MP3 - A meteorology and physical properties package to explore air-sea interaction on Titan

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Introduction: The exchange of mass, heat and momentum at the air:sea interface are profound influences on the terrestrial environment, affecting the intensity of hurricanes, the size of waves and lake-effect precipitation. Titan presents us with an opportunity to study these processes in a novel physical context, with a different sea, atmosphere and gravity. The MP3 instrument, under development for the proposed Discovery mission TiME (Titan Mare Explorer [1,2]) is an integrated suite of small, simple sensors that combines the function of traditional meteorology packages with liquid physical properties and depth-sounding : these latter functions follow the concept of - and indeed use spare elements from - the Huygens Surface Science Package (SSP,[3]). However, unlike Huygens' brief and dynamic 3 hours of measurement, in TiME's 6-Titan-day (96 Earth day) nominal mission enabled by radioisotope power, MP3 will have an unprecedented long-term measurement opportunity in one of the most evocative environments in the solar system, Titan's sea Ligeia Mare.

Concept and Goals: Titan's seas are a scientifically-rich environment where even simple measurements are of great value. Each sensor measures only one or two physical quantities, facilitating parallel development and calibration. Together, however, they will make vital in-situ measurements that will constrain the processes at work in and between Titan's atmosphere and seas.

The topside meteorology sensors (METH, WIND, PRES, TEMP) exposed to the atmosphere will yield the first long-duration in-situ data to constrain Global Circulation Models. The sea sensors (TEMP, TURB, DIEL, SOSO) allow high cadence bulk composition measurements to detect heterogeneities (such as methane-rich rain layers or muddy river plumes in the ethane-methane sea) as the TiME capsule drifts across Ligeia, while a depth sounder (SONR) will measure the bottom profile, constraining the size of Ligeia as a planetary volatile reservoir. The combination of these sensors (and vehicle dynamics, ACCL) will characterize air-sea exchange.

In addition to long-duration measurements on the surface, a subset (ACCL, PRES, METH, TEMP) are made during descent to characterize the structure of the polar troposphere and marine boundary layer, which is expected to be somewhat different from those encountered by Huygens in the equatorial desert.

Instrument Design and Expected Results: A single electronics box inside the vehicle performs supervising and data handling functions and is wired to the sensors on the exterior. A novel element in MP3 is the use of a fiber optic harness for turbidity and methane measurements - this allows the optoelectronic components to be mounted in the benign internal thermal environment of the electronics box. The ocean sensors are mounted on a single plate on the bottom of the vehicle; topside sensors are mounted to minimize vehicle perturbations on airflow.

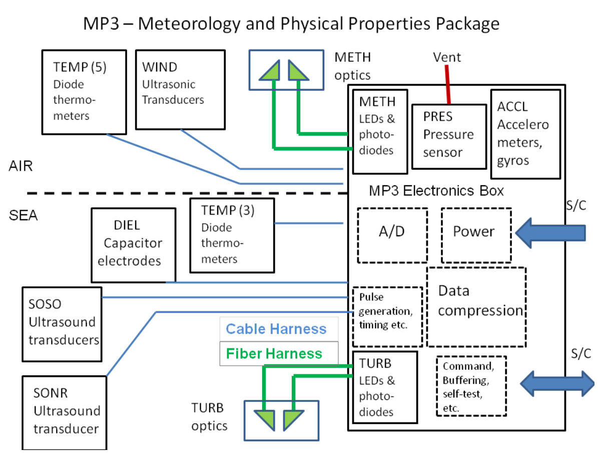

Figure 1. MP3 block diagram.

ACCL. MEMS accelerometers and angular rate sensors, mounted in the MP3 box, are used to characterize the vehicle motion during descent and on the surface. Ocean engineering simulation tools such as Orcaflex are used to reconstruct wave height, shape and period from these dynamics data. These sensors are also needed, as on ships on Earth, to correct wind measurements for vehicle motion.

TEMP. Precision space-qualified cryogenic temperature sensors are installed at several locations above and below the 'waterline' to measure air and sea temperatures. The dense Titan atmosphere keeps the response time low. Installation of topside sensors at several locations ensures that at least one is on the upwind side of the vehicle. One sensor is heated to act as a backup thermal anemometer.

