Hydrogeology Journal – Electronic Supplementary Material

Comparison of GRACE data and groundwater levels for the assessment of groundwater depletion in Jordan

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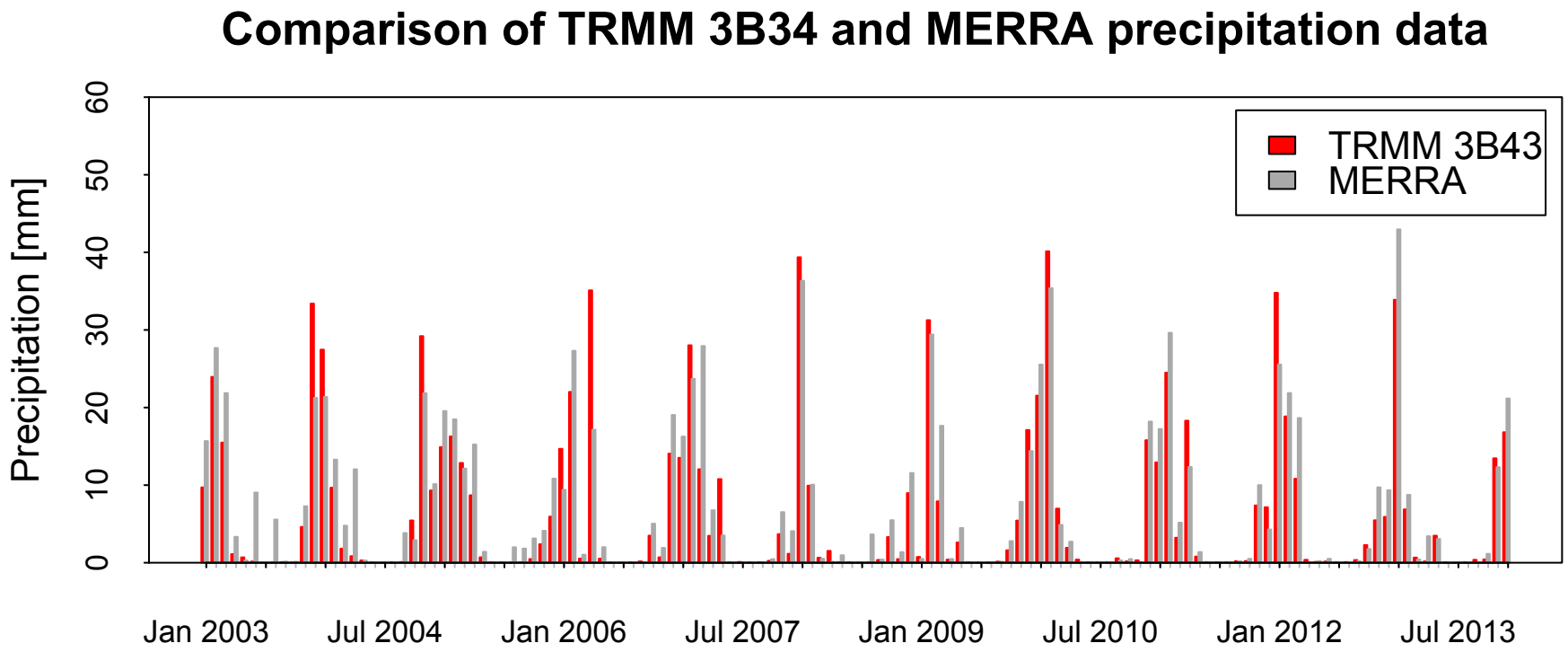
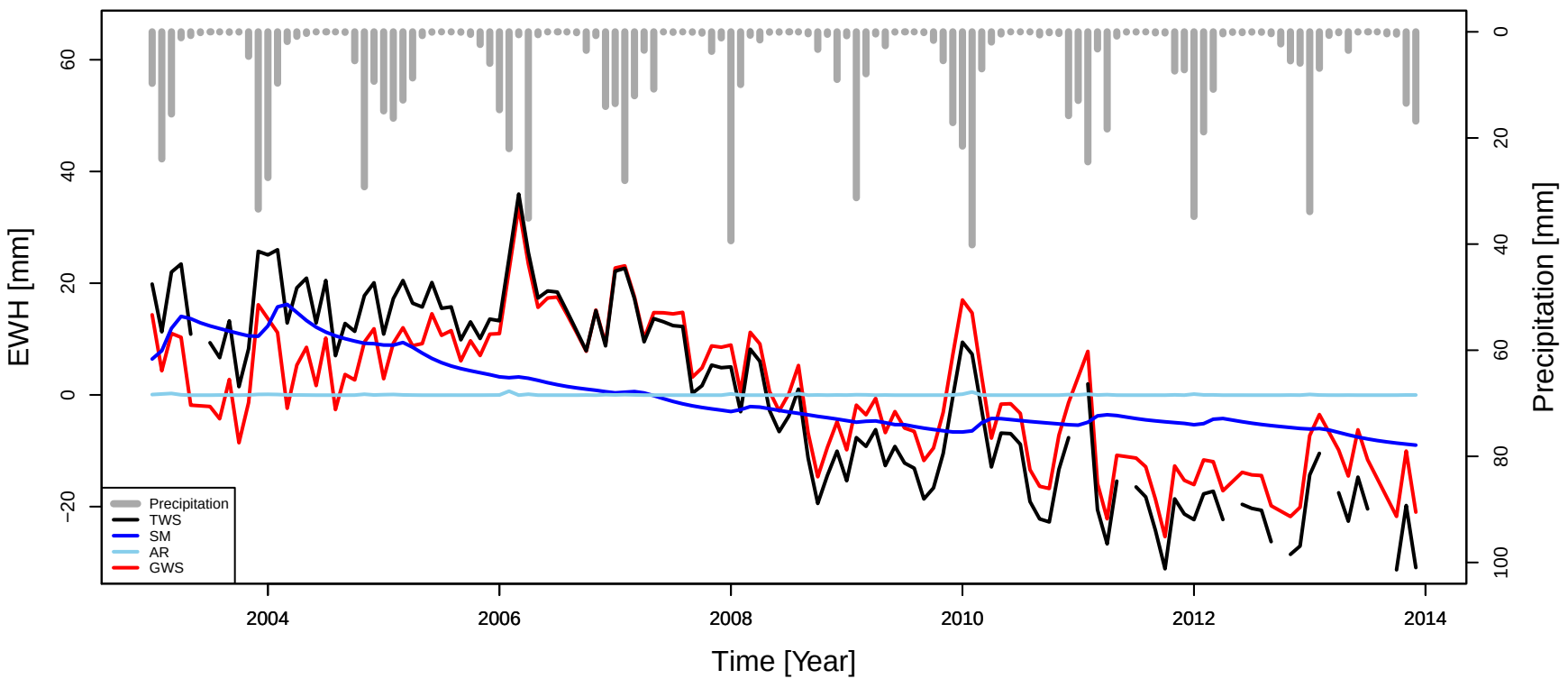
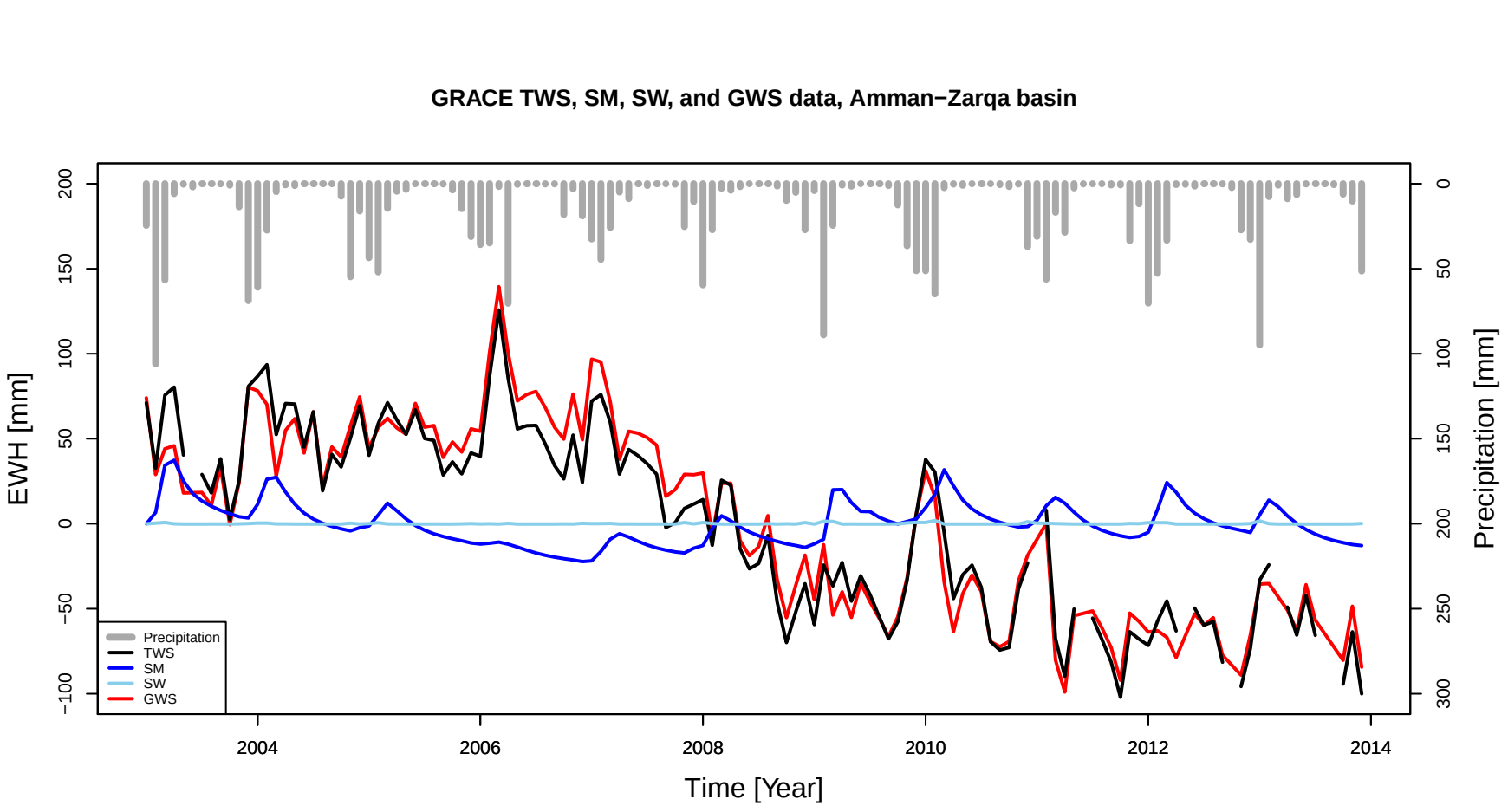

