The Climate Adjustment Process

- Goal is to adjust the record at a wind monitoring site to the historical norm.
- Average wind speeds can substantially vary from the norm over periods of a year or longer.
- The uncertainty in the long-term mean speed based on a year of measurement is 3-5%, corresponding to 5-10% uncertainty in mean wind power production.

Measure, Correlate, Predict (MCP)

- Winds measured at a site over a year or so.
- Correlate site measurements with those from a long-term reference site, and relate them.
- This reduces the uncertainty in the estimate of the site's long-term mean wind.

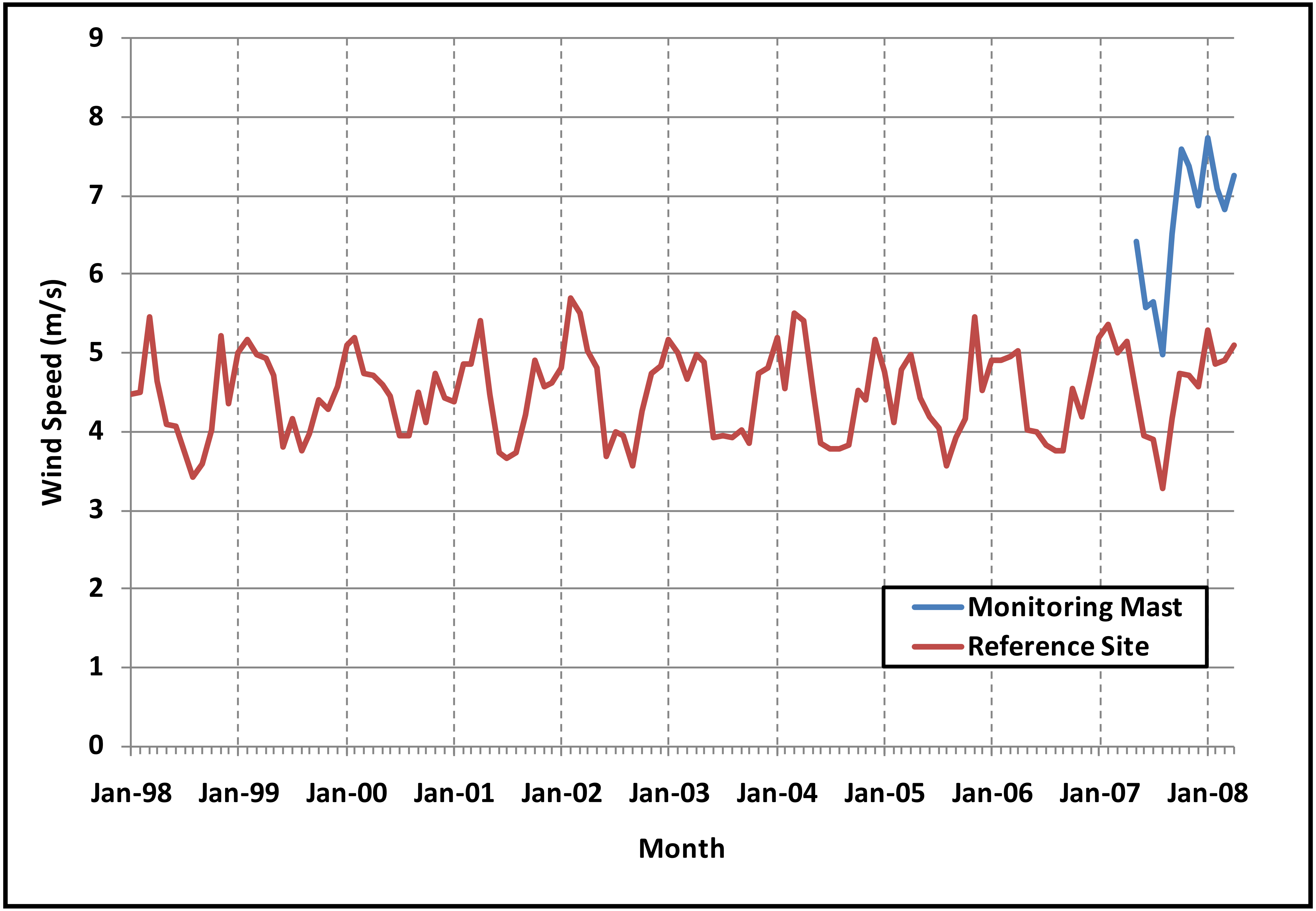


Figure 12-1 Example period of record for a reference site and a monitoring mast.

