EXTRACTION AND VALIDATION OF WATER ICE CLOUD INDICATORS FROM MARS EXPRESS / OMEGA SPECTRAL IMAGERY – DETERMINATION OF THE DIURNAL CYCLE

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Introduction:

Water ice clouds have been first observed from space in the 1970-80's (by Mariner and Viking spacecrafts), and more intensively in the 1990's, starting with the MGS mission. But due to their heliosynchronous orbits, most past and current Martian satellites have observed the planet only at a specific local time (LT) during the day (typically at 2-3 p.m. and 2-3 a.m. LT) over most regions, and therefore cannot provide information about the diurnal cloud life cycle. Recently launched satellites MAVEN and MOM/Mangalaayan) move along non-heliosynchronous orbits, but have only provided images over a short period (~2 years). The OMEGA spectrometer onboard the (non-heliosynchronous) Mars Express satellite has been providing spectral images at various times of the day over ~7 Martian years (MY 26-34, i.e. 2003-2017). For each valid pixel from this abundant spectral image data, we derived two parameters representative of the presence and abundance of clouds, the ice cloud index and the percentage of cloudy pixels, and used them to construct a daily and annual climatology on a regular spatial grid.

Methodology: The detection of clouds is based on the measure of the depth of a water ice absorption band, initially applied at 1.5 mm [1]. In practice, we now use the slope of an absorption band around 3.4 μm to define the original ice cloud index (ICIo) and the normalized ice cloud index (ICI = 1 – ICIo) [2]. After comparison with a threshold value, this ICI indicates if the pixel is cloudy or not.

In a second step a cloud climatology is constructed. The pixels are binned into two 4D arrays (cloudy and cloudy+non-cloudy) according to their longitude, latitude, Ls and LT, and counted. The bins have sizes of 1° in latitude and longitude, 5° in Ls and 1 (Martian) hour in LT. ICI values are also binned and averaged on the same 4D grid. An error bar is also calculated at each gridpoint.

The cloud coverage, i.e. the percentage of cloudy pixels (PCP) of each bin is obtained by dividing the number of cloudy pixels in the first array by the number of all pixels in the corresponding bin in the second array.

In a third step, several 4D bins covering larger spatial areas and longer time periods are assembled (averaged) in order to form 2D subsets showing temporal evolutions of clouds. On fig.1, the ICI highlights the main cloudy areas around the northern summer solstice (at Ls=[45°-135°] and LT=[7-17h]) : the equatorial/North tropical area (including the aphelion belt, Olympus and Elysium volcanoes), Hellas Planitia, the southern polar cloud belt and north polar clouds (at latitude > 60°).

ICI error estimation : The error bar of the ICI has also been calculated ; it results from two components : instrumental errors of the OMEGA spectrometer [3] at the two wavelengths used, and the variablility of the OMEGA ICI pixels averaged on the grid. Fig. 2 (also at Ls=[45°-135°] and LT=[7-17h]) shows that larger error bars are calculated in general over areas with reduced solar illumination (around 50°S – where clouds are present), or with low surface albedo, where clouds can be present (Syrtis Major) or not. Error bar values are small, less than 10 % for the vast majority of original (ICIo) values.

Comparison of the OMEGA ICI with optical depths from TES and the MCD: The optical depth of clouds and other atmospheric and surface products have been derived from spectra measured by the TES instrument onboard MGS [4]. In this study, we reexamined the water ice optical depth τ_{ice} at 12.1 μm from MY 24 hybrid (Mainly MY 24, completed by the beginning of MY 25), which has been mapped on a regular grid, to the average Ice Cloud Index ICI from OMEGA, rebinned onto the same grid (7.5° longitude x 3° latitude x 5° Ls, and LT 14 h (determined by MGS's heliosynchronous orbit).

A preliminary comparison [2] had shown that areas with high (resp. low) ICI are coincident with high (low) TES τ_{ice} values. A more thorough examination of both datasets reveals a decreasing trend of TES τ_{ice} towards high (N and S) latitudes in comparison with ICI. A possible explanation is the biased estimation of the optical depth from very cold TES-derived temperatures.

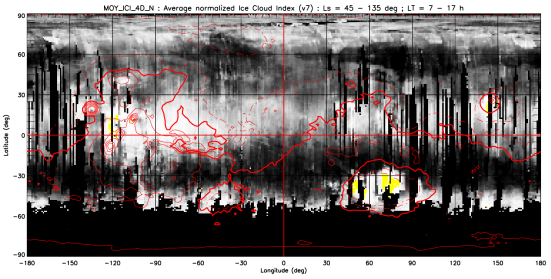

Figure 1: averaged ICI map around N summer solstice (Ls=45-135°), highest values in yellow.

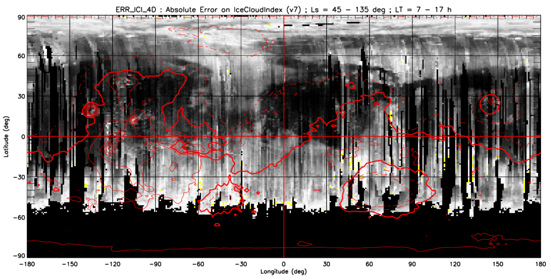

Figure 2: absolute error on IClo averaged over the same period.

We also derived a TES-equivalent optical thickness from the most recent version of the Mars Climate Database (MCD 5.3) [5], derived from the General Circulation Model (GCM) developed at the LMD. We compared this τ_{ice} to the ICI on the standard (1° lon x 1° lat x 5° Ls x 1h LT) grid. Similar cloudy areas can be observed again on both datasets, similar also to areas covered by the MCD-derived water ice column.

Diurnal cloud life cycle: The 4D gridded ICI has been aggregated and averaged over 26 large regions, covering several degrees of longitude and latitude during specific seasons. Although data coverage is sometimes sparse, clouds are more frequent around summer solstice (Ls=45-135°) early in the morning and in middle and late afternoon than around noon (12 h LT) in the tropics and northern temperate regions (lat < 40°N). Fig. 3 shows a different cloud life cycle configuration observed in the Argyre region (55-35°S ; 65-25°W). In this area of the southern hemisphere, high ICI values indicate an abundance of clouds at two separate periods at the beginning of southern autumn (Ls ~30°) and at the end of southern winter (Ls ~150°), probably in relation with the motion of the southern polar cloud belt away from / towards the south pole.

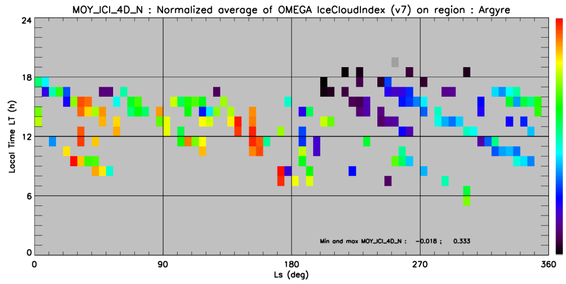

Figure 3: Normalized Ice Cloud Index (**I**CI) over the Argyre region (55°S-35°S ; 65°W-25°W). Color scale : light gray : no data ; black : no cloud ; form purple (low ICI, very thin or small clouds) to red (high ICI, thick clouds).

Conclusion: Although the spatial and temporal coverage by OMEGA data is sparse (~1-2 % of all 4D grid-points), the derived ICI and PCP are valuable indicators for detecting and characterizing Martian water ice clouds when they are aggregated or averaged over larger regions or longer periods. They may be useful for the validation of results produced by high-resolution Martian GCMs [6].

References:

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