Ocean Colour Remote Sensing in Turbid Waters

Lecture 3
(Applications, Conclusions, The Future)

by Kevin Ruddick

with support from RBINS/REMSEM researchers, past and present

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APPLICATIONS

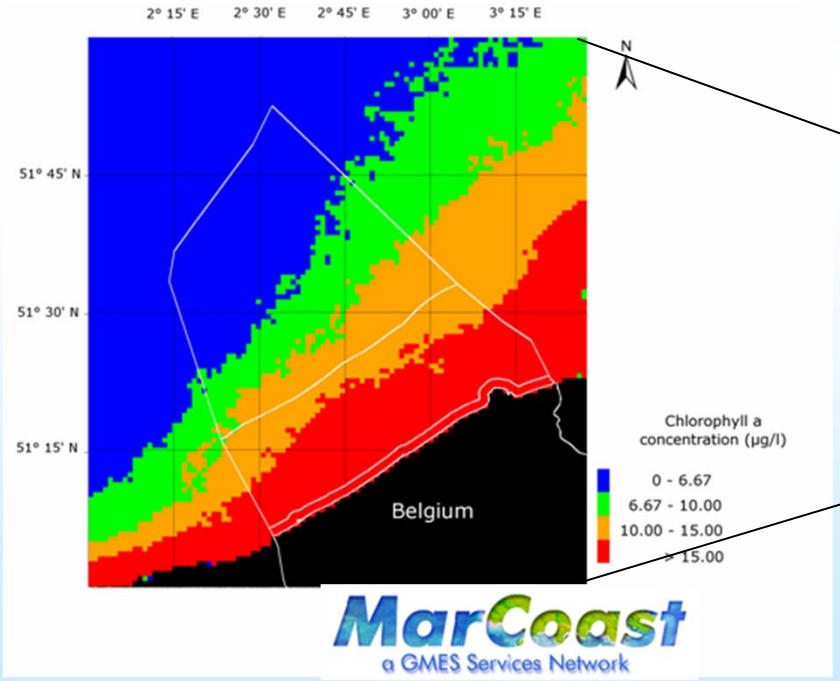
Some examples in turbid coastal waters
(very Belgian-focussed)

App #1: Coastal eutrophication

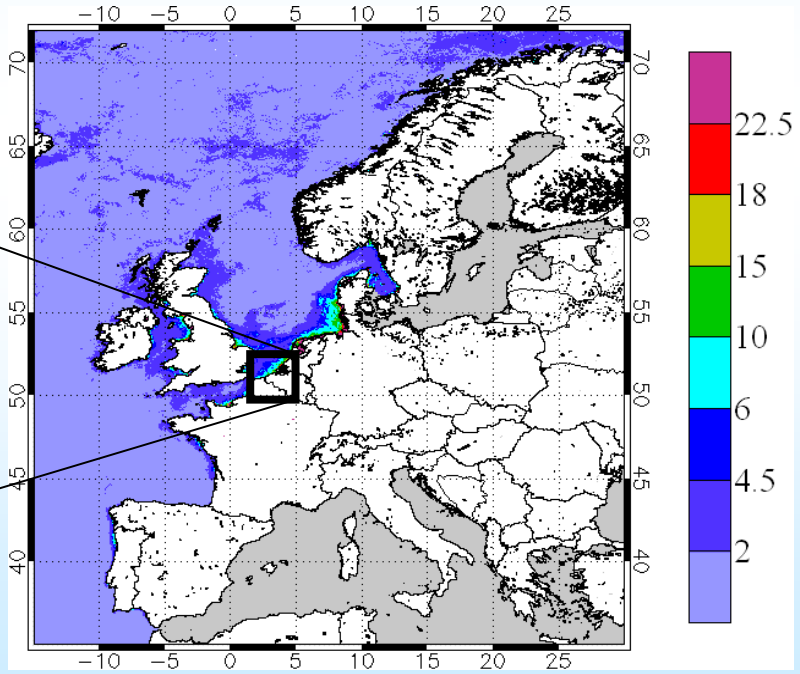
- Eutrophication = excessive supply of nutrients (e.g. from agriculture/industry/homes via rivers)
- Water quality monitoring (EU Water Framework Directive)

Belgian CHLa 90% Mar-Oct 2005-2010,
Water Framework Directive product

[Image: D. Vanderzande]



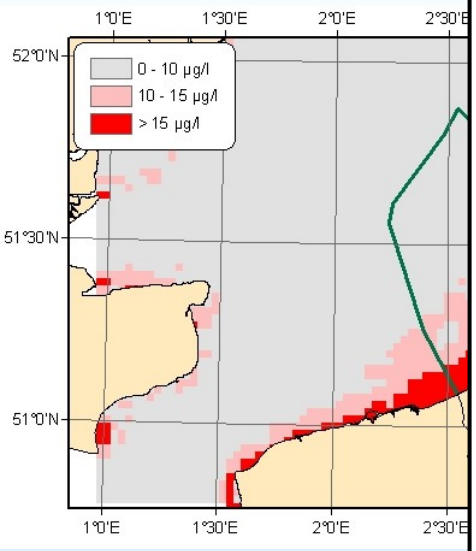
CHLa 90 percentile (MERIS,2005)



App #2, Coastal water quality monitoring

- e.g. Monthly mean chlorophyll a (April 2003-2005) [Y.Park, MARCOAST project]

Full MER



Main limitations are:

- Chlorophyll a is just one of many aspects of coastal water quality (heavy metals, organic pollutants, etc.)
- Quality of CHL *a* data may be suspect in coastal waters: effects of CDOM and Non-algae Particles ...
- ... especially very close to coast (<1 nautical mile): atmospheric correction problems inc. adjacency effects

