A Preliminary Study of Ground Water Level Change due to Earthquake using Time-Frequency Analysis

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Data Source: Water Resource Agency, MOEA.
2007/9/27

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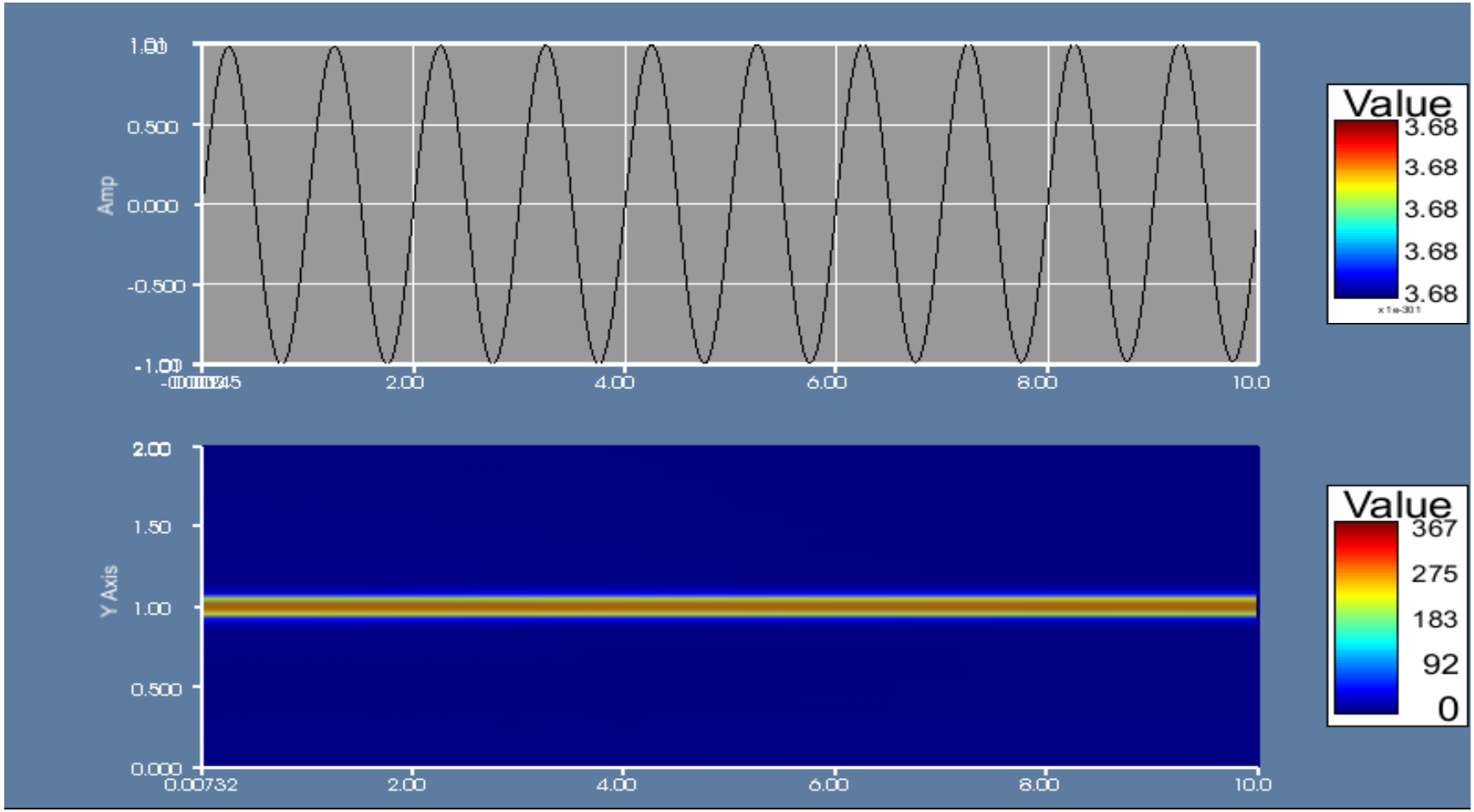
- Time-Frequency Analysis
- Single Frequency and Harmonics
- Diurnal/Semi-Diurnal Tide
- Precursor to Earthquake
- Summary

What is Time-Frequency Analysis?

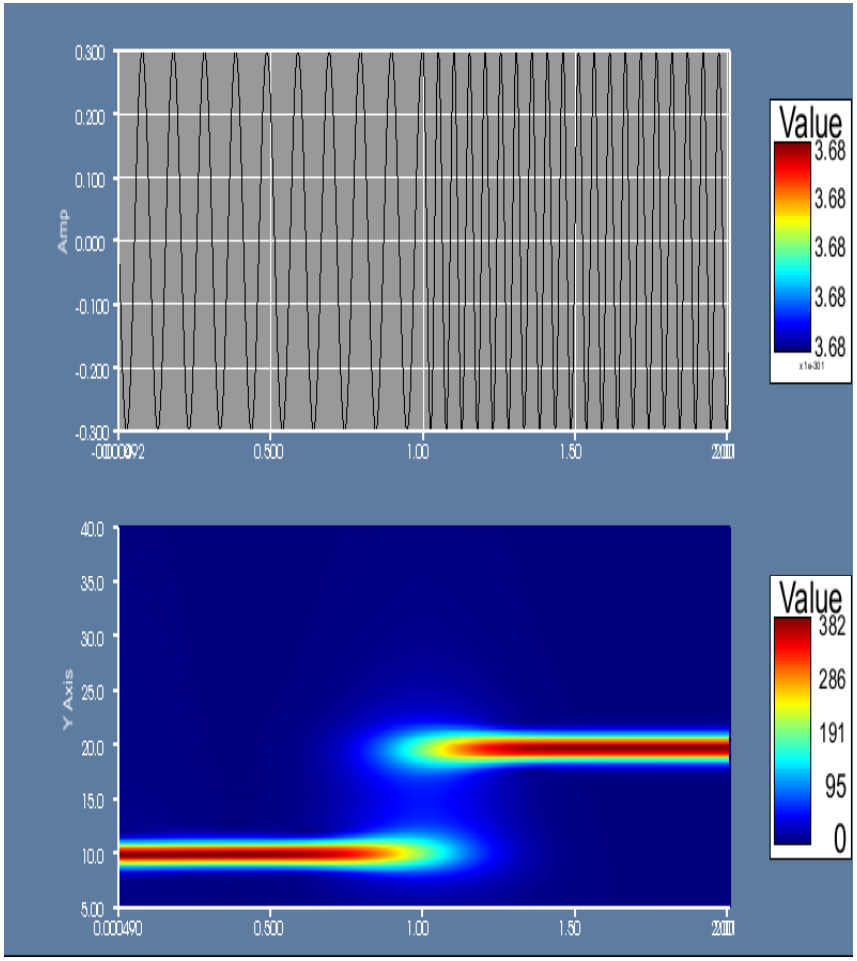
TF Plot: Single frequency



TF Plot: Change of frequency

- Signal with abrupt change of frequency.

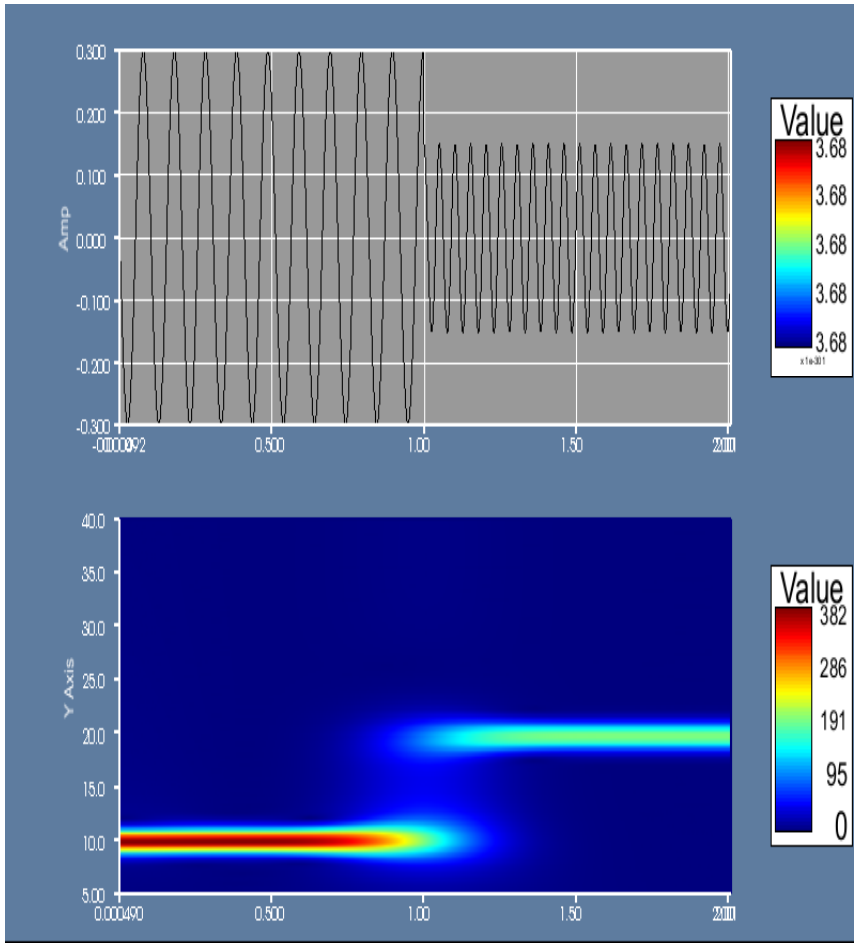
$$x(t) = \begin{cases} 0.30\cos(2\times 10\pi t) & ,0 \le t < 1 \\ 0.30\cos(2\times 20\pi t) & ,1 \le t < 2 \end{cases}$$



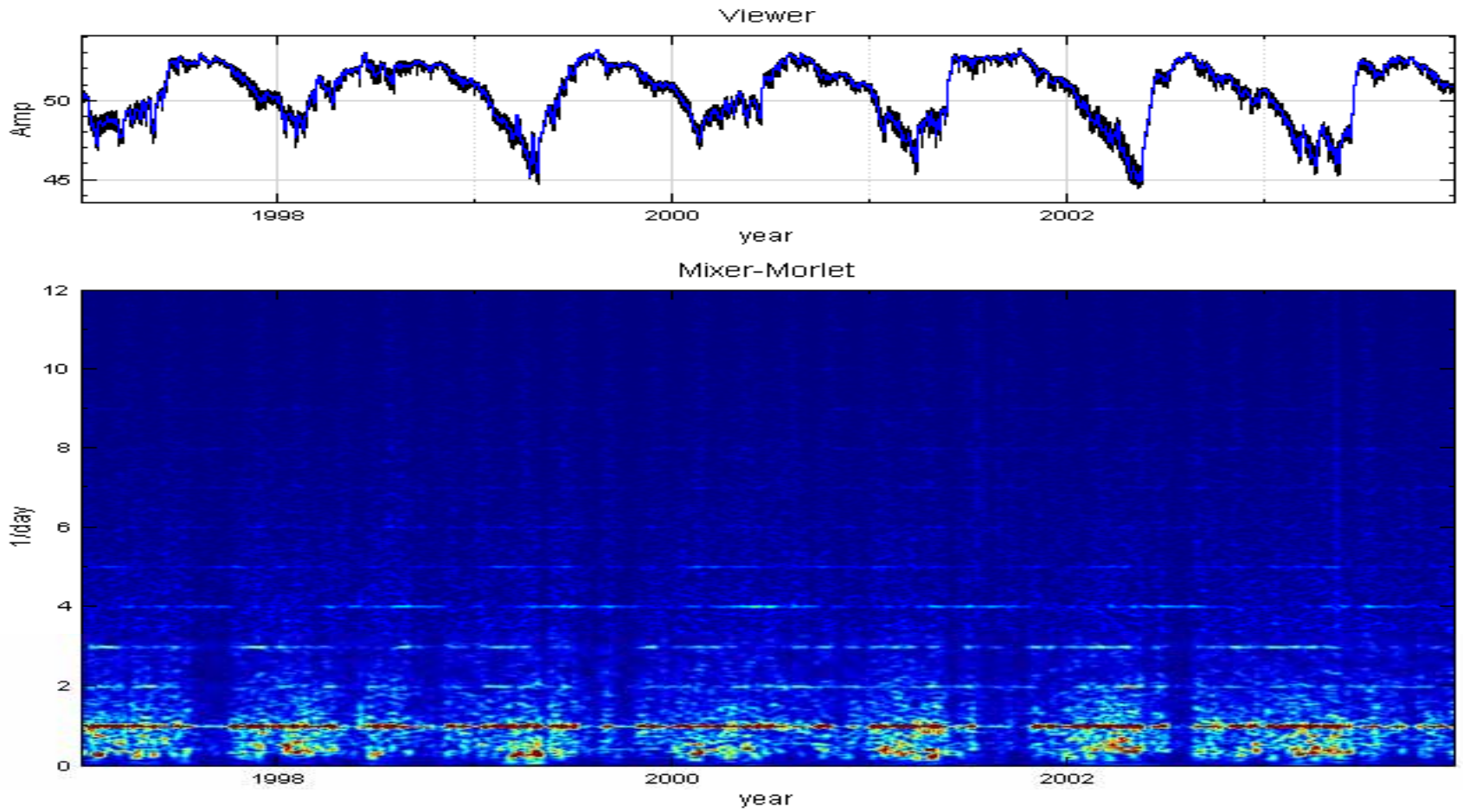
TF Plot: Change of frequency and amplitude

- Signal with abrupt change of frequency and amplitude

$$x(t) = \begin{cases} 0.30\cos(2 \times 10\pi t) & ,0 \le t < 1 \\ 0.15\cos(2 \times 20\pi t) & ,1 \le t < 2 \end{cases}$$



TF Plot of 美濃(1)



Time-Frequency Analysis in Visual Signal

	Fourier Transform	STFT	**Morlet / Enhanced Morlet***	Hilbert Transform	**HHT***
Instantaneous frequency	n/a	distribution	**distribution**	Single value	**Discrete values**
Frequency change with time	no	yes	**yes**	yes	**yes**
Frequency resolution	good	ok	**ok/good**	good	**good**
Adaptive base	no	no	**no**	n/a	**yes**
Handling non-linear effect	n/a	no	**no**	yes	**yes**

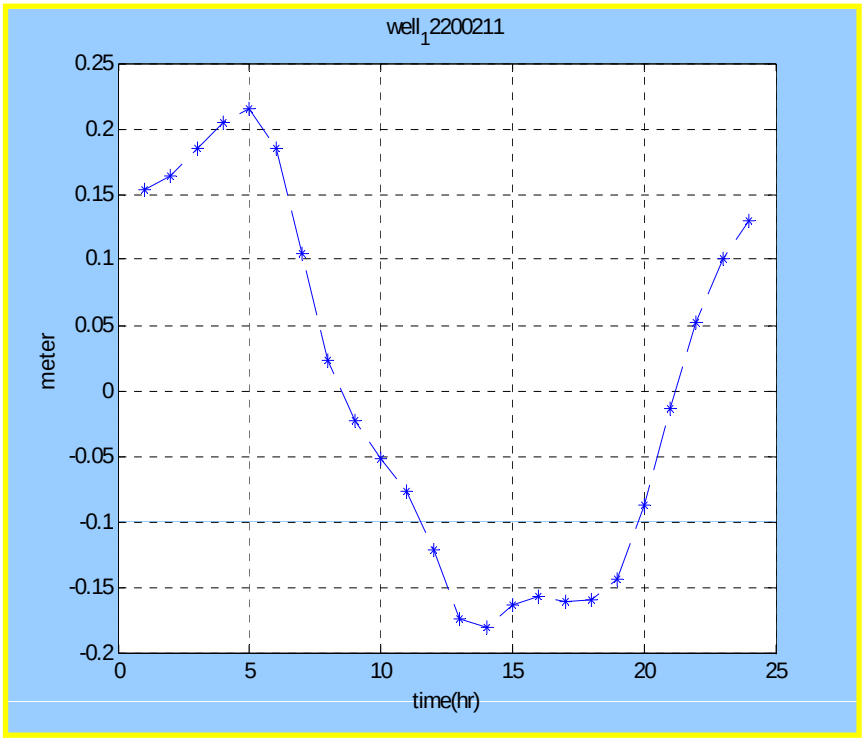
*Algorithm used in this study

Suggested Criteria for Doing Time-Frequency Analysis

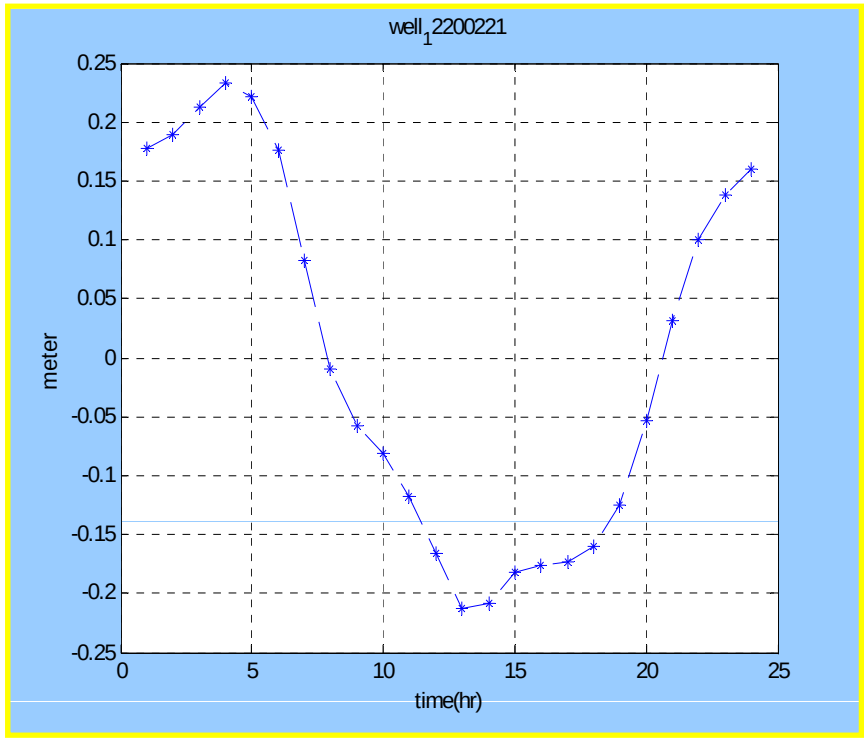
- recorded length: over 10000 points in total.
- Bit rate: more than 8 bits.
- Sampling rate/Data Length:
  - Once per day => 24 years
  - Once per hour => 1 year
  - Once per minute => 1 week
  - Once per second => 3 hours
  - Vice versa…

Single Frequency and Harmonics

Average Daily Variation of GWL in Agriculture Region

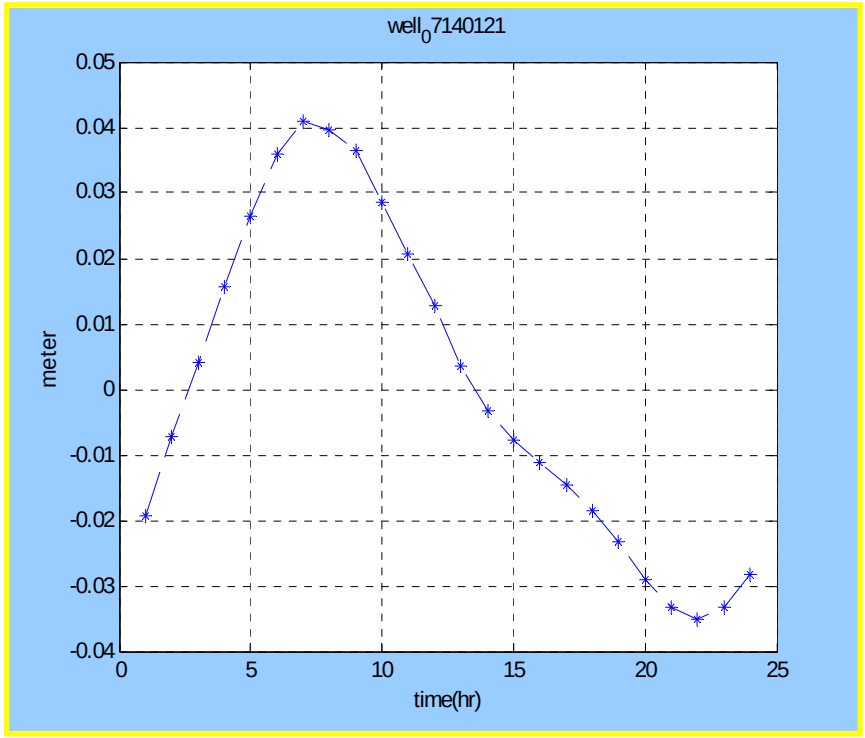


美濃(1)



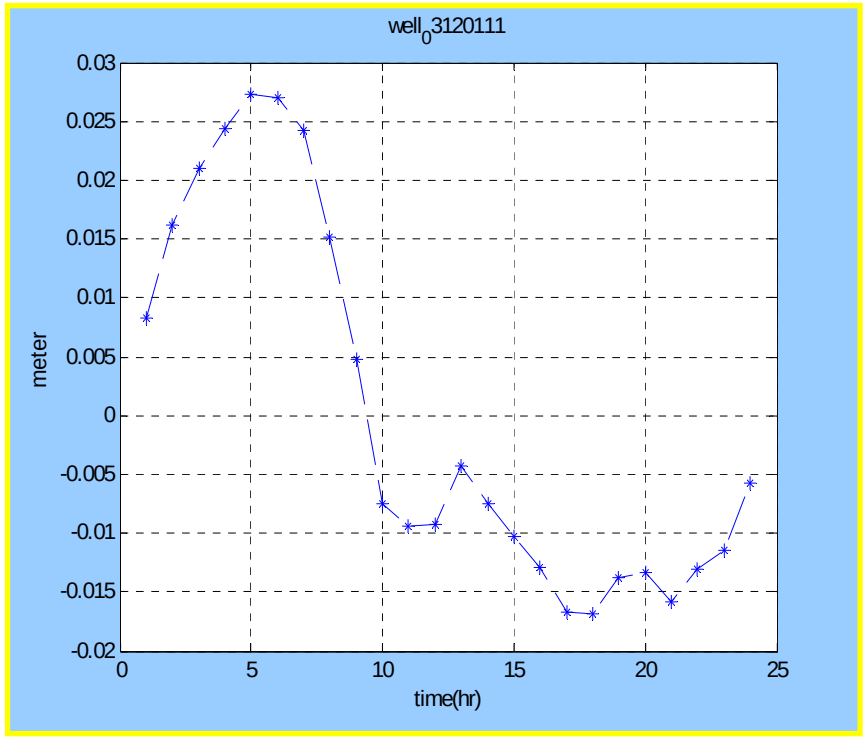
美濃(2)

Average Daily Variation of GWL in Industrial Region

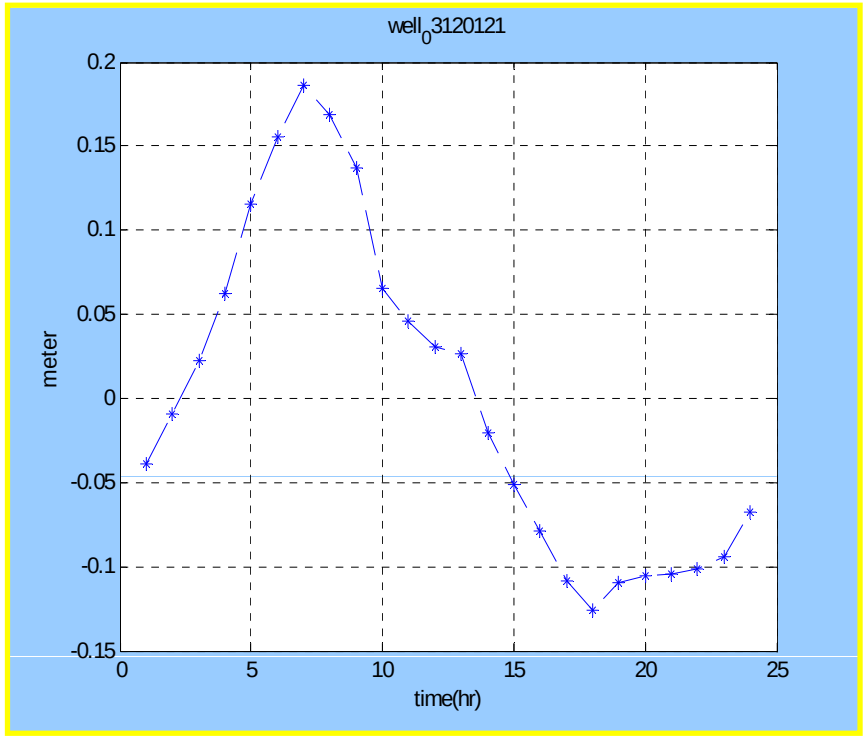


彰化・好修 (2)

Average Daily Variation of GWL in Mixed Region

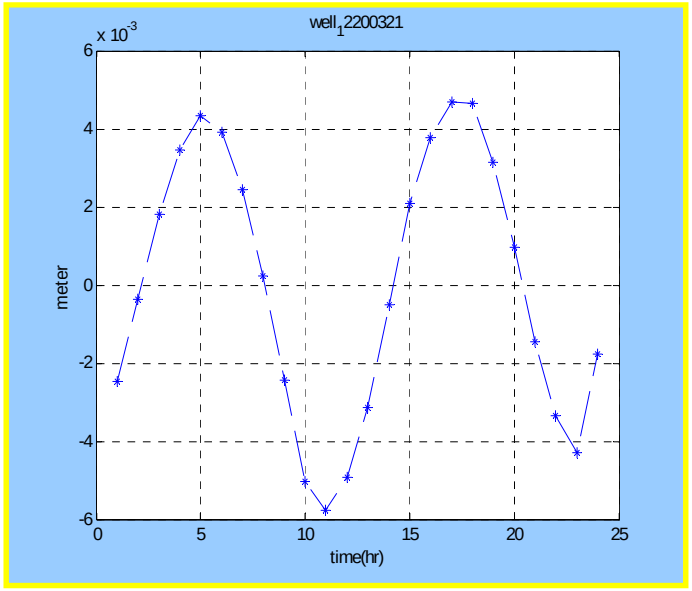


桃園樹林 (1)

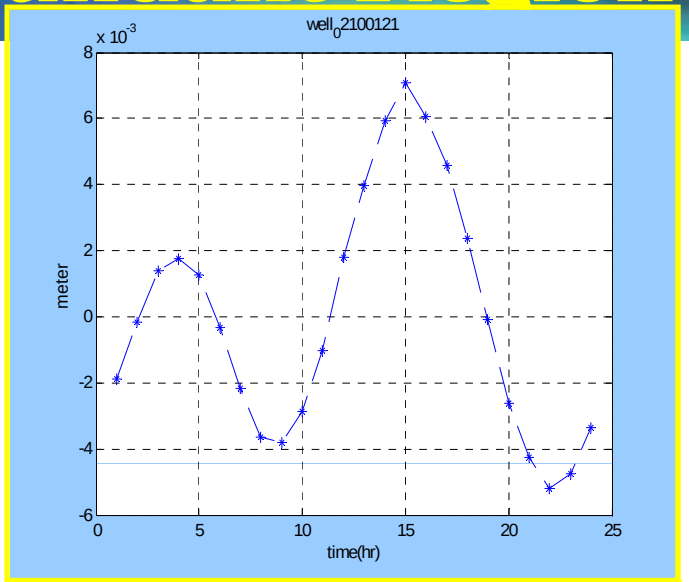


桃園樹林 (2)

