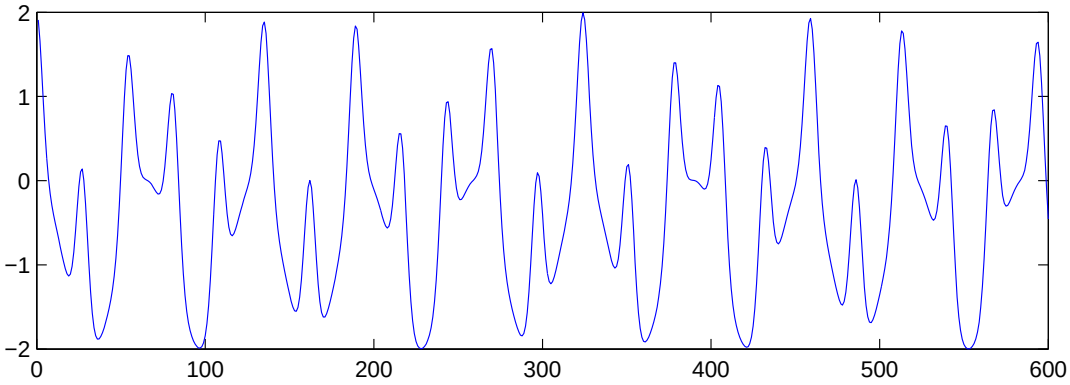
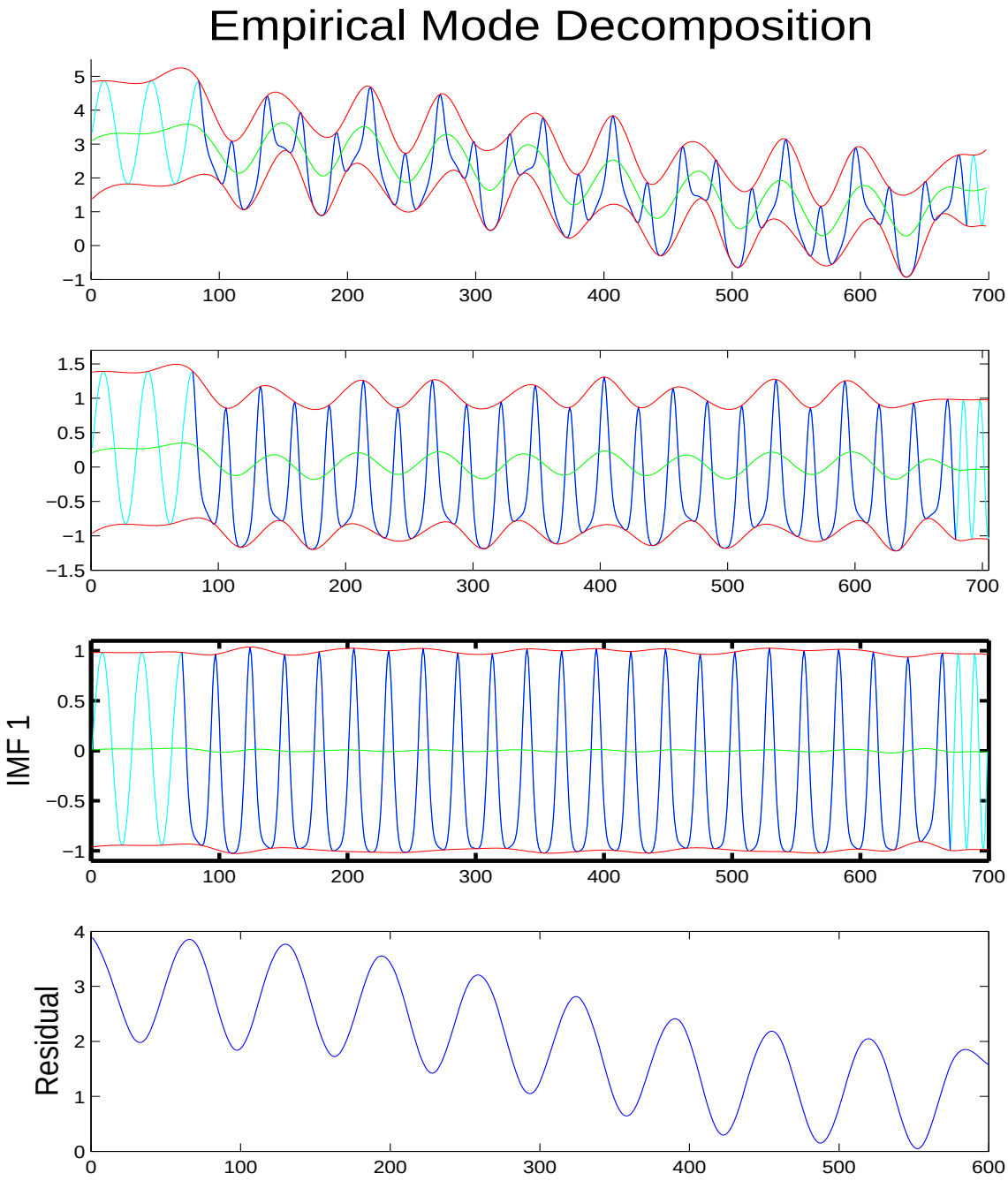
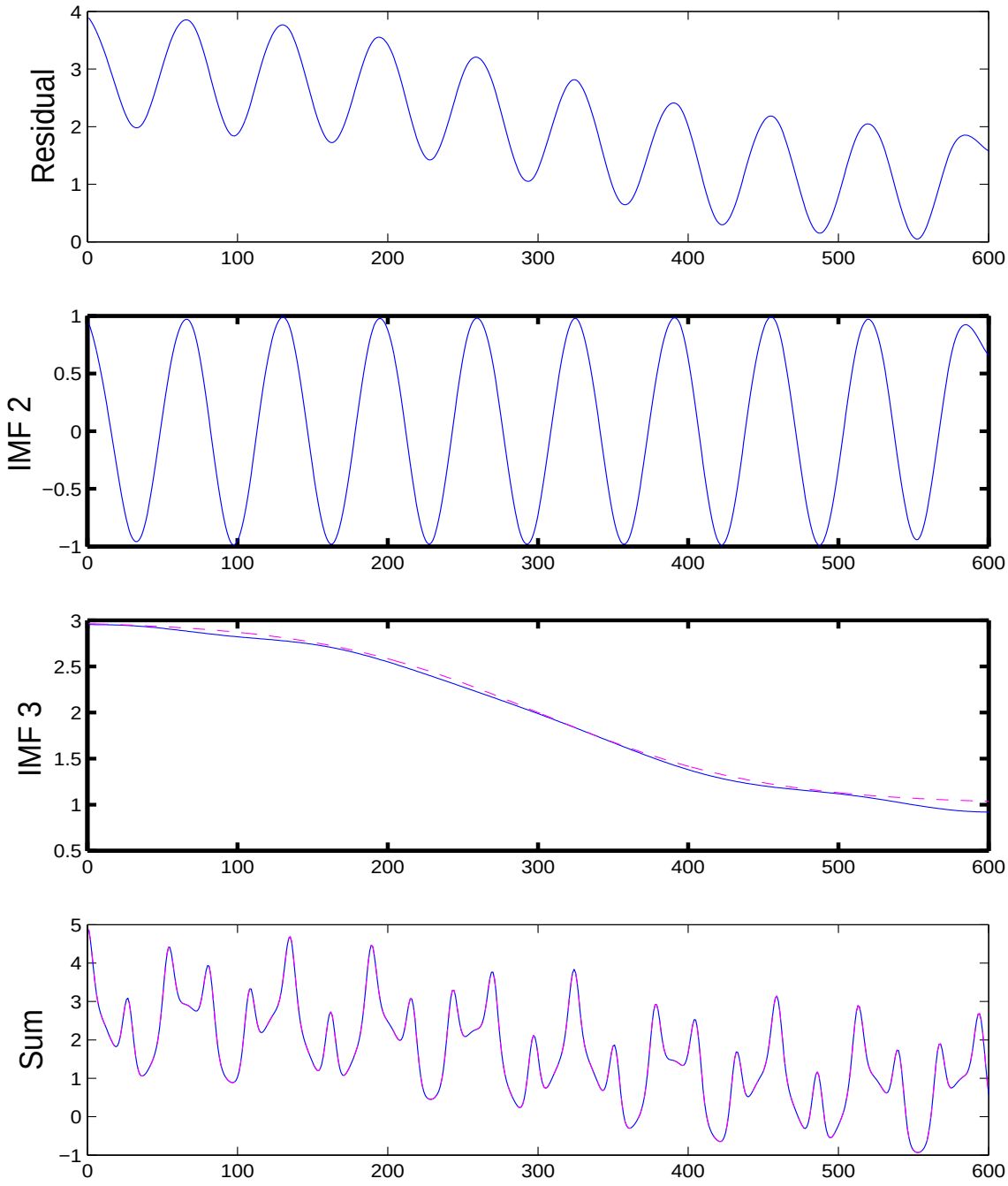
Sample Problem: Stokes Wave + Cosine + Trend

