Martian cloud coverage and diurnal cloud life cycle derived from Mars-Express / OMEGA data

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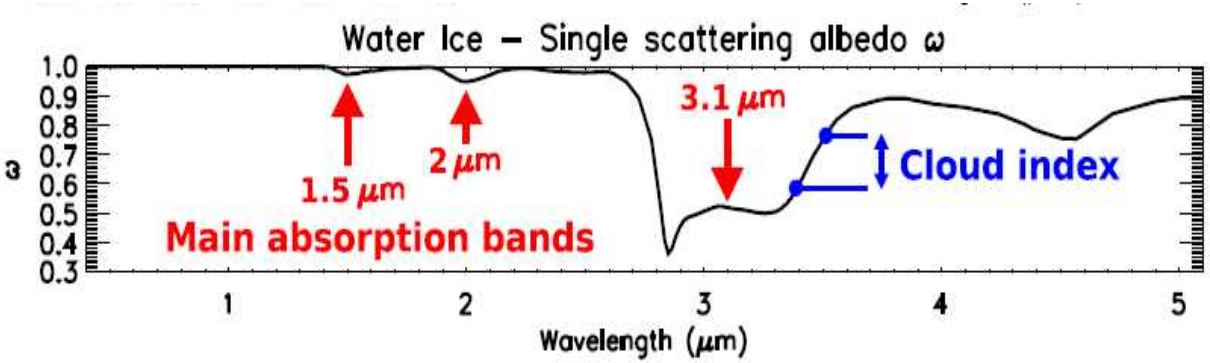
1. Introduction

- **Objective of this study**
  - Construct a 4D gridded (spatio-temporal) water ice cloud database extracted from Mars Express/OMEGA spectro-imager data
  - Use the derived products to determine the diurnal cloud life cycle.
- **OMEGA instrument :**
  - VNIR + SWIR (0.36 – 5.2 μm ; 352 spectels)
  - Long period of observation : MY 26-32 (1/2004 - 4/2015 ; 7722 (useful) orbit segments, > 1 billion pixels).
  - Improved temporal coverage in comparison with recent heliosynchronous satellites (~fixed local time) and recent non-heliosynchronous satellites (MOM, MAVEN, ExoMars ; short duration of operation).
  - Near global coverage

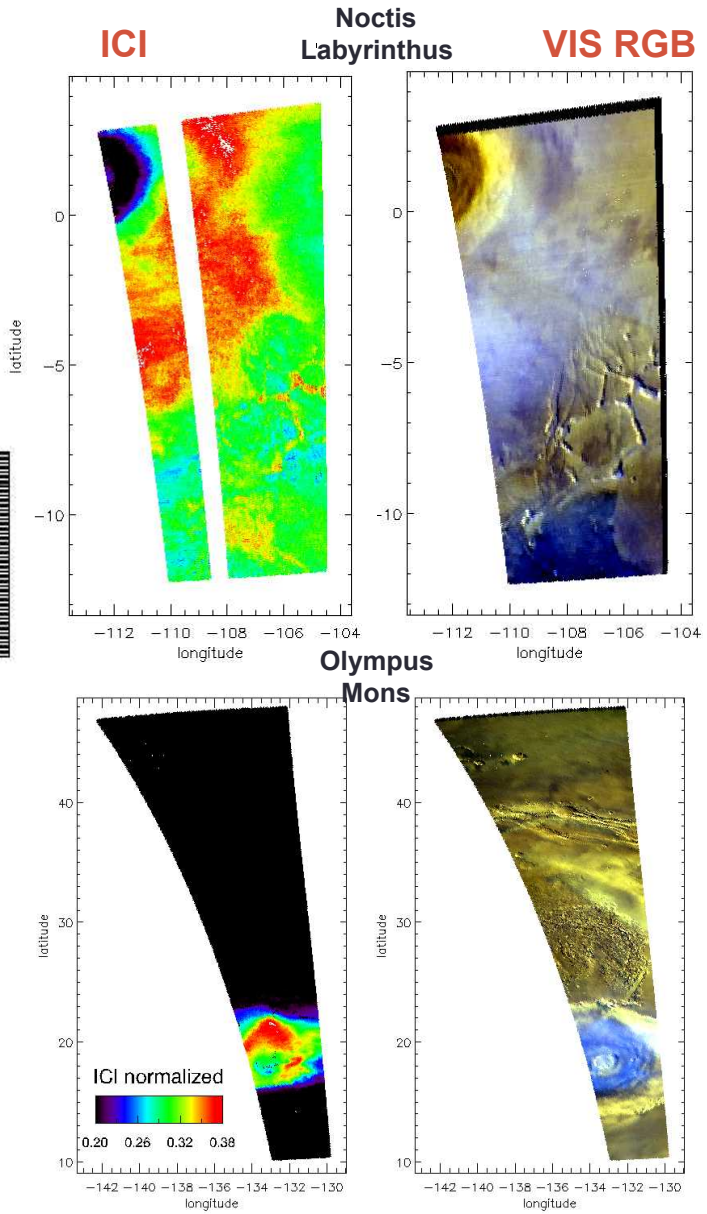
2. Ice Cloud Index and Percentage of Cloudy Pixels

Calculation of the Ice Cloud Index (ICI)

- **Pixel-based**
- **Derived from Langevin et al., 2007**



- **Slope ➔ original ICI :** $ICIo = I_{3.38\mu m} / I_{3.52\mu m}$
- **Normalized IceCloudIndex :** $ICI = 1 - ICIo$



