

POLAR WINDS FROM HIGHLY ELLIPTICAL SATELLITES: A NEW PERSPECTIVE

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Abstract

The Polar Communications and Weather (PCW) mission is a Canadian proposal for two satellites in a highly elliptical “Molniya” orbit (period 12-h, inclination 63.4 deg., apogee ~39,500 km). The main meteorological instrument is a 20-channel advanced imager with characteristics similar to imagers planned on the next generation of geostationary satellites (MTG, GOES-R). Such a constellation would provide geostationary-like imagery over the circumpolar domain 55-90 N refreshed very 15 minutes. This opens new perspectives for the derivation of atmospheric wind vectors (AMV) over the Arctic. Polar winds are currently derived from MODIS and AVHRR data provided by LEO satellites. There are large gaps in coverage, notably in the latitude band 55-70 degrees. A recent polar AMV impact experiment is presented, using up to 7 LEO satellites. Results indicate a relatively modest positive impact in both polar regions in comparison to earlier results obtained by most centers a few years ago. This is attributed to improved trial fields from better model physics and the assimilation of additional data such as radiances from hyper-spectral sounders. It is also noted that low-level polar AMVs are currently not assimilated. Recently, the AMV community started to study the error characteristics of AMVs using simulated imagery on which the AMV retrieval software is applied. Preliminary work in that direction is presented here, making use of 2.5 km model output over a 1300 X 1500 km Arctic area. Results indicate the potential of improving AMV quality control, notably by recognition of semi-transparent clouds. An observing system simulation experiment (OSSE) is planned to evaluate the potential impact of PCW AMVs. The identification of AMV locations will be derived from the extraction of likely targets from model output. This approach allows in principle to characterize the AMV error as a function of physical attributes of the tracked features.

INTRODUCTION

The Polar Communications and Weather (PCW) mission, lead by the Canadian Space Agency, is planned for 2016. The aim is to provide continuous communications (Ka and X bands) and meteorological services over the Arctic. Space weather instruments will also monitor the satellite environment. Environment Canada will have the responsibility to distribute the meteorological data and derived products to national and international users in near real time. PCW is defined by a constellation of two satellites in a highly elliptical orbit (HEO), the classical “Molniya” orbit defined by a period of 12-h, and an apogee near 39,800 km, which is close to the geostationary height (~35,800 km). The inclination is 63.4 degrees. The two satellites will be placed in the same orbital plane, resulting in four apogee positions as depicted in Fig.1. It should be noted that the apogee positions are fixed, and all occur at the same local time. From each orbit, full Earth disks would be acquired during an 8-h period centered on apogee (at 4-h to apogee the satellite height is ~24000 km). Satellites in HEO orbits have been used in the past for communications, but not for Earth observation. The idea was originally proposed by Kidder and Von der Haar (1990). A few years ago, a HEO demonstration mission based on a 5-channel imager was proposed by NASA, but was not realized (Riishojgaard, 2009). The Russian Federation is currently working on a mission similar to PCW called Arctica. The proposed PCW imager has 20-

channels covering the range 0.45 to 14.5 μm . Pixel resolution varies from 0,5-1 km for visible channels to 2 km for IR channels. Channels identical to ABI on GOES-R (16 channels, 2015 launch) are selected with the intent of continuity of applications. Similar channels are also proposed for the MTG imager (16 channels, 2016 launch). PCW requirements require a few additional channels in the 13-14.5 μm range for cloud height estimation.

