Aerosols optical properties in Titan's detached haze layer before the equinox

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Introduction

First observed in the 80's by Voyager 1 and 2 flybys [1, 2], Titan's atmosphere presents a complex stratified succession of haze layers above the main haze. One of these layers, the Detached Haze Layer (DHL), presented a large extent at 350 km and could be seen all along the limb surrounding Titan between 90°S up to 45°N. Voyager 2 radial intensity scans at high phase angles [3] reveal an important depletion of the aerosol particle density below this layer. The arrivial of the Cassini spacecraft in the Saturnian System in 2004, was a unique opportunity to investigate the persistence of the DHL over time [4]. The Imaging Science Subsystem (ISS) instrument on board performs a continuous survey of the Titan's atmosphere. In 2011, West *et al.* [5] confirm the persistence in time of the DHL at the equator at 500 km before the equinox followed by a collapse at 380 km in 2008. Recent observations confirmed its disappearance in 2012 and a new emergence is reported in early 2016 [6]. This seasonal cycle, predicted by previous Global Circulation Models (GCM) [7, 8, 9], tended to be confirmed by theses recent observations. In this study our purpose is to characterize the physical properties of the DHL and its latitudinal variability during the 2005-2007 period.

Observations

To determine the properties of the aerosols in the DHL, we made a survey over the ISS images taken with the Narrow Angle Camera (NAC) before its collapse in 2008 [5]. We limit our analysis on the CL1-UV3 filter (λ=338 nm) where only the aerosols scatter and to minimize the multiple scattering.

Table 1: List of ISS NAC images used in CL1-UV3 filter

ISS ID	Date	Phase	Pix. Scale
N1506288442	2005/09/24	145°	5.5 km
N1506300441	2005/09/25	151°	5.5 km
N1509304398	2005/10/29	155°	6.1 km
N1521213736	2006/03/16	68°	7.3 km
N1525327324	2006/05/03	147°	7.2 km
N1540314950	2006/10/23	120°	5.7 km
N1546223487	2006/12/31	66°	7.4 km
N1551888681	2007/03/06	143°	7.9 km
N1557908615	2007/05/15	25°	7.8 km
N1557919415	2007/05/15	25°	8.2 km
N1559282756	2007/05/31	20°	7.7 km
N1562037403	2007/07/02	14°	7.8 km
N1567440117	2007/09/02	20°	7.9 km
N1570185840	2007/10/04	27°	7.3 km
N1571476343	2007/10/19	80°	8.2 km