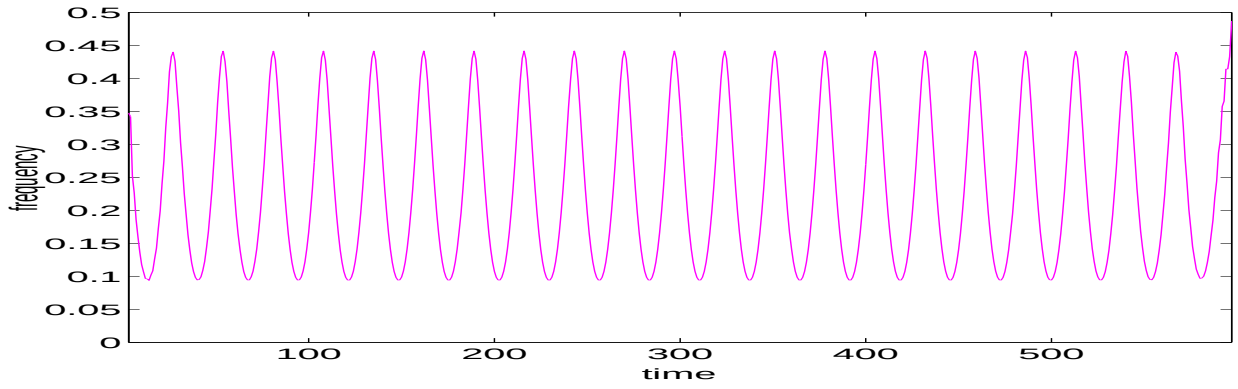


$$data = \cos(\frac{2\pi t}{27} + a\sin(2\pi t/27)) + \cos(\frac{2\pi t}{65}) - tanh(\frac{t-30}{150}$$

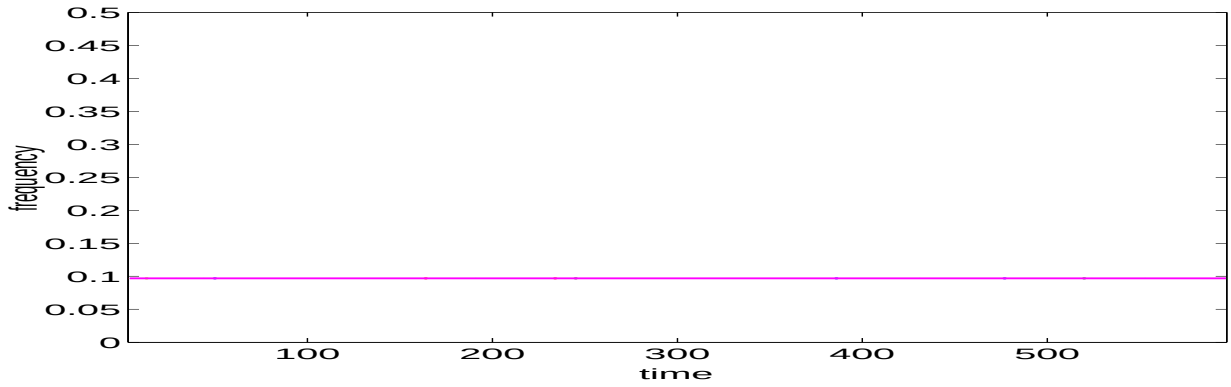

Empirical Mode Decomposition
IMF 1
Residual


Residual
IMF 2
IMF 3
Sum
0
100
200
300
400
500
600

Reconstruction of the Data Structure

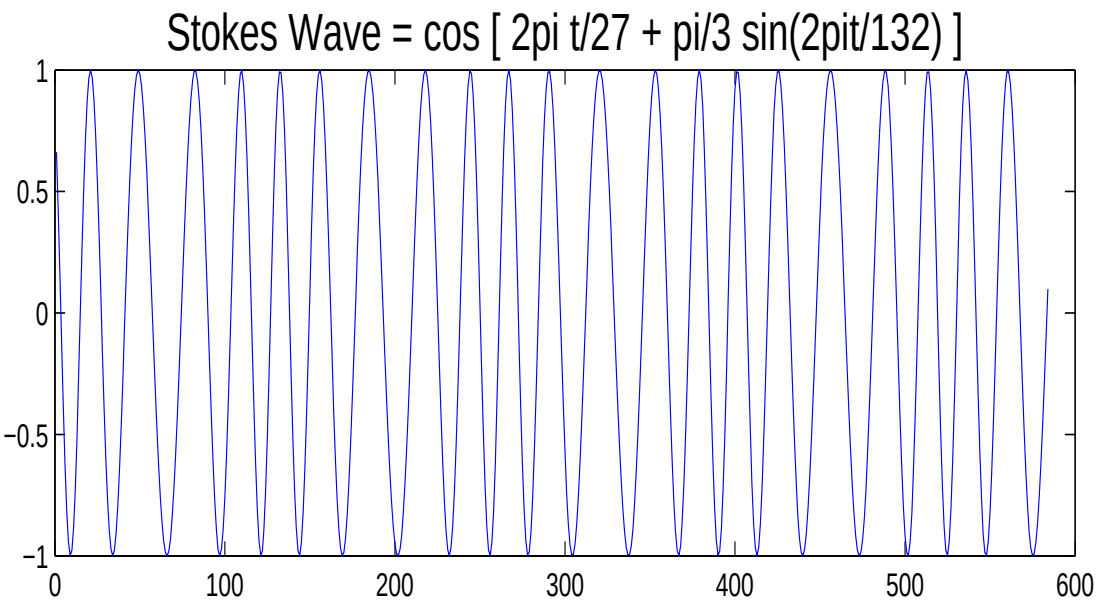


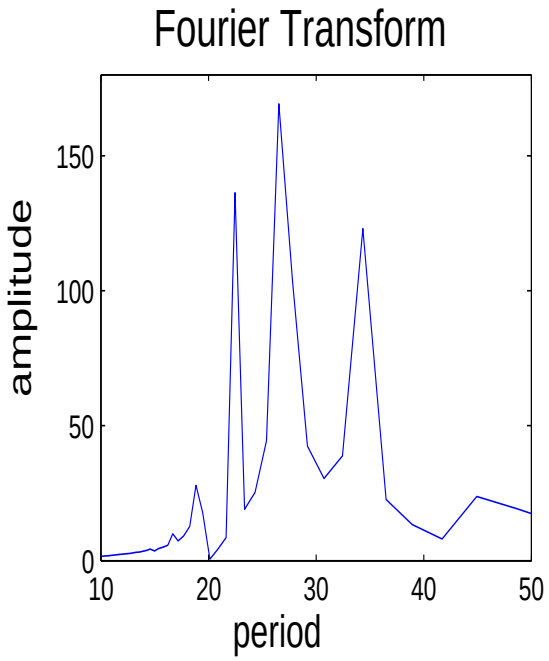
A Hilbert Transform of the first IMF yeilds an oscillating frequency oscillating about a mean frequency of .23. $\rightarrow \cos(.23t + sinusoidal)$

