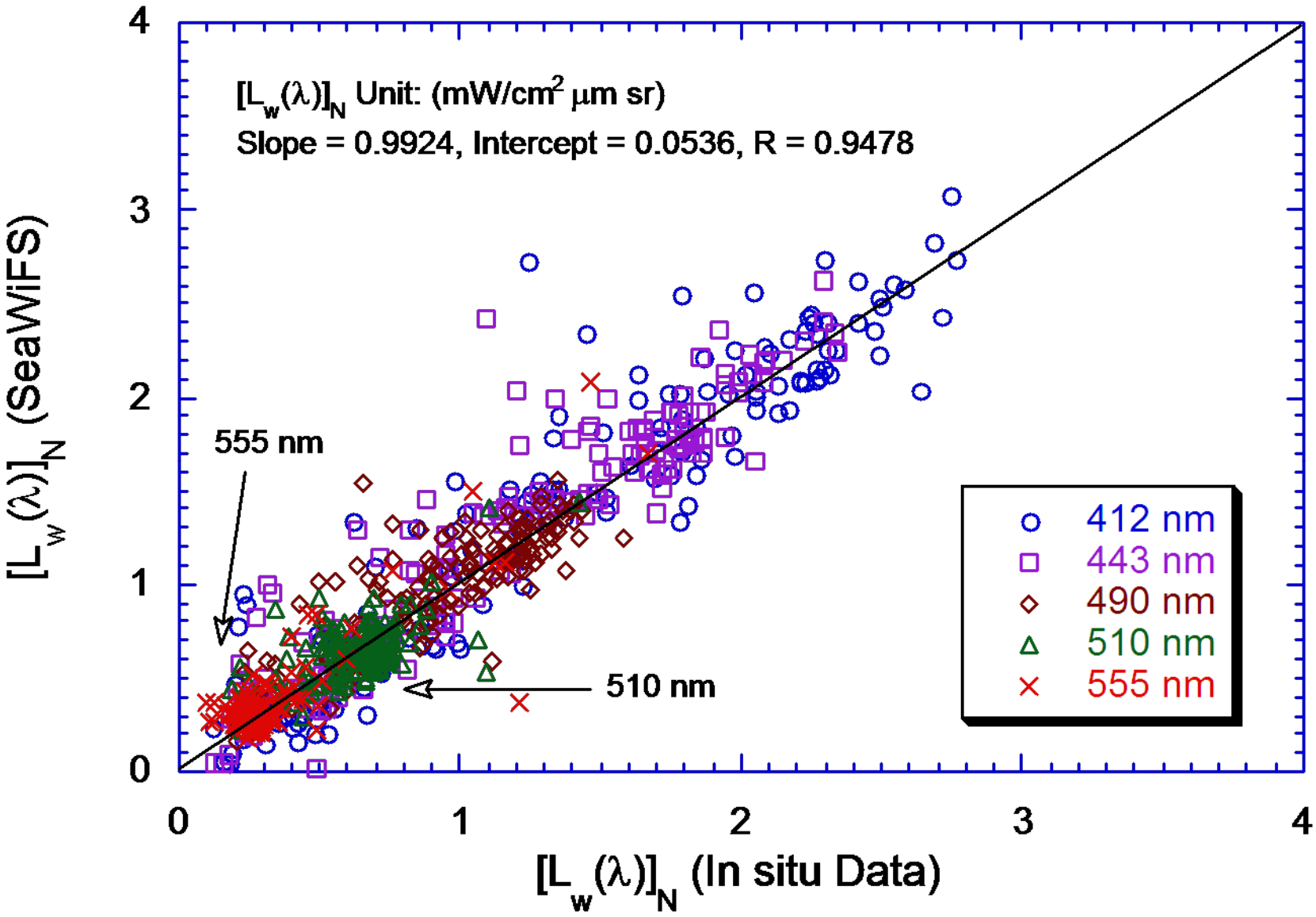
SeaWiFS Global Deep Ocean Results

(Wang et al., 2005)

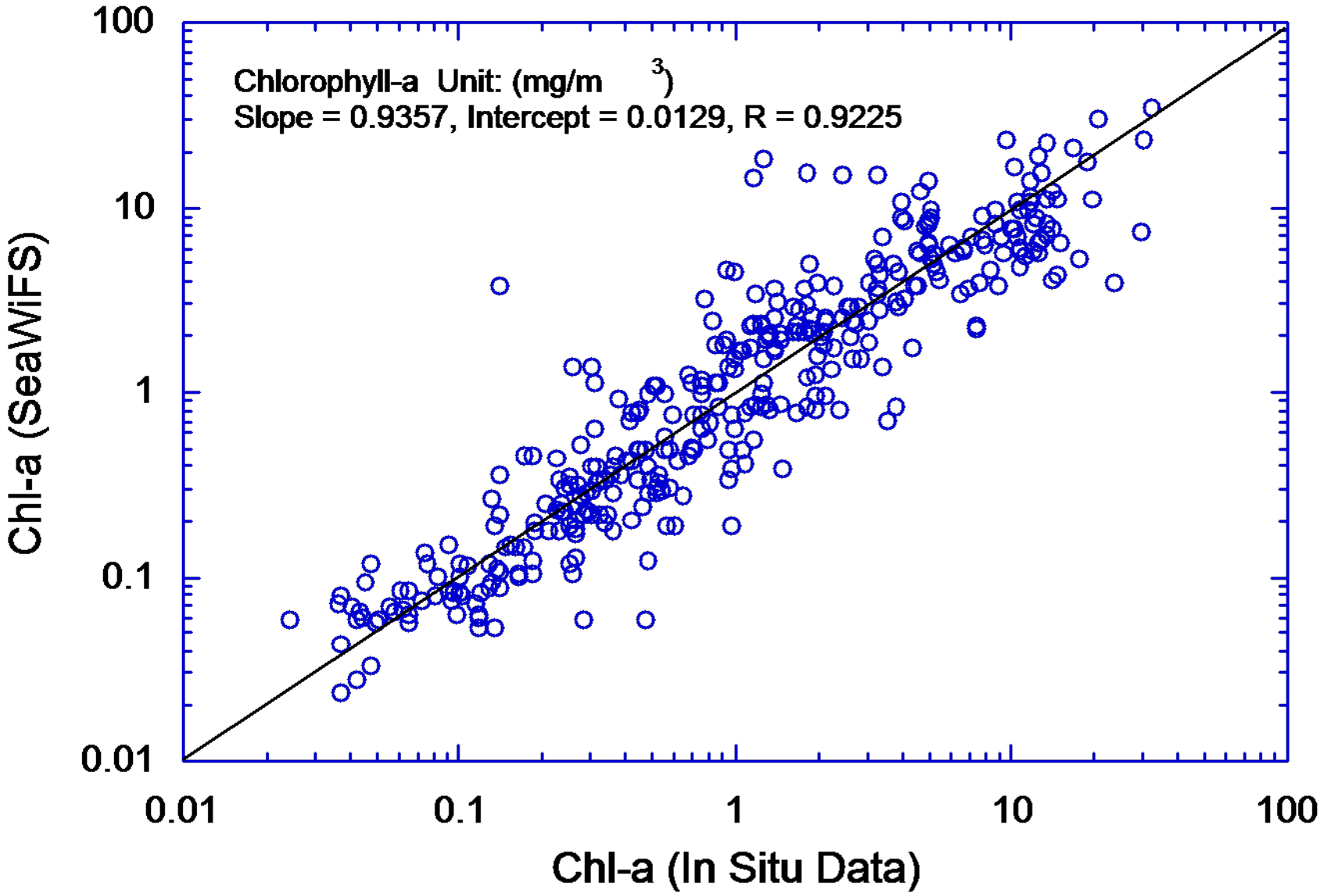


Stability of Products

SeaWiFS experiences demonstrate that the atmospheric correction works well in the **open oceans**.



SeaWiFS Chlorophyll-a Comparison



SeaWiFS and MODIS Experiences Show:

High quality ocean color products for the global open oceans (Case-1 waters).

Significant efforts are needed for improvements of water color products in the inland & coastal regions:

- **Turbid Waters**
  (violation of the NIR black ocean assumption)
- **Strongly-Absorbing Aerosols**
  (violation of non- or weakly absorbing aerosols)

