Transport of black carbon from planetary boundary layer to free troposphere during the summer monsoon over South Asia

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Highlights

- Presence of persistent black carbon (BC) plume from 500 hPa and above over central India during the summer monsoon season
- On a daily scale, strong CAPE/ Helicity is able to transport significant amount of BC from the surface to around 850 hPa, but not up to upper troposphere/lower stratosphere
- Advection of BC from the Indo-Gangetic Plain to central Himalaya mountain cities need better parameterization for improvement in model performance over these cities/regions

Background

- Black carbon (BC) contribution to global temperature rise by ~1°C and changes in rainfall by ~1mm have been reported in the literature (Levy et al., 2013)
- Several studies have reported positive feedback of aerosols on precipitation; more aerosols leads to less precipitation which in turn contributes to more aerosol concentration over the region (Menon et al., 2002; Bollasina et al., 2008; Li et al., 2016).
- South Asia is referred to as a hotspot of BC (Fig. 1). Sources of BC in the region are mainly anthropogenic as well as natural (such as forest fires).

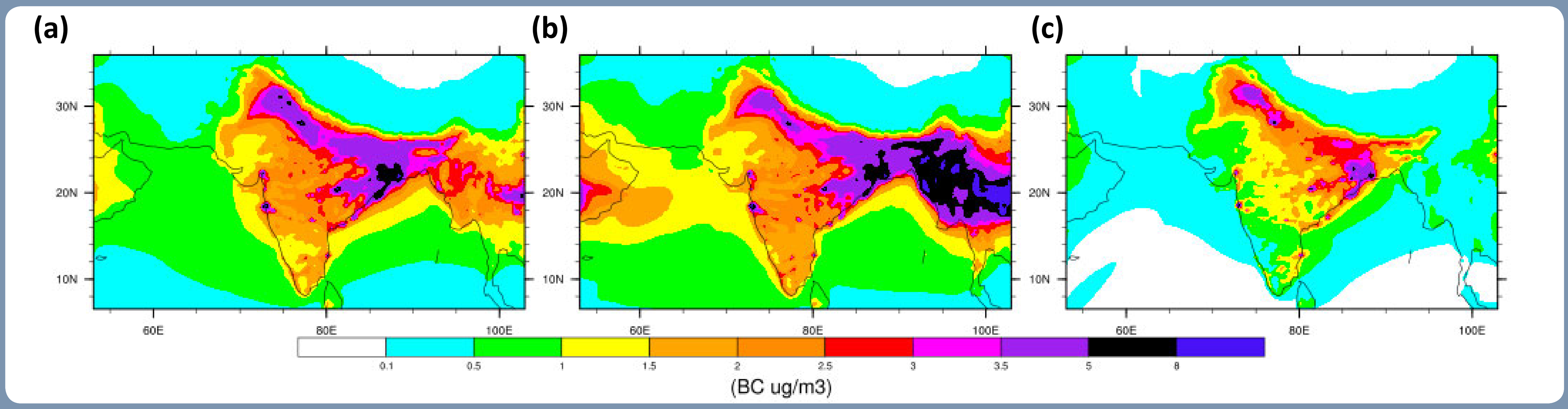

Fig. 1. BC surface concentration (a) annual (b) pre-monsoon and (d) monsoon

Climatology

- Asian monsoon is an intercontinental climate circulation system impacting about 60% of the world's population.
- El Niño–Southern Oscillation (ENSO) effects are very pronounced on the South Asian monsoon cycle.
- Thunder and lightning are considered as a signature of deep convection events.

