Coupling Fast All-season Soil Strength Land Surface Model with Weather Research and Forecasting Model to Assess Low-Level Icing in Complex Terrain

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1. Introduction

Icing poses as a severe hazard to aircraft safety with financial resources and even human lives hanging in the balance when the decision to ground a flight must be made. Ground icing reduces traction for aircraft lifting and takeoffs, causing 12% of weather-based accidents from 1990-2000. Ice accretion not only occurs on the ground and major aircraft components such as propellers, windshield, and wings, but also occurs on antennas, vents, intakes, and cowlings which also aid in the ability of the aircraft to fly safely. When analyzing the effects of ice on aviation, a chief cause for danger is the disruption of smooth airflow, which increases the drag force on the aircraft therefore decreasing its mechanisms' ability to create lift.

Forecasting conditions where ice may pose these types of hazards is a crucial element in assuring safety as well as aiding research efforts. Complex terrain, in particular, poses difficulty in creating accurate and robust forecasts, because of the many processes occurring between the land and atmosphere in the unique alpine environment.

Because of the complexity of these processes, land-surface models are a critical component of forecast models because they serve as a link between water sources and the atmosphere through surface and groundwater. These models have varied throughout time to become more sophisticated, from ignoring soil/vegetation effects to considering many different layers of soil and how processes at the surface interact with those layers below. Land-surface models are meant to update surface variables such as ground temperature, soil temperature and moisture profiles, snow cover, and canopy properties. All of these are often handled differently in each scheme because of the sophistication of dealing with multiple layers and their heat, moisture fluxes.

Focusing on the Presidential Mountain Range of New Hampshire under the NASA EPSCoR Icing Assessments in Cold and Alpine Environments project, one of the main goals is to create a customized, high resolution model to predict and assess ice accretion in complex terrain. The purpose of this research is to couple the Fast All-Season Soil STrength (FASST) land-surface model land-surface model with the Weather Research and Forecast (WRF) model Advanced Research WRF (WRF-ARW)to improve icing forecasts in complex terrain. Coupling FASST with the WRF-ARW may improve icing forecasts because of its sophisticated approach to handling processes such as meltwater, freezing, thawing, and others that would affect the water and energy budget and in turn affect icing forecasts.

2. The WRF-ARW and FASST Land-surface Models

2.1 The WRF-ARW Model

The WRF-ARW is a collaboratively created, flexible model designed to run on distributed computing systems for a variety of applications including forecasting research, parameterization research, and real-time numerical weather prediction. Major programs in the model include the WRF pre-processing system (WPS), ARW solver, and post-processing and visualization tools (Fig. 1).

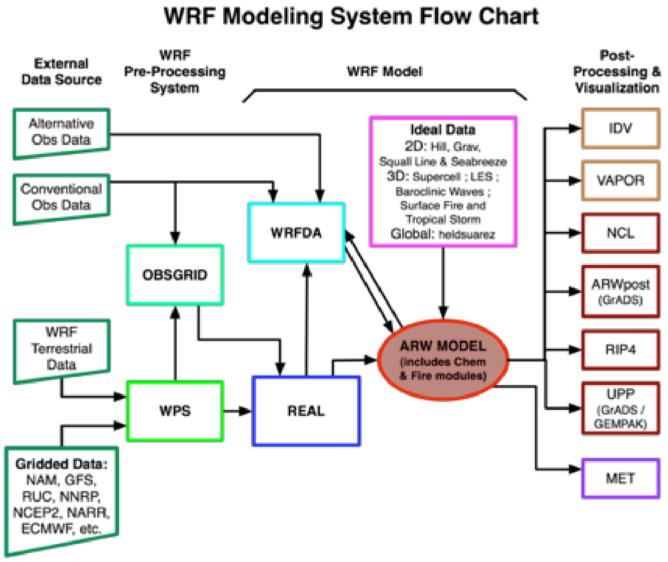

Figure 1. WRF-ARW Flowchart (WRF-ARW User's Guide)

Physics options available in the WRF-ARW include microphysics, cumulus parameterization, surface and planetary boundary layers, land-surface model, and radiation. Land-surface models provide output data on surface heat and moisture fluxes given radiation, precipitation, and surface properties (such as soil type) as input. The purpose of this type of output is to provide lower-boundary condition for use in the planetary boundary layer schemes. Table 1 specifies the land-surface models available in the WRF-ARW.

