SEASONAL VARIABILITY OF TITAN'S GLOBAL WIND FIELD. S. L. Light[1,3], M. A. Gurwell[2], C. A. Nixon[3], A. E. Thelen[3], [1]University of Maryland, College Park, MD 20742, USA (slight@umd.edu) [2]Center for Astrophysics | Harvard & Smithsonian, Cambridge, MA 02138, USA [3]Planetary Systems Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

Introduction: Titan is home to complex atmospheric chemistry that surpasses any other atmosphere in our solar system [1]. Acetonitrile (CH_3CN) was first detected in Titan's atmosphere with the IRAM 30-m telescope in 1993 [2]. Subsequent work using Cassini Ion and Neutral Mass Spectrometer (INMS) and Atacama Large Millimeter/submillimeter Array (ALMA) observations have shown significant temporal and spatial variations in the abundance and spatial distribution of CH_3CN, providing insight into the dynamics of Titan's atmosphere [3,4,6,7,9,10]. Doppler line shift measurements of CH_3CN enabled the first direct determination of mesospheric (mean altitude of $\bar{z}$=345 km [7]) wind speed on Titan, and established that zonal wind flow is prograde in Titan's upper atmosphere [5]. The recent discovery of unexpectedly intense winds that defied previous atmospheric models for Titan [7], and subsequent work to understand their driving mechanisms [3] has highlighted the strong time-variability and altitude dependence in Titan's atmosphere. Longer-term seasonal differences in wind speed and distribution have remained mostly unconstrained. In this study, we analyzed observational data from 2009 and 2010 in order to extend the time series of CH_3CN observations on Titan. These results will improve general atmospheric circulation models.

Observations: Interferometric observations of Titan were conducted on 2009 March 23 and 2010 February 12 with the extended Submillimeter Array (eSMA) at a rest frequency of 349.415 GHz and channel resolution of 203.1 kHZ. In 2009, the configuration of the eSMA involved 8 SMA antennas (6-m diameter) with baselines out to 508 meters, the James Clerk Maxwell Telescope (JCMT) single-dish antenna (15-m diameter) and the Caltech Submillimeter Observatory (CSO) single dish (10.4-m diameter) resulting in a combined baseline up to 780 meters. In 2010, 7 SMA antennas and the JCMT single-dish were used, resulting in a combined baseline of 625 meters. Further observational details are outlined in Table 1.

The data for both years were calibrated using standard methods in MIR, the SMA's suite of calibration routines[1]. The spectral passband response was calibrated versus the strong blazar 3C273 in both years. The SNR was sufficiently high that self-calibration of the complex gains vs. time was performed using the well-understood Titan continuum, producing superior results by removing atmospheric instability on short timescales. The flux density scale was also set using the Titan continuum, which is known to roughly 3% in the submillimeter [12]. The output from MIR was calibrated visibility data for each spectral channel, in the UVFITS format. The UVFITS data was imported into the Astronomical Image Processing System (AIPS) for creation of images from the visibility data, via a modified CLEAN process.

Time of Observations	Opacity at 225 GHz	Mean Diameter	Synthesized Beam Size	Mean Angular Separation	Beam Position Angle
2009 Mar 23	T ~ 0.4 (0.8 mm PMW)	0.84"	0.39" x 0.19"	181.79"	48.8° CCW
2010 Feb 12	T ~ 0.05 (1.0 mm PMW)	0.82"	0.37" x 0.22"	120.47"	52.65° CCW

Table 1. Further Observational Details. Mean angular separation refers to the average angle between Saturn and Titan as seen by an Earth observer.

Analysis: Initial analysis of the 2009 eSMA data revealed increasing CH_3CN abundance with altitude, and suggested a decrease of its abundance at 2.5 mbar by a factor of 6 to 10 in the decade leading up to the observations [8]. Doppler shift measurements were consistent with a prograde zonal wind field with a lower limit of v_{zonal}>78±27 m/s, consistent with Moreno et al., 2005, but the effects of beam smearing were not accounted for [8].

For the 2010 data, a continuum map was made over the whole data flux density dataset of around 3.25 Jy. The result is shown in Figure 1.

