Impacts of MM5 Model Data on the Validity of a Frost Prediction Model

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Outline

- Introduction to the frost model
- Investigate MM5 errors/surface temp. differences
- Find affect on frost model
- Suggest a pavement surface model
- Summary

Why forecast frost anyway?

- Frost on bridges is hazardous to motorists
- Frost suppression is expensive
- Chemicals corrode cars, pavement
- Chemicals pollute the environment

- Goal: forecast frost accurately
  - Avoid unnecessary treatment
  - Apply necessary treatment in time

How the frost model works

- Uses:
  - air temperature
  - dewpoint
  - windspeed
  - pavement temperature
- Calculates the depth of frost
- Values from MM5

Possible Problems

- MM5 error
- MM5 surface temp. › pavement temp.

Finding Model Errors

- Runs analyzed separately
- Compared against hourly observations
- Skin temp. compared against data taken by hand

Model error results

*with OSULSM

0 UTC run	Temperature (°F)	Dewpoint (°F)	Windspeed (kts)
Bias	-0.08	1.36	4.58
Av. Error	3.16	2.86	5.36
St. Dev.	3.81	3.65	4.38
12 UTC run			
Bias	-3.41	-0.20	3.86
Av. Error	4.18	2.65	4.99
St. Dev.	3.95	3.43	4.60

Surface temperature

- Only observations taken by hand in ~~CC~~ field
- Infrequent observations
  - ~one or two times a day
- Can test model s performance for one instant.
- Cannot judge accuracy of:
  - heating/cooling rates
  - timing