Construction of a 4D cloud database

1) **Definition of a regular grid**

1° longitude X 1° latitude X 5° Ls X 1 h LT

2) **Binning of individual (pixel-based) ICIs onto grid**

3) **Average of ICI on each gridpoint**

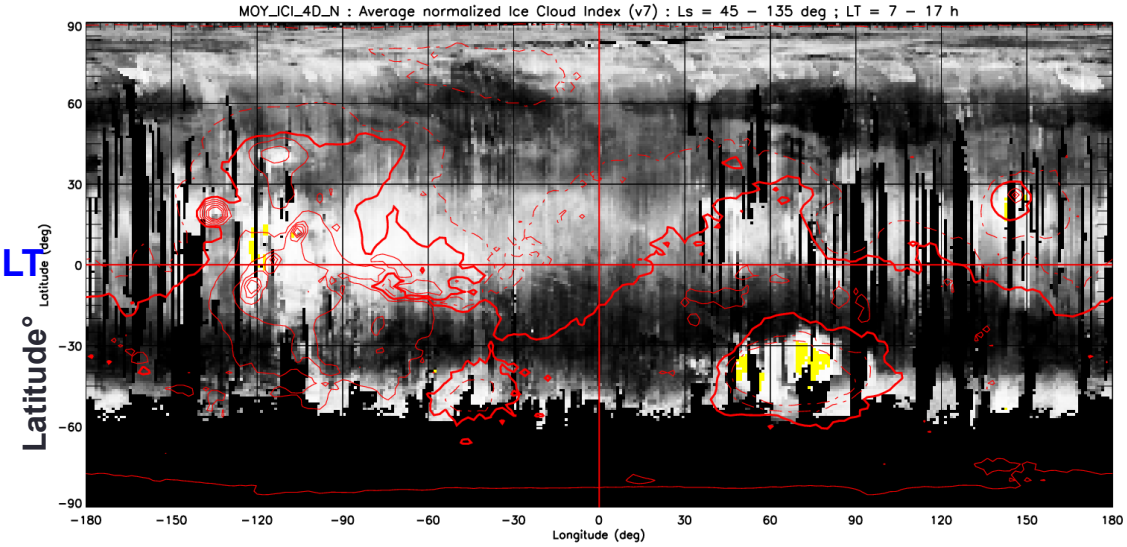
4) **Illustration : 2D ICI maps**

Main cloud features identified : aphelion belt, Hellas, major volcanoes, cloud edges of polar hoods

But :

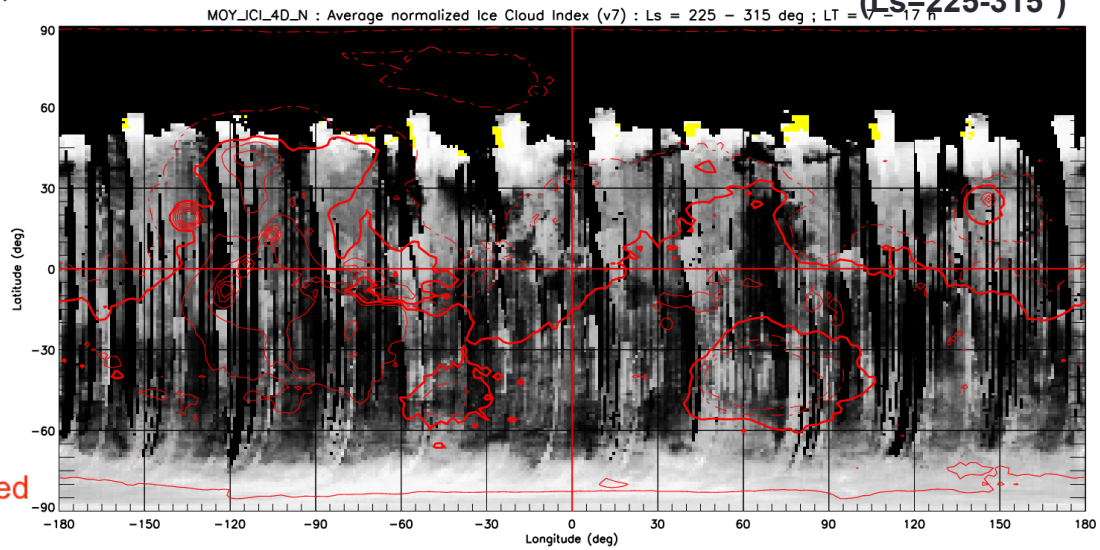
Only ~2% of daytime gridpoints have ICI values

N summer solstice (Ls=45-135°)



Longitude °

N winter solstice (Ls=225-315°)

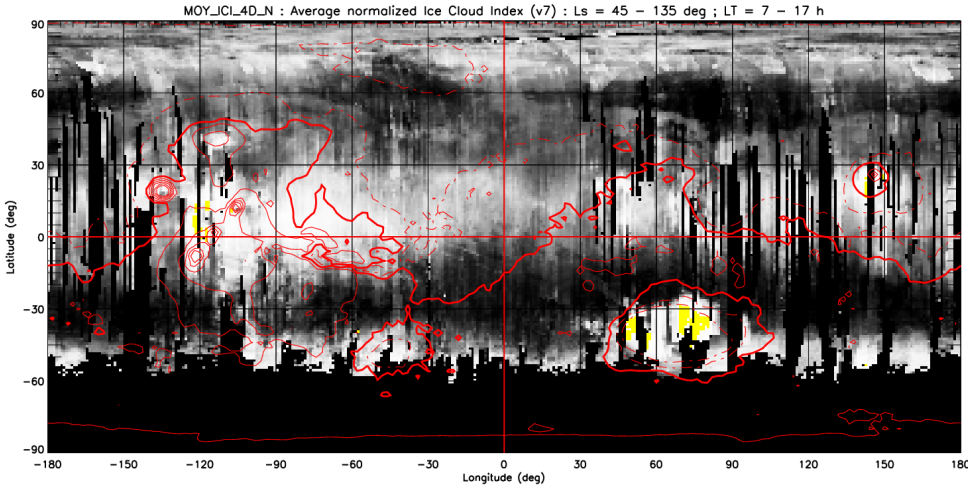


Main elevation contours : red

Highest ICI value : yellow

Percentage of cloudy pixels (PCP)

1) **Selection of a threshold to extract cloudy pixels :**
   - **ICI > ICI_{thr} ➔ the pixel is cloudy**
   - **ICI_{thr} = 0.28 (based on Madeleine et al., 2012; Audouard et al., 2014)**

