PHY 499S

Section 1: Introduction to Earth Observations

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References for Section 1 - Introduction

- *Kidder and Vonder Haar: chapter 1*
- *Houghton, Taylor, and Rodgers: chapter 2*
- *Jelly, Canada: 25 Years in Space, Polyscience Pubs. Inc., Montreal, 1988*

Why Observe the Earth and Its Atmosphere?

- To understand the chemical and physical processes occurring on the land surface, in polar regions (the cryosphere), in the oceans, and in the atmosphere
- To monitor temporal and spatial changes due to natural and anthropogenic causes (e.g., Antarctic ozone hole, El Nino, greenhouse effect)
- To enable predictions of future conditions (e.g., weather forecasting, disaster control)

What Can Be Measured?

- Atmospheric properties :
  - → chemical composition
  - → temperature and pressure
  - → precipitation
  - → clouds and aerosols
  - → winds
  - → radiation budget
- Surface properties :
  - → oceans – surface temperature, height, currents
  - → ice – distribution and motion of ice sheets and sea ice
  - → geology – rock types, faults, plate motions, Earth's shape
  - → surface elevation
  - → vegetation, soil types, land use
  - → water resources

How Do We Observe Earth and Its Atmosphere?

1) extractive techniques
   - → collection of samples for later laboratory analysis
   - → high sensitivity and selectivity, poor real-time monitoring, possible contamination problems

2) in situ techniques
   - → direct measurement at the location of the instrument
   - → lower sensitivity and selectivity, good real-time monitoring, limited spatial coverage, possible contamination problems

3) remote sensing/sounding techniques
   - → "measurement at a distance"

remote <u>sensing</u> → generally applies to observations of the surface

remote <u>sounding</u> → generally applies to observations of the atmosphere

Remote Sensing / Sounding

"Measurement at a distance"

- Information is carried by electromagnetic radiation
- Provides a method of obtaining information about the properties of the atmosphere without coming into physical contact with it.
  - → in contrast to extractive or in situ techniques
- Advantages
  - → no perturbation of the sample being observed
  - → sensitive to many gases and surfaces
  - → can provide point, column or profile data
- Disadvantages
  - → limited spatial resolution
  - → interpretation of data can be difficult

Remote Sensing / Sounding

- Because the location of the object of interest is a distance away from a remote sensing/sounding instrument, the information must be propagated in some way.
- In this course, we will concentrate on remote sensing/sounding techniques for which the information is carried by electromagnetic radiation.

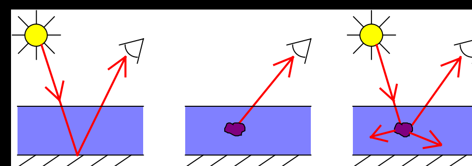
  e.g., excludes sonar, seismic, geomagnetic techniques

Remote Sounding Approaches

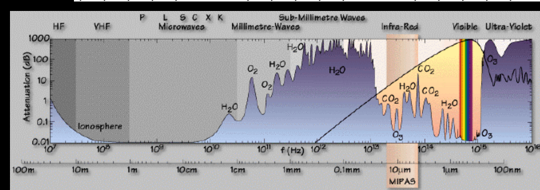
Remote sounding techniques can be classified by:

1) Radiation source
- → passive – use natural radiation (solar, stellar, terrestrial)
- → active – use artificial sources of radiation (lasers, radar)

2) Type of interaction between radiation and the atmosphere
- → absorption
- → emission
- → scattering



3) Spectral region
- → ultraviolet
- → visible
- → infrared
- → microwave



Remote Sounding Platforms

Remote sounding can be performed from many platforms:

- Ground
- Balloons
- Aircraft
- Rockets
- Space shuttle ⇐ Focus of
- Satellites ⇐ this course
- Interplanetary spacecraft

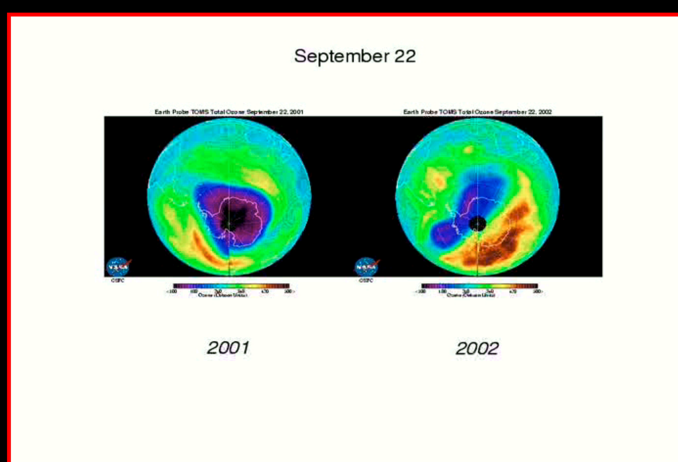
Why Study Earth from Space?

