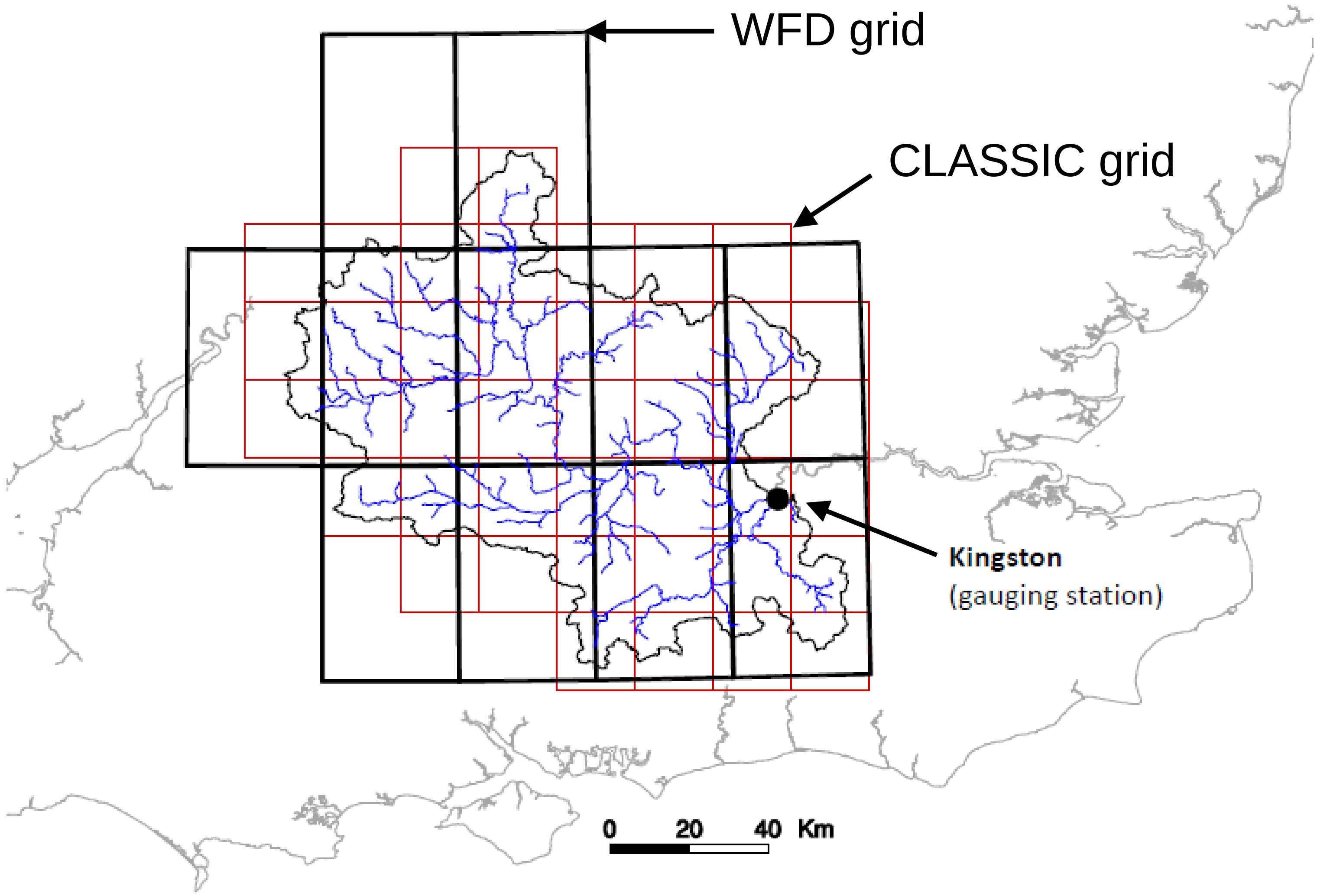
A spectral approach to assessing JULES performance: case study of late twentieth century discharge from the Thames Basin

Graham Weedon(1), Christel Prudhomme(2), Sue Crooks(2),

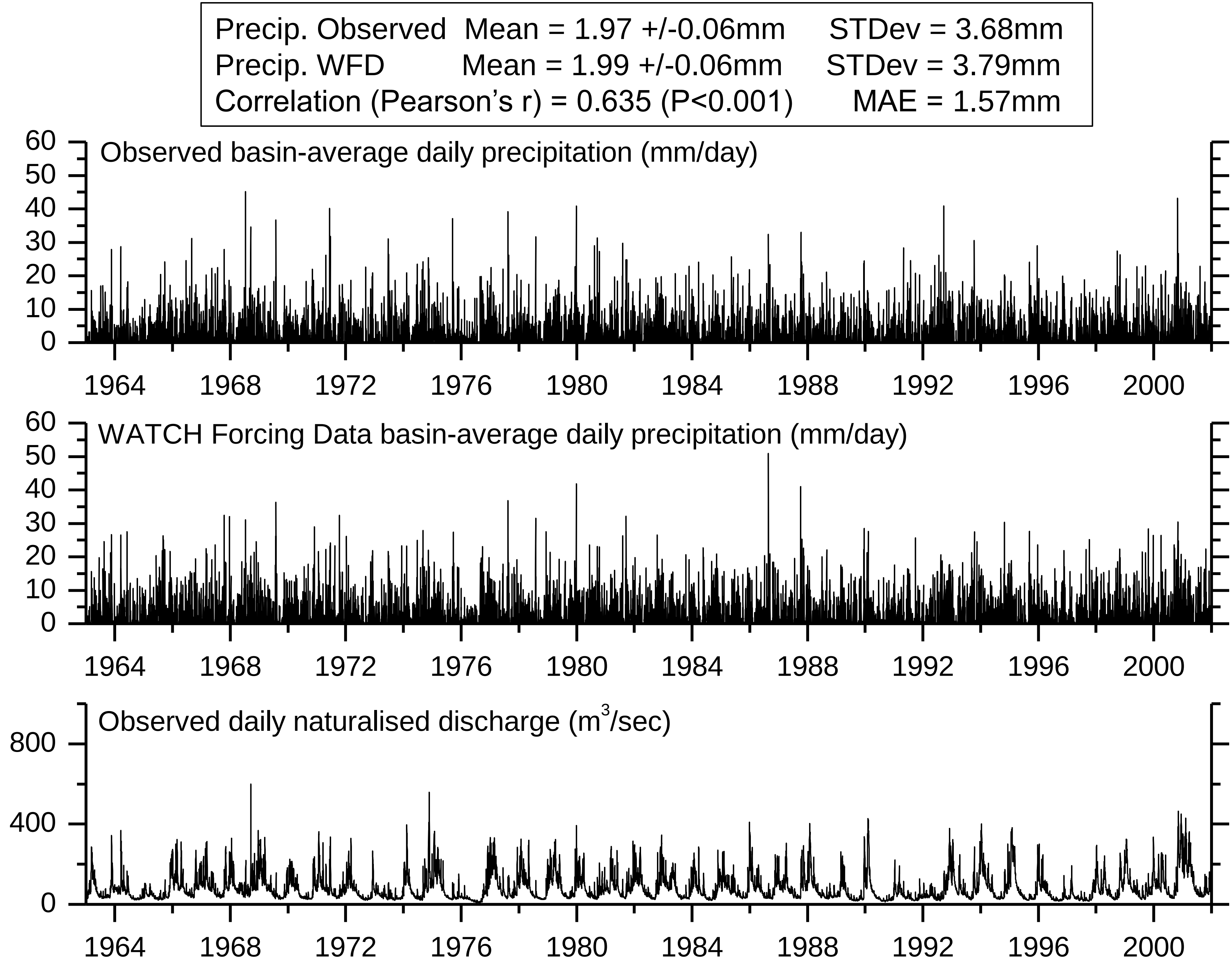
Richard Essery(2), Sonja Folwell(2) and Martin Best(1)