Application of MCP

- Assumptions underlying MCP
- Requirements for successful MCP
- Data sources most widely used for MCP
- Methods of relating winds at monitoring site and reference site(s)

Is the wind climate stable?

- The key assumption underlying all MCP methods is that the wind resource in the future will be similar to what it has been in the past.

- Historical evidence concerning the long-term stability of the wind climate is mixed.

- A key problem is that there are few wind monitoring stations where the wind has been measured continuously (at the same height and at the same location, with consistent measurement protocols, and using the same instrument or instrument type) for more than 10 to 15 years.

- The lack of truly homogeneous long-term data sets makes it difficult to distinguish a trend caused by climate change or other processes from one that is the result of normal fluctuations.

- Various researchers have nonetheless attempted to detect changes in wind resources over time. The following examples illustrate the difficulties.

- An examination of global reanalysis data - the product of a global weather model driven by historical weather observations - from 1974 to 2004 revealed both moderate decreases and moderate increases in the mean annual wind speed (from -0.2 to +0.2 m/s per decade) in different parts of North America. Some of these patterns are not confirmed by reliable observations, however, and are probably caused by changes in the observational platforms and protocols used to create the reanalysis data set (such as the introduction of weather satellites in the 1970s and 1980s).

- An examination of surface observations from weather stations reveals an unambiguous decline in mean wind speeds in the United States since 1973. It seems likely that the advent of the Automated Surface Observing System (ASOS) in the mid-1990s, as well as other changes such as urbanization and tree growth, are responsible for much of this decrease.

- Rawinsonde data for North America show an increasing trend in mean annual wind speeds at a pressure height of 850 hPa (about 1500 m above sea level) from 1987 to 2006; this follows a decreasing trend in the previous two decades.

- In summary, there are no grounds for concluding that the wind resources in North America have either increased or decreased significantly in the past several decades as a result of climate change.

- Considering the uncertainties in the data, any changes that have occurred are below the level of confident detection.

Prospects for Change in the Future

- What about the future? Although the results of research are far from definitive, overall they point to a probable moderate decrease in wind resources in North America over the next 50-100 years.

- A study drawing on the results of two global climate models under a single scenario of future greenhouse-gas levels suggested that mean annual wind speeds over the lower 48 states could decrease from 1.0% to 3.2% by 2050 and from 1.4% to 4.5% by 2100, compared to a 1948-1975 baseline.

- The two models disagree strongly over the magnitude of the reduction, indicating substantial uncertainty in the conclusion.

- Researchers applied a statistical “downscaling” method to four GCM models under two greenhouse-gas scenarios and projected the impacts of climate change at five weather stations in the Northwestern United States.

- They found that mean wind speeds at these stations could decrease by amounts ranging up to 10%, depending on the station and time of year, with the greatest reductions occurring in summer at most sites.

- The results were fairly consistent across models and scenarios.

- A high-resolution numerical weather prediction model was used to downscale a single GCM model and greenhouse-gas scenario over southern California.
- This study found a pattern of both moderate increases and decreases in mean wind speed in 2041-2060 compared to 1980-1999.
- Unlike other studies, this one looked specifically at an area where wind projects are operating: Tehachapi Pass.
- A 2-4% decrease in the mean annual wind speed was predicted where the wind projects are concentrated.
- Most of this decrease occurred from fall to winter; relatively little change was forecast for the main power-producing months of April to August.

- Based on the historical evidence and modeling studies to date, any changes in the wind climate over the time horizon of wind project investments - up to 25 years - are likely to be modest.

- Even a 5% decrease in the mean annual wind speed over 50 years, if it occurred in a linear fashion, would result in only a 0.5% decrease in the average resource over the first 10 years of a wind project's life.

Other Factors That May Affect the Local Wind Climate

- ?
- ?
- ?

