Magnitudes, Patterns and Causes of 20th Century Floods

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USGS science for a changing world

Flood Magnitudes

Significant Floods of the 20th Century

ABSTRACT

During the 20th century, floods were the number-one natural disaster in the United States in terms of the number of lives lost and property damage. The deadliest flood of the 20th century claimed more than 6,000 lives-- people who drowned in the storm surge from a hurricane that inundated Galveston, Texas, in 1900. The costliest flood on record was the $20 billion flood on the Missouri and upper Mississippi Rivers and their tributaries during the summer of 1993. Thirty-three of the most significant floods (in terms of number of lives lost and (or) property damage) in the United States during the 20th century are listed below according to the various types of floods.

The U.S. Geological Survey has published National Flood Summaries periodically to document the occurrence of floods nationally.

For more than 110 years the U.S. Geological Survey (USGS) has measured flood magnitudes for the Nation's benefit while supplying additional streamflow data with its extensive stream-gaging network. Near-real-time flood information is now available for most streamflow-gaging stations nationwide via the World Wide Web.

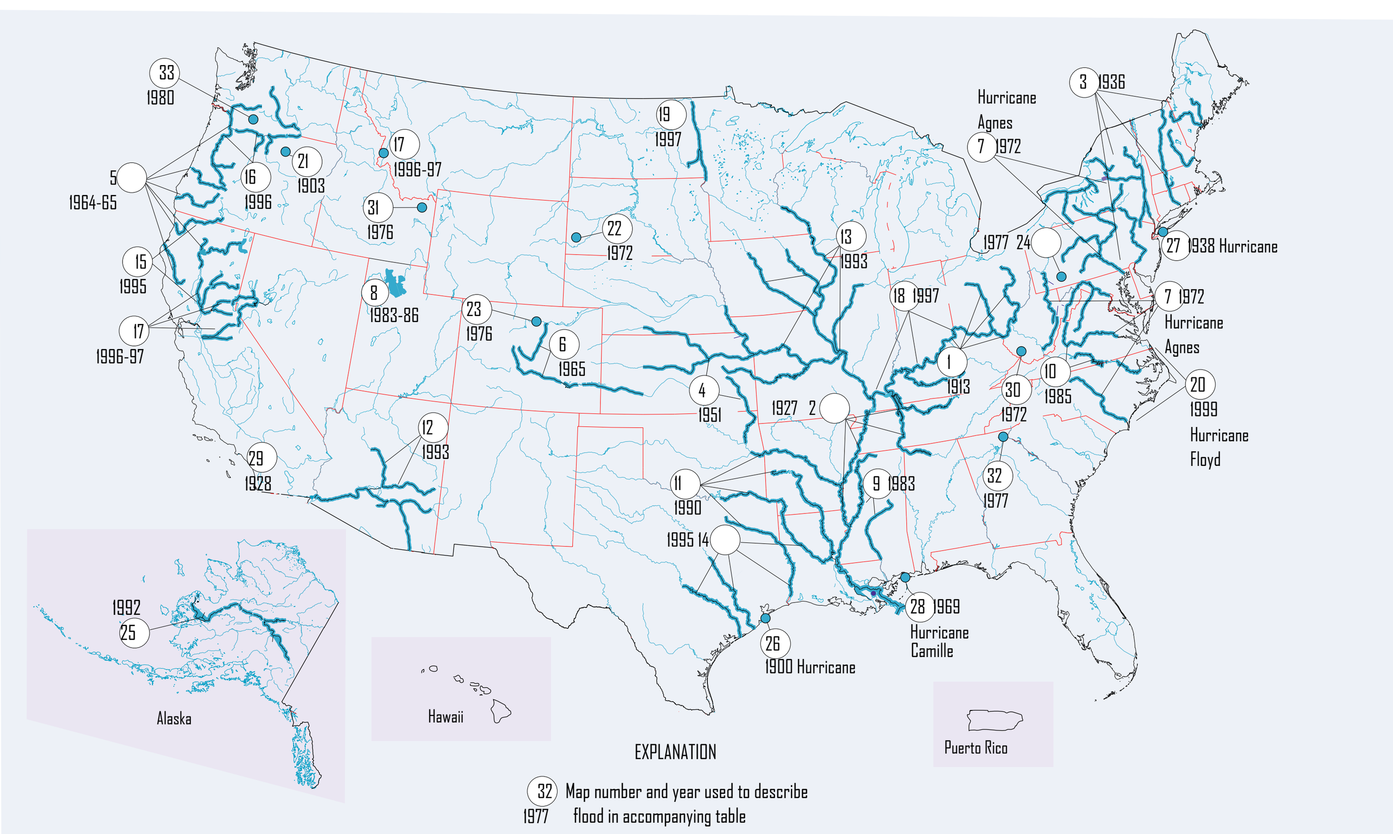
Patterns and causes of floods are examined and a method for prediction of floods using solar irradiance variations is presented.

Confluence of Mississippi and Missouri Rivers, August 1993. Extensive floods in the Mississippi River Basin during the spring and summer of 1993 caused $20 billion in damages. (Photograph, Srenco Photography, St. Louis, Mo.)

Floods can occur at any time of the year, in any part of the country, and at any time of the day or night. Most lives are lost when people are swept away by flood currents, whereas most property damage results from inundation by sediment-laden water. Flood currents also possess tremendous destructive power, as lateral forces can demolish buildings and erosion can undermine bridge foundations and footings leading to the collapse of structures.

Floods are the result of a multitude of naturally occurring and human-induced factors, but they all can be defined as the accumulation of too much water in too little time in a specific area. Flood types include regional floods, flash floods, ice-jam floods, storm-surge floods, dam- and levee-failure floods, and debris, landslide, and mudflow floods.

The accompanying map and table locate and describe 33 of the most significant floods of the 20th century.



