Evaluation of System φ_{DP} at Environment Canada's Research Radar

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1. Introduction

At the Environment Canada's dual polarization C-band research radar in King City, the dual polarization differential phase measurement, φ_{DP}, is used in attenuation corrections for Z and Z_{DR}. These corrections require an estimate of the differential phase due to the radar system itself, φ_{DP}^0, which is a quality that is not measured directly. We present and inter-compare a couple variations of methods to determine φ_{DP}^0 from the radar observations of weather echoes. There are weak but clear differences between the methods, which suggests that the φ_{DP}^0 estimates are only accurate to about one degree.

In addition, over the last 4 years we have seen that the calculated φ_{DP}^0 values vary significantly in time. Some of these deviations were thought to be correlated to variations of temperature as measured at various locations in our system. We present a statistical study of the φ_{DP}^0 estimates and temperature data..

2. Motivation

To estimate attenuation and differential attenuation operationally, Environment Canada is looked algorithms based on path integrated changes in differential phase similar to that in Gourley et al (2007), where the total two way attenuation may be approximated by the form

$$A = \alpha\ (\ \varphi_{DP} - \varphi_{DP}^0),$$

where A is the two way path integrated attenuation, α is a proportionally constant and φ_{DP}^0 is the value of φ_{DP} that would result from an idealized measurement of a target immediately outside the radome, before any attenuation could take place (and in the absence of phase changes on backscatter).

The values of the coefficient **α** are a topic of themselves, since they depend on drop size distribution and temperature (see Smyth et al 1998), and they are not addressed here. It suffices to say that representative values are in the vicinity of 0.1 dB/degree for dbZ at C-band, e.g. Gourley (2007), and thus φ_{DP} variations of 10 degree imply variations of 1 dB in attenuations estimates of dBZ. Note also the temperature dependence of **α** is a separate issue from any temperature effects with φ_{DP}^0.

This method implicitly assumes that one knows φ_{DP}^0. This initial value, immediately outside the radome, reflects phase differences between the vertical wave and the horizontal wave after they have passed from the transmitter, through the wave guide, the magic T splitter, the antenna and the radome, and then back again to the receivers. In the real world there is the additional complication that the T/R cell attenuators can introduce noticeable transient phase differences between the H and V channels, so real world measurements in the first kilometre or so could reflect both precipitation attenuation and T/R cell effects. φ_{DP}^0 is not measured directly and, to the extent it is modified by the radome or water on the radome, it is almost impossible to measure. The only practical approach for EC is to look for reflected φ_{DP} values from targets for which φ_{DP} have not been modified by hydrometeors.

The specific methodology is discussed below, but Figure 1 illustrates the issue being encountered. It shows a history of an estimate of φ_{DP}^0 over the year 2013. Known hardware changes were done around Day 100, but excursions of 20 degrees over a week are common in other periods

3. Radar Hardware

The King Radar facility is a 5 cm wavelength magnetron radar, using a 6 m antenna from Andrews, and a Vaisala signal processor. The transmitter is at ground level with a single wave guide to the antenna, where signal is split to H and V channels to the feed horn. The receivers are mounted in a temperature regulated box on the antenna ("AMR"), together with

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the signal processor. The antenna is surrounded by a radome, which is cleaned every 4 or 5 years. The temperature inside the radome is not controlled to a significant degree although heaters are used to moderate winter temperatures. Transmission is simultaneous H and V.

The initial moments processing is done by Vaisala's IRIS system, with subsequent quality control and products being done with EC's own software. Moments recorded from IRIS include Doppler corrected reflectivity (dBZ), total reflectivity (dBT), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), differential phase (φ_{DP}) and signal quality index (SQI).

The initial AMR system was installed in 2004, with an RVP-8 signal processor, and then upgraded by Vaisala in April 2013 to an RVP-900 in a new box with better temperature control. The system also has sensors recording a number of parameters including temperature in the radome, at the antenna pedestal and inside the receiver box.

Ideally φ_{DP}^0 would be invariant, at least between deliberate changes to the radar hardware, but our observations of φ_{DP} clearly show that this is not the case. Occasionally the changes have an obvious cause, such as especially heavy rain on the radome. But in addition to that, our estimates of φ_{DP}^0 show variations on both short and long time frames. There are a number of candidate sources for these changes that could be dependent on temperature, including changes in receivers and changes in the length of wave guides.