REQUIREMENTS FOR ACCURATE MCP

- *The site and reference station must be in substantially the same wind climate.*
  - This means that variations in wind speed at each location should be well correlated in time.
- *The target and reference station must have a homogenous wind speed record.*
  - A wind speed record is said to be homogeneous if the measurements have been taken continuously at the same location and height with equivalent instrumentation.
  - In the case of the reference station, its record should be substantially longer than, and overlap with, that of the target site.

- *The concurrent target-reference period should capture seasonal variations in the relationship.*
    - In practice this means at least nine continuous months, and preferably a year or more.

Correlation

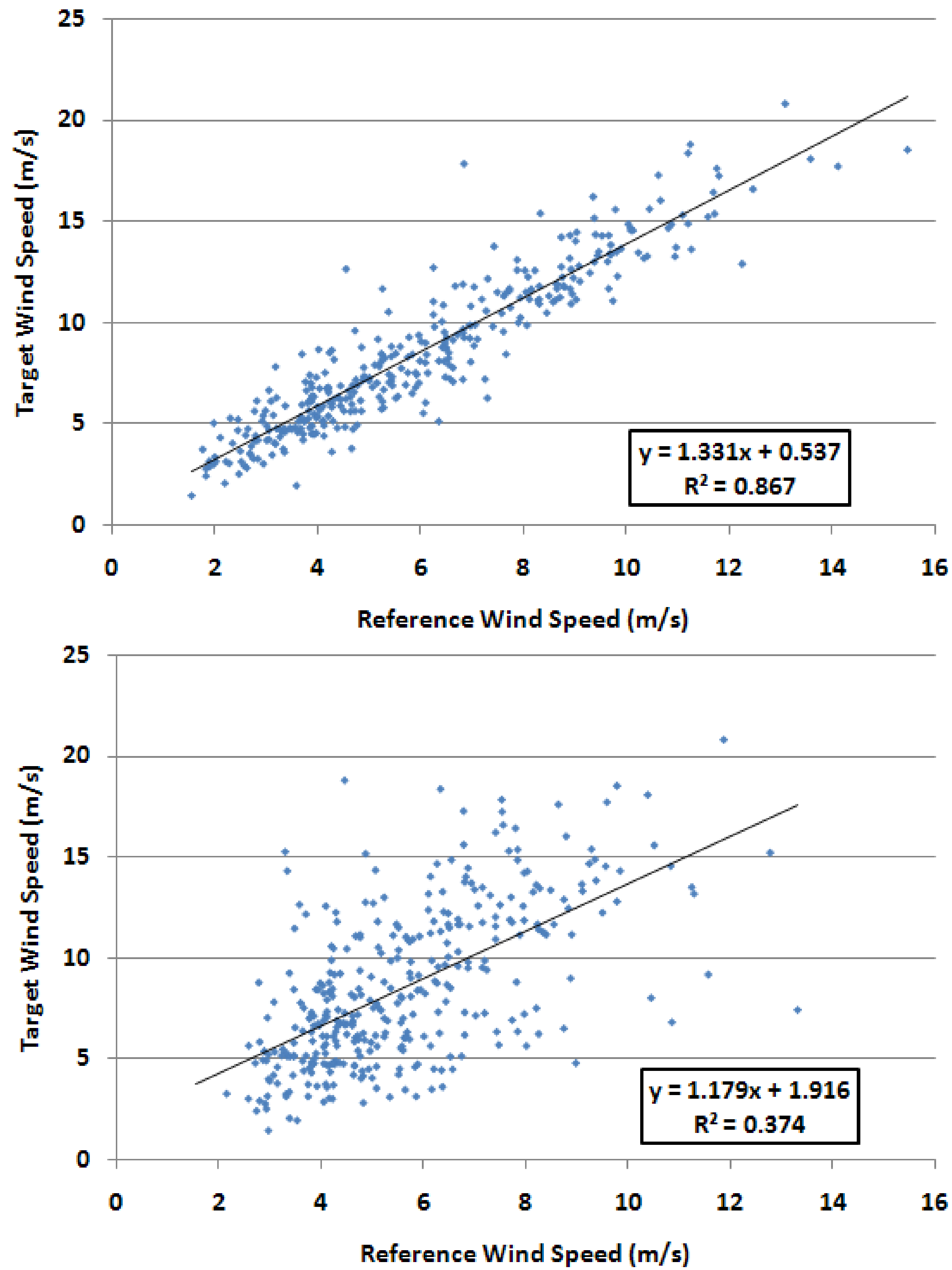


Figure 12-2 Typical scatter plots of target and reference wind speeds. The upper plot shows a relatively high r^2 value, indicating the two sites experience very similar wind climates, whereas the lower plot shows a relatively poor correlation. (Source: AWS Truepower)

