NLDAS Views of North American 2011 Extreme Events

Hualan Rui, Bill Teng, Bruce Vollmer, David Mocko, and Guang-Dih Lei

Introduction

Year 2011 was one of the most extreme years of natural disasters in recent history. Over the course of the year, weather-related extreme events, such as floods, heat waves, blizzards, tornadoes, and wildfires, caused tremendous loss of human life and properties. Numerous studies and research projects have focused on acquiring observational and modeling data and revealing linkages between the intensity and frequency of extreme events, the global water and energy cycle, and global climate change. However, drawing definitive conclusions is still a challenge due to observational data inadequacy and scarcity, particularly at the land surface and sub-surface.

The North American Land Data Assimilation System (NLDAS) data (Mitchell et al., 2004; Xia et al., 2012; http://ldas.gsfc.nasa.gov/nldas/; http://www.emc.ncep.noaa.gov/mmb/nldas/) has high spatial and temporal resolutions (0.125° x 0.125°, hourly since Jan 1979) and multiple water- and energy-related variables, including precipitation, soil moisture, snow cover/amount, runoff, evapotranspiration, latent heat, etc. NLDAS is an excellent data source for supporting meteorological and hydrological research [e.g., Lee et al., 2010, Mo et al., 2011, Anderson et al., 2013, and the NLDAS Drought Monitor http://www.emc.ncep.noaa.gov/mmb/nldas/drought/]. This article illustrates the breadth of NLDAS Phase 2 (NLDAS-2) data by showing examples of descriptions for extreme events of 2011 in North America, including Hurricane Irene, Tropical Storm Lee, the July heat wave, and the February blizzard. Of which, snowfall and snow water equivalent are used for illustrating the winter blizzard event; precipitation, 0-10cm soil moisture, total runoff, and surface wind fields are shown for describing the two East Coast tropical storm events; and 2-meter above ground air temperature data is selected for demonstrating the heat wave event. The NLDAS-2 stream flow data from NCEP (ftp://nomad6.ncep.noaa.gov/pub/raid2/wd20yx/nldas/Streamflow/) is also shown for describing the effect of the heavy rainfall from the Tropical Storm Lee on rivers.

In addition, this article also briefly introduces the recently-released NLDAS monthly means and monthly climatology datasets, and provides a description of the major characteristics of NLDAS data and data accessing methods.

2011 Extreme Events in the United States

Based on a NOAA announcement issued on January 19, 2012, two additional severe weather events during 2011 reached the $1 billion damage threshold, which raised 2011's billion-dollar disasters count from 12 to 14 events. And therefore, the year 2011 has been classified as a year of climate extremes in the United States (http://www.noaanews.noaa.gov/stories2012/20120119_global_stats.html). The list of the 14 billion-dollar disasters (Table 1) shows that extreme weather events occurred in all seasons of 2011. However, the spatial distribution of the billion-dollar disasters (Figure 1) shows that all of them occurred in the eastern half of the United States. The one thing that these events all have in common is they are related to extremes in water and/or energy, particularly near the land-surface, where humans live and work. Most of them occurred in large river basins. Information provided by NLDAS data on land surface properties and soil and water characteristics could play an unique role in exploring and understanding the extreme events and addressing underlining science questions.

The bar chart in Figure 2a shows inter-annual variations of the number of billon dollar weather/climate disasters 1980-2011. The number of disaster events and associated economic losses show pronounced interannual variations with an increasing trend, particularly during the latest ten years, although the upward trend is partially due to the total economic increase and other factors. It is important to pinpoint global weather/climate anomalies and local environmental conditions in addressing extreme events and variations, and in mitigating impacts of the disasters. In these efforts, NLDAS, with a set of water- and energy-related variables and the long temporal coverage (1979 to present), is capable for facilitating the inter-annual variability study. Phase 2 of the NLDAS project, detailed in [Xia et al., 2012], goes from Jan 1979 to the present day, typically updated 3.5-days behind the current time. As an example, shown in Figure 2b is the central United States area-averaged time series from NLDAS-2 data. Three variables from 1979 to 2012 are selected for demonstration: (black line) the inter-annual variations and month-to-month changes of precipitation; (red line) 2-meter above ground temperature; and (green line) top 1-meter soil moisture from one of the NLDAS LSMs. It is clear that larger precipitation anomalies are correspond well to the anomaly peaks of soil moisture and they are generally negatively correlated to the anomaly peaks of surface temperature. For this central U.S. region, periods with low precipitation thus tend to have less soil moisture and higher surface temperatures. It is also interesting to notice that some of the largest anomalies in all three variables occur after 2010.

We have selected four of these 2011 extreme events to demonstrate the capability of the NLDAS system in capturing and describing their structures and variations. NLDAS data will also be used to view the detailed evolutions of these extreme events and to analyze relationships between different variables for consistency and coherency.

Groundhog Day Blizzard

The first billion-dollar disaster of 2011 is the Groundhog Day Blizzard, a large winter storm that impacted several central, eastern, and northeastern states, with total losses greater than $1.8 billion. At least 36 deaths are attributed to this sprawling storm.

The two-and-half-day (12Z Jan. 30 to 23Z Feb. 2, 2011) accumulated snowfall (Figure 3a) seen by the NLDAS-2 Noah LSM shows a large amount of snowfall from Oklahoma, Missouri, Illinois, Indiana, Wisconsin, to New York, Massachusetts, and other northeastern states, with the heaviest snowfall in Wisconsin along the eastern shores of the Great Lakes. Very strong winds were associated with this storm for an extended period of time and many locations had blizzard conditions. The two-and-half-day average wind (Figure 3b), overlaying on the accumulated precipitation (snowfall + rainfall), shows the heavy winds along the storm track. The accumulated precipitation map (Fig. 3b background image) indicates that the storm brought not only heavy snow and blizzard conditions to northern states, but also heavy rainfall to southern states.

With the hourly NLDAS data, the snowfall amount can be viewed hour by hour. The time series of the NLDAS-2 Noah snowfall (Figure 3c) shows that Missouri (black line) had a snowfall peak during the middle of the night on Feb. 1 to an area-average snowfall rate of about 2 mm/hr (liquid equivalent). Illinois and Indiana (green line) had two snowfall peaks, as did Massachusetts and the other surrounding northeastern states, as the storm progressed from west to east. Note that these rates are in units of mass of liquid; a rough calculation is a ratio of 10:1, resulting in snowfall accumulations as high as 2 cm/hr.

The high resolution NLDAS data is clearly able to capture and describe the details in evolutions and structures of this unusual snow blizzard, and information provided here is very much consistent with in-situ and remote sensing observations during the events, as well as results from various model simulations and assimilations.

The daily anomaly of Snow Water-Equivalent (SWE) from the NLDAS-2 Noah model for Feb. 02, 2011 (Fig. 3d) shows that most areas along the blizzard path had the SWE anomaly greater than 50 kg/m^2. SWE is one of the most important cold season process variables and it quantifies the amount of frozen moisture storage and will in turn determine the amount and timing of runoff during subsequent spring melt [Pan, et al., 2003 and Sheffield, et al., 2003].

NLDAS contains many other winter weather related variables, such as snow depth, snow cover, snow melt, snow phase change heat flux, 2-meter above ground temperature, soil temperatures, and averaged surface albedo.

Heat wave on the Great Plains

During the spring to fall seasons of 2011, drought and excessive heat had major impacts across Texas, Oklahoma, New Mexico, Arizona, southern Kansas, and western Louisiana. The total direct economic losses have approached $10 billion.

Looking into Figure 2b again here, the central United States had positive anomalies of the 2-meter above ground temperature (red line) during 2010-2012, with magnitudes exceeds 3 K.

This region suffered extreme drought, with negative anomaly of the top 1-meter soil moisture exceeding 50 kg/m^2 (green line). The significant low and high peaks of soil moisture anomalies are well inversely correspondent to the peaks of the temperature anomalies.

A close examination of drought anomalies in July 2011, using the monthly-averaged 2-meter above ground temperature from NLDAS-2 Primary Forcing, as shown in Figure 4a, reveals that the heat wave is centered in Texas and Oklahoma with temperatures above 305^{o}K (90^{o}F).

Figure 4b shows the time-series of the average daily NLDAS-2 Primary Forcing 2-meter above ground temperatures for the Oklahoma region from 100-94.5W and 34-37N. It indicates a persistent high temperature throughout the entire month with very little relief, and the highest daily average temperature reached an astonishing 309 K (96.5° F). The monthly average 2-meter above ground temperature, shown as the red line in the figure, was 307.4 K (93.6° F), is comparable to 88.9° F, the averaged statewide temperature for all of Oklahoma in July 2011 as reported by the National Climatic Data Center using weather station data.

The diurnal cycle time series over a slightly larger region centered over Oklahoma is plotted in Figure 4c for July 2011 using the hourly 2-meter above ground air temperature from NLDAS-2 Primary Forcing. There were more than 20 days in July 2011 with area-averaged daily maximum temperature above 100^{o}F (310.93^{o}K, red line), and both daily maximum and minimum temperatures were trending upward during July. To examine spatial coverage of instantaneous temperature maxima, plotted in Figure 4d is the hourly 2-meter above ground temperature at 21Z July 21, 2011 (one of the peaks shown in Figure 4c). Temperatures above 312.5^{o}K (103^{o}F) extended from large areas of Texas, the entire state of Oklahoma, the majority of Kansas, to more than the northern half of Missouri, and beyond.

Hurricane Irene

Hurricane Irene, as it moved northward along the East Coast of the United States from the Caribbean Sea through New England states, brought tremendous rainfall and wind and caused more than $7.3 billion in damages. The passage of Hurricane Irene killed at least 55 people, and left millions of people in the dark due to power outages. Fallen trees caused power outages persisted for more than a week. Flood damage was particularly extensive in the state of Vermont, with parts of several other coastal states declared disaster areas.

