An Introduction to The Localized Aviation MOS Program (LAMP)

National Weather Service
Meteorological Development Laboratory
Mesoscale Prediction Branch

David E. Rudack, March 2008

Outline of Presentation

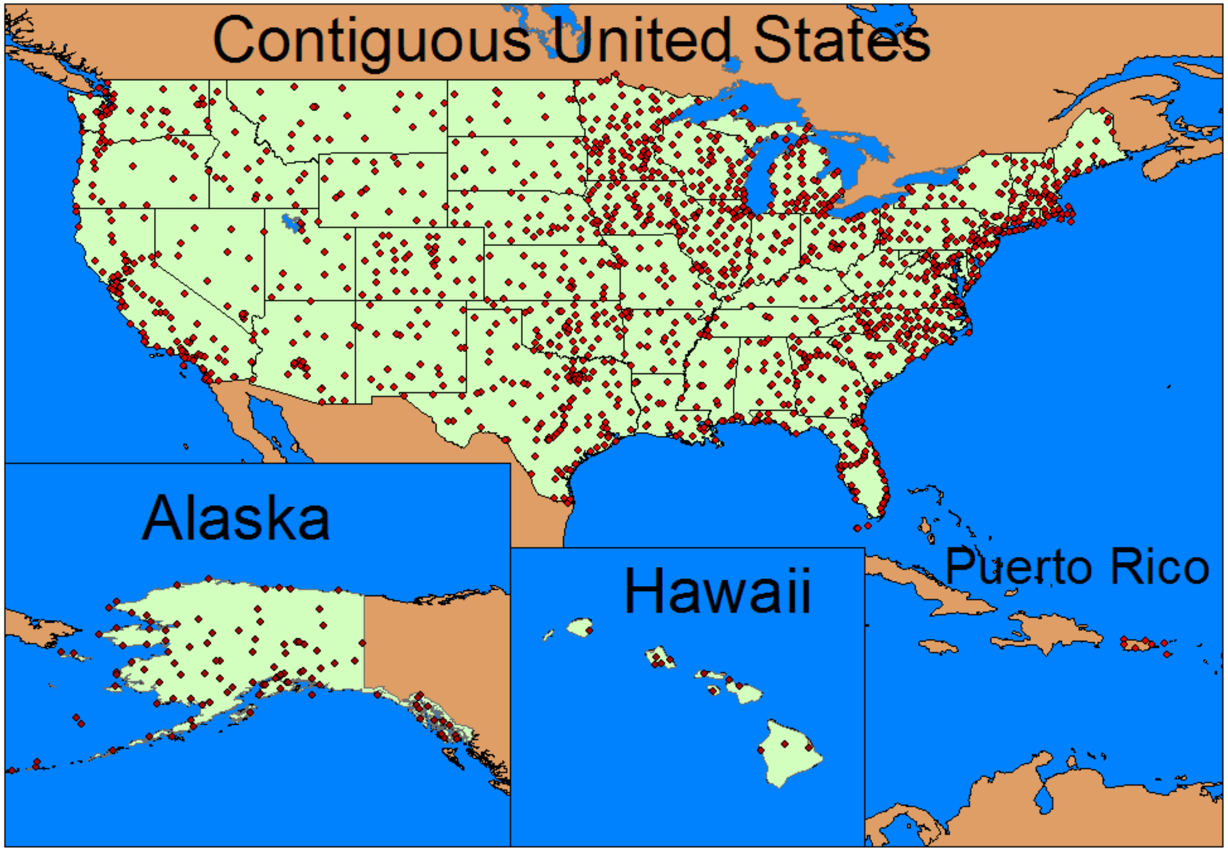
- What is LAMP?
- What weather elements does LAMP forecast?
- What steps are taken to create LAMP forecasts?
  - Data inputs
  - Predictand and predictor types
  - Generating LAMP regression equations
  - Post-processing forecasts
- LAMP Verification and Products
- Summary

Click the hyperlink headings to navigate to the desired portion of the presentation or click to continue

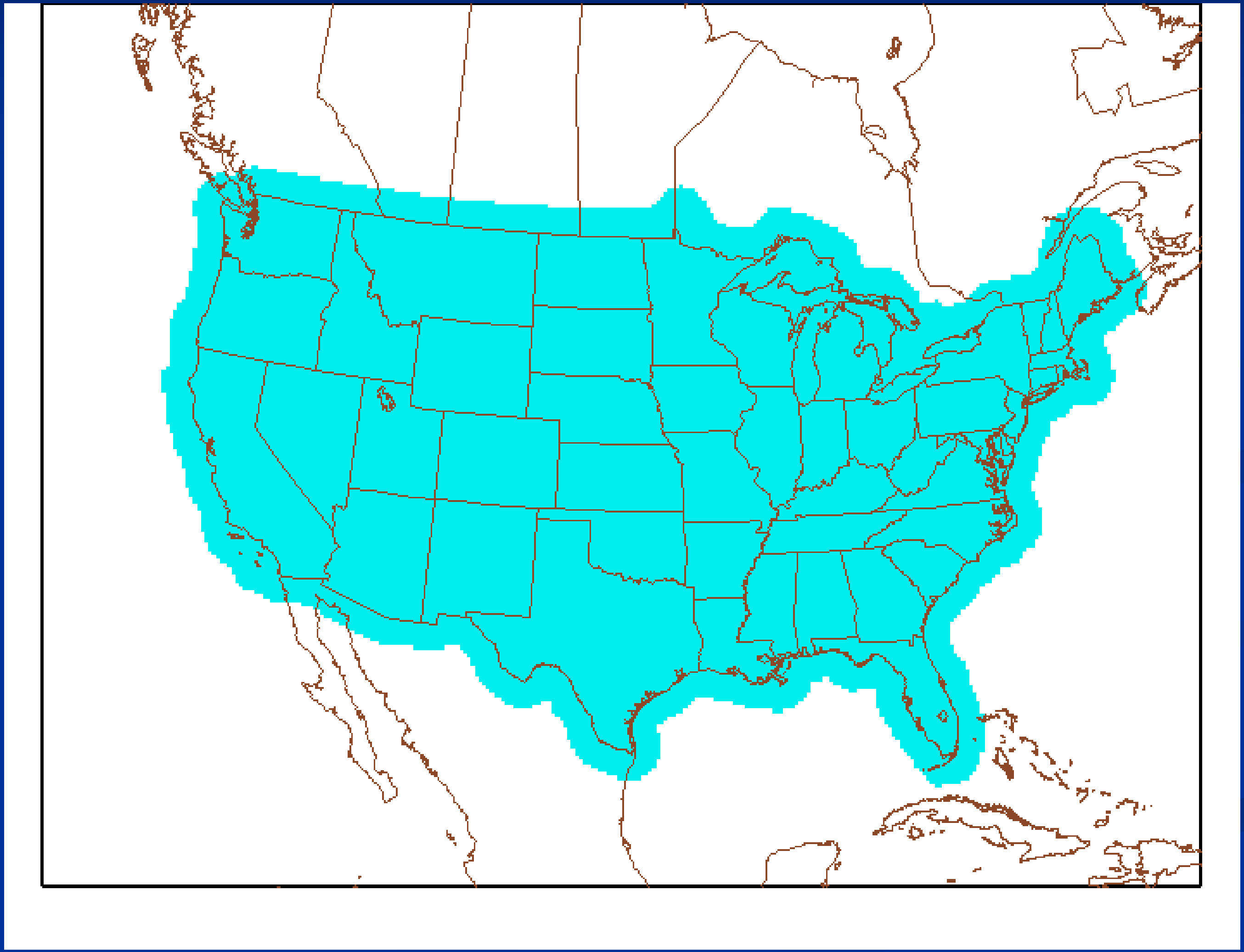
Basic Properties of LAMP

- LAMP provides hourly updates of Global Forecast System (GFS) MOS forecasts from 1 - 25 hours.
- LAMP updates MOS by utilizing the latest observational data (METAR, lightning, radar), GFS MOS forecasts, output from simple advective models, and geo-climatic data (hi-res topography and relative frequencies).
- Many of the LAMP weather elements are important to aviation operations.
- LAMP provides guidance for the contiguous United States (CONUS) and Alaska, Hawaii, and Puerto Rico (OCONUS), except the thunderstorm guidance is limited to the CONUS.
- Forecasts are issued for METAR stations, except gridded thunderstorm forecasts are issued on a 20-km grid.