Comparison of TRMM 3B34 and MERRA precipitation data
Precipitation [mm]
0
10
20
30
40
50
60
Jan 2003
Jul 2004
Jan 2006
Jul 2007
Jan 2009
Jul 2010
Jan 2012
Jul 2013
TRMM 3B43
MERRA

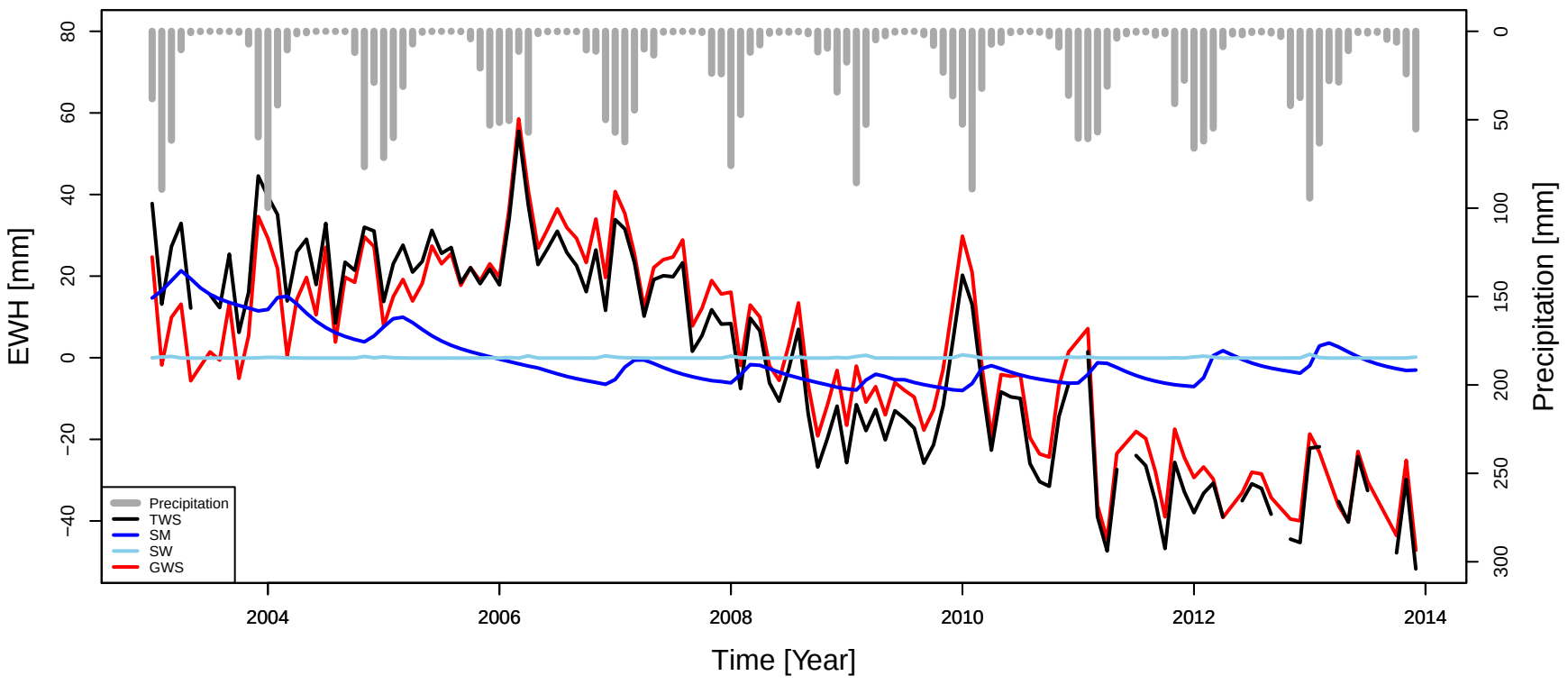
GRACE TWS, SM, AR, and GWS data, Azraq basin



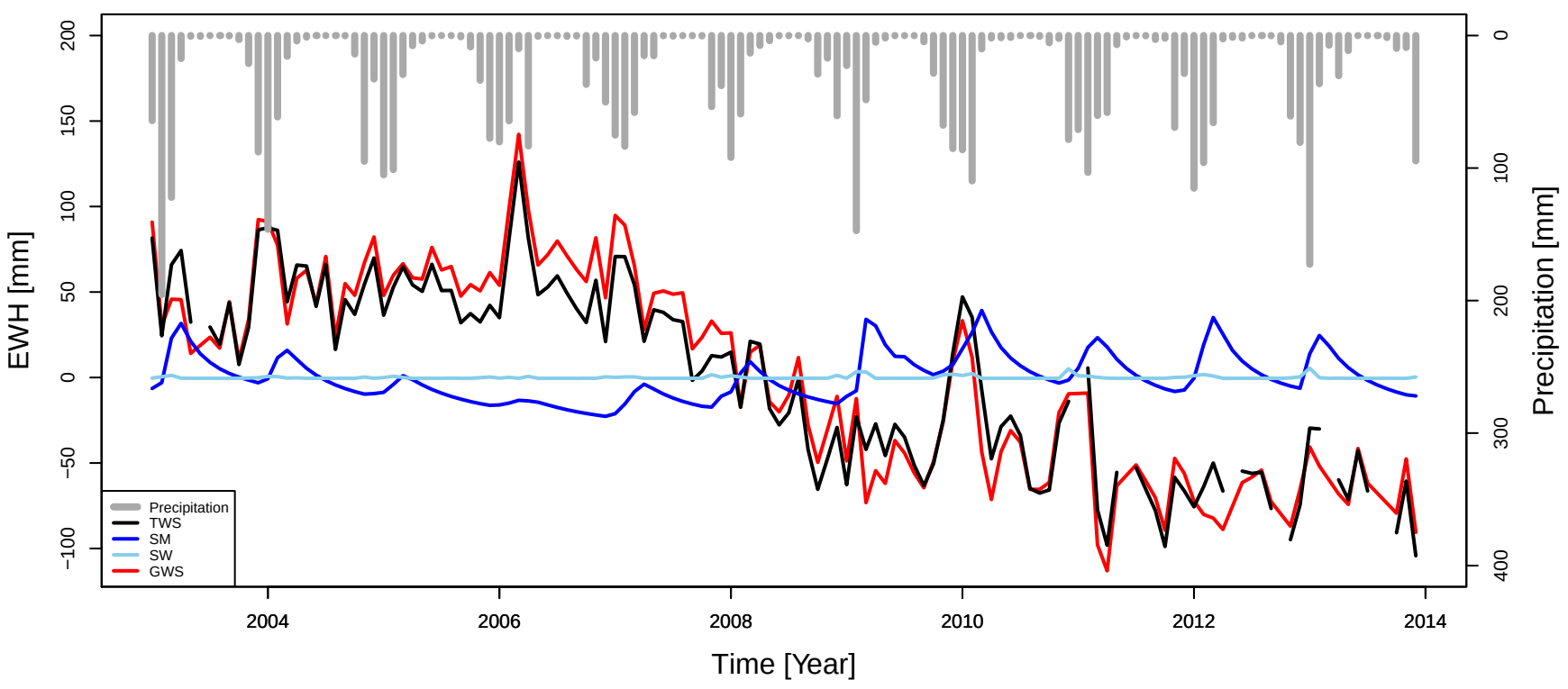
GRACE TWS, SM, SW, and GWS data, Amman−Zarqa basin



