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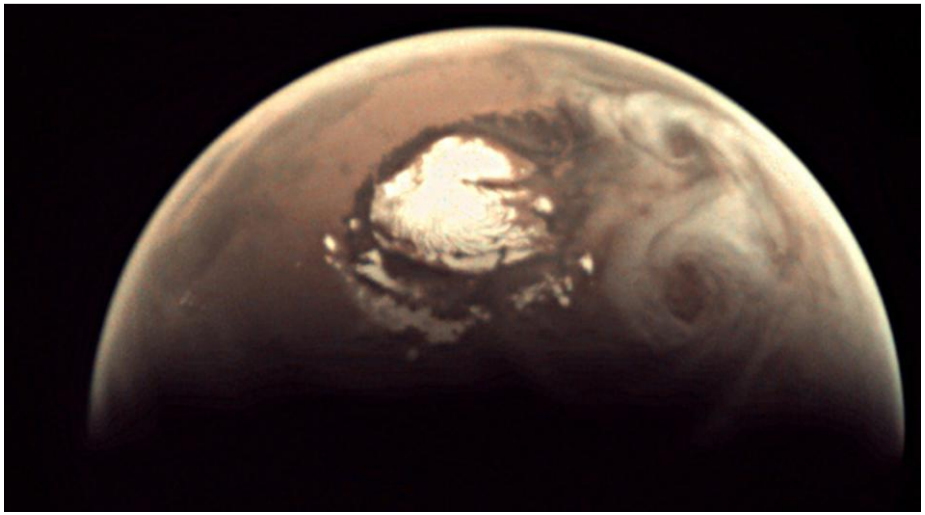
Universidad del País Vasco

Euskal Herriko Unibertsitatea



Grupo de Ciencias Planetarias

A singular seasonally recurrent double vortex on Mars

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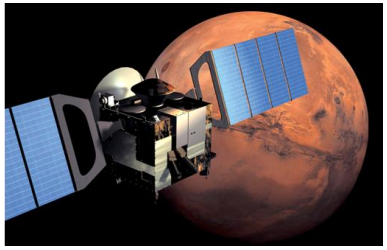
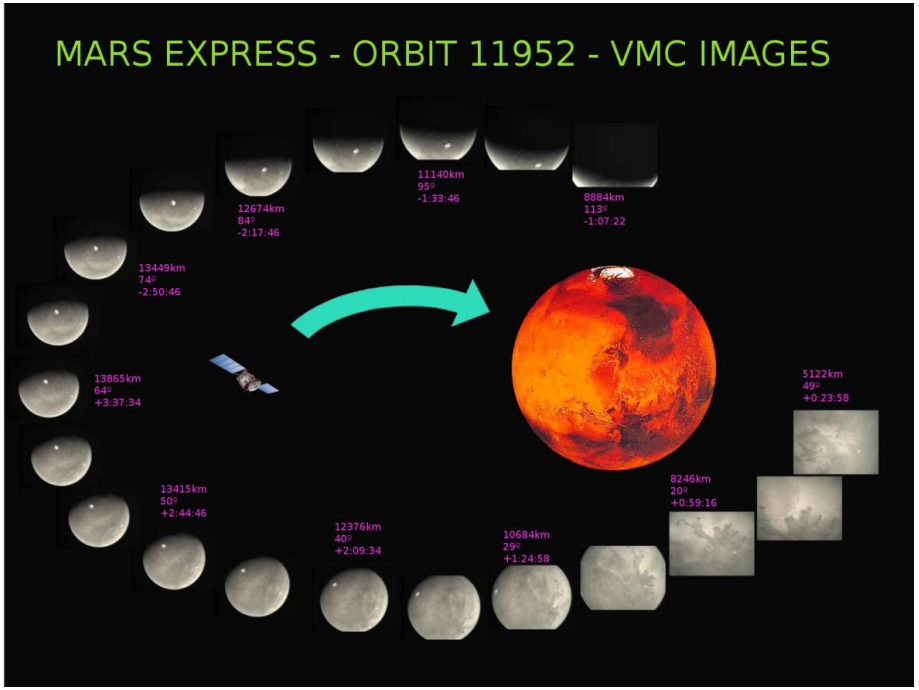
From Mars Express to Exomars – 28 February 2018

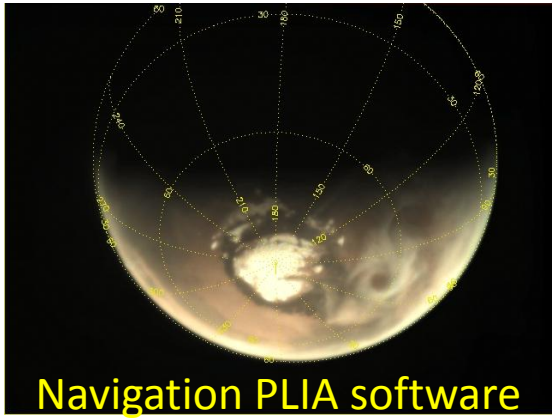
Visual Monitoring Camera (VMC) – Mars Express (MEx)



VMC
* Beagle descent
* Outreach
→ **Science Instrument (*)**

Detector
• CMOS
• Bayer RGB (COLOR)
• Wavelength: 400-650 nm



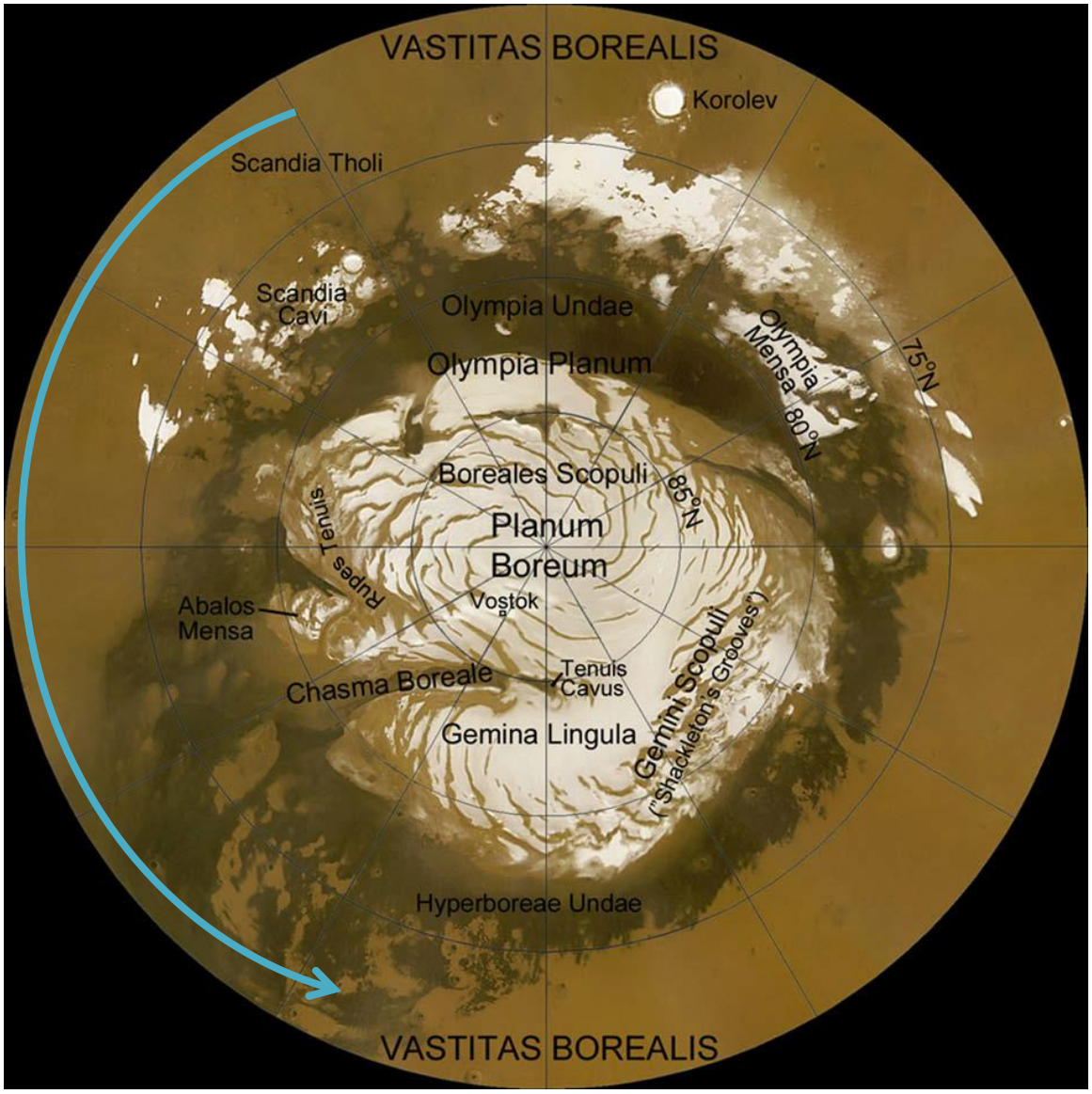


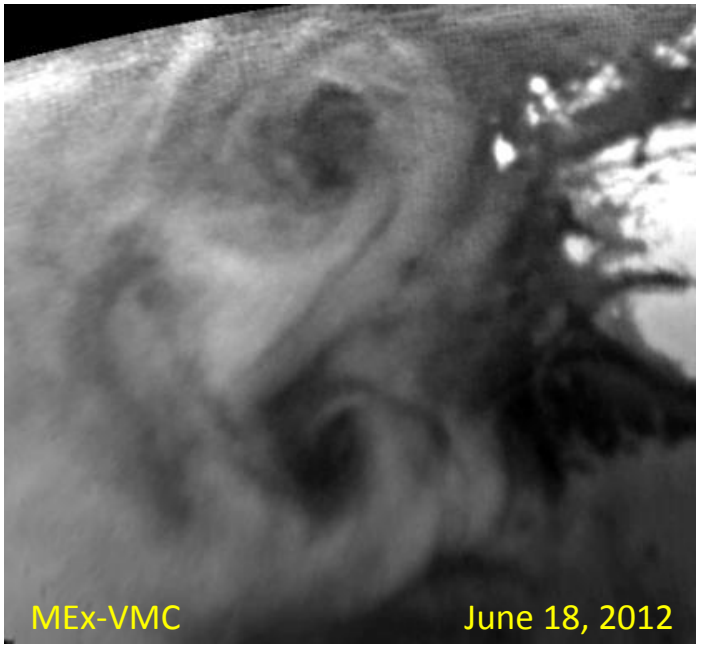
VMC/MEx (June-July 2012)
Additional images used in this study (NASA – PDS)
MARCI/Mars Reconnaissance Orbiter
MOC/Mars Global Surveyor

(*) Sánchez-Lavega A. et al., Limb clouds and dust on Mars from images obtained by the Visual Monitoring Camera (VMC) onboard Mars Express, ***Icarus***, **299**, 194 (2018).

