It's About TIMED

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Abstract: For Centuries, scientists have realized that Earth's natural environment is greatly impacted by the abundance of solar energy striking the Earth from a constantly changing sun. Over the last few years, they have begun to realize that human activities are also playing a role in changing our environment. Up to now, scientists haven't had a benchmark against which future changes in Earth's upper atmosphere can be globally compared, analyzed or predicted because there are still portions of this solar-terrestrial chain, including regions within Earth's atmosphere, that are poorly understood. A 2-year mission, scheduled to begin in late 2001, in the National Aeronautics and Space Administration (NASA) Solar Terrestrial Probes Program, called TIMED (Thermosphere * Ionosphere * Mesosphere * Energetics and Dynamics), will study the influences of the sun and humans on the Mesosphere and Lower Thermosphere/Ionosphere (MLTI) atmospheric region which is located approximately 60-180 kilometers above the surface. This is the region where the sun's energy is first deposited into Earth's environment. The important elements of the TIMED mission include the 625-kilometer circular orbit, the 587 kg spacecraft with its suite of instruments, the mission operations ground system, and supporting science and engineering teams. TIMED will allow scientists to look, for the first time in detail, at composition changes in the upper atmosphere; acquire unique measurements of atmospheric cooling as gases radiate energy back into space; measure the primary energy that's deposited into the MLTI region; and measure the speed and direction of winds in this region. The Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, is responsible for the design, construction, integration, testing, and operation of the spacecraft.

Keywords: TIMED; Mesosphere; Lower Thermosphere/Ionosphere

1. INTRODUCTION

TIMED is the first of four missions in the Solar-Connections Program planned by the NASA's Space Physics Division. The Solar Connections Program is designed to study the Sun's variability and its influence on the Earth's space environment. TIMED is a two year atmospheric remote sensing mission which will study the influences of the sun and humans on the least explored and understood region of the Earth's atmosphere – the Mesosphere and Lower Thermosphere/Ionosphere, sometimes referred to as the MLTI region (Figure 1). The mission consists of a single spacecraft and four attached instruments which is scheduled to be launched in late 2001 on a Delta II into a 625-km circular orbit, inclined 74.1° with a 720° per year nodal precession.

Previous studies of the MLTI, which is located approximately 60-180 km above the surface, have been limited because it is difficult to reach. This atmospheric region is too high for balloons to reach and ground-based instruments can only see a small part of the atmosphere over the observation site. Rockets flown into the region can only provide local snapshots of its activity.

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) will build the TIMED spacecraft, lead the science effort, and conduct TIMED mission operations.

This paper is a brief discussion of the TIMED mission science, and includes an overview of the spacecraft and the mission operations.