An animation of hourly wind overlay on precipitation can be viewed with the Giovanni NLDAS Hourly Portal (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=NLDAS0125_H, http://disc.sci.gsfc.nasa.gov/gesNews/images/hurricane_nldas_rainfall_animation) to illustrate status and evolutions of Hurricane Irene in greater detail. A few images from the animation (Figure 5a) capture the major characteristics of Irene, as seen from satellites images (http://www.nasa.gov/mission_pages/hurricanes/archives/2011/h2011_Irene.html). Irene made the first landfall in eastern North Carolina early on August 27, and then moved northward along the mid-Atlantic Coast, where the well-defined center and strong winds remained for more than 10 hours. While it continued moving northward to Virginia and Maryland, Irene was slowly weakening. After merging with an approaching cold front and getting energized, Irene made landfall in southeastern New Jersey on August 28, then passed near New York City a few hours later, dropping torrential rainfall that caused widespread flooding. The time series of hourly precipitation (Figure 5b) from NLDAS-2 Primary Forcing, averaged over (86W~67W, 25N~53N) shows three rainfall peaks at 03Z August 27, 2011 for North Carolina, 19Z August 27, 2011 for Virginia, and 13Z August 28, 2011 for New York. The heaviest rainfall was observed at 13Z Aug. 28, 2011 in New York (Figure 5c, left). The NLDAS-2 Noah Soil Moisture of 14Z Aug. 28, 2011 (Fig. 5c, right) shows high soil moisture content centered on New York at the same time.

The total runoff from NLDAS-2 Noah model [Xia et al., 2012] shows large positive daily anomaly on Aug. 28, 2011 (Fig. 5d) and the positive anomaly region overlays with the region of the high rain and soil moisture.

Tropical Storm Lee

Tropical Storm Lee poured huge amounts of water on top of the already saturated Northeast and again inundated many inland cities, causing at least 21 deaths and more than $1.0 billion in damages. During early September 2011, as the East Coast, Middle Atlantic, and New England states were still recovering from record flooding caused by Hurricane Irene, Tropical Storm (TS) Lee compounded previous damages by dumping additional rainfalls, as well as strong winds to the Northeast states and cities. Examples of these data views are shown below.

As an animation of hourly precipitation (http://disc.sci.gsfc.nasa.gov/hydrology/gesNews/nldas_views_ts_lee) from the NLDAS-2 Primary Forcing showed from September 2-4, Tropical Storm Lee produced heavy rains that saturated Louisiana, stalled off the coast, continuously expanded and intensified, and then slowly weakened and moved northeastward, spreading rain to Mississippi and Alabama. The animation also shows that, as Lee dissipated and moved northeastward, the rain system interacted with subtropical and middle-latitude systems and brought heavy rain to Virginia, Maryland, Pennsylvania, and New York. NLDAS-2 accumulated precipitation between 08Z Sep. 02 and 12Z Sep. 09 (Figure 6a) shows three heavy rain centers, one over Louisiana and Mississippi, another over Alabama/Georgia/Tennessee, and another over Pennsylvania, with accumulated rainfall exceeding 10 inches (254 mm).

The area-averaged time series of hourly Precipitation (Fig 6b) for the three heavy rain regions depicted by the boxes in Fig. 6a shows temporal variations of rainfall and clearly marked the start and end of the heaviest precipitation. The time series of precipitation and soil moisture overlay (Fig. 6c) shows the soil moisture peaks well correlated with the rainfall peaks. The persistence of high soil moisture content following the heavy rain period during the Tropical Storm Lee has contributed to flash flooding in many areas.

The anomaly of total runoff from NLDAS-2 Noah model for Sep. 05, 2011 (Fig. 6d) shows larger positive anomaly over Louisiana, Mississippi, and Tennessee, where Tropical Storm Lee dropped heavy rain during Sep. 2 – 6, 2011. The anomaly of Routed Streamflow from NLDAS-2 Noah model for Sep. 08, 2011 also shows large positive anomaly over the path of Tropical Storm Lee, with the largest anomaly over Pennsylvania, coinciding with the double peak rainfall over Pennsylvania in Fig. 6b. Runoff and streamflow are very important water cycle variables. They are affected by weather and directly impact on the water quality and living creatures in the streams. The runoff, and streamflow data from NLDAS [Xia et al., 2012], along with precipitation, soil moisture, evaporation, snow water (SWE), have been used for monitoring drought/flood over United States [http://www.emc.ncep.noaa.gov/mmb/nldas/drought/Stream/].

NLDAS Data

NLDAS is a collaboration project among several groups (NOAA/NCEP/EMC, NASA/GSFC, Princeton University, University of Washington, NOAA/OHD, and NOAA/NCEP/CPC) and is a core project of NOAA/MAPP. To date, NLDAS, with satellite- and ground-based observational forcing data, has produced more than 34 years (1979 to present) of quality-controlled, spatially and temporally consistent, land-surface model data [Xia et al. 2012, Xia et al. 2013, and Luo et al. 2002]. The original NLDAS-2 data generated by NOAA/NCEP/EMC, both retrospective and realtime, are accessible via ftp from http://www.emc.ncep.noaa.gov/mmb/nldas/.

To further facilitate analysis of water and energy budgets and trends, the NASA GSFC Hydrological Sciences Laboratory (HSL) has generated NLDAS monthly and monthly climatology data sets. NLDAS monthly data are generated from the NLDAS hourly data, consisting of monthly accumulations for precipitation, runoff, evaporation, and snow melt; and monthly averages for other variables. NLDAS monthly climatology data are generated from the NLDAS monthly data as an 11-year (1997 – 2007) monthly average for NLDAS Phase 1 (NLDAS-1) data, and a 30-year (1980 – 2009) monthly average for NLDAS Phase 2 (NLDAS-2) data. More information about NLDAS is provided in NLDAS README documents at http://disc.sci.gsfc.nasa.gov/hydrology/documentation and the NLDAS web sites. Table 2 below lists all the NLDAS data sets currently available at the NASA GES DISC. The NLDAS-2 data sets from Sacramento (SAC) model and Variable Infiltration Capacity (VIC) model will also become accessible from the Hydrology Data Holdings Portal in the near future.

The NLDAS data sets (listed in Table 2) currently available from the NASA GES DISC can be accessed, along with the README documents, from the Hydrology Data Holdings Portal, http://disc.sci.gsfc.nasa.gov/hydrology/data-holdings, through the following access methods:

- **Mirador search and download:** http://mirador.gsfc.nasa.gov/
- **Simple Subset Wizard (SSW):** http://disc.gsfc.nasa.gov/SSW/
- **Direct ftp:** ftp://hydro1.sci.gsfc.nasa.gov/data/s4pa/NLDAS/
- **GrADS Data Server (GDS):** http://hydro1.sci.gsfc.nasa.gov/dods/
- **Giovanni Visualization and analysis:** Giovanni is a Web-based application developed by the GES DISC that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science remote sensing data without having to download the data. NLDAS data sets can be accessed through following Giovanni portals:
  - NLDAS Hourly Portal for hourly data visualization and analysis: http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=NLDAS0125_H
  - NLDAS Monthly Portal for monthly, and monthly climatology and anomaly visualization and analysis: http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=NLDAS0125_M
  - NLDAS Monthly Climatology Portal for monthly climatology visualization and analysis: http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=NLDAS0125_MClim

Summary

Four of the 2011 billion-dollar weather/climate disasters are illustrated by using NLDAS-2 Primary Forcing and Noah model data. The high resolution data is clearly able to capture and describe the details in evolutions and structures of these extreme weather events, such as winter blizzard, hurricane, heat wave, and drought. The data shows very well the major characteristics of these extreme events, spatially and temporally. The information provided by NLDAS-2 data is very much consistent with in-situ and remote sensing observations during the events. NLDAS-2 data is an excellent data source for case studies of extreme events.

To date, NLDAS has generated more than 34 (1979 – present) years of data. These quality-controlled, spatially and temporally consistent, terrestrial hydrological data could play an important role in characterizing the spatial and temporal variability of water and energy cycles and, thereby, improve our understanding of the land-surface-atmosphere interaction and the impact of land-surface processes on climate extremes.

NLDAS data are accessible from the Hydrology Data Holdings portal at the NASA GES DISC. Giovanni NLDAS Portals provide a simple and intuitive way to visualize, analyze, and inter-compare NLDAS data without having to download the data.

References

Anderson et al., 2013: An Intercomparison of Drought Indicators Based on Thermal Remote Sensing and NLDAS-2 Simulations with U.S. Drought Monitor Classifications. *J. Hydrometeor*, **14**, 1035–1056. doi: http://dx.doi.org/10.1175/JHM-D-12-0140.1

Ek, M. B., et al., 2011: North American Land Data Assimilation System Phase 2 (NLDAS-2): its Development and Application to Support US Drought Monitoring and Prediction of National Integrated Drought Information System (NIDIS). *GEWEX News*, **21**, 7-9.

Lee, S., et al., 2010: Assessing the hydrologic performance of the EPA's nonpoint source water quality assessment decision support tool using North American Land Data Assimilation System (NLDAS) products. *Journal of Hydrology*, ISSN 0022-1694, 2010, Volume 387, Issue 3, pp. 212 – 220. DOI: http://dx.doi.org/10.1016/j.jhydrol.2010.04.009

Luo, L., et al., 2002: Validation of the North American Land Data Assimilation System (NLDAS) retrospective forcing over the Southern Great Plains, *J. Geophys. Res*., 108 (D22), 8843, doi:10.1029/2002JD003246, 2003.

Mitchell et al., 2004: The multi-institution North American Land Data Assimilation System (NLDAS): Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system, *J. Geophys. Res.*, 109, D07S90, doi:10.1029/2003JD003823.

Mo, Kingtse C., Lindsey N. Long, Youlong Xia, S. K. Yang, Jae E. Schemm, Michael Ek, 2011: Drought Indices Based on the Climate Forecast System Reanalysis and Ensemble NLDAS. *J. Hydrometeor*, **12**, 181–205, doi: http://dx.doi.org/10.1175/2010JHM1310.1.

Pan, M., et al., Snow process modeling in the North American Land Data Assimilation System (NLDAS): 2. Evaluation of model simulated snow water equivalent, *J. Geophys. Res*., 108 (D22), 8850, doi:10.1029/2003JD003994, 2003.

Sheffield, J., Y. Xia, L. Luo, E.F. Wood, M. Ek, K. E. Mitchell, and the NLDAS Team, 2012: The North American Land Data Assimilation System (NLDAS): A framework for merging model and satellite data for improved drought monitoring, in: Remote Sensing and Drought, edited by: Wardlow, B.,25 Anderson, M., and Verdin, J., *CRC Press*, 480 pp., 2012.