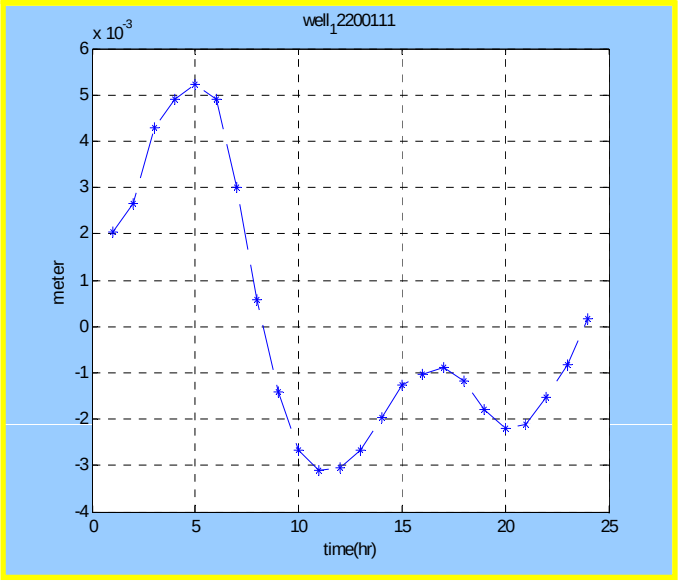
Average Daily Variation of GWL in Recharge Abundant Region



吉洋人工湖

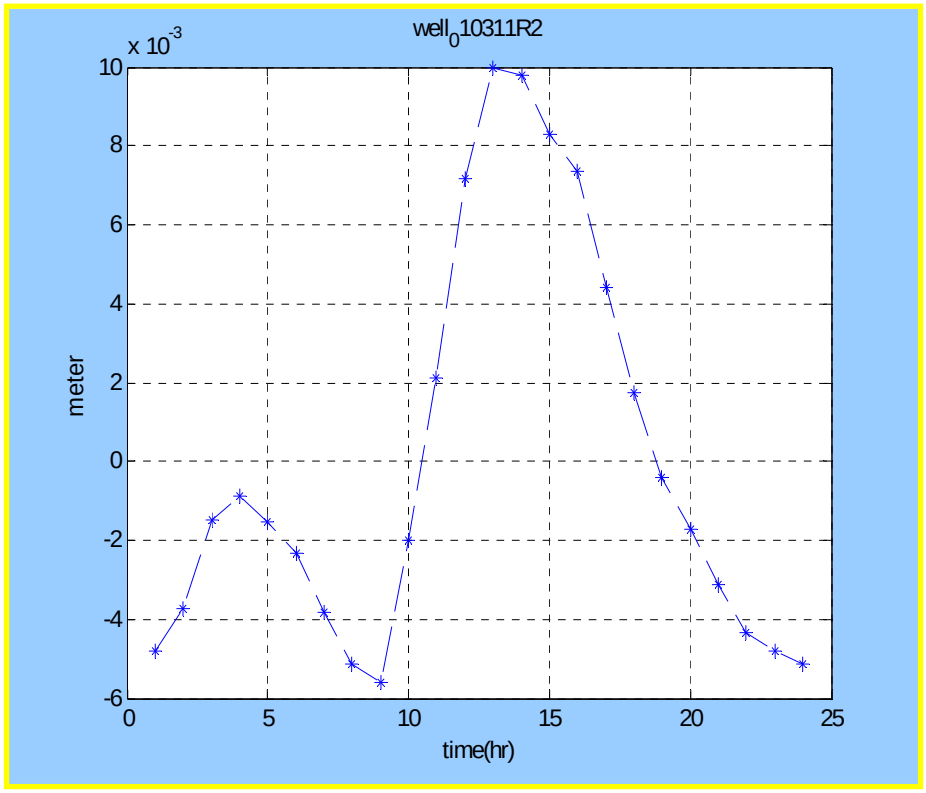


吉洋工作站



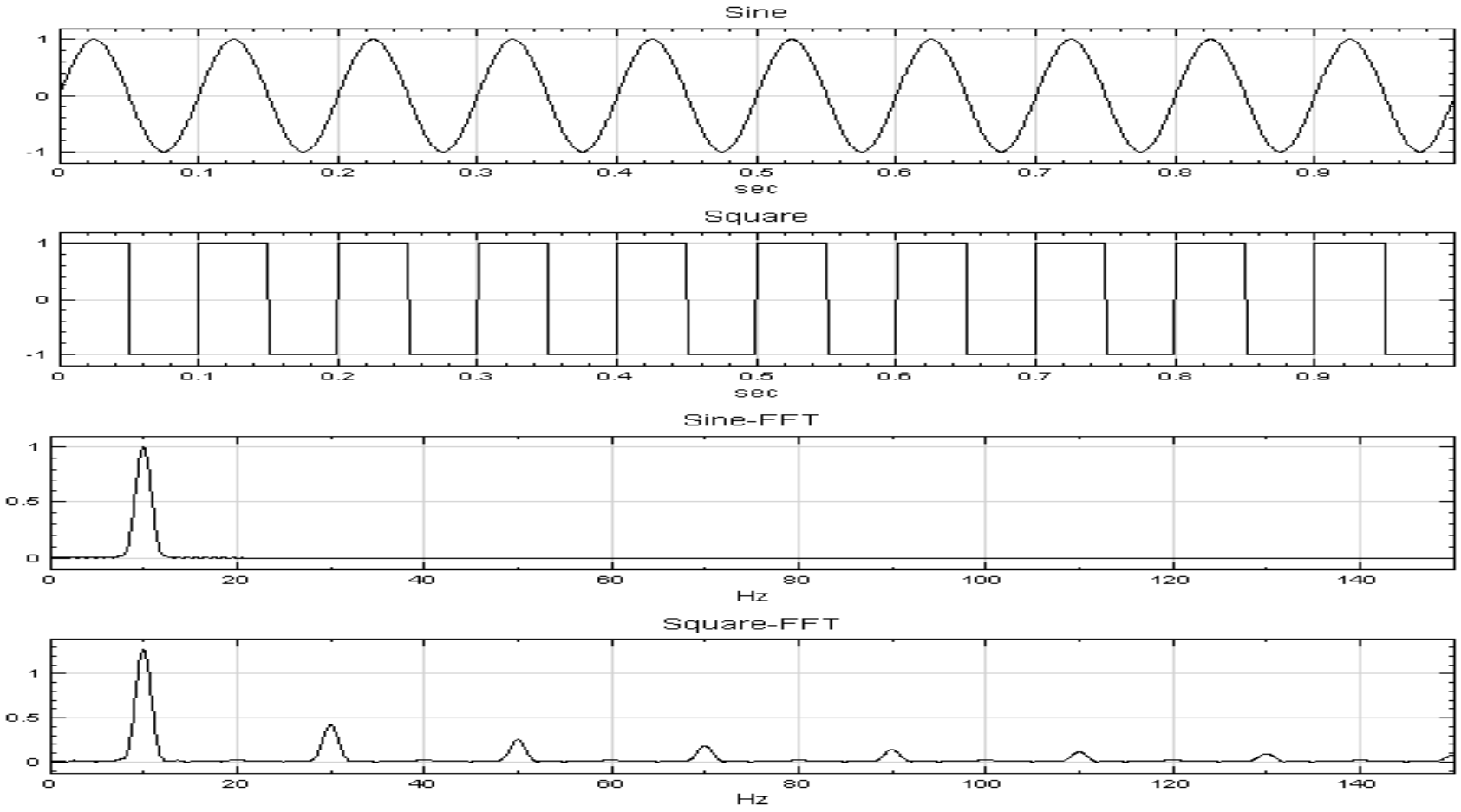
宜蘭・大隱

Average Daily Variation of GWL in Region without Pumping

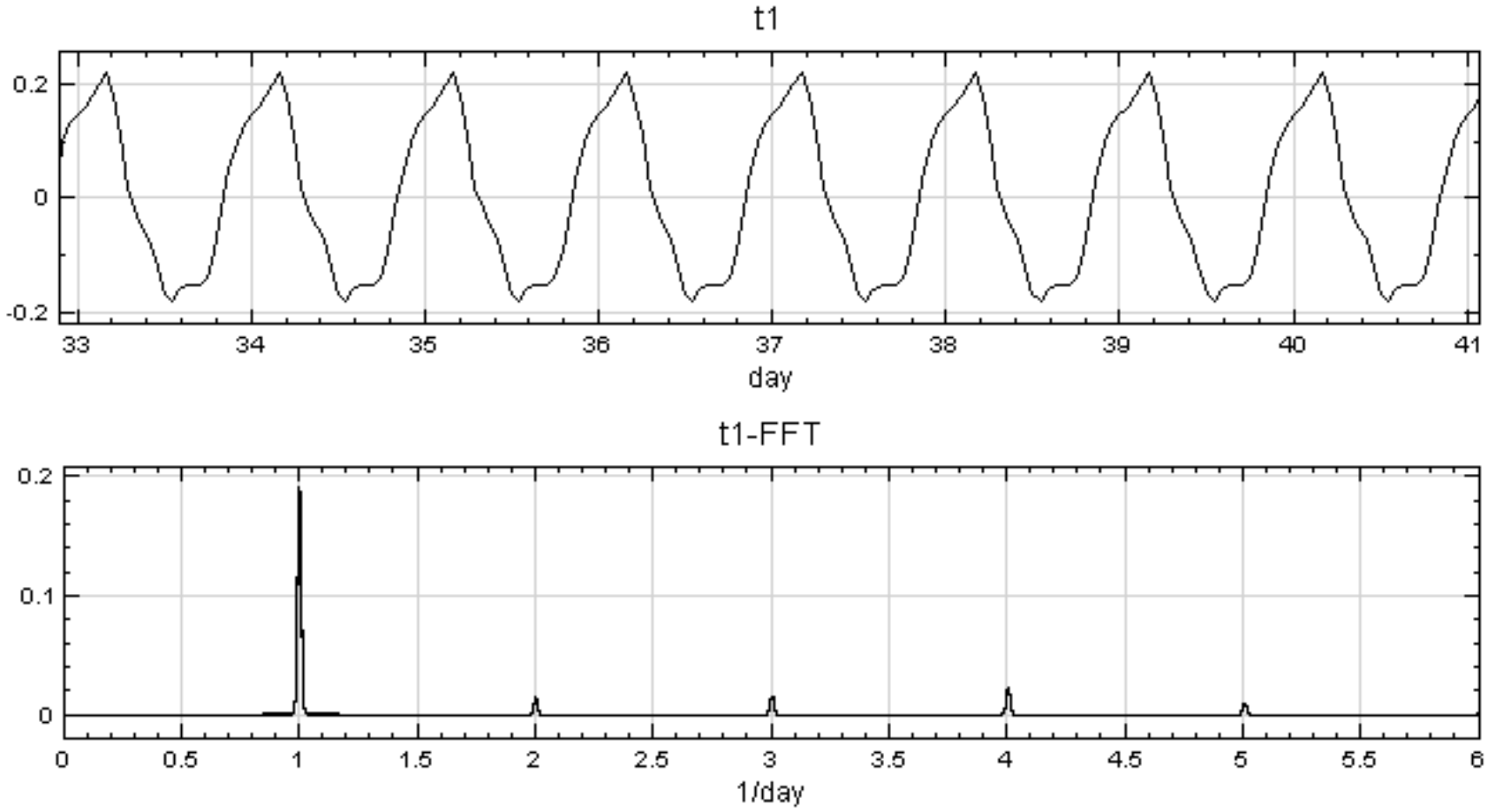


中和 **Well, Taipei**

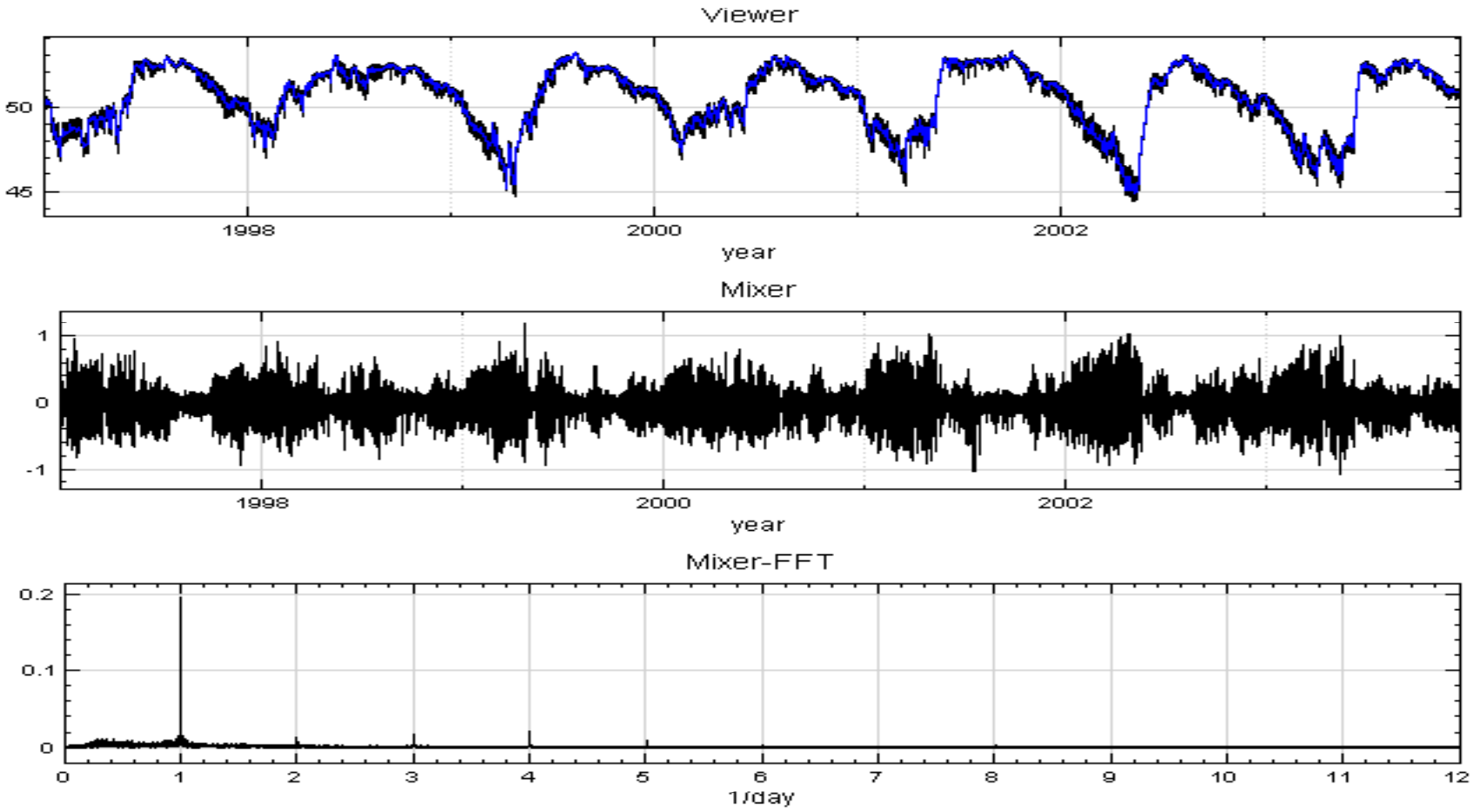
Single Frequency and Harmonics



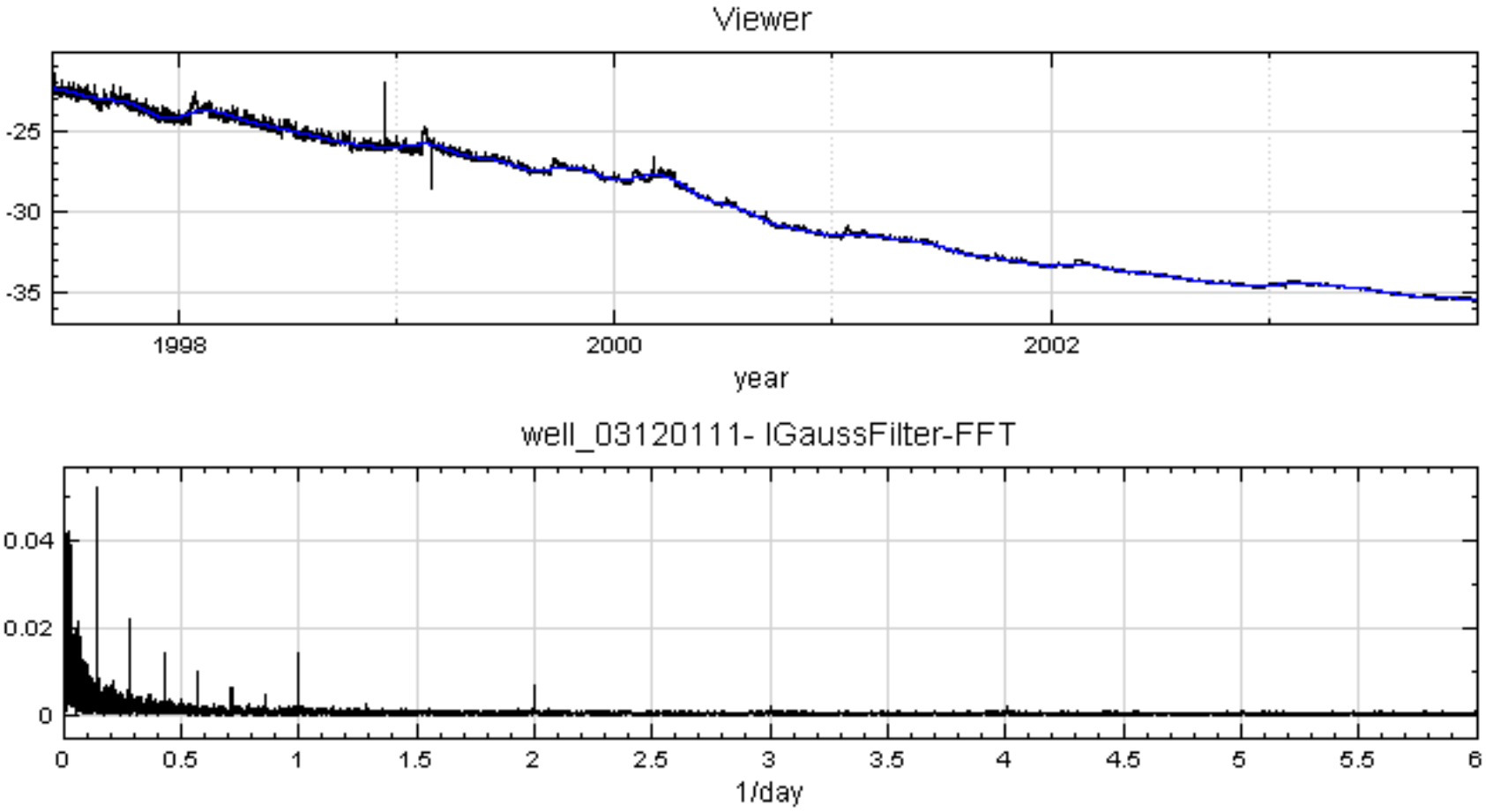
Spectrum of 美濃(1)



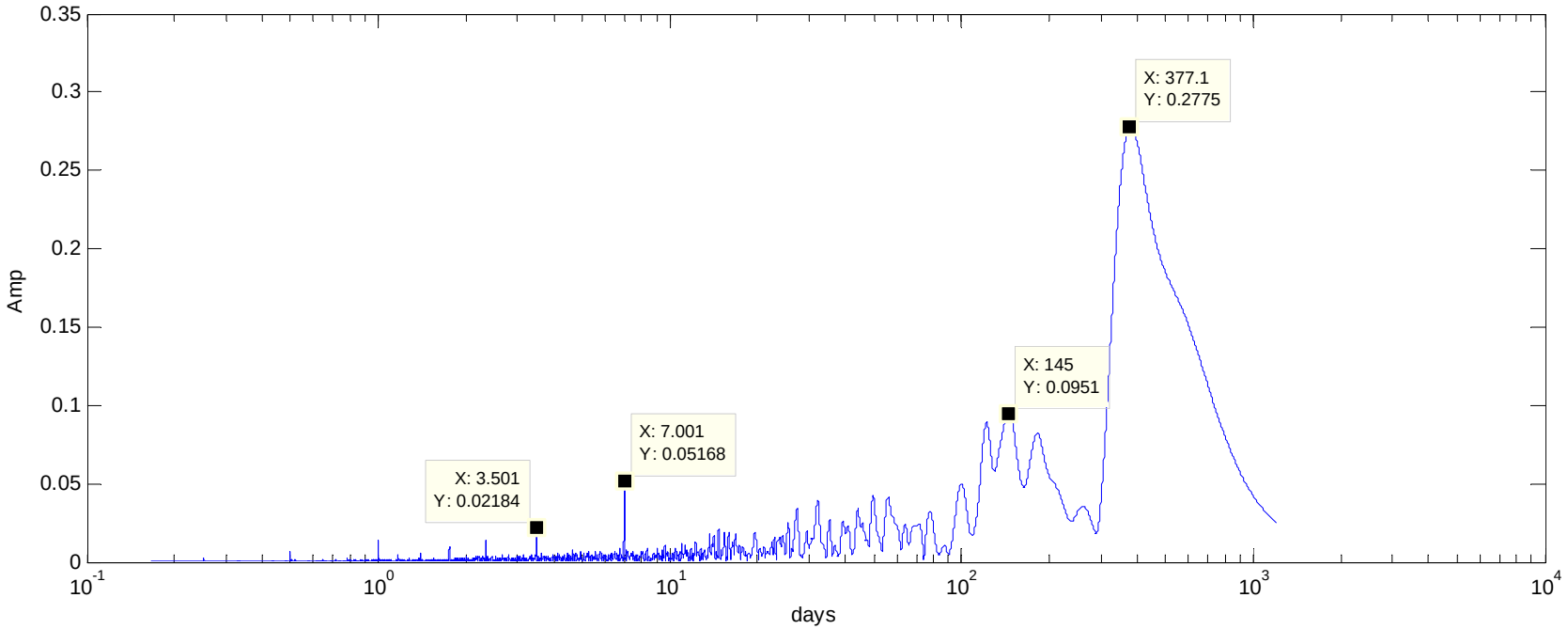
美濃(1)


Viewer
50
45
1998
2000
2002
year
Mixer
1
0
-1
1998
2000
2002
year
Mixer-FFT
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
1/day

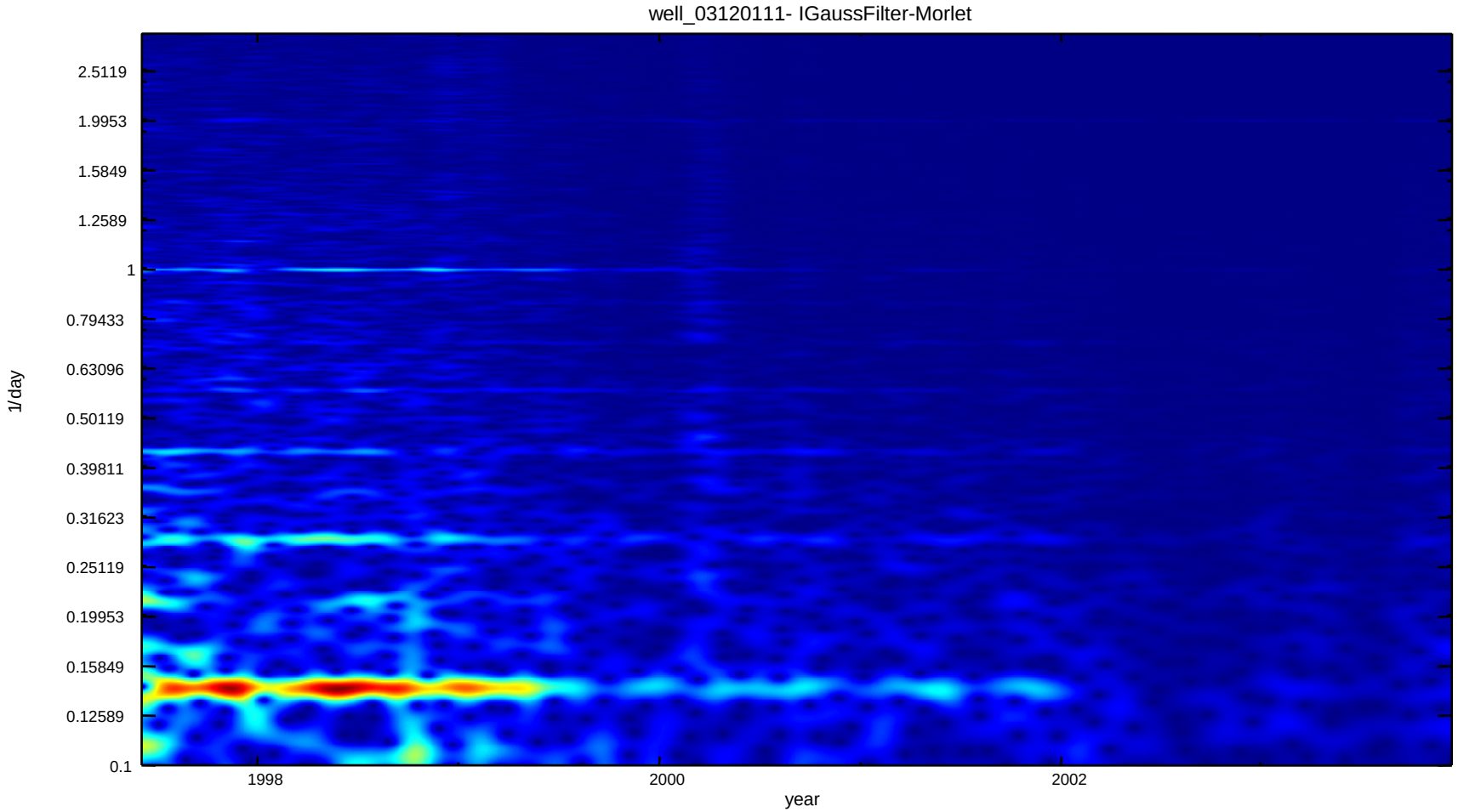
樹林(1)


Viewer
-25
-30
-35
1998
2000
2002
year
well_03120111- IGaussFilter-FFT
0.04
0.02
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
1/day

