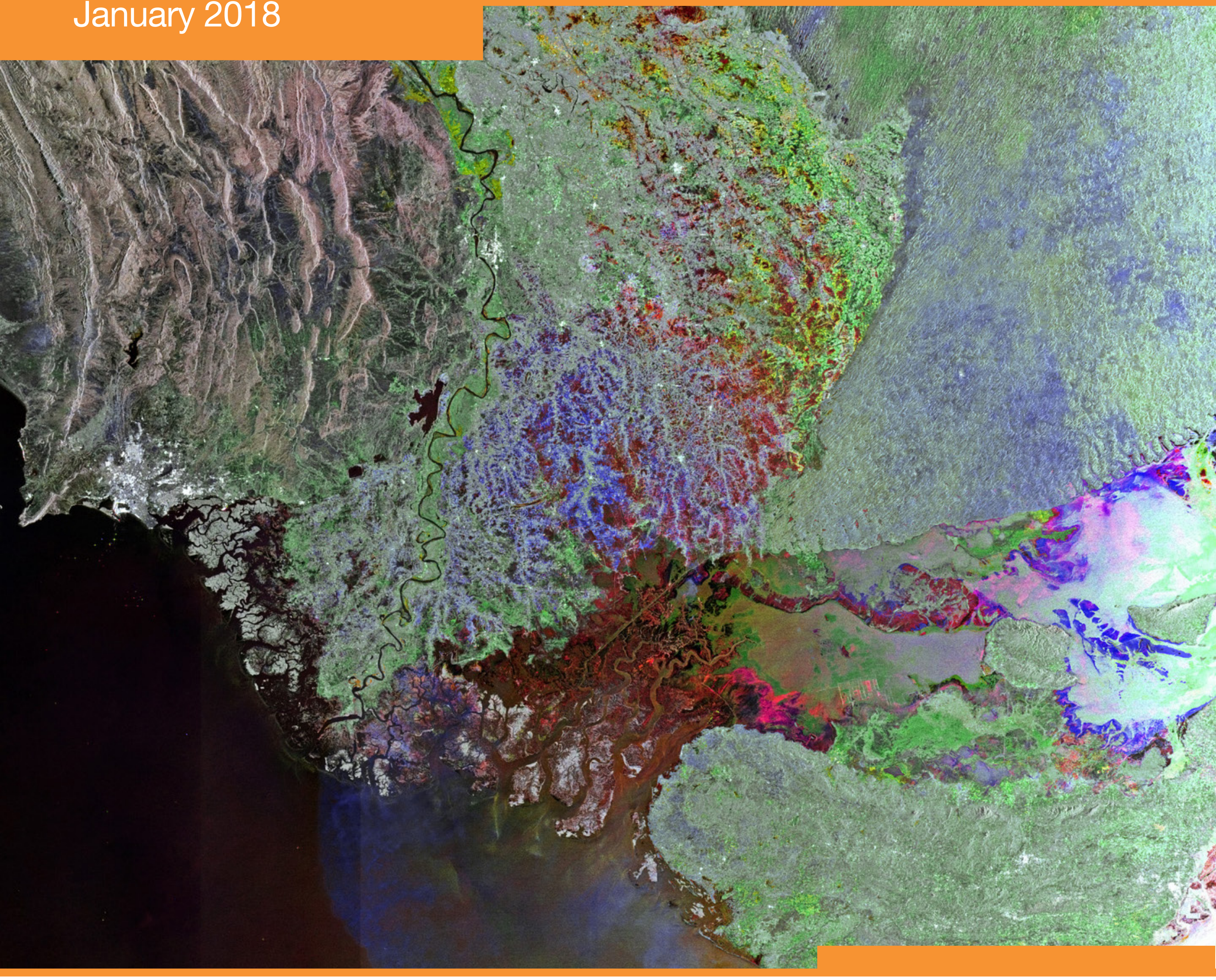
Enhancing Freshwater Monitoring Through Earth Observation

Report of Workshop 19-21 June 2017

January 2018



INDIA-UK
Water Centre
भारत-यूके
जल केन्द्र

Enhancing Freshwater Monitoring Through Earth Observation

Report of Scientific Workshop: 19–21 June 2018

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www.iukwc.org

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NERC SCIENCE OF THE ENVIRONMENT

Ministry of Earth Sciences
Government of India

The India-UK Water Centre promotes cooperation and collaboration between the complementary priorities of NERC-MoES water security research.

भारत-ब्रिटेन जल केंद्र एमओईएस-एनईसीआरसी(यूके) जल सुरक्षा अनुसंधान के पूरक प्राथमिकताओ के बीच सहयोग और सहयोग को बढ़ावा देने के लिए करना है

Front cover image: Indus River © ESA

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Executive Summary

This report represents an overview of the participation, activities and conclusions at a joint India-UK science workshop on Enhancing Freshwater Monitoring through Earth Observation. The activity was convened on the 19-21st June 2017 by the India-UK Water Centre and hosted by Prof. Andrew Tyler (University of Stirling) and Prof. Mihir Kumar Dash (Indian Institute of Technology, Kharagpur). The report highlights the state of the art in exploring Earth Observation (EO) capability in the UK and India and the opportunities and challenges in taking this capability forward in tackling the challenges of UN Sustainable Development Goal 6 (SGD6). The report summarises the many opportunities that EO can contribute to water quality and quantity monitoring. It concludes that EO has the potential to provide data on water quality and quantity that if developed effectively, through co-designed research and development initiatives, coupled with effective communication, could deliver information that would be transformative to economic and social development. The report is intended for the workshop participants, India-UK Water Centre members and relevant stakeholders.

Figure 1: Delegates of the Workshop.

1. Workshop Conveners

The Workshop was convened by the India-UK Water Centre (IUKWC), hosted by the University of Stirling in the UK and led by the Activity Leads:

Prof. Andrew Tyler

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University of Stirling
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Prof. Mihir Kumar Dash

Associate Professor
Centre for Oceans, Rivers, Atmosphere and Land Science
Indian Institute of Technology, Kharagpur
Kharagpur, India - 721302
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The Workshop was held at the University of Stirling, UK 19–21 June 2017.

2. About the Workshop

An Open Call to propose and run a workshop was hosted on the IUKWC website, open to members of the Open Network of India-UK Water Scientists. The selection of the successful application was based on the:

- Differing practices in India and the UK in monitoring water quality of freshwater;
- Fit to the scientific scope of the Centre;
- Timeliness of the topic;
- Risk of successful delivery;
- Capability of the individuals to run the activity;
- Relevant expertise of the individuals;
- Anticipated added value.

Inland waters provide us with the most fundamental of resources for survival and yet maintaining water quality does not always receive the highest priority. Inland waters are sensitive to land use change and integrate the impacts of human activity within their catchment, the negative consequences for which are confounded further by climate change. Access to clean and sustainable water is highlighted as a priority within the UN's Sustainable Development Goals (SDG 6), but monitoring and managing inland water quality adequately through conventional methodologies retains significant challenges in spatial and temporal coverage and the timely provision of data. The Workshop aimed to bring together scientists to explore the latest generation of Earth Observation (EO) capabilities in the Indian and UK water sectors. The workshop addressed the following topics:

- Current and near future Earth Observation data products available for freshwater monitoring;
- Practical applications to enhance water security, for example to improve water resource quantity and quality for water supply, agriculture and aquaculture;
- Synergies and opportunities to develop and exploit EO capability for effective early warning of freshwaters;

3. Workshop Participants

An Open Call for participants was hosted on the IUKWC website, open to members of the Open Network of India-UK Water Scientists (http://www.iukwc.org/open-network), and delegates were selected based on:

- Applicant expertise relevant to the workshop theme;
- Motivation for attending the workshop;
- Expected contribution to the workshop;
- Potential benefit to the applicant in attending;
- Organisational balance.

Thirty-seven delegates (21 from UK and 16 from India) and seven members of the organising committee attended the workshop representing a broad variety of Indian and UK organizations involved in research in freshwater monitoring and EO. Delegates included representatives of the Government of India and UK, numerous Indian Institutes of Technology, research centres and universities in the UK and India. A full list of the organising committee and delegates can be found below in Tables 1 and 2; further details about participants' interests and contact information can be found on the Open Network of India-UK Water Scientists (http://www.iukwc.org/open-network).