Sheffield, J. et al., 2003: Snow process modeling in the North American Land Data Assimilation System (NLDAS): 1. Evaluation of model-simulated snow cover extent, *J. Geophys. Res.*, 108 (D22), 8849, doi:10.1029/2002JD003274.

Xia, Y. et al., 2013: Validation of Noah-Simulated Soil Temperature in the North American Land Data Assimilation System Phase 2. *J. Appl. Meteor. Climatol.*, **52**, 455–471. DOI: http://dx.doi.org/10.1175/JAMC-D-12-033.1

Xia, Y., B. A. Cosgrove, M. B. Ek, J. Sheffield, L. Luo, E. Wood, K. Mo, and the NLDAS team, 2013: Overview of the North American Land Data Assimilation System (NLDAS), in: Land Data Observation, Modeling and Assimilation, edited by: Liang et al., *World Scientific*, pp337-375.

Xia, Y., et al, 2012: Continental-scale water and energy flux analysis and validation for North American Land Data Assimilation System project phase 2 (NLDAS-2): 2. Validation of model-simulated streamflow, *J. Geophys. Res.*, 117, D03110, doi:10.1029/2011JD016051.

Xia, Y., M.B. Ek, H. Wei, H. and J. Meng, 2012: Comparative analysis of relationships between NLDAS-2 forcings and model outputs. *Hydrol. Process.,* 26: 467–474. doi: 10.1002/hyp.8240.

Xia, Y., et al., 2012: Continental-scale water and energy flux analysis and validation for the North American Land Data Assimilation System project phase 2 (NLDAS-2): 1. Intercomparison and application of model products. *J. Geophys. Res.*, DOI: 10.1029/2011JD016048

List of Tables

Table 1: A list of the 14 billion-dollar disasters 2011 in United States.

Extreme Event	**Date**
Groundhog Day blizzard	Jan. 29 - Feb. 3, 2011
Midwest/Southeast tornadoes	April 4-5, 2011
Southeast/Midwest tornadoes	April 8-11, 2011
Midwest/Southeast tornadoes	April 14-16, 2011
Southeast/Ohio Valley/Midwest tornadoes	April 25-28, 2011
Midwest/Southeast tornadoes	May 22-27, 2011
Midwest/Southeast tornadoes and severe weather	June 18-22, 2011
Southern Plains/Southwest drought and heat wave	Spring-Fall, 2011
Mississippi River flooding	Spring-Summer, 2011
Rockies and Midwest severe weather	July 10-14, 2011
Upper Midwest flooding	Summer 2011
Hurricane Irene	August 20-29, 2011
Texas, New Mexico, Arizona wildfires	Spring-Fall 2011
Tropical Storm Lee	Early Sep., 2011

Table 2: NLDAS data set available at NASA GES DISC.

Data set short name	Description	Temporal coverage
Hourly		
NLDAS_FOR0125_H.001	NLDAS-1 hourly forcing	00Z01Aug1996 - 23Z31Dec2007
NLDAS_FORA0125_H.002	NLDAS-2 hourly primary forcing	13Z01Jan1979 - present
NLDAS_FORB0125_H.002	NLDAS-2 hourly secondary forcing	13Z01Jan1979 - present
NLDAS_MOS0125_H.002	NLDAS-2 hourly Mosaic model	00Z02Jan1979 - present
NLDAS_NOAH0125_H.002	NLDAS-2 hourly Noah model	01Z02Jan1979 - present
Monthly		
NLDAS_FOR0125_M.001	NLDAS-1 monthly forcing	Aug1996 - Dec2007
NLDAS_FORA0125_M.002	NLDAS-2 monthly primary forcing	Jan1979 - present
NLDAS_FORB0125_M.002	NLDAS-2 monthly secondary forcing	Jan1979 - present
NLDAS_MOS0125_M.002	NLDAS-2 monthly Mosaic model	Jan1979 - present
NLDAS_NOAH0125_M.002	NLDAS-2 monthly Noah model	Jan1979 - present
Monthly Climatology		
NLDAS_FOR0125_MC.001	NLDAS-1 monthly climatology forcing	Jan1997 - Dec2007
NLDAS_FORA0125_MC.002	NLDAS-2 monthly climatology primary forcing	Jan1980 - Dec2009
NLDAS_FORB0125_MC.002	NLDAS-2 monthly climatology secondary forcing	Jan1980 - Dec2009
NLDAS_MOS0125_MC.002	NLDAS-2 monthly climatology Mosaic model	Jan1980 - Dec2009
NLDAS_NOAH0125_MC.002	NLDAS-2 monthly climatology Noah model	Jan1980 - Dec2009

Figure Captions

Figure 1: Spatial distribution of billion- dollar disasters 2011 in United States (Curtsey: NOAA http://www.noaanews.noaa.gov/stories2012/20120119_global_stats.html)

Figure 2a: 1980-2011 billion dollar weather /climate disasters. (Courtesy: NOAA, http://www.noaanews.noaa.gov/stories2011/20111207_novusstats.html)

Figure 2b: Area-averaged time series of anomaly precipitation, temperature, and soil moisture content. The precipitation anomalies (black line) are the monthly accumulated precipitation from NLDAS Primary Forcing, with the climatology removed. The temperature anomalies (red line) are the monthly 2-meter above ground temperature from NLDAS-2 Primary Forcing, with the climatology removed. The soil moisture anomalies (green line) are the monthly top 1-meter soil moisture content from NLDAS-2 Noah model, with the climatology removed. The climatology is a 30-year (1980 – 2009) monthly climatology. The region for the area-averaged is the central United States (100W ~ 90W, 32N ~ 42N). 3-month running mean was applied to each of the time series.

Figure 3a: Accumulated snowfall from NLDAS-2 Noah model, accumulated between 12Z Jan. 31, 2011 and 23Z Feb. 2, 2011. "Z" refers to Coordinate Universal Time (UTC), also known as Greenwich Mean Time.

Figure 3b: NLDAS-2 10-meter above ground wind (averaged between 12Z Jan. 31 and 23Z Feb. 2, 2011) overlaying on the NLDAS-2 precipitation (liquid and frozen rain, accumulated between the same temporal rang).

Figure 3c: Time series of the snowfall from NLDAS-2 Noah model, area-averaged over the parts of Missouri (black line: 95W ~ 90W, 37N ~ 39N), the parts of Illinois/Indiana (green line: 90W ~ 80W, 40N ~ 42N), and Massachusetts and the parts of other northern states around (blue line: 76W ~ 71W, 41N ~ 43N).

Figure 3d: Anomaly of Snow Water-Equivalent (SWE) from NLDAS-2 Noah model for Feb. 02, 2011, with respect to 28-year (1980 – 2007) daily climatology. The NLDAS-2 Noah SWE daily climatology data are provided by Dr. Youlong Xia Environmental Modeling Center (EMC), National Centers for Environmental Prediction (NCEP), National Oceanic and Atmospheric Administration (NOAA).

Figure 4a: Monthly-averaged 2-meter above ground temperature for NLDAS-2 Primary Forcing data for July 2011.

Figure 4b: Daily average 2-meter above ground temperatures of NLDAS-2 Primary Forcing over most of Oklahoma, July 2011, in degrees Kelvin. ***The red line indicates the average temperature of the data points displayed in the plot.***

Figure 4c: Time-series of 2 meter above ground air temperatures from hourly NLDAS-2 Primary Forcing data for the central United States, July 2011.

Figure 5a: NLDAS-2 Primary Forcing hourly wind overlaid on NLDAS-2 hourly precipitation every 6 hours from 00Z 27 August 2011 to 00Z 29 August 2011.

Figure 5b: Time series of hourly precipitation (black line, from NLDAS-2 Primary Forcing) and 0-10cm soil moisture content (green line, from NLDAS-2 Noah model), averaged over (80W~67W, 33N~53N).

Figure 5c: Hourly precipitation (left, from NLDAS-2 Primary Forcing) and 0-10cm soil moisture (right, from NLDAS-2 Noah model), at 14Z Aug. 28, 2011.

Figure 5d: Anomaly of total runoff from NLDAS-2 Noah model for Aug. 28, 2011 (averaged over 00Z to 23Z), with respect to 28-year (1980 – 2007) daily climatology. The NLDAS-2 Noah total runoff daily climatology data are provided by Dr. Youlong Xia, EMC/ NCEP/NOAA.

Figure 6a: Accumulated precipitation between 08Z Sep. 02 and 12Z Sep. 09, 2011 (right-top, NLDAS-2 Primary Forcing) shows three heavy rain centers, with accumulated rainfall exceeding 10 inches (254 mm).

Figure 6b: Area-averaged time series of hourly Precipitation (right-bottom, NLDAS-2 Primary Forcing) for the three heavy rain regions depicted by the boxes in Figure 13 shows clearly when the heaviest rain started and ended.

Figure 6c: Time series of precipitation and 0-10 cm soil moisture, from NLDAS-2 Primary Forcing and Noah model respectively, averaged over the three heavy rain regions depicted by the boxes in Figure 6a.

Figure 6d: Anomaly of total runoff (no-infiltrating) from NLDAS-2 Noah model for Sep. 05, 2011 (averaged over 00Z to 23Z), with respect to 28-year (1980 – 2007) daily climatology. The NLDAS-2 total runoff daily climatology data are provided by Dr. Youlong Xia, EMC/ NCEP/NOAA.

Figure 6e: Anomaly of Routed Stream flow from NLDAS-2 Noah model for Sep. 05, 2011 (averaged over 00Z to 23Z), with respect to 28-year (1980 – 2007) daily climatology. The NLDAS-2 hourly stream flow and daily climatology data are provided by Dr. Youlong Xia, EMC/ NCEP/NOAA.

