Cloud identification in the Canadian High Arctic using the UV-visible colour index

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I. Introduction

In UV-visible spectroscopy, Rayleigh and Mie scattering contribute to the broadband extinction seen in spectra of scattered sunlight. The relative intensity of these two components of scattering is highly dependent on the cloud condition of the sky. The colour index (CI), defined as the ratio of light intensities at dfferent wavelengths, typically 350 nm and 550 nm, provides a means of determining the cloud conditions[1].

$$CI = \frac{Intensity(550nm)}{Intensity(350nm)}$$

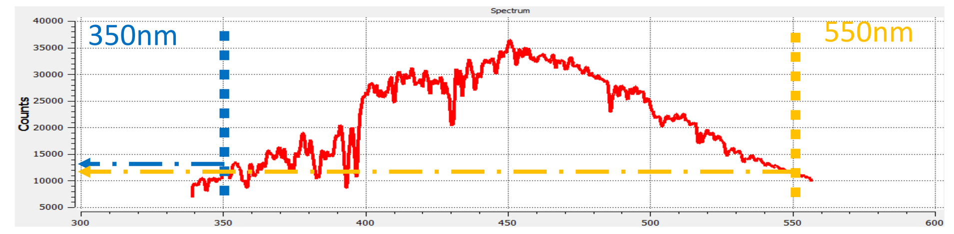

Fig. 1 UV-visible spectrum of zenith-scattered sunlight

One of the reasons to choose the 350 nm and 550 nm wavelengths is that they have minimal interference from ozone, NO_2 or O_4, which have strong absorption features in the UV-visible spectrum. The colour index can be used for detecting polar stratospheric clouds (PSCs) and also tropospheric clouds[2].

II. Measurement Site and Instrument

- The Polar Environment Atmospheric Research Laboratory (PEARL) (see Figure 2(a)) is located on Ellesmere Island, Nunavut, Canada (80°N, 86°W)
- The University of Toronto Ground-Based Spectrometer (UT-GBS) (see Figure 2(b)) measures vertical column densities of ozone and NO_2, as well as slant column densities of enhanced BrO and OClO, by using the Differential Optical Absorption Spectroscopy (DOAS) technique[3].
  - ✓ A UV-visible triple-grating spectrometer
  - ✓ Installed at PEARL in 1999: daily measurements during spring from 1999-2009
  - ✓ Year-round measurements, with the exception of polar night, from 2010-2013

