Nightsky Imaging Tomography Experiment to measure Ozone with Starlight

NITEOWL

A proposal for the Small Payloads Program
of the Canadian Space Agency

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1. NiteOwl Research Program (NiteOwl Science)

1.1 Introduction

Since its inception in the 1920s, major advances in the study of atmospheric ozone have been made, progressing from ground based observations to balloon, aircraft, rocket and satellite platforms. Observations from the ground are convenient and provide long term data but cover only a small area of Earth and cannot provide a global picture of the ozone distribution and its complex dynamical variations. Satellite instruments are capable of remotely sensing total ozone levels and height distributions, providing comprehensive current data over most of the Earth. Over the last three decades many satellite missions have involved ozone measurements [1], and several other missions are now operating or in preparation [2]. Significant progress has been achieved in understanding the major processes involved in ozone dynamics. Despite this, no comprehensive model capable of predicting long term trends of the ozone layer exists. Recent satellite missions are directed toward obtaining comprehensive data which will support the development of such models.

Over the last two decades, ozone chemistry has ceased to be a purely scientific problem, as major ozone depletion has taken place, both in the polar regions and elsewhere. The associated potential for human health problems and disruption of plant life, including effects on the agriculture, forestry, and fisheries industries, have made this subject one of intense public interest and concern. In light of the potentially disastrous consequences of ozone depletion both for key sectors of the national economy and for public health, it is imperative to provide an effective, low cost means of global ozone monitoring which can provide data on ozone levels both to the Canadian public and to the scientific community. It is worth noting that recent specialized ozone satellite missions are not able to meet this requirement fully because of their extreme complexity and high scientific specialization. Due to the extremely high costs associated with these missions they are normally conducted with broad international cooperation.

The goal of the proposed project is to develop and validate an instrument capable of providing data on spatial and temporal variations of ozone distributions during a polar winter. The instrument will be deployed on a parachute from a sounding rocket. The ultimate goal is to create within the Canadian space science community and Canadian industry a capability for construction and deployment of a microsatellite-based system for global ozone monitoring. Such a system would be an efficient low-cost national alternative to the presently contemplated systems (TOMS, SBUV, GOMOS), and would provide important and timely information about the ozone layer to both the Canadian public and the atmospheric science community.

1.2 Mission Objectives

We propose to develop an imaging spectrograph to measure the vertical and horizontal distributions of ozone, NO_2 and NO_3 at altitudes of 10 - 50 km during an Arctic winter night. The

instrument is deployed by parachute from a sounding rocket at apogee near 80 km. Ozone, NO_2, and NO_3 concentrations are determined from stellar occultation measurements by a tomographic technique. The launch site for the mission will be Churchill, Manitoba.

-Quantify the spatial and temporal variations of ozone (especialy in the low stratosphere region?) and its effects on the global ozone balance as required by existing theoretical models of global ozone trends.

Despite of wealth of experimental data on ozone distribution currently there are no global altidute resolved measurements of ozone. TOMS is producing now outstanding maps of total tropospheric ozone but they are of low accuracy (of the order of 50 %) and provide little detail on altitude distributions. Currently existing models of ozone dynamics predict large vertical (in 2-3 km) and horisontal (100-500 km) variations of ozone distributions. They also predict an importance of low amplitude (of the order of 10 %) variations of ozone concentrations in the low stratosphere. For further validation and contraint of theoretical and computational models for global ozone trends it is imperative to possess experimental data with horizontal resolution of ~ 100 's km and vertical resolution of 2-3 km with overal precison less than 10 %.

?Elucidate the role of "nighttime species" No2 and NO3 in the global ozone dynamics

National Space Science and Technology Objectives:

-Maximize training potential for students and young researchers by providing them wide opportunities for project development in the environment of a multidisciplinary team comprising academic and industrial partners

-Develop in Canadian industrial sector a potential to create and manufacture a relatively low-cost microsatellite-based system for high-resolution global ozone monitoring, drawing upon the national capabilities

International Collaboration Objectives:

-Maintain and increase Canadian involment in the international efforts to understand and predict global ozone trends via providing it with high quality data on spatial ozone distributions

Public Service and Educational Outreach Objectives:

-Increase public awareness of space science missions via communicating issues involved in ozone depletion

This project will further the Canadian contribution to the study of internationally relevant research and is sure to be of benefit to all interested parties, including Canadian technological

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industries, academia, government agencies and the business community. The benefits are further compounded by both increasing the global exposure of the Canadian Space Agency while maintaining Canadian ownership of the knowledge acquired with most of the money remaining in this country.

It is hoped that this type of instrument and analysis will lead to a relatively low-cost microsatellite-based system for global ozone monitoring, drawing upon the national capabilities of Canadian universities and industry.

1.3 Global Ozone/Dynamics/Scientific Issues

There are two main regions where ozone is prevalent in the atmosphere: stratospheric ozone lying in the region between altitudes of 10 - 50 km and tropospheric ozone below 10 km. Churchill ozonesonde data from the fall and winter of 1965 showed peak ozone partial pressures between 0.16 and 0.25 μbar at altitudes from 18 to 25 km, with negligible ozone above 40 km altitude. One commonly refers to the stratospheric portion as the "ozone layer". This layer is responsible for the absorption of biologically damaging ultraviolet sunlight, known as UV-B. The result of the ozone absorption is a heating in this region of the atmosphere which is ultimately responsible for the temperature structure of the stratosphere.

