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INSIDE

Science FINDINGS

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"Science affects the way we think together."

Lewis Thomas

The Hot-Dry-Windy Index: A New Tool for Forecasting Fire Weather

Kari Greer

Firefighters hike toward the 2017 Brian Head Fire, Utah. Weather plays a crucial role in wildfire behavior. Fire meteorologists need tools such as the newly developed Hot-Dry-Windy Index to predict dangerous conditions. These forecasts help protect firefighters and help incident commanders strategically allocate firefighting resources.

IN SUMMARY

Accurate predictions of how weather may affect a wildfire's behavior are needed to protect crews on the line and efficiently allocate firefighting resources. Since 1988, fire meteorologists have used a tool called the Haines Index to predict days when the weather will exacerbate a wildfire. Although the Haines Index is widely believed to have value, it never received rigorous testing on the line. Even Don Haines, the U.S. Forest Service meteorologist who developed the index, has said the Haines Index needs further refinement.

Recognizing that a new fire weather prediction tool was needed, a team composed of meteorologists with the U.S. Forest Service and St. Cloud State University developed the Hot-Dry-Windy Index. The index is based upon the three weather conditions—hot, dry, and windy—that significantly affect a wildfire's behavior.

When the Hot-Dry-Windy Index and the Haines Index were evaluated on four wildfires that burned in the United States between 2002 and 2011, the Hot-Dry-Windy Index proved better at identifying days when weather contributed to dangerous wildfire conditions. Because of the positive feedback received during subsequent field testing, the National Weather Service has recommended that fire meteorologists evaluate the Hot-Dry-Windy Index as a fire weather tool for use on wildfires.

"An ill wind that bloweth no man to good."

—John Heywood, writer

Following a day of presentations at the 2013 Fire Behavior and Fuels Conference, U.S. Forest Service colleagues Brian Potter, Joseph (Jay) Charney, Scott Goodrick, and postdoctoral researcher Alan Srock, who at the time had recently joined Charney's lab, met over dinner. Everyone around the table was a research meteorologist specializing in how weather influences wildfire.

One topic dominated their conversation: what to do about the Haines Index? Hearing the presenters during the conference tout the benefits of the Haines Index in predicting how weather will affect a wildfire's behavior was vexing. "If we had to go back tomorrow and give them something else, what would we recommend?" the group wondered. What could they recommend? There was no other fire weather prediction tool comparable to the Haines Index, and such a better tool was needed by the wildfire community.

It's time for us to develop a new tool then, they unanimously decided.

What Is the Haines Index?

The Haines Index was borne out of tragic circumstances. On May 5, 1980, in the Mio Ranger District of the Huron-Manistee National Forest in lower Michigan, what was supposed to be the Crane Lake prescribed burn in a stand of jack pine slash flared up into the Mack Lake Fire. When the fire was contained 6 hours later, it had burned 20,000 acres, destroyed 44 structures, injured one civilian, and killed one firefighter.

Don Haines, a meteorologist with what was then the U.S. Forest Service North Central Research Station, was tasked with both determining how weather conditions led the prescribed burn to escape control and creating a fire weather tool to avoid future tragedies. Out of this research, he developed the Lower Atmosphere Severity Index. Inputting the stability component (how readily air moves vertically) and moisture content of air above the ground into a formula yielded a value between 2 and 6; values of 5 or 6 signaled that fire managers should prepare for a high level of wildfire activity as a result of the weather.

Following its release in 1988, the Lower Atmosphere Severity Index was later shortened to the Haines Index in Haines' honor. Other meteorologists assessed the index's performance and it gradually became widely used amongst the fire meteorologist community.

In 1994, Potter joined the North Central Research Station as a meteorologist. Having no background in fire weather, he was directed toward the Haines Index as a promising fire weather tool to learn about. However, as Potter studied the research underpinning the Haines Index, he grew concerned about the claims of a relationship between the index values and a wildfire's behavior. When speaking to other fire meteorologists, including Goodrick with the Southern Research Station, they too admitted to not seeing the relationship.

