

VALIDATION OF MIPAS ON ENVISAT BY CORRELATIVE MEASUREMENTS OF MIPAS-STR

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ABSTRACT

We report a preliminary validation of profiles from the MIPAS-Envisat on-line processor of ESA with correlative measurements derived from MIPAS-STR onboard the high-altitude aircraft M55-Geophysica. The validation is made for the 22 July 2002 orbit 2051 in the region of the campaign base in Forli, Italy. Profiles of HNO₃ and O₃ seem to agree well with the correlative measurements but vertical zigzag features, alternating for even and odd scans, are observed in the MIPAS profiles from Envisat. This behaviour, not observed by MIPAS-STR, is mostly pronounced in the CH₄ and N₂O data from channel B but also present in the temperature profiles derived from channel A. It is probably caused by deficiencies in the radiometric calibration of the atmospheric spectra which is independently performed for forward and backward interferometer sweeps.

1 DESCRIPTION OF THE FLIGHT ON 22 JULY 2002

The flight of 22 July 2002 was planned on the basis of the best information available on the location of the tangent points of MIPAS-Envisat and cloud forecasts made available by the University of l'Aquila and the Deutsche Wetterdienst. It started in Forli (44.2 N; 12.1 E) at 6:00 UTC. The flight track (see Fig. 1) followed the way points Florence (44.0 N; 11.0 E), Talin (41.0 N; 9.6 E), Velex (40.0 N; 11.5 E), Balen (41.0 N; 5.7 E), Tersi (45.8 N; 7.5 E), Cioggia (45.1 N; 12.3 E) before returning to Forli. Ascent and descent rates at Forli between 10 km and the flight level were 10 m/s. The flight levels (see Fig. 2) of the Geophysica were 17.5 km between Florence and Velex, 18.5 km between Velex and Balen and 19 km between Balen and Tersi. The overpass of Envisat was at 9:20 UTC when the Geophysica reached the highest altitude of about 19.5 km. During the complete flight no clouds were observed by the Lidars ABLE and MAL onboard the Geophysica.

2 SHORT DESCRIPTION OF INSTRUMENT AND LEVEL-1 PROCESSING

MIPAS-STR (MIPAS-STRatospheric aircraft) is a cryogenic Fourier transform emission sounder operating in the middle infrared. The emission method allows limb and upward viewing, yielding about 2 km vertical resolution below the Geophysica flight level (about 20 km) and mainly column data above. Reduced vertical information above the flight level is obtained by upward measurements with several elevation angles. The final results are 2-dimensional distributions of the trace gases in an altitude range covering the lowest stratosphere and the upper troposphere. The first deployment of MIPAS-STR was made during the Antarctic campaign APE-GAIA in 1999. The performance of the instrument has been considerably improved in recent years.

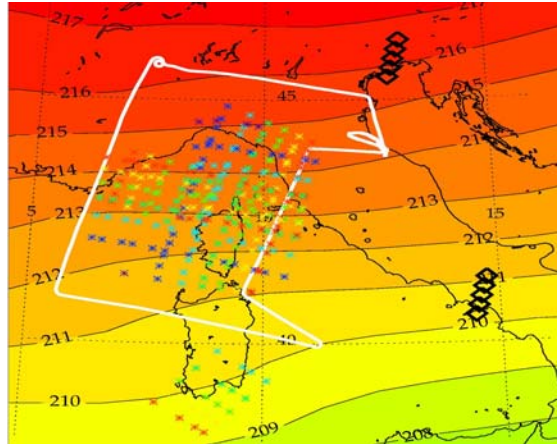


Fig. 1. M55 flight route of 22 July 2002, and MIPAS-STR tangent points above 11 km tangent altitude (blue: high, red: low tangent altitudes), as well as tangent points of scan12 and scan13 of MIPAS-Envisat.