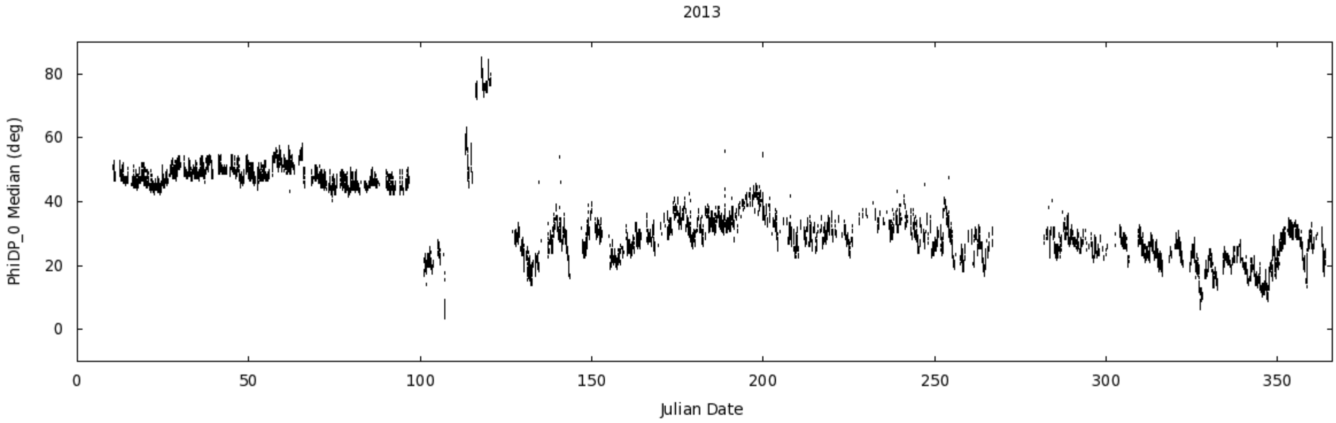

Figure 1 Variation of one estimate of φ_{DP}^0 through 2013. The system was upgraded in April.

4. Estimating φ_{DP}^0 Operationally

EC has used a number of variations on a method to assess φ_{DP}^0 from operational radar moment data, which all follow a similar approach of looking outward for unattenuated weather targets and then choosing a representative φ_{DP} from measurements of those targets.

For the estimation of φ_{DP}^0, measured signals are considered to be suitable if they have good signal to noise (based on dBZ), a suitably high correlation coefficient, ρ_{HV}, and differential reflectivity values Z_{DR} not to far from 0 dB. For some versions, the signal quality index (SQI) is also considered, since it does good rejection of RF interference and removal of second trip echoes. Along each ray, individual radar bins are examined, moving outwards from the radar until a sequence of consecutive bins (5 or more) are considered suitable and the φ_{DP} values in those bins are noted. The search starts at a range of two kilometres. The algorithms diverge in terms of which bins and statistics are used to represent φ_{DP}^0.

- Collect φ_{DP} values for all of the first 4 bins in the first series encountered along every ray.
- Collect median φ_{DP} values of the first 3 bins in the first series encountered along every ray.
- Consider φ_{DP} values only in the first bin encountered in the first sequence along every ray
- Consider φ_{DP} values in the 2nd bin encountered in the first sequence along every ray.

If a sufficient number of values has been found, choose the mode, the median or the mean from the distribution of values selected.

One of the first examinations of the φ_{DP}^0 calculations was to cross compare them to see if there were either systematic biases or large variations between them. Figure 2 shows a typical result, in this case a scatterplot comparing the use of median and mode to select φ_{DP}^0 from the distribution of extracted values. The values deviate 2 or 3 degrees between the

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methodologies and a slight high bias of the median compared to the mean, but that is small compared to the total range of changes of approximately 30 degrees (Figure 1). The smaller collection of points at lower φ_{DP}^0 values was a brief period of hardware change.