Atmospheric Correction: SWIR Bands

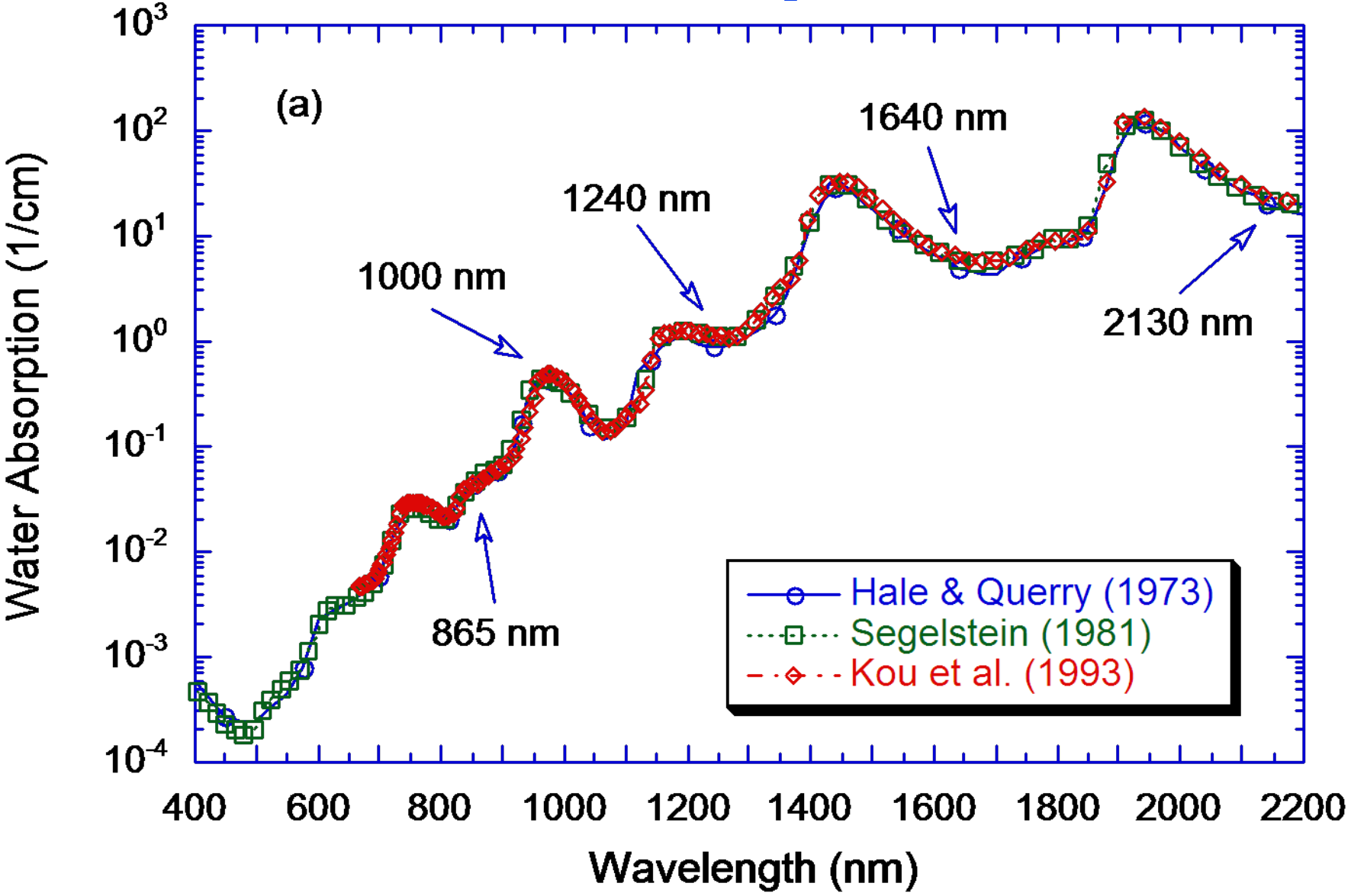
(Wang & Shi, 2005; Wang, 2007)

- At the shortwave IR (SWIR) wavelengths (>~1000 nm), ocean water has much strongly absorption and ocean contributions are significantly less. Thus, atmospheric correction can be carried out for coastal regions **without using the bio-optical model**.
- Water absorption for 869 nm, 1240 nm, 1640 nm, and 2130 nm are 5 m^{-1}, 88 m^{-1}, 498 m^{-1}, and 2200 m^{-1}, respectively.
- Examples using the MODIS Aqua **1240** and **2130 nm** data to derive the ocean color products are provided.

➢ We use the SWIR band (1240 nm) for the cloud masking. This is necessary for coastal region waters.

✓ Require sufficient **SNR** characteristics for the SWIR bands and the SWIR atmospheric correction has slight larger noises at the short visible bands (compared with those from the NIR algorithm).

Water Absorption



Results from SWIR Atmospheric Correction for turbid ocean waters in US east coastal

