Mars Northern Spring: Transport of Water Across the Retreating Cap Edge

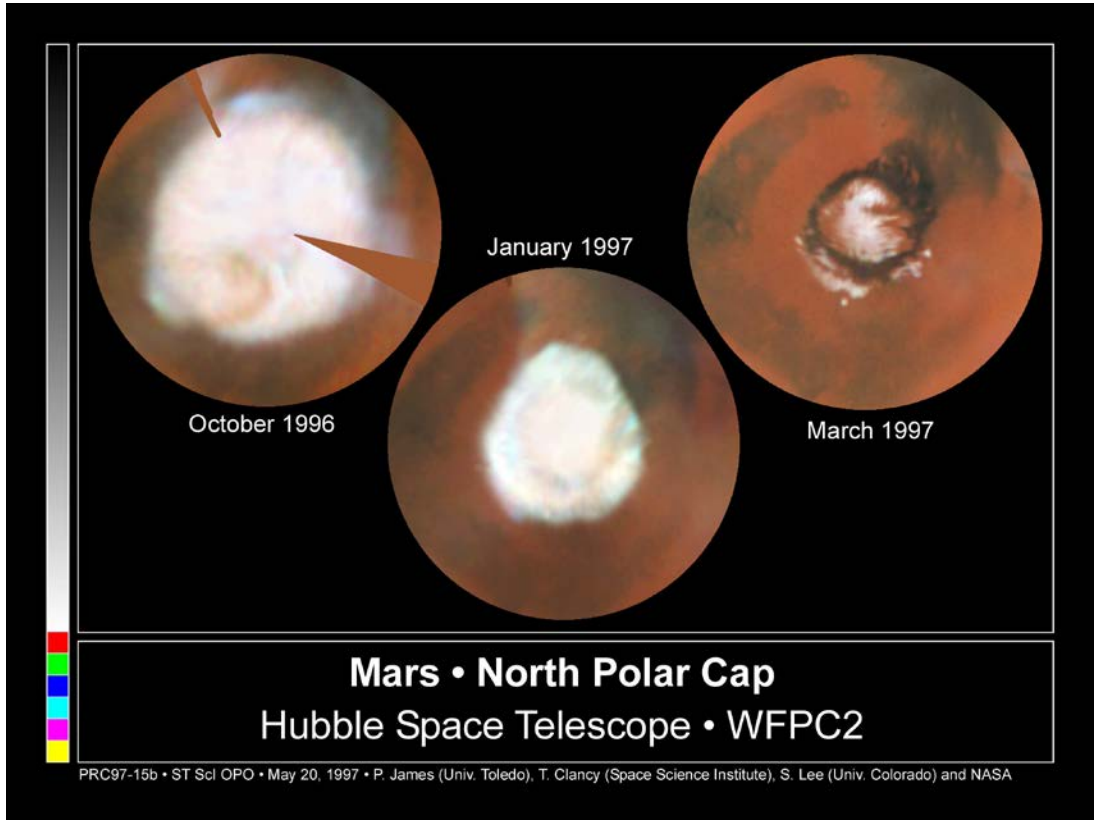
Titus

Cushing

Williams

Mars Northern Spring:
An Overview of Polar Processes

- CO2 Cycle
  - Atm is 95% CO2
  - 25% of the Atm is cycled
  - Ts = 148 K (like ice water)
- H2O Cycle
  - 1 part in 10,000
  - Ts ~ 180 K
  - Northern Hemisphere is wet
  - Southern Hemisphere is dry
- These 2 cycles are coupled.



