The atmosphere-space interactions monitor (ASIM) for the international space station

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Abstract. The Atmosphere-Space Interactions Monitor (ASIM) is an instrument suite to be mounted on an external platform on the International Space Station (ISS). ASIM will study the coupling of thunderstorms processes to the upper atmosphere, ionosphere and radiation belts and energetic space particle precipitation effects in the mesosphere and thermosphere. The scientific objectives include (1) investigations into sprites, jets, elves and relativistic electron beams injected into the magnetosphere above thunderstorms, (2) studies of gravity waves in the thermosphere above severe thunderstorms, (3) lightning-induced precipitation of radiation belt electrons, (4) auroral electron energetics, and (5) ozone and NOx concentrations in the upper atmosphere. The instruments are 4 TV frame-rate, narrow-band, optical cameras and 4 photometers viewing towards the limb, and an X-ray sensor, 2 cameras and 2 photometers viewing towards the nadir. ASIM is currently in Phase A.

Index Terms. Airglow and aurora, particle precipitation, atmospheric electricity, mesospheric dynamics.

1. Introduction

The mesosphere and lower thermosphere are the regions of the atmosphere about which the least is known. They are too low for *in situ* spacecraft observations, too high for balloon observations, and remote sensing is hampered by low densities and a high degree of variability over a range of temporal and spatial scales. As a consequence, these regions have received less attention than more readily accessible regions above and below. In many respects, the mesosphere and lower thermosphere represent an uncharted "frontier" for upper atmospheric science. The Atmosphere-Space Interactions Monitor (ASIM) will study the interaction of thunderstorms with the upper regions of the atmosphere – reaching into the ionosphere and magnetosphere and energetic space particle radiation effects on the thermosphere and mesosphere.

Thunderstorm-driven processes studied include the newly discovered Transient Luminous Emissions (TLES). The most commonly observed from ground is the "sprite", a manifestation of electrical break-down in the mesosphere. Other classes include the "blue jet", a discharge propagating upwards into the stratosphere from cloud tops, and the "elve", a concentric ring of emissions from neutrals excited by a lightning EMP at the bottom edge of ionosphere. Observations have further documented giant discharges creating electrical breakdown of the atmosphere from the top of thunderstorms to the bottom ionosphere (Pasko et al., 2002; Su et al., 2003). The pantheon of the most commonly observed emissions of the upper atmosphere, also referred to as "Transient Luminous Events" (TLEs), is shown in Fig. 1.

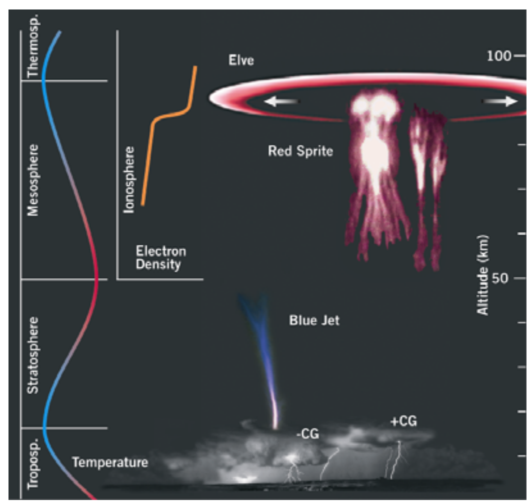

Fig. 1. The anatomy of upper atmospheric flashes (*Neubert*, 2003).

Within the past decade, a different, but possibly related, category of flashes has been discovered. These are the Terrestrial Gamma-ray Flashes (TGFs) from the atmosphere above thunderstorms, first recorded from the Compton Gamma Ray Observatory (CGRO) satellite (Nemiroff et al., 1997). TGFs are of a few msec-duration with energies from ~100 keV to beyond 1 MeV. More recent observations are now available from the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) satellite launched in 2002, which is detecting 10 to 20 TGFs per month with energies up to 20 MeV. This rate of observations is much higher than CGRO (75TGFs/9years) because of a better suited triggering algorithm. It suggests an average global TGF rate of ~50 per 24 hours (Smith et al., 2005). The distribution of events over a 2-month period (satellite ground track position) is shown in Fig. 2 on top of a color coded representation of the average global lightning activity. The distribution is correlated with thunderstorm activity except over the Americas.

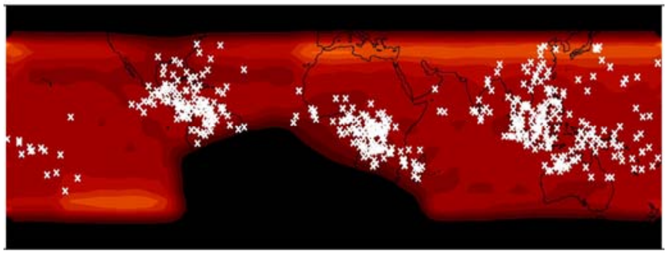

Fig. 2. RHESSI observations of TGFs. (Smith, personal communication).

