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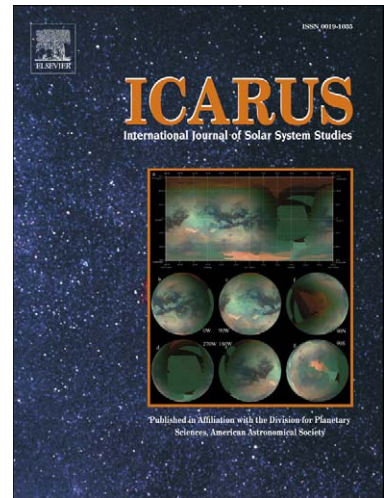
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In situ* Thermal Conductivity measurements of Titan's Lower*Atmosphere.**

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Abstract

Thermal conductivity measurements, presented in this paper (Fig. 3), were made during the descent of the Huygens probe through the atmosphere of Titan below the altitude of 30 km.

The measurements are broadly consistent with reference values derived from the composition, pressure and temperature profiles of the atmosphere; except in narrow altitude regions around 19 km and 11 km, where the measured thermal conductivity is lower than the reference by 1% and 2% respectively. Only single data point exists at each of the two altitudes mentioned above; if true however, the result supports the case for existence for molecules heavier than nitrogen in these regions (such as: ethane, other primordial noble gases, carbon dioxide, and other hydrocarbon derivatives).

The increasing thermal conductivity observed below 7 km altitude could be due to some liquid deposition during the descent; either due to condensation and/or due to passing through layers of fog/cloud containing liquid nitrogen-methane. Thermal conductivity measurements do not allow conclusions to be drawn about how such liquid may have entered the sensor, but an estimate of the cumulative liquid content encountered in the last 7 km is 0.6% by volume of the Titan's atmosphere sampled during descent.

Keywords: ATMOSPHERES, COMPOSITION, ABUNDANCE, TITAN, INSTRUMENTATION.

Introduction

Titan's dense and extended atmosphere, retained by a small gravitational force equivalent to only a seventh of the Earth's gravity, has been and continues to be studied by various remote observation techniques. The Huygens probe (Lebreton *et al.* 2005) provided the first opportunity to make *in situ* measurements of Titan's atmosphere during its descent on 14th January 2005. The atmospheric composition of Titan was resolved during the Huygens descent by mass spectroscopy, a part of the GCMS instrument suite, whose results are described in Niemann *et al.* 2005, and complemented by infrared spectroscopy measurements in the wavelength range 840 to 1700 nm from the DISR instrument (Tomasko *et al.* 2005). The atmospheric structure of Titan, in terms of its vertical pressure, temperature and density profiles, were resolved by measurements from the HASI instrument suite (Fulchignoni *et al.* 2005). Given this background of accurate knowledge of Titan's atmosphere acquired from such high fidelity *in situ* measurements, the purpose of measuring a vertical thermal conductivity profile, rather than inferring from our present knowledge, seems to yield no extra information on Titan at first sight. However, none of the above measurements were able to distinguish the physical state of the atmosphere, in terms of how much liquid, if any, was encountered along the path of the probe's descent. Compositional measurements such as the mass/charge (m/z) ratio measurements of the ions from GCMS, or methane absorption bands in the IR spectra from DISR are unable to detect any liquid that may either be present in the form of 'methane rain on Titan' (Toon *et al.* 1988), or liquid accumulated from condensation.

In addition to complementing the above *in situ* measurements, thermal conductivity is a highly sensitive parameter to the physical state of the constituents; for instance, the ratio of liquid to gas thermal conductivity is > 20 (NIST14 1993) in conditions similar to those found in Titan's atmosphere below 20km (i.e. for a binary mix of 0.95 N₂-

0.05 CH₄ (in mole fraction) at temperature of ~ 80 K and pressure of ~ 0.07x10⁶ Pa.).

The thermal conductivity profile presented in this manuscript should contribute to the debate of some important, but as yet unresolved, issues pertaining to Titan, such as: the regions containing methane super saturation (Samuelson *et al.* 1997) and more recently, the inferred ‘methane drizzle on Titan’ (Tokano *et al.* 2006). Later in this paper, we estimate the mean molecular mass of Titan’s atmosphere from the thermal conductivity measurements under the assumption that the constituents exist only in gaseous state.

