Exploring the Role of Essential Water Variables (EWVs) in Monitoring Indicators for the Sustainable Management of the Water-Energy-Food (WEF) Nexus, UN-SDGs & Climate Change

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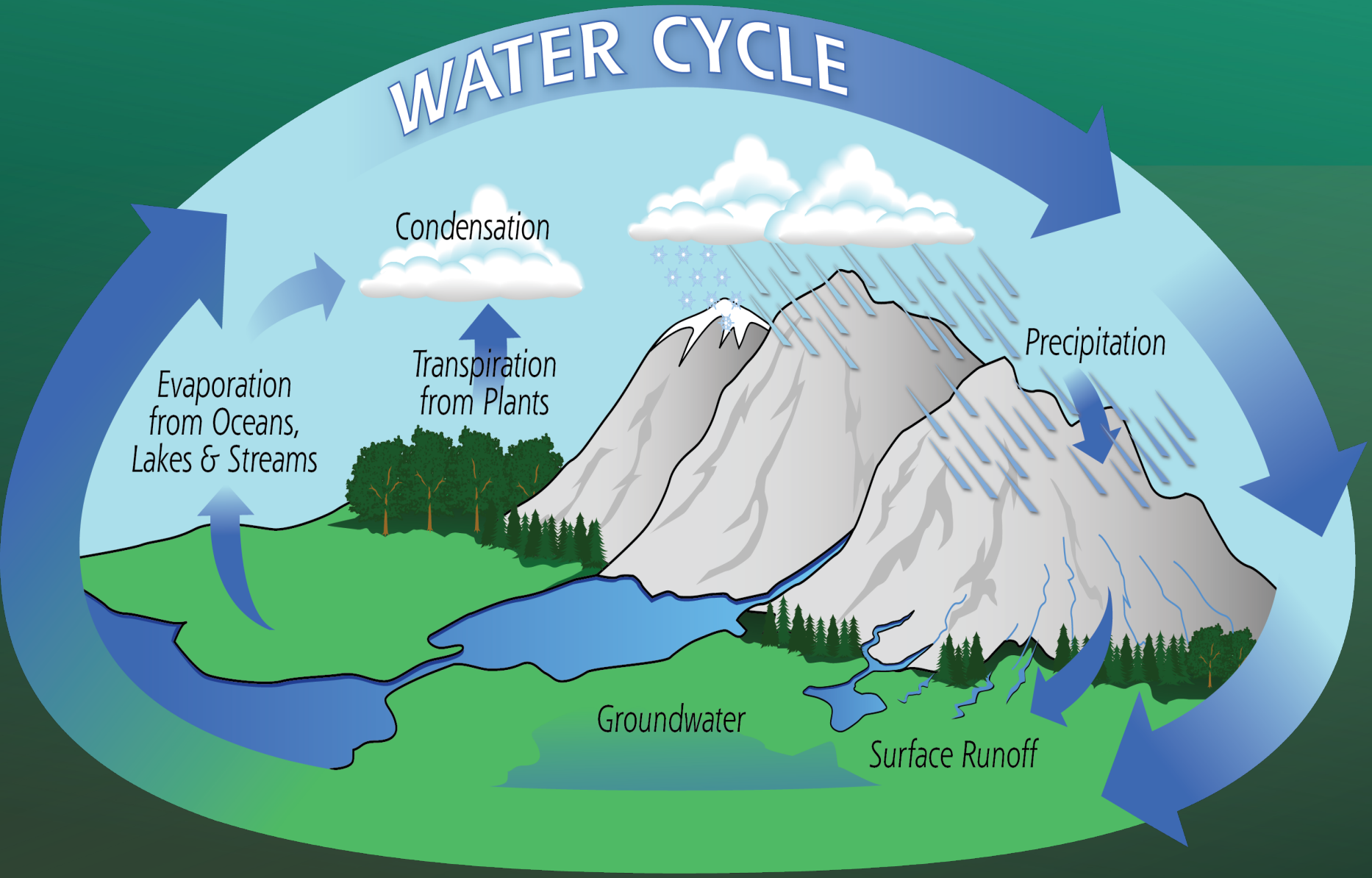
Earth Observations (EO) systems aim to monitor nearly all aspects of the global Earth environment. Observations of Essential Water Variables (EWVs) together with advanced data assimilation models, could provide the basis for systems that deliver integrated information for operational and policy level decision making that supports the Water-Energy-Food-Nexus (EO4WEF), and concurrently the UN Sustainable Development Goals (SDGs), and UN Framework Convention on Climate Change (UNFCCC). Implementing integrated EO for GEO-WEF (EO4WEF) systems requires resolving key questions regarding the selection and standardization of priority variables, the specification of technologically feasible observational requirements, and a template for integrated data sets. This paper presents a concise summary of EWVs adapted from the GEO Global Water Sustainability (GEOGLOWS) Initiative and consolidated EO observational requirements derived from the GEO Water Strategy Report (WSR). The UN-SDGs implicitly incorporate several other Frameworks and Conventions such as The Sendai Framework for Disaster Risk Reduction; The Ramsar Convention on Wetlands; and the Aichi Convention on Biological Diversity. Primary and Supplemental EWVs that support WEF Nexus & UN-SDGs, and Climate Change are specified. The EO-based decision-making sectors considered include water resources; water quality; water stress and water use efficiency; urban water management; disaster resilience; food security, sustainable agriculture; clean & renewable energy; climate change adaptation & mitigation; biodiversity & ecosystem sustainability; weather and climate extremes (e.g., floods, droughts, and heat waves); transboundary WEF policy.

