# More NE Drought sources

Compiled by LCI for Northeast Compact project… incomplete, almost random….

See, for valuable regional info, website of NortheastREgaionalm Climate Center at Cornell.

THIS ONE IS VERY INTERESTING ---

Seager, Richard, Neal Pedersen, Stephanie Jurburg, Jennifer Nakamura, and Yochanan Kushnir. n.d. Dynamics of the 1960s northeast drought and the subsequent transition to a wetter clmate: preliminary results. Powerpoint Presentation. On Web.

http://www.ldeo.columbia.edu/res/div/ocp/glodech/PDFs/Seager_Catskills.pdf

NAMIAS, JEROME, 1966: NATURE AND POSSIBLE CAUSES OF THE NORTHEASTERN UNITED STATES DROUGHT DURING 1962–65. *Mon. Wea. Rev.*, **94**, 543–554.
doi: 10.1175/1520-0493(1966)094<0543:NAPCOT>2.3.CO;2

Dickerson, W. H. and B. E. Dethier. 1970. Drought frequency in the Northeastern US. West Virginia University. Agr Exp Sta. Bulletin 595. June. NE regional research publication. 21 pp.

*International Journal ofWildland Fire* **2010**, *19*, 346–363 www.publish.csiro.au/journals/ijwf

**Turbulent kinetic energy during wildfires in the north central and north-eastern US**

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Web doc by USGS:

Comparison of recent droughts in Northeastern US up to 1999.

U.S. Geological Survey Water-Supply Paper 2375
National Water Summary 1988-89--Floods and Droughts:

# MAINE
# Floods and Droughts

Maine's location at the northeastern comer of the continental United States places it in the path of many frontal systems. These systems generally move eastward across the continent until they reach the Atlantic Ocean and then travel northeastward along the coast to Maine (fig. 1). Low-pressure cells embedded in frontal systems generate counterclockwise winds that bring warm, moist air from the Atlantic Ocean onto the mainland. Rain or snow is released as the airmass meets a cold front or as the airmass rises over hills or mountains. Precipitation averages about 42 inches and is distributed evenly throughout the year.

Widespread flooding generally is caused by intense rainfall from frontal systems that have stalled over the eastern seaboard. Local flooding generally is caused by rainfall from convective storms. The flood of April 1, 1987, was the most destructive in the history of Maine. Record to near-record flood discharges were observed at many streamflow-gaging stations in the central and western parts of the State. Frozen ground, melting of a snowpack that provided as much as 10 inches of water, and rainfall of as much as 8 inches contributed to the severity of the flood. Damage in excess of $100 million was reported, and 14 of Maine's 16 counties were declared disaster areas.

Although widespread droughts are rare because of Maine's fairly dependable supply of precipitation, hydrologic records indicate several droughts. The most severe and widespread drought to affect Maine lasted from 1963 to mid-1969. Drought conditions were most severe during 1965 when many streams had record low flow, ground-water levels were seriously low, and the risk of forest fire was greatest.

Maine has developed comprehensive flood-plain management regulations that have been adopted by more than 90 percent of the municipalities in the State. The Maine Emergency Management Agency coordinates an extensive flood-warning system that relies on hydrologic and meteorologic data-collection networks operated by the U.S. Geological Survey and the National Weather Service. The Maine River Flow Advisory Committee provides technical advice to the State through analysis of snowpack conditions, reservoir storage, and ground-water-level conditions that may indicate potential for floods or droughts.

## GENERAL CLIMATOLOGY

The climate of Maine is dominated by three airmasses: (1) polar continental, which are cold, dry airmasses originating in Canada and arctic areas; (2) tropical maritime, which are warm, moist airmasses originating in the Gulf of Mexico and adjacent subtropical waters of the Atlantic Ocean; and to a lesser degree, (3) polar maritime, which are cool, damp airmasses from the North Atlantic. Airmasses that have less effect on Maine's weather are tropical continental from the dry areas of the Southwest and Mexico and maritime moisture from the Pacific Ocean, Pacific airmasses are greatly modified as they move across the continent.

In addition to the oceans, important moisture sources include local and upwind land surfaces, as well as lakes and reservoirs, from which moisture evaporates into the atmosphere. Typically, as a moisture-laden ocean airmass moves inland, it is modified to include some water that has been recycled one or more times through the land-vegetation-air interface.

The climate of Maine is generally classified as continental; however, the Atlantic Ocean moderates the climate in areas near the coast. Weather also differs with altitude and terrain. Most of the weather systems that produce storms in Maine are frontal systems that move eastward across the continent, reach the eastern seaboard, and move northeastward into New England. The counterclockwise winds from low-pressure cells embedded in frontal systems bring warm, moist air from the Atlantic Ocean to the mainland. Thus, the State has acquired a reputation for frequent weather changes and fairly dependable precipitation.

Maritime airmasses deliver the greatest quantity of moisture to the State (fig. 1). Most precipitation is associated with frontal systems wherein either warm air is pushed over a cold air wedge (warm front) to cause precipitation or an advancing wedge of cold air (cold front) lifts the warm air above condensation levels. Convective showers, often thunderstorms, also contribute considerable precipitation in the summer, especially inland. Tropical cyclones, including tropical storms or hurricanes, bring excessive rains in some years.

Annual precipitation ranges from about 34 inches in the northeast to 55 inches in the northwest and north-central mountains and averages about 42 inches statewide (Knox and Nordenson, 1955). Most of the State receives 38-43 inches per year. Seldom does annual precipitation vary more than 25 percent from normal. Extremes are illustrated by the 116-year precipitation record at Portland, where precipitation has ranged from 35.4 inches in 1941, which was 58 percent of normal, to 66.3 inches in 1983, which was 152 percent of normal.

As in most of New England, Maine has a relatively uniform distribution of precipitation through the year; there are no distinct wet or dry seasons. Long-term records for Portland indicate that mean monthly precipitation ranges from 2.6 inches in August to 4.9 inches in November. In the northern part of the State, the greatest precipitation normally occurs during summer. Long-term records for Caribou indicate that mean monthly precipitation ranges from 2.0 inches in January to 4.0 inches in July. Most winter precipitation falls as snow. Snowfall ranges from about 60 inches along the coast to about 100 inches in the northwest. Snowfall at Portland for 106 years of record ranged from 27.5 inches in 1979-80 to 141.5 inches in 1970-71.

Droughts are caused by persistent anticyclonic circulation that is produced by high-pressure systems over the eastern part of the United States. During droughts, dry continental air prevails, and coastal- and tropical-cyclone activity lessens. Although dry periods in the summer warrant crop irrigation, prolonged droughts are rare. An exception was during the 1960's, when dry air from the north caused cooler spring and summer temperatures in the entire Northeastern United States. Northerly winds forced frontal systems out to sea along the southeastern coast and prevented the Northeast from receiving normal moisture (U.S. Geological Survey, 1986). The drought, which was most severe in 1965, caused agricultural and water-supply problems. Nevertheless, during 1965, no precipitation station in Maine recorded less than 65 percent of normal precipitation, and most stations recorded from 70 to 85 percent of normal.

