Fuzzy case-based prediction of cloud ceiling and visibility

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Outline

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- *Fuzzy Logic*
- *Case-Based Reasoning*
- *Ceiling and Visibility Prediction*

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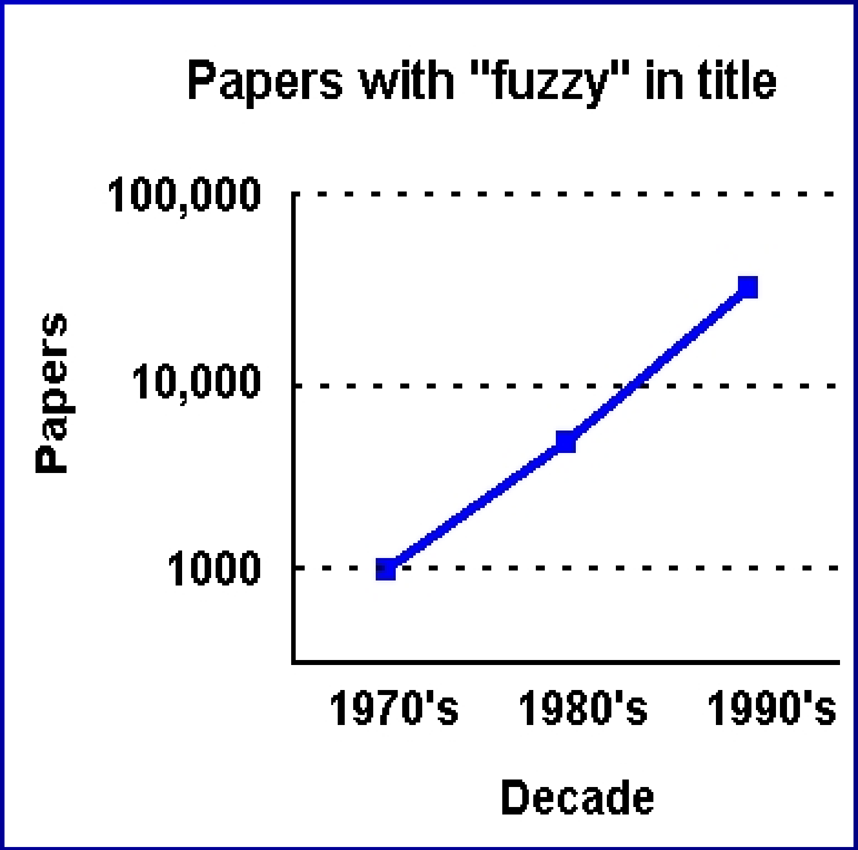
Fuzzy Logic

Use of fuzzy logic has increased exponentially over the past three decades, based on the number of uses of the word "fuzzy" in titles of articles in engineering and mathematical journals. *