WATER CYCLE. Source NASA Global Precipitation Mission (https://gpm.nasa.gov/education/water-cycle)



- **Essential Water Variables (EWVs) are required to describe the water storage and transport/flux terms in the water cycle that supports food, water resources, and renewable energy systems**
- **Different components of the system requires observations at varying space and time resolutions—from weather extremes to climate change**
- **EWV observations are required for the sustainable operational and strategic management of the water-energy-food nexus**

Defining Essential Water Variables (EWVs):

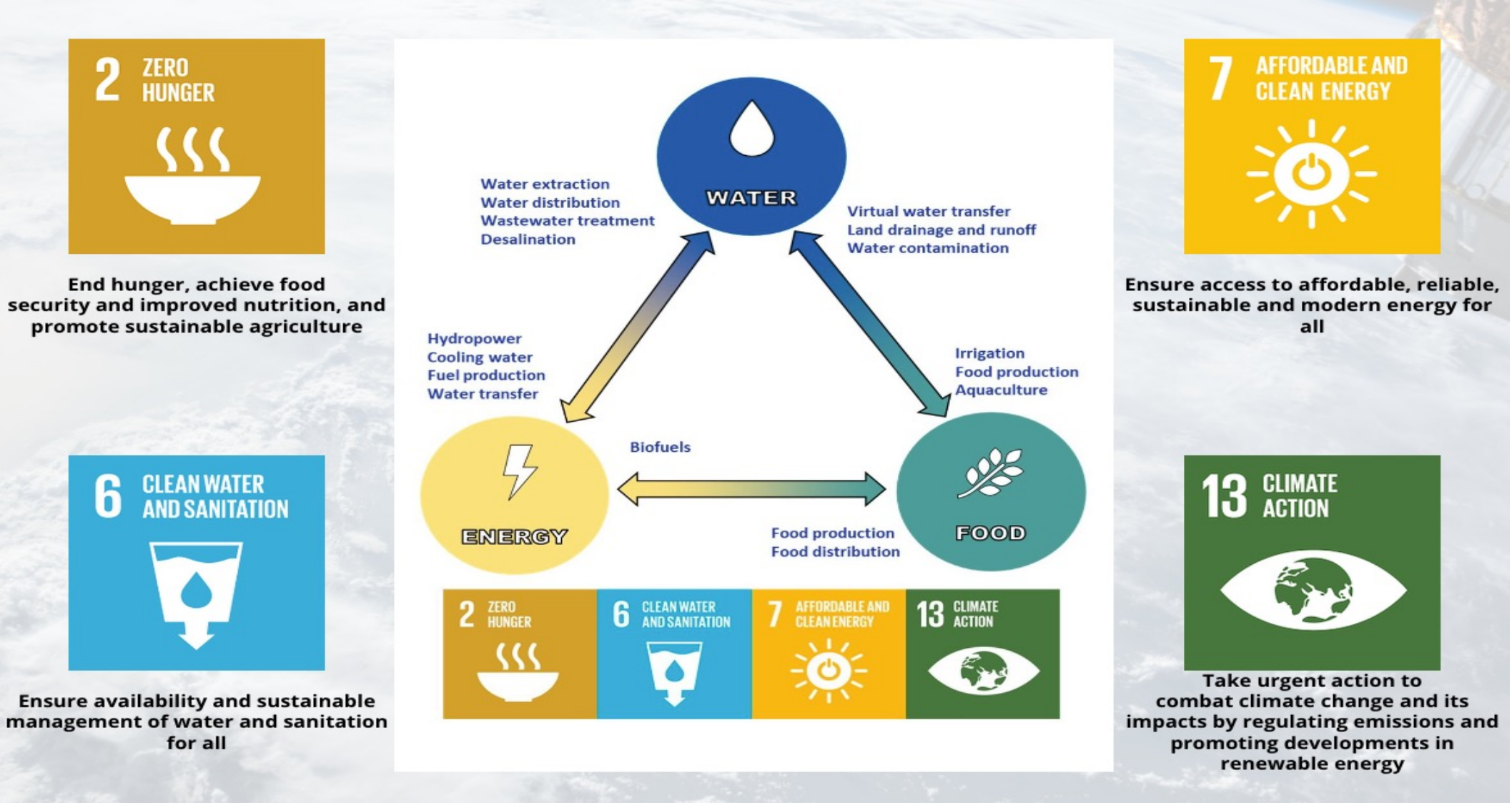
Water variables and parameters that address "user" defined critical requirements for one or more of the following (https://www.geoglows.org/pages/workinggroup3):

- **Observational "monitoring" of key elements of the global and regional/local water cycle**
- **Observations required by diagnostic and/or land surface/hydrological prediction models that are used to generate products for the end-user communities, and**
- **Observations and model-derived variables and parameters required by users of water data/information products as applied to various inter-disciplinary decision support systems and tools.**

Current List of Primary and Supplemental Essential Water Variables (EWVs)– Adapted/Updated from GEOGLOWS-WG3 and Huffman et al., 2021 following end-user feedback & review at international conferences (https://www.geoglows.org/pages/workinggroup3).

Primary EWVs	Supplemental EWVs
Precipitation	**Surface meteorology**
Evaporation & Evapotranspiration	**Surface and atmospheric radiation**
Snow	**Water vapor, clouds & aerosols**
Soil moisture	**Land cover, vegetation**
Soil temperature	**Permafrost**
Groundwater	
Runoff/streamflow/river discharge	**Surface altimetry**
Surface water extent	**Bathymetry**
Lake/Reservoir Levels & Aquifer volumetric change; terrestrial water storage	**Elevation/topography**
Mass balances of glaciers and Ice sheets	**Geological stratification**
Water use/demand (agriculture, hydrology, energy, urban, others…)	
Water quality (E.g., EO-based Chl-a, HAB, TSS, T, and in-situ-based D-O2, Nitrates/Sulphates, Ph/Salinity, EC, Turbidity, Heavy Metals, E.coli)	**Land use**

EWVs support the monitoring needs of the WEF Nexus, UN-SDGs (Especially Goals 2, 6, 7, 13), and international Frameworks & Conventions. Below: Depiction of GEO Earth Observations for WEF showing interaction pathways between critical WEF resource management sectors. Source: With permission from GEO EO4WEF (2022): https://eo4wef.org/.



Sustainable Development and Climate Change need to be explicitly incorporated in integrated WEF Nexus implementation; EWVs play a significant role

The Water-Energy-Food (WEF) Nexus represents a community activity effort to transform the manner in which the respective water, renewable energy, and food production systems are designed, monitored and managed.

Frequently (especially in the past), each sector optimizes its own protocols to yield the best margins of logistical efficiency and economic returns. Other sectors are considered only when they are needed for the production cycle.

