VENUS ATMOSPHERE VARIABILITY AS ERROR SOURCE FOR SURFACE EMISSIVITY, N. Mueller[1], C. Tsang[2], S. Smrekar[1], J. Helbert[3], and M. D. Dyar[4], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109 USA, nils.muller@jpl.nasa.gov, [2] Department of Space Studies, Southwest Research Institute, Boulder, CO 80302 USA, [3]Institute for Planetary Research, DLR, Rutherfordstrasse 2, 12489 Berlin, Germany, [4]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075 USA.

Introduction: Venus surface thermal emission is observable through spectral windows in the atmosphere. It is possible to derive surface emissivity from nightside near infrared observations by correcting for the effects of the atmosphere, but the uncertainty might be affected by some unknown variables not included in our radiative transfer model. Here we compare the variability of surface emissivity derived from Venus Express VIRTIS-M IR data at 1.02 µm with the instrumental error budget, in order to estimate the magnitude of non-instrumental error sources. We show that emissivity precision is mostly limited by instrumental noise, not by unaccounted atmospheric variability.

Model: We use a radiative transfer model [1] to calculate the top of atmosphere radiance for Venus' nightside in the range of 1 to 1.4 µm with parameters including a) cloud particle number density, b) lower atmosphere water vapor, c) topography, d) and surface emissivity.

a) The clouds of Venus are mostly composed of sulphuric acid/water droplets of various size that are scattering with little absorption [2]. We assume that particle number density is sufficient to model the effect of the cloud layer on radiance in all of the windows. If the radiance of windows at 1.73 and 2.3 µm is modelled, then the variable particle size distribution becomes relevant [3].

b) Water vapor in the lower atmosphere affects the 1.1 and 1.18 µm windows but has no impact on the 1.02 µm window studied here. The water vapor abundance in the lower atmosphere is expected to be constant within the VIRTIS uncertainty of 1.5 % [4]. When deriving surface emissivity from these windows water vapor variability can be corrected for. The shortward flank of the 1.18 µm window is sensitive to the presence of water vapor but much less sensitive to surface emissivity. This provides an opportunity to disentangle these parameters [4].

c) Topography determines both surface temperature (using the adiabatic temperature lapse rate) and atmospheric column thickness and thus lower atmosphere gaseous extinction. The lower atmosphere is thought to be well-mixed thermally because convective heat transfer is much more efficient than radiative cooling and heating[5].This results in very small horizontal temperature variation. Near-infrared observations by Galileo have been used to constrain horizontal temperature variation of the atmosphere in contact with the surface to < 2 K [6].

d) Surface emissivity is the locally constant quantitiy that we wish to derive using the above simplified assumptions. Any variability in the atmospheric parameters not accounted for will manifest as variability in derived emissivity.

Instrumental precision: The VIRTIS spectra archived in the ESA Planetary Science Archive need to be processed further before they can be compared to RT model spectra. VIRTIS data show a non-linear detector response and some straylight from the sun or the bright side of the planet [7]. This is corrected for by statistically analyzing spectra observing space following the approach of [8].

The instrumental noise and uncertainty introduced by the detector response and straylight corrections are estimated from the standard deviation of the corrected radiance of spectra showing space. Relevant here are band 0, which is the wavelength of the 1.02 µm window observing the surface, and band 30, which is at the wavelength of the 1.31 µm window observing cloud opacity (see Table 1).

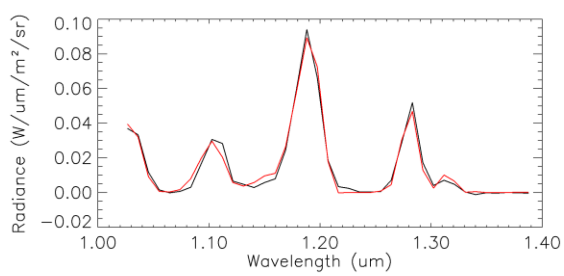

Figure 1. Corrected VIRTIS spectrum (black) fitted with a RT model spectrum (red) by shifting spectral registration and changing bandwidth.

Derived emissivity standard deviation: To have a large sample with little horizontal variance, we select all VIRTIS M IR spectra with 3sec exposure from the nightside of the planet with footprints corresponding to a topography between -50m and +50m relative to the mean planetary radius and within -50° to -10° N and 260° and 280°E, an area observed by many images. Spectra are corrected for non-linear detector response, straylight and limb darkening [9].