- Provides a unique global view
- Allows us to see all parts of the Earth regularly
- Easier to study the atmosphere looking down from above than looking up from below

Example: Antarctic Ozone Hole

Unusual double Ozone Hole over Antarctica in 2002:

15 million sq. km, well below ~25 million sq. km seen in last six years.



Caused by peculiar stratospheric weather patterns in 2002 with warmer-than-normal temperatures over Antarctica.

Ground-Based Measurements

Advantages:

- Can provide long time series and high temporal resolution
- Enable simultaneous measurements of many trace gases under well-calibrated conditions
- Allow comparison and development of different techniques
- Essential for the validation of new satellite instruments
- Inexpensive compared to balloons, rockets, satellites

Example: Network for the Detection of Stratospheric Change

- "formed to provide a consistent, standardised set of long-term measurements of atmospheric trace gases, particles, and physical parameters via a suite of globally distributed sites"

Balloon-Based Measurements

Advantages:

- Carry a variety of instruments, payloads up to several tons
- Reach float altitudes of 40 km
- Provide height-resolved measurements
- Can be designed for special flights, e.g., long duration
- Inexpensive compared to rockets and satellites

Disadvantages:

- Depend on meteorological conditions at launch and float
- Logistical factors
- Don't provide global view or long time series
- More expensive than ground-based measurements

Space-Based Measurements

Advantages:

- Provide a unique global view
- Provide comprehensive coverage and sampling not available from any other platform, so that all parts of the Earth can be observed regularly
- Can provide total column or height-resolved measurements
- Easier to study all but the lowest layers of the atmosphere looking down from above than looking up from below

Disadvantages:

- Expensive and high risk
- Require complex space-qualified instrumentation
- Can have limited lifetimes (~a few years)

Applications of Space-Based Measurements

- atmospheric science
- meteorology and climatology
- agriculture, forestry, botany
- planning applications
- geology
- geodesy
- hydrology
- oceanography
- glaciology
- mapping
- disaster control
- military applications
- archaeology *etc...*

E.g.: Atmospheric Measurements

- Measurements of trace gases, aerosols, and physical parameters are essential for studying global change.
- Such measurements
  - → provide information on the temporal and spatial variability of atmospheric composition and structure
  - → allow early detection and long-term monitoring of changes in the physical and chemical state of the atmosphere
  - → provide the means to determine the causes of such changes
  - → establish links between such phenomena as changes in stratospheric ozone, UV radiation at the ground, tropospheric chemistry, and climate
- Atmospheric measurements are also needed for testing and improving multidimensional models of both the stratosphere and the troposphere.

What Measurements Are Needed?

Long-term global observations are needed:

- To further improve our understanding of the coupled processes controlling the global climate system
- To understand how the atmosphere is changing with time
- To assess the accuracy of models and their predictions
- To elucidate the links between ozone and climate change

Required measurements:

- Chemical composition
  - → greenhouse gases, ozone, source gases, reactive gases, reservoirs, dynamical tracers
- Related atmospheric variables
  - → T and P, precipitation, clouds, aerosols, radiation, winds

Remote Sounding - Some History 1

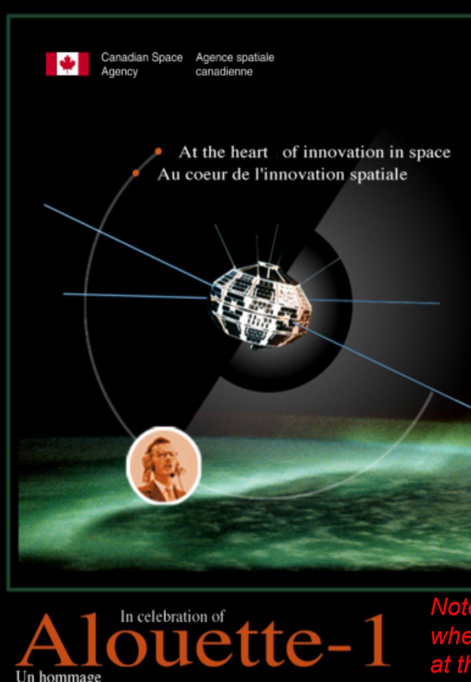
- 1858 - Tournachon made the first aerial photograph from a balloon floating at 80 m
- 1860 – Jules Verne wrote about "lunanauts" observing clouds
- late 1800s – balloons used to measure pressure, temperature, and humidity in the lower atmosphere, leading to the discovery of the tropopause at 10-15 km (met with disbelief)
- 1909 – first aerial photographs recorded from airplanes
- late 1940s – rockets used to probe the upper atmosphere
- 1945 – Arthur C. Clarke proposed the use of three satellites in geostationary orbit for global communications (Wireless World radio journal, October 1945)
- 1947 – Arthur C. Clarke predicted manned satellites by 1970 (Prelude to Space)