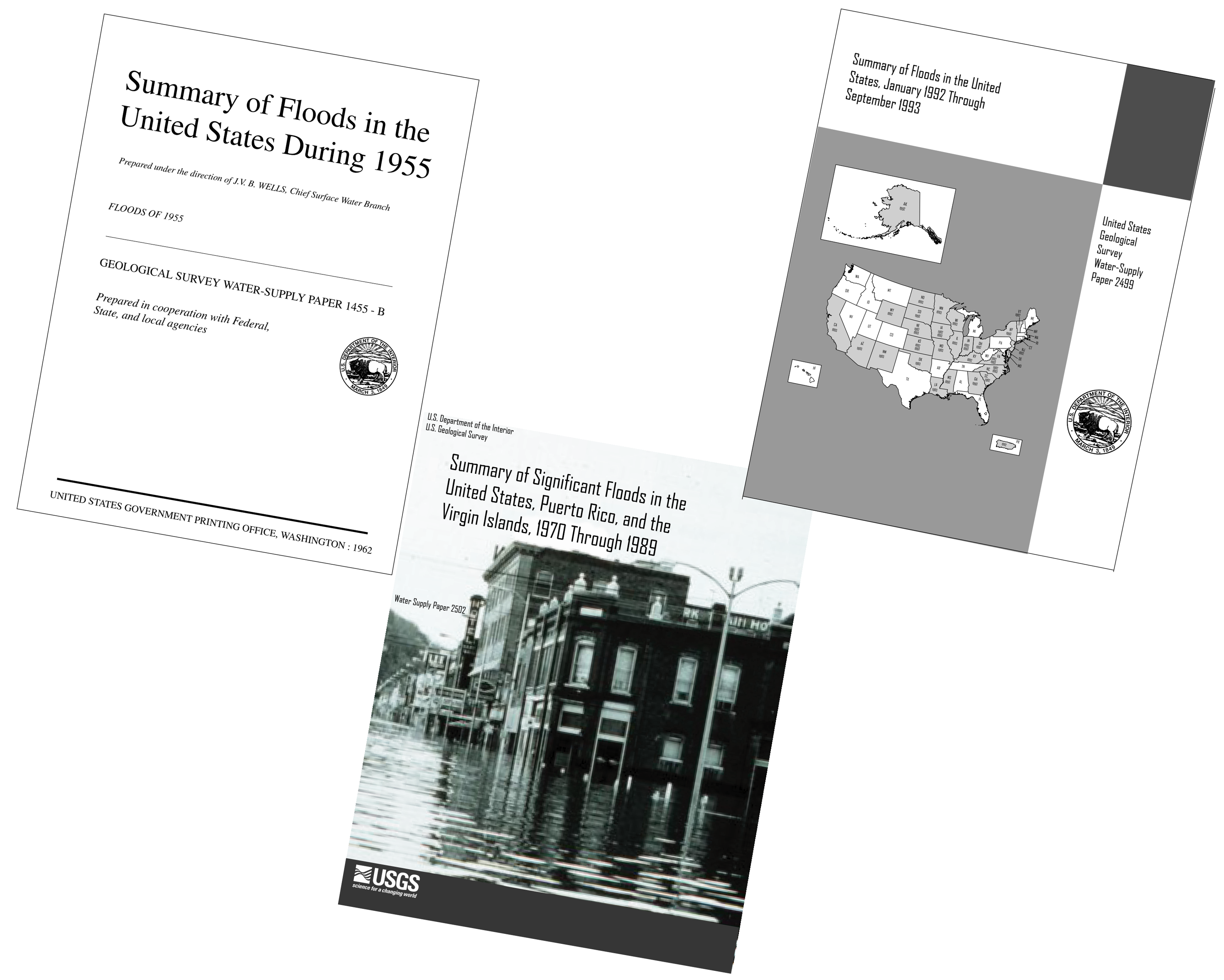
[M, million; B, billion]

Flood type	Map no.	Date	Area or stream with flooding	Reported deaths	Approximate cost (uninflated)	Comments
Regional flood	1	Mar.-Apr. 1913	Ohio, statewide	467	$143M	Excessive regional rain.
	2	Apr.-May 1927	Mississippi River from Missouri to Louisiana	313	$230M	Record discharge downstream from Cairo, Illinois.
	3	Mar. 1936	New England	150+	$300M	Excessive rainfall on snow.
	4	July 1951	Kansas and Neosho River Basins in Kansas	15	$800M	Excessive regional rain.
	5	Dec. 1964-Jan. 1965	Pacific Northwest	47	$430M	Excessive rainfall on snow.
	6	June 1965	South Platte and Arkansas Rivers in Colorado	24	$570M	14 inches of rain in a few hours in eastern Colorado.
	7	June 1972	Northeastern United States	117	$3.2B	Extratropical remnants of Hurricane Agnes.
	8	Apr.-June 1983 June 1983-1986	Shoreline of Great Salt Lake, Utah	unknown	$621M	In June 1986, the Great Salt Lake reached its highest elevation and caused $268M more in property damage.
	9	May 1983	Central and northeast Mississippi	1	$500M	Excessive regional rain.
	10	Nov. 1985	Shenandoah, James, and Roanoke Rivers in Virginia and West Virginia	69	$1.25B	Excessive regional rain.
	11	Apr. 1990	Trinity, Arkansas, and Red Rivers in Texas, Arkansas, and Oklahoma	17	$1B	Recurring intense thunderstorms.
	12	Jan. 1993	Gila, Salt, and Santa Cruz Rivers in Arizona	unknown	$400M	Persistent winter precipitation.
	13	May-Sept. 1993	Mississippi River Basin in central United States	48	$20B	Long period of excessive rainfall.
	14	May 1995	South-central United States	32	$5-6B	Rain from recurring thunderstorms.
	15	Jan.-Mar. 1995	California	27	$3B	Frequent winter storms.
	16	Feb. 1996	Pacific Northwest and western Montana	9	$1B	Torrential rains and snowmelt.
	17	Dec. 1996-Jan. 1997	Pacific Northwest and Montana	36	$2-3B	Torrential rains and snowmelt.
	18	Mar. 1997	Ohio River and tributaries	50+	$500M	Slow-moving frontal system.
	19	Apr.-May 1997	Red River of the North in North Dakota and Minnesota	8	$2B	Very rapid snowmelt.
	20	Sept. 1999	Eastern North Carolina	42	$6B	Slow-moving Hurricane Floyd.
Flash flood	21	June 14, 1903	Willow Creek in Oregon	225	unknown	City of Heppner, Oregon, destroyed.
	22	June 9-10, 1972	Rapid City, South Dakota	237	$160M	15 inches of rain in 5 hours.
	23	July 31, 1976	Big Thompson and Cache la Poudre Rivers in Colorado	144	$39M	Flash flood in canyon after excessive rainfall.
	24	July 19-20, 1977	Conemaugh River in Pennsylvania	78	$300M	12 inches of rain in 6-8 hours.
Ice-jam flood	25	May 1992	Yukon River in Alaska	0	unknown	100-year flood on Yukon River.
Storm-surge flood	26	Sept. 1900	Galveston, Texas	6,000+	unknown	Hurricane.
	27	Sept. 1938	Northeast United States	494	$306M	Hurricane.
	28	Aug. 1969	Gulf Coast, Mississippi and Louisiana	259	$1.4B	Hurricane Camille.
Dam-failure flood	29	March 12, 1928	St. Francis Dam, California	420	unknown	Structural dam failure
	30	Feb. 2, 1972	Buffalo Creek in West Virginia	125	$60M	Dam failure after excessive rainfall.
	31	June 5, 1976	Teton River in Idaho	11	$400M	Earthen dam breached.
	32	Nov. 8, 1977	Toccoa Creek in Georgia	39	$2.8M	Dam failure after excessive rainfall.
Mudflow flood	33	May 18, 1980	Toutle and lower Cowlitz Rivers in Washington	60	unknown	Result of eruption of Mt. St. Helens.

