Climate Prediction Center Soil Moisture Products

By Jessica Lowrey, WWA

Soil moisture is the amount of water contained in the soil pores above the saturated groundwater zone that is available for plants to use or for evaporation into the atmosphere. Soil moisture affects runoff because snowmelt fills soil pores first, then it either flows through the soil (interflow) or over the soil (surface runoff) and eventually into streams. Once the soil pores are saturated with moisture, the water percolates down into the groundwater. Soil moisture can be measured directly by sensors in the ground at specific locations, or indirectly using radio waves to observe the amount of moisture in the ground. Neither one of these methods is trivial. Direct measurements are expensive to set up and do not provide data for a continuous area. Remote sensing with radio waves requires airplane or satellite flyovers, and while this provides continuous measurements, these are expensive and time consuming. National Weather Service (NWS) River Forecast Centers and the Natural Resources Conservation Service (NRCS), who produce water supply forecasts, have developed sophisticated methods for modeling the influence of soil moisture on water supplies based on variables like temperature, precipitation, and evapotranspiration (see text box, page 22). In addition, forecasters at the NOAA Climate Prediction Center (CPC) calculate soil moisture because it is an important factor in monthly and seasonal temperature and precipitation outlooks. This page focuses on the soil moisture calculations and outlooks produced by CPC.

Why does CPC calculate soil moisture?
CPC uses soil moisture outlooks as a predictor in monthly and seasonal temperature and precipitation outlooks. Forecasters at CPC have noticed that precipitation one month has a large impact on the temperature the next month in the summer due to its contribution to soil moisture. Soil moisture is more predictive in temperature forecasts than precipitation alone, and the correlation between soil moisture and temperature is highest in warm months when evaporation is the highest. It works like this: solar radiation is used either to evaporate soil moisture or to warm the air. If it is evaporating the soil moisture, then the solar radiation cannot raise the air temperature. Therefore, higher soil moisture will effectively lower air temperature below what it would normally be. Researchers also found that soil moisture is a good predictor for future precipitation because increased evaporation from the soil and resulting humidity increases the likelihood of future precipitation. However, using soil moisture adds more skill to temperature forecasts than to precipitation forecasts.

How can water managers use CPC soil moisture products?
Soil moisture in late winter and early spring (February-April) may be used to make qualitative projections about how much snowpack may become runoff. This qualitative assessment is possible because soil moisture changes little during the winter. In the spring, melting snow first fills the soil moisture “reservoir” before it becomes spring and summer streamflow. Therefore, higher soil moisture in the fall means more snowmelt will become streamflow rather than infiltrate into the soil.

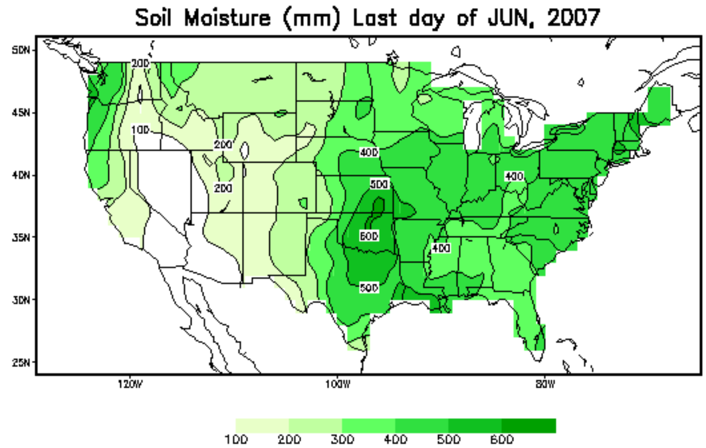

Figure 14a: Current soil moisture conditions as of June 30, 2007. The scale is in mm, which represents the amount of water the soil is holding with a possible total of 760mm. If you divide the soil moisture number in these figures by 760, you will get the % water by volume.

