AMORE: AN AUTONOMOUS CONSTELLATION CONCEPT FOR ATMOSPHERIC AND OCEAN OBSERVATION

T. P. Yunck, G. A. Hajj, E. R. Kursinski, J. A. LaBrecque, S. T. Lowe, M. M. Watkins
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

Gerald R. North
Texas A&M University, College Station, Texas

Abstract

The Atmospheric Moisture and Ocean Reflection Experiment—AMORE—is a proposed constellation of microspacecraft for atmospheric and ocean observation. AMORE would observe atmospheric radio occultations and ocean reflections from an array of 12 or more microspacecraft to support climate process studies and the testing and refinement of climate models. The spacecraft would track the L-band signals of 48 GPS and GLONASS satellites, directly and reflected off the ocean, and would exchange occultation crosslinks at 10, 14, 18, and 23 GHz to map tropospheric water vapor from the surface to the tropopause, the detailed refractivity and thermal structure of the global atmosphere, and difficult-to-observe eddy-scale changes in ocean circulation.

GPS occultation Earth remote sensing
ocean reflectometry

Introduction

In the past decade, the US and Russia have placed in high Earth orbit several dozen brilliant L-band beacons making up the GPS and GLONASS navigation constellations—known collectively as Global Navigation Satellite Systems (GNSS). Each beacon bathes the earth in a penetrating microwave glow, exposing formerly hidden features to direct observation almost everywhere at once. The proposed Atmospheric Moisture and Ocean Reflection Experiment—AMORE—would unite several GNSS sensing techniques with advanced microspacecraft technology, and introduce high-frequency radio occultation crosslinks of its own, to provide powerful new atmosphere and ocean data sets for use in climate studies, meteorology, and other Earth science disciplines.

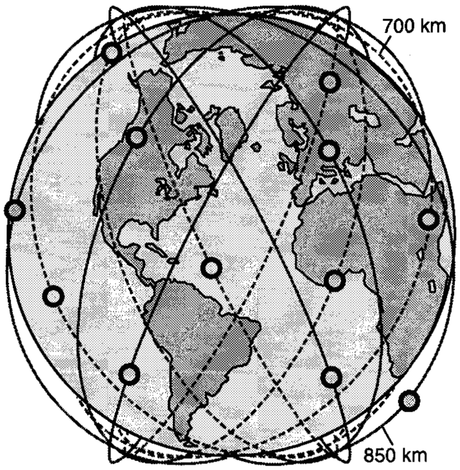

Fig. 1. *Two 6-satellite arrays at 700 and 850 km, 65° inclination, make up the constellation.*

The baseline mission concept features 12 small low Earth orbiters (LEOs) in two nested arrays of six planes each (Fig. 1). The satellites, in circular orbits at 700 and 850 km, would make three types of measurements: 1) GNSS L-band atmospheric occultations to measure refractivity; 2) LEO-LEO crosslink occultations to observe water vapor absorption; and 3) GNSS ocean reflections to observe ocean height and state. The LEOs will track all visible GNSS occultations fore and aft and all ocean reflections having an incidence angle >15°. In addition, the LEOs will exchange crosslinks at 10, 14, 18, and 23 GHz. Crosslink occultations and GNSS reflection data will provide several complementary new measurements including precise global water vapor distribution from the surface to the tropopause and eddy-scale to mesoscale global ocean circulation with few-day resolution. AMORE also offers a rich source of "conventional" GNSS occultation data, more than tripling the acquisition of atmospheric temperature, pressure, density, moisture, and geopotential height data from currently planned missions.

Individual LEOs will exploit onboard GNSS navigation information to maintain a predetermined array configuration (each LEO maintaining its own absolute position) to allow full mission autonomy. A principal strength of AMORE is its concurrent or "synoptic" global sampling, in complement to the sequential sampling of typical single-platform observing systems. Near-uniform global coverage is reached within a few hours (and rapidly densifies thereafter), alleviating a number of sampling problems of conventional instruments and enabling new investigations. Examples include observing ocean eddy formation and evolution and the full diurnal atmospheric temperature cycle each day.