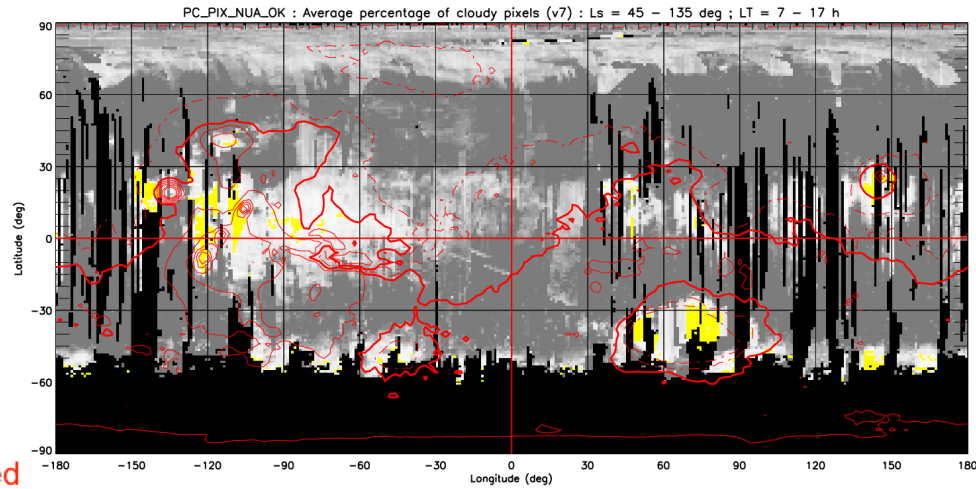


Average Ice Cloud Index (Ls = 45 - 135°, LT = 7 - 17 h)

2) **Percentage of cloudy pixels (PCP) ⇔ cloud coverage**

PCP = 100 x N_{cloudy_pixels} / N_{all_pixels} (%)

3) **PCP filters out areas with limited average cloud coverage**

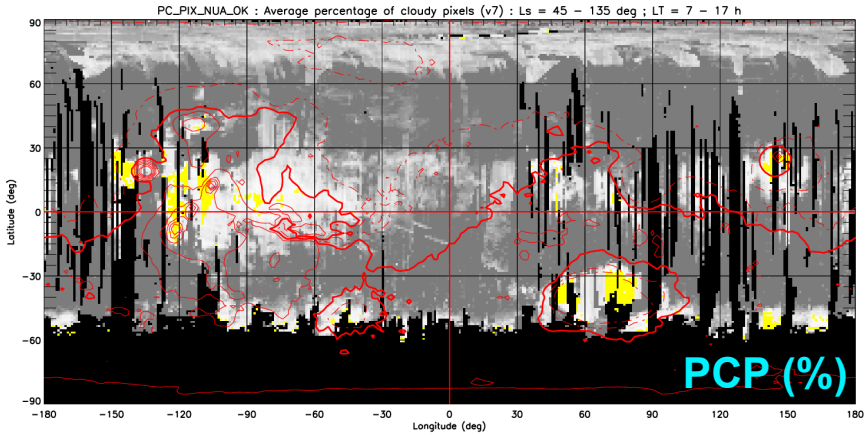


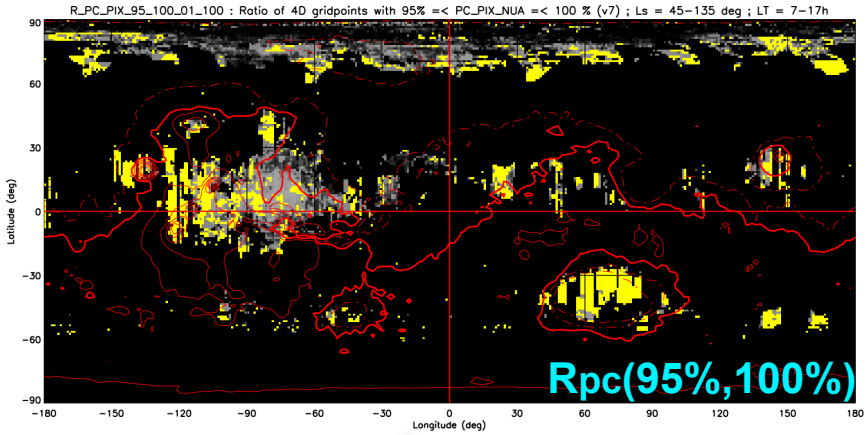
Main elevation contours : red
Highest value : yellow