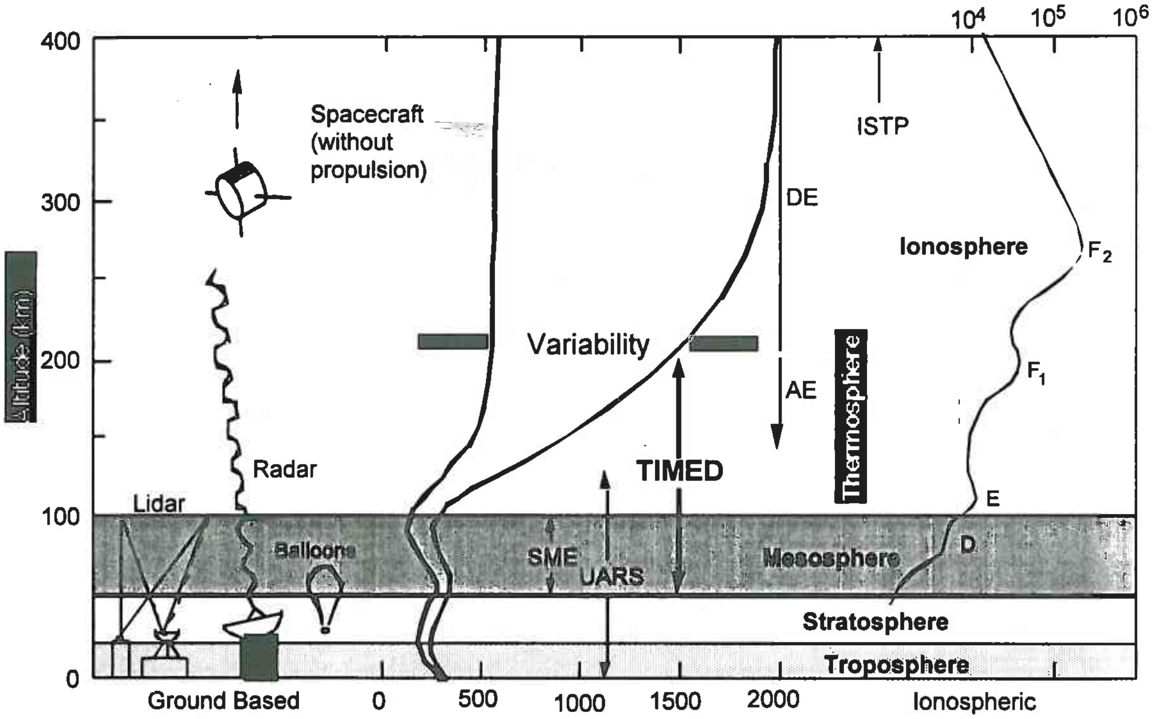

Figure 1. The Mesosphere and Lower Thermosphere/Ionosphere

2. SPACECRAFT OVERVIEW

The TIMED spacecraft (Figure 2) consists of a spacecraft bus and an instrument suite. The instrument suite is supported on-orbit by the spacecraft bus which provides power, thermal control, attitude control, current and predicted navigation (position, velocity, time) data, command control, data storage and science and engineering data downlink.

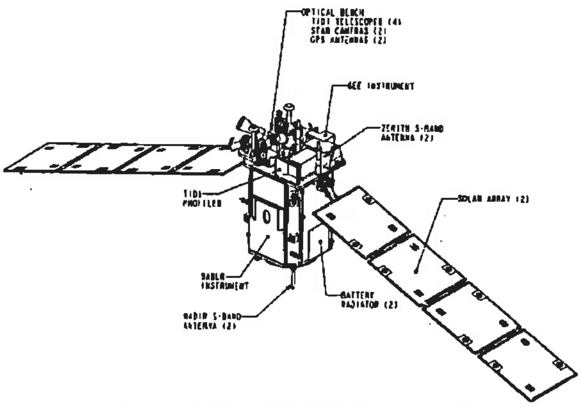

Figure 2. The TIMED Spacecraft

The 587-kg spacecraft bus is primarily an aluminum structure constructed of aluminum honeycomb panels. It is 3-axis stabilized with on-board autonomous GPS navigation. Two solar panel wings (GaAs cells) with single axis drive and nickel hydrogen battery provide the power for the various subsystems. The nominal flight attitude is nadir pointing with the attitude controlled to 0.5°. An attitude knowledge requirement of 0.03° is satisfied using two onboard star trackers. Figure 3 is a system block diagram of the spacecraft.

The four instruments that measure the basic state parameters and energy balance of the MLTI region of the atmosphere consist of the following:

- GUVI - The Global Ultraviolet Imager (GUVI) is a spatial spanning UV spectrograph designed to measure the composition and temperature profiles of the MLTI region, as well as high-latitude auroral energy inputs.
- TIDI - The TIMED Doppler Interferometer (TIDI) is a Fabry-Perot Interferometer which gathers light using four telescopes pointing +/-45 degrees from the velocity vector of the spacecraft TIDI measures the region's winds and temperature profiles.
- SABER - The Sounding of the osphere using Broadband Emission Radiometry (SABER) instrument is a multi channel radiometer designed to characterize infrared radiation, allowing calculation of cooling rates and determination of composition and temperature profiles in the lower altitude portion of the MLTI. SABER looks at the limb

perpendicular to the TIMED spacecraft orbit plane on the cold side of the spacecraft.

- SEE - The Solar Extreme-Ultraviolet Experiment (SEE) is a suite of photometers and spectrometer which views perpendicular to the orbit plane on the sunward side. It will measure solar X-ray, ultraviolet, and far ultraviolet radiation – the primary energy source of the MLTI region.

TIMED was initially integrated at APL, environmentally qualified at the Goddard Space Flight Center (GSFC), and will be launched from Vandenberg Air Force Base in California. TIMED will launch on a Delta II 7920 Medium Expendable Launch Vehicle.

The TIMED orbit provides the four TIMED instruments with global coverage and allows the orbit plane to precess such that measurements can be made of the MLTI region over all temporal zones (times of day). The rate of precession is selected to provide an integral number of precessions over a year so that the second year of measurements roughly parallels the measurements taken in the first year; this helps separate seasonal variations from other effects.

