ABSTRACT

GEROS-ISS (GEROS hereafter) stands for GNSS REreflectometry, Radio Occultation and Scatterometry onboard the International Space Station. It is a scientific experiment, proposed to the European Space Agency (ESA) in 2011 for installation aboard the ISS and was accepted by ESA to proceed to Phase A. GEROS is an innovative ISS experiment primarily focused on exploiting reflected signals of opportunity from Global Navigation Satellite Systems (GNSS) at L-band to measure key parameters of ocean surfaces. GEROS will utilize the U.S. American GPS (Global Positioning System) and pioneer the exploitation of signals from Galileo and possibly other GNSS systems (GLONASS, QZSS, BeiDou), for reflectometry and occultation, thereby improving the accuracy as well as the spatio-temporal resolution of the derived geophysical properties. The GEROS mission idea and the current status are briefly reviewed.

1. BACKGROUND

The European Space Agency Directorate of Human Space Flight and Operations (HSO) released an announcement of opportunity in July 2011 in coordination with the Directorate of Earth Observation Programmes (EOP) soliciting scientific experiments for the International Space Station relevant to global climate change studies. 25 Letters of intent were received from 237 science team members. After a peer-review of the received proposals and a scientific and technical evaluation, the GEROS-ISS proposal [1] was accepted to proceed to Phase A feasibility studies.
2. MISSION IDEA

GEROS-ISS is a new and innovative ISS experiment primarily focused on exploiting reflected signals of opportunity from the GNSS satellites at L-band to measure key parameters of ocean surfaces which are relevant to characterise climate change. Secondary mission goals are global atmosphere and ionosphere observations using the GNSS radio occultation technique and the monitoring of land surface parameters utilizing reflected GNSS signals (see Fig. 1).

Figure 1. Schematic overview of the GEROS experiment to be installed aboard the International Space Station. Yellow lines indicate the reflectometry measurements for water, ice and land surface monitoring. Red lines indicate GNSS RO and coherent reflectometry observations and the green lines symbolize the GNSS signals, received from zenith for Precise Orbit Determination (POD) of the GEROS payload and 3D upside ionosphere monitoring (from [2]).

Complementing the Earth system observations from other current satellite missions, GEROS will especially pioneer the exploitation of GNSS remote sensing signals from the European Galileo system, thereby improving the accuracy as well as the spatio-temporal resolution of the derived geophysical properties compared to GPS only measurements. The additional use of signals from the Russian GLONASS, Chinese BeiDou and Japanese QZSS navigation satellite systems is also intended. A detailed overview on GEROS and the current status of the mission and recent scientific and technical activities is given in [2].

GEROS will contribute to the long-term and climate relevant observation of the major components of the Earth System: Oceans/Hydrosphere, Cryosphere/Snow, Atmosphere/Ionosphere and solid Earth/Landcover with innovative and complementary aspects compared to established Earth Observation satellite missions. Therefore the data from GEROS will allow for climate change related scientific studies addressing the challenges of ESA’s Earth Observation strategy [3], [4].
GEROS will mainly provide mid- and low-latitude observations on submesoscale or longer oceanic variability (Fig. 2) with focus on coastal regions, surface ocean currents, surface winds, wave heights and the vertical atmospheric temperature, water vapour and electron density structure for a period of at least two years, probably longer, depending on the life-time of the International Space Station. The GEROS observations will lead to a better understanding of the climate system, e.g., of ocean barotropic variability, Rossby wave large-scale structures, eddy-current systems, fronts and coastal upwelling. GEROS hereby takes advantage of the capacious infrastructure aboard the ISS, which is a unique platform for the development of further and advanced GNSS reflectometry (GNSS-R) techniques, due to minor limitations with respect to, e.g., antenna size or availability of appropriate electric power. Due to the application of the novel and innovative GNSS-R remote sensing methods GEROS is also supported by the ESA Directorate of Technical and Quality Management (TEC).

GEROS will also provide a sensor calibration/validation option for other operational and upcoming satellite missions including, e.g., the European twin platform ocean remote mission Sentinel-3 (duration 7-12 years), U.S./European SWOT (Surface Water Ocean Topography, launch foreseen 2020, duration three years), Metop-A/B/C and Metop-SG (Second generation) and the U.S./Taiwan 12 satellite constellation Formosat-7/COSMIC-II for GNSS radio occultation (planned launch 2017, duration at least 5 years). The GNSS remote sensing data from GEROS will also complement the innovative GNSS scatterometry measurements from the U.S. mission CYGNSS (CYclone Global Navigation Satellite System, [5]), the UK mission TechDemoSat-1 (launched July 8, 2014, [6]) and Cat-2 (launched August 15, 2016, [7]). CYGNSS is an eight small satellite mission, which was 2012 confirmed to be funded from NASA’s Earth System Science Pathfinder program and is foreseen for launch in November 2016. It will study the relationship between ocean surface properties, moist atmospheric thermodynamics, radiation and convective dynamics for the investigation of tropical cyclones.