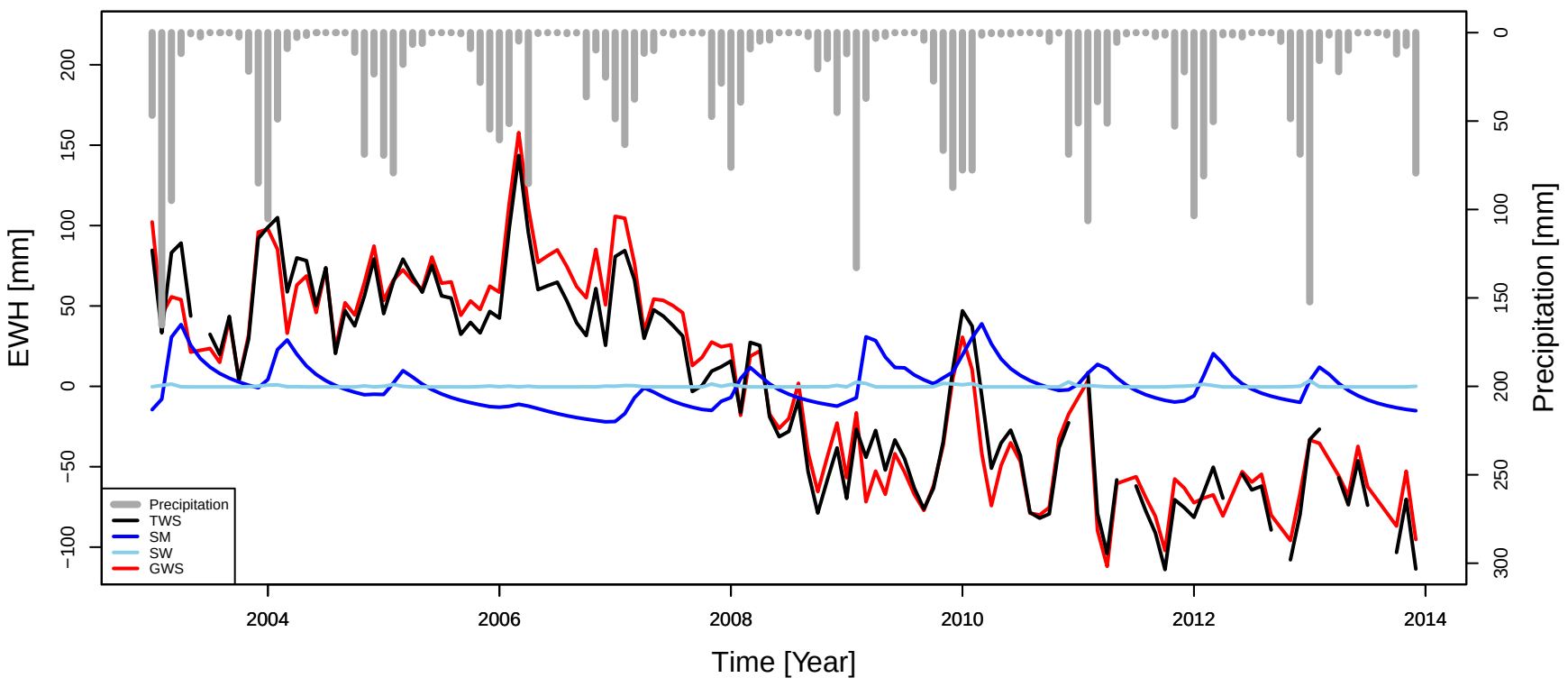
GRACE TWS, SM, SW, and GWS data, Dead Sea basin