Surface temperature stats

	0 UTC run	12 UTC run
Bias	5.76	1.47
Av. Error	6.32	5.29
St. Dev	5.72	6.53

Values in degrees Fahrenheit

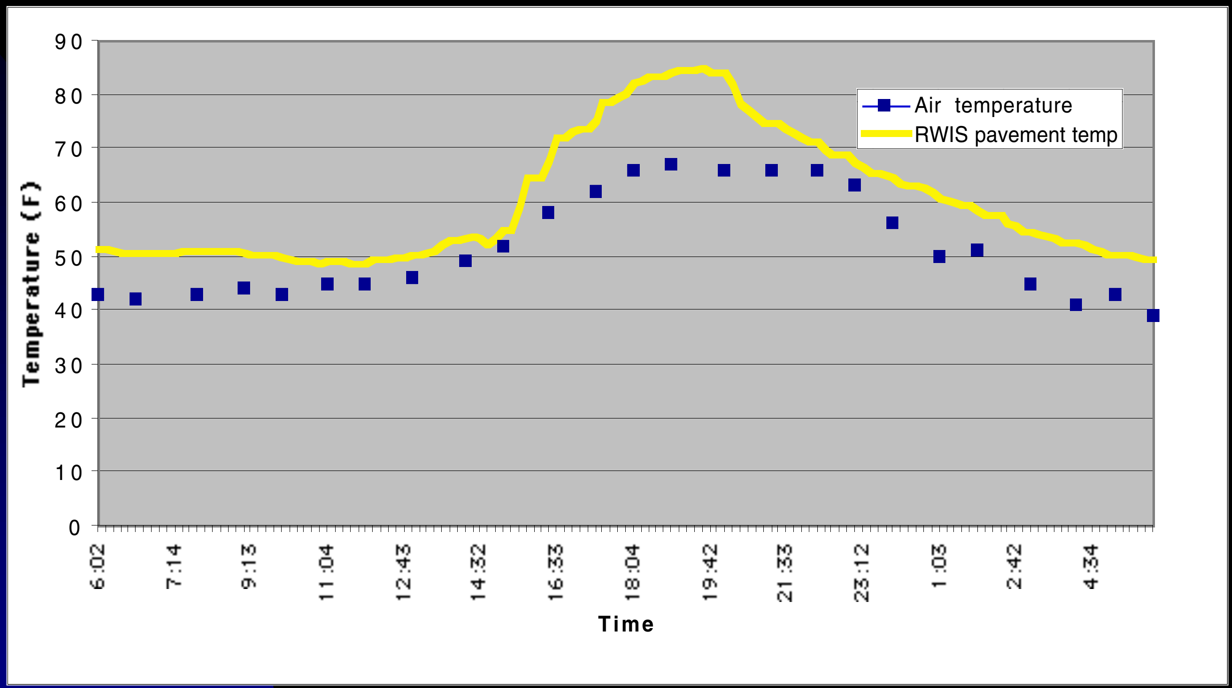
Problem with MM5 surface temperatures

- The MM5 assumes a *ground/vegetation* surface
- The frost model is designed to take *pavement* temperature
- Question: Is the MM5 surface temperature close enough?

Comparison of MM5 surface temperatures and RWIS bridge surface temperatures

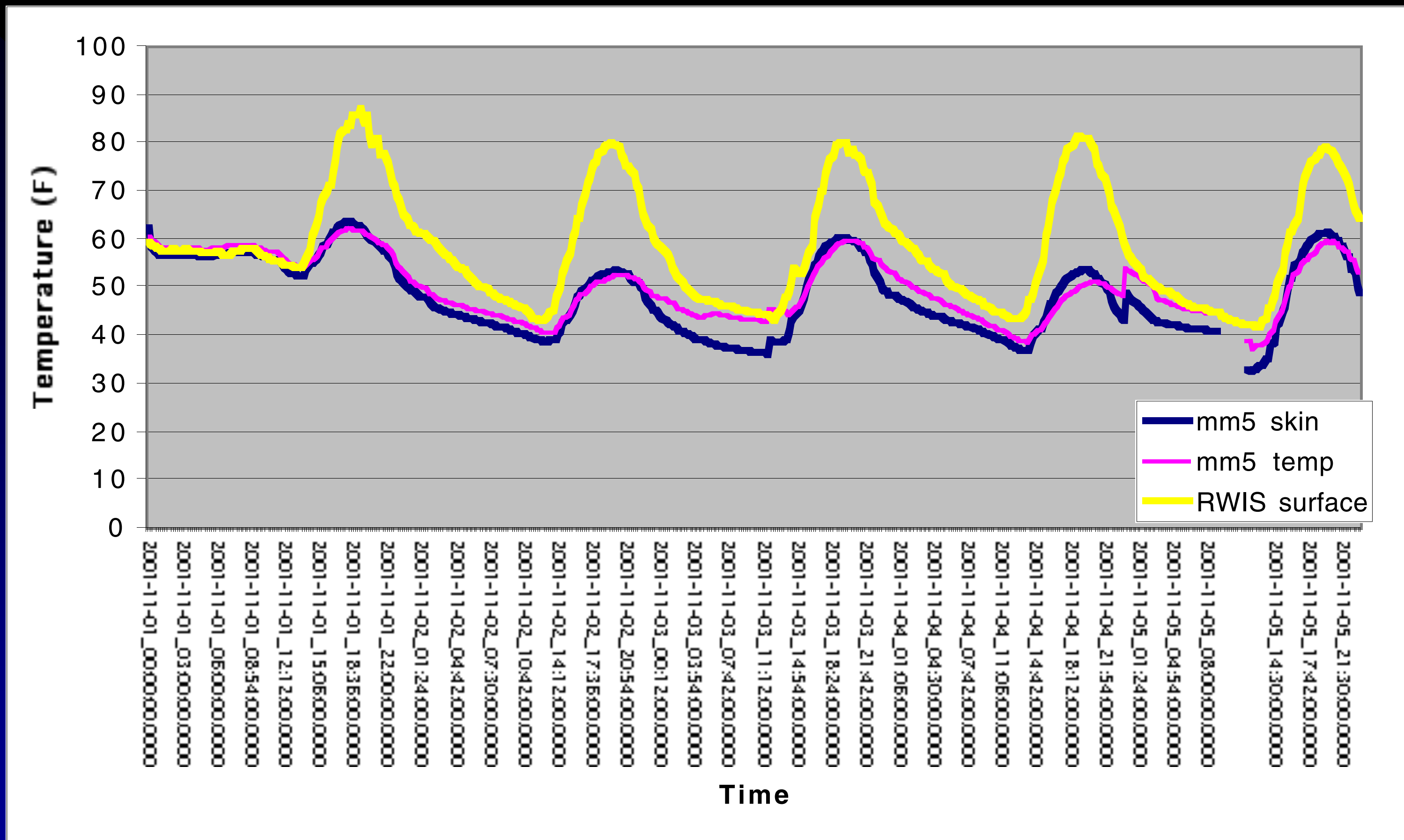
- RWIS observations from the southbound I-35 overpass near Ames
- RWIS surface temperatures compared to:
  - observed air temperature
  - MM5 surface temperature