Figure 1

Figure 2a

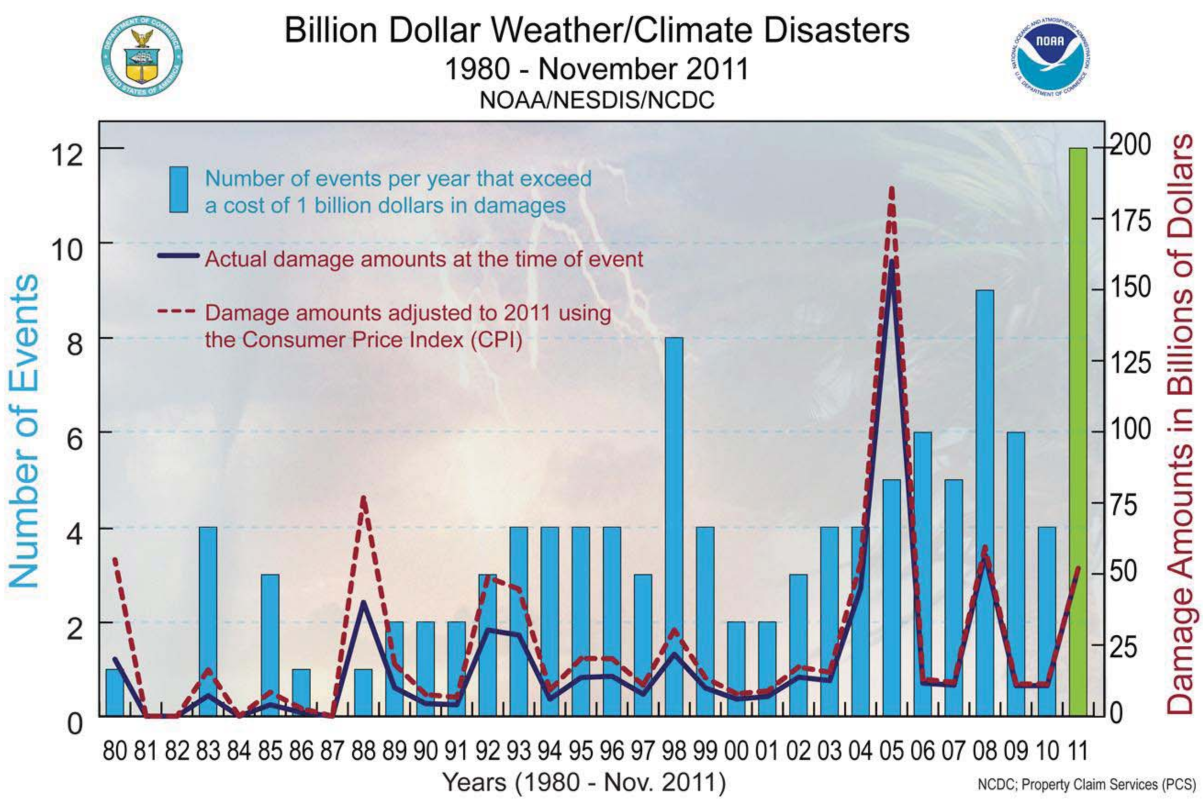


Figure 2b

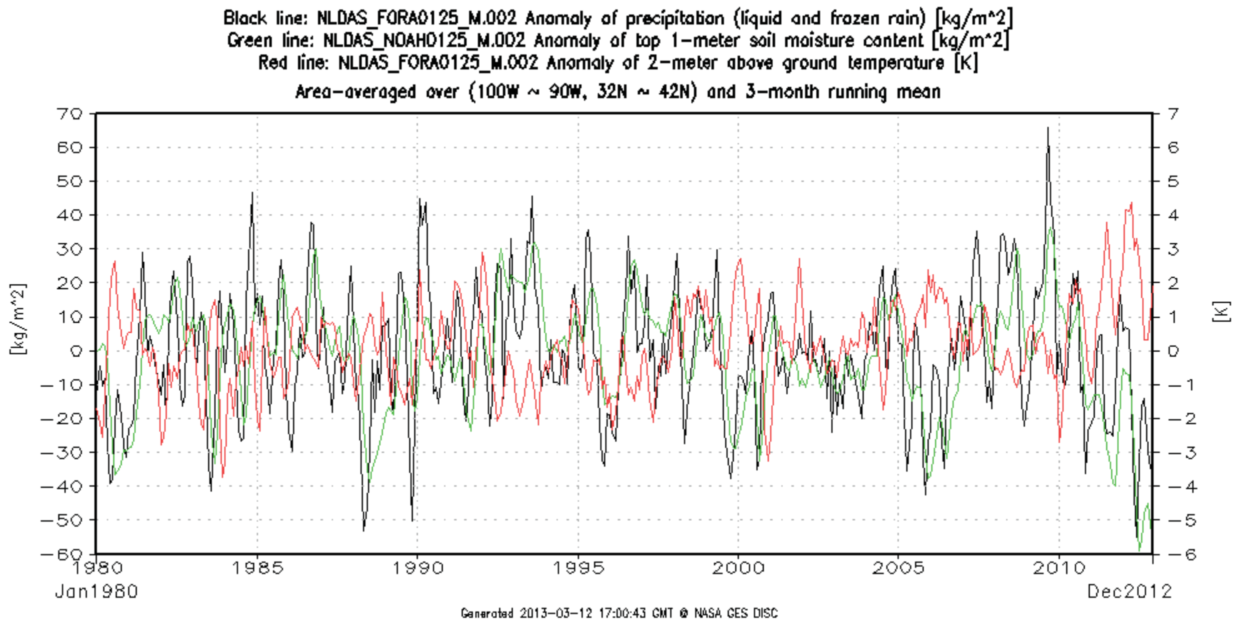


Figure 3a

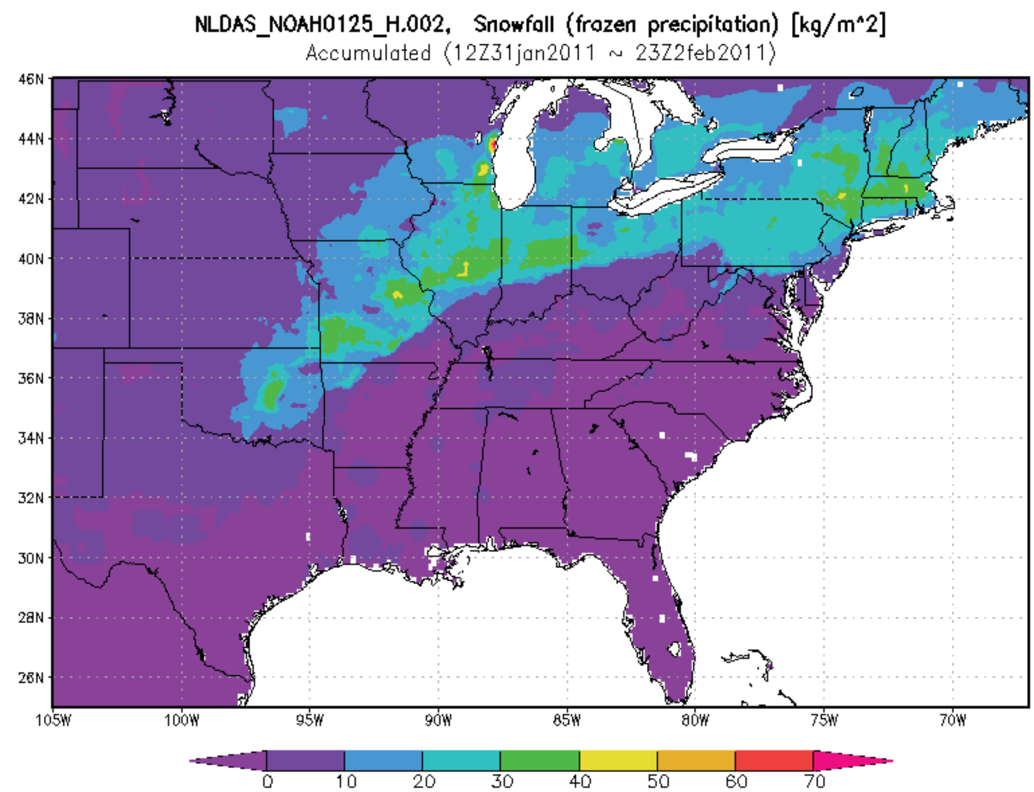


Figure 3b

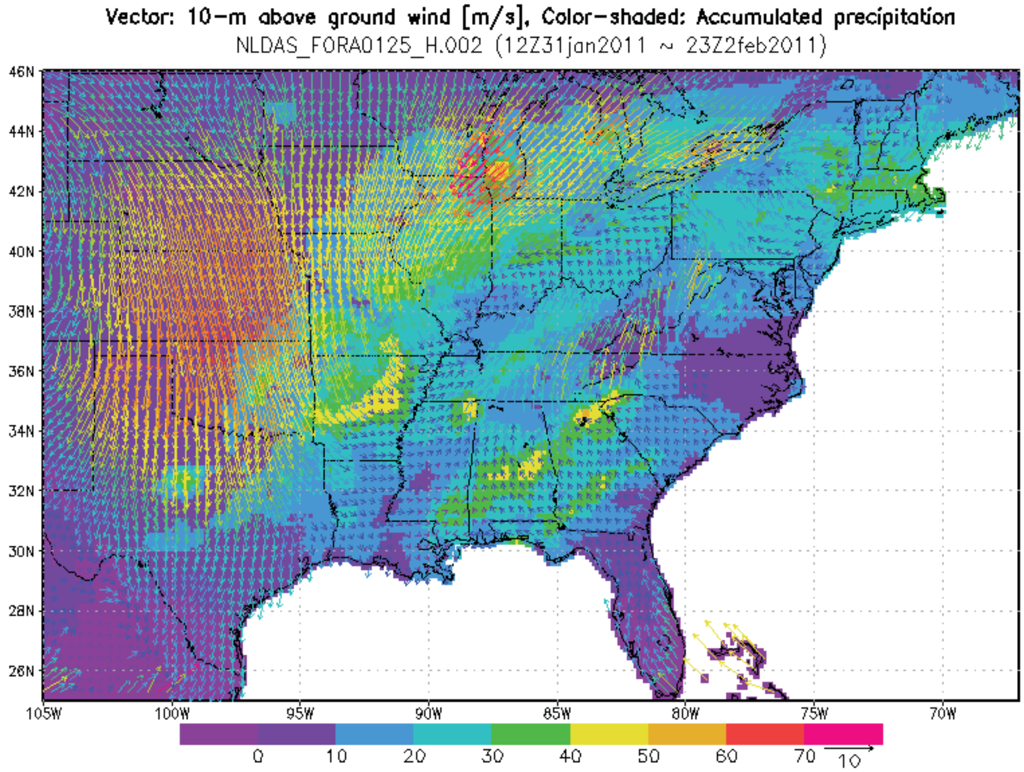

Vector: 10-m above ground wind [m/s], Color-shaded: Accumulated precipitation
NLDAS_FORA0125_H.002 (12Z31jan2011 ~ 23Z2feb2011)
46N
44N
42N
40N
38N
36N
34N
32N
30N
28N
26N
105W
100W
95W
90W
85W
80W
75W
70W
0
10
20
30
40
50
60
70
10

