LADCO | LAKE MICHIGAN AIR DIRECTORS CONSORTIUM

Satellites, machine learning, and numerical weather prediction

Applications to lake breeze events in the Great Lakes Basin

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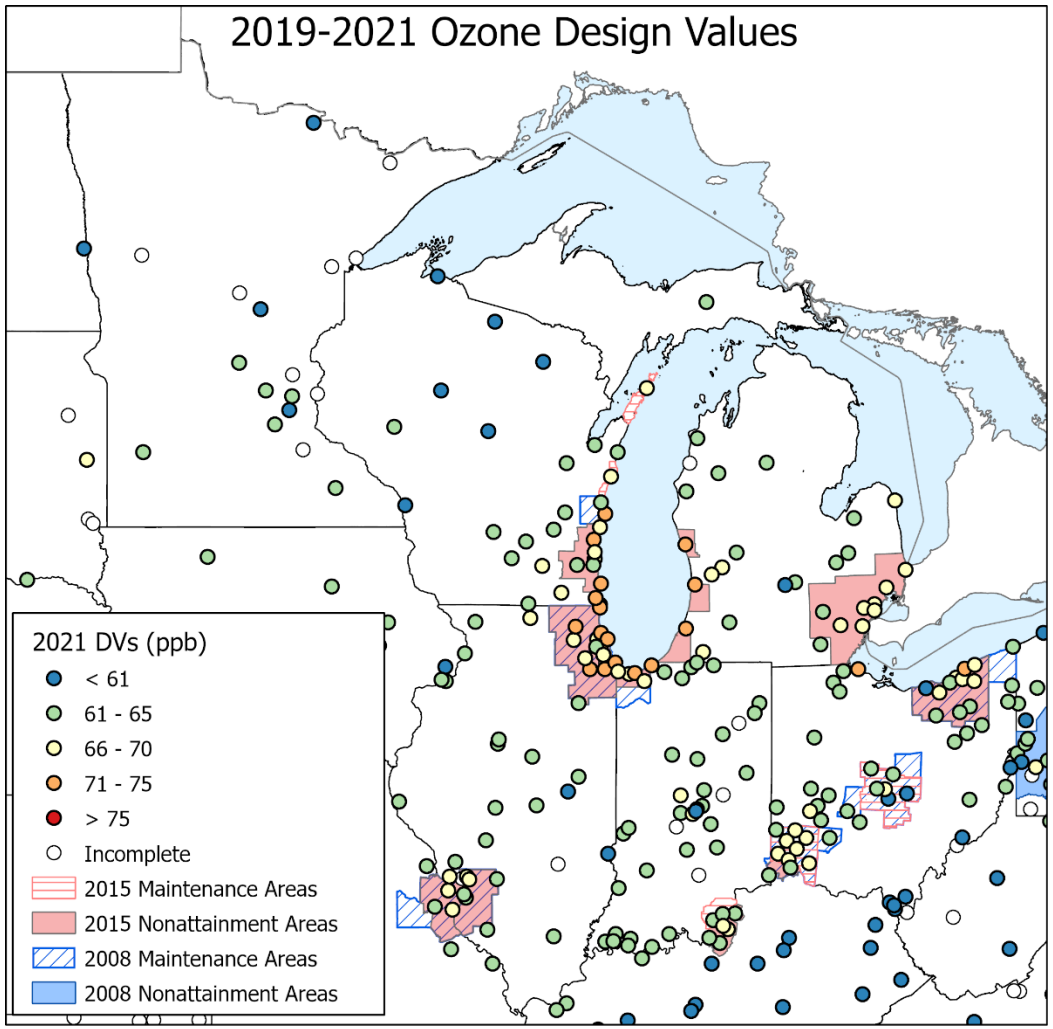
Lake Michigan Air Directors Consortium, Hillside, IL

The 21th Annual CMAS Conference

Session: Multiscale Model Applications and Evaluations

Chapel Hill, NC, October 17-19, 2022

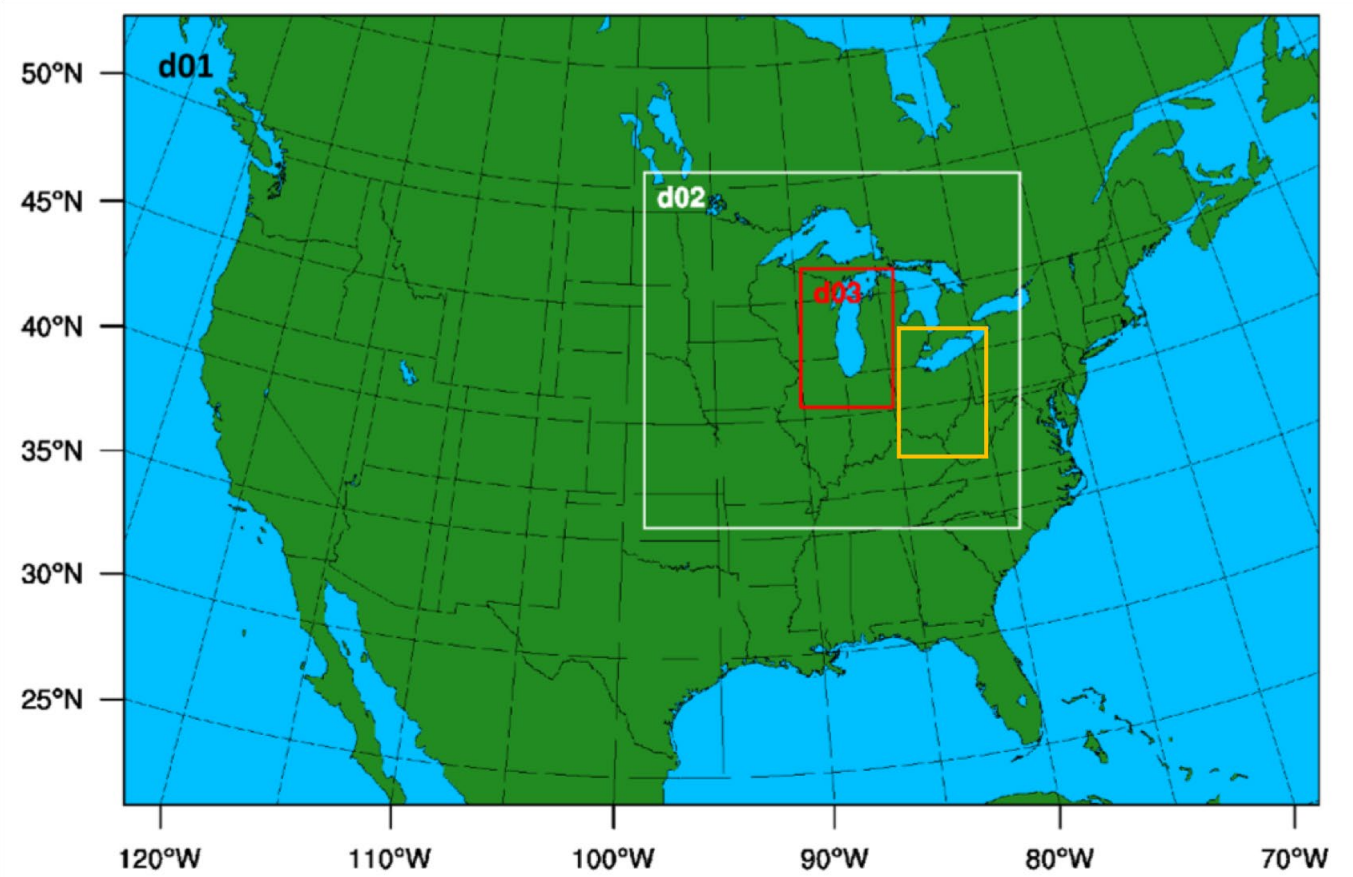
Motivation



Courtesy: Angela Dickens, LADCO

- The highest ozone concentrations in the Great Lakes Basin
  - Human settlement close to the water bodies
  - The land-and-water interface exacerbates
- Lake breeze plays a role in some enhanced ozone readings
- For policy application, the adequacy of the model performance and **whether the model accurately simulates the lake breeze dynamics** are often questioned
- **A challenge of identifying lake breeze conditions using limited routine surface observations**