Multi- and cross-sectoral Integrated planning could reduce the competition between the sectors, identify synergistic elements, and develop policies that maximizes overall social, economic, and importantly environmental benefit.

Long-term sustainability is of vital interest, especially in the context of the UN Sustainable Development Goals (SDGs). With climate change, it becomes important if not critical to incorporate long-term strategies that take into account future climate scenarios that impact the Water-Energy-Food sectors.

The WEF is part of UN Sustainable Development Goals (17) (https://www.un.org/sustainabledevelopment/)

WEF Elements include:

SDG 6-WATER (Clean water and sanitation)--includes:
- Integrated water resources management
- Water quality
- Water use efficiency
SDG-7-ENERGY (Affordable and clean energy)—includes:
- Renewable energy
- Energy intensity
- Energy consumption
SDG 2-FOOD (End hunger)—includes:
- Food security, resilience
- Sustainable agriculture
- Improved nutrition
SDG-13-Climate Action--incl.
-Climate variability and prediction
-Climate change assessments, adaptation, mitigation action
-Climate Policy

Source/Credit: UN Dept. Global Communications: https://www.un.org/sustainabledevelopment/news/communications-material

WEF sub-elements highlighted by UN-SDG monitoring targets & indicators encapsulated in SDG-6, 7, 2 & 13

- **SDG 6-WATER (Clean water and sanitation) --including:**
  - Integrated water resources management
  - Water quality
  - Water use efficiency
- **SDG-7-ENERGY (Affordable and clean energy)—including:**
  - Renewable energy
  - Energy intensity
  - Energy consumption
- **SDG 2-FOOD (End hunger)—including:**
  - Food security, resilience
  - Sustainable agriculture
  - Improved nutrition

In addition, EWVs support cross-cutting climate action SDG goals and targets:

- **SDG-13-Climate Action—including:**

  - Strengthen resilience & adaptive capacity to climate related hazards & natural disasters

  - Sustainable use of terrestrial and inland freshwater ecosystems

  - Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss.

  - Implement UN Framework Convention on Climate Change

EWVs of the WEF Nexus Also Support International Frameworks and Conventions

- Sendai Framework for Disaster Risk Reduction: Understanding disaster risk; strengthening governance; investing in resilience; enhancing preparedness for effective response

- The Ramsar Convention on Wetlands: Conservation and sustainable use of wetlands. Works closely with IUCN (conservation of nature), IWMI (Water management), Wetlands International, WWF/WWT

-The Aichi Convention on Biological Diversity: Biological diversity; sustainable use of biodiversity; equitable sharing

-The Framework Convention on Climate Change (UN-FCCC): Stabilize GHGs causing global warming; Prevent human-induced interference w/climate system; linked to Aichi and Convention to combat desertification.

EWVs overlap with Essential Climate Variables (ECVs) that support the Global Climate Observing System (GCOS) co-sponsored by WMO, IOC/UNESCO, UNEP, and ICSU.

Primary EWV EO Requirements for W-E-F and UN-SDG Decision Making, including UN-FCCC (Climate Change)—SDG-13. [Derived/Updated from GEOGLOWS=WG3 and GEOSS-WSR. Specifications are technology and applications dependent. Not included here: Sub-meter to meter spatial resolutions and sub 1-hr time resolutions needed for some local and sub-regional applications and/or global monitoring systems especially for disaster warnings and mitigation, but generally unavailable in near-real time in the public (free of charge) domain.] [GEOGLOWS-WG3: https://www.geoglows.org/pages/workinggroup3)]

Primary EWVs	W-E-F Decision Making	UN-SDGs Decision Making	Space Resolutions Loc/Reg-Glob	Time Resolution Loc/Reg-Glob
Precipitation	W, E, F	SDG 6, 2, 3, 7, 13, 14, 15	0.1 - 1 km/10 km - 100 km	~ 1hr/3hr-1
Evaporation	W, E, F	SDG 6, 2, 3, 13,	0.1 - 1 km/ 0 km – 100 km	~ 1hr/1d - 1mo
Evapotranspiration	W. F	SDG 6, 2, 3, 13	0.1 - 1 km/10 km – 100 km	~ 1hr/1d – 1mo
Snow	W, E, F	SDG 6, 2, 13	0.1 -- 1 km/10 km – 100 km	~ 1d/1d – 1mo
Soil moisture	W, E, F	SDG 6, 2, 3, 13, 15	0.1 – 1 km/10 km – 100 km	~ 1-6hr/1d – 1mo
Soil temperature	W, F	SDG 6, 2, 3, 13, 15	0.1 - 1 km/10 km – 100 km	~ 1-6hr/1d – 1 mo
Groundwater	W, F, E	SDG 6, 2, 3, 13,	1 km/10 km – 100 km	~ 1 mo/3mo – 1yr
Runoff/streamflow/river discharge	W, E, F	SDG 6, 2, 13, 14, 15,	1 km/10 km – 100 km	~ 1– 6hr/1d – 1mo
Surface water extent	W, E, F	SDG 6, 3, 7, 9, 11, 12, 15	0.1 - 1 km/10 km – 100 km	~ 1 w/1mo – 1 yr
Lake/Reservoir Levels & Aquifer volumetric change; terrestrial water storage	W, E, F	SDG 6, 2, 7, 13, 15,	1 km/10 km – 100 km	~ 1 mo/3mo – 1 yr
Mass balances of glaciers and Ice sheets	W	SDG 6, 13	1 km/10 km – 100 km	~ 1 mo/1yr – 10yr
Water use/demand (agriculture, hydrology, energy, urban, others…)	W, E, F	SDG 6, 2, 3, 7, 13, 15	1 m - 0.1 km/10 km – 100 km	~ 1 mo/3mo- 1yr
Water quality (Including T, D-O2, Sulphates/Nitrates,, Ph/salinity, Turbidity/TSS, Color, EC-Elect. Cond., Chl-a, Harmful Algal Blooms, fecal coliform bacteria—E.coli	W, E, F	SDG 6, 2, 3, 13, 14, 15	1 m - 0.1 km/1 km – 100 km	~ 1 d/1wk – 1 yr