RWIS vs. Air Temperature



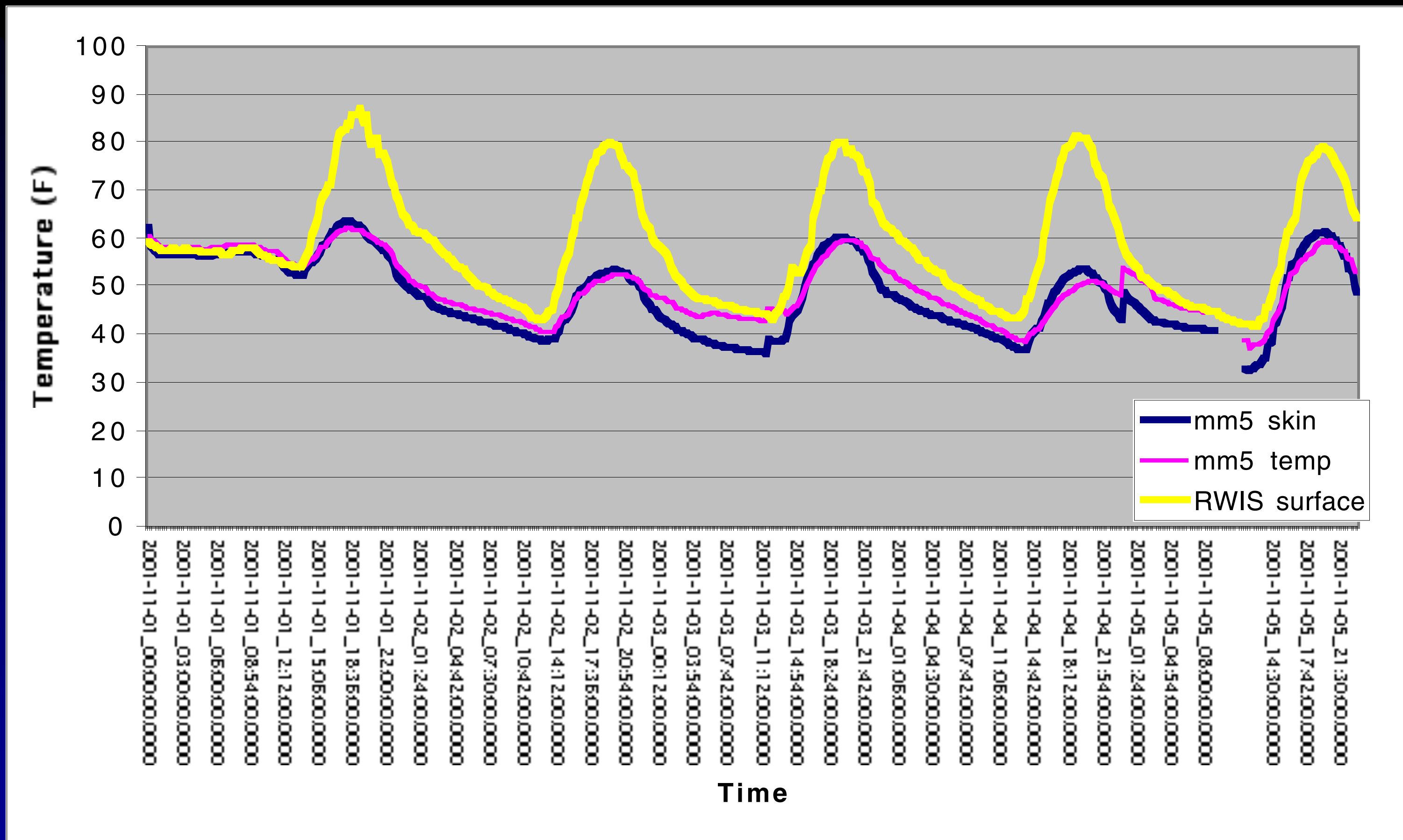
- Comparison of RWIS surface temp. to 2 meter air temp.
- Between 01 September, 2001 and 24 October, 2001, RWIS surface temperature averaged 9.4 degrees warmer

