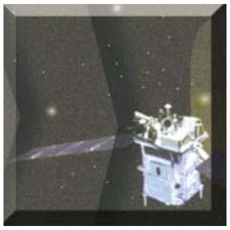

TIMED Instruments

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The Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) mission is providing a core set of measurements defining the basic states of the mesosphere and lower thermosphere/ionosphere (MLTI) region (approximately 60–180 km above the Earth's surface) and its global energy balance. This article discusses the TIMED spacecraft's suite of four remote sensing instruments designed to observe the parameters that define the atmospheric basic state and energy inputs and outputs in the MLTI. The Global Ultra-Violet Imager (GUVI) is a spatial scanning far-ultraviolet spectrograph that measures composition and temperature in the lower thermosphere, as well as auroral energy inputs. The Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument is an infrared radiometer that measures pressure, temperature, and infrared cooling rates in the stratosphere, mesosphere, and lower thermosphere. The Solar Extreme Ultraviolet Experiment (SEE) is a spectrometer and a suite of photometers measuring incoming solar irradiance. The TIMED Doppler Interferometer (TIDI), a Fabry-Perot interferometer, measures horizontal vector winds and composition in the mesosphere and lower thermosphere.

TIMED SCIENCE AND MEASUREMENT OBJECTIVES

NASA's TIMED mission[1] is designed to study the mesosphere and lower thermosphere/ionosphere (MLTI), the least understood and least explored region of the Earth's atmosphere. The MLTI, located approximately 60 to 180 km above the Earth's surface, is the region where energetic solar radiation is absorbed, energy input from the aurora maximizes, intense electrical currents flow, and upwardly propagating waves and tides break. Since these different forms of energy input are highly variable both spatially and temporally, the basic structures of the MLTI (i.e., density, wind, and pressure) exhibit large variability as well. Yet this region has never been the subject of a comprehensive, long-duration, global investigation. The MLTI is too high for probing by balloons and too low for direct *in situ* measurements by long-lived satellites without onboard propulsion. Ground-based systems and sounding rockets can only study small portions of the MLTI. As a result, the atmospheric research community still lacks the global measurements needed for a detailed understanding of the processes that govern the variability of the region's basic structure.

The suite of instruments on the TIMED spacecraft provides the first systematic measurements required to determine (1) the temperature, density, and wind structures in the MLTI as well as their seasonal and latitudinal variations, and (2) the relative importance of various radiative, chemical, electrodynamic, and dynamic sources and sinks of energy in the region. With these benchmark measurements, scientists will be able to understand quantitatively for the first time how the Sun from above and atmospheric disturbances from below affect the MLTI.

The primary objectives of the TIMED mission are to investigate and understand the basic structure and energy balance of the MLTI region. The TIMED spacecraft uses its four remote sensing instruments to obtain simultaneous measurements of state variables and the energy inputs and outputs of the MLTI. The mission also includes 14 ground-based investigations that provide local measurements using a variety of optical and radar instruments. These ground-based measurements yield the needed validation for the spaceborne instruments as well as complementary and supplementary data for collaborative scientific studies.

This article describes the TIMED instruments and their measurement capabilities (Table 1). The Solar Extreme Ultraviolet Experiment (SEE) consists of a spectrometer and a suite of photometers that provide measurements of solar X-ray and extreme ultraviolet (EUV) irradiance.[2] The Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument is a 10-channel infrared radiometer that measures the pressure, temperature, key gases, and infrared cooling rates in the stratosphere, mesosphere, and lower thermosphere.[3] The Global Ultra-Violet Imager (GUVI) is a spatial scanning UV spectrograph that measures the thermospheric composition and temperature, as well as the auroral particle energy input.[4] The TIMED Doppler Interferometer (TIDI) is a single-etalon, Fabry-Perot interferometer that measures horizontal vector winds in the mesosphere and lower thermosphere.[5] (Details of the TIMED mission, including participants, status, science, etc., may be found at http://www.timed.jhuapl.edu/mission/.)

