The Future of Water Quality from Space

The Rising Demand for Water Quality Monitoring, and how Remote Sensing can Cover it

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with contributions by:

The GEO Water Quality Working Group/Community of Practice
The Physics of Aquatic Systems Laboratory at EPFL-ENAC
The ESA DUE Diversity II Project Team
and many others

International Ocean Colour Science Meeting 2015 | Advancing Global Ocean Colour Observations

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Brockmann Consult

eawag aquatic research

Content

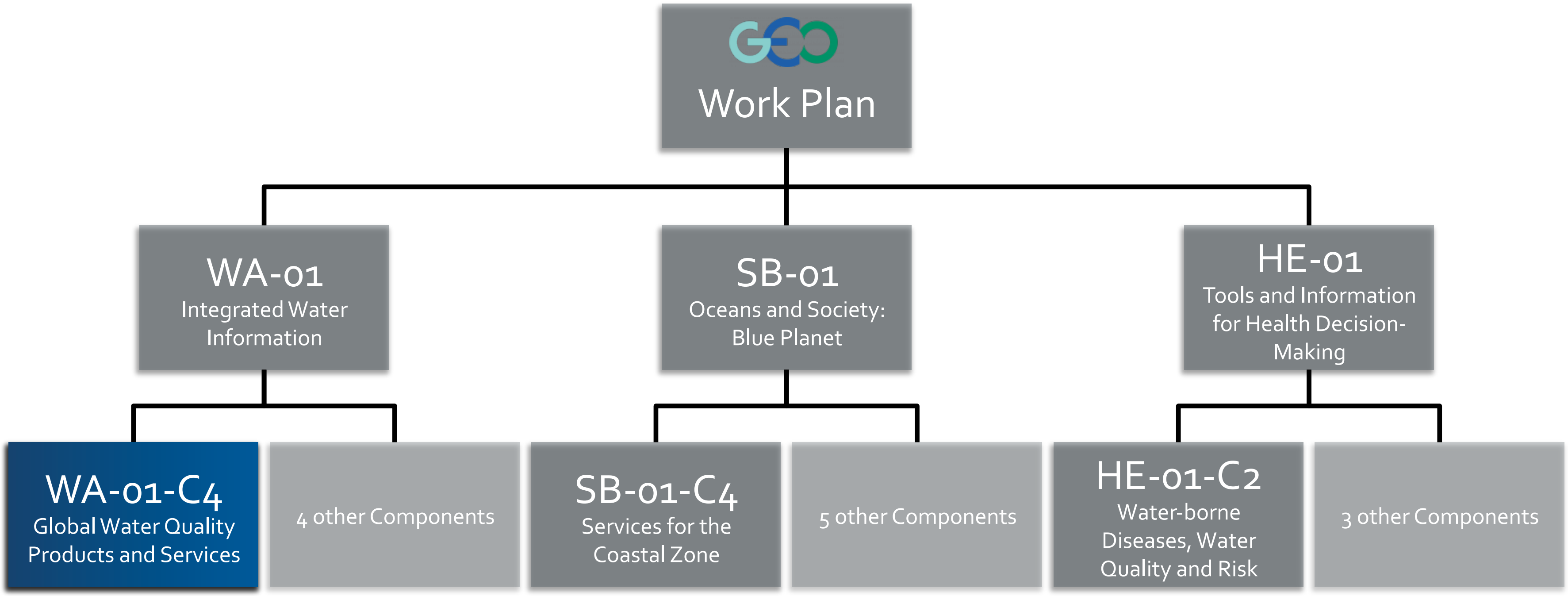
Introduction: GEO Context and State-of-the-Art

Water Resource Management Concepts, Constitution of Demand and Stakeholders

Opportunities and Challenges from a Remote Sensing Point of View

GEO Inland and Near-Coastal Water Quality Working Group

"Aims to develop international water quality information systems based on EO with a focus on the developing world"



http://www.geo-water-quality.org, http://www.earthobservations.org/geoss_imp.php

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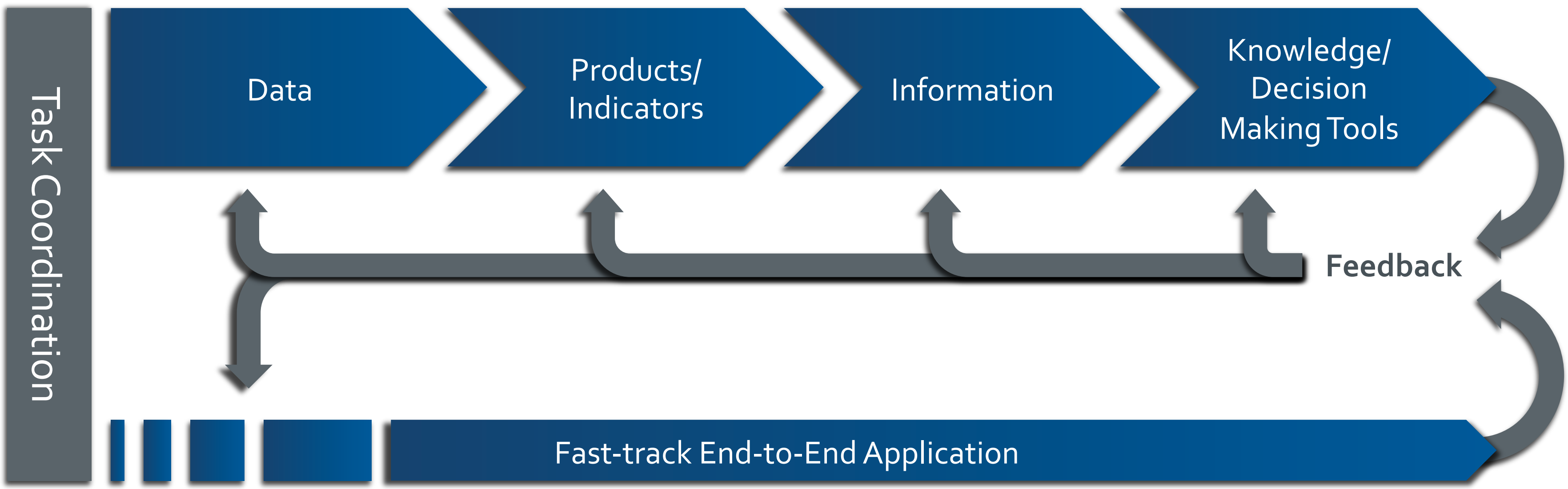

http://www.geo-water-quality.org

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Emerging from *Case 2* Remote Sensing

"Hence, the classification scheme rendered a huge service to the bio-optical oceanography and ocean colour remote sensing communities. However, the continued use of Case 1 and Case 2 today ***is no longer helping us solve the remaining scientific problems****. In truth, this classification scheme may bring ambiguity, confusion, misuse, or an excuse for poor performance of algorithms."*

- For oceans, the scheme enabled the development of standard algorithms and operational applications
- For inland waters, mainly MERIS enabled the establishment of quasi-operational applications, although methods remain unconsolidated

Mobley, C.D., Stramski, D., Bisset, W.P., and Boss, E. (2004). Optical modeling of ocean water: Is the case 1 - case 2 classification still useful? Oceanography 17, 60–67.

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Review of Prevalent Methodology

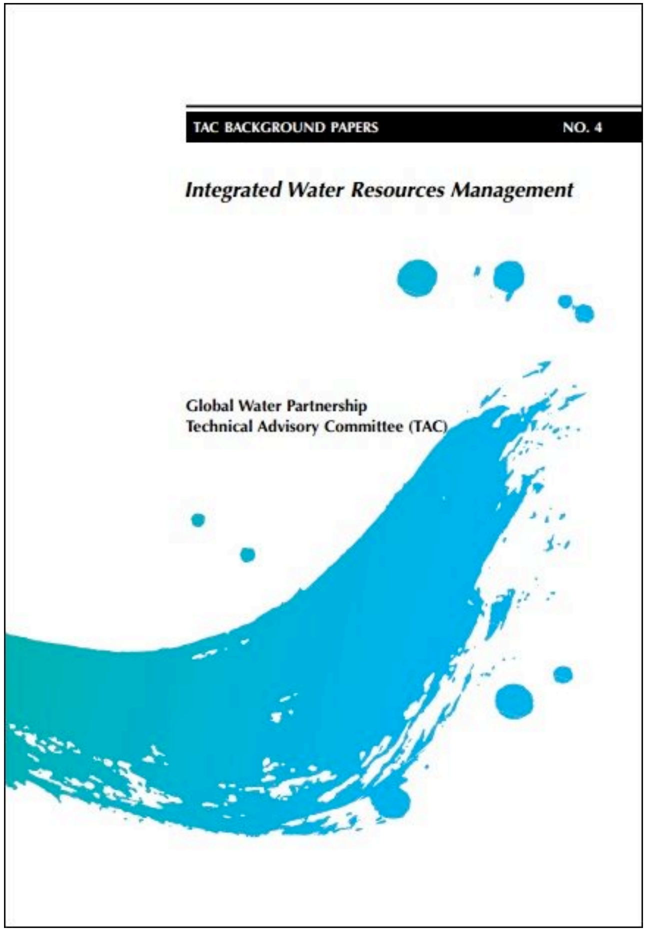
- Out of 50 ISI papers on constituent retrieval in optically complex and deep waters published between 2006-2011, 75% referred to band arithmetic algorithms
- Accurate atmospheric with unsupervised, automated methods is difficult for inland waters, and therefore often avoided (BRR, retrieval from R_{TOA})
- Neural networks provide a robust means for spectral inversion, but lack the flexibility provided by non-linear optimization procedures

Odermatt, D., Gitelson, A., Brando, V.E., and Schaepman, M.E. (2012). Review of constituent retrieval in optically deep and complex waters from satellite imagery. Remote Sens. Environ. 118, 116–126.

Integrated Water Resource Management

- Global Water Partnership (2000):
  *"Integrated water resource management is a process which promotes the **coordinated development and management of water, land and related resources**, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems"*

- Extends across several levels:
  - A normative idea
  - A strategic policy
  - An operational approach



Global Water Parthership (2000). Integrated Water Resources Management. TAC Background Paper, No. 4 (Stockholm, Sweden).
Watson, N. (2004). Integrated river basin management: A case for collaboration. Int. J. River Basin Manag. 2, 243–257.