RWIS vs. MM5 Surface Temperature



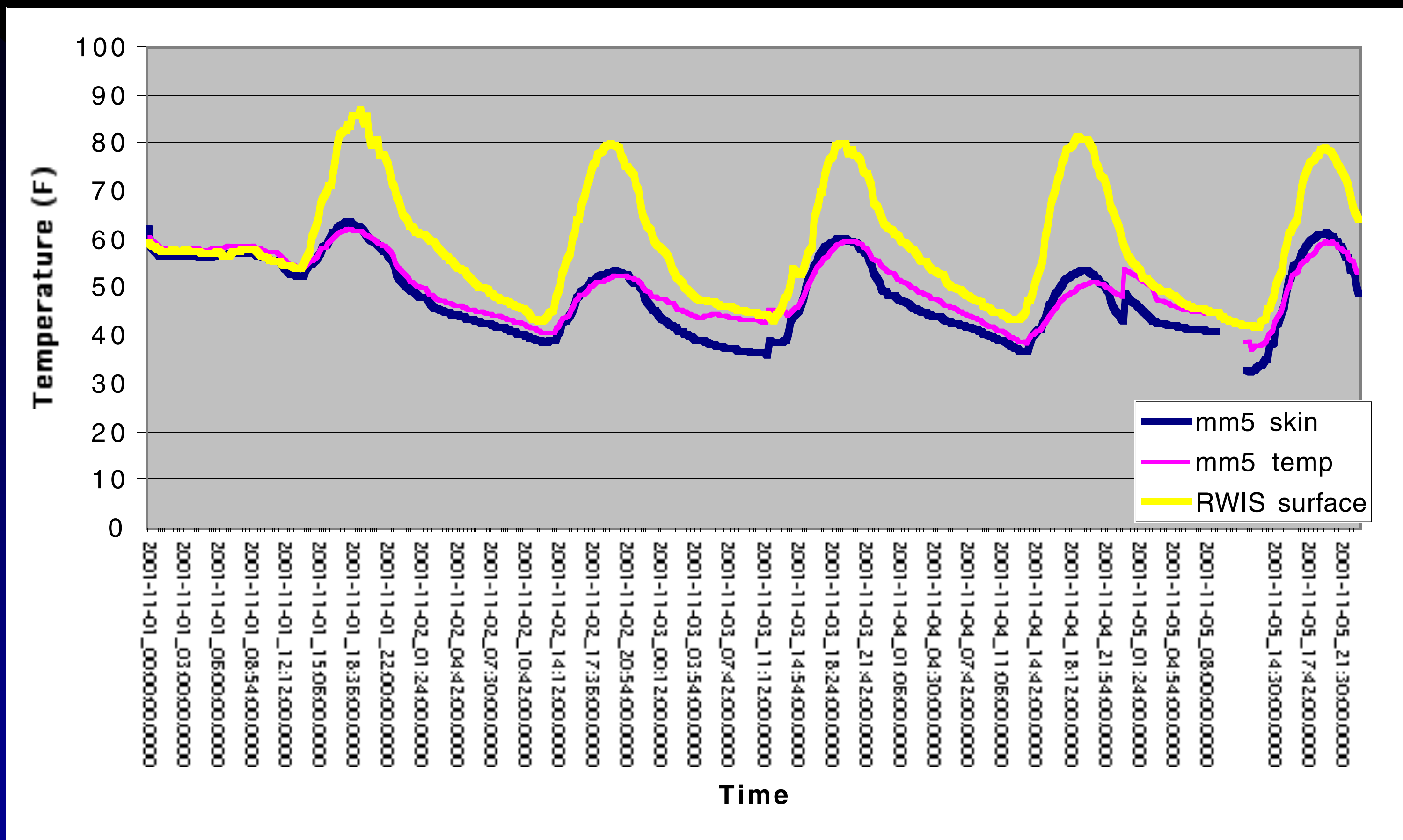
- 125 hour comparison of RWIS surface temperature and MM5 2-m air and surface temperature

