Supplementary Material

Set A

The figures in Set A of the Supplementary Material are referred to in the main part of the paper as, for example, Supplementary Figure A(i, BP) which indicates Set A and Figure (i) for Balta Pier. Figures are provided for each of the measurement sites in Table 1, in a similar way to Figure 2(a-d) is provided for Lerwick in the main part of the paper. They show:

(i) Time series of sea level residuals (defined as explained in the text).
(ii) Time series of the standard deviation of residuals within 2-hour windows centred on each residual.
(iii) Power spectral density (PSD) of the total sea level variability (red).
(iv) Wavelet spectrum of the residual time series.

'Sea level' here means the measured quantity: either real sea level or SSP as shown in Table 1. Note that the plots are made from records of different lengths and at different times.

Plots (ii) for Busta House, Toft and Gutcher also include in red the standard deviation of the tide within the same windows, divided by 10 and offset by 80, 50 and 90 mm respectively for presentation purposes.

Plots (iii) start at 0.1 cph in order to cut off the large peaks of the diurnal and semidiurnal tides and the error bar indicates 95% confidence level. The black curve presents a low-pass filtered version of the spectrum above 0.5 cph obtained by smoothing into bins of 0.05 cph.

The wavelet plots (iv) are intended only to give a qualitative impression of the time dependence of energy. Zero energy is indicated by light blue and greater energy by the stronger colours. Cones of influence are not drawn as they are important only at low frequencies off the bottom of the plots

Set B

Meteorological data (1-min values) for Lerwick for 1-3 July 2015 (a) surface air pressure (hPa), (b) wind speed (knots), (c) wind direction (clockwise meteorological convention of 0° indicating wind blowing from the north, 90° from the east etc.), (d) maximum wind gust (knots). The red dots indicate missing sections of data.

Set C

Additional figures for some sites referred to as, for example, Supplementary Figure C(iii) in the text. Each figure shows on the left the median standard deviation of residuals within 2-hour windows through the record as a function of the height of the tide (in blue). Also shown are the 10 and 90 percentile standard deviations (in red). On the right is shown the median standard deviation for the whole record once again (in blue) and also the median standard deviations for tidal range above (red) and below (green) the mean tidal range (i.e. spring and neap tides). The red curves inevitably span a greater range of tide height than the green ones.

Plots are shown for residuals that are band-passed filtered using the 'digital_filter' function of IDL so as to select particular individual seiche peaks:

(i) Lerwick with a 20-40 min (1.5-3 cph) filter
(ii) Lerwick with a 25-35 min (1.7-2.4 cph) filter
(iii) Balta Pier with a 25-35 min (1.7-2.4 cph) filter
(iv) Toft with no band-pass filtering

(v) Scalloway with a 15-23 min (2.6-4 cph) filter
(vi) Sella Ness with a 25-35 min (1.7-2.4 cph) filter
(vii) Sella Ness with a 60-120 min (0.5-1 cph) filter
(viii) Gutcher with no band-pass filtering
(ix) Whalsay with no band-pass filtering

In the case of Lerwick, its '28-minute' peak is wider than at Balta Pier, so we show plots for (i) a wide band spanning the whole Lerwick peak, and (ii) the narrower band as for Balta Pier. In the case of Sella Ness, we show plots for its two main peaks.

Set D

This set includes figures provided by the numerical model:

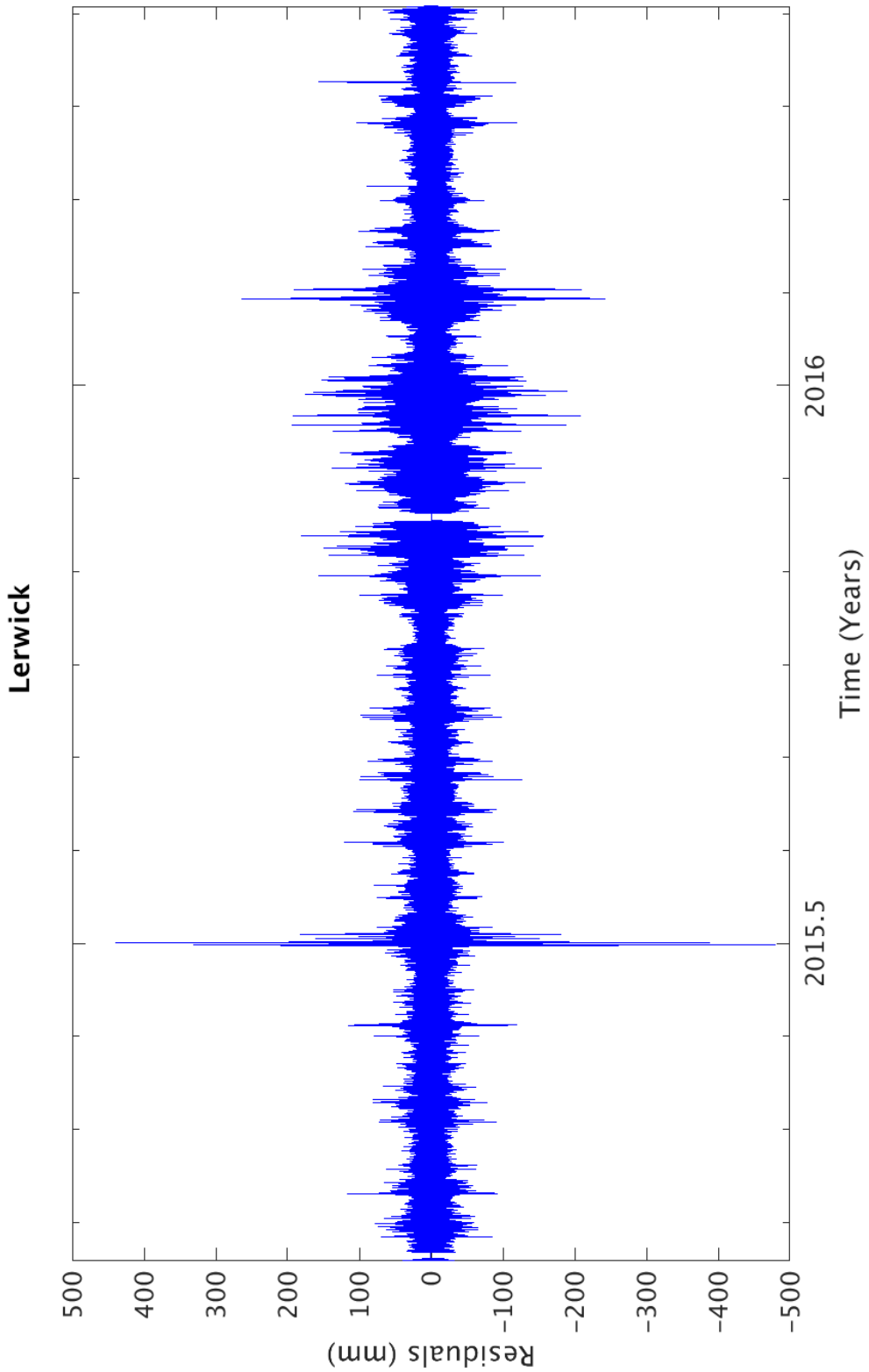
(i) Map of the variance (cm^2) of sea level variability at frequencies larger than 0.5 cph from the January 2015 model run.
(ii) As (i) but from the July 2015 model run.
(iii) Histogram of wind direction measured by the Lerwick weather station during the period of the January 2015 model run.
(iv) As (iii) but during the period of the July 2015 model run.
(v) As (iii) but during days 270-335 2015 when most of the measurements represented in Figure 6(a) were obtained.
(vi) Spectra of 1-minute model sea levels for Lerwick and Balta Pier from the July 2015 run, and Scalloway and Sella Ness from the January 2015 run, at times when the east and west coasts were energised preferentially as shown in (ii) and (i) respectively.
(vii) Map of the variance (cm^2) of sea level variability in the band 0.5-1.5 cph from the January 2015 model run,
(viii) in the 1.5-2.5 cph band and
(ix) for the band >2.5 cph.
(x) Map of the variance (cm^2) of sea level variability in the band 0.5-1.5 cph from the July 2015 model run,
(xi) in the 1.5-2.5 cph band and
(xii) for the band >2.5 cph.

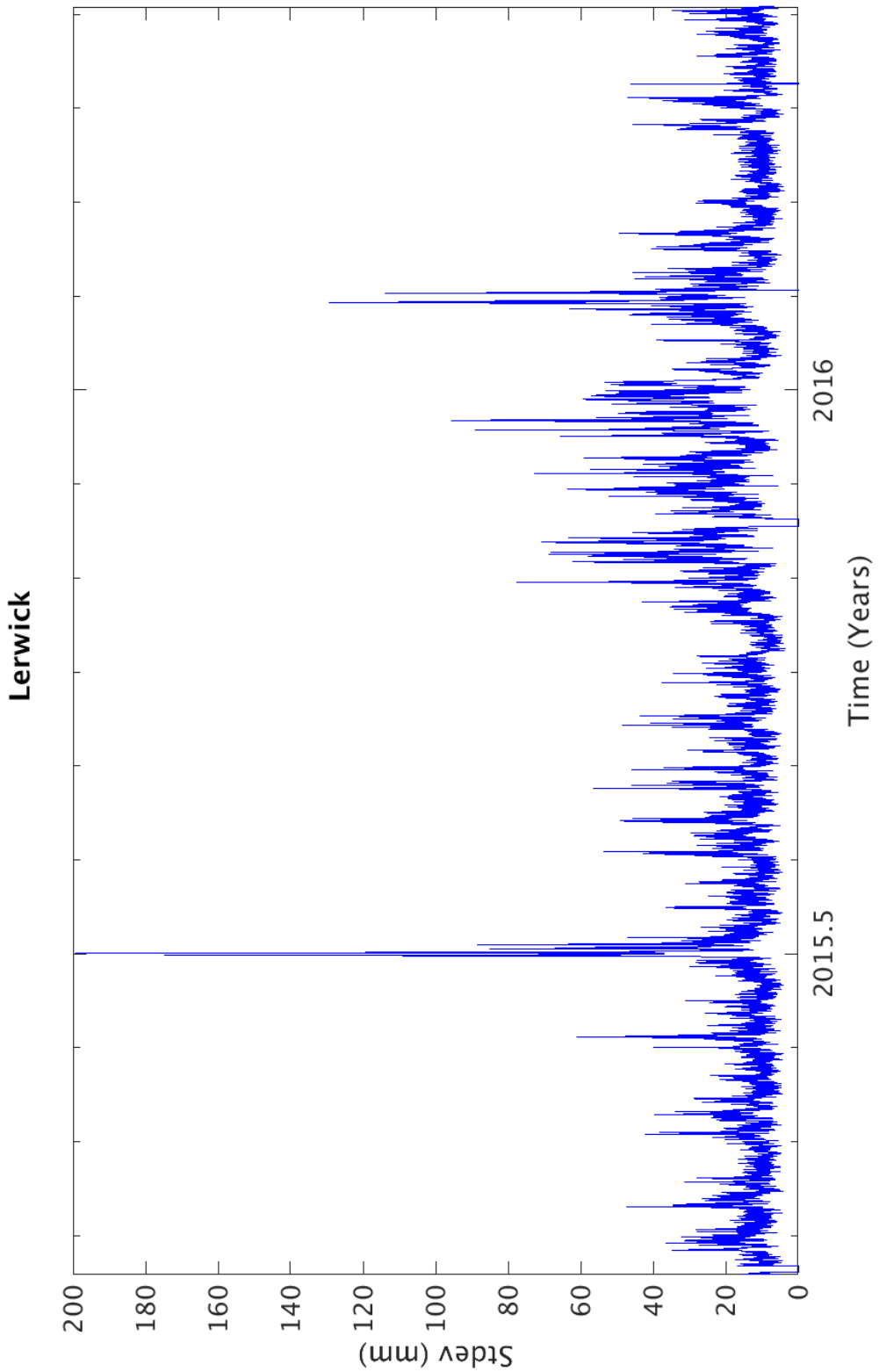
(xiii-xvii) Variance of sea level, zonal and meridional components of current (denoted U and V respectively) from the July 2015 numerical model run. (Those for the January 2015 run are similar). (xiii) Lerwick and (xiv) Balta Sound and Burra Firth. Units are cm^2 and $(cm/sec)^2$. Model time series in each case have been band-pass filtered to isolate variability within the common 25-35 minute band (see Supplementary Material Set C). (xv) Dury Voe for variability within the band 1.6-2.2 cph, which corresponds to the span of the observed peak at Whalsay, (xvi) Sella Ness for the band 0.5-1.0 cph, which spans the main observed peak at this location, and (xvii) Blue Mull Sound for the highest frequencies with periods less than 25 minutes (see also discussion of Gutcher in the text).

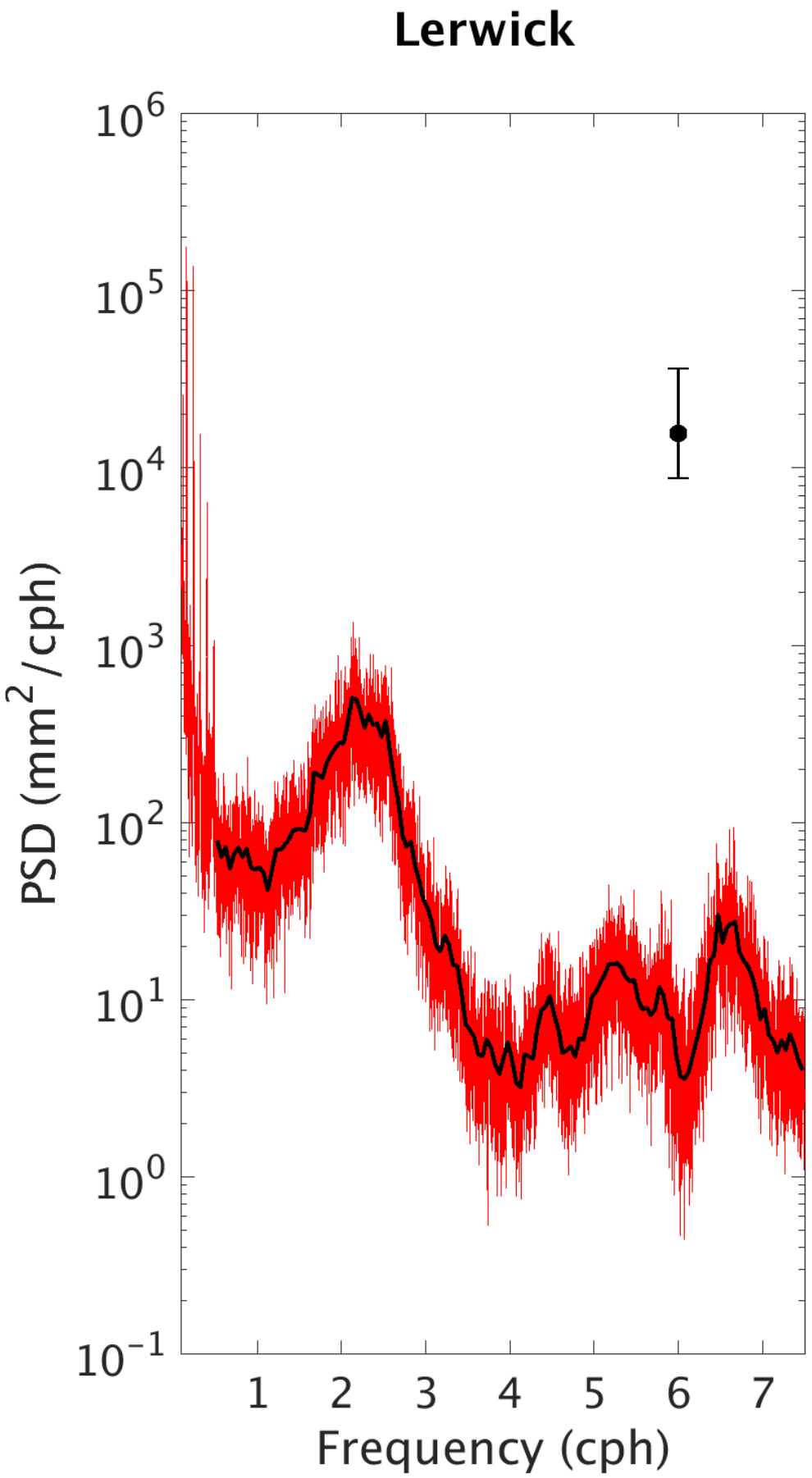
Set E

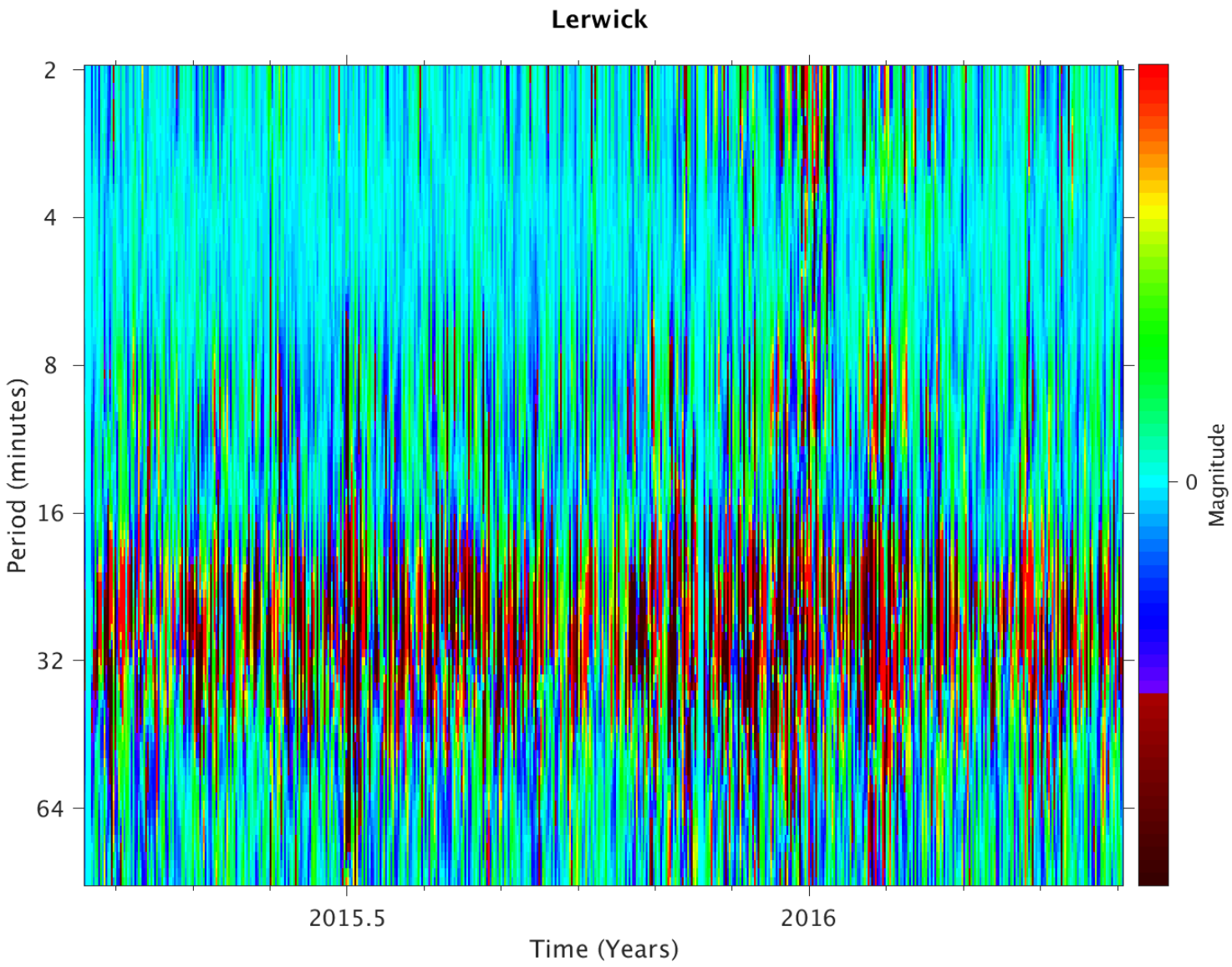
Supplementary Figure E1 shows the amplitudes of M4 to M12 for the seven northern stations in Figure 1(b) and also Lerwick for comparison (calculated using harmonic analysis, even harmonics only). Balta Pier and Balta Offshore are shown by red dots. Also shown are Sella Ness (black diamonds), Whalsay (black dots), Toft (black asterisks), Out Skerries (blue diamonds), Gutcher (blue dots) and Lerwick (green dots).

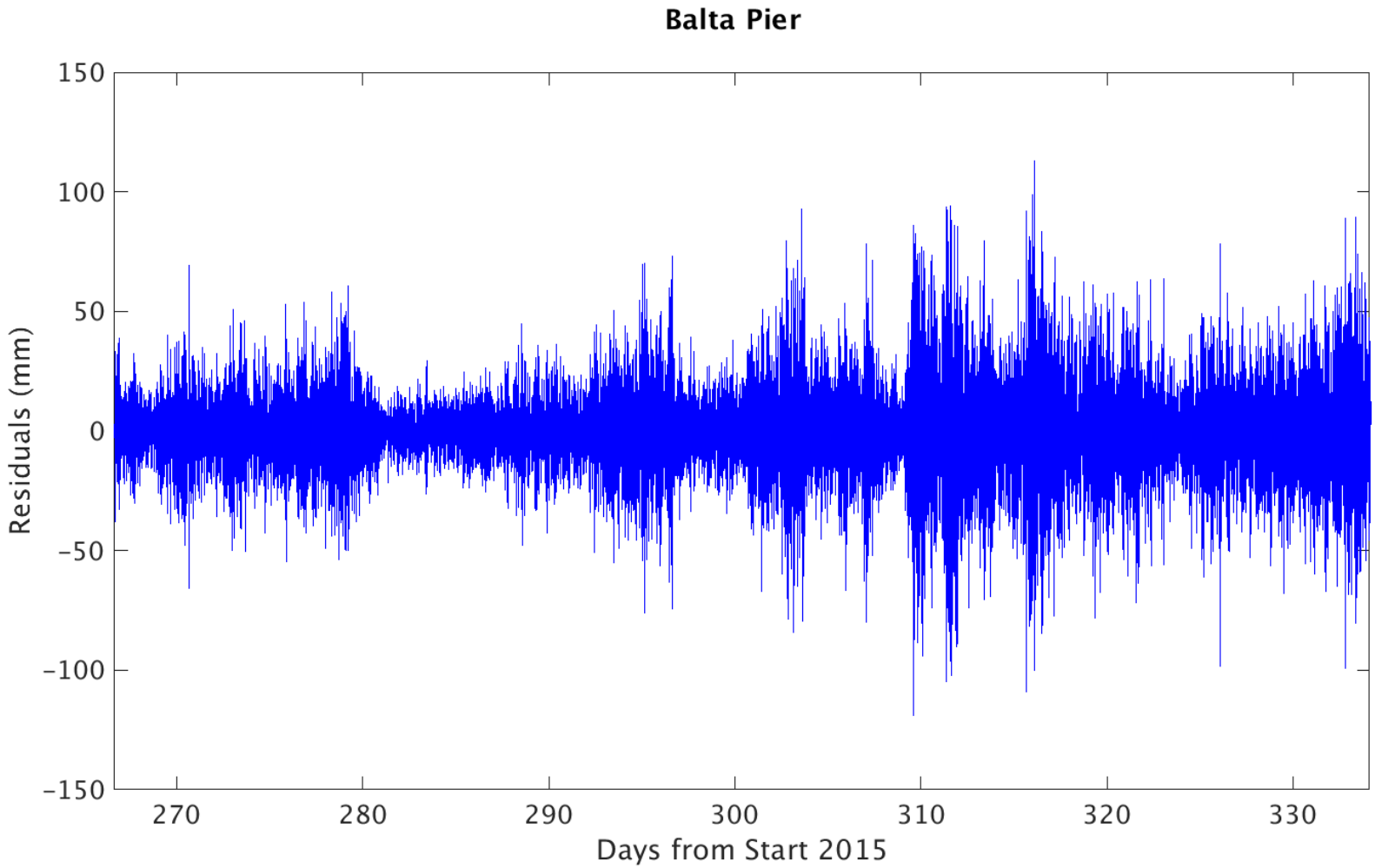
Set A

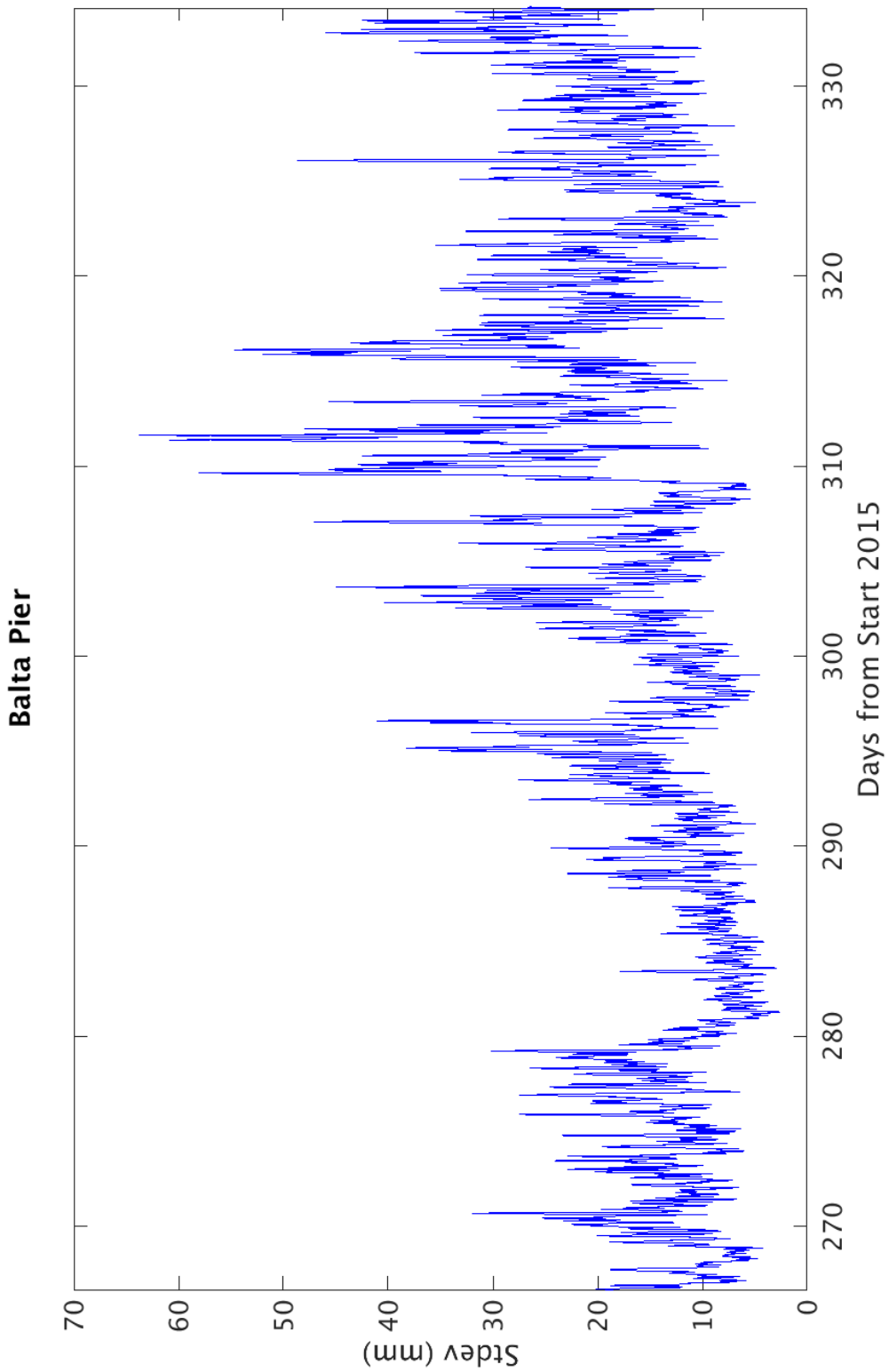

Lerwick
500
400
300
200
100
0
-100
-200
-300
-400
-500
Residuals (mm)
2015.5
2016
Time (Years)

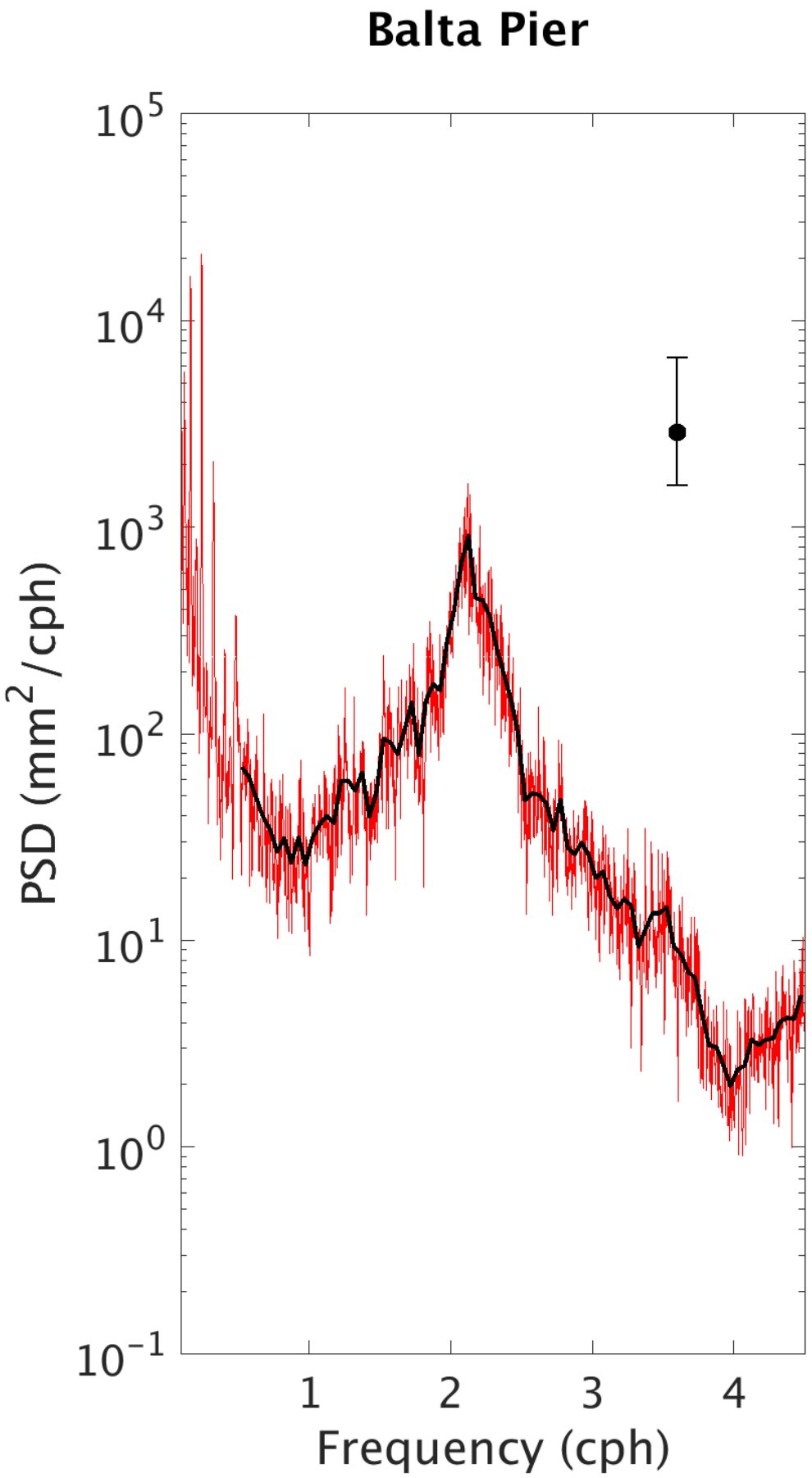

Lerwick
Stdev (mm)
200
180
160
140
120
100
80
60
40
20
0
2015.5
2016
Time (Years)

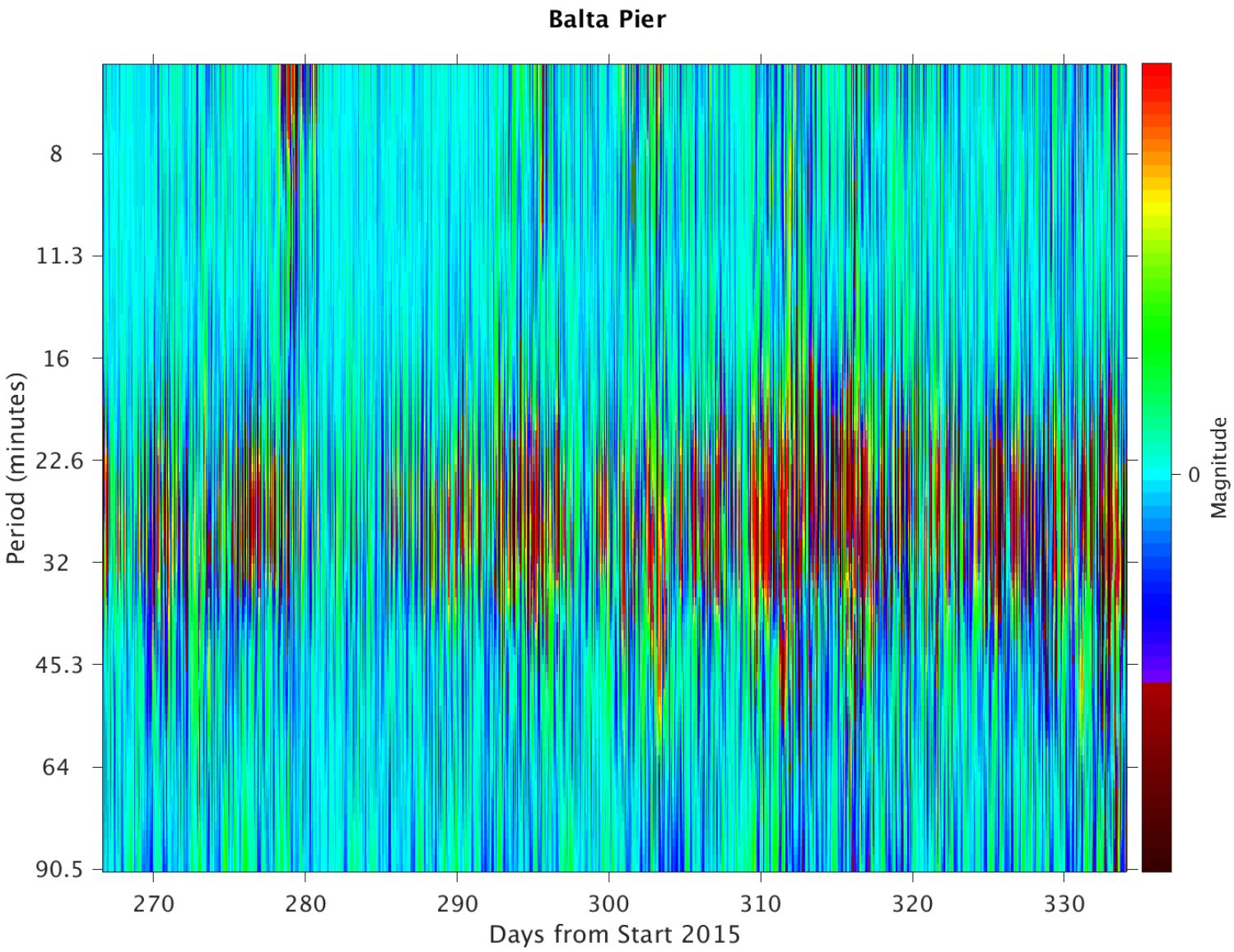

Lerwick
PSD (mm^2/cph)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
1
2
3
4
5
6
7
Frequency (cph)