Table 1. Organising Committee

	Name	Institution
		UK
1	Bell, Chris	CEH (IUKWC Project Administrator)
2	Dixon, Dr Harry	CEH (IUKWC UK Coordinator)
3	Jobson, Anita	CEH (IUKWC Project Manager)
4	Diffenthal, Dr Carol	CEH (IUKWC Project Administrator)
5	Colston, Joan	Stirling University
		India
6	Joshi, Ms. Priya	IITM, Pune (IUKWC Stakeholder Engagement Manager)
7	Sahai, Prof. A.K.	IITM, Pune (IUKWC Indian Coordinator)

table 2. List of Delegates

	Name	Institution
		UK
8	Aalders, Dr Inge	James Hutton Institute
9	Bonsor, Helen	British Geological Society
10	Carvalho, Prof. Laurence	Centre for Ecology & Hydrology
11	Chapman, Dr Deborah	UN Environment GEMS/Water Capacity Development Centre, Environmental Research Institute, University College Cork
12	Cutler, Dr Mark	Dundee University
13	Carbonneau, Dr Patrice	Durham University
14	Haq, Dr Mohammed	Scottish Environment Protection Agency
15	Kelman, Dr Ruth	NERC
16	Maberly, Prof. Stephen	Centre for Ecology & Hydrology
17	Morton, Dr Daniel	Centre for Ecology & Hydrology
18	Mulholland, Rachel	Stirling University
19	Oliver, Dr David	Stirling University
20	Philomina, Kika	Stirling University
21	Sathyendranath, Dr Shubha	Plymouth Marine Laboratory
22	Scott, Prof. Marian	Glasgow University
23	Simis, Dr Stefan	Plymouth Marine Laboratory
24	Spyrakos, Dr Evangelos	Stirling University
25	Tebbs, Dr Emma	Kings College London
26	Telfer, Prof. Trevor	Stirling University
27	**Tyler, Prof. Andrew**	**Stirling University (Activity Lead)**
28	Willby, Dr Nigel	Stirling University
INDIA		
29	Abhilash, Dr S.	Indian Institute of Tropical Meteorology, Pune
30	Ali, Dr Yunus	Aligarh Muslim University
31	Chattopadhyay, Dr Rajib	Indian Institute of Tropical Meteorology, Pune
32	Chowdhury, Mr. Arindam	North Eastern Hill University
33	**Dash, Prof. Mihir**	**Indian Institute of Technology Kharagpur (Activity Lead)**
34	Gaurav, Dr Kumar	Indian Institute of Science Education and Research Bhopal Madhya Pradesh
35	Labhasetwar, Dr Pawankumar	CSIR-NEERI
36	Maulik, Dr Dipanjana	Government of West Bengal
37	Mishra, Dr Vimal	Indian Institute of Technology Gandhinagar
38	Mujumdar, Dr Milind	Indian Institute of Tropical Meteorology, Pune
39	Prasad, Prof. Jyothi	G B Pant University of Agriculture and Technology, Pantnagar
40	Sarkar, Miss Priyanka	Assam University, Silchar
41	Singh, Dr Ravi Prakash	National Remote Sensing Centre
42	Singh, Prof. Anupam Kumar	Institute of Engineering and Technology, JK Lakshmipat University
43	Singh, Prof. Rajendra	Indian Institute of Technology Kharagpur
44	Sinha, Prof. Rajiv	Indian Institute of Technology Kanpur

Report of Scientific Workshop: Enhancing Freshwater Monitoring Through Earth Observation

4. Workshop Structure

The workshop commenced with an introductory session outlining the backgrounds of the IUKWC and a description of previous and current India-UK collaborative research in water science and the funding landscape within the UK/NERC. The conveners outlined the ambitions of the workshop and then placed those within the context of the UN Sustainable Development Goals (SDG). The Workshop Agenda is detailed in Annex A and presentation abstracts are presented in Annex B. The workshop also hosted a number of posters from participants. Copies of presentations are available online at http://www.iukwc.org/workshop-presentations.

The Workshop was structured around five themes over three days. Sessions 1 to 3 contained a series of presentations (Figure 2) to highlight the challenges and opportunities. These presentations, along with poster presentations, formed the framework for ongoing discussion within and between sessions:

1. **Current Challenges, Needs and Best Monitoring Practice**

   An overview of the current state of the art of inland water quality and quantity monitoring was presented for both UK and India. The challenges for water quality monitoring and assessment within the context of the UN Sustainable Development Goals (SGD 6) were also presented and discussed.

2. **Current research and applications of EO data in freshwater monitoring**

   The second session focused on the world leading research activities being led by the UK in exploiting the new generation of ESA Sentinel satellites for monitoring of inland waters. An example of how EO data could be exploited for the lake of Kerala was also presented.

3. **Challenges and Solutions**

   A series of eleven presentations summarised the key challenges, opportunities and solutions in exploiting EO capability including: water quality/quantity, groundwater (SMOS), characterising catchment change, making data available and accessible

The discussion points from Sessions 1 to 3 then fed into lengthy discussions focussed within the second day of discussions: Sessions 4 and 5 (Figure 3), where participants in small facilitated breakout groups had the opportunity to focus discussions around key questions (a summary of key points in included in Annex C):

Figure 2: Presentations session at the Workshop.

4. **Future collaborative opportunities for developing new data products**

   The discussions explored the mechanisms by which we can promote the sharing and adoption of best practice from both Indian and UK research and identify the SDG relevant products observable from space, and how EO can contribute to the social and economic development requirements.

5. **Developing improved frameworks and products for freshwater monitoring Exploring gaps and requirements**

   The availability and access to in-situ and EO data on water quality was identified as the key challenge that required attention. Validation approaches were highlighted as a need and opportunity also to promote Citizen Science and raising societal awareness to issues around water quality and quantity. Research opportunities, knowledge gaps, collaborations and prospects were discussed.

Figure 3: (L) Poster display; (R) Breakout group for discussion Sessions 4 and 5.

A third day of the workshop was dedicated to a field trip to Loch Leven (Figure 4), a local research lake that has been the focus for long-term monitoring and more recently satellite calibration and validation. The delegates had the opportunity to hear a history of the scientific research undertaken over the years, particularly around monitoring and restoration activities. A field campaign with three vessels was undertaken to demonstrate a range of radiometers and sampling equipment used for satellite (EO) validation work.

Figure 4: (L): Introductory presentation about the research at Loch Leven; (R): Delegates on Loch Leven.

Figure 5: Delegates at the harbour, Loch Leven.

5. Conclusions and Outputs

The workshop presentations and discussions were wide ranging and covered the challenges and opportunities that EO presented in the monitoring and understanding of the quality and quantity and freshwater systems, including lakes, reservoirs and rivers. The scope included in-situ, airborne AUV and satellite platforms and with sensors that included: optical radiometers for water quality; synthetic aperture radar for water level; and gravitometry for groundwater fluctuation. The key points are presented in Annex C and summarised here.

5.1. Key themes arising

Session 1: Discussion – exploring ways to learn from Indian and UK research and practical experiences

The discussion highlighted the significant monitoring contributions that EO could make within the context of SDG 6 and summarised in Table 3. Many of these parameters are reaching sufficient development in maturity that they have the potential for operationalization, e.g. water quality parameters of chlorophyll, suspended particulate matter (SPM), colour dissolved organic matter (CDOM) and temperature, whilst others are still the focus of research and development, such as primary productivity and river discharge. In addition to the contributions EO has to make to catchment scale freshwater management, a number of other water related SDGs were highlighted that EO can contribute to, including SDG12 (responsible consumption and production) and SDG15 (life on land).

Table 3. List of variables that EO could monitor in relation to SDG6

Water Quality (SDG 6.3.2)	Ecosystems (SDG 6.6.1)	Water Resources (SDG 6.5)
i) Temperature ii) Chlorophyll iii) Suspended particulate matter/ water clarity iv) Erosion/siltation/ catchment indicators v) Eutrophication vi) Harmful algal blooms vii) Population pressure viii) Colour Dissolved Organic Matter (CDOM) ix) Pathogenic bacteria – Chlorophyll relations x) Erosion/siltation xi) Point source identification	i) Vegetation/habitat ii) Phenology iii) Extent/changes iv) Biomass v) Primary production vi) Quality and quantity of water (incl flooding) vii) Some ecosystem services viii) Habitats, species/ invasive species ix) HABs	i) Ground water level / fluctuations (GRACE) ii) Water level (altimetry) iii) Flooding iv) Surface water quantity (lake level)/ bathymetric mapping v) River discharge vi) Rainfall and run off

Overall, EO was identified as being most useful for larger bodies of water and larger expanses of rivers and estuaries with the Ocean and Land Colour Instrument (OLCI) and Sea and Land Surface Temperature Radiometer (SLSTR) on Sentinel 3 and the MultiSpectral Instrument (MSI) on Sentinel 2, whilst narrower rivers still require further work exploiting higher resolution platforms such as MSI on Sentinel 2. These data were highlight as potentially highly valuable in providing water quality monitoring and reconstructing the change in the ecological status of inland waters

and providing some consistent measures of water quality across the water continuum and across the country. By making EO-derived water quality data freely available will grow the opportunity for data democracy. This will enable communities, NGOs, scientist and others to affect change in policy, regulation and practice to the benefit of all.

There is real potential in providing consistent quality assured products from the local to regional scales, but the impact of these data on stakeholders can only be affected if the derived information is delivered in a palatable format through effective communication and estimates of uncertainties on the products. Lessons can be learned from other environmental indicators such as the air quality index published in Delhi. A similar index related to water quality might be effective in promoting change within governance and remediation.

It was recognised that around 80% of India's water is derived from groundwater due to the poor status of the surface waters. Sub-continental resolution of groundwater recharge can be estimated from GRACE (Gravity Recovery and Climate Experiment) and its successor mission GRACE-FO (Follow-on). At the local scale, groundwater upwelling could be mapped from thermal imaging from helicopters or UAVs.

In moving forward, the co-design and co-production of programmes of work with stakeholders was flagged as essential; whilst there was also much opportunity to share resources between the UK and India, develop open access tools, and provide training and capacity building opportunities. The GEO-AquaWatch Initiative (https://www.geoaquawatch.org/) presents an important networking platform to promote new initiatives and seek further intergovernmental support and space agency backing.

