# CLIMATOLOGY OF MARTIAN WATER ICE CLOUDS FROM MARS EXPRESS / OMEGA OBSERVATIONS : DERIVATION OF THE DIURNAL CYCLE

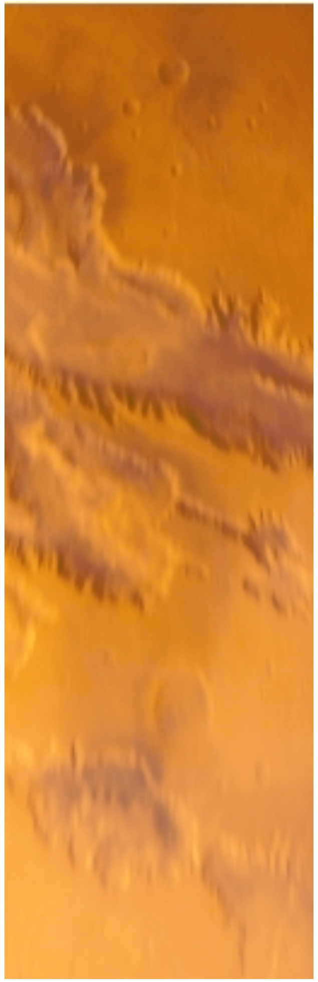
André Szantai*, Joachim Audouard+, Jean-Baptiste Madeleine*, François Forget*,

Alizée Pottier*, Brigitte Gondet+, Yves Langevin+, Jean-Pierre Bibring+,

* Laboratoire de Météorologie Dynamique/IPSL, Université P. et M. Curie, Paris, France,

+ Institut d'Astrophysique Spatiale, Université Paris-Sud, Orsay, France

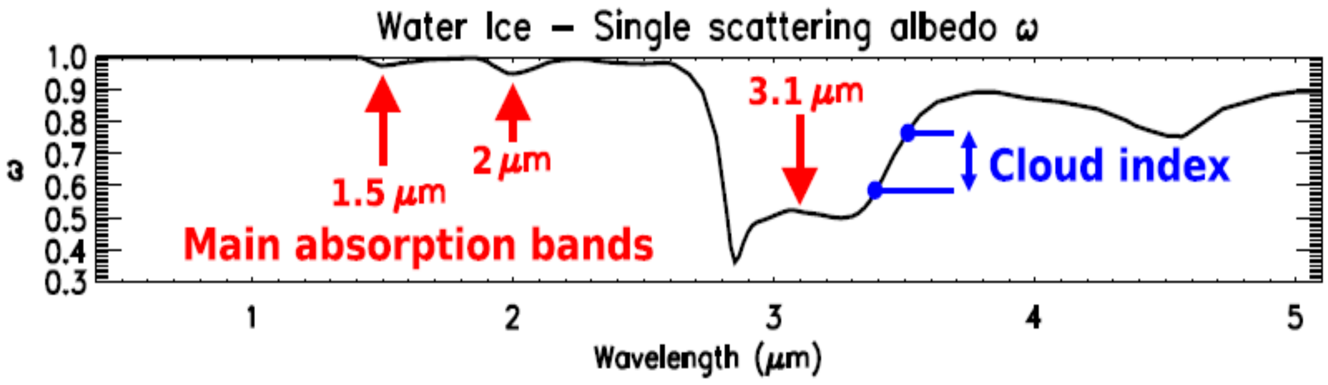
# 1. Introduction



- **Goal of this study**
  - Determine the diurnal cycle of Martian clouds from Mars Express / OMEGA spectro-imager data.
- **Currently : limited observations of cloud life cycle from satellites :**
  - Mariner 9 and Vikings (1970s) : first observations
  - MGS, Mars Odyssey, MRO (1990s and 2000s) : heliosynchronous satellites ➔ limitation : unique local time (14 h and 2 h).
- **OMEGA : improved temporal coverage with recent data (and good spatial coverage) :**
  - Spectro-imager : VNIR + SWIR (0.36 – 5.2 μm ; 352 spectels)
  - At all local (day)times ;
  - Long period of observation : MY 26-30 (end 2004-2011 ; 966 useful orbits, 3877 orbit segments).

