Environmental Factors in Traffic Accident Reconstruction Determining Ambient Lighting Conditions

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Driver vision is a factor in every traffic accident and ambient lighting may need to be considered. The most common situation is one involving a pedestrian. Was there sufficient light and contrast for a driver to see the pedestrian? This is particularly important when producing a trial exhibit that demonstrates what a driver could, or could not see, under identical conditions using still photographs or videotape.

There are legal requirements for vehicle headlights to be illuminated at certain times or under certain conditions. The time, in local laws, most often correlates with civil twilight or sunrise and sunset. Determining what effect ambient lighting has on an accident scenario, or if a driver was or was not required to have his headlights on at the time, requires a basic understanding of astronomical events and definitions of the relevant terms.

During the course of a day, the Earth rotates once on its axis, presenting the phenomena of sunrise and sunset. All celestial bodies, stars and planets included, appear in the sky at the horizon to the east of any particular place, then to cross the sky and again disappear at the horizon to the west. The most significant of these events, in regard to ordinary affairs, is the rise and set of the sun.

The definitions of relevant timekeeping and astronomical terms were first established at the International Meridian Conference in 1884. As timekeeping technology advanced, the definitions were revised and refined[1]. For precision timekeeping, the International Bureau of Weights and Measures in Paris, France, synchronizes a number of atomic clocks maintained around the world. This precision time coordination, Universal Coordinated Time (U.T.C.), is extremely important to a number of applications including the military, airlines and communications services. For the accident reconstructionist, it provides accepted time frames for the analysis of ambient lighting.

A convenient method for obtaining the correct time is to access the U.S. Naval Observatory (U.S.N.O.) Timekeeping Service[2] through the Internet. Using a web browser, the time on a local computer clock can be set to match the U.T.C. reported by the U.S.N.O. atomic clocks. Several free computer programs are available on the U.S.N.O. web site to automate the process.

Under good atmospheric conditions, the apparent diameter of the sun is 1.666°, or 100 [arc]minutes. The apparent size can be greater when the sun is at a low angle, due to atmospheric refraction. Since the sun is observed as a disk, not a small point of light, it is not seen to rise or set all at once.. Before sunrise and after sunset, light from the sun is reflected from the upper atmosphere onto the Earth. These are periods of twilight. There are specific time periods for twilight and specific times for the occurrence of sunrise and sunset.

Civil twilight, sunrise and sunset occur at different times throughout the year, and many places use Daylight Saving Time or British Summer Time. It is not practical to set numerically absolute times in local laws for the use of headlights. The requirement must be able to vary with the seasons. “Civil Twilight” is a reference commonly used to establish when vehicle lights are required. For example, a local law may require that vehicle lights be illuminated between the end of civil twilight in the evening and the beginning of civil twilight in the morning, or a variation of this concept. Civil twilight is defined to “begin in the morning and to end in the evening when the center of the sun is 6° below the horizon.”

Civil twilight is the period during which ambient illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished; the horizon is clearly defined and the brightest stars are visible. In the morning, before, and in the evening, after civil twilight, artificial illumination is required to conduct ordinary activities.

There are definitions for “Nautical Twilight” and “Astronomical Twilight,” as well. Although these events are not of great concern, it may be useful to be aware of their existence. Nautical twilight begins and ends when the center of the sun is 12° below the horizon. During the period between nautical twilight and civil twilight, general outlines of ground objects may be distinguishable, but detailed outdoor operations are not possible and the horizon is indistinct. Astronomical twilight begins and ends when the center of the sun is 18° below the horizon. During the period between astronomical twilight and nautical twilight, illumination is so faint that it is practically imperceptible.

Civil twilight is not the only astronomical event reference for the use of vehicle lights; the times of sunrise and sunset may be used. Sunrise and sunset occurs when the upper edge of the sun is at the horizon, unobstructed to the observer. To be more precise, “sunrise or sunset occurs when the center of the sun is at 90.8333°, or 0.8333° below the horizon.”