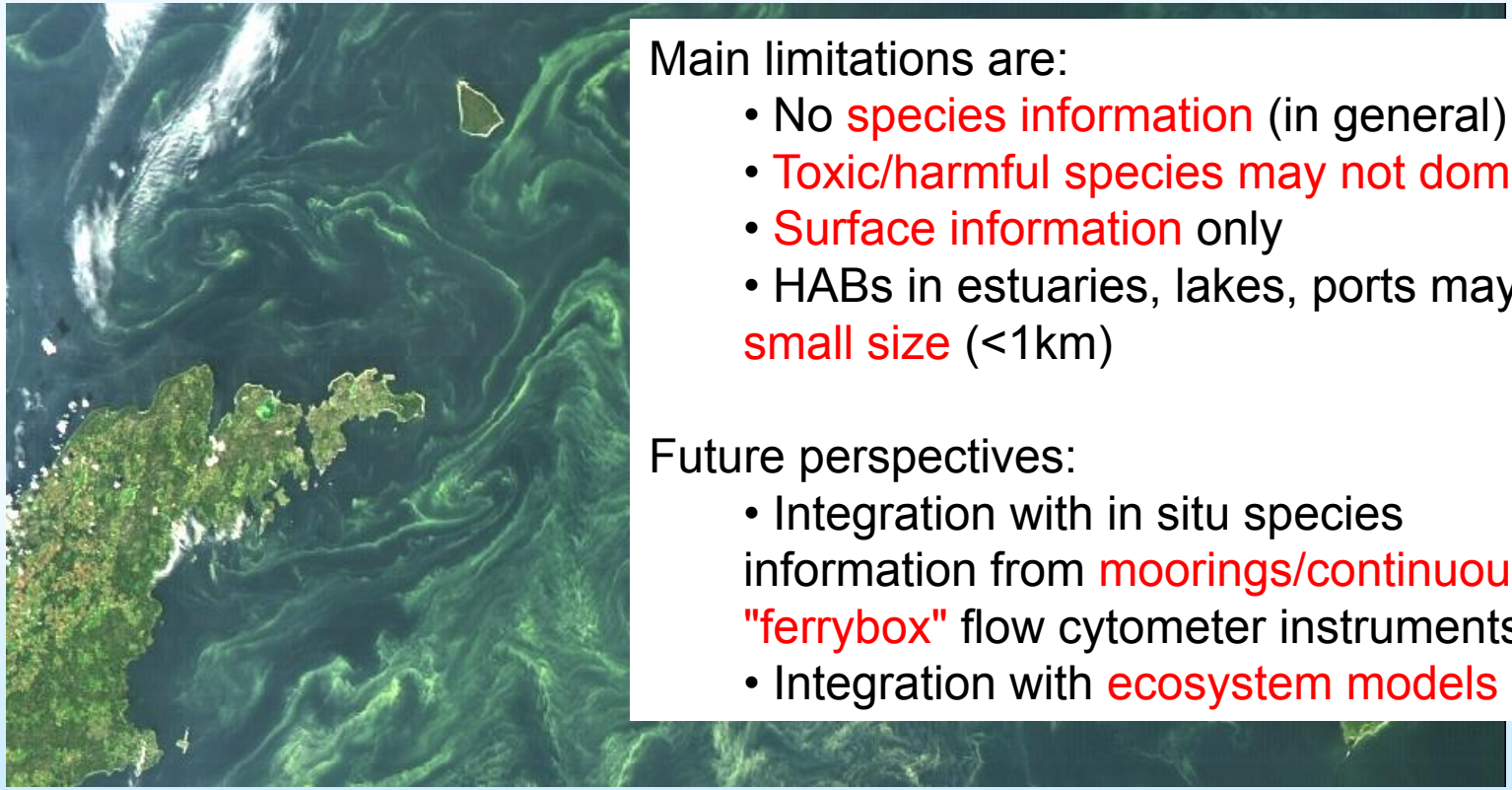
Future perspectives:

- Improvement of spatial resolution (1km ... 300m)
- Improvement of processing close to coast
- Improvement of quality control, flagging suspect data

=> Seaborne sampling can be reduced from ~20 points to about 9

App #3. Harmful Algae Blooms

- Level 1 (RGB TOA) or CHL a maps
- e.g. Baltic *Nodularia spumigena* [Kahru, MODIS-AQUA]



Main limitations are:

- No species information (in general)
- Toxic/harmful species may not dominate
- Surface information only
- HABs in estuaries, lakes, ports may have small size (<1km)

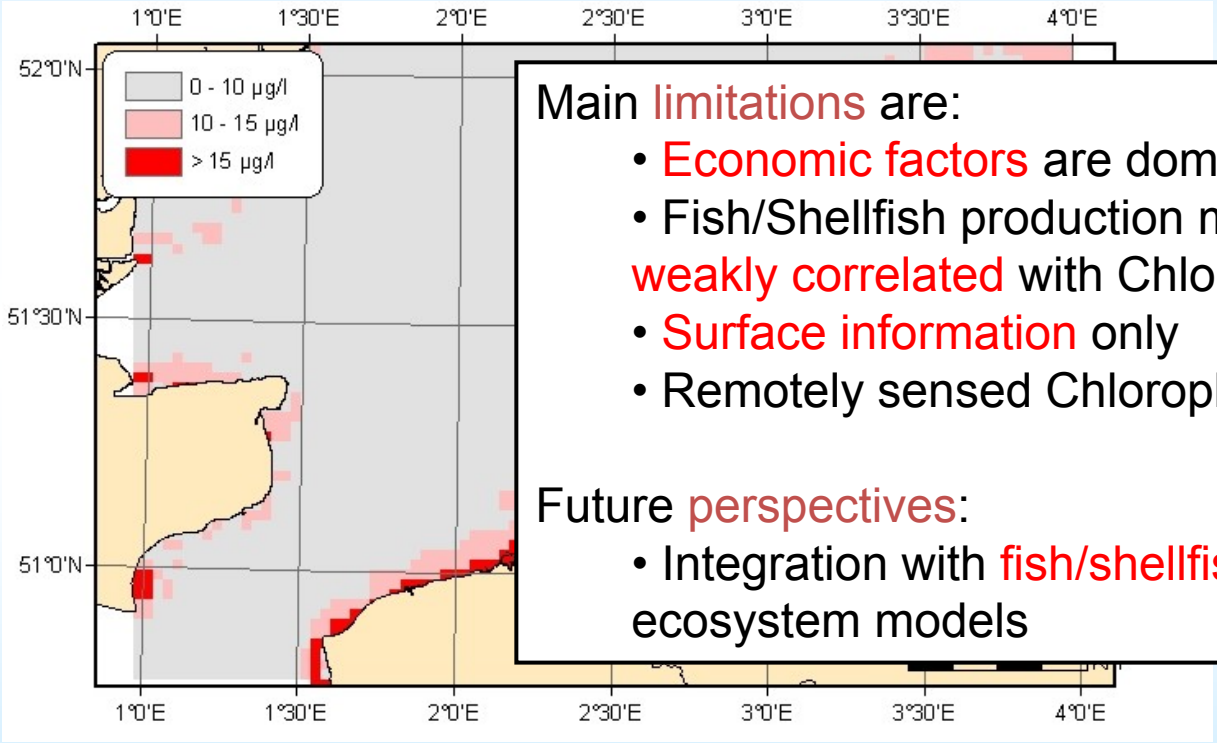
Future perspectives:

- Integration with in situ species information from moorings/continuous "ferrybox" flow cytometer instruments
- Integration with ecosystem models

~150km

App #4, Aquaculture/fisheries

- Satellite images show spatial variability of Chl a concentration (potential food for aquaculture)



Main limitations are:

- Economic factors are dominant
- Fish/Shellfish production may be weakly correlated with Chlorophyll *a*
- Surface information only
- Remotely sensed Chlorophyll *a* quality

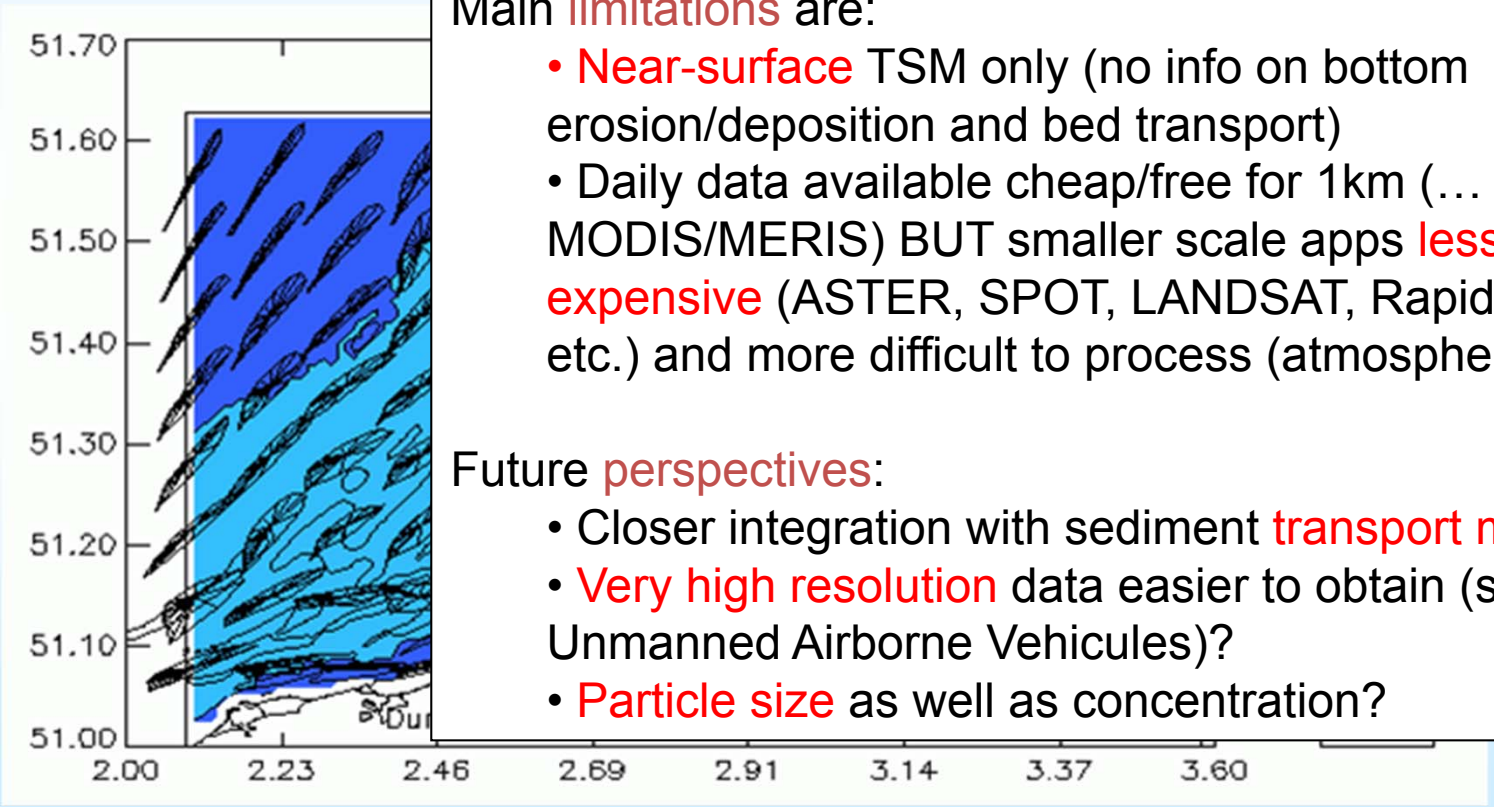
Future perspectives:

- Integration with fish/shellfish production ecosystem models

[MERIS April 2003-2005; processed by Y. Park]

App #5, Sediment transport

- E.g. sediment transport model results from RBINS-SUMO team
- Satellite TSM data used for initialisation and surface validation



Main limitations are:

- Near-surface TSM only (no info on bottom erosion/deposition and bed transport)
- Daily data available cheap/free for 1km (… 250m-MODIS/MERIS) BUT smaller scale apps less frequent, more expensive (ASTER, SPOT, LANDSAT, RapidEye, airborne, etc.) and more difficult to process (atmospheric correction!)

