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# NEW ENGLAND COASTAL AIR POLLUTION DISPERSION MODELING

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## 1. INTRODUCTION

The presence of a coastline poses significant problems for understanding, monitoring and forecasting of transport and dispersion of pollutants in the atmosphere. At the same time, coastal areas are among the most highly populated, with consequences for effects on health and on the ecosystem from emissions of different pollutants to the sea and the air. The coastline constitutes a step-change in all surface parameters: surface roughness, temperature, terrain height etc. The responses in the lower atmosphere – the boundary layer – are many and diverse. The most commonly known resulting mesoscale phenomena are the sea breeze and the formation of offshore internal boundary layers.

The sea breeze is probably the most prototypical mesoscale circulation and was one of the very first to be simulated in mesoscale numerical models (cf. e.g. Estoque 1961). With the development of more advanced models, it has been revisited many times (e.g. Colby 2004, Marshall et al. 2004). With the efforts invested, one would think that almost all there is to know about it should be known by now. However, although the theoretical background is well understood and is simple enough, the actual appearance is complicated by its sensitivity to real environmental complexities, such as variations in coastline orientation and coastal terrain, and to the background (synoptic scale) flow.

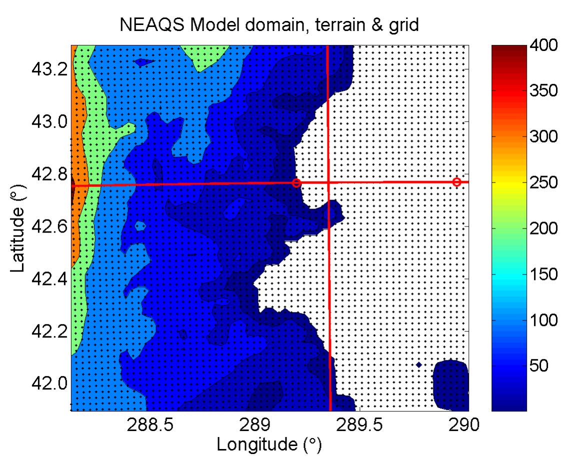


Figure 1. The NEAQS model domain, showing terrain heights in color shading, model grid points (black dots) and two target points used in this study (red circles). The north-east corner of Cape Cod is visible in the lower right corner of the domain and Boston is situated in the bay south of the model center.

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The need to better understand this complex system partly arises from its impact on transport and dispersion of airborne pollutants. When pollutants from coastal emissions are transported out over colder water, the increased static stability reduces mixing, thus maintaining high local concentrations. If a sea breeze subsequently transports air in over land again, this can lead to high concentrations of pollutants at locations very far from the emission sources. The exact timing of mesoscale circulations with respect to emissions and to the time scales of chemical conversions is critical.

## 2. THE NEW ENGLAND AIR QUALITY STUDY

The New England Air Quality Study (NEAQS 2002) was conducted in July and August 2002 (e.g. Angevine et al. 2004a, b, http://www.al.noaa.gov/neaqs for details). The background to NEAQS was the frequently exceeded regulatory standards for ozone along the coast of New Hampshire and Maine, in spite of limited local emissions of pollutants. These are instead located farther south, e.g. along the Boston/New York metropolitan corridor and are often transported to these coasts across colder ocean water; a persistent pool of cold water typically exists offshore in the northern and eastern Gulf of Maine and the Bay of Fundy. As a result, high-pollution episodes here are often not related to stagnation periods as in some other highly polluted coastal areas, for example Los Angeles in California or Athens in Greece.

## 3. MODEL SIMULATIONS

The aim of this study was to investigate effects of sea breezes and other coastal effects on the dispersion in this area, using a passive tracer released in a mesoscale model. The model used here was COAMPS™, developed at the Naval Research Laboratory in Monterey, California, (Hodur 1997). Simulations were performed for two episodes, 11 – 15 August and 21 – 24 July, see Angevine et al. (2004b). The simulations utilize the tracer routine that is part of COAMPS™ and the model was run in two configurations. In the first, four domains were nested into 6-hourly analyses from the European Centre of Medium-Range Weather Forecasts (ECMWF), with a target resolution of 2.5 km (see Figure 1) and the tracer was released over an area representing Boston. The second set of runs used three domains and a target resolution of 7.5 km to resolve tracer released separately from New York and Boston, and dispersed over a larger area. All simulations use 40 vertical levels to 31 km, with 13 levels below 1 km and 5 below 100 m. The tracer is considered inert and does not deposit. It was released at a constant rate from each horizontal grid point in the release area and was instantly mixed through the lowest ~ 25 m. When tracer was released from the two different

