Microsats for Environmental Monitoring - and Some Current Canadian Initiatives

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Abstract:

This paper examines the usefulness of microsats for environmental monitoring. It is based in part on a study done by Routes Incorporated for the Canadian Space Agency in 1995, plus more recent information. We define microsats and their instruments as missions whose overall payload, platform, launch, ground segment and operations costs is within a $2M to $10M range. The paper describes several types of environmental atmospheric and earth surface monitoring task that could be achieved with microsats, e.g. observation of atmospheric phenomena such as polar stratospheric clouds, gravity waves and ozone profiles. Compact, simple, low-cost imaging spectrographs are candidates for earth surface monitoring. Currently, the Canadian Space Agency and other agencies have funded a number of preliminary design/assessment studies that will lead toward microsat environmental missions. The paper concludes by briefly describing these projects.

Introduction

The overall conclusion of the 1995 study [1] was that microsats definitely can be useful for nadir-looking atmospheric monitoring, such as total ozone measurements; they likely would be useful for limb-imaging monitoring; and microsat-sized instruments could readily investigate gravity waves, greenhouse gas measurement at various altitudes and polar stratospheric clouds. Meaningful multi-band imaging of land and water might also be achievable, using simple imaging spectrographs offering reasonable spectral resolution and spatial resolution on the order of 50-100m.

Microsats and Instruments

A microsat is defined primarily by its cost. It must be inexpensive, considering all eight cost elements *viz.* payload development, payload recurring cost, platform development, platform recurring cost, assembly integration and test, launch, ground station development and the first year of operation. Typically the total cost is in the range of $2-$10M US dollars per launched operating satellite. Microsats are usually launched as a group on one small launch vehicle such as Pegasus-XL, or else as a secondary payloads to a launch vehicle such as Delta or Ariane.

Microsats have one advantage over Pegasus class smallsats, in that for approximately the same amount of money several microsats can be inserted in an orbit plane to do multi-satellite coverage observations, yielding better temporal resolution and more complementary measurements than a single satellite. The drawback to a microsat is the limited size and power of the instrument it can carry. A challenge for an operational or near-operational microsat mission is to design in enough reliability to assure adequate availability and mission life. We assumed the following maximums for an instrument borne by a microsat:

maximum mass	20 kg
maximum stowed volume	20 x 20 x 10 inches
peak/orbital average power demand	20/15 W

Environmental Priorities

Readers are familiar with our Earth's environmental problems. Of course we also study the environment for pure scientific knowledge. Nevertheless the following are some of humankind's most important environmental priorities now, and will likely remain so for the next few generations:[2,3,4]

- Global warming
- Ozone depletion
- Air pollution
- Ocean pollution
- Pollution of inland and coastal waters
- Pollution of ground water, aquifers
- Acid rain/fog/clouds and resultant acidic deposition
- Deforestation and loss of habitat
- Extinction of animal, insect, fish and plant species
- Environmental accidents
- Disposal/storage of toxic substances and nuclear waste
  - weather change
  - Site remediation

They all result from human activities (anthropogenic) . Other environmental conditions such as volcanoes are simply the nature of the planet (natural variation).

Methodology

Considering the environmental priorities, Routes asked scientists to recommend tasks microsats might fulfill. Instruments types were then identified and assessed for compatibility with a microsat type of mission. Some of the environmental areas covered are as follows:

Global Warming and GCMs

A global average increase of approximately 0.6 C has been documented over the last 100 years, and most (not all) scientists believe it is anthropogenically caused. What is indisputable is that greenhouse gasses (GHG's) have increased since the late 1800's. Water is the most important GHG. Other GHG's are carbon dioxide, methane, and nitrous oxide These are sometimes referred to as trace gasses because altogether they are still a very small percentage of the atmosphere. As we all know, CFC's have also increased.

