2001 Fire & Climate Workshops

Workshop Proceedings

February 14-16, 2001
March 28, 2001
Tucson, Arizona

edited by
**Gregg Garfin and
Barbara Morehouse**

CLIMAS Climate Assessment for the Southwest
THE UNIVERSITY OF ARIZONA® • Institute for the Study of Planet Earth

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Foreword

Welcome to the printed version of the presentations and discussions of the 2001 fire-climate workshops, *Fire and Climate 2001* (convened February 14-16, 2001) and *Fire and Climate in the Southwest 2001* (convened March 28, 2001). The information contained herein consists of illustrated summaries of the presentations given at the workshops. All presentations, with the exception of the introductory and logistical remarks, are represented. Discussion summaries are limited to syntheses of the breakout group presentations, as these represent the culmination of formal and informal discussions that occurred throughout the workshops. A list of attendees is provided at the end of this volume.

As this volume contains presentations from both fire-climate workshops, we have presented the material in the order in which the presentations were given at each workshop. In order to make this proceedings volume easy to read and to put the presentations in context, workshop agendas have been included, and the table contents has been arranged in two ways, by order of presentation and by presenter.

The climatic backdrop for convening of these workshops in the spring of 2001 was not as spectacular or certain as the persistent and strong La Niña conditions that prompted our February 2000 workshop, *The Implications of La Niña and El Niño for Fire Management*. However, the smoldering aftermath of the devastating 2000 fire season, provided a strong impetus for us to bring together for a second time fire managers, climate scientists, and fire researchers, in order to discuss the role of climate in wildfire regimes, and the needs of fire management professionals for climate information. Moreover, the very uncertainty accompanying the winter-spring 2001 climate forecasts, as we transitioned out of La Niña conditions, underscored the need for further dialogue: for fire managers to better understand climate forecast tools, their correct interpretation and their limitations, and for climate forecasters to better understand the decision support needs of fire management professionals and the constraints under which they need to make decisions that affect ecosystem health, property and human life.

Fire and Climate 2001. Due to the fact that resource allocation for fire management requires coordinated decision-making at regional and national levels, the ability to make accurate climate forecasts for any part of the country has ramifications for resource allocation nationwide. The experience of the blazing summer of 2000 highlighted the need for the climate/weather and wildfire/land management communities to work toward a more integrated understanding of the role of climate, as well as more immediate weather, in wildfire occurrence and land management decision-making. Thus, we invited regional-level representatives of the fire management, climate science, integrated assessment, and fire research communities from much of the continental United States and Alaska to attend *Fire and Climate 2001*. For two and one-half days, we discussed the linkages between fire, long and short-term climate variations, communication and interpretation of long-range climate forecasts and forecast uncertainty, and user-driven integrated climate assessment and climate service initiatives. We developed a set of recommendations for promoting education about climate for fire managers, as well as fostering communication between climatologists and fire managers. Moreover, we identified areas of research that will facilitate better management decisions with regard to the confluence of fire, climate and society.

Fire and Climate in the Southwest 2001. The Southwest, home to CLIMAS and the University of Arizona, is a region of special focus. The arid foresummer and summer monsoon, characterized by intense, spatially scattered, downpours and spectacular fire-igniting pyrotechnics, provide a unique set of circumstances for fire management. Rapid population growth in the Southwest and increased development along the outskirts of major cities, has accelerated the trend toward conflation of urban and rural land use patterns and associated increase in fire risk at the urban-wildland interface. The escaped prescribed fire at Bandelier National Monument, accelerated by prolonged drought and locally intense winds, which threatened Los Alamos during the spring of 2000, brought the issue of climate-fire-society relationships into sharper focus. As part of CLIMAS' ongoing commitment to dialogue, communication, and collaboration with decision makers in our region, we invited representatives of the Arizona and New Mexico fire management and climate science communities to Tucson for the one-day meeting, *Fire and Climate in the Southwest 2001*. Fire managers were given a whirlwind tour of Southwest climate, historical climate-fire patterns, and climate forecast skill, uncertainty and interpretation. At the meeting, we discussed the needs of the Southwest fire management community for climate information and education, and we developed a set of recommendations for fire-climate research, decision-support tools and ways to negotiate institutional constraints with regard to the specific needs of Southwest fire managers.

In retrospect, the meetings were highly successful. Workshop participants were enthusiastic and the recommendations developed during each of the meetings have formed the core for research proposals, training initiatives and continued communication between the climate science and fire management communities. Moreover, workshop evaluations and breakout group recommendations provided valuable information about the direction of future workshops.

We thank the participants for the contribution of their expertise and their enthusiastic participation. We offer special thanks to the presenters for having taken time from their busy schedules to share their expertise and experience.

Tim Brown, Director, CEFA
Gregg Garfin, Assistant Staff Scientist, CLIMAS
Barbara Morehouse, Program Manager, CLIMAS
Jonathan Overpeck, Director, ISPE
Thomas Swetnam, Director, LTRR

Note: Many of the figures in this volume are best viewed in color. You can download the full-color version of the proceedings from our wesite:

http://www.ispe.arizona.edu/climas/fire/

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Richard Okulski, National Weather Service, Tucson
Kelly Redmond, Western Regional Climate Center, Desert Research Institute

As with all such endeavors, considerable effort, creativity, and good humor were required to make these workshops a success. Special thanks go to the following individuals for their assistance. We apologize if we have left anyone's name off the list.

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Weather, Climate, Fire
The 2000 Fire Season and Beyond

Climate and Fire: Framing the Issues in Context of the 2000 Fire Season

Tim Brown (Desert Research Institute)
February 14, 2001 8:45 AM

La Niña and the 2000 Fire Season
The 2000 fire season was one of the most severe and devastating fire seasons in recent decades. There were 92,250 wildfire starts and 7,393,493 acres burned according to end of season National Interagency Fire Center (NIFC) statistics. On August 29, 2000, the peak day of the fire season, 84 large fires were burning, including 1,642,579 acres burning in 16 states, and the following resources were in use:

- 28,462 fire personnel
- 667 crews
- 1,249 engines
- 226 helicopters
- 42 air tankers

In order to put the key issues of this workshop into perspective, I have selected some statements about the 2000 fire season from NIFC. The statements refer, in large part, to NIFC's interpretation of the effects of La Niña on the weather and climate of the continental U.S. during 2000. Accompanying illustrations show that patterns of U.S. temperature, precipitation and drought associated with extremes in La Niña are fairly predictable. These patterns also show predictable spatial and temporal variation (Figure 1) during extreme years.

- "A pool of cool water in the Pacific Ocean determined much of the country's weather in the last two years. La Niña changed normal weather patterns when it formed, and it's still dominating the weather as it wanes." *NIFC Public Statement, August 2000*

- "La Niña usually brings dry weather to the southern states and that is a big part of why Florida and the Southwest have had such a severe fire season. La Niña has spread dry weather to the West this spring and summer, and even though it is waning, the weather pattern is already set for the rest of the summer and fall. Hotter and drier than normal weather is on tap through September." *NIFC Public Statement, August 2000*

- "The Southwestern monsoon, which usually ends the fire season in Arizona and New Mexico in early July, has been sporadic this year. It's into August, and the Southwest is still having an active fire season." *NIFC Public Statement, August 2000*

- "So, here's the summary: hot temperatures, low relative humidities, little or no precipitation,

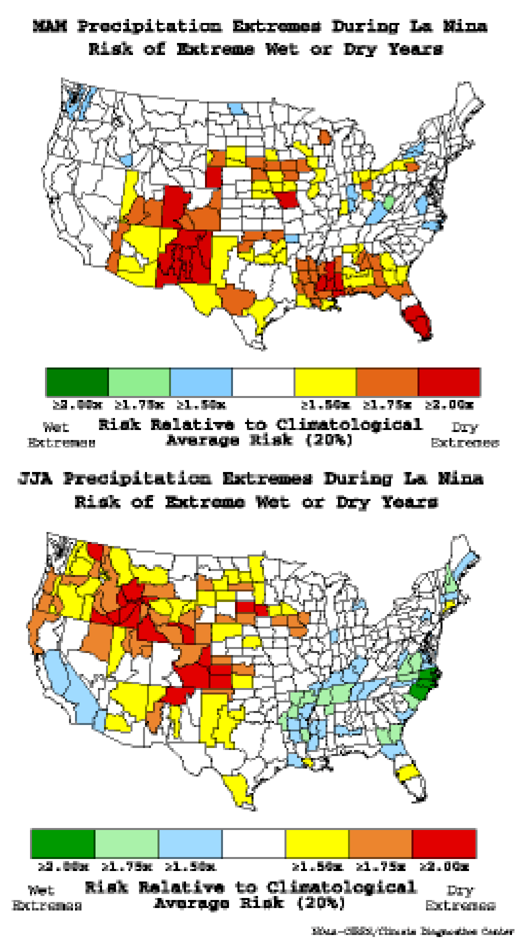

Figure 1. Risk of extreme wet or dry years during La Niña for spring (MAM, March-May; top) and summer (JJA, June-August; bottom). Note that the risk of extreme dry conditions migrates from the southern tier to the northern tier of the U.S. as the fire season progresses. Map source: NOAA-CIRES Climate Diagnostics Center.

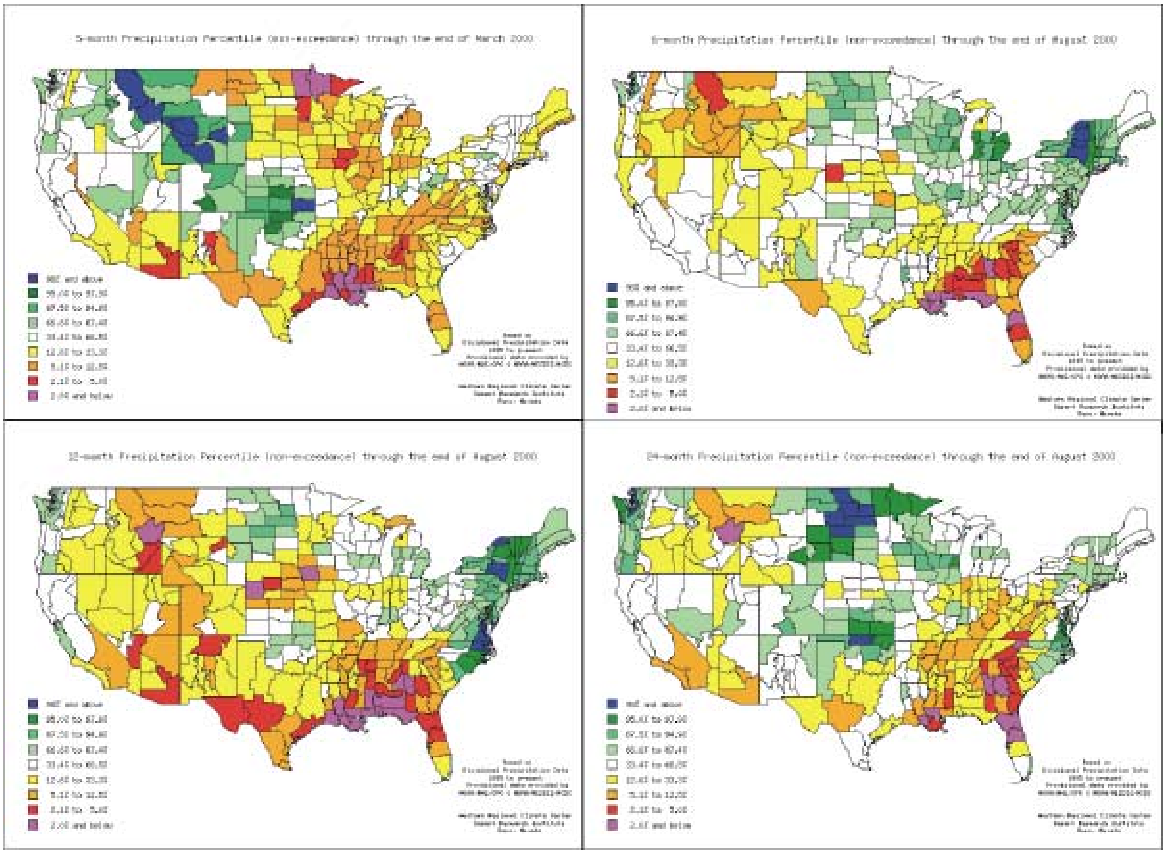

Figure 2. Maps of Standardized Precipitation Index (SPI) percentile of non-exceedance for various lead times from the spring and summer of 2000. Five-month lead from the end of March 2000 (upper left); 6-month lead from the end of August 2000 (upper right); 12-month lead from the end of August 2000 (lower left); 24-month lead from the end of August 2000 (lower right). Map source: Western Regional Climate Center.

plenty of wind, and the consequence is easy to predict: the potential for a nasty fire season...None of this was unexpected by the federal firefighting agencies. They expected a tough season and planned accordingly." *NIFC Public Statement, August 2000*

- "As a result of La Niña and its influence on weather patterns, a combination of dry fuels and dry, hot weather led to what some are declaring one of the most severe wildland fire seasons in U.S. history." *NIFC Public Statement, October 2000*

The sequence of Standardized Precipitation Index (SPI) percentile of non-exceedance maps shown in Figure 2 indicates that even though short-term conditions in the spring of 2000 along the northern Rockies (around the Idaho-Montana border) were relatively moist, long-term drought (including conditions 24 months prior to summer 2000 in the Northern Rockies) produced conditions that led to extreme fire danger in that region during the 2000 fire season. The purpose of the SPI is to assign a single numeric value to the precipitation that can be compared across regions with markedly different climates (McKee et al 1993; 1995; Guttman 1998; 1999). The SPI was designed to explicitly express the fact that it is possible to simultaneously experience wet conditions on one or more time scales, and dry conditions at other time scales, often a difficult concept to convey in simple terms to decision-makers. The SPI percentile of non-exceedance indicates the degree of "unusualness" of a particular value of SPI. A value of 0 means that zero percent of the other values in the record do not exceed that value, or in other words, that all other values exceed that value, i.e., the value in question is so low that it seldom if ever occurs. A value of 50 indicates that half of the historical values are higher and 50 percent are lower. Values near 50 are not unusual; values near 0 or 100 are very unusual. The SPI may have higher value for fire management than the Palmer Drought Severity Index (PDSI) due in part to its ability to integrate precipitation occurrence over long time periods.

The maps of precipitation percentiles for summer 2000 (Figure 2) make an important point, i.e., that it

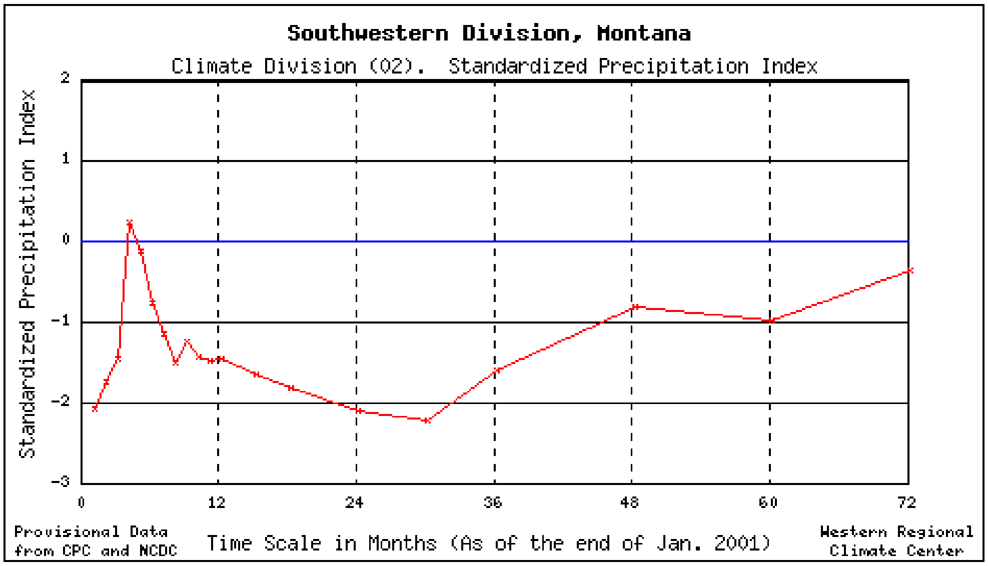

Figure 3. Standardized Precipitation Index for Montana climate division 2 (Southwestern Montana) going back to 72 months prior to January 2001. The graph indicates long-term precipitation deficit for this region. See text (above) for an explanation of the SPI. Graph source: Western Regional Climate Center.

is important to look at long-term conditions, with regard to assessing the status of fuels and fire danger. Looking back one or two years shows that the Southwest and, in particular, the northern Rocky Mountain states exhibit precipitation amounts below the lowest one-third of the historical record back to 1895. In fact, Figure 3 shows that Montana climate division 2 (Southwestern Montana) experienced below average precipitation conditions overall for 72 months prior to the height of the 2000 fire season. Moreover, Montana division 2 continues to experience drought conditions at present. However, if you only looked at conditions for the winter prior to March 2000, when some seasonal resource allocation decisions were being made, one would have seen a vastly different picture and perhaps drawn different conclusions, due to the recent winter precipitation.

Some Uses of Climate Information During 2000

SPI is just one of many climate variables relevant to a fire season. The program for Climate, Ecosystems and Fire Applications (CEFA) tracked the use of climate information by various collaborators in the fire management community during the 2000 fire season. We noted that some of the most frequently used climate information included the following:

- Local and regional anomalies
- Large-scale climate (La Niña)
- Regional climate systems (southwest monsoon)
- Climate forecasts
- Climate impacts and assessments

However, the mere use of information brings up questions regarding the accessibility and usefulness of the products currently available. Such questions, important to the nature of this meeting, include the following:

- Is current information accessible?
- Is current information sufficient?
- Is climate information being satisfactorily incorporated into planning and decision-making processes?
- How is climate information being used?
- Is sufficient training and education in the use of climate information available?
- In what areas can the use of climate information be improved?

CEFA gathered information from users through our Great Basin Remote Access Weather Station (RAWS) Network Analysis project. We found a wide array of uses for these data including the following:

- Prediction or assessment of fire severity based on historical information
- Examination of fire history
- Fire investigations
- Court cases
- Post-fire erosion and erosion potential

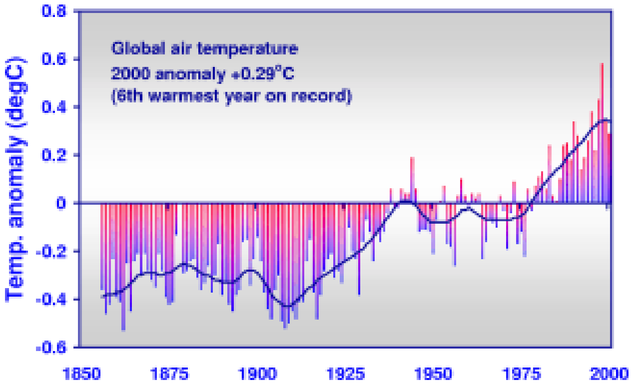

Figure 4. Time series compiled jointly by the Climatic Research Unit and the UK Met. Office Hadley Centre showing the combined global land and marine surface temperature record from 1856 to 2000 (Jones et al. 1999; http://www.cru.uea.ac.uk/cru/info/warming).

- Historic season ending events
- Risk appraisals for wildland fire use
- Prescribed burn planning
- Rehabilitation
- Budget analysis
- Fire behavior
- Fire severity funding requests
- Development of programmatic fire management plans
- Ground water and hydrologic assessments
- Summaries to visitors and visitor guides
- Wildlife impacts
- Forest health assessment
- Soils studies
- Vegetation change and response studies

Using Climate Forecasts

Areas of special interest with regard to use of climate information for fire management include the use of long-term climate forecasts and the effect of climate variability and climate change on fire regimes and fire management. The NOAA Climate Prediction Center (CPC), as well as several other agencies, produces climate forecasts with long-lead times of up to one year in advance. Unfortunately, it is relatively difficult for typical users and decision-makers to find information on how to interpret forecast maps and assessments of forecast skill. Several questions germane to the use of climate forecasts by fire managers, include the following:

- How well is uncertainty understood and portrayed?
- How are climate forecasts used in decisions?
- What role do climate forecasts currently play in planning?
- How could climate forecasts be better utilized in planning?
- Do climate forecasts have sufficient skill for use in planning?
- Are climate forecasts easily accessible to users?

Climate variability and change

As Figure 4 shows, there has been a long-term increase in global land-based and marine sea surface temperatures that has been especially pronounced during the past two decades. Paleoclimate studies have shown pronounced natural climate variability on the scale of decades-to-centuries. Thus, it is incumbent upon us to take into account the effects that climate variability and possible human-induced climate change might have on fire regimes. The following questions come to mind:

- Can climate variability and change be adopted into longer-term management strategies?
- Can budgets and planning be invoked for longer than a fiscal year?
- How will climate variability and change affect components of fire danger, such as fire severity and fire potential?
- What are the human and environmental impacts of fire danger change and variability (economics; resources, wildland/urban interface)?

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Related Resources

Program for Climate, Ecosystem and Fire Applications
http://www.dri.edu/Programs/CEFA/

Standardized Precipitation Index
http://www.wrcc.dri.edu/spi/spi.html

National Interagency Fire Center
http://www.nifc.gov/

Weather and the 2000 Fire Season

Rick Ochoa (National Interagency Fire Center)
February 14, 2001 9:15 AM

The 2000 wildland fire season was one of the most severe in the last 75 years, not only in terms of the number of acres burned, but also due to its duration and size. The fire season began on January 1 with a small fire in Florida and ended in late December in southern California (Figure 1). Highlights of the 2000 season include:

- 92,250 fires burned 7,393,493 acres
- Over 860 structures lost
- Estimated cost of fire suppression is $1.6 a billion
- Over 30,000 firefighters and support personnel involved

Precursors to the 2000 Fire Season

While the fire season may have officially started with a small fire on New Year's Day, the seeds of the 2000 fire season began with the emergence of La Niña in 1998. Florida experienced one of their worst fire seasons during the spring and summer of 1998. Hot and dry conditions during August-October, 1998 in the West lead to a very active fire season in Idaho and Montana. Even though the winter of 1998-99 saw record-breaking snows in the Pacific Northwest, much of the area east of the Mississippi suffered under a severe drought that began in 1998. Fires were quite active in the Florida during the spring of 1999 and also in the Appalachians during the fall. In 1999, the West had a windy spring, followed by a hot dry summer, including dry lightning in August and September, and topped off by a warm and dry fall. This resulted in major fires for

Figure 1. Map of fire locations for the record 2000 fire year (Source: National Interagency Fire Center).

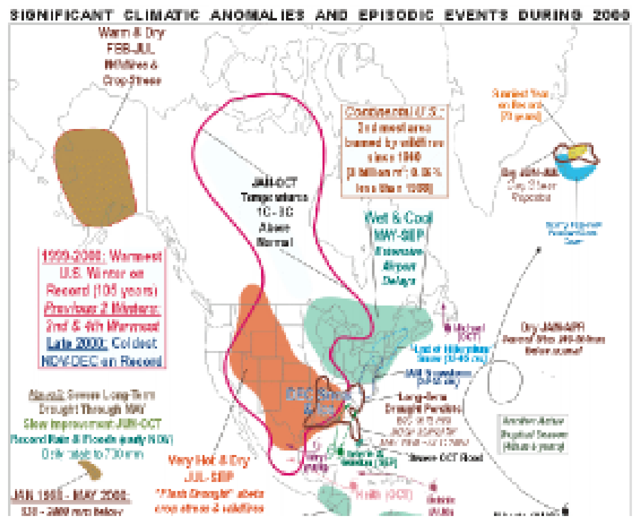


Figure 2. Significant climatic anomalies during 2000 (Source: NOAA Climate Prediction Center).

California and over 1.7 million acres burned in Nevada. The 2000 wildland fire season was the culmination of many factors (Figure 2) including:

- Drier and warmer than normal weather since 1998, due primarily to La Niña.
- Extremely dry fuels...at record dryness levels in some areas.
- Greatly reduced spring rains, including failure of May-June rains in the Northwest and Northern Rockies. Poor relative humidity recovery and general moisture deficit.
- Dry lightning events.

Some of the hardest hit areas were:

- Idaho (1.36 million acres), including Clear Creek Complex (216,961 acres)
- Montana (0.95 million acres), including Valley Complex (292,070 acres)

- Alaska (0.75 million acres).
- New Mexico (0.52 million acres), including Cerro Grande (47,650 acres).

The fire season in the Northwest, Northern Rockies and Great Basin ended, for the most part, with the arrival of the rains in early September. Fire activity picked up in the Southeast during October, with large fires reported in Virginia, North Carolina, South Carolina, Kentucky and Tennessee. Fire activity in December was generally confined to Florida and California.

Related Resources
National Interagency Fire Center
http://www.nifc.gov/

Figure 1. Map of 11 U.S. GACCs.

NIFC Resource Impacts During the 2000 Fire Season

Rick Ochoa (NIFC); assisted by Jan Hendrick (NIFC)
February 14, 2001 10:00 AM

The National Interagency Fire Center (NIFC; http://www.nifc.gov) in Boise, Idaho is the national support center for coordination of wildland firefighting and other incidents. Member organizations include the Bureau of Indian Affairs, Bureau of Land Management, Forest Service, Fish and Wildlife Service, National Park Service, National Weather Service, and the Office of Aircraft Services.

Orders for firefighting resources originate from the incident and are passed to the local dispatch center. If the needed resource is not available in the local area, the request is sent to one of the eleven Geographic Area Coordination Centers (GACCs; Figure 1). Similarly, if the needed resource is not available within the Geographic Area, the GACC forwards the request to the National Interagency Coordination Center (NICC). In turn, NICC will find the closest available resource and coordinate its movement with the affected GACCs. It is important to remember that NICC is a coordination unit and the local incident retains command and control authority.

When competition for resources arises, a Multi-Agency Coordinating Group (MAC) may be formed at the regional or national level. The MACs set priorities, allocate and/or reallocate resources, develop and recommend contingency action plans and issue coordinated situation reports.

Commensurate with the large number of fires and acres burned (Figure 2), the NICC processed a record 46,245 resource requests with 32,362 for overhead positions alone (note: overhead mobilization positions include technical experts, GIS specialists, etc.). In addition to civilian firefighters, the military provided six battalions (500 personnel per battalion) with over 1,500 total personnel from Australia, Canada, Mexico, and New Zealand. On August 29, 2000, the peak day of the 2000 fire season, the following resources were committed nationally:

- 28,462 people
- 1,249 engines
- 226 engines
- 42 airtankers
- 18 Type I teams
- 84 large fires (100+ acres in timber or 300+ acres in grass/brush)

Adjustments to resource allocations are accomplished through severity funding and pre-positioning/re-positioning of existing forces. Examples of severity funding include: additional funds to bring crews on earlier than normal due to increased fire risk, or extending air tanker contracts for a longer than normal fire season. Such resource adjustments save money in the long run and they allow for substantial decreases in lag time for getting resources to the incident. Climate forecasts are very important in order to coordinate pre-positioning.

One example of re-positioning that occurred during

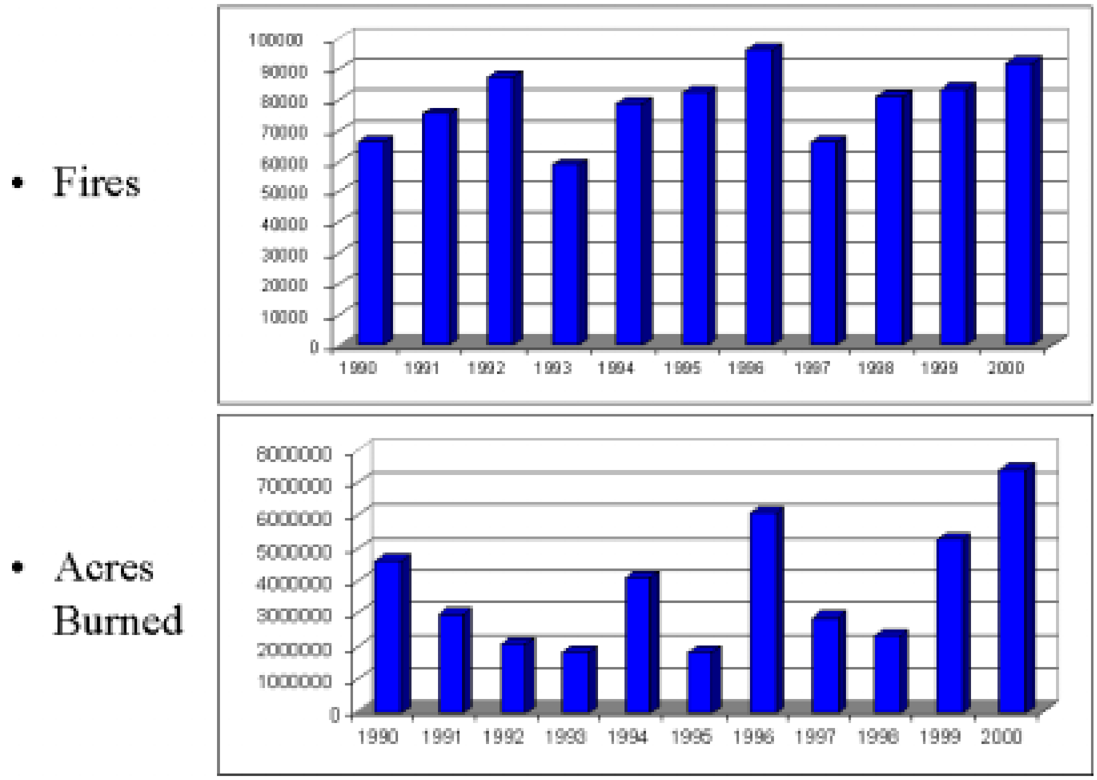


Figure 2. Wildfires and acres burned reported to NICC. Note the steady increase in fires approximately every 4 years.

the 2001 fire season was when a very strong wind event was forecast for August 19 in Montana. In preparation for this event, the Northern Rockies MAC requested several strike teams of engines and crews for public safety and structure protection. The national MAC tasked the various geographic areas for these resources, even though these areas were experiencing wildfires. The greater risk of wildfires moving through communities necessitated this mobilization of forces. The crews and engines were in place by August 19, but fortunately were not needed as the strong ridgetop winds did not mix down into the valleys. This example shows an excellent use of long range forecast information to enhance coordination efforts.

Related Resources
National Interagency Fire Center
http://www.nifc.gov/

Climate Forecasts for 2000 and 2001

Klaus Wolter (NOAA-CIRES Climate Diagnostics Center)
February 14, 2001, 10:30 AM

Tools of the Trade
In talking about the climate forecasts it is important to give some background on the tools of the trade. There are statistical tools and modeling tools. Statistical tools include the following:

- Optimal climatological normals (OCN). This gives an indication of the long-term trend.
- Canonical correlation analysis (CCA). This shows the spatial evolution of anomalies.
- Persistence (or anti-persistence). The tendency for conditions to remain the same, relative to past months.
- Analogs. Situations similar to the past.
- Composites. Looking at the average of similar events in the past as a guide to what might happen in the future.