The potential for EO to contribute to social and economic development was also discussed, specifically in delivering information to support food and water security under conditions of environmental change. The provision of data was seen as essential to build resilience and manage resources more effectively and efficiently water in terms of both quality and quantity and in transboundary/upstream/downstream conflicts of demand in addition to the economic, energy and environmental considerations of over abstraction of groundwater. There is a very real need to share best practice and build capacity and capability in understanding of process, technology and methodology to improve water policy and practice.

Session 2: Developing improved frameworks and products for freshwater monitoring exploring gaps and requirements – Strategies for sharing best practice

The availability of data on water quality, temperature and quantity is generally difficult to access publically, and those data sets that are available are insufficient to assess long-term change from drivers of environmental change. There is a very real demand for data at the local and regional scale and to assess transboundary issues for informed decision making and delivering pressure on policy and governance in addition to promoting environmental stewardship. Data from the India Space Agency can be difficult to access.

There are opportunities where existing water quality management could be combined with broader scale coverage of EO – for complimentary use to target scarce resources more effectively for monitoring – i.e. in the identification of hotspots. There is also an opportunity to build on existing citizen science schemes to collect additional validation data for EO. Smartphone availability is widespread and provides a powerful platform for data acquisition and information dissemination.

The development of simple user interfaces is necessary to ensure information is delivered effectively to all stakeholders. There are exemplars of best practices, e.g. Air Quality, that the water quality community could learn from and the engagement of the local press for routine reporting of water quality may provide the most effective forms of communication to local communities. Funding is important and engagement of local and regional government is key to the provision of services.

A number of challenges were identified, such as the need to monitoring water quality parameters that are not observable optically. Equally these challenges provide research opportunities to develop modelling/artificial intelligence/machine learning approaches to resolve these problems. The opportunities and gap in science and understanding are summarised in Table 4.

5.2. Conclusions and recommendations

The activity provided a valuable opportunity to share a greater experience and knowledge to build a greater understanding of the challenges and opportunities for EO in delivering services to address the challenges of SDG6 and key SDGs reliant on the availability of good quality water, including SDGs 12 and 15. In conclusion, EO has potential to provide data on water quality and quantity that if developed effectively through co-designed research and development initiatives could deliver information that would be transformative in economic and social development. This could be achieved through effective communication of the resulting information with community groups and those responsible for governance and the local, national and international level.

The discussions highlighted:

- That resolving issues of Water Quality and Quantity is a multi-dimensional problem, but that EO could make a real difference by delivering freely available data to promote data democracy.
- The need to grow capacity and capability to exploit EO capability; this would benefit from a two-way exchange of knowledge and skills, including making data available and promoting the development of validation sites.
- EO data can be used to understand water use and promote water-use efficiency and resolve the tensions and conflicts in water use between agriculture, energy, the need for groundwater recharge and the need to reduce pressures on groundwater by improving surface water quality.
- The need to link EO-derived water quality information with conventional parameters of water quality such as nutrients and pathogens.
- The need to promote a knowledge exchange platform through PhD programmes.
- The opportunity of using citizen science based observatories to promote data exchange, data supply for validation and environmental stewardship.
- The need to integrate across systems to:
    - o Exploiting multiple platforms and systems for monitoring (Satellite, UAV-Drone, In-situ and Citizen – smartphone);
    - o Inter-comparison of different EO data to provide consistent products for freshwater monitoring; Coupling satellites with in-situ capability to deliver higher frequency data to characterise the changing phenology of events in addition to filling gaps in observation by limitations in sensors resolution and repeat observation;
    - o Link terrestrial/catchment processes to water, groundwater to surface water, headwaters to coastal waters for a more complete understanding of the pressures on water resources and the consequences of policy and management decisions;
    - o Cross-discipline to couple hydrology understanding with point/diffuse pollution, water management and societal behaviour to seek mechanisms to promote societal and economic benefits;
    - o Promote interaction between universities, research institutions, business and industry, governance and society for develop sustainable futures.

An accompany Brief summarizing the key thematic points arising from the Activity can be found at www.iukwc.org

5.3. Participant feedback

At the conclusion of the workshop a feedback form was circulated to participants who were asked to provide comment on:

- the Workshop content;
- the meeting venue and organisation;
- networking opportunities; and
- provide an overall score out of 10 for the workshop.

Overall, the workshop delegates were very satisfied with the workshop content, with a good balance of presentations, facilitated and informal discussions and the field trip was particularly welcome to promote the informal discussion as well as understand the challenges of water quality monitoring in a different environmental context. The participants appreciated the enthusiastic team of organisers. The delegates generally thought an extra day or two would have been.

The venue was highlighted as a beautiful vibrant location that was in easy reach of the airports. Participants at this workshop were on the whole complementary about the meeting space and hospitality provided.

Networking at workshops is often one of the most beneficial occurrences and 95% of respondents identified that the networking at this workshop was useful for developing future collaborations and that they had made developed new networking opportunities. Over 50% of respondents found the workshop provided opportunity for them to consider future funding opportunities whilst the majority of respondents found the knowledge exchange aspect of the workshop to have been highly beneficial with a clear recommendation to continue these events.

The need to develop PhD exchanges and funding opportunities was highlighted as one of the priorities going forward by several delegates but all enjoyed the Workshop with a mean and median scores of 9.3 and 9/10 respectively.

Table 4. List of the opportunities, gaps and requirements highlighted during workshop discussions.

Opportunities - structural	Opportunities - science
• Impact agenda and priority for UK funding helps • Sharing of different technologies, training • GCRF upcoming call- very large consortia • Scientific opportunity to work with different systems • Engage more with stakeholders • Exchange scientists/students • IUKWC- PhD Program? Training network. Training and capacity building is a gap that we could be addressed • Connect to other disciplines such as glaciology • Co-develop training courses	• Including wetlands, basic mapping function of time still in India • Opportunities exist in testing whether different water systems function in similar or different ways over large spatial scales (global) and in different environments and climates. • Explore hyperspectral sensors to extend products (chemical compounds) • Volume and flow of water • Developing aproaches to estimate water quality parameters not observable optically • Change in geomorphology (siltation, change in reservoir storage capacity) • Develop drone technology (rivers, small body, validation) • Carbon storage • Fixed observation points • Biological pollution • ID of areas of groundwater recharge

Gaps and requirements for knowledge	Gaps and Requirements for Science
• The gap in existing EO monitoring system is: o length of the data, o Resolutions/temporal scale, o Parameters – multi-variables in situ – higher temporal, o Downscaling, o Setting up climate data observation platform network (multi-variable), o Monitoring of multivariable in wetland/ paddy farms, o Compatibility of EU and ISRO data sets for temporal scale- quality control; better coverage, o Collaboration on learning from EU for forming policies on climate change and adaptation. • Data and information sharing • Cheap sensors- develop smartphone apps • Knowledge exchange needed – students and scientists. Specific training courses and co-developed courses • More engagement with stakeholders and regulators needed, e.g. Env Agencies, water companies, wildlife and conservancy agencies • Potential for awareness raising at high government level in India by a special conference, and brainstorming workshops might be used to look forward for future needs and collaboration. • Need to identify potential funding possibilities in India	• Spring watershed management o Darjeeling, dry districts, o Target: improve water retention, o Audience: local government to help regulation, o Mechanism: research requirement: quantitative assessment (see session 4) • Kerala fisheries: o target: optimise catch, o audience: local fishermen, o mechanism: info flow through INCOIS o research requirement: integrated obs & monitoring, • Kerala Surface water quality monitoring for health: o target: limit disease outbreak, o research: drainage, observation modes, o e.g Kerala – during monsoon; In Bombay & Calcutta drainage monitoring exists, in other areas no implementation yet • Sikkim high elevation water bodies, Eastern Himalayas, glacial dynamics; o target: climate change impacts & forecasting / risk mapping flooding in downstream areas, including effects on hydropower; can EO data be used to fill in the blanks in high altitude regions? Future water resources assessment in relation to climate change impacts on glaciers, o mechanism: there are existing institutional collaborations to build on and links to BAS to look at bathymetry, o audience: local communities, tourists, through state disaster management departments

6. Annexes

ANNEX A: Agenda

Day 1 – 19 June 2017

Time	Agenda item
08:45–09:30	**Arrival and Registration** Refreshments - Tea / coffee
09:30–10:00	**Welcome Addresses** • Welcome and Introduction to the IUKWC aims and functions *Harry Dixon (IUKWC Coordinator, CEH)* • Overview of IUKWC activities *Atul Sahai (IUKWC Coordinator, IITM)* • India-UK joint research activities *Ruth Kelman (NERC)* • Objectives and Opportunities *Andrew Tyler (University of Stirling)*
10:00–11:15 20 min talks Plus 15 min questions	**Session 1: Current Challenges, Needs and Best Monitoring Practice** • Overview of Water Quality and Quantity Monitoring in the UK *Laurence Carvalho (Centre for Ecology & Hydrology)* • Water Quality Monitoring Issues of Rivers in Uttarakhand *Jyothi Prasad (G B Pant University of Agriculture and Technology, Pantnagar)* • Challenges for global water quality monitoring and assessment in the context of the new Sustainable Development Goal for Water, SDG 6 *Deborah Chapman (Director UNEP GEMS/Water Capacity Development Centre, Environmental Research Institute, Cork)*
11:15–11:45	Tea, Coffee & Discussion
11:45–13:00 20 min talks Plus 15 min discussion	**Session 2: Current research and applications of EO data in freshwater monitoring** • Water quality monitoring and surveillance in rural India: An update *Pawan Kumar Labhasetwar (CSIR-NEERI, Hagpur)* • State of Art in EO of Inland Waters: a UK perspective *Andrew Tyler (University of Stirling)* • Example Challenge: Vembanad Lake of Kerala: Stresses and potential solution *Shubha Sathyendranath (Plymouth Marine Laboratory)* • Discussion
13:00–14:00	Lunch & Discussion

