Climatic Visibilities of the United States[1]

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ABSTRACT

Climatological visibility data for fifty-three sites is used to evolve seasonal visibility maps of the United States. The analysis is presented in the form of cumulative visibility frequency distribution maps. A brief discussion of their use and limitations to describe atmospheric opacity is included.

1. Introduction

Regular observations of visibility probably first became a part of "the Ship's Log" during the 18th century, though visibility was often noted centuries before when man first put to sea. With the coming of the age of aviation, visibility became a routine observation with the emphasis on specifying lower visibilities. Even in the 20th century, reduced visibility still remains a problem to "all-weather aircraft." Visibility is an important atmospheric environmental property which must be considered as an input to the analysis of tactical and strategic systems, especially those systems which utilize human observation and/or the detection of ultraviolet, visible and infrared radiation.

Optical wavelengths of electromagnetic radiation are attenuated, in varying degrees, by the medium through which they are transmitted. All atmospheric constituents, such as haze or dust aerosols, air molecules, fog droplets, precipitation elements, etc., contribute to increasing the atmospheric opacity. The most common, but by no means precise, description of the atmospheric transmissivity is the meteorological visibility. Estimates of the prevailing visibility are made by trained weather observers throughout the world. Though these subjective estimates of visibility have inherent limitations, they are available and applicable indicators of the atmospheric opacity.

2. Descriptions of atmospheric opacity

Atmospheric opacity is a general term used to describe the ability of the atmosphere to attenuate electromagnetic energy. In the optical portion of the electromagnetic spectrum, it is generally defined as the attenuation coefficient, σ, which is composed of two primary parts, i.e.,

$$\sigma=\sigma_s+\sigma_a, \tag{1}$$

where σ_s is the scattering coefficient and σ_a is the absorption coefficient. The atmospheric opacity at a wavelength of 0.55 μ is related to visibility, V, by the empirical equation

$$V=\frac{3.912}{\sigma}, \tag{2}$$

where the units of visibility and of atmospheric opacity are the same. The wavelength of 0.55 μ is used because it is the wavelength of maximum relative luminous efficiency of the human eye for photopic vision (Walsh, 1953).

Atmospheric visibility. Visibility may be simply defined as the clarity with which an object can be seen. According to Huschke (1959), a more informative definition, the one in common use in the United States, is that the visibility is "the greatest distance in a given direction at which it is just possible to see and identify with the unaided eye: in the daytime, a prominent dark object against the sky at the horizon; and at night, a known, preferably unfocused, moderately intense light source. After visibilities have been determined around the entire horizon circle, they are resolved into a single value of prevailing visibility for reporting purposes."

Difficulties with the conventional requirement that an object be both detected and recognized are avoided with the more rigorous definition of visual range. If the recognition requirement is deleted, the visibility becomes a subjective estimate of the visual range. Daytime estimates of visibility are subjective evaluations of the range at which the threshold of contrast is just reached, while estimates of visibility at night represent attempts to evaluate the reduction of flux density. This results in visibility data falling into two classes: those obtained during daylight, and those at night.

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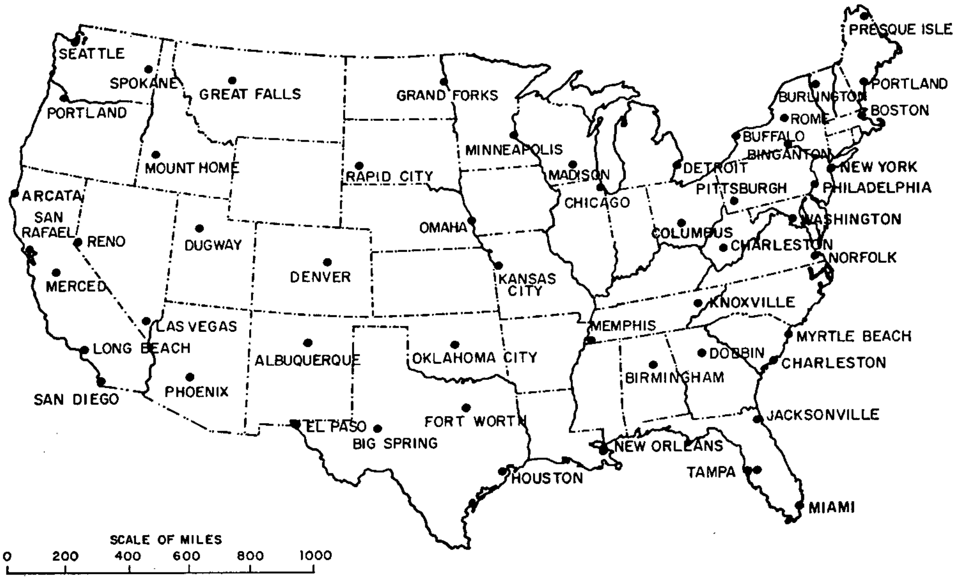