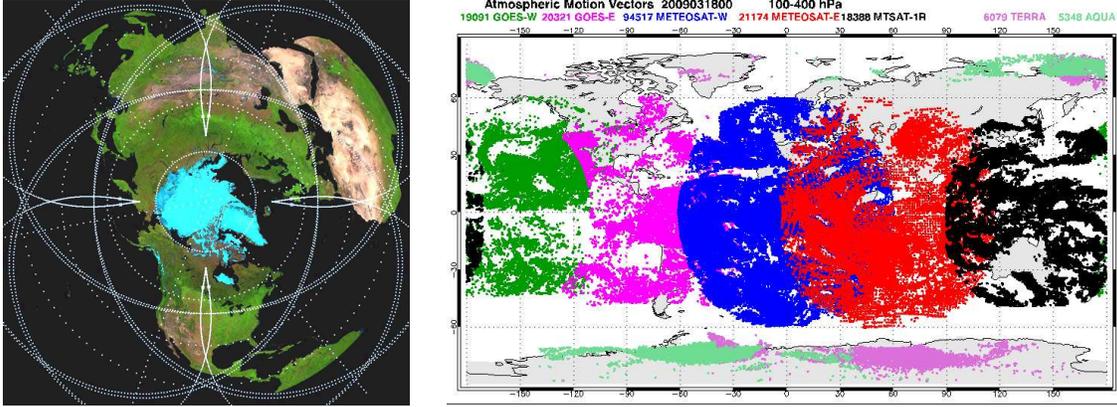


Fig. 1 (left). Ground track and apogee positions at 100 W, 170 E, 80 E and 10 W. Circles indicate coverage from each satellite 4-h from apogee.

Fig.2 (right). Typical 6-h AMV coverage from geostationary satellites and MODIS.

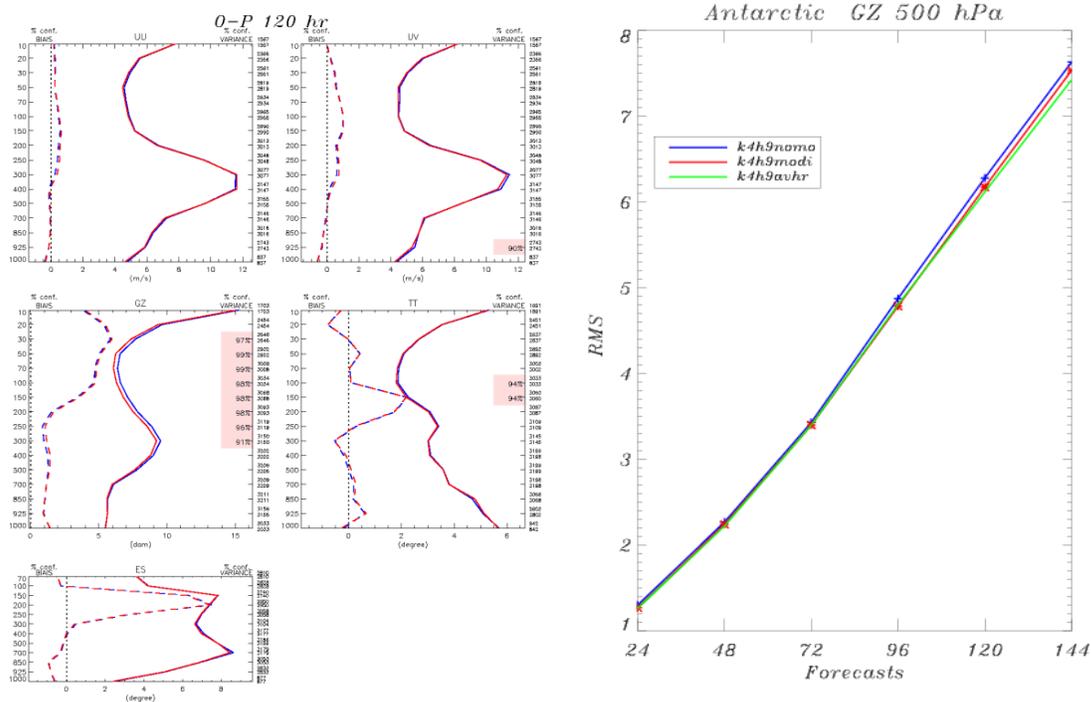


Fig. 3 (left) Validation against radiosondes at 120-h over Arctic. Red is experiment including MODIS+AVHRR AMVs. Blue is control without polar winds. Pink shading indicates a significant difference. Statistics for wind components, GZ, temperature, and dew point depression shown.

Fig. 4 (right) 500 hPa anomaly correlation for Antarctic region. Blue: no AMV; red: with MODIS AMVs; green with MODIS+AVHRR AMVs.