How does CPC calculate soil moisture?
The CPC began calculating soil moisture because there is not a spatially complete soil moisture monitoring network in the U.S., with the exception of a few states (Illinois, Iowa, and Nebraska). Observed precipitation and temperature[1] and estimated evapotranspiration, runoff, and groundwater loss are the parameters used in soil moisture calculations. The CPC soil moisture model can be represented by this equation[2]:

Change in soil moisture over time =
Precipitation – Evapotranspiration – Surface Runoff – Groundwater loss

Precipitation (and temperature) comes from observations, but the other variables in the soil moisture equation are calculated based on current weather conditions and constants that represent the water retention properties of soil. Evaporation estimates come from Thornthwaite’s expression for potential evaporation, which uses temperature as an input. Soil properties, such as the capacity of soil pores to hold water and the infiltration rate, affect the runoff and groundwater loss by influencing the way water flows through the soil. The runoff estimate is based on a simple hydrologic model that includes soil conditions: a surface

[1] Precipitation and temperature observations come from COOP station data.
[2] See Huang, van den Dool, and Georgakakos et. al., 1996 or http://www.cpc.noaa.gov/products/soilmst/paper.html for a more detailed description of the soil moisture model. CPC now uses a high resolution and physically comprehensive four-layer Noah model (Fan, et al., 2006) alongside the simple Huang, et al. (1996) model.

The Intermountain West Climate Summary is published monthly by Western Water Assessment, a joint project of University of Colorado and NOAA/ESRL Physical Sciences Division; researching water, climate and societal interactions.

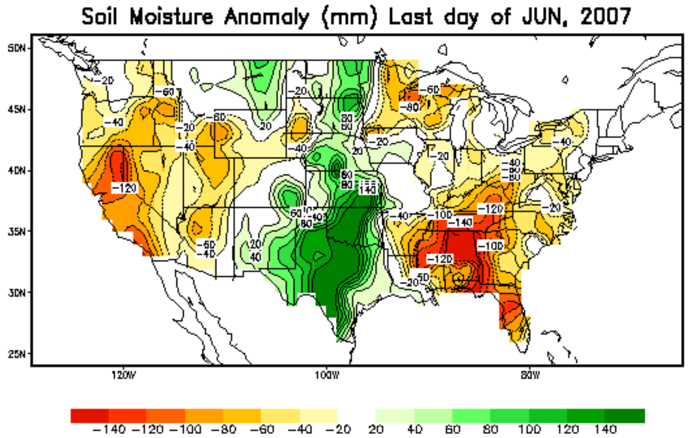

Figure 14b: Soil moisture anomalies as of June 30, 2007, relative to 1971-200- climatology. (CPC also shows maps of anomalies in terms of percentiles.)

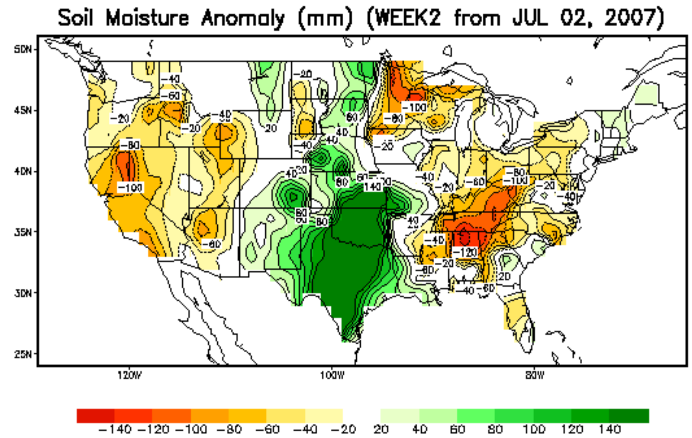

Figure 14c: Soil moisture anomalies forecasted for two weeks ahead (starting July 2, 2007) using temperature and precipitation forecasts from the GFS atmospheric model. CPC also produces maps of week 1 soil moisture outlooks and soil moisture anomaly change in the next two weeks.

runoff component and a subsurface (base flow) runoff component[3]. However, the model does not differentiate for different soil types in different locations because there is not an extensive soil moisture monitoring network across the country[4]. Instead, the model was calibrated with data from two small watersheds in Oklahoma using 1961-1990 data, and keeps these parameters constant across the entire US. Therefore, all of the variables in the soil moisture equation, except precipitation, come from data about soils in Oklahoma.