FIG. 1. The geographical locations of the fifty-three U. S. Weather Bureau and U. S. Air Force Air Weather Service stations for which climatic visibility data were used.

The theory of day and night visibility is treated in detail by Middleton (1952). He also discusses the techniques and problems associated with estimates of visibility. Middleton (1951) summaries the status of visibility in meteorology as "the theory—being in fairly satisfactory condition—" but in reference to instrumentation techniques to "measure the appropriate optical constants of the atmosphere—" he states that "theory—is well in front of practice." He further states "that the chief reason for this state of affairs is to be found in the definition of 'the visibility' itself."

Visual range. The visual range is "the distance, under daytime conditions, at which the apparent contrast between a specified type of target and its background become just equal to the threshold contrast of an observer" (Huschke, 1959). This is not true for nighttime visual range for the reason expressed above. The visual range is a function of the atmospheric attenuation coefficient, the albedo, and the visual angle of the target as well as the observer's threshold contrast at the moment of observation. The visual range V_R may be expressed as

$$V_R=\frac{1}{\sigma}\ln\frac{|C|}{E}, \tag{3}$$

where $|C|$ is the absolute contrast of the visibility target and E is the momentary threshold contrast. The visibility or, more exactly, the meteorological range may be determined for the case of a black target where $|C|$ equals unity, and the commonly used threshold of $E=0.02$, which is considered applicable for a human observer during the daytime. Under these conditions Eq. (3) reduces to Eq. (2). Middleton (1948) has defined the meteorological range "as the distance for which the contrast transmittance of the atmosphere is two per cent."

Climatic visibilities. The concept of climatic visibility evolves from the above discussion. Observations of visibility or visual range, as the case may be, are summarized as to the percentage of time the visibility is less than a minimum value, between specific visibilities, or greater than a specific value. Routine observational data is summarized, tabulated by the United States Weather Bureau in terms of monthly averages, and deposited at the National Weather Records Center. Climatic visibilities are expressed as the distance at which an object can be seen, i.e., the visual range. Normally, climatic summaries of visibilities do not consider the nature of the obstructing atmosphere. This deficiency must be recognized and considered when using climatic visibilities in a practical application.

3. Seasonal climatic visibility data

The climatic visibility data used in this study were obtained from fifty-three sites staffed by U. S. Weather Bureau and U. S. Air Force Air Weather Service personnel (Fig. 1) during a period of approximately ten years between 1948 and 1958. The monthly visibilities were averaged into seasonal averages and plotted as cumulative frequencies of occurrence for each season. Spring includes the months of March, April and May; summer, June, July and August; autumn, September, October and November; and winter, December, January and February. The cumulative frequency curves are terminated (100 per cent) at a maximum visibility of 80 kilometers. This assumption must be made because during good seeing conditions the visibility is reported by weather observers as being greater than the local horizon or the most distant known object used as a range marker. Therefore, a maximum visibility had to be postulated in order to construct the cumulative frequencies of visibility for each geographic location. Obviously, this is a compromise because the maximum visibility can be quite different for various regions of the country.

4. Seasonal visibility analysis

After constructing the seasonal cumulative frequency of visibility for each location, seasonal maps were plotted in terms of the percentage of time of occurrence of visibility less than a specific distance. The visibility frequency distribution maps, Figs. 2 through 6, represent the percentage of time during each season when the visibility is less than 2.5 km (Fig. 2); less than 5.0 km (Fig. 3); less than 10 km (Fig. 4); less than 20 km (Fig. 5); and less than 40 km (Fig. 6). Isopleths of frequency of occurrence of visibilities less than a specific value are drawn for each ten percentiles, and for smaller increments when these isolines will aid interpolation for specific geographical locations. The zero per cent isopleth should be interpreted as meaning that visibility occurs a negligible per cent of the time.