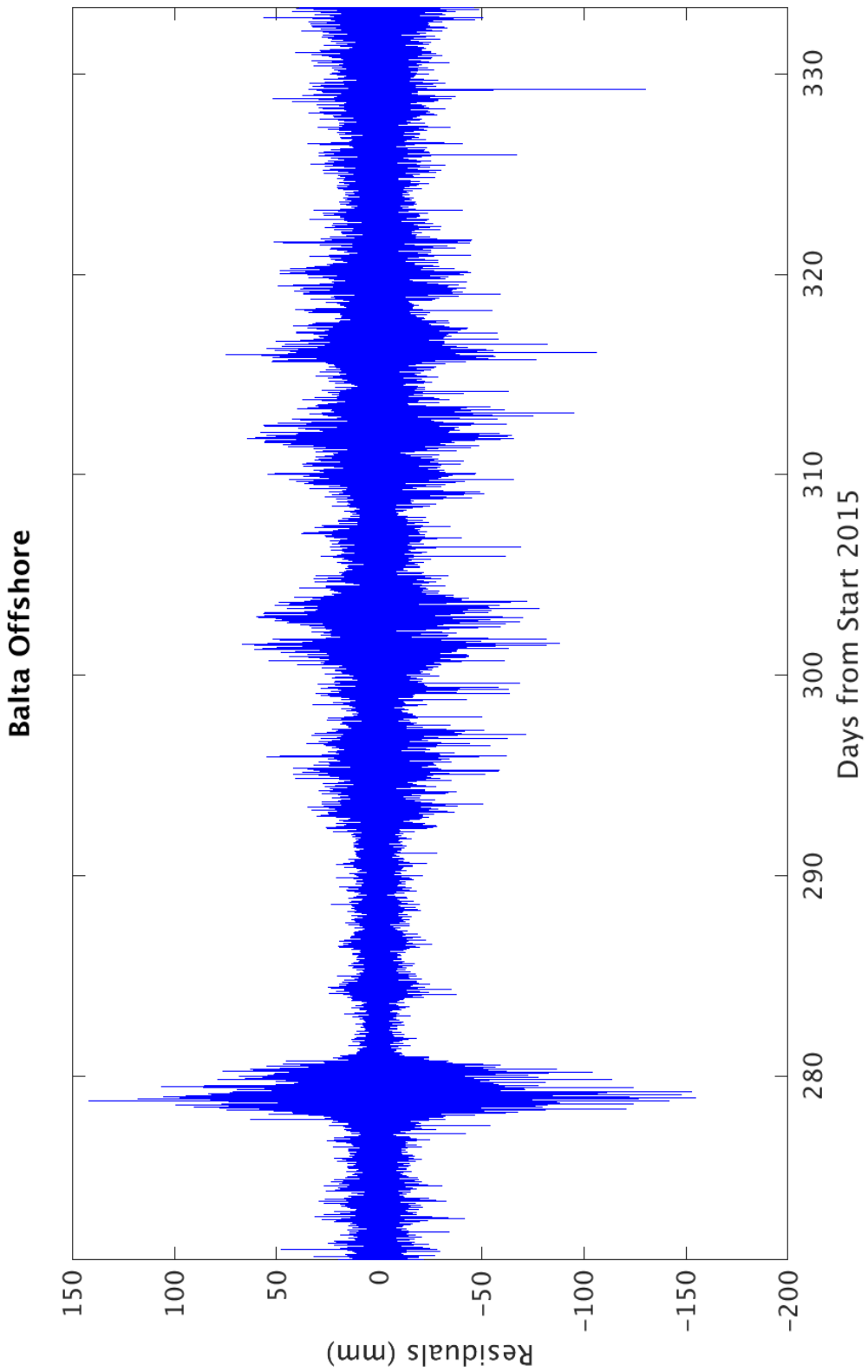

Lerwick
Period (minutes)
2
4
8
16
32
64
2015.5
2016
Time (Years)
Magnitude
0

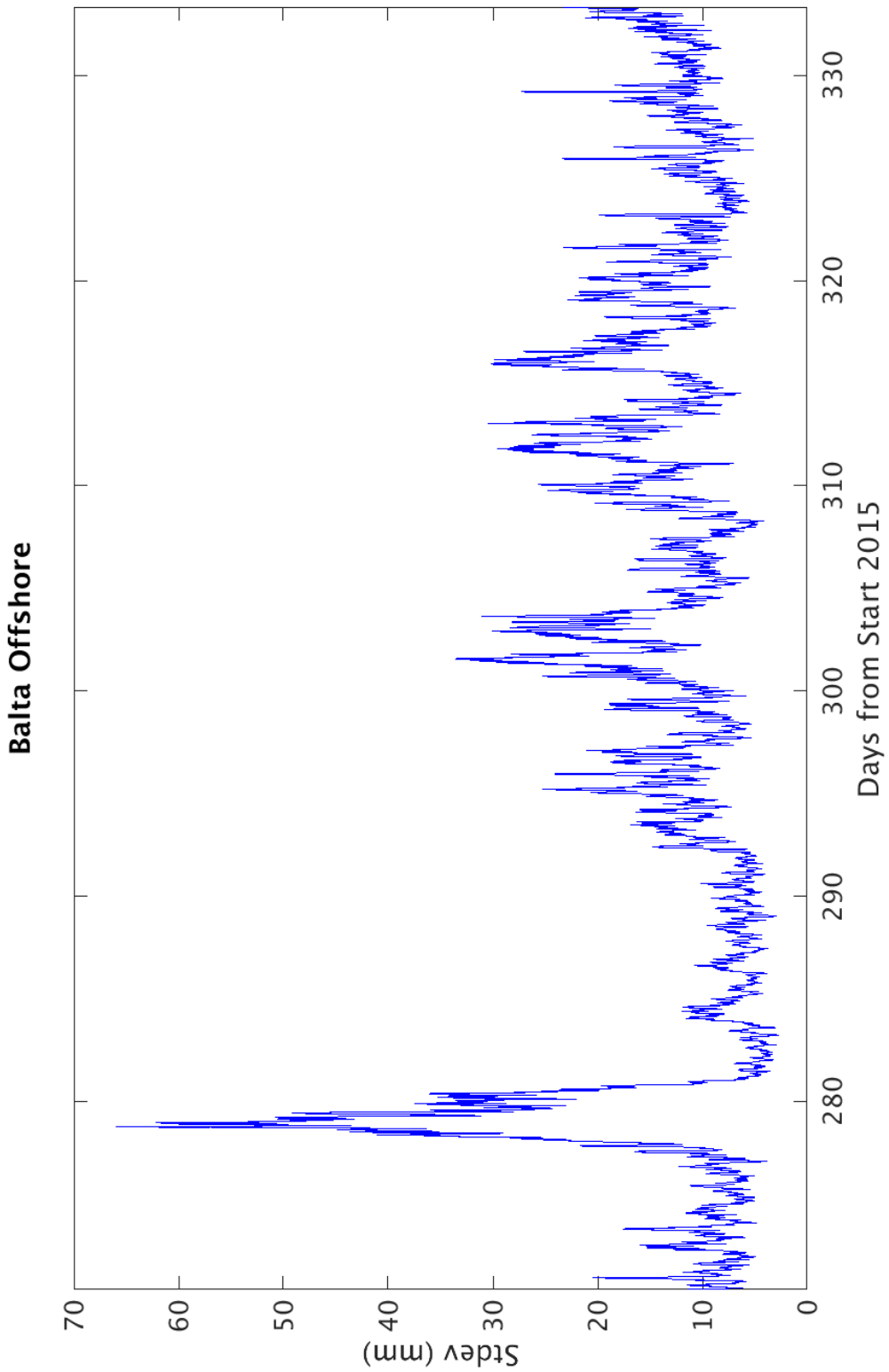

Balta Pier
150
100
50
0
−50
−100
−150
Residuals (mm)
270
280
290
300
310
320
330
Days from Start 2015

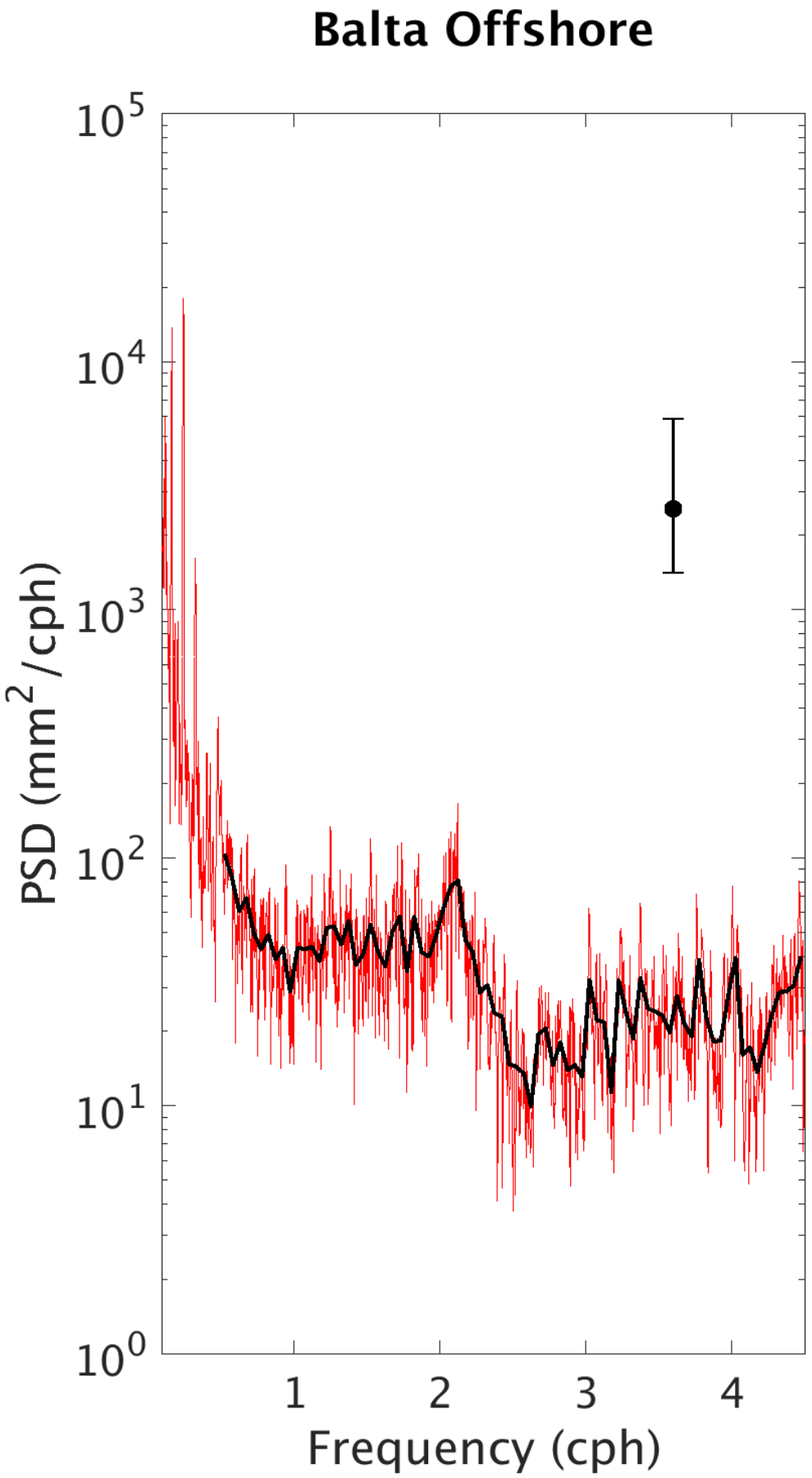

Balta Pier
Stdev (mm)
0
10
20
30
40
50
60
70
270
280
290
300
310
320
330
Days from Start 2015

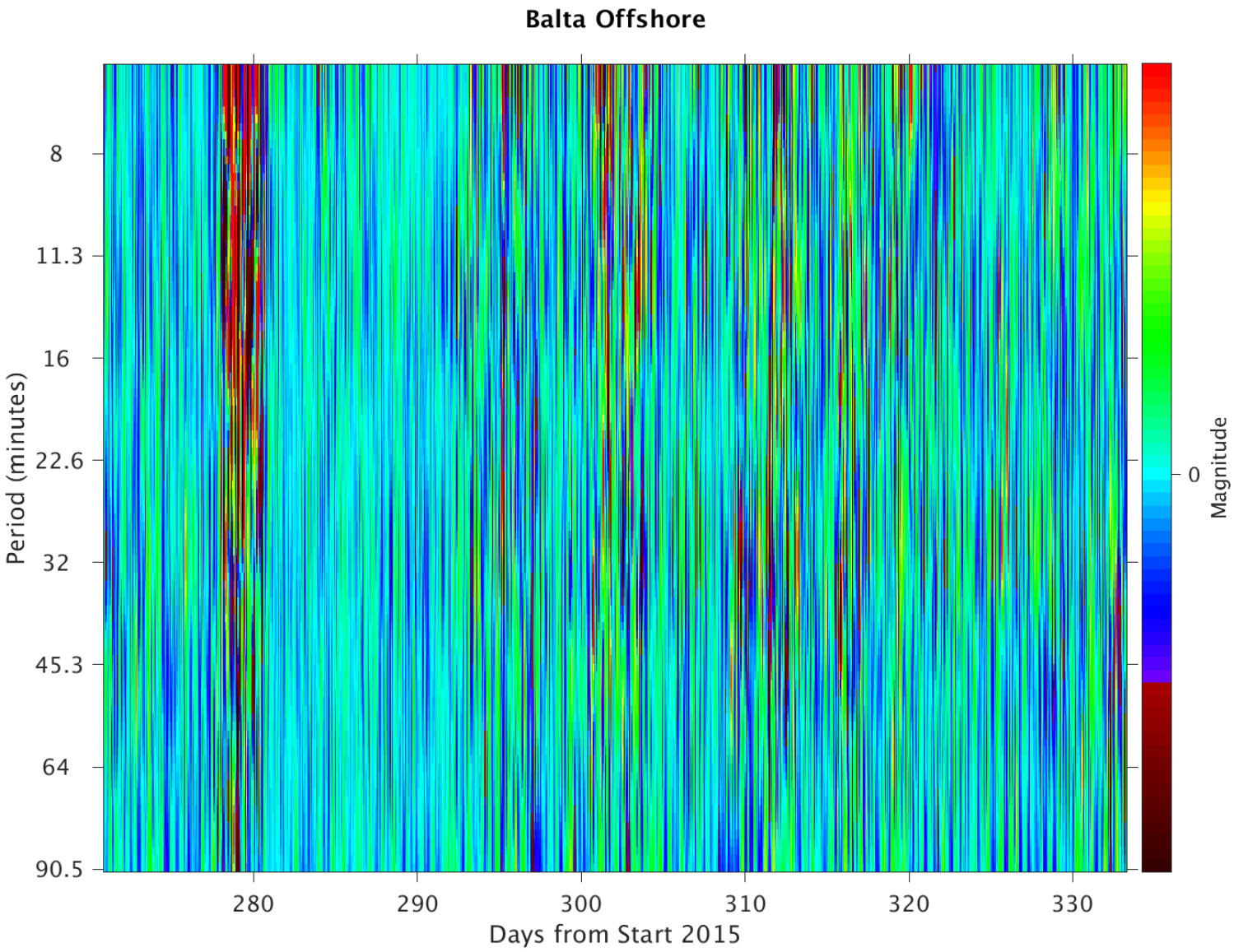

Balta Pier
PSD (mm^2/cph)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
1
2
3
4
Frequency (cph)

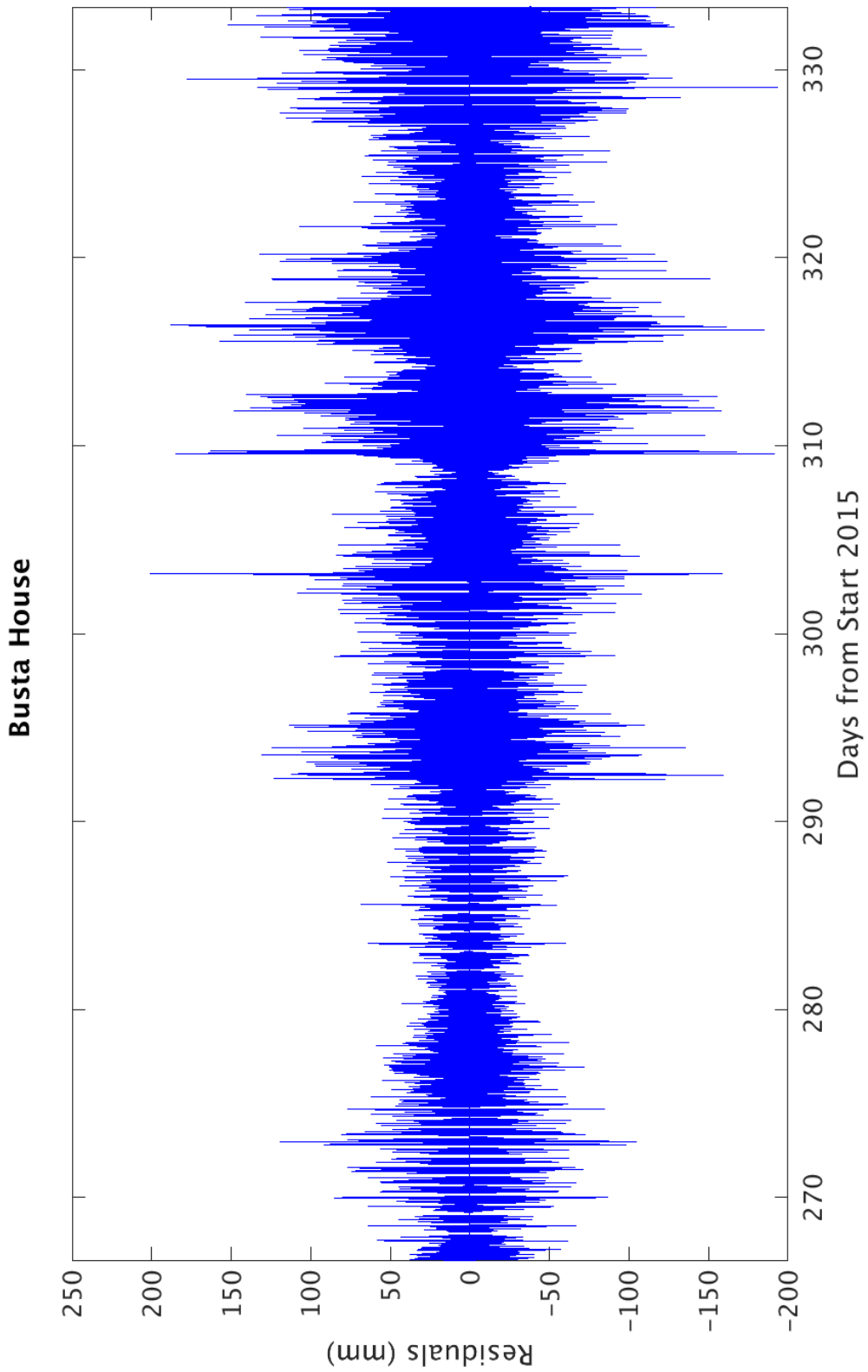

Balta Pier
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
270
280
290
300
310
320
330
Days from Start 2015
Magnitude
0

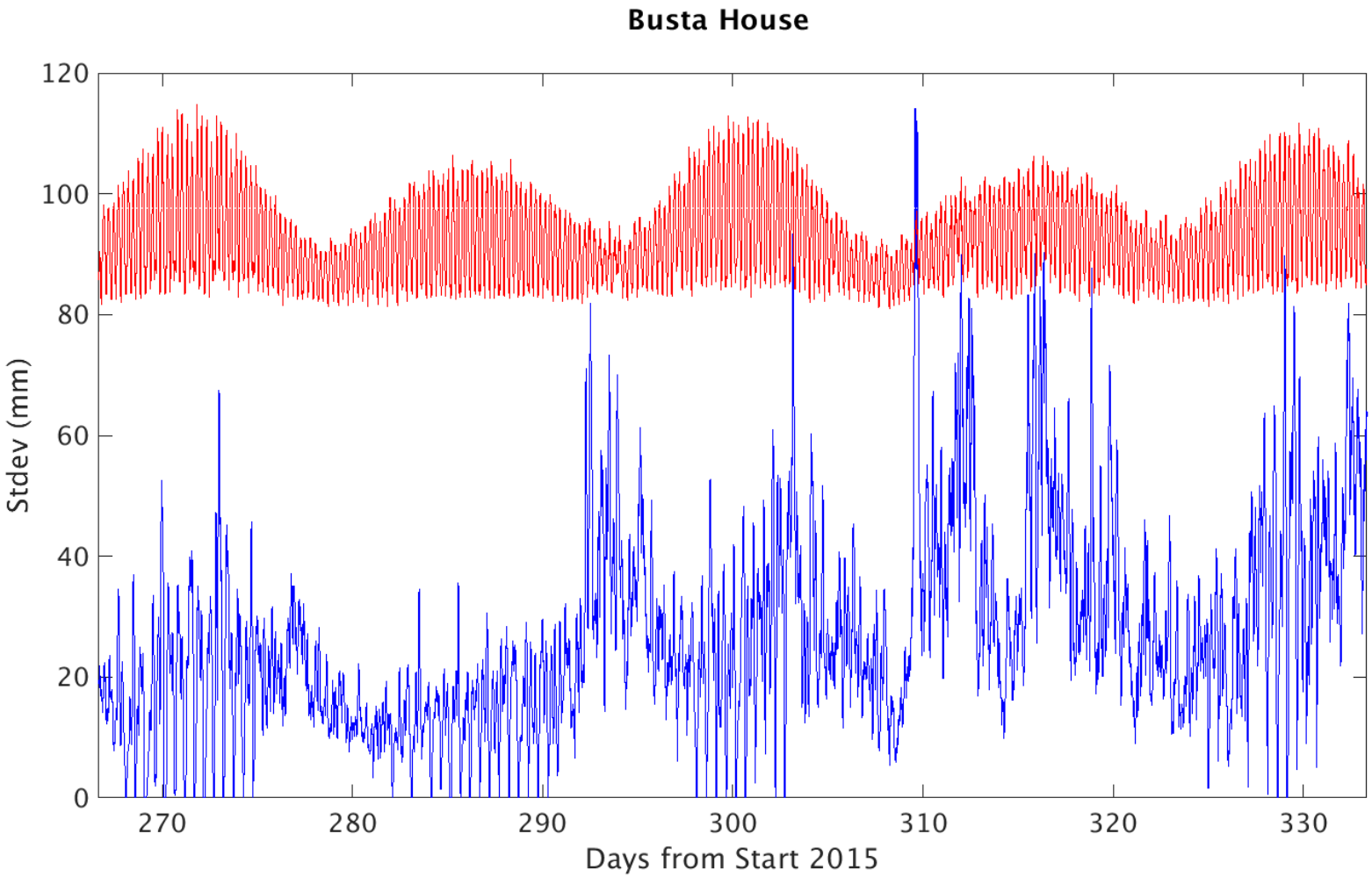

Balta Offshore
Residuals (mm)
150
100
50
0
-50
-100
-150
-200
280
290
300
310
320
330
Days from Start 2015

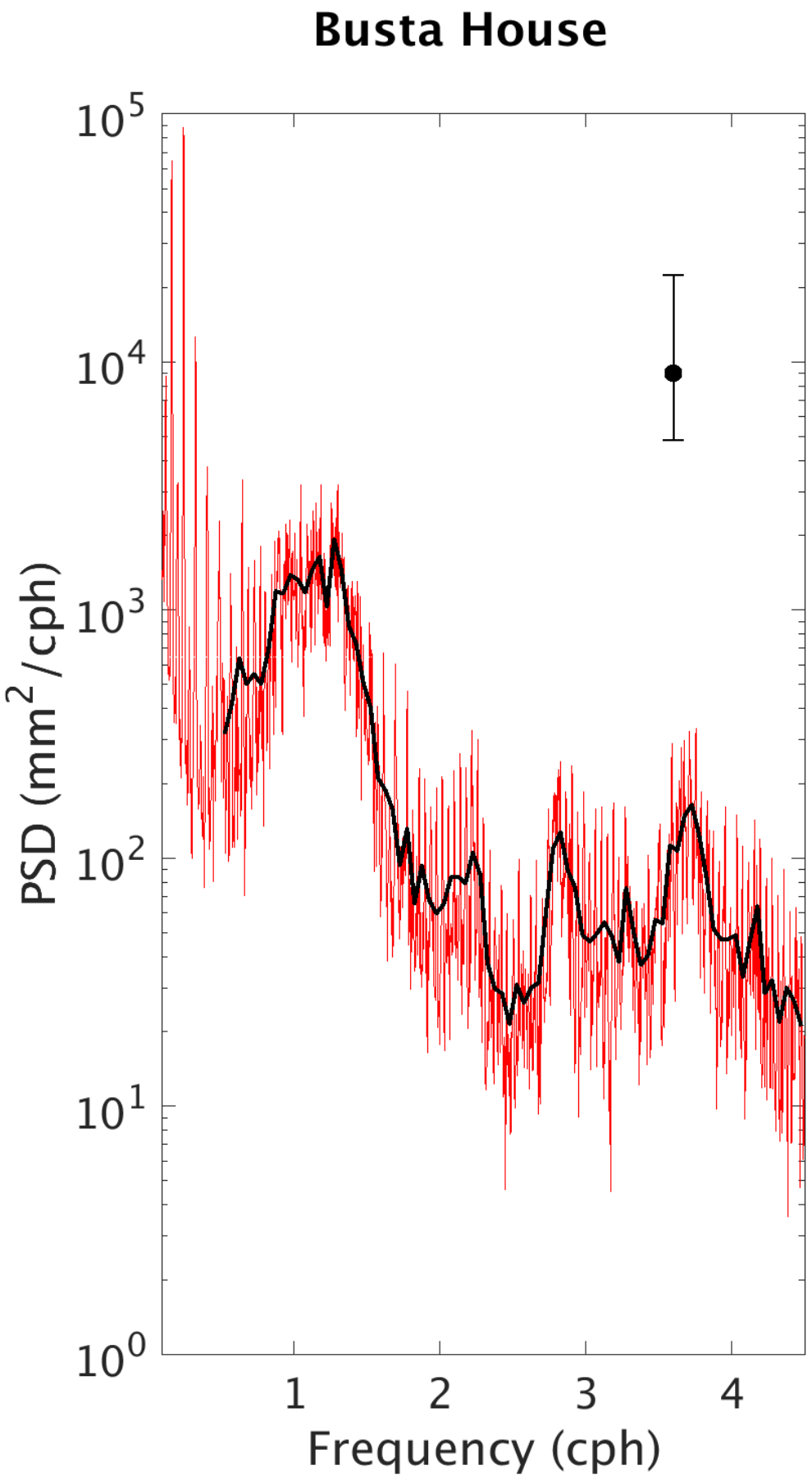

Balta Offshore
Stdev (mm)
70
60
50
40
30
20
10
0
280
290
300
310
320
330
Days from Start 2015

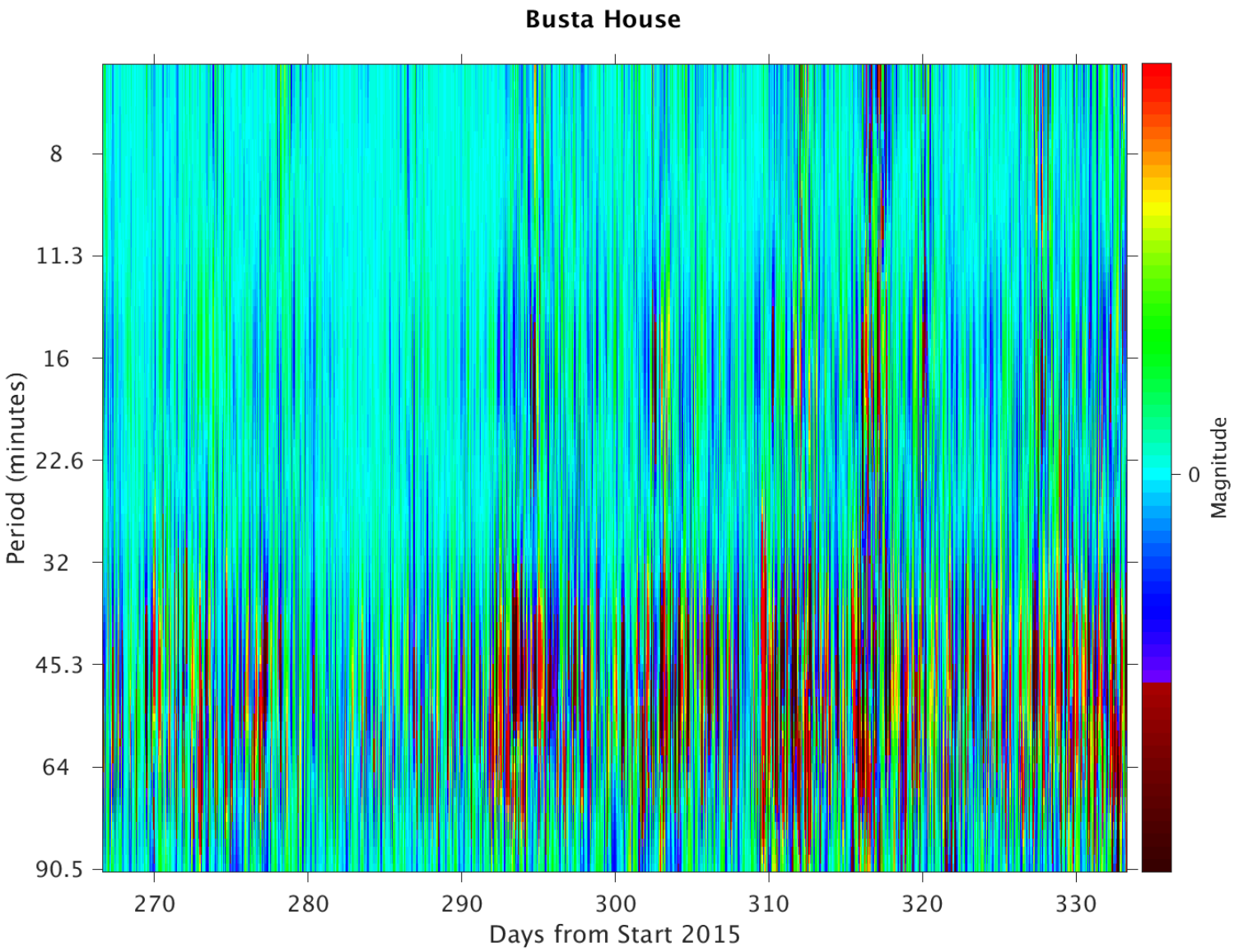

Balta Offshore
PSD (mm^2/cph)
10^5
10^4
10^3
10^2
10^1
10^0
1
2
3
4
Frequency (cph)

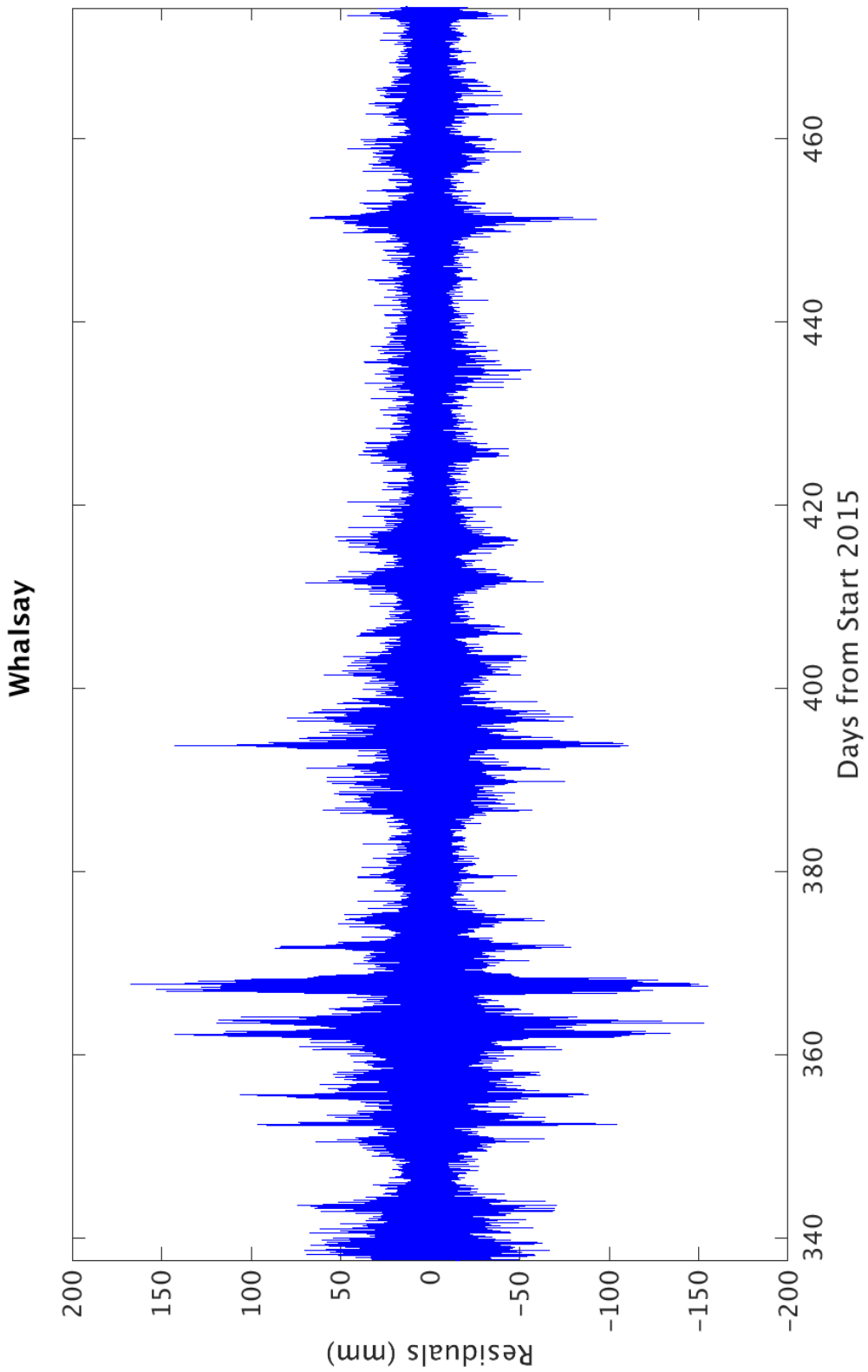

Balta Offshore
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
280
290
300
310
320
330
Days from Start 2015
Magnitude
0

