Traps for the Unwary Subsurface Geoscientist

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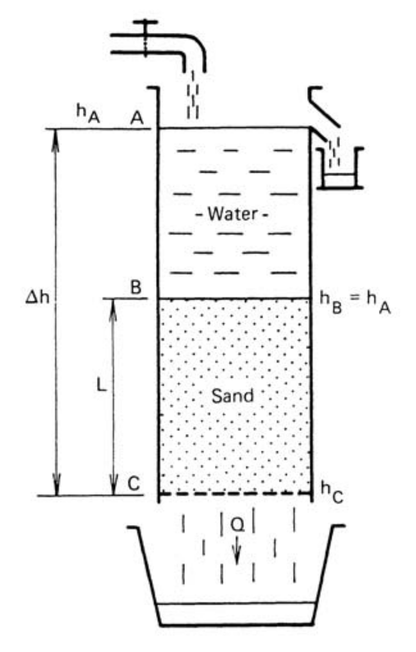
Role of the Earth Scientist

- Selection of an appropriate method to predict the unknown value of an attribute at an unmeasured location.
  - Linear regression
  - Mapping (by hand, triangulation, kriging etc)
- Geologist
  - Maps of reservoir properties
- Geophysicist
  - Maps of structure, facies architecture and attributes
- Petrophysicist
  - Predictions of hydrocarbon pore volume and permeability

1. DETERMINISTIC MAPS

3 Types of Model - Deterministic and Stochastic

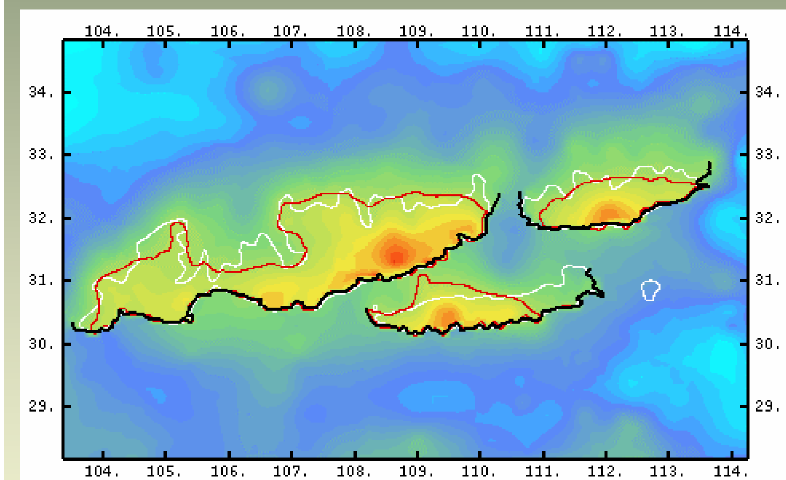
- Deterministic
  - A model from which predictions are determined directly via a functional relationship.
  - E.g. Darcy's Law, chemical reaction rate, laws of motion
- Best Estimate
  - A model which minimises the prediction error.
  - Kriging, regression models, Wyllie's Equation.
- Stochastic
  - A model which generates non-unique solutions.
  - A model which honours higher order statistics.



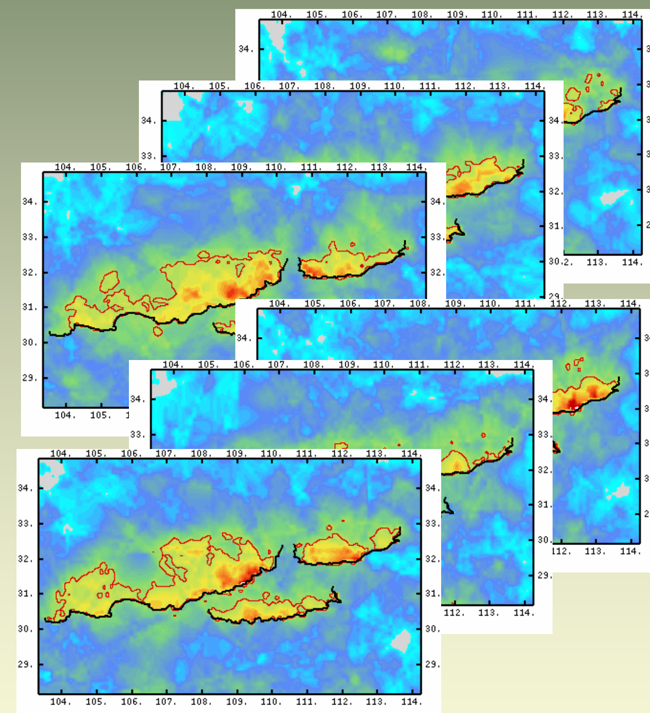
Best Estimate vs Stochastic

- These are complementary. Choice depends on the answers required
  - Best estimate for prediction/prognosis (linear problems)
  - Stochastic for volumes/connectivity/fluid flow behaviour (non-linear problems)
- The best estimate is the average of the (infinite) set of realisations.
- Different best estimate cases are NOT realisations
- In geostatistics, a spatial best estimate is called kriging - a minimum variance of error