PLIA software: Hueso et al., Adv. Space Res. , 2010

Vortex properties





The vortex repeat in location and date

Latitude: 60°N

Longitude: 70°W – 110°W

(~ 800 Km East of PHOENIX lander)

L_S = 120°-140°

(Northern summer solstice: L_S =90°)

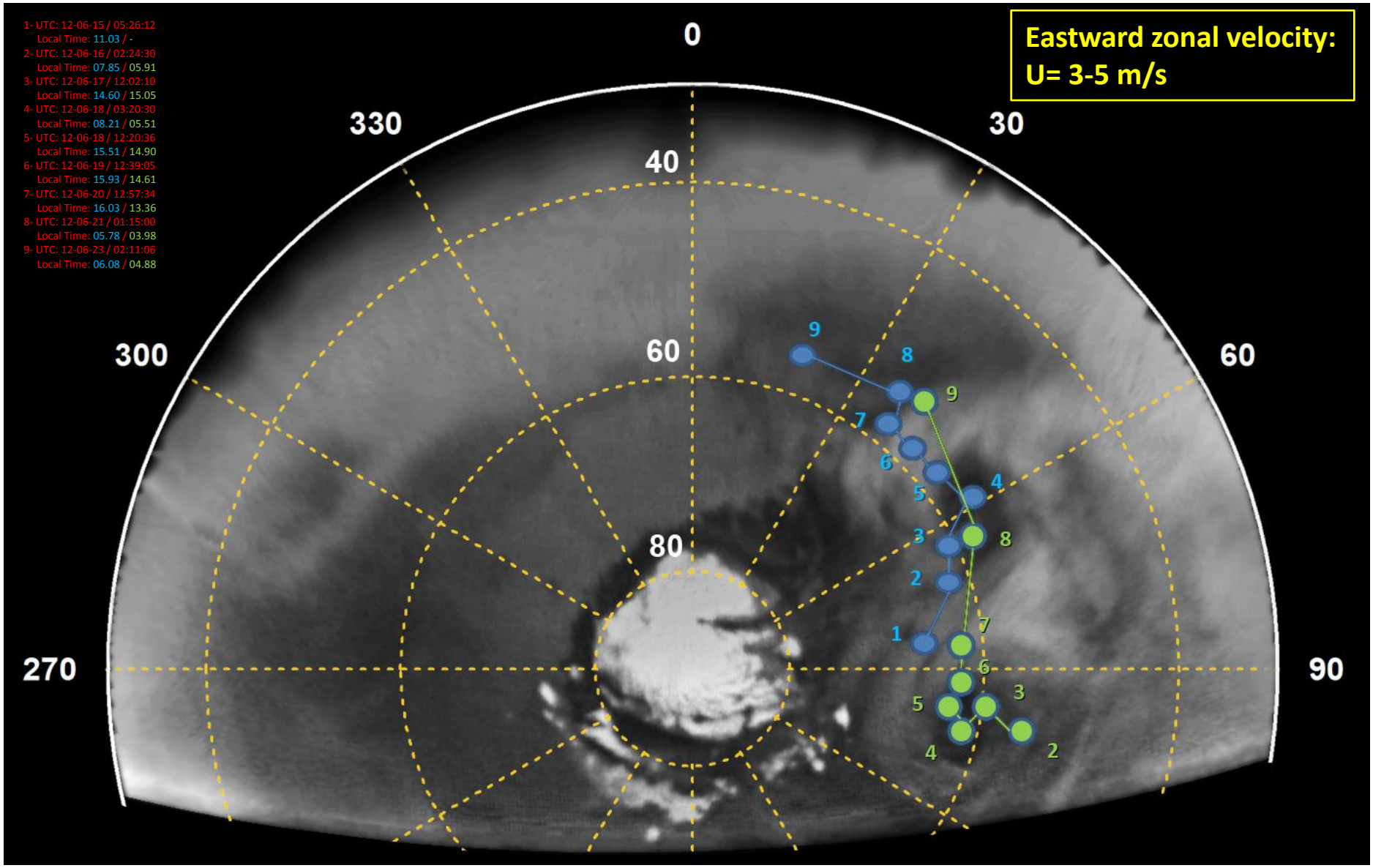
Size (each vortex): 600 - 800 km

Wavelength → 90°

Wavenumber → m = 4

Vortex Motion

June 15-23 (2012) - MEx/VMC

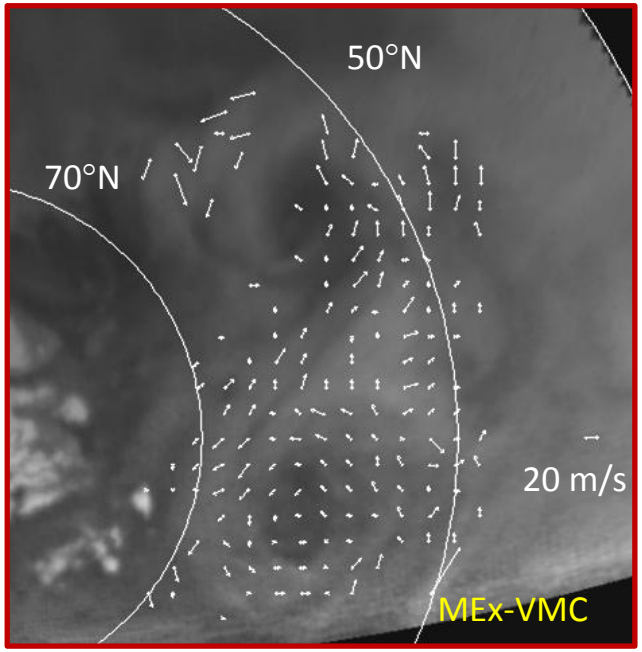


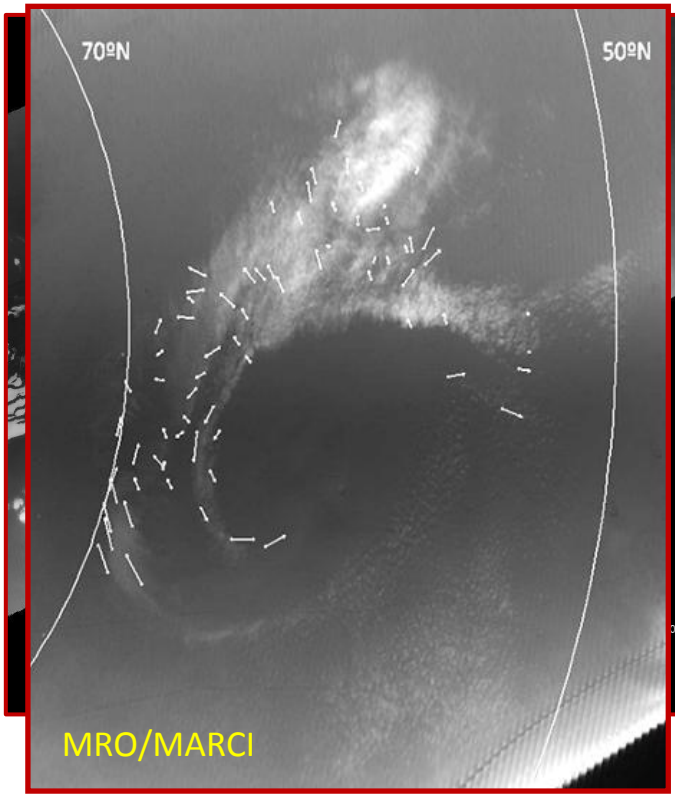
Vortex wind field

June 18, 2012 (LT = 6hr – 15 hr)
Winds from image pairs separated by ~ 16 min

Manual cloud tracking

Cloud image correlation velocimetry (PICV)

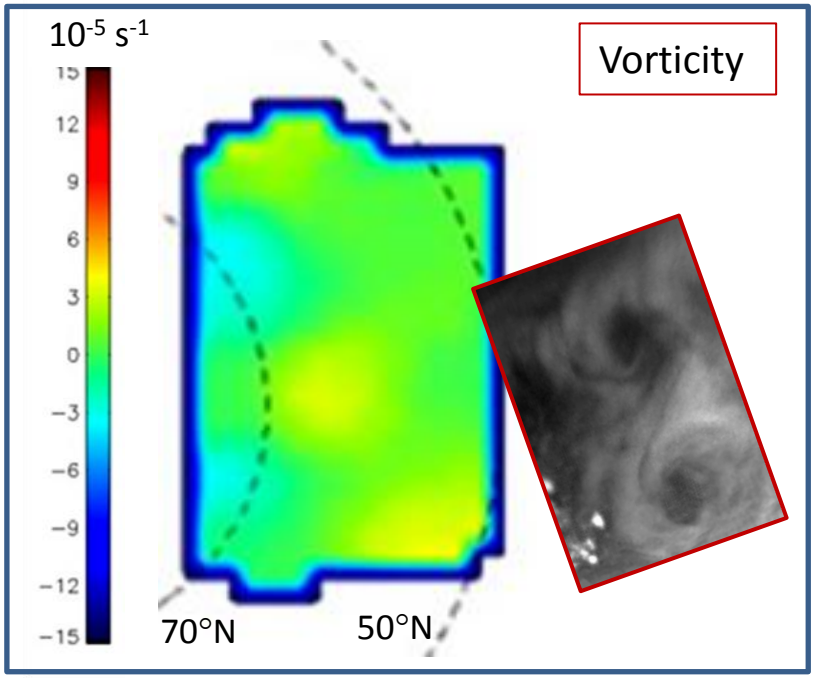




Anticlockwise rotation:
Cyclones: <V> = 10-30 ms^{-1}

PICV: R. Hueso et al., *Icarus* (2009)