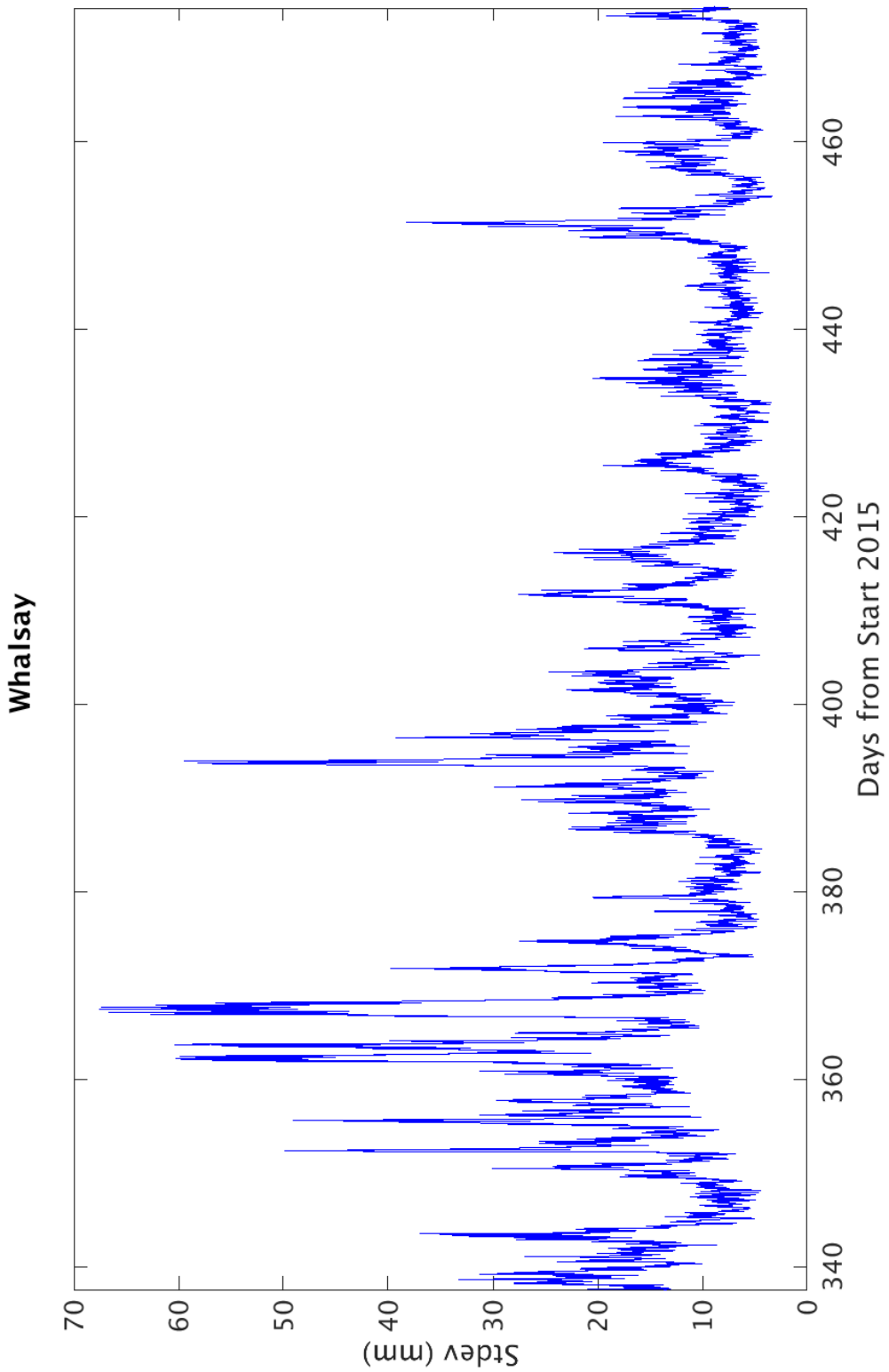

Busta House
Residuals (mm)
250
200
150
100
50
0
-50
-100
-150
-200
270
280
290
300
310
320
330
Days from Start 2015

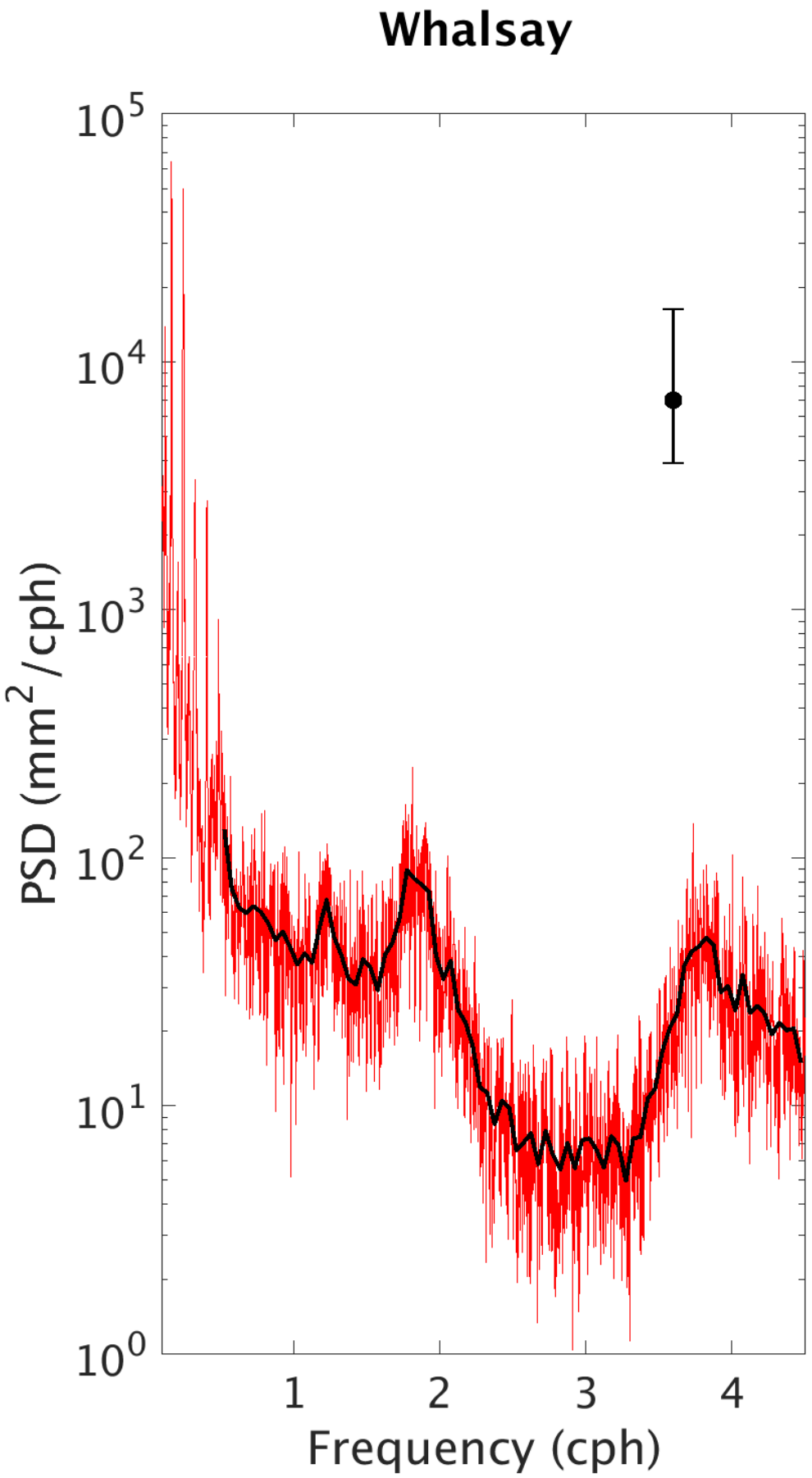

Busta House
120
100
80
60
40
20
0
Stdev (mm)
270
280
290
300
310
320
330
Days from Start 2015

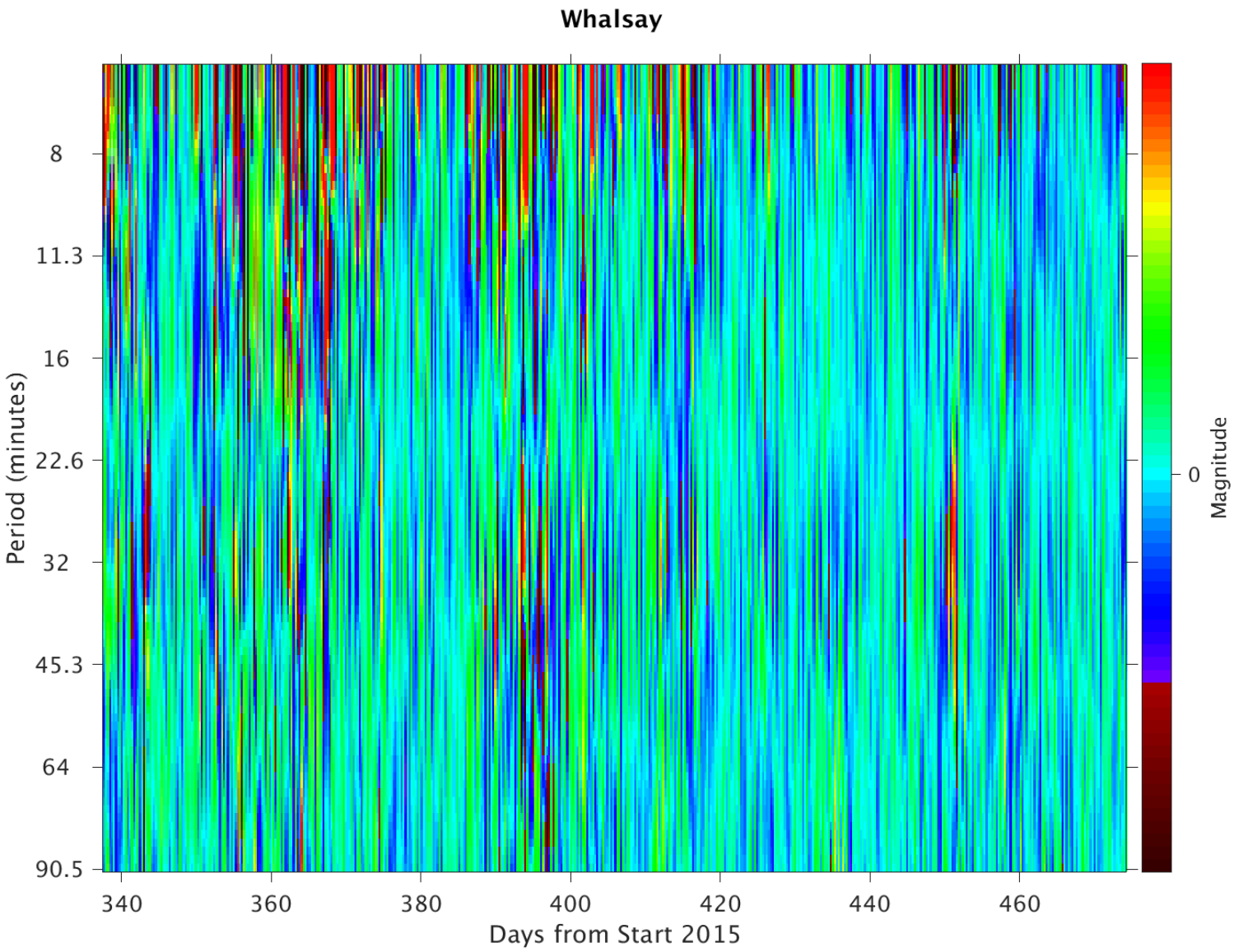

Busta House
10^5
10^4
10^3
10^2
10^1
10^0
PSD (mm^2/cph)
1
2
3
4
Frequency (cph)

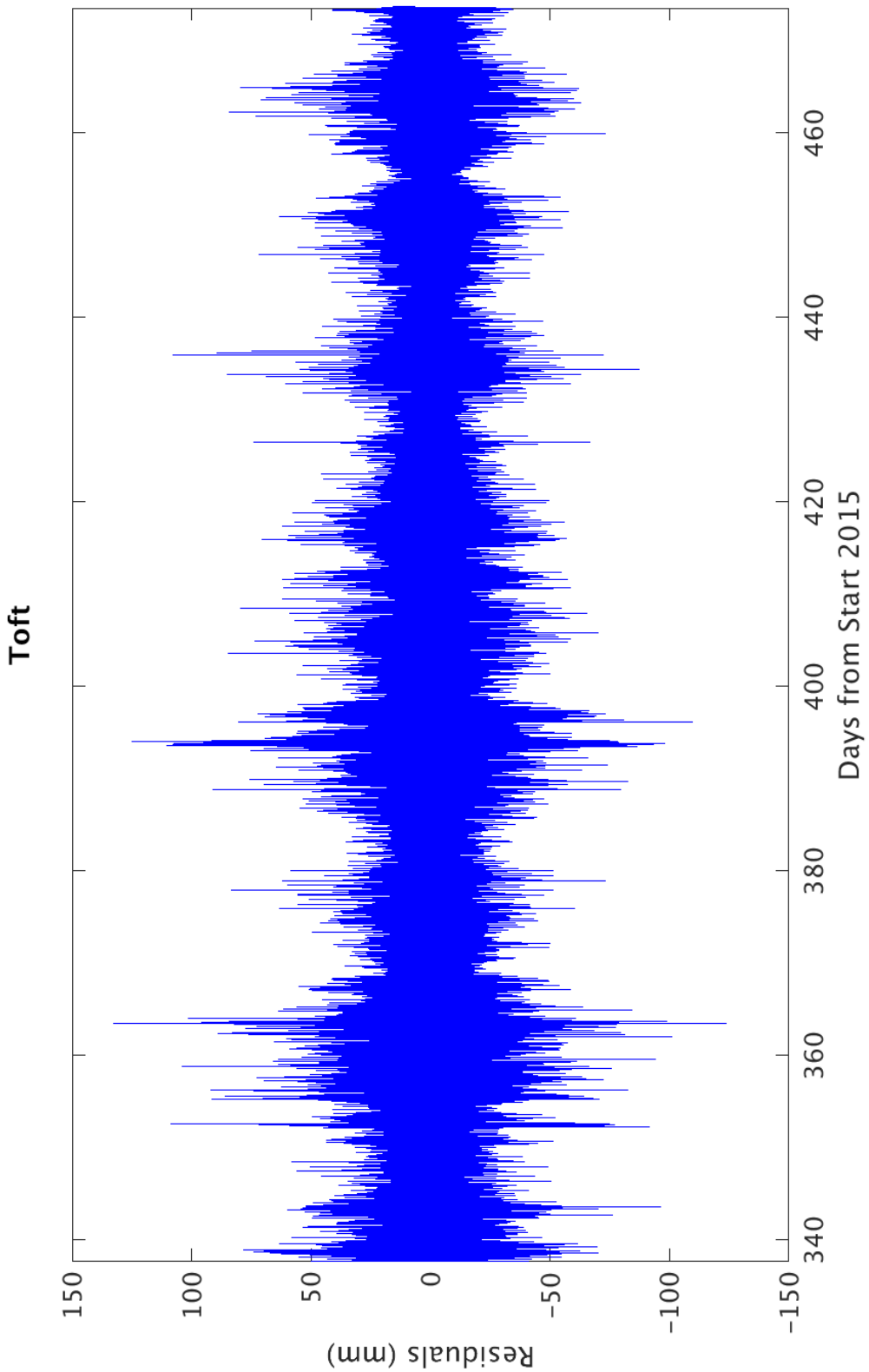

Busta House
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
270
280
290
300
310
320
330
Days from Start 2015
0
Magnitude

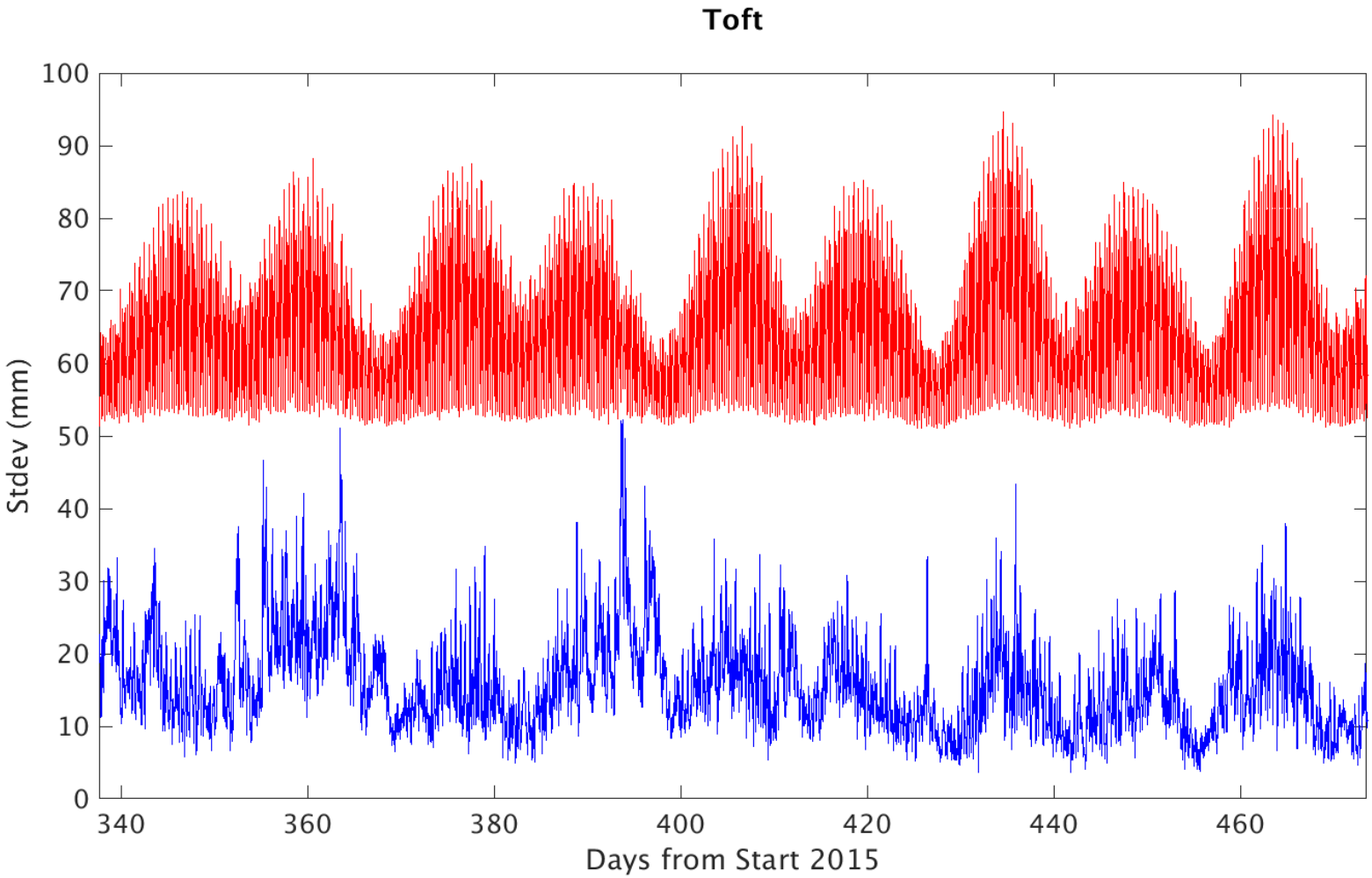

Whalsay
Residuals (mm)
200
150
100
50
0
-50
-100
-150
-200
340
360
380
400
420
440
460
Days from Start 2015

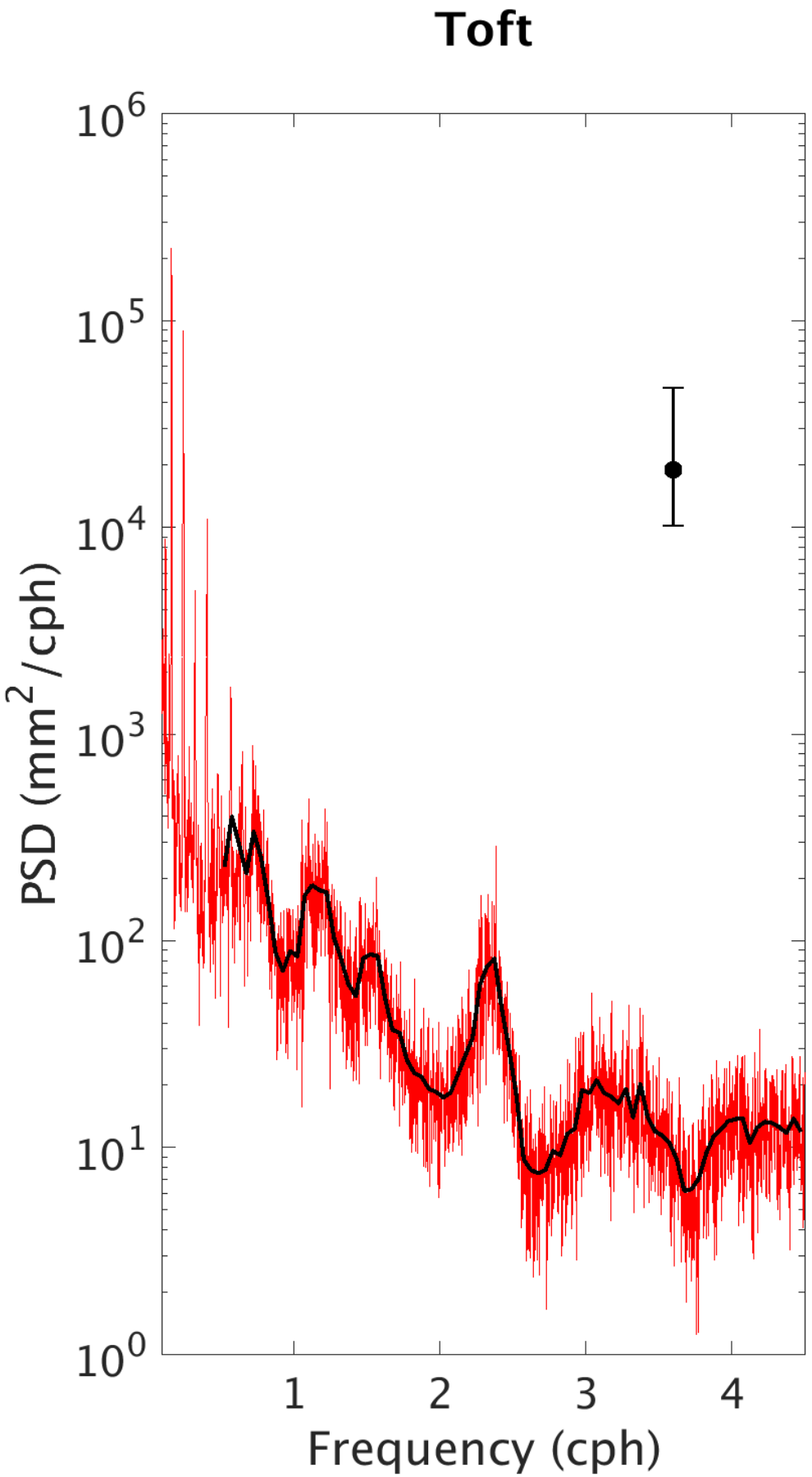

Whalsay
Stdev (mm)
70
60
50
40
30
20
10
0
340
360
380
400
420
440
460
Days from Start 2015

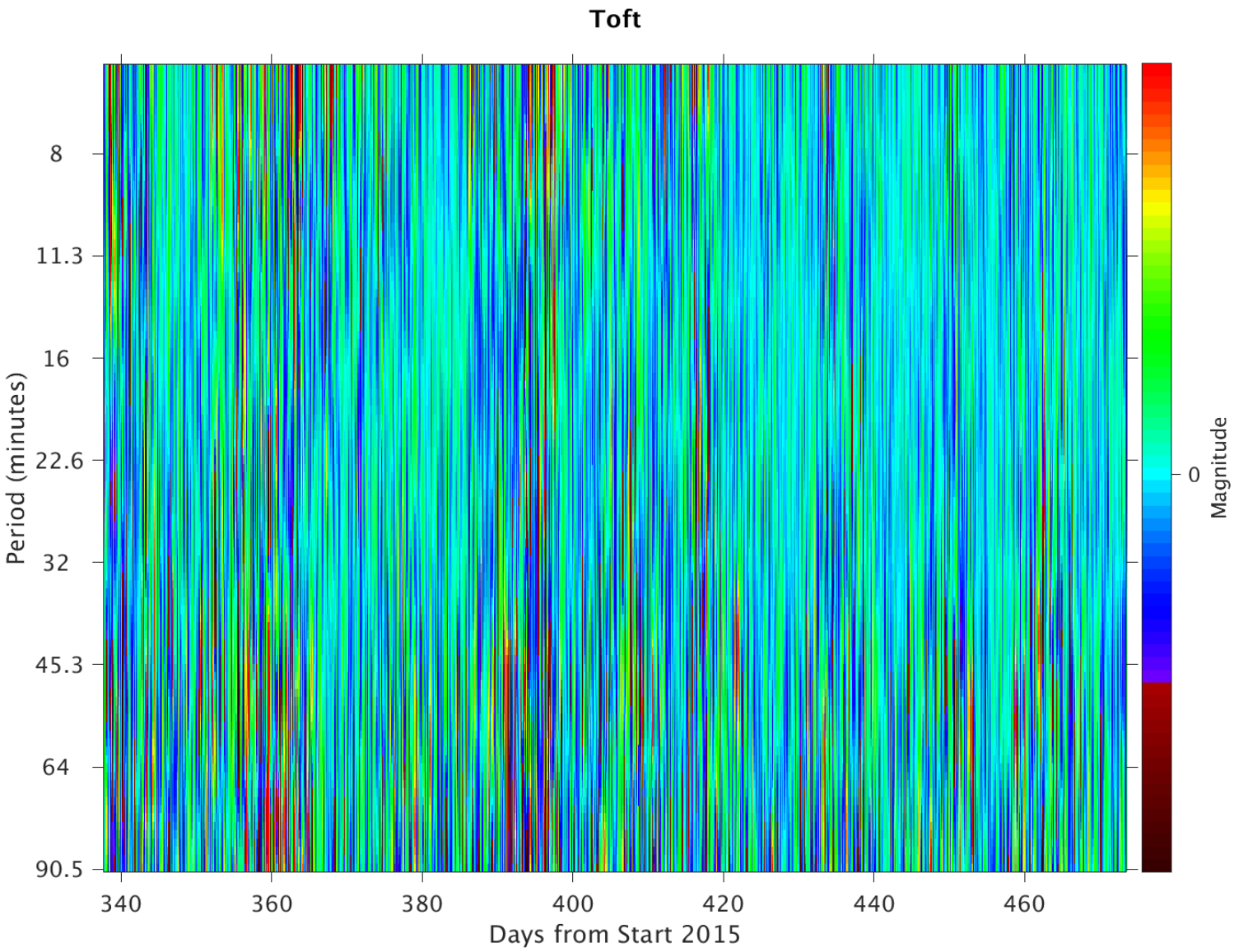

Whalsay
PSD (mm^2/cph)
10^5
10^4
10^3
10^2
10^1
10^0
1
2
3
4
Frequency (cph)

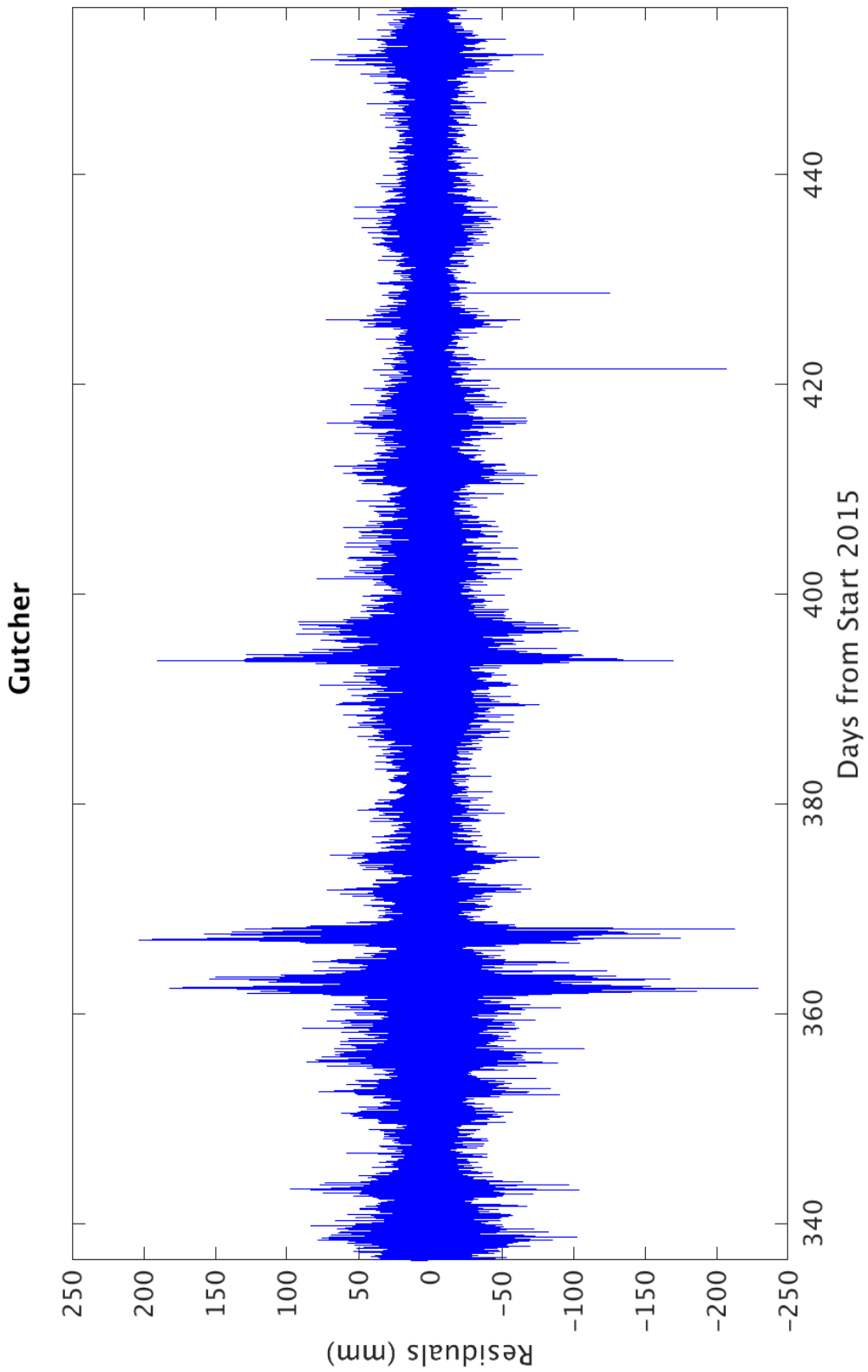

Whalsay
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
340
360
380
400
420
440
460
Days from Start 2015
Magnitude
0

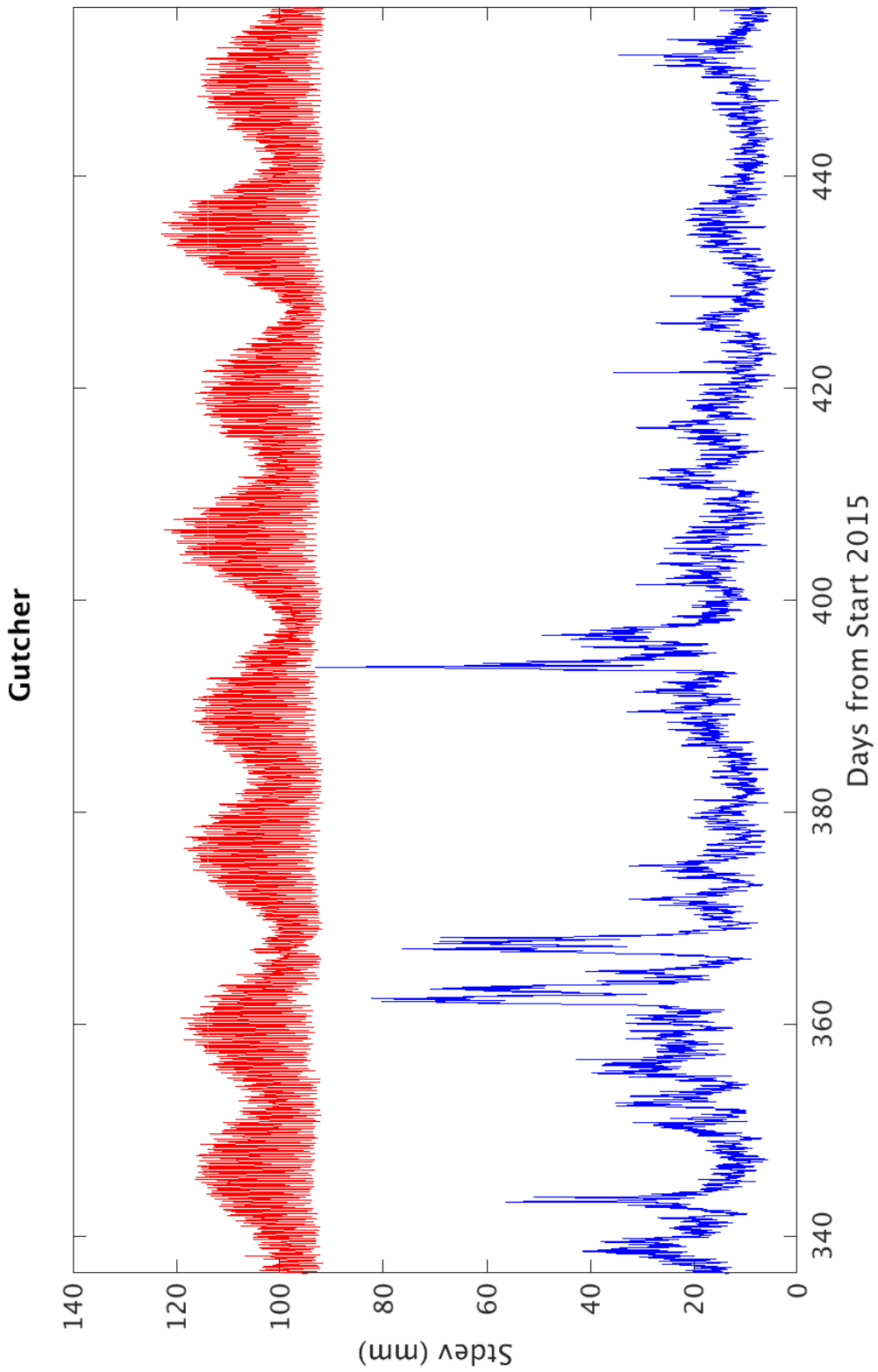

Toft
Residuals (mm)
150
100
50
0
−50
−100
−150
340
360
380
400
420
440
460
Days from Start 2015