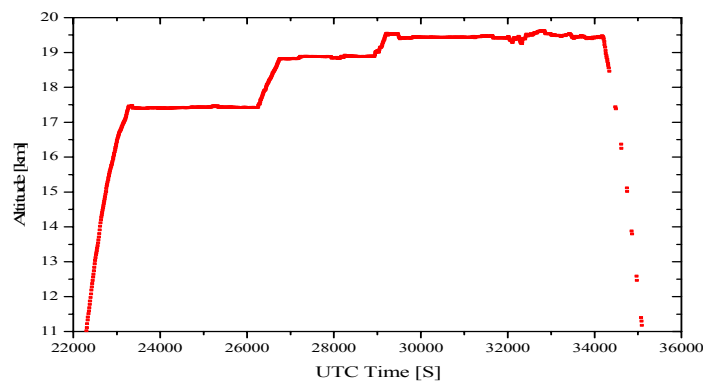


Fig. 2. M55-Geophysica flight altitude profile of 22 July 2002

The pointing of the limb measurements of July 2002 campaign was made at fixed tangent heights between 6.0 km and the flight altitude with a spacing of 1.25 km. Considering the instrumental field of view of 0.44 degrees (FWHH) oversampling by a factor 2-3 was applied at the lower tangent heights. In addition upward measurements at elevation angles of 0, 1, and 3 degrees, as well as 10 degree “deep space”, cold- and hot- blackbody measurements were performed. Two-sided interferograms were obtained with a maximum optical path difference L of 12.5 cm, resulting in a spectral resolution ($1/2L$) of 0.04 cm^{-1} . For a flight altitude of 18 km the complete sequence, including calibration, takes some 160 seconds and, without averaging, a horizontal resolution in flight direction of about 30 km is achieved.

The data shown in this paper are obtained from channel 1 which covers the wavenumber range of $770 - 970 \text{ cm}^{-1}$. In channel 1 spectral features of CO_2 (used for temperature retrieval), O_3 , HNO_3 , CFCs and several other trace constituents are present.

Level-1 processing of the MIPAS-STR data provides the input data for the profile retrieval described in the next section. Basically, it converts raw interferograms of the atmospheric measurements (so called science data) stored during the flight into radiometrically calibrated atmospheric spectra (in radiance units) for each tangent height or elevation angle [1]. For the July 2002 measurements the spectral gain and offset of the instrument was obtained from

the deep-space and cold blackbody measurements of each individual sequence. Corrections were made for the atmospheric features present in the deep-space spectra. The about 50 individual gain and offset spectra were analysed to obtain average values and their linear variation with time. Level-1 processing also provides the necessary auxiliary data which are derived from the stored house-keeping information and additional calibration measurements (line of sight calibration and field of view measurements) made after the flight. The auxiliary data include information on the corrected flight altitudes, elevation- and azimuth angles, and relevant instrument parameters.

3 DATA RETRIEVAL SCHEME

The inversion model KOPRAFIT (algorithm extension from KOPRA (Karlsruhe Optimised and Precise Radiative transfer Algorithm)) was used. In the procedure the Tikhonov-Philips regularisation method [2-3] was adopted:

$$x_{i+1} = x_i + \left(K_i^T S_y^{-1} K_i + \gamma L^T L \right)^{-1} \left[K_i^T S_y^{-1} (y - f(x_i)) + \gamma L^T L (x_a - x_i) \right] \quad (1)$$

Where i denotes the iteration index; x the vector with the unknowns; x_a the a-priori values; y the measurement vector; S_y the measurement covariance matrix of y ; f the forward model; K the spectral derivatives matrix; γ the regularisation parameter and L means the first derivative regularisation operator. Regularisation is necessary for each retrieved atmospheric parameter because (i) the chosen retrieval grid (0.5 km) is much finer than the tangent altitude spacing and (ii) at lower tangent altitudes spacing was smaller than the instrumental field-of-view (oversampling). The regularisation strength has been made as small as possible and adjusted just to avoid oscillations in the results [4]. We can judge whether its value is suitable by viewing the vertical resolution. This is determined as FWHH of each column of the averaging kernel matrix. It should be in the order of the tangent altitude distance.

4 COMPARISON OF MIPAS-STR AND MIPAS-ENVISAT PROFILES

From each single limb-scan of MIPAS-STR of flight 22 July 2002 temperature and trace gas profiles of HNO₃, O₃ and CFC-11 were retrieved from channel 1. The spectral microwindows which were used for these retrievals are listed in Table 1 (CO₂ lines for temperature, specific gas lines for trace gases). Since MIPAS-Envisat profiles are given only above 12 km, for our analysis of MIPAS-STR measurements only spectra with tangent altitudes larger than 11 km were used. For temperature retrieval a-priori profiles were constructed by interpolation of ECMWF fields (resolution 1.125° × 1.125°) to the geolocation of the actual tangent points for each limb-scan. In the following steps the resulting temperature profiles were used for trace gas retrieval. The vertical resolution of temperature, HNO₃, O₃ and CFC-11 profiles is shown in Fig. 3. The values which are around 2 km show that regularization strength is reasonable. The resolution is smaller than the vertical resolution of MIPAS-Envisat which is about 3 km.