1 = Met Office, UK 2 = CEH Wallingford, UK

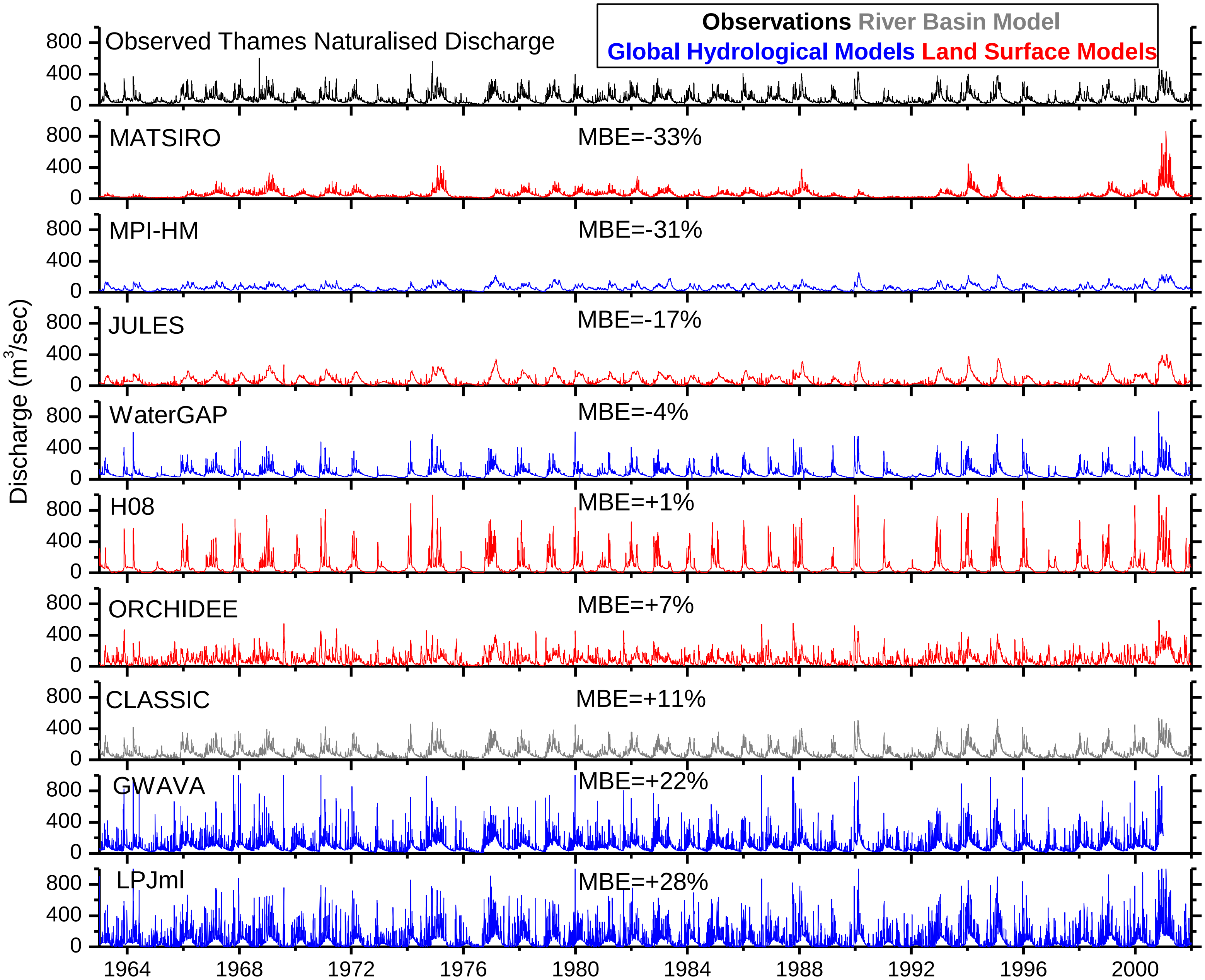


Modelling the Thames Basin

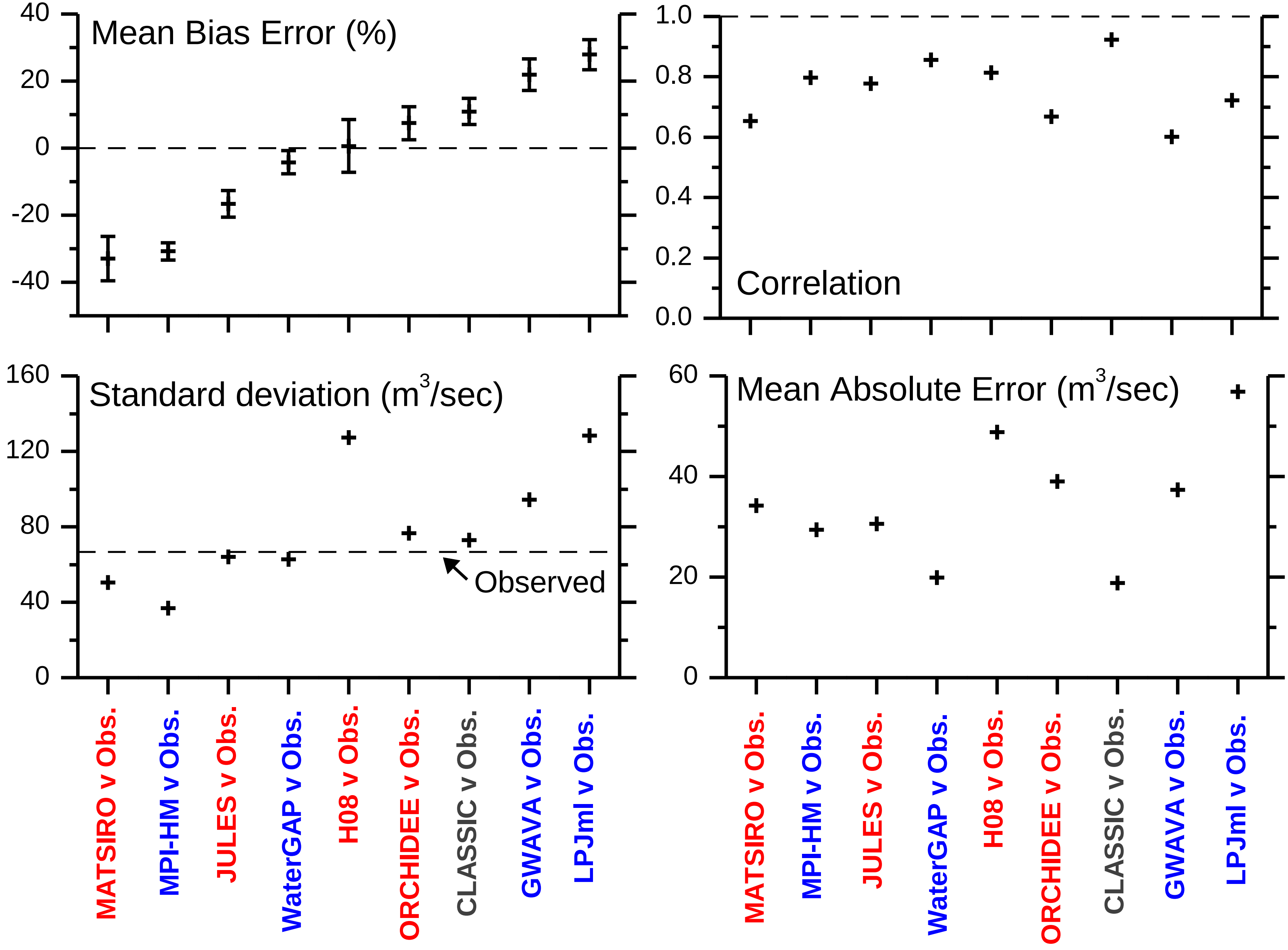
Fig 1 of Crooks, 2011 WATCH Technical Report 53



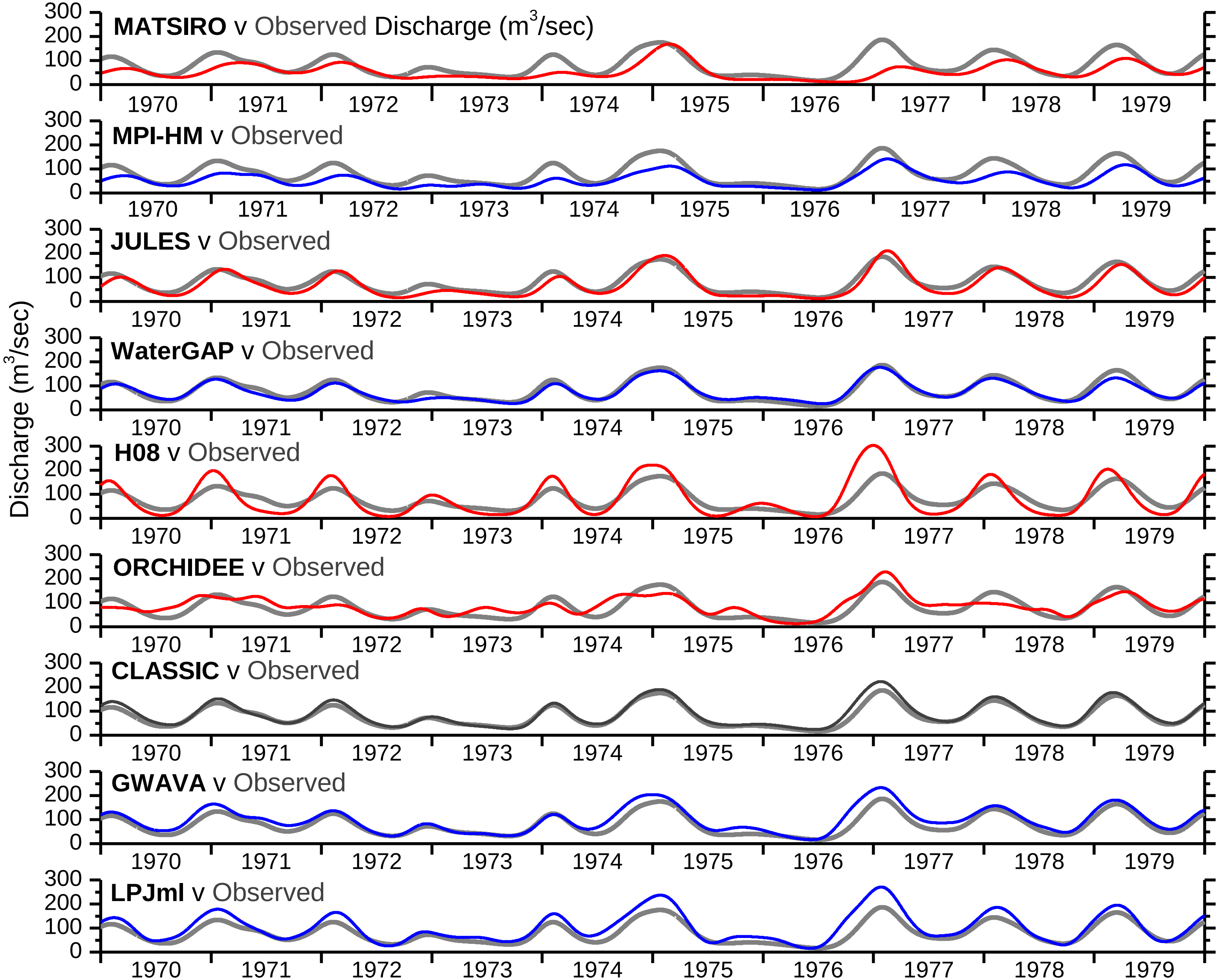
Precip. Observed Mean = 1.97 +/-0.06mm STDev = 3.68mm
Precip. WFD Mean = 1.99 +/-0.06mm STDev = 3.79mm
Correlation (Pearson's r) = 0.635 (P<0.001) MAE = 1.57mm
Observed basin-average daily precipitation (mm/day)
WATCH Forcing Data basin-average daily precipitation (mm/day)
Observed daily naturalised discharge (m3/sec)
0
10
20
30
40
50
60
400
800
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000



