PCW/PHEOS-WCA: QUASI-GEOSTATIONARY VIEWING OF THE ARCTIC AND ENVIRONS FOR WEATHER, CLIMATE AND AIR QUALITY

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ABSTRACT

The Polar Communications and Weather mission proposes to use two satellites each in a highly eccentric orbit with apogee ~ 42,000 km and a period in the 12-24 hour range in order to have quasi-stationary 24x7 viewing over the Arctic. The baseline operational meteorological instrument is a 21-channel spectral imager similar to MODIS. The CSA is also exploring the possibility of a suite of innovative vertical sounding FTS and UVS science instruments with an imaging capacity for Arctic and mid-latitude weather, climate and air quality science. We report on the outcome of a Phase A study completed in March 2012 conducted by ABB, COM DEV and the Science team, a group of atmospheric scientists from university and government with international collaborators.

1. INTRODUCTION

The Canadian Space Agency, in partnership with Environment Canada and the Department of National Defence and several other government ministries, is planning an innovative operational mission called PCW (Polar Communications and Weather) that will combine communications and meteorology over the Arctic region. This mission will provide high capacity, continuous communication services over the Canadian Arctic as well as meteorological observations which will lead to improved weather forecasting for the Arctic region. The PCW mission includes an imaging spectroradiometer (PCW/ISR) much like the MODIS or ABI imagers. It is planned to have ~21 channels overlapping with standard meteorological imaging channels to cover the visible, NIR and MIR. The goal for the spatial resolution of the shortest wavelength visible channel is ~ 0.5x0.5 km^2. The communications and meteorological goals of 24x7 coverage will be achieved using 2 satellites flying in tandem in a highly elliptical orbit (HEO) with an apogee ~ 42,000 km and an orbital period to be chosen between 12 and 24 hours. To date, the 3 orbital periods considered are the 12 hour, or Molniya orbit, the 16 hour TAP (three apogee orbit) and a 24 hour or Tundra orbit. The Molniya orbit is better for Earth observations since it has a lower apogee. But with its lower perigee ~ 500 km the instruments are subjected to more intense high energy proton and electron radiation as the satellite crosses the Van Allen belts 4 times a day. The TAP orbit [1] (Trishchenko et al., 2011) is the most likely candidate and has a lower apogee than the modified Tundra orbit (24 hour period, inclination > 80 deg.). The nadir location of the orbit in an Earth-based frame is shown in Fig. 1. Both the TAP and Tundra orbits have reduced radiation hazards as compared with the Molniya orbit as their perigees are higher. The PCW/ISR is designed to image the entire planetary hemisphere under the spacecraft from several hours before and after apogee, the exact time depending on the orbit chosen. This should provide meteorological observations 24 h/day, 7 days/week of entire northern latitudes with high temporal resolution (of the order of 15 minutes) at MIR wavelengths and reduced coverage in the solar reflected light channels during the Arctic winter. This should provide more timely weather advisories and, more specifically, information about tropospheric winds using cloud images.

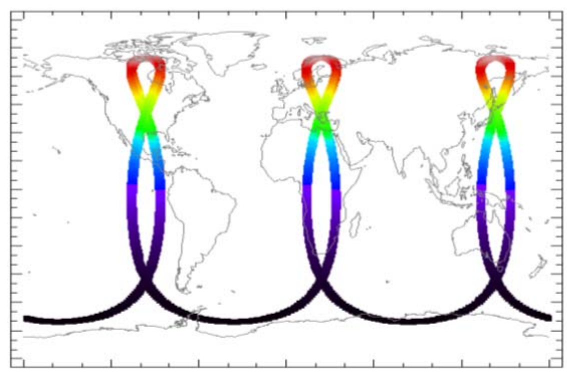

Figure 1. The ground track for a satellite in a Three Apogee (TAP) Orbit during a 48-hour period. The color scale indicates the satellite altitude from a perigee of 8100 km (black) to an apogee of 43,000 km (red). A second satellite in the same TAP orbital plane, would have an identical ground track, offset by 8 hours [1].