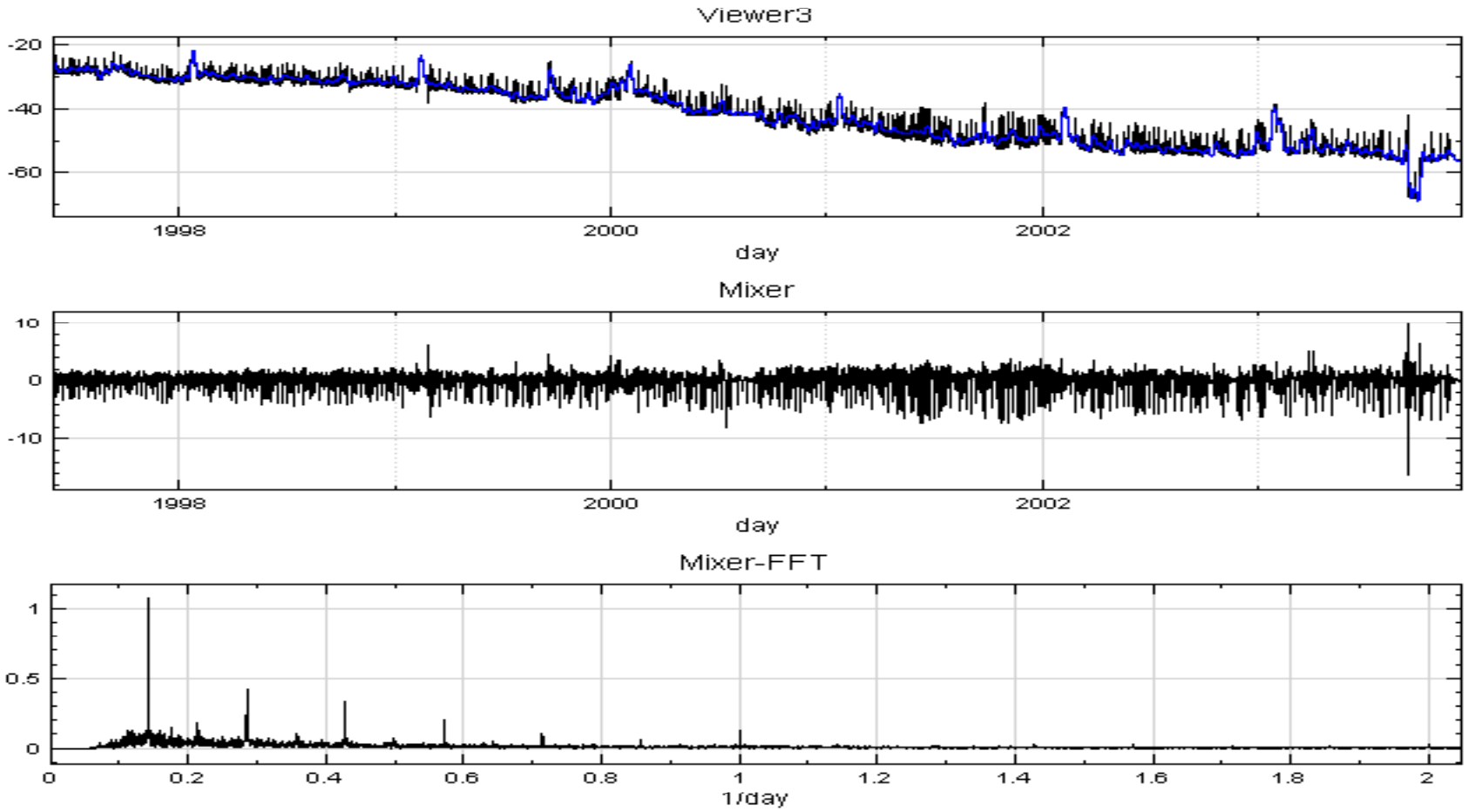
Spectrum of Ground Water Level (樹林1)



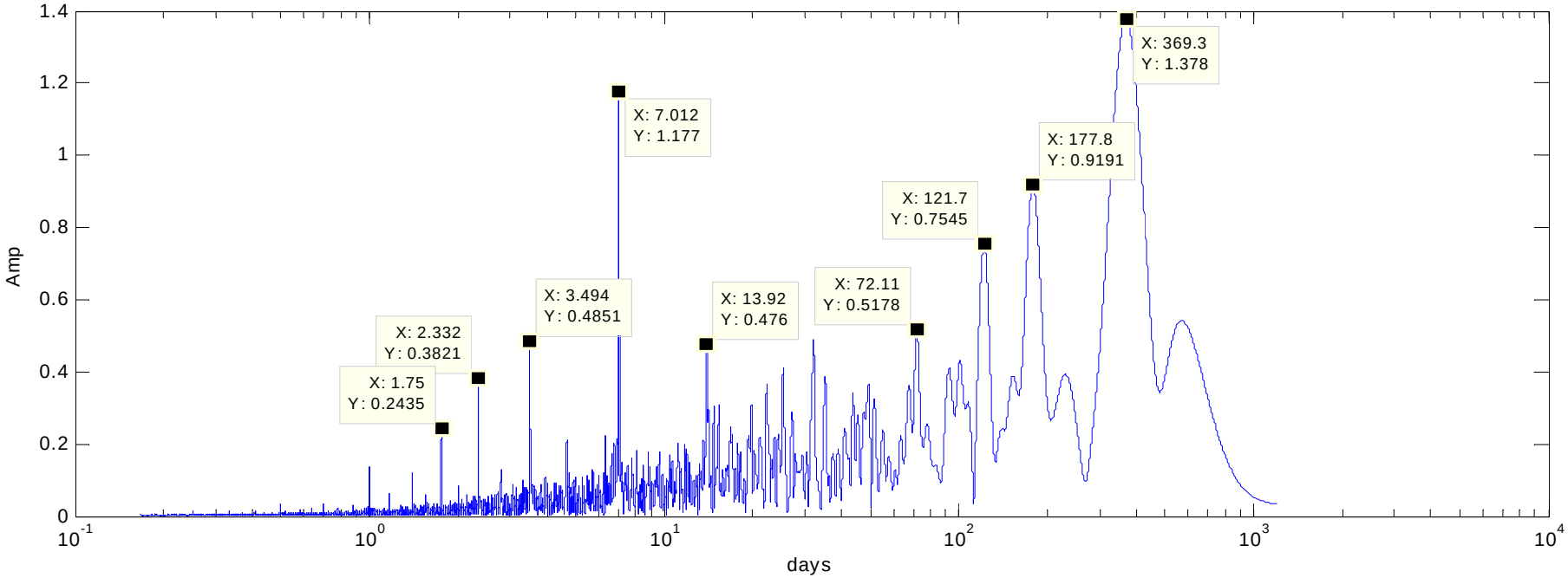
TF Plot of GWL (樹林1)



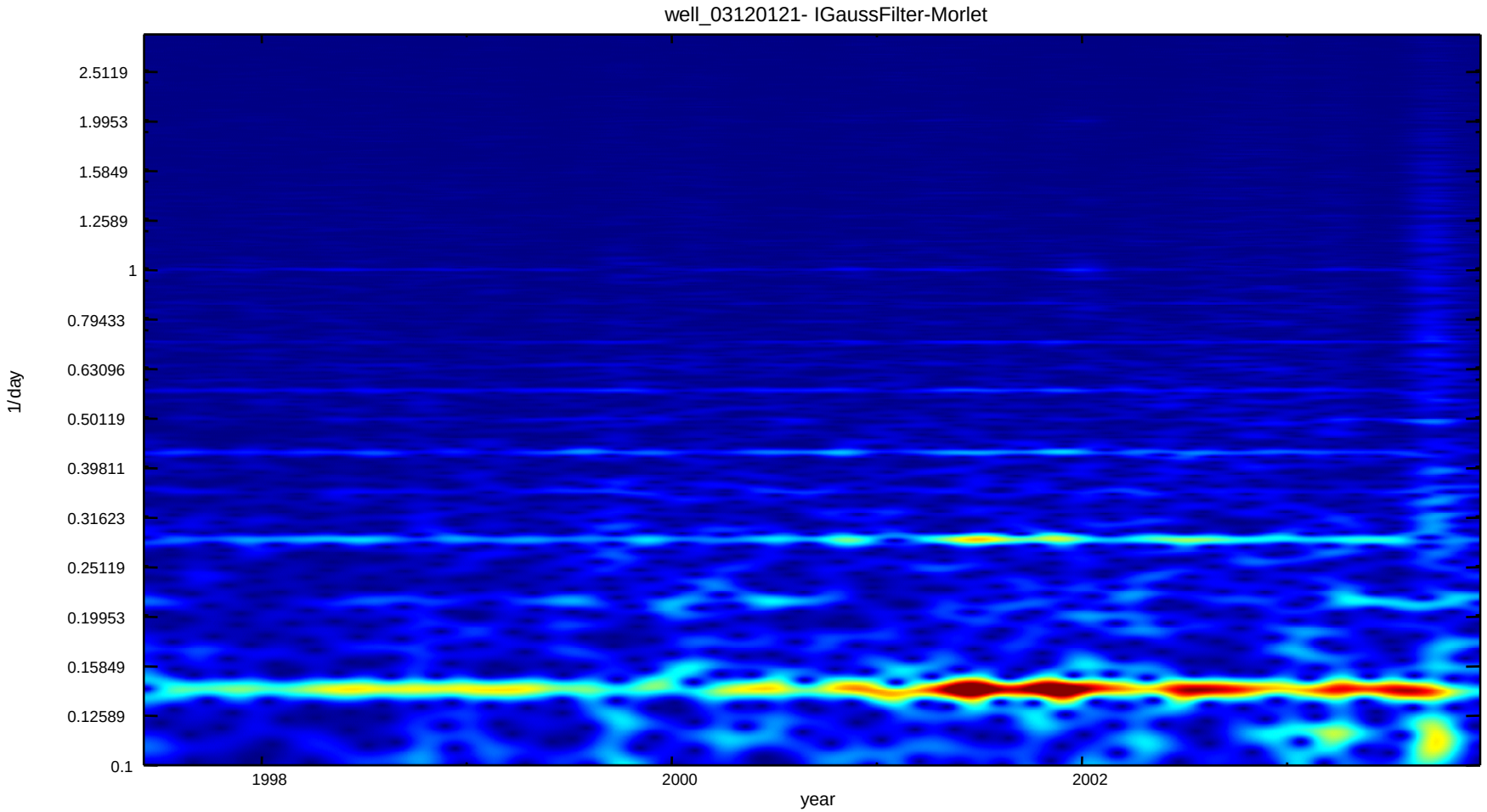
樹林(2)


Viewer3
-20
-40
-60
1998
2000
2002
day
Mixer
10
0
-10
1998
2000
2002
day
Mixer-FFT
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
1/day

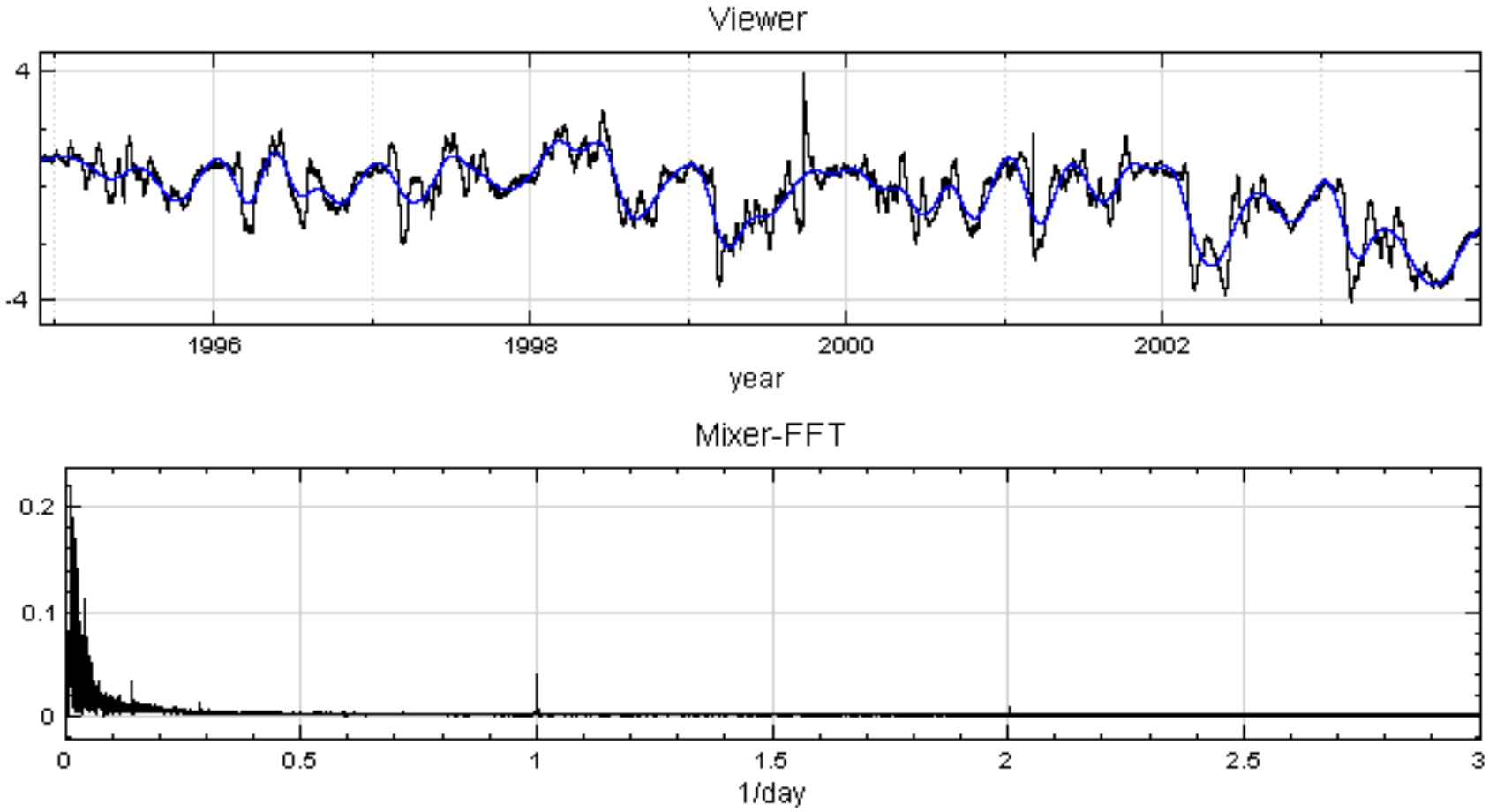
Spectrum of Ground Water Level (樹林2)



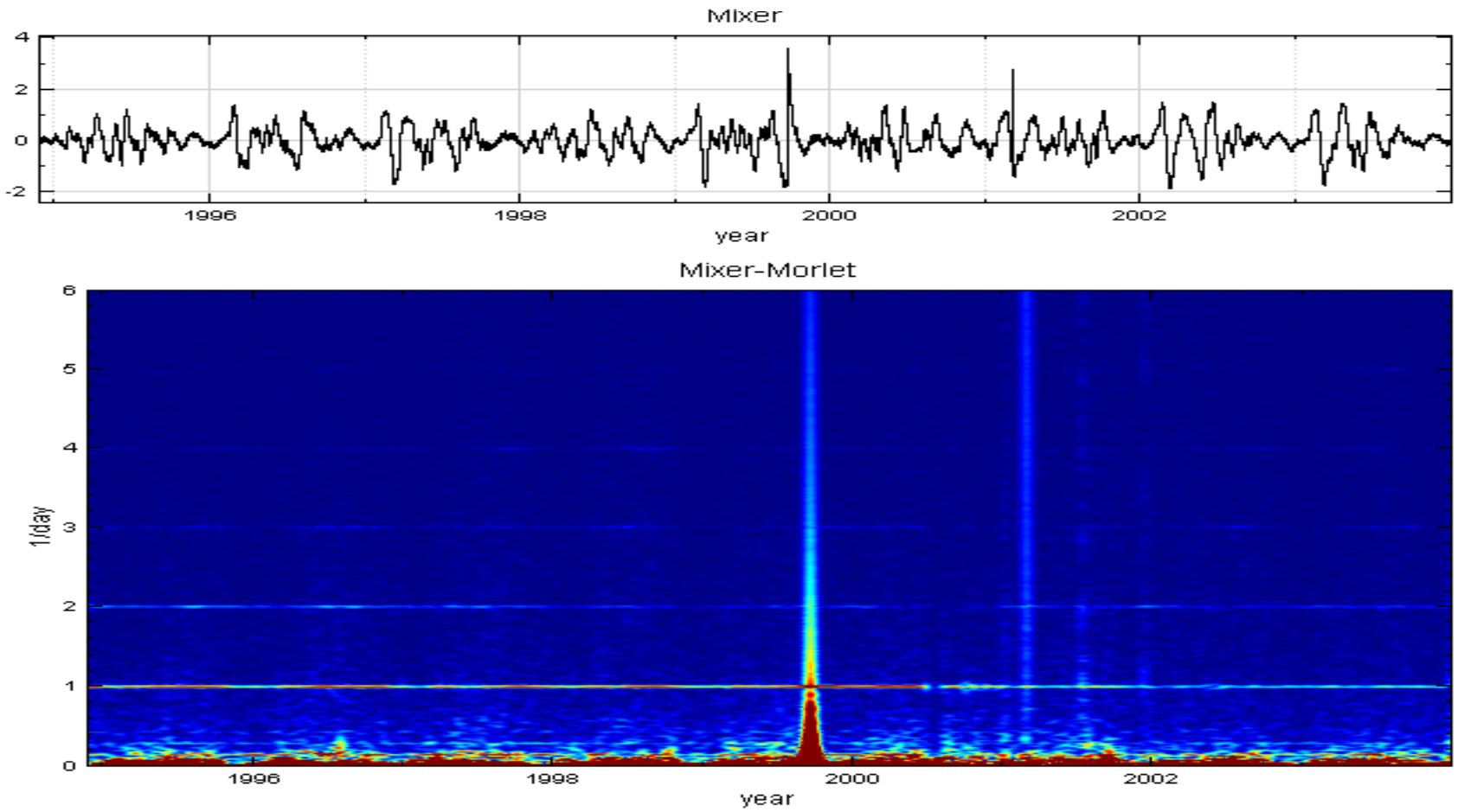
TF Plot of GWL (樹林2)



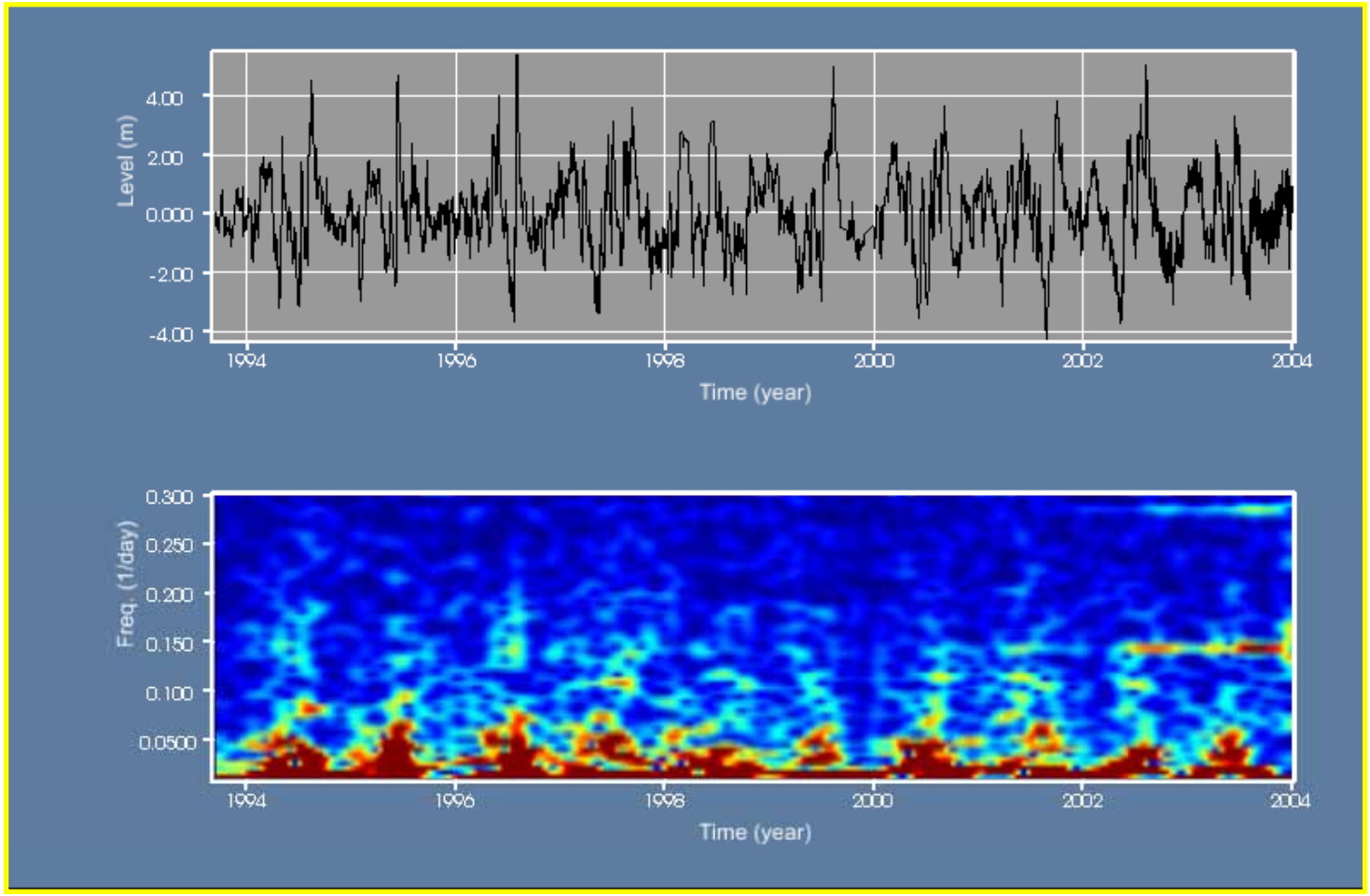
彰化好修


Viewer
4
-4
1996
1998
2000
2002
year
Mixer-FFT
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
1/day

彰化好修


Mixer
4
2
0
-2
1996
1998
2000
2002
year
Mixer-Morlet
6
5
4
3
2
1
0
1/day
1996
1998
2000
2002
year

Abnormal Pumping



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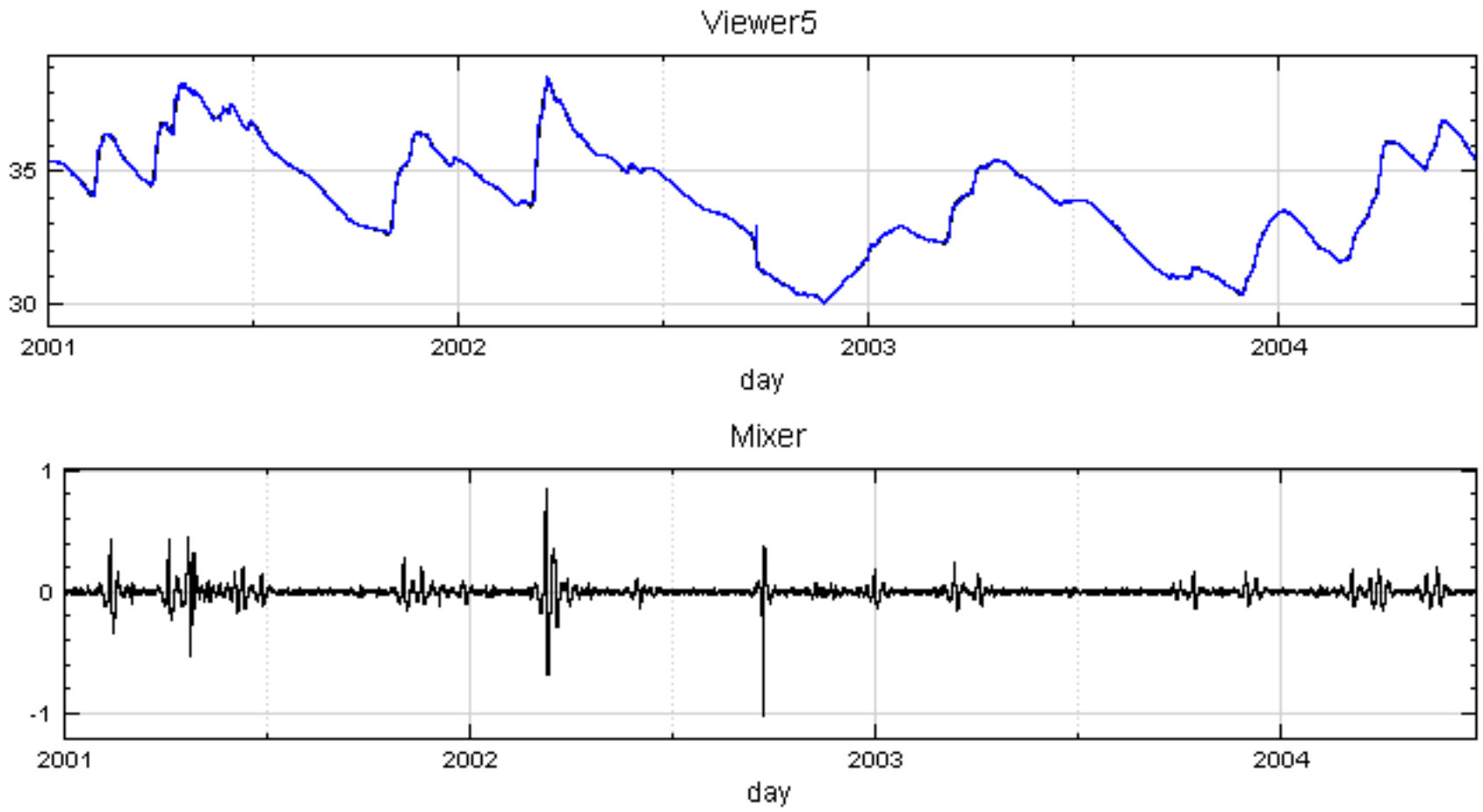
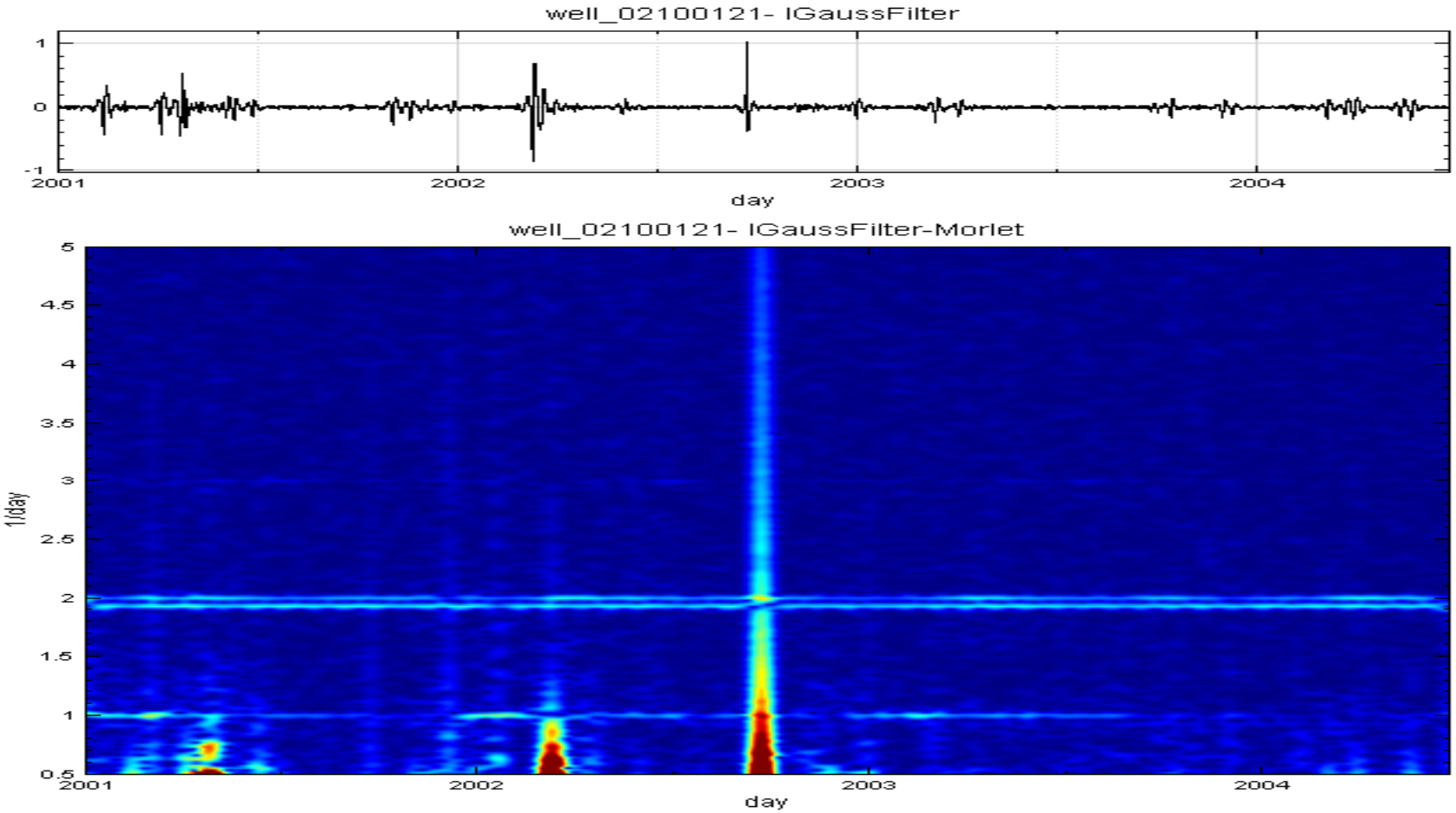
Diurnal/Semi-Diurnal Tide