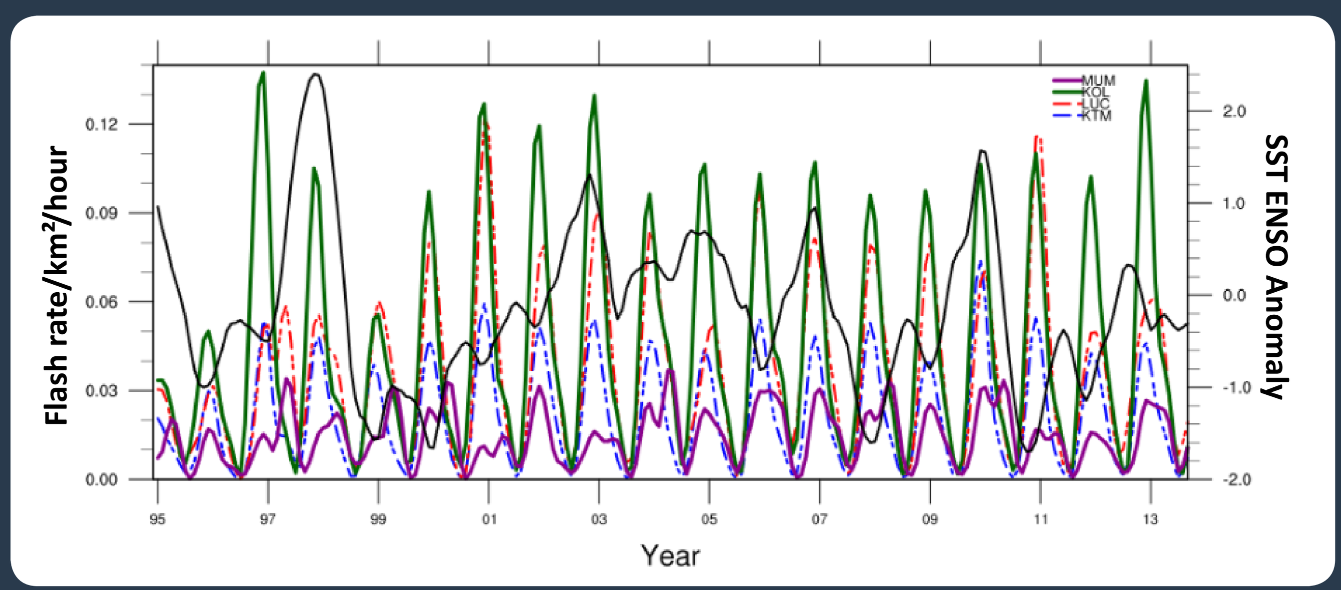

Fig. 2: **Time series of the lightning flash rate over Mumbai (solid dark pink), Kolkata (solid dark green), Lucknow (dashed red), and Kathmandu (dashed blue) with sea surface temperature (SST) anomaly (solid black).**

