MANTRA 2000
Middle Atmosphere Nitrogen TRend Assessment
A Second Balloon Flight

Mission Description Document
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1. Introduction

1.1 The First MANTRA Flight

MANTRA (Middle Atmosphere Nitrogen TRend Assessment) is a balloon mission to investigate changes in the concentrations of nitrogen and chlorine compounds and ozone in the stratosphere. The first flight involved the launch of an 11.6 mcf (million cubic foot) balloon from Vanscoy, Saskatchewan on August 24, 1998. The balloon carried a payload of instruments to measure atmospheric composition, and made measurements from a float altitude of about 35 km for one day.

Stratospheric ozone depletion has received considerable attention since the 1985 discovery of catastrophic reductions in ozone concentration over Antarctica during spring (the "Antarctic ozone hole"). MANTRA is focusing on mid-latitude stratospheric ozone, which has declined by about 6% over the past 20 years. Losses of ozone at mid-latitudes have been greater than can be accounted for by current theories regarding ozone destruction. This is important because predictions for the future evolution of the ozone layer are based on these theories, and form the scientific basis for the terms of the Montreal Protocol, which regulates the global production and release of ozone-depleting substances.

With the first MANTRA flight, possible causes for the lack of agreement between theory and observations were investigated by flying a total of eight instruments. Four of these were flown on balloons in the 1970s and early 1980s (MSC NO_2 spectrophotometer, two MSC HNO_3 radiometers, MSC OH spectrometer), and four employ newer technologies (two MSC photodiode array spectrometers, CRESTech/York U acousto-optic tunable filter spectrometer, U of Denver Fourier transform spectrometer). This enabled a dual intercomparison: one between measurements obtained by the same instruments after an interval of 15-20 years, and the other between the old and new measurement techniques.

The primary gases of interest were ozone, NO_2, HNO_3, $ClONO_2$, and HCl, but a number of other stratospheric gases were also measured by the balloon-borne instruments. The balloon was launched before sunrise so that emission measurements could be made during ascent and in order to reach float altitude in time for several of the instruments to track the sun as it rose. The balloon then remained at this altitude for the day, allowing several instruments to scan the Earth's horizon through a range of altitudes, recording spectra of scattered sunlight. The final series of measurements was taken by again tracking the sun as it set.

Detailed background atmospheric studies were also conducted using ozonesondes, radiosondes, and aerosol sondes, as well as a ground-based MSC Brewer spectrophotometer and two zenith-sky spectrometers (MSC and U of Toronto). All of the data are being used in a modelling effort focused on determining whether there have been long-term changes in the concentrations or partitioning of those nitrogen compounds that indirectly control ozone destruction.

Further scientific background to the MANTRA project is available in the original proposal to CSA. A detailed summary of the launch preparations, flight profile, and mission results for MANTRA 1998 is given in the Post-Flight Report provided to CSA on October 16, 1998. Three Data Workshops have been held since the August 1998 flight - the Proceedings from these three Workshops include all of the materials presented at each, with a focus on the progress of the data analysis. A set of seven scientific papers has been submitted for publication and a number of talks and conference presentations arising from the MANTRA 1998 campaign have been given.

1.2 Development of a New Pointing System

During the 1998 MANTRA flight, two pointing control systems were used: a sun-tracking system that included both azimuth and elevation control, and a new limb-scanning system that was developed for MANTRA jointly by MSC and the University of Toronto, with support from SIL. Three of the instruments were co-aligned and mounted on a tilting table controlled by this limb-scanning system.

It consisted of a small microprocessor controller, a Litton G2000 two-axis mechanical gyro, several clinometers (gravity referenced inclinometers) and a pointing table shaft encoder. The microprocessor controller, running at 10 Hz, generated a temperature-corrected integrated rate output from gyro readings. During ground testing in August 1998, this system demonstrated a pointing stability of better than 0.25°. It is anticipated that the performance could be improved to 0.1° with modifications to the microprocessor and sampling circuitry. During the MANTRA flight, the system behaved nominally until just before float altitude when a power supply failure prevented further operation. The system was therefore not used in closed loop operation during flight as this failure occurred before the balloon attained float altitude and so no operational data is available. The cause of the power supply failure has since been isolated to an incorrectly installed capacitor. This system will not be used again, and has been replaced with a sealed commercial design that will be tested prior to flight.