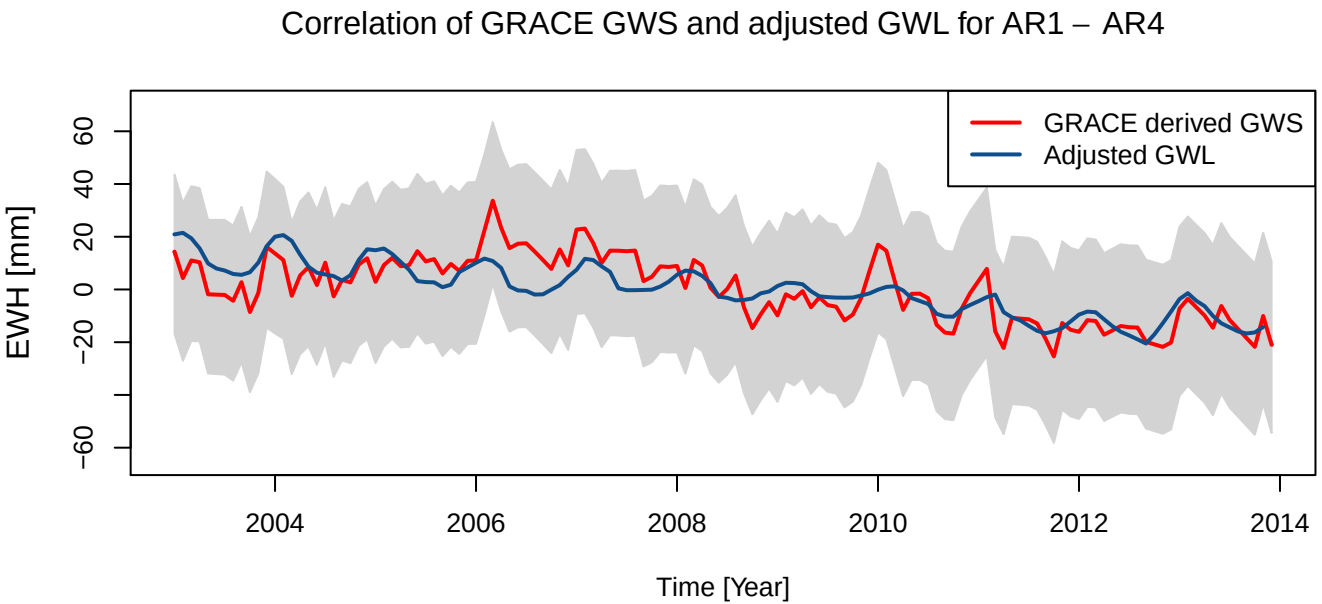


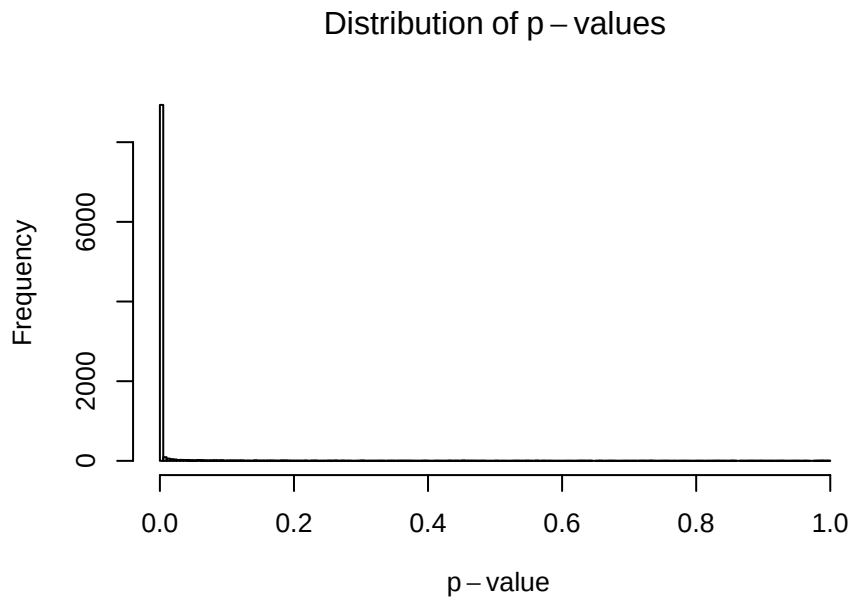
GRACE TWS, SM, SW, and GWS data, Side Wadis basin

