National Aeronautics and Space Administration

SENTINEL-6

MICHAEL FREILICH LAUNCH

PRESS KIT

OCTOBER 2020

www.nasa.gov

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Introduction

Sentinel-6 Michael Freilich Launch

Rising seas are one of the most distinctive and potentially devastating effects of Earth's warming climate. Measuring and understanding changes in sea level allows us to assess the vulnerability of coastal cities and towns to flooding as we look toward the future. Precise sea level measurements can also be used to track ocean currents, which transport heat from one part of the planet to another, which in turn influence Earth's energy budget and weather patterns.

An uninterrupted series of satellites has collected sea level measurements for nearly 30 years. And now, a joint U.S.-European effort will launch the next spacecraft to take on the mantle of monitoring sea surface height: The Sentinel-6 Michael Freilich satellite will collect the most accurate global data yet on sea level and how it changes over time. The spacecraft will also collect precise data of atmospheric temperature and humidity that will help improve weather forecasts and climate models.

The Sentinel-6/Jason-CS (Continuity of Service) mission consists of two identical satellites that will be launched five years apart. The first spacecraft is Sentinel-6 Michael Freilich, named for the former director of NASA's Earth Science Division, Dr. Michael Freilich. He was a pioneer in oceanography from space and dedicated his career to better understanding the Earth, with the goal of improving the lives of those who call it home. Sentinel-6 Michael Freilich will launch from Vandenberg Air Force Base in California no earlier than Nov. 10, 2020. Its twin satellite, Sentinel-6B, is slated for liftoff in 2025.

Both satellites will measure sea level down to a few centimeters for 90% of the world's oceans. The data they collect will add to a long-term dataset that began with a joint U.S.-French effort called TOPEX/Poseidon that launched in 1992. The sea level monitoring effort continued with Jason-1, OSTM/Jason-2, and Jason-3, which launched in 2016 and is currently operational.

Update: As of Nov. 3, the launch is targeted for no earlier than Nov. 21, 2020. Additional updates can be found on the mission's blog at blogs.nasa.gov/sentinel-6/

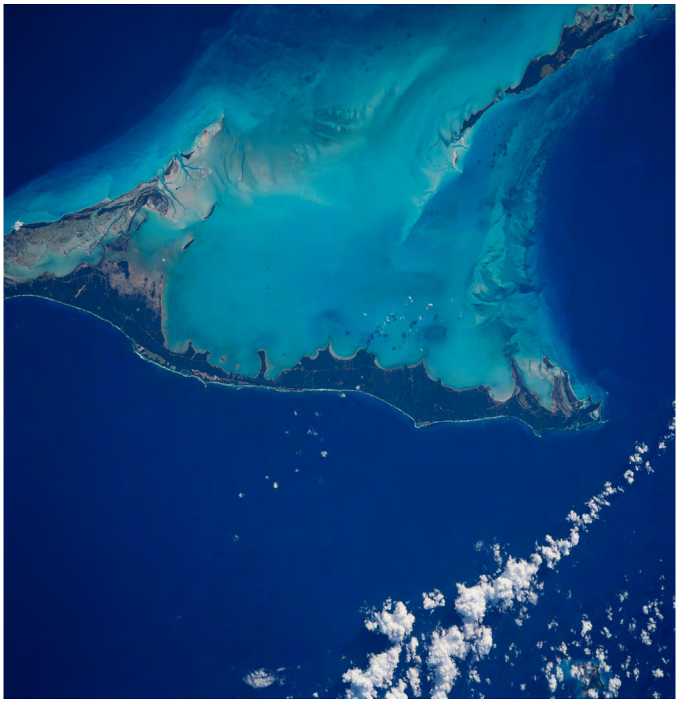
5 Things To Know About Sentinel-6 Michael Freilich

The satellite and its twin will add to a long-term sea level dataset that's become the gold standard for climate studies from space. The spacecraft will each carry an instrument to measure sea level for nearly the entire globe, three instruments to help determine the precise position and orientation of the satellite, and one to measure atmospheric temperature and humidity. How will Sentinel-6 Michael Freilich further our ocean and climate knowledge? Here are five things you should know:

1. It will provide information that will help researchers understand how climate change is reshaping Earth's coastlines – and how fast this is happening.

Earth's oceans and atmosphere are inextricably connected. The sea absorbs more than 90% of the heat trapped by rising greenhouse gases, which causes seawater to expand. This expansion accounts for about one-third of modern-day sea level rise, while meltwater from glaciers and ice sheets accounts for the rest.

The rate at which the oceans are rising has accelerated over the last 25 years, and scientists expect it to speed up even more in the years to come. Sea level rise will change coastlines and influence how tides and flooding from storms affect cities. To better understand how rising seas will impact humanity, researchers need to know how fast sea level is changing. This means that they need long climate records – something Sentinel-6 Michael Freilich and its successor will help to provide.

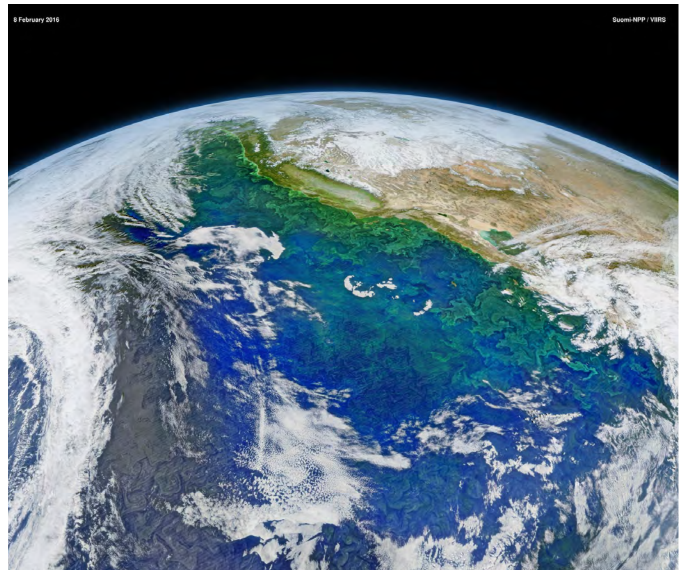


Coastlines and islands are being reshaped by sea level rise; observations by Sentinel-6 Michael Freilich will help us prepare for these changes
Image Credit: NASA

2. The satellites will see things that previous sea level missions couldn't.

In monitoring global sea levels since 2001, the Jason series of satellites has been able to track large ocean features like the Gulf Stream and climate phenomena like El Niño and La Niña that stretch over thousands of miles. However, measuring smaller sea level variations near coastlines, which can affect ship navigation and commercial fishing, has been beyond their capabilities.

Sentinel-6 Michael Freilich will collect measurements at higher resolution. What's more, it will include new technology in the Advanced Microwave Radiometer (AMR-C) instrument that, along with the mission's Poseidon-4 radar altimeter, will enable researchers to see these smaller, more complicated ocean features, especially near the coastlines.



Sentinel-6 Michael Freilich will get a high-resolution view of sea level heights and ocean currents close to the coasts where communities are most affected by sea level rise
Image Credit: NASA/NOAA

3. Sentinel-6 Michael Freilich builds upon a highly successful U.S.-European partnership.

Sentinel-6 Michael Freilich is the first NASA-ESA (the European Space Agency) joint effort in an Earth science satellite mission, and it marks the first international involvement in Copernicus, the European Union's Earth Observation Programme. It continues a decades-long tradition of cooperation between NASA, the National Oceanic and Atmospheric Administration (NOAA), and European partners, including ESA, the intergovernmental European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and France's National Centre for Space Studies (CNES).