Thermal conductivity measurements were carried out by a dedicated Thermal properties (THP) sensor, within the Surface Science Package (SSP) payload (Zarnecki *et al.* 2002). The THP sensor measures thermal conductivity by monitoring the heat flow between a heat source; a platinum wire enclosed by a cylinder in this case (see Fig. 1), and the surrounding medium; a fluid sample from Titan’s atmosphere. The sensor operates on the principle of ‘transient hot wire’ (de Groot *et al.* 1974), whereby, changes in temperature (dT) relative to the initial temperature of the wire are recorded after applying a step heat input over a preset time interval (15 seconds in the case of THP during descent).

Details pertaining to the THP sensor in terms of its design, operation and the technique used to calculate thermal conductivity are described in Hathi *et al.* 2007.

<insert Figure 1 and caption 1 here>

Although the THP sensor started operating above 100km altitude, the combination of measurement duration (15 seconds) and the low atmospheric pressure (< 0.02 MPa) , are deemed to be unsuitable conditions to allow sufficient heat exchange between the medium and the source, hence we present data below 30 km. Data from the Huygens

mission and THP are being made available on NASA's PDS archive at the time of this publication for further analysis by the wider planetary science community.

Measurements

The process of calculating thermal conductivity, upon which the results in Fig. 3 are based, is described in Hathi *et al.* 2007. In summary, an initial estimate of thermal conductivity is obtained from a gradient of raw measurements (see 'Raw data' points in Fig. 2) and is used to generate a new temperature profile after applying various correction factors (see 'corrected data' points in Fig. 2). The iterative process generates a corrected data curve for each gradient calculation from raw data until the thermal conductivity values from the raw and corrected data sets converge. The method yields two values (minimum and maximum) at each altitude step; the actual thermal conductivity value may lie anywhere within the boundary defined by these minimum and maximum values.

The measurements presented here cover the last 30 km of the Huygens descent and vary in altitude resolution from 1 km per sample at higher altitudes, to 0.5km. Under stable calibration conditions, the thermal conductivity calculations were accurate to within 1% for the three gaseous media: methane, ethane, and nitrogen. However, under descent conditions, where continuously changing pressure and internal-external temperature gradients determine gas flow rates through the THP sensor, the errors may be greater than the 1% encountered during calibration.

The errors (or the spread in values) in general decrease with decreasing altitude; in some regions the errors are well confined by a narrow range (see data around 11 to 10 km, and closer to surface below 5 km). The relatively large error bars in the upper atmosphere are due to poor convergence in the iterative method resulting from ill-confined residuals (see Fig. 2d) which in turn might be a result of the atmosphere sample within the measuring cell having a combination of either thermal gradients or

a more turbulent gas flow. A constant eddy diffusion coefficient of $5000 \text{ cm}^2/\text{s}$ has been estimated below 90km (Barth and Toon, 2003) however, the eddy size of Titan's lower atmosphere is unknown and therefore it is not possible to compare turbulence length with those observed in high altitude THP measurements.

<insert Figure 2 and caption 2 here>

Data in Appendix 1, summarised in Fig. 3 (below) describe Titan's vertical atmospheric structure in terms of its thermal conductivity. The measurements show a general trend of increasing thermal conductivity closer to the surface. The THP sensor measurements are time stamped, so the average altitude during a measurement can be correlated from the Huygens descent profile in Lebreton *et al.* 2005 (i.e. time-altitude profile).

The present analysis assumes that the gas sample in the THP sensor during a measurement is approximately similar to the external atmosphere sample (i.e. no gas flow lag between the THP sensor and the external atmosphere is considered). This assumption is based on the qualitative argument of increasing atmospheric pressure during the descent should result in some internal-external pressure differential ensuring that gas sample is similar to the external atmosphere sample.

<insert Figure 3 and caption 3 here>

In order to identify regions of interest (i.e. regions of the atmosphere where measurements differ from our present understanding of the atmosphere gained during the Huygens descent), we compare the measured thermal conductivity values to the reference values, shown in Fig. 3 by the "Titan reference λ " line.