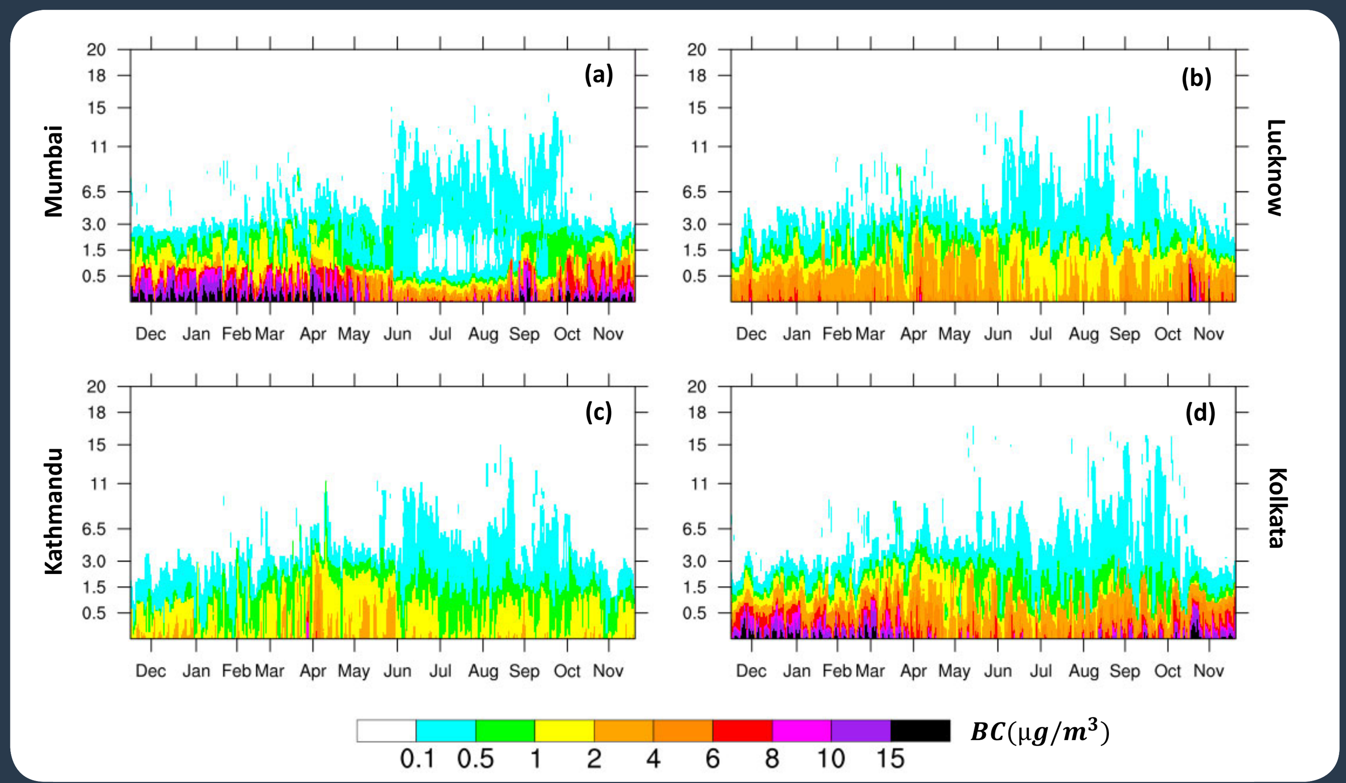

Fig. 3: **Annual atmospheric profile concentration of BC (above ground level) for the selected cities of (a) Mumbai, (b) Lucknow, (c) Kathmandu, and (d) Kolkata.**

