Remote sensing of water quality in inland and other coastal waters: Sensors, products & applications

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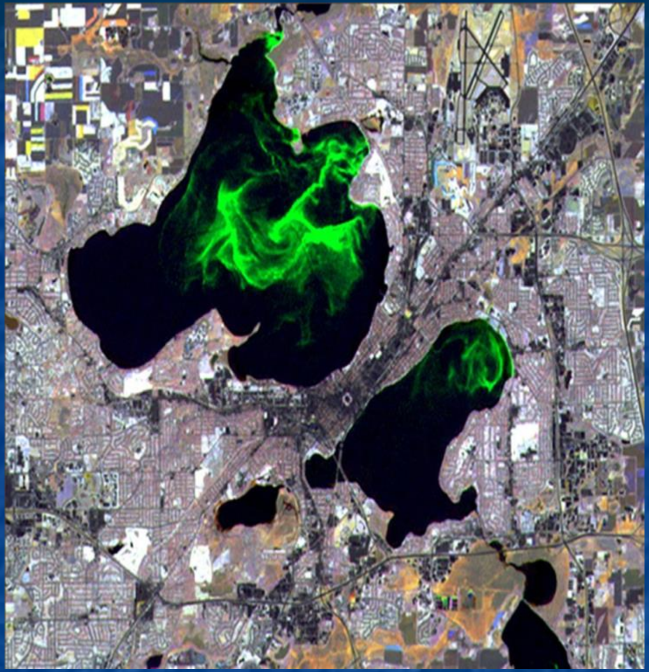
NOAA Satellites and Information
National Environmental Satellite, Data, and Information Service

Remote Sensing of Water Quality in Inland & other Coastal Waters

- Declining water quality has become a global issue of significant concern as anthropogenic activities expand and climate change threatens to cause major alterations to the hydrological cycle

- Globally, water quality monitoring is receiving inadequate attention particularly in developing countries and in countries in transition where existing water quality monitoring networks are deficient

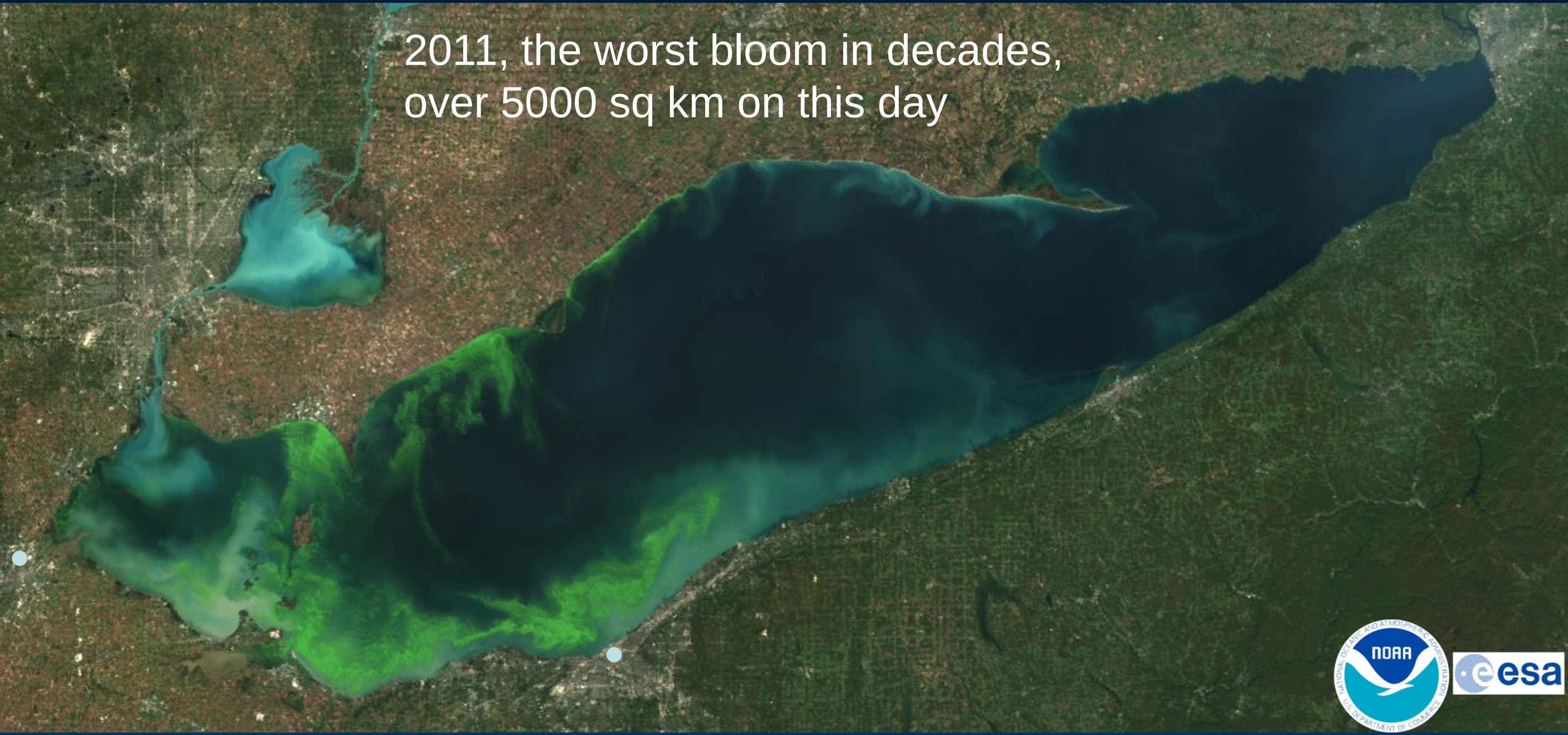
- Even in developed nations (e.g., the U.S.), opportunities exist to leverage satellite and other remote sensing data to a much greater extent.



Lakes Mendota & Monona
University of Wisconsin SSEC image

Courtesy S. Greb

2011 Lake Erie cyanobacteria bloom



09 October 2011 : Data from MERIS
(European Space Agency

Ocean Color Radiometry and Water Quality Applications

Table 7.1 Products or state indicators and their applications.

Product Name	Standard and Advanced Product Requirement (Data sets)	Application
Transparency / Secchi disk depth	Pigments, total suspended matter (TSM), light attenuation coefficient, dissolved organic matter (DOM),	Water quality monitoring
Primary production	Pigments, TSM, DOM, inherent optical properties of water constituents, SST, surface irradiance	Water quality monitoring, ecosystem and habitat assessment
Differential biomass/ phytoplankton community structure	Pigments, chemotaxonomic equations	Water quality monitoring, ecosystem assessment, hazards
Eutrophication index	Chlorophyll, primary production , nutrients, SST	Water quality monitoring, hazards
Turbidity index	Transparency, phytoplankton biomass	Water quality monitoring
Submerged benthic vegetation index	Pigments, sediment, dissolved organic matter, bathymetry, albedo data base	Aquaculture, water quality monitoring, impact assessment
Bloom/ plume dynamics	Chlorophyll, TSM , DOM	Hazards, ecosystem and habitat assessment

Hoepffner et al., "Ocean Colour Radiometry and Water Quality", in, *Why Ocean Colour?* IOCCG Report #7, 2008

Overview of Presentation

- Satellite sensors: Existing and future observing capabilities; gaps, challenges and recommendations for inland and other coastal waters

- Requirements, data and products

- Representative applications

- International coordination for remote sensing of water quality

Observing Needs, Issues, Gaps and Challenges

- Users require timely, accurate and consistent data at regular intervals over sustained periods that adequately resolve the processes, phenomena & characteristics of interest for inland and other coastal ecosystem monitoring and management.

- The IGOS Coastal Theme Report (IGOS, 2006) provides a thorough overview of user needs, requirements and gaps from a coastal as well as a satellite perspective. It addresses *knowledge, resolution/coverage and knowledge* challenges.

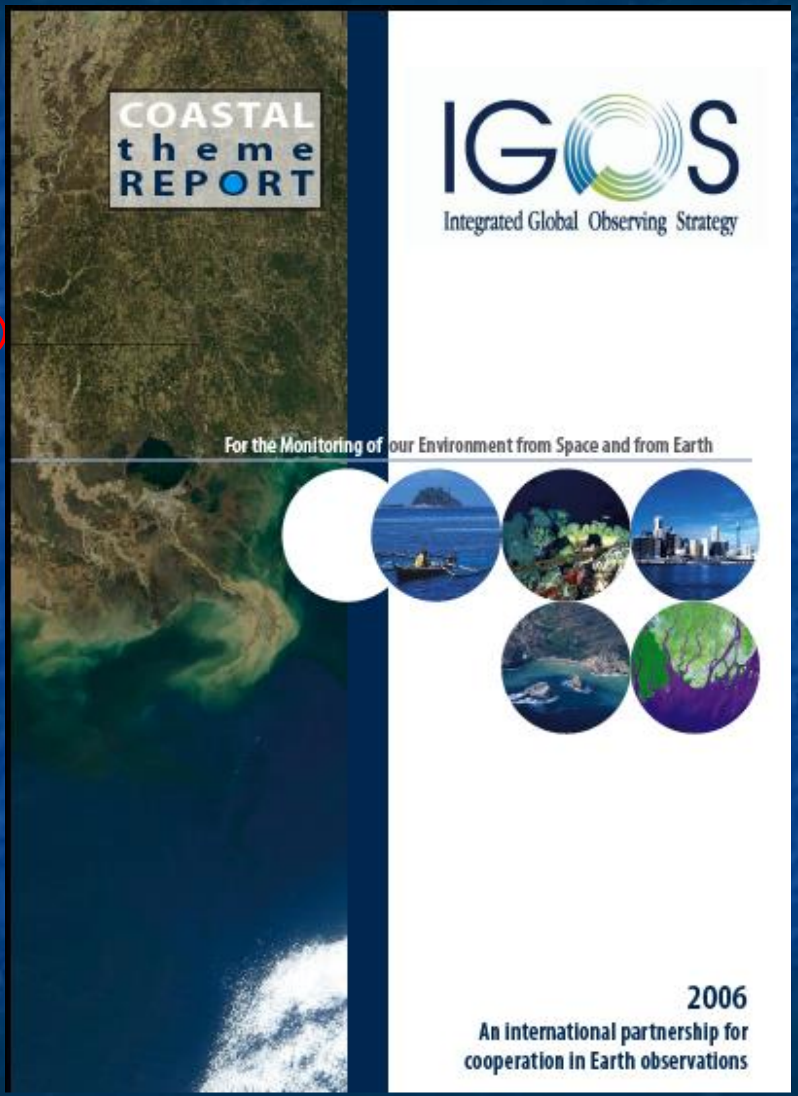
- More specifically, satellite ocean color observations were identified in the *2007 GEOSS Water Quality Remote Sensing Workshop* as having the greatest value utility for water quality applications, but a host of supporting geophysical observations is strongly desired, e.g., surface temperature, winds, roughness, and land cover.

- Aside from issues of cal/val and data access, a key concern amongst users is ensuring continuity of consistent data, both from *in situ* and satellite sources. There are numerous systems that have already proven valuable, particularly moderate resolution ocean color (e.g. MERIS, MODIS,) and high spatial resolution imagery (e.g. Landsat, ASTER).

- That said, existing/planned satellite observing capabilities often provide inadequate spatial, temporal and/or spectral resolution of important biological and geophysical parameters for inland/coastal ecosystem applications, with some key measurements not presently made at all from space (e.g. estimates of river discharge).

IGOS Coastal Theme Report: Coastal Observing Priorities

PROVIDE	Geostationary, hyperspectral visible spectral radiance (i.e., ocean colour) data for coastal waters
	Higher resolution/improved coverage for ocean vector winds & sea surface height
	High spatial and spectral resolution capacity to assess changes in coral reef & other terrestrial and aquatic habitats (e.g., estuaries)
	Ocean surface current observations and river discharge in coastal regions
	InSAR measurements for coastal subsidence and erosion
IMPROVE	Calibration/validation of measurements in coastal regions
	Data management infrastructure (near-real-time delivery; climate data records)
SUPPORT	Development of an integrated COastal Data Assimilation System
	Adaptive, coordinated remote and *in situ* sampling



IGOS Coastal Theme Report, 2006

Solutions and Priorities: Continuity

- Moderate resolution global water color continuity (e.g. MERIS, MODIS) for synoptic context and climatology. Associated with these sensors are specific needs including: at least two sensors in orbit at any one time (e.g. ideally AM & PM); facilitation of greater access/distribution of regional moderate resolution data; continued inclusion of fluorescence and SWIR bands (atmospheric corrections); need for merged/blended products to address data dropouts along coast.

- High resolution land/optical imager continuity (e.g. ASTER, Hyperion and Landsat/LDCM). Needs include thermal bands as well as water optical bands (e.g. blue sensitive) bands.

- Fine resolution optical imagery (e.g. IKONOS, SPOT and QuickBird class). Specific needs include greater accessibility to these datasets.

Additional sensor continuity in other electromagnetic regions includes:

- SAR continuity. The present coverage/access is inadequate, so a constellation is needed with widely available data.

- Global and regional surface temperature continuity (e.g. AVHRR, GOES, SEVIRI) for synoptic context and climatology. There is a need for multiple low Earth orbit satellites complemented by geostationary orbits for intensive regional looks. Additionally, there is a sustained need for merged/blended products to address data dropouts along the coastal areas.

- Global ocean vector wind continuity (e.g. ASCAT and QuikSCAT). There is a need for improved spatial resolution and a constellation to provide improved temporal coverage.

GEO Inland & Nearshore Coastal Water Quality Remote Sensing Workshop Report

Solutions and Priorities: New and Improved Capabilities (R&D needed)

Existing satellite observations generally provide inadequate spatial, temporal and/or spectral resolution of important biological and geophysical parameters for inland and nearshore coastal applications.

- The top two priorities are for *nested local and regional aquatic imagers*:

  => High resolution *local* aquatic imaging mission(s) in low Earth orbit, with a goal of 10m or better ground resolution and ideally weekly or better repeats, with pointing capabilities and/or a constellation of imagers utilized to provide more frequent looks than currently available through existing high resolution sensors; potential partnership opportunities with the terrestrial observing community.

  => Constellation of *regional* geostationary ocean color imagers to provide regional high frequency temporal revisits. Goal of 1 hour for revisiting dynamic events, moderate (~ 100-300 m) spatial resolution and good offshore (e.g. EEZ) coverage of coastal regions ~ globally. Potential partnership opportunities with the atmospheric community.

  => Hyperspectral capabilities are desired for each of the above, with a minimum of twenty (or greater), narrow (~5-10 nm) spectral bands covering a broad spectral range extending from the UV (0.35µm) through NIR (1.1 µm) with discrete SWIR bands also needed to support improved atmospheric corrections and thermal bands desirable for physical dynamics; high signal-to-noise ratio (SNR) is a crucial need for aquatic (versus land) applications.

GEO Inland & Nearshore Coastal Water Quality Remote Sensing Workshop Report

Solutions and Priorities: New and Improved Capabilities (R&D needed)

• Other desired geophysical measurement capabilities include:

=> High resolution/improved coverage altimetry for lake, wetland and reservoir storage, river discharge, nearshore sea level, bathymetry and others (e.g. SWOT mission).

=> Salinity at an adequate spatial resolution for some coastal applications (potential for next generation SMOS/Aquarius heritage instruments with improved capabilities, or else via proxy).

=> Surface currents from space as a global coverage; especially for developing countries where shore-based HF radar is potentially prohibitively expensive.

=> LIDAR aerosol column profiles for improved atmospheric corrections; other space based or airborne active measurements (e.g. particle profiles, bathymetry, shoreline position and topography).

Recommendations from GEO Inland and Nearshore Coastal Water Quality Remote Sensing Workshop (March 2007) Report

Short-Term

• *Water Quality Community*: Should become active in future mission concept studies and scoping efforts, with guidance and advisement to be provided by the water quality remote sensing working group (or community of practice) to be formed as a result of this workshop.

• *GEO*: Help communicate water quality observing requirements associated with this workshop to space agencies and other relevant partners, and identify appropriate individuals and mechanisms for follow-up (including facilitating the following recommendation).

• *CEOS*: Insert/address aquatic requirements in current/upcoming mission concept studies and scoping efforts; particularly for future high resolution land imagers (especially hyperspectral designs) - make these requirements part of the mission trade space.