Horizon is another term that requires definition. Wherever one is located, the Earth can be perceived as a flat plane. The sky resembles one-half of a sphere centered over the observer. If there are no visual obstructions, such as buildings, mountains or trees, the apparent intersection of the sky with the Earth is the horizon. For astronomical computations, the observer is considered to be on the

Earth and the horizon is a level line 90° from the observer's vertical direction. (See figure1.)

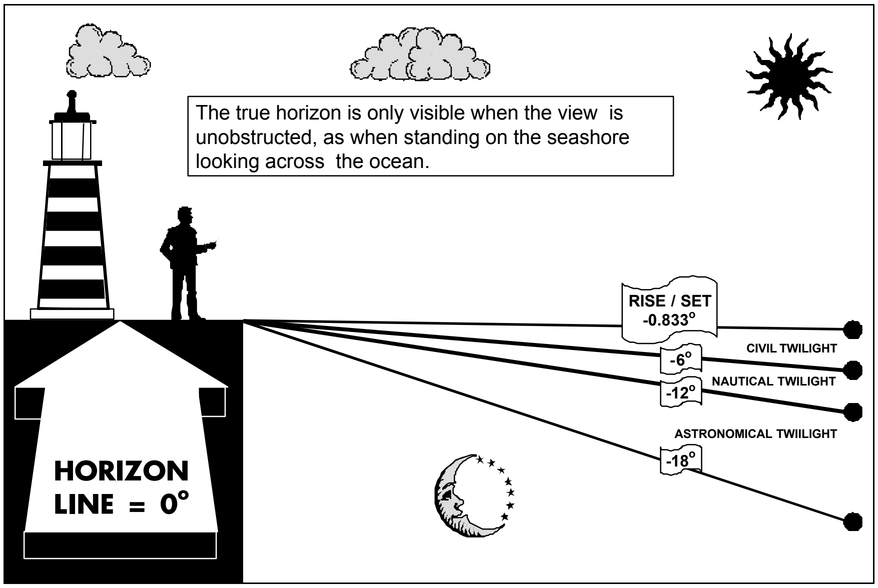

Figure 1

The unobstructed visible distance to the horizon, in statute miles, is calculated by taking the square root of the observer's eye height and multiplying it by 1.322. For kilometers, multiply the square root of the observer's eye height by 2.119. (See table 1.)

Eye Height (feet/inches)	Distance to Horizon Line in Miles	Distance to Horizon Line in Kilometers
6'0"	3.238	5.190
5'6"	3.100	4.969
5'0"	2.956	4.738
4'6"	2.804	4.495
4'0"	2.644	4.238
3'6"	2.473	3.964
3'0"	2.289	3.670
2'6"	2.090	3.350
2'0"	1.869	2.996

Table 1

Astronomical event times can be obtained by consulting the U.S.N.O. web site. This site provides the local times of sunrise, sunset, beginning and end of civil twilight and other astronomical data for any specified location on Earth, on any date, past, present or future. The same information, in table file format, is available from Her Majesty's Nautical Almanac Office (H.M.N.A.O.) web site[3].

In order to use either service, a location must be provided. Every point on Earth has an address, expressed as latitude and longitude. The first part of the address is latitude, the distance north or south of the equator (0° latitude). The second part of the address is longitude, the distance east or west of a line going from the north pole to the south pole through Greenwich, England (Greenwich Meridian, 0° longitude). Since the Earth is a sphere, these distances are expressed as angles.

There are two ways to express latitude and longitude. The invention of the first method is credited to the Babylonians, about 5000 years ago. It divides angles into 360 degrees (°), each degree into 60 [arc]minutes ('), and each minute into 60 [arc]seconds ("). The Washington Monument, in Washington, D.C., is located 38°53'21.5" north of the equator, and 77°2'8.0" west of the Greenwich Meridian. At this latitude, it is accurate to about 60 feet, or 0.5 [arc]seconds.