3. MISSION OPERATIONS

TIMED Mission Operations is required to:

- Plan and execute effective mission operations in accordance with the science objectives
- Command the spacecraft from launch to the end of the mission
- Collect, process, and transmit commands from the TIMED Mission operations center to the instruments.
- Collect all raw telemetry.
- Process all spacecraft health and status telemetry data and maintain the spacecraft.
- Assess spacecraft performance and adapt operations to changes.

- Collect all science data for processing and distribution to POCs.

These requirements are addressed using the TIMED Mission Operations System (Figure 3).

This system is comprised of four instrument payload operation centers (POC), a mission operation center (MOC), a mission data center (MDC) and a network of ground systems (GS). These elements are interconnected by commercial grade communications circuits. Internet/Ethernet protocols are employed throughout. The instrument POCs are located and operated by the instrument teams. The MOC and MDC are located at and developed by JHUAPL. The GS network is located strategically so as to provide adequate spacecraft to ground communications coverage to support mission requirements.

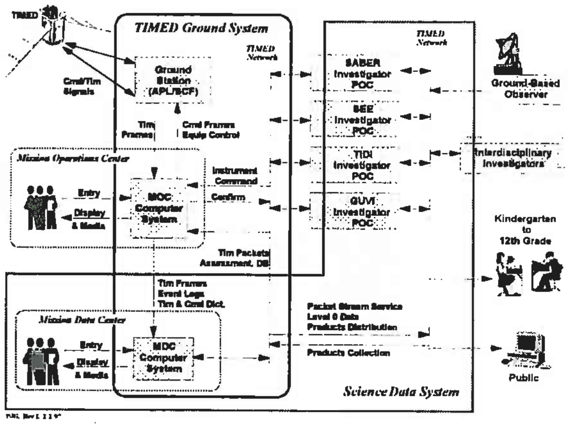

Figure 3. Mission Operation System

The POCs (SABER, SEE, TIDI and GUVI) are networked to science investigators, ground-based observers, and public users as well as to the operations network connecting the MOC and MDC.

4. MISSION SCIENCE

The goal of upper atmosphere research is to understand the chemistry, dynamics, and energy balances above the troposphere as well as the coupling between these processes and between the atmosphere regions. These important physical processes that couple energy and momentum from above and below into the MLTI region are depicted in Figure 4.

The Ionosphere-Troposphere-Mesosphere (ITM) system in the MLTI region provides the interface between interplanetary and lower-atmospheric processes (Figure 4). It absorbs the bulk of solar radiation and precipitating particle energies, and supports and distributes large electrical currents and potentials. It interacts with the incoming solar radiations and auroral particle precipitations, produces ionization, and provides the plasma to the magnetosphere above. It also couples to the troposphere and stratosphere below by large-scale circulation, atmospheric tides, and gravity waves, and lightening storms. Within the ITM system, its composition, wind structure, and thermal structure are inter-related and governed by the three basic laws of physics, namely conservations of mass, momentum, and energy. It is one of the most complex and significant regions for the study of solar terrestrial relations.

There has been increasing concern and interest in recent years about the variability, both natural and man-made, of the ITM system. Natural variability is introduced by the variable solar inputs and lower atmosphere wave inputs. The transport of "anthropogenically" produced minor species such as CO_2 and H_2O may cause the ITM system to experience first order change in its composition, temperature distribution and dynamics within the next two or three decades.

