Extraction and validation of water ice indicators from Mars Express / OMEGA spectral imagery – determination of the diurnal CLOUD LIFE cycle

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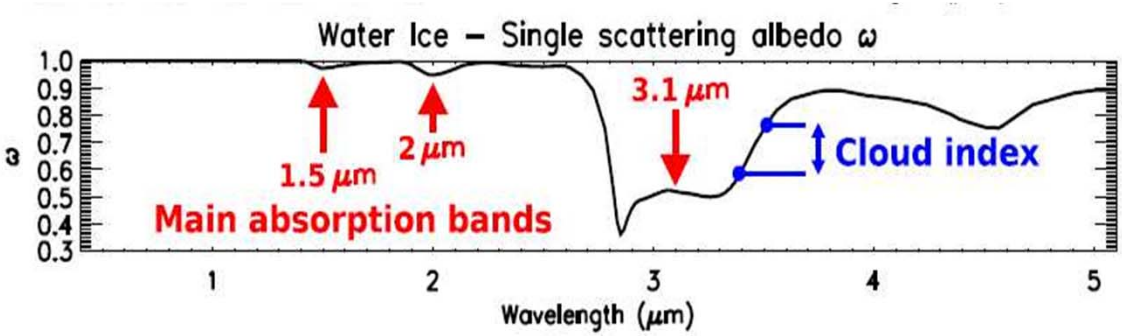
1. Introduction

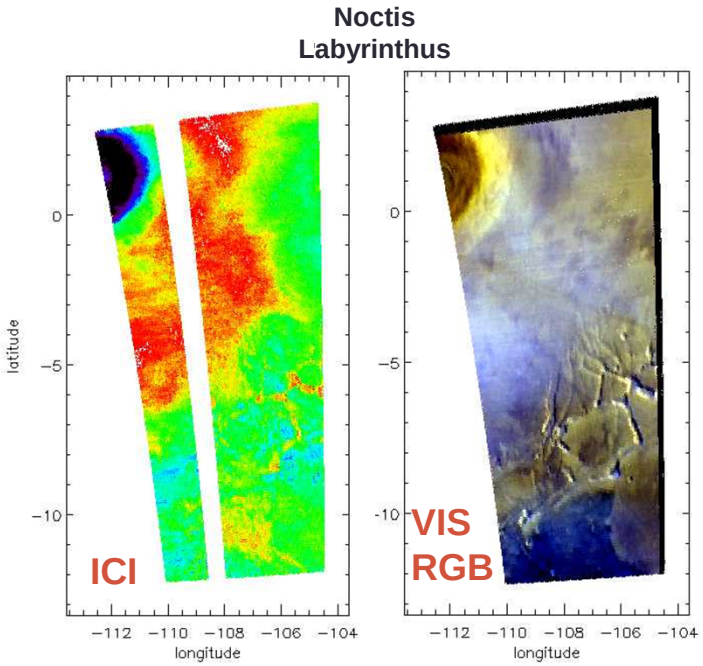
- **Objective of this study**
  - **Construct a 4D gridded (spatio-temporal) water ice cloud database extracted from Mars Express/OMEGA spectro-imager data**
  - **Use the derived products to determine the diurnal cloud life cycle.**
- **OMEGA instrument :**
  - VNIR + SWIR (0.36 – 5.2 μm ; 352 spectels)
  - **Long period of observation : MY 26-32 (1/2004 - 4/2015)**
  - **Non-heliosynchronous orbit ==> Better temporal 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**