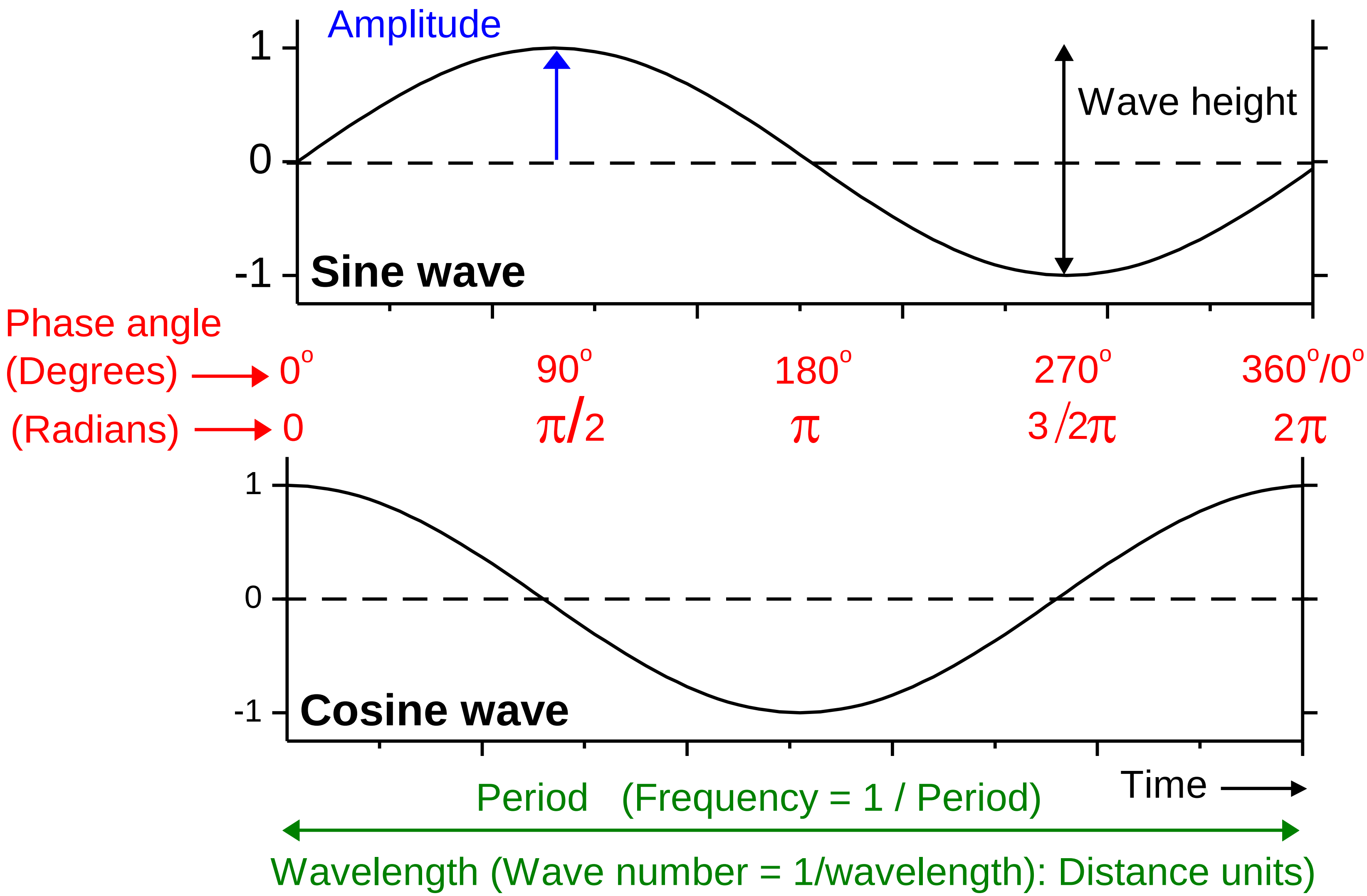
Observations River Basin Model
Global Hydrological Models Land Surface Models
Observed Thames Naturalised Discharge
MATSIRO
MBE=-33%
MPI-HM
MBE=-31%
JULES
MBE=-17%
WaterGAP
MBE=-4%
H08
MBE=+1%
ORCHIDEE
MBE=+7%
CLASSIC
MBE=+11%
GWAVA
MBE=+22%
LPJml
MBE=+28%
Discharge (m3/sec)
800
400
0
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000



Mean Bias Error (%)
Correlation
Standard deviation (m3/sec)
Observed
Mean Absolute Error (m3/sec)
40
20
0
-20
-40
1.0
0.8
0.6
0.4
0.2
0.0
160
120
80
40
0
60
40
20
0
MATSIRO v Obs.
MPI-HM v Obs.
JULES v Obs.
WaterGAP v Obs.
H08 v Obs.
ORCHIDEE v Obs.
CLASSIC v Obs.
GWAVA v Obs.
LPJml v Obs.


MATSIRO v Observed Discharge (m3/sec)
MPI-HM v Observed
JULES v Observed
WaterGAP v Observed
H08 v Observed
ORCHIDEE v Observed
CLASSIC v Observed
GWAVA v Observed
LPJml v Observed
Discharge (m3/sec)
300
200
100
0
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979

Three parameters describe sinusoidal oscillations: Amplitude, Period and Phase



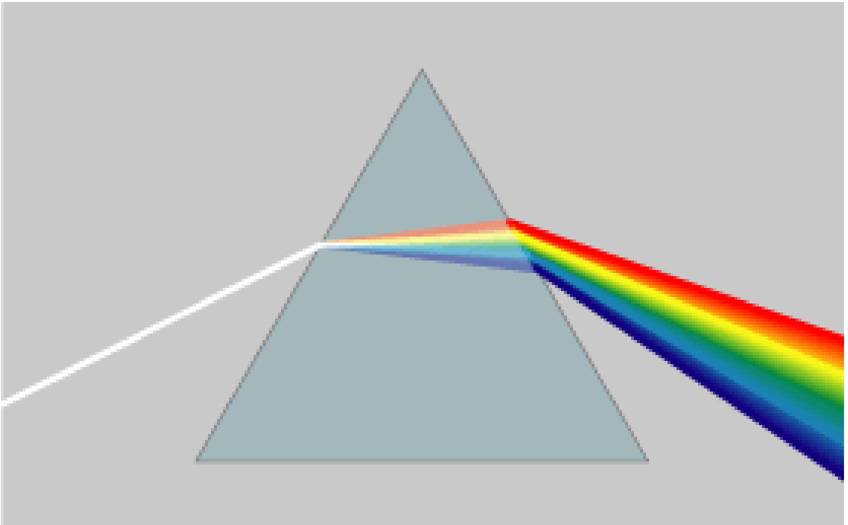
Fourier's Theorem:

Any time series* can be represented as the sum of sine and cosine components having the appropriate amplitudes.

* **Caveat**: The time series must include oscillations, but exclude infinite values.

Methodology: Apply the Fourier Transform to the time series.

