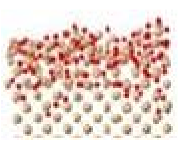
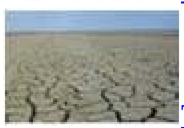
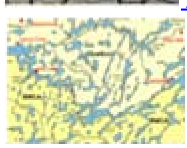
Environmental Context Characterization and Model Approaches

Stochastic Modeling | Ontological Organization and Process Modeling

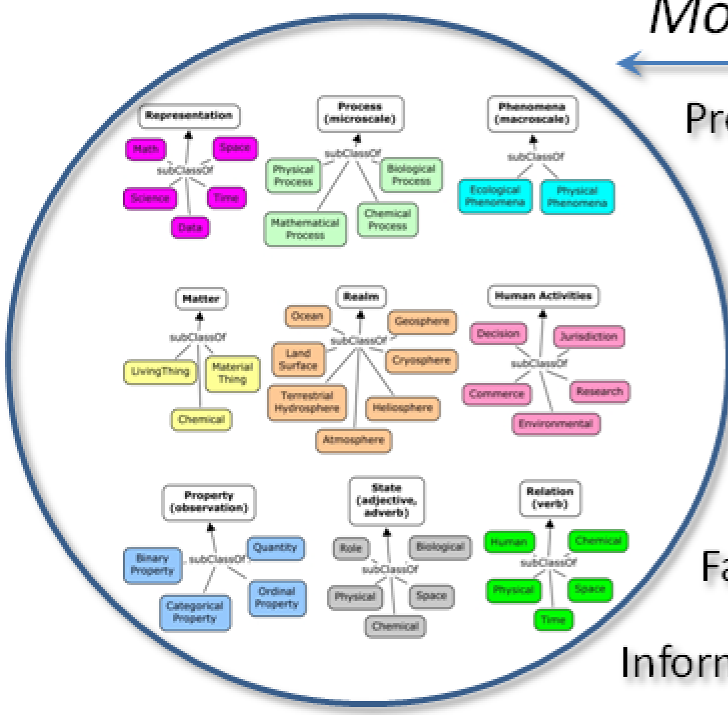
1.  Gross Terrain Features - Simple distribution for sampling likelihood of terrain slopes
2.  Fine Terrain Features - Methods for modeling spatial frequencies for power spectral densities (PSD)
3.  Wave Energy Statistics - Simple approach for generating PSD's, pulling data from real-time stations
4.  Wind Energy Statistics - General results for modeling wind energy distribution and autocorrelations for persistence
5.  Rainfall Statistics - General model for rainfall distributions within storms using composite process
6.  Corrosion and Oxidation - Model of oxidation and corrosion growth which improves on the Deal-Grove formulation.
7.  Thermal Dispersion - Simplification of thermal diffusion model to account for disorder and variability in the media.
8.  Lake Size Statistics - Maximum entropy estimation for lake size distributions for regions
9.  Particle Size Statistics - General method for modeling size distribution of particulates such as ash and ice crystals
10.  Clutter Modeling - Maximum entropy models for E-M signals and noise

Insanely Great Idea

- Applying an *ontological classification* strategy to *stochastic models* of the environment.
  - Simple, efficient while comprehensive
  - A workflow-driven semantic web provides services

Ontology (SWEET)

Stochastic Modeling



Probability Theory
- MaxEnt

Complexity Theory

Superstatistics

Pattern Theory

Fat-Tails and Fractals

Information Theory —*apply* / *to design*→ Probability of Correctness

The challenge, "Capture and Harness Stochasticity in Nature", was motivated by David Mumford's pattern theory ideas:

> *"stochastic models and statistical reasoning are more relevant i) to the world, ii) to science and many parts of mathematics and iii) particularly to understanding the computations in our own minds, than exact models and logical reasoning"*

He concludes with this:

> *"stochastic methods will transform pure and applied mathematics in the beginning of the third millenium. Probability and statistics will come to be viewed as the natural tools to use in mathematical as well as scientific modeling. The intellectual world as a whole will come to view logic as a beautiful elegant idealization but to view statistics as the standard way in which we reason and think."*

Use established scientific criteria and ontological methods to derive and classify the stochastic models

Ontological Organization and Process Modeling
Extracting commonality and providing reusable and scalable extractions

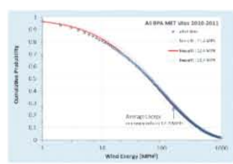
Land — *Atmospheric* — *Aquatic*

To estimate probabilities of correctness or a PCC to certify a design, the context models must be in the form of continuous or discrete probabilities. For the latter, the discrete probabilities could evaluate to Go/NoGo outcomes over a sampled set of contexts.