RWIS vs. MM5 Surface Temperature



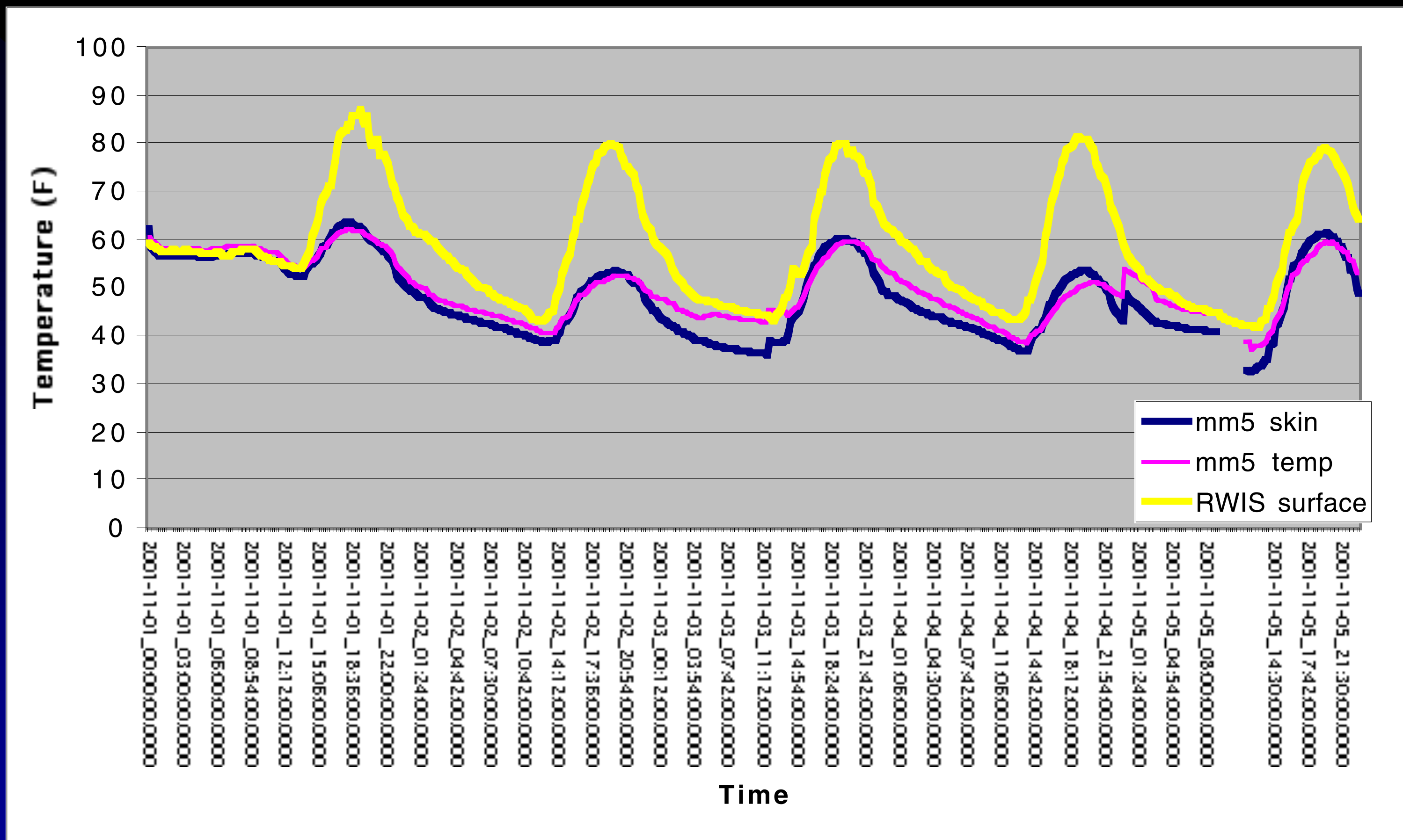
- RWIS surface temperature averaged 10.8 degrees warmer than the MM5 surface temperature.