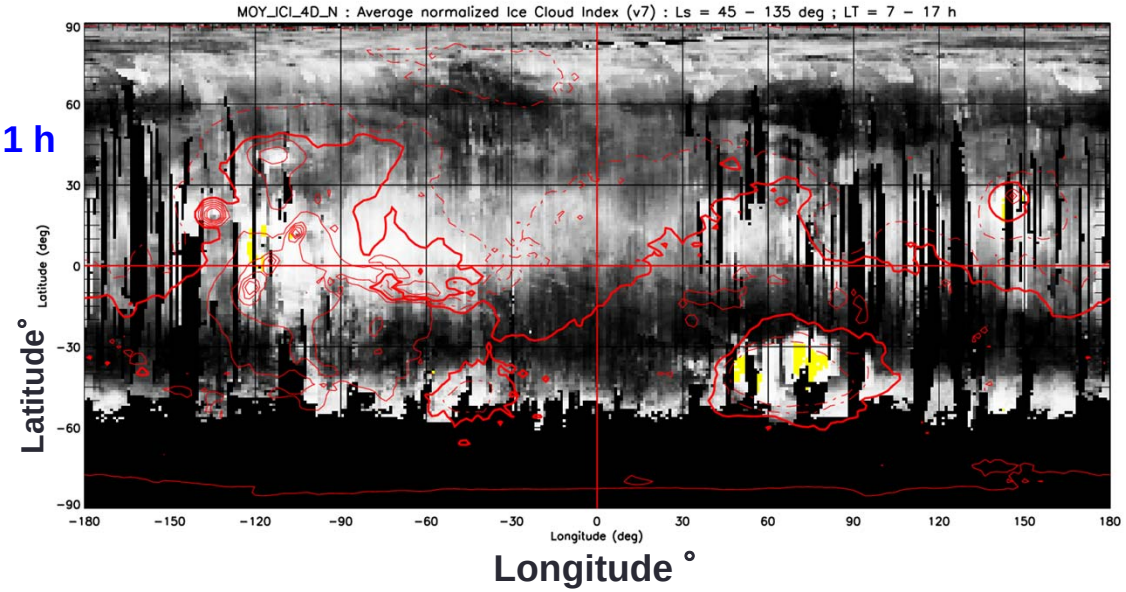
1° longitude X 1° latitude X 5° Ls X 1 h LT

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

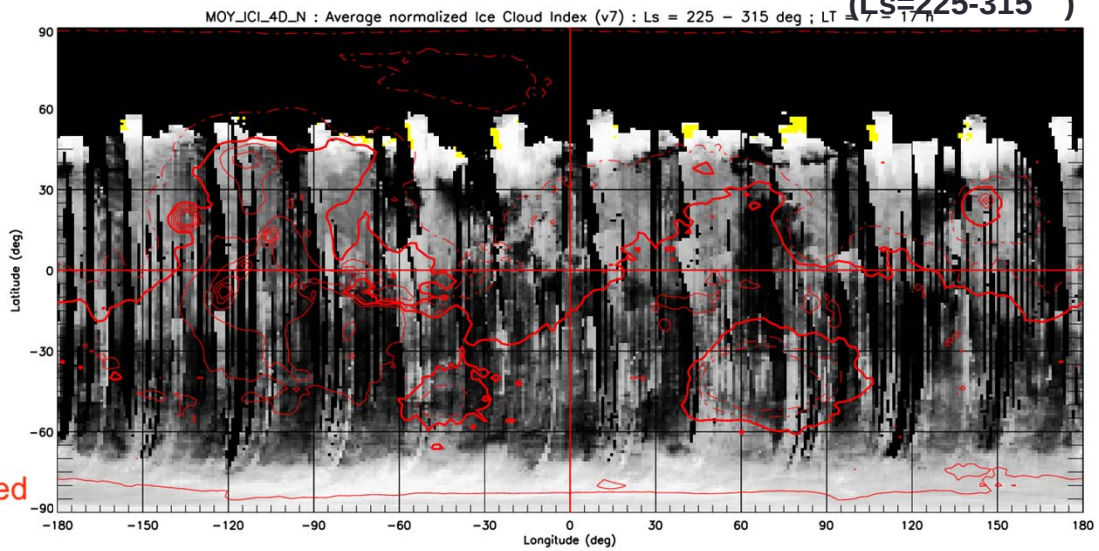
3) **Average of ICI on each gridpoint**

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

N summer solstice (Ls=45-135°)



N winter solstice (Ls=225-315°)



-**Main cloud features identified : aphelion belt, Hellas, cloud edges of polar hoods.**

-**Average ICI higher in Northern hemisphere than in Southern hemisphere** (in tropics and non-polar hood and non-Hellas midlatitudes)**.**

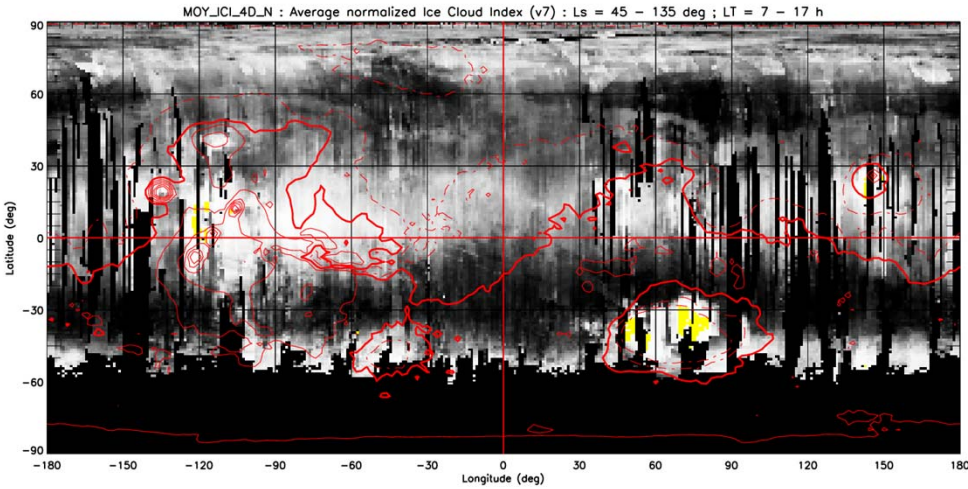
But :