Figure 3c

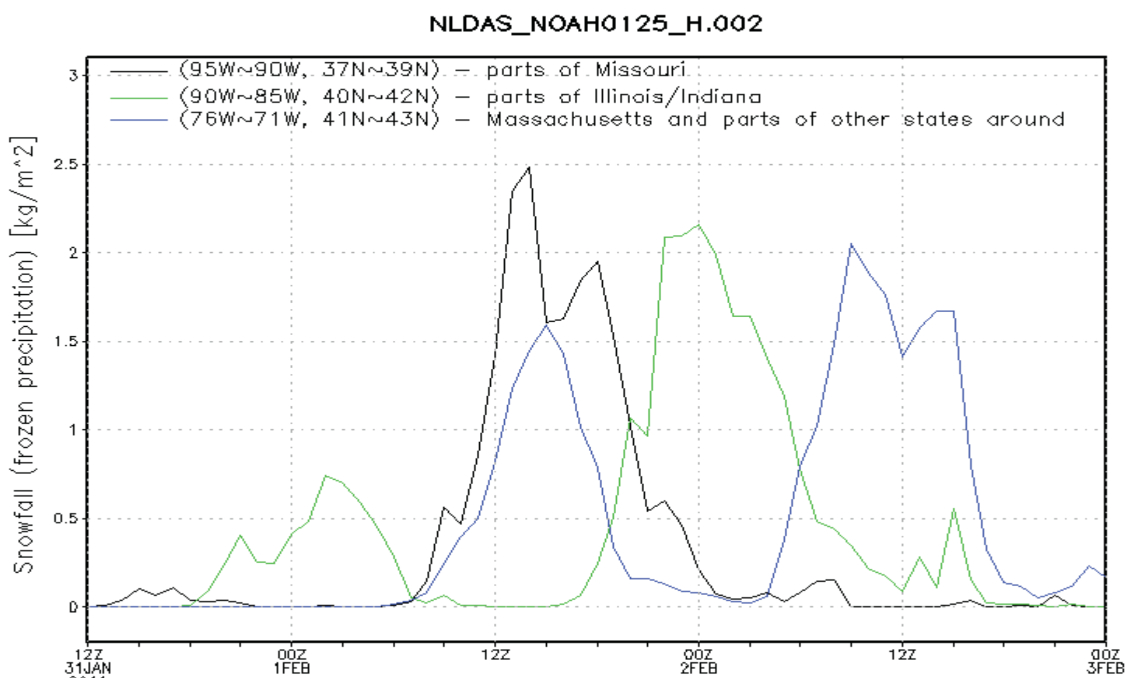

NLDAS_NOAH0125_H.002
(95W~90W, 37N~39N) – parts of Missouri
(90W~85W, 40N~42N) – parts of Illinois/Indiana
(76W~71W, 41N~43N) – Massachusetts and parts of other states around
Snowfall (frozen precipitation) [kg/m^2]
3
2.5
2
1.5
1
0.5
0
12Z
31JAN
2011
00Z
1FEB
12Z
00Z
2FEB
12Z
00Z
3FEB