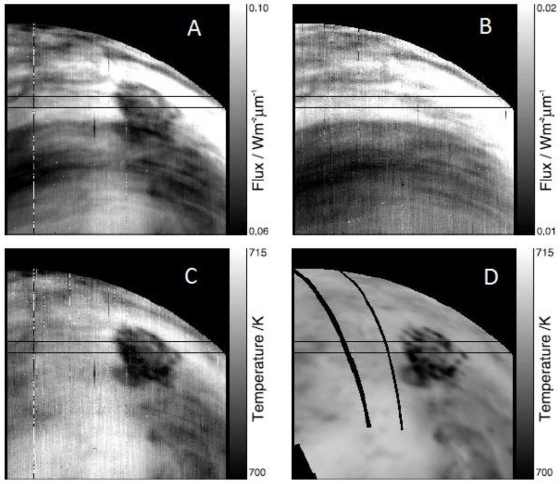

Figure 2. VIRTIS 18 sec exposure image of Alpha Regio, Venus, illustrating the correction for atmospheric variability as in [9]. Shown is (A) near infared flux at 1.02µm and (B) 1.31µm. Both wavelengths are combined to derive (C) surface brightness temperature. (D) is brightness temperature predicted based on Magellan altimetry.

The spectral registration of VIRTIS apparently shifted during the Venus orbit insertion maneuver [7]. Thus we fit the spectra with RT model spectra using band width and a spectrally flat offset to the original band center wavelenths as free parameters (see Fig. 1 for an example).

The new spectral registration matching RT model and data allows us the derivation of emissivity following the approach of [9], however using RT model as lookup tables instead of data statistics. Figure 2 illustrates the process of combining two band to reduce the effect of atmospheric variability.

The radiance of band 30 is inverted into the cloud particle density factor that results in the same RT model radiance. This same factor is then used to find the emissivity that results in a RT model adiance matching that of band 0 at the appropriate cloud opacity. The standard deviation of the resulting emissivity is 0.09. To compare this standard deviation to the instrumental precision, we derive the relevant partial derivatives of RT model radiances at the average conditions. These are the partial derivative of the surface observing band radiance I_s with respect to emissivity e and the partial derivative of the surface observing band with respect to the band used for cloud correction I_c. The values are given in table 1. Assuming independent and normally distributed errors in the two bands, the estimated error of emissvity is then:

$$\Delta e = \sqrt{\left(\frac{de}{dI_s}\Delta I_s\right)^2 + \left(\frac{de}{dI_s}\frac{dI_s}{dI_c}\Delta I_c\right)^2} = 0.07.$$

Discussion: The estimated 1σ precision of emissivity derived from a VIRTIS single spectrum is 0.07, close to the observed standard deviation of 0.09. Some part of the remaining discrepancy of predicted and observed variance could be due to the uncertainty of the VIRTIS spectral registration, which also introduces errors into the emissivity derivation. These errors will be studied further together with any correlations of derived emissivity with latitude and local time.

However, the small discrepancy of prediction and observation mean the simplified assumptions of the RT model and unknowns of the atmosphere do not introduce a large variance into our derived emissivity. There is no indication that our assumption of a horizontally uniform lower atmosphere is incorrect. Even though the accuracy of the derived emissivity is difficult to verify owing to the lack of in-situ data, the precision of emissivity and thus the ability to distinguish geological units based on emissivity is mostly limited by the instrumental precision of VIRTIS.

References: [1] Tsang C. et al. (2008) *J. Quant. Spectrosc. Radiat. Transf.*, *109*, 1118–1135. [2] Grinspoon D. et al. (1993) *Planet. Space Sci.. 41*, 515-541. [3] Carlson R. et al. (1993) *Planet. Space Sci.*, *41*, 477-485. [4] Bezard B. et al. (2009) *JGR*, *114*, E00B39. [5] Stone P. (1975) *J. Atmos. Sci.*, *32*, 1005-1016. [6] Hashimoto G. et al. (2008) *JGR*, *113*, E00B24. [7] Cardesín Moinelo A. et al. (2010) *IEEE Trans. Geosci. Remote Sens.*, *48*, 3941. [8] Kappel D. et al. (2012) *Adv. in Space Res.*, *50*, 228–255. [9] Mueller N. et al. (2008) *JGR*, *113*, E00B17.

Table 1. Values used in the calculation of predicted variability of derived emissivity.

Description	[Symbol] = unit	Value
Instrumental precision of surface observing band at ~1.02 µm	[ΔI_s] = mW/µm/m²/sr	1.5
Instrumental precision of surface observing band at ~1.31 µm	[ΔI_c] = mW/µm/m²/sr	0.5
Standard deviation of surface observing band	[σI_s] = mW/µm/m²/sr	4.9
Standard deviation of cloud observing band	[σI_c] = mW/µm/m²/sr	1.4
Partial derivative of surface observing band wrt to emissivity	[dI_s/de] = mW/µm/m²/sr	35
Partial derivative of surface observing band wrt cloud observing band	[dI_s/dI_c]	3.7
Estimated precision of derived emissivity	[Δe]	0.07
Standard deviation of derived emissivity	[σe]	0.09

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