The second method is to express the angles in decimal form. North latitudes and east longitudes are positive (+), while south latitudes and west longitudes are negative (-). For example, the Washington Monument is at +38.8893° latitude and -77.0356° longitude.

To determine local astronomical event times, the latitude and longitude must be known with some precision. Many roadway engineering drawings indicate latitude and longitude as base reference points. A portable geographic positioning system (G.P.S.) receiver will provide latitude and longitude with sufficient accuracy. The greater the precision in locating the accident site, the more reliable the results from the computations. At median latitudes, an error of just one degree can result in a sunrise/sunset time error of four minutes. For accidents that occur in a time period near these events, the error would be unacceptable. At lower latitudes, greater precision than illustrated above may be required.

The U.S.N.O. web site can also provide sun transit data that will help determine what effect, if any, glare from the sun would have had on a driver. The position of the sun in transit, stated as azimuth and elevation, can be determined in one minute (time) intervals and correlated to the driver's heading and field of view. If the initial research indicates the sun was between 5° below and 70° above the horizon, and on an azimuth within 60° of either side of the center of the driver's field of view, then a more detailed analysis is warranted. Consideration must be given for variables such as the position of the item of interest relative to the driver, condition of the windshield, atmosphere, and the individual's inherent propensity to have their visual acuity diminished by the situation.

The legal requirements for the admission or use of astronomical data in rendering an opinion varies among jurisdictions. Astronomical data records are not "certified" by any government agencies. Event times are calculated, not observed and recorded, as is weather data.

There are various conventions used to express the position of the sun. Some information providers use the terms altitude, elevation and angle, all referring to the sun's position relative to the horizon, interchangeably. Azimuth is the compass direction, in degrees, from true north. Some astronomical computer programs relate the latitude and longitude of the sun's subpoint above the Earth. This is the location where the sun is directly overhead, an elevation, altitude or angle of 90.0000°.

More than just astronomical event time is required to complete the analysis. Local weather conditions and terrain will affect ambient light. At any location, ambient light can be limited by surrounding objects. It is necessary to observe lighting conditions at the accident site, and at the same astronomical time, to determine if such obstructions existed and what influence they had on the situation. It is entirely possible, that while a driver was in compliance with the legal time requirements for the use of headlights, the functional equivalent of civil twilight in an unobstructed area was not available due to the terrain. An inspection of the accident site, at the appropriate time and under similar conditions, will reveal what natural lighting was available.

It is a mistake to return to the accident site on the same calendar day, a year or more later, at the same time as the accident, expecting the angle and azimuth of the sun, or the angle, azimuth and phase of the moon, to be the same it was on the day of the accident. The orbit and rotation of the Earth undergoes constant, albeit small, variations and the calendar does not match the solar or lunar year precisely. Cesium atomic clocks, the recognized standard for timekeeping, keep very precise time; far more precise than celestial time.

In 1956, scientists at the U.S.N.O. and the U.K. National Physical Laboratory, determined the relationship between the frequency of the cesium atom (the standard of time) and the rotation of the Earth. They defined the second as "the length of time required for 9,192,631,770 cycles of radiation, corresponding to the transition between two hyperfine levels of the ground state of the cesium 133 atom, at zero magnetic field." While this extremely precise timekeeping works with small time periods, the celestial clockworks has variables.

Along with other influences, the Earth undergoes a deceleration caused by the braking action of the tides. This is an effect which causes the Earth's rotational time to slow in respect to atomic clock time. The atomic second was set equal to an average second of Earth rotation time in 1900. Since it has been nearly a century since the defining year of 1900, the difference is roughly 2 milliseconds per day per century. To correct the differences between the Earth's rotational time and atomic clock time, a leap second is periodically added to the atomic time.

The Julian calendar, devised by the Alexandrine astronomer Sosigenes, and implemented by Julius Caesar in 46 B.C., assumed a solar year has exactly 365.25 days. To account for the one-quarter day, a 366 day leap year occurs every fourth year. Around 720 A.D., The Venerable Bede[4], an Anglo-Saxon monk, found Sosigenes' calculations made the Julian year 11 minutes, 14 seconds too long; an error of one day every 128 years. By 1582, with no adjustments made in the intervening years, the cumulative error was approximately twelve days. Religious holidays, most notably the Easter holidays, were occurring out of season. March 23rd had effectively regressed to March 11th.