National Flood Summaries

During 1950's and 1960's, the U.S. Geological Survey summarized floods of each year in an annual series of Water-Supply Papers. The series was discontinued after the 1969 volume; however, in 1987 a program was begun to prepare and publish summaries for 1970 and succeeding years. These reports were published in several formats and cover the years 1970 to 1989, 1990 to 1991, and 1992 to 1993. Currently the summaries are being published in 5-year increments beginning with 1994-98. Other various reports are available through the U.S. Geological Survey's online library that document selected individual flood occurrences. The library can be accessed at:

http://water.usgs.gov/pandp.html



U.S. Geological Survey Flood Measurements

The basic building block for a streamflow data network is the stage-discharge relation that is developed at each gaging-station location. Measurements of the flow (discharge) are related graphically to the respective water levels (stage), which then enables discharge to be determined from stage data.

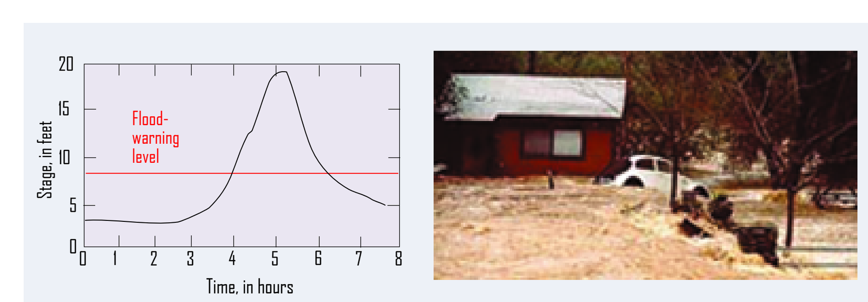
Discharge measurements can either be direct, using a current meter, or indirect, using mathematical flow equations. Both methods require that an elevation of the floodwater surface be determined by a water-level gage or by a detailed survey of high-water marks. If time allows and conditions are safe, a direct measurement by USGS hydrographers is preferred. However, during major floods, direct measurements often are impossible or extremely dangerous, and indirect methods must be used.

Accurate identification and measurement of high-water marks from floods are very important in the accurate mapping of inundated areas as well as in the analysis of water-surface profiles for indirect discharge measurements. These elevations, in combination with flood-frequency analysis using many years of annual flood maximums, are used by the Federal Emergency Management Agency (FEMA) to determine flood-insurance rates.

The USGS currently (2000) maintains more than 7,000 stream-gaging stations throughout the United States, Puerto Rico, and the Virgin Islands that monitor streamflow and provide data to various Federal, State, and local cooperating agencies as well as the general public. Some of these stream-gaging stations have been in operation since before 1900, providing more than a century of water informaton for the Nation. In addition to providing critical information on flood heights and discharges, these stations provide data used in the effective management of water-supply and water-quality needs, protection of aquatic habitat, recreation, and water-resources research.

Discharge measurements made during floods are used to develop stage-discharge relations at each gaging station. (Photograph, Lawrence Journal World, Lawrence, Kans.)

Some floods are measured by USGS hydrographers using indirect methods that involve surveys of valley cross sections, bridge-opening measurements, and high-water marks that are used in mathematical flow equations to compute discharge.



USGS stream-gaging stations quickly provide early flood warnings for many flash-flood-prone-areas. (Photograph, Darel Noceti, Rapid Shooters, Coloma, Calif.)

