

SABER Data Processing

Ricky L. Fielding

Abstract – SABER is an infrared multi-spectral radiometer aboard the TIMED satellite. It measures radiatively active species in the atmospheric region from 60 km to 130 km altitude. We are particularly interested in the 2.06 μm and 1.67 μm bands as an indication of the Hydroxyl (OH) concentration in the atmosphere. Here, we detail visualization work along with early results from the SABER OH radiometer channels.

I. INTRODUCTION

ABOARD the TIMED (Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics) satellite is the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) experiment. After a brief introduction to TIMED and SABER we will discuss work at Utah State University (USU) looking at the infrared emissions of Hydroxyl in two bands.

II. TIMED SATELLITE

The TIMED satellite's mission is to "explore the mesosphere and thermosphere globally" [1]. A major portion of this mission is to study the Sun's effect on the Earth's atmosphere between 60 and 130 km of altitude. This is the portion of the atmosphere that first receives the Sun's energy, and is considered the boundary between Earth and Space. The Sun's energy drives the chemical dynamics and transport of the Upper Atmosphere. To study these effects, scientists look at "radiatively active" molecules in the atmosphere. Hydroxyl (OH) for example, emits infrared radiation as it rotates and flexes.

Until now, studies of the upper atmosphere have been ground-based such as those taken by the All-Sky Imager at the Bear Lake Observatory, or rocket-borne like those taken by rockets launched from several sites around the world. All of these measurements are inherently limited to their own geographic region and other factors. The All-Sky Imager, for example, cannot provide information about emissions at different altitudes, but does give a clear overall picture of the OH emissions. The All-Sky Imager is also able to record high-frequency dynamics that are impossible to observe using either rocket-borne instruments or the satellite to be discussed.



Figure 1 OH emission as seen by the All-Sky Imager at the Bear Lake Observatory. The image is approximately 250 km wide. Image courtesy of Mike Taylor.

Rocket measurements are able to give detailed altitude profiles, but are limited in duration and frequency of observations. The TIMED satellite, however, is capable of returning information from the upper atmosphere, around the globe, every single day. TIMED is the first global investigation of the upper atmosphere.

III. SABER INSTRUMENT

The SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) instrument is one of four instruments carried by the TIMED Satellite. It uses a limb-scanning radiometer to retrieve infrared emissions in 11 different bands.

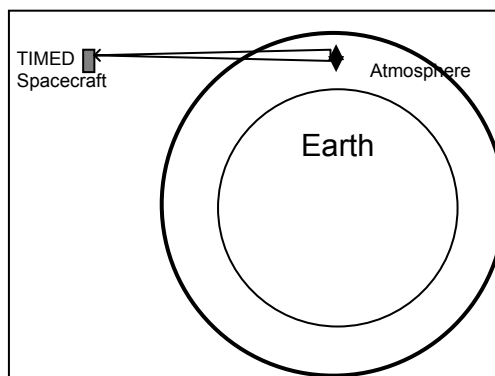


Figure 2. Timed Spacecraft and limb-scanning SABER Instrument

Thanks to the Rocky Mountain NASA Space Grant Consortium for its generous support during this project.

Since the SABER instrument must look through several kilometers of atmosphere in order to measure the emission from a tangent point, a deconvolution algorithm is used to remove the upper layers' contributions from the measurements of lower atmospheric layers [2]. Figure 3 is a comparison of the original data and the deconvolved data. The original limb scan is essentially an integration from top to bottom of the actual emission. Several deconvolution methods exist. One of the simplest is to start at the top and sequentially subtract the upper value from all lower values. This is sometimes called onion-peeling. Onion-peeling can lead to high errors at the lower altitudes due to the successive subtractions, so the Abel transform method is used with the SABER data. The Abel transform is line-integral method used in tomography applications.