Fig. 2 (a) photo of PEARL, (b) photo of UT-GBS

III. Colour Index Dataset

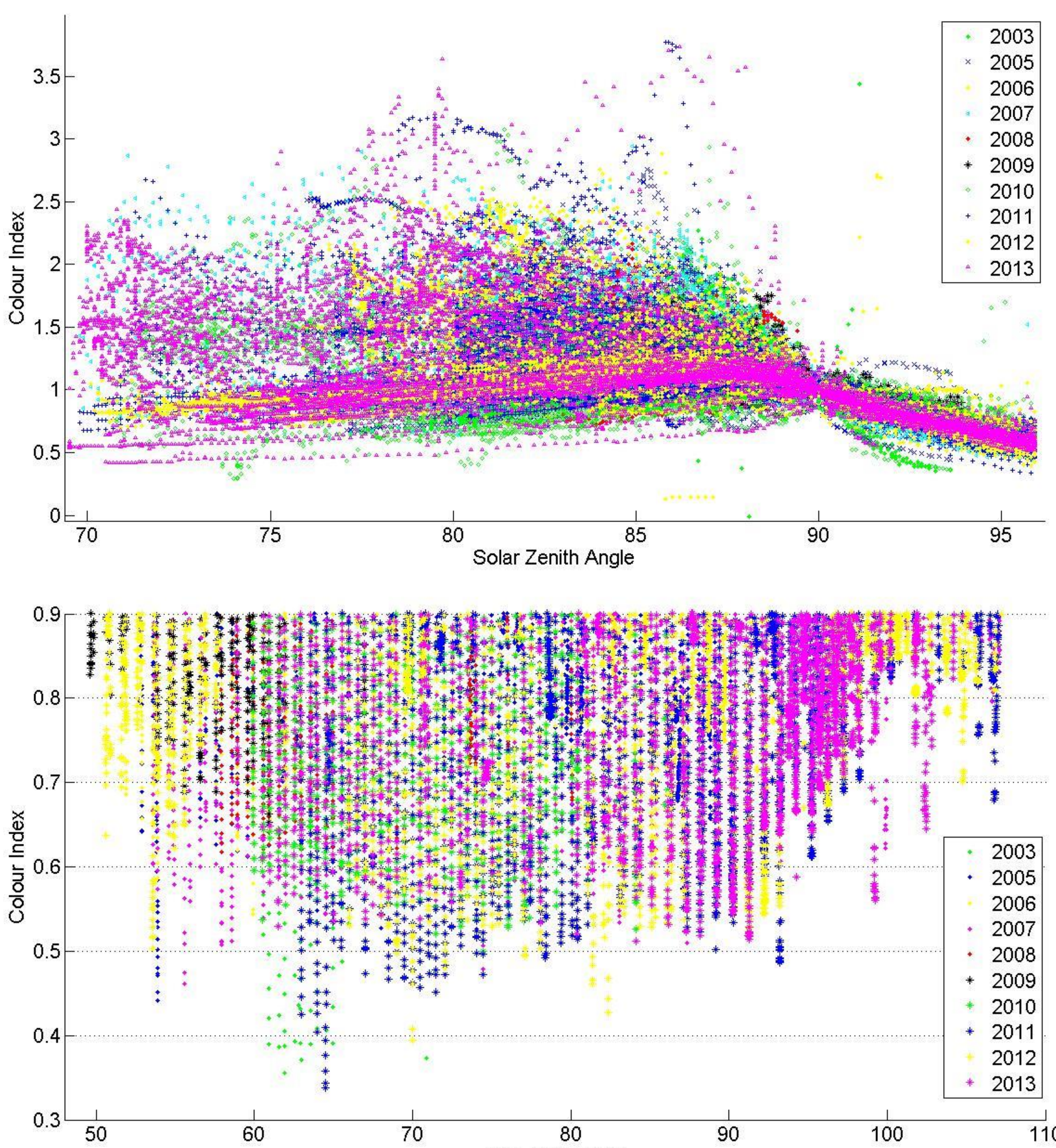

Fig. 3. The colour index dataset as a function of: (upper panel) solar zenith angle, and (lower panel) day of the year (y-axis zoomed in).

UT-GBS has made UV-visible zenith-sky measurements since 2003 using a 600 gr/mm grating centered at 450 nm.

The 10-year spring time dataset (2003-2013) has been analyzed to study both PSCs and tropospheric clouds.

To use the colour index as evidence of PSCs, we normalized the data by the CI calculated at solar zenith angle (SZA) = 90° as shown in Figure 3. All the CIs in following context are normalized ones.

$$CI_{normalized} = \frac{CI(SZA)}{CI(90°)}$$

Colour index data from SZA 85° to 96° can be used to identify PSCs. On a typical clear-sky day, the normalized CI (for 85-95°) should be close to 1. However, if PSCs are present, the CI can be shifted to a lower value (<0.5).

Strong stratospheric ozone depletion occurred in 2011, and very low colour indices were observed from day 64 to 71. During this period, the polar vortex was over Eureka, and lower stratospheric temperatures were cold enough for PSC formation, as seen in the scaled potential vorticity (sPV) and temperature on the 490 K isentropic surface as shown in Figure 4.