Time	Agenda item
14:00–15:30 15 minute presentations, including 5 minutes for questions	**Session 3: Challenges and Solutions I** Challenges include: include water quality/quantity, groundwater (SMOS), characterising catchment change, making data available and accessible • Progress and challenges towards a global near real-time inland water quality observation service. *Stefan Simis (PML)* • Retrieving catchment variables to explain changes in lake behaviour: the GloboLakes catchment database. *Mark Cutler (University of Dundee)* • Coherency in lake response to environmental change drivers *Marian Scott (University of Glasgow)* • Remote sensing to estimate the mean discharge of rivers from the Himalayan Foreland. *Kumar Gaurav (Indian Institute of Science Education and Research Bhopal Madhya Pradesh)* • Real-time monitoring of reservoir storage using satellite observations in India. *Vimal Mishra (Indian Institute of Technology Gandhinagar)* • Reforming fresh water conservation practices by using 'Earth Observation *Dipanjana Maulik (Government of West Bengal)*
15:30–16:00	Tea, Coffee & Discussion
16:00–17:30 15 minute presentations, including 5 minutes for questions	**Session 3: Challenges and Solutions II** • Monitoring water pollution in the River Ganga: preliminary findings from image spectroscopy. *Patrice Carbonneau (University of Durham)* • Monitoring water pollution in the River Ganga with innovations in airborne remote sensing and drone technology. *Rajiv Sinha (Indian Institute of Technology Kanpur)* • Application of GRACE data, and other earth observation datasets, to understand groundwater resources – examples from Africa and SE Asia. *Helen Bonsor (BGS)* • A case study on Earth's groundwater recharge hotspots based on GRACE observation *Rajib Chattopadhyay (Indian Institute of Tropical Meteorology, Pune)* • Freshwater Lake Mapping and its Volumetric Estimation in the Glaciated Valley of Chhombu in Sikkim Himalayas Using High-Resolution Optical (Sentinel-2 MSI) Imagery. *Arindam Chowdhury North Eastern Hill University, India)* • The field scale soil moisture analysis using COSMOS-India network to explore water resource quantity and quality for water supply, agriculture and aquaculture over the Indian regions. *Milind Mujumdar (Indian Institute of Tropical Meteorology)*
17:30–18:00	Wrap-up of Day 1
18:00–19:00	Poster Session with refreshments
19:00–21:00	Workshop Dinner at Stirling Court Hotel

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Day 2 – 20 June 2017

Time	Agenda item
08:30–09:00	Arrival and Registration
09:00–09:15	Welcome to Day 3
09:15–09:30	**Session 4: Future collaborative opportunities for developing new data products** • Overview of Opportunities *Andrew Tyler (Head of Biological and Environmental Sciences, University of Stirling)*
09:30–10:30	Break out groups: Facilitated discussion-exploring ways to learn from Indian and UK research and practical experiences • Challenges and Opportunities for Collaboration • SDG relevant products - those that are observable from space • Identifying & adopting best practice EO • Strategies for sharing best practice
10:30–11:00	Report back from discussion groups and summarise findings
11:00–11:30	Tea, Coffee & Discussion over Posters
11:30–12:30	**Session 5: Developing improved frameworks and products for freshwater monitoring Exploring gaps and requirements** Break out groups: Facilitated discussion exploring ways of integrating EO data and products into existing freshwater monitoring • Exploring gaps and requirements
12:30–13:00	Report back from discussion groups and summarise findings
13:00–14:00	Lunch with Poster Session
14:00–15:00	Summary of the Workshop Findings • Summary and key points from the morning discussions • Contributions to Position Paper • Focus for further funding o Funding to facilitate focussed workshops o Funding for research and developments
15:00–15:30	Agreed next steps and actions
15:30–16:00	Poster Session with refreshments
16:00–18:30	Cultural Programme: Stirling Castle
19:00–21:15	Dinner: Stirling Highland Hotel

ANNEX B: Presentation Abstracts

Copies of presentations, where authorized by speaker, will be made available on the IUKWC website www.iukwc.org

Session 1: Current Challenges, Needs and Best Monitoring Practice

Overview of Water Quality and Quantity Monitoring in the UK
Laurence Carvalho *(Centre for Ecology & Hydrology)*
The UK has a strong south-east to north-west gradient in rainfall and also a south-north gradient in population density and terrain. These gradients greatly affect water resources, both quantity and quality. This presentation outlined the current monitoring of water quantity and quality in the UK and then areas of innovation in monitoring. In relation to the monitoring of water quantity, the UK has a large network of river and groundwater monitoring sites. The data from these are made publicly available through the National River Flow Archive (NRFA) & the National Groundwater Level Archive (NGLA), managed by the Centre for Ecology & Hydrology (CEH) and British Geological Survey (BGS) respectively. Together they deliver a National Hydrometric Information Service which provides current outlooks of water resources and analysis of extreme events. In terms of water quality, these are either long-term monitoring of a few flagship sites, largely maintained for research purposes (e.g. by CEH at Loch Leven) or large-scale monitoring of many rivers, lakes, groundwaters and coastal waters undertaken by the national environment agencies for regulatory monitoring under the Water Framework Directive (WFD). The WFD emphasises the monitoring of ecological health through 4 biological groups: phytoplankton, macrophytes, benthic invertebrates and fish. A number of areas of innovation are developing to make monitoring both more comprehensive in frequency and coverage and also more cost-effective. Particular developments in Earth Observation, in-situ automatic sensors, citizen science (including smartphone apps) and eDNA were highlighted as areas under development in the UK.

Water Quality Monitoring Issues of Rivers in Uttarakhand
Jyothi Prasad *(G B Pant University of Agriculture and Technology, Pantnagar)*
Human activities like religious (Kumbh Mela, Shraddhs etc.), tourism, bathing, washing, open defecation, cultivation, sand, stone and gravel quarrying, stone crushing, mining, hydro power construction activities, human body cremation, fishing, irrigation for agriculture purposes, rafting, drinking water intake, industrial water supply, river rafting, land sliding, forest fire, floods etc. have affected the water quality of the rivers in India, in particular a national live river Ganges system.
This presentation highlights some of the issues of Uttarakhand, a hilly state in the Upper Ganga catchment with respect to quality standards of Central Pollution Control Board (CPCB), Govt of India in particular Biological Water Quality Criteria (BWQC) including Physico-Chemical water quality.

Challenges for global water quality monitoring and assessment in the context of the new Sustainable Development Goal for Water, SDG 6
Deborah Chapman *(Director UNEP GEMS/Water Capacity Development Centre, Environmental Research Institute, Cork)*
This presentation will outline the activities and role of the UN Environment GEMS/Water programme and its current involvement in the new SDG for water. Some of the challenges being experienced by countries globally to monitor, assess and report national water quality will be summarised and the support offered by UN Environment to assist countries with these challenges will be highlighted.

Session 2: Current research and applications of EO data in freshwater monitoring

Water quality monitoring and surveillance in rural India: An update
Pawan Kumar Labhasetwar *(CSIR-NEERI, Hagpur)*
Since Independence, Government of India (GoI) and State governments have spent more than 2 Trillion Indian Rupee on rural water supply, however, there is still lot to be done to improve the situation. India largely depends on groundwater sources to meet drinking water demand in rural areas and it is found that ground water sources are deteriorating and many areas are classified as water quality affected. Water quality monitoring was a big challenge prior to 2005; however, efforts by Rural Water Supply agencies in the State and Ministry of Drinking Water and Sanitation (MDWS) led to improved water quality monitoring system. Uniform drinking water quality monitoring protocol, jointly prepared by MDWS and NEERI in 2013 paved the way for accelerating resource allocation for water quality monitoring even at sub-district level. Subsequent to introduction of the Protocol, network of laboratories are set-up in most of the States. It is also proposed that water quality testing laboratories at State and district levels, should obtain accreditation from the National Accreditation Board for Laboratories. These laboratories are primarily responsible to monitor rudimentary physico-chemical parameters such as turbidity, conductivity (total dissolved solids), hardness, alkalinity, residual chlorine etc. In addition water quality parameters affecting heath such as nitrate and fluoride are monitored even at district level laboratories in some States, whereas arsenic is being verified at State-Level laboratories. Analysing water samples for presence of even indicator bacteria such as E.coli, thermotolerant coliforms etc. still remain a major challenge. Considering efforts being made and emphasis on water quality affected habitations, major improvement in laboratory infrastructure, training of chemists/microbiologists, procurement of advance analytical instruments such as ICP-MS, GC etc. are expected in near future. Application of earth observation tools seems to be limited in rural water quality monitoring due to present emphasis on health based parameters such as nitrate, fluoride, arsenic and indicator bacteria.