2. PHEOS

The PHEOS (Polar Highly Elliptical Orbital Science) Weather, Climate and Air Quality instrument suite and science mission would be an essential complement to the PCW meteorological mission. The proposed instruments will enhance the PCW meteorological mission by adding imaging vertical sounding measurements to the suite of meteorological information gathered by the PCW meteorological imager. The basic instruments are a Fourier transform spectrometer (FTS) operating in the near-IR (NIR) and Mid-IR (MIR) and a dispersive UV-Vis (ultraviolet-visible) spectrometer (UVS). The FTS will allow measurement of temperature and water vapour vertical profiles and a number of other species essential for understanding and prediction air quality in the Arctic and environs and monitoring changes in climate gases while the UVS instrument will provide additional critical measurements on air quality. The idea of (quasi-) geostationary viewing allows observation of continuous change for the fields of interest under the satellite. Thus for fields such as temperature and water vapour one can measure the evolution of the weather with height thus allowing a better assessment of the ability of models to represent processes.

3. WEATHER, CLIMATE CHANGE AND AIR QUALITY MONITORING

Changes in the Arctic region, such as the rapid disappearance of multi-year ice [2], appear to be a harbinger of early climate change and global temperature changes are amplified at polar latitudes by changes in surface albedo, water vapour amount and possibly changes in the Arctic Ocean currents. As temperatures increase and summer multi-year ice recedes, ice melts for longer periods, the ocean warms and there is more moisture in the air which can lead to reduced radiative cooling, increasing the potential for storm formation. The increased radiative forcing also accelerates the melting of the ice.

3.1 meteorological measurements

The Arctic region is a fundamental driver critical for the development of winter storms in boreal latitudes. And as all major forecast centres use global models to drive higher-resolution, regional forecasts, the PCW and PHEOS data set will be a major contribution to this international effort.

Studying climate change at high latitudes requires a better understanding of weather and climate processes, such as convection, ice formation and precipitation and interaction with the changing snow and ice surface in polar regions. PHEOS instruments will contribute to these improvements.

3.2 Greenhouse gas measurements

It is important to accurately monitor greenhouse gases (GHGs) in the atmosphere to understand and quantify their sources and sinks and this is no less important in the Arctic and high latitudes. In fact, there are concerns that methane could be released in significant amounts from either warming permafrost or possible release from shallowly buried clathrates off the polar shelf [3]. The potential rapid release of Artic methane would accelerate global warming around the world.

The potential increase in release of CO_2 from permafrost thaw or other manifestations of Arctic climate change is also an issue. Although in wetter permafrost regions, methane is the dominant GHG released, CO_2 dominates in drier regions and understanding the balance between emissions of these two GHGs in a changing Arctic will continue to be important [4].

The net CO_2 balance of boreal forests (between photosynthesis and respiration) is another topic of interest for scientific and policy reasons. Quasi-continuous PHEOS CO_2 observations over the Boreal forests would be valuable for studies of the CO_2 uptake and release from these forests.

Canadian and international groups will be able to use the PHEOS CO_2 and CH_4 data in concert with ground-based and aircraft data in data assimilation systems to better estimate GHG emission sources and sinks and improve our understanding of carbon cycle processes..

3.3 Arctic air quality

With the decrease in the polar multi-year ice the summer time Arctic becomes much more accessible to shipping and also to mineral and gas exploration under the cold Arctic waters. Already large ships are making their way across the Arctic Ocean and this is likely to increase dramatically over the next 10-20 years [5]. As a result one anticipates that the air quality of the north will degrade and there will be a need for continuous monitoring of many species related to air quality (see below). Some of the emissions expected from shipping and drilling will be volatile organic compounds and NOx and so, in sunlight, ozone, a GHG, will be generated adding to the radiative forcing in the Arctic. In addition, SO_2 and NO_2 and particulate levels are expected to increase during the summer shipping and exploration period compromising health of all Arctic inhabitants. Furthermore, with the potential drying of the boreal forest it is anticipated that the number of incidents of air pollution from the burning of the boreal forest impacting the Arctic will increase and much of this pollution ends up in the Arctic. PHEOS measurements will provide an unprecedented view of air quality and, because of its flexibility of viewing, will also be able to monitor severe air quality incidents at mid-latitudes as necessary.

