FINAL REPORT

Atomic Oxygen Database for Models

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by

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Atomic Oxygen Database for Models

I. Introduction

The objective of this research was to develop an analytical representation of an empirical database of atmospheric atomic oxygen abundance in the terrestrial mesopause region at an altitude of 95 km which is near the peak of atmospheric atomic oxygen abundance. The atomic oxygen density database was developed and resides at JHU/APL. It is based on a recently developed airglow chemistry-based retrieval process (Yee et al. 1997) using the Upper Atmospheric Research Satellite (UARS) airglow data for the period March 1994 to March 1995. The results are provided to guide the Spill Model Integrated Product Team (SMIPT) effort that aims to develop a detailed model of trail radiance from fuel vents that react with atmospheric atomic oxygen.

This final report summarizes the research findings and also discusses scientific issues related to the climatological variability as a guide for the proper use of the current analytical representation of the UARS 95 km [$O(^3P)$] database. JHU/APL also participated in SMIPT meetings with this grant support.

II. Empirical Amplitude Model

<u>Analytical Representation for Fitting to Data</u>

The initial assumption was made that the retrieved [$O(^3P)$] densities at 95 km can be represented by the following general functional form and the resultant amplitudes (for different time scales) can be used to represent variability as a function of latitude, longitude and day of the year:

$$\begin{aligned} N(t)=N_0(t) &+ A_{SA}*\mathrm{Sin}(2\pi\omega_{SA}t + \phi_{SA}) + A_S*\mathrm{Sin}(2\pi\omega_S t + \phi_S) \\ &+ A_{DT}*\mathrm{Sin}(2\pi\omega_{DT}t + \phi_{DT}) + A_{SDT}*\mathrm{Sin}(2\pi\omega_{SDT}t + \phi_{SD}T) \\ &+ A_{TDT}*\mathrm{Sin}(2\pi\omega_{TDT}t + \phi_{TDT}) \\ &\quad \{+ \text{ others (planetary waves/gravity waves with unknown phases)}\}, \quad (1) \end{aligned}$$

where the subscripts denote the following time scales of variability with their known natural phases:

SA = Semi-annual   S = Seasonal
DT = Diurnal Tide   SDT = Semi-diurnal Tide
TDT = Ter-diurnal Tide

<u>Analytical Representation for Empirical Model</u>

In the last collective term (in curly brackets) of eq. (1), the phases of gravity waves and planetary waves are variable, unknown, and as such will remain unpredictable from a model. The amplitudes from the fit can still give a general guidance for system design on any expected variability due to these phenomena (see plates 1 and 2). The planetary waves that are significantly excited include the so-called 2-day waves (period of 2.5 days) and 5-day (period of 6.5 days).

The approach used at this time was to build a climatology of atomic oxygen [$O(^3P)$] based only on the observed 1994 amplitudes for 3 dynamical features with known natural phases: (ϕ_{SA}, ϕ_S, ϕ_{DT}). The SDT and TDT terms are neglected here since they are relatively small compared to other uncertainties.