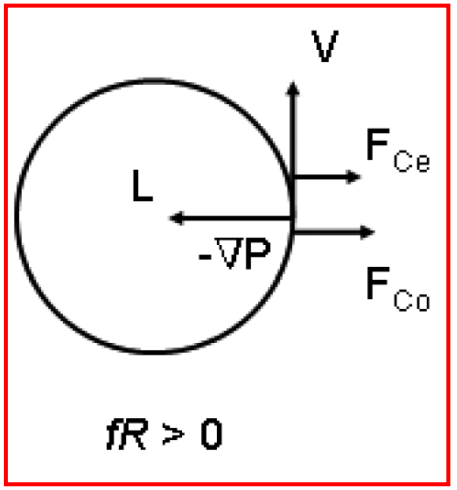
Vorticity and pressure gradient



Rossby number $Ro = V / fL \approx 0.3$

Gradient wind balance:

$$\frac{V^2}{R} + fV = -\frac{1}{\rho}\frac{dP}{dr}$$



Cyclonic vorticity = 4×10^{-5} s^{-1} $\sim 0.3\, f$ (Coriolis vorticity)

$$\frac{dP}{dr} = (6 \pm 3) \bullet 10^{-4}\ mbar/km \rightarrow \Delta P\big|_{\substack{Center \\ Border}} = 0.2\, mbar$$

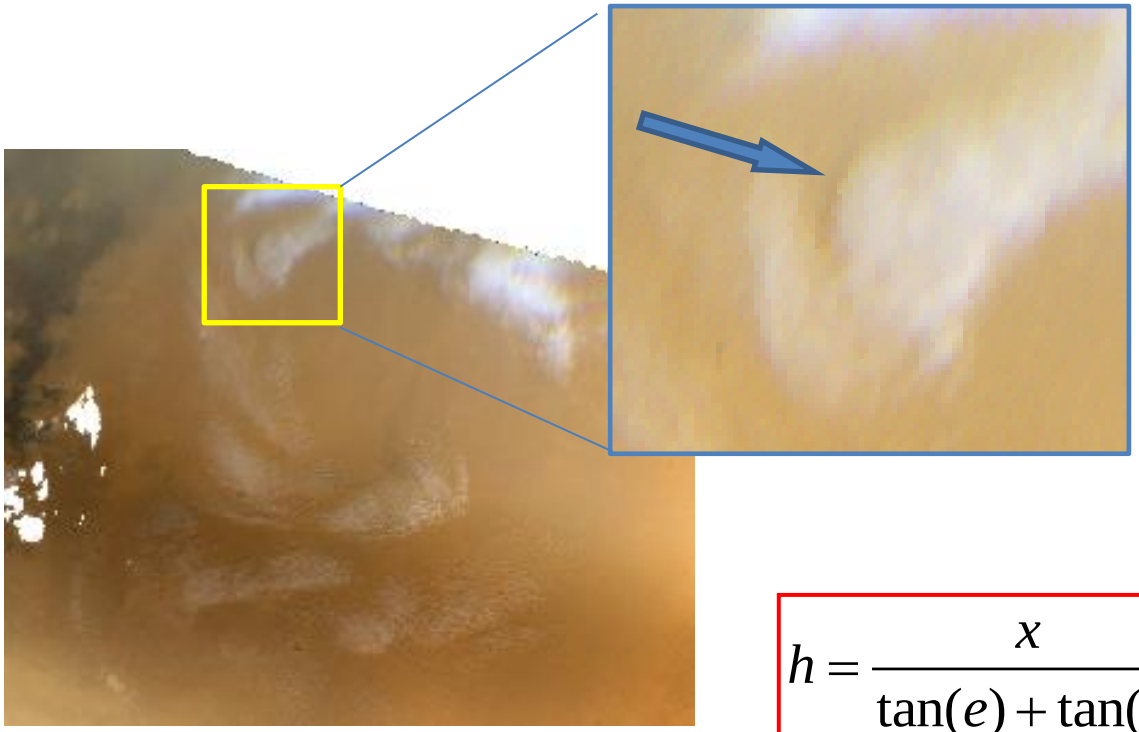
$\rightarrow$ weaker than Terrestrial Extratropical Cyclones

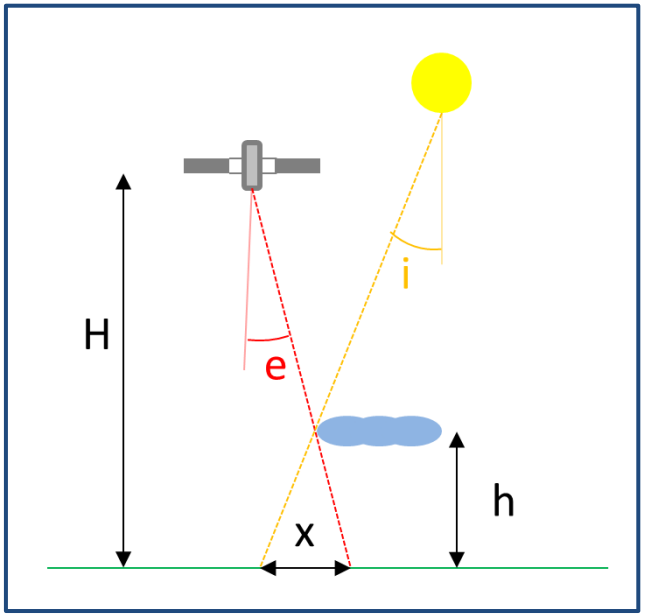
$\rightarrow$ agreement spirals vortices by Hunt et al. Nature (1979)

A. Sánchez-Lavega, An Introduction to Planetary Atmospheres, Taylor-Francis – CRC Press (2011)

Clouds altitude

Altitude from shadows on MARCI/MRO images

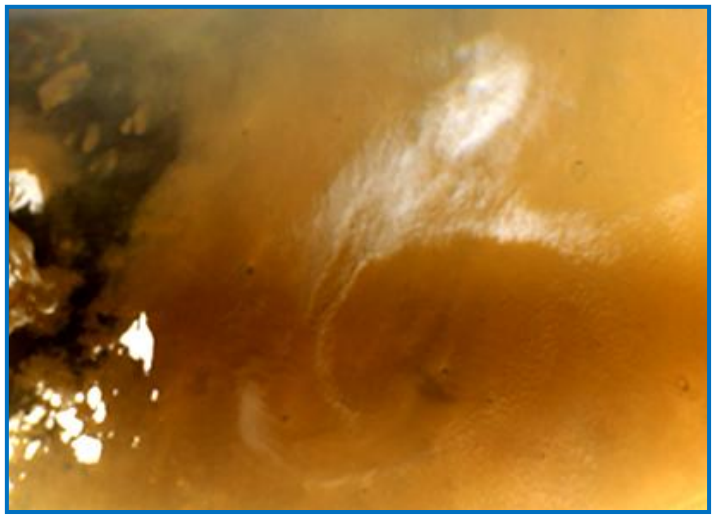




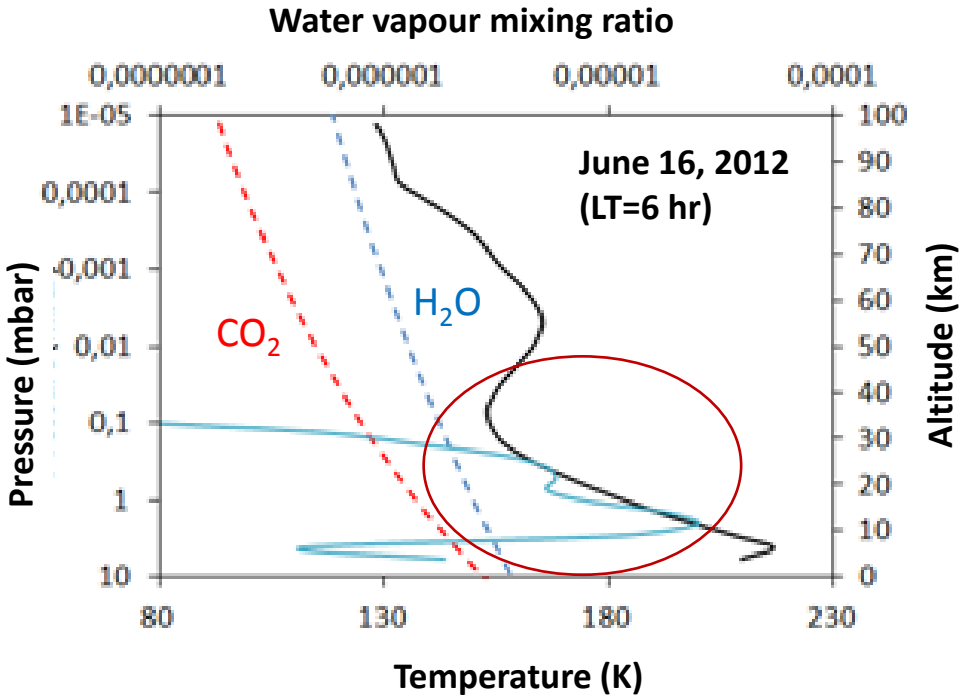
$$h = \frac{x}{\tan(e) + \tan(i)} = 10 \pm 3\,km$$