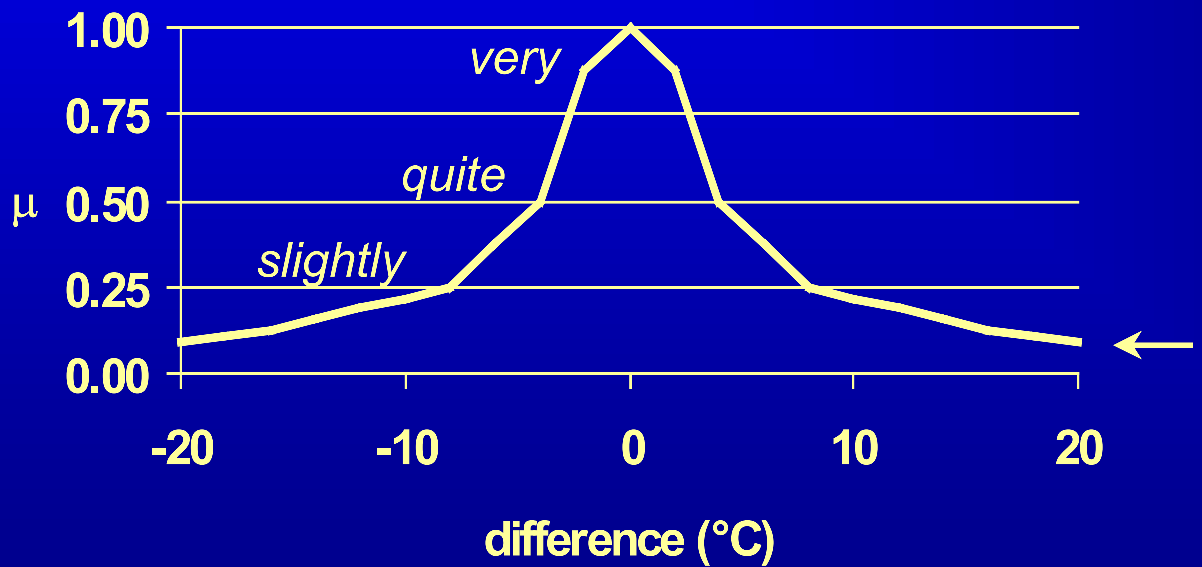


In meteorological systems, use of fuzzy logic began about ten years ago.

* Lofti Zadeh 2001: Statistics on the impact of fuzzy logic, www.cs.berkeley.edu/People/Faculty/Homepages/zadeh.html

Fuzzy Logic

Fuzzy logic is often used to model continuous, real-world systems. There are hundreds of fuzzy logic based systems that deal with environmental data. *



Fuzzy set to describe the degree to which two numbers are similar, for example, *degree of similarity* of temperatures.

* Hansen et al. 1999, www.chebucto.ca/~aimet/fuzzy_environment

Case-Based Reasoning

Meteorological view: CBR = analog forecasting

AI view: CBR = retrieval + analogy + adaptation + learning [1]

CBR is a way to avoid the "knowledge acquisition problem."

CBR is very effective in situations "where the acquisition of the case-base and the determination of the features is straightforward compared with the task of developing the reasoning mechanism." [2]

CBR and analog forecasting recommended when models are inadequate, e.g., for ceiling and visibility, sub-NWP-grid scale, strongly determined by local effects.

1. Leake 1996, 2. Cunningham and Bonzano 1999

Ceiling and Visibility Prediction

Cloud ceiling height and horizontal visibility are critical elements in aviation forecasts. Cause about 50% of flight delays.

Ceiling height and visibility prediction is very demanding:

- Ceiling height, when low, accurate to within 100 feet;
- Visibility, when low, accurate to within 1/4 mile;
- Time of change from category accurate to within one hour.

The NWS estimates that a 30 minute lead-time for identifying cloud ceiling or visibility events could reduce the number of weather-related delays by 20 to 35 percent and that this could save between $500 million to $875 million annually. *

* Jim Valdez, NWS Reinventing Goals for 2000, www.nws.noaa.gov/npr5.html

Prediction System

WIND: Weather Is Not Discrete

Two main parts:

- Data;
- Fuzzy similarity-measuring algorithm.