These international collaborations enable access to a larger pool of resources and scientific expertise than would be available otherwise. Researchers have published thousands of scientific papers using the sea level data collected by the series of U.S.-European satellite missions that began with the 1992 launch of TOPEX/Poseidon.

sealevel.jpl.nasa.gov/gallery/videos/?ImageID=196

Since 1992, spaceborne altimeters have measured global sea surface height. Watch this video to learn more about how altimeters work and why international collaboration is important.
Video Credit: NASA/JPL

4. By expanding the global atmospheric temperature data record, the mission will help researchers better understand how Earth's climate is changing.

Climate change doesn't just affect Earth's oceans and surface; it impacts all levels of the atmosphere, from the troposphere to the stratosphere. A science instrument on Sentinel-6 Michael Freilich uses a technique called radio occultation to measure the physical properties of Earth's atmosphere.

The Global Navigation Satellite System - Radio Occultation (GNSS-RO) instrument tracks radio signals from navigation satellites that orbit Earth. When a satellite dips below (or rises above) the horizon from Sentinel-6 Michael Freilich's perspective, its radio signal passes through the atmosphere. As it does, the signal slows, its frequency changes, and its path bends. Called refraction, this effect can be used by scientists to measure minute changes in atmospheric density, temperature, and moisture content.

When researchers add this information to existing data from similar instruments currently in space, they'll be able to better understand how Earth's climate is changing over time.

The Earth's climate and oceans are dynamic and connected; Sentinel-6 Michael Freilich will study both.
Image Credit: NASA

5. Sentinel-6 Michael Freilich will help to improve weather forecasts by providing meteorologists information on atmospheric temperature and humidity.

The satellite's radar altimeter will collect measurements of sea surface conditions, including significant wave heights, and data collected by the GNSS-RO instrument will complement existing observations of the atmosphere. These combined measurements will give meteorologists further insights to improve weather forecasts. Moreover, information on the temperature and humidity of the atmosphere, as well as the temperature of the upper layer of the ocean, will help to improve models that track the formation and evolution of hurricanes.

Observations from space can help boost our understanding of hurricanes and Sentinel-6 Michael Freilich will carry instruments to study this weather phenomenon.
Image Credit: NASA

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Products and Events

News Releases, Features, and Status Reports

The Sentinel-6 Michael Freilich team will issue periodic news releases, feature stories, media advisories, and status reports on launch and mission activities and make them available online at nasa.gov/sentinel-6. Media advisories in advance of the launch will include details on media accreditation, briefings, prelaunch media activities at Vandenberg Air Force Base in California, and NASA Television and web coverage.

Video and Images

Video and images related to the Sentinel-6 Michael Freilich satellite are available at the following websites:

nasa.gov/sentinel-6
go.nasa.gov/Sentinel6Gallery

Media Events

The most up-to-date information about upcoming Sentinel-6 Michael Freilich mission media events and where they may be viewed can be found at nasa.gov/nasalive. More information on NASA TV and streaming channels can be found below.

BRIEFINGS AND AVAILABILITIES

A news conference presenting an overview of the mission will take place on **Oct.16 at 7 a.m. PDT (10 a.m. EDT, or 4 p.m. CET)**.

For the Nov. 10, 2020, launch, **a prelaunch news conference** open to accredited news media is scheduled on **Nov. 9 at 2 p.m. PST (5 p.m. EST, or 11 p.m. CET)** at Vandenberg Air Force Base.

A **science briefing** is scheduled on **Nov. 9 for 12:30 p.m. PST (3:30 p.m. EST, or 9:30 p.m. CET)** at Vandenberg Air Force Base.

All news briefings will be broadcast and streamed. A phone bridge for media will be provided for each news briefing.

ON-SITE MEDIA LOGISTICS

News media representatives who would like to cover the Sentinel-6 Michael Freilich launch and prelaunch media briefings in person from Vandenberg Air Force Base must be accredited through Kennedy Space Center. All accreditation requests should be submitted online at media.ksc.nasa.gov. For questions about accreditation, journalists should contact the credentialing team at KSC-Media-Accreditat@mail.nasa.gov.

Due to the ongoing COVID-19 pandemic, NASA will be credentialing a limited number of media to cover the launch from Vandenberg Air Force Base. Media interested in attending this launch must have applied by **1 p.m. PDT (4 p.m. EDT) Sunday, Sept. 27**. Due to COVID-19 safety restrictions at Vandenberg Air Force Base and quarantine requirements, international media who would be traveling from overseas will not be able to register for this launch. International media based in the U.S. were eligible to apply.

Interviews with mission team members in the Vandenberg Air Force Base area around the time of launch may be arranged by calling **818-354-5011**.

NASA Television

NASA Television channels are digital C-band signals, carried by QPSK/DVB-S modulation on satellite Galaxy-13, transponder 11, at 127 degrees west longitude, with a downlink frequency of 3920 MHz, vertical polarization, data rate of 38.80 MHz, symbol rate of 28.0681 Mbps, and ¾ FEC. A Digital Video Broadcast (DVB) compliant Integrated Receiver Decoder (IRD) is needed for reception. For NASA TV information and schedules on the Web, visit: nasa.gov/ntv.

Live NASA TV programming on NASA's public channel is available on the web at nasa.gov/live. The NASA TV media channel is also available live at youtube.com/NASA. Archived NASA TV programming is available soon after it airs at images.nasa.gov.

ADDITIONAL LIVE VIDEO STREAMS

Additional livestreaming video of the Oct. 16 overview news conference, news conferences in the days before launch at Vandenberg Air Force Base, and coverage of the launch itself is available at: youtube.com/nasajpl/ and www.ustream.tv/nasajpl2.

AUDIO

Audio of the pre-launch readiness and science news conference at Vandenberg Air Force Base the day before launch and NASA TV launch coverage will be carried on "V-circuits," which may be accessed by dialing **321-867-1220, -1240, -1260, or -7135**.

Eyes on the Earth

Shortly after launch, the public can follow the Sentinel-6 Michael Freilich satellite in real time as it orbits Earth through NASA's Eyes on Earth at https://climate.nasa.gov/earth-now/#/.