Polar winds from PCW

Fig. 2 shows the typical 6-h coverage of atmospheric wind vectors (AMV) available to weather centers. It is clear that there are large gaps in the polar region. Winds from MODIS onboard Aqua and Terra are typically available only above 70 degrees latitude from successive passages every 90 minutes. Polar winds with similar characteristics are also derived from AVHRR data provided by NOAA and Metop LEO satellites. PCW will completely fill the gap shown in Fig. 2, and AMV will be derived from imagery triplets which are 15 min apart, as is typically the case for geostationary AMVs. Environment Canada recently conducted an observing system experiment (OSE) to evaluate the impact of polar AMVs from MODIS AQUA and TERRA as well as five AVHRR satellites. The experiment covered the months of January and February 2008. The control experiment had no polar winds. One test experiment added MODIS winds and another one MODIS+AVHRR. Representative results are shown in Figs 3 and 4. The impact is positive, but modest. The positive impact of MODIS AMVs noted only 5-6 years ago was much more evident. This is attributed to the fact that the Canadian Meteorological Center now assimilates radiances from 87 AIRS channels as well as GPS-RO temperature profiles. The model was also improved. Stronger impacts are expected from PCW AMVs thanks to improved coverage, quality and timeliness.

Simulated AMV retrievals

The nature of AMV errors in speed and direction is complex. Height assignment remains an important cause of errors. Targets may not follow the ambient wind direction and speed, notably in regions of ascending motion. Error characteristics depend also on the channels involved, time differences between images and resolution. AMV errors are typically studied in terms of observed minus first guess values pertaining to various AMV production conditions as noted above (Cotton and Forsythe, 2010). Simulated retrievals offer new perspectives. This research avenue is now possible from the availability of both realistic forecast models and fast and reliable radiative transfer models for the simulation of all sky radiances. Recently the IWWG community started to investigate this avenue (Bremen et al, 2008, Wanzong et al, 2008).

Here, 2.5 km model output from a limited area model is used over an Arctic domain centered near 90 W between 70-85 N (Ellesmere Islands to Nunavut, about 1500 X 1300 km). A sequence of 3 images, 30 minutes apart around 15 UTC 21 October 2009 was generated simulating MODIS channel 31 (11 μm) and MODIS channel 28 (7.3 μm) radiances using RTTOV-8.7, assuming standard optical properties. A simulated PCW orbit provided the viewing angles. Images were sent to CIMMS for AMV calculations. Only the 11 μm winds were extracted although the 7.3 μm image depicts water vapor features in clear air which are suitable for tracking. Model cloud height is defined from the cloud transmittance t_c pertaining to the 11 μm channel, taking into account cloud emissivity. Starting from the model top (TOA) where t_c is unity, the model cloud top is defined at the level l where $t_c(\text{TOA},l)$ drops to 0.9. Previous research showed that this definition matches quite well the cloud top obtained from CALIPSO lidar observations. The effective cloud amount is defined by $1-t_c(\text{TOA},\text{surface})$. A low effective cloud amount corresponds to a semi-transparent cloud. Fig. 5 shows the simulated imagery in the two channels and the model cloud height and effective amount at 15 UTC. The dominant feature is a frontal system in the southern part with semi-transparent clouds ahead of the front. Fig. 6 compares the retrieved wind speed to the "true" model wind speed at the retrieved height (left panel) and at the "true" height (right panel). It is seen that the "true" height is for many points much higher (blue dots in right panel) than the retrieved height. These points correspond to the cirrus outflow region. For these points, the retrieved wind speed is lower than the "true" wind speed. Height underestimation results from relying on the 11 μm BT matched with the model background temperature profile. Fig. 7 shows similar scatter plots pertaining to wind direction. The fit is improved if the retrieved wind direction is compared to the wind direction at the "true" cloud height rather than at the retrieved cloud height, notably for southerly winds between 100 and 250 degrees along and south of the frontal

structure. This unique example is representative of the possibilities to improve understanding on error characterization. Research in that direction will be pursued from larger datasets.