State of Art in EO of Inland Waters: a UK perspective
Andrew Tyler *(University of Stirling)*
The potential of exploiting remote sensing platforms has been explored for many years and has ranged from the exploitation of satellites original designed for terrestrial applications (e.g. Landsat TM) through airborne hyperspectral imaging systems to the adoption of ocean colour platforms (MODIS and MERIS). However, only recently has there been sufficient developments in the availability of data from satellite platforms for Earth observation (including ESA's Copernicus Programme) to offer an unprecedented opportunity to deliver measures of water quality across a range of water body types. The UK NERC-funded GloboLakes project is a six-year research programme investigating the state of lakes and their response to climatic and other environmental drivers of change through the realization of a near-real time satellite based observatory (Sentinel-3) and archive data processing (MERIS) to produce a ~15-year time-series of observed ecological parameters and lake temperature for more than 1000 lakes globally. Working with partners at the Plymouth Marine Laboratory, the Centre for Ecology and Hydrology, and the Universities of Glasgow, Dundee and Reading in addition to other EC and ESA funded initiatives, the GloboLakes project is overcoming many operational challenges to by developing a processing chain (Calimnos: a partnership between PML, Brockman Consult and University of Stirling) whereby algorithms are dynamically selected according to the optical properties of the lake under observation. The development and validation of the Calimnos has been supported by access to extensive in situ data from more than thirty partners around the world that are now held in the LIMNADES community-owned database. This approach has resulted in a step-change in our ability to produce regional and global water quality products for optically-complex waters and a framework for delivering greatly improved uncertainty estimates.

Example Challenge: Vembanad Lake of Kerala: Stresses and potential solution
Shubha Sathyendranath *(Plymouth Marine Laboratory)*
Vembanad Lake is a Ramsar site in the S.W coast of India, which is about 100 km long. Some 10 rivers drain into the lake. A broad range of environmental pressures influences the water quality of the lake. Human activities are mainly responsible for the deteriorating quality of water resources, and the negative impacts on human health and socio-economic progress. The lake environment is a complex matrix that requires careful stewardship to ensure sustainable ecosystem services well into the future. It calls for an extensive study incorporating in situ monitoring, remote sensing studies, and ecosystem modelling and citizen science. The methods developed for this lake would be transposable to other fresh-water bodies, in India and elsewhere.

Session 3: Challenges and Solutions I

Progress and challenges towards a global near real-time inland water quality observation service.
Stefan Simis *(PML)*
In this overview we will provide examples of current capabilities and limitations of global satellite observation of optical water quality, developed in NERC GloboLakes and services emerging from the Copernicus Land Service in the coming year. The presentation will include a demonstration of our user interface to interact with the satellite data and provide an outlook of foreseen future applications of operational satellite services dedicated to inland water quality.

Retrieving catchment variables to explain changes in lake behaviour: the GloboLakes catchment database.
Mark Cutler *(University of Dundee)*
The NERC-funded GloboLakes project seeks to understand changes lake water quality for over 1000 lakes across the globe, including any coherence in lake behaviour over both time and space. In order to explain these changes it is necessary to have access to critical climatic and catchment variables relating to each lake, describing how lake catchments have changed in terms of land cover, productivity, hydrological regimes etc. In this paper we explore the various datasets that have been used to derive the GloboLakes catchment database, identifying critical gaps in existing data provision to aid the explanation of lake change. As an example, we will explore the lack of critical lake hydromorphology data and present results of modelling lake depths for lakes where such information is unknown. The presentation will finish with a proposed lake catchment scoring system which will allow us to predict the sensitivity of lakes to change.

Detecting spatial and temporal patterns- coherence in lake water quality
Marian Scott, Claire Miller and Ruth O'Donnell*(School of Mathematics and Statistics, University of Glasgow)*
Earth Observation has the potential to change how we monitor and manage our natural resources. Huge volumes of data are being generated every day, and in this presentation, we discuss some of the statistical tools needed to allow us to explore and model the data and visualise the results. Using new data streams, we can assess how lakes in all parts of the world are responding to environmental and climate change. In Globolakes (a NERC funded project NE/J022810/1), we have observed more than 1000 lakes, including measurements of temperature, chlorophyll, TSM, and CDOM. The data are available at pixel level, ranging from several thousands to millions, depending on the size of the lake and the satellite resolution. For each lake pixel, we have a time series of measurements, our goal is to Identify patterns of temporal coherence for individual remotely sensed lake characteristics and the spatial extent of coherence. In statistical terms, we want to identify common patterns. The satellite data streams present interesting statistical challenges including dealing with missing data, ice cover and handling retrieval uncertainties. We have been developing new statistical tools based on functional data analysis to address these new data streams.

Remote sensing to estimate the mean discharge of rivers from the Himalayan Foreland.
Kumar Gaurav *(Indian Institute of Science Education and Research Bhopal Madhya Pradesh)*
Quantitative estimates of a river discharge is required to investigate channel morphology, sediment transport, flood monitoring and for managing water resources. Here we show how an estimate of annual average discharge for any river in the Himalayan foreland can be derived by using remote sensing images. Our procedure relies on the automated width extraction from individual threads of alluvial rivers using Landsat-TM and Landsat-8 images. The width of individual threads is then translated into discharge using a regime equation that probably applies to any river, despite their planform morphology, of the Himalayan foreland.

To evaluate this, we use the near-infrared band of Landsat images to extract the width of individual threads of six braided rivers from the Himalayan Foreland, the Indus, Cheenab, Ganga, Kosi, Teesta, and Brahmaputra. Using a regime relation based on threshold theory and the width of a thread extracted from Landsat images, we then estimate the discharge passing through a given river section. We show that the discharge estimated from satellite images actually compares with the annual average discharge measured at nearby gauging stations. Finally, we discuss limitations and potential of this approach for further improvements

Real-time monitoring of reservoir storage using satellite observations in India
Vimal Mishra *(Indian Institute of Technology Gandhinagar)*
Real-time reservoir storage information at a high temporal resolution is crucial to mitigate the influence of extreme events like floods and droughts. Despite large implications of near real-time reservoir monitoring in India for water resources and irrigation, remotely sensed monitoring systems have been lacking. Here we develop remotely sensed real-time monitoring systems for 91 large reservoirs in India for the period from 2000 to 2017. For the reservoir storage estimation, we combined Moderate Resolution Imaging Spectroradiometer (MODIS) 8-day 250 m Enhanced Vegetation Index (EVI), and Geoscience Laser Altimeter System (GLAS) on board the Ice, Cloud, and land Elevation Satellite (ICESat) ICESat/GLAS elevation data. Vegetation data with the highest temporal resolution available from the MODIS is at 16 days. To increase the temporal resolution to 8 days, we developed the 8-day composite of near infrared, red, and blue band surface reflectance. Surface reflectance 8-Day L3 Global 250m only have NIR band and Red band, therefore, surface reflectance of 8-Day L3 Global at 500m is used for the blue band, which was regridded to 250m spatial resolution. An area-elevation relationship was derived using area from an unsupervised classification of MODIS image followed by an image enhancement and elevation data from ICESat/GLAS. A trial and error method was used to obtain the area-elevation relationship for those reservoirs for which ICESat/GLAS data is not available. The reservoir storages results were compared with the gauge storage data from 2002 to 2009 (training period), which were then evaluated for the period of 2010 to 2016. Our storage estimates were highly correlated with observations ($R2 = 0.6$ to 0.96), and the normalized root mean square error (NRMSE) ranged between 10% and 50%. We also developed a relationship between precipitation and reservoir storage that can be used for prediction of storage during the dry season.

Reforming fresh water conservation practices by using 'Earth Observation
Dipanjana Maulik *(Government of West Bengal)*
The need for use of earth observation in fresh water reserve monitoring is increasing. Because number and magnitude of interventions in form of water intake, point and nonpoint discharges are escalating with fast growing population and urbanization. It is difficult to spatially and temporally cover all fresh water reserves for monitoring by conventional techniques. However, use of earth observation along with appropriate water quality modelling may help to introduce a new water quality/quantity monitoring regime. As for example the state of West Bengal has more than hundred plus first order streams and huge number of ponds and wetlands. Use of remote sensing data along with appropriate modelling techniques like SAM (Sequential Analytical Models), WASP or Qual 2K can provide deeper insight about the drivers, which

impact fresh water reserves. A case study on the River Hooghly, shows that the water quality for a non-linear system can also be predicted by use of SAM. Use of earth observations for input data generation as well as calibration and validation shall further improve the reliability of water quality profile obtained from a model like SAM. Obtaining more precise and timely information about condition of fresh water reserves help the policy makers to plan and implement far more effective fresh water conservation schemes.

Session 3: Challenges and Solutions II

Monitoring water pollution in the River Ganga: preliminary findings from image spectroscopy.

