On the Statistical Significance of Climate Trends

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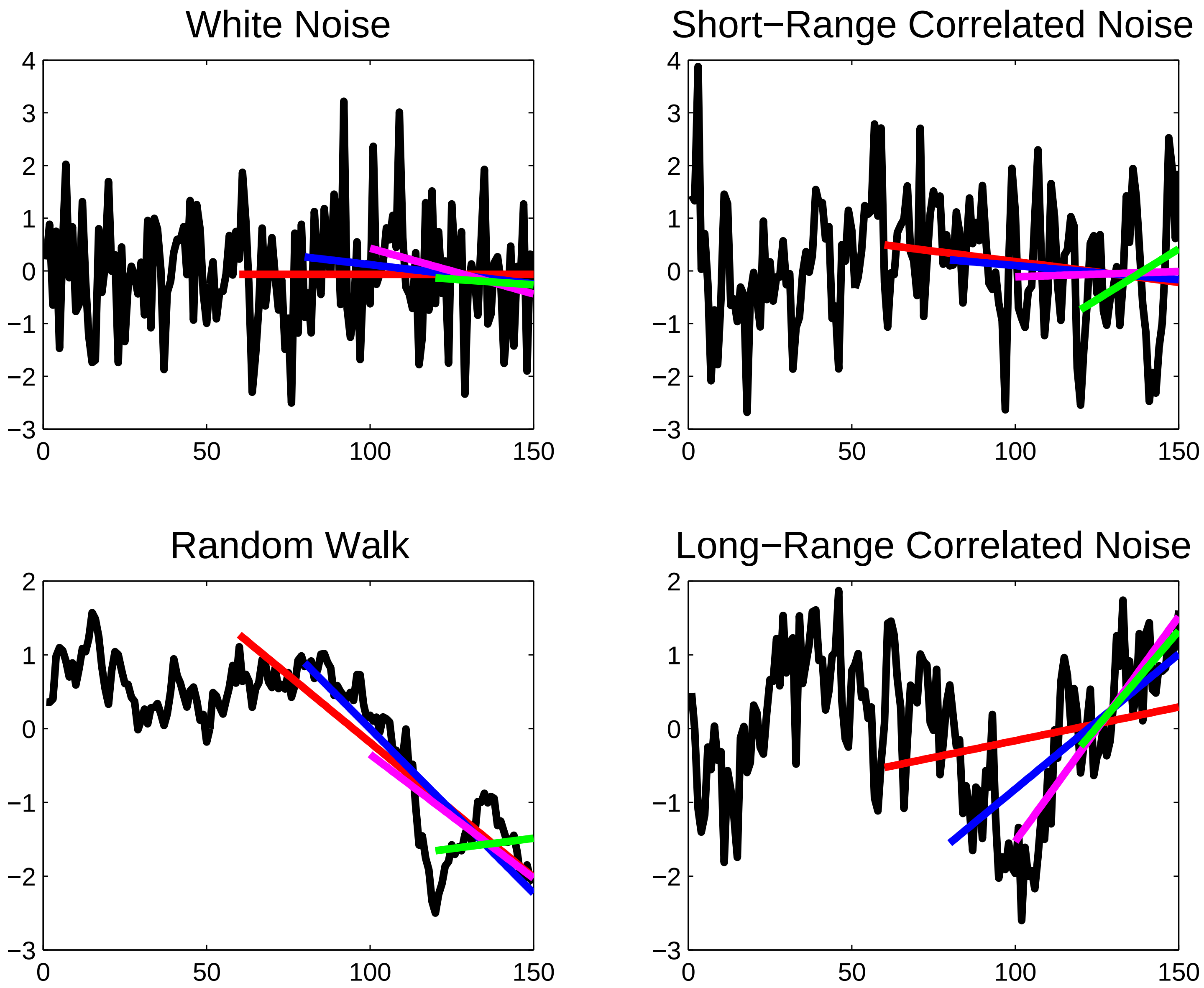
Motivation

- An important problem in climate science is the identification of statistically significant trends
- **Problem**: Even simple noise processes can exhibit ’trends’ over finite periods of time
- Trends are not necessarily linear and also have to be distinguished from internal climate variability
- A recently developed time series analysis technique is Empirical Mode Decomposition (EMD). This method can analyse nonlinear and non-stationary time series and is able to detect non-linear trends
- We apply this method to Antarctic station temperature time series

Are there trends in noise?



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How to model the background climate variability

- Most used model for background climate variability is an **Autoregressive Process of First Order AR(1)**. This is a short-range dependent process with exponential decay of autocorrelation.
- There is increasing evidence for long-range dependence in surface temperatures (e.g. Koscielny-Bunde et al. 1998; Huybers and Curry 2006; Vyushin and Kushner 2009).
- The paradigmatic model for long-range dependence is a FARIMA(0,d,0) (Hosking 1981; Stoev and Taqqu 2004).
- For both processes we only need to estimate 2 parameters from the data.

’Physical’ models with long-range dependence

- Critical Phenomena (Ising model)
- Aggregation of short-range dependence models (different climate components have different intrinsic time scales)