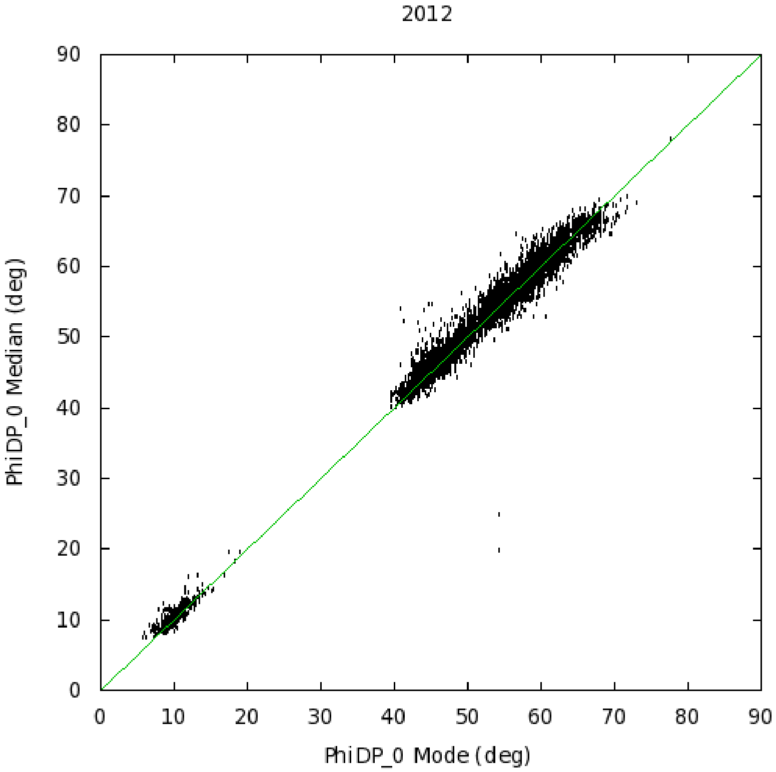

Figure 2: Scatterplot of φ_{DP}^0 estimates using either mode or median.

5. Looking for temporal patterns.

As mentioned above, occasional offsets in φ_{DP}^0 are unsurprising after hardware changes, but the EC staff also believed they could see a relation between changes of φ_{DP}^0 and temperature changes at various points in the system. This working hypothesis is the subject of this section.

Prior to 2013 variations in the temperatures were moderately well correlated to each other because they all were ultimately were driven by atmospheric air temperature. After April 2013 the temperature in the antenna mounted receiver box was almost completely stabilized by an upgrade, Figure 3, but the excursion in φ_{DP}^0 estimates continued, with even greater magnitude than prior to the upgrade (Figure 1). At this point temperatures of the receivers were dismissed as a contributing factor to the φ_{DP}^0 variations.

In the time series from the temperature and φ_{DP}^0, there are visually two sources of difference at two temporal scales. The φ_{DP}^0 values do not show the strong seasonal variation seen in temperature. On the other hand there is a lot of variation of the estimates at short time scales below about an hour. Given these differences at long and short time scales the time series of both temperature and φ_{DP}^0 were high and low pass filtered, by doing an FFT of the data, removing high and low frequencies, and then reconverting to a time series. This was done annually, but years were split into sub-periods when there were known discontinuities due to hardware changes. Figure 4 shows air temperature and one of the φ_{DP}^0 estimates after FFT filtering. At this point the correlation between the air temperature and φ_{DP}^0 estimates is around 0.7 to 0.8, depending on the exact estimation method used for φ_{DP}^0. It would appear that there is indeed some correlation between φ_{DP}^0 and air temperature on times scales of a few days to a month. That said, the need to high pass the data to obtain this correlation suggests that temperature itself would not be a good predictor for variations of φ_{DP}^0. One could equally speculate that some other factor related to weather systems, such as relative humidity or air pressure, could change on these same temporal scales and be more causal than temperature.

Another feature of the time series of φ_{DP}^0 estimates is occasional spikes. These usually are present in all or most of the variations of our estimate techniques. Occasionally the most significant excursions of φ_{DP}^0 often seem to coincide with

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temperature spikes inside the dome, but not always. No defendable explanation has been found for these spikes in φ_{DP}^0, although in the future we would like to cross compare them with periods of heavy rain on the radome.