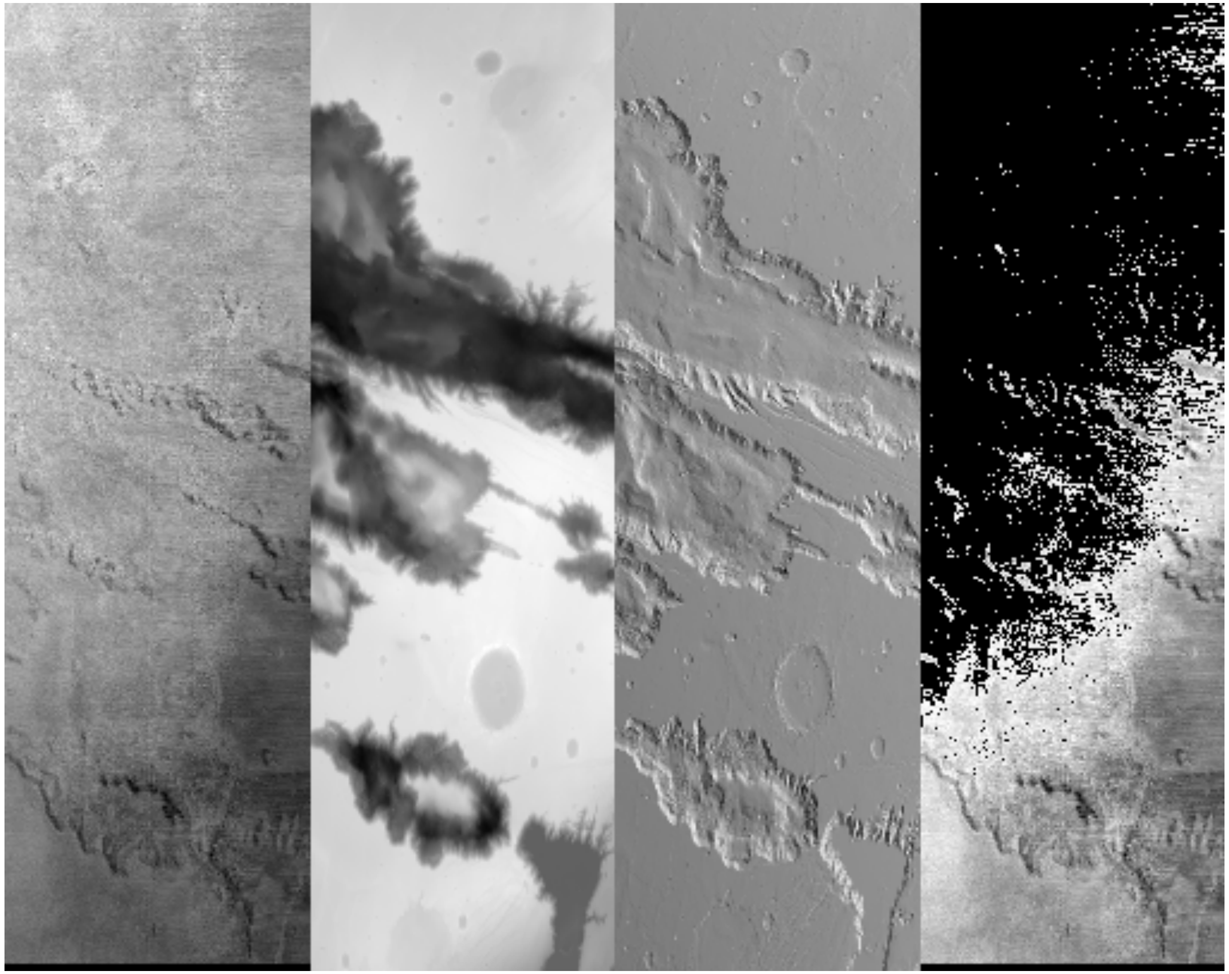
# 2. Calculation of the Ice Clouds Index (ICI)

- **Selection of 2 OMEGA spectels in a water ice absorption band**




- **Slope :** $ICI = I_{3.38\mu m} / I_{3.52\mu m}$
  - **Strong slope ⇔ strong absorption ⇔ ICI << 1 ⇔ Water ice cloud**
  - **Weak slope ⇔ ICI ~ 1. ⇔ no cloud**
- **Extraction of clouds with threshold**
  - $ICI \leq I_{thr}$ ➔ **water ice cloud**

# Example : IceCloudsIndex image



ICI raw (after QC)

Elevation (MOLA)

Incidence (w.r.t. local normal)

