Land Data Assimilation Systems at NCEP: Predicting Extreme Hydrometeorological Events

Michael Ek and others in the EMC Land-Hydrology Team:
Jesse Meng, Rongqian Yang, Helin Wei, Youlong Xia,
Yihua Wu, Weizhong Zheng, Jiarui Dong,
Roshan Shrestha (COLA/GMU),
Caterina Tassone (EMC mesoscale modeling branch)

Environmental Modeling Center (EMC)
National Centers for Environmental Prediction (NCEP)
NOAA/NWS
Outline

• Hydrometeorological extremes, e.g. drought, flood, and steps to increase their predictability

• NCEP Weather and Climate Modeling Suite and Noah land model

• NCEP Land Data Assimilation Systems (LDAS) and hydrometeorological prediction

• Summary
Hydrometeorological Extremes: Drought

Meteorological: Precipitation
Agricultural: Soil moisture
Hydrological: Streamflow

Drought
From Wikipedia, the free encyclopedia

For other uses, see Drought (disambiguation).

Drought is an extended period when a region receives a deficiency in its water supply, whether atmospheric, surface or ground water. A drought can last for months or years, or may be declared after as few as 15 days.\(^1\) Generally, this occurs when a region receives consistently below average precipitation. It can have a substantial impact on the ecosystem and agriculture of the affected region. Although droughts can persist for several years, even a short, intense drought can cause significant damage\(^2\) and harm to the local economy.\(^3\) Prolonged droughts have caused mass migrations and humanitarian crises.
Hydrometeorological Extremes: Drought

October 2012

Drought loosens grip on region, rice farms

Reservoirs not as low as year ago

Drought Continued from A1

rice farmers harvested 180,000 acres in 2013, valued at $68.0 million.

"I am happy the staff is recognizing that there's a different set of hydro-logical conditions from a year ago," said Ron Gerster, who leads the Colorado Water Issues Committee, which works on behalf of rice producers.

The lakes, the major reservoirs for Central Texas, remain less than half full. Still, they’re in a better situation than they were a year ago.

In September 2011, the combined storage of the lakes was 808,000 acre-feet and holding steady. In 2012, the reservoirs were 402,000 acre-feet and holding steady. In 2013, the reservoirs were 602,000 acre-feet and holding steady.

An irrigation canal that feeds water to a field of rice on the Leher property is fed by the main LCRA canal in Garwood. RODOLFO GONZALEZ / AMERICAN STATESMAN
Hydrometeorological Extremes: Flood

2013 Colorado Flooding

From Wikipedia, the free encyclopedia

For other uses, see Flood (disambiguation).

A flood is an overflow of water that submerges land which is usually dry.[1] The European Union (EU) Floods Directive defines a flood as a covering by water of land not normally covered by water.[2] In the sense of "flowing water", the word may also be applied to the inflow of the tide. Flooding may occur as an overflow of water from water bodies, such as a river or lake, in which the water overtops or breaks levees, resulting in some of that water escaping its usual boundaries,[3] or it may occur due to an accumulation of rainwater on saturated ground in an areal flood. While the size of a lake or other body of water will vary with seasonal changes in precipitation and snow melt, these changes in size are unlikely to be considered significant unless they flood property or drown domestic animals.
Predicting Hydrometeorological Extremes

How to get there?

- Important: Potentially strong inertia in soil, e.g. soil moisture, also local land-atmosphere interaction (e.g. precip “recycling”), and large-scale/global land-atmosphere-ocean interaction.
- Land initial conditions (e.g. soil moisture), i.e. via a Land Data Assimilation System (LDAS).
- LDAS requires good forcing data, and relevant land model physics and parameters & companion land data sets including near-realtime, e.g. green veg. frac. (GVF), snow, soil moisture.
- “Parent” coupled atmosphere-ocean-land-sea ice model.
NOAA’s Operational Numerical Guidance Suite (January 2014)
• Relevant land physics & associated parameters, provides lower boundary conditions (heat, moisture, momentum) for NAM, GFS, CFS.
• Noah partners: UT-Austin, U Ariz, U Wash, Princeton, NASA.
Land Data Sets

Vegetation Type

Soil Type

Max.-Snow Albedo

Green Vegetation Fraction

Snow-Free Albedo
Atmospheric Forcing

- Forcing from atmospheric analysis or re-analysis system (e.g. NARR/RCDAS, GDAS, CFSR/CDAS).
- Precipitation especially important: use observations, e.g. CPC gauge-based, radar, satellite, or model.
Operational North American Land Data Assimilation System (NLDAS): Monitoring

- Land models: Noah, SAC, VIC, Mosaic run in “uncoupled” mode.
- Forcing: NCEP Climate Prediction Center obs precip (gauge-based, radar/satellite disaggregated), and atmospheric forcing from NCEP North American Regional Climate Data Assimilation System. Output: 1/8-deg. land & soil states, surface fluxes, runoff/streamflow.
- Climatology from land model assimilation runs for 30-years provide anomalies used for drought monitoring; supports USDM, NIDIS etc.
- Operational at NCEP Aug 2013. Future: higher resolution, land model upgrades, improved forcing, snow and soil moisture assimilation, etc.

