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A Cumulant-Based Approach to Understanding Magnetospheric Dynamics and Predicting Geomagnetic Indices

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Improving Neural Networks

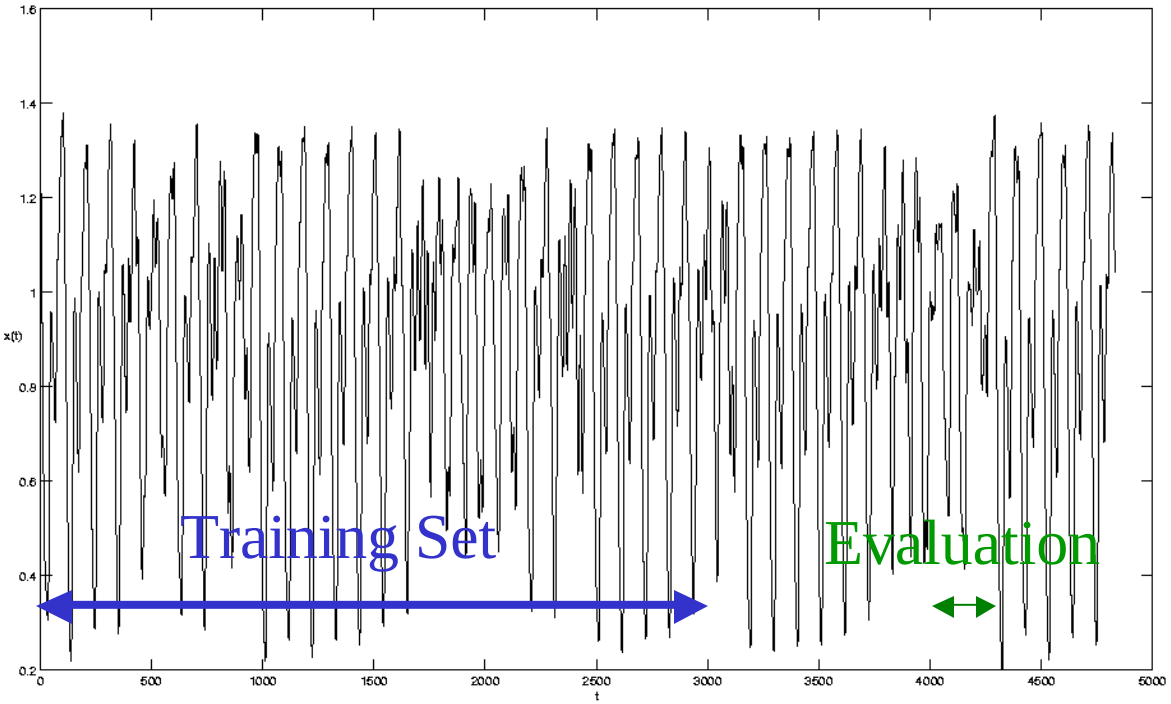
- Cumulant-based significance can be used to identify noisy data
- Noisy data can be removed from the training set
- Example: Mackey-Glass equation that describes white blood cell production exhibits chaotic dynamics

Example: Mackey Glass Model

$$\frac{dx}{dt} = \frac{ax(t-\tau)}{1+x^c(t-\tau)} - bx(t)$$

$a = 0.2$, $b = 0.2$,
$c = 10$, $\tau = 30$

x(t)