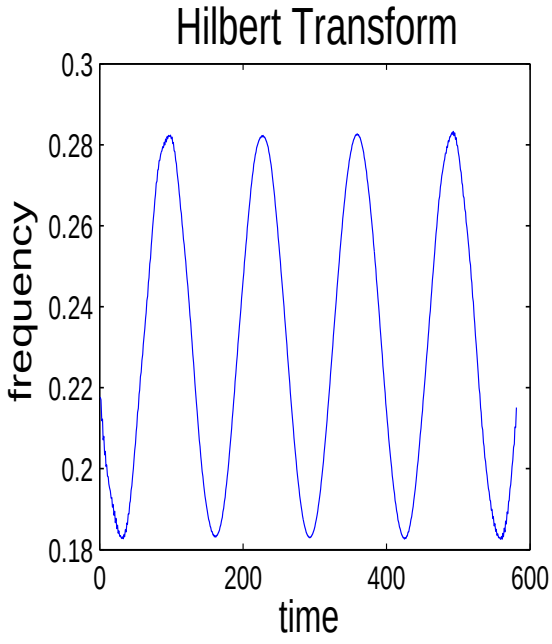


A Hilbert Transform of the second IMF is a straight line at the frequency .1. $\rightarrow \cos(.1t)$

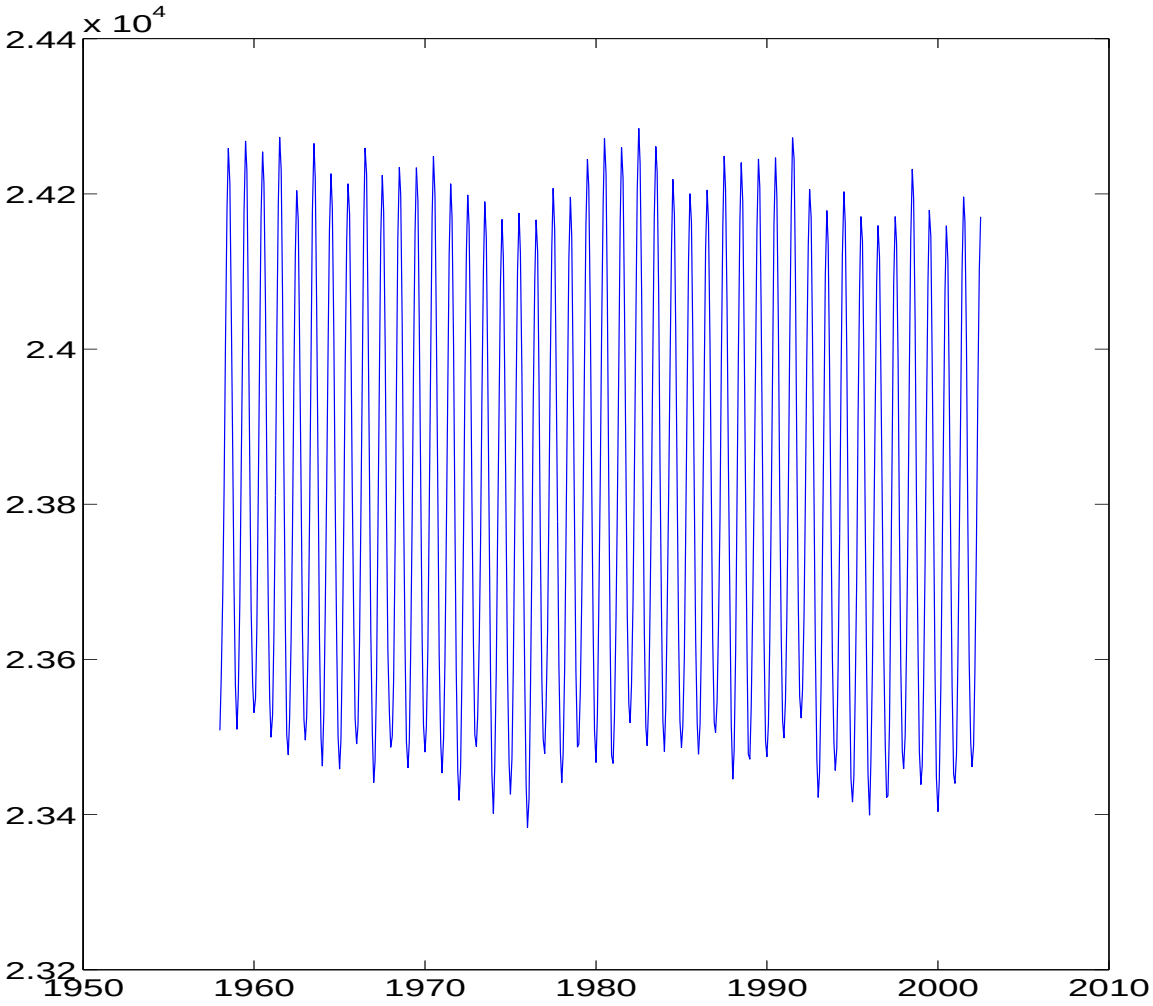
$$\rightarrow \cos(.23t + .7\sin(.23t)) + cos(.1t)$$

