Early Mission Planning for the MOPITT Instrument

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ABSTRACT

The Measurements Of Pollution In The Troposphere (MOPITT) instrument will monitor the global concentrations of carbon monoxide and methane. It will be flown on the Earth Observing Satellite, Terra (EOS-AM1), scheduled for launch late in 1999. This paper describes the proposed early mission operations of MOPITT.

Keywords: MOPITT, EOS-AM1, Terra, Methane, Carbon Monoxide, Correlation Spectroscopy, Infra Red

1. INTRODUCTION

1.1 Science Goals

The objective of the **M**easurements **O**f **P**ollution **I**n **T**he **T**roposphere (MOPITT) experiment is to measure some of the pollutants in the lower atmosphere, in particular the global concentrations of carbon monoxide (CO) and methane (CH_4). The instrument will be flown on the EOS-AM1 platform, scheduled for launch from Vandenberg Airforce Base in late1999, and is designed for a five year mission life. The results will not only be used to map the global CO and CH_4 concentrations but will also be assimilated into 3-D models in order to study the chemistry and dynamics of the lower atmosphere.

CO is a relatively short lived gas (3 months) in the troposphere and is thus susceptible to atmospheric transport phenomena without completely mixing, it exhibits a three to one inter-hemispheric surface difference [1] (50-150 ppbv). CO profiles and column measurements will be used to identify surface sources, natural and anthropogenic. The profile measurements will reflect the CO concentration in the lower, mid and upper troposphere and improve understanding of the transport properties from surface source to the upper layers. Global CO measurements will also help in understanding the chemistry of the OH (hydroxyl) radical, which due to its short life (2 minutes) and low concentration cannot be directly measured (CO along with Nitrogen Oxide and Ozone are the major agents in the recycling of OH and HO_2). The OH radical induces much of the chemical activity in the troposphere. In spite of its importance the only global CO tropospheric data set is that measured by Reichle et al [2] using the MAPS instrument (**M**easurement of **A**tmospheric **P**ollution from **S**atellites) on board the Space Shuttle. MOPITT will be the first instrument to comprehensively measure global concentrations and temporal variations.

CH_4 is the most abundant hydrocarbon in the atmosphere [3] ($\approx$1650 ppbv) and as an infra red (IR) active gas contributes to the greenhouse effect (at 7.7µm at the edge of the 8-13µm atmospheric window). It has a long lifetime (7 years) and as a result is almost completely mixed in the troposphere. It shows an 8% inter-hemispheric difference as well as a seasonal variation. Since CH_4 is well mixed, global column measurements are sufficient in order to identify surface sources (with 3-D tracer models). However since it is evenly mixed, higher precision is required to measure any global and temporal variations.

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1.2 Instrument Methodology

CO and CH_4 concentrations will be measured using correlation spectroscopy. The spectral selection of CO and CH_4 radiation is done with a sample of the same gas as a filter. The correlation effect refers to the fact that the gas cell spectral lines will align perfectly with the CO and CH_4 incoming radiance spectral lines. By modulating the gas between two states, in this case by either changing the path length or the gas pressure, the transmission at the frequencies of the spectral lines varies and an average and difference transmission is obtained. The difference signal carries information on the gas of interest whilst the average signal carries information on total incoming radiance (minus the gas of interest). A detailed discussion of correlation techniques can be found elsewhere [4,5,6].

The CO profile measurements are made using upwelling thermal radiance in the 4.6µm fundamental band. The troposphere is resolved into about four layers with approximately 3km vertical resolution, 22km horizontal resolution and 10% accuracy. Pressure Modulated Cells (PMCs) are used to view the upper layers whilst Length Modulated Cells (LMCs) are used for the lower troposphere measurements. By varying the cell pressures the modulators can be biased to view the different layers.

