Historical winter weather assessment for snow fence design using a numerical weather model

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Problem Statement

This proposed research has a strong tie to one of the WYDOT strategic goals, keeping people safe on the state transportation system.

Snow fence is known as an effective aid for people driving in hazardous high wind and blowing snow conditions in Wyoming. The proposed work will provide the comprehensive wind and snow data by a numerical weather prediction model in the historical period. A snow fence system supported by better weather information would inherently improve the safety of the Wyoming transportation system. Therefore, direct benefits from the research are in the form of fewer on-road traffic collisions and reduced road closures (frequency and duration) achieved by having a more robust transportation system.

The need for this research is to update the existing wind and precipitation tables used in snow fence design so that the design can better reflect the current meteorological condition. The tables that are currently being used were manually generated by Dr. Ron Tabler and reflect the limited amount of data that was available in the early 1990's. This project will update the wind and precipitation data with recently available modeling technology.

Background

Wyoming has always faced problems with snow and wind. This came to the forefront after I-80 opened in October 1970; not long after, it was closed due to blowing snow. In response to this, the first stretch of snow fence was installed in 1971 (WYDOT, 2009). Since then, Wyoming Department of Transportation has developed one of the most extensive snow fence programs in the country with the Winter Research Services leading the way since 2004.

Blowing snow is a condition common to Wyoming, which has led to extensive research on blowing snow for over 40 years in the state. Most notable is the work of Dr. Ron Tabler, who developed an international reputation as one of the founding fathers of snow fence research and blowing snow through his research work in Wyoming (Tabler, 1988; 1991a; 1991b; 1994; 2003). More recent research efforts by Tabler focused on the blowing snow conditions associated with near snow issues (Tabler, 2006; 2009). Tabler's work has been incorporated into the WYDOT's road design practices and snow fence design and implementation and has led to reduced crashes and road closures (Tabler & Meena, 2006).

While the engineering technology has been improved, the placement and size of snow fences are mainly determined by the manually-measured wind direction and annual snowfall records developed by Dr. Tabler in the early 1990's. However, a pilot study performed by the P.I. using a numerical weather model, showed that the wind field was extremely dynamic during a winter storm event. Figure 1 shows the sample wind field simulated by the numerical weather model during April-2013 winter storm event in Southeast Wyoming. This suggested that the wind fields were most likely to keep changing and very heterogeneous during blowing snow events. This effect of the changing wind direction was considered in some extent in the snow fence system while the effectiveness of the existing system could not be evaluated due to lack of the complete wind field information. In order to improve determining the placement and size of snow fences, as a first step, it is desirable to re-assess the historical wind and snowfall condition data used by Winter Research, WYDOT, using this state-of-the-art numerical weather model.