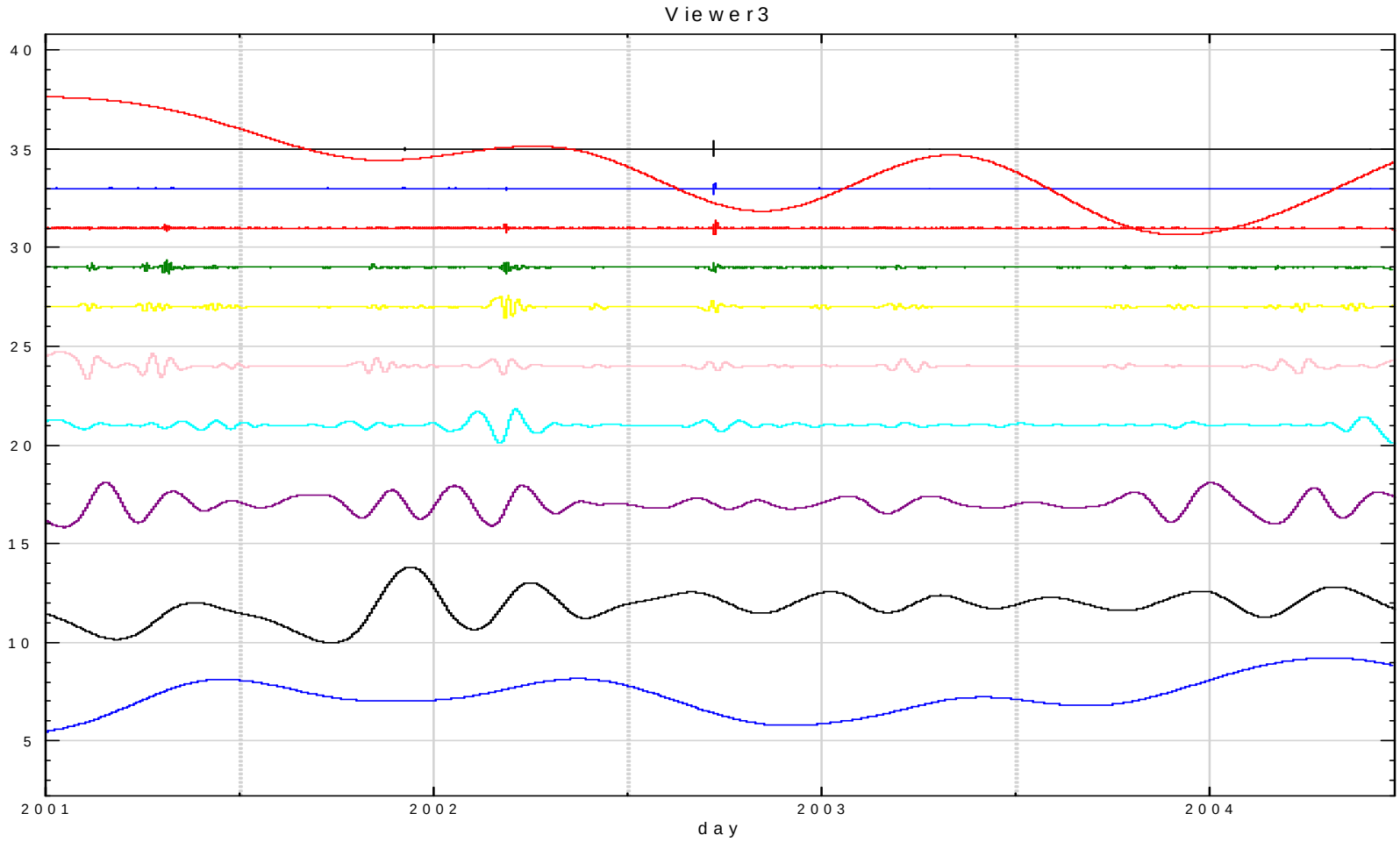
宜蘭大隱


Viewer5
35
30
2001
2002
2003
2004
day
Mixer
1
0
-1
2001
2002
2003
2004
day

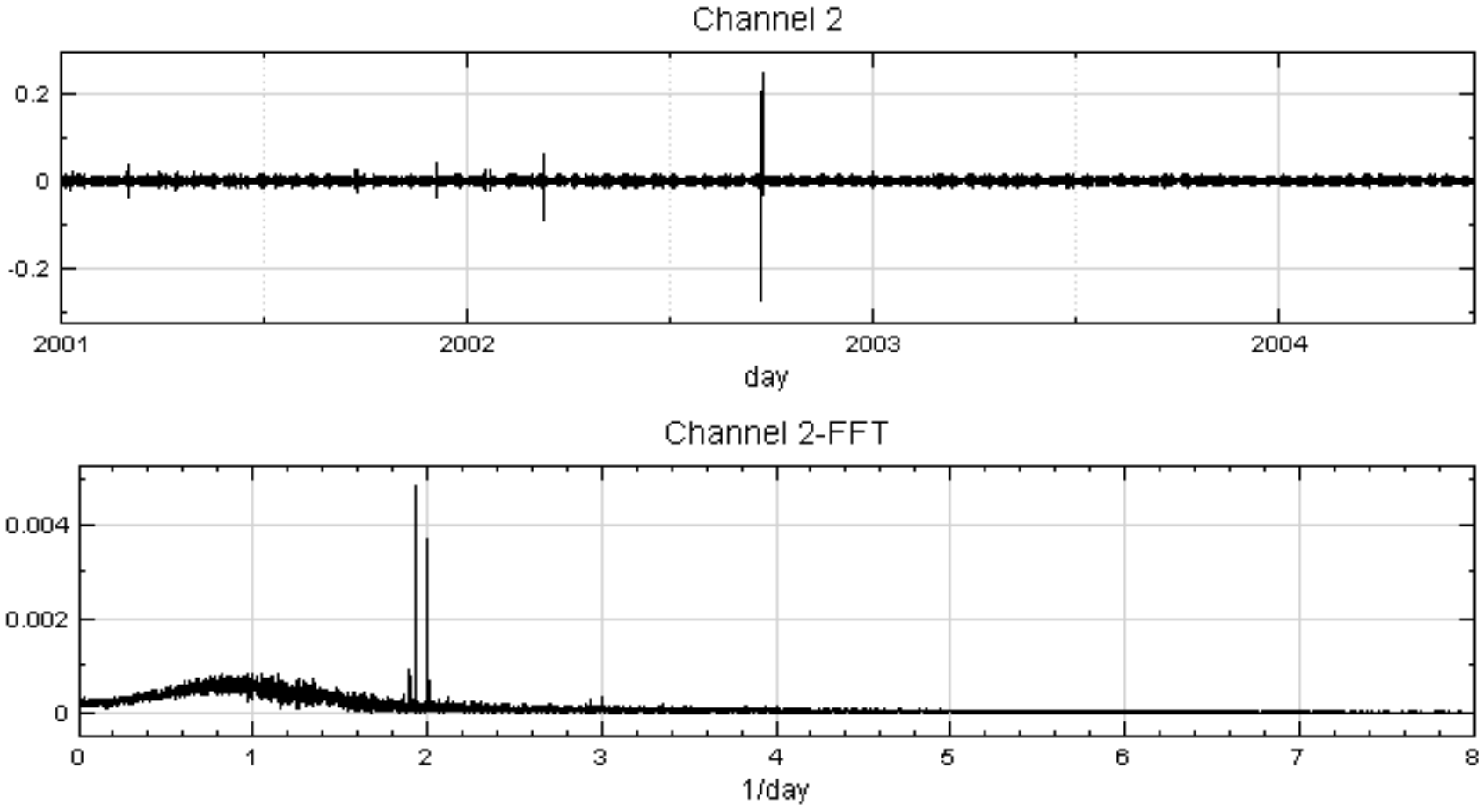
宜蘭大隱


well_02100121- IGaussFilter
1
0
-1
2001
2002
2003
2004
day
well_02100121- IGaussFilter-Morlet
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
1/day
2001
2002
2003
2004
day

宜蘭大隱(EMD)

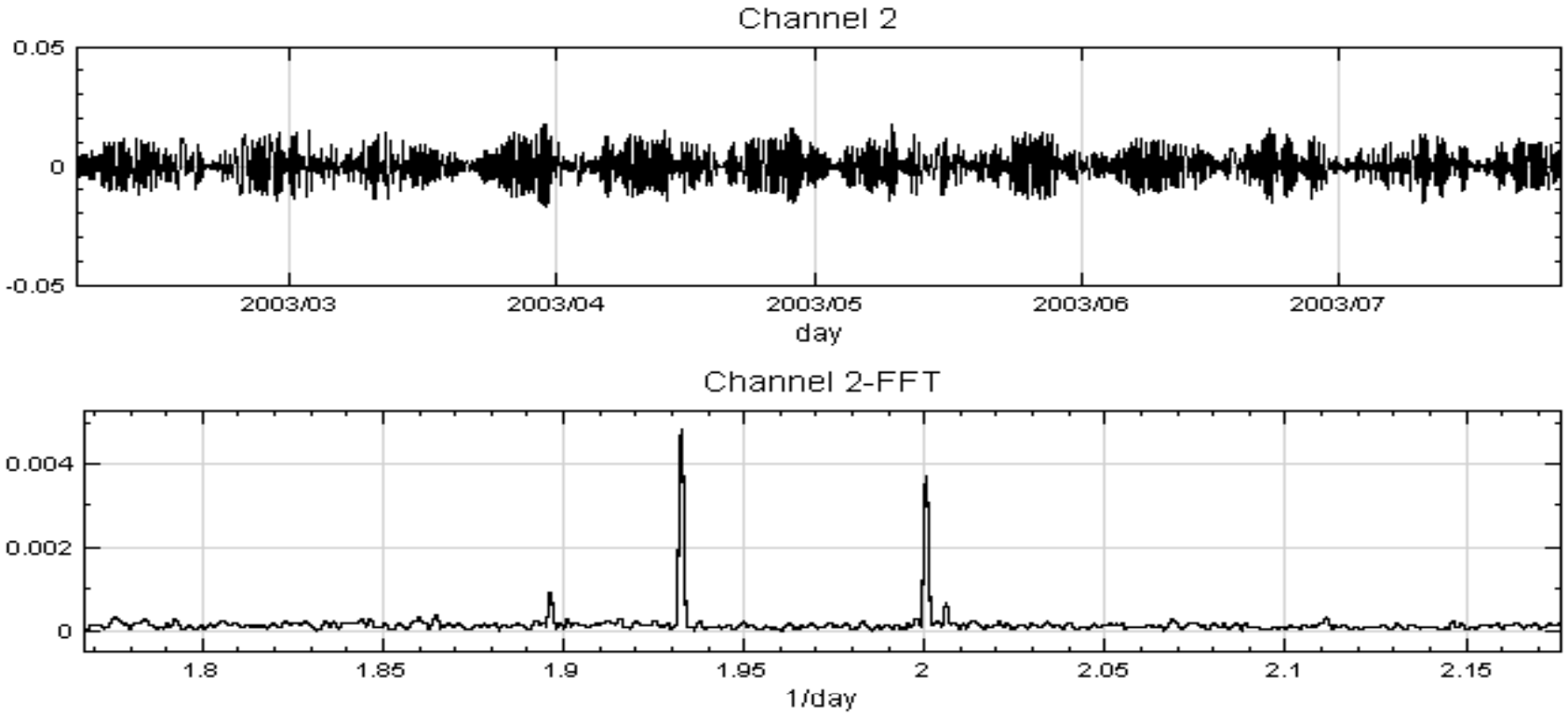


IMF2 (semi-diurnal tide)

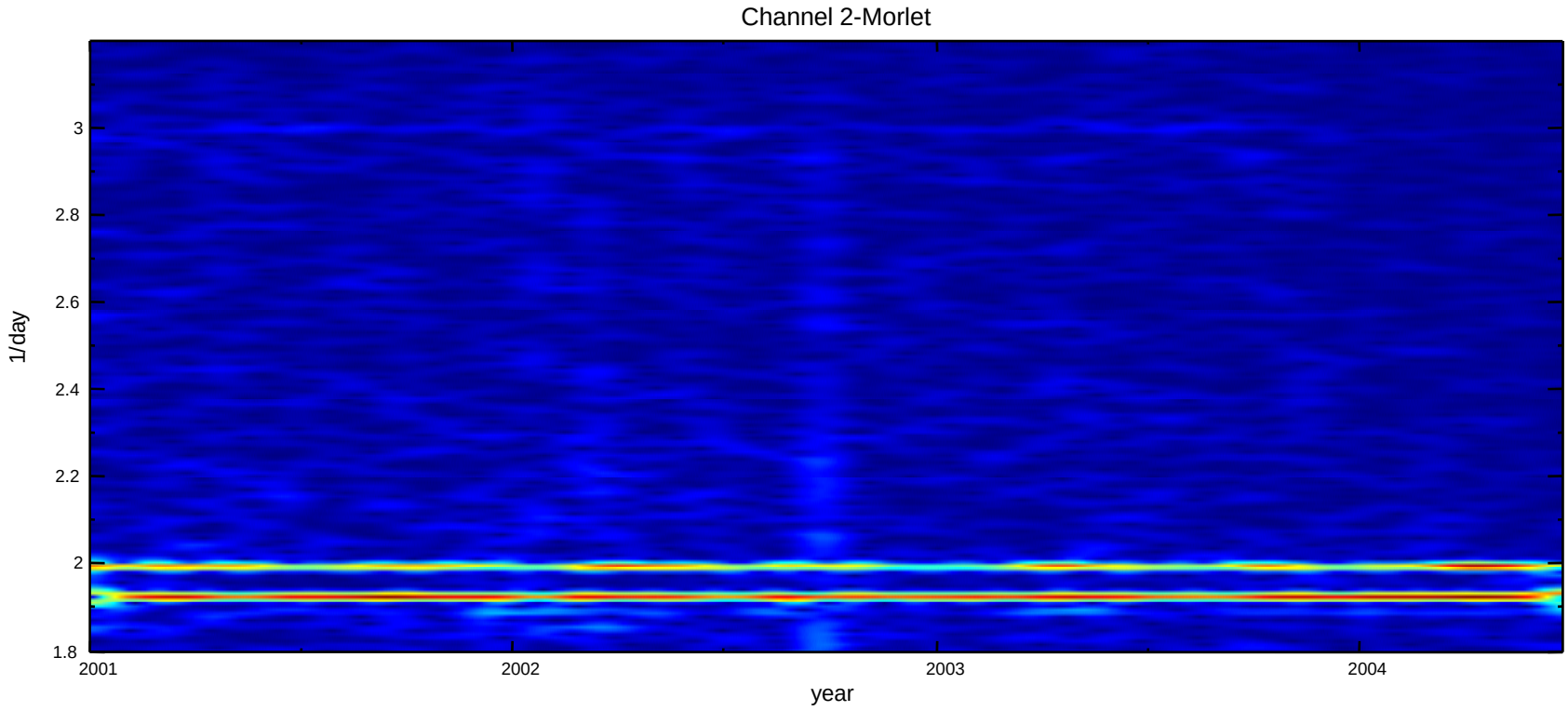


IMF2 (semi-diurnal tide)

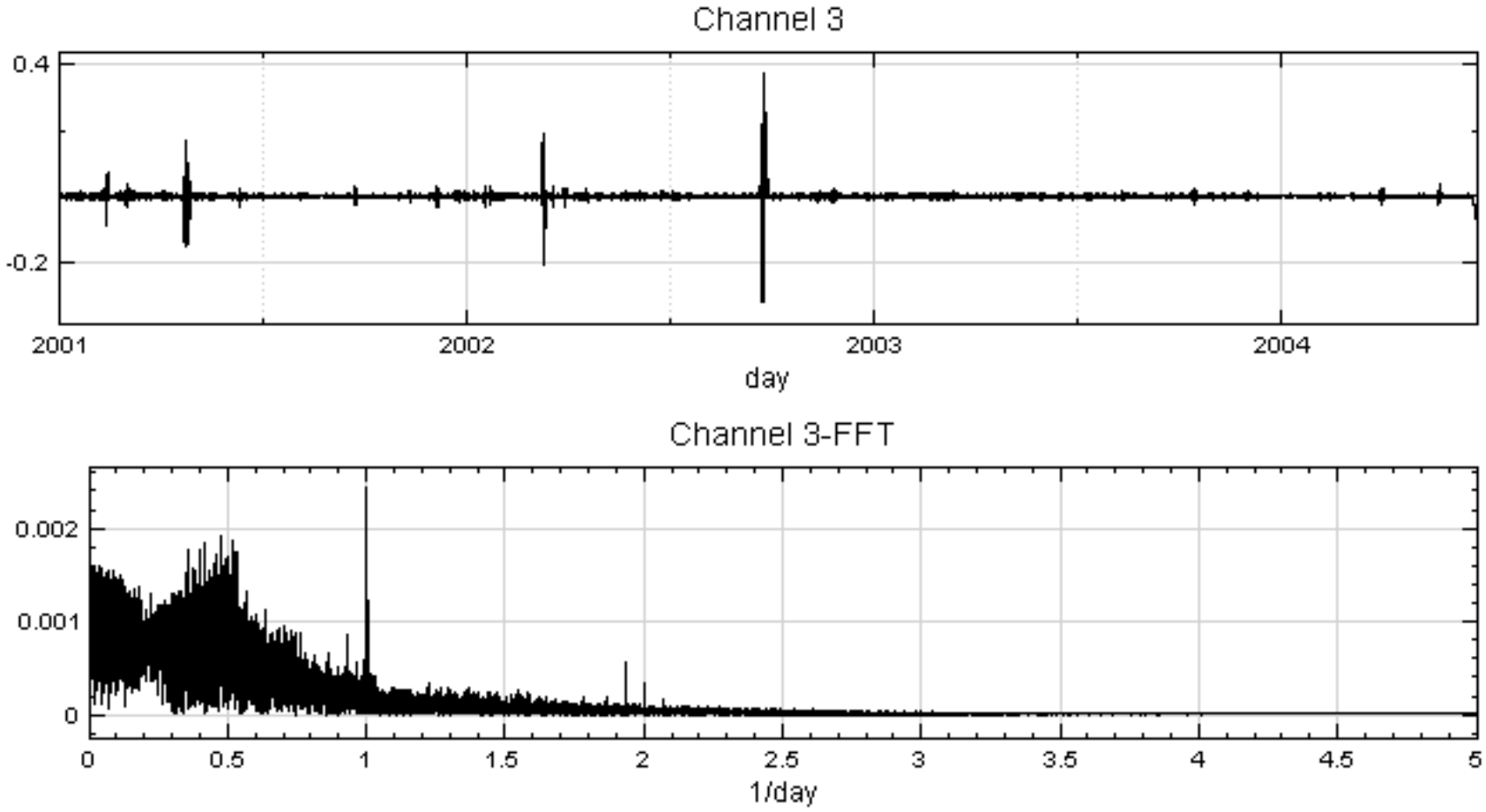
Beat wave occurs twice per month.



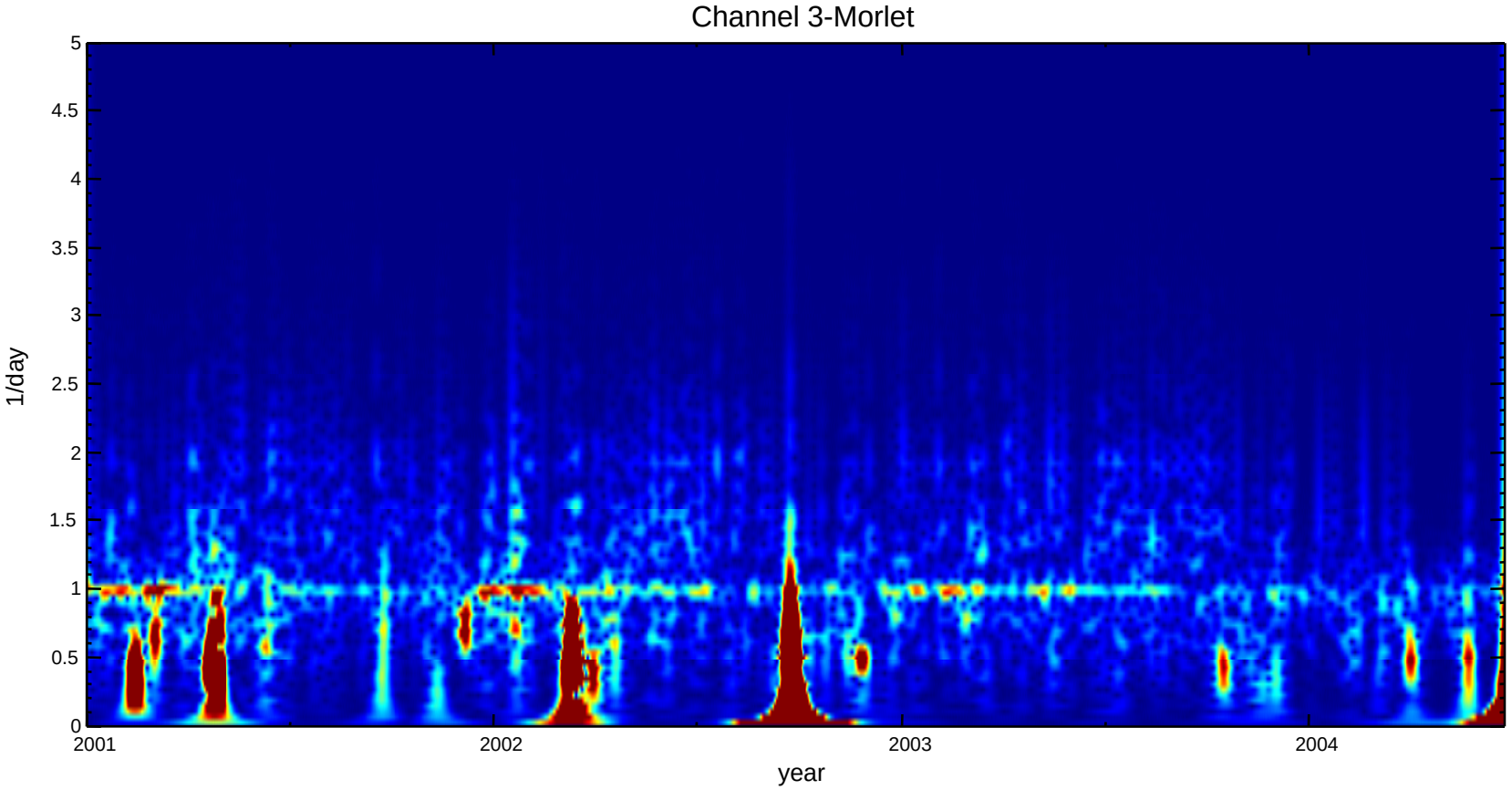
IMF2 (semi-diurnal tide)



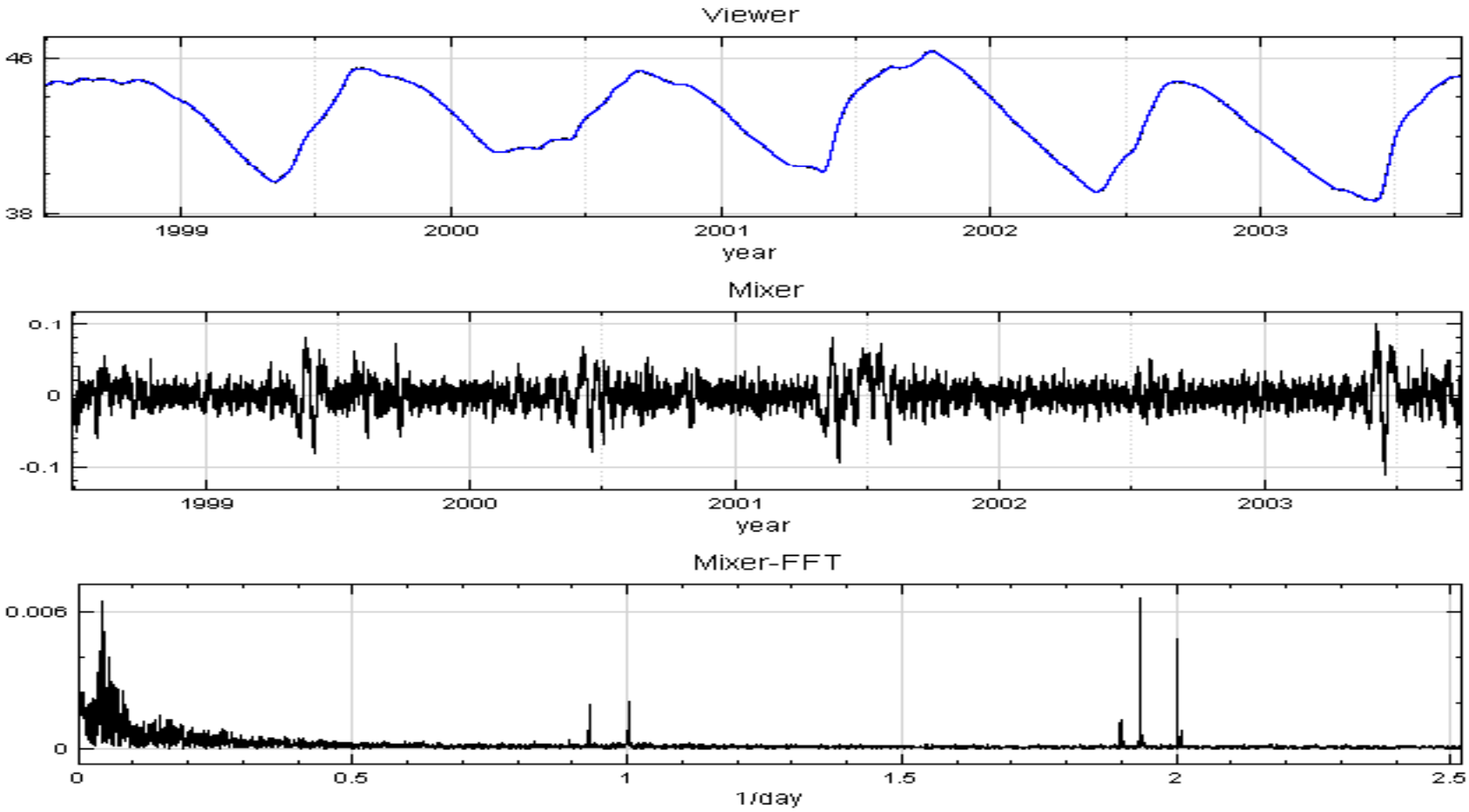
IMF3 (once per day)



