

The next task for SSC

Atmosphere Climate Experiment Plus - ACE+

ACE+ is an atmospheric sounding mission using radio occultation techniques and is a combination of the two Earth Explorer missions ACE and WATS earlier proposed to ESA. ACE+ is the response to ESA's 2nd Call for Earth Explorer Opportunity Missions in 2001 and was ranked no 1 out of 25 candidate missions.

ACE+ will considerably advance our knowledge about atmosphere physics and climate change processes. The mission will demonstrate a highly innovative approach using radio occultations for globally measuring profiles of humidity and temperature throughout the atmosphere and stratosphere.

The baseline constellation of 4 small satellites, tracking L-band GPS/GALILEO signals and X/K-band LEO-LEO cross-link signals, will be launched in 2 counter-rotating orbits with 2 satellites in each at 650 and 850 km respectively. The system design is aimed to optimise the science return by proper distribution of the observations in space and time. The LEO-LEO cross-link instrument is driven by accuracy requirements that drive antenna design, transmitter power, and transmitter and receiver stability. Spacecraft design is driven by the relatively high power consumption of the instruments, and their pointing requirements. Satellite characteristics include a mass of 160 kg, and available power of 125 W. In order to meet the cost envelope of the Earth Explorer Opportunity Missions the spacecraft will be a simple and robust design and makes use of the latest, but proven, technology. Low cost launch is envisaged to be with Rockot or START-1, and can take place in 2006-2007. Finally, the ground segment processes data from all satellites, using also data obtained on ground, and distributes it to the meteorological community.

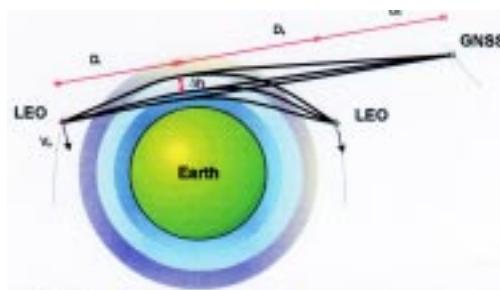


Figure 1: Outline of the geometry for Radio Occultation measurements based on LEO-LEO and GNSS/GALILEO-LEO observation schemes

Introduction

This extended abstract gives a mission overview and describes and technical solutions for ACE+. At the time of writing this abstract the mission is just before the start of a phase A study, and the paper therefore presents a range of design solutions together with preferred, or so-called first iteration solutions.

SSC designs European fleet of satellites for climate investigations

In April ESA selected SSC for the design of a European satellite "fleet" for climate investigations called the "Atmosphere and Climate Explorer Plus", ACE+. This project comprises four satellites in different orbits around the Earth to determine profiles of temperature and humidity. With thousands of profiles per day theoretical models of the Earth's climate can be enhanced and calibrated. The system will use both signals from GPS and Galileo satellites as well as signals emitted by two ACE+ satellites. The signal propagation in the atmosphere is measured by ACE+ in order to determine temperature and humidity.

The ACE+ project could be materialised with launches around 2008. The work now given to SSC by ESA covers the first design phase of the project and is carried out in the period May 2003-March 2004 by SSC's Space System Division at the company's engineering centre in Solna, Sweden. SSC is the prime contractor for an international consortium with well known space companies as Astrium in France and UK, Dutch Space in the Netherlands, EMS Technologies in Canada, Laben in Italy and Terma in Denmark.

(Summary of Press Release from SSC.)