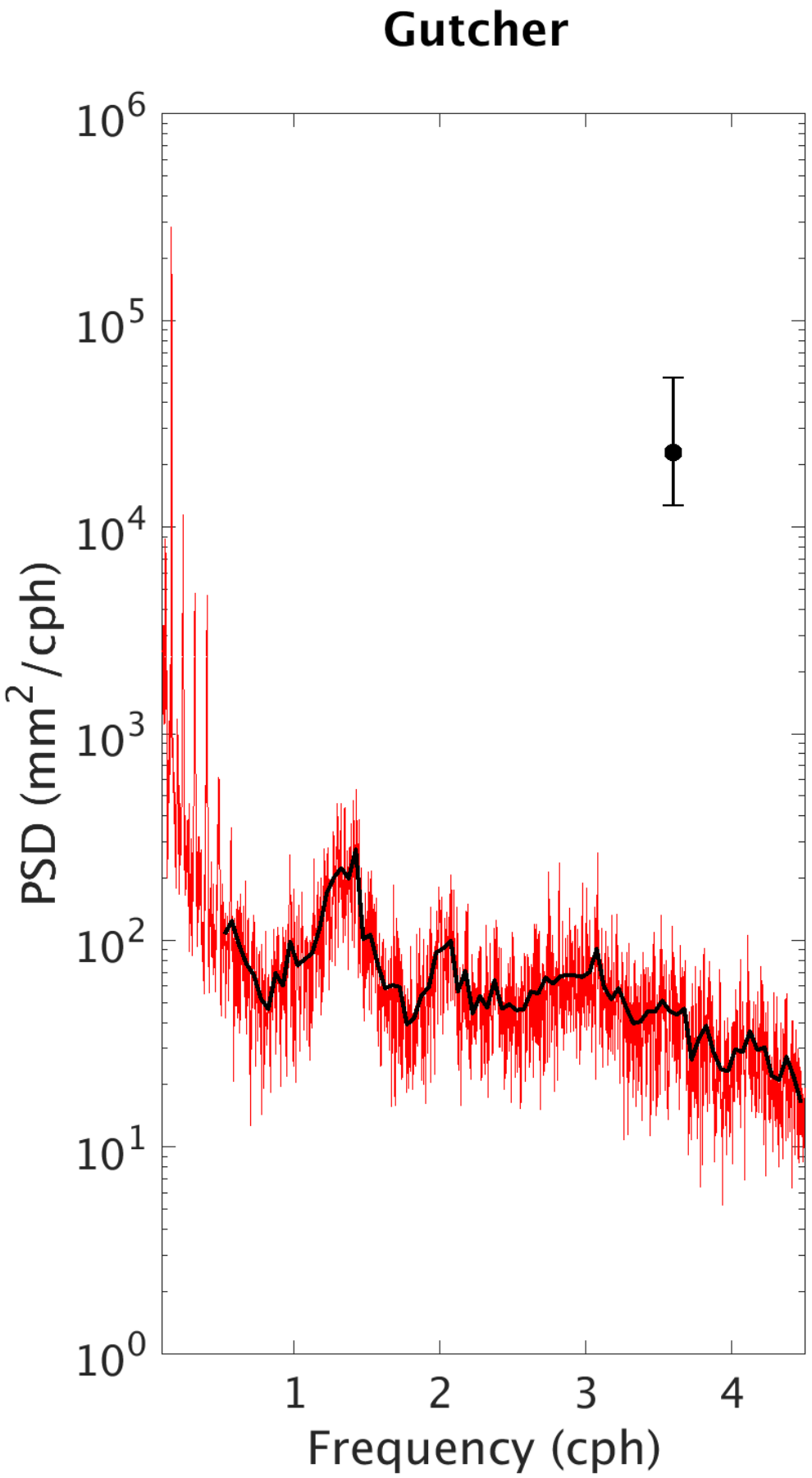

Toft
Stdev (mm)
Days from Start 2015
0
10
20
30
40
50
60
70
80
90
100
340
360
380
400
420
440
460

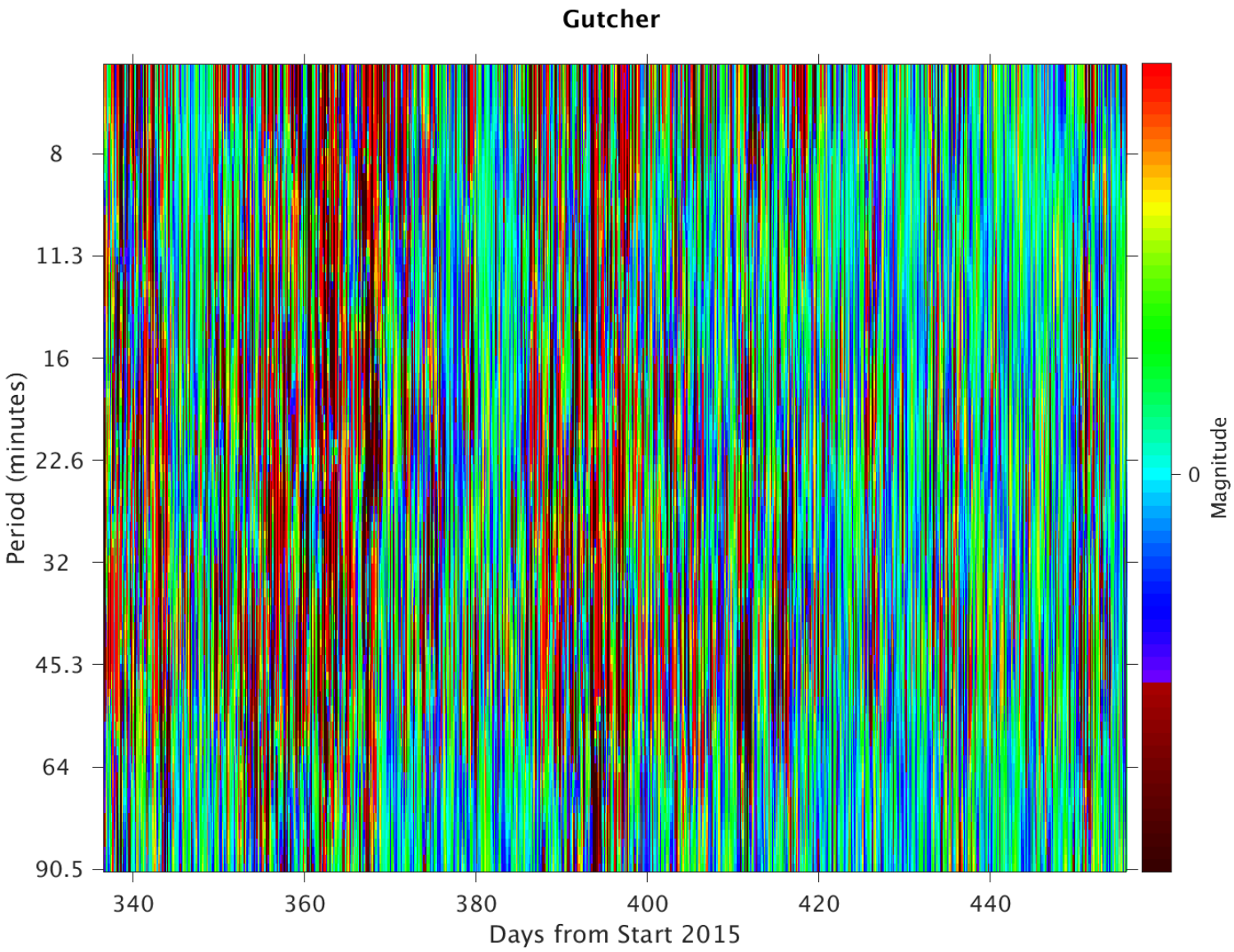

Toft
10^6
10^5
10^4
10^3
10^2
10^1
10^0
PSD (mm^2/cph)
1
2
3
4
Frequency (cph)

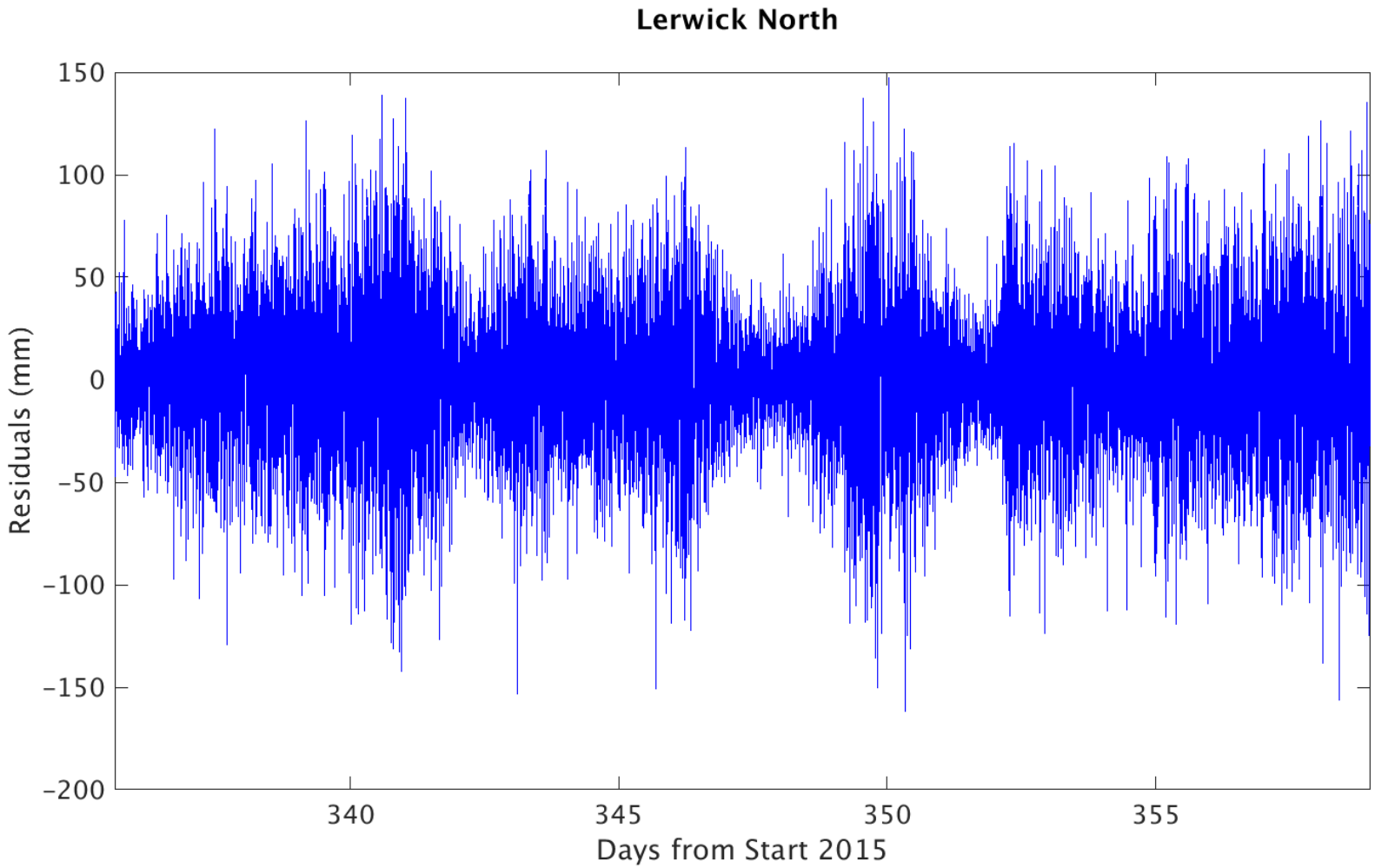

Toft
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
340
360
380
400
420
440
460
Days from Start 2015
Magnitude
0

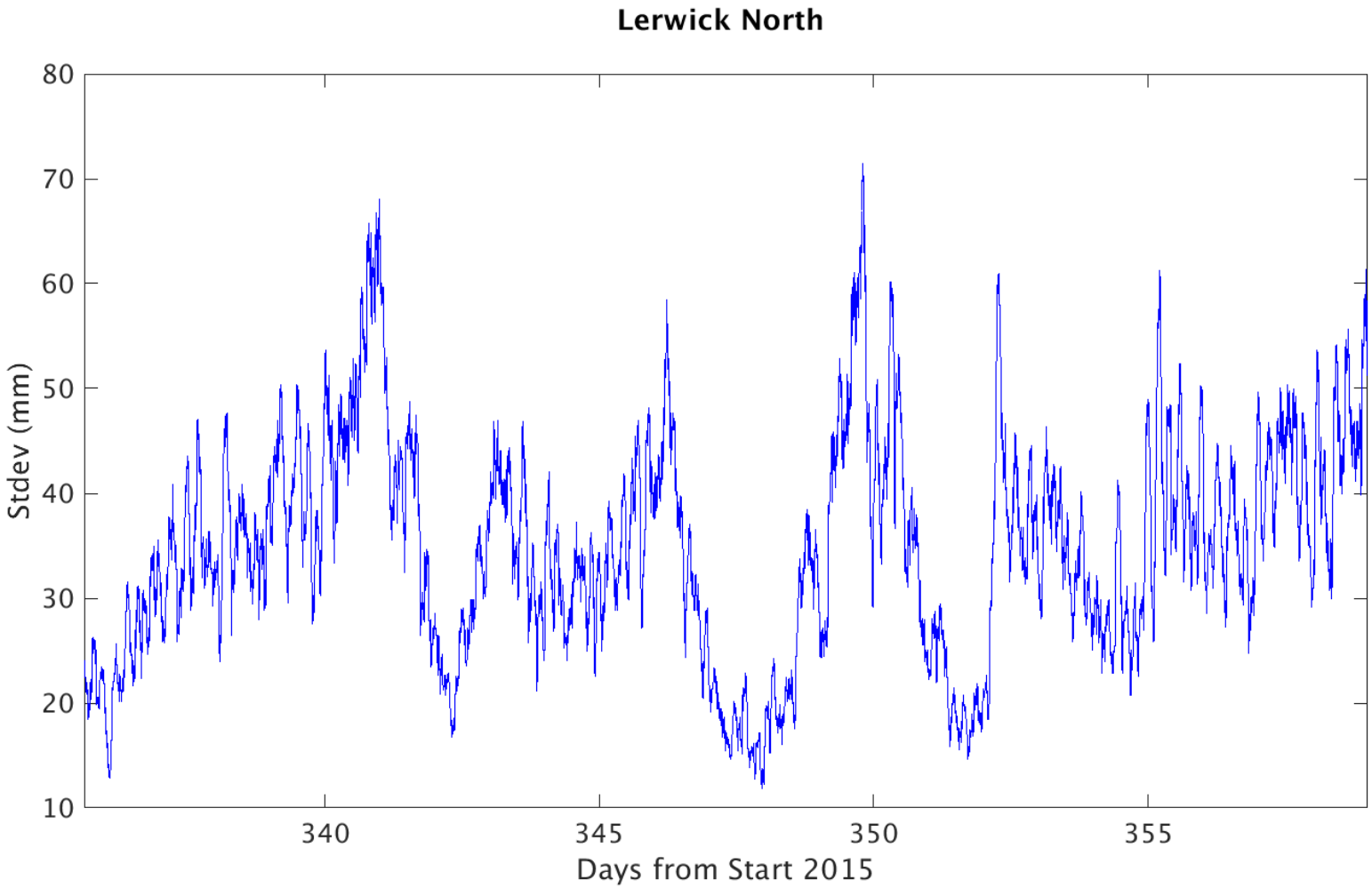

Gutcher
Residuals (mm)
250
200
150
100
50
0
-50
-100
-150
-200
-250
340
360
380
400
420
440
Days from Start 2015

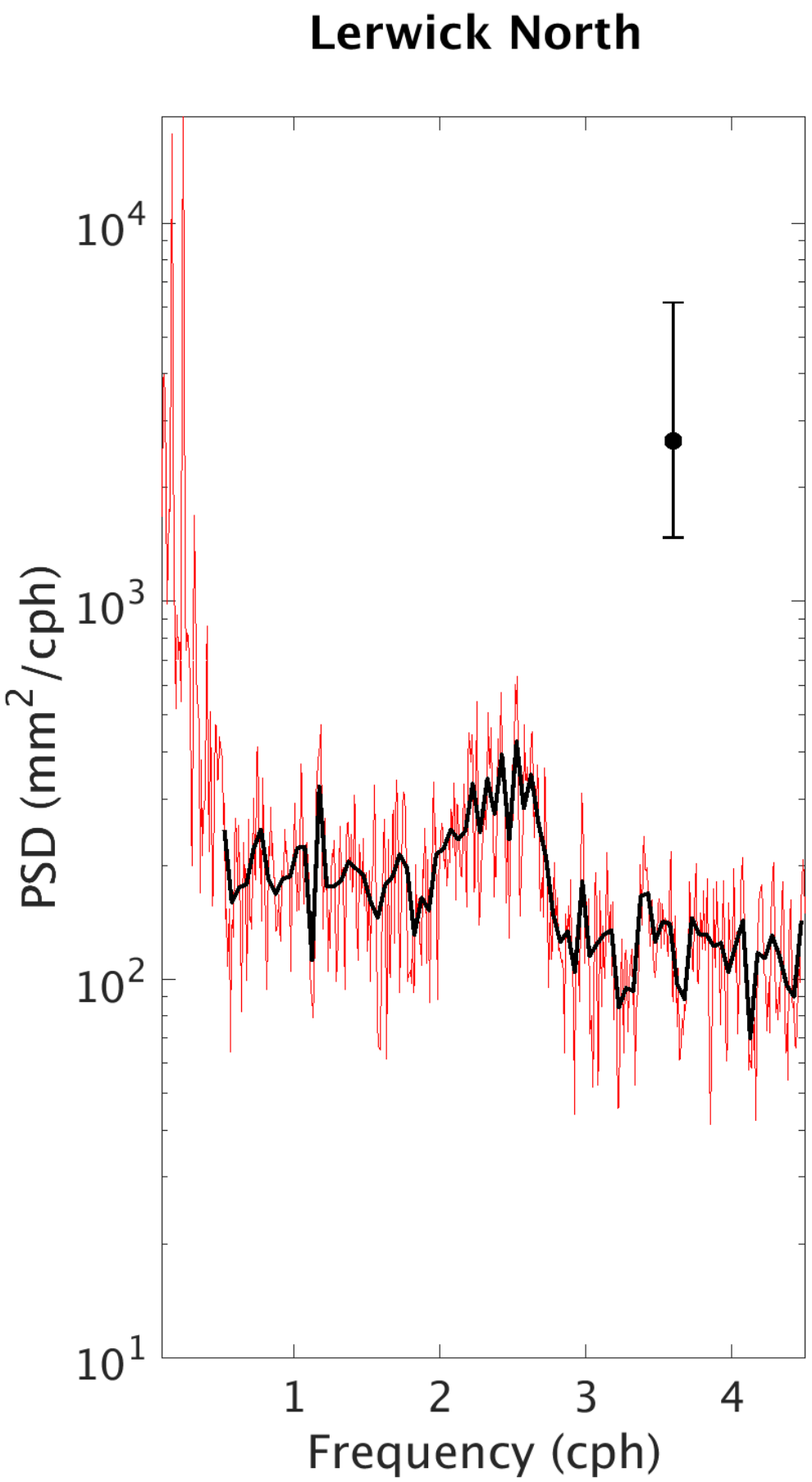

Gutcher
Stdev (mm)
0
20
40
60
80
100
120
140
340
360
380
400
420
440
Days from Start 2015

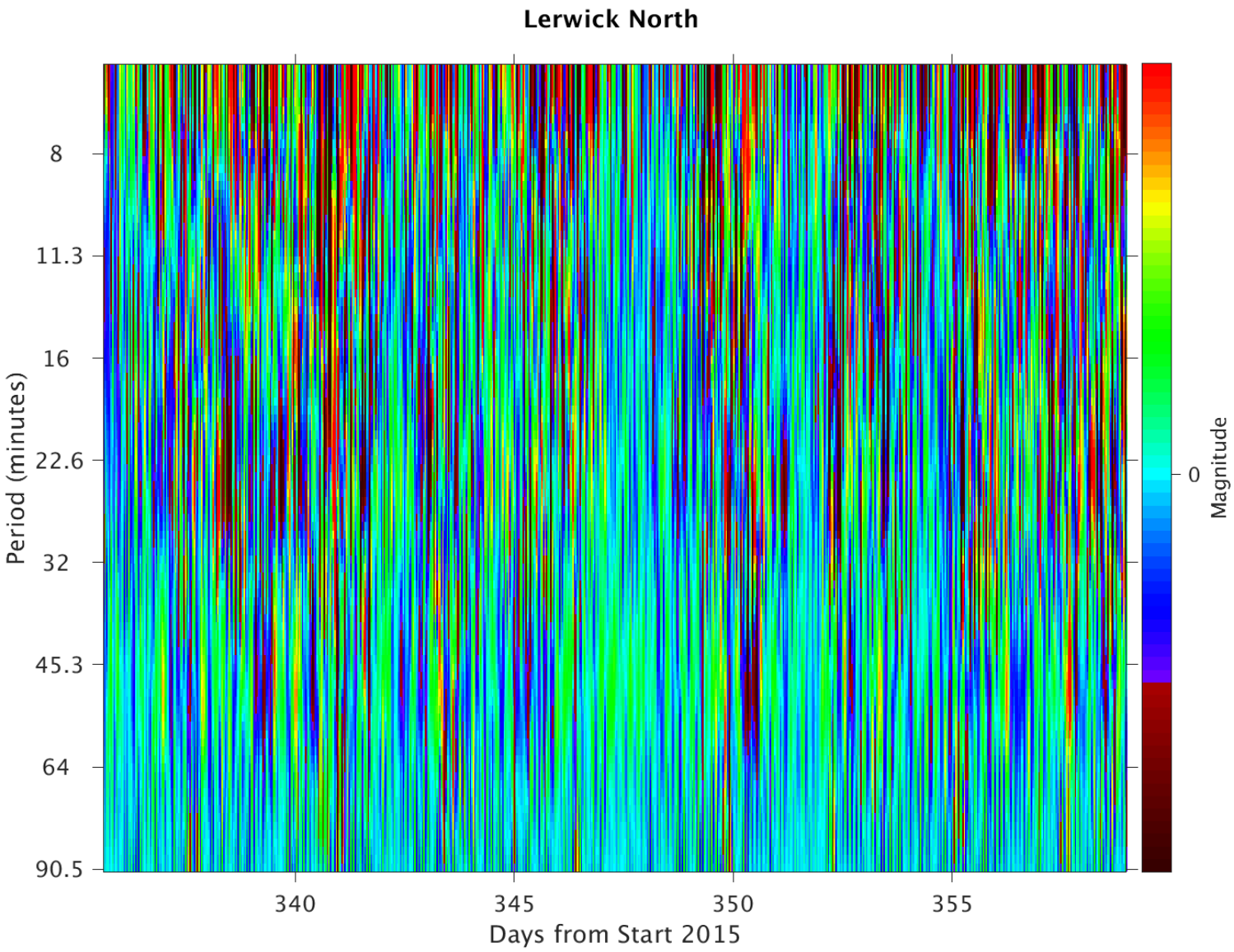

Gutcher
PSD (mm^2/cph)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1
2
3
4
Frequency (cph)

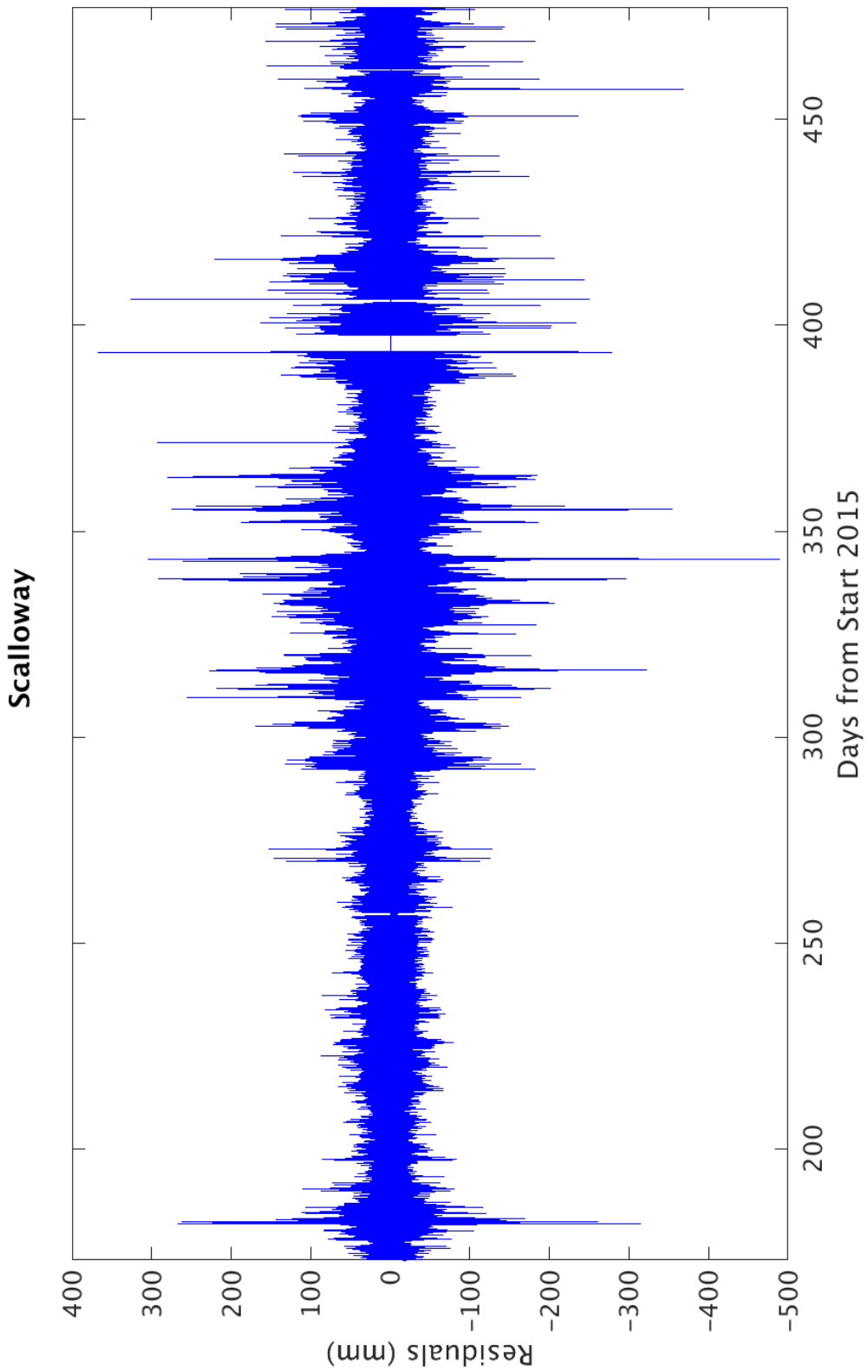

Gutcher
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
340
360
380
400
420
440
Days from Start 2015
Magnitude
0

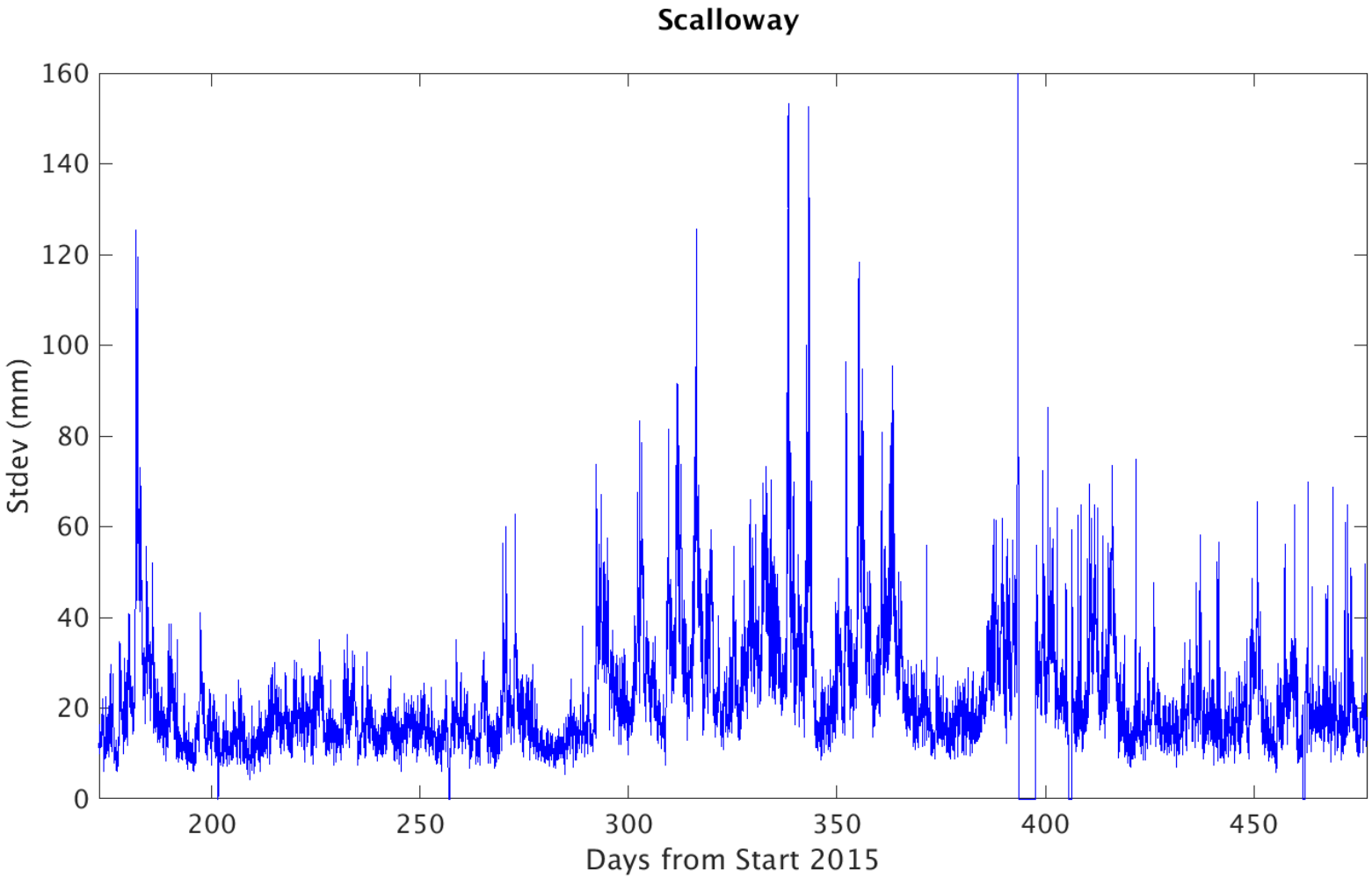

Lerwick North
150
100
50
0
-50
-100
-150
-200
Residuals (mm)
340
345
350
355
Days from Start 2015

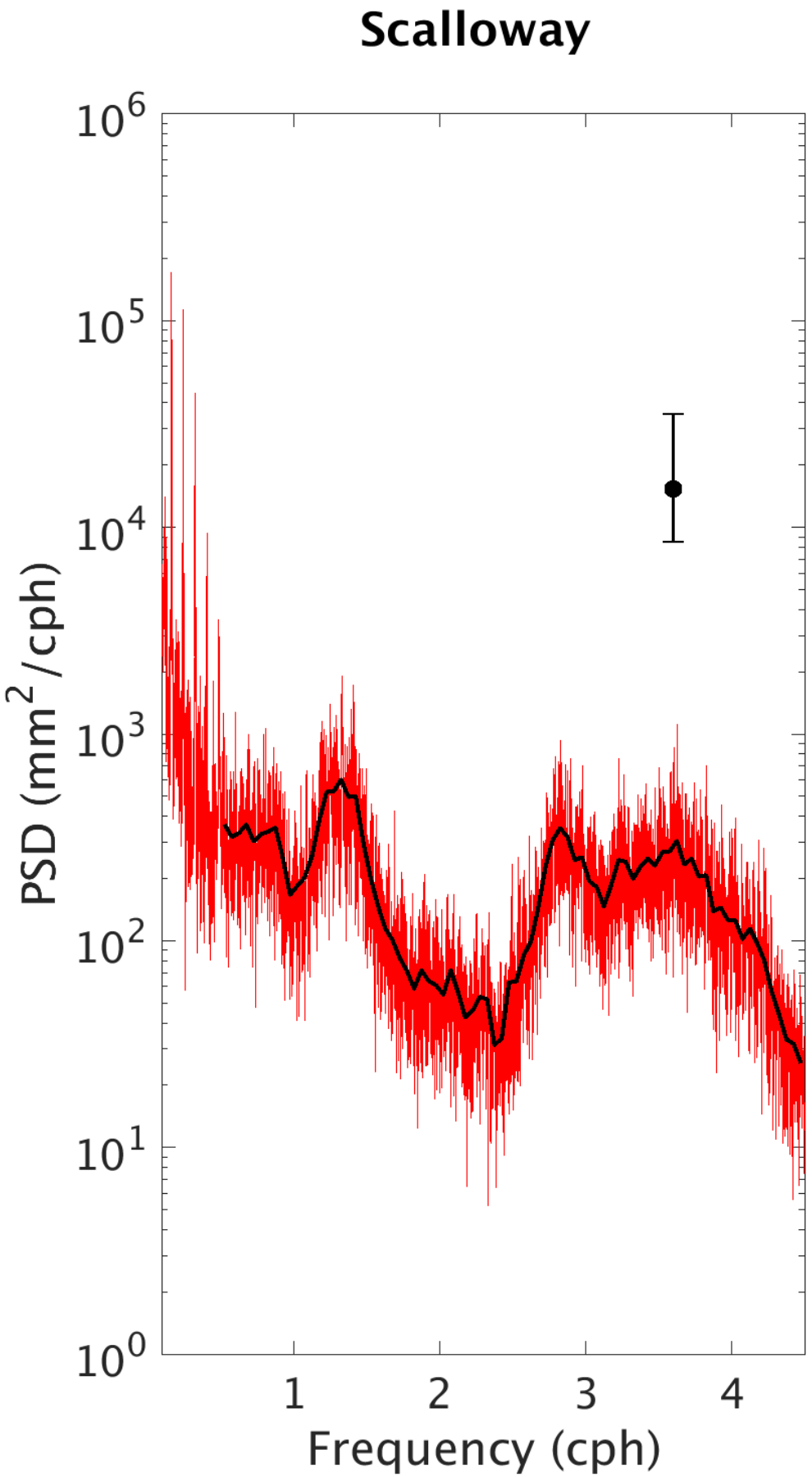

Lerwick North
Stdev (mm)
80
70
60
50
40
30
20
10
340
345
350
355
Days from Start 2015