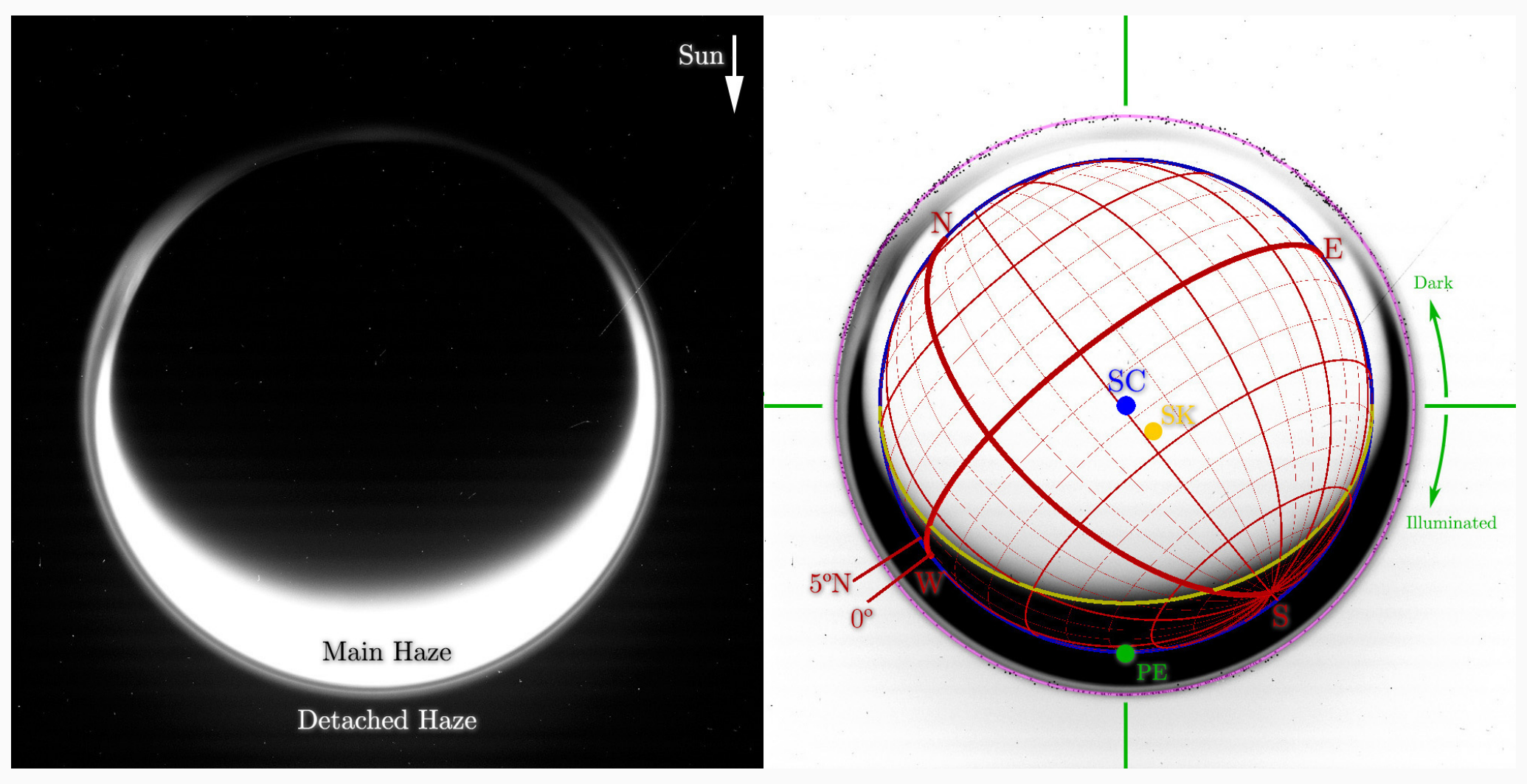

Figure 1: (left) Overexposed and contrasted ISS NAC N1551888681. (right) Same image inverted with geo-reference grid, sub-spacecraft point (SC), Spice Kernels predicted center (SK) and photometric equator (PE).

Vertical profile, altitude and light curve

For each image the limb profiles are extracted by 5° bins in latitude on the illuminated side of Titan and smooth with a moving average. The local maximum I/F corresponding to the DHL is located in altitude and intensity. The DHL presents a very high stability in altitude (500±8 km) for all latitude lower than 45°N. The I/F light curve content information about the shape of the aerosols.

