The Impact of Cloud Type on Surface Radiation and Road Pavement Temperature

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Writing Mentor: Jeff Custer

Impacts of Adverse Weather on Roads

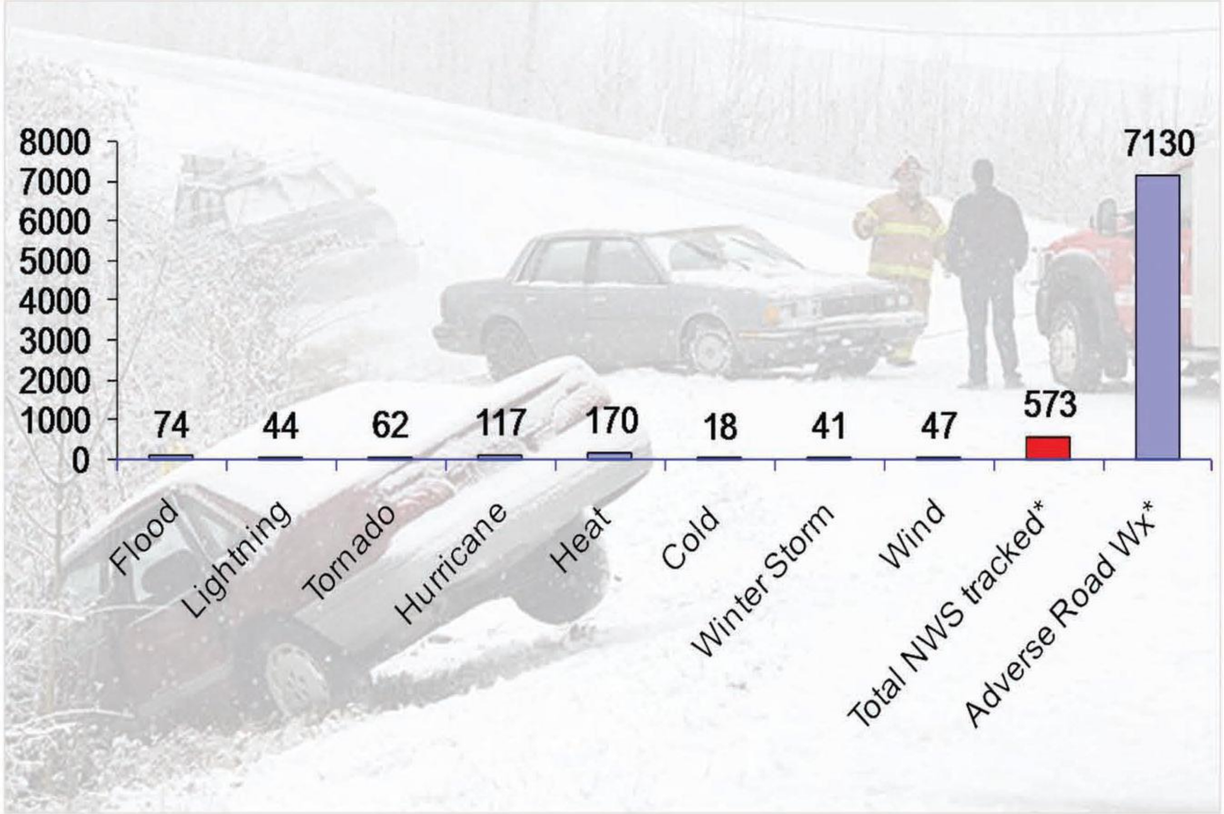
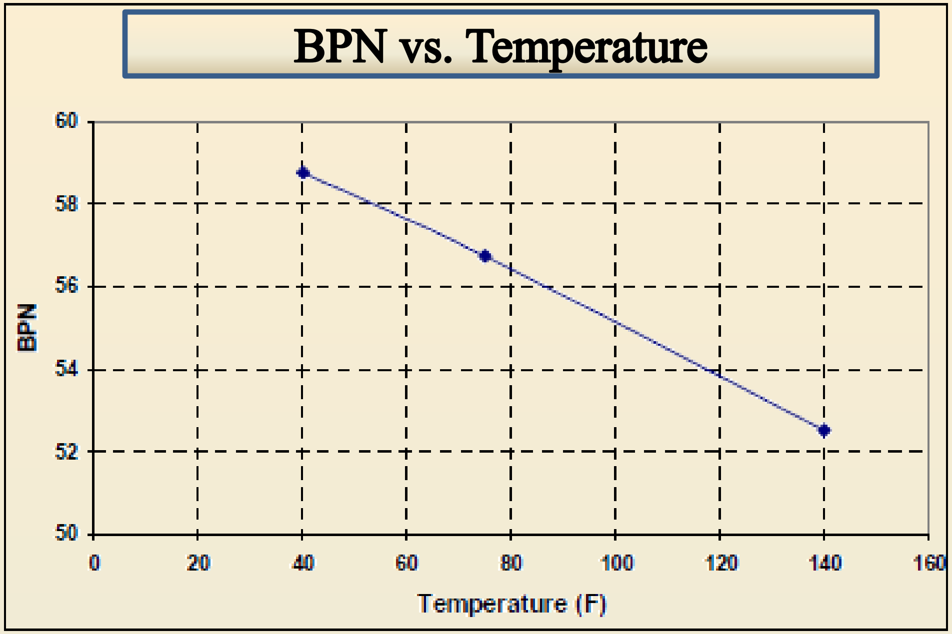


Fig 1. National Weather Service tracked average annual fatalities (1995 – 2008) due to weather hazards (USDOT, 2010).

- **Safety** – 24% of U.S. Highway crashes are weather-related; ~673,000 injuries
- **Economic** – Avg. cost per crash is $14,100; congestion costs ~$9.5 billion
- **Environmental** – Air quality and local watershed pollution
- **Social** – Inconvenience of traffic delays

Pisano et al. 2008

Tire Friction & Temperature



*BPN – British Pendulum Number, surface friction measurement

- Khasawneh and Liang (2012)
- As temperature increases, tire friction (grip) decreases
- Tire expands vertically, less surface area in contact with ground

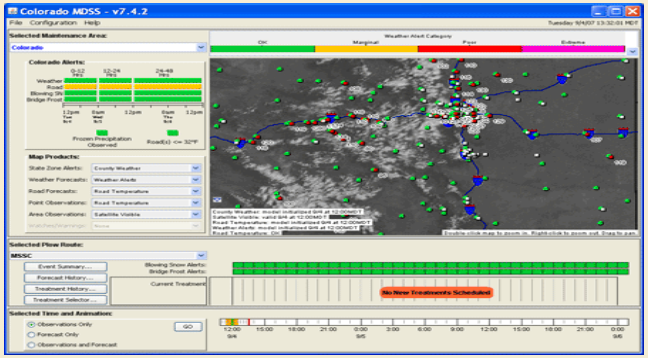
Motivation

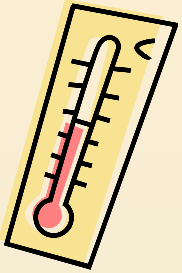
- Forecast systems are impacted by inaccurate radiation forecasts
- Cloud amount and type influences radiation forecasts
- Inclusion of cloud type may improve forecasts for a variety of end-users

Pavement Temperature Energy Balance Models

Road Weather Information System stations

Pavement Temperature Energy Balance Model

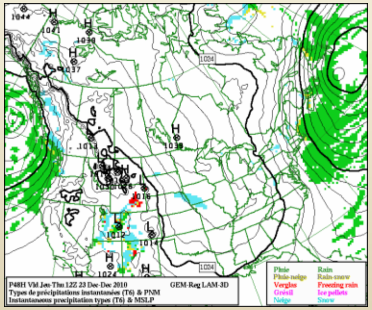




Pavement Temperature Forecast

Weather Decision Support for:

- Snow removal/deicing
- Road maintenance
- Driver awareness



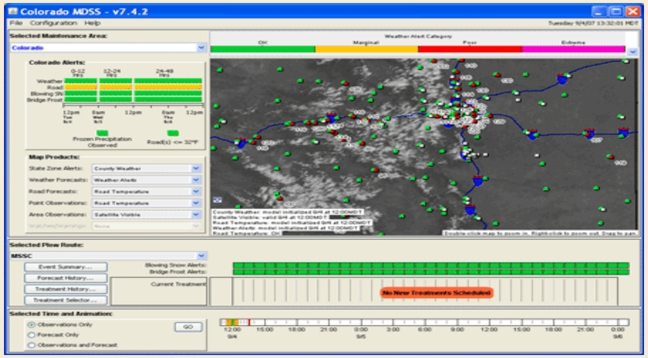
Numerical Weather Prediction Model

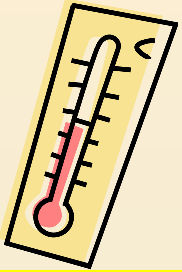
Walker et al. 2011

Pavement Temperature Modeling Improvements

Road Weather Information System stations

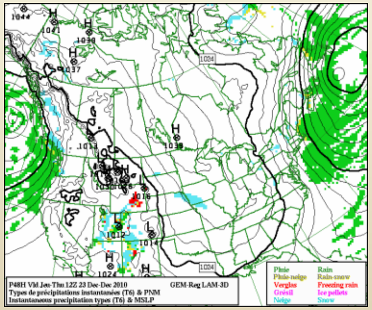
Pavement Temperature Energy Balance Model





More Accurate Pavement Temperature Forecast

Improved Weather Decision Support & Increased Safety



Numerical Weather Prediction Model

Better Cloud Type and Radiation Data

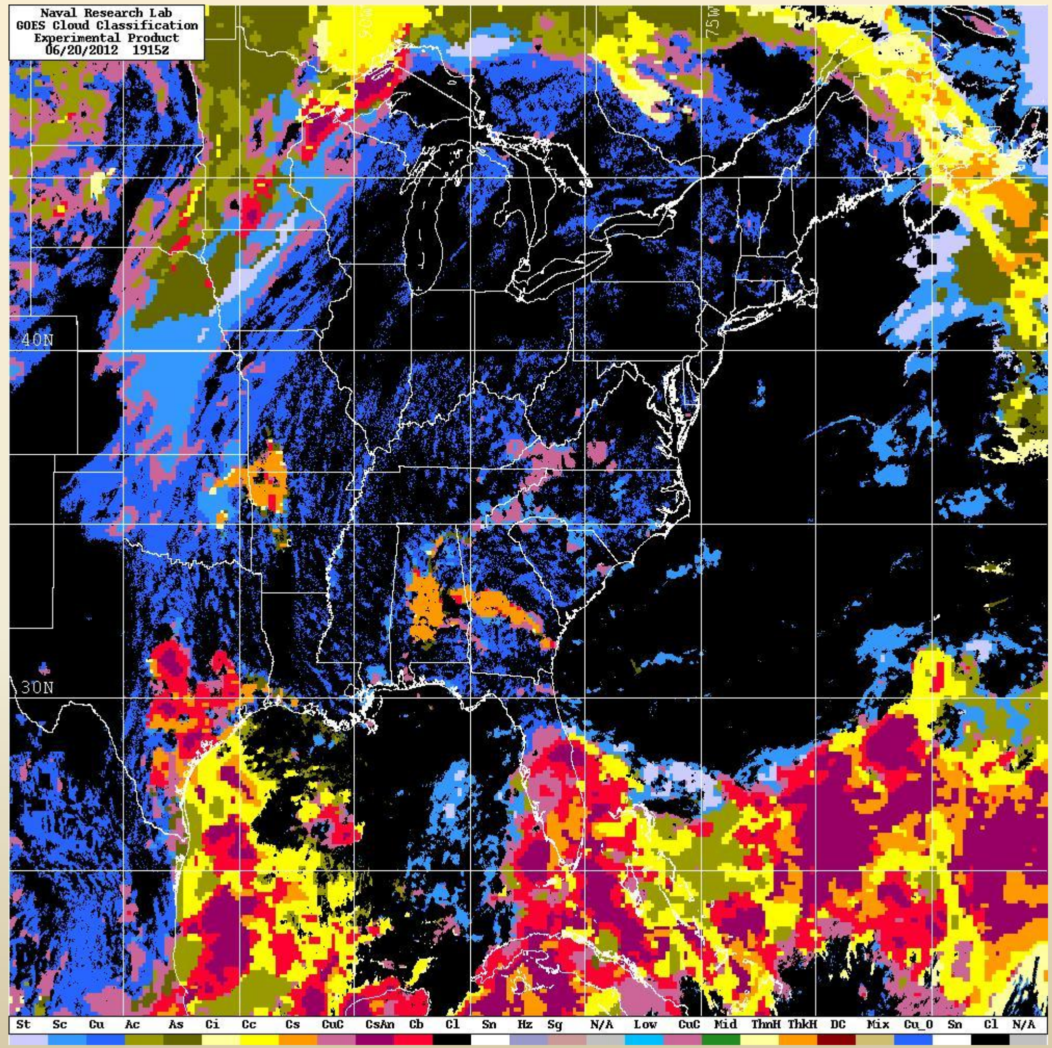
Walker et al. 2011

Naval Research Laboratory Cloud Classifier

- Utilizes combination of visible and infrared satellite channels to produce cloud type

