

Surface-Air Interaction and Hydrology Mission

(Response to RFI on Concepts for Science and Application Missions in the Post-2002 Era)

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Summary

A mission concept is proposed that will provide near-all-weather, global measurements of ocean, cryosphere, and land parameters for research and long-term monitoring applications in surface-air interaction, hydrology, and climate. The principal measurements include: **Ocean** – surface salinity, surface temperature, surface wind speed and direction, surface precipitation and precipitation profile; **Land** – surface soil moisture and precipitation profile; and **Cryosphere** – sea-ice motion. Additional information on parameters including vegetation biomass, snow cover, land surface temperature, latent heat fluxes among many others, will also be provided by this concept. *These measurements are highly relevant to three (questions 1, 2, and 4) of the five key questions posted by the Earth Science Enterprise for this RFI.*

The instrument concept employs an innovative new-technology approach, consisting of a light-weight, large-aperture, conically-scanning, multichannel, passive/active microwave system operating in the 1 to 14 GHz range. This system will provide higher spatial resolution and accuracy for the proposed measurements than are attainable using existing sensors on international, EOS, and NPOESS platforms. In addition, the ocean salinity and soil moisture measurements will be unique in that no current spaceborne capability exists for measuring these parameters. Providing the suite of measurements in a single integrated sensor package is a major advantage for geophysical retrievals and model assimilation. The concept can be considered a logical follow-on to the SMMR, SSM/I, SeaWinds, and AMSR sensors, and addresses a significant subset of the NASA Earth Science and NPOESS measurement requirements.

1. Scientific Rationale

A few decades ago, we speculated that the atmosphere was chaotic and we could, at best, predict weather a week in advance. We now can anticipate climatic swings (e.g., El Nino) a season ahead, using improved observations for initial and boundary conditions of our prognostic models. To meet the scientific challenge in the post-2002 era, which will be the prediction of long-term climate change, we must prepare long-term (15-25 years) monitoring of a varieties of surface conditions, including surface temperature, moisture, precipitation and ice cover. The atmosphere and the ocean are under-sampled turbulent fluid with non-linear interactions; processes at one scale affect processes at other scales. Adequate observations at significant temporal and spatial scales can only be achieved through continuous observation from the vantage point of space, at the highest possible spatial and temporal resolutions.

1.1 Ocean-atmosphere Interaction

The ocean, which covers over 70% of the Earth, is forced at the surface largely through the exchanges of water, momentum, and heat. Without surface forcing, the ocean would just be a dead pool of water. The exchanges drive the transport and change the storage of heat, water, and greenhouse gases, and thus moderate the world's climate. They also affect ocean biological productivity and ecology. The ocean feedback to climate changes must be manifested through these exchanges, without which the Earth would be a more hostile habitat.

The flux of momentum and kinetic energy are resulted from wind shear. Heat flux can be divided into four components; sensible heat resulted from thermal gradient, latent heat carried by evaporation, shortwave radiation from the sun and longwave radiation from the atmosphere and the ocean. Shortwave radiation and latent heat flux are the larger variable components over most of the tropical and temperate oceans. Fresh water flux is the difference between precipitation and evaporation. Oceanic responses to these forcing can be observed from space through surface signatures, e.g., sea level, sea surface temperature, surface salinity, and ocean color. The most recent review of space-based estimation of these forcing and responses is given by Liu [1997].

The proposed instrument will complement or extend measurements of wind and rain forcing, as well as all-weather sea surface temperature, made by other missions. It will measured ocean surface salinity to sufficient accuracy, not yet achieved by any space-based sensors. Together with sea level measured by microwave altimeters, surface radiative flux derived from data of the International Satellite Cloud Climatology Project or spaceborne sensor like CERES, and surface evaporation and latent heat flux derived from microwave radiometers and humidity sounders, the data from the proposed sensor will help to monitor global air-sea fluxes and the corresponding oceanic responses. The significant higher spatial resolution of wind and rain, made possible by new technology, will provide unprecedented opportunity to study coastal regions and marginal seas which are close to a large portion of the Earth's population, as well as small-scale weather systems and storms, which have intense effects to human livelihood.