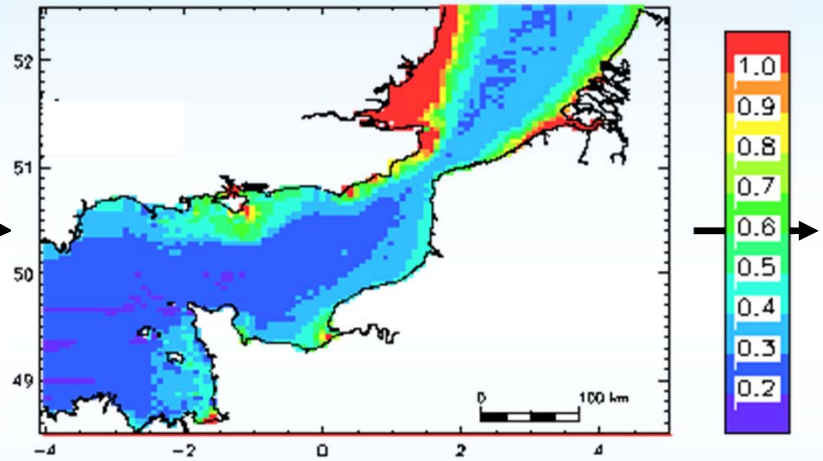
Future perspectives:

- Closer integration with sediment transport model
- Very high resolution data easier to obtain (small satellites, Unmanned Airborne Vehicules)?
- Particle size as well as concentration?

App #6 Ecosystem Modelling (eutrophication)

- 3D-MIRO&CO model [Lancelot et al, 2005; Lacroix et al, 2007]

PAR attenuation (/m), annual average
[Ruddick and Lacroix, 2008; COMETS]



Meteo. info

e.g. PAR

TSM (KPAR) forcing

calculate PAR (light) availability in water column

ECOSYSTEM MODEL

calculates Primary Production

CHL validation

Main limitations are:

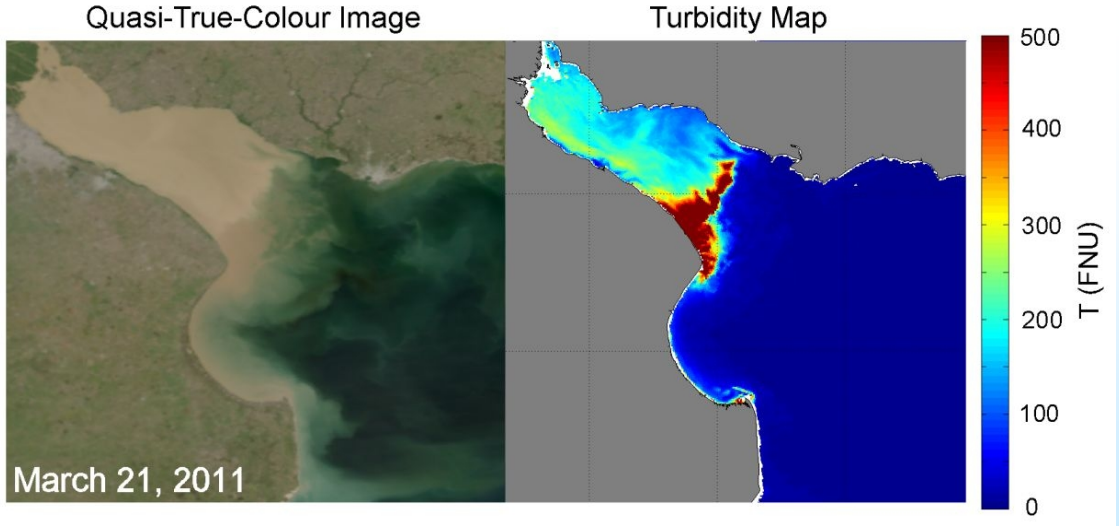
- Limited temporal resolution

Future perspectives:

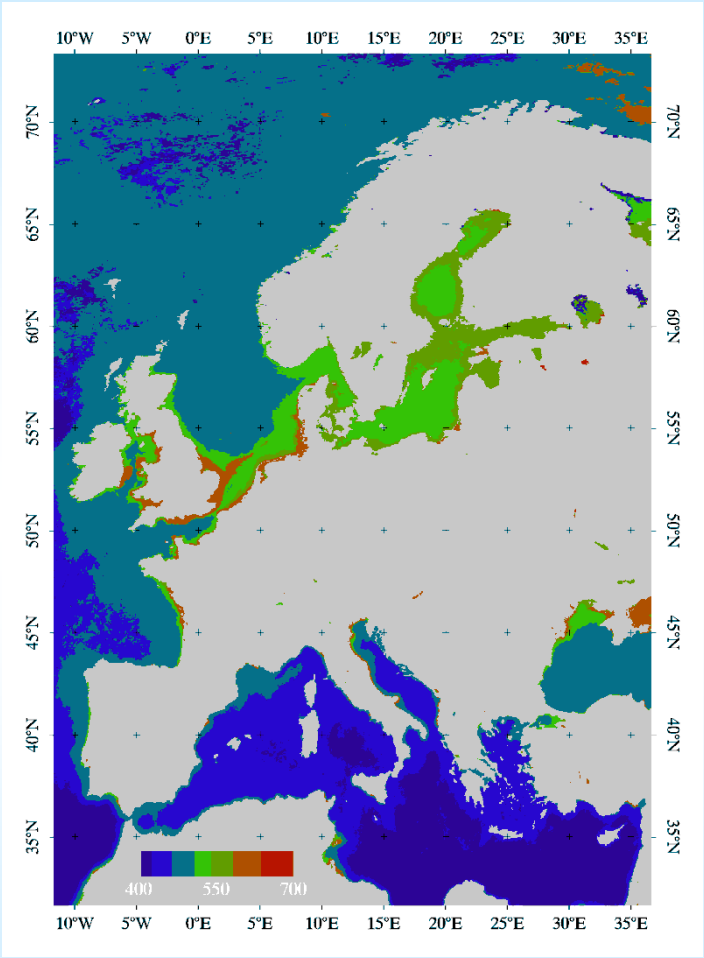
- Synergy remote sensing/model
- Synergy polar/geostationary