Among the statistical tools, I most often use OCN and CCA. Anti-persistence has not been too successful recent years. I will examine model-based forecasts in my talk on climate prediction, tomorrow.

The Seasonal Cycle and Interannual Rainfall Variability

I have examined some SNOTEL (SNOwpack TELemetry) data for the Southwest and determined that during ENSO events variability at these mountains stations is in sync with variability at valley stations. Note that there seems to be a monsoon dipole between Arizona/New Mexico and states to the north, Utah/northern Colorado/Southern Montana, during July and August. If we look at climatology, charts of average precipitation by season, note that above normal spring precipitation in the Southwest might not help you too much in terms of fire hazard conditions. In the Southwest, if you do not get precipitation by April 1st, then conditions will be dry during the spring; in contrast over the plains states and Montana there is a significant component of spring precipitation. There some interesting patterns with regard to coherence in signal between COOP (National Weather Service Cooperative Observational Network)/NCDC U.S. climate division data, which are mostly based at valley locations, and SNOTEL data, which are based at mountain locations. When these valley and mountain data are used independent of each other it does not give that good an idea of what is going on, although there are some core regions of spatial and temporal coherence. In Colorado, when looking at variance in precipitation patterns in stations within these regions I see little coordination between valley stations, e.g., Denver and many of the mountains stations (e.g., Alamosa), which is very perplexing. In the Southwest, for example, western New Mexico does not have a good regional monsoon signal; most of the signal is local, at isolated stations; this is in contrast to the signal in central and southern Arizona. So I would say that there is a pressing need for more station data.

The State of ENSO — 3 Years of La Niña, and Still Not Dead!

Knowing the state of ENSO has helped increase the skill of climate forecasts. At present, we're in the third year of La Niña conditions, (though these are relatively weak La Niña conditions), and there is a possibility that these conditions will persist. It is important, however, to note that we've never had four La Niña years in a row. Only the SST model is calling this year a La Niña year. Thus, as we're likely to transition out of La Niña conditions, 2001 will be a tough year to forecast. During the last 50 years, 2000 was only the 8th strongest La Niña (Figure 1). It was an unusual year, and La Niña conditions started very late. If we continue to have La Niña conditions in 2001 it will be very strange. During a La Niña winter, there is three times the risk for a dry spring in the Southwest. Nevertheless, with La Niña the strength of the event has less do with the U.S. precipitation outcome, whereas during El Niño the greater the strength of the event, the higher the amplitude of teleconnected outcomes.

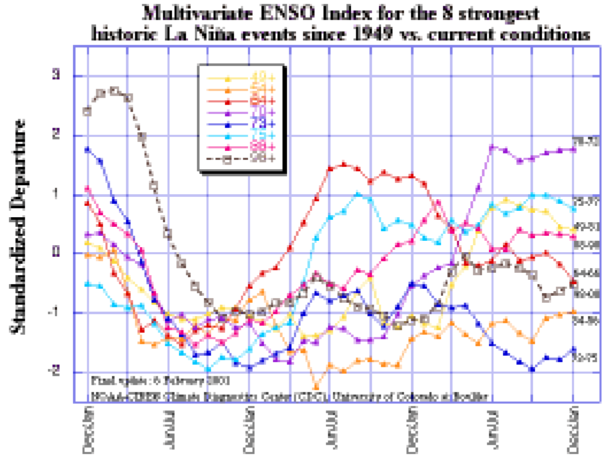


Figure 1. Multivariate ENSO Index (Wolter & Timlin, 1993; 1998) for La Niña events. Note that the recent (1998-2001) La Niña is not the strongest; however, its behavior has been quite erratic. (http://www.cdc.noaa.gov/~kew/MEI/mei.html)

CPC/IRI Forecasts For Water Year 2000 — What Happened?

Reviewing summer 2000, the hallmark of 2000 was in the temperature signal (Figure 2). Many temperature records were broken, temperatures were very high throughout the western U.S., there was enhanced fire danger, and especially high temperatures in the Southwest (Figure 3). I will point out that we did not have a good forecast for climatic conditions in the Northwest and Intermountain West during 2000 (Figure 4).

CPC/IRI Forecasts For The Rest Of Water Year 2001

With regard to 2001 forecast, as I said before, this will be a tough year. We have some skill predicting between 3-10 days for precipitation; however, beyond three days, prediction remains difficult. If we look back at the October 2000 climate forecasts and the January 2001 forecast for February-April 2001, you will note a change. The October forecast indicates warm conditions throughout the West and an enhanced probability of wet conditions in Texas (based on trend). In contrast, the January forecast indicates far less confidence

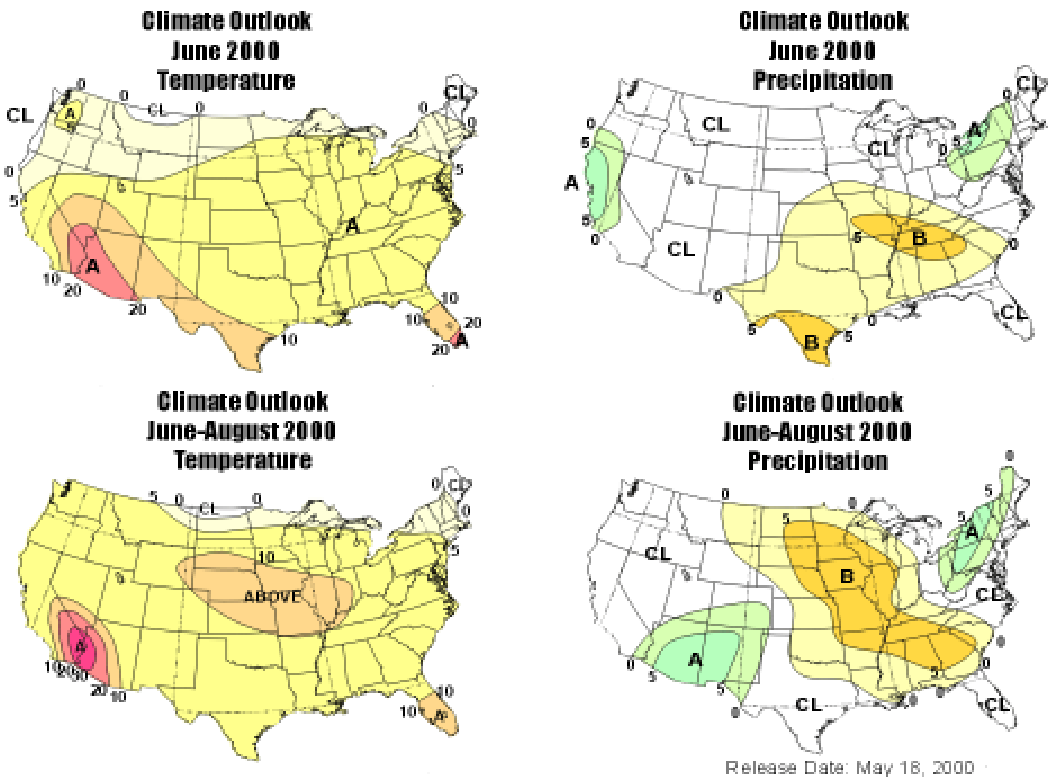


Figure 2. NOAA/CPC climate forecast for summer 2000. “CL” indicates that no prediction has been made. (http://www.cpc.noaa.gov/products/predictions/multi_season/13_seasonal_outlooks/color/seasonal_forecast.html)

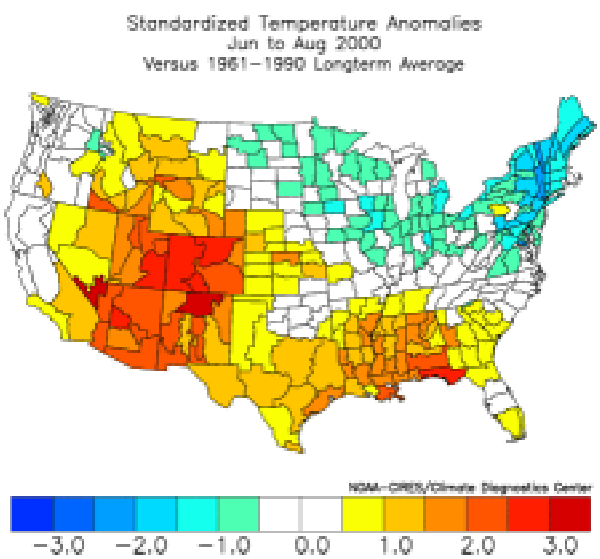


Figure 3. U.S. climate division summer 2000 temperature anomalies. Contrast these with the predicted shift in probabilities of temperature in Figure 1. (http://www.cdc.noaa.gov/USclimate/USclimdivs.html)

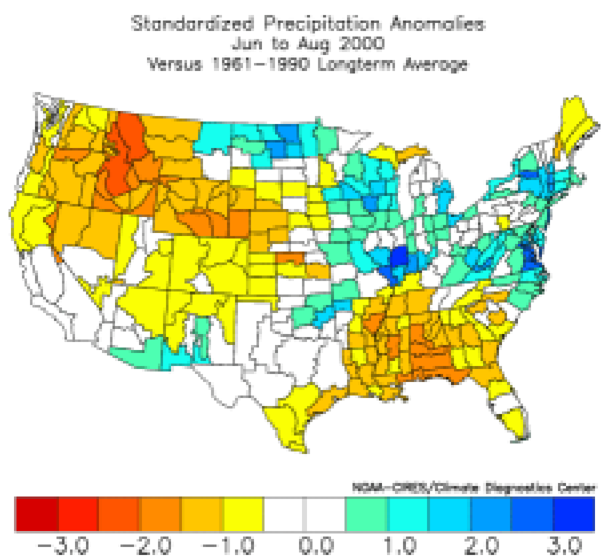


Figure 4. U.S. climate division summer 2000 temperature anomalies. (http://www.cdc.noaa.gov/USclimate/USclimdivs.html)

for temperatures above the 1961-1990 mean, and there's no indication of enhanced probability of wet conditions in Texas. The January forecast shows an enhanced probability of below normal precipitation in Florida, based on strengthening of La Niña conditions during the past two months. These contradicting indicators, and the lack of consensus on future La Niña-related ocean temperatures (about which I will speak tomorrow), make for great uncertainty in the forecasts.

If we look at the skill of temperature predictions during recent winters, we find the following: predictions were very good during the winters of 1997 and 1998, whereas predictions for fall 2000 were very bad. Since 1999, precipitation predictions have generally been poor.

References

Wolter, K., and M.S. Timlin, 1993: Monitoring ENSO in COADS with a seasonally adjusted principal component index. Proc. of the 17th Climate Diagnostics Workshop, Norman, OK, NOAA/NMC/CAC, NSSL, Oklahoma Clim. Survey, CIMMS and the School of Meteor., Univ. of Oklahoma, 52-57.

Wolter, K., and M.S. Timlin, 1998: Measuring the strength of ENSO - how does 1997/98 rank? Weather, 53, 315-324.

Related Resources

International Research Institute for Climate Prediction (IRI) Forecasts:
http://iri.columbia.edu/climate/forecast/

NOAA-CIRES Climate Diagnostics Center (CDC)
http://www.cdc.noaa.gov/

CDC El Niño and La Niña Pages
http://www.cdc.noaa.gov/ENSO/

NOAA/NWS/CPC Suite of Official Forecasts
http://www.cpc.ncep.noaa.gov/products/predictions/

SNOTEL Data
http://www.wrcc.dri.edu/snotel.html

Fire Forecasts for 2001

Tim Brown (Desert Research Institute)
February 14, 2001 11:00 AM

The main message of this talk is that, reviewing current conditions and looking at model forecasts for the spring through midsummer, there is still a high fire risk for the West in 2001. Fire risk is particularly high for the Pacific Northwest.

Review of Recent Precipitation and Streamflow Conditions

Water year precipitation both at SNOTEL (SNOwpack TELemetry, an automated system to collect snowpack and related climatic data in the Western United States) sites (Figure 1) and for NOAA climate divisions is particularly low in the Pacific Northwest/Northern Rockies and near to above average in the Southwest. As of February 1st, 2001, streamflow forecasts suggest spring and summer streamflow at less than 70% of the 1961-1990 average for almost all of the western U.S. What is particularly significant about this is that a large portion of the western U.S. receives the majority of its precipitation during the winter and early spring.

Climate Forecasts for 2001

A variety of consensus climate forecasts and ensemble climate forecast model results suggest a greater likelihood of above average temperature and below average precipitation for the West this spring and summer. The Climate Prediction Center (CPC) long-range seasonal temperature outlooks show a high likelihood of above-average temperatures throughout the Southwest and

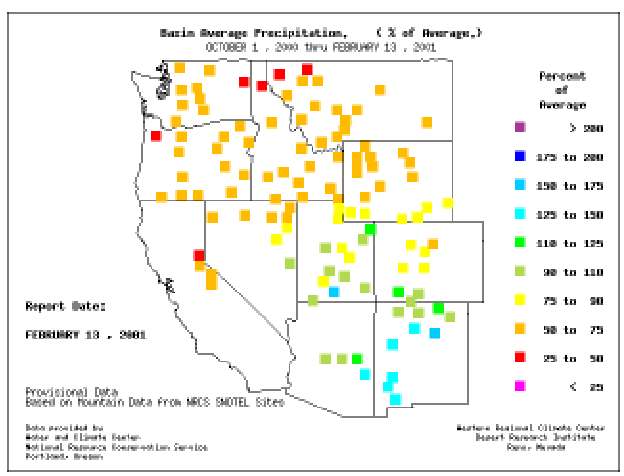


Figure 1. SNOTEL basin average water year (October-present) precipitation for the western U.S.

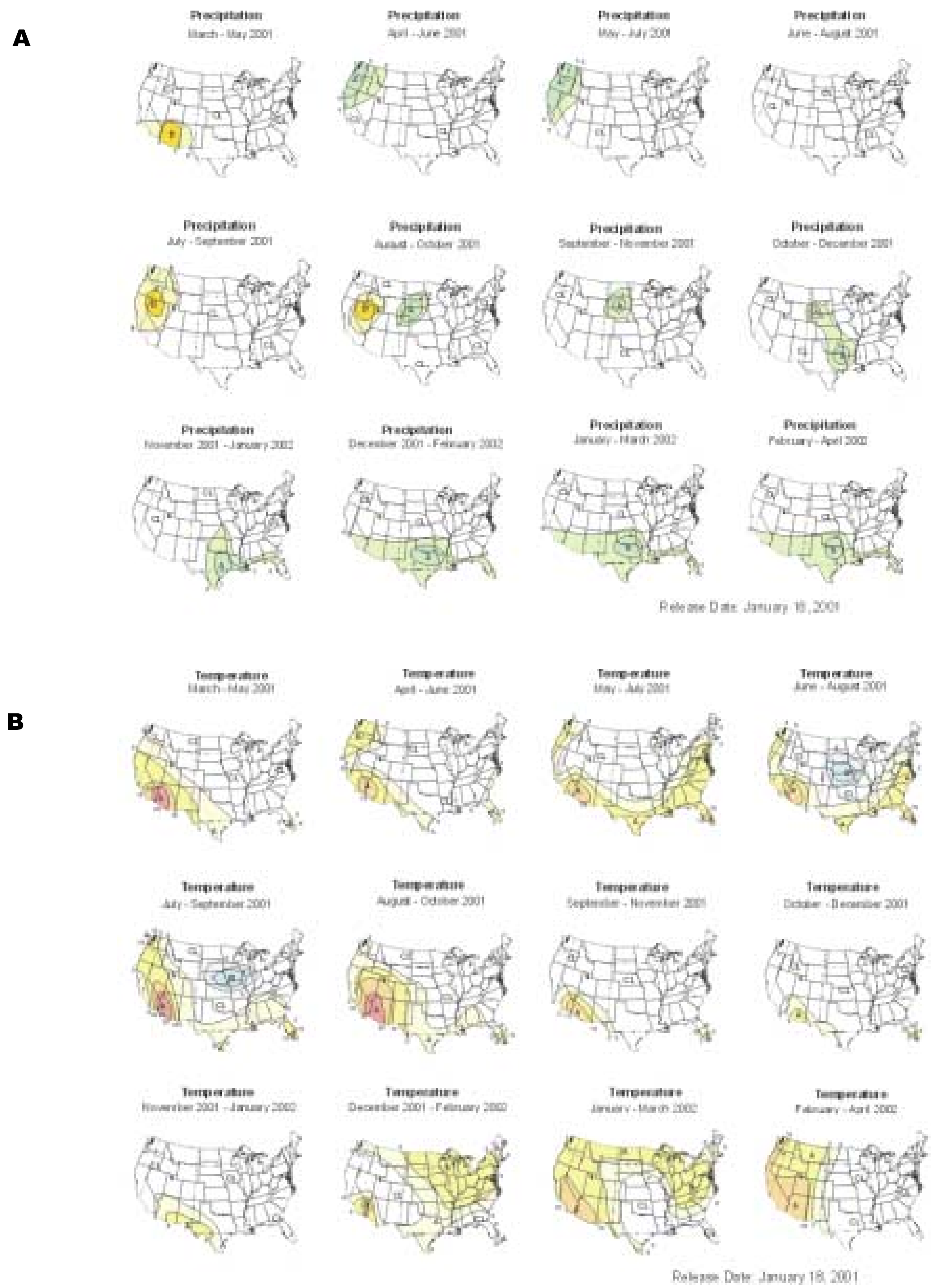


Figure 2. (a) NOAA Climate Prediction Center (CPC) seasonal precipitation outlooks for 2001-2002. Contours indicate percent change in probability of A above-average and B below-average precipitation (based on the 1961-1990 average). CL indicates that no forecast has been made. (b) CPC seasonal temperature outlooks for 2001-2002 (contours and symbols are the same as in (a), except for temperature).

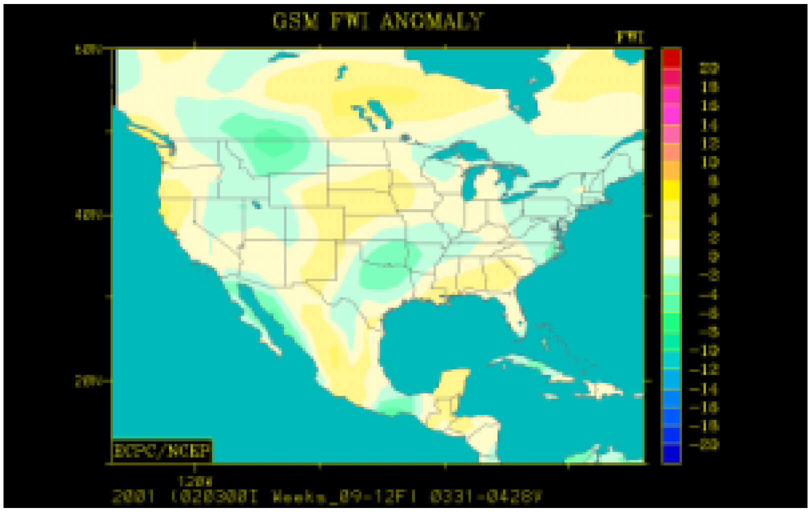


Figure 3. GSM (Global Spectral Model) Fire Weather Index forecast for March-April, 2001, produced by the Experimental Climate Prediction Center (ECPC) at Scripps Institution of Oceanography.

coastal West for the spring and throughout the fire season (Figure 2a); CPC long-range seasonal precipitation outlooks show a slightly greater likelihood of above-average spring precipitation in the Pacific Northwest and a slightly greater likelihood of below average of fire season precipitation in northern California and Nevada (Figure 2b). Remember, that the climatological mean precipitation for the Pacific Northwest is fairly low for the spring; therefore, increased spring precipitation will not likely make up for the lack of winter precipitation in the Pacific Northwest. The International Research Institute for Climate Prediction (IRI) predicts a greater likelihood of above-average temperatures throughout the West for April-June 2001, with particularly high likelihood of above-average temperatures in the Pacific Northwest and the Southwest. A variety of ensemble forecasts show similar results. For example, the NCEP (National Centers for Environmental Prediction), ECHAM (European Community Hamburg), NCAR CCM3 (National Center for Atmospheric Research Community Climate Model) ensemble forecasts all indicate below average spring and early summer precipitation, especially in California and the central and southern Rockies.

On the basis of these analyses, I predict high fire risk in West. Of course, fires are both lightning and human caused, and lightning predictions would be helpful for fire forecasting, but about half of all fires are human caused and climate predictions probably give some indication of the risk of spread.

The GSM, a weekly forecast model produced by the Experimental Climate Prediction Center (ECPC) at Scripps (running a variation on the NCEP model) indicates continued dry conditions throughout the West, with some precipitation in late spring in the Intermountain West. GSM predictions also include forecasts of Fire Weather Index (FWI), wherein temperature humidity and wind are used to create an integrated measure of fire danger. Such integrated measures have not been evaluated thoroughly in the "fire business." The GSM FWI forecast for spring (Figure 3) suggests elevated fire danger in the Pacific Northwest and northern California, as well as across the central and southern Rockies and the Plains states.

Summary

In summary, fire danger is still pretty high for most of the western U.S., especially for the Pacific Northwest and northern California, where winter conditions have been exceptionally dry. Again, increased precipitation in the Pacific Northwest this spring will not be able to ameliorate precipitation deficits that have accumulated over the winter months. However, it is important to evaluate separately spring precipitation predictions for areas such as the central Rockies, where spring is the season of highest precipitation. The most important things about fire prediction include fuel conditions, weather/climate and topography. CEFA in conjunction with researchers at Scripps ECPC will be incorporating measures of these variables in order to produce weekly predictions of fire danger.

Related Resources

Program for Climate, Ecosystem and Fire Applications
http://www.dri.edu/Programs/CEFA/

SNOTEL Data (Western Regional Climate Center)
http://www.wrcc.dri.edu/snotel.html

Scripps Institution of Oceanography Experimental Climate Prediction Center
http://ecpc.ucsd.edu/ecpc.html

Recent Developments in Data Access at Western Regional Climate Center

Kelly Redmond (Desert Research Institute, Western Regional Climate Center)
February 14, 2001 1:15 PM

The Climate of the 2000 Fire Season and Current Conditions.
As a starting point, we begin by looking at the average number of acres burned per decade in the U.S. Far more acres burned per year before 1940 than during the past several decades; in fact, during the 1930s more acres burned than the total for the last few decades. Confining attention to the changed regime of the past 40 years, the active 2000 fire year emerges as comparable to three or four of the years since 1960 (e.g., 1996, 1988, 1969, 1963). For the recent winter, we obtain a historical perspective from Standardized Precipitation Index percentiles for 1-4 month periods extending back from January 2001 through the prior 1 to 4 months. The heart of winter was quite dry, but the extremely unusual wet conditions in the Southwest during October make it appear that this entire period was moist. Every winter brings a mystery, it seems. La Niña is present for a third consecutive winter. Typically, La Niña brings dry winters to the Southwest and wet winters to the Northwest. However, Southwest precipitation has been near to slightly below average his winter, and the Northwest is experiencing record drought, almost the exact opposite of widespread expectations. So, why?

Right now (February 6, 2001) moderate drought conditions are prevalent over the Pacific Northwest and northern Rockies (Figure 1). Snowpack is far lower than usual, and there has been very low precipitation in the Columbia River basin this year. A quick look at precipitation climatology for the first half of the water year (Figure 2a) and for the spring season (Figure 2b) shows us that there's a very low chance of recovery from current drought conditions in the Pacific Northwest. This is because normally about 80% of annual precipitation in the Pacific Northwest is received during the months of October-March, whereas only a small percentage is received between April-June. The situation has been a little bit different for the northern Rockies, where a climatological second maximum of spring precipitation allows for some degree of recovery before summer sets in.

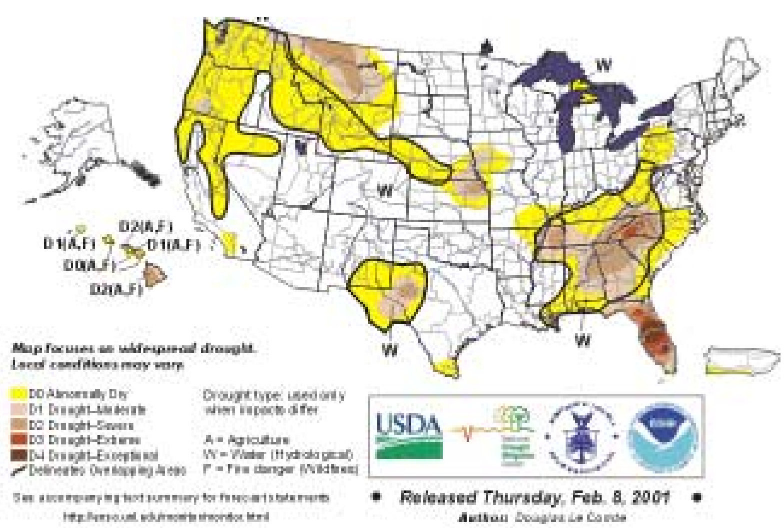


Figure 1. U.S. Drought Monitor (http://enso.unl.edu/monitor/monitor.html) for February 6, 2001 indicates drought conditions throughout the Pacific Northwest and Northern Rockies, due to low precipitation and extremely low winter snowpack (see text).

The situation is quite different for the southwestern U.S. The Southwest receives upwards of 40% of annual precipitation during the summer monsoon (Figure 3), which usually starts around the 4th of July. A new research initiative called the North American Monsoon Experiment (NAME) is forming, in order to (1) understand the monsoon (summer rain) and what drives it and (2) examine ways in which this experiment could produce improved information about the monsoon that would be useful for decision-making. The area affected encompasses New Mexico and Arizona, and northern Mexico.

Climate Monitoring
The Western Regional Climate Center (WRCC) monitors several major western data sources to track climate in the region. WRCC is the repository for an important network used extensively by the fire community known as RAWS (Remote Access Weather Station). This network currently consists of 930 stations (1700-1800 hundred have existed over time). RAWS has primarily a summer orientation, and data arrive hourly via GOES satellite. WRCC is in the process of developing web tools to improve the access to RAWS information. By way of example, we plan to develop map-clickable access to the following types of products:

- daily summary
- monthly summary

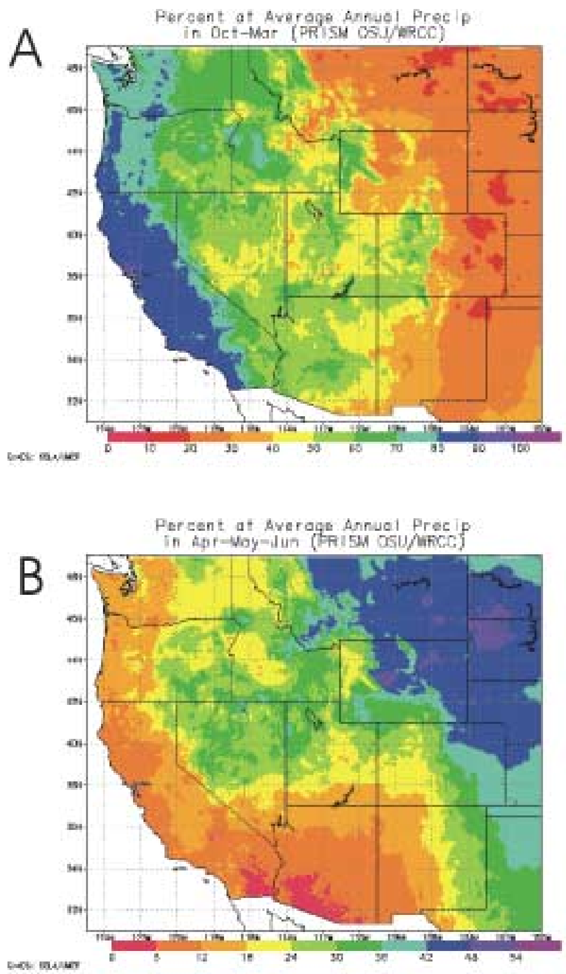


Figure 2. Percent of annual average precipitation (1961-1990) that falls in (a) October-March and (b) April-June. Joint product of Western Regional Climate Center and OSU/PRISM.

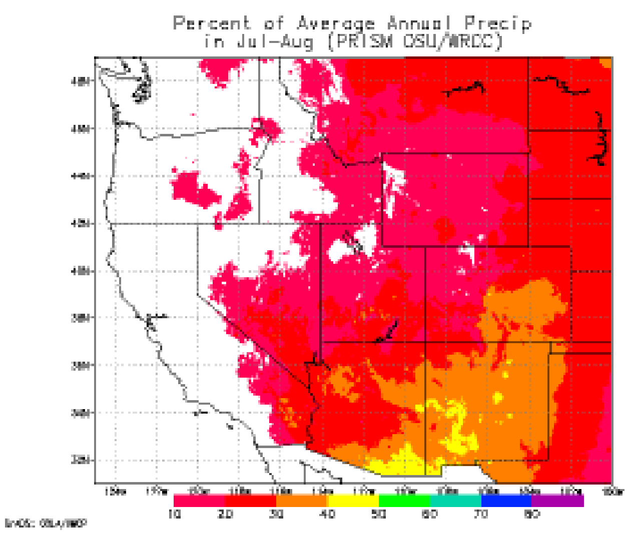


Figure 3. Percent of annual average precipitation (1961-1990) for July-August. Joint product of the Western Regional Climate Center and OSU/PRISM.

- graph of the last seven days
- historical time series (since 1985)
- wind statistics and wind roses

The basic time increment of the raw data is hourly. Among the elements which are measured are:

- wind speed and direction
- air temperature and fuel temperature
- humidity
- solar radiation (about 60 percent of the sites).

In addition we would like to make available composite daily summaries for every station. It is important to note that RAWS stations are not all-season gauges; they are solar powered, and thus do not have sufficient heating to melt solid winter precipitation. The best spatial coverage for RAWS data stations is between 5000 and 7000 feet in elevation. Given the region's extreme spatial heterogeneity, RAWS does not currently sample all major western vegetation zones in all geographic areas.

However, there are excellent complements to the RAWS network that greatly extend climate and weather station coverage of the western states (and Alaska/Hawaii). The National Weather Service operates about 2500 cooperative observation stations, and at higher elevations there is the SNOTEL (SNOwpack TELemetry) network, with about 700 sites run by USDA/NRCS. Each of these networks measures different quantities in support of differing missions. Hopefully new RAWS stations can be sited to provide long-term climate data for currently insufficiently sampled elevation bands or ecological zones.