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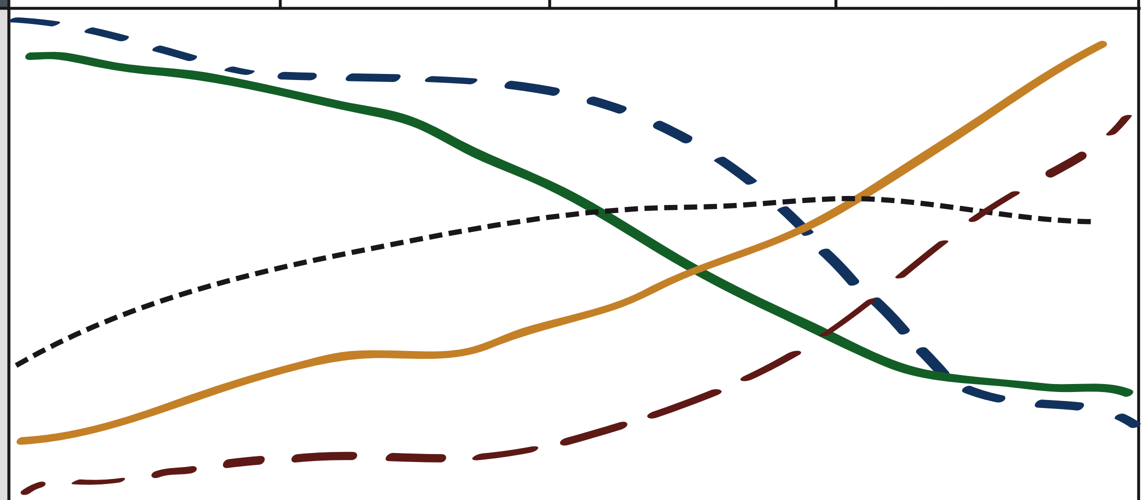
A Normative Idea across Development Stages

	Stage I: Completely Informal	Stage II: Largely Informal	Stage III: Formalizing	Stage IV: Highly Formal Water Industry
% of water users in the formal sector	**<5%**	**5-35%**	**35-75%**	**75-95%**
Examples	Sub-Saharan Africa	India, Pakistan, Bangladesh	Mexico, Thailand, Turkey, Eastern China	USA, Canada, Western Europe, Australia
Dominant mode of water service provision	Self-supply and informal mutual-help community institutions	Partial public provisioning but self-supply dominates	Private-public provisioning; attempts to improve service and manage the resource	Rise of modern water industry; high intermediation; self supply disappears
% of total water use self-supplied **Rural population as % of total** **Cost of water service provision** **Cost of domestic water as % of per capita income** **Human, technical, financial resources used by water sector**				
Concerns of the Governments	Infrastructure creation in welfare mode	Infrastructure and water services, especially in urban areas	Infrastructure and service in towns and villages; cost re-covery; resource protection	Integrated management of water infrastrcture, service and resource; resource protection
Institutional Arrangements	Self-help; mutual help and feudal institutions dominate	Informal markets; mutual help and community management institutions	Organized service providers; self-supply declines; informal institutions decline in significance	Self-supply disappears; all users get served by modern water industry

Shah, T. (2007). Issues in reforming informal water economies of low income countries: Examples from India and elsewhere. In: Community-based water law and water resources management reform in developing countries (Oxford, United Kingdom: CABI), p. 31.

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- Little interface between users and public institutions
- Regulations are ineffective
- Incentive-based social and technological measures needed
- Identify emerging problems

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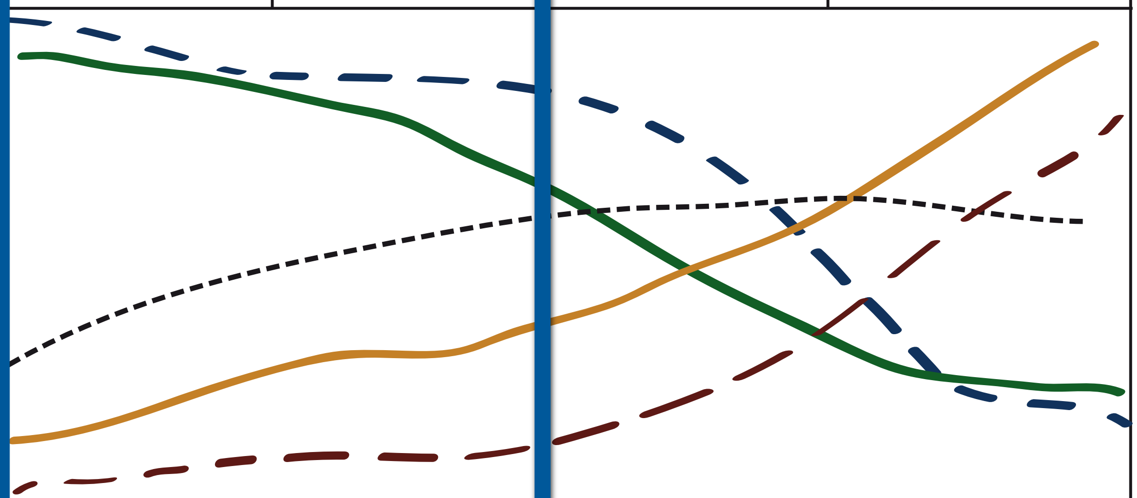
Human, technical, financial resources used by water sector



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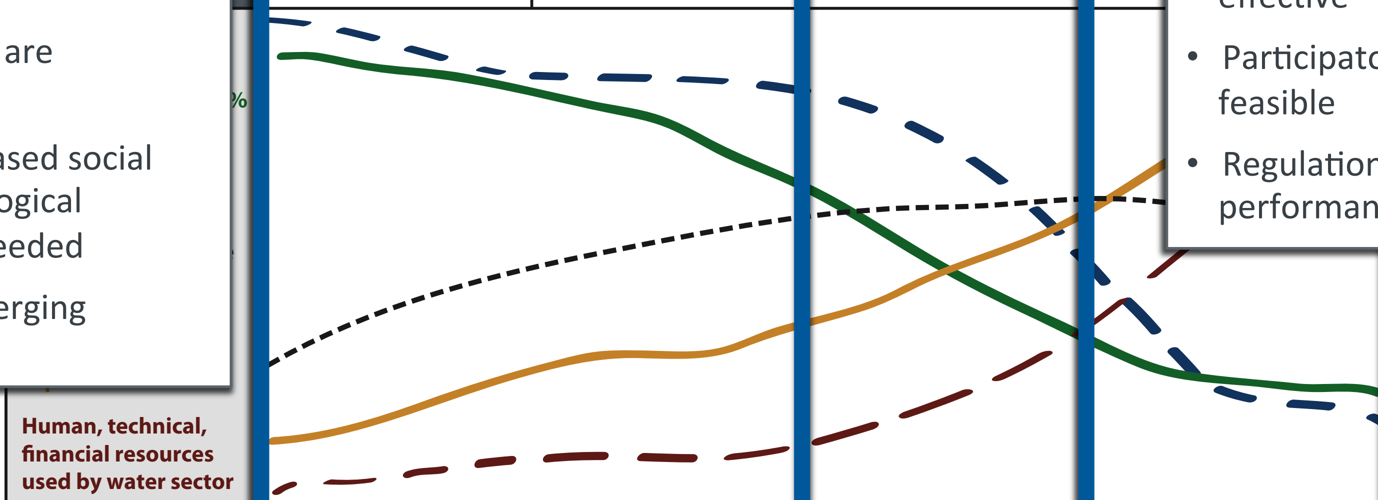

- Economical, fiscal and legal measures are effective
- Participatory conception feasible
- Regulations call for performance assessment

Shah, T. (2007). Issues in reforming informal water economies of low income countries: Examples from India and elsewhere. In: Community-based water law and water resources management reform in developing countries (Oxford, United Kingdom: CABI), p. 31.

Specific Requirements of Development Stages

Water Resource Management Concepts, Constitution of Demand and Stakeholders

Formal Water Industries

Informal Water Industries

Opportunities and Challenges from a Remote Sensing Point of View

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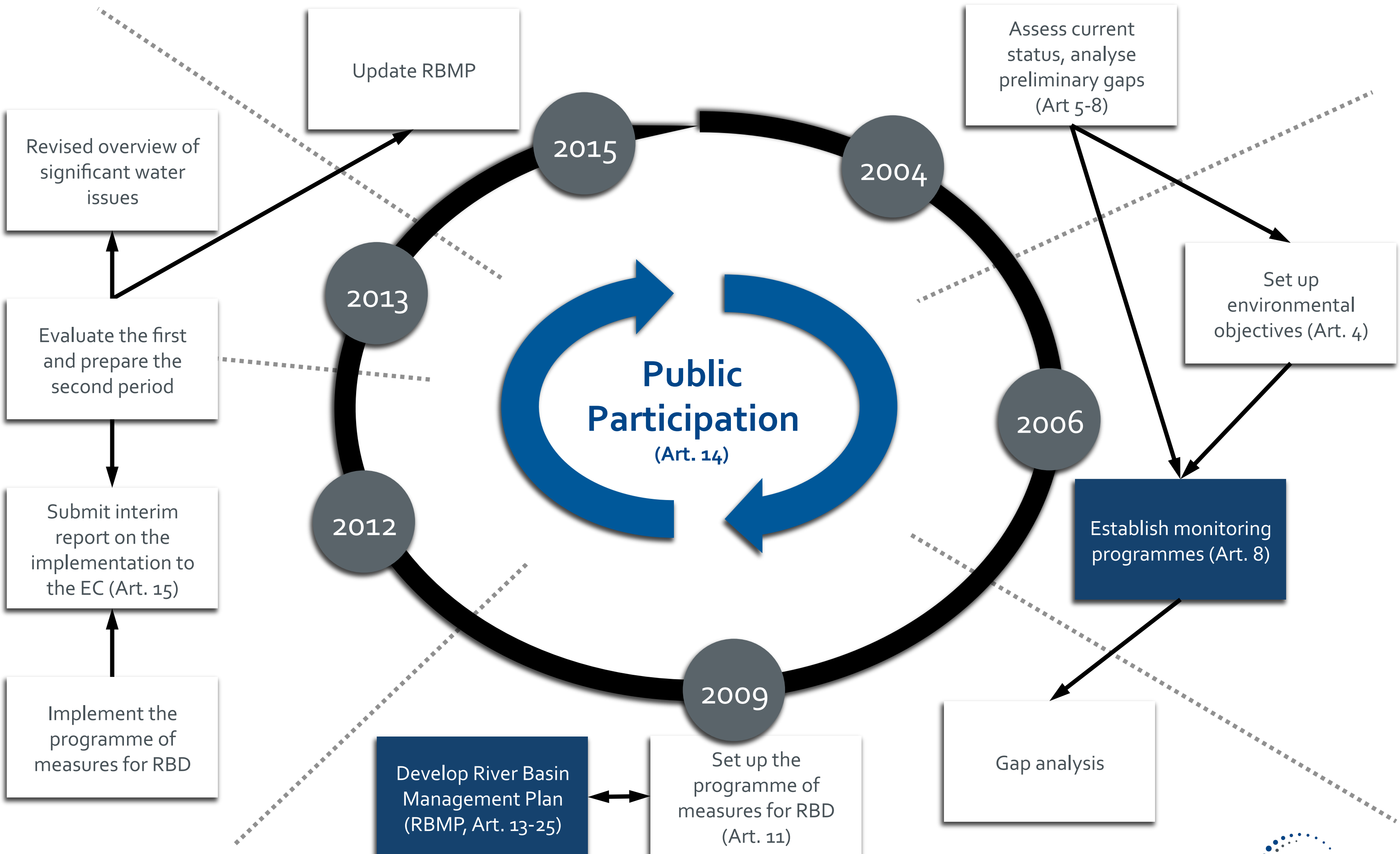
A Strategic Policy: WFD Implementation



http://www.eea.europa.eu/themes/water/water-management/river-basin-management-plans-and-programme-of-measures

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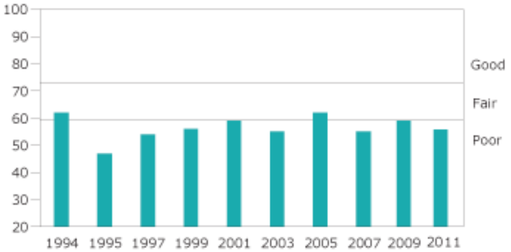
Monitoring Formalized Water Sectors

- Commissioning/executing organizations:

Comprehensive

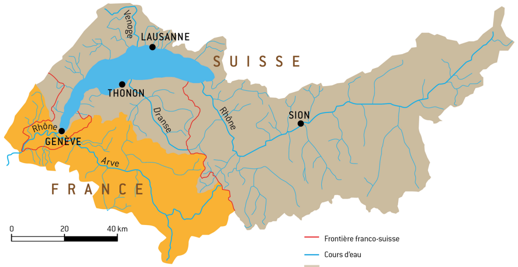
e.g. Tennessee Valley Authority, a "socialistic" multi-functional bureaucracy funded under the New Deal and today's largest public power utility in the US

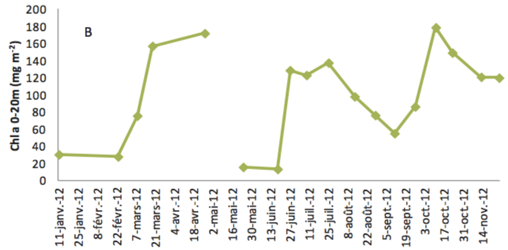


Russell, D. (1949). The TVA Idea. The Foundation for Economic Education (Irving-On-Hudson, New York).