Kriging = Mean of Realisations



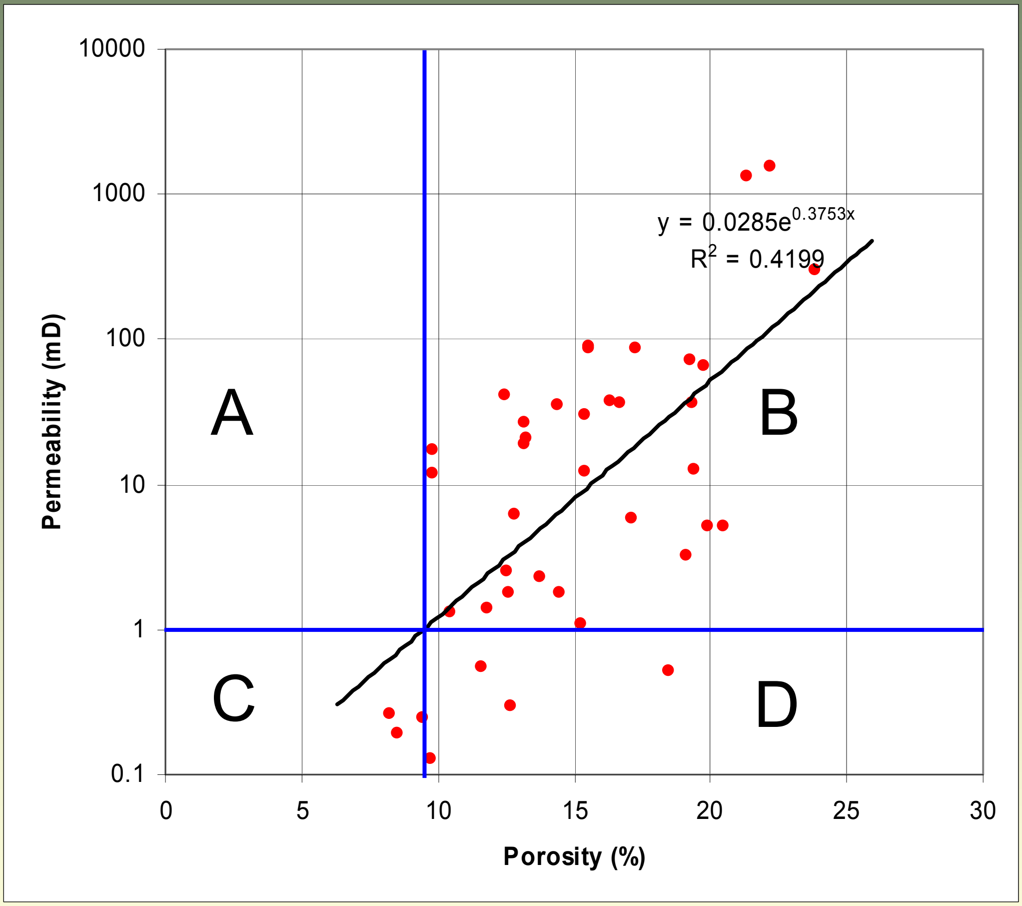
$$= \frac{1}{n} * \sum_{i=1}^{i=n}$$



2. THE DATA

Linear Regression and Cutoffs

- Equation is best predictor of permeability from porosity (under certain assumptions)
- Cutoff 1mD = 9.5% porosity
- Porosity cutoff (B+D):
  - 92.5% net
- Permeability cutoff (A+B):
  - 82.5% net
- It is only correct to do this if r ≈1!
- Cutoff calculations require higher order statistics to be honoured

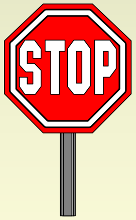


No cutoffs!

- Cutoffs are wrongly used for estimating
  - Porosity
  - Net:Gross
  - Net pay
  - Saturations
  - Permeability
  - Gross rock volume
- Cutoffs on best estimates = BIASED ESTIMATES
- Cutoff calculations should only be applied to realisations
  - Simulated using geostatistics
  - Actual exhaustive subsurface measurements

Is it valid to map…?

- Depth………………………….. ✓
- Time…………………………. ✓
- Velocity…………………….. ✓
- Thickness………………….. ✓
- Permeability……………….. ✓ (If log transformed)
- Porosity…………………….. ✗
- Net:Gross………………….. ✗
- Saturation………………….. ✗



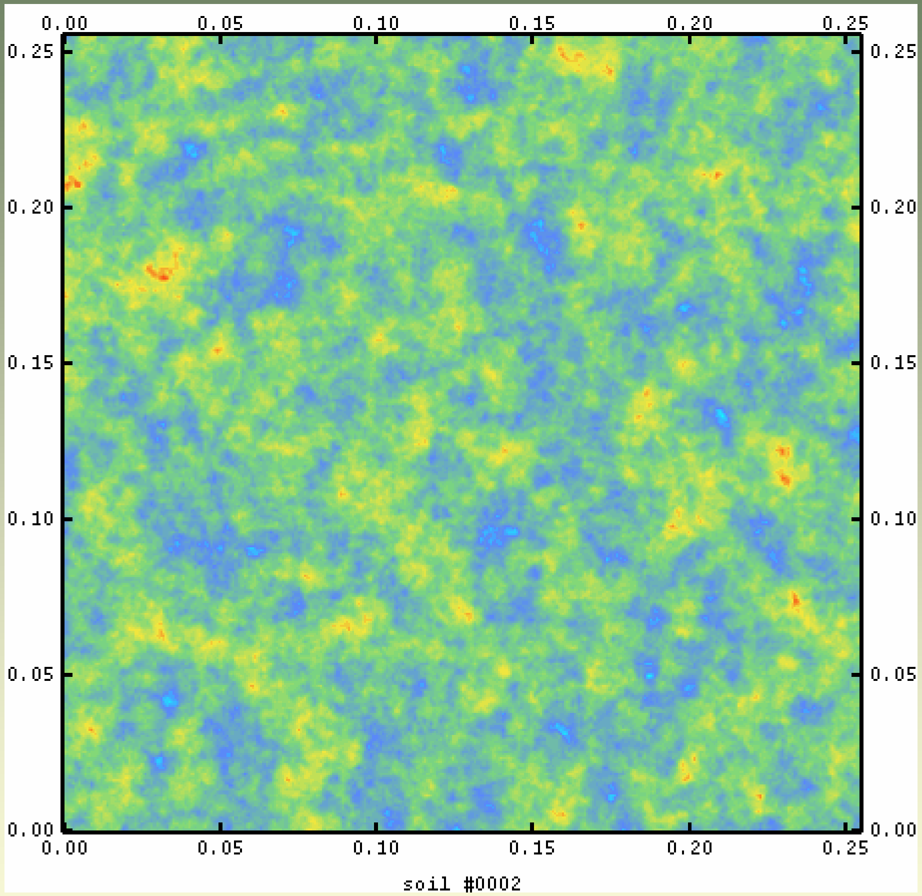
Average Net:Gross

- Well #1
  - N:G = 20%
- Well #2
  - N:G = 50%
- Therefore average N:G
  - = (50 + 20)/2
  - = 35% ✗
- THIS IS WRONG!

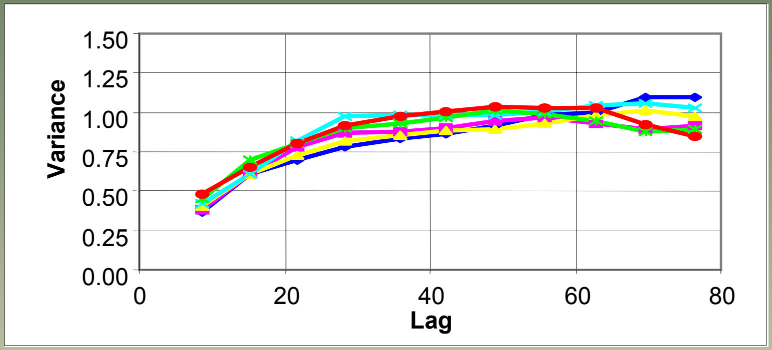
- Well #1
  - Gross thickness = 10 m
  - Net thickness = 2 m
- Well #2
  - Gross thickness = 40 m
  - Net thickness = 20 m
- Therefore:
  - Total net thickness = 22 m
  - Total gross thickness = 50 m
- Average N:G = 44% ✓

3. THE EXPERIMENTAL VARIOGRAM

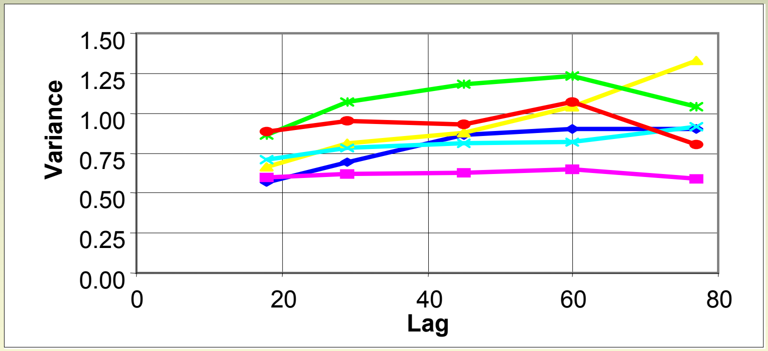
A “Good” Variogram



Webster and Oliver (1992)

