BDSD 2022
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Satellite Orbit and Gravity Field Determination for Earth Observation

The Satellite Geodesy Group
of the Astronomical Institute,
University of Bern

Low Earth orbiting satellites for Earth observation

For the purpose of Earth observation numerous satellites orbit the Earth in low Earth orbits (i.e. with an orbital altitude between 200 and 2'000 km), abbreviated as LEOs (Low Earth Orbiters). For many missions **the precise knowledge of their orbits** at any time is crucial. For example, if one wants to measure global and regional sea level rise with satellite altimetry (see Figures 1 and 4), the satellite position must be known with cm or even better accuracy.

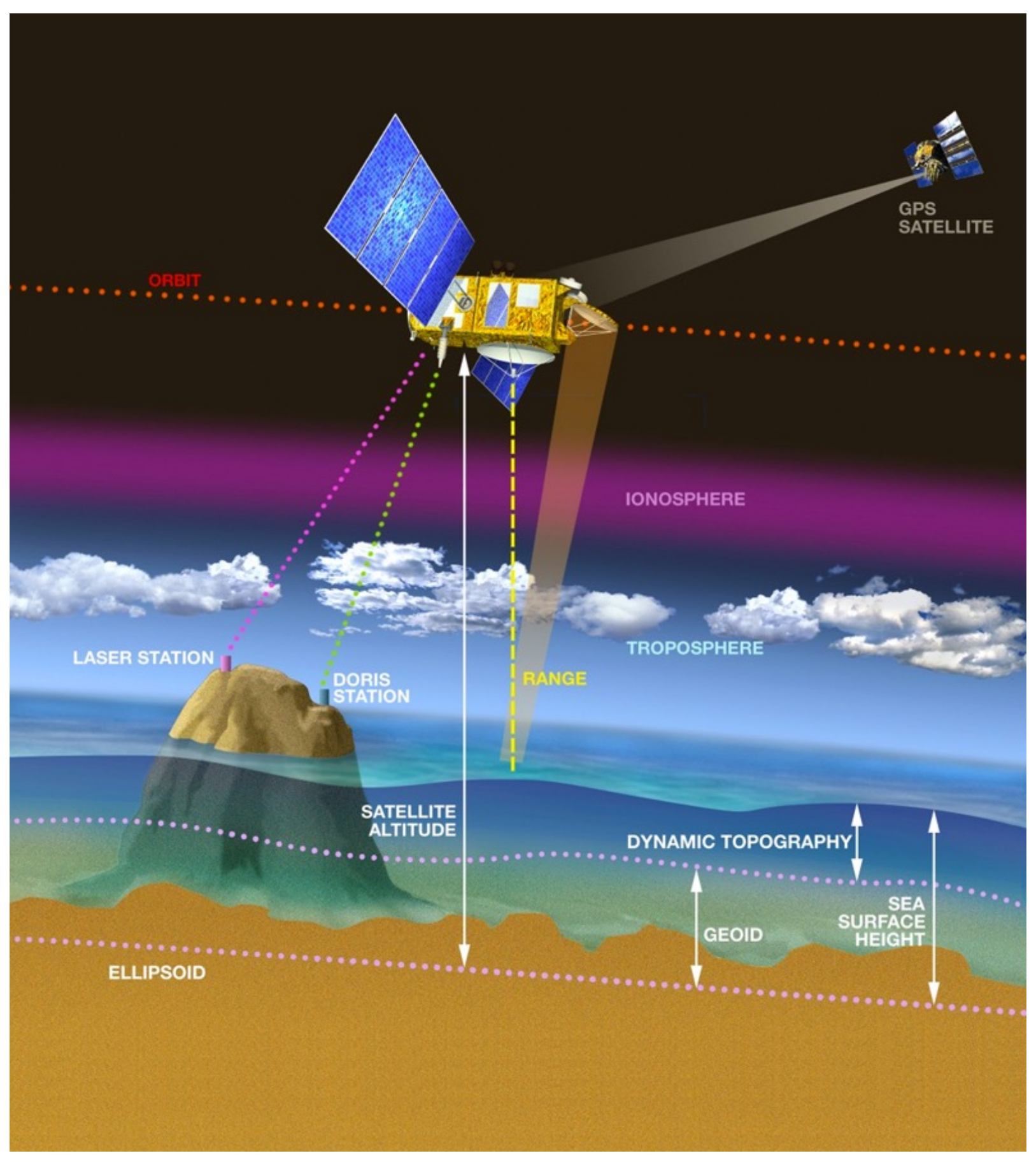

Figure 1: Principle of satellite altimetry. ©CLS/AVISO

To achieve this accuracy, these LEOs usually carry a **GNSS (Global Navigation Satellite System) receiver** on board (Fig. 1) – in most cases to receive the signals from the GPS satellite constellation, but more recent LEOs are also capable to receive the signals from other GNSS constellations, e.g., from the European Galileo satellites. At the Astronomical Institute of the University of Bern (AIUB) we compute high-precision LEO orbits from these data by making use of the orbits of the (high-flying) GNSS satellites, which are computed at AIUB, as well. For this purpose, we use the **Bernese GNSS Software** developed at AIUB, which is meanwhile used by more than 700 institutions worldwide (other universities, research centers, federal agencies, etc.).