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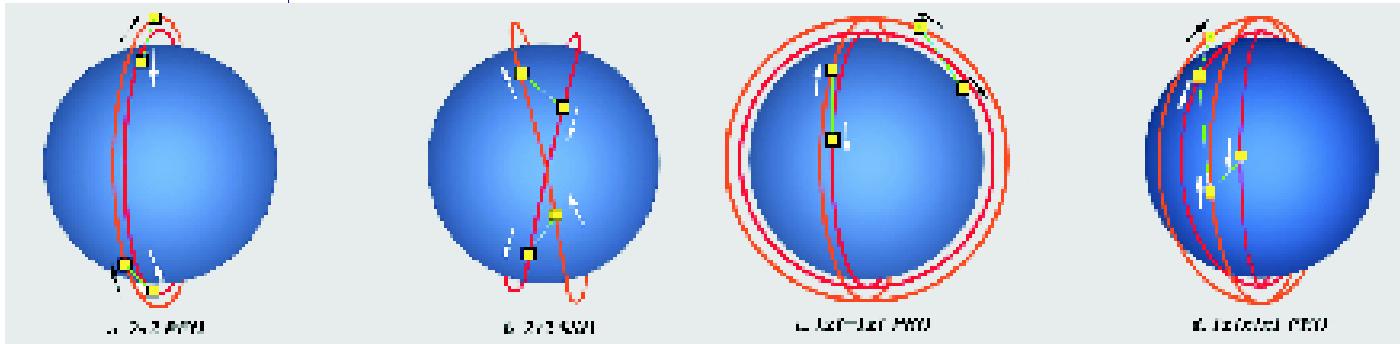


Figure 2: Examples of possible constellation options

Mission overview

The Atmosphere and Climate Explorer mission (ACE+) was proposed in Jan 2002 in response to ESA's 2nd call for Earth Explorer Opportunity Missions. The concept involves systematic gathering of data over a five-year period of precise profiles up through the atmosphere of temperature and humidity around the Earth. These profiles are subsequently used in conjunction with climate modelling and climate prediction techniques developed by meteorological institutions to improve the understanding of the driving forces behind climate change and variability. The ACE+ mission will contribute in a significant manner to ESA's Living Planet Programme under the themes of "Physical Climate" and "Atmosphere and Marine Environment" with the mission goals:

- To monitor climatic variations and trends at different vertical levels and for each season in order to improve the understanding of the climate system as well as to detect the different fingerprints of global warming
- To improve the understanding of climatic feedbacks defining the magnitude of climate changes in response to given forcings
- To validate the simulated mean climate and its variability in global climate models
- To improve and tune - via data assimilation - the parameterisation of unresolved processes in climate models and to detect inter-annual variations in external forcing of climate.

The mission will demonstrate a highly innovative approach using Radio Occultations for globally measuring profiles of humidity and temperature throughout the troposphere and stratosphere. A constellation of 4 small satellites, tracking L-band GPS/GALILEO signals and X/K-band LEO-LEO cross-link signals, will map the detailed refractivity profile and structure of the global atmosphere using a configuration of 2 counter-rotating orbits with 2 satellites in each at 650 and 850 km respectively.

The Radio Occultation technique illustrated below has so far been studied for ESA using signals from the Global Navigation Satellite System (GNSS) to determine phase and amplitude changes caused by the atmosphere. The observations have been done from Low Earth Orbiting (LEO) satellites. In the ACE+ mission the GRAS-2 instrument will provide such data for GPS and possibly GALILEO with unprecedented coverage.

In order to improve the separation of the contributions of water vapour and temperature in the lower troposphere, without using external data, ACE+ will also actively sound the atmosphere using LEO-to-LEO signal transmission at three frequencies around the 22 GHz water vapour absorption line (10, 17, and 23 GHz). Measurements of the occulted phase and amplitude of the electric field from the LEO transmitter at these frequencies will deduce independent information on temperature and water vapour distributions with an unprecedented accuracy. This technique was suggested in the WATS Core Mission proposal to ESA's Earth Explorer Programme (ESA, 2001) and examined in subsequent pre-phase A studies for the Agency.

System Design

The overall system is quite well defined, following the studies of APEW, ACE and WATS and consists of the following major components:

- GRAS-2 receiver for GRO and navigation, consisting of a multiple channel, high accuracy GNSS receiver, fore and aft antennas pointed at the horizon, and a zenith antenna for navigation. GNSS timing data will also be used to update the spacecraft onboard time.
- LEO-LEO Radio Occultation Instrument, consisting of a transmitter, receiver and antennas to measure bending angle and transmission of at least three frequencies around the water absorption line.

- Ultra Stable Oscillator (USO), which supplies a reference frequency to the instruments, and which can be used to update the on-board time ? Satellite platform, supplying: Data handling services, Communication on S-band with ground, Power generation, control and distribution, Attitude and orbit control, Thermal control and Structural functions
- Ground Segment, supplying: Mission operations and Satellite Control Element (MSCE) for mission control and planning, Ground station with S-band antennas for nominal operations, LEOP network for communication during LEOP and contingencies, Processing and Archiving Element (PAE) providing data collection, processing, archiving, distribution, and Communication channels between the centres, ground station, LEOP network and certain end-users.