Assuming normally distributed annual wind speed fluctuations and a homogeneous reference station data record, the following simple equation approximates the overall uncertainty in the long-term mean wind speed as a function of the correlation coefficient, r^2

$$\sigma = \sigma_A \sqrt{\frac{r^2}{N_R} + \frac{1-r^2}{N_T}}$$

N_R is number of years of reference data.
N_T is number of years of concurrent target and reference data.

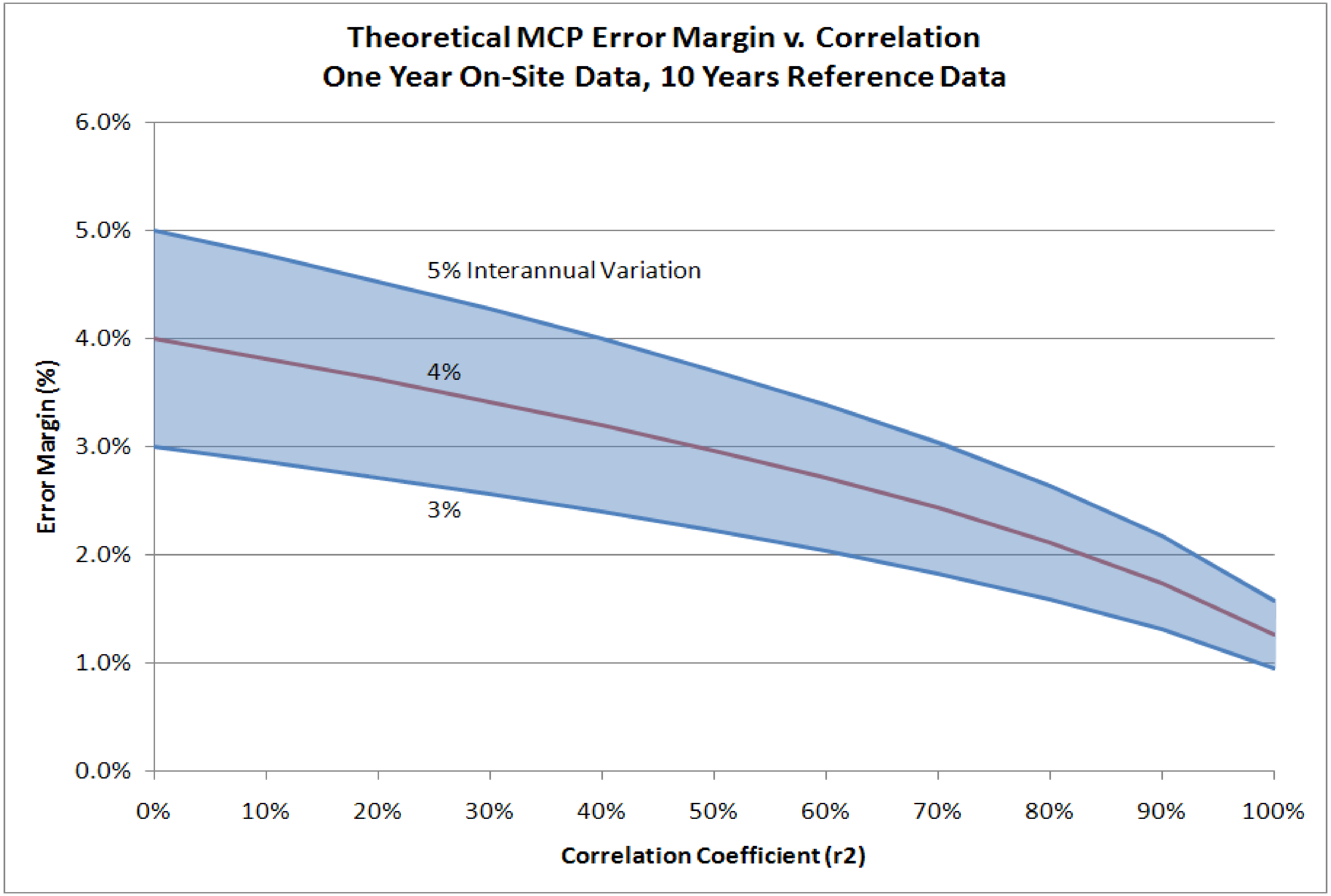


Figure 12-3 Uncertainty margin in the estimated long-term mean wind speed at a site, assuming one year of on-site data and 10 years of reference data, as a function of the r^2 coefficient between them and of the interannual variation in the wind at the site (the standard deviation of annual mean wind speeds divided by the long-term mean). (Source: AWS Truepower)

