Illinois Wind Resource Maps and Methodology
40 meters and 80 meters

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October 2015

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Methodology

Wind Sensitivity and Distribution Analysis

Provided to us was hourly wind data at nearly 40 sites across Illinois. The data included surface temperatures and wind speed/direction at multiple height levels, usually between 10 and 70 meters, for time periods lasting anywhere from several months to three years. Our goal was to extrapolate 40 and 80 meter wind speeds from these data points across the entire state. From the data we had available, we elected to apply the wind profile power law (eq. 1) to the wind speeds we had available.

$$\frac{u_x}{u_r} = \left(\frac{z_x}{z_r}\right)^{\alpha} \qquad \text{(Eq. 1)}$$

Referring to equation 1, u_x is the wind speed at any height z_x, given a reference wind speed u_r at a reference height z_r. The exponent, α, is a coefficient that describes the present stability of the atmosphere. In past studies, it has been determined that a constant value of 1/7 for α would be acceptable for wind power assessments such as this. However, we believed this value to be inaccurate for such a large study area, and that α can be significantly variable at times. To verify this suspicion, we chose to calculate α at every time interval and compare these values to the accepted value of 1/7. Rearranging equation 1 to solve for α gives us:

$$\alpha = \frac{\log_{10}\left(\frac{u_x}{u_r}\right)}{\log_{10}\left(\frac{z_x}{z_r}\right)} \qquad \text{(Eq. 2)}$$

This was then used to determine α at every time step. From this point, an average α could be calculated for each station, and then 40 and 80 meter wind speeds could be extrapolated. However, some inconsistencies in the data led to obstacles that needed to be overcome.

Firstly, not every station had readings at the same heights. Some stations had data starting at 30m, while others started at 10m, and maximum height levels varied from 30m to 70m. This meant that determining α for each station required different heights to be used. For the best possible uniformity, α was found at each station by comparing the wind speeds at the lowest and the highest heights for each station.

Secondly, about 1/3 of the stations already had 40m winds documented. For consistency's sake, 40m winds were still extrapolated from lower levels using the power law. The recorded 40 m winds were kept only for comparison.

Thirdly, every station ran for a different time period. Most data spanned anywhere from 2004 to 2008, with each station possessing only about one year's worth of data. Seasonal and yearly variations may have been a factor when calculating an average α across the entire life span of the stations. This, however could not be easily controlled, so no adjustments based on time of year were made.

Lastly, and most importantly, using two heights to derive α at a time resolution of anywhere from 10 minutes to an hour, wind speeds proved to be quite erratic and varied quite largely from one height to another. Because of this variable nature of the measurements, α could have been determined to be anything from -3 (negative α meant winds decreasing with height) to 3 (positive indicated an increase in wind speed with height), when values between 0 and 1 were expected. Most likely, data falling outside the range of 0 to 1 were considered outliers, since α had such a large opportunity to vary between time steps. To avoid possible skewing of averages, a filter was applied to each station set of data, so that only values within a certain window would be included in the calculation. However, since α could be very different between stations, we chose to use a dynamic filter, based on a frequency chart of the values for each station. The goal was to include at least 60% of the data in the filter. The remaining alpha values that satisfied the filter requirements were then averaged together to produce a single value for each station. These values were tabulated along with their respective latitude and longitude coordinates so as to ready the data for use in a GIS framework.

GIS Analysis and Interpolation

The outlined procedure for the GIS portion of the project consisted of interpolation of alpha values, extraction of interpolated values to a network of Automated Surface Observing System (ASOS) stations, and then later re-interpolation of the 40 and 80 meter winds with a more substantial sample size consisting of both IIRA provided stations and newly integrated ASOS stations.

The input data for this experiment consisted of point shapefiles containing wind data within the attribute table and a 3 kilometer DEM-derived curvature raster. A 3 kilometer resolution for DEM was deemed sufficient for the purposes of this project due to its ability to still accurately visualize wind-topography interactions. Furthermore, high resolution wind sensitivity would not be possible considering the limited amount of station points. Therefore, the use of a 10-30m DEM during the project would offer very little to no benefit and would only greatly lengthen the computational time required for each process.

The initial sample of wind stations was deemed insufficient for interpolation due to the irregular spacing of stations and sparse coverage provided by the network. However, the combination of IIRA provided stations with ASOS stations would result in a dense network of observation sites that would then allow for a more effective interpolation. However, the lack of any observations above the surface within ASOS networks meant that alpha values derived from the preexisting multi-level wind observation stations needed to be applied to the ASOS stations.