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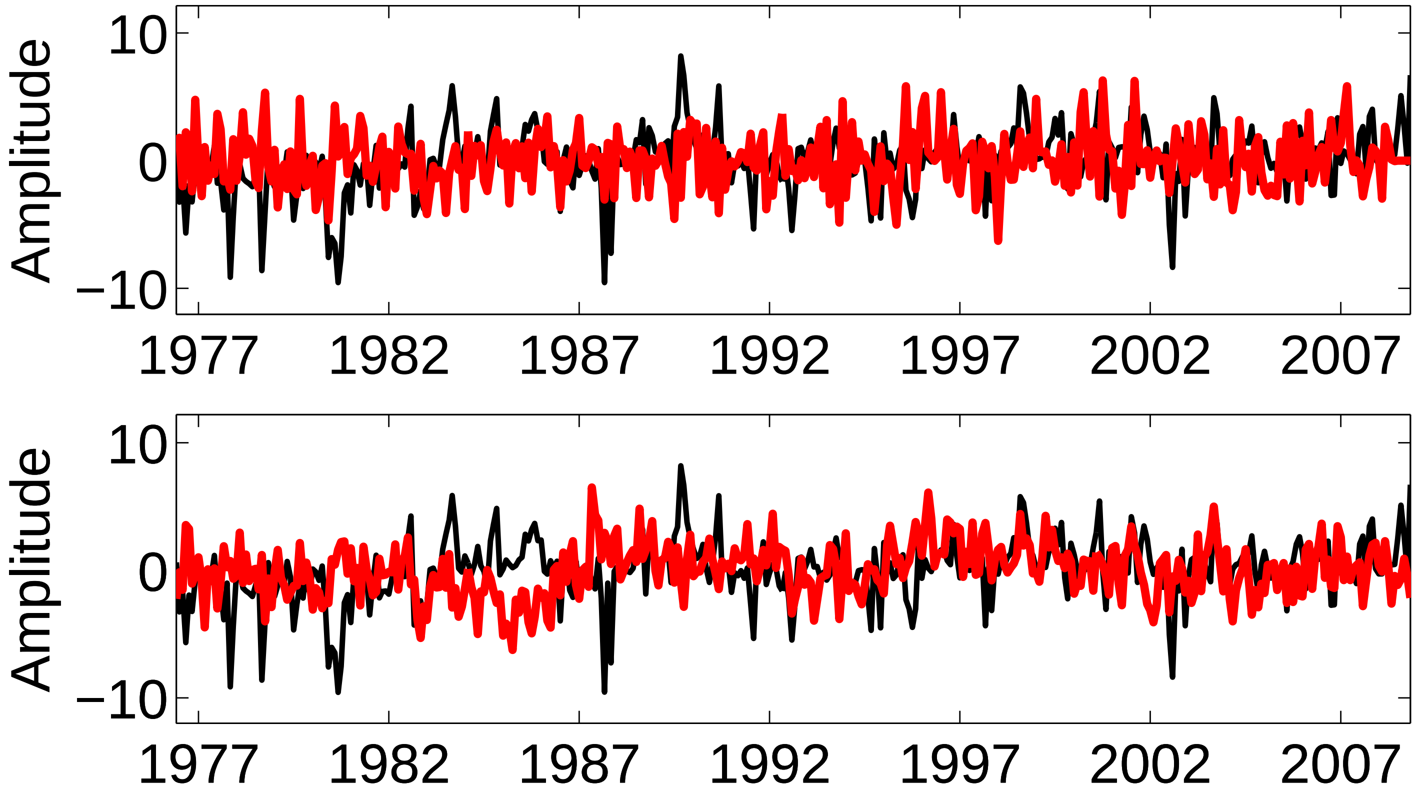
Climate Variability

Can the observed variability be representated by a simple stochastic process?



Sequence of a monthly temperature time series (deviations from climatological mean) at Rothera (black line) and sequence of the corresponding AR(1) (top) and FARIMA(0,1,0) (bottom) process (red line).

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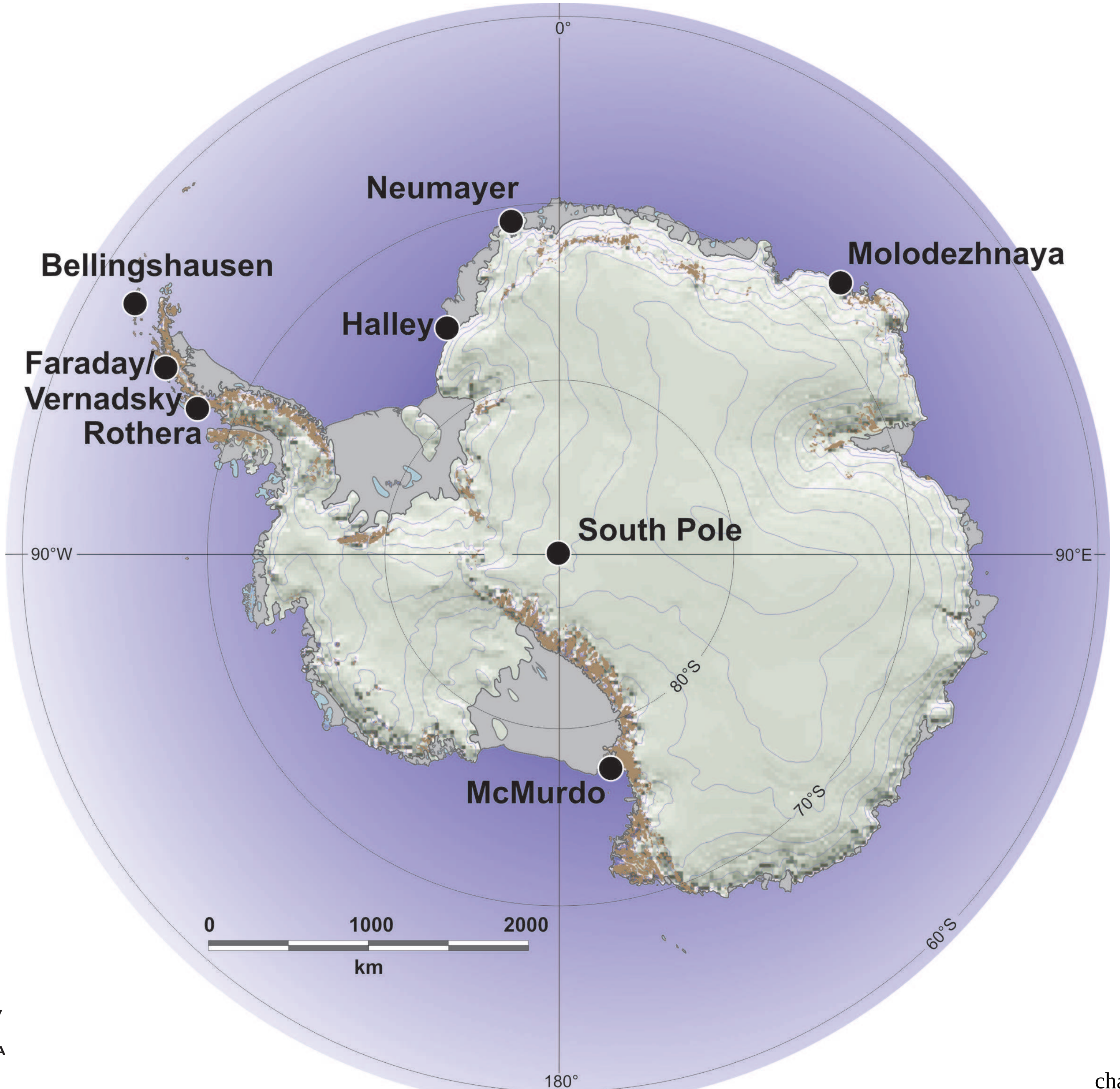
Statistical Significance Test