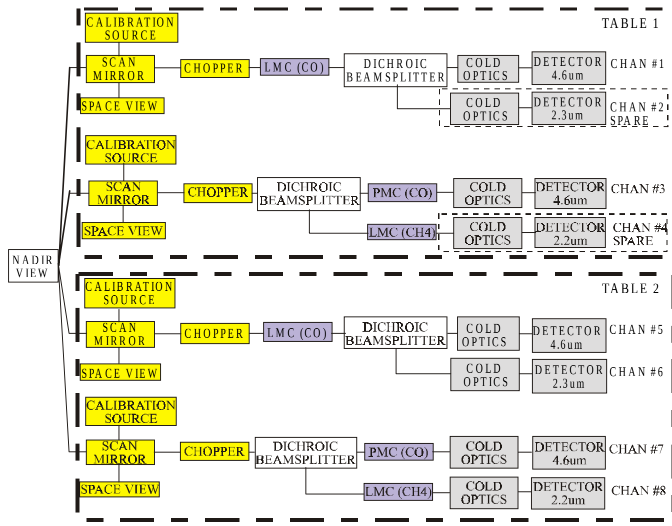

Figure 1 MOPITT Optical Schematic. Radiation enters from the left-hand side

CO and CH_4 column measurements are made using reflected solar radiance in the 2.3µm CO and the 2.2µm CH_4 bands. The horizontal resolution is 22km with a 10% and 1% precision requirement for the CO and CH_4 columns respectively. Column measurements will be made using LMCs and will only be possible over the sunlit side of the orbit. The MOPITT instrument requirements are summarised in Table 1 below.

Table 1 Summary of Science Requirements

Parameter	CO Profiles	CO Column	CH_4 Column
Wavelength (µm)	4.617	2.334	2.258
Mid Wave number (cm^{-1})	2166	4285	4430
Wave number Range (cm^{-1})	52	40	139
Modulator Type	LMC/PMC	LMC	LMC
Vertical Resolution (km)	3	-----	-----
Horizontal Resolution (km)	22 x 22	22 x 22	22 x 22
Temporal Resolution (secs)	0.4	0.4	0.4
Precision (%)	10	10	1

1.3 MOPITT Instrument Description

MOPITT is a scanning, nadir viewing eight channel IR radiometer. Figure 1 shows the optical system, the heart of the instrument, in diagrammatic form and Figure 2 shows the isometric layout. The instrument has two identical "mirror imaged" optical tables with calibration sources, scan mirrors, choppers, modulators and cold dewar assemblies containing the cold optics and detector packages. The dewar is cooled by a pair of low vibration, back to back Stirling Cycle Coolers (SCC's). The largest heat dissipating units, namely the coolers and cooler drive electronics modules, are located on the coldplate and other critical electronic modules are placed close to the coldplate.

The coldplate is located underneath the MOPITT baseplate (Figure 2). It is dedicated to the instrument and provides a stable thermal environment (20-25°C if the heat flux does not exceed $1W/in^2$). It operates using capillary action with ammonia as the working fluid. The loop extracts heat at the coldplate and radiatively rejects it to space. The coldplate is used as a thermal sink for all modules except the main power supply module which is thermally isolated from the baseplate and radiatively cooled to space (Figure 2).