Stations for which LAMP generates forecasts



Geographical Coverage of Thunderstorm Forecasts on 20-km Grid



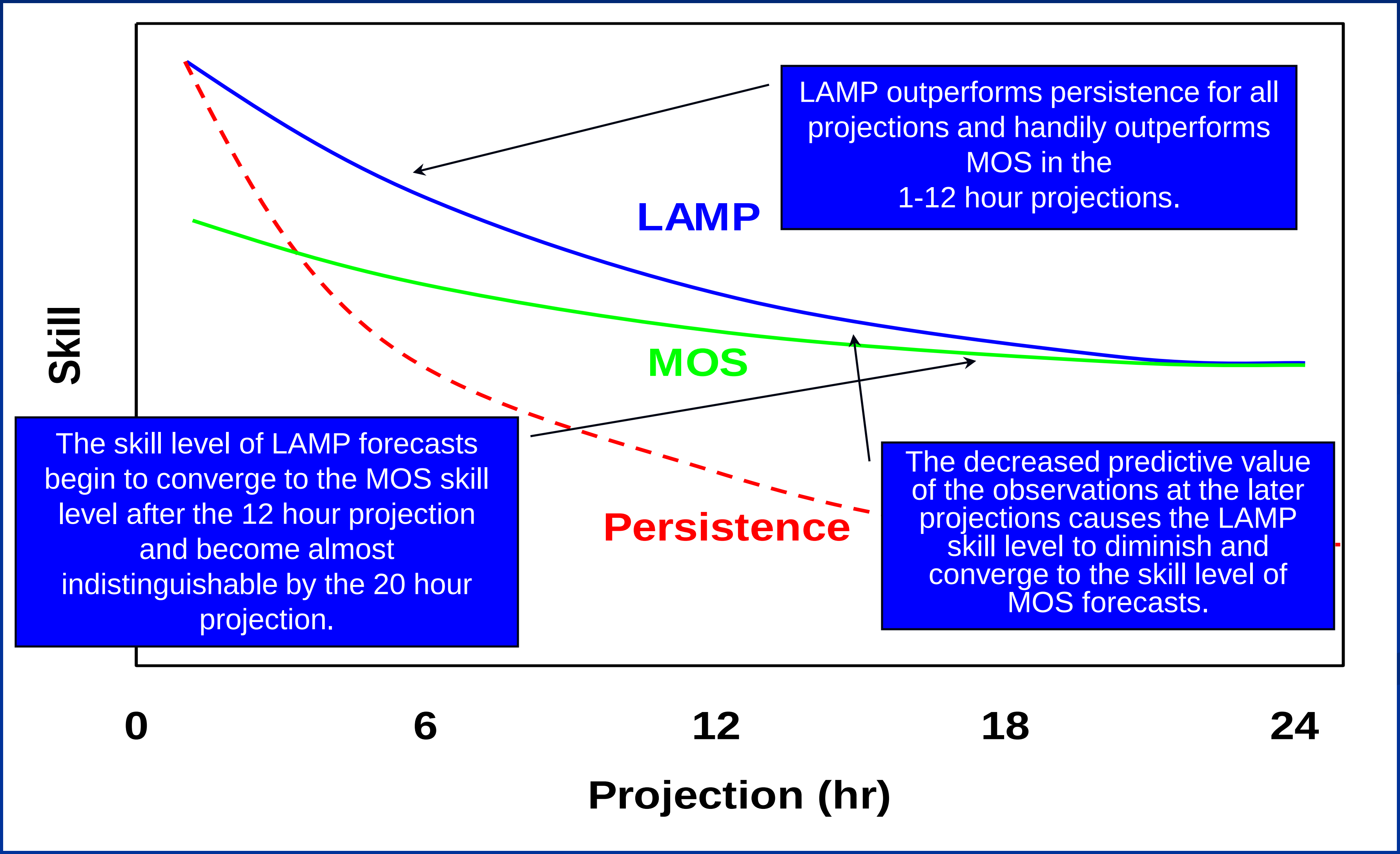
Attributes of the MOS Approach

- The MOS approach is followed in developing LAMP guidance.
- This approach:
  - relates observations of the weather element to be predicted (predictands) to appropriate variables (predictors) through multiple linear regression
  - is mathematically straightforward
  - yields forecasts which are accurate and/or skillful
  - generates non-probabilistic (e.g., temperature) and probabilistic forecasts (e.g., probability of precipitation)
  - improves upon direct model output forecasts and generates forecasts of elements not directly output from dynamical models (e.g., ceiling and visibility)

Conceptual Approach of LAMP

- The objective of LAMP is to improve on MOS forecasts and persistence out to 25 hours through rapid infusion of current observational data.
- The predictive information in observational data is extrapolated through the application of advective models.

Theoretical Model Forecast Performance of LAMP, MOS, and Persistence



LAMP Updates of GFS MOS

- LAMP produces hourly updates for the most recent GFS MOS cycle.

LAMP updates the GFS MOS

The following LAMP cycles update the 1800 UTC GFS MOS cycle

The following LAMP cycles update the 0000 UTC GFS MOS cycle

The following LAMP cycles update the 1200 UTC GFS MOS cycle

1800 UTC MOS	0000 UTC MOS	0600 UTC MOS	1200 UTC MOS
2200 UTC LAMP	0400 UTC LAMP	1000 UTC LAMP	1600 UTC LAMP
2300 UTC LAMP	0500 UTC LAMP	1100 UTC LAMP	1700 UTC LAMP
0000 UTC LAMP	0600 UTC LAMP	1200 UTC LAMP	1800 UTC LAMP
0100 UTC LAMP	0700 UTC LAMP	1300 UTC LAMP	1900 UTC LAMP
0200 UTC LAMP	0800 UTC LAMP	1400 UTC LAMP	2000 UTC LAMP
0300 UTC LAMP	0900 UTC LAMP	1500 UTC LAMP	2100 UTC LAMP

LAMP Forecasts of Continuous Weather Elements

- 2-m temperature and dewpoint (F)
- Wind speed (kts), wind gusts (kts), and wind direction (degrees)

LAMP Forecasts of Categorical Weather Elements

- Categorical forecast (yes/no) indicating if precipitation, not necessarily measurable, will occur on the hour
- Categorical forecast of precipitation type (liquid, freezing, or frozen) conditioned on precipitation occurring
- Categorical forecast of precipitation characteristics (drizzle, continuous, or showers) conditioned on precipitation occurring

LAMP Categorical Forecasts

Elements of special interest to aviation forecasters

- Total sky cover (clear, few, scattered, broken, or overcast)
- Ceiling height
- Conditional ceiling height (if it is precipitating)
- Visibility
- Conditional visibility (if it is precipitating)
- Obstruction to vision (no obstruction, haze, mist, fog, or blowing phenomena)
- Occurrence/non-occurrence of thunderstorm
  - Thunderstorm is defined as one or more cloud-to-ground (CTG) lighting strikes in a 20-km grid box in a 2-h period (CONUS only)

LAMP Probabilistic Forecasts

Probability of:	Event
Liquid Equivalent Precip. ≥ 0.01 inch during past 6 hours/12 hours	Yes/No
Precipitation occurring *on* the hour (not necessarily measurable) *	Yes/No
Precipitation type (Conditional on Precipitation)	Freezing Frozen Liquid
Precipitation Characteristics (Conditional on Precipitation)	Drizzle Continuous Showers

*****This is *not* the same as precipitation occurring *during* the hour.

LAMP Probabilistic Forecasts

Elements of special interest to aviation forecasters

Probability of:	Event
Ceiling Height	< 200 feet 200 – 400 feet 500 – 900 feet 1000 – 1900 feet 2000 – 3000 feet 3100 – 6500 feet 6600 – 12,000 feet > 12,000 feet
Conditional Ceiling Height (Conditional on Precipitation)	Same as above

LAMP Probabilistic Forecasts

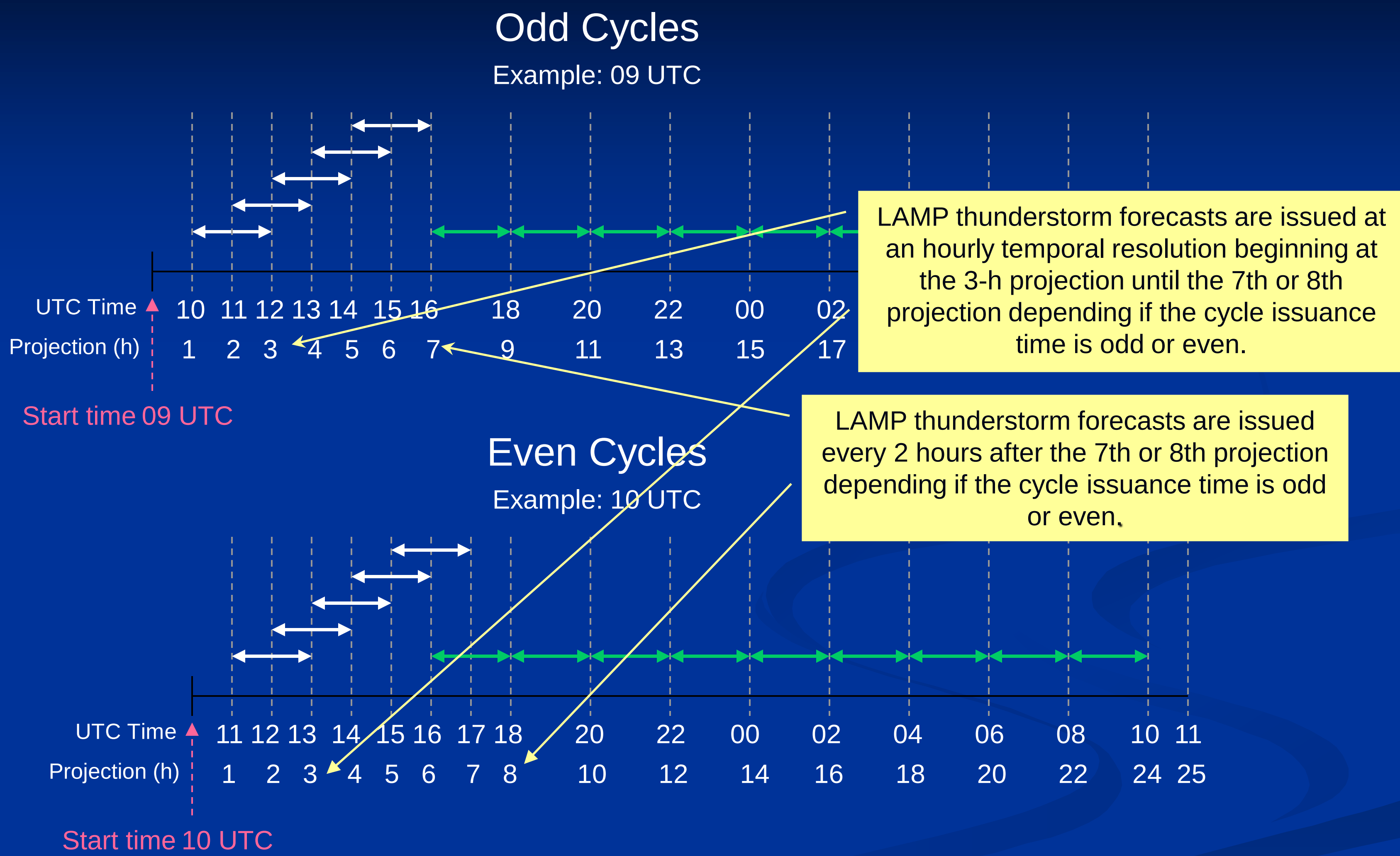
Elements of special interest to aviation forecasters

Probability of:	Event
Visibility	< ½ mile < 1 mile < 2 miles < 3 miles ≤ 5 miles ≤ 6 miles
Conditional Visibility (Conditional on Precipitation)	Same as above
Thunderstorms within a 20-km grid box and within a 2-h period	Occurrence/non-occurrence of one or more CTG lightning strikes

Temporal Resolution of LAMP Forecasts

- LAMP weather elements have an hourly temporal forecast resolution except for probability of measurable precipitation in a 6 and 12 hour period (PoP6/PoP12) and thunderstorms.
- LAMP PoP6 forecasts have a temporal resolution of 6 hours and are valid over the 6 hour forecast periods ending at 0000, 0600, 1200, and 1800 UTC.
- LAMP PoP12 forecasts have a temporal resolution of 6 hours and are valid over the 12 hour forecast periods ending at 0000, 0600, 1200, and 1800 UTC.
- LAMP 2-h thunderstorm forecasts are issued at hourly intervals to 7 or 8 hours (depending on the cycle time) and at 2-h intervals thereafter (see subsequent slide).