Main topic of this talk:
Does the model for the background variability (short- or long-range dependence) make a difference in practical applications?
Here testing for statistically significant trends in Antarctic temperatures.

Antarctic Stations



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Antarctic Stations

Station	Time period
Bellingshausen	01.03.1968-30.09.2008
Faraday-Vernadsky	01.01.1951-28.02.2007
Halley	01.01.1957-30.09.2008
McMurdo	01.04.1956-28.02.2007
Molodezhnaya	01.03.1963-30.06.1999
Neumayer	01.02.1981-28.02.2007
Rothera	01.04.1976-30.09.2008
South Pole	01.02.1957-30.11.2000

Empirical Mode Decomposition

The Empirical Mode Decomposition (Huang et al. 1998,Huang and Wu 2008) is an algorithm to decompose a time series into a finite number of Intrinsic Mode Functions (IMF)

$$x(t) = \sum_{j=1}^{M} \psi_j(t) + R(t) \tag{1}$$

where the IMF ψ_j can be written in polar coordinates

$$\psi_j(t) = r_j(t) \sin(\theta_j(t)) \tag{2}$$

where r_j is the j-th amplitude, θ_j the j-th instantaneous frequency and R the residual. Both, the amplitude and frequency are time-dependent. As (2) shows, an IMF is different from Fourier modes where both r_j and θ_j are time independent.

Empirical Mode Decomposition

An IMF is defined by the following two properties (Huang et al. 1998)

- Each IMF ψ_j has exactly one zero-crossing between two consecutive local extrema.
- The local mean of each IMF ψ_j is zero

The residual R(t) will be interpreted as a trend in this study.

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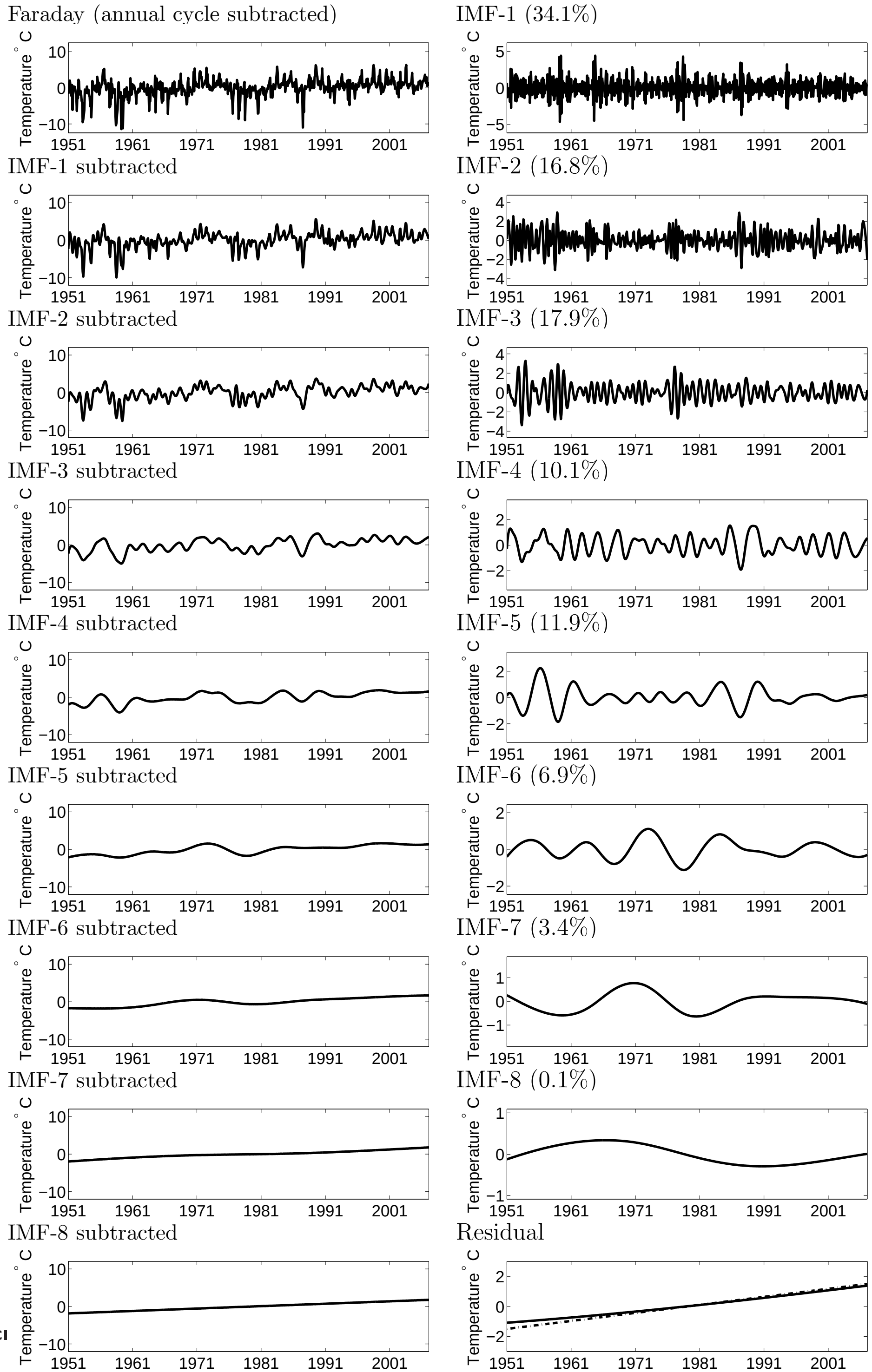
IMF