Table 1. WRF-ARW Land-surface Models

Scheme	Vegetation Processes	Soil Variables (Layers)	Snow Scheme
5-Layer Thermal Diffusion	N	Temperature (5)	None
Noah LSM	Y	Temperature, water + ice, water (4)	1-layer, fractional
Rapid Update Cycle (RUC) Model LSM	Y	Temperature, ice, water + ice (6)	Multi-layer
Pleim-Xiu LSM	Y	Temperature, moisture (2)	Input only

2.2 FASST Land-surface Model

The FASST land-surface model was developed by the U.S. Army ERDC-CRREL in Hanover, New Hampshire. Originally, FASST was intended for military purposes of providing information to mobility and sensor performance algorithms, but has since been utilized in civilian applications and research. Designed to use both meteorological and terrain data, the model calculates heat and moisture within the surface layer as well as the exchange of these parameters between the soil, surface elements (such as snow and vegetation), and atmosphere (Fig. 2).

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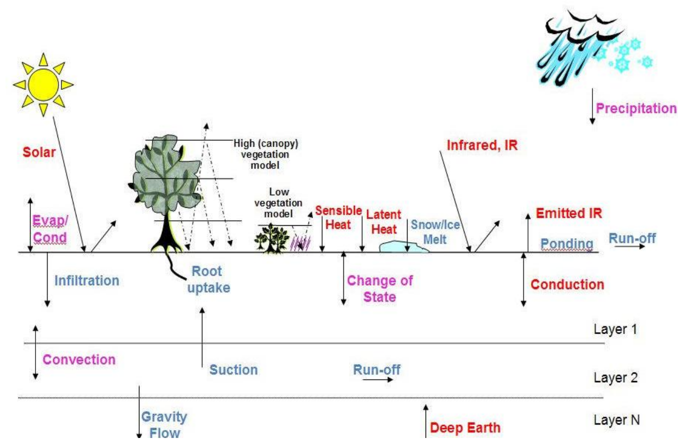

Figure 2. FASST Water and Energy Balance (https://webcam.crrel.usace.army.mil/FASST/)

The FASST program is primarily written in FORTRAN90 and is divided into nine modules designed to read in meteorological and control (soil and foliage) information to calculate new soil/ground properties.

3. Coupling Considerations

The purpose of this research is to fully couple the FASST land-surface model so that it could be treated as another land-surface modeling option when running the WRF-ARW. The structures of both the WRF-ARW and FASST land-surface model had to be considered in order to develop an approach to proceed with coupling the models.

When the WRF-ARW calls a land-surface model as well as other physics components, a driver program passes meteorological variables to the scheme based on the option chosen in the namelist file. These variables are passed through subroutines which will later be utilized by the land-surface model scheme that has been turned into a module for the WRF-ARW.

Originally intended to serve as a stand-alone model, FASST is designed to read meteorological variable from a file that is specified in a main input file. This input file also specifies other variables such as those representing single-point forecast or multi-point forecast, output file names, vegetation type, initial snow/ice depth, surface roughness length, number of soil layers, and soil type. For the purpose of coupling this model to the WRF-ARW, FASST was altered to accept input from the WRF-ARW as well as calculate the output flux variables needed by the WRF-ARW.

4. Procedure and Verification Data

4.1 Coupling Procedures

The first step taken in integrating FASST into the WRF-ARW physics was to add a new land-surface scheme to the Registry which allows it to be chosen in the namelist for runtime. To accomplish this, FASST was added as a new package to the Registry, given the name “FASSTSCHEME”, and a namelist option of 13 also had to be added to the physics initialization as well as the surface driver responsible for passing variables to the land-surface schemes.

After adding FASST to the WRF-ARW structure and editing files for the new physics package to be called, the land-surface model had to be altered to accept WRF-ARW data as input. When beginning the coupling, the main goal was to run a very simple case through an entire time step, so for simplicity, other processes such as reading soil and vegetation input were bypassed and re-introduced at a later time. After assigning WRF-ARW meteorological variables in FASST and successfully running through a time step with WRF-ARW input being processed by FASST, the previously mentioned sections of the driver that read in soil and vegetation were re-introduced to allow the model to run with more accuracy in the way it was intended, which included this data. At this time, FASST variables and calculations had to be assigned to outputted WRF-ARW variables (such as heat and moisture fluxes) so that this data could be updated based on FASST’s determined land-atmosphere interactions.