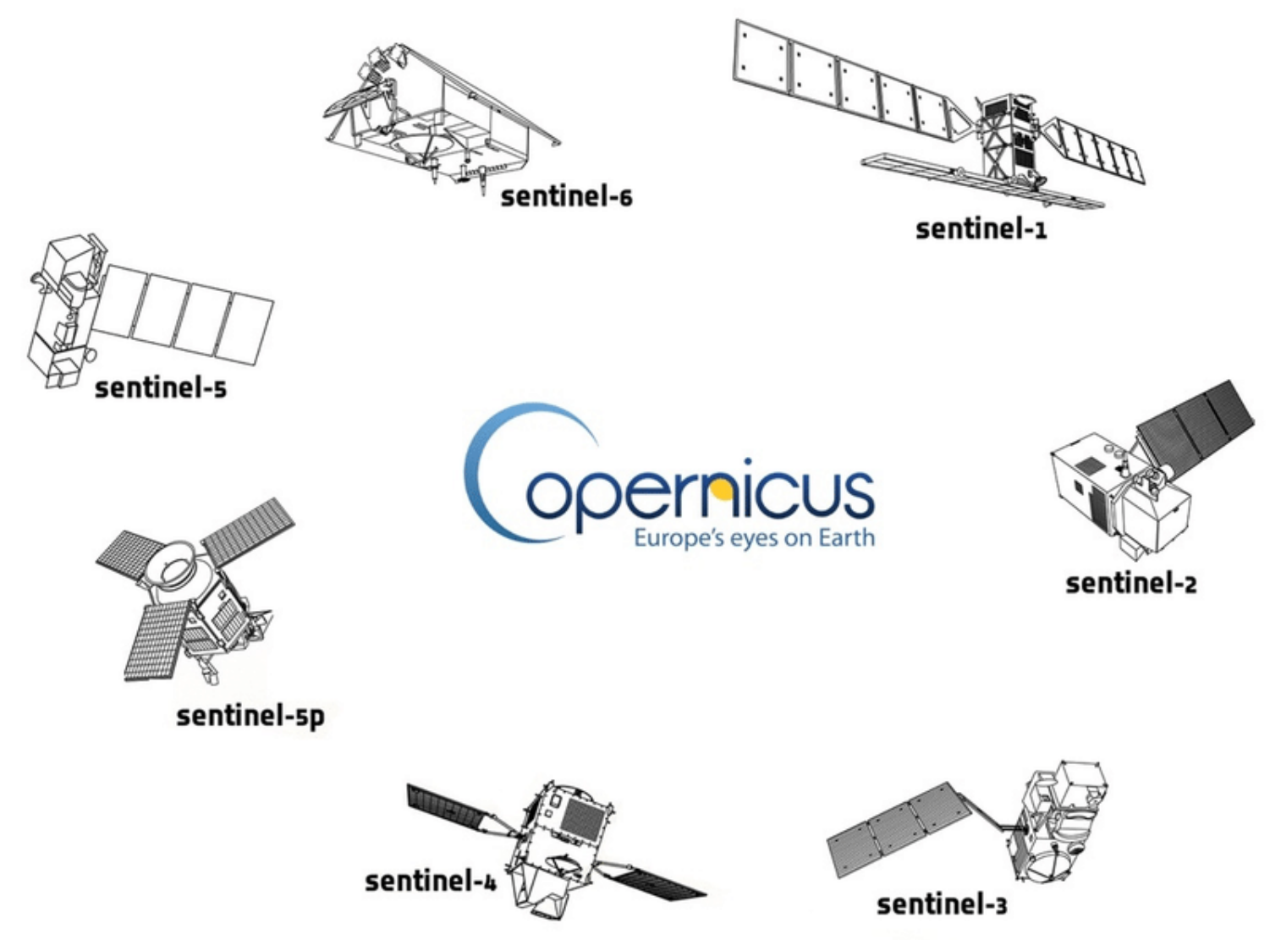

Figure 2: The fleet of ESA's Copernicus Sentinel satellites. ©ESA

The AIUB is, besides many other LEO project activities, part of the **Copernicus Precise Orbit Determination Quality Working Group**, for which we operationally compute the orbits of ESA's Copernicus Sentinel-1, -2, -3 and -6 Earth observation satellites for the purpose of orbit comparison and validation (Figures 2 and 5). These satellites are building up the space segment of Copernicus, the European Union's Earth observation program (`https://www.copernicus.eu`), see Fig. 3.