Only ~2% of daytime gridpoints have ICI values

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)**

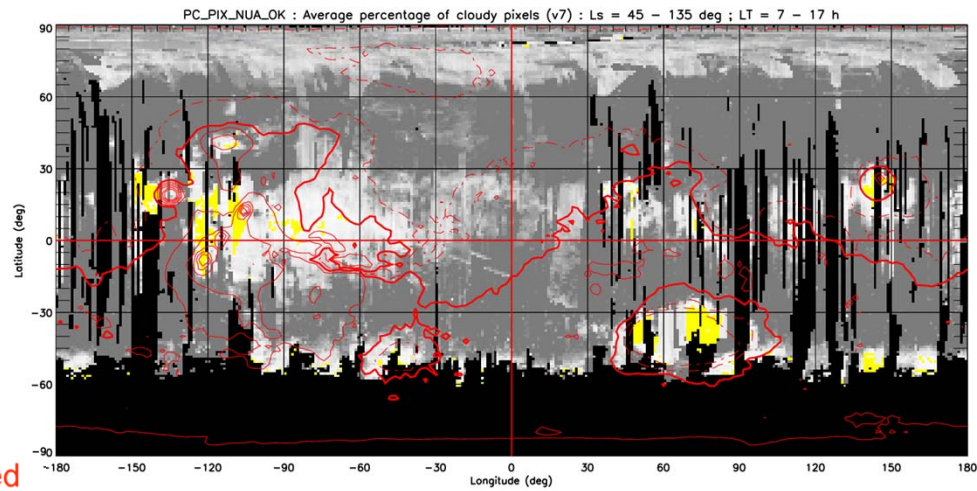


Average Ice Cloud Index (Ls = 45 - 135° , LT = 7 - 17 h)

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

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

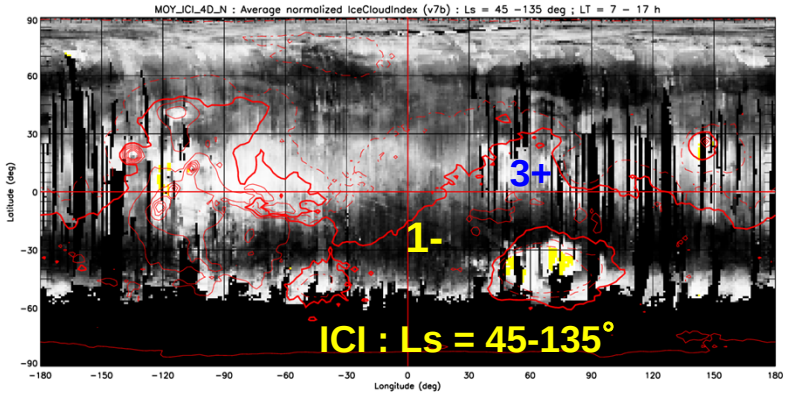
1) **PCP filters out areas with limited average cloud coverage and thin clouds (thin cirrus = lower ICI)**