Integrative

e.g. CIPEL, a multi-national commission coordinating the protection of Lake Geneva in political, technical and administrative regards

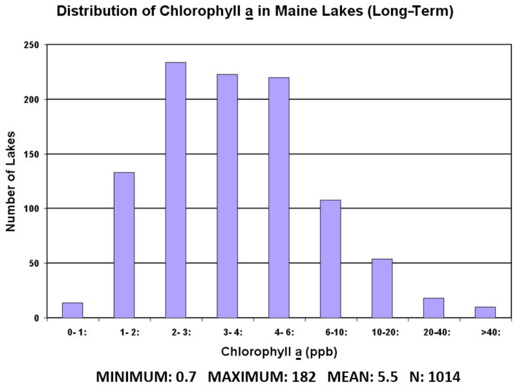




http://www.cipel.org

Private industry

e.g. Nestlé Water, holding 32% of US bottled water market, subject of critical media reports and sponsor of the Maine Volunteer Lake Monitoring Program



http://www.mainevlmp.org

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Monitoring in Formalized Water Sectors

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Summary of Water Quality Monitoring Objectives

Formal Water Industries (EPA):

http://water.epa.gov/type/watersheds/monitoring/monintr.cfm

- Characterize waters and changes or trends in water quality
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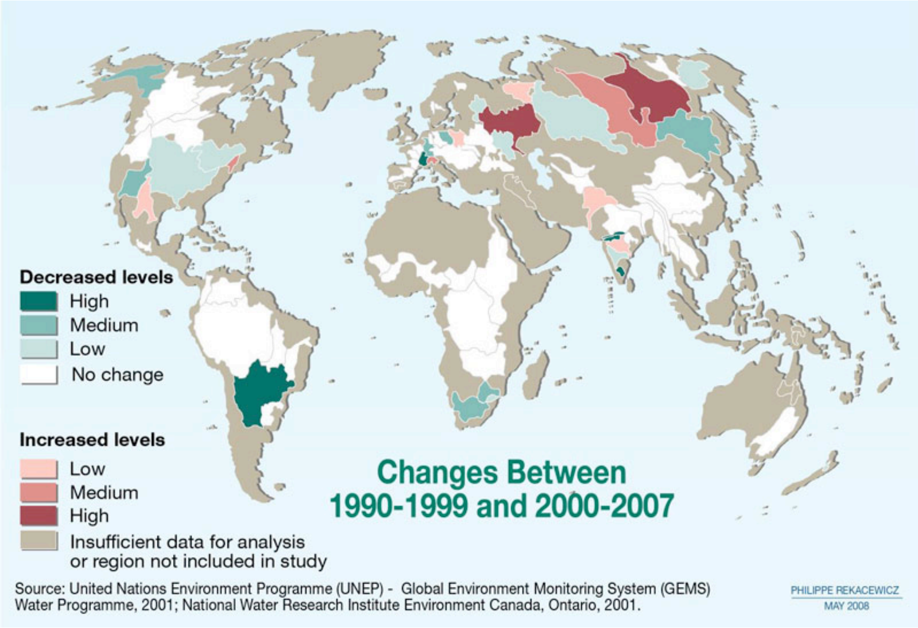
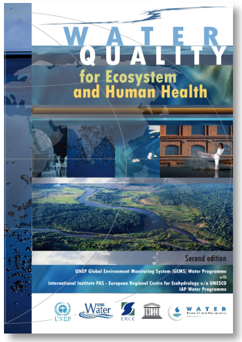
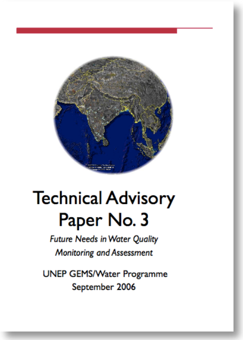
UNEP GEMS/Water Monitoring Database

- Voluntary UNEP program of about 100 countries (2008)
- Was recently revived by the German Federal Institute for Hydrology
- Aims to collect, analyse and re-distribute global water quality data



Changes in Nitrate at river mouths
(http://www.un.org/waterforlifedecade/quality.shtml)





UNEP GEMS/Water Programme (2006). Future Needs in Water Quality Monitoring and Assessment (Burlington (Canada)).
UNEP GEMS/Water Programme (2008). Water Quality for Ecosystem and Human Health, 2nd Edition (Burlington (Canada)).

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Millennium Development Goals (MDGs)

- Focus on WAter, Sanitation and Hygiene (WASH)
  - Drinking water target (88%) surpassed already in 2012
  - Sanitation target (75%) unlikely to be achieved

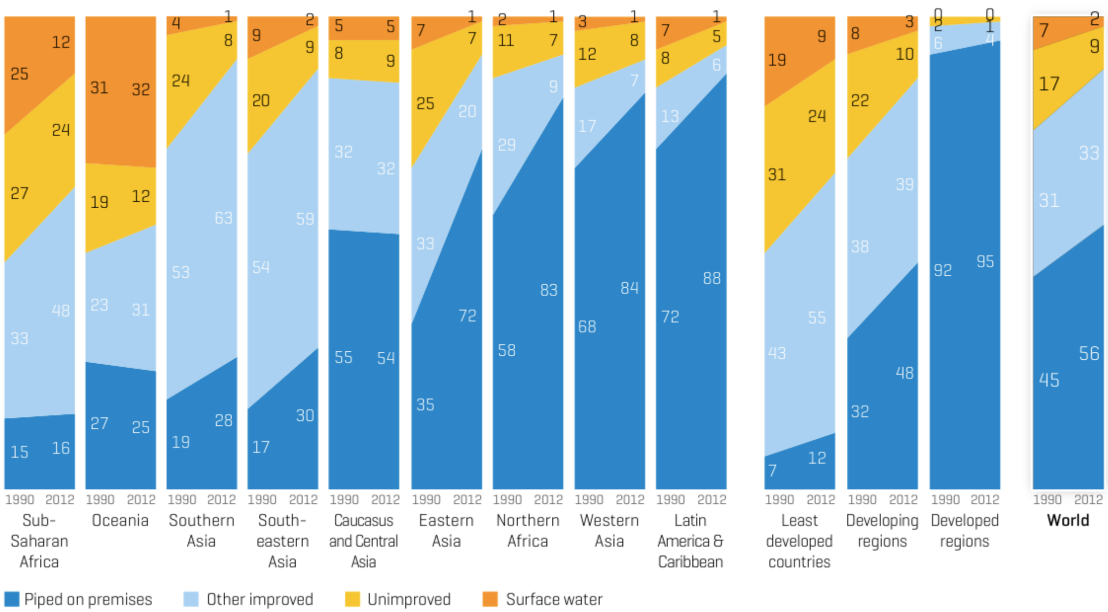
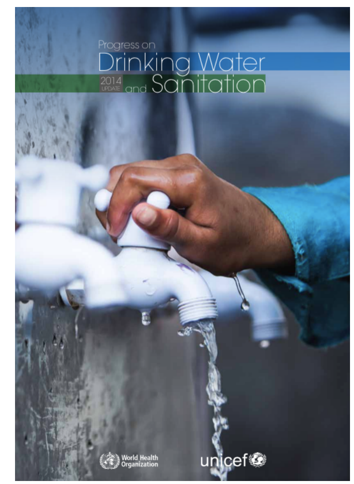


Fig. 5. Trends in drinking water coverage (%) by developing region, 1990–2012



WHO/UNICEF (2014). Progress on Drinking Water and Sanitation - 2014 Update (Geneva, Switzerland: WHO Press).

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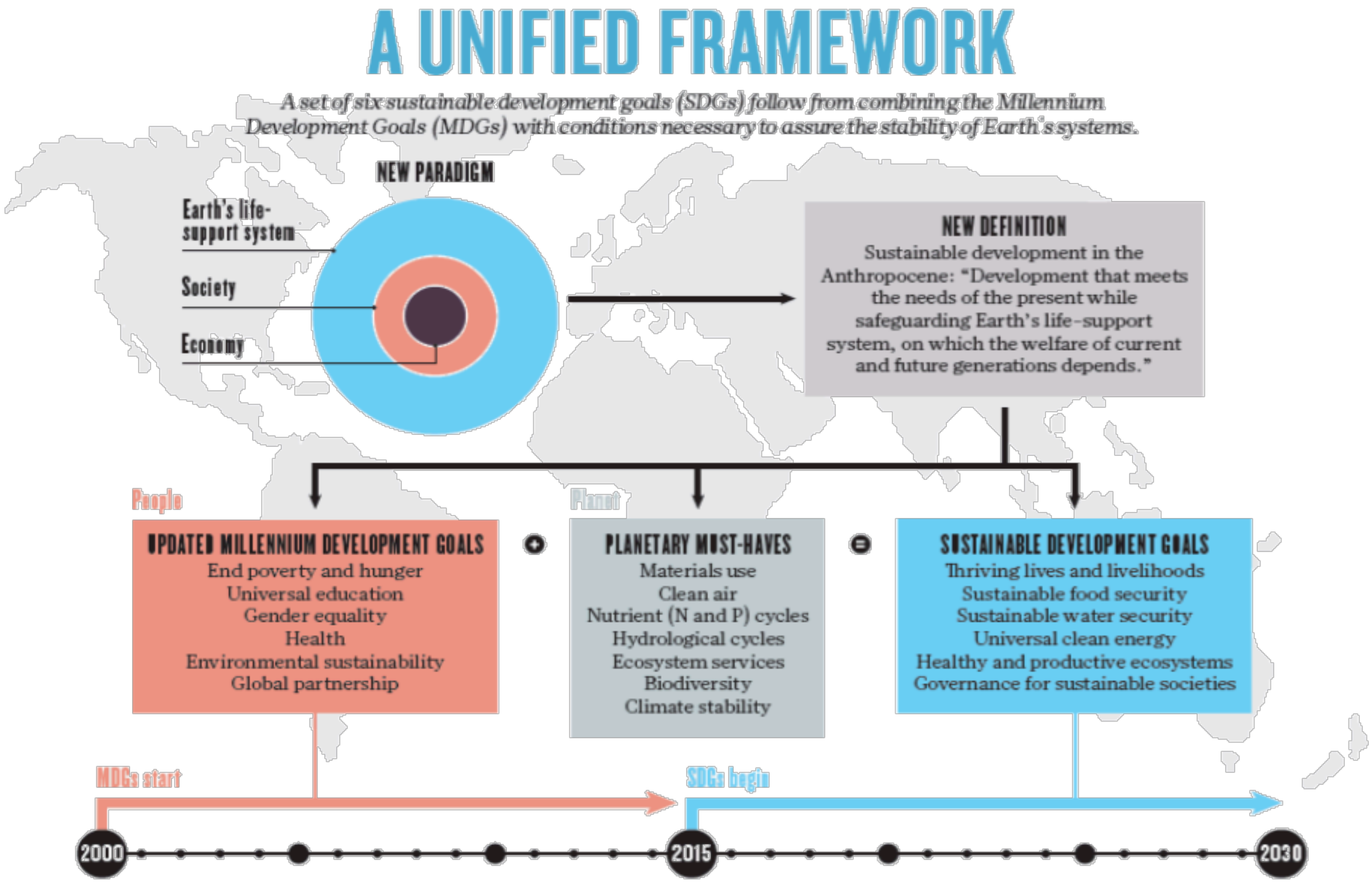
Post-2015 Development Concept



Griggs, D., Stafford-Smith, M., Gaffney, O., Rockstrom, J., Ohman, M.C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., and Noble, I. (2013). Policy: Sustainable development goals for people and planet. Nature 495, 305–307.