Agreement with spiral vortex in Hunt et al. (1979)

Water ice clouds



Cyclone clouds white color in HST, MOC and MARCI
Clouds show high contrast at blue wavelengths
→ **water ice**

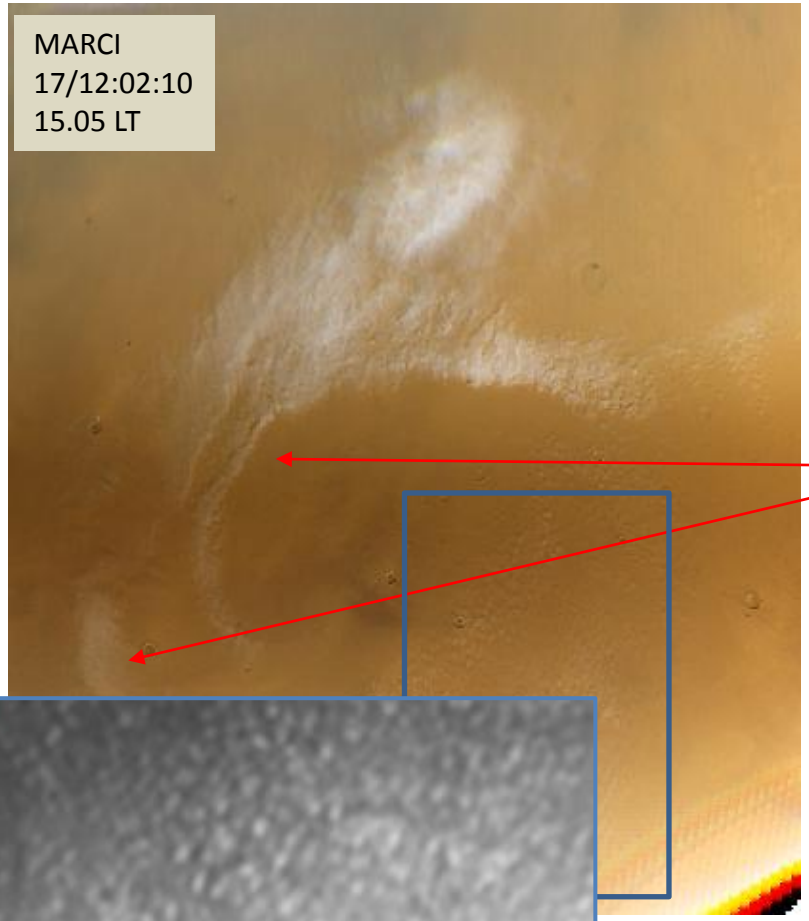


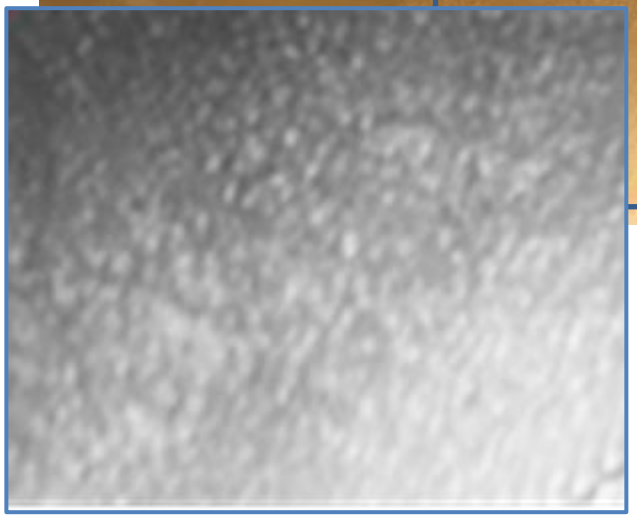
Mars Climate Database -LMD (*):
Temperature & water vapour mixing ratio
Saturation vapour pressure curves $P_{vsat}(T)$

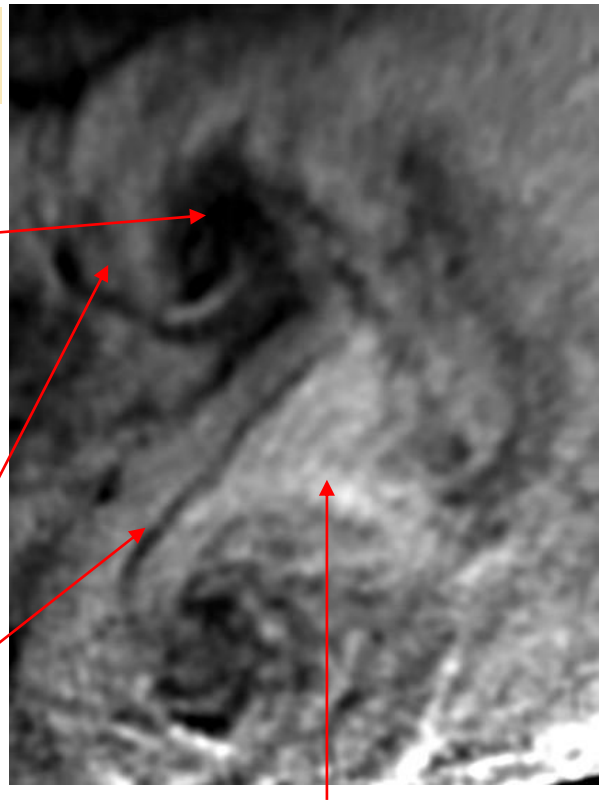
→ Localized temperature drop is required for water ice clouds to form at Z ~ 10 km

(*) MCD-Laboratoire Météorologie Dynamique: Forget et al., JGR, 104, 24155 (1999)

Cloud morphology - I







Core (cloud-free)
D ~ 75-100 km

Arcs
L ~ 1,000 km

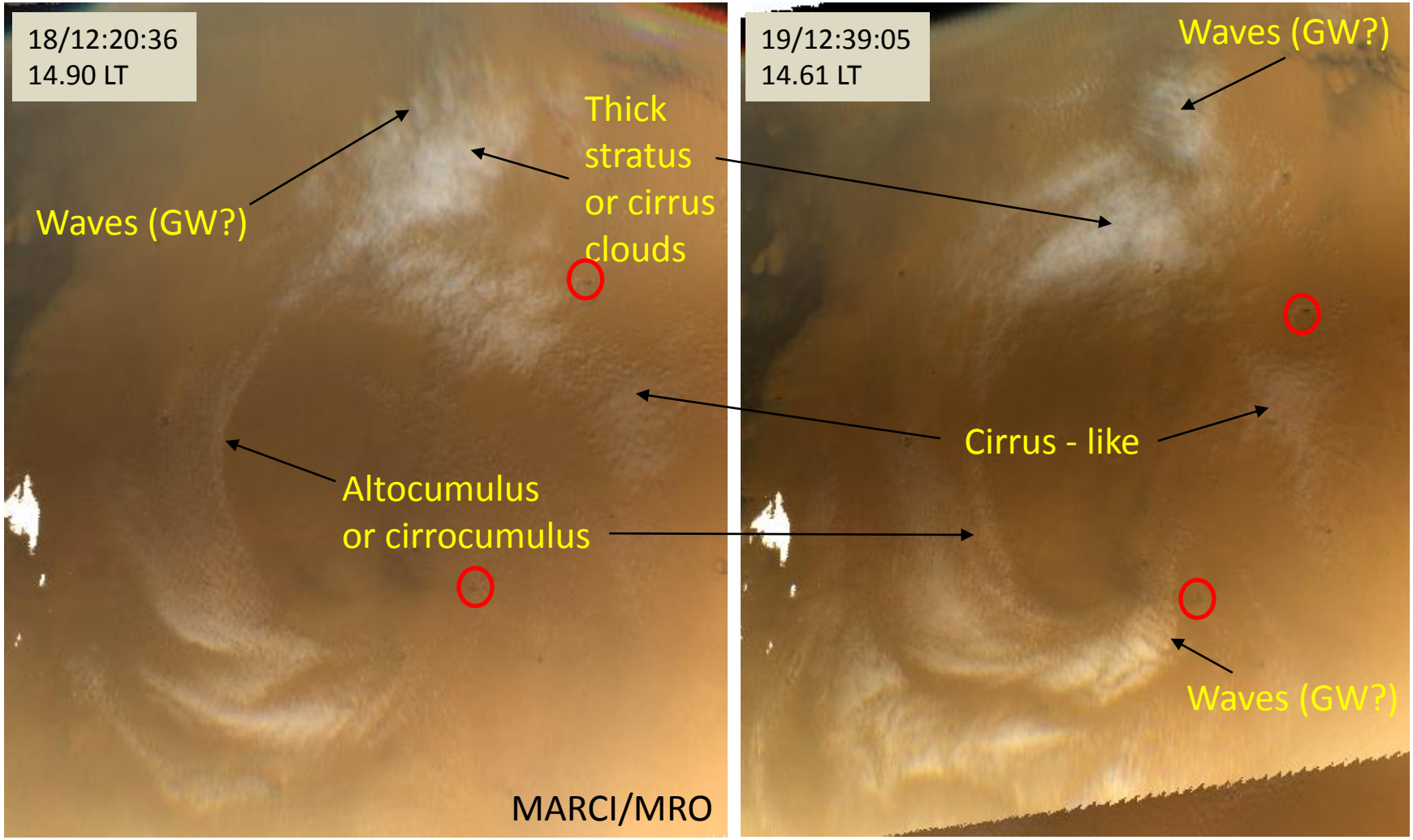
Spiral bands
L ~ 500 km

Waves (GW?) λ ~ 20-25 km

Altocumulus cloud field: D (cells) ~ 5-15 km (H ~ 8-10 km)
Water-ice moist convection in a shallow layer?
(Spiga et al., Nat. Geos., 2017)