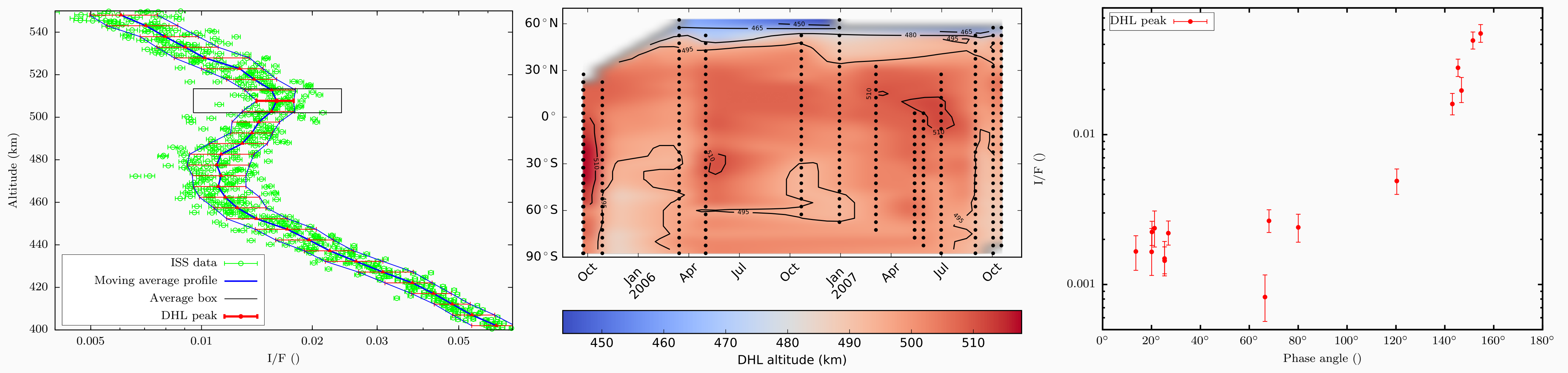

Figure 2: (left) N1551888681 vertical profile between 0 to 5°N. (middle) Altitude of the DHL as function of time and latitude. (right) Light curve on the local maximum I/F between 0 and 5°N.

Atmospheric and scattering model

We consider that above the DHL, the atmosphere of Titan is optically thin and the incoming flux from the Sun is not significantly attenuated down to the DHL, then the output flux can be simply described as:

$$I/F = \frac{\omega \cdot P(\theta)}{4} \cdot \left(1 - e^{-\tau_{\text{ext}}}\right) \text{ with } \tau_{\text{ext}} = \text{N}_{\text{los}} \cdot \sigma_{\text{ext}} \qquad (1)$$

with ω the single scattering albedo, $P(\theta)$ the phase function at the scattering angle θ, τ_{ext} the tangential opacity, σ_{ext} the extinction cross-section and N_{los} the number of aggregates along the light of sight

We assume that the DHL is composed of fractal aerosols composed of single-size spherical primary particles [10, 11] which can be described by only two parameters: R_m the monomer radius and R_v the bulk radius. The optical index is based on a tholin composition (n=1.64, k=0.17) [12]. These optical properties are calculated using the model developed by Tomasko *et al.* [13] for a fractal dimension fixed at 2.0 and a number of monomers: $N = (\text{R}_m/\text{R}_v)^3 \leq 1024$.