LADCO 2016 WRF modeling specification



CASE = LADCO_2016_WRFv39_YNT_GFS_LIS[1]

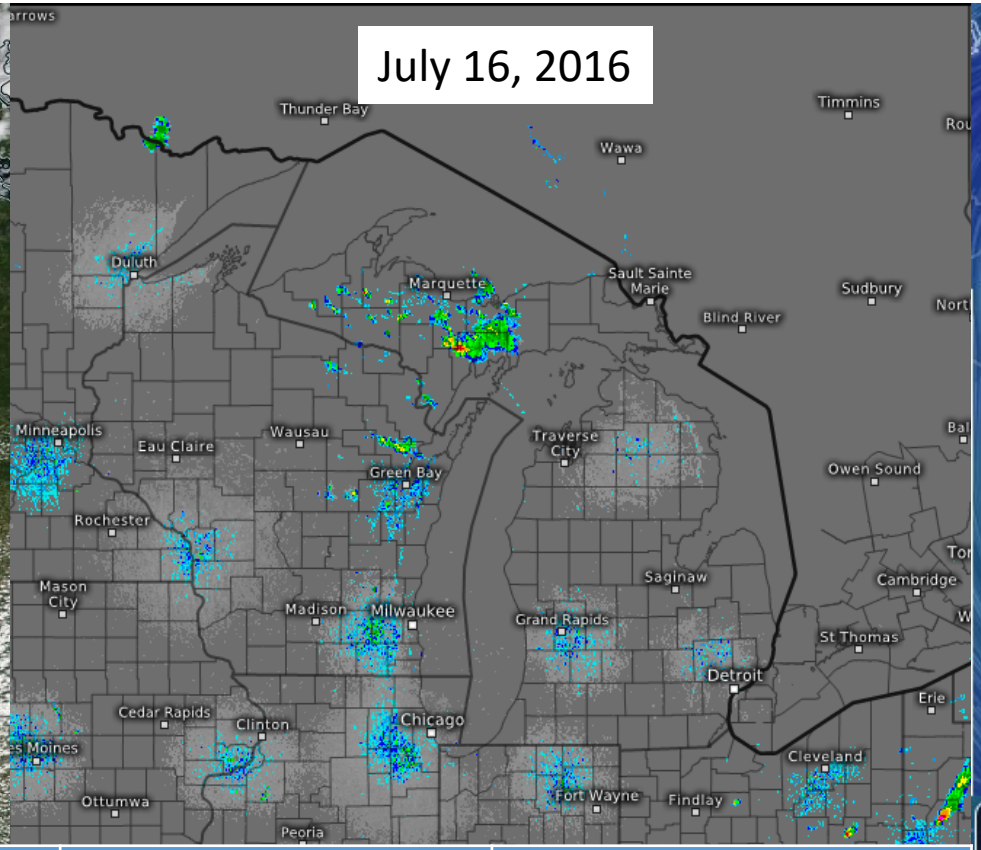
- **Y**SU PBL
- Unified **N**oah LSM
- **T**hompson's microphysics, MM5 Monin-Obukhov surface layer option
- **GFS** Grid4 (~25km, 6hr fdda)
- 3D grid (wrffdda) and surface observation nudging (wrfsfdda)
- **GLSEA SST** over the Great Lakes (daily, 1.3-2.6 km res, Great Lakes Surface Environmental Analysis SST)
- **SPoRT LIS[2]** soil T&Q for d02-d04

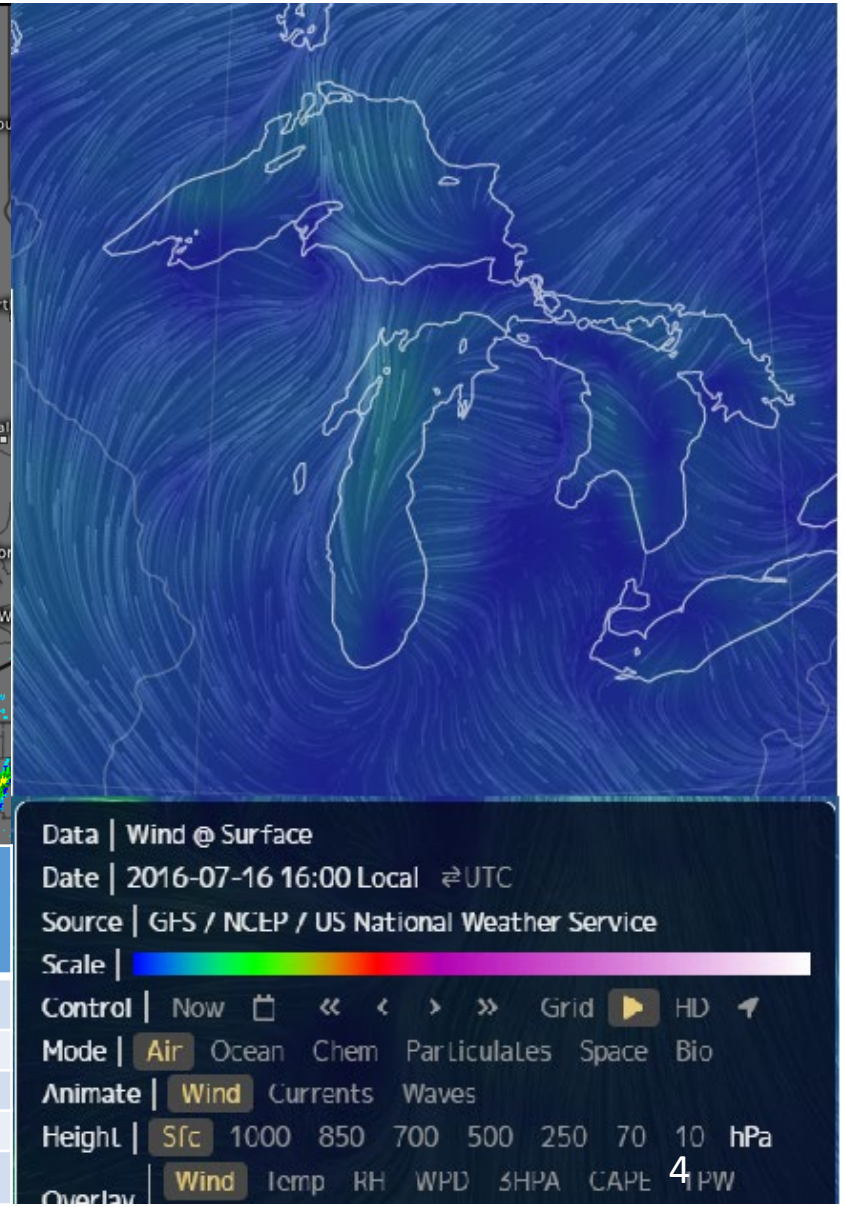
WRFv3.9.1.1 Annual Simulation:

- 4 nested domains, 35 layers up to 50 hPa
- ~38 jobs with 24 cpu/job at AWS
- 10.5-day run with 12h spin-up

[1] Brad Pierce's Group, University of Wisconsin-Madison, WI
[2] Jonathan Case, Short-term Prediction Research and Transition (SPoRT) Center, AL

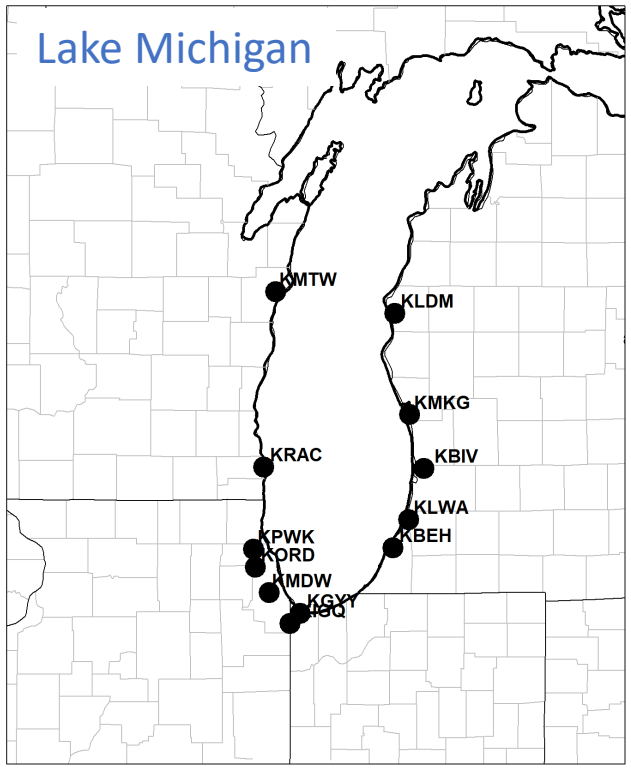
Identifying Lake Breeze Days using Satellite imagery, Doppler radar, and GFS wind

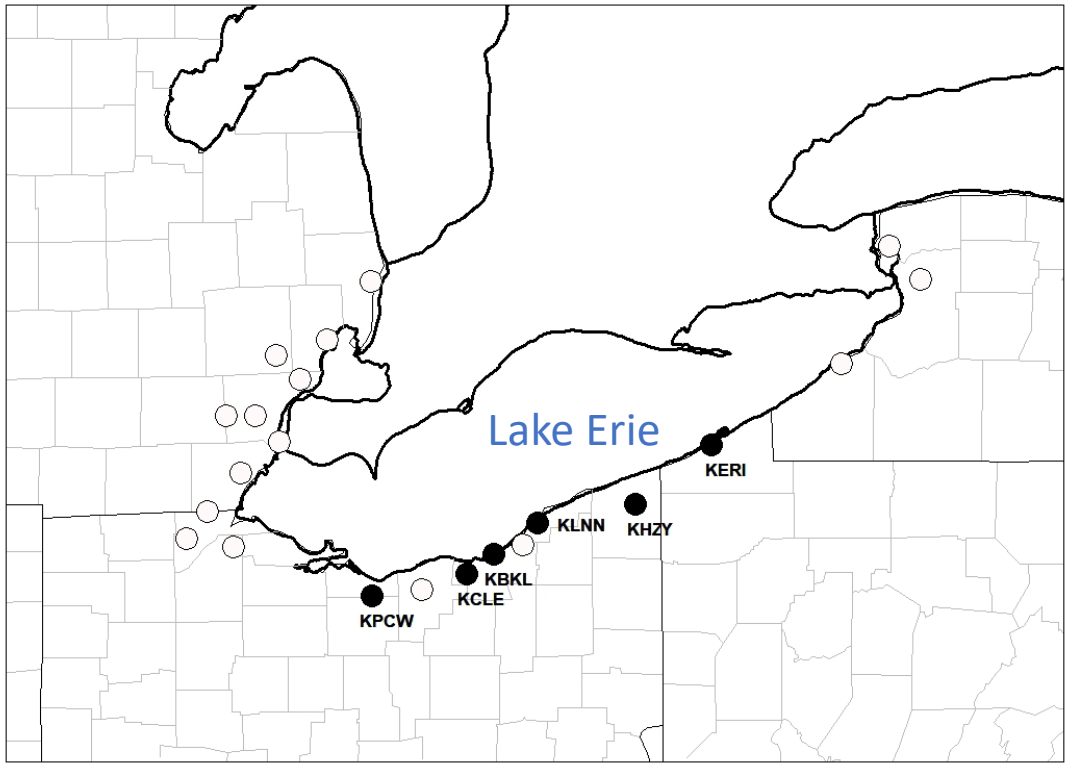




Date	VIIRS Surface Reflectance (https://worldview.earthdata.nasa.gov/)	Doppler Radar Reflectivity Composite (https://weather.us/radar-us)	GFS/NCEP/National Weather Service Surface Wind (https://earth.nullschool.net)
…	…	…	…
6/8/2016	cloud cover	no data	Y
6/30/2016	Y	Y	N
7/16/2016	Y	Y	Y
…	…	…	…

Classification and Regression Tree Analysis (CART)





TOOL: R Statistical Software Package, rpart::rpart()

METAR stations in Lake Michigan and Lake Erie shores

- Elevation < 200 m a.s.l.
- Latitude < 44 N degree

INPUT DATA (May-Aug, 2016):

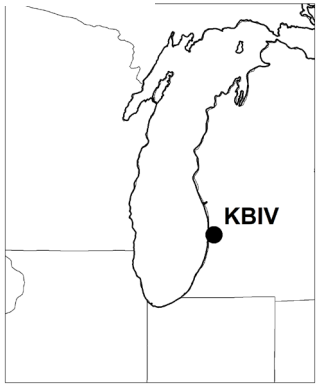
1. Lake breeze date_time (Y/N):
   Satellite-driven date and 12-16 LST
2. Temp_oC
3. Specific humidity
4. Wind speed
5. Wind direction