For intercomparison with MIPAS-Envisat two mean profiles were constructed from the MIPAS-STR results of single limb-scans. One of them, flagged as ‘south’ in the following comparison figures, is the mean of 12 retrieved profiles from the southern flight track (flight altitude: 18.9 km; UTC time: 27000s - 28800s); the other, flagged as ‘north’, is that of 9 limb scans from the northern flight track (flight altitude: 19.5 km; UTC time: 32700s - 33800s) (see Fig. 1 and Fig. 2).

MIPAS-Envisat profiles of temperature and trace gases were extracted from the ESA-supplied level-2 file of orbit 2051: MIP_NL_2PTETB20020722_090326_000060262007_00494_02051_0000.N1. To determine the absolute tangent altitudes of MIPAS-Envisat, i.e. the altitude grid related to the given profiles, the retrieved tangent pressures were used together with ECMWF fields of geopotential height.

The error bars, which are given in the following comparison plots are reflecting only the error contribution of the spectral noise.

Since the level 1 analysis of channel 2 is still in progress, CFC-11 from channel 1 was used to derive CH₄ and N₂O. This is possible due to the strong correlations between CFC-11 and CH₄ and N₂O determined during the actual flight by in-situ measurements of HAGAR (High Altitude Gas chromatograph for Atmospheric Research):

$$\text{CH}_4 = 0.896 + 3200 \times \text{CFC-11}$$

$$\text{N}_2\text{O} = 0.158 + 613 \times \text{CFC-11}.$$

In the following results of temperature, HNO₃, O₃, CH₄ and N₂O are compared with corresponding data of MIPAS-Envisat.

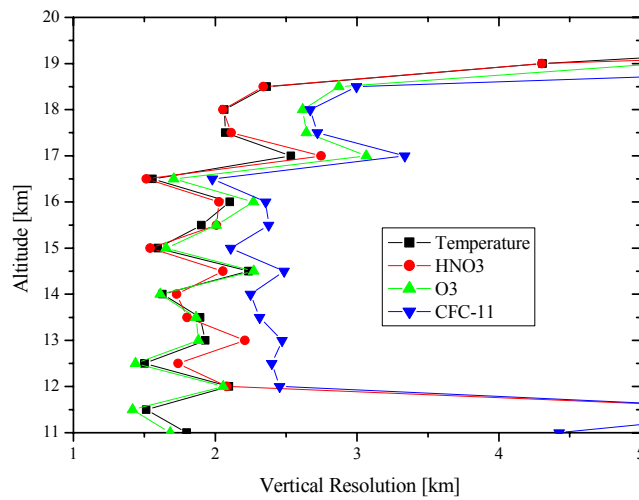


Fig. 3. Vertical resolution of MIPAS-STR profiles.

Table 1. Microwindows[cm⁻¹] chosen for retrieval of temperature, HNO₃, O₃ and CFC-11

	Microwindows [cm ⁻¹]			
	Temperature	HNO ₃	O ₃	CFC-11
1	779.5-781.0	866.0-868.0	779.5-781.0	838.0-856.0
2	802.9-803.5	868.0-870.5	782.5-783.5	
3	804.2-805.2	872.0-874.0	785.3-786.5	
4	805.9-806.8		787.0-788.0	
5	807.4-808.2		788.5-789.6	
6	810.4-811.4		794.2-795.2	
7	811.9-813.0		795.5-795.8	
8	814.9-816.0		804.9-806.0	
9	941.5-945.0		806.5-807.6	
10	950.5-952.0		811.1-812.3	
11	952.0-953.5		812.6-813.7	
12	954.0-957.0			

4.1 Temperature

H₂O, O₃, CCl₄ and ClONO₂ were included as co-fitted gases in the retrieval process. Results are shown in Fig. 4.