Schematic of LAMP Thunderstorm 2-h Valid Periods



White arrows indicate overlapping 2-h valid periods out to 6 hours from issuance

Green arrows indicate subsequent 2-h valid periods, which end on even UTC hours

The Development Process of Generating LAMP Forecasts

1) Collate the data from a variety of sources for the regression analysis

2) Generate a regression equation for each element at each projection using a specific training period of data

3) Post-process the forecasts to ensure consistency (e.g., ensure that the temperature is always equal to or greater than the dewpoint)

4) Verify the weather element at each projection hour using a station list (typically includes the entire station list used to produce LAMP forecasts) over an independent sample

LAMP Predictand Data

- The predictand data (which are observations) are extracted from two possible sources:
  - Hourly METAR observations (All LAMP elements except thunderstorms)
  - Lightning strike data from the National Lightning Detection Network (For LAMP thunderstorm development only)
- All predictands in the LAMP system are defined at stations except for the probability of thunderstorms which is defined on a 20-km grid.
- The data is quality checked for gross errors as well as for temporal consistency.

LAMP Predictand Data

- Predictand data can take two forms:
  - Continuous values such as temperature and dewpoint
  - Binary values are used to define the predictand in terms of the occurrence (“1”) or non-occurrence (“0”) of an event.

    Example of binary value:

    Event: Wind speed $\geq$ 14 kts
    If yes → binary value = “1”
    If no → binary value = “0”

LAMP Predictor Data Sources

- Predictors are data (e.g., temperature) that explain a portion of the behavior exhibited by the predictand.
- Possible predictor sources used in LAMP developments include:
  - Hourly METAR Data
  - GFS MOS forecasts
  - Simple models (such as advection of moisture)
  - Radar mosaic data
  - Lightning strike data* from the National Lightning Detection Network
  - GFS model output
- Only those predictors that make physical sense are chosen from these data sources as predictors.

* Archives obtained from Global Hydrology Resource Center (GHRC)

LAMP Predictor Types and Transformations

- For station development, all gridded predictor values are interpolated to stations by either:
  - Bilinear interpolation for continuous values such as temperature, or
  - Nearest neighbor interpolation for discontinuous values such as visibility
- There are four types of predictors that may be used in the regression analysis:
  - Predictors possessing the actual values of the forecast element (e.g., temperature in degrees)
  - GFS MOS probability forecasts
  - Point binary predictors (Values of “0” or “1”)
  - Grid binary predictors (Values range between “0” and “1”)

Multiple Linear Regression Basics

- Multiple linear regression relates a dependent variable Y (predictand) to a set of "n" independent variables $X_1, X_2, \ldots X_n$ (predictors). The relationship is expressed through a linear equation:

$$Y = b + a_1x_1 + a_2x_2 + \ldots + a_nx_n$$

  where the values of a_1 through a_n are the coefficient values for each of the predictor terms x_1 through x_n, and "b" is the equation constant.

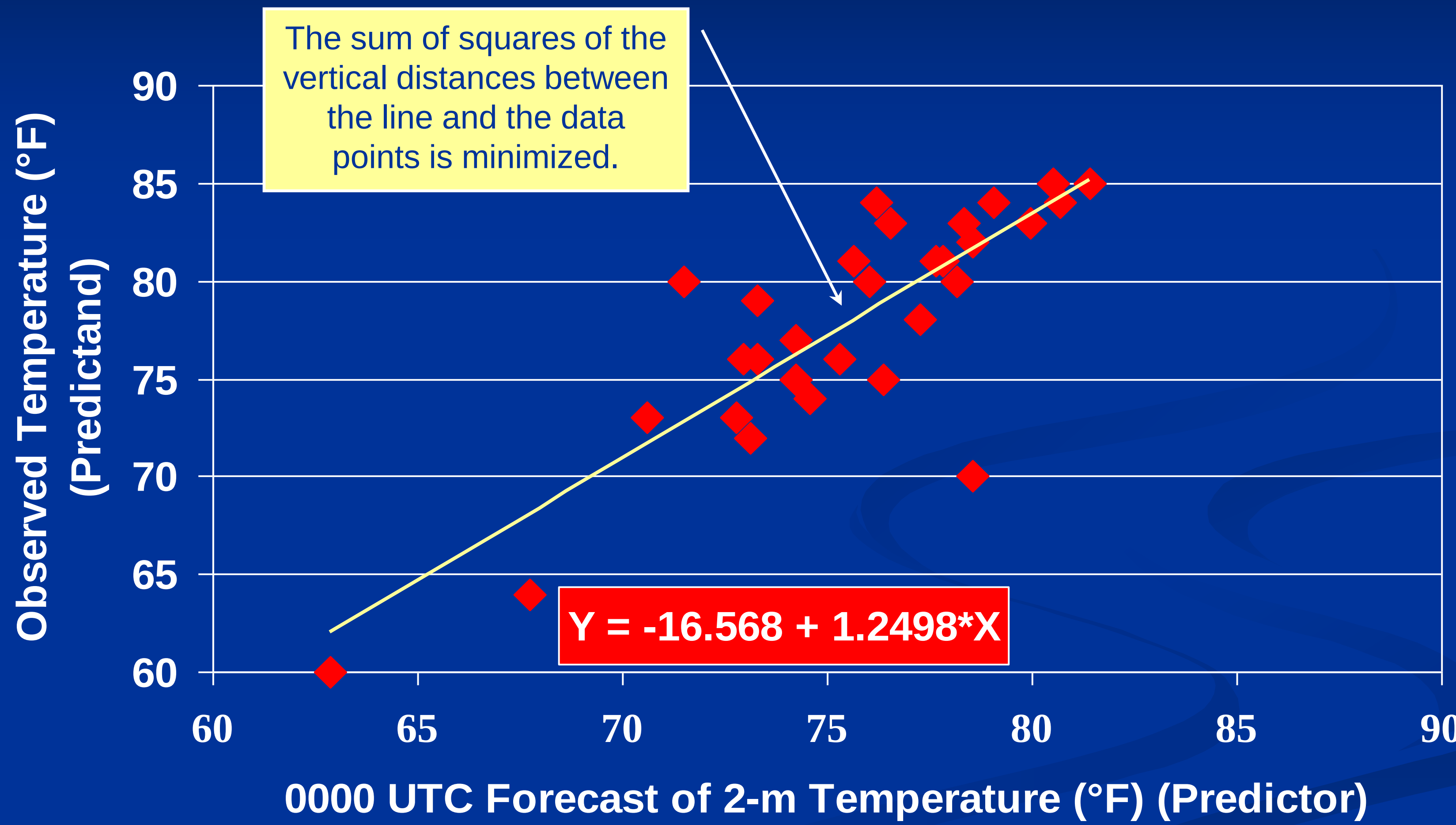
- Each term "$a_i\, x_i$" represents the contribution of the predictor x_i to the estimate of the predictand.

Multiple Linear Regression Basics

- The predictors, $X_1 \ldots X_n$, can be nonlinear. That is to say, the predictors can be derived from values that were raised to a power other than one (e.g., $X=Z^3$).

- The equation represents the best possible least squares fit to the data of any other possible linear equation with the same predictors.

Sample Linear Regression for KATL, June 2005



LAMP Equation Development Technique

- The regression analysis first determines the predictor from the set of potential predictors that explains more of the predictand variability than any other potential predictor.
- Each subsequent predictor is selected based on its ability, in conjunction with the predictors already selected, to explain more of the remaining predictand variability than any other potential predictor.
- The regression analysis for a particular equation stops when either:
  - the maximum number of allowable terms is reached (pre-defined by the developer – usually 10-15 predictors), or
  - none of the remaining predictors further reduces the remaining variability observed in the predictand by a predefined amount (also stipulated by the developer)

LAMP Equation Development

- Seasonal Stratification -

- Separate equations are developed for each season to address the wide range of intra-seasonal weather variability

  - All LAMP weather elements with the exception of precipitation type and thunderstorms
    - ✓ Cool season (October 1 – March 31)
    - ✓ Warm season (April 1 – September 30)

  - Precipitation Type
    - ✓ Cool season (September 1 – May 31)
    - ✓ Warm season (June 1 – August 31) (Alaska only)

  - Thunderstorms
    - ✓ Spring season (March 16 – June 30)
    - ✓ Summer season (July 1 – October 15)
    - ✓ Winter season (October 16 – March 15)

- This seasonal stratification “fine-tunes” the equations to the appropriate season’s type of weather.

- For a smoother transition of forecasts between seasons, an additional thirty days of training data is included in the development sample for each year - fifteen days prior to and subsequent to the development season.