The reference thermal conductivity, shown by “Titan reference λ ” in Fig. 3, is constructed at a given altitude, from temperature and pressure measurements made by the atmospheric structure instrument during the descent (Fulchignoni *et al.* 2005) and the binary nitrogen-methane composition measured by GCMS (Niemann *et al.* 2005). The reference thermal conductivity is calculated using the above measured parameters and the NIST database (NIST14 1993). Since the input parameters used to calculate the reference thermal conductivity are based on Titan measurements made by other independent instruments, it is reasonable to assume that the reference atmosphere, based on reference thermal conductivity, takes our current understanding of Titan’s atmosphere into account.

The succeeding analysis focuses on the ratio of measured thermal conductivity relative to Titan reference (Titan λ / Titan reference λ). If the ratio is close to unity, then the measurements agree well with the reference. The regions where the thermal conductivity measurements are lower than reference (i.e. ratio < 1), suggest a presence of gas with heavier constituents than the nominal nitrogen-methane expected in the atmosphere at a given altitude.

<insert Figure 4 and caption 4 here>

Using thermal conductivity to infer Titan’s atmospheric composition at 19 km and 11 km region

Thermal conductivity as a stand alone parameter cannot yield a unique solution to determine composition of an atmosphere (or gas mixing ratios), however it is possible to deduce the ratio of mean molecular mass of an atmosphere relative to the reference atmosphere by comparing thermal conductivity values (see Appendix 2 for details).

Also if we assume that the atmosphere consists of predominantly two constituents, then it is possible to infer composition in terms of mole fraction.

Since each thermal conductivity measurement in Fig. 3 is confined by a minimum and a maximum value, a balanced analysis at first sight might appear to be the one that compares both values versus its reference counterpart. However, we only consider the ratio of maximum thermal conductivity relative to the reference atmosphere (Titan λ_{\max} / Titan reference λ), as this approach helps in two ways: (1) in identifying regions of the atmosphere that most likely contain liquid, (2) in defining the minimum limit of other constituents present that are heavier than the reference atmosphere.

The thermal conductivity measurement around 19km is below the reference value and this observation is coincident with the Huygens imaging spectrometer (Tomasko *et al.* 2005) detection of a cloud/haze layer at 20 km. At the time of writing this paper, we are not aware of any observations just above 11 km.

From thermal conductivity ratios, the lower limit for the mean molecular mass μ of the cloud/haze layer (around the 19km region) is 28.7 atomic mass units (i.e. 2.5% higher than nitrogen) . Nothing further can be deduced solely from thermal conductivity measurements but the observation is consistent with, but not limited to, the hypothesis: ‘ethane in smog particles’ (Hunten 2006), as the cloud layer could consist of a mixture of several constituents whose average μ is 28.7 .

The region around 11 km gives a slightly higher μ of 29.3 atomic mass units.

These measurements do not confirm or rule out the existence of methane clouds in the 3σ error range around 28 to 26 km (i.e. the region where Tokano *et al.* 2006 suggest a probable existence of ‘solid methane cloud’). However, there is no evidence for the

existence of the lower liquid methane/nitrogen cloud between 15 to 10km suggested in Tokano *et al.* 2006.

Estimating the liquid content in Titan's atmosphere below 7 km to the surface

Our current knowledge of constant methane abundance of 4.92 % (+/- 0.25 %) below the altitude of 7km comes from GCMS measurements (Niemann *et al.* 2005), yet the thermal conductivity measurements in this region (Fig. 3), show a gradual increase in thermal conductivity relative to the reference values. There are two ways of interpreting the thermal conductivity data in this region: one is to assume that the conduction of heat occurs in a pure gaseous medium and the other is to assume an additional component of thermal conductivity is due to some liquid accumulated during the last 7 km of the probe's descent.

On using the pure gas conduction assumption, the molecular mass implies methane abundance of up to 30% below 2.5 km. This is clearly a significant departure from our present knowledge of approximately 5% methane abundance in this region. Therefore, the latter assumption (i.e. assuming some liquid deposition) is more likely to be valid in explaining the apparent high thermal conductivity. Liquid deposition might have occurred either due to condensation, or if the probe had descended through a cloud/haze layer containing liquid. The analysis outlined below attempts to derive the volumetric liquid content encountered by the THP sensor during the descent.