Principal Science Objectives

AMORE seeks to advance our knowledge of climate behavior and climate processes, and to test and refine climate models by:

- characterizing climatic behavior and variability
- measuring atmospheric and oceanic quantities affecting climate system feedback;
- quantifying the response of the atmosphere-ocean system to external forcings;
- further elucidating oceanic heat transport.

To address these issues the mission will continuously and synoptically observe:

- global water vapor distribution throughout the troposphere at <1 km vertical resolution;
- atmospheric temperature and geopotential heights from the surface to 85 km;
- precise atmospheric refractivity (and derived quantities) from 0 to 85-km altitude;
- global profiles of cloud liquid water;
- sea-surface topography and eddy-scale ocean circulation with near-daily resolution.

Further processing of refractivity data yields temperature, pressure, geopotential heights, and wind fields, from the surface upward; the bulk temperature of the troposphere; and (model-dependent) water vapor in the lower troposphere. High frequency AMORE crosslinks will directly measure water vapor concentration throughout the troposphere independent of other data or models. Further processing of sea-surface topography will yield both currents and heat fluxes due to eddies in the ocean mixed layer.

Several features distinguish AMORE from other sensors: Because all occultations begin or end above the atmosphere where bending is zero, each profile is self-calibrating and virtually unbiased; because limiting errors are effectively random, many refractivity profiles can be averaged to yield an equivalent temperature accuracy of ~0.1 K in a climate region of interest, or roughly an order of magnitude below that of more conventional techniques; GNSS occultation and reflection products are virtually unaffected by weather and clouds; Over 1,600 daily LEO-LEO links at 14-23 GHz will map water vapor in the upper troposphere to nearly 3 ppm, and will extend refractivity mapping from the 50 km altitude limit of GNSS to a maximum of about 85 km; LEO-LEO links at 10-14 GHz, together with thousands of GNSS occultations, will extend global water vapor mapping to the surface; reflected GNSS signals will provide ocean height measurements precise to a few cm (after massive averaging), achieving an average resolution of 25 km globally within 1 day.

The AMORE concept is distinguished by its unusually rapid global coverage. Figures 2 and 3 show the distribution of the 12,000 GNSS occultations and 1,600 crosslink occultations to be obtained each day. The near uniformity of the latter depends on the different altitudes of the two sub-arrays. Ocean reflection coverage is even more dramatic producing 16-20 million 1-second ocean height samples with 1 m precision every day.

Instrument Description

All science measurements are obtained with a single core instrument: an extended TurboRogue Space Receiver (TRSR) of the kind being flown on several upcoming international occultation flights, including GRACE, for which an inter-spacecraft crosslink has been developed. Apart from front end changes to deal with new frequencies and the addition of GLONASS tracking, the basic TRSR is little altered from flight proven models.

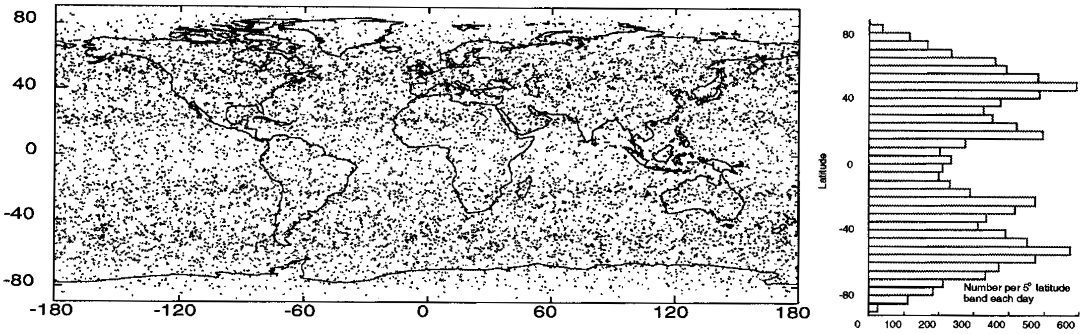

Fig. 2. Typical one-day GNSS occultation coverage with a 12-satellite constellation.