- Pixel-by-pixel brightness thresholds

- Day and night operation



1915 UTC 20 June 2012 NRL

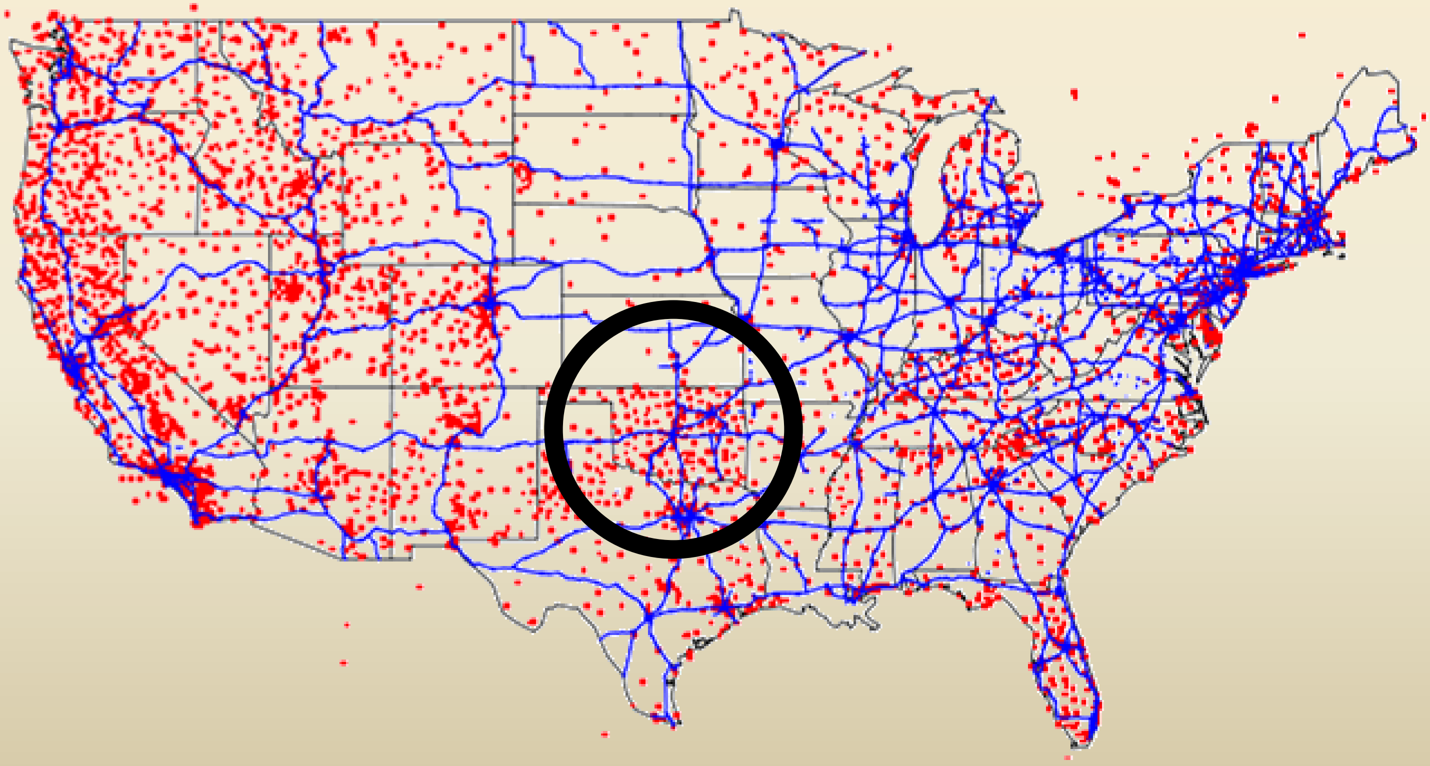
Case Study Analysis

- 9 cases from Salisbury, NC, May-June 2012
- Radiation – Cloud Type Distribution Analyses
- Theoretical Max Radiation and Water Vapor Assessments

Google Maps

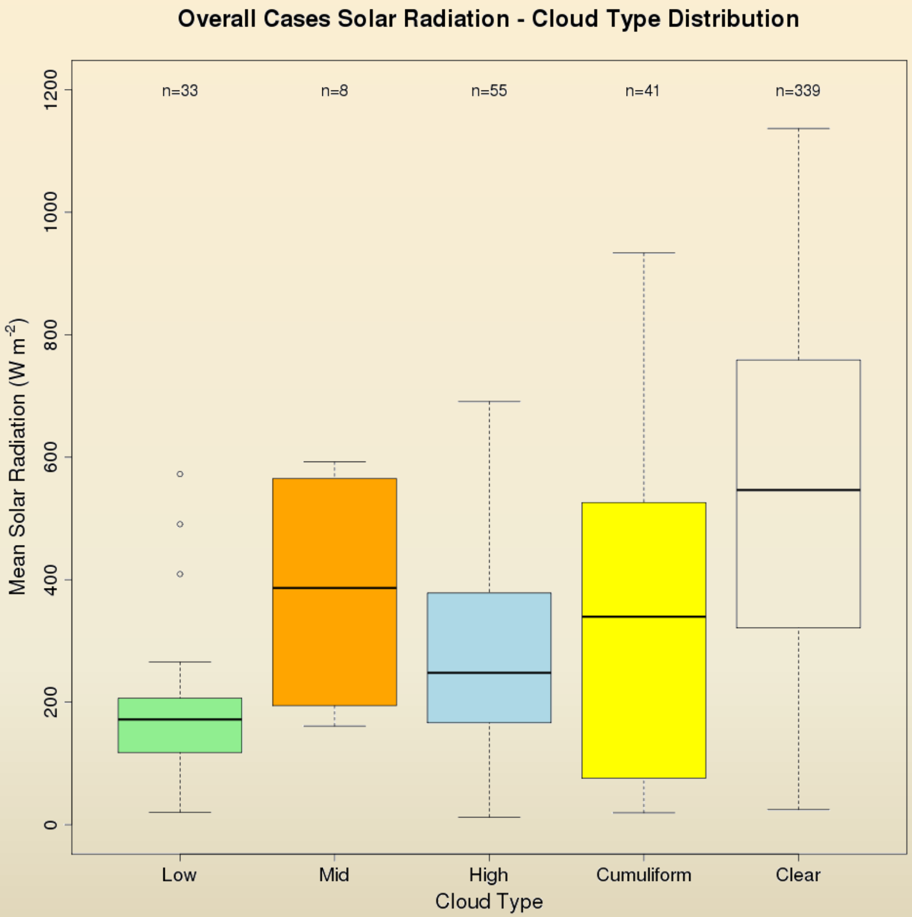
Bulk Statistical Assessment

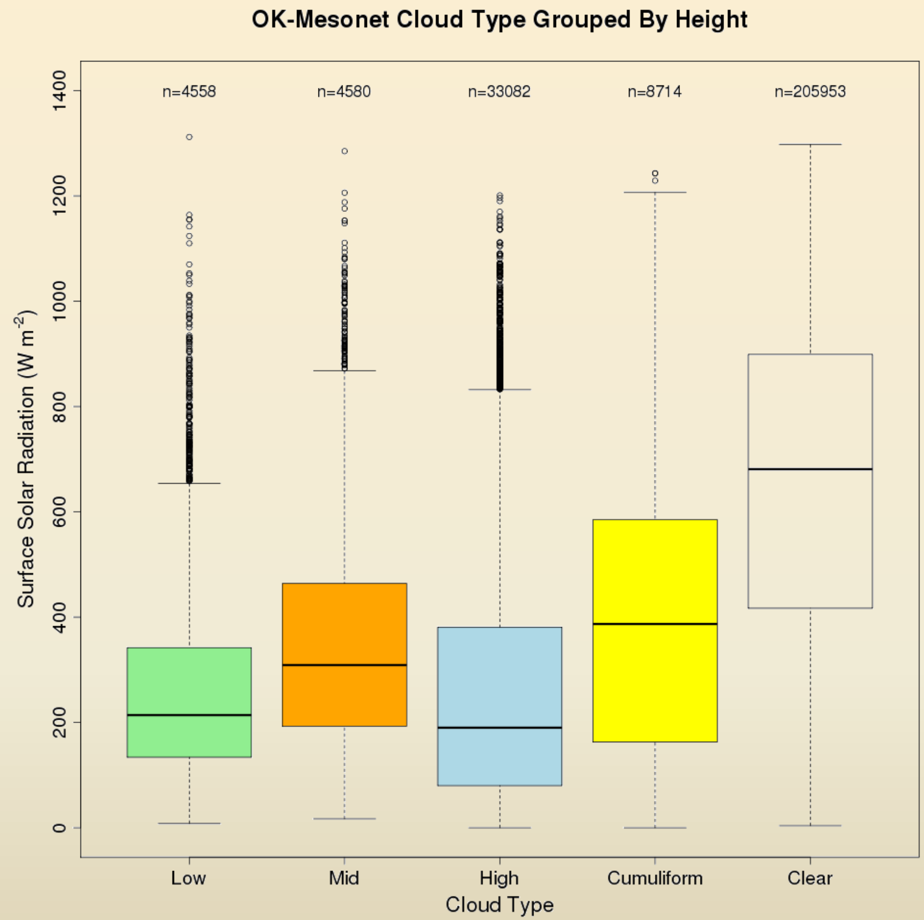
- June 2012 OK-MESONET
- Radiation – Cloud Type Distribution Analyses