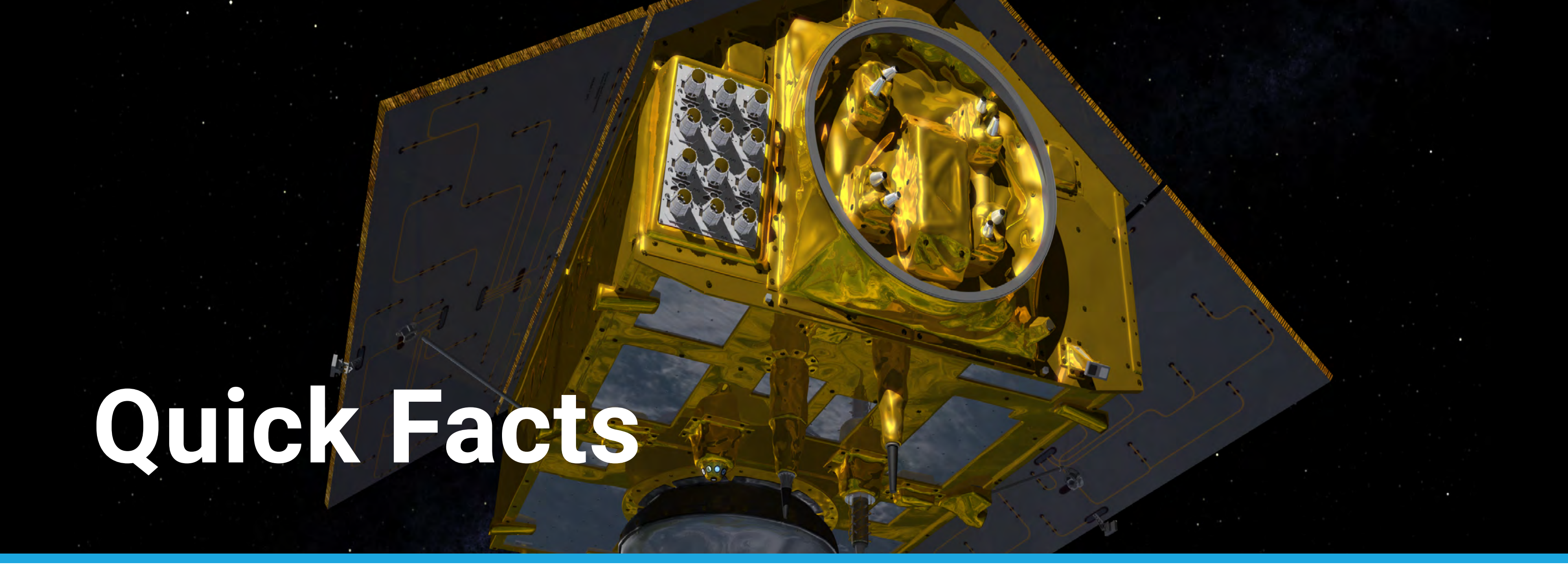
Sentinel-6 Michael Freilich on the Web

nasa.gov/sentinel-6

Social Media

Join the conversation and get mission updates on Sentinel-6 Michael Freilich, JPL and NASA via these accounts:

- **Twitter:** @NASAEarth, @NASAJPL, @NASA
- **Facebook:** @NASAEarth, @NASAJPL, @NASA
- **Instagram:** @NASAEarth, @NASAJPL, @NASA



Quick Facts

Sentinel-6 Michael Freilich undergoes tests at an IABG cleanroom in Germany
Image Credit: IABG

Spacecraft

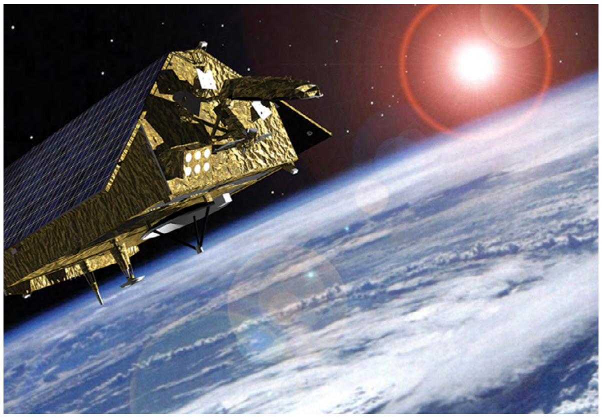
SIZE: 16 feet, 11 inches (5.15 meters) long; 7 feet, 7 inches (2.35 meters) high; 8 feet, 5 inches (2.58 meters) wide (the approximate size of a small pickup truck).

MASS: 2,628 pounds (1,192 kilograms), including onboard propellant at launch.

POWER: Two fixed solar arrays, plus two deployable solar panels.

BATTERIES: 200-amp-hour battery consisting of 1,152 lithium-ion cells.

INSTRUMENTS: Radar altimeter, advanced microwave radiometer for climate, GNSS for radio occultation (RO), laser retroreflector, DORIS, and GNSS for precise orbit determination (POD).



Sentinel-6 Michael Freilich orbits Earth in this artist's impression.
Image Credit: ESA/NASA

Mission

LAUNCH: No earlier than Nov. 10, 2020.

LAUNCH LOCATION: Vandenberg Air Force Base, California.

PRIME MISSION: 5 ½ years.

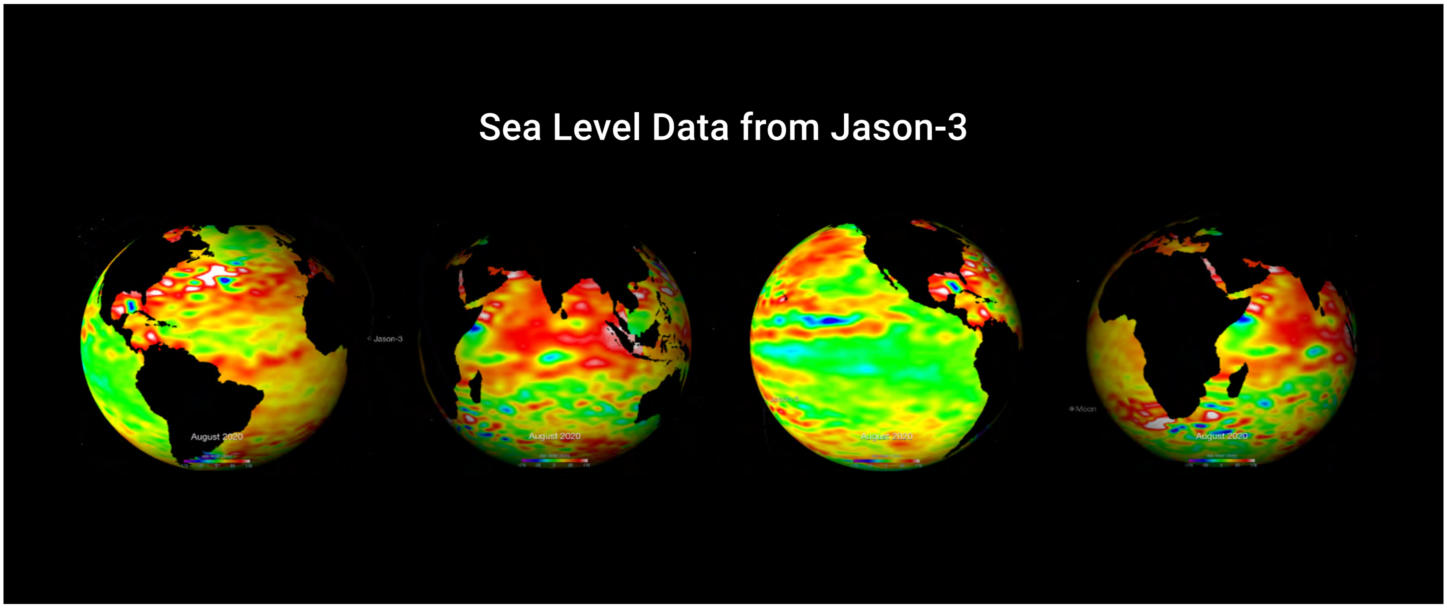
ORBITAL ALTITUDE: 830 miles (1,336 kilometers).