Fourier Transform: analogy with optics

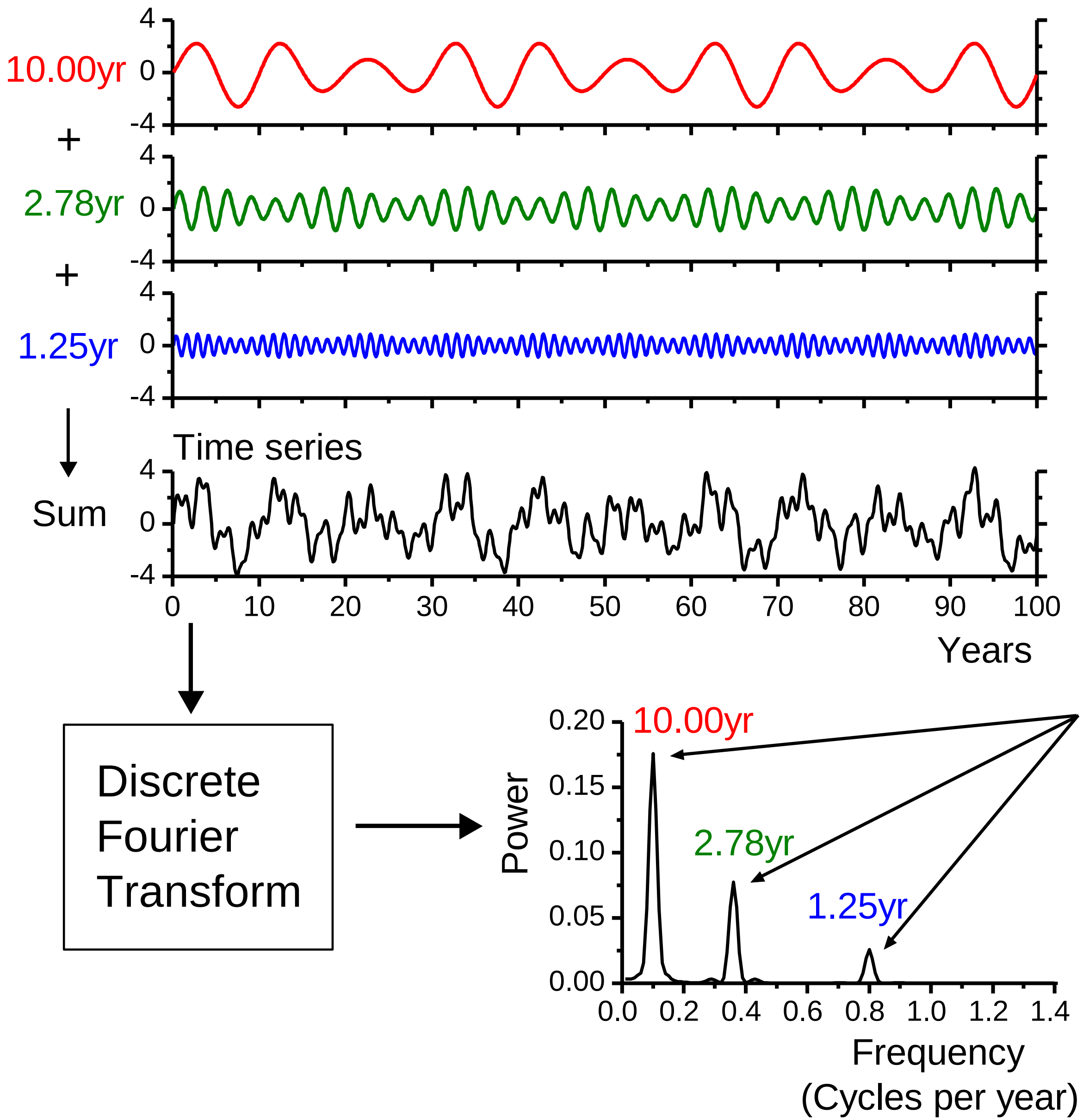


Theory:
White light is separated into frequency components using a glass prism. Different wavelengths are refracted by different amounts. Red light has a longer wavelength than blue light.

Image: Merganser.math.gvsu.edu

White light from a Mercury vapour lamp passed through a flint glass prism.

Image: en.wikipedia.org/Visible_spectrum



Spectral analysis of "time series" involves the use of amplitude and frequency (= 1/period) only.

The power spectrum plots the ***average*** squared amplitude (= power or variance).

The spectrum shows regular cycles emerging as spectral peaks.

INPUT

Observed Precipitation

↓

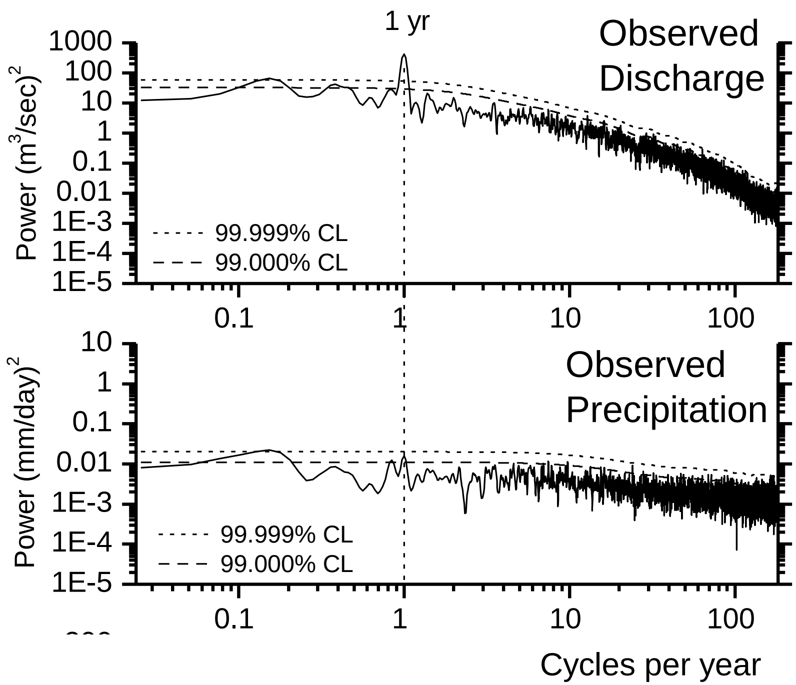
SYSTEM

Thames Basin

↓

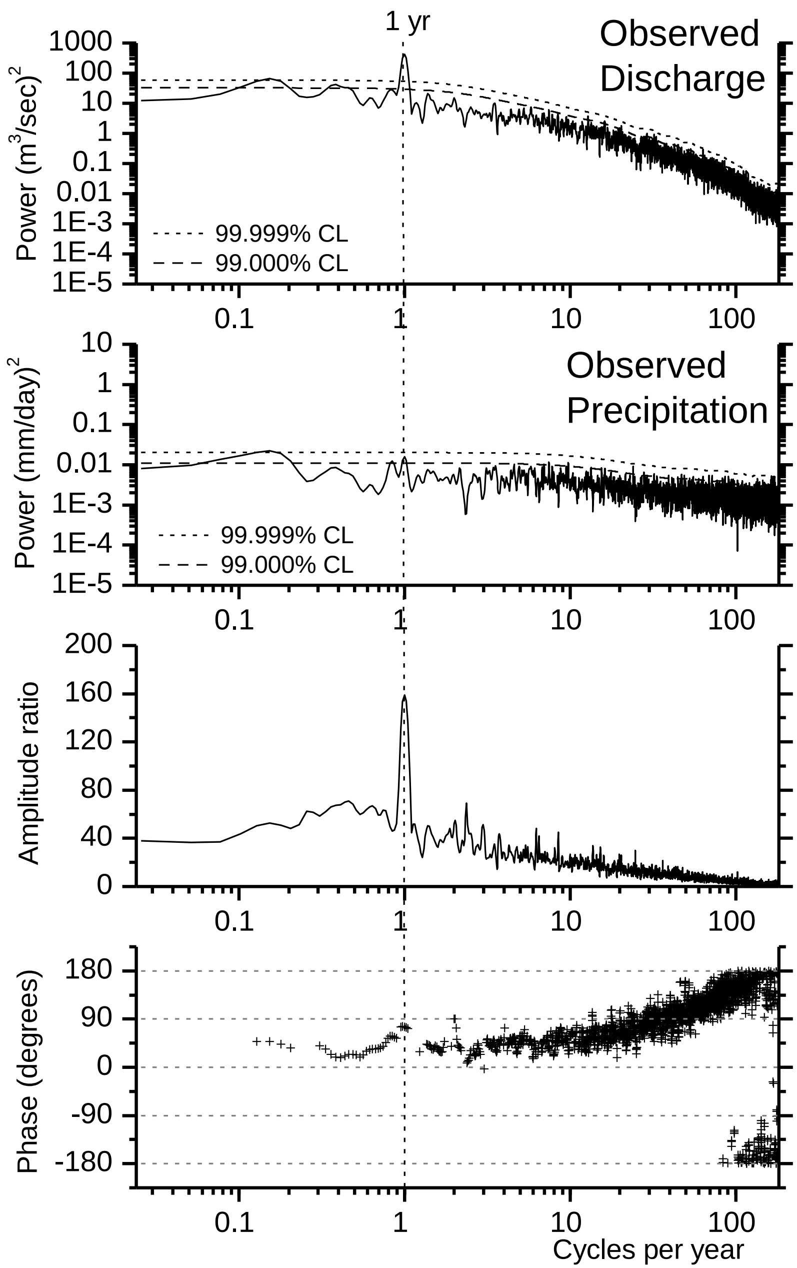
OUTPUT

Observed Naturalised Discharge



Shape of Discharge power spectrum implies strong annual cycles plus strong autocorrelation (“memory”).

Shape of Precipitation power spectrum implies weak annual cycles plus weak autocorrelation (“memory”).



Power spectrum of output

Power spectrum of input

Amplitude-ratio spectrum indicates strong amplification of annual cycle variation.

Phase (difference) spectrum indicates difference in timing of oscillations of the output series compared to the input.