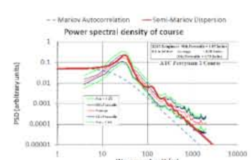
Probability Density Functions
PDF

Cumulative Density Functions
CDF

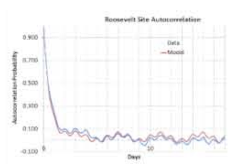
Histograms



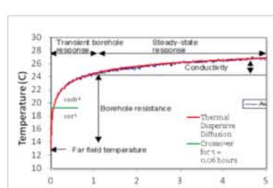
Power Spectral Densities
PSD



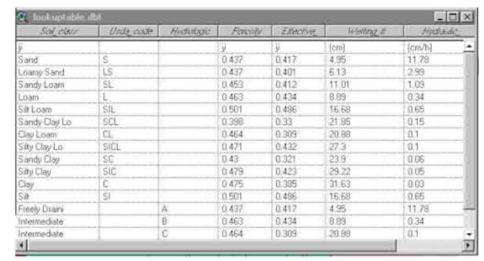
Autocorrelation Functions
ACF



Growth Curves



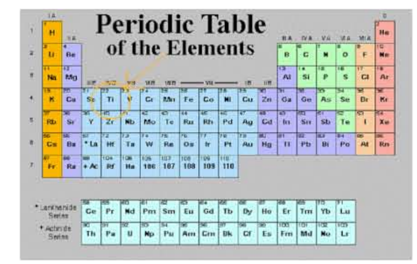
Data and Lookup Tables



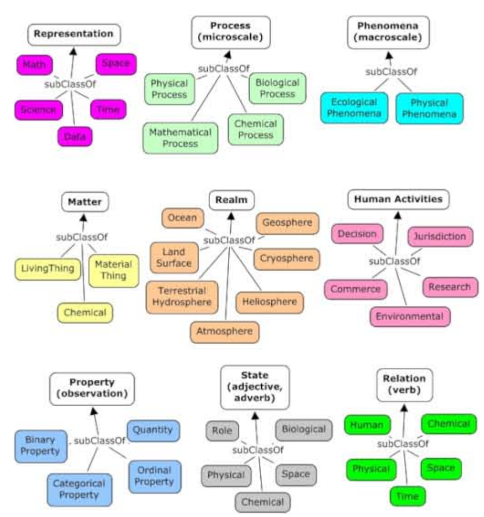
lookuptable.dbf

Soil_class	Unda_code	Hydrologic	Porosity	Effective_	Wetting_fr	Hydraulic_
y			y	y	(cm)	(cm/h)
Sand	S		0.437	0.417	4.95	11.78
Loamy Sand	LS		0.437	0.401	6.13	2.99
Sandy Loam	SL		0.453	0.412	11.01	1.09
Loam	L		0.463	0.434	8.89	0.34
Silt Loam	SIL		0.501	0.486	16.68	0.65
Sandy Clay Lo	SCL		0.398	0.33	21.85	0.15
Clay Loam	CL		0.464	0.309	20.88	0.1
Silty Clay Lo	SICL		0.471	0.432	27.3	0.1
Sandy Clay	SC		0.43	0.321	23.9	0.06
Silty Clay	SIC		0.479	0.423	29.22	0.05
Clay	C		0.475	0.385	31.63	0.03
Silt	SI		0.501	0.486	16.68	0.65
Freely Draini		A	0.437	0.417	4.95	11.78
Intermediate		B	0.463	0.434	8.89	0.34
Intermediate		C	0.464	0.309	20.88	0.1

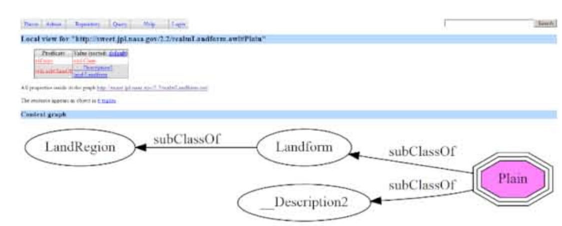
Constants and Properties



Dynamic Models
e.g. *compliant contact model*

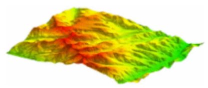


Semantic Web for Earth and Environmental Terminology (SWEET)

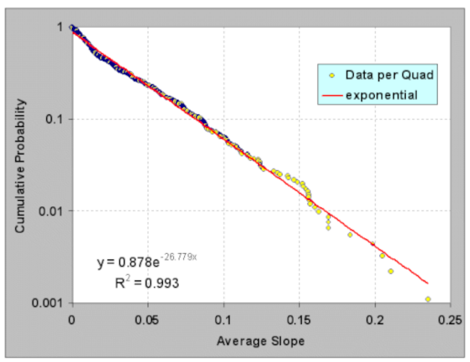


Gross Terrain Features and Topography
Key : Simple distributions for sampling likelihood of terrain slopes

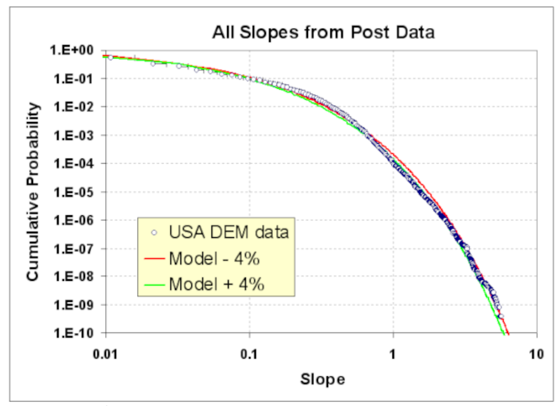
Generate distributions of terrain slope which match empirical data



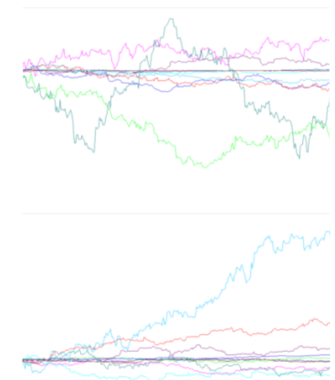
Individual regions map to mean value maximum entropy estimators



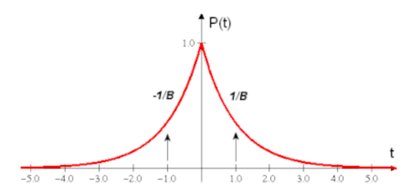
Aggregated regions such as the continental USA (CONUS) map to doubly stochastic distributions (Modified Bessel function of the 2nd kind)



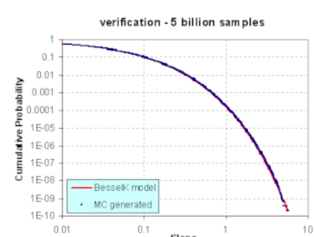
Generate spatial profiles from sampled slopes by random walk generation.



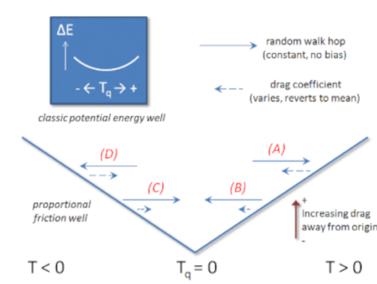
Red noise random walk based on exponential autocorrelation function



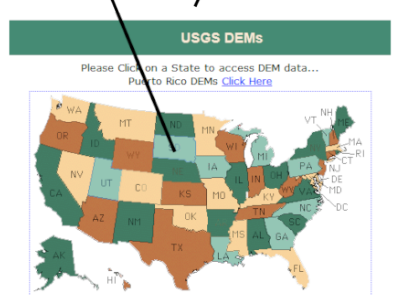
Simple two-level sampling generates Bessel distribution



Ornstein-Uhlenbeck model provides reversion to the mean statistics



Applications use sampled data for vehicle mobility studies



Data from USGS DEM archive.
100 Meter post resolution, converted to average local slope in two dimensions

Fine Terrain Features

Key : Methods for modeling spatial frequencies and power spectral densities

Figure 4.0-1. Aerial View of the 2-in Washboard and Radial Washboard Courses

Fine terrain at the vehicle scale is represented by features such as washboard roads, cobblestones, chatter bumps, etc