# MAJOR FLOODS AND DROUGHTS

Major floods and droughts discussed are those that were are-ally extensive, caused excessive damage, and generally had relatively large recurrence intervals. The most significant floods and droughts in Maine are listed chronologically in table 1; rivers and cities are shown in figure 2. Data from 40 streamflow-gaging stations were used to determine the areal extent and severity of floods and droughts in Maine. Six gaging stations were selected from the statewide network to depict floods and droughts (figs. 3 and 4). Selection of these stations was based on areal distribution, basin size and hydrologic setting, and a lack of substantial streamflow regulation. Data from unregulated streams reflect fluctuations in natural runoff rather than fluctuations caused by human activities. Streamflow data are collected, stored, and reported by water year (a water year is the 12-month period from October 1 through September 30 and is identified by the calendar year in which it ends).

Floods and droughts affect public water-supply systems, hydropower systems, tourist industries, agriculture, and forestry in Maine. Stage and discharge data from gaging stations operated by the U.S. Geological Survey document the extent of floods and droughts in the State. A State-Federal network of gaging stations was begun in the early 1900's, but the network did not include most of the major basins until the early 1930's. Supplemental data used to define floods and droughts in Maine include precipitation records collected by the National Weather Service, historical flood information, and water-level records from the monitoring-well network that is operated by the U.S. Geological Survey in cooperation with the State. Historical floods in New England between 1620 and 1955 have been researched and documented by Thompson and others (1964).

## FLOODS

Major floods occur in Maine during each season. Floods are most widespread in the spring when large frontal systems bring steady rainfall to much of the State. At that time, steady rainfall can be augmented by significant snowmelt. Runoff may not infiltrate into the ground if the ground is frozen or saturated. Under these conditions, substantial runoff can result and can cause rivers to rise rapidly. Backwater from ice dams that are created when ice floes meet a constriction in the river valley can aggravate flooding conditions.

In the summer, floods caused by intense rainfall from thunderstorms can be destructive to small local areas. On August 21, 1939, a cloudburst released as much as 12 inches of rain in 3 hours in West Baldwin. The storm affected an area less than 100 square miles but caused severe flash flooding that resulted in three deaths and extensive damage (Stackpole, 1946).

In the fall, floods generally result from intense rainfall after light to moderate rainfall has saturated the ground. Normal monthly rainfall in southern and central Maine is greatest during the fall. Every few years, during summer or fall, tropical cyclones affect Maine. The most destructive tropical cyclones have been in August or September. Since 1900, 17 hurricanes or tropical storms have caused damage in Maine (Interagency Hazard Mitigation Team, 1987).

In the winter, floods are uncommon because most precipitation is received in the form of snow and because the sparse precipitation received as rain generally is absorbed by snowpack. Severe winter storms on February 2, 1976, and February 7, 1978, caused extensive damage in coastal areas. Both of these storms had hurricane-force winds that caused storm surges during high tide. The areal extent of these coastal storms was determined from onsite observations of high-water levels (Morrill and others, 1979; Gadoury, 1979). Estimated damage was $2.6 million from the 1976 storm and $20 million from the 1978 storm (Interagency Hazard Mitigation Team, 1987).

The major floods of 1936, 1953, 1961, 1979, and 1987 were selected for discussion because they affected wide areas of the State, caused extensive damage, or had large recurrence intervals. Areal extent and severity of flooding were based on data from the statewide network of gaging stations. Annual peak-discharge data for the six representative gaging stations, the theoretical 10- and 100-year recurrence interval, and the dates and areal extent of memorable floods are shown in figure 3.

Meteorologic and soil conditions before the flood of March 19, 1936, were conducive to rapid rises in river stages and to large discharges. Early in the winter, the ground had frozen and was almost impermeable to infiltration of moisture. During January and February in many river basins of the State, significant quantities of snow created a deep snowpack that stored a large quantity of water. Warm weather about March 9 began an early spring thaw. Snowmelt and icemelt were accelerated by intense rains from two major storms in the Northeastern United States during the following 10 days. Most of the precipitation fell during March 11-12 and 17-18. The rainfall was most intense in a zone that extended northeastward from the southern part of Vermont, across New Hampshire, and into central Maine (Grover, 1937).

The March 11-12 storm was accompanied by the breakup of the thick ice that had formed on streams during January and February. Analysis of streamflow records indicates that the runoff was about equal to the quantity of precipitation; therefore, snowmelt runoff was not significant. Runoff during the March 17-18 storm, however, greatly exceeded the quantity of precipitation. Water from melting snow combined with the intense rainfall of the second storm and flowed into river systems that were still swollen with water from the first storm. Peak discharges after the second storm were far greater than those of the first storm (Grover, 1937, p. 47).

Large ice jams formed during the March 19, 1936, flood. Ice jams on the Kennebec River caused damage in the tidewater reaches downstream from the dam at Augusta. Elevated river stages at Augusta and Hallowell, caused by ice jams, were 3.6 feet higher than the previous high-water record established on March 2, 1896. A large ice jam also formed in the Androscoggin River in a reach several miles long, just upstream from the pond of the powerplant above Lewiston. According to powerplant records, this ice jam broke on March 20 and released a large volume of water that caused a rise of 1.75 feet in the pond in less than one-half hour. Inflow to the pond was estimated to have been at least 250,000 $ft^3/s$ (cubic feet per second) for several minutes (Grover, 1937).

Flooding on March 19, 1936, was significant throughout southwestern and central Maine; the worst damage was in the Kennebec, Androscoggin, and Saco River basins (fig. 3). The peak discharge on the Androscoggin River at Aubum was 135,000 $ft^3/s$, the largest discharge ever recorded at that gaging station. The peak discharge of the Mattawamkeag River near Mattawamkeag (fig. 3, site 3) was the highest on record. Ice floes increased damage on several rivers by battering structures in the flood path and forming dams that increased flood levels. Five lives were lost as a result of the flooding, and property damage was about $25 million (Interagency Hazard Mitigation Plan, 1987). Eighty-one highway bridges were destroyed or damaged by the flooding (Grover, 1937). Telephone, telegraph, and radio services kept the public advised about the severity of the floods well in advance of the flood crests. As a result, the loss of life was less than it might otherwise have been.