Cloudy ICI

*Black : no cloud, high ICI (> $I_{thr}$)*

*Light grey : thin clouds, relatively high ICI*

*Dark grey : clouds, low ICI*

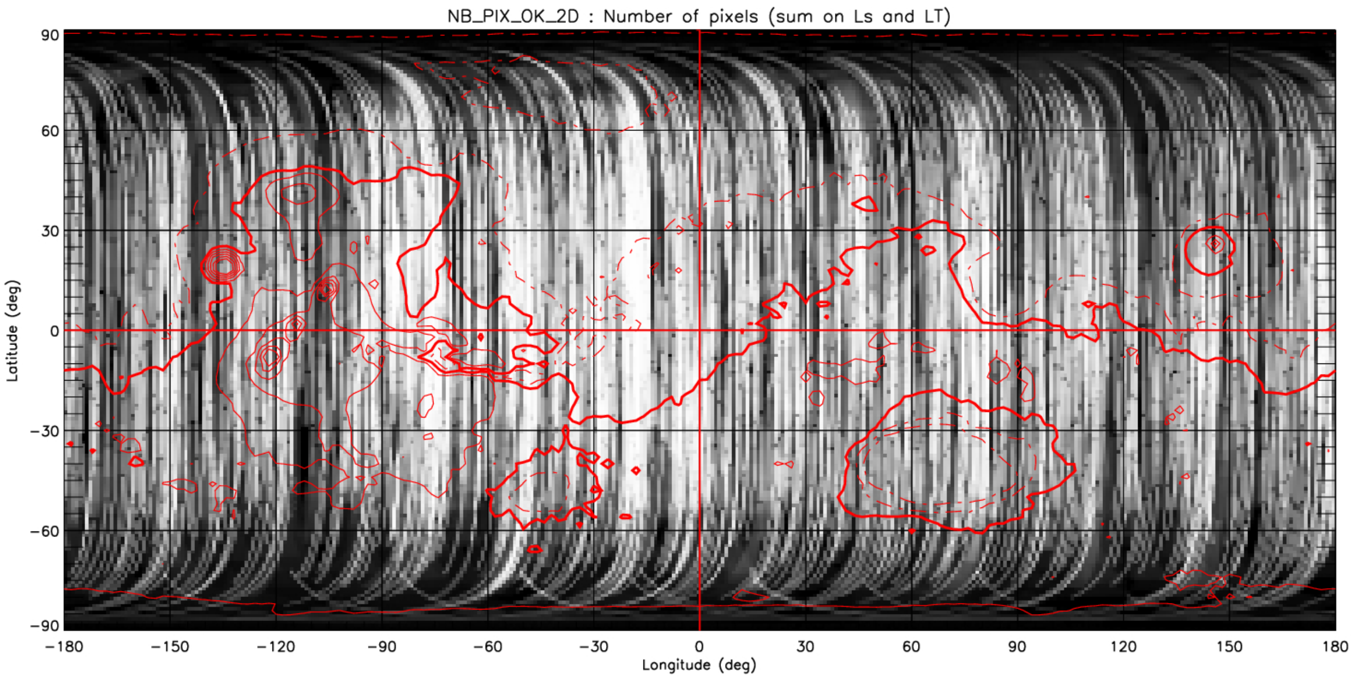
# Construction of a 4D cloud database

- **Calculation of IceCloudsIndex for each pixel**
  - **after quality control**
- **Database on a regular 4D grid :**
  - **1° longitude X 1° latitude X 5° Ls X 1 h LT (local time)**
  - **All pixels of usable orbits are binned onto the grid.**
  - **Average IceCloudsIndex :** $\overline{\mathrm{ICI}}$
  - **Number of pixels / 4D-bin**
  - **Number of cloudy pixels / 4D-bin** $(\mathrm{ICI} < I_{thr} = 0.72)$
- **Calculation of the cloud coverage for each bin :**
  - $\mathrm{CC} = (N_{cloudy\_pixels} / N_{all\_pixels}) \,.\, 100 \quad (\%)$

# 3. Global results

- **Good spatial coverage (over ~ 4 MYs)**
- **Limited number of 4D bins with data**
  - **99 % bins empty (no pixel)**
  - **Data from max. 9 orbits in a 4D bin :**
  - **➔ summation of several bins➔ larger lon-lat coverage and larger seasonal coverage.**

**Latitude**




**Longitude (°E)**

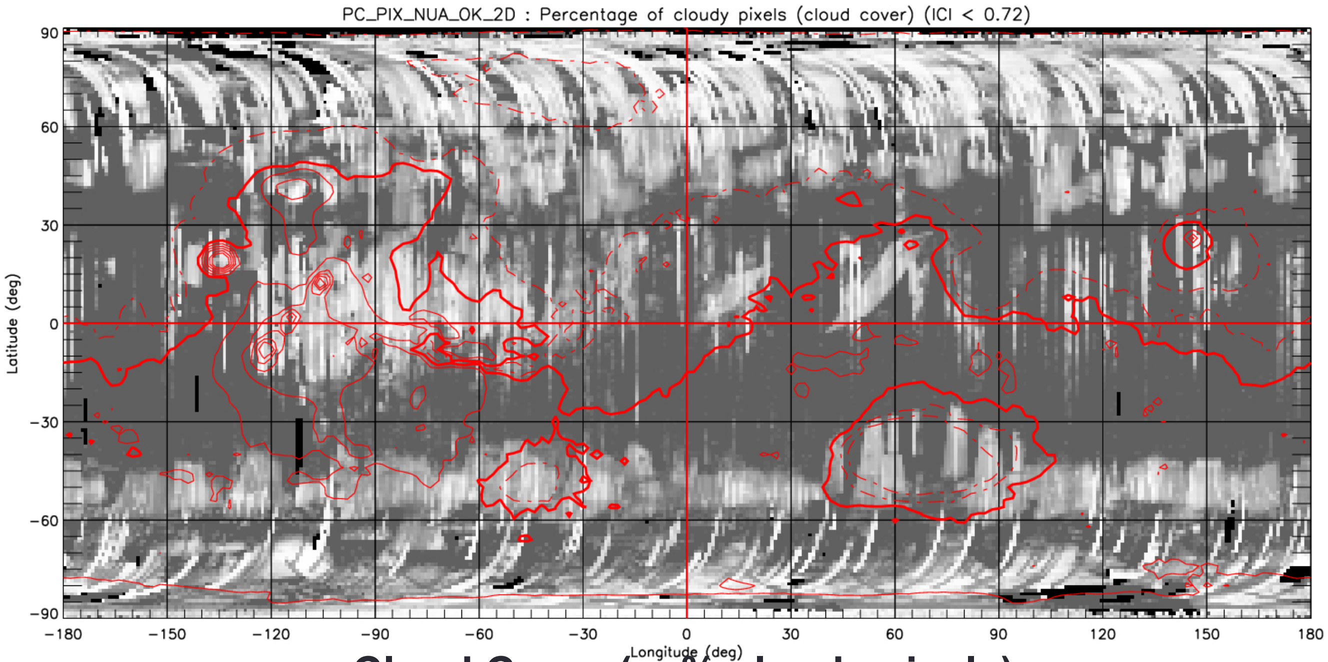
**Number of pixels / square degree**

# Cloud detection

- **Relation between average Ice Cloud Index & Cloud Coverage**
  - **Integrated CC for all Ls and all LTs**
  - **High <ICI> ⇔ Low cloud coverage (CC)**