• *CEOS and/or IOCCG*: Conduct ocean color geostationary constellation scoping study – need to plan/implement these geostationary observations in a coordinated manner across multiple regions/basins to provide adequate coverage; explore and identify platforms of opportunity in addition to “free flyers” to facilitate build-out of this constellation. (Note: IOCCG report in 2012)

Recommendations from GEO Inland and Nearshore Coastal Water Quality Remote Sensing Workshop (March 2007) Report

Long-Term

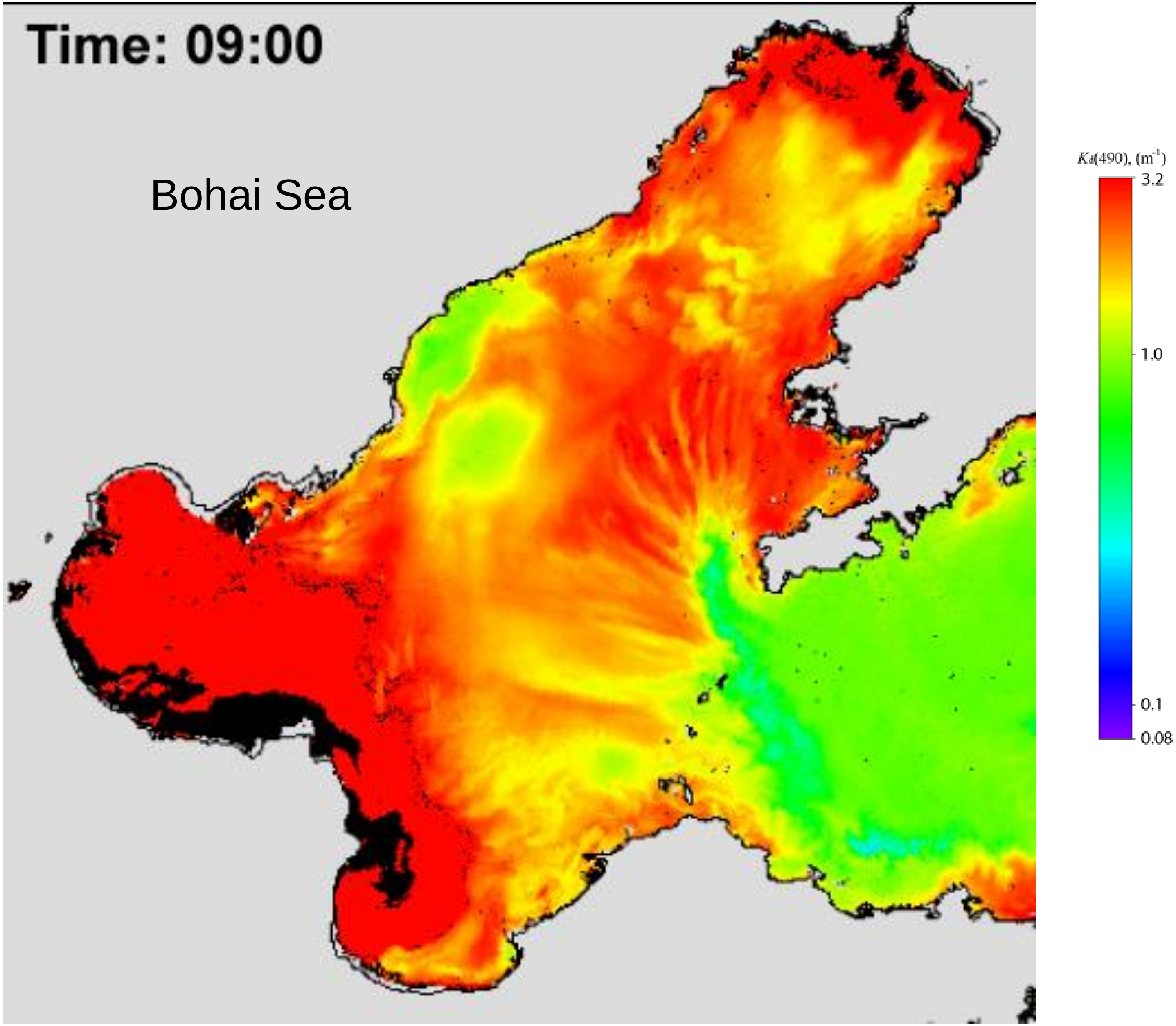
GEO: Continue to gather evolving user requirements for inland and nearshore coastal waters and reconcile planned measurement capability with user requirements.

CEOS: Ensure continuity of existing sensors/capabilities of priority need for water quality use as articulated above; multispectral ocean/land color observations are heavily utilized and thus represent a particularly important continuity need.

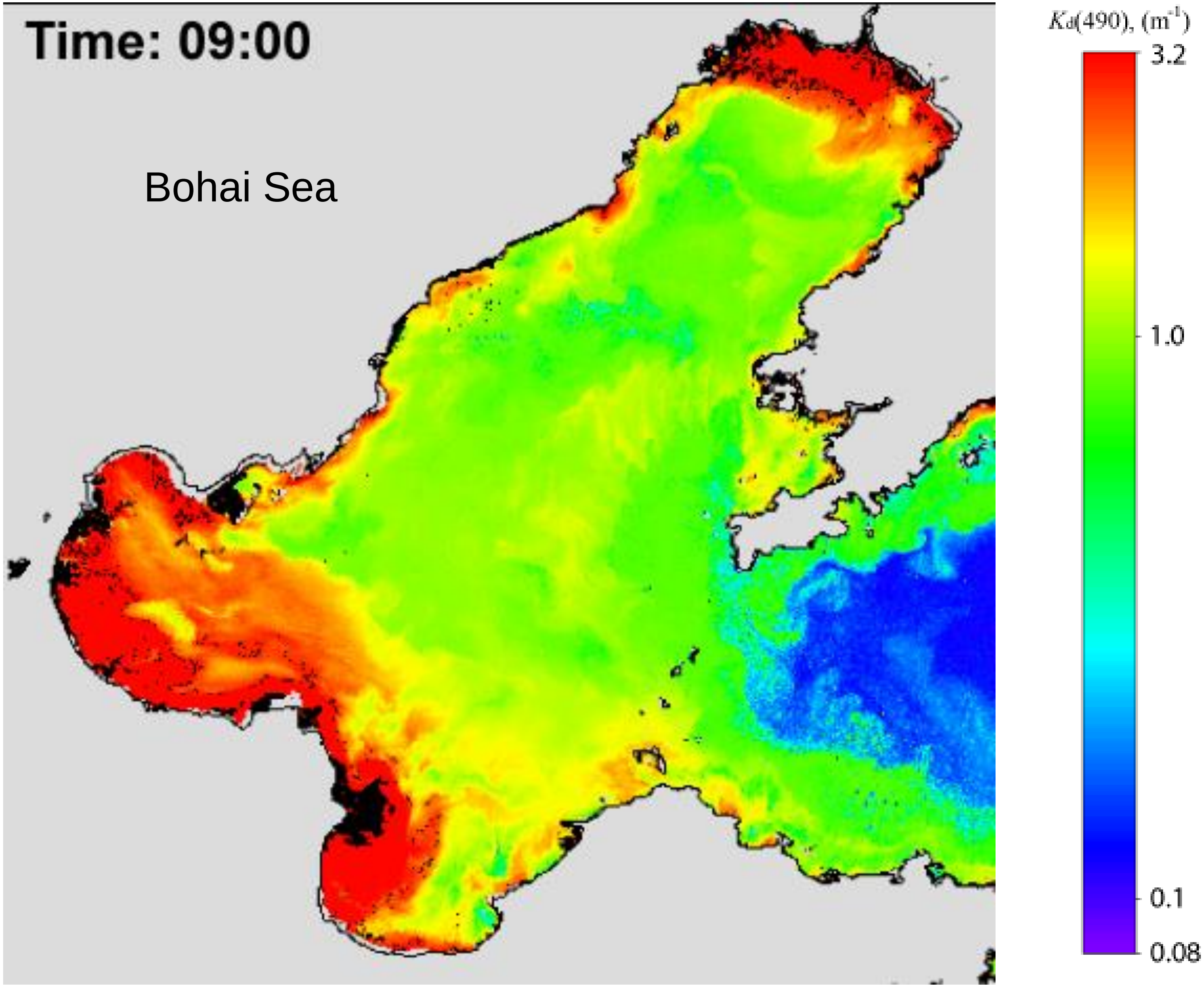
CEOS: Develop and implement new and improved inland and nearshore coastal capabilities as identified earlier; particular priorities are for local and regional aquatic imagers with high SNR and improved temporal and spatial resolution.

CEOS: Plan for and facilitate the transition of existing (as well as planned/future) research and developmental missions for use with water quality assessments and applications into sustained operations in support of user needs (i.e. management and decision-making as well as for research).

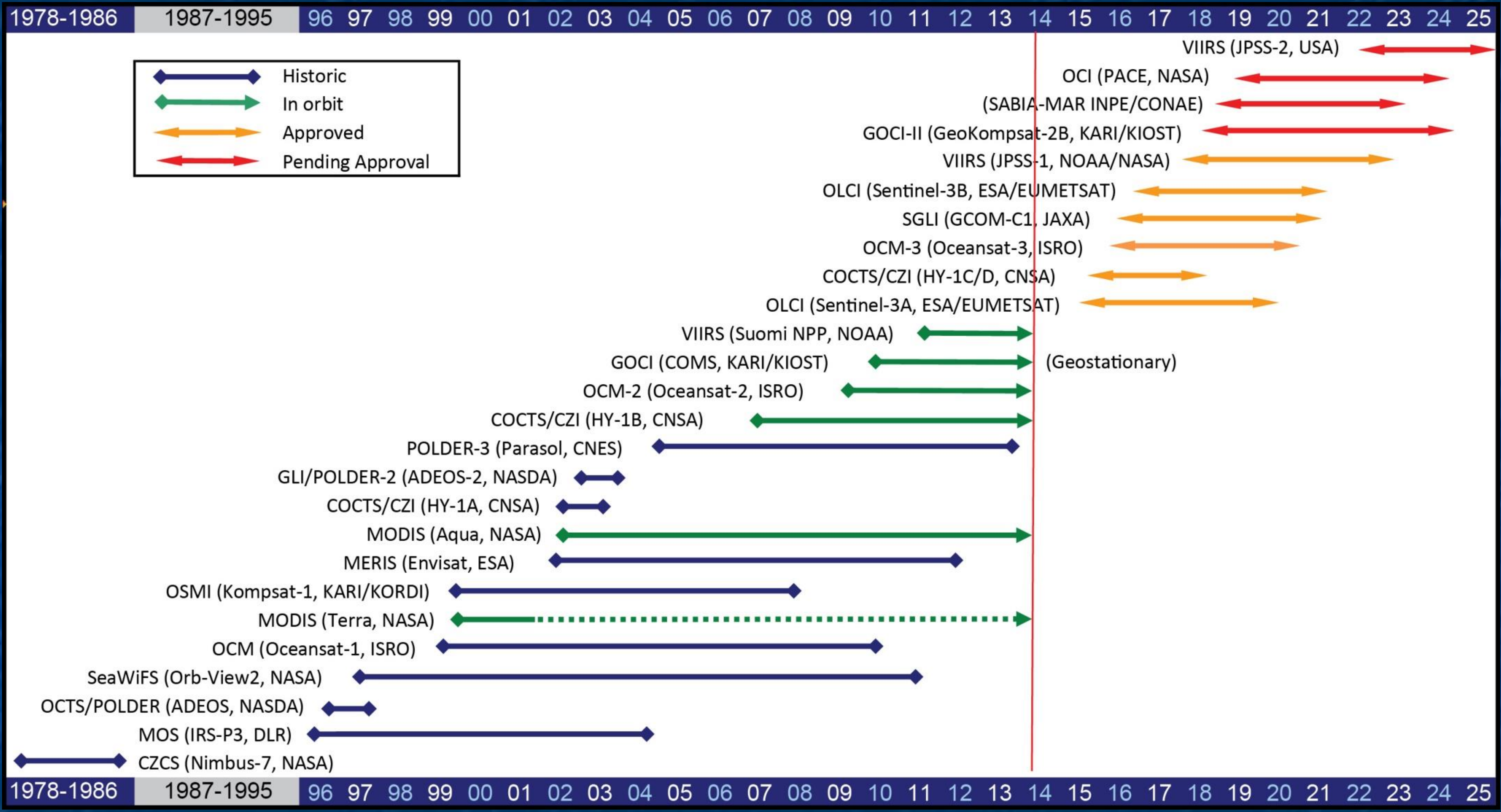
GOCI NOAA-MSL12 K_d(490) (Turbidity) (2012-03-25) (Early Spring)



GOCI NOAA-MSL12 K_d(490) (Turbidity) (2012-08-23) (Summer)