Current Flood Conditions

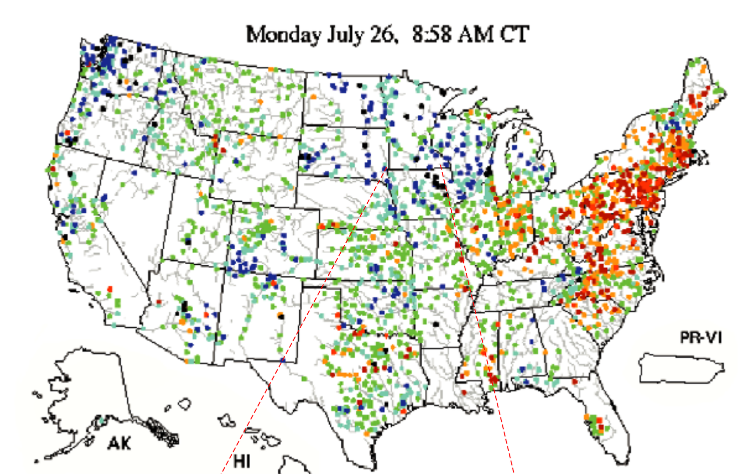
Flood Information on the Internet

Streamflow information can be accessed through the Internet at several adresses, including:

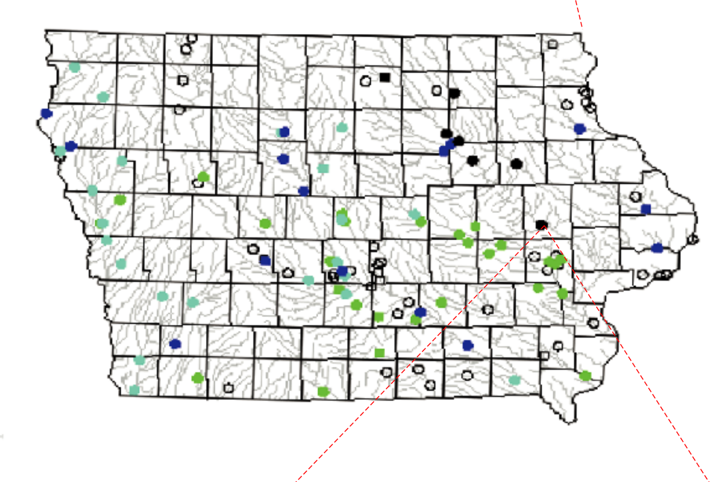
http://water.usgs.gov/public/dwc/

which will display the map shown below.

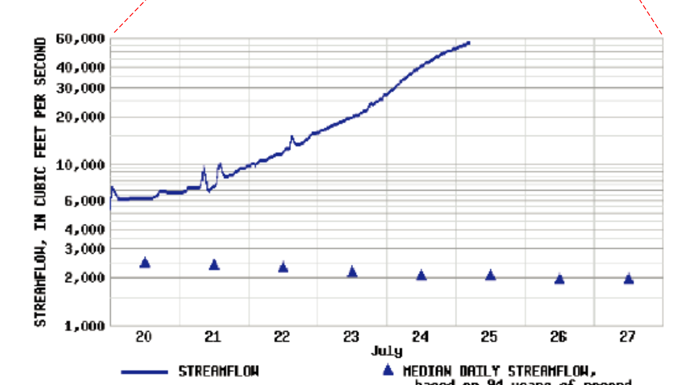
National streamflow conditions



By clicking on the area of interest, the State map for that area is accessed. Clicking on the station of interest results in the Web page for that station being displayed. Stage and discharge for several days and links to other data, such as the annual peak-flow file and historic data, are provided.



Streamflow for Cedar River at Cedar Rapids, Iowa



Most USGS stream-gaging stations transmit river stage and other water information directly to geostationary satellites and on to a national hydrologic data network that disseminates information to cooperating agencies and to the public through the Internet.

Flood Damage Information

Flood damage information and number of deaths are available from the National Climatic Data Center. The information can be accessed at:

http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms

Flood damages in the Red River of the North 1997 Flood were nearly $2 billion. (Photograph, Grand Forks Herald, Grand Forks, North Dakota.)

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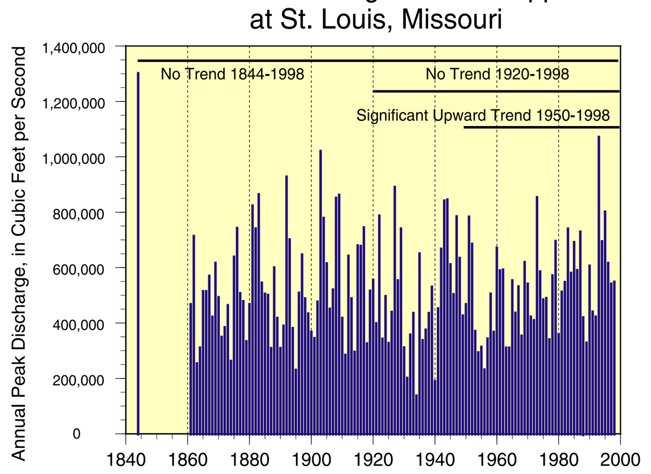
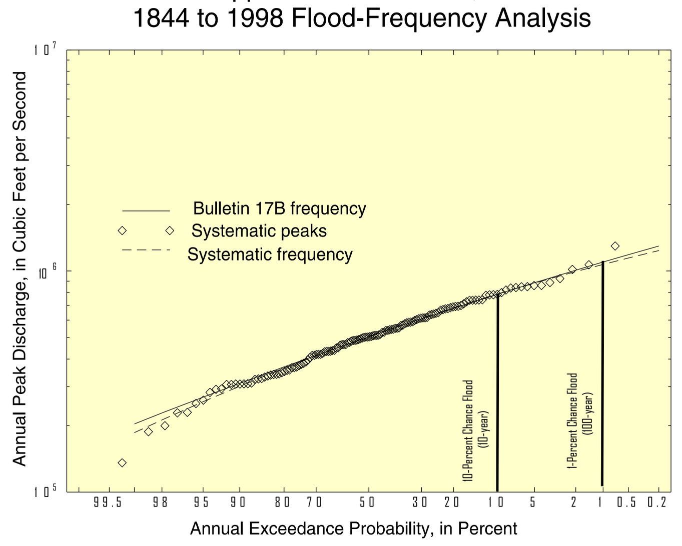
Patterns of Flooding in the United States