Potter also chatted with Haines, who had since retired from the Forest Service. During those conversations, Haines shared crucial information overlooked following the Haines Index's adoption.

"'This is just a first guess,' Potter recalls Haines saying. 'The index needs to be figured out, fixed, and refined. And you can do that with the science now available, and with the tools you now have that I never had.'"

Even as Potter questioned the validity of the Haines Index, he admired and respected Haines' scientific breakthrough. "For the time, considering the tools and technology available, the Haines Index was the state of the art," Potter explains, adding that "prior to the Haines Index, the only weather considered as influencing a wildfire was surface weather. Fire managers only wanted to know is it hot, is it dry, or is it windy at the ground."

The meteorology community understood that weather conditions above the surface (above the height of an average person) influenced a wildfire, but this information wasn't easily shared with fire managers. Additionally, it was difficult to collect weather measurements above the surface. During the 1970s, launching a satellite was still a novelty. Today's handheld gadgets that record, transmit, and archive temperature, windspeed, and humidity data weren't even conceivable then because the technology and computing power hadn't been invented. If a meteorologist wanted to measure the air temperature above human height, they needed a tower or a weather balloon.

KEY FINDINGS

- The widely used Haines Index has fundamental flaws in its design. These were acknowledged in the original paper by Don Haines, but could not be addressed by the science and technology available in the 1980s. Until recently, the Haines Index had never been rigorously tested.
- When tested based on its intended use, the Haines Index poorly predicts large fire-growth events. Alternative applications of the index, sometimes used in the field, perform even worse.
- The newly developed Hot-Dry-Windy Index shows potential as a replacement for the Haines Index and is easily understood by operational fire meteorologists.

Kari Greer

Measuring wind speed. Wind is a weather variable that can turn an ember into a wildfire. Knowing the wind direction and speed allows fire managers to effectively deploy resources or pull firefighters back from the line.

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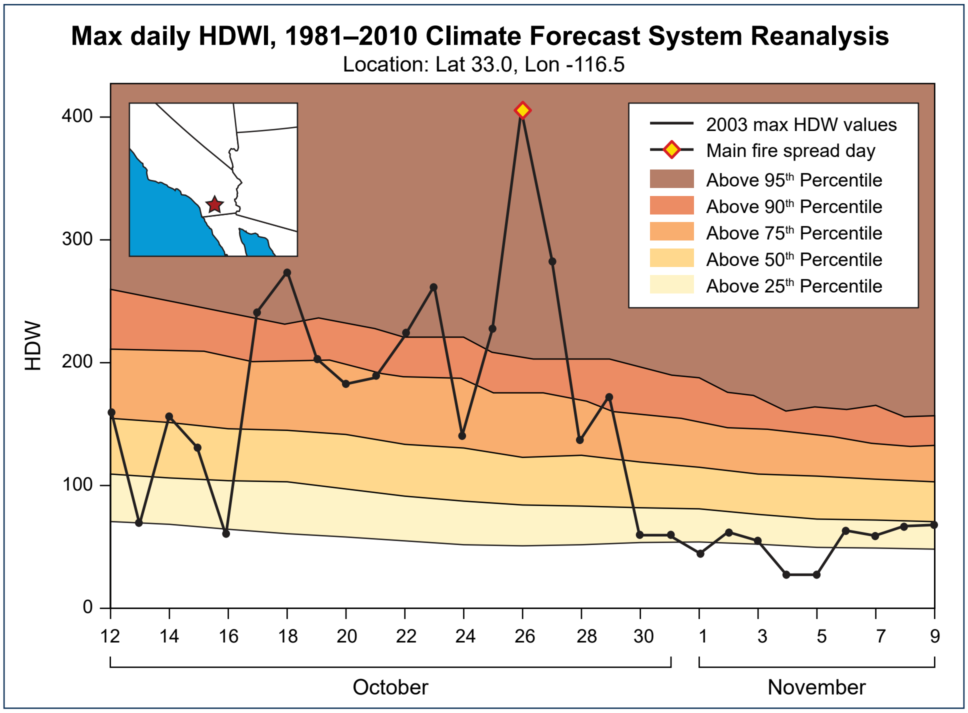
By incorporating the stability and dryness components into the Haines Index, Haines attempted to create a picture of the weather conditions above the surface so fire managers could quickly grasp how those conditions could affect a wildfire. Unfortunately, he was unable to successfully incorporate the winds into the equation—and it was primarily wind effects that tragically transformed a prescribed burn into the Mack Lake wildfire. A delayed ignition, coupled with increased winds, caused the fire to escape control lines.