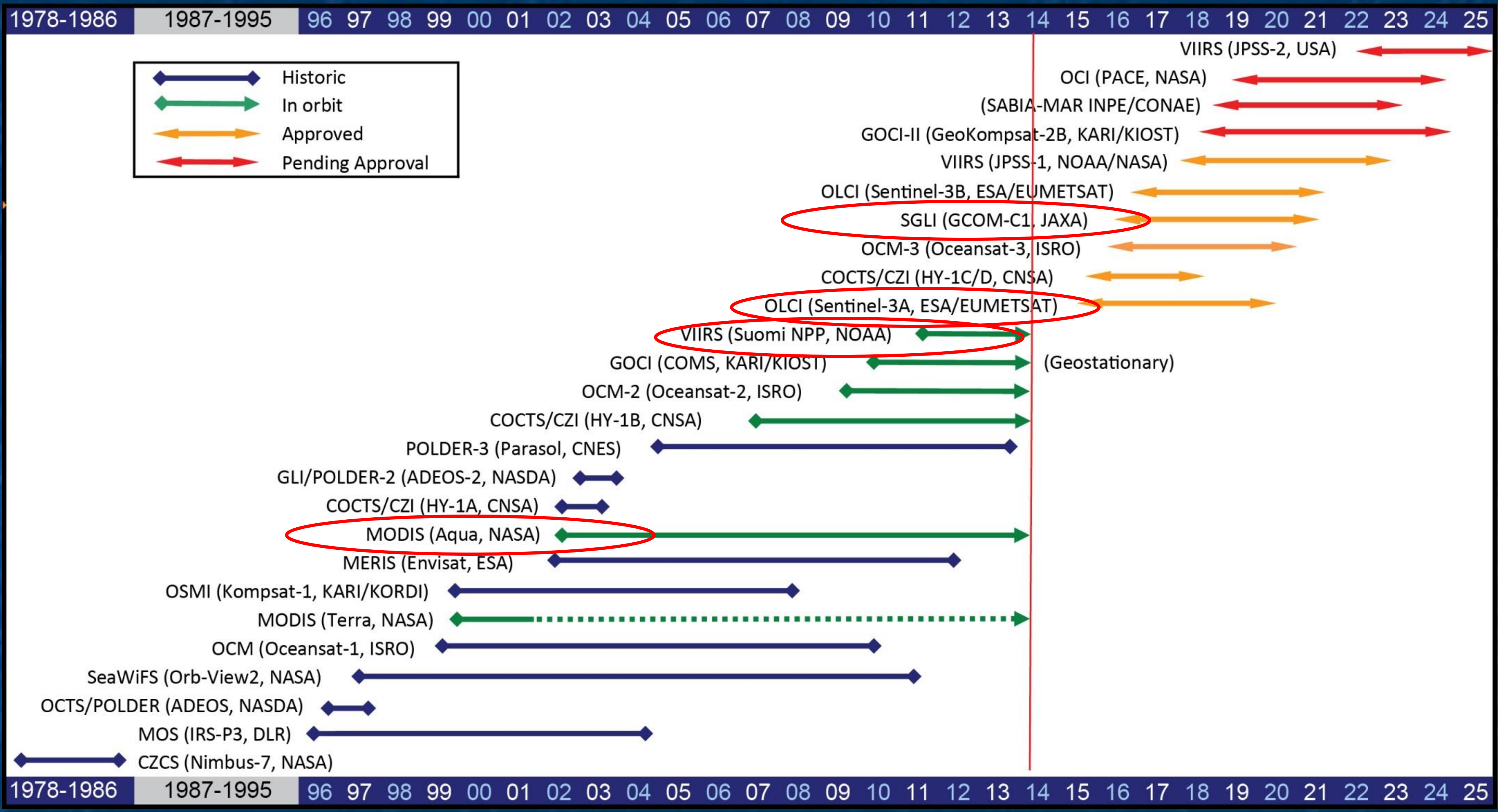


Ocean Color Radiometry Sensors: Past, Present and Future



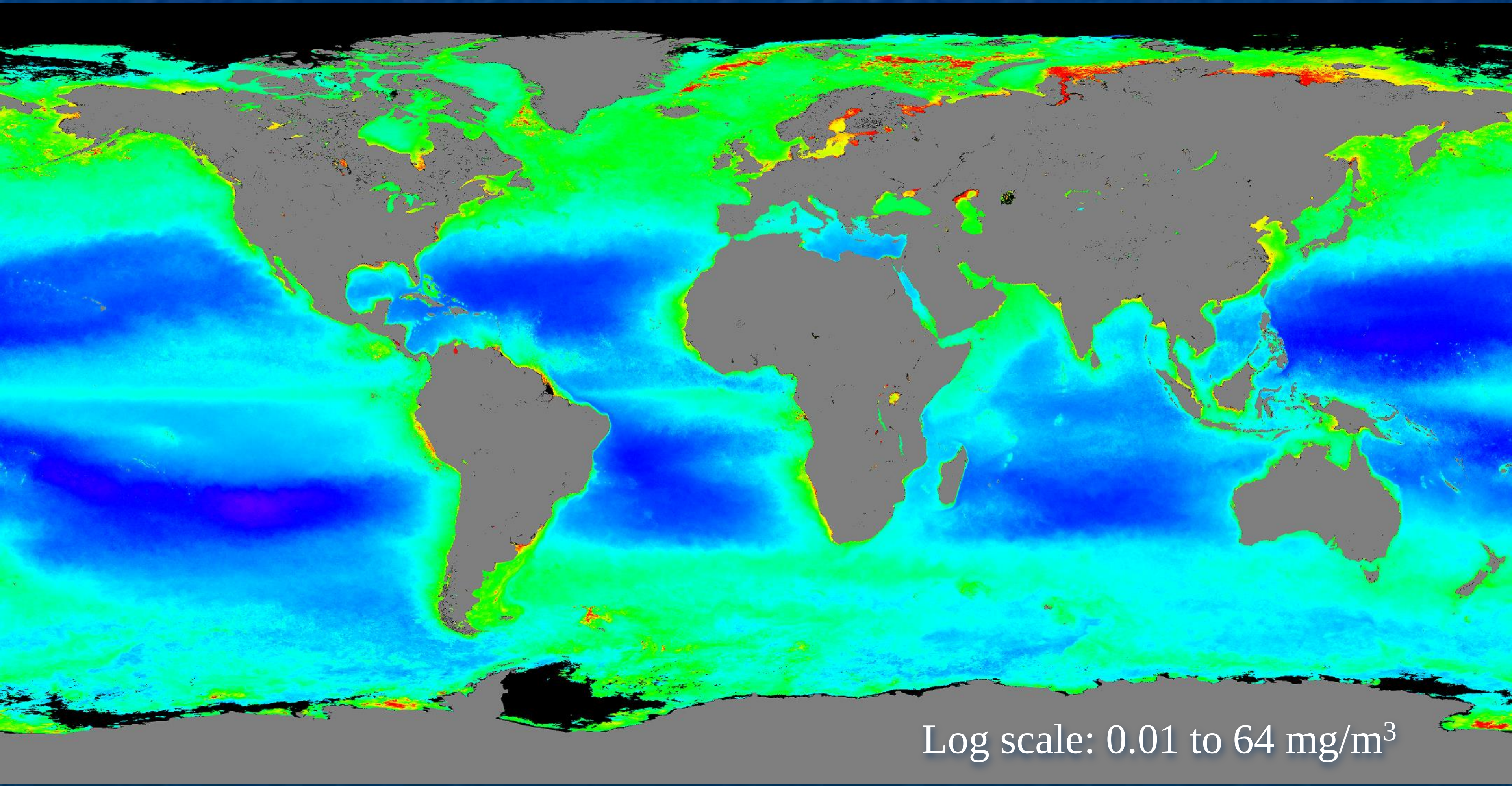
IOCCG, 2014 (Courtesy Venetia Stuart)

Ocean Color Radiometry Sensors: Past, Present and Future



IOCCG, 2014 (Courtesy Venetia Stuart)

VIIRS Climatology Chlorophyll-a Image
(Feb. 2012 to Sep. 2013)



Generated from VIIRS IDPS Ocean Color EDR

VIIRS Spectral Bands for Ocean Color

VIIRS on Suomi NPP has Ocean and SWIR spectral bands similar to **MODIS**

VIIRS		MODIS		SeaWiFS
Ocean Bands (nm)	Other Bands (nm)	Ocean Bands (nm)	Other Bands (nm)	Ocean Band (nm)
412 (M1)	640 (I1)	412	645	412
445 (M2)	865 (I2)	443	859	443
488 (M3)	1610 (I3)	488	469	490
—		531	555	510
555 (M4)	*SWIR Bands*	551	*SWIR Bands*	555
672 (M5)	1240 (M8)	667	1240	670
746 (M6)	1610 (M10)	748	1640	765
865 (M7)	2250 (M11)	869	2130	865

Spatial resolution for VIIRS M-band: 750 m, I-band: 375 m

Summary of VIIRS OCC EDR Algorithms

- **Inputs**: VIIRS M1-M7 bands SDR data, terrain-corrected geo-location file, SST EDR data (not used for current OC3V chlorophyll-a algorithm), cloud mask Intermediate Product (IP), on-board calibrator IP, 7 ancillary data files, 7 lookup tables, and 1 configurable parameter file.

- **Outputs**: Chlorophyll-a (Chl-a) concentration, normalized water-leaving radiance (nLw's) at bands M1-M5, Inherent Optical Properties (IOP-a and IOP-s) at VIIRS bands M1-M5, and quality flags. Primary outputs are chlorophyll-a and normalized water-leaving radiances.

- There are three sets of algorithms in the IDPS OCC-EDR data processing:
  - The Gordon & Wang (1994) atmospheric correction algorithm: including corrections for ozone, Rayleigh (molecules) and aerosols, ocean surface reflection, sun glint, whitecap, and sensor polarization effects.
  - chlorophyll-a algorithm: currently with OC3V algorithm (heritage algorithm), with option to switch between the OC3V and Carder chlorophyll-a algorithms.
  - IOP algorithm: Carder IOP algorithm (*QAA presently being evaluated for potential implementation*).

➢ Data quality of OC EDR are extremely sensitive to the SDR quality. It requires ~0.1% data accuracy (degradation, band-to-band accuracy…)!

NPP EDR Product Maturity Levels

1. Beta

- Early release product
- Minimally validated
- May still contain significant errors.
- Versioning not established until a baseline is determined.
- Available to allow users to gain familiarity with data formats and parameters
- Product is not appropriate as the basis for quantitative scientific publications studies and applications

2. Provisional

- Product quality may not be optimal
- Incremental product improvements are still occurring.
- Version control is in affect
- General research community is encouraged to participate in the QA and validation of the product, but need to be aware that product validation and QA are ongoing
- Users are urged to consult the EDR product status document prior to use of the data in publications
- May be replaced in the archive when the validated product becomes available
- Ready for operational evaluation

3. Validated

- Product performance is well defined over a range of representative conditions
- Ready for use by the Centrals and in scientific publications
- There may be later improved versions
- There are three validation stages (see next column)

Stage 1 Validation: Product performance has been demonstrated to comply with the specification using a small number of independent measurements obtained from selected locations, periods, and associated ground-truth/field program efforts.

Stage 2 Validation: Product performance has been demonstrated to comply with the specification over a widely distributed set of locations and periods via several ground-truth and validation efforts.

Stage 3 Validation: Product performance has been demonstrated to comply with the specification and the uncertainties in the product well established via independent measurements in a systematic and statistically robust way representing global conditions.

VIIRS Ocean Color EDR:

⇒ Beta status declared January 2013

⇒ Provisional status declared January 2014

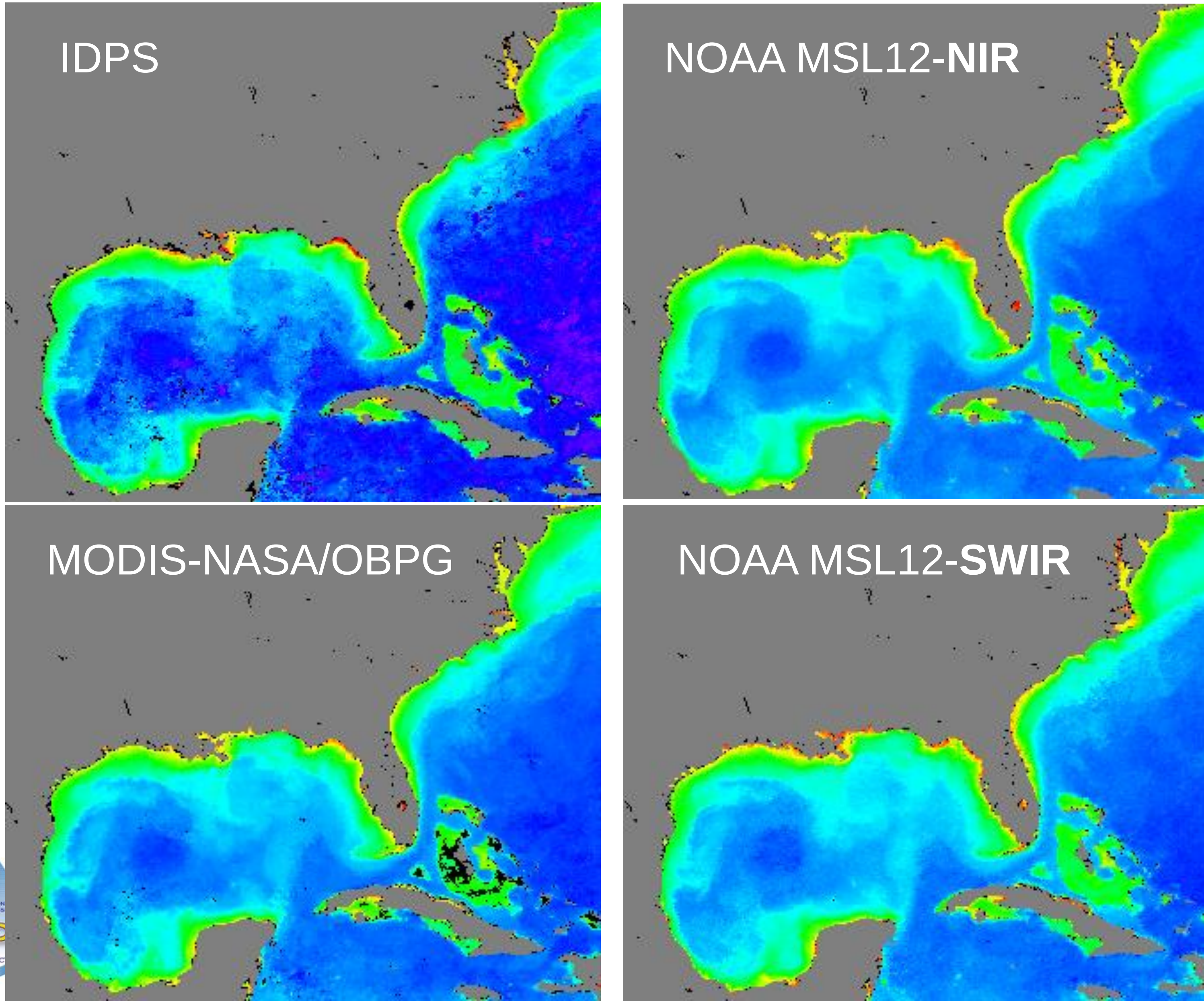
JPSS EDR Provisional Maturity Definition

- Product quality may not be optimal
  - Product accuracy is determined for a broader (but still limited) set of conditions.
  - No requirement to demonstrate compliance with specifications.
- Incremental product improvements still occurring
- General research community is encouraged to participate in the QA and validation of the product, but need to be aware that product validation and QA are ongoing
- Users are urged to consult the EDR product status document prior to use of the data in publications
- Ready for operational evaluation (but some calibration et al. issues still to resolve….)

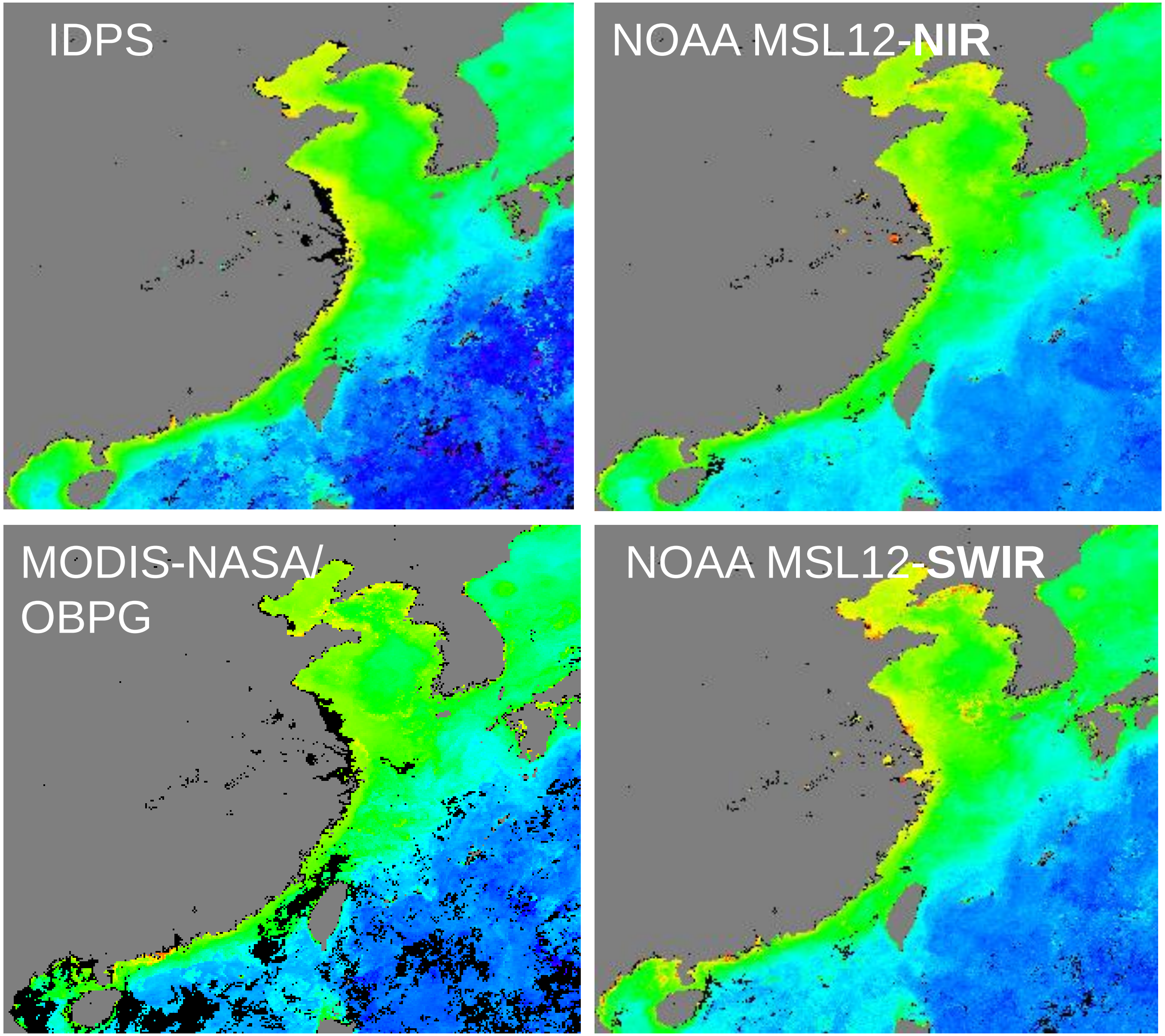
Multi-Sensor Level-1 to Level-2 (MSL12) Ocean Color Data Processing

- Multi-Sensor Level-1 to Level-2 (MSL12)
  - ✓ MSL12 was developed by *Wang and Franz* (2000) during NASA SMIBIOS project (1997-2003) for a consistent multi-sensor ocean color data processing.
  - ✓ It has been used for producing ocean color products from various satellite ocean color sensors, e.g., SeaWiFS, MOS, OCTS, POLDER, MODIS, etc.
- NOAA-MSL12 Ocean Color Data Processing
  - ✓ NOAA-MSL12 is based on SeaDAS version 4.6.
  - ✓ Some significant improvements: (1) the SWIR-based data processing, (2) improved Rayleigh and aerosol LUTs, (3) algorithms for detecting absorbing aerosols and turbid waters, (4) ice detection algorithm, (5) improved straylight and cloud shadow algorithm, (6) improved K_d(490) data, and other new products.
- NOAA-MSL12 for Multi-Sensor Ocean Color Data Processing
  - ✓ Routine global **VIIRS** ocean color data processing for Level-2 and Level-3 products.
  - ✓ Coastal turbid and inland waters from other approaches, e.g., **SWIR approach**, results in the US east coastal, Chesapeake Bay, China's east coastal, Lake Taihu, Lake Okeechobee, **Great Lakes**, Aral Sea, etc.
  - ✓ Capability for multi-sensor ocean color data processing, e.g., MODIS-Aqua, VIIRS, GOCI, and will also add OLCI/Stentinel-3 and SGLI/GCOM-C data processing capability.