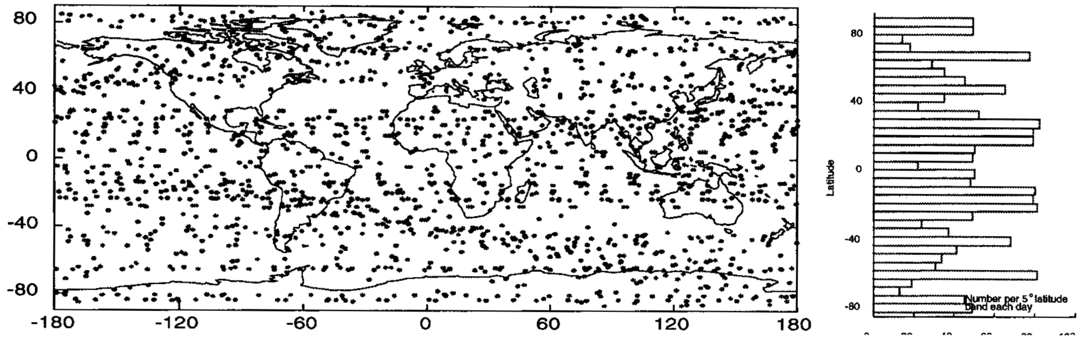

Fig. 3. Typical one-day crosslink occultation coverage with a 12-satellite constellation.

The receiver will perform similar functions on all signals: measure signal amplitude; compute pseudoranges; and measure precise carrier phase. Integral to the receiver is a high-speed microprocessor which will control all receiver operations, compute the onboard navigation solutions, and control the autonomous operation of the spacecraft.

The microwave crosslinks are engineered to survive the water vapor absorption. In the lower troposphere, where water vapor is abundant, we employ the less strongly absorbed 10 and 14 GHz signal. Transmitted power and receive antenna gains are sized to achieve a voltage SNR of 3,000 within 1 sec for a worst case moisture concentration of 20 g/kg at the bottom of the troposphere in the tropics. This will deliver a typical water vapor measurement accuracy of 4%. In the upper troposphere, where the moisture concentration is far lower, the prime consideration is detecting the weak effect with a precision sufficient for a measurement accuracy of 3 ppm. A frequency close to the 22.2 GHz water line is therefore essential. An instrument block diagram is shown in Fig. 4.

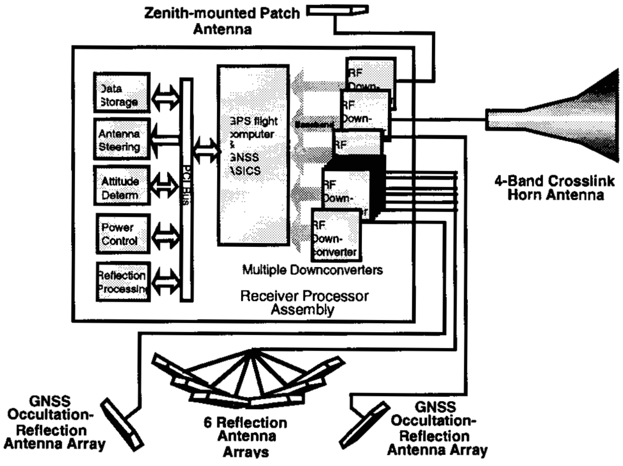

Fig. 4. High level block diagram of the TurboSounder-4 GNSS occultation receiver.

Refractivity from Carrier Phase

As the signals pass through the atmosphere they are retarded and bent, inducing a Doppler shift. The instrument continuously measures the carrier phase, from which we can isolate the atmospheric Doppler shift. From there we can determine the bending angle and, by applying a series of simple geometric assumptions and the ideal gas laws, atmospheric refractivity, density, pressure, temperature (or moisture), geopotential heights, and a variety of other products.