Adapted from Clarus Archive data

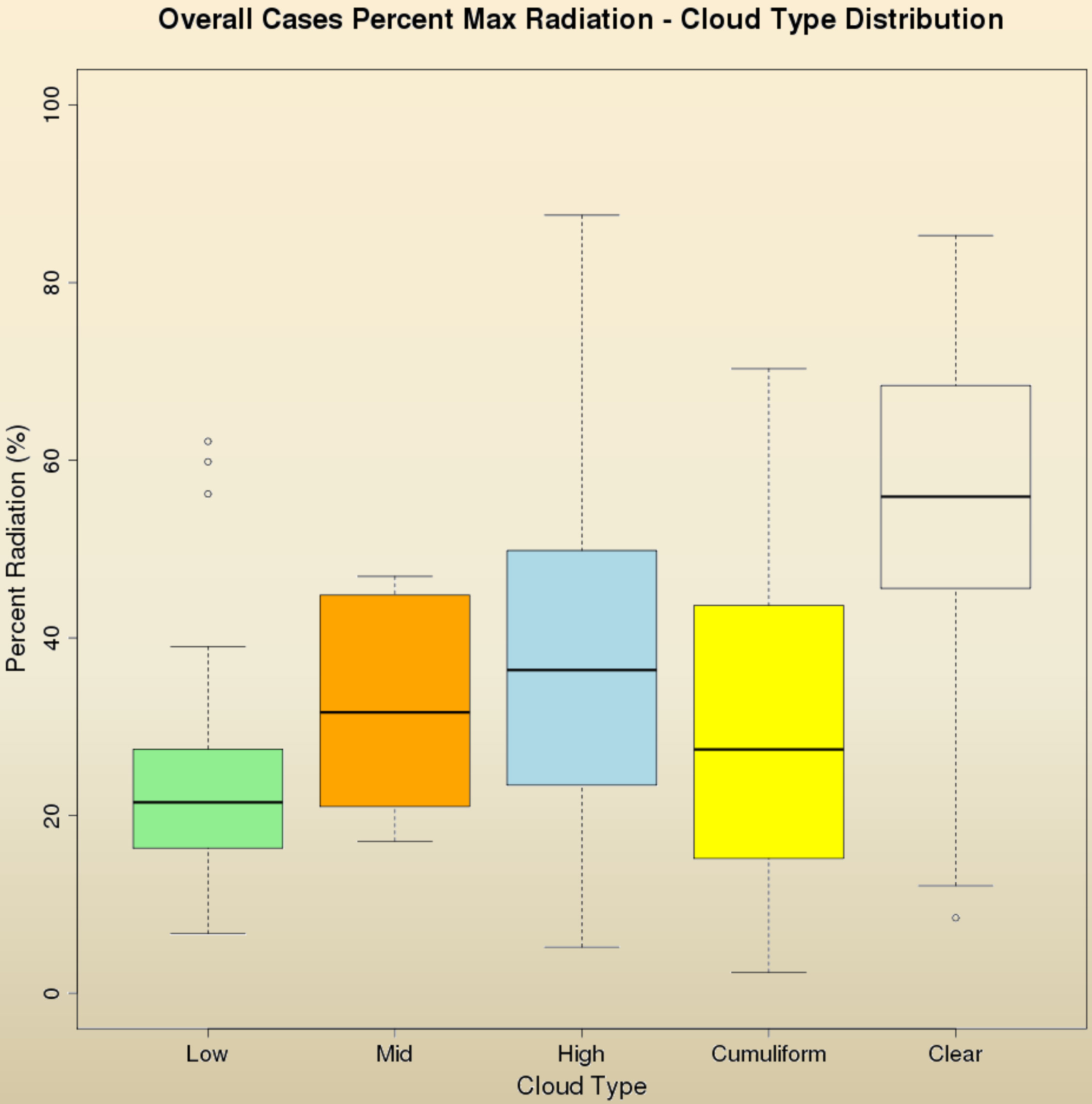
Case Studies Vs. OK-Mesonet





OK-Mesonet distributions similar to case studies

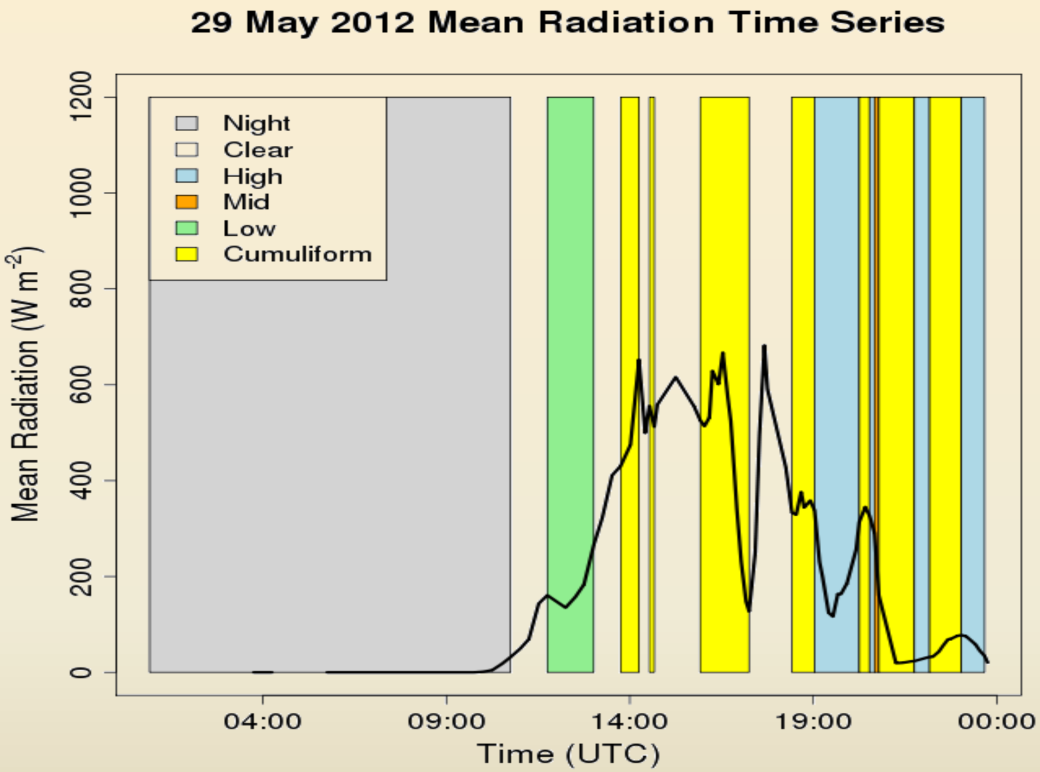
Summary of All 9 Cases



Percent of Max Radiation

- Low clouds
  ~20%
- Mid-level clouds*
  ~34%
- High clouds
  ~40%
- Cumuliform clouds
  ~30%
- Clear
  ~60%