CSA subsequently provided support for the development of an improved pointing control system for future MANTRA flights. The primary objectives of this work have been to demonstrate elevation-pointing control to 0.1° and to flight-harden the system. Excellent progress has been made on this project over the past year. The new system has been designed based on a detailed review of requirements, and the hardware has been assembled and demonstrated. The Critical Design Review for the new pointing control system was held in conjunction with the MANTRA Third Data Workshop on December 1, 1999. The remaining tasks are the implementation of software control algorithms, and performance and vacuum testing under realistic table loads on a gondola mock-up. These will be completed by July 2000.

2. MANTRA 2000

2.1 Scientific and Technical Objectives

The original MANTRA proposal to the CSA’s Small Payloads Program included a proposal for a second balloon flight. It was tentatively proposed that this might involve a reflight of the full MANTRA payload in August 1999, possibly at a higher latitude and in collaboration with the SAGE III validation process. However, SAGE III has not yet been launched and the MANTRA Science Team now proposes to undertake a second flight in August 2000 from Vanscoy, SK.

Based on what was learned from the first flight, and given the constraints of time, effort, and personnel available to support an August 2000 flight, a scaled down payload will be flown with the following scientific and technical objectives.

(i) To undertake a test flight of the new pointing control system in order to demonstrate its performance and capabilities for future balloon flights.
(ii) To continue the investigation of the stratospheric odd nitrogen budget at mid-latitudes, focusing on the measurements of vertical concentration profiles of ozone, HNO_3, and NO_2, and the comparison of these measurements with historical data in order to identify trends.

(iii) To continue the investigation and validation of techniques for the retrieval of NO_2 vertical profiles from ground-based zenith-sky spectra.

(iv) To investigate the feasibility of retrieving vertical profiles of temperature and pressure from solar occultation measurements of the O_2 A and B bands, in support of the MAESTRO project.

2.2 Mission Requirements

For Objective (i):

A test flight of the pointing control system is essential in order to assess its performance. As there will only be a limited launch opportunity at turnaround, we prefer to minimize the risks of this test flight by reducing the science payload significantly from that of the first MANTRA flight. However, a test flight requires that the pointing system be deployed with an appropriate instrument that can be operated in both solar occultation and limb scanning modes. Three of the original MANTRA instruments could serve this purpose, however, the most appropriate is the MSC photodiode array spectrometer (or SunPhotoSpectrometer - SPS), given its performance during the first flight, its broad spectral coverage, and its size. Of the other two instruments, the MSC NO_2 spectrophotometer requires significant refurbishment for flight readiness and would only measure one trace gas, while the large size and mass of the CRESTech/York University AOTF spectrometer means that significant effort would be needed to integrate it with the new pointing system.

For Objective (ii):

A complete assessment of the stratospheric ozone budget would require the measurement of vertical profiles of all of the key nitrogen and chlorine compounds: ozone, NO, NO_2, HNO_3, $ClONO_2$, HCl, and aerosol. In addition, measurements of CFC-11, CFC-12, CFC-22, N_2O_5, HNO_4, BrO, OClO, N_2O, CH_4, J-values, pressure, and temperature would be useful. Such a set of measurements could be obtained by a combination of UV-visible and infrared instruments, such as was flown on the first flight.

In particular, the University of Denver FTS is required for the measurement of NO, $ClONO_2$, HCl, CFC-22, N_2O_5, HNO_4, and CH_4. However, this instrument is currently committed to a SAGE III validation flight sometime in 2000, and has been configured to work at ~700 nm (12,800 to 13,300 cm^{-1}) for O_2 measurements. Given that the FTS would have to be reconfigured for MANTRA operation and that the Denver group currently has no funds for a second MANTRA flight (a proposal to NSF was unsuccessful), it is unlikely that this instrument will be available for an August 2000 flight. While the absence of the FTS from the payload will reduce the scope of the chemistry that can be measured, it will also significantly reduce the payload mass and will thus simplify the gondola integration.