LAMP Equation Development

- Station vs. Regionalized Equations -

- Some elements such as temperature are reported regularly at every station while hazardous events of visibility and/or ceiling height occur less frequently.
- When a station reports a sufficient number of cases for a particular element, (usually no less than 200), a regression equation is generated for that element that applies to that specific station.
- To increase equation stability for certain elements that are less common, an equation is developed by pooling other station datum into a region. This *regionalized* regression equation can then be applied to any station in that particular region.
- Regions are determined based upon similar geoclimatic features (e.g., terrain or relative frequencies of the event).
- Regionalization allows for the LAMP guidance to be produced at sites with poor, unreliable, or non-existent observation systems.
- All LAMP elements with the exceptions of temperature, dewpoint, wind speed, and wind direction are developed regionally.

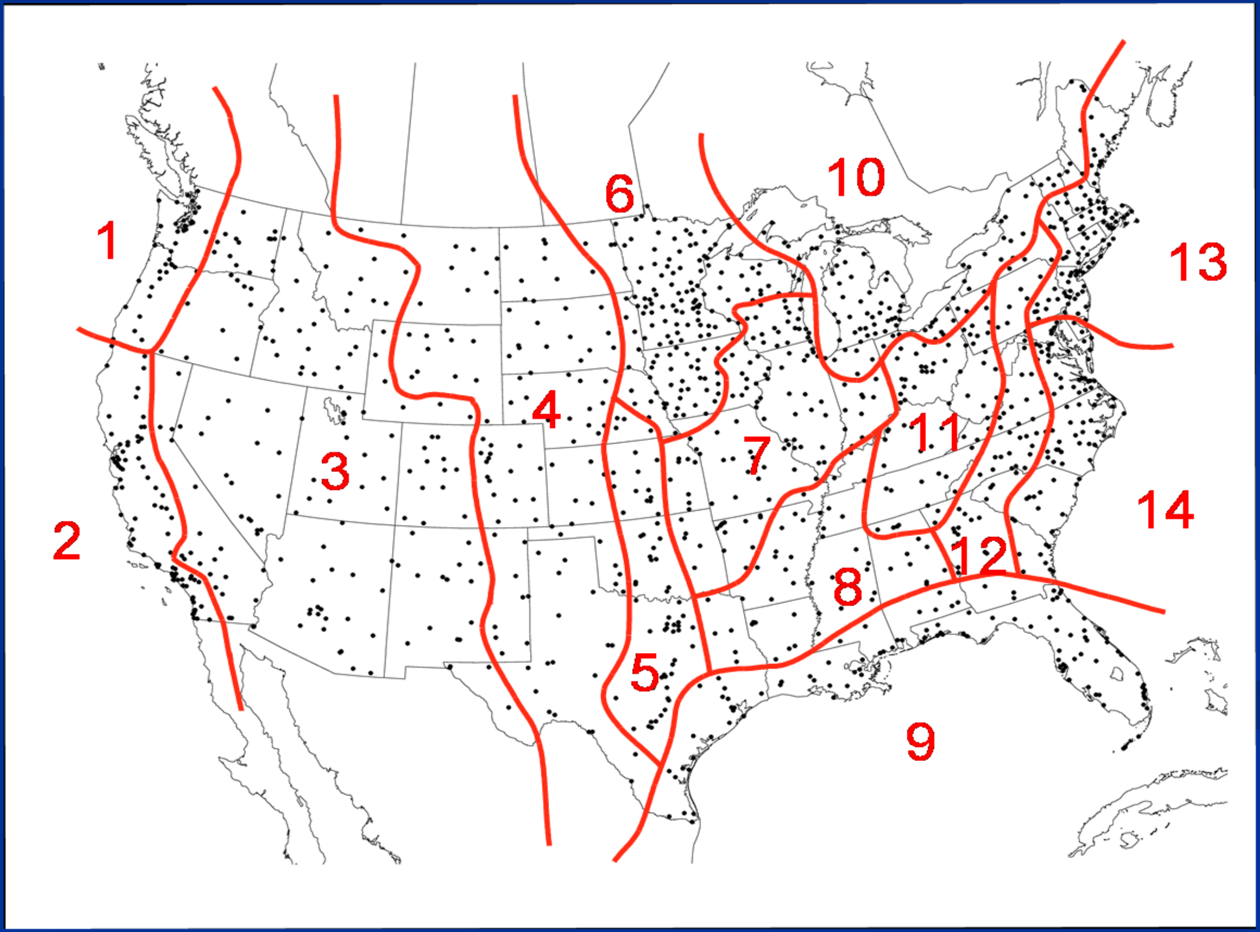
LAMP Equation Development

- Station vs. Regionalized Equations (Cont.) -

- The figure to the right is an example of how the CONUS might be subdivided into regions for equation development.

- It is important to find a balance between larger region sizes which help to create more stable equations and smaller region sizes which help to better model the local effects.

- Each element has its own set of regions, which usually differs by season.



LAMP Equation Development

- Primary vs. Secondary Equations -

- Primary equations use observations, MOS forecasts, and other variables as predictors.

- Secondary equations do not use observations as predictors.
  - They use values interpolated from the LAMP analysis of available observations, as well as MOS forecasts and other variables.
  - The analyzed value is used as a “surrogate” observation.
  - Secondary equations are used in instances where a station does not report an observation.

- Primary equation forecasts are generally better than secondary equation forecasts because the primary equations contain the station’s actual observation and not its proxy.

LAMP Equation Development

- Simultaneous Development -

- To help ensure better consistency across related forecast elements (e.g., temperature and dewpoint), it is beneficial to develop related predictands simultaneously.
- When weather elements are developed simultaneously, each element’s equation shares the same set of variable predictors but differs in its coefficient values and the value of its equation constant.

Practical Example of Solving a LAMP Temperature Equation

$$Y = b + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$$

Y = LAMP temperature forecast

Equation Constant b = -6.99456

Predictor x_1 = observed temperature at cycle issuance time (value 66.0)

Predictor x_2 = observed dewpoint at cycle issuance time (value 58.0)

Predictor x_3 = GFS MOS temperature (value 64.4)

Predictor x_4 = GFS MOS dewpoint (value 53.0)

Coefficient values: a_1 = 0.15147, a_2 = -0.041273, a_3 = 0.84864, a_4 = 0.18787

Y = -6.99456 + (.15147 x 66.0) + (-.041273 x 58.0) + (.84864 x 64.4) + (.18787 x 53.0)

Y = 65.2 F

Note that the equation contains at least one observation predictor indicating that it is a primary equation.

Post-Processing LAMP Forecasts

Reasons for post-processing forecasts include:

- Reconciling meteorological inconsistencies between weather elements (e.g., ensuring that the dewpoint temperature remains less than or equal to the forecast temperature at a specific projection)
- Ensuring that the probabilistic forecasts behave properly (e.g., the probabilities range between zero and one inclusively, or that select probability forecasts for certain elements sum to a value of one, etc.)
- Generating threshold values for elements that are used in producing categorical forecasts for specific weather elements such as visibility and ceiling height

Generating LAMP Threshold Values for Categorical Forecasts

- Typically, threshold values are generated for each probability category except for the most common category.
- For a specific weather element, regional threshold values are generated using the same regions that were used to generate the equations for that element.
- All stations in a particular region possess the same threshold value but the values vary by projection.
- A set of threshold values is developed from the primary forecasts, and another set is developed from the secondary forecasts.
- Primary probability forecasts are compared to the primary threshold values when a station reports an observation.
- Secondary probability forecasts are compared to the secondary threshold values when a station does not report an observation.

Process of Generating LAMP Categorical Forecasts

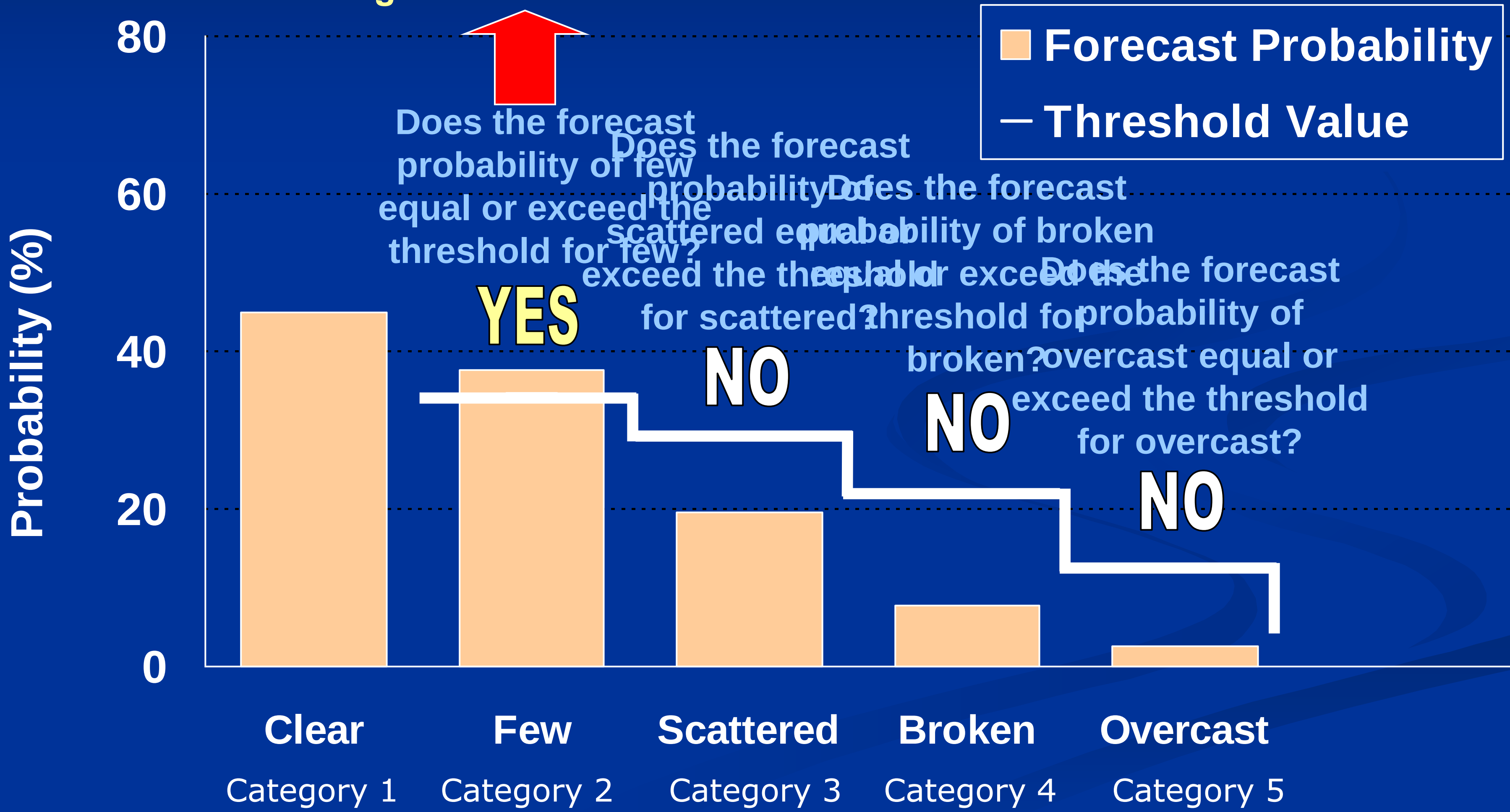
- To illustrate how LAMP computes a categorical forecast, consider the 5 categories of sky conditions:

  (1) Clear
  (2) Few
  (3) Scattered
  (4) Broken
  (5) Overcast

- For this element, threshold values would be generated for categories (2)-(5).
- For a particular station and projection, the probability of the greatest threat event (in this case overcast) is compared to the threshold for overcast skies.
- If the threshold equals or exceeds the probability of overcast skies, the LAMP categorical forecast is "Overcast."
- Otherwise, the algorithm continues and the same question is asked of the next greatest threat event, "Broken."
- This process continues for the next two categories, "Scattered" and "Few." If the probability forecast for each one of these two categories does not equal or exceed its respective threshold value, the LAMP categorical forecast is "Clear."

LAMP Categorical Forecast Selection Process

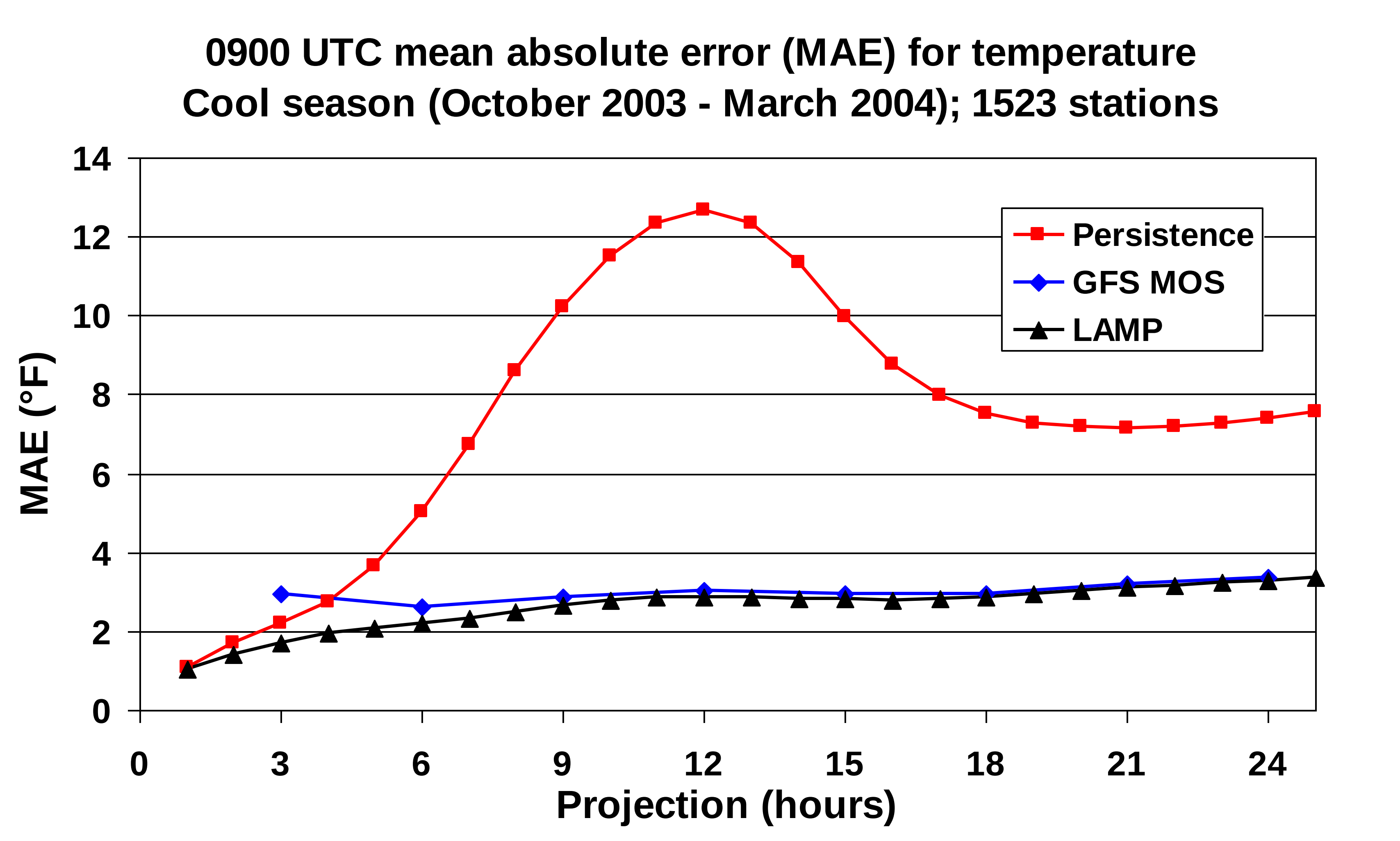
The probability of “few” exceeds the threshold value for “few” – LAMP categorical forecast is “few”



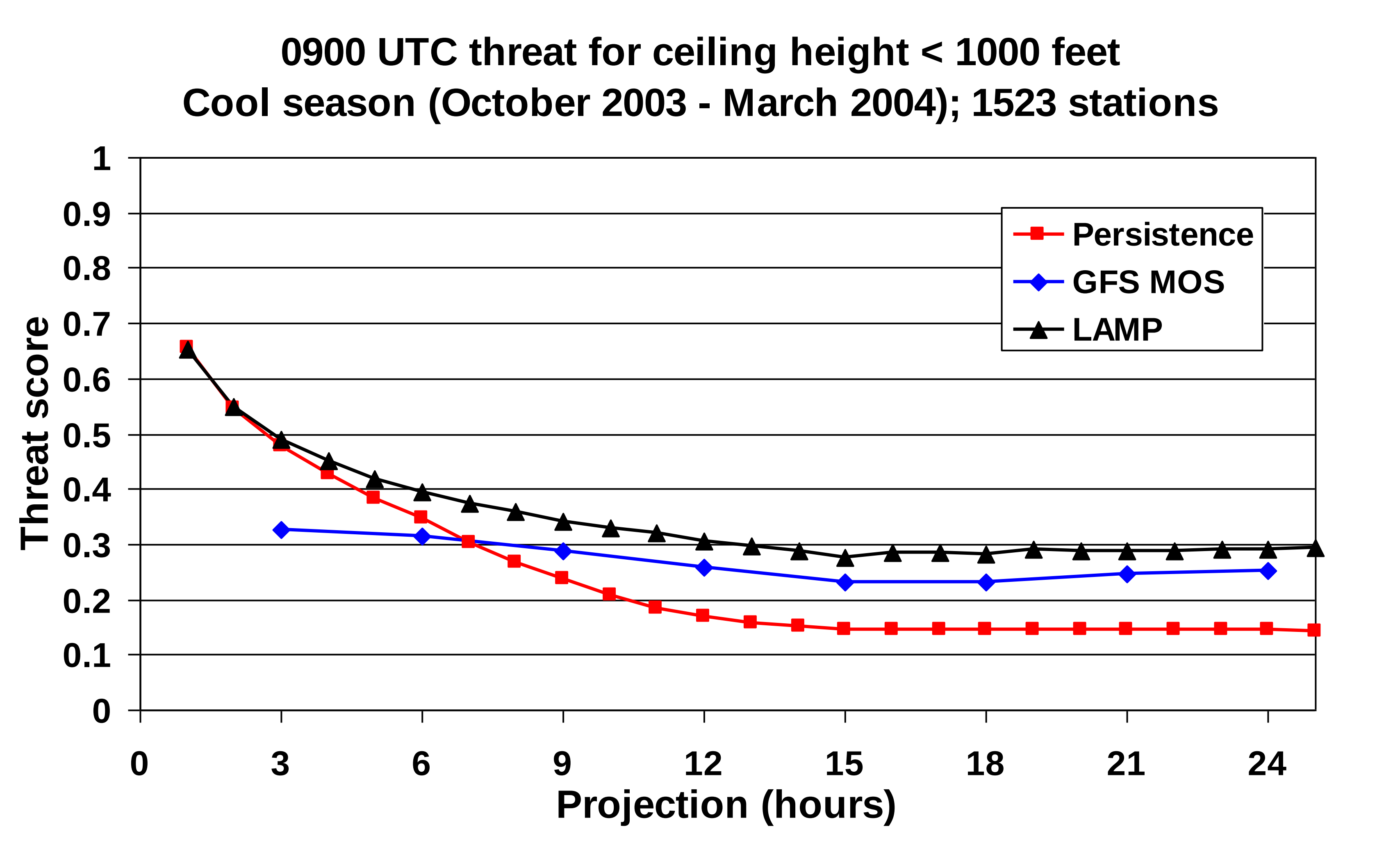
Performance Scores for LAMP Non-Probabilistic Forecasts