Predictions for global warming and other phenomena are made using General Circulation Model's (GCM's). There are a number of GCM's but to date (1995) they all have limitations and they don't correlate well with each other. One shortcoming is the coarseness of the global grid areas used in the models. But smaller grid areas require more computing power and more localized measurements. Another shortcoming is the challenge of understanding and subsequently modeling the effects of clouds. Another area that needs work is understanding the boundaries between layers of the atmosphere and measurements are needed for tracer species to understand more about the transfer across boundaries. For example for flow across the tropopause, measurements can be made of ClO3, O3, NO2, ClONO2, HCl, N2O5, CH4, water vapor and CFC's. Sets of microsats carrying environmental sensing instruments could therefore fill in some of the data needed to improve GCM's.

Air Pollution

Carbon monoxide (CO) is the most prevalent pollutant by weight, and correspondingly transportation is the largest sector causing air pollution. (CO is absorbed by the ground fairly readily, otherwise it would be a lethal hazard.)

Aerosols are solid particles and liquid droplets that are small enough to remain suspended in air. Depending on their size this can be for days to months. They include soot (carbon), dust, smoke, pollen, asbestos, arsenic, sulfuric acid, PCB's, oil, pesticides, metals such as iron, copper, lead plus numerous other substances. Some are obviously hazardous to human health, others are probably not in small quantities . Extremely small particles less than 10 μm in size (called PM-10) can penetrate the human lung's screening defenses.

Ozone Depletion in the Stratosphere and Mesosphere

While ozone in the troposphere is an irritating pollutant, ozone at higher altitudes is essential because it absorbs some 18 W/m^2 of UV radiation from the incoming sunlight (in the 200 to 300 nm spectral range) throughout the 20 to 50 km altitude region [5], and if this amount of UV radiation were not intercepted and absorbed before reaching the surface of the Earth, many species of biological life on earth would be stressed, humans particularly.

The observed shrinkage of the ozone layer in the Antarctic is most pronounced in September and October. The area of the "hole" is roughly twice that of the Antarctic land/ice mass. Ozone depletion over the Arctic is not as severe but still a major concern. Scientists suggest the difference may have to do with the different circulation pattern of air over the Arctic and the fact that the Arctic is warmer and has less clouds. But clouds (water vapor) aid in activating the chlorine molecules resulting from the CFC's.

Although CFC production has been curtailed since the Montreal Protocol of 1987, the problem is the 100 year or so lifetime of CFC's in the atmosphere and the long migration time of CFC molecules upward from the lower troposphere. Five billion kilograms of CFC's had been released into the troposphere as of 1993 and it will take decades for them to diffuse upwards to the stratosphere. Taking into account the Montreal protocol agreements and estimating the impact of the developing nations and world population growth the peak of the problem will likely occur in 10-30 years.

Measuring Ozone

Ozone and other gasses can be assessed by total column measurements from the ground or space, or measurements that indicate species density as a function of altitude. A fairly extensive ground-based system is now in place.

One technique to measure stratospheric ozone from space, suggested by D. Degenstein and E. Llewelyn of the University of Saskatchewan, is to measure scattered or transmitted light in the Hartley-Huggins and Chappuis bands. This can be done through occultation of sun or stars or direct viewing of incident scattered sunlight/moonlight. The technique requires a high resolution, vertical imaging, limb viewing, spectrograph, but with a limited wavelength range. This type of instrument is a candidate for a microsat.

A simple method of measuring mesospheric ozone is to monitor singlet delta (1.27 micron) molecular oxygen emissions. A vertical imager with filters giving multi-wavelength region coverage would suffice. By having three channels, each with a filter approximately 10 nm wide, centered on different parts of the singlet delta emission band, one can deduce temperature, band intensity and background intensity. This in fact will be part of the OSIRIS mission, and a simple near-infrared imager as described would in itself be a candidate instrument for a microsat.[6]

The infrared imager portion of OSIRIS provides a unique method for measuring ozone. It also assists in measuring the overall structure in the mesosphere. An instrument virtually identical to the IR Imager within OSIRIS onboard a spacecraft dedicated to collecting tomographic data would provide extremely useful atmospheric data. Limb staring is the preferred mode of operation for tomographic inversions. It could:

- Produce two dimensional (vertical and angle along satellite track) maps of mesospheric ozone and structures in the mesosphere.
- Produce two dimensional maps of aerosol clouds and PSCs

Measuring Trace Gasses

Methane and NOx molecules can also be measured by a simple spectrograph, similar to the type discussed. Also other trace gasses. For example the EOS TES (not a microsat instrument) will measure NO and HNO_3.

