ASSIMILATION OF MODIS SNOW COVER DATA INTO SNOWMODEL

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MOTIVATION

One of the big unanswered questions within the snow modeling and snow remote sensing communities is how to best and fully assimilate high resolution snow covered data observations like those provided by Moderate Imaging Spectroradiometer (MODIS). The object of this work is to assess the impact of using MODIS snow cover product with a snow evolution model. The significance of this work is that it allows us to model snow pack, and hence snow water equivalence, in remote areas where there are fewer land based observations. As the sources of many rivers in the Western part of the United States are based in the Rockies we need observations of snow cover to ascertain the drought or flooding prospects later in the year. Given these observations we need a model to evolve the information as the observations can be cloud contaminated and hence we do not know how much snow has melted or been increased. The snow evolution model enables us to model the life of snow in areas where MODIS observation may not be able to see the snow below canopies as well as in canyons or on the side of mountains. However, MODIS gives us information to correct processes that the model does wrong in areas where MODIS can view.

EXPERIMENTAL DESIGN

In this work we are starting to build an assimilation system with the SnowModel system (Liston and Elder, 2006). SnowModel is a spatially-distributed snow-evolution modeling system designed for application in all landscapes, climates and conditions where snow occurs. It is designed to run on grid increments of 1 to 500m and temporal increments of 10 minutes to 1 day. Simulated processes in SnowModel include accumulation from snow precipitation; blowing snow redistribution and sublimation; interception, unloading, and sublimation within forest canopies; snow density evolution; and snowpack ripening and melt.

For the initial set up we have chosen two different areas where the topography and vegetation represent an interesting challenge for SnowModel as well as for MODIS. The first is a 2 degree latitude by 2 degree longitude box between 40N to 42N and from -105E to -103E. This area covers North East Colorado, South East Wyoming and Western Nebraska. Included in this region is the Cheyenne Ridge, part of the Medicine Bow Mountain Range as well as the South Platte river basin. The two cities of Cheyenne, WY and Greeley, CO are included in this domain. There is also a 350m difference in elevation from the southern part of the domain to the northern part.

The second area that the model is run over is a 1 degree latitude by a 2 degree longitude box between 37 N to 38N and from -104E to -102E. This the south east corner of Colorado. In this domain is the Purgatory Canyon as well as a 600 meter decrease in elevation from the western part to the eastern part. See Figure 1 for topographical and land cover plots of the two domains.

The reason for choosing these two areas is that the model is run over the 2006 – 2007 winter. This was the winter where two large blizzards hit Colorado and Wyoming about 7 days apart. These two storms left large parts of Colorado and Wyoming covered with snow for over 60 days.

The external forcing for the model comes from the North American Land Data Assimilation system (NLDAS; Mitchell *et al.* 2004). From this output the model uses air temperature, relative humidity, wind speed, wind direction, and precipitation. The hourly NLDAS data are available on a 1/8th degree grid covering the conterminous United States.

MODIS

The Moderate Resolution Imaging Spectroradiometer is a 36 channel visible to thermal-infrared sensor that was first launched as part of the Earth Observing System (EOS) Terra payload on the 18th December, 1999. A second MODIS was launched as part of the payload on the Aqua satellite on May 4th, 2002. There are a variety of snow and ice products which are produced form the MODIS sensor, and the products are available at many different spatial and temporal resolutions. Most of the products are archived at the National Snow and Ice Data Center (NSIDC) in Boulder, CO.

The product that will be used first in this project is the snow cover product. This product is at 500m resolution over the 2330km swath. The product is in a sinusoidal projection. The snow cover product is generated using the MODIS calibrated radiance data products (MOD02HKM and MYD02HKM), the geolocation products (MOD03 and MYD03), and the cloud mask products (MOD35_L2 and MYD35_L2) as inputs. More details of the algorithm can be found in Hall *et al.* (2002).

MODEL TEST DOMAINS

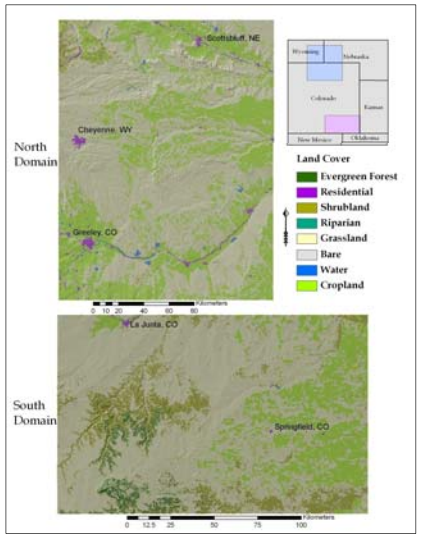


Figure 1: Topographical and land cover maps for the two domains that the data assimilation system is to be run on

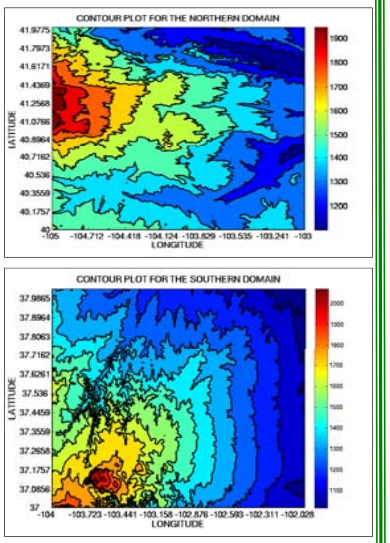


Figure 2: Contour plots of the elevation changes over the two test domains. Units are in meters.