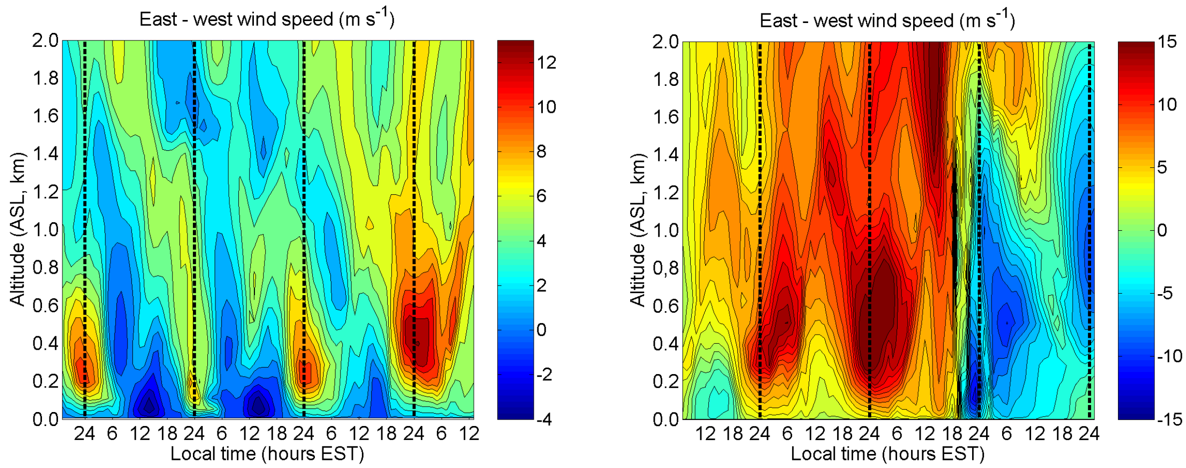


Figure 2. Time-height cross-sections of cross-coast wind speed component (ms$^{-1}$) taken at the coastal point outlined in Figure 1, for (left) 11 – 15 August and (right) 21 – 24 July, 2002.

metropolitan areas, it was artificially kept separated to be able to compare their respective contribution. Note that since the area of New York is significantly larger than the Boston area, there will be more total tracer mass coming from New York than from Boston.

## 4. MODEL RESULTS

The temporal development of the cross-coast wind speed component at a coastal location (see Figure 1) for the two time-periods is illustrated in Figure 2. For the Aug gust episode the background off-shore flow is about 3 – 5