CPC's Soil Moisture Products

Current Conditions

CPC uses the soil moisture equation to create daily and monthly maps of current soil moisture conditions across the country[5] (Figure 14a). CPC found that the *spatial pattern* of soil moisture is largely determined by precipitation, but the *annual cycle* of soil moisture is largely determined by evaporation. Also, *anomalies* in soil moisture are driven by precipitation anomalies, but the *timescales* of soil moisture anomalies are determined by mean precipitation and mean evaporation (Huang, et al.1996). CPC used calculations of soil moisture from 1931 – present to establish a climatology of soil moisture, which they use to establish and interpret anomalies (Figure 14b).

Outlooks

Forecasters have developed two methods for creating soil moisture outlooks from forecasts of temperature and precipitation. While both methods use forecasts of temperature and precipitation in the soil moisture calculation explained above, they differ in forecast methodology and how far into the future they forecast soil moisture. One method uses an atmospheric model and the other uses a statistical model. The first method uses temperature and precipitation forecasts 1-2 weeks ahead from the GFS (Global Forecast System) atmospheric model as input for soil moisture outlooks for 1-2 weeks in the future (Figure 14c).

The second method, the Constructed Analogue Outlook for Soil Moisture (CAS), uses a statistical relationship between current soil moisture and future temperature and precipitation to generate temperature and precipitation outlooks 1-3 months ahead. CPC forecasters then use these temperature and precipitation outlooks to calculate soil moisture outlooks (Figure 14d). CPC found that they have about a 0.6 correlation in forecasting monthly soil moisture with a lead of one month (i.e. forecast for the month of July made at the end of May), and that the correlation is somewhat higher in early spring and lower in early fall (Van den Dool, et al. 2003).

Comparing CPC Soil moisture Calculations to Soil Moisture Observations

CPC verified their calculations with a long record of soil moisture observations in Illinois (19 sites with observations since 1981). The correlation was about 0.7 (Huang, et al.1996). However, it is difficult to compare CPC calculations to observations at NRCS SNOTEL and SCAN sites in the West. First, there is not a complete network of soil moisture sensors at all SNOTEL sites: only Utah and Nevada have soil moisture sensors at all sites. The SCAN network of soil moisture sensors is also incomplete across the West. Second, the soil moisture sensors at SNOTEL sites are relatively new and the network in Utah has a complete data set only back to April 2004, so there are not enough years of obser-

[3] CPC soil moisture calculations are also affected by runoff. Huug van den Dool of CPC says, "runoff depends on precipitation as well as soil moisture (the wetter the soil the more runoff). But soil moisture is depleted by the runoff obviously [soil moisture infiltrates and becomes subsurface flow, which moves laterally through the soil towards the stream, and eventually becomes baseflow]. This is commonplace in numerical modeling and taken care of in certain time stepping schemes."

[4] The NRCS is installing soil moisture sensors at some SNOTEL sites and other climate monitoring locations around the country, but the spatial coverage is still limited (see On the Web box).

[5] CPC uses daily COOP station data of temperature and precipitation for daily soil moisture maps and monthly climate division data for monthly soil moisture maps and climatology.