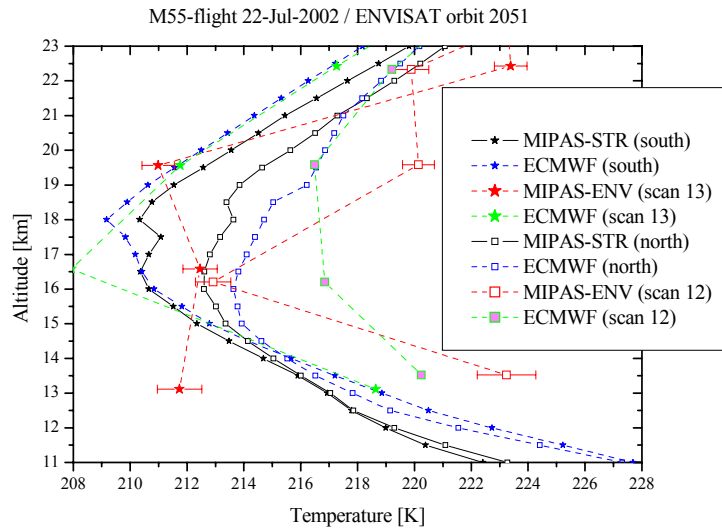


Fig. 4. Retrieved temperature profiles from MIPAS-STR, MIPAS-Envisat and the a-priori from ECMWF.

Above 14 km MIPAS-STR temperatures in the south are maximally 3 K lower compared to the northern measurements. Below 14 km the profiles are similar since there the tangent point geolocations are overlapping (see Fig. 1). The MIPAS-STR profiles correspond very well to those of ECMWF with average differences of around 1 K.

MIPAS-Envisat profiles of temperature (blue) show significant deviations from the MIPAS-STR results as well as from the ECMWF profiles (green) which are located exactly at the time and the location of the MIPAS-Envisat tangent points. The strong differences at the lowest profile point could be due to cloud contamination. However, the entire profiles seem to be oscillating. This zigzag of the temperature profiles of MIPAS-Envisat can also be detected in the differences to the mean profile along a part of the orbit which are shown in Fig. 5. The oscillating structure with amplitudes of several K exists in the horizontal as well as in the vertical direction.

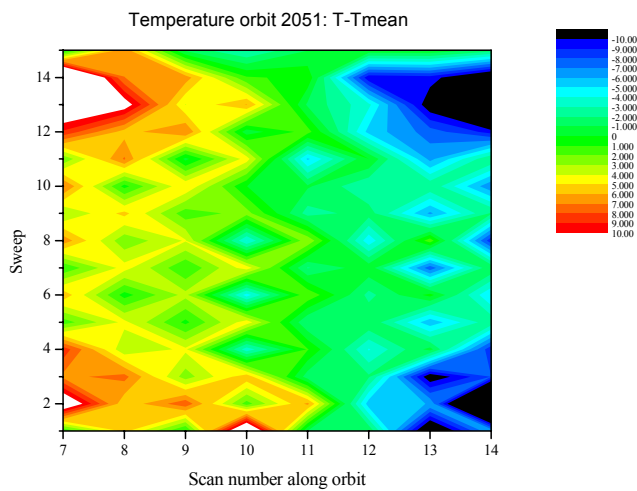


Fig. 5. The difference between temperature and mean temperature ($T - T_{\text{mean}}$) of MIPAS-Envisat orbit 2051.

4.2 Nitric Acid (HNO₃)

Profiles of HNO₃ are shown in Fig. 6. MIPAS-STR profiles from the south and the north are very similar. In comparison with MIPAS-Envisat all profile points of scan 13 fit very well with MIPAS-STR while of scan 12 only the measurement at 16 km is near to MIPAS-STR.

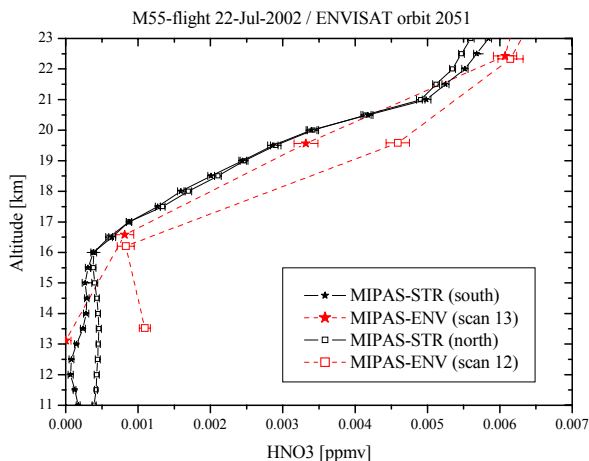


Fig. 6. Retrieved VMR profiles of HNO₃ from MIPAS-STR and MIPAS-Envisat.