    CC ~ inverted <ICI> image
  - **Main global cloud features detected :**
    - Aphelion belt (Northern summer), Hellas, Polar hood edges (| lat | ~ 50°)

**Latitude**




**Longitude (°E)**

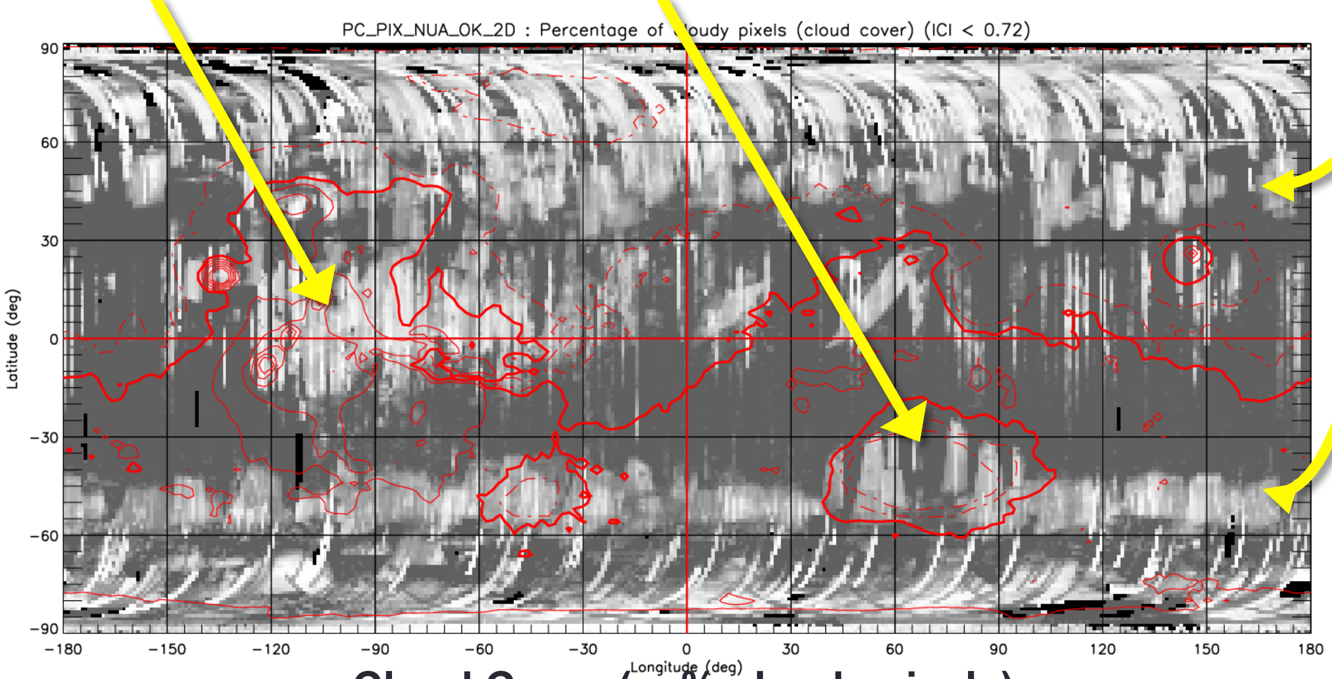
**Cloud Cover ( = % cloudy pixels)**

# Cloud detection

- **Relation between average Ice Cloud Index & Cloud Coverage**
  - **Integrated CC for all Ls and all LTs**
  - **High <ICI> ⇔ Low cloud coverage (CC)**

    CC ~ inverted <ICI> image
  - **Main global cloud features detected :**
    - Aphelion belt (Northern summer), Hellas, Polar hood edges (| lat | ~ 50°)