MEASUREMENT CAPABILITIES OF THE TIMED INSTRUMENTS

GUVI

The GUVI instrument (Fig. 1) supports the TIMED mission science objectives to determine the

- Spatial and temporal variations of constituent number densities and temperature in the thermosphere
- Relative importance of auroral inputs, Joule heating, and solar EUV for the thermal structure of the lower thermosphere

GUVI is a spatial scanning imaging spectrograph designed to observe the sources of the far ultraviolet (FUV) airglow emissions in the Earth's upper atmosphere.[1] It is designed to provide cross-track scanned images of these FUV emissions at wavelengths ranging from 115 to 180 nm, including the major emission features of hydrogen's (H) Lyman-α line, atomic oxygen

Table 1. TIMED instrument measurement summary.

Instrument	Prinicipal Investigator	Objective	Measurement
GUVI	Andrew Christensen Aerospace Corporation	State variables	Daytime thermospheric temperature, O, N_2, O_2, and O/N_2 column density ratio; low-latitude nighttime electron density profiles
		Energy inputs	Precipitating particle energy and fluxes and Qeuv, a proxy of solar EUV irradiance
SABER	James Russell III Hampton University	State variables	Temperature, pressure, density; O_3, H_2O, CO_2, O, and H mixing ratio profiles
		Energy inputs and outputs	Heating rates from reactions involving O, H, and O_3; cooling rates from CO_2, O_3, NO, and H_2O
SEE	Thomas Woods University of Colorado	Energy inputs	Solar soft X-ray, EUV, and FUV irradiance from 0.1 to 195 nm
TIDI	Timothy Killeen National Center for Atmospheric Research	State variables	Horizontal vector winds

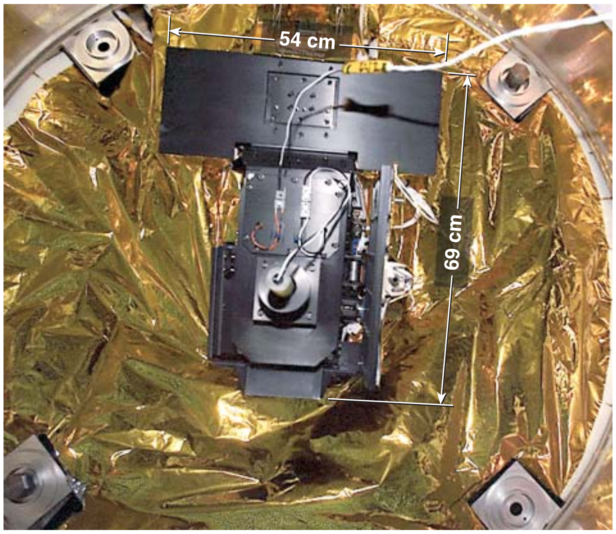

Figure 1. The Global Ultra-Violet Imager, GUVI, is located on the bottom (nadir-viewing) surface of the spacecraft, inside the adapter ring, the mechanical interface to the launch vehicle.

(O) emission lines, and molecular nitrogen (N_2) Lyman-Birge-Hopfield (LBH) bands. The instrument uses a microprocessor-controlled cross-track scan mirror to sweep its 11.78° field of view through an arc of up to 140° in the plane perpendicular to the orbital plane, beginning 60° from nadir across the Earth's disk and through the limb on the anti-sunward side of the satellite (Fig. 2). The field of view is imaged via an *f*/3 Rowland circle spectrograph into a two-dimensional microchannel plate intensified wedge-and-strip anode detector with 14 spatial and 160 spectral "pixels." A detector processor bins the spectral data into five selected spectral bands, or "colors," (H at 121.6 nm, O at 130.4 and 135.6 nm, and N_2 at 165 and 185 nm) every 0.034 and 0.062 s on the limb and disk, respectively. With its cross-track scanning capability, GUVI obtains a two-dimensional disk image (a spatial resolution of ≈8 km at the nadir, and swath width of ≈3000 km) and a limb brightness profile at these five selected spectral colors every ≈15 s.