4. INSTRUMENTS

In order to provide meteorological, climate and air quality data to complement the PCW/ISR imager, instruments with an imaging capacity are essential. The CSA imposed rather strict limits on the total mass, power and volume available for the PHEOS instrument package of 50 kg, 100 W and ~(30 cm)^3, respectively. These tight constraints impose strict limitations on telescope size, spectral and spatial resolution. One of the innovations is to house the FTS and UVS within the same structure as shown in Fig. 2.

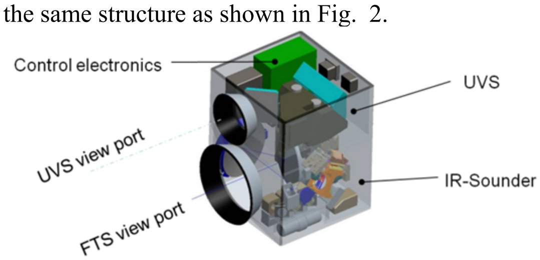

Figure 2. Preliminary design for the FTS/UVS instrument combination for PCW/PHEOS.

The scientific objectives as outlined in the User Requirement Document (URD), developed in Phase 0, call for an observation quality for species and temperature to be at least as good as currently available from a low Earth orbit (LEO) instrument such as IASI. Thus an FTS was chosen with spectral range 0.7 to 14 µm, with 4 bands, 1, 2, 3 and 4, listed in Tab. 1. There are two MIR bands viz., Band 1 from 6.7 to 14.2 µm and Band-2 from 3.7 to 5.6 µm and two NIR bands, Band-3 ~1.6 µm and Band-4 at 0.76 µm. The goal for the FTS spatial resolution is 10x10km^2. The spectral resolution is 0.25 cm^{-1} for Bands 1 to 4, and 0.5 cm^{-1} for Band-4. The sensitivity required is slightly better than the current version of IASI flying on MetOp. The FTS instrument is described more fully in [6] in this issue. To achieve the S/N requirements the FTS is required to stare at the same ground spot for ~100 seconds during which it is estimated that cloud movement in the image will not be a serious problem.

The UVS instrument is a grating spectrometer with 1 nm spectral resolution (3 samples) in order to retrieve the target AQ gases listed in Table 2 (see below). The goal for the spatial resolution of the UVS instrument is ~8x8 km^2. The UVS instrument will only stare for a few seconds during which it will take many images of the same spot to satisfy detector constraints. The UVS instrument is described in more detail in [7] and also in [8]

It is anticipated that the Field of Regard (FoR), an area ~ 3400x3400 km^2 at apogee, will be imaged by both instruments. During the viewing period the spacecraft antenna will be pointing at the ground receiving station in Northern Canada and it is anticipated that for a TAP orbit that observations will be taken ±6 hours of apogee which may be extended by an additional ±4 hours under certain circumstances for possible stereo-viewing with both satellites. During the descent the spatial resolution will improve by about 30%. In addition, during this period the ground track of the space craft will move at < 300 m/s.

5. VIEWING STRATEGY

A zero order viewing strategy is that the field of regard (FOR) for both PHEOS instruments will overlap with that of the PCW/ISR. However, for a significant part of the year the Arctic region will be in darkness and only the MIR channels of the PCW/ISR and the FTS can collect data if viewing is constrained to be towards the communications receiver. Thus it is planned to design viewing flexibility that the UVS and also FTS can be targeted at a different location from the PCW/ISR. For simplicity the imaging UV and FTS have a fixed range of viewing angles and a fixed number of pixels within this range. It is planned to design flexibility into the viewing/scanning sytem so that special events can be tracked more rapidly with the PHEOS instruments but with reduced spatial coverage. It is anticipated that boreal forest fires, volcanic eruptions, east coast pressure bombs or regional air quality events will be targeted.