**Latitude**




**Longitude (°E)**

**Cloud Cover ( = % cloudy pixels)**

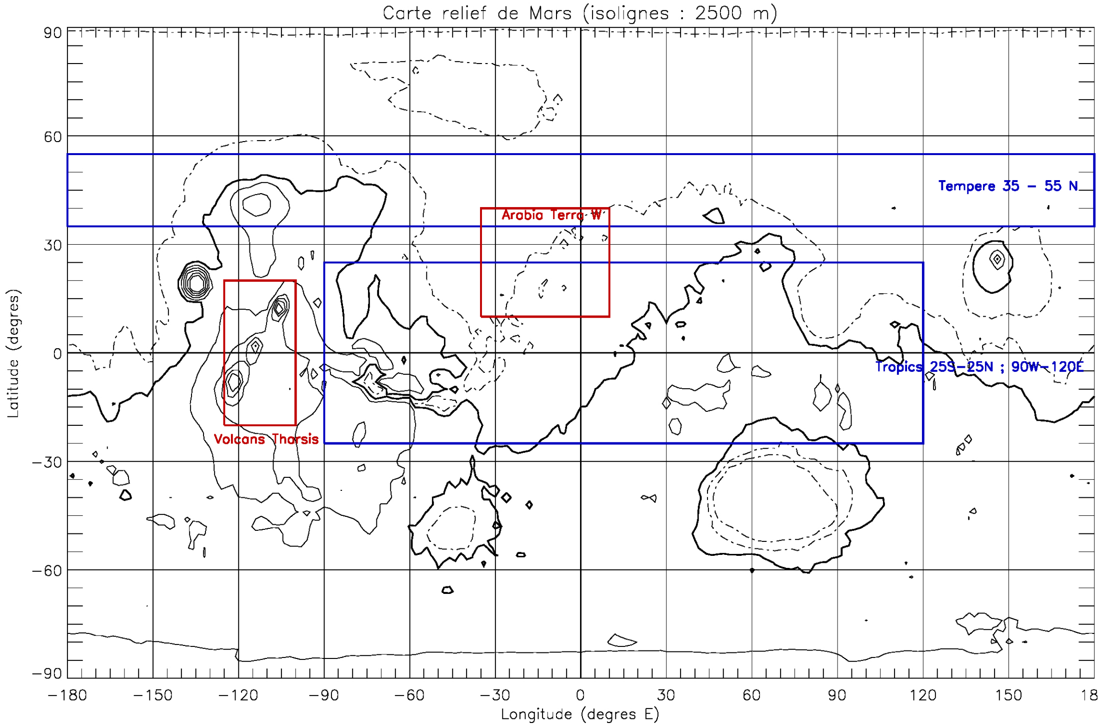
# 4. Determination of the cloud cover life cycle

- **Insufficient data for individual 4D-bin series of local times**
  - **Need to cover larger spatial domains and larger time periods (season)**
- **Summation over selected areas**
  - **« Non-volcanic » tropics :**

    **25°S-25°N ; 90°W-120°E**
  - **Northern temperate region :**

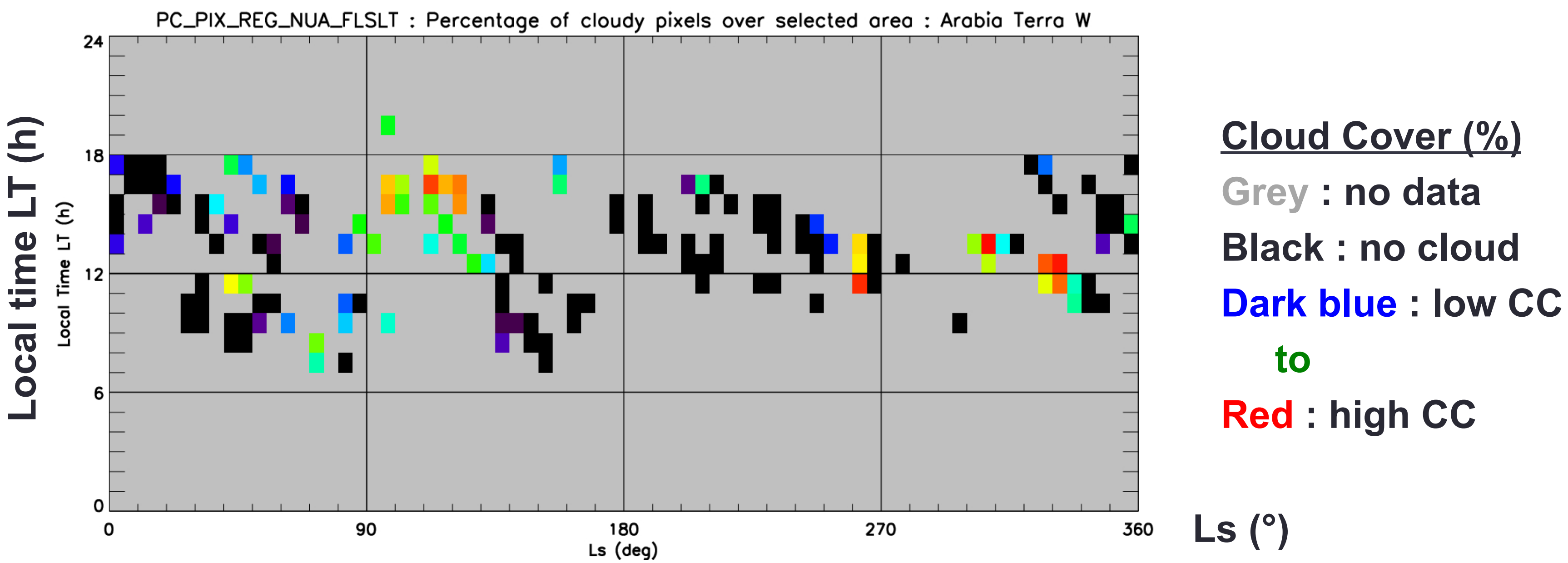
    **35°N-55°N ; all longitudes**
  - **Arabia Terra West :**