t

Neural Network Predictor

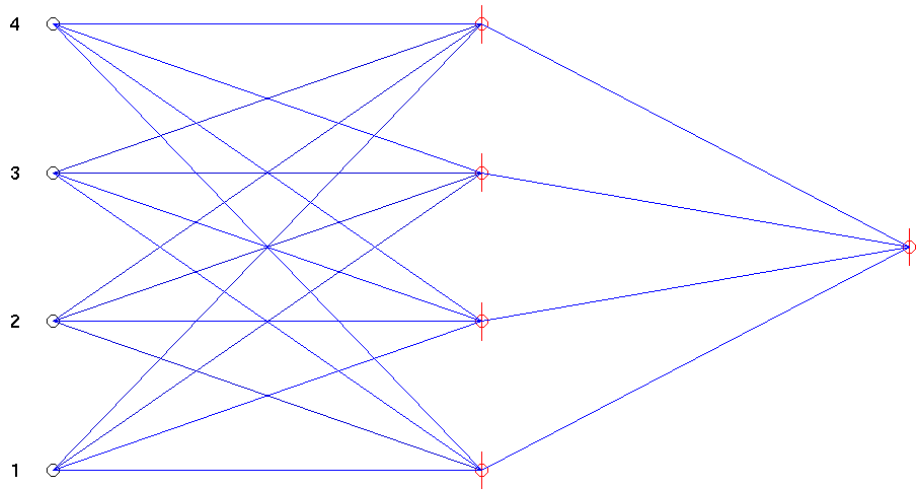
Input | Hidden Layer | Output

x(t-3Δ)

x(t-2Δ)

x(t-Δ)

x(t)

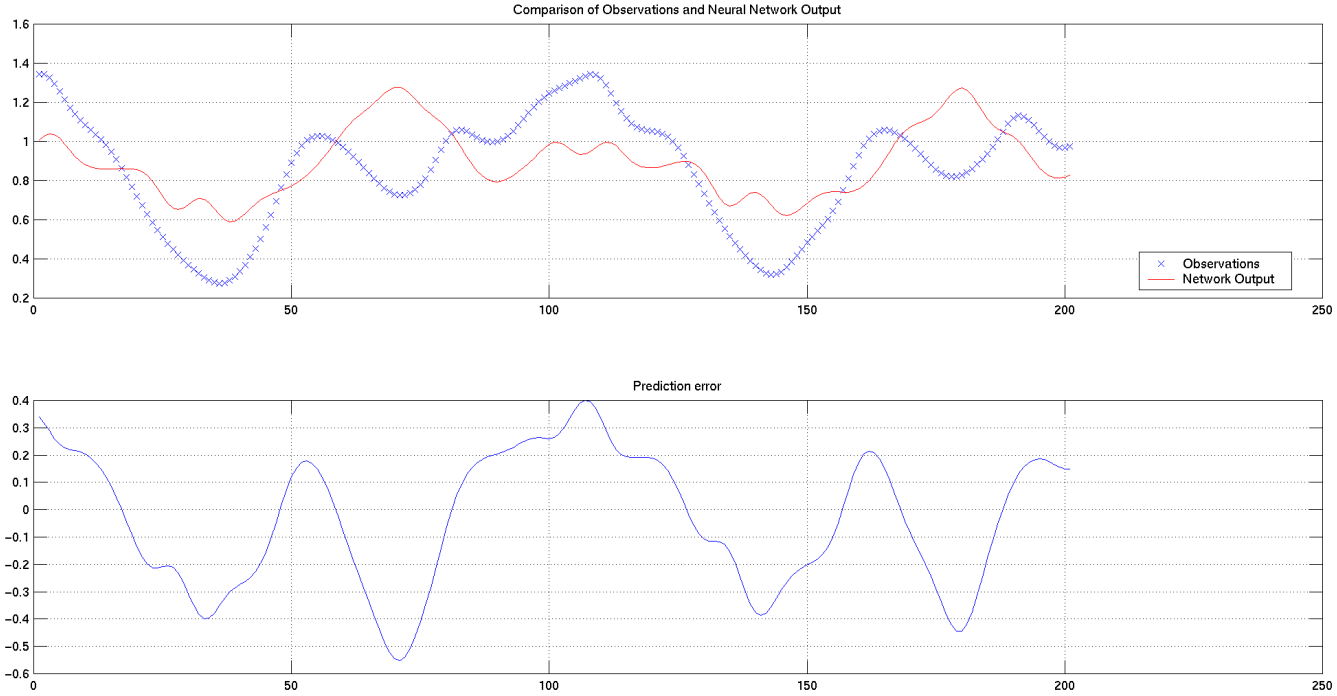


x(t+p)