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The “Houben” Effect

- Houben et al., 1997
- Richardson & Wilson 2002
- Montmessin et al., 2004

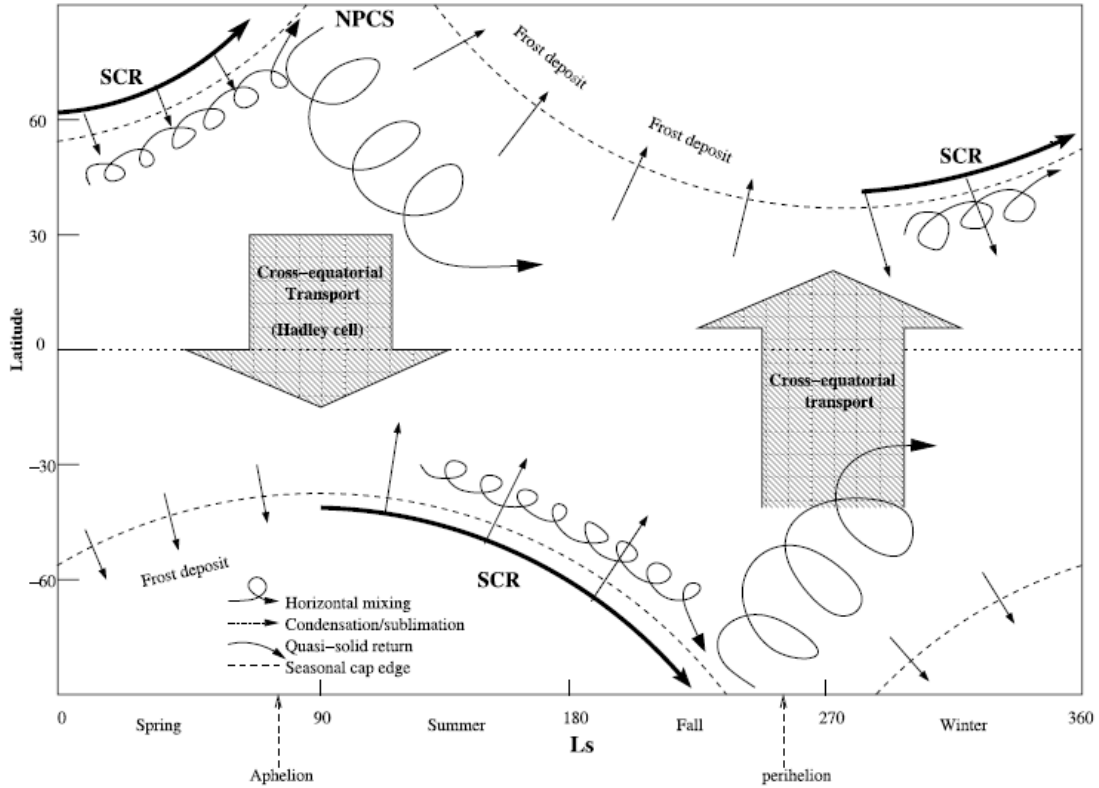


Figure 3. Chart describing the principal events affecting the Martian water cycle over the course of a year. NPCS stands for North Polar Cap Sublimation; SCR stands for Seasonal Cap Recession.

The Parts observed

- H_2O Ice Annulus
- Cold Trapped Layer
- Vapor Transport

Early Fall: Layer of H_2O Ice condenses on the ground.

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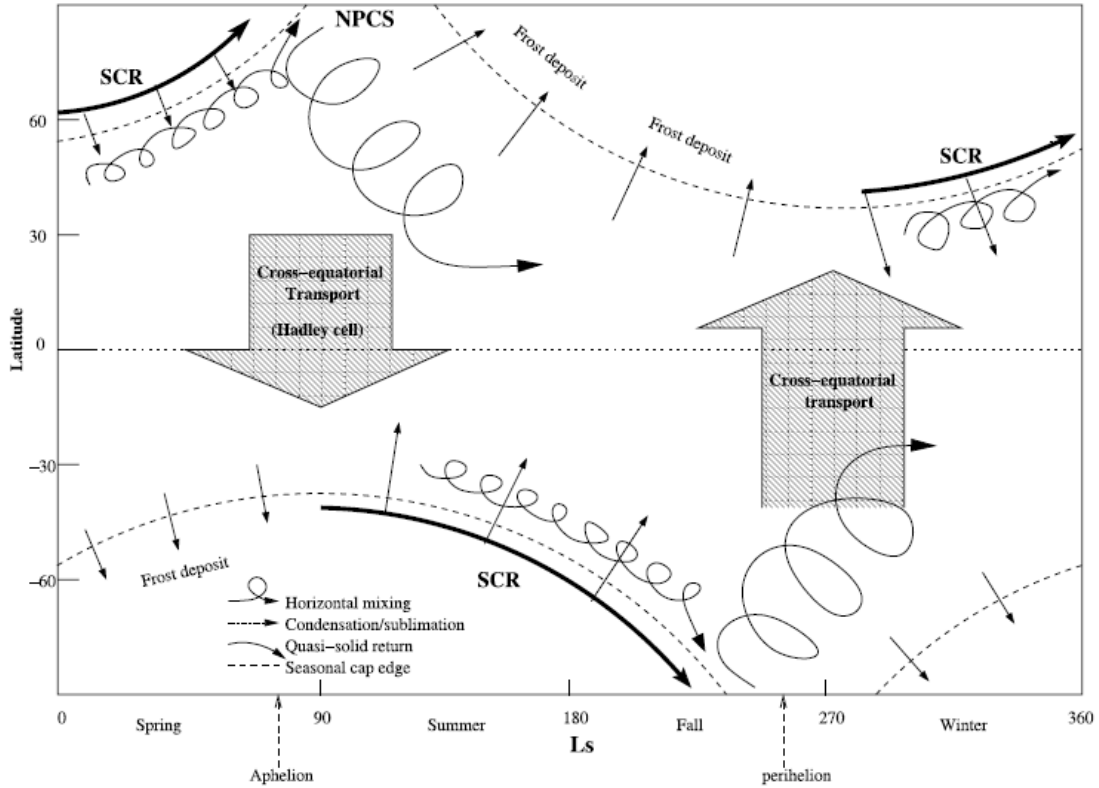


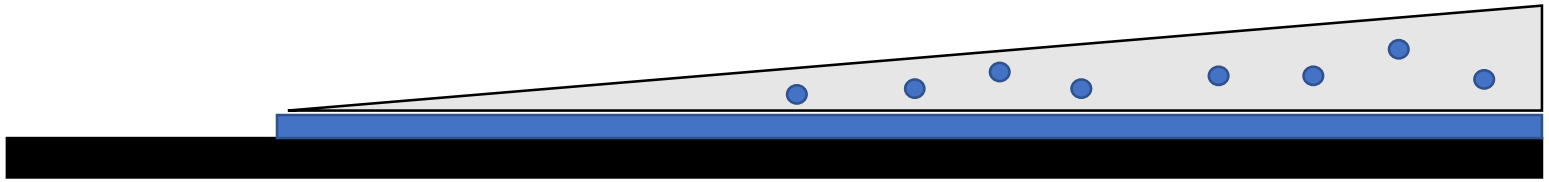
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Credit: Montmessin et al., 2004

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Mid-Fall/Winter: CO_2 Seasonal Cap forms with some mixed H_2O.