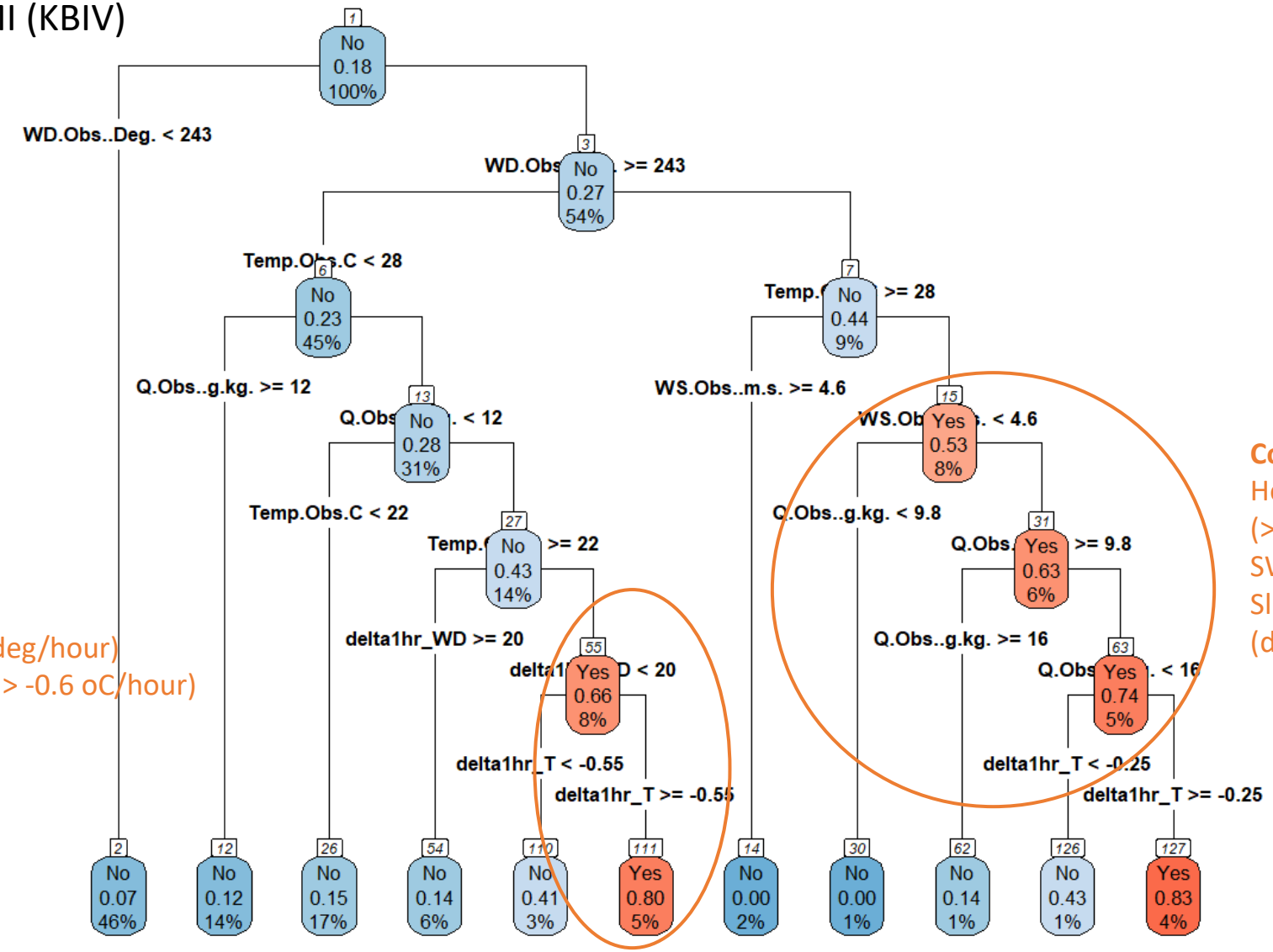
Changes in T, W, WS, WD from previous hour reading:

6. Delta1h_T
7. Delta1h_Q
8. Delta1h_WS
9. Delta1h_WD

Example: Classification Tree for lake breeze date_time (Yes/No)

METAR station: Allegan, MI (KBIV)

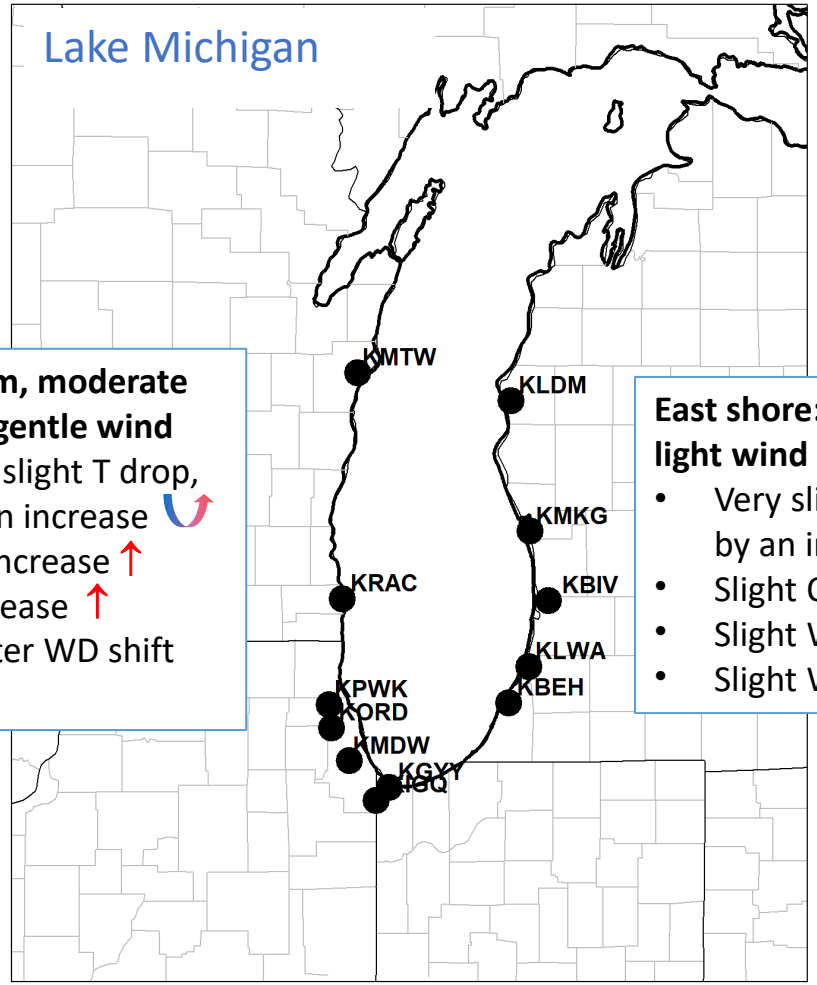




Condition 1:
Warm and moist air
(22-28 oC, 10-12 g/kg)
SW to N wind (WD shifts <20 deg/hour)
Slight T drop and rebound (dT > -0.6 oC/hour)

Condition 2:
Hot and moist air
(>28 oC, 10-16 g/kg
SW-N wind
Slight T drop and rebound
(dT> -0.3 oC/hour)

Classified meteorological conditions for lake breeze events in Lake Michigan and Lake Erie

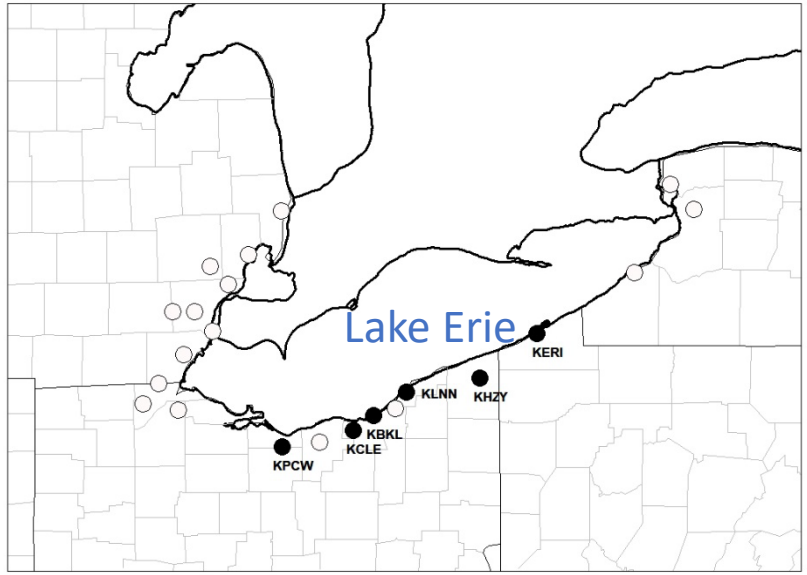


West shore: Warm, moderate humid and calm-gentle wind

- No change or slight T drop, followed by an increase
- Moderate Q increase ↑
- Slight WS increase ↑
- Slight to greater WD shift (<40 deg/h)