Constellation design

A probable constellation design is as follows (see Figure 2a):

- 2 satellites in a PEO 650 km orbit, separated 90° in-orbit, and carrying the GRAS- 2 receiver and a LEO-LEO TX instrument
- 2 satellites in a PEO 850 km counter-rotating orbit, separated 90° in-orbit, and carrying the GRAS-2 receiver and a LEO-LEO RX instrument

Several other constellation options as depicted below will be investigated. Constellation selection will be based on coverage (horizontal domain and local time), skewness of measurement, ground contact, failure tolerance, impact on satellite design and instrument design, and last but not least cost.

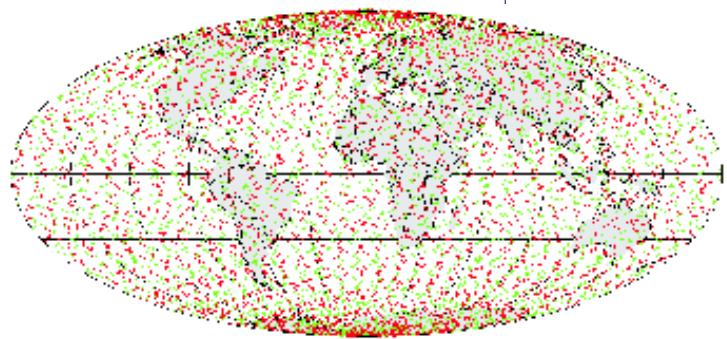
LEO-LEO radio occultation instrument design

The LEO-LEO instrument consists of a signal generator, transmitter, two pairs of antennas, a receiver, and a processing back-end. The amplitude measurement is most critical, and requires a very good knowledge or control of any gain variation within the system.

The transmitter will probably employ signal modulation and coding similar to GPS, as to take full advantage of the experience in this field. Horn antennas are envisaged that yield high gain, good pattern knowledge, and easy manufacturing. Pointing of the narrow beam antennas during an occultation is performed by the satellite. The receiver will employ the same techniques as the transmitter. Finally, a digital processing backend similar to GRAS-2 is foreseen.

GRAS-2 instrument

The GRAS-2 instrument will be based on current instrument designs such as Lagrange RO from Laben, or GRAS on MetOp.



Spacecraft design

In order to cope with the main design drivers (occultation antennas free fields of view, power generation on drifting orbits, multiple launch), the ACE+ satellite configuration has the following features (see Figure 4):

- The payload occultation antennas are implemented on the velocity and anti-velocity sides, and are pointed towards the horizon (about 25° tilt);
- The solar array is implemented on the side perpendicular to the velocity. This solar array features one deployable wing and additional solar panels fixed on the side panels of the structure;
- The star trackers are implemented also on the velocity and anti-velocity sides: they look in opposite direction, and are tilted from about 30° towards the anti-sun side, in order to minimise the occurrence of star tracker blinding.

The ACE+ satellite is compatible with a 2 m diameter launcher fairing for dual launch in terms of mass and dimensions. Typical figures for the satellites are mass 160 kg, power 125 W (including margins).

Figure 3: Spatial LEO-LEO RO coverage during one month for one of the possible constellations: 4 satellites in counter-rotating orbits, 90° incl. 650 and 850 km, 90° in-orbit arc separation.

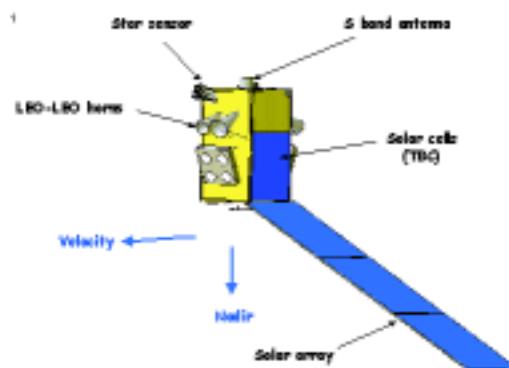


Figure 4: ACE+ satellite orbital configuration 4