Two methods were employed when determining how to extract alpha values derived from the IIRA provided stations to the ASOS stations. The first method was done by first loading the table of alpha values created in the last portion and displaying them in ArcMap 10.3.1 as point shapefiles. The projection used for this shapefile (and all subsequent data) was the UTM Zone 16 projection. We decided on interpolating alpha values, extracting the values from the resulting raster to ASOS station points, and then extrapolating ASOS surface wind values upwards to 40 and 80 meters. When determining interpolation methods, it was decided that cokriging would be the most appropriate method. Other methods were considered such as IDW and Spline, however there were glaring errors such as artificially delineated "barriers" between different data categories and "bullseye" effects. A similar study done in England advocated for the use of the cokriging method as its potential for the inclusion of a second variable in the interpolation process allowed for a better estimation of regions with sparse station coverage (Luo, Taylor, Parker 2007). A cokriging interpolation method was used with the 3 kilometer curvature raster file as the variable in which wind was cokriged against.

The second method involved a regressional analysis with alpha as the dependent variable and curvature readings as the independent variable. An equation was formulated based on the relationship between IIRA alpha values and their curvature readings. This equation was then applied to curvature values of all ASOS stations which did not possess an alpha value. The result was a derived alpha value for each station.

It was decided that the alpha values from the regressional analysis would be used over the values acquired from interpolation due to the uncertainty in the validity of the interpolated alpha map due to limited sample size.

Derived alpha values were then extracted to the ASOS station points and used in conjunction with the wind profile power law to extrapolate ASOS values upwards to 40 and 80 meters. With the wind values successfully extrapolated, a combined network of IIRA and ASOS stations was developed and loaded into ArcMap as a point shapefile. A trend analysis run on the point shapefile indicated the presence of a slight binomial trend amongst the data. Another cokriging operation was performed with the combined station wind observations and 3 kilometer curvature raster with the binomial trend removed. This allowed for a more effective interpolation and reduced the chance for any skewed readings. Initial interpolation runs using Illinois ASOS and IIRA stations showed signs of an edge effect along the outside boundaries. An edge effect is defined here as an artificial reduction or increase in value along the borders of a study area. To rectify this problem, ASOS stations within 60 miles of the Illinois border were included in the interpolation process which included a re-extraction of alpha values to these new station points and then reinterpolating them. The new resultant interpolated wind map still showed remnants of the edge effect but to a less severe extent.

Upon completion of the interpolation procedure, the data was smoothed with a 15 kilometer focal mean window and then clipped to the border of Illinois. The smoothing procedure reduced the accuracy of the map in terms of real world values, but facilitated visual analysis of wind speed in a relative sense. That is, wind speed values (in mph) were reduced in accuracy, but the perception of the strength of wind areas in relation to other areas within the state was improved.

A series of error statistics were performed comparing interpolated raster values to input wind observation readings. The average error at 40 meters was about 1.6 mph and the average error at 80 meters was about 1.8 mph. This error difference highlights a problem with interpolation of meteorological data. Wind, in particular, exhibits a strong local sensitivity to factors such as land use, terrain roughness, and slope. This sensitivity cannot thoroughly be accounted for in GIS.