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SDG 6 objectives proposed by the Open Working Group on Sustainable Development Goals and UN-Water:

- 6.1 by 2030, achieve universal and equitable access to safe and affordable drinking water for all
- 6.2 by 2030, achieve access to adequate and equitable sanitation and hygiene for all, and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
- 6.3 by 2030, **improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials**, halving the proportion of untreated wastewater, and increasing recycling and safe reuse by x% globally
- 6.4 by 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity, and substantially reduce the number of people suffering from water scarcity
- 6.5 by 2030 **implement integrated water resources management** at all levels, including through trans-boundary cooperation as appropriate
- 6.6 by 2020 **protect and restore water-related ecosystems**, including mountains, forests, wetlands, rivers, aquifers and lakes

http://www.un.org/waterforlifedecade/waterandsustainabledevelopment2015/open_working_group_sdg.shtml

SUSTAINABLE DEVELOPMENT GOALS

More at sustainabledevelopment.un.org/sdgsproposal

Global Expanded Monitoring Initiative (GEMI)

- Fundamental part of the SDG implementation concept
- Builds on existing UN efforts related to monitoring
  - WHO/UNICEF Joint Monitoring Programme for Water (JMP)
  - FAO AQUASTAT
  - UNEP GEMStat
- Standalone measure to obtain global environmental information
- Complementary measure to assess the sustainability of development aid projects (e.g. WASH)

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Informal Water Industries (GEMI):

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- Enlarge and complement existing monitoring
- Efficiently fill gaps in existing monitoring framework
- Provide evidence of WASH SDG and align data collection and reporting
- Enable informed decisions in the allocation of resources towards WASH related SDG targets

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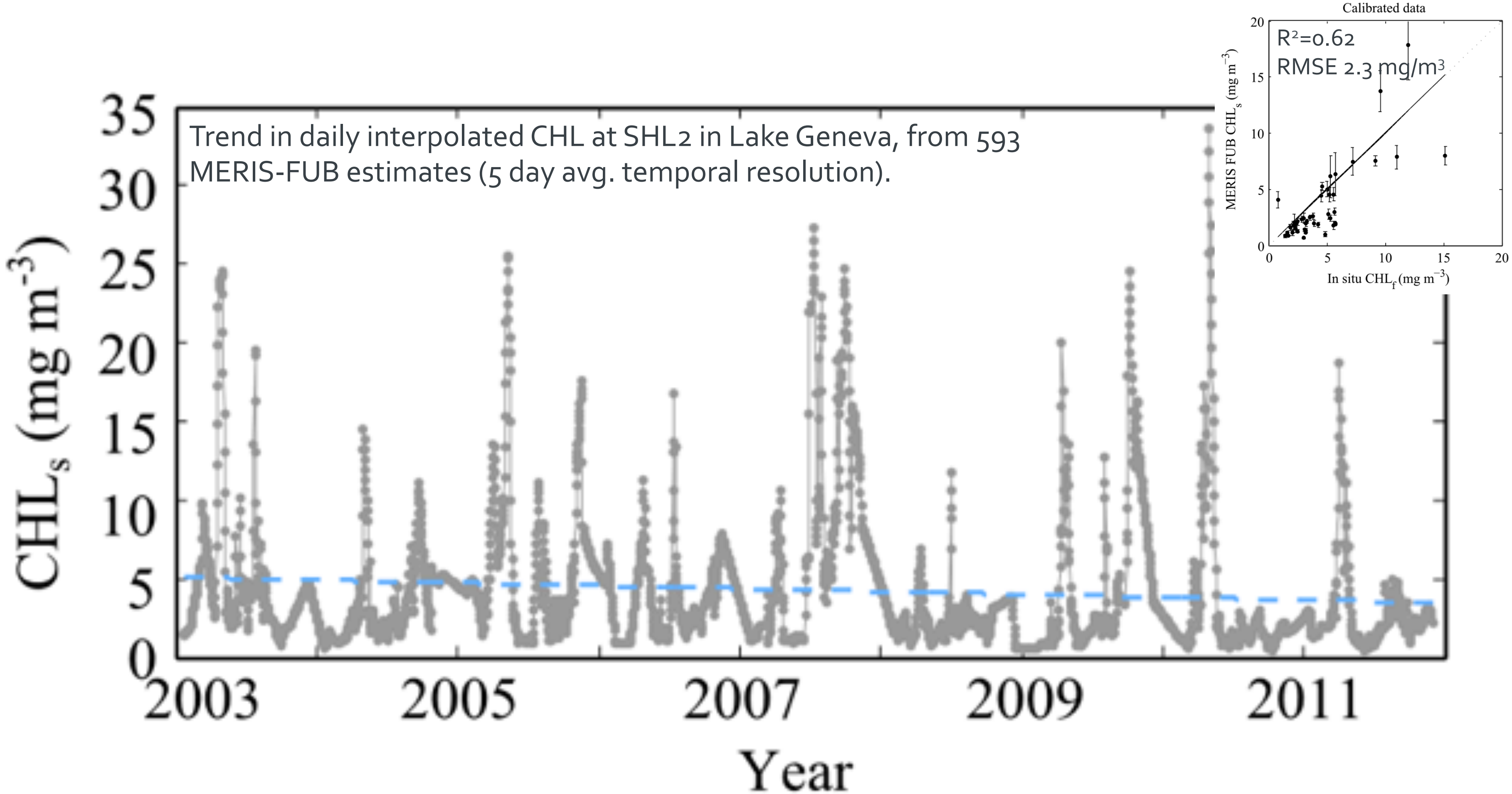
Characterize Changes or Trends in Water Quality



Kiefer, I., Odermatt, D., Anneville, O., Wüest, A., and Bouffard, D. (2015). Application of remote sensing for the optimization of in-situ sampling for monitoring of phytoplankton abundance in a large lake. Sci. Total Environ. 527–528, 493–506.

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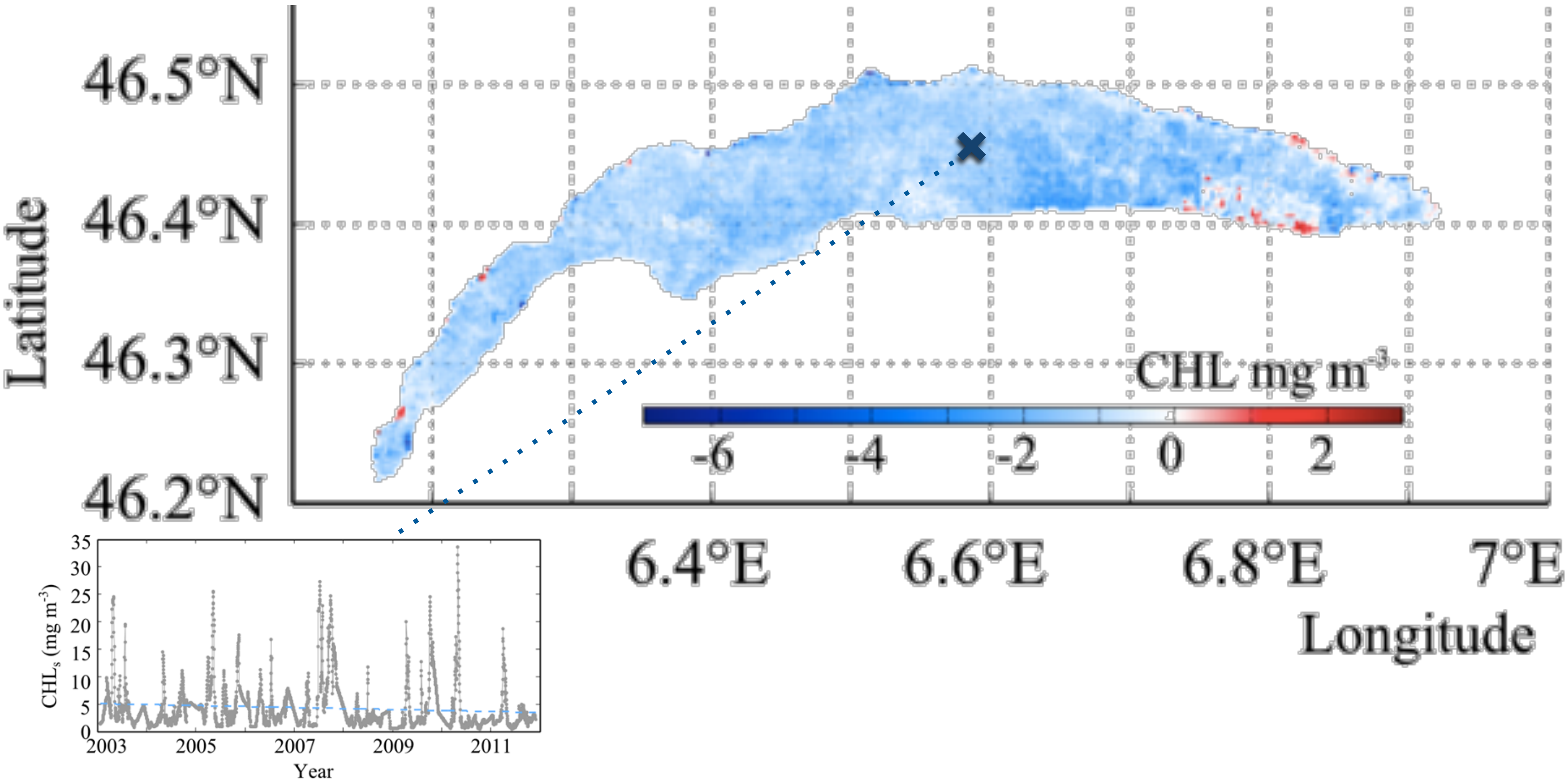