Remote Sounding - Some History 2

- 1954 – governing committee of the International Geophysical Year (IGY) challenged nations of the world to launch scientifically instrumented satellites to complement ground, balloon, and rocket observations of Earth
- October 4, 1957 – USSR launched Sputnik 1, Earth's first artificial satellite
  - → 92 day lifetime, 1400 orbits, 216 km altitude
  - → 58 cm diameter shell with instruments inside to measure temperature and to emit radio signals
- Sputnik 2 (November, 1957) – carried the dog Laika
- Sputnik 3 (May, 1958) – 970 kg payload of instruments to measure pressure and composition of the atmosphere, solar radiation, magnetic field, cosmic rays, micrometeorite impacts, and the satellite temperature

Remote Sounding - Some History 3

- January 31, 1958 – USA launched Explorer 1
  - → small cylinder 200 cm long, 15 cm in diameter, 14 kg
  - → measured cosmic ray intensities, meteorite impacts, and the satellite temperature
  - → discovered intense radiation zones – the Van Allen Belts
- September 29, 1962 – Canada launched Alouette 1
  - → third country to put a satellite into orbit
  - → included instruments to observe the ionosphere (300-1000 km) and energetic particles
  - → operated for 10 years (designed for 1-year lifetime)
- April 1, 1960 – TIROS 1 launched, first satellite dedicated to atmospheric measurements (TIROS = Television and Infrared Observational Satellite)



- **First Canadian satellite**
- **Launched 1962**
- **Studied ionosphere**
- **Made Canada the third country in space**
- **Canada was the first nation to go into space solely for peaceful, scientific enquiry**
- **1965-1971 three more Canadian science satellites**

Note: Canadian space science began in 1839 when Sir Edward Sabine set up an observatory at the University of Toronto to study Earth's magnetism.

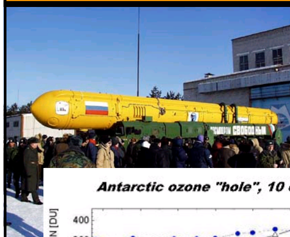
Remote Sounding - Some History 4

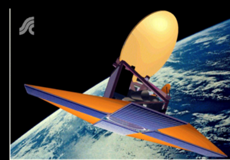
- This was followed by
  - → nine more TIROS satellites (1960-1965)
  - → seven Nimbus satellites (experimental atmospheric measurements)
  - → nine ESSA (= Environmental Science Service Administration) satellites for operational meteorology
  - → many subsequent meteorological satellites
- July 23, 1972 – Landsat 1 launched, first satellite for remote sensing of the Earth's surface
- Since then …
  - → between 1957 and 1986 – 2869 satellite launches
  - → 1809 satellites were in orbit on December 31, 1988
  - → an average of 120 satellites launched every year since 1967:
    - * ~60% military
    - * ~16% science
    - * ~8% communications
    - * ~4% meteorology
    - * <4% manned missions
    - * ~8% development

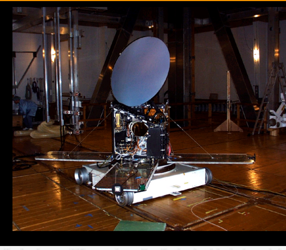
Canadian Space Missions to Study the Atmosphere

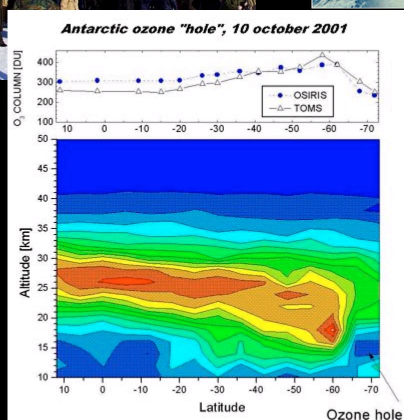
- WINDII (on UARS) - 1991
- MOPITT (on Terra) - 1999
- OSIRIS (on Odin) - 2001
- MANTRA balloon missions - 1998 to 2004
- ACE (on SCISAT) - 2003
- CloudSat - 2005
- SWIFT - 2007?