### Table 1. Chronology of major and other memorable floods and droughts in Maine, 1785-1988

[Recurrence interval: The average interval of time within which streamflow will be greater than a particular value for floods or less than a particular value for droughts. Symbol: >, greater than. Sources: Recurrence intervals calculated from U.S. Geological Survey data; other information from U.S. Geological Survey, State and local reports, and newspapers]

| Flood or drought | Date | Area affected (fig. 2) | Recurrence interval (years) | Remarks |
|---|---|---|---|---|
| Flood | 1785 | Southwestern areas | Unknown | Flood used for comparison in historical documents. |
| Flood | March 2, 1896 | Kennebec, Androscoggin, and Saco River basins. | Unknown | On Androscoggin River, the next largest flood after 1936 and 1953 floods. Peak discharge of record on Penobscot River at West Enfield and Passadumkeag River at Lowell. Damage, $2 million. |
| Flood | May 2, 1923 | Aroostook, Meduxnekeag, St. Croix, Union, Piscataquis, and Penobscot River basins. | >50 | |
| Flood | March 19, 1936 | South-central Maine | >50 | Peak discharge of record on Androscoggin River at Auburn. Deaths, 5; damage, $25 million. |
| Drought | 1938-43 | Western areas | 15 to >30 | Severe in Androscoggin and |

| | | | | |
|---|---|---|---|---|
| | | | | Kennebec River basins. |
| Flood | August 21, 1939 | Town of West Baldwin | Unknown | Rain of cloudburst intensity covering about 100 square miles. Deaths, 3. |
| Flood | June 1943 | Upper Androscoggin River basin and along boundary with northeast New Hampshire. | >50 | Peak discharge of record on Diamond River at Wentworth Location, N.H. |
| Drought | 1947-50 | South-central areas | 15 to >30 | Severe in central coast region. |
| Flood | March 27-30, 1953 | Southwestern Maine | >50 | Greatest peak discharge on Saco River at Conway, N.H. Severe flooding in Little Androscoggin and Sandy River basins. |
| Drought | 1955-57 | Nearly entire State | 15 to >30 | Severe in northern and eastern parts of State. |
| Flood | May 28, 1961 | Eastern Maine | >50 | Greatest peak discharges on St. Croix River at Baring near Milltown, Machias River at Whitneyville near Machias, and Narraguagus River at Cherryfield. Damage, $1 million. |
| Drought | 1963-69 | Statewide | >30 | Most severe of record in Maine. |
| Flood | November 4, 1966 | Headwaters of Kennebec and Piscataquis Rivers. | >50 | |
| Flood | April 30, 1973 | Northern and eastern Maine | >50 | Greatest peak discharges of record on Fish River near Fort Kent and Dennys River at Dennysville. |
| Flood | Feb. 2, 1976 | Penobscot Bay, southern Maine | Unknown | Storm flood inundated downtown Bangor. Damage, $2.6 million. |
| Flood | Feb. 7, 1978 | Southwestern coastal areas | Unknown | The blizzard of 1978. Damage, $20 million. |
| Flood | April 30, 1979 | St. John River basin | >25 | Peak discharge of record on St. John River at Fort Kent. Damage, $650,000. |
| Flood | April 18, 1983 | Allagash River basin | >50 | Peak discharge of record on Allagash River at Allagash. |
| Drought | 1984-88 | Statewide | 15 to >30 | Severe in northern Maine. |
| Flood | April 1, 1987 | Central and south-central Maine. | >50 | Peak discharges of record on the Kennebec, Piscataquis, Carrabassett, and Little Androscoggin Rivers. Most devastating of record in Maine. Damage, $100 million. |

During March 1953, greater than average rainfall was recorded throughout Maine. The largest totals were about 11 inches at sites in the southwestern part of the State. Runoff from this precipitation caused the flood of March 27-30, 1953. The resultant peak discharge of the Little Androscoggin River near South Paris (fig. 3, site 6) was the largest since 1896, and the discharge of the Nezinscot River at Turner Center was the largest since 1913. The discharge of the Androscoggin River at Aubum was the second largest since 1850 and probably since 1785. The discharge at the Saco River at Conway, N.H., was the largest since data collection began in 1904.

The relative severity of the March 27-30, 1953, flood is shown in the peak discharges for the gaging stations on the Carrabassett River near North Anson (fig. 3, site 5) and on the Little Androscoggin River near South Paris (fig. 3, site 6). Peak discharge of the Carrabassett River was nearly equal to that during the 1936 flood. On the Little Androscoggin River, the 1953 peak was much larger than the peak of 1936. Despite record runoff, the March 1953 flood is not well remembered because damage was minimized by the absence of ice jams and moving ice (Thompson and others, 1964).

During May 26-29, 1961, a frontal system that had stalled over eastern Maine caused rainfall totals of more than 7 inches from Ellsworth to Woodland. Rainfall totals in adjacent areas were about 3 inches as far north as Caribou and as far south as Eastport. Some precipitation stations in the southeastern part of the State reported 5.0-5.5 inches of rain on May 27. The storm caused flooding in the St. Croix and eastern coastal river basins. Record discharges that exceeded earlier record discharges by as much as 25 percent were measured at gaging stations on the Machias, Narraguagus, and Dennys Rivers. Peak discharge of the St. Croix River generally equaled earlier record discharge. The peak discharge of the gaging station on the Narraguagus River at Cherryfield (fig. 3, site 2) was more than 10,000 $ft^3/s$.

During the May 28, 1961, flood, pulpwood and logs were swept downstream on the St. Croix and Machias Rivers when booms were breached and several small dams were destroyed. Many roads, highways, and railroads were washed out, and a bridge on the St. Croix River was damaged. Water damaged structures in the towns of Calais, Milltown, Woodland, Machias, and others. Total damage, estimated from newspaper accounts, was $1 million.

On April 30, 1979, a warm, moist airmass entered Maine from the south. This airmass continued a pattern of seasonally warm temperatures that had been evident for about 10 days. During the next 4 days, as much as 6 inches of rain fell on parts of the State. Snowmelt in northwestern Maine, together with the intense rainfall, caused excessive runoff in the St. John River basin and resulted in recors peak discharges (Fontaine and Haskel, 1981). The April 30 peak discharge of the St. John River below Fish River at Fort Kent (fig. 3, site 1) had a recurrence interval of about 50 years. Peak discharges having recurrence intervals greater than 25 years were recorded at several other gaging stations in the St. John River basin. Damage was severe in Fort Kent and Van Buren. Total damage of $650,000 was reported to homes and commercial and industrial establishments (Interagency Hazard Mitigation Team, 1987).

The flood of April 1,1987, was the most destructive on record. On March 30, a slow-moving frontal system moved northeastward in a path almost perpendicular to the mountainous region in the western part of the State. The slow speed of the storm and orographic effects combined to cause extreme rainfall totals in the headwater areas of several river basins-the Piscataquis, Sandy, Carrabassett, Wild, and Little Androscoggin. The storm, continuing through the morning of April 2, released an average of 4-8 inches of rain in the central and western parts of the State. The largest rainfall totals during this storm were 8.3 inches at Pinkham Notch, N.H., and 7.3 inches at Blanchard. Runoff from the storm was augmented by meltwater from a snowpack that contained an average water equivalent of about 5-7 inches and as much as 10 inches of water equivalent in the higher altitudes (F. Ronco, National Weather Service, written commun., 1987).