A typical GUVI orbit includes day, night, and auroral observations. Successive orbits provide overlapping coverage at the poles and nearly contiguous coverage at the equator. GUVI monitors three general regions on each orbit: the daytime low- to mid-latitude thermosphere, the nighttime low- to mid-latitude ionosphere, and the high-latitude auroral zone.

The instrument's data products are maps of the characteristics of the ionosphere and thermosphere, including maps of the auroral oval, the characteristic energy and flux of the electrons that excite it, F-region (≈160–400 km) ionospheric electron density profiles, and dayside neutral composition information.

GUVI is the first instrument from space to simultaneously provide systematic high spatial resolution measurements of high-latitude auroral particle characteristics and to monitor thermospheric composition changes on a global scale.

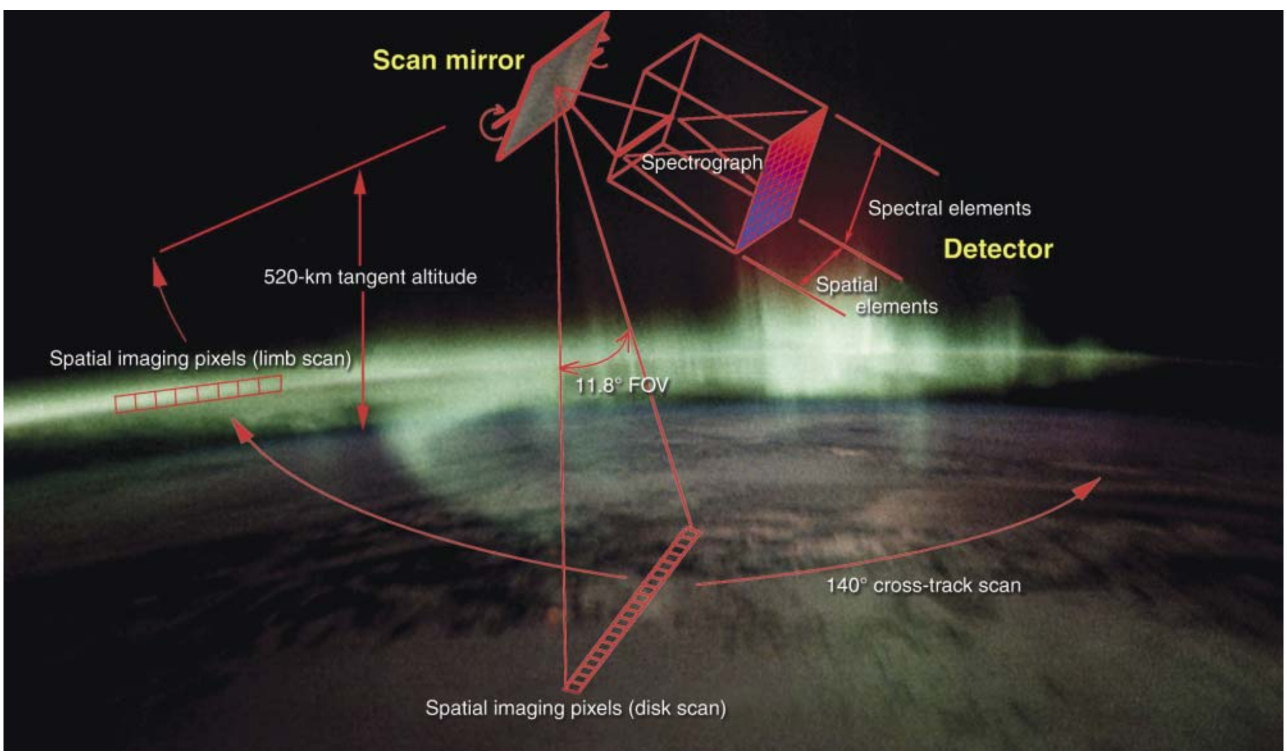

Figure 2. GUVI scans across the Earth's disk and onto the limb (five colors are sent down), providing column density and auroral particle information on the disk and altitude profiles on the limb (FOV = field of view).