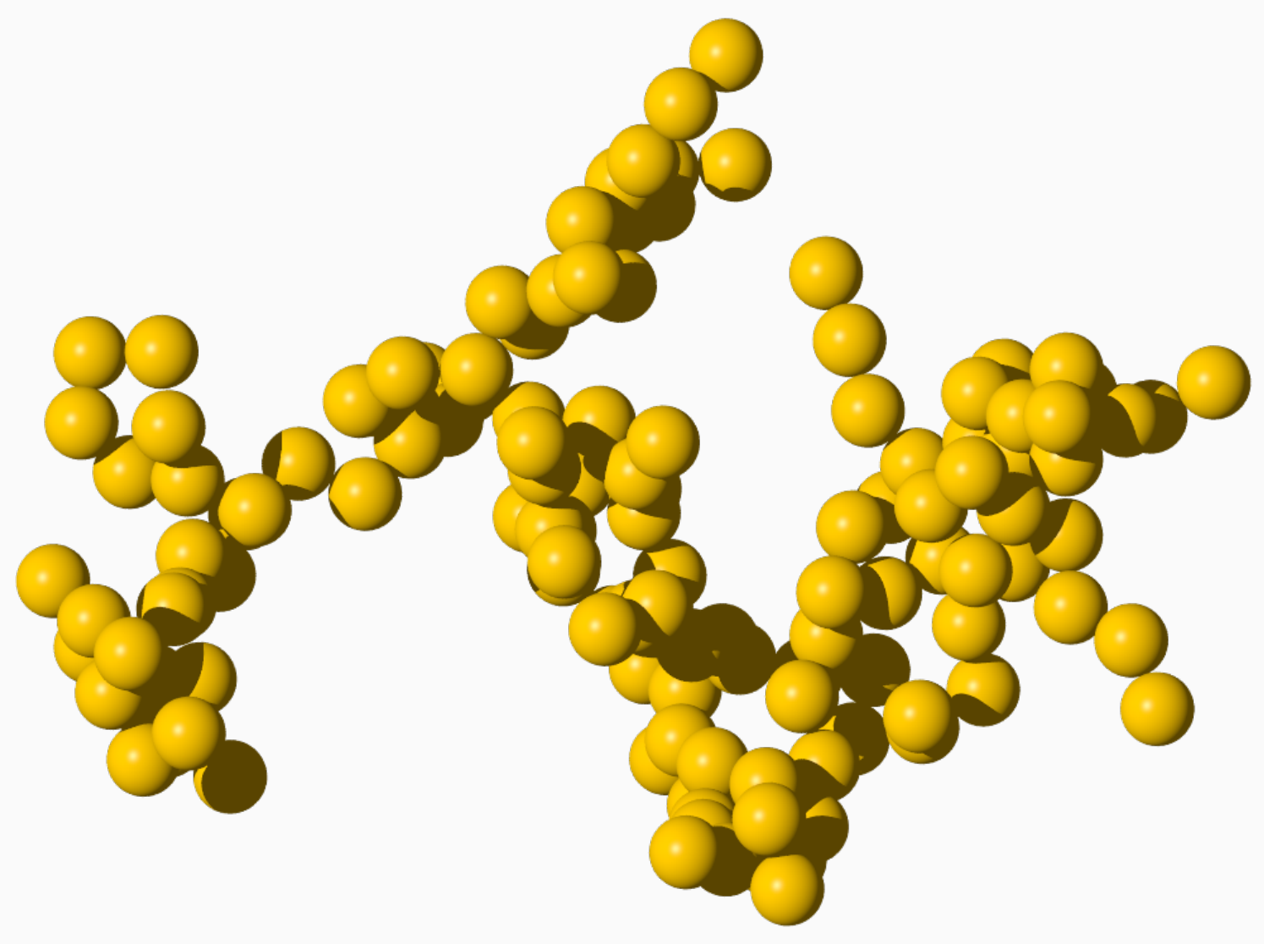

Figure 3: Typical fractal aggregates of 128 monomers used in the model.

Results

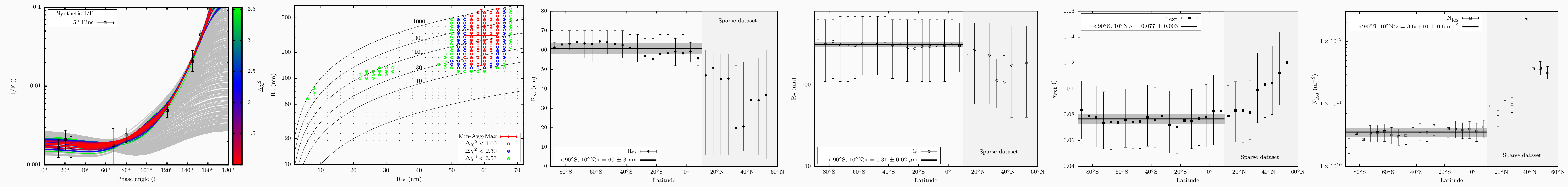

Figure 4: (left to right) Light curve best fits between 0 and 5°N. χ^2 map of pairs (R_m,R_v) explored by the fit. Latitude retrievals at $\Delta\chi^2 < 1$ for R_m, R_v, τ_{ext} and N_{los}.

To derive the shape of the aerosols and their density along the line of sight we compute a synthetic I/F at each latitude for all pairs of (R_m,R_v) and we keep the best fit on τ_{ext}. Latitudinal variations of these parameters (for $\Delta\chi^2 < 1$) can be split into two main areas below and above 10°N. Below 10°N, our retrievals are consistent with an homogeneous content of aerosols with $\text{R}_m = 60 \pm 3$ nm, $\text{R}_v = 0.31 \pm 0.02\,\mu$m and $\tau_{\text{ext}} = 0.077 \pm 0.003$. Then the optical properties derived correspond to $\omega = 0.68$ and $\sigma_{\text{ext}} = 2.2 \cdot 10^{-12}$ m^2. Above 10°N, we find a decrease in the aerosols size R_m and R_v associated with an increase of τ_{ext} (i.e. smaller and more particles or smaller and particles with a higher extinction). However theses results inside this sparse dataset region need to be taken with caution due to the lower number of observation available at these latitude during the 2005-2007 period (northern winter).