A correction was devised by a German astronomer, Christopher Clavius[5]. In the Papal Bull *"Inter Gravissimas . . ."* [Among the Most Serious], Pope Gregory XIII introduced the reform of the calendar; a task called for by the 1563 Council of Trent. By this decree, the day following October 4, 1582 was October 15, 1582.

To prevent having to make such a drastic correction again, the addition of a leap day to every fourth year was also modified. Years ending in "00" (epoch years) are common years, rather than leap years as in the Julian system; except for those epoch years divisible by 400. The epoch year 2000, being divisible by 400, is a leap year. February 29th, when it occurs, is a bissextile.

Although the Italian states adopted the new calendar immediately, Great Britain did not recognize the reformed calendar until the reign of Elizabeth I. In the British Empire, which included the American colonies, September 2, 1752, was followed by September 15, 1752, commensurate with the Gregorian Calendar.

To this day, the Gregorian Calendar is the most widely recognized, but, it is not fully synchronized with the solar year. By the year 3300, using the current formula, there will be a cumulative error of one day.

Using the U.S.N.O. service, multiple dates can be entered to determine when the sun or moon will next be at a position the same as, or closely approximating that, on the day of the accident. On site observations are then made under those conditions with allowance for the known differences.

The world is divided into a number of standard time zones. There are essentially 24 time zones spaced at intervals of 15° longitude. The zones are specified by the number of hours they differ from Greenwich Mean Time (G.M.T.). Greenwich, England, is defined as 0 longitude and is the center of G.M.T. Almost all time zones differ an integral number of hours from G.M.T., but there are a few in remote areas which differ by a half-hour. A construct related to time zones is the International Date Line, at the 180° meridian, which occurs in the middle of the time zone offset twelve hours from G.M.T.

Standard time in the U.S. and its territories is observed within eight zones. Standard time within each zone is an integral number of hours offset from U.T.C.

To obtain U.S. civil time from U.T.C., use the following table.

To convert U.T.C. to:	Subtract this many hours from U.T.C.
Atlantic Daylight Time	3
Atlantic Standard Time	4
Eastern Daylight Time	4
Eastern Standard Time	5
Central Daylight Time	5
Central Standard Time	6
Mountain Daylight Time	6
Mountain Standard Time	7
Pacific Daylight Time	7
Pacific Standard Time	8
Alaska Daylight Time	8
Alaska Standard Time	9
Hawaii/Aleutian Standard Time	10
Samoa Standard Time	11

Table 2

When converting zone time to or from U.T.C., dates must be taken into account. For example, 10 March, 02:00 U.T.C. is the same as 9 March, 21:00 E.S.T.

When approximating the position of the sun or moon for a recreation of lighting conditions, Daylight Saving Time (British Summer Time)[6] may be a factor. Up until the fall of 2005, in the U.S., Daylight Saving Time began at 2:00 a.m. local on the first Sunday of April and ended at 2:00 a.m. local on the last Sunday of October. In 2005, the U.S. Congress changed the effective dates. Daylight Saving

Time began at 2:00a.m. on the first Sunday of April 2005 and ended at 2:00a.m. on the first Sunday of November 2005. For 2006 and beyond, the effective dates are the second Sunday in March through the first Sunday in November. In most of Europe and Great Britain, Daylight Saving Time begins at 01:00 G.M.T. on the last Sunday of March and ends at 01:00 G.M.T. on the last Sunday of October.

During the summer, Russia's clocks are two hours ahead of standard time. In the winter, all eleven Russian time zones fall back to one hour ahead of standard time. South of the equator, where mid-summer comes in December, Daylight Saving Time is observed from October to March, opposite that in the northern hemisphere. Equatorial and tropical countries don't observe Daylight Saving Time since the daylight hours are similar througout the year.