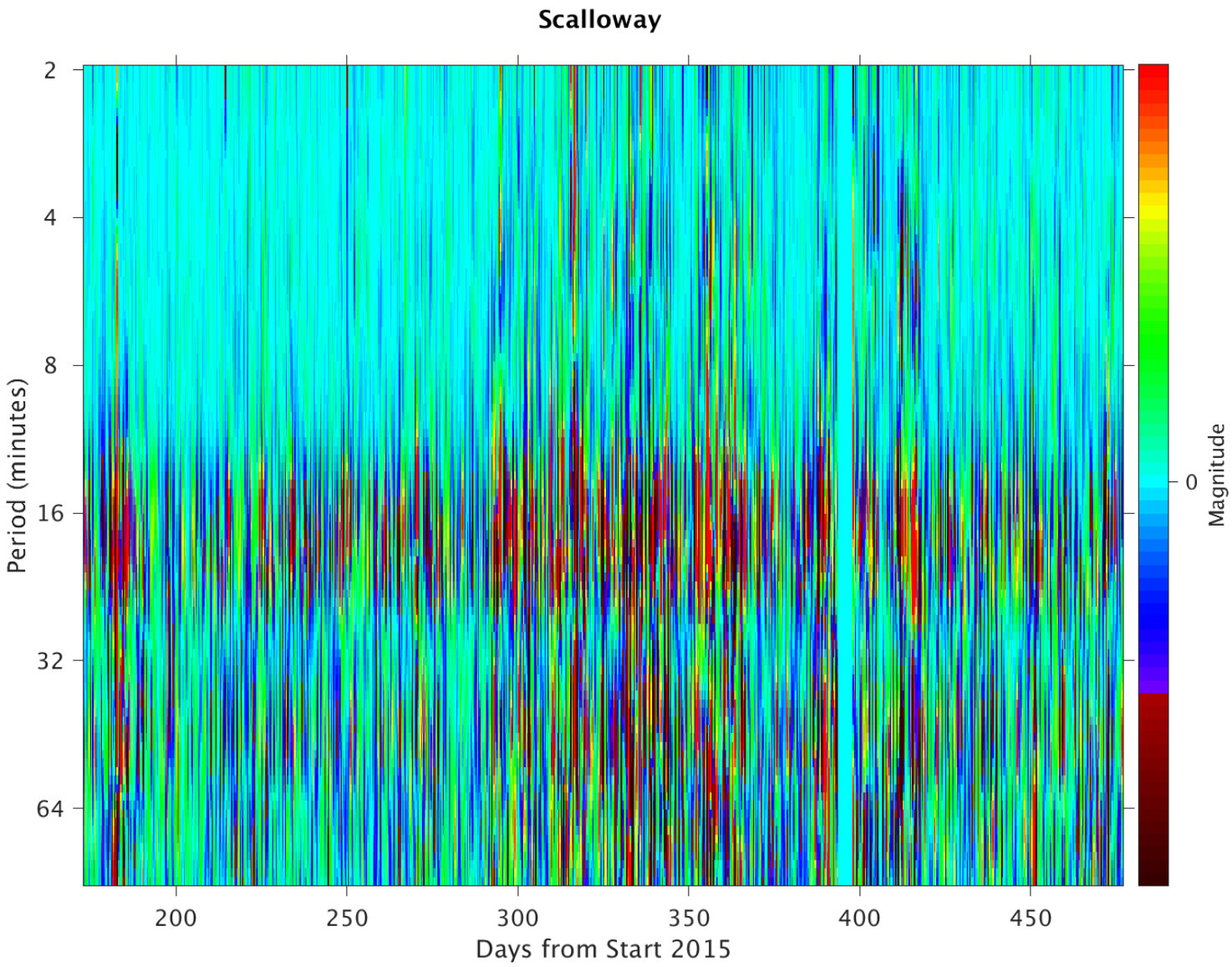

Lerwick North
PSD (mm^2/cph)
10^4
10^3
10^2
10^1
1
2
3
4
Frequency (cph)

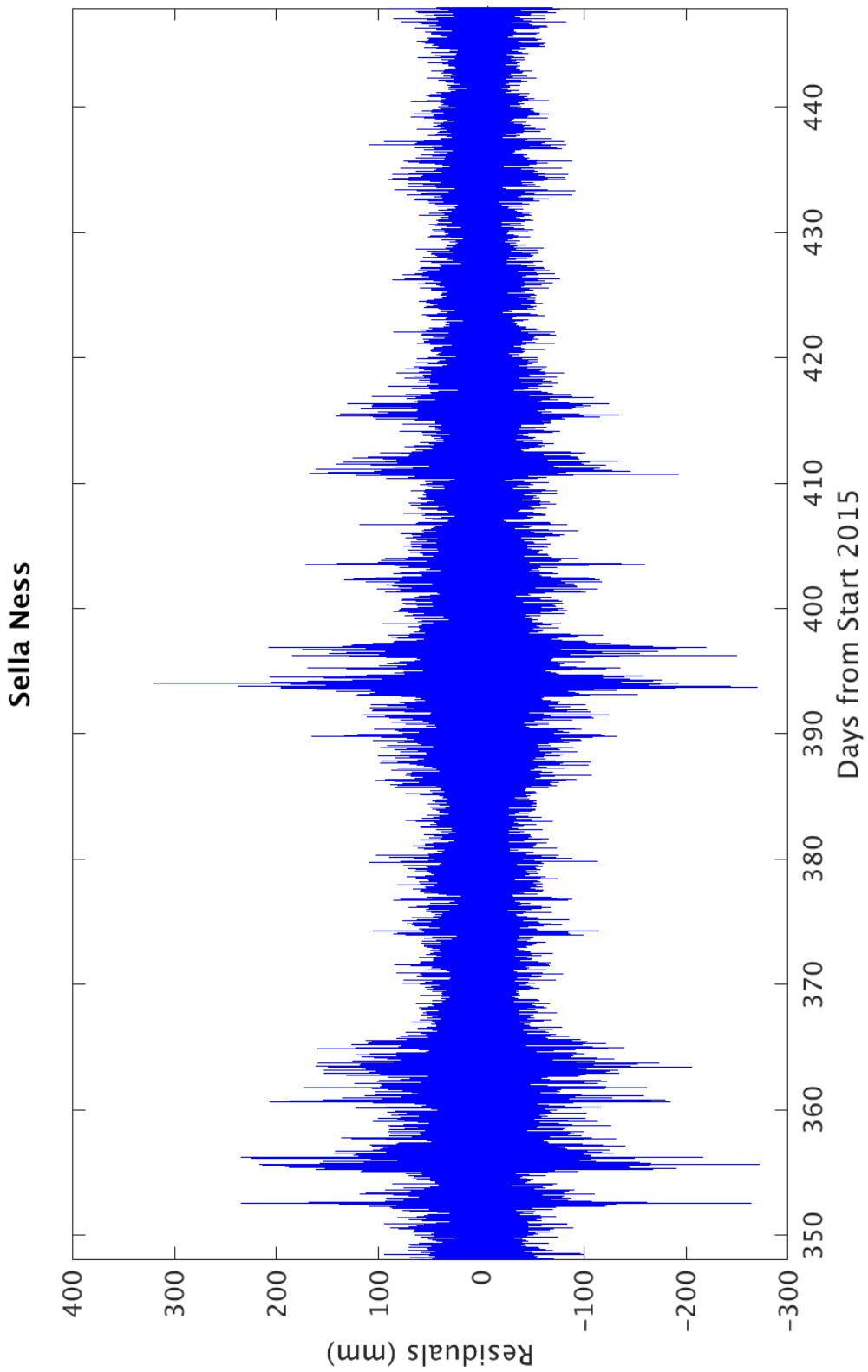

Lerwick North
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
340
345
350
355
Days from Start 2015
Magnitude
0

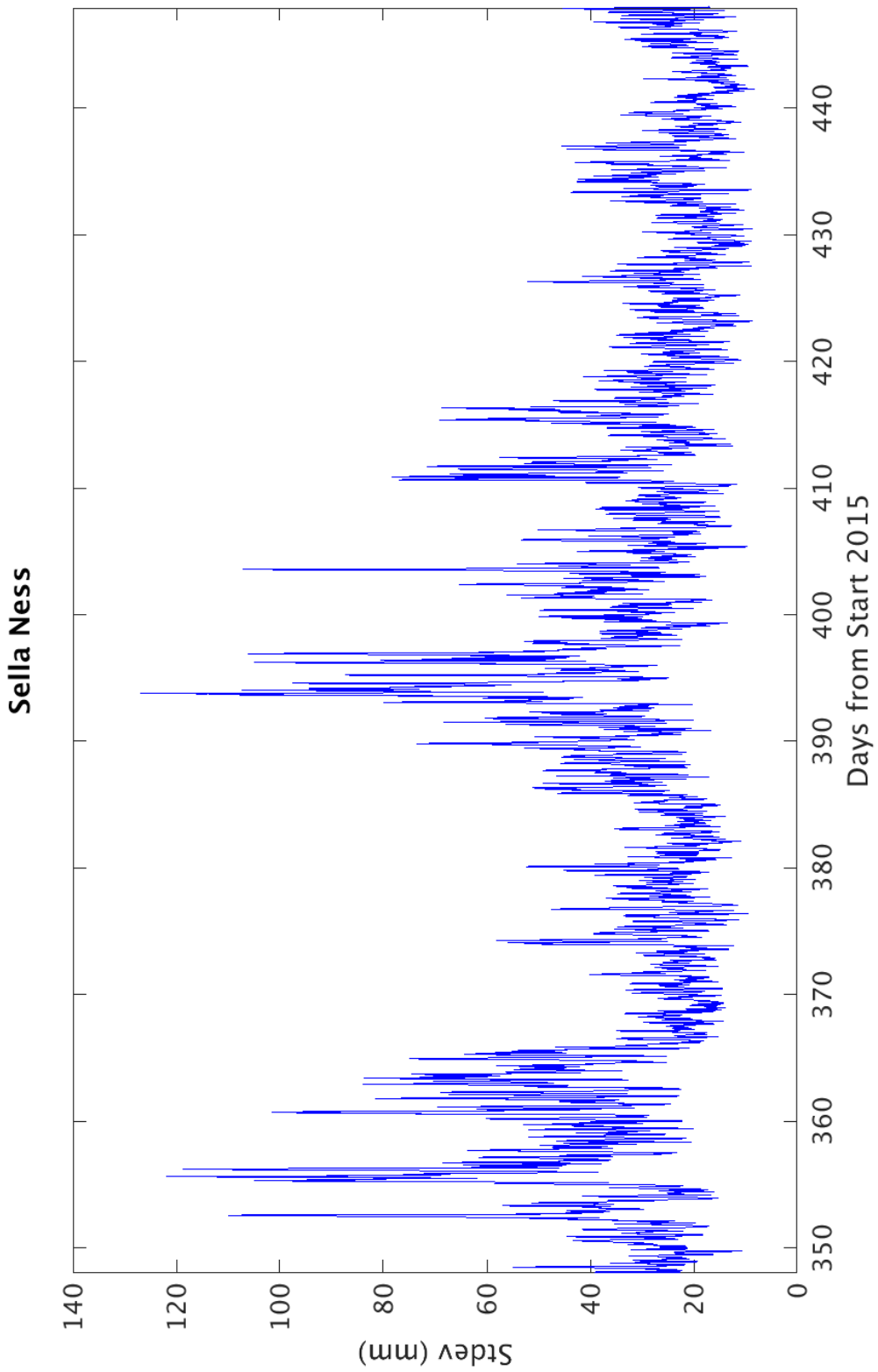

Scalloway
Residuals (mm)
400
300
200
100
0
-100
-200
-300
-400
-500
200
250
300
350
400
450
Days from Start 2015

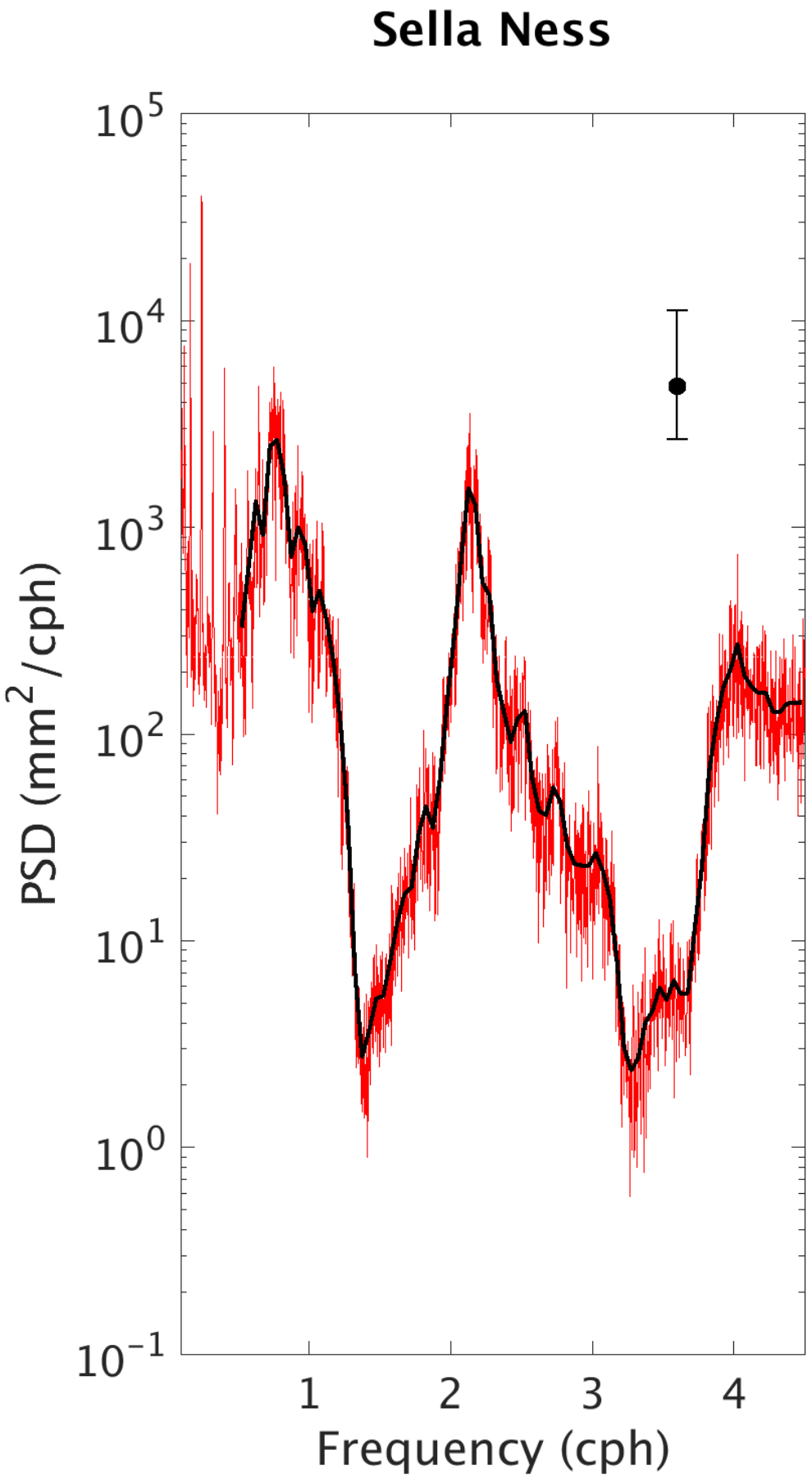

Scalloway
Stdev (mm)
Days from Start 2015
0
20
40
60
80
100
120
140
160
200
250
300
350
400
450

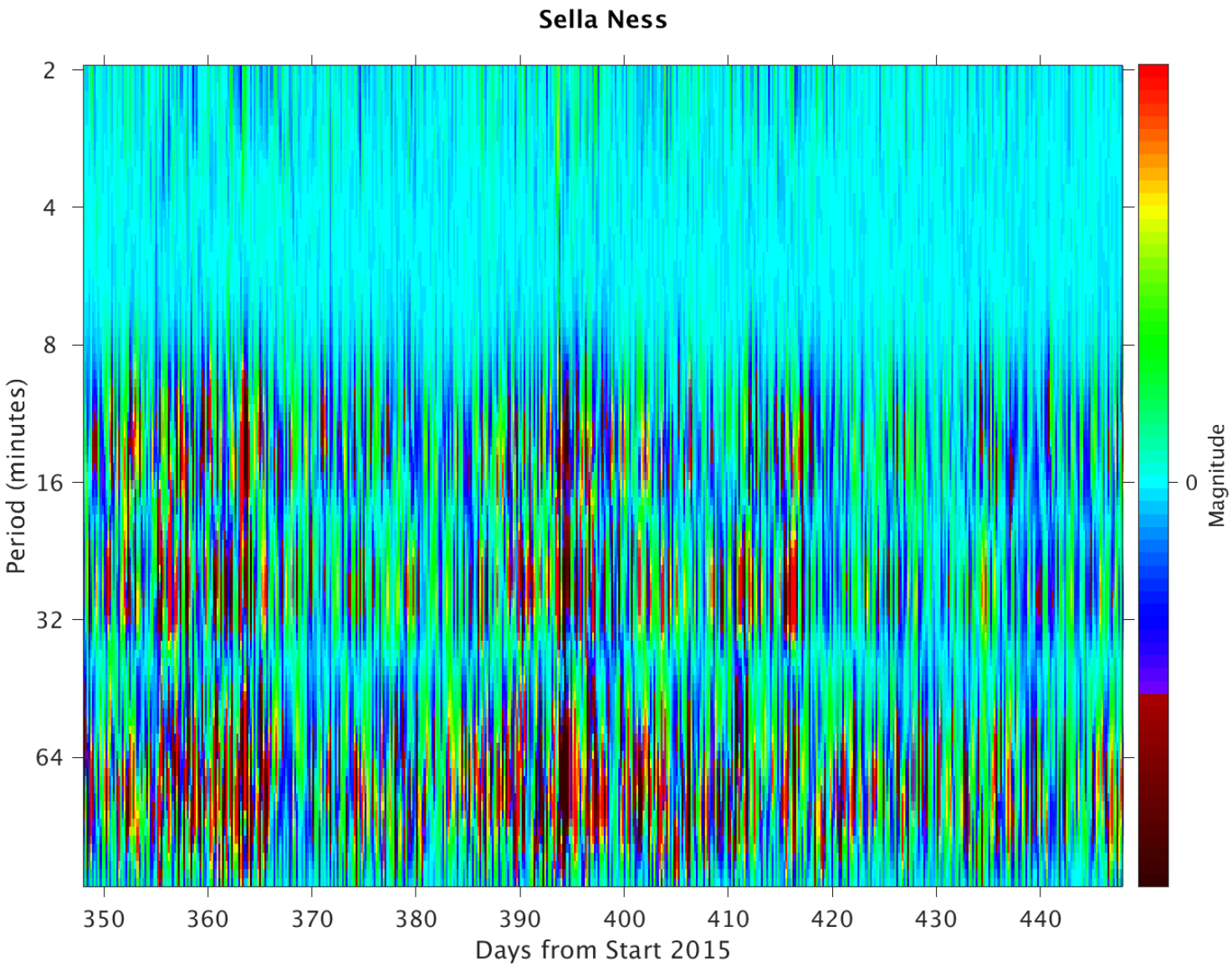

Scalloway
PSD (mm^2/cph)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1
2
3
4
Frequency (cph)

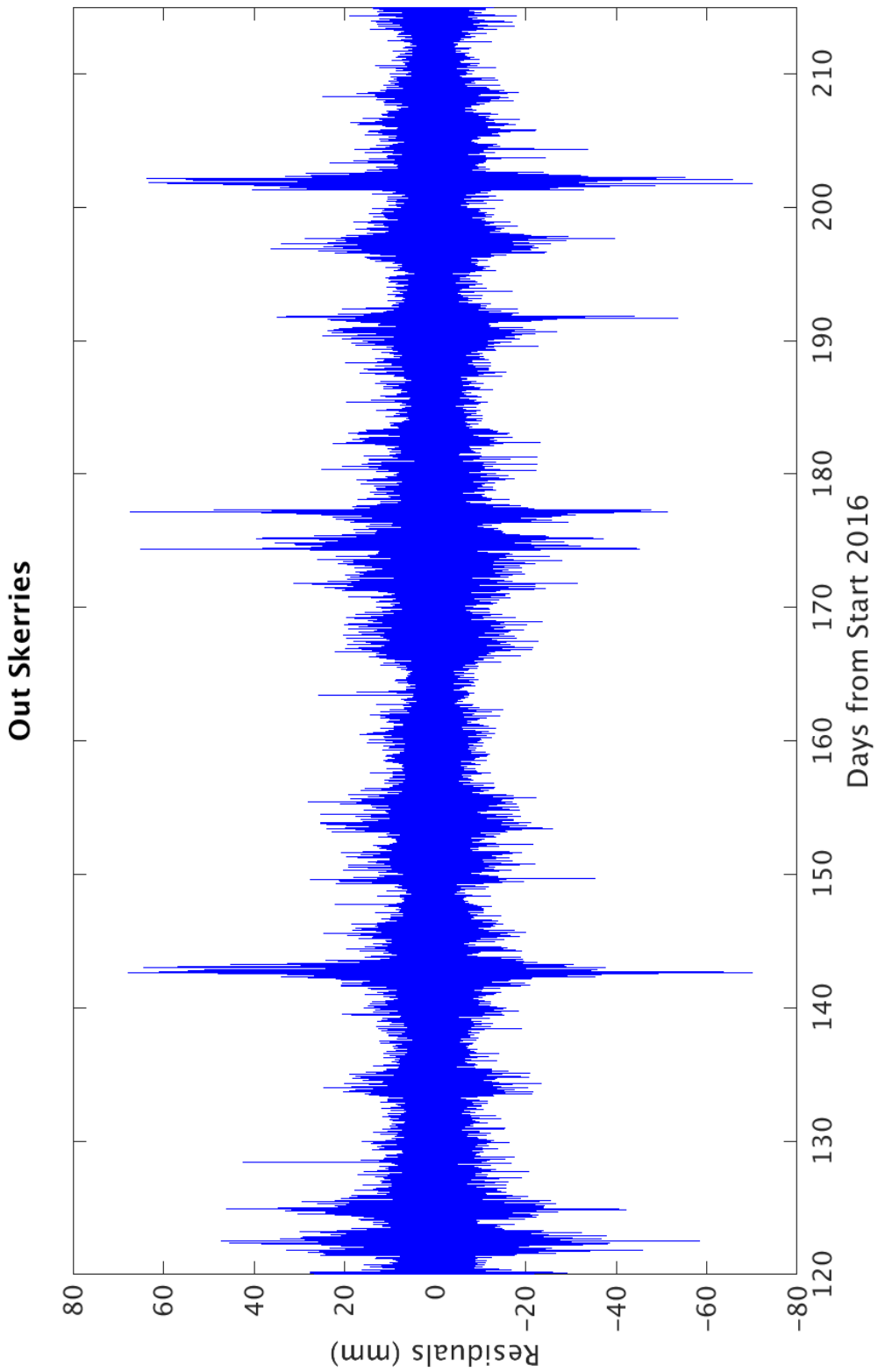

Scalloway
Period (minutes)
2
4
8
16
32
64
200
250
300
350
400
450
Days from Start 2015
Magnitude
0

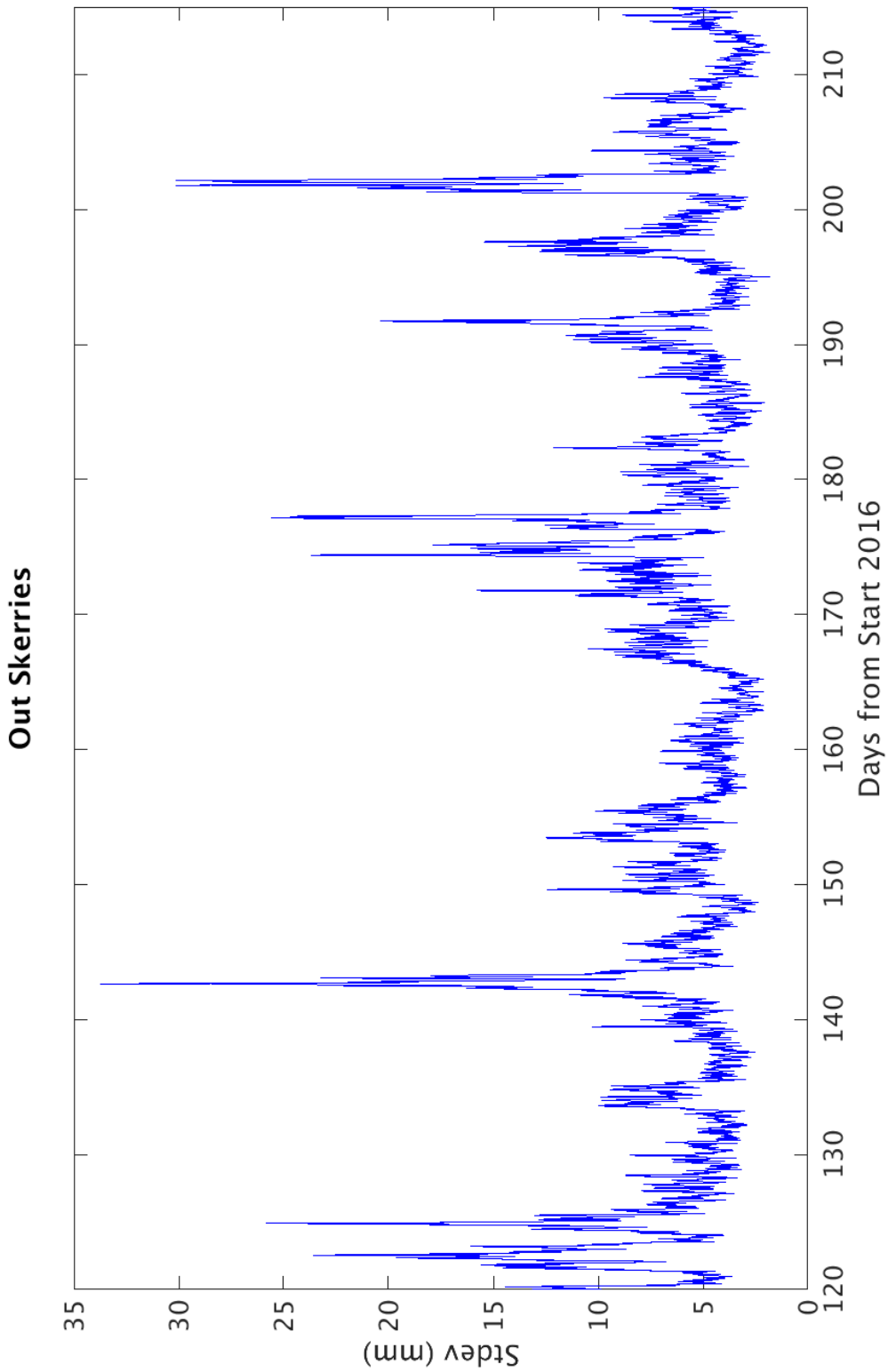

Sella Ness
Residuals (mm)
400
300
200
100
0
-100
-200
-300
350
360
370
380
390
400
410
420
430
440
Days from Start 2015

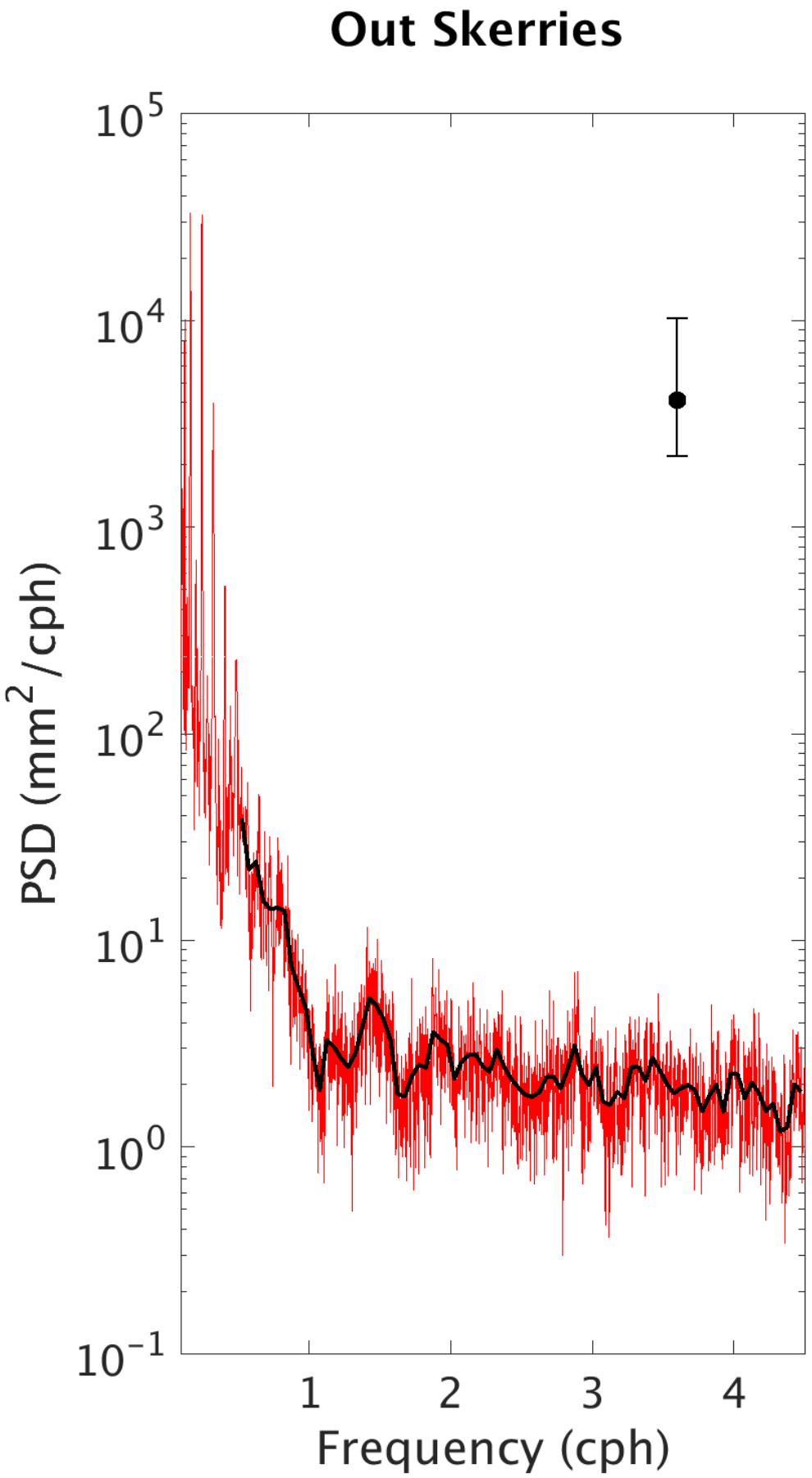

Sella Ness
Stdev (mm)
0
20
40
60
80
100
120
140
350
360
370
380
390
400
410
420
430
440
Days from Start 2015

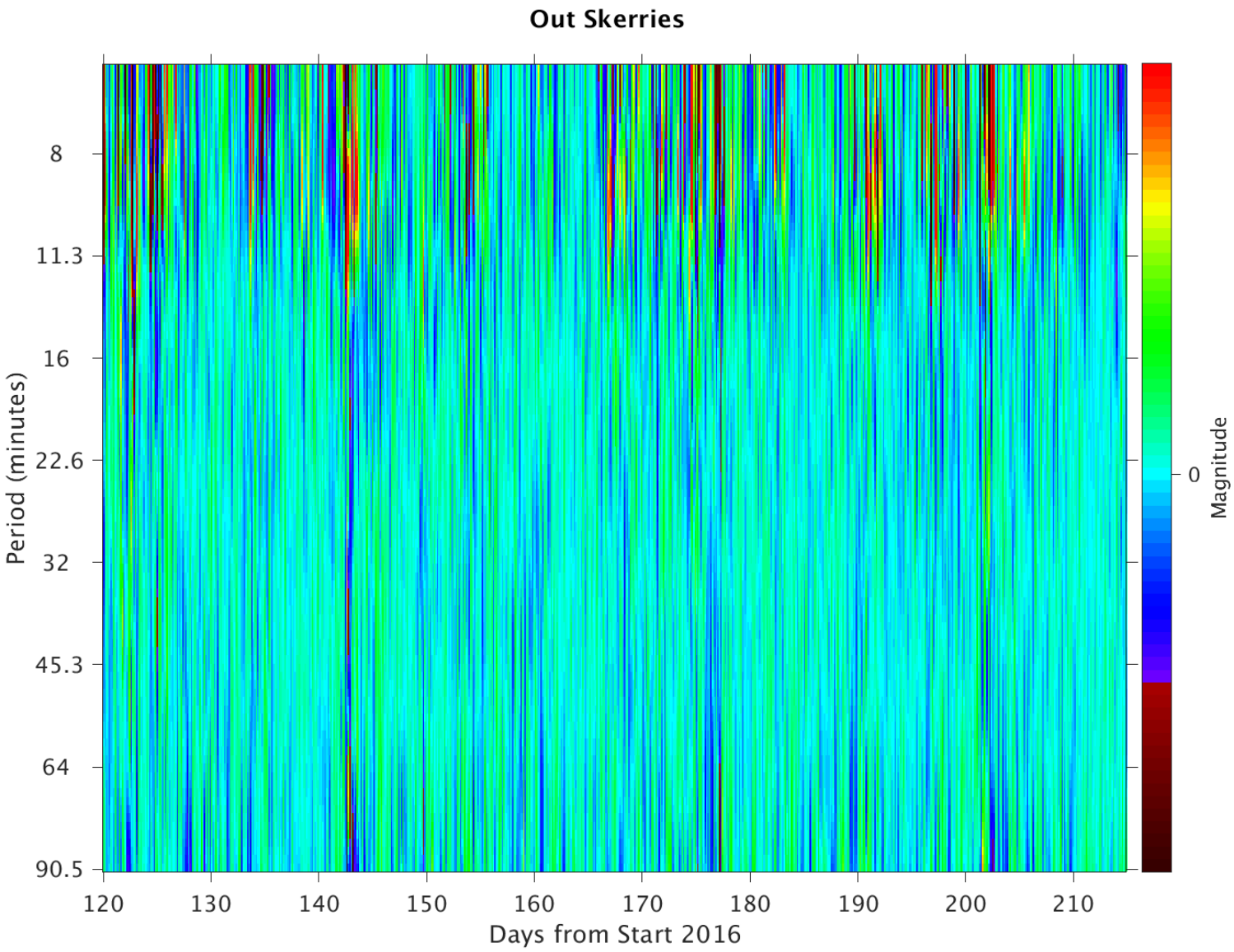

Sella Ness
PSD (mm^2/cph)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
1
2
3
4
Frequency (cph)