Figure 3d

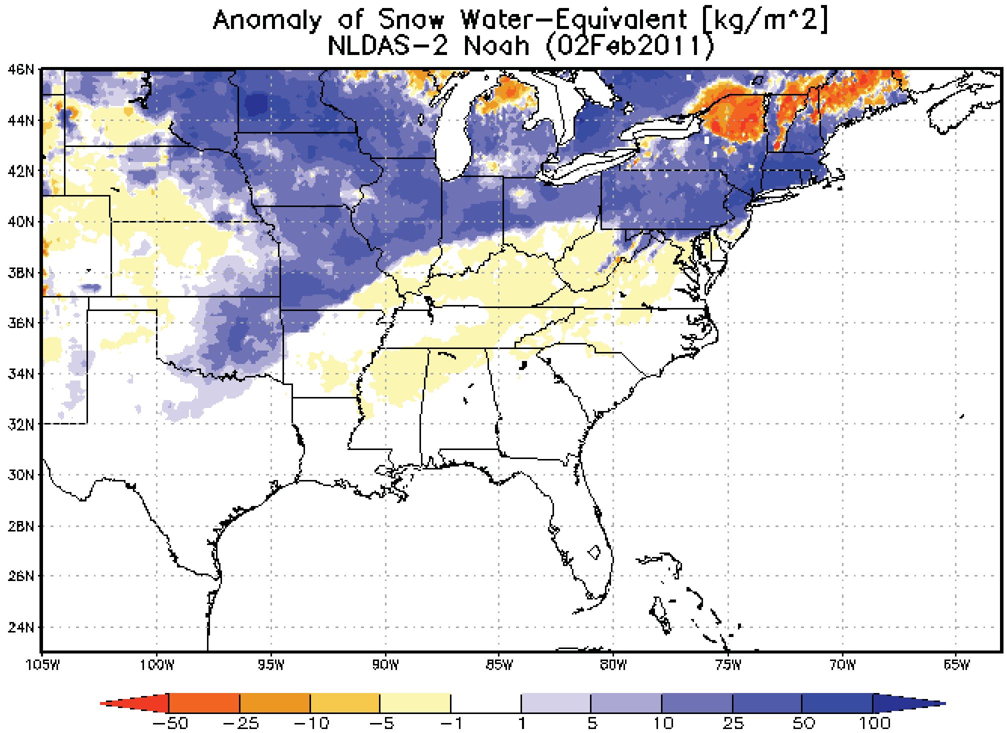


Figure 4a

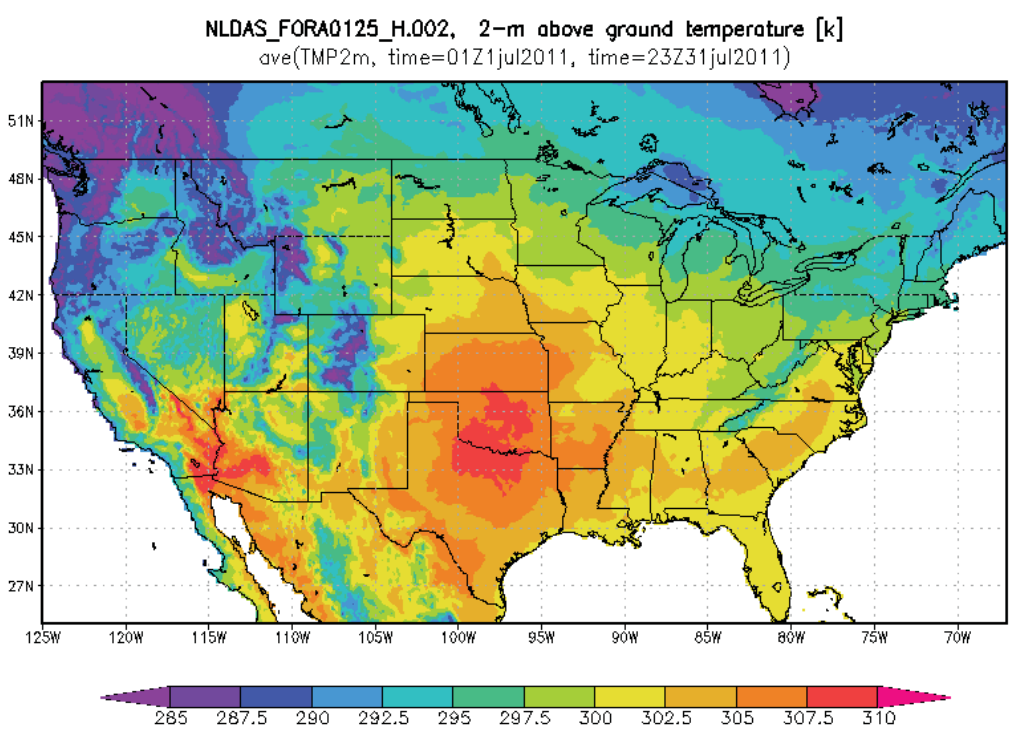


Figure 4b

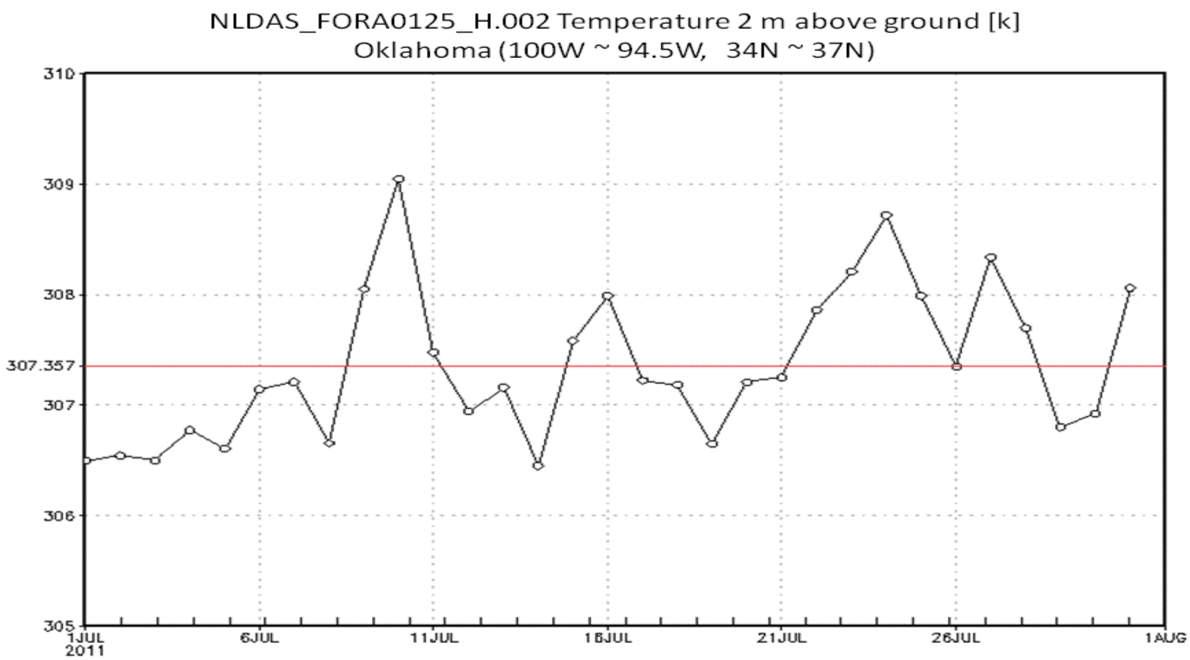


Figure 4c

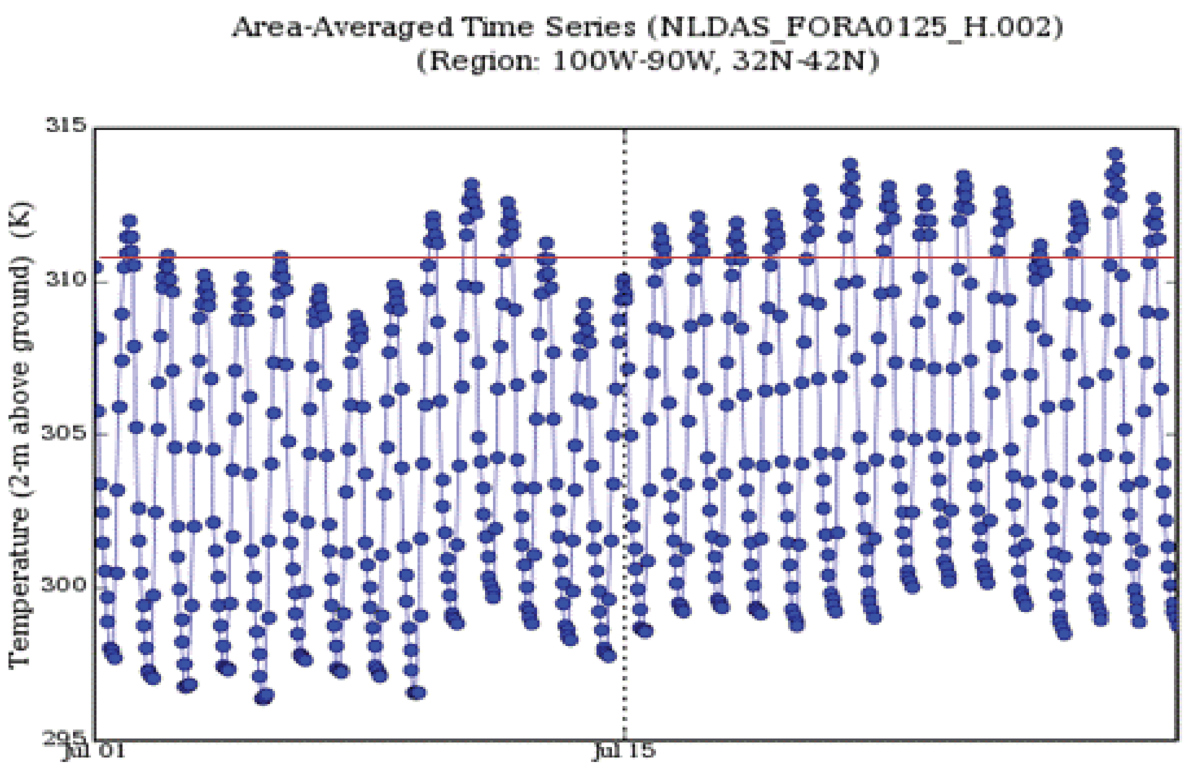


Figure 4d

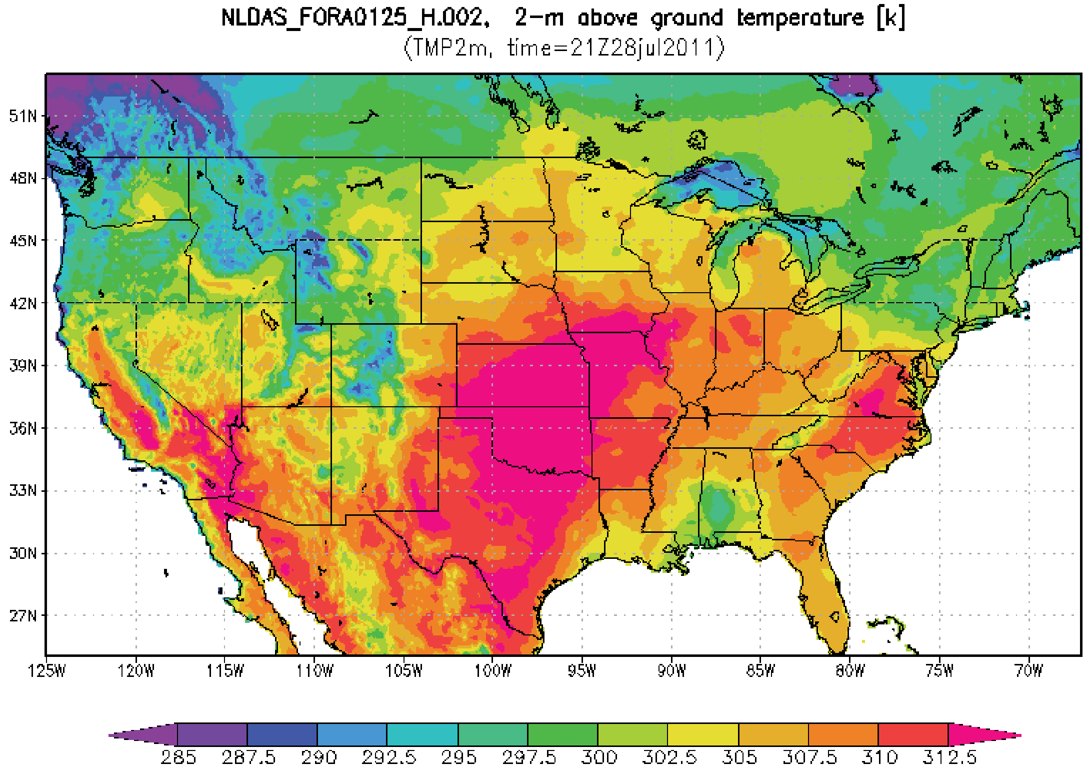

NLDAS_FORA0125_H.002, 2-m above ground temperature [k]
(TMP2m, time=21Z28jul2011)
51N
48N
45N
42N
39N
36N
33N
30N
27N
125W
120W
115W
110W
105W
100W
95W
90W
85W
80W
75W
70W
285
287.5
290
292.5
295
297.5
300
302.5
305
307.5
310
312.5

Figure 5a

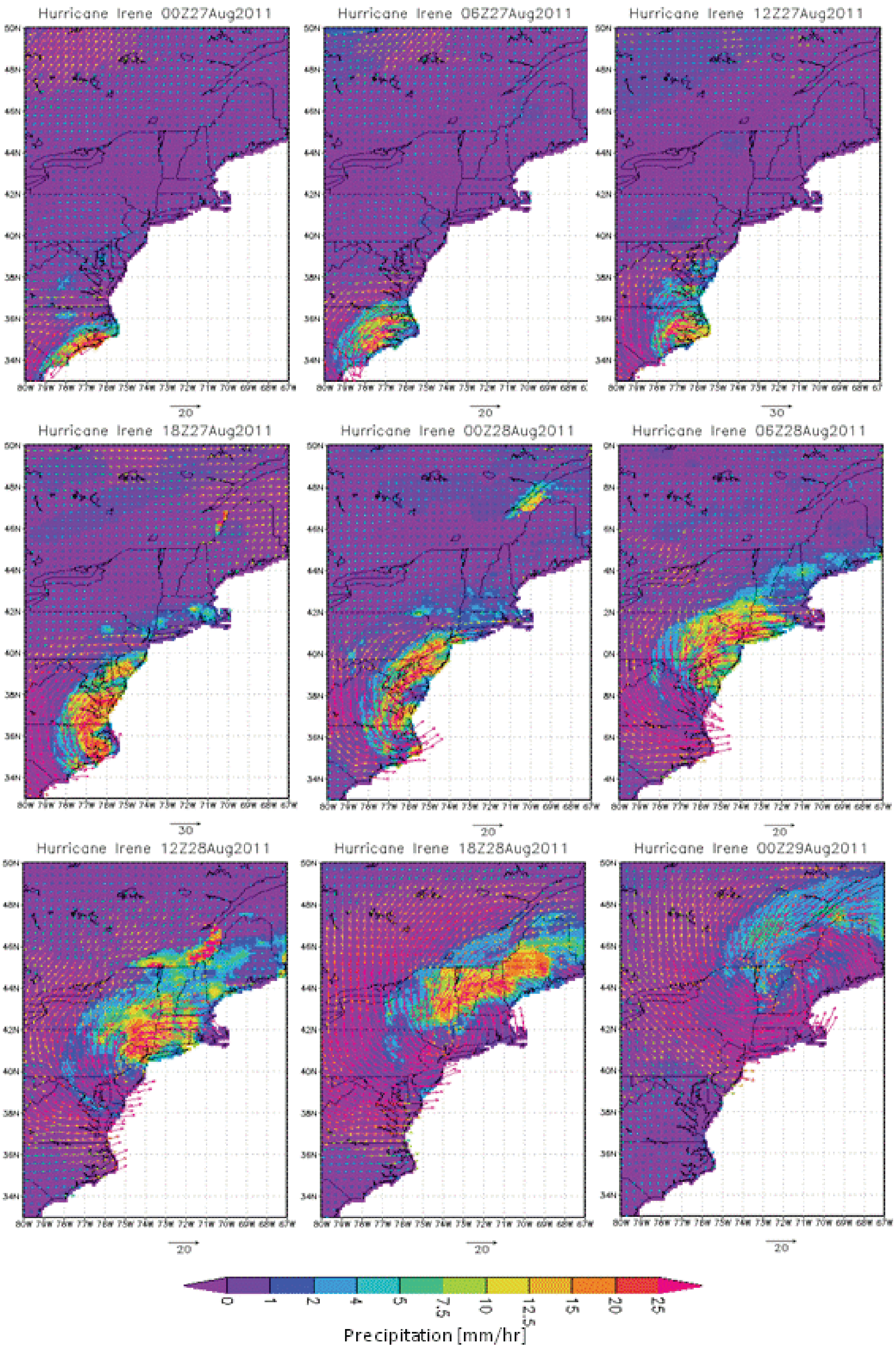

Hurricane Irene 00Z27Aug2011
Hurricane Irene 06Z27Aug2011
Hurricane Irene 12Z27Aug2011
Hurricane Irene 18Z27Aug2011
Hurricane Irene 00Z28Aug2011
Hurricane Irene 06Z28Aug2011
Hurricane Irene 12Z28Aug2011
Hurricane Irene 18Z28Aug2011
Hurricane Irene 00Z29Aug2011
0
1
2
4
5
7.5
10
12.5
15
20
25
Precipitation [mm/hr]