    **10°N-40°N ; 35°W-10°E**
  - **(and others).**
- **Daily / yearly 2D histograms**



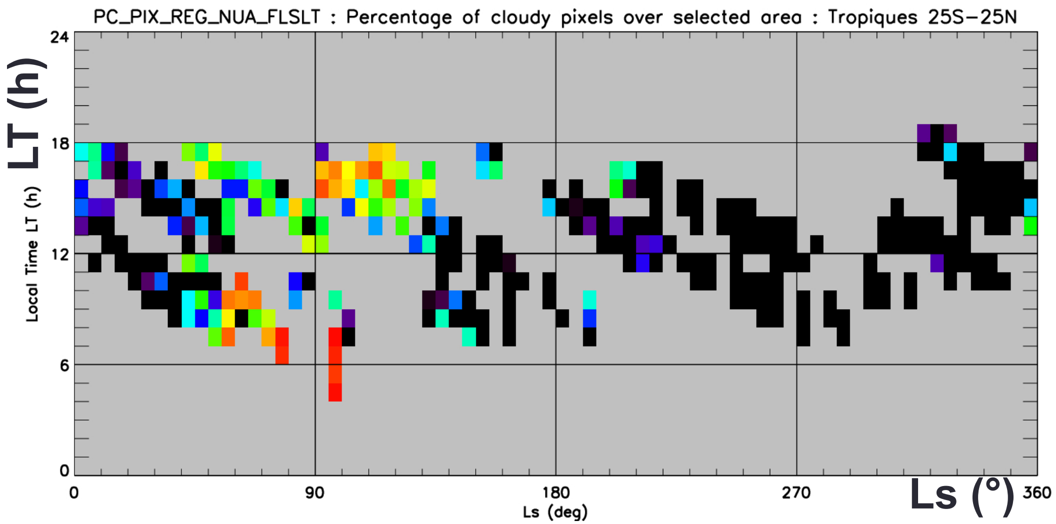
# Temporal results over selected areas (1)

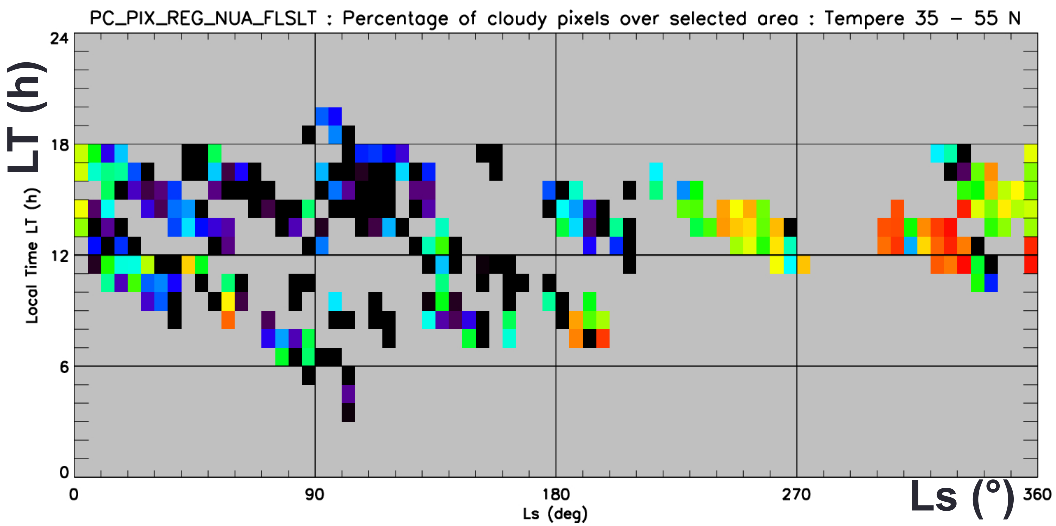
- **Arabia Terra (West)**
  - **Few clouds in Northern spring, afternoon clouds in summer ( Ls=[90°,120°] )**
  - **Clouds around 12h in winter ( Ls=[250°,350°] )**



# Temporal results over selected areas (2)

- **Tropics (non volcanic)**
  - **Higher CC percentage in the morning and late in the afternoon, only during N spring and summer (Ls=[45°, 150°])**
  - **➔ Aphelion belt**
- **Temperate region**
  - **Low cloud coverage in spring and autumn before 12 h**
  - **Higher cloud coverage during the afternoon during the late autumn and winter ( Ls = [220°, 360°] )**