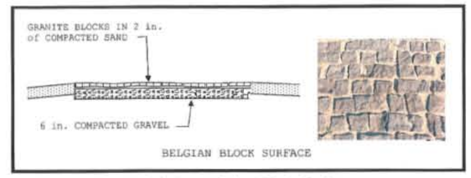


Figure 4.4-1. Belgian Block Surface

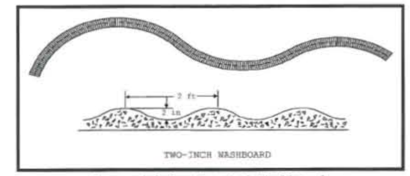


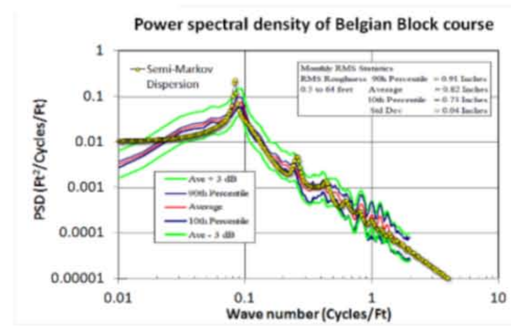
Figure 4.1-1. Two-Inch Washboard

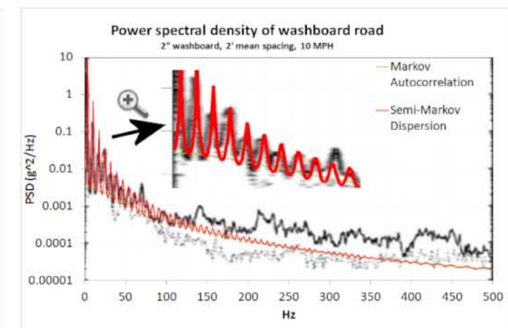

Figure 4.4-2. HMMWV with Trailer on Belgian Block Course

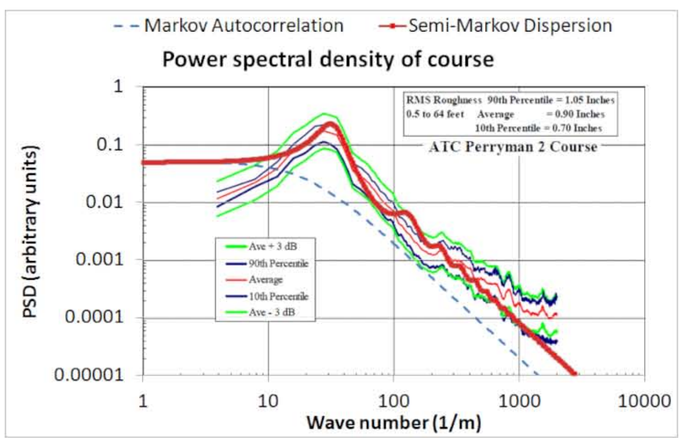

Figure 4.1-2. HMMWV on Two-Inch Washboard

Washboard roads show spatially cyclic features. Dispersion of the waves leads to characteristic damped spectra harmonics as shown below.

Terrain is described by its roughness or "bumpiness". Dispersed periodicities in the fine terrain is revealed by power spectral density (PSD) curves. Use the techniques perfected by diffraction spectroscopy to model the damped harmonics in the spatial frequency plane. PSD's provide stimuli to vehicle mobility models.





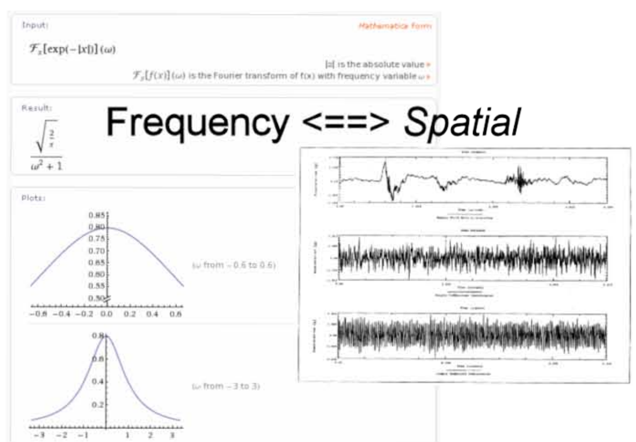


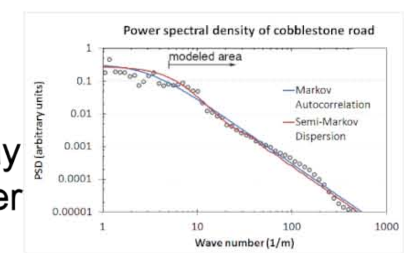
Cobblestones such as the Belgian Block course show order in surface roughness.

stronger

weaker

Other cobbles may show weaker order

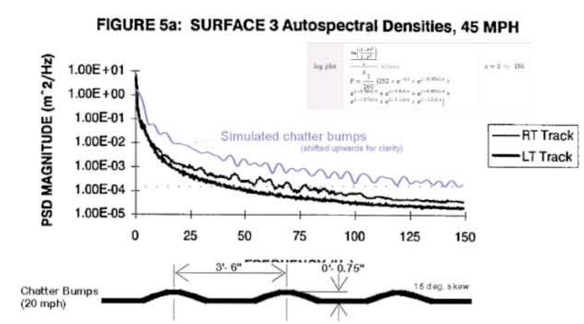




Courses such as Perryman feature range of terrain features with either random or slight spatial periodicities.

Markov or semi-markov models of the terrain roughness are characterized first as autocorrelation functions. A Fourier transform of the autocorrelation generates the corresponding PSD.

An autocorrelation of a rough surface generates a damped exponential and a Cauchy PSD in the spatial frequency domain. Other periodic fluctuations generate harmonics.



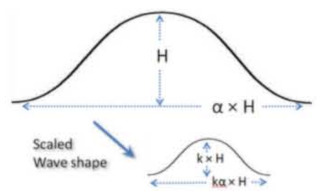
Simulated chatter bumps in the fine spectra. Only right track contains chatter bumps

Wave Energy Statistics

Key : Simple approach for generating PSD's, extracting data from real-time stations

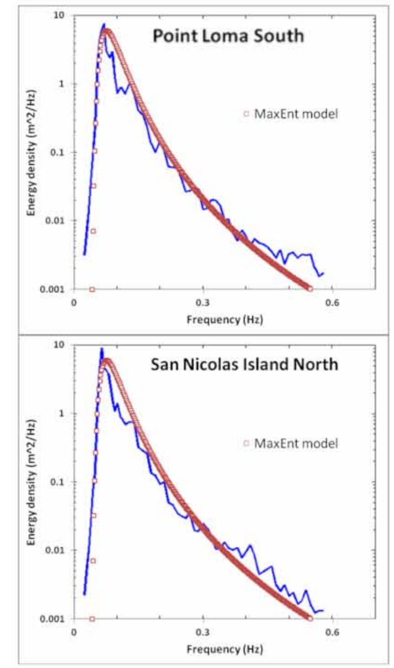
Simulated waves from a commercial rendering package

How are waves characterized and modeled?



A single wave contains potential energy generated by wind and tidal forces. This energy is released as the wave is dissipated. This leads to the power-law shape shown to the right as a power spectral density.