"It's not usually the weather on the ground that kills firefighters," Potter says grimly. "It's the weather that comes down from above and surprises them because you can't see the air above."

Developing a New Fire Weather Prediction Tool

Flash forward to 2013, when the group set out to create a new fire weather index. Following the conference, they dispersed to their offices to resume other work, but continued to work on the side project via email and conference calls.

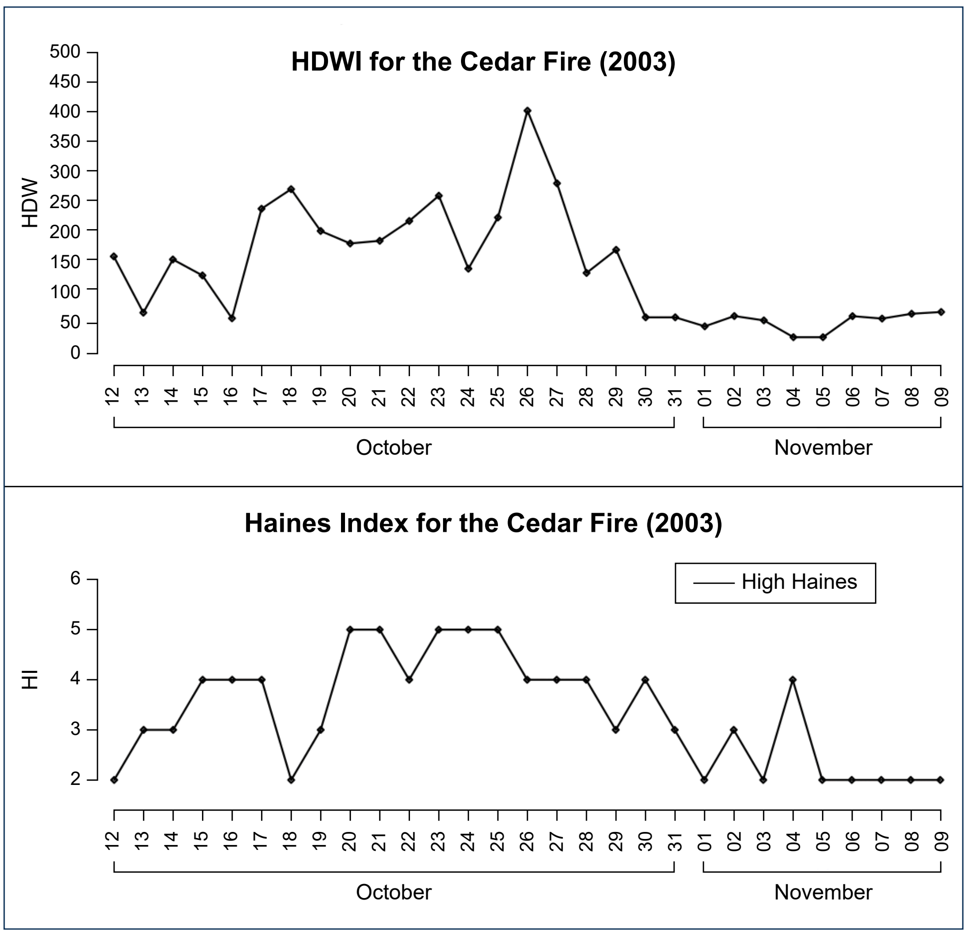
Because of his experience working with climatological datasets, Srock took the lead in identifying the datasets the new index would be built upon. For the real-time weather data, he chose the Global Ensemble Forecast System (GEFS) because it provides global ensemble forecast data and is familiar to the fire weather community. It also included 21 forecast possibilities, which provided a better estimation of future weather. "If all the possibilities peak or all of them are very low, you have more confidence of future weather conditions than if the possibilities are each all over the place," Srock explains.