SABER

The SABER instrument (Fig. 3) supports the TIMED mission objectives to determine the

- Spatial and temporal variations in the density and temperature structure of the mesosphere and lower thermosphere
- Relative importance of various atmospheric heating and cooling mechanisms
- Roles played by key chemically and energetically important chemical species

SABER is a 10-channel radiometer that is designed to measure infrared Earth limb emissions. The instrument telescope is a Cassegrain design with a picket-fence tuning fork chopper at the first focus and a clam-shell re-imager to focus the image on the focal plane. The telescope has been designed to reject stray light from the Earth and atmosphere outside the instrument's instantaneous field of view (IFOV). The baffle assembly contains a single-axis scan mirror that permits the 2-km vertical IFOV of each detector to be scanned from the Earth to a 400-km tangent height. Accurate vertical registration of the tangent height of the data in the atmosphere is achieved by analysis of the 14.9- and 15.2-μm CO_2 channels. The telescope and baffle assembly are cooled to 240 K by a dedicated radiator. The focal plane assembly, consisting of a filter array, a detector array, and a Lyot stop, is cooled to 75 K by a miniature cryogenic refrigerator. The detector array contains discrete HgCdTe, InSb, and InGaAs detectors. The conductive heat load on the refrigerator is minimized by a Kevlar support system that thermally isolates the focal plane assembly from the telescope. The telescope is supported and thermally isolated from the instrument base plate by a glass composite structure. The cryogenic refrigerator and electronic heat load is dissipated to space by the plate radiator. Drifts in instrument responsiveness due to changes in telescope and focal plane base temperatures as well as other causes are corrected by an in-flight calibration system.

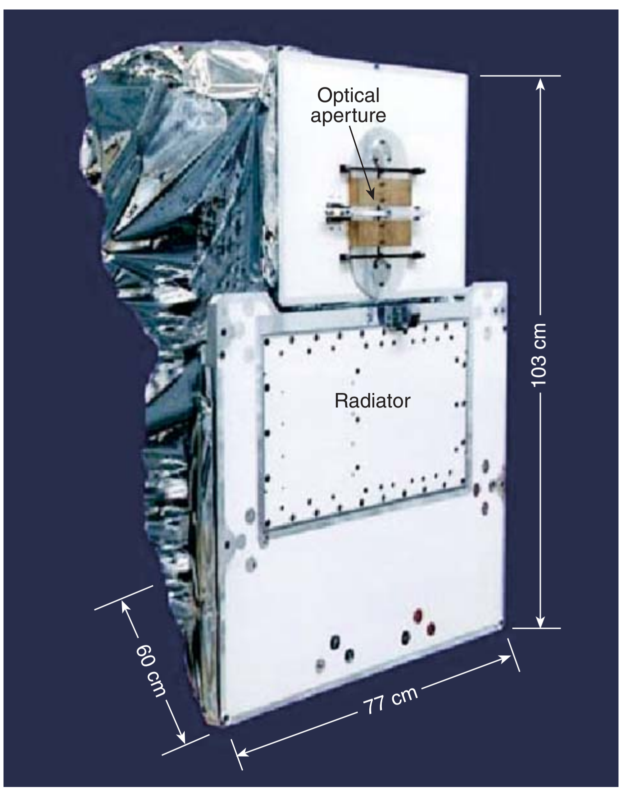

Figure 3. The Sounding of the Atmosphere using Broadband Emission Radiometry, SABER, is located on the cold (anti-sunward) side of the spacecraft.

The technique that SABER is using on TIMED to "sound" or measure the atmosphere has never before been used to study the MLTI region in such detail. Once every 58 s, SABER scans up and down the Earth's horizon, collecting data over an altitude range from approximately 180 km down to the Earth's surface. It measures key infrared emissions originating from the atmosphere from 1.27 to 15.4 μm. Among them, CO_2 15.4-μm and NO 5.3-μm emissions are key atmospheric cooling agents in the mesosphere and lower thermosphere, respectively. Based on the thermal emission characteristics of its measured CO_2 15.4-μm emission, SABER provides atmospheric temperature measurements critically needed to study atmospheric momentum and energy balance. In addition, SABER measures the vertical distributions of molecular constituents (e.g., ozone, water vapor) that are important for their direct role in solar photon energy absorption and their indirect role in chemical reactions involving energetically important chemical species. Over the course of one orbit, SABER observes the polar region in one hemisphere to the high latitudes in the opposite hemisphere; over the course of a day, it makes measurements covering 15 longitude bands; and over the course of the mission, the instrument is assembling a global picture of how the MLTI region is changing with latitude, longitude, altitude, and time.