It will still be possible to continue the investigation of certain aspects of the stratospheric mid-latitude odd nitrogen budget by reflying the MSC HNO_3 emission radiometers, along with the MSC SPS. The two emission radiometers flown in August 1998 worked very well, making observations during ascent and for the duration of the seven-hour liquid nitrogen hold time. Both radiometers performed nominally and vertical profiles have been retrieved. New retrieval algorithms, based on a high-resolution line-by-line code, were developed specifically for the analysis of these measurements. These have been successfully used to obtain vertical profiles of HNO_3, as well of several other gases having emission features in the 8-12 μm region: ozone, CFC-11, CFC-12, and N_2O. We have recently obtained raw emission radiometer data from flights conducted by MSC in 1989, 1990, 1991, and 1992 (two per year), and are planning to reanalyse these data with the new algorithms. Preliminary results for 1989 indicate good agreement between the retrieved ozone profile and a corresponding ozonesonde profile. There is a five-year gap between these measurements and those of the 1998 MANTRA flight. The 2000 flight will produce six years of coverage in the past eleven years.

The focus of this work will be on the investigation of trends in HNO_3, which acts as an important reservoir species in the stratosphere. Reflying the emission radiometers in August 2000 will enable validation of the new retrieval algorithms by providing an independent data set. It will also provide additional current data for comparison with the historical data obtained over the past decade, and will help ensure that the 1998 data are representative. Reflight will permit further instrument intercomparison, which is required in order to resolve some of the differences observed between measurements made in 1998 (for example, the SPS and radiometer gave similar ozone profiles, but both differed from the ozonesonde profile). We will again fly two emission radiometers, pointed at elevation angles of ~20° and ~40° (to increase the atmospheric slant path), in order to provide redundancy and to enable a careful assessment of their accuracy.

In addition to the measurements of HNO_3, ozone, CFC-11, CFC-12, and N_2O by the emission radiometers, the SPS instrument mounted on the pointing system will measure vertical profiles of ozone, NO_2, aerosols, and possibly upper limits on BrO and OClO.

For Objective (iii):

One of the objectives of the original MANTRA flight was "To take advantage of the opportunity offered by the combination of balloon-borne and ground-based instruments to investigate two techniques for the retrieval of NO_2 vertical profiles from ground-based zenith-sky spectra." For this purpose, during the week prior to the August 24th flight, the University of Toronto grating spectrometer was used to make ground-based measurements of ozone and NO_2 slant columns as a function of solar zenith angle. This represented the first deployment of this instrument, and these measurements have been successfully used to derive vertical columns and to investigate the sensitivity of the retrievals to the parameters used in generating air mass factors. We are currently in the process of implementing several algorithms for the retrieval of NO_2 vertical profiles from the slant column measurements, in collaboration with Dr. Kathy Preston (Jacques Whitford Ltd., Calgary) and Dr. Chris McLinden (University of California at Irvine). Validation of these retrievals requires comparison with an independently measured vertical profile of NO_2. During the first MANTRA flight, only one data set appropriate for this purpose was obtained: the SPS sunrise occultation measurements. A preliminary NO_2 profile has been derived from these data.

We will continue the investigation and validation of techniques for the retrieval of NO_2 vertical profiles from ground-based zenith-sky spectra by redeploying the University of Toronto grating spectrometer on the ground at Vanscoy and obtaining additional balloon-based NO_2 profile measurements with the SPS instrument. Solar occultation measurements by the SPS will also enable further refinement of the retrieval technique used to derive ozone and NO_2 profiles from this instrument. In addition, limb scanning measurements by the SPS, which will have a very similar viewing geometry to the OSIRIS (Optical Spectrograph and InfraRed Imaging System) instrument on the Odin satellite, will enable testing of the retrieval algorithms that have been developed for OSIRIS.

We will also operate the CRESTech/York University AOTF spectrometer in zenith-sky mode on the ground at Vanscoy to measure vertical columns of ozone and NO_2, and upper limits on BrO and OClO. A number of improvements to this instrument have been made since August

1998. Deployment at Vanscoy during MANTRA 2000 would enable the performance of the modified instrument to be assessed in comparison with other instruments, and would also add redundancy to the University of Toronto UV-visible zenith-sky measurements. MSC will also contribute a Brewer spectrophotometer and ozonesondes which will provide accurate measurements of ozone total columns and vertical profiles, respectively.