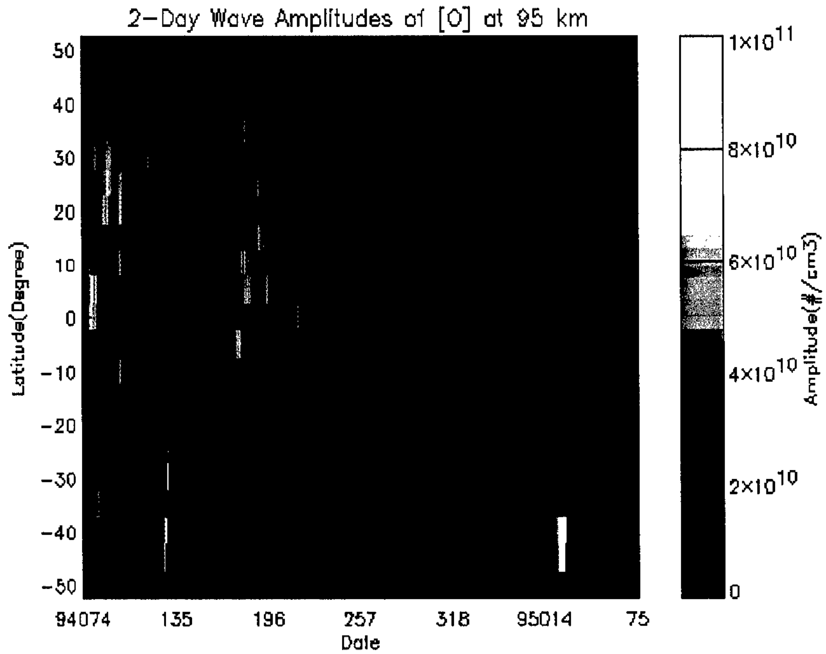


Plate 1: Latitude and time dependence of 2-Day wave amplitudes

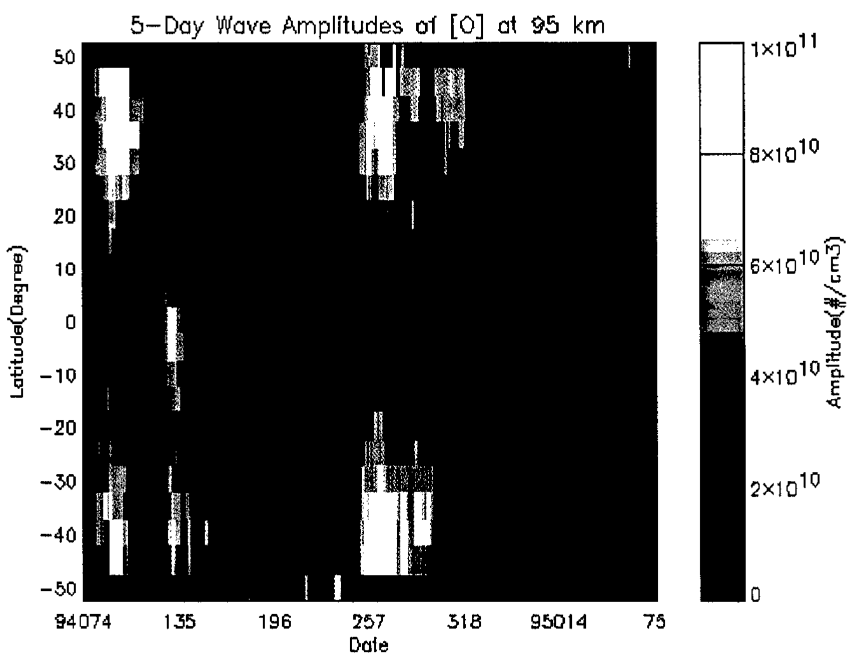


Plate 2: Latitude and time dependence of 5-Day wave amplitudes

Global Behavior of Fitted Amplitudes

Fig. 1 shows the data statistics versus latitudes covered in the UARS satellite scans. The data statistics reveals that the available UARS database primarily covers the latitude range (-40S, 40N) since less than a percent of the data points are at higher latitudes. So the applicability of the resultant fits are cautiously limited to the equatorial and mid-latitude regions (not global). Fig. 2 shows the latitude dependence of the annual mean [O(^{3}P)] values. The behavior of the semiannual (180 day) and seasonal (90 day) time scale amplitudes are shown in fig 3 (a) and (b) respectively as a function of latitude. The "normal" and "reflected" curves are purposely shown to indicate the anomalous hemispherical asymmetry in the fits which are probably due to the sparse data gathered in the higher latitude regions. The fits in the (-30,30) latitude region are seen to be relatively robust and can be used for [O(^{3}P)] estimates.