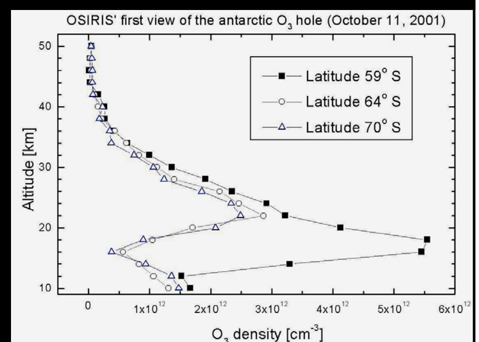
Optical Spectrograph and InfraRed Imager System











MANTRA Balloon Missions

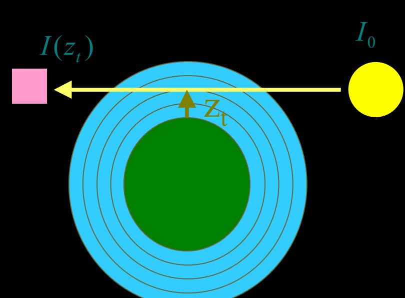
- Series of campaigns to study the ozone layer
- Measurements are made from ~35 km (near-space)

Atmospheric Chemistry Experiment

- Launched on SCISAT-1 on August 12, 2003
- 1st Canadian science satellite in 30 years

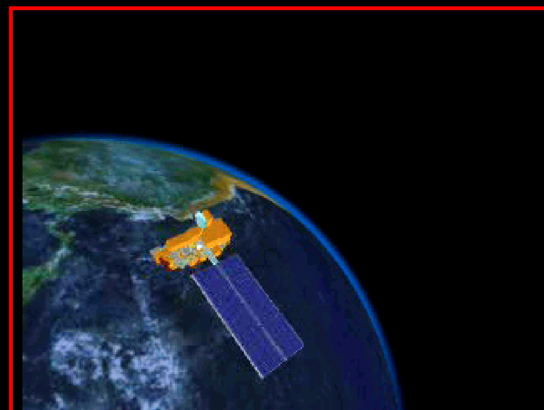
Atmospheric Chemistry Experiment

- Carries two instruments to measure gases and aerosols using solar occultation
- Goal: to gain a better understanding of stratospheric ozone processes

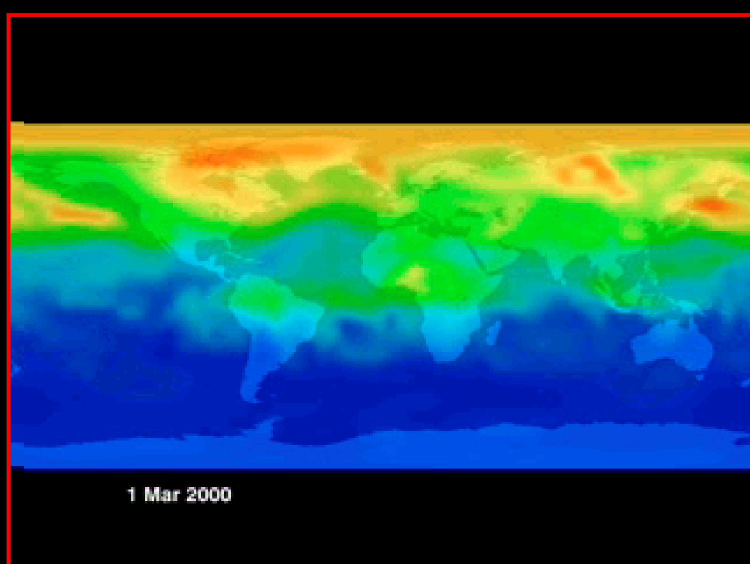


Measurements Of Pollution In The Troposphere

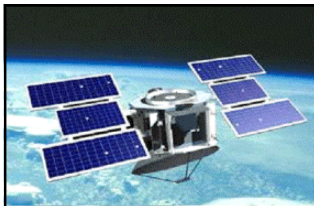
First major instrument to measure pollution from space (carbon monoxide and methane)



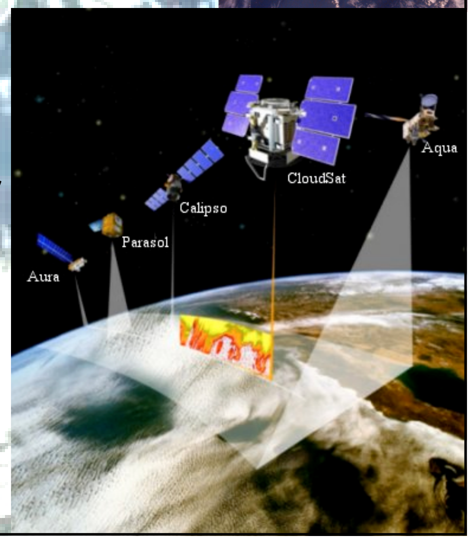
Measurements Of Pollution In The Troposphere