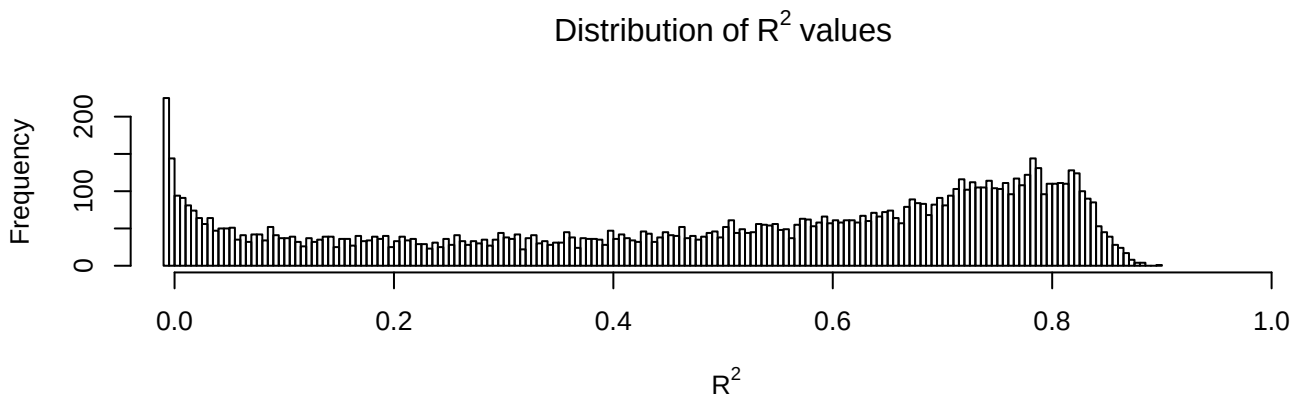


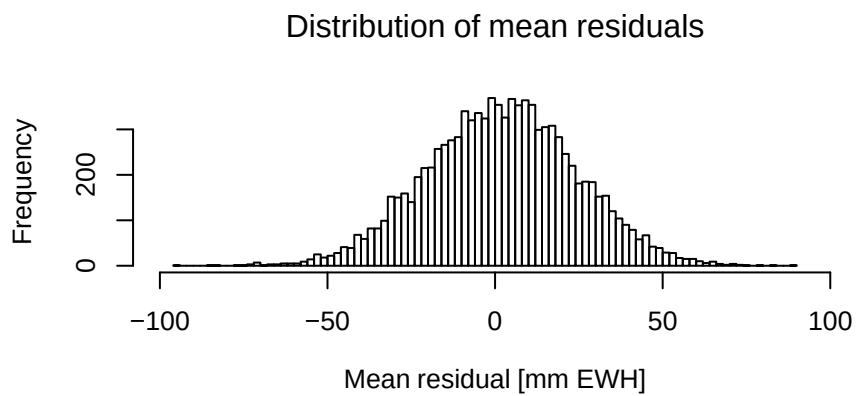
GRACE TWS, SM, SW, and GWS data, Yarmouk basin

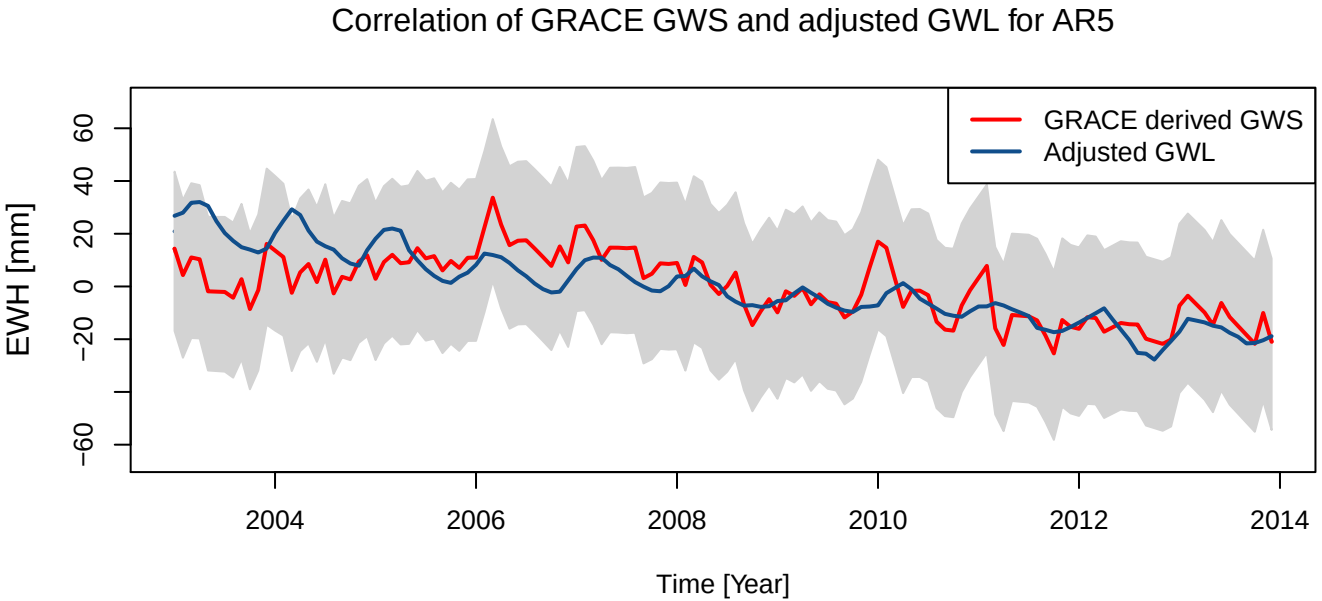


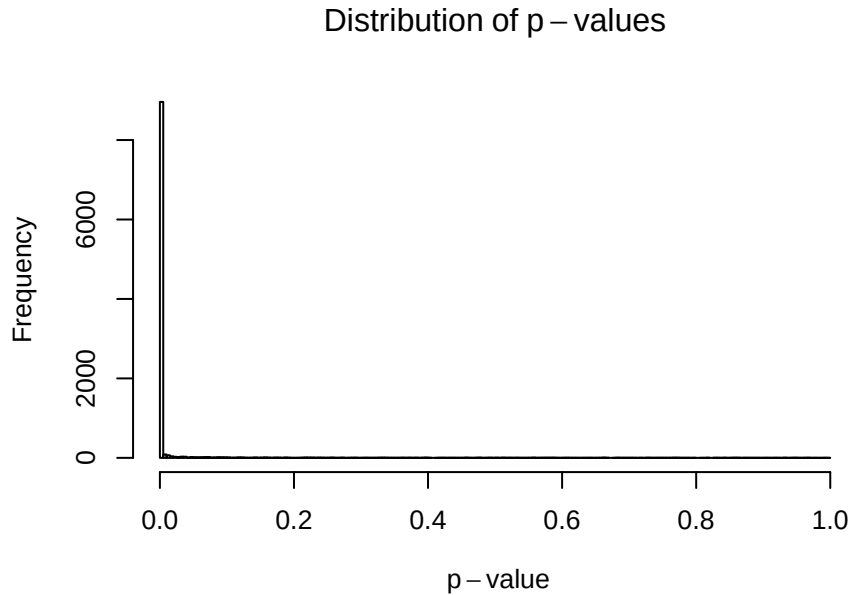

Correlation of GRACE GWS and adjusted GWL for AR1 – AR4
GRACE derived GWS
Adjusted GWL
EWH [mm]
60
40
20
0
−20
−60
2004
2006
2008
2010
2012
2014
Time [Year]