For Objective (iv):

The flight of the SPS instrument, which covers the spectral range from 300 to 785 nm, will enable a study of the feasibility of retrieving temperature and pressure profiles from solar occultation measurements of the O_2 A and B bands (at 760 and 680 nm, respectively). Loss of accurate temperature and altitude data due to telemetry dropouts during the first MANTRA flight prevented assessment of this capability in 1998. The SPS is the forerunner of the MAESTRO (Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation) instrument, and so this flight is an excellent opportunity to provide science support to the MAESTRO project, without requiring any additional instrumentation or resources. The SPS measurements would be used to validate line-by-line models that are being developed at MSC for MAESTRO temperature and pressure retrievals. Ideally, the University of Denver FTS would also be flown in its current configuration (optimized for O_2 measurements) for comparison with the SPS pressure and temperature retrievals, but as discussed above, this is unlikely. In the absence of correlative data from the FTS, the analysis will utilize temperature and pressure data collected during the balloon flight by conventional means (radiosondes, pressure and temperature sensors, GPS altitude sensor).

2.3 Payload and Measurements

The primary balloon payload will consist of the following:

(i) the new pointing control system (with integrated pressure and temperature sensors),
(ii) two MSC emission radiometers,
(iii) one MSC SPS instrument,
(iv) two MSC ozonesondes,
(v) one MSC/University of Wyoming aerosol sonde, and
(vi) one U of T star camera (added on to measure background sky light levels).

This payload does not include the three large and heavy instruments that drove the gondola design in the first flight (OH spectrometer, AOTF spectrometer, FTS). The mass and power requirements will thus be significantly reduced relative to the MANTRA 1998 flight, making the flight operationally simpler.

Additional supporting measurements will be made by the following:

(i) the University of Toronto ground-based zenith-sky grating spectrometer,
(ii) the CRESTech/York University acousto-optic tunable filter spectrometer (ground-based),
(iii) an MSC Brewer spectrophotometer,
(iv) regular MSC ozonesondes flights,
(v) one additional MSC/University of Wyoming aerosol sonde, and
(vi) possibly one ground-based MSC SPS instrument.

Table 1. Measurements proposed for MANTRA 2000.
Note: GBS = University of Toronto ground-based zenith-sky spectrometer.

TRACE GAS	PLANNED MEASUREMENTS	VIEWING GEOMETRY
ozone profiles	• SPS • radiometers • ozonesonde (to 10%)	• solar occultation and limb scan • thermal emission • in situ
NO_2 profiles	• SPS • GBS	• solar occultation and limb scan • zenith-sky scattered light
HNO_3 profiles	• radiometers (to ~20%)	• thermal emission
CFC-11 profiles	• radiometers	• thermal emission
CFC-12 profiles	• radiometers	• thermal emission
N_2O profiles	• radiometers	• thermal emission
aerosol	• SPS • aerosol sonde (OD to 0.002)	• solar occultation and limb scan
BrO column or upper limit	• SPS • GBS (to 15-35%) • AOTF (ground-based)	• solar occultation and limb scan • zenith-sky scattered light • zenith-sky scattered light
OClO column or upper limit	• SPS • GBS (to 15-35%) • AOTF (ground-based)	• solar occultation and limb scan • zenith-sky scattered light • zenith-sky scattered light
pressure, temperature	• SPS • radiosonde	• solar occultation (O_2 A, B bands)
wind, humidity	• radiosonde	
ozone columns	• GBS (to 5%) • AOTF (ground-based)	• zenith-sky scattered light • zenith-sky scattered light
NO_2 columns	• GBS (to 10-12%) • AOTF (ground-based)	• zenith-sky scattered light • zenith-sky scattered light

2.4 Launch and Operations

As with MANTRA 1998, the launch facilities for the MANTRA 2000 flight will be provided by Environment Canada, which has continued to maintain the station at Vanscoy, SK (52°N, 107°W). Scientific Instrumentation Limited (SIL) operates this permanent balloon launch facility and will provide the launch services for the flight.

