Error

Train wreck at Montparnasse, France, 1895

Dr. Christopher M. Godfrey
University of North Carolina at Asheville

Gaussian Distribution

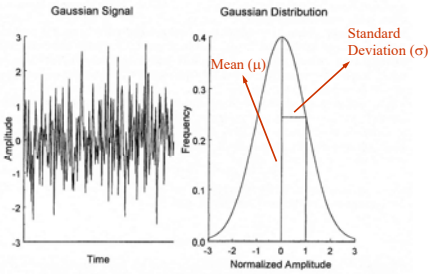
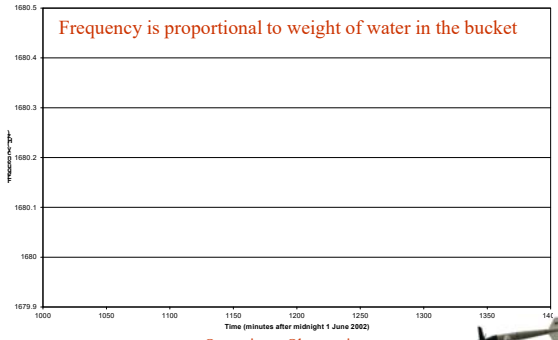


Fig. 3-4 Sample of a Gaussian distributed signal in the left-hand panel and the corresponding Gaussian distribution in the right-hand panel.

Sources of Random Errors

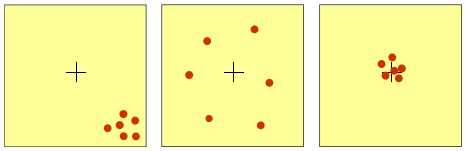
- Sudden or uncontrollable changes within the measuring environment that are significant enough to affect the measurement
- Electronic or electrical noise
- Random, careless errors of the operator

Noise in the Geonor vibrating wire rain gauge



One-minute Observations

Bias vs. Precision



- Biased
- Precise

- Unbiased
- Imprecise

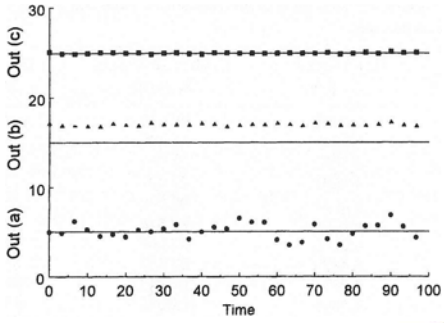
- Unbiased
- Precise

Bias vs. Precision

- Unbiased
- Precise

- Biased
- Precise

- Unbiased
- Imprecise



Accuracy Measures
Root-mean squared error

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} e_i^2}$$

- Sensitive to large errors
- Same physical dimensions as calibrated output

Accuracy Measures
Root-sum square

$$RSS = \sqrt{\sum_{i=1}^{N} e_i^2}$$

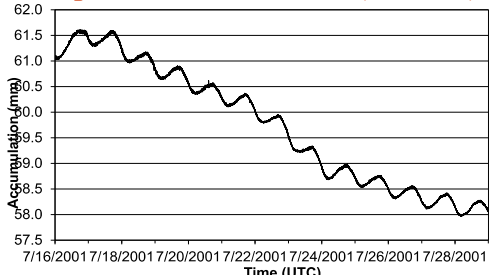
Table 3-2 Errors for a certain barometer.

Error Source	Imprecision
Linearity	0.15 hPa
Hysteresis	0.03 hPa
Repeatability	0.03 hPa
Calibration uncertainty	0.20 hPa
Temperature dependence	0.10 hPa
Long-term stability	+0.20 hPa/year
Combined error	0.3 hPa + 0.2 hPa/year

RSS

- Assesses total error from multiple independent, measurable sources
- Often less than simple sum of the error components

Multiple Sources of Error (Geonor)



Significant Figures

- An example:
  - Thermometer has imprecision of 0.12 K
  - Thermometer reads 273.781 K
  - Correct value likely lies within the range 273.661 K and 273.901 K (or 273.781 ± 0.12 K)
    - Last two digits are not significant (they vary wildly!)
    - Tenths digit is uncertain (between 7 and 9 when rounded), so we keep four significant digits, including the uncertain one
  - Observation should be reported as 273.8 ± 0.1 K

Significant Figures

- Rules for applying significant digits:
  - Nonzero digits are significant
  - Zeros between nonzero digits are significant
  - Zeros to the left of the first nonzero digit in a number are not significant
  - Zeros to the right of the decimal point are significant
  - Some ambiguity when a number ends in zeros that are not to the right of the decimal point
    - Fix this problem by using scientific notation

Significant Figures

- Rules for mathematical operations processed with calculators or computers
  - Store all intermediate results to the precision of the computer or calculator (don't confuse this with the precision of the instrument!)
  - Round the final result to the appropriate precision
    - Accuracy of the final result is limited by the least accurate measurement
  - Mathematical operations do not improve precision of result, but careless handling of intermediate results can decrease the final precision
    - Do not round or truncate sums when calculating transfer coefficients using the method of least squares!