PRES. The barometer subsystem uses pressure sensors of the type flown on the Huygens Atmospheric Structure Instrument : the sensors are mounted in the MP3 box and connect to the exterior via a small vent tube. The pressure history will constrain waves and gravitational tides in the atmosphere.

METH. Methane humidity (and the presence of fog) is measured with a simple 2-channel differential absorption spectrophotometer in the near-IR (~1.6µm), as in terrestrial field instruments. The humidity may be a function of local time and fetch, as well as of nearby cloud systems and rainfall.

WIND. An ultrasonic anemometer, mounted on the camera mast to minimize vehicle flow perturbations, measures wind speed and direction. The dense Titan atmosphere makes this type of instrument much easier to implement than at Mars and recent tests have confirmed transducer performance at Titan temperature. Wind direction measurement is a key navigation input at night. High-cadence (10Hz) measurements in 3D will inform estimates of air:sea fluxes.

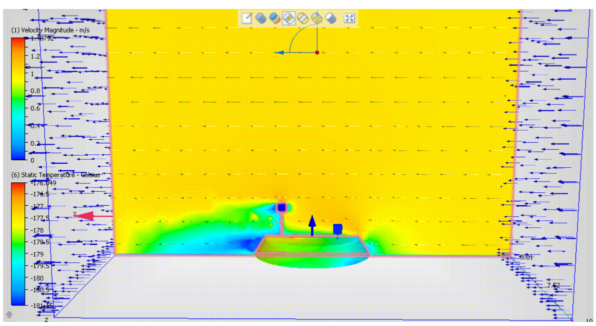

Figure 2. APL Computational Fluid Dynamics simulation demonstrating minimal vehicle perturbation to windspeed at mast-level. (Capsule color denotes temperature, fluid color denotes windspeed).

DIEL. An immersed parallel-plate capacitor (spare from Huygens) fills with liquid allowing the real and imaginary parts of the dielectric constant to be measured. This is sensitive to the methane/ethane ratio, and to the possible presence of nitriles such as HCN.

SOSO. A pair of ultrasound transducers (spares from Huygens, where they operated successfully in the Titan environment) are used to measure the speed of sound in the liquid, a function of the methane/ethane ratio (minimally affected by trace nitriles : the DIEL/SOSO pair therefore are a useful composition diagnostic that can be made quickly and often). This measurement facilitates interpretation of the SONR.

SONR. A down-looking piezoelectric transducer is used as a depth-sounder (much like a fishfinder) to measure the depth of Titan's sea. The echo record will also indicate suspended scatterers and the presence of bubble or precipitation noise at the sea surface. Acoustic propagation models used in terrestrial ocean work at APL have been adapted for Titan to model the echo profiles from various seabed characteristics with various sea temperature and composition profiles. The echo from a 500m deep sea (a likely estimate for Ligeia, hundreds of km across) will return in about 1 second.

TURB. A visible light beam is passed via optical fibers across a gap in the liquid and the direct and scattered intensity is measured to determine the presence of absorbing and scattering particles in the liquid, which are important determinants in the deposition of solar heat with depth and thus on the temperature structure of the liquid. The principle is the same as terrestrial turbidity meters (or can be thought of as an underwater nephelometer). This measurement complements camera observations of the sea surface under different natural and artificial illumination conditions.

Measurement Sequence: A microcontroller triggers sensor operation, selects and compresses data, and interfaces with the spacecraft. The low power consumption allows the instrument to run continuously, with measurements routinely recorded (e.g. hourly) but with occasional higher rate sequences to characterize turbulent fluctuations, and with the option to record extra data on detection of changes. Measurement sets are tagged with an APID (application identifier) which allows adaptable downlink, with highest-priority data being sent first.

Conclusion: The TiME mission is presently in Phase A : MP3 transducers are undergoing qualification (e.g. radiation tests, soak tests in liquid ethane, operation in liquid nitrogen, etc.) for risk reduction and TRL maturation. If selected for implementation in summer 2012, TiME would launch in 2016 to arrive in 2023. The modular MP3 instrument architecture is intrinsically adaptable and can serve as a framework for meteorology or atmospheric structure packages on other missions. For the TiME application with ocean vehicle dynamics and sonar opportunities, APL's expertise in naval systems has been a useful adjunct to its space instrumentation capability.

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