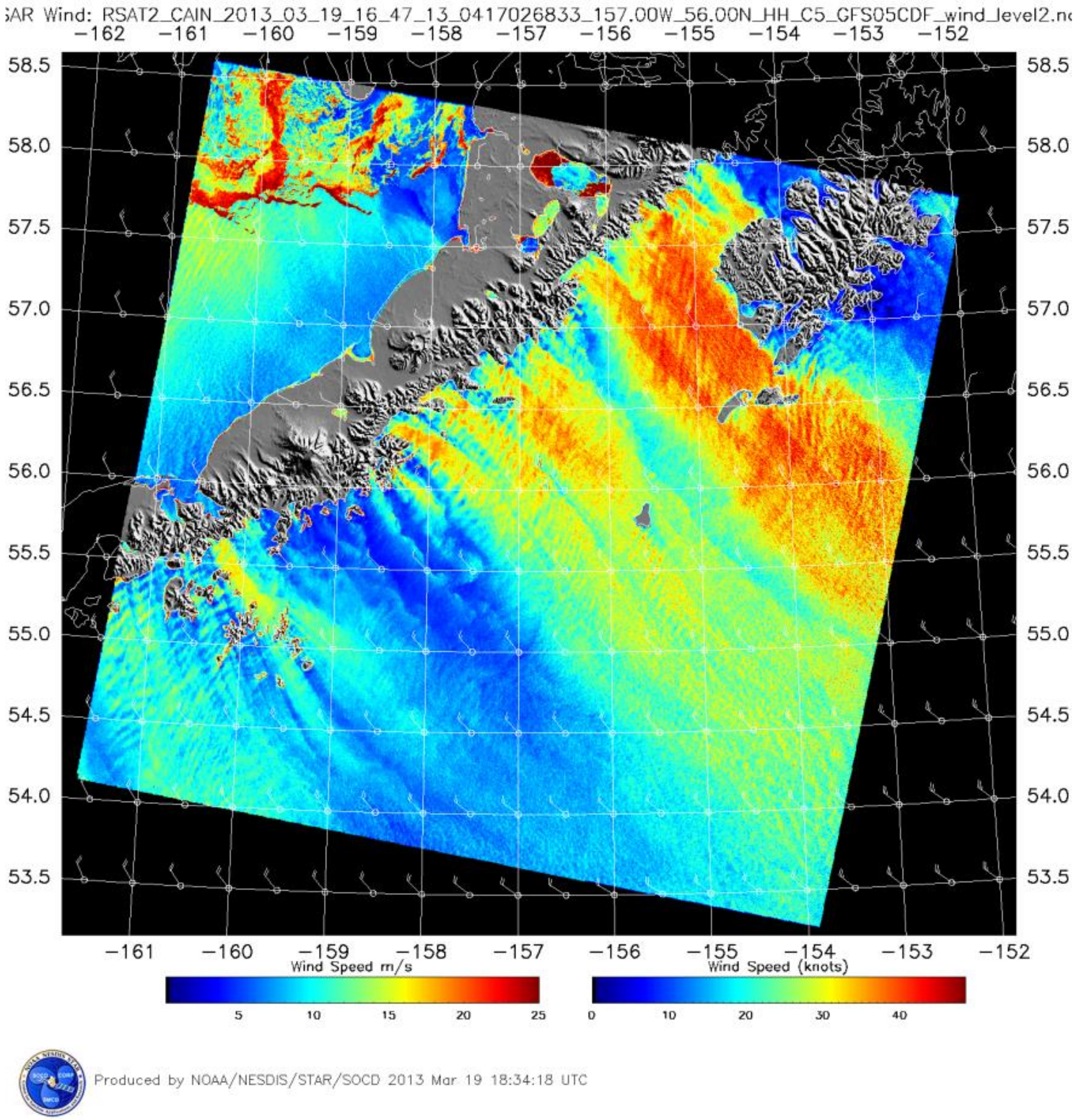
Performance in Coastal and Inland Waters (1)
(US East Coast—October 2013 Monthly)



Performance in Coastal and Inland Waters (2)
(China East Coast—October 2013 Monthly)



Synthetic Aperture Radar (SAR)
High-resolution Coastal Winds Product



Superstructure Icing

SAR-derived Wind Image – Alaska Peninsula 3/19/2013, 16:47 UT, RADARSAT-2.

Original SAR image © MDA, 2013. Winds processed for the National Ice Center by NOAA/NESDIS

Addressing Coastal User Data and Information Needs

- In response to user requests, satellite data & products are initially generated by NOAA/NESDIS on an experimental basis, and as appropriate, ultimately transitioned into operations

- Data sets include: ocean color, SST, winds, SAR et al. derived products

- Coverage is regional (e.g., Great Lakes) through global

- Distribution mechanisms include:
  - NOAA CoastWatch http://coastwatch.noaa.gov/
  - CoastWatch Great Lakes Regional Node http://coastwatch.glerl.noaa.gov/
  - NOAA CLASS (NPP mission repository) http://www.class.noaa.gov

NOAA's Consolidated Observation Requirements List (CORL)

CORL Requirements with Great Lakes Geo Coverage

Survey Title	Line Office	Priority	Validation Complete (Yes/No)	Geographic Coverage	Vertical Resolution	Horizontal Resolution	Measurement Accuracy	Sampling Interval	Data Latency	Number of DAS/Flt Hrs/HODs
Buoy/Platform Support										
ST-OAR_PMEL - Maintain Observing Systems and Produce Key Data Sets, Ocean Reference Stations - KEO/Kuroshio Extension Observatory	OAR	1	Yes	Great Lakes				1 yr		5 DAS
Ecosystems Characterization										
ST-OAR_GLERL - Region 4: Ecosystem Charecterization, Coastal and Great Lakes - Integrative Regional Assessments (Coastal Ecosystem, Great Lakes Waters Condition, NMSs)	OAR	1	Yes	Great Lakes				1 yr		117 DAS
ST-OAR_Sea Grant - Region 4: Ecosystem Characterization, GREAT LAKES, Sea Grant Research to Characterize Coastal, Ocean, and Great Lakes Ecosystem to support ecosystem management	OAR	1	Yes	Great Lakes				1 yr		77 DAS
Harmful Algal Bloom										
RC-NCCOS_CSCOR - HAB Forecasting: WC, AK & GL Lakes (Alternating 45 DAS over 3 yrs, one Geo Cov area/yr) (Great Lakes)	NOS	1	Yes	Great Lakes				1 yr		45 DAS
RC-NCCOS_CSCOR - HAB Forecasting: WC, AK & GL Lakes_Small Boats (Alternating 30 DAS over 3 yrs, one Geo Cov area/yr) (Great Lakes)	NOS	1	Yes	Great Lakes				1 yr		30 DAS
ST-OAR_GLERL - Region 4: Forecasting and Modeling Ecosystem Events - Ecology and Oceanography of Harmful Algal Blooms	OAR	1	Yes	Great Lakes				1 yr		39 DAS

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Ice Depth/Thickness										
RC-NIC - Lake Ice: Thickness, Local	NESDIS	1	Yes	Great Lakes	na	50 m	30 cm	3 hr	1 hr	na
ST-OAR_GLERL - Ice Thickness	OAR	R3	Yes	Great Lakes	tbd	antenna dependent	2 cm			tbs Flt Hrs
Ocean Color/Chlorophyll Concentration										
RC-NCCOS - HAB forecasting - GL (1) - Chlorophyll Concentration	NOS	1	No	Great Lakes	na	300 m	30 %	1 day	1 day	na
RC-NCCOS - HAB forecasting - GL (1) - water reflectance (ocean color)	NOS	1	No	Great Lakes	na	300 m	1 %	1 day	1 day	na
ST-OAR_GLERL - Mapping, forecasting Great Lakes HABs: blue-green algae	OAR	R3	Yes	Great Lakes		tbd				tbs Flt Hrs
ST-OAR_GLERL - Mapping, forecasting Great Lakes HABs: chlorophyll	OAR	R3	Yes	Great Lakes		tbd				tbs Flt Hrs
ST-OAR_GLERL - Mapping, forecasting Great Lakes HABs: phycocyanin	OAR	R3	Yes	Great Lakes		tbd				tbs Flt Hrs
Teleconnections										
ST-OAR_GLERL - Region 4: Forecasting and Modeling Ecosystem Events - Ecological Forecasting	OAR	1	Yes	Great Lakes				1 yr		39 DAS
ST-OAR_GLERL - Region 4: Forecasting and Modeling Ecosystem Events, Forecasting and Modeling Ecosystem Events - Cumulative Impacts of Multiple Stressors	OAR	1	Yes	Great Lakes				1 yr		35 DAS

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CORL Requirements with Great Lakes Geo Coverage

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ST-OAR_GLERL - Mapping, forecasting Great Lakes HABs: chlorophyll	OAR	R3	Yes	Great Lakes		tbd				tbs Flt Hrs
ST-OAR_GLERL - Mapping, forecasting Great Lakes HABs: phycocyanin	OAR	R3	Yes	Great Lakes		tbd				tbs Flt Hrs
Teleconnections										
ST-OAR_GLERL - Region 4: Forecasting and Modeling Ecosystem Events - Ecological Forecasting	OAR	1	Yes	Great Lakes				1 yr		39 DAS
ST-OAR_GLERL - Region 4: Forecasting and Modeling Ecosystem Events, Forecasting and Modeling Ecosystem Events - Cumulative Impacts of Multiple Stressors	OAR	1	Yes	Great Lakes				1 yr		35 DAS

SENTINEL-3 Satellite

Operational mission in high-inclination, low earth orbit

- **Ocean and Land Colour Instrument (OLCI):**
  - 5 cameras, spectral range from 400 to 1020 nm
  - 15 (MERIS) & 6 additional bands; Swath: 1270 km
  - Camera tilt in west direction (12.20°)
  - Full res. 300m acquired systematically (land/ocean)
  - Reduced res. 1200m binned on ground (L1b)
  - Ocean coverage < 4 days, (< 2 days, 2 satellites)
  - 100% overlap with SLSTR

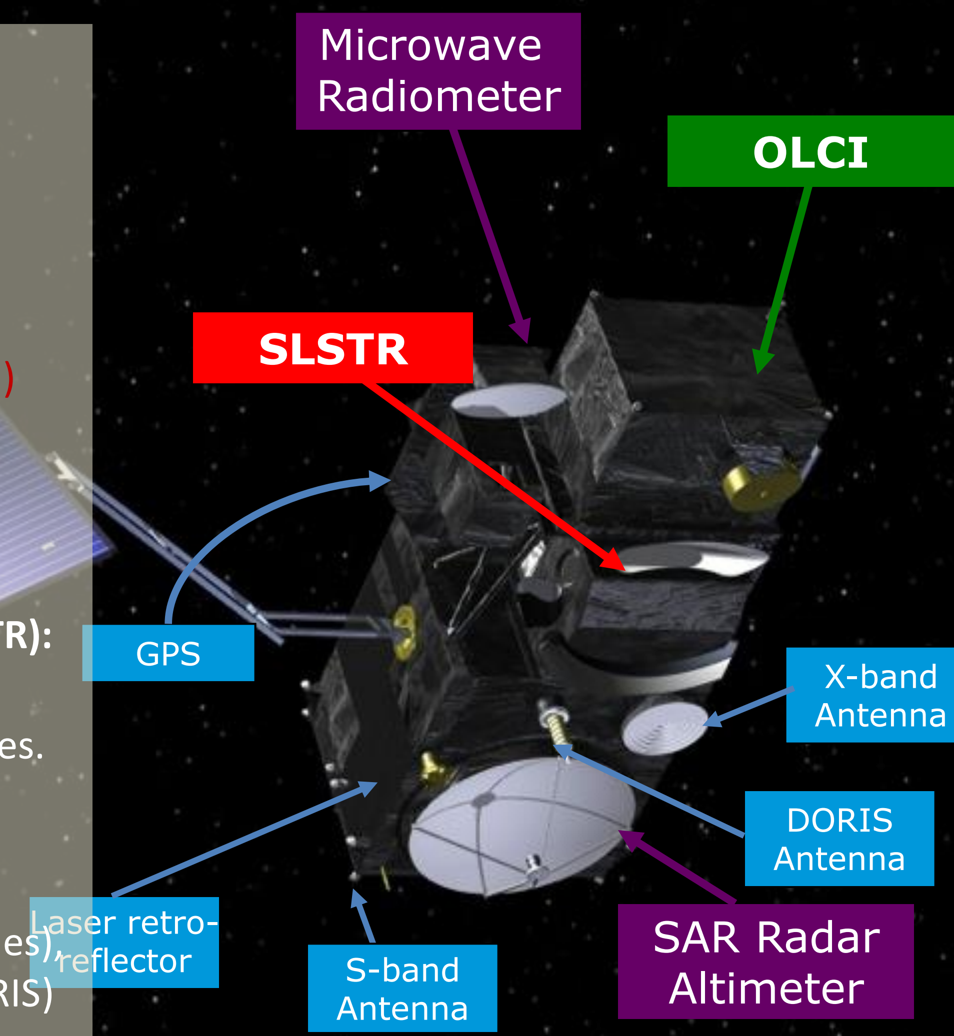
- **Sea & Land Surface Temperature Radiometer (SLSTR):**

  7 AATSR & 2 additional bands, plus 2 additional Fire channels, with 500 m (solar) and 1 km (TIR) ground res. Swath: 1420 km/750 km (single or dual view)

- **Topography package:**

  SRAL Ku-C altimeter (LRM & SAR measurement modes), MWR, POD (with Laser Retro Reflector, GPS and DORIS)

Full performance will be achieved with 2 satellites in orbit



Courtesy: P. Regner/ESA

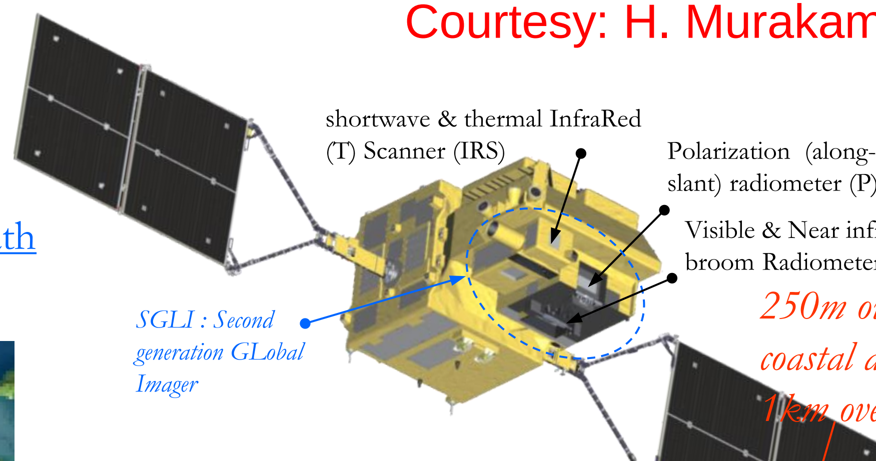
GCOM-C1/ SGLI

Courtesy: H. Murakami/JAXA

Improvement of the land, coastal, and aerosol observations

✓ 250m spatial resolution with 1150~1400km swath

✓ Polarization/along-track slant view



250m over land and coastal areas, and 1km over offshore

SGLI/VNR daily coverage

250m resolution

GCOM-C SGLI characteristics	
Orbit	Sun-synchronous (descending local time: 10:30), Altitude: 798km, Inclination: 98.6deg
Launch Date	**JFY 2016**
Mission Life	5 years (3 satellites; total 13 years)
Scan	Push-broom electric scan (VNR: VN & P) Wisk-broom mechanical scan (IRS: SW & T)
Scan width	1150km cross track (VNR: VN & P) 1400km cross track (IRS: SW & T)
Digitalization	12bit
Polarization	3 polarization angles for POL
Along track tilt	Nadir for VN, SW and TIR, & +/-45 deg for P
On-board calibration	VN: Solar diffuser, Internal lamp (LED, halogen), Lunar by pitch maneuvers (~once/month), and dark current by masked pixels and nighttime obs. SW: Solar diffuser, Internal lamp, Lunar, and dark current by deep space window TIR: Black body and dark current by deep space window All: Electric calibration