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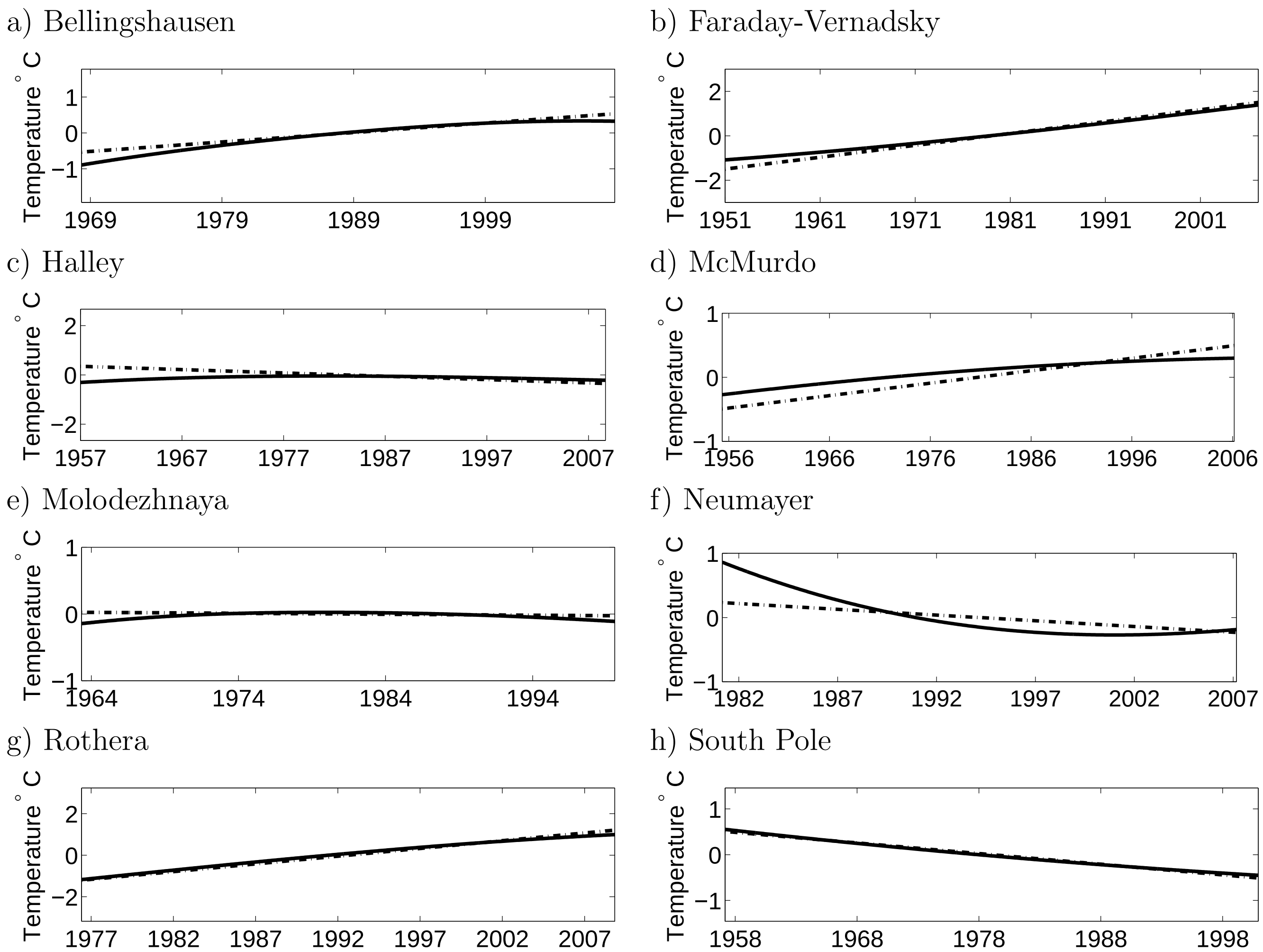
EMD Trends



Surface temperature trends in °C from monthly mean data at selected Antarctic stations (annual cycle removed). Solid line: EMD trends, Dashed line: linear least-squares fit.

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Estimation of long-range dependence

A series with long-range dependence has a spectral density proportional to $|\lambda|^{1-2d}$ close to the origin. Since $\hat{S}(\lambda)$ is an estimator of the spectral density, a regression of the logarithm of the periodogram versus the logarithm of the frequency λ should give a coefficient of $1 - 2d$. Thus having calculated the spectral density estimate $\hat{S}(\lambda)$, semiparametric estimators search to find a power law fit of the form

$$f(\lambda; b, d) = b\,|\lambda|^{1-2d} \tag{3}$$

where b is the scaling factor, a posititve and finite rational. The long-range dependency parameter d is inferred by the Geweke Porter-Hudak semi-parametric estimator (Geweke and Porter-Hudak 1983; Hurvich and Deo 1999).

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EMD Trends

Coefficients of the AR(1) parameters α and σ and the long-range dependence parameter d and with the corresponding 5% confidence bounds.