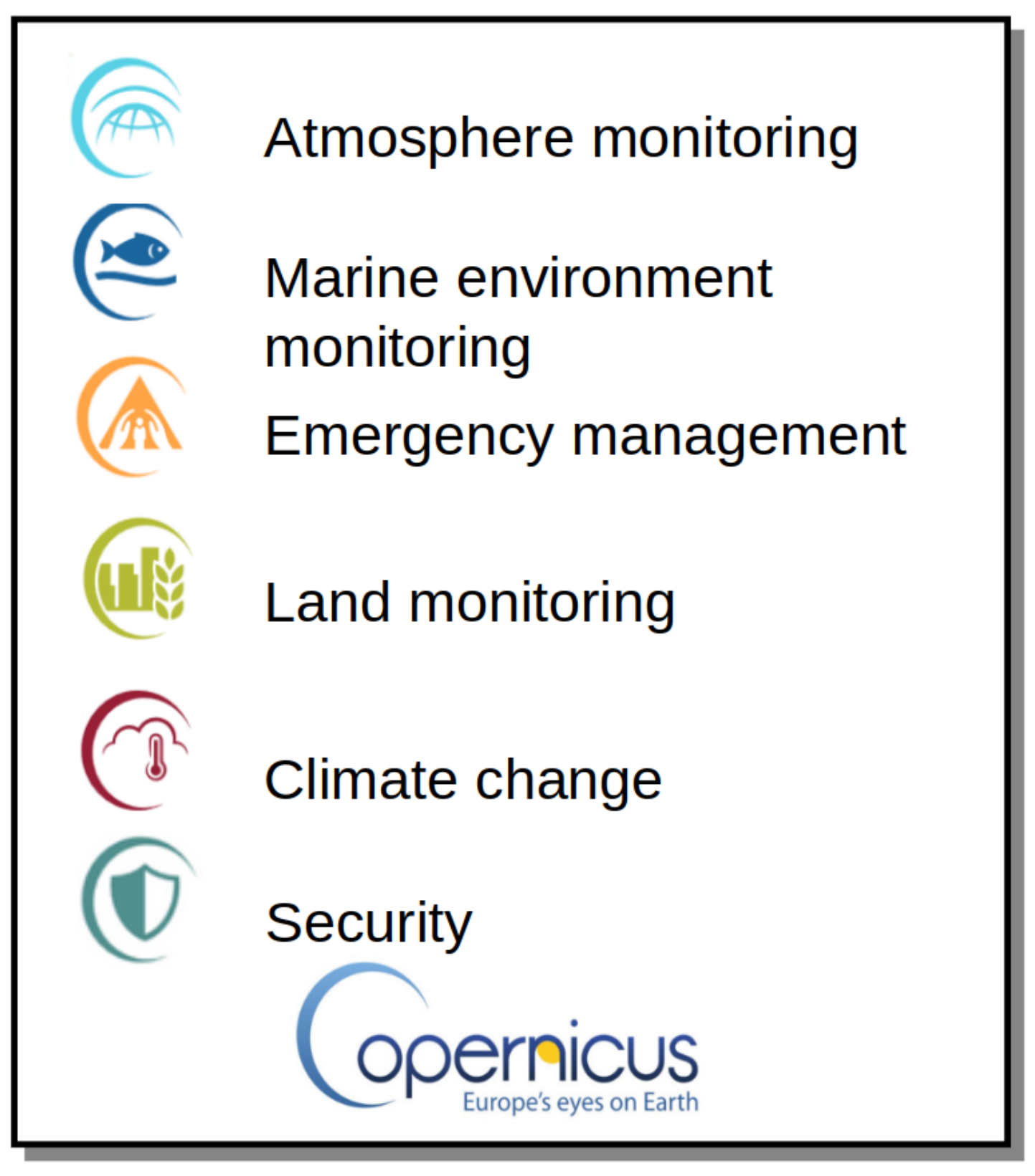

Figure 3: The European Earth Observation Program Copernicus provides freely available data for environmental and security-related issues. It is thematically organized in six services. ©Copernicus

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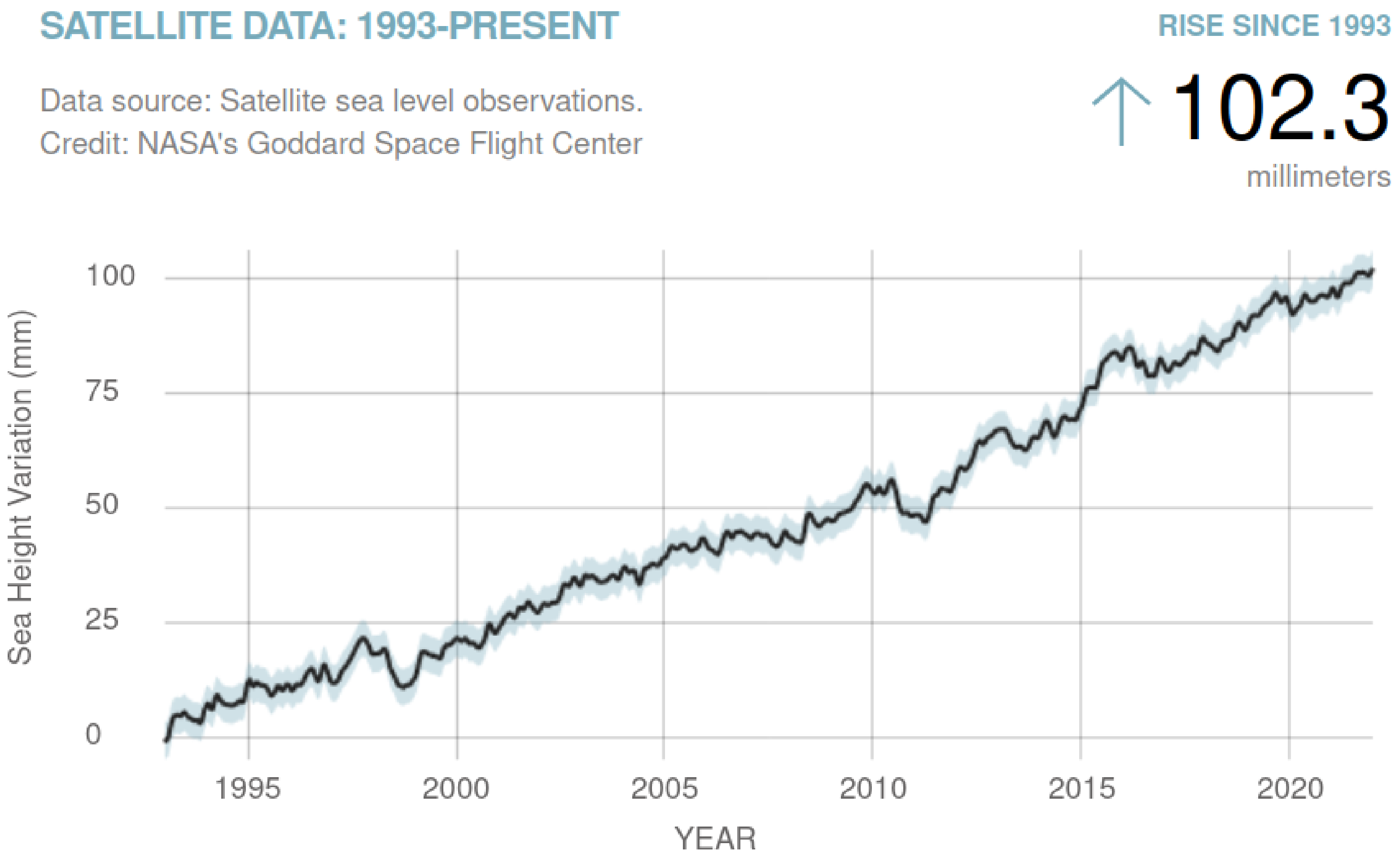