NLDAS four-model ensemble monthly soil moisture anomaly

Youlong Xia
NLDAS Total Soil Column Soil Moisture Anomaly: March 2012 – December 2013

US Drought

Youlong Xia

NOAA/NCEP/EMC
NLDAS Total Soil Column Soil Moisture Anomaly: January 2013 – August 2014

California Drought

Youlong Xia
US Drought Monitor: 04 September 2012

U.S. Drought Monitor
CONUS

September 4, 2012
(Released Thursday, Sep. 6, 2012)
Valid 7 a.m. EST

Drought Conditions (Percent Area)

<table>
<thead>
<tr>
<th>Current</th>
<th>D0-D4</th>
<th>D1-D4</th>
<th>D2-D4</th>
<th>D3-D4</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22.54</td>
<td>77.46</td>
<td>63.39</td>
<td>42.48</td>
<td>21.45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Last Week 02/20/12</th>
<th>D0-D4</th>
<th>D1-D4</th>
<th>D2-D4</th>
<th>D3-D4</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22.31</td>
<td>77.69</td>
<td>62.89</td>
<td>42.34</td>
<td>23.18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3 Months Ago 05/2012</th>
<th>D0-D4</th>
<th>D1-D4</th>
<th>D2-D4</th>
<th>D3-D4</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>36.01</td>
<td>63.99</td>
<td>38.60</td>
<td>18.92</td>
<td>4.60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Start of Calendar Year 01/2012</th>
<th>D0-D4</th>
<th>D1-D4</th>
<th>D2-D4</th>
<th>D3-D4</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50.41</td>
<td>49.59</td>
<td>31.90</td>
<td>18.83</td>
<td>10.18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Start of Water Year 05/27/2011</th>
<th>D0-D4</th>
<th>D1-D4</th>
<th>D2-D4</th>
<th>D3-D4</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>56.45</td>
<td>43.55</td>
<td>29.13</td>
<td>23.44</td>
<td>17.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>One Year Ago 05/5/2011</th>
<th>D0-D4</th>
<th>D1-D4</th>
<th>D2-D4</th>
<th>D3-D4</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>56.53</td>
<td>43.47</td>
<td>30.00</td>
<td>23.37</td>
<td>18.05</td>
</tr>
</tbody>
</table>

Intensity:
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author(s):
Brian Fuchs
National Drought Mitigation Center

http://droughtmonitor.unl.edu/
NLDAS output: 04 September 2012

Total Column Soil Moisture

Top 1m Soil Moisture

Total Runoff

Evapotranspiration

Youlong Xia
Streamflow from NLDAS routing scheme: Hurricane Irene & Tropical Storm Lee 20 Aug – 17 Sep 2011

Ensemble mean daily streamflow anomaly (m$^3$/s)

Youlong Xia
Streamflow from NLDAS routing scheme: Superstorm Sandy
29 Oct – 04 Nov 2012

Ensemble mean daily streamflow anomaly (m³/s)

Youlong Xia
Streamflow from NLDAS routing scheme: Colorado Front Range Flooding September 2013

Ensemble mean daily streamflow anomaly (m³/s)

Ensemble–Mean: Current Streamflow Anomaly (m³/s)
NCEP NLDAS Products Valid: SEP 01, 2013

Ensemble mean daily streamflow anomaly (m³/s)

Youlong Xia
NLDAS Seasonal Hydrological Forecast System

- System jointly developed by Princeton University and U. Washington.
- Transitioned to EMC in Nov 2009, as an experimental seasonal hydrological forecast system.
- Hydrological forecasts use downscaled/ensemble forcing from three sources: CFSv2, traditional ESP, and CPC forecasts.
- Run at the beginning of each month and forecast products are staged on NLDAS website by the 15th of each month.
NLDAS Hydro. Fcst: Drought Lead Time

- **CFSv2**
  
  - 1-month lead
  
  - 01 AUG 2012
  
  - Initial conditions

- **CPC**
  
  - 2-month lead
  
  - 1 JUL ICs

- **ESP**
  
  - 3-month lead
  
  - 1 JUN ICs

- **Analysis**
  
  - AUGUST 2012
  
  - AUGUST
  
  - AUGUST

Youlong Xia
NLDAS Hydro. Fcst: Drought Persistence

- CFSv2
- CPC
- ESP
- Analysis

01 AUG 2012
Initial conditions

AUGUST 2012

MORE WORK REQUIRED

1 AUG ICs

SEPTEMBER

1 AUG ICs

OCTOBER

Youlong Xia
NLDAS: Web Site Information

USGS Geo Data Portal

This page is a catalog of the datasets that have been tested to work well for access with the Geo Data Portal. Select one of the buttons below to see a list of these datasets. At its core, the Geo Data Portal is an advanced Open Geospatial Consortium Web Processing Service that can be used in a wide variety of applications against any web-accessible standards-compliant dataset. If you'd like to see all the datasets that are compatible with one of the processing types the Geo Data Portal can perform, select one of those buttons below.