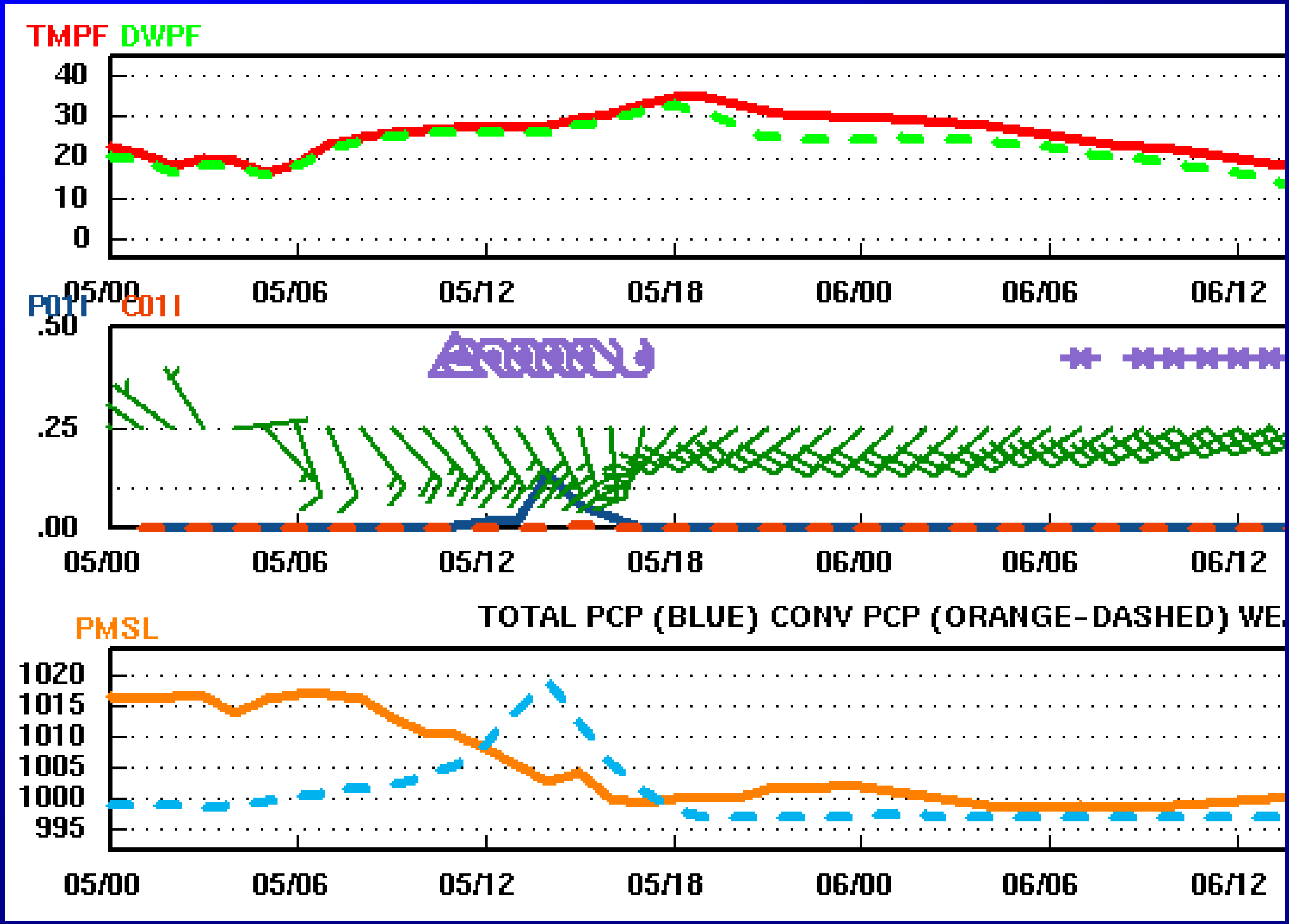
Data:

- Past airport weather observations, 32 years of hourly observations;
- Recent and current observations;
- NWP-based guidance.

Past and current observations

Category	Attribute	Units
temporal	date	Julian date of year (wraps around)
	hour	hours offset from sunrise/sunset
cloud ceiling and visibility	cloud amount(s) cloud ceiling height visibility	tenths of cloud cover (for each layer) height in metres of ≥ 6/10ths cloud cover horizontal visibility in metres
wind	wind direction wind speed	degrees from true north knots
precipitation	precipitation type precipitation intensity	nil, rain, snow, etc. nil, light, moderate, heavy
spread and temperature	dew point temperature dry bulb temperature	degrees Celsius degrees Celsius
pressure	pressure trend	kiloPascal $\times$ hour $^{-1}$