Figure 4: Global sea level rise from satellite data since 1993. ©NASA

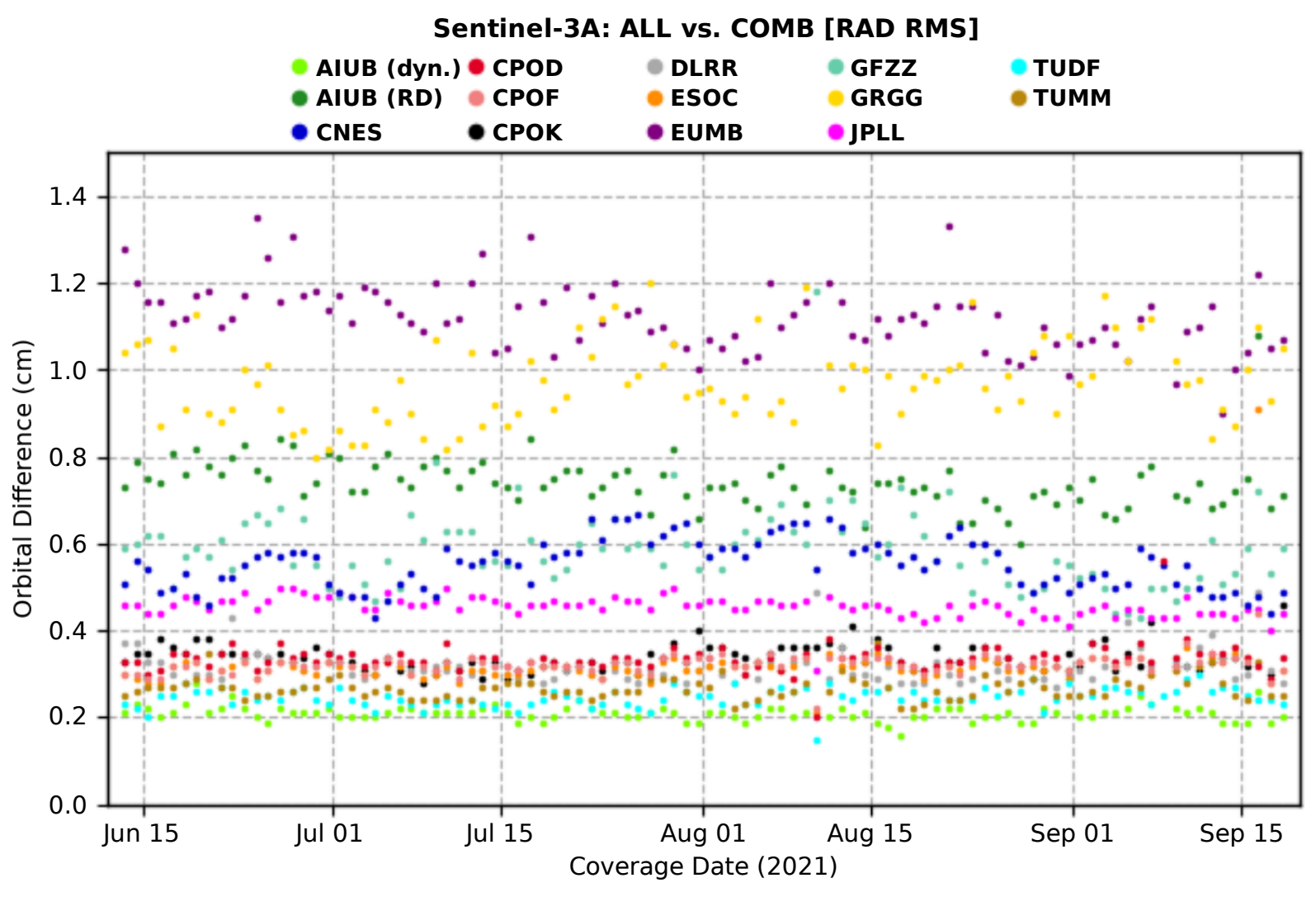


Figure 5: Radial differences of different orbit solutions for Sentinel-3A (an altimetry satellite) and a combined solution. The orbits were computed for the Copernicus Regular Service Review #22. AIUB contributes with dynamic (light green) and reduced-dynamic (dark green) orbit solutions. The former AIUB solutions are among the best in the Quality Working Group.