Station	α	σ (AR(1))	d
Bellingshausen	0.62 ± 0.013	2.77 ± 0.03	0.28 ± 0.038
Faraday-Vernadsky	0.74 ± 0.009	3.06 ± 0.04	0.28 ± 0.038
Halley	0.73 ± 0.009	4.17 ± 0.06	0.11 ± 0.048
McMurdo	0.79 ± 0.008	3.09 ± 0.05	0.12 ± 0.051
Molodezhnaya	0.58 ± 0.014	3.82 ± 0.04	0.17 ± 0.028
Neumayer	0.60 ± 0.016	5.04 ± 0.07	0.08 ± 0.056
Rothera	0.77 ± 0.011	2.99 ± 0.06	0.26 ± 0.049
South Pole	0.77 ± 0.010	3.73 ± 0.06	0.12 ± 0.053

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Monte Carlo Experiments

- Generate ensembles of 1000 AR(1) and FARIMA(0,d,0) member with accounting for parameter uncertainty
- Estimate EMD trends from ensemble members
- If observed EMD lies outside 95% percentile then I claim that observed EMD trend is significant against the respective null model

EMD Trends

The EMD trends are tested against 2 different null models: AR(1) and FARIMA(0,d,0); see text for explanation. EMD trends significant at the 5% level are indicated by a X.

Station	AR(1)	FARIMA(0,d,0)
Bellingshausen	X	
Faraday-Vernadsky	X	X
Halley		
McMurdo		
Molodezhnaya		
Neumayer		
Rothera	X	
South Pole		

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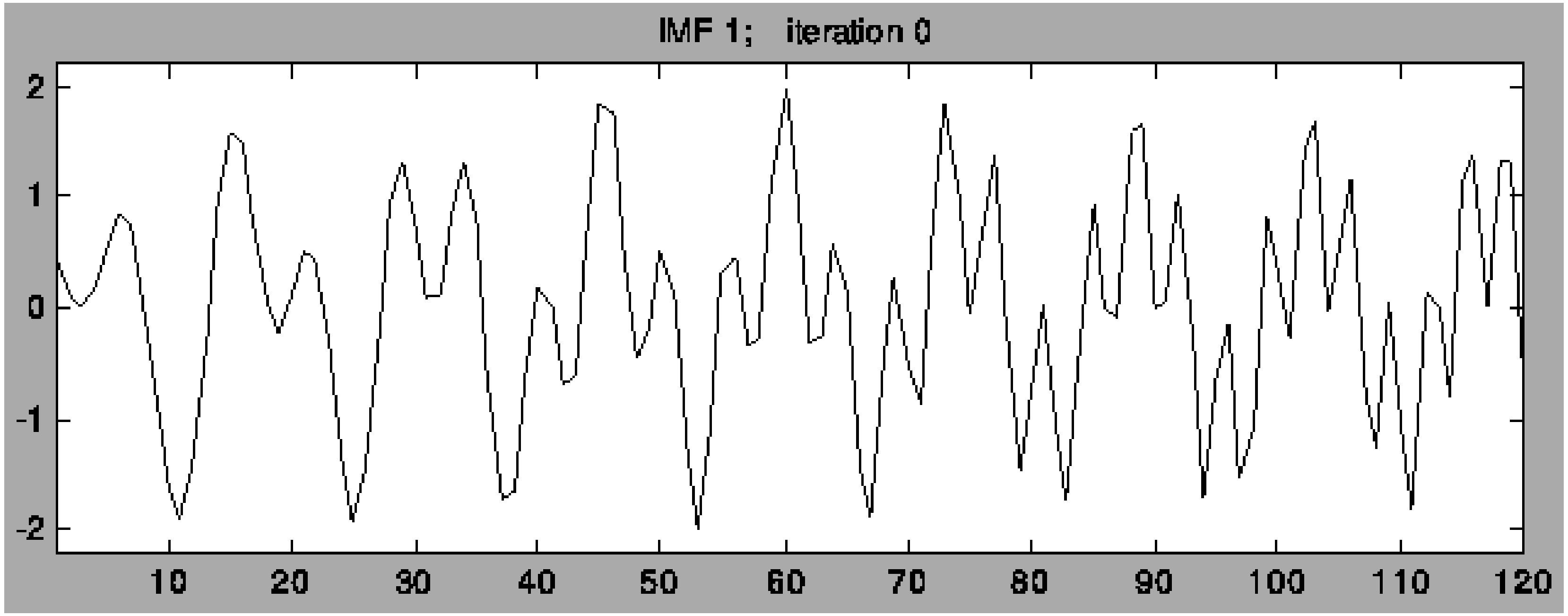
Summary

- The choice of a long-range, rather than a short-range, dependent null model negates the significance of temperature trends at 2 out of 3 stations in Antarctica.
- All trends and mode functions should be tested against various null models (e.g. short- and long-range dependent)
- These results emphasize the need to better investigate the correlation structure of climatic time series.