IMF3 (cont'd)

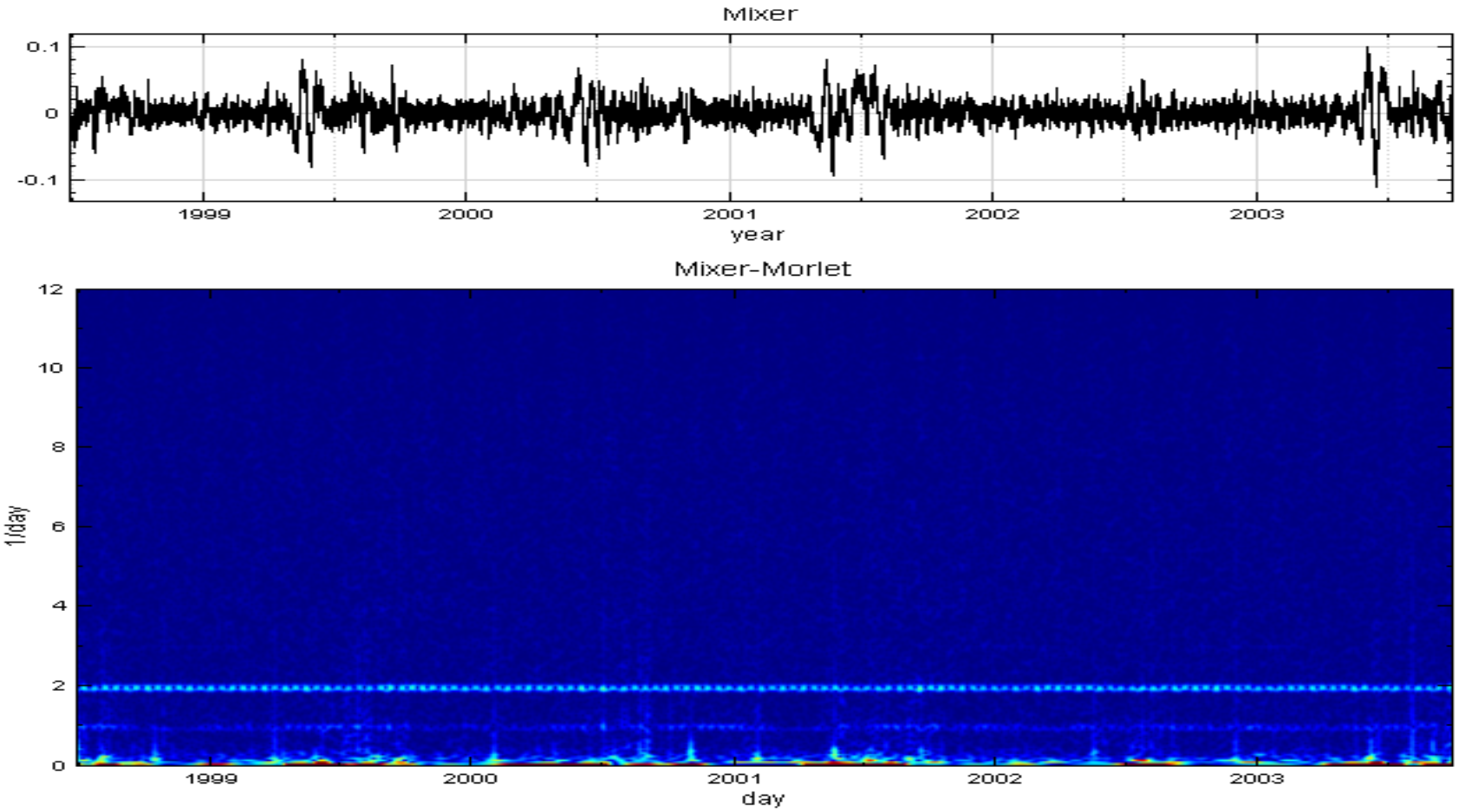

Channel 3-Morlet
1/day
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2001
2002
2003
2004
year

吉洋人工湖(2)

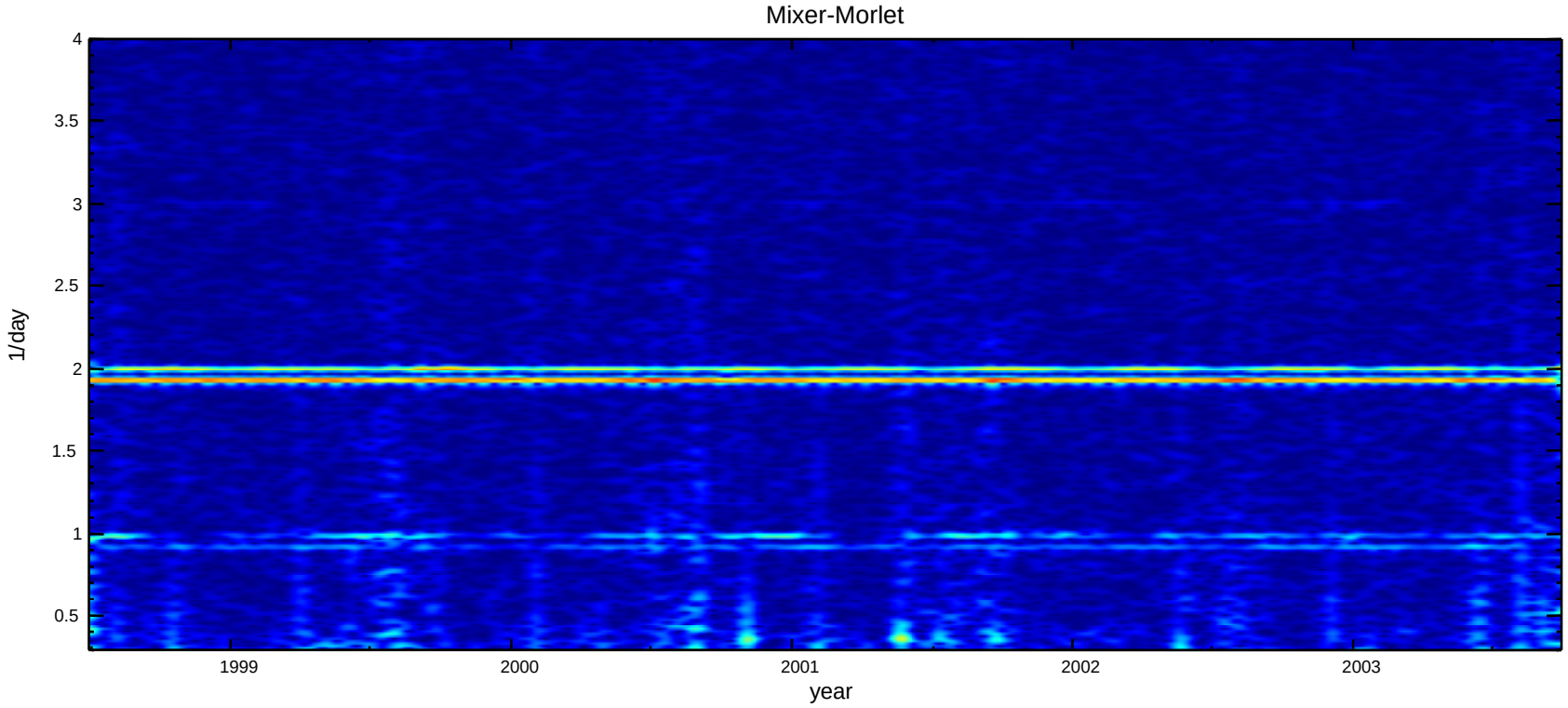


Non-periodical signal is separated via EMD. The periodical part is shown in the middle plot. Its spectrums follows.

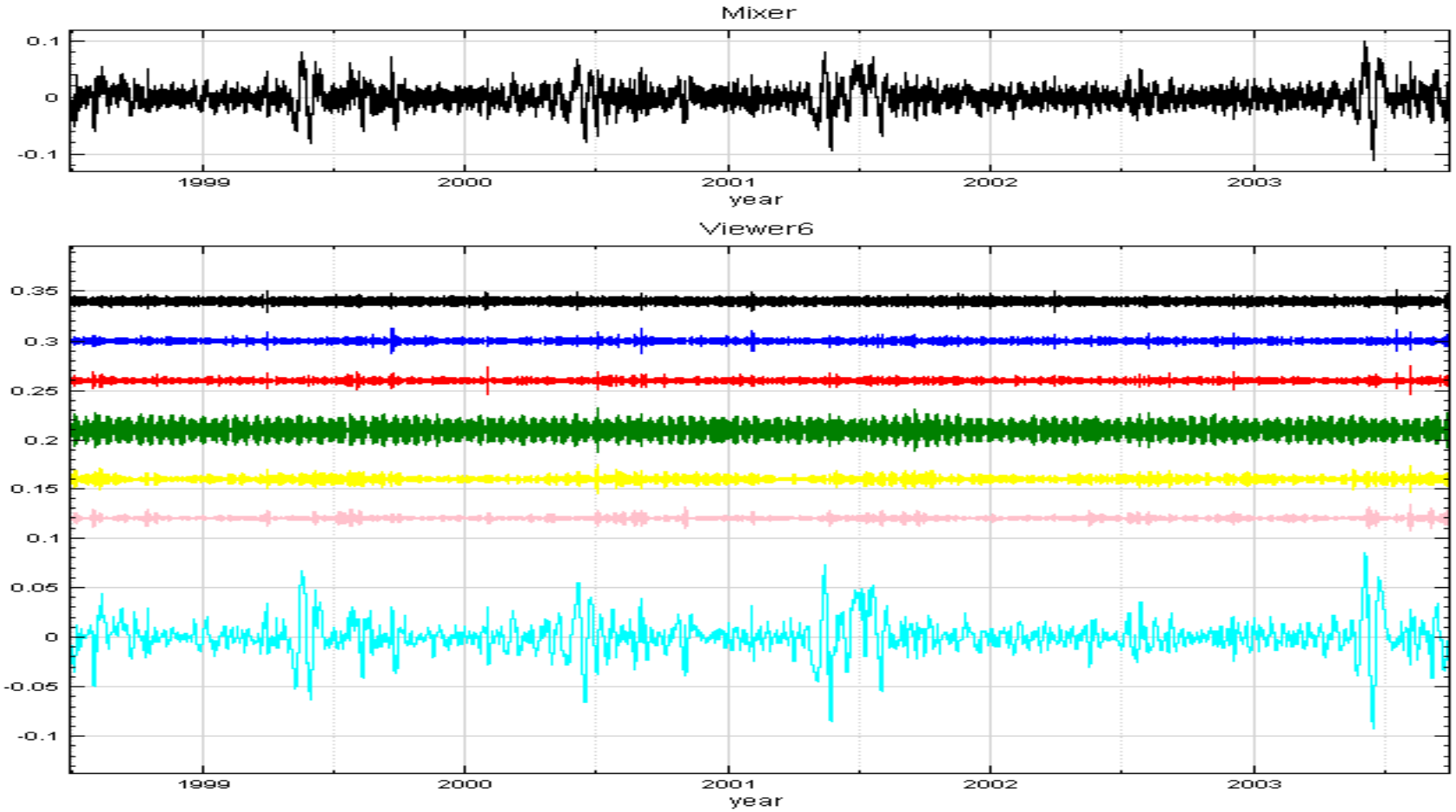
TF Plot of 吉洋人工湖(2)



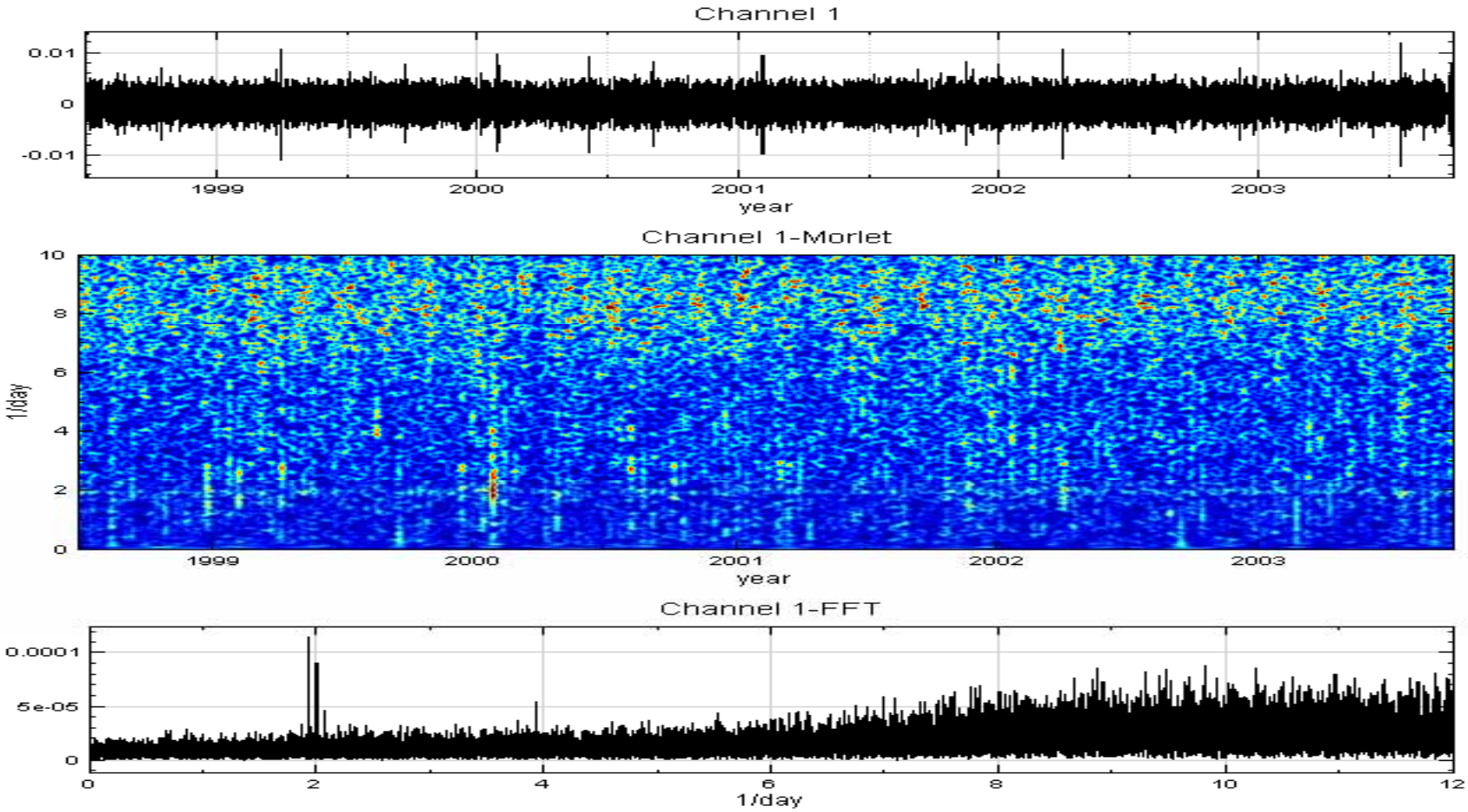
TF Plot


Mixer-Morlet
4
3.5
3
2.5
2
1.5
1
0.5
1/day
1999
2000
2001
2002
2003
year

Empirical Mode Decomposition

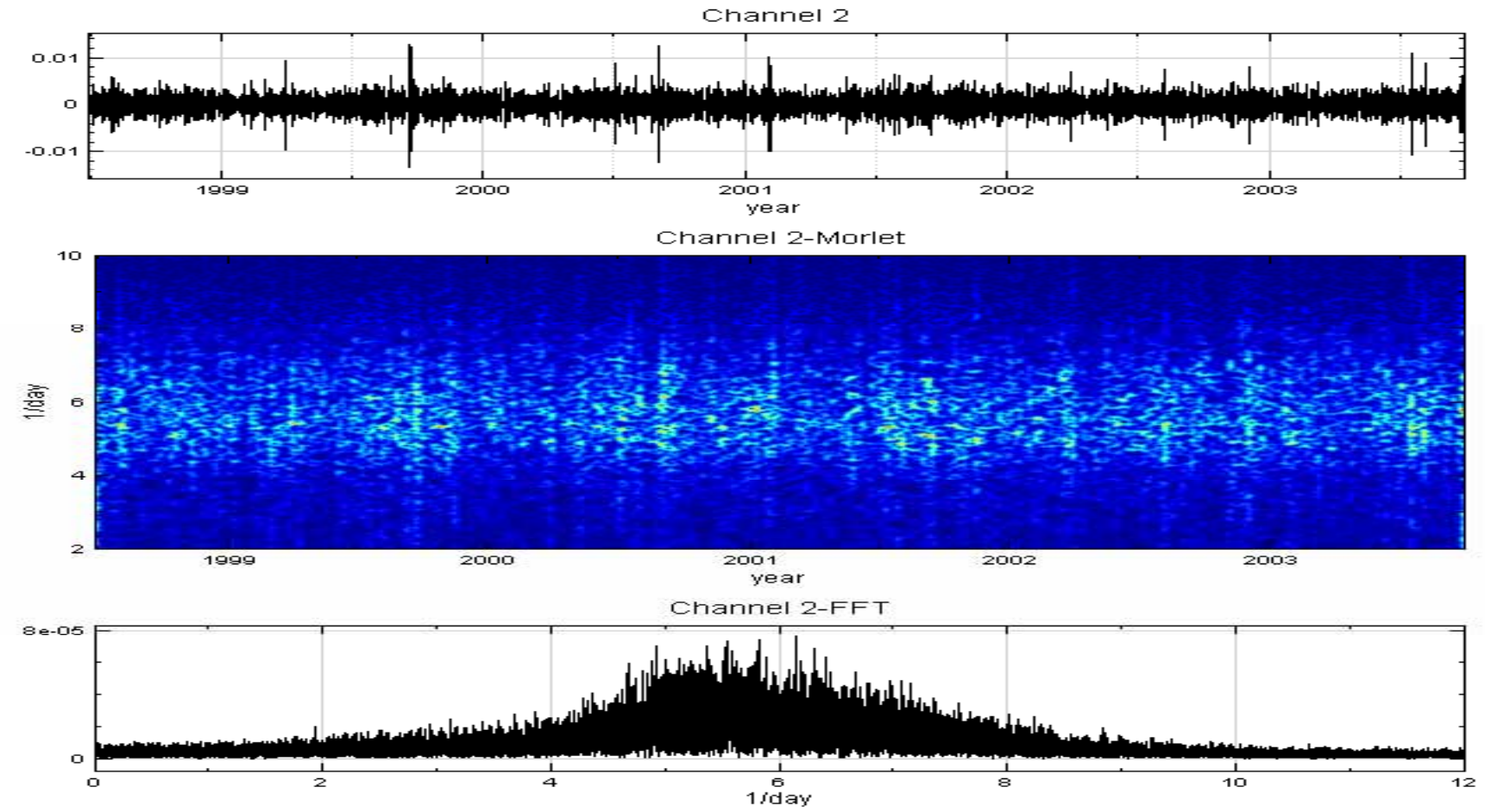


IMF1



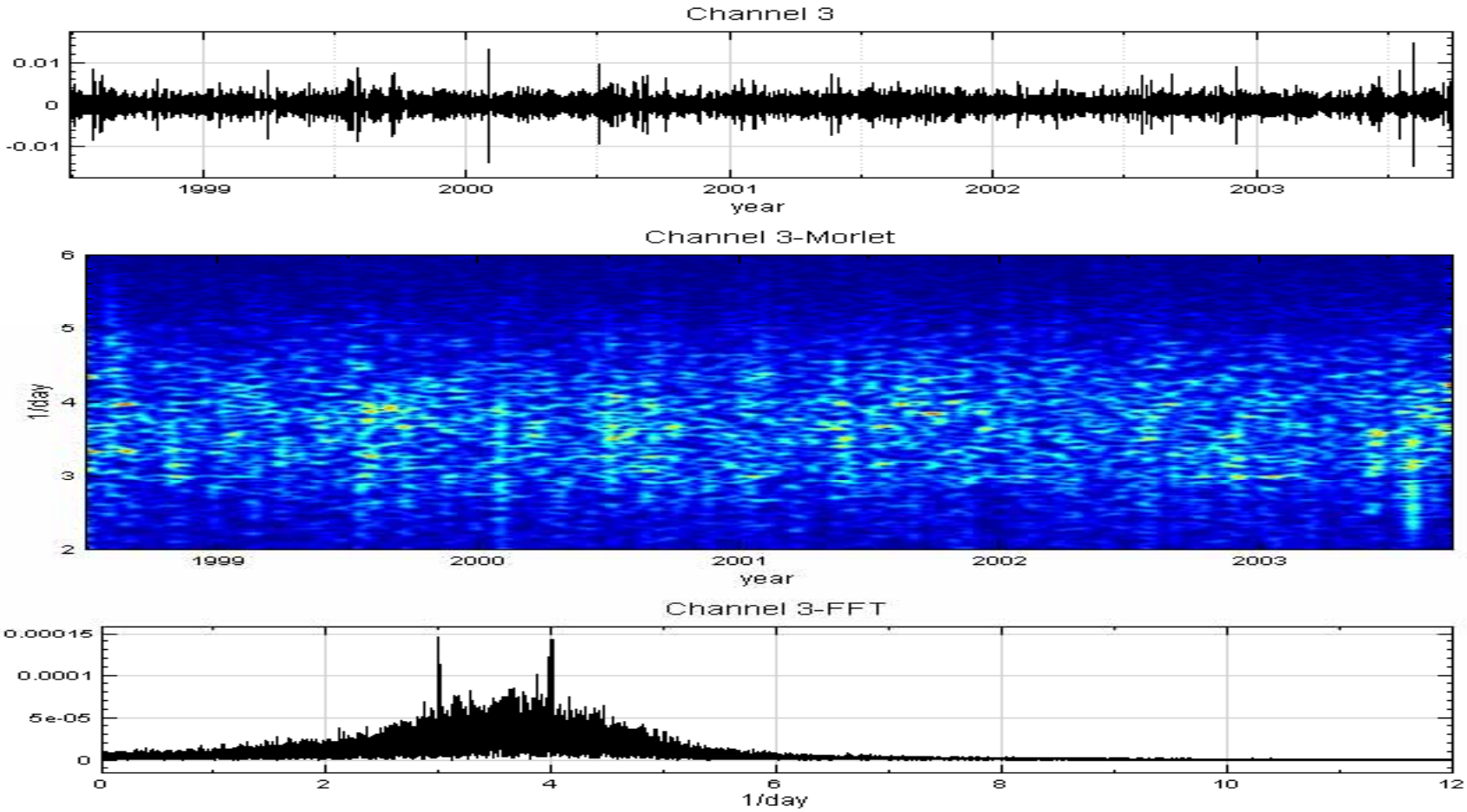
The first IMF is mostly high frequency noise. Though semi-diurnal Frequency appears, its amplitude is small.

IMF2

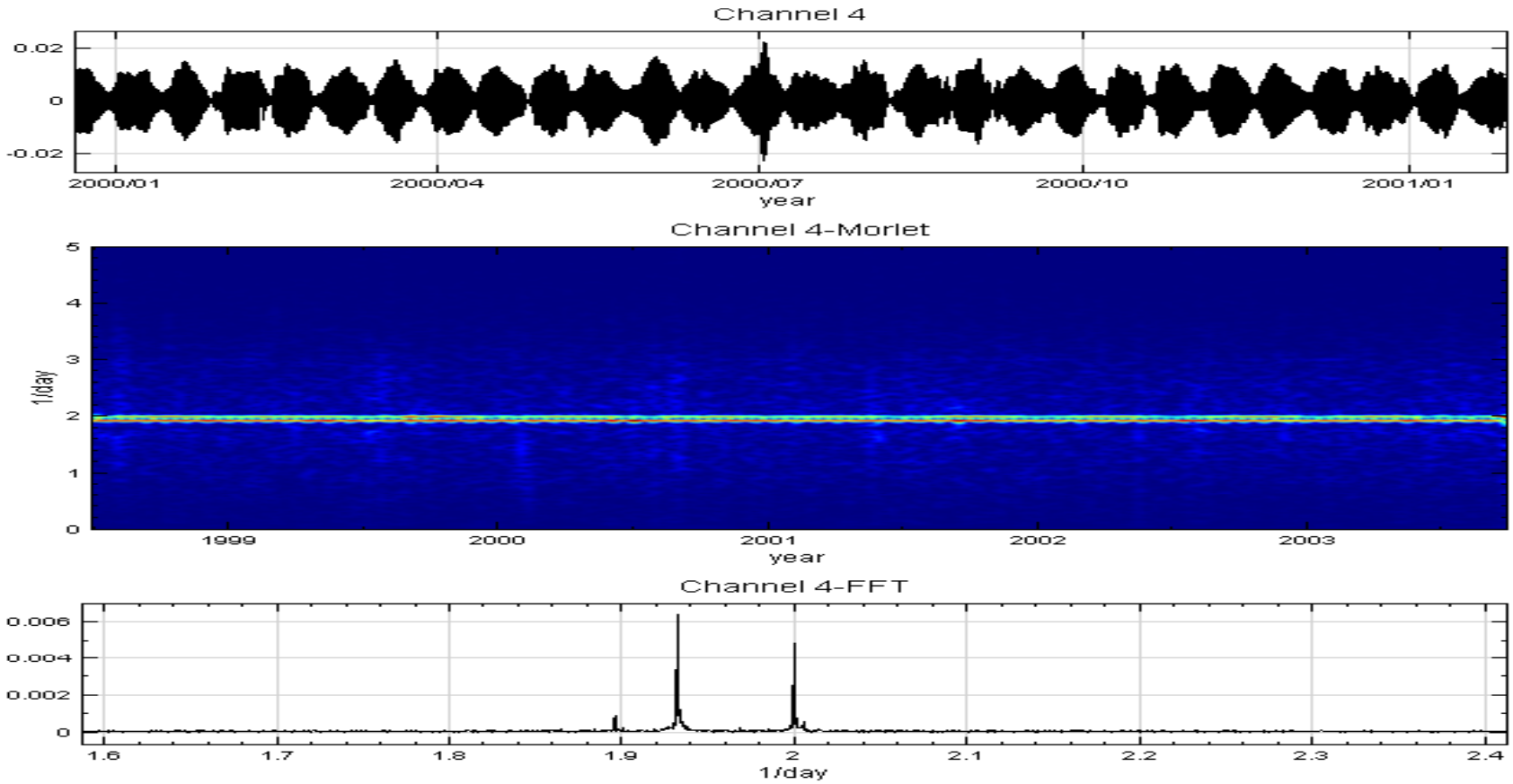


The component is relatively small compared to other IMFs.