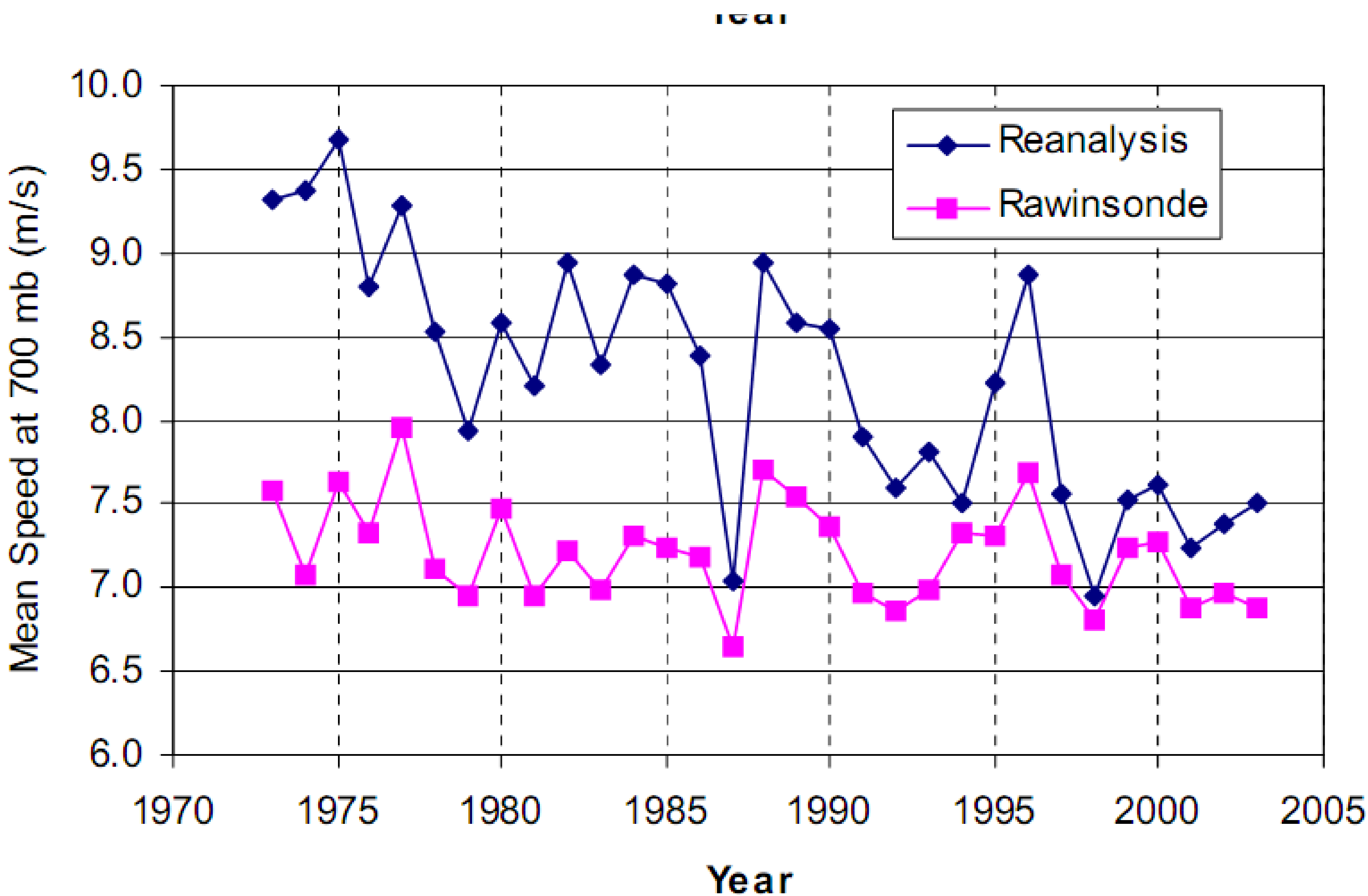