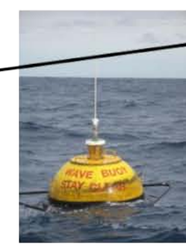
Typical data is gathered over a time frame to gather sufficient statistics.



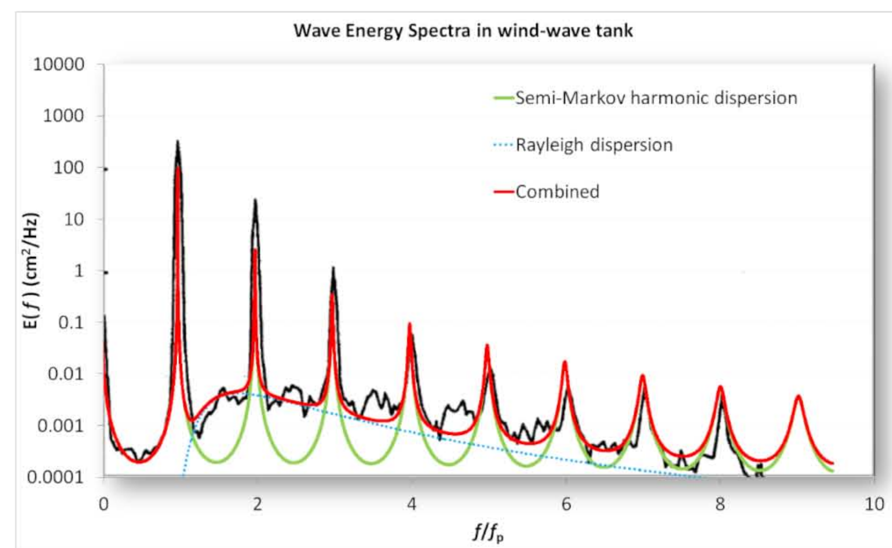
PSD data collected at locations spatially separated but sharing the same weather patterns will show similar profiles.

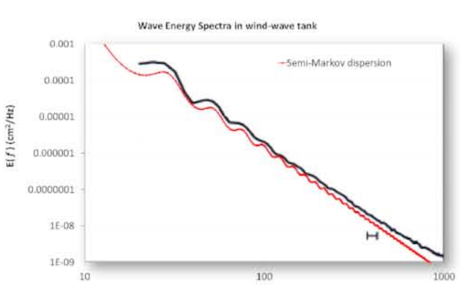
Point Loma South

Data gathered from real-time measuring stations is available from gov sites



Spectra showing strong order mixed with background





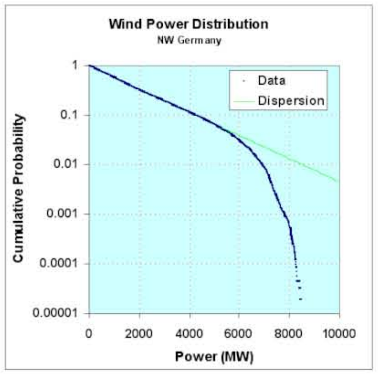
If the waves are sufficiently coherent, then we can apply the same spectral techniques as used for fine terrain characterization. Data from wave tank experiments show excellent agreement with dispersive models. The left model shows weaker dispersion than the strong harmonics in the right model.

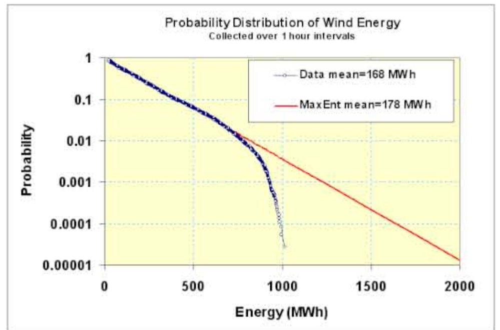
Wind Energy Statistics

Key : Modeling wind energy distributions and autocorrelations for temporal persistence

Wind statistics available from wind turbine farms

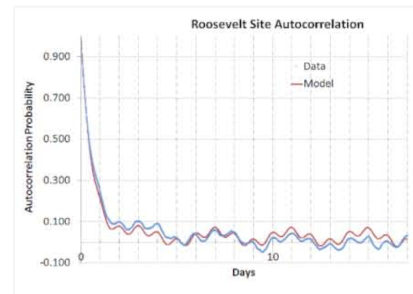
Germany



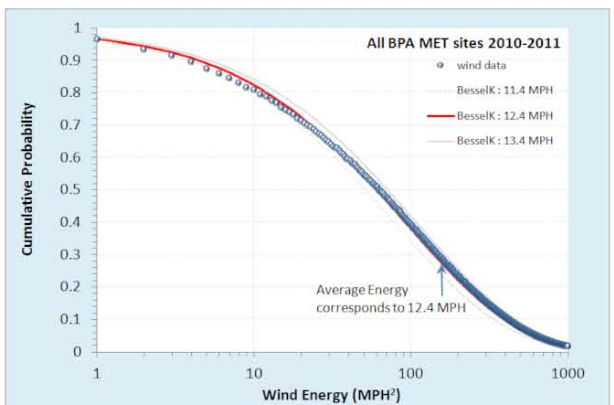


Ontario

Bonneville Power Authority in the Pacific Northwest provides sets of data from several MET stations



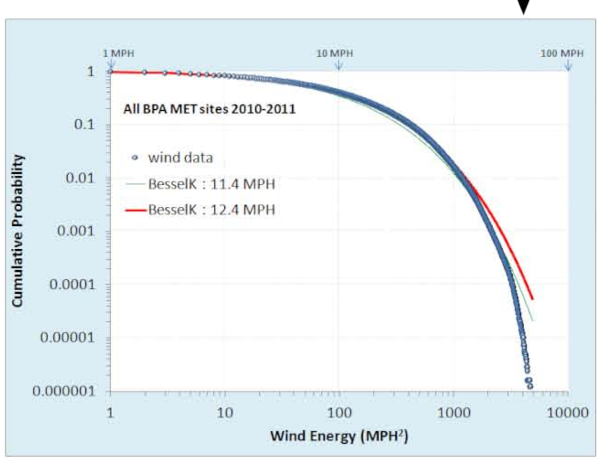
The autocrrelation function of wind speed over a period of time from a single MET station shows a fast damping and then a repeat cycle corresponding to a single day and a weaker signal over several days



An individual station shows a distribution which follows a Max Entropy Rayleigh wind speed profile (subject to a high speed governor cut-off).

