Applications of Remote Sensing & Satellite Data: Observations from 800 km above California

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First Remote sensing of an algal bloom, 1974

letters to nature

Nature 250, 213 - 214 (19 July 1974); doi:10.1038/250213a0

Remote sensing and lake eutrophication

ROBERT C. WRIGLEY & ALEXANDER J. HORNE

An infrared photograph of part of Clear Lake, California (Fig. 1) shows beautiful, complex patterns of blue-green algal blooms which were not observed by conventional limnological techniques. Repeated observations of patterns such as these can be used to chart the surface movement of these buoyant algae and can also be used to help control algal scums in eutrophic lakes.
Where Are We With Satellite

- We are concentrating on cyanos for this project
- Cyano blooms are observable.
- Cyano blooms are distinguishable from other blooms depending on the sensor
  - Some uncertainties on distinction between cyanos and non-cyanos
  - We are examining strategies to reduce these.
- All sensors can find scum
- Most sensors have limitations
  - Resolution trade-offs: spatial, spectral, temporal
- Experimental systems and field radiometers allow for evaluation of future high resolution strategies (not going to discuss that today).
### Satellite Comparison for cyano applications

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Spatial</th>
<th>Temporal</th>
<th>Key Spectral</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERIS 2002-12</td>
<td>300 m</td>
<td>2 day</td>
<td>10 (5 on red edge)</td>
</tr>
<tr>
<td>OLCI Sentinel-3a 2016-</td>
<td>OK</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>MODIS high res</td>
<td>250/500 m</td>
<td>1-2 day</td>
<td>4 (1 red, 1 NIR)</td>
</tr>
<tr>
<td>Terra 1999; Aqua 2002</td>
<td>OK</td>
<td>good</td>
<td>marginal</td>
</tr>
<tr>
<td>MODIS low res</td>
<td>1 km</td>
<td>1-2 day</td>
<td>7-8 (2 in red edge)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OK</td>
</tr>
<tr>
<td>Landsat</td>
<td>30 m</td>
<td>8 or 16 day</td>
<td>4 (1 red, 1 NIR)</td>
</tr>
<tr>
<td>Sentinel-2 (2015)</td>
<td>20 m</td>
<td>10 day (5 day with 2nd satellite in 2017)</td>
<td>5 (1 red; 2 NIR, 1 in red edge)</td>
</tr>
</tbody>
</table>

- Clouds take out 1/2 to 2/3 of imagery
- Some sunglint is not a problem for our algorithms
- Minimum resolution, 3 pixels across (2 mixed land/water)
MERIS (Medium Resolution Imaging Spectrometer)
OLCI (Ocean Land Colour Instrument)

MERIS on Envisat-1 Launched April 2002; Ceased operations April 2012.
• Spectral Resolution = 13 visible bands
• Spatial Resolution = 300 meters
• Temporal Resolution = 3-4 scenes a week.
• Cost = Free

OLCI launched on Sentinel-3a February 2016.
• Same basic configuration as MERIS
OLCI data

Feb 28, 2017 Central California
OLCI (MERIS replacement)

Ocean Land Colour Instrument on Sentinel-3
Sentinel-3a launched February 2016.
Data after Oct 20 available
Summer data pending.

1270 km swath 300-m data
will be routine

Sentinel 3b launch planned within the year
Satellite Spatial Resolution, limits on detection

3 Pixels minimum width

Land  Land  Land  Land  Land

Land  Water  Water  Mixed  Land

Land  Mixed  Water  Water  Mixed

Land  Land  Land  Land  Land

Lake shore

300 m
Intense blooms in water, red/NIR bands provide discrimination.
CI/SS681, Cyanos have weak chlorophyll fluorescence and presence of phycocyanin
“CI” algorithm detects and quantifies blooms
Even when the bloom is not obvious.

Enhanced true color, Aug 16, 2014

Cyano index

MODIS Cyano Index (CI)
Example of non-cyano

2009Apr14 image showing “noncyano” spring bloom in south SF Bay.
Example quantification for CI, Lake Erie transferred to many other lakes

Relationship to chl-a
Tomlinson et al., 2016

Lunetta et al., 2014
Satellite sees either surface scum or surface concentration. Winds "dilute" blooms. We use 10-day maximum to correct for clouds and wind.

Figure from Wynne et al., 2013)
Considerations

CyAN project will address algorithm improvements.