1.2 Wind

The proposed wind vector measurements will extend the time series established by the AMI on ERS1-2, NSCAT on ADEOS-1, SeaWinds on Quikscat and ADEOS 1-2. While the European scatterometers measure at C-band, have 50 km wind resolution, and have a single swath of 500km, the U.S. scatterometers measure at Ku-band and have 25 km resolution. NSCAT scanned two 600 km bands and SeaWinds will scan a continuous 1800 km swath, thus providing far superior coverage. The proposed mission will complement potential operational measurements on European METOP and the U.S. NPOESS systems. A dual swath C-band scatterometer (ASCAT) is planned for METOP with scheduled-launch in 2003, but it will have less coverage than NSCAT. The possibility of a passive system on NPOESS has been suggested. The proposed mission with 1500 km swath at 5 km spatial resolution will contribute to the validation of the passive microwave technique through direct comparison with collocated and simultaneous vector wind measurements at full spectrum of environmental conditions.

1.3 Precipitation

To advance our knowledge and our ability to better predict the heating state of the atmosphere from weather to climate time scales, more precise and long-term time series of global rainfall and its variability is crucial. The Precipitation Radar (PR) aboard the recently launched US/Japan Tropical Rainfall Measuring Mission (TRMM) is the first ever spaceborne mission dedicated to three dimensional, global precipitation measurements and the latent heat release over

the tropics and the subtropics. The TRMM radar instrument, in particular, can measure vertical profiles of rain reflectivity and rain rate over both land and sea areas. From all indications thus far, all TRMM science instruments, including the radar, are performing flawlessly and providing unprecedented insights into rainfall producing cloud systems over tropical land masses and oceans. The intents of the rain radar on our proposed mission are: (1) to continue the progress on rain processes that is being made by TRMM; (2) to extend the time series of TRMM radar measurements for at least three additional years; and (3) to increase the latitudinal surface coverage in order to gain insights into the intensity and mass flux of the mean meridional circulation. Moreover, the radar swath of over 1000 km as proposed will provide more frequent sampling, and thus smaller sampling error, at any part of the observable latitudes (the TRMM radar swath is ~220 km).

1.4 Salinity

The principles, as well as technical challenges, of satellite SSS remote sensing using low microwave frequencies (1-3 GHz) have been recognized for over two decades (Lagerloef et al, 1995; Swift and McIntosh, 1983). The multi-channel radiometer and radar proposed here is designed to yield the highest salinity accuracy relative to any of the low frequency microwave systems under consideration. Based on careful simulations, 100 km resolution and 1-week averages are expected to have errors of .1-.15 psu in the tropics and sub-tropics, and about 0.3 psu in sub-polar regions where the low water temperatures reduce SSS accuracy. Additional accuracy can be realized with further space-time filtering and co-analysis with in-situ surface data to resolve weaker signals on longer time scales, such as the Great Salinity Anomaly. Observing the global surface salinity is viewed as a high priority for CLIVAR and GOOS.

In high latitude oceans where the low water temperatures reduce SSS accuracy to about 0.3 psu, this sensor can show the position of coastal currents and salinity fronts. The salinity range across the Greenland and Norwegian Seas is about 1 psu, and the interannual salinity variability such as the Great Salinity Anomaly is only about 0.3 psu, so this sensor is not particularly suited to studying these issues. However, tracking the front between the East Greenland current and the Greenland gyre, and the dispersal of the freshwater inflow from the Siberian rivers and the MacKenzie River to the Arctic Ocean at the end of the summer melt would be very well suited to this sensor, as would determine where Bering water inflow propagates and where the Chukchi coastal current separates from the coast. These surface currents affect ice formation and growth at the end of the melt season, and ice growth in the ensuing winter.

1.5 Sea surface temperature

Measurements of SST from space currently rely on visible and thermal infrared sensors. The AVHRR is the present operational sensor, which will be improved upon by MODIS on the EOS AM1 platform. The accuracy of ~0.5–0.7°C available from visible/infrared sensors is limited to cloud-free areas, however. Large ocean regions of persistent cloud cover, particularly around the equatorial convergence zones, are therefore sparsely sampled by these sensors even on a monthly basis. These regions, however, are dominant sources of latent and sensible heat fluxes into the atmosphere, and it is critical that the SST in these regions be monitored more frequently and reliably than presently feasible. The SST derived from the microwave sensor in this concept, though primarily intended to optimize the SSS retrieval accuracy, will be complementary to the visible/infrared measurements by providing measurements of SST in the presence of clouds (without precipitation). It will be provided at a resolution of 10 km or better, versus the resolution of ~60 km that will be provided by the AMSR microwave instrument on EOS PM1.

