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Expanded Atmospheric Monitoring for the Utah Telescope Array

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Four methods are proposed to complement and upgrade the atmospheric monitoring techniques currently being transitioned to the Telescope Array near Delta, Utah from the High Resolution Fly's Eye (HiRes) observatory. The four methods include lidar systems for neutral atmosphere and aerosol measurements, multi-wavelength all-sky imaging with CCD cameras, continuous cloud monitoring with ventilated radiation stations, and computational methods for aerosol modeling and atmospheric tomography. This paper reviews the proposed methods and the capabilities they will provide for cosmic ray fluorescence measurements.

1. Introduction

The Telescope Array (TA) near Delta, Utah will comprise three fluorescence detector stations and a surface array of 576 scintillation counters for the study of ultrahigh energy cosmic rays. Determination of cosmic ray energies and compositions from air fluorescence measurements requires accurate monitoring of aerosols, clouds, and atmospheric density profiles. Current atmospheric monitoring methods implemented at the High Resolution Fly's Eye (HiRes) observatory primarily use UV lasers in conjunction with the air fluorescence detectors. These methods provide basic capabilities for characterizing aerosols and resolving temporal variations in the optical properties of the atmosphere, but are limited with respect to cloud monitoring, vertical and horizontal variations in aerosols, and *in situ* measurement of vertical density profiles. Development and implementation of additional atmospheric monitoring methods is therefore a vital step in improving the accuracy of cosmic ray measurements at the TA.

In collaboration with the University of Utah, four methods are proposed by Utah State University (USU) to complement and upgrade the atmospheric monitoring techniques currently being transitioned to the TA from the HiRes observatory. These four methods are lidar measurements of aerosols and atmospheric density, all-sky digital imaging with CCD cameras, continuous cloud monitoring with radiometric stations, and advanced computer methods for aerosol modeling and atmospheric tomography. These methods will provide a set of complementary capabilities for detailed resolution of molecular scattering, cloud cover, aerosol distributions, and aerosol characteristics (size, shape, and composition) over the TA viewing region.

2. Lidar Measurements

Lidar methods have been extensively researched and developed at the Center for Atmospheric and Space Sciences (CASS) and the Space Dynamics Laboratory (SDL) for the study of the atmosphere from 0 to 80 km [1]. Two lidar systems are proposed for atmospheric monitoring at the TA. The first system, a three-color lidar, will utilize a three-wavelength, diode pumped laser (355, 532 and 1064 nm) for measuring the optical backscatter, extinction, and depolarization of aerosols. The three-color lidar system will also provide high-resolution imaging of aerosol layers and cloud structures in the atmosphere (Figure 1). Additional parameters that determine the scattering and extinction properties of aerosols, specifically size and shape, will be obtained by multi-wavelength and polarization measurements. The three-color lidar is a robust, portable, and remotely operated system currently being developed for monitoring of agricultural aerosols.