Characteristics of SGLI spectral bands

CH	λ	$\Delta\lambda$	L_{std}	L_{max}	SNR@L_{std}	IFOV	Tilt
	nm		$W/m^2/sr/\mu m$ K: Kelvin		- K: NEΔT	m	deg
VN1	380	10	60	210	250	**250** /1000	0
VN2	412	10	75	250	400	**250** /1000	0
VN3	443	10	64	400	300	**250** /1000	0
VN4	490	10	53	120	400	**250** /1000	0
VN5	530	20	41	350	250	**250** /1000	0
VN6	565	20	33	90	400	**250** /1000	0
VN7	673.5	20	23	62	400	**250** /1000	0
VN8	673.5	20	25	210	250	**250** /1000	0
VN9	763	12	40	350	1200*	250 /**1000***	0
VN10	868.5	20	8	30	400	**250** /1000	0
VN11	868.5	20	30	300	200	**250** /1000	0
POL1	673.5	20	25	250	250	**1000**	±45
POL2	868.5	20	30	300	250	**1000**	±45
SW1	1050	20	57	248	500	**1000**	0
SW2	1380	20	8	103	150	**1000**	0
SW3	1630	200	3	50	57	**250** /1000	0
SW4	2210	50	1.9	20	211	**1000**	0
TIR1	10800	0.7	300K	340K	0.2K	250 /**500** /1000	0
TIR2	12000	0.7	300K	340K	0.2K	250 /**500** /1000	0

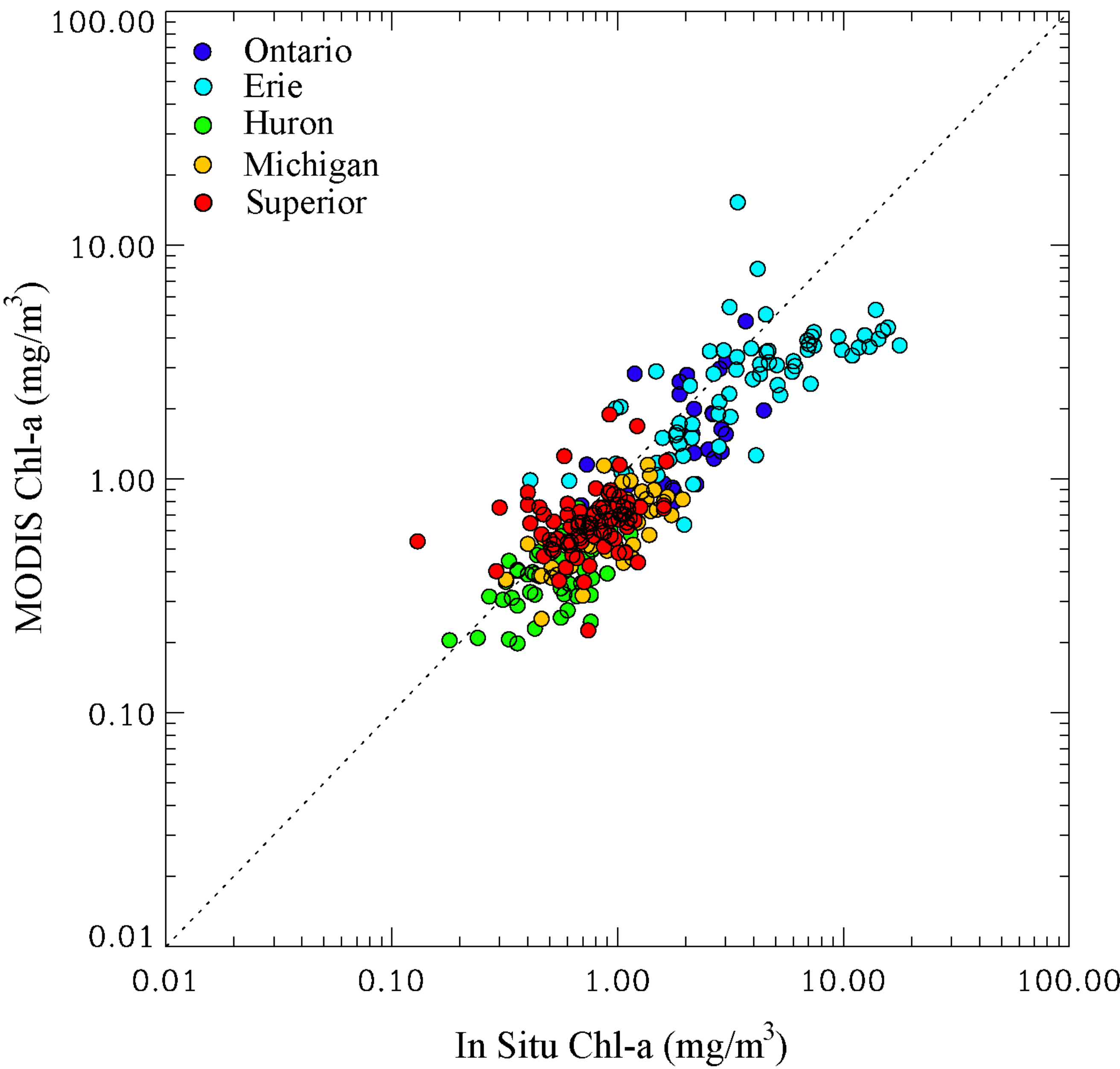
Multi-angle obs. for 674nm and 869nm

250m-mode possibility

- In situ chlorophyll-a (Chl-a) measurements are compared with the MODIS-derived Chl-a using the NASA OC-3 model measurements in Great Lakes.
- There is a good correlation between in situ and MODIS Chl-a data, but the standard MODIS Chl-a products are biased lower in Great Lakes.
- Developing regional Chl-a model for the Great Lakes

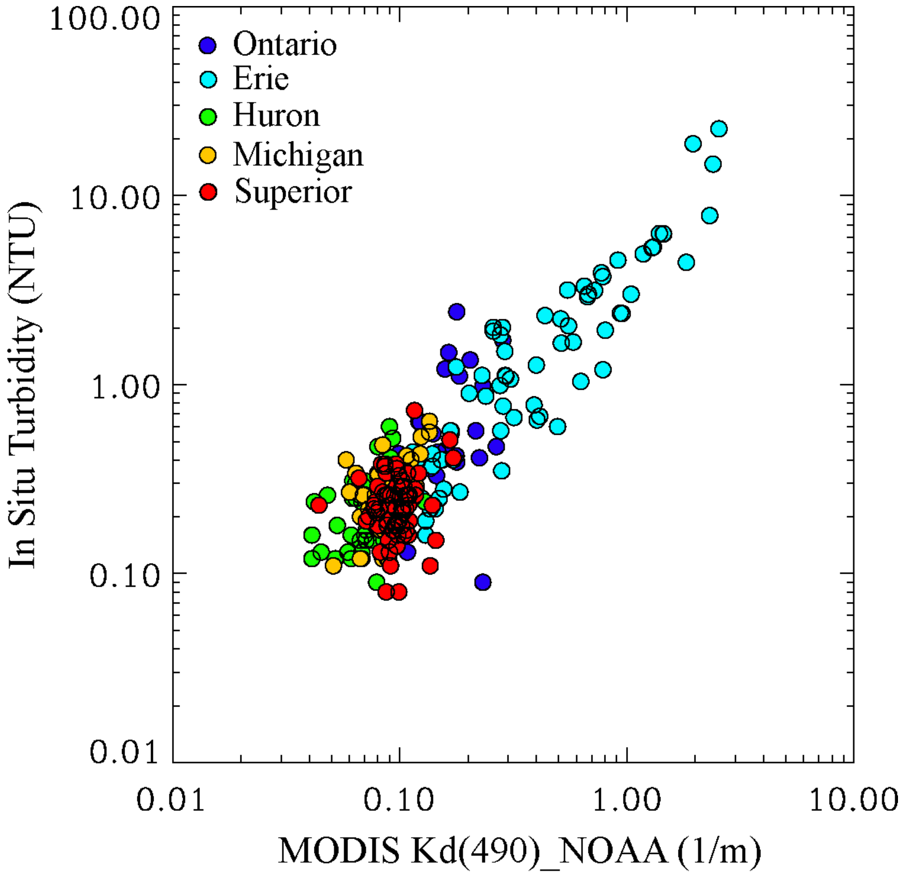
The NIR-SWIR Data Processing

(NOAA-MSL12)



MODIS-Aqua data being reprocessed for Great Lakes (Collection 6 L1B data)

Menghua Wang, NOAA/NESDIS/STAR

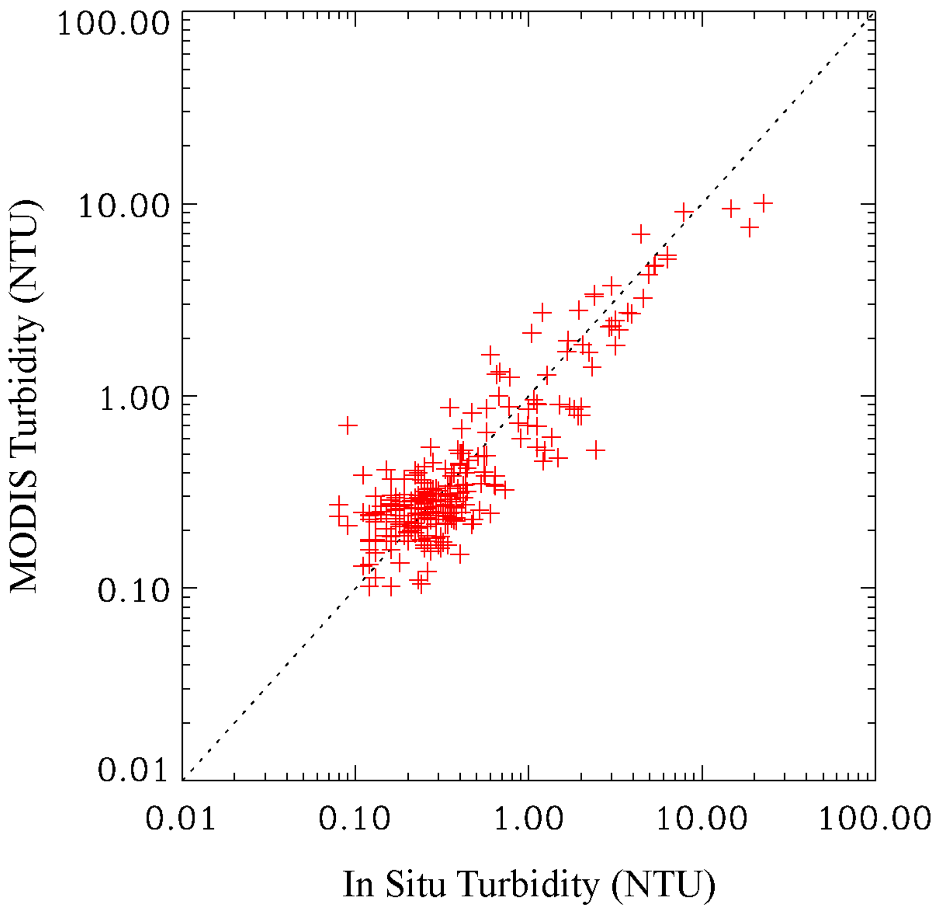


➢ In situ turbidity data are compared with MODIS-derived water diffuse attenuation coefficient at 490 nm, $K_d(490)$ using Wang et al. (2009) model.

➢ Water turbidity is well correlated to MODIS-derived $K_d(490)$ in Great Lakes.

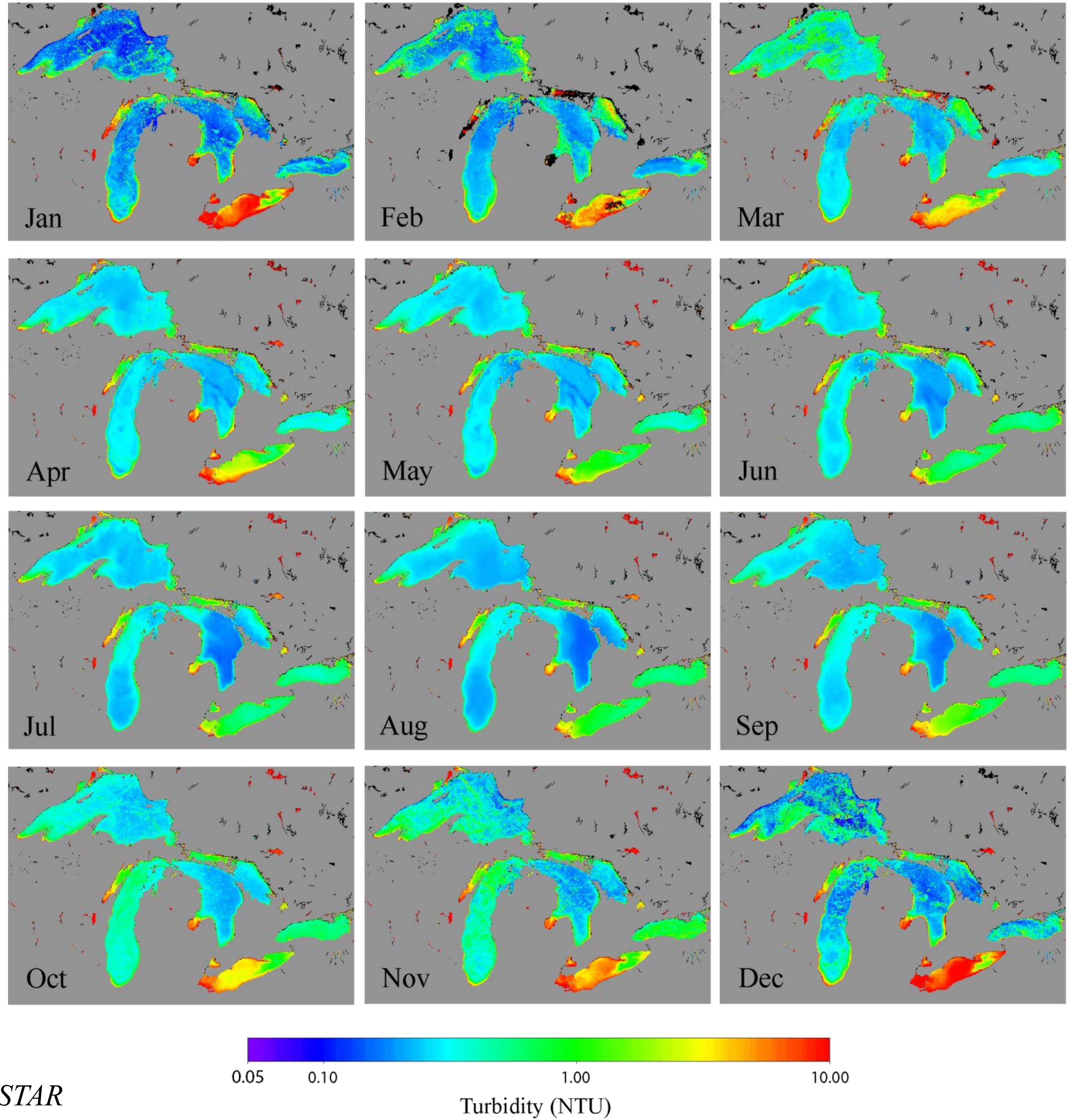
➢ Satellite turbidity (NTU) data were derived using the relationship between in situ turbidity and $K_d(490)$ data.

