Winter Weather Services and Forecasting Options for Local Agencies

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Acknowledgements

Kim Hoogewind
Derrick Snyder
Brad Fehnel
Chase Miller
Tyler Heckstall
Steven Chun
Peter Boyd, Weston Phillips, Stephen Remias, Alexander Hainen
Prof. Darcy Bullock and everyone at JTRP
INDOT/JTRP projects

providing INDOT with:
- detailed weather forecasts produced by students
- detailed analyses of weather observations
- evaluation of new products

Forecast for Monday, Feb 17 2014
Purdue: “forecast club”

- students work in teams on daily forecasts
- student-generated forecasts are *extremely* valuable experiences for the students
- “customers” include: local agencies, Purdue Grounds, school districts
forecast valid: 3 Mar 2015
Tuesday
freezing rain and sleet early on Tuesday, changing to all rain by Tues afternoon
High pressure is shifting to the east of the state today, bringing substantial sunshine and a brief break in the wintry weather for Monday. Melted snow and residual water on surfaces will re-freeze after sunset tonight as surface temperatures fall quickly below freezing. Winds aloft are predicted to shift out of the southwest, bringing clouds and much warmer air aloft, while dry and cold air will remain in the lower levels overnight. An area of precipitation is expected to move in from the west during the early morning hours of Tuesday, mainly across the northern half of the state. Initially, the precipitation should begin as sleet (or snow in the northern/northeastern portion of the state), before changing to freezing rain. Areas in the far southern portion of the state have lower chances of precipitation, and surface temperatures that will not be as cold as further, so there is a lower chance of freezing precipitation near the Ohio River. On our forecast map, the 90% area represents locations where we expect freezing rain to last longer than 3 hours in duration, with ice accumulation near 0.1”. The 60% area represents shorter duration (less than 3 hours) and/or less ice accumulation (less than 0.1”). Surface temperatures are predicted to warm during the morning hours across the state. This should produce a transition line between rain and freezing rain that is expected to move northward during the morning and early afternoon hours. We have included a freezing rain-rain transition time map below. After the transition from freezing rain to rain occurs, air and surface temperatures are predicted to warm well above freezing statewide and remain above freezing throughout the evening hours on Tuesday. Numerical forecasts are indicating the potential for heavier rainfall amount along and south of I-70 on Tuesday. This rainfall on top of a substantial snowpack and frozen ground should produce flooding in many areas of the state, especially along and south of I-70. In addition, widespread dense fog and drizzle should be expected Tuesday evening over most of the state, especially areas north of I-70 where lighter precipitation is predicted.

A strong cold front is predicted to enter the northwest corner of the state at around midnight Wednesday morning, and quickly move south during the early morning hours of Wednesday. While some snow flurries
Georgia Governor Nathan Deal

"If we closed the city of Atlanta and our interstate system based on maybe, then we would not be a very productive government or a city. We can't do it based on the maybe."  
January 29, 2014
unfortunately for Governor Deal, forecasts are always “maybes”

precise, error-free predictions of the future state of the atmosphere are impossible forecasts are never perfect forecasts are never going to be perfect a forecaster can only reduce the degree of uncertainty regarding the future forecaster’s job: effectively communicate the uncertainty to their customers
when is a forecast *useful*?
when is a forecast *harmful*?

“essentially, all models are wrong, but some are useful”
George E.P. Box, referring to statistical models

“first, do no harm”
part of the Hippocratic Oath

same can be said about forecasts
be prepared for when the forecast is wrong...