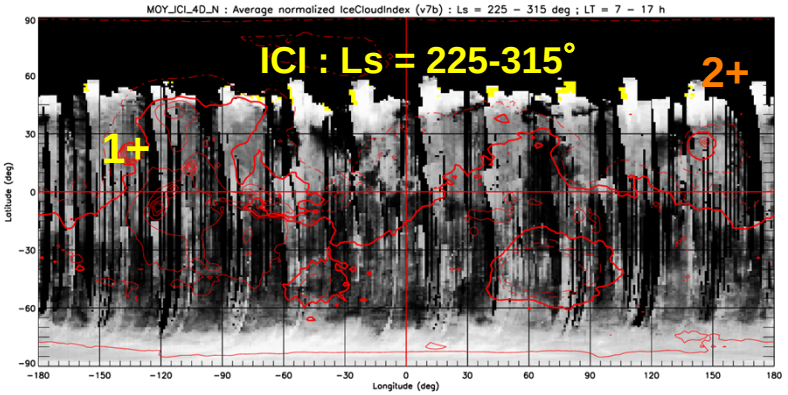


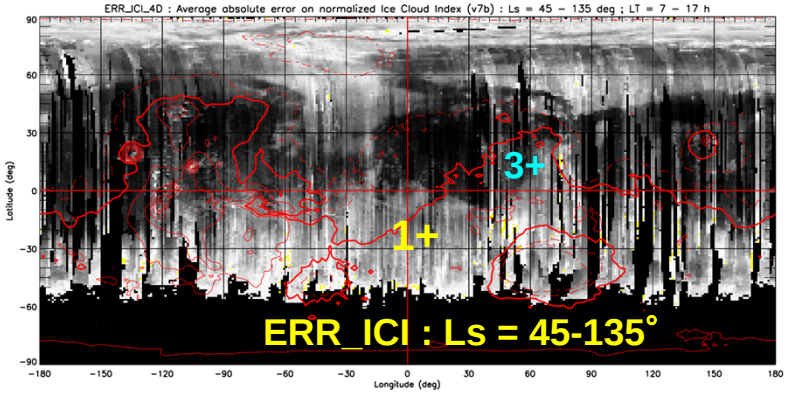
Main elevation contours : red
Highest value : yellow

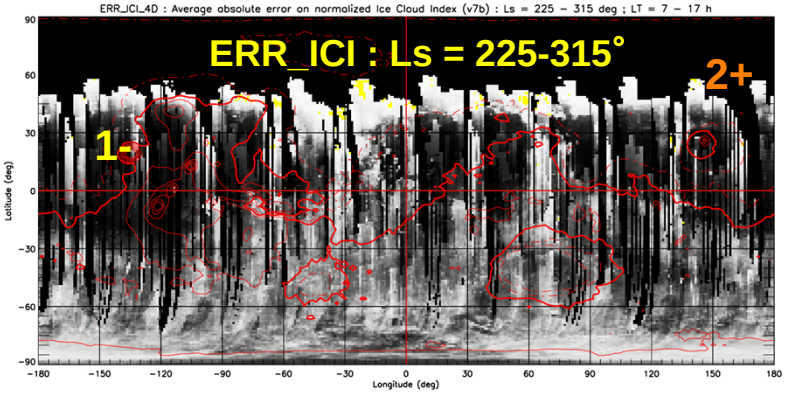
Average Percentage of Cloudy Pixels

Error Estimation









- **Main observation-based rules on ICI error bar (ERR_ICI)**

1) **Higher (resp. lower) ICI <==> lower (resp. higher) ERR_ICI**

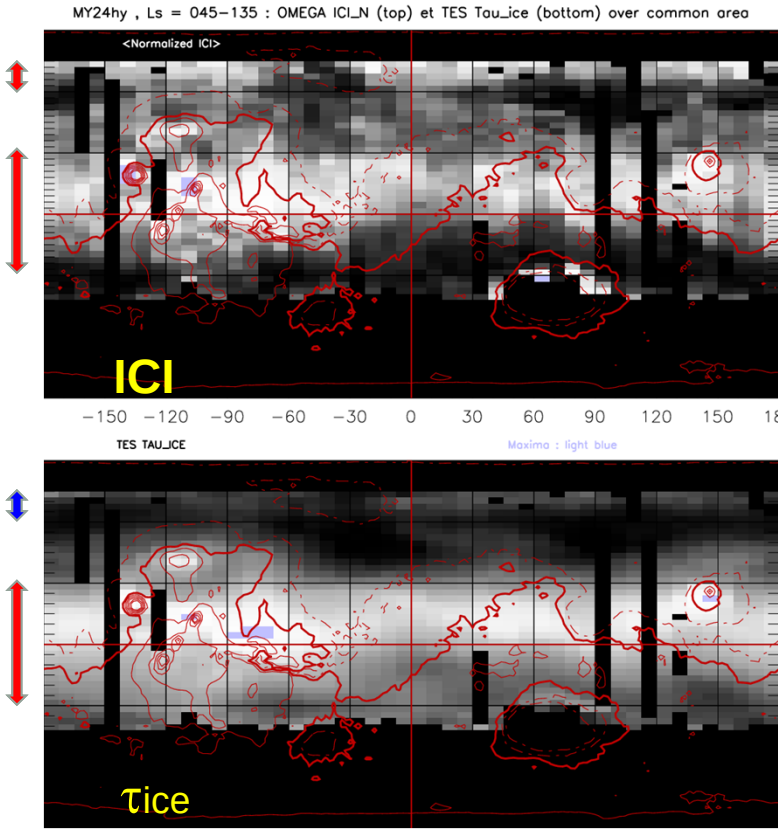
2) **Exception 1 : high ERR_ICI for high ICI in high-latitude areas at edge of the polar hood.**
   - **Cause : reduced solar illumination ==> reduced reflectance ==> higher relative instrumental error**

