TITAN'S MIDDLE-ATMOSPHERE DYNAMICAL AND CHEMICAL SEASONAL CHANGES AT NORTHERN SPRING EQUINOX. N. A. Teanby[1], P. G. J. Irwin[2], C. A. Nixon[3], R. de Kok[4], S. Vinatier[5], A. Coustenis[5], E. Sefton-Nash[1,6], S. B. Calcutt[2], and F. M. Flasar[3], [1]School of Earth Sciences, University of Bristol, Bristol, BS8 1RJ, UK (n.teanby@bristol.ac.uk), [2]Atmospheric, Oceanic, and Planetary Physics, University of Oxford, UK. [3]Planetary Systems Laboratory, NASA Goddard Space Flight Center, Greenbelt, USA, [4]SRON Netherlands Institute for Space Research, Sorbonnelaan 2, Utrecht, Netherlands, [5]LESIA-Observatoire de Paris, CNRS, UPMC Univ. Paris 06, Univ. Paris-Diderot, France, [6]Department of Earth & Space Sciences, University of California Los Angeles, Los Angeles, USA.

Introduction: Titan is the largest satellite of Saturn and is the only moon in our solar system with a significant atmosphere – composed of nitrogen (~98%), methane (~2%), and a vast array of photochemically produced trace gases. Titan's middle-atmosphere (stratosphere and mesosphere) circulation usually comprises a single hemisphere to hemisphere meridional circulation cell, with upwelling air in the summer hemisphere and subsiding air at the winter pole with an associated winter polar vortex. Titan has an axial tilt (obliquity) of 26.7°, so during its 29.5 Earth year annual cycle pronounced seasonal effects are encountered as the relative solar insolation in each hemisphere changes. The most dramatic of these changes is the reversal in global meridional circulation as the peak solar heating switches hemispheres after an equinox. Titan's northern spring equinox occurred in August 2009, and since then many middle-atmosphere changes have been observed by Cassini that were previously impossible to study. Highlights so far include the reversal of the hemispheric circulation [1] and changes in the altitude of the detached haze layer [2]. Both observations indicate global scale dynamical changes have occurred. Here we present a detailed analysis of the post equinox changes in middle-atmosphere temperature and composition, use these to infer changes in atmospheric circulation, and explore implications for atmospheric photochemical and dynamical processes.

Observations: Our observations comprise almost nine years of Cassini Composite InfraRed Spectrometer (CIRS) data – spanning northern fall to northern spring. CIRS' vantage point on Cassini allows detailed views of the polar regions, which are impossible from Earth because of orbital geometric constraints, so provides us with the best dataset yet for studying Titan's seasonal processes. CIRS is a fourier transform spectrometer and covers the spectral range 7-1000 microns, or 10-1400 cm^{-1} with a resolution of between 0.5 and 15 cm^{-1} [3]. This spectral range is ideal for studying thermal emission from Titan's large trace gas inventory, so provides a way to measure both temperature and composition of the atmosphere on a global scale.

We focus on observations taken at resolutions of 0.5, 2.5, and 13.5 cm^{-1} covering 600-1400 cm^{-1}. This range provides the best spatial resolution and sensitivity to most of Titan's IR-active trace species. Data were observed in both nadir (downward) and limb (horizontal) viewing configurations. The nadir data is best suited to global mapping of temperature and composition over a restricted altitude range, whereas the limb data is more limited in coverage but provides the best vertical information on temperature and composition.

Methods: We combined in-situ constraints from the Huygens probe with Cassini CIRS remote sensing observations to determine middle atmosphere temperature and composition over the nine years of the mission so far. Each flyby was analysed individually providing a long time series over which to study the atmospheric seasonal evolution.

Infrared CIRS spectra were inverted using the NEMESIS optimal estimation retrieval suite [4], which employs the correlated-k approximation and a non-linear inversion scheme. We determined atmospheric temperature profiles and the abundances of C_4H_2, C_3H_4, CO_2, HC_3N, HCN, C_2H_2, C_2H_6, C_6H_6 and C_2H_4 by fitting a synthetic spectrum to the observed CIRS spectra.

Results: Figure 1 shows cross sections of temperature at the south pole either side of equinox derived from CIRS limb data. An atmospheric hot spot develops soon after equinox over Titan's south pole at ~400 km altitude – indicating sinking air that is being compressed and heated adiabatically. This observation shows that the circulation direction over the south polar region has now reversed compared to earlier in the mission [5]. The transition happens almost immediately after equinox, showing that Titan's atmospheric dynamics can respond very rapidly to changes in solar heating. Using a simple energy balance calculation shows that vertical velocities over the south pole are approximately 0.5-2 mm/s (downwards).

Figure 2 shows cross sections of atmospheric composition approximately one and two years after equinox. Unlike temperature, atmospheric composition does not respond immediately to changes in atmos-