Measuring Wind and Temperature in the Stratosphere and Mesosphere

Airglow and/or aurora can be used as radiation emission sources to determine the temperature and wind of the upper atmosphere. Aurora is brighter, but only occurs over the poles and sporadically. Airglow is present day and night throughout the world. The emissions from the airglow occur at roughly 85 km.

Gravity Waves

Dr. R. Lowe of the University of Western Ontario suggested that gravity waves in the airglow could be studied very profitably with an instrument of the size weight and power described. He and colleagues operate a network of ground-based scanning radiometers for gravity wave studies, and the concept could be modified for space use. The hydroxyl radiation which they use is strong throughout the near infrared and is a good choice. The instrument would probably involve an InGaAs camera of some type.

An alternative simple instrument has been suggested by Dr. Brian Solheim and colleagues at York University, looking at molecular oxygen emissions in the 763 nanometer band. This instrument would be a relatively simple CCD camera with wide-field optics, imaging the limb from a gravity-gradient or 3-axis stabilized microsat.[7]

Clouds

Clouds are very important for GCM's and assessment of global warming. Low altitude clouds can be viewed with a variety of ground and airborne instruments, including multispectral imagers and radiometers.

Polar stratospheric clouds (PSC) seem to be part of the complex process of stratospheric ozone depletion, and they are god candidates for satellite measurements. PSCs are produced from condensation onto H_2SO_4 forming spherical, super cooled solution droplets (aerosols) by conversion of SO_2 to H_2SO_4 vapor through oxidation with OH radicals. A vertical imaging spectrograph with the ability to make polarization measurements would be useful to investigate PSCs. It would also be able to measure scattered light from other aerosols. Tomographic inversions could be made to provide a two dimensional map of PSC's. Spatial extent information of individual PSCs is not currently available.

Land and Water Measurements

Dr. Catherine Bjerklund of Canada Centre for Remote Sensing (CCRS), and others, noted that since airborne multispectral imagers are well suited to water observations, a simple satellite-borne imaging spectrograph would also be a very useful tool, even if its spatial resolution was not high. Forests and agriculture could be monitored using the same instrument. Likely it would use a CCD, possibly also an InGaAs detector, folded optics and it would have to fit a microsat's volume and budget.

Regarding agriculture, Dr. Dan Pennock of the University of Saskatchewan said, "In order for measurements to be useful to people in the agricultural community the data must be timely and easily accessible. The problem agricultural scientists have with existing satellites is that they can only get the very expensive data months or even years after it is produced."
He added the ground coverage resolution for such measurements can be coarse, even one kilometer, as long as the data arrived in time.

Assessment

Instruments were assessed considering four factors: as shown below. Assessments are shown on the following page.

Factor	Explanation	Grades		
Interface Constraints	Fit within the mass/weight/power 'box'?	Yes	No	?
Utility	How useful will the observations be?	High	Mod.	Low
Dev. Cost	Fit in cost 'box' ?	High $1.5M - $3M	Mod. $500K - $1.5M	Low L.T. $500K
Recurring Cost	Recurring models ?	High $500K - $1M	Mod. $200K - $500K	Low $25 - 200K