Refinement of algorithms to address identified errors ("non-water", halobacteria)

OLCI data processing will shift to CyAN system for long-term
CA Surface Water Ambient Monitoring Program (SWAMP) contracted with SFEI

Develop infrastructure to process satellite imagery
Analyze data for 255 water bodies (20 in detail)
  – Historic Data
    • MERIS data from ENVIS satellite (2002-2012)
  – New Data
    • OLCI data from Sentinel-3a satellite (Oct 2016)
CA Surface Water Ambient Monitoring Program (SWAMP) contracted with SFEI

- Reporting
  - MERIS
    - Write Status and Trends report
  - MERIS and OLCI
    - Create web portal to view imagery and related data
  - OLCI
    - Inform water body managers when blooms occur
    - Issue regular bulletins and newsletters
Pixels

- Pixel size is 300m x 300m
- Pixel location always the same
- Each pixel assigned a value based on concentration

225 meters
Satellite Basics

- Estimate pixel concentrations separately for:
  - Total algal biomass
    - Cyanobacteria
    - Non-cyanobacteria
- Doesn’t measure toxins
- Generate composite images
  - 10 day running max composites
    - Detailed analysis
  - Monthly max composites
    - Statewide summary
Create Composite Images

- Review all scenes for 10 day period
- For each pixel location, determine maximum value
- Generate running 10 day max composites
Generate Statistics

- Valid composites need >17 pixels
  - NOAA recommended
- Estimate concentration in:
  - Cyanobacterial Index (CI)
  - Chlorophyll-a (ug/L)
  - *Microcystis* sp. equivalents (cells/mL)
- From each composite, generate water body-wide estimates for:
  - Mean
  - Median
  - 90th percentile of max

10 Day Max Composite
6/30/09 - 7/9/09
Generate Statistics

- Mean and median may underestimate public health risk
- 90<sup>th</sup> percentile value shows area of higher public health risk
  - Similar to event response grab samples

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<th>end_date</th>
<th>Pixels</th>
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<th>Cyano Median (cells/mL)</th>
<th>Cyano 90th % (cells/mL)</th>
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10 Day Max Composite
6/30/09 - 7/9/09
## Trigger Levels and Satellite Thresholds

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<tr>
<th>Date Range</th>
<th>Pixels</th>
<th>MC (cells/mL)</th>
<th>Median MC (cells/mL)</th>
<th>90th % MC (cells/mL)</th>
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### Primary Thresholds

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<th>Threshold</th>
<th>Action Trigger</th>
<th>Warning Tier 1</th>
<th>Danger Tier 2</th>
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<tr>
<td>Total Microcystin (^b) (\mu g/L)</td>
<td>0.8 (\mu g/L)</td>
<td>6 (\mu g/L)</td>
<td>20 (\mu g/L)</td>
</tr>
<tr>
<td>Anatoxin-a Detection (^c) (\mu g/L)</td>
<td>Detection</td>
<td>20 (\mu g/L)</td>
<td>90 (\mu g/L)</td>
</tr>
<tr>
<td>Cylindrospermopsin (\mu g/L)</td>
<td>1 (\mu g/L)</td>
<td>4 (\mu g/L)</td>
<td>12 (\mu g/L)</td>
</tr>
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### Secondary Thresholds

- **Cell Density (Toxin producing cells)**: 4,000 cells/mL
- **Site Specific Indicators of Cyanobacteria**: Blooms, scums, mats

### Satellite detection range

- **Microcystis sp. equivalents**: 10,000 – 3,100,000 cells/mL
- **Satellite 'background' level**: ~10,000 cells/mL
### Trigger Levels and Satellite Thresholds

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**Satellite detection range**
- *Microcystis sp.* equivalents
- 10,000 – 3,100,000 cells/mL
- Values have +- 15% uncertainty

**Primary Thresholds**
- Total Microcystins $^b$
  - Action Trigger: 0.8 µg/L
  - Warning TIER 1: 6 µg/L
  - Danger TIER 2: 20 µg/L
- Anatoxin-a
  - Action Trigger: Detection $^c$
  - Warning TIER 1: 20 µg/L
  - Danger TIER 2: 90 µg/L
- Cylindrospermopsin
  - Action Trigger: 1 µg/L
  - Warning TIER 1: 4 µg/L
  - Danger TIER 2: 12 µg/L

**Secondary Thresholds**
- Cell Density (Toxin producing cells): 4,000 cells/mL
- Site Specific Indicators of Cyanobacteria: Blooms, scums, mats

**Level**
- CA Action Trigger: 4,000 cells/mL
- Satellite 'background' level: ~10,000
- Low Risk (WHO): <20,000
- Moderate Risk (WHO): 20,000-100,000
- High Risk (WHO): >100,000
- Very High Risk (Proposed): >1,000,000
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**Primary Thresholds**
- Total Microcystins: 0.8 µg/L (TIER 1), 6 µg/L (TIER 2), 20 µg/L (TIER 2)
- Anatoxin-a: Detection (TIER 1), 20 µg/L (TIER 2), 90 µg/L (TIER 2)
- Cylindrospermopsin: 1 µg/L (TIER 1), 4 µg/L (TIER 2), 12 µg/L (TIER 2)

