CLOUD MORPHOLOGIES ON THE NIGHTSIDE MIDDLE ATMOSPHERE OF VENUS CAUSED BY AN EQUATORIAL JET THAT PRODUCES ZONAL WIND SHEAR. J. Chesal[1] and I. B. Smith[1,2], [1]York University (4700 Keele St, Toronto, ON M3J 1P3, chesal@yorku.ca), [2]Planetary Science Institute

Introduction: Venus has an atmosphere that super-rotates at windspeeds up to 400 times faster than the solid body planet. The windspeeds increase with altitude, reaching a maximum of 100 m/s, on average, at the cloud top. The winds are strongly zonal and retrograde, with a weak meridional circulation. In the middle atmosphere, at an altitude of 50 km, the meridional flow is approximately 6 m/s and the zonal flow is 70 m/s on average. At this altitude, we see irregular cloud morphologies on the nightside of Venus that contrast to the dayside clouds in the middle atmosphere that appear smooth and stratified (Figure 1). In this project, we analyzed nighttime infrared images from the Venus Climate Orbiter, taken by the IR2 camera, seeking cloud morphologies indicative of shear, such as eyes and eddies.

The Richardson number (Ri) is the ratio of the Brunt Vaisala frequency to the squared vertical wind shear. For Ri <0, convection is possible, and when Ri <1, turbulence is possible. For Ri>>1, the conditions are stable. Below 60 km altitude on Venus, Ri is small or negative, indicating the possibility of turbulence or convection [1]. The convective layer is caused by radiative heating from the lower atmosphere at the cloud base and cooling at the middle cloud layer [2].

Methods: We collected images taken by the Japanese spacecraft Akatsuki, or the Venus Climate Orbiter (VCO). The VCO has an IR2 camera aboard which takes images from wavelengths from 1.74 µm to 2.32 µm. The IR2 camera studies the nightside of the planet and looks at the lower clouds' opacity to the thermal emission from the surface and the lower atmosphere. The wavelength of 2.26 µm is used for cloud tracking Because this band isn't absorbed by higher elevation atmospheric constituents, the IR2 camera is most sensitive to radiation originating from a layer between 35 to 50 km.

Using the atmospheric windows in the infrared at 1.7 µm and 2.2 µm to 2.3 µm, we can see the variation of the clouds' opacity to outgoing radiation from the lower atmosphere and the surface. Previously, high contrast features in the lower cloud deck were automatically determined and compared over 4 hour intervals to calculate the zonal and meridional wind speeds for many latitudes and longitudes [3].

We used the inhomogeneities in the cloud deck's opacity to determine the location of eddies, hooks, eyes, and other cloud morphologies related to wind shear. Because the radiation originates from a layer between 35 and 50 km in altitude, it is not immediately clear that the morphologies observed are due to horizontal wind shear alone. It is possible that we are seeing a two-dimensional projection of an eddy with vertical motions as well as horizontal. If the eddies are horizontal, then we can assume that there is barotropic instability in the atmosphere. If there is a vertical component, this assumption cannot be made.

We visually analyzed 1671 images, taken at a wavelength of 2.26 µm of the night side of Venus for cloud morphologies associated with wind shear. These morphologies include eddies, hooks, and eyes, shown in Figure 1. In total, 45 different examples of wind shear formations were found. Using ArcMap and the available raster data from the Planetary Data System (PDS), the longitude and latitude for each shear formation was noted. The shear formations persisted over several hours, and we tracked their locations manually to determine the speed in m/s.

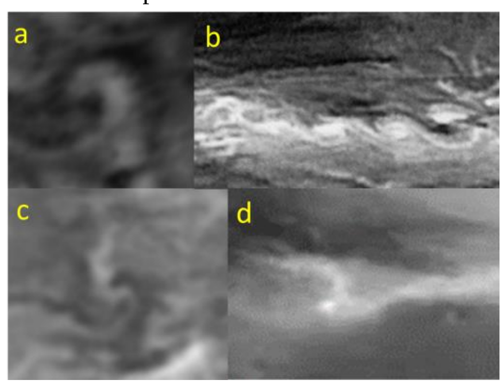

Figure 1 examples of cloud morphologies: a) eddy, b) eyes, c) eddy, d) hook.

The Rossby number is an important property in atmospheric dynamics. It is a ratio of the zonal wind speed to characteristic length and the Coriolis force. When the Rossby number is larger than unity, the internal inertial forces dominate the Coriolis force. The characteristic length was measured for each wave, equal to one wavelength. We calculated the Coriolis parameter to be $\Omega = 2.99 \times 10^{-7}$ s^{-1}. Then, we used the average zonal wind speed.

We obtained additional data from [3], including wind speed, local time, and locations of high contrast features in the lower cloud deck. Some of these high contrast features were eddies and hooks and were added to our list. The wind speeds show a periodic equatorial jet found by [3]. To show this feature, we used a distance weighted interpolation to create a continuous wind speed field. We assumed that the winds are completely zonal since the meridional component of the wind is an order of magnitude lower than the zonal component. If the winds are solely zonal, the wind shear must also be zonal. The wind shear was calculated between the data points (Figure 3), and then we used a distance weighted interpolation to create a continuous plot. The sample size of the wind speed data varies, so the accuracy of each continuous plot varies due to the changing distance between data points.