3) **Exception 2 : specific areas of relatively high ICI ==> Relatively high ERR_ICI**
   - **Dark areas <==> Reduced reflectance ==> higher relative instrumental error. (Syrtis Major)**

4) **Sunlit polar regions : intermediate and variable ERR_ICI (around summer solstice)**

3. Comparison with other datasets

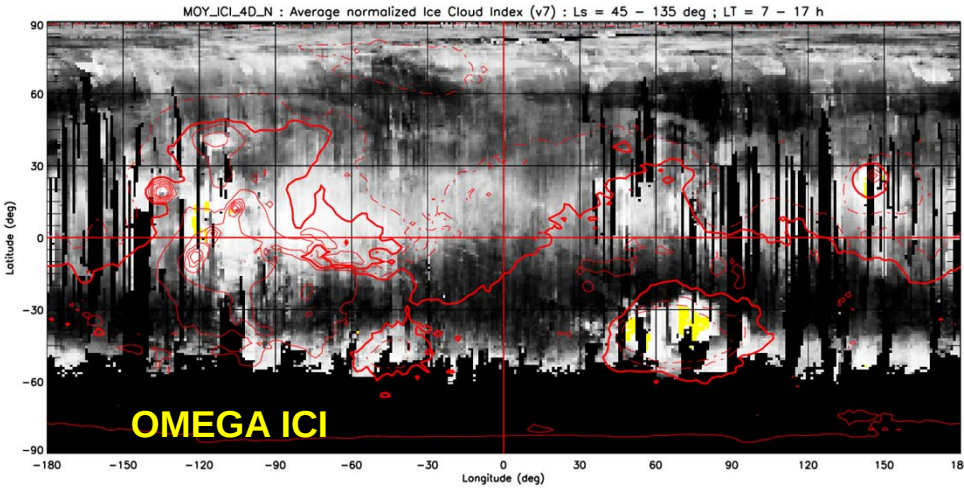
- **ICI vs. TES water ice optical thickness (τ_{ice})**
  - **ICI gridded onto same resolution as TES climatological τ_{ice}** (Smith, 2004) :
    - **7.5° lon x 3° lat x 5° Ls x LT=14 h**
    - τ_{ice} : Optical thickness at 12 mm.
  - **TES τ_{ice} of MY 24 hybrid year :**
  - **Similar cloudy features and cloudless areas**
  - **Differences :**
    - Reduced τ_{ice} values in comparison with ICI between high latitudes and tropics
    - Possible explanations : biased estimation of τ_{ice} derived from very low temperatures, poor detection of low-level clouds for TES.



Ls = 45 –135°

Comparison : ICI vs. MCD Water Ice Column

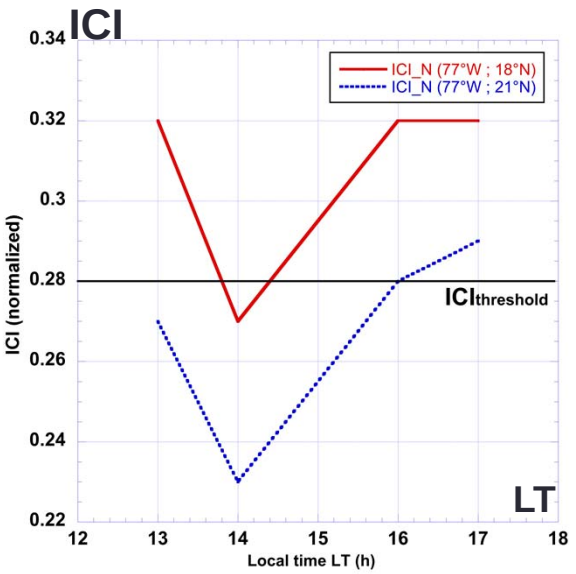
- **ICI 4D dataset**
- **Mars Climate Database (MCD 5.3)**
  - Derived from Martian General Circulation Model from the LMD.
  - MCD value to compare : water ice column (WaterIceCol), extracted on the same 4D grid as ICI
- **Comparison :**
  - Overall similar cloudy and cloudless areas on both 2D images
  - Smoother aspect of WaterIceCol image