- They said “rain likely”, and it's snowing
  - Rain is usually snow at top of the cloud
  - Snow melts on the way down
  - Melting cools the air
  - Could drop the temperature to freezing
  - Allow snow to reach the ground

- They said 6-8” of snow, and it's sleet ing
  - Must have warmer air aloft than expected
  - Could turn into freezing rain
weather forecasting data available
show some websites that I use to help with monitoring and predicting weather
UTC time = EST + 5h = EDT + 4h
→ http://www.extremeweathermakers.com/indot-forecasts
→ http://new.aviationweather.gov/metar
→ http://mping.nssl.noaa.gov/display/
→ http://weather.eaps.purdue.edu/
→ http://weather.gov/
→ http://www.wpc.ncep.noaa.gov/
→ https://nwschat.weather.gov/
→ http://www.meteor.iastate.edu/~ckarsten/bufkit/data/index.html
→ http://www.spc.noaa.gov/exper/sref/
→ http://www.spc.noaa.gov/exper/sref/fplumes/
monitoring current weather
weather models

numerical weather prediction models are computer programs
physical processes are turned into equations
observed data are analyzed to begin the forecast
step forward in time...
U.S. models (from National Weather Service)

"GFS" Global Forecast System
  global domain - 16 days - updated every 6 hours

"NAM" North American Mesoscale
  regional domain - 84 hour forecast - updated every 6 hours

"RAP" Rapid Refresh
  regional domain - 18 h - update hourly
international modeling centers

U.K. Met Office
Canada (CMC)
European Centre (ECMWF)
Japan
China
Australia
...


weather.cod.edu

NWS forecast discussions
WPC probability forecasts
Precipitation type

- check for:
  - warm layer aloft
  - cold layer near ground
snowfall amount

depends on the density of the snow
low density: a lot of space between snow crystals
high density: not much space
● measure the depth of snow
● melt it
● measure the depth of liquid
"snow ratio" is snow depth divided by liquid depth
typical snow ratio

Average Snow to Liquid Ratios 1971-2000
Factors influencing snow ratio

- temperature
  - cold temps associated with high snow ratios
  - warm temps lower snow ratios
  - melting aloft and/or at the ground
- total precipitation
  - weight of snow acts to compact fallen snow
  - large precip lower snow ratios
- wind speed
  - high wind causes dendrites to fracture
ensembles
fog/freezing fog

"radiational cooling"
a surface (roads, bridges, ground) will radiate heat
the warmer the surface is, the more heat it radiates
clear air will absorb (and radiate) some of that heat
clouds absorb and radiate as well
clear sky, light winds, dry air
these are excellent conditions for strong cooling at night
bridge/elevated surface will radiate above and below, so will cool even more than road/ground
several degrees colder than air temperature
fog

if air cools to below the dewpoint, cloud drops will begin to form fog
freezing fog occurs when we have enough cloud drops and surfaces below freezing
particularly hazardous on elevated surfaces since they tend to be colder
recent project: severity index for winter weather

- INDOT asked us to develop an index that estimates the severity of winter weather
- use this to help assess their performance for road maintenance
- requested that it would be based on weather information alone
  - no traffic/speed data
  - no road treatment information
  - no cost/expense information
costs per lane mile per “weather hour”

a weather hour is defined as any hour with snow, freezing rain, or ice pellets with air temperature less than 35 F

significant variation across the state: how much of this variation is due to differences in the severity of weather?
standard deviation = 0.286
weather processes related to snow/ice

- Precipitation
- Energy from radiation
- Energy from air/wind
- Evaporation/sublimation
- Blowing snow
- Mass of snow/ice deposited on 1 m²
- New snow/ice in past 1h
- Road surface
- Melt
Road Weather Severity Based on Environmental Energy (RWSBEE)

ergy-based index
Qmelt = energy required to raise temp and melt new snow/ice deposited in past 1h
Qavail = environmental energy freely available to warm the surface during past 1h

RWSBEE = Qmelt - Qavail
how much energy required to melt 1 kg of snow?

- 1 cm of new snow at a temp of -10 C
- for a typical density of snow, this has a mass of 1 kg (assuming area of 1 square meter)
- 21000 Joules of energy are needed to raise the temp to melting point (0 C)
+ 334000 Joules of energy to melt the ice
= 355000 Joules
= 0.355 MJ of energy
(roughly 1 inch of new snow = 1 MJ of energy)
energy available from the weather/environmental conditions