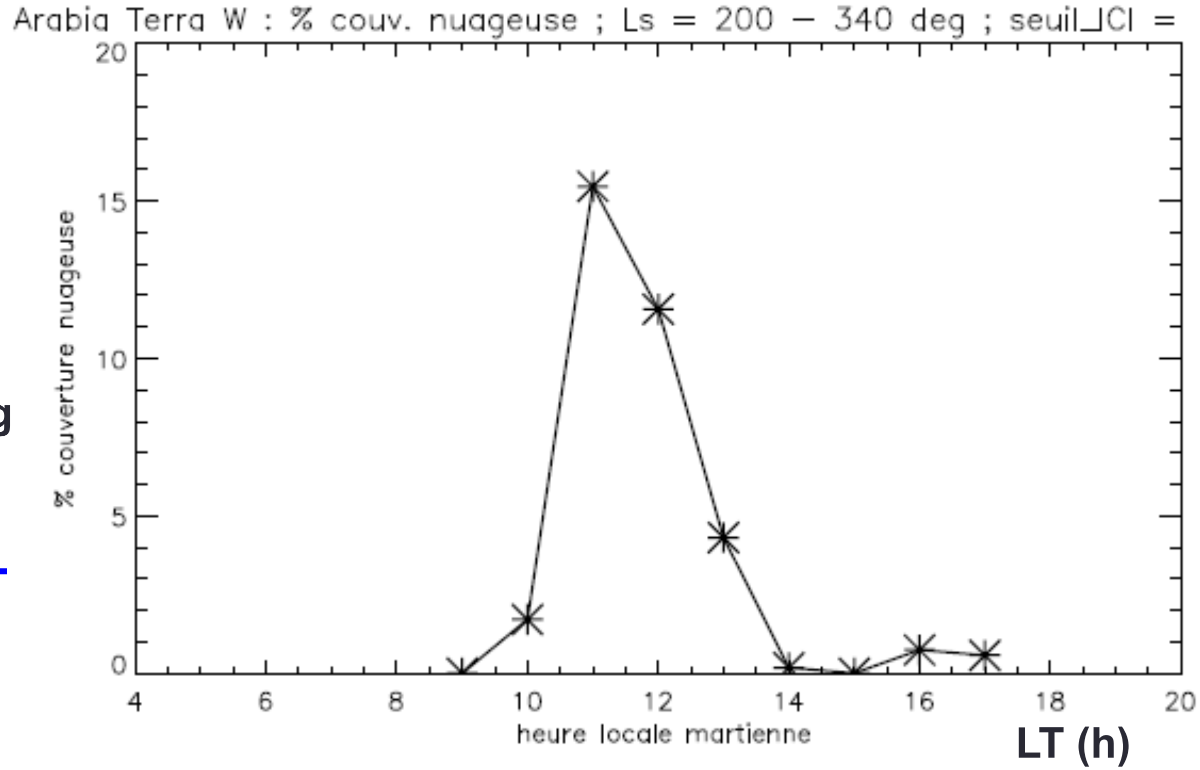


# Diurnal cloud life cycle

- **Summation over a season ➔ daily cloud cover profiles**
  - **Late Northern spring – early summer : Ls = [45° , 135°]**
  - **Autumn – winter : Ls = [200° , 340°]**

**Autumn-winter Cloud Cover (%)**

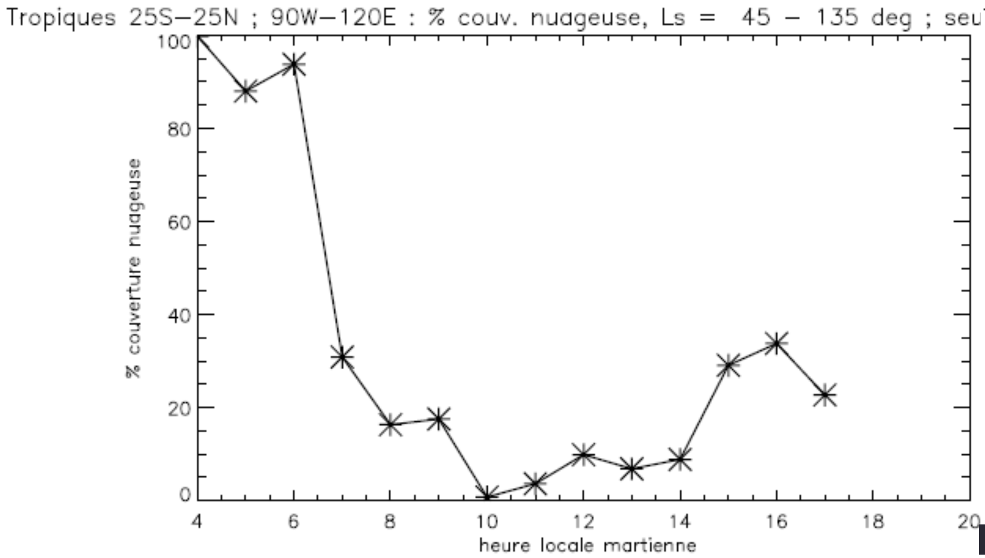



- **Arabia Terra West**
  - **Low CC (max. 25 % in summer, 15 % in winter)**
  - **Irregular, increasing during the day in spring-summer**
  - **Peak at 11 h LT in autumn-winter**