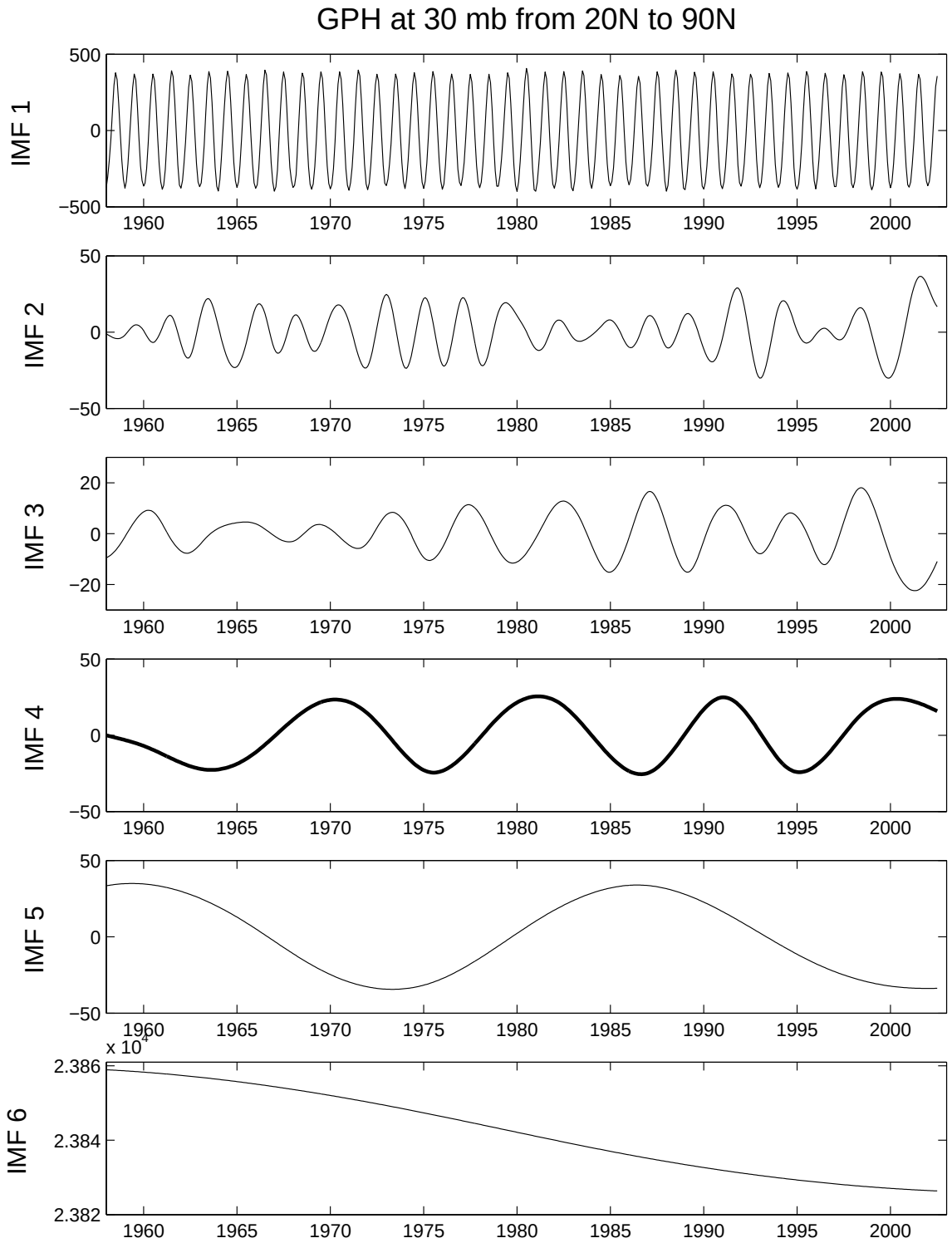

Stokes Wave = cos [2pi t/27 + pi/3 sin(2pit/132)]
1
0.5
0
−0.5
−1
0
100
200
300
400
500
600

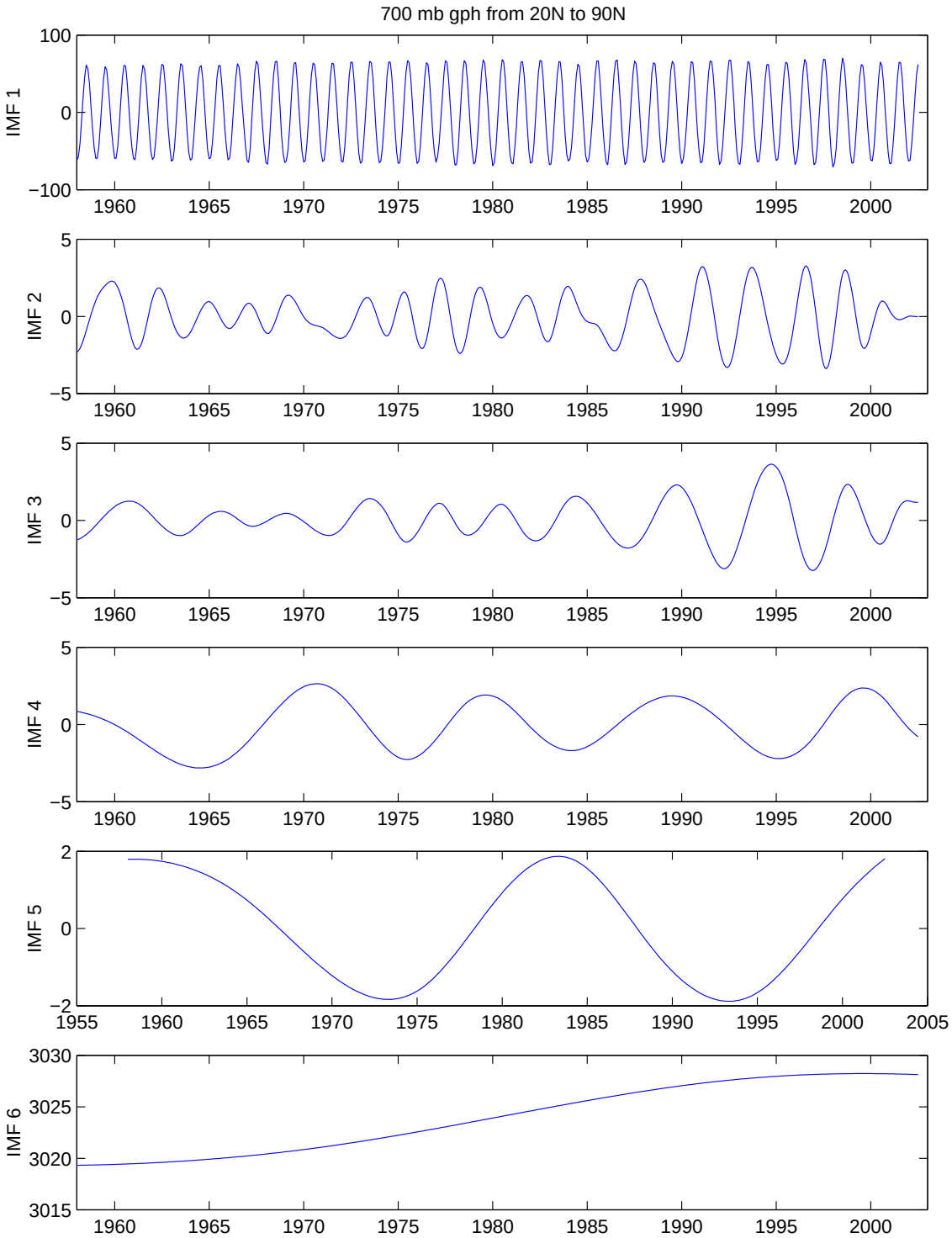

Fourier Transform
amplitude
150
100
50
0
10
20
30
40
50
period


Hilbert Transform
frequency
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0
200
400
600
time

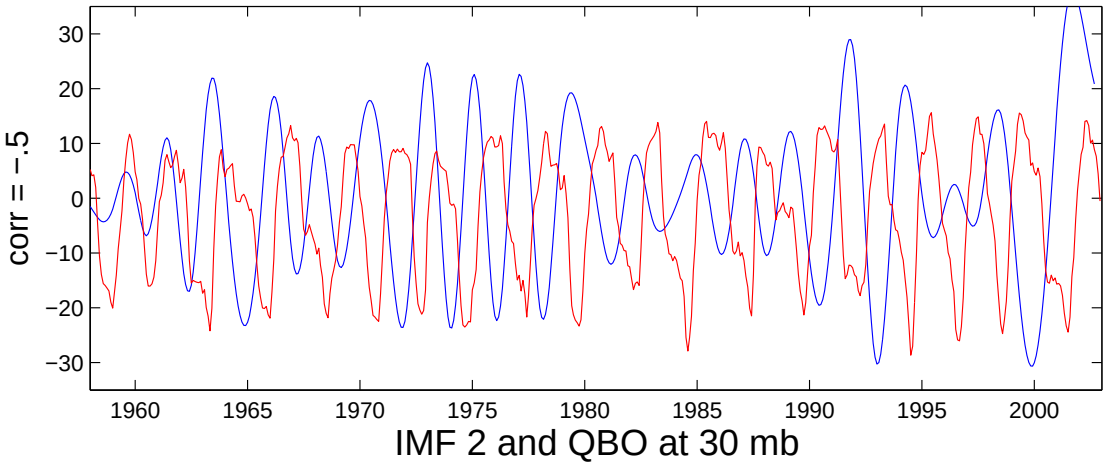
GPH at
30 mb spatially averaged from 20N to 90N



