

**TRANSIENT EDDIES, WATER ICE CLOUDS, AND NOCTURNAL MIXED LAYERS AT HIGH NORTHERN LATITUDES IN EARLY SUMMER.** D. P. Hinson<sup>1</sup>, H. Wang<sup>2</sup>, R. J. Wilson<sup>3</sup>, A. Spiga<sup>4</sup>, M. A. Kahre<sup>3</sup>, and J. L. Hollingsworth<sup>3</sup>; <sup>1</sup>SETI Institute, Mountain View, CA 94043, USA, dhinson@seti.org; <sup>2</sup>Smithsonian Astrophysical Observatory, Cambridge, MA 02138, USA; <sup>3</sup>NASA Ames Research Center, Moffett Field, CA 94035, USA; <sup>4</sup>Laboratoire de Météorologie Dynamique, Paris, France.

**Introduction:** We are using observations from Mars Global Surveyor (MGS) and simulations by two numerical models to investigate water ice clouds and atmospheric dynamics at high northern latitudes in early summer. Through analysis of radio occultation (RO) profiles [1], primarily from Mars Year (MY) 27, and contemporaneous wide-angle images from the Mars Orbiter Camera (MOC) [2], we have obtained a detailed characterization of the spatial structure, radiative effects, diurnal cycle, and seasonal evolution of the clouds.

This is an extension of previous work concerning frontal/annular clouds that appear each year in early summer ( $L_s \approx 120^\circ$ ) near  $270^\circ\text{E}$ ,  $60^\circ\text{N}$  [2, 3, 4, 5]. The transient eddies that produce this type of cloud have been explored with a mesoscale model [6].

**Nocturnal Mixed Layers:** High-resolution temperature profiles retrieved from RO data contain unique information about the vertical structure of the lower atmosphere [1]. Profiles at some locations and seasons contain a distinctive nocturnal mixed layer (NML), which forms at night when radiative cooling by a water-ice cloud layer triggers convective instability [7, 8]. In the polar profiles considered here, the presence of a NML is indicated by a detached layer of near-neutral static stability with an overlying temperature inversion, as shown in Fig. 1. Analysis of RO profiles yields basic properties of the NMLs as well as constraints on their spatial distribution and seasonal evolution.

We have examined  $\sim 1600$  RO profiles from MY27 in a latitude band roughly centered on the Phoenix landing site ( $234^\circ\text{E}$ ,  $68^\circ\text{N}$ ), where nighttime water-ice clouds were observed by the LIDAR instrument [9, 10]. Many NMLs were present in early summer of MY27 at  $\sim 5$  h local time, primarily at  $L_s = 112\text{--}133^\circ$ ,  $56\text{--}68^\circ\text{N}$ ,  $210\text{--}330^\circ\text{E}$ , as shown in Fig. 2. The top of the NML is typically 5–6 km above the ground, consistent with the detached cloud layer observed by the Phoenix LIDAR at the same season and local time in MY29. The RO observations in Figs. 1 and 2 confirm that nighttime radiative cooling by the Phoenix cloud is sufficient to cause convective instability, confirming a key prediction of a Large-Eddy Simulation (LES) [8].

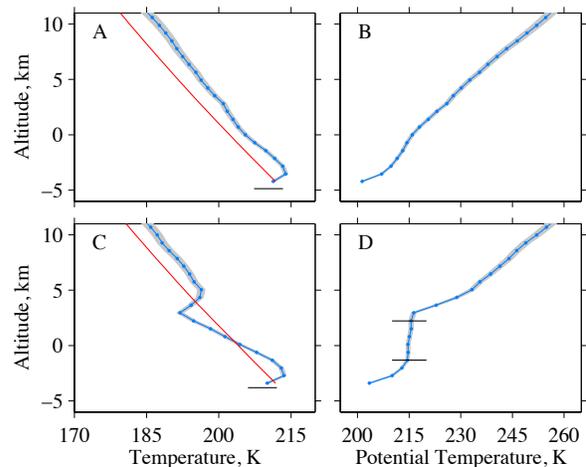


Fig. 1. (A, B) An ordinary MGS RO profile. Gray shading shows the 1-sigma uncertainties. (C, D) A profile with a NML. Horizontal lines indicate (A, C) the surface elevation and (D) the upper and lower boundaries of the NML. Both observations are at  $65^\circ\text{N}$ , 5.1 h local time, and  $L_s = 128^\circ$  (MY27). The longitudes are (A, B)  $357^\circ\text{E}$  and (C, D)  $271^\circ\text{E}$ . A model for the saturation temperature of water vapor (red line) is consistent with the presence of a detached cloud layer in C.

**Polar Clouds:** Contemporaneous wide-angle images from the MGS MOC provide compelling evidence that NMLs originate from water-ice clouds. For example, Fig. 3 shows a remarkable observation of an extratropical cyclone with a symmetrical, spiral cloud and a small, clear center. The RO measurement from the same orbit sounded the atmosphere within the cloud at a local time of 4.7 h, when the Sun was  $10^\circ$  above the horizon; the profile retrieved from those data contains a NML like the one shown in Fig. 1C and 1D.

Wide-angle images from successive orbits show that the cloud structure has a strong diurnal cycle, confirming the results of a previous investigation [5]. The spiral cloud in Fig. 3 dissipates rapidly as the Sun moves to higher elevation and the surface warms. By  $\sim 14$  h local time the central clearing is much larger and the cloud has lost its symmetry.