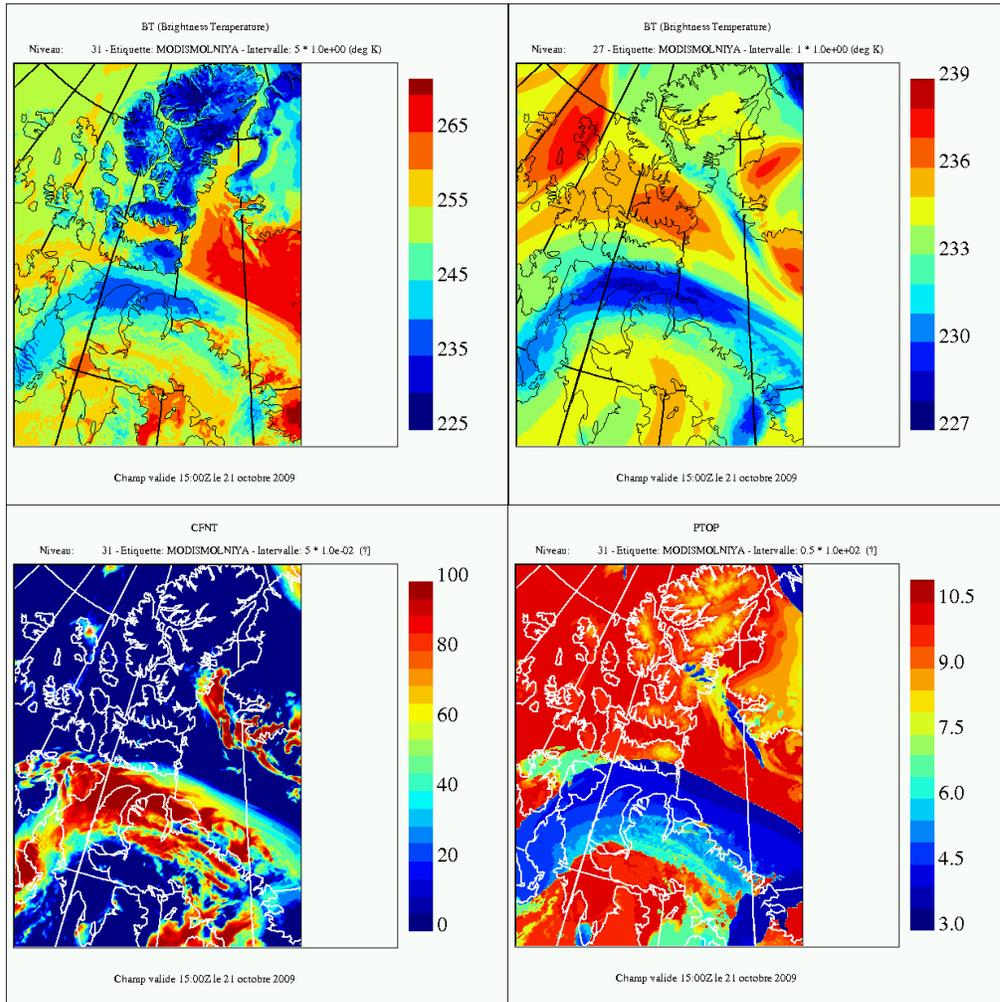


Fig. 5. Simulated 11 μm (top left) and 7.3 μm (top right) BT (K) at 15 UTC October 21, 2009. Effective cloud amount (% , bottom left) and cloud top (bottom right, 6.0 means 600 hPa).