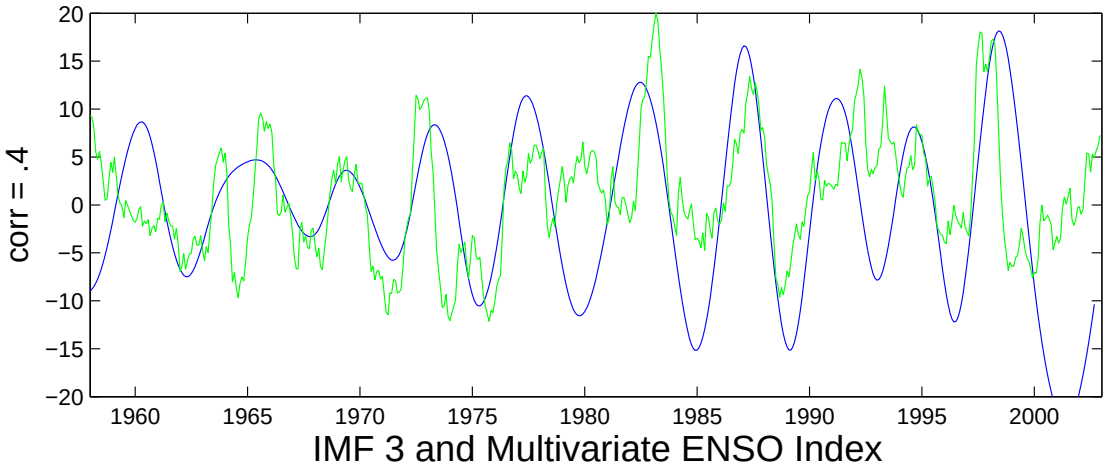

GPH at 30 mb from 20N to 90N
IMF 1
500
0
−500
IMF 2
50
0
−50
IMF 3
20
0
−20
IMF 4
50
0
−50
IMF 5
50
0
−50
IMF 6
x 10^4
2.386
2.384
2.382
1960
1965
1970
1975
1980
1985
1990
1995
2000


700 mb gph from 20N to 90N
IMF 1
100
0
−100
IMF 2
5
0
−5
IMF 3
5
0
−5
IMF 4
5
0
−5
IMF 5
2
0
−2
IMF 6
3030
3025
3020
3015
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

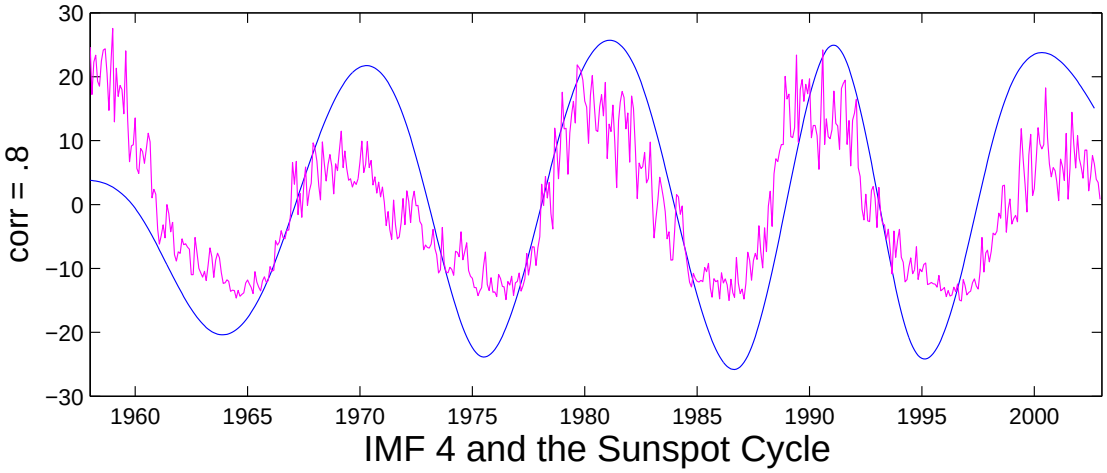
IMFs Correlated with Physical Phenomenon