4.3 Ozone (O₃)

H₂O and ClONO₂ were included as co-fitted gases in the retrieval calculations. Results are shown in Fig. 7. As in the case of HNO₃ scan 13 of MIPAS-Envisat compares well with both MIPAS-STR profiles. For scan 12 only the lowest profile point is deviating.

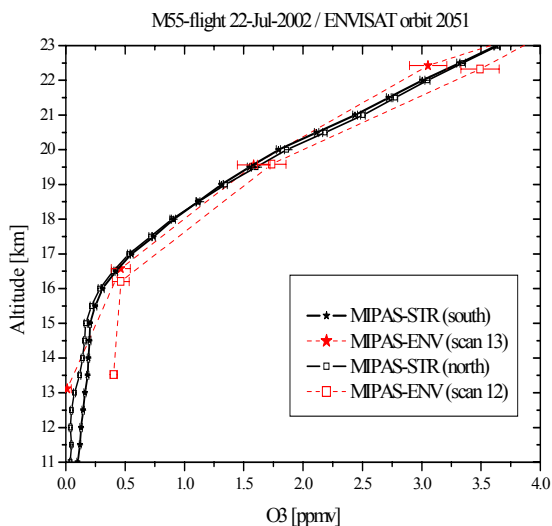


Fig. 7. Retrieved VMR profiles of O₃ from MIPAS-STR and MIPAS-Envisat.

4.4 Trichlorofluoromethane (CFC-11)

Comparison with in-situ data of HAGAR (measured during descent close to Forli) is shown in Fig. 8. The agreement of both profiles is very good above 13 km.

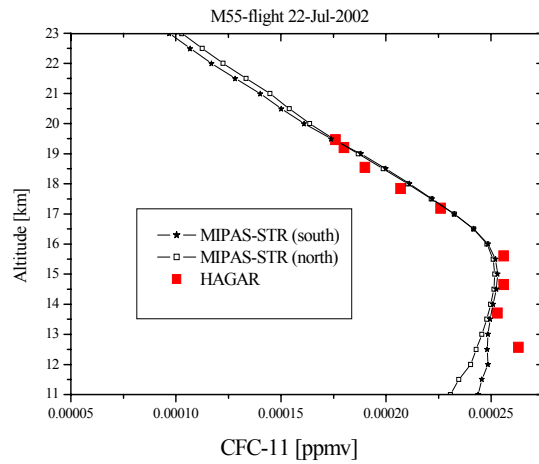


Fig. 8. Retrieved VMR profiles of CFC-11 from MIPAS-STR and data from HAGAR.

4.5 Methane (CH₄)

As introduced above, VMR profiles of CH₄ and N₂O were derived from MIPAS-STR CFC-11 results using the in-situ correlations. Results of CH₄ are shown in Fig. 9. The two profiles of MIPAS-STR have a good agreement, yet strong oscillations in results of MIPAS-Envisat exit around profiles of MIPAS-STR. The oscillations can also be detected in the differences to the mean profile along a part of the orbit which is shown in Fig. 10. The zigzagging structure with amplitudes of about 0.5 ppmv exists in both the horizontal and the vertical direction.

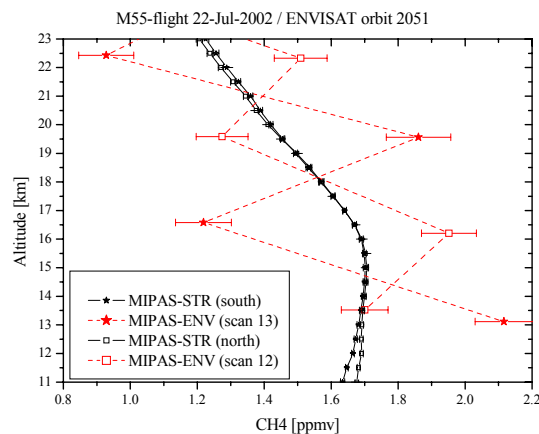


Fig. 9. Retrieved VMR profiles of CH₄ from MIPAS-STR and MIPAS-Envisat.