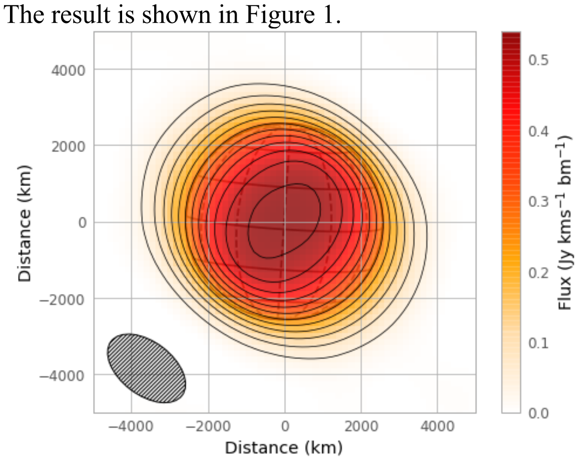

Figure 1: Continuum map for 2010 eSMA observations drawn to reflect Titan's surface and alignment in the observation's field of view. In the lower left, an ellipse shows the spatial resolution (beam FWHM) for the map. The contours

[1] https://www.cfa.harvard.edu/~cqi/mircook.html

surrounding the continuum image are 25σ levels of rms noise (σ~1.75 mJy/beam).

Next, an integrated map of the continuum subtracted flux across the full spectrum was initially formed and is shown in Figure 2, displaying a strong concentration of CH_3CN to the North and to a lesser extent the East of Titan.

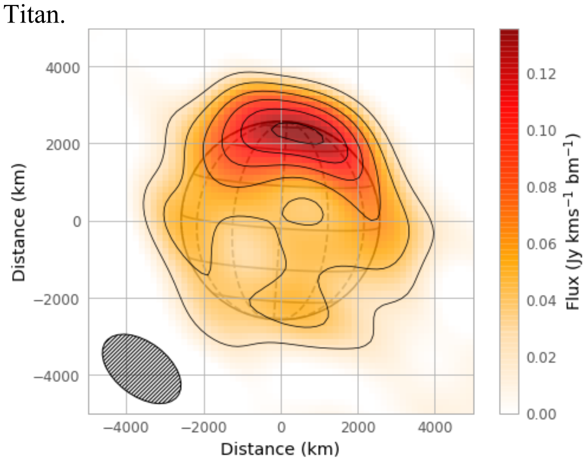

Figure 2: Integrated map over 91 MHz of Titan's flux using 2010 eSMA observations. East-west asymmetry is primarily due to the beam shape. Measured rms noise (σ) was about 7.26 mJy/beam, and 3σ contour intervals are shown.

An integrated spectral flux was extracted from a circle with the radius of Titan, including its atmosphere, and a smoothed version is shown in Figure 3 along with the $J = 19_3\text{-}18_3$, $19_2\text{-}18_2$, $19_1\text{-}18_1$, and $19_0\text{-}18_0$ transition lines for CH_3CN.

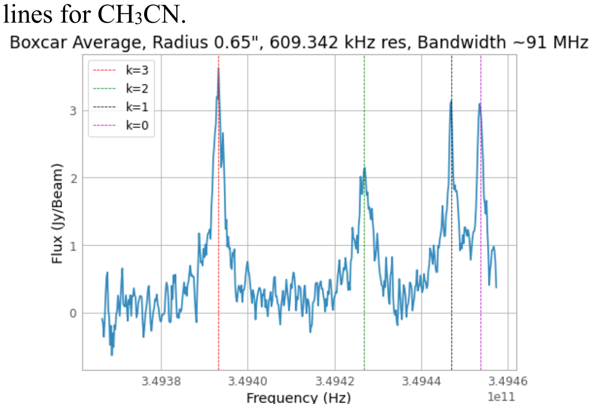

Figure 3: Boxcar average of the integrated flux with a radius of 0.65" centered on Titan. Three channels with individual resolutions of 203.114 kHz were averaged together (effective resolution 609.342 kHz).

Next, Gaussian fits were calculated for these spatially resolved observations for the north, east, south, and west regions of Titan with a radius of 0.30". In Table 2, preliminary Doppler shift measurements are shown between the East and the West (Δv) and compared to previous work at similar atmospheric altitudes of around 350 km. This approximate altitude is based on the radiative transfer models of [7].

Work.	Observational Year	$\bar{z}$ (km)	Δv (m/s)
Moreno et al. 2005	2003	300 (±150)	191 ± 42
Moreno et al. 2006	2004	300 (±150)	178 ± 74
This Work	2009	~345	Prograde[2]
This Work	2010	~345	Prograde[2]
Lellouch et al. (2019)	2016	345 (+60/-140)	220
Cordiner et al. (2020)	2016	345 (+60/-140)	254 ± 4
Cordiner et al. (2020)	2017	345 (+60/-140)	185 ± 3

Table 2. Comparison of Titan zonal wind speeds across various studies.

Future Studies: Further analysis remains to be done with the 2009 data. The results of the analysis of the 2009 and 2010 data will be compared to observations with ALMA and the Cassini Composite Infrared Spectrometer in order to form a better understanding of just how Titan's winds vary temporally and spatially. With these results, newly constrained radiative transfer modelling of Titan's atmosphere will be performed.

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[2] Absolute magnitude to be determined.