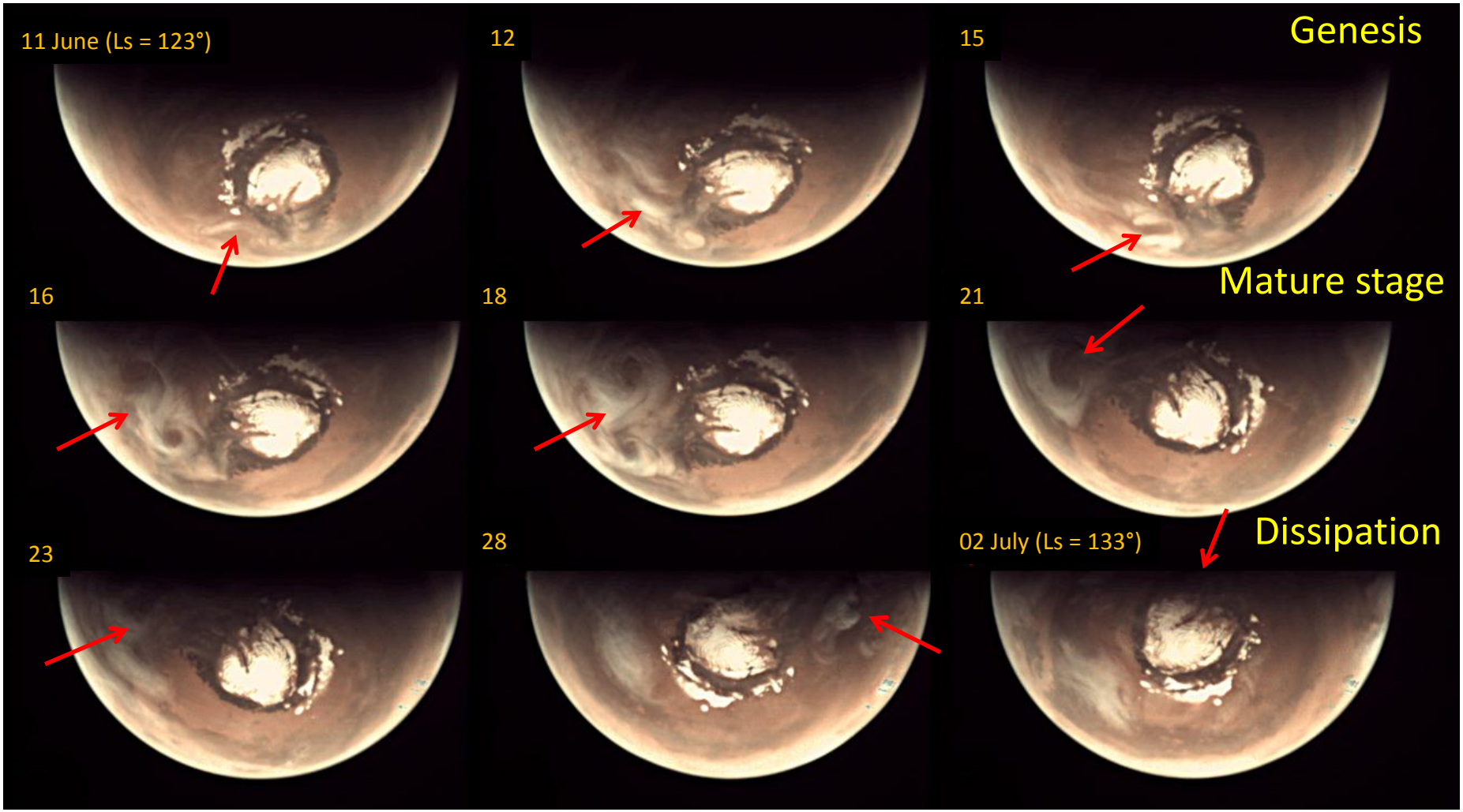
Cloud morphology-II

Changes in one sol at the same LT



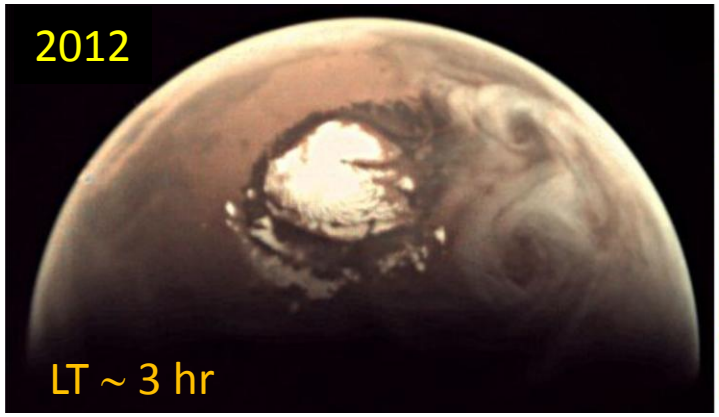
Vortex Lifetime: Formation - Dissipation

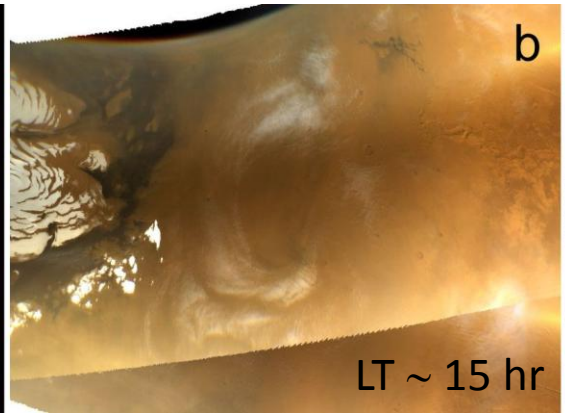
June 11 - July 02 (2012) - Different LT – MEx/VMC sequence

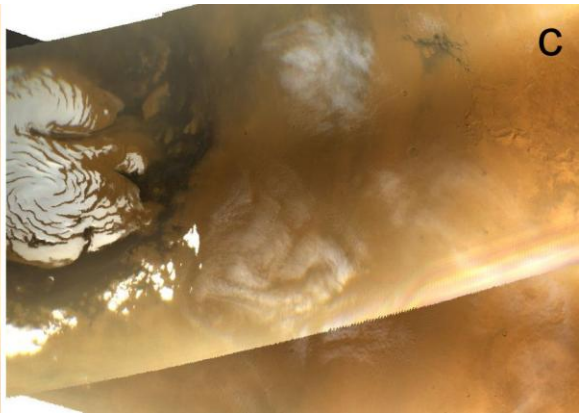


Lifetime ~ 20 days

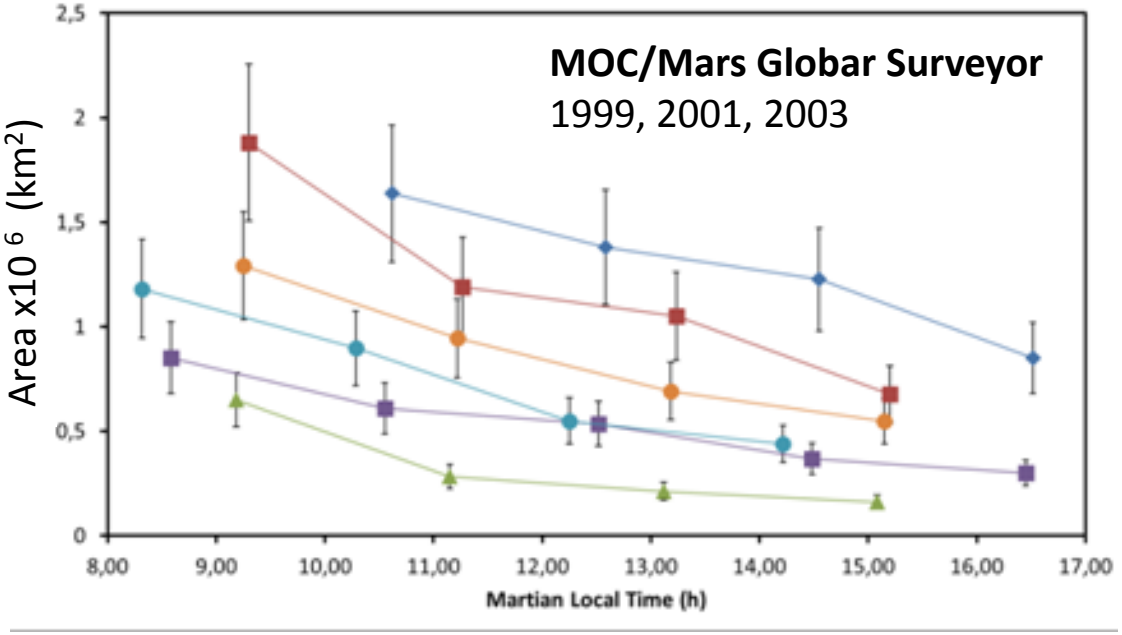
Daily (sol) evolution with local time







Morning: double, coherent, cloudy vortex
Afternoon: double but broken / single, weak (open circulation), less clouds