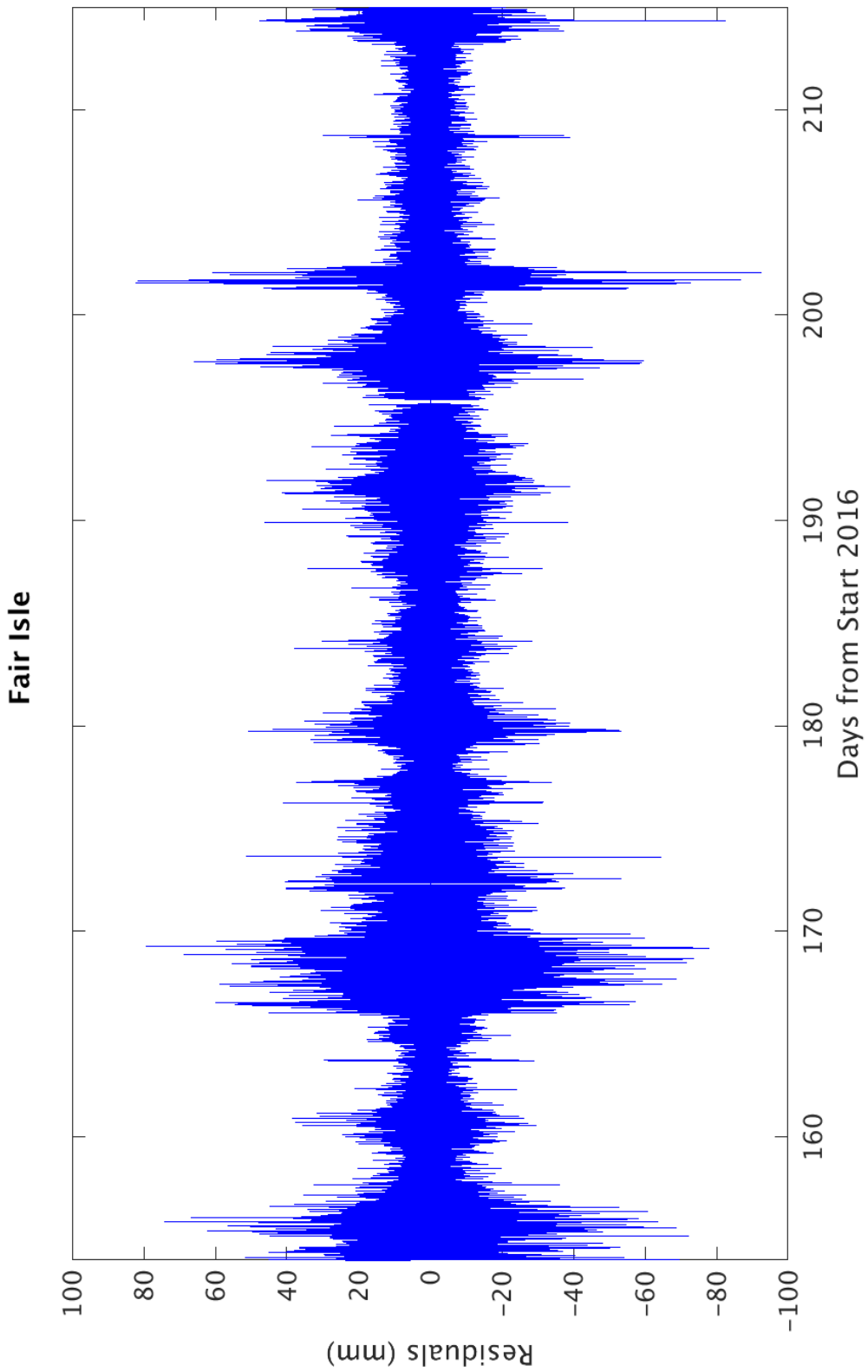

Sella Ness
Period (minutes)
2
4
8
16
32
64
350
360
370
380
390
400
410
420
430
440
Days from Start 2015
Magnitude
0

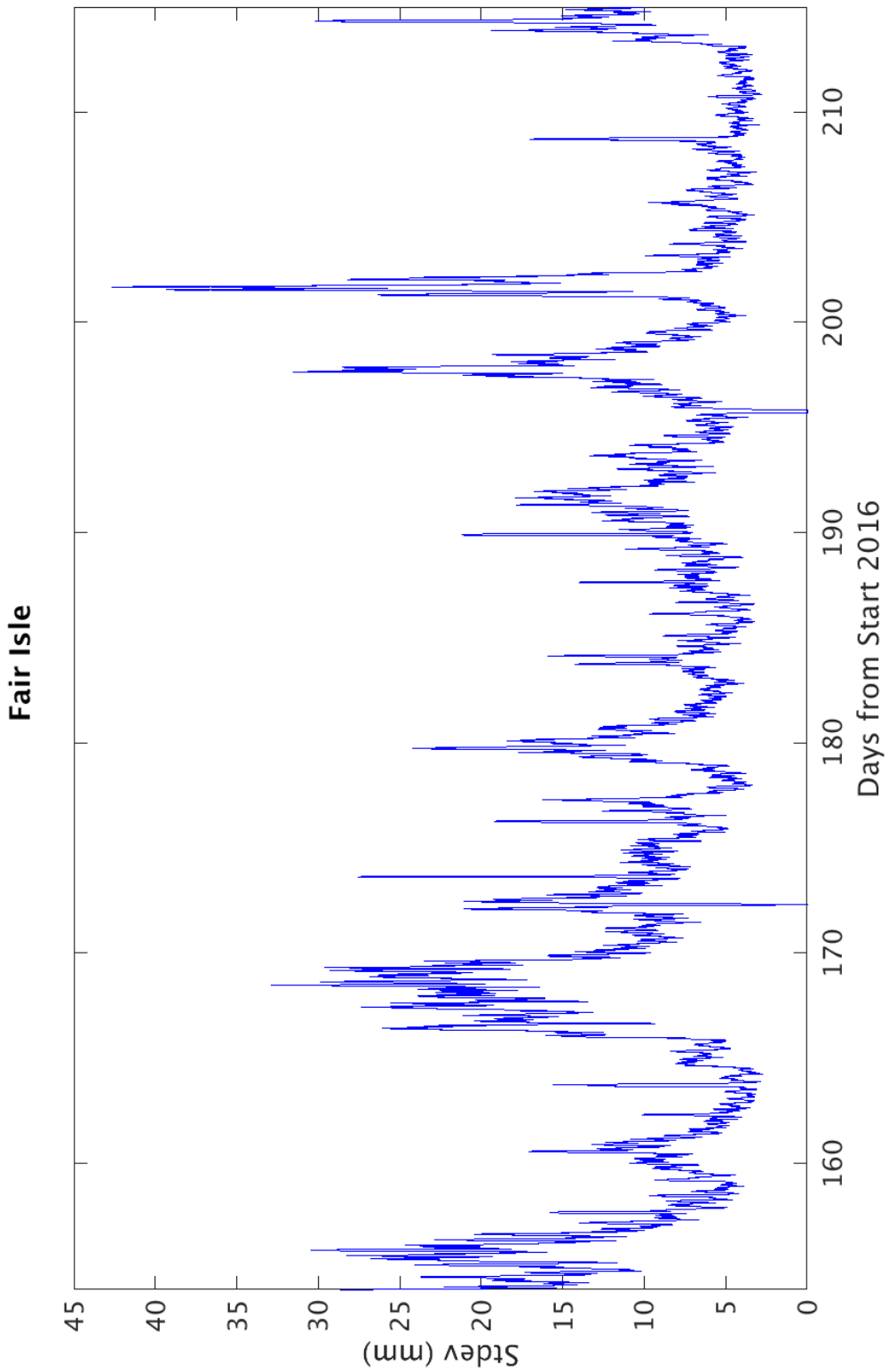

Out Skerries
Residuals (mm)
80
60
40
20
0
−20
−40
−60
−80
120
130
140
150
160
170
180
190
200
210
Days from Start 2016

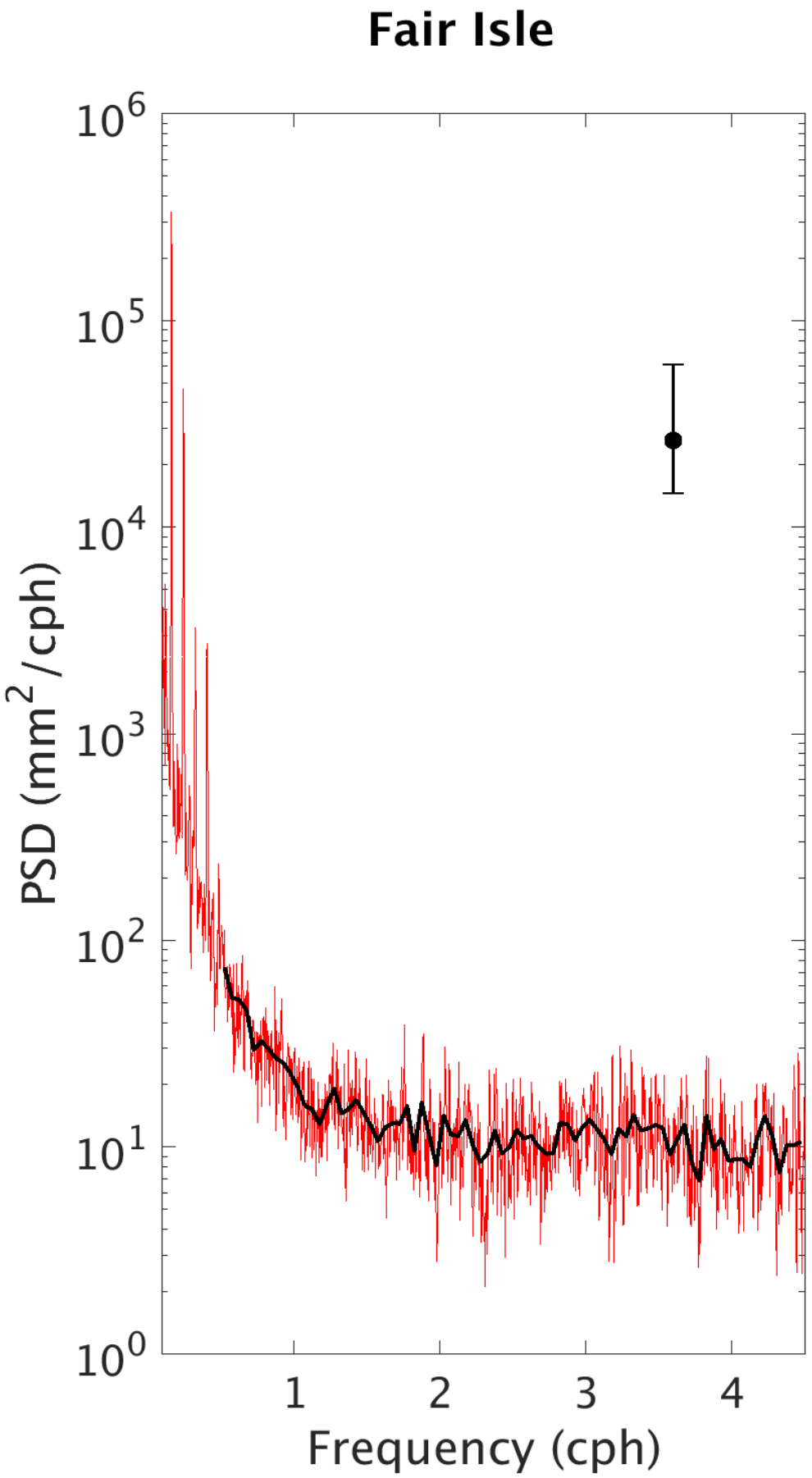

Out Skerries
Stdev (mm)
35
30
25
20
15
10
5
0
120
130
140
150
160
170
180
190
200
210
Days from Start 2016

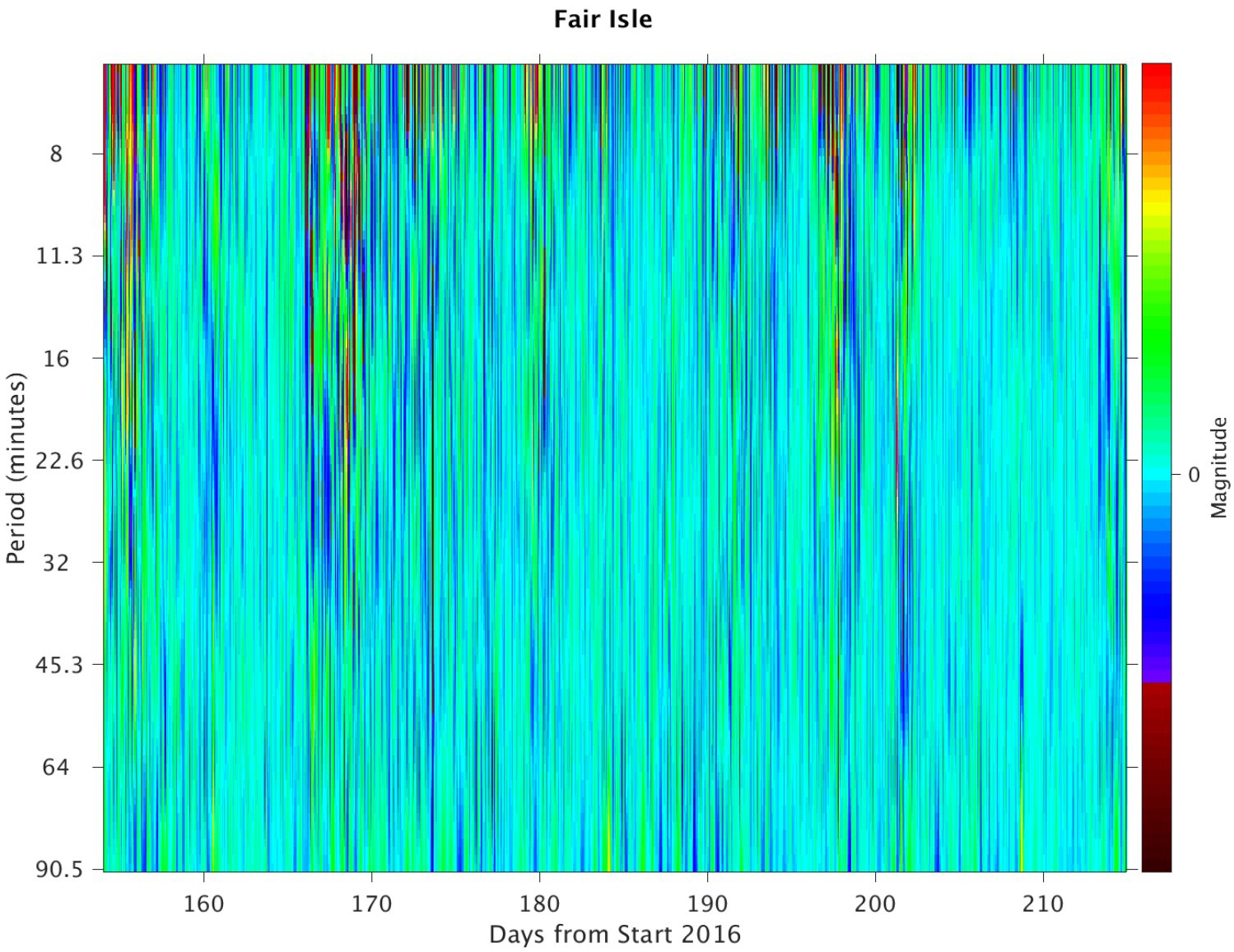

Out Skerries
PSD (mm^2/cph)
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
1
2
3
4
Frequency (cph)


Out Skerries
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
120
130
140
150
160
170
180
190
200
210
Days from Start 2016
Magnitude
0

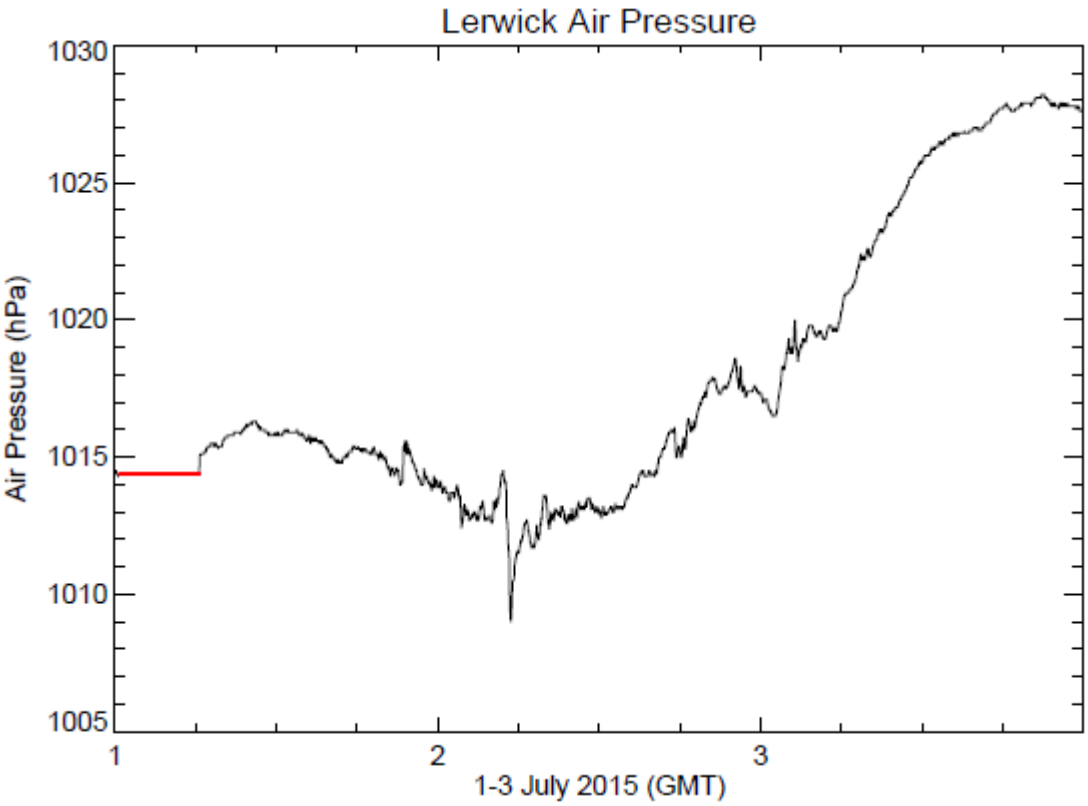

Fair Isle
Residuals (mm)
100
80
60
40
20
0
−20
−40
−60
−80
−100
160
170
180
190
200
210
Days from Start 2016


Fair Isle
Stdev (mm)
45
40
35
30
25
20
15
10
5
0
160
170
180
190
200
210
Days from Start 2016

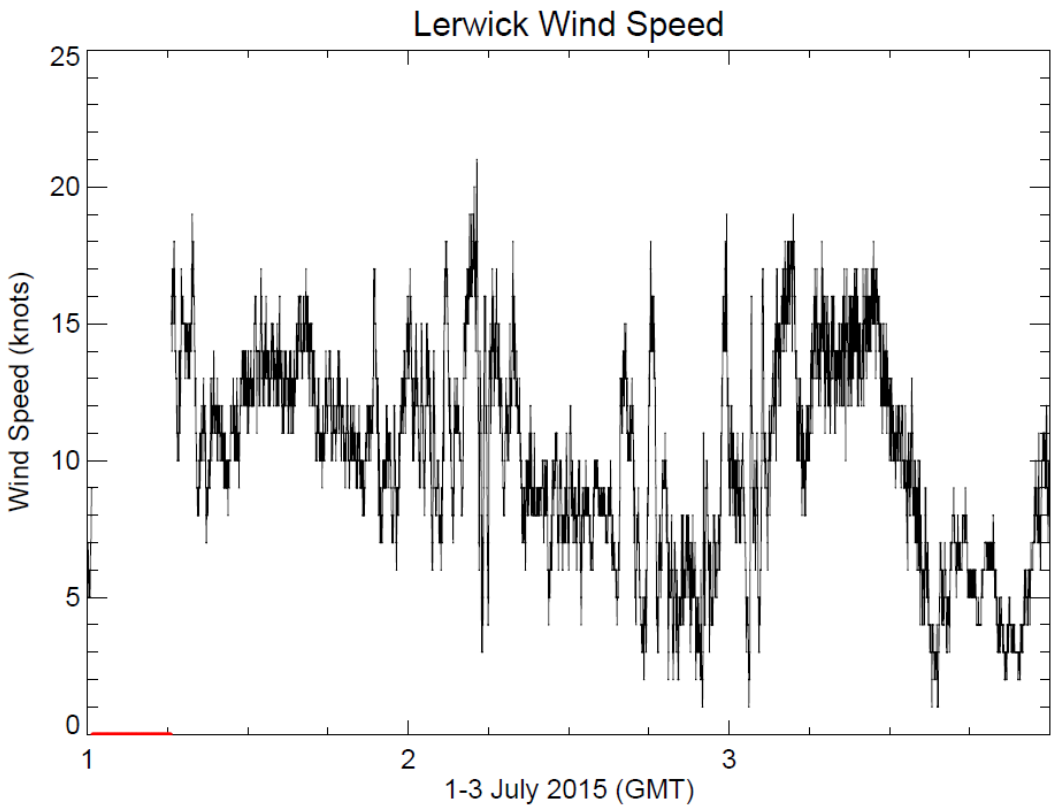

Fair Isle
PSD (mm^2/cph)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1
2
3
4
Frequency (cph)


Fair Isle
Period (minutes)
8
11.3
16
22.6
32
45.3
64
90.5
160
170
180
190
200
210
Days from Start 2016
Magnitude
0

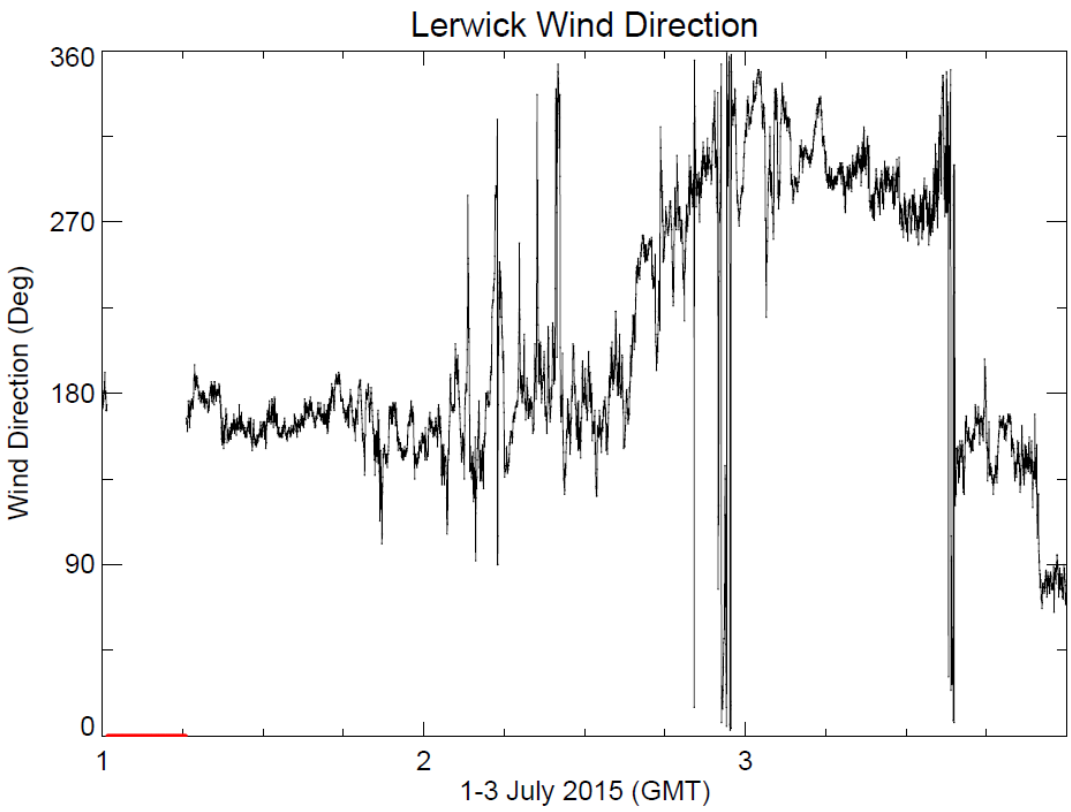
Set B


Lerwick Air Pressure
Air Pressure (hPa)
1030
1025
1020
1015
1010
1005
1
2
3
1-3 July 2015 (GMT)

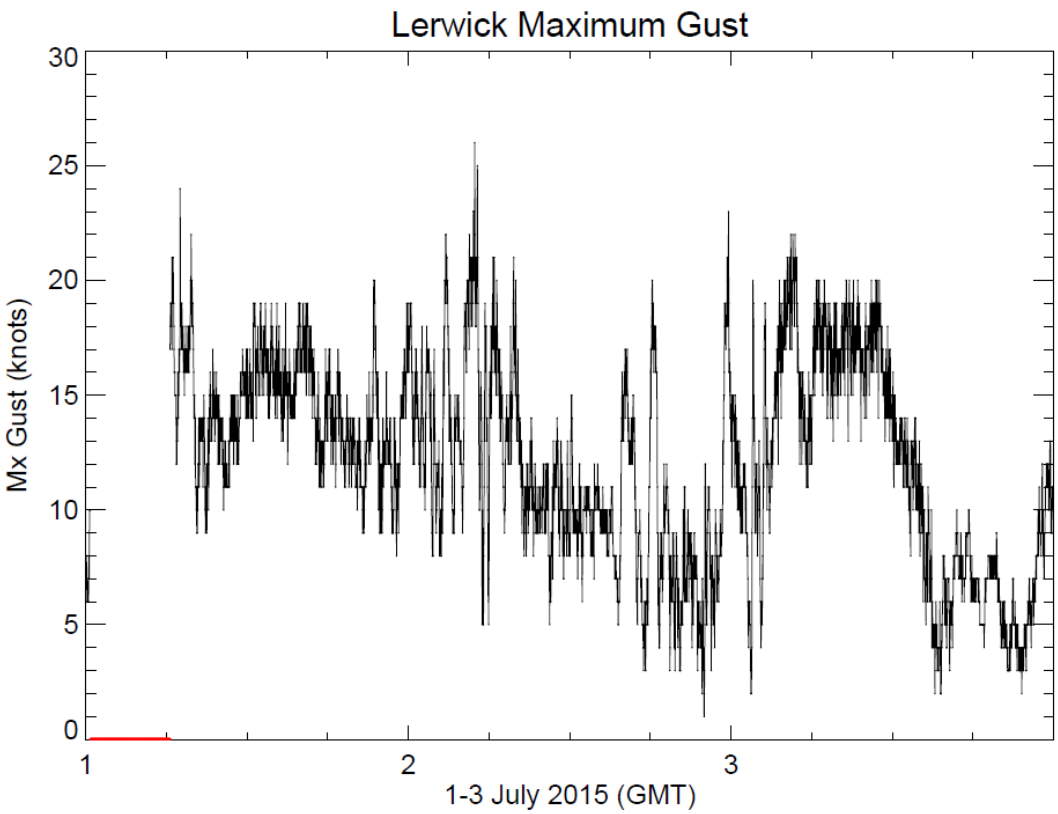
(a)


Lerwick Wind Speed
Wind Speed (knots)
25
20
15
10
5
0
1
2
3
1-3 July 2015 (GMT)

(b)

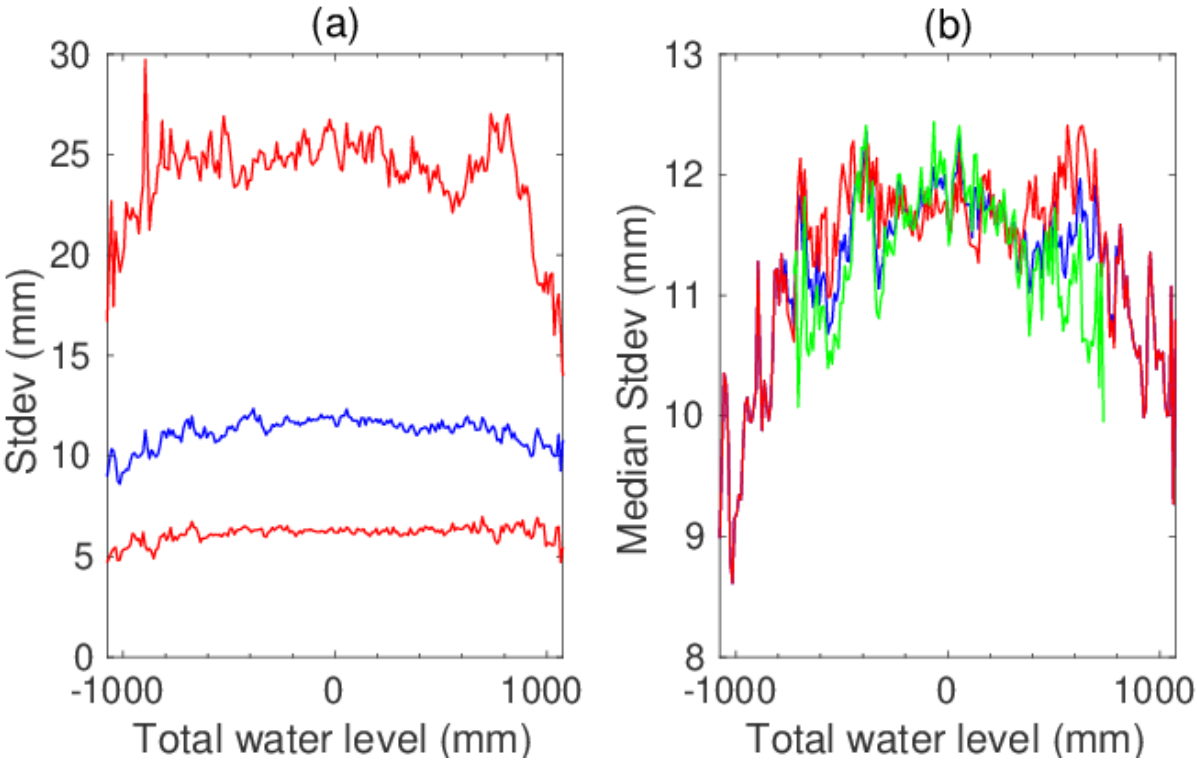

Lerwick Wind Direction
Wind Direction (Deg)
360
270
180
90
0
1
2
3
1-3 July 2015 (GMT)

(c)

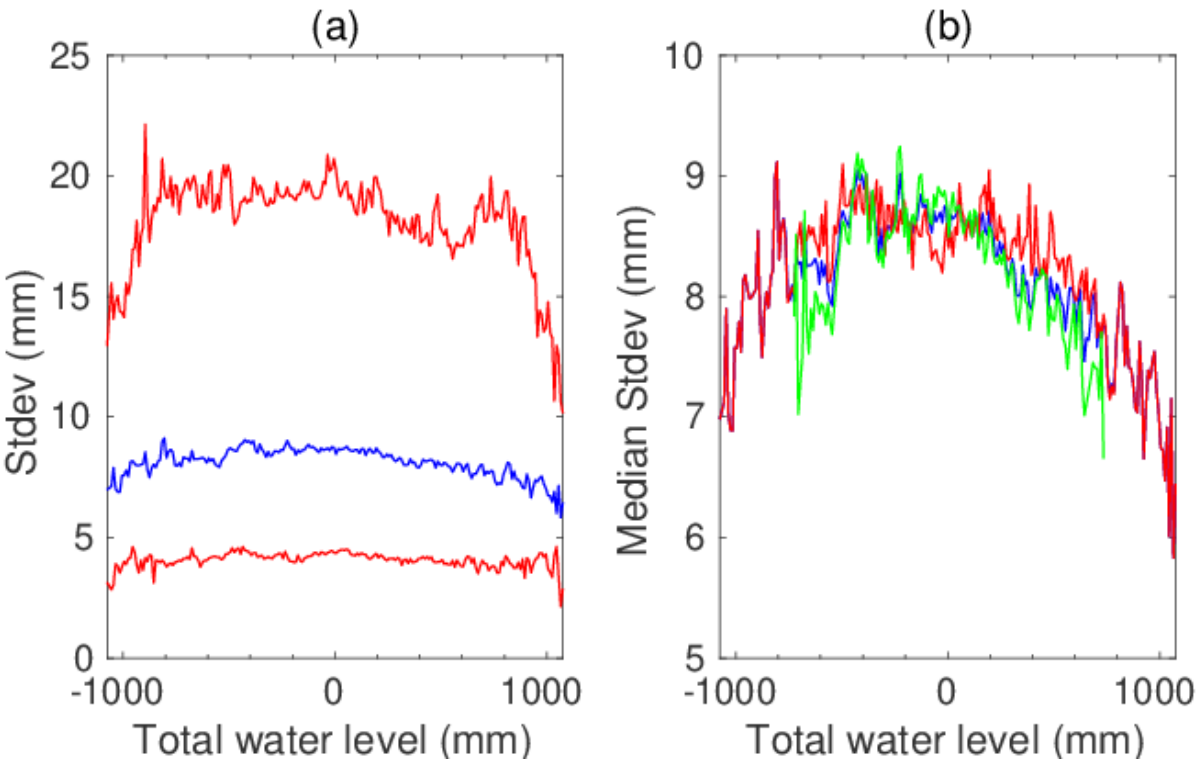

Lerwick Maximum Gust
Mx Gust (knots)
30
25
20
15
10
5
0
1
2
3
1-3 July 2015 (GMT)

(d)

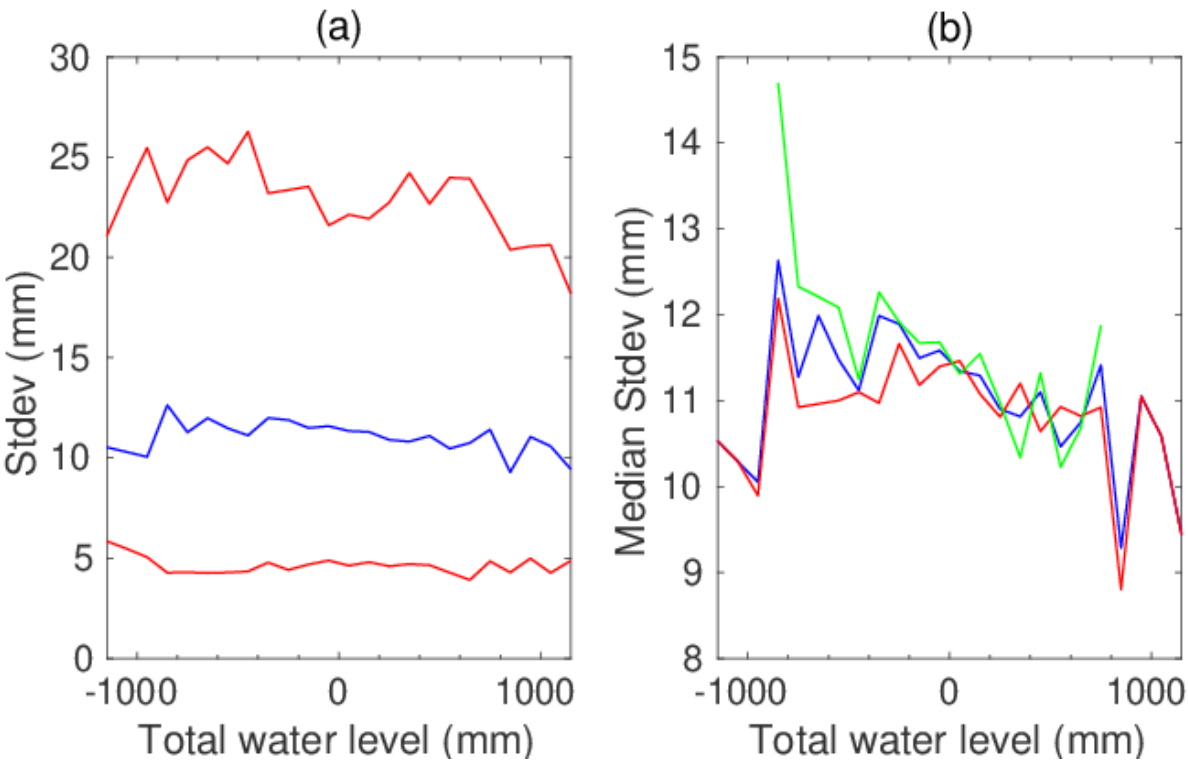
Set C



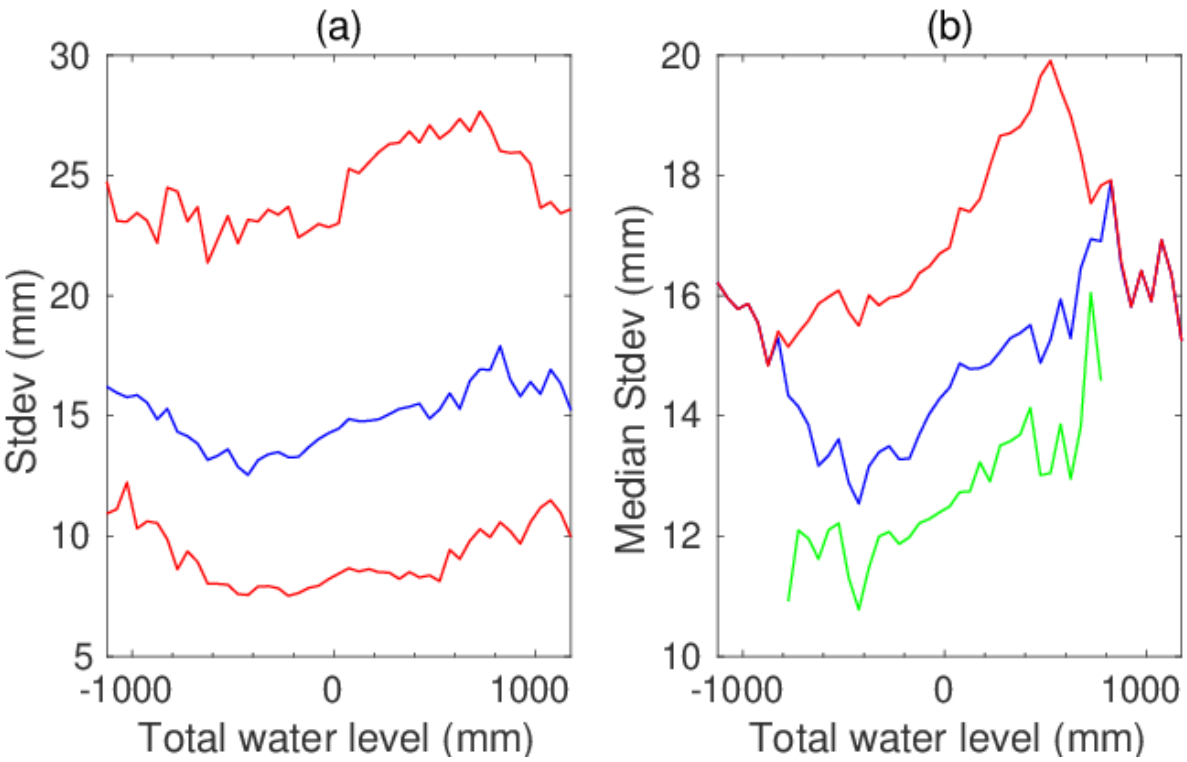
Lerwick with 1.5-3 cph filter.