Refractivity is recovered with a vertical resolution of 0.5-1.0 km and a horizontal resolution of ~200 km. The fractional refractivity error of a single profile is 0.2-1.0%, due mostly to random error from atmospheric inhomogeneity; long-term averaging yields a fractional refractivity error of less than 3×10^{-4}. This translates into 0.1 K and 1 meter of temperature and geopotential height accuracy where water vapor is negligible (T<250K).

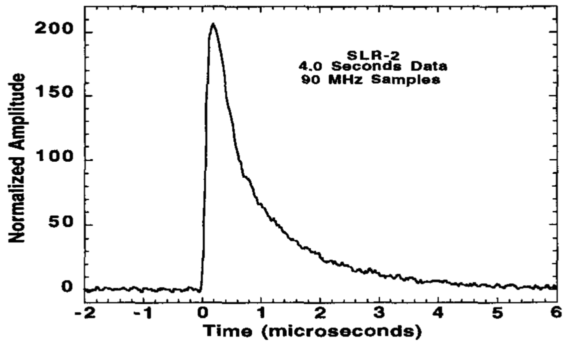

Fig. 5. *Amplitude of ocean-reflected GPS L2 signal viewed by the SIR-C antenna aboard the space shuttle [LaBrecque et al., 1998].*

Altimetry with Reflected Pseudorange

Reflections received from orbit are far weaker than the direct signals, typically by 30-40 dB. We will require a downlooking antenna gain of about 26 dB to acquire reflected pseudorange data with an average precision of 1 m in 1 sec. Figure 5 shows a seminal event in GNSS reflectometry: the first carefully observed ocean reflection received from space [LaBrecque et al., 1998]. The sharp rising edge provides a precise measure of the range; the long tail is the result of scattering about the specular point and provides data on surface roughness and other quantities.

Water Vapor from Crosslinks

Water vapor absorbs strongly at 22.2 GHz and less strongly at lower frequencies. Changes in measured amplitude thus directly reveal water vapor distribution. In practice, moisture profiles will be recovered by combining phase and amplitude information. Phase enables determination of the atmospheric bending angle, and thus the path taken by each ray and its tangent height, permitting estimation of diffraction and defocusing effects. The amplitude measurements reveal the total extinction along the ray path. The unattenuated signal above the atmosphere is measured for calibration. The attenuation through the atmosphere then gives a direct measure of the amount of attenuating matter along the path. In the upper troposphere, where the moisture concentration is low, we employ the strongly absorbed 23 GHz signal; in the moist lower troposphere we switch to 10 GHz. In both cases 14 and 18 GHz are used. Environmental errors include defocusing due to atmospheric bending (derived from phase data), diffraction and scintillatons (estimated with a 2nd frequency), and signal absorption by other constituents such as O_2 (derived by reconstructing the atmospheric temperature-pressure structure). Atmospheric moisture will reduce the signal level by absorption and scattering; this will be calibrated with multiple frequencies.

Spacecraft Description

The AMORE spacecraft is derived directly from, and shares many subsystems with, the COSMIC spacecraft now in development. The core science instrument, a GNSS receiver, serves as a multi-function spacecraft nerve center. In addition to acquiring science data, the receiver will determine real-time state, attitude, and time; provide onboard computing for all spacecraft operations; provide all onboard data storage; and receive and decode uplinks. It also features an integrated star camera, for precise attitude knowledge. The spacecraft includes a power system, 3 reaction wheels, 3 magnetic torque rods, an inertial reference unit, S-band downlink, and hydrazine propulsion.

Reference

LaBrecque, J., S. Lowe, L. Young, E. Caro, S. Wu, L. Romans, Recent advances in the study of GPS Earth surface reflections from orbiting receivers, UNAVCO Community Meeting, and in prep (1998).