The U.S. Department of Transportation is responsible for U.S. time zone boundaries but each state individually determines if it uses Daylight Saving Time. Time zone boundaries are not necessarily defined by state lines. Texas, Kansas, Nebraska, South Dakota, North Dakota, Oregon, Montana, Alaska, Florida, Tennessee, Kentucky and Michigan have two time zones within their boundaries.

Arizona (except the Navajo Indian Reservation), Hawaii, American Samoa, Guam, Puerto Rico and the U.S. Virgin Islands do not use Daylight Saving Time. Indiana is a unique case. Until April 2, 2006, most of Indiana was on Eastern Standard Time all year long. The state statute created three different time arrangements:

1. Seventy-seven counties were in the eastern time zone, but did not use Daylight Saving Time. They remained on Eastern Standard Time all year.

2. Ten counties, five in the northwest corner of the state, Jasper, Lake, LaPorte, Newton and Porter, and five in the southwest corner of the state, Gibson, Posey, Spencer, Vanderburgh, and Warrick Counties, were in the Central Time Zone and used Daylight Saving Time.

3. Five counties, two along the southern border near Louisville; Dearborn and Ohio, and three in the southeast corner near Cincinnati; Clark, Floyd and Harrison Counties, were in the Eastern Time Zone and used Daylight Saving Time.

On April 2, 2006, all of Indiana began to observe Daylight Saving Time. Eighteen Indiana counties; Jasper, Lake, LaPorte, Newton, Porter, Gibson, Posey, Spencer, Vanderburgh, Warrick, Starke, Pulaski, Knox, Daviess, Martin, Pike, Dubois and Perry are in the Central Time Zone while the remaining 74 counties are in the Eastern Time Zone.

The ambient lighting change when standard time replaces Daylight Saving Time each fall results in a marked increase in the occurrence of traffic accidents. According to the National Highway Traffic Safety Administration Fatal Accident Reporting System, there is an average increase of 400% in the number of fatal pedestrian accidents around sunset. Ten years of statistical data is presented in the next figure.