Page 5: Illinois Wind Resource Map 40 Meters

Page 6: Illinois Wind Resource Map 80 Meters

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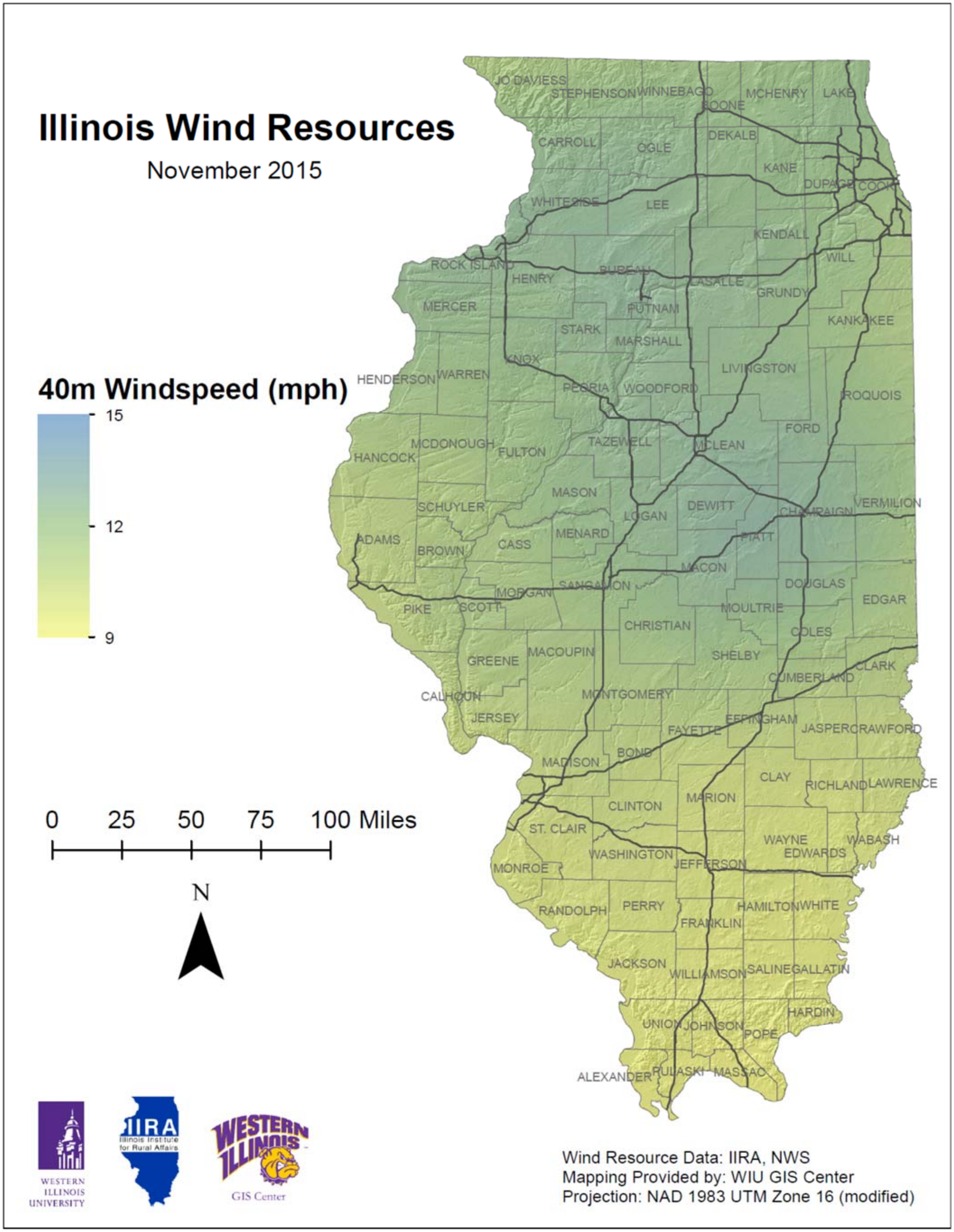
Illinois Wind Resources
November 2015
40m Windspeed (mph)
15
12
9
0 25 50 75 100 Miles
N
JO DAVIESS
STEPHENSON
WINNEBAGO
BOONE
MCHENRY
LAKE
CARROLL
OGLE
DEKALB
KANE
DUPAGE
COOK
WHITESIDE
LEE
KENDALL
ROCK ISLAND
HENRY
BUREAU
LASALLE
WILL
GRUNDY
MERCER
PUTNAM
KANKAKEE
STARK
MARSHALL
KNOX
LIVINGSTON
HENDERSON
WARREN
PEORIA
WOODFORD
IROQUOIS
FORD
MCDONOUGH
TAZEWELL
MCLEAN
HANCOCK
FULTON
MASON
DEWITT
CHAMPAIGN
VERMILION
SCHUYLER
LOGAN
PIATT
ADAMS
BROWN
CASS
MENARD
MACON
MORGAN