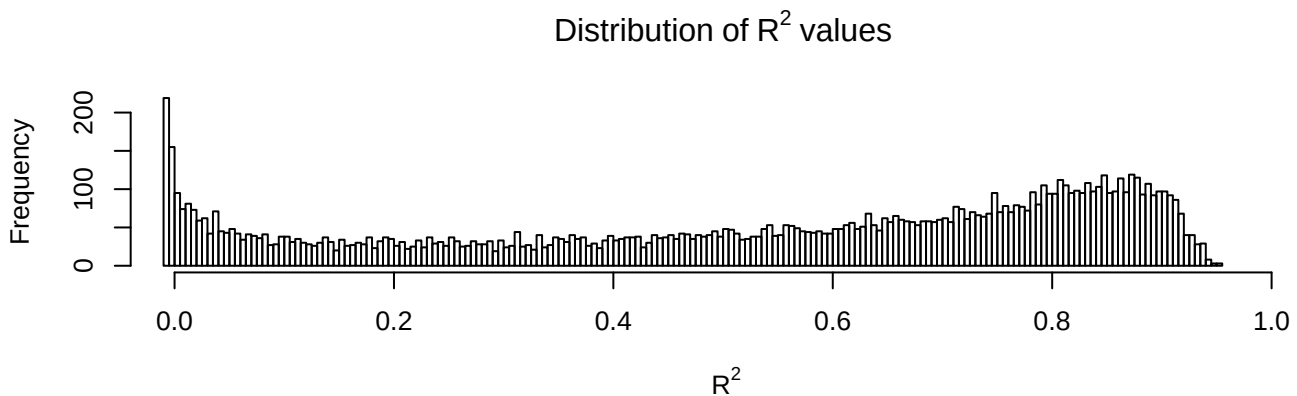

Distribution of p – values
Frequency
6000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value

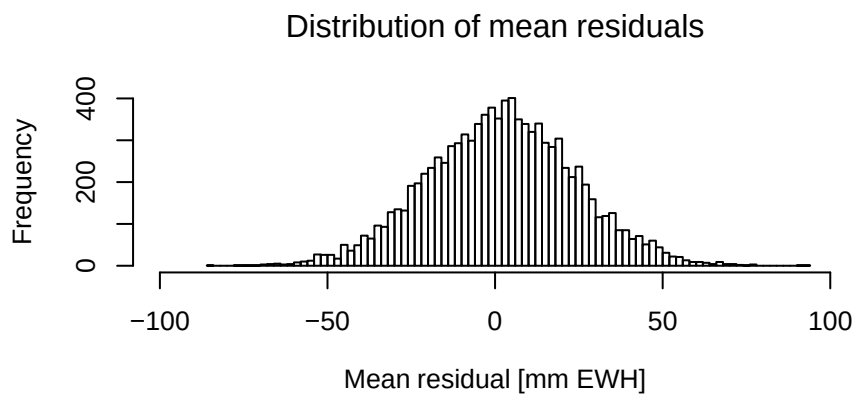

Distribution of R2 values
Frequency
200
100
0
0.0
0.2
0.4
0.6
0.8
1.0
R2

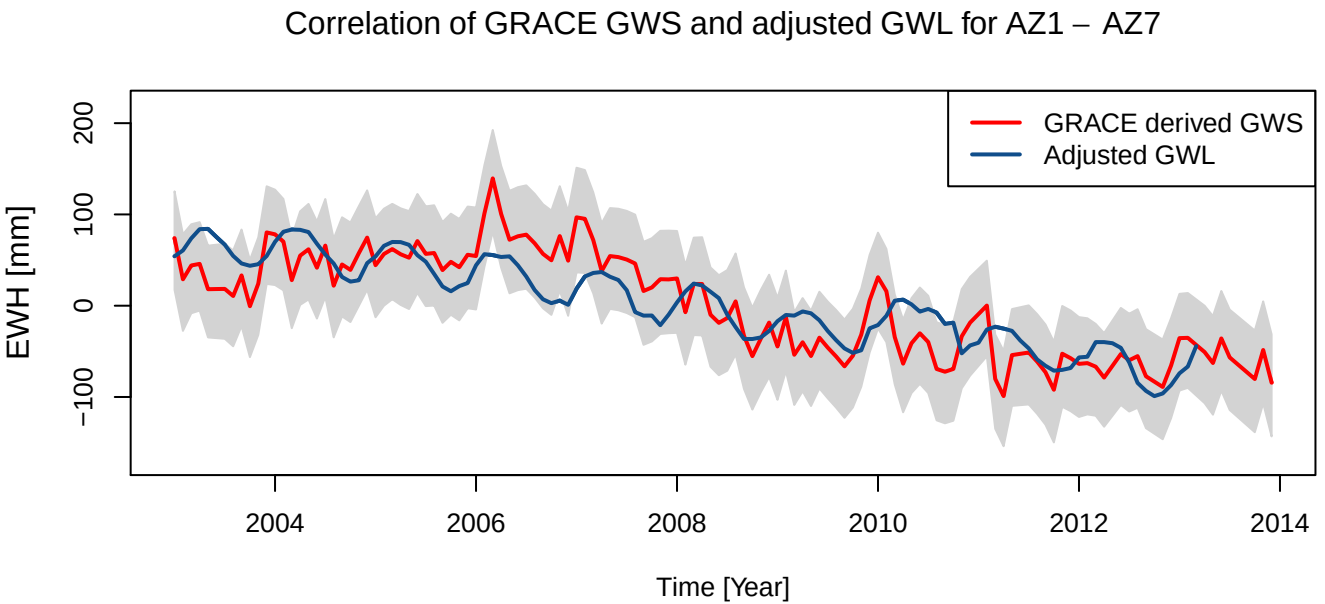

Distribution of mean residuals
Frequency
200
0
−100
−50
0
50
100
Mean residual [mm EWH]