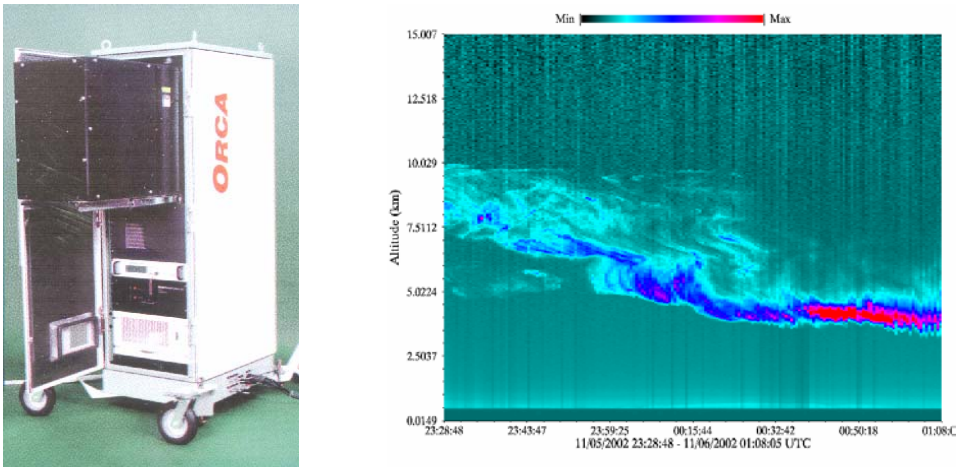

Figure 1. Left: Photo of the AROL-2 lidar system at the Space Dynamics Laboratory, Logan, Utah. Right: Altitude-time plot of lidar backscatter from the USU/SDL AROL-2 lidar, showing the development of high cirrus haze into low clouds over a 1.5-hour period near sunset (4:30-6:00 PM local) in Logan, Utah.

The second lidar system will use Rayleigh backscatter to determine the neutral density profile of the atmosphere, which is necessary for molecular scattering corrections in the air fluorescence measurements. The method would rely on subtracting the aerosol (Mie) scattering from the Rayleigh scattering, and would provide independent measurements with greater temporal and spatial resolution than currently available with radiosonde data or adiabatic models. In particular, this lidar method would be useful for tracking upper tropospheric disturbances such as gravity waves arising from mountain leeward waves or distant storms.

3. All-Sky CCD Imaging

An all-sky (180°) digital imaging system is proposed for high-resolution, high-sensitivity night sky measurements at the TA. The all-sky CCD imager is a robust, proven field instrument designed for unattended operations [2]. The system is based on a cooled (-40° C) bare CCD array camera with 1024x1024 pixels, 400-950 nm range, and high stability for long-term measurements. The imager is fitted with a six-position filter wheel, temperature stabilized interference filters, and a fast (f/4) telecentric lens system enabling narrowband (1.5-2.0 nm FWHM) measurements of a range of faint night sky emissions. To date the all-sky camera has been used to investigate atmospheric gravity waves and their effect on upper mesospheric dynamics. These studies use several naturally occurring airglow emissions that originate in well-defined layers from 80 to 100 km (Figure 2, left and middle). The imager has also been used to research auroral and equatorial thermospheric emissions, meteor trails, and lightning-associated sprites.

An all-sky imager is proposed for the TA to obtain spectrally filtered, near UV to near IR measurements to quantify the night-time seeing conditions over the site using the star background (Figure 2, right). Such measurements would be comparable to stellar photometry measurements proposed for the Pierre Auger array in Argentina [3]. Star field images would be analyzed to extract variations in star brightness from their clear-sky magnitude, and to construct all-sky maps of the optical depth of the atmosphere at various wavelengths. Such data sets will be useful for characterizing the types of aerosols as well as their distribution in the atmosphere. In addition to starlight extinction, diffuse scattering could also be used to map the distribution of aerosols over the field of view, and detailed information on cloud coverage could also be obtained that would complement measurements from ventilated radiation stations and lidar.

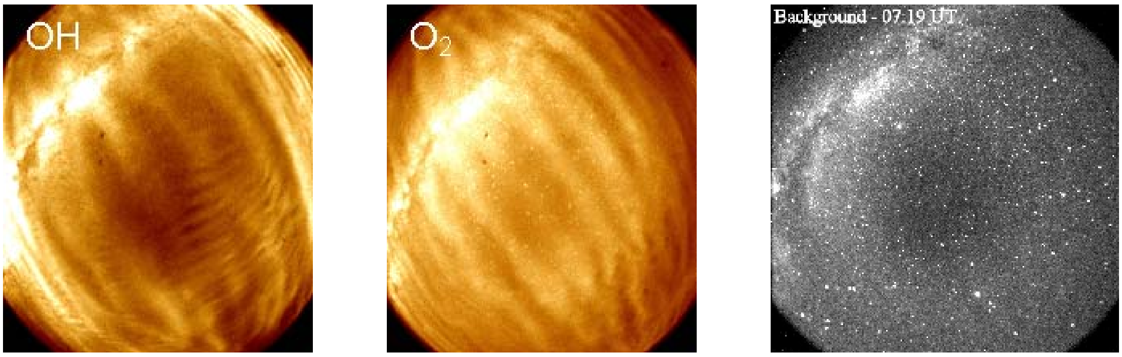

Figure 2. Left and middle: Gravity waves at the mesopause imaged with airglow emissions at two different wavelengths. Right: All-sky CCD camera background image displaying star field and diffuse atmospheric scattering of starlight.