Climate Information Needs For Fire Management

For sound natural resources management, we need to provide climate information that can be interpreted from a long-term perspective (several decades). Needs by the fire community for atmospheric data range over time scales from hours to many decades, and the RAWS network has both meteorological and climatological characteristics. The condition of range and vegetation with respect to fire susceptibility is affected by events over the past several seasons, and often longer. For this reason, there is strong incentive to improve the RAWS network to be able to provide accurate and timely data all year long, including winter. We need to be working toward synergistic operation and coordination of all federal networks, to obtain the most value for the public dollar, to provide requisite information at the spatial scales needed, and to develop the long data sets which will be expected by future generations in order to perform the more sophisticated analysis they will require. In addition, there is an equally strong need for web-based tools to efficiently access and summarize this wealth of data that exist.

Related Resources

Desert Research Institute, Western Regional Climate Center http://www.wrcc.dri.edu/

North American Monsoon Experiment (NAME) http://www.cpc.ncep.noaa.gov/products/precip/monsoon/NAME.html

The Role of Weather and Climate at Cerro Grande: A Quick Overview

John Snook (United States Forest Service)
February 14, 2001 1:45 PM

Pre-Burn Background Information

By way of introduction, the initial prescribed burn at Upper Frijoles, a higher elevation site, was very tame compared to the raging Cerro Grande wildfire of three to seven days later. Due to 0.22 inches of rain that occurred April 29 to May 1, the initial burn would barely carry in the timber fuels on evening of May 4. In contrast, the wildfire raged uncontrollably a few days later, following significant changes in wind, fuel type, aspect, and in an adjacent, low elevation, environment where drought-effects were brought to the forefront.

A graph of precipitation at stations within the region shows that all stations recorded lower than normal winter precipitation (Figure 1). On May 6, drought conditions were worse in southern and western New Mexico than in Bandelier (Figure 2). Nevertheless, conditions at Bandelier were still dry. In fact, the local ski area never opened that winter.

Just days before the fire, Jeff Baares presented a study on wind and fire danger at Los Alamos National Laboratory. The study looked at the joint probability of the co-occurrence of strong winds, from South to WNW, and high or very high fire danger. The data used covered the period April-June for 1980-1998. For the purpose of the study, fire danger was assessed using the Bandelier, NM energy release component. Strong winds were defined as 15-minute winds greater than10 mph. Winds this strong typically produce instantaneous gusts of approximately 30-40 mph.

Findings

The conclusions of Baares' study were as follows:

- March-June is the windiest time of year in New Mexico.
- The aforementioned combination of fire danger, wind direction, and wind speed occurs over a 3-day period once every four years. When such 3-day periods occur, there is usually more than one episode in that year.
- Thus, a major fire moving up to the edge of the Los Alamos National Laboratory is not only credible, but likely, with a frequency of one occurrence per 10 years.

The following discussion documents the conditions leading up to the burn and the escape of the burn. The governing weather patterns prior to the Upper Frijoles burn were as follows:

- Most of April 2000 was warmer and drier than normal, under the influence of strong high pressure. April 29 to May 1 was an exception, with a weather system bringing 0.22 inches of precipitation to the site. The high pressure ridge re-intensified during the first four days of May and remained strong from May 4-7
- The weather on the day of the Upper Frijoles burn, Thursday May 4, 2000, recorded by the

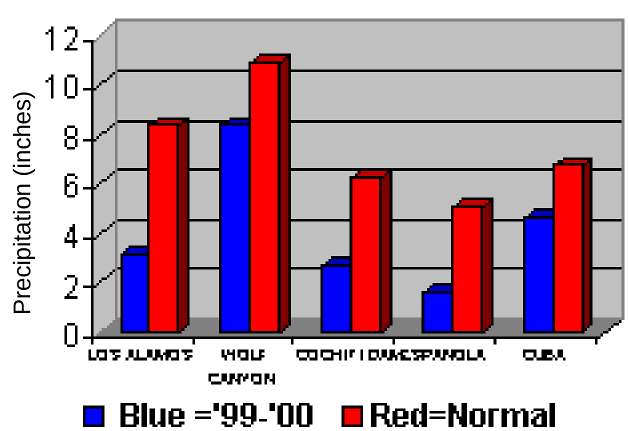
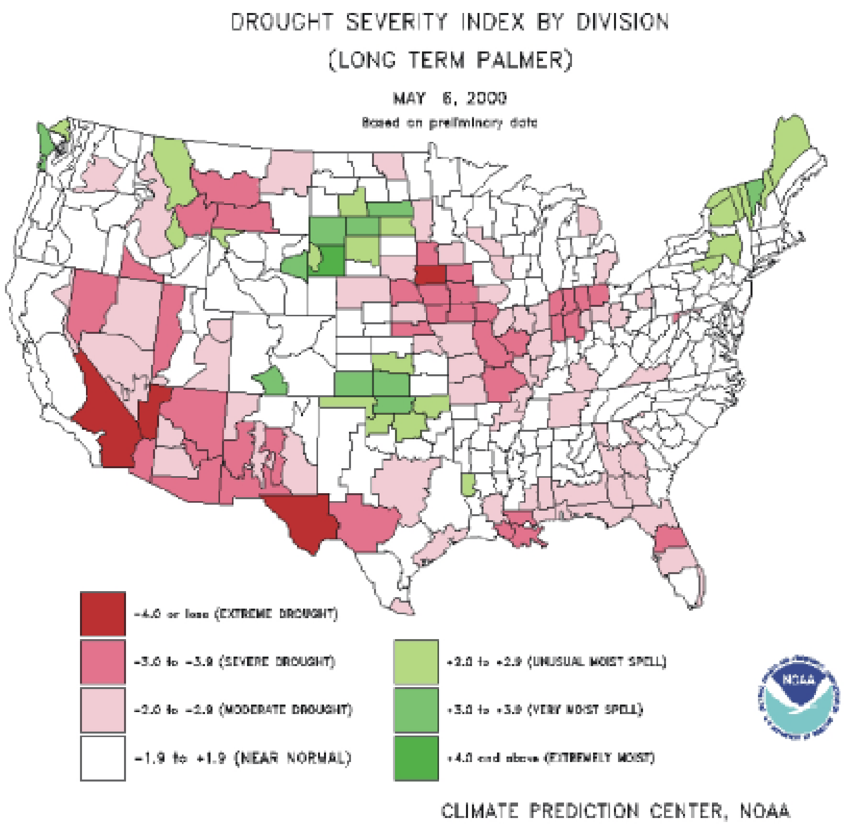


Figure 1. Comparison of 1999-2000 winter with normal precipitation at Los Alamos area stations.



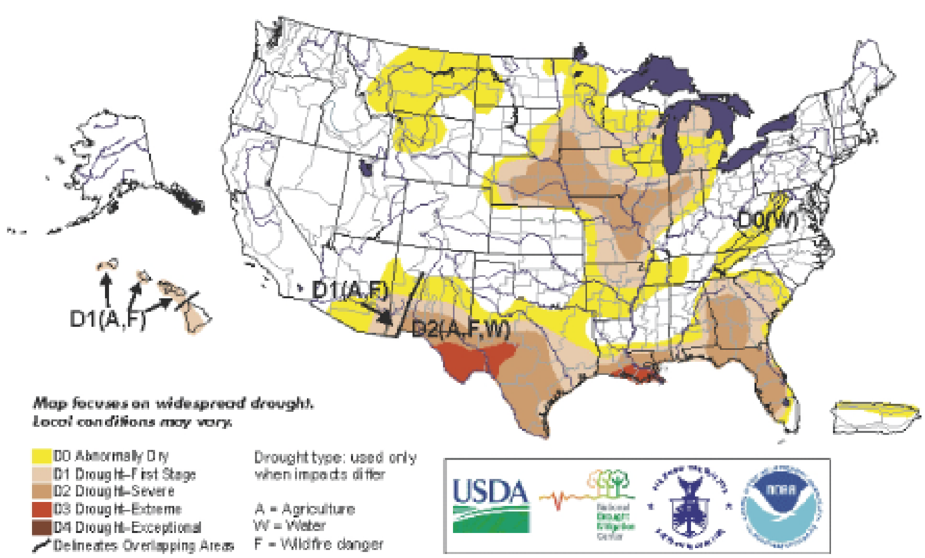


Figure 2. Drought conditions prior to the Cerro Grande burn.

portable weather station (9170 ft.):

- Sky: Sunny skies
- Maximum Temperature: 72°F
- Minimum Relative Humidity (RH): ~15-20%
- Minimum Temperature: 48°F

A test burn was conducted at about 7:20 p.m. The weather conditions at that time were as follows:

- Upper Elevation Temperatures: in the 50s
- RH: ~25-30%
- Evening Winds:
- On the ridgetops: NW 8-12 mph
- On the slopes:1-5 mph

Thus it was still not very windy during the test burn, but conditions started to change on Friday and Saturday in that winds increased a bit. The weather during the next several days, Friday, May 5 to Monday May 8, was as follows:

- Friday May 5: Mostly sunny through midday, some clouds p.m. Warm temperatures, with minimum RH 14-18%; 20' winds W to SW, increasing to 15-18 with gusts of 20-22 mph.

- Saturday May 6: Cloudier and a little cooler, with RH similar to Friday. Eye level winds were SW to West 1-5 mph with gusts of 8-11 mph.

- Sunday May 7: Variable clouds and little temperature change; RH rose to 20-30%; 20' winds increased to SW 10-15 with gusts of 28-40 mph. At this point the fire escapes along the south perimeter. There were attempts to contain the escape, which led to a bigger problem.

- Monday May 8: Winds again fairly strong and gusty. The passage of a low-pressure trough shifted the high elevation winds from SSW to W or NW at 3:00 p.m.

Within the prescribed fire area, small and medium fuels on the ground did not burn, due to local ground moisture. This is because smaller dead fuels react more quickly to daily weather changes. The long-term drought's biggest effects were on live fuels and large dead fuels. These were more affected by seasonal trends than by daily weather.

Maximum Wind Gusts at Los Alamos National Laboratory May 4-8, 2000

Date	May 4	May 5	May 6	May 7	May 8
Gusts (direction; mph)	NE 30	W 37	W 30	WSW 35	SW 40
Time	2:12 PM	10:25 PM	1:15 AM	1:57PM	2:37 PM

Lessons

Shorter time-frame weather events, such as the late April rainfall in northern New Mexico, can temporarily and/or locally mask the criticality of the "big picture," i.e., the long-term regional drought. This was the situation with the initial prescribed burn, and the fuel moisture conditions at the high elevation burn site. Therefore, we need to look at all scales and conditions, both local conditions and wider regional conditions. One should not automatically conclude that simply because there is a drought in effect, every fire will have extreme fire behavior. Each fire situation should be addressed on a case-by-case basis, and both short-term and long-term factors must be considered.

Related Resources

Bandelier National Monument Cerro Grande Fire Web Site
http://www.fs.fed.us/r3/sfe/fire/cerrogrande/

Bandelier National Monument Cerro Grande Prescribed Fire Investigation Report
http://www.nps.gov/cerrogrande/

Cerro Grande Fire Board of Inquiry Final Report and other Reports
http://www.fire.nps.gov/fireinfo/cerrogrande/reports.htm

Beyond the 2000 Fire Season

MAPSS: Mapped Atmosphere Plant Soil System

Ron Neilson (USDA Forest Service, Pacific Northwest Research Station)
February 14, 2001

(Editor's Note: Ron Neilson generously offered to give an impromptu talk on his innovative modeling of interactions between climate, vegetation and fire).

MAPSS is a vegetation distribution model that was developed to simulate the potential biosphere impacts and biosphere-atmosphere feedbacks from climatic change. MAPSS was originally a steady-state biogeography model, able to simulate a map of potential natural vegetation under a long-term average climate. Emerging technology couples the biogeographical rule base of MAPSS with two different ecosystem nutrient cycling models and a process-based fire model in order to simulate the spatially explicit dynamics of vegetation at landscape to global scales under both stable and changing climates. These new dynamic vegetation models (DVM) will be useful for exploring management options at all scales from landscape to regional, national and global.

The climate component of the new models incorporates data generated from PRISM (Parameter-elevation Regressions on Independent Slopes Model; http://www.ocs.orst.edu/prism/prism_new.html). PRISM uses point data, a digital elevation model (DEM), and other spatial data sets to generate estimates of climatic elements that are gridded and GIS-compatible. PRISM employs a coordinated set of rules, decisions, and calculations, designed to accommodate the decision-making process an expert climatologist would invoke when creating a climate map. The strong variation of climate with elevation is the main premise underlying the model formulation. PRISM adopts the assumption that for a localized region, elevation is the most important factor in the distribution of temperature and precipitation.

The conceptual framework for the MAPSS model is that vegetation distributions are, in general, constrained either by the availability of water in relation to evapotranspirational demands, or the availability of energy for growth. In temperate latitudes, water is the primary constraint, while at high latitudes energy is the primary constraint. The model calculates the leaf area index (LAI) of both woody and grass life forms in competition for both light and water, while maintaining a site water balance consistent with observed runoff. Water in the surface soil layer is apportioned to the two life forms in relation to their relative LAIs and stomatal conductance, i.e. canopy conductance, while woody vegetation alone has access to deeper soil water.

Biomes are not explicitly simulated in MAPSS; rather, the model simulates the distribution of vegetation lifeforms (trees, shrubs, grass), the dominant leaf form (broadleaf, needleleaf), leaf phenology (evergreen, deciduous), thermal tolerances and vegetation density (LAI). These characteristics are then combined into a vegetation classification consistent with the biome level.

The biogeochemistry component of the new DVMs simulates monthly carbon and nutrient dynamics for a given ecosystem. Above- and below-ground processes are modeled in detail, and include plant production, soil organic matter decomposition, and water and nutrient cycling.

The fire component simulates the occurrence, behavior and effects of severe fire. Allometric equations, keyed to the lifeform composition are used to convert aboveground biomass to fuel classes. Fire effects (i.e., plant mortality and live and dead biomass consumption) are estimated as a function of simulated fire behavior (i.e., fire spread and fire line intensity) and vegetation structure. Fire effects feed back to the biogeochemistry module to adjust levels of various carbon and nutrient pools.

The vegetation component integrates long-term vegetation and soil moisture responses to weather and climate. Various climate scenarios can be used to project vegetation change. The model simulates "natural" pre-European ecosystems (it does not yet include historical or current land uses) and uses observed climate conditions to generate fire scenarios (i.e., biomass consumed).

We believe that MAPSS-based dynamic vegetation models, incorporating fire simulations, can be used to determine which climate variables and scenarios generate hot spots for future fire risk. We plan to use a fine-resolution model to evaluate this. In the future, we will be incorporating land use and change to refine the model.

Related Resources
MAPSS (Mapped Atmosphere-Plant-Soil System)
http://www.fs.fed.us/pnw/corvallis/mdr/mapss/

An Overview of the Joint Fire Science Program and RFPs for 2001

Bob Clark (Joint Fire Science Program, NIFC)
February 14, 2001

(Editor's Note: Bob Clark generously offered to give an impromptu talk about the Joint Fire Science Program and upcoming research opportunities offered by the program).

The Joint Fire Science Program (JFSP), a six agency partnership to address wildland fuels issues, was authorized and funded by Congress in October, 1997. The six agencies, designated by the Congress, are the USDA Forest Service and five bureaus of the Department of the Interior: Bureau of Indian Affairs, Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and the U.S. Geological Survey. The purpose of the program is to provide wildland fire and fuels information and tools to specialists and managers who make wildland fuels management decisions. The information and tools will also help agencies develop sound, scientifically based land use and activity plans.

A Joint Fire Science Plan was prepared at the request of the Congress. The plan describes four principal purposes. Task statements in requests for proposals (RFPs) are developed to further one or more of the principal purposes. The four purposes are:

- Fuels inventory and mapping
- Evaluation of fuels treatments
- Scheduling of fuels treatments
- Monitoring and evaluation of fuels treatments

RFPs that are designed to answer specific questions or solve specific problems related to wildland fuels issues are issued periodically as funding is available (http://www.nifc.gov/joint_fire_sci/RFPs.htm). This year's RFPs include some new elements, including interactions between flora, fauna, fuels and climate, as well as issues regarding water and cultural resources. The basic elements of two RFPs germane to this meeting are:

- Development of methods and systems to incorporate weather and climate data into tactical and strategic fire planning (rfp 2001-1)

- Development of decision support tools for fuels and fire management (RFP 2001-2).

The JFSP requires face-to-face technology transfer to hand off research results to end-users. Moreover, all proposals must have a federal cooperator.

Climate Prediction

Climate Modeling Overview and Climate Forecast for 2001

Klaus Wolter (NOAA-CIRES Climate Diagnostics Center)
February 15, 2001, 8:00 AM

Background to Forecasting and General Circulation Models

Forecasting a complex system, such as the climate system, is a difficult task. This is because there is an enormous amount of chaos inherent in the climate system. If we use a pinball machine as an analogy, even given the same initial conditions, there are a myriad of possible outcomes, although some will occur more often than others. In order to determine the most likely outcome of the chaotic climate system, we run ensembles of general circulation models and sea surface temperature (SST) prediction models and extract the mean model prediction. General circulation models are run every week, and monthly and seasonal predictions are displayed as an "anomaly plume."

Recent Model Predictions

If we look at recent SST predictions, for regions of the tropical Pacific that are sensitive ENSO indicators, the ECMWF model shows a change over to El Niño conditions by spring, strengthening into summer; two forecasts from the National Centers for Environmental Prediction (NCEP) model also show increases in SSTs in the Niño 3.4 regions developing by late spring and stabilizing by summer. On the other hand, NOAA forecasts show conditions returning to normal by summer and maintaining throughout the end of the year, whereas the University of Maryland model actually shows strengthening of La Niña conditions by summer 2001. Thus, there is no definite consensus among models, and no clear forecast. As I mentioned in my previous talk, at this point in time, the indicators are not clear for good predictions of summer precipitation.

The Most Recent Model Forecasts

The most recent seasonal precipitation forecast (from February 2001; Figure 1) from NCEP shows lower than normal precipitation across a wide swath of the United States. The strongest negative anomalies are centered around Colorado and Northern California, as

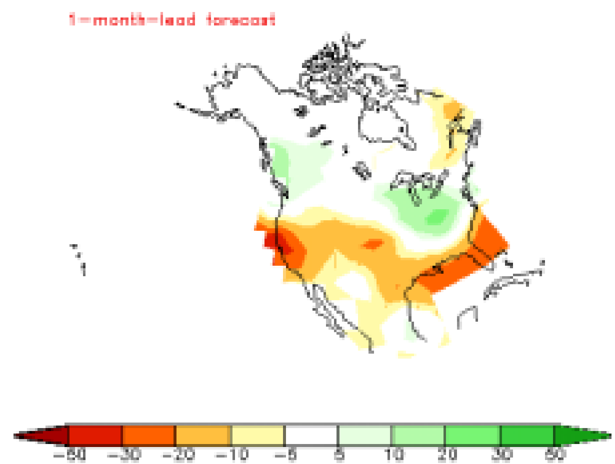


Figure 1. NCEP precipitation forecast (issued February 2001) for March-May 2001. Units are mm/month anomaly from 1961-1990 mean. (http://www.emc.ncep.noaa.gov/research/cmb/atm_forecast)

well as particularly strong negative anomalies across Florida. The dryness in Florida is probably a function of La Niña conditions. Note that there is the slight possibility that the Pacific Northwest may recover from the dry conditions during the winter.

The model predicts that these conditions will persist throughout the spring and into the summer, tapering off slightly during the summer. Temperature predictions indicate above-normal temperatures for the Southwest and the Central Plains throughout the spring, tapering off during the summer.

Recent, as yet unpublished, model sensitivity studies done by Martin Hoerling of NOAA's Climate Diagnostic Center show that the location of tropical Pacific warming during El Niño events is a strong influence on winter precipitation anomalies across the United States. Preliminary results show that tropical SST anomalies centered further west in the Pacific result in a more typical Northwest/Southwest dipole in precipitation, whereas those centered further east result in a very different pattern.

Recent Rainfall Anomalies

In order to put the forecasts into perspective, we can look at recent precipitation anomalies. We can see normal to above-normal precipitation across the western

U.S. (with the exception of western Washington state; Figure 2) during the fall of 2000, progressing to extremely dry conditions across the coastal states and Northern Rockies, with above-average precipitation over much of the Southwest and Central Plains (Figure 3). If we refer back to Hoerling's studies, we see that warm anomalies over the Central and eastern Pacific result in a wet west coast, as happened during the 1983 and 1998 El Niños. It is quite possible that, similarly, the location of La Niña anomalies has an effect on U.S. precipitation anomalies, such as during this winter.

If we look forward to the summer season, if tropical Pacific SST anomalies, in fact, are positive by spring, then we can expect good Southwest monsoon conditions and dry conditions in the Midwest. However, our ability to predict summer monsoon rainfall has not been particularly good. We are finding that it is important to consider the Atlantic side of the continent, because SSTs in the Caribbean also influence the monsoon. An interesting angle is to look at the North Atlantic Oscillation (NAO), which has been mainly negative this year. If we use historical negative NAO conditions as an analog for what might happen during the summer, we see a pattern of dry conditions in the Pacific Northwest and wet conditions in Arizona (Figure 4). However, we have not yet figured out all of pieces of the puzzle. Certainly there's a lot of work yet to be done on the empirical side, in order to figure out pertinent relationships.

References

Wolter, K., and M.S. Timlin, 1998: Measuring the strength of ENSO - how does 1997/98 rank? Weather, 53, 315-324.

Related Resources

Climate Diagnostics Center (NOAA-CIRES) http://www.cdc.noaa.gov

ECMWF European Centre for Medium-Range Weather Forecasts http://www.ecmwf.int/
NCEP National Centers for Environmental Prediction http://www.ncep.noaa.gov

NAO The North Atlantic Oscillation http://www.ldeo.columbia.edu/~visbeck/nao/presentation/html/NAO.htm

NOAA Climate Prediction Center (CPC) http://www.cpc.ncep.noaa.gov

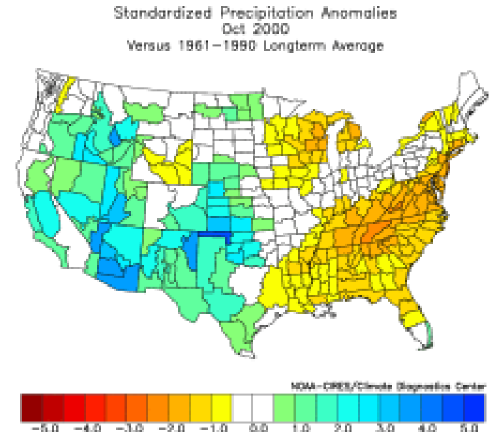


Figure 2. U.S. climate division precipitation anomalies for October 2000, an unusually wet month in the Southwest. (http://www.cdc.noaa.gov/USclimate/USclimdivs.html)

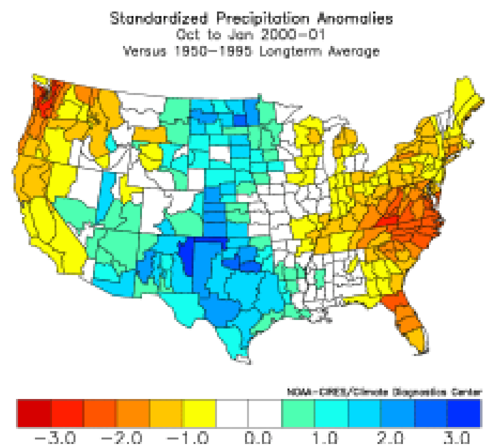


Figure 3. U.S. climate division precipitation anomalies for October 2000-January 2001. Note the extremely dry conditions across the coastal states and Pacific Northwest. (http://www.cdc.noaa.gov/USclimate/USclimdivs.html)

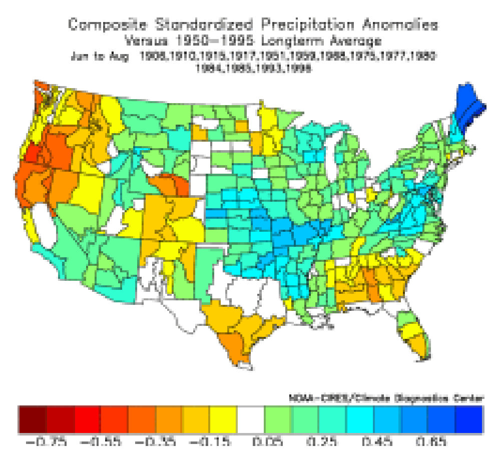


Figure 4. U.S. climate division summer precipitation anomalies for the 14 lowest NAO values in the 20th century. (http://www.cdc.noaa.gov/USclimate/USclimdivs.html)

Seasonal Climate Forecasts: Wildfire Applications

Dan Cayan (Scripps Institution of Oceanography)
February 15, 2001 8:20 AM

Seasonal Forecast Characteristics

In order to best understand seasonal climate forecasts, it is important to understand the characteristics that determine the results of model runs. In general the following characteristics of seasonal climate forecasts are important:

- boundary conditions, not model initialization conditions dictate model results
- models are an aggregate overtime and do not yield synoptic details
- most models have coarse spatial resolution
- model results are probabilistic, not deterministic ensembles
- methods include: statistical, dynamical, statistical/dynamical hybrid
- climate forecast model skill has been poor-to-modest
- skill may depend upon any of the following factors: season, state of ENSO, model
- minimum skill is at 2-4 weeks

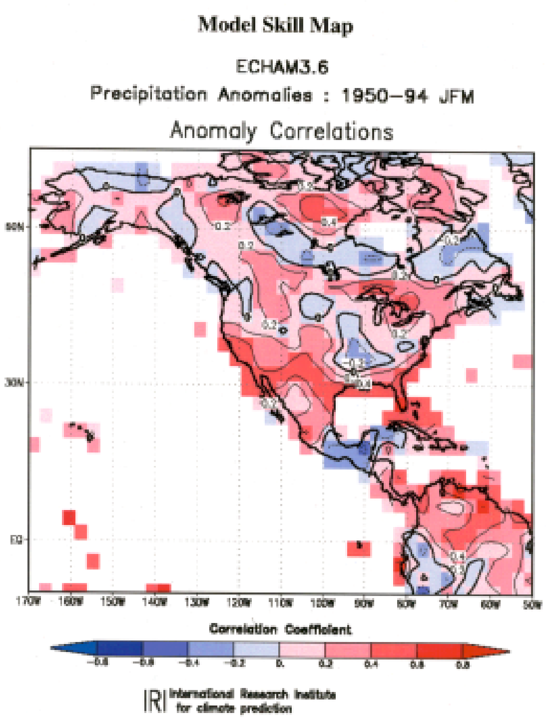


Figure 1. Skill map for ECHAM (European Community Hamburg) winter (January-March) precipitation forecasts, expressed as correlations between forecast and actual precipitation. Source: IRI.

Thus far, seasonal climate forecasting does not account well for multi-year trends, a point that I will examine at length, below.

The International Research Institute for Climate Prediction (IRI) produces skill evaluations for 3 different models, NCAR CCM (National Center for Atmospheric Research Community Climate Model), NCEP (National Centers for Environmental Prediction), and ECHAM (European Community Hamburg). If we look, for example, at a skill map for the ECHAM model winter precipitation (January-March), correlations are mostly positive, but weak (especially for North America), and overall skill is pretty good (Figure 1). For summer, correlations are far lower and the spatial pattern seems to be random. Again, model skill is subject to initialization conditions, spatial resolution and, most clearly, season.

Some new studies by Sasha Gershunov of Scripps compares statistical and dynamical seasonal climate forecast models. If we look at Gershunov's model validation for winter 1998, we can see that the statistical model underestimates the total amount, because it cannot reproduce the extremes; the RSM (dynamical) model overestimates precipitation amount, but gets precipitation intensity pretty well. A hybrid of statistical and dynamical models is considerably more skillful than the individual approaches. Similarly, a hybrid forecast model has higher El Niño forecast skill.

Long-Term Trends

The state of the ENSO system has a clear signal in large precipitation and large streamflow events, especially during La Niña years, when stations in the Pacific Northwest exhibit a high number of large streamflow events between January and July. However, skill in predicting precipitation and related streamflow peaks, is mitigated by long-term trends. For example, since 1950 there has been an increase in spring (March-May) temperature, in excess of 2°C over the western U.S. and into Alaska and Canada. This trend has been verified in phenological data on the first date of lilac blooms, which now bloom about one week earlier than in the early historical record. Our data from spring temperature trends in the Pacific Northwest, lilac blooms and the date of spring snowmelt shows a clear positive relationship between the three, such that during the past 20 or so years both the date of 1st snowmelt and the date of lilac blooms have occurred about one week earlier than they did to prior to 1976 (Figure 2).

This research has powerful implications not just for the hydrological cycle, but climate prediction for wildfire, because both depend on the timing of snowmelt. Work by Mike Dettinger shows that there is a nonlinear trend in predicted and observed streamflow. Streamflow predictions from ensemble models are pretty accurate up until the point of snowmelt, then ensemble predictions vary greatly, probably due to trends in spring temperature. These regional trends pose a great challenge for medium-range climate prediction.

Wildfire Applications
Tony Westerling of Scripps has produced some statistically-based fire predictions, using Palmer Drought Severity Index (PDSI) as a predictor. Westerling's research shows strong regional spatial coherence in fire starts. Correlations of seasonal fire activity, in various parts of the country, with lagged PDSI show that, depending on the region, there are strong positive correlations between PDSI months in advance of the current fire season and seasonal fire activity. These lagged relationships are related to fuel buildup and ground moisture, so high PDSI values (high moisture) lead to fine fuel buildup. The fine fuels dry out as the PDSI drops to drought levels during the current fire year.

Westerling has found that when wildfire measures (e.g., acres burned) are correlated with atmosphere circulation variables for the winter and spring prior to the fire season, as well as the summer of the fire season, large-scale atmospheric circulation and global-scale climate anomalies become evident. For most of the West, wildfire activity appears not to be well related to El Niño and La Niña, but rather to circulation patterns that create first wet, then hot and dry conditions. Thus, there is an ability to predict fire danger, seasons in advance. We do not specifically need El Niño/La Niña conditions in order to predict fire activity. However short-term events and ignition events are still problematic for seasonal prediction; lightning, Santa Ana winds and hot spells are difficult to predict with any accuracy.