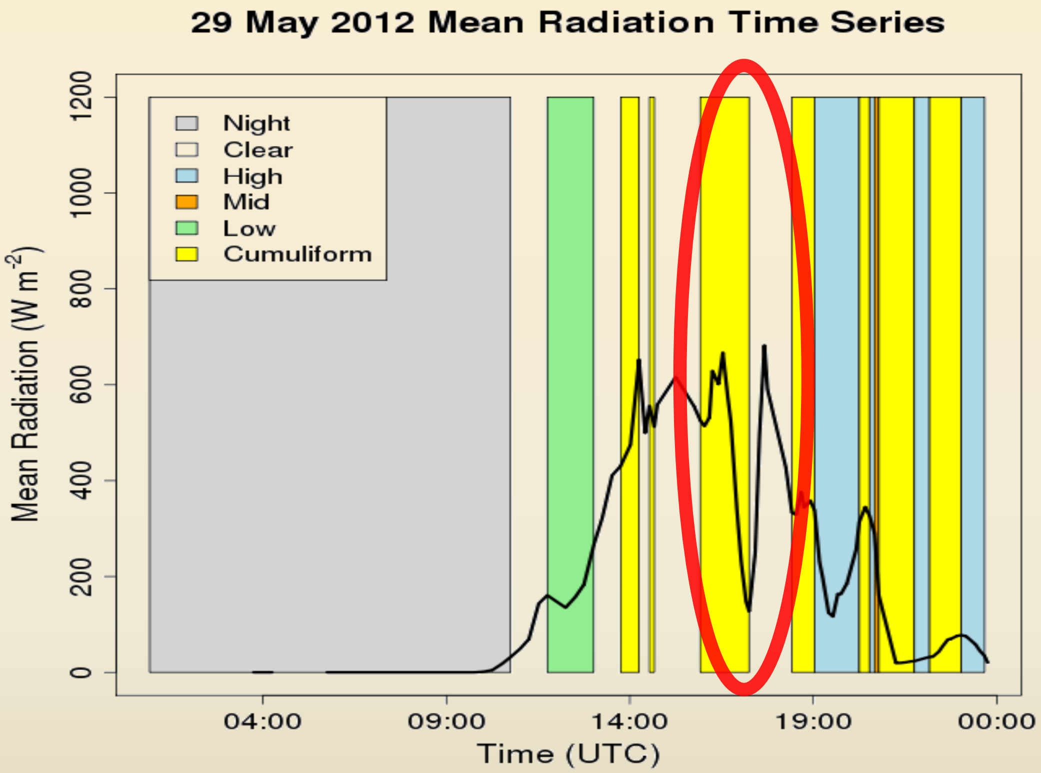
Tactical Forecasting



Time (UTC)	Mean Radiation (Wm^{-2})	Cloud Type
1615	628.8	Cumuliform
1625	601.25	Cumuliform
1632	667	Cumuliform
1640	575.3333	Cumuliform
1645	524.2	Cumuliform
1655	339.5455	Cumuliform
1702	231.25	Cumuliform
1710	147.5455	Cumuliform
1715	127.1818	Cumuliform
1725	250.3333	Clear
1732	497	Clear
1740	682.2	Clear
1745	590.5	Clear

- 45 min radiation reduction
- 25 min radiation recovery

Tactical Forecasting



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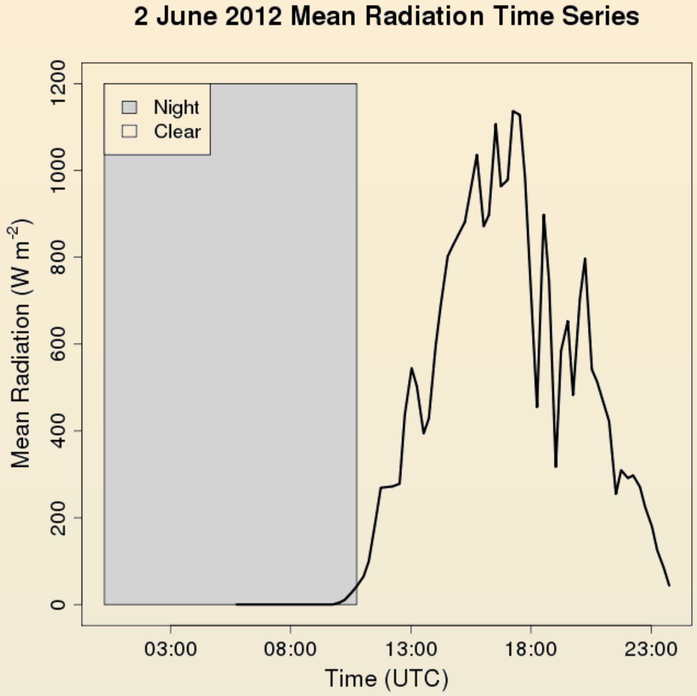
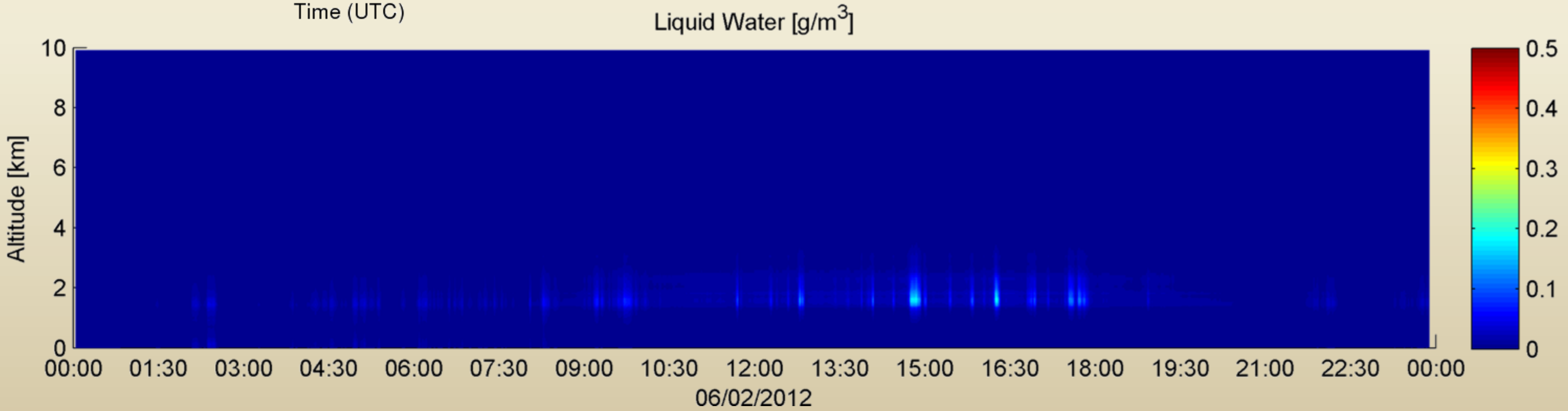
Challenges: Clear Day?



- ➢Noisy radiation observations on this "clear" day
- ➢Liquid water on the radiometer shows notable signal



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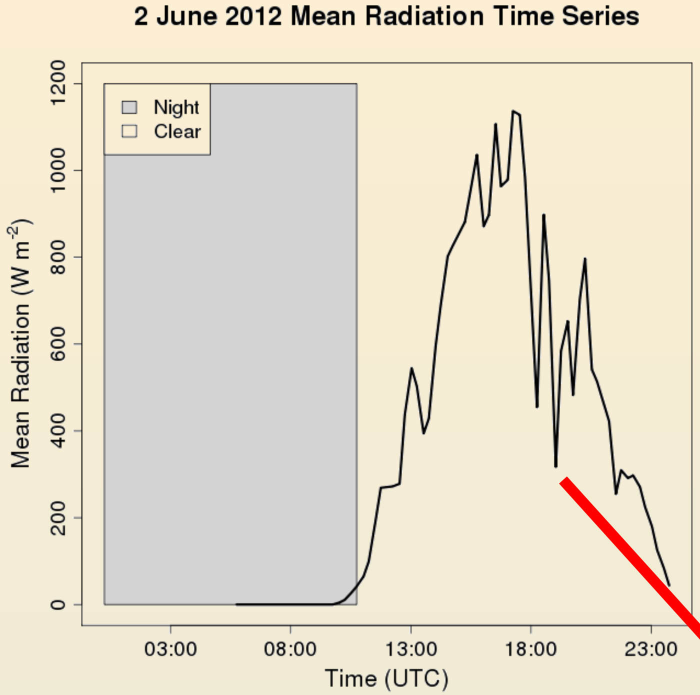

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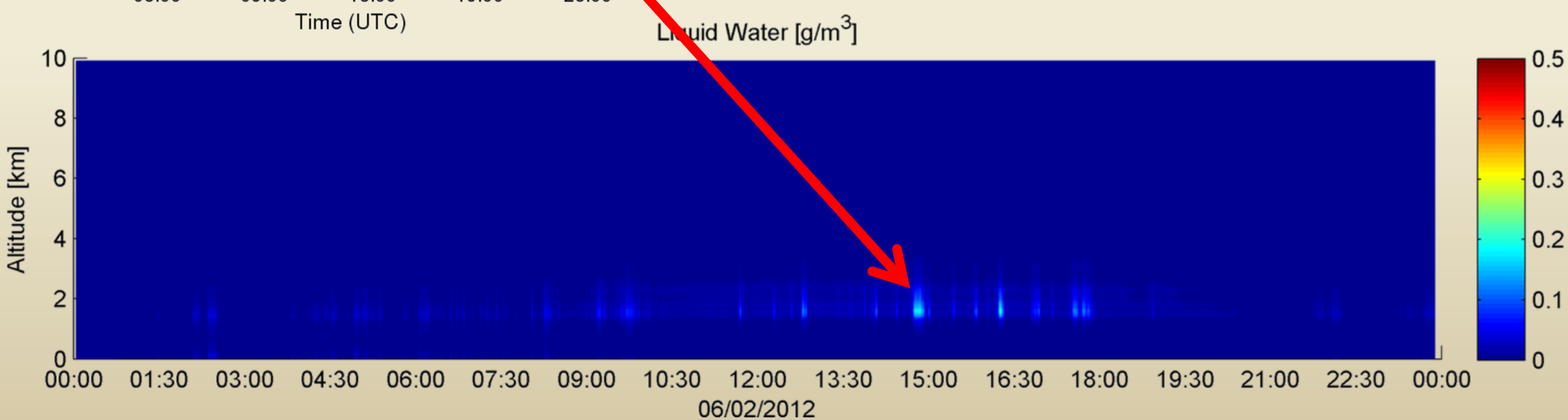

