water quality monitoring: the role of HyspIRI

Arnold Dekker, Tim Malthus, Erin Hestir
Earth Observation & Informatics - Transformational Capability Platform
29th May 2013  NASA GSFC
In situ bio-optical observations

★ Current (2009-10 & 2012-13)
Drivers for our EO of water quality research

- Legislation:
  - National Plan for Environmental Information
  - State of Environment
- Algorithms
- New Technologies
- Ecosystem science
  - Climate change and variability
  - Drivers of water quality
  - Resilience
  - Prediction
2013

"CSIRO is Australia’s lead R&D Agency"

2013

"...giving priority to Earth observations from space..

2013

Australian Government

"..better domestic co-ordination and focused international engagement"

National Space Policy

"..certainty and strategic direction for satellite technology users"

National Earth Observations from Space Infrastructure Plan

"Continuity of Earth Observation Data for Australia: Research and Development Dependencies to 2020

January 2012"
Australian Context for Water Quality

• The Challenge: Ongoing monitoring of Australia’s inland water quality
• Australia’s water quality is poor and is negatively trending
• But water quality data are scarce, potentially declining and with poor temporal coverage
• We need rapid, cost-effective assessments of water quality to assess baseline conditions and study responses to existing and potential environmental stressors
• Such assessments are needed across a range of scales
• Includes from continuous in situ measurements to satellite remote sensing, the latter overcoming some of the costs of remote sampling
The potential solution

- **Satellite remote sensing**
  - Provides an objective, high frequency and spatially continuous measurement tool to overcome these challenges
  - But for a limited set of water quality parameters
  - Using inversion approaches
  - Will need calibration and validation over low reflecting targets
EO-resolvable water bodies in Australia

**Continental Australia**

- Count of water bodies vs. Pixel Size
- Area of water bodies vs. Pixel Size

**Murray Darling Basin**

- Count of water bodies vs. Pixel Size
- Area of water bodies vs. Pixel Size

Legend:
- Count of water bodies
- Area of water bodies

Maps show the percent of area of water bodies and the percent of number of water bodies for different pixel sizes.
EO-resolvable water bodies in Australia

![Graph showing the percent of number of water bodies by pixel size for different types of water bodies: watercourses, lakes, storages, and floodplains. The graph displays data for pixel sizes of 30, 60, and 250.](image-url)
## Relative capability for wq retrieval using free satellite data

<table>
<thead>
<tr>
<th></th>
<th>Pixel Size (m)</th>
<th>Bands (400-900 nm)</th>
<th>Revisit cycle</th>
<th>CHL</th>
<th>CYP</th>
<th>TSM</th>
<th>CDOM</th>
<th>SD</th>
<th>K_d</th>
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<tbody>
<tr>
<td><strong>Low res.</strong></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>MODIS</td>
<td>1000</td>
<td>9</td>
<td>Daily</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>MODIS</td>
<td>500</td>
<td>2</td>
<td>Daily</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>MODIS</td>
<td>250</td>
<td>2</td>
<td>Daily</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>MERIS</td>
<td>300</td>
<td>15</td>
<td>2-3 days</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>VIIRS</td>
<td>750</td>
<td>7</td>
<td>2x/day</td>
<td></td>
<td>●</td>
<td></td>
<td>●</td>
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</tr>
<tr>
<td><strong>Med res.</strong></td>
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<td></td>
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<tr>
<td>Landsat</td>
<td>30</td>
<td>4</td>
<td>16</td>
<td></td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Future</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Sentinel-3</td>
<td>300</td>
<td>21</td>
<td>Daily</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>LDCM</td>
<td>30</td>
<td>5</td>
<td>16</td>
<td></td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Sentinel-2</td>
<td>10-60</td>
<td>10</td>
<td>3-5 days</td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>HySpIRI</td>
<td>60</td>
<td>60</td>
<td>19 days</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

- **Highly suited**, ● Suited, ● Potential, ● Not suited

Water quality variables from remote sensing e.g. WV-2

<table>
<thead>
<tr>
<th>Chlorophyll</th>
<th>Colored dissolved organic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyanopigments</td>
<td>Total suspended matter</td>
</tr>
</tbody>
</table>

Water column optically active components

- **Vertical attenuation of light**
- **Secchi depth**
- **Bathymetry**
- **Vegetation**

Estimated from water column properties

- **CHL**
- **CDOM**
- **CYP**
- **TSM**
**Current**
- Chlorophyll
- Cyanobacteria
- Total suspended matter

**Future**
- Phytoplankton functional types
- Sources of coloured dissolved organic matter
- Fraction inorganic to organic matter
- Particle size distributions

**Current**
- Climate change
- Run off loads
- Catchment sources
- Nutrient dynamics
- Net primary production
- Vegetation biomass & ecophysiology
- Emergency management

**HYSPIRI**
- Vertical attenuation of light
- Secchi depth
- Bathymetry
- Vegetation

**CURRENT & FUTURE MSS**
- Climate change
- Run off loads
- Catchment sources
- Nutrient dynamics
- Net primary production
- Vegetation biomass & ecophysiology
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Pigment signals in spectral reflectance

Spectral resolution:
- Detect significant spectral features
- Discriminate different water quality parameter signals
Colouring Material: Pigments in phytoplankton cultures: their light absorption and scattering

From left to right on the photo:

- *Dunaliella tertiolecta*
- *Emiliania huxleyi*
- *Pavlova lutheri*
- *Porphyridium cruentum*
- *Synechococcus sp.*
- *Gymnodinium catenatum*
- *Thalassiosira pseudonana*
- *Chaetoceros socialis*
Algal bloom as seen by WorldView-2 2m
Algal bloom as seen by Landsat 30 m
Algal bloom reflectance simulation~ HyspIRI 60m
Needs bio-optical parameterisation of algorithm to estimate water quality or hyperspectral from space.