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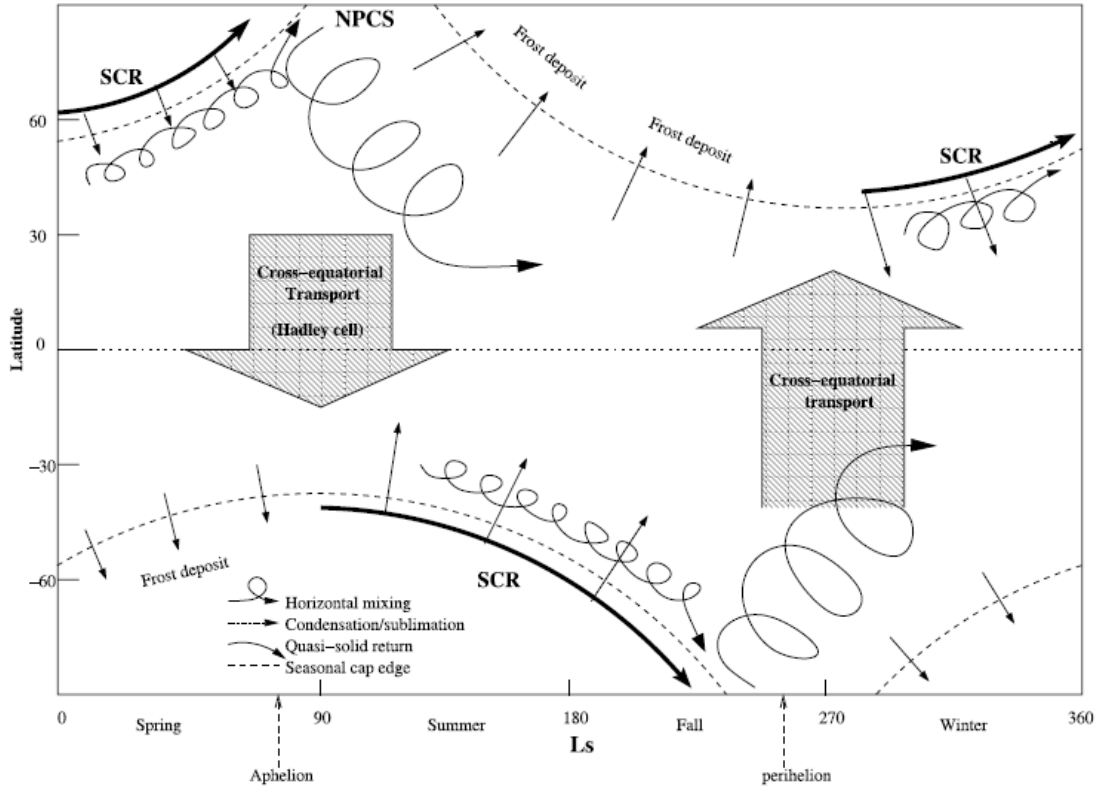


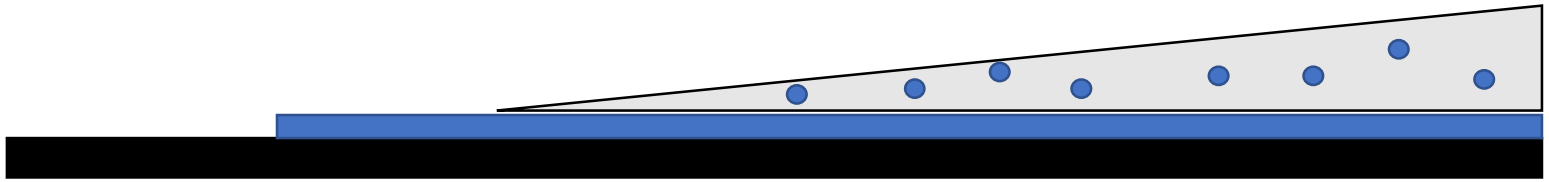
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- Cold Trapped Layer
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Early Spring: CO_2 ice sublimes at cap edge, leaving H_2O ice lag.