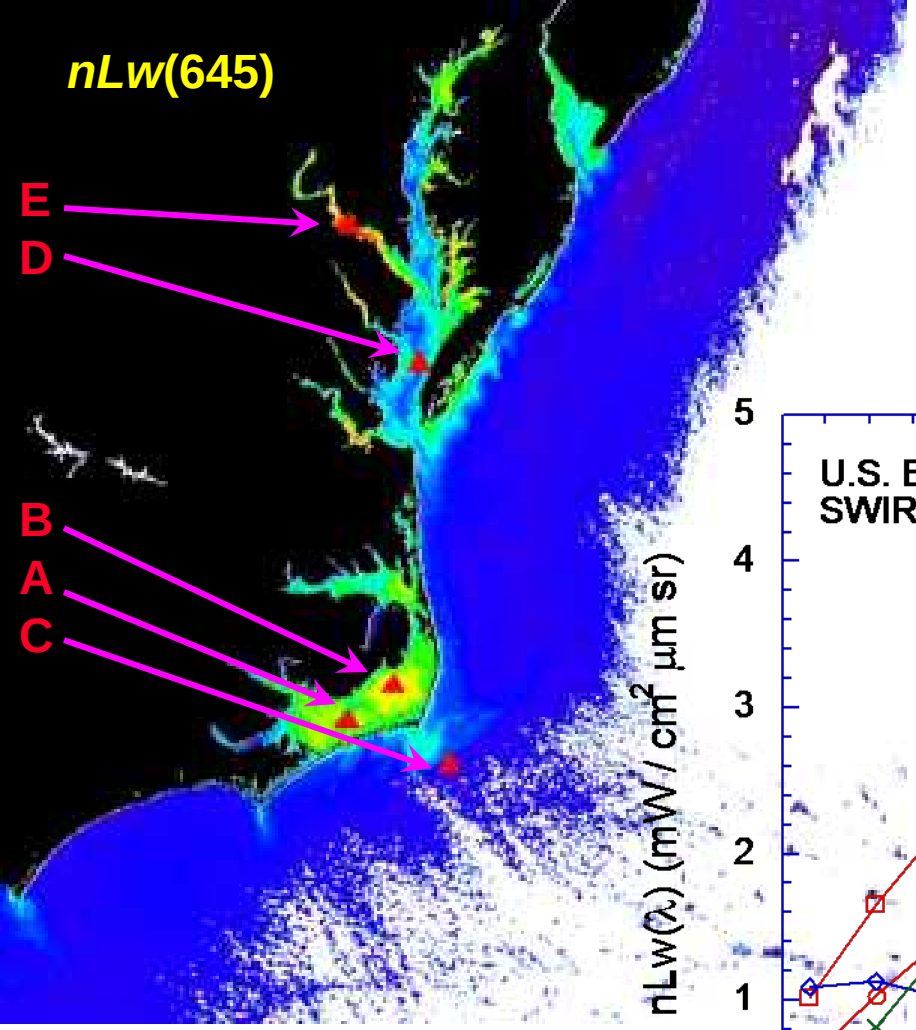
MODIS-Aqua True Color Image

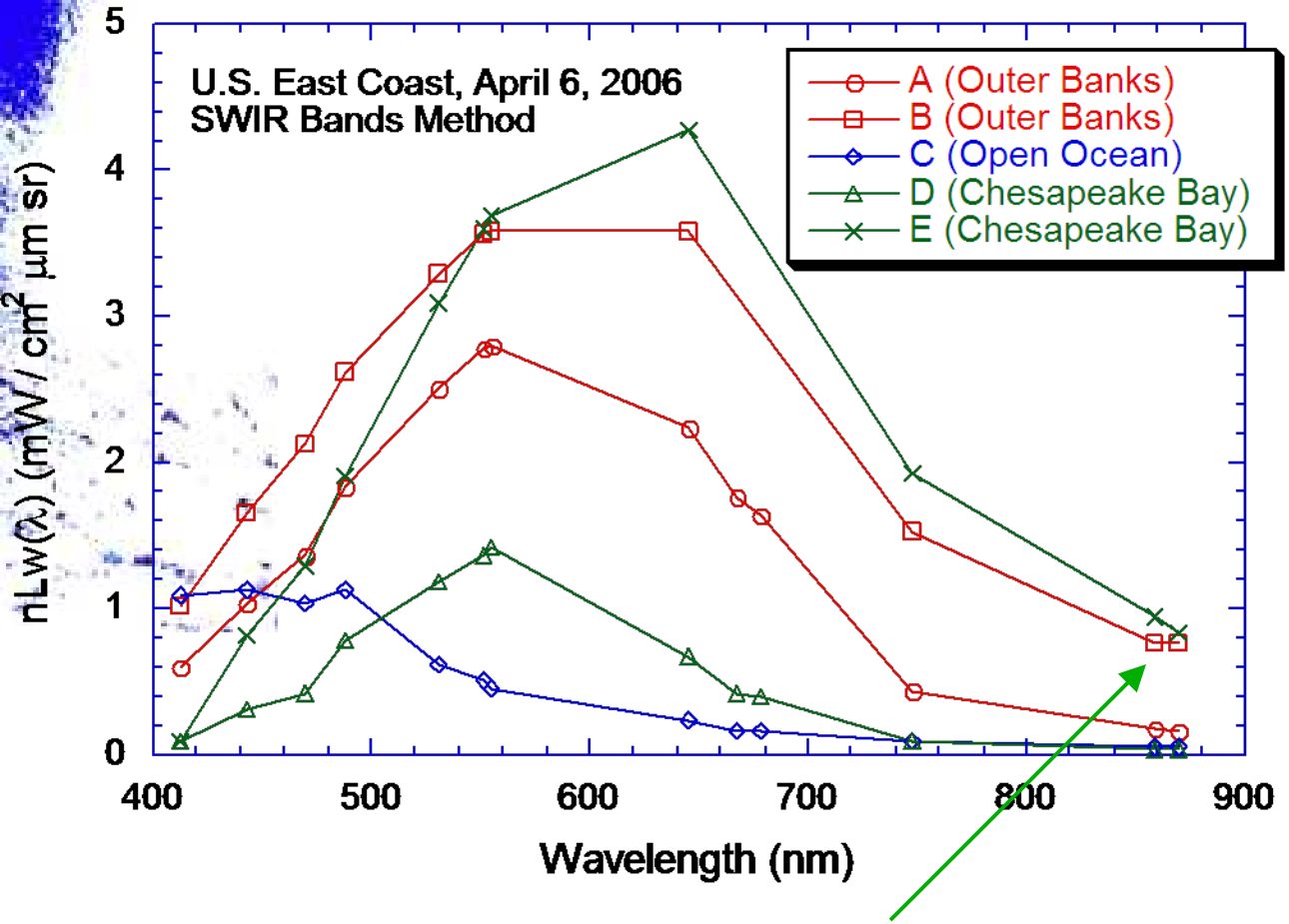
U.S. East Coastal

April 6, 2004

Menghua Wang, NOAA/NESDIS/STAR

Ocean Spectra from Visible to NIR for Various Ocean Waters

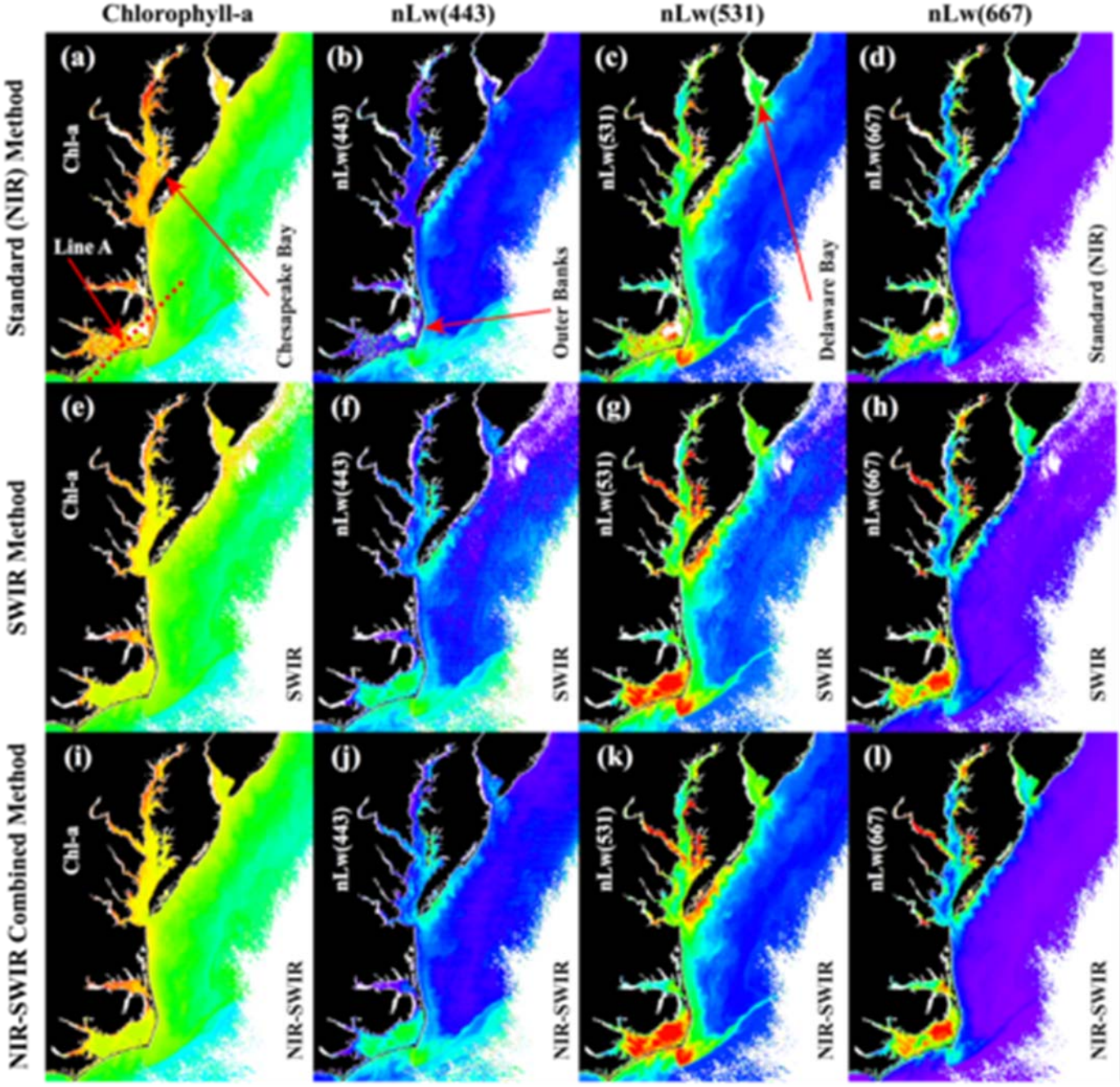




$\tau_a(869) \sim 0.3$

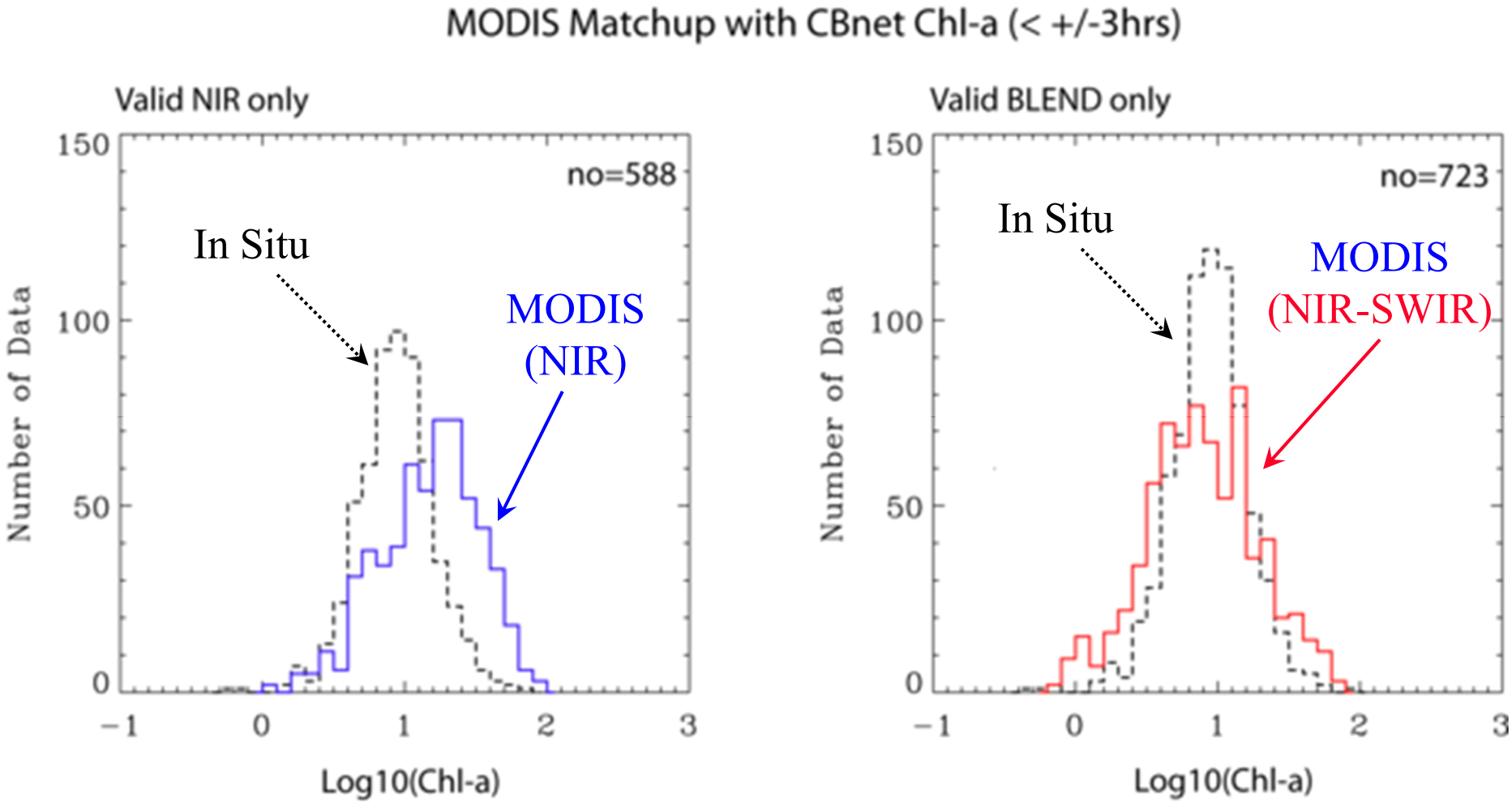
Comparisons of MODIS Ocean Color Products from NIR, SWIR, and NIR-SWIR Combined Methods

Example: U.S. East Coast



Wang, M. and W. Shi (2007), "The NIR-SWIR combined atmospheric correction approach for MODIS ocean color data processing," *Optics Express*, **15**, 15722-15733.