Semi-log

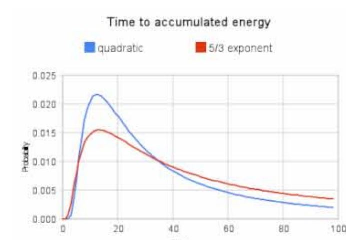
Log

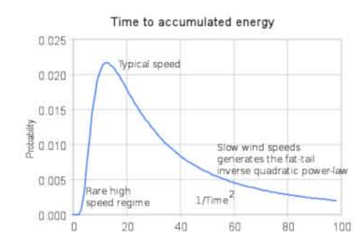


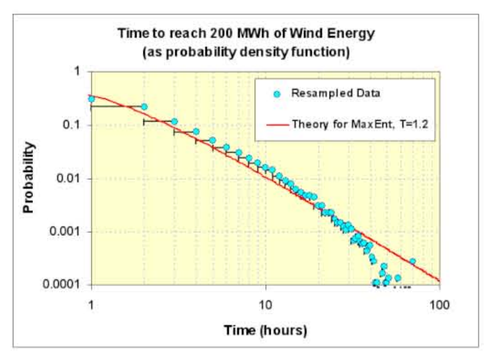
Collection of all wind speeds from the BPA sites reveals a doubly stochastic distribution.

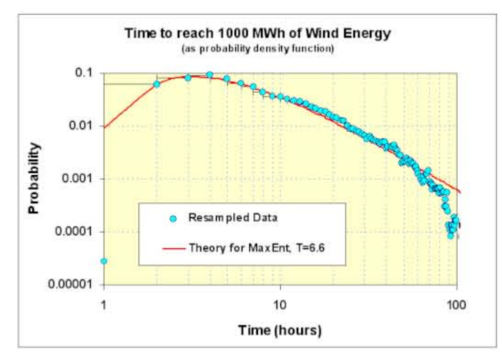
The characteristic function is a Modified Bessel.

Various tests such as may be required for convection dissipation or vehicle drag are simulated by integrating the wind speed or wind energy distributions.

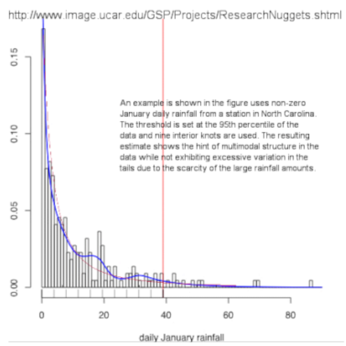




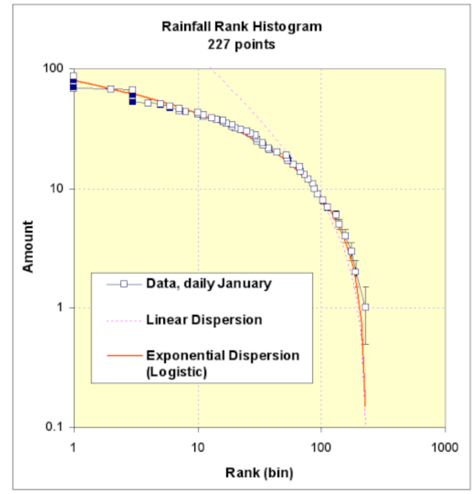




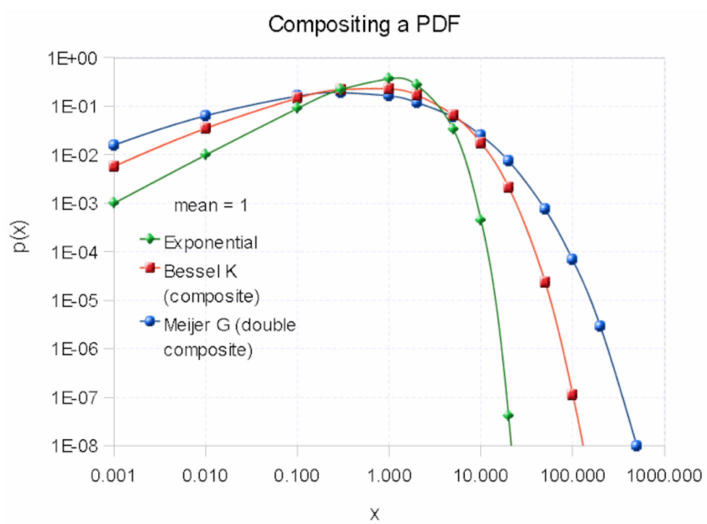
Rainfall Statistics
Key : General model for rainfall distributions using a composite process



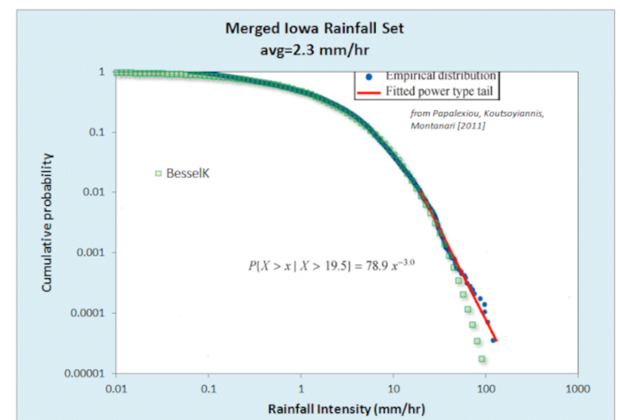
Rainfall shows a wide dynamic range and is considered a multi-scale phenomena. Heavy storms generate high amounts of rainfall within short periods.



A ranked histogram of the rainfall statistics describes the rare events. The data set to the left has a limited amount of entries while the data set below captures high resolution rainfall rates over the course of several events.

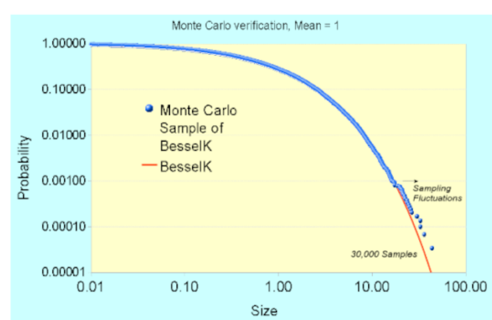


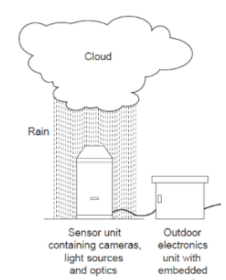
The composite process of gathering statistics from several events leads to a fattening of an originally narrow distribution. The modified Bessel K results from a two-level composite.

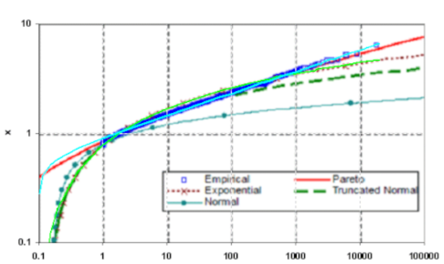


The result fitted to the high-res Iowa data shows excellent agreement

Generating simulation sampling statistic from the Bessel K requires drawing two samples from a maximum entropy exponential distribution and multiplying the results.