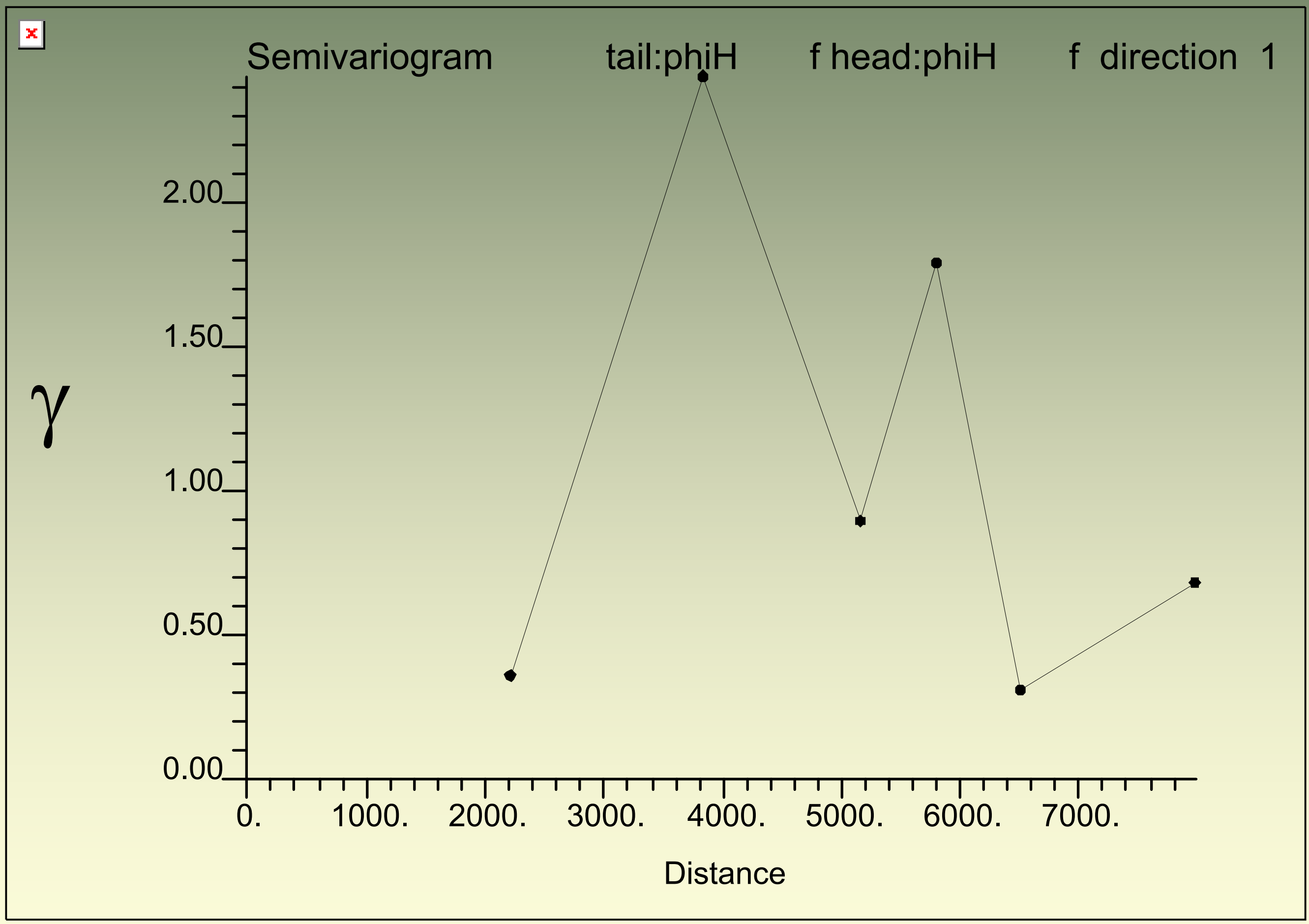


Variograms from 225 points on a 15 x 15 grid at 7 unit intervals



Variograms from 49 points on a 7 x 7 grid at 15 unit intervals

Variogram of 7 wells

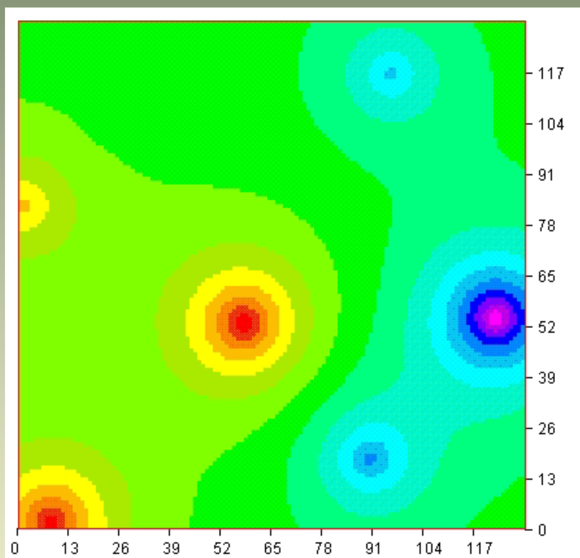


4. THE VARIOGRAM MODEL

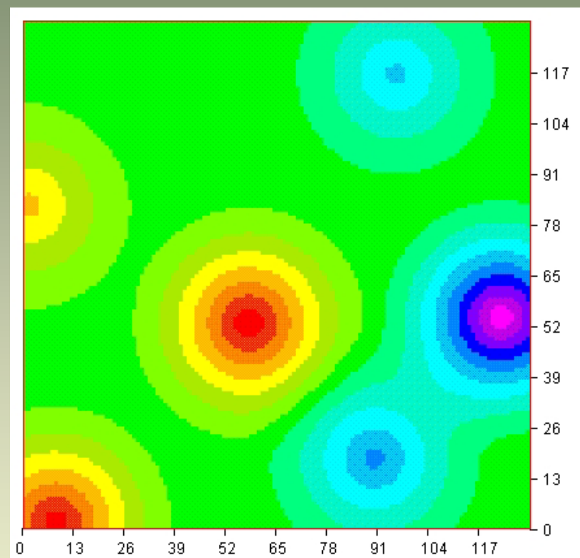
Key Components of Variogram Model

- Slope at the origin (model type)
- Nugget effect
- Range
- Sill
- Anisotropies

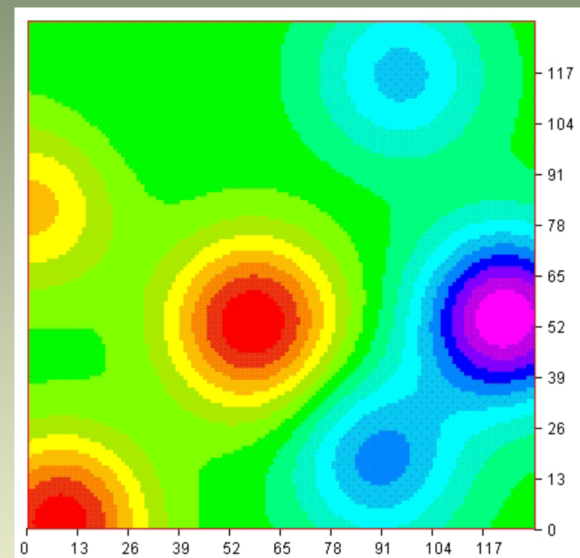
Comparison of Kriging Different Variogram Model Types