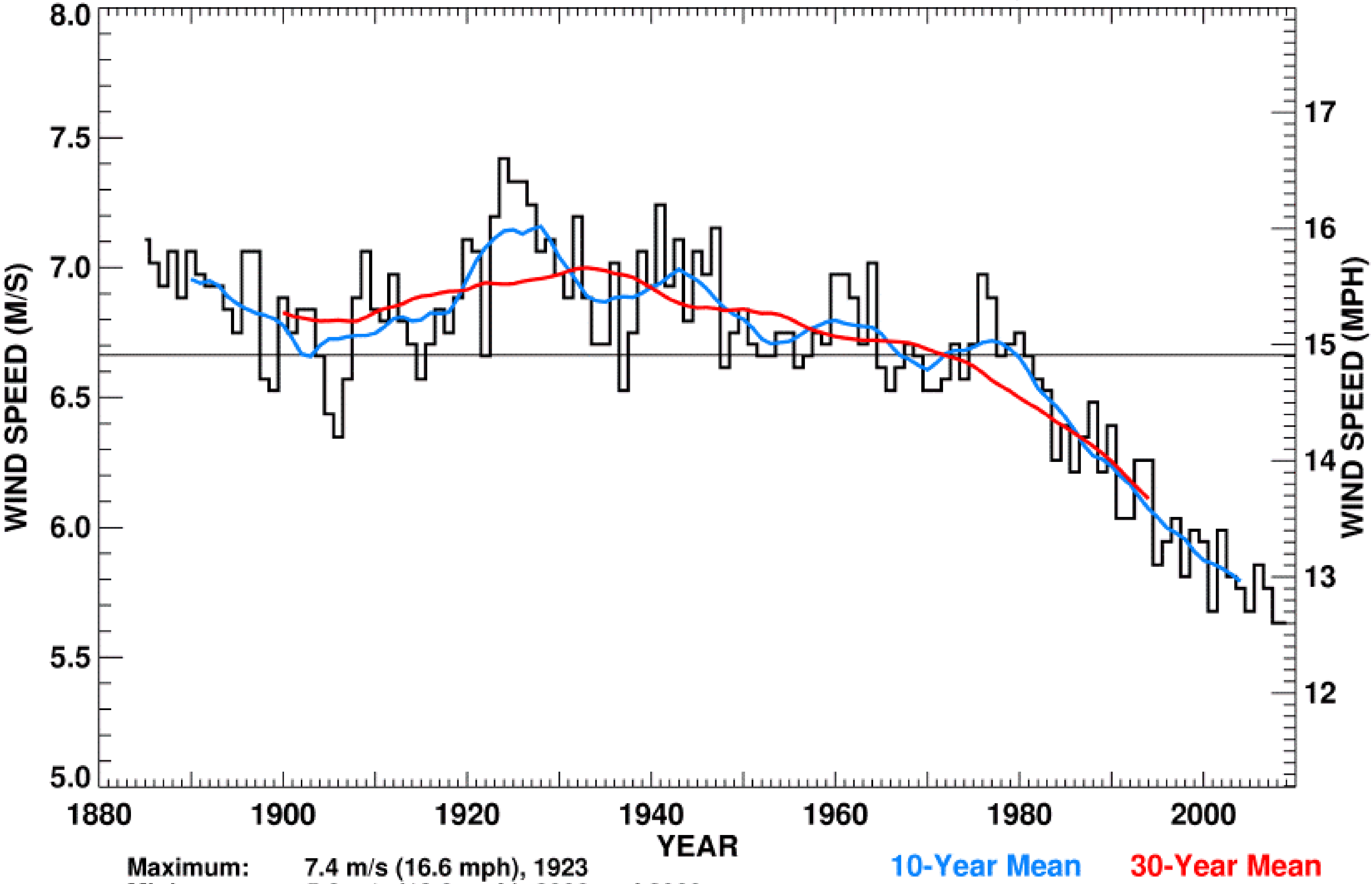