NWP-based guidance

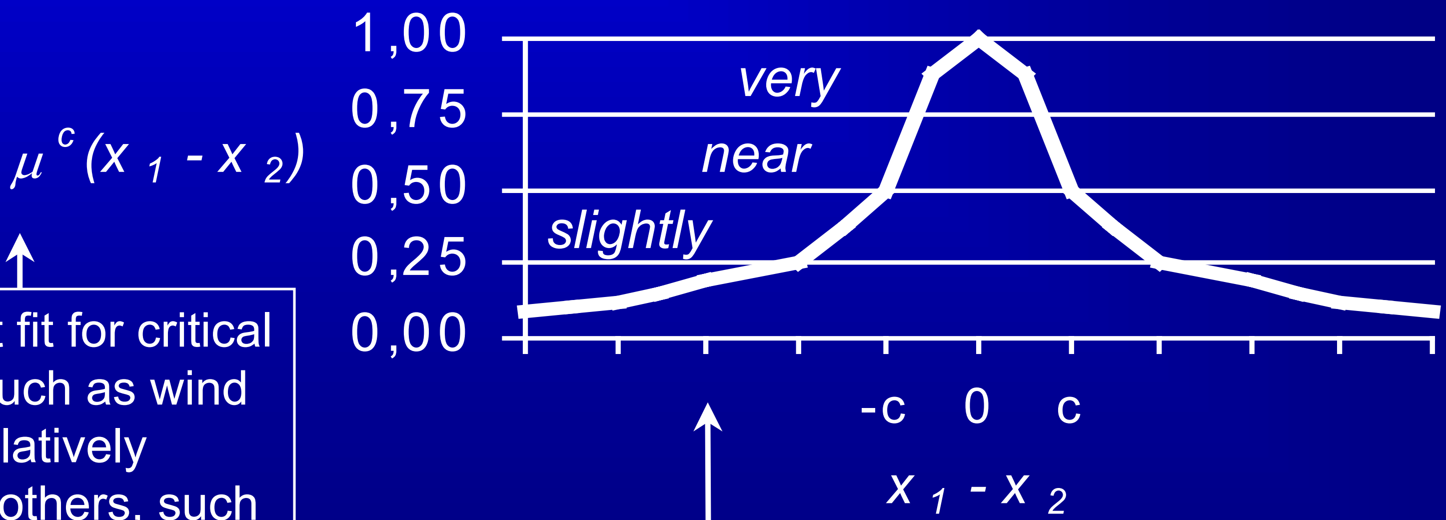


NCEP, www.emc.ncep.noaa.gov/mmb/meteograms/images/718010.meteogram.gif

Fuzzy similarity-measuring function

Three types of fuzzy operations designed to measure *degree of similarity* between three types of attributes.

1. Continuous. (e.g., wind direction, temperature, etc.)



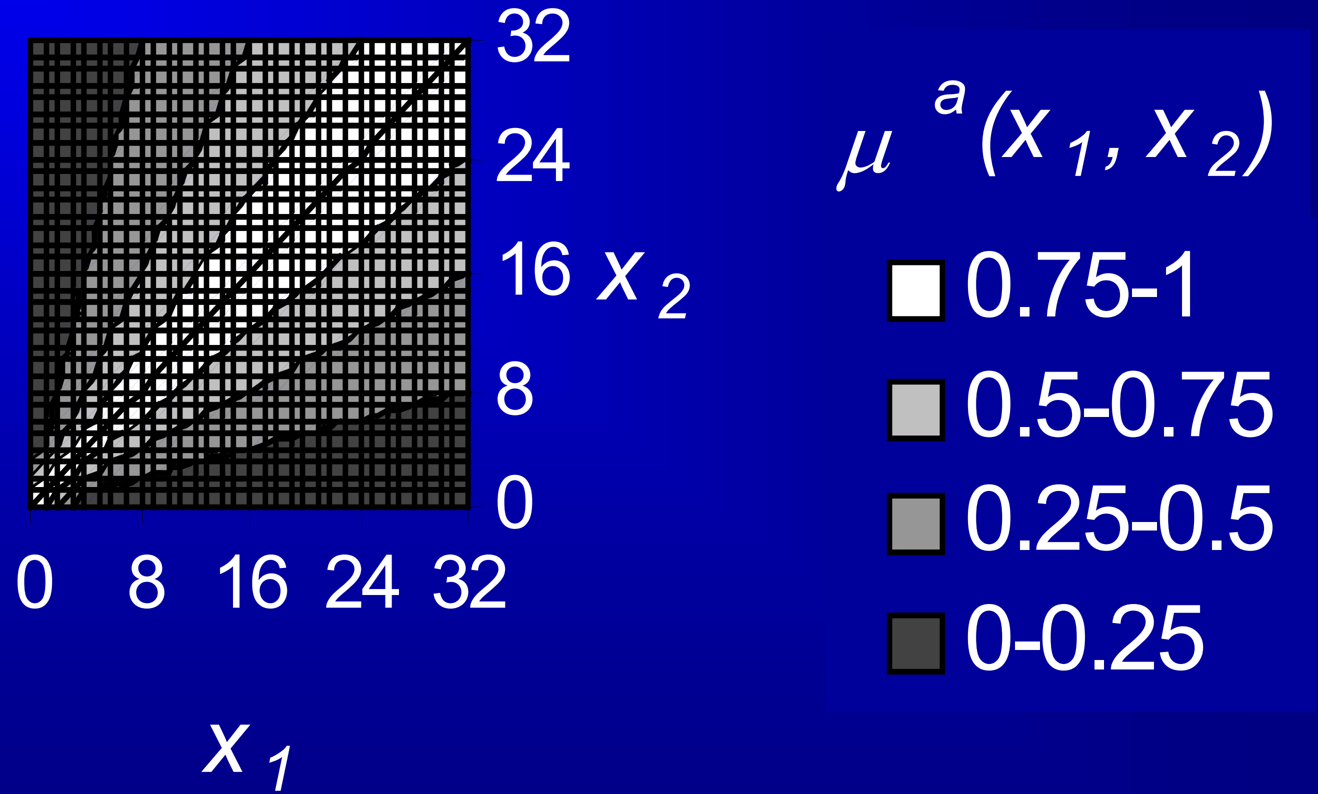
Design tight fit for critical elements, such as wind direction, relatively loose fit for others, such as temperature.