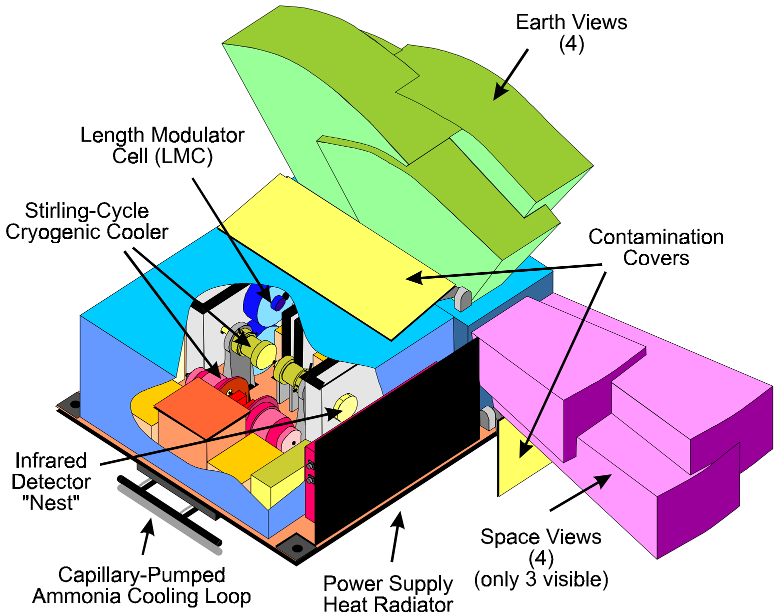

Figure 2. MOPITT Instrument Layout

The optical channel diagram (Figure 1) shows the four MOPITT inputs. The front end of each input consists of a calibration source, a deep space view, an input scan mirror and a chopper. Each beam is split resulting in eight output channels. Two inputs have modulator cells before the dichroic beam splitter and two have them after the beam splitter. This configuration minimises the number of modulator cells needed to make the required measurements. Fore, mid and rear optics are used to relay the beam from the input scan mirrors, through the modulator cells and onto the cooled detectors. Each detector is a four by one array, giving four pixels in-line along the velocity vector. This results in a 88 x 22 km imprint on the Earth (MOPITT has a 7.2 x 1.8° degree nadir field of view). However, in order to improve global coverage MOPITT uses cross track scanning. The input mirror scans across track by ±14 fields resulting in an overall Earth swath of 88 x 612 km. The same mirror also rotates through 90° to view "space" as radiation zero through ports on the side of the instrument and through a further 90° to view the calibrated blackbody sources.

Figure 1 shows that the CO and CH_4 column channels have full redundancy (channel 2 redundant with 6 and 4 redundant with 8). The profile channels (1,3,5 and 7) can be re-configured by changing fill pressure in order to cover for a failed channel.

A detailed description of the instrument is available in the MOPITT Mission Description Document [7] and a summary of the MOPITT channel characteristics is given in Table 2 below

Table 2 MOPITT Channel Characteristics

Channel Characteristics	**Ch 1**	**Ch 2**	**Ch 3**	**Ch 4**	**Ch 5**	**Ch 6**	**Ch 7**	**Ch 8**
Optical Table	#1				#2			
Scan Mirror/Chopper Number	#1		#2		#3		#4	
Modulator Type	LMC1		PMC1	LMC2	LMC3		PMC2	LMC4
Modulator Gas	CO		CO	CH_4	CO		CO	CH_4
Modulator Pressure (kPa)	20		7.5	80	80		3.8	80
Modulator Frequency (Hz)	11		52	11	11		42	11
Chopper Frequency (Hz)	518		518		600		600	
Filter Mid-Waveno. (cm^{-1})	2166	4285	2166	4430	2166	4285	2166	4430
Filter FWHM (cm^{-1})	2192-2140	4305-4265	2192-2140	4500-4360	2192-2140	4305-4265	2192-2140	4500-4360
5% Cut Off Waveno. (cm^{-1})	2199-2136	4316-4254	2199-2136	4519-4344	2199-2136	4316-4254	2199-4344	4519-4344
Minimum Peak Trans (%)	70	50	70	55	70	50	70	55
Out of band Blocking (%)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Filter Temperature (K)	95-110				95-110			
NER ($\mu W/m^2/sr$)	84	2.69	55	10.60	68	3.48	23.4	10.6

2.0 NORMAL OPERATIONS

2.1 Introduction

MOPITT is designed as a semi-autonomous instrument. It collects data in an unattended mode and only requires occasional commanding to complete the mission. Thus the nominal mode of operation is maintained through over 90% of the time. The nominal mode of operation consists of a regular scan of the planet's surface interspersed with calibration views of the space and internal targets. The timing of these events will be "tuned" on-orbit, the pre-selected values are given here.