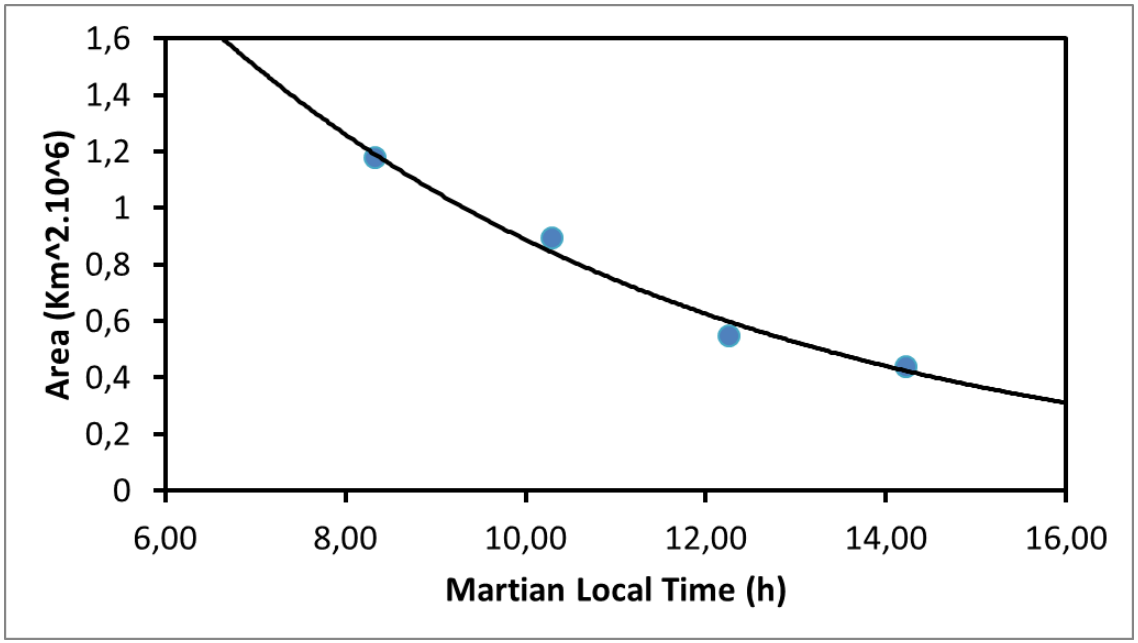


Cloud covered area decreases with increasing sunligth:

Cloudy area (morning) =
4x cloudy area (afternoon)

Cloud sublimation with Local Time

Cloud extent and density due to:
Water condensation (morning, low T)
Sublimation with (afternoon, higher T



Heating rate $dE/(dAdt) = K \rightarrow$

$$m_{(cloud)}(t) = m_{0(cloud)} \exp(-t/\tau)$$

Sublimation time constant:

$$\tau_{subl} = \frac{L_{subl}\rho_{H_2O}\left(\frac{4}{3}a\right)\tau_{opt}}{1-\varpi_0}$$

For:

$\tau_{opt} = 0.1-3$

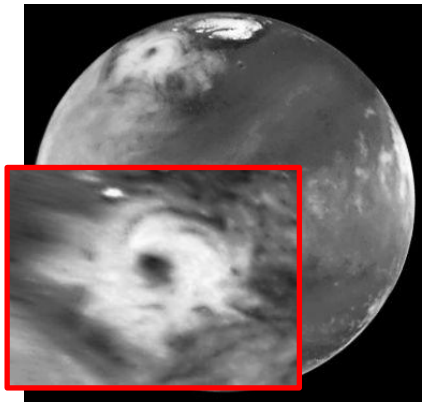
$a = 0.1-6\mu m$

$\varpi_0 = 0.99-0.9999$

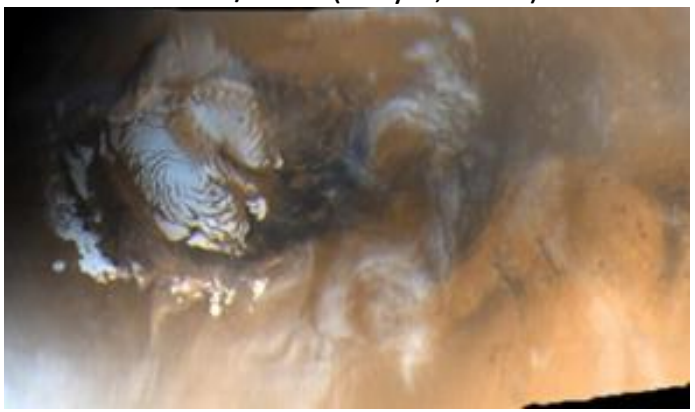
$\rightarrow \tau_{subl} \approx 6-8$ hr

Seasonal recurrence

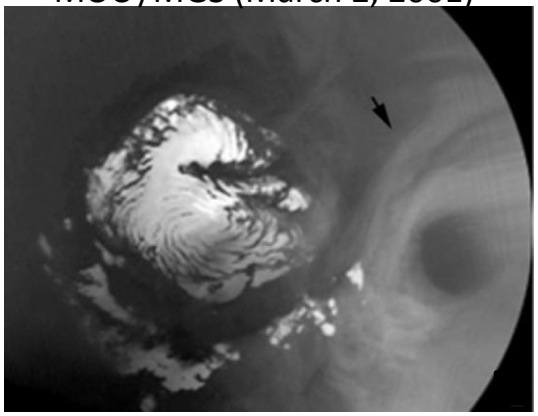
HST (May 20, 1999)



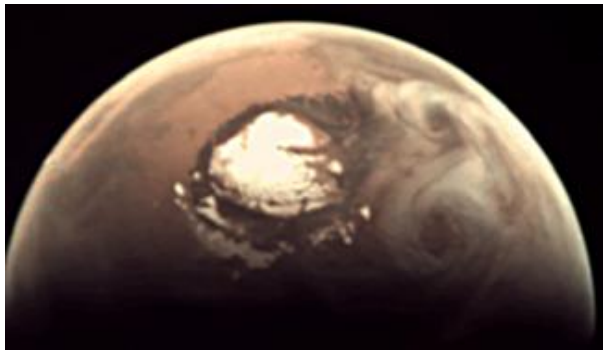
MOC /MGS (May 4, 1999)



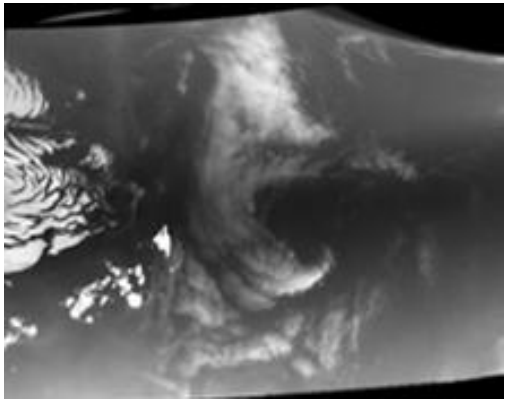
MOC /MGS (March 2, 2001)



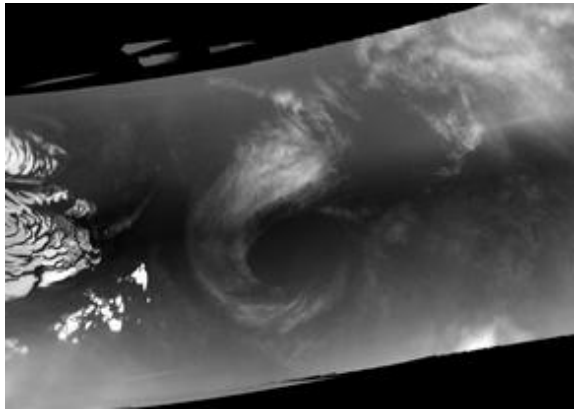
"Annular cloud" : Cantor et al., JGR (2002), Icarus (2010), Malin et al., Icarus (2008), Malin et al. Mars I.J.MarsSci.Exp (2010)



VMC/MEx (June 18, 2012)



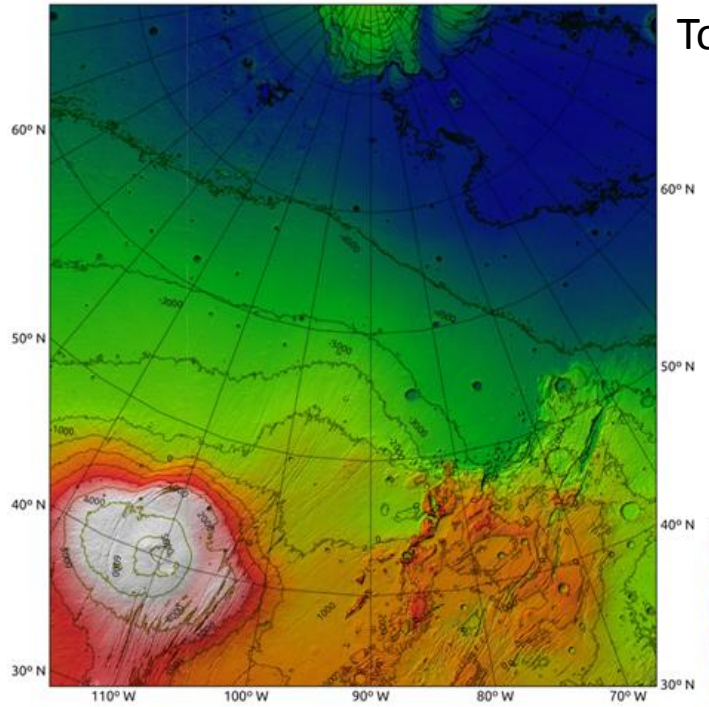
MARCI/MRO (May 3, 2014)



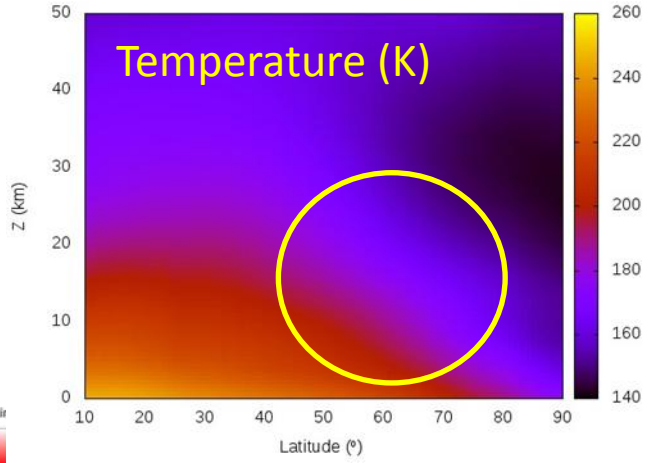
MARCI/MRO (MARCH 21, 2016)