ORBIT'S INCLINATION TO EARTH'S EQUATOR: 66 degrees (non-Sun-synchronous orbit).

ORBIT DURATION: 112 minutes, 26 seconds.

ORBITS PER DAY: Approximately 13.

VELOCITY: 4.5 miles per second (7.2 kilometers per second) or 16,200 mph (26,071 kph).

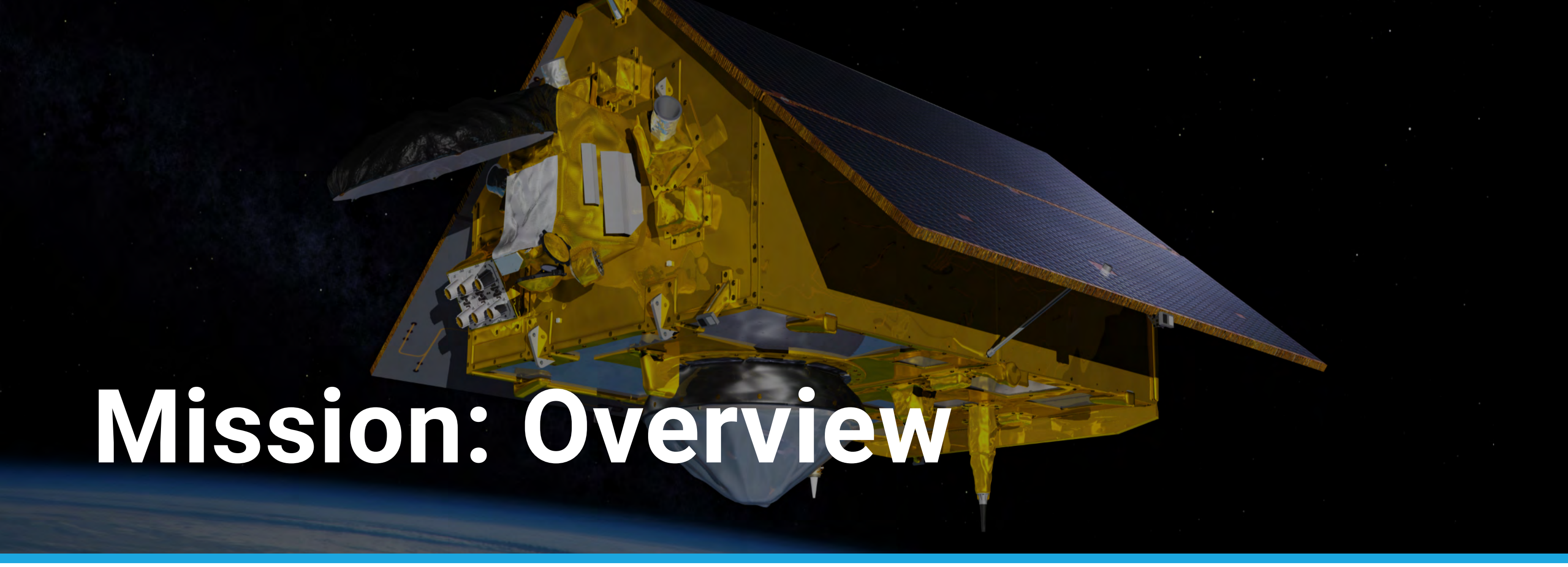


International Collaboration

The mission is being developed jointly by ESA (European Space Agency) in the context of the European Copernicus program led by the European Commission, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), NASA, and the National Oceanic and Atmospheric Administration (NOAA), with funding support from the European Commission and contributions from France's space agency, Centre National d'Etudes Spatiales (CNES).

Budget

NASA INVESTMENT: Approximately $500 million.



Mission: Overview

Earth's climate is changing. To understand what that means for the planet and for humanity, scientists need a long view. For nearly 30 years, an uninterrupted series of satellites has circled Earth, keeping an eye on one of the clearest signals of global warming – sea level rise. The Sentinel-6 Michael Freilich satellite and a second identical satellite, both part of a joint U.S.-European effort, will add another 10 years of sea level measurements to that dataset. Sentinel-6 Michael Freilich was named for the former director of NASA's Earth Science Division, who substantially contributed to the mission's realization.

The two identical spacecraft, launched five years apart, will study ocean heights from an orbit 830 miles (1,336 kilometers) above the planet's surface. Sentinel-6 Michael Freilich has a prime mission of 5.5 years and will launch no earlier than Nov. 10. Its doppelganger, Sentinel-6B, will lift off in 2025. Along with measuring global sea level rise and ocean circulation, the satellites will record vertical profiles of atmospheric temperature and humidity. The data will help scientists to forecast how much the ocean could encroach on coastlines, improve weather forecasts and hurricane predictions, and advance the study of ocean tides and phenomena like El Niño and La Niña.

Both satellites will follow in the flight path of four previous U.S.-European missions focused on ocean heights. The first, TOPEX/Poseidon, launched in 1992. It was followed in 2001 by Jason-1, then OSTM/Jason-2 in 2008, and then by the still-operational Jason-3 in 2016. Like the others, Jason-3 flies in the same orbit as its predecessor and was launched before the previous one was decommissioned. This approach has allowed scientists and engineers to cross-calibrate the data that the satellites collect to ensure the continuity of measurements from one mission to the next.

When Sentinel-6 Michael Freilich reaches orbit, it will fly about 30 seconds behind the Jason-3 satellite. Scientists and engineers will spend about a year cross-calibrating the data collected by the two spacecraft. Following this, Jason-3 will be moved into a complementary interleaved orbit and Sentinel-6

Michael Freilich will take over the role of providing primary measurements. Then, in 2025, engineers will perform the same cross-calibration with Sentinel-6B as Sentinel-6 Michael Freilich's prime mission winds down.

The Sentinel-6/Jason-CS mission is being jointly developed by ESA (the European Space Agency), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), NASA, and the National Oceanic and Atmospheric Administration (NOAA), with funding support from the European Commission and support from France's National Centre for Space Studies (CNES).

WHAT'S UP WITH SEA LEVEL?

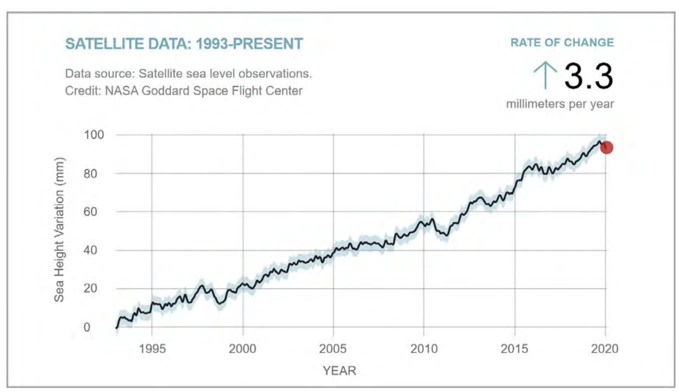
Measuring the height of the ocean gives scientists a real-time indication of how Earth's climate is changing. The oceans absorb more than 90% of the excess heat from the planet's warming climate. Seawater expands as it heats up, resulting in about a third of the modern-day global average sea level rise. Melting ice from glaciers and ice sheets accounts for the rest.

Currently, sea levels rise at a rate of over 0.13 inches (3.3 millimeters) per year, more than twice the rate at the start of the 20th century. Knowing how this rate is changing gives climate scientists an idea of how rising seas will encroach on coastlines around the world.