Figure 2. Oceanic observations carry signals of a wide range of related processes. The observed fingerprints of these processes have temporal time scales from 1 hour to thousands of years and spatial scales from ten to tens of thousands of kilometres. The figure illustrates the spatial and temporal scales for these processes and indicates phenomena, which can be investigated with GEROS data complementary to and distinct from, the planned NASA SWOT mission and ESA’s and NASA’s radar altimetry missions (from [2], [8]).
3. MISSION GOALS

The primary mission objectives of GEROS are:

(1) to measure the altimetric sea surface height of the ocean using reflected GNSS signals to allow methodology demonstration, establishment of error budget and resolutions and comparison/synergy with results of satellite based nadir-pointing altimeters and

(2) to retrieve scalar ocean surface mean square slope (MSS), which is related to sea roughness, wind speed and direction, with a GNSS spaceborne receiver to allow methodology testing, establishment of error budget and resolutions. Secondary objectives include the generation of the 2D MSS or directional MSS retrieval and the associated proof-of-concept scientific data product.

Secondary mission objectives, which increase the scientific value of the GEROS data, but are not driving the instrument developments, are:

(1) to further explore the potential of GNSS radio occultation data (vertical profiles of atmospheric bending angle, refractivity, temperature, pressure, humidity and electron density), particularly in the Tropics, to detect changes in atmospheric temperature and climate relevant parameters (e.g., tropopause height) and to provide additional information for the analysis of the reflectometry data from GEROS and

(2) to assess the potential of GNSS scatterometry for land applications and in particular to develop products such as soil moisture, vegetation biomass, and mid-latitudes snow/ice properties to better understand anthropogenic climate change.

4. STATUS

GEROS was selected in result of a complex review process, initiated by ESA. The review results and decision on further activities was officially announced end of 2012. An interdisciplinary and international Science Advisory Group (SAG) of acknowledged experts in Oceanography, Geodesy, Atmosphere and GNSS Science started to work in June 2013 on details of the preparation of the GEROS mission. This SAG consists of key members of the proposing GEROS team and additional experts, nominated by ESA. The first important task of the SAG and ESA, the definition of the initial version of the GEROS Mission Requirements Document, was finished in mid-November 2013 [9]. The first baseline of System Requirements [10] was given in December 2013. Two competitive industrial phase A studies for the GEROS mission implementation were performed between November 2014 and April 2016 for the GEROS mission implementation. These studies were led by Airbus Defense and Space (ADS, Madrid, Spain) and Thales Alenia Space (Rome, Italy). Fig. 3 shows the preliminary GEROS payload design.

In parallel the scientific study GARCA (GNSS-R Assessment of Requirements and Consolidation of Retrieval Algorithms), which is funded by ESA [11], was also started in November 2014. GARCA is performed by 17 scientists, GNSS-R experts and Oceanographers, from 7 institutions in 6 European countries (France, Germany, Norway, Portugal,
Spain, and U.K.). The team is supported by the work of 12 external experts from Denmark, Germany, Italy, Sweden, Switzerland, and U.S. The main goal of GARCA is to support the assessment and consolidation of scientific requirements and the consolidation of retrieval algorithms for a spaceborne GNSS-R experiment, focusing on the GEROS concept and its primary and secondary data products (SSH and ocean surface roughness). The main GARCA work is the development of an end-to-end simulator for the GEROS measurements (GEROS-SIM), and the evaluation of the expected geophysical data products. Additional work packages are included, aimed to assess the oceanographic significance of the expected GEROS measurements by means of Observing System Simulation Experiments (OSSE). The external scientific experts support the GARCA project and are involved in the work to test the developments and also to initiate the sustainable formation of an interdisciplinary GEROS user community. The scientific results of GARCA were published by the international project team in six technical notes ([12]–[17]). These documents describe in detail the GEROS-SIM and its test and performance.