East shore: Hot, humid and light wind

- Very slight T drop, followed by an increase
- Slight Q increase ↑
- Slight WS decrease ↓
- Slight WD shift (<20 deg/h)

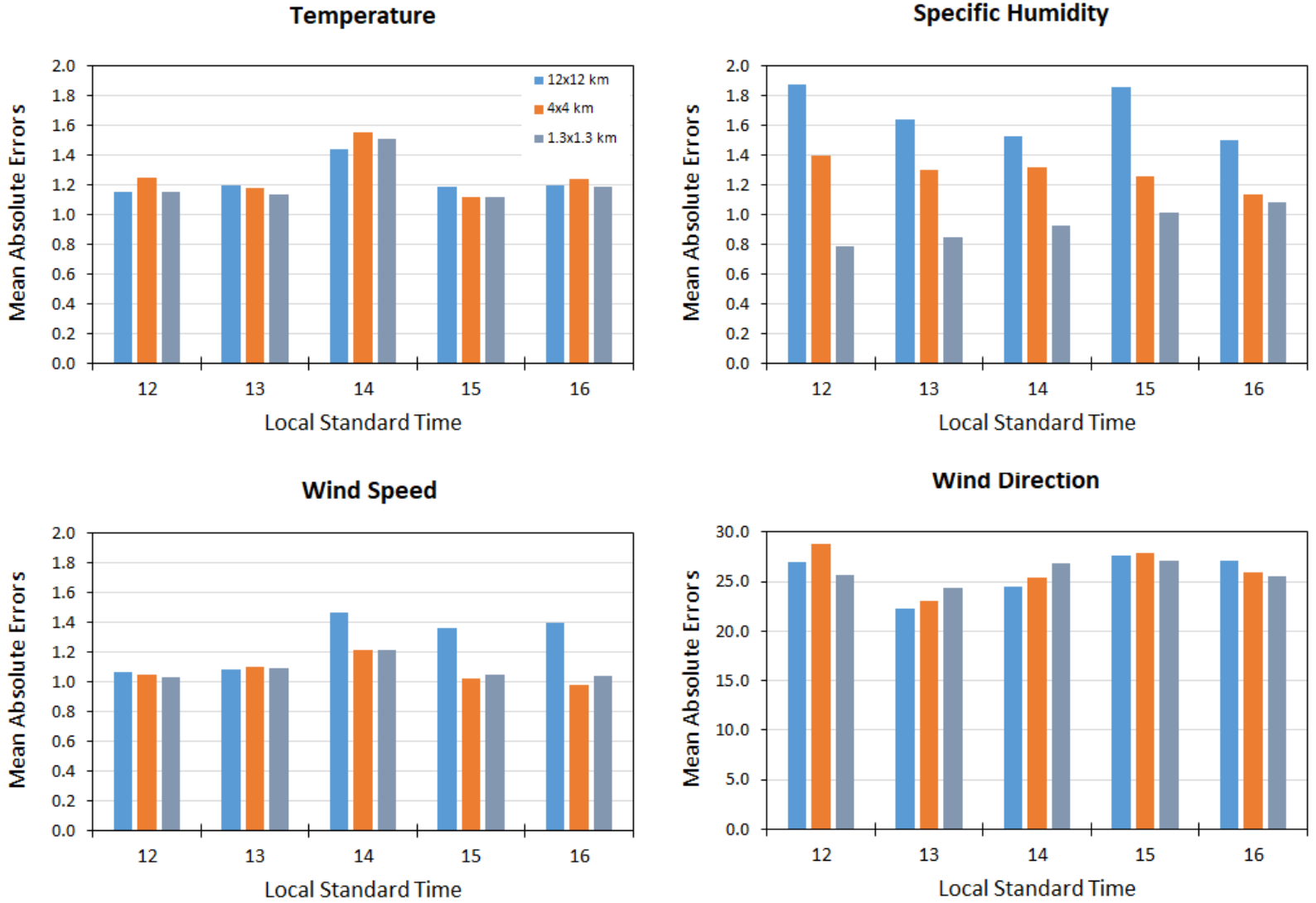


South shore: Warm-very hot, moderate humid and calm-light breeze

- No change or slight T increase ↑
- Slight drop in Q ↓
- Moderate WS decrease ↓
- Slight to moderate WD shifts (<30 deg/h)

The CART statistical model accuracies were ~92% for Lake Michigan and 82% for Lake Erie, on average.

WRF Performance for lake breezes in Lake Michigan shore



Model Performance Benchmark

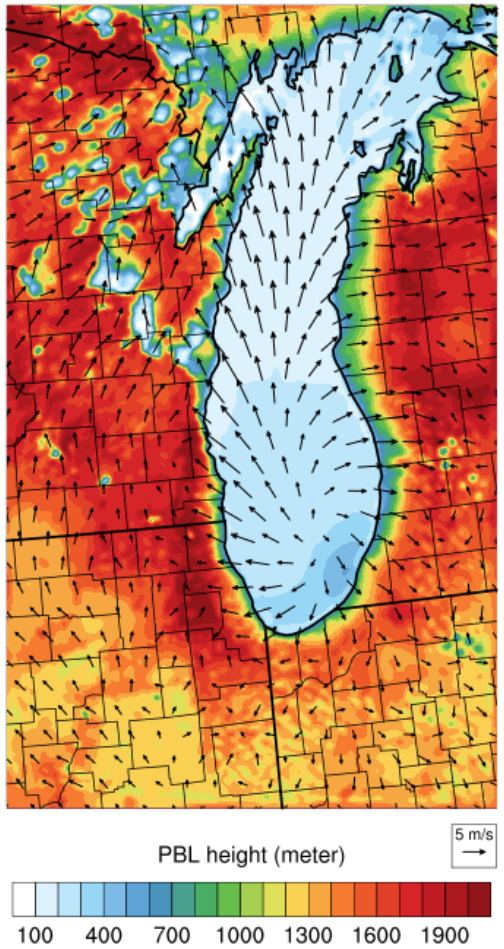
Emery et al. (2001), Kemball-Cook et al. (2005), NcNally (2009)

Conclusions

- Built CART statistical model for predicting lake breeze periods using a limited surface observations
- LADCO's 2016 WRF performs relatively well for lake breeze days, performance statistics were within the commonly used benchmark
- The model performance was slightly improved from the coarse to finer grid resolution
- Local scale convective processes were better resolved by the finer grids

The PBL height and wind field, 1.3x1.3km grid

VIIRS reflectance imagery
July 16, 2016, 2-3pm



Future Research and Operational Plans

- The analysis will be refined for Lake Erie and quantification of ozone enhancement due to lake breeze
- Development of an advisory tool for predicting lake breeze events for states' air quality forecasts
- Integration of a diagnostics for lake breeze evaluation into LADCO's model evaluation operation (a chain to AMET)