Chlorophyll-a Comparison Results in Chesapeake Bay



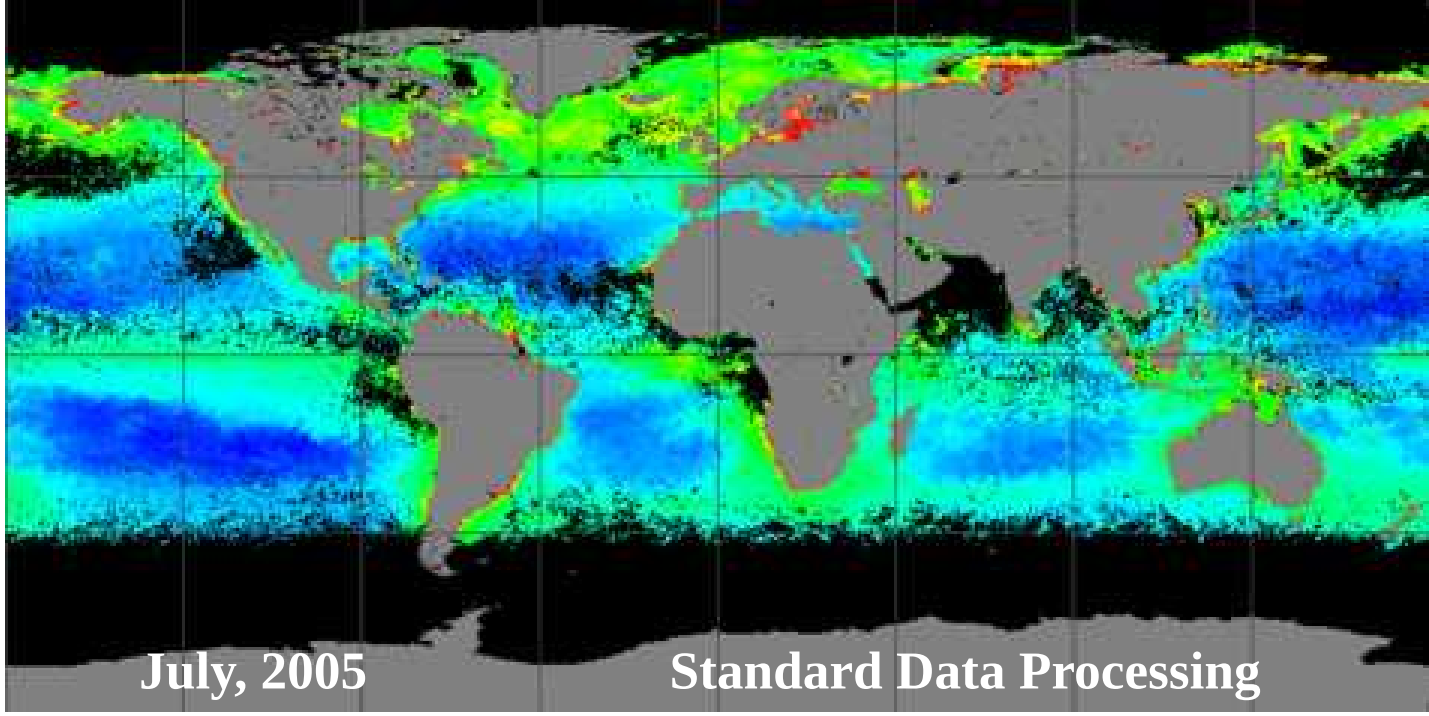
Menghua Wang, NOAA/NESDIS/STAR

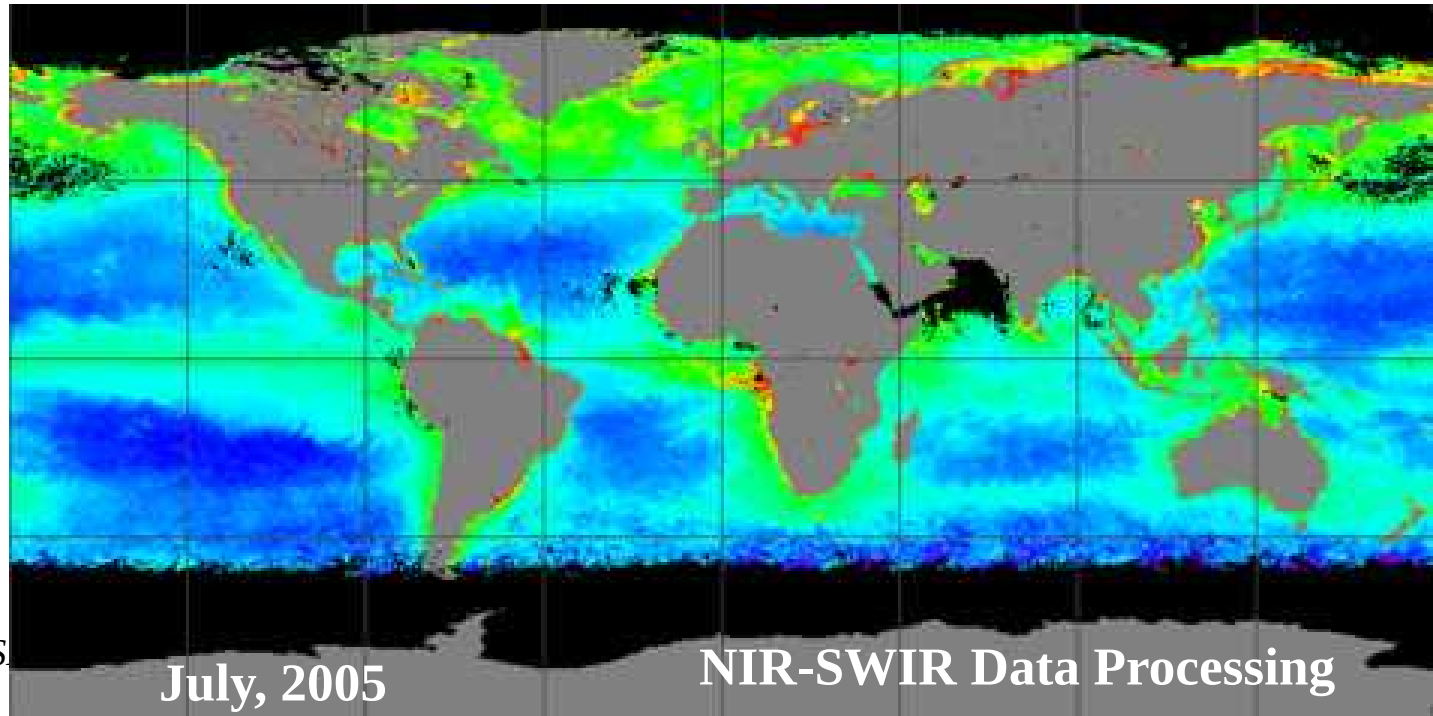
SWIR-based Global Ocean Color Data Processing at NOAA/STAR

Chlorophyll-a

0.01-10 (mg/m^3)

(Log scale)





Wang, M., S. Son, and W. Shi (2009), "Evaluation of MODIS SWIR and NIR-SWIR atmospheric correction algorithms using SeaBASS data," *Remote Sens. Environ.*, **113**, 635-644.

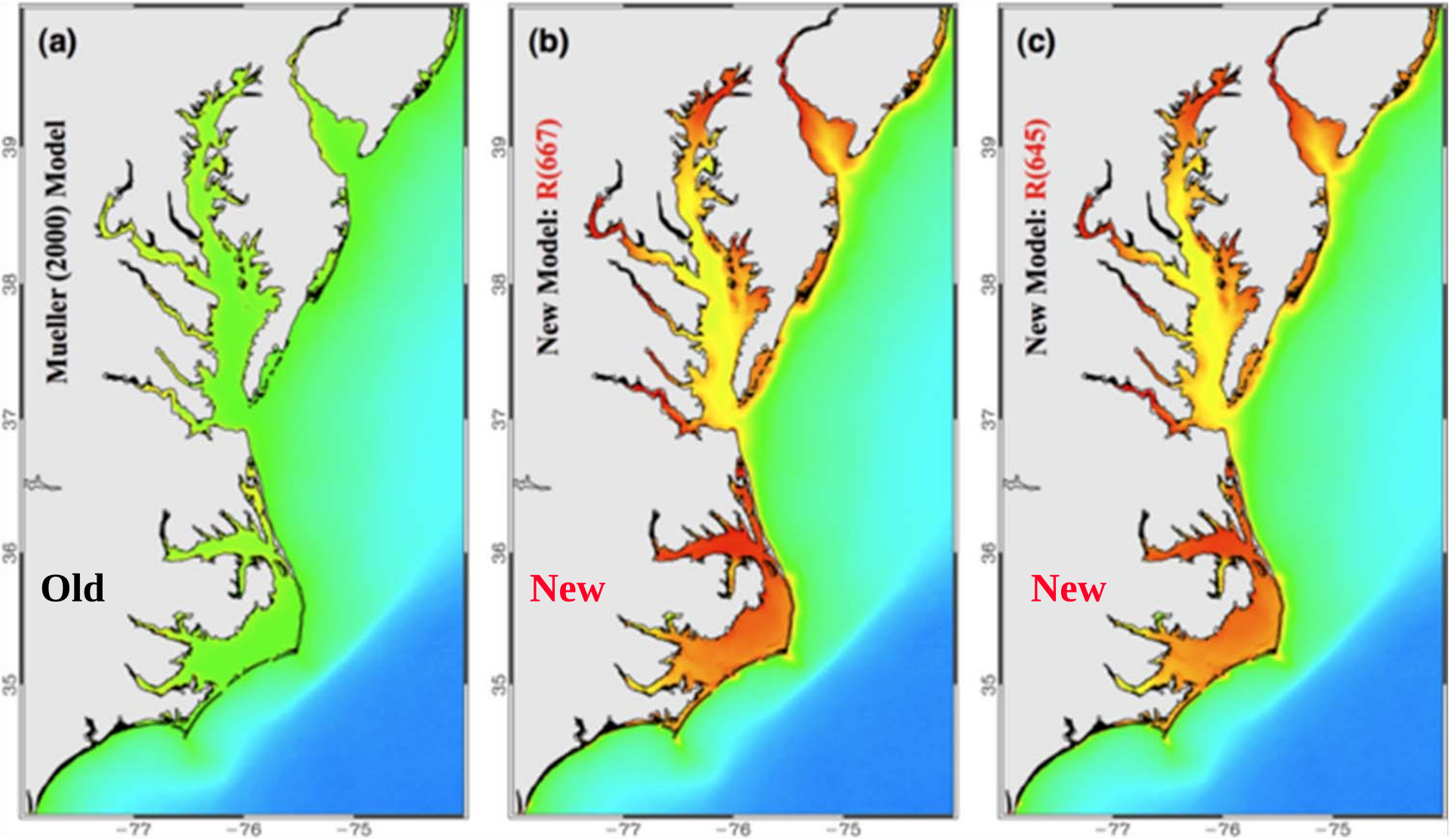
Menghua Wang, NOAA/NESDIS

Development of New Water Diffuse Attenuation Coefficient Kd(490) Algorithm for the Chesapeake Bay and Turbid Coastal Waters Using the MODIS Data