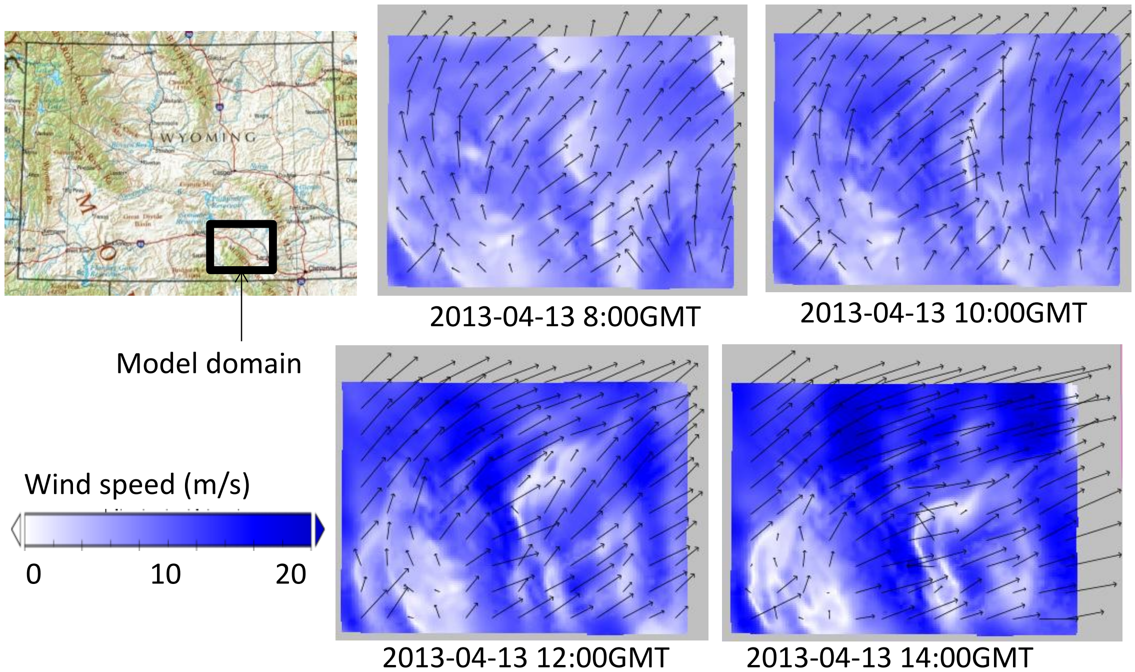

Figure 1 - Simulated wind fields during April-2013 winter storm event

As regional numerical weather modeling has become increasingly essential for daily weather forecasting, the modeling and computational technologies have remarkably improved over the past few decades (e.g. Lynch 2008). These regional atmospheric models can also be used for the reconstruction of historical weather conditions by downscaling the larger scale reanalysis data such as the North American Regional Reanalysis (NARR). These models are readily available for obtaining much finer and reliable regional weather information during the historical period.

Using a regional atmospheric model, this project will reconstruct the historical weather conditions, particularly wind and snow, which are essential information for snow fence design (Tabler 2003). The regional atmospheric model used in this project is the Weather Research and Forecasting (WRF) model, which is widely used in operational and research applications. This numerical weather and prediction system was developed by various US research centers (Leung et al. 2006, Skamarock et al. 2008). The WRF model solves the non-hydrostatic version of the Navier-Stokes equations using a 4^{th} order Runge-Kutta scheme using a finite difference method. The output of the model provides full atmospheric information including rain, snow, temperature, moisture, pressure, radiation, wind gust, etc. The output frequency of the WRF model is hourly, which is sufficient to derive the weather data for the wind field evolution assessment. The initial and boundary conditions of the WRF model will be prepared from the North America Regional Reanalysis data (http://www.esrl.noaa.gov/psd/data/gridded/data.narr.html). The NARR project covers the North American Region and the model uses the 32km resolution NCEP Eta Model together with the Regional Data Assimilation System (RDAS). The NARR dataset includes 8 times daily data at 29 levels and atmospheric state variables. This modeling project will provide the seamless and continuous weather conditions during blowing snow events in Wyoming.

Study Objectives

The objectives of this research are to:

1. develop new wind and winter precipitation tables for snow fence design using the WRF model;
2. compare the existing Tabler's tables to the new data to see if there have been significant changes in what WYDOT has been using; and
3. determine the appropriate timeframe and frequency for continuous data updating.

This research will compute the wind fields during the extreme wind events using the WRF model, and provide the bias-corrected precipitation data during the winter seasons. Then, the wind and precipitation data will be processed for snow fence design and snow deposit prediction models.

The first phase will focus on the wind data including the wind direction and blowing snow event frequency. The second phase will focus on the precipitation, mainly snowfall quantification for blowing snow and snow fence design across the State of Wyoming.

Study Benefits

The main benefit of this study will be the update of the existing manually-measured wind direction and annual snowfall data for snow fence design, using the contemporary WRF model. The model-based wind and precipitation data will be seamless and continuous during the historical high wind period. Specifically the deliverables from this project will be:

- evaluation of the winter wind and precipitation data by Dr. Tabler using the new model-based data;
- prevailing wind direction maps during the historical high wind period in 1981-2014 ;
- mean wind speed maps during the historical high wind period in 1981-2014;
- maximum wind speed maps during the historical high wind period in 1981-2014;
- annual mean winter precipitation;
- frequency and trend analyses of the historical extreme wind events in 1981-2014; and
- recommendation for the further study (e.g. how often this research will have to be repeated).

The spatial data will be provided both in gridded (raster) format as well as ArcGIS shape format. This data will benefit all programs working with snow fence design as well as winter road maintenance.

Applicable Question

This is a model implementation project based on the public-domain programs and input data. Therefore, any obvious barriers, uncontrollable factors, or permission requirements for the project implementation are not identified. The computing resources (hardware and network) will be managed by the Advanced Research Computing Center, the University of Wyoming. Once the data is delivered to WYDOT, the data will be stored on WYDOT servers and will be made available to persons, programs, and departments as needed.

Statement of Work

Work plan

Phase 1: Wind condition assessment

This phase of the project will reconstruct the historical wind conditions using the WRF model described above. The anticipated outcome is the model-driven wind statistics in ArcGIS shape format at every 4km or finer resolution grid in Wyoming.