Thank you for your attention

Contact: nergui@ladco.org, (847)720-7881

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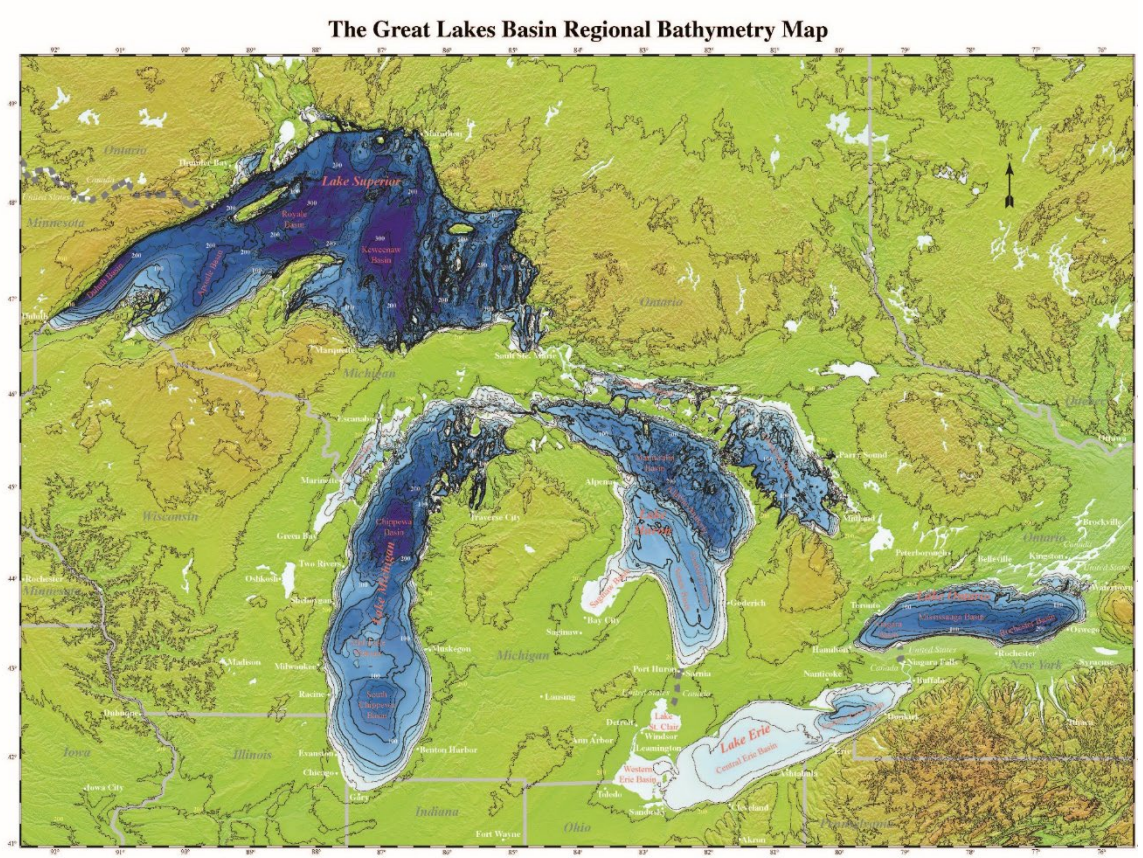
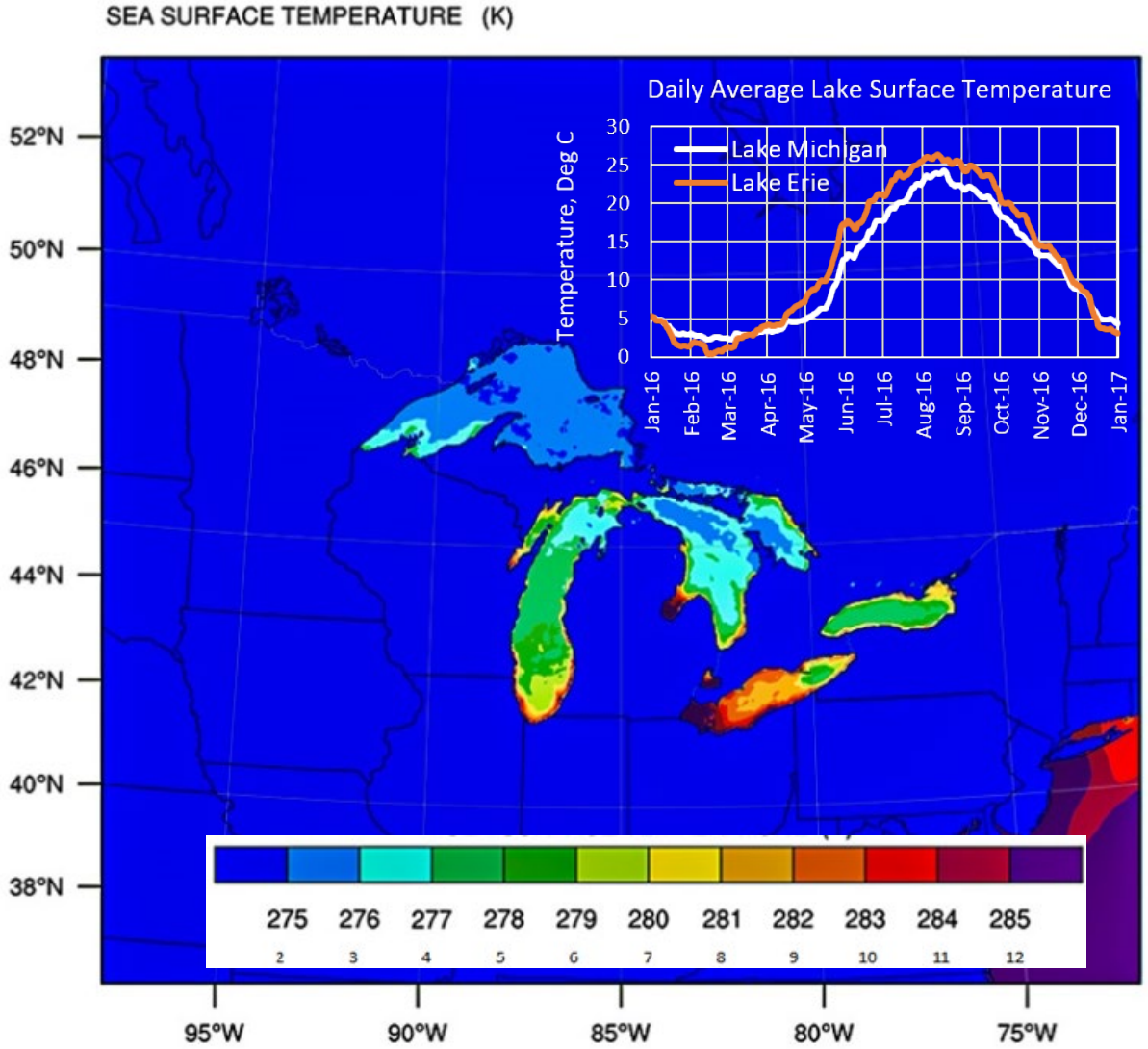
The Great Lakes Depth and Surface Temperature

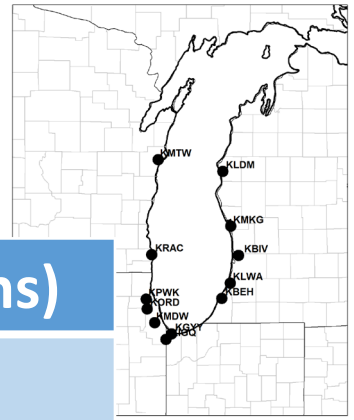




https://www.ncei.noaa.gov/sites/default/files/2021-09/greatlakesbasin.jpg
https://coastwatch.glerl.noaa.gov/glsea/
https://coastwatch.glerl.noaa.gov/statistic/

The CART model accuracies were ~92% for Lake Michigan and 82% for Lake Erie, on average.
Top two most important variables: WD and T for Lake Michigan, while T and WS/Q for Lake Erie.