Time variability

Considering now that aggregates can be described as fractal aerosols with $\text{R}_m = 60$ nm and $\text{R}_v = 0.3\,\mu$m, then it is possible to derive the local τ_{ext}. The DHL can vary up to a factor 3 at the equator but is stable in the southern hemisphere. These variations are not correlated with the geometry or tidal effects but could be due to the propagation of small time scale waves.

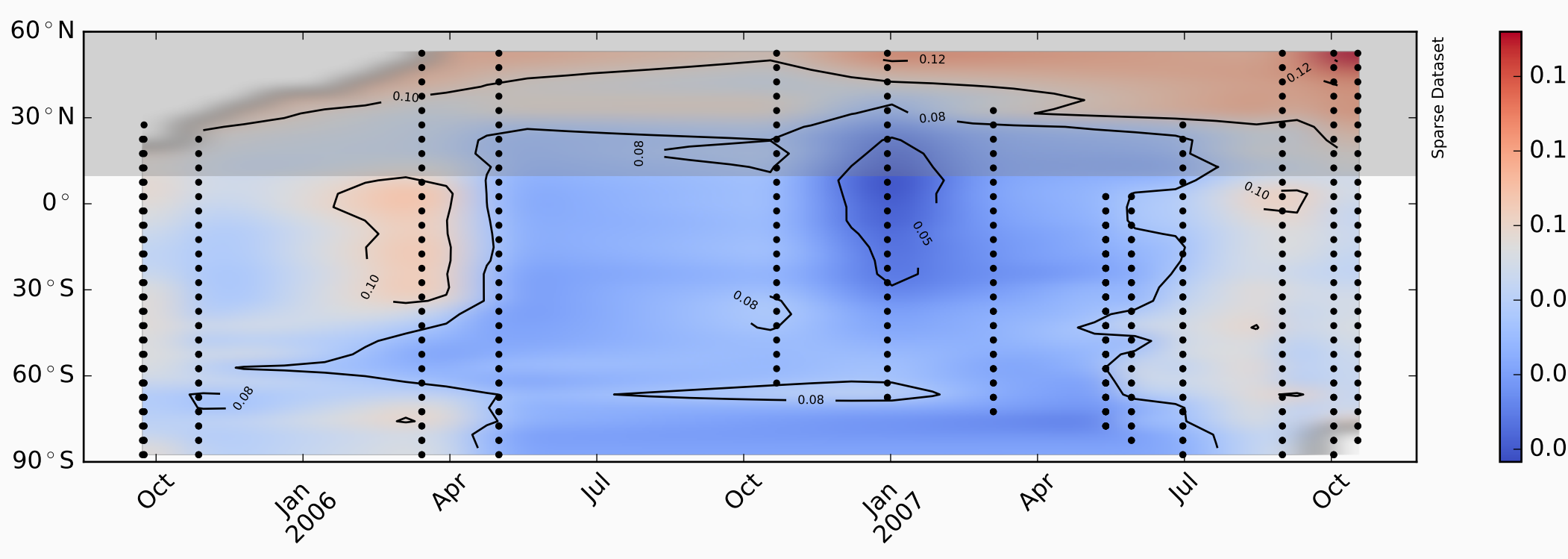

Figure 5: Latitude variation of τ_{ext} for each image in the DHL.

Conclusions

We demonstrated that before the equinox the DHL is a very stable feature at 500±8 km altitude at all latitude below 45°N. The optical properties that match the observations is constant for the latitude below 10°N and can be describe by fractal aggregates with a monomer radius of 60 nm and a bulk radius of 0.3 μm. Finally, we observed the temporal variability of the DHL between 2005 and 2007. During this period the tangential opacity can vary locally up to a factor 3 and its origin is still not well constrain yet.

The future developments of this work will be focus on the seasonal variability of the DHL after the equinox at different latitudes to compare it with recent GCM, but also on the vertical profile variability to compare it with CIRS and UVIS instruments onboard Cassini.

References

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