Assuming any liquid that may exist in the lower atmosphere of Titan also consists of the nominal nitrogen-methane mix (0.95-0.05 by molar fraction) , found in the gaseous state of the atmosphere, then its thermal conductivity can be calculated using NIST to be 0.19 W/m.K . The last measurement of 0.0113 W/m.K lies within the boundaries set by the gas thermal conductivity of 0.0102 W/m.K and that of liquid at

0.19 W/m.K; simple interpolation places a maximum limit of 6 % liquid to exist within the THP sensor. In effect, the measurement implies 6 % of the THP wire's (of 5 cm length and 10 μm diameter) surface to be covered in liquid; this could mean as little as few drops covering 6% of the wire's surface area, to 6 % of the THP's cylindrical volume of 45.4 cm^3 (i.e. 2.7 cm^3). In the last 7 km of the descent, the sensor must have traversed through a column of atmosphere of $\sim 6.4 \text{ m}^3$ (THP's external cylindrical enclosure is of 3.4 cm diameter, therefore: $7 \text{ km} \times \pi \cdot (1.7 \text{ cm})^2 \sim 6.4 \text{ m}^3$).

The significance of a maximum of 2.7 cm^3 liquid accumulated during the last 7 km of descent remains open to debate.

The embedded assumption in the above figure of 2.7 cm^3 is that the heat pulse, active for the duration of the measurement (delivering ~ 0.035 Watts for 15 seconds), does not vaporise any liquid during a thermal conductivity measurement. The latent heat of vaporisation for liquid nitrogen-methane mixture at conditions encountered in Titan's lower atmosphere is $\sim 3 \times 10^5 \text{ J/kg}$ and density $\sim 670 \text{ kg/m}^3$ (NIST14 1993).

Therefore, the heat energy required to evaporate such a liquid mix is $\sim 450 \text{ J}$; with the THP heat pulse delivering $\sim 0.5 \text{ J}$ per measurement, the above assumption should be valid.

Estimating the mean molecular mass profile of Titan's atmosphere from thermal conductivity measurements.

Hot wire based thermal conductivity sensors have been used for many years (Daynes 1933) in the field of Gas Chromatography to detect (unknown) gas components relative to a (known) reference gas. Since the THP sensor works on the same underlying principle (i.e. measuring thermal conductivity by using a hot wire sensing

element and comparing to the reference), we can estimate the mean molecular mass of Titan's atmosphere by using the method outlined in Appendix 2.

<insert Figure 5 and caption 5 here>

Summary and future work

The thermal conductivity measurements are broadly in line with the expected values derived from the reference model. There are two regions at 19 km and 11 km, where the measured values depart from reference suggesting possible existence of ethane and/or other heavier (than nitrogen) constituents. The minimum molecular mass is 28.7 and 29.3 atomic mass units respectively but lack of data supporting the case for heavier mass relative to nitrogen limits confidence. The region below 7km (particularly below 2.5km), must contain some liquid mix of nitrogen-methane for the measurements to be plausible; either due to condensation or from the probe descending through a liquid layer, with some liquid entering the THP sensor. Vertical error bars, though not shown in Fig. 3, must exist in terms of altitude resolution; some further work to improve our understanding of the gas flow within the THP sensor, should improve the altitude aspect of the altitude-thermal conductivity profile. However, such work requires a model based on gas dynamics, experiments and simulations to verify the gas flow rates (not available at the time of this publication).

Thermal conductivity is a useful property in modelling atmospheres and is one of the parameters used in general circulation atmosphere models. The data set from Titan is still being analysed to recover post-landing thermal conductivity and, if possible, to extend the upper atmosphere range. In order to evaluate the Titan's surface constituents (and volatiles) that maybe present in the post-landing thermal

conductivity measurements, we need to first quantify the contribution of the heat injected by the THP sensor against a background of general heat from the probe.

Appendix 1 – Thermal conductivity measurements of Titan’s atmosphere

<insert Table 1 here>

<insert Table caption here>

Appendix 2 – Thermal conductivity and mean molecular mass

An atmosphere (or a closed system) tries to reach equilibrium by minimising temperature and pressure gradients. One of the mechanisms for achieving equilibrium is through transport of energy (heat).