An expert forecaster suggests values that correspond to varying degrees of similarity.

Fuzzy similarity-measuring function

2. Magnitude. (e.g., wind speed)

Fuzzy Decision Surface



Low wind speeds require special interpretation.

Fuzzy similarity-measuring function

3. Nominal. (e.g., precipitation)

Fuzzy Relationships

Nil	1.00			
Drizzle	0.02	1.00		
Showers	0.03	0.50	1.00	
Rain	0.01	0.50	0.75	1.00
…	…	…	…	…
	Nil	Drizzle	Showers	Rain

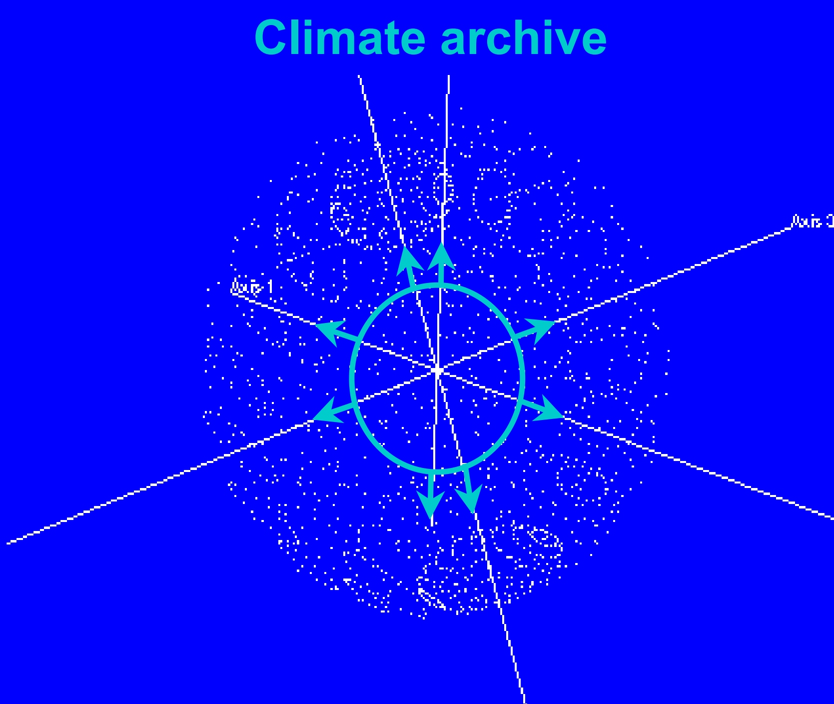
Different types of weather have different degrees of similarity.

Algorithm: Collect Most Similar Analogs, Make Prediction

Details not presentable in 2 minutes...

Archive search is like expanding hypersphere centered on present case. Axes are weather elements.