INPUT

WFD Precipitation

↓

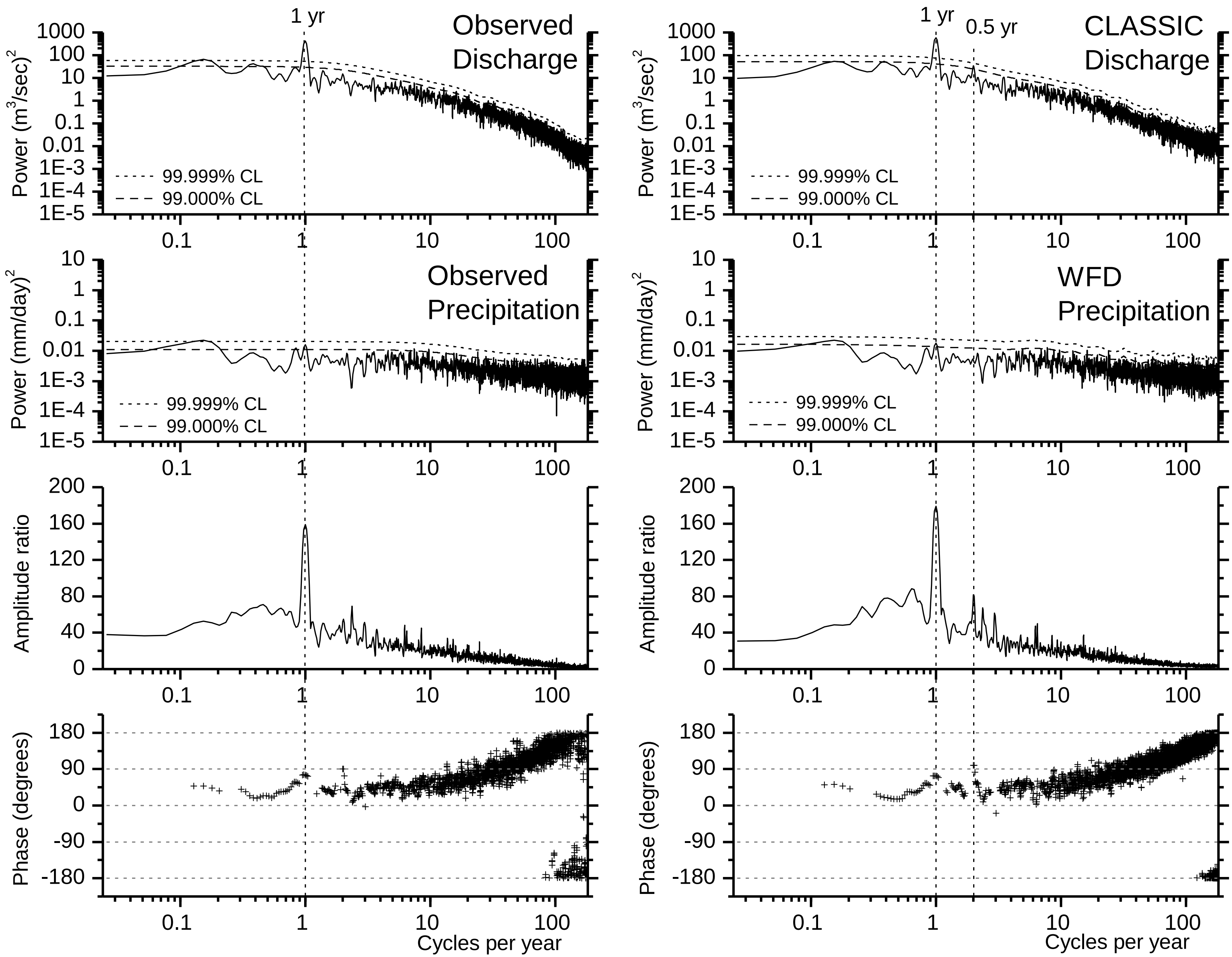
SYSTEM

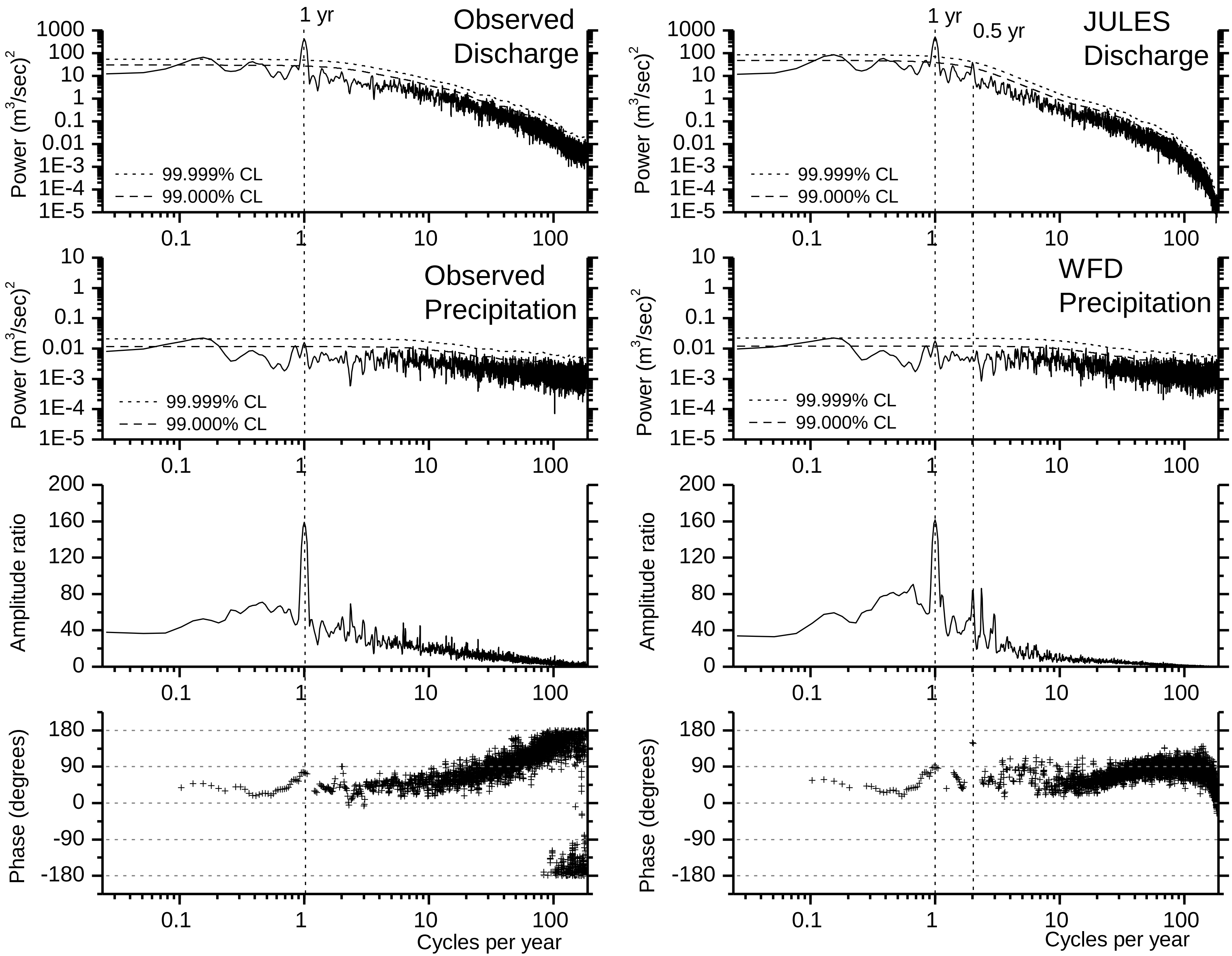
Hydrological model

↓

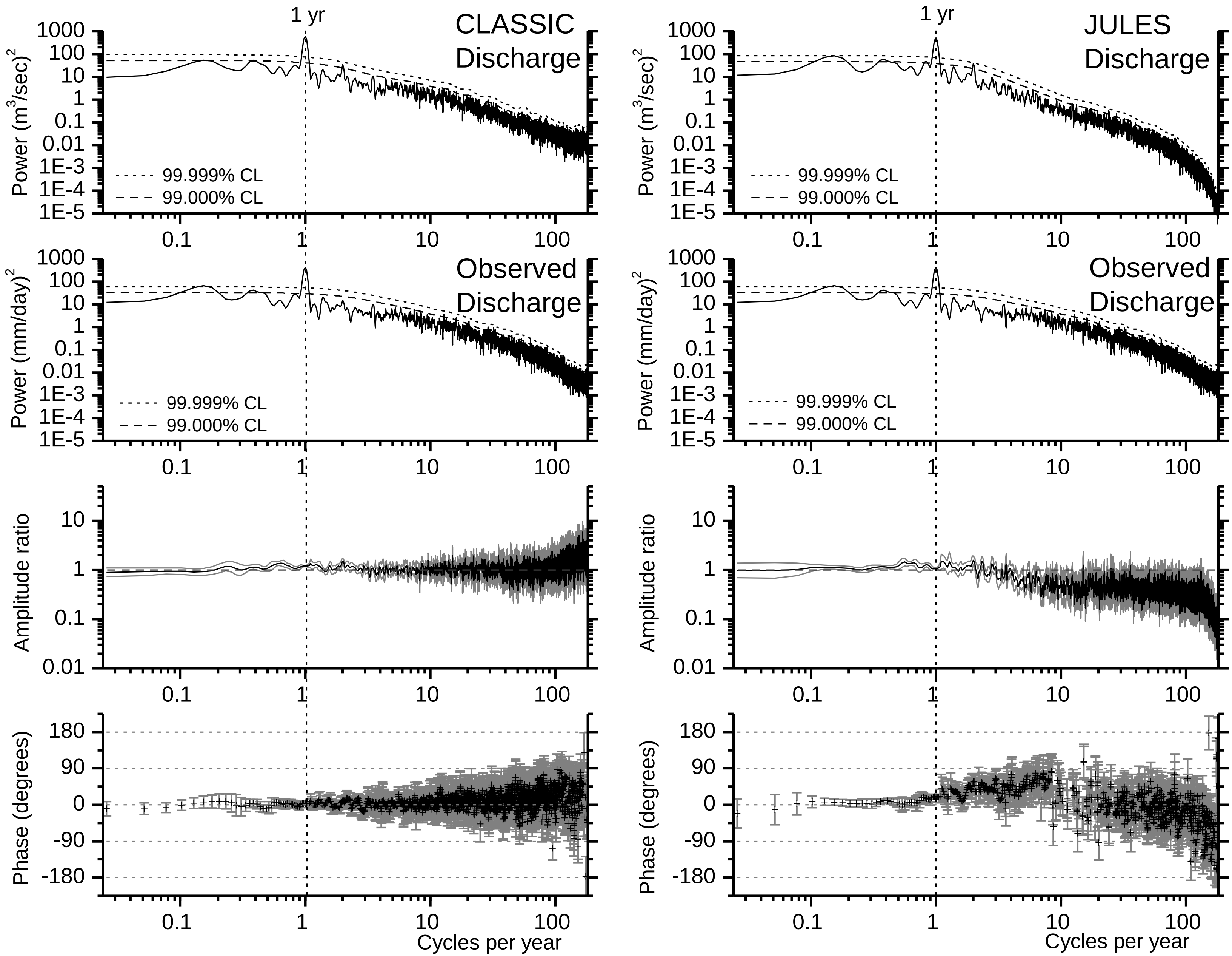
OUTPUT

Modelled Discharge

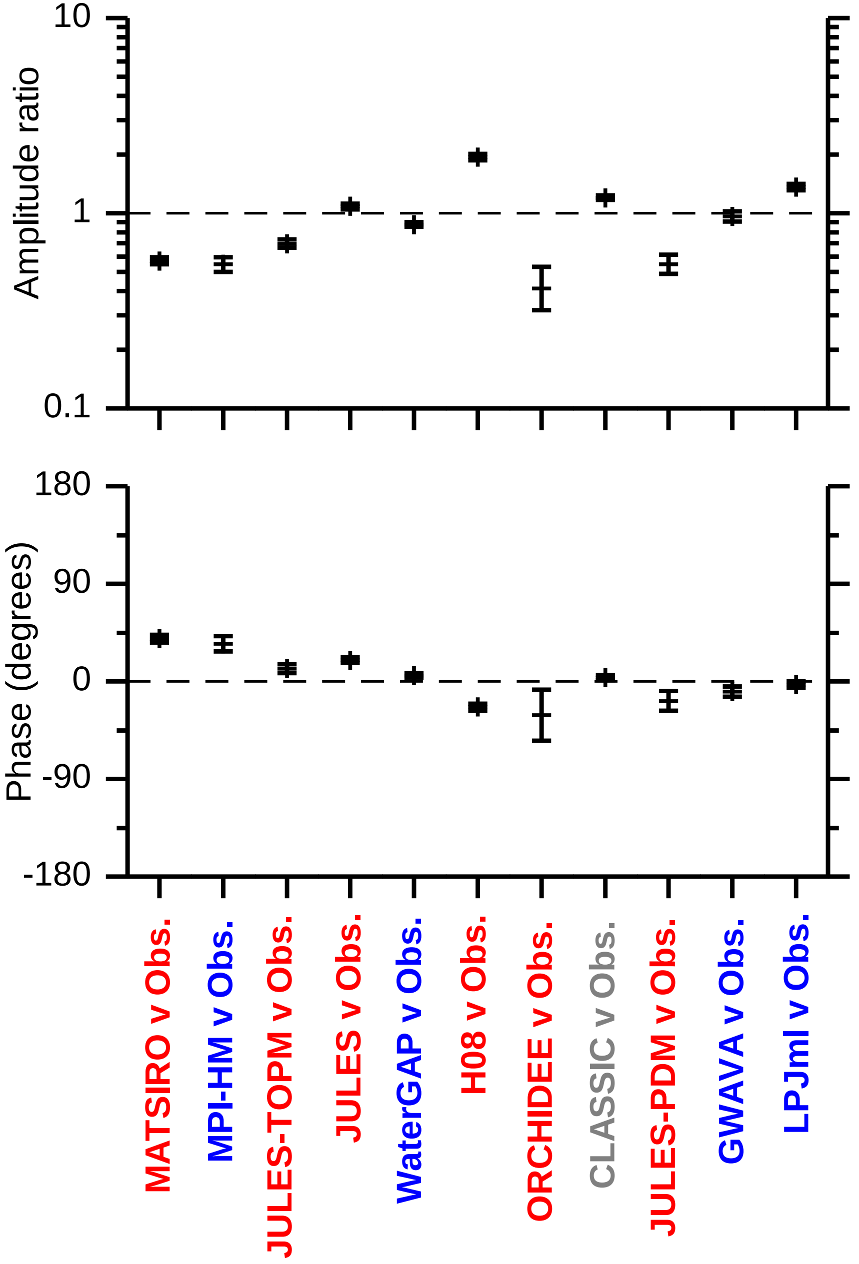

Observed Discharge
CLASSIC Discharge
Observed Precipitation
WFD Precipitation
1 yr