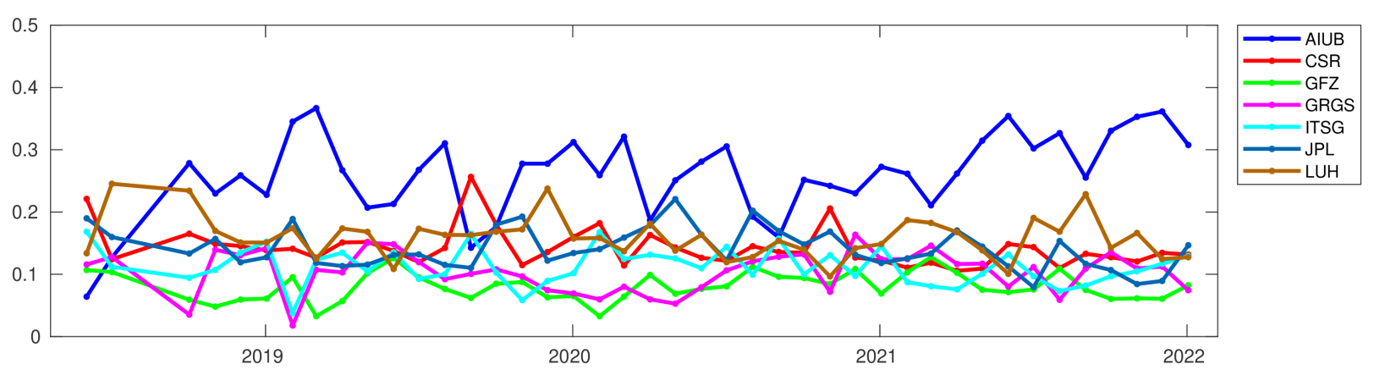


Figure 6: Weights with which different monthly GRACE-FO gravity field solutions are incorporated into a combined solution. The combination is operationally performed at AIUB within the framework of COST-G. For most months, the monthly gravity field solutions calculated at AIUB contribute with the largest weights.

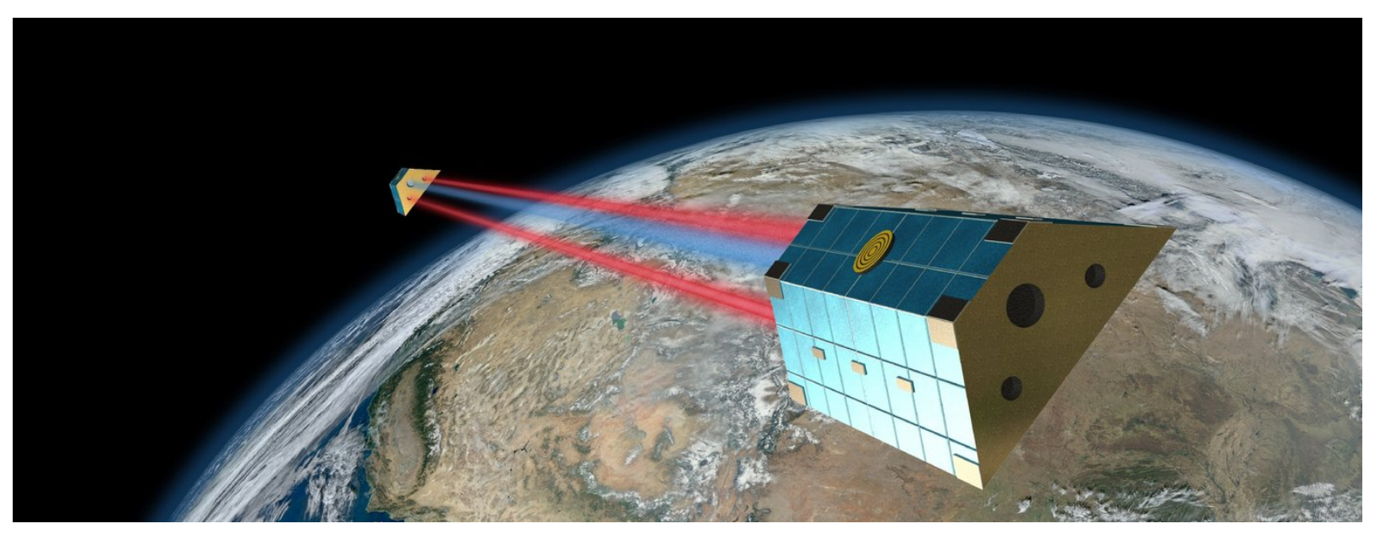


Figure 7: The GRACE-FO (Gravity Recovery and Climate Experiment Follow-On) mission to measure the time-varying Earth's gravity field. ©NASA

From orbits to gravity field

The **Earth's gravity field**, i.e., the representation of the local gravitational attraction, is variable, both in space and time (see Fig. 8) and is changed by mass redistributions below, on or above the Earth surface. Because gravitation causes the major force acting on a satellite, it has an influence on its orbit. Conversely, the detailed analysis of the motion of a satellite for an extended time span allows to measure the Earth's gravity field.