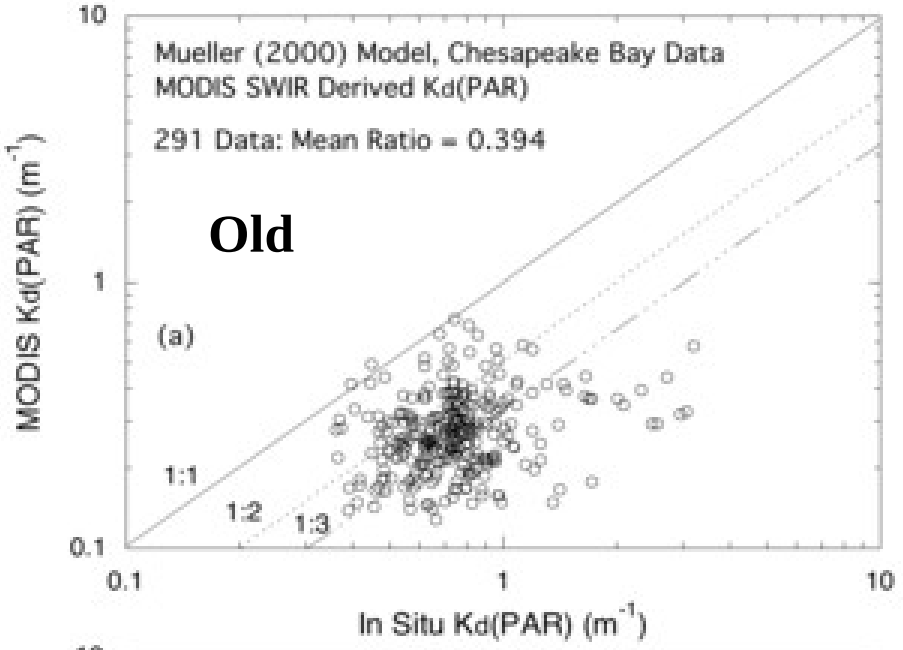
Wang, M., S. Son, and L. W. Harding Jr., "Retrieval of diffuse attenuation coefficient in the Chesapeake Bay and turbid ocean regions for satellite ocean color applications," *J. Geophys. Res.*, **114**, C10011, doi:10.1029/2009JC005286, 2009.

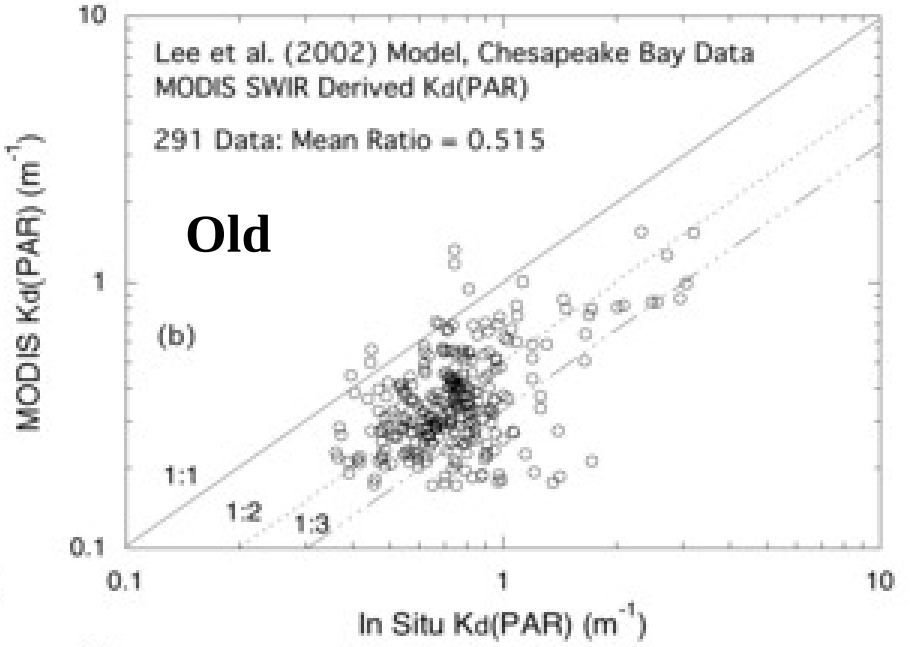
Menghua Wang, NOAA/NESDIS/STAR

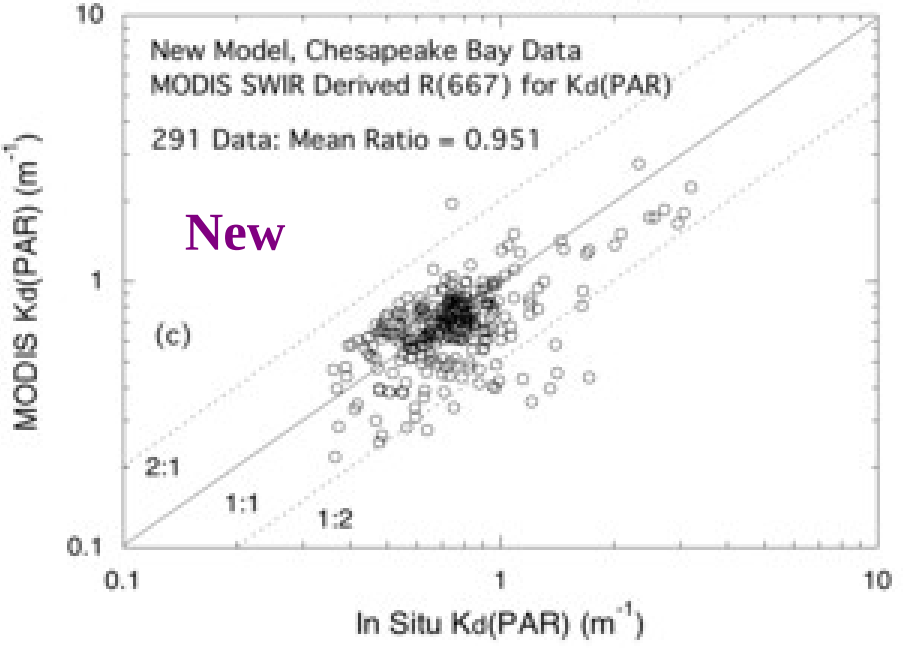
Composite Images of MODIS Kd(490) (July 2002-Dec. 2007)