Needs for Future Research
In order to improve climate forecasts for wildfire applications and statistical wildfire prediction models, we need the following:

- more and better wildfire data
- models to elucidate climate/weather/fire links
- historical forecast archives

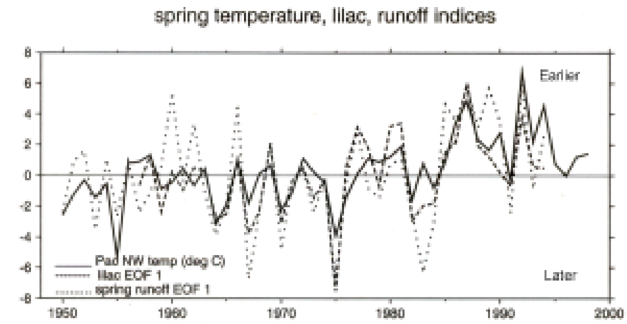


Figure 2. Pacific Northwest temperatures (°C), first principle component of the date of western U.S. lilac blooms, first principle component of the date of western U.S. first snowmelt, 1950-1998. Note the post-1976 shift toward higher temperatures, earlier lilac blooms and earlier spring snowmelt. Source: Dan Cayan, Scripps Institution of Oceanography.

At Scripps, we are in the process of building an archive of seasonal and medium-range forecasts back to 10 years, with the cooperation of the Climate Diagnostics Center. Moreover we're working on unraveling the links between climate and fire in the western U.S.

Related Resources
Scripps Institution of Oceanography Climate Research Division http://meteora.ucsd.edu/

California Applications Program
http://meteora.ucsd.edu/cap/

Climatology of Western Wildfire and Experimental Long-Range Forecasts of Wildfire Season Severity

Anthony Westerling (Scripps Institution of Oceanography)
February 15, 2001 8:40 AM

The number and extent of wildfires in the western United States each season are driven by natural factors such as fuel availability, temperature, precipitation, wind and relative humidity anomalies, and the location of lightning strikes, as well as anthropogenic factors. It is well known that climate fluctuations significantly affect these natural factors at a variety of temporal and spatial scales. It is of great interest to know how strongly climate patterns affect wildfire, and furthermore, whether there may be time lags imposed by climate forcing such that prediction skill may be possible at a season's or longer lead time. At longer lead times, fuel availability, being substantially determined by previous seasons' or years' climate, may be amenable to even longer-range forecasting. A group of us at Scripps have developed a seasonal fire severity forecast based upon a number of parameters, including climate factors.

Data

We compiled and combined some 330,000 individual fire reports from United States Forest Service (USFS), Bureau of Land Management (BLM) and the Navajo Indian Reservation (BIA) to construct a data set of monthly fire start counts and acres burned as 1° x 1° grid cells (Westerling et al., 2001a). For our analysis, we assumed that there is a dominant fuel type in each grid cell that can be classified as either heavy or fine for general descriptive purposes. In the resulting series, less than 1% of the USFS data and less than 3% of the BLM data are excluded for lack of proper location information or dates. Despite their limitations, an amalgamation of these data sets yields a spatial and temporal history that is of sufficient quality, spatial resolution and duration to resolve regional characteristics of the wildfire season.

Climate data are represented by the Palmer Drought Severity Index (PDSI). The PDSI is an auto-regressive measure of combined precipitation, evapotranspiration and soil moisture conditions. It represents accumulated precipitation anomalies and, to a very small extent, temperature anomalies. When the PDSI is negative (positive), soil moisture is below (above) average for a location. PDSI has been used before in studies of climate and fire relationships and, despite the considerable limitations of the PDSI, the index has been widely adopted and used for a number of climatological studies (Alley, 1984).

Seasonality of Wildfire

Wildfire in the western coterminous U.S. is strongly seasonal, with 95% of fires occurring between May and October. Fire starts peak during July and August. Depending on location, 50 to 80% of the western U.S. precipitation occurs between October and March. By contrast, the peak of fire season occurs during the hottest and driest portion of the climatological annual cycle.

In conjunction with the hottest and driest time of year, monthly mean acres burned also peaks in July and August, but shows somewhat different spatial features than do fire starts. The areas with the largest number of acres burned tend to be in regions of smaller fuel types (e.g., grasses, shrubs, chaparral), though not exclusively. Smaller fuels typically lose moisture more rapidly than heavier fuels, increasing their fire consumption potential. These same regions tend to be climatologically windy areas, such that once a fire starts, the combination of fuel factors and wind cause rapid spread.

The progression of the fire season varies geographically. The fire season develops earliest (May and June) and ends earliest (August) in New Mexico and Arizona. The start of the fire season spreads north and west through July and August. To the north, the fire season in northern Idaho and western Montana is more concentrated toward the later part of the summer, with roughly 50% of fire starts occurring in the hottest month, August. The fire season in California peaks in September, aggravated by hot, dry conditions that build through the summer.

Examples of Links Between Climate and Wildfire Season Severity: Sierra Nevada and Great Basin

Given that weather, fuels, topography and human intervention all affect fire in varying degrees, one needs to be cautious in attributing the number of acres burned to individual factors. It is an over-simplification to claim that a large fire was caused solely by low humidity or no precipitation. The question then becomes, to what extent do certain climate factors affect wildfire characteristics? A primary role of climate seems to be affecting vegetation conditions favorable for ignition and spread, in addition to determining the frequency and location of ignition by lightning. Our research demonstrates that moisture anomalies can exert a strong influence on fire severity over large spatial scales and long lead times.

Lagged correlations for August fire starts and acres burned with lagged, prior-season divisional PDSI scores (Figure 1) show interesting regional relationships. In the Sierra Nevada (Figure 1a), anomalous fire starts are negatively correlated with PDSI scores from the preceding year and a half; that is, increased numbers of fire starts in August are associated with deficit PDSI in the prior winter and spring, and concurrent summer. August anomalous acres burned in the Sierra Nevada appear to be associated with a deficit in PDSI in spring and summer. This suggests that during the spring and summer of the previous year, moist conditions are conducive to the growth of some fine fuels, while prolonged dryness in the nearer term increases fuel flammability through vegetation mortality, loss of vegetation moisture and duff dryness. Thus, in the Sierra Nevada, fuel loads are relatively more important for acres burned than for fire starts, and fuel flammability is more important for the number of fire starts.

In the Great Basin, by contrast, the correlation between August fire starts and acres burned is much higher. Figure 1b indicates that deficit PDSI in spring and summer is not very important to either anomalous fire starts or acres burned in August. Much of the region is comprised of grasses, which follow an annual curing cycle providing a readily available fuel source for fire, thus an anomalous precipitation deficit might have little impact. Invasion of grasses, in particular by exotic species, have increased fire occurrence across the Great Basin during the past few decades. The seasonal growth and development of these fuels are strongly affected by precipitation anomalies. Large positive correlations with PDSI 12 to 15 months prior to August (Figure 1a) suggest that anomalous precipitation affects the previous season's fine fuel production, and thus increases the current season's fuel load. The correlation between August acres burned and previous year PDSI is higher in the Great Basin (Figure 1a) than in the Sierra Nevada (Figure 1b). We believe that fire dynamics, especially, large acreage fires, in the Great Basin are dominated by fine fuels, whereas the Sierra Nevada has both fine fuels and heavy fuels. The heavy fuels are slower growing and burn less frequently than those in the Great Basin. This suggests that one year's precipitation is not as important in determining the fuel load in the Sierras as it is in the Great Basin.

It is important to reiterate that fire starts and acres burned are not determined solely by climate and vegetation, but despite idiosyncracies in human intervention and recording, these our studies tell us a great deal about how climate forcing affects fire risk in different locations.

Western Wildfire Seasonal Forecast

The links between seasonal climate anomalies and seasonal fire activity in the Western US prompted us to forecast seasonal acres burned (May to October) on a 1° x 1° grid using lagged values of PDSI (Westerling et al., 2001b). The forecast model is estimated using principal components (PC) regression to calculate linear relationships between PCs of the seasonal acres burned and lagged PDSI. Acres burned per grid cell were summed for fires starting between May 1 and

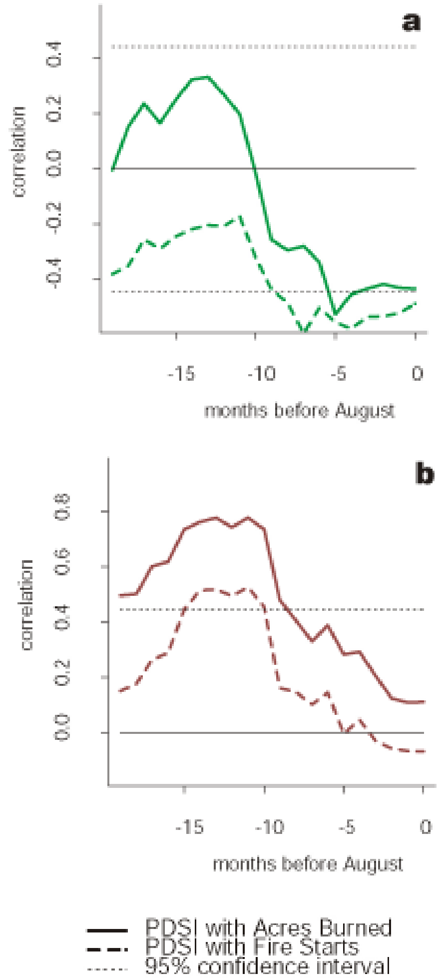


Figure 1. Correlations of PDSI with August Fire Activity in the (a) Sierra Nevada, (b) Great Basin.

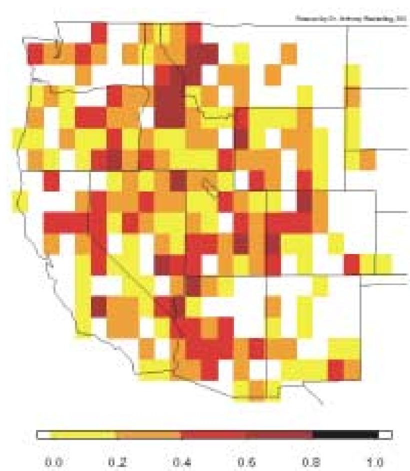


Figure 2. Map of forecast model skill. Yellow areas indicate where the model has little skill and red to dark brown areas indicate where the model has good skill. This figure shows the correlation of jacknifed, cross-validated forecast anomalous acres burned with actual anomalous acres burned, 1980-2000.

Figure 3. Forecast number of acres burned for May-October 2000 (a); actual number of acres burned for the May-October 2000 forecast (b).

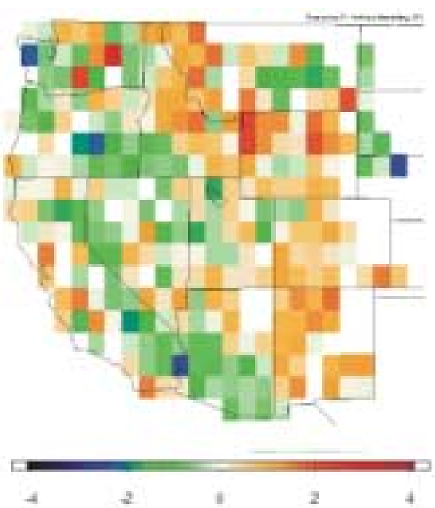


Figure 4. Map of forecasted acres burned for May-October 2001. This forecast was made early in the spring of 2001. Forecasted acres burned are shown as anomalies, thus orange to red areas indicate an above average number of forecasted acres burned and green to blue areas show a below average number of forecasted acres burned.

October 31 and scaled using a $\log_{10}$ transformation. The 312 grid cells averaging more than one fire per year comprise the predictand data set. For predictors, 110 western U.S. Climate Division PDSI series are used at 7 different lags: January and March immediately preceding, January, March, May, and August one year previous to, and May two years prior to the fire season, for a total of 770 predictor variables. The dimensions of the predictor and predictand data sets were reduced by substituting the first 8 PCs for each of the two data sets.

Forecast skill is measured here by the correlation between cross-validated model output and the predictand—$\log_{10}$ of seasonal acres burned—for each grid cell (Figure 2). While this model was not optimized for any particular region, the map in Figure 2 shows the greatest skill in the Rocky Mountains, the Sierra Nevada, central Arizona, and the Great Basin. Note that clear areas can indicate either no data or no skill.

A forecast, developed retrospectively, for the very active fire season of summer 2000, was fairly successful in reproducing the observed acres burned. Cross-validated forecast anomalous acres burned for the 2000 fire season (Figure 3a) show a similar spatial pattern in sign and intensity to the actual anomalies (Figure 3b). Considering that the 2000 fire season was an extreme year in many locations compared to the previous 20-year record used to estimate the model, this result strongly indicates the utility of this approach to forecasting the western US wildfire season.

Finally, the 2001 fire season was predicted using a similar set of lagged PDSI predictors. The 2001 fire season forecast (Figure 4) uses persistence in the February 2001 PDSI to model March 2001 PDSI; otherwise variable definitions are the same as for the 2000 forecast. Note that the forecast, while exhibiting positive anomalies in an arc from eastern Washington through the Rockies and New Mexico, seems to indicate a much less extreme fire season than in 2000.

Conclusions

Gridded numbers of wildfire starts and acres burned from the BLM, USFS and BIA can be used to characterize the seasonal and interannual evolution of fire seasons over the last two decades. These data show important relationships between fire season severity and current and previous years' climate. Acres burned in dry shrub and grasslands as in the Great Basin appear to depend strongly on fuel accumulation governed by climate conditions 10-18 months before the fire season (in addition to annual carryover fuel), and may be relatively unaffected by contemporaneous climate. In the Sierra Nevada range, central Cascades, and Northern Rockies, fire season severity is negatively correlated with contemporaneous PDSI and positively correlated with PDSI from the previous summer. This result reflects a trade-off between fuel accumulation and flammability, with wet conditions the previous year contributing to fuel accumulation and wet conditions in the current year suppressing fire activity.

The relationship between ENSO phases and fire starts lacked statistical strength. Correlations with climate indices at scales of one season to a year or longer lead times indicate that fire season prediction is possible on a similar scale. It is commonly assumed that fire season severity depends on precipitation and temperature conditions earlier in the year; however, our results demonstrate regional variability in the importance of *antecedent* seasons' precipitation for determining fire season severity. In many locations the climate conditions with the greatest relevance for future fire season severity occur at lead times of one year or greater.

Our 2000 wildfire season severity hindcast showed sufficient skill, we believe, to indicate that future forecasts can be used to guide fuel management and resource allocation decisions. Our 2001 forecast indicates greater than average fire severity in an arc from eastern Washington through the Rockies and New Mexico, a much less severe fire season in the Mojave and Great Basin, and only a marginally more intense season in the Sierra Nevadas compared to last year's prediction. A wide variety of choices for predictor variables and model specifications remain to be explored.

References

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Westerling, A. L., Cayan, D. R., Gershunov, A., Dettinger, M.D., Brown, T. J., 2001b, Statistical Forecast of the 2001 Western Wildfire Season Using Principal Components Regression. *Experimental Long-Lead Forecast Bulletin* (http://www.iges.org/ellfb)

Related Resources

California Applications Program (CAP) Web Page
http://meteora.ucsd.edu/cap

Western Wildfire Season Forecast
http://meteora.ucsd.edu/%7Emeyer/fire_forecast.html

Climate Prediction: ENSO vs Non-ENSO Conditions

Douglas Le Comte (NWS/NCEP/Climate Prediction Center)
February 15, 2001 9:00 AM

NOAA Climate Prediction Center (CPC) Long-lead Forecast Tools

- Coupled Model (CMP)—Ensemble mean forecast of a suite of 20 GCM (general circulation model) runs forced with tropical Pacific sea surface temperatures (SSTs), produced by a coupled ocean-atmosphere model. Available for leads of 1-4 months.

- Canonical Correlation Analysis (CCA)—Predicts patterns of temperature and precipitation based on predictor patterns of global SSTs, atmospheric 700 mb heights, and U.S. surface temperature and precipitation from the past year.

- ENSO composite—Supplies historical frequencies of three forecast classes (above, within, below the 1961-1990 mean — this will change to 1971-2000 mean in May 2001) for past years when Equatorial Pacific SSTs indicate moderate or strong El Niño or La Niña conditions.

- Optimal Climate Normal (OCN)—Predicts temperature and precipitation based on persistence (trends) of observed average anomalies for temperature (past 10 years) and precipitation (15 years).

- Constructed Analog on Soil Moisture (CAS)—Constructs a soil moisture analog from a weighted mean of past years. Proportional weights are used for temperature and precipitation.

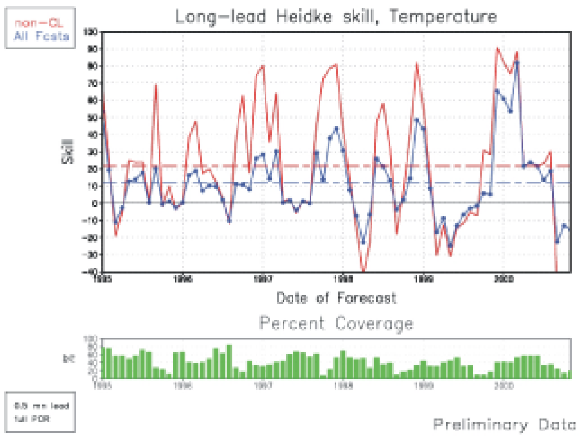


Figure 1. Heidke skill score summary for NOAA CPC 3-month temperature outlooks. Skill is aggregated over the entire U.S. And is estimated for forecasts issued 0.5 months in advance of the season of interest.

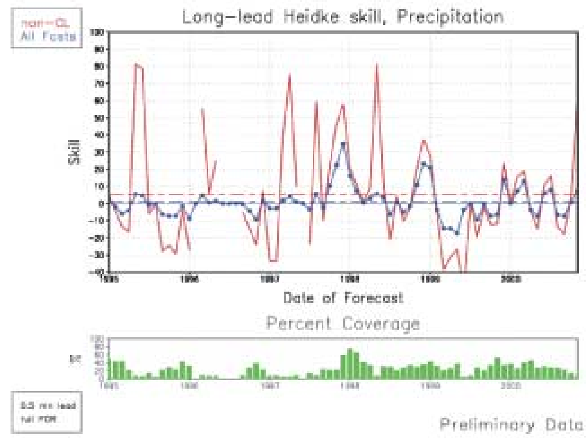


Figure 2. Heidke skill score summary for NOAA CPC 3-month precipitation outlooks. Skill is aggregated over the entire U.S. And is estimated for forecasts issued 0.5 months in advance of the season of interest.

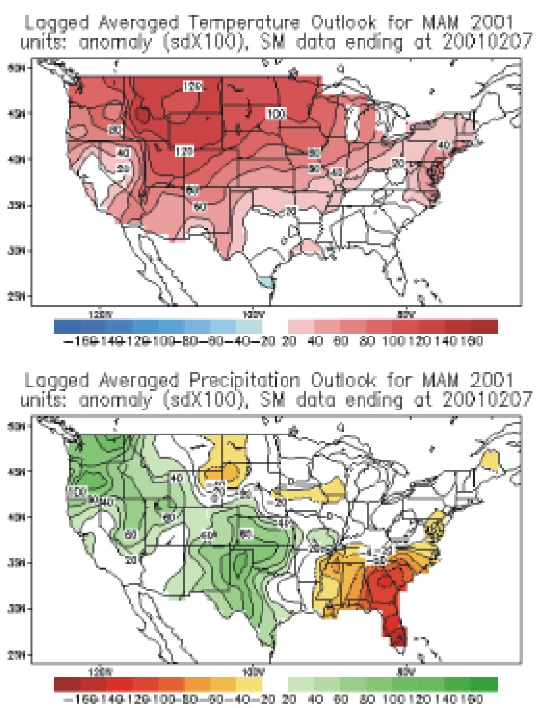


Figure 3. Constructed analog (CAS) temperature (top) and precipitation forecasts for spring 2001 (March-May) from soil moisture data.

- Screening Multiple Linear Regression (SMLR)—Uses the same fields as CCA, but these predictors are used to predict conditions at single stations. This method also uses soil moisture as a predictor.

Forecast Skill

In terms of seasonal skill, most forecasting tools do not work well in late spring (April-May) and summer. This is especially true for NOAA CPC precipitation outlooks. Due in part to its stronger spatial coherence, temperature is easier to predict than precipitation. NOAA CPC 3-month temperature outlooks have some skill, with considerable skill mainly during winter (Figure 1). Although precipitation skill is, in general, lower, precipitation skill is relatively high in winter and high during El Niño events (Figure 2).

Specific forecast tools include:

- *CAS*. The analog forecast from soil moisture, which combines data from 1932-1997, can be used to forecast temperature and precipitation for the next few seasons. Seasonally, the highest skill for temperature forecasts is from April-September, with peak skill for early summer forecasts. For 2001, the CAS (based on February 7, 2001 conditions) forecast for spring (March-May) shows below-average precipitation in the Southeast and wetter than average conditions over the southern Plains and Pacific Northwest. The temperature outlook for spring shows above-average warmth over the Rocky Mountain states (Figure 3). CAS soil moisture forecasts show negative soil moisture anomalies in the Southeast and positive soil moisture anomalies across the southern Plains states continuing through the summer.

- *ENSO Composites based on CPC Soil Model*. This tool is also used to monitor drought; 5,000-6,000 temperature and precipitation station reports are input each day and, unlike the Palmer drought severity index (PDSI), it is updated daily. The CPC Soil Moisture Composite demonstrates some interesting patterns with regard to ENSO (Figure 4). In July preceding La Niña winters, there is a tendency for negative soil moisture anomalies across the northern tier of the country and positive soil moisture anomalies across the Southwest, especially New Mexico. During neutral Julys, the tendency is for the Southwest and central Plains to be dry. During El Niño Julys there is a tendency for the Southwest to be dry (except New Mexico), whereas the northern Plains, Texas and Florida have positive soil moisture anomalies.

- *OCN*. The most skillful seasons for OCN precipitation forecasts are September-November through January-March. In contrast, the other tools tend to be most skillful for late winter forecasts.

- *CCA*. The best skill for this tool is for winter temperature and precipitation forecasts and summer temperature forecasts.

- *SMLR*. Unlike CCA, this tool shows great skill for fall forecasts.

- *CMP*. Coupled model skill appears to be heavily dependent on ENSO extremes.

- *NOAA Seasonal Drought Outlooks*. These take large-scale trends based on subjectively derived probabilities guided by numerous indicators, including soil moisture forecasts, extended range forecasts, long-lead outlooks, and other tools to forecast drought trends over the next 3_ months. The outlook through April 2001 shows improvement likely over the northern Rockies, the central Plains, West Texas and most of the Southeast, but drought is likely to persist in Florida.

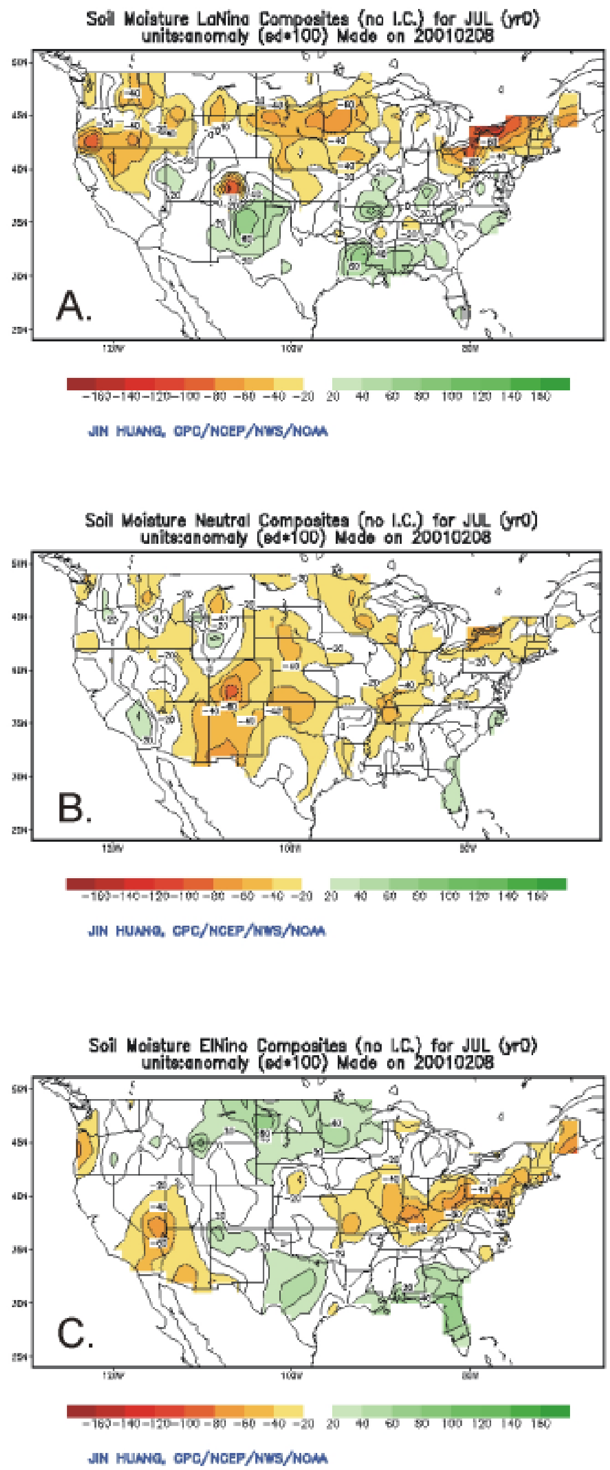


Figure 4. NOAA CPC July soil moisture composites. A. La Niña conditions. B. Neutral conditions. C. El Niño conditions.

ENSO vs. Non-ENSO Forecast Skill

Skill for official CPC climate outlooks varies with season, variable and phase of ENSO. Temperature outlooks for the lower 48 states are most accurate for late

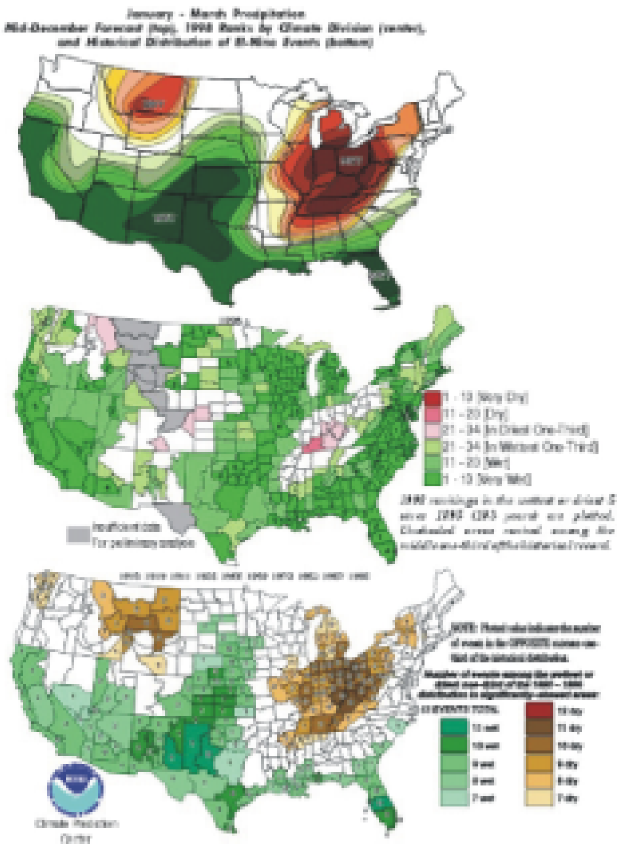


Figure 5. Comparison of (top) NOAA CPC Precipitation Outlook for January-March 1998 with (middle) observed precipitation rankings in the wettest or driest 5 years (since 1895), and (bottom) a composite of 13 20th century El Niño events. Green indicates wet conditions and red/brown indicated dry conditions.

winter and late summer; they are least accurate for late spring and late fall. Precipitation forecasts are generally less skillful than temperature forecasts, with marginal skill for all tools even in their best seasons and locations under "normal" circumstances. El Niño gives forecasters a real advantage. For example the January-March 1998 forecast was exceptionally accurate (Figure 5). During strong El Niños or La Niñas, precipitation skill can be as high as temperature skill for cool season forecasts. Areas of enhanced skill include the southern third of the country, the northern Rockies, the High Plains, and the Ohio Valley. Strong La Niña conditions imply the possibility of moderate precipitation skill for some parts of the warm season as well, especially for the Southeast. Note that part of the problem with precipitation forecast skill is due to problems with snow and rainfall data. Mountain reports and high elevation stations are discarded in favor of longer-term records from the cooperative network. There are discussions between United States Department of Agriculture (USDA) and the National Weather Service (NWS) on upgrading the cooperative network, and SNOTEL reports from western mountain areas are now included in a unified CPC rainfall analyses.

An examination of Heidke skill scores shows the following:

- Skill is correlated with ENSO. Precipitation forecasts do improve with ENSO conditions and there is a significant correlation between precipitation skill and an ENSO index (the MEI; Wolter and Timlin, 1993),

- During El Niño, precipitation skill scores have been positive for 12 forecasts and negative for 3, whereas during La Niña, precipitation skill scores have been positive for 12 forecasts but negative for 9.

- Temperature skill scores are high in winter, regardless of ENSO conditions.

In summary, CPC outlooks for temperature and precipitation are best in winter. The best precipitation forecasts are during El Niños, especially for non-CL areas (i.e., regions for which forecasts are ventured). Nevertheless, there is hope in summer that forecasts based on antecedent soil moisture will lead to improvements.

U.S. Drought Monitor

A brief word about the weekly Drought Monitor. The Drought Monitor is an expert consensus based on many different forecast tools. The principal inputs for the Drought Monitor are the CPC daily soil model, PDSI estimates, United States Geological Survey (USGS) streamflow reports, the most recent 30-day precipitation, USDA soil ratings and the satellite vegetation health index. The satellite vegetation health index monitors growing conditions using information from visible, near-infrared, and thermal bands. It is based on anomaly data back to 1985. The Drought Monitor is produced by three interagency partners, NWS/CPC, USDA/NOAA Joint Agricultural Weather Facility (JAWF), and the National Drought Mitigation Center (NDMC). A fourth agency, the National Climatic Data Center, will be added in the spring of 2001. Numerous outside experts, including the USGS, state climatologists, regional climate centers and NWS hydrologists, provide valuable feedback that is used in the final weekly product. It is posted on the Internet every Thursday morning.

Related Resources
NOAA CPC Seasonal Climate Outlooks:
http://www.cpc.noaa.gov/products/predictions/90day/

U.S. Drought Monitor:
http://enso.unl.edu/monitor/monitor.html

U.S. Seasonal Drought Outlooks:
http://www.cpc.noaa.gov/products/expert_assessment/seasonal_drought.html

Climate Prediction Interpretation and Evaluation Workshop

Holly Hartmann, Thomas Pagano and Soroosh Sorooshian (Department of Hydrology and Water Resources, University of Arizona)
February 15, 2001 10:00 AM

Introduction
The goals of this workshop were to examine monthly and seasonal climate forecasts. In order to meet these goals the workshop will include the following: (1) a survey of the different types of forecasts available, (2) explanation of the correct interpretation of climate forecasts and a hands-on exercise in forecast interpretation, (3) a discussion of forecast evaluation methods (including a hands-on forecast evaluation exercise and discussion), and (4) some examples of evaluations of official government climate outlooks, with an emphasis on evaluations that are useful for fire management. The latter two aspects, part of research in progress on forecast evaluation products to be released later this year, have been omitted from the following brief summary of the workshop.