5. Application and limitations of visibility maps

The visibility frequency distribution maps are considered to be a general summary of climatic visibility data. As such, they are of interest to the climatologist and meteorologist and have direct application in systems analysis.

The most gross limitation of the visibility maps is that they are at best a macroscale representation of mesoscale phenomena. These maps can only indicate the general climatic visibility for various regions of the United States. Visibility observations are generally made at airports, located in the suburbs, because of the needs of aviation. How representative these observations are of urban and rural regions of the United States is subject to question, and indeed would make an interesting study. Local influences on visibility, such as terrain, pollution sources (both industrial and natural), etc., are immersed in the resulting climatic visibility maps.

An inherent limitation to the visibility maps results from the use of climatic visibility data. Climatic visibilities are summaries of observed horizontal visibilities with no consideration being given to the nature of the obstruction; that is, whether the reduced visibility is caused by haze, smoke, fog, rain, snow, etc. This deficiency in the tabulation of climatic visibilities must be recognized and considered when atmospheric transmissions are computed for specific wavelength regions.

The use of climatic visibility maps to assess the range of an optical sensor or human observer requires the employment of an atmospheric model. Most such models are limited to haze weather conditions. These models, realistic as they may be, are nevertheless restricted to atmospheres composed of haze aerosols

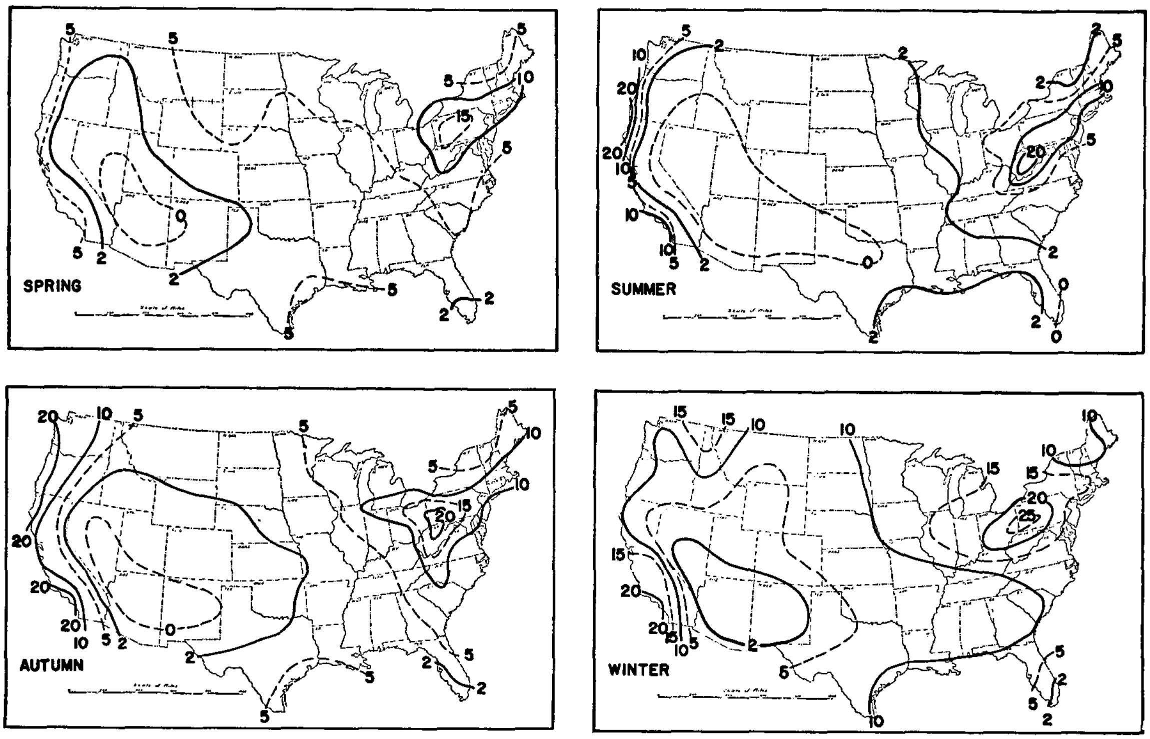

FIG. 2. Percentage of time by seasons the visibility is less than 2.5 km.