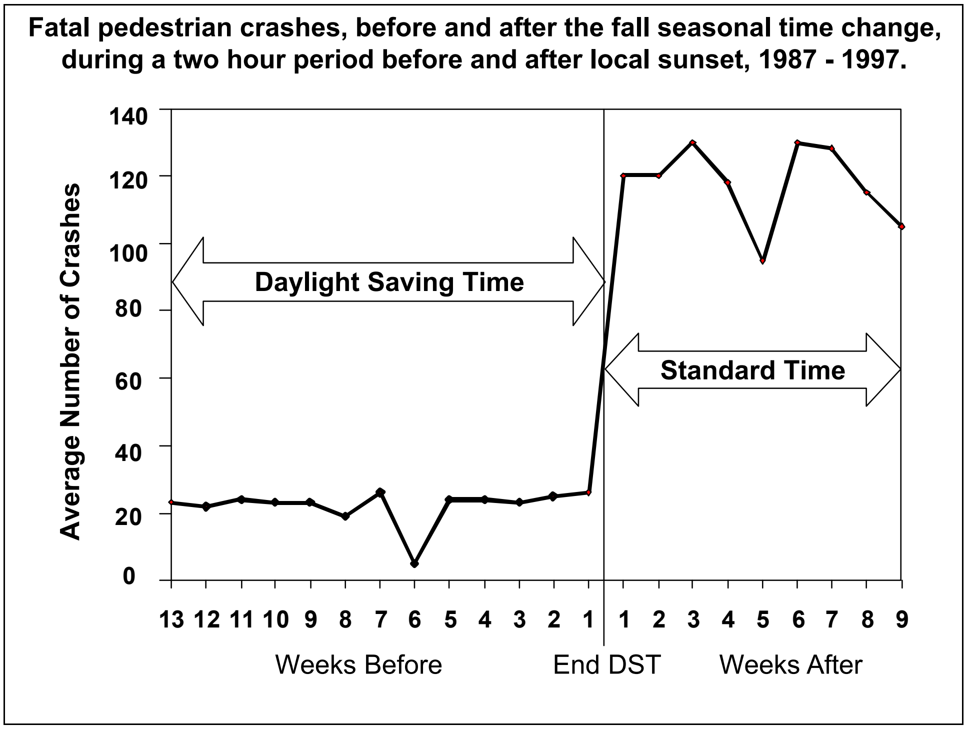

Figure 2

In some instances, the phase and position of the moon may be a factor. Illumination by the moon in rural areas can be notable, but is less so in urban areas with abundant artificial illumination. Information regarding the moon's phase, altitude and azimuth is available at the U.S.N.O. web site in the same manner as solar event data.

The rising and setting of the moon is not synched to the solar day. Due to an eccentric orbit, the time from one moonrise to the next moonrise can vary between 24.5 and 26 hours. On any particular day the moon may rise before it sets, set before it rises, set only or rise only. To recreate conditions, the variables require an analysis of the moon's phase and position on the date of the accident and then identifying a corresponding astronomical date and time.

Weather plays an important role in ambient light levels. The previous descriptions of twilight assumed no adverse atmospheric factors. Consideration must be given to cloud cover, haze or fog. Recent weather data may be obtained from a local newspaper, but it seldom contains sufficient information. Detailed historical weather data is available from regional climate centers. These centers are maintained by the National Meteorological Office[7] in the U.K., and by the National Oceanic and Atmospheric Administration[8] in the U.S. For those areas not served by regional or national weather services, contact one of the world climatic data centers[9].

The information contained in the weather station reports varies, dependent upon the types of observations performed by any particular station. Station reports are available going back many years. Typically, a report will note the percentage of cloud cover, up to an altitude of 10,000 feet (3000 meters), over periods of one to four hours, and the presence of haze or fog along with other relevant data. For remote accident locations, it may be necessary to obtain reports from several surrounding stations to ascertain average conditions throughout a region. Satellite imagery reports, when available, are particularly useful in determining the percentage of cloud cover.

The U.S. National Weather Service Glossary defines the terms used in observation reports. Some of the more common terms are listed below:

CLEAR - Sky condition of less than 1/10th cloud coverage.

SCATTERED CLOUDS - Sky condition when between 1/10th and 5/10ths are covered.

PARTLY CLOUDY - Sky condition when between 3/10ths and 7/10ths of the sky is covered.

OVERCAST - Sky condition when greater than 9/10ths of the sky is covered.

DEWPOINT - The temperature to which the air must be cooled for water vapor to condense.

DRIZZLE - Small, slowly falling water droplets, with diameters between 0.2 and 0.5 millimeters.

FAIR - Less than 4/10ths opaque cloud cover, no precipitation, and no extremes in temperature, visibility or winds.

FREEZING RAIN - Rain which falls as liquid then freezes upon impact, resulting in a coating of ice on exposed objects.

FOG - The visible aggregate of minute water droplets suspended in the atmosphere near the earth's surface. Essentially a cloud whose base is at the earth's surface, limiting visibility.

HAZE - Fine dry or wet dust or salt particles in the air that reduce visibility.

PRECIPITATION - Liquid or solid water molecules that fall from the atmosphere and reach the ground.

RAIN - Liquid water droplets that fall from the atmosphere, having diameters greater than drizzle.
RELATIVE HUMIDITY - The amount of water vapor in the air, compared to the amount the air could hold if it was totally saturated. (Expressed as a percentage).

SHOWER - Precipitation that is intermittent, both in time, space or intensity.

SUSTAINED WINDS - The wind speed obtained by averaging the observed values over a one minute period.

THUNDERSTORM - A storm with lightning and thunder, produced by a cumulonimbus cloud, usually producing gusty winds, heavy rain and sometimes hail.

VISIBILITY - The horizontal distance an observer can see and identify a prominent object.

