PCW/PHEOS-WCA: Quasi-geostationary viewing of the Arctic of the Arctic and environs for Weather, Climate and Air quality

Polar Communications & Weather (PCW) Mission

Mission proposed to focus on Arctic:
- **Goal** to provide 24x7 quasi-geostationary coverage with
- Two satellites in Highly Elliptical Orbits with 12 - 24 hour periods
- Baseline meteorological instrument
  - 21-channel (V+NIR+MIR) spectral imager similar to MODIS or ABI
  - Imagery refresh rate: 20 min
- Visible pixel resolution goal: 0.5 km
- Infrared pixel resolution goal: 3 km
Mission Objectives

- **Reliable communications services** in the high latitudes (North of 70°) to ensure:
  - Security
  - Sustainable Development
  - Support to Northern Communities
  - Safety of the Air and Marine Navigation
  - Arctic Science

- Provide **high temporal/spatial resolution meteorological data** above 50° N in support of:
  - Numerical Weather Prediction (short to medium range)
  - Environmental monitoring, emergency response
  - Climate change monitoring

- **Space weather monitoring**

CMOS Congress, Montreal, 29th May, 2012

---

**Why Geostationary?**

**HEO / Molnya**
- Apogee: 39850.5 km
- Perigee: 500 km
- Inclination: 63.4°
- Sensor: 4.5° × 4.5°

**LEO (Terra)**
- Apogee: 703 km
- Perigee: 702 km
- Inclination: 98.2°
- Swath: 300 km
Viewing geometry from Molnya orbit locations. The 3 views are for an apogee at 90°W longitude. Images have been scaled to show approximate angular size difference due to altitude change over the 8 hr period they span. Note that rotation of the Earth almost exactly compensates for satellite motion in longitude.

Air quality – summer Hi-Pressure  Boreal Forest burning/Volcanoes

Apogee – 4 hours  Apogee  Apogee + 4 hours
### PHEOS: Polar Highly Elliptical Orbital Science for PCW

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Spectral Range</th>
<th>Spectral Resolution</th>
<th>Spatial Resolution</th>
<th>Some Species</th>
</tr>
</thead>
</table>
| FTS        | 700-1500 cm\(^{-1}\)  
200-2700 cm\(^{-1}\)  
5990-6010 cm\(^{-1}\)  
13060-13168 cm\(^{-1}\) | 0.25 cm\(^{-1}\) 0.5 cm\(^{-1}\) | 10x10 km\(^2\) | H\(_2\)O, T, CO, O\(_3\), HNO\(_3\), NH\(_3\), CH\(_4\), CO\(_2\), CH\(_4\), ... |
| UV-Vis     | 280 – 650 nm | 1 nm | 6.8 x 8.5 km\(^2\) | O\(_3\), NO\(_2\), HCHO, BrO, SO\(_2\), ... |

- May be some adjustments to these bands / resolutions to be fully compliant with configuration required by CSA
  - For example, splitting or limiting NIR band in FTS

---

**PHEMOS IFTS Scan Pattern**

- UVS – push broom

- Deep space cal ~ 10 degrees from center of FOR
- 42 stares to cover FOR
- Chess board pattern (half the pixels)
- GIFOV at nadir at 42 100 km
- 10 x 10 km all bands
- Nominally 1.25 hr repeat

**Field of Regard Limits**

**N.B.: FOV at approximate scale with Earth**
Instrument suite concept

Dimensions 30 wide x 32 deep x 38 cm high
Not including electronics modules

Baseline resources:
50kg, 100W and 30x30x30cm allocation;

Separate viewing apertures
UVS and FTS

Introduction: PHEOS Science Team

- Principal investigators:
  - J.C. McConnell, York University (science PI)
  - C.T. McElroy, York University (UVS PI)
  - K.A. Walker, University of Toronto (FTS PI)
  - B. H. Solheim, York University
  - K. Semeniuk, York University
  - Y. Chen, York University
  - A. Lupu, York University
  - V.-H. Peuch, ECWMF
  - I.C. McDade, York University
  - J. J. Shan, York University
  - W.F.J. Evans, York University
  - D. Jones, University of Toronto
  - K. Strong, University of Toronto
  - P. F. Fogal, University of Toronto
  - J. Drummond, Dalhousie University
  - R. Martin, Dalhousie University
  - T. Duck, Dalhousie University
  - N. O’Neill, University of Sherbrooke
  - K. Chance, HCO/SAO
  - L. Garand, Environment Canada