App #7 – Fish biology

- Wavelength of maximally transmitted light (WMTL) may affect genetic adaptation of fish
- Possible future applications: link between light climate (habitat) and visual predators? e.g. Rio de La Plata Estuary, Argentina



[Dogliotti et al, 2011]



[Larmuseau et al, 2009]

Miscellaneous
Data Processing in turbid waters

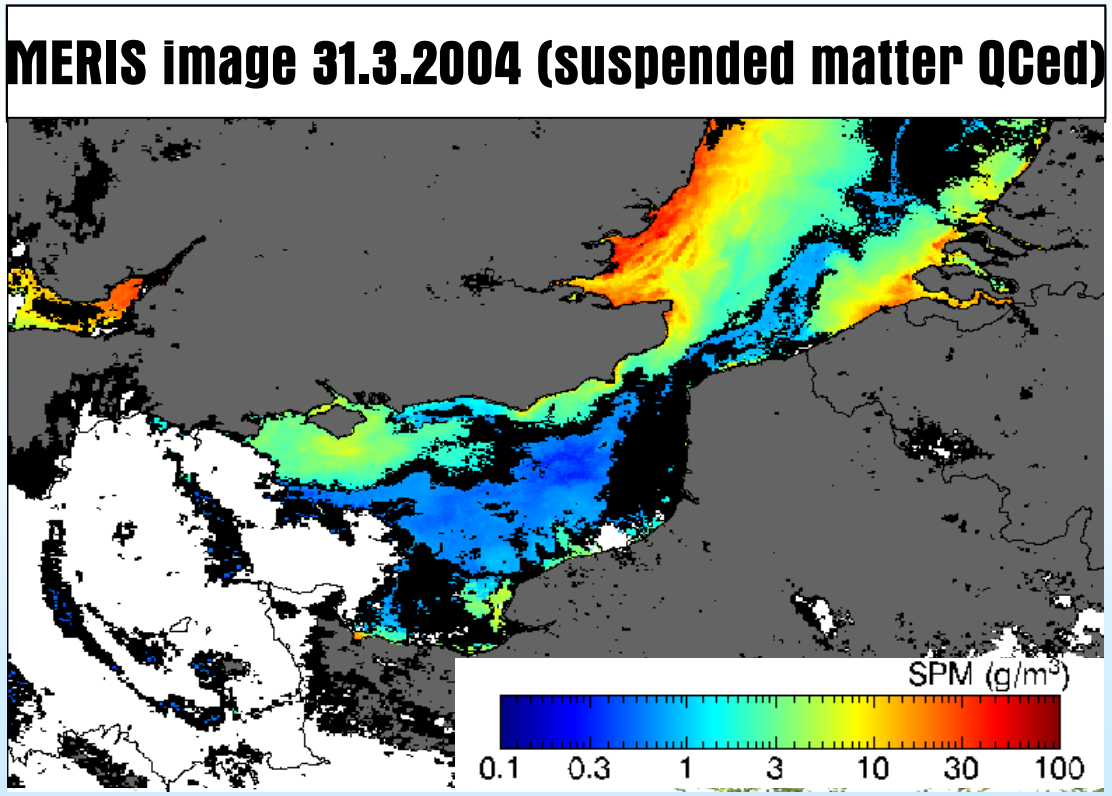
Turbid waters - Miscellaneous

- Cloud flagging in turbid waters
  - Simple TOA 865nm reflectance thresholds (SeaDAS) do not work because turbid water is also bright
  - Raise threshold or use better algos, e.g. [Nordqvist et al, 2009]
- Bidirectional effects
  - Light field is more diffuse, BRDF less important than in Case 1 waters but some variability [Loisel and Morel, 2001; Park and Ruddick, 2005]
  - Case 1 CHL-based BRDF corrections, f/Q [Morel and Gentili], are not appropriate => DO NOT USE
  - Case 2 BRDF corrections are emerging, e.g. neural net-based [Doerffer]
- Stratification
  - Remote sensor sees “near-surface” (but depth depends on wavelength)