Current balloon stock at Vanscoy consists of:

(i) one 7.6 mcf balloon left from MANTRA 1998 that will fly the same payload (1250 kg payload, 300 kg ballast, 200 kg chute, etc.) to 36 km (118,000 ft),
(ii) one 4.25 mcf balloon left from CRAYBEX (CSA) that will fly 360 kg to 36 km,
(iii) four 1.35 mcf balloons left from MSC programs that will fly 110 kg to 36 km,
(iv) one 10.72 mcf balloon (suspect material) that will fly 1800 kg to 36 km.

With the current payload mass estimate of 84 kg + gondola (~70 kg) + ballast to hold altitude at sunrise, we will use the 4.25 mcf balloon as the primary, with the 1.35 mcf balloon as backup. There is currently enough helium on site for the 4.25 mcf balloon, but not for the ozonesonde flights. Sufficient helium for the ozonesondes and backup balloon will be purchased as needed.

As with the first MANTRA flight, the launch is planned for turnaround in August 2000. The baseline flight profile will be the same as in 1998: a night launch at 3 AM, stabilizing at float altitude by 6 AM to allow sunrise occultation measurements, float and limb viewing through the day (for ~13 hours from 7 AM to 8 PM), sunset occultation, and start descent at 10 PM.

A new smaller gondola will be constructed based on existing structures which have flown successfully, and will include the new pointing system as well as the existing sun-pointing azimuth control (coarse sensor ±0.5°, fine sensor ±0.05°). As much as possible of the gondola assembly and integration will be done at the University of Toronto, in collaboration with MSC and SIL, in order to minimize launch preparation time required at Vanscoy.

SIL will have primary responsibility for start-up and launch preparations, refurbishment of the old azimuth solar pointing system, telemetry set-up, ground station operation, on site payload integration, launch and ground support, and balloon and instrument recovery (as described in the original MANTRA proposal).

Table 2. Primary tasks and responsibilities.

TASKS	PRIMARY RESPONSIBILITY	ADDITIONAL SUPPORT
Overall organization and implementation	U of T (Quine/Strong)	U of T (Strong/Drummond)
Logistics	U of T (Hartford/Strong)	
New pointing control system	U of T (Quine/PERC)	MSC, SIL
MSC emission radiometers	U of T (Wunch/Quine/Bennett)	MSC (McElroy/Hall)
MSC SPS instrument	U of T (Nowlan/Drummond)	MSC (McElroy/Hall)
MSC ozonesondes and radiosondes	MSC (Davies)	SIL
MSC/U of Wyoming aerosol sondes (two)	MSC (Davies)	SIL
U of T ground-based zenith-sky spectrometer	U of T (Farahani/Adcock/Anstey)	U of T (Strong/Bassford)
CRESTech/York U AOTF spectrometer (on ground)	York U (Solheim/Brown)	
Pre-flight technical support and integration at U of T	U of T (Chen /PTS)	
Gondola design	U of T (Quine), SIL	MSC (Ullberg)
Batteries	SIL	
Launch support, including telemetry set-up, main and downrange ground station operation, on site payload integration, launch, balloon and instrument recovery	SIL	

3. MANTRA 2000 Schedule and Milestones

DATE	MILESTONE
May 1, 2000	CSA contract start date
June 5, 2000	Flight Requirements Review & FDR for pointing system
July 27, 2000	Flight Readiness Review (at U of T)
July 31, 2000	Ship gondola back to SIL via ground (to arrive by August 4)
Saturday, August 12, 2000	Ship instruments to Vanscoy
Wednesday, August 16, 2000	Science team to arrive at Vanscoy
Wednesday, August 16, 2000	Begin payload integration at Vanscoy
Thursday, August 17, 2000	SIL to start ozonesonde flights
Wednesday, August 23, 2000	Flight Readiness Date
Thursday, August 31, 2000	Preferred latest date for end of field campaign
October 1, 2000	Submit Post-Flight Report
December 1, 2000	Fourth Data Workshop (at U of T)
December 31, 2000	End of CSA contract (seven months)
January/February 2001	Possible participation in Odin/OSIRIS validation in Kiruna, Sweden