The oceans and lakes showed a slightly warm bias after which it was realized that the water flag indicating an open water gridpoint was not being updated for each gridpoint during a timestep. The FASST driver was re-arranged to move water and land properties, including soil and vegetation, to the main calculation loop so that each gridpoint would be identified as land or water according to WRF-ARW’s flag value (XLAND where 1 indicated land and 2 indicated water). After this change, the same forecast produced considerably cooler water areas and allowed the cooler pockets of air seen in the initial conditions to remain (Fig.17). After a 6-hour forecast comparison between the FASST lsnd-surface model and WRF-ARW’s default NOAH land-surface model, FASST’s resulting ocean and water temperatures were still warmer (and less accurate) than NOAH’s. Since water temperatures would not noticeably change during the short-term forecasts used for the purposes of this project, the FASST code was further altered to only update heat and moisture fluxes for land points. After this additional adjustment, the water grid points resulting from the use of FASST closely resembled those of the NOAH for the same foreccast event. To increase accuracy in portraying the geographical region we are modelling, WRF-ARW vegetation and soil types determined by WPS, ivgtyp and isltype, respectively, were passed through the driver for FASST usage.

4.1 Data Used in Verification

As an earlier goal of the NASA/EPSCoR project, WRF-ARW had been configured with nested domains over the forecast are. A 3:1 nesting ratio is used with a parent domain of 12-km resolution and child domain of 4-km resolution centered over the Presidential Moutnain Range Fig. 3).

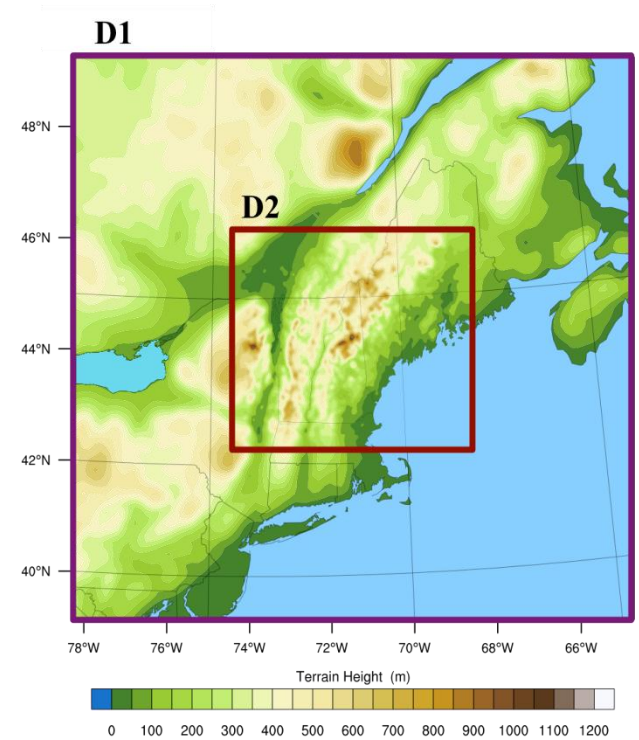

Figure 3. WRF-ARW Domain Over Presidential Mtn. Range

As another part of the NASA/EPSCoR project, observation stations were placed at critical areas in the presidential mountain range (Table 2). This instrumentation will provide us with observational data to compare to model output in order to assess the newly-coupled model's performance. Forecasts were assessed using LEWICE to determine icing generation. Dates used for verification were determined based on the duration and intensity of the icing event.

Table 2. Observation Station Locations

Station	Location (lat, lon)
Mt. Washington Cog Site	44.16N, 71.21W
Mt. Mansfield, VT	44.32N, 72.48W
Mt.Washington Summit	44.16N, 71.18W
Cannon Mountain, NH	44.10N, 71.41W

5. Project Status and Preliminary Results

5.1 Project Status

To date, the WRF-ARW and FASST land-surface model can be considered as fully coupled with variables from the WRF-ARW being passed to and from the land-surface model resulting in a forecast. For the purpose of this project a forecast window of 12 hours is being considered and used for current preliminary results although a 24-hour forecast has successfully been run with the coupled models. Vegetation, soil, and meteorological variables are updated for each gridpoint at each time step for FASST to use in its calculations of surface moisture and heat fluxes to be fed back to the WRF-ARW for use by other physics schemes.