Miscellaneous

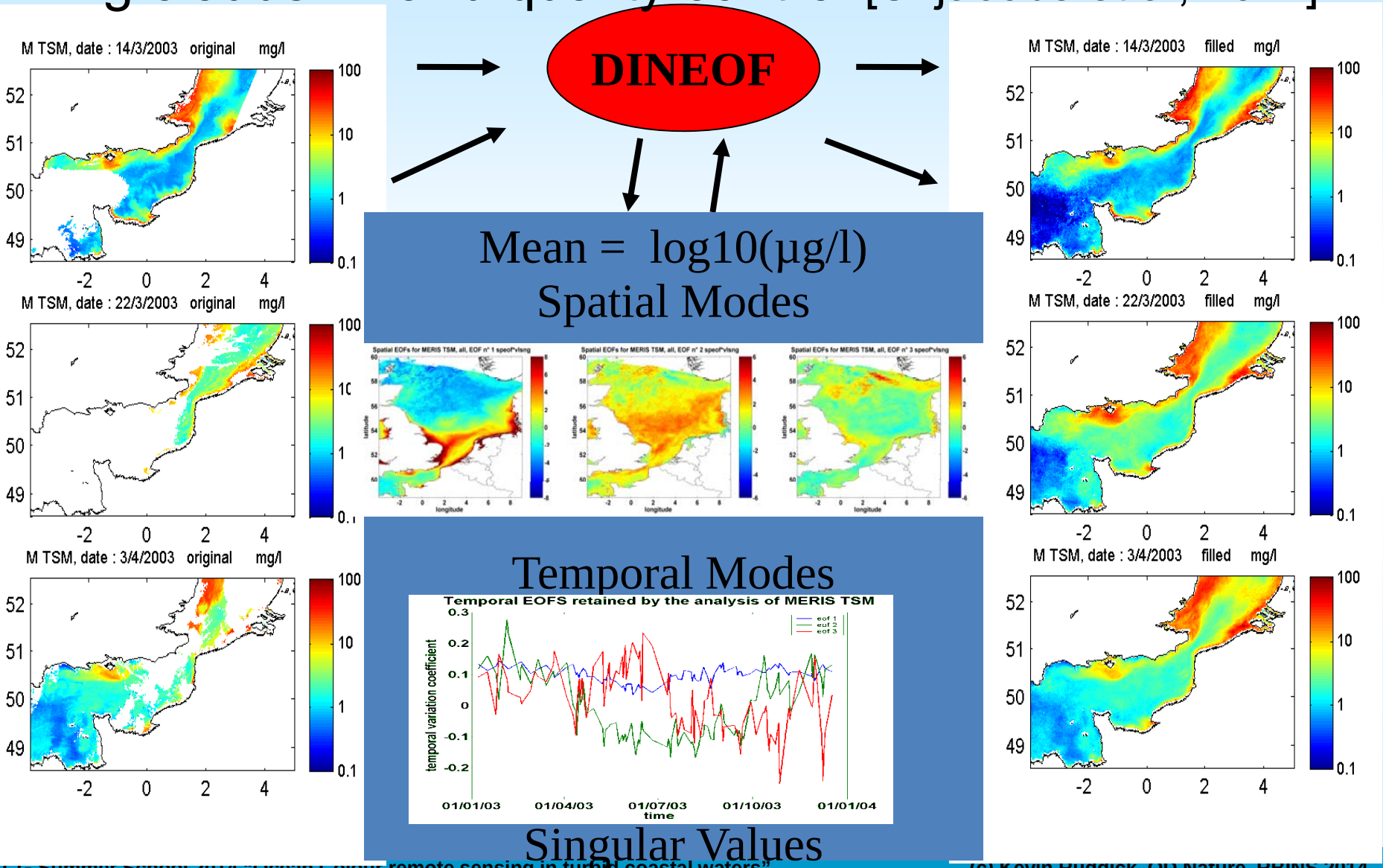
- Quality flagging and product uncertainty estimation are growing research field:
  - E.g. a) Spectral fit-based uncertainty, b) multitemporal EOF [Sirjacobs et al, 2011], c) multi-factor a priori uncertainty estimation

e.g. MERIS Product Confidence Flag [Processing: Y.Park]



D. Sirjacobs, et al. Cloud filling of ocean color and sea surface temperature remote sensing products over the Southern North Sea by the Data Interpolating Empirical Orthogonal Functions methodology. Journal of Sea Research, 65(1):114-130. 2011.

Filling clouds … and quality control [Sirjacobs et al, 2011]



CONCLUSIONS and FUTURE PERSPECTIVES

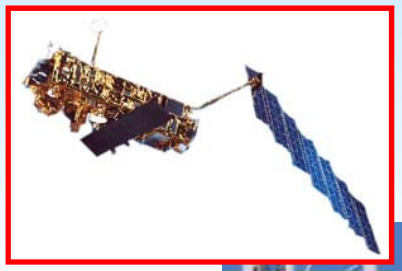
Ocean colour remote sensing in turbid waters

	Capabilities	Limitations	Research
Parameter	TSM, CHLA, Kd	Just TSM, CHLa, Kd No vertical structure No flux info	
Temporal	~Daily since 2003 ★ Near Real Time (~2h)	Clouds! No tidal info	
Spatial	300m-1000km ★		
Conc.	0.1-500 g/m3	Extreme high conc.	
Accuracy	Absolute: 30-50% TSM? Relative: good		
Issues		Near land (~1km) Atmospheric Corr. CHL in turbid waters	

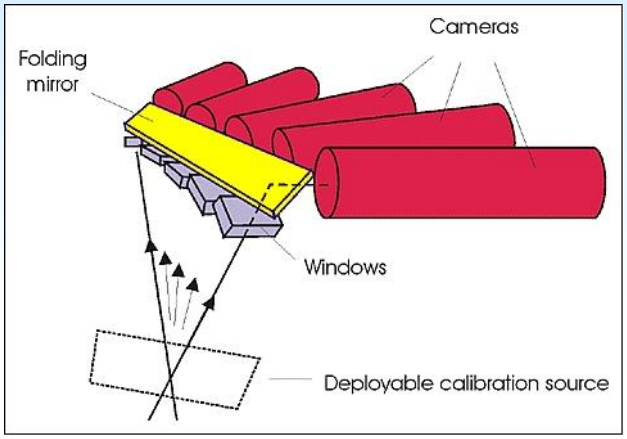
★ e.g. MERIS/MODIS, different for airborne or high res satellite

Optical Remote Sensing – future systems

Platform

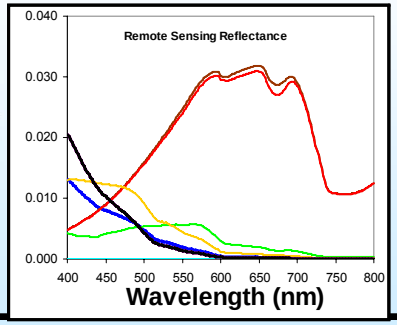


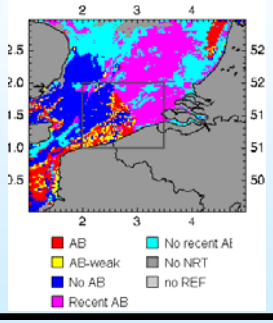
Sensor



Processing/Distribution

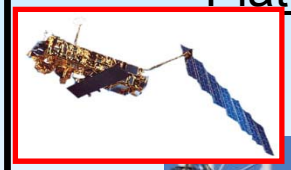
$$S = A\frac{\rho_w}{1-\rho_w/C}$$





Optical Remote Sensing – future systems

Platform



Geostationary

Hourly GOCI data since 2010 (Korea/Japan/China)

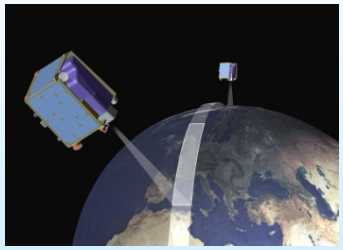
For Europe in 2020 …or earlier?