- Typical verification scores used for checkout of LAMP forecasts:
  - Continuous weather elements (e.g., temperature and dewpoint) are verified by:
    - mean absolute error (MAE) – lower is better
  - Categorical forecasts (e.g., visibility category) are verified by:
    - Heidke skill score (HSS) – higher is better
    - threat score (also called Critical Success Index) – higher is better
    - bias - values near one are good

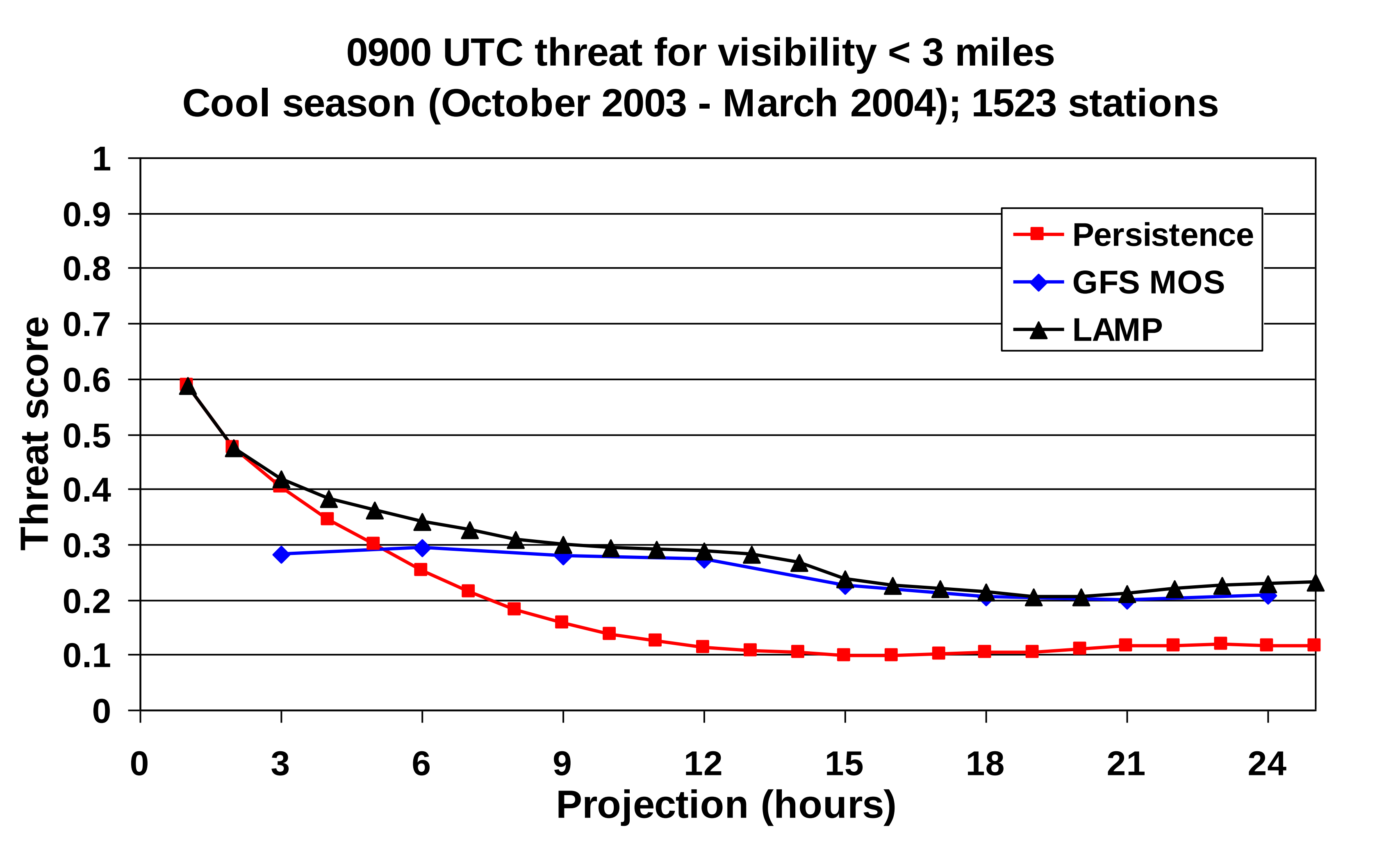
Verification of LAMP 2-m Temperature Forecasts



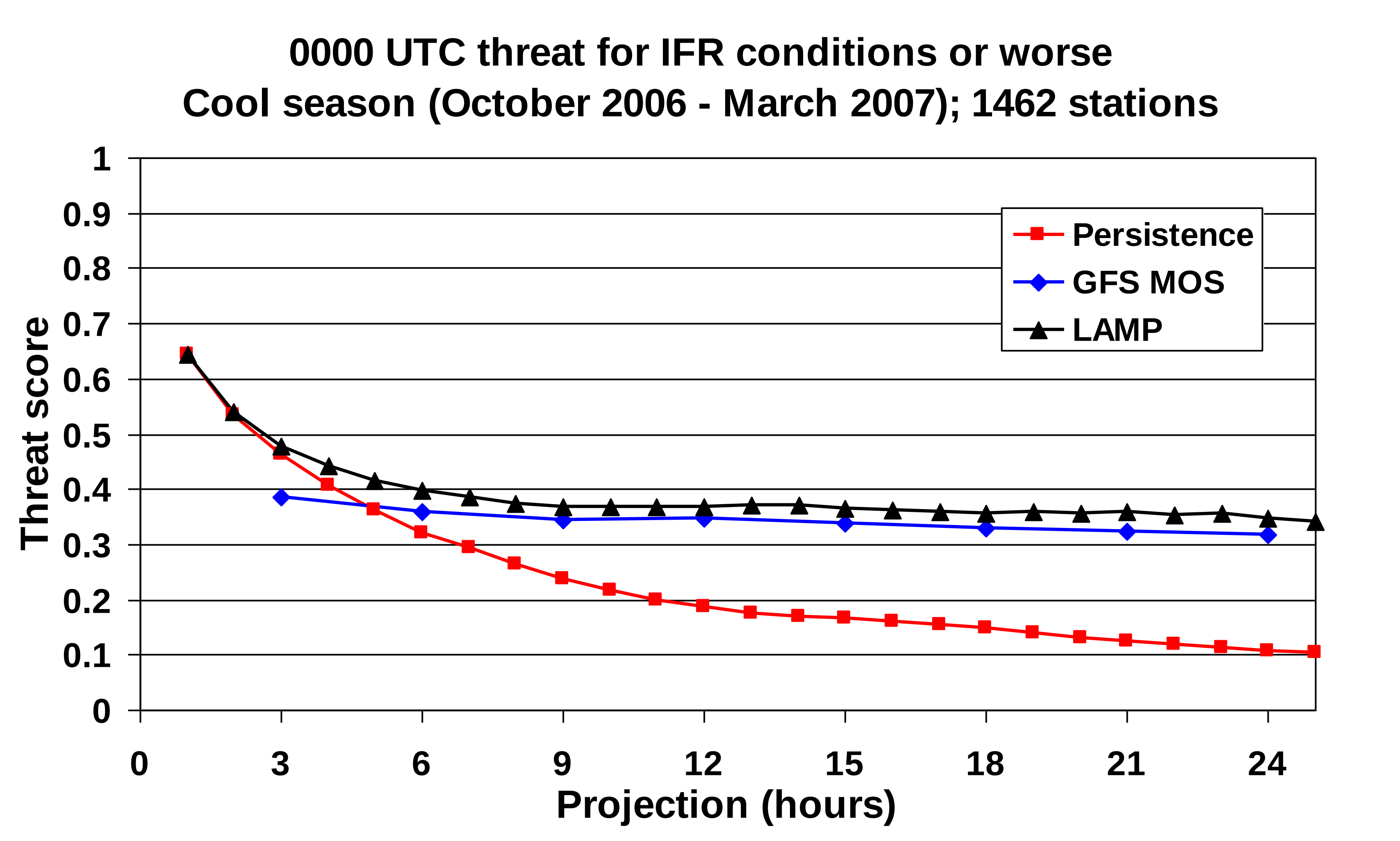
Verification of LAMP Categorical Ceiling Height Forecasts