Like its predecessors, Sentinel-6 Michael Freilich will measure sea level by bouncing electromagnetic signals off the ocean's surface and measuring the time it takes for the pulses to return. The satellite's high-resolution capabilities also mean that scientists will be able to monitor the ocean closer to the coasts than they could with previous sea level missions. Researchers will be able to track features, including small coastal currents and eddies that pinch off of larger currents such as the Gulf Stream.

Because eddies that break off the Gulf Stream can be several degrees warmer than the surrounding ocean, tracking them can be especially important for monitoring hurricanes. These storms run on warm seawater, and the warmer the water, the more fuel is available to supercharge them.

The Sentinel-6 Michael Freilich satellite will also give climate researchers a better understanding of phenomena like El Niño and its counterpart, La Niña. Triggered by a huge fluctuation in the winds that normally blow from east to west across the equatorial Pacific Ocean, El Niño can shift ocean currents and global weather patterns, bringing torrential rain to the Southwestern U.S. and triggering droughts in Asia and Australia. La Niña can have the opposite effect.



This chart shows the rise in global average sea level from January 1993 to January 2020 as measured by satellite missions.
Image Credit: NASA Goddard Space Flight Center

One prior discovery to come out of the existing sea level dataset that the mission will extend is the far-reaching effects of these weather phenomena. So much seawater evaporated and formed rain clouds during a massive La Niña in 2010 that it flooded huge parts of Australia and Southeast Asia, and temporarily dropped global sea levels by 0.4 inches (1 centimeter). Before then, scientists had no idea that these weather systems could have such an outsized, short-term impact on global sea levels.

A BIRD'S-EYE VIEW OF THE ATMOSPHERE

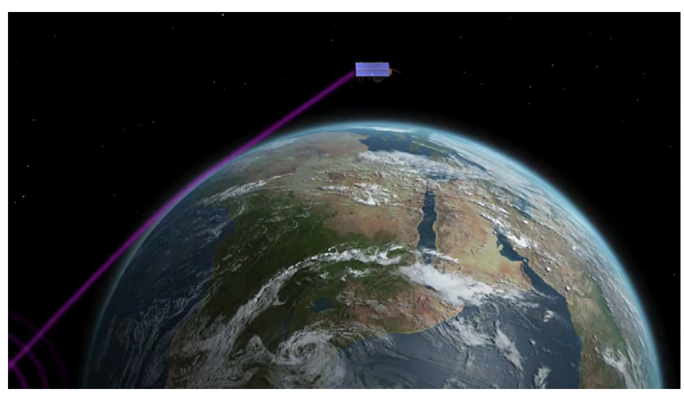
A secondary science objective of Sentinel-6 Michael Freilich is to gather vertical profiles of atmospheric temperature and humidity. The instrument responsible for these measurements, the Global Navigation Satellite System - Radio Occultation (GNSS-RO) sensor, can see down through Earth's atmosphere to within 1,600 feet (500 meters) of the surface, even through heavy rain and thick clouds.

Temperature and humidity drive what happens in the planet's atmosphere, shaping weather patterns and the formation of storms. Advancing the accuracy of information that scientists collect on these aspects of the atmosphere is key to improving forecasts.

Meteorologists feed data, including air temperature, humidity, and wind speed and direction into computer models to formulate their weather forecasts. The information comes from a variety of sources, including satellite-based radiometers, weather balloons, and instruments aboard commercial airliners. But each platform can have its limitations. In some cases, researchers may need to compensate for biases in the data: For example, air temperature readings from a thermometer on an airplane can be influenced by its immediate surroundings.

Data from the GNSS-RO doesn't have these constraints. The instrument on Sentinel-6 Michael Freilich will provide globally-distributed vertical profiles, and its data won't be biased by things such as proximity to airplane fuselages. Meteorologists will be able to include accurate atmospheric temperature and humidity data into their models within three hours after Sentinel-6 Michael Freilich collects it. They will also be able to use that information as a reference point for correcting data from other similar atmospheric instruments.

The GNSS-RO instrument derives its measurements by analyzing radio signals from global navigation satellites. As these radio signals travel through different layers of Earth's atmosphere, they bend and slow down by varying degrees. The GNSS-RO measures these changes, and researchers can then derive atmospheric characteristics such as temperature and humidity at different altitudes. The technology in this instrument was developed at JPL and has been included on other satellite missions.



Sentinel-6 will also carry an instrument that will track radio signals from orbiting navigation satellites to measure the physical properties of the atmosphere.
Image Credit: NASA/JPL-Caltech

Mission: Launch Events and Mission Phases

Launch Site and Vehicle

The Sentinel-6 Michael Freilich satellite will be launched aboard a SpaceX Falcon 9 Full Thrust rocket from Space Launch Complex 4E (SLC-4E) at Vandenberg Air Force Base in California.

The NASA/German Research Centre for Geosciences GRACE Follow-On spacecraft launched onboard a SpaceX Falcon 9 rocket in 2018 from Space Launch Complex 4E at Vandenberg Air Force Base in California. Sentinel-6 will launch from the same location aboard another Falcon 9.
Image Credit: NASA

Launch Timing

The Sentinel-6 Michael Freilich spacecraft will be launched no earlier than 11:31 a.m. PST (2:31 p.m. EST) on Nov. 10, 2020. The launch date is based on the readiness of the satellite, the Falcon 9 launch vehicle, and the Western Test Range at Vandenberg Air Force Base. The instantaneous launch window on subsequent days falls earlier by approximately 12 minutes each day.

The Falcon 9 rocket will launch Sentinel-6 Michael Freilich into a non-Sun-synchronous orbit. This illustration shows the launch vehicle's first stage boosting the satellite into space before Main Engine Cut Off (MECO).
Image Credit: SpaceX

Launch Sequence

The two-stage Falcon 9 rocket will launch Sentinel-6 Michael Freilich from SLC-4E down an initial flight azimuth of 151 degrees from true north, carrying it in a south-southeast direction over the Pacific Ocean off the California coastline.