2.2 Nominal Operations

The normal MOPITT scan (Figure 3) is an interlaced scan of 29 views (+- 14 views either side of nadir plus the nadir view) which is timed so as to nearly "tile" the planet under the spacecraft. Each view lasts approximately 0.45 seconds and the views are interlaced to make the left-right scanning equivalent to the right-left direction, thus reducing the moments on the spacecraft and evening the wear on the scan mirror drive mechanisms. A complete scan takes approximately 13 seconds.

After every 10 scans or 133 seconds, the mirrors are rotated to view deep space through a space-view port in the instrument. Since MOPITT operates in the thermal infrared, it is very sensitive to temperature changes and frequent calibration of the instrument zero is required to adjust for these changes.

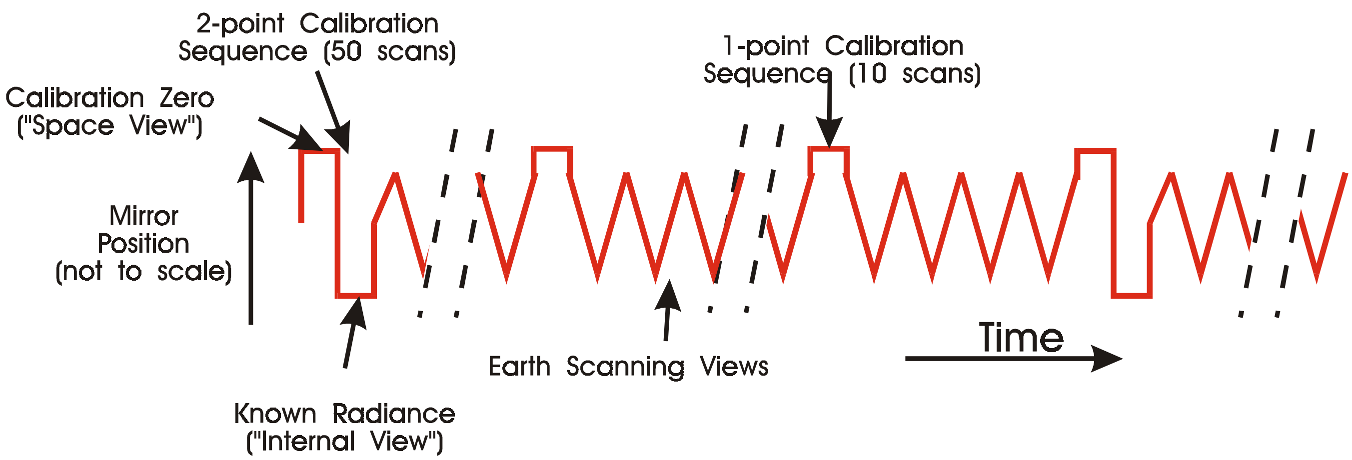

Figure 3. MOPITT Scanning Sequence

After fifty scans, the mirrors further rotate to view the internal calibration sources in the instrument. This, together with the space view provides a two-point calibration for the instrument.

Only the 4.7um channels (1,3,5 and 7) can be calibrated by this method. The 2.3/2.4um channels (2,4,6 and 8) receive too little radiation from the calibration targets at room, or near-room, temperature to enable a satisfactory calibration to be made. The calibration of the even-numbered channels is accomplished through a more intermittent "long calibration" which is initiated by ground command

2.3 Long Calibration

A long calibration sequence consists of heating four targets to a temperature of 400-450K. Because of power and design limitations, only one target can be heated at one time and the available power is low. Heating of a target takes about fourteen hours and therefore the four targets take about 56 hours overall. During the target heating, opportunity is taken to vary the drive parameters of the pressure modulator cells to trace out the resonance curve. This curve gives information about the cell pressure which is required in the retrieval.