A 3-sol animation of single-orbit swaths, including the one in Fig. 3, shows that the diurnal cycle largely repeats from sol to sol as the transient eddy moves

toward the pole. The area covered by the cloud is largest at about the local time of the RO measurements (Fig. 3). Within this 3-sol span, NMLs appear only in profiles that sounded the atmosphere within the spiral cloud.

**Numerical Simulations:** The RO and MOC observations provide valuable guidance for numerical simulations. We will use two complementary atmospheric models to interpret these results: the FV3 Mars Global Circulation Model at the NASA Ames Research Center [11] and Large-Eddy Simulations at the Laboratoire de Météorologie Dynamique [12]. The main objectives are to understand the dynamical origin and seasonal evolution of the transient eddy, the diurnal cycle of cloud structure, and the impact of NMLs on nighttime weather and the vertical mixing of water vapor and dust. Fig. 4 shows a sample of results from a previous LES [8].

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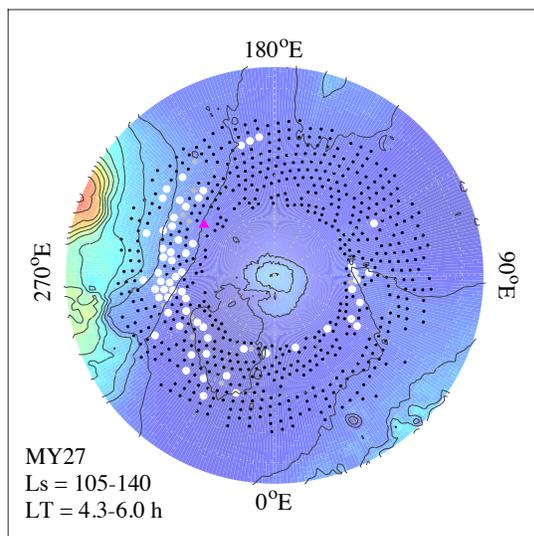


Fig. 2. Distribution of NMLs in early summer of MY27. This sequence of RO measurements began at 52°N and ended at 72°N; the local time drifted from 4.3 h to 6.0 h. Among these 661 profiles, 71 contain a NML (white and gray dots) and 590 do not (black dots). A red triangle marks the Phoenix landing site.

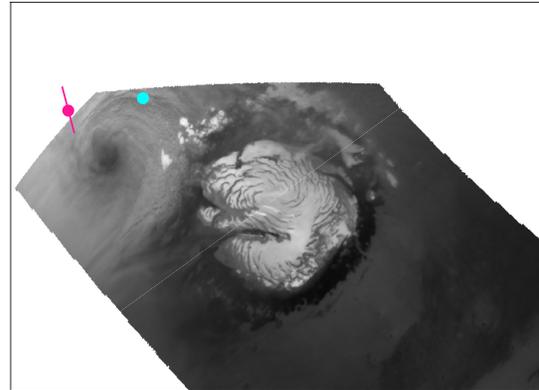


Fig. 3. Part of a single-orbit swath from the MOC wide-angle camera at  $L_s = 119.85^\circ$  (MY27), showing a symmetrical, spiral cloud centered at  $260^\circ\text{E}$ ,  $68^\circ\text{N}$ . The RO measurement from the same orbit sounded the atmosphere within the cloud at the location shown by the red circle ( $248^\circ\text{E}$ ,  $60^\circ\text{N}$ , 4.7h local time). The red line indicates the horizontal resolution of the RO profile along the limb-sounding line of sight. The blue circle is the Phoenix landing site.

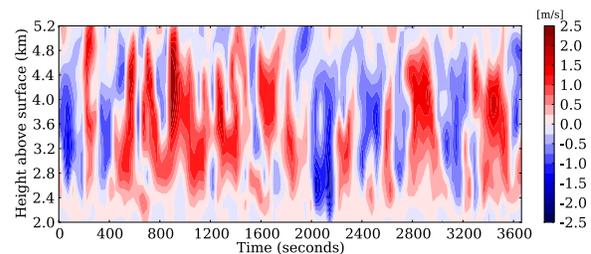


Fig. 4. Vertical velocity associated with a NML in a Large-Eddy Simulation at the Phoenix landing site [8]. The strong updrafts and downdrafts ( $\pm 2.5 \text{ m s}^{-1}$ ) are a consequence of radiatively-induced convective instability in a detached cloud layer.

**References:** [1] Hinson D. et al. (1999) *JGR*, 104, 26,997–27,012. [2] Malin M. et al. (2010) *Mars*, 5, 1–60. [3] Cantor B. et al. (2002) *JGR*, 107, 5014. [4] Wang H. and Fisher J. (2009) *Icarus*, 204, 103–113. [5] Sánchez-Lavega A. et al. (2018) *JGR*, 123, 3020–3034. [6] Tyler D. and Barnes J. (2014) *Icarus*, 237, 388–414. [7] Hinson D. et al. (2014) *Icarus*, 243, 91–103. [8] Spiga A. et al. (2017) *Nat. Geosci.*, 10, 652–657. [9] Whiteway J. et al. (2009) *Science*, 325, 68–70. [10] Daerden F. et al. (2010) *GRL*, 37, L04203. [11] Wilson J. et al. (2017) *6<sup>th</sup> International Workshop on Mars's Atmosphere: Modelling and Observations*, [www-mars.lmd.jussieu.fr/granada2017](http://www-mars.lmd.jussieu.fr/granada2017). [12] Spiga A. and Forget F. (2009) *JGR*, 114, E02009.