For more information about the Geo Data Portal, please visit the Geo Data Portal Documentation Home.

Datasets

- All
- Climate
- Landscape

Processing

- Areal Statistics
- Data Subsets

Select Dataset

0.125 Degree Hourly Primary Forcing Data for NLDAS-2

North American Land Data Assimilation System Phase 2
0.125 Degree Hourly Primary Forcing Data for NLDAS-2

The goal of the North American Land Data Assimilation System (NLDAS) is to construct quality-controlled, and spatially and temporally consistent, land-surface model (LSM) datasets from the best available observations and model output to support modeling activities. Specifically, this system is intended to reduce the errors in the stores of soil moisture and energy which are often present in numerical weather prediction models, and which degrade the accuracy of forecasts. NLDAS is currently running in near real-time on a 1/8th-degree grid over central North America; retrospective NLDAS datasets and simulations also extend back to January 1979. NLDAS constructs a forcing dataset from gauge-based observed precipitation data (temporally disaggregated using Stage II radar data), bias-correcting shortwave radiation, and surface meteorology reanalyses to drive several different LSMs to produce model outputs of surface fluxes, soil moisture, and snow cover. For more information visit: http://ldas.gsfc.nasa.gov/ldas/NLDAS is a collaboration project among several groups:
Global Land Data Assimilation System

- **Noah land model** running under NASA Land Information System forced with CFSv2/GDAS atmospheric data assimilation output and "blended" precipitation in a semi-coupled mode.
- **Blended precipitation** via satellite (CPC/CMAP; heaviest weight in tropics), gauge (heaviest in mid-latitudes) and GDAS (model; high latitude).
- **Snow** cycled in CFSv2/GLDAS if snow from Noah LSM within a 0.5x/2.0x envelope of observed value (IMS cover, AFWA depth).
**NASA Land Information System**

**Inputs**
- Topography, Soils (Static)
- Land Cover, Leaf Area Index (MODIS, AMSR, TRMM, SRTM)
- Meteorology: Modeled & Observed (NLDAS, DMIP II, GFS, GLDAS, TRMM, GOES, Station)
- Observed States (Snow, Soil Moisture, Temperature)

**Physics**
- Land Surface Models
  - SAC-HT/SNOW17
  - Noah, CLM, VIC, Catchment

**Outputs**
- Surface Energy Fluxes ($Q_h, Q_L$)
- Soil Moisture Evaporation
- Surface Water Fluxes (e.g., Runoff)
- Surface States (Snowpack)

**Applications**
- Water Supply & Demand
- Agriculture Hydro-Electric Power, Water Quality
- Improved Short Term & Long Term Predictions

**Data Assimilation Modules**
- DI, EKF, EnKF

Christa Peters-Lidard et al., NASA/GSFC/HSB
NCEP Realtime Operational GLDAS

GDAS
Atmospheric analysis

Day 1 → Day 2 → Day 3 → Day 4 → Day 5 → Day 6 → Day 7 → Day 8

GLDAS
Land analysis

GLDAS
Land analysis

Precip observation

Precip observation

Jesse Meng
GLDAS soil moisture

Climatology: 1980-2008

MAY

NOVEMBER

MAY 1988

MAY 1993

Anomalies

Mid-west drought

Mid-west flood
GLDAS soil moisture anomaly July 2012

- Russian drought
- US drought
- Ugandan flood
CFSv2 Total Soil Moisture Anomaly (mm)

Jun 2012

Jul 2012

Aug 2012

Sep 2012

Analysis

1-month lead

2-month lead

3-month lead

MORE WORK REQUIRED
**Future NLDAS: Extend to entire North America and Mesoscale NAM domain**

Configuration:
- 0.04-deg (~4km)
- Noah land model ver. 3.3 or later
- NAM/NDAS forcing

**Monthly Mean Total Soil Moisture in 2012 over NAM Domain**

Jiarui Dong
Summary

- Hydrometeorological prediction of extremes (e.g. drought, flood) requires **proper initial conditions** (e.g. soil moisture memory), **correct physics** (e.g. land-surface model) & corresponding parameters, and **representative land data sets**, some near-realtime (e.g. green vegetation fraction, soil moisture, snow, etc) and some may be assimilated.

- **Improve land** data assimilation systems (LDAS) and land-surface model physics, i.e. “Noah-MP” with explicit canopy, CO2-based photosynthesis, dynamic vegetation (plant growth), groundwater, multi-layer snowpack, refine soil processes.

- **Earth-System models**: Improve other components in increasingly fully-coupled (atmosphere-ocean-land-sea ice/etc) modeling systems as they expand to make **connections** between **Weather & Climate** and **Hydrology** (including **Water Quality**), **Biogeochemical** cycles (e.g. carbon, ecosystems), & **Air Quality** on local as well as large scales.

**Thank you!**