The run-away electron discharge is suggested in lightning, sprites and TGFs (Roussel-Dupré and Gurevich, 1996; Gurevich et al., 1999). Evidence for the process builds on X- and γ-rays associated with thunderstorm charging/discharging measured from balloons, mountain tops, and in rocket-induced lightning (Parks et al., 1981; McCarthy et al., 1985; Eack et al., 1996; Dwyer et al., 2004a,b; 2005). Simulations of sprites indicate that 10^6-10^7 electrons/cm^2, accelerated in the ~100 MV potential between cloud tops and the ionosphere following a lightning discharge, are injected into the magnetosphere (Lehtinen et al., 1997). Thunderstorms also provide a sink of radiation belt electrons. It is well known, that lightning produced whistler waves may scatter energetic electrons into the loss-cone (Voss et al., 1998). LEPs and sprites are observed in perturbations of ground transmitter signals induced by patchy changes in plasma densities of the lower ionosphere (Haldoupis et al., 2002).

Sparked by the discovery of TLEs and TGFs, our understanding of fundamental processes related to atmospheric electricity and energetic charged particle effects are under re-evaluation (Arnold and Neubert, 2002). It is now understood that thunderstorms in the troposphere couple to the stratosphere, mesosphere and the near-earth space through electric fields, energetic charged particles, and gravity waves, and that precipitating charged particles from space, such as auroral and radiation belt particles and cosmic rays, couple to the atmosphere. The current research efforts into the perturbation of the atmosphere induced by these processes further support the view, also put forward in other areas of atmospheric research, that global models of atmospheric chemistry and circulation, for proper representation of the dynamics, must include all atmospheric layers reaching from the surface to the ionosphere. An in-depth understanding of the newly discovered TLEs and TGFs holds the additional promise of improving our knowledge of the regions in which they occur – the mesosphere – the least known region of the atmosphere.

2. ASIM scientific objectives

The goal of the mission is to advance our understanding of electrical- and energetic charged particle effects on the stratosphere, mesosphere, and lower thermosphere. The Research Objectives (RO) of the mission are given below.

Primary objectives based on observations:

- RO1: A comprehensive global survey (lat, UT, season) of TLEs and TGFs rates.
- RO2: Study the physics of TGFs and their relationship with TLEs and thunderstorms.
- RO3: Study the physics of TLEs.
- RO4: Determine the characteristics that make thunderstorms TLE- and TGF-active.
- RO5: Study the coupling to the mesosphere, thermosphere and ionosphere of thunderstorms and TLEs.
- RO6: Study the effects of thunderstorms and TGFs on the Earth’s radiation belts

Primary objectives based on modeling:

- RO7: Quantify chemical effects of TLEs, TGFs and energetic particle precipitation on the stratosphere, mesosphere, and lower thermosphere
- RO8: Quantify effects of TLEs and TGFs on the atmospheric electric circuit
- RO9: Quantify perturbations to atmospheric dynamics from thunderstorms, TLEs, TGFs, and energetic particle precipitation

Secondary objectives based on observations:

- RO10: Auroral spectroscopic studies with high- temporal and spatial resolution imaging
- RO11: Studies of greenhouse gas concentrations above thunderstorms (NOx, O_3)
- RO12: Studies of meteor ablation in the mesosphere and thermosphere

RO 1-6 establish the foundation for answering questions relating to the basic physics of TLEs and TGFs and their global occurrence rates as a function of season and local time. This information is needed in order to estimate perturbations to the chemical and electrical properties of the atmosphere induced by the emissions contained in RO 7-8. The estimates are based on models of the global electric circuit to be refined during the project, and on chemical models of effects from energetic particle precipitation from space primarily at high latitudes adapted for the study of TLEs and TGFs. Both electrical and chemical properties may affect the radiation properties and thus the dynamics of the atmosphere. This aspect as studied in RO 9 by means of local and global modeling of the atmosphere.

3. ASIM mission scientific requirements

The primary research objectives of the mission require the following measurements:

RQ1: Optical detection of TLEs with high spatial- and time resolution in selected spectral bands (detailed below). The requirement is met by optical imaging cameras with the required spatial resolution and photometers with the required time resolution. The instruments must view towards the Limb.

RQ2: X- and γ-ray detection of TGFs with high time resolution and at photon energies reaching down to 10keV (detailed below). The requirement is met by a detector with the required sensitivity and time resolution. Viewing must be towards the Nadir in order to minimize atmospheric absorption.

RQ3: Simultaneous optical detection of thunderstorm- and TLE activity with TGF activity. The optical instruments must view with the X- and γ-ray detector towards the Nadir.

RQ4: Observations from space during minimum one year at all local times to observe seasonal and local time variations in thunderstorm-, TLE-, and TGF activity.

The optical instruments make up the Miniature Multi-spectral Imaging Array (MMIA) of 3 modules each housing 2 video-rate cameras and two photometers. Two modules view in the ram-direction towards the limb and one module towards the nadir. A Miniature X- and Gamma-Ray sensor (MXGS) view towards the nadir.