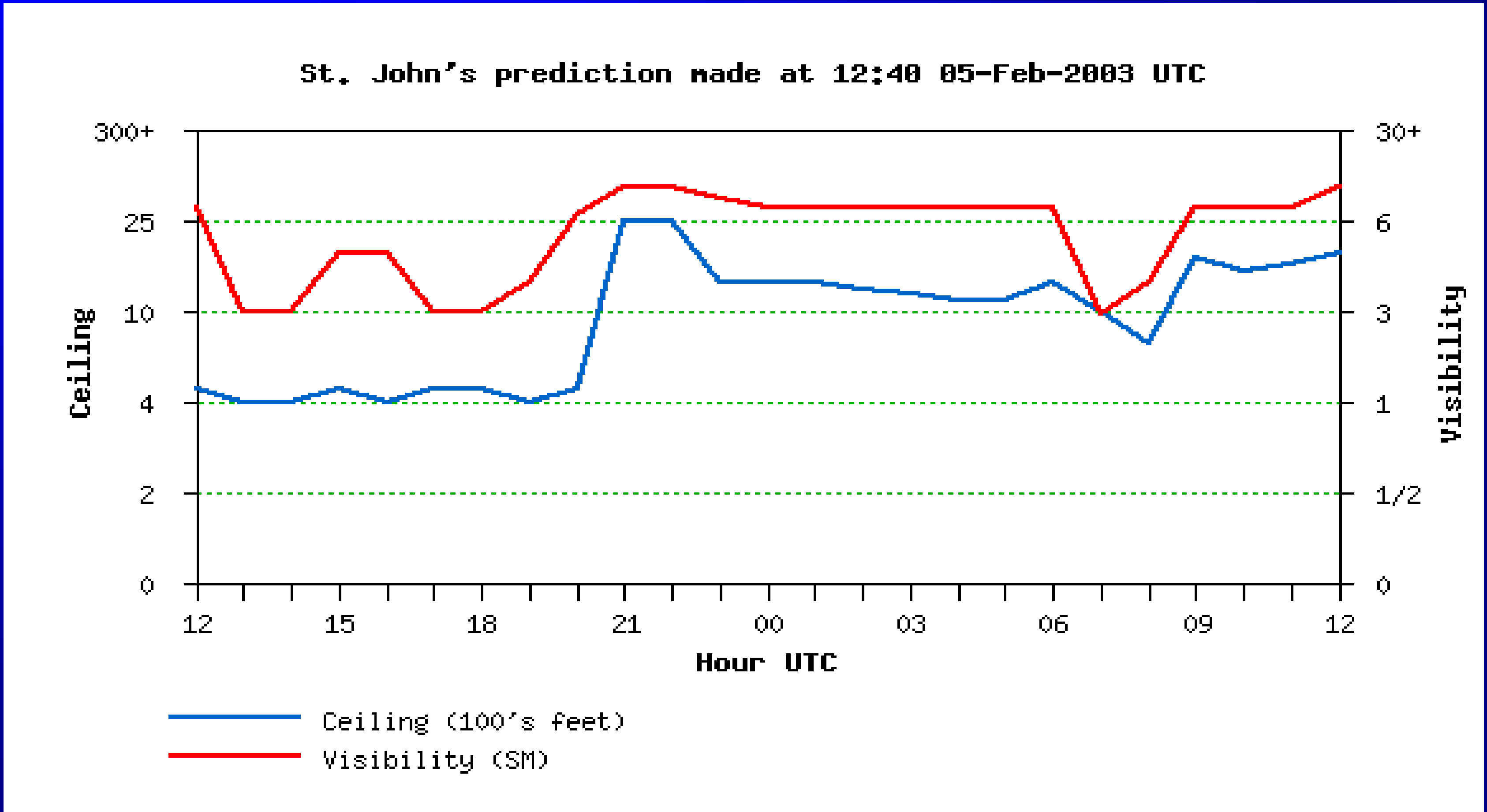
"Distances" determined by fuzzy similarity-measuring functions, all applied together.



Forecast ceiling and visibility based on outcomes of most similar analogs.

