STRATOSPHERIC CHEMISTRY IN SATURN'S ATMOSPHERE DURING THE BEACON STORM. E.S. Armstrong[1] (eleanor.armstrong@jesus.ox.ac.uk) and J. I. Moses[2], L.N. Fletcher[1], P.G.J. Irwin[1], B.E. Hesman[3], P.N. Romani[4]; [1]Atmospheric, Oceanic and Planetary Physics, University of Oxford, [2]Space Science Institute, CO, [3]University of Maryland, MA, [4]NASA Goddard.

Introduction: The storm that recently erupted in Saturn's northern hemisphere, first observed on 5th December 2010 [1], was primarily a tropospheric disturbance, noticed due to its typical storm signatures such as lightning and clouds [2]. However, there was also an unexpected stratospheric response seen in elevated temperatures and molecular abundances, which has come to be known as the 'beacon' region. The beacon was initially two smaller regions, called B1 and B2, which existed at two different latitudes (25°-35°N) but which merged in April 2011, around 120 days after the start of the tropospheric disturbance [3]. This merger resulted in the formation of one larger, hotter anticyclonic vortex that continued to circle Saturn after the tropospheric disturbance had dissipated.

The presence of *Cassini* gave unprecedented data on the stratosphere's thermal and compositional response to the disturbance [3], compared to previous storm systems on Saturn, where only ground-based data were available.

The *Cassini* Composite InfraRed Spectrometer (CIRS) instrument [4] detected significant variation in stratospheric temperatures during the storm [3,5], with greatest sensitivity at the 1mbar region. The retrievals suggest significant deviation from prestorm abundances of many hydrocarbons [3,5,6], in particular in the mole fraction of ethene (C_2H_4), for which Hesman et al [6] find that their photochemical model profile must be multiplied by a factor of 91 to account for the observed emission.

Procedure: The KINETICS code [7] is used to model the hydrocarbon and oxygen photochemistry in the beacon region [8, 9]. The procedure solves the coupled continuity equations (conservation of mass) where the rate of change of the number density of a species is balanced by its flux divergence (assuming diffusive transport) and chemical production and loss. The model is run with chemical species containing only H, He, C and O, and the "Model C" reaction list from Moses et al [9]. A total of 78 species vary through 522 reaction pathways (see Moses et al. [9]). The eddy diffusion coefficient profile that reproduces the prestorm retrievals of Fletcher et al [3]. Our prestorm temperature profile is a CIRS average from July-August 2010 over the eventual beacon latitudes. The temperatures during the storm are taken from the Cassini/CIRS analysis of Fletcher et al. [3].

The models run over the time length of the storm, but we specifically focus on the results from the 4th May 2011, comparing our output on this date with that of Hesman et al. [6]. The observation data are spaced unevenly over the duration of the storm, and we simply update the model temperature profiles at the halfway point between each observation. Note that the CIRS temperature profiles are retrieved from the observed infrared emission in the 7.7 μm CH4 band, assuming that the chemically stable methane does not change during the storm. Given these retrieved temperature profiles, the abundances of other hydrocarbons can be derived from the molecular band emissions observed in the CIRS data [3, 5, 6].

Varying the Model: Three methods are investigated to attempt to reconcile our model predictions with the observed C_2H_4 emission in the beacon (Hesman et al. [6]): updating the rate coefficients in the model; proposing a higher temperature at the merge of the B1 and B2 features; and introduction of winds to simulate the expected downwelling in the system.

Results: Initial runs of the "Model C" chemistry from the Moses et al. [9] paper, with the elevated temperature profiles seen in the beacon, produced a distinct peak in C_2H_4. This peak was not as large as derived from the CIRS observations [6]. The model, which predicted no change in C_2H_2 and C_2H_6 profiles in the beacon, under-predicted the abundance of these species. By contrast, the prestorm results from the model actually over-predicted the C_2H_2 abundance compared with the *Cassini*/CIRS retrievals [3].

Kinetics. The primary mode of production of C_2H_4 in our beacon models at 1-mbar is

$$H_2 + C_2H_3 \rightarrow H + C_2H_4 \quad \text{(R1)}$$

Despite recent theoretical efforts by Tatuermann et al. [11] the low-temperature rate coefficients are still not well known for this reaction. The model output with the new Tautermann et al. [11] rate expression does not match the Hesman et al. [6] retrieved C_2H_4 abundance. In fact it provides a smaller beacon increase than our nominal model. The largest published rate coefficient [12] for R1 is adopted in the nominal model.

Other reaction rate coefficients were also investigated:

$$H + C_2H_2 \rightarrow C_2H_3 \quad \text{(R2)}$$

$$H + C_2H_3 \rightarrow H_2 + C_2H_2 \quad \text{(R3)}$$

$$H + C_2H_3 \rightarrow C_2H_4 \quad \text{(R4)}$$

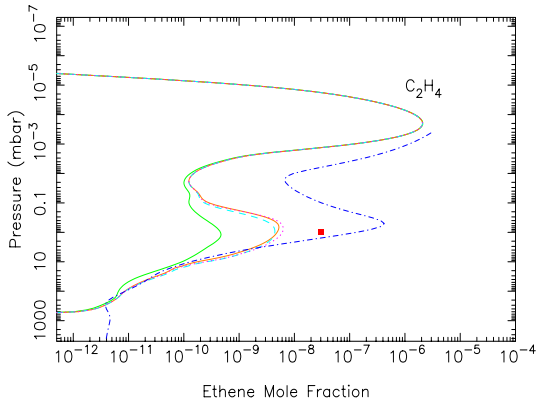

Fig 1 – The ethene (C_2H_4) mole fractions at different pressures, both before the storm (green) and on the 4th May 2011 as produced by the nominal model (orange, solid), the downwelling model (cyan, dashed), and the higher temperature (magenta, dotted). The dark blue dot-dashed line is the retrieved profile of Hesman et al. (2012). The red marker is an alternative peak estimation of the C_2H_4 profile required to reproduce the emission from *Cassini*/CIRS (from Fletcher)