IMF 2 and QBO at 30 mb

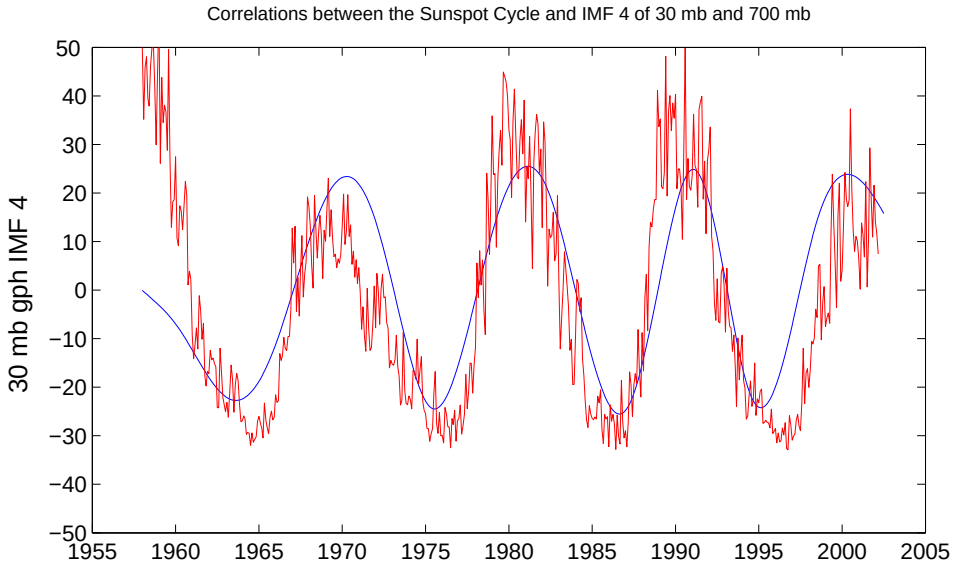


IMF 3 and Multivariate ENSO Index

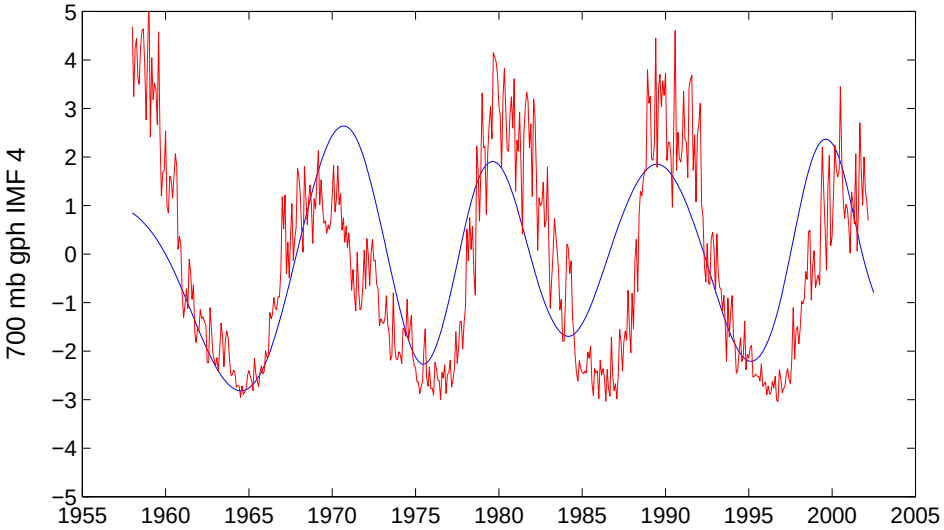


IMF 4 and the Sunspot Cycle

Correlation with the Solar Cycle



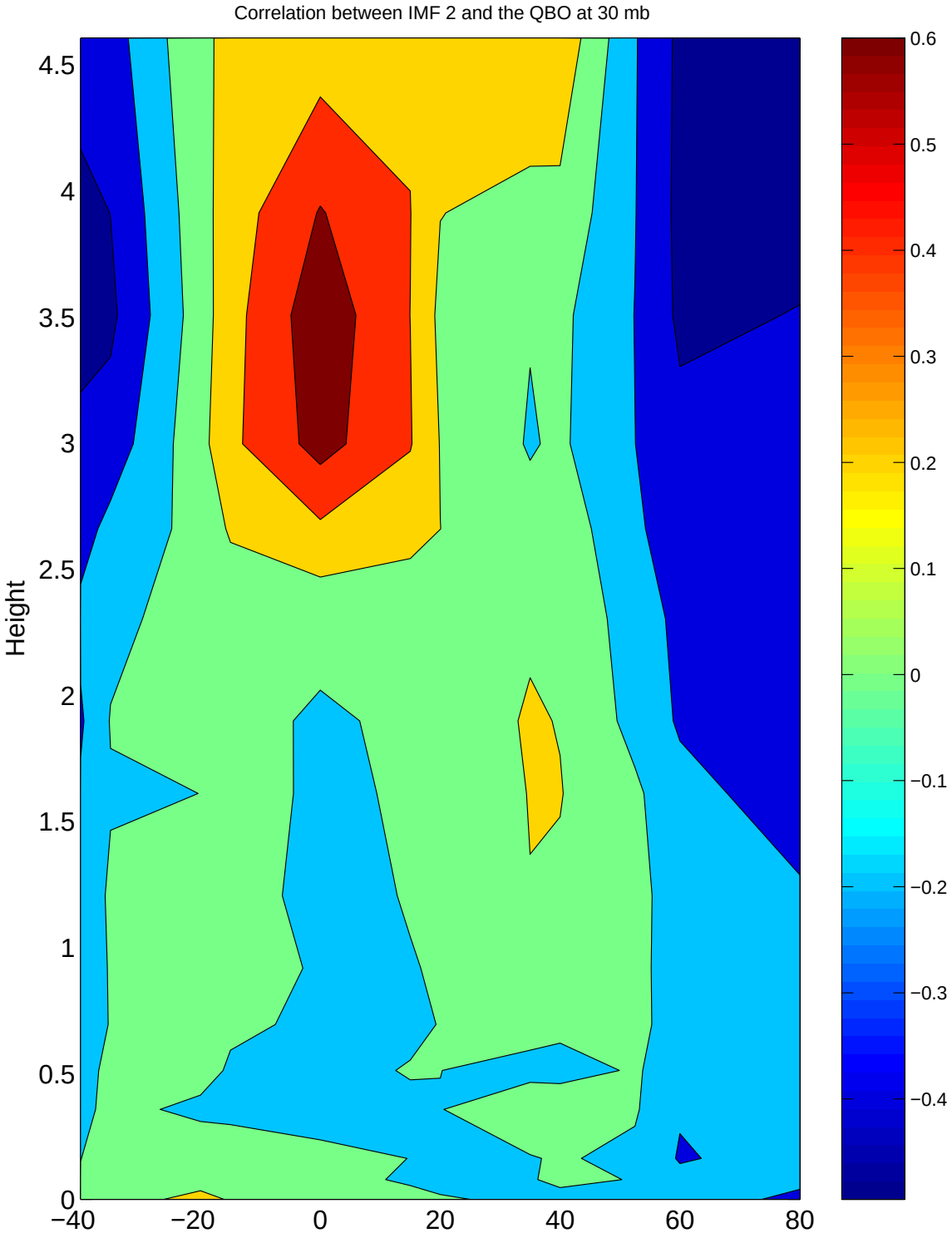
correlation coefficient = .72