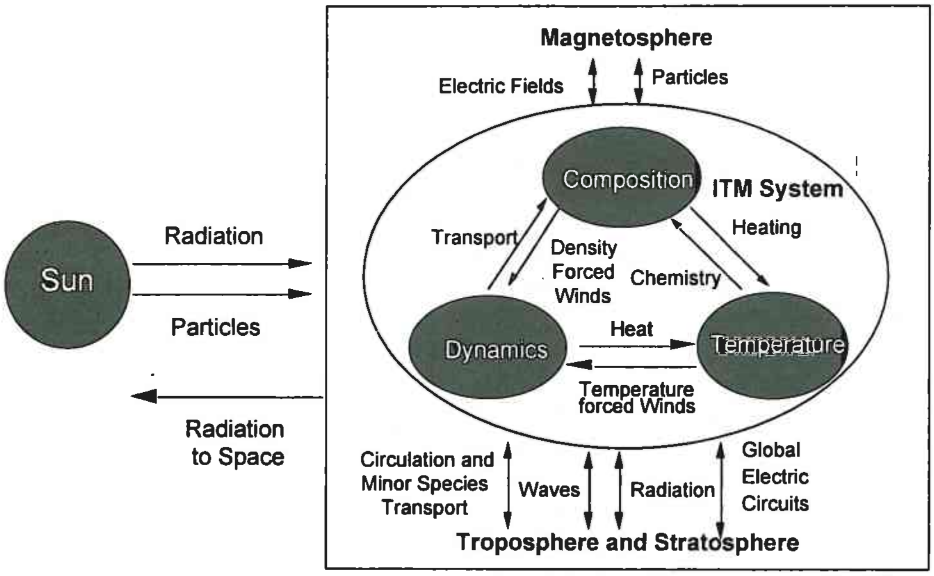

Figure 4. Solar Terrestrial Connections

The altitude region above 140 km, its composition, temperature structures, and photochemical chemical processes have been extensively studied by the Orbiting Geophysical Observatory (OGO) [Johnson, 1975] and Atmospheric Explorer (AE) series of satellite missions in the 60's and 70s. The Dynamics Explorer (DE) mission in the early 80s devoted to the understanding of the neutral and plasma dynamics in the region [Kramer, 19944]. The main interest of the Upper Atmosphere Research Satellite (UARS) mission is the chemical and dynamical processes of the stratosphere, especially those related to the ozone hole [Reber, 1993].

The knowledge about the region between 60 and 180 km is mainly obtained through the observations of groundbased optical and radar network and limited sounding rocket experiments. Global observations of this region are still lacking. The Solar Mesosphere Explorer (SME) is the only space mission dedicated to the study of the mesosphere. However, it is only limited to the observations related to the ozone photochemistry. Although much has been learned from these ground-based studies about the processes that control this region, relatively little is known about its global characteristics because atmospheric densities in the region are too great to allow long-term in situ satellite reconnaissance and because the geographical distribution of ground-based observatories is limited. The fundamental structures and energy balance in the region are still poorly understood [Johnson, 1995].

It was to fill this gap in knowledge that the TIMED mission was designed primarily to determine the temperature, density, and wind structure of the mesosphere/lower thermosphere/ionosphere (MLTI), and to determine the relative importance of the various sources and sinks of energy for the thermal structure of the MLTI. The main scientific objectives of this mission are the following:

- Basic Structure: To determine the temperature, density, and wind structure (state parameters) in the Mesosphere, Lower Thermosphere, and Ionosphere (MLTI) region (60-180 km), including the seasonal and latitudinal variations.
- Energetics: To determine the relative importance of the various radiative,

chemical, electrodynamical, and dynamical sources (input) and sinks (output) of energy for the thermal structure of the MLTI.

TIMED will support the continued development of models that specify and predict the state of the solar-terrestrial system. All of the measurement capabilities of the TIMED mission will be utilized

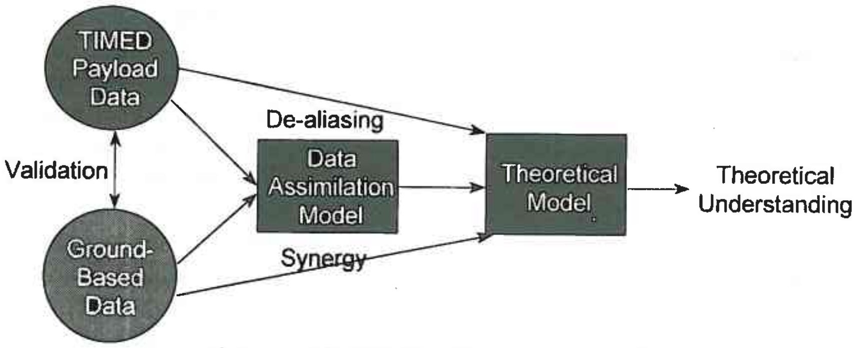

Figure 5. TIMED Investigative Approach

to provide inputs to these models or tests of the model outputs and will be incorporated into investigations of the impacts of solar and magnetospheric inputs on the MLTI system. To optimize the science output of the mission and provide important constraints on our theoretical models, TIMED observations will be combined with those from networks of spacebased and groundbased monitors of solar and magnetospheric energy and momentum inputs to construct the most complete picture possible of the interaction. The TIMED investigative approach is depicted in figure 5.

Different models are in different stages of maturity. Some are empirical, some are "physics based"; many are hybrids. Existing and Under-development models include Global electron [Khazanov, 1996.] and ion [Kozyra, 1982.] transport codes, extending from superthermal to relativistic energies, E-region ionosphere model [Rasmussen, 1988.] and MLTI neutral chemical models [J.L.Fox, www-personal.engin.umich.edu/~jukozyra/timed_ids.html]. This suite of models can be used to provide a bridge between geosynchronous observations of high-energy particles and observations by TIMED of their impacts on the MLTI region.