5.2 Preliminary Results

The first icing case used for a forecast resulted in very different results between FASST and the WRF-ARW default land-surface model, NOAH (figures 4 and 5).

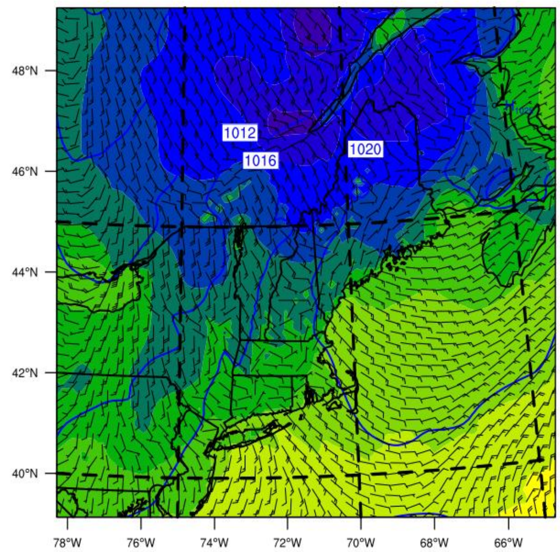

Figure 4. FASST Option (00z Jan 20, 2012)

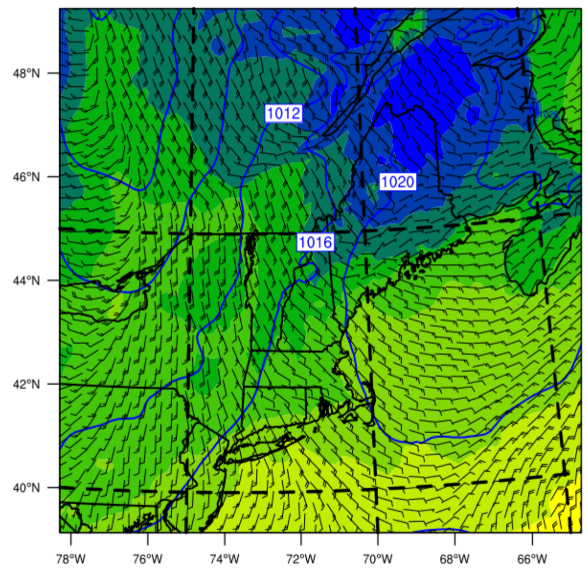

Figure 5. NOAH Option (00z Jan 20, 2012)

Observations for the time of icing revealed NOAH having more accuracy in predicting surface temperatures, but further consideration of FASST output revealed that although the surface temperature were being updated, these updates were by a small amount. This prompted investigation into the currently coupled code and it was discovered that FASST was not updating soil temperatures because the flux equations used require 'old' soil values to calculate the difference in temperature and moisture from the last time step to the current one. Because of this, further work is needed in correcting the currently coupled code to allow FASST to use old values in the equations forecasting flux which are essential for icing forecast from WRF-ARW. The FASST land-surface model, in its uncoupled state, allowed for an option to read these past values for use in the flux equations so making this change is a matter of reintroducing the option to read old values.

6. Future Work

The first order of business is to make the previously discussed update to the coupled model to give FASST the ability to read old soil variables for use in the flux calculation equations. This change is expected to increase accuracy in FASST's operation as a land-surface model available in the WRF-ARW suite. Following this change, additional 12-hour forecasts of icing events will be run with both FASST and NOAH as the land-surface physics option and the results will be examined against observation data to determine skill in prediction low-level temperatures and atmospheric conditions leading to icing. Also to be completed is the parallelization of the coupled model to allow for FASST to be run in a multi-processor environment, allowing it to be a more viable option for use in operational forecasting. During this final step, the WRF-ARW operations group will be consulted in order to include FASST as the possible fifth land-surface model option available in the next release of the WRF-ARW.

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