4. Continuous Cloud and Weather Monitoring

USU has developed radiometric instrumentation and an associated algorithm that provide continuous 20-minute cloud data (cloud base height, cloud base temperature, and percentage cloud cover) both day and night throughout the year [4]. This approach has been incorporated into a ventilated radiation station (Figure 3, left), comprised of pyranometers, pyrgeometers (Figure 3, right), and a net radiometer that continuously measure incoming, outgoing, and net shortwave and longwave radiation. The algorithm provides accurate long-term, day/night cloud monitoring by using air temperature, moisture, the incoming cloudless longwave radiation, and the longwave radiation in the 8-13 μm band from clouds. The station also provides surface temperature, air temperature, pressure, humidity, precipitation, and wind velocity and direction.

Figure 3. Left: Ventilated radiation station at Dugway, Utah. Right: Pyrgeometer (left of support) and pyranometer (right of support) for measuring incoming longwave and shortwave radiation, respectively.

We propose to implement this system at the TA as a primary cloud monitoring system. One to four permanent radiation stations would be required depending on the extent of clouds and weather conditions affecting the air fluorescence measurements. Continuous cloud measurements will enable the collection of additional fluorescence measurements during variable and rapidly changing cloud conditions, thereby increasing the database of cosmic ray observations. Both weather and cloud base data will also be valuable in verifying density profiles for molecular scattering corrections, and for correlating with lidar and imager measurements to help resolve the temporal and 3D structure of the atmosphere over the TA.

5. Computational Modeling

Both multiple scattering and intrinsic aerosol properties (shape, structure, and composition) can significantly alter the optical scattering characteristics of aerosols from those of homogeneous spherical particles. Computer models are being developed at USU to address these scattering effects. The models use vector multipole expansions, addition theorems, and iterative algorithms to simulate multiple scattering in random dispersions of spherical particles. The models are currently being expanded to include spheroidal, layered, aggregate, and compound particles. The objectives of this modeling will be to improve the accuracy of aerosol phase functions and extinction properties needed for air fluorescence corrections. The models will use polarization and multi-wavelength data from lidar measurements and all-sky CCD images to determine the size, structure, and concentration of aerosols as a function of altitude, azimuth, and elevation angle.

In addition to aerosol scattering models, algorithms will be developed to reconstruct the 3D distribution of aerosols in the atmosphere. Of specific interest is the use of tomographic methods to reconstruct aerosol distributions from stellar photometry data acquired from all-sky CCD cameras. Atmospheric tomography with all-sky CCD imaging has already been demonstrated for auroral and airglow emissions, and would be of significant value for improving cosmic ray energy measurements by providing the 3D structure of aerosol concentrations and other atmospheric properties in the line of sight of air fluorescence events [5]. For mapping aerosol distributions with stellar photometry, simultaneous observations of a star by two or more all-sky imagers would provide atmospheric extinction data along a set of parallel paths through the atmosphere. Observations of multiple stars would yield multiple intersecting paths through the atmosphere. With the use of straightforward tomography methods, a 3D map of the atmospheric extinction could then be computed. Correlation of the spatially resolved aerosol reconstructions with lidar ranging measurements would provide verification and calibration of the method.

6. Conclusions

The proposed lidar systems, all-sky CCD imaging, radiometric cloud instrumentation, and computational modeling will provide a comprehensive measurement capability for monitoring atmospheric conditions at the TA site, and represents the next step in atmospheric monitoring at cosmic ray observatories.

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