Conclusions

- It is plausible to remotely sense clouds and quantify their impact on radiation

- Tactical forecasting is also possible

- Clouds and other atmospheric effects **impede 60-80% of total possible radiation**

- Still uncertainty with other influences on radiation
  - Water vapor?
  - Aerosols?

Future Work

- Compute regression analysis for OK-Mesonet
- Similar assessment for other regions / seasons
- Test other important cloud properties
- **Road pavement temperature** + radiation analyses

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research | mentoring | community
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Photo Credits / References

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  - Snowplow: http://www.paullarosa.com/2010/12/even-snow-plows-get-the-blues/
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  - NASCAR: http://topics.wsj.com/subject/N/nascar/1676
- Tire Friction Slide
  - Research: Khasawneh, M. A., and R. Y. Liang, 2012: Temperature Effect on Frictional Properties of HMA at Different Polishing Sites. *Jordan Journal of Civil Engineering*, **6**, 39–53 .
  - BPN Instrument: www.highwaysmaintenance.com/skidtext.htm
  - Tires: http://sports.espn.go.com/rpm/news/story?series=2&page=nascar101/tires
- Pavement Temperature Energy Balance Model Slide:
  - Road Weather Information System station: http://climateillinois.files.wordpress.com/2012/01/rosa_210x170.jpg
  - Numerical Weather Prediction: http://www.weatheroffice.gc.ca/model_forecast/global_e.html
  - Pavement Temperature Energy Balance Model: http://www.rap.ucar.edu/projects/rdwx_mdss/screenviews.php
  - Pavement Temperature: Microsoft Clip Art
  - Maintenance Decision Support System: http://www.rap.ucar.edu/projects/rdwx_mdss/images/mdss_splash_screen_3_07sm.jpg
  - Clouds: http://www.theboucher.com/?cat=5
- NRL Slide and Cloud Type Data
  - NRL: http://www.nrlmry.navy.mil/sat-bin/goes_cc2/clouds?AREA=cclass_east_area1&PROD=cclass
- Case Study Analysis Slide
  - Radiometer: http://www.radiometrics.com/products.htm
  - Google Maps: https://maps.google.com/maps?q=salisbury,+nc&oe=utf-8&aq=t&client=firefox-a&ie=UTF-8&hl=en&authuser=0
- Bulk Stat Assessment Slide and Mesonet Data
  - Clarus: http://www.clarus-system.com/
  - Weather Station: http://www.novalynx.com/110-ws-16.html
- Summary Slide: http://www.bluefishplc.com/wp-content/uploads/2011/09/road_to_clouds.jpg

Summary

- **Pavement temperature is crucial to vehicle response to weather conditions**
- **Clouds are the primary source of forecast error due to influence on surface radiation**
- **Better inclusion of clouds in forecast systems will improve pavement temperature modeling**

Thank You, Questions?

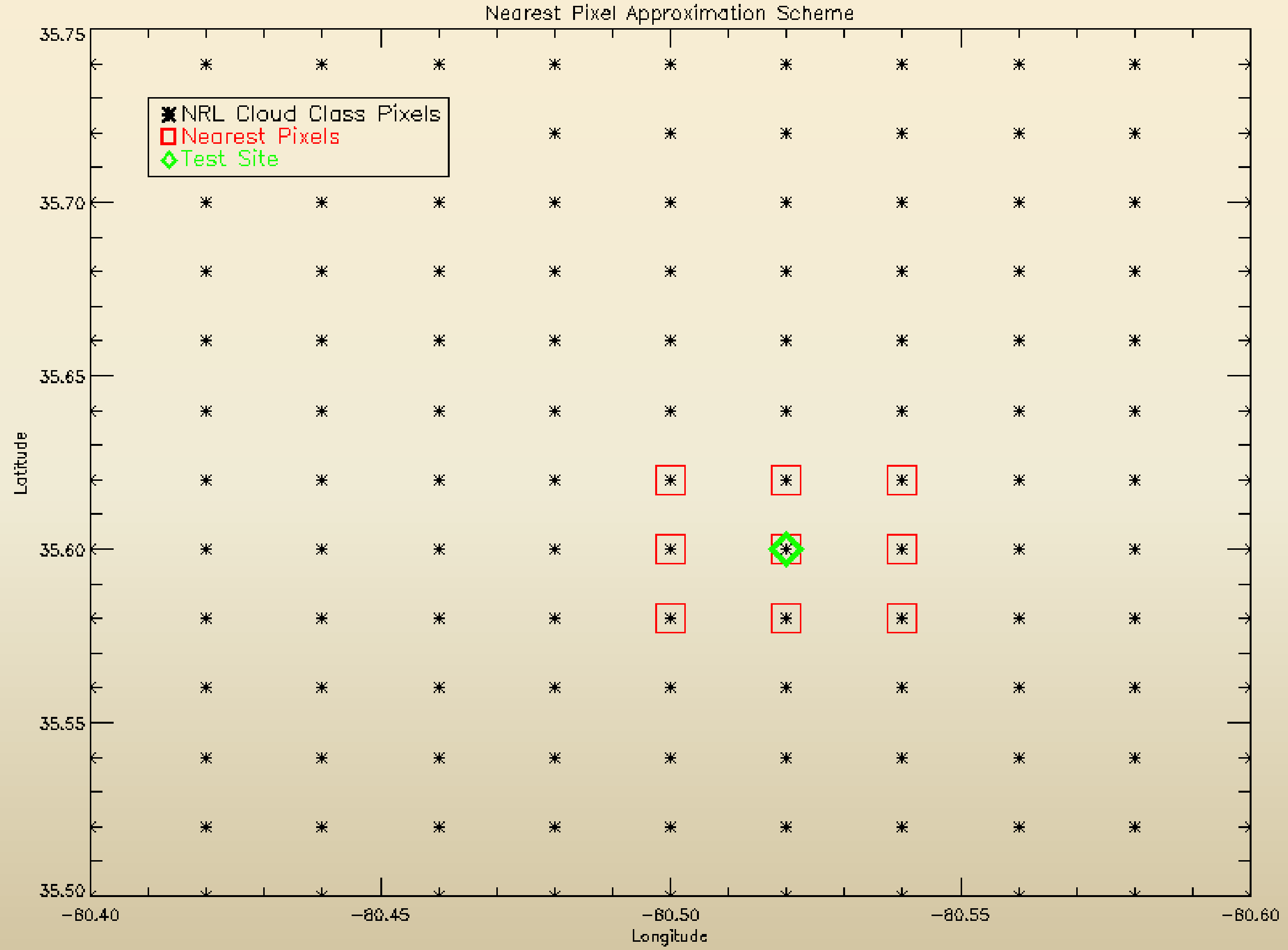
Cloud Type Groups

Height Cloud Type Groups			
Low	**Mid**	**High**	**Cumuliform**
Stratus Stratocumulus	Altocumulus Altostratus	Cirrus Cirrostratus Cirrocumulus	Cumulus Cumulus Congestus Cumulonimbus Cirrostratus Anvil