It is apparent that during a long calibration sequence, the instrument thermal balance is disturbed. It is expected that during this time no usable scientific data will be generated and therefore there is a desire to minimize the time spent in this activity. A nominal timing of once per month is expected during normal operations.

2.4 Detector Decontamination

The detector and filter systems of MOPITT are run at about 100K. This cold temperature means that outgassing products from the instrument and nearby condense on the cold systems. This has been observed to reduce the gain of the optical systems and it is therefore necessary to prevent the layer from building up. This is accomplished by periodically turning the Stirling cycle coolers off and heating the detectors up. This process takes about 72hours in total since it is undesirable to heat the detectors up fast or to cool them down too fast. Since it can be expected that the vapor pressure of outgassing components will decline during the missions, it is expected that decontamination will be required at less frequent intervals. Previous experience on other spacecraft indicates that every three months may be adequate after the first year of operation.

3.0 INSTRUMENT ACTIVATION

3.1 Introduction

Launch is a very traumatic experience in many senses. Although the instrument has been designed to withstand the launch environment, there is a possibility of changes during launch and therefore a careful check of the systems is warranted. There are also early spacecraft operations that have a direct impact on the operation of the instrument which require special care. Finally, there is an extremely long period during which the instrument and the spacecraft are coming to an equilibrium and during this time there are significant changes in the environment which will lead to changes in the instrument calibration. All these dictate a thorough and cautious approach to instrument activation.

3.2 Activation Phases

There are three phases to the activation of the instrument. Each phase lasts approximately 30 days. In the first phase the instrument is brought on-line and basic functionality is verified. In the second phase the operational and calibration parameters are determined. In the third phase the scientific aspects of the data are dealt with. During all three phases the spacecraft and the other instruments on the platform are undergoing a similar process and some account must be taken of those activities.

The MOPITT activities are detailed on the MOPITT activation timeline which is part of the Integrated Mission Timeline (IMT). A simplified version of the timeline is given in Table 3.

Table 3 MOPITT Activation Timeline (Simplified)

Day after Launch	**Activation Phase**	**Activity**
0	Launch	Survival Mode
6	Initial Check-out	Activate cooling loop and apply power
23	Initial Check-out	Open Doors
23-36	Initial Check-out	Verify engineering and outgas
36	Operational Parameters and Calibration	Activate coolers and detectors
36-65	Operational Parameters and Calibration	Verify signal channels and performance
36-65	Operational Parameters and Calibration	Primary Calibration
65	Operational Parameters and Calibration	MOPITT fully operational (engineering)
65-90	Science Parameters	
65-90	Science Parameters	Cell parameters confirmed
65-90	Science Parameters	FOV validation
65-90	Science Parameters	Main Instrument Validation begins

3.3 Launch

The MOPITT instrument will be powered at launch to provide a slow rotation of the mechanisms. This strategy is used to ensure that the minimum stress is placed on the bearings at launch to reduce a phenomenon known as "brinelling". Immediately after launch the instrument is placed in survival (least power) mode while the spacecraft is placed in the appropriate orbit and the spacecraft systems are activated.

The limitations to activating MOPITT are the spacecraft operations schedule and the activation of the Capillary-Pumped Heat Transfer System (CPHTS) which removes much of the heat from MOPITT. Once this system is available MOPITT can be turned on and given the initial check-out.

3.4 Initial Check-out

During the initial check-out phase the instrument mechanisms are initialized and verified. Besides the obvious benefits of this activity, the resultant power usage heats the instrument up and accelerates the out-gassing from the instrument structure. At day 23 it is judged that the contamination from outside the instrument is smaller than that within and the doors are opened to accelerate the minute flow of products away from the instrument. All available heaters are exercised at this time to ensure that they are operational and to accelerate the out-gassing process.