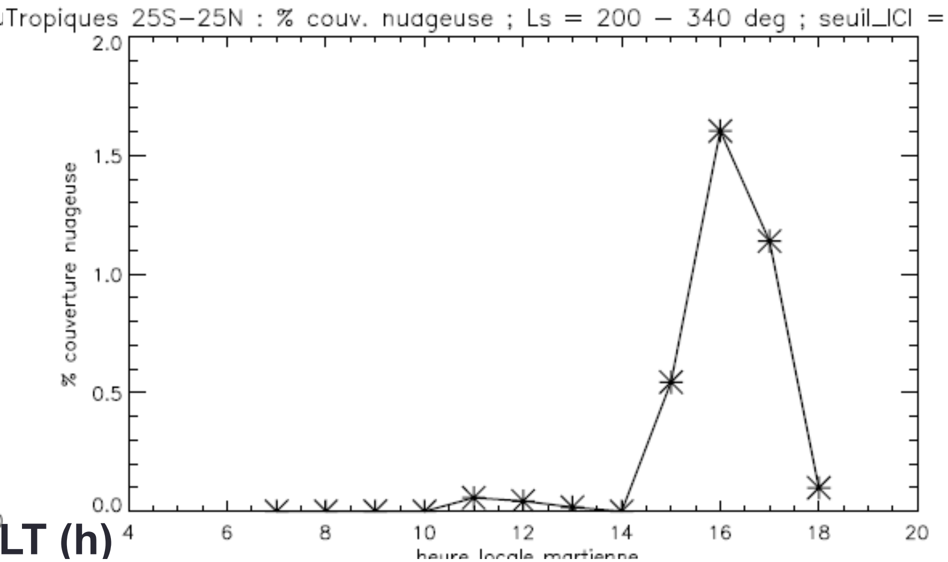
# Diurnal cloud life cycle (2)

- **Tropics (25°S – 25°N)**
  - **High CC at sunrise, low CC around 12 h, increasing in the afternoon (➚30%) in N spring-summer**
  - **➔ Morning fog, afternoon convection**
  - **Very low values in autumn-winter, peak at 16 h (~1.5 %)**

**Cloud cover Ls = [45 ; 135°]**




**Cloud cover Ls = [240 ; 340°]**




**LT (h)**

# Conclusions

- **Identification of main ice cloud-covered areas at large spatial scale, and their temporal evolution :**
  - **➔ Seasonal and diurnal cycle, period of convection**

- **Prospects**
  - **Extension of IceCloudsIndex and Cloud Coverage extraction to the recent period (2011-2015)**
  - **Validation of ICI and CC products :**
    - Comparison with model data (Integrated ice Water column) from LMD (Martian GCM or MCD database)
    - Comparison with data from heliosynchronous satellites at common local time (TES ; around ~14 h LT).
    - Use of ICI, CC and other OMEGA data to extract optical thickness and particle size.

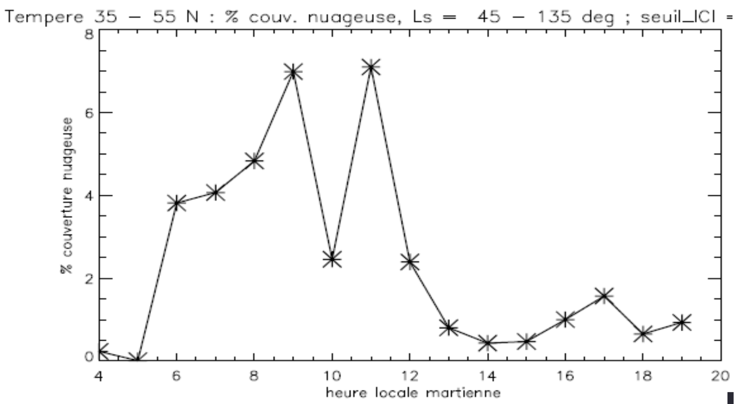
# Plan

1. **Introduction**
2. **Methodology**
    1. **Ice Clouds Index**
    2. **4-D cloud database**
3. **Global results**
    - **2D cloud cover maps**
4. **Cloud cover life cycle**
    1. **Seasonal variations**
    2. **Daily cycle**
5. **Conclusions and prospects**

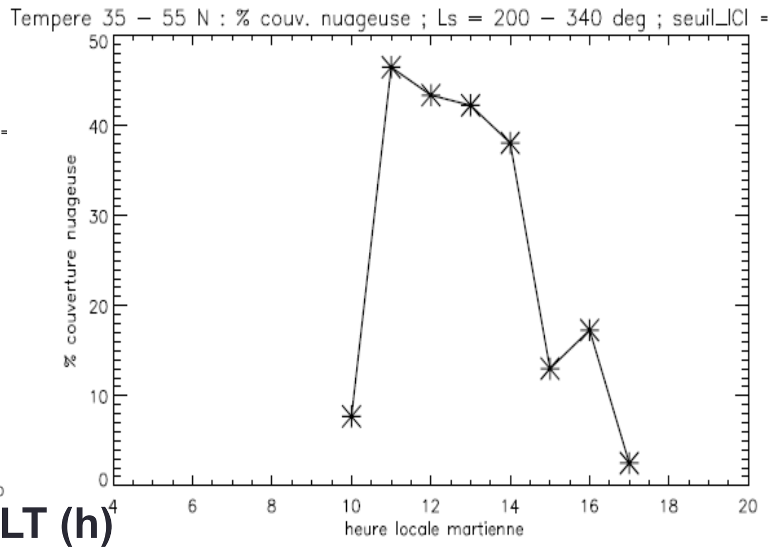
# Diurnal cloud life cycle (3)

- **Temperate region (35°N – 55°N)**
  - **Low CC (< 8 %) in N spring-summer, increasing in the morning, fast decrease around 12 h.**
  - **High CC around 12 h (max. ~50 %), in autumn-winter, decreasing in the afternoon**
  - **Polar hood diurnal cycle ?**

**Spring-summer**




**LT (h)**




**Autumn-winter**