➢ MODIS-derived water turbidity (NTU) compared well with in situ data.



Menghua Wang, NOAA/NESDIS/STAR

MODIS-Aqua Climatology Monthly Turbidity (Great Lakes)



- MODIS-Aqua-measured seasonal climatology water turbidity (NTU) images in Great Lakes.
- Highly turbid waters in winter and in Lake Erie, somewhat turbid in Lake Ontario, and part of Lakes Huron, Michigan, etc.

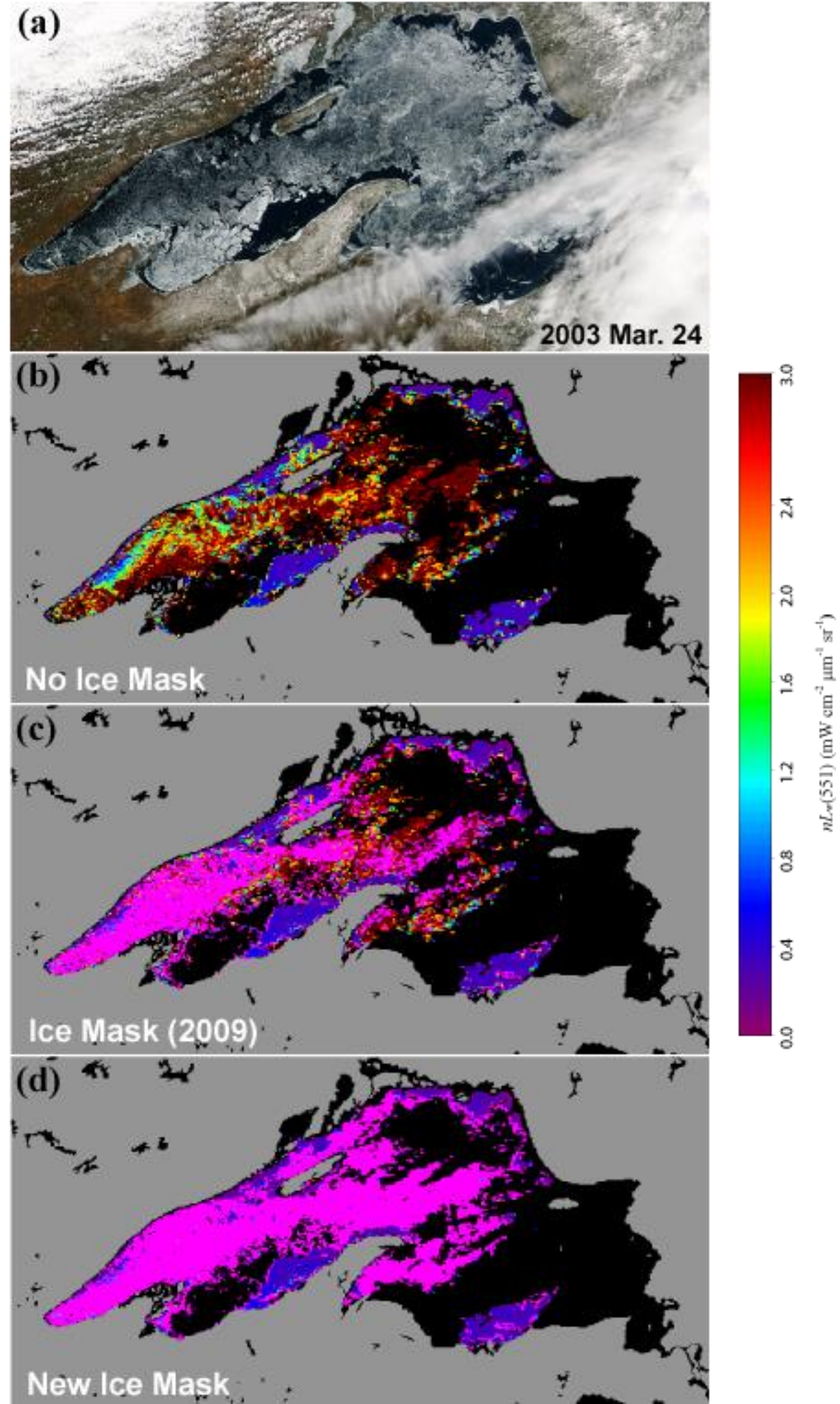
The NIR-SWIR Data Processing

(NOAA-MSL12)

Menghua Wang, NOAA/NESDIS/STAR

MODIS-Aqua-derived (a) true color image, and normalized water-leaving radiance at 551 nm, $nL_w(551)$ using (a) without an ice masking method, (b) with ice detection masking from *Wang and Shi* (2009) (pink), and (d) a new ice masking from a new method (pink) in the Great Lakes acquired on March 4, 2003.

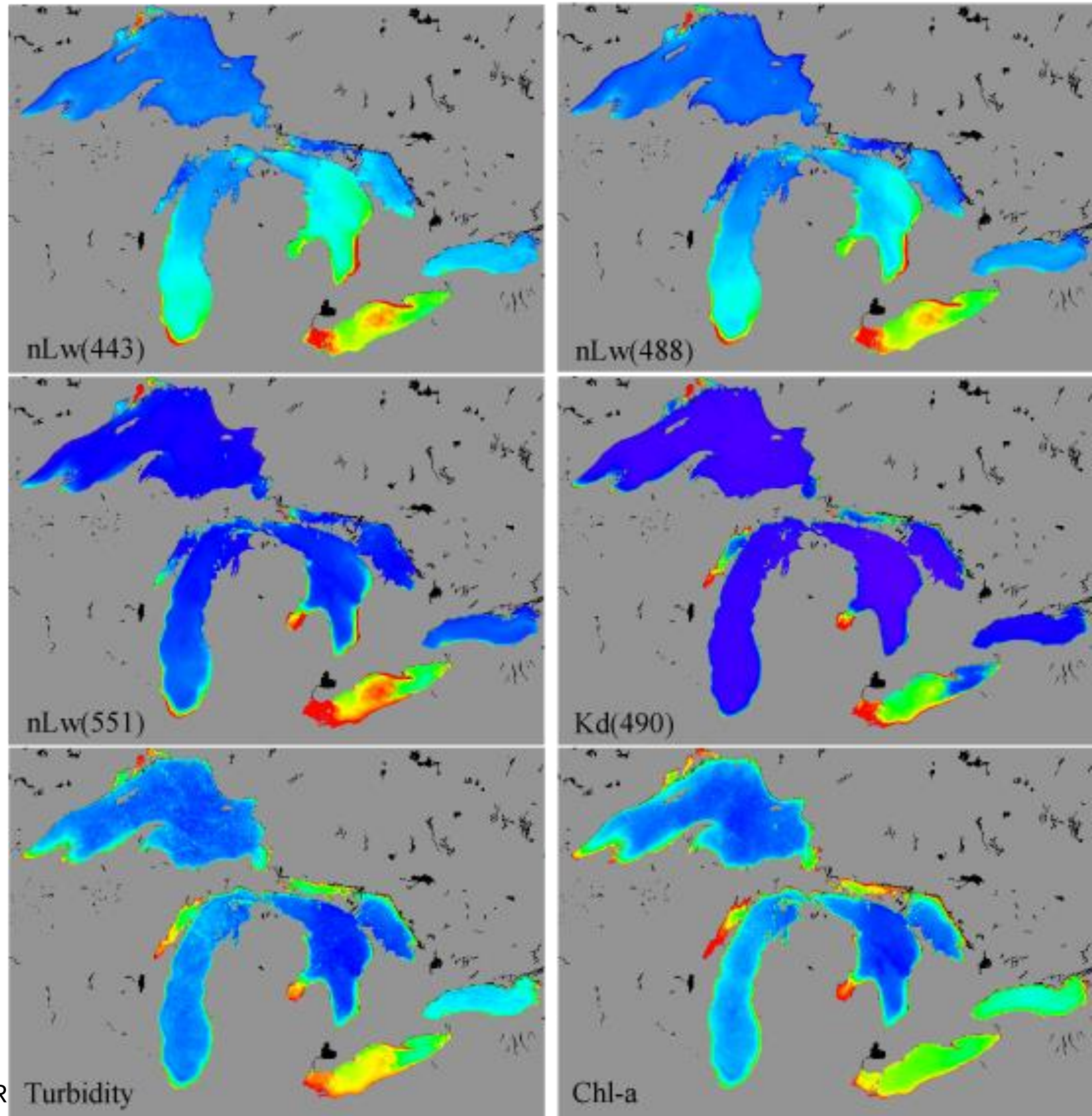
New method for ice masking



Menghua Wang, NOAA/NESDIS/STAR

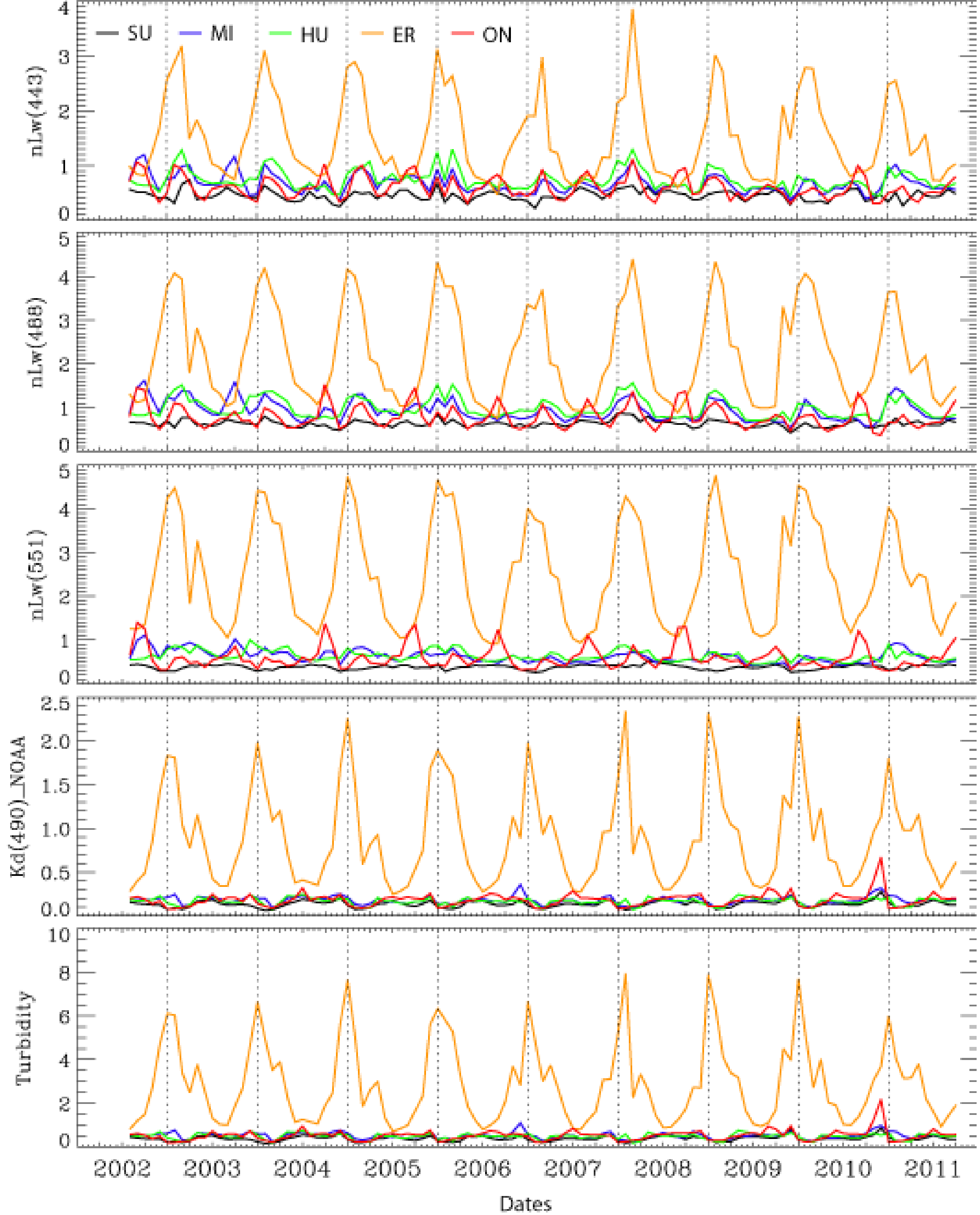
Climatology composite (July 2002 to Sep. 2011) images of the MODIS-Aqua-derived (a) $nL_w(443)$, (b) $nL_w(488)$, (c) $nL_w(551)$, (d) $K_d(490)$, (e) water turbidity, and (f) Chl-a using the NIR-SWIR atmospheric correction algorithm and the new ice detection method in the Great Lakes.