0.5 yr
Power (m3/sec)2
Power (mm/day)2
Amplitude ratio
Phase (degrees)
99.999% CL
99.000% CL
Cycles per year

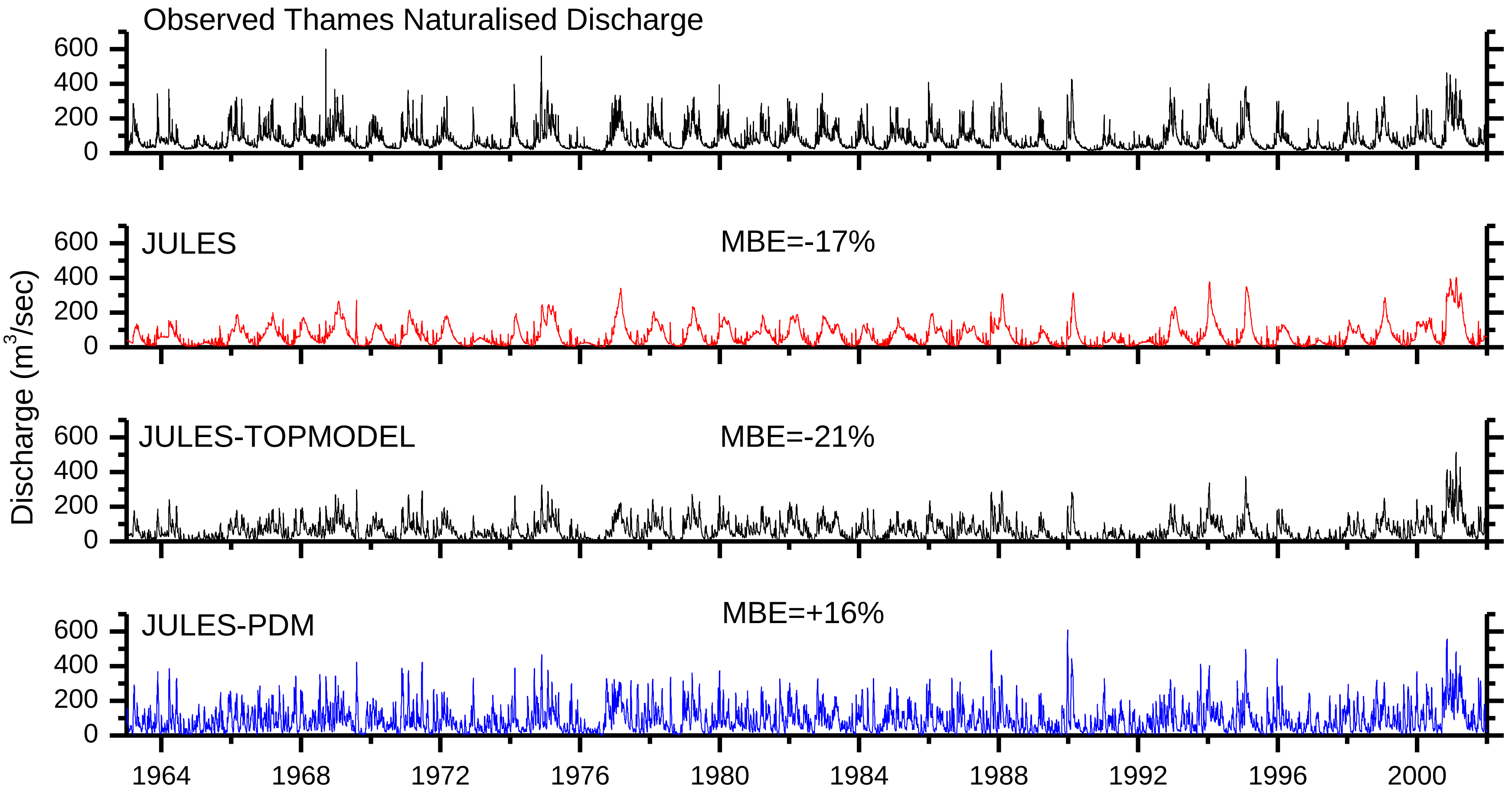


1 yr
Observed Discharge
Power (m^3/sec)^2
99.999% CL
99.000% CL
1 yr
0.5 yr
JULES Discharge
Observed Precipitation
WFD Precipitation
Amplitude ratio
Phase (degrees)
Cycles per year