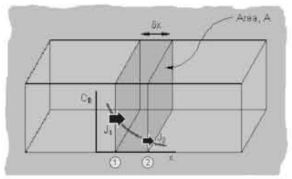




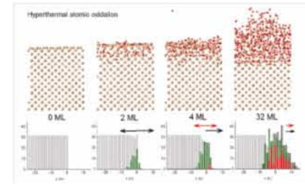
World-wide rain statistics

Corrosion and Oxidation

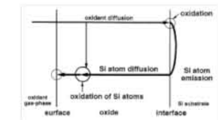
Key : Model of oxidation and corrosion growth which improves on the Deal-Growth formulation

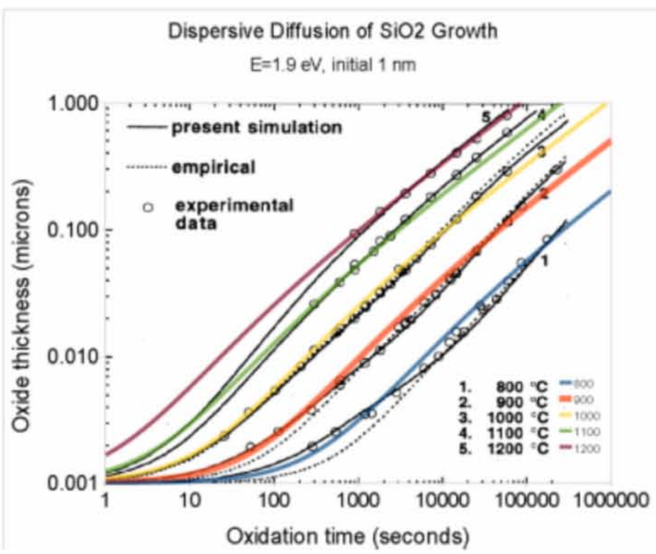


The processes of corrosion and oxidation are driven significantly by diffusional behavior. A gradient in the concentration will drive a diffusional process.

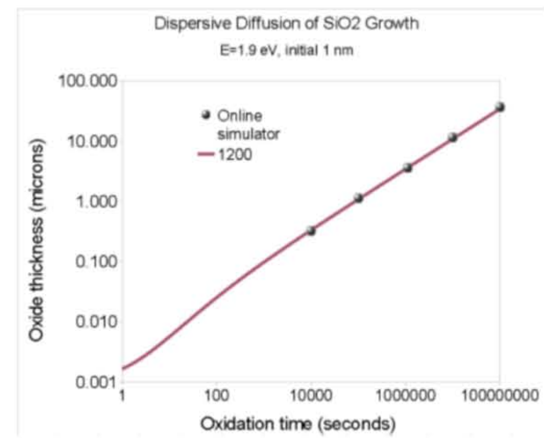


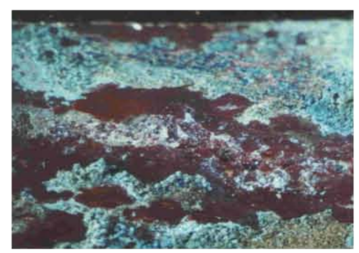
A growing oxide interface will likely show disordered diffusional rates corresponding to the various elemental species involved.

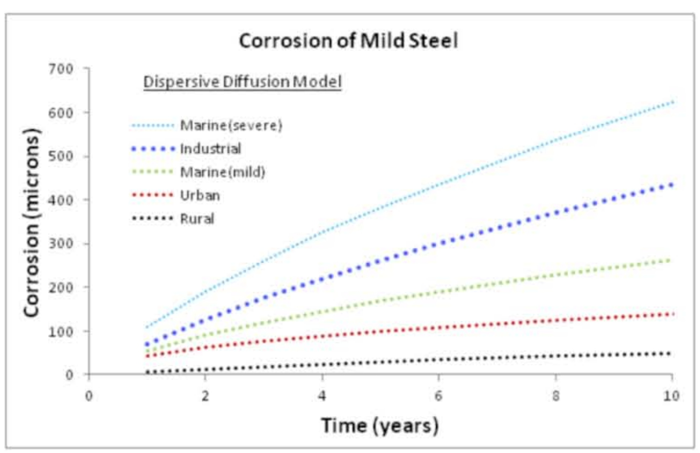




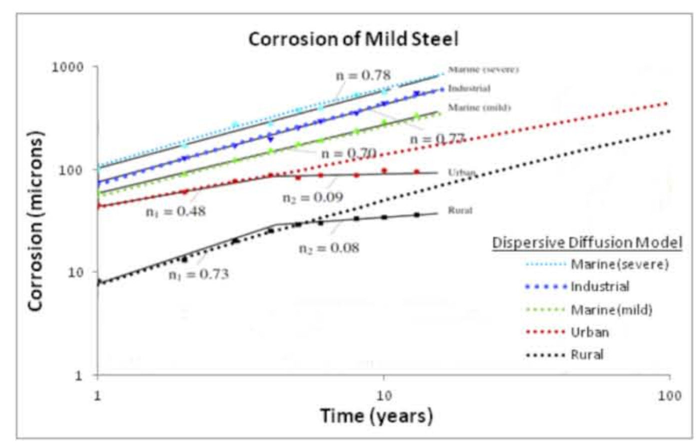
Solving the diffusional Fokker-Planck master equation while assuming a maximum amount of variance in the diffusivities gives excellent agreement with otherwise anomalously predicted growth rates at short time durations. The limit at long times agrees with Fick's law and the conventional Deal-Grove oxidation formulation.







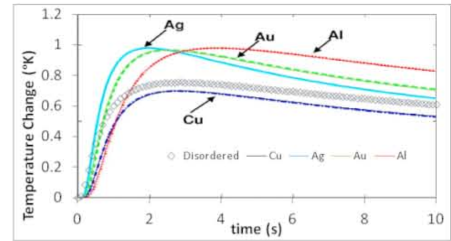
Applying this strategy to general modeling of corrosive environments shows some promising results. The power-law exponent of 0.7 indicates a transition from early linear disordered growth to the square root for long durations.