Exponential



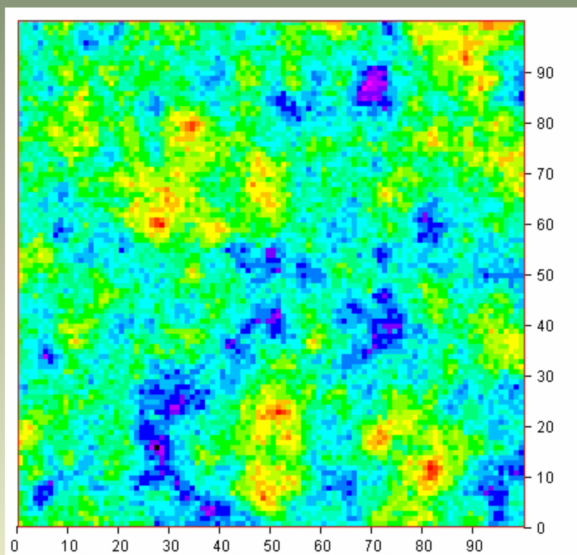
Spherical



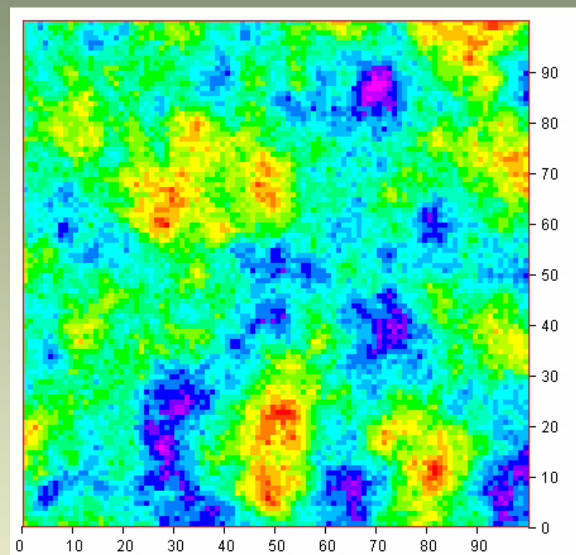
Gaussian

(Range = 38 nodes)

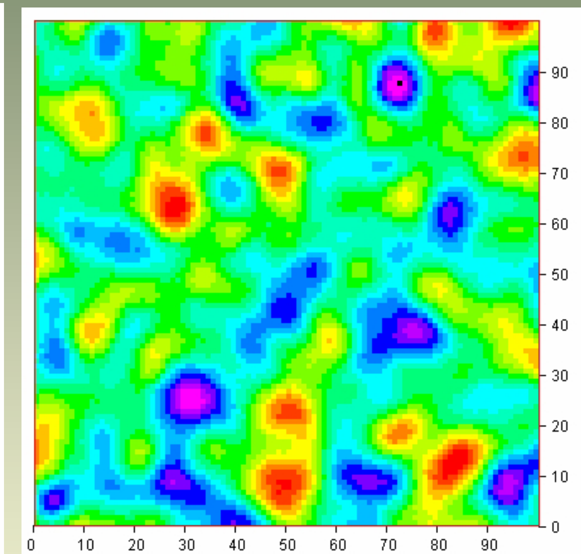
Comparison of Realisations Different Variogram Model Types



Exponential



Spherical



Gaussian

(Range = 38 nodes)

5. THE FASHIONABLE OBJECT

Reservoir Models Today

- Too big, too complex, too ambitious
  - Build simple, generic models
  - Sector models
  - Focus on flow units, not facies
- Finished Late, never updated, too few realisations
- Objects only, SIS only, TG only: algorithm fixation
  - Consider relevance of different methods to model the problem at hand
  - SIS and TG are the “geostatisticians choice”
  - Objects are the “geologists choice”
  - Parameterising objects is difficult from well data

Facies Models

- Indicator/Truncated Gaussian (Pixel) methods
  - Spatial model honoured independently for each facies ✓
  - Sound theory of spatial correlation ✓
  - Any facies organisation ✓
  - Do not look very “AAPG Bulletin” ✘
  - Entropy too high? ✘
- Object Models
  - Weak spatial theory. ✘
  - Trivial best estimate equivalent is average (stationary) N:G ✘
  - Parameters estimated from analogues/surmise ✘
  - Entropy ok ✓

Object Model Parameters

Body Type	Low sinuosity Channel	
Shape	Half-cylinder	
Thickness	Triangular	2 – 4 – 10 m
Width	Expression	Thickness * 25
Orientation	Triangular	10 – 50 – 90
Amplitude	Expression	Width
Wavelength	Triangular	1000 – 3000 - 5000
Stop Criterion	Volume	26 %
Branch Points	Uniform	10 – 20/1000
Branch Location	Uniform	0 - default

Reservoir Model Weaknesses

- All effort is focussed on lithofacies
- Porosity is often kriged
- Coupling of porosity and permeability fields ignored
- Outcrop analogues are a poor substitute for multipoint statistics.
  - All projects use the same channel width/thickness references
  - Not enough outcrop exposure/study
  - Well statistics are *censured*
- More use of shallow, high resolution 3D seismic

6. BEYOND THE VARIOGRAM

Entropy

- Entropy H(X) is a statistic that quantifies the intrinsic variability of some variable X and can be computed from the pdf p(X):

$$H(X) = -\sum_i p(x_i)\log[p(x_i)]$$

- Consider a categorical value X = {shale,sand}
  - If P(X) = {0.5,0.5} then H = 0.693
  - If P(X) = {0.9,0.1} then H = 0.325
- If entropy is reduced, then there is now less disorder, less uncertainty and therefore more predictability

  - Mukerji *et al* (2001)