**net radiation:**
depends upon sun angle, clouds, air temperature, surface temperature, reflectance of surface (albedo)

energy from radiation

**sensible heat flux:**
depends upon air temperature, wind speed/turbulence, surface temperature

energy from air/wind

**latent heat flux:**
depends upon moisture content of air, wind speed/turbulence, surface temperature
evaporation/sublimation

mass of snow/ice deposited on 1 m²

new snow/ice in past 1h

road surface

melt
RWSBEE winter severity index

larger numbers:
- large mass of snowfall, ice accumulation, and/or blowing snow deposition
- cold surface temperatures
- environment acting to make the surface colder

smaller numbers:
- light precipitation
- warm surface
- environment warming the surface
deposition = transport in - transport out

deposition = suspension in - suspension out

saltation in = saltation out = zero (due to immobile snow)

suspension in = suspension out

30m

vegetation stubble

road surface

snow depth
blowing snow

need to determine:
mobility of snow
  no melting or liquid precip since last snow
  depth greater than 2X roughness length
velocity threshold
  function of air temperature
saltation transport rate
  function of wind speed
# variables and data sources

<table>
<thead>
<tr>
<th>variable (units)</th>
<th>source</th>
</tr>
</thead>
<tbody>
<tr>
<td>roughness length (m)</td>
<td>NLDAS</td>
</tr>
<tr>
<td>2m air temperature (K)</td>
<td>NLDAS</td>
</tr>
<tr>
<td>10m wind speed (m/s)</td>
<td>NLDAS</td>
</tr>
<tr>
<td>surface temperature (K)</td>
<td>NLDAS</td>
</tr>
<tr>
<td>net surface shortwave and longwave radiation (W/m**2)</td>
<td>NLDAS</td>
</tr>
<tr>
<td>sensible and latent heat fluxes (W/m**2)</td>
<td>NLDAS</td>
</tr>
<tr>
<td>vertical temperature profile (K)</td>
<td>RAP</td>
</tr>
<tr>
<td>categorical precipitation type (snow, freezing rain, ice pellets, rain)</td>
<td>RAP</td>
</tr>
<tr>
<td>visibility (m)</td>
<td>RAP</td>
</tr>
<tr>
<td>10m wind gusts (m/s)</td>
<td>RAP</td>
</tr>
<tr>
<td>snow depth (m)</td>
<td>SNODAS</td>
</tr>
<tr>
<td>hourly accumulated precipitation (kg/m**2)</td>
<td>Stage IV</td>
</tr>
</tbody>
</table>
NLDAS

http://ldas.gsfc.nasa.gov/nldas/NLDASgoals.php
RAP

http://rapidrefresh.noaa.gov/
SNODAS

http://www.nohrsc.noaa.gov/NSA/
Stage IV

http://water.weather.gov/precip/
road maintenance costs normalized by state average

cost per lane mile per RWSBEE relative to state average

districts/subdistricts/units

standard deviation = 0.335
database

• working with research staff at Purdue ITaP Research Computing
• database/web portal specialists
• database design
  – data that will be stored
  – calculations/queries that will be performed
  – products to be returned
surface temperature prediction

Methodology

- Sub-hourly data, including road and bridge deck surface temperatures, dewpoint, and air temperature, were collected from six RWIS sites (Frankfort, Sullivan, Amity, Gas City, Westfield, and Kokomo) from November 2012 - March 2013.
- Purdue WRF (Weather Research and Forecasting) forecast data were gathered from the same time period for each of the sites. The configuration of the model used a 6km grid spacing, 00Z runs using NAM IC/BC, forecast hours 07-30 were evaluated.
- RWIS data were interpolated to the top of each hour, hours were considered missing if there were more than 120 minutes to the nearest RWIS observation.
- A persistence forecast was obtained via a 24-h lag from the observations at each site from the previous day.
- We calculated the bias (average of the forecast-observed for each category), mean absolute error (MAE), and root mean squared error (RMSE) for each of the variables.
- Persistence was used as the reference forecast in order to determine the skill of the WRF model forecasts

\[
\text{Skill} = 1 - \frac{\text{MAE}_{\text{WRF}}}{\text{MAE}_{\text{PERS}}}
\]

- A “bias-adjusted” WRF forecast was produced next. The average hourly bias from the previous seven days was determined and applied to the next WRF forecast.