 *Thermal Dispersion*

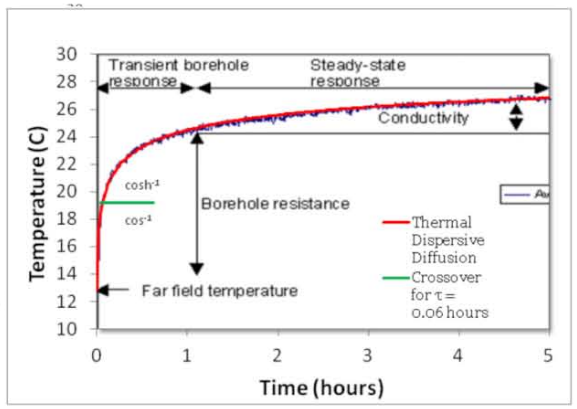
Key : Simplification of thermal diffusion model to account for disorder and variability in the media

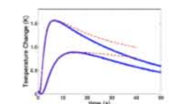
Thermal diffusion typically assumes a homogenous media, yet few environmental contexts will show absolute uniformity

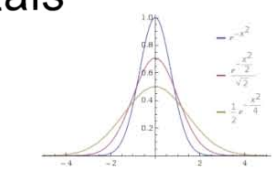


The usual diffusion formulation matches well with uniform materials such as metals

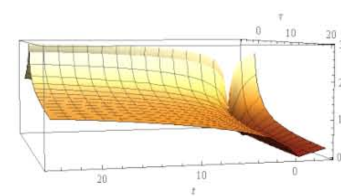
Thermal conduction into a non-uniform earthen heat sink can be modeled well with a dispersive formulation





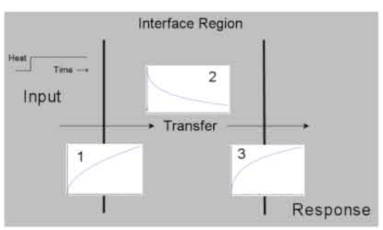


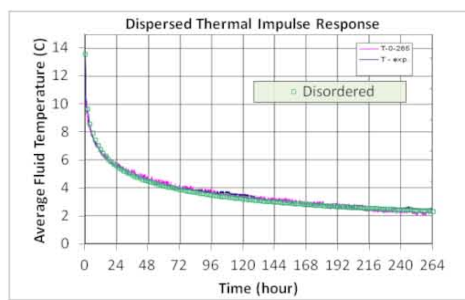
By assuming a coefficient with random variation, a more general thermal dispersion model can be formulated.



scaling surface

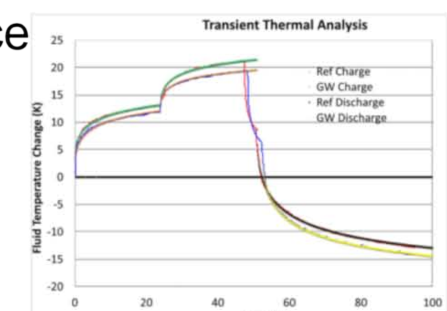
The general recipe assumes a compartment model of heat transfer.



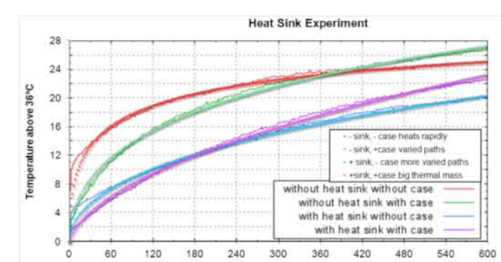


This formulation works well for heat-sinking applications whereby a source of thermal energy is dissipated by an environmental context.

A thermal impulse transfers heat energy across an interface which is partly transferred via non-uniform pathways resulting in a dispersed response.

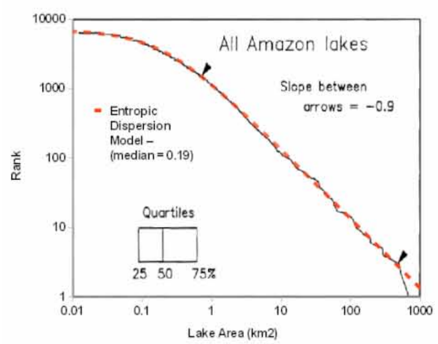


The small-scale version of this application is a CPU heat sink.



Lake Size Statistics

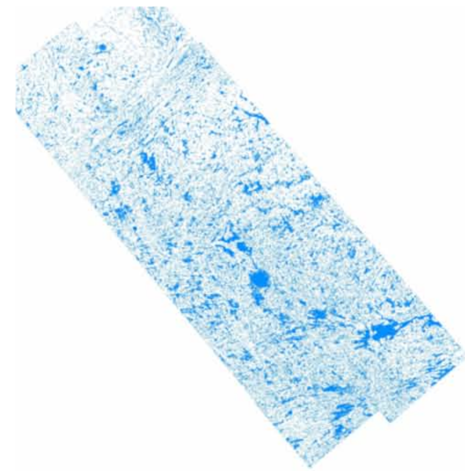
Key : Maximum entropy estimation for lake size distributions within regions

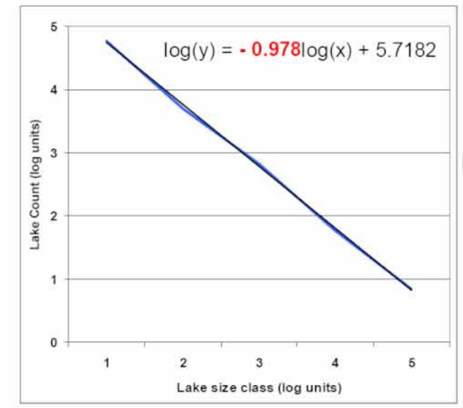


Amazon region

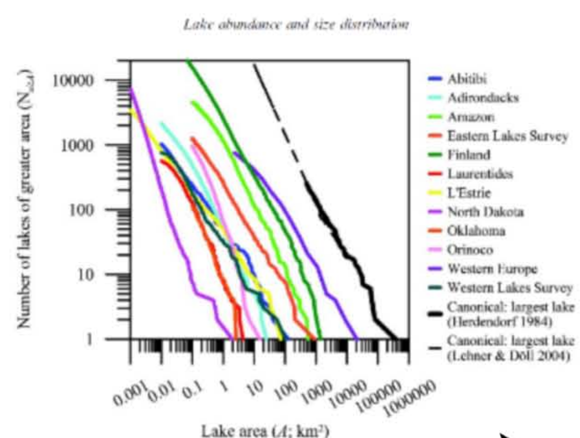
Lake size distributions follow a power-law over several orders of magnitude.

BWCA



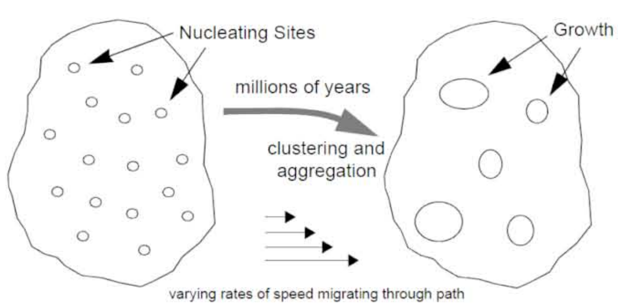


Boundary Waters between USA and Canada



World shows self-similar scaling

Statistics of large-scale enviromental obstacles such as lakes and streams are needed for mobility studies. Scaling behavors provide a concise means of modeling sampling statistics.