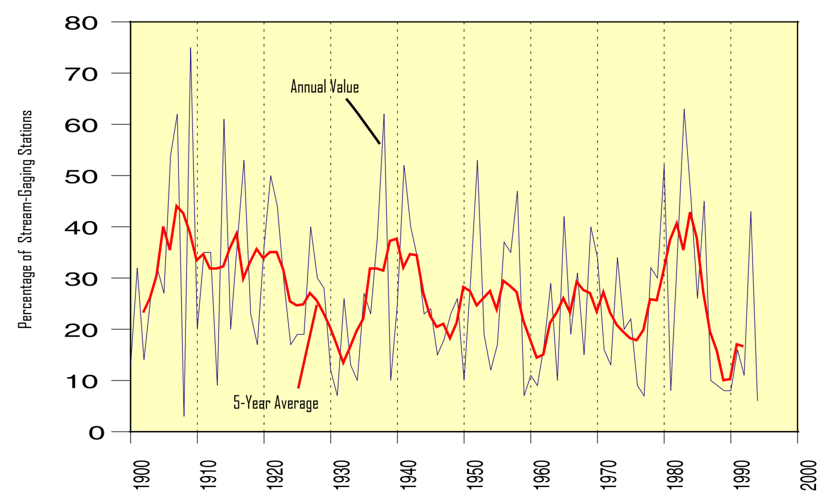
Trends in Flooding over Time

Streamflow records on some rivers extend back in time for more than 100 years. The Mississippi River at St. Louis, Missouri, has a record of annual peak discharges that extends back to 1844. Analyses of peaks from 1844 to 1998 show no significant trend. However, from 1950 to 1998 (48 years) there is a statistically significant upward trend in peak flow. When and how long streamflow records exist is important is whether a trend is detected.



Flood-Frequency Analysis

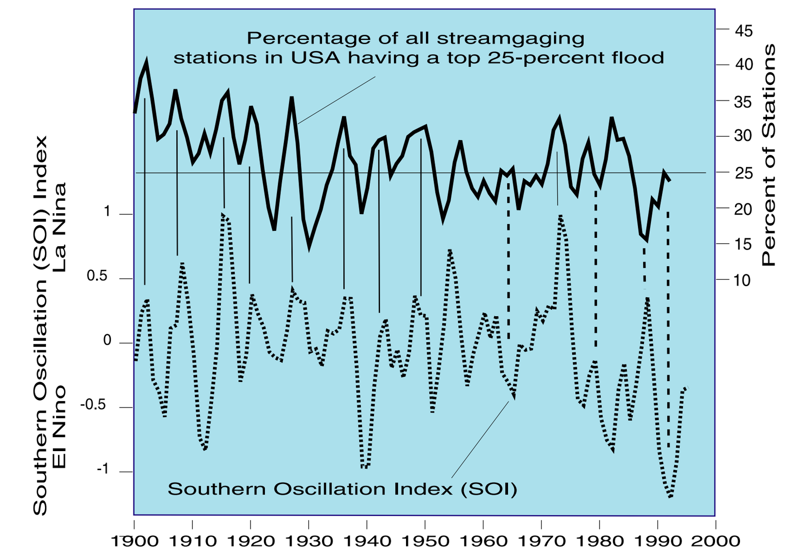
In the past, long records of streamflow and annual peak streamflow have been used in frequency analyses to estimate the risk of a certain magnitude flood in any given year. For example, on a particular stream, a flood magnitude that has a 1-percent chance of happening in any year is called the 100-year flood. Regulation of some rivers by flood-detention structures have changed the flood-frequency curves.



Regional Flooding Patterns

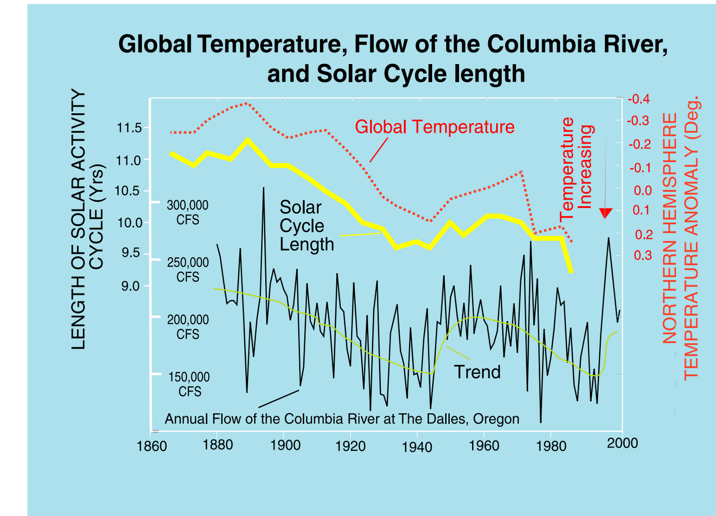
Patterns in flooding vary across the nation. When a 5-year moving average is applied, the percentage of all gaging stations with basins over 50 square miles in the Pacific Northwest experiencing the top quartile (25-percent) floods for each year shows a pattern of increased flooding every 14 years after 1920 . When a pattern is detected, extrapolation of that pattern into the future may provide insight on future floods and their causes.

Causes of Floods



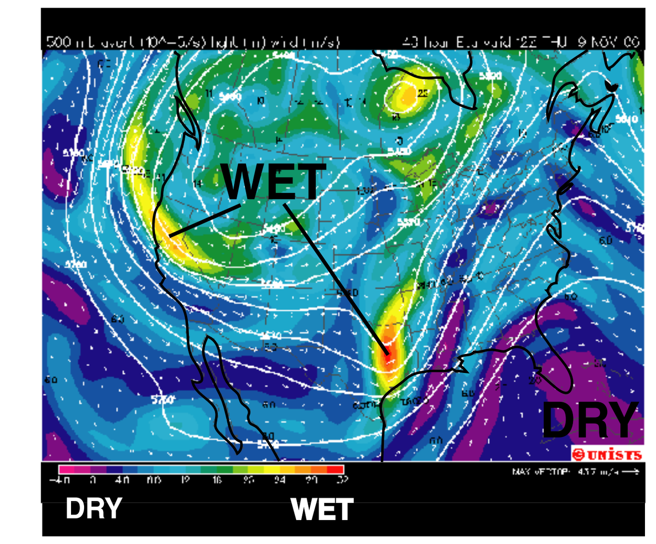
El Nino / La Nina

The percentage of all gaging stations throughout the nation with basins over 50 square miles that experienced the top quartile (25-percent) floods for each year displays a good visual correlation with the Southern Oscillation Index (SOI) during the first part of the century. The relation is one that shows La Nina condtions occurring simultaneously with increased flooding. This relation appears to have reversed during the last 50 years, with El Nino conditions being associated with increased flooding.