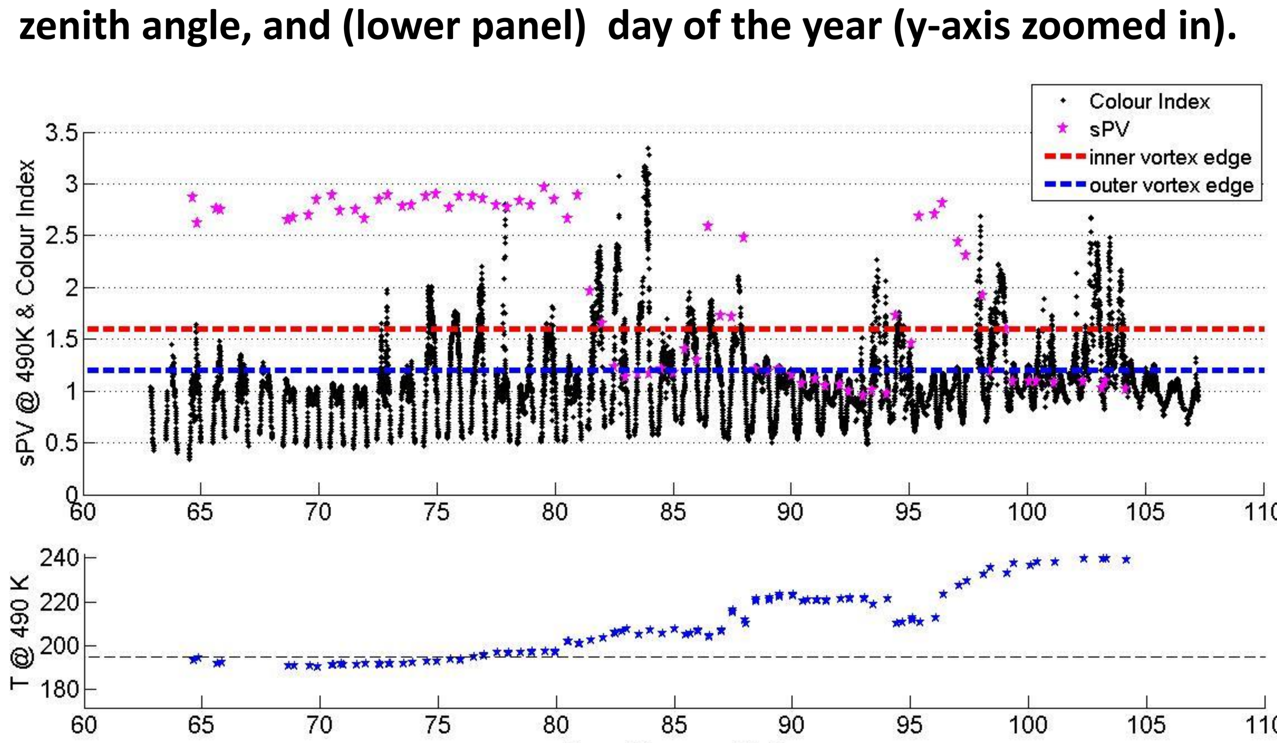

Fig. 4. Upper panel: colour index and sPV in 2011 (CI and sPV on same scale). Lower panel: temperature on the 490K potential temperature surface.

IV. Sensitivity of the Colour Index to Tropospheric Clouds

In clear-sky conditions, the CI will vary slowly with SZA (see Fig. 5, days 90, 91, and 95). However, in the presence of clouds, which affect the Rayleigh and Mie scattering, the CI can change significantly during the day (see Fig. 5, days 93 and 94.

The Millimetre Cloud Radar (MMCR) measures equivalent radar reflectivity, Doppler velocity, spectral width, and Doppler spectra, from which information about cloud heights, thicknesses, internal structure and vertical motions can be determined.