1.6 Soil Moisture

Soil moisture plays a key role in determining weather and climate. Soil moisture information is therefore needed to quantify the influence of soil moisture on interannual variations of the global atmosphere, and for parameterization of land-surface water and energy balances and fluxes for climate system models. Understanding the role of soil-water anomalies in climate variability and persistence, especially in continental interiors, is a high priority. The operational forecasting community also has a need for soil moisture information to initialize and calibrate forecast models. Uncertainty in the surface soil moisture status is a major contributing source of error in the operational forecasts. Soil moisture is also an extremely important control on the location and functioning of terrestrial ecosystems. Unfortunately, there are currently no capabilities for obtaining soil moisture routinely on a global basis as required for hydrologic and ecologic modeling and monitoring. For these applications, soil moisture information at a resolution of ~30 km or better, with global repeat coverage of 3 days or less is desirable. Soil moisture accuracies of ~4% by volume over the range from dry to saturated are needed.

Evaporation over vegetated regions depends not only on soil moisture but also on surface temperature and vegetation cover and type (and on biophysical processes). This mission concept has the potential to provide information, simultaneously, on three important land surface variables—surface soil moisture, surface temperature, and vegetation water content. As a global time history of the diurnal and seasonal cycle of these parameters becomes available, it will be possible to consider an optimum data utilization process constrained by physical models. 4DDA is an ultimate example of this, where the full global data assimilation system can be used to interact with the satellite data stream. Careful attention can be paid to the freeze-thaw transition of the soil at higher latitudes, which should be detectable from the mission data. Many forecast models are not yet accurate in their handling of this phenomenon, which consequently leads to significant forecast errors in the transition seasons.

1.7 Sea Ice

The motion of sea ice is important in a wide range of problems in polar oceanography. On scales larger than several hundred kilometers, there is a general circulation of the ice cover that determines the advective part of the ice mass balance and provides a velocity boundary condition on the ocean surface. Smaller scale processes involve the detail motion of individual floes, aggregate of floes and the formation of leads. Ice motion controls the abundance of thin ice and the surface processes dependent on thin ice, such as heat flux, ice production and salinity forcing of the ocean. This concept can provide polar scale sampling of the ice motion with an accuracy of better than 5 km, better than that provided by lower resolution passive microwave sensors. It contributes to the continued monitoring of the polar oceans on the post-2002 timeframe.

2. Measurement approach and Specific Objectives

The mission concept for the proposed science measurements described above will use the lightweight, large-aperture deployable mesh antenna technology to provide adequate spatial resolution for ocean salinity, soil moisture and rain measurement. The proposed large-aperture antenna concept will also provide unprecedented spatial resolution for ocean surface winds, polar sea ice, and sea surface temperature studies.

Our baseline mission concept is to use a rotating 10-m diameter lightweight mesh deployable reflector to measure accurately the radiometric microwave emission and scatterometer reflectivity of the Earth's surface at several channels in the 1 to 14 GHz range. The conical-scanning antenna configuration will provide the wide-swath coverage necessary for global imaging of hydrological

forcing and responses. Multiple offset feeds will provide collocated multi-frequency radiometer and radar measurements with a constant footprint size and constant incidence angle. The conical scan provides polarized measurements over entire swath for improved geophysical retrieval accuracy. L- and S-band dual-polarized radiometers with a low RMS noise (ΔT) per pixel, and well calibrated antenna temperatures, will provide the primary measurements for ocean salinity and soil moisture retrieval. A third Stokes parameter channel will be incorporated into the L-band radiometer to calibrate the ionospheric Faraday rotation. This will enable day and night observations for the detection of diurnal signals. An L-band scatterometer is included to provide direct information on the surface roughness, enabling a high precision sea surface salinity retrieval. A C-band radiometer will provide accurate sea surface temperature measurements under nearly all weather conditions. To provide rain and ocean wind measurements, an integrated wind scatterometer and rain radar will share the same electronics with multi-antenna-beams to obtain contiguous coverage.

The following table summarizes the accuracy, coverage and spatial resolution objectives for the principal measurements of the concept.

| Parameter | Accuracy | Swath | Global coverage | Resolution |
|----------------------|---|---------|-------------------------------|------------|
| Wind Speed/Direction | 2 m/s, 20 deg | 1500 km | >92% ice free ocean in 2 days | 5 km |
| SST | 0.5 deg C | 1050 km | 3 days | 30 km |
| Ocean Salinity | 0.2-0.3 psu weekly | 1050 km | 3 days | 100 km |
| Soil moisture | 0.04 g cm ⁻³ | 1050 km | 3 days | 30 km |
| Rain | 0.8 m/s (vertical velocity), 15% instantaneous and monthly avg. rain rate | 1050 km | 3 days | 5 km |
| Sea Ice Motion | 3 km tracking accuracy | 1050 km | daily | 5 km |

One of the most important aspects of this design is that this antenna concept can easily be scaled to larger diameters and additional frequencies for further resolution enhancement and broader science applications.