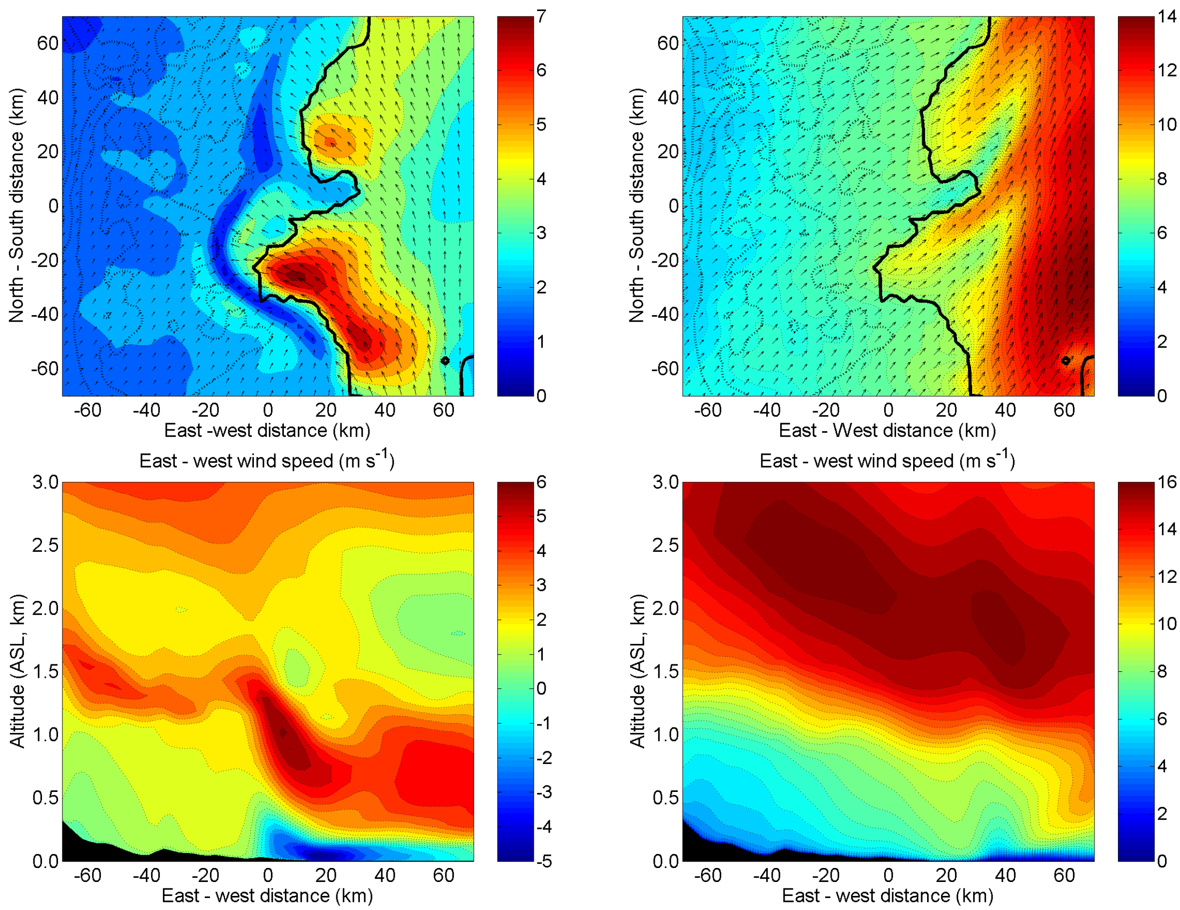


Figure 3. Horizontal cross sections at the height of ~ 50 m above the surface (top) and vertical cross-sections of the cross-coast wind component (bottom), for (left) 13 August and (right) 23 July, all at 14 EST.

5 ms$^{-1}$ and there are obvious sea breezes for the three days 12 – 14 August, although weaker on the last day. On the 15th no sea breeze occurs, due to the onset of a stronger off shore flow, presumably due to a changing synoptic scale flow. Another significant feature for this time-period are the cores of quite strong low-level off shore flow during the nights, well over 10 m s$^{-1}$. The second episode, in July, also starts with a sea breeze on 21 July, but during the two days that follow, 22 – 23 July,

The cross-coast wind component never reverses, although there is a clear day-time low-level reduction indicating a sea-breeze like component, superimposed on a stronger background off-shore flow. Interestingly, the strong off-coast flowing nighttime jets occurs also here even stronger. Into the evening of the 23rd a sharp frontal zone passes after which the background flow below ~1.5 km becomes on-shore.

Figure 3 shows horizontal cross-sections of the boundary-layer (~ 50 m) wind field in the early afternoon of 13 August and 23 July, respectively (top panels). It is clear that the first case is dominated by a sea breeze. Actually, there are two separate systems with Cape Ann in the middle, and the effect of the local coastline geometry is obvious; the circulation on the 12th is very similar. In the second (July) case, the effects of the land/sea temperature contrast are subtler. The background offshore flow is stronger, but the low-level winds offshore are much stronger and more southerly than inland. This may be the geostrophically balanced response to the east-west temperature gradient occurring when the off-shore background flow is strong enough to prevent the formation of a proper sea breeze. Local acceleration of the flow is also found along pieces of the coast with a local partly north-south oriented coastline and thus an east-west oriented temperature gradient, see for example along the southern parts of Cape Ann.