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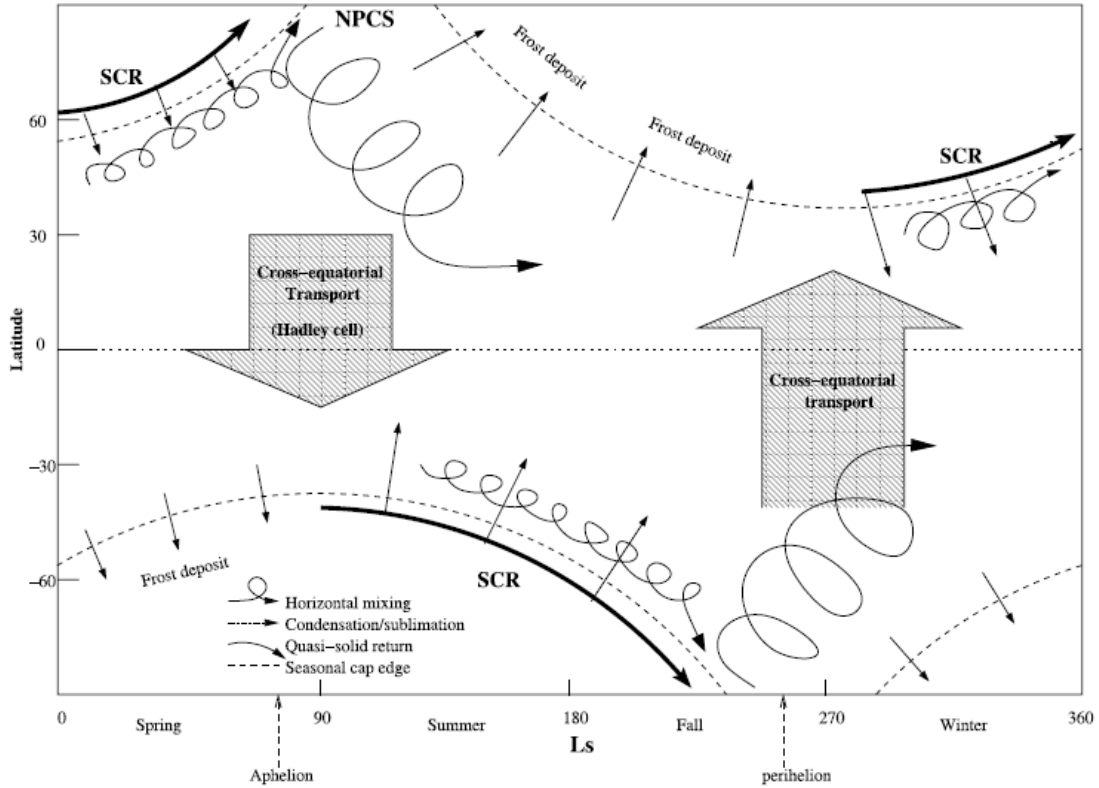


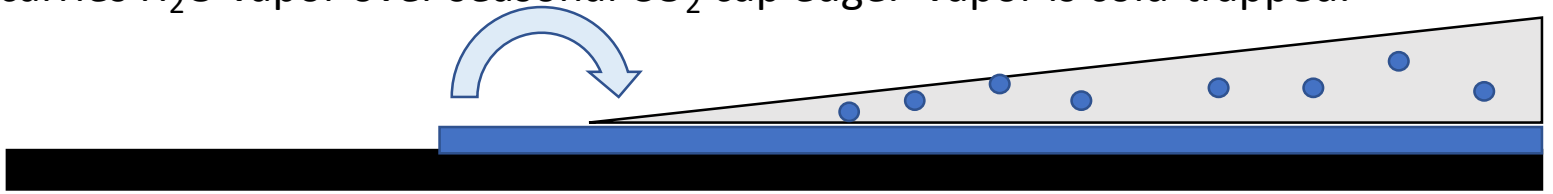
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The Parts observed

- H_2O Ice Annulus
- Cold Trapped Layer
- **Vapor Transport**

Mid-Spring: CO_2 ice continues to sublime. H_2O ice lag also sublimes. Winds carries H_2O vapor over seasonal CO_2 cap edge. Vapor is cold-trapped.