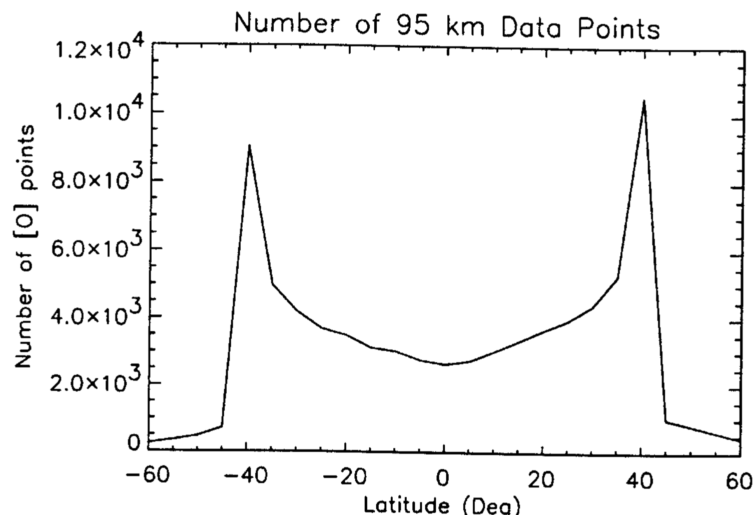


Figure 1. Latitude distribution of number of data points

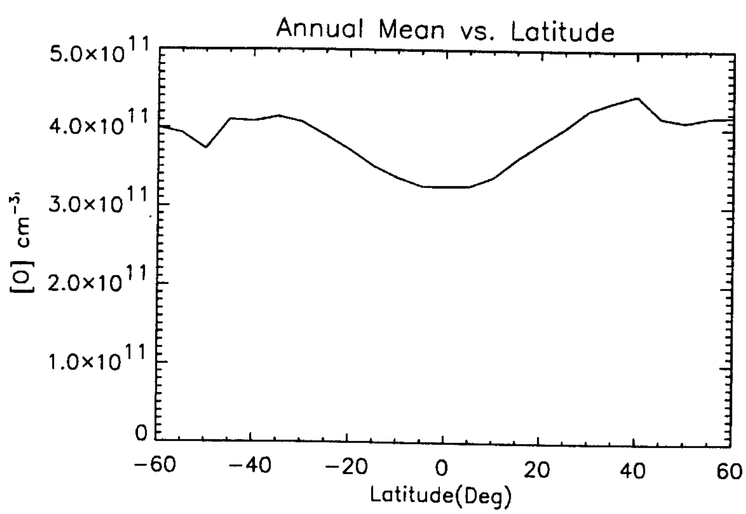