An example of output from the Hot-Dry-Windy Index (HDWI) for the 2003 Cedar Fire in southern California. From the interactive website, users can select a location in North America and see the HDWI values for the past 10 days and the forecast for the next 7 days. A high spike indicates a bad fire weather day. Adapted from McDonald et al. 2018.

National Interagency Fire Center

A remote, automatic weather station collects weather data during a fire. This information is incorporated in near-real time to the models that feed the Hot-Dry-Windy Index.



The spike in Hot-Dry-Windy Index (HDWI) coincides with the big growth event on the 2003 Cedar Fire. In contrast, the Haines Index was higher on days of more moderate growth and dropped on the big growth day. Adapted from Srock et al. 2018.

To place the real-time data in a climatological context, Srock selected the Climate Forecast System Reanalysis (CFSR), which contained weather data dating back to 1979. "The reanalysis dataset, I would argue, is the best representation of the state of the atmosphere going back into history," says Charney. Another benefit of using the CFSR is that it uses the same grid as the GEFS, so all the points overlap. This means a user can see both the historical weather conditions for a given area as well as the forecasts.

As for the weather components to be included in the index, three were a given. "If you go to any fire manager or fire weather meteorologist and ask what are the weather components that affect fire, most of them are going to say some combination of hot, dry, and windy," Charney explains. "When it's hotter, drier, and windier, that's when you're going to have problems with fire."

The challenge was finding which weather variables best correspond to hot, dry, and windy conditions. Potter suggested that the index needed to capture the variability in those factors in the air above, but still near, the ground. His research into the weather conditions that resulted in Australia's Black Saturday Fires on February 7, 2009, suggested that these aboveground conditions played a role in creating the extreme winds during that event. (The Black Saturday Fires were Australia's worst bushfires on record: 400 fires broke out and 173 people died.)

It took 4 years of experimentation to work through developing and testing the formula. "At its heart, the Hot-Dry-Windy Index is just windspeed multiplied by vapor pressure deficit—which is a function of temperature and moisture in the air," Potter says. (Included in the vapor pressure deficit variable are the weather variables of temperature and absolute humidity.)

The team picked four geographically diverse wildfires (Pagami Creek in Minnesota, Bastrop County Complex in Texas, Double Trouble in New Jersey, and Cedar in California) to compare the ability of the HDWI and the Haines Index to identidy the bad weather days. "We chose those fires because we knew that there was a day or a couple of days when the wildfire was affected by the weather, when things got bad, and we wanted to see whether the index highlighted those days," Potter says.

The results: The HDWI value leapt upward on bad weather days, which the team hoped to see. In comparison, the Haines Index didn't consistently identify the bad weather days.

Considering the User Experience

While Srock worked with the team to develop the formula, he also worked with Jessica McDonald, an undergraduate at St. Cloud State University where Srock is now a professor, to develop the user interface of the future HDWI forecasting product.

McDonald wanted to develop her Python coding skills, so Srock gave her the weather data used to calculate the HDWI to experiment with. "I started coming up with ideas of what to do with the HDWI data, and eventually I just turned to developing plots [of the daily values]," she says.

McDonald and Srock deliberated about how much information to include within these plots. They wanted the output to display the needed information but not overwhelm the user. "One of my pet peeves in science is when you see plots without correct labels or the labels are really small, or the color bar isn't colorblind friendly," McDonald says. "We spent a lot of time making sure the plots were both intuitive but also easy to read and nice to look at. We wanted something functional but also beautiful."

Eventually, they decided the plots would display a given day's HDWI value against 30 years of historical values at that location to show the long-term trends for the area. Charney credits Goodrick's on-the-ground knowledge of how fire managers make decisions for keeping the group focused on the numbers and a final product that would be useful to the fire managers.