Table 1

Instrument	Band	Spectral Range cm^{-1}	Spectral Res. cm^{-1}	Spatial Res.
FTS	1	700-1500	0.25 cm^{-1}	10x10 km^2
	2	1800-2700		
	3a	5990-6010		
	3b	5990-6257		
	4	13060-13168 cm^{-1}	0.5 cm^{-1}	
UVS		280–650 nm	1 nm	8x 8 km^2

As stated earlier the multiband imager will scan the full earth disk and hence provide the maximum arctic coverage in addition to extensive coverage at lower latitudes. On the other hand the imaging UV and FTS instruments have a limited field of regard and hence will concentrate nominal viewing in the high arctic region.

6. SPECIES

The species to be measured by the PHEOS instruments are important for weather (W), climate (C), and air quality (AQ) applications and the target species are listed in Tab. 2. Although the instruments for PCW/PHEOS are science (as opposed to operational) instruments, some of the anticipated products may be assimilated by weather forecast centres. In particular, it is anticipated that measurements of the tropospheric temperature and water vapour profiles using FTS measurements from Bands 1 and 2 will be important in improving Arctic weather information and this could lead to more accurate forecasting of winter storms that break out from the Arctic. It is anticipated that the radiances will be assimilated by the forecast centres rather than retrieved profiles.

In addition, the spectral range of the FTS will allow measurements of CO_2 and CH_4 columns in both the NIR and MIR. The NIR measurements will yield total columns of these GHGs while the MIR kernels contain abundance information from the mid-troposphere. In order to be useful for source inversion, the assigned precision requirements for CO_2 and CH_4 are high. The NIR Band 3 of the FTS has been allocated for these measurements. A critical support measurement for GHG retrievals is the O_2 A-band in the FTS Band-4. The resolution targeted (Tab. 1) will allow the retrieval of surface pressure for converting the GHG column densities to column-averaged mixing ratios (XCO_2 and XCH_4), along with an assessment of the amount of aerosol or thin cirrus present.

Table 2 – Target Measurements

	Data product	Vertical resolution	Precision, Column amount	instruments
W	Water profile	2 km	10%	FTS (1,2)
W	Temp.	2 km	1°C	FTS (1)
C	CH_4	PC	4%	FTS (1)
C	CH_4	TC	4%	FTS (3)
C	CO_2	TC	1%	FTS (1)
C	CO_2	TC	1%	FTS (3)
C/AQ	AOD	5 km	0.03 15%	FTS (4)
C/AQ	Ozone	TC/SC	0.8×10^{19} – 3×10^{19}	UVS, FTS (2)
AQ	NO_2	TC/SC	10^{15} - 10^{16}	UVS
AQ	CO	PC	1.3×10^{18}	FTS (2)
C/AQ	AI	PC	0.03 15%	UVS

PC, TC, SC: partial, tropospheric and stratospheric columns respectively, AOD: Aerosol optical depth

Tropospheric air quality (AQ) products are also targets for PHEOS and are also listed in Tab. 2. In this case it is anticipated that the vertical resolution will be ~5-10 km, so that in effect, vertical columns will be measured by the UVS instrument and partial columns by the MIR channels of the FTS. Also for NO_2 and ozone the stratospheric columns (SC) have generally larger amounts than the tropospheric columns and care must be taken to extract the SC with sufficient accuracy that the tropospheric column (TC) has useful accuracy, hopefully for assimilation in air quality models in the post-2018 era. In addition, to ozone and NO_2 as target species, we also intend to include CO as a target species in the MIR. Although the kernel is not optimised for full TC amounts, measurements of the MIR channel of MOPITT [9] and IASI [10] have shown that useful profile information can be extracted.

As noted above, aerosol information can be obtained from the O_2 A-band. But useful aerosol information can be obtained from the Aerosol Index (AI) [11], which yields information on the aerosol amount and aerosol location in the vertical.