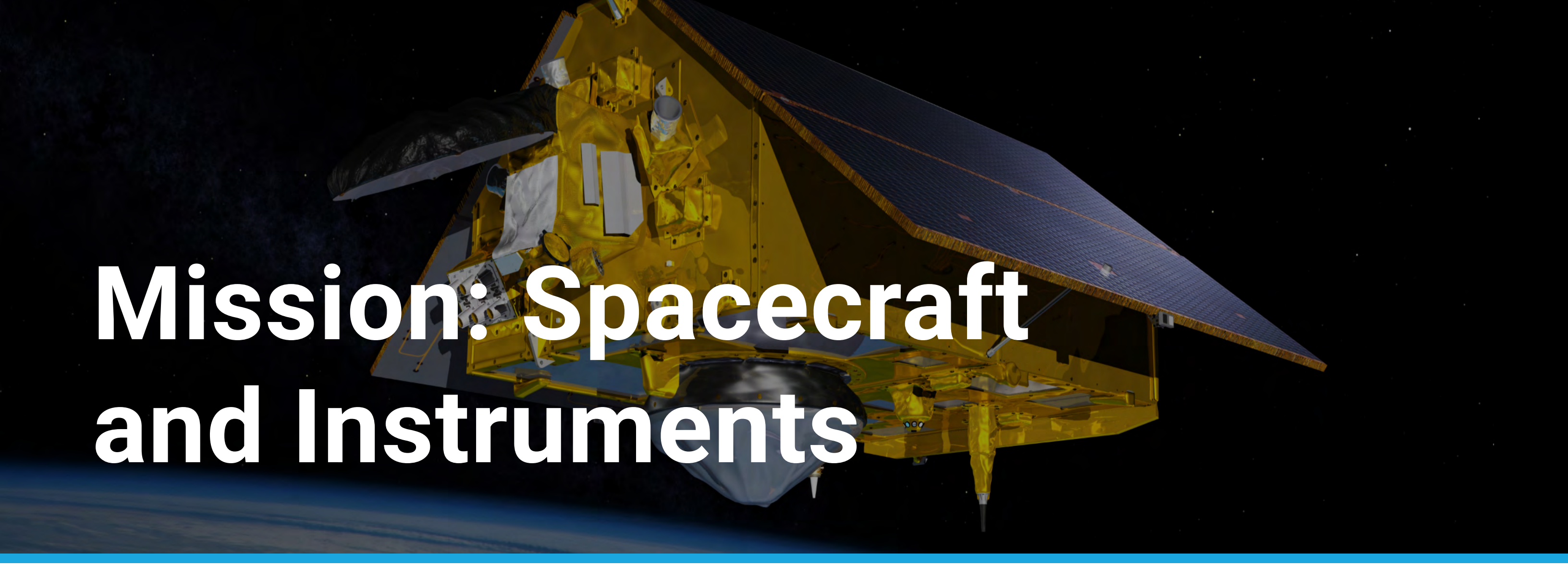
Please see the online version of this press kit for launch sequence updates: go.nasa.gov/sentinel6presskit.

Orbital Characteristics

The spacecraft will be launched into a non-Sun-synchronous orbit with an inclination of 66 degrees with an orbital period of 112 minutes and 26 seconds. This orbit was chosen because it is the same as previous sea level missions (the TOPEX/Poseidon, Jason-1, OSTM/Jason-2, and Jason-3 satellites) to ensure data consistency for long-term sea level time series. Like its predecessors, Sentinel-6 Michael Freilich's non-Sun-synchronous orbit was chosen to allow the spacecraft to pass over locations at different times of the day and night, allowing it to measure local sea level changes that may vary throughout the 24-hour cycle, like the tides.

Ground System

Satellite antennas located in Kiruna (Sweden) and Fairbanks (U.S.) are the ground stations that will provide X- and S-band communications with the Sentinel-6 Michael Freilich spacecraft. The Kiruna ground station coverage is provided by EUMETSAT; the Fairbanks ground station coverage is provided by NOAA.



Mission: Spacecraft and Instruments

The Sentinel-6 Michael Freilich spacecraft undergoes tests at its manufacturer Airbus in Friedrichshafen, Germany, in 2019.
Image Credit: Airbus

Satellite Bus

The Sentinel-6 Michael Freilich spacecraft was built by Airbus Defence and Space in Friedrichshafen, Germany. It is 16 feet, 11 inches (5.15 meters) long, 7 feet, 7 inches (2.35 meters) high, 8 feet, 5 inches (2.58 meters) wide and weighs 2,628 pounds (1,192 kilograms) including onboard propellant.

POWER SYSTEM

The electrical system of the Sentinel-6 Michael Freilich satellite comprises all the necessary hardware to operate the spacecraft while allowing the onboard systems to execute the software. The electrical power subsystem generates energy via sunlight collected by the 185.1-square-foot (17.5-square-meter) body-mounted solar arrays. Each array consists of gallium arsenide (GaAs) solar cells that cover the top and sides of the satellite like a tent. Excess energy is stored in a lithium-ion battery (based on 1,152 cells, split into two modules) with a total capacity of approximately 200 amp hours. The system provides an average of 1 kilowatt of electrical power in orbit.

THERMAL CONTROL

A spacecraft's thermal control subsystems keep it, and the science instruments it carries, within allowable temperature limits. The Sentinel-6 Michael Freilich spacecraft utilizes a combination of passive- and active-control elements to achieve this. The passive elements include multilayer insulation blankets and dedicated radiators covered with secondary surface mirrors that radiate heat away from the spacecraft. The main structure is partly painted black internally to minimize temperature gradients inside the spacecraft. For active temperature control, heaters are installed in dedicated areas.

TELECOMMUNICATIONS

Communication between the satellite and the ground is accomplished using microwave S-band and X-band transmitters and antennas located on the nadir (Earth-facing) panel of the spacecraft.

The tracking, telemetry, and command (TT&C) system is composed of two permanently active receivers and two transmitters (one that is permanently active and one that acts as backup, and is used only in contingencies) that allow conventional S-band communications with Earth, providing an uplink data rate of up to 32 kilobits per second and a downlink data rate of 1 megabit per second.

In addition, the payload data handling and transmission (PDHT) system has its own X-band antenna that is only used to transmit scientific and telemetry data to the ground at a downlink data rate of 150 Mbit/s.

Onboard data handling
The Sentinel-6 Michael Freilich onboard data handling systems provide the central processor and mass memory software resources for the spacecraft and management of the science data.

The data handling subsystem is in charge of the overall spacecraft command and control. It provides necessary input and output capabilities for the attitude and orbit control system as well as for power and thermal systems operations. In addition, it performs spacecraft health functions, including fault detection, isolation, and recovery operations.

The PDHT system includes the mass memory and formatting unit (MMFU), a standalone solid mass memory unit that is based on SDRAM (synchronous dynamic random-access memory) technology, providing 352 GB of data storage. The MMFU also processes the science data and links it to the X-band subsystem (XBS), which then transmits it to ground stations via the X-band antenna.

ATTITUDE AND ORBIT CONTROL SUBSYSTEM

The satellite's "attitude," or orientation and orbit control, is managed by a system consisting of sensors, actuators, and software. Subsystems include reaction wheels, magnetic torquers, magnetometers, a coarse Earth and Sun sensor, a rate measurement unit, a star tracker, and precise orbit determination (POD) instruments. They work together to provide three-axis stabilized Earth-pointing attitude control during all mission modes, and they measure spacecraft rates and orbital position.

The POD instruments include a global navigation satellite system (GNSS) and precise orbit determination receiver (GNSS-POD), a Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) instrument, and a laser retroreflector array (LRA). These instruments work in concert to determine the exact orbital position of the satellite so that sea level measurements can be made by the altimeter to a high degree of accuracy and precision. Although not required to meet mission requirements, the GNSS-Radio Occultation (GNSS-RO) instrument also produces data that can be optionally used by scientists to further improve the estimate of the satellite orbit.

Poseidon-4 SAR Altimeter

Sentinel-6 Michael Freilich carries the Poseidon-4 synthetic-aperture radar (SAR) altimeter that measures mean sea levels by bouncing radio wave pulses off the ocean surface, and precisely timing how long those pulses take to travel back to the spacecraft. The instrument is also used to determine significant wave height and wind speed. Because the radar pulses travel through the ionosphere, which contains electrons that interfere with the propagation of radio waves, the altimeter uses two separate frequencies (the C-band and Ku-band) to correct for ionospheric interference. This was developed by ESA.