MODIS-Aqua Climatology (2002 Jul - 2011 Sep) Images

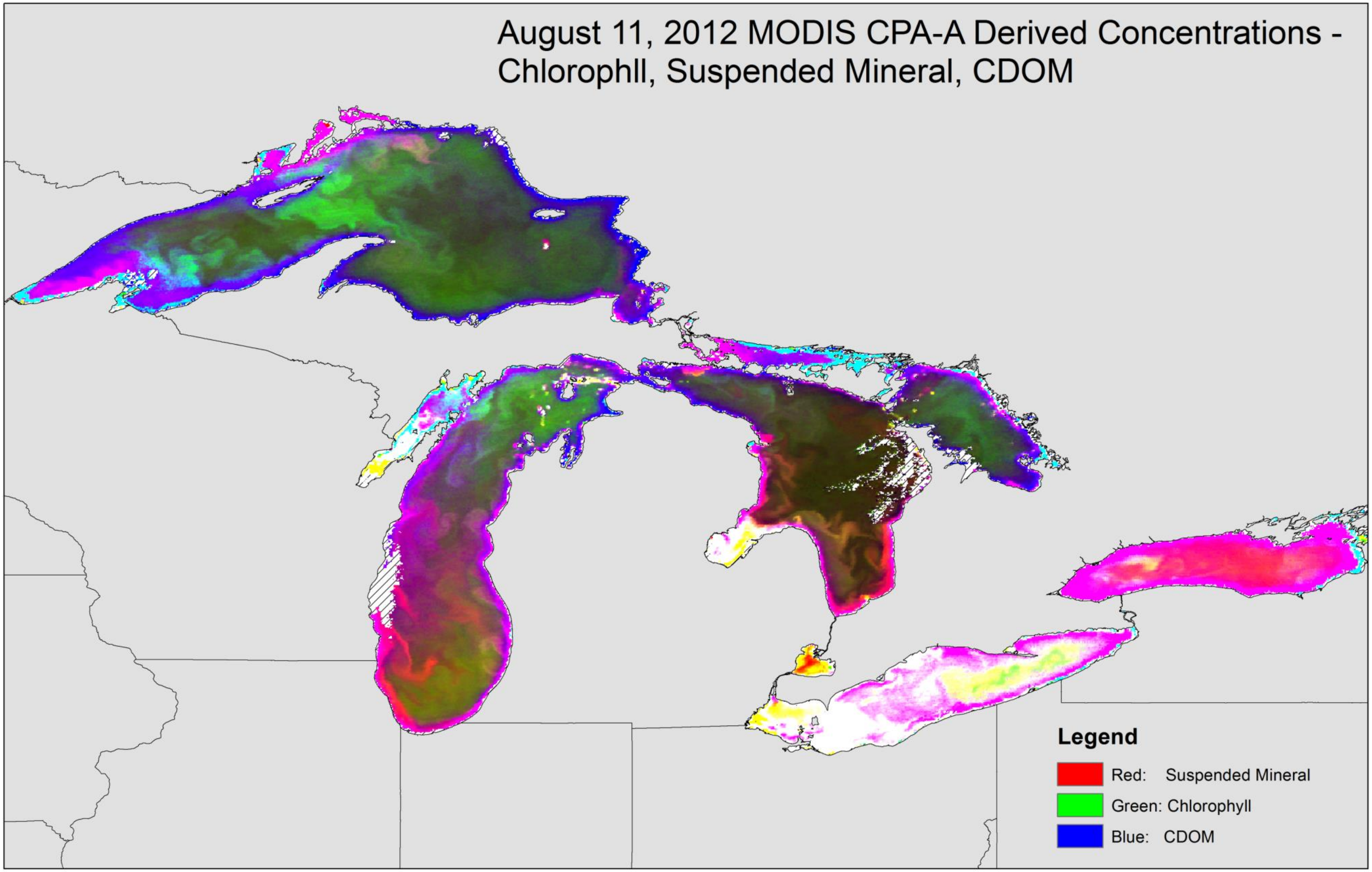


Menghua Wang, NOAA/NESDIS/STAR

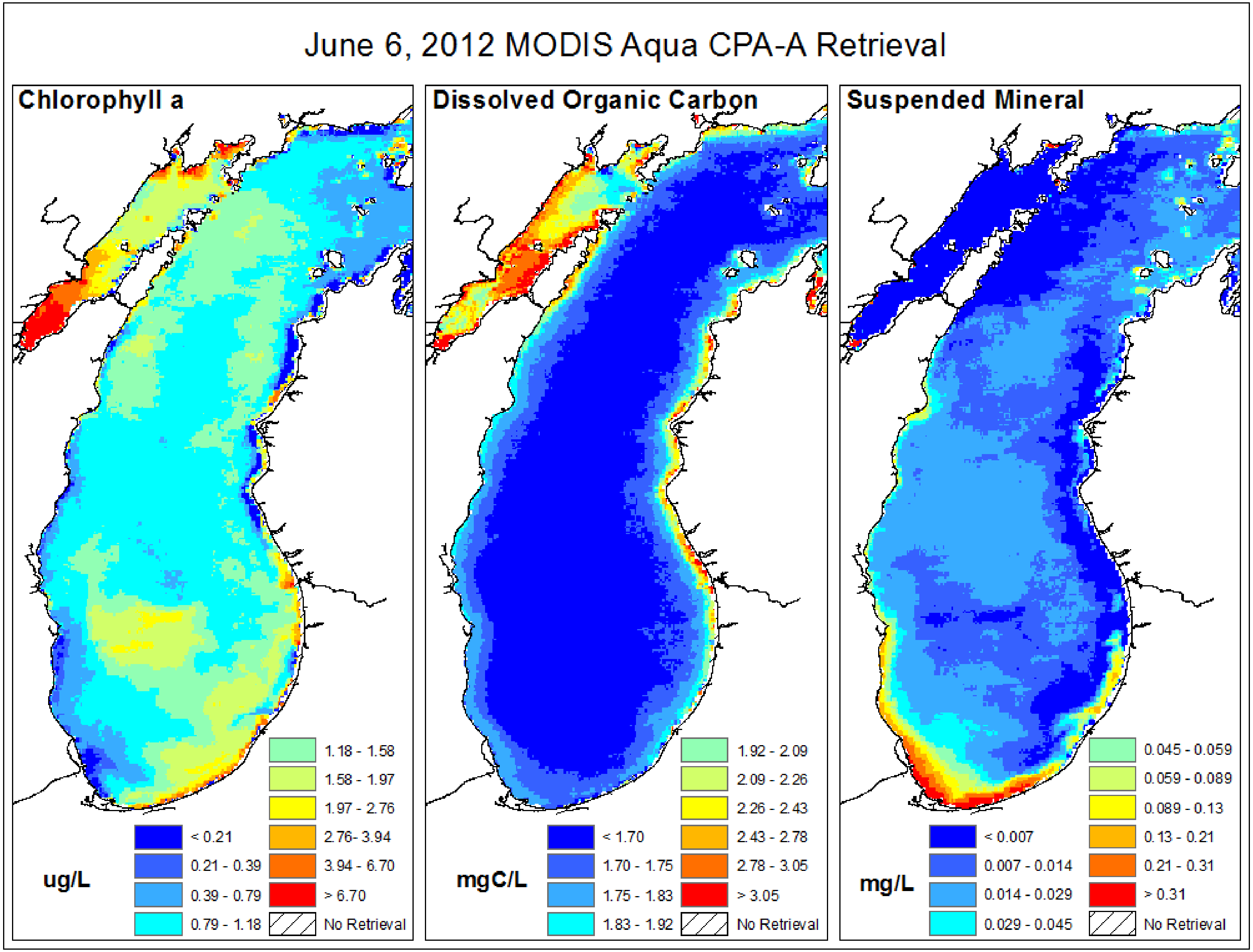
Time series of the MODIS-derived monthly composite images of $nL_w(443)$, $nL_w(488)$, $nL_w(551)$, $K_d(490)$, and water turbidity using the new ice detection method in the Lakes Superior, Michigan, Huron, Erie, and Ontario



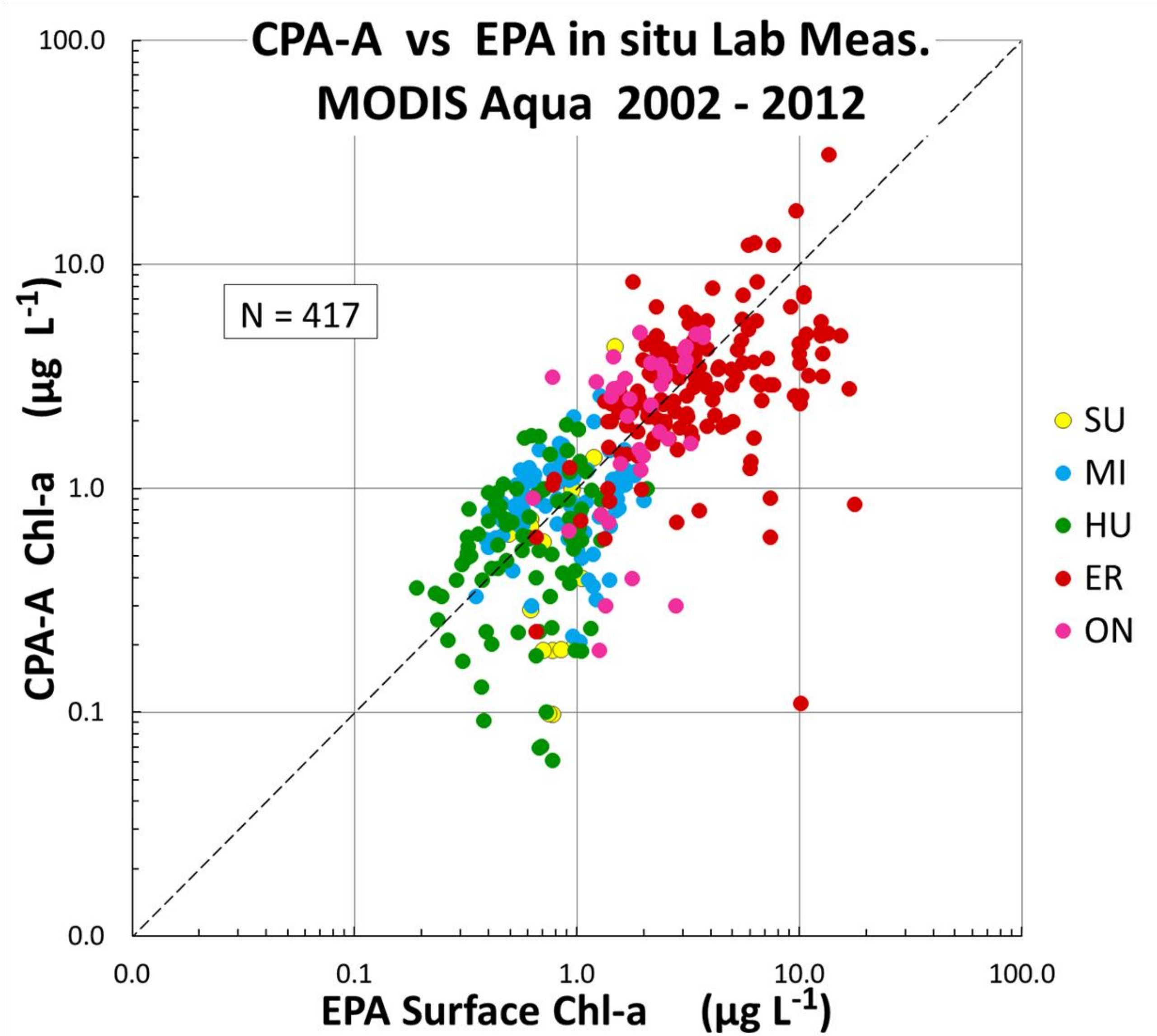
Menghua Wang, NOAA/NESDIS/STAR



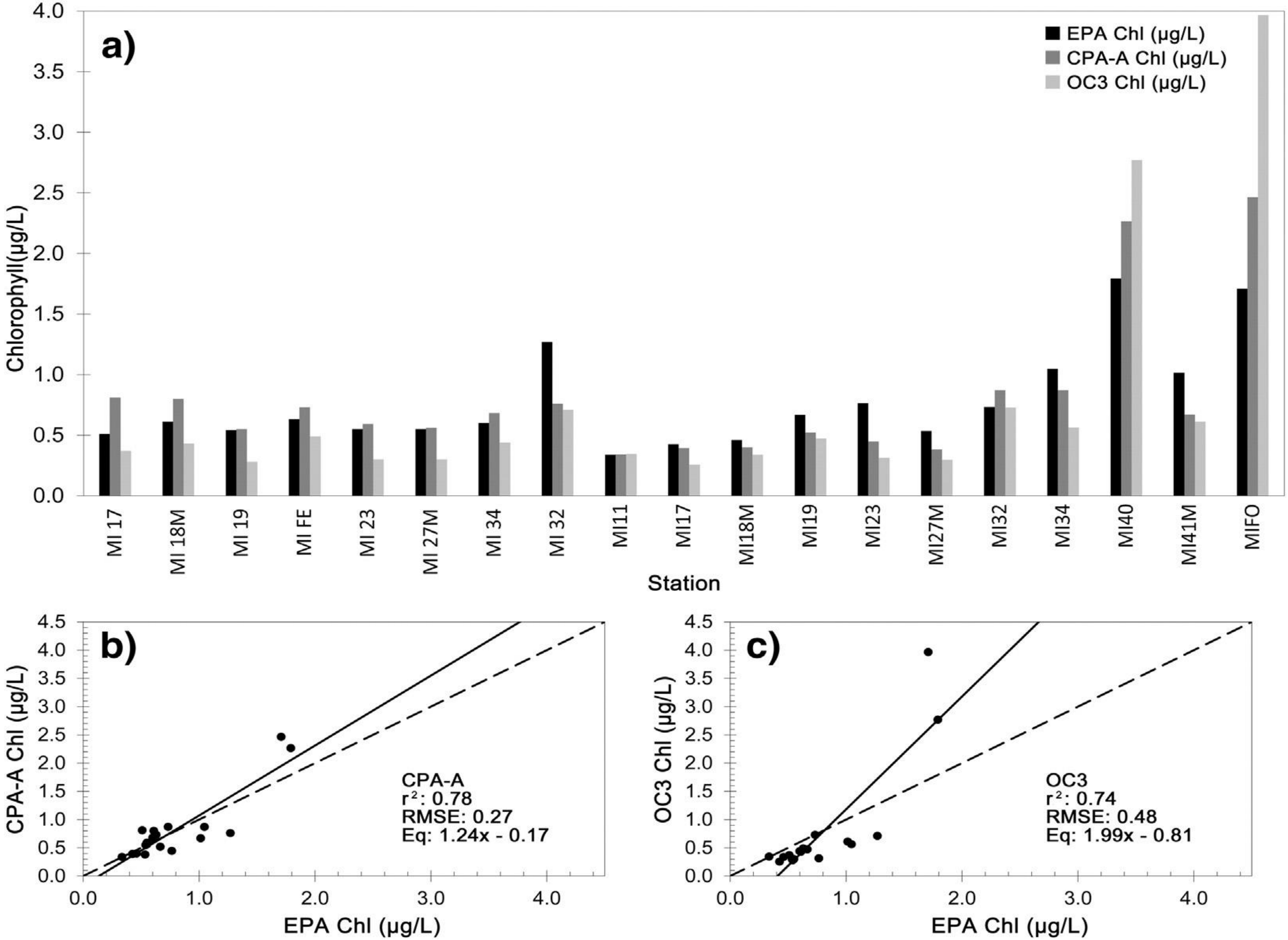
Courtesy: Shuchman, Leshkevich, Sayers et al.



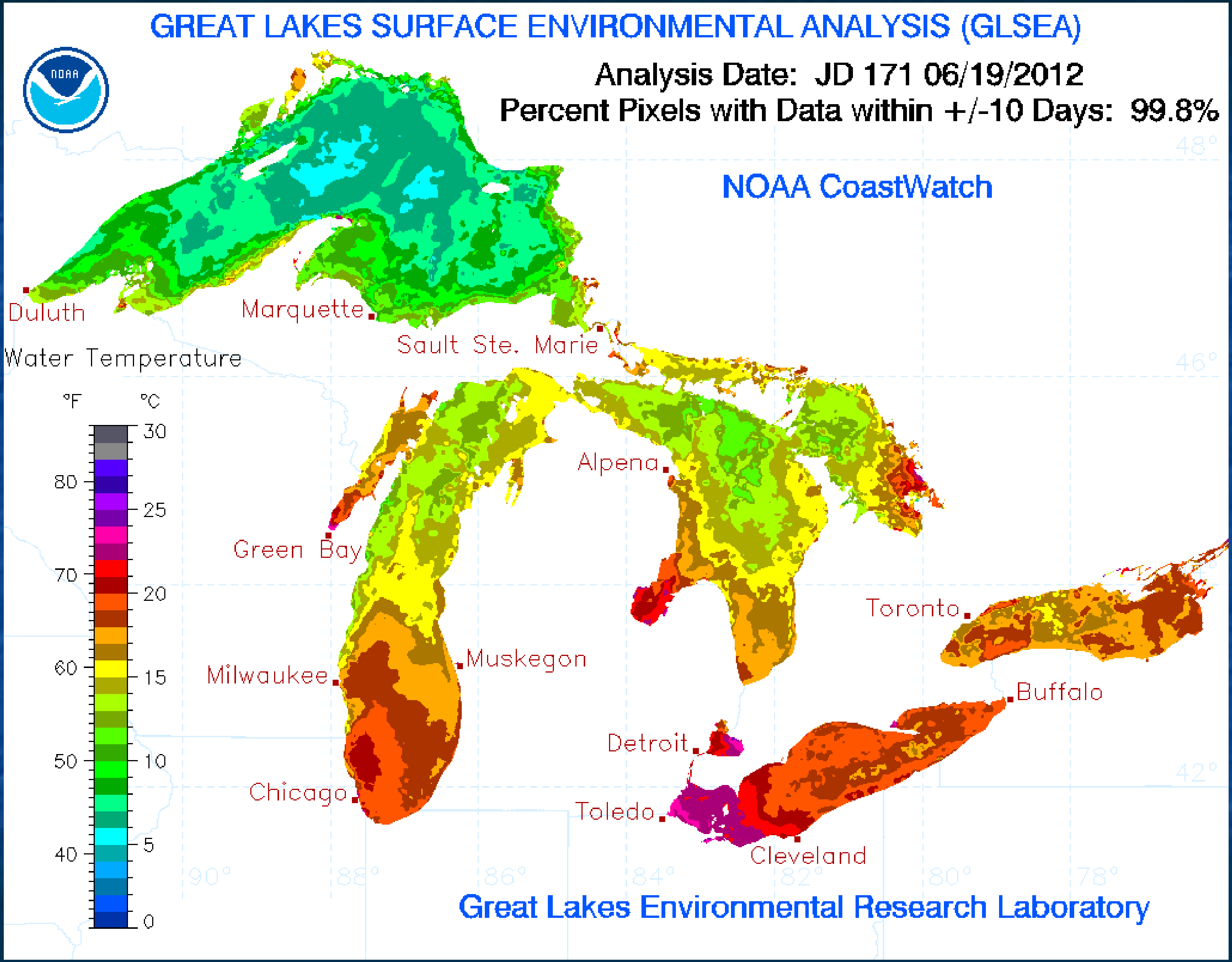
Courtesy: Shuchman, Leshkevich, Sayers et al.



Courtesy: Shuchman, Leshkevich, Sayers et al.