Unmanned airborne

OCTOCOPTER [terraluma.net]

GATEWING X100 [www.gatewing.com]

Pointable minisats



e.g. Rapideye: daily revisit, 5m

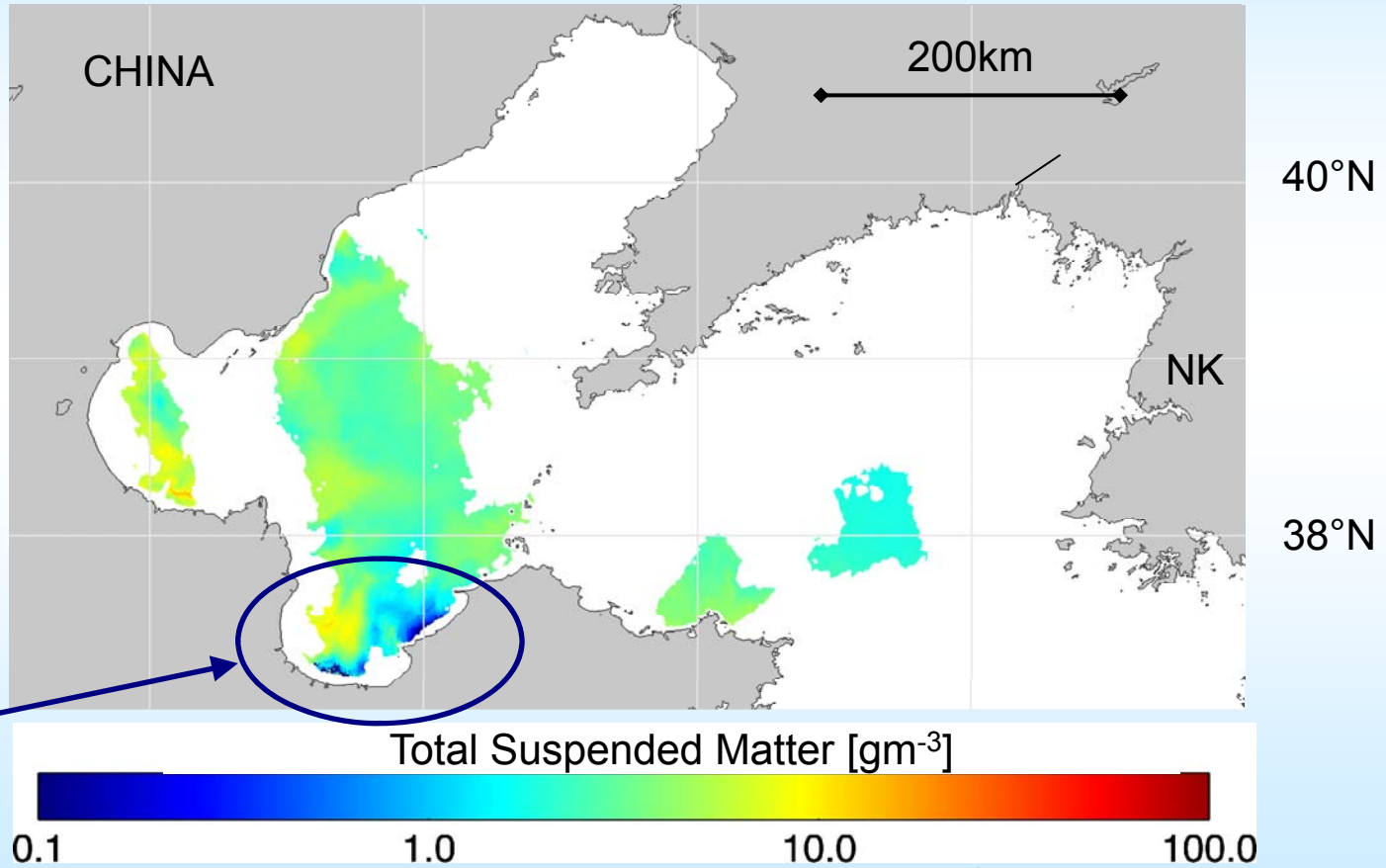
[Ruddick et al 2012. Variability of suspended particulate matter in the Bohai Sea from the Geostationary Ocean Imager (GOCI). Ocean Science Journal. 47(3):331-345]

Bohai Sea (<60m)

GOCI

12.6.2011

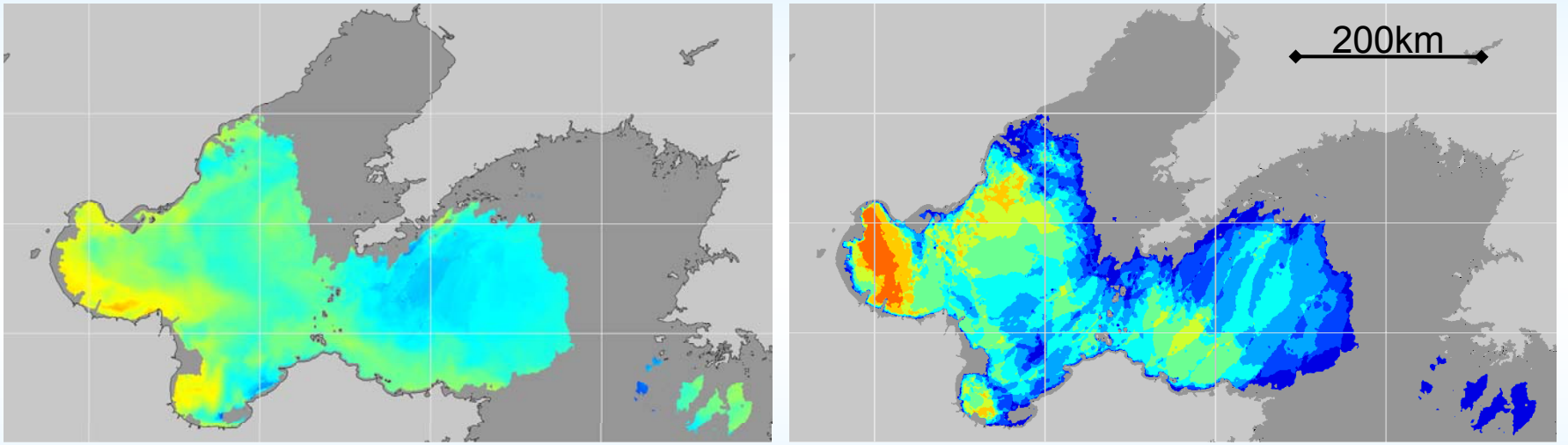
00:16 UTC
01:16 UTC
02:16 UTC
03:16 UTC
04:16 UTC
05:16 UTC
06:16 UTC
07:16 UTC