RWIS vs. MM5 Surface Temperature



- RWIS and MM5 surfaces began heating at nearly the same time, but the pavement heated faster

RWIS vs. MM5 Surface Temperature



- At their minimum temperatures, the two surface temperatures got closer, but were still separated by several degrees

Rules for Frost Formation

1. pavement temperature < freezing
2. pavement temperature < dewpoint temperature
3. pavement temperature < air temperature

- For significant frost depth, dewpoint must be near freezing or well above pavement for an extended period of time.

(Takle, 1990)

- A few degrees in model error can mean correctly forecasting the presence of frost or not.
- Ex. The dewpoint forecasted a degree colder than the pavement temperature, when it was actually above, might result in a false 0-frost forecast.
- The average dewpoint error was greater than 2.5 degrees.

MM5 error and frost accumulation rates

- Wind speed, air temp., dewpoint temp., and pavement temp influence the rate of accumulation R(t)
- R(t) can be found by:

$$R(t) = (\frac{1}{\rho_f})e * (\frac{1}{R_d}) * C_e(D\frac{U}{T_a})$$

  - U = windspeed
  - Ta = air temperature
  - D depends on dewpoint and pavement temps.

- D is:

$$D = e_s(T_\circ)\{\exp(\frac{L_d}{R_v}(\frac{1}{T_f} - \frac{1}{T_d})) - \exp(\frac{L_d}{R_v}(\frac{1}{T_f} - \frac{1}{T_p}))\} \quad ,$$

  - Td is dewpoint temperature
  - Tp is the pavement temperature
  - Tf is the freezing temperature
  - D gets larger when Tp gets smaller in relation to Td. A larger D increases R(t).

Error Effect on Accumulation

- 0 UTC Run:
  - warm bias in dewpoint
  - fast bias in wind speed.
- May cause frequent overestimation of accumulation rate