Rainfall from the March-April 1987 storm and snowmelt runoff combined to produce record to near-record stream discharges; many of the peak discharges had recurrence intervals that greatly exceeded 50 years. Record peak discharges were recorded at 15 gaging stations in western and central Maine during the flood (Fontaine, 1987). Peak discharges of the Piscataquis River near Dover-Foxcroft (fig. 3, site 4), the Carrabassett River near North Anson (fig. 3, site 5), and the Wild River at Gilead were 45, 33, and 42 percent larger, respectively, than any peak discharges previously recorded at these sites.

Estimated damage sustained by individuals and businesses was $70 million, which included $16 million to homes; $45 million to small businesses; $8 million to electrical utilities, railroads, paper mills, and other industries; and $0.5 million to farms. Federal disaster areas were declared in 14 of Maine's 16 counties (Interagency Hazard Mitigation Team, 1987). Estimated damage to public buildings and facilities was $33 million, which included $ 17.1 million to roads and bridges, $3.6 million to sewage-treatment plants, about $1 million to public water supplies, and about $11 million to other public facilities (Hasbrouck, 1987).

## DROUGHTS

Droughts have not been as well documented as floods. Fieldhouse and Palmer (1965), however, used monthly temperature and precipitation data for January 1929 through December 1963 to determine the severity of droughts in three climatic regions in Maine. The results of their study compared well with the drought analysis in this report, which is based on streamflow records. The areal extent of droughts is more accurately defined by streamflow data than by climatic data because streamflow data depict conditions on a river-basin scale rather than on the larger scale of regional climatic divisions.

Droughts are not as easily defined as floods because droughts commonly do not have a distinct beginning or end and are difficult to quantify. Drought analysis in this report is limited to multiyear hydrologic events determined from streamflow records. Sixteen gaging stations in Maine and three gaging stations in New Hampshire were used to define the severity and extent of droughts that have affected the State. Cumulative departures were analyzed and recurrence intervals were determined for five major droughts: 1938-43, 1947-50, 1955-57, 1963-69, and 1984-88. Annual-departure graphs for the six selected gaging stations are shown in figure 4. Bars above the line of zero departure on these graphs indicate years having greater than average streamflow; bars below the line of zero departure indicate years having less than average streamflow.

The 1938-43 drought had a recurrence interval greater than 30 years in the Androscoggin, Kennebec, and western Penobscot River basins (fig. 4). The long duration of the drought is apparent from the annual-departure graphs for the Little Androscoggin River near South Paris (fig. 4, site 6), Carrabassett River near North Anson (fig. 4, site 5), and Piscataquis River near Dover-Foxcroft (fig. 4, site 4). In the rest of the State, the drought had a recurrence interval of between 15 and 30 years except for the St. Croix and Passadumkeag River basins.

The drought of 1947-50 was most pronounced in the central coastal and northern areas. The recurrence interval of the drought exceeded 30 years on the Piscataquis River near Dover-Foxcroft (fig. 4, site 4) and St. John River below Fish River at Fort Kent (fig. 4, site 1). Data from gaging stations in the southwestern part of the State indicate that the drought had a recurrence interval there of between 15 and 30 years.

The 1955-57 drought affected nearly the entire State, the northern and eastern parts most severely. At gaging stations in these areas, such as St. John River below Fish River at Fort Kent (fig. 4, site 1) and Mattawamkeag River near Mattawamkeag (fig. 4, site 3), the drought had a recurrence interval greater than 30 years. In the rest of the State, except for southwestern and central coastal areas where the drought was less intense, the recurrence interval was 15-30 years.

The drought of 1963-69 was the most widespread and severe in Maine since the gaging-station network had been implemented. The recurrence interval of the drought was greater than 30 years at all gaging stations. Statewide drought conditions were most apparent in 1965 when streamflow ranged from less than average to a record minimum, and much of the State had low ground-water levels (Barksdale and others, 1966). Dry conditions conducive to forest fires were most severe in 1965.

The drought of 1984-88 affected the entire State. In the northern part, the recurrence interval was greater than 30 years. In the rest of the State, the drought had a recurrence interval of 15-30 years.

The destructive effect of a flood is immediately apparent, but a drought causes damage over an extended period. In Maine, drought interrupts water supplies for public-utility, domestic, industrial, and agricultural uses. Direct crop damage and forest fires also are of concern.

Although ground water accounts for only 8 percent of water withdrawn statewide, it is the source of domestic water for about one-half of Maine's population (U.S. Geological Survey, 1990). Long-term declines in ground-water levels often result from extended droughts. Few wells in Maine are used to monitor ground-water levels; however, where water-level records are available, the data indicate that climate affects long-term ground-water levels more than does pumping stress (U.S. Geological Survey, 1985).

Hydropower systems in Maine depend on adequate reservoir storage, which in turn depends on adequate precipitation. Winter droughts lessen spring snowmelt, an important source of water for the reservoirs, which generally reach their lowest annual levels in late winter.

Periods of extended drought are rare, and irrigation is generally sufficient to cope with fairly common short dry spells during the growing season. Nonetheless, more intense, albeit short droughts during the growing season can cause substantial agricultural damage.

http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R30/R30.pdf

**Periodic 18.6-year and cyclic 10 to 11 year signals in northeastern United States precipitation data**

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# Abstract

Evidence for a narrow band-limited signal with period near 18.6-years is found in 126 out of 136 yearly total precipitation records, and in 1531 out of 1668 monthly records in the northeastern United States. From 1840 to near the end of the 19th century, rainfall minima in the wavetrain are highly correlated with tidal maxima of the 18.6-year luni-solar tide, the twelfth largest tidal constituent in Newton's theory; the wavetrain then switched phase by 180° and for most of the 20th century rainfall maxima are correlated with tidal maxima at 1917.5, 1936.1, 1954.7, and 1973.3. This bistable phenomenon of atmospheric science was discovered by Currie (1983) in a study of tree-rings from the Patagonian Andes, and O'Brien and Currie (1988) have suggested a dynamical explanation in terms of mathematical physics. In terms of yearly rainfall, the mean percentage amplitude modulation of the wave was near ±6% until 1940 after which it began to increase rapidly, reaching ±10% in the 1960s and 1970s. These results provide a rational explanation for the severe water shortage crisis that occurred at tidal minimum 1964.0 (Namias, 1966; 1967), and reoccurred 19 years later. In addition, a smaller band-limited term with period 10 to 11-years is found in a little more than half of the records.