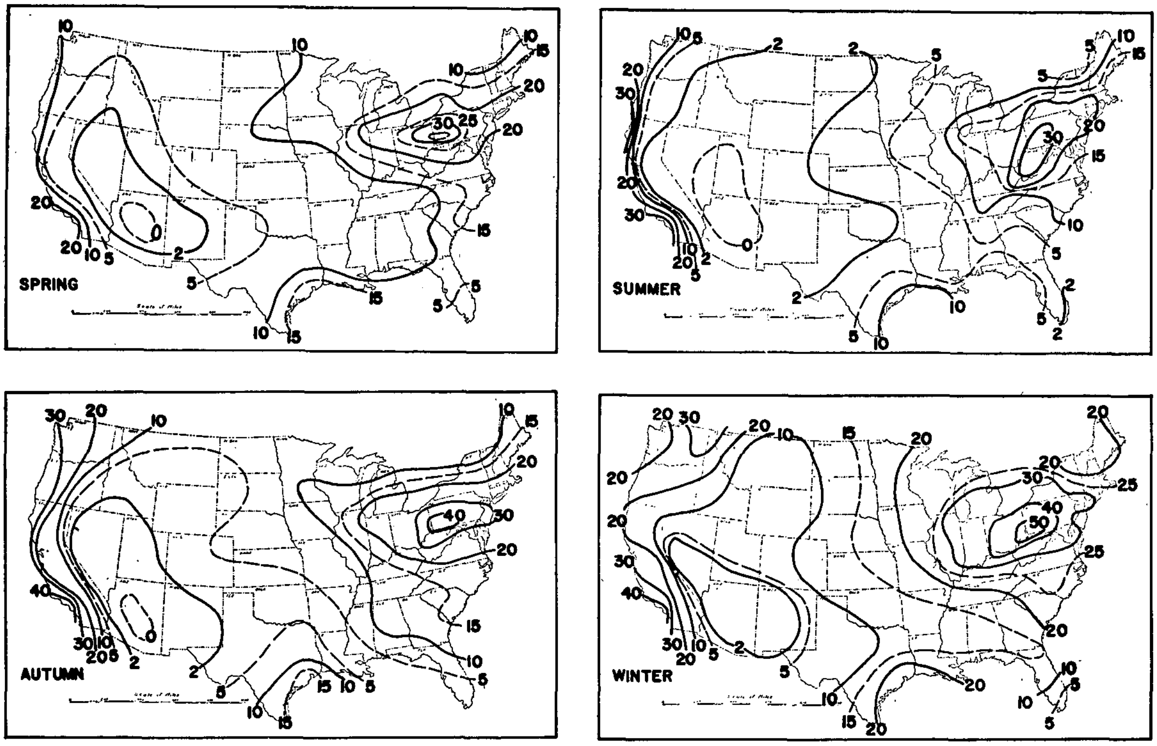

FIG. 3. Percentage of time by seasons the visibility is less than 5.0 km.