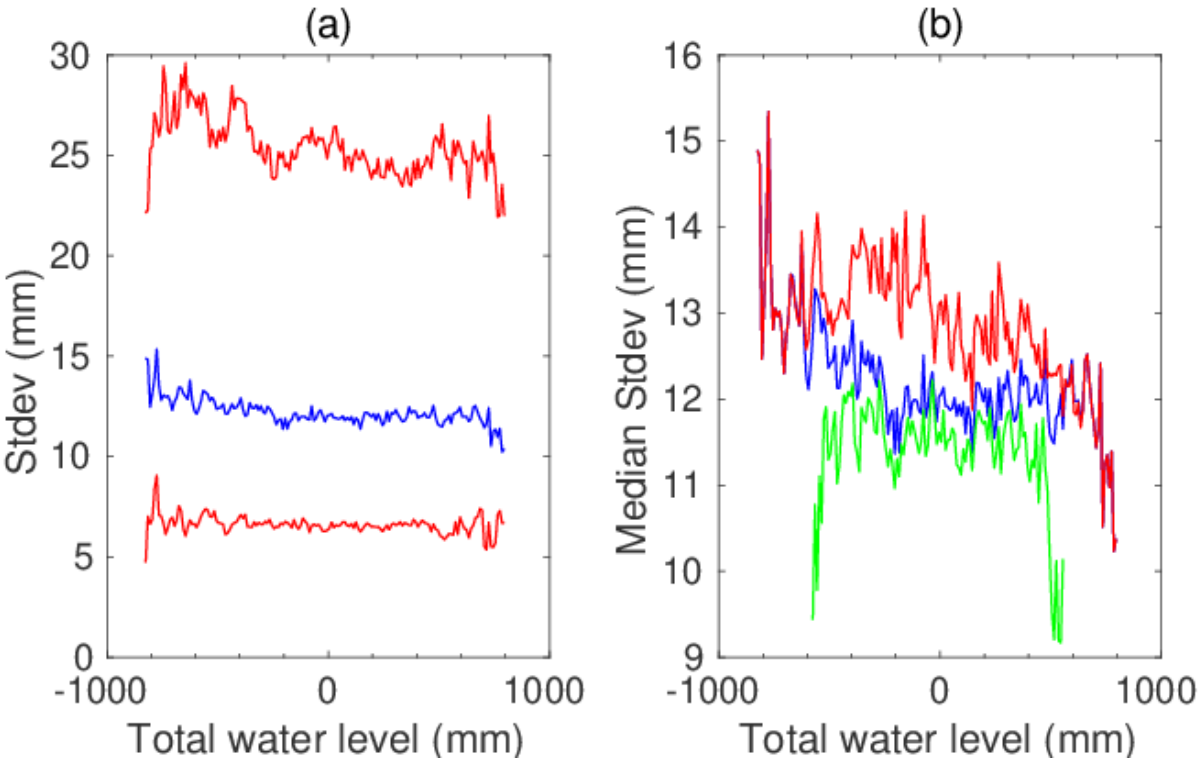
Lerwick with 1.7-2.4 cph filter.



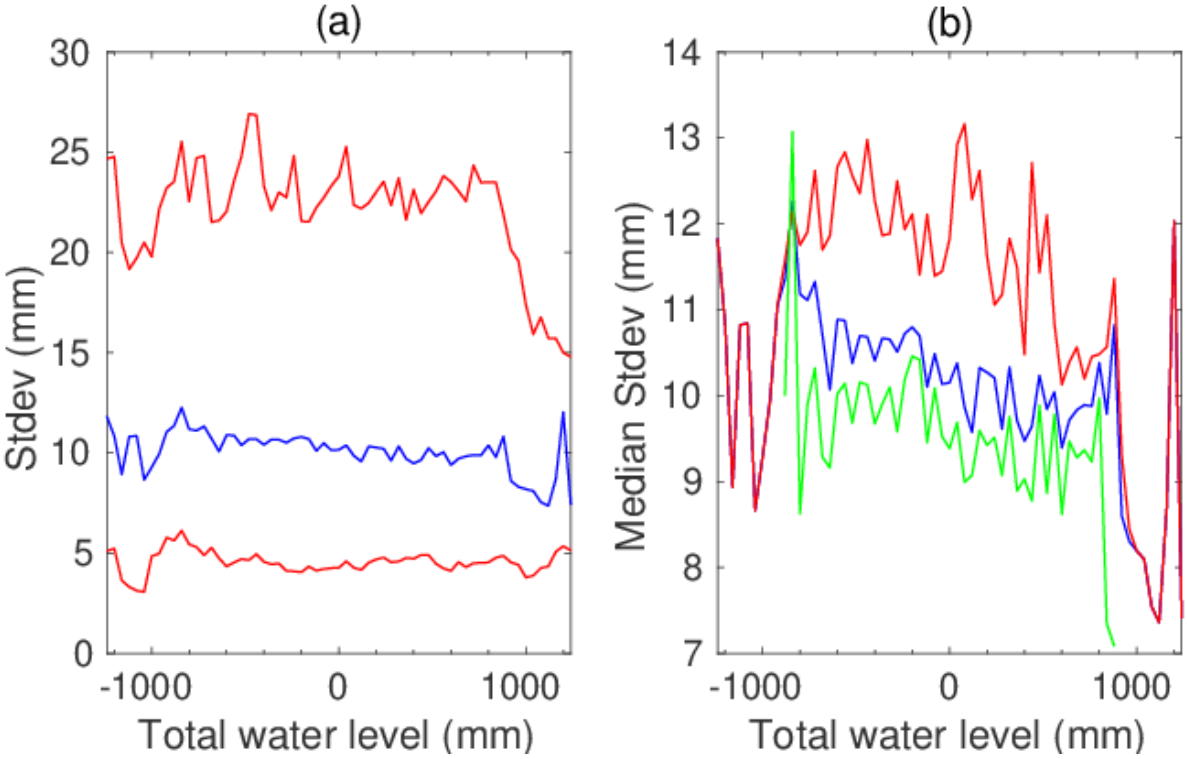
Balta Pier with 1.7-2.4 cph filter.



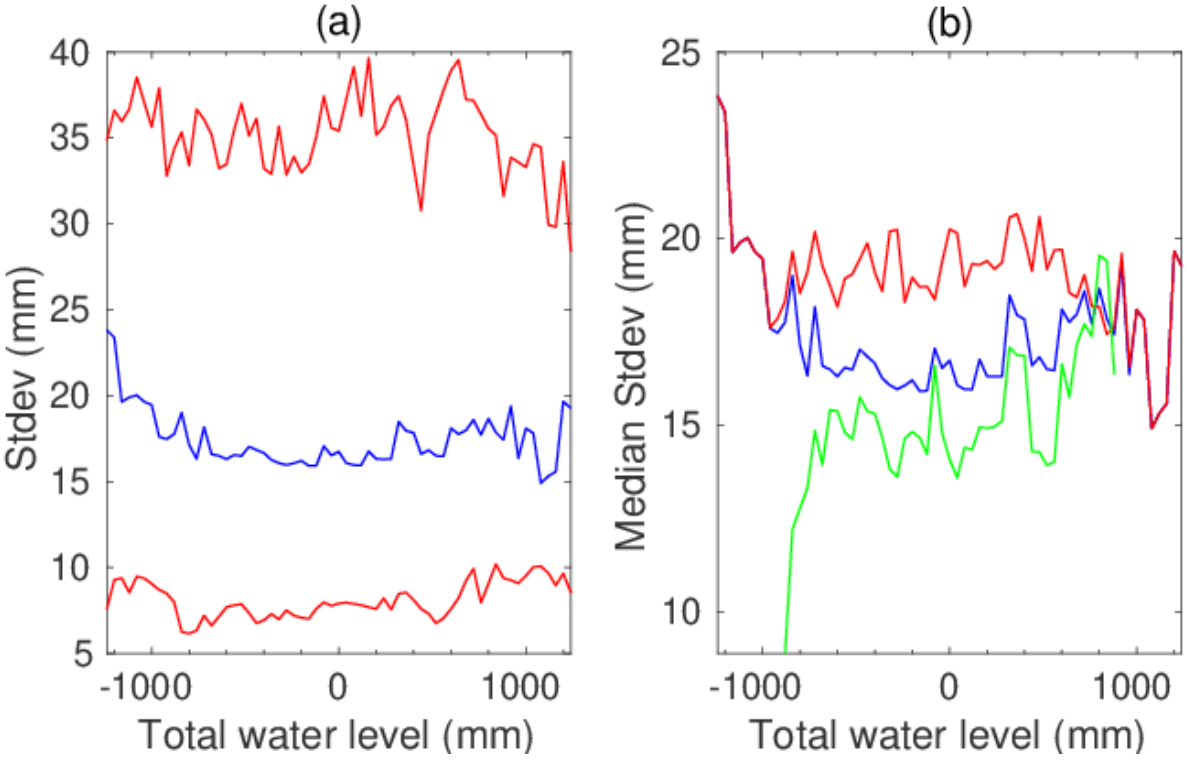
Toft with no band-pass filtering.



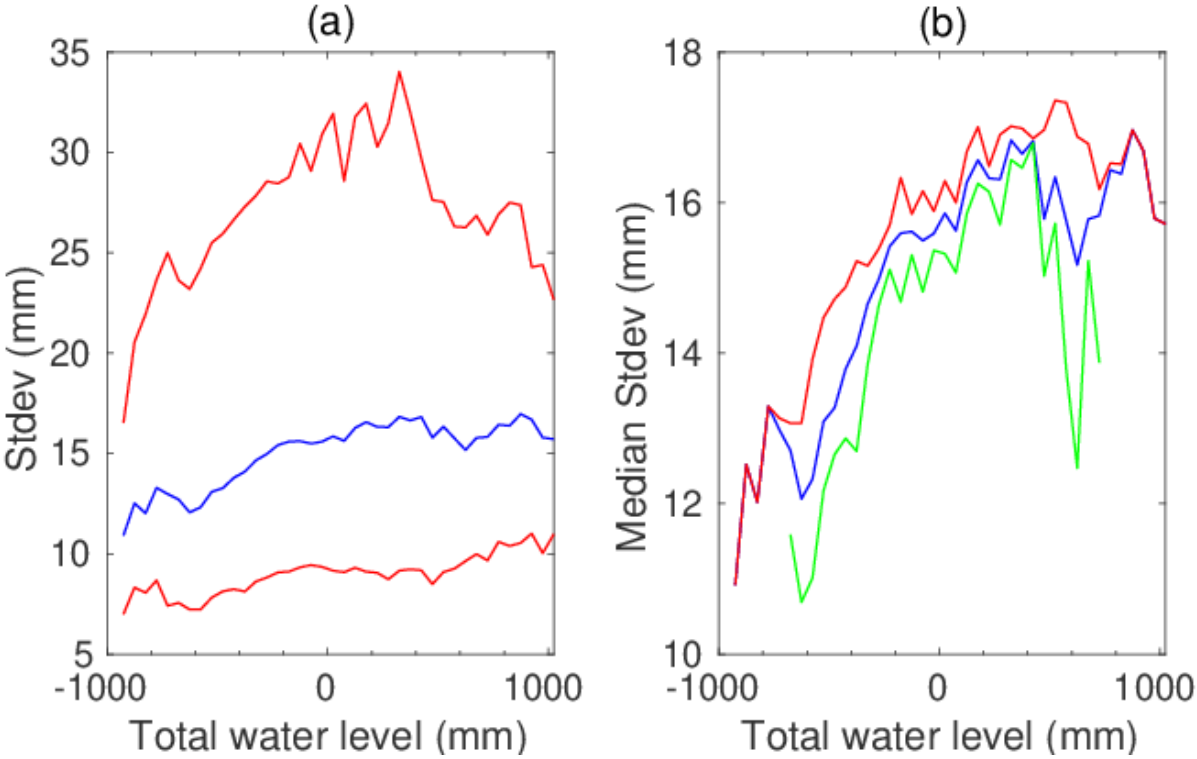
Scalloway with 2.6-4 cph filter.



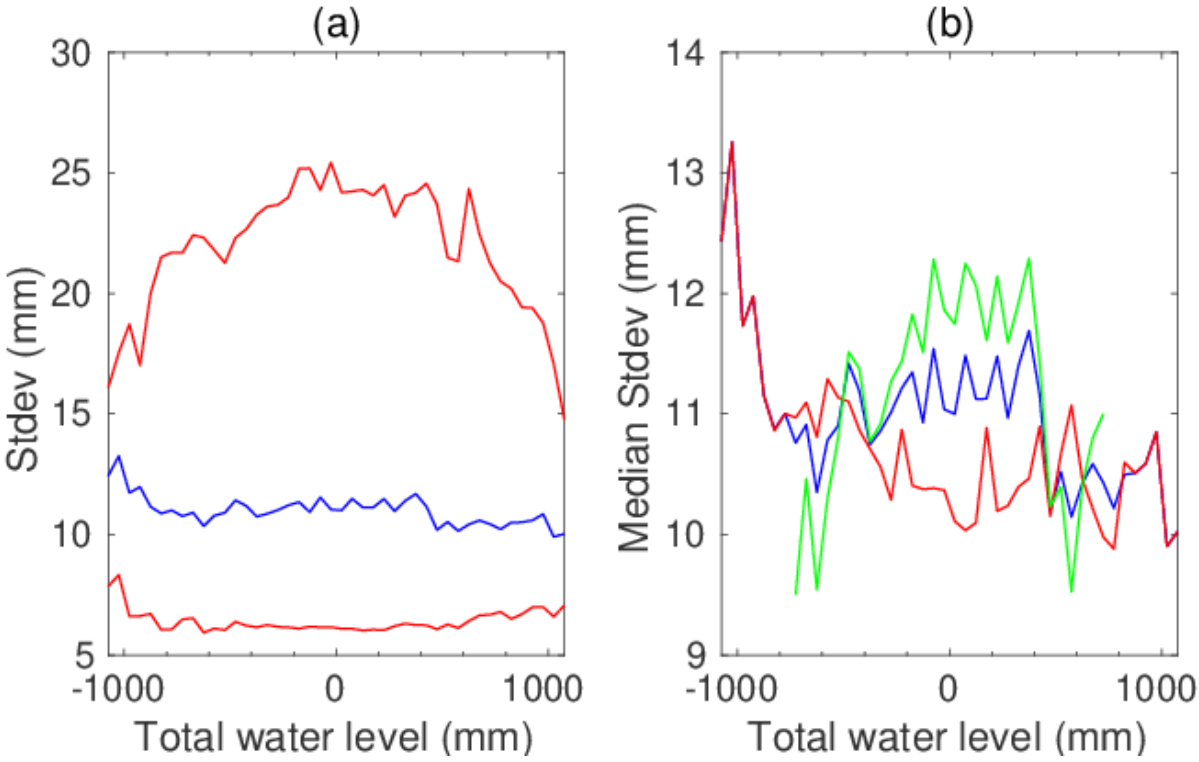
Sella Ness with 1.7-2.4 cph filter.



Sella Ness with 0.5-1 cph filter.

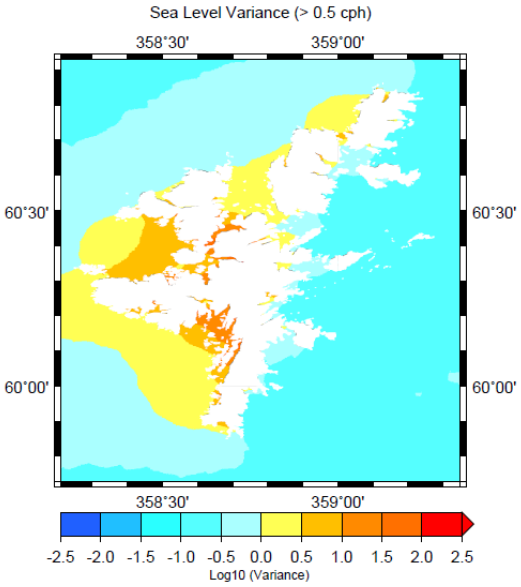


Gutcher with no band-pass filtering.

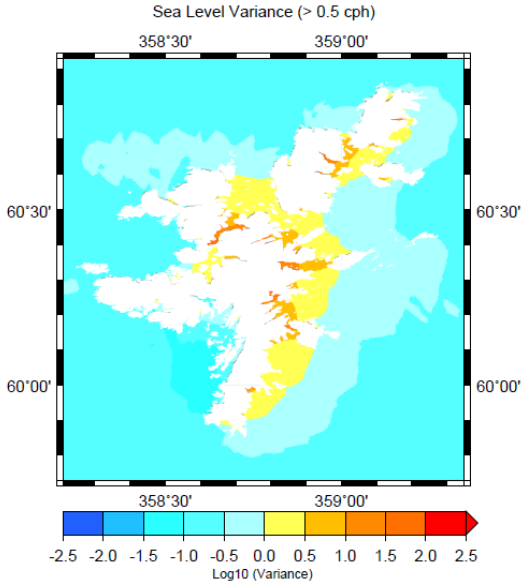


Whalsay with no band-pass filtering.

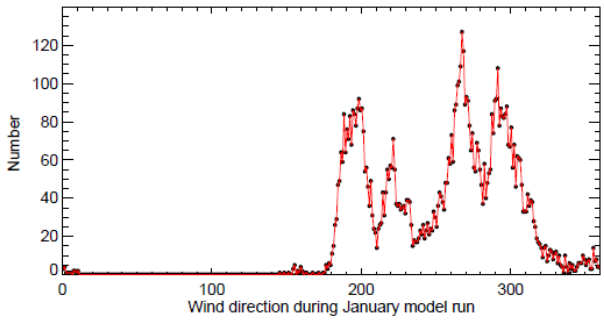
Set D



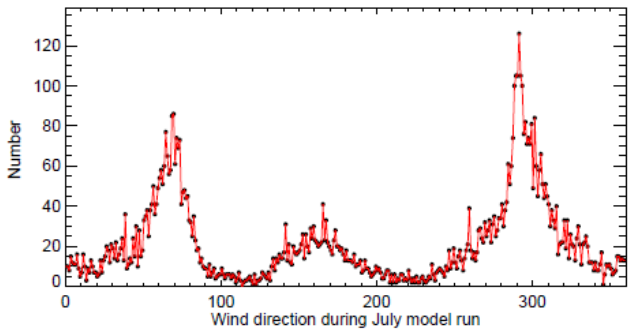
(i)



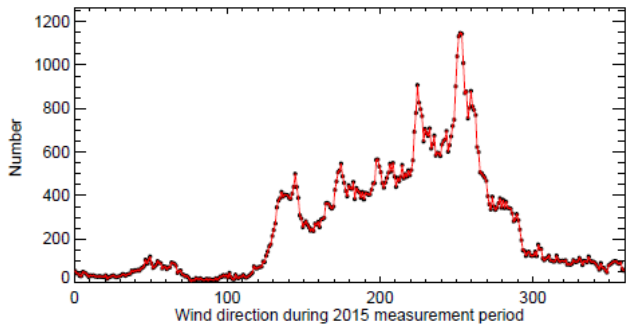
(ii)



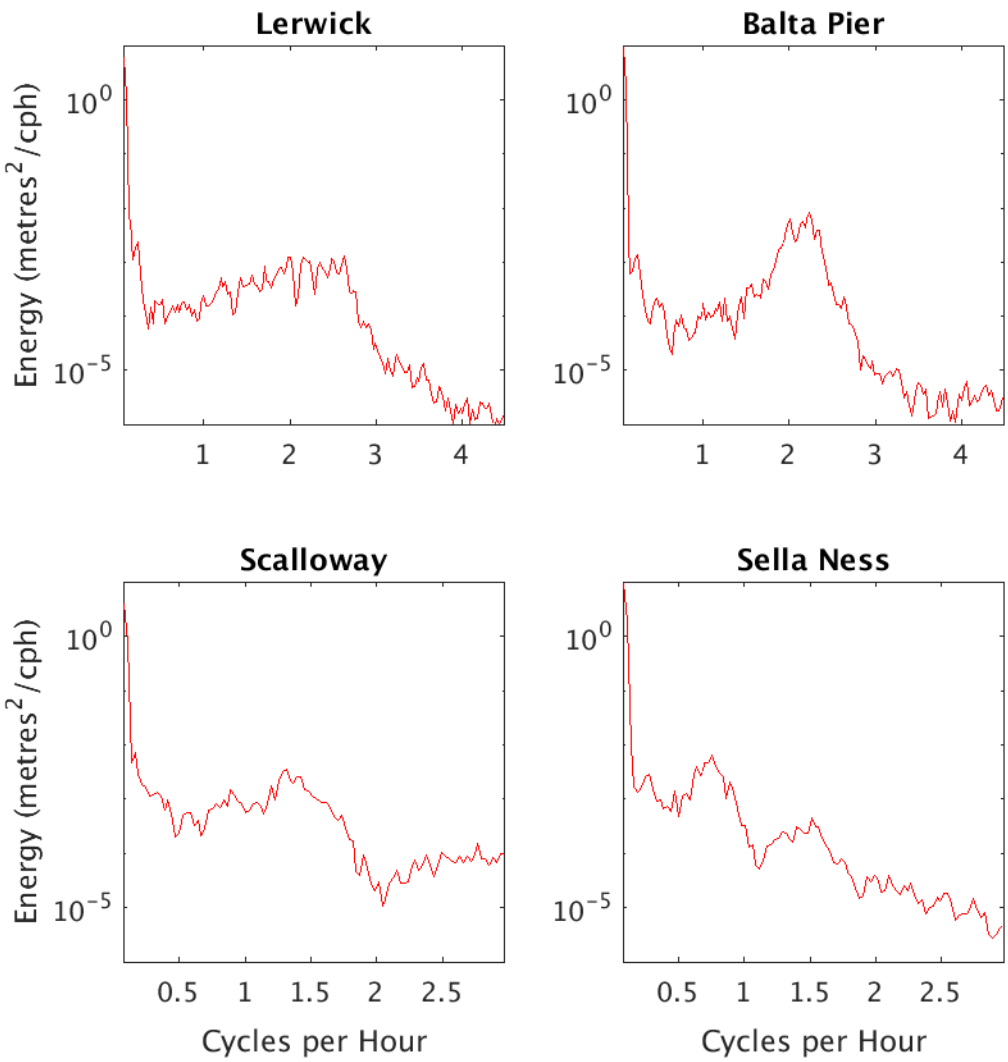
(iii)



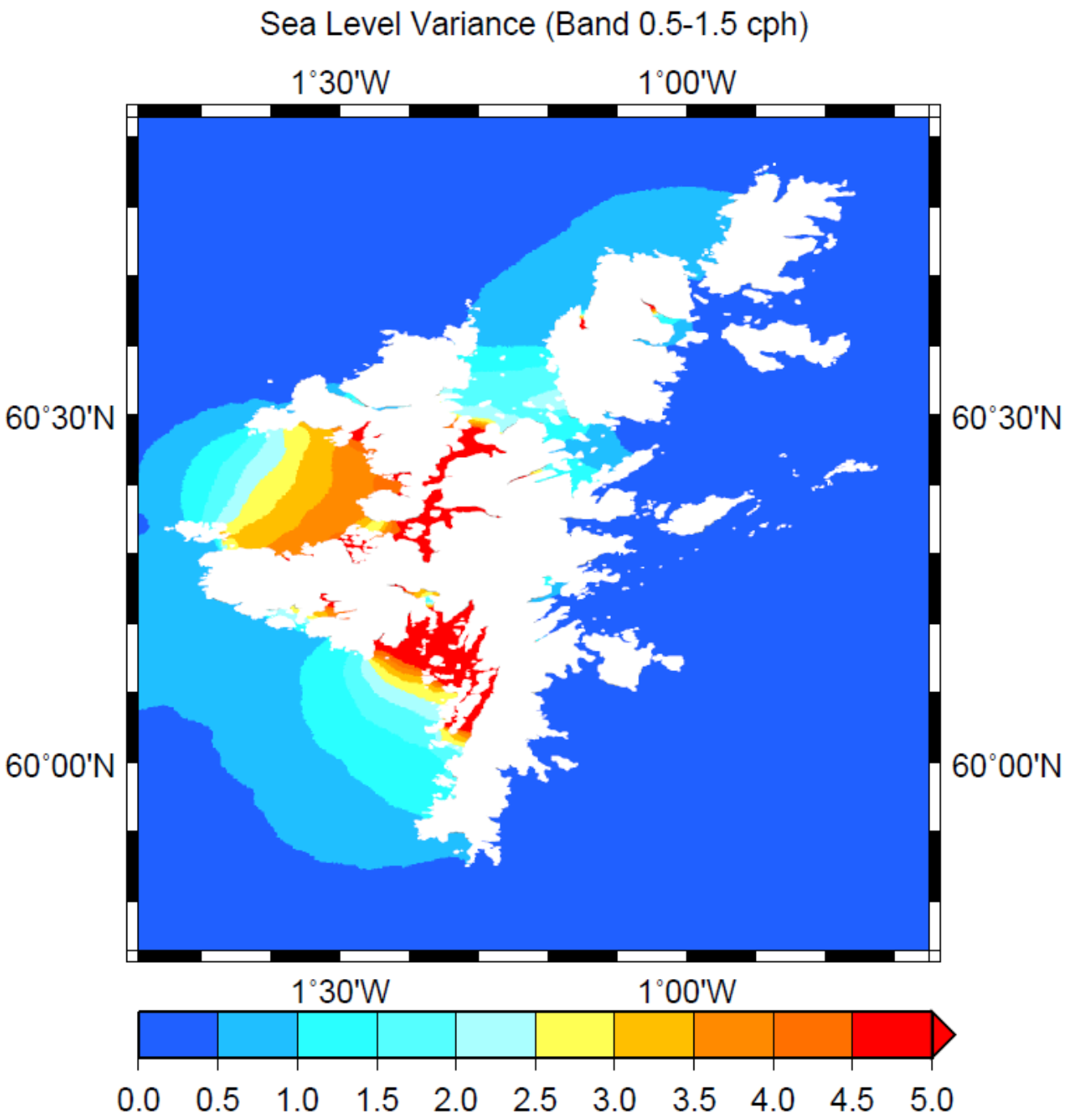
(iv)



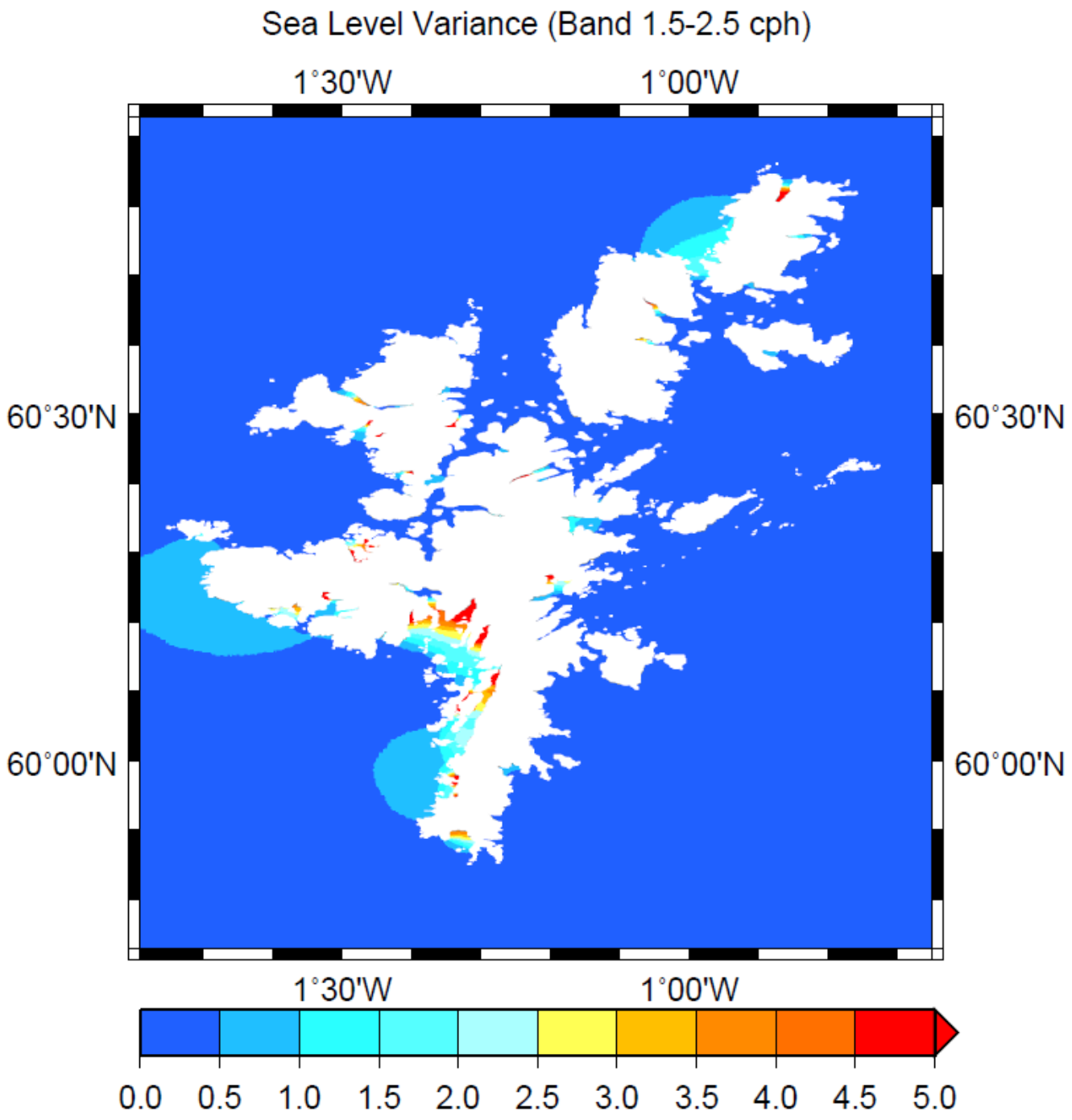
(v)