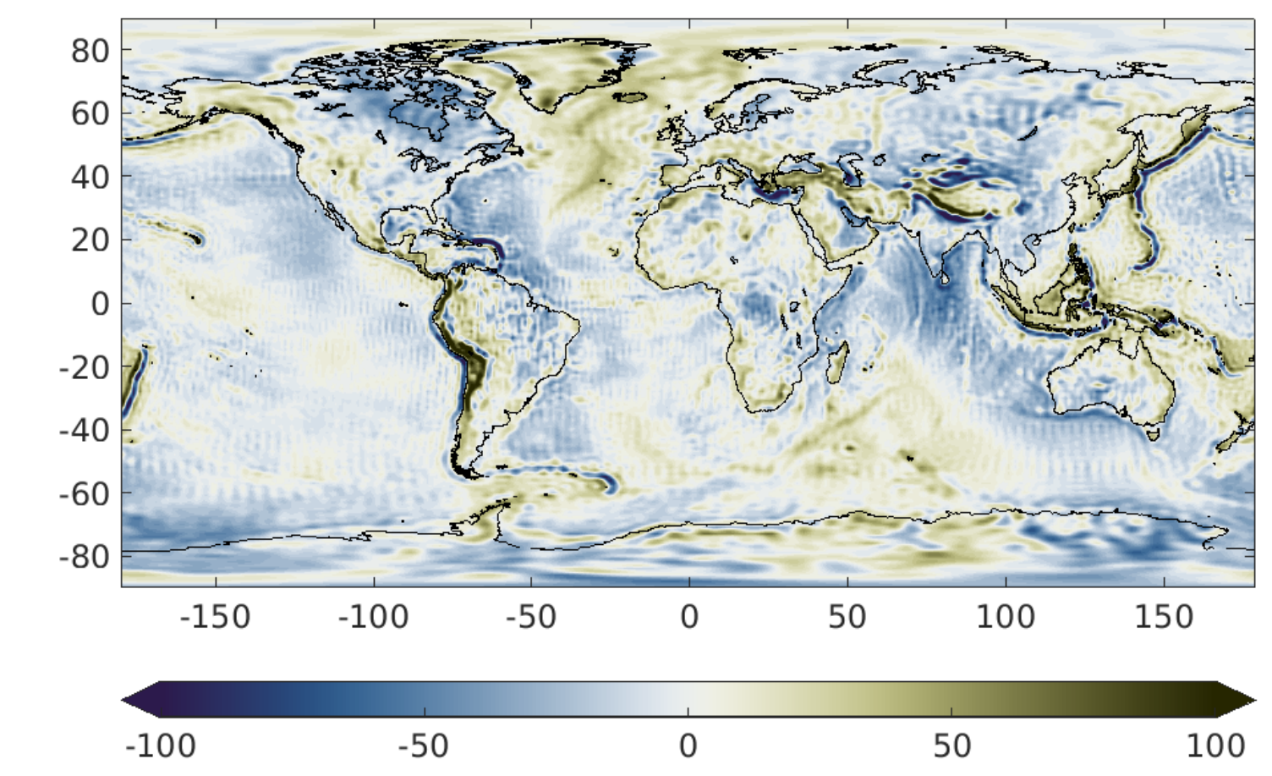


Figure 8: Deviations of local gravitational accelerations from a theoretical acceleration if the Earth's surface was a perfect ellipsoid. Units: mGal = 0.00001 m/s^2.

In order to most precisely measure the Earth's gravity field, and in particular its temporal variations, the **GRACE** (2002-2017) and **GRACE-FO** (since 2018) satellite missions also make use of a high-precision microwave or laser link (for GRACE-FO) between two LEOs on identical orbits (Fig. 7). This is used to measure the distance changes between the satellites (separated by about 220 km) with high precision (in the range of μm with microwave and nm with laser). Numerous geophysical processes can be studied and quantified from the monthly gravity field models derived from these data (Figs. 9 and 10).

COST-G
Combination Service for Time-variable Gravity Fields
IAG

The official GRACE/GRACE-FO gravity field models are computed by NASA's Jet Propulsion Laboratory (JPL), the University of Texas' Center for Space Research (UTCSR), and the German Research Center for Geosciences (GFZ). In addition, there are numerous other analysis centers, including AIUB, which compute independent models and are continuously improving the outcome of the mission with their activities. The **Combination Service for Time-variable Gravity Fields, COST-G** (`http://cost-g.org`) of the International Association of Geodesy (IAG), coordinated by AIUB, is developing and investigating strategies to combine the monthly gravity field models of diverse analysis centers to produce best possible models for a large user community (Figs. 6 and 10).