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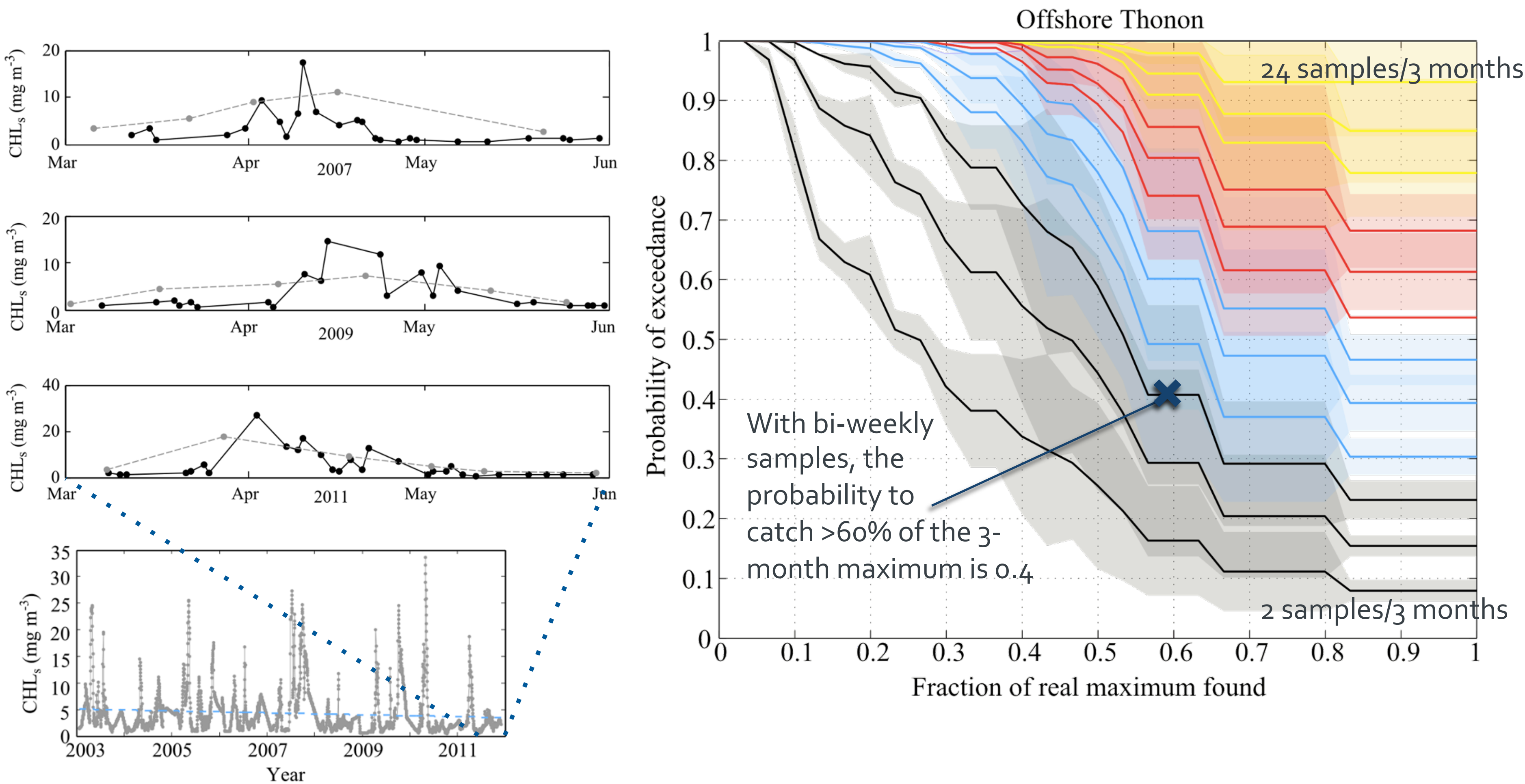

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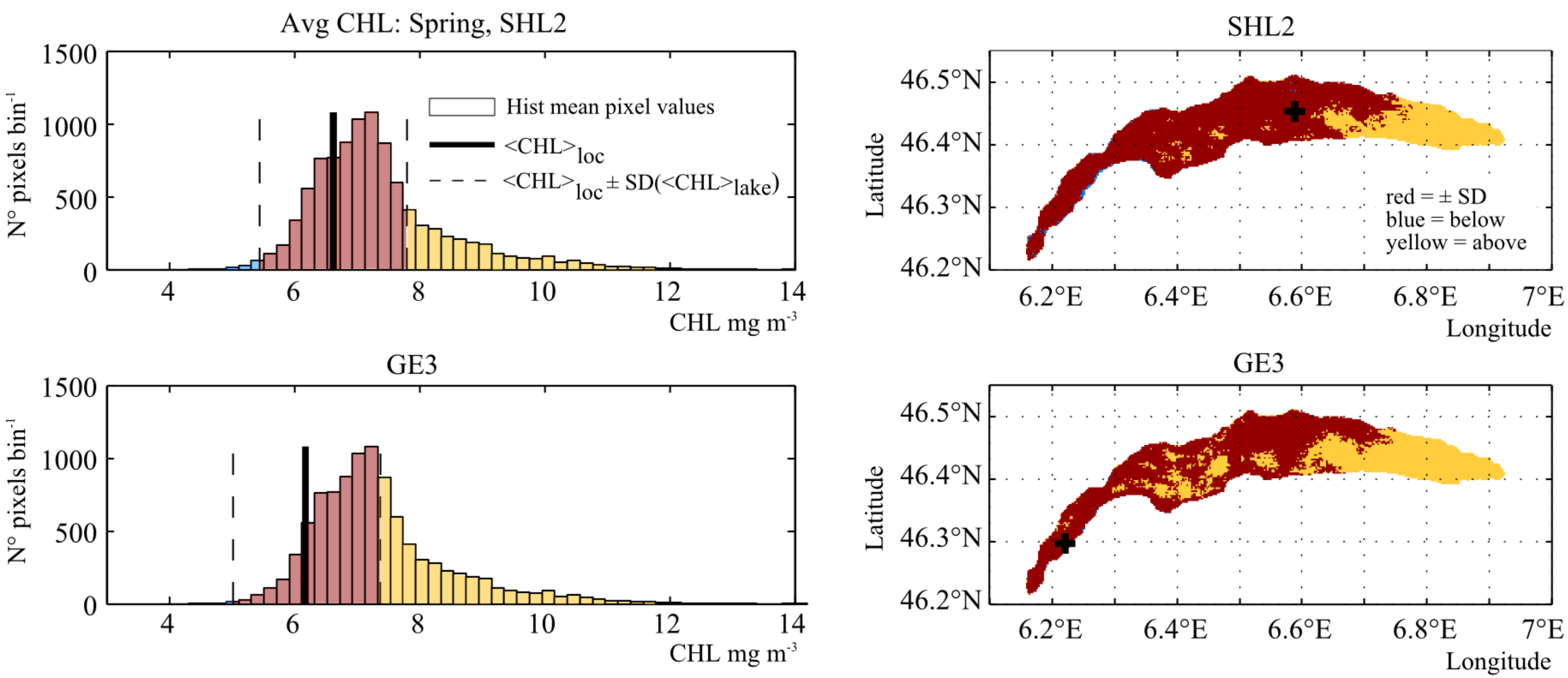
Gather Information to Design Water Management Programs



MERIS-FUB 9-year averaged spring CHL in sampling sites SHL2 and GE3, and areas represented by +/- std. dev.

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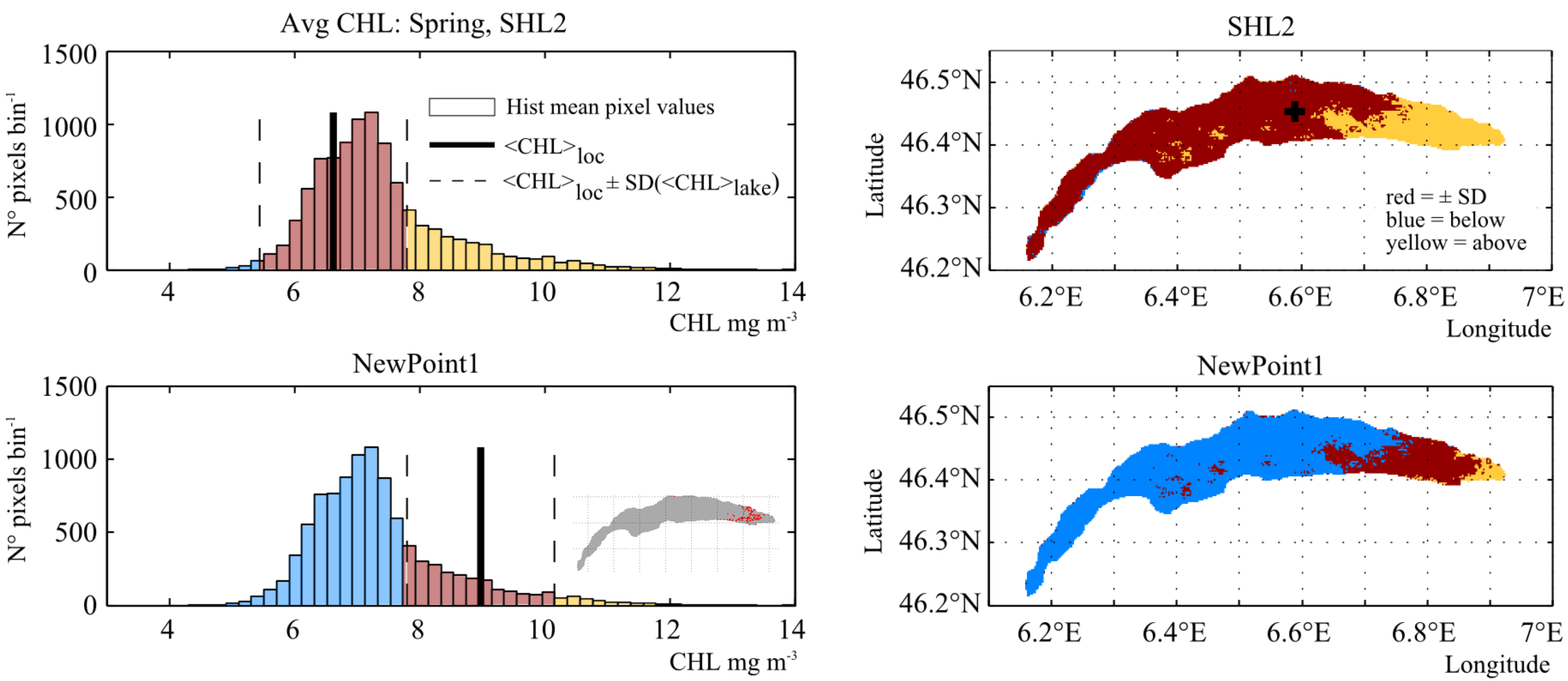

NewPoint1: Suggested locations to represent the area with average spring CHL above SHL2 + std. dev.

Kiefer, I., Odermatt, D., Anneville, O., Wüest, A., and Bouffard, D. (2015). Application of remote sensing for the optimization of in-situ sampling for monitoring of phytoplankton abundance in a large lake. Sci. Total Environ. 527–528, 493–506.