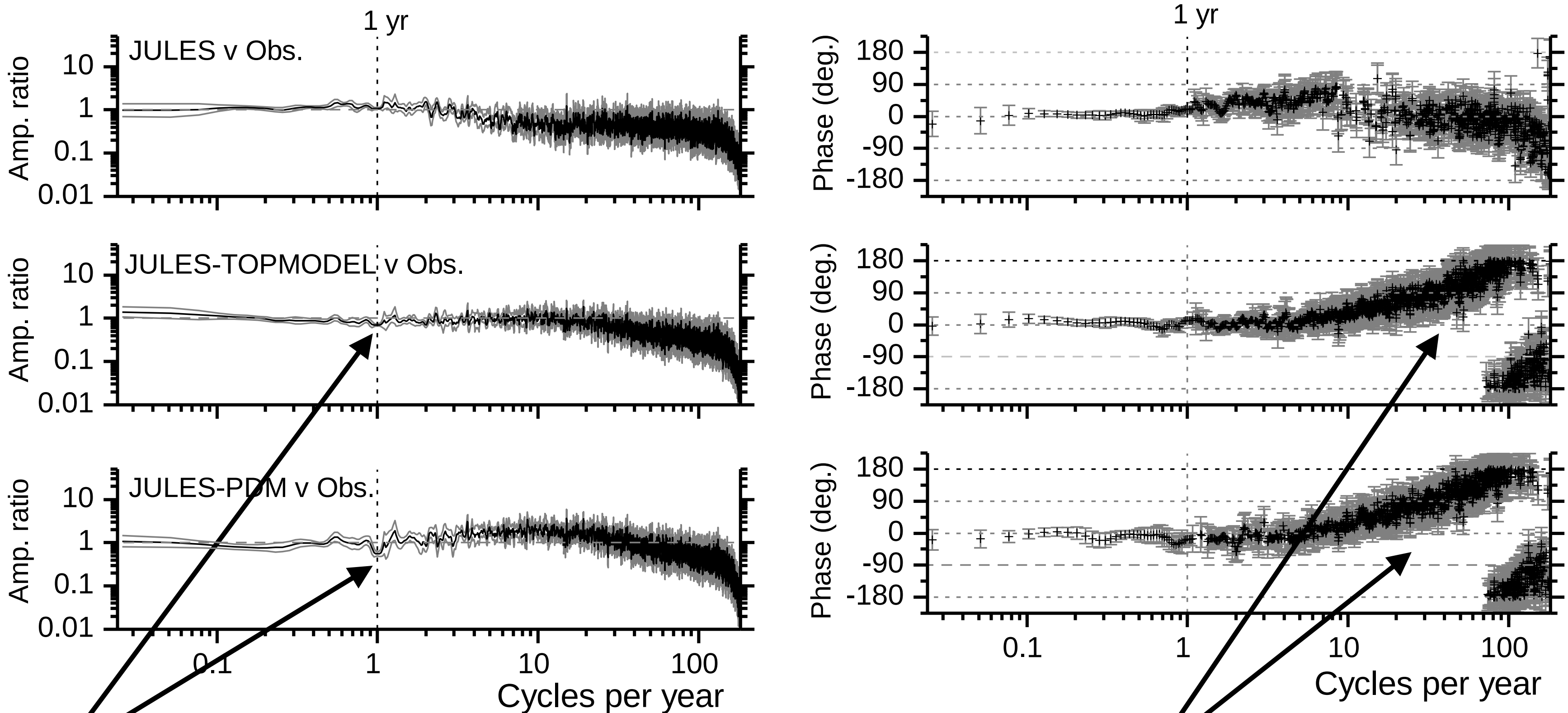

1 yr
CLASSIC
Discharge
JULES
Discharge
Observed
Discharge
Power (m3/sec)2
Power (mm/day)2
99.999% CL
99.000% CL
Amplitude ratio
Phase (degrees)
Cycles per year

Model evaluation at the annual scale



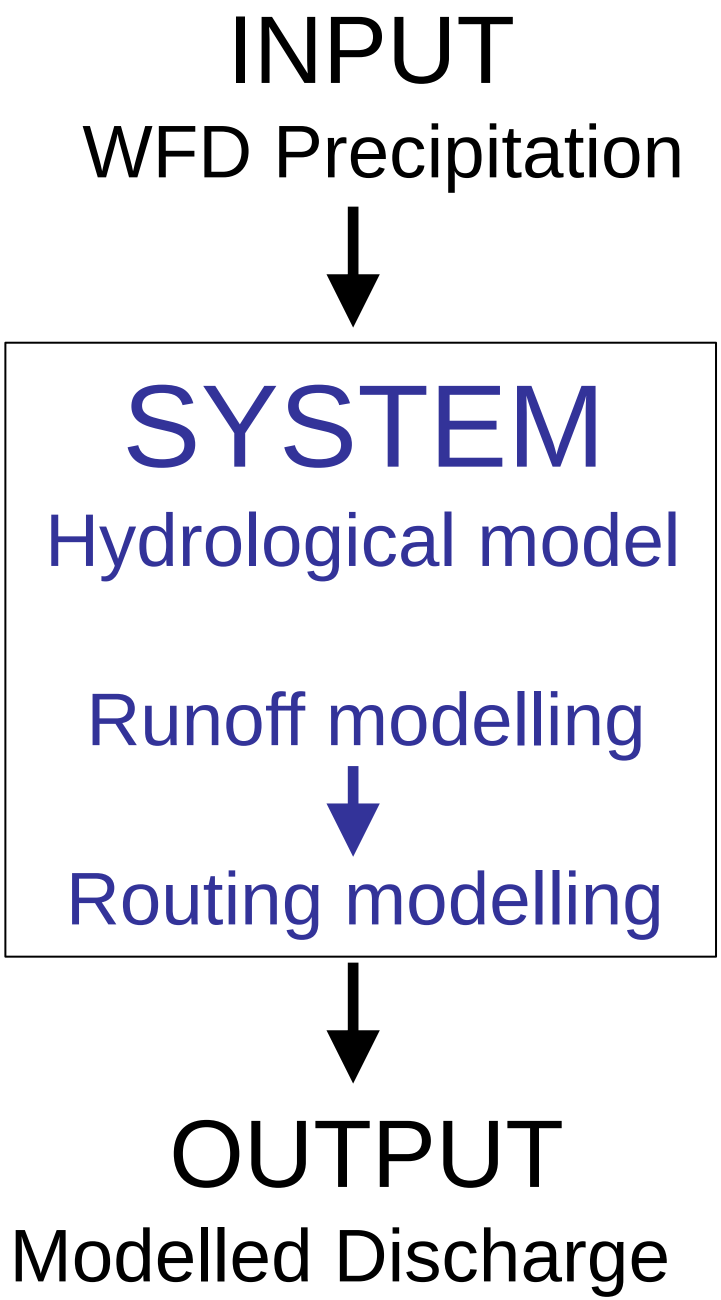


Observed Thames Naturalised Discharge
JULES
MBE=-17%
JULES-TOPMODEL
MBE=-21%
JULES-PDM
MBE=+16%
Discharge (m3/sec)
0
200
400
600
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000

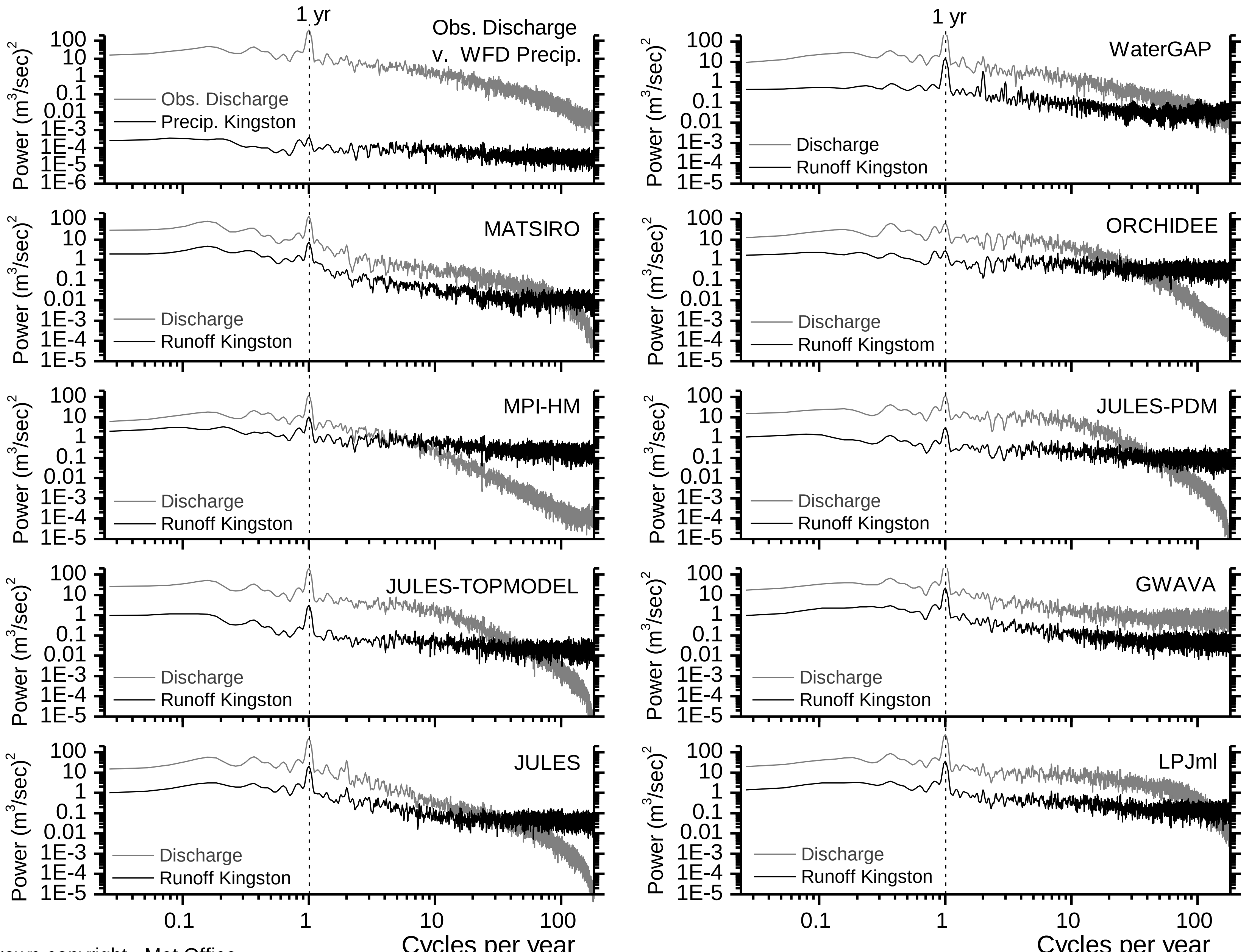


JULES-TOPMODEL & JULES-PDM have worse reproduction of the observed annual amplitude of discharge compared to JULES.