Lerwick
Balta Pier
Scalloway
Sella Ness
Energy (metres^2/cph)
10^0
10^{-5}
1
2
3
4
0.5
1.5
2.5
Cycles per Hour

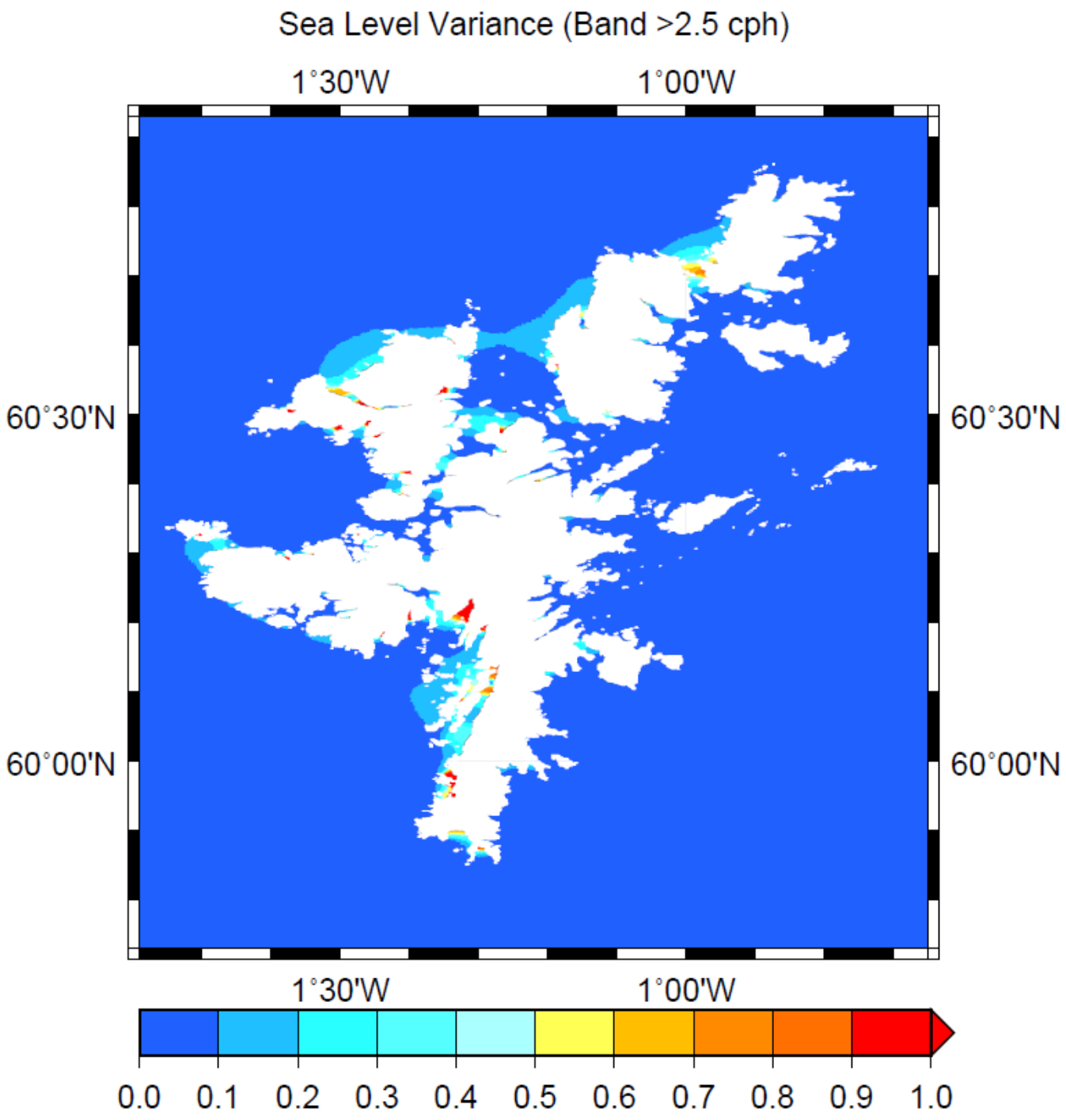
(vi)


Sea Level Variance (Band 0.5-1.5 cph)
1°30'W
1°00'W
60°30'N
60°00'N
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

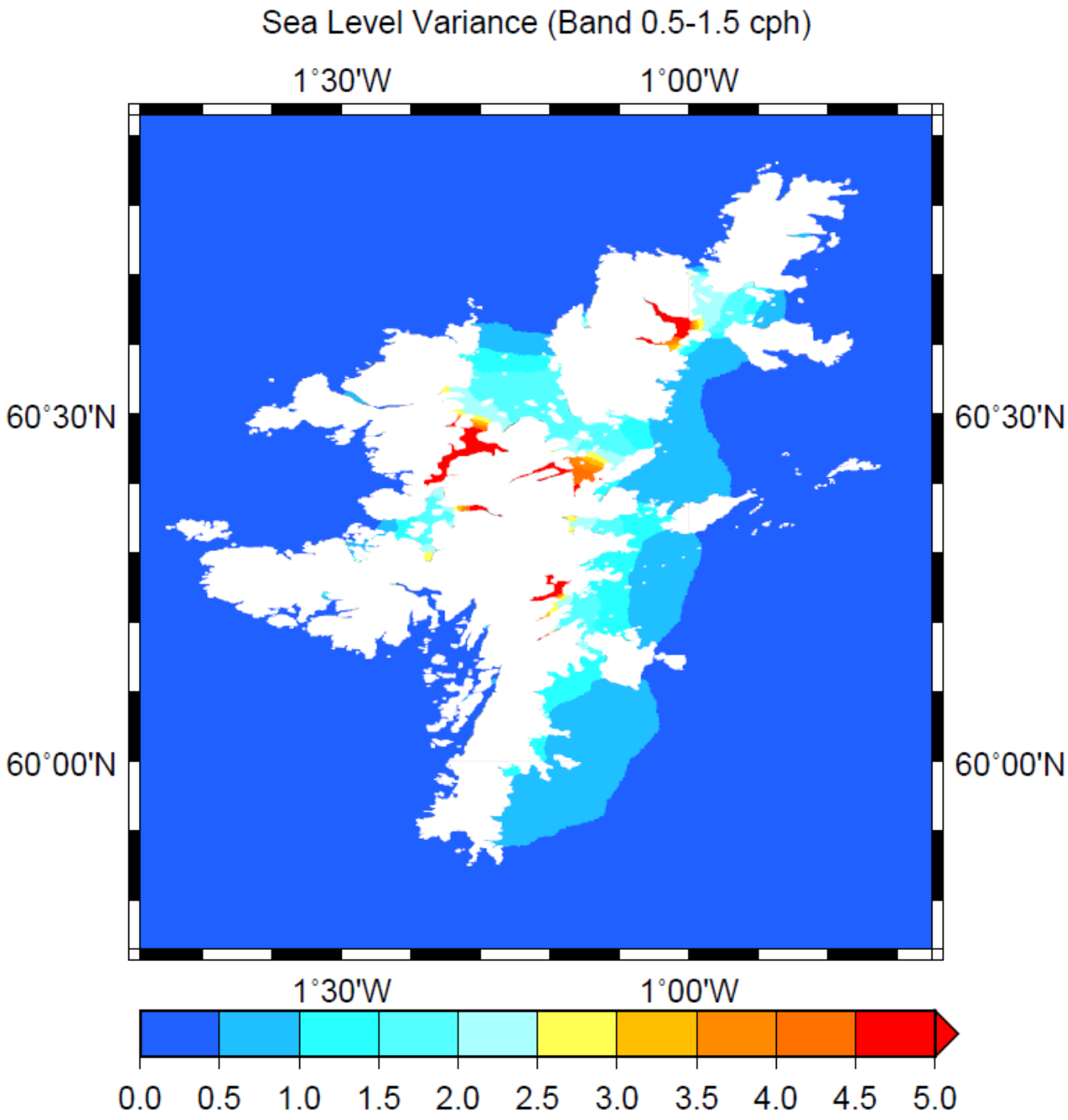
(vii)


Sea Level Variance (Band 1.5-2.5 cph)
1°30'W
1°00'W
60°30'N
60°00'N
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

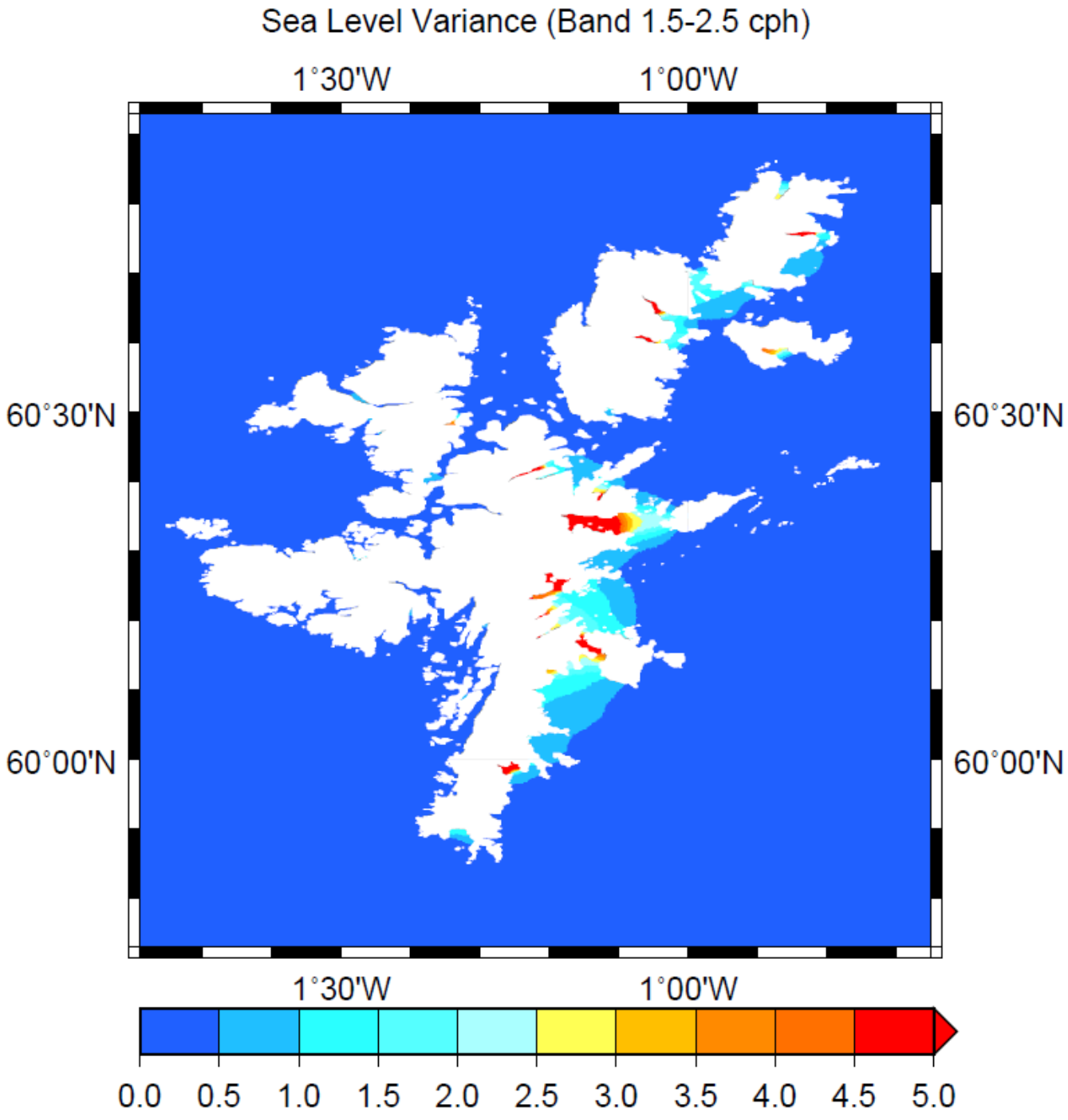
(viii)


Sea Level Variance (Band >2.5 cph)
1°30'W
1°00'W
60°30'N
60°00'N
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

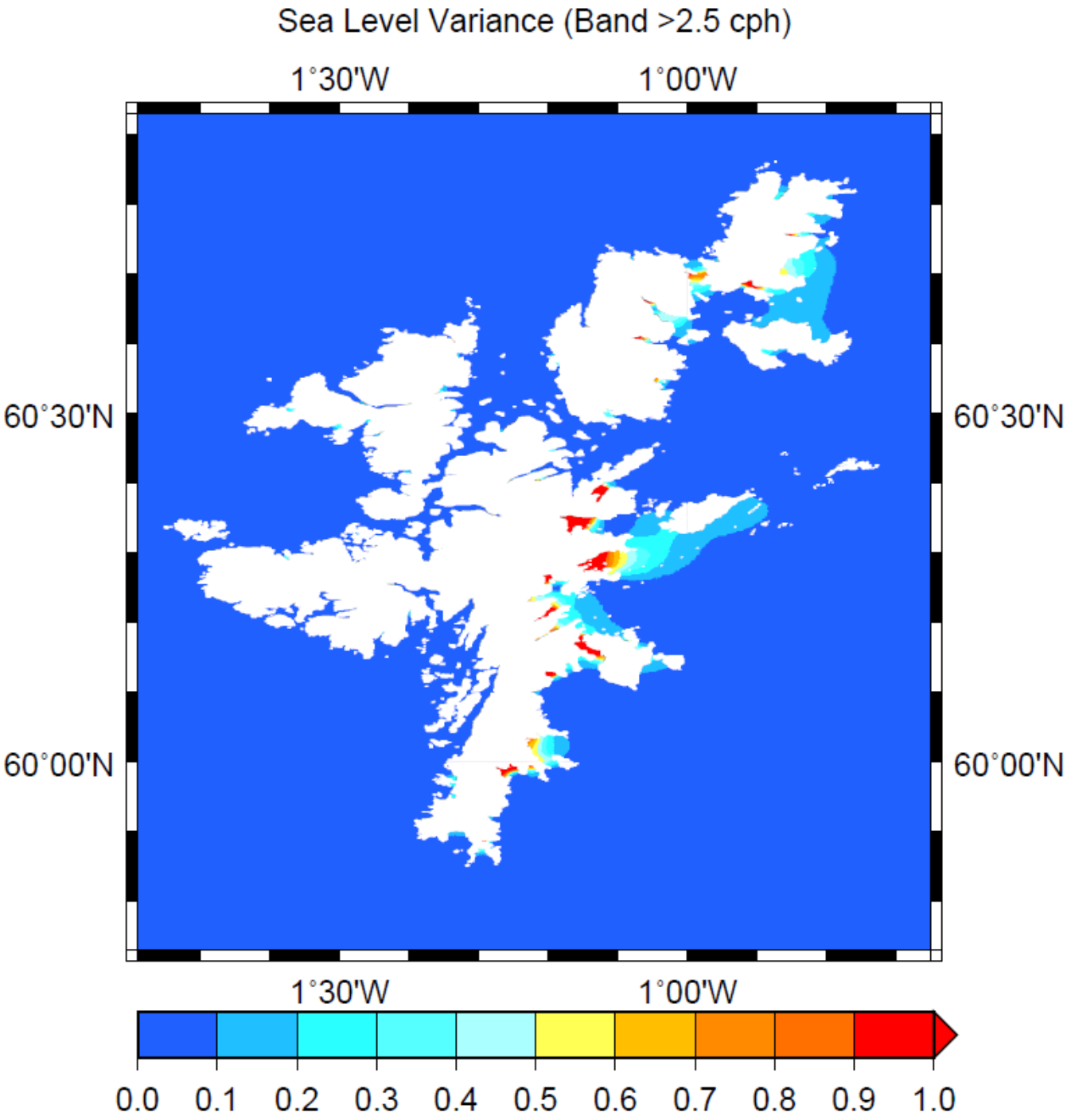
(ix)


Sea Level Variance (Band 0.5-1.5 cph)
1°30'W
1°00'W
60°30'N
60°00'N
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

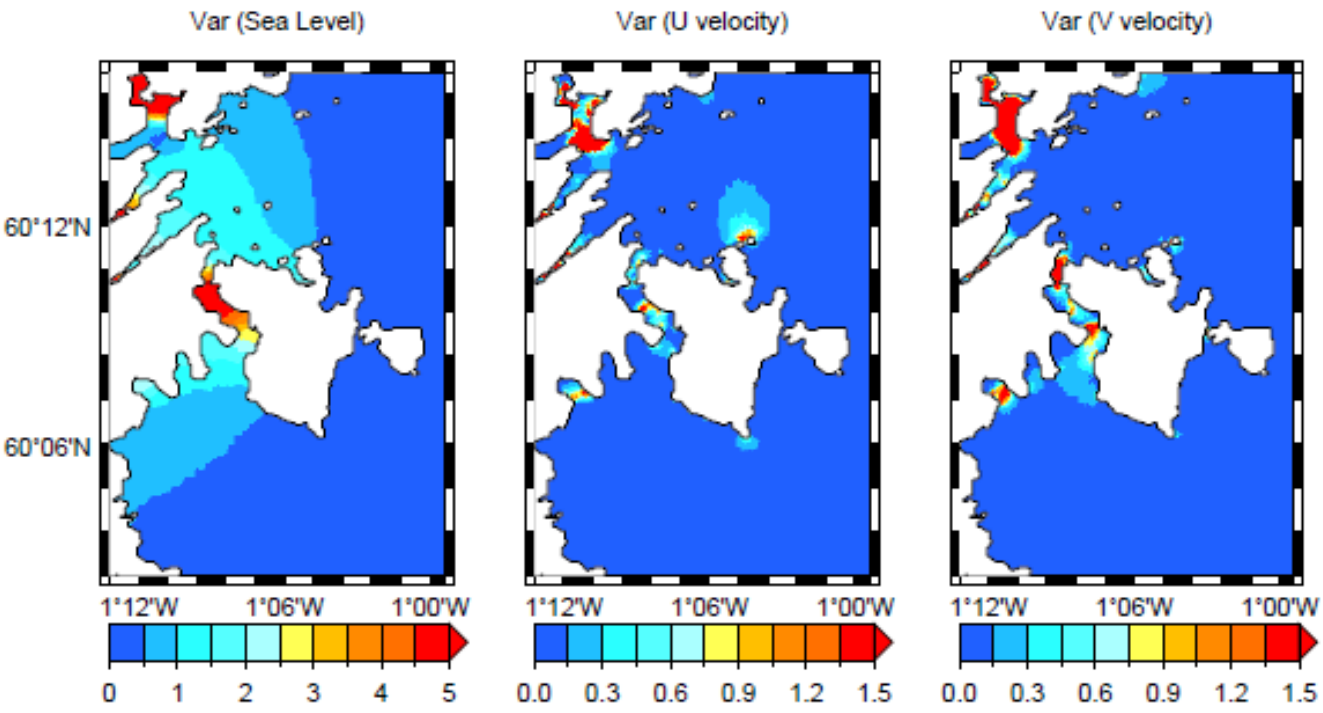
(x)


Sea Level Variance (Band 1.5-2.5 cph)
1°30'W
1°00'W
60°30'N
60°00'N
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

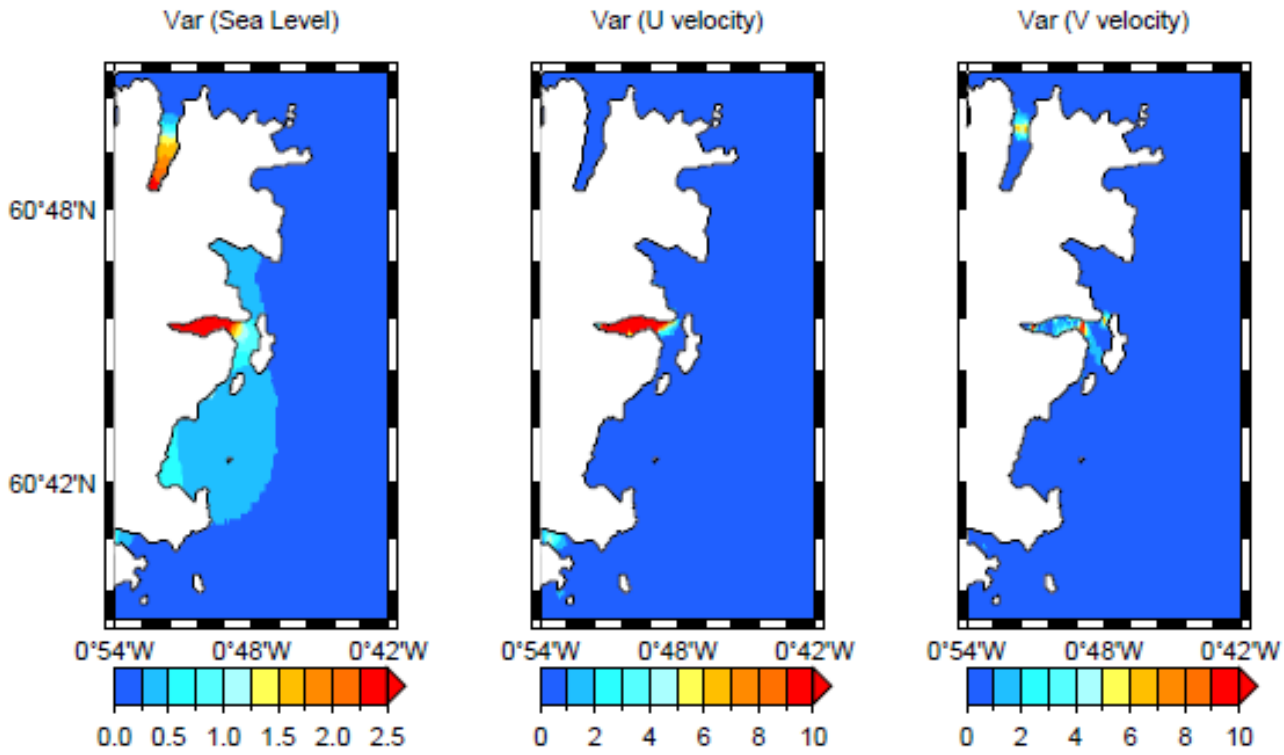
(xi)


Sea Level Variance (Band >2.5 cph)
1°30'W
1°00'W
60°30'N
60°00'N
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

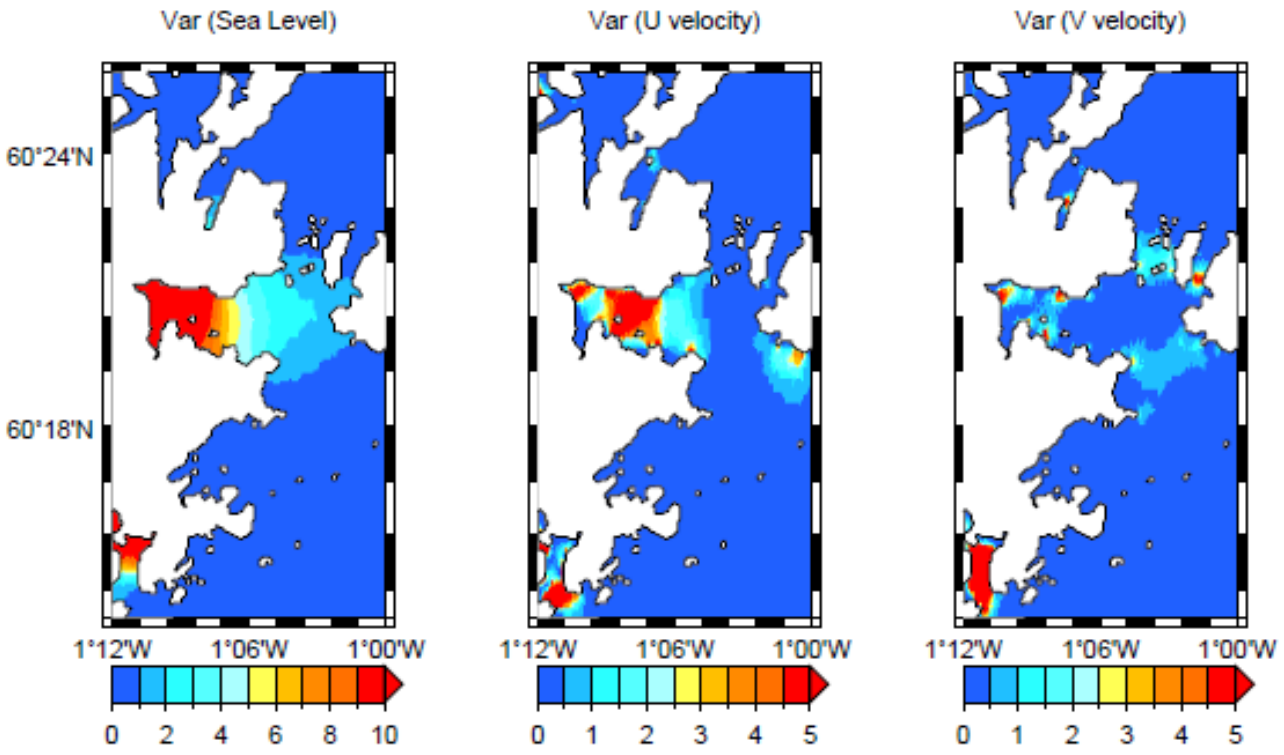
(xii)


Var (Sea Level)
Var (U velocity)
Var (V velocity)
60°12'N
60°06'N
1°12'W
1°06'W
1°00'W
0 1 2 3 4 5
0.0 0.3 0.6 0.9 1.2 1.5
0.0 0.3 0.6 0.9 1.2 1.5

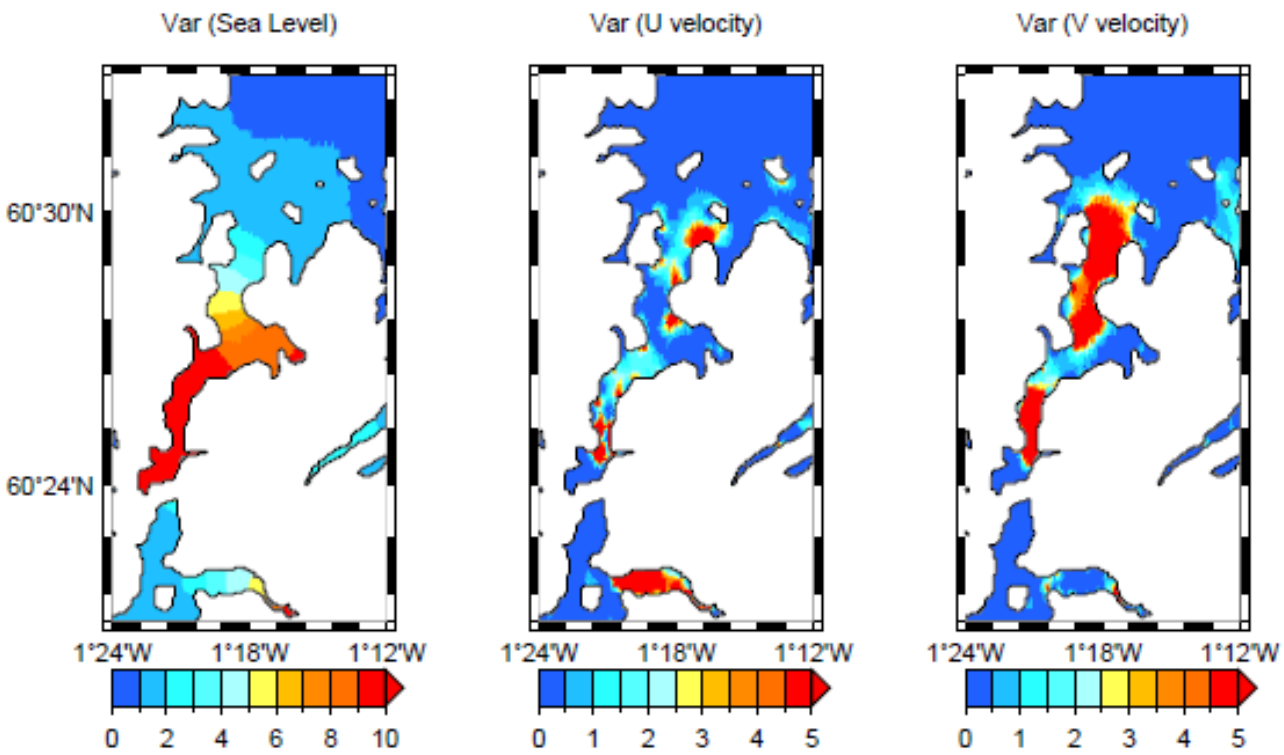
(xiii)


Var (Sea Level)
Var (U velocity)
Var (V velocity)
60°48'N
60°42'N
0°54'W
0°48'W
0°42'W
0.0 0.5 1.0 1.5 2.0 2.5
0 2 4 6 8 10
0 2 4 6 8 10

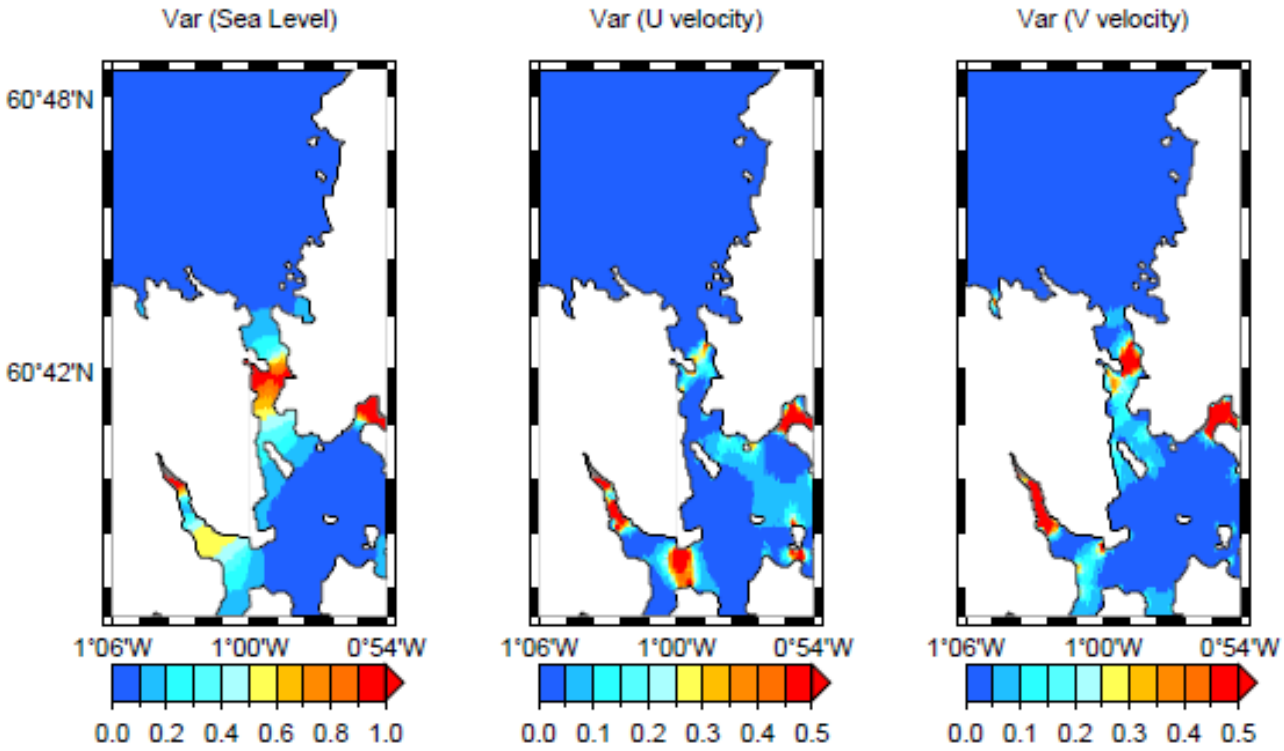
(xiv)


Var (Sea Level)
Var (U velocity)
Var (V velocity)
60°24'N
60°18'N
1°12'W
1°06'W
1°00'W
0 2 4 6 8 10
0 1 2 3 4 5

(xv)

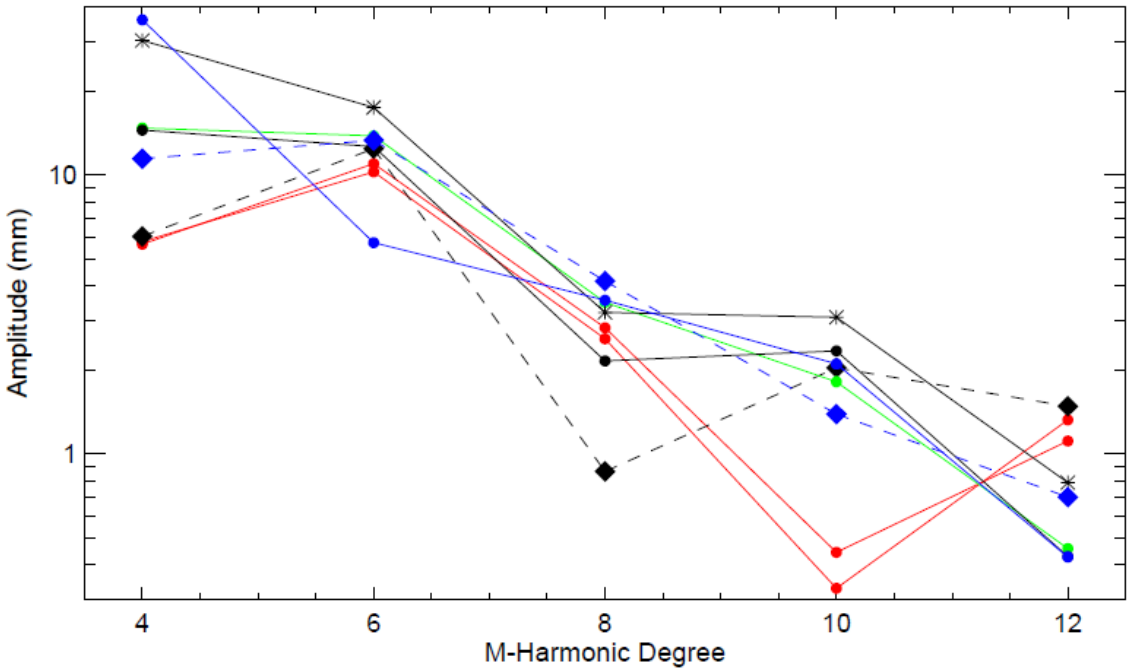

Var (Sea Level)
Var (U velocity)
Var (V velocity)
60°30'N
60°24'N
1°24'W
1°18'W
1°12'W
0 2 4 6 8 10
0 1 2 3 4 5

(xvi)


Var (Sea Level)
Var (U velocity)
Var (V velocity)
60°48'N
60°42'N
1°06'W
1°00'W
0°54'W
0.0 0.2 0.4 0.6 0.8 1.0
0.0 0.1 0.2 0.3 0.4 0.5
0.0 0.1 0.2 0.3 0.4 0.5

(xvii)

Set E



Supplementary Figure E1