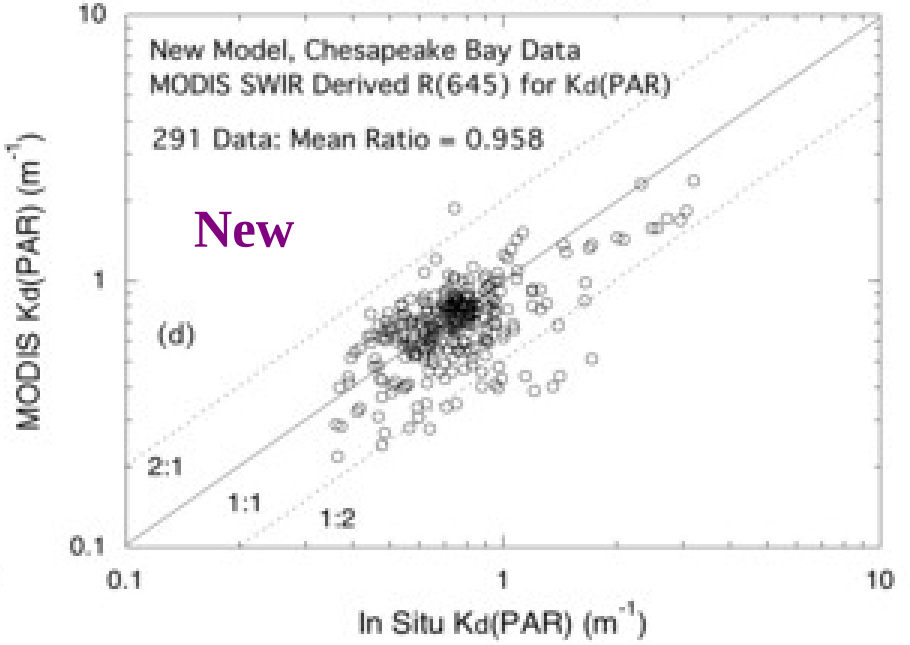


Validation Kd(490) Results for Chesapeake Bay





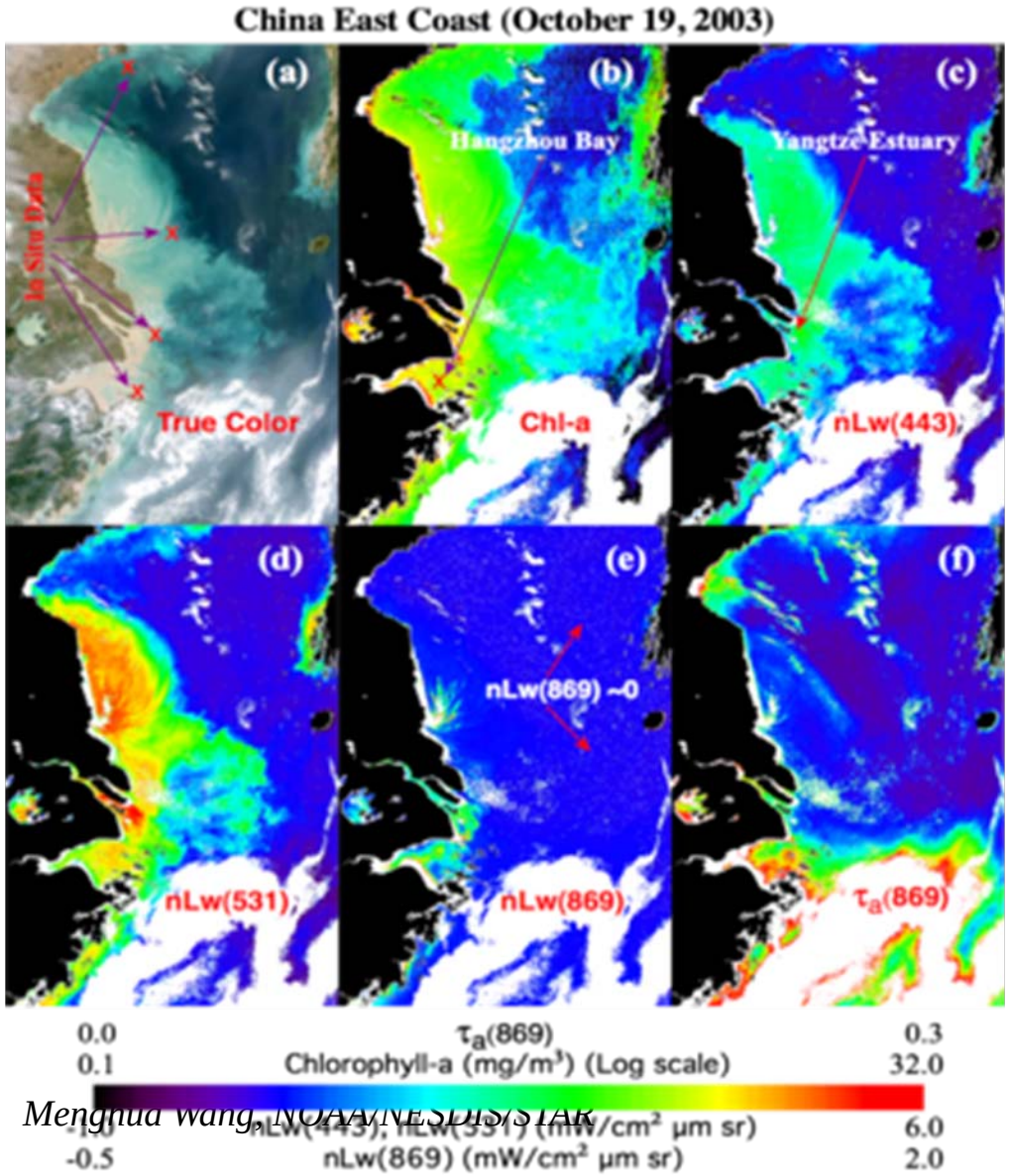


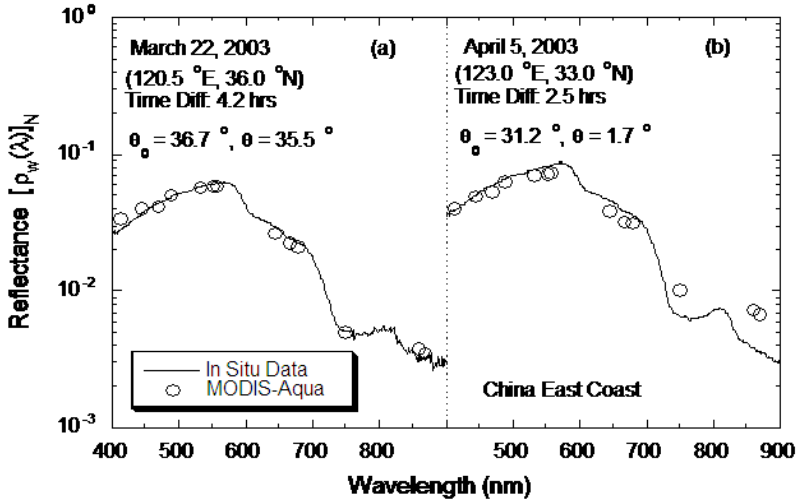


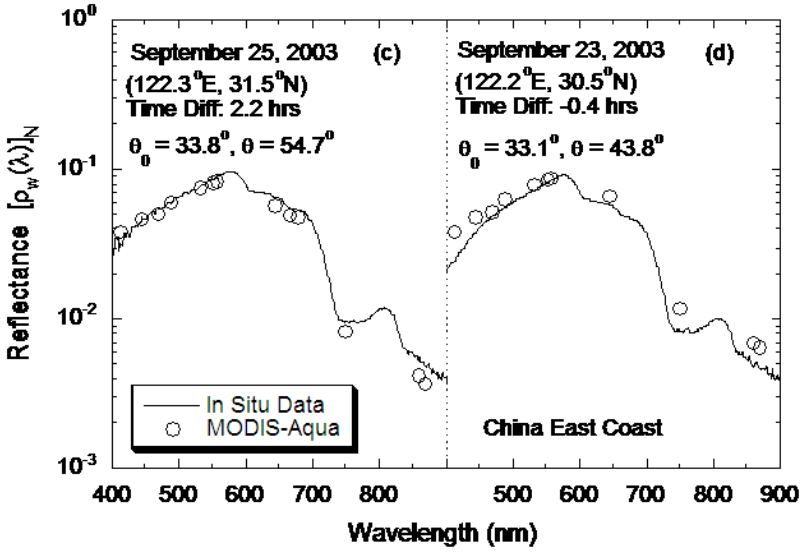
Ocean Color Retrievals In the Turbid Coastal Region

MODIS-derived ocean color products along the China east coastal region

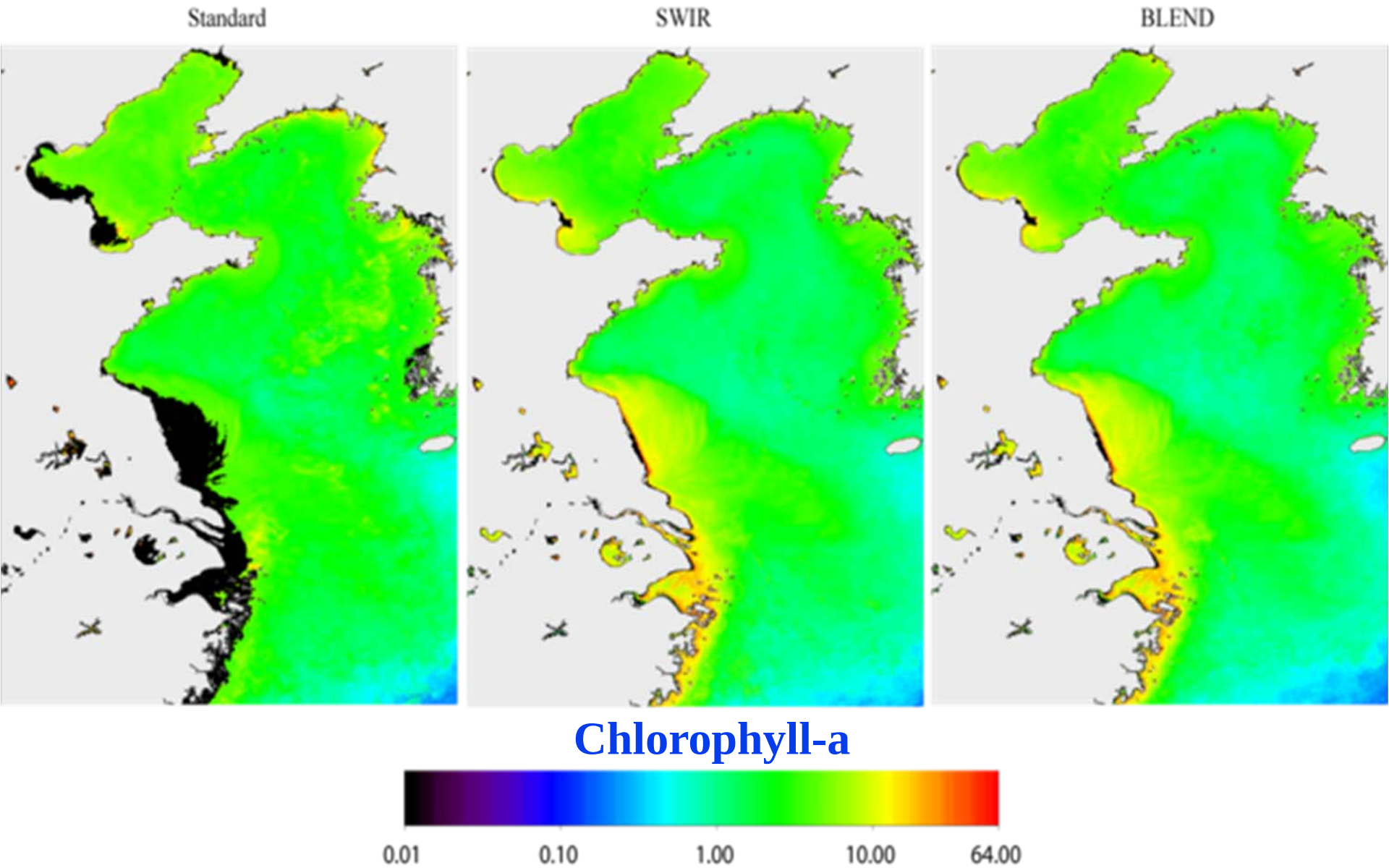
Wang, M., J. Tang, and W. Shi (2007)







MODIS-Aqua Climatological Monthly Chl-a Images in YECS (April)



Menghua Wang, NOAA/NESDIS/STAR

Composite from April 2002-2007 Data

The SWIR-based Ocean Color Products for Various Applications

- **Coastal Phytoplankton Bloom Study:** Observations of Hurricane Katrina-induced phytoplankton bloom in the Gulf of Mexico (Shi and Wang, 2007; Liu et al., 2009).
- **Ecosystem Responses to Major Weather Event:** Three-dimension observations from MODIS and CALIPSO for ocean responses to Cyclone Nargis in the Gulf of Martaban (Shi and Wang, 2008).
- **River Estuary, River Dynamics and River Plume:** Satellite observations of flood-driven Mississippi River plume in the spring 2008 (Shi and Wang, 2009).
- **Stormwater Plume Detection:** Stormwater plume detection in the southern California coastal ocean (Nezline et al., 2008).
- **Coastal and Inland-water Hazard Monitoring:** Satellite-observed blue-green algae blooms in China's Lake Taihu (Wang and Shi, 2008).
- **Environmental Responses to a Land Reclamation Project:** Satellite-observed drastic changes in marine environment in response to the Saemangeum Reclamation Project in South Korea (Son and Wang, 2009).
- **Monitoring Green Macroalgae Blooms in Yellow Sea:** Satellite observation and monitoring of green macroalgae blooms in the Yellow Sea during the spring and summer of 2008 (Shi and Wang, 2009).