Figure 2. Annual Mean vs. Latitude

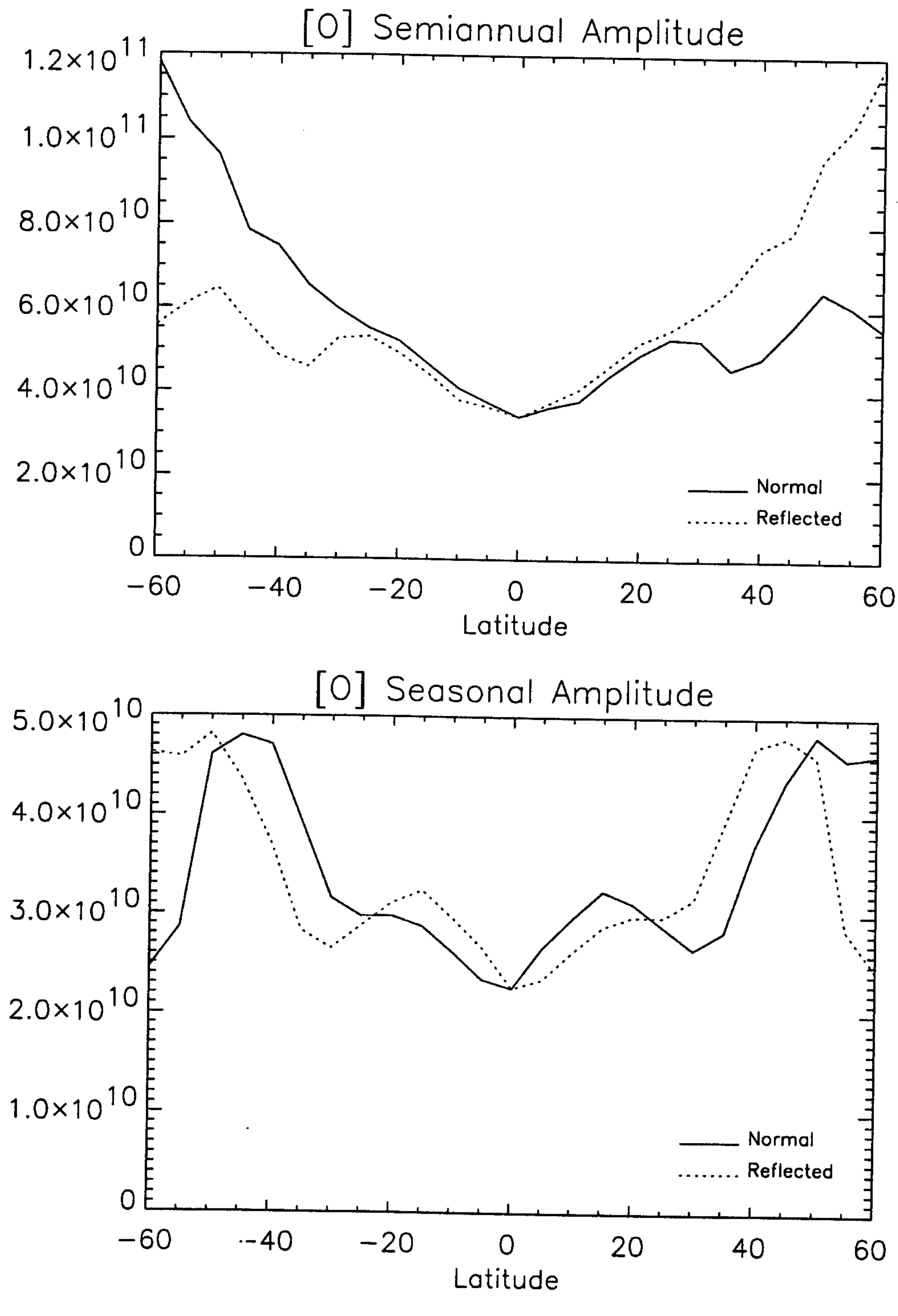
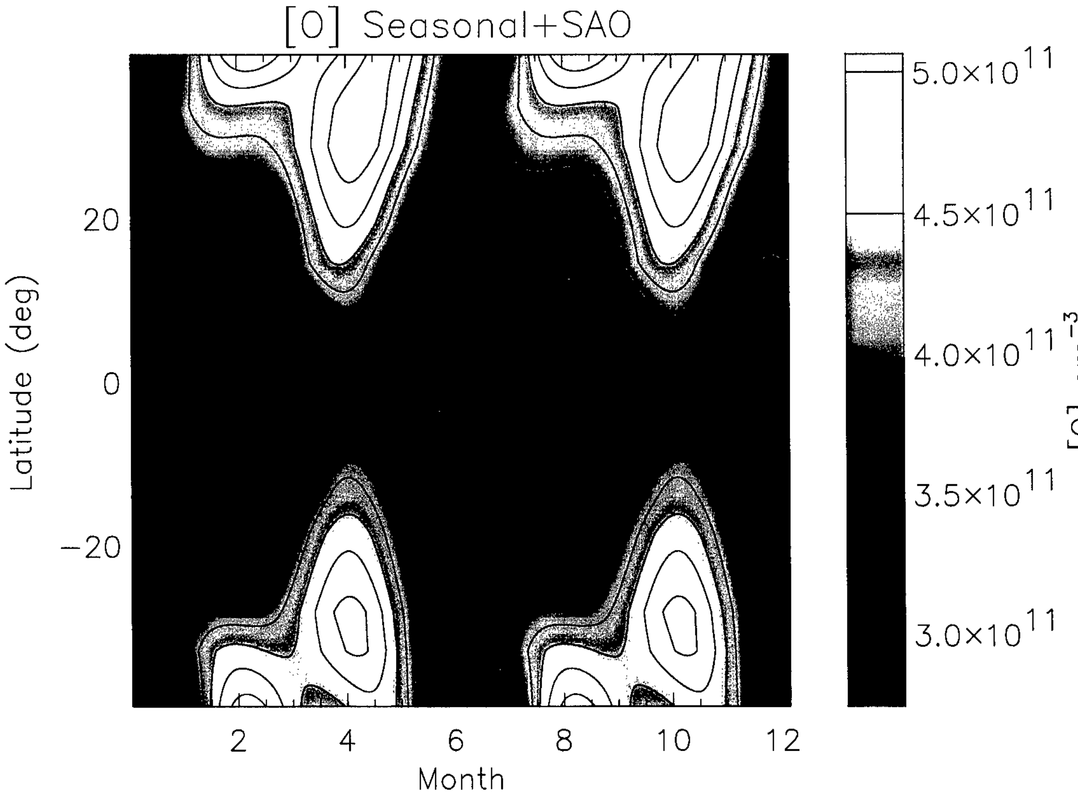