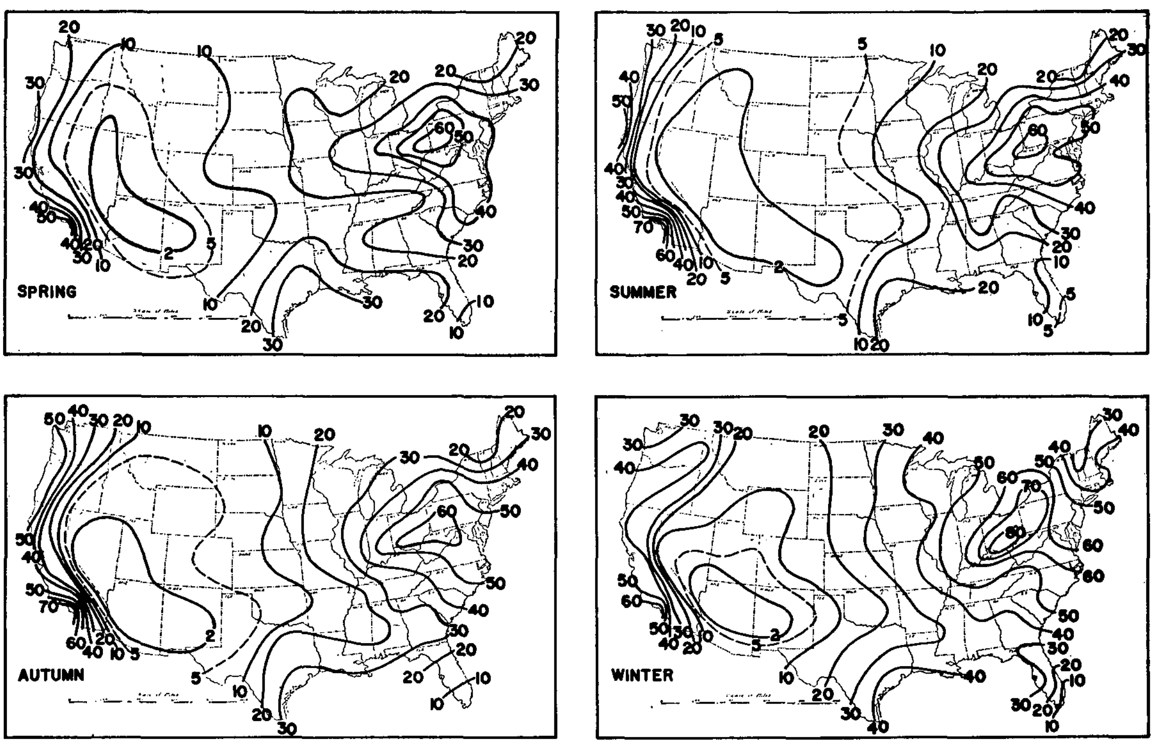

FIG. 4. Percentage of time by seasons the visibility is less than 10 km.

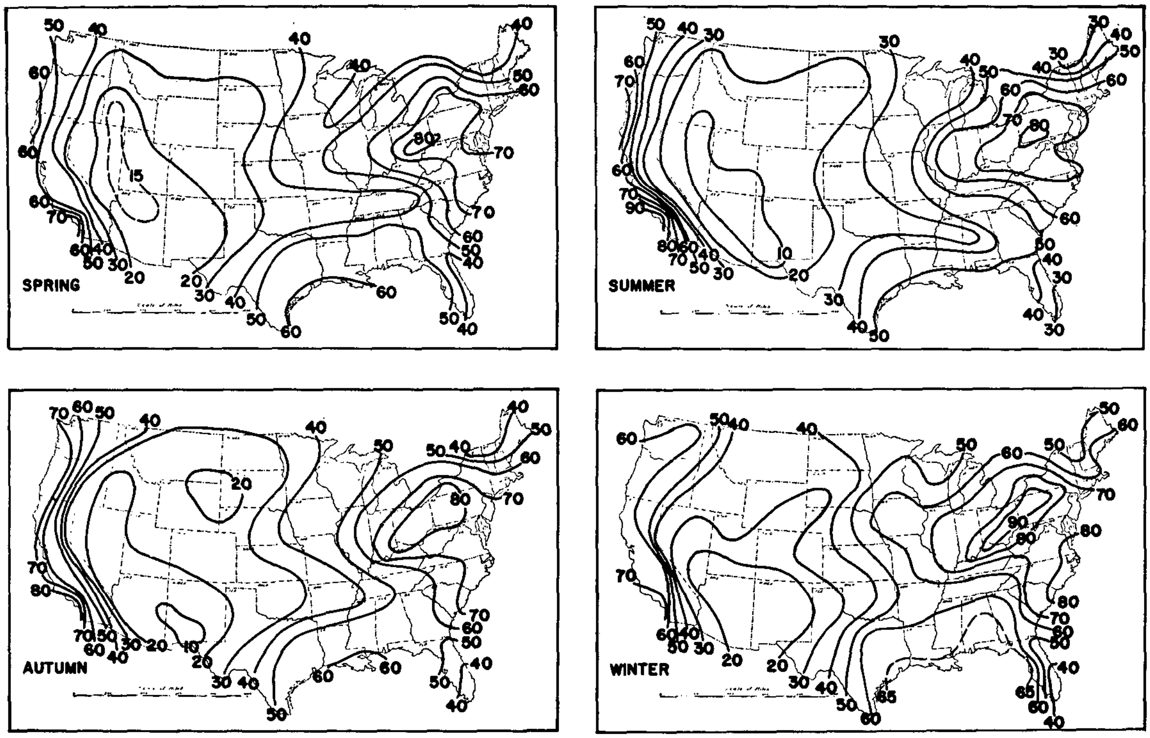

FIG. 5. Percentage of time by seasons the visibility is less than 20 km.