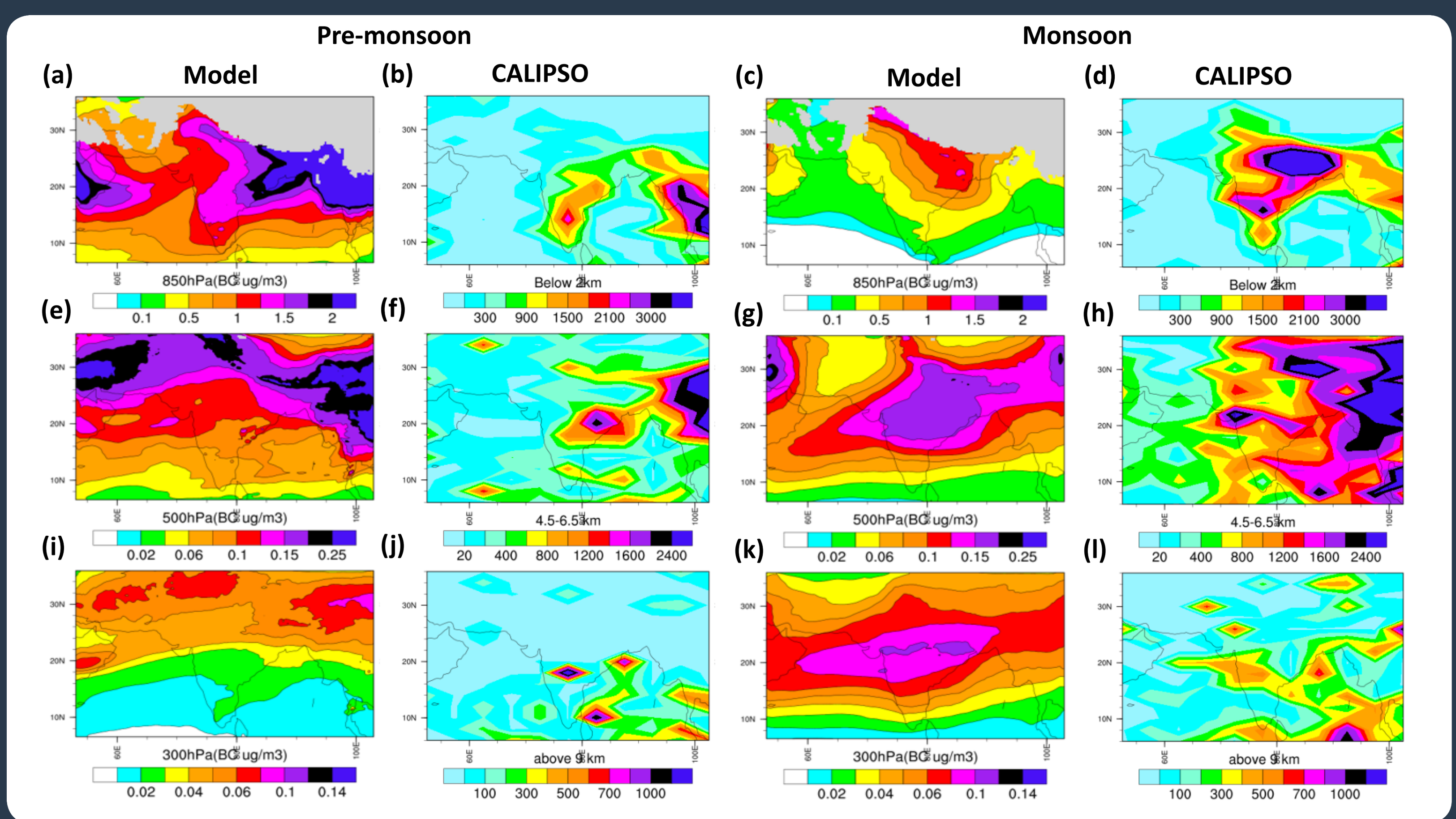

Fig. 4: **Seasonal average BC concentration from model during pre-monsoon (a,e,f) and monsoon (c,g,k) at different pressure levels (850hPa, 500hPa, 300hPa) respectively. CALIPSO smoke detection frequency during pre-monsoon (b,f,j) and monsoon (d,h,l) at different heights (below 2 km, 4.5–6.5 km, above 9 km from mean sea level) respectively.**

Case studies

- High helicity and CAPE values represent an unstable atmosphere conducive for active convection (Table 1).
- Helicity is the strength of cyclonic updraft rotation in the atmosphere, calculated from the surface to 3 km in the model.
- CAPE provides the strength of air parcel updraft due to buoyancy, calculated between the level of free convection (LFC) and level of environmental equilibrium (EL) or level of neutral buoyancy.