ESA initiated two flight campaigns in the Baltic Sea not far from the Finish coastline at Helsinki in May 2015 as a proof-of-concept for the altimetric GNSS-R approach foreseen for GEROS. Results from these campaigns are introduced in [2].

The finalization of the industrial Phase A studies in March 2016 and the GARCA study in October 2016 will end with the decision from ESA on the continuation of GEROS in Phase B. As defined in the ISS Strategic Plan, GEROS deployment is foreseen between September 2019 and March 2020 in case of successful preparative studies and provision of appropriate funding. It is foreseen to be deployed at the upper Columbus External Payload Facility (CEPF) “upper balcony” of the ISS Columbus module (Fig. 4). The launch is planned from the Kennedy Space Center (KSC) with a Dragon C3-1 launcher from Space-X and will be followed by a short commissioning phase period. A minimum lifetime of one year is expected, an extension is targeted up to 5 years.

Figure 4. GEROS deployment at the upper Columbus External Payload Facility “upper balcony” of the ISS Columbus module with limited field of view (credits ESA, from [2]).

5. SCIENTIFIC STUDIES

Part of the GARCA project including external experts activities are Observation System Simulation Experiments (OSSE), which were performed by GFZ [18], NERSC [16] and JPL [19]. These experiments indicated in part significant impact of the potential GEROS measurements to the current oceanographic modelling and forecast systems on top of the currently assimilated radar altimetry data. Exemplarily we briefly refer to [16] and [19], the investigation of the GEROS capability for the observation of highly energetic mesoscale ocean currents (eddies) with changes of <20 cm sea surface within regions of <100 km. Knowledge on these eddies is important for the characterisation of nutrients and/or pollutants with many societal and scientific applications. Presently the tracking and forecasting of eddies is limited due to the capability of the current ocean altimetry missions.

The initial OSSE study [19] used artificial GEROS measurements (only GPS, conservative accuracy, one month) and a regional ocean model. The results indicated that GEROS data, even with measurements from only one GNSS constellation and with conservative accuracy assumption, could be used to improve current regional ocean topography
forecasting with special focus to highly energetic mesoscale currents. NERSC performed a more detailed study [16] and investigated the influence of simulated observation data from three different simulated GEROS constellations with different but realistic Field of View (FoV) configurations against the present performance of state-of-the-art eddy resolving ocean data assimilation system. GNSS-R data are expected to bring complementary observation data especially in the case of severe storms due to the high transmissivity of the GNSS L-band signals in the presence of rain. A regional HYCOM model of the South China Sea (SCS) was considered, equipped with an Ensemble optimal interpolation assimilation system for traditional along-track altimeter data and SST (Sea Surface Temperature). As period of interest July 2014 was selected, during which the SCS has been hit by the typhoon Ramasun. The model and assimilation systems were described in [20] and the simulated GEROS data [16, 17] were assimilated in addition to the "present day" observing system, together with their specified uncertainty properties including realistic atmospheric/ionspheric propagation effects. A "truth" run was generated by assimilation of (real) traditional altimeter and SST data. Then its initial conditions are perturbed by a shift of the initial date tag and two runs are integrated without GEROS (standard observing system) and with GEROS data as would have been obtained from three observing scenarios: GEROS-ISS with realistic Field of Views 1 and 2, and two scenarios for the GEROS payload aboard a potential FreeFlyer separately for FOV1 and FOV2 (not shown here, see [16, 17]). The results in Fig. 5 (GEROS-ISS run) indicate that the GEROS data can improve the rendering of mesoscale features in the SCS over the satellite constellation that was active in July 2014. Statistics over the whole month of July 2014 indicate that GEROS can reduce the RMS errors of sea level anomalies by 13%, which is a significant improvement in an operational ocean forecasting system, whereas the GEROS-FoV1 and FoV2 (FreeFlyer) achieve even greater reductions by 20% and 29%, respectively.

![Fig. 5. Daily SLA maps of "Truth" (left), standard (middle), and GEROS-ISS runs (right) from 16 to 19 July, 2014 (unit: cm). The contour interval is 4 cm, and the green line indicates the Ramasun typhoon track during the 24 h of the daily average map. The symbols of "TD, TS, STS, T, ST, SUPER T" are related with the Tropical Cyclone Classification considering the maximum wind near the centre (km/h): TD: Tropical Depression (<63); TS: Tropical Storm (63–87); STS: Severe Tropical Storm (88–117); T: Typhoon (118–149); ST: Severe Typhoon (150–184); SuperT: Super Typhoon (≥185) from [2], [16].](image)
6. REFERENCES