Process by which lake sizes aggregate follows a random growth and decline rate scenario. This is a maximum entropy process leading to the characteristic power law observed.

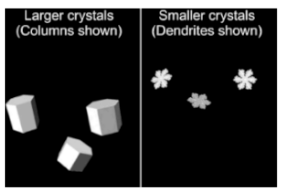
Particle Size Statistics

Key : General method for modeling size distribution of particulates such as ash and ice crystals

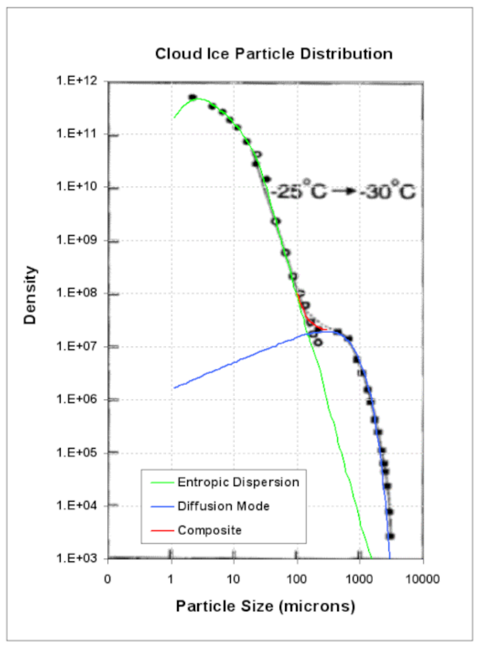
Once characterized, the density and size distribution of airborne particulates follow simple probability density functions (PDF).

Aerosols are small particles and liquid droplets suspended in air.

Small particulates outnumber larger particulates according to maximum entropy considerations

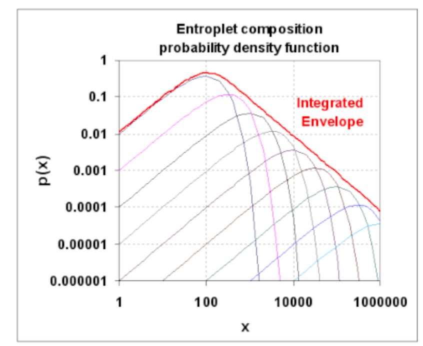


(from Centre for Atmospheric Science, U of Manchester)

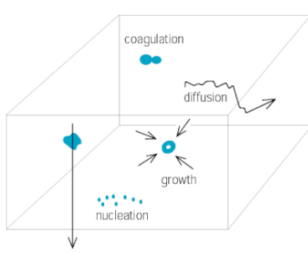


The size distribution of ice crystals can span orders of magnitude in dynamic range. Various nucleation regimes provide superstatistical structure to the empirically measured PDF curves.

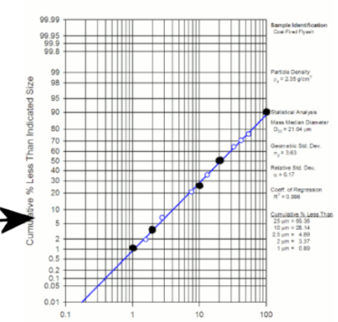
Superstatistical composition envelope



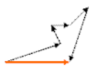
Growth, migration, and nucleate regimes



Particulates affect reliability. Particularly damaging to engines are the ash residues left behind volcanic events. Sizes plotted on a log-normal graph.

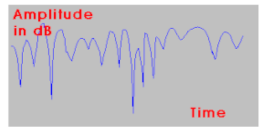


Clutter Modeling
Maximum entropy models for electromagnetic signals and noise

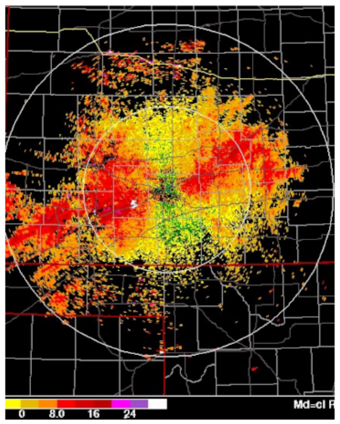


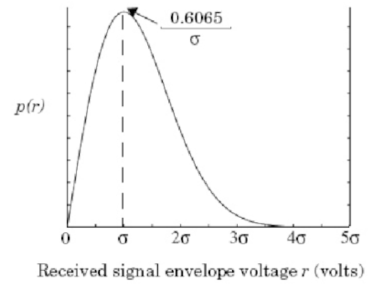
Random vector sum of electromagnetic waves generates a Rayleigh distribution in noise amplitude.

Vector sum



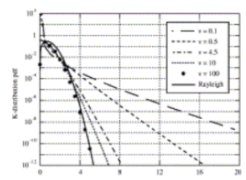
Wave amplitude



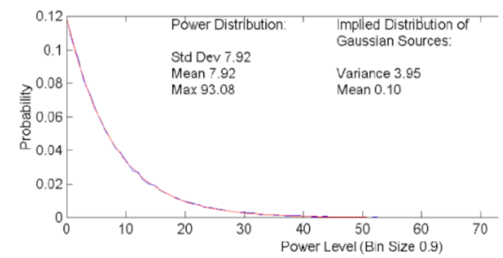


Rayleigh Distribution

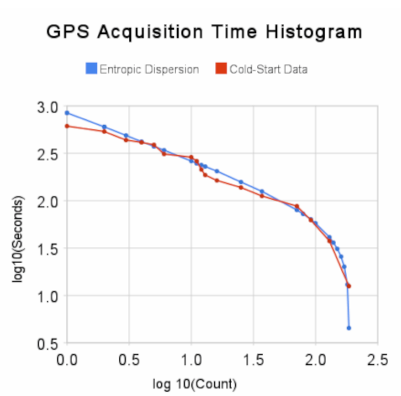
In terms of power the spectrum is a maximum entropy damped exponential. This is referred to as noise clutter.



Superposition of Rayleigh noise of different mean frequencies leads to K-Distribution clutter, which is the same distribution to that generated by wind and terrain over a large area.



Maximum Entropy Exponential



A practical and very common outcome of noise clutter pertains to "cold start" acquisition times for GPS receivers. The amount of time to lock into satellites depends on the noise level and the quadrature algorithm used to search the satellite doppler frequency spectrum.