Global Warming

Global warming may be changing the runoff characteristics of some river systems. The Columbia River at the Dalles, Oregon, demonstrates a trend that is similar to the trend in Northern Hemisphere air temperatures. The relation appears to be one of more runoff during cooler temperatures. The air temperature curve is very similar to the length of the solar cycle, which relates shorter cycles to warmer air temperatures. Solar variability may be an important factor in regional runoff characteristics as well an important factor in global warming.



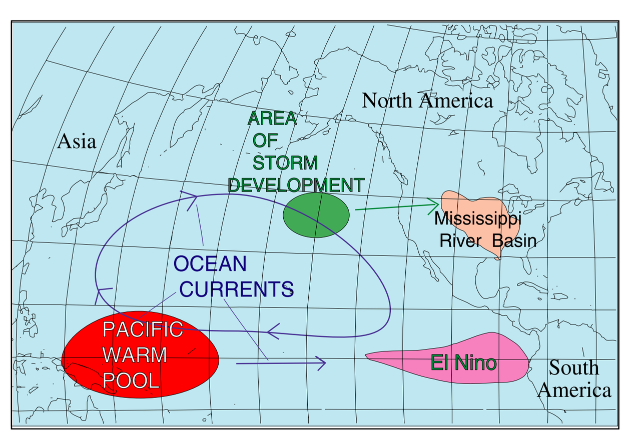
Upper-Level Wind Characteristics

Persistent upper-level atmospheric wind patterns including the velocity, position and curvature of the jet stream, are unquestionably vital for the development of flood situations. Semi-stationary, long wave patterns, including troughs and ridges, and transient short waves dictate intensity and persistence of weather systems that produce flooding.

A Physicial Mechanism that Provides an Opportunity to Make Streamflow Predictions

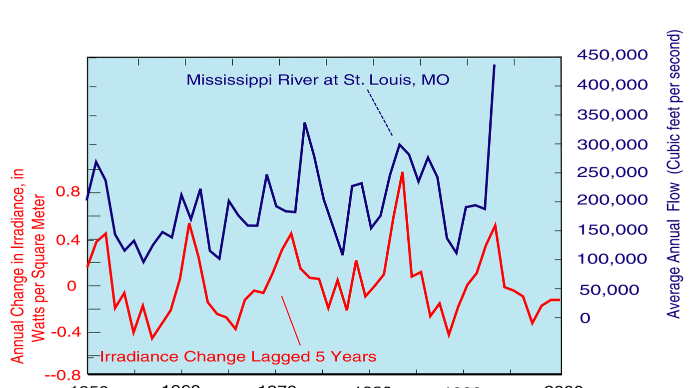
Regional Droughts and Floods Have Oceanic Temperature Connections

A global connection exists between the temperature of the Pacific Ocean, and the amount of rainfall and runoff in North America and in the Mississippi River Basin. The El Nino\La Nina Souther Oscillation has been known to affect rainfall patterns in different parts of the world. During the warm phase (El Nino), rain is more likely from Texas to Florida and less likely in Australia. During the cool phase (La Nina), the opposite occurs. Temperatures in other parts of the North Pacific Ocean also affect North American precipitation.



Small Changes in the Incoming Solar Energy May Affect Ocean Temperatures

The processes responsible for ocean temperature anomalies are not completely understood but may be linked to solar energy variations. Variations of the total solar energy absorbed by the Pacific Warm Pool have been shown to take approximately 3 to 5 years to affect runoff in the Mississippi River Basin .The time lag may be a function of the speed of the ocean currents, which transport slightly warmer or slightly cooler water to locations where they can affect the atmospheric jet stream and moisture supply patterns that help create floods or droughts in the Mississippi River Basin. This relation provides an opportunity to develop a technique for estimating water shortages and excesses for certain regions.



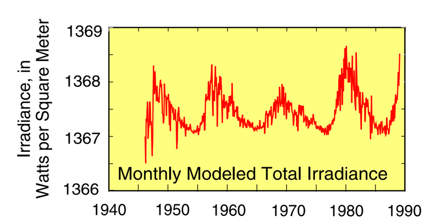
Solar-Climate Connections

Prediction of weather conditions beyond several days has been met with many difficulties. Estimates of climatic conditions 3 months to 1 year in advance have improved only slightly through the years even though Global Climatic Models (GCM's) have improved our understanding of climatic processes.

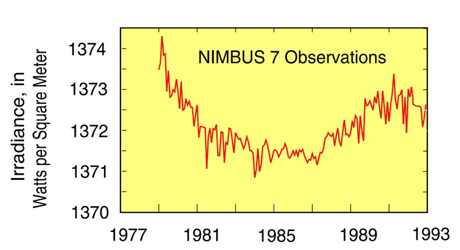
Other methods of climate predictions using Sunspot cycles have had a history of scientific speculation and controversy. Eleven and 22-year cycles have occurred in the Great Plains climate. However, the cycles have been erratic, and most importantly, no physical processes could be proven for the apparent correlation between the number of dark spots on the Sun's surface and climate at specific locations.

New Solar Information

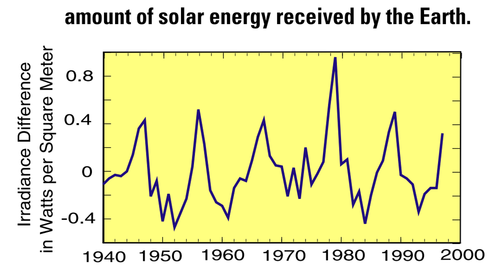
By the middle 1980's, observations of the Sun by Earth satellite confirmed the controversial idea that the Sun's total energy output was higher during solar activity (sunspot) maximum. In fact, the energy reaching the Earth varies on daily, monthly, yearly and decadal time scales. A forcing function for climatic variability is now available, and a physical mechanism for climatic variability can be used to develop predictive models.