1. NAMIAS, JEROME, 1966: NATURE AND POSSIBLE CAUSES OF THE NORTHEASTERN UNITED STATES DROUGHT DURING 1962–65. *Mon. Wea. Rev.*, **94**, 543–554.
2. doi: 10.1175/1520-0493(1966)094<0543:NAPCOT>2.3.CO;2

3. http://docs.lib.noaa.gov/rescue/mwr/094/mwr-094-09-0543.pdf

4. **North American droughts / edited by Norman J. Rosenberg**

Rosenberg, Norman J., 1930-

[ Book : 1978 ]

Keywords: Droughts - United States.

At 12 libraries

5. **Proceedings of the conference on the drought in the Northeastern United States, Sterling Forest, New York 15-17 May 1967 / sponsored by New York State Science and Technology Foundation, arranged by Department of Meteorology and Oceanography, New York University, Jerome Spar editor**

Conference on the Drought in the Northeastern United States Sterling Forest, N.Y.) (1967 :

[ Book : 1969 ]

Keywords: Droughts - United States - Congresses.

At Nat Met Library

6. **Drought in northeastern United States : report to the President / Water Resources Council**

Water Resources Council (U.S.)

[ Book : 1965 ]

Keywords: Droughts - United States.

Mitchell, J.M., 1968, Further studies of drought over the northeastern United States: Conference on the Drought in the Northeastern United States, New York, N.Y., New York University, Proceedings, no. TR-68-3, p. 129-159.

Namias, Jerome, 1966, Nature and possible causes of the northeastern United States drought during 1962-65: Monthly Weather Review, v. 94, no. 9, p. 543-554.

http://geochange.er.usgs.gov/sw/changes/natural/drought/

Parsons, Margaret R., et al, 1978. Extreme value analysis of annual minimum temperatures in New Jersey. *Bulletin of the New Jersey Academy of Science*, vol. 23, no. 2, 43-49.

Scott, Cynthia M., et al, 1976. An extreme value analysis of heavy precipitation in New Jersey. *Bulletin of the New Jersey Academy of Science*, vol. 21 no. 2, 1-5.

# Northeast US precipitation variability and North American climate teleconnections interpreted from late Holocene varved sediments

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## Abstract

A more thorough understanding of regional to hemispheric hydroclimate variability and associated climate patterns is needed in order to validate climate models and project future conditions. In this study, two annually laminated (varved) sediment records spanning the last millennium were analyzed from Rhode Island and New York. Lamination thickness time series from the two locations are significantly correlated to hydroclimate indicators over the period of instrument overlap, demonstrating their usefulness in reconstructing past conditions. Both records are correlated to climate teleconnection indices, most strongly the Pacific/North American (PNA) pattern, suggesting regional to hemispheric influences on hydroclimate. Such a linkage is interpreted to be due to tropospheric circulation patterns in which positive PNA periods are associated with meridional circulation, leading to the dominance of southern moist air masses in the Northeast United States. Alternatively, the zonal flow over North America associated with negative PNA periods produces dominant dry continental air masses over the region. A composite record from the two locations reveals variability of hydroclimate and atmospheric circulation over the late Holocene and shows similarities to previously published reconstructions of the circumpolar vortex and of the Aleutian Low-pressure system, supporting the hypothesized PNA linkage. The record is correlated to continental-scale droughts, many of which have been reconstructed in the American Southwest. These results demonstrate the PNA's influence on hydroclimate over North America, and suggest that this teleconnected pattern may have a significant role in continental drought dynamics.

- **Green Lake**

- **Pettaquamscutt River Estuary**

- **Quaternary**

- **New England**
- **paleolimnology**

### Footnotes

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# Spatiotemporal Variability of Precipitation, Modeled Soil Moisture, and Vegetation Greenness in North America within the Recent Observational Record

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## Abstract

Dominant spatiotemporal patterns of precipitation, modeled soil moisture, and vegetation are determined in North America within the recent observational record (late twentieth century onward). These data are from a gridded U.S.–Mexico precipitation product, retrospective long-term integrations of two land surface models, and satellite-derived vegetation greenness. The analysis procedure uses three statistical techniques. First, all the variables are normalized according to the standardized precipitation index procedure. Second, dominant patterns of spatiotemporal variability are determined using multitaper method–singular value decomposition for interannual and longer time scales. The dominant spatiotemporal patterns of precipitation generally conform to known and distinct Pacific SST forcing in the cool and warm seasons. Two specific time scales in precipitation at 9 and 6–7 yr correspond to significant variability in soil moisture and vegetation, respectively. The 9-yr signal is related to precipitation in late fall to early winter, whereas the 6–7-yr signal is related to earlysummer precipitation. Canonical correlation analysis is finally used to confirm that strong covariability between land surface variables and precipitation exists at these specific times of the year. Both signals are strongest in the central and western United States and are consistent with prior global modeling and paleoclimate studies that have investigated drought in North America.

Keywords: Soil moisture, Vegetation, Precipitation, North America

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A Synoptic Climatology for Forest Fires in the NE US and Future

Implications from GCM Simulations

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Abstract. We studied surface-pressure patterns corresponding to reduced precipitation, high evaporation potential, and enhanced forest-fire danger for West Virginia, which experienced extensive forest-fire damage in November 1987. From five years of daily weather maps we identifiedeight weather patterns that describedistinctive flow situations throughout the year. Map patterns labeled extended-high, back-of-high, and pre-high were the most frequently occurring patterns that accompany forest fires in West Virginia and the nearby four-state region. Of these, back-of-high accounted for a disproportionately large amount of fire-related damage. Examination of evaporation and precipitation data showed that these three patterns and high-to-the-south patterns all led to drying conditions and all other patterns led to moistening conditions. Surface-pressure fields generated by the Canadian Climate Centre global circulation model for simulations of the present (IxCO,) climate and 2xC0, climate were studied to determine whether forest-fire potential would change under increased atmospheric CO,. The analysis showed a tendency for increased frequency of drying in theNE US, but the results were not statistically significant.

Keywords:

## Introduction

Wildfires are known to correlate with climatic events on short time scales of El Niiio events (Simard et a1 1985) and much longer time scales as determined by charcoal stratigraphic analysis and fire scars (Clark 1990; Meyer et a1 1992; Swetnam 1993). The linkage of forest fires to meteorological events includes both likelihood of severe drought conditions due, for instance, to persistent high-pressure conditions (Schroeder et a1 1964) and frequency of lightning events (Price and Rind 1993). In fact, a worst-case fire scenario would

have an extended drought followed by a synoptic pattern conducive to thunderstorms with minimal precipitation and strong surface winds to propagate new or pre-existing fires. Brotak and Reifsnyder (1977) found that most major wildland fires in the eastern US occurred during surface frontal passage with strong winds and no precipitation. Such events were associated with a specific type of 500-mb trough that was intense but of small latitudinal extent. Whether these larger fires are ignited by lightning or human causes, meteorological conditions play a dominant role in determining the extent of their societal impact. These studies point out the need for examination of the types and sequences of types of synoptic-scale meteorological events that accompany large forest fires.