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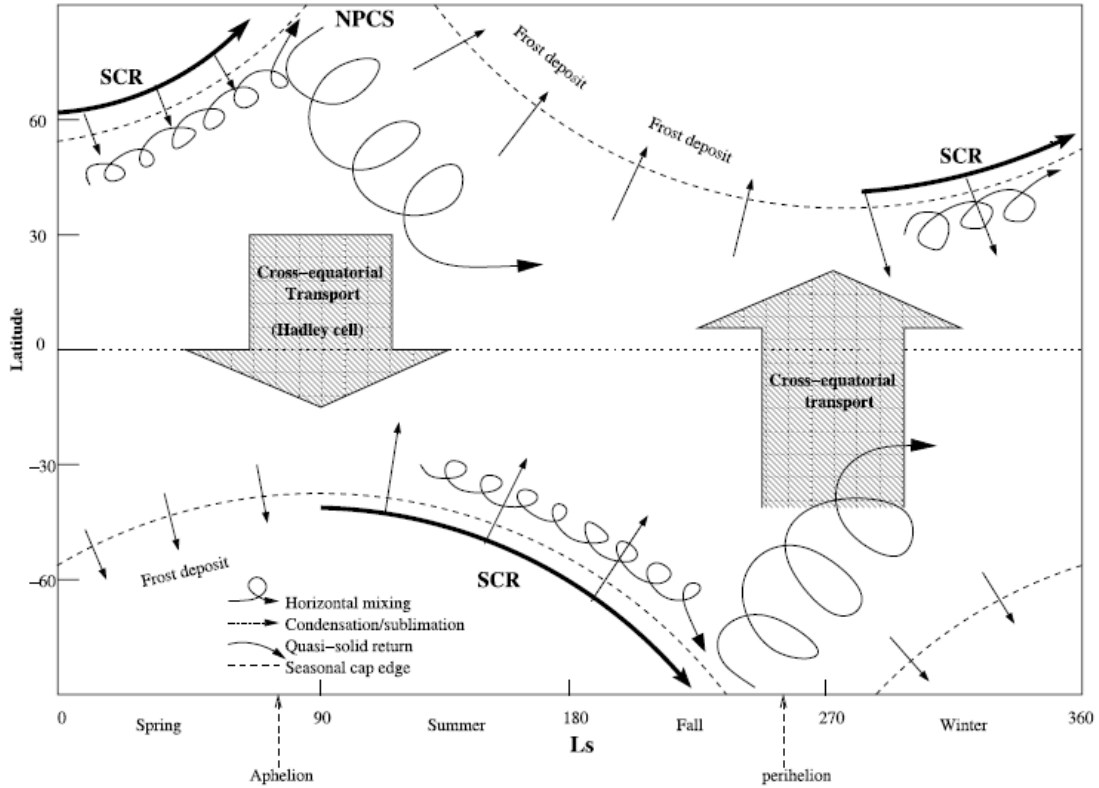


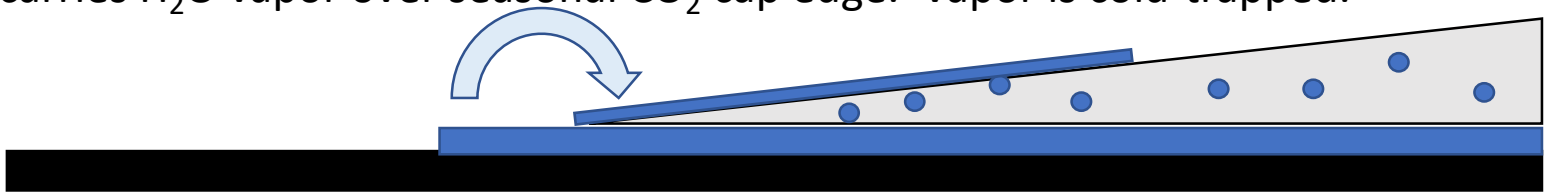
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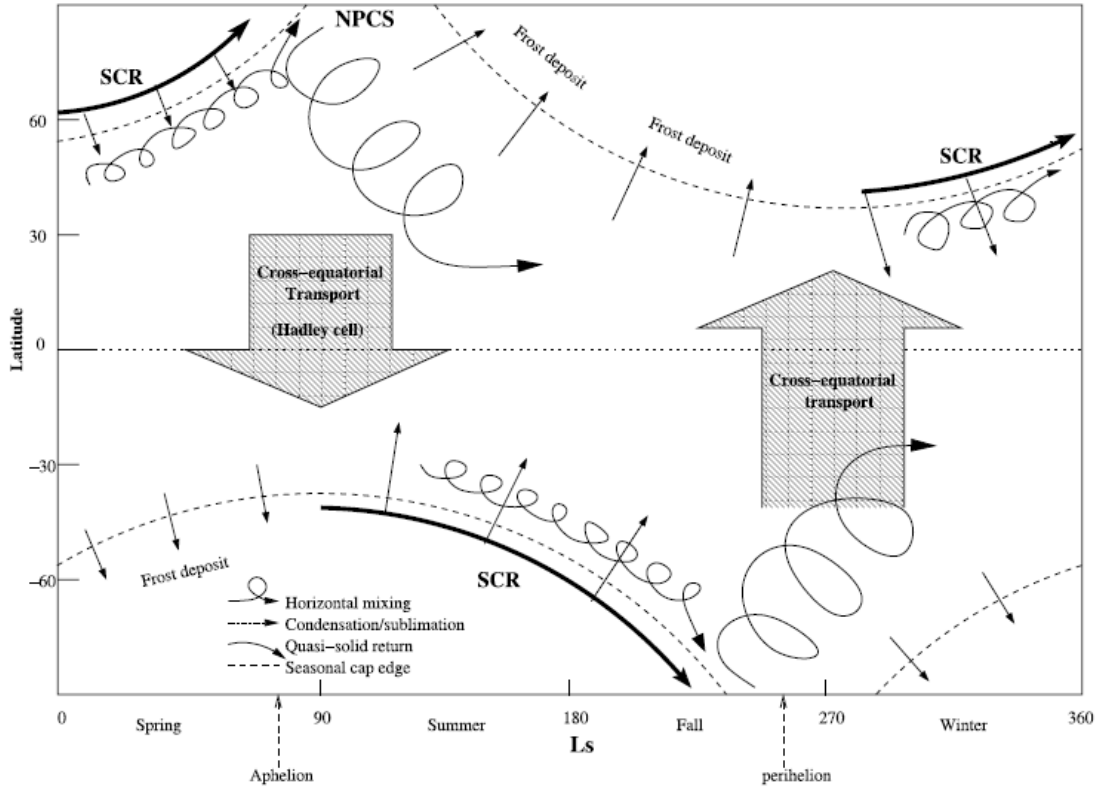


