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
(Ana Dogliotti, Bouchra Nechad, Griet Neukermans, Youngje Park, Dimitry Vanderzande, Quinten Vanhellemont, Barbara Van Mol) and BELCOLOUR project partners
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)


[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]

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
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]

ECOSYSTEM MODEL calculates Primary Production

Meteo. info e.g. PAR

TSM (KPAR) forcing

calculate PAR (light) availability in water column

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

Main limitations are:
- Limited temporal resolution

Future perspectives:
- Synergy remote sensing/model
- Synergy polar/geostationary

CHL validation
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.

[Larmuseau et al, 2009]
[Dogliotti et al, 2011]
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

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

DINEOF

Mean = $\log_{10}(\mu g/l)$

Spatial Modes

Temporal Modes

Singular Values
CONCLUSIONS and FUTURE PERSPECTIVES
# Ocean colour remote sensing in turbid waters

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

*Also see 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?
- Pointable minisats
  - e.g. Rapideye: daily revisit, 5m

**Unmanned airborne**
- OCTOCOPTER
  - [terraluma.net]
- GATEWING X100
  - [www.gatewing.com]
• TSM dynamics: tidal resuspension, advection of river plumes, etc.

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

Number of pixels in day

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 uncertainty 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 100km²

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

• Much of the content provided here was funded by the Belgian Science Policy Office (BELSPO) BELCOLOUR-2 project
• NASA, ESA and KORDI/KOSC for MODIS-AQUA, Meris and GOCI data