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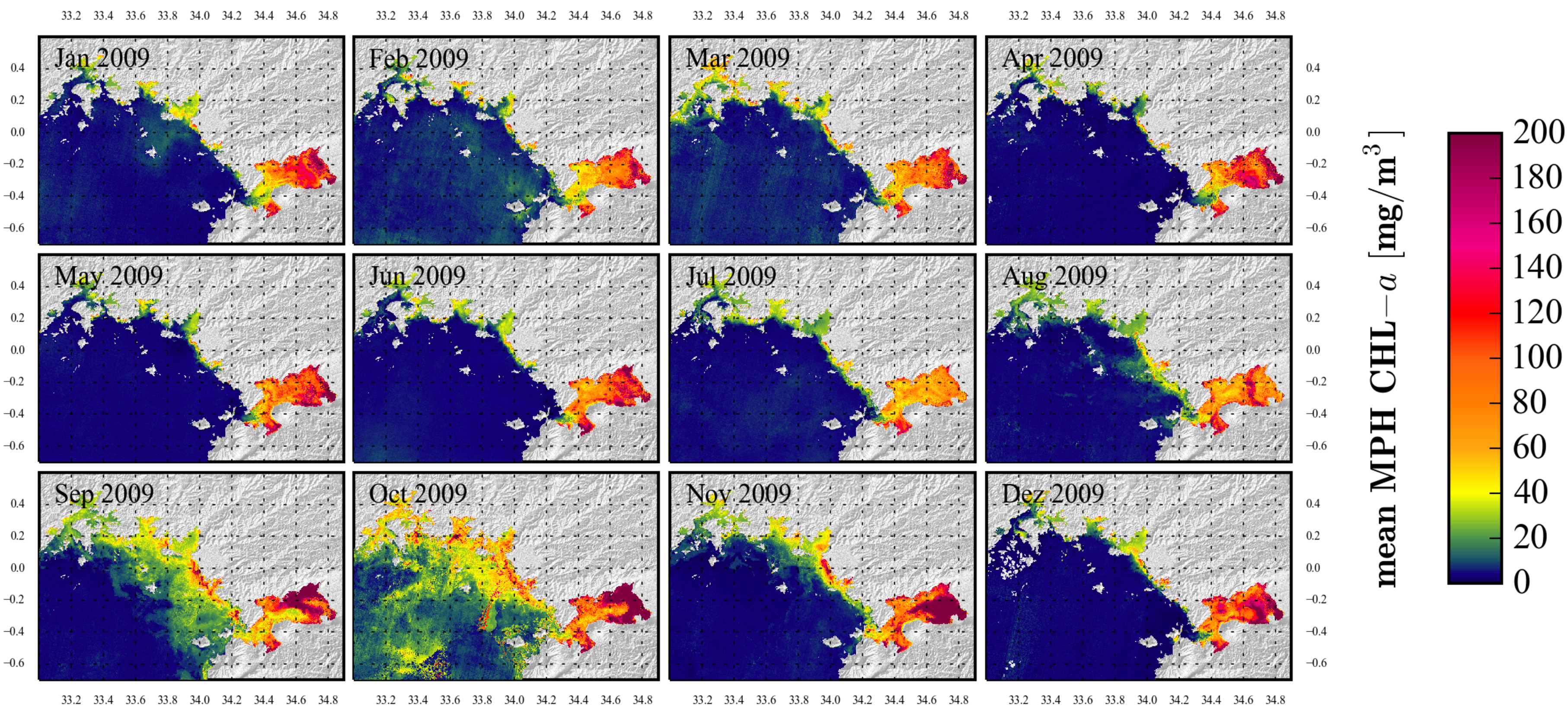
Identify Specific Existing or Emerging Water Quality Problems

Lake Victoria monthly mean chl-*a*



Ledang, O. & Odermatt, D.: Traces of Eutrophication in Winam Gulf, Lake Victoria
Products and Biodiversity story available from www.diversity2.info

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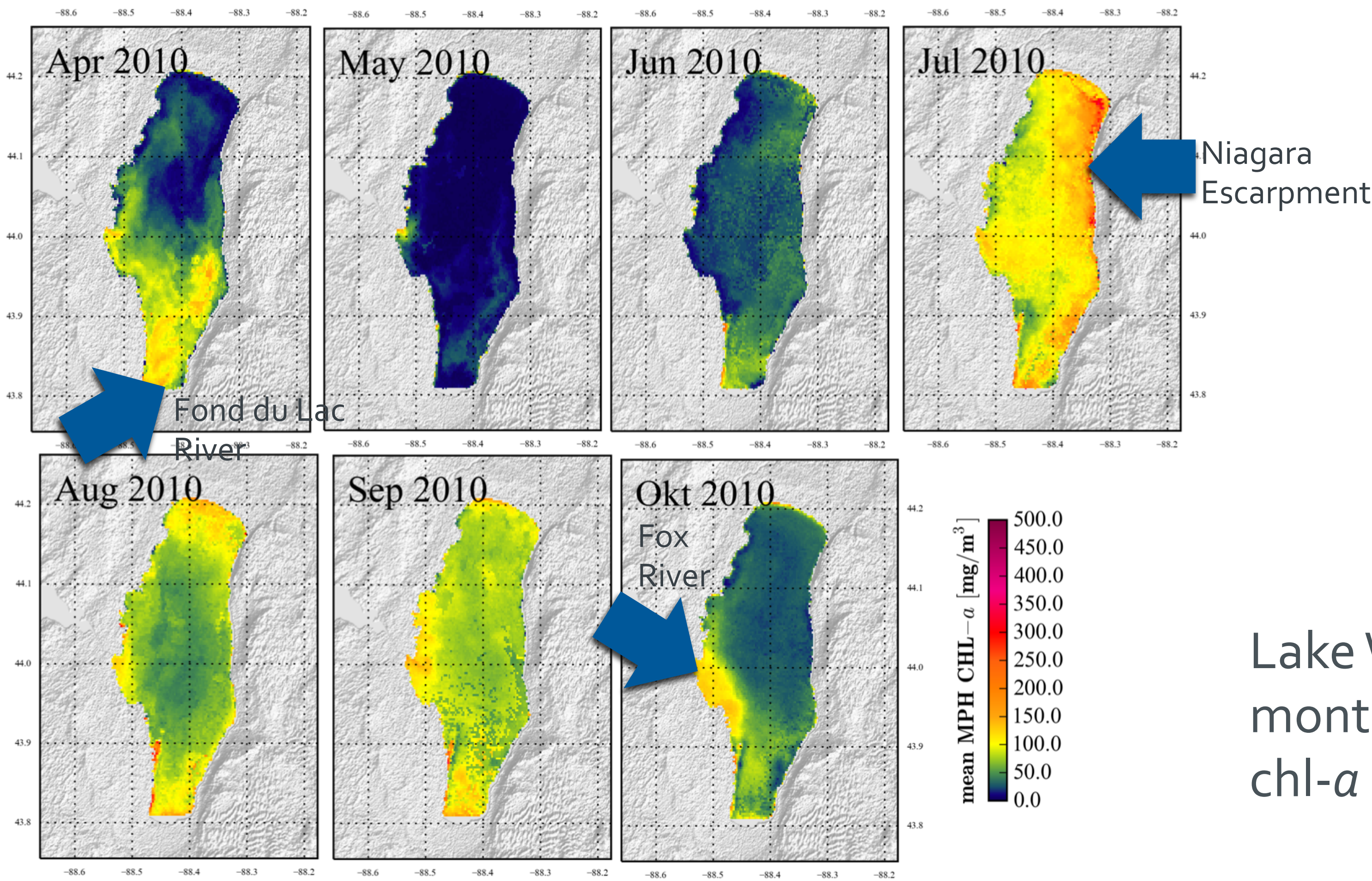

Lake Winnebago monthly mean chl-*a*

Greb, S. & Miller, T.: Toxic Cyanobacterial Blooms in Lake Winnebago
Products and Biodiversity story available from www.diversity2.info

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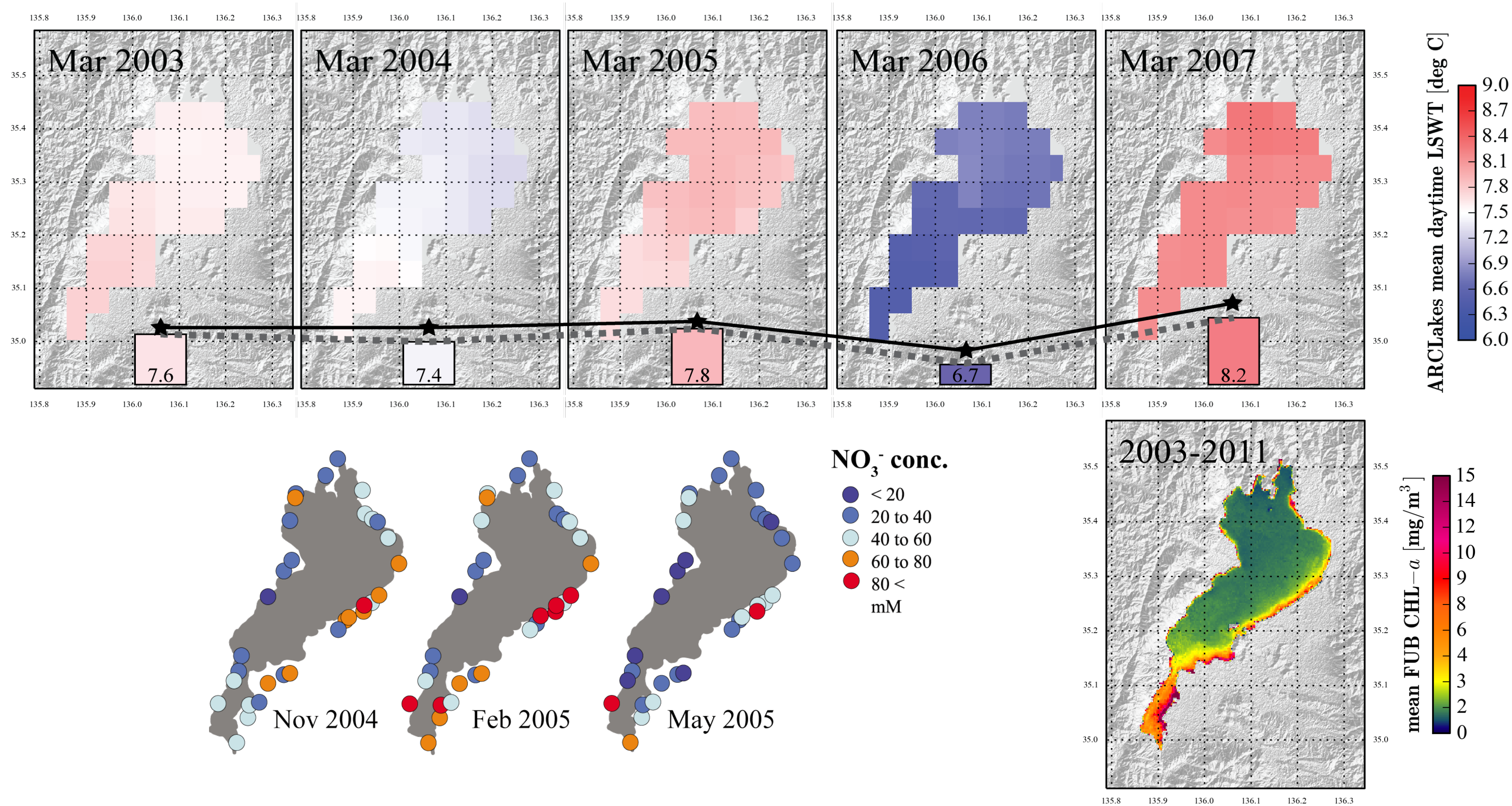

Odermatt, D.: Earth Observation indicators for hypoxia in Lake Biwa
Products and Biodiversity story available from www.diversity2.info
Temperature data (solid line) from Univ. Tsukuba, Nitrate concentrations from Ohte et al. (2010)

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Usefulness of CaLimnos per Monitoring Objective