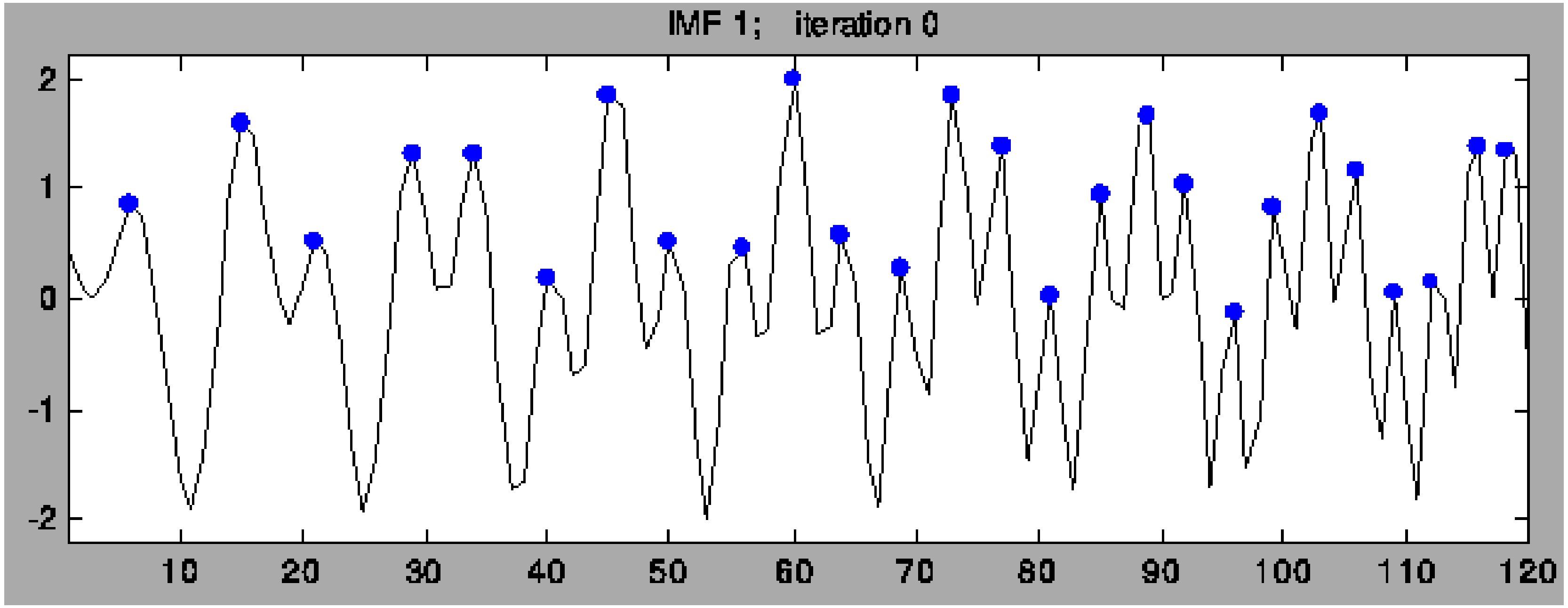
Franzke: Long-Range Dependence and Climate Noise Characteristics of Antarctic Temperature Data. J. Climate, accepted, 2010.

EMD Iteration



Source: P. Flandrin

EMD Iteration



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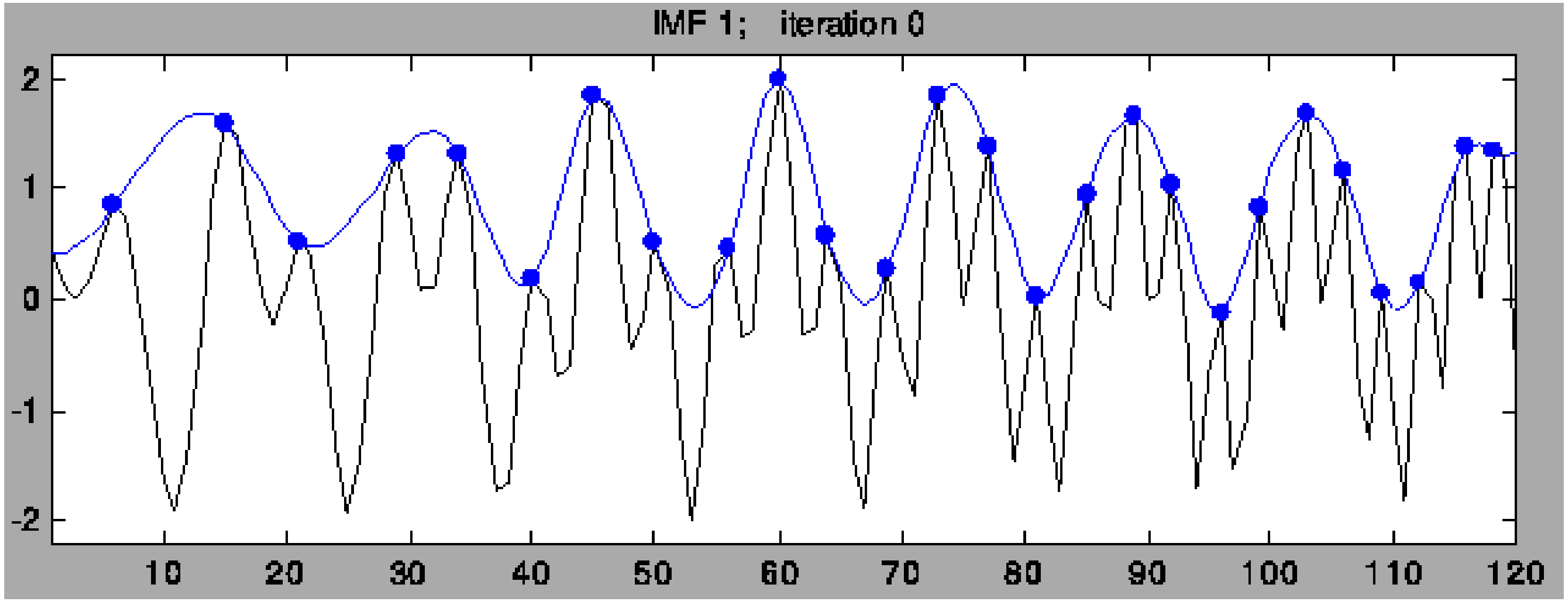