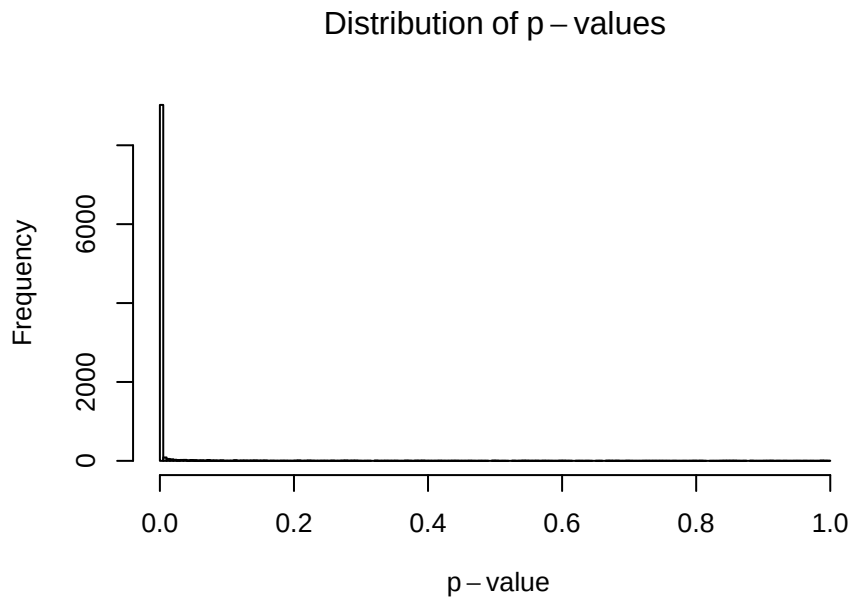

Correlation of GRACE GWS and adjusted GWL for AR5
GRACE derived GWS
Adjusted GWL
EWH [mm]
−60
−20
0
20
40
60
2004
2006
2008
2010
2012
2014
Time [Year]

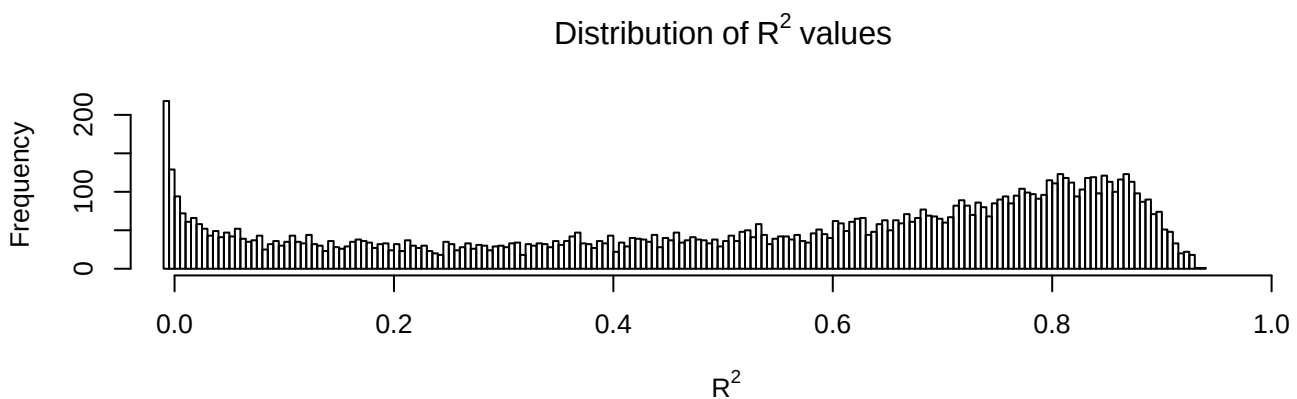

Distribution of p – values
Frequency
0
2000
6000
0.0
0.2
0.4
0.6
0.8
1.0
p – value

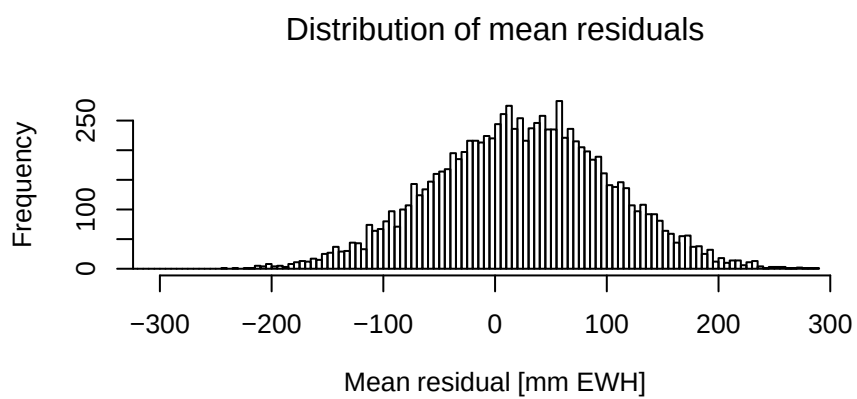

Distribution of R2 values
Frequency
0
100
200
0.0
0.2
0.4
0.6
0.8
1.0
R2