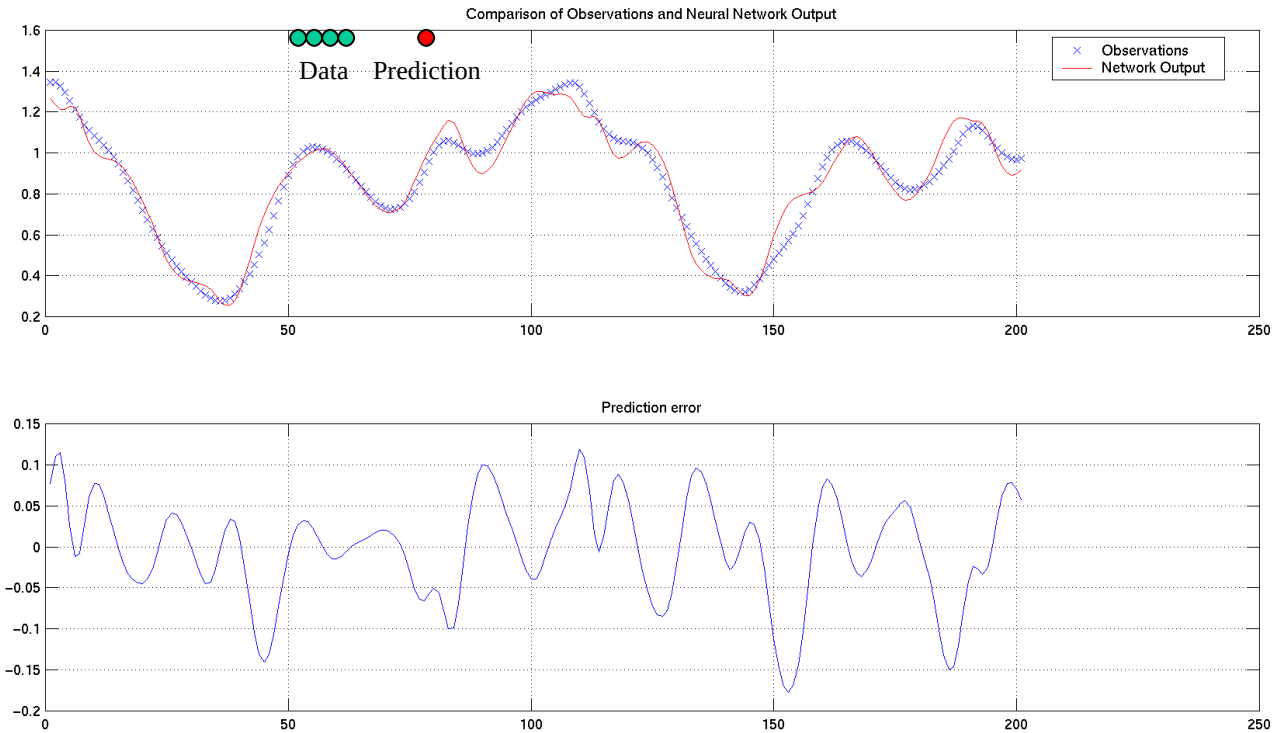
$$X_j = g(\sum_k w_{jk} x_k)$$

where $g(h) = \tanh(\beta h)$ is the transfer function for a nonlinear model and $g(h) = h$ for a linear model where w_{jk} and β_j are to be trained.