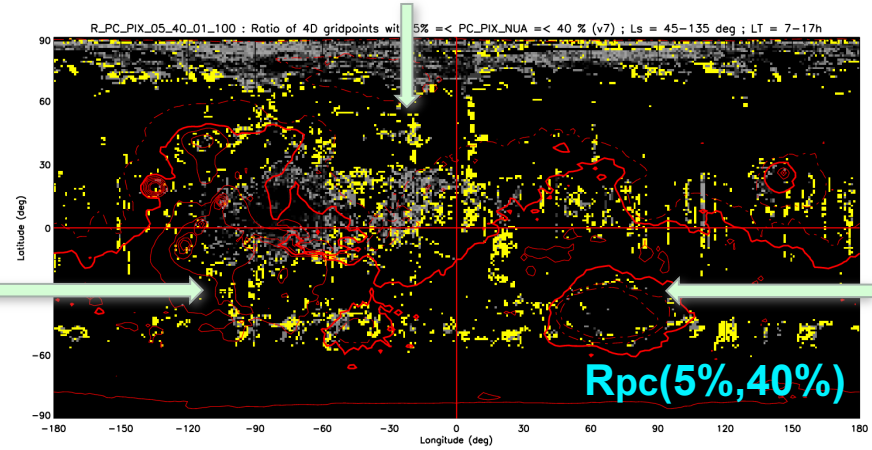
Average Percentage of Cloudy Pixels

3. Location of partially cloud-covered areas : examples

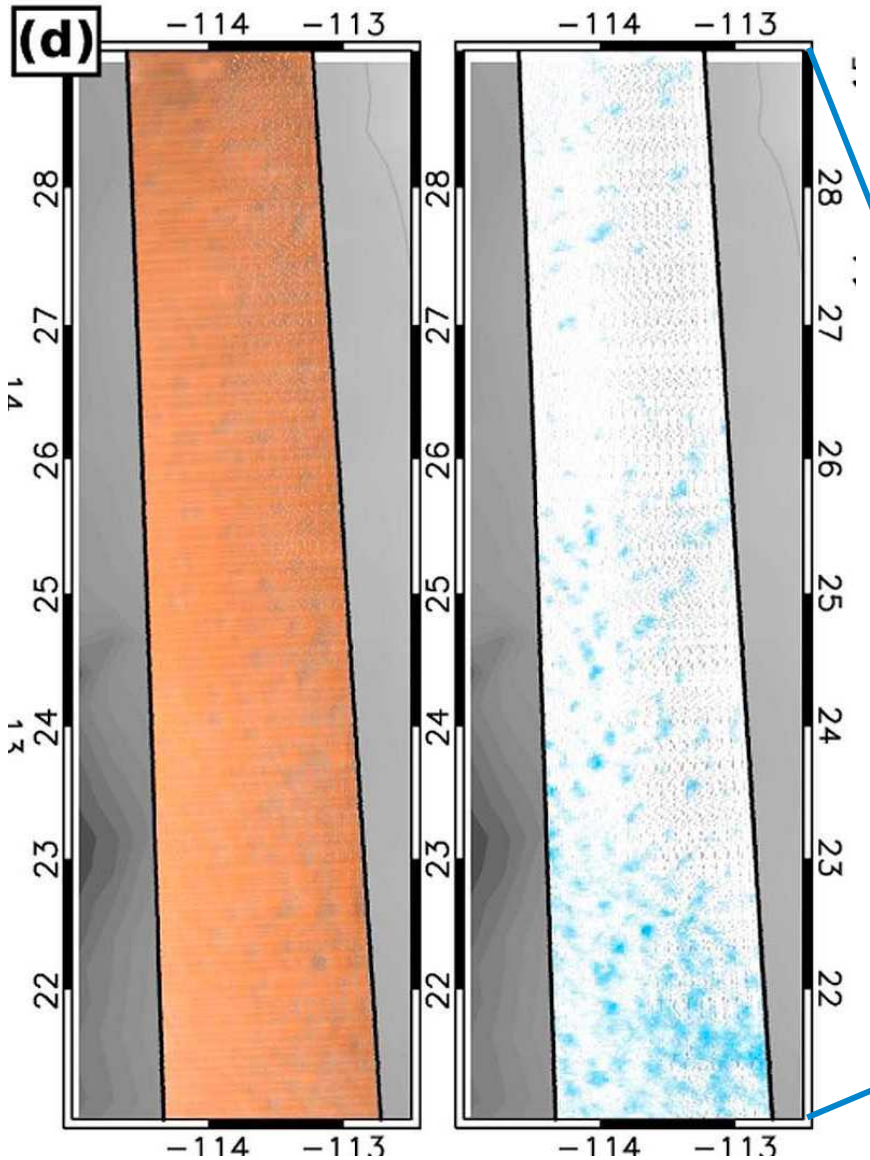
- **Ratio of partially clouded instants**
  - at a given gridpoint (lon, lat) : $Rc_{(PCPmin, PCPmax)}$
- **Thick cloud cover ($Rc_{(95\% < PCP < 100\%)}$)**
  - Major locations : Hellas, Lunae pl., Tharsis volcanoes, Olympus and Elysium M., Arabia Terra, S (reduced) and N polar hood cloud edges.
- **Thin cloud cover ($Rc_{(5\% < PCP < 40\%)}$) :**
  - Complementary locations to thick cloud cover.
  - Original locations => edges of Hellas, cloud bridges between aphelion belt and S polar hood clouds, Chryse and Acidalia Planitia.



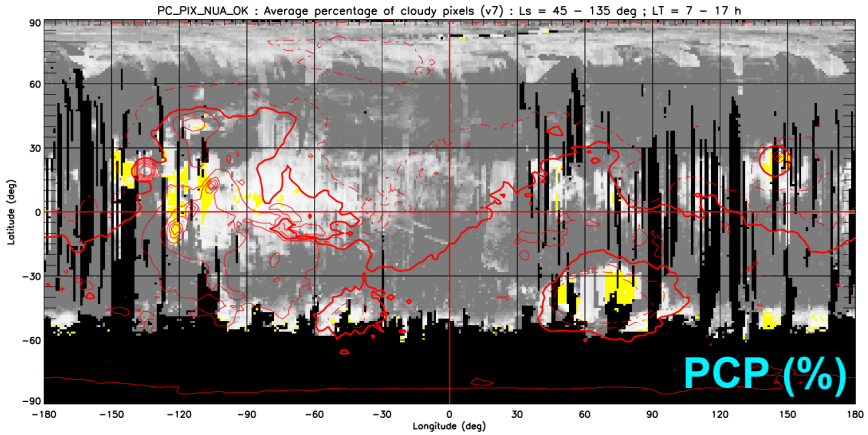


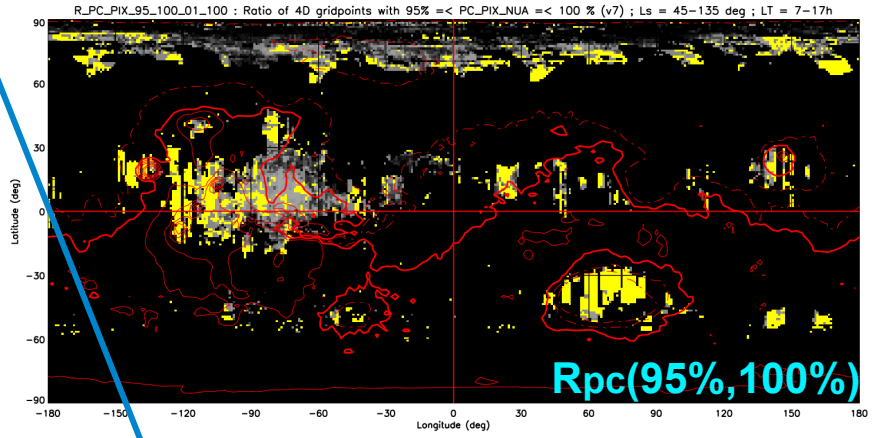


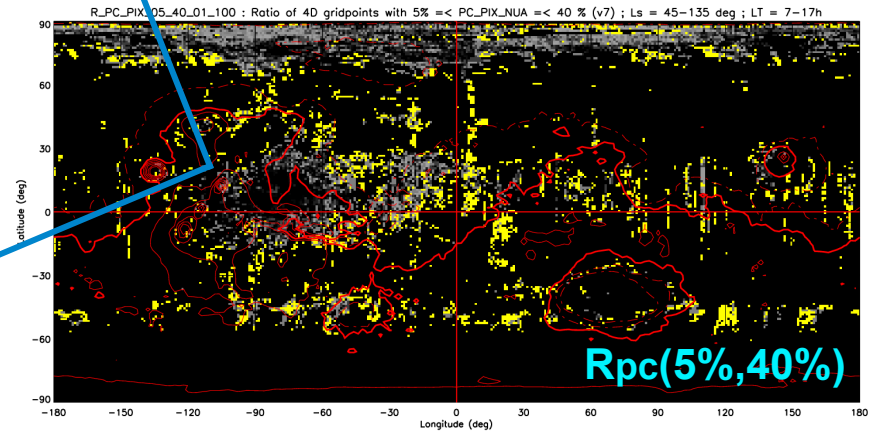
Partial cloud coverage :