Our measurement plan for the proposed mission concept is to conduct studies to make the concept ready for implementation in two years. We have identified several issues detailed in Section 4 for technology tradeoffs and development of the large-aperture mesh antenna concept. These issues are highly suitable for studies under the support of the Earth Science Enterprise's Instrument Incubator Program, including a detailed design for the mission concept and instruments, specifications of spacecraft characteristics and cost and performance tradeoffs.

3. Mission Type

The proposed mission concept is for a systematic measurement program. A mission duration of 3 years minimum is envisaged, with 5 years as the goal. Consecutive deployments are required to develop data records with a long time series. There are two important features for this mission concept:

- (1) It will extend and provide a higher performance over existing EOS missions.
 - < High resolution ocean winds (factor of five better than NSCAT, Quikscat, and SeaWinds missions)
 - < Wide swath rain profile (1000 km swath width versus 220 km for TRMM)

< High resolution sea surface temperature (factor of five better than AMSR)

- (2) It will also acquire new types of environmental parameters, including ocean salinity and soil moisture measurements. There are no existing spaceborne capabilities for these two parameters.

4. Remote Sensing Measurement Technique

4.1 General Characteristics and Technical Background

The proposed mission utilizes mature measurement techniques inherited from present EOS missions or demonstrated by numerous aircraft and field campaigns. The baseline instrument characteristics of the proposed concept are summarized in the following table.

| Parameter | Hydrology (SSS/Soil moisture/Ice) | SST | Wind/Rain/Ice |
|---------------------|--------------------------------------|------------------|----------------------------------|
| Instrument | Radar/Radiometer | Radiometer | Radar |
| Frequency | L (1.2/1.4 GHz), S (2.7 GHz) | C-band (6.8 GHz) | Ku (13.4 GHz) |
| Transmit Power | 20 W | - | 100 W |
| Incidence Angle | 45° | 45° | 45° (Wind/Rain) 56° (Wind) |
| Footprint | 30 km | 8 km | 5 km |
| Sampling Resolution | 15 km | 30 km | 5 km |
| Vertical Resolution | - | - | 100 m (Rain) |
| Swath Width | 1050 km | 1050 km | 1500 km (Wind) 1050 km (Rain) |

Low frequencies in the 1–3 GHz range are preferred for soil moisture sensing due to their ability to penetrate moderate vegetation. Simulations have shown that a multichannel system, such as Osiris, can retrieve soil moisture to an accuracy of 4% by volume in the presence of vegetation with water content up to $\sim 5 \text{ kg m}^{-2}$ (comparable to a mature corn crop). Dual-polarized 1.4 GHz measurements at a constant incidence angle are essential to this technique. The brightness temperature varies with incidence angle, and also with the amount of vegetation. A cross-track-scanning instrument, operating at a single channel (say 1.4 GHz, horizontal polarization), will experience significant soil moisture measurement error in correcting for variable incidence angle and vegetation, even if ancillary data from other sensors are available to aid in this correction (these ancillary data have associated retrieval and time-space registration errors). By making measurements at a constant incidence angle (near 40°), and with both V and H polarizations, one can avoid the need to correct for variable incidence angle, and can make use of the additional polarization information to correct for the effect of vegetation. Additional channels at S- or C-band will enable independent estimates of the surface temperature to be made, and provides additional information on vegetation through the spectral dependence of attenuation and vegetation water content.

Low frequency microwaves are also suitable for SSS and SST remote sensing. L-band (1.4 GHz) brightness temperatures are sensitive to SSS as well as SST and sea surface roughness. S-band or C-band radiometers will provide necessary information for SST retrieval and L-band radar data will provide direct information of surface roughness, enabling an unambiguous retrieval of SSS. A rigorous and careful simulation of the satellite SSS measurements has suggested that coincidental dual-frequency, dual-polarization radiometer and L-band radar data sets allow the retrieval of SSS with a weekly accuracy of 0.15 psu in the equatorial and 0.3 psu at high latitudes, meeting operational NPOESS requirements.