IMF3

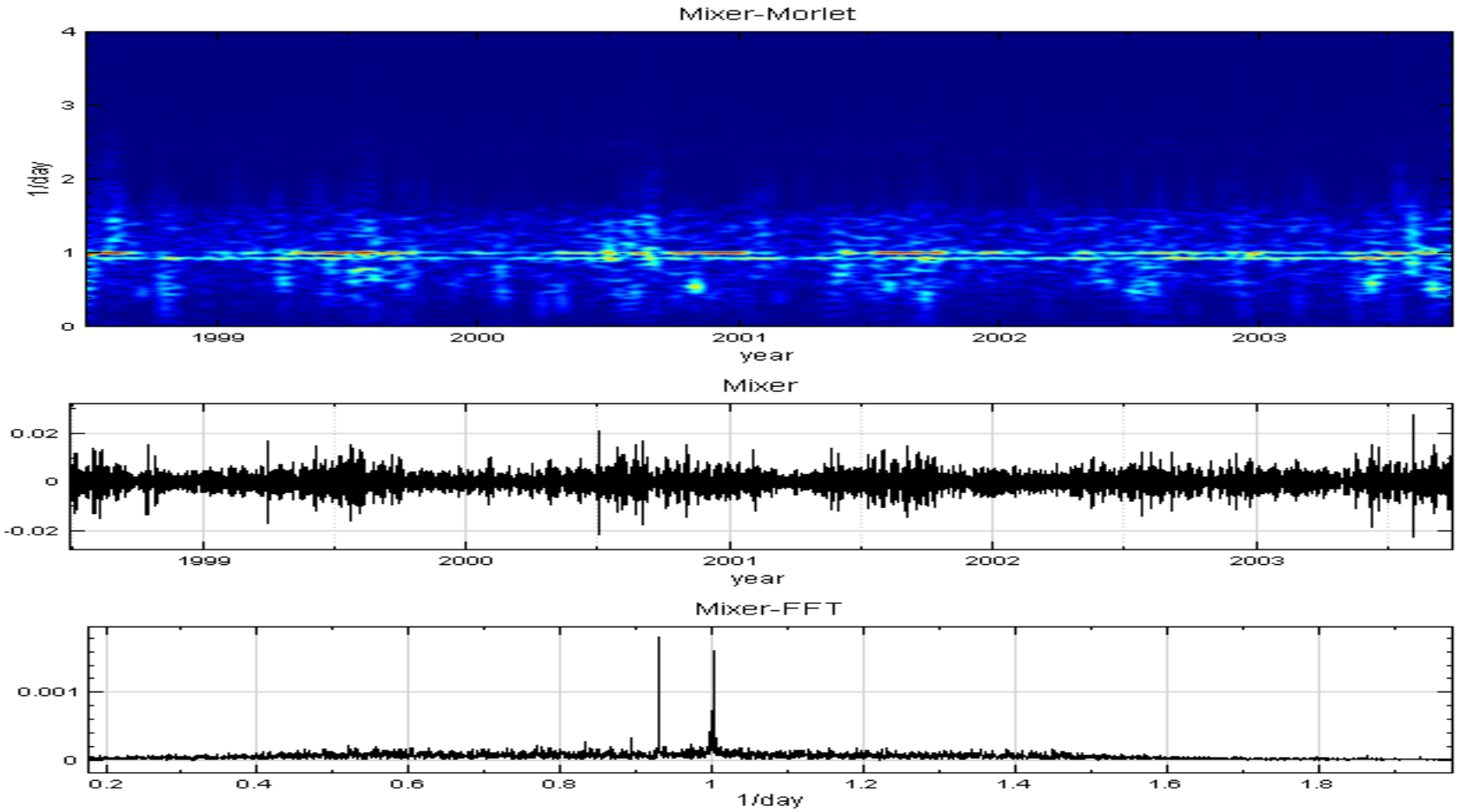

Channel 3
0.01
0
-0.01
1999
2000
2001
2002
2003
year
Channel 3-Morlet
6
5
4
3
2
1/day
1999
2000
2001
2002
2003
year
Channel 3-FFT
0.00015
0.0001
5e-05
0
0
2
4
6
8
10
12
1/day

IMF4: Semi-diurnal tide



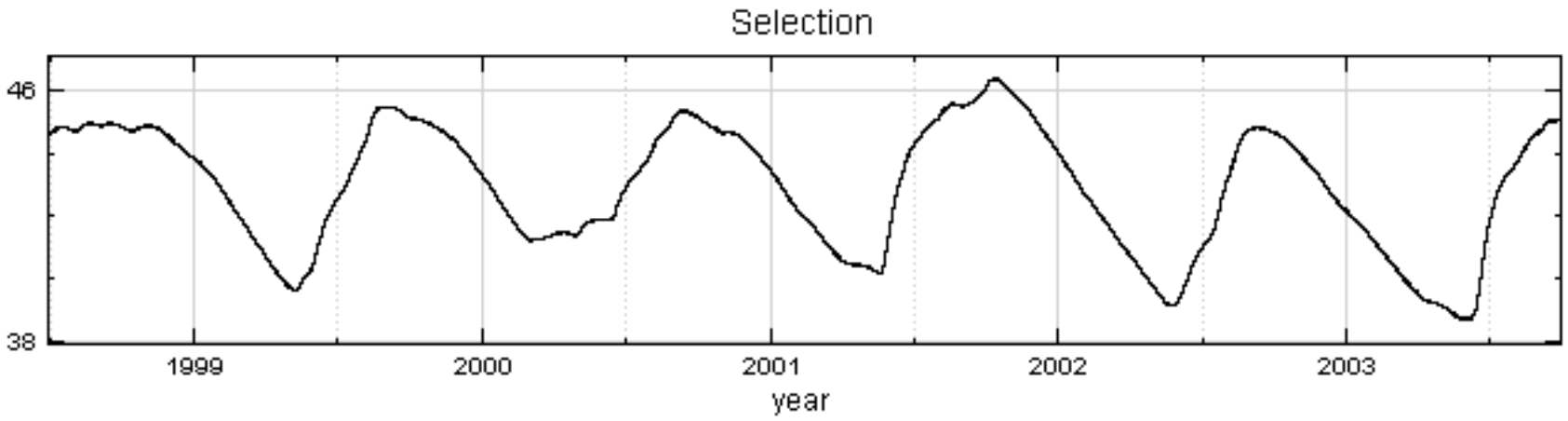
The frequency does not change seasonally. It appears nothing to do with precipitation. The centrifugal and centripetal forces from the Sun cause the semi-diurnal variation. Gravitational force from the Moon results in the monthly beat wave phenomena.

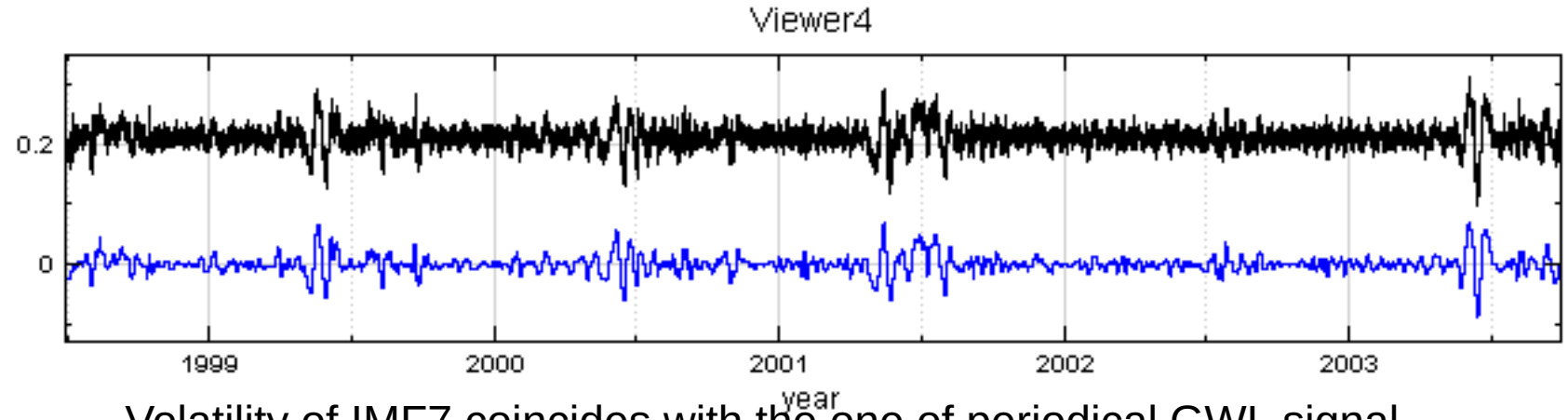
IMF5+IMF6: diurnal period



Note that in TF plot diurnal intensity varies with precipitation.
It might suggest diurnal frequency is caused by precipitate injection to the reservoir.

IMF7: precipitation

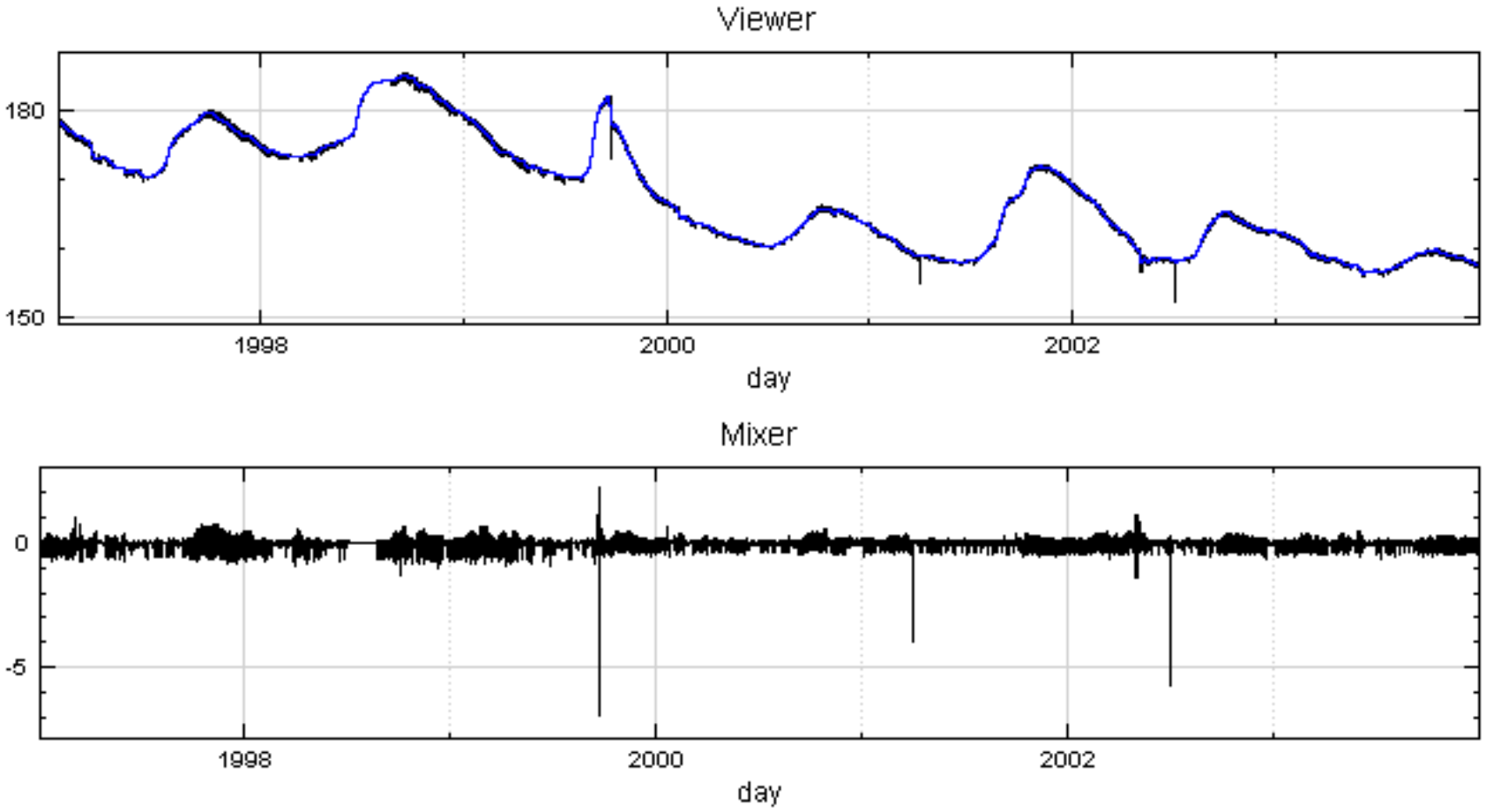




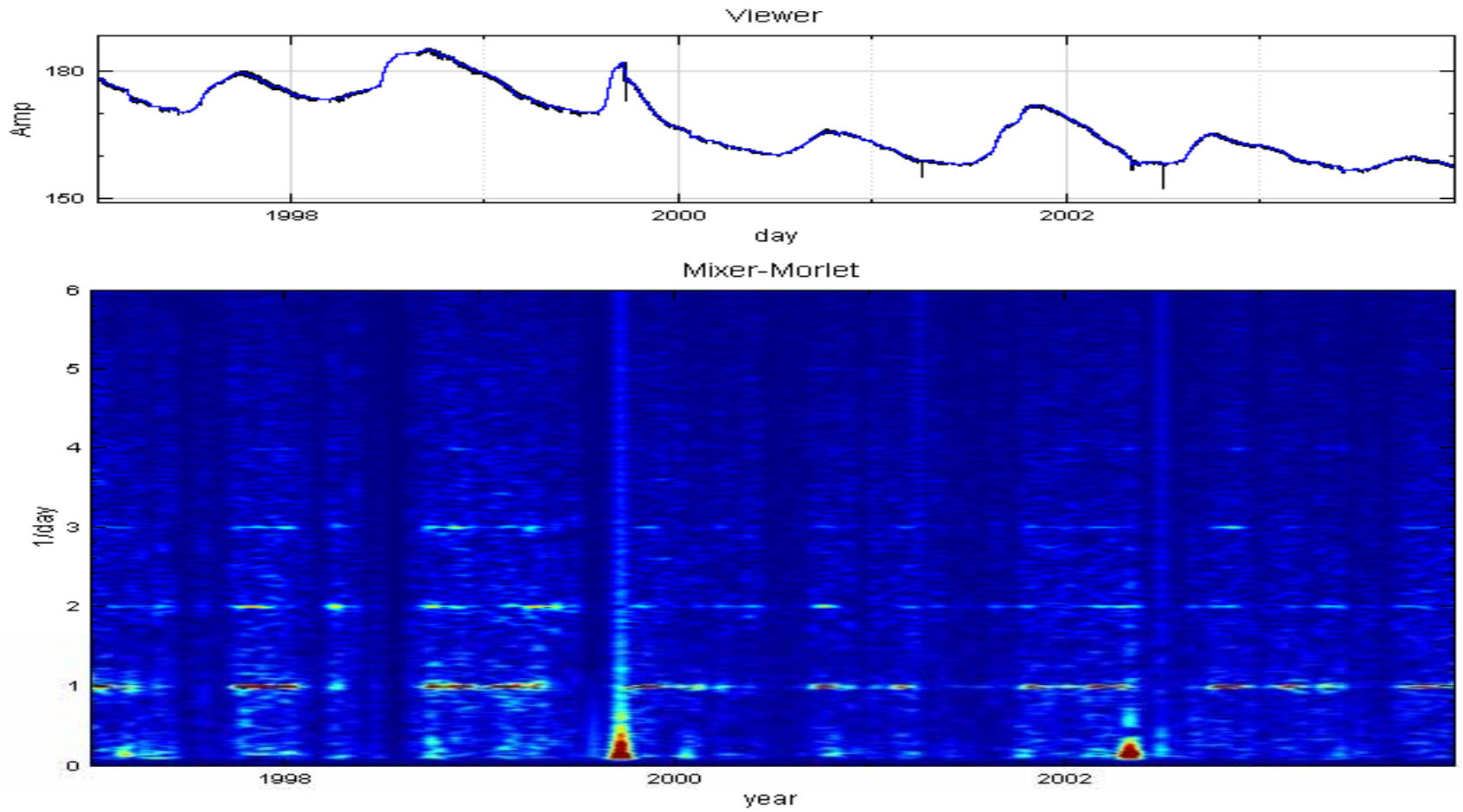
Volatility of IMF7 coincides with the one of periodical GWL signal. Increase of volatility correlates with the increase of GWL. This suggests IMF7 is related to precipitation which in this case is the major contribution to the raise of GWL.

Precursor to Earthquake?

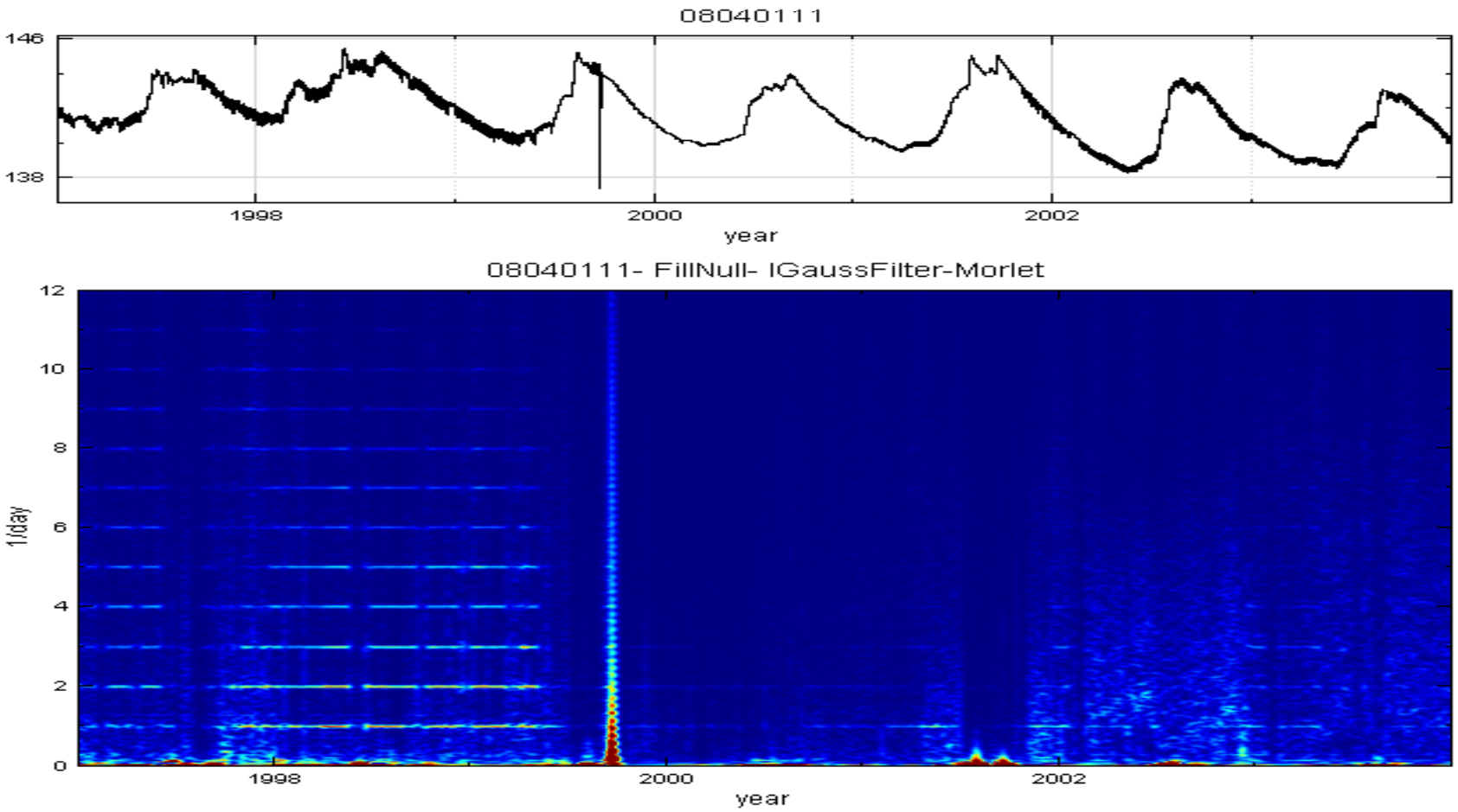
Well around Chi-Chi Earthquake (南投新光)



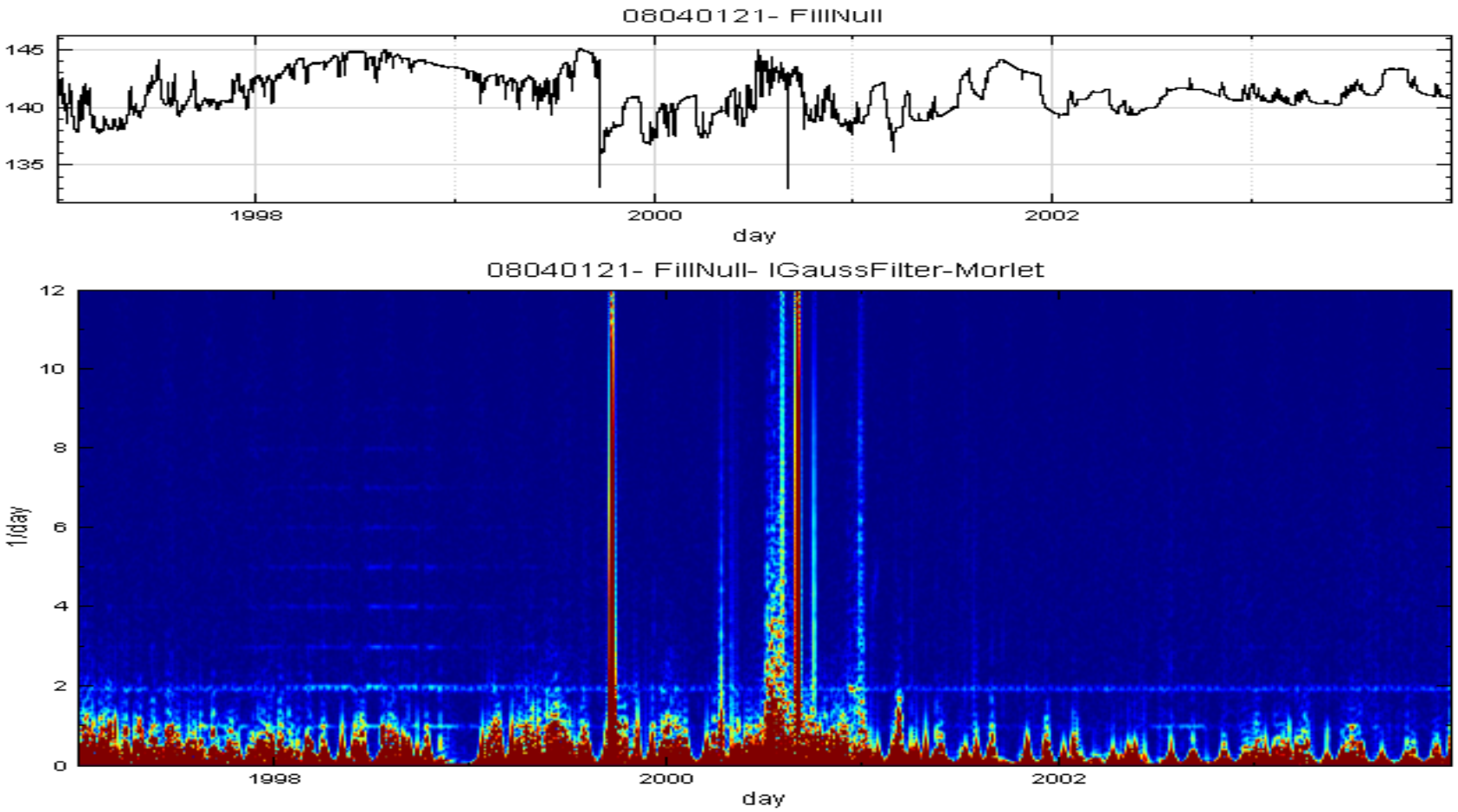
Well around Chi-Chi Earthquake (南投新光)



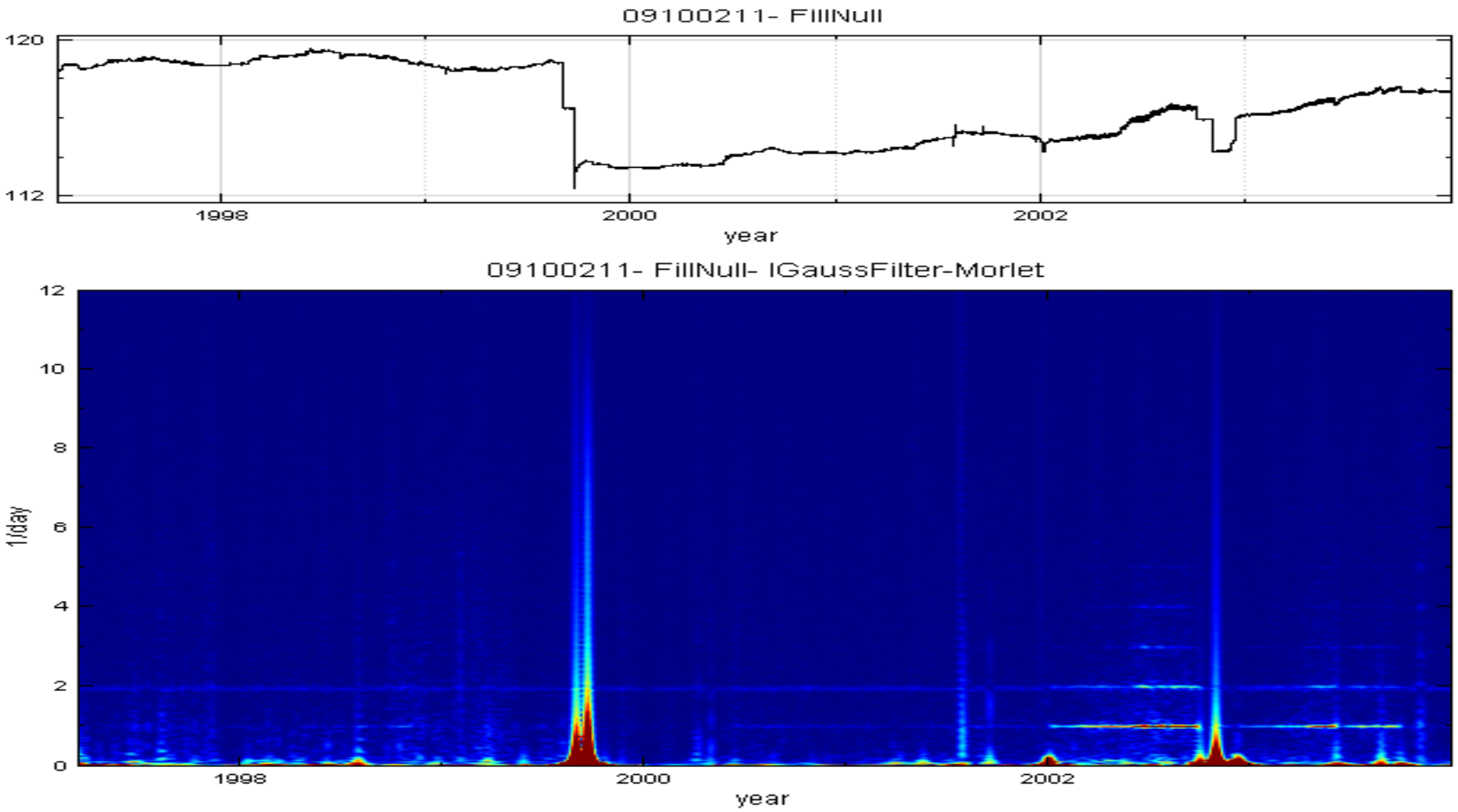
Well around Chi-Chi Earthquake (南投竹山(1))



Well around Chi-Chi Earthquake (南投竹山(1))



Well away from Chi-Chi Earthquake 雲林觸口(1)



Summary

- Time-frequency analysis provides insightful information related to recharge, precipitation, earth tide, and event anomaly.
- In some cases, EMD (Empirical Mode Decomposition) can be used to separate earth tide. The strength of earth tide might serve as an indicator to the size of ground water reservoir.
- The abrupt rise of GWL without recharge nor daily pumping harmonics suggests abnormal water injection to reservoir. It is worthy of further investigation to see if it is a precursor to earthquake.
- All the analysis is done using Visual Signal of AnCAD.