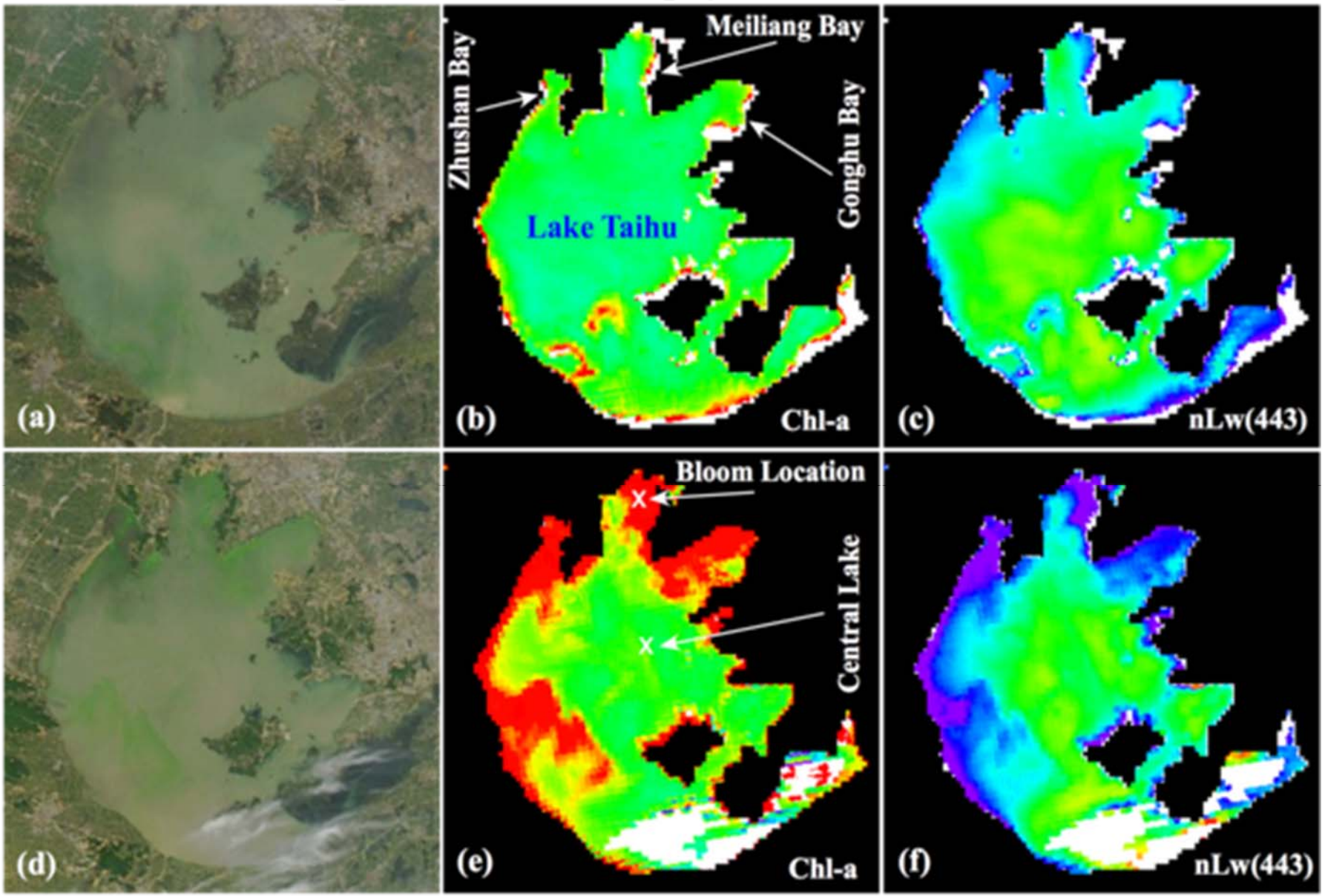
Results from Inland Lake Taihu

Using the **SWIR** algorithm, we have derived the water optical properties over the Lake Taihu using the **MODIS-Aqua** measurements during the spring of 2007 for monitoring a **massive blue-green** algae bloom, which was a major natural disaster affecting several millions residents in nearby Wuxi city.

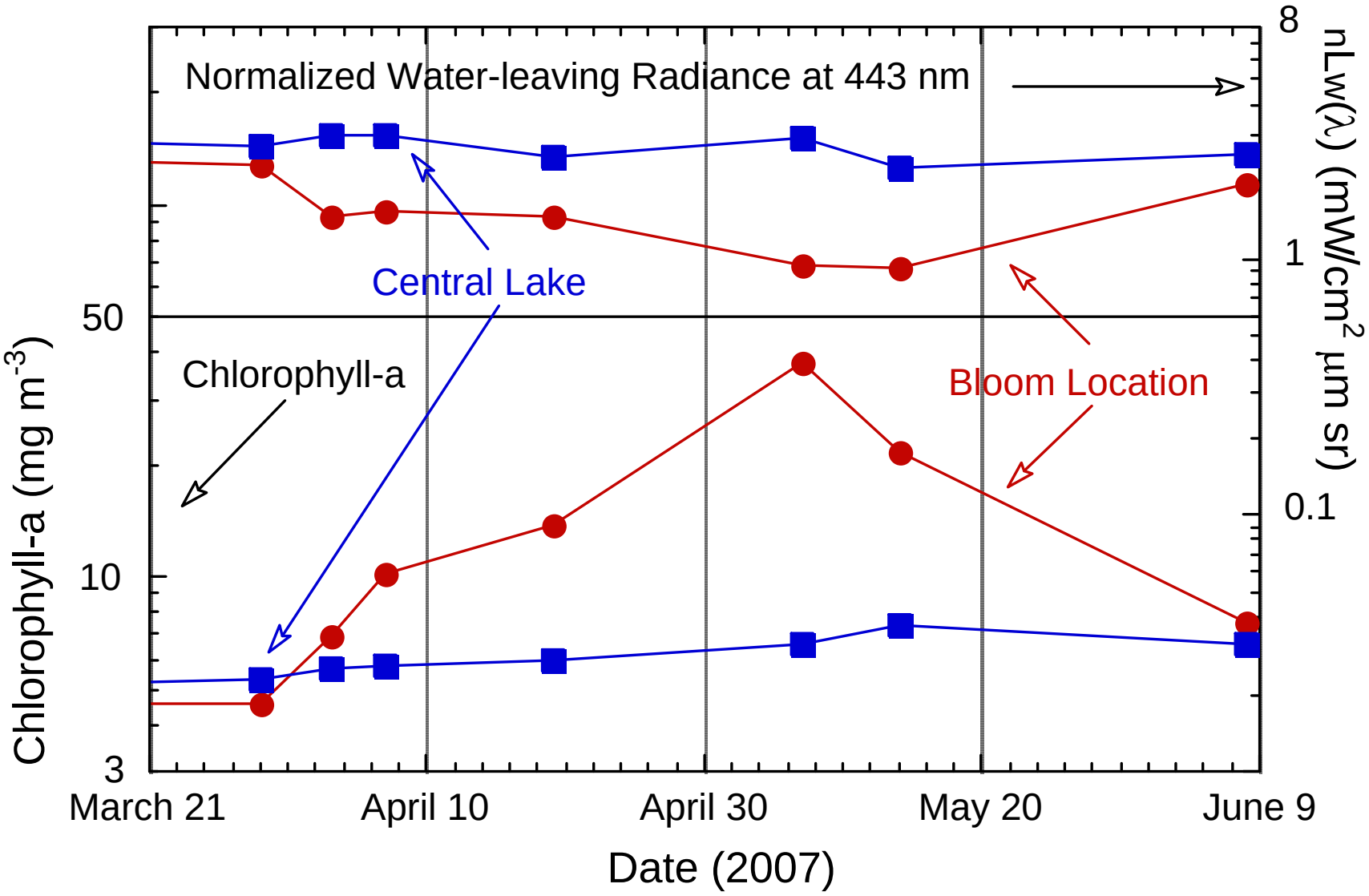
Wang, M. and W. Shi, "Satellite observed algae blooms in China's Lake Taihu", *Eos, Transaction, American Geophysical Union*, **89**, p201-202, May 27 (2008).