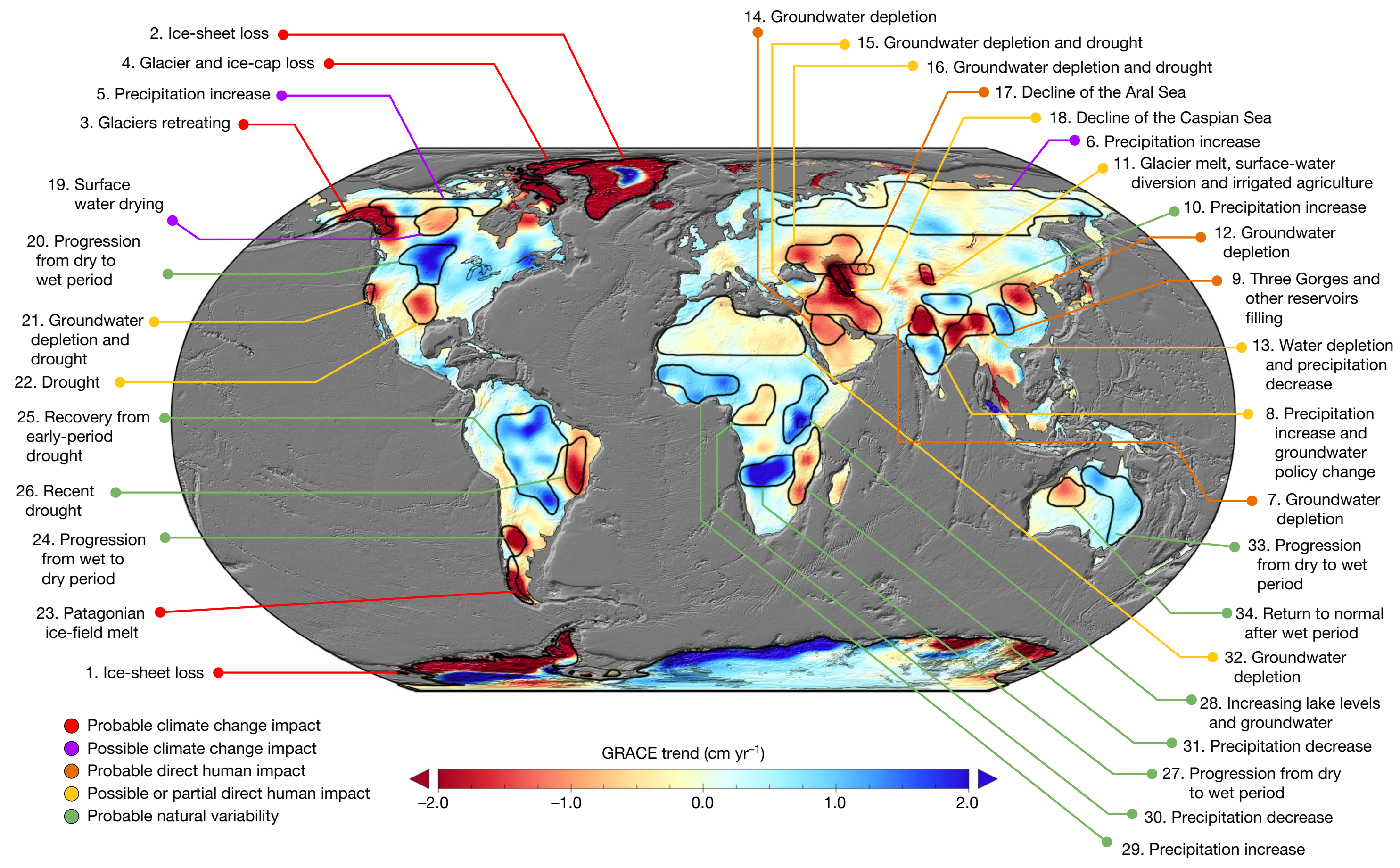
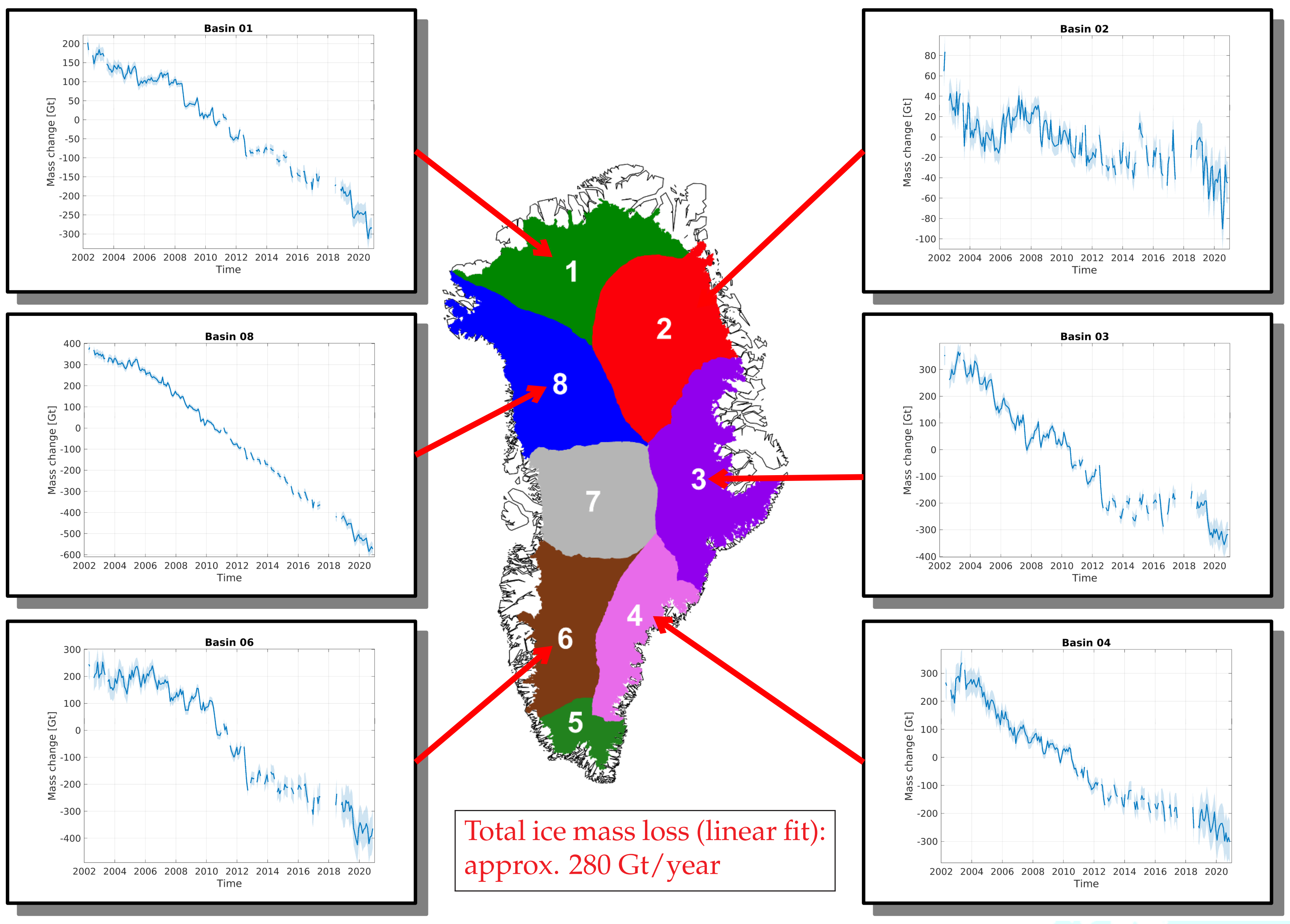


Figure 9: Geophysical trends measured with GRACE between 2002 and 2016. Red indicates areas with mass loss, e.g., due to ice melt or droughts. Blue indicates areas with mass gain, e.g., due to increased precipitation or human-made constructions such as dams. From Rodell et al, (2018).