Figure 5b

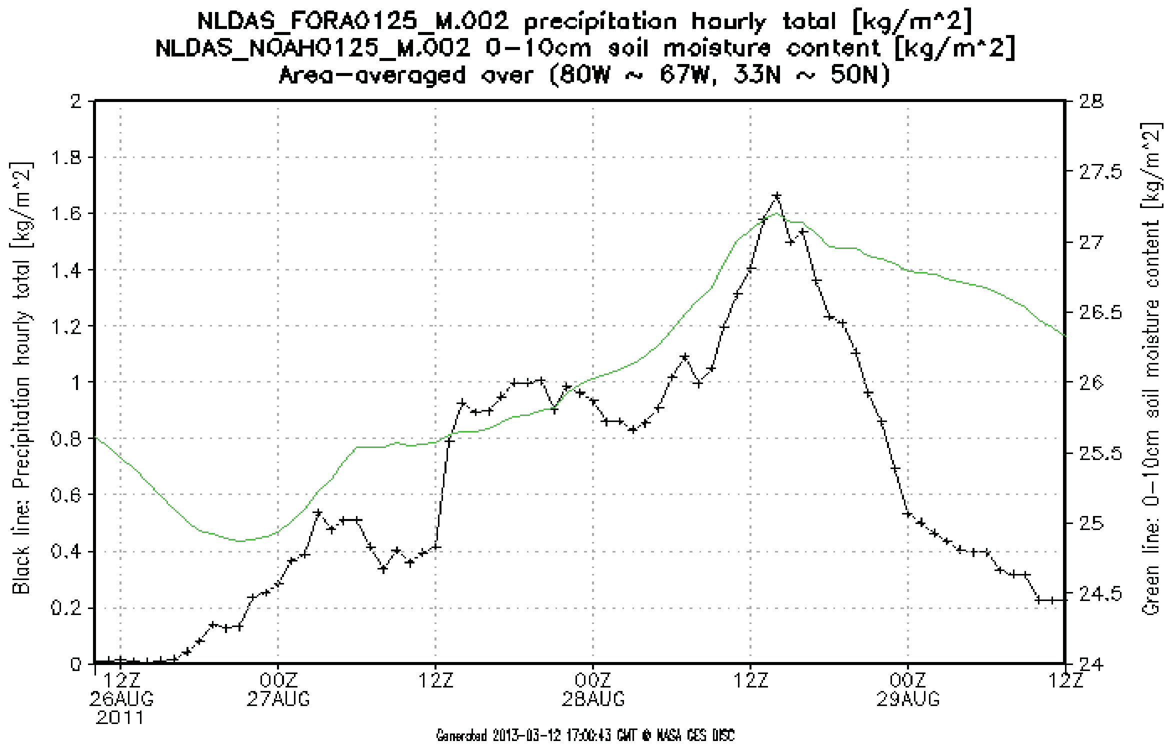


Figure 5c

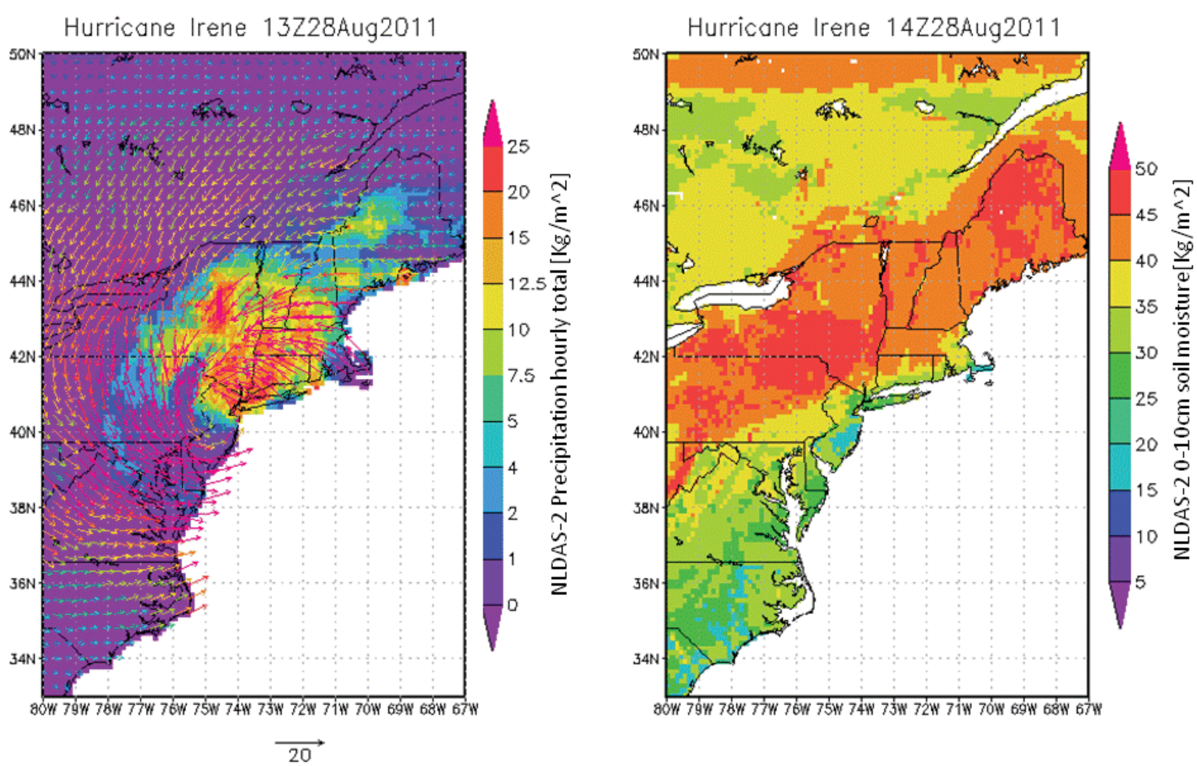
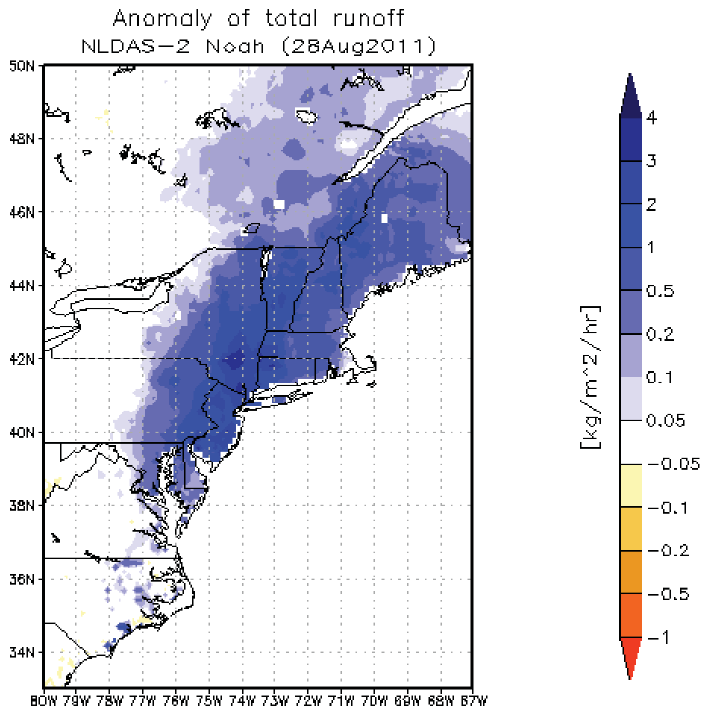


Figure 5d



Anomaly of total runoff
NLDAS-2 Noah (28Aug2011)
50N
48N
46N
44N
42N
40N
38N
36N
34N
80W 79W 78W 77W 76W 75W 74W 73W 72W 71W 70W 69W 68W 67W
[kg/m^2/hr]
4
3
2
1
0.5
0.2
0.1
0.05
−0.05
−0.1
−0.2
−0.5
−1