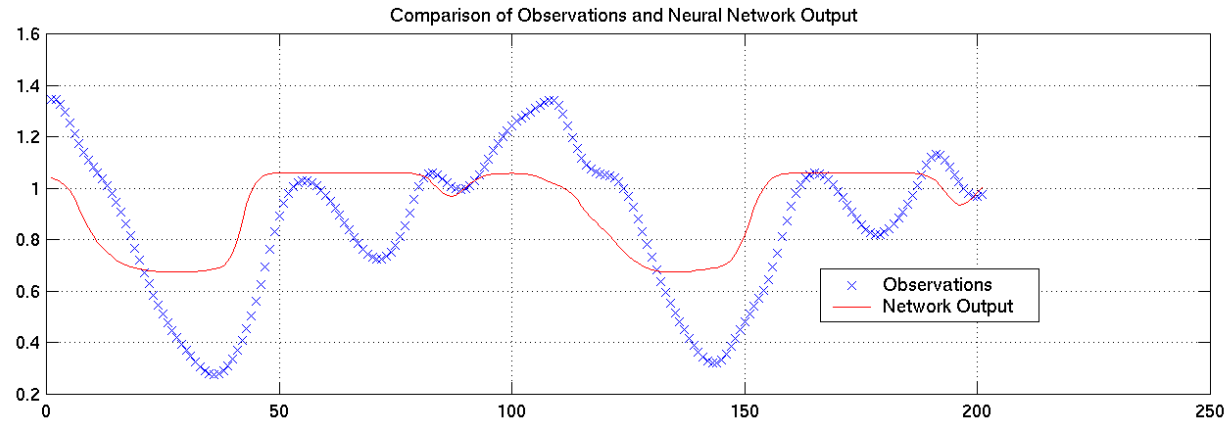
Linear Model (Quite Bad)