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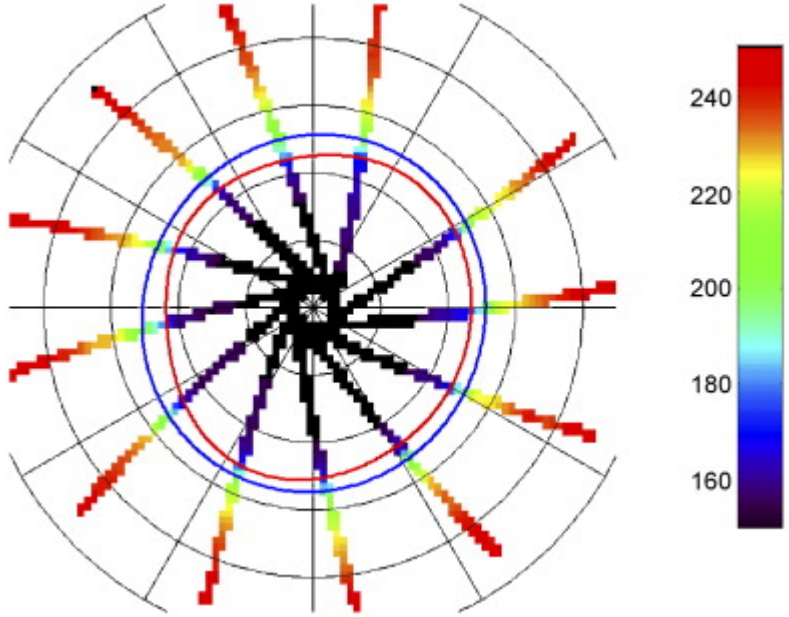
- H_2O Ice Annulus
- Cold Trapped Layer
- Vapor Transport

Early Summer: CO_2 ice completely sublimed. H_2O transported and trapped on the residual cap.

North Polar Residual Cap

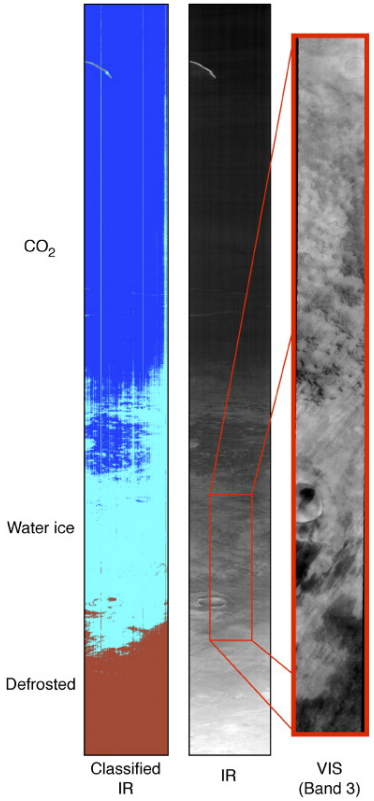
Observations: The Annulus

- Thermal Infrared
  - Kieffer & Titus, 2001
  - Wagstaff et al., 2008
- Near Infrared
  - Appere et al., 2011
  - Brown et al., 2012



Seasonal cap edges in the north polar region as observed in TES data at Ls23◦.

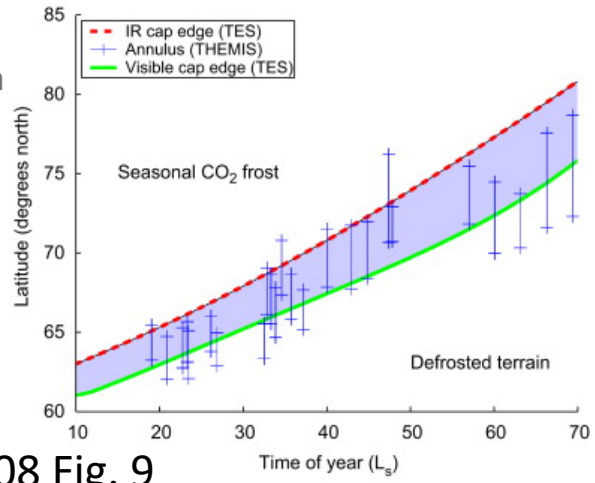
Credit: Figure 2 - Wagstaff et al., 2008



THEMIS IR (band 9 radiance) image I11622002 (Ls66.38◦, longitude 345.72◦E), with skewed aspect ratio to permit display of the full image. Left: our classification of this image into three components (CO2, water ice, and defrosted terrain) based on the temperature histogram analysis. Right: the accompanying visible image, V11622003 (band 3), where the presence of ice can be confirmed visually.