- TSM dynamics: tidal resuspension, advection of river plumes, etc.

[Ruddick et al 2012. Variability of suspended particulate matter in the Bohai Sea from the Geostationary Ocean Imager (GOCI). Ocean Science Journal. 47(3):331-345]

GOCI imagery for Bohai Sea, 12.6.2011



Daily Average Total Suspended Matter [gm^{-3}]

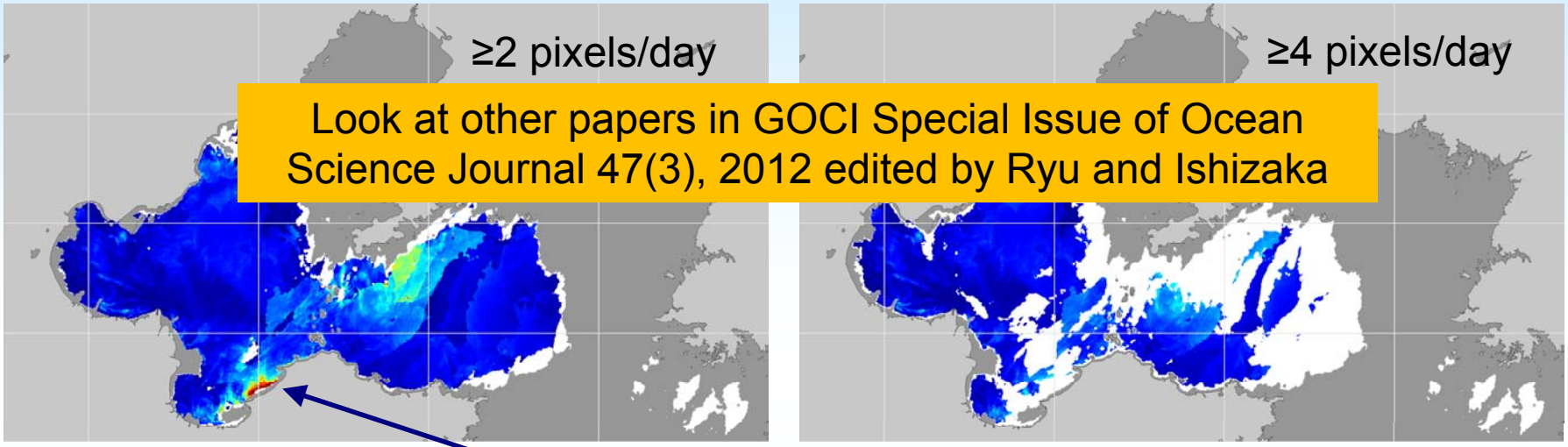
0.1 1.0 10.0 100.0

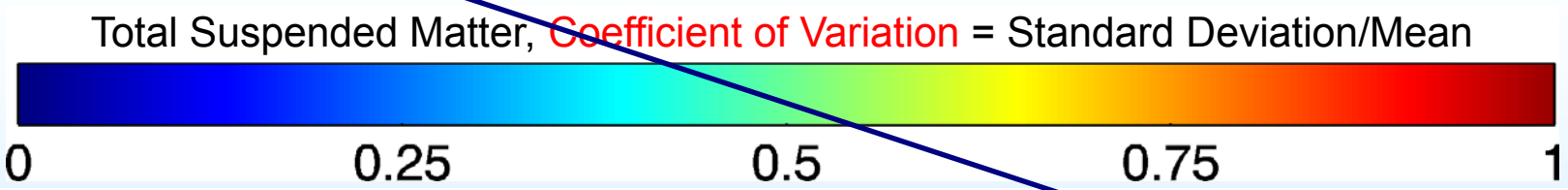
Number of pixels in day

1 2 3 4 5 6 7 8

[Ruddick et al 2012. Variability of suspended particulate matter in the Bohai Sea from the Geostationary Ocean Imager (GOCI). Ocean Science Journal. 47(3):331-345]

GOCI imagery for Bohai Sea, 12.6.2011





- Coefficient of Variation over day => natural or artificial variability
- Relevant for automatic outlier detection?

CONCLUSIONS

- Turbid waters have high socio-economic importance
  - User need => more intensive use of r/s for science, monitoring, etc.
- Processing problems include:
  - CHL retrieval in presence of high non-algal particle absorption
  - Aerosol correction where near infrared marine reflectance non-zero
- Many new algorithms are products are emerging:
  - Inherent Optical Properties
  - Spectral and PAR diffuse attenuation, turbidity
  - Specific phytoplankton blooms
  - Quality and/or uncertainity estimates
- What does the future hold?
  - High frequency data from geostationary (SEVIRI, GOCI, …)
  - More and more information on particles (size, type, organic content…)
  - High spatial resolution (Landsat-8, Rapideye, Sentinel-2, Pléiades, Unmanned Airborne Vehicles)
  - Hardware improvements very fast …

Very high res sats, e.g. Pléiades

2 pointable sats,up to daily, 2m multisp., 50cm panchro, <1000€ for 100km^2

Port of Zeebrugge 17.7.2014
ATCOR and SPM retrieval feasible
[Processing: Q. Vanhellemont]

Acknowledgements

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