Supplemental EWV EO Requirements for W-E-F and UN-SDG Decision Making, including UN-FCCC (Climate Change)—SDG-13. [Derived/Updated from GEOGLOWS=WG3 and GEOSS-WSR. Specifications are technology and applications dependent. Not included here: Sub-meter to meter spatial resolutions and sub 1-hr time resolutions needed for some local and sub-regional applications and/or global monitoring systems especially for disaster warnings and mitigation, but generally unavailable in near-real time in the public (free of charge) domain.] [GEOGLOWS-WG3: https://www.geoglows.org/pages/workinggroup3)]

Supplemental EWVs	W-E-F Decision Making	UN-SDGs Decision Making	Space Resolutions Loc/Reg-Glob	Time Resolution Loc/Reg-Glob
Surface meteorology	W, E, F	SDG 6, 3, 2, 3, 13	0.1 - 1km/10 km - 100 km	~ 1 hr/3hr – 1d
Surface and atmospheric radiation	W, E, F	SDG 6, 7, 13	0.1 - 1km/10 km - 100 km	~ 1 hr/ 3hr – 1mo
Clouds & water vapor	W, E, F	SDG 6, 13	0.1 - 1km/10 km - 100 km	~ 3 hr/1d
Aerosols	E, F	SDG 6, 13	0.1 - 1km/10 km - 100 km	~ 3 hr/1d
Land cover, vegetation	W, E, F	SDG 6, 13, 14, 15,	0.1 - 1km/10 km - 100 km	~ 1 d/1wk– 1yr
Permafrost	W, F	SDG 6, 13	0.1 - 1km/10 km - 100 km	~ 1 mo/1yr –10yr
Surface altimetry	W, E	SDG 6, 13, 15	0.1 - 1km/10 km - 100 km	~ 1 mo/3mo – 1yr
Bathymetry	W	SDG 6, 3, 7, 13	0.1 - 1km/10 km - 100 km	~ 1 mo/3mo – 1yr
Elevation/topography	W, E, F	SDG 6, 2, 7, 13, 15	0.1 - 1km/10 km - 100 km	~ 1 mo/3mo – 1yr
Geological stratification	W, E,F	SDG 6, 2, 13, 15	0.1 - 1km/10 km - 100 km	~ 5 yr/10yr –50yr
Land use	W, E, F	SDG 6, 2, 7, 13, 15,	0.1 - 1km/10 km - 100 km	~ 10 d/3mo – 10 r

Needs for EWV EO EWV Integrated Data/Information Products for WEF-Climate Nexus:

- **Sustainable water resources, including assessments of water stress, water use efficiency, water quality and health impacts**
- **Food security and sustainable agriculture, including cross-sectoral assessments to ensure optimized integrated WEF management**
- **Renewable energy assessment, production, distribution, especially wind & solar; including possible impacts on integrated WEF systems**
- **Improving water quality, improving food quality, reducing health impacts of contaminants in water and food production and delivery systems**
- **Disaster resilience, including surveillance and early warning of extreme events**
- **Climate variability & change prevention, mitigation, adaptation**
- **Urban water and waste management**
- **Health and vector borne diseases**
- **Transboundary WEF policy**

Challenges in using satellite data:

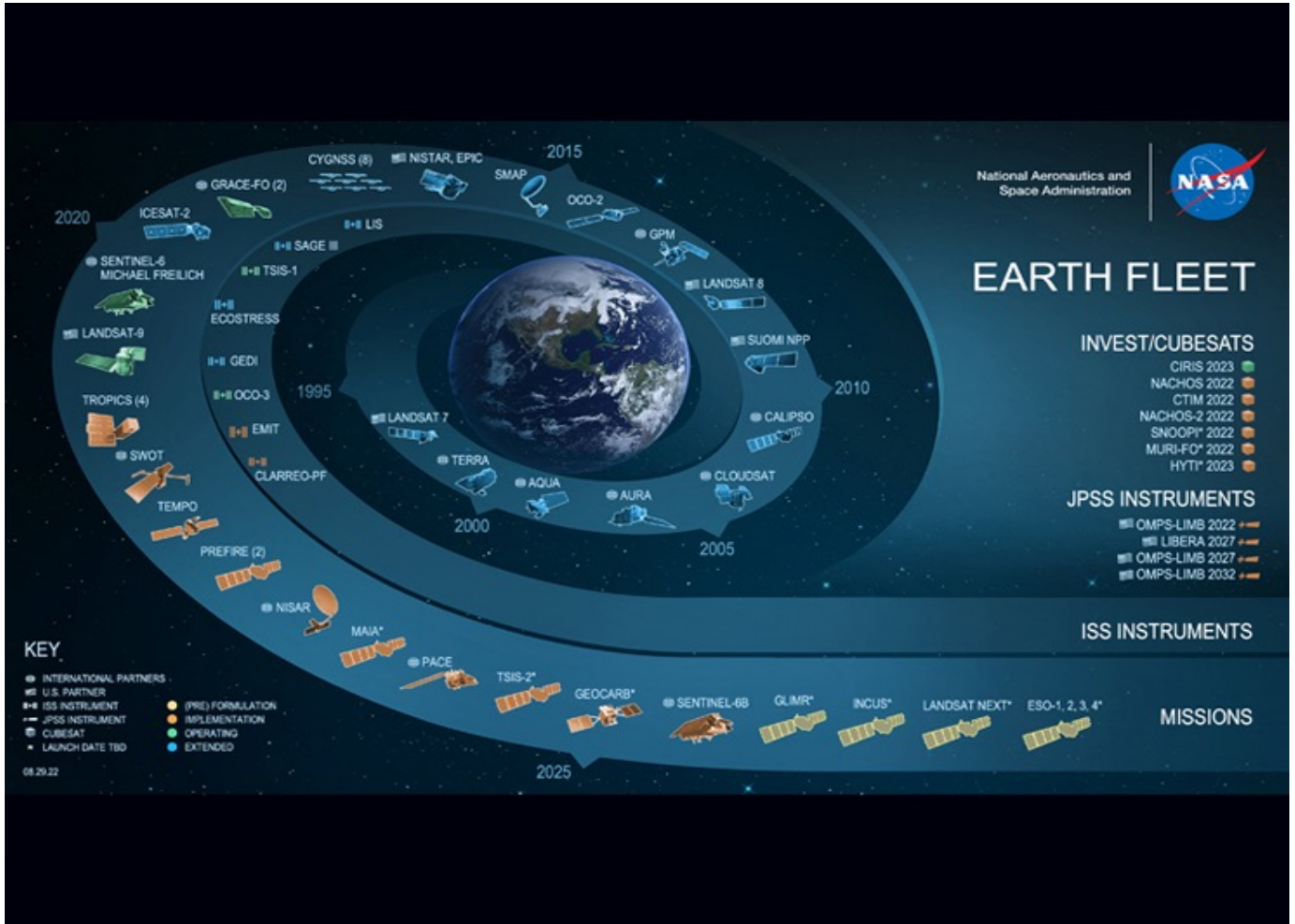
1) Satellites measure radiances so algorithms are needed to turn satellite measurements from radiances into reliable geophysical data and information. Sometimes these algorithms are very accurate for the location where they were developed but may be less reliable in other locations.