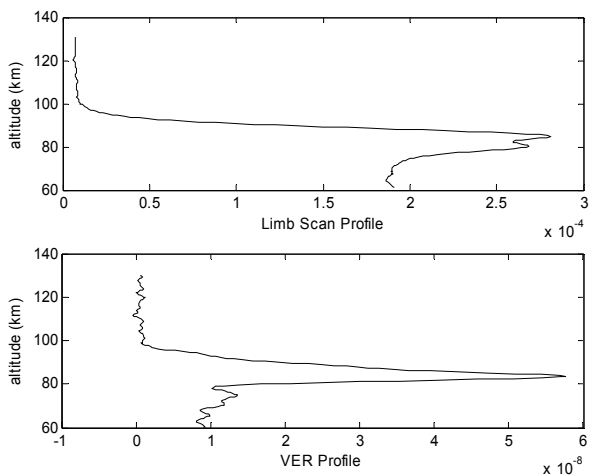


Figure 3. Comparison of original limb scan (top) with processed VER profile (bottom)

The SABER instrument has several scientific objectives including investigation of the Sun-Earth energy budget, dynamics and transport studies, “analysis of O_y and HO_y chemistry”, and the development of climatology for key atmospheric parameters between 60 km and 130 km [3]. USU has been tasked with studying OH emissions as recorded in the 1.67 μm and 2.06 μm infrared bands.

IV. VISUALIZATION

Visualization is an important component in our studies since we are looking for trends across the globe. One part of this project has been the development of a visualization environment in Matlab that allows the user to easily navigate through the information returned by the SABER instrument. The SABER Data Explorer (SDE) is a simple Matlab GUI that allows the user to navigate through the datasets and plot the desired analysis. New analyses can be registered with the explorer allowing it to perform simple graphing or complex investigations designed by the investigator. The SDE makes use of a mapping toolbox for Matlab by Rich Pawlowicz [4].

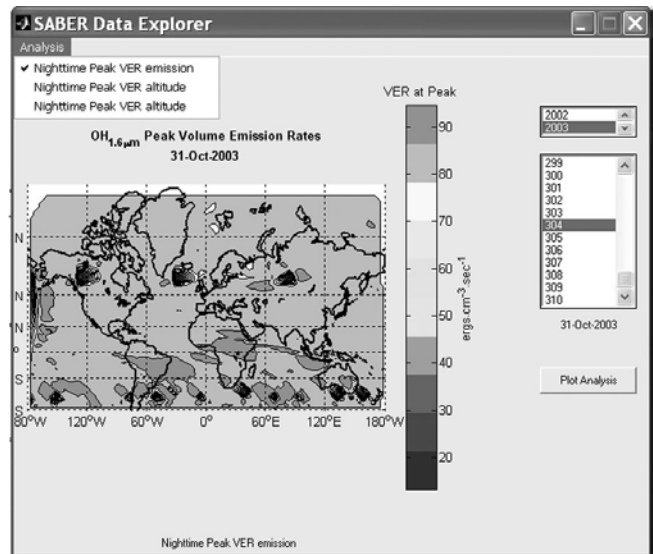


Figure 4. Screenshot from the SABER Data Explorer

Future plans for the SDE include integration of a viewer for Solar data such as sun spots, flares, and solar storms.

V. SOME RESULTS

A. November 2003 Solar Flare

On November 4, 2003 a solar flare occurred that was larger than any flare previously recorded. X-ray radiation levels increased by a factor of 60 as recorded by both the TIMED and SORCE (Solar Radiation and Climate Experiment) spacecraft [5]. This energy input causes the atmosphere to heat and expand. One indication of solar activity is the sunspot number. Just before the November flare, The sunspot number began to increase significantly. What follows is a comparison of emission plots preceding, during, and after the flare. Each emission plot is a contour plot of compiled night time emissions data. The value is a cumulative emission summed from 60 km to 130 km. Thus, with scaling, the plots represent the energy emitted from a unit volume of atmosphere per second.