Original OMEGA image, ICI image

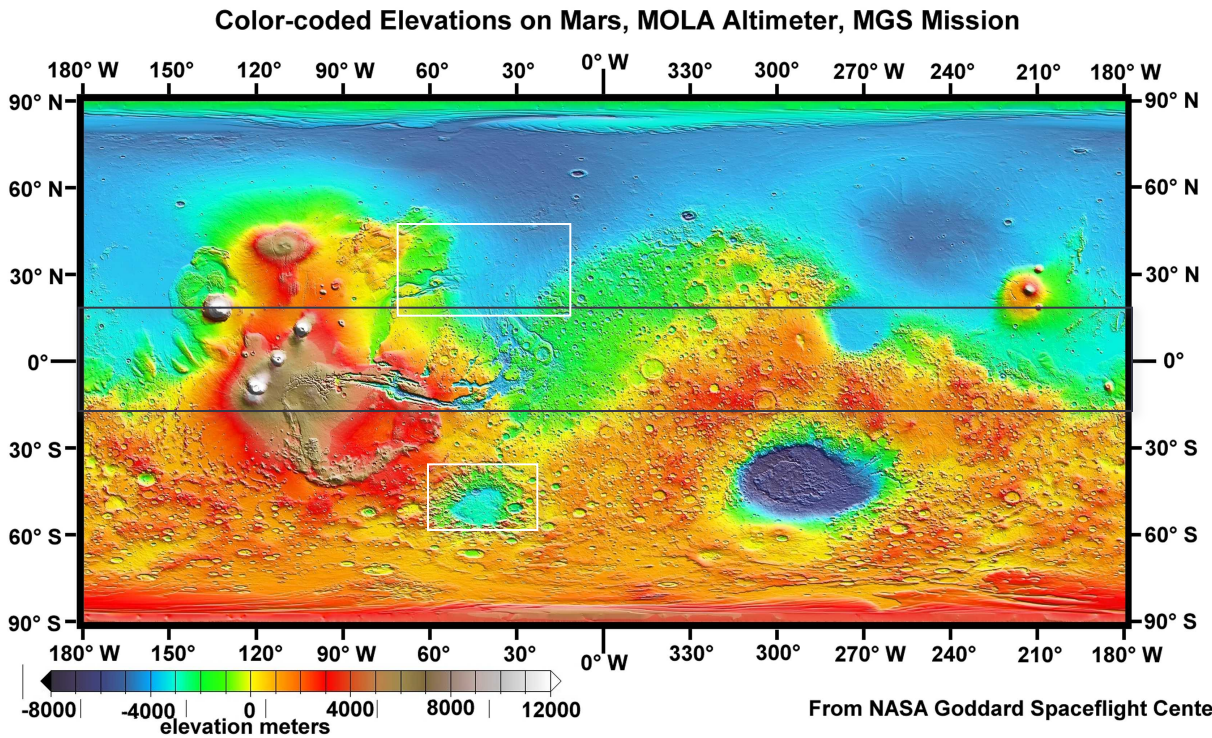






4. Diurnal cloud life cycle

- **At one gridpoint (lon, lat, Ls), the longest life cycle :**
  - **4 h in the tropics (possible : 12 h)**
- **Long daily cloud life cycle :**
  - **Need to integrate over larger areas**
  - **26 areas of variable coverage :**
  - ➢ **Large latitudinal bands (all longitudes) ==> limited areas covering specific topographic features (ex. : Olympus Mons)**