Empirical models of solar irradiance extend the record back in time and reveal variations in the amount of solar energy received by the Earth.



Observations of solar irradiance since 1978 by Earth orbiting satellites have shown a cyclic fluctuation.

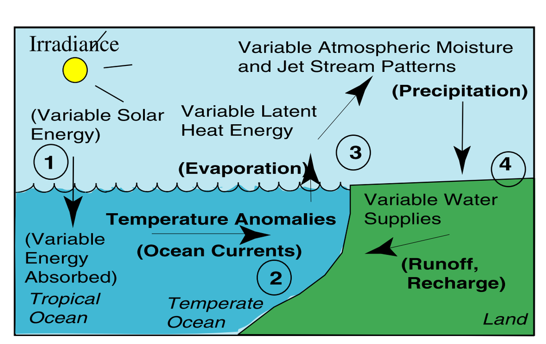


Just as differences in temperature and pressure drive daily weather, differences in the total energy reaching the Earth may be driving climate.

Sun to Streamflow Pathway

The mechanism responsible for a link between irradiance and climate involve four important physical processes.

1. Variable solar irradiance is absorbed by tropical oceans, creating large pools with different amounts of stored energy.
2. Pools of ocean water with varying amounts of stored energy are transported by major ocean currents.
3. Differential evaporation rates and heat from pools alter global jet stream patterns.
4. Jet stream patterns dictate regional climate and streamflow.

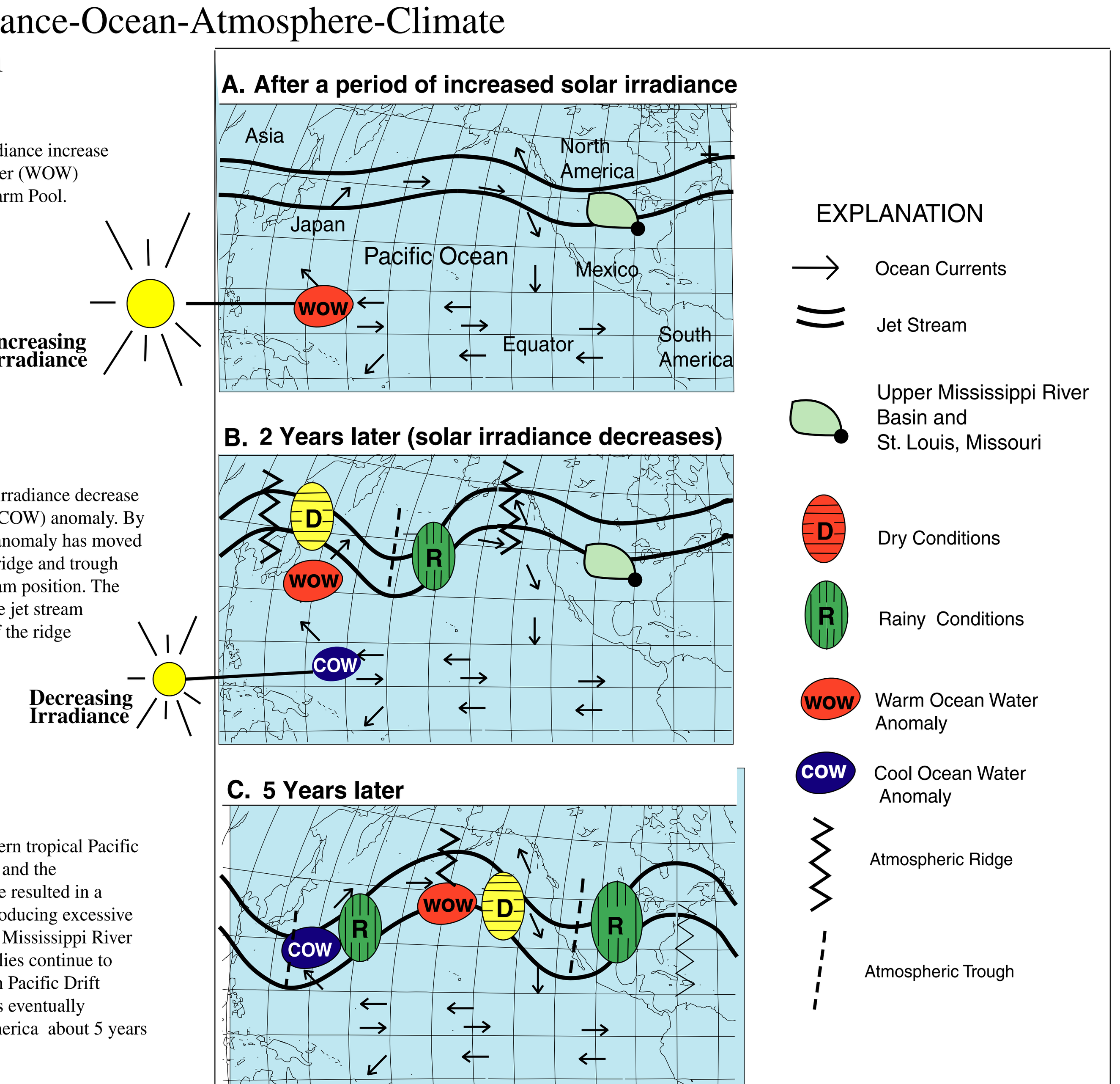


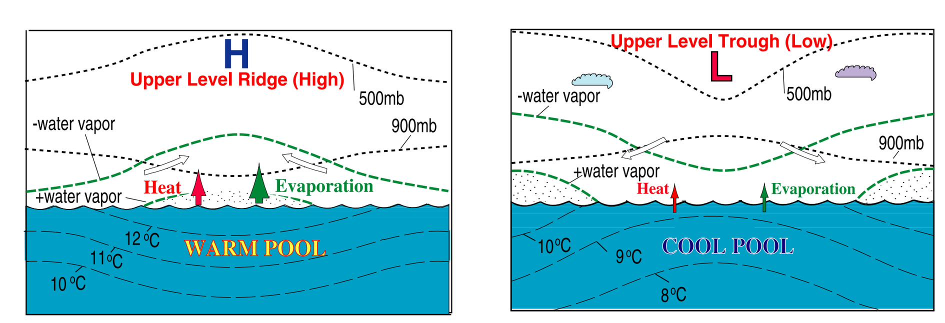
Solar Irradiance-Ocean-Atmosphere-Climate Mechanism