Figure 6a

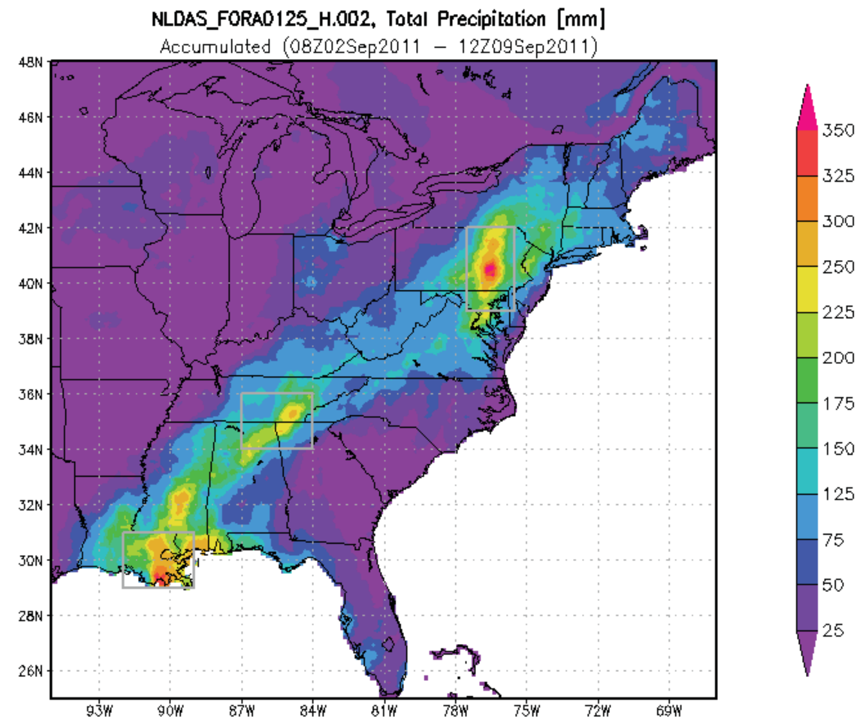


Figure 6b

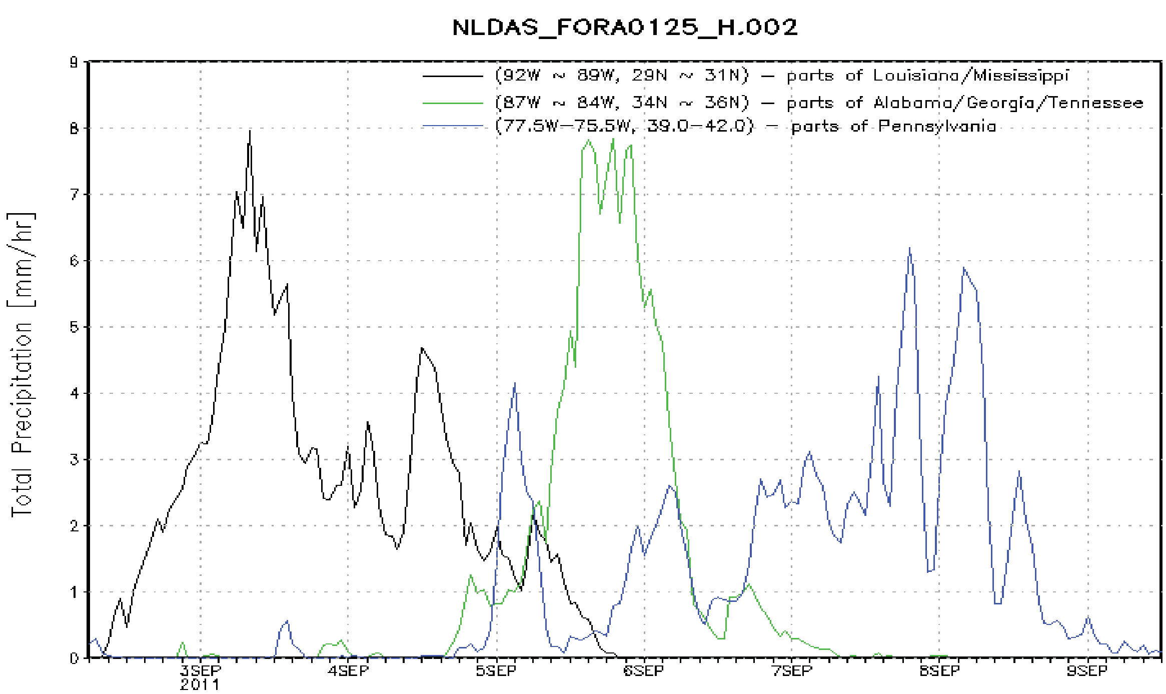
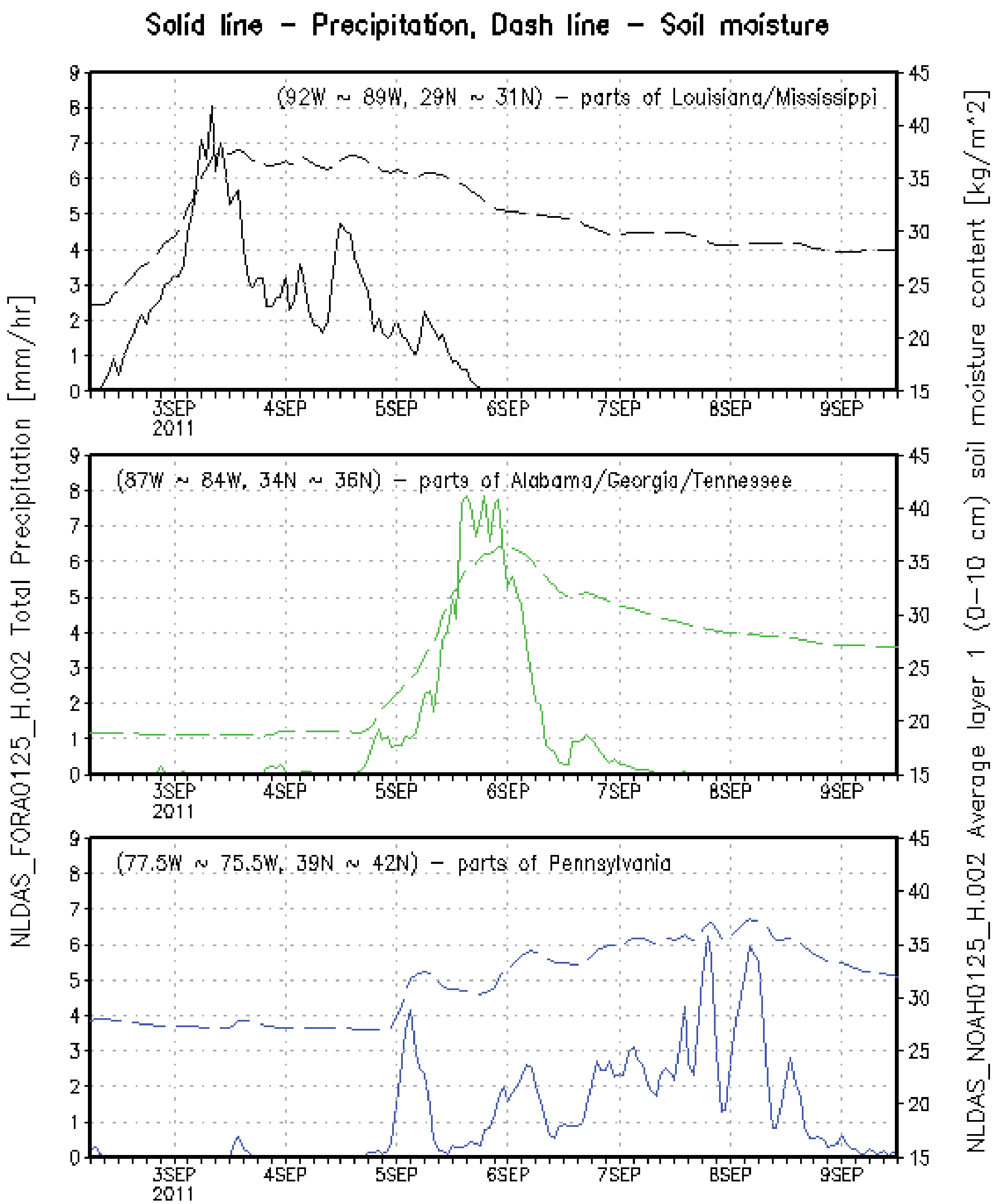


Figure 6c



Solid line - Precipitation, Dash line - Soil moisture
(92W ~ 89W, 29N ~ 31N) - parts of Louisiana/Mississippi
(87W ~ 84W, 34N ~ 36N) - parts of Alabama/Georgia/Tennessee
(77.5W ~ 75.5W, 39N ~ 42N) - parts of Pennsylvania
NLDAS_FORA0125_H.002 Total Precipitation [mm/hr]
NLDAS_NOAH0125_H.002 Average layer 1 (0-10 cm) soil moisture content [kg/m^2]
3SEP
2011
4SEP
5SEP
6SEP
7SEP
8SEP
9SEP

Figure 6d

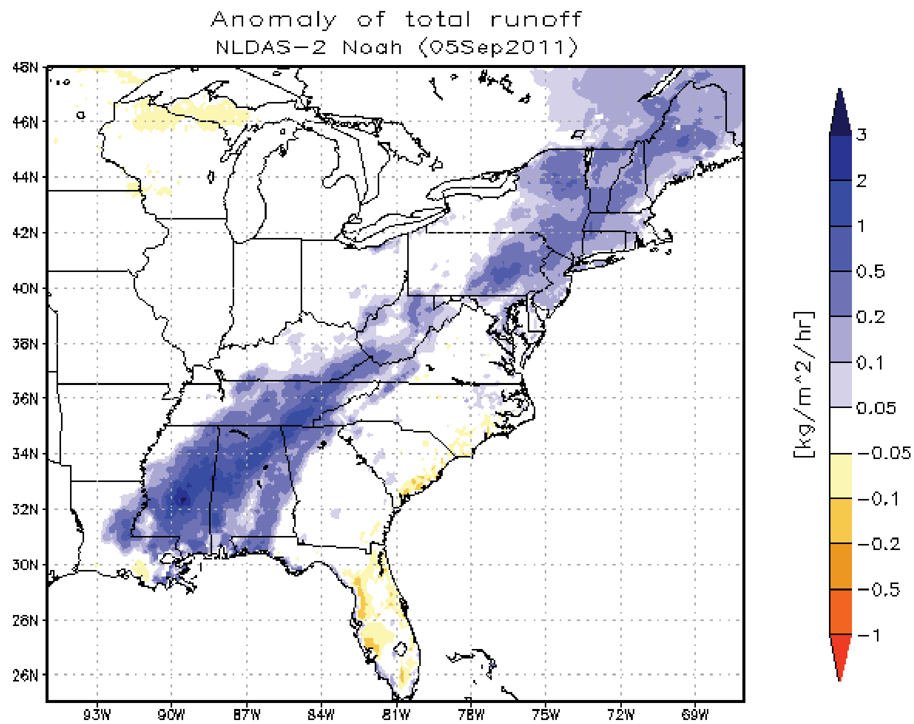


Figure 6e