- Responsibilities:
  - ABB: Prime, IFTS
  - Science Team: Science
  - COM DEV: UVS
  - C. Clerbaux, ISPL, ULB
  - A. Royer, University of Sherbrooke
  - A. Hakami, Carleton University
  - D. Degenstein, U. of Saskatchewan
  - A. Bourassa, U. of Saskatchewan
  - P. Bernath, Old Dominion U.
  - C. Boone, University of Waterloo
  - B. Kerridge, RAL, UK
  - Y. Rochon, Environment Canada
  - C. Sioris, York University
  - A. Bourassa, U. of Saskatchewan
  - D. Degenstein, U. of Saskatchewan
  - P. Bernath, Old Dominion U.
Primary Mission Objectives

Weather – Air Quality – Climate Gases

• Improve weather forecasting and climate modelling in the Arctic
• Better understand the impact of industrial and agricultural pollution and Boreal forest burning on the Arctic
• Assess emissions of GHGs in Arctic Environs

Air Quality

• Goals:
  – Human and biosphere exposures, gaseous, PM
  – source estimates
• Low(er) latitude urban areas
  – Natural sources
    • Trees
    • Boreal forest burning
• High latitude industrial sources
  – Current Northern Industry
  – New oil, gas, mineral exploration
  – Ship traffic increasing
• Volcanoes
• Aircraft
Comparison of in-Arctic trends for black carbon, organic carbon, and SOx emissions under (a) high growth and (b) BAU (business as usual) scenarios. (Corbette al, 2010)

CMOS Congress, Montreal, 29th May, 2012

Target Meteorological Species + Temperature

<table>
<thead>
<tr>
<th>Data Product</th>
<th>Horizontal Resolution (km²)</th>
<th>Vertical Resolution (km)</th>
<th>Precision</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water vapour profile</td>
<td>10x10 (G)</td>
<td>2 km (G)</td>
<td>10%</td>
<td>FTS</td>
</tr>
<tr>
<td></td>
<td>20x20 (T)</td>
<td>3 km (T)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature profile</td>
<td>10x10 (G)</td>
<td>2 km (G)</td>
<td>1°C</td>
<td>FTS</td>
</tr>
<tr>
<td></td>
<td>20x20 (T)</td>
<td>3 km (T)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Mission Requirements

**Target Air quality Gases**

<table>
<thead>
<tr>
<th>Data Product</th>
<th>Horizontal Resolution (km²)</th>
<th>Vertical Res.</th>
<th>Typical col. (mole cm⁻²)</th>
<th>Precision</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>10x10 (G) 20x20 (T)</td>
<td>SC</td>
<td>0.8x10⁻¹⁹ – 3x10⁻¹⁹</td>
<td>3% (G)</td>
<td>5% (T)</td>
</tr>
<tr>
<td>Ozone</td>
<td>10x10 (G) 20x20 (T)</td>
<td>TC</td>
<td>0.3x10⁻¹⁸ – 2x10⁻¹⁸</td>
<td>5% (G),</td>
<td>15% (T)</td>
</tr>
<tr>
<td>NO₂</td>
<td>10x10 (G) 20x20 (T)</td>
<td>SC</td>
<td>10⁻¹⁵ – 10⁻¹⁶</td>
<td>3% (G),</td>
<td>5% (T)</td>
</tr>
<tr>
<td>CO</td>
<td>10x10 (G) 20x20 (T)</td>
<td>TC</td>
<td>1.3x10⁻¹⁸</td>
<td>5% (G),</td>
<td>15% (T)</td>
</tr>
</tbody>
</table>

**Anticipated Air quality Species:** HCHO, BrΟ, BrΟ, SO₂, HNO₃, PAN, CH₃OH, HCOOH, HCN, NH₃, CH₃COOH, Al (Aerosol Index), (HCO)₂