Total column ozone abundances have been analyzed from 1979 to present showing a general downward trend. From both ground-based and satellite measurements, a 4-5% decrease per decade has been observed for both hemispheres at mid-latitudes [1]. Furthermore, there are annual variations in ozone concentrations with most destruction of ozone occurring during the winter/spring seasons in both hemispheres. This coincides with the formation of extremely cold, stable vortices. Under these conditions, polar stratospheric clouds (PSC) are able to form. PSCs allow chemistry to occur on surfaces (ice, nitrate and sulfate particles, etc.) rather than in gas phase. Some examples include the conversion of inert chlorine to its reactive forms, and the holding cycles of nitrogen dioxide which make this species unavailable to stop the destruction of ozone. This is the main cause of Antarctic ozone depletion, due to the extreme cold of this region and thus high occurrences of PSCs. In the Arctic, the temperatures are higher and the possibility of PSC formation is less. However, chlorine and other reactive species have similar concentrations in both hemispheres. Should the temperature of northern regions reach comparable temperatures as the south, we could expect the same destruction of the ozone layer. Due to the significance of these formations in the Arctic, it is our intention to map any of these formations that we might encounter.

Ozone suffers diurnal variations as well. (These are the concerns with validation with Brewer technology: what will happen to concentrations if we compare daytime Brewer to our data? Will we have to go with moonlit Brewer?) Several species undergo large diurnal variations. Measurements of radicals and other representatives from the important chemical family, NO_x, will provide valuable information to enhance the interpretation of the ozone results.

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The conversion of NO to NO_2 at night is a rapid process, while the photolysis rate of NO_3 is large, such that NO_3 is nearly unmeasurable during the day. The object of our stellar occultation method is to determine vertical profiles of these nighttime species. Both NO_2 and NO_3 have strong absorption features within the spectral range of 400-700 nm. From studies at the tangent altitude of 24 km, NO_2 suffers at least an estimate 7% loss in transmission at 431 nm (without scattering). This should be detectable with the target resolution of our instrument. The full spectral range (400-800 nm) of our instrument allows better separation amongst atmospheric constituents, including aerosols, and does not rely on unique spectral signatures.

The effects of extinction in the atmosphere will be included in our retrieval algorithms which includes Rayleigh and Mie scattering. Rayleigh scattering involves particles which are much smaller than the incident wavelength. The cross-section is well known, and we have confidence in our models of this effect. Mie scattering involves particles which are comparable or larger than the incident wavelength. The size, shape and density of the scattering molecule all contribute to the extinction. A simple Mie scattering model will be included in our analysis. The advantage that our mission provides in order to map PSCs or determine the best Mie scattering model is that there will be more than one viewing angle for each radiance measurement. The viewing angle dependence of the retrieved aerosol optical thickness has been suggested as evidence of particle nonsphericity and may also be used to reject unreasonable aerosol models (GRL,22,1077,1995 - practically word for word). The substantial effect of PSCs on the abundance of trace gases in the stratosphere (GRL,20,2059,1993) may also be revealed by our measurements should a PSC occur.

1.4 Remote ozone measurements

Various efforts have been made to determine profiles of the atmospheric constituents. Canadian missions include the ground-based Stellar Brewer as well as the ODIN and MOPITT satellite projects. The Stellar Brewer project measures the total ozone column from atmospheric absorption of solar ultraviolet radiation using four channels from 310-320 nm. They plan to extend the operation of this instrument to include a stellar source in order to monitor ozone in the high Arctic during the polar night. The commitment to furthering the understanding of ozone trends is shown by the Canadian involvement in missions such as ODIN and MOPITT.

Onboard Nimbus 7, the TOMS instrument provided nearly fifteen years of reliable, global ozone maps. This coverage is still being provided today by other TOMS instruments which highlights the international interest in monitoring global ozone trends. Unlike TOMS, which uses individual spectral signatures to measure ozone, HALOE identifies absorption features within selected spectral bands through a solar occultation technique. HALOE is another instrument which is aimed to obtain ????. All of these missions exclude the polar night.

In order to provide ozone coverage during the polar night, the GOMOS project was initiated. GOMOS will perform stellar occultation measurements to study ozone, similar to the NiteOwl

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project, but at a much higher cost which may partially be attributed to the number of targeted species and the necessary spectral resolution. In an attempt to reduce costs while still realizing similar GOMOS science objectives, the COALA study is intended to make complementary nighttime or validation measurements for other missions. Although the NiteOwl objectives also include nighttime ozone retrieval, we plan to provide similar science results at a reduced cost from a Canadian perspective.

It is our intention to provide a Canadian polar night ozone measurement by tomographic technique. A key element for quality tomographic results is redundant measurements. These would be of the same atmospheric cell taken from different vantage points during descent and improved by multiple lines-of-sight provided by the various stars in our field of view. Presently, this is accomplished by making observations over multiple passes of the same area. Our technique is to have the payload rotate as it descends, thereby getting multiple looks through the same cells, each from a different angle. This allows the required redundancy to be achieved in one pass. In addition, the broad ozone absorption feature of the Chappuis band (450 - 750 nm) does not place heavy restraints on the spectral resolution of our instrument. This may affect the number of recoverable species but will reduce the cost of the mission.

1.5 Broad Design of Experiment

The NITEOWL experiment is to be launched from Churchill, MB aboard an “Orion” rocket. This rocket will take the experiment to an altitude of 80km. From apogee the experiment will fall to earth beneath a parachute specially designed to provide a known, low rate of spin. As the payload falls measurements allowing the calculation of the abundance of ozone will be taken using an optical spectrograph. The position of the rocket and instrument will be monitored using a (GPS) Global Positioning System. This will be used both to track the altitude and geographic position of the instrument during flight and to facilitate post-flight recovery. An attitude video camera (AVC) will be included in the payload to monitor the direction from which the ISP is recieving its input signal. There will be two data streams sent from the NITEOWL experiment to receiving equipment on the ground. The first data stream will include the measurements made by the ISP and the GPS. The second will transmit the information generated by the AVC. A block diagram of the entire instrument is shown in Figure 1-1.

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