Thickness / Coverage Cloud Type Groups		
Thick	**Thin**	**Scattered**
Stratus Stratocumulus Cirrostratus Anvil Cumulonimbus	Altostratus Cirrus Cirrostratus	Cumulus Altocumulus Cirrocumulus Cumulus Congestus

Cloud Type – Location Pixel Matching

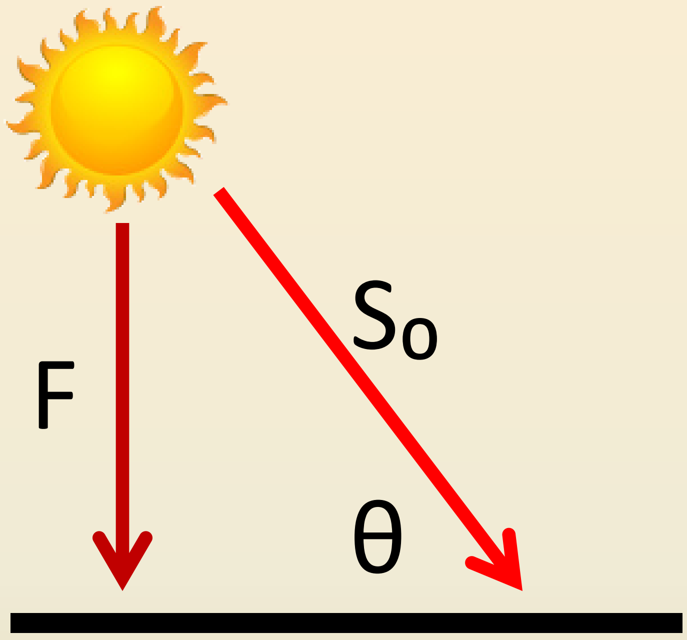
- 9 pixel box, 8x8 km
- Most frequent cloud type selected – grouped by height



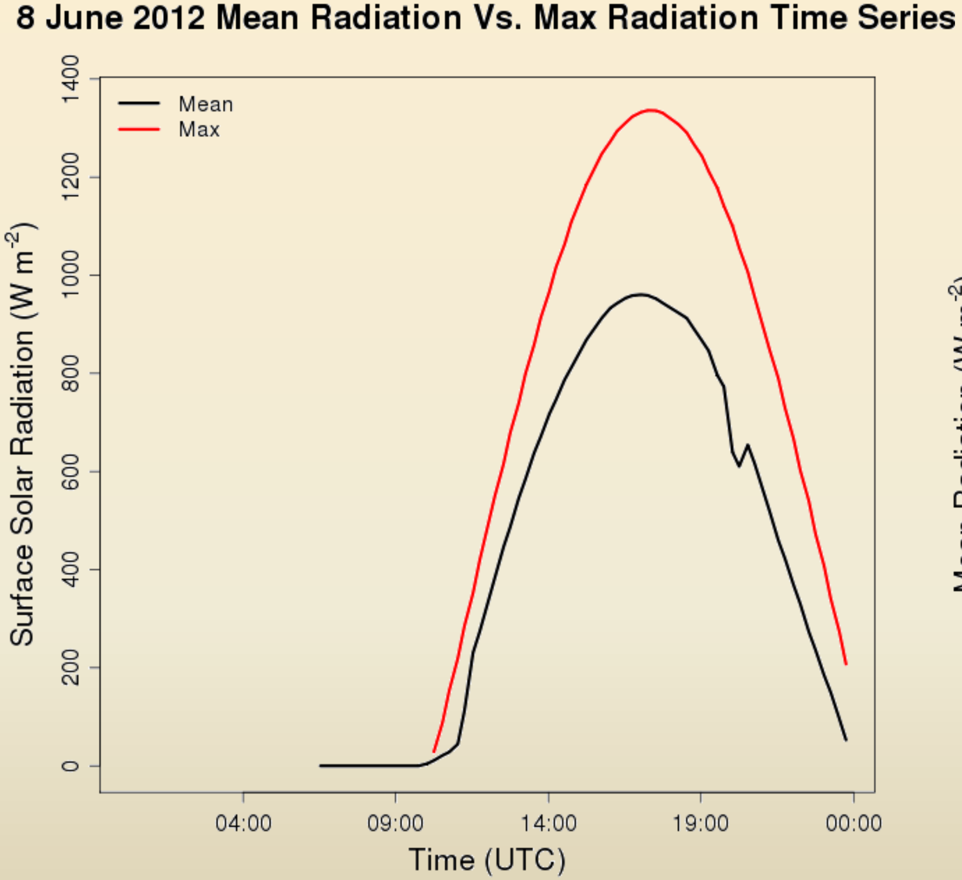
Theoretical Solar Max Calculations

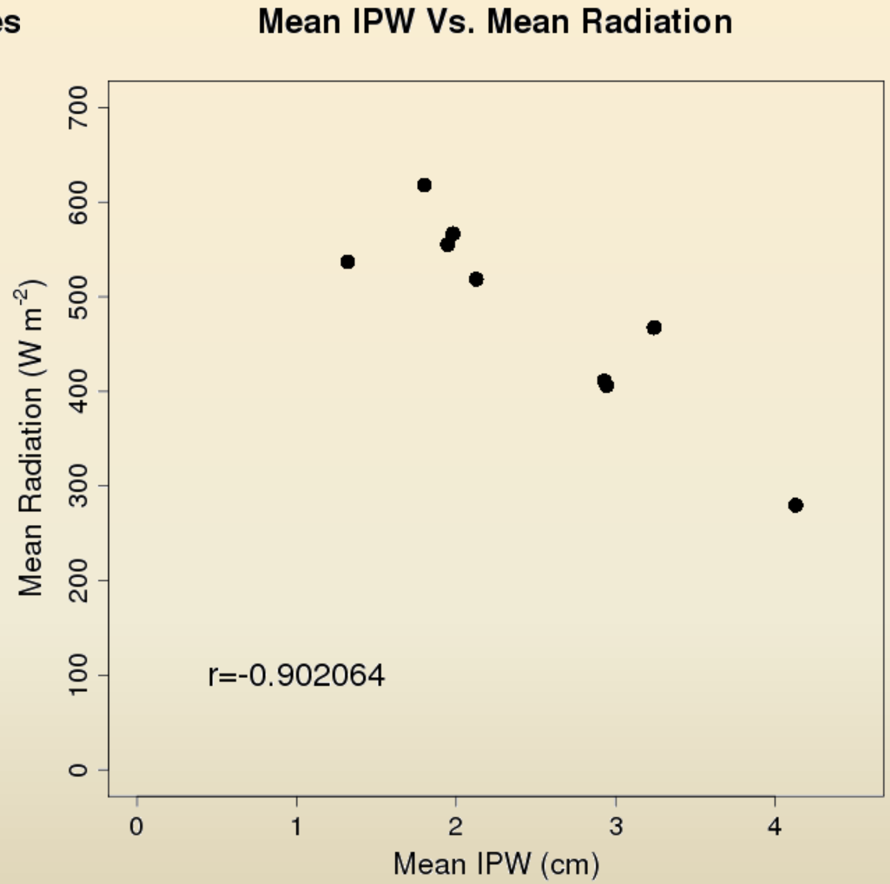
$$F = S_o\ (\sin \theta)$$

- F top of atmosphere solar flux (Wm^{-2})
- S_o is the solar constant: 1370 Wm^{-2}
- Θ:
  local solar zenith angle