Credit: Wagstaff et al., 2008 Fig. 8

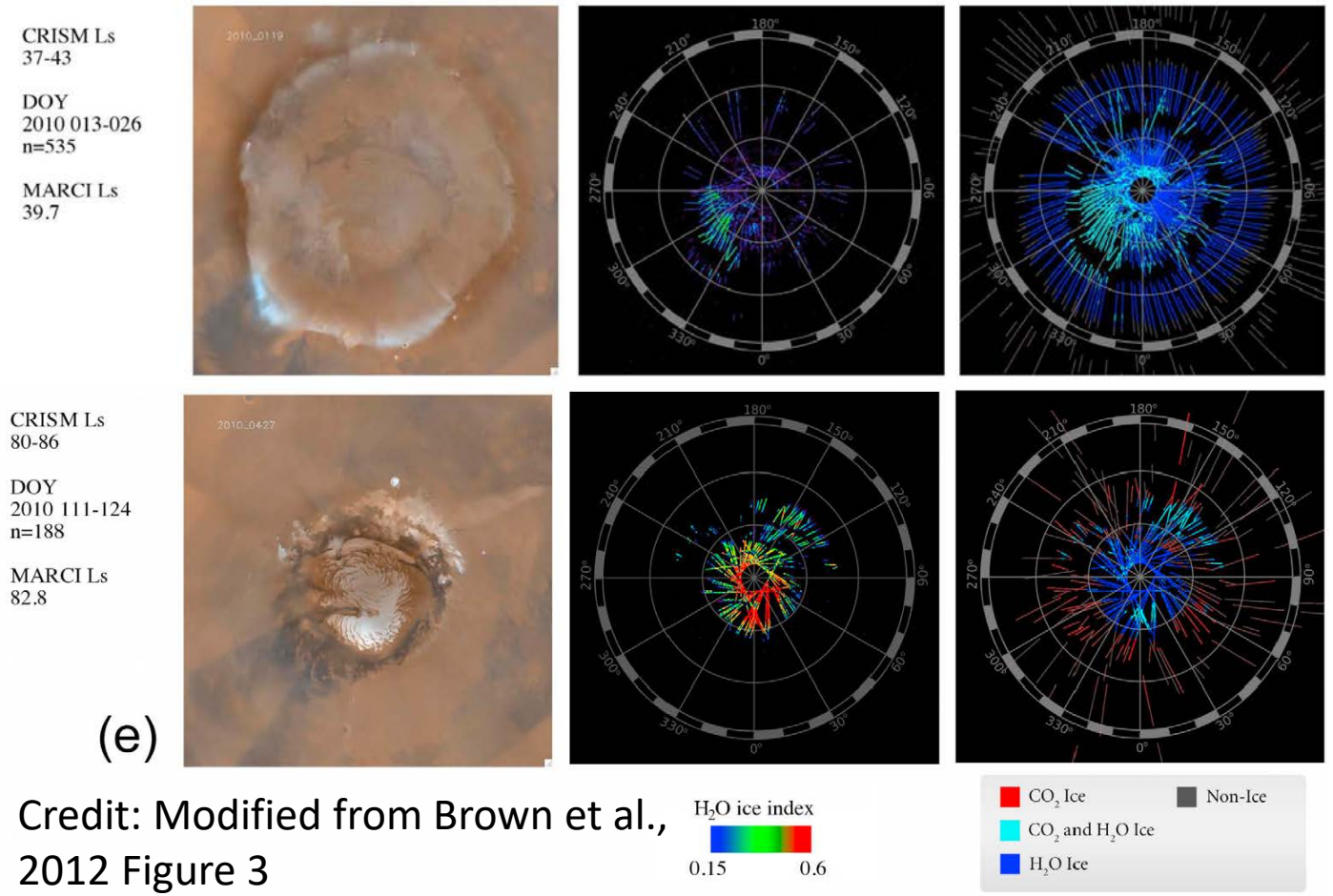
Latitude and extent of the northern water ice annulus for the 2004 northern cap recession observed in THEMIS data as a function of time of year. Vertical lines show the width of the annulus; observations cover a variety of longitudes. For reference, the longitudinally averaged IR and VIS cap edges observed by TES (Titus, 2005) are also shown.



Credit: Wagstaff et al., 2008 Fig. 9

Observations: Cold Trapping

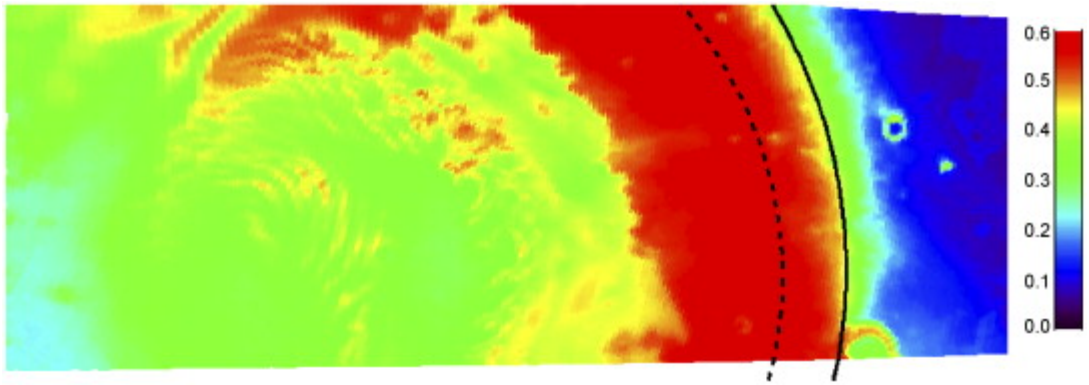
- OMEGA
  - Wagstaff et al., 2008
  - Appere et al., 2011 (JGRE)
- CRISM
  - Brown et al., 2012 (JGRE)



Credit: Modified from Brown et al., 2012 Figure 3

Fig. 13. Water ice index (1.5μm band depth) computed from OMEGA observations of the north polar seasonal cap around Ls40◦. The north pole is in the middle left of this image. The two curved lines indicate the best fit estimate of the IR (dashed line) and VIS (solid line) cap edges based on TES data (Titus, 2005).