The electron & ion/neutral transport codes will be designed to accept as input TIMED and, when available, other spacecraft (e.g., NOAA, DMSP, SAMPEX, UARS, IMAGE, etc.) and ground-based (e.g., riometers, etc.) observations of energetic particles. They will produce global-scale patterns of neutral heating, ionization, minor species production, and excited chemistry.

To streamline the transport codes for computational speed, a version of the model is under development that does not solve for the full pitch-angle distribution of the particles but only deals with the omnidirectional flux at each altitude. This is all that is required to calculate the neutral heating, ionization, and minor species production. The streamlined version of the codes will be used for daily estimates of the energy deposition; the full code will be used for campaigns and event studies.

Besides providing information on temporal variations in the global scale heating, ionization and minor species production, these energy deposition models will supply large-scale inputs to global circulation models and atmospheric chemistry models in collaborative studies.

In the Space Weather Research Program, one significant modeling tool for the study of atmospheric density structure is National center for Atmospheric Research's Thermosphere-Ionosphere Electrodynamics General Circulation Models (TIEGCMs) which can self-consistently calculate density perturbations and neutral wind systems on a global, 3-D, time-dependent basis from physical principles [www.geo.nsf.gov/atm/nsup.htm].

As a first step in thermospheric nowcasting, empirical or semi-empirical models, exemplified by the Mass Spectrometer and Incoherent Scatter (MSIS) model, have been continuously improved and extended over the years. These models provide a critical first-order validation of any operational model and, indeed, can be used as such where high spatial resolution or time-dependency is not an issue. It is important to continue the development of these models that enable different data sets to be quantitatively reviewed and intercompared. Several operational models of thermospheric density and temperature, currently based on such semi-empirical models, reflect the mean behavior of the thermosphere as described by the large bodies of data from the various previous experimental programs. The semi-empirical or hybrid models use analytical functions to fit to randomly selected subsets of the available data, and spectral coefficients are generated that can be used conveniently to reconstitute thermospheric densities and temperatures as a function of space, time, and geomagnetic and solar activity levels.

The fully coupled thermosphere-ionosphere models being developed for nowcasting and forecasting will use a variety of prescriptions and parameterizations based on geophysical and solar indices to describe the thermospheric energy inputs and solve the coupled governing equations to calculate all the thermospheric state variables (temperature, density, composition, and wind) on a global time-dependent grid.

Data obtained during the TIMED mission will be available to the public and accessible through TIMED's Web site (www.timed.jhuapl.edu).

5. CONCLUDING REMARKS

TIMED is a tightly cost-capped mission, and it has been recognized from the beginning that this mission could only make a first step towards fulfilling these overall goals. Nevertheless, this mission as currently configured should provide the core subset of measurements that define, at least to first order, the basic state of the MLTI, but only the major parameters will be measured. Reduced to the most fundamental level, these parameters are the energy input, the energy output, and the major consequences of this energy exchange, namely temperature, winds, and density/composition.

The anticipated accomplishments of this program include the following:

- Complete the first exploration of the MLTI regions and establish the distribution and variability of the state parameters (Basic Structures).
- Examine the major energy sources (solar radiation, and auroral power inputs), transport processes (air motions and heat conduction) and energy sinks (chemically active and radiatively significant molecules) in this region, and apply this information to define the channels by which energy enters into, travels through, and is lost in the region (Energy Balance).
- Understand the influences of the sun and outer space on the Earth's middle/upper atmosphere and use this knowledge to increase our ability to predict space weather (e.g. satellite drag) (Space Weather).
- Provide a benchmark for the current state of the sensitive MLTI region for future studies of natural and human induced changes to the Earth's atmosphere, providing an avenue for early warning of global change (Anthropogenic Change).
- Supply knowledge of the upper atmospheric circulation pattern, important in the transport of chemically and radiatively active species (e.g. ozone).

6. ACKNOWLEDGEMENTS

TIMED is sponsored by NASA Headquarters, Office of Space Science and is managed by NASA's Goddard Space Flight Center. Appreciation is expressed to Dave Grant, the JHUAPL Project Manager and Dr. Jeng-Hwa Yee, the Project Scientist. Appreciation is also given to the instrument teams, the Mission Operation team and Integration & Test team.

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