SABER is the first instrument from space to provide systematic global measurements of atmospheric density and temperature as well as key atmospheric heating and cooling rates. These phenomena are critical for an understanding of the relative importance of various atmospheric momentum and energy sources and sinks.

SEE

The SEE instrument (Fig. 4) supports the TIMED mission by providing the irradiance of the highly variable solar EUV radiation, one of the major energy sources for the upper atmosphere. The SEE observational system includes two instruments, the EUV Grating Spectrograph (EGS) and the X-ray Photometer System (XPS), designed to measure the full-disk solar

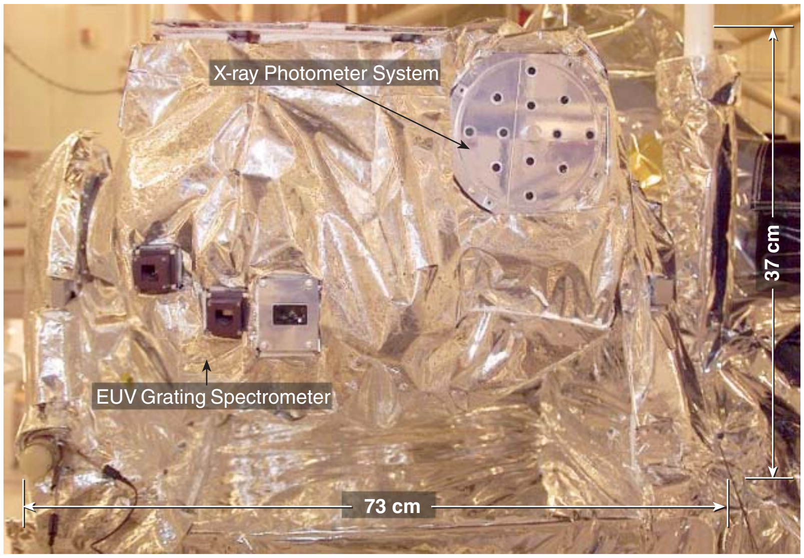

Figure 4. The Solar Extreme Ultraviolet Experiment, SEE, is mounted on the top deck of the spacecraft in a solar-viewing orientation.

vacuum ultraviolet (VUV) spectral irradiance from 0.1 to 200 nm.

The EGS is a normal-incidence 1/4-m Rowland circle design with a 64 × 1024 Codacon microchannel plate detector (with a coded anode position array) so that a complete spectrum can be obtained in a few seconds with the grating fixed. It has two slits so that both the grating and detector are illuminated on two separate areas. One illumination configuration is used for daily measurements and the other for weekly calibration checks and possible degradation correction. The EGS's spectral coverage is 25 to 195 nm (0.17-nm bandpass per anode) and its effective spectral resolution is 0.4 nm. This moderately high resolution is important for resolving blended lines such as the H I Lyman-β (102.6-nm) and O VI (103.2- and 103.8-nm) lines. To maximize the efficiency at the shortest wavelengths, the grating has a gold coating with sufficient reflectivity down to 25 nm.

The XPS consists of a set of nine silicon photodiodes (metallic thin films are deposited directly on the diodes) and is designed to measure the full-disk solar soft X-ray spectral irradiance at several fixed spectral wavelengths. It provides solar irradiance measurements from 0.1 to 35 nm, with each photometer having a spectral bandpass of 5 to 10 nm. An additional filtered photometer is a bare X-ray ultraviolet photodiode with Acton Lyman-α filters for a redundant measurement of the important Lyman-α irradiance.