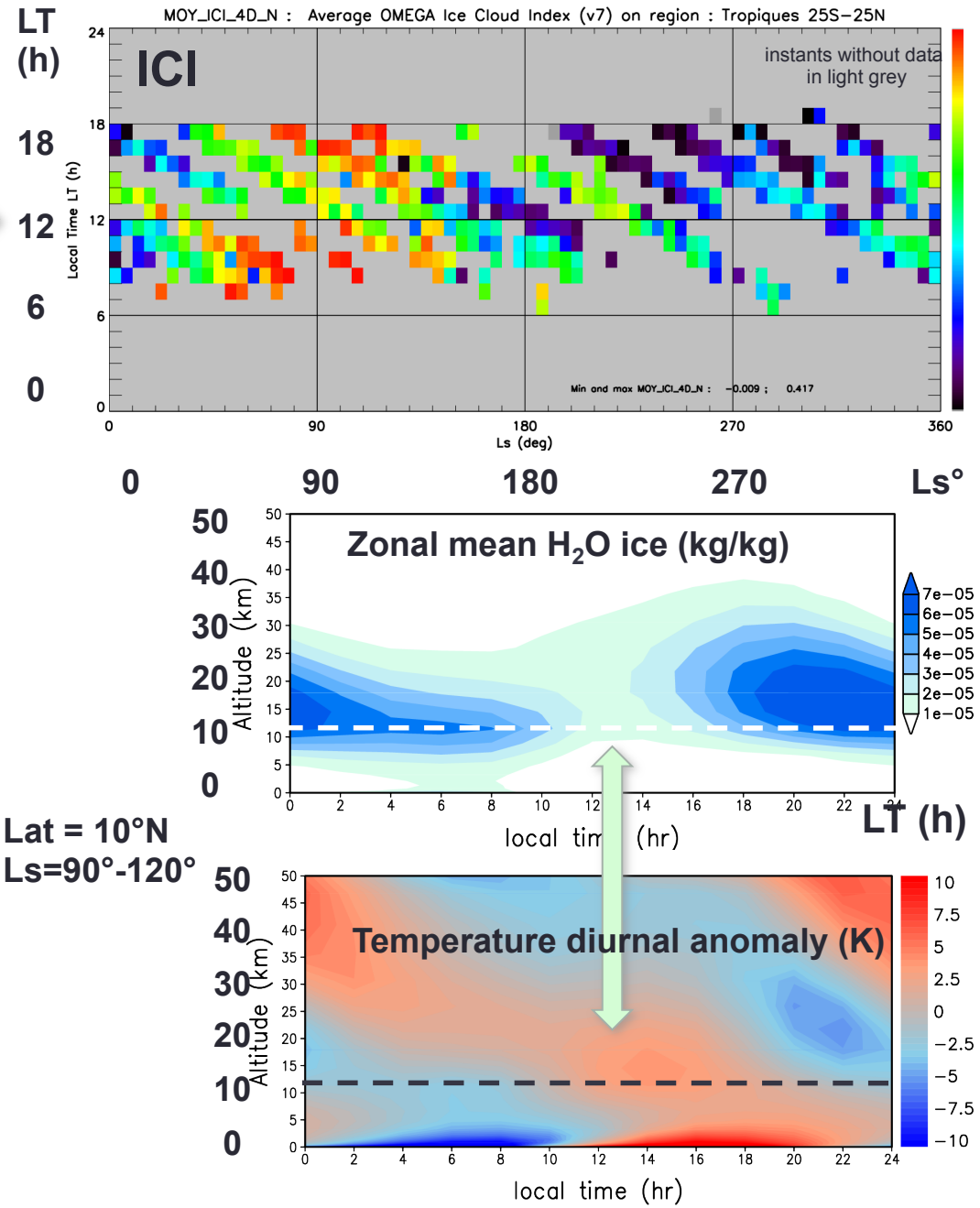


Martian map with 3 studied areas (out of 26)

Tropical region
(25°S – 25°N ; all longitudes)

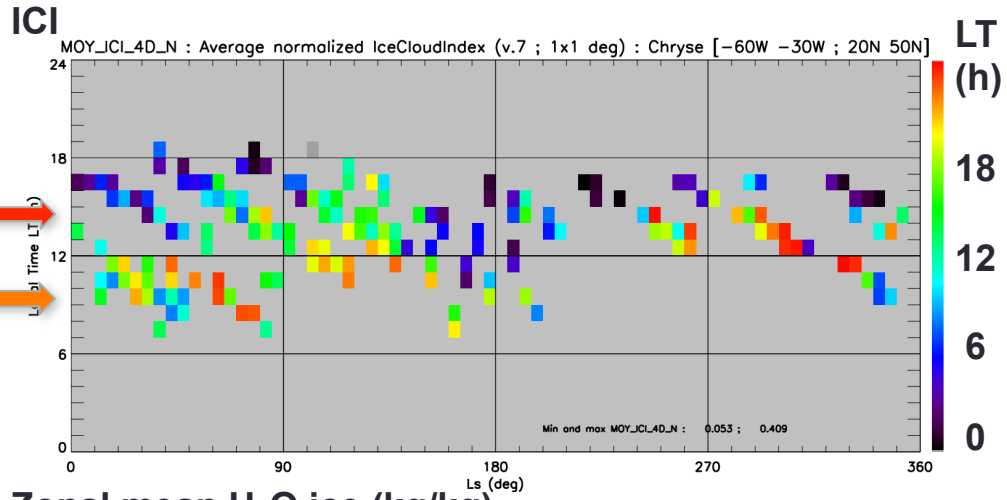
- **N summer solstice :**
  - **Most cloudy period**
  - **Dominant cloud structure : aphelion belt.**
  - **Diurnal cycle : important cloudiness in the morning and later in the afternoon, reduced around noon.**

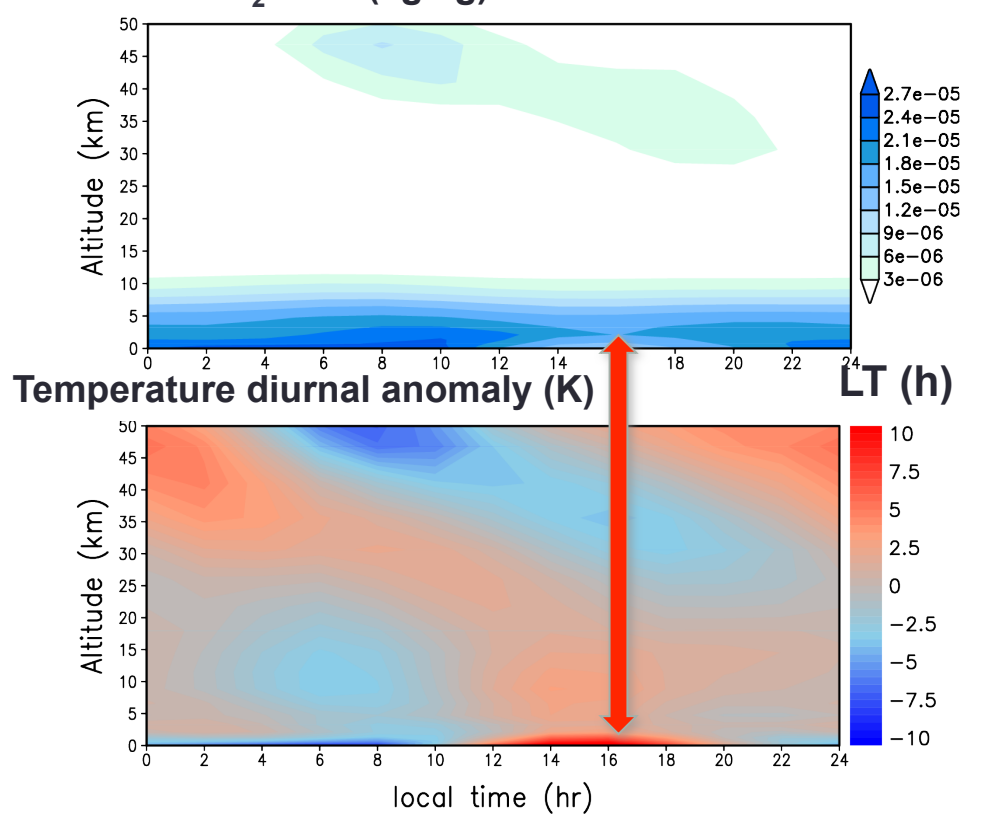
- **GCM-based interpretation :**
  - **Clouds tend to form above hygropause (10-20 km) at minimal temperatures.**
  - **Temperatures are controlled by thermal tides.**
  - **Max. temperature at cloud altitude around midday => cloud minimum around noon (not due to radiative heating of surface by the sun).**