The goal of our research is to examine the relationship of forest-fire occurrence to weather patterns and sequences of weather patterns. Success in this goal gives a basis for estimating future forest-fire likelihood by using global-climate models that project changes in climate patterns. We examined the relationship between weather patterns and forest fires by analyzing dady surface-pressure maps and precipitation and evaporation data for a subregion of the northeastern US (West Virginia) that experienced extensive forest-fie damage in November 1987. Synoptic weather maps for five years were used to identify distinctive flow situations throughout the year. These patterns served as a basis for categorizing data on evaporation, precipitation, and forest-fire occurrence.

Surface-pressure fields generated by the Canadian Climate Centre global circulation model for a three-year simulation of the present (IxCO,) climate and a three-year simulation of the 2xC0, climate were then studied to determine whether a global climate model can simulate typical surface-pressure patterns common to this region. We compiled statistics on frequency of occurrence of characteristic synoptic patterns in the IxCO, simulations to determine the model bias for simulating the ensemble of observed surface-pressure fields and their seasonal distribution. This model bias together with pressure-pattern distributions produced by the 2xC0, simulation allow us to speculate on the prospects for forest fires in the northeastern US under a doubled-CO, climate.

## Forest Fire Data

We examined data on forest-fire occurrence in the northeastern US for the periods 1971-84 and 1987-90 (available from the USDA Forest Service, North Central Forest Experiment Station) that were used in the development of the METAFIRE fire-severity prediction system (Simard and Eenigenburg, 1990). These data give the subarea of a state affected and the number of acres burned for fires that burned more than 500 acres. This database does not include the many small fires during this period but includes those that have major impact on fire suppression activity. We had no accompanying data on ignition agents or fire-suppression activity, so human intervention contributes uncertainty to the fire event data. By limiting our attention to large-scale fires, however, we increase the likelihood that the events considered have a meteorological connection.

Fires recorded in the dataset peaked very strongly in April and November, with approximately one third of occurrences being in each of these two months. The fire damage in West Virginia in 1987 stands out as the most devastating period within the record examined for the NE US region. We used this location and year to examine in detail the synoptic meteorology patterns leading up to and accompanying the fire period. The selection of this particular location means that when we examined and assigned a particular synoptic weather pattern to each day, we looked for the pattern that affected the fire-damaged area of West Virginia. On a particular day, the pattern affecting a nearby state might differ from the pattern assigned to West Virginia.

## Synoptic Meteorology Patterns

Schroeder, et al. (1964) presented an extensive analysis of synoptic weather types associated with crilical fire weather. They related fire danger to persistent high-pressure centers and pre- and post-frontal areas associated with these centers. In the eastern US, if a high-pressure center moves to the north of a possible fire region, the high fire danger tends to be in the post-frontal area on the leading side of the high; if the center passes south of the location, high

fire danger is more likely to be in the pre-frontal area west and north of the center of the high.

Yarnal (1993) extensively analyzed synoptic patterns for the eastern US. He concluded that almost all weather systems affecting this area throughout the year could be divided into eight synoptic patterns. He labeled these patterns as follows:

-Rain-Qclones Back-of-High

-Cold-Frontal-Passage Ee-~i~h

-Extended-Low -High-to-the-SorthExtended-High -High-to-the-South

These patterns are shown in Figure 1. Discussion of the weather characteristics accompanying each of these patterns is given in Yarnal (1993). This classification system differs from the scheme of Schroeder et al (1964), for instance, in that Yarnal uses wind speed, wind direction, relative humidity, weather, and other factors as well as the surface weather patterns, whereas Schroeder focuses only on the surface-pressure patterns and upper-air flow fields. Brotak and Reifsnyder (1977) also examined the meteorological patterns accompanying the occurrence of wildland fires, but their analysis was focused on the conditions that transformed small fires into large fires. This focus emphasizes wind conditions that led to spread of fires rather than the series of synoptic conditions that create the environment for fires to begin. More objective computer-based synoptic climatology analyses are possible by use of empirical orthogonal functions, correlation coefficients and other methods (Yarnal, 1993). We chose a more subjective synoptic meteorology pattern approach because it uses realistic patterns that are easily recognized by forest meteorologists. This method also allows us to bridge from observed evaporation and precipitation data to the climate model results without having to use (notoriously poor) representations of precipitation by the climate model.

We classified daily weather maps for five years (NOAA 1979, 1980, 1982, 1983, and 1987) using the Yarnal categories. These years were chosen because for these years we had access to axasonably complete set of daily weather maps and because the evaporation and precipitation records for four stations in West Virginia for this period do not have major gaps. We forced all maps to fit into one of the eight patterns shown, since only about 3% of the total number of maps were ambiguous.

Yarnal gives plots of the distribution of patterns throughout the year for the Pittsburgh, PA area for the years 1978-87. It would be expected that, on a few days, the dominant pattern would be different for

Figure 1. Synoptic meteorology patterns that influence the eastern United States as defined by Yarnal (1993): (a) cold-front, (b)

extended-low, (c)pre-high, (d) rain-cyclone, (e) back-of-high, (f) extended-high, (g) high-to-the north, and (h) high-to-the-south.

Pittsburgh than for West Virginia. However, our annual distribution of patterns generally agreed with the distributions given for each respective year by Yarnal. Table 1 gives the distribution, in percent of available number of days, of synoptic patterns we found for West Virginia for these five years. Also given is the distribution of patterns Yarnal (1993) reported for ten years of data for Pittsburgh. Our seasonal distribution (not shown) of patterns also is in general agreement with the results of Yarnal.

## Relation of Synoptic Patterns to Forest Fires

It is informative to look at the sequence of weather patterns leading up to occurrences of major fires. The PH pattern frequently, although not always, was observed to be a transition pattern to more drier conditions. Several times during the summer of 1987, a PH would become established with a clearing sky, increasing temperature, and decreasing relative humidity. The PH pattern would persist for about a day, in some cases permitting fires to start. However, fires ignited during these conditions were generally small, burning areas of

500 to 2,000 acres.

The PH pattern typically was replaced by an EH pattern, which was accompanied by calm winds, high temperatures, low humidities, and clear skies. This system typically would dominate for about two days. Some EH patterns lingered for as long as five days. This was a common pattern accompanying the onset of large fires with damaged areas between 500 and 4,000 acres, some blackening 15,000 acres.