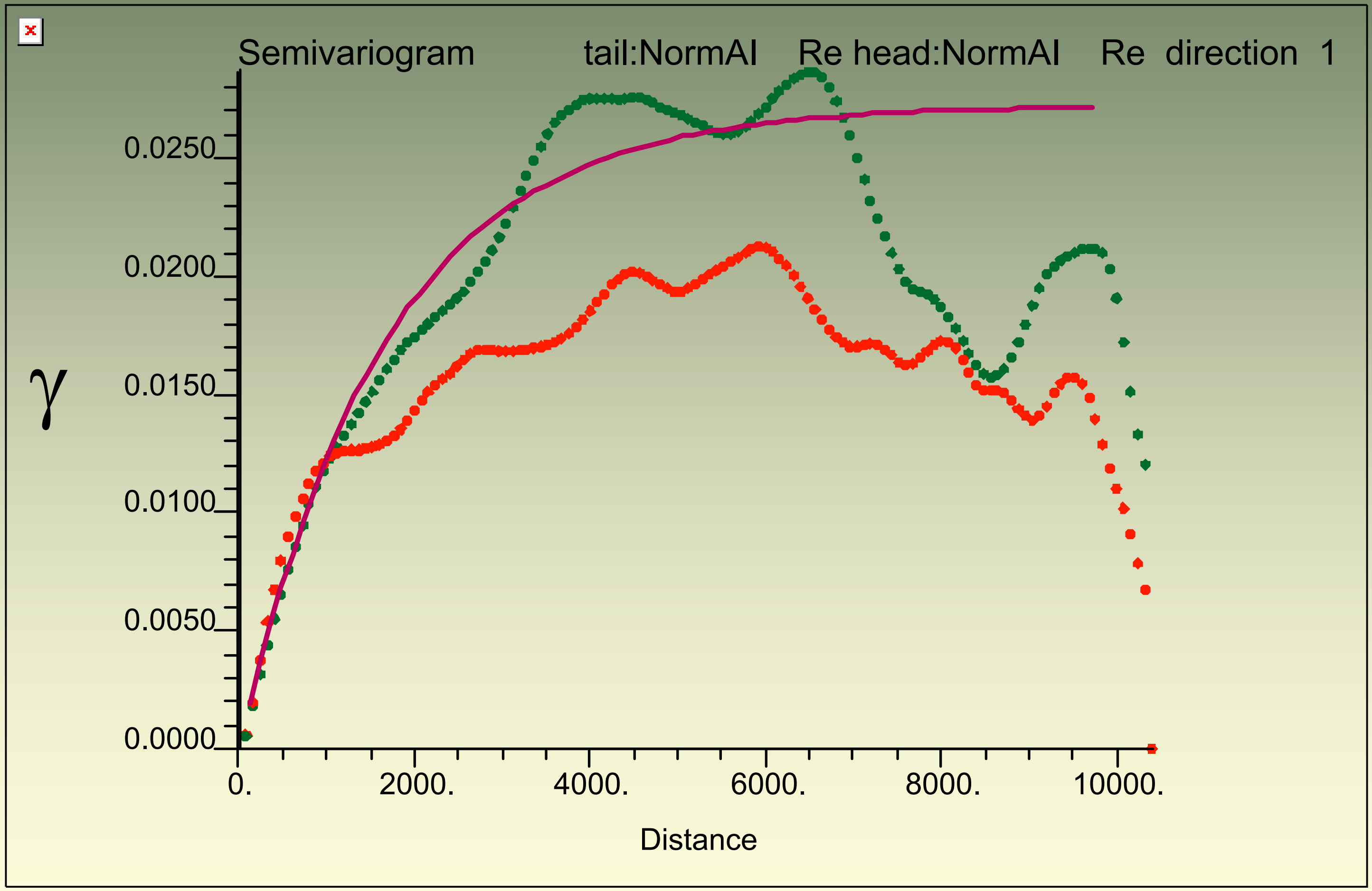
Entropy

- Consider a univariate variable X = {-2, -1, 0, 1, 2}
- If P1(X) = {0.03, 0.44, 0.06, 0.44, 0.03}
  - Variance = 1.12
  - Entropy = 1.10
- If P2(X) = {0.09, 0.20, 0.42, 0.20, 0.09}
  - Variance = 1.12
  - Entropy = 1.44
- Variance is a measure of deviation from central tendency and is not always sensitive to uncertainty. P1 and P2 have the same variance but P2 has larger entropy and is therefore more uncertain
  - after Mukerji *et al* (2001)

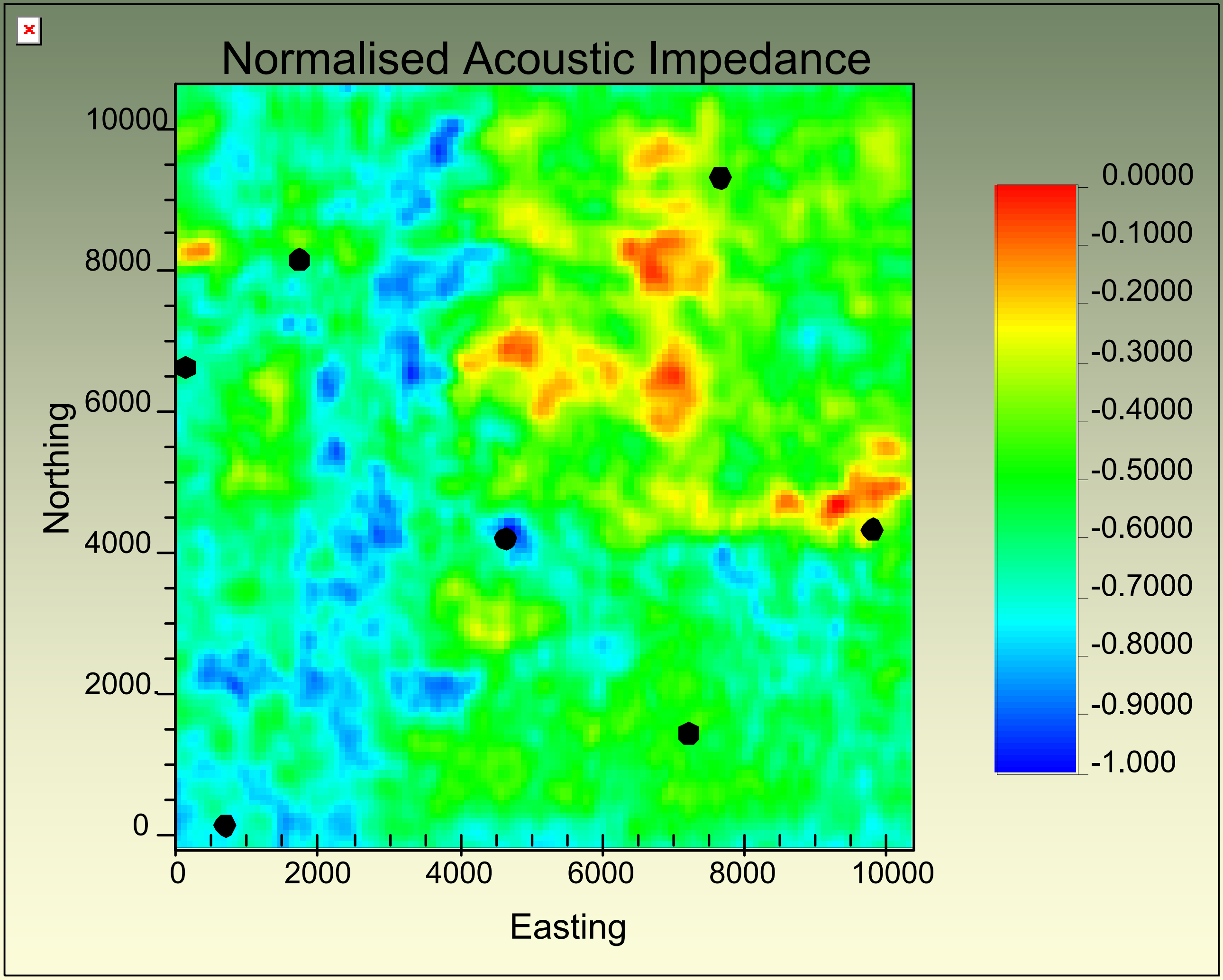
7. THE TREND

(Getting the Drift)