Chryse Planitia
(20°N – 50°N ; 60°W – 30°W)

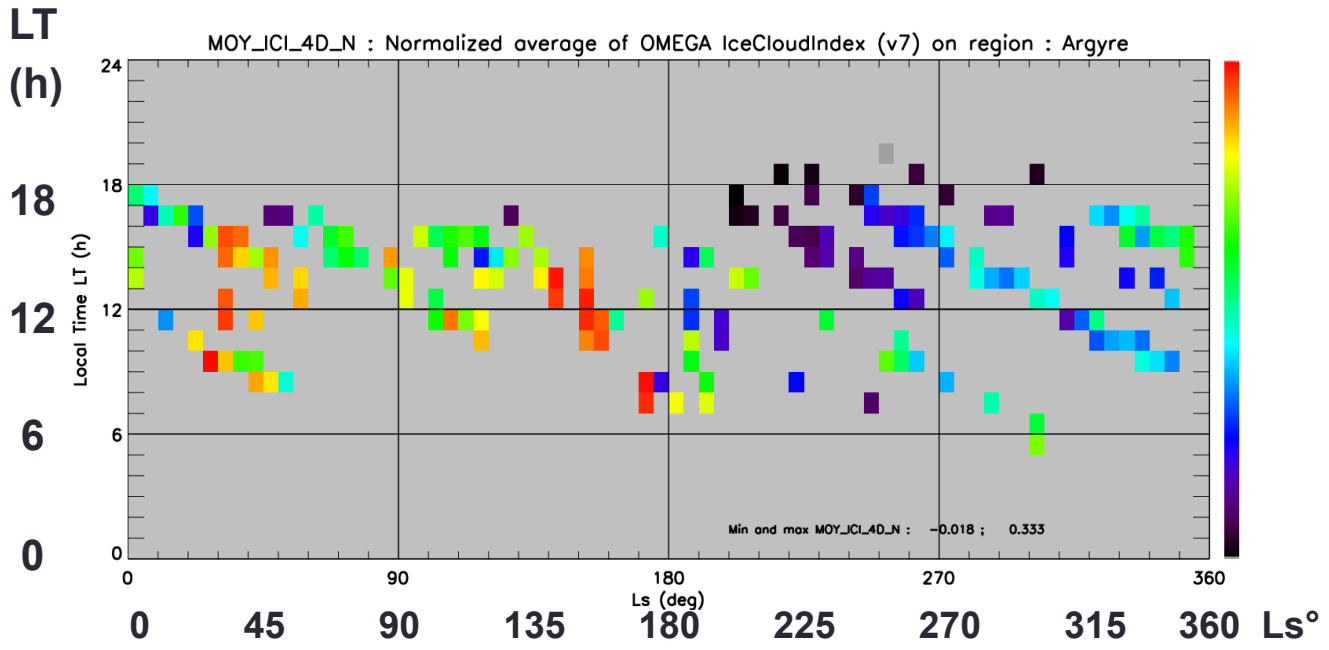
- **Spring (Ls = 15-90°)**
  - **Morning clouds appear earlier and earlier**
  - **Related to the presence and retreat of polar hood cloud edge**
- **Winter (Ls = 245-335°)**
  - **Clouds present around noon, dissipate in the middle of afternoon.**
  - **GCM-based Interpretation : low-lying fogs, formed during the night, dissipate in the afternoon after sufficient heating by the sun.**
  - **Thin high clouds, undetected by OMEGA but predicted by MGCM, are controlled by thermal tides.**





Argyre
(55°S – 35°S ; 65°W – 25°W)

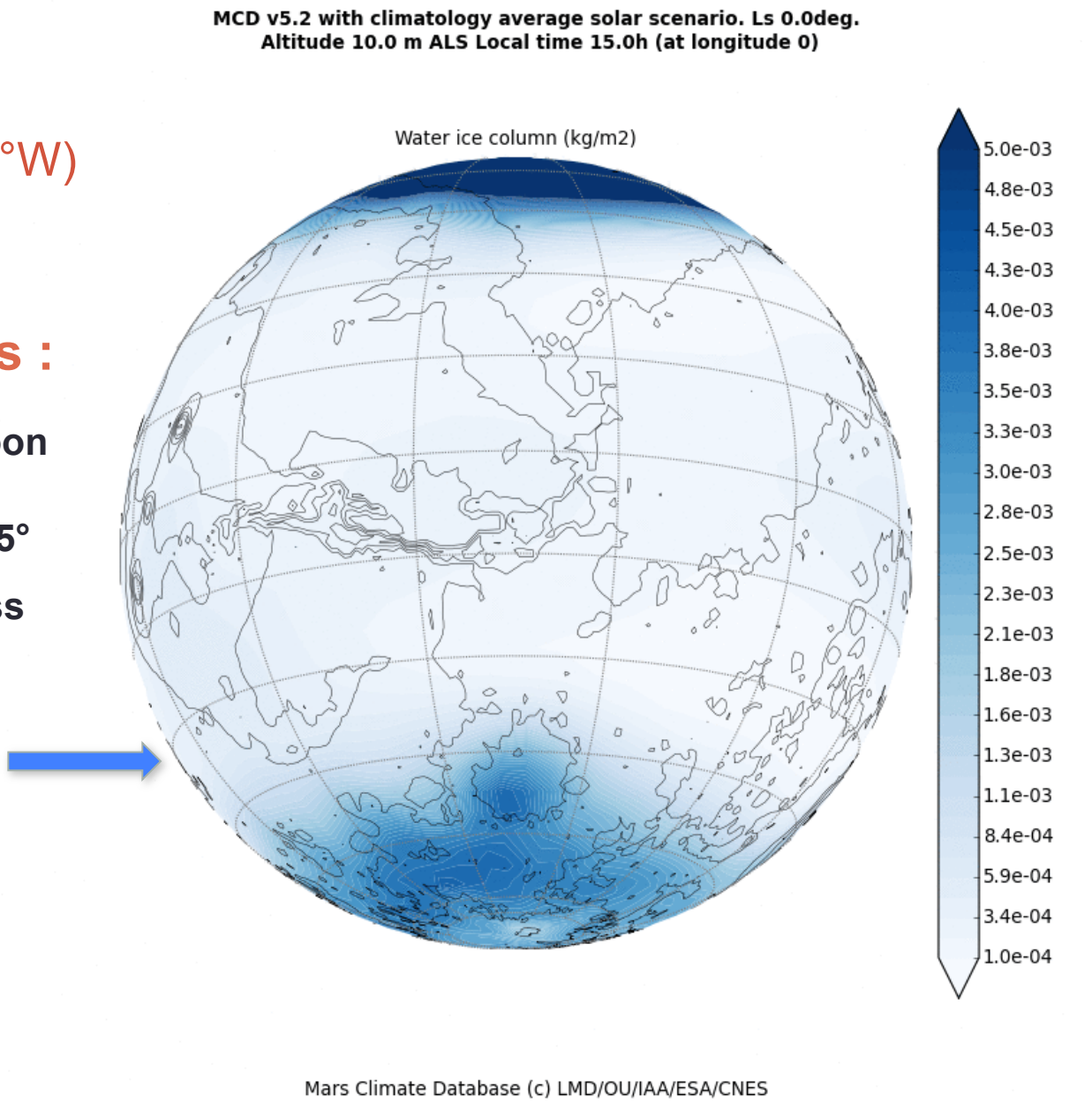
- **2 main periods of cloud coverage :**
  - **Beginning of spring (Ls ~30°) and end of summer (Ls ~ 150°)**
  - **During all day (from morning to evening)**