Patrice Carbonneau *(Department of geography, Durham University, Durham, UK)* and **Rajiv Sinha** *(Indian Institute of Technology, Kanpur. India)*

Recent work by Durham University and IIT-Kanpur has estimated that 84% of the residents in the Ganges watershed can expect their nearest surface waters to fail both safe bathing and safe drinking standards. Addressing this state of environmental degradation in the most populated river basin in the world will require a step change in our ability to monitor water quality over large freshwater systems at timescales which are societally relevant and costs that are acceptable. In this presentation, we present some laboratory findings that support the notion that water contaminants can be detected with remote sensing technology. We demonstrate that chromium, a key pollutant in the Kanpur reach of the Ganga, can be detected in low concentrations with imaging spectroscopy. We find that the use of spectral frequency ratios can deliver linear predictive relationships that allow for remotely sensed predictions of toxic chromium concentrations down to concentrations as low as 0.2 mg/L. We also find that these predictive relationships hold in the presence of 1g/L of fine silt. This work therefore lends support to the notion that remote sensing is a suitable basis for a continental-scale water quality monitoring infrastructure.

Monitoring water pollution in the River Ganga with innovations in airborne remote sensing and drone technology.

Rajiv Sinha *(Indian Institute of Technology Kanpur)*

We have recently initiated a pilot project supported by WWF-India employing four cameras using monochrome sensors fitted in specially designed a frame designed for the Cessna aircraft at IIT Kanpur. The cameras have a resolution of 1.3 megapixels and at a flying height of 700 meters they have given us a resolution of 1 meter. Further, we have acquired 7 narrow-pass light filters for wavelengths of 394nm, 450nm, 492nm, 520nm, 650nm, 800nm and 852nm. Appropriate combinations of these filters were used to research the detection of specific pollutants. For example, it is well known that plant matter, both terrestrial and aquatic, reflects infrared light from the sun very strongly. Therefore, we used the 800 and 852 nm filters to study the levels of reflectance in the infrared. The preliminary processing of the flight data has provided us fairly good results. We have prepared false colour composite from the raw images and have been able to distinguish different parts of channel with varying concentrations of suspended sediments. From another flight, we could also map one of the major drain of the Kanpur city discharging effluent into the Ganga river and could also map its dispersion pattern downstream. Further experiments are ongoing to explore this technology for mapping specific pollutants.

Application of GRACE data, and other earth observation datasets, to understand groundwater resources – examples from Africa and SE Asia.

H Bonsor, A MacDonald, M Lark, K Smith, L Longuevergne

We explore the application of the Gravity Recovery and Climate Experiment (GRACE) earth observation dataset for observing long-term and intra-annual changes in Terrestrial Water Storage (TWS), in some of the major groundwater resources of Africa and SE Asia, where widespread groundwater monitoring is largely absent.

The work applies a statistical approach to analyse GRACE data (2003-2011) in conjunction with rainfall and soil moisture data above the zero flux plane. We find distinct seasonal changes and long-term trends in TWS can be characterised within the major Africa basins. No significant regional long-term TWS depletion is observed within any of the basins. Groundwater accumulation is indicated within the North Kalahari and Iullemmeden Basins, amounting to TWS changes of 10km3 per year and 2.1km3 per year respectively.

Interpreting GWS changes within the Indo-Gangetic groundwater system in SE Asia from GRACE data is much more difficult, due to the complexity of the heavily abstracted groundwater system, and the spatial variability of recharge processes. The availability of in-situ monitoring data is essential to interpret GWS storage changes from GRACE data at a fine resolution in this basin.

A case study on Earth's groundwater recharge hotspots based on GRACE observation

Rajib Chattopadhyay *(Indian Institute of Tropical Meteorology, Pune)*

he study provides an estimation of the precipitation-groundwater link, and its application to a smaller region of India (West Bengal). Surface recharge of groundwater is a crucial factor in regions where monsoon rainfall is strong and surface geology permits. This study would try to establish this link for regional applications.

Freshwater Lake Mapping and its Volumetric Estimation in the Glaciated Valley of Chhombu in Sikkim Himalayas Using High-Resolution Optical (Sentinel-2 MSI) Imagery.

Arindam Chowdhury *(North Eastern Hill University, India)*

High altitude fresh water lakes are an effective indicator of glacial dynamics and sensitive to climate change. Floods resulting from the outbursts of glacial lakes (i.e. Supraglacial, Ice-dammed, Moraine-dammed, etc.) upon failure of the dam can produce greater magnitude peak flows of water than that of average rainfall-derived, which in turn can affect fragile mountain ecosystems as well as human life and infrastructure in the downstream. Therefore, it is a prime concern for monitoring those fresh water glacial lakes which contribute as the main source of the Tista River in Chhombu Valley, Sikkim Himalayas. With the advent of the Sentinel-2 satellite in mid-2015 and its high-resolution optical data, a detailed experiment of the proposed method are assessed for reliable mapping of selected glacial lakes located in the remote and difficult terrain of the mentioned study area. The performance of the satellite data is best during the cloud-, snow- and ice-free season. First, various image pre-processing techniques and radiometric band rationing indices are being incorporated after resampling all 13 bands into 10 m resolution for better results. Second, Pan-sharpening algorithms, like Principal Component Analysis (PCA), Intensity Hue Saturation (IHS), High Pass Filter (HPF), À Trous Wavelet Transform (ATWT) are also applied in the study. Thus, results are analysed and compared for final mapping of those water bodies. Finally, different existing empirical relationships are employed to predict the lake volume. Relationships are based on the notion of lake depth, area and volume scale predictably in various literature. Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) is also used to get the elevation information. In summary, the main objective of the study is to test the suitability of Sentinel-2 Multispectral Imager's (MSI) data for glacial lake mapping with best-suited image transformation methods.

The field scale soil moisture analysis using COSMOS-India network to explore water resource quantity and quality for water supply, agriculture and aquaculture over the Indian regions.

Milind Mujumdar *(Indian Institute of Tropical Meteorology)*

The field scale soil moisture observations, using Cosmic ray soil moisture sensors of India network (Cosmos-India), are being analysed and validated with various available resources. This unique soil moisture analysis over the regions of India is being applied for exploring the regional water resource quantity and quality for water supply, agriculture and aquaculture. Further, available regional data base of types of irrigation, irrigation scheduling, and ground water recharge can be jointly applied to develop various effective water management applications over the Indian regions.

Poster Abstracts

Name of the participant; Poster title
Assessing seasonal changes in LULC of a floodplain wetland using Earth Observation techniques— a case study from Northeast India **Priyanka Sarkar,** *(Assam University, Silchar)* LANDSAT 8 satellite data of the floodplain wetland were obtained for both dry and wet seasons. LULC maps were prepared using hybrid approach in ArcGIS (9.1) followed by ground verification. Prepared LULC maps were 98-99% accurate.
An overview of the application of earth observation in water science - Water related monitoring in Scotland: Multi-disciplinary view **Inge Aalders** *(James Hutton Institute)* Catchment research in Scotland and the James Hutton Institute, in particular, have been using earth observation approaches. We present an overview of research projects which have used different sensors and platforms to answer a research question in relation to water quality, management and monitoring. We will outline the application and present some examples of results to illustrate the challenges as well as the benefits for catchment related monitoring.
Estimation and verification of small reservoir storage using GAGAN and GIS **Anupam K Singh** *(JK Lakshmipat University)* Small reservoir storage are backbone of agriculture in semi-arid India, and they are seldom considered. Space borne capability of recently developed GAGAN and GIS databases are used for indirect estimation of fresh water potential.
Bathymetric Mapping in Lake and Coastal regions using Sentinel 2 images **Yunus Ali** *(Aligarh Muslim University)* Aquatic environments are some of the dynamic regions of the earth. Among the aquatic systems, bathymetry or the depths of underwater terrain is one of the most important parameter that is constantly reworked and changing both in space and time. The rapid reworks in bathymetry are because of the change in the patterns of energy dispersal and related sediment transport pathways. This paper focuses on the application of the Sentinel-2 OLCI images for satellite-derived bathymetry (SDB) maps of the lakes and nearshore, at a high resolution (10 m) images. The algorithm was tuned with available bathymetric Light Detection and Ranging (LiDAR) data. A comparison of the retrieved depths is presented, enabling the configuration of nearshore profiles and extracted isobaths to be explored and compared with traditional topographic/ bathymetric techniques. The results demonstrate that the linear algorithm is efficient for retrieving bathymetry from OLCI data for shallow water depths (0 to 12 m), showing a root mean square error of less than 1m. The use of freely available satellite imagery proved to be a quick and reliable method for acquiring updated medium resolution, high-frequency, low-cost bathymetric information for large areas.
Combining multiple EO datasets for investigating the drivers of spatial and temporal patterns in water quality. **Emma Tebbs** *(Kings College London)* An example is presented, which applies current satellite products to examine the influence of hydrological regime on productivity in Lake Turkana. A discussion of how these methods can be applied more generally is included.