The legal requirements for the admission or use of weather data in rendering an opinion varies among jurisdictions. In some instances, it is necessary to obtain “certified” weather observation reports directly from a regional climate data center or National Weather Service office.

The weather and lighting information in a police traffic crash report should not be considered correct in all instances. The time from the beginning of civil twilight to sunrise can be very short. At median latitudes, the sun will appear to move a distance equal to it's own diameter in about three minutes. The response time of the first police accident investigator to the scene may be of such length that the lighting situation, when they arrive, is entirely different from the conditions that existed at the time of the collision. Using police dispatch records, indicating when the first call was received, and then extrapolating back, allowing the caller time to comprehend the situation and make the call, could provide a more accurate estimate of the time of the accident than indicated in the crash report.

When the ability of a driver to perceive a hazard is at issue, an ambient lighting analysis, using reliable data sources and meticulous attention to detail, can reveal environmental factors previously overlooked. The analysis, as part of a reconstruction, can help explain how, and why, the accident happened.

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Footnotes

1. The definitions of sunrise, sunset and twilight came from a variety of sources. As presented here, they comply with the definitions accepted by the International Council of Scientific Unions, the International Bureau of Weights and Measures, the U.S. National Climate Data Center, the U.S. Naval Observatory's Astronomical Applications Division, the U.K. National Physical Laboratory, Her Majesty's Nautical Almanac Office, the National Maritime Museum's Astronomy Information Service, and the U.K. National Meteorological Office. The Royal Greenwich Observatory was closed in 1998. Astronomical services are now provided by the National Maritime Museum.

   Astronomy Information Service
   National Maritime Museum
   London
   Tel: 0181 858 4422

2. U.S. Naval Observatory web site: http://www.usno.navy.mil/

   Public Affairs Office
   U.S. Naval Observatory
   3450 Massachusetts Avenue, N.W.
   Washington, D.C. 20392-5420 USA
   Tel: 202-762-1437

3. U.K. Nautical Almanac Office web site: http://www.ast.cam.ac.uk/nao/

4. The Venerable Bede (672-735 A.D.), *De Temporum Ratione* [On the Reckoning of Time], c. 725 A.D.

5. Christopher Clavius (1538-1612), *Opera Mathematica*, vol. V, c.1570.

6. For the U.S., see Title 15, United States Code, Chapter 6, Subchapter IX - *Standard Time*, amended in 2005. In 1998, the European Union and U.K. Parliament adopted the *European Parliament and Council Directive on Summer Time Arrangements.* There were no rules for the dates of British Summer Time for the years 1995, 1996 and 1997, but the ad hoc dates were: March 26 to October 22, 1995; March 31 to October 27, 1996 and March 30 to October 26 in 1997. All changes took place at 1:00 a.m. G.M.T.

7. U.K. Regional Weather Centres:

The Met. Office
London Road
Bracknell, Berkshire RG12 2SZ.
Tel: 01344 420242

Ireland Climate Office
Belfast, Ireland
Tel: 01232 328457

Scotland Climate Office
Edinburgh, Scotland
Tel: 0141 303 0110

8. U.S. Regional Climate Centers:

High Plains Regional Climate Center
Lincoln, Nebraska
Tel: 402-472-6706

Midwestern Regional Climate Center
Champaign, Illinois
Tel: 217-244-8226

Northeast Regional Climate Center
Ithaca, New York
Tel: 607-255-1751

Southeastern Regional Climate Center
Columbia, South Carolina
Tel: 803-737-0849

Southern Regional Climate Center
Baton Rouge, Louisiana
Tel: 504-388-5021

Western Regional Climate Center
Reno, Nevada
Tel: 702-677-3106

9. World Climate Data Centers:

World Climate Data Center -A
National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, North Carolina 28801-5001
U.S.A.
Tel: 828-271-4800
e-mail: questions@ncdc.noaa.gov

World Climate Data Center -B
Russian Academy of Sciences
National Geophysical Committee
Molodezhnaya 3
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Russia
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e-mail: vitaly@wdcb.rssi.ru

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