If we assume the heat flux to be isotropic (i.e. same in all directions x , y , and z) and consider the heat flux equation in one dimension, then the rate of heat flow (dQ/dt) in an atmosphere (of area = A) is proportional to the temperature gradient (dT/dx) over a vertical distance dx .

$$\frac{dQ}{dt} = \lambda \cdot A \cdot \frac{dT}{dx} \quad (\text{where } \lambda = \text{Thermal conductivity}) \quad [1]$$

The relationship quoted in Eq.2 from Holman 1980, is for a gas containing n molecules (where molecules are assumed to be rigid spheres), with heat capacity C_v , confined in area A ,

$$\lambda = \frac{1}{3} \cdot \frac{n}{N_A} \cdot C_v \cdot \bar{v} = \frac{1}{3} \cdot \frac{C_v}{N_A} \cdot \frac{\bar{v}}{A} \quad [2]$$

(where \bar{v} = mean molecular velocity, N_A = Avogadro's number)

From Maxwell-Boltzmann’s probability distribution, several versions of ‘average’ molecular velocities can be derived (Hirschfelder, Curtiss, and Bird 1954¹).

$$\text{probable } v = \sqrt{\frac{2kT}{M}}, \text{ root - mean - square } v = \sqrt{\frac{3kT}{M}}, \text{ mean } v = \sqrt{\frac{8kT}{\pi M}}$$

In all cases, the mean molecular velocity is proportional to square root of temperature and inversely proportional to square root of molecular mass (M). Therefore, at a given temperature, the thermal conductivity is also inversely proportional to the square root

of molecular mass. If we take the ratio of measured thermal conductivity with reference gas, then we should get a good estimate of the molecular mass.

$$\text{since } \bar{v} \propto \sqrt{\frac{T}{M}}, \text{ Ratio } \frac{\lambda_1}{\lambda_2} \propto \frac{\sqrt{M_2}}{\sqrt{M_1}} \text{ at temperature } T$$

Heat capacity C_v can be approximated by the product of the number density n and Boltzmann constant K_B (in the limit that Titan's atmosphere can be approximated by ideal gas).

The thermal conductivity ratio ($\lambda_{Titan} / \lambda_{Ref}$) can be used to deduce atmospheric mean molecular mass M_{Titan} (in atomic mass units) if the reference mass M_{Ref} is known.

$$M_{Titan} \approx \frac{1}{\left(\frac{\lambda_{Titan}}{\lambda_{Ref}}\right)^2} \cdot M_{Ref}$$

Detailed studies of thermal conductivity consider the effects from the contributions of rotational and vibrational energy components (also known as Eucken correction) in the case of polyatomic gases. Readers wishing to seek further details should refer to Hirschfelder, Curtiss, and Bird 1954², and Bird, Stewart, and Lightfoot 1960.

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Tables

Table I (below)