Climate Forecasts
Various branches of the National Oceanic and Atmospheric Administration (NOAA), most prominently the National Weather Service (NWS) have been issuing monthly and seasonal weather and climate outlooks for over 30 years. Beginning in the mid-1990s the NOAA Climate Prediction Center (CPC) has been issuing seasonal climate outlooks, consisting of probabilistic temperature and precipitation forecasts, more than one season in advance. In addition, other agencies, including the Research Institute for Climate Prediction (IRI) and private forecast providers have been issuing seasonal climate forecasts for the past several years. The official source for seasonal climate forecasts is NOAA/NWS, and their work will be the focus of much of this workshop.

Forecast types include categorical, deterministic, and probabilistic seasonal outlooks. *Categorical outlooks* forecast whether future conditions will fall into a particular category, such as normal, above normal, below normal. These forecasts can literally be interpreted as saying that there is a 100% chance that forecasted category will occur and a 0% chance that any other category will occur. Forecast quality is judged by whether or not the observed parameter fell into the forecasted category. Categorical outlooks were issued by NOAA prior to 1983.

Deterministic outlooks are framed in terms of a specific quantity, e.g., 4 inches of rainfall or 60% of normal. Such forecasts are intuitively appealing and easy to use in planning. Forecast quality is judged by how close the observed is to the forecasted quantity. The forecast value, however, is unlikely to ever exactly equal the outcome. Deterministic forecasts often lead to unrealistic ideas about forecast confidence, especially when they neglect confidence bounds.

Probabilistic forecasts have been issued by NOAA since the early 1980s. Probabilistic forecasts indicate the probability of the forecast observation being in a certain category, e.g., a 55% chance of precipitation falling in the wettest 1/3 of the historical record. NOAA presently forecasts the probability of parameters falling into three categories (i.e., terciles) determined by rank-ordering observed values for a recent 30-year period (10 values in each category). Evaluation of probabilistic forecasts is also troublesome because they always give every category some chance of happening. The IRI also issues probabilistic seasonal climate forecasts, with predicted outcomes expressed in terms of terciles.

Future forecast tools, so-called *next generation seasonal outlooks*, are expressed in terms of probability of exceedance. These forecasts express information about the entire range of possibilities (not just terciles as in the NOAA/CPC seasonal probabilistic outlooks). Moreover, probability of exceedance forecasts provide probabilities *and* quantities for individual locations. These forecasts are often difficult to understand and apply, however they contain much more information than any of the previously available forecast formats.

Interpretation of Climate Forecasts
In order to understand how to interpret forecasts, it is important to know (1) what the forecast provider con-

siders *normal*, (2) how probabilities are expressed in maps and legends, and (3) how to identify and interpret *non-forecasts*. CPC and IRI currently base *normal* on 1961-1990 data; later this year, normal will be based on 1971-2000 data. *Normal* is not a single value, but the range of values experienced in the 10 most-average years in the 30-year period. Note: this method does not represent the range of variability in the entire period of historical record (which, in the Southwest, is ~100 years long), which may be much greater and should not be forgotten.

The CPC method for expressing changes of probability in their climate outlooks is as follows: CPC divides the normal period (1961-1990) data into terciles and indicates probabilities on their climate outlook maps in terms of *the increase in the probability of being in the top or bottom tercile*. Thus, a value of 5% in an area of "A" (excess likelihood of *above normal*) on a precipitation outlook map corresponds to:

- 38% chance of precipitation in the *highest* tercile of the 1961-1990 data distribution (i.e., 33% + 5%)
- 33% chance of precipitation in the *middle* tercile of the 1961-1990 data distribution (i.e., probability unchanged)
- 28 % chance of precipitation in the *lowest* tercile of the 1961-1990 data distribution (i.e., 33% - 5%)

The designation *CL* on NOAA/CPC seasonal probabilistic outlooks *does not mean climatology or normal*. Rather it indicates insufficient skill to issue a forecast or disagreement among individual forecast techniques. Where a CL rating covers much of U.S. a manager would do well to consult more regional or localized forecasts, which may have more skill. Where no forecast exists with adequate skill, the conservative approach is to avoid actions that assume any particular climate condition (i.e., respond more to current conditions while being prepared for any event). The important distinction is not to misinterpret "unknown/not predicted" (CL) as "normal".

The Results of Hands-On Forecast Interpretation Exercises

This survey investigated how fire managers perceive and interpret the current generation of climate forecasts. In particular, it focused on the forecast format, forecast probabilities, the interpretation of "climatology" (CL) designations on forecast maps, and the operational definitions of terms like *dry* and *wet*.

Methodology

As part of the workshop on forecast evaluation, climatologists and fire managers were asked to write on notecards their responses to questions about forecast interpretation. This helped to focus discussion on certain aspects of the CPC forecast format (i.e., CL forecasts). At the beginning of the workshop, participants were asked to divide into working groups according to the following categories:

- Climatologists/Meteorologists
- Fire planning
- Fire operations
- Other (e.g., fire research).

This was done to prevent climatologists from influencing the responses of fire managers, and to allow fire managers an opportunity to interact with peers.

In order to ascertain how well climatologists "know their mate", they were asked to respond in terms of how they thought the fire managers would respond, instead of in terms of what they personally believed to be the correct answer. Every time a new question was asked, the climatologists were reminded to answer in this way. The results of this survey were briefly summarized at the beginning of the February 15, 2001 afternoon session and are analyzed more in depth here. The reader should keep in mind that these answers are not representative of the broader fire management community – workshop attendees were clearly interested in climate and have experience in interpreting forecasts.

CPC forecasts had been presented and discussed frequently during the sessions prior to this workshop. Indeed, the two hours of presentations immediately prior to the workshop focused specifically on the most recent CPC forecasts in the context of the coming fire season (see presentations by LeComte, Wolter and others elsewhere in this volume). Members of the "other" category (fire research) had the table farthest in the back and may not have been able to read the smaller print on the slides about IRI forecasts. There were many answers left blank on the notecards of these respondents.

Interpretation of Forecast Probabilities

Question 1: While looking at a CPC forecast map for precipitation for the winter 2000, participants were asked to write down their answer to the question "What is the

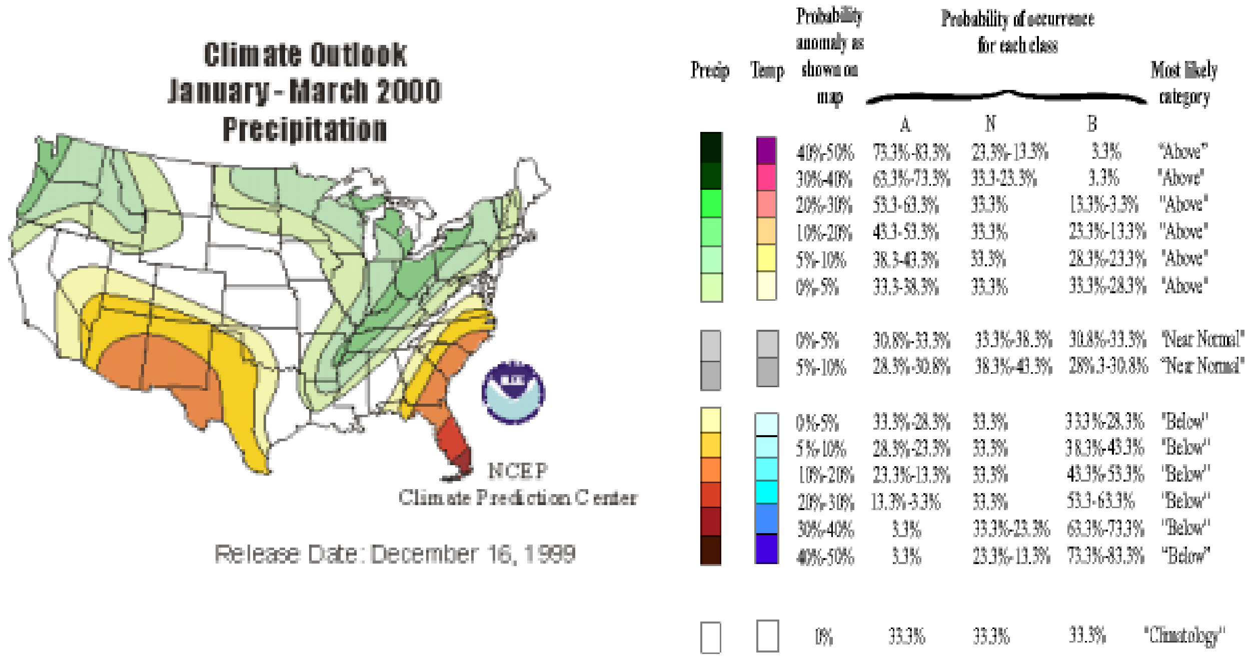


Figure 1. Seasonal climate forecast issued by the National Weather Service Climate Prediction Center and used in the hands-on forecast interpretation exercises.

forecast for Tucson, Arizona?" The forecast legend was not shown, because it is often left out when CPC forecasts are communicated by other groups. The map, as shown in Figure 1, indicated that there was a 53-63% probability that Tucson would be in the driest tercile of the 1961-1990 historical record, a 33% probability it would be in the middle tercile and a 3-13% chance of being in the wettest tercile of the record. The responses were categorized into 6 different classes as follows:

- Categorical and "correct" (e.g. "warm and dry", "below normal precip", "dry, less precipitation")
- Categorical and "incorrect" (e.g. "above average precip" – the forecast was for an enhanced probability of *dry*)
- Probabilistic and "correct" ("greater likelihood of dry", "48% chance it will be drier than normal"[1])
- Probabilistic but "incorrect"
- Deterministic ("48% of normal")
- Other ("wetter than normal temps", "drier by 3 units of some kind")

In Table 1 the correct response is highlighted in gray. In this table, as in all of the following tables, the numbers shown represent the number of responses for each category, among each class of users. The total number of users in each class is given in parentheses at the top of each table. For example, Table 1 under "Planning," 6 planners participated and 5 responded with a categorical "correct" answer and 1 responded "other".

Interpretation of CL forecast

Question 2: While looking at a CPC forecast map for precipitation for the winter 1999-2000, participants were asked to write down their answer to the question "What is the forecast for Reno Nevada?" The forecast legend was also omitted for this question. The map (Figure 1) showed this area had a CL forecast, which can be alternatively interpreted as saying *complete lack of forecaster confidence* or *all conditions equally likely*. We have classified the answers as follows:

- Normal (e.g. "near normal," "normal")
- Climatology (e.g. "no skill," "no forecast," "climatology")
- Other ("nothing significant forecasted," "slightly above normal")

The Effect of Making the Forecast Legend Available

Questions 3 and 4: After making the CPC legend available, participants were asked questions one and two again. Participants responded in the following ways:

[1] This probability may not match with the actual probability because the CPC contour intervals are uneven; that is the first two contours have intervals of 5% and deeper contours have intervals of 10%. See legend for details.

Table 1. “What is the forecast for Tucson, AZ?”					
Response framed in terms of:	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire* (n=21)	Climatologists & Meteorologists (n=15)
Categorical and correct	5	6	6	17	10
Categorical and incorrect	0	0	0	0	1
Probabilistic and correct**	0	1	1	2	2
Probabilistic but incorrect	0	0	0	0	0
Deterministic	0	0	0	0	0
Other	1	0	1	2	2
*Total fire represents all non-climatologists. **Correct answer.					

Table 2. "What is the forecast for Reno NV?”					
Response framed in terms of:	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire (n=21)	Climatologists & Meteorologists (n=15)
Normal/Average	5	3	4	12	8
Climatology/Total uncertainty*	0	1	3	4	7
Other	1	3	1	5	0
*Correct answer.					

Table 3. After seeing the legend: “What is the forecast for Tucson AZ?”					
Response framed in terms of:	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire (n=21)	Climatologists & Meteorologists (n=15)
Answer already correct*	0	1	1	2	2
Kept incorrect answer	3	1	5	9	7
Changed from categorical to probabilistic*	1	3	1	5	4
Other	2	2	1	5	4
*Preferred responses.					

Table 4. After seeing the legend “What is the forecast for Reno?”					
Response framed in terms of:	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire (n=21)	Climatologists & Meteorologists (n=15)
Answer already correct*	0	1	3	4	7
Kept incorrect answer	4	2	3	9	8
Changed to climatology*	1	2	0	3	1
Other	1	2	2	5	1
*Preferred responses.					

Table 5. "According to this forecast, which will be wetter, Tucson or Florida?"					
Response	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire (n=21)	Climatologists & Meteorologists (n=15)
Florida	0	4	2	6	4
Arizona	4	2	2	8	7
Neither*	1	1	4	6	4
Other	1	0	0	1	1
*Correct response.					

Table 6a. With respect to the CPC seasonal outlooks, how is "dry" defined?					
Response framed in terms of:	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire (n=21)	Climatologists & Meteorologists (n=15)
Below Mean/Less than Normal	1	6	3	10	10
Reference to terciles*	0	0	0	0	1
Less precipitation, other form	4	1	3	8	4
Other	1	0	2	3	0
*Correct response.					

Table 6b. How does IRI define "dry"?					
Response framed in terms of:	Planning (n=6)	Operations (n=7)	Other (n=8)	Total Fire (n=21)	Climatologists & Meteorologists (n=15)
Same, incorrect answer as for CPC	4	1	4	9	7
Reference to terciles*	0	0	0	0	1
Different from CPC and incorrect	1	6	1	8	5
Other	1	0	3	4	2
*Correct response.					

- They kept their previous correct answer
- Kept their same, but incorrect, answer
- Changed from a categorical to a probabilistic forecast (e.g., "53-63% chance of below normal," "10-20% chance of below normal," "there is a 10-20% probability anomaly"
- Gave some other answer, usually mistaking a probability anomaly for a "percentage of normal" forecast (e.g., "10-20% below normal precip," "below," "43.3-53.3% [no units]," "precipitation 50% below normal")

Definitions of "Dry" and "Wet"

Question 5: Using the same CPC map, participants were asked to compare the forecast for Tucson and the forecast for central Florida and were asked to answer the question "Which do you think will be wetter, Tucson or central Florida?" The probability anomalies were stronger in Florida than in Tucson. However, Florida is generally a wetter place. The correct answer is that one does not know. The CPC maps cannot answer the question for two reasons (1) They are not forecasts for a quantity of rainfall (they forecast the probability of precipitation falling in one of three categories), and (2) the definition of dry is relative to the location and season. There were four types of answers:

- Arizona will be wetter
- Florida will be wetter
- Neither/Can't tell

- Other (e.g., one respondent gave a probabilistic forecast for Florida)

Question 6a: What is the CPC definition of "dry"?. CPC takes a 30-year historical period, ranks those years from wettest to driest and then divides that list into 3 parts with 10 years in each category. The wettest 10 years are considered "wet", the driest 10 years are considered "dry" and the other 10 are considered normal. When CPC says there is a higher probability of dry conditions, they define dry by using the driest 10 years of the 30-year record. Workshop participants' responses to the question fell into four categories, in which "dry" is defined as:

- Below mean/Less than normal, with no other quantities identified
- Location in lowest tercile ("lowest third")
- Less precipitation, but in some other form (e.g., "10-20%","lesser degree of precipitation", "predicting no precipitation", "drier has meaning, dry has none", "5-10% below normal")
- Other (e.g., blank, "don't know")

Question 6b: Participants were asked to answer questions about an IRI forecast. One of the questions was "How does IRI define "dry"?" IRI and CPC have the same definition of dry, although their forecast map formats are significantly different. One climatologist inquired about whether we were referring to the terciles or IRI's special designation of "dry season", which appears as a grayed out "D" area on the IRI maps. "Dry season" means that less than 15% of the annual precipitation usually falls during this particular 3-month period. We clarified to all participants that we were not referring to the "D" on IRI maps. There were three categories of answers:

- The same as the answer given for CPC, but incorrect (i.e., they answered "below mean")
- the correct interpretation, which is "in the lowest tercile"
- A different answer than the one given for CPC, but still incorrect ("lack of moisture?" "less than 75% of normal," "8% or more probability of being dry," "dry outside mean with confidence interval")
- Other (blank, "don't know")

Summary and Conclusions of Workshop Survey

The current probabilistic CPC seasonal climate forecast format represents a great improvement in information content over the simplified "wetter than normal/drier than normal" forecasts of the 1970's and earlier. These forecasts convey forecaster confidence and uncertainty in ways that categorical forecasts cannot. High probability anomalies indicate that forecasters are highly confident in their predictions that the observed will be in a particular tercile of the historical record. On the other hand, CL (the white areas on the CPC monthly and seasonal outlook maps) indicates a complete lack of forecaster confidence – perhaps the most important forecast of all.

The results of the survey show that fire managers do not view the current generation of forecasts in probabilistic terms. The most common misinterpretation of the CPC forecasts is that the contours indicate the severity of drought/wetness expected. This is not true, especially in the case of CL, which was often misinterpreted as a forecast for normal conditions. Contours showing weak probability statements (5-10% probability anomalies) can be dangerous, especially when they are the strongest statement on a map. We found that users may not interpret the forecast for their region, but rather in terms of their region relative to the rest of the country for a given forecast. This problem is particularly relevant during non-ENSO conditions.

Given that almost all fire managers interpreted the CPC outlooks as categorical forecasts, categorical forecast evaluation measures (i.e., Probability of Detection, False Alarm Rate) may be an appropriate and understandable entry point into forecast evaluation. However, probabilistic evaluation scores should also be used to remind forecast users of the probabilistic information contained within (otherwise, if they only see categorical evaluation measures, they might think the forecasts are categorical).

Finally, there were divergent interpretations of CPC's definition of fundamental terms such as *wet*, *dry* and *normal*. The base period (1961-1990) rarely entered into the discussion when a CPC forecast was presented. Likewise, some users may not have been aware that terciles were being used; many interpreted the forecasts as above-normal or below-normal without reference to the middle category (given the fixed probability in the "normal"/middle category, this misinterpretation is relatively benign). However, users that have more extreme definitions of dry (e.g., "predicting no precipitation") have a greater potential to be disappointed by the forecasts. Although they were not discussed, recent temperature forecasts have been strongly influenced by frequent warm conditions throughout the 1990's. For example, a forecast for *warm* conditions may have a different meaning to someone who has only experienced the climate of the past 5 years as opposed to all of 1961-1990.

In summary, fundamental work on forecast format and communication remains to be done. This effort is not only the responsibility of the forecasters, but of the users as well. Before a user bases a decision on a forecast, it is extremely important for them to understand the precise (albeit non-intuitive) interpretation of the forecast. Likewise, it is often just as important to know about the past as it is to know about the future. Fire managers could benefit from increased exposure to historical climate data, in particular the baseline period of the climate forecasts.

Clearly the utility of the climate forecasts is enhanced when forecast users and producers share a common language about the forecasts, their uncertainty and their application. However, it is probably not realistic to expect all fire managers to become versed in climatology or forecast producers to become versed in fire management. We believe that both communities would benefit from an intermediary group — personnel versed in both the language of the forecasters and the users, in order to facilitate the transfer of information between groups. CLIMAS, the program for Climate, Ecosystem and Fire Applications and/or the various interagency coordination elements of the fire management community may help to fill this role.

Related Resources
NOAA CPC Climate Outlooks:
http://www.cpc.noaa.gov/products/forecasts/

International Research Institute for Climate Prediction (IRI) Forecasts:
http://iri.columbia.edu/climate/forecast/

Integrated Assessments

Interagency Integrated Assessments

Roger Pulwarty (NOAA Office of Global Programs)
February 16, 2001 8:00 AM

Introduction

What should an interagency approach to integrated assessment look like? The Regional Integrated Science Assessment (RISA) program is one approach. The RISA approach is based on the concept of integration among disciplines, and between science and society. Such assessments seek to improve our understanding of climatic systems, climate variability, and the impacts of climate on human and natural systems through synthesizing and evaluating knowledge and projections generated from different sources and using an array of different disciplinary approaches. The end goal is to develop decision support tools and climate services applications.

The RISA program stresses the importance of relevance and practical problem solving. The objective is to characterize the state of knowledge about climate and its impacts, and to identify knowledge gaps that can be filled through answering carefully formulated research questions. Through integrated assessment, syntheses of climate projections and evaluations can be produced that incorporate physical and social science considerations, economic factors, and environmental knowledge in a manner that improves society's ability to address and respond to climatic events, including variability and long-term changes. The process, involves developing new forms of integrated knowledge by identifying social needs and risks. University scientists, the agencies that attempt to address social needs and risks, and the people who are affected act as collaborators in the process. There is a two-way flow of knowledge between these collaborators. In many cases it has been in the administrative arena where traditional research efforts have failed: the questions may be known, but remaining largely unknown is how to manage large, complex systems. We cannot look at only one sector in isolation.

Building and maintaining stakeholder relationships at local and regional levels is essential to developing such knowledge and capacity. People need to know that research is ongoing, and is leading to better information for management and decision making. Further, the focus needs to be on more than just preparedness and early warning capabilities. Mitigation must be included as well.

The problem may be framed in terms of risk management (proactive, oriented toward mitigation and preparedness, framed around desire to improve predictive and early warning capacity before disaster strikes) versus traditional crisis management (reactive response after an event such as a flood or drought has arisen). Public perception of hazards has usually arisen only after development has occurred, resulting in a greater focus being placed on reactive measures. Moving toward more proactive approaches can be difficult, however; for example, strengthening land-use and building codes may provide a proactive means of adapting to climate variability, but may generate strong opposition. It is essential to identify who is doing what, and where, and to determine what they need. This can be complex. For example, 12 federal agencies deal with flood hazards; in addition, all 50 states have flood-prone areas; there are 3000 flood control districts, and 20,000 local governments having flood-prone areas!

Climate, RISAs and Fire Management

An Interagency Review and Update of the 1995 Federal Wildland Fire Management Policy was issued this year (2001). The review reaffirms that what we knew in 1995 was basically correct, but now realization has struck that it is time to act. Conditions continue to deteriorate, and are even worse than was expected in the 1995 report. Fire in the urban/wildland interface has become more complex and extensive. Likewise, ecosystem sustainability, issues regarding the use and role of fire, and science applications, communications, and education have all become more immediate. Implementation of the 1995 policy was incomplete due to the quality of the planning, the degree of interdisciplinary coordination involved, limited interagency collaboration, and criteria used for program evaluation. Also important was the need for program evaluation criteria that cut across agencies, programs and disciplines. Further, issues associated with public health, private property and infrastructure were not addressed.

We do not yet have a process for effectively incorporating climate into fire management, although we do have a good system for integrating weather into decision-making. The problem, however, is not *what to do*, but *how to do it*. Cooperative research is needed to overcome this barrier. Joint development of tools to identify, assess, and mitigate risks is required. The ultimate goal is to improve predictability and understanding of wildland fire-climate relationships before, during and after events. The societal values to be protected need to be defined, as well as long-range interagency objectives and optimal interagency preparedness levels.

In terms of policy strategy, the *how* of accomplishing these tasks, we need to seek authorization to eliminate barriers to funds transfers. We also need to develop partnerships with stakeholders and others, improve data collection mechanisms, and standardize both the language and process we use. It is important also to communicate effectively with property owners and others. Among the challenges are determining how to communicate with the public about paradoxes, such as that the same condition may be both a benefit and a hazard. How and when to move across scales from the very local to national and international/global is an equally important challenge. Addressing contradictions associated with land use planning and management is likewise essential, particularly in cases where implementation and enforcement of strong codes is needed but strong opposition to such regulation exists.

Moving fire-climate initiatives forward requires local feedback and support. How receptive are the agencies? Will such a push from the bottom up generate resistance at the top? Right now there is receptiveness to alternative approaches to fire management, so, I suggest, conditions may be more favorable than they have been in the past for making progress.

Related Resources

NOAA Office of Global Programs Regional Integrated Assessments Program
http://www.ogp.noaa.gov/mpe/csi/rgas/index.htm

Climate and Human Impacts on Fire Regimes in Forests and Grasslands of the U.S. Southwest

Barbara Morehouse (Institute for the Study of Planet Earth, The University of Arizona) and Steve Yool (Department of Geography and Regional Development, The University of Arizona)
February 16, 2001 8:30 AM
March 28, 2001 11:20 AM

An interdisciplinary group of researchers at the University of Arizona has recently been awarded a three-year, $1.26 million grant from the Environmental Protection Agency (EPA) through its STAR Grant program to build an integrated GIS-based decision support tool for use in fire management. The project team includes

- Barbara Morehouse, principal investigator and specialist in social science surveys and institutional/policy analysis; Institute for the Study of Planet Earth
- Thomas Swetnam, dendrochronologist and specialist in fire history analysis; Director, Laboratory of Tree-Ring Research
- Steven Yool, biogeographer and specialist in GIS-based wildfire modeling; Department of Geography and Regional Development
- Gary Christopherson, archaeologist and GIS specialist; Director, Center for Applied Spatial Analysis
- Barron Orr, specialist in remote sensing; Arid Lands Center
- Jonathan Overpeck, climate specialist and Director of the Institute for the Study of Planet Earth

The integrated model will be built to provide decision support for four specific areas: the Catalina-Rincon Mountains, Huachuca Mountains, Chiricahua Mountains, (all in Arizona) and the Jemez Mountains in New Mexico (Figure 1).

The model is being structured to integrate physical/natural processes and human components into a single system.

Research questions driving the project include:

- How might climate changes, in combination with changing land use patterns affect forest health, biodiversity, and ecosystem function?

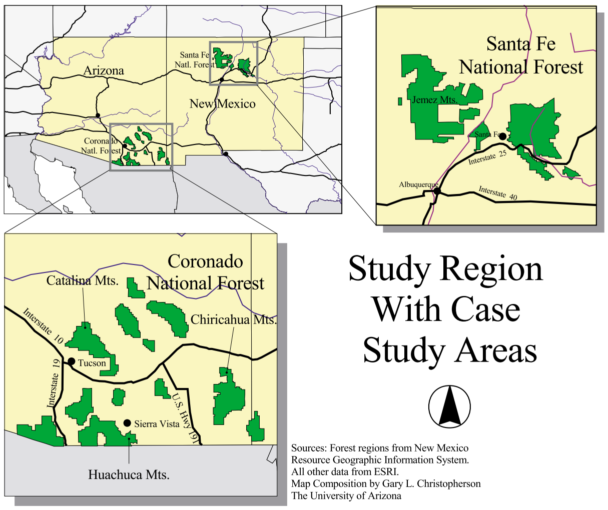
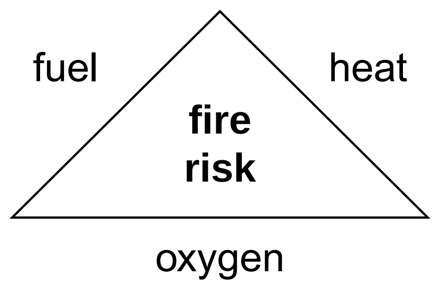


Figure 1. Maps of study region and case study areas in southeastern Arizona and north-central New Mexico.

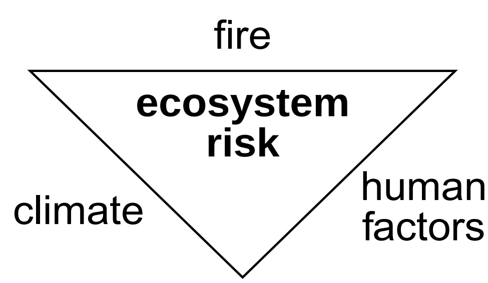
- How might land use choices increase or decrease ecosystem vulnerability to extreme weather events?
- What roles do human factors and behaviors play in elevating or reducing fire hazard?
- What roles do policies, organizational structures, and communication patterns play in ability to manage fire hazard effectively?
- What roles do public values and expectations play in fire hazard and in decision-making latitude and effectiveness?

The physical/natural process component is being constructed using FARSITE as the foundation. FARSITE is a commonly used GIS-based fire hazard model that allows fire managers to identify likely trajectories and intensities of fires based on an array of parameters such as fuel moisture, topographic factors, vegetation characteristics, and so on. The existing data fields in FARSITE will be incorporated and expanded, when necessary, into the new model. Among the data to be included in the new model are vegetation greenness, topography, vegetation and fire history, land cover characteristics, soil characteristics, soil and vegetation moisture. Climate data, including time series of precipitation and temperature data, time series data on seasonal to interannual and decadal climate trends (including El Niño-Southern Oscillation [ENSO] data patterns), and relative humidity data will also be incorporated into this component of the model. Concurrent with development of GIS-based data on natural and physical processes, work is being carried out to build a human dimensions component. This component, which constitutes a major innovation in fire risk modeling, includes data such as population numbers, density, and distributions, land use patterns, roads and other access pathways, infrastructure, built environment, economic data, and real estate values. Also included will be pertinent data derived from laws and policies, social values, and cultural history.

The construction of the physical-process component may be understood as a variation on the traditional fire triangle, wherein fuel, heat and oxygen combine to create a certain level of *fire* risk, into one where fire, climate and human factors combine to generate *ecosystem* risk. The integrated model will feature remote-sensing algorithms that link climate and vegetation moisture in a manner that will produce a scaled assessment of impact and risk. Fuel moisture will be derived by combining variables related to topography and greenness. This entails use of high-resolution data that reflect dynamics over time. Thus, fuel moisture status will be constructed at the pixel level. The model will provide one-kilometer resolution, backed up by finer-scale fuel load data, at 60-meter resolution. Thus, the standard fire risk model shown below



becomes inverted into this configuration:



The model will include current biogeography data, and data for the past twenty years, for each of the study areas; these data will cover soils, vegetation, fuel load factors, elevation, aspect, and so on. Correlations will be made between climatic conditions over this time period and specific fire-related events. The intent is to determine how these factors interact to produce particular types and levels of fire and fire hazard.