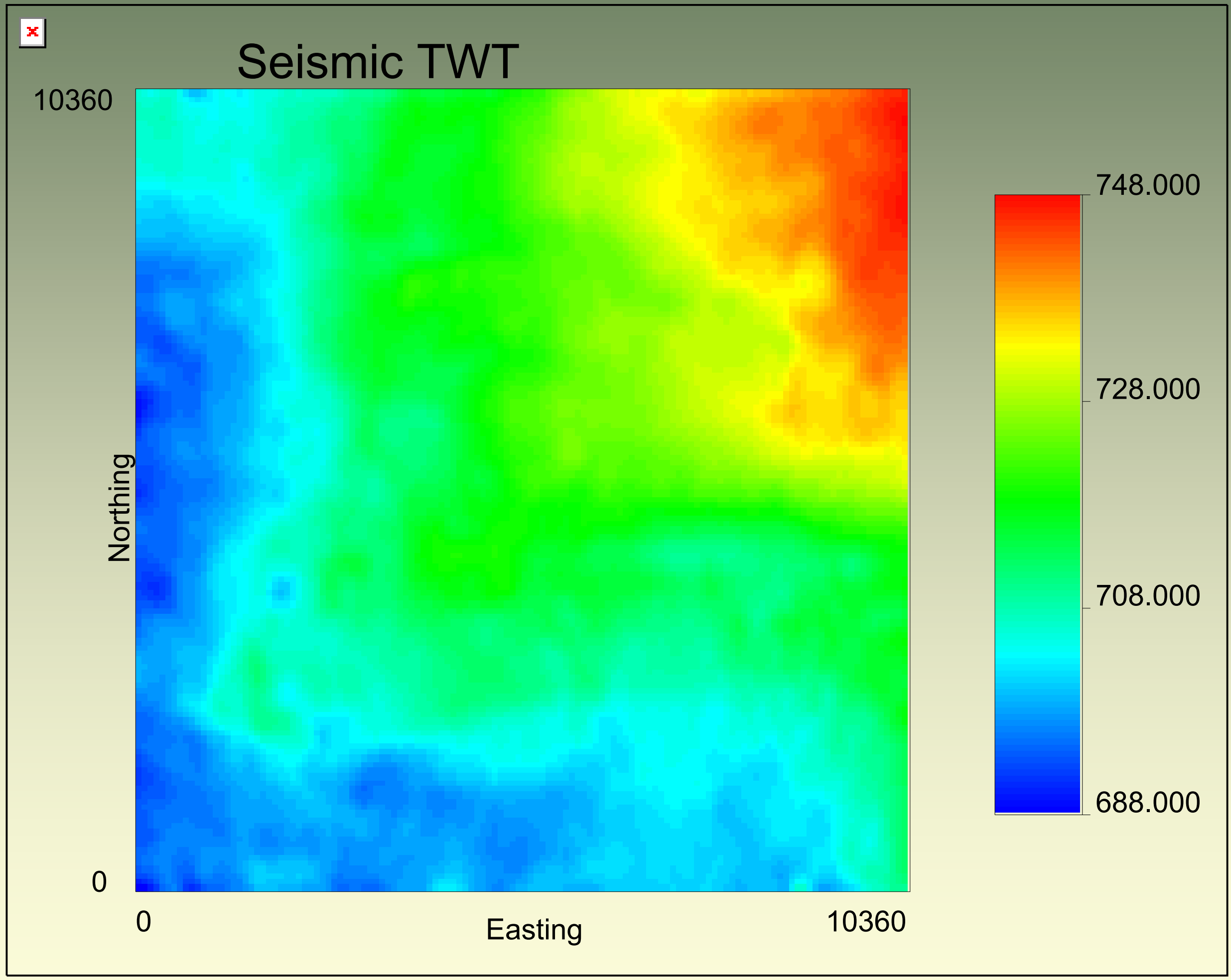
Variography
Normalised Acoustic Impedance