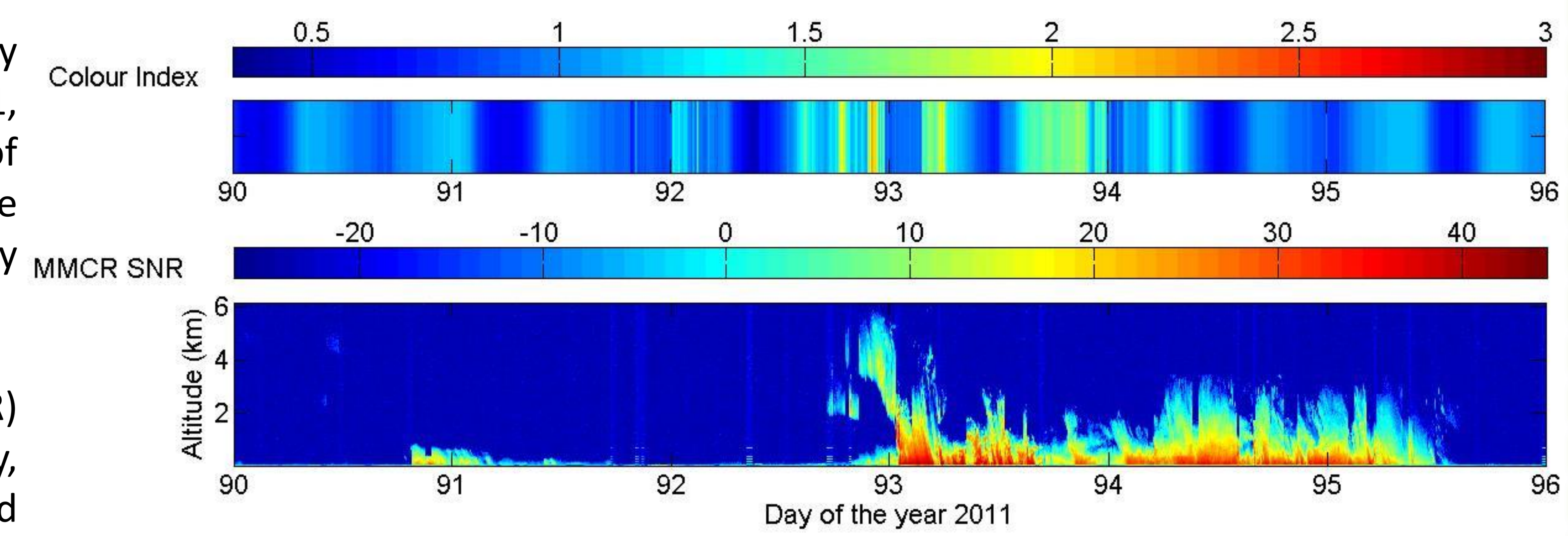

Fig. 5. Upper panel: UT-GBS colour index from March 31 (day 90) to April 5 (day 95) at Eureka. Bottom panel: MMCR data for the same period. Note both MMCR and CI data are in UTC, and CI data are only available during sunlit conditions (SZA< 96°).

V. Sensitivity of the Colour Index to Polar Stratospheric Clouds

Cloudy days (only tropospheric clouds) can be identified by CI and MMCR data as shown in Section IV. Potential PSC days can be identified by their extremely low CIs when SZA = 95° as described in Section III.

If cloudy days (examples in Figure 6(c) and (e)) are filtered out of the colour index dataset, a decreasing trend in the colour index can be seen, as shown in Figure 6(b). The full colour index dataset is shown in panel (a) and the filtered data are shown in panel (b), with PSC days for both plotted in red. Evidence for PSCs is presented in panels (d) and (f).