The largest fires in West Virginia, however, were associated with the next phase (BH) of the movement of the dominating high-pressure system. As the high moved out over the Atlantic Ocean, moist on-shore surface air was orographically lifted, occasionally leading to shower activity on the eastern slopes of the Appalachians. But by the time air parcels arrive in West Virginia, the moisture level was reduced, and a 'chinook' condition developed with one or more of the

Table 1. Annual distribution (%) of Yarnal classes.

MEAN 25 7 16 10 14 17 6 5 5

Yamal 18 7 24 13 14 16 5 2 1

following conditions existing in West Virginia compared to the eastern side of the mountains: 5°F higher temperature, 5°F lower dew-point temperature, or 5 kt higher windspeed. Not only was the damage area largeunder these conditions (ranging from 500 to 10,000acres), but there was a higher incidence of multiple fires. In some cases, fire damage exceeded 30,000 acres. The BH system was by far the most destructive pattern found for West Virginia in 1987.

To increase the number of fire events for comparison with daily weather maps, we also examined the distribution of fire-damaged areas for the four-state region of West Virginia, Ohio, Pennsylvania, and New York over the period for which we have fire-damage data (1971-84 and 1987-90). The synoptic climatology was re-done separately for each state. The results, given in Table 2, add further evidence linking of EH, BH, and PH patterns to major fire damage and the relative absence of fires, particularly large fires, with other patterns. The BH system is comparable to the pre-frontal zone of high fire potential identified by Schroeder et al. (1964) for a high-pressure center passing south of the fire area.

Evaporation and Precipitation Data

Four stations in West Virginia (Bluestone, Coopers Rock, Kearneysville, and Parsons) report daily pan evaporation and precipitation data during the warm season. The periods of record were not consistent among the four stations in that for some stations in some years, evaporation measurements were reported as early as April whereas for other locations or years measurements started in June. Likewise, the ending date sometimes was in September and sometimes October. For each year studied, we took only the period of record that was common to all four stations and calculated the four-station average for each day. Evaporation measurements can be contaminated by a number of factors and will have a different spatial variability than precipitation measurements. Furthermore, combining daily evaporation values from June with values from October for the same map class surely raises the variance. Despite these acknowledged sources of uncertainty, we have found some consistencies across the data we analyzed. We calculated evaporation minus precipitation (E-P) for each station for 1979, 1980,1982,1983, and 1987 for each day of record (676 days were analyzed) and tabulated values for each

Yarnal synoptic weather type. The results are shown in Table 3.

Table 2. Number of fire events under various synoptic meteorology patterns for different damage categories (acres) for WV, OH, PA, and NY.

ACRES YARNAL CLASS

x 1030 BH PH EH HN CF HS RC EL

From this table we conclude that:

1) EH and BH patterns consistently lead to drying conditions

2) HN and HS patterns tend to produce drying conditions

3) EL, PH, and CF patterns tend to produce moistening conditions

4) RC patterns consistently lead to moistening conditions.

In decreasing order of drying potential for West

Virginia, we rank order the patterns as follows: EH, BH, HN, HS, PH, EL, CF, RC. As previously noted for 1987, PH seemed to be a dry pattern leading the transition to even drier EH and BH patterns. However, this is not always the case, as shown in Table 3, where the PH pattern shows a slight tendency to support moistening conditions.

## Global Climate Model Results

Global climate models have been widely used for climate-change impact assessments (Smith and Tirpak, 1989). These studies have used monthly mean values of meteorological variables generated by GCMs as the basis for determining the impact of a doubling of CO, on agriculture, forests, sea level, biological diversity, water resources, and electricity demand. Althoughsuch studies give a general overall view of impacts of climate change, their use of mean monthly variables, rather than daily means and extremes, may significantly underestimate impacts in some areas such as agriculture. Improved impact assessments are now possible because of the twice-daily values of meteorological variables available from models such as the Canadian Climate Center (CCC) GCM.

The CCC GCM (Canadian Climate Centre, 1990) is a T32L10 model with a transform grid of 3.75' x 3.75" with upgraded physics, including full diurnal and annual cycles. It has a thermodynamic ice model and a slab ocean with transports that permit good simulation of the present ocean-temperature distribution and ice boundaries. Its surface hydrology is an improvement on the standard "bucket" method. The model projects a 3S°C global warming [which is near the center of the 1.5 to 4S°C "consensus" range of the Intergovernmental Panel on Climate Change (IPCC, 1992)l and a precipitation increase of 4% (which is drier than most other models) for a doubling of atmospheric carbon dioxide. A description of the second generation of this model (GCMII) and the equilibrium

Table 3. Daily mean values of evaporation minus precipitation (E-P) in units of inches for each Yarnal map classification for five

years. Period evaluated each year is given in parentheses. The second line under each year gives the number of occurrences that

contributed to the value for each respective category and year.

YEAR

1979 (JUN-SEP)

1980(JUN-OCT)

1982 (JUN-SEP)

1983(JUN-OCT)

1987 (MAY-SEP)

MEAN

TOTAL DAYS

YARNAL MAP CLASS

HS CF BH EH RC PH EL HN

-.0514

-.2121

.1323

.1445

-.0419

.0411

.0413

.02

6

.073

-.0714

.1416

.1330

-.2413

-.0119

-.0413

-.056

.02 -.09 .ll .14 -.I4 -.01 -.04 .0333 89 112 21 1 83 68 47 33 climate it produces are given by McFarlane et a1 (1992), and the greenhouse-gas induced climate changes simulated by the model are given by Boer et al(1992). The North American grid for this model is shown in Figure 2.

We analyzed three years of daily data for each of the lxCO, and 2xC02 simulations produced by GCMII. Surface-pressure values produced by the model are reduced to sea level by the hydrostatic method used by the National Meteorological Center for the NGM and Eta models (Russ Treadon, private communication). Sea-level pressure maps were plotted for the 12 UTC (5 AM EST) model data, since this time was reasonably close to the times of the daily weather maps (6 AM EST). Fronts were not analyzed on the maps from the climate model, so the CF designation was assigned to events having a pressure trough with northwest winds to the west and southwest winds to the east of West Virginia.

Model sea-level pressure maps resemble observed surface maps except for an anomalous and persistent high-pressure value at one grid point in the Gulf of Mexico and one in the Atlantic Ocean. These values were excised and replaced by the mean of their four nearest neighbors to eliminate distortion of the isobars. A sample sea-level pressure map is shown in Figure 3.

Results of our preliminary analysis of three years (except for three days that were lost in data transmission) of the model data for lxCO, and 2xC0, are shown in Table 4.

Although the maps derived from the climate model look similar to daily weather maps, fronts are not plotted and details characteristic of the daily weather maps are missing, so there may be some human bias in assigning a Yarnal pattern to each map. This could be particularly problematic for EL and CF patterns. For this reason, even though we make qualitative comparisons, we caution against making definitive statements on the comparisons between the model results and the observed maps. Comparison between model results for lxC02 and 2xC0, minimizes this bias, however, and provides some interesting observations.