Figure 3. Latitude distribution (a) Semiannual and (b) Seasonal [O(^{3}P)] amplitudes (cm^{-3})

III. Data Comparison with Calculated Results for [O]



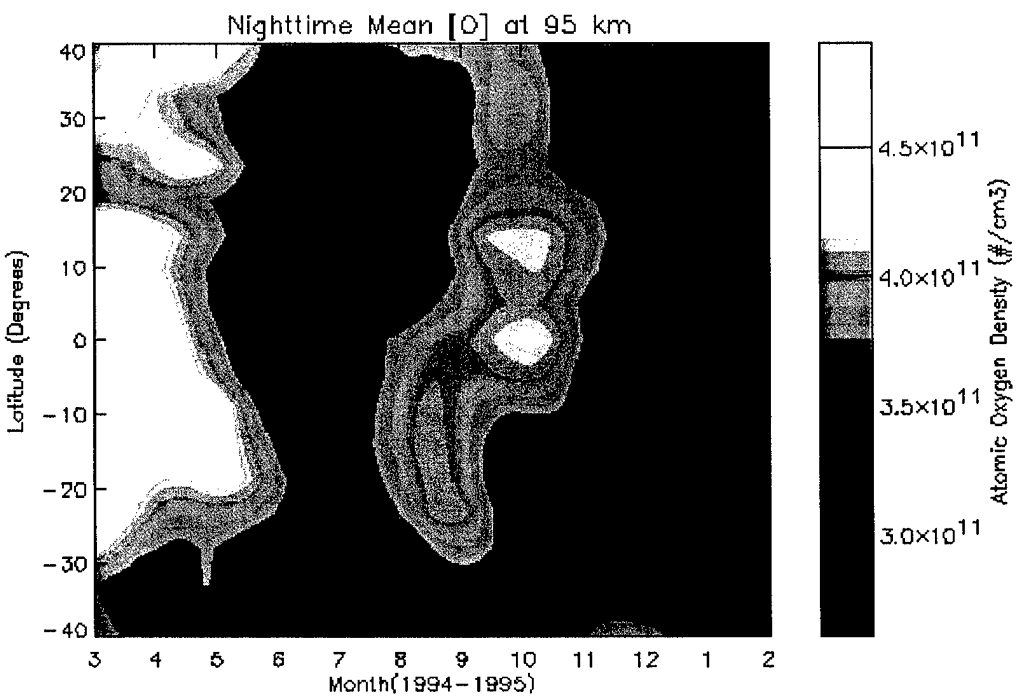


Plate 3. Comparison of Model for Semiannual plus Seasonal part of [$O(^3P)$] (Top) with Data (Bottom) to emphasize other variabilities that are present

At this stage in our model development, the calculated model results for atomic oxygen are based on including only the semiannual and seasonal amplitudes as fitted to the UARS data set. Plate 3 shows a comparison of the resultant model estimates (not valid for higher than mid-latitudes – see data coverage discussion above) for atomic oxygen with the actual corresponding data. A few points are noted. There is an asymmetry in the semiannual oscillation of the data showing a larger equinox abundance in March compared to September. A simple model of the semiannual oscillation combined with seasonal variability can never reproduce such an asymmetry. Anyhow, there may also be interannual variability of this type of asymmetric behavior. This asymmetry could also be due to data aliasing issues typical of a satellite collections over a long time – the asymmtery issue certainly needs further study.