High-frequency monitoring **Stephen Maberly** *(CEH)* Abstract not available
Development and Testing of a conceptual “Satellite Based Hydrological Model” **Rajendra Singh** *(IIT Kharagpur)* Abstract: A large scale conceptual hydrological model, “Satellite based Hydrological Model (SHM)”, has been developed with an objective to use remote sensing data from Indian satellites for preparing sustainable water management scenarios to handle the fresh water crisis in India. The model has been developed dividing entire Indian landmass into 5km x 5km square grid cells with the assumption that centre of the cells represent the properties of the cells. SHM has five modules namely, Surface Water (SW), Forest (F), Snow (S), Groundwater (GW) and Routing (ROU). The SW module uses SCS-CN method (SCS, 1972), to find out surface runoff for the grid cells comprising of LULC other than snow and forest. The surface runoff, soil moisture and evapotranspiration are the major outputs from this module. The F module is based on the dynamics of subsurface which gives the output in the form of runoff generation, soil moisture and evapotranspiration. The S module determines the snow density from snow albedo (Smith and Halverson, 1979) for estimating snow melt depth by using two different algorithms viz. temperature index algorithm and radiation-temperature index algorithm. The GW module uses the input contributed from SW, F and S module and generates base flow which ultimately contributes to the streamflow. Each cell is modelled using the appropriate modules out of the SW, F or S modules, based on the LULC pattern of the cell, and the resultant runoff, snow melt depth and base flow is routed up to the outlet. The model has been calibrated and validated for streamflow at Kabini dam site for six years (2001 to 2006) and four years (2007 to 2010), respectively. NSE is found to be 0.53 and 0.43 for calibration and validation period, respectively. Results show that model performs satisfactorily

ANNEX C: Breakout Group Summary

The followings summarises the key points from each of the group breakout Sessions.

Session 1: Discussion-exploring ways to learn from Indian and UK research and practical experiences

Discussion Topic	Key Points Raised
A. SDG relevant products - those that are observable from space (remotely)	EO clearly has a significant role in contributing to Sustainable Development Goal 6 (clean water and sanitation), alongside a number of goals that contain elements food security and catchment-scale freshwater management, such as 12 (responsible consumption and production) and 15 (life on land). However, in the Indian sub-content context there are also a series of challenges to which EO could contribute to effective solutions
	I. For water quality (indicator 6.3.2) EO can be used for: • Temperature • Chlorophyll • suspended particulate matter/ water clarity • erosion/siltation/ catchment indicators • eutrophication • harmful algal blooms • population pressure • CDOM • Pathogenic bacteria – Chlorophyll relations • Point source identification
	II. For ecosystems (indicator 6.6.1): • vegetation/habitat • phenology • extent/changes • biomass • primary production • quality and quantity of water (incl flooding) • some ecosystem services • Habitats, species/invasive species • HABs
	III. For water resources (target 6.5) EO is useful for: • Ground water level/fluctuations (GRACE) • Water level (altimetry) • Flooding • Surface water quantity (lake level)/ bathymetric mapping • River discharge • Rainfall and run off

	IV. Analysis from GRACE: • Soil moisture availability over North-India : SMOS, COSMOS India • Surface fluxes – Evapotranspiration • Water availability over NE-India, Hilly regions • Soil moisture anomalies- hilly regions, topographic region • Soil moisture, ground water, surface water
	V. General points: • Currently EO mostly useful for lakes – further work needed to make products useful also in rivers • Need for information collection and monitoring to direct management • Need for simplified index of water availability and quantity to direct management • Inconsistency in monitoring of water quality and quantity: This lack of consistency relates to both frequency and scale of monitoring, and the quality of measurement and analysis. It should be recognised too that these issues are apparent at multiple scales, from local, state, national and across national borders. • EO has the potential to address some of these issues but matters of validation, quality of in situ data and scale of observable features need to be addressed. • Governance: There is a thirst for research and understanding of freshwater systems in India, but translating this thirst into changes to policy and practice remains elusive. Partly this is due to scale (multiple scales of monitoring, responsibility and practice) as well as transboundary issues. • EO can contribute by effectively making data available. The wealth of data coming from Indian and other space agency satellite-systems could be made open-source, enabling communities, NGOs, scientists and others to put pressure on policy-makers and practitioners to effect change. There is also an opportunity for scientists to leverage funding and pressure from developing impact agendas. • Water use efficiency: from catchment to coast there is considerable water loss and inefficiency of water use, management and distribution from multiple users.
B. Identifying & adopting best practice EO	I. EO should provide the opportunity to address **monitoring water quality at a variety of scales, from local to national and global.** Validated products and standardised approaches are needed to use ground-truthed data for different satellites; also taking a multi-satellite approach may be useful. However, taking these data and then disseminating the results and outputs as information palatable to a wide variety of stakeholders (from the public to policy relevant bodies) requires effective communication (perhaps working in a participatory manner), including the need to communicate the uncertainty in outputs. Lessons could be learnt from examples such as the air quality index published in Delhi (and elsewhere) daily. Such an index relating to freshwater could

	not only inform relevant stakeholders of conditions, but also put pressure to effect changes in governance and remediation, leading to benefits in human health and well-being. At a global scale the Globolakes project may provide a working example.
	II. **Groundwater – surface interactions.** Due to the quality of much of India's surface waters, up to 80% of agriculture relies upon groundwater. EO should provide relevant information both on groundwater (e.g. GRACE) as well as the state of surface waters, climate and recharge. However, there needs to be an understanding of the scale at which information is required and/or can be effective when making policy and management decisions (from effective communication from both scientists and policy makers). Whilst estimates of groundwater can be effectively retrieved from systems such as GRACE, this information is at a coarse spatial resolution. Whilst this provides an effective assessment at sub-continental scales this needs to be supported by local assessment from heli-borne surveys and potentially thermal imaging of upwelling from aircraft/UASV platforms to provide information relevant to local / state management bodies.
	III. At a fine scale a combination of **EO and citizen science could be used to map point source pollution**. In particular, drains could be mapped using drone and airborne sensors, which could also be used to determine optical water types. Smart phone technology/ apps could also be used to validate and monitor differences in water colour, engaging local. There is the opportunity toutilise UAVs for pollution monitoring at smaller/local scales and making observations public (a side benefit can be prevention of illegal practices such as logging).
	IV. Other areas: • glaciology interest – link to risk assessment studies done in/by UK • learn from stronger focus on rivers in India
	V. For sharing best practice: • Engage stakeholders: co-design and co-production; greater communication is needed between producers and users of data. Stakeholders need to be engaged more (how?) at all stages. • Resource sharing between UK-India • Networking- aquawatch, eye on earth • Open access tools; Better awareness of what is available (networks and tools, software etc.) also needed • Free and timely access to satellite data • Training, capacity building. Use and interpretation is difficult for non-experts and more user-friendly systems are needed
C. What are the social/economic development requirements and how could EO contribute	EO has the potential to contribute to developing food and water security under conditions of changing environmental and climatic conditions, and at scales from local to national.

	Drinking water quality and quantity i) Drinking water availability index from EO products • Coastal water quality and drinking water availability • Coastal groundwater from EO • Salinization in-formation (?) • Water temperature • Vegetation cover • Land cover data sets to identify drivers
	ii) (spring) **water supply management needed** – there are good examples, but positive impact is difficult to assess • **GRACE groundwater** sensing may help here for baseline data and to help understand impact of watershed management. • small scale: network of **small weather stations** and early warning of rain helps time harvest, repair roofs, this is a **real-time solution** • **Participatory approach** - local involvement and awareness must be developed in parallel. Local government has this responsibility. • Understanding **regional water demand / budget** essential. • **quantitative assessment** of approaches to retain water (e.g. microchannels) • disparity between EO products and e.g. coliforms an issue – approach using machine/deep learning techniques (i.e. proxies of proxies) – challenges is to review in situ archive data availability to define case studies.
	iii) **monitoring ponds and wetlands**, which are most under pressure for encroaching population pressure, adopting a broad approach to water quality monitoring and implementing an alerting system • there are **early warnings**: fly ash, plastics • audiences: government + public • **local involvement is challenge**
	iv) **urban vs rural** area discussion. (very) generally speaking urban pollution/use differences is more influenced by industry. Rural influence e.g. fertiliser. Groundwater concerns (arsenic). Clear that there are large regional differences, macro/micro approaches needed
	v) Monitoring pollution sources and disseminate information publically • EO could provide more timely information for management allowing ecosystem quality and services to be maintained • EO can detect change and these changes can be attributed to changes to observed impacts • EO can be used for early warning of changes before serious harm occurs (e.g. fishing intensity) • EO could be combined with prediction of climate change and impacts, i.e. used in forecasting different scenarios • Some issues need a shorter time scale of information provision than is possible with 'traditional' monitoring

	vi) Integrate socioeconomic observation data and water resource data to value the latter per ecosystem service – steer policy to set priorities. Based on 10-yr census (2011 most recent) which is detailed at the level of municipalities
	i) Other socio-economic issues where EO may contribute: • Inland and coastal fishing support / management. both short term (blooms) and long term (climatologies/atlas) • Overuse in headwaters /Insufficient downstream water: Governance • Understanding land use vs climate change • Local ecosystem services assessment (Village level) • Understanding scale and impact / changing climate conditions o Food security- irrigation o Water security o Cultural requirements • Surface water resilience. In particular, noting that surface water infrastructure lacks development there is a need to develop awareness around water use efficiency in relation to both water quantity and water quality. This should also acknowledge the role of groundwater in freshwater systems in India and the need for recharge. • Groundwater abstraction: there needs to be understanding of the economic and environmental costs of groundwater abstraction (particularly the increased need for energy to abstract groundwater). In particular, when does groundwater abstraction become uneconomic and how can changes in surface water use efficiency be used to make surface water of sufficient quality available for multiple uses? • Capacity building. This is required on multiple levels, from water scientists sharing knowledge and understanding of process, technology and methods, to policy makers and scientists understanding scale and scope of information required to improve water policy and practice. Where possible, initiatives should be developed using participatory methods to involve communities and stakeholders in determining what information is required.