There are many more species in addition to those listed in Tab. 2 than can be obtained with the PHEOS instruments. These include in the UVS, BrO, HCHO, AI, $(HCO)_2$, in the MIR HNO_3, PAN, CH_3OH, HCOOH, HCN, NH_3, CH_3COOH, and SO_2 is available in both the UVS and MIR while CH_4, CO_2 can be measured in both MIR and NIR.

Some of these species will only be accessible by temporal and/or spatial averaging. Other species will only be available for special events such as, for example, a volcanic eruption where SO_2 was measured by IASI [12] using SO_2 bands at 4 and 7.3 µm, or as HCN emissions, for example, from forest fires species [13] or Arctic Spring ozone depletion events when marine boundary layer BrO in the Arctic becomes very abundant [14].

7. SYNERGY WITH THE METEOROLOGICAL IMAGER

There is a strong potential for an important synergy between the PCW/ISR and the PHEOS instruments. PCW/ISR has higher surface spatial resolution, and a more rapid repeat viewing period, but its spectral resolution is much lower and, as compared to the FTS in the mid-IR, there is almost no capacity for vertical information retrieval. For example the PCW/ISR aims to have column ozone amounts, but the product derived from both the UV and mid-IR instruments will have height information and promises to be more quantitative. One of the important uses of the imager using the highest spatial resolution visible channel is for cloud clearing (see below).

8. CLOUDINESS ISSUES

Cloudy pixels are an issue for both PHEOS instruments, although sometimes cloudiness can be turned to an advantage. For example if the cloud top height is known then the amount of material above that level is known and if there is a nearby cloud-free pixel then the differing amount of material lies beneath the cloud level. However, generally cloudiness poses a problem if it is not 100% or less than some small number depending on the retrieval problem. To some extent, the spectral information in the MIR also contains useful cloud clearing information. However, it will also be useful to have the more detailed spatial information available from the PCW/ISR.

Nadir observations can be adversely affected by clouds in the field of view. Reference [15] studied the effect of sensor resolution on the number of cloud-free observations. However, if MIR channels with a higher altitude weighting function, such as at 14.5 µm (~ 100 hPa) are chosen then much more temperature data becomes useful [16]. Also the ECMWF are now using completely cloudy pixels [17]. Given the 10x10 km^2 ground pixel, approximately 18% of the pixels would be cloud-free globally, 21% would be at the 5% threshold and 26% would be at the 20% threshold. Given a 3x3 km^2 ground pixel, approximately 25% of the pixels would be cloud-free, 25% would be at 5% threshold and 27% would be at 20% threshold. As stated above, the PCW/ISR imager data would be used for selecting the cloud-free ground pixels.

9. AEROSOLS

The PCW/ISR has the potential for retrieving AOD much like MODIS but, as for MODIS, it will be difficult to get accurate absolute amounts in the case of the high surface reflectance and low sun angle conditions of the Arctic. However, the combination of the imager with the UV-Vis data and also the O_2 A-band (band-4) data can yield a more quantitative product. As well, in combination with other information such as groundbased sunphotometer data as well as ground and satellite-based backscatter lidar data, the AOD retrievals can be improved over dark targets such as open water and developed over bright Arctic surfaces such as snow and ice. With the high spatial and temporal resolution of the PCW/ISR, there will be detailed information on the spatio/temporal evolution of plumes from biomass burning and dust storms pollution dispersion, dust and ash advection from volcanic events. Combined with species data from ground-based and satellite data it will be possible to back out quantitative information on emission strengths, vertical profiles and the geographic positions for these aerosol sources.

10. CONCLUSIONS FROM PHASE-A

The PHEOS Phase A was focused on the refinement of the URD (User Requirements Document) and the preparation of a Mission Requirements Documents (MRD) based on the URD. The instruments and the ground segment concepts of PHEOS-WCA were defined in a more detailed fashion. The requirements from the MRD were flowed-down into a preliminary system requirements document (PSRD) for the space segment and for the ground segment of PHEOS WCA.