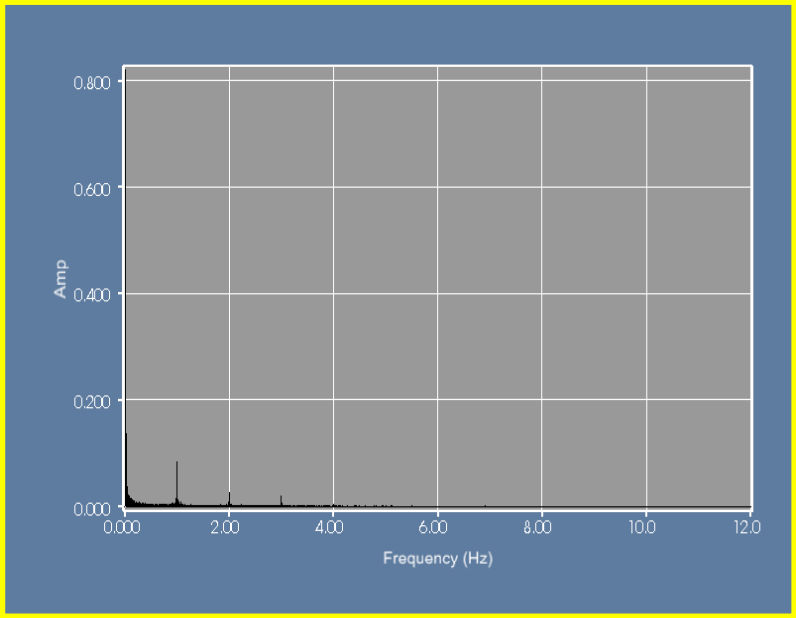
Thank You!!

Visual Signal
http://www.ancad.com/VisualSignal/downloadform.php

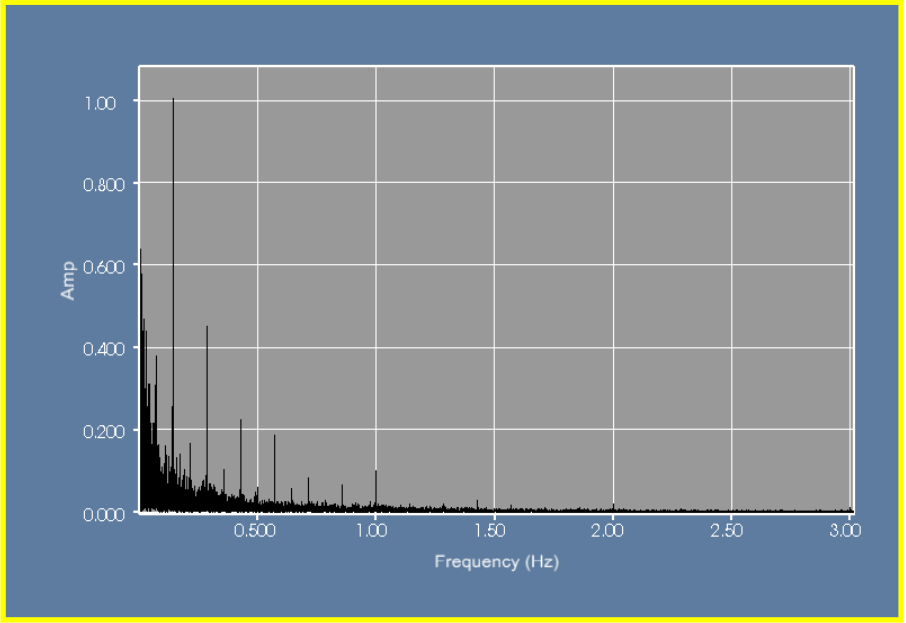
yetmen@ancad.com

Thank You!!

頻譜分析

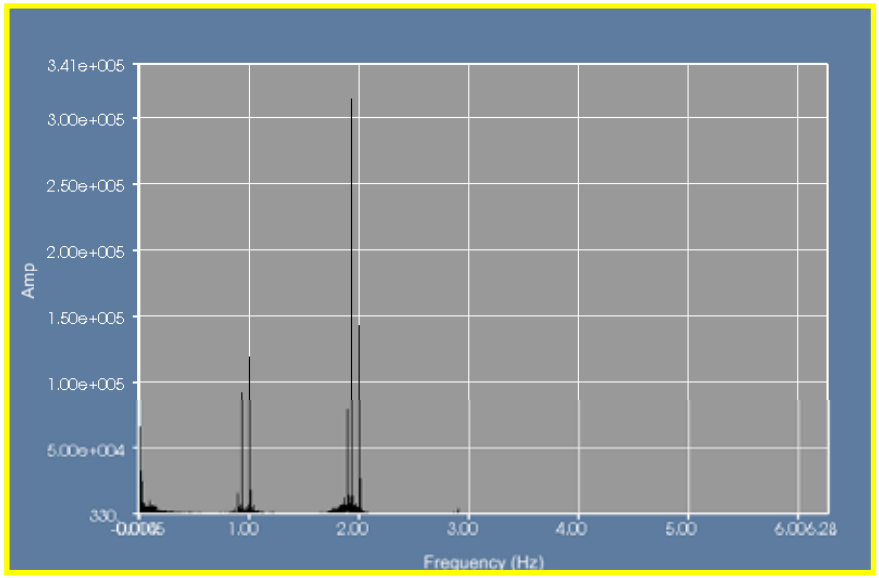


南投・新光

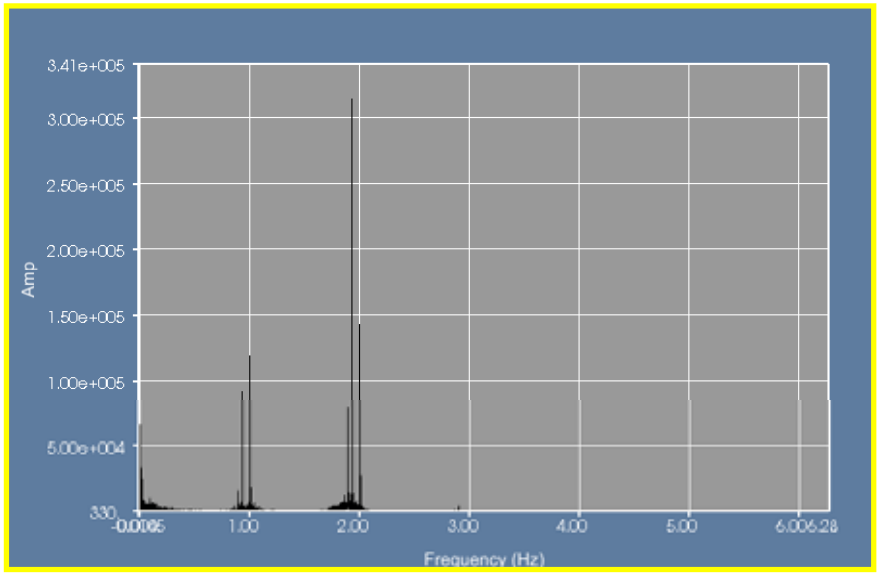


桃園・樹林

海潮(Tide Signal)與海水入侵

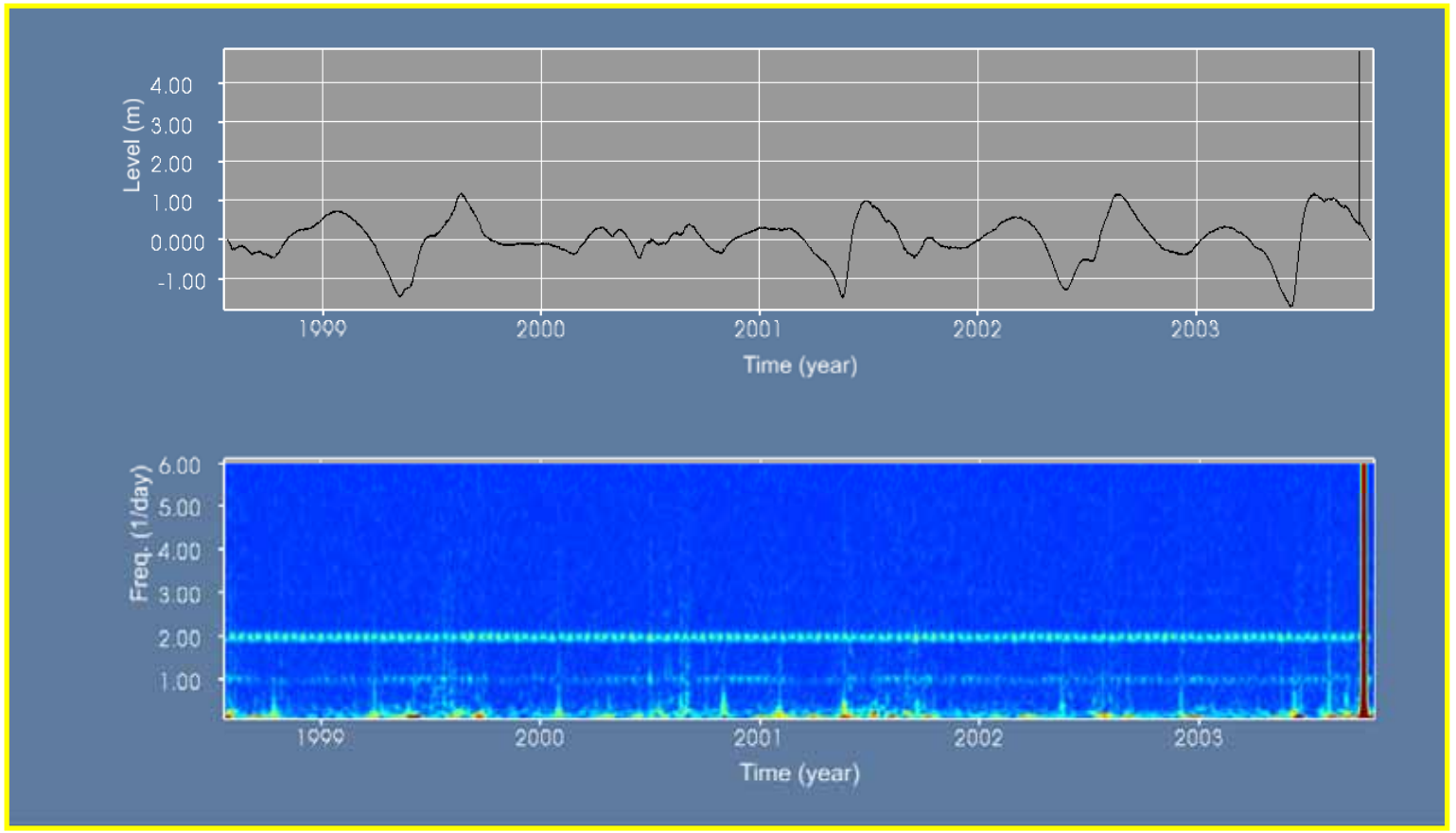


海潮(Tide Signal)



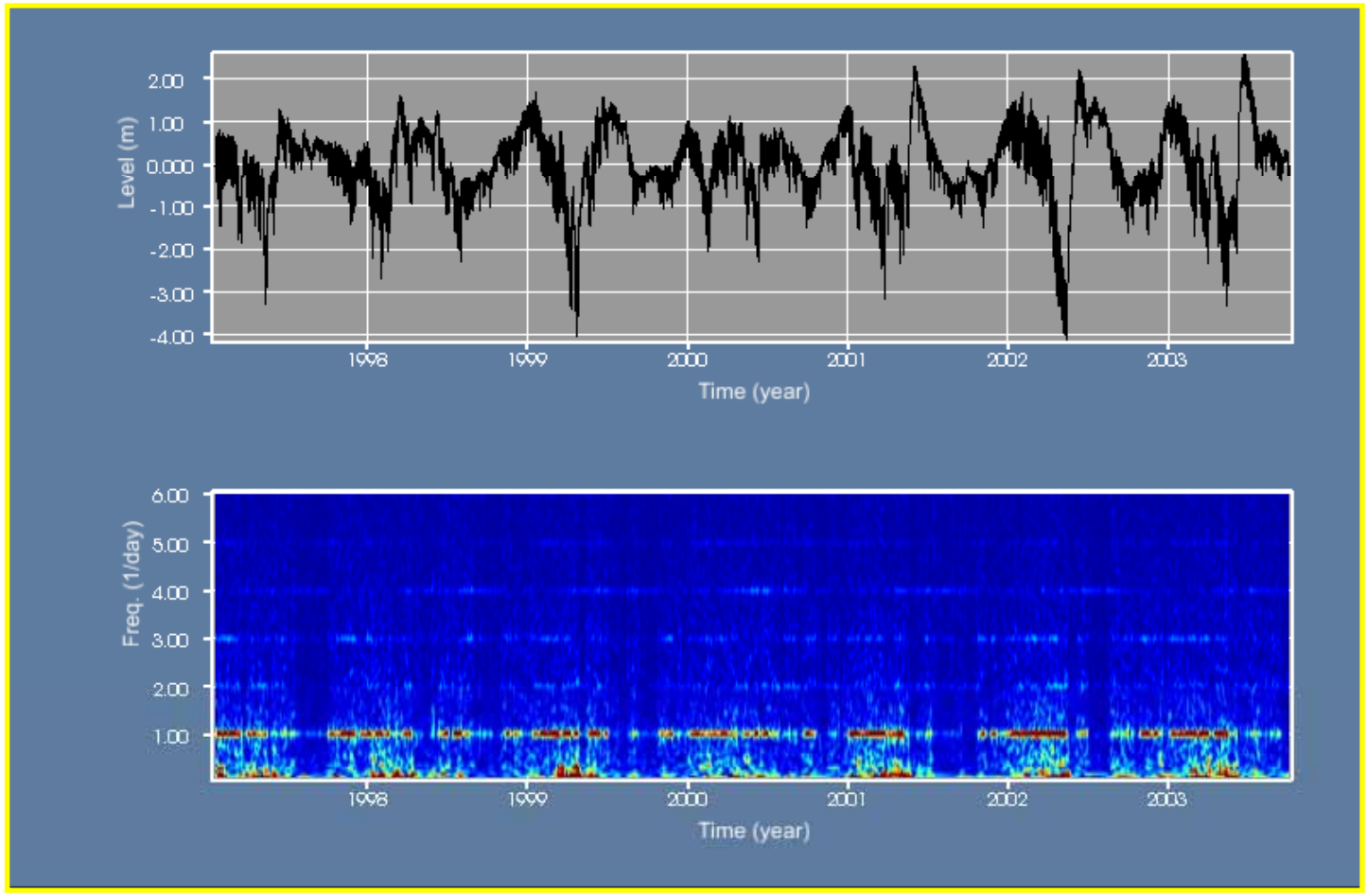
海水入侵－台南安平

時頻分析結果—地潮分析



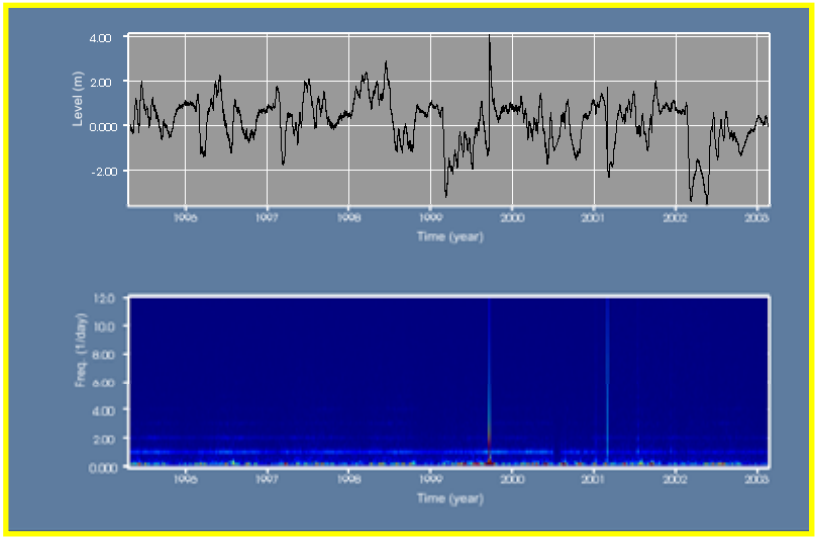
吉洋人工湖

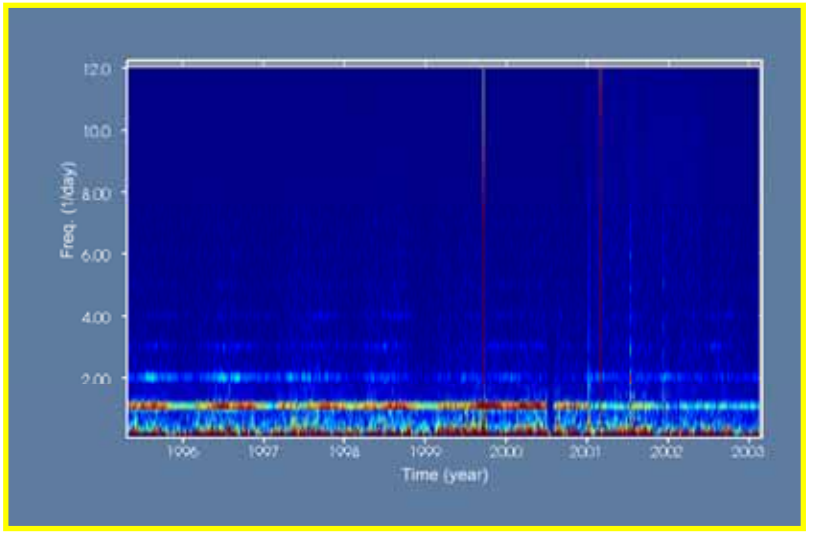
時頻分析結果—雨季、旱季



美濃

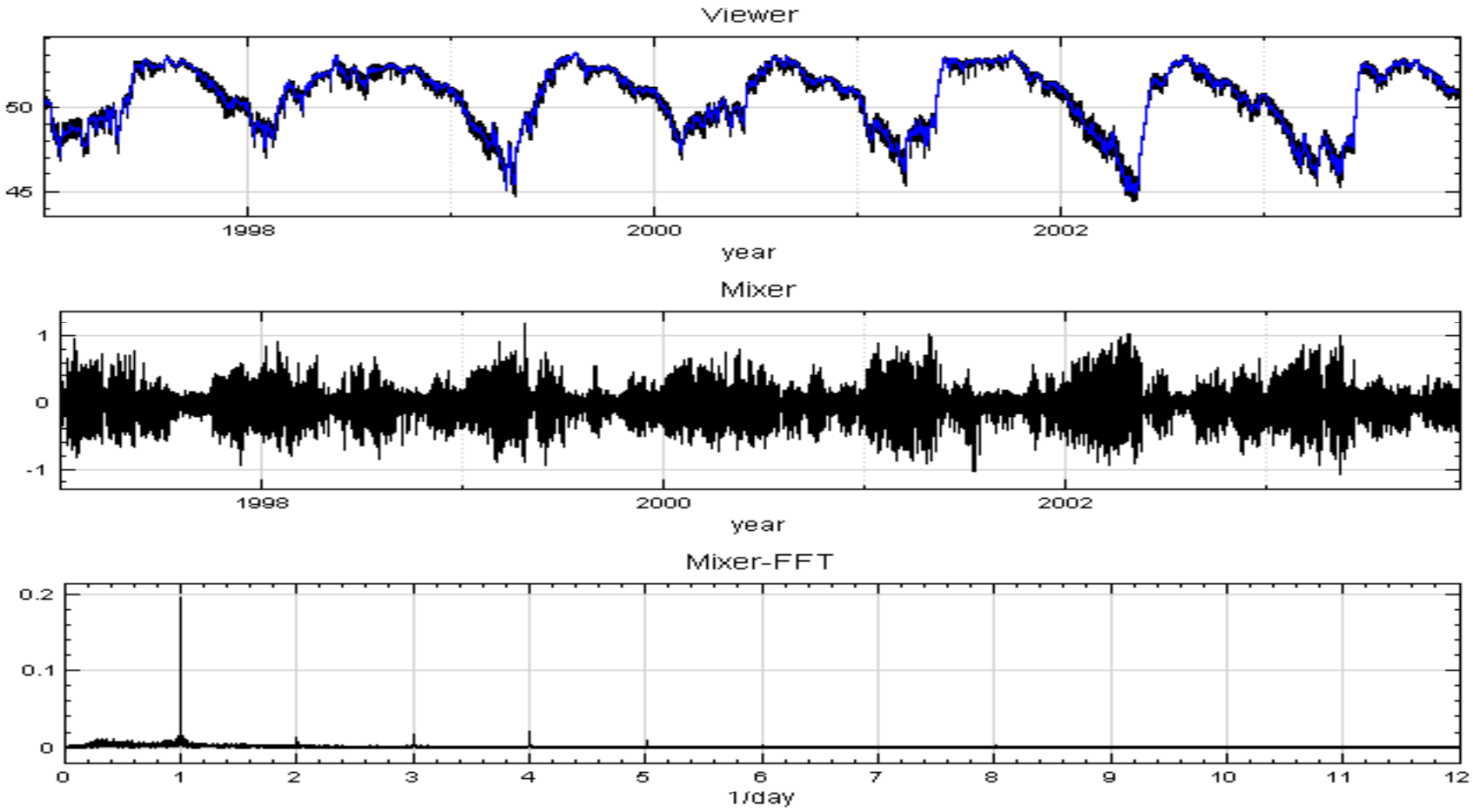
時頻分析結果—地震與資料補遺



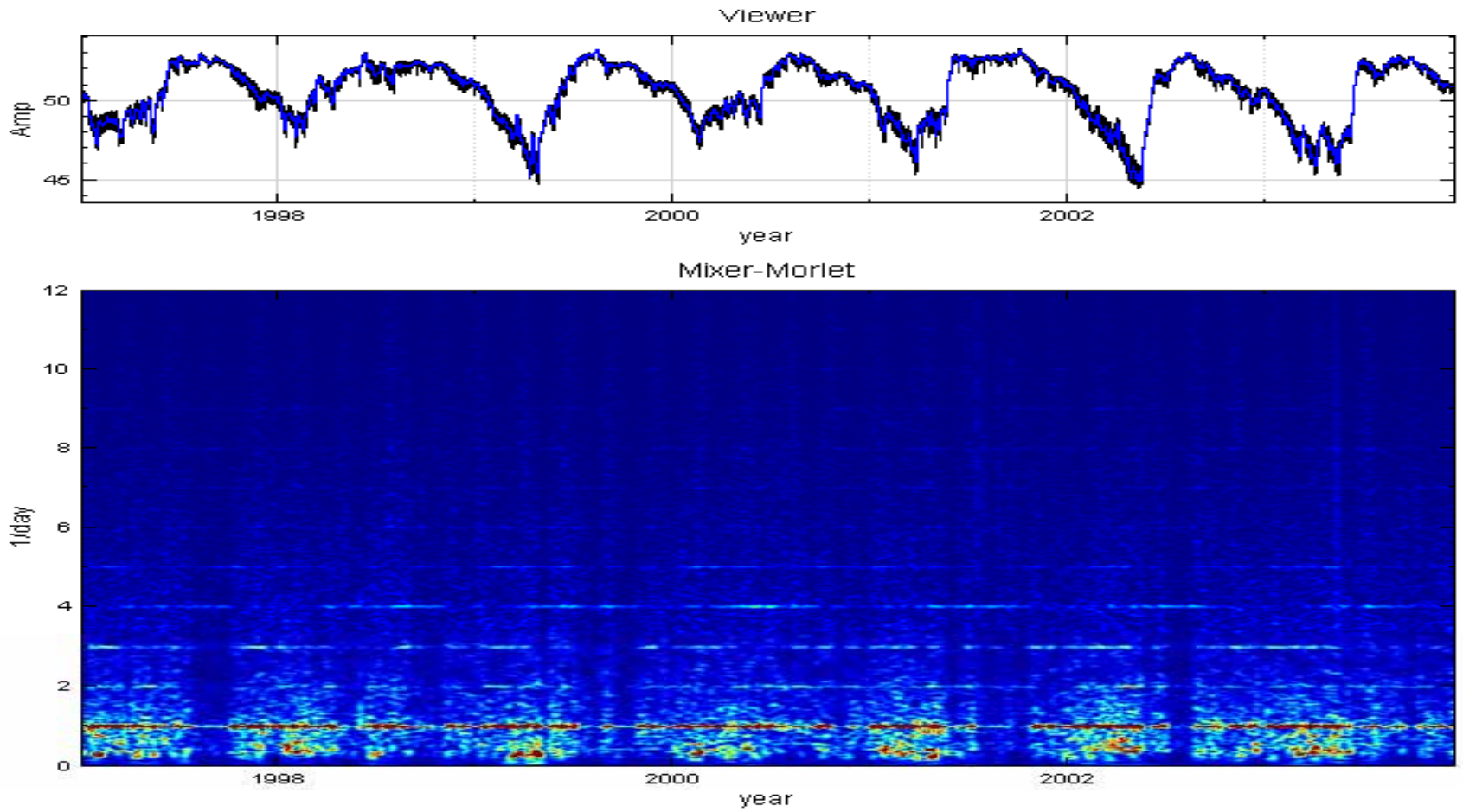


彰化・好修

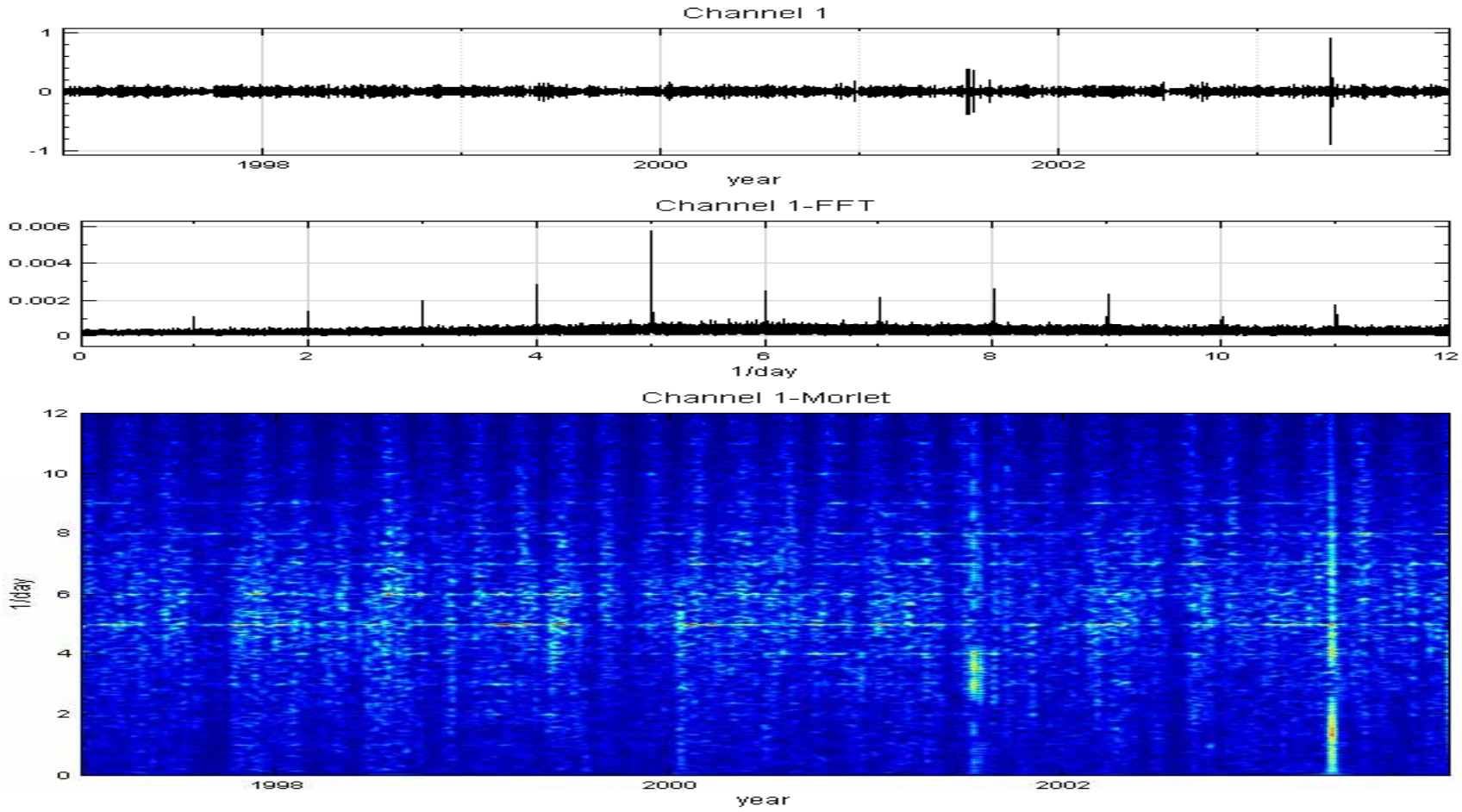
美濃(1)