Argyre

(55°S – 35°S ; 65°W – 25°W)

- **GCM Cloud predictions :**
  - **At 45°W (Argyre), around noon**
  - **Maximal cloudiness at Ls=45° and 135°, minimal cloudiness and WV around S winter solstice (Ls=90°).**

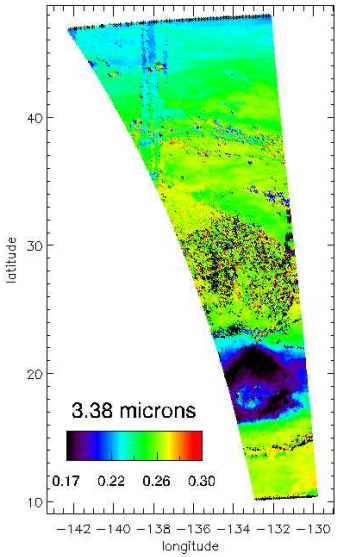


UPWARDS
UNDERSTANDING PLANET MARS

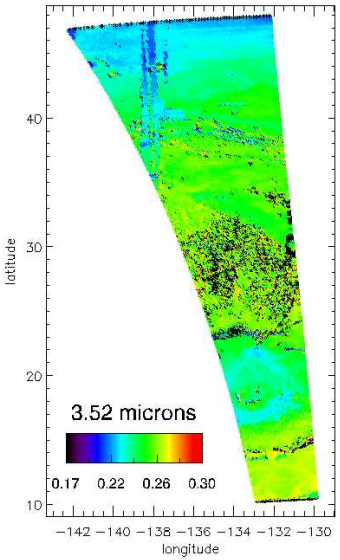
5. Conclusion and prospects

- **ICI and PCP : complementary products**
  - Ice Cloud Index : general indicator of presence of water ice clouds.
  - Percentage of Cloudy Pixels = cloud coverage : better adapted to discriminate thick clouds and partial cloud coverage.
  - ICI and PCP are robust products for water ice clouds global and regional studies.
- **Diurnal cloud life cycle**
  - 4D products : unprecedented dataset of water ice clouds for Martian climatology.
  - Taking advantage of MEx elliptical orbit: the diurnal cycle can be addressed.
  - Regions: trade-off between spatial and temporal coverage.
  - Can help to identify or check specific meteorological features.
- **In the future :**
  - Use of OMEGA ICI and PCP products for the validation of high-resolution Martian GCMs.
  - Analysis of OMEGA spectra to retrieve cloud optical depth and cloud particle size (with K. Olsen, LMD).

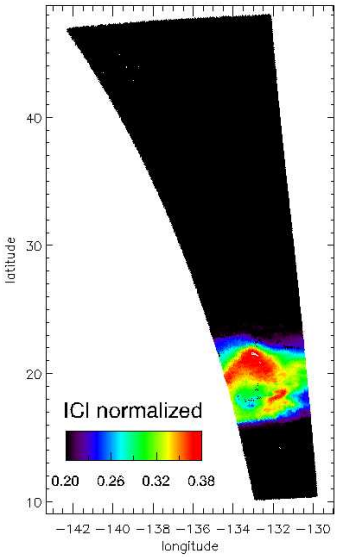
Thank you



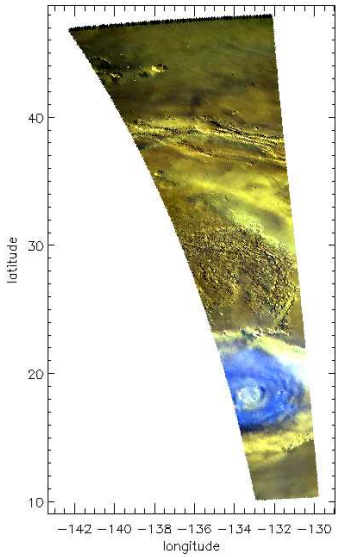
Albedo (3.38 μm)



Albedo (3.52 μm)



ICI



VISible

3. Location of partially cloud-covered areas

1) **Extraction of the number of cloudy instants from PCP**
   - for a given gridpoint (lon, lat) : $Nc_{(1\% < PCP < 100\%)}$
2) **Extraction of the number of partially-covered instants**
   - $Nc_{(PCPmin\ \% < PCP < PCPmax\ \%)}$
3) **Proportion of partially cloud-covered instants**
   1) $Rpc_{(PCPmin,PCPmax)} = Nc_{(PCPmin\ \% < PCP < PCPmax\ \%)} / Nc_{(1\% < PCP < 100\%)}$
   2) Strong / thick cloud cover : $PCP_{min} = 95\ \%$; $PCP_{max} = 100\ \%$
   3) Intermediate partial cloud cover : $PCP_{min} = 60\ \%$; $PCP_{max} = 95\ \%$
   4) Reduced partial cloud cover : $PCP_{min} = 5\ \%$; $PCP_{max} = 40\ \%$

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