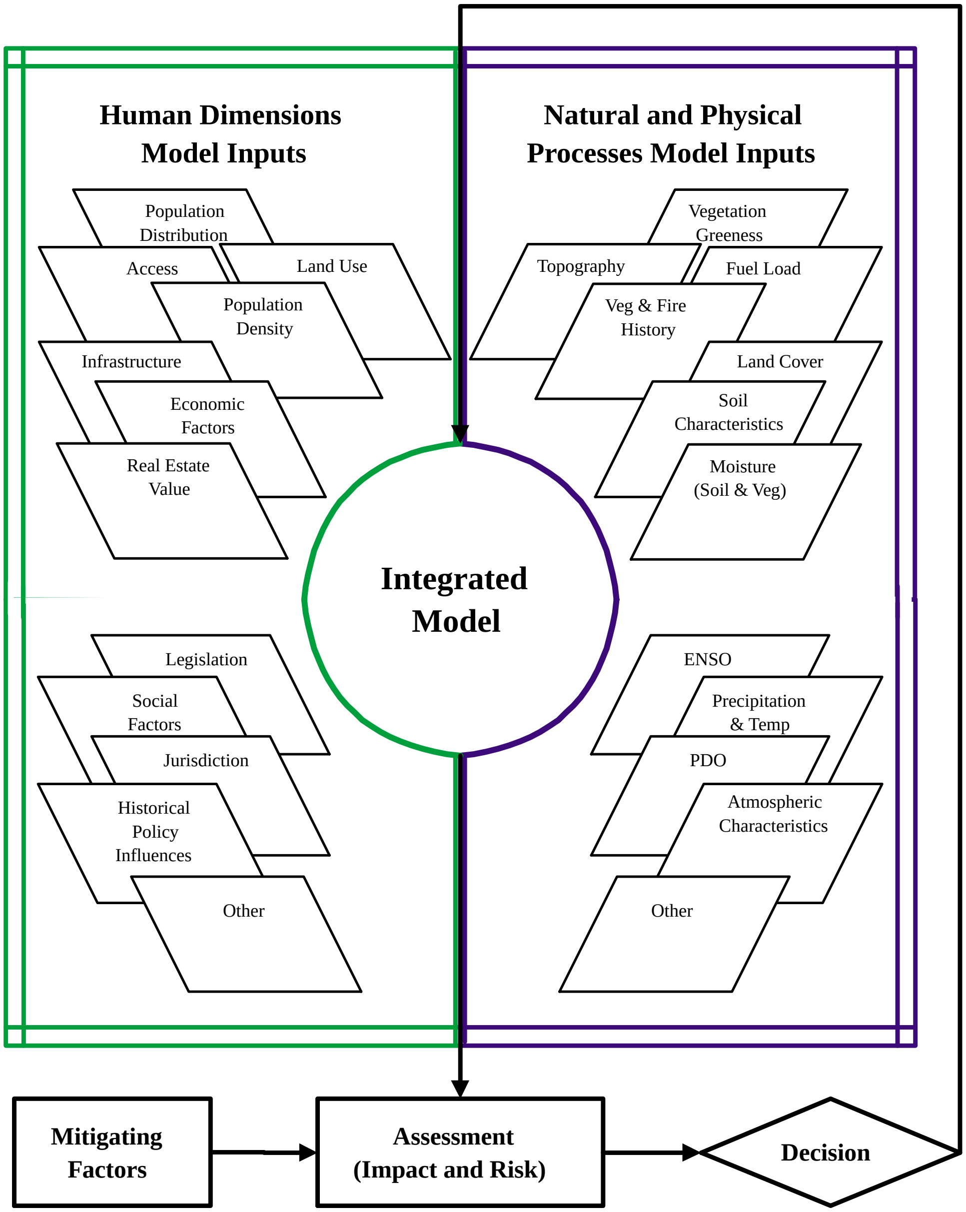


Figure 2. Schematic diagram of the factors used in the integrated model, including socioeconomic factors, as well as land use and climate factors.

The goals of the project are to improve our understanding of the interactions among climate, fuel load, fire history and human factors that lead to particular fire and fire hazard contexts; to integrate stakeholders into all phases of the project from design through implementation; and to make the final product available through the Web, using advanced map server technology. The model will provide spatially explicit, fine-scale data layers, which in turn will allow users to produce fire hazard maps, based on different scenarios, for each of the four specific study areas. The model is being designed to provide the following benefits:

- Improved ecosystem management
- Improved capacity to reduce fire threat, plan for prescribed burns, and manage watersheds
- Better integration of climate and human factors information into wildfire hazard assessments, at longer time scales and at a variety of spatial scales
- Availability of detailed fire history data and maps
- Potential for improved policy making at the urban-wildland interface
- Improved capacity to engage in effective pub-

lic relations and education about wildfire and fire management
- Enhanced capacity to manage for carbon sequestration

The products will include an ArcInfo-based GIS model, including three-dimensional models of the study areas; fire hazard maps and data layers; supporting data, graphs, and tables; user instructions; a final report; and peer-reviewed research publications in appropriate professional and scientific journals. A special symposium will be held at the end of the project; this symposium will include a workshop for participants to experiment with using the model.

Related Resources
CLIMAS Fire and Climate in the Southwest Web Pages http://www.ispe.arizona.edu/climas/fire/

Program for Climate, Ecosystem and Fire Applications Overview

Tim Brown (Desert Research Institute)
February 16, 2001 9:00 AM
March 28, 2001 10:50 AM

What is CEFA?
CEFA, the Desert Research Institute (DRI) Program for Climate, Ecosystem and Fire Applications (CEFA), was formed on October 1, 1998 through an assistance agreement between the Bureau of Land Management (BLM) Nevada State Office and DRI. As of November 2000, a new 5-year assistance agreement was signed with the BLM national Office of Fire and Aviation at the National Interagency Fire Center to perform basic climate studies and product development for fire management at the national level. CEFA resides within the Division of Atmospheric Sciences of DRI at Reno, Nevada, and works closely with the Western Regional Climate Center (WRCC).

The primary functions of CEFA are to:

- Perform studies and applied research to improve the understanding of relationships between climate, fire and natural resources.
- Serve as a liaison between the user and the research community by providing product training, assisting in technology transfer and eliciting user feedback.

Figure 1. CEFA home web page (http://www.dri.edu/CEFA).

- Provide climate and weather information directly for fire and ecosystem decision-making and planning.
- Improve operational fire weather forecasting using new knowledge of climate and meteorology.
- Develop and maintain a data warehouse for fire, ecosystem and related climate information.
- Develop tools for fire applications.
- Provide a social interaction component related to climate and wildfire.

CEFA partners include:

- Bureau of Land Management
- U.S. Forest Service
- California Department of Forestry and Fire Protection
- National Park Service
- California Interagency Fire and Forecast Warning Units
- Scripps Institution of Oceanography
- California Applications Program
- Experimental Climate Prediction Center
- Western Regional Climate Center

CEFA maintains a website (http://www.dri.edu/CEFA; Figure 1) that was developed and is maintained to a large extent from input by users in the wildfire decision-making and planning community. Many of CEFA's products are the result of project suggestions from the user community including those from last year's fire-climate meeting here in Tucson. I suspect that we will engage in several projects as a result of the outcome of discussions from this meeting.

CEFA Research and Products

CEFA has been performing research and developing climate products of relevance to wildfire management. A few of these projects are given here along with example products, but many additional ones are also in progress or are being initiated.

Recently CEFA developed a lightning climatology for the entire western U.S. using data from the Automated Lightning Detection System (ALDS) operated by the Bureau of Land Management from April 1985 through November 1996 (Figure 2). We are currently in the process of developing a new lightning (cloud-to-ground strike) climatology over the western U.S. using National Lightning Detection Network™ (NLDN; 1990-present) data from Global Atmospherics, Inc. Individual strike counts will be binned into a 0.5° spatial resolution grid across the western U.S. for 1990-2000. Maps of monthly strike counts and hour by month counts will be produced and made available to agency users on the CEFA web site. Since NLDN data are proprietary, access to these maps will be limited to government wildfire agencies that pay annual access charges for these data.

CEFA has developed a surface climatology of fire weather variables for the Great Basin including temperature, relative humidity, wind speed and wind direction from Remote Automatic Weather Stations (RAWS). These products are similar to lightning in that monthly and hour by month climatologies are available in graphics and animations. We have also recently performed a network analysis of Great Basin RAWS sites. One of the primary purposes of this study was to assess the adequacy of the network for fire danger and other purposes. Figure 3 shows RAWS locations in Nevada (circle symbols) with a background of the Köppen climate classification provided by the Idaho State Climate Services office. CEFA is also working, in collaboration with the California Wildfire Agencies and WRCC to perform quality control on historical RAWS data and improved metadata for approximately 240 RAWS sites in California. These improved data will then be available to perform fire danger rating analyses and determine RAWS climatological characteristics across the state.

One major project currently in progress is the climate analysis of the 2000 season. This project is an analysis of the most relevant climatological factors responsible for the year's activity across the western U.S. The primary project goal is to develop an understanding of

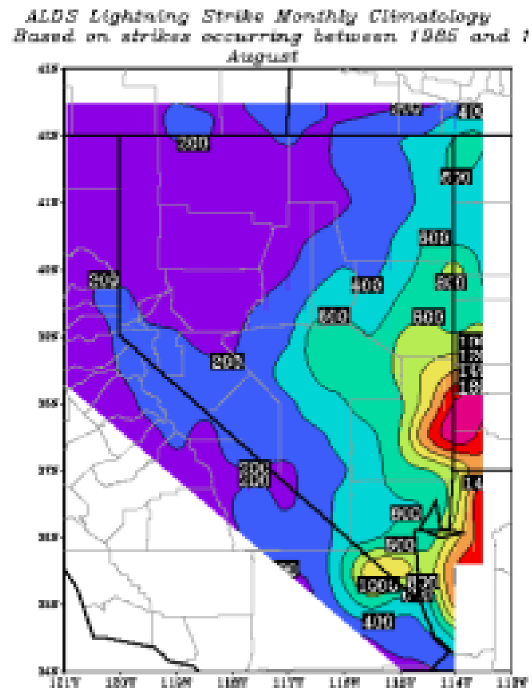


Figure 2. Automated Lightning Detection System (ALDS) August lightning strike climatology (1985-1996 period) for Nevada.

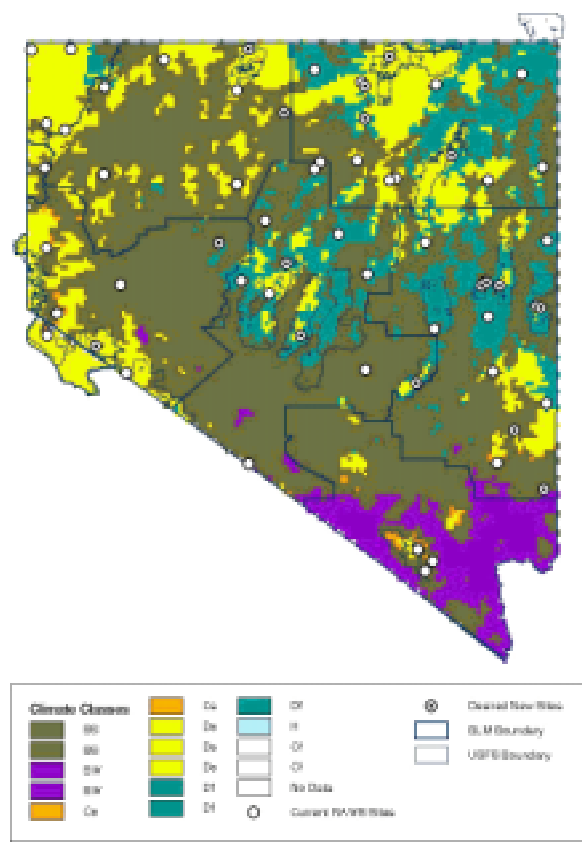


Figure 3. Nevada Remote Automatic Weather Station (RAWS) locations (circle symbols) and Köppen climate classification provided by the Idaho State Climate Services office.

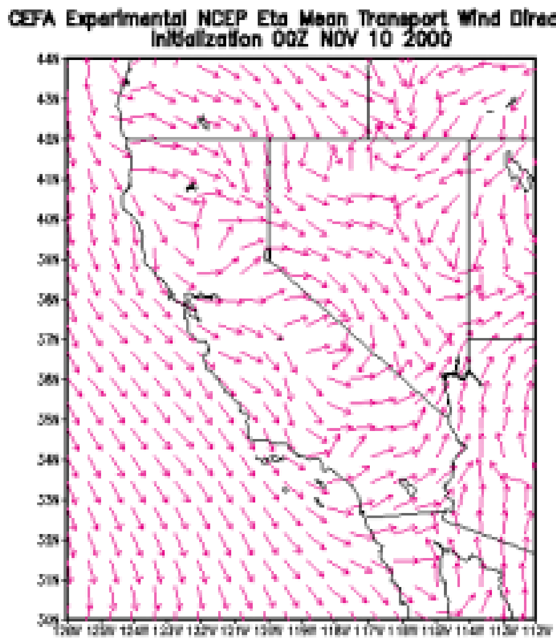


Figure 4. An example of CEFA experimental daily NCEP Eta model smoke management forecasts for California and Nevada.

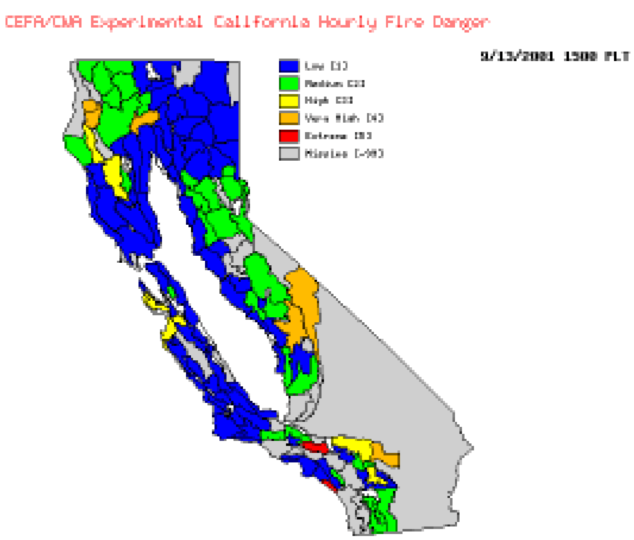


Figure 5. Example hourly fire danger map for California.

the climate patterns preceding and during the fire season. Specific tasks include (1) analyzing climate anomalies on monthly and seasonal time scales for a number of surface and upper-air variables (e.g., temperature, precipitation, relative humidity, wind speed and direction, lightning); (2) relating this information to National Fire Danger Rating System (NFDRS) indices such as 1000-hour fuel moisture; and (3) assess the possible role of La Niña or other teleconnection patterns in relation to the fire season.

CEFA's current primary operational product is experimental daily NCEP Eta model smoke management forecasts (Figure 4). This experimental product consists of forecasts of mixing height and mean transport wind speed and direction from the most recent 00 UTC and 12 UTC Eta model run for the western United States. Graphic forecast displays are available for 6-hour periods out to 48 hours. The California Interagency Fire and Forecast Warning Units receive forecast data in a text format. The project is a collaboration between CEFA and the California Wildfire Agencies, partly in response to the need for air quality and smoke management forecasts in California.

CEFA is currently in the process of developing a prototype operational hourly fire danger map for California (Figure 5). It has been noted that in many areas across the state fire danger can change substantially during a 24-hour period. In an attempt to identify those situations where fire danger rapidly rises or decreases during the late night or early morning hours, we are producing hourly maps for each fire danger rating area across the state using components of the NFDRS and hourly RAWS data.

CEFA, working with the Scripps Institution of Oceanography joint NOAA Office of Global Program California Applications Program, is taking part in the Department of Energy's Accelerated Climate Prediction Initiative (ACPI). Our primary objective is to examine future potential change and variability in seasonal fire danger based on NFDRS indices such as the energy release component and burning index. The analysis will be done using approximately 150 years (1950-2099) of 6-hourly climate model output for a large portion of North America. Elements such as temperature, relative humidity and precipitation available from the National Centers for Environmental Prediction (NCEP) reanalysis and the National Center for Atmospheric Research parallel climate model are used as input for NFDRS calculations. The results will allow us to examine regional changes in fire danger strictly as a function of climate variability and trend, and can be used for economics and land use policies related to future suppression and rehabilitation planning.

CEFA also makes available on our web site products such as:

- Standardized Precipitation Index (SPI) maps.
- A number of monthly and seasonal weather and climate forecasts.

- A variety of operational and assessment products for fire and climate monitoring

Most of these products are produced by other agencies and organizations, such as WRCC, Scripps Institution of Oceanography Experimental Climate Prediction Center, and the International Research Institute. For some of these products we provide value-added information. A primary purpose here is to provide one-stop "shopping" access to climate products and information relevant to wildfire management.

Climate, Fire, and the Need for a National Climate Service

Jonathan Overpeck (Institute for the Study of Planet Earth, The University of Arizona)
February 16, 2001 9:30 AM

Introduction: Why a National Climate Service?
We have worked out the dynamics of the El Niño-Southern Oscillation climate process, but these achievements failed to excite interests in Washington DC. The national climate community is now trying to figure out where to get the resources to move forward. Climate prediction, facilitated by the wealth of data being produced by terrestrial, marine, and atmospheric observing systems, is moving forward. But the state of knowledge is not yet as good as it needs to be. We need a global climate observing system that includes institutional mechanisms as well as satellites and other observing hardware. To achieve this synergy, we need to work from the bottom up, while at the same time entities at the federal level continue to work from the top down.

Regional decisions require integration of climate knowledge into a context that recognizes the existence of multiple stresses and that recognizes the specific attributes and challenges of the places where people live and work. There is a new initiative afoot to introduce a regionally based, *national climate service*, analogous but not identical to the National Weather Service. The driving force behind the initiative is emanating from the fire community, as well as from stakeholders and jurisdictions at all levels from the local to the international. Thus, the goal is to provide useful information to the wide array of stakeholder sectors, while at the same time acknowledging that the concerns of different stakeholder sectors may sometimes conflict.

We have learned, through our research and interactions with stakeholders—including fire managers and decision makers—that there are many commonalities with regard to areas of risk and information needs. Indeed, demand is growing for place-based science. But to respond to this demand, we must convince our congressional representatives to be constituents for this type of science. Developing and maintaining stakeholder partnerships is fundamental, as is developing and maintaining mutual trust; this can only take place at local to regional scales. Likewise, regional partnerships must be sustained in order to sustain credibility. Such relationships must be ongoing; they cannot be terminated at the end of any given research phase or specifically funded research project.

A well-designed climate services operation is needed to ensure that this occurs. Our work must be built on the premises of sustained responsiveness (which requires continual evaluation), continually improving communications (including honesty with regard to what can and cannot be delivered to stakeholders, given current scientific knowledge and technological capacity), and ever improving science. At the same time, major gaps in scientific knowledge must be addressed at the regional level.

For example, in the Southwest, topographic complexity poses challenges to monitoring, understanding and modeling regional climate variability. Among the processes that are high on the research agenda for the Southwest are monsoon dynamics and forecasting, linkages between climate-snow-hydrology, and forecasting wind, relative humidity and atmospheric stability. Equally important is developing an understanding of climate impacts on human and natural systems that will allow development of integrated decision support systems.

A Model for Building a NCS and Some Things to Ponder…
Bottom-up advocacy of science oriented toward users at the regional level is essential. This involves three steps:

1. Identification of the knowledge/information needs of stakeholders
2. Advocacy of existing programs that are meeting regional needs
3. Advocacy for new efforts to fill the gaps

An optimal timeline for development of a formal, regionally-based and regionally-focused climate services operation would progress from an initial proportion of 90% science and 10% operations, to 50% research and 50% operations by 2025. To make this happen, there needs to be (1) a more effective consortium among agencies, universities, NOAA and stakeholders, (2) a regional project management office, (3) a regional steering committee, and (4) NOAA-led national activities.

Many questions remain to be answered as the initiative unfolds; for example:

- How broad should the climate service mandate be? Should it be "environmental services" instead of a more narrowly focused "climate services"? If this is the case, could such an operation form the basis for a new level of bottom-up interagency cooperation and partnership?

- Would one-stop shopping and a single voice serve stakeholders better?

- Would this lead to broader support for science and/or federal land managers' missions, objectives, goals?

- Before developing new climate products and services, how can we use what is already available? To what extent has this already been tried?

- What is the current political reality? What is the most "sellable" package in today's political world?

    - We need to stress the multiagency aspects.
    - We need to work with other states.

Moreover, there are other points to keep in mind:

- No scale matters more than any other.

- We need more local interaction; face-to-face interactions are important.

- The research and outreach activities we are carrying out now, particularly through involvement of students and community members, are allowing us to produce essential next-generation knowledge.

- NOAA should be funded at the billion dollar level to achieve the kinds of goals outlined here.

- We need to make it clear to Congress how much it really costs to "put out a fire."

- We need to take seriously concerns about conflicting responsibilities and accountability.

- We need to assure that the regional climate services initiative does not get absorbed into the global warming debate.

- We need to continue supporting improvements and enhancements to our observation systems.

- We need to continue working to assure that the work and insights of the regional assessments are well integrated into the climate service framework—at the national level, climate factors and impacts are beginning to be reflected in planning documents; what is missing is that some agencies are not thinking hard enough.

- We need to continue working to raise congressional awareness of the issues.

Fire and Climate in the Southwest 2001

Climate of the Southwest

Andrew Comrie (Department of Geography and Regional Development, The University of Arizona)
March 28, 2001 9:00 AM

Basic Characteristics of the SW Climate

Climate v. Weather. Weather includes events that occur over timescales of minutes to several days, whereas climate is, roughly speaking, a summary of weather over timescales that range from months to thousands of years. However, climate is more than just the average weather. It is the range of atmospheric conditions at a location experienced or expected over time. It is important to note that climate is always changing. What we think of as normal climate is a relative concept. Even though it is convenient to use the convention of the average of the most recent 30 years' weather as "normal" climate, we know that climate changes over the course of a century, and that records of changes over several centuries show 30-year periods that would seem quite far from what we presently consider to be normal. To use a financial market analogy, weather is like day trading, whereas climate is like long-term investing. In long-term investing, large forces (climate) shape the general performance of companies over time, but they play out as complex daily patterns (weather) of ups and downs on the market.

Defining the Southwest Climate. For our purposes the core region of SW climate is AZ and NM, with some extension into northern Mexico and the Upper Colorado River Basin (Figure 1). The annual average precipitation totals shown in figure 1 indicate spatial variation of precipitation over the Southwest region. The complex topography of our Southwest region leads to intricate spatial patterns of precipitation. Precipitation increases with elevation, as seen in the high totals over the Mogollon Rim, sky islands, Southern Rockies and Colorado Plateau. However, precipitation is sparse in regions in the lee of mountain ranges, relatively far from moisture sources, and those out of the path of the dominant westerly flow in the Northern Hemisphere midlatitudes. Thus, there are very low precipitation amounts in northeastern AZ and northwestern NM. Overlaid on figure 1 are the boundaries of the NOAA state climate divisions, which are regional averages of NOAA-NWS cooperative observation network stations.

Basic Characteristics of the Southwest Climate. Figure 2 shows average monthly precipitation totals for each of the climate divisions in our region. Seasonal precipitation varies throughout the region, but for the most part in AZ and NM there is a primary summer precipitation maximum, accounting for approximately 50% of annual precipitation, and a secondary maximum in winter, accounting for approximately 30% of annual precipitation. Summer and winter are, however, largely unconnected, and are governed by altogether different climatic processes (see below). Temperature follows the typical seasonal cycle, with maximum temperatures during the summer months and minimum temperatures during winter months. Average temperature in our region is strongly influenced by elevation.

Atmospheric Controls of SW Climate

Some of the key characteristics of our Southwest semi-arid/desert climate are the low precipitation, clear skies and warm weather that attract so many people to our

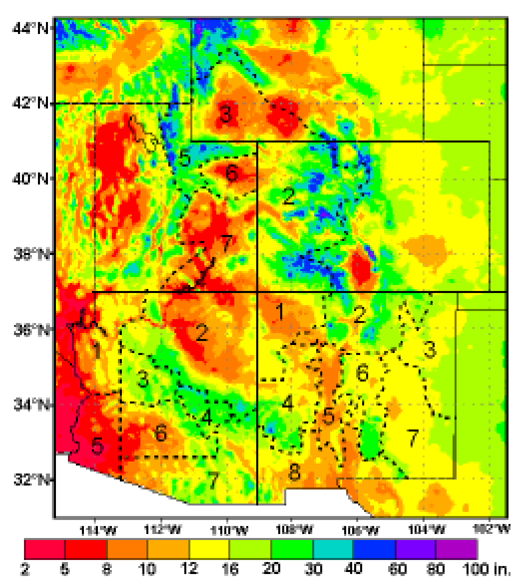


Figure 1. Average annual precipitation totals for the Southwest core region. NOAA state climate division boundaries are shown. Figure from Sheppard et al. 2001, "The climate of the Southwest," in review for the publication, *Climate Research*.

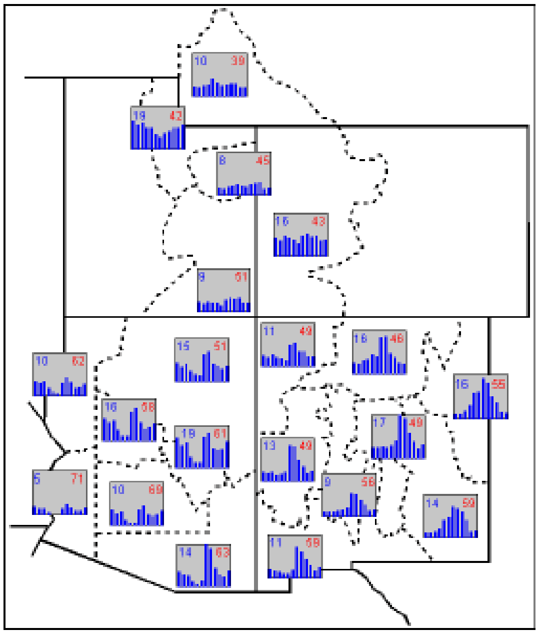


Figure 2. Seasonal precipitation cycle for NOAA climate divisions as shown by graphs of average monthly precipitation for each climate region. Note the increase in summer precipitation peak in southeastern AZ and across NM. Figure from Sheppard et al. 2001, "The climate of the Southwest," in review for the publication, *Climate Research.*

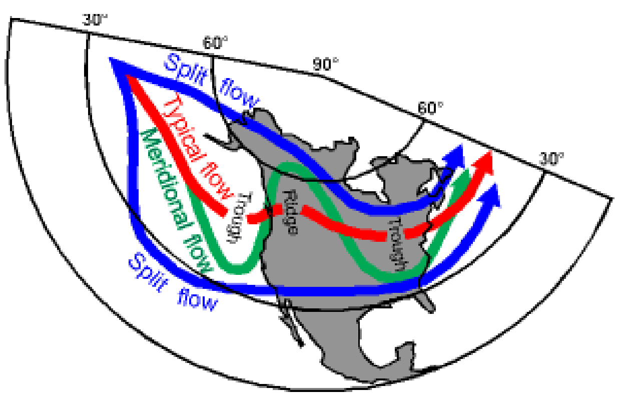


Figure 3. Average midtropospheric (700 mb) storm tracks. Typical flow results in dry winters in the Southwest, whereas meridional or split flow often associated with El Niño results in wet winters. Figure from Sheppard et al. 2001, "The climate of the Southwest," in review for the publication, *Climate Research.*

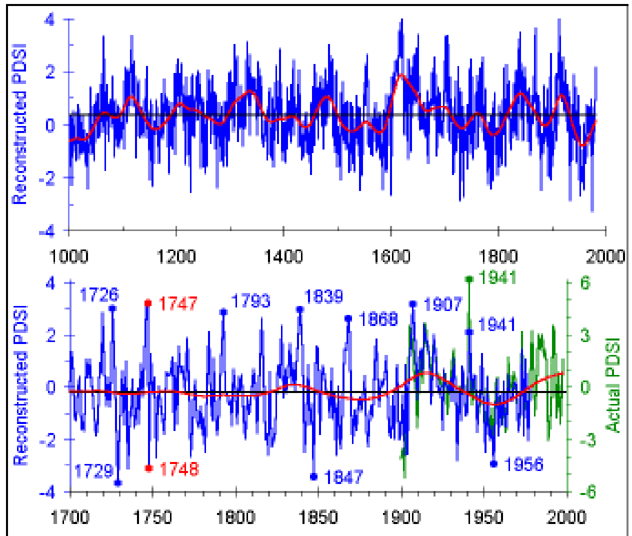
region. These characteristics are the result of several factors, chief of which is the subtropical high-pressure that dominates our weather from much of the year. The semi-permanent high-pressure cells over the North Pacific and North Atlantic oceans are the result of the return flow from thermally direct atmospheric circulation originating in the tropics. The subsiding air in these high-pressure cells inhibits precipitation.

Topography introduces spatial variation in precipitation and temperature; areas in the lee of mountain ranges experience the so-called rainshadow effect, in which much of the rainfall is forced out of moist air parcels as they rise on the windward side of high mountain ranges. Moreover, proximity to moist air plays a key role in the spatial distribution of precipitation. The moisture sources for our region include the Eastern Pacific, which dominates in winter, and the Gulfs of Mexico and California, which provide moisture for our summer rainfall. In general, the aridity of our region is accompanied by high temperatures and high rates of evapotranspiration.

The climate of our region is strongly affected by feedbacks between the atmosphere and the ocean. Thus, El Niño and La Niña, which result from the effects of Pacific Ocean heating and cooling, respectively, on the atmosphere, play a key role. The large degree of tropical Pacific Ocean heating and cooling during El Niño and La Niña, affects atmospheric moisture availability, as well as the path of storms over distant locations, such as our region. Such long distance connections in atmospheric phenomena are called "teleconnections." It is important to note that although on average El Niño enhances winter precipitation in our region and La Niña results in dry winters, no two El Niño or La Niña events are exactly alike.

Wintertime Atmospheric Controls. Figure 3 shows typical winter storm tracks over the U.S. The midtropospheric jet stream, which steers high and low-pressure systems, typically enters the western U.S. at around the U.S.-Canada border, as shown by the red line. Note that the storm track follows a sinusoidal path, as it is forced by the Rocky Mountains to ridge northward and trough southward once over the Eastern U.S. This typical storm track results in dry winters in the Southwest; this effect is enhanced during La Niña. Wet winters frequently result from an amplification of the ridging and troughing, which allows more moist tropical air to enter our region. This amplified pattern is frequently referred to as the Pacific/North American (PNA) pattern, or "meridional flow." El Niño can lead to this kind of enhancement of the PNA pattern, or it can lead to split flow, in which the dominant westerly winds split around high-pressure in the Eastern Pacific, and storms are steered south into our region.