Viewer
50
45
1998
2000
2002
year
Mixer
1
0
-1
1998
2000
2002
year
Mixer-FFT
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
1/day

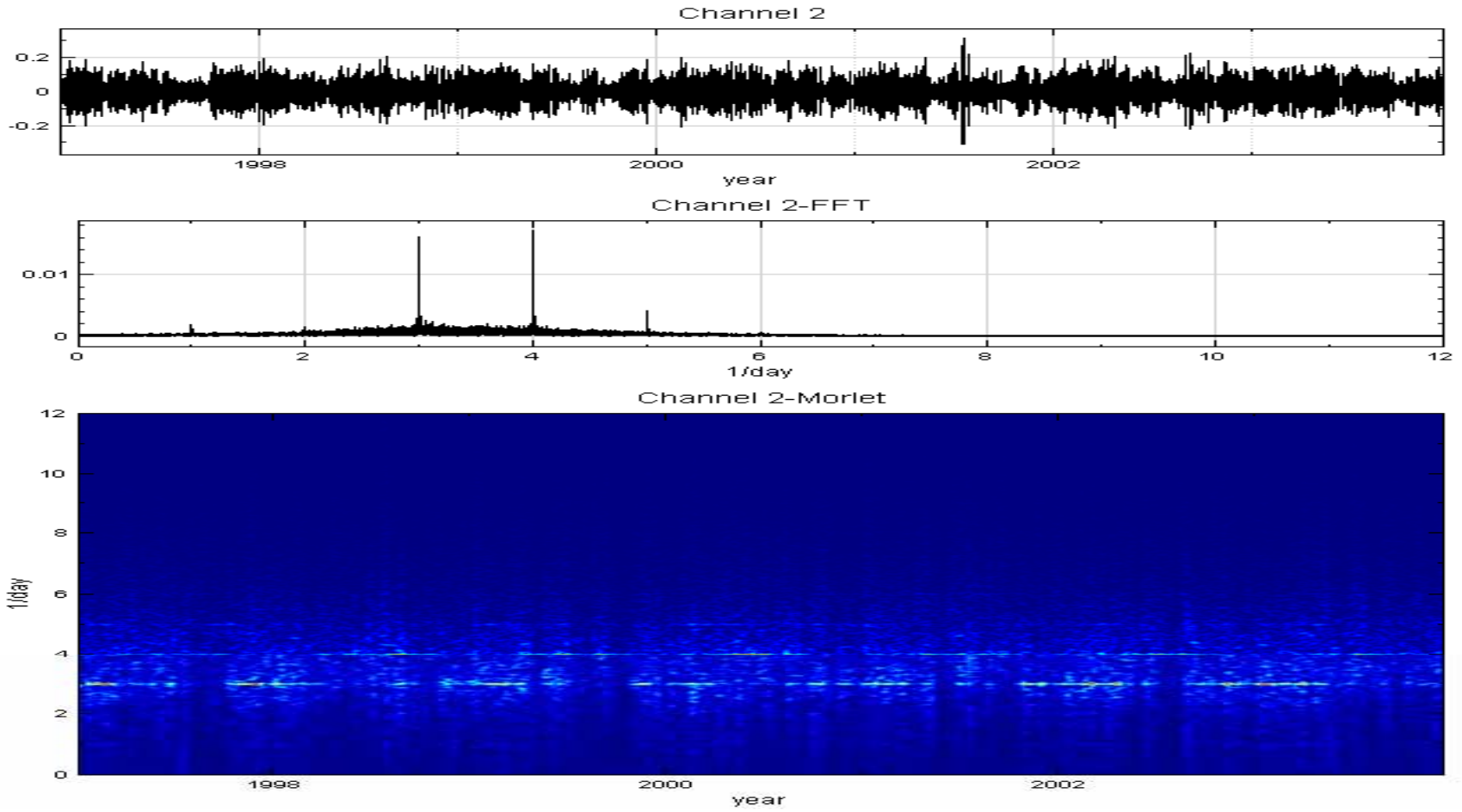
美濃(1)


Viewer
Amp
50
45
1998
2000
2002
year
Mixer-Morlet
1/day
12
10
8
6
4
2
0
1998
2000
2002
year

IMF1

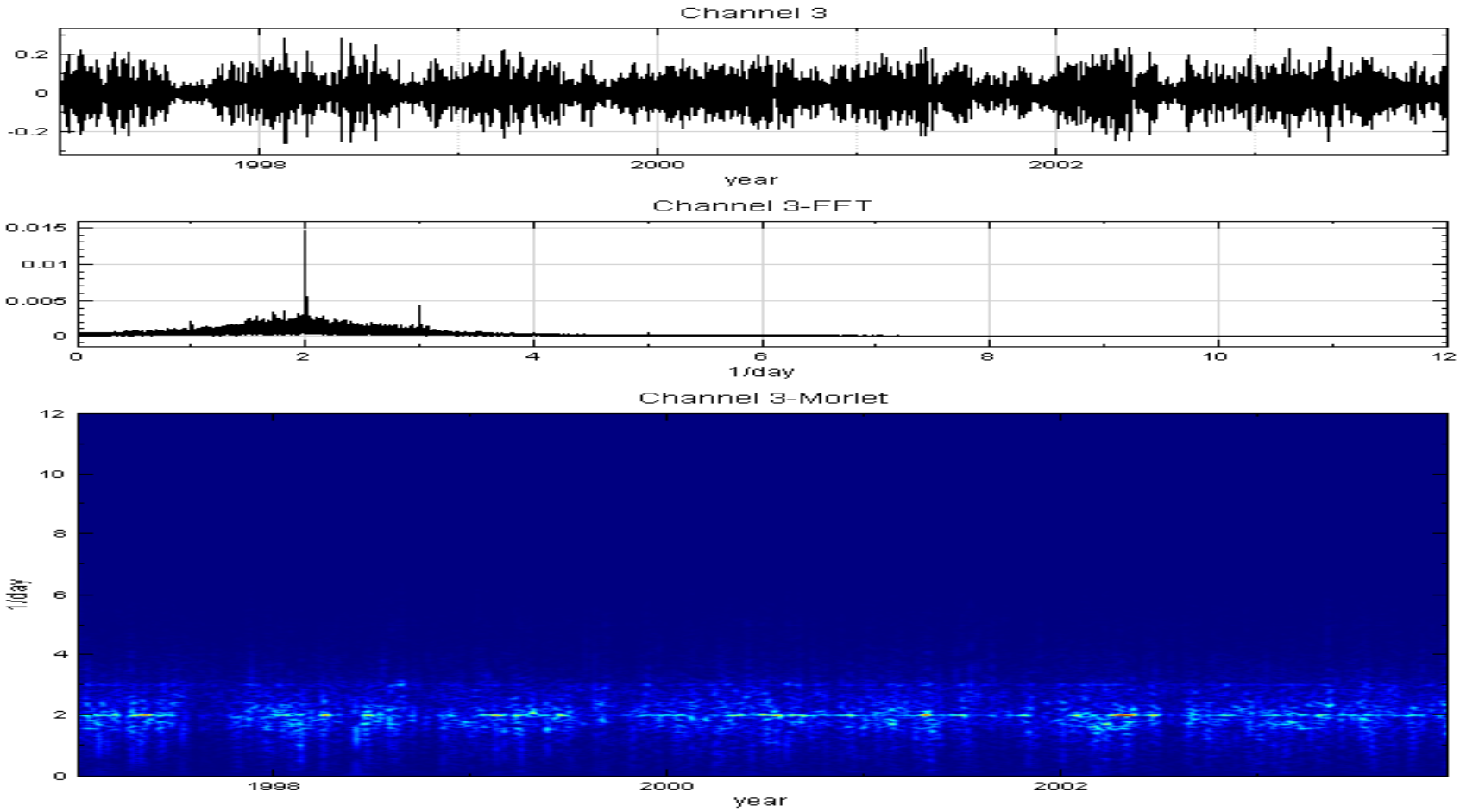

Channel 1
1
0
-1
1998
2000
2002
year
Channel 1-FFT
0.006
0.004
0.002
0
0
2
4
6
8
10
12
1/day
Channel 1-Morlet
12
10
8
6
4
2
0
1/day
1998
2000
2002
year

IMF2

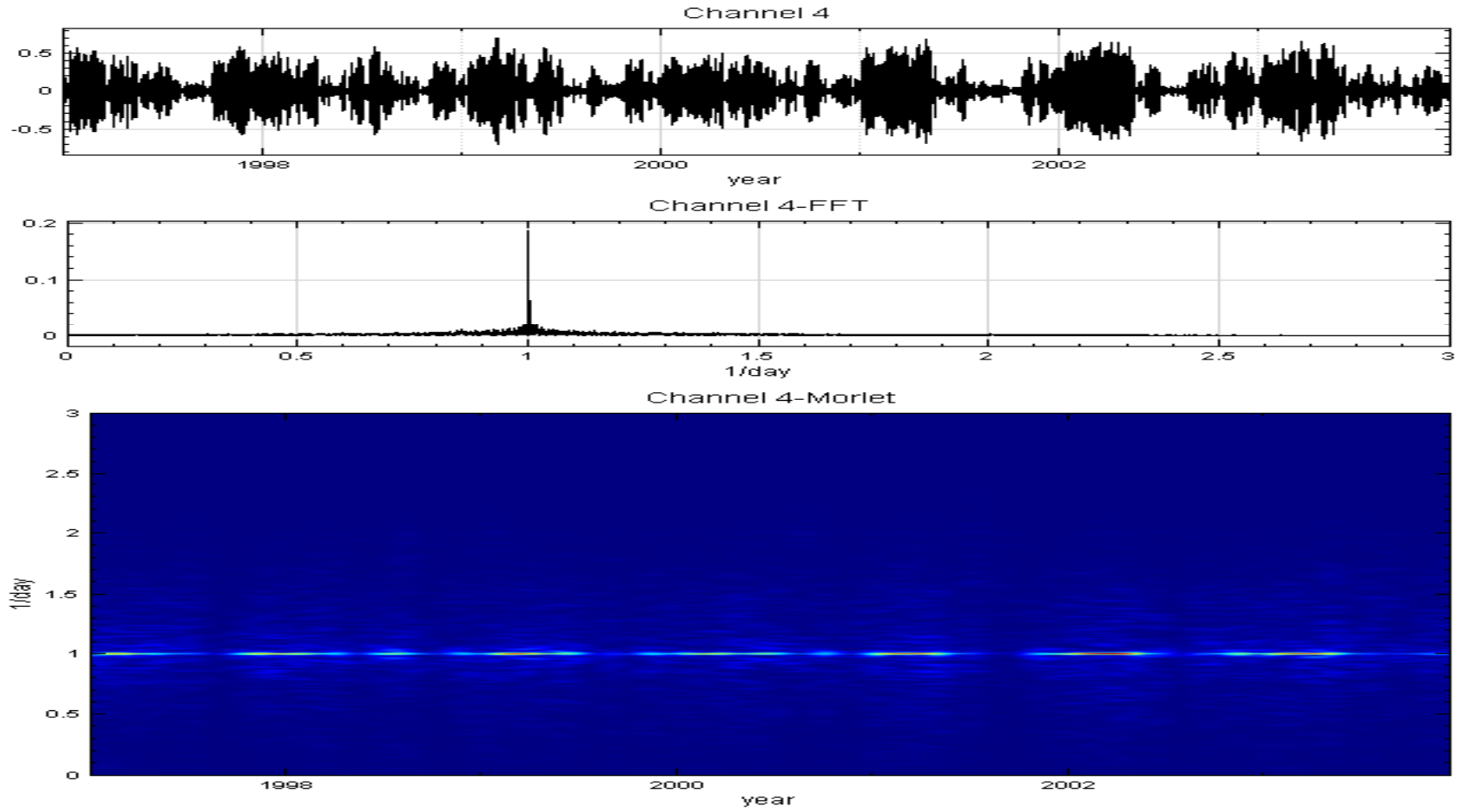


Frequency 3 (times a day) and 4 always come together in the same IMF.
It is interesting to note that the intensities of these two frequency components comprise each other.

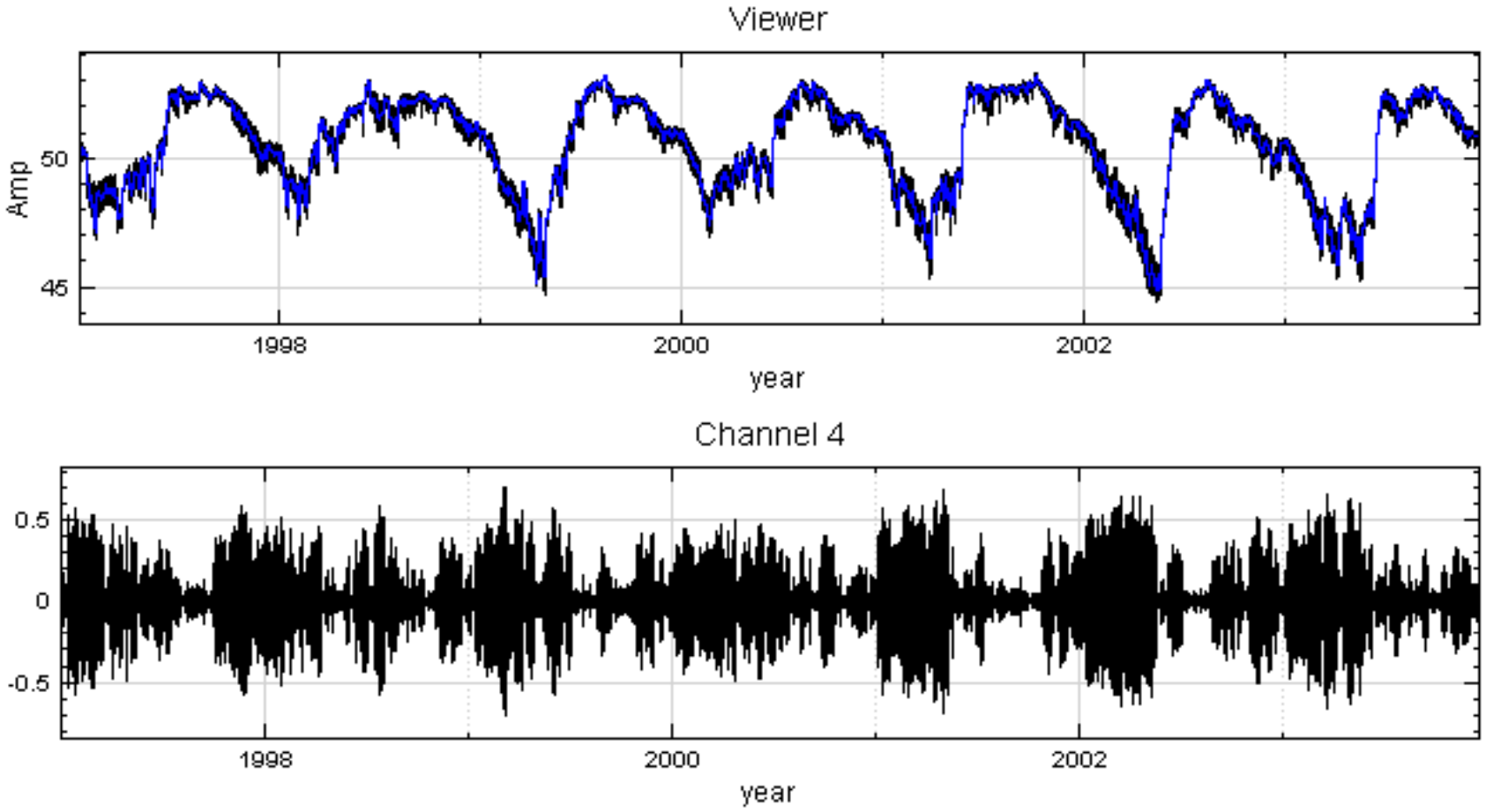
IMF3


Channel 3
0.2
0
-0.2
1998
2000
2002
year
Channel 3-FFT
0.015
0.01
0.005
0
0
2
4
6
8
10
12
1/day
Channel 3-Morlet
12
10
8
6
4
2
0
1/day
1998
2000
2002
year

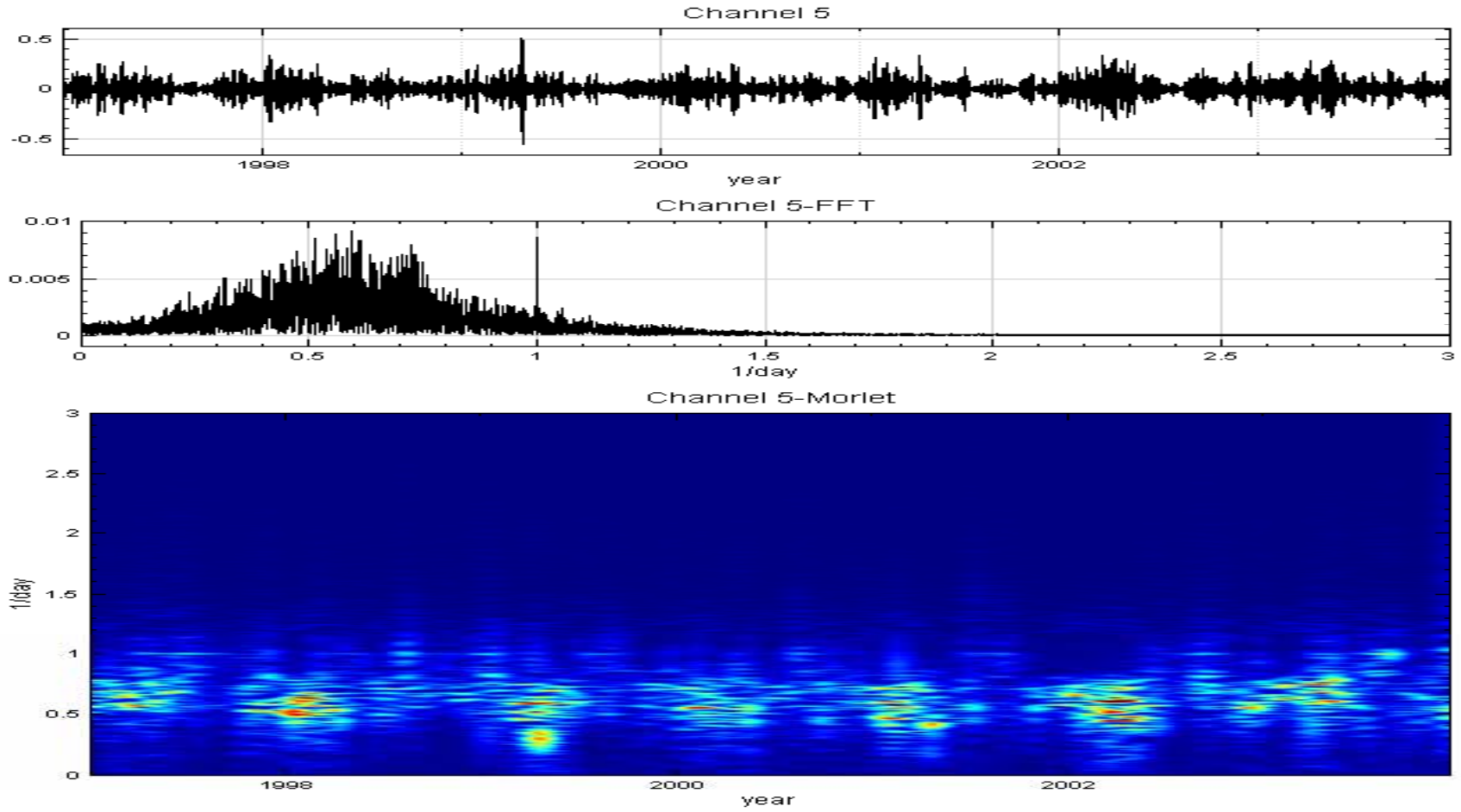
IMF4


Channel 4
0.5
0
-0.5
1998
2000
2002
year
Channel 4-FFT
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
1/day
Channel 4-Morlet
3
2.5
2
1.5
1
0.5
0
1/day
1998
2000
2002
year

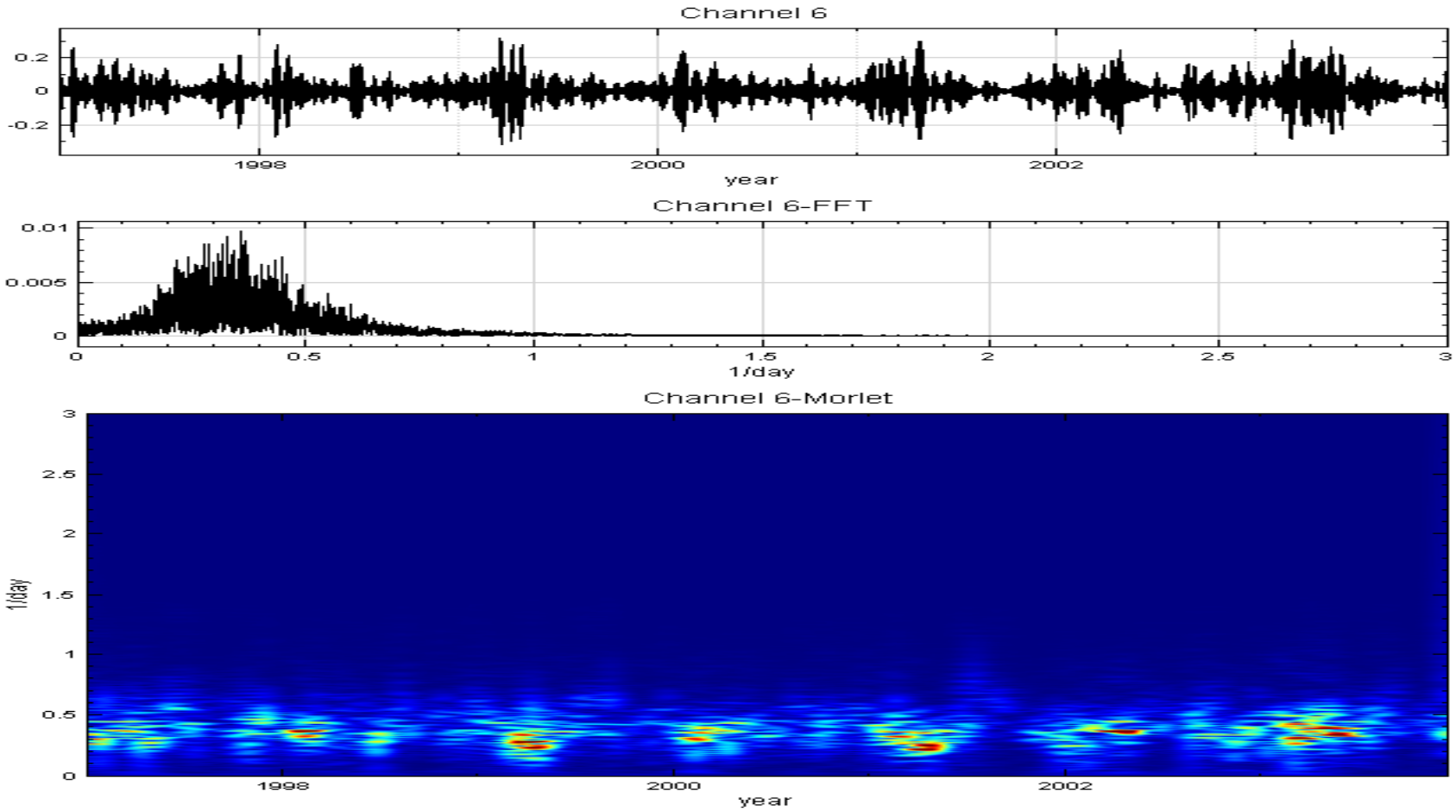
Precipitate Injection



IMF5


Channel 5
0.5
0
-0.5
1998
2000
2002
year
Channel 5-FFT
0.01
0.005
0
0
0.5
1
1.5
2
2.5
3
1/day
Channel 5-Morlet
3
2.5
2
1.5
1
0.5
0
1/day
1998
2000
2002
year

IMF6


Channel 6
0.2
0
-0.2
1998
2000
2002
year
Channel 6-FFT
0.01
0.005
0
0
0.5
1
1.5
2
2.5
3
1/day
Channel 6-Morlet
3
2.5
2
1.5
1
0.5
0
1/day
1998
2000
2002
year