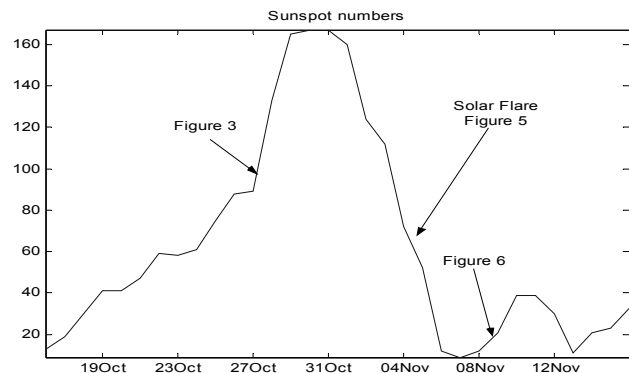


Figure 5 Sunspot numbers spanning the Nov-2003 solar flare

Figure 5, above, is a plot of the sunspot numbers spanning the events and figures shown below. There is a correlation between the sunspot peak, and increased OH emission

dynamics. Here it seems that that an increase in the sunspot number leads the increase in upper atmosphere activity by approximately two days. In the future, SABER data will be compared to other solar data, some time-series based, such as solar flux; and others event-based, such as storm and flare dates. Solar flares release photonic energy in the form of visible, X-Ray, and Ultraviolet radiation that reaches Earth several minutes after the flare. At the same time, however, charged particles are also released which travel at much slower speeds. These charged particles can reach the earth from several hours to a few days after the flare, depending on the energy of the flare.

A contour plot of the 1.6 μm emissions on October 28th shows that the higher OH concentration is over Northern Asia. By this date the sunspot number had already begun to increase toward the early November peak.

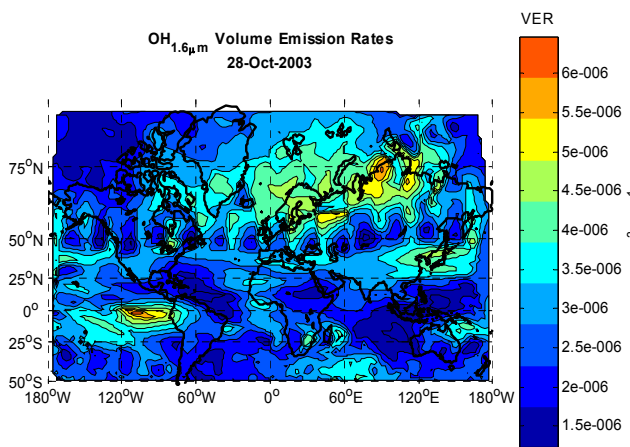


Figure 6. OH infrared emission -- 28-Oct-04

In Figure 7, the effect of increase energy input is evident as the sunspot number rises and the date the date of the solar flare comes closer. Here, the areas of high concentration have moved down and out across the middle latitudes.

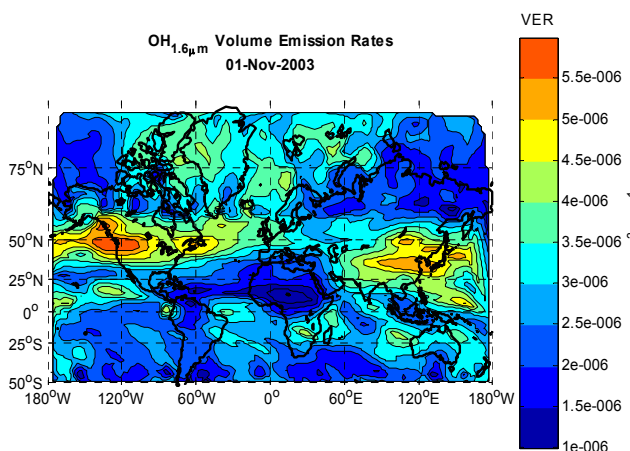


Figure 7. OH infrared emission -- 1-Nov-03

Figure 8 shows the OH emission on the date of the flare, where the concentration on the western hemisphere has begun to break up and move north, while the concentration on the eastern hemisphere has spread and moved south.