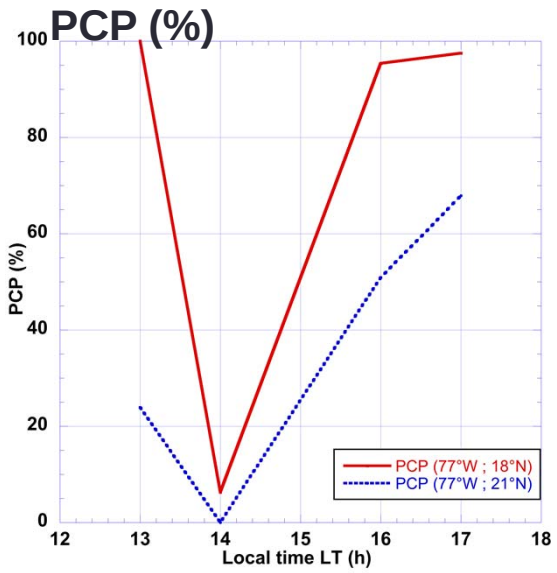


Ls = 45-135° ; LT = 7–17 h

4. Diurnal cloud life cycle

- **Principle**
  - **1 individual gridpoint (lon, lat, Ls) ==> maximum 4 h LT available in the tropics**
  - **Average of ICI, PCP, WaterIceCol values over larger spatial areas (lon, lat)** ==> longer daily sequences.
  - **21 areas defined** :
    - Small areas : single volcano + surroundings (Arsia, Olympus, Elysium)
    - Intermediate size areas : Hellas, Argyre, Chryse Planitia...
    - Large climatic areas : tropical (lat < 25°) : midlatitudes (25° N-55° N),... (over all or a large band of longitudes).