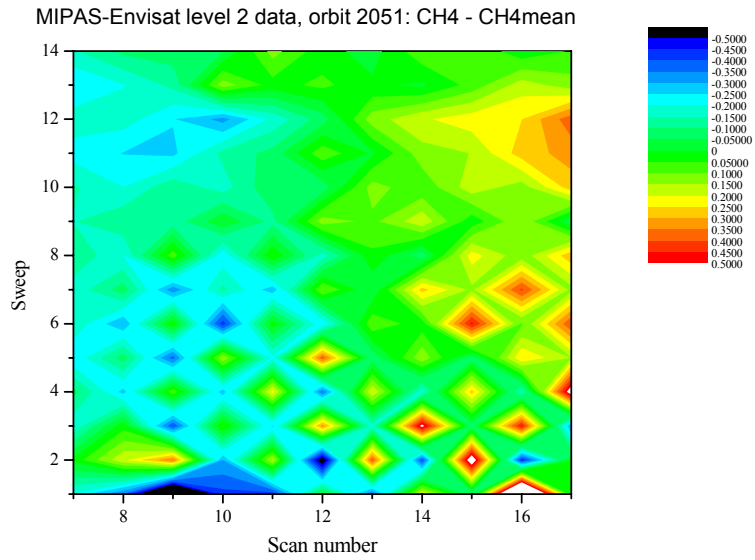


Fig. 10. The difference between the VMR of CH₄ and the average profile of limb scans 7-17 (CH₄ - CH₄mean) for MIPAS-Envisat orbit 2051.

4.6 Nitrous Oxide (N₂O)

Results of N₂O are shown in Fig. 11. The two profiles of MIPAS-STR fit to each other quite well. Just like that of CH₄, strong oscillations also showed in the two profiles of MIPAS-Envisat yet biasing to smaller values.

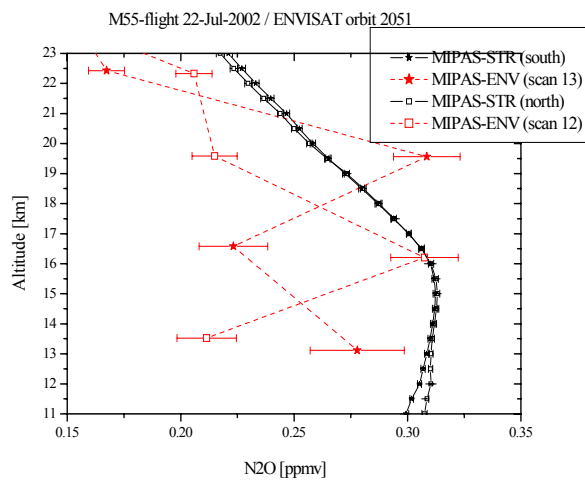


Fig. 11. Retrieved VMR profiles of N₂O from MIPAS-STR and MIPAS-Envisat.

5 CONCLUSIONS

Three main points of conclusions were obtained from this validation:

- On temperature: strong zigzag exists in MIPAS-Envisat.
- On O₃ and HNO₃: good agreement with scan 13; lower values than scan 12.
- On CH₄ and N₂O: there is ± 15 -20% zigzag of MIPAS-Envisat profiles (CH₄: around MIPAS-STR, N₂O: 10% lower).

Oscillations in retrieved vertical profiles can, in principle, be due to the level 2 processing, but the systematic zigzag behaviour described above is not expected and most probably already present in the MIPAS level-1 products. In the standard mode of MIPAS an odd number of interferograms measured. Since each scan starts at the highest tangent height and the interferograms are measured by forward and backward interferometer sweeps, measurements at the same tangent height in two consecutive scans are performed with different interferometer directions. Further, the radiometric calibration of atmospheric spectra for forward and backward interferometer sweeps is independent. It is therefore likely that the systematic oscillations observed in the temperature and trace gas profiles are caused by deficiencies in the radiometric calibration of the atmospheric spectra.

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