BLIZZARDS OF 2006

The **Holiday Blizzard I** was an intense blizzard that covered Colorado's Front Range, Eastern plains and the surrounding states. It started in Colorado on the 20th December, 2006. Blizzard I closed Denver International Airport (DIA), (see Figure 3), from 2:45pm MST on the 20th till 12pm MST on the 22nd. There were reports of snow drifts up to 6 feet deep in parts of Denver and on the road to DIA. Figure 4 shows the show totals from Blizzard I.

Figure 3: Photo of snow cover at DIA on the 21st December 2006

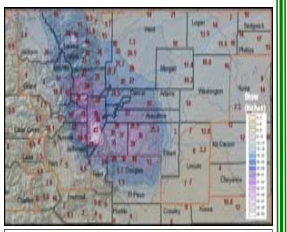


Figure 4: Snowfall totals from Holiday Blizzard I. (From the NWS office Boulder)

Holiday Blizzard II was arguably a more intense storm than the first blizzard but hit the south eastern corner of CO. The storm struck CO on December 28th and 29th. Out in the plains snow drifts as high as 10' were reported. Many of the farms and smaller towns are cut off with cattle having hay air dropped to try and save them . Figures 5 and 6 show the snow totals for Blizzard II and the combined snowfall totals respectively

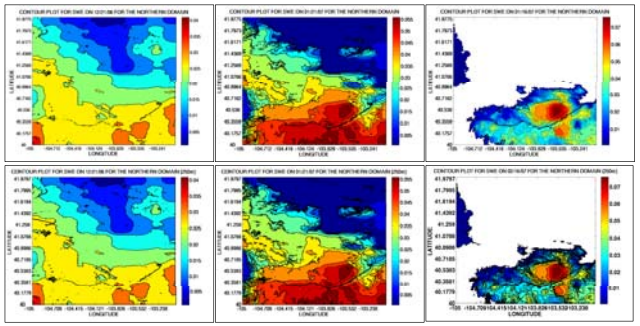
Figure 5: Snowfall totals for Holiday Blizzard II. (From the NWS Boulder)

Figure 6: Combined snowfall totals from Holiday Blizzards I and II. (NWS Boulder)

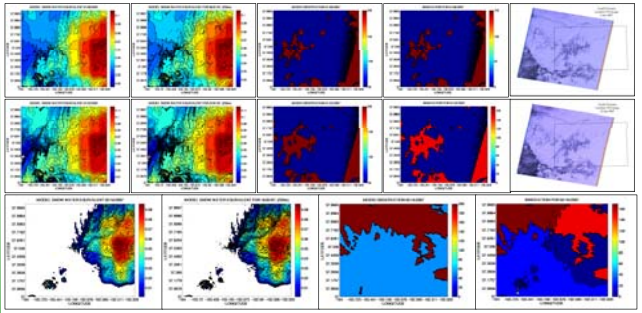
DATA ASSIMILATION

The aim of this work is to take the snow water equivalent control variable from SnowModel and convert it to the equivalent MODIS snow cover observation. Where cloud cover is present in the MODIS observation then these pixels are ignored. The eventual data assimilation system will be a 2D variational (VAR) system. However, there are challenges with MODIS observing snow cover but not how deep the snow is or how much SWE (measured in meters) is present. The next phase of development of the 2D VAR system after the MODIS observations have been assimilated first is to introduce the AMSR-E SWE observations. There are drawbacks with the AMSR-E observations; the first being that the observations are very coarse (every 25km), a second drawback is the fact AMSR-E has problems over tree canopies. Below are some snap shots of the model output for both domains (the 500m and 250m resolution), the MODIS observation for that day (***y***) (South Domain only currently), the model equivalent of the MODIS observation (***h(x)***) and the difference ***y-h(x)***.

NORTHERN DOMAIN MODEL RUNS



SOUTHERN DOMAIN MODIS OBS AND INNOVATIONS



CONCLUSIONS AND FURTHER WORK

While this work is in its early stages there are signs that the MODIS data should help to constrain SnowModel, where at the moment the model clears the snow faster than MODIS suggests. This work also is demonstrating the need to combine SWE obs with snow cover obs to give more information to the model than just the forcing conditions described in the model section.

Acknowledgments

We are grateful to Mr. John Forsythe at CIRA for his time on truncating the MODIS data to the domains that we are using. We are also grateful to Dr. Peter Romanov at NOAA/NESDIS for his help in searching for verification data for this project. The work is supported by NASA grant NNX08AV21G.