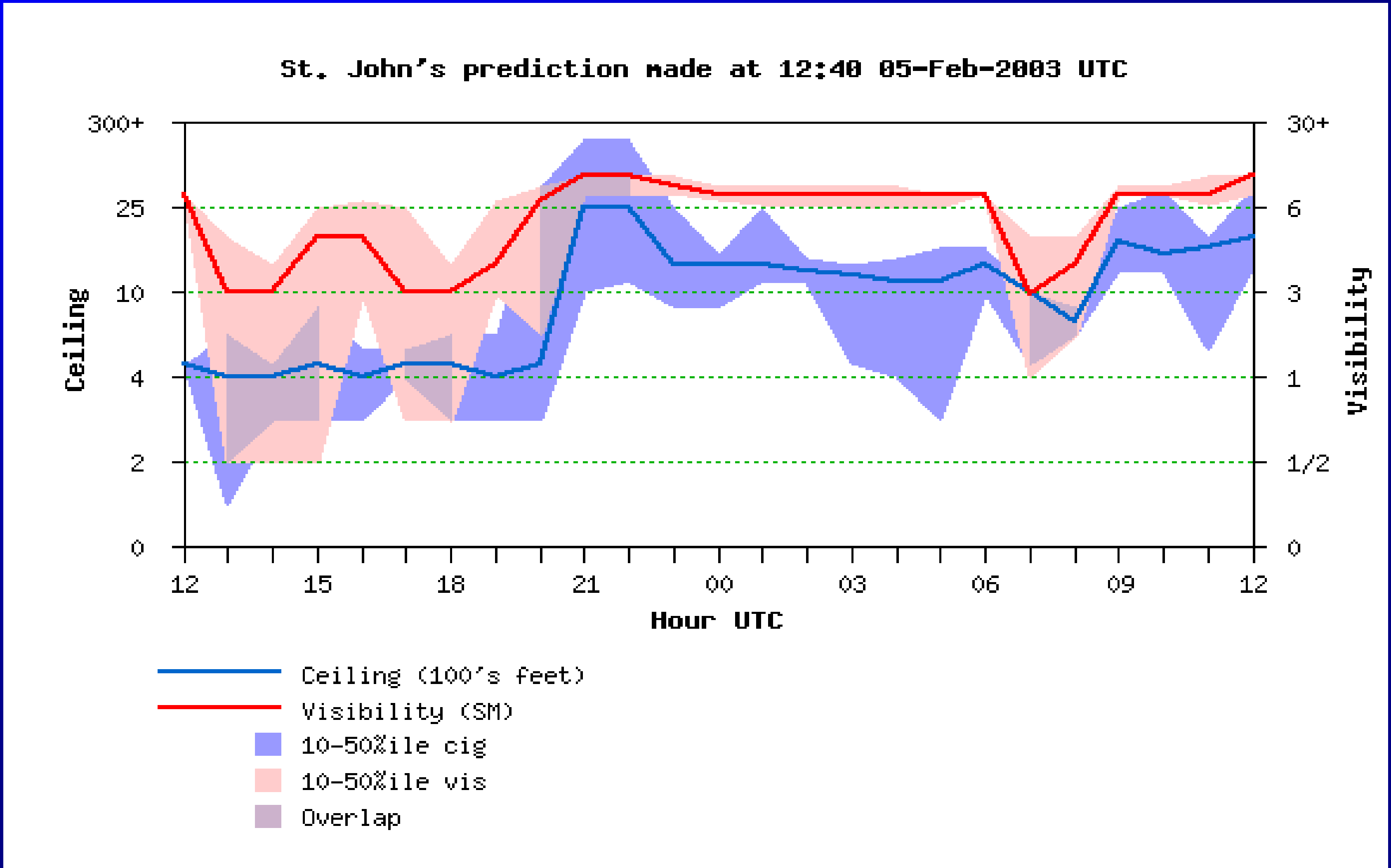
Prediction

Forecast: ceiling and visibility based on 30$^{\%ile}$ of analogs



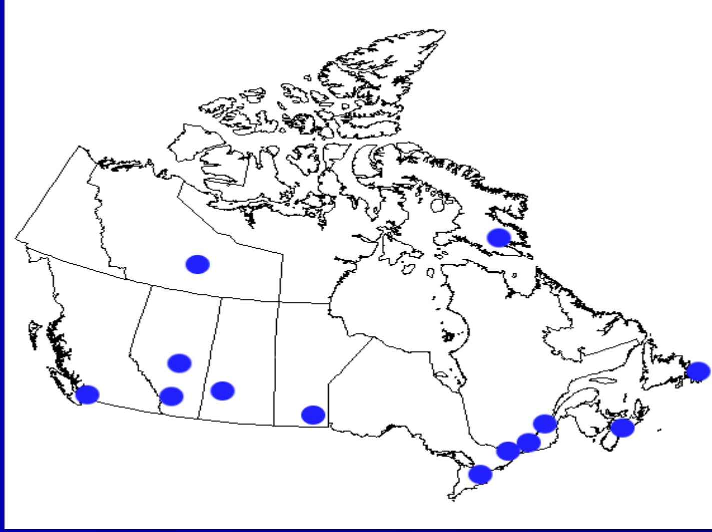
Prediction

Probabilistic forecast: 10 %ile to 50%ile cig. and vis. from analogs



Results

Forecasts are competitive with persistence in 0-to-6 hour range, based on FOH, FAR, POD, HSS of alternate and VFR forecasts.



WIND runs in real-time for climatologically different sites. Data-mining/forecast process takes about one second.

First impressions and forecaster feedback:

- Probabilistic forecasts of cig. & vis. informative, high “glance value”.
- Timing of category changes often “eerily good”. [When guidance good.]
- Rare events hinted at in displayed analog set, e.g., during recent cold snap a few analogs showed ice fog.
- A message about the current “forecasting issue” would be helpful, e.g., if wind > 8 knots and temp > -40°C then Chance(ice fog) = Low.

Results ⇒ Possible improvements

WIND only uses three predictors: climatology, recent observations, and NWP-based weather elements.

Additional predictive fields, such as radar nowcasts and satellite image projections, would improve forecast quality.

For data-mining and prediction, it uses a non-optimized, nearest-neighbors algorithm.

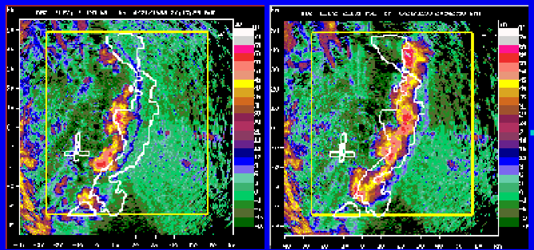
Genetic algorithms