Ku-band (13.4 GHz) frequencies employed by the NSCAT, Quikscat, SeaWinds and TRMM missions are highly sensitive to precipitation and centimeter-scale roughness generated by ocean surface winds. Radar reflectivity influenced by rain and winds allows the retrieval of wind velocity and rain from Ku-band measurements. The same measurement techniques utilized by these missions are proposed for the proposed mission concept with shared Ku-band radar electronics to provide both functions.

4.2 Advances beyond the performances of the first EOS satellite series

This system will provide higher spatial resolution and accuracy for the proposed measurements than are attainable using existing sensors on international, EOS, and NPOESS platforms. In addition, the ocean salinity and soil moisture measurements will be unique in that no current spaceborne capability exists for measuring these parameters. Providing the suite of measurements in a single integrated sensor package is a major advantage for geophysical retrievals and model assimilation. The concept can be considered a logical follow-on to the SMMR, SSM/I, SeaWinds, and AMSR sensors, and addresses a significant subset of the NASA Earth Science and NPOESS measurement requirements.

4.3 Technology readiness and development plan

The generic types of mesh deployable antennas considered for this mission concept include (a) radial rib, (b) double Articulated Radial Concept and (c) truss perimeter structural concepts. These concepts have been developed to the point of flight readiness. The radial rib concept has already flown in the size range of 12 to 15 meters. The disadvantage of this concept is the length of the stowed antenna structure. The other two concepts are scheduled for flight within a few years. The two best examples of the double articulated radial concept are the TRW PAMS and the Harris Corp. DTS antennas. Harris has just completed the manufacture of two 12 meter DTS antennas for a Mobile Communication Mission to be launched in late 1999. The TRW antenna has been developed to the point of flight readiness in the 10 meter size. The deployed stiffness and orbital thermal stability for Harris and TRW antennas is high. The double articulated radial concept has potential for structures up to 20 meters. The best example of the perimeter truss concept is The Astro Aerospace Astro-Mesh Reflector. Astro Aerospace is currently building two 12-meter antennas for a Mobile Communication Satellite, which is scheduled to be launched in early 2000. This concept has potential for antenna structures up to 25 meters in diameter and possibly larger. The orbital thermal stability of these antenna reflector surfaces is more than adequate for the proposed mission concept. This is because the elements of the support structure are all based on using extremely thermally stable composite materials. Additionally, the surface shaping cables and flexible ties are also based on thermally stable materials such as carbon, kevlar, quartz and others.

Our technology development plan of this mission concept are to studies to obtain an optimized system in two years. The key issues to be analyzed include:

- (1) Antenna mechanical performance: The issue remains to be resolved is a redesign of surface support structure that will compensate the reflector surface distortion due to mechanical rotation.
- (2) Antenna/Spacecraft/Launch Vehicle Configuration, Integration: A preliminary spacecraft design has been performed based on a TRW STEP-4 spacecraft bus with selected modifications. The design configuration fits easily with the large Taurus launch shroud. A large momentum wheel is required to make the spacecraft a zero momentum bias system, countering the angular momentum of the spinning spacecraft. A lower cost and mechanical risk system will result from the identification, optimization, and the integration of antenna

and its interface structure/spacecraft system/launch vehicle.

- (3) Lightweight multi-channel feed horn and RF radar electronics: Lowering the spinning mass will ease the required momentum compensation mechanisms. Advance space-qualified electronics will be evaluated to lower the instrument and hence cost.

We anticipate that two years of IIP support will make the instrument concept ready for implementation for post-2002 EOS missions.

5. Technical Characteristics

The key mission parameters are for a polar, sun-synchronous orbit of ~600 km altitude, with ~6am/6pm equator crossing times, and global coverage in 3 days or less. The proposed instrument payload will consist of microwave radiometers and radars sharing one deployable 10-m parabolic antenna with offset feed horns. The spacecraft bus will rotate around the nadir axis at a spinning rate of about 14 rotations per minute (RPM). The satellite orbit for the proposed mission will be sun synchronous at 600 km altitude.

The projected mass of the proposed payload is about 200 kg, including the weight of antenna and deployable mechanisms (~40 kg), antenna feed horns, radiometers and radars. The DC power required from the spacecraft bus by the payload is 250 W. Based on the estimate of payload mass, volume, and power requirements, the total system mass is within the launch capability of a Taurus class launch vehicle.

References

- Liu, W.T., 1997: Observation of global ocean-atmosphere exchanges from spaceborne sensors. *Proceedings of IGARSS '97*, 1435-1437.