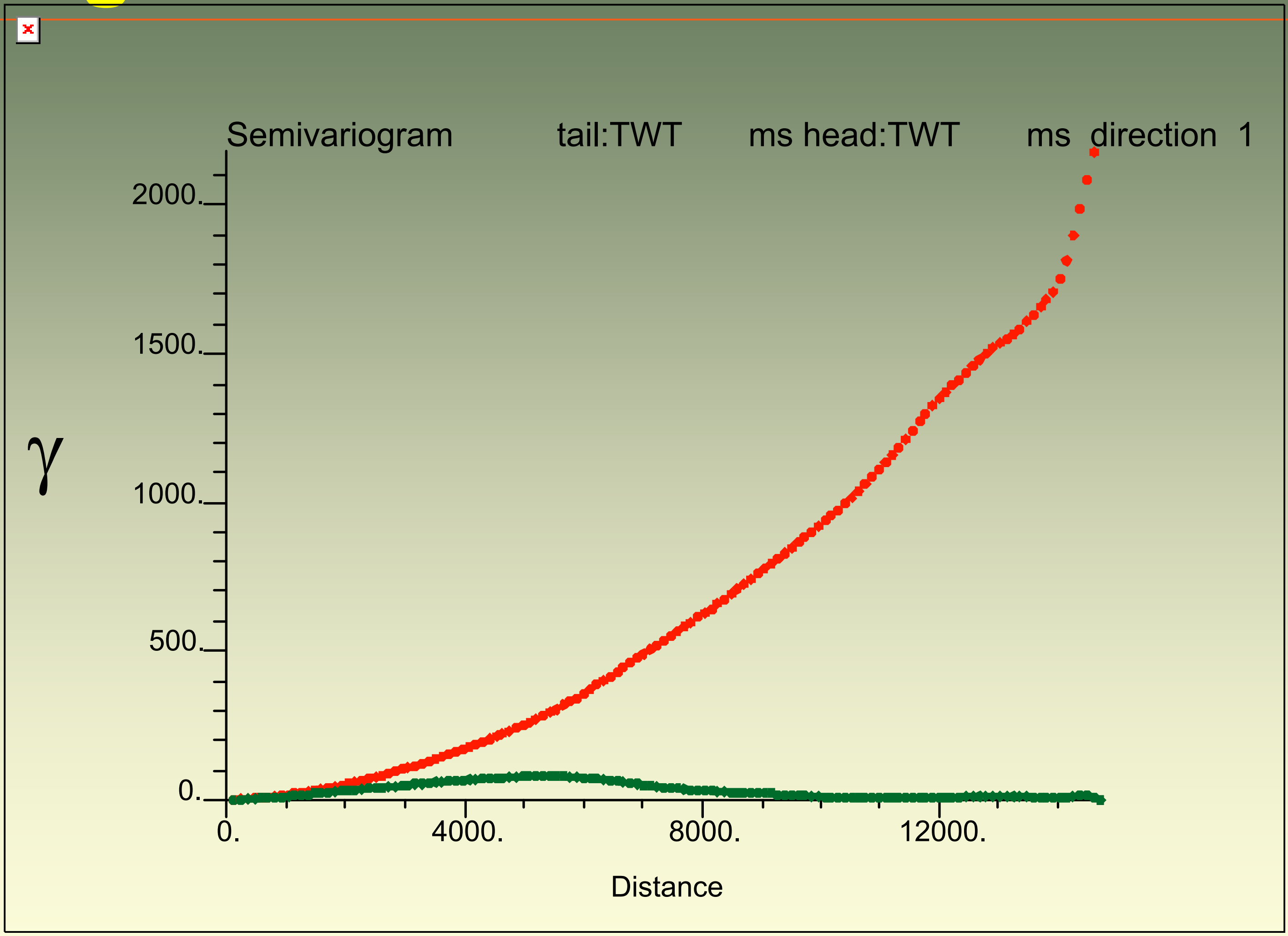
Petroleum Case Study
07 Wells



Variogram with Trend



Variogram with Trend



Explanation of Stationarity

Stationary Stochastic Process

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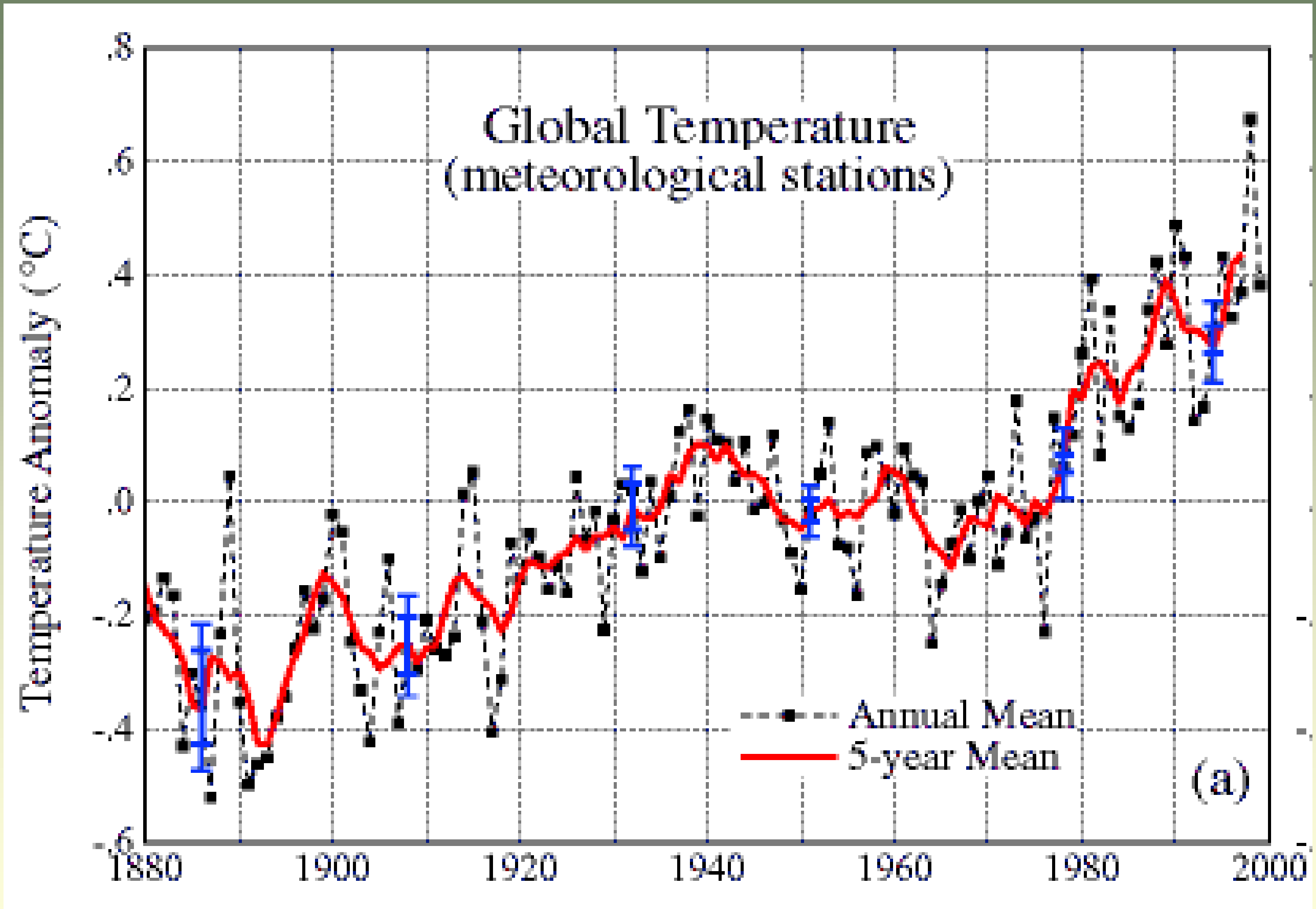
Data (Realisation)