Time from T_0 (s)	Internal (initial) Temperature (K)	External (Titan) Temperature (K)	Pressure (MPa)	Altitude (km)	Titan Max λ (W/m.K)	Titan Min λ (W/m.K)	Reference atmosphere λ (W/m.K)
4120	89.04	72.31	0.0279	29.4	0.0099	0.0068	0.0077
4241	87.79	72.77	0.0299	28.3	0.0094	0.0068	0.0078
4362	86.43	73.22	0.0319	27.3	0.0099	0.0067	0.0078
4483	85.82	73.73	0.0340	26.2	0.0091	0.0073	0.0079
4605	85.34	74.21	0.0361	25.2	0.0087	0.0075	0.0080
4726	84.92	74.72	0.0383	24.2	0.0088	0.0073	0.0080
4847	84.73	75.19	0.0406	23.3	0.0086	0.0075	0.0081
4968	84.35	75.68	0.0429	22.4	0.0089	0.0074	0.0081
5089	84.32	76.19	0.0453	21.5	0.0083	0.0076	0.0082
5169	84.38	76.53	0.0469	20.9	0.0083	0.0075	0.0083
5290	84.38	77.06	0.0494	20.0	0.0084	0.0076	0.0083
5411	84.60	77.61	0.0519	19.1	0.0083	0.0078	0.0084
5532	84.64	78.11	0.0545	18.3	0.0084	0.0076	0.0084
5653	84.88	78.63	0.0572	17.5	0.0088	0.0078	0.0085
5774	85.13	79.15	0.0599	16.7	0.0092	0.0077	0.0086
5896	85.45	79.69	0.0627	15.9	0.0092	0.0078	0.0086
6017	85.56	80.17	0.0655	15.2	0.0097	0.0085	0.0087
6138	85.90	80.74	0.0684	14.4	0.0090	0.0083	0.0088
6259	86.16	81.31	0.0713	13.6	0.0092	0.0082	0.0088
6380	86.49	81.83	0.0743	12.9	0.0090	0.0085	0.0089
6501	86.90	82.35	0.0773	12.2	0.0090	0.0086	0.0090
6622	87.28	82.89	0.0804	11.5	0.0089	0.0089	0.0091
6743	87.62	83.43	0.0835	10.8	0.0091	0.0089	0.0091
6864	88.08	83.98	0.0867	10.1	0.0093	0.0090	0.0092
6985	88.40	84.55	0.0900	9.4	0.0095	0.0088	0.0092
7107	88.90	85.12	0.0933	8.7	0.0094	0.0091	0.0093
7167	89.36	85.37	0.0949	8.4	0.0096	0.0092	0.0093
7208	89.10	85.54	0.0961	8.2	0.0102	0.0091	0.0093
7269	89.67	85.79	0.0978	7.9	0.0099	0.0097	0.0094
7329	89.62	86.04	0.0995	7.6	0.0097	0.0094	0.0094
7390	90.24	86.38	0.1012	7.2	0.0096	0.0094	0.0094
7450	89.99	86.64	0.1029	6.9	0.0098	0.0096	0.0094
7511	90.65	86.90	0.1047	6.6	0.0098	0.0094	0.0095
7571	90.50	87.16	0.1064	6.3	0.0101	0.0096	0.0095
7692	91.03	87.69	0.1100	5.7	0.0102	0.0096	0.0096
7813	91.52	88.31	0.1136	5.0	0.0103	0.0098	0.0097
7935	91.94	88.86	0.1172	4.4	0.0103	0.0100	0.0098
8056	92.47	89.41	0.1209	3.8	0.0106	0.0094	0.0098
8177	93.04	89.87	0.1246	3.3	0.0103	0.0102	0.0099
8298	93.56	90.44	0.1284	2.7	0.0105	0.0104	0.0099
8418	94.07	91.01	0.1322	2.1	0.0107	0.0106	0.0100
8540	94.68	91.59	0.1360	1.5	0.0108	0.0105	0.0100
8661	95.30	92.07	0.1399	1.0	0.0109	0.0106	0.0101
8782	95.89	92.67	0.1439	0.4	0.0110	0.0108	0.0102
8843	96.37	92.96	0.1459	0.1	0.0113	0.0105	0.0102

Figure captions

Caption 1 (below)

Figure 1. Huygens probe (A) in descent configuration showing the atmosphere inlet via the SSP's instrument suite (B). The THP sensor is shown in detail in schematic (C) illustrating the active sensing element – a centrally suspended Platinum wire, and photograph (D) showing the external cylinders enclosing each wire and limiting the fluid flow within each cell.

Caption 2

Figure 2. Illustrates two cases where the uncertainty in thermal conductivity (i.e spread in minimum and maximum values) differ. (a) - Top left, shows raw data set obtained around 11.5 km which results in good convergence when correction factors are applied and is reflected by small spread in residuals shown in plot (b). The higher altitude data typically result in greater uncertainty and ill-confined residuals as shown by plot (c) at 28.3 km and the corresponding residual plot (d). The residuals shown in plots (b) and (d) are calculated relative to the least squares fit over the linear region used to calculate thermal conductivity.

Caption 3

Figure 3. Thermal conductivity (λ) values from *in situ* sampling of Titan's atmosphere shows a general trend of increasing λ towards the surface. The final measurement before landing is taken at 100m above the surface. The two reference lines show differences in λ due to instantaneous differences in internal-external temperatures. If the gas sample is at similar temperature to that of the Huygens probe at THP sensor location, then the thermal conductivity will follow the "internal reference λ ", alternatively if one assumes gas flow (i.e. incoming gas sample is approximately at Titan's atmosphere temperature), then the reference value will follow the path shown by "Titan reference λ ".

Caption 4

Figure 4. Thermal conductivity ratio suggests that there maybe a presence of heavier gas around 19km and 11km regions, but lack of data with ratio < 1 limits confidence. The increase in ratio below 7km maybe attributed to the THP sensor having encountered some moisture during the lower descent, or due to higher methane mole fraction. Nothing can be inferred from the values above 22 km due to large range of possible thermal conductivity values.