A. A period of solar-irradiance increase creates a warm ocean water (WOW) anomaly in the Pacific Warm Pool.

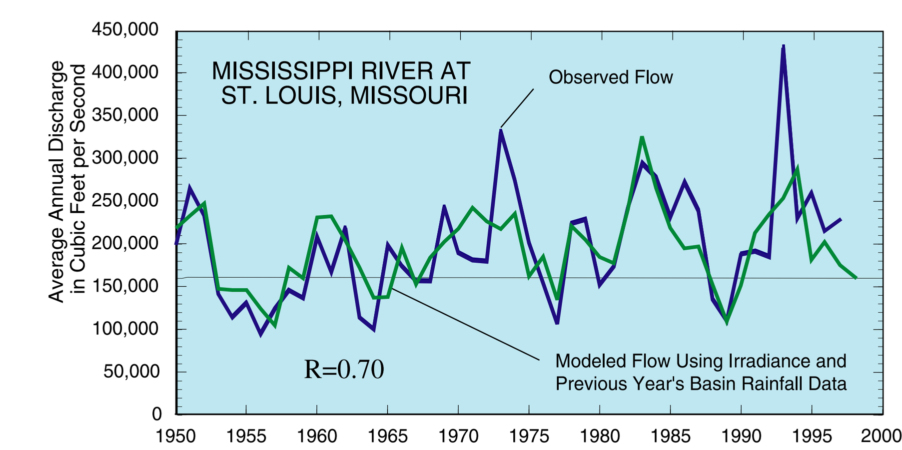
B. Two years later, a solar-irradiance decrease creates a cool ocean water (COW) anomaly. By then, the 2-year-old WOW anomaly has moved northward and is causing a ridge and trough to form in the mean jet-stream position. The atmospheric dynamics of the jet stream create dry conditions east of the ridge and rainy conditions east of the trough.

C. Five years after the initial warming of the western tropical Pacific Ocean, the WOW anomaly and the trailing COW anomaly have resulted in a jet-stream pattern that is producing excessive rains and flooding over the Mississippi River Basin. As the ocean anomalies continue to move eastward in the North Pacific Drift Current, drought conditions eventually would move into North America about 5 years after the COW formation.



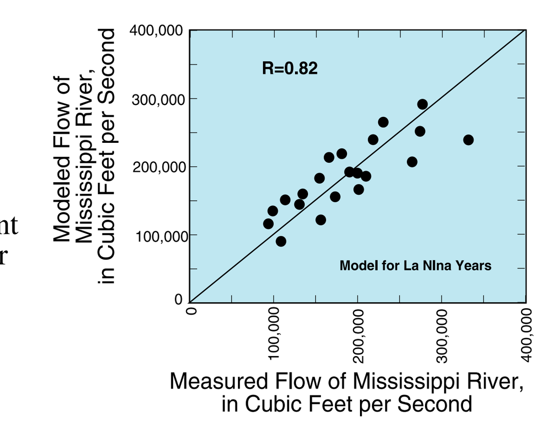


Warm water adds moisture and heat to the lower atmosphere and creates a ridge (high pressure) in the upper atmosphere. A trough forms over cool water.

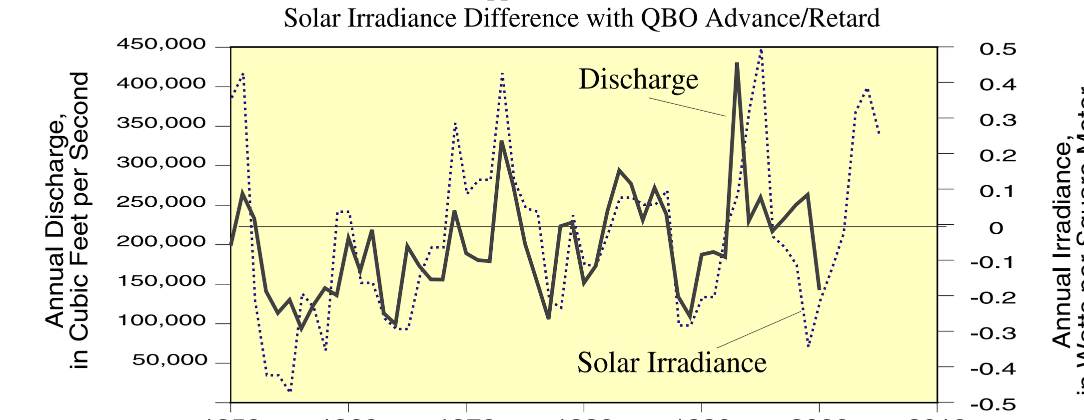


The relations amoung discharge, solar irradiance variation, and the previous year's basin precipitation can be combined by multiple regression analysis into an empirical equation that can be used to estimate future basin runoff.

If only cold-phase (La Nina) years are considered, almost 70 percent of the variability is explained. Similar improvements to the empirical model exist when the stratospheric winds near the equator are considered.



Mississippi River at St. Louis and Solar Irradiance Difference with QBO Advance/Retard



Two other important climatic variables are the direction and speed of the high stratospheric winds (30 millibar level near the Equator) known as the Quasi-Bienniel Oscillation (QBO), and the warming and cooling of the eastern North Pacific Ocean known as the Pacific Decadal Oscillation (PDO). Systematic adjustments of the solar irradiance variations according to the strength and phase of the QBO and the phase of the PDO result in a good match between irradiance variation and runoff in the Mississippi River Basin.