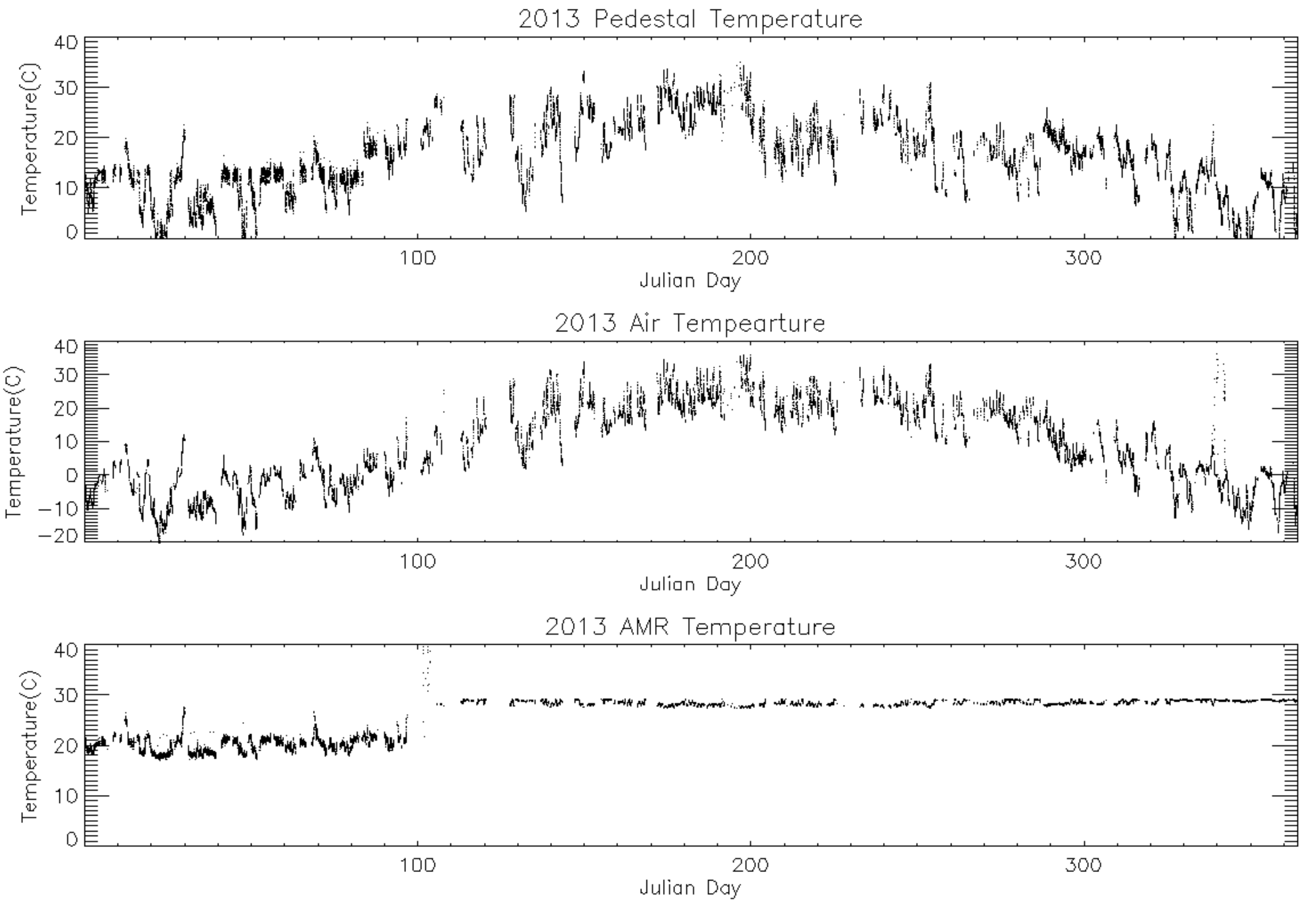

Figure 3: History of temperature in 2013 at three points of the radar system (c.f. Figure 1).