Session 2: Developing improved frameworks and products for freshwater monitoring exploring gaps and requirements - Strategies for sharing best practice

Discussion Topic	Key Points Raised
A. Ways of integrating EO data and products into existing freshwater monitoring	*I Availability & Accessibility:* • In situ data are made publically available; e.g. temperature, rainfall. Temporal/spatial to validate/bias correct EO observations, • Length of the available data sets to get insight into climate change aspect. Challenge for projection • CWC data can be very difficult to obtain or classified (not always publishable).

	• Restrictions on transboundary regions • National vs regional vs state level vs local level information/ products - need a mix; Scaling up the data using EO sources; optimise the network • Regions tend to have richer data sources. • EO data can be expensive. • Indian space agency so data can be hard to access: data requires an application, justification and sometimes payment. • CWC - water discharge data and EO data water rating curve
	II Validation • Existing data can be used for validation and possibly older data sets (although there are challenges in the latter) • Existing WQM could be used and combined with the broader scale coverage of EO – complimentary use • EO could be used as a sampling management tool to identify hotspots in which regulators might need to concentrate more monitoring effort and also to make current monitoring more effective/ representative • EO would benefit from encouraging the collection of radiometry data alongside routine WQM point sampling to help with validation (but expensive) • Long-term datasets from insut measurements are needed to complement EO to improve outcomes and management options • Citizen science could be encouraged to increase validation data – Secchi data already available as well as some apps but others could be developed, together with cheap kits for citizen use (accuracy and detection limits issues)
	III Reporting w.r.t to management action • EO generates large amounts of data that need to be converted to simple outputs for management • Data storage capacity issues exist • Summarising time-series type data from EO so that it can be related to a single point in time is an issue (probably need to use worst case scenario?) • Need user interface o Translate data and product to indices for reporting o Visualisation tools o Summarise data in right formats • Consistency - pan scalar across regions; times; methods • Data production o Processing o Availability - Potential of smart phones - Citizen science for validation - make your data open o Other cheap sensors for greater participation o Example of Delhi PM2.5 data as best practice o Communication to local press - the Water quality report?

	o 'River health' share and app o Data mining and database creation
	IV. Standardisation • broad spread of responsibilities: o monitoring is organised bottom-up, from local to regional to national. This differs from EU (e.g. WFD) top down requirements o data integration needed
	V. Dissemination • different reporting strategies per state. • Working with CWC will have advantages of centralized management, • but information may or may not reach regional offices. • Who should pay? Expectation that government provides service i.e. different from EU/UK perspective of service partner.
B. Challenges and Opportunities for Collaboration - exploring gaps and requirements	*I. Challenges* • Challenges exist in development and sharing of technology. Also in developing EO to detect chemical contaminants for regulatory or remediation purposes. International sharing of instrumentation is both an opportunity and a challenge • Scales o District level planning but how to scale up across states • Structural o Funding models (?)
	II. Opportunities - structural • Impact agenda in the UK helps • sharing of different technologies, training • GCRF upcoming call- very large consortia • Scientific opportunity to work with different systems • Engage more with stakeholders • Exchange scientists/students • IUKWC- PhD Program? Training network. Training and capacity building is a gap that we could address • Connect to other disciplines such as glaciology • Co-develop training courses
	III. Opportunities - science • Including wetlands, basic mapping function of time still in India • Opportunities exist in testing whether different water systems function in similar or different ways over large spatial scales (global) and in different environments/climates. • Explore hyperspectral sensors to extend products (chemical compounds) • Volume and flow of water • Change in geomorphology (siltation, change in reservoir storage capacity) • Develop drone technology (rivers, small body, validation) • Carbon storage

	• Fixed observation points • Biological pollution • ID of recharge (?) • Spread of epidemic
	IV. Gaps and requirements for knowledge • Gap in existing EO monitoring system is o length of the data o Resolutions/temporal scale o Parameters – multi variables in situ– higher temporal o Downscaling o Setting up climate data observation platform network (multi variable) o Monitoring of multivariable in wetland/paddy farms o Compatibility of EU and ISRO data sets for temporal scale-quality control; better coverage o Collaboration on learning from EU for forming policies on climate change and adaptation • Data and information sharing • Cheap sensors- develop smartphone • Knowledge exchange needed – students and scientists. Specific training courses and co-developed courses • More engagement with stakeholders and regulators needed, e.g. Env Agencies, water companies, wildlife and conservancy agencies • Potential for awareness raising at high government level in India by a special conference, and brainstorming workshops might be used to look forward for future needs and collaboration. • Need to identify potential funding possibilities in India
	V. Gaps and requirements science • Spring watershed management o Darjeeling, dry districts. o Target: improve water retention o Audience: local government to help regulation o Mechanism: o research requirement: quantitative assessment (see session 4) • Kerala fisheries o target: optimise catch o audience: local fishermen o mechanism: info flow through INCOIS o research requirement: integrated obs & monitoring • Kerala Surface water quality monitoring for health: o target: limit disease outbreak o research: drainage, observation modes e.g Kerala – during monsoon; . in Bombay & Calcutta drainage monitoring exists, in other areas no implementation yet

	• Sikkim High elevation water bodies, Eastern Himalayas, glacial dynamics o target: climate change impacts & forecasting / risk mapping flooding in downstream areas, including effects on hydropower; can EO data be used to fill in the blanks in high altitude regions. Future water resources assessment in relation to climate change impacts on glaciers o mechanism: there are existing institutional collaborations to build on - and links to BAS to look at bathymetry o audience: local communities, tourists, through state disaster management departments

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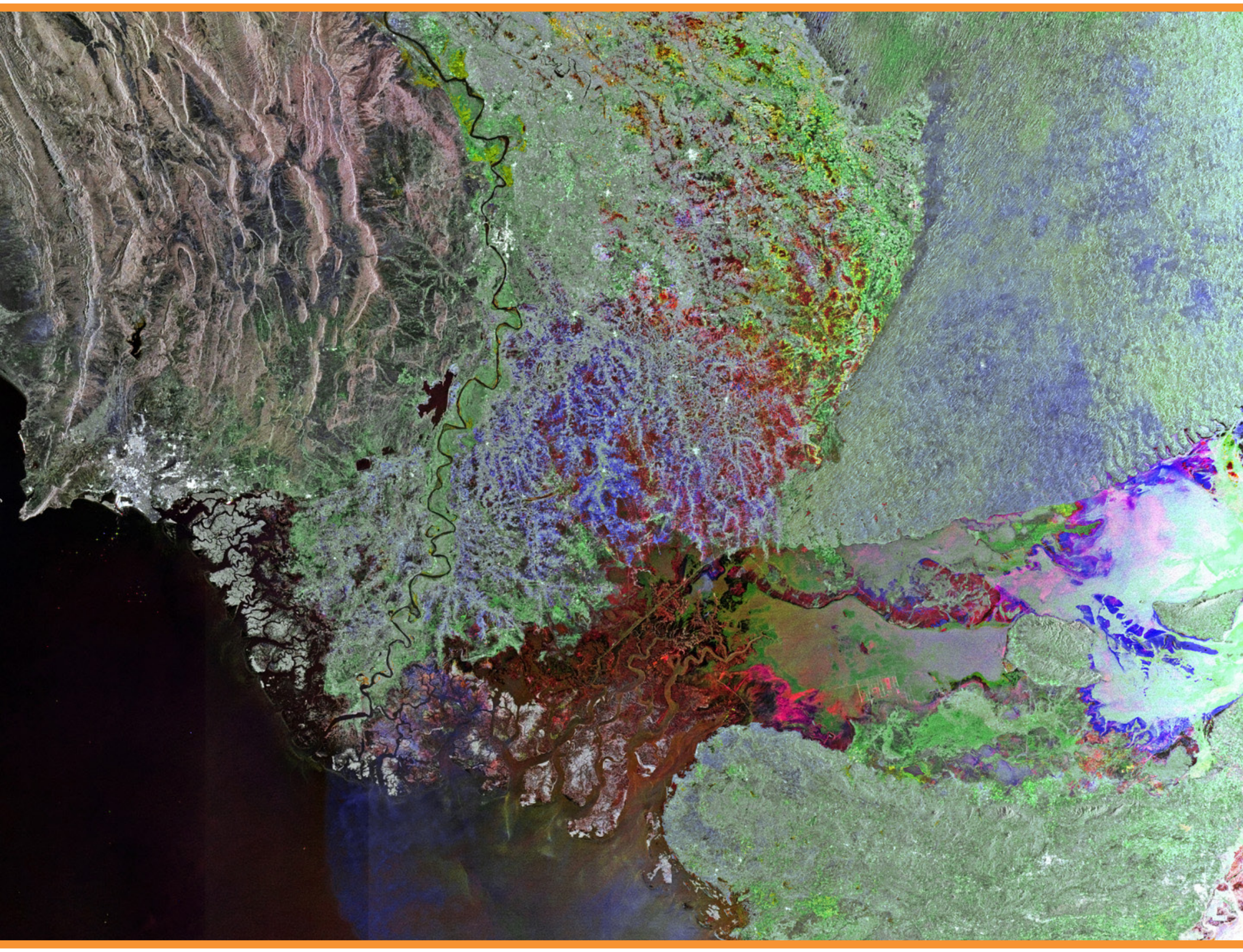

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