Cardington Transfer functions
Latent Heat v Downwards shortwave flux

![Graphs showing transfer functions between Latent Heat and Downwards shortwave flux.](image)

- **Latent Heat (Observed)**: Power (W m\(^{-2}\))
- **SWdown (Observed)**: Power (W m\(^{-2}\))
- **Amplitude ratio (+/-95% CI)**: 0.364
- **Phase (+/-95% CI)**: (degrees)

Cycles per year:
- 0.1
- 1
- 10
- 100
- 1000

Power (W m\(^{-2}\)):
- 10000
- 1000
- 100
- 10
- 1
- 0.1
- 0.01
- 0.001
- 1E-3

Phase (degrees):
- -180
- -90
- 0
- 90
- 180

Amplitude ratio range:
- 0.1
- 1
- 10
- 100
- 1000

Phase range:
- -180
- -90
- 0
- 90
- 180

Observed values:
- Latent Heat
- SWdown

0.1 1 10 100... (W m\(^{-2}\))

Latent Heat
JULES-Card-Obs
Latent Heat
Observed
12th - 15th July 2008 Cardington

SWdown: Observed vs WFDEI

Latent Heat: Observed vs JULES-Card-Obs

Latent Heat: Observed vs JULES-WFDEI

Latent Heat: Observed vs Empirical estimate

SWdown-Obs x 0.364
Cardington Evaluation of output variable
JULES Latent Heat v Observed Latent Heat

Latent Heat
JULES-Card-Obs

Latent Heat
Observed

Latent Heat
JULES-WFDEI

Latent Heat
JULES-Card-Obs

Latent Heat
Observed

Cardington Evaluation of output variable
JULES Latent Heat v Observed Latent Heat

Latent Heat
JULES-Card-Obs

Latent Heat
Observed

Latent Heat
JULES-WFDEI

Latent Heat
JULES-Card-Obs

Latent Heat
Observed
Comparing bias according to forcing data: JULES-Card-Obs and JULES-WFDEI

Sensible Heat: Observed v JULES
Latent Heat: Observed v JULES

Diurnal scale
Annual scale

Amp. ratio

Phase (°)

Comparing bias according to forcing data:
JULES-Card-Obs and JULES-WFDEI
Comparing bias according to forcing data: JULES-Card-Obs and JULES-WFDEI

Latent Heat: Observed v JULES
- Annual scale
- Diurnal scale

Sensible Heat: Observed v JULES
- Annual scale
- Diurnal scale

Seasonal variation in diurnal scale bias

Comparing bias according to forcing data:
- JULES-Card-Obs
- JULES-WFDEI
Frequency response from the spectral transfer function

INPUT
Observed Precipitation

SYSTEM
Cardington site

OUTPUT
Soil saturation 0-10cm

INPUT
Observed Precipitation

JULES
Cardington site

OUTPUT
Soil saturation Top layer
Precipitation and top-layer soil saturation

Precipitation

- Observed
- WFDEI 30 min
- WFDEI 3 hour

Soil saturation (top layer)

- Observed
- JULES-Card-Obs
- JULES-WFDEI 30 min
- JULES-WFDEI 3 hr

Data spans from 2008.6 to 2008.8.
Investigating the phase of impulse v. response (soil saturation variations after precipitation events)
Investigating the phase of impulse v. response (soil saturation variations after precipitation events)
Investigating the phase of impulse v. response (soil saturation variations after precipitation events)
Sum of harmonics 1 to 5

Revised observed precipitation

$\lambda = 4.18$ days First harmonic (Fundamental)

$\lambda = 2.09$ days Second harmonic

$\lambda = 1.39$ days Third harmonic

$\lambda = 1.05$ days Fourth harmonic

$\lambda = 0.84$ days Fifth harmonic
Repeated observed precipitation

\[ \lambda = 4.18 \text{ days First harmonic (Fundamental)} \]

\[ \lambda = 2.09 \text{ days Second harmonic} \]

\[ \lambda = 1.39 \text{ days Third harmonic} \]

\[ \lambda = 1.05 \text{ days Fourth harmonic} \]

\[ \lambda = 0.84 \text{ days Fifth harmonic} \]

Repeated observed soil saturation

\[ \lambda = 4.18 \text{ days First harmonic (Fundamental)} \]

\[ \lambda = 2.09 \text{ days Second harmonic} \]

\[ \lambda = 1.39 \text{ days Third harmonic} \]

\[ \lambda = 1.05 \text{ days Fourth harmonic} \]

\[ \lambda = 0.84 \text{ days Fifth harmonic} \]

Sum of harmonics 1 to 5
Repeated observed precipitation

\[ \lambda = 4.18 \text{ days First harmonic (Fundamental)} \]
\[ \lambda = 2.09 \text{ days Second harmonic} \]
\[ \lambda = 1.39 \text{ days Third harmonic} \]
\[ \lambda = 1.05 \text{ days Fourth harmonic} \]
\[ \lambda = 0.84 \text{ days Fifth harmonic} \]

Repeated observed soil saturation

\[ \lambda = 4.18 \text{ days First harmonic (Fundamental)} \]
\[ \lambda = 2.09 \text{ days Second harmonic} \]
\[ \lambda = 1.39 \text{ days Third harmonic} \]
\[ \lambda = 1.05 \text{ days Fourth harmonic} \]
\[ \lambda = 0.84 \text{ days Fifth harmonic} \]

Sum of harmonics 1 to 5

About 90°
"Expected" response: Positive phase of about +90°.

"Intermittent" response: Memo: Phase spectra give averages. Negative phase due to a few, large precipitation events at a time spacing that matches many large dry-downs. NB: Precip. events and dry-downs NOT coincident in time.
Conclusions:

1) Cross-spectral analysis, adapted for data with missing time steps, provides a useful way to investigate how a model (e.g. JULES) represents physical processes. In evaluations this is achieved by examining the mis-matches between observations and model output time series at different frequencies using amplitude and phase estimates.

2) The frequency responses of JULES for: a) energy fluxes (latent heat v SWdown) and b) soil moisture (saturation v. precipitation) are a good match to the real world frequency responses (unlike JULES running TRIP for Discharge v precipitation).