

Measuring water from space



The use of satellite technology is revolutionizing the measurement of Earth's water.

The water cycle, or hydrological cycle, describes how water is exchanged through Earth's land, ocean, and atmosphere. Looking back, the water cycle was first explained by ancient Greek mythology¹. Our modern concept of the water cycle could be traced back to Leonardo da Vinci², who in the late 15th century built his own experimental instruments and conceptualized the water cycle based on hydrological observations. However, it was not until the time of John Dalton, about 300 years later, that the major mechanism of the water cycle, as we know it today, was understood³.

Water exists in three phases. Measuring it in all its forms has always been critical to our understanding of the water cycle. We have benefited from visual observations, ship and ground measurements, and now remote sensing with aircraft (unmanned aerial vehicles and piloted aircraft) and satellites as we progressed from mythology to science, from phenomena to mechanisms.

Satellite technology can capture small changes in Earth's gravitational pull, tracking the water movement on our planet. Scientists can now better describe and predict changes in the water cycle based on satellite measurements and hydrological models. However, the application of satellite technology in water research and practice has not always been fully embraced.

Matthew Rodell and John Reager⁴ told the story of how satellite gravimetry has moved from the fringes of hydrology to become a staple of large-scale water cycle and water resources science, as well as the only source of global observations of terrestrial water storage, now an 'essential climate variable'. In 2002, the US and German space agencies (NASA and DLR) launched the twin satellites of the Gravity Recovery and Climate Experiment (GRACE) mission. A remarkable innovation at the time, GRACE's measurements revealed changes in sea level, soil moisture, and ice sheets. In more than 15 years of operations, GRACE flew around Earth to measure



changes in distance between the two satellites in response to gravity, providing new insights into changes in large-scale terrestrial water storage (TWS) under the warming climate^{4,5}.

Although groundwater is a vital resource for humans and society, it is hidden beneath the Earth's surface, making large-scale measurements of changes in its storage difficult. To this end, GRACE has been crucial in understanding where, when, how fast and whether groundwater is rising or declining. In 2018, GRACE Follow-On (GRACE-FO) was launched. The TWS data assimilation derived from GRACE/GRACE-FO continues to improve our knowledge of global freshwater availability and hydroclimatic extremes⁶.

Groundwater and surface water are inextricably linked when it comes to sustainable water management and water security. Our tools for measuring water have just been sharpened with the launch of the Surface Water and Ocean Topography mission, known as SWOT, led by the US and French space agencies (NASA and CNES), with contributions from the Canadian Space Agency (CSA) and United Kingdom Space Agency (UKSA). Launched in December 2022, SWOT is now orbiting the Earth, measuring the height of almost all of our planet's surface water with unprecedented accuracy and resolution from space. As emphasized in the Q&A with Nadya Vinogradova Shiffer, present in this issue, our view of Earth's surface water and its movement will be revolutionized by this water mission.

Flying over land, SWOT provides information on the variability of water storage in estuaries, lakes, reservoirs, and wetlands, which is essential for drought monitoring, flood forecasting, reservoir storage and river regulation. Flying over the ocean, SWOT detects the fine-scale transport of ocean heat and carbon,

allowing us to better map the ocean currents for societal benefits such as coastal operations and maritime industries. With this first comprehensive data on the Earth's surface water, even in remote regions, scientists and decision makers will be better informed to address the challenges we face today with freshwater resources, the ocean and coastal environment, climate change and much more.

Satellite technology is exceptionally advanced, but measuring water is so much more than just watching our planet from space. One of the key challenges is translating the measurements into solutions for both water quantity and water quality. In our first issue, Meagan Schipanski and colleagues⁷ proposed a major shift in research, extension and policy priorities to build polycentric governance capacity and strategic planning tools to sustain aquifer-dependent communities. A good example is the early engagement of policymakers, environmental managers, and stakeholders in an open and effective dialogue with SWOT scientists. Another exciting development is that the SWOT community has fully transitioned to commercial cloud solutions for data storage, redesigned data science systems, and built a set of open-source tools to help future users transition to open science and open data practices.

Although we hope to learn more about the freshwater resources and ocean dynamics that link the water cycle, part of the excitement lies in the unknown these satellite missions will reveal. Will our description of the water cycle remain broadly the same, or will those unknowns reshape it into something new?

Published online: 22 February 2023

References

1. Koutsoyiannis, D. & Mamassis, N. *Hydrol. Earth Syst. Sci.* **25**, 2419–2444 (2021).
2. Pfister, L., Savenije, H. & Fenicia, F. *Leonardo Da Vinci's Water Theory: on the Origin and Fate of Water* (IAHS, 2009); <https://water.usask.ca/hillslope/documents/pdfs/2008/08-05%20SP009.pdf>
3. Dooge, J. C. I. *Hyd. Sci. Bul.* **19**, 279–302 (1974).
4. Rodell, M. & Reager, J. T. *Nat. Water* **1**, 47–59 (2023).
5. Scanlon, B. R., Fakhreddine, S. & Rateb, A. et al. *Nat. Rev. Earth Environ.* **4**, 87–101 (2023).
6. Chen, Y., Wang, J., Scanlon, B. R. & Rodell, M. Satellites for Water. *Nature Water Talks* (18 August 2022); <https://doi.org/10.52843/cassyni.g9fyjo>
7. Schipanski, M. E. et al. *Nat. Water* **1**, 30–36 (2023).