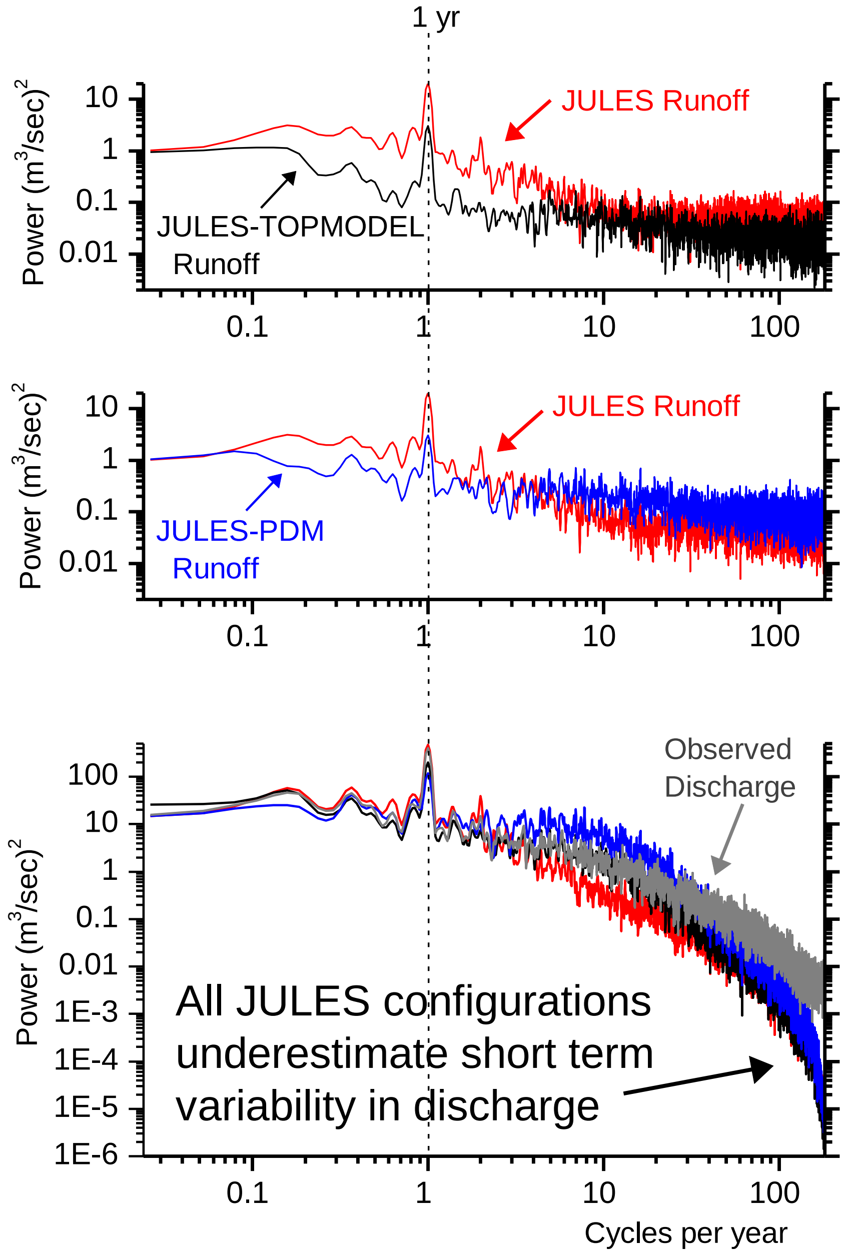
JULES-TOPMODEL & JULES-PDM have worse reproduction of the observed high frequency discharge phases compared to JULES.


INPUT
WFD Precipitation
SYSTEM
Hydrological model
Runoff modelling
Routing modelling
OUTPUT
Modelled Discharge

Power spectra of Kingston grid box **Runoff** v. power spectra of **Discharge**



Runoff v. Discharge power spectra for JULES



Simulation of runoff and discharge spectral characteristics

$P(t)$ = Observed daily precipitation

Simulating annual cycle in evaporation

$R(t) = P(t)$ + Sine(1yr)

Adding weak autocorrelation (Runoff "memory")

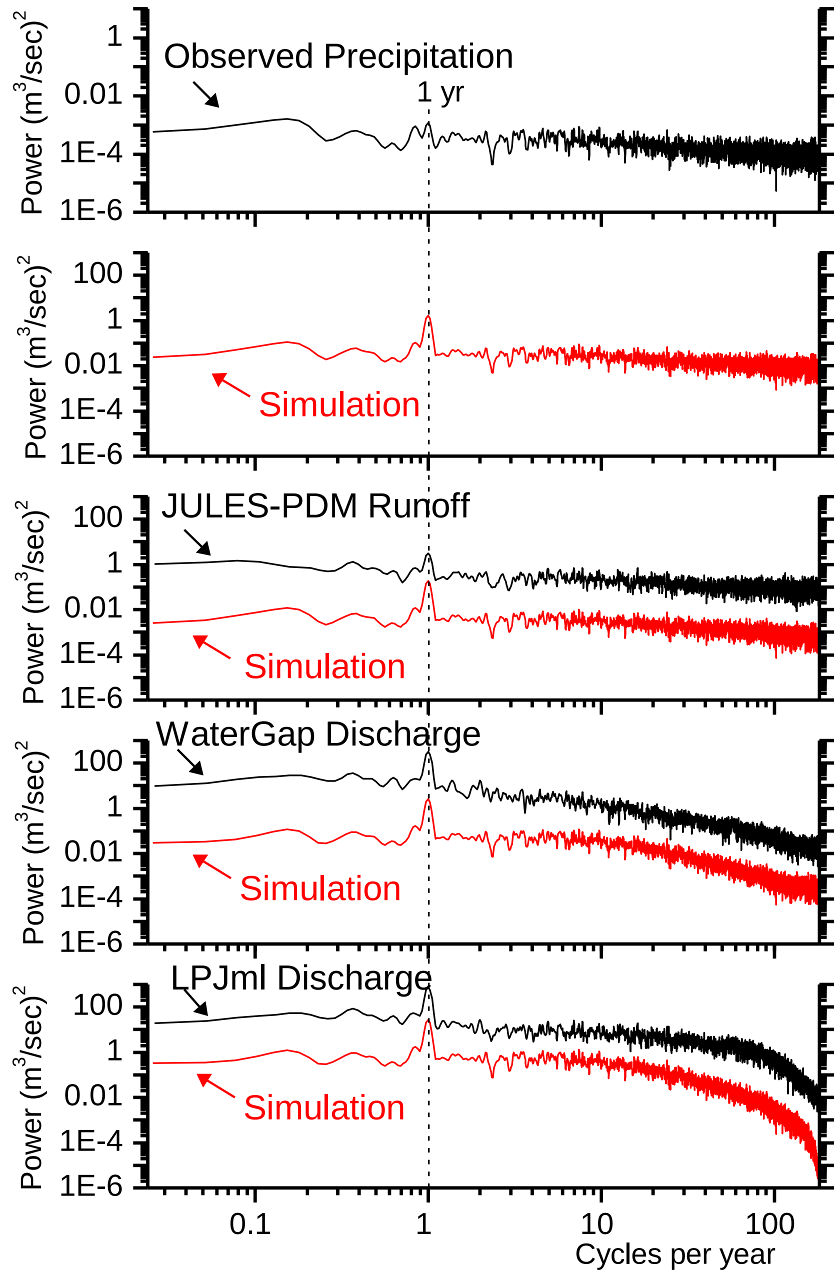
$R(t) = R(t) + 0.1*R(t)$

Adding Strong autocorrelation (Routing "memory")

$D(t) = R(t) + 0.7*R(t\text{-}1)$

Adding moving-average (Routing artifact)

$D(t) = [D(t) + D(t\text{-}1)]/2$



Conclusions:

1) Cross-spectral analysis provides quantitative assessment of model performance in terms of reproducing observed amplitude and phase at different time scales. Separation of performance into different time scales allows consideration of model performance in terms of different physical processes.

2) Although using TOPMODEL or PDM allows some improvement of short-term (weekly) variability in discharge, it also leads to degraded performance in terms of amplitude at annual scales.

3) In terms of reproducing discharge variability, provided the overall evaporation is right (assessed via MBE): then modelling of routing is more important than modelling runoff.

4) JULES (and other models) introduces a “moving-average artifact” causing suppression of very short-term (few days) variability when simulating discharge related to representation of routing (caused by grid box to grid box transfer of water).