Total ice mass loss (linear fit):
approx. 280 Gt/year

Figure 10: Ice mass loss on Greenland determined from COST-G products. Between 2002 and 2020, the total annual loss in Greenland is about 280 Gigatons, or about 10'000 ice cubes with a 1 m edge length per second.

G3P

Groundwater represents about 30 % of the Earth's global freshwater storage and is a so-called **Essential Climate Variable** (ECV) of the Global Climate Observing System (GCOS), i.e., a quantity which is critical to characterize the climate and its changes.

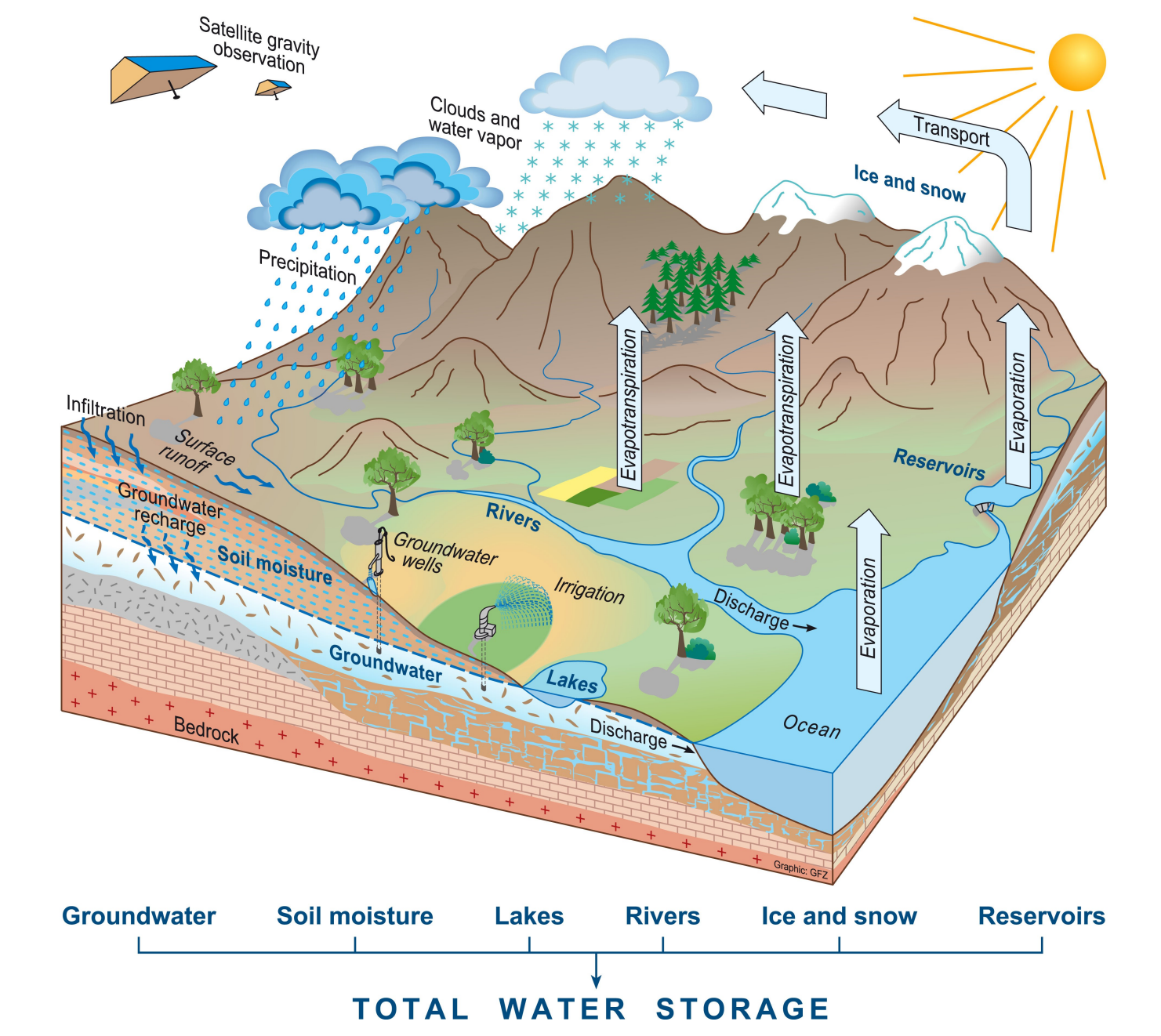


Figure 11: GRACE/GRACE-FO is the only technique that can directly measure **Total Water Storage** (TWS) changes, i.e. the change of the total amount of water on and below the Earth's surface. TWS was recently declared by the GCOS as a new ECV.

The Horizon 2020 project **Global Gravity-based Groundwater Product G3P** (`https://www.g3p.eu`), co-initiated by AIUB and coordinated by GFZ, aims to characterize groundwater occurrences and their variations globally and with monthly temporal resolution, and to create a prototype for generating an operational global groundwater product. The idea: GRACE/GRACE-FO provides the Total Water Storage via gravity field models (Fig. 11). If the observable constituents of glaciers, snow, soil moisture, and surface water are subtracted from this, groundwater can be inferred. G3P uses TWS from COST-G and the data from various Copernicus services for the subtraction process (Fig. 3). Later on, the groundwater product shall be incorporated into the Copernicus "Climate change" service.

All calculations presented on this poster are performed on UBELIX, the HPC cluster of the University of Bern.

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