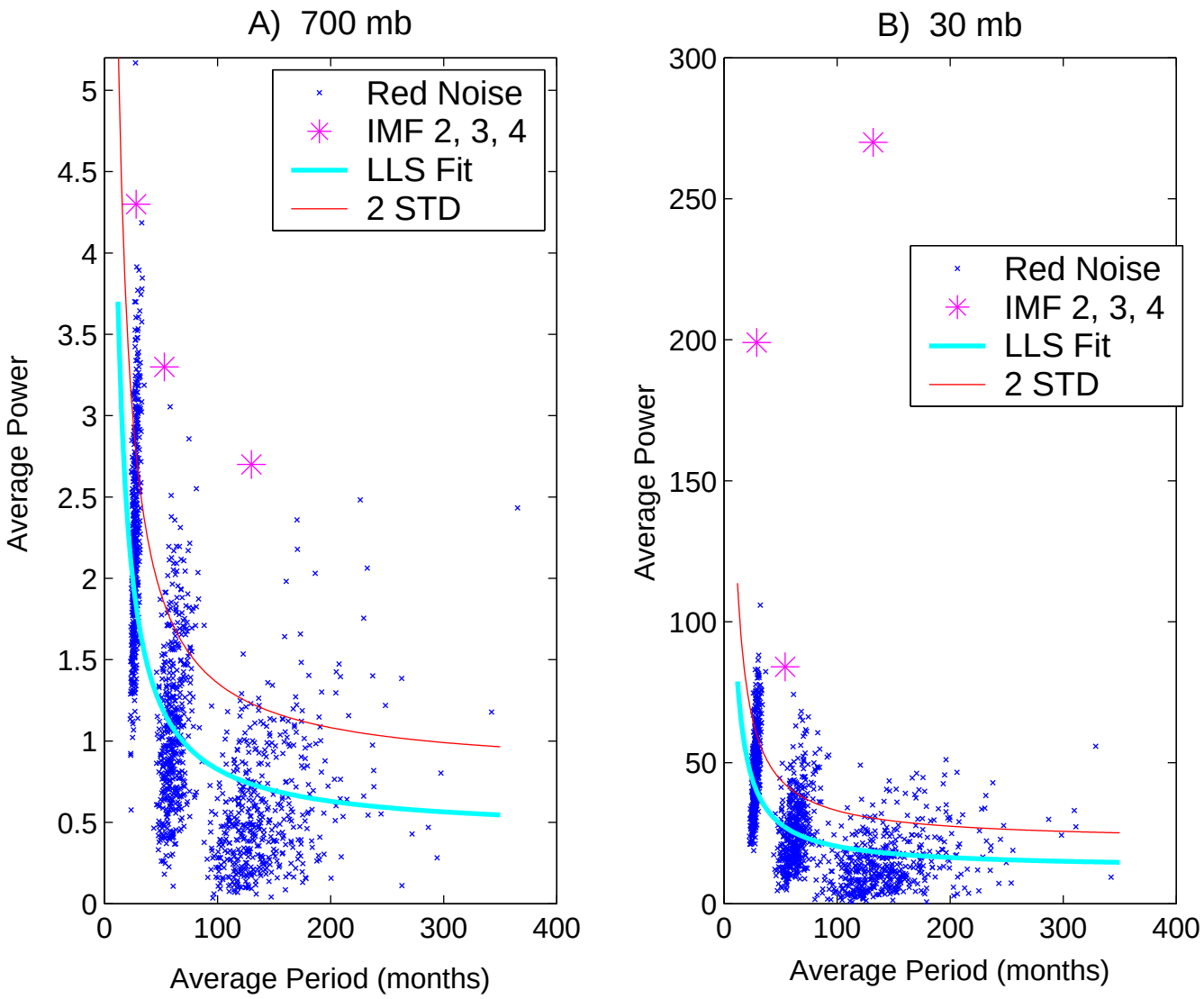


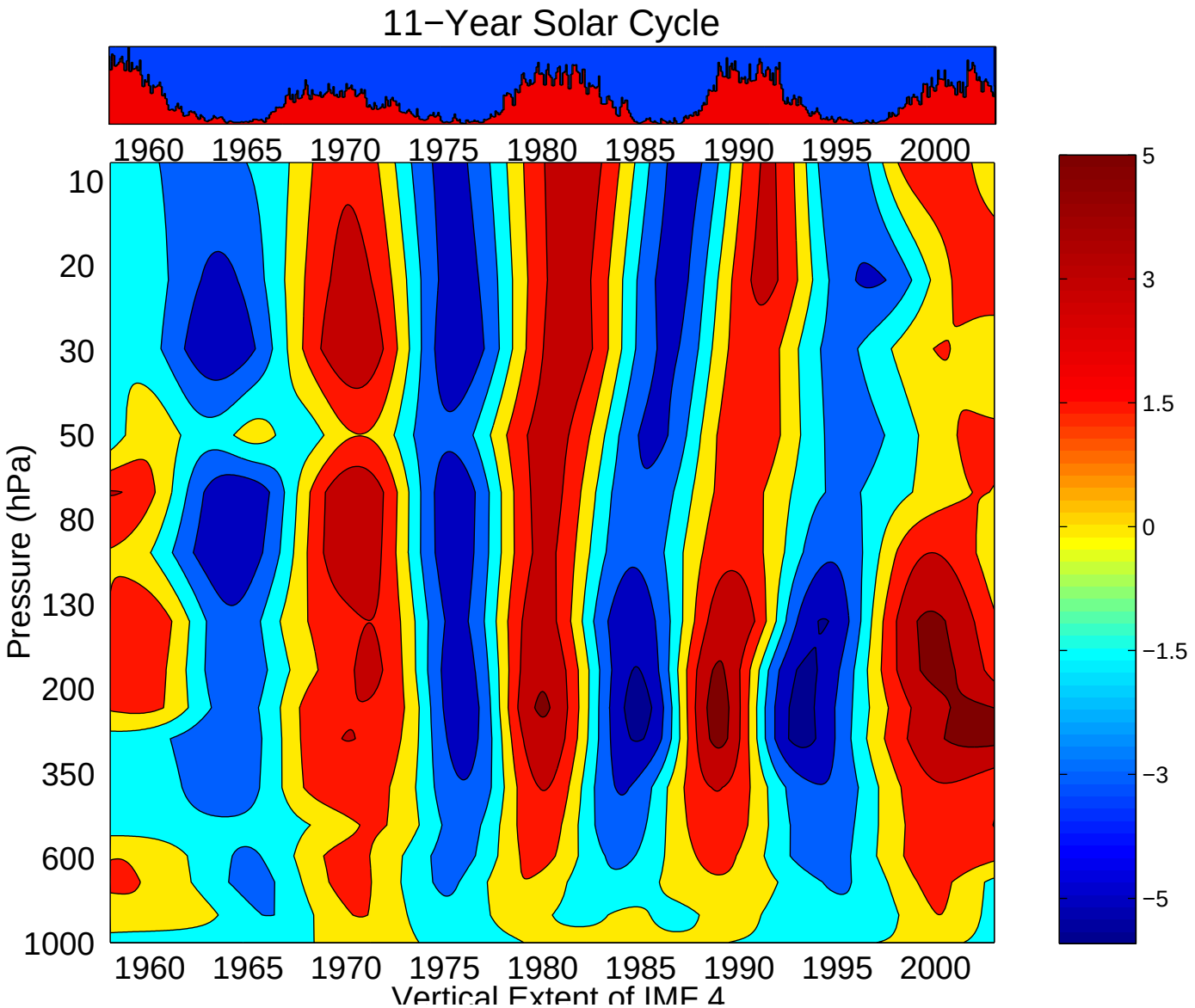
correlation coefficient = .65

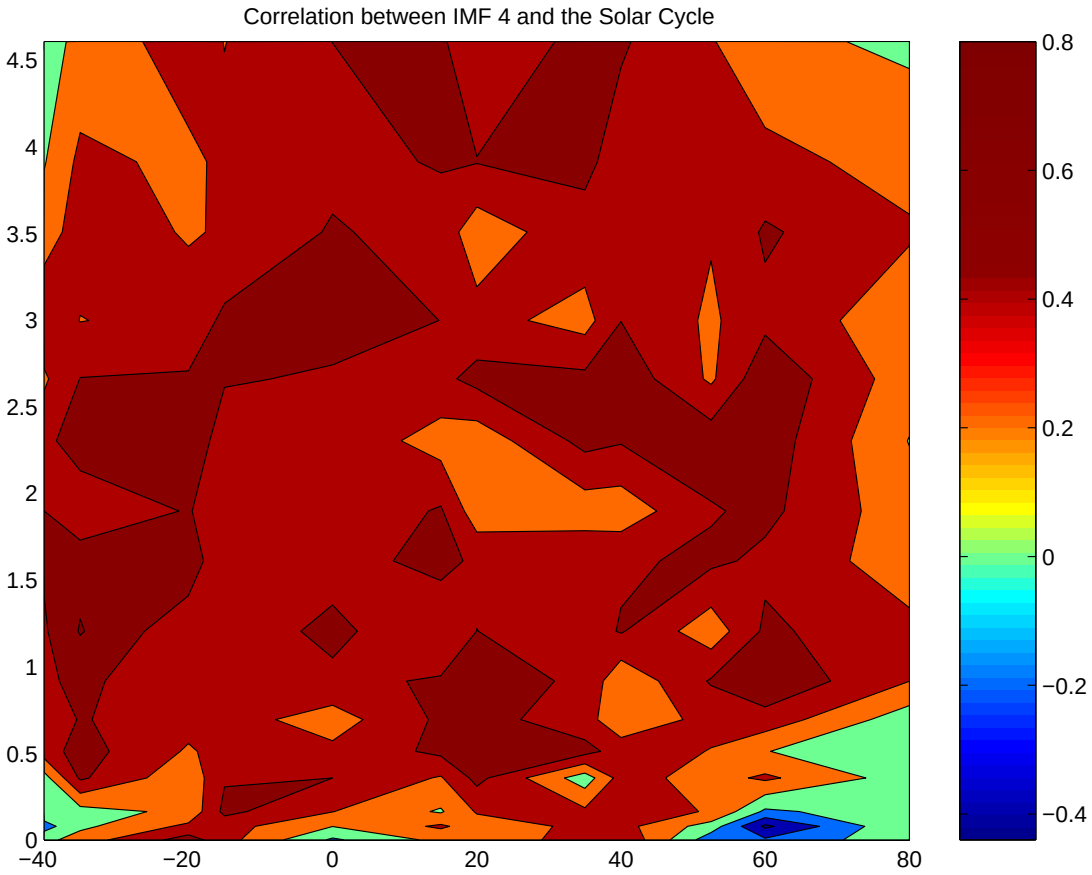
Significant Correlation is .70 for 30 mb and .58 for 700 mb.

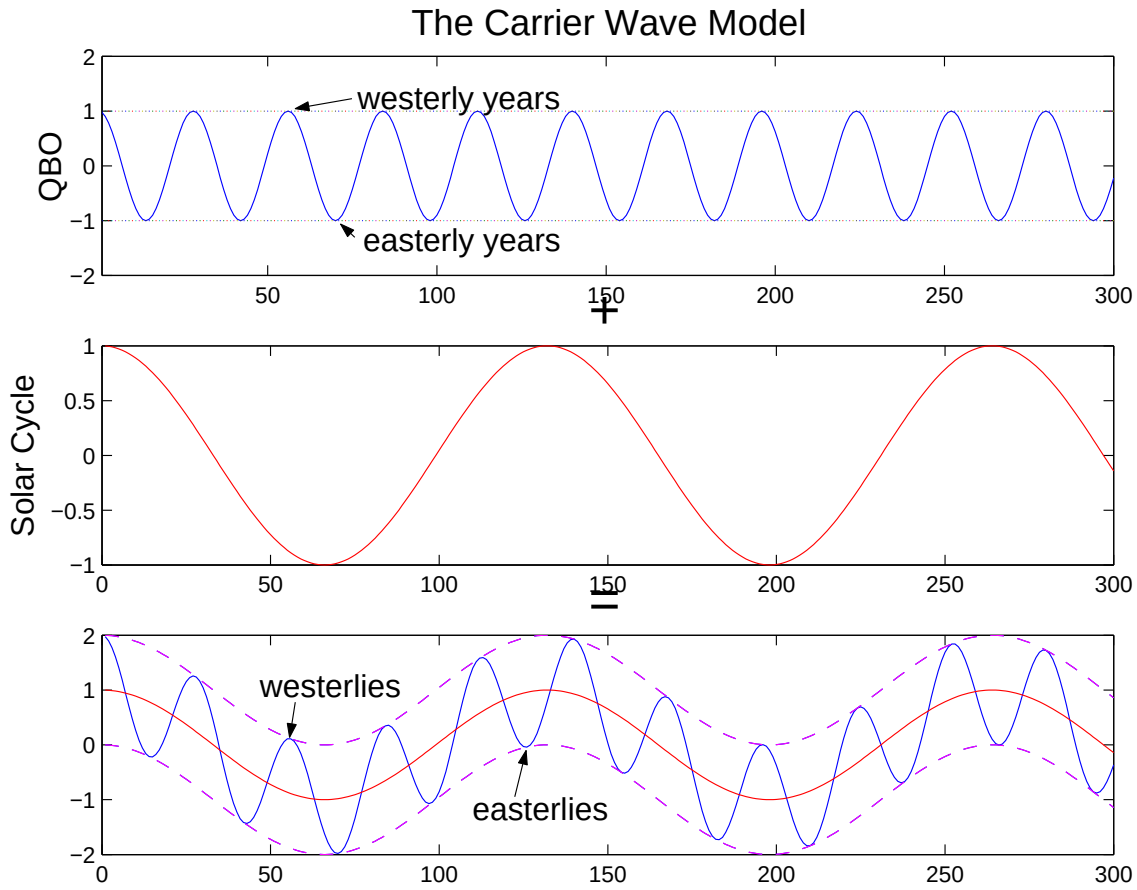
Significance assumes that the mode has only 7 dof.