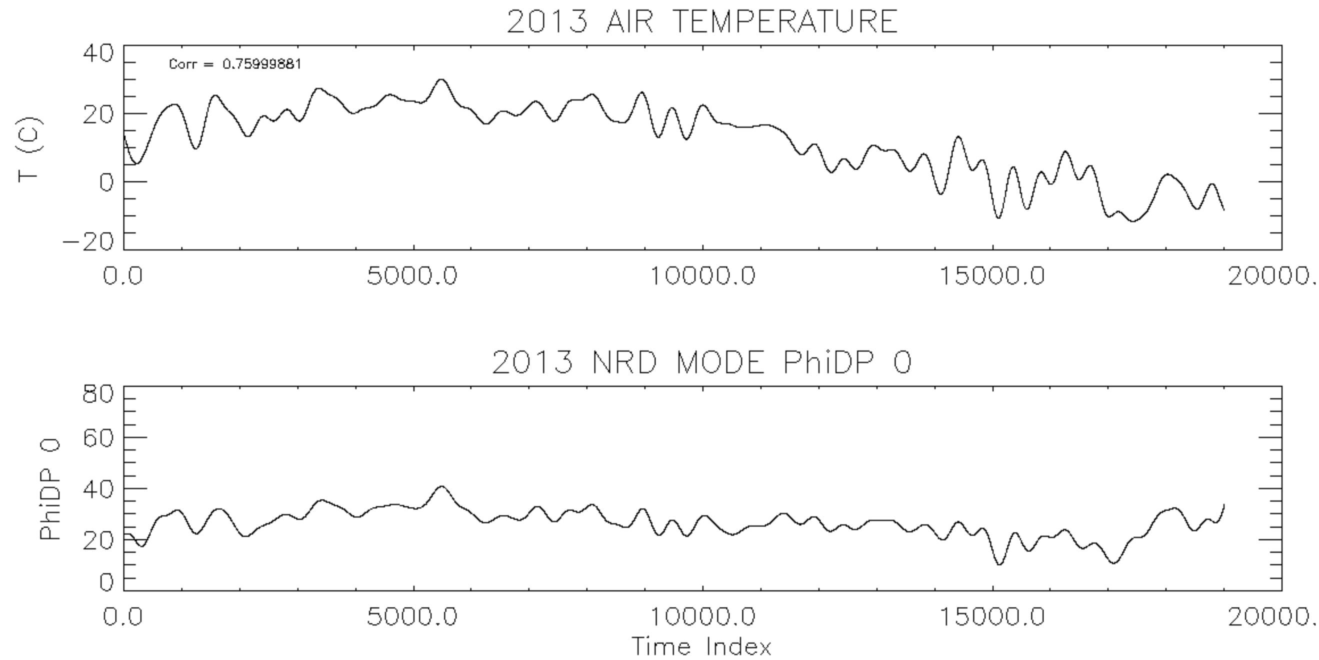

Figure 4 Comparison of band-passed temperature in the radome and one of the φ_{DP}^0 estimates. Here the time axis is time index (one each 10 minutes)

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6. Conclusions

The presented methods for estimating the system's differential phase φ_{DP}^0 from observed radar moments seem to be sufficiently accurate. Observed radar moments are used to reject echoes that seem to be non-meteorological and the first sequence of good φ_{DP} data along each radial are analyzed. The weak but clear differences between variations on the method suggest that the φ_{DP}^0 estimates are only accurate to about one degree. Regardless of the method chosen it is clear that we need to update the φ_{DP}^0 regularly but updating every scan might be too noisy.

The exploration of a relationship between deviations in φ_{DP}^0 and temperature variations is less conclusive. In 2013 the temperatures in the antenna mounted receiver were stabilized and the φ_{DP}^0 excursions continued, which ruled out receiver temperature as a source of the variability. There is a significant correlation of φ_{DP}^0 to air temperature in the radome and antenna pedestal temperatures. This correlation is present but weak in the raw data and is stronger if the data is low and high passed data to focus on scales on the order of weeks. Occasional significant excursions of φ_{DP}^0 remain without a solid explanation. It remains unclear whether the relation between temperature and φ_{DP}^0 estimates is causal or if both are correlated to some other factor(s), such as atmospheric pressure, that change on similar time scales. Other issues that have not yet been investigated include effects of heavy rain on the radome and the potential for azimuthal dependency.

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