Courtesy: Shuchman, Leshkevich, Sayers et al.



http://coastwatch.glerl.noaa.gov/

Weekly Lake Erie Bulletin: MERIS 2009-2011

Experimental
Lake Erie Harmful Algal Bloom Bulletin
2011-008
08 September 2011
National Ocean Service
Great Lakes Environmental Research Laboratory
Last bulletin: 22 July 2011

Bloom from MERIS

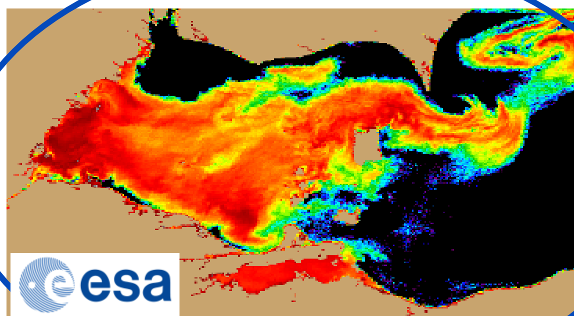


Figure 1. MERIS image from the European Space Agency. Imagery shows the spectral shape at 681 nm from September 03, where colored pixels indicate the likelihood of the last known position of the *Microcystis* spp. bloom (with red being the highest concentration). *Microcystis* spp. abundance data from shown as white squares (very high), circles (high), diamonds (medium), triangles (low) , + (very low) and X (not present).

Forecast (with Great Lakes CFS)

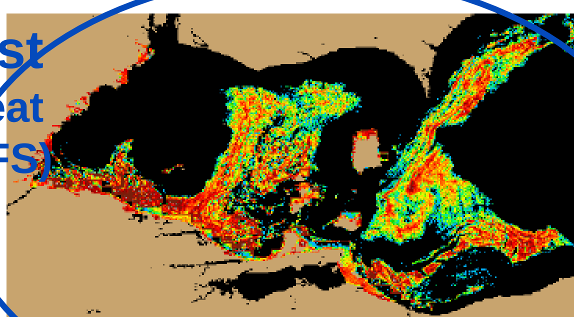


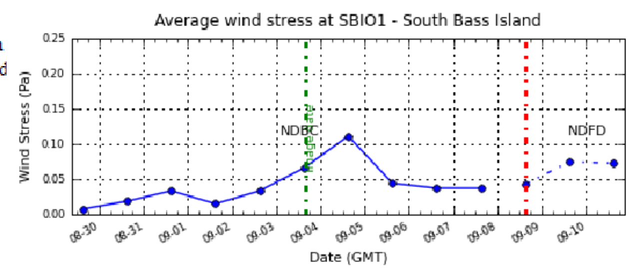
Figure 2. Nowcast position of *Microcystis* spp. bloom for September 08 using GLCFS modeled currents t move the bloom from the September 03 image.

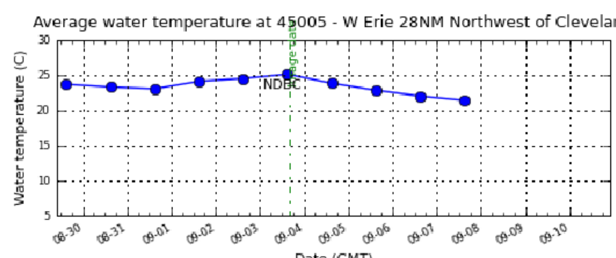
Conditions: A massive *Microcystis* bloom persists throughout most of Lake Erie's Western Basin.

Analysis: As indicated in satellite imagery from Saturday (9/3/2011), an enormous *Microcystis* bloom was present in western Lake Erie. The southern extent of the bloom was remotely observed along the coast of Ohio from Maumee Bay to Catawba Island. The northern extent of the bloom was observed to be consistent along the Michigan coast from Northern Maumee Bay to the mouth of the Detroit River. The eastern-most portion of the bloom was observed past Point Pelee and to the northeast up in to Rondeau Provincial Park.

At the mouth of the Detroit River, a five day nowcast shows a southward suppression of the western-most portions of the bloom. However, the bloom is likely to still persist in much of the Western Basin. The nowcast also suggest the bloom has spread to the east of Sandusky and into the Cleveland area. **(Note: Due to a lack of clear imagery the bloom has not been remotely observed in the Cleveland area.)** A three day forecast also suggests that the bloom will persist to the north of Cleveland through the weekend. Water temperatures remain above 20 degrees Celsius and are forecast to decrease into the weekend; however, conditions remain favorable for bloom growth.

Briggs, Wynne

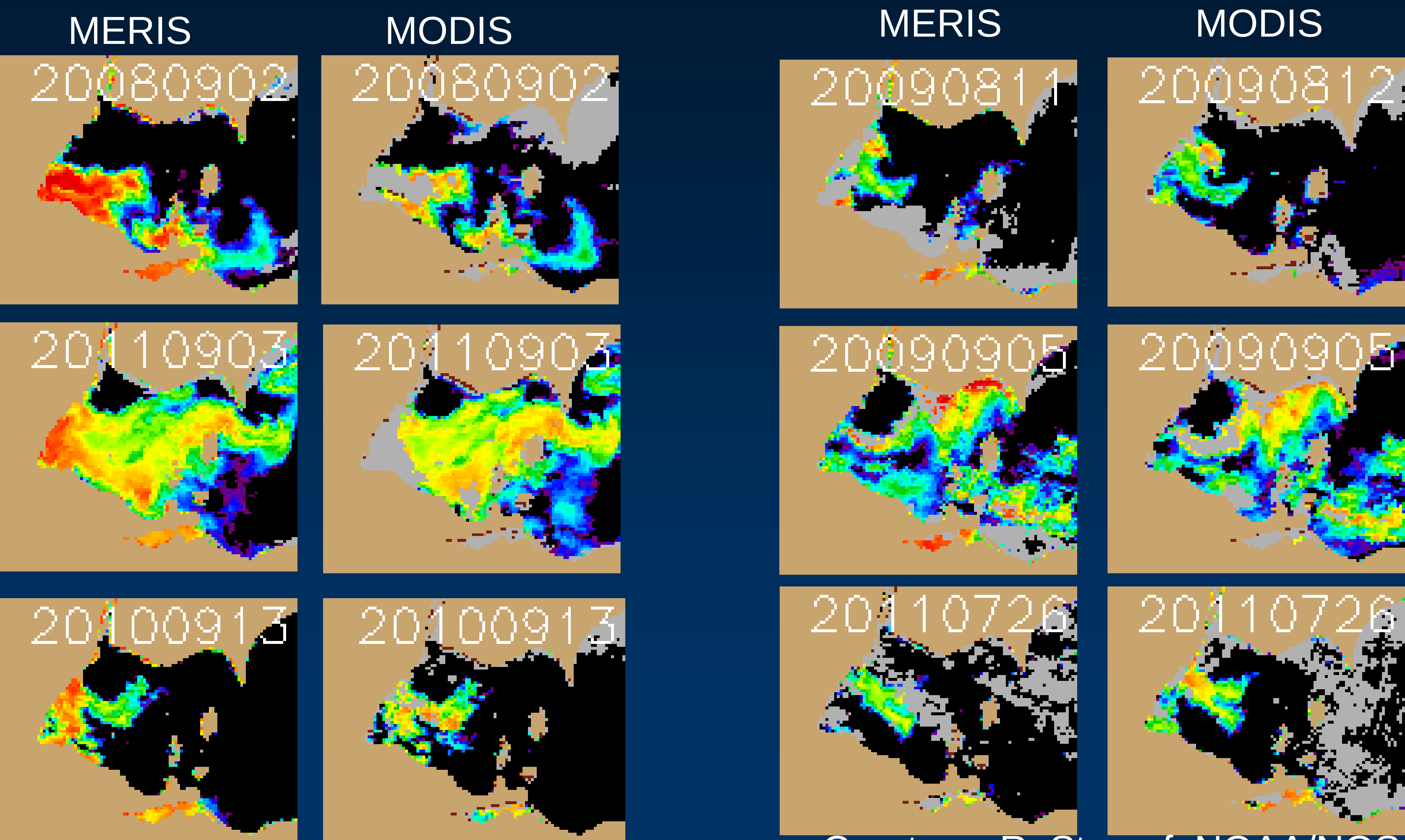




Courtesy: R. Stumpf, NOAA/NOS

Loss of MERIS: MODIS comparable but less sensitive)

(Wynne, Stumpf & Briggs., 2013 Intl J. Remote Sensing)



Courtesy: R. Stumpf, NOAA/NOS

Weekly Bulletin Switch to MODIS for 2012-2013

2012 (and 2013) Bulletins: MERIS data stopped, shifted to MODIS.

Impact: Loss of resolution, MODIS is noisier and less sensitive. But MODIS algorithm is equivalent to MERIS.

Transports with the NOAA Great Lakes Coastal Forecast System

Experimental Lake Erie Harmful Algal Bloom Bulletin

National Centers for Coastal Ocean Science and Great Lakes Environmental Research Laboratory

23 August 2013; Bulletin 15

Microcystin concentrations in some areas of the bloom near Maumee Bay may reach 56 ug/L. Dense cyanobacteria is present along some of the western shore. There may be small patches of scum from the Bass Islands west to Maumee Bay.

Slight eastward transport is forecasted for the next few days. Winds today >15 knots could possibly cause mixing of the bloom. Low winds (<8 knots) are expected over the weekend which could cause the bloom to intensify at the surface and produce patchy areas of scum.

- Dupuy, Stumpf, Tomlinson

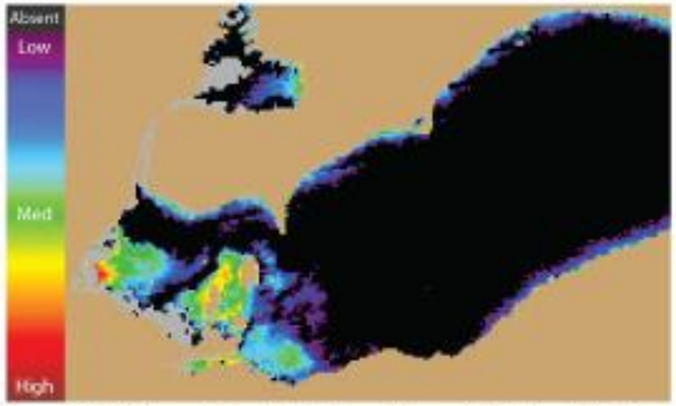


Figure 1. MODIS Cyanobacterial Index from 20 August 2013. Grey indicates clouds or missing data. Black represents no cyanobacteria detected. Colored pixels indicate the presence of cyanobacteria. Cooler colors (blue and purple) indicate low concentrations and warmer colors (red, orange, and yellow) indicate high concentrations. The estimated threshold for cyanobacteria detection is 35,000

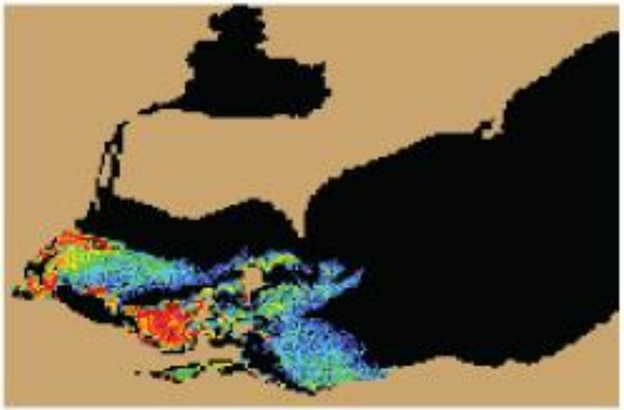
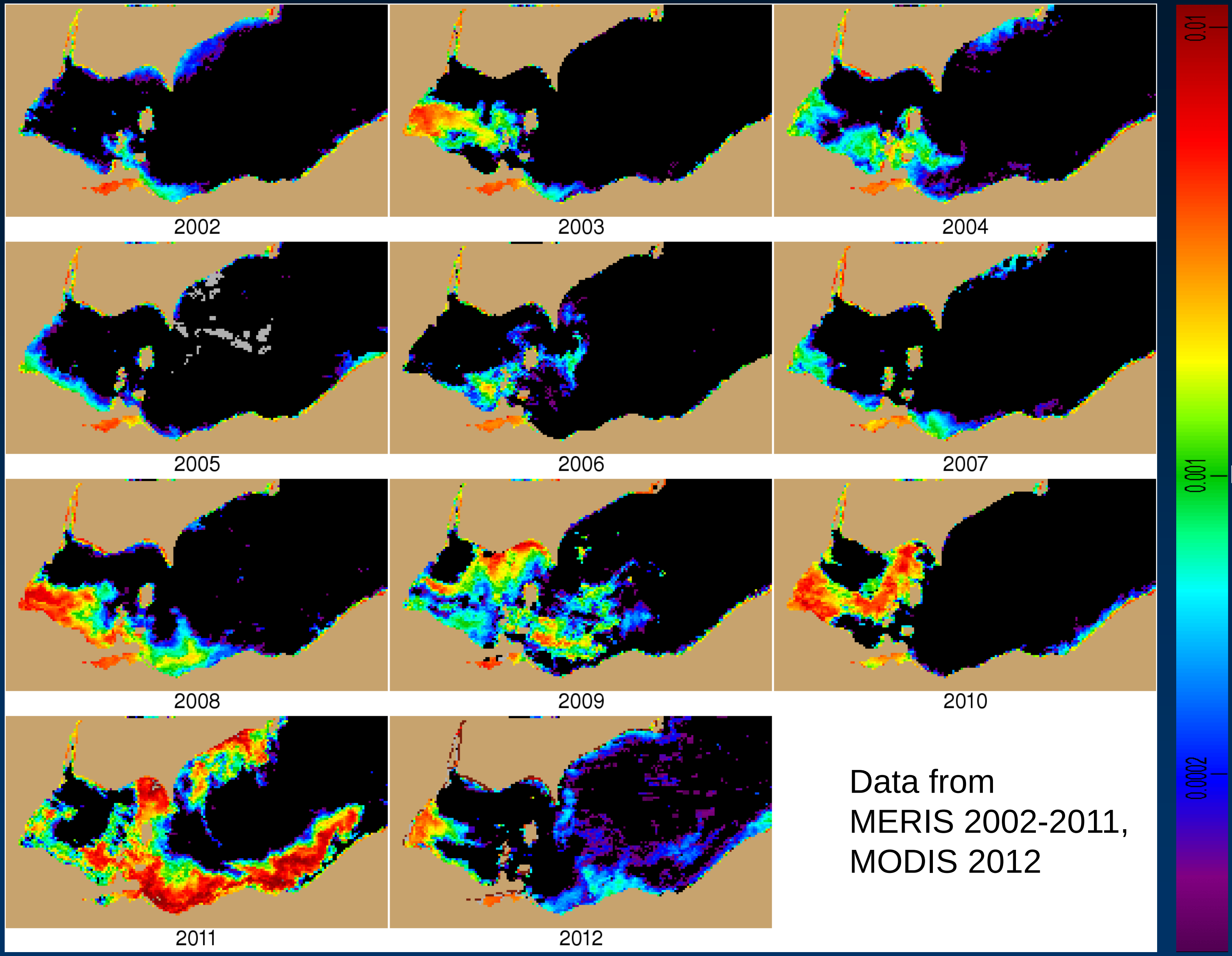


Figure 2. Nowcast position of bloom for 23 August 2013 using GLCFS modeled currents to move the bloom from the 20 August 2013 image.

Over 700 subscribers to bulletin

Courtesy: R. Stumpf, NOAA/NOS

11 years of satellite data provide bloom extent



Courtesy: R. Stumpf, NOAA/NOS

International Coordination for Remote Sensing of Inland and Coastal Water Quality

- Group on Earth Observations (GEO) and the Global Earth Observation System of Systems (GEOSS)
  - ⇒ Ad hoc working group on remote sensing of inland and coastal water quality; international community workshops in 2007, 2009 et al., upcoming workshop in April 2015 (Geneva)
  - ⇒ Facilitate development of pathfinder activity for a global coastal and inland water quality monitoring service as part of the GEO *Blue Planet* Task and the Water Societal Benefit Area.

- Committee on Earth Observation Satellites (CEOS)
  - ⇒ Under auspices of CEOS Ocean Color Radiometry Virtual Constellation (OCR-VC), support development of GEO Water Quality Community of Practice and other related WQ activities.

- International Ocean Colour Coordinating Group (IOCCG)
  - ⇒ Working group on *Earth Observations in Support of Global Water Quality Monitoring just* approved at January 2014 IOCCG meeting in Cape Town, South Africa.

Thanks for listening!

We are interested in hearing and learning more about your satellite data and broader water quality information needs for the Great Lakes.

Feel free to contact me:

Paul.DiGiacomo@noaa.gov