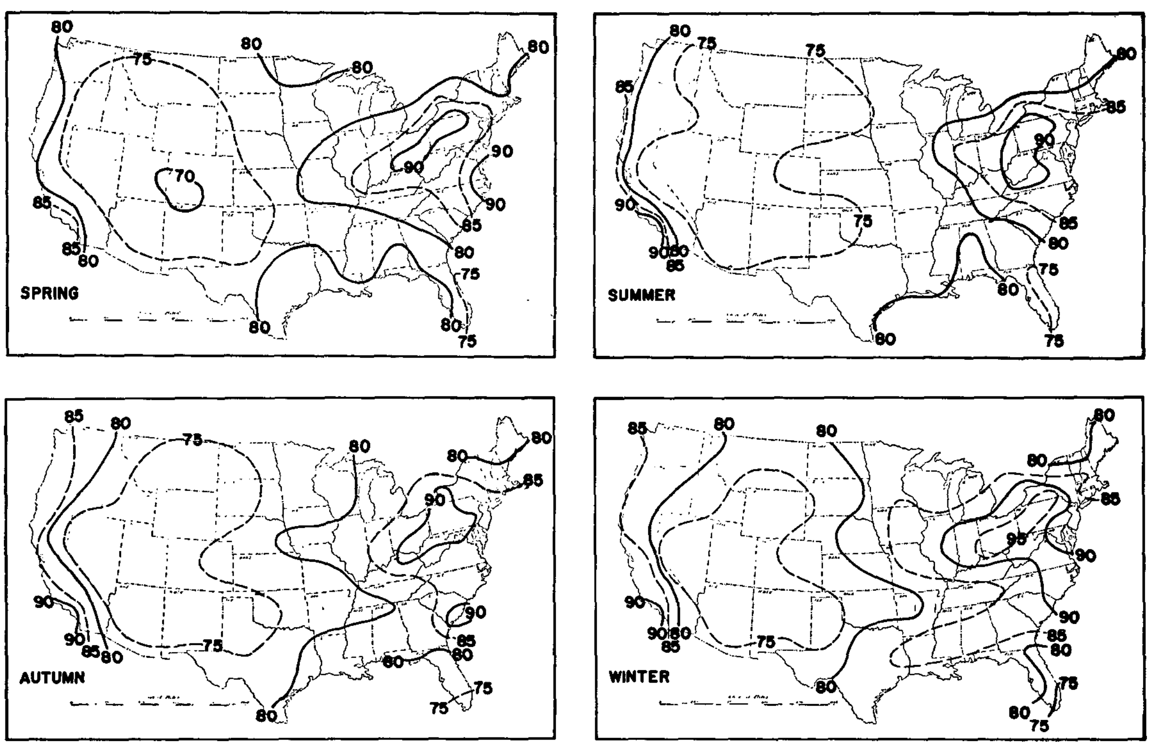

FIG. 6. Percentage of time by seasons the visibility is less than 40 km.

which decrease in concentration with increased altitude. When the visual range deteriorates to less than a kilometer, it is doubtful that the atmosphere can truly be called hazy, but rather is becoming foggy. As noted above, climatological summaries of visibilities are not normally correlated with the particular atmospheric obstruction to the visibility; therefore, when using climatic visibility data with an atmospheric model, consideration must be given to the aerosol distribution of the medium through which the thermal radiation is being transmitted.

The climatic visibilities used in this analysis are monthly averages, which, like most statistical representations, cannot be applied reliably to a particular time and/or place. The visibility frequency maps are, at best, seasonal averages, whereas it is the daily (even hourly) visibility with which the operating system is concerned. However, these maps have considerable usefulness as a guide in determining the performance capabilities of nationwide optical surveillance systems and the seasonal transmission properties of the atmosphere.

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