---

### Target PHEMOS Level 2 Products for GHG Assimilation

<table>
<thead>
<tr>
<th>Data Product</th>
<th>Horizontal Res. (km²)</th>
<th>Vert. Res.</th>
<th>Precision</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>10x10 (G) 20x20 (T)</td>
<td>C</td>
<td>4% (G), 10%(T)</td>
<td>FTS, bands 2, 3</td>
</tr>
<tr>
<td>CO₂</td>
<td>10x10 (G) 20x20 (T)</td>
<td>C</td>
<td>1% (G), 2%(T)</td>
<td>FTS Bands 1, 3</td>
</tr>
<tr>
<td>Surface Pressure</td>
<td>10x10 (G) 20x20 (T)</td>
<td>NA</td>
<td>0.1%</td>
<td>FTS Band 4</td>
</tr>
<tr>
<td>Aerosol OD O₂⁻A Band</td>
<td>10x10 (G) 20x20 (T)</td>
<td>TC</td>
<td>0.03 15% (G) 0.5 5% (G)</td>
<td>FTS Band 4</td>
</tr>
</tbody>
</table>
### Anticipated Air quality Species

<table>
<thead>
<tr>
<th>Data Product</th>
<th>Horizontal Resolution (km²)</th>
<th>Vertical Resolution</th>
<th>Range of Typical column amounts (molec. cm⁻²)</th>
<th>Precision (C1 below)</th>
<th>Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCHO</td>
<td>10x10</td>
<td>TC</td>
<td>5x10⁻⁷ - 5x10⁻⁵</td>
<td>10⁻⁴ (G), 2x10⁻⁴ (T)</td>
<td>UV/IR</td>
</tr>
<tr>
<td>BrO</td>
<td>10x10</td>
<td>C ≥ SC + TC</td>
<td>1-10⁻⁷ - 10⁻⁵</td>
<td></td>
<td>UV/IR</td>
</tr>
<tr>
<td>BrO</td>
<td>10x10</td>
<td>TC</td>
<td>1-10⁻⁷</td>
<td></td>
<td>UV/IR</td>
</tr>
<tr>
<td>SO₂</td>
<td>10x10</td>
<td>C</td>
<td>1-10⁻⁷ - 10⁻⁵</td>
<td></td>
<td>UV/IR, FTS</td>
</tr>
<tr>
<td>HNO₃</td>
<td>10x10</td>
<td>C</td>
<td>2x10⁻⁸ - 10⁻⁶</td>
<td></td>
<td>FTS</td>
</tr>
<tr>
<td>PAN</td>
<td>10x10 (G)</td>
<td>TC</td>
<td></td>
<td></td>
<td>FTS</td>
</tr>
<tr>
<td>CH₃CHO</td>
<td>10x10 (G)</td>
<td>TC</td>
<td>5-10⁻⁷ - 3-10⁻⁶</td>
<td></td>
<td>FTS</td>
</tr>
<tr>
<td>HCOOH</td>
<td>10x10 (G)</td>
<td>TC</td>
<td>5-10⁻⁷ - 3-10⁻⁶</td>
<td></td>
<td>FTS</td>
</tr>
<tr>
<td>HCN</td>
<td>10x10 (G)</td>
<td>TC</td>
<td>2-3-10⁻⁷</td>
<td></td>
<td>FTS</td>
</tr>
<tr>
<td>NH₃</td>
<td>10x10 (G)</td>
<td>TC</td>
<td>2-3-10⁻⁷</td>
<td></td>
<td>FTS</td>
</tr>
<tr>
<td>CH₂COOR</td>
<td>10x10 (G)</td>
<td>TC</td>
<td></td>
<td></td>
<td>FTS</td>
</tr>
<tr>
<td>AI (Aerosol Index)</td>
<td>10x10 (G)</td>
<td>C</td>
<td>1-10</td>
<td></td>
<td>UV/IR, FTS (band 4)</td>
</tr>
<tr>
<td>HCOO₂</td>
<td>10x10 (G)</td>
<td>TC</td>
<td>2-10⁻⁸ - 10⁻⁶</td>
<td></td>
<td>UV/IR</td>
</tr>
</tbody>
</table>