During this time the cooling system for the detectors is not active and only engineering data are collected. This phase closes with the activation of the Stirling Cycle coolers on day 36 and the subsequent activation of the science data channels.

3.5 Operational Parameters and Calibrations

With the science channels active, the second phase permits the operations team to verify the operational parameters. The instrument computer is loaded with the appropriate values of these parameters determined from ground testing, but these need to be verified on launch. The major parameters are the phasing of the signal collection with the mechanisms, which are collectively referred to as the "blanking and processing" parameters. These need to be exercised through all the possible values on each of the eight channels and, after review by the science team, the best values are selected which are most likely to be the default values.

Primary calibration is now performed on all eight channels. Since the degree of out-gassing is not known at this time, some time is permitted for decontamination of the cooler system and this stretches out the time required. Other spacecraft constraints also increase the time required.

At the end of the second phase of the activation at day 65 the instrument is set up correctly from an engineering standpoint. A few additional procedures are performed to ensure that the spacecraft is providing all necessary services to MOPITT in both normal and contingency situations.

3.6 Science Parameters

The third phase of the activation requires the scientific interpretation of the data and is dependent upon the availability of at least Level 1 (geophysical and/or engineering units) data. One such activity is the verification of the location of the MOPITT fields-of-view (FOVs).

The MOPITT FOVs were co-aligned pre-flight to an accuracy an equivalent of about +-2km on the surface. The MOPITT pixel is 22km square. The instrument was installed into the satellite with a similar knowledge of location relative to the satellite axes. Launch could disturb the relative alignment of the four scanning mirrors, and with somewhat less likelihood disturb the alignment relative to the spacecraft axes. This would create difficulties in the analysis, particularly in the cloud-clearing algorithms if the relative alignment changed. Thus it is important that the alignment be verified in-flight.

The alignment check will consist of observing times when the MOPITT signals change very suddenly in a known manner. This happens when the instrument traverses a coast-line from ocean to a desert or similar uniform surface. The coast-line is well-known from geographic data, the satellite position is also well-known, and so the geometric problem of the MOPITT FOV can be solved in one dimension. In order to obtain a solution in two dimensions and to reduce the errors in the method, several different coastlines will be used over a period of time to build up a complete picture of the MOPITT relative and absolute FOV alignment.

The pressure of the correlation cells in flight is also an issue and this third period of activation will permit us to optimize the pressure for the maximum science return.

3.6 Validation Activities

The final part of the activation which will occur during the third phase and beyond will be the validation of the MOPITT data using other instrumentation to measure the same gases, carbon monoxide and methane, co-located in time and space with MOPITT. A full validation plan has been prepared for the instrument. The latest version can be found at http://www.eos.ucar.edu/mopitt/val_plans.html. The plan involves a number of experimental groups using ground-based and airborne equipment for the validation. The use of the aircraft version of MOPITT, MOPITT-A, will also assist in this activity. More details on MOPITT-A are given elsewhere in this session.

Some of the groups who are involved in the validation effort have already made significant efforts in this endeavor. A pre-MOPITT Validation Experiment (pre-MOVE) was held in Oklahoma in March 1998[8] with the objective of intercomparing a number of different techniques and a second experiment will be held later this year in the Denver area.

Validation will be an on-going activity throughout the five years of the MOPITT flight. It is also necessary to attempt validation at as many geographic locations as possible. A global measurement set requires a global validation effort. To this end several international efforts are planned. There is a collaborative program in place with some Russian groups, discussions are being held with Argentina and MOPITT-A will participate in the SAFARI 2000 mission in Southern Africa. It is hoped that more validation efforts will be undertaken as the instrument data become available.

4.0 CONCLUSIONS

The early mission planning for the MOPITT instrument is well advanced. It requires participation from many groups for the varied activities that must be undertaken. It is hoped that after the first 90 days, that reliable calibrated and validated data will be available from the MOPITT instrument for the duration of the flight.

ACKNOWLEDGEMENTS

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