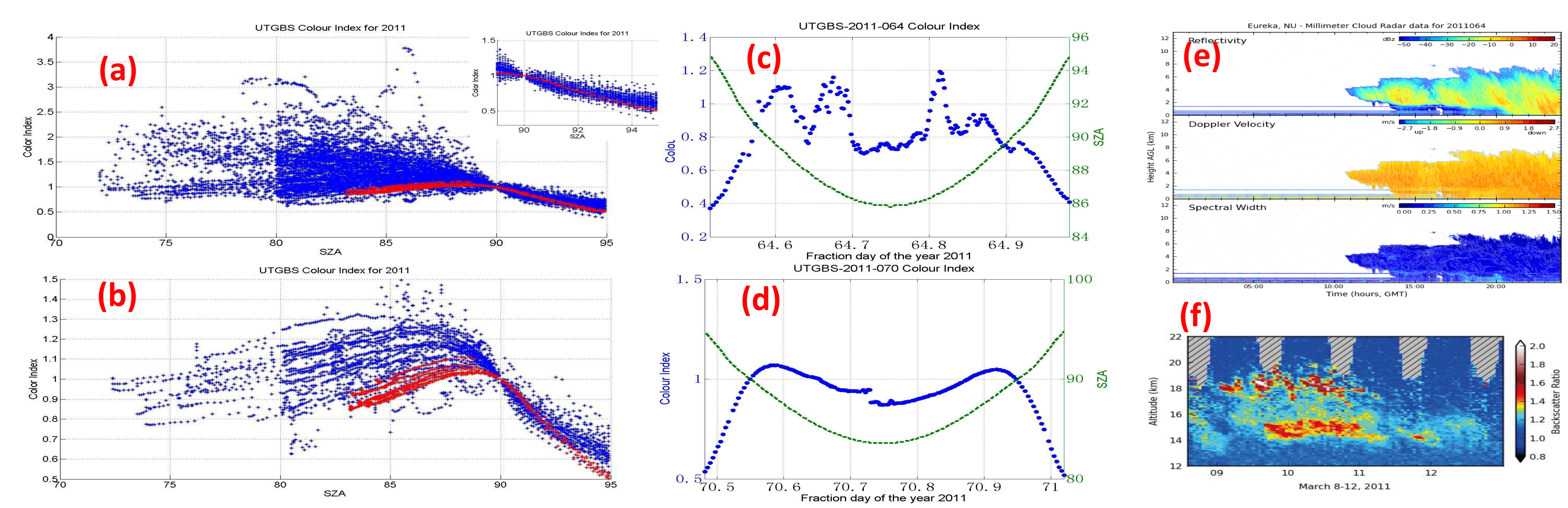

Fig 6. (a) All colour index data for 2011, with days having PSCs indicated in red, (b) 2011 colour index data filtered to remove days with tropospheric clouds, and PSC days again indicated in red, (c) CI for the lowest CI day in 2011 (day 64), (d) CI for a day with PSCs (day 70), (e) MMCR data for day 64, (f) PSCs observed by the Rayleigh-Mie-Raman lidar at Eureka for days 68 to 71[4]. The RMR lidar uses ultra-short pulses of light from two lasers, operating at ultraviolet (355 nm) and visible (532 nm) wavelengths, it measures the vertical distribution of aerosols, temperature, and water vapour in the troposphere and lower stratosphere.

VI. Summary

- A 10-year (2003-2013) colour index dataset for Eureka (80°N, 86°W) has been derived from UV-visible zenith-sky spectra. The colour index provides information about sky conditions and a means of detecting PSCs over Eureka.
- An initial comparison between cloud radar and colour index has been performed, confirming sensitivity of the CI to tropospheric clouds.
- The enhancement of scattered light in the presence of PSCs results in a distinctive decrease in colour index with SZA.
- The colour index was used to identify PSCs in 2011, giving results that were consistent with information about the location of the polar vortex, stratospheric temperatures, and cloud radar and lidar data.

VII. References

1. Sarkissian, A., J. P. Pommereau, and F. Goutail, Identification of polar stratospheric clouds from the ground by visible spectrometry, *Geophys. Res. Lett., 18, 4, 779-782, 1991.*
2. Wagner, T., Erle, F., Marquard, L., Otten, C., Pfeilsticker, K., Senne, T., Stutz, J., and Platt, U.: Cloudy sky optical paths as derived from differential optical absorption spectroscopy observations, *J. Geophys. Res.: Atmospheres, 103, 25307-25321, 10.1029/98jd01021, 1998.*
3. Platt, U., and J. Stutz, Differential Optical Absorption Spectroscopy (DOAS), *Springer, Germany, 2008*
4. Lindenmaier R., K. Strong, R. L. Batchelor, M. P. Chipperfield, W. H. Daffer, J. R. Drummond, T. J. Duck, H. Fast, W. Feng, P. F. Fogal, F. Kolonjari, G. L. Manney, A. Manson, C. Meek, R. L. Mittermeier, G. J. Nott, C. Perro, and K. A. Walker, Unusually low ozone, HCl, and HNO_3 column measurements at Eureka, Canada during winter/spring 2011, *Atmos. Chem. Phys., 12, 3821-3835, 2012*

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