10.1 Ground Segment

The data captured by PHEOS-WCA will follow two main streams: an operational stream to be included in the weather data assimilation to serve the daily needs of weather forecasting and a science stream to provide data for research in atmospheric science as well as monitoring of Arctic air quality. The operational stream will also include data to monitor special events such as volcanic eruptions, severe storms and forest fires. The reception of the PHEOS-WCA data and the processing and management of the operational data stream will be performed by the Ground Segment of PCW. The Ground Segment of PHEOS-WCA will handle the processing, archiving and distribution of the science data stream. The Ground Segment of PHEOS-WCA will be supervised by the PHEOS WCA Science Operation Centre (SOC). The SOC will also be in charge of coordination with the PCW Ground Segment, of early orbit phase data validation and of outreach and education.

10.2 Instrument Design Status

Based on detailed design analysis, three instrument concepts were proposed at the end of Phase A.

- C1 is a configuration which is compliant with the imposed mass and volume constraints and which includes a three-band version of the imaging infrared FTS with a small telescope aperture.
- C2 is a configuration which includes all four of the URD bands for the imaging FTS with a small telescope aperture and also includes an imaging ultraviolet-visible spectrometer.
- C3 is the configuration which includes a four-band imaging FTS with a large aperture telescope and an imaging ultraviolet-visible spectrometer.

As noted, C1 complies with the very tight resource allocations imposed by the CSA. It complies with all threshold sensitivity requirements for the channels chosen for the FTS and addresses all the higher priority objectives outlined in the URD. In addition, we have chosen to maintain the goal of 10x10 km^2 spatial resolution rather than relax to the threshold of 20x20 km^2. However, in most other cases the goals are not attained.

Configuration C2 complies with the threshold sensitivity requirements and covers all the science objectives but exceeds the linear dimensions allocation by 2 cm.

C3, the optimal configuration, complies with all goal sensitivity requirements, covers all the science objectives but exceeds the mass and the linear dimensions allocation by 16 kg and 23 cm respectively. Once the actual allocations are better known, it will be possible to make a trade between the required resources and the scientific return.

The compliant configuration, achieved with a 10 cm aperture telescope and consisting of an IFTS with Bands 1, 2, and 3a with no UVS instrument, compromises the SNR requirements. However in spite of this, most, if not all of the MIR target gases will be within the threshold. Thus important weather forecast (NWP) information, T and water vapour versus height will be retrieved and with a horizontal spatial resolution uncompromised. This latter point is extremely important as if and when pixel averaging is required the smaller pixels will provide better cloud clearing opportunities than larger pixels as described in the URD.

In addition, with the current MIR spectral range, ozone partial columns in the troposphere and stratosphere should be retrieved as well as tropospheric column CO. This represents all the target MIR air quality (AQ) gases. As well as this, there are many other species which will be accessible on a serendipity basis, such as methanol, HCN, NH_3 or SO_2 from volcanoes. Their detection may require some spatial averaging but the small 10x10 km^2 pixel size (our goal) will be better for cloud clearing than our target pixel size of 20x20 km^2.

Greenhouse gases, methane and CO_2 are also accessible in the MIR Bands 1 and 2 but there is reduced surface sensitivity in the MIR as compared to the near infrared (NIR) and only partial columns will be retrieved. However, the single NIR channel, Band 3a which targets methane, and which has always been a prime goal, should have adequate SNR because of the narrower spectral band and is expected to give excellent total column methane data. Lack of aerosol information from Band 4 is compromised for retrievals but is much less serious for methane than for CO_2 retrievals. Band 4 is missing, which targets aerosols and clouds. This information, which is useful for retrievals for GHG species in the NIR as scattering by aerosols can impact the retrievals. However, the PCW meteorological imager can provide some information about the aerosol layer

The lack of a UVS instrument does compromise one of the target air quality gases, NO_2. Of course tropospheric O_3 is also compromised but, as noted above, there will be information from the FTS in the MIR, although the near-surface/lower troposphere information is less robust because of reduced thermal contrast in the lower atmosphere. In addition, it will not be possible to have access to the aerosol index (AI), which is useful as it gives information on absorbing aerosol and its altitude.