Figure 12-9 Comparison of mean annual speeds at 700 mb (3500 m above sea level) from reanalysis data (dark blue) and rawinsonde (magenta) observations over Denver, Colorado. [30]

BLUE HILL OBSERVATORY ANNUAL WIND SPEED, 1885-2009



Maximum: 7.4 m/s (16.6 mph), 1923
Minimum: 5.6 m/s (12.6 mph), 2008 and 2009
Record Mean: 6.7 m/s (14.9 mph)

Michael J. Iacono, Atmospheric and Environmental Research, Inc. / Blue Hill Observatory

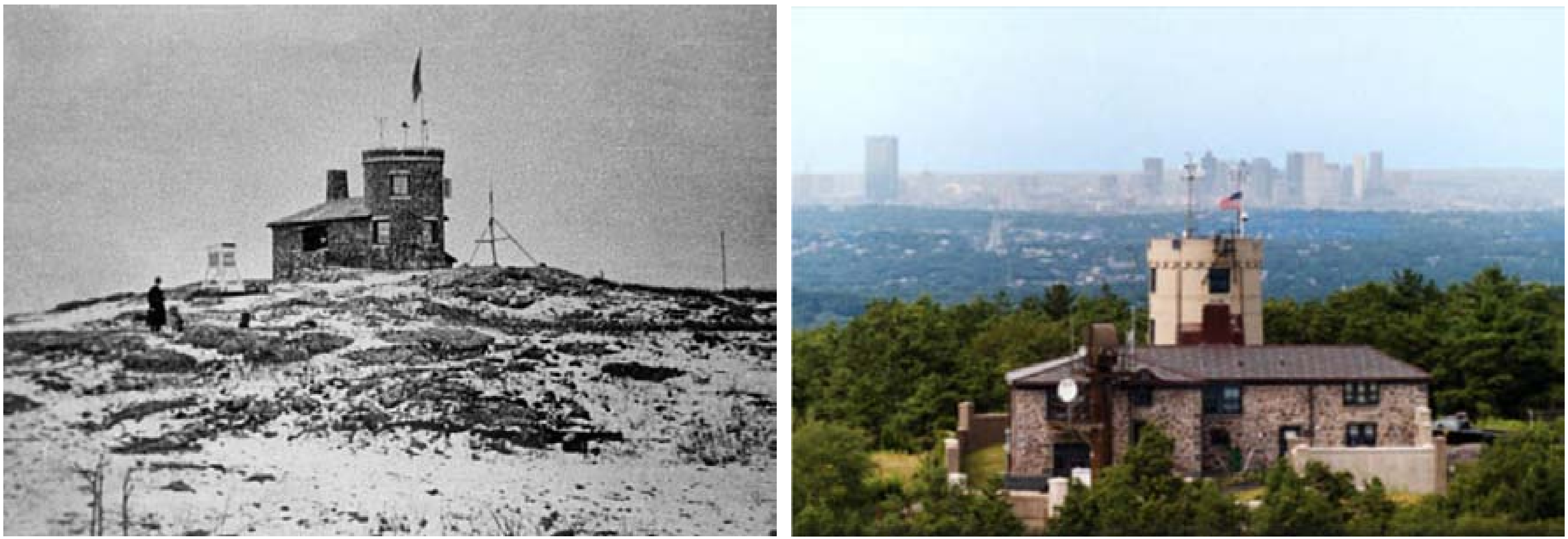


Figure 12-4 ***Top*: Wind speeds recorded at the Blue Hill Observatory outside Boston. *Bottom*: Photographs of Blue Hill Observatory taken in 1886 (left) and present day (right). (Source: Blue Hill Observatory – www.bluehill.org)**