The bands of interest for optical observations are shown in Table 1. The electron energy shown (band 1, 2, 4) is the minimum energy of the free electrons sampled by the selected band. Band 1 and 2 are selected because they are relatively simple to interpret in terms of electron energetics and ionization, but difficult to observe from the ground because of UV absorption in the atmosphere. Band 4 covers the spectral range of maximum sprite emission rate. Band 3 is one of the brightest airglow emission lines and comes from a layer around 90 - 100km altitude. Their intensity is modulated by gravity waves. The limb-viewing geometry is best for TLE observations, while the nadir module is needed to correlate lightning and TLE activity with MXGS observations of TGFs.

Table 1. Optical Bands for Cameras and Photometers. The Limb-Instrument Point towards the Ram-Direction

No.	B/ ΔB (nm)	Transition	Process	Pointing	Instrument
1	337/10	N_2(2P)	11.1eV	Limb, Nadir	Cam/Phot
2	391/5	N_2^+(1N)	18.5eV	Limb	Cam/Phot
3	762/5	O_2(0,0)	Grav.w.	Limb	Cam
4	650..800	N_2(1P)	7.5eV	Limb, Nadir	Cam/Phot
5	TBD	TBD	NOx	Limb	Phot

The optical bands are well known in auroral research. Thus ASIM provides an opportunity to observe aurora during magnetic storms when the auroral oval extends to low latitudes covered by the ISS (51.6^o inclination). The aurora is first seen by the Limb instruments pointing in the ram-direction – then during overflight by the nadir instruments. Further specifications of the optical instruments are shown in Table 2.

Table 2: Optical Instrument Specifications

Cameras	FOV [deg]	Lens [mm]	Pixels XY	Pixel-res [km]	Frame-rate [Hz]
Limb	20	50	1000	0.6-0.8	25
Nadir	80	11	1000	0.7	25
Photometer					**Sample-rate [kHz]**
Limb	20	TBD			10
Nadir	80	TBD			10

The MXGS instrument is a ~550 cm^2 detector of CdZnTe crystals sampling the energy range ~10-500keV. The energy range is chosen to sample the range affected by atmospheric absorption and thus sensitive to the altitude of TGF generation. This range is also well suited to study auroral processes and lightning-induced electron precipitation.

The ASIM instruments are baselined for the external platforms of the European Space Agency (ESA) laboratory module, Columbus. The module is scheduled for launch in 2007 and ASIM is scheduled for 2009. Should shuttle launches not be available for ASIM, the modular design of the payload will allow for a launch on the European Automated Transfer Vehicle (ATV) or the Russian Progress. Likewise, ASIM can be adapted to the Russian (or other) external platforms available on the ISS. Fig. 3 shows the ASIM instruments on the adaptor plate used for the Columbus module.

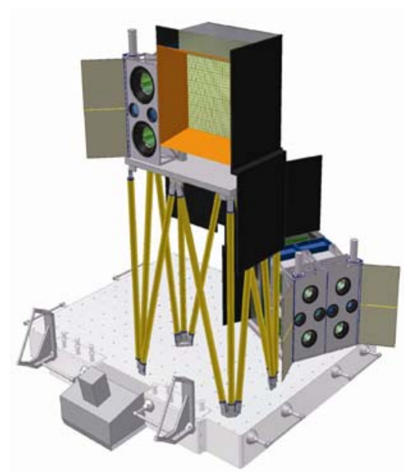

Fig. 3. The ASIM payload.

4. ASIM for the ILWS programme

The secondary science objectives are met by the instruments required for the primary science objectives. Optical and x-ray measurements are used to study aurora, differential absorption of light emissions from lightning-illuminated thunderstorm clouds measured by photometers defines ozone column densities, NOx production in TLEs is to be monitored by photometer 5, and optical imaging and photometers will be used to study meteor ablation.

Of primary interest to the ILWS programme are the auroral studies. The measurements include imaging in 4 auroral bands simultaneously, coupled with high time-resolution photometer observations and X- and γ-ray observations. The inclination of the ISS orbit at 51.6^o brings the instruments over the auroral oval during periods of high solar (geomagnetic) activity when the auroral oval expands to lower latitudes. These are also periods with high auroral activity. The aurora is first seen towards the limb in the ram-direction (the direction of the ISS velocity vector) in 4 optical bands and then in the nadir direction in to optical bands and in the x- and gamma-ray band as the ISS passes over the aurora. Fig. 4 shows the aurora from the space shuttle in the limb-viewing geometry.

Fig 4. The aurora seen from the space shuttle (Hallinan).

Of particular interest are passes over Canada, where the auroral region extends to relatively low geographic latitudes due to the 11.4^o shift in latitude towards Canada of the geomagnetic pole relative to the geographic pole. Canada is in the process of extending their ground network of optical all-sky auroral cameras and magnetic stations. The combination of space and ground observations provides for a powerful tool for studying auroral processes and their dependence on solar and space activity.

The ASIM mission can be an important component of the International Living With a Star (ILWS) programme. It would in particular complement the Canadian-Chinese KuaFu-B dual satellite mission (formerly Ravens), the radiation belt mappers of NASA, and the SWARM mission of ESA.

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