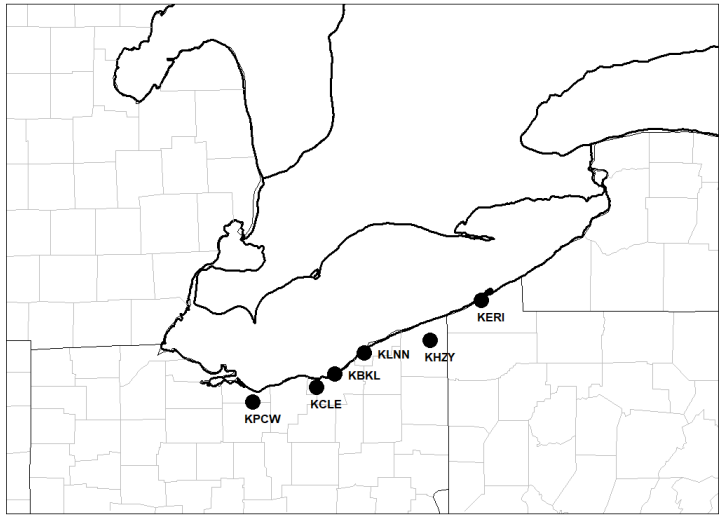
Classified meteorological conditions for lake breeze events in Lake Michigan



	West shoreline (5 stations)	South (1 station)	East shoreline (5 stations)
Met condition	**Warm, moderate humid and calm-gentle breeze:** 18< T <25 oC 5-14<Q<8.8-16 g/kg 0.5-2.5<WS<4-6 m/s 84<WD<114-164 deg	27< T <31 oC Q<10 g/kg WS< 5 m/s 84<WD<114-164 Deg	**Hot, humid and light breeze:** T>25-28 oC 10< Q <16 g/kg 3.6< WS < 4.4 m/s 223-256 < WD < 248-360 deg
Hourly Indicators	No change or slight T drop and rebound		Very slight T drop and rebound (0.5-0.6 oC/hour)
	Moderate Q increase (0.5-0.85 g/kg hour)	Slight Q increase (< 0.2 g/kg hour)	Slight Q increase (< 0.2 g/kg hour)
	Slight WS increase (0.5-1.0 m/s hour)		Slight WS drop (0.5-1.0 m/s hour)
	Slight to greater WD shift (10-40 deg/hour)		Slight WD shift (10-20 deg/hour)

Classified meteorological conditions for lake breeze events in Lake Erie

	Lake Erie south shore (6 stations)
Met condition	**Warm-hot, moderate humid and calm-light breeze:** 21< Temperature <31 or >31 oC 10< Humidity <17 g/kg 0.5 < Wind speed <6.0 m/s 280< Wind direction <20 deg
Hourly Indicators	No change or slight temperature increase (0.0-0.8 oC/hour)
	Slight drop in humidity (0.0-0.6 g/kg hour)
	Slight wind speed decrease (0.5-1.3 m/s hour)
	Slight to moderate wind direction shifts (<30 deg/hour)



WRF Performance for lake breeze events in Lake Erie south shore

LADCO

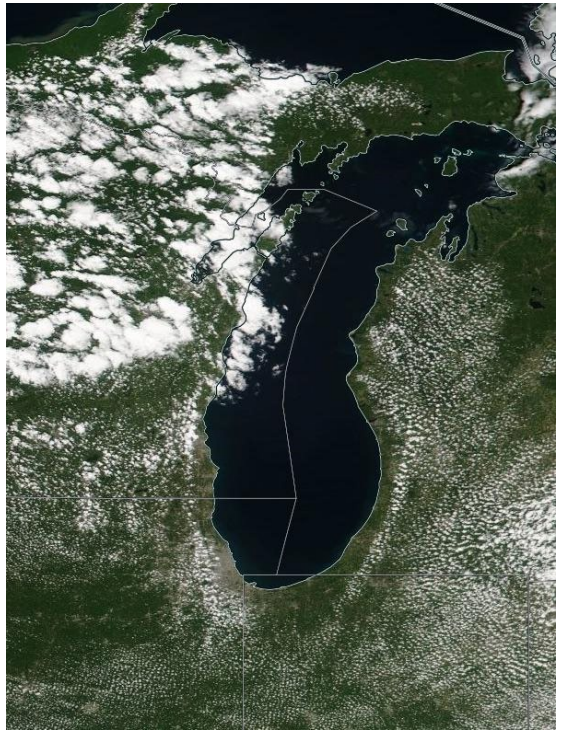
Model Errors and Biases for Lake Breeze and Non-Lake Breeze Days

Variable	Lake Breeze events		Non-lake-breeze events	
	MAE	MB	MAE	MB
Temperature 2m	1.1	-0.4	1.3	-0.6
Specific humidity 2m	1.2	-0.5	1.2	-0.3
Wind speed 10m	1.1	-0.6	1.1	-0.5
Wind direction 10m	29.0	-4.3	26.7	0.2

Model Errors and Biases for lake breeze events by different grid resolution

Variable	12x12 km		4x4 km		1.3x1.3 km	
	MAE	MB	MAE	MB	MAE	MB
Temperature 2m	1.2	-0.6	1.0	-0.2	1.1	-0.3
Specific humidity 2m	1.4	-1.0	1.2	-0.6	1.0	0.1
Wind speed 10m	1.2	-0.9	1.0	-0.5	1.1	-0.3
Wind direction 10m	30.7	-5.2	27.6	-4.7	28.7	-2.9