1) Initial data analysis using 12 km resolution data

The continuous simulation at a course resolution (12 km) from 1981 to 2014 will be performed. This initial continuous simulation will identify the winter blowing snow events (wind speed > 12mph) in the historical period.

2) WRF model configuration for finer resolution simulation

The model domains for Wyoming will be arranged for optimal performance and computational efficiency. Then, a test simulation will be performed at a workstation in the PI's office to find the best model option for the long term simulation. The anticipated model resolution is 4 km or better.

3) Model implementation

The configured WRF model will be copied to a super computer at the Advanced Research Computing Center, University of Wyoming. The high performance computing (HPC) will accelerate the processing and computing. The very large WRF outputs will be converted into compact binary format data so that we can save the disk storage and increase data manageability.

4) Wind data processing

The WRF output will be compared against Tabler's data during 1994-1996 to check the performance of the model. Then, the prevailing wind direction, wind speed, and maximum wind speed during the winter blowing snow events (wind speed > 12mph) in 1981-2014 will be extracted from the computation results. These wind statistics will be converted to an ArcGIS shape file for snow fence design. Winter-time wind direction diagrams at several representative locations along I-80 will also be produced.

Phase 2: Snow condition assessment

This phase requires completion of phase 1 because the precipitation assessment is based on the WRF simulations. The model-based precipitation and snow condition simulation for the historical period (1981-2014) will be performed. The anticipated outcome is the model-driven snow statistics at every 4km or finer resolution grid in Wyoming in ArcGIS shape format.

1) Data assimilation to existing historical records

The WRF output will be compared against the existing ground-observed atmospheric data (e.g. SNODAS) to evaluate the model errors. Especially the modeled precipitation, which is likely to have significant biases, will be assimilated to the existing historical climatological data, such as PRISM data (the Parameter-elevation Regressions on Independent Slopes Model, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu). These data processes will require an additional desktop workstation for the intensive spatial data analyses.

2) Winter precipitation data compilation for snow fence design

The bias-corrected model outputs will be used for annual mean snowfall and precipitation estimation over Wyoming. The derived quantities will be converted into an ArcGIS shape file for the snow fence design.

Work Schedule

The project is scheduled for 12 months, beginning in June of 2015 and ending in May of 2016.

Cost Estimate

The total cost estimate for the tasks outlined in this proposal is ***$19,178.***

PROJECT TITLE: Historical winter weather assessment for snow fence design using a numerical weather model

Research Agency:	University of Wyoming Department of Civil and Architectural Engineering 1000 E. University Avenue, Dept. 3295 Laramie, WY 82071	
Budget Period:		
Contract Period:	12 Months	
A. Senior Personnel		
1. Noriaki Ohara	1 month	$8,300
	(A) Total Senior Personnel	**$8,300**
B. Other Personnel		
	(B) Total Other Personnel	**$0**
C. Fringe Benefits		
1. Senior Personnel * 45.56%		$3,781
	(C) Total Fringe Benefits	**$3,781**
D. Operating Expenses		
1. Computer Usage and Service		$2,000
2. Communication		$100
3. Office Supplies		$500
	(D) Total Operating Expenses	**$2,600**
E. Technology Transfer		
1. Presentation at TRB Conference		$700
2. Reporting (final report and quarterly report)		$600
	(E) Total Technology Transfer	**$1,300**
F. Equipment		
	(F) Total Equipment	**$0**
G. Total Direct Costs (A through F)		**$15,981**
H. Indirect Costs (Specify Rate and Base)		
1. Indirect Costs	20% of Total Direct Costs	$3,196

	(H) Total Indirect Costs	**$3,196**
I. Tuition and Fees		
	(I) Total Tuition and Fees	**$0**
J. Total Direct and Indirect Costs (G+H+I)		**$19,178**

Technology Transfer

Technology transfer will be done through dialog with the Wyoming Department of Transportation and other stakeholders throughout the entire project. The data products will be provided in GIS format (ArcGIS shape) as well as GRID format. Results will be disseminated through a final report, peer-reviewed publication(s), and technical presentations at national conferences such as the annual meeting of the Transportation Research Board. The results will be transferable to other agencies operating roads subject to high wind conditions.

Special Requirements

The special requirements including the computational skill and resource accesses will be met by the P.I, who has extensive experiences in model operations through various national and international hydrological projects (e.g. Ishida et al. 2014, Ohara et al., 2014, Chen et al., 2011ab, Ohara et al., 2011abc, Shaaban et al., 2011, Amin et al., 2015).

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