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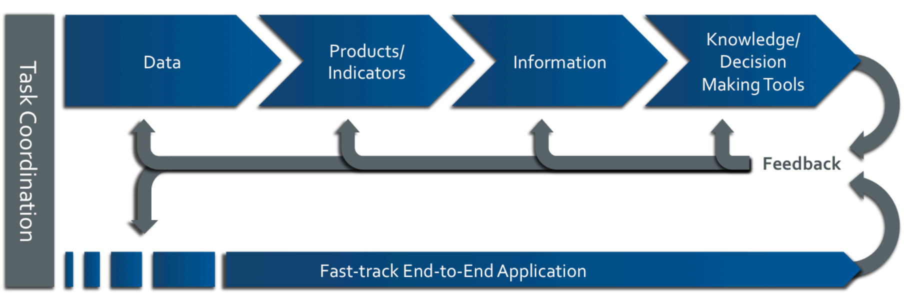
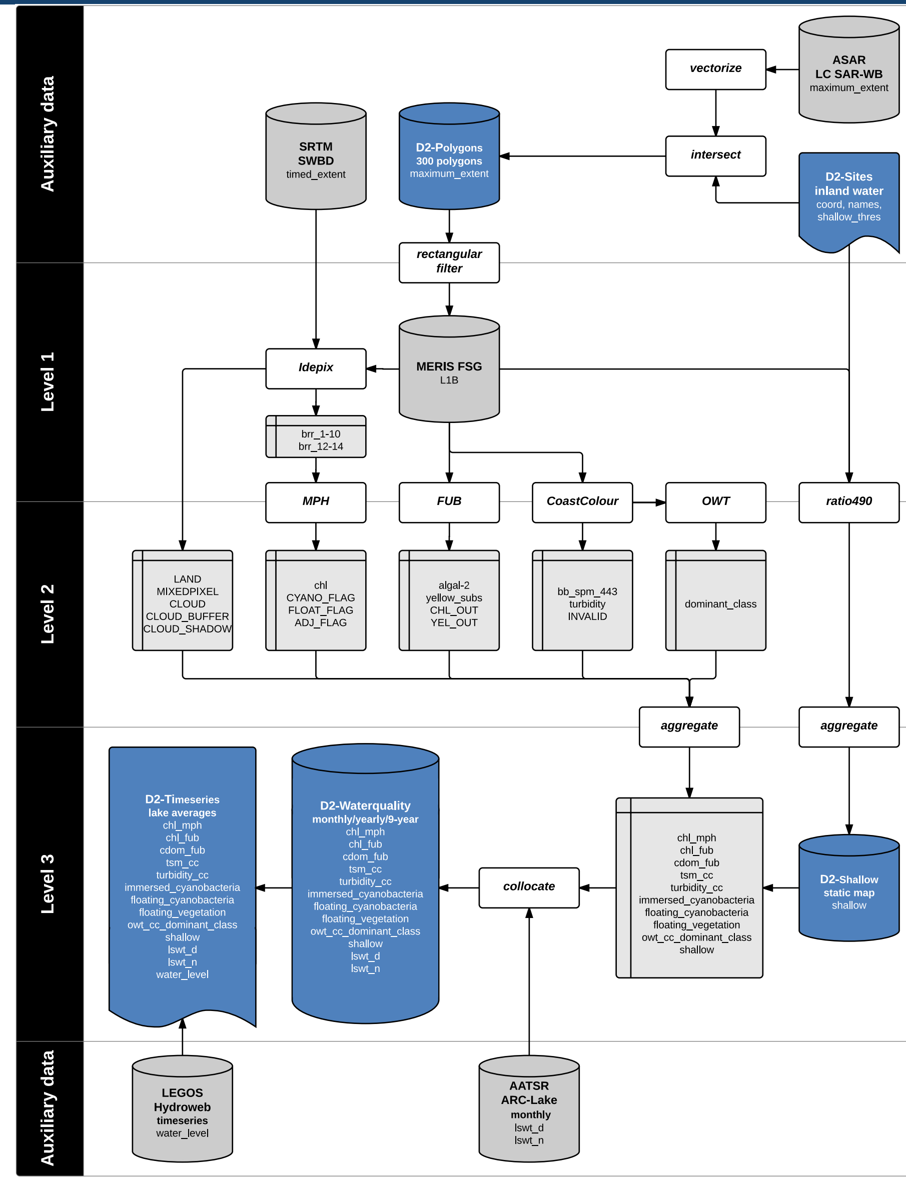
Diversity II: End-to-end Application Prototype

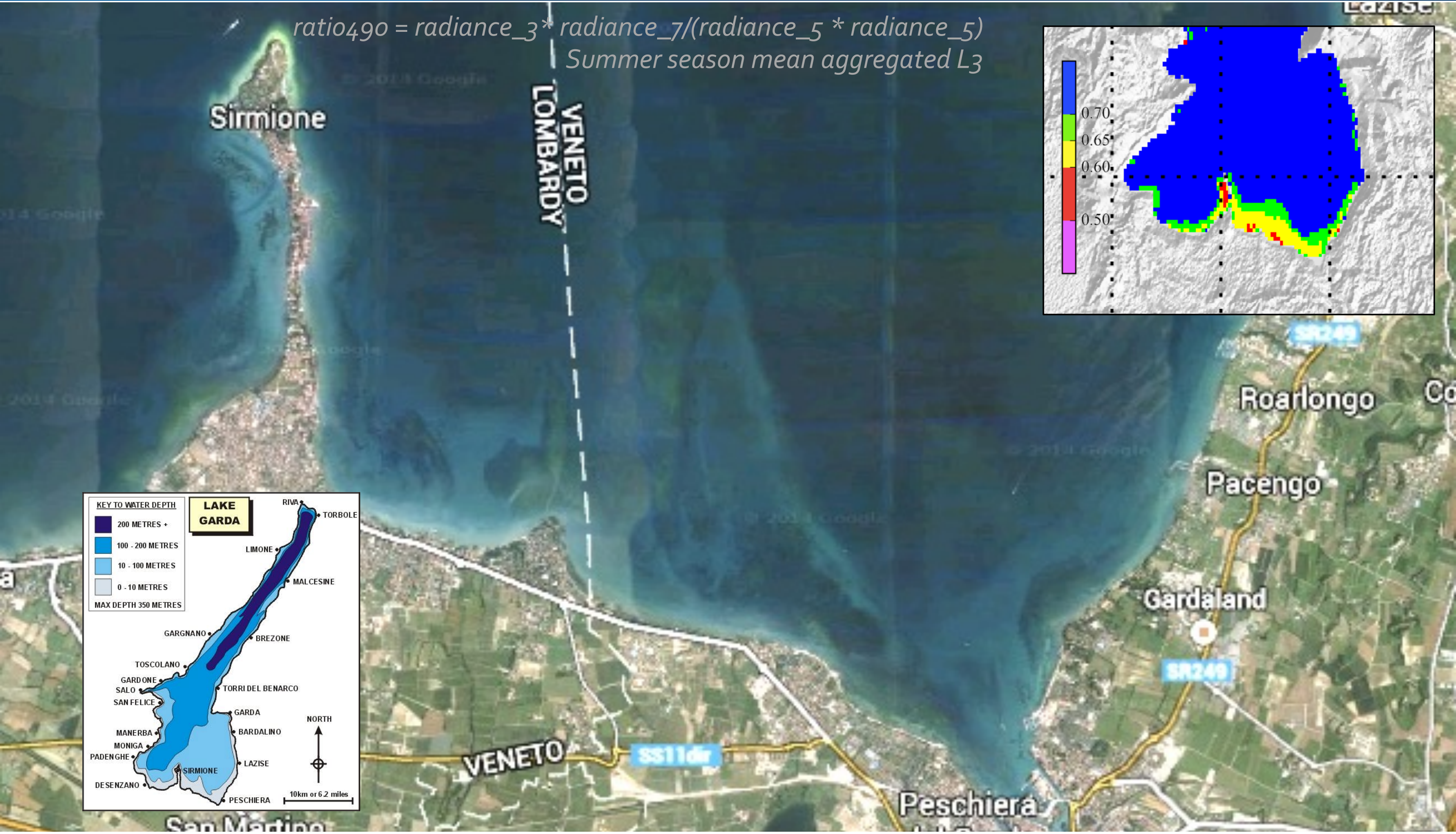
- CaLimnos automated processing chain for MERIS FR
- Validated with chl-*a* measurements from 40 lakes
- Applied to 350 lakes
- chl-*a*, tsm, turbidity, cdom, lswt, water level
- Further development in Globolakes





Delineating Optically Shallow Waters

ratio490 = radiance_3 radiance_7/(radiance_5 * radiance_5)*
Summer season mean aggregated L3

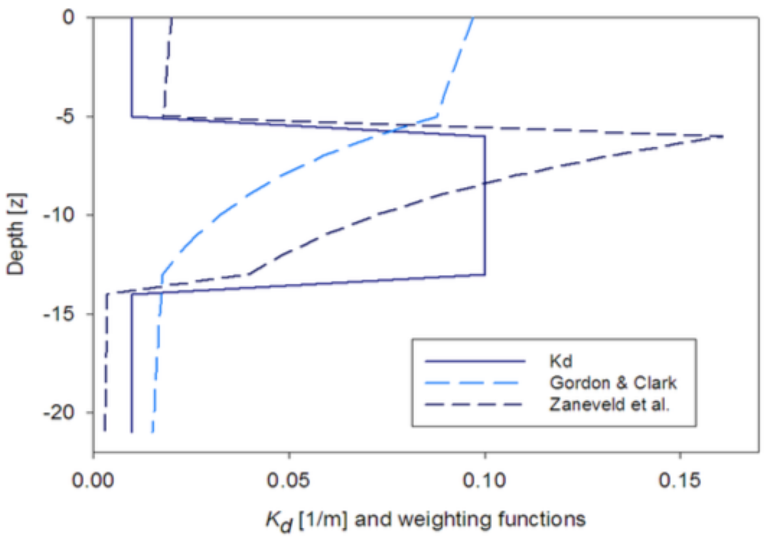


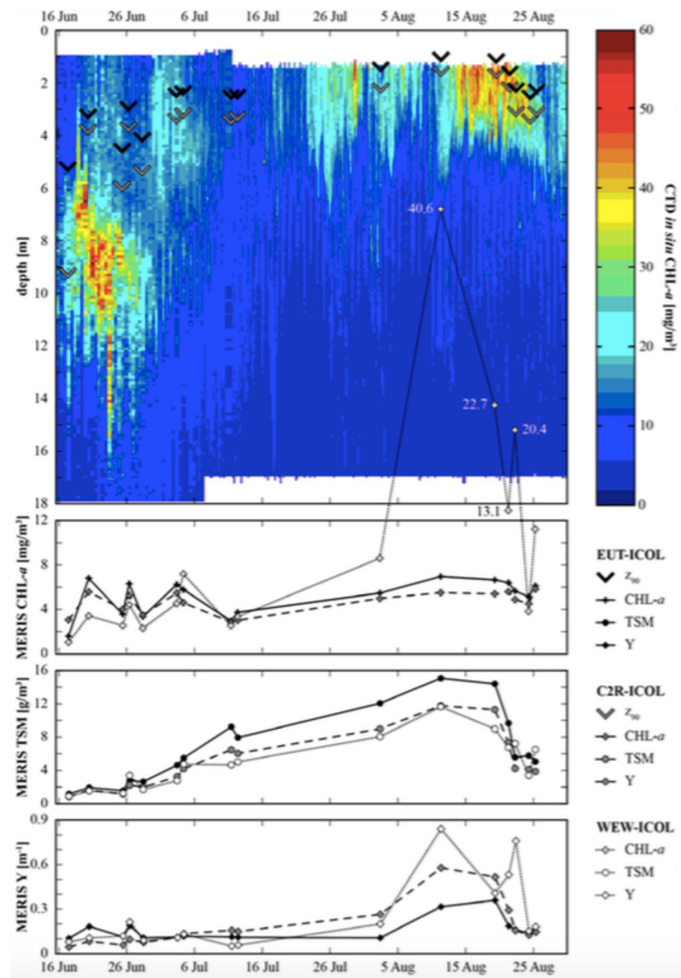
Challenges on the Way Ahead

- Identify and bridge gaps in existing methodology, including scientifically less rewarding ones

Stratification and Vertical Heterogeneity

- Signal depth represented by the derivative of the round-trip attenuation
- How is chl-*a* calculated with wave-lengths representing different depths?