The vertical cross-sections of the cross-coast wind component show a clear sea breeze with an anvil-shaped front on 13 August. The offshore flow aloft resembles a gravity wave rather than a traditional so-called return flow. Although the second episode has no proper sea breeze, it is clear that the offshore flow is decelerated offshore in the lowest 100’s of meters. The vertical winds (not shown) also feature an up/down-wind couplet

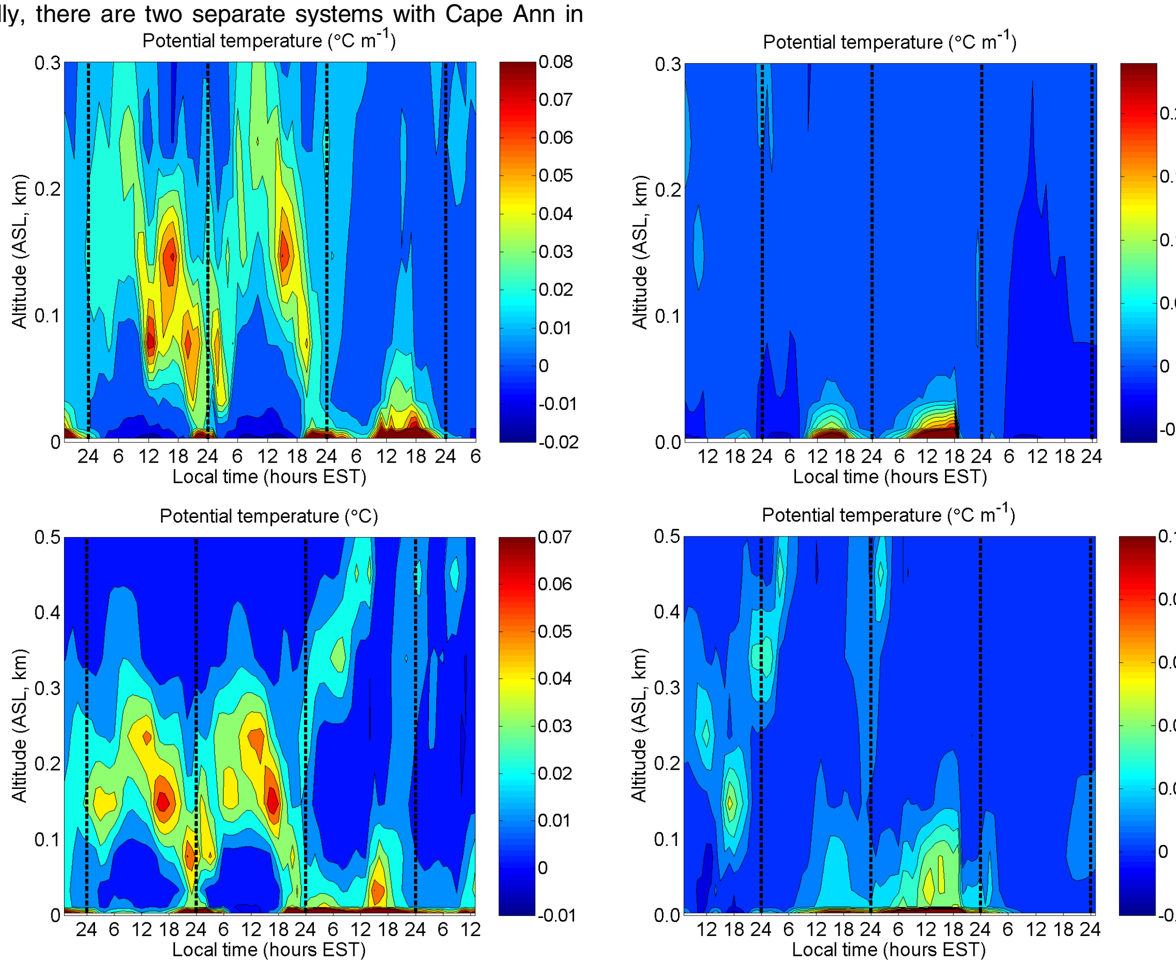


Figure 4. Time-height cross-sections of the vertical gradient of the potential temperature for (left) the August and (right) the July case, for locations (upper) near the coast and (lower) some 60 km off shore.