Error Effect on Accumulation

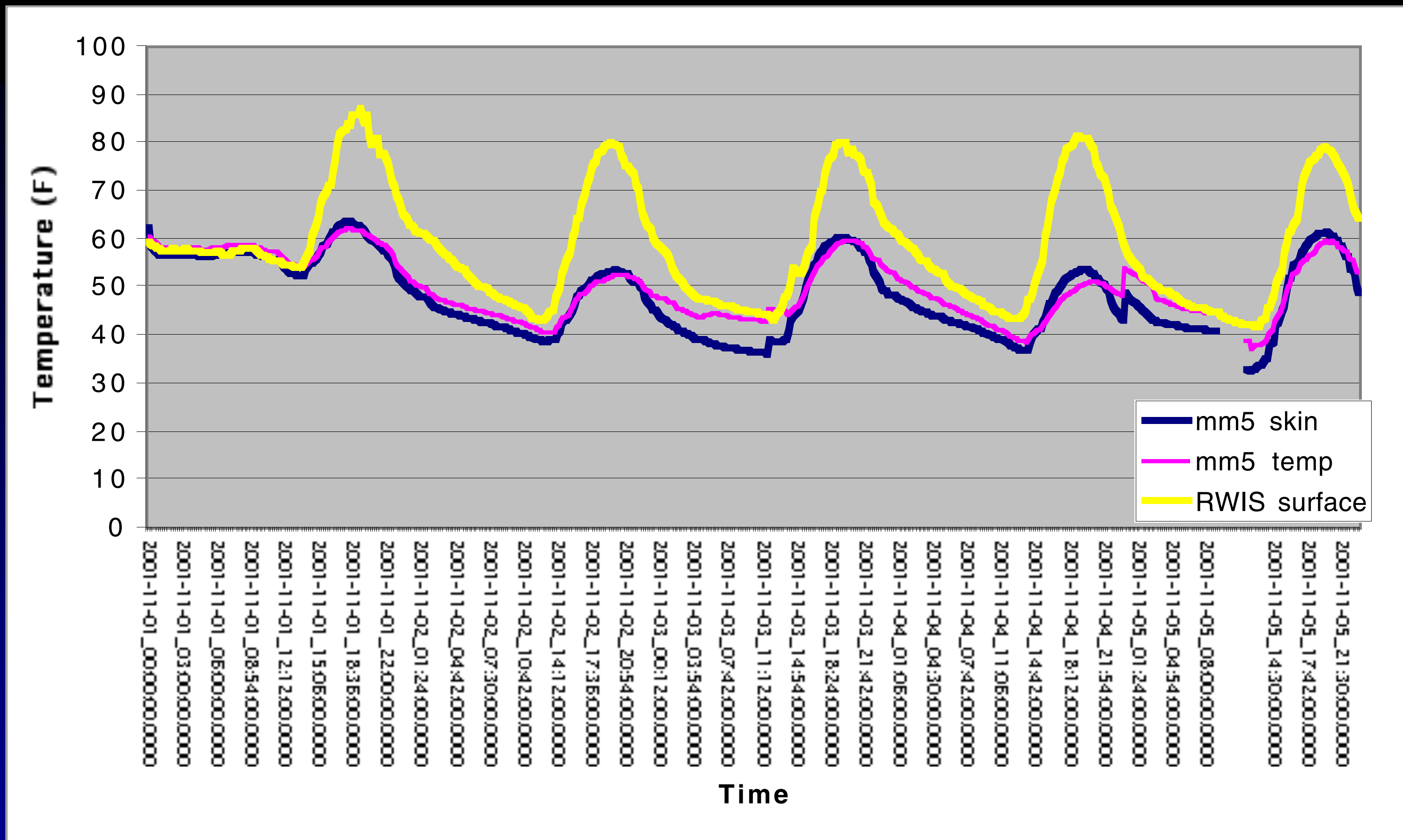
- 12 UTC Run:
  - small cold bias in dewpoint
  - fast bias in wind speed
  - cold bias in air temperature
- Air temperature inversely related to R(t)
- Air temp. and wind speed tend towards more frequent overestimation

Error Effect on Accumulation

All MM5 biases may lead to more frequent overestimation of R(t) given an accurate pavement temperature.