When the HDWI was released to a select group of beta testers, that attention to the user experience was immediately noticed. "We've had incident meteorologists say that showing that graph [plot] of the HDWI forecast at their morning briefings has become so effective at getting the quick-and-dirty picture to the fire crews that they use it every day," Potter says.

Using the Hot-Dry-Windy Index

Joel Curtis is one of the incident meteorologists who beta tested the HDWI and sings the praises of the new fire weather prediction tool. He used the HDWI when assigned to the Davis and Gold Hill Fires near Libby, Montana. Watching the HDWI, he saw that subsequent forecasts on days 1 through 4 were consistent with the HDWI spread used on the day 5 projection, and day 5 had a spike. Also disconcerting, all the forecast possibilities were converging and within the top 5 percent of worst days in the climatology for this time of year. Curtis examined other meteorological data and realized that day 5 would be a critical fire weather day.

Because of that information, Curtis says, the firefighting strategy and tactics were directed to bring the fire under control before day 5. "That approach saved thousands of dollars and [improved] the safety of the firefighting crews," he says.

Curtis considers the HDWI as a tool that looks at a broader scale of the region, and it signals when it's necessary to dig deeper into the meteorological data to determine what the weather will do.

Kari Greer

Firefighters carefully conduct a controlled burn around houses during the 2018 Taylor Creek and Klondike Fire on the Rogue-Siskiyou National Forest, Oregon. Accurate fire weather forecasts, which provide critical information for timing this type of activity.

And that's how Potter and the team envision the HDWI being used. "It's like a check engine light in your car," says Srock. "You're not sure what's wrong, but it encourages you to take another look."

"It provides a relative sense of how much the weather could make the fire bad, the atmospheric potential for how strong or dangerous a fire could be," adds Potter.

After hearing positive feedback from beta users, National Weather Service incident meteorologists, organizers, coordinators, and managers have since asked that HDWI training be presented to all the incident meteorologists.

The Work Isn't Finished

The HDWI is now live, and Potter says they are collecting feedback on how incident meteorologists, fire weather forecasters, and fire managers are interpreting and using the index. In Alaska, they realized that the HDWI isn't as applicable during times when the fuels aren't burnable. "The index can be high in conditions that don't really lead to bad fire just because it's windy and dry," Potter says. Since it doesn't address fuels or topography, he adds that he encourages fire meteorologists to use other fire prediction tools in conjunction with HDWI.

The user experience has also undergone improvements based upon feedback. "We added new things, such as 'point-and-click' to get a forecast, as well as a section that shows probabilities of HDWI exceeding certain values," McDonald says. "That was directly from feedback we received, and it was cool we could get feedback and then develop the tool that was requested."

Despite its positive reception, Charney cautions, "We can't yet say that the HDWI is absolutely optimized or will give us the best answer every time. However, we have yet to find a better way of sampling the hot-dry-windy characteristics in the atmosphere than what we've chosen for the analysis we've done so far."

As for Potter, he can finally tell Haines that the Haines Index has been replaced. "Don has constantly encouraged me to keep tearing the Haines Index apart," says Potter. "Why has it taken this long, he always asked?"

"Many may brook the weather that love not the wind."

—William Shakespeare

LAND MANAGEMENT IMPLICATIONS

- Using the Haines Index creates a false sense of security among wildland firefighters because it focuses on a conceptual model of fire behavior that is highly limited and out of date. Failing to account for these flaws in the model can jeopardize wildfire firefighters' safety.
- The Hot-Dry-Windy Index (HDWI) is based on basic fire behavior and weather interactions. Users immediately grasp its nature and underlying science.
- The HDWI provides fire weather forecasters with a new tool to guide their daily planning for both point concerns and regional/national concerns.

Kari Greer

Taking field notes during a prescribed burn. Feedback from early users of the Hot-Dry-Windy Index has helped shape the tool's user interface.

For Further Reading

Hot-Dry-Windy Index: https://www.hdwindex.org.

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