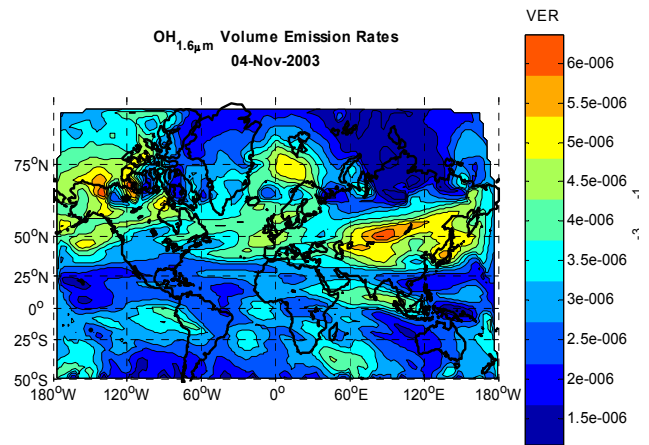


Figure 8. OH infrared emission -- 4-Nov-03

Figure 9, below, shows a return to a more homogenous mixture, and demonstrates the effect of upper atmosphere winds which mix the regions of OH.

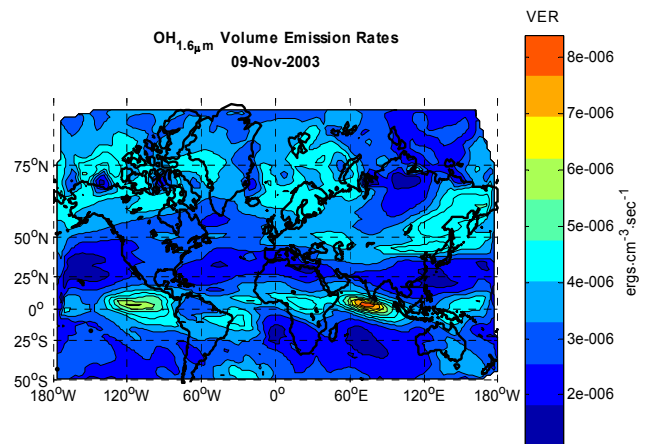


Figure 9. OH infrared emission -- 9-Nov-03

VI. FUTURE WORK

The work of processing the data from SABER is just beginning. We have in place a visualization system that will grow according to the needs of the science team. We can now add analysis capabilities and bring important information together. In the future there are several avenues of investigation left open to us.

A. Inverse Kriging

One avenue of investigation is the integration of SABER data with ground-based observations. While SABER is giving us an unprecedented global look at atmospheric species, it is a relatively coarse dataset. The TIMED satellite orbits the Earth

approximately 15 times daily which results in 24° of longitudinal separation between orbits. In other words, the satellite might overpass the continental United States only twice per day. In addition, observations from sky imagers shows that there are high frequency waves present in the upper atmosphere that are not visible from SABER due to its coarse global resolution.

Inverse Kriging is a method proposed by Petrie to increase the utility of low-resolution satellite imagery. In inverse kriging, two images are required: one large area, low-resolution image and an overlapping, but smaller, high-resolution image. Statistical correlations between the overlapping images are used to infer high resolution characteristics of the low-resolution image in non-overlapping areas [6]. It may be possible to apply inverse kriging by using ground-based measurements as high-resolution images overlapping the low-resolution SABER measurements. Such information, while not absolutely accurate, would go a long way toward inferring the behavior of the upper atmosphere.

B. Solar Correlation

Another pressing future task is correlation of important solar events with SABER data. Since the purpose of TIMED is to study the Sun-Earth link, it is important to investigate cause and effect relationships between solar and upper atmospheric events. Fortunately solar datasets are freely available through the Space Physics Interactive Data Resource 2 (SPIDR) initiative [7]. Shortly, the data visualization modules will allow the investigator to browse solar data interactively alongside upper-atmospheric datasets.

C. Orbital considerations

It is important to realize that the satellite spends approximately half of each orbit over the night time sky of the Earth. Future work should take closer accounting of the Sun's input to the atmosphere being observed by SABER. It is reasonable to expect different dynamics when comparing daytime and nighttime observations.

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