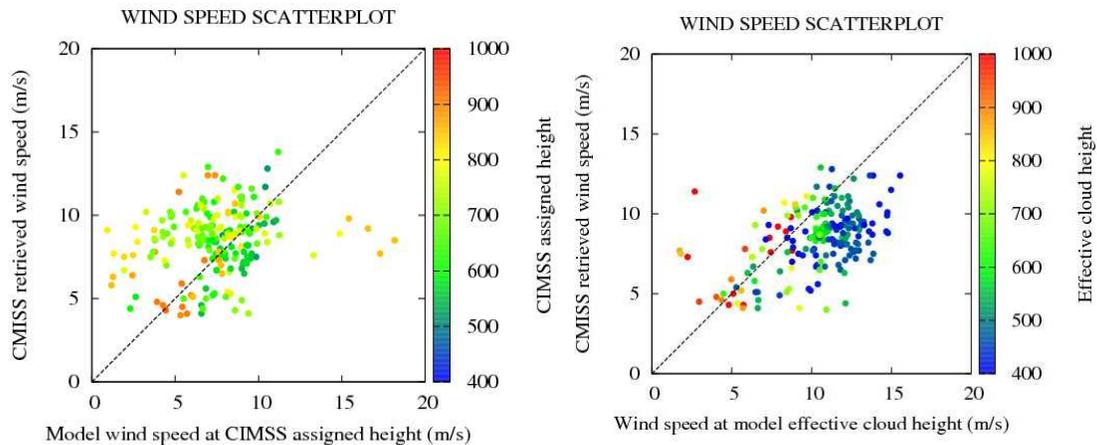


Fig. 6 Retrieved wind speed versus model wind speed at retrieved height (right) and versus model true height (left). Color indicates retrieved height (left) and true height (right).

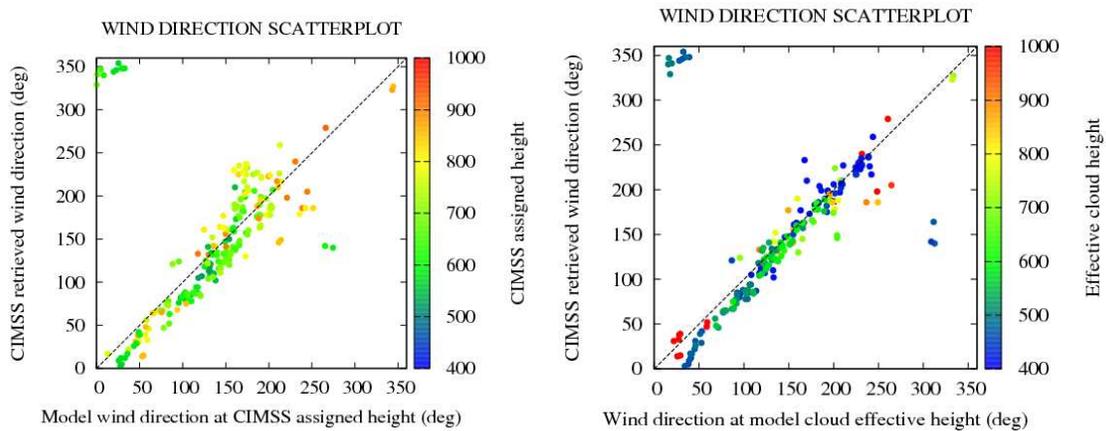


Fig 7. Retrieved wind direction versus model wind direction at retrieved height (left) and versus wind direction at true cloud height (right). Color indicates assigned height (left, hPa) or true height (right).

OSSE for PCW AMVs

The planning of an OSSE for PCW AMVs must consider some limitations. It is not possible at the present time to simulate PCW imagery over the entire circumpolar domain from a model at ~1-3 km resolution. Consequently, the AMV software cannot be used for the simulation, but as expressed earlier, can be used for better error characterization. The current plan is to use the nature run from 2005 in the NOAA OSSE framework. The observations will be simulated from the nature run in Environment Canada's assimilation system in 3D-var mode. It is possible to change data times to include data types such as AIRS radiances and GPS-RO not present in 2005. AMV locations are currently assigned from real locations after thinning. Since real AMV observations do not cover well the circumpolar area, AMV locations will have to be extracted from the nature run, with height assignment based on model cloud top (for 11 μm AMVs). Limitations include the spatial and temporal resolution of the nature run (35 km, 3-h), compensated by full coverage of the circumpolar domain. Current rules pertaining to AMV error assignment and perturbation method will characterize the baseline experiment.

Conclusion

The PCW mission will provide geostationary-like imagery over the entire circumpolar area 55-90 N. AMVs will therefore be available at high temporal and spatial resolution over that domain. The Science Team is planning a classical OSSE to demonstrate the added value of AMVs derived from PCW imagery. As well, research toward improving AMV error characterization has started based on simulated retrievals.

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