Observational records → 9 Martian Years (MY24 → MY 34)
1999 (*HST, MOC/MGS*), 2001 (*MOC/MGS*), 2003 (*MOC/MGS*), 2004 (*MOC/MGS*), 2006 (*MOC/MGS*), 2008 (*MARCI/MRO*), 2010 (*MARCI/MRO*), 2012 (*VMC/MEX*, *MARCI/MRO*), 2014 (*MARCI/MRO*), 2016 (*MARCI/MRO*), **2018 (*MARCI/MRO*)**

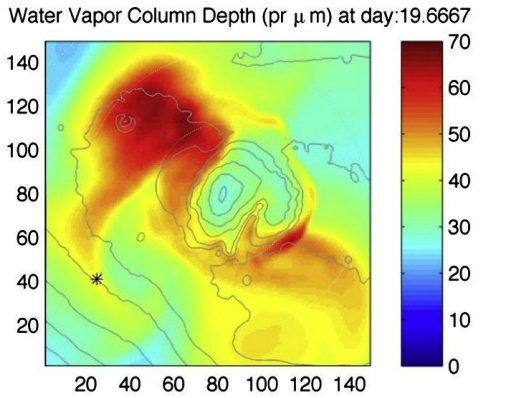
Vortex formation mechanism

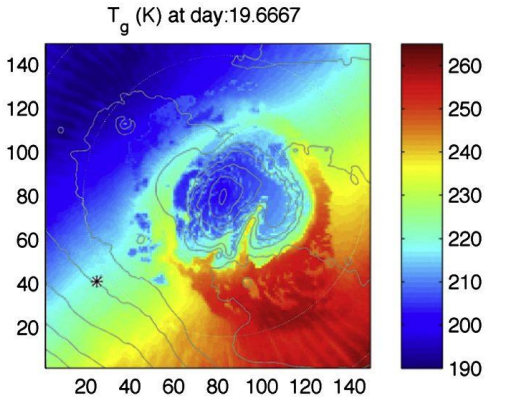


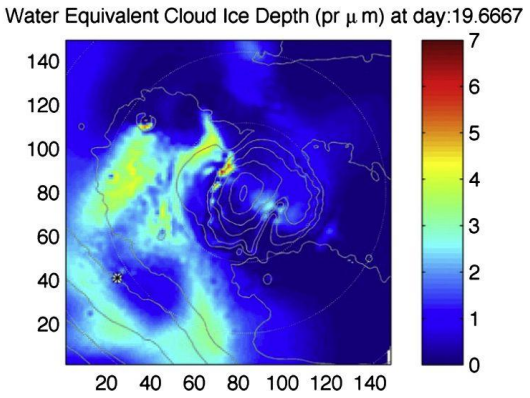
Topography: 4 km slope (S→N)



MCD-LMD data





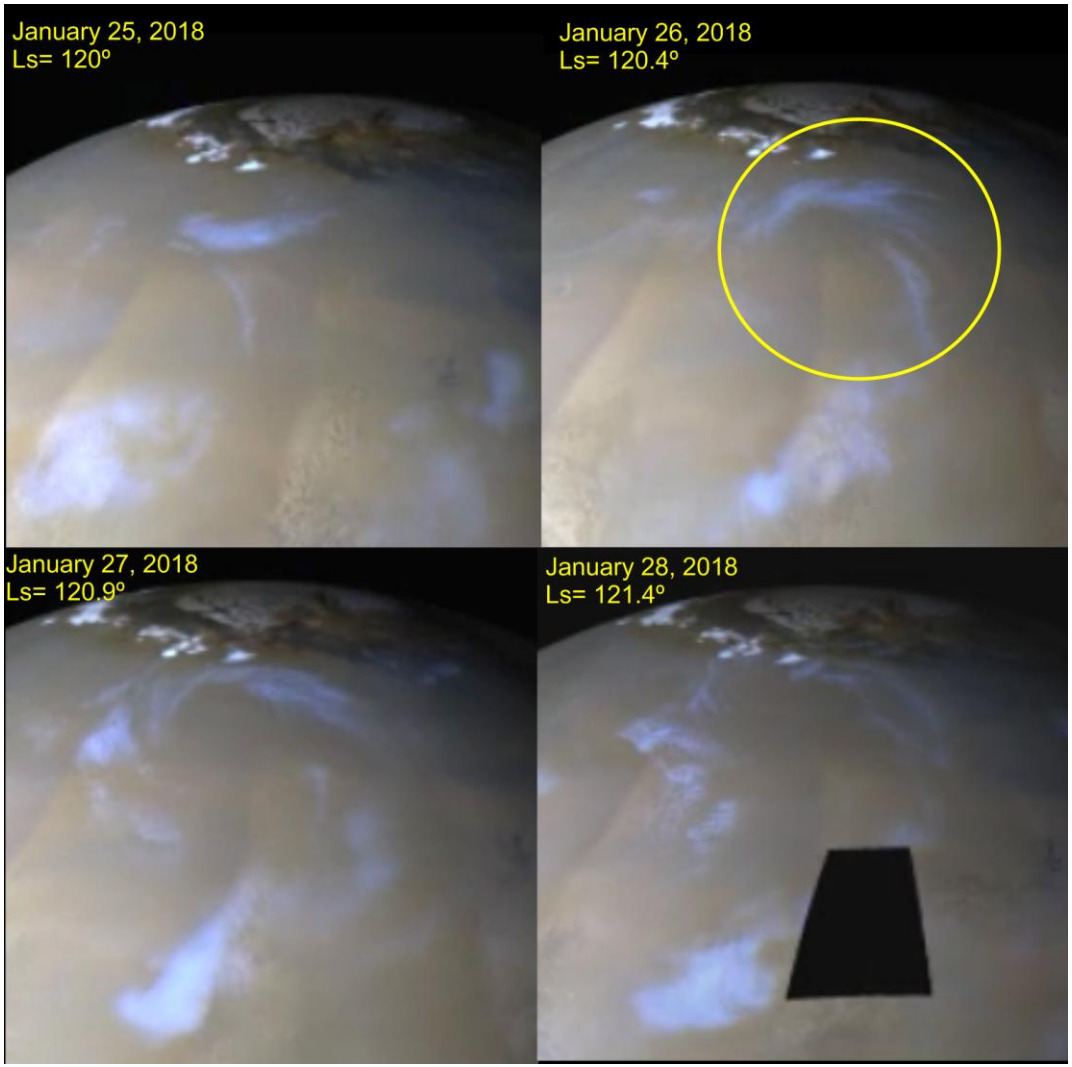


Tyler and Barnes, Icarus (2014): "Storm Zone" at Ls ~ 135°
Mesoscale simulations → Dynamical forcing:

- Western boundary currents
- Topographically excited large-scale thermal circulation
- Strong slope flows

→ Diagnostic to asses Martian interannual variability
→ Diagnostic to cycles (CO2, H2O, dust) → Global dust storms ?

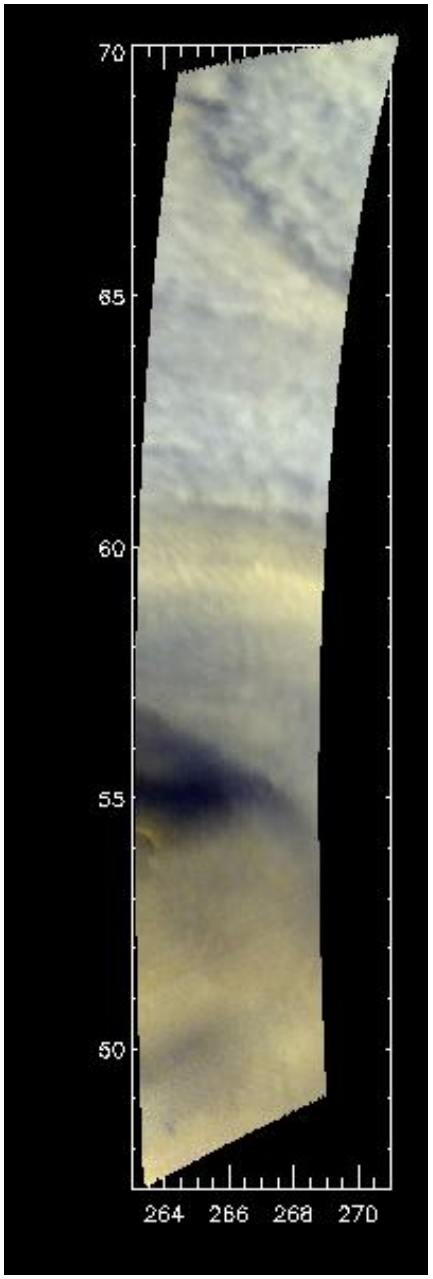
2018: The vortex is back “faithful to its appointment”