The Poseidon-4 radar altimeter, which will measure the ocean surface topography, is located on the bottom of the spacecraft (the cone-shaped instrument shown here during testing at the IAGB space test center in Ottobrunn near Munich, Germany).
Image Credit: ESA

HERITAGE AND EVOLUTION

Similar altimeters have been used aboard Sentinel-6 Michael Freilich's predecessors (Poseidon-2, 3A, and 3B were used by the Jason-1, 2, and 3 missions, respectively), but Poseidon-4 marks a significant evolution. By inheriting the SAR High Resolution Altimeter mode of the CryoSat-2 mission's SIRAL (SAR Interferometry Radar Altimeter) and the Sentinel-3 mission's SRAL (SAR Radar Altimeter), much higher along-track resolution can be achieved. With support of the precise orbit determination (POD) package (which determines the position of the satellite above the Earth) and the Advanced Microwave Radiometer for Climate (AMR-C) instrument (which estimates the quantity of atmospheric water vapor, and has new features to improve stability), improved measurements of sea level height are possible (to a global mean sea level stability of 1 millimeter over a one-year period).

Advanced Microwave Radiometer for Climate (AMR-C)

The Advanced Microwave Radiometer for Climate (AMR-C) instrument incorporates AMR technology evolved from the Jason-2 and Jason-3 missions. The purpose of the system is to measure the amount of water vapor between the satellite and the ocean. Water vapor affects the propagation of the radar pulses from the Poseidon-4 radar altimeter, which can make the ocean look higher or lower than it actually is. AMR measurements are therefore required to correct for this effect, thus preventing over- or underestimation of sea level measurements. The AMR-C includes a new onboard calibration system to improve the multiyear stability of the radar delay measurement compared to the predecessor missions, ensuring the altimeter system is capable of tracking changes in the global mean sea level extremely accurately. The AMR-C instrument was developed by NASA-JPL.

This photograph shows the AMR-C instrument undergoing tests at NASA's Jet Propulsion Laboratory in Southern California.
Image Credit: NASA/JPL-Caltech

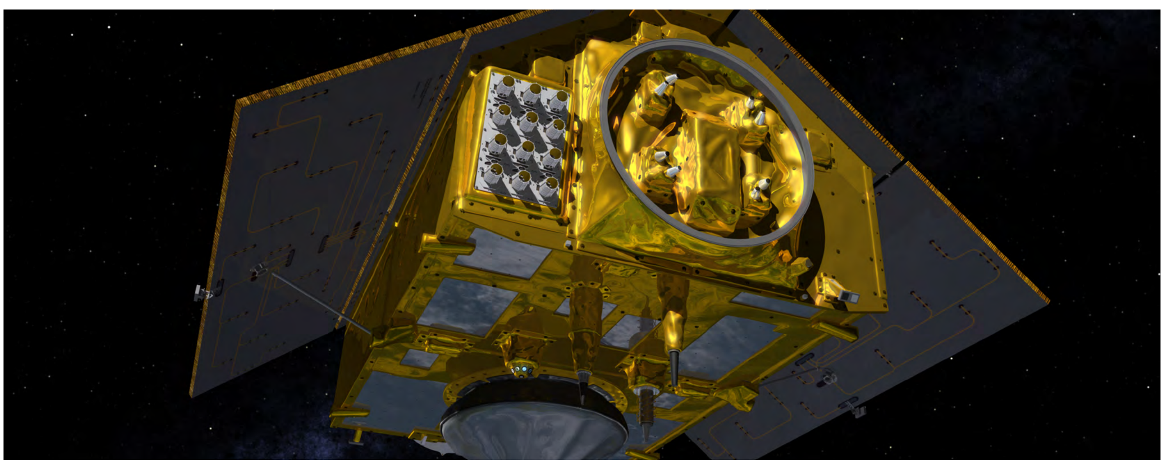
HIGHER RESOLUTION

The AMR-C instrument also includes an experimental High-Resolution Microwave Radiometer (HRMR) that will provide the radar delay measurements to a higher resolution, therefore allowing radar delay measurements along coastal areas, which is not currently possible with other missions.

Global Navigation Satellite System – Radio Occultation (GNSS-RO)

The Global Navigation Satellite System – Radio Occultation (GNSS-RO) experiment is used to measure the physical properties of the atmosphere, such as temperature, pressure, and water vapor. To achieve this, GNSS-RO detects the occultation of global navigation satellites' radio signals as they disappear beyond the limb of the Earth from the perspective of Sentinel-6 Michael Freilich orbit.

The instrument is composed of three antennas: one that is used for precise orbit determination and two others that are directed toward the Earth's limb. As the signal from a global navigation satellite is acquired by the fore or aft antennas, it will drop toward or rise from the horizon. As it does so, the satellite's radio signal will travel through the atmosphere. These signals can be detected through the vertical extent of the atmosphere – even through thick clouds – from the very top and almost all the way to the ground. Measurements of the amount of refraction (or change in frequency) of these signals reveal the atmosphere's physical properties and may be used to improve weather forecasting, provide information about the ionosphere, and support climate studies. The GNSS-RO instrument was developed by NASA-JPL.



This artist's impression shows the aft of the satellite, including sensors of the GNSS-RO instrument (the grey rectangle to the left)
Image Credit: NASA/JPL-Caltech

UNLIMITED AND INDEPENDENT

Like the GNSS precise orbit determination (GNSS-POD) receiver, GNSS-RO is not limited to only tracking GPS satellites; navigation satellites from other networks (such as the GLONASS and Galileo constellations) can also be tracked. As a secondary mission instrument, its operation is independent from sea level measurements made by Sentinel-6 Michael Freilich's radar altimeter.

Precise Orbit Determination (POD) Package

Precisely determining the position of the Sentinel-6 Michael Freilich spacecraft in orbit is of paramount importance when recording extremely small variations in sea level data (on the millimeter scale). To achieve this, Sentinel-6 Michael Freilich carries a state-of-the-art precise orbit determination package that works in conjunction with the mission's scientific instruments to accurately define its position in space and time. This is accomplished by the following key instruments:

GLOBAL NAVIGATION SATELLITE SYSTEM – PRECISE ORBIT DETERMINATION (GNSS-POD)

The Global Navigation System – Precise Orbit Determination (GNSS-POD) antennas are attached to Sentinel-6 Michael Freilich's zenith panel (facing away from Earth) and support the precise determination of the spacecraft's position in orbit. While GPS and GNSS systems work in a similar way, GNSS instruments can use navigational satellites from other networks and are not limited to GPS. In the case of GNSS-POD, navigation data from the GPS and Galileo satellite constellations can be accessed arbitrarily, boosting positioning measurements to an accuracy of a few centimeters. This instrument was provided by ESA.

DOPPLER ORBITOGRAPHY AND RADIOPOSITIONING INTEGRATED BY SATELLITE (DORIS)

The Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) instrument measures the radio signals from 55 global ground stations that compose the International DORIS Service (IDS). Each ground station acts as a beacon to broadcast two stable radio frequencies at 2036.25 MHz (S-band) and 401.25 MHz (VHF). Every 10 seconds, the DORIS instrument aboard Sentinel-6 Michael Freilich measures the Doppler shift of the radio beacons' frequencies to precisely determine its line-of-sight velocity. Over time, an accurate 3D position of the satellite can be determined. This instrument was provided by ESA.