Compared to the observed patterns, the CCC model for IxCO, produces too many HS, too few CF and EH, with about the right number of HN, BH, RC, PH, and EL. In the model, high-pressure systems to the west of the West Virginia area slide south and southeast too frequently and too infrequently move to the northeast or elongate on a NE-SW axis over the Ohio valley. Comparison of these biases with the evaporation potential of each category shows some tendency for off-

Figure 2. Grid used for the Canadian Climate Centre Global Circulation Model.

Table 4. Annual distribution (%, within roundoff error) of Yarnal classes from observed data and a global climate model for West

Virginia.

Drying

EH BH HN HS

5-yr 25 17 5 6

YR 01YR02YR 033-yr Mean

817

7

11

2214

24

20

23

4

3

20

17

27

21

8 22 3 24

3-yr Mean 8 23 4 28

setting effects within generally drying or generally moistening patterns.

The model results for 2xC0, (Table 4) show decreased occurrences of EH, EL, RC, and PH, but increased occurrence of BH and HS. These data also show some degree of compensation, but a general

Moistening

RC CF EL PH Missing

Observed16 10 7 14 5

Climate Model 1XC02

20

19

12

17

Climate Model 2XC02

19

14

7 11 10 01 7 21 1

3 10 14 0

4 9 15 0

7 9 8 0

5 7 i 1 0

increase in the evaporation potential. If we qualita-

tively consider EH, BH, HN, and HS to be drying

patterns and RC, CF, EL, and PH to be moisteningpatterns, then the results of Table 5 show that the

observed data have about equal divisions of drying and

moistening patterns and that the IxCO, results have

CCC 1XC02 SLPRESS 122 JUL 04, YR03

120" W 110" W 100" W 90"W 80" W 70' W

LONGITUDE

Figure 3. Typical sea-level pressure map produced from the CCC model surface pressure fields.

Table 5. Comparison of drying patterns and moistening

pattern (% of available days) for the daily weather maps

(DWM), lxCO,simulation, and2xC02 simulationof the CCC

model.

Map Pattern DWM IxCO, 2xC0,

Drying: EH+BH+HN+HS

Moistening: RC+CF+EL+PH

53

47

55

45

63

37

essentially the same distribution. The 2xC0, results

show a higher tendency for drier conditions compared

to the IxCO, results, but when the results are subjected

to a Tukey test for significance, the difference was not

significant at the 95% level.

## Summary

Analysis of surface daily weather maps for West Virginia indicate that map patterns defined by Yarnal (1993) as EH, BH, and PH are the most frequently occumng patterns that accompany forest fires in West Virginia and the nearby four-state region. Of these, BH accounted for the most fire-related damage. A tabulation of daily evaporation and precipitation by map pattern for the warm season for four stations in West Virginia revealed that EH, BH, HN, and HS patterns are associated with drying conditions, and RC, CF, EL, and PH patterns are associated with moistening conditions.

Analysis of results from a global climate model show that the model produces too many HS patterns and too few CF and EH patterns. High-pressuresystems west of West Virginia tend to slide too far to the south and east and too rarely move north of West Virginia. Movement of these high-pressure systems is very important for fire-weather potential in the NE US, so inability of the GCM to capture this movement may limit its usefulness for projecting impacts of doubling CO,. Nevertheless, we have analyzed data for three years from the global model output for lxC02 and 2xC02, and we find that doubling CO, gives a tendency for an increase in drying patterns and a decrease in moistening patterns. Additional data from the climate model are needed to compare the interannual variability of the model with observed data and to increase the sample size for testing statistical significance.

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## References

Brotak, E. A., and W. E. Reifsnyder, 1977: An investigationof the synoptic situations associated with major wildland fires. Journal of Applied Meteorology, 16, 867-870.

Boer,G.J.,N. A.McFarlane andM.Lazare. 1992. Greenhouse gas-induced climate change simulated with the CCC second-generation general circulation model. Journal of Climate, 5, 1045-1077.

Canadian Climate Centre. 1990. Application of the Canadian

Climate Centre General Circulation Model output for regional climate impact studies -Guideline for users. Atmospheric Environment Centre, Downsview, Ontario, Canada 24pp.

Clark, James S. 1990. Fire and climate change during the last 750 yr in northwestern Minnesota. Ecological Monographs, 60, 135-159.

Intergovernmental Panel on Climate Change (IPCC). 1992. Climate change 1992: The supplement report to the IPCC Scientific Assessment. J. T. Houghton,B. A. Callander, and S. K. Vamey, Editors. Cambridge University Press, Cambridge,UK. 200 pp.

Meyer, G. A., S. G.Wells, R. C. Balling, Jr., and A. J. T. Jull. 1992. Response of alluvial systems to fire and climate change in Yellowstone National Park. Nature, 357,147-

150.

McFarlane, N. A., G.J. Boer, J.-P. Blanchet and M. Lazare. 1992. The Canadian Climate Centre second-generation general circulation model and its equilibrium climate. Journal of Climate, 5, 1013-1044.

Nationaloceanic and Atmospheric Administration. 1979,1980, 1982, 1983, and 1987: Daily Weather Maps, Weekly Series. Climate Analysis Center. Washington DC.

Price, C., and D. Rind. 1993. Lightning and forest frres in a changing climate. In The World at Risk: Natural Hazards and Climate Change, Rafael Bras, Editor. AIP Conference Proceedings 277. American Institute of Physics. 352 pp.

Schroeder, M. J., M. Glovinsky, V. F. Hendricks, F. C. Hood, M. K. Hull, H.L. Jacobson, R. Kirkpatrick, D. W. Krueger, L. P.Mallory, A. G. Oertel, R. H. Reese, L. A. Sergius, and C. E. Syverson. 1964. Synoptic Weather Types Associated with Critical Fire Weather. Pacific Southwest Forest and Range Experiment Station, Berkeley CA. 281 pp.

Simard, A. J., D. A. Haines, and W. A. Main. 1985. Relations between El NinoJSouthem Oscillation anomalies and wildfire activity in the United States. Agriculmral and Forest Meteorology, 36,93-104.

Simard, A. J. nd 3. E. Eenigenburg. 1990. METAFIRE: A system to support high-level fire management decisions. Fire Management Notes, 51, 10-17.

Smith, J. B., and D. A. Tirpak (editors). 1989. The Potential Effects of Global Climate Change on the United States, US Environmental Protection Agency, Washington, DC.

Swetnam, Thomas W. 1993. Fire history and climate change in giant Sequoia groves. Science, 262, 885-889.

Yarnal, B. 1993. Synoptic Climatology in Environmental Analysis: A Primer. Belhaven Press. London. 195 pp.