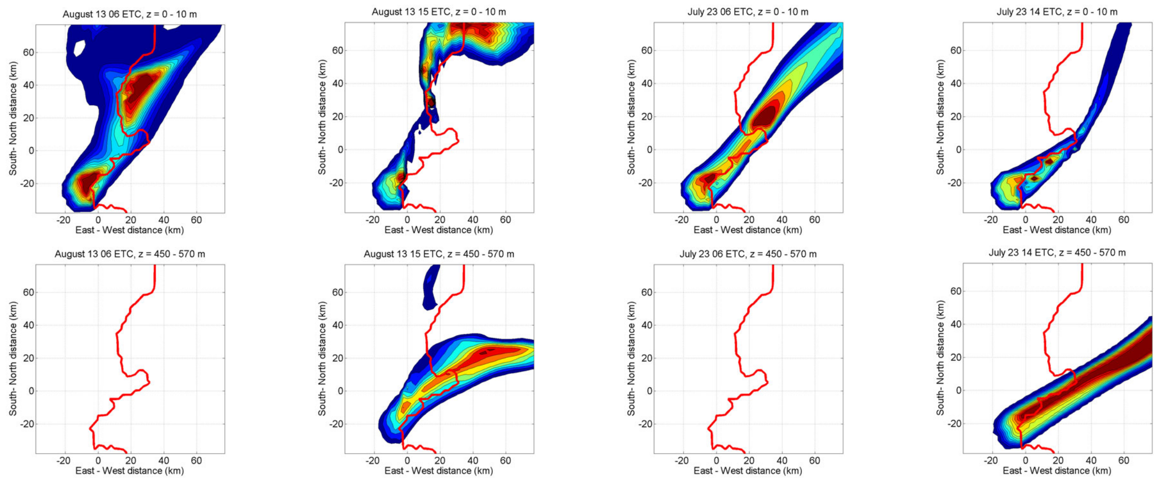


Figure 5. Tracer concentration in arbitrary scales from emission over Boston on 13 August (four left panels) and 23 July (four right panels) for the early morning and mid-day at two heights, near surface (upper row) and around 500 m (upper row) – see each panel for details.

in both cases, for 13 August in association with the obvious sea breeze front and for 23 July in a zone off shore, indicating low-level convergence.

Although the diurnal behavior of the inland boundary layer is reasonably well understood, the off shore boundary layer in situations like this is not well understood. Figure 4 shows the temporal development of the vertical temperature gradient at two locations along the transect in Figure 1, near the coast and far (~ 60 km) offshore. The August case, with a significant sea breeze, shows a development of a well-mixed layer capped by an inversion descending to a surface inversion as the sea breeze stops each afternoon. This mixed layer becomes somewhat deeper farther off shore. In contrast, the July case with off shore flow, a relatively persistent surface inversion forms immediately offshore, that only deepens somewhat with off shore distance.

## 5. DISPERSION

To illustrate the effects of these two cases, with and without a proper sea breeze, on the dispersion, plots of tracer concentration (arbitrary color scale) are shown in Figure 5 for two heights on August 13 and July 23, respectively. In both cases, the early morning plume is shallow and does not reach the 500 m level in the model. The early morning low-level concentration in the case with a weaker offshore flow has quite high concentrations at the source area and in a broad plume offshore mostly following the coast. The case with a higher offshore wind has much narrower and linear plume, more or less being advected downwind. At the peak of inland heating, the sea breeze on 13 August has taken the low-level plume and advected it inland while the deeper inland boundary layer, with intense vertical mixing, has caused a deeper plume that at heights above the seabreeze is advected off-shore with the background flow. The higher parts of the 23 July plume are also advected offshore, while the low-level plume is caught in the low-level convergence (see Figure 3), thus forming a narrow bent plume that tend to follow the coastline. The longer-range dispersion is illustrated in Figure 6. Note that this is a snapshot although the concentration obviously shows the integrated effects of several days. For the period dominated by a sequence of sea breezes (August 11 – 15), the tracer released from both Boston and New York combine to high concentrations along the entire coast. The plume is piece-wise patchy and one may imagine the contributions from successive coastal convergences, due to each days sea breeze, being advected up the coast. For the concentrations at higher levels, the tracer released from New York dominates the concentrations far up the coast; this may be an artifact of the higher total amounts of tracer released over New York due to its larger area. For the July 21 – 24 episode, concentrations reaching far north show a more equal division between releases from the Boston and New York areas, but the concentrations are lower than during the August episode. The plumes at higher elevations show a larger dispersion and a clear tendency to be advected downwind and offshore but still makes landfall in Canada, due to the wind direction in this particular case. It is clear however, that for both episodes the near-surface concentrations are highest along the coastline and remain so for large distances away from the emissions sources.