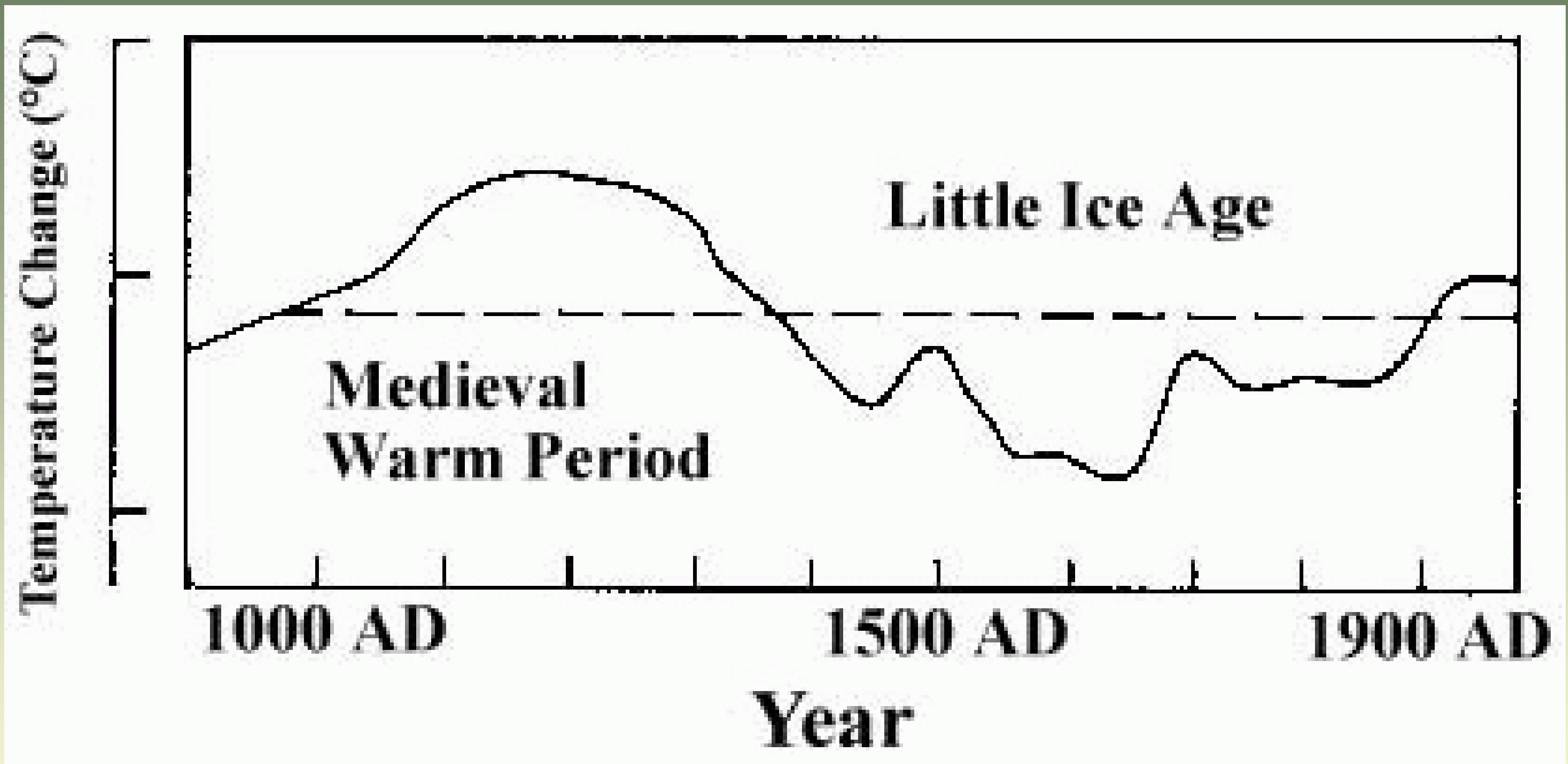
6.43	9.07	7.83	0.74	8.95	9.24	6.64	9.04	2.96	3.63
7.88	9.12	9.61	4.11	3.58	6.54	1.78	1.17	8.61	6.37
8.58	3.31	1.04	2.61	8.01	7.71	0.58	6.23	9.18	1.22
6.52	0.56	3.73	2.86	4.52	9.61	9.04	9.42	1.86	1.25
1.37	3.23	6.68	5.16	5.49	4.49	7.42	5.49	5.51	6.73
0.16	4.51	5.89	8.44	6.35	1.13	4.33	5.89	8.94	1.48
8.80	1.91	2.71	2.50	2.21	7.41	7.36	0.23	1.69	3.04
9.64	2.19	5.92	2.06	1.71	5.84	1.83	2.79	5.52	7.86
4.08	5.84	3.50	4.81	0.78	1.52	2.46	4.07	8.71	7.54
9.64	6.07	2.56	9.76	2.53	3.95	2.74	2.03	6.24	3.68

- Stationarity is a property of the *model* not of the data
- Stationarity is a *decision*

Trend or Stationary Time Series?

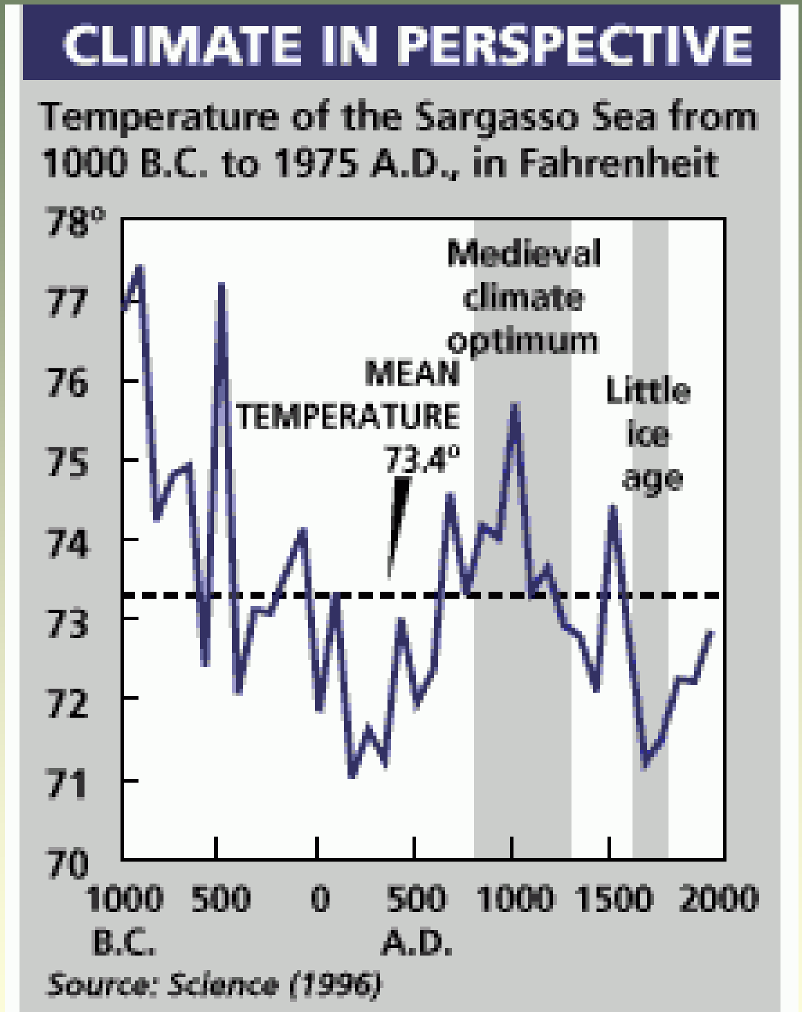


1000 year climate



- From the Intergovernmental Panel on Climate Change report 1995 (which stated there is “a discernible human influence on global climate”)

3000 year climate



- **From Keigwin L.D., "The Little Ice Age and Medieval Warm Period in the Sargasso Sea", Science, v.274 pp.1504-1508, 1996**

8. WORST CRIMES

(Some conclusions)

Worst Crimes

- Confusing maps with reality
  - Subsurface maps are representing the local expectation, they are a mathematical construct
  - Cartographers represent on a sheet of paper *that which they already know*
  - Geologists, geophysicists and petrophysicists *make predictions of attributes at unmeasured locations*
- Cutoff calculations should not be applied to estimates, ONLY to realisations
- There is no “Quantification of Uncertainty”!
- We can explore uncertainty with geostatistics.

Unknown uncertainty

- Unknown unknowns
- "How can we know that which we do not know?"
- "And having discovered something new, how can we be sure that that is what we did not know?"
  - Socrates

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EARTH WORKS

ENVIRONMENT & RESOURCES