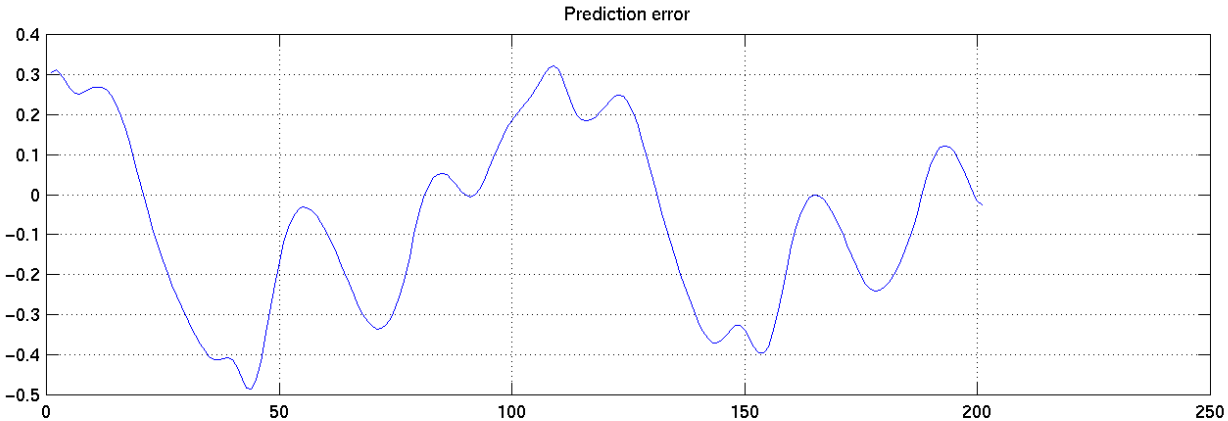


Nonlinear Model



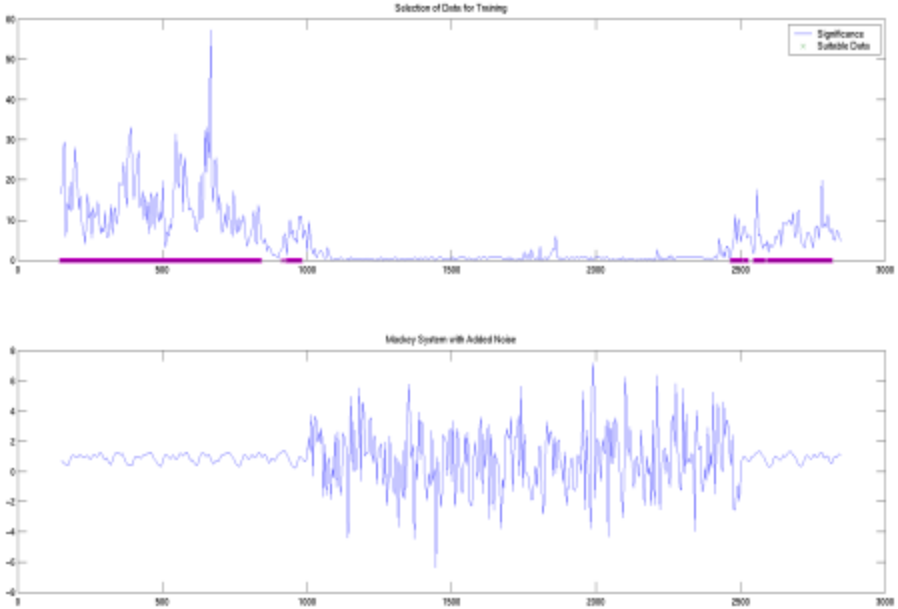
Noise Spoils the Network



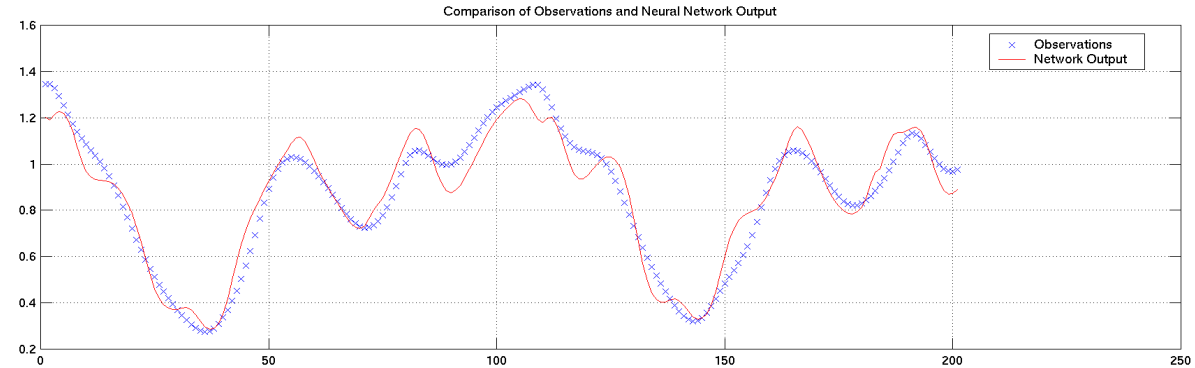


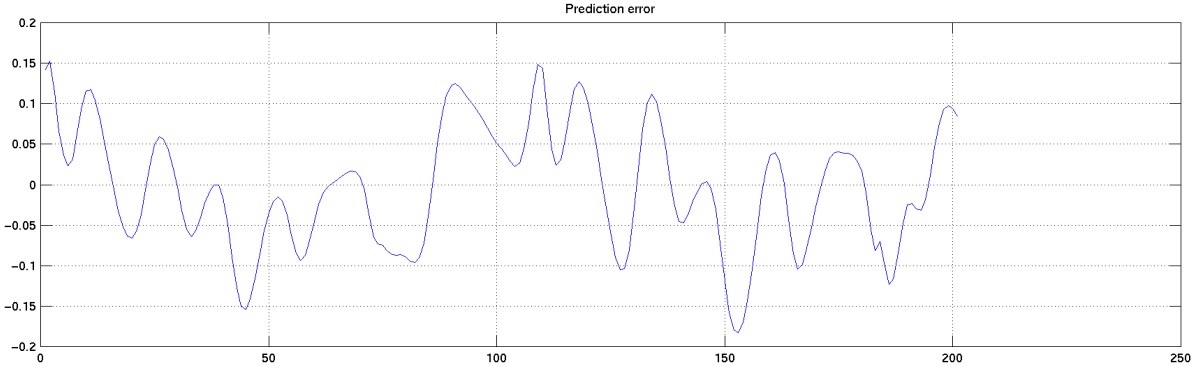
Data Selection Using Windowed Significance