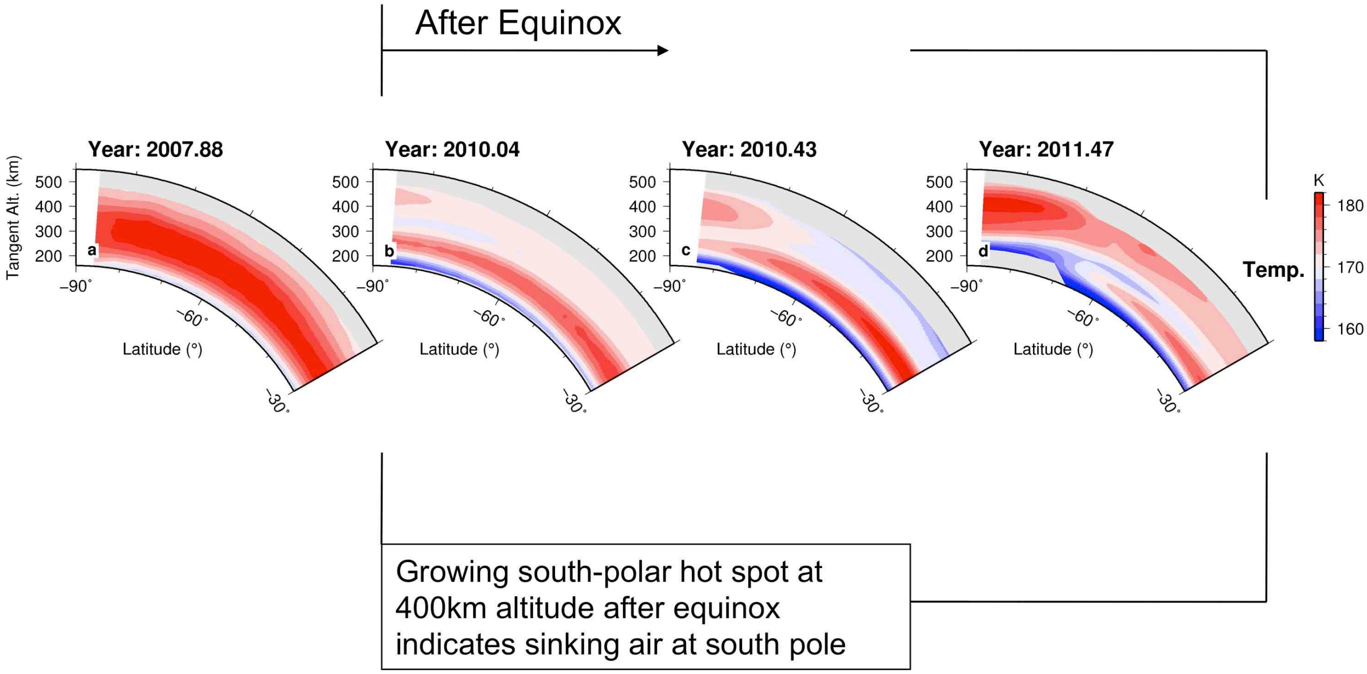

Figure 1: Cross sections of temperature through Titan's south polar atmosphere, showing the development of a south polar hotspot soon after equinox, which indicates subsidence over the south pole and a reversal of the middle-atmosphere meridional circulation.

pheric circulation. However, after two years the south polar subsidence has produced significant enrichment of trace gases, with some gases (HC_3N) increasing in abundance by a least three orders of magnitude. These large increases are produced by prolonged transport from the upper atmosphere photochemical source regions and suggest that subsidence must extend to perhaps 600 km or more. The observed trace gas enrichment also implies subsidence velocities of around 2 mm/s – consistent with the temperature results.

Discussion: Our results show that Titan's atmospheric circulation extends higher than previously thought – to perhaps 600 km or more – and can change surprisingly rapidly. These detailed observations of the reversal process provide stringent new constraints for numerical models [6,7]. The polar observations are especially important as changes in these regions are the largest and most rapid anywhere on the planet, so provide the best window into Titan's dynamics. The fact that atmospheric circulation extends to 600 km or more also has implications for the detached haze origin. Dynamical factors, while undoubtedly contributing to modification of the haze, cannot be wholly responsible for its formation. Further observation of Titan's atmosphere during Cassini's solstice mission promise to further illuminate processes occurring in its complex atmosphere.

References: [1] Teanby N. A., et al. (2012) *Nature, 491,* 732-735. [2] West R. A., et al. (2011) *GRL, 38,* L06204. [3] Flasar F. M., et al. (2005) *Science, 308,* 975–978. [4] Irwin P. G. J., et al. (2008) *JQSRT, 109,* 1136-1150. [5] Teanby N. A., et al. (2009) *Phil. Trans. R. Soc. Lond. A 367,* 697–711. [6] Newman, C. E., et al (2011) *Icarus, 213,* 636-654. [7] Lebonnois, S., et al (2012) *Icarus, 218,* 707-722.

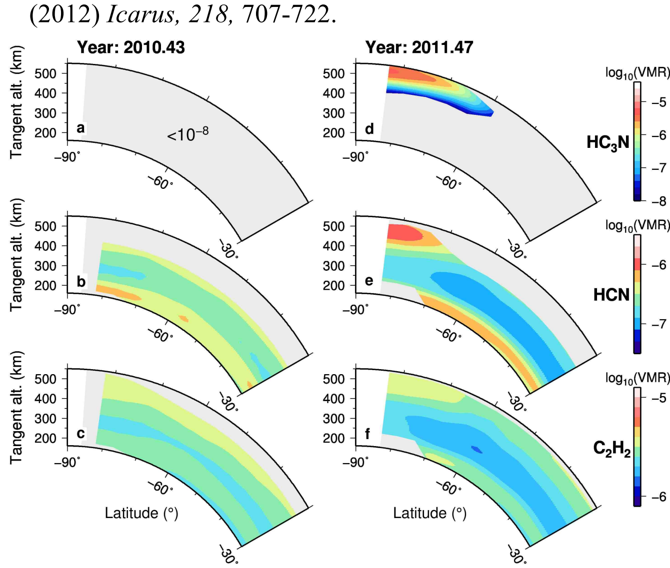

Figure 2: Cross sections of composition through Titan's south polar atmosphere. Two years after equinox trace gas abundances over the south pole have increased by up to three orders of magnitude – indicating prolonged subsidence from high altitudes.