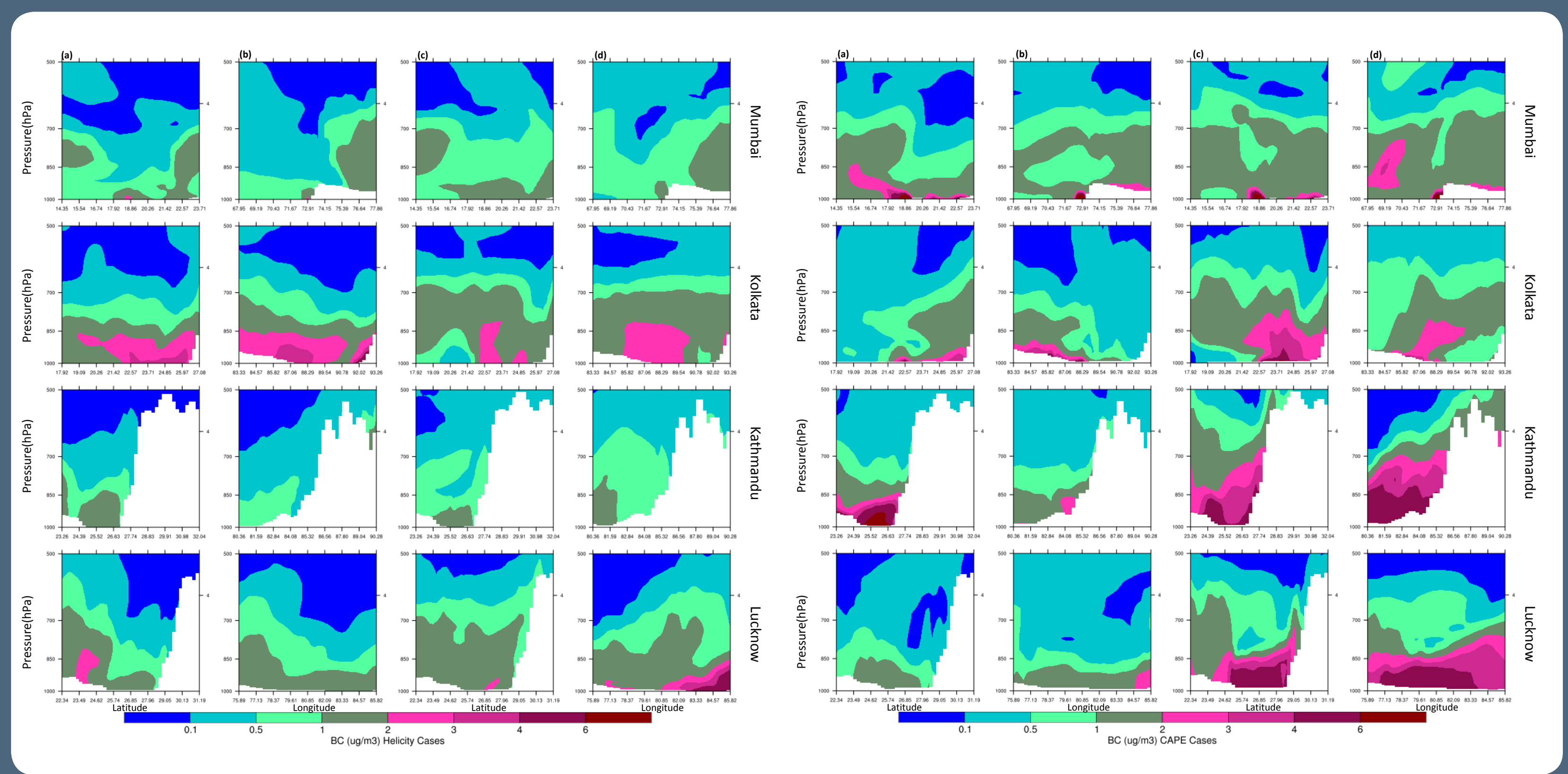

Fig. 5: **Seasonal average BC concentration from model during pre-monsoon (a,e,f) and monsoon (c,g,k) at different pressure levels (850hPa, 500hPa, 300hPa) respectively. CALIPSO smoke detection frequency during pre-monsoon (b,f,j) and monsoon (d,h,l) at different height (below 2 km, 4.5–6.5 km, above 9 km from mean sea level) respectively.**

Table 1: **Dates for helicity and CAPE-based case study**

City (lat., long.)	Helicity cases (0-3 km)				CAPE cases (J/kg)			
	Low		High		Low		High	
	Date	Helicity	Date	Helicity	Date	CAPE	Date	CAPE
Mumbai (19.08°N,72.88°)	20/03	-2.96	14/03	319.60	27/04	13	23/04	2242
Kolkata (22.57°N,88.36°)	24/03	-47.53	31/03	344	16/05	261	03/05	4754
Kathmandu (27.72°N,85.32°)	07/03	-3.31	10/03	264.88	10/04	0	17/04	837
Lucknow (26.85°N,80.95°)	16/04	-0.75	14/03	518	06/04	0	18/04	1688

Results/discussion

- Lightning climatology obtained from Tropical Rainfall Measuring Mission (TRMM) lightning dataset from 1995 to 2014 suggests the pre-monsoon and early monsoon periods as the active convective time over South Asia (Fig. 1).
- Time-series analysis (Fig. 3) for different cities and seasonal analysis show vertical transport of BC during pre-monsoon and monsoon.
- A persistent layer of BC plume during monsoon is observed at 500 hPa and above over the central part of South Asia (Fig. 4). While several studies have reported on the elevated BC layer over India during the pre-monsoon season with implications on monsoon, this study, to our knowledge, identifies for the first time a persistent BC plume over central India during the monsoon season.
- During high convective periods (the date reported in Table 1 and Fig. 5(A) and (B)), BC is easily transported to the free troposphere (FT) from the surface but not much higher, i.e., up to the upper troposphere/lower stratosphere (UTLS).

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