The SEE instrument uses a one-axis pointing platform; its solar sensors are designed to let the Sun drift through their fields of view once per orbit (about 3 min per orbit while the Sun is in full view). When possible, SEE also views the Sun as it sets through the atmosphere and determines the atmospheric density through the amount of solar radiation absorption.

The principal SEE data product is a daily averaged solar irradiance spectrum in 1-nm intervals on 0.5-nm centers. In addition, the irradiances of about 50 bright emission features are listed as part of this SEE product. Data collected from SEE's observations of the Sun show where the solar energy, or radiation, originates as a function of wavelength and how each wavelength varies with time.[6]

Solar radiation below 200 nm is completely absorbed in the Earth's mesosphere and thermosphere. Changes in the amount of solar radiation within an 11-year solar cycle, ranging from ≈20% at the longer wavelengths to factors as much as 1000 at the shorter wavelengths, can result in significant changes in the photochemistry, dynamics, and energy balance of the MLTI region. In addition to changes associated with the 11-year solar cycle variability, a detailed quantitative understanding of atmospheric responses to changes in the solar energy inputs arising from flares and solar rotation (27 days) is fundamental to the TIMED investigations. The daily measurement of the full-disk solar VUV irradiance by SEE directly supports the TIMED mission requirement.

TIDI

TIDI (Fig. 5) supports the TIMED mission by providing global measurements of the horizontal winds in the MLTI region. It determines the speed and direction of winds in the atmosphere by measuring tiny changes in the color of light emitted from some specific chemical constituents in the atmosphere such as atomic oxygen and molecular oxygen. TIDI uses these changes in color the way a change in pitch from a passing ambulance's siren helps determine its speed.

The TIDI instrument comprises three major subsystems: four identical telescopes, a single-etalon Fabry-Perot interferometer with a charge-coupled device (CCD) detector, and an electronics box. Light from the selected regions of the atmosphere is collected by the telescopes and fiber-optically coupled to the detection optics. The four fields of view are scrambled along with a calibration field input and converted to an array of five concentric circular wedges. This input passes through a selected filter and the Fabry-Perot etalon, and is finally imaged onto a CCD via a circle-to-line imaging optic (CLIO) device. The filter wheels for TIDI contain a complement of 14 interference filters that are carefully chosen to allow full daytime/nighttime latitudinal and altitudinal coverage of neutral wind measurements throughout the MLTI.

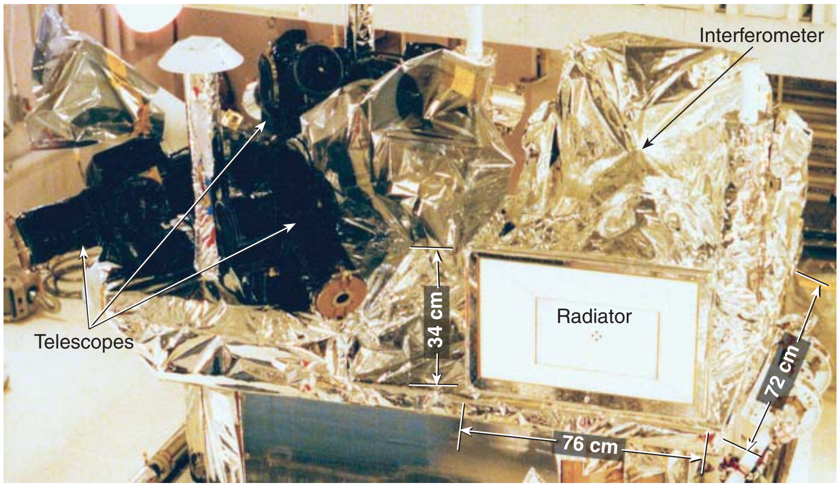

Figure 5. The TIMED Doppler Interferometer, TIDI, is mounted on the top deck but has a field of view outward from the sides of the spacecraft perpendicular to nadir (one of the four telescopes is not visible in this photograph).