SANGAMON
DOUGLAS
EDGAR
PIKE
SCOTT
MOULTRIE
CHRISTIAN
COLES
GREENE
MACOUPIN
SHELBY
CLARK
CUMBERLAND
CALHOUN
MONTGOMERY
JERSEY
EFFINGHAM
JASPER
CRAWFORD
FAYETTE
BOND
MADISON
CLAY
RICHLAND
LAWRENCE
CLINTON
MARION
ST. CLAIR
WAYNE
WABASH
EDWARDS
WASHINGTON
JEFFERSON
MONROE
RANDOLPH
PERRY
HAMILTON
WHITE
FRANKLIN
JACKSON
WILLIAMSON
SALINE
GALLATIN
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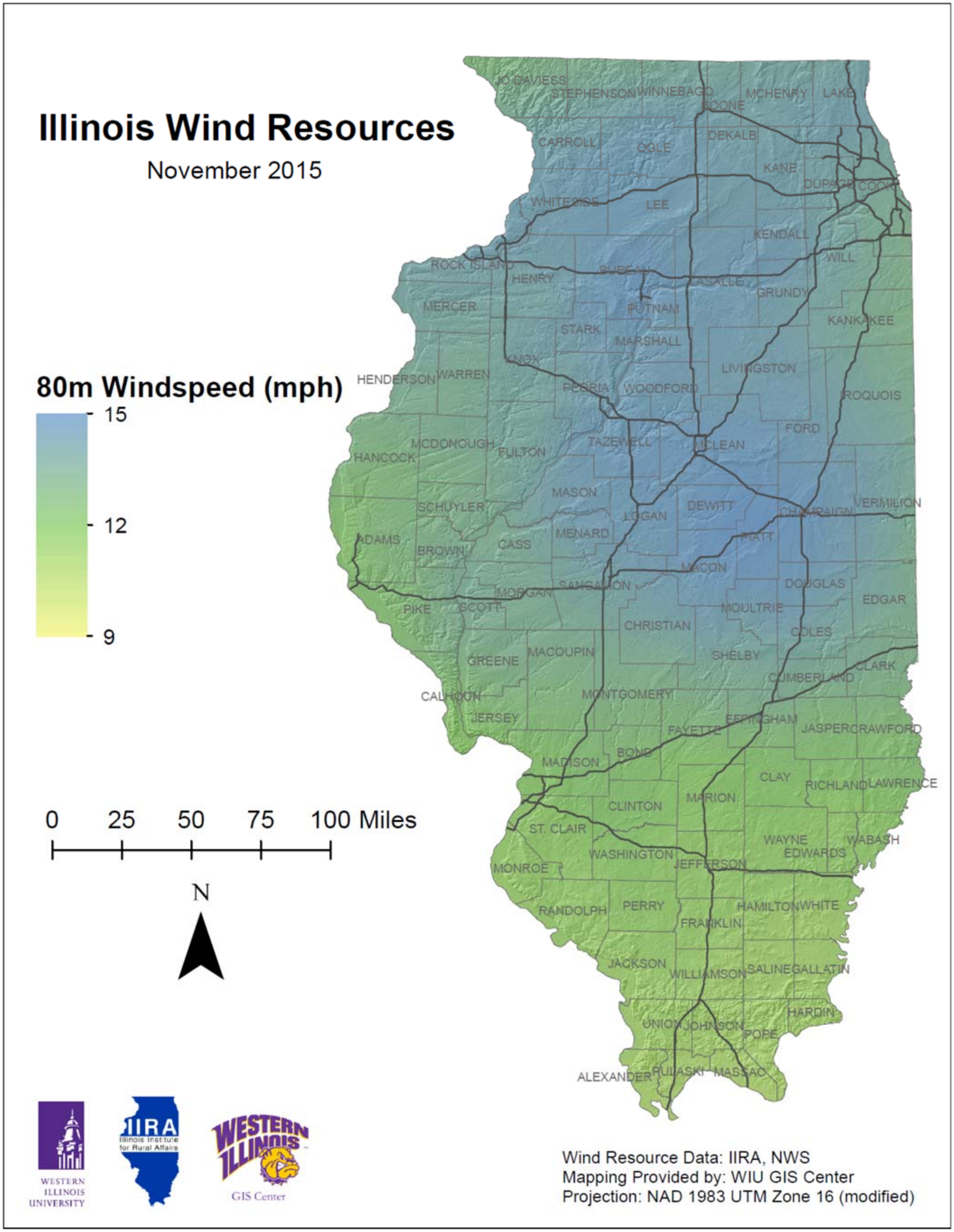
GIS Center
Wind Resource Data: IIRA, NWS
Mapping Provided by: WIU GIS Center
Projection: NAD 1983 UTM Zone 16 (modified)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PUTNAM
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