9\textsuperscript{th} May 2009

28\textsuperscript{th} March 2011
MERIS inland – coastal water example (from G. Campbell USQ)
Burdekin Falls Dam and Burdekin to GBR
MERIS: every two days a scene @ 300 m resolution
Semi-analytical approaches: the forward problem

Index of refraction, distribution, particle size and properties of all constituents → Inherent Optical Properties (IOPs) → Remote Sensing Reflectance

\[ \cos \theta \frac{dL(z, \theta, \phi, \lambda)}{dz} = \ldots \]
Semi-analytical approaches: the inverse problem

\[ R_{rs}(\lambda) = f[a(\lambda), b_b(\lambda), \rho(\lambda), H, \Theta_w, \Theta_v, \psi] \]

Solution: The adaptive Linear Matrix inversion (a-LMI) hyperspectral parameterisation-E rich sensor agnostic

Loop RTE inversion over candidate model parameter sets

**SIOP**$_k$ = Candidate model parameter set $k$

$[a^{*\text{phy}}(\lambda), S_{\text{CDOM}}, a^{*\text{NAP}(440)}, S_{\text{NAP}}, b^{*\text{bphy}}(555), Y_{\text{phy}}, b^{*\text{NAP}(555)}, Y_{\text{NAP}}]_k$

$[C_{\text{CHL}}, C_{\text{CDOM}}, C_{\text{NAP}}]_k = f(r_{\text{rs}}^{\text{input}}, \text{SIOP}_k)$

$\Delta k = \Delta (r_{\text{rs}}^{\text{input}}, r_{\text{rs}}^{\text{model}_k})$

Brando et al, 2012, Applied Optics
Current & pending global mapping capabilities
# Sentinel-2 as an Optically Deep Water Sensor

<table>
<thead>
<tr>
<th>Band Nr</th>
<th>Resolution (m)</th>
<th>Spectral Width (nm)</th>
<th>Optically Deep Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>20</td>
<td>433 to 453</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>65</td>
<td>458 to 523</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>35</td>
<td>543 to 578</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>30</td>
<td>650 to 680</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>15</td>
<td>698 to 713</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>15</td>
<td>733 to 748</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>20</td>
<td>773 to 793</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>115</td>
<td>785 to 900</td>
</tr>
<tr>
<td>8a</td>
<td>20</td>
<td>20</td>
<td>855 to 875</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>20</td>
<td>935 to 955</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
<td>30</td>
<td>1360 to 1390</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>90</td>
<td>1565 to 1655</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>180</td>
<td>2100 to 2280</td>
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</tbody>
</table>
Users need decade-long term perspectives

### GMES Space Component Long-Term Scenario

<table>
<thead>
<tr>
<th></th>
<th>2011-2013</th>
<th>2014-2020</th>
<th>2021 ==&gt;</th>
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</thead>
<tbody>
<tr>
<td><strong>Access to Contributing Missions</strong></td>
<td></td>
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<tr>
<td>Sentinel-1 A/B/C</td>
<td></td>
<td></td>
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<tr>
<td>Sentinel-1 A/B/C 2nd Gen</td>
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<tr>
<td>Sentinel-2 A/B/C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sentinel-2 A/B/C 2nd Gen</td>
<td></td>
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</tr>
<tr>
<td>Sentinel-3 A/B/C</td>
<td></td>
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<tr>
<td>Sentinel-3 A/B/C 2nd Gen</td>
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<tr>
<td>Sentinel-4 A/B (MTG-S1/2)</td>
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<tr>
<td>Sentinel 5 Precursor</td>
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<tr>
<td>Sentinel 5 A/B (MetOp-SG)</td>
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<tr>
<td>Jason-CS A/B</td>
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<tr>
<td>Jason -CS Follow-on A/B</td>
<td></td>
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<tr>
<td>GSC Evolution</td>
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</tbody>
</table>
Current blending opportunities

[Diagram with bands, resolution, and revisit days showing blending opportunities involving LS, S2, S2 + MODIS, S2 + MODIS, S3, MODIS, MODIS, and VIIRS.]
Hyspiri’s contribution to global mapping
Future blending potential

![Graph showing future blending potential for different satellite missions. The graph includes bands (256) on the x-axis, resolution (m) on the y-axis, and revisit (days) on the z-axis. Different satellite missions are represented by distinct colors and markers.]

- HyspIRI
- Landsat (LS)
- MERIS
- Sentinel-2 (S2)
- MODIS
- VIIRS

The graph illustrates the potential for future blending of data from these missions, showing how they can be combined to improve environmental monitoring and research.
Towards an Aquatic Earth Observation System: using tools such as hydrodynamic and biogeochemical models, in situ observations and multi-and hyperspectral earth observation to:

- Eutrophication- Nutrients Fluxes & Budgets
  - Inland waters, bays and estuaries: water quality, macrophytes & habitat

- Carbon Fluxes & Budgets
  - Land to inland water body to sea: fluxes and reservoirs

- Climate Change
  - Retrospective time series analyses for trend and anomaly detection (including areas in Australia where nothing has been measured previously)

- Shoreline erosion and flooding
  - Effect of land-use changes on run-off
  - Riparian and flood plain
  - Bathymetry and DEM

- National Environmental Accounts
  - Habitat status, State of Environment reporting

- Emergency management
  - Potentially harmful algal blooms
  - Oil & Chemical Spill Response;