2) In the case of optical satellite data, clouds sometimes block the object being observed and night-time data are limited.

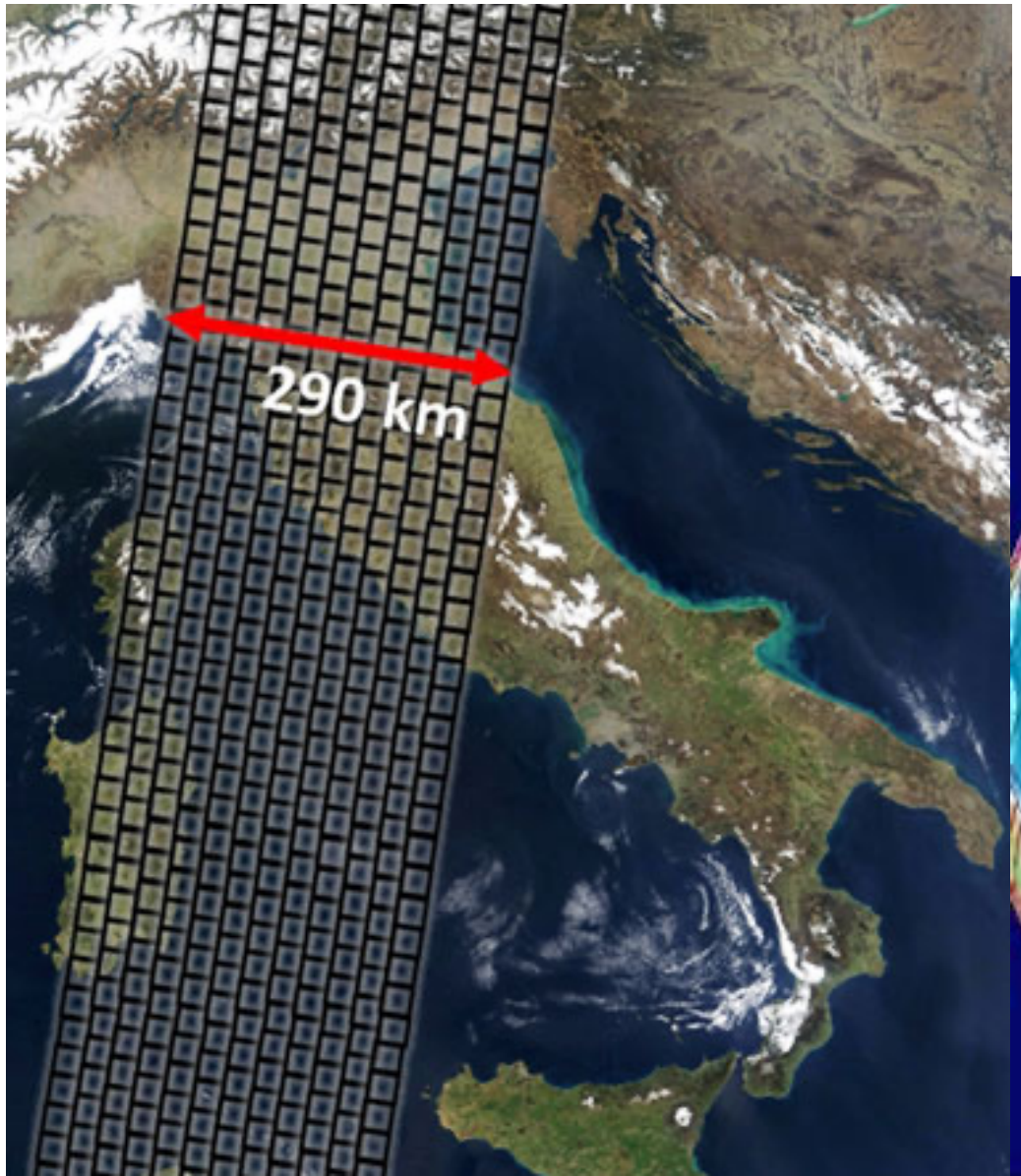
3) Operational applications rely on stable satellite platforms. Some satellites are in orbit to support operations (e.g., NOAA, EUMETSAT) while others are in orbit to support research programs (NASA, ESA, JAXA). Ideally research satellites are followed by operational satellites once their usefulness for a significant societal sector is proven.

4) The growth of the private sector involvement in Earth Observations may lead to new polices on making data available at no cost.