Credit: Wagstaff et al., 2008

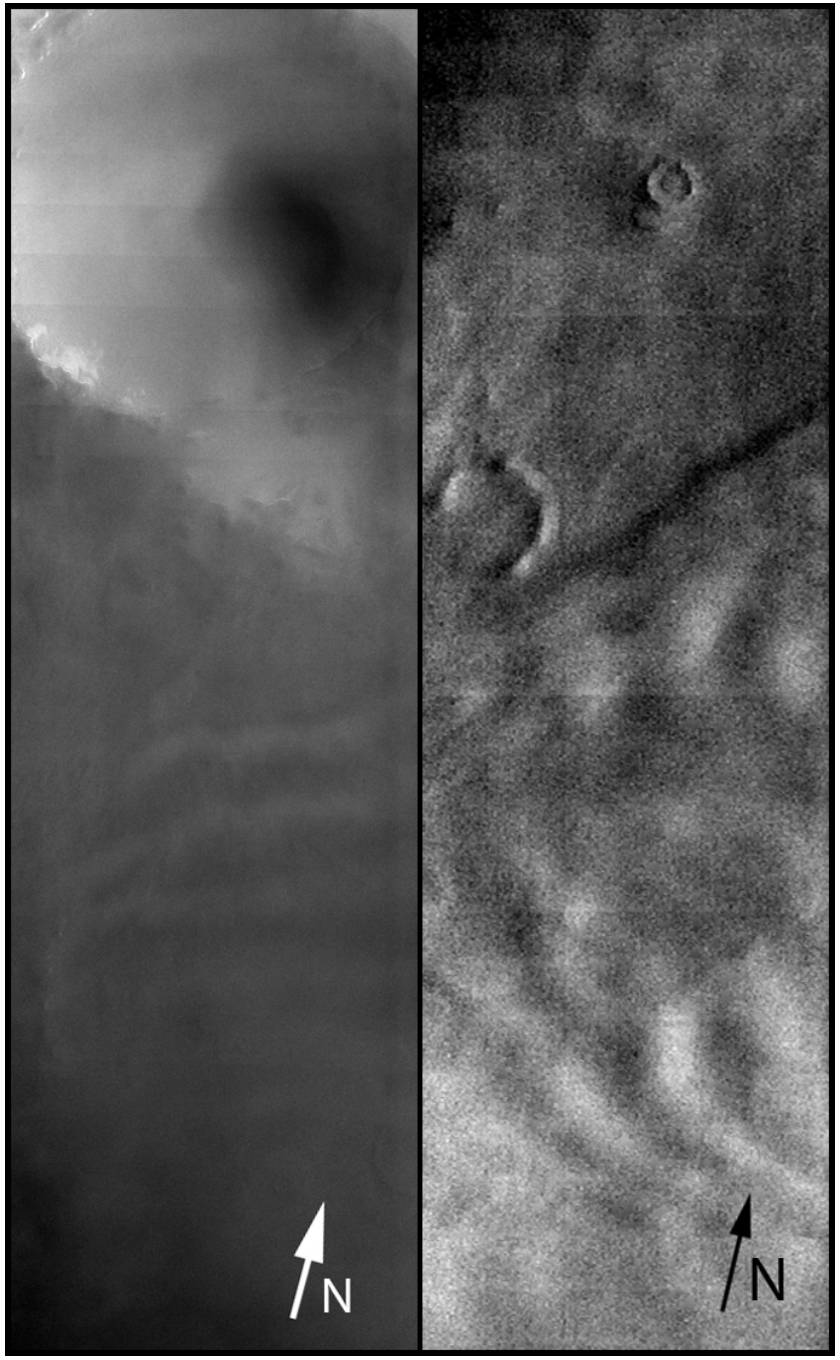


What observations are missing?
Vapor Transport across cap edge.

Observations

- Indirect Evidence
  - H_2O Ice Annulus
  - Cold Trapped H_2O
- Direct Evidence
  - That's harder
    - H_2O vapor retrievals become unreliable at cap edge
  - Could Clouds be a tracer?
    - THEMIS now is in an early morning orbit
    - Compare to late afternoon in previous years
    - Compare to mid-afternoon from MRO.

Topographically induced atmospheric lee waves. Left panel shows waves in H_2O clouds south of Escorial crater. Right panel shows waves in possible CO_2 ice clouds northeast of Koralev crater.



Credit: Cushing et al., 2017 Fig 3.