CloudSat

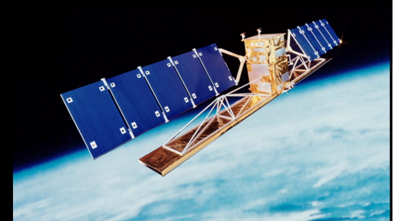


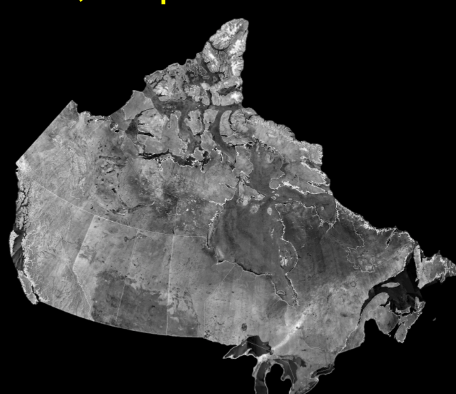
- Launch: 2005
- First vertical cloud profiling from space
- Goal: to improve weather forecasts and understanding of key climate processes
- Canada providing:
  - → amplifier for cloud radar
  - → receiver for radio electronics subsystem



RADARSAT-1

Canada's first commercial Earth Observation satellite (1995; #2 planned for 2005)





Collects images of the Earth day and night and through clouds using a powerful microwave Radar system

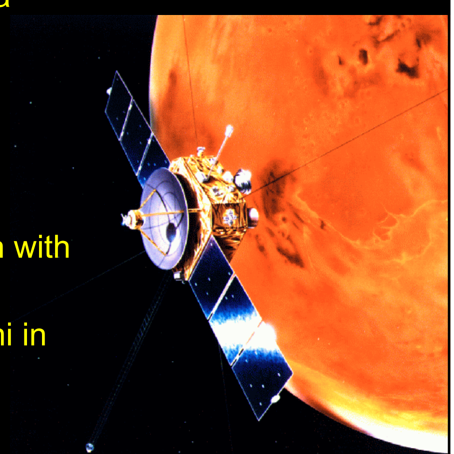
Canadian Space Exploration

- Canada aims to play a major role in a scientific mission to Mars in this decade.
- Scientists wish to learn more about the climate and geology of Mars.
- They also want to prepare the way for human exploration.
- They would like to answer the most intriguing question of all: is there, or was there ever, life on Mars?

Canada's First Mars Mission

Thermal Plasma Analyzer

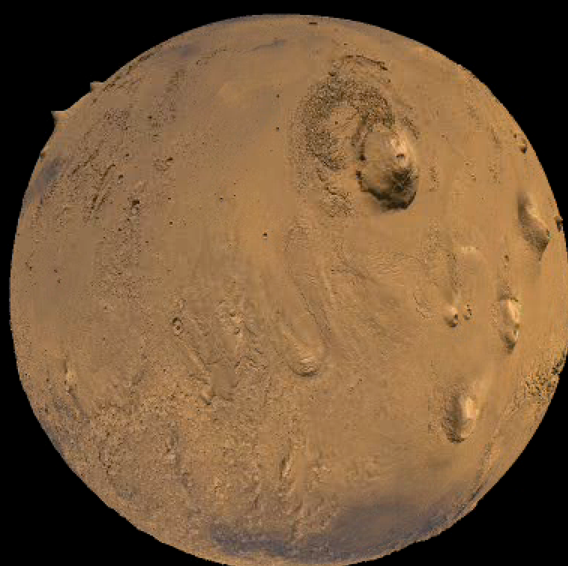
- Canada's first involvement in a mission to another planet
- Launched in 1998
- One of 14 instruments on the Japanese spacecraft Nozomi
- Was to to study the Martian atmosphere and its interaction with the solar wind
- In 2003, attempt to put Nozomi in orbit around Mars failed



Next Mars Mission: Phoenix

- In August 2003, NASA selected the "Phoenix" Scout mission to go to Mars in 2007.
- Phoenix will land on the surface of Mars.

- Canada will provide a meteorological station and lidar to study the Martian atmosphere and provide detailed information on dust and water-ice clouds in the atmosphere.
- Primary Canadian participants: CSA, York U, Optech



SAMPLE FLEDERMAUS VISUALIZATION