Satellite imagery, modeled PBL height and wind fields



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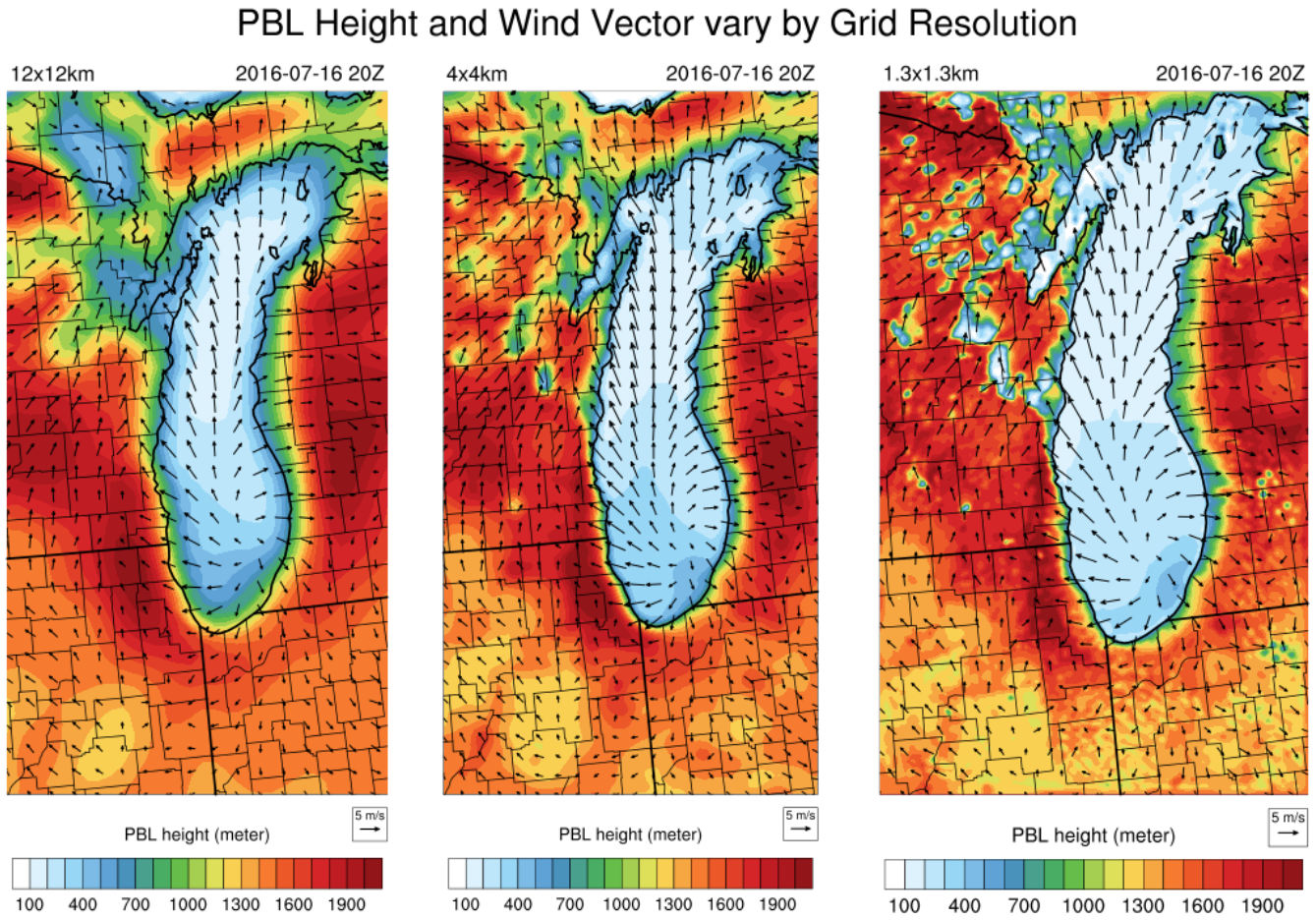
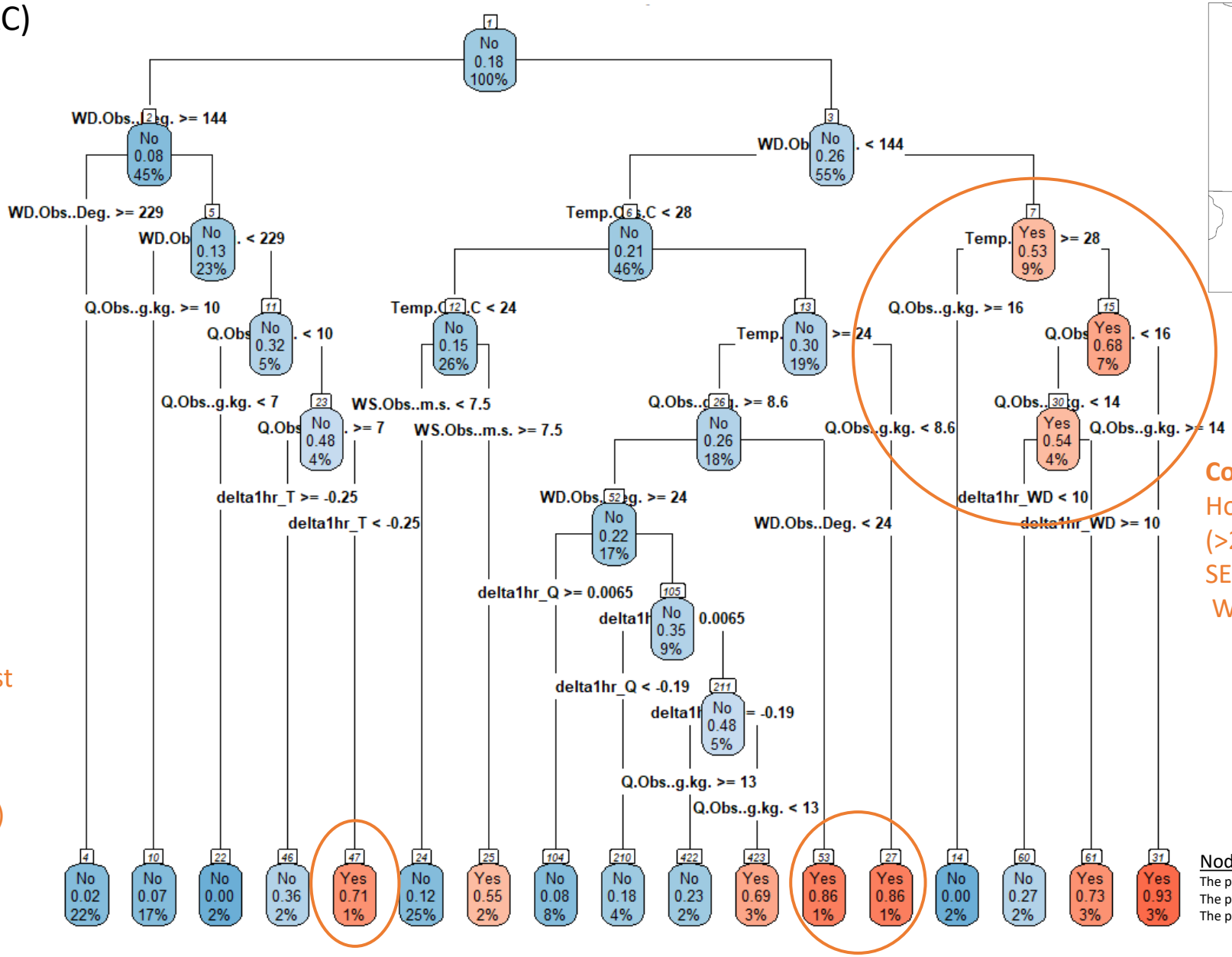


Local scale convective processes were better resolved by the 4km and 1.33 km grid resolutions, which likely impacted on better simulating the land and lake circulation near the lake shores.

Classification Tree for lake breeze date_time

Station: Racine, WI (KRAC)



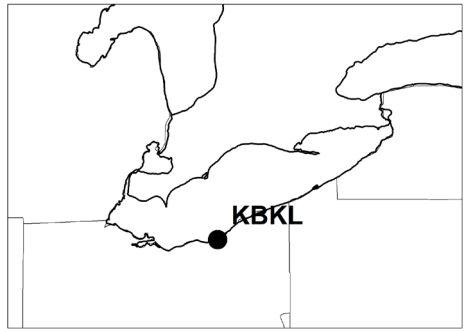
Condition 2:
Hot and humid condition
(>28 oC, 14-16 g/kg)
SE-to-N wind
WD shifts > 10°/hour

Condition 1:
Warm and moderate moist air (24-28 oC, 7-13 g/kg)
S-to-N wind
Slight T drop and rebound (delta1h_T > -0.3 °C/hour)

Node number
The predicted class: Yes
The predicted probability of Yes class: 0.93
The percentage of obs in the node: 3% of 586

Classification Tree for lake breeze date_time

Station: Cleveland, OH (KBKL)



Conditions:
Hot and moist condition (25-30 oC, Q>15 g/kg) with NW-NE wind, a slight or no change in hourly temperature and wind speed decreases; and/or direction shifts 0-30 deg.