In summary, it can be seen that the compliant version meets many of the objectives outlined in the URD. One of the target air quality gases is not obtained, viz. tropospheric and stratospheric column NO_2. And the total column GHG CO_2 is not measured although the partial column is measured. The lack of Band 4 and UVS limits aerosol information although semi-quantitative information can be obtained from the met-imager and the FTS can also detect volcanic ash. Some species of opportunity (e.g. HCHO) also would be lost.

For the configuration C2, the main differences from the compliant version above are the inclusion of Band 3b, which is broad enough to capture both CO_2 and methane, and the inclusion of Band 4 and the UVS instrument. The FTS aperture remains at 10 cm and so SNR does not change for Bands 1 and 2. Band 3b differs in two ways from Band 3a, viz. Band 3a is narrower and the SNR is higher than for the wider Band 3b. However Band 3b also includes CO_2 as well as methane and the CO_2 is an important target climate gas. The lower SNR compromises both the methane and CO_2 retrieval which would likely require pixel averaging as discussed in the URD. As noted above the small pixel size ameliorates the poorer SNR as it can be enhanced by averaging local cloud-free pixels. Thus CO_2, an important GHG is accessible and preliminary OSSE-like calculations (Ray Nassar private communication, 2012) show that these temporally resolved measurements can have a dramatic impact on estimates of the CO_2 sources and sinks over the Boreal Forest.

In the case of the configuration, C3, the instrument has the same bands as for C2 and thus the arguments about the scientific usefulness made for configuration C2 also apply to C3. The main difference between both configurations is that the SNR of the Optimal Configuration is improved so that goals are made rather than thresholds and this will likely lead to reduced spatial averaging. The relative sizes of the three concepts are shown in Fig. 3.

The PCW mission is an innovative mission to provide communications and meteorological data for the Arctic

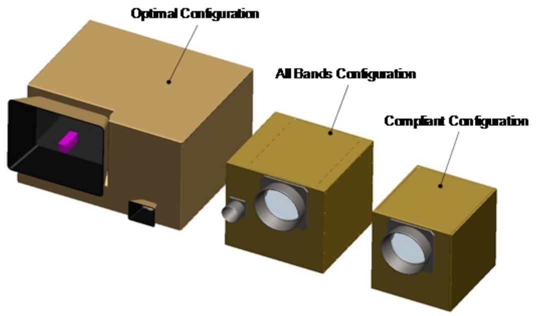

Figure 3: The 3 final configurations, C1 (Compliant), C2 (All Bands), and C3 (Optimal) .

and environs. PHEOS WCA will take advantage of the unique opportunity provided by the highly elliptical orbit planned for PCW to monitor the atmospheric and surface exchange processes taking place in the high northern latitudes not only to conduct atmospheric and climate research, but also monitoring of air quality and to complement the meteorological instrument of PCW by adding hourly sounding data to the information that will be collected by PCW.