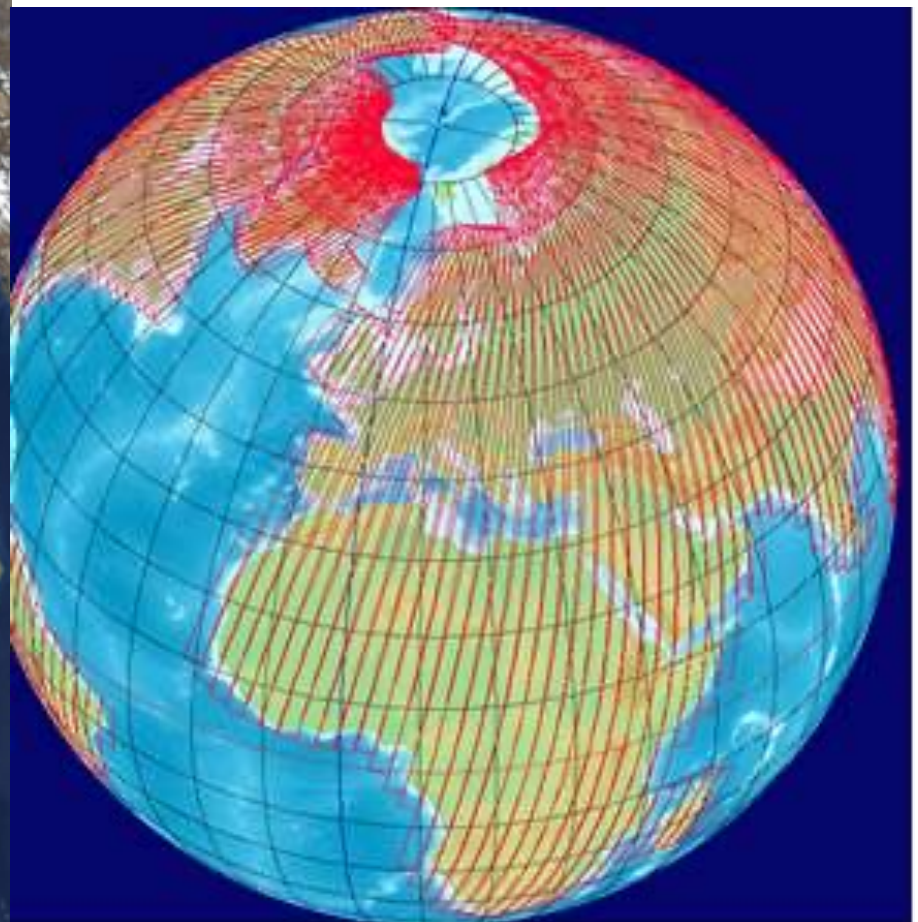
NASA Earth Observation Satellite Fleet. [Source: NASA: https://eospso.nasa.gov/content/nasas-earth-observing-system-project-science-office]



ESA Sentinel-2a and 2b (Downy)



With two satellites all areas will be revisited every five days under the same viewing conditions.

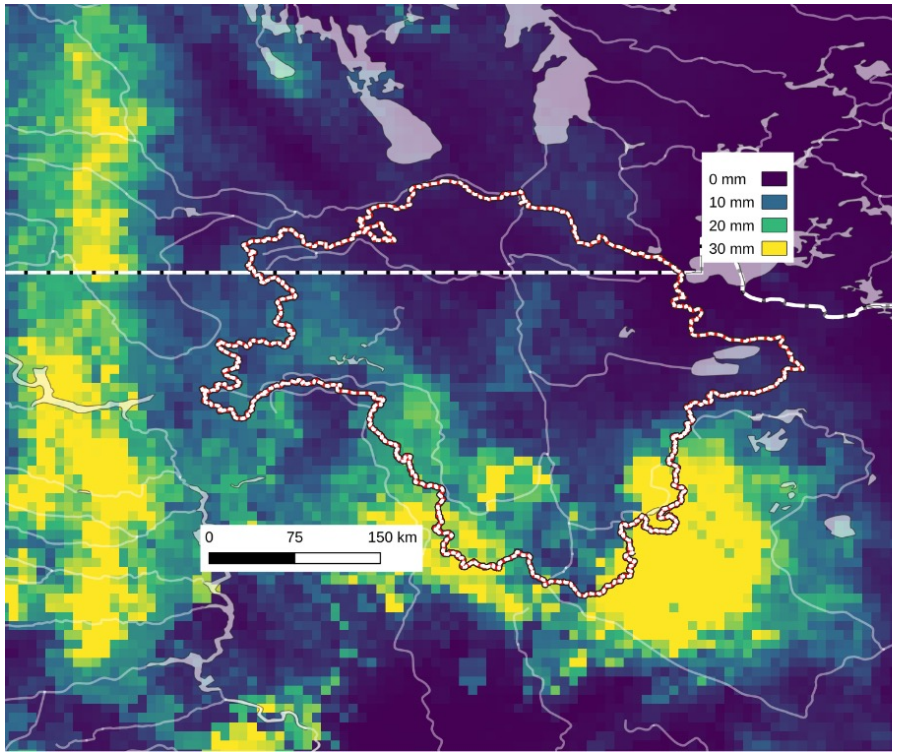


Relevant Datasets for the Water-Energy-Food (WEF) nexus from the Sentinel satellites

Water products	Food/agricultural products	Energy products
Water quality, watershed land use/land use change, snow and glacier monitoring, wetlands monitoring, water reservoir mapping; irrigation water management, aquifer monitoring, precipitation, soil moisture, evapotranspiration…	Land use/land use change maps, crop location & type mapping, crop acreage mapping, early warning indicators, yield assessment, precision agriculture, land degradation, clear cut/burnt area maps, soil moisture, ocean colour, sst, (for fisheries)…	Geological mapping, habitat assessment maps, logistic planning support, mine waste monitoring, illicit mining detection, renewable resources mapping and monitoring – solar, wind, wave, tidal, hydropower; crop yield estimates for biofuels…