- The work was featured in the NASA 2008 Sensing Our Planet (http://nasadaacs.eos.nasa.gov/articles/2008/2008_algae.html)

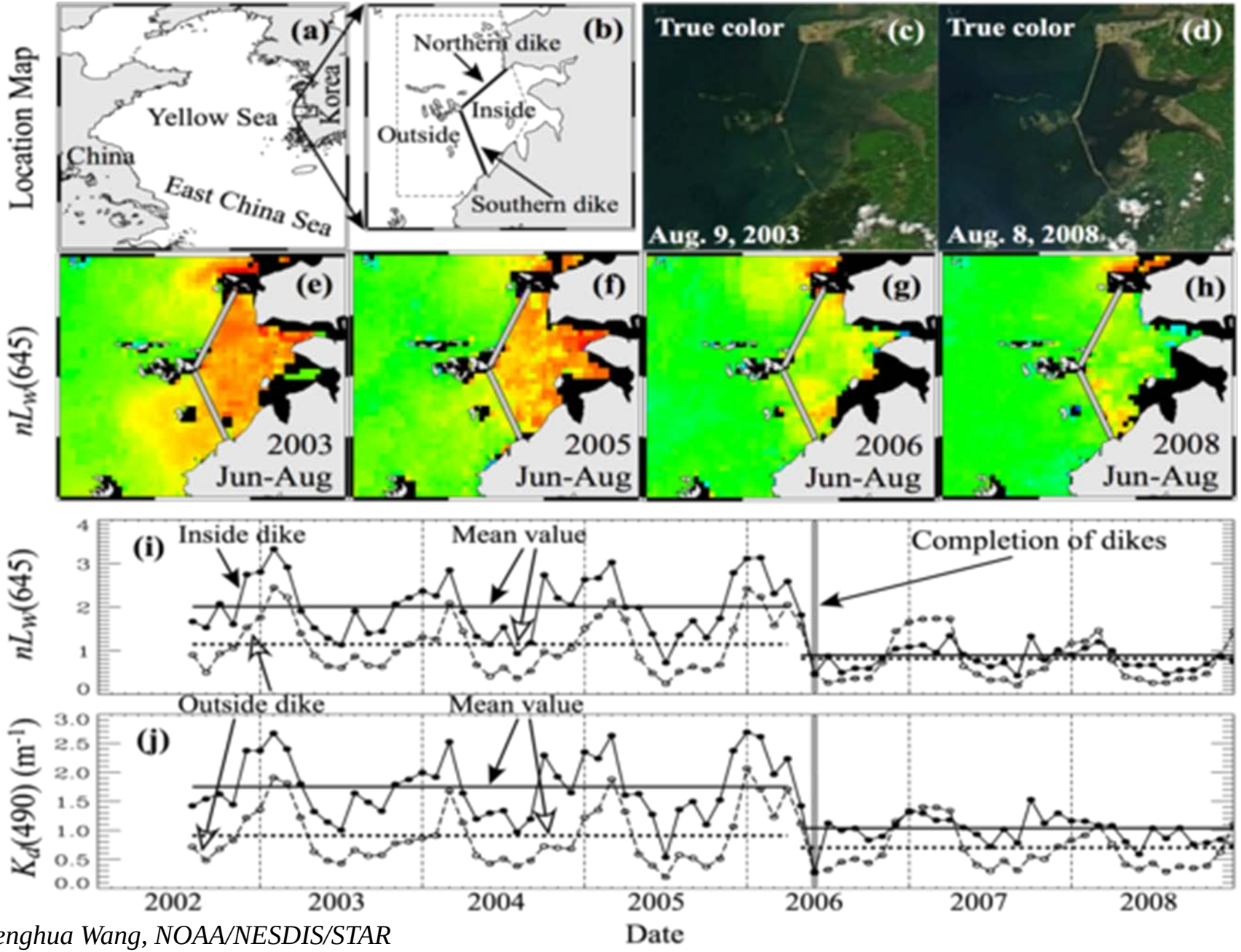
Blue-Green Algae (Microcystis) Bloom Crisis in Lake Taihu (Spring 2007)


True Color Image
Chlorophyll-a
nLw(443)
March 29, 2007
May 7, 2007
Meiliang Bay
Zhushan Bay
Gonghu Bay
Lake Taihu
Bloom Location
Central Lake
(a)
(b)
Chl-a
(c)
nLw(443)
(d)
(e)
Chl-a
(f)
nLw(443)
0.0
nLw(443) (mW/cm² μm sr)
5.0
1.0
Chlorophyll-a Concentration (mg/m³)
32.

Time Series of Chlorophyll-a (index) and *nLw*(443) at Wuxi Station (bloom) and Central Lake (non-bloom)



The Saemangeum Reclamation Project in South Korea



Current Research and Development Activities

- **Transition of Research to Operational for the SWIR-Based Algorithms**:
  - Working with the NOAA data operational partners, we have been working on implementing the SWIR-based ocean color data processing system into the NOAA operational data processing system.
  - Near real time ocean color products will be produced using the SWIR-based algorithms for the U.S. coastal regions in the NOAA CoastWatch Program.
  - Improved ocean color data, e.g., new Kd(490) product for turbid waters, will be generated.
- **NPOESS (NPP)-VIIRS Ocean Color Cal/Val:**
  - On-orbit Vicarious Calibration for the VIIRS ocean color products.
  - NOAA VIIRS ocean color data processing.
  - VIIRS ocean color product validation.
- **Algorithm Development and Ocean Color Data Applications:**
  - Algorithms development (e.g., for dealing with the absorbing aerosols in coastal region) and refinement for ocean coastal and inland waters.
  - Various ocean color data applications for ocean coastal and inland waters.
  - Chesapeake Bay TSM (total suspended matter) work and COCE (coastal ocean characterization experiment) in STAR
- **Future Ocean Color Satellite Missions:**
  - NASA Aerosol, Cloud, and Ecosystem (ACE) Mission.
  - NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) Mission.

The SWIR Algorithm Related Publications (1)
(Algorithms and Validations)

Wang, M., S. Son, and L. W. Harding Jr., "Retrieval of diffuse attenuation coefficient in the Chesapeake Bay and turbid ocean regions for satellite ocean color applications," *J. Geophys. Res.*, **114**, C10011, doi:10.1029/2009JC005286, 2009.

Zhang, H. and M. Wang, "Evaluations of Sun glitter models using MODIS measurements," *J. Quant. Spectr. Rad. Trans.*, **111**, 492-506, doi:10.1016/j.jqsrt.2009.10.001, 2010.

Wang, M. and W. Shi, "Detection of ice and mixed ice-water pixels for MODIS ocean color data processing," *IEEE Trans. Geosci. Remote Sensing*, **47**, 2510-2518, 2009.

Shi, W. and M. Wang, "An assessment of the ocean black pixel assumption for the MODIS SWIR bands," *Remote Sens. Environ.*, **113**, 1587-1597, 2009.

Wang, M., S. Son, and W. Shi, "Evaluation of MODIS SWIR and NIR-SWIR atmospheric correction algorithms using SeaBASS data," *Remote Sens. Environ.*, **113**, 635-644, 2009.

Wang, M. and W. Shi, "The NIR-SWIR combined atmospheric correction approach for MODIS ocean color data processing," *Optics Express*, **15**, 15722-15733, 2007.

Wang, M., J. Tang, and W. Shi, "MODIS-derived ocean color products along the China east coastal region," *Geophys. Res. Lett.*, **34**, L06611, doi:10.1029/2006GL028599, 2007.

Shi, W. and M. Wang, "Detection of turbid waters and absorbing aerosols for the MODIS ocean color data processing," *Remote Sens. Environ.*, **110**, 149-161, 2007.

Wang, M., "Remote sensing of the ocean contributions from ultraviolet to near-infrared using the shortwave bands: simulations," *Appl. Opt.*, **46**, 1535-1547, 2007.

Wang, M. and W. Shi, "Cloud masking for ocean color data processing in the coastal regions," *IEEE Trans. Geosci. Remote Sensing*, **44**, 3196-3205, 2006.

Wang, M. and W. Shi, "Estimation of ocean contribution at the MODIS near-infrared wavelengths along the east coast of the U.S.: Two case studies," *Geophys. Res. Lett.*, **32**, L13606, doi:10.1029/2005GL022917, 2005.

The SWIR Algorithm Related Publications (2)
(Various Applications)

Son, S. and M. Wang, "Environmental Responses to Land Reclamation Project in South Korea," *Eos, Transaction, American Geophysical Union*, **90**, p398-399, Nov. 3, 2009.

Shi, W. and M. Wang, "Green macroalgae blooms in the Yellow Sea during the spring and summer of 2008," *J. Geophys. Res*. **114**, CXXXXX, doi:10.1029/2009JC005513, 2009.

Shi, W. and M. Wang, "Satellite observations of flood-driven Mississippi River plume in the spring of 2008," *Geophys. Res. Lett.*, **36**, L07607, doi:10.1029/2009GL037210, 2009.

Liu, X, M. Wang, and W. Shi, "A study of a Hurricane Katrina-induced phytoplankton bloom using satellite observations and model simulations," *J. Geophys. Res*., **114**, C03023, doi:10.1029/2008JC004934, 2009.

Shi, W. and M. Wang, "Three-dimensional observations from MODIS and CALIPSO for ocean responses to Cyclone Nargis in the Gulf of Martaban," *Geophys. Res. Lett.*, **35**, L21603, doi:10.1029/2008GL035279, 2008.

Nezlin, N. P., P. M. DiGiacomo, D. W. Diehl, B. H. Jones, S. C. Johnson, M. J. Mengel, K. M. Reifel, J. A. Warrick, and M. Wang,"Stormwater plume detection by MODIS imagery in the southern California coastal ocean," *Estuarine, Coastal and Shelf Science*, **80**, 141-152, 2008.

Wang, M. and W. Shi, "Satellite-observed blue-green algae blooms in China's Lake Taihu", *Eos, Transactions, American Geophysical Union*, **89**, p201-202, May 27, 2008.

Shi, W. and M. Wang, "Observations of a Hurricane Katrina-induced phytoplankton bloom in the Gulf of Mexico," *Geophys. Res. Lett.*,**34**, L11607, doi:10.1029/2007GL029724, 2007.

Thank You!