Another Clear Day? – Water Vapor

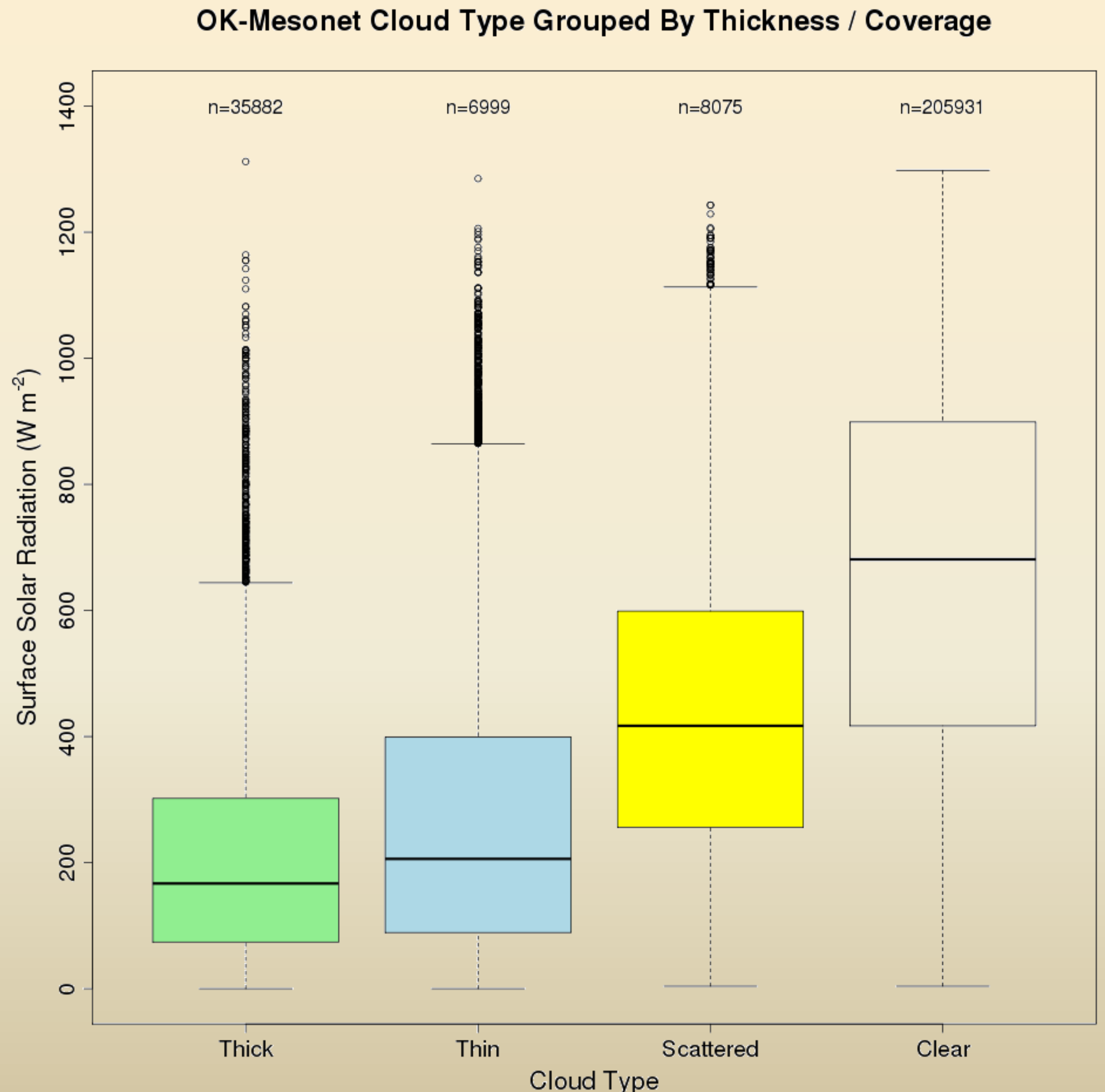




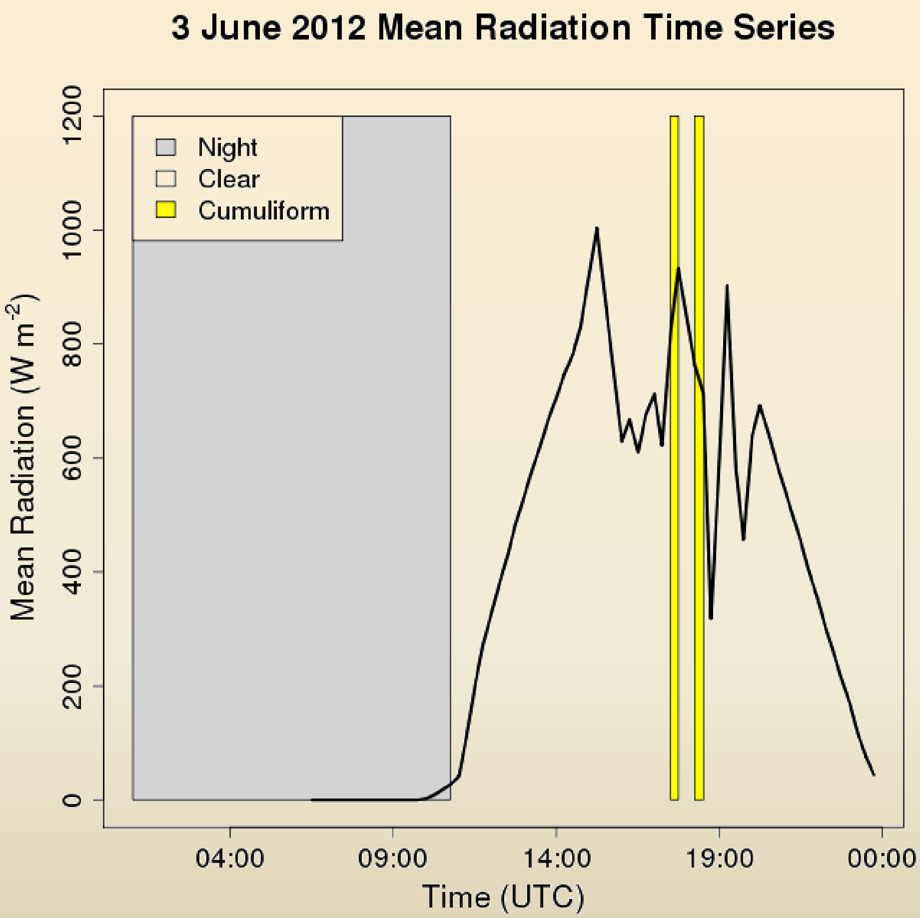
Clear day comes nowhere near maximum radiation

Mean Radiation Vs. Mean Water Vapor for all 9 cases
Correlation = -0.902

OK-Mesonet ALT Cloud Groups



Another Tactical Forecasting Case



Time (UTC)	Mean Radiation (Wm^{-2})	Cloud Type
1731	821.6667	Clear
1745	933.4	Cumuliform
1815	764.8	Clear
1831	713	Cumuliform
1845	318	Clear
1901	603.3333	Clear
1915	902.4	Clear

Part 1 - Case Studies

Case Date (2012)	Cloud / Weather Conditions	Synoptic Comments
19 May	Variable, mostly high clouds	Tropical system offshore (Beryl)
23 May	Overcast with AM rain, late clearing	Stationary front, severe weather to the east
24 May	Variable with AM mist/fog, late clearing	Summer southeast moisture flow
29 May	Mostly cloudy, PM thunderstorms	Tropical depression (Beryl) combined with cold front
30 May	Overcast with AM rain/mist, PM partly cloudy	Tropical depression (Beryl) combined with cold front
2 June	Partly to mostly cloudy all day	AM cold front
3 June	Mostly clear with few/scattered high clouds	Clear, warm front ahead of next system
8 June	Data Not Available	Clear, systems north and south
9 June	Data Not Available	Gulf Coast storm approaching from southwest

British Pendulum Number

- British Pendulum Test
- Pendulum swings with a rubber sensor at the bottom
- Rubber sensor grazes the surface in question
- BPN = 100 x coefficient of friction (μ)

Khasawneh and Liang (2012)