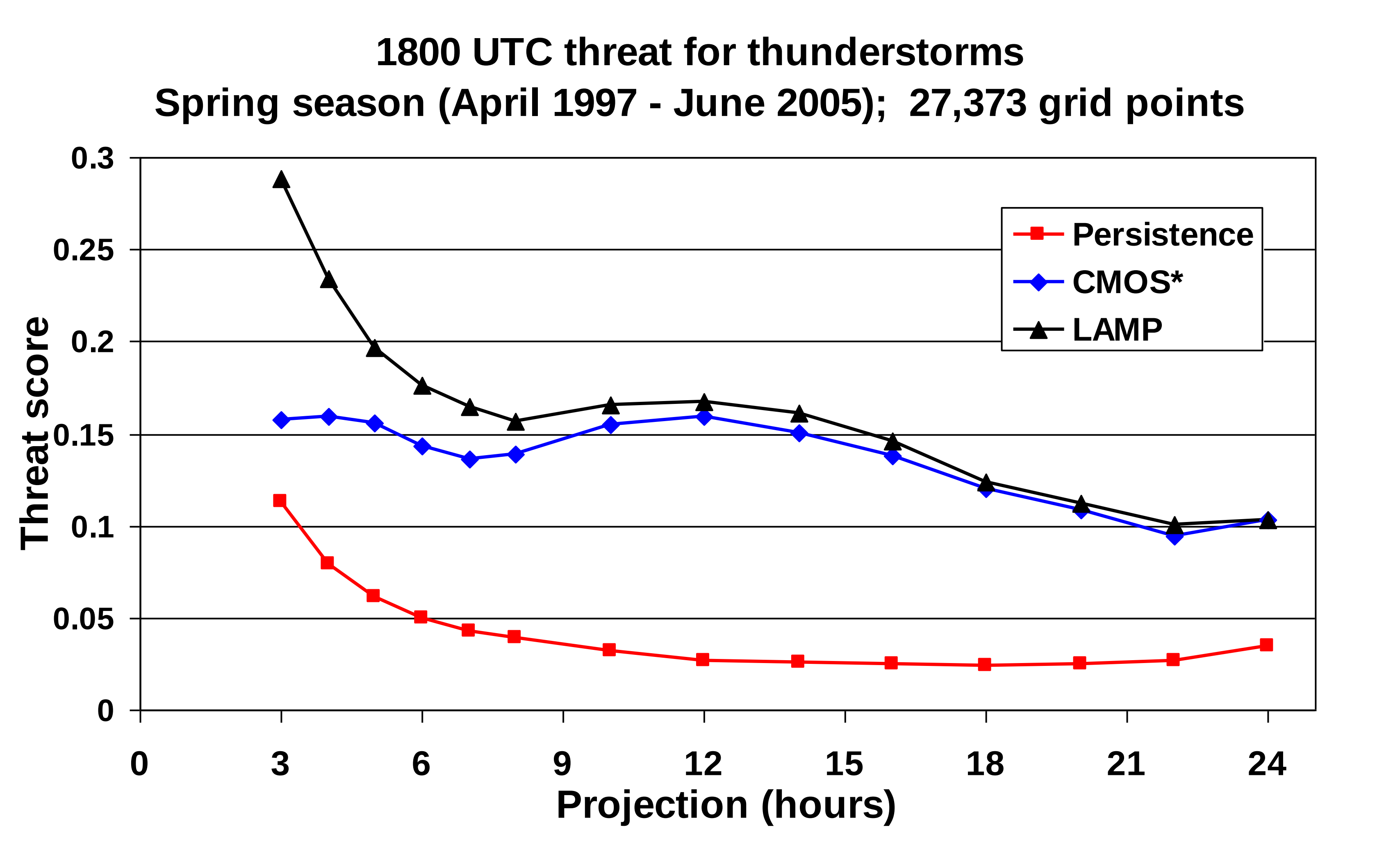
Verification of LAMP Categorical Visibility Forecasts



Verification of LAMP IFR or Worse Forecasts



Verification of LAMP Categorical Thunderstorm Forecasts

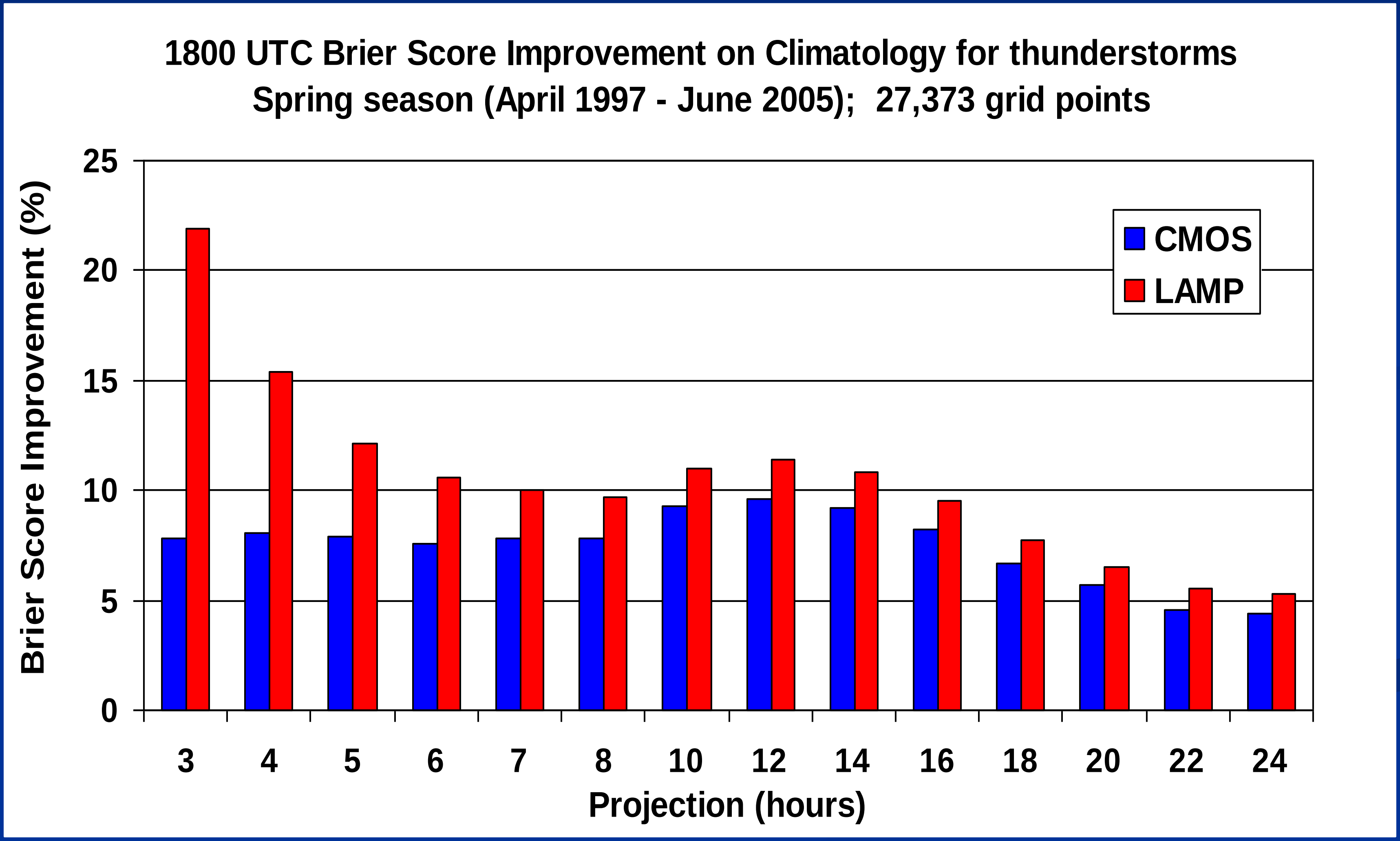


* CMOS stands for calibrated MOS, wherein the GFS MOS is calibrated from a 3-h valid period to a 2-h valid period.

Performance Scores for LAMP Probabilistic Forecasts

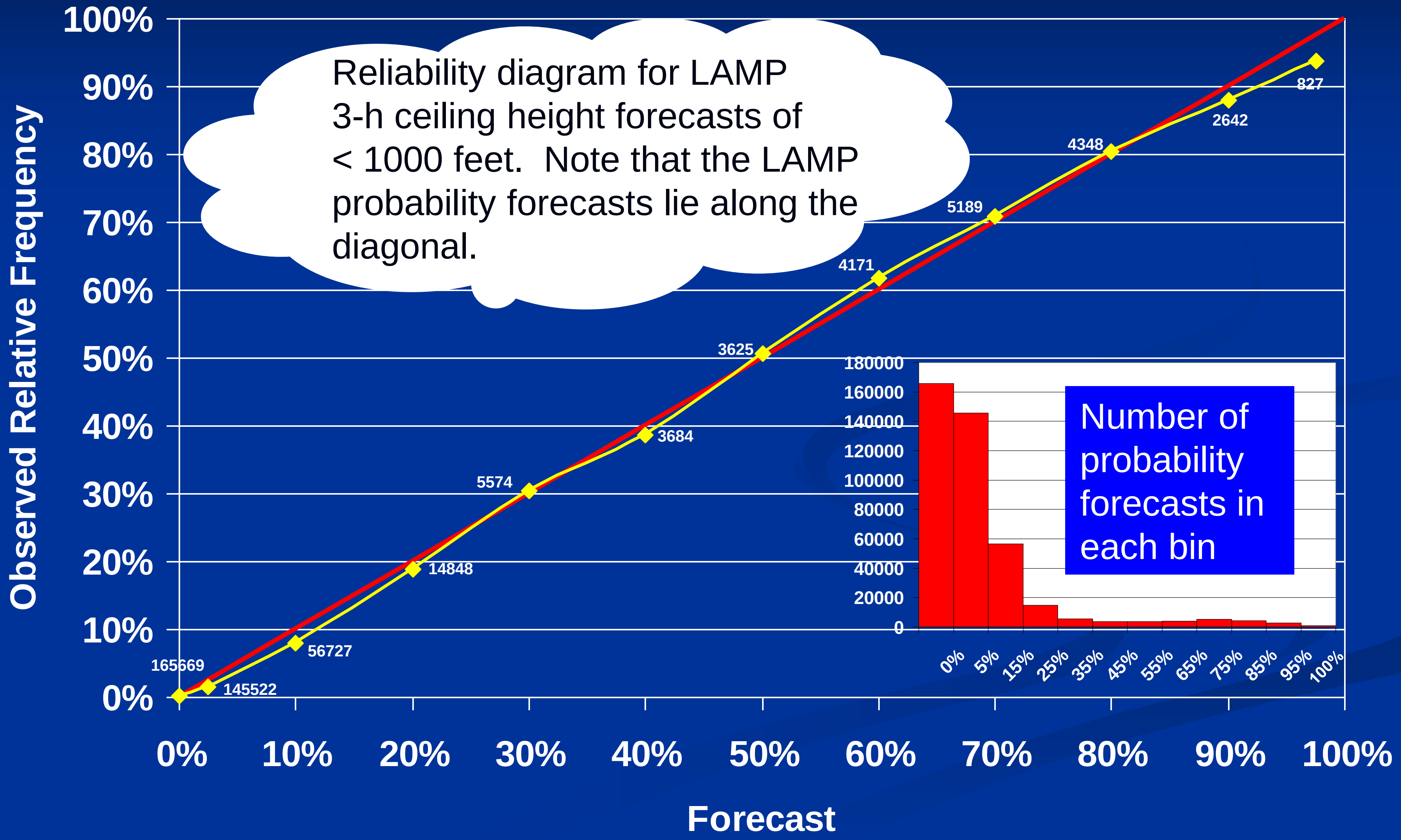
- Basic measure of accuracy is Brier score (lower is better).
- Measure of skill is the improvement in Brier score over a benchmark standard, such as climatology.
- The reliability of probability forecasts describes the degree to which the observed relative frequency of the weather event has a overforecasting or underforecasting bias.
- When the average forecast probability within a bounded range:
  - exceeds the observed relative frequency → overforecasting bias
  - equals the observed relative frequency → perfect reliability
  - is lower than the observed relative frequency → underforecasting bias