Caption 5

Figure 5. The mean molecular mass of Titan's atmosphere (calculated using the method outlined in Appendix 2) is broadly consistent with that derived from the binary nitrogen-methane mole fractions from GCMS data (27.6 amu at 30 km and 27.2 amu at ~ 3km) . Regions near 19km and 11km (as shown by A and B on the plot) indicate the presence of constituents heavier than the reference atmosphere and the near surface region (C) can only be plausible if liquid has accumulated incrementally on the sensing element below 7km. See text for further details.

Table caption

Table I. Thermal conductivity measurements of Titan's atmosphere during Huygens descent below 30 km. The reference atmosphere's thermal conductivity is derived using Nist database (NIST14 1993) by feeding compositional and physical parameters (at corresponding altitude) measured independently during the descent (i.e. nitrogen and methane mixing fractions measured by Niemann *et al.* 2005 and Titan's atmospheric properties (i.e. temperature and pressure) measured by Fulchignoni *et al.* 2005).

Figures

Figure 1 (inserted below)

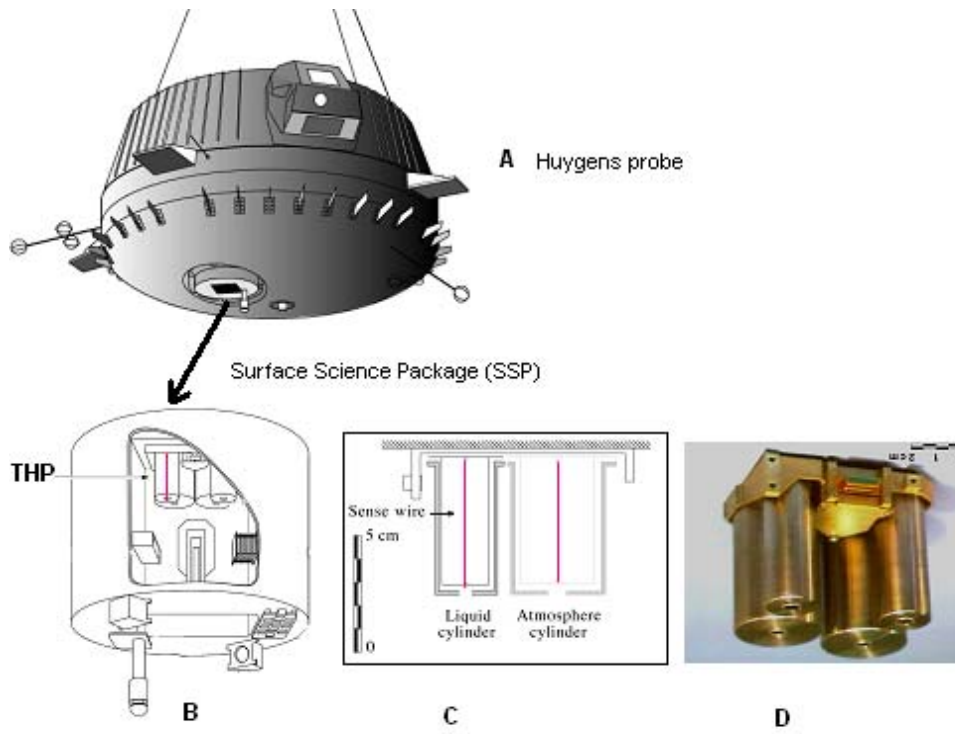


Figure 2

Thermal conductivity computations and residuals

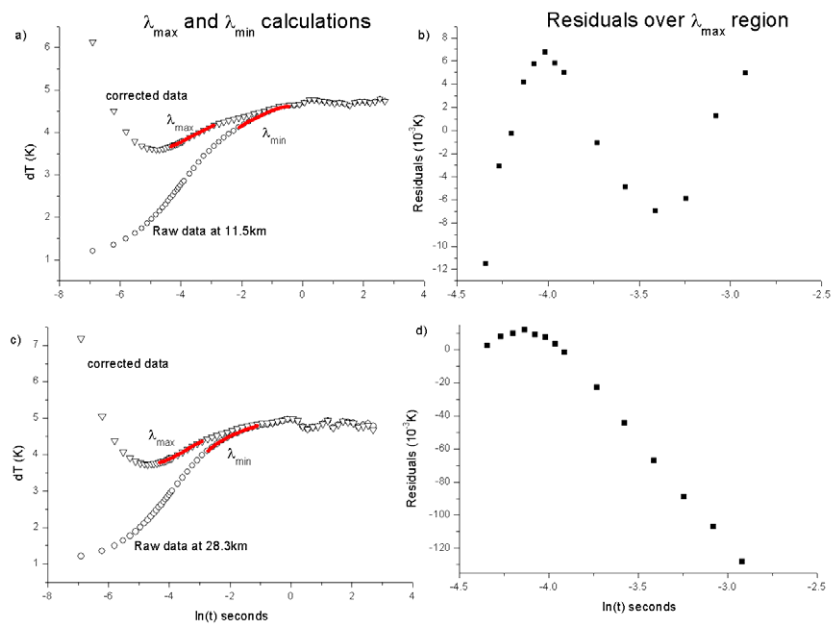


Figure 3

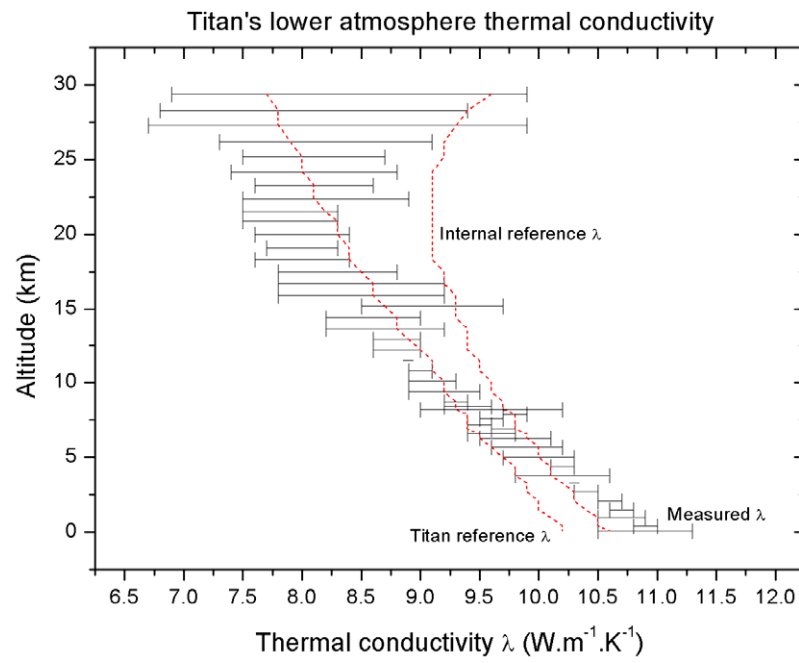


Figure 4

Titan's (maximum) thermal conductivity relative to Titan reference

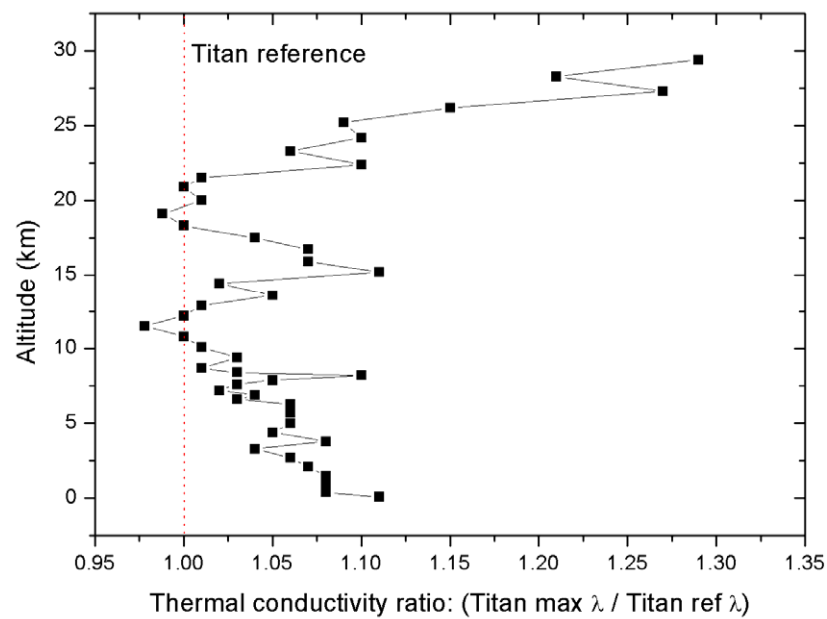


Figure 5