Instrument Type	Function and Description	Potential for a Microsat.	I/F	Utility	Dev.$	Rec. $
Brewer spectrophotometer	measure total column ozone	ground based instrument, many stations worldwide. Small version now being developed that will fit onto a Microsat	Yes	High	Low	Low
Fabry-Perot interferometer	measure wind temperatures, velocities and trace gasses	airborne instruments	Yes	Mod	High	Mod
Gas Correlation Radiometer	Measure carbon monoxide, CH4 SO2 and NO2 and N2O.	Resonance Inc. now building a space instrument that would fit onto a Microsat	Yes	High	Low	Low
Michelson Interferometer	Measure upper atmosphere winds and trace gasses. Best examples is WINDII. A mesospheric wind MI instrument, called MIMI is now in the preliminary design stage.	MIMI is smaller than WINDII, but still not likely to be compatible with a Microsat volume.	Probably Not	Mod	High	High
Three channel near infrared imager	Can deduce ozone, possibly measure gravity waves.	Essentially the 1.27 μm subsystem of OSIRIS	Yes	High	Low	Low
NIR (1-3μm) imaging spectrograph	Using a 2-D InGaAs detector. Could detect trace species.	The microsat version would use passive cooling for the detector.	Yes	High	High	Mod
Ultraviolet spectrograph	Trace species and aerosols in the troposphere and atmosphere	UV spectrograph design developed for AURIO would fit on a Microsat. .	Yes	Mod	High	Mod
Visible region imager	Spatial observations, multispectral, of land, cloud cover, water surface, ice, snow, O2 emissions.	An inexpensive 50-100 m spatial resolution version for a microsat.	Yes	High	High	Low
Visible region spectrograph (vertical slit)	Emission lines of trace gasses, and aerosols in troposphere and stratosphere. Also PSC's.	Based on OSIRIS or ALIVE designs.	Yes	High	Mod	Mod

Canadian Microsat Environmental Missions

The following missions or instrument concepts are now being studied in Canada. Most are funded by CSA:

Microsat Experiment for Sounding Oxygen Atomic Densities (MESO)

Dr. Ian McDade of York University in Toronto is the P.I. The objective is to measure global distributions of atomic oxygen in the upper mesosphere and lower thermosphere. Conventional filter photometers are being used in a simple instrument that would point toward the nadir from a microsat.

Mesospheric Imaging Michelson Interferometer (MIMI).

This is NOT a microsat instrument, but it is an interesting follow-on from the very successful WINDII instrument that flew on NASA's Upper Atmosphere Research Satellite (UARS). MIMI would fly on a small satellite.

Mesopause Temperature Limb Sounder (MTLS)

The conceptual design of this instrument has been completed. The Principal Investigators are from the University of western Ontario in London, Ontario. It will measure global temperature in the mesopause region using limb measurements of the hydroxyl night airglow.

Bistatic Observations Using Low-Altitude Satellites (BOLAS).

This mission is now beginning to be developed as one of the CSA Small Payloads Program mission studies. Dr. Gordon James is the P.I. Routes Inc. is participating. Bristol Aerospace, Winnipeg, is developing the bus design. This would be a Canada-NASA collaborative effort, using two very small microsats, attached by a tether, and flown as a secondary payload to a Delta. BOLAS will continue the tether dynamics and Ionospheric wave electromagnetic propagation science last done on the OEDIPU-C sounding rocket mission.[8]

A Limb Imaging Vertical Spectrograph Experiment (ALIVE)

Dr. Ian McDade of York University, Toronto, is leading this instrument definition study. Routes Inc. is participating. In a sense this instrument study is an outcome from a recommendation made in our 1995 report for CSA, as well as work on the OSIRIS project.

Polar Outflow Probe (POP)

This microsat mission, now under study, will investigate plasma flow processes in the 300-2000 km region of the polar ionosphere. Though perhaps not strictly an environmental mission as we have defined it , POP is exciting space science which will lead to better understanding of earth's overall atmospheric processes. Dr. Andrew Yau of the University of Calgary is the P.I.

Conclusion

This paper outlines some useful environmental measurements that can readily be done in an operational, or near-operational program using microsats. Our survey indicated that timeliness of delivery of data to end users was one of the most sought after features for any environmental monitoring program. The paper concludes by listing some exciting microsat and small sat missions and instruments now under funded study in Canada.

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