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12. REFERENCES

1. Trishchenko, A. P., L. Garand, and L. D. Trichtchenko. Three apogee 16-h highly elliptical orbit as optimal choice for continuous meteorological imaging of the polar regions. J. Atmos. Oceanic Tech., 28, 1407-1422, 2011. DOI: 10.1175/JTECH-D-11-00048.1
2. Wang, M., and J. E. Overland, A sea ice free summer Arctic within 30 years? Geophys. Res. Lett., **36**, L07502, 2009, doi:10.1029/2009GL037820.
3. Shakova et al ,Geochemical and geophysical evidence of methane release over the East Siberian Arctic Shelf, J. Geophys. Res., **115,** C08007, doi:10.1029/2009JC005602, 2010.
4. Schurr, E.A.G, et al.: Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle, BioScience, **58**, 8, 701-714, 2008.
5. Corbett, J.J., D. A. Lack, J. J. Winebrake, S. Harder, J. A. Silberman, and M. Gold, Arctic shipping emissions inventories and future scenarios, Atmos. Chem. Phys., **10**, 9689–9704, 2010.
6. McConnell et al, Development of an FTS for thermal and near-infrared sounding of weather, air quality and greenhouse gases in the Arctic, this issue, ATMOS-2012, 2012
7. Rahnama, P., et al., UV-VIS Spectrometer (UVS) for the Polar Communications and Weather (PCW) Mission, Proceedings of ASTRO'12, 16th CASI Astronautics conference, Quebec City, Canada, 24-26 Apr 2012, *Polar Communications and Weather Mission*, 186, 2012. Available at: FTP://casi:ASTRO-2010@astroconference.ca
8. McElroy et al, PCW/PHEOS UV-VIS Spectrometer: Air Quality from a Quasi-Geostationary Orbit, this issue, 2012.
9. Yurganov, L.N., W. W. McMillan, A.V. Dzhola, E. I. Grechko, N. B. Jones, and G. R. van der Werf, Global AIRS and MOPITT CO measurements: Validation, comparison, and links to biomass burning variations and carbon cycle, J. Geophys. Res., 113, D09301, doi:10.1029/2007-JD009229, 2008.
10. Clerbaux, C., A. Boynard, L. Clarisse, M. George, J. Hadji-Lazaro, H. Herbin, D. Hurtmans, M. Pommier, A. Razavi, S. Turquety, C. Wespes, and P.-F. Coheur, Monitoring of atmospheric composition using the thermal infrared IASI/MetOp sounder, Atmos. Chem. Phys. **9**, 6041-6054, 2009.
11. Guan, H., R. Esswein, J. Lopez, R. Bergstrom, A. Warnock, M. Follette-Cook, M. Fromm, and L. Iraci, A multi-decadal history of biomass burning plume heights identified using aerosol index measurements, Atmos. Chem. Phys., **10**, 6461-6469, 2010.
12. Karagulian, F., L. Clarisse, C. Clerbaux, A. J. Prata, D. Hurtmans,and P. F. Coheur, Detection of volcanic SO_2, ash, and H_2SO_4 using the Infrared Atmospheric Sounding Interferometer (IASI). J. Geophys. Res., **115,** D00L02, doi:10.1029/2009JD012786, 2010.

13. Lupu, A., J.W. Kaminski, L. Neary, J. C. McConnell, K. Toyota, C. P. Rinsland, P. F. Bernath, K. A. Walker, C. D. Boone, Y. Nagahama, and K. Suzuki, Hydrogen cyanide in the upper troposphere: GEM-AQ simulation and comparison with ACE-FTS observations, Atmos. Chem. Phys., **9**, 4301–4313, 2009.
14. Toyota, K., J. C. McConnell, A. Lupu, L. Neary, C. A. McLinden, A. Richter, R. Kwok, K. Semeniuk, J.W. Kaminski, S.-L. Gong, J. Jarosz, M. P. Chipperfield, and C. E. Sioris, Analysis of reactive bromine production and ozone depletion in the Arctic boundary layer using 3-D simulations with GEM-AQ: inference from synoptic-scale patterns Atmos. Chem. Phys., 11, 3949–3979, 2011
15. Krijger, J.M., van Weele, M. and Frey, R., Technical Note: The effect of sensor resolution on the number of cloud-free observations from space, *Atmos. Chem. Phys.*, 7, 2881-2891, 2007.
16. McNally, A. P., and P.D. Watts, A cloud detection algorithm for high-spectral-resolution infrared sounders, Q. J. R. Meteorol. Soc., **129**, 3411–3423, 2003. doi: 10.1256/qj.02.208
17. McNally, A. P., The direct assimilation of cloud-affected infrared radiances in the ECMWF 4D-Var, ECMWF/EUMETSAT NWP-SAF Workshop on the assimilation of IASI in NWP , 6 – 8 May 2009.