Summer Atmospheric Controls. The dominant westerly flow that characterizes winter atmospheric circulation across the western U.S. moves northward during the summer in response to atmospheric heating in the Northern Hemisphere. Heating over the North American landmass draws warm moist air in from adjacent ocean regions to the southeast and southwest of the continent. A seasonal peak in rain accompanies this seasonal change in wind direction from July through early September in the Southwest. The overall circulation is called the North American Monsoon and it is part of a larger continental-scale circulation pattern over the Mexican highlands. The moisture sources are the Gulfs of California and Mexico, as well as the eastern Pacific Ocean. The effects of El Niño and La Niña on the monsoon are unclear, due to complex interactions between moisture characteristics over the land, and sea surface temperatures over the oceans. Sometimes, but not always, dry winters (La Niña) precede wetter summers. The monsoon varies within the summer season in the form of "bursts" and "breaks," that is, periods when storms are active or inactive for 1-3 weeks at a time; these bursts and breaks are connected with surges of moisture from the Gulf of California. Also in summertime, tropical hurricanes are a factor, especially during late summer/early fall. In general, they are relatively rare in the SW, though they can cause substantial rainfall events.



Occurrences ~80-Year-Period Variation In Southwest PDSI

Occurrence	Below Average	Above Average	Length (yrs)
antepenultimate	1770-1825	1825-1840	70
penultimate	1840-1905	1905-1925	85
ultimate	1925-1980	1980-present	>75

Figure 4. Reconstructed Southwest PDSI for the past millennium (top) and the past 300 years (bottom). PDSI is a drought index of moisture variability. The blue line indicates interannual variation; the red line indicates low-frequency variation; the green line indicates instrumental PDSI values. Years of unusually high or low reconstructed PDSI are noted in the bottom graph. Figure from Sheppard et al. 2001, "The climate of the Southwest," in review for the publication, *Climate Research*.

Climate Variability over Time & Space

Climate Change Over Time. The instrumental climate record extends back only about 100 years. Thus, we need to use paleoclimate records in order to extend our knowledge of climate variation back in time. Due to an abundance of long, well preserved, tree-ring records, we are able to extend Southwest climate records back in time 1000 years or more.

The Palmer Drought Severity Index (PDSI), a single variable derived from variation in precipitation and temperature, is well reconstructed from tree-ring records. The PDSI is a handy representation of SW precipitation and, to a lesser extent, temperature. Figure 4 shows variation in moisture as represented by reconstructed PDSI. It is most important to note that the Southwest has experienced frequent dry and wet periods, that vary widely in intensity and timing. The sustained drought of the 1950s was clearly among the worst in the last 1000 years. Significant wet periods occurred around 1726, 1793, 1839, 1868, and 1907. The greatest annual wet-dry switch was from 1747 to 1748. If we take a long-term view of SW moisture variability, we can see that the 20-year wet period of the early 1900s was exceeded only in the early 1600s, and the longest drought of the millennium was in the 1500s. The smooth red line in figure 3 shows low-frequency moisture variation, and exhibits a ~80 year pattern of variation characterized by alternating below to above average PDSI. This feature might possibly relate to fluctuations in solar output. The recent rise in temperature (figure not shown) is unprecedented in the last 400 years. Temperature records show a ~20-year pattern of variability, with significant warmth during the mid-1600s and 1930s, and cold periods commencing around 1907 and 1600. The greatest extremes in the temperature record are relatively recent, with extreme warmth in 1865, 1881, 1934, (equaled around 1651) and cool in 1725, 1835, 1866 and 1965.

Recent work from the CLIMAS project documents spatial variability in SW climate. We are in the process of gridding temperature, precipitation and PDSI at 1 km resolution, with an improved algorithm to capture variation due to elevation, slope and aspect.

References

Sheppard, P., A. Comrie, G. Packin, K. Angersbach, and M. Hughes, 2001. The Climate of the Southwest.

In review for *Climate Research*.

Related Resources

The Climate of the Southwest (P. R. Sheppard et al.)
http://www.ispe.arizona.edu/climas/reportseries/index.html

Climate and the 2000 Fire Season in the Southwest

Tom Swetnam (Laboratory of Tree-Ring Research, University of Arizona)
March 28, 2001 9:40 AM

Background on the Relationship Between Climate and Fire

Regional to continental-scale fire years are a natural feature of the western US. These exceptional fire years are usually associated with droughts that begin in or persist through the winter preceding the fire year. In some regions they are also related to wet conditions in prior seasons and years. Lags in fuels and climate conditions associated with exceptional fire years provide an opportunity for early warning. The 2000 fire season is a classic case in point.

The largest fire year in the United States in the 20th century was 1910, a year similar to 2000 in that large fires occurred in almost every western state. More than 5 million acres burned across the western US, of which more than 300,000 acres were located in the Southwest. Large fires typically account for more than 95% of all area burned through time. A key aspect of such regional fire years and large fire events is that they result in highly synchronized fire activity at regional to continental scales. The 2000 fire season occurred in the historical context of an increasing trend in acres burned over much of North America (Figure 1).

Using Tree-Rings to Record Fire History

Fires that do not kill a tree often leave a scar (catface), which is recorded in the tree's annual growth ring (Figure 2). By carefully examining the tree rings, we can determine the year and season in which the fire occurred. Tree-ring core and stump sections are obtained from 20 to 30 different trees per acre in each study site; the collection of multiple samples is necessary because no individual tree gives a complete history. Spatial scales of tree-ring analysis range from that of individual stands to the watershed level, entire mountain ranges, up to the broader regional scale. At this larger scale, broad patterns can be discerned through crossdating of tree rings. This allows identification of the year a fire occurred and the synchrony of fire across space. We have 300-500 years of fire history data in the Southwest, based on more than 100 sites and several thousand fire-scarred trees (Figure 3).

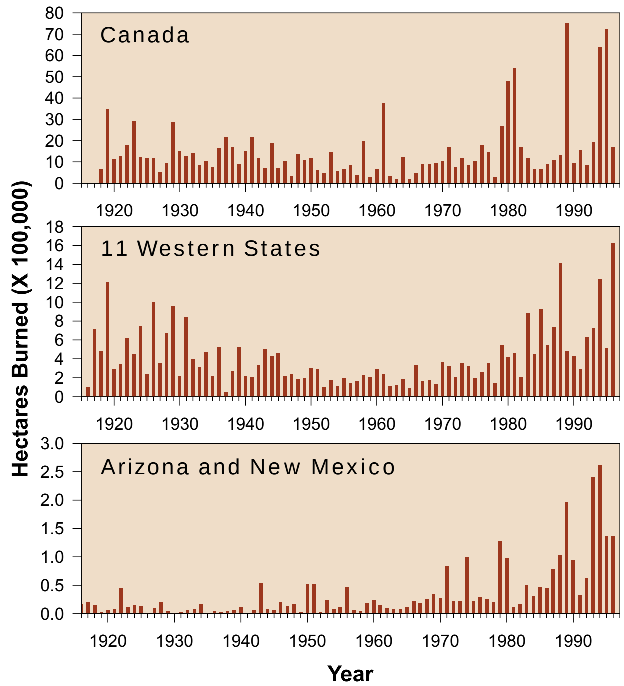


Figure 1. Area burned appears to increase in many areas of North America since the 1960s. Possible causes of these trends include fuel accumulations since effective fire control began, and climatic change (Source: Swetnam T. and J. Betancourt, 1998: Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate* 11:3128-3147.)

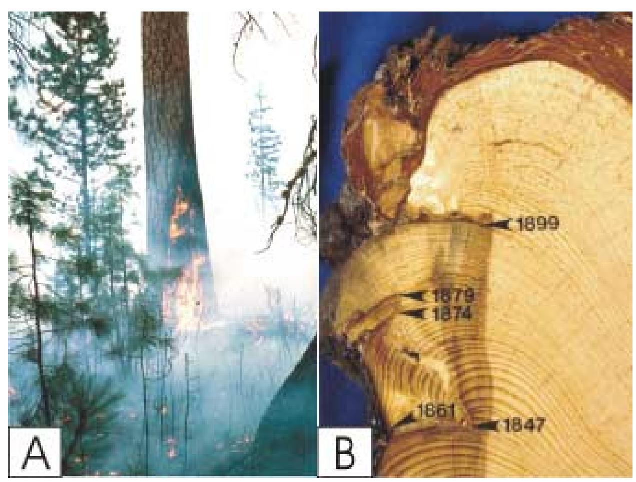


Figure 2. (A) Tree in the process of being fire scarred. (B) Dated fire-scarred tree-ring slab specimen. Photos courtesy of UA Laboratory of Tree-Ring Research.

To examine long-term relationships between climate and fire in the southwestern United States, regional values for tree-ring growth in drought-sensitive trees growing at sites unaffected by fire are compiled. These values can then be used to reconstruct gridded Palmer Drought Severity Index (PDSI) values. The fire history records are then compared with reconstructed PDSI (and other proxy records, including records of El Niño-Southern Oscillation [ENSO]). These comparisons highlight the effects of climate on fire occurrence.

Multi-Century Fire-Climate Relationships

Long-term trends in fire scar records show a drop-off in frequency and extent of fires due to grazing and fire suppression which began around 1900 (Figure 4). Annual area burned in the 20th century was probably one or two orders of magnitude lower than in the pre-20th century period, but a recent increase is evident after the 1960s (Figure 1). This increase may be associated primarily with a 20th century increase in fuels and forest density, but climate variability probably played a role as well.

In addition to decadal trends, historical fire climatology also illustrates the importance of interannual patterns. In the Southwest, for example, the year 1747 was very wet and had low fire activity, and 1748 was the most synchronous (extensive) fire year in the past 300 years (Figure 4). Historical reconstructions of ENSO indicate that 1747 was probably an El Niño Year and 1748 a La Niña year. Similar patterns of rapid switching of wet to dry conditions have been identified in assessments of the past three centuries of fire and climate in the Southwest and in the Colorado Front Range.

These combinations of wet and dry years are probably more important at lower elevations, where presence of fine fuels (grasses, needles, etc.) is a limiting factor for fire ignition and spread. In semi-arid landscapes these "fine fuels require 2 to 5 years, or longer to recover following a surface burn. Most conspicuously, the wet/dry pattern is often associated with ENSO, when dry La Niña years follow on the heels of wet El Niño years (Figure 5). Fortunately, our ability to forecast climatic conditions, especially with regard to ENSO, has greatly improved.

The Cerro Grande Fire

In the Bandelier National Monument and the Santa Fe National Forest area, the high elevations (~10,000 feet) are typically characterized by fir and spruce forests and montane grasslands. At lower elevations, ponderosa

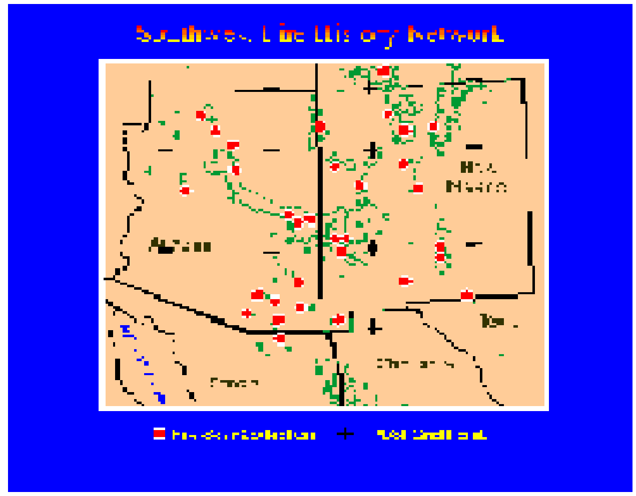


Figure 3. Southwest tree-ring fire history chronology sites. (Source: UA Laboratory of Tree-Ring Research.)

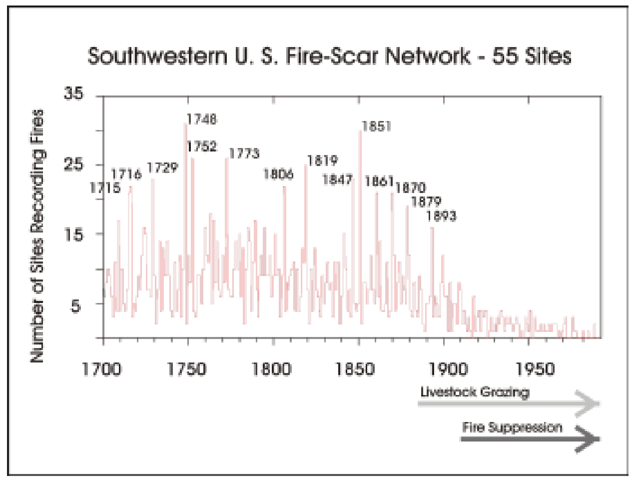


Figure 4. Synchrony of fires in the Southwest U.S. Note the decrease in number of sites recorded fires due to grazing and fire suppression activities beginning at the end of the 19th-century. 1748 is the most synchronous year in the record, a classic example of large-scale fire when exceedingly dry years follow wet years.

pine dominates. The Cerro Grande prescribed fire in May 2000 was set in the high elevation environment, where conifers had invaded former montane grasslands.

The fire prescription called for fairly dry conditions for this burn to succeed in consuming fuels and killing some trees, which was needed to restore the montane grassland.. Sufficiently dry conditions may occur at high elevations only during moderate to extremely dry years. Given these kinds of relatively dry conditions needed for prescribed burning at high elevations, extra preparedness and precautions are needed to avoid the possibility of fire reaching lower-elevations, where more extreme fire behavior can be expected. Prescribed burning in dry springs has always been hazardous in the Southwest, especially because high winds can occur without much warning (see Snook, this volume). There were undoubtedly some factors that led to the Cerro Grande Fire disaster which could not have been anticipated in advance. However, it is my opinion that greater awareness and incorporation of long-term and broad-scale fire history and climatological patterns could assist in avoiding future disasters of this kind.

Into The Future

In my view, we need to do more to plan for worst-case scenarios. The potential hazard of escaping fires associated with prescribed burning during drought years, e.g., extreme La Niña years following wet years, requires fire managers to exercise a higher level of caution during dry springs that follow dry winters. We also must recognize that, although long-range climate forecasts have a high degree of uncertainty, this does not mean that the "misses" during some years (e.g., 1999 was forecast to be a very bad season in the Southwest, but was only average) mean that future forecasts can be safely discounted. An analogy is hurricane forecasts. Forecasts of hurricane landfalls are frequently used to warn communities for possible evacuation, and often the hurricane veers off the forecasted pathway at the last minute. It would be foolhardy to use such error in past forecasting as justification to discount future forecasts.

Our planning and preparations for exceptional fire seasons do not yet fully incorporate our understanding of multi-year and multi-decade climate changes. If, for example, we are shifting into an extended period of warmer sea surface temperatures in the southeastern North Pacific, then there is a higher likelihood of extended drought in the Southwest. I recommend building a larger fire fighting resource base, one that might seem excessive in average fire years, but which would be available during the big fire years. Such a strategy would probably turn out to be more cost-effective than the current process of raising and allocating extra resources on short turnaround during high fire years. In addition, better climate information, such as the climatology of wind, would help put potential fire hazard in a better context.

Finally, I suggest that we all exercise some humility in thinking about fire. There is much that we do not know, especially with regard to the climatic and meteorological mechanisms and processes that drive large fire events and regional fire years.

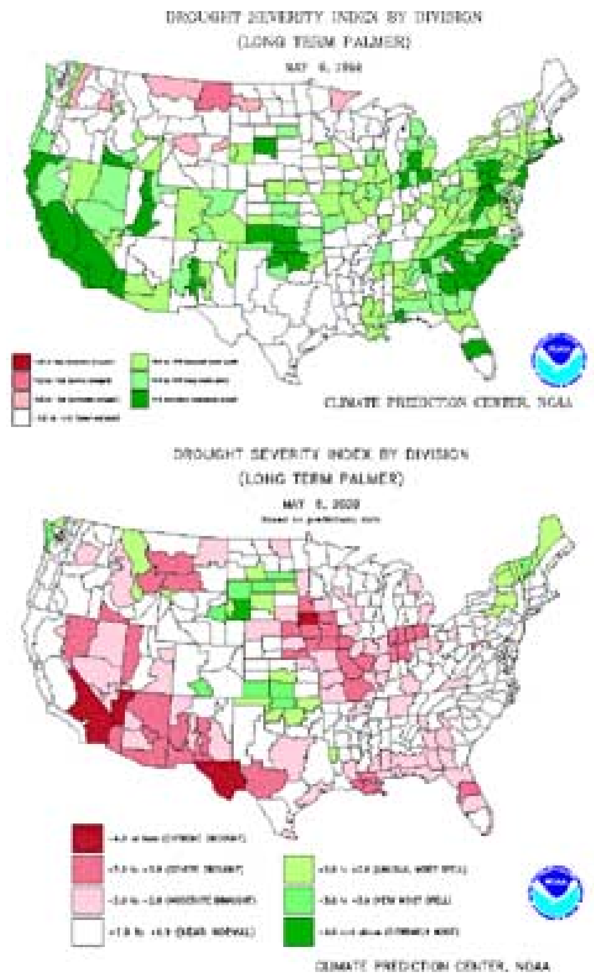


Figure 5. Wet conditions in the Southwest during the 1997-1998 El Niño increased fine fuel loads and understory growth. Dry conditions were brought on by the late 1998-2001 La Niña. The combination of wet and dry years created conditions right for large-scale fire. (Source: NOAA Climate Prediction Center).

Related Resources

Tom Swetnam's Dendroecology Reprints (PDF format)
http://tree.ltrr.arizona.edu/~tswetnam/pdf.htm

CLIMAS Fire History Analysis Using Tree Rings
http://www.ispe.arizona.edu/climas/fire/overview/history.html

Fire and Emergency Management in Arizona

Alex McCord (Arizona Department of Emergency Management)
March 28, 2001 10:10 AM

The purpose of this very brief talk is to give some background about the Arizona Division of Emergency Management's fire management activities. Arizona Division of Emergency Management (ADEM) coordinates emergency services and the efforts of governmental agencies to reduce the impact of disasters on persons and property. We do this through (a) mitigation activities, which may lessen the damages and losses caused by various hazards; (b) preparedness activities, such as planning and training, which enable the state and local governments to better respond to emergency events; (c) response activities during actual emergencies, such as the issuing of warnings, mobilization of response personnel, coordination of resources; and (d) recovery activities after an emergency or disaster which assist local governments and individuals to restore public facilities, homes, and businesses. The objective of all of our programs, upon the occurrence of a fire emergency in Arizona, is to minimize injury and loss of life, reduce personal property damage and economic loss, and to restore essential community and public services.

ADEM's major wildfire concerns are at the urban-wildland interface. We would like to take action to mitigate against any "Los Alamos types of situations." The public perceives a basic conflict/contradiction with regard to using fire for forest restoration. Thus, there is resistance to prescribed fires. We need a better way to deal with these kinds of issues at the urban-wildland interface. In particular, we would like to initiate a community education program, stressing things like the need to clear around residences, the hazard of shingle roofs, etc. However, we lack the funding for this. Along these lines, a few years ago we began a disaster-proofing and education initiative called *Project Impact*, oriented around Tempe and Yuma as pilot communities. We held a workshop in order to bring the Project Impact communities together to discuss their successes, challenges and projects. We still await funding to continue this project and urban-wildland corridor work in Yavapai County.

One ray of hope for fire emergency management in Arizona is FEMA, which has tightened rules for funding reconstruction after hazardous events. FEMA has implemented a rule that they will only pay out once to those without insurance coverage. This will certainly have an influence on urban-wildland interface impacts. Another important concern for ADEM is preparedness for evacuations. Last year's large and intense fires made people in Yavapai County very nervous. This is especially worrisome for situations, such as church camps, where large numbers of people are dropped off at remote cabins and left without any transportation for a week or more. For example, there can be 5,000 to 10,000 people in remote areas of the Bradshaw Mountains of central Arizona at any given time during the fire season, with no transportation out in an emergency. ADEM would like better climate and fire-related products that can assist in persuading the Arizona legislature to fund mitigation activities in areas such as this.

Related Resources
Arizona Division of Emergency Management
http://www.dem.state.az.us/

A Brief Introduction to Climate Forecast Resources for Fire Management

Ron Melcher (Arizona State Land Department)
March 28, 2001 10:20 AM

In this talk, I would like to introduce you to some climate and fire forecast products (available on the World Wide Web) used by Arizona State Lands, and to discuss some issues about the correct interpretation of these products.

Probably the best of the lot are short-term (1 to 3 days) fire weather forecasts. Similarly, short-term weather forecasts from NOAA and local National Weather Service offices are excellent for short-term fire management. NOAA also provides a series of longer-term outlooks (available at http://www.cpc.noaa.gov/products/forecasts/), which have a variety of virtues and a variety of problems. Their 6-to-10 day and 8-to - 14 day outlooks seem less dependable than most of their other products. These outlooks are just plain hard to understand and interpret (Figure 1).

NOAA's Climate Prediction Center (CPC) also puts out monthly and seasonal climate forecasts (http://www.cpc.noaa.gov/products/predictions/30day/). These forecasts come in a couple of different formats

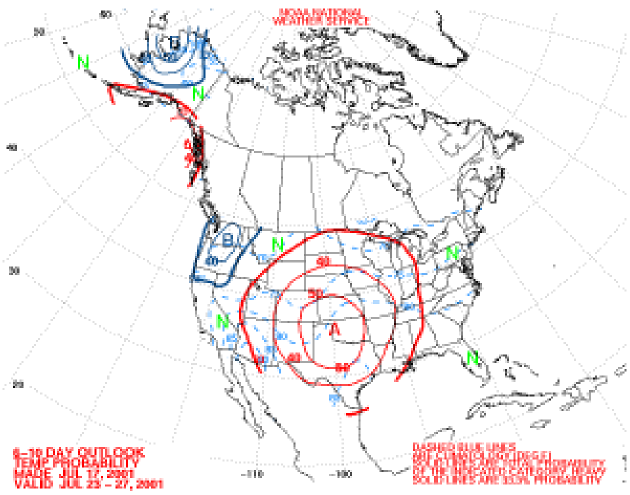


Figure 1. NOAA Climate Prediction Center 6-10 day outlook. Note how complicated this figure is and how difficult to interpret.

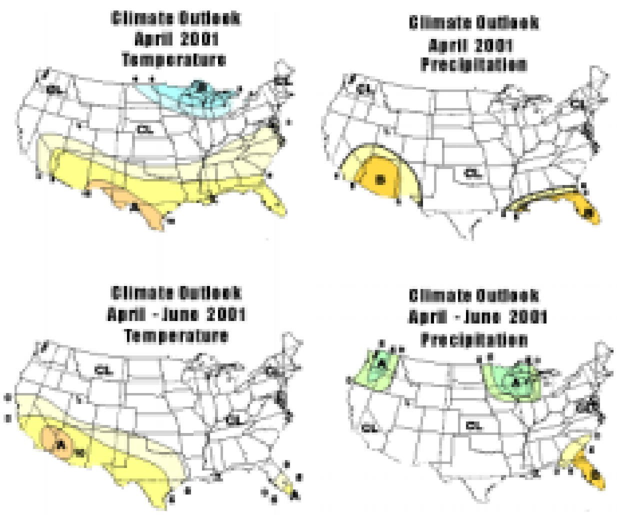


Figure 2. NOAA monthly/seasonal climate outlook (color version). Note that areas marked "CL" lack of a forecast.

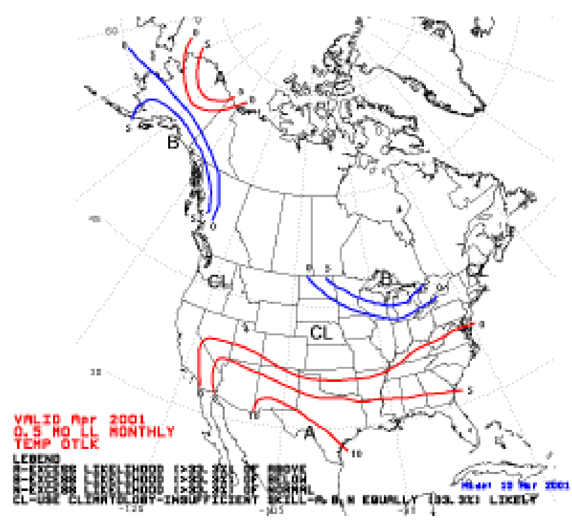


Figure 3. NOAA monthly climate outlook for April, 2001. Compare this format with the one in Figure 2.

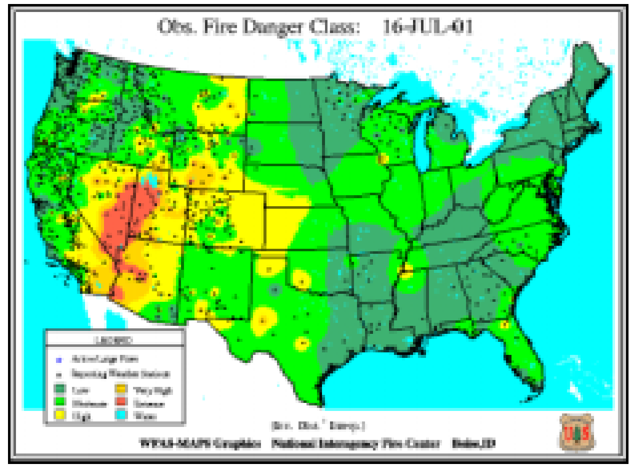


Figure 4. Wildland Fire Assessment System daily fire danger map.

(Figure 2 and Figure 3). The key point with these maps is: How do you interpret them? I find the color maps very misleading. These are not maps of forecasted temperature and precipitation, they are maps of the change in probability from normal conditions. How do you interpret the statewide areas with "CL" in them? If you look carefully at Figure 3, which I find to be much easier to interpret, you can see that CL means *insufficient skill*...in other words they aren't even making a prediction for huge portions of the country. When using the color maps, it is really important to check against the legend, which isn't even available on the same page, otherwise it's all too easy to make the mistake of saying that this area is going to have above-average precipitation and this area is going to have normal precipitation.

Other products that are useful for monitoring conditions associated with fire are maps from the Wildland Fire Assessment System (WFAS; http://www.fs.fed.us/land/wfas/welcome.htm) in Missoula. WFAS has maps that show greenness, fuel moisture, fire potential index, and fire danger (Figure 4). They also have handy four-panel displays with forecast climate parameters (Figure 5) and measures of greenness and fuel moisture (http://www.fs.fed.us/land/wfas/4pannd.gif).

NESDIS (National Environmental Satellite, Data, and Information Service) also has greenness-type maps of fire risk and vegetative health. Their vegetative health map is very useful, because it compares a day in the current year with the same day the year before (http://orbit-net.nesdis.noaa.gov/crad/sat/surf/vci/usafr.html). I find this kind of comparison very useful. It can also act as a way to gauge current conditions against conditions with which I am familiar.

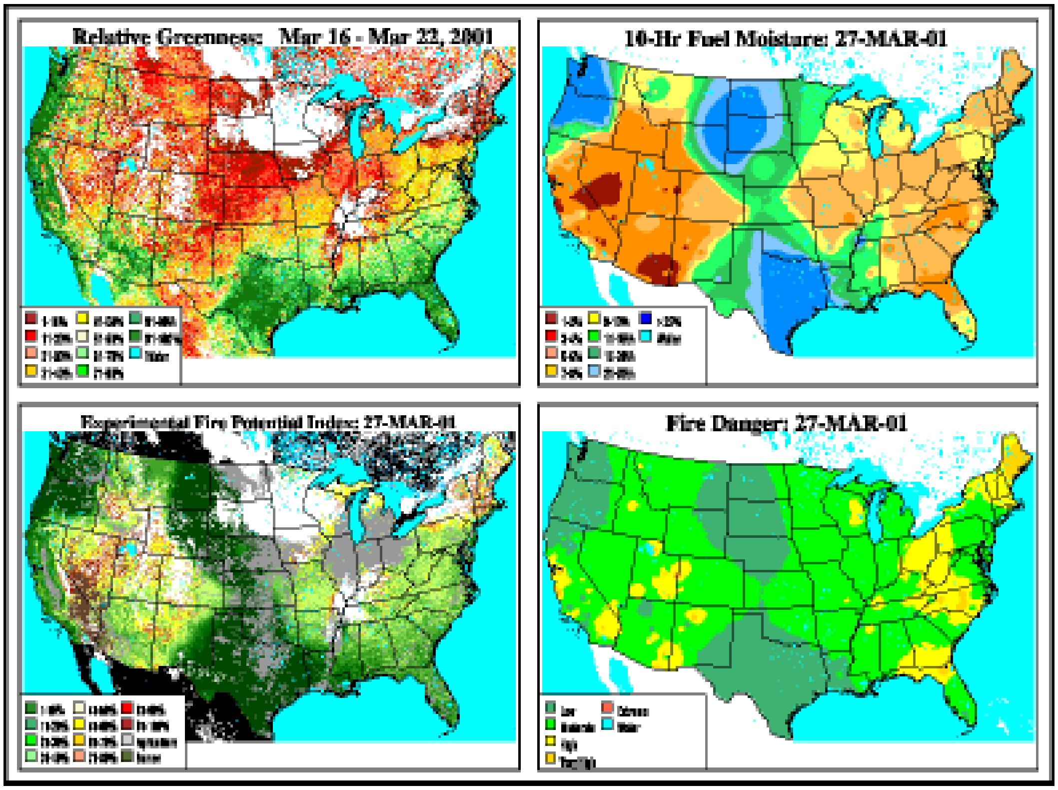


Figure 5. Wildland Fire Assessment System daily fire weather observations and next day forecasts.

Fire History in the Jemez Mountains: The Bandelier Perspective

L. Dean Clark (U.S. National Park Service, Bandelier National Monument)
March 28, 2001 1:10 PM

Background

The Los Alamos area gets 9,300 to 24,000 lightning strikes per year; at Los Alamos, there about 62 thunderstorm days a year. May and June lightning strikes are important for fire incidence.

From 1800 to 1900, data indicate a close correspondence between climate and fire. Since 1900, the correspondence has decreased significantly (see, e.g., data collected along Los Alamos Pipeline Road). Frequent fires ceased when intensive livestock grazing (notably sheep) began, around 1900. Since that time, there have been conditions favorable for tree growth and forest expansion, including fire suppression policy. We know that grasslands are sustained through frequent surface fires. However, with suppression, the ecological dynamics have changed to favor trees over grass. A climate shift, which brought on extended drought during the 1950s, resulted in the movement of ponderosa pines a quarter of a mile up the mountain and the death of ponderosa pine stands at lower elevations.

Prescribed Burns and the 2000 Cerro Grande Fire

In order to put the Cerro Grande burn in context, we need to remember that two large wildfires occurred previously in or near Bandelier: the 1977 La Mesa fire and the 1996 Dome fire. The La Mesa fire was ignited by lightning, whereas the Dome fire was human-caused. The Dome fire was a big fire that got the attention of federal entities and Los Alamos. After the Dome fire, fire breaks were established at Bandelier. Thus, there was a well established need for an active prescribed fire program at Bandelier.