The model code (in IDL) given in appendix uses the fitted amplitudes and reproduces the top part of Plate 3. The only significant additional variability that we may need to add to it is the diurnal one of known phase (peaking at noon everyday) and we provide that in plate 4 as a guide to the amplitude of this time dependent source. This is basically the amplitude of the 24hr cycle of variability that should be superimposed on any results from the IDL code of the appendix below. Finally, the gravity wave and planetary wave sources of unknown phase should be borne in mind or estimated based on Plates 1 and 2 in any assessments of engineering bounds thereof.

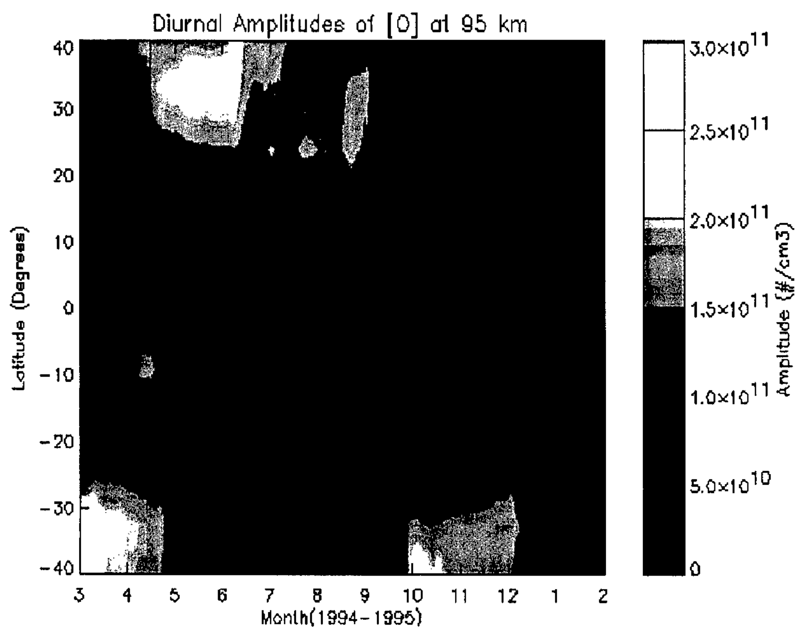


Plate 4. Latitude and time dependence of Diurnal Tidal [$O(^3P)$] amplitudes (cm^{-3})

IV. Appendix:

Simple IDL Computer Program of 95 km Empirical [O] Model

```
restore,'O3P_365.sav' ; Restores the IDL saveset provided with this report
;
; Construct the climate model of [O] using
; Annual mean = ann_mean(25)
; Arrays of seasonal and SAO amplitudes (Aseason, Asao),
; corresponding phases (Pseason, Psao) and latitude (lat) are fltarr(25)
;


;
; Define Empirical derived O_model array
 O_model=fltarr(25,365)


;
; Include 1-day time resolution at each Latitude
 time=findgen(365)+1
;
; Model is based on derived latitude-dependent phases ( phase difference is ~90 degrees)
for i=0,364 do O_model(*,i)=ann_mean(*)+Aseason(*)*sin(2.*!pi*time(i)/91.+Pseason(*)) $
+Asao(*)*sin(2.*!pi*time(i)/182.+Psao(*))


;
;PLOTTING
;device,/color,bits=8,file='Model_seas+sao.eps',/encapsulated
;loadct,5
contour,transpose(O_model(4:20,*)),time/30.,lat(4:20),xtit='Month',ytit='Latitude (deg)',title='[O] cm!u-
3!n',charsize=1.2,/c_ann
;
;device,/close
end
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14. ABSTRACT
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15. SUBJECT TERMS
Atomic Oxygen $(O(^3P))$, Diurnal, Semidiurnal and Terdiurnal Tides, Gravity Waves, Planetary Waves, Climatological Variability

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