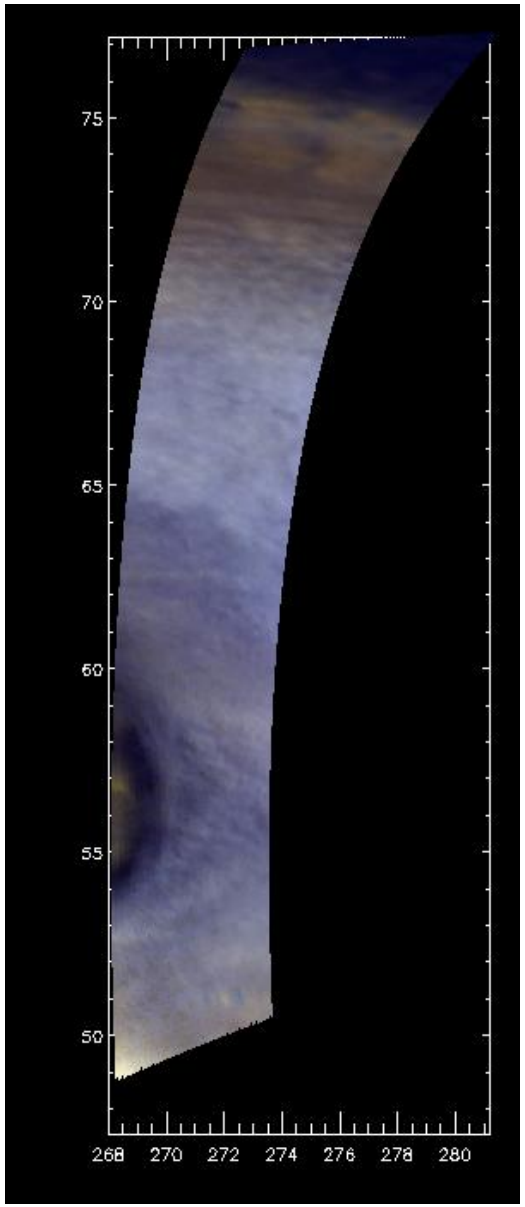


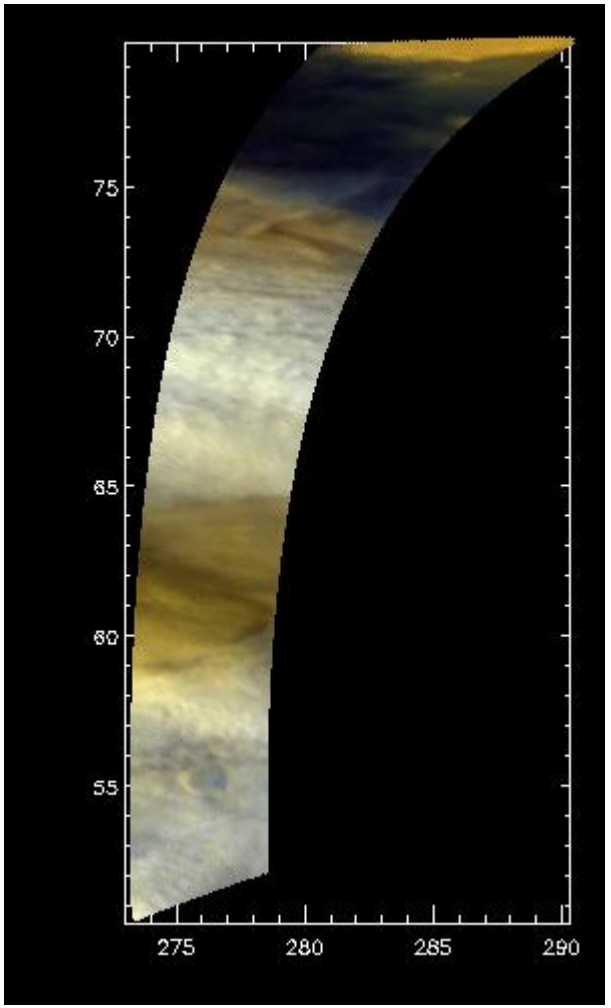
Not seen in January 24
First signatures in January 25

Malin, M. C., B. A. Cantor, A. W. Britton (2018), MRO MARCI Weather Report for the week of 22 January 2018 – 28 January 2018, Malin Space Science Systems Captioned Image Release, MSSS-515, http://www.msss.com/msss_images/2018/01/31/.

2018: MEx/Omega

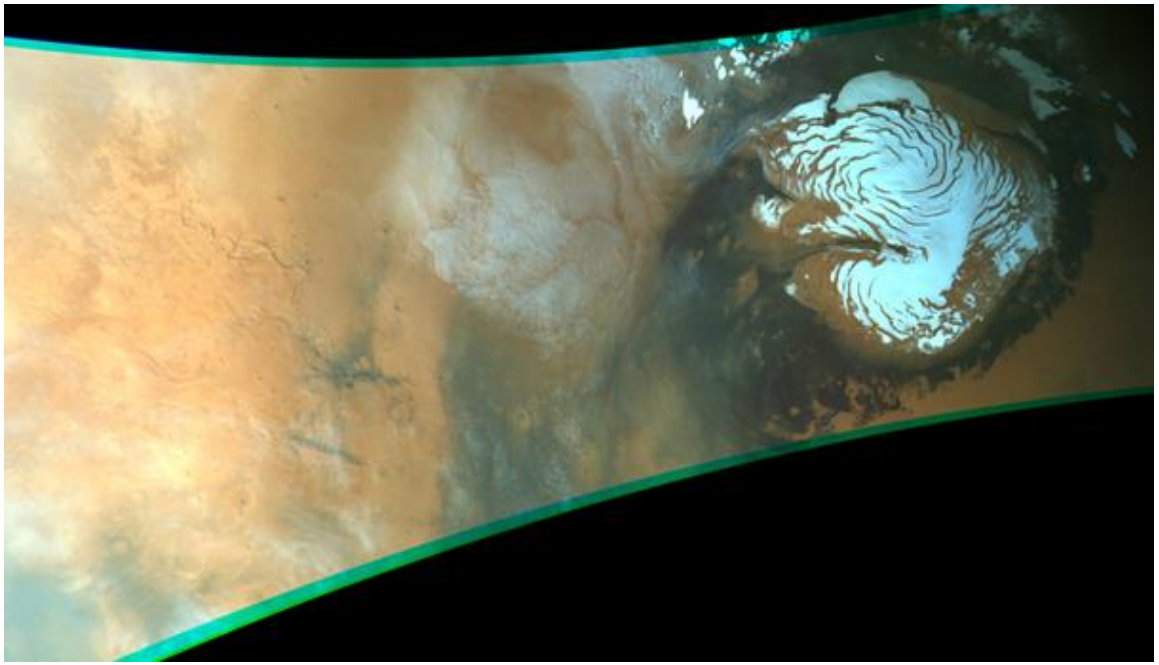




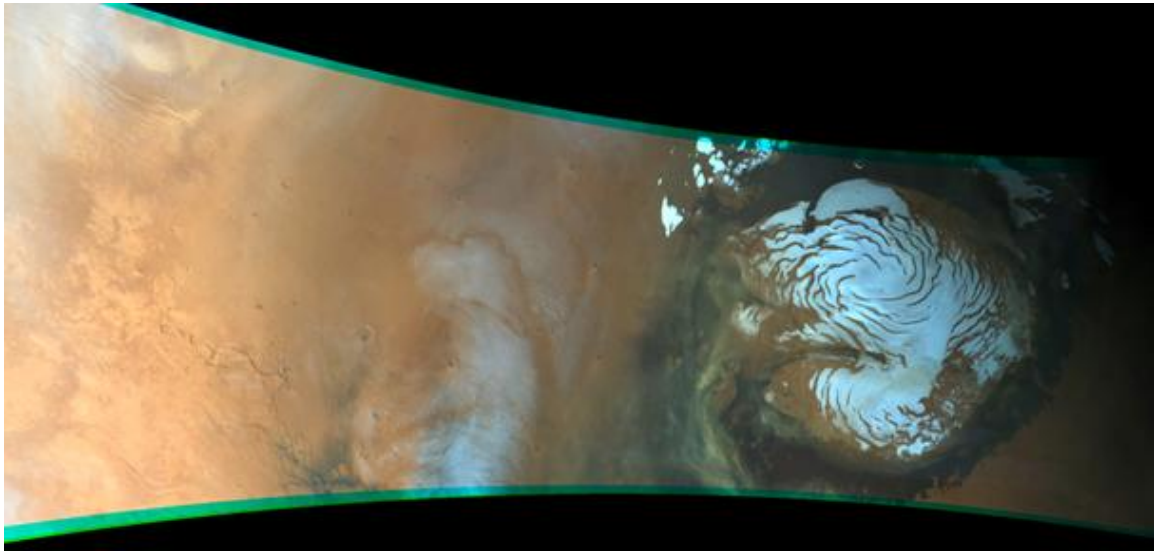


Courtesy of Brigitte Gondet, Anni Määttänen et al.

MEx/HRSC search: observed in 2014



Orbit 13125
02 May 2014
Ls = 124.81
broom observation,
RGB stretched



Orbit 13185
20 May 2014
Ls = 133.19°
broom observation
RGB stretched

Courtesy of
Harald Hoffmann (DLR)

Conclusions

• **Cyclone pair:**
Yearly (MY) recurrent double cyclone forms at Ls = 120°
Aerographical location: latitude = 60°N and longitude = 70°-110°W
Years observed: 1999, 2001, 2003, 2008, 2010, 2012, 2014, 2016, 2018

• **Properties:**
Size (single/double cyclone) → Individual size = 600 – 800 km
Lifetime ~ 20 sols
Wavelength = 90º (wavenumber m = 4)
Zonal drift U = 3-5 m/s
Local cloud velocity = 10-30 ms^{-1}
Cyclonic vorticity (~ 0.3 Coriolis vorticity) under gradient wind balance
Cloud altitude: 10 km
Water ice clouds with cyclone area decreasing with increasing insolation (LT)

• **Genesis and demise**
Cyclones generated in early morning
Destruction and dissipation with increasing insolation
Cloud condensation – sublimation → time scale = 6-8 hr
Formation favored by topography (poleward surface slope)
Intense baroclinic conditions

Future work → Additional measurements, numerical modeling
→ Explore its use as diagnostic of Martian yearly atmospheric behaviour

Thank you very much
for your attention