**Instrument and viewing considerations**

© ABB Group
PHEMOS MRR | Slide 23

© ABB Group
CMOS Congress, Montreal, 29th May, 2012
TAP viewing 2 satellites +/- 6 hours about Apogee

Jinjiun Shan and Yuan Ren, York U

- The period of the orbit is 57442.7 sec
- The eccentricity is 0.55
- The inclination is 63.4°
- The viewing angle with ground < 65°
1/ Meteorology
Weather forecast

2/ Atmospheric composition measurements
Climate gases monitoring
Understand atmospheric chemistry

**bonus**

3/ Operational applications
Eg fires detection, volcanic plumes
T + 2.5 heures

List of species that were measured/detected by IASI:
- H$_2$O
- CO
- N$_2$O
- O$_3$
- CO
- HNO$_3$
- HDO
- NH$_3$
- PAN
- HONO
- C$_2$H$_6$
- C$_2$H$_4$
- CH$_4$
- C$_2$H$_2$
- HCN
- OCS
- SO$_2$
- H$_2$S
Boreal Forests - Carbon Emissions
A new Carbon Data Assimilation system under development at Environment Canada

Boreal Forests: The largest contributor to the northern hemisphere carbon cycle and a major component of the global carbon cycle


Ray Nassar, EC

Number of Observations Obtained

<table>
<thead>
<tr>
<th></th>
<th>LEO 2009-07</th>
<th>TAP 2009-07</th>
</tr>
</thead>
<tbody>
<tr>
<td>~36 000 early afternoon obs</td>
<td>~2.7x10^6 daytime obs</td>
<td></td>
</tr>
</tbody>
</table>

after removing obs over ocean, sea-ice, old snow, clouds (cloud frac < 0.1)
Summer months give most northern high latitude observations
(Numbers must be verified)
CO₂ Summary and Conclusions

- OSSEs demonstrate larger CO₂ flux error reductions from HEO relative to LEO for northern mid- and high latitudes (accounting for observational coverage and sensitivity, surface properties, cloud cover, snow cover, etc.)

- Annual CO₂ biospheric flux uncertainties for “large province-sized regions” of Canada, Alaska, Northern Europe and Northern Asia are ~70% lower with TAP observations than from LEO, and more than 95% lower than a priori uncertainties (although transport errors, retrieval biases and horizontal spatial correlations have not yet been accounted for)

Links to other missions
- EPS MetOp
- NPOESS
- EarthCare - ESA
- Sentinel-5 precursor
- Sentinel-3
- PREMIER
- ESA MTG-I & MTG-S/Sentinel 4
- GEMS - Korea
- GEO-Cape - USA
Ground Segment: Overall Principles

- Three main data streams (DSn):
  - DS1: operational meteorological and air quality
    - Complement to PCW MP
  - DS2: special events (volcanic eruption, etc.)
  - DS3: research products

- Use the PCW Ground Segment for DS1 and DS2
- Use the PHEMOS Ground Segment for DS3

PHEOS Instrument Options

- Optimal Configuration
  - Address priority science objectives
  - Satisfies allocations
  - Satisfies threshold sensitivity requirements

- All Band Configuration

- Compliant Configuration
  - Address all science objectives
  - Slightly exceed allocations
  - Satisfies threshold sensitivity requirements
In this concept, the electronics has been packaged with the optics to reduce the overall volume. This is not the ideal thermal configuration. A more appropriate configuration would be to put the electronics in separate boxes mounted in the spacecraft. The overall volume occupied by the electronics is 9600 cm³.
Conclusions

- The IFTS and the UVS, as defined, are within the capacity of current technology.

- There is no technical issue that prevent PHEOS from going forward.

- Complement the PCW Meteorological Payload and improve the meteorological data coverage of the high latitudes and of the Canadian Arctic.
  - To improve weather forecasting in the Canadian Arctic and improve medium and long-term forecasting in the Northern Hemisphere.
  - Collect invaluable data to better understand the surface and atmospheric processes taking place in the Canadian Arctic.

- Monitor critical parameters affecting the climate and the air quality in the Canadian Arctic and northern latitudes.

- Can also be a candidate instrument for other geostationary platforms

- Funding from Canadian Space Agency for Phase 0/A studies for PCW/ PHEOS