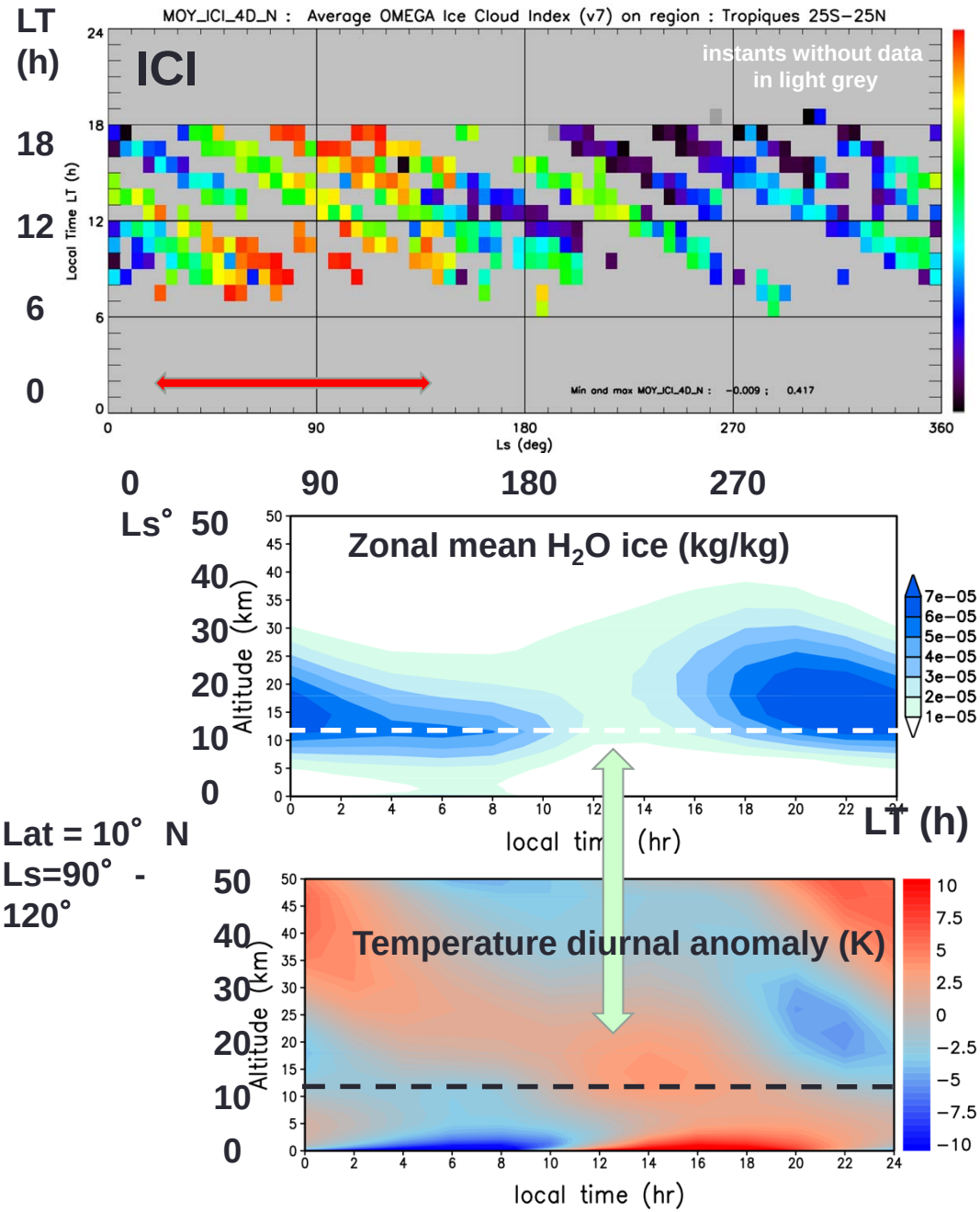


Diurnal cycle : 77° W ; 18 and 21° N ; Ls=80

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).**



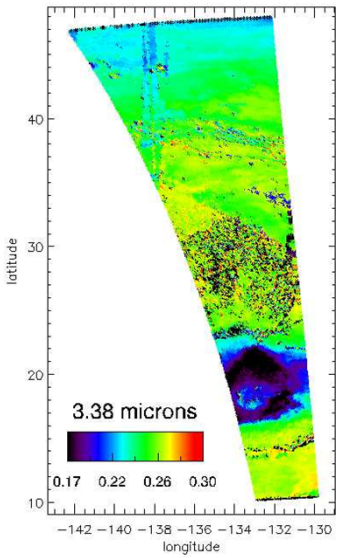
UPWARDS

5. Conclusion and prospects

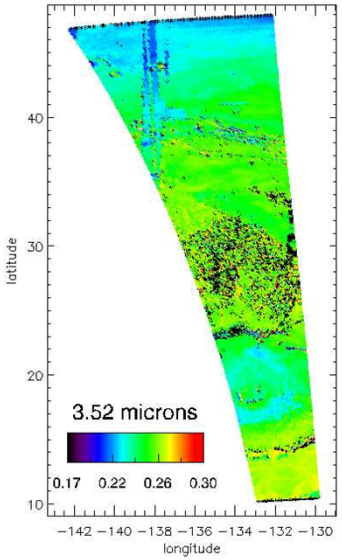
- **ICI and PCP : complementary products**
  - Ice Cloud Index : general indicator of presence of water ice clouds.
  - Percentage of Cloudy Pixels = cloud coverage : better adapted to discriminate thick clouds and partial cloud coverage.
  - ICI and PCP are robust products for water ice clouds global and regional studies.
  - ICI (+error) and PCP in PDS-4 format soon available in the frame of UPWARDS project WP 4.
  - ICI : basic element for derivation of cloud optical thickness and effective radius of ice particles (presentation of Kevin Olsen et al.)
- **Diurnal cloud life cycle**
  - 4D products : unprecedented dataset of water ice clouds for Martian climatology.
  - Regions: trade-off between spatial and temporal coverage.
- **In the future :**
  - Use of OMEGA ICI and PCP products for the validation of high-resolution Martian GCMs (Pottier et al., 2017) and comparison with other datasets.

- **Aknowledgement :**
  - This study was partially funded in the frame of the UPWARDS project.

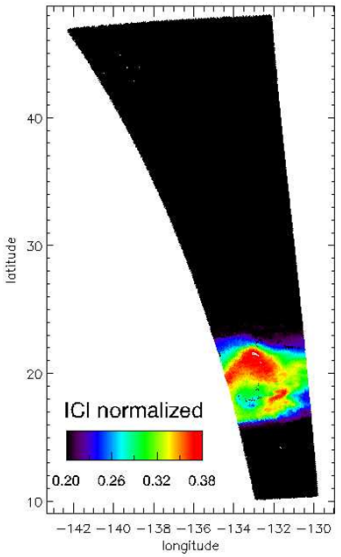
Thank you



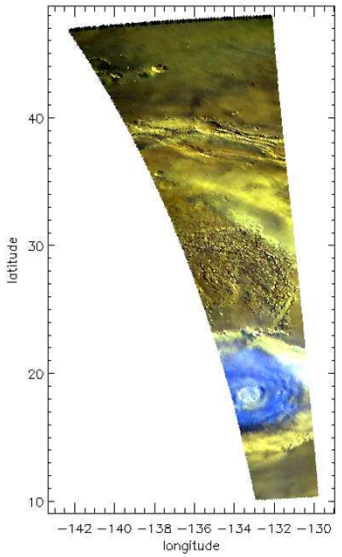
Albedo (3.38 μm)