**Secondary Thresholds**
- Cell Density (Toxin producing cells): 4,000 cells/mL
- Site Specific Indicators of Cyanobacteria: Blooms, scums, mats

**Level** | **Value (cells/mL)**
--- | ---
Low Risk | 10,000-20,000
Moderate Risk | 20,000-100,000
High Risk | 100,000-1,000,000
Very High Risk | >1,000,000

Understand exceedance of ‘thresholds’
- How often?
- How long?
- How many waterbodies?
Historic satellite data for San Luis Reservoir

All data is preliminary
Please do not cite
Mean cyanobacteria cell concentration, estimated in Microcystis sp. equivalents (cells/mL) for San Luis Reservoir, CA, 2002-2012

Estimated Cell Concentration (cells/mL)
Mean and 90% percentile of max value for cyanobacteria cell concentration, estimated in both Microcystis sp. equivalents (cells/mL) for San Luis Reservoir, CA, 2002-2012
90th percentile of maximum cyanobacteria cell concentration, estimated in Microcystis cells/mL for San Luis Reservoir, CA, 2002-2012
Daily minimum, average, and maximum of 90th percentile of maximum cell concentration, estimated in Microcystis cells/mL for San Luis Reservoir, CA, 2002-2012
Region 7, 8, and 9 Summary
monthly composites (not 10 day)
Number of months where composites meet >17 pixels threshold for water bodies within Regions 7, 8, and 9 for June, 2002- March 2012
Number of months where 90th percentile 90th percentile values exceed Moderate, High, or Very High Risk thresholds for water bodies within Regions 7, 8, and 9 for June, 2002- March 2012
Number of months where 90th percentile values exceed Moderate, High, or Very High Risk thresholds for water bodies within Regions 7, 8, and 9 for June, 2002- March 2012

![Bar chart showing number of months exceeding risk thresholds for various water bodies](chart.png)
Statewide Summary

- 255 water bodies
- Monthly composites
Monthly number of 255 water bodies where pixel counts are >17; <=17; or 0, from June 2002 to March 2012
Number of water bodies where 90th percentile values within monthly composites exceed Moderate, High, or Very High Risk thresholds for June 2002 to March 2012.
Annual average number of water bodies where 90th percentile concentration estimates within monthly composites exceed Moderate, High, or Very High thresholds for June, 2002- March 2012
Monthly average number of water bodies where 90th percentile concentration estimates within monthly composites exceed Moderate, High, or Very High Risk thresholds, for June, 2002- March 2012.
Mean and 90% percentile of max value for cyanobacteria cell concentration, estimated in Microcystis sp. equivalents (cells/mL) for Big Bear Lake, CA, 2002-2012

Blooms at high altitude lakes in winter?!
Re-run statewide analysis to remove likely false positives
Assess monthly data for May – October only
Monthly Exceedances (May - Oct) Southern California
Monthly Exceedances (May - Oct)
Central California
Monthly Exceedances (May - Oct) Northern California
What do satellite images tell us about harmful algal blooms?

DRAFT CyanoHAB Satellite Imagery Analysis Tool
CyanoHAB Satellite Imagery Analysis Tool

- Display spatial and time series data
CyanoHAB Satellite Imagery Analysis Tool

- Compare satellite data to WQ data in CEDEN
CyanoHAB Satellite Imagery Analysis Tool

- Download satellite or CEDEN data
Cyanobacteria blooms can be detected but…
- Clouds and glint block images
- Estimates all cyanobacteria (not just toxin producers)
- Doesn’t measure toxin levels
- No direct comparisons to HAB thresholds
- Values are estimates (NOAA recommends +/-15% uncertainty)
- Less confidence with data for lowest concentration
- False positives can occur
- Limited to large lakes (currently)
Satellites - What They Can Do

- Cyanobacteria blooms can be detected and...
  - Provide understanding of bloom conditions from 2002-2012
    - Identify trends and severity of blooms
  - Data can help understand bloom drivers, management
  - Screening tool - Monitor ~150 waterbodies in CA at once
  - Inform public about changing bloom status and location
  - Communicate data to help guide event response monitoring by:
    - Water body managers
    - County public health officials
    - Others involved in management or response

SWAMP needs YOUR contact information!
Further Research Needed

• Continue testing satellite data for interference:
  – Snow/ice?
  – Alkali lakes?
  – Halobacteria? (Owens Lake)
  – Clear water? (Lake Tahoe)
• Satellite raster data is available through SFEI. Compare against:
  – Water quality/cyanoHAB data
  – Weather
  – Inflow/lake levels
  – Geology
  – 303 (d) listings
  – Etc.
Questions?

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