Correlation between IMF 2 and the QBO at 30 mb
Height
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
−40
−20
0
20
40
60
80
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4


A) 700 mb
Red Noise
IMF 2, 3, 4
LLS Fit
2 STD
Average Power
Average Period (months)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
100
200
300
400
B) 30 mb
Red Noise
IMF 2, 3, 4
LLS Fit
2 STD
Average Power
Average Period (months)
0
50
100
150
200
250
300
0
100
200
300
400

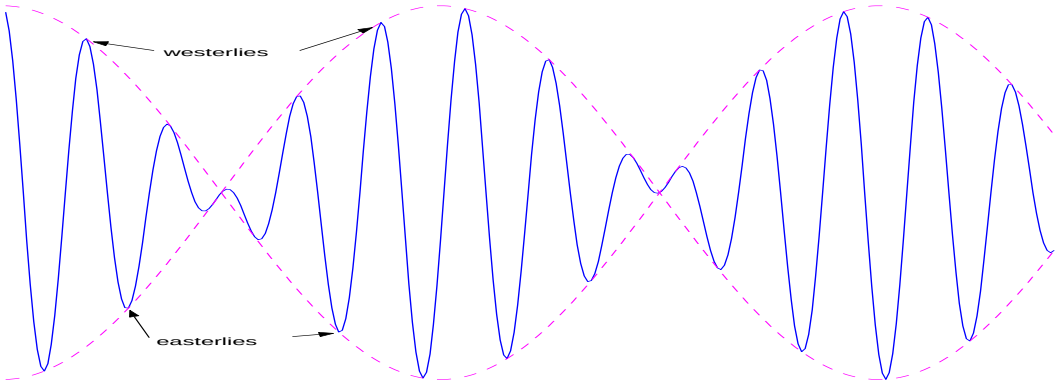

11−Year Solar Cycle
1960
1965
1970
1975
1980
1985
1990
1995
2000
Pressure (hPa)
10
20
30
50
80
130
200
350
600
1000
5
3
1.5
0
−1.5
−3
−5
Vertical Extent of IMF 4


Correlation between IMF 4 and the Solar Cycle
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
−40
−20
0
20
40
60
80
0.8
0.6
0.4
0.2
0
−0.2
−0.4



Envelopes positively correlate with solar cycle for both easterly and westerly years, contrary to LvL, But more consistent with our understanding of dynamics.

A Model of QBO Amplitude-Modulated by the Solar Cycle



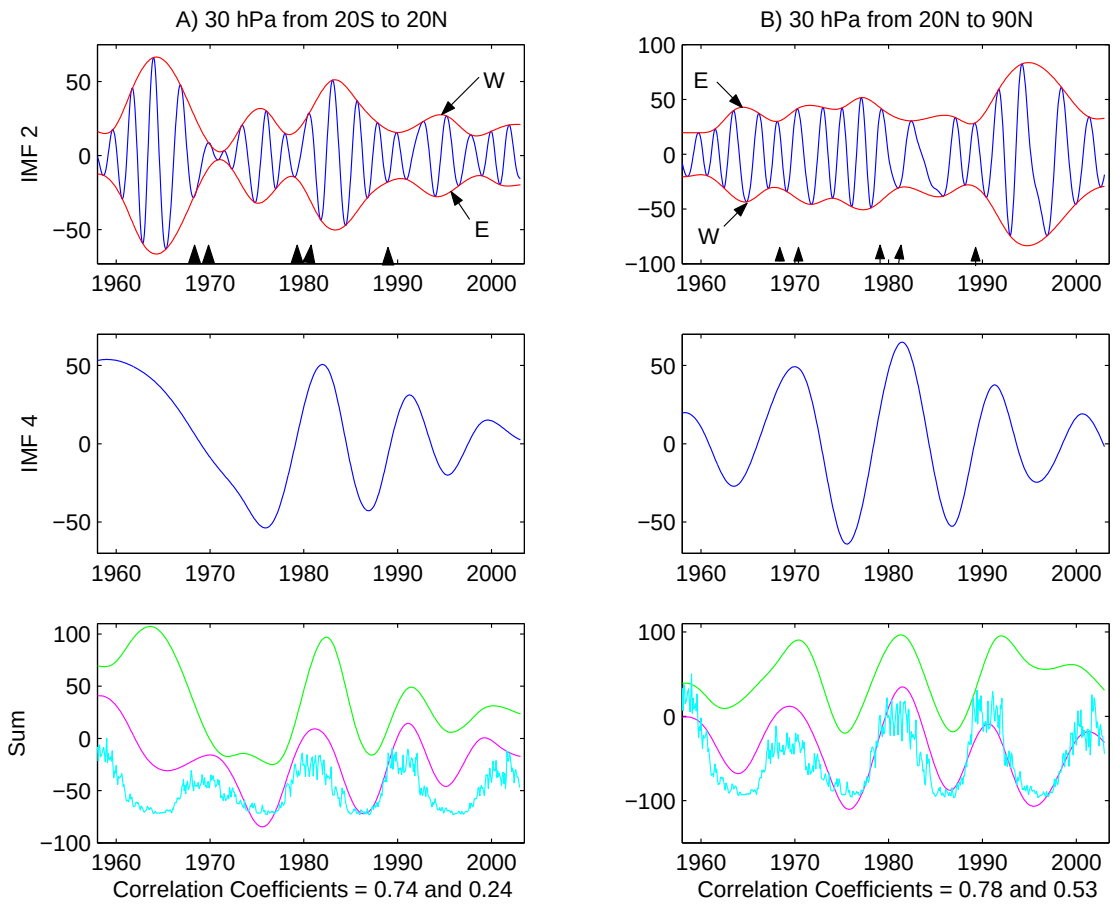
In the Tropics:

- Easterly years positively correlated with the solar cycle
- Westerly years negatively correlated with the solar cycle

Poleward of 50°N :

- Easterly years negatively correlated with the solar cycle
- Westerly years positively correlated with the solar cycle

Explains results of Labitzke and van Loon, but contrary to our understanding of dynamics.



Effect of stratifying the data:

Westerly years:

tropics not significantly correlated
positively correlated with solar cycle in extratropics

Easterly years:

positive correlation in the tropics
not correlated in the extratropics

Solar cycle $\rightarrow$ GPH signal in the lower atmosphere positively correlated with 10.7 cm solar flux EVERYWHERE!

Not related to the QBO!

Not in the AO index.

SUMMARY

• Null Hypothesis:
statistical evidence firmly established for *surface* manifestation of phenomena of *stratospheric* origin:

1. QBO found in AO index in 150 years of sea-level data. *Coughlin and Tung; 2001*
2. Solar Cycle found throughout the lower atmosphere in 44 years of NCEP data. *Coughlin and Tung; 2003*

• How is the QBO transmitted from the stratosphere to the troposphere? via NAM.

• How is the solar cycle transmitted from the stratosphere to the troposphere?
? solar cycle transmitted through QBO ciculation? Labitzke and van Loon ... X
? via NAM? X

• Further speculations ... please keep it simple!

Work joint with Katie Coughlin at the University of Washington.

Publications and Manuscripts:
http://amath.washington.edu