LAMP vs. CMOS* Thunderstorm Brier Score Improvement on Climatology

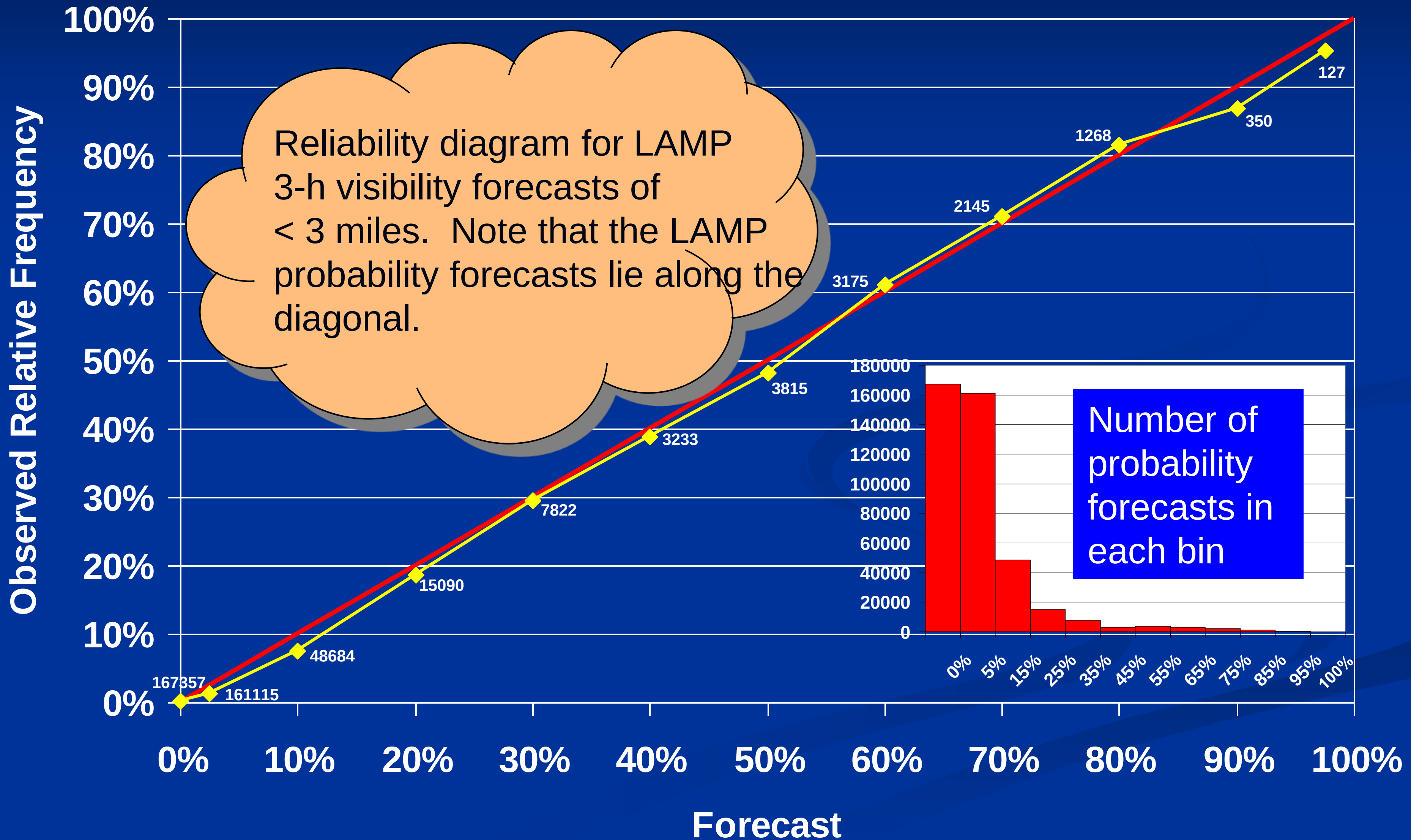


* CMOS stands for calibrated MOS, wherein the GFS MOS is calibrated from a 3-h valid period to a 2-h valid period.

Reliability of 0300 UTC 3-h Ceiling < 1000 feet
2006 August - 2007 May, 1522 sites

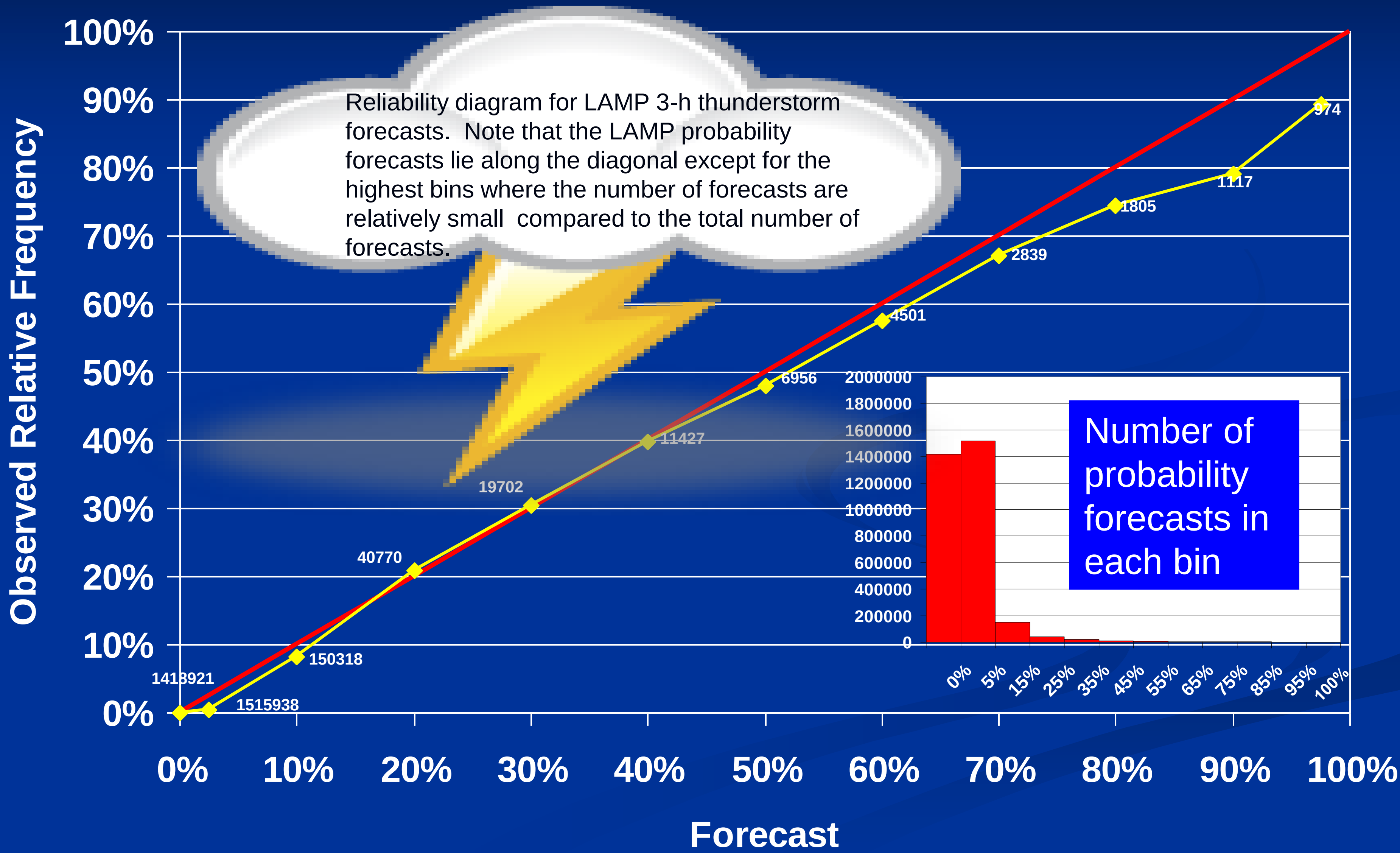


Reliability of 0300 UTC 3-h Visibility < 3 miles
2006 August - 2007 May, 1522 sites



Reliability of 0300 UTC 3-h Thunderstorms

2006 August - September, 2007 April - May, 27373 grid points



Overview of Available LAMP Forecast Products

- Sent out on SBN/NOAAPort and available on NWS FTP Server
  - ASCII text bulletins
  - BUFR data
  - GRIB2 thunderstorm data
- AWIPS
  - Displayable in D2D
  - Guidance available for display and Terminal Aerodrome Forecast (TAF) preparation via the Aviation Forecast Preparation System (AvnFPS)
- LAMP Website
  - Forecast products available:
    - ASCII text bulletins
    - Station plot forecast images
    - Gridded thunderstorm forecast images
    - Meteograms
  - Products Page: http://www.nws.noaa.gov/mdl/gfslamp/gfslamp.shtml

Summary

- LAMP provides hourly updates of four-daily GFS MOS forecasts to 25 hours for the CONUS and OCONUS.
- LAMP forecasts are in probabilistic and non-probabilistic forms.
- LAMP weather elements include those important to aviation operations, such as surface wind, ceiling height, visibility, and thunderstorms.
- LAMP forecasts improve most on GFS MOS in the early forecast projections and on persistence at all projections.
- Please consult http://www.weather.gov/mdl/lamp/ for further information, inquires, and comprehensive performance scores.