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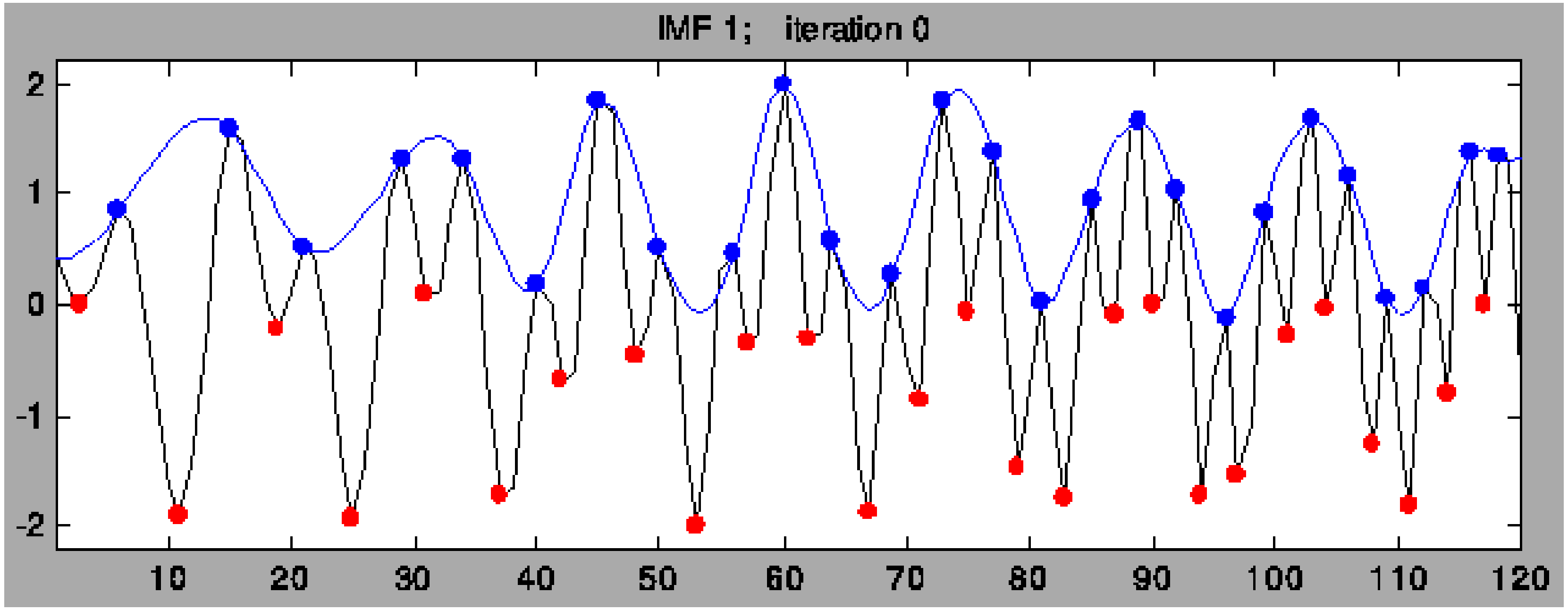

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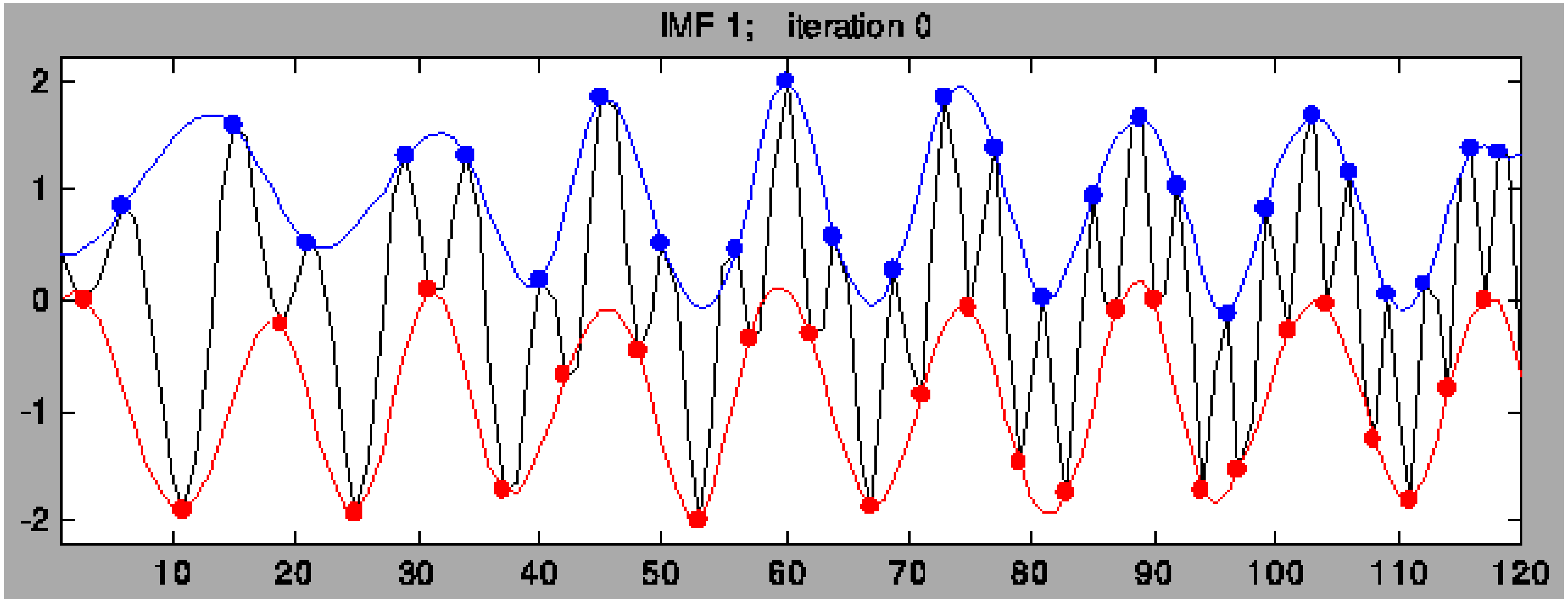