- Compute windowed significance
- Set criterion for elimination of data (S < 5)
- Check to make sure all data (x_{t+p}, x_t, $x_{t-\Delta}$, $x_{t-2\Delta}$, $x_{t-3\Delta}$) is available



Network Trained on Limited Data





Points About Noise and Network

- Nonlinear Dynamics are well approximated by the neural model because of low dimensionality
- Requires nonlinear model
- Noise spoils the network
- Significance may be used to eliminate noise systematically
- Output describes system dynamics nearly as well as the clean system

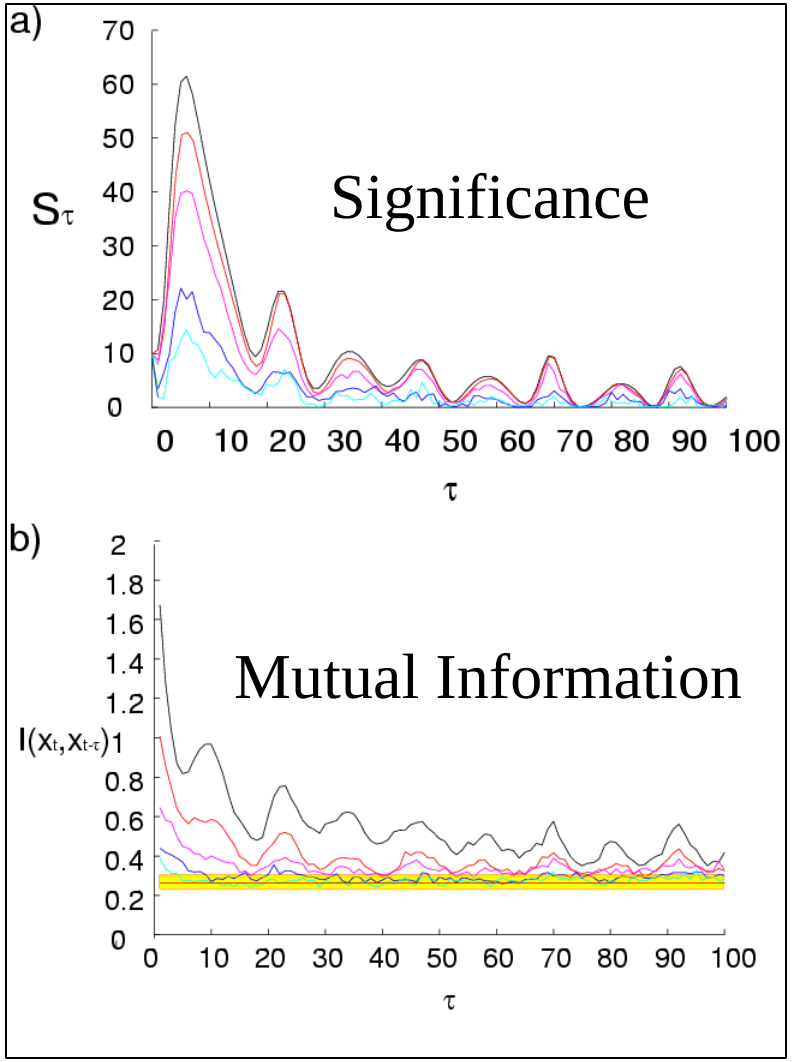
Significance vs Mutual Information

- Cumulant-based signifincance does better with limited datasets
- Cumulant-based significance detects underlying dynamics better in a noisy system
- Example: Lorenz system + additive noise

  $x_j = x_{j,\mathrm{Lorenz}} + \alpha\, \nu_j$

  where ν is a random Gaussian variable

Significance vs MI



- Lorenz System
- Significance > 1.6 detects deviation from surrogate noise
- MI computed from surrogate noise lies in yellow bar
- α = 0,0.25, 0.5,0.75,1
- C-B significance still works well for α = 1
- MI fails beyond α = 0.75