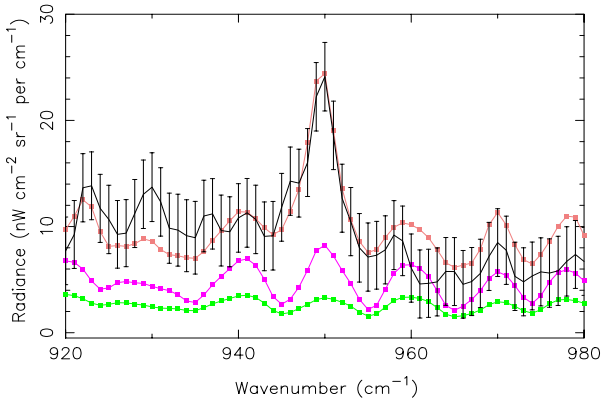

Fig 2 – The emitted radiance as a function of wavelength in the ethene emission region. The green curve is the prestorm model, the magenta has high April temperatures, and the coral curve is the same model but the ethene profile has been scaled uniformly by a factor of 5 and the temperatures have been re-retrieved based on an optimization of all hydrocarbon profiles (see [3] for details).

R2 has a more recent rate coefficient recommendation [13], but the adoption of this rate coefficient does not result in a distinct C_2H_4 post-storm peak, and both prestorm and post-storm fits to all the C_2H_4 hydrocarbons are significantly worse than in our nominal model. None of these kinetic optimizations could successfully reproduce the magnitude of the C_2H_4 peak abundance derived in Hesman et al. [6] (see Figure 1). Happily, the scaling factor was significantly reduced compared to previous work, down from 91 [6] to ~6.

Temperature. The higher temperatures for the April merger date caused a small increase in peak C_2H_4 abundance compared to the nominal kinetic model, but not the necessary magnitude (see Figure 1). In Figure 2 the synthetic emission from the model is compared with the *Cassini*/CIRS data.

Winds. The introduction of a subsidence wind produced a small downward shift in the profiles of hydrocarbons, and a more notable decrease in the local CH_4 abundance and a resulting increase in the retrieved temperatures, but these changes were not significant enough to reproduce the observed infrared emission (see Figure 1).

Discussion: The peak in C_2H_4 abundance is likely to be a result of a temperature-dependent reaction in the system, because of its notable appearance only during the elevated temperatures of the storm system. R1 is the only reaction identified as having the desired temperature dependency and thus likely plays a key role in the observed behavior. The work done during this project has reduced the scaling factor required to match the model output to the *Cassini*/CIRS emission from a factor of 91 [6] to a factor of 5-6. However, it was still not able to match the observed emission.

It is possible that the reaction pathways used in this model do not reproduce the expected abundance because they either have incorrect rate coefficients, or because the scheme does not include all the necessary reactions in these highly interdependent systems. This means that the kinetic input to the system is not matching the reality of Saturn's atmosphere, suggesting work can be done to more accurately match the model to the chemistry of the system.

A second consideration is that all C_2H_x hydrocarbons are under predicted in the beacon models. This suggests there may be a complex wind interaction in the system that cannot be reliably reproduced in simple 1D models, affecting both temperatures and abundances. The use of a 3D general circulation model that includes chemistry may be needed to understand the beacon behavior. One implication of a downwelling wind in this system is that the mole fraction profile of CH_4 can also change, complicating the derivations of temperature from the methane emission band.

Additional Information: Thanks to Leigh Fletcher who has patiently helped us, comparing our models to the *Cassini*/CIRS emission, and to Brigette Hesman for supplying her retrieved and model profiles.

References: [1] Sanchez-Lavega A., et al 2011, *Nature,* **475** 71. [2] Fischer G., et al. 2011, *Nature* **475** 75. [3] Fletcher, L. N., et al. 2012, *Icarus*, **221** 560. [4] Flasar F. M., et al 2004, *Space Sci. Rev.*, **115** 169. [5] Fletcher L. N., et al 2011 *Science* **332** 1413. [6] Hesman B. E. et al. 2012 *Astrophys. J.,* **760** 24. [7] Allen, M., et al. 1981, *J. Geophys. Res.* **86** 3617. [8] Moses J. I., et al., 2000, *Icarus,* **143** 244. [9] Moses J. I., et al., 2005, *J. Geophys. Res,* **110** E08001. [10] Smith G. P, & Nash, D. 2006 *Icarus* **182** 181. [11] Tautermann C. S., et al., 2006, *Mol. Phys.* **104** 151. [12] Weissman M. A., & Benson, S. W. 1988, *J. Phys. Chem.* **92** 4080. [13] Baulch D. L., et al., 2005, *J. Phys. Chem. Ref. Data* **34.**