Perhaps it is most important to emphasize that the prescribed burn program had been successful for 20 years prior to the Cerro Grande fire. Photographic evidence indicates that there was a change in vegetation in this area from grassland to ponderosa pine after the 1950s drought. The trees had taken over about three-quarters of the high elevation grassland. In the early 1990s, forest managers at Bandelier tried to clear the area through light burns, but these did not succeed in changing the forest structure. All they got were light, patchy, scabby burns. Thus objectives were not achieved. Moreover, the timing of prescribed burns at Bandelier is an issue, because burns cannot necessarily be scheduled to correspond to times of the year when fire would be most beneficial to ecosystem dynamics. Natural fires occur during the spring growth period. The situation around the May 2000 fire is that a high-intensity burn was required to achieve the objective of restoring the high elevation grassland. However, lower-elevation areas, with vegetation such as aspen and brush, where no fuel load modification had previously been done, and which are prone to high-intensity burns, were not included in the burn prescription. Wind, a large factor in any burn situation, pushed the initial fire beyond the boundary of the prescription.

I expect the final report on the Cerro Grande fire to be released very soon. I believe that the strength of the data will get us over the political furor over the fire, and allow us to re-establish a successful and necessary prescribed burn program.

Related Resources
Landscape and Fire Ecology Studies at Bandelier National Monument and the Jemez Mountains
http://www.mesc.usgs.gov/projects/landscape-fire-ecology.html

Landscape Changes in the Southwestern United States: Techniques, Long-term Data Sets, and Trends
http://biology.usgs.gov/luhna/chap9.html

Climate Forecasts Overview for the Southwest

Thomas Pagano and Holly Hartmann (Department of Hydrology and Water Resources, University of Arizona)
March 28, 2001 1:40 PM

Introduction
In this talk, I will introduce official climate forecasts made by the U.S. government, I will talk about how to interpret these forecasts, what their performance has been to date, the current forecasts and their implications for this fire season. It is important to distinguish between weather and climate. *Weather forecasts* are made for periods of 0-3 days; *long-range weather forecasts* are made for periods of 4-12 days; and *seasonal climate outlooks* are made for periods of one season to one year. Of course, forecasting is quite an uncertain business, or as Victor Borge said, " Forecasting is difficult, especially about the future."

Figure 1. The location of the town of Willcox in southeastern Arizona.

What Are Climate Forecasts and Who Makes Them
Official climate forecasts are called *long-lead climate outlooks* and they are made by the NOAA Climate Prediction Center (CPC; http://www.cpc.ncep.noaa.gov). These products are made by a team of 20 or more forecasters, blending six classes of tools with human expertise. All other climate forecasts are either experimental or unofficial. The tools used by climate forecasters include physical models, trends (such as long-term warming), statistical models (including pattern recognition and information based on the state of El Niño-Southern Oscillation [ENSO]), and human expertise (including knowledge of the strengths and weaknesses of various models, and common sense).

An Example of a Simple Statistical Forecast
In this example we take winter (December-February) precipitation at Willcox, Arizona and make forecasts based on the state of ENSO. First, we classify the observations by taking all winter precipitation observations from Willcox (Figure 1) for the period 1898-1989, and dividing them into upper, middle, and lower thirds (y-axis in Figure 2), and then dividing them again into three ENSO modes, La Niña, non-Niño and El Niño based on an El Niño sea surface temperature (SST) index (x-axis in Figure 2). Next we count the number of observations in each category. Then we convert the tallied observations to percentages. Now we can begin to make forecasts based on our record. We can say, for example, if it is a La Niña year, then there is a 10% chance of wet conditions, 30% chance of normal conditions and a 60% chance of dry conditions in Willcox, AZ. Note that there is never a 100% chance of any of these three precipitation conditions; however, there is a very poor chance of wet conditions during La Niña and, conversely, a very poor chance dry conditions during El Niño. We can do the same sort of exercise for summer monsoon

precipitation. Summer precipitation, however, shows far more variability during the different phases of ENSO. Therefore, there is far less predictability, and only a 5% increased chance of wet conditions during La Niña and a 5% increased chance of dry conditions during El Niño.

Understanding CPC Forecasts

In order to understand CPC forecasts, it is important to know what CPC considers *normal*. CPC uses as its baseline the most recent 30 years of record. At the time of this conference the CPC baseline is 1961-1990; later this year the baseline will change to 1971-2000. They then select the 10 wettest years, which are considered *wet*, the 10 middle years, which are considered *normal*, and the 10 driest years, which are considered *dry*. CPC then expresses their climate outlooks maps in terms of the increase in the probability of being in the wet or dry category. Thus, in the map in Figure 3 there is a 5% increased chance of wet conditions in Seattle and a 10% increased chance of dry conditions in Miami. Put another way, the probability of precipitation for Seattle is

- 38% chance of wet
- 33% chance of normal
- 28% chance of dry

and the probability of precipitation for Miami is

- 23% chance of wet
- 33% chance of normal
- 43% chance of dry

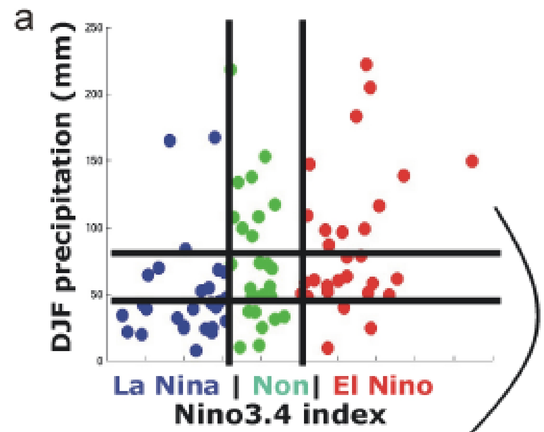
In Figure 3 the CL over Boise, Idaho indicates that forecasters are completely uncertain about what is going to happen. Thus, the probability of precipitation for Boise is

- 33% chance of wet
- 33% chance of normal
- 33% chance dry

Note that private sector companies often based their forecasts on the CPC forecasts, but they substitute *normal* for *CL*. This is a very bad misinterpretation of the actual forecast. In fact, it would probably be better if the CPC used a designation such as "no skill," "no forecast," or "don't know," rather than CL.

CPC Forecast Performance

Forecast performance is multifaceted, and some users require information about *false alarms* (i.e., predictions that never came to bear), whereas other users require information about *surprises* (i.e., situations that came to bear, but were never forecast). One measure for



b

	La Nina	Non	El Nino
Wet	3	12	14
Normal	8	8	12
Dry	16	7	3
Total	27	27	29

c

	La Nina	Non	El Nino
Wet	10%	44%	50%
Normal	30%	30%	40%
Dry	60%	26%	10%

Figure 2. A simple statistical forecast based on past precipitation at Willcox, Arizona. (a) Willcox winter precipitation divided into terciles (y-axis; *wet, normal, dry*) and ENSO phase (x-axis). (b) Tally of the number of times Willcox winter precipitation falls into each tercile. (c) Percent chance of winter precipitation falling into each tercile, based on ENSO phase. Note the increased likelihood of dry conditions during La Niña.

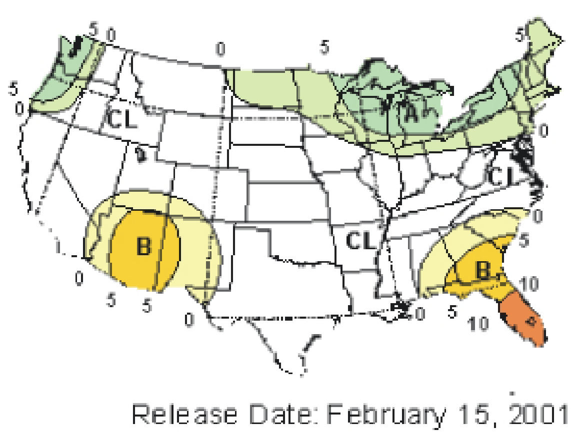


Figure 3. Official NOAA Climate Prediction Center climate outlook for March-May, 2001 precipitation.

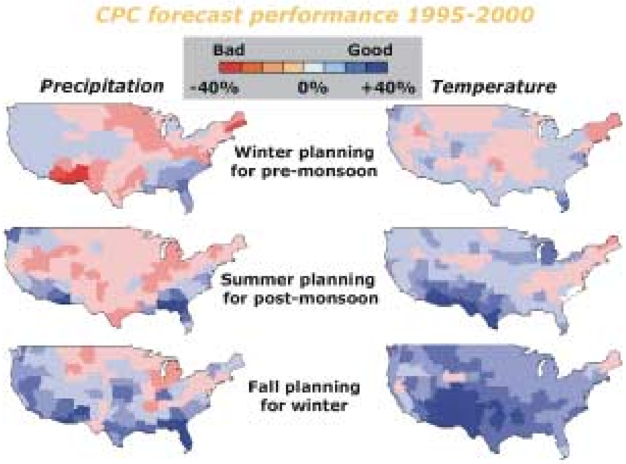


Figure 4. CPC forecast performance 1995-2000, based on the ranked probability score. *Winter planning…* refers to pre-monsoon season forecasts made during winter months; *summer planning…* refers to post-monsoon season forecasts made during summer months, and so on.

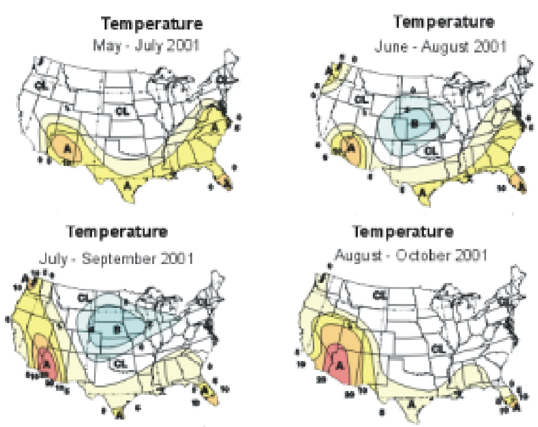


Figure 5. NOAA CPC climate outlooks for summer 2001 to (released March 15, 2001) call for increased chances of above-average temperatures for the SW.

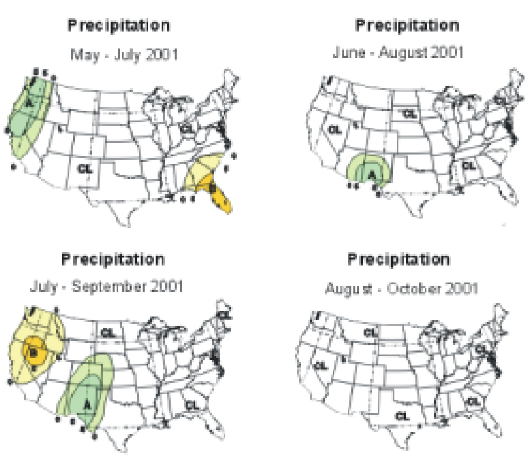


Figure 6. NOAA CPC climate outlooks for summer 2001 precipitation (released March 15) call for slightly increased chances of above-average precipitation for the SW.

evaluating probabilistic forecasts is the ranked probability score, which rewards strong probability statements that fall into the correct category and penalizes probability statements that are far off the mark. Work by Holly Hartmann, evaluating all CPC seasonal forecasts for a particular season (Figure 4), shows that CPC's forecasts for pre-monsoon precipitation have had negative skill, whereas forecasts made during the summer and fall for fall and winter precipitation, respectively, have pretty good skill, especially for Arizona. CPC temperature outlooks for fall and winter for the Southwest have very high skill.

The Current Forecast

At present, we have a La Niña that is nearly dead, i.e., very weak negative SST anomalies in the equatorial Pacific. There is a weak tendency toward wet summers in the Southwest during La Niña. For April, the climate outlook for the Southwest U.S. indicates the following precipitation probabilities: 27% wet, 33% normal, 40% dry. As for temperatures, there has been a long-term warming trend in the Southwest. For example, the 1990s were very warm compared to the 1961-1990 average, so the most recent climate outlook, which incorporates this trend as a major predictor, indicates an increased chance of above-average temperatures for the Southwest (38-43% chance of warm). Long-term seasonal temperature outlooks also indicate increased chances of above-average temperatures for the Southwest, with the highest probabilities centered over western Arizona (Figure 5).

Spring/summer seasonal climate outlooks for precipitation (Figure 6) show a marginally lower chance of a dry monsoon (27%), chances of a "normal" monsoon are unchanged (33%), and a slightly higher chance of a wet monsoon (40%). Increased probability of above-average monsoon precipitation is only for the June-August and July-September long-range outlooks. There is much uncertainty in these outlooks, as we are in a transition in the phase of ENSO.

When no forecast is available, as in the May-July 2001 precipitation outlook (Figure 6), it is best to study climate history. Learn the range of variability for the region, look at climate changes for past years, and study the recent past in order to best discern fuel conditions and possible effects of long-term climate conditions on fuels.

Related Resources

NOAA/NWS/CPC Suite of Official Forecasts
http://www.cpc.ncep.noaa.gov/products/predictions/

Breakout Groups

Breakout Group Recommendations

The participants in each workshop were invited to participate in large and small group discussions with the goal of identifying key issues and making recommendations for future research, and information transfer, collaboration, and policy. February workshop participants engaged in several discussions, including an open floor discussion entitled *Lessons from the 2000 fire season: What can we do better in 2001?* and breakout group discussions on the topic *The use of climate information by fire managers*. During the course of open floor discussions in the February meeting, participants identified the following key topics for small group discussion:

- databases and observation networks
- information transfer and decision analysis tools
- training

March workshop discussions were more open-ended, however, the topics identified by February meeting participants were used as guidelines for discussion. Given that the geographic focus of the February meeting was national, whereas the geographic focus of the March meeting was the Southwest, the breakout group reports have been summarized separately, below.

Climate and Fire 2001 (February)

Databases and observation networks

Breakout group remarks regarding databases and observation networks tended to fall into three categories, as follows: observation networks, parameters of interest (including issues of spatial and temporal scale), and remarks synthesizing a number of concerns.

Observation Networks. With regard to observation networks, the overall sentiment was that we do not and could never have too much data. Participants suggested selective increases in the number of observation stations. There was concern regarding the aging and maintenance of stations and a well-organized replacement program was recommended. One of the key points during the workshop was that fire danger in the western U.S. is often dependent on winter precipitation; thus, participants recommended an increase in the number of all-weather observation stations.

Parameters and Research. Participants identified a variety of meteorological and ecosystem variables that would aid effective fire management. All breakout groups identified wind as a key variable for further analysis. Fire managers expressed interest in greater and easier access to wind data and summaries of wind data. Participants emphasized to that more wind observations are necessary for good fire management and for fire-climate studies. Participants recommended that extreme and locally intense winds, such as Santa Ana winds and Chinooks, be the subjects of further study. The study of the relationship between these extreme winds and large-scale synoptic climate patterns was recommended. Participants suggested that variables such as precipitation, relative humidity, stability and wind were more important for fire management than was temperature. Participants suggested further research into climate indicators of fire, such as fire/drought indices (e.g., PDSI, Keetch-Byram), and recommended research into the relationships between standard climate variables, atmospheric circulation and fire/drought indices. Similarly, participants suggested research into the relationships between climate variables and National Fire Danger Rating System data, in order to provide links between weather, climate, and fire. It was recommended that such analyses incorporate nested spatial resolution at timescales ranging from days to seasons, and that results be presented as continuous time series, as well as seasonal averages. The addition of climatology to *Fire Family* was suggested. Participants also highlighted the need for better access to non-climatic data, such as fire starts, historical fire data, and escaped/prescribed burn data. They recommended that these data be synthesized for fire-climate research.

Overall Remarks. A key focus of the participants' remarks was that fire management and the relationship between fire and climate is mitigated by other important land/ecosystem management concerns, such as restoration, range management, wildlife management, resource management and resource availability. Participants acknowledged the complexity of the interrelationships between all of these factors and suggested that database and observation network needs be put in a long-term context: *What will our needs be 5, 10, 15 years from now?* Finally, participants suggested that there were far too many individual databases, spread among many agencies; they stressed that easy access to data was essential and they recommended interagency sharing and coordination of databases.

Information Transfer and Decision Analysis Tools

The discussion of information transfer and decision support tools focused on issues of access to information, usability of information and products (*tools*), research needs, and remarks regarding practical operational concerns.

Information Access. Key issues regarding information access, continued the thread of remarks about database needs. Participants pointed out the need for better access to databases, including access to information at global, national, regional and local scales and the occasional context-sensitive need for access to information outside the fire manager's particular region. As information to support resource allocation in both the short-and long-term was a prime concern of workshop participants, access to both forecasts and historical and information was recommended. Participants recommended access to information on a variety of timescales ranging from short-term (2-3 months), to annual, to long-term (3-10 years), to "really long-term" (pentad-decade-century). Participants pointed out that information needs vary, depending upon the timescale of decision-making. For example, short-term timescale data fulfilled needs for operational use, crew training, and water management. Regionally specific seasonal forecasts were identified as a much needed product. At annual and longer timescales, more qualitative information is needed for prescribed fire planning, landscape preparation and NEPA (National Environmental Policy Act) process. Participants suggested that variables such as precipitation, temperature, and index data were required at the annual timescale at spatial resolutions from national-to-landscape (30 m).

Usability. In order to make the aforementioned data and information, as well as any decision support tools, most useful to fire managers participants recommended *one-stop shopping*, as much as is possible. Participants emphasized that information needs varied by issue, by job, and by time; therefore, they recommended that information be available at a variety of scales and levels of analytical complexity. They stressed that products need to have *telescoping* or *layering* features, in order to give users the ability to move up and down temporal and spatial scales with ease, and to give users the ability to specify levels of complexity. In addition, participants pointed out that graphical and map presentation is far more useful than data tables and lists. Participants recommended that decision support tools and information transfer products that allow for interaction and dynamic decision-making. Participants emphasized the need to provide historical information in order to support resource allocation, restoration timing, and *healthy ecosystems* long-term planning. Historical information was also identified as an important means of justifying funding for land/ecosystem management objectives in *out years*. With regard to the latter, participants identified geographic relationships based on the response to ENSO (e.g., regional bipole relationships), and long-term trends and oscillations (e.g., the Pacific Decadal Oscillation) as phenomena of interest for further research.

Finally, participants in the breakout groups underscored the need to publicize to the fire management community that present-day climate forecasting is approximately as well-developed as weather forecasting was in the 1960s. Participants agreed that there is cause for optimism with regard to the future of long-term climate and associated fire forecasting.

Training

Training and knowledge transfer were identified as important goals by the workshop participants. Their remarks focused on what training should consist of and how to best achieve this kind of knowledge transfer. All breakout groups recommended more training on climatology and on issues of the relationship between fire and climate.

Training Needs. Workshop participants recommended the development of a primer on climate-fire relationships, written by instructional and design experts (in consultation with climatologists and meteorologists). They emphasized the need for crisp graphics ("a picture is worth a thousand words"), and the use of video and satellite imagery and technology. They suggested that the primer and other climate tutorial information should be easy to interpret, available on video and the Internet, and that it also be presented in a range of training courses such as the S190-S590 training series. In order to improve access to this information, participants recommended good visualization, user-friendliness and the ability to keep track of and update information available at all related Internet sites. Two approaches suggested for transfer of climate information to fire managers were (1) hire a group of meteorology/climatology specialists to serve as *translators* of climate/weather information to fire managers, and (2) train climate and fire to researchers to simplify the way they express information and train managers to *complexify* their way of thinking about climate issues in fire management. The philosophical framework for climate information training for fire managers was a model of life-long learning accompanied by a process of continual updating of information to reflect the state-of-the-art. Another key aspect of the training model was the need for a *two-way street*, i.e. training of fire managers in the use of climate information, as well as the training of climatologists in the operations of fire managers on both short-and long-planning horizons. Participants expressed concern that training is usually the first thing to be cut from their budgets.

Who To Train? In addition to requesting more training, workshop participants recommended the following people as the recipients of climate training for fire management and information about the complex relationships between climate, fire and land/ecosystem management:

- on-the-ground managers
- regional managers
- national policy and budget managers
- Congress

Participants identified new hires, fire behavior analysts and incident meteorologists as key recipients of this training. They recommended intensive work with personnel at the Geographic Area Coordination Centers (GACCs) and National Interagency Coordination Center.

Finally, participants recommended a nested design for decision support tools and climate information, such that all spatial and temporal scales are represented. They highlighted the need for tools and information with emphases on operational contexts (e.g., district scale) and planning contexts (e.g., regional-scale for proactive/strategic planning).

Climate and Fire 2001 in the Southwest (March)

Data and Information Transfer Needs

Workshop participants agreed that accurate climate forecasts, especially for the period six months-one year in advance, are needed. They highlighted the fact that if accurate information is available by January, then sufficient time is available for additional severity funding to be requested. Participants identified easy access to historical analog data as a critical need for decision-making. Many participants noted that fire management protocol required management decisions to be made based on data from the previous 20 years. They suggested, however, that data from an *analogous* 20 years would be more appropriate for their decision-making needs. Breakout group participants suggested that one way to present historical data would be to show them as a time series of recent conditions coordinated with a time series ensemble of past analogous years. Thus, managers could trace recent conditions and then see a range of possible future conditions. Expanding on this idea, participants suggested that review of past climatic conditions would enable the identification of *trigger points* during the fire season that would serve as prompts for fire managers to make key decisions. They suggested further research to connect climate and fire danger indices with forecasts. Historical and recent data of interest to workshop participants included the following parameters: temperature, precipitation, relative humidity, buildup index, energy release component (ERC), FSI, as well as drought indices, vegetation health and wind speed and wind direction. They stressed that the language by which data and results are communicated needs to be understandable to users and communicated consistently; they pointed out that this is particularly important for communication of risk factors and indices. Moreover, they pointed out the need for more data on smoke, in particular interaction of smoke with terrain and smoke transport by wind.

Participants at the March workshop also highlighted the need for access to data on social factors. They suggested that intra-agency and interagency issues need to be factored in, as well as political considerations, such as issues regarding elected officials at local, judicial and executive levels.

Research

Participants recommended a variety of research programs, including physical science and sociocultural research with regard to fire management. The breakout groups recommended an overall framework for research, as follows:

- take advantage of the fact that at the moment the Western Governors' Association is extremely interested in the issue of fire
- build a consortium of university researchers throughout the West, with the goal of collaboration between institutions (in contrast to the usual competitive grant funding process)
- focus each institution's research on their particular strengths
- address the highest priorities in fire management and fire-climate research within the geographic region (e.g., improvements in forecasting six months-one year in advance, in order to improve resource allocation decision-making)

Participants recommended research to identify *trigger points* where climate conditions push fire danger above or below a certain threshold. With regard to trigger points participants suggested that it would be useful to compare climate and fire forecasts with burn histories. Participants recommended research that investigates the relationship between indices and forecasted values such as burn index and ERC. In addition, they recommended research on the impact of climate on factors such as plant and fuel flammability, curing, drying, etc. Participants also recommended research on smoke transport, sinks and dispersion that takes into account interactions between terrain and climate conditions.

Social science research recommendations included analyses of regional and community sociocultural differences, in order to better understand perceptions with regard to tolerance of smoke, political power relations (in terms of preparedness and receptivity to forest health and restoration programs), and analyses of human-caused risk factors.

With regard to deterministic models, participants recommended stochastic modeling and that the level of confidence in model output be made explicit.

Operations, Management and Decision Making

Arizona and New Mexico fire managers emphasized the need for sustainable multi-year budgets. They noted that the Western Governors' Association has a 10-year planning horizon, and they pointed out the 20-year retrospective period to suggested by the National Fire Management Analysis System. Nevertheless, they noted, budgets are only allocated one year at a time; consequently, unused funds cannot be accrued in order to achieve longer-term objectives mandated by multi-year planning horizons. As a corollary to this, participants pointed out that the larger and more complex an area is, the more lead time required to carry out programs and change existing procedures and rules. Participants recommended that climate information needs to be better incorporated into decision-making, and that it should be mandatory in prescribed burning plans, contingency plans and preparedness plans. They recommended the use of the NOAA Drought Monitor, as well as current and historical Palmer Drought Severity Index data (preferably downscaled to 1 km^2 resolution). The fire managers agreed that they were able to observe ecosystem/vegetation changes on the order of around two years if there were persistent climate conditions, such as drought. They suggested that this has important implications for trying to do restoration work, because if fuels increase during a favorable climate years, then there are significant changes at ecotones; if the favorable years are followed by dry years, then when fuels die at low elevation, high elevation snowpack is no longer a significant factor for fire management, as the low elevation areas are still exceedingly prone to fire (cf., Cerro Grande).

Training and Education

Workshop participants heartily endorsed further training in the use of climate information for fire management. They recommended training classes such as the S490 training class. They highlighted the need to know how to incorporate new and more climate/weather information into decision-making processes. Participants also recommended that local and regional National Weather Service meteorologists be encouraged to attend fire-climate workshops, in order to facilitate the integration of short-term weather and long-term climate information in fire management and fire weather forecasting. They recommended that meteorologists be trained to serve as climate specialists for fire weather decision-making.

Of equal, and perhaps greater, importance, workshop participants recommended education and training for the public. A prime concern was that the public needed better education with regard to existing forest conditions, and the relationship between climate, forest management, and fire. They stressed that a better educated public would provide increased support for political maneuvering to secure adequate funding for forest management efforts. Participants noted that the public needs to understand that *just because we have a single year of adequate precipitation does not mean that forest health has been restored, nor does it mean that drought conditions have ended*. A well-informed public, participants pointed out, is particularly important for management at the urban-wildland interface. Participants also emphasized that agency officials and Congresspeople in Washington D.C. need to hear about the synergy between long-term climate conditions and the ability of the fire and ecosystem managers to achieve land management objectives. They noted that they are under a lot of pressure to get out the burn and that the expectations of agency officials and Congresspeople in Washington D.C. are unrealistic. In order to remedy this situation, they recommended that congressional aides be invited to attend future fire-climate meetings.

Fire Management in Mexico

A situation unique to the March workshop was the attendance of Everardo Sanchez Camero, a Mexican fire management official, at the workshop. Sr. Sanchez Camero provided the following insights into fire management and the need for climate information for Mexican fire management. He noted that currently Mexico contracts to agencies and Canada for climate data. He recommended that 30-, 60-, and 90-day climate forecasts would be extremely useful to Mexican fire managers. He pointed out a change in Mexican fire management practice toward fire suppression, in contrast with past policy, which allowed fires to burn. He suggested that technical training is necessary for managers and firefighters working on the ground. He also suggested that, similar to Southwest fire managers' experience with U.S. agency and political officials, state and federal level Mexican fire managers and politicians needed to be informed about climate-fire relationships, as well as the need for greater levels of funding for training, prevention, suppression and research. In addition, Sr. Sanchez Camero suggested that people in different levels of management to have different perceptions of forest management problems; government officials, he noted, tend not to realize the importance of proactive management policy until a crisis is at hand.

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Agenda: Fire & Climate 2001

February 14-16, 2001
Four Points by Sheraton Tucson University Plaza
1900 E. Speedway Boulevard
Tucson Arizona

Wednesday February 14

Morning	*Weather, Climate, Fire The 2000 Fire Season and Beyond*
8:15-8:45	Welcome and Introductions – *Barbara Morehouse and Tom Swetnam*
8:45-9:15	Climate and Fire: Framing the Issues in the Context of the 2000 Fire Season – *Tim Brown*
9:15-9:45	Weather and the 2000 Fire Season – *Rick Ochoa*
10:00-10:30	NIFC Resource Impacts During the 2000 Fire Season – *Rick Ochoa*
10:30-11:00	Climate Forecasts for 2001 – *Klaus Wolter*
11:00-11:30	Fire Forecasts for 2001 – *Tim Brown*
Afternoon	*Weather, Climate, Fire The 2000 Fire Season and Beyond (continued)*
1:15-1:45	Climate Information: Recent Developments in Data Access at WRCC – *Kelly Redmond*
1:45-2:15	The Cerro Grande Fire - *John Snook*
	Beyond the 2000 Fire Season
	MAPSS: Mapped Atmosphere Plant Soil System – *Ron Neilson*
	An Overview of the Joint Fire Science Program and RFPs for 2001 – *Bob Clark*
2:15-3:15	Open Discussion: Prescribed burns after Cerro Grande
3:30-5:00	Open Discussion: Lessons from the 2000 fire season: What can we do better in 2001?

Thursday February 15

Morning	*Climate Prediction*
8:00-8:20	Climate Modeling Overview – *Klaus Wolter*
8:20-8:40	Climate Modeling and Diagnostics – *Dan Cayan*
8:40-9:00	An Experimental Seasonal Fire Weather Forecast for the Western U.S. – *Anthony Westerling*
9:00-9:45	Climate Prediction: ENSO versus non-ENSO Conditions – *Douglas LeComte*
10:00-12:15	Climate Prediction Interpretation and Evaluation Workshop – *Holly Hartmann and Tom Pagano*
Afternoon	*The Use of Climate Information by Fire Managers*
1:30-2:15	Open Discussion: Identification of Issues around the use of Climate Information by Fire Managers
2:15-5:00	Breakout Groups

Friday February 16

Morning	*Integrated Assessments*
8:00-8:30	Interagency Integrated Assessments – *Roger Pulwarty*
8:30-9:00	Tools to Improve Fire Risk Management – *Barbara Morehouse and Steve Yool*
9:00-9:30	An Overview of CEFA and its Tools for Fire Managers – *Tim Brown*
9:30-10:00	Climate, Fire and the Need for a National Climate Service – J*onathan Overpeck*
10:00-12:00	Discussion

Agenda: Fire & Climate in the Southwest 2001

March 28, 2001
Arizona Ballroom, Student Union Building
The University of Arizona
Tucson, Arizona

8:30-9:00	Introductions and Overview
9:00-9:40	Climate of the Southwest — Andrew Comrie, *Department of Geography and Regional Development, University of Arizona*
9:40-10:10	Fire, Climate and the 2000 Fire Season in the Southwest — Tom Swetnam, *Laboratory of Tree-Ring Research, University of Arizona*
10:10-10:40	Fire and Emergency Management in Arizona – Alex McCord and Ron Melcher, *Arizona Department of Emergency Management, and Arizona State Land Department*
10:50-11:20	CEFA Climate Products for Fire Managers — Tim Brown, *Program for Climate, Ecosystem and Fire Applications*
11:20-11:50	EPA Decision Support System for Fire Managers — Barbara Morehouse and Steve Yool, *CLIMAS and Department of Geography and Regional Development, University of Arizona*
11:50-12:10	Discussion
1:10-1:40	Fire History in the Jemez Mountains: The Bandelier Perspective – L. Dean Clark, *National Park Service, Bandelier National Monument*
1:40-2:30	2001 Climate Forecasts for the Southwest — Tom Pagano, *Department of Hydrology and Water Resources, University of Arizona*
2:30-2:50	Discussion of Fire Management Climate Information Needs
3:00-5:00	Breakout Groups