The TIDI Fabry-Perot interferometer provides the spectral brightness of the atmospheric airglow emission lines at a very high spectral resolution using the four telescopes that perform limb scans through the terrestrial airglow layers throughout the spacecraft's orbit. It obtains these scans simultaneously in four orthogonal, azimuthal directions: two at 45° forward but on either side of the spacecraft's velocity vector and two at 45° rearward of the spacecraft (Fig. 6). These four views provide the measurements necessary to construct the horizontally resolved vector winds as a function of altitude within the MLTI region along two parallel tracks, one on either side of the spacecraft. Each vertical scan consists of individual views of the limb at 2.5° (horizontal, along the limb) × 0.05° (vertical, normal to the limb) angular resolution or at 125.0 × 2.5 km spatial resolution. The altitude step size ranges from 2.5 km in the mesosphere to 25.0 km in the thermosphere. Each up/down acquisition cycle takes about 100–200 s to complete, resulting in a nominal horizontal spacing between profiles of approximately 750 km along the orbit track. The exact time per vertical scan depends on the data collection mode being run and the integration or dwell time needed at each altitude step.

The TIDI instrument provides vector wind measurements that are critical for an understanding of how the chemical species are transported and how the solar and auroral energies absorbed in the atmosphere are redistributed spatially.

SUMMARY

TIMED has been successfully conducting its mission for over 1.5 years now. Since January 2002, the beginning of its data collection phase, TIMED and its ground-based partners have collected an unprecedented global observational data set of the MLTI basic structure, as well as simultaneous measurements of the solar energy inputs and atmospheric radiative outputs. Figure 7 summarizes the TIMED combined measurement capabilities of the four payload instruments and the ground-based instrument suite. In order to understand atmospheric structure and the processes governing its variability, it is essential that momentum and energy balances at any geographical location under any geophysical condition are fully understood. TIMED is the first mission to provide the critical simultaneous systematic measurements of pressure, density, temperature, and winds necessary to understand MLTI momentum balance. TIMED is also the first mission to provide simultaneous measurements of energy inputs and outputs along with the state variables necessary to understand MLTI energy balance. Although TIMED is only slightly over 1.5 years into its mission, it is well on its way to meeting its scientific goals.

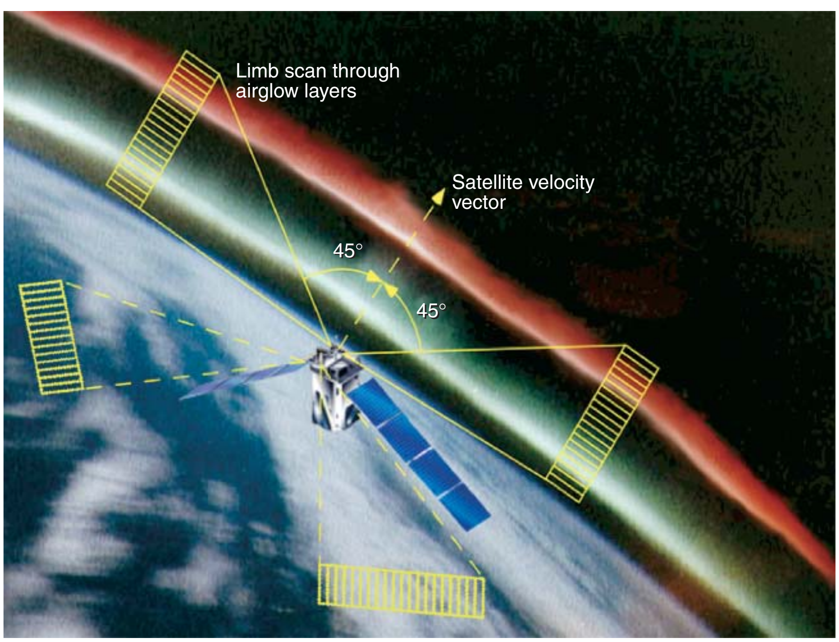

Figure 6. TIDI views in four orthogonal directions, two at 45° on either side of the forward velocity vector and two at 45° on either side of the rearward direction.