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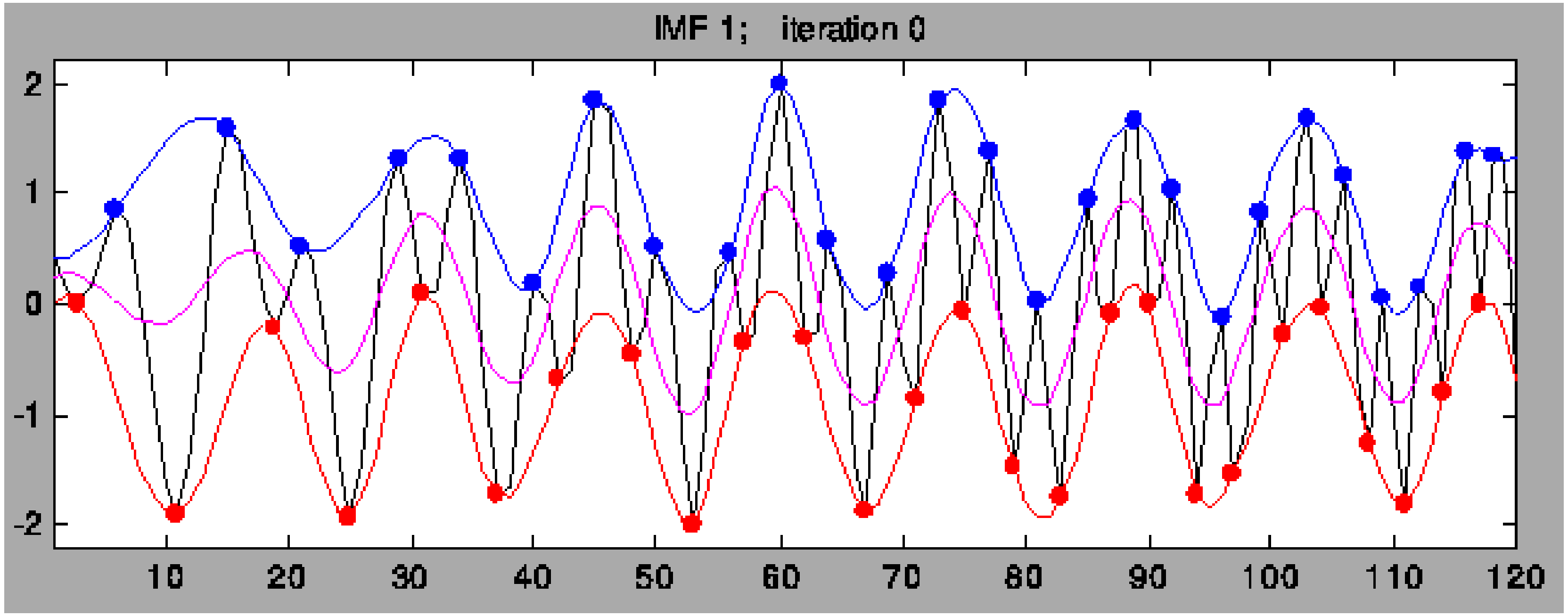

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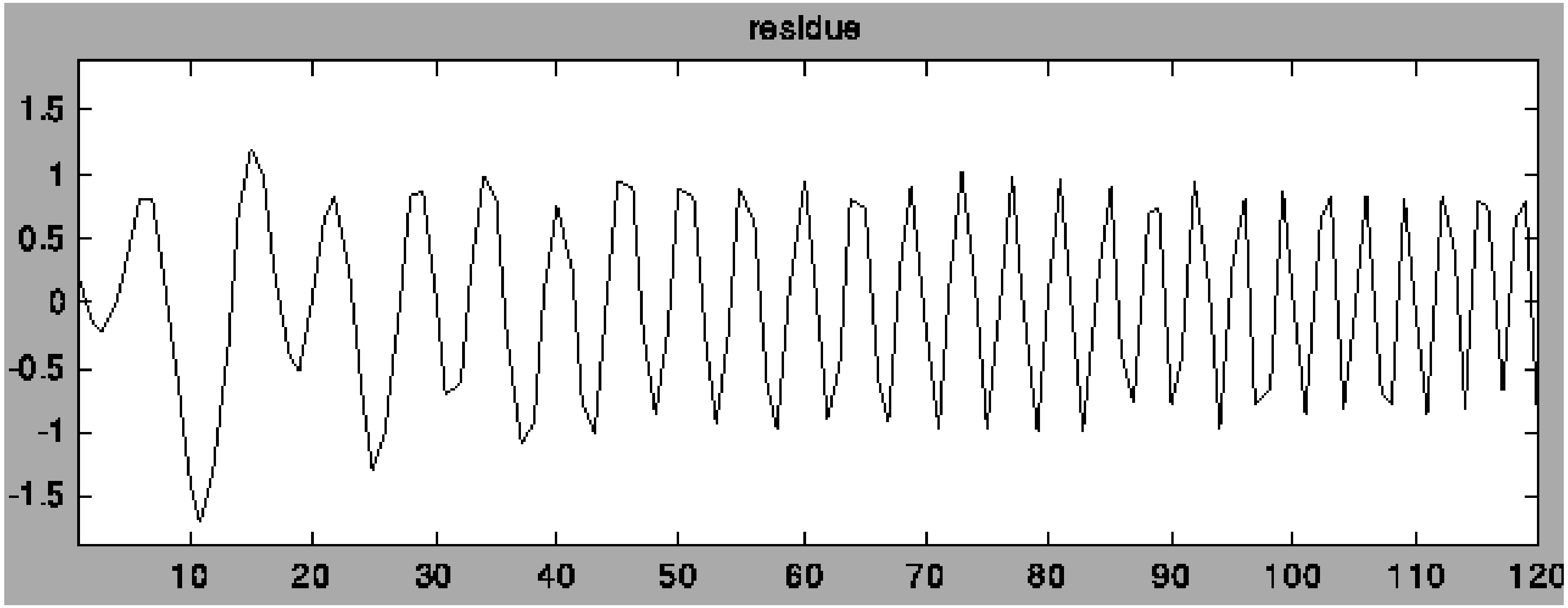

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