As well as other relevant information e.g. climate change data sets

Satellite Data for Water Security



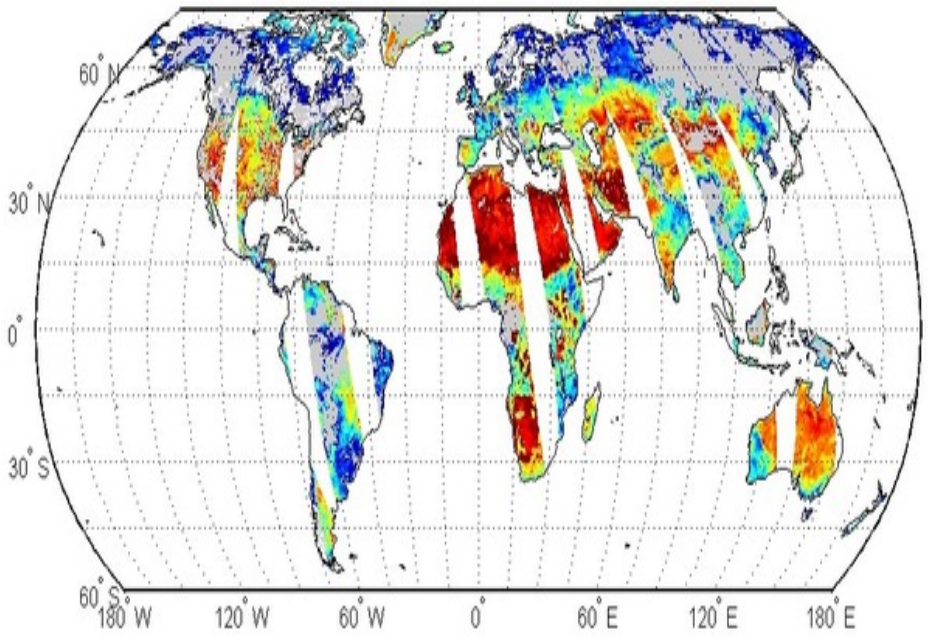
Variable: Precipitation (Amount and Rate)

Use: Determine inputs to river systems, replenishment of soil water, flood potential and erosion rates.

Data Characteristic: Useful scales and frequencies
The security issues:
Water Quantity: too much (floods; too little: low flows, no water recharge,)
High rain rates: can lead to flash floods and high erosion rates.

Data Sources:
Satellite: GPM (Global Precipitation Mission) Constellation,
Merged products: IMERG,

Predictive Capability: Predicted by meteorological models
Used in hydrologic forecasting: Precipitation is a critical input to hydrologic models
Special Features:



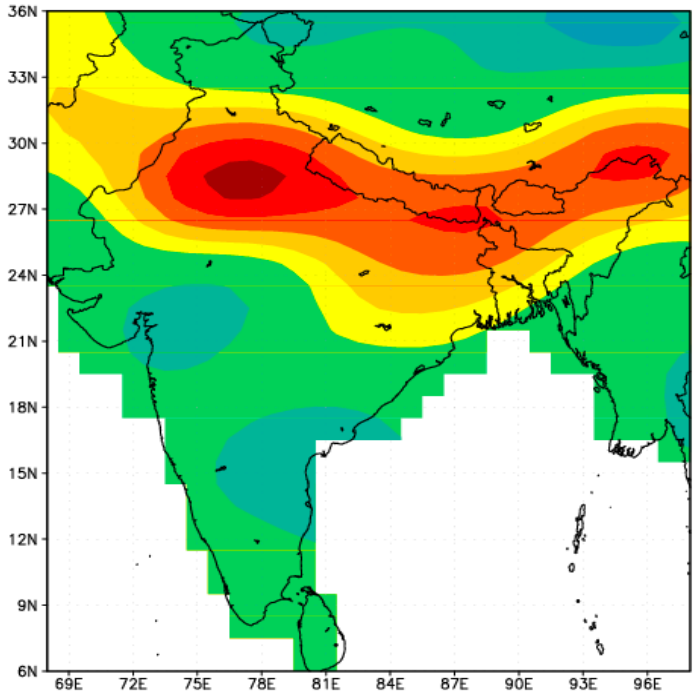
Variable: Soil Moisture

Use: Determine the water in the vadose zone where plants draw their moisture from

Data Characteristic: Useful scales and Frequencies (once per week)
The security issues: Food security threatened when soil moisture is too low
High soil moisture: increases the risk of flooding
Controls the rate of climate warming

Data Sources:
Satellite: SMOS, SMAP, AMSER/E, Sentinel

Predictive Capability: Predicted by meteorological models
Used in hydrologic forecasting through inputs to hydrologic models
Special Features:



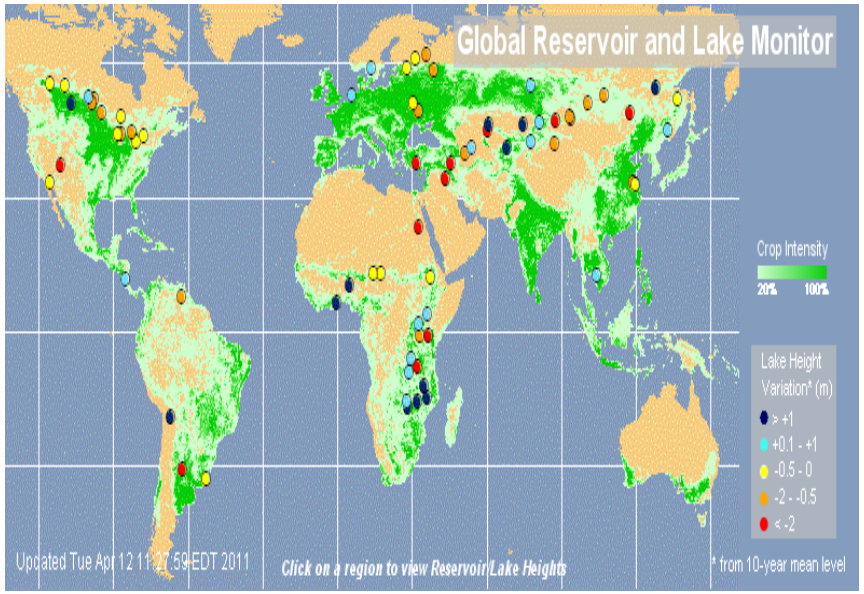
Variable: Groundwater

Use: Determine where groundwater aquifers are available and where they are being depleted from overuse
Determine when contamination such as salinization may be a threat.

Data Characteristic: Useful scales and Frequencies (once per day)
The security issues: Ground water depletion or contamination leads to the inability to use this source to meet water needs.