Albedo (3.52 μm)



ICI



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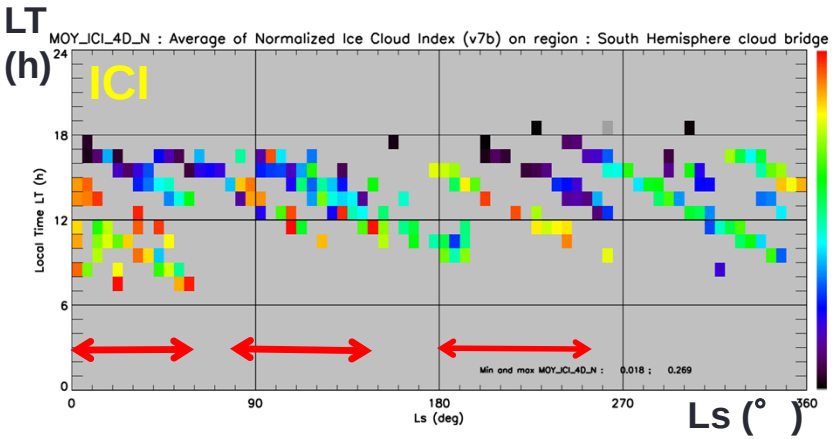
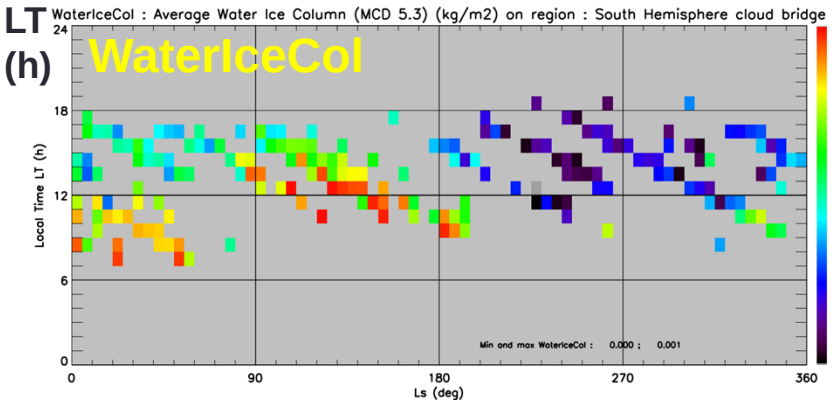
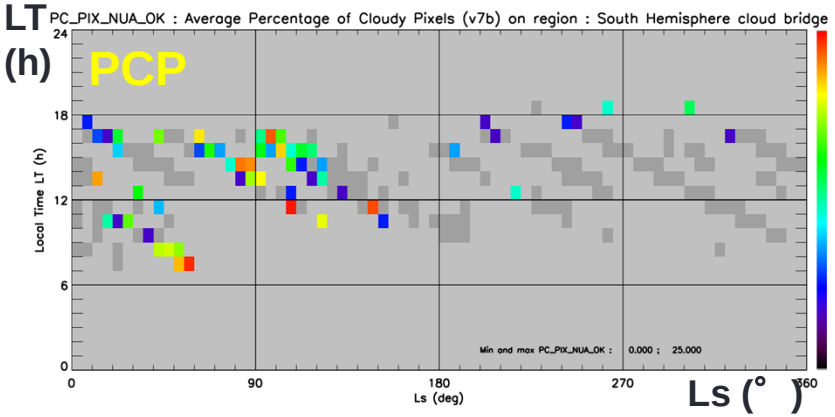
Example : South Hemisphere cloud bridge

- **SH cloud bridge : 35° S – 20° S ;150° W – 60° W :**
  - **Reduced cloudiness** : ICImax = 0.27 (vs. 0.41 in tropical belt)
  - **Partial cloud coverage frequent** (PCPmax = 25 %)
  - **Cloud presence during spring (Ls=0-60°), summer (80-150°) and autumn (180-250°).**
  - **Diurnal cycle** :
    - **Spring** : presence in the morning, dissipation around noon (LT).
    - **Spring and summer** : clouds dissipate earlier and earlier during the day.
  - **Reflects the limited water transport between the aphelion belt and the south polar hood**, decreasing in summer and autumn, and during the day.







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