- Again, frost will only form when:
  - pavement temperature < freezing
  - pavement temperature < dewpoint temperature
- A few degrees means the difference between having frost or not
- An accurate pavement temperature is needed for frost model accuracy

These temperatures are *not* the same



- Timing will be off
- Differences will affect the frost model’s ability to forecast the occurrence of frost

We need a new way to forecast pavement temperature

- A program can be designed to forecast pavement temperature
  - Modify for bridge surface
    - Heat conduction equations
    - Energy balance equations
  - Use necessary values from the MM5 to calculate these equations

Equations as stated by Shao and Lister(1996)

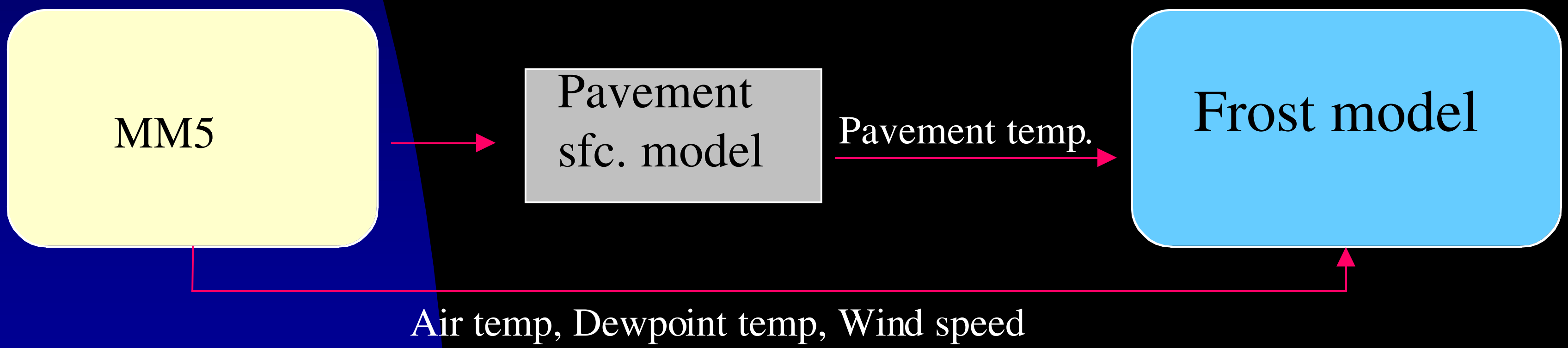
- Heat conduction eq.
  - Cm = heat capacity
  - k = conductivity
  - T = temperature at time, t and depth, z.

$$C_m \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\kappa \frac{\partial T}{\partial z}\right)$$

- Energy balance eq.
  - S = solar irradience
  - α = albedo
  - L = net longwave irradience
  - H = sensible heat flux density
  - LE = latent heat flux density
  - G = ground conductive heat flux density

$$(1-\alpha_s)S + L'(T_s) + H(T_s) + LE(T_s) + G(T_s) = 0,$$

- After the new pavement temperatures have been calculated they can be used by the frost model
  - Air Temp., Dewpoint temp. and wind speed will come directly from MM5
  - Pavement temp will come from the pavement sfc. model



Summary

- Frost model runs off MM5 forecast data
  - Errors and surface temp differences can affect frost model

- Investigation of model error and surface temperature differences

  - Error, bias in MM5 runs
  - Differences between MM5 surface temps. and actual pavement temps

Summary (cont.)

- MM5 error can affect performance of the frost model
  - Frost occurrence accuracy
  - Frost accumulation rate accuracy
    - All model biases would increase frequency of accumulation rate overestimation

- MM5 surface temp. differences affect performance of the frost model
  - Frost occurrence, accumulation rate accuracy
    - Frost model needs better accuracy for a reliable forecast

Summary (cont.)

- A pavement model can be developed to forecast pavement temperature
  - Use heat conduction and energy balance eqns
    - Modify for bridge surface
    - Get variables from the MM5
  - Frost model will accept MM5 air temperature, dewpoint temperature and windspeed
  - Frost model will accept pavement temperature from the pavement temperature model

Acknowledgements

Thanks to my mentors, Daryl Herzmann, David Flory, and Dr. Takle.

Thanks to Caleb Huitt for the use of his computer, and to all who reviewed the thesis paper.