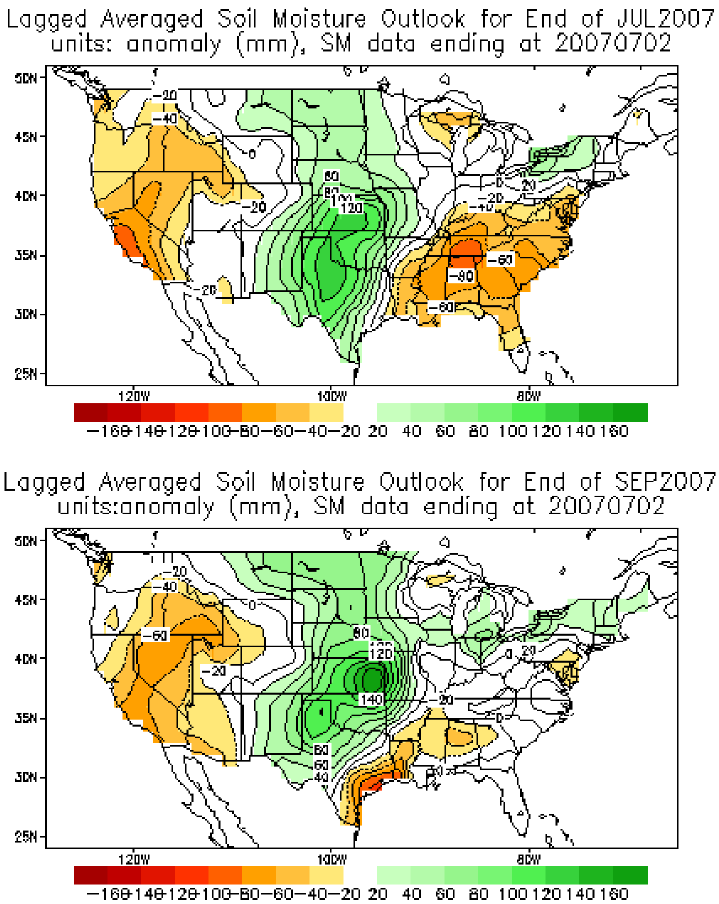

Figure 14d: Soil moisture anomalies forecasted for the end of the current month (July) and the current 3-month season (July-September) from the CAS model. The CAS model uses a statistical relationship to create temperature and precipitation forecasts from calculations of current soil moisture, and then it uses the forecasted temperature and precipitation values to calculate future soil moisture values.

vations to compare to the calculations. Finally, the biggest problem is that the SNOTEL sites are not co-located with the COOP weather stations where CPC gets the temperature and precipitation data for their soil moisture calculation. The weather data is likely to be very different at SNOTEL stations located at higher elevations compared to COOP stations located mostly at lower elevations. Therefore, the CPC soil moisture calculations might not be accurate for the higher elevation locations. SNOTEL stations also record temperature and precipitation, so in the future it is possible to include SNOTEL data in the CPC soil moisture calculations. Also, as the soil moisture observation network grows, and there is a longer record of observations, it will be possible to compare calculations to observations across the west. See On the Web box for websites with more information about soil moisture observations at NRCS SNOTEL and SCAN sites.

Sacramento Soil Moisture Accounting Model

The NWS River Forecast Centers, along with the NRCS, use a soil moisture model in their water supply forecasts of April-July streamflows. Like the CPC calculations, the Sacramento Soil Moisture Accounting Model (SAC) uses temperature, precipitation, and evapotranspiration inputs to model soil moisture, but the SAC goes a step further and models the effect of soil moisture on runoff. The SAC also has a much more complex mathematical description of the soil layers and the movement of water through these layers (Burnash and Ferral, 1996). Streamflow forecasters at NWS and NRCS are working on adding observations of soil moisture into their streamflow models as the data set becomes longer and more complete.

The author thanks the following people for their information and guidance in the research for this article: Huug van den Dool (NWS Climate Prediction Center), Randy Julander (NRCS), Tom Pagano (NRCS Water and Climate Center), Kevin Werner (NWS Western Region Office), and Seann Reed (NWS Office of Hydrology).

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Huang, J., H. M. van den Dool and K. G. Georgakakos, 1996: "Analysis of model-calculated soil moisture over the US (1931-1993) and applications to long-range temperature forecasts." *J. Climate*, **9**:1350-1362.

van den Dool, H., J. Huang, and Y. Fan, 2003: "Performance and analysis of the constructed analogue method applied to U.S. soil moisture over 1981-2001." *J. Geophys. Res,* **108**: 8617.

On the Web

CPC

- Soil moisture monitoring main page, including links to maps of current runoff, evaporation, precipitation and temperature: http://www.cpc.noaa.gov/products/soilmst/.
- Soil moisture maps: http://www.cpc.noaa.gov/products/soilmst/w.shtml.
- Detailed description of soil moisture model: http://www.cpc.noaa.gov/products/soilmst/paper.html.

Soil Moisture observations:

- NRCS Snotel: http://www.wcc.nrcs.usda.gov/snotel/.
- NRCS Utah soil moisture data: http://www.ut.nrcs.usda.gov/snow/climate/ or see the Focus Page in the June 2006 IWCS.
- NRCS SCAN: http://www.wcc.nrcs.usda.gov/scan/.