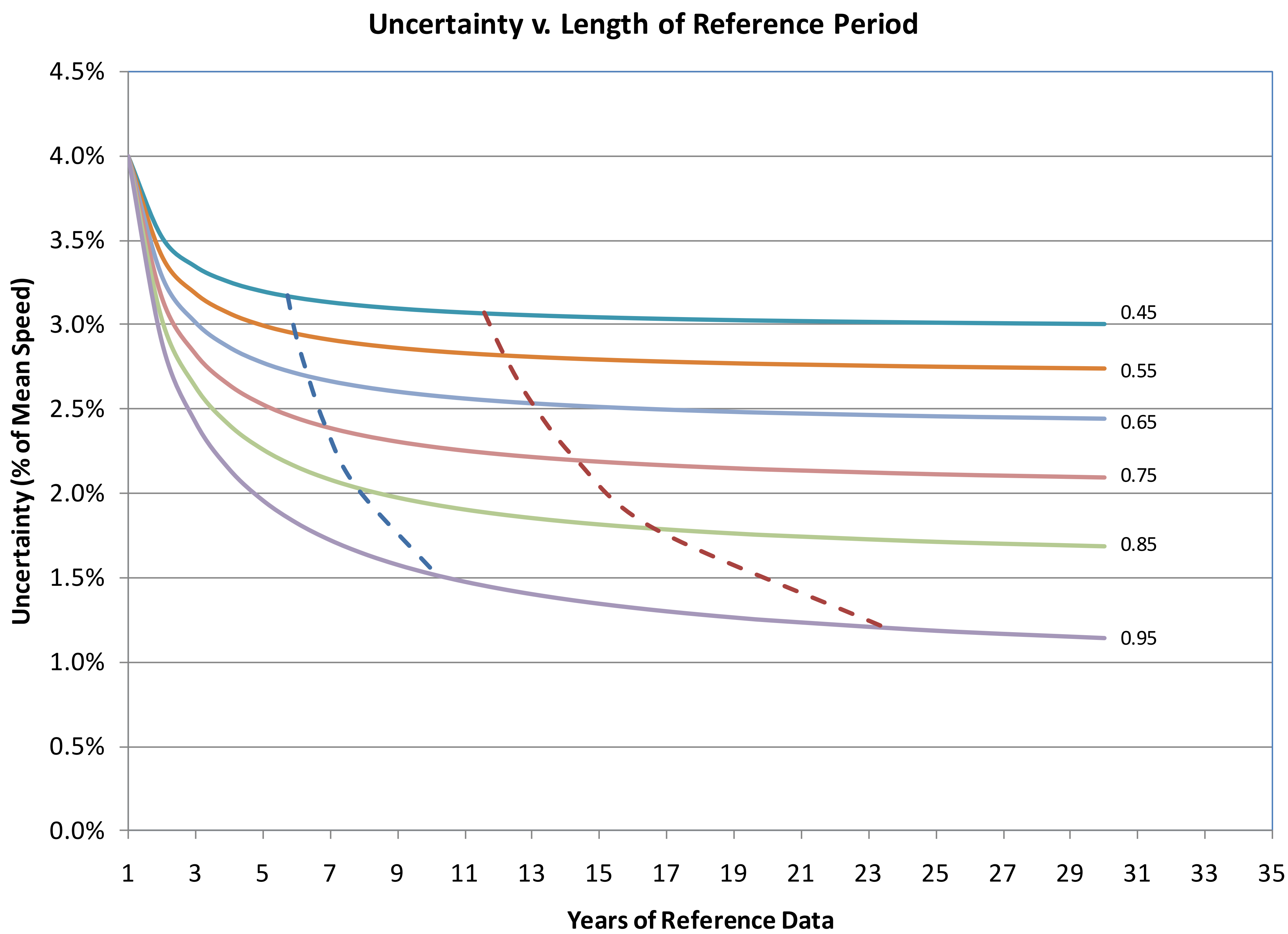


Figure 12-5 Plot of the statistical uncertainty in the long-term mean annual wind speed at the target site as a function of number of years of reference data and for different values of r^2. The two dashed curves show the number of years required to achieve 80% (left-hand dashed curve) and 90% (right-hand dashed curve) of the maximum possible reduction in uncertainty. The curves are derived from the equation in the text, assuming 4% inter-annual wind speed variation, one year of overlapping reference and on-site data, and no significant trends or discontinuities in the reference data set. (Source: AWS Truepower)