## 6. SUMMARY

The New England Air Quality study was conceived to understand observed high-pollution episodes in an area with small local emissions of pollutants. This study uses the dispersion of a passive tracer in a high-resolution model mesoscale model to attempt an understanding of the meteorological processes responsible for high-pollution episodes observed during NEAQS.

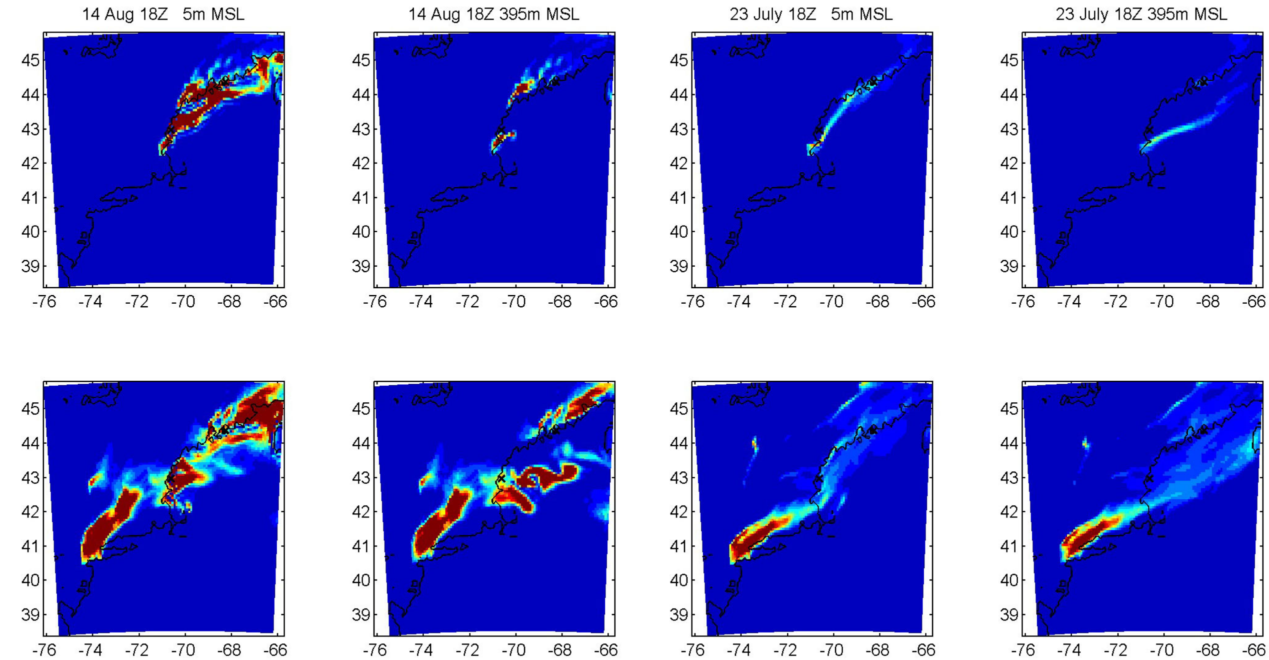


Figure 6. Tracer concentrations calculated on the larger and coarser grid for (left) 14 August and (right) 23 July, both at 11 EST, for tracer released (top) from Boston and (bottom) New York for two heights (see figure legend).

It is clear that coastal mesoscale atmospheric phenomena have a strong impact on the dispersion both on a local but also on a regional scale. It is rather self evident that a sea breeze will have a large local impact on the transport of a pollutant plume, but the convergent character of the sea breeze front has received less attention. It seems that the largest near-surface concentrations occur in the sea breeze front. Also, the convergent behavior of the local flow in cases where a proper sea breeze is prevented by strong synoptic scale flow is overlooked. At least in the simulations carried out here, the low-level tracer follows the coast for a quite long distance, even in cases where the elevated part of a plume is advected off shore.

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