Data Sources:
Satellite: GRACE II, Sentinel

Predictive Capability: Quantity Predicted by hydrological models tracking inputs over time and quality is predicted by models that track the flow paths for individual contaminants (gasoline, etc.)
Special Features:



Variable: Reservoir and Lake Storages

(assessed by lake level measurements)

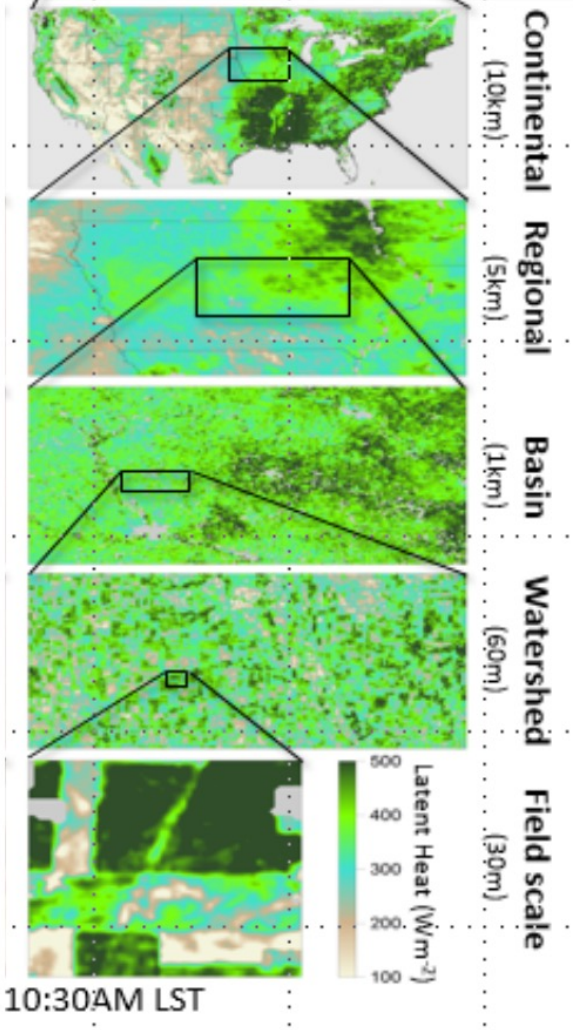
Use: Lake levels are either used as inputs to the calculation of storage volumes in reservoirs or as proxies for storage volumes.

Data Characteristic: Useful scales and frequencies
Security issues: - Water Quality: too much (flood); too little (drought),
- Availability for hydropower, irrigation and recreation.

Data Sources:
Satellite: SWOT (Future), OSTM/Jason 2 , GRACE-II, Sentinel

Predictive Capability: Based on hydrometric inputs to hydrologic models (infows, outflows)

Special Features:



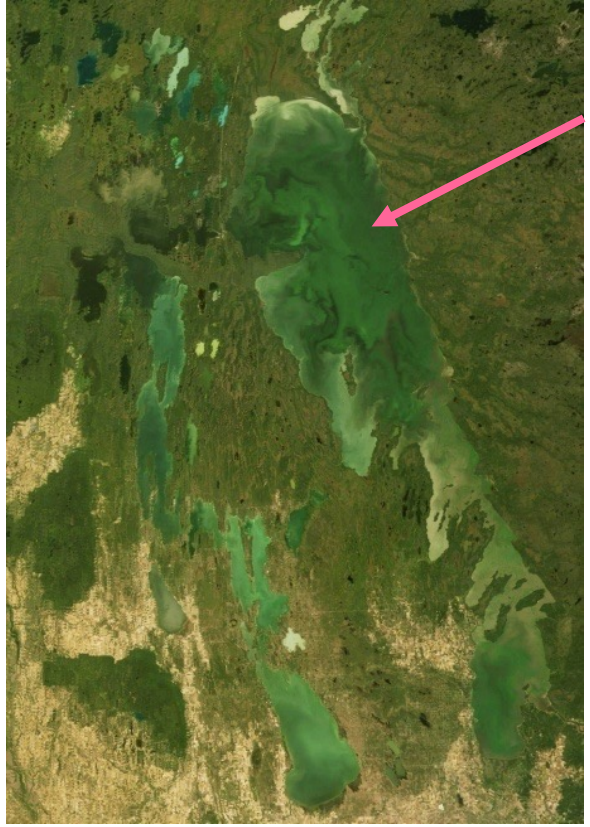
Variable: Evapotranspiration

Use: Determine the need for irrigation and aids the evaluation of the use of water by irrigation.

Data Characteristic: Useful scales and Frequencies (every half hour)
The security issues: Evapotranspiration is considered a major use (loss) of water in the agricultural use of water.

Data Sources:
Satellite: LANDSAT, MODIS, Sentinel, ECOSTRESS

Predictive Capability: Different approaches are used to derive ET from satellite measurements including land surface temperatures.



Algal bloom on Lk. Winnipeg

Variable: Water Quality

Use: Identification of areas with potential water quality problems (Phytoplankton blooms, Total Suspended Solids)

Data Characteristic: Useful scales and Frequencies
The security issues: Use of water affected if blue-green alagae or other pollutants are present.

Data Sources:
Satellite: LANDSAT, MODIS, Sentinel

Predictive Capability:

Conclusions/ Recommendations

Conclusions:

- **Earth Observations (EO) systems aim to monitor nearly all aspects of the global Earth environment. Observations of Essential Water Variables (EWVs) together with advanced data assimilation models, could provide the basis for systems that deliver integrated cognitive/knowledge-based information for operational and policy level decision making that supports integrated Water-Energy^{R}-Food-Nexus management, monitored by progress towards achieving the UN-Sustainable Development Goals (SDGs).**
- **Implementing integrated EO4WEF systems requires resolving key questions regarding the selection and standardization of priority variables, the specification of technologically feasible observational requirements, and a template for integrated data sets**
- **Key EWV and WEF end-user needs include EO-based decision-making information for water resources management; water quality; water stress and water use efficiency; urban water management; disaster resilience; food security, sustainable agriculture; clean & renewable energy; climate change adaptation & mitigation; biodiversity & ecosystem sustainability; weather and climate extremes such as floods, droughts and heat waves; transboundary WEF policy**
- **To ensure the stability of existing systems and for the development of next-generation observational platforms, it is important that a concise set of EWVs are recognized and adopted by international and national programs.**

Recommendation:

- **AGU-2022 is invited to review the priority EWVs presented here, specifically those relevant to the EO4WEF GEO Community of Activity (CoA) covering the WEF-Nexus and UN-SDGs.**
- **Suggest next steps for the elaboration of more specific EWV observational requirements relevant to the WEF Nexus, including observing instruments platforms and networks, data analytics and end user products for WEF decision support systems.**

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