Next, we calculated the horizontal divergence and used distance weighted interpolation to create a continuous plot. For each instance of a wind shear formation, these three plots were created where the wind speed data was available. If the horizontal divergence was low, then the vertical motions in that area were low as well. If the divergence was high, then vertical motion was occurring, and horizontal wind shear was not be sufficient to describe these waves.

Results: The bivariate histogram in Figure 2 shows that the eddies most often form around 50 degrees E, and following the wind direction westward, the number of shear formations decreases with respect to longitude. The positions of all 45 shear formations are restricted to a latitude band of 27 degrees N and 33 degrees S, telling us that this is an equatorial phenomenon. The lower longitudes favour eddy formation. No shear formations occur at the equator. The Northern flank of the jet forms more eddies.

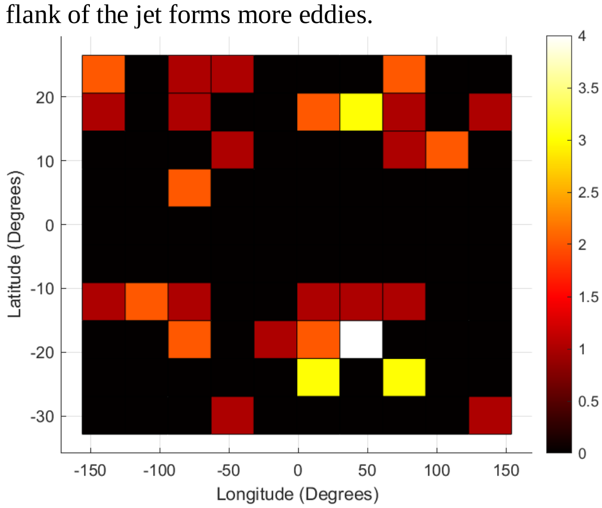

Figure 2 Bivariate histogram of wind shear formation positions with respect to latitude and longitude.

We also learned that after the winds moved from day to night, the wind speeds were seen to significantly decrease linearly with respect to local time. The rates of decrease were highest at latitudes ranging from 30° N to 30° S, and lowest in the latitudes ranging from 30° S to 90° S. The equatorial jet, then, could possibly be formed due to the variation of wind speed across the terminator, so the day-to-night transition is a subject worth studying further.

We calculated the regression of zonal wind speed with respect to local time and discovered a significant linear decrease in wind speed as the air flows west of the terminator. This matches expectations because as the winds flow past the terminator, they are no longer subject to radiative heating by the Sun, and we expect them to slow down. This acceleration changes with respect to latitude, and can help explain why the northern flank of the jet produces more eddies on average.

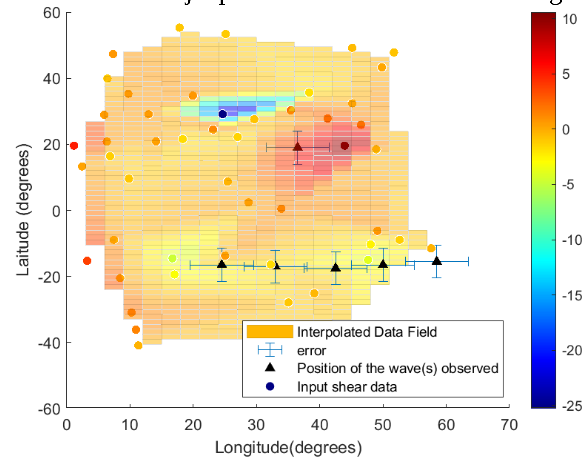

Figure 3 Wind shear values, with the respective wind shear formations' positions, for the data of August 13th, 2016.

Of the 25 dates that show evidence of wind shear, 18 were accompanied by wind speed data from [3]. We analyzed those 18 cases with the following criteria: the shear formations are in the domain of the wind speed field, and the wind speed field shows an equatorial jet.

Overall, we find that these cloud morphologies exist within areas of high wind shear and low horizontal divergence.

The Rossby numbers for these shear formations are in the order of 10^2. This large Rossby number regime tells us that the Coriolis force is negligibly affecting these waves.

Future Work: Having the vertical profiles of wind speed and temperature would allow us to calculate the vertical component of wind shear and eliminate the possibility of barotropic instability. With access to more data, we will assess the frequency of the equatorial jet and the accompanying waves. Modelling the equatorial jet will allow us to constrain the formation mechanisms of the jet and calculate the contribution of the atmospheric mixing to the chemical composition of the lower and middle atmosphere.

References: [1] Piccialli, A. (2010). *Thesis, University Carolo-Wilhelmina.* [2] Sánchez-Lavega, A., Lebonnois, S., Imamura, T. et al.. *Space Sci Rev* 212, 1541–1616 (2017). [3] Peralta, et al (2018). *The Astrophysical Journal Supplement Series*, 239(2), 29.