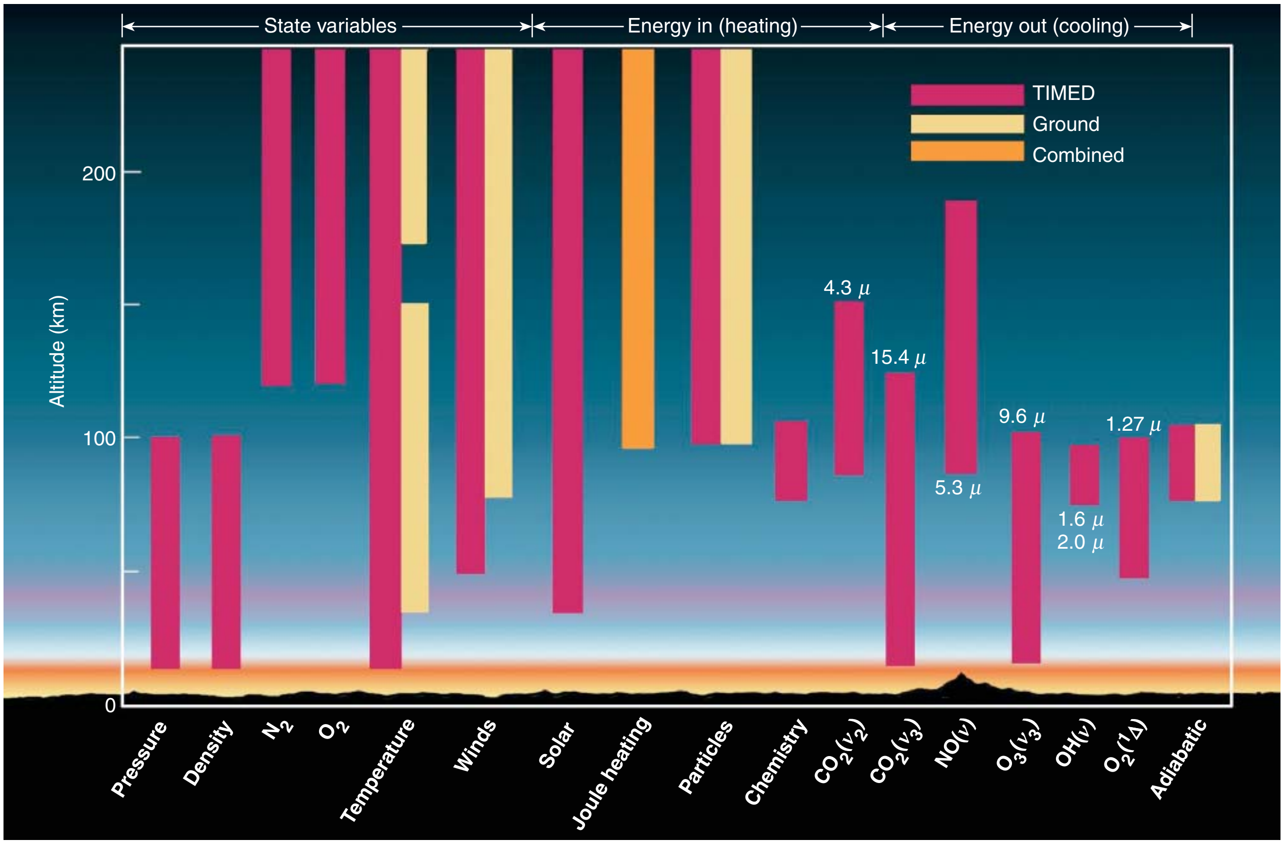

Figure 7. TIMED satellite and ground-based measurement coverage in altitude. Cooling results from radiative emissions through electronic and/or vibrational relaxations; ν refers to vibrational states and $O_2(^1\Delta)$ is an electronically excited state of O_2.

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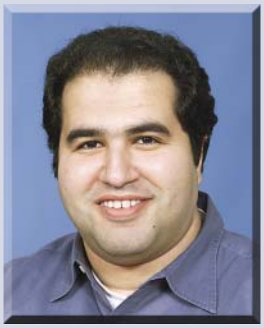

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