LASER RETROREFLECTOR ARRAY (LRA)

Located on the Earth-facing (nadir) plate of the spacecraft, the laser retroreflector array (LRA) is a completely passive component of the navigation instrumentation on Sentinel-6 Michael Freilich. The LRA consists of nine precisely shaped mirrors that reflect laser beams back to their point of origin on the ground. Ground-based laser-ranging stations can then determine how long the laser beam took to travel to the satellite, reflect off the LRA, and return to the station. Doing this enables a measurement of the distance between the station and satellite to be made. Over time, many ground-based laser-ranging stations will combine their distance estimates, and the spacecraft's orbit can be reconstructed and tracked, thereby supporting measurements made by the spacecraft's other navigation systems. This instrument was provided by NASA-JPL.

GLOBAL NAVIGATION SATELLITE SYSTEM – RADIO OCCULTATION (GNSS-RO)

Although the NASA-provided GNSS-RO instrument's purpose is for atmospheric sounding measurements completely independent of the primary altimetry mission, the GNSS-RO instrument also records measurements that can be used by scientists to determine the satellite's precise orbit. This is not required to meet the baseline mission requirements, but it is anticipated that some in the scientific community will take advantage of the GNSS-RO data to further improve the POD estimates.

Program/Project Management

The Sentinel-6/Jason-CS mission is a partnership between NASA, ESA (the European Space Agency), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and the National Oceanic and Atmospheric Administration (NOAA), with funding support from the European Commission and support from France's National Centre for Space Studies (CNES). NASA's Jet Propulsion Laboratory (JPL), a division of Caltech in Pasadena, California, manages the mission for the Earth Science Division (ESD) in the Science Mission Directorate (SMD) at NASA Headquarters in Washington.

At **NASA JPL**, **Parag Vaze** is the project manager and **John Oswald** is the deputy project manager. **Josh Willis** is the project scientist.

At **NASA HEADQUARTERS**, **Thomas Zurbuchen** is the associate administrator for SMD. **Karen St. Germain** is the director of ESD. **Steve Neeck** is program executive for Sentinel-6/Jason-CS, and **Nadya Vinogradova Shiffer** is program scientist for Sentinel-6/Jason-CS.

At **ESA**, **Pierrik Vuilleumier** is the project manager, and **Craig Donlon** is the mission project scientist.

At **EUMETSAT**, **Manfred Lugert** is the project manager, and **Remko Scharroo** is the project scientist.

At **NOAA**, **Chris Sisko** is the project manager, and **Eric Leuliette** is the project scientist.

Appendix: Gallery

Image Galleries

Sentinel-6 Spacecraft Images and Illustrations
nasa.gov/sentinel-6/images

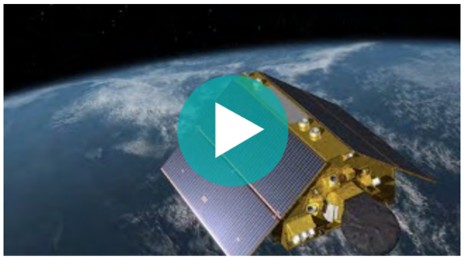
Explore NASA HQ Photos on Flickr
flickr.com/photos/nasahqphoto

NASA Image and Video Library
images.nasa.gov/album/Sentinel-6_Michael_Freilich

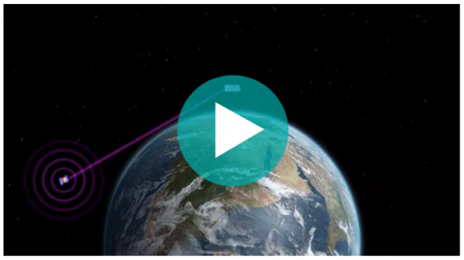
Note: Requires registration and approval for access.
esa-photolibrary.com

Videos and Animations

Mission Overview
youtu.be/3_lbADMwD7A



Explainer: New U.S.-European Satellite Tracking Sea Level Rise
youtu.be/ErRLf6d2anI



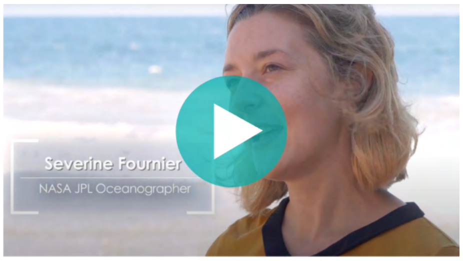
Explainer: NASA Instrument Uses GPS to Improve Weather Forecasts
youtu.be/uiwyIs8YlTs

JPL-produced animation
bit.ly/sentinel6animations

Behind the Spacecraft: Ben Hamlington
youtu.be/C4lw9MBxzjU

Behind the Spacecraft: Shailen Desai
youtu.be/Xbhg3NDupOk

Behind the Spacecraft: Parag Vaze
youtu.be/42DC0bkLx4U



Behind the Spacecraft: Severine Fournier
youtu.be/86w9PFd_7z8

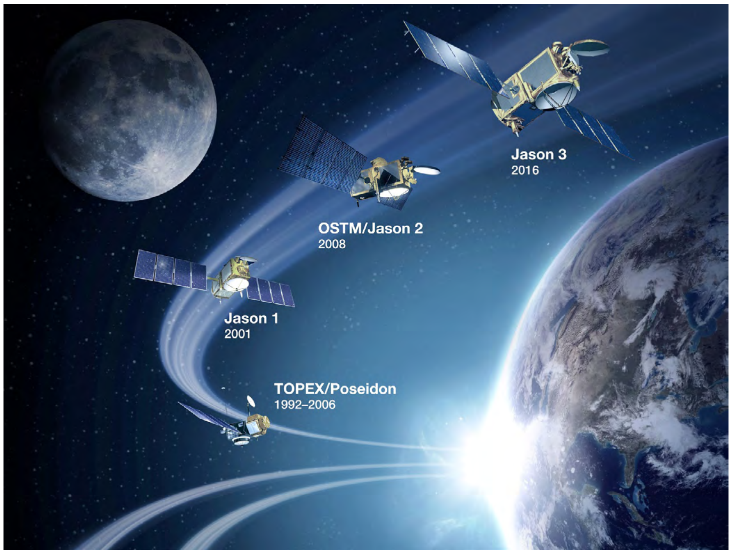
Behind the Spacecraft: Shannon Statham
youtu.be/1Vy0IlTUNZ0

Sentinel-6 Spacecraft Arrival & Offload - VAFB Airfield; SpaceX PPF SLC-4
bit.ly/sentinel6arrival

Sentinel-6 Spacecraft Removal from Container, Lift to MPT
bit.ly/sentinel6removal

Appendix: Historical Sea Level Missions

In addition to the Sentinel-6/Jason-CS mission, past joint U.S.-European sea level missions are listed below. Each item includes mission name, duration, and partners.



The ocean surface topography legacy; TOPEX/Poseidon, Jason-1, OSTM/Jason-2, and Jason-3 satellites.
Image Credit: NASA

TOPEX/POSEIDON: 1992 – 2006;
NASA and France's National Centre for Space Studies (CNES).

JASON-1: 2001 – 2013;
NASA and CNES.

OSTM/JASON-2: 2008 – 2019;
NASA; NOAA; CNES; EUMETSAT.

JASON-3: 2016 – CURRENT;
NASA; NOAA; CNES; EUMETSAT.