Graphical user interface could let forecasters fine-tune critical predictors, e.g., timing of a wind shift based on their analysis.

Fuzzy rule base, based on knowledge from experts, to intelligently combine additional predictive fields for data-mining and prediction (i.e., more intelligent pre- and post-processing.

Synthesis: Intelligent Weather Systems (RAP/NCAR) *

Nowcast



30-min. Forecast 30-min. Verification

RAP, Thunderstorm Auto-Nowcasting,
www.rap.ucar.edu/projects/nowcast

Weather Radar Nowcasts

Human Input (> 15 min)

Real-Time Data Preprocessing

Real-Time Data Algorithms

Graphic User Interface

Sensor Systems

Quality Control

Fuzzy Logic Integration Algorithm

Product Generator

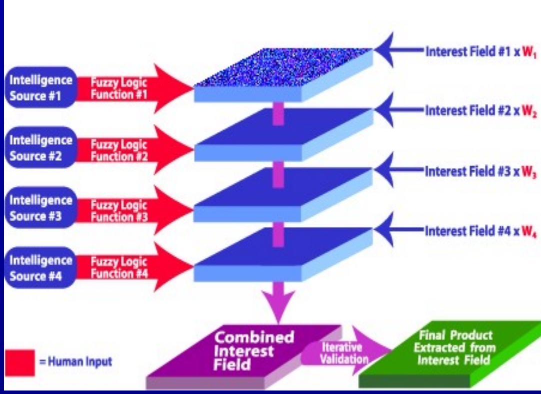
User

Data Assimilation Mesoscale Model

Model Output Algorithms

WIND works here

Selective Climatological Input



* RAP, Intelligent Weather Systems, www.rap.ucar.edu/technology/iws/design.htm

Conclusion

Through a fuzzy logic based intelligent weather systems approach, we can:

- Make forecast-production software more helpful,
- Increase forecaster efficiency, and
- Increase forecast accuracy.

References:

- WIND results, **www.bjarne.ca/wind**
- RAP, Intelligent Weather Systems, **www.rap.ucar.edu/technology/iws**
- John McCarthy, NRL 1999: A Vision for an Aviation Weather System, **www.nws.noaa.gov/om/jm**