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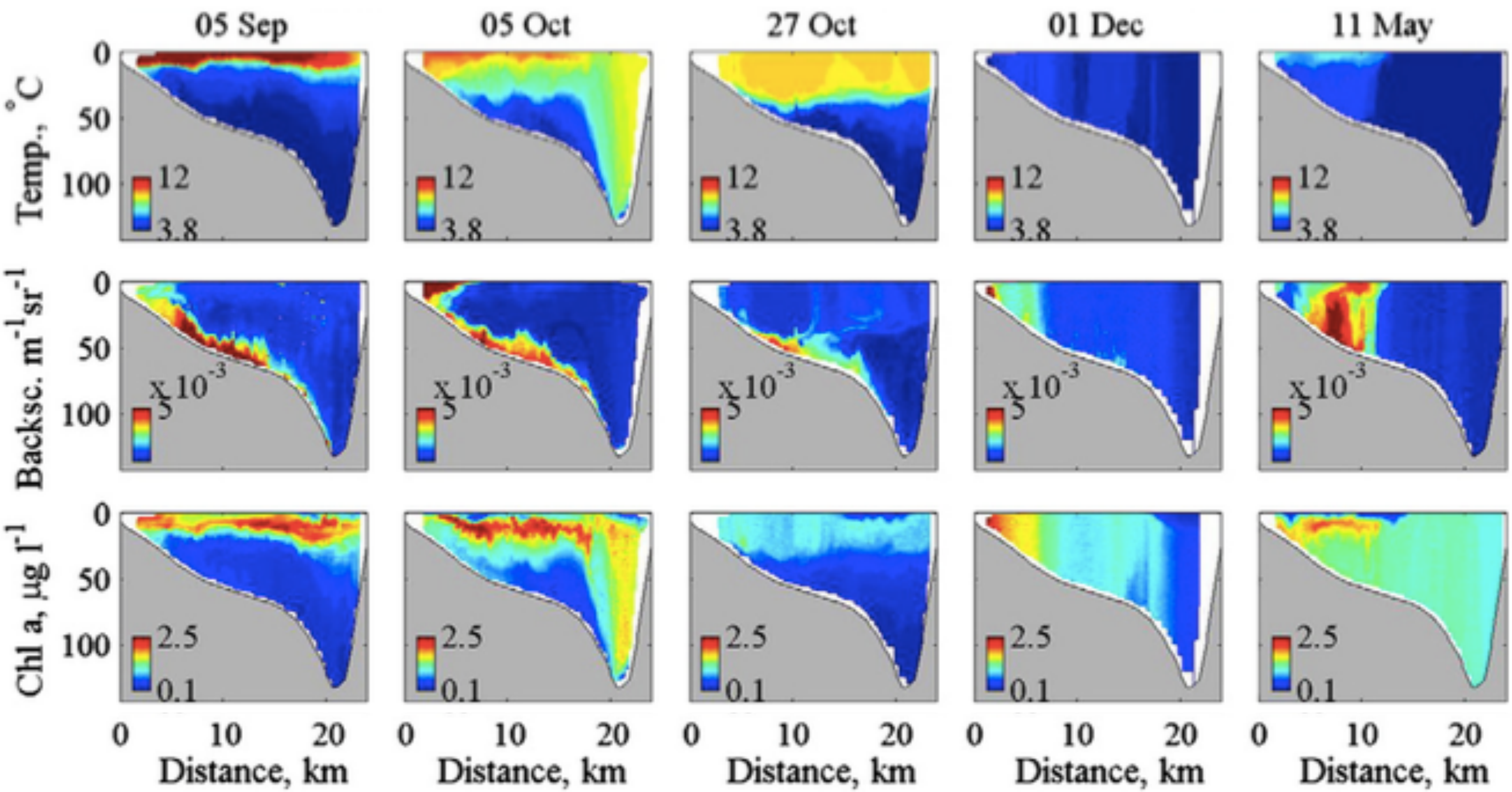
Stratification and Vertical Heterogeneity



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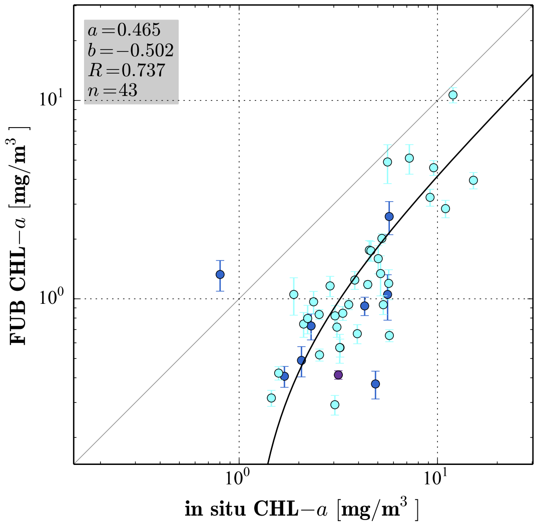
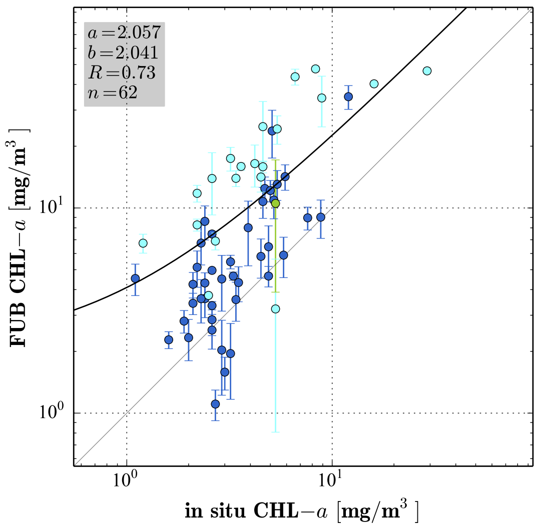
Challenges on the Way Ahead

- Identify and bridge gaps in existing methodology, including scientifically less rewarding ones
- Assimilate complementary information sources
  - Automated profilers
  - Autonomous underwater vehicles
  - Hydrodynamic modeling

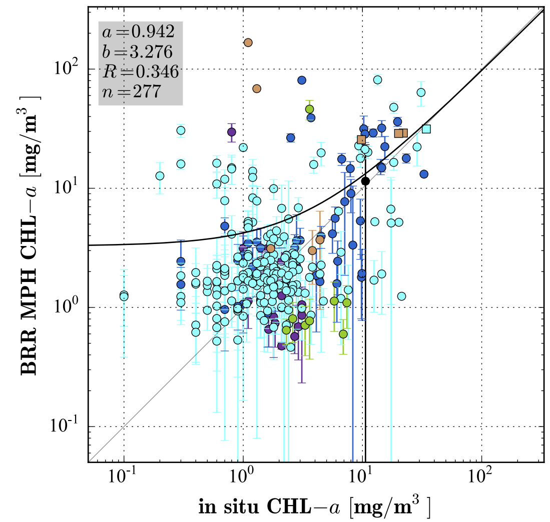
Comparability of *in situ* Monitoring data

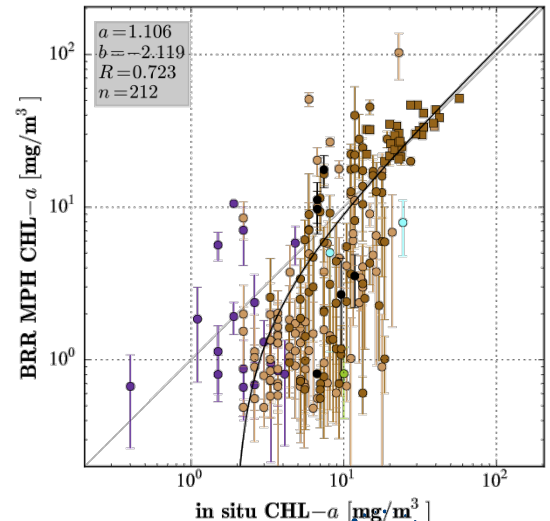


FUB neural network:
Lake Geneva (top)
Lake Vanern (bottom)



- *In situ* methods are just as manifold as remote sensing algorithms
- Sufficient absolute agreement requires calibration





MPH band arithmetic:
Lake Ontario (top)
Lake Balaton (bottom)

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Challenges on the Way Ahead

- Identify and bridge gaps in existing methodology, including scientifically less rewarding ones
- Assimilate complementary information sources
  - LSWT
  - Automated profilers
  - Autonomous underwater vehicles
  - Hydrodynamic modeling
- Convey understanding that remotely sensed and *in situ* chl-*a* are similarly valid indicators even if they don't agree in absolute terms

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Increasing the Monitoring Coverage

- Benefits of improved spatial resolution for the proven concept and most valuable, optically feasible indicator (OLCI/chl-*a*)

Lake size	Required GSD*	% Total Area	Total Number
≥ 1 km^2	333 m	60	353,552
≥ 0.1 km^2	**105 m**	80	4,123,552
≥ 0.01 km^2	33 m	90	**27,523,552**
≥ 0.002 km^2	15 m	100	**117,423,552**

+1066%

- Should be traded off against spectro-radiometric upgrades that may enable the development of additional indicators (e.g. PFT)

- May promote technical priorities that differ from ocean colour

Table by Mark Matthews (CyanoLakes), data from Verpoorter, C., Kutser, T., Seekell, D.A., and Tranvik, L.J. (2014). A global inventory of lakes based on high-resolution satellite imagery. Geophys. Res. Lett. 41, 6396–6402.

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Challenges on the Way Ahead

- Identify and bridge gaps in existing methodology, including scientifically less rewarding ones
- Assimilate complementary information sources
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  - Automated profilers
  - Autonomous underwater vehicles
  - Hydrodynamic modeling
- Convey understanding that remotely sensed and *in situ* chl-*a* are similarly valid indicators even if they don't agree in absolute terms
- Obtain consensus in sensor and algorithm requirements

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Conclusions

- We expect a significant increase in water quality information demand in the near future
- Activities enclosed by the GEO Water Quality CoP demonstrate several successful proofs of concept
- chl-*a* (OLCI) and turbidity are the most promising indicators regarding relevance and feasibility
- Consolidation of bio-optical algorithms is needed
- Collaboration with a variety of local users as well as developing agencies and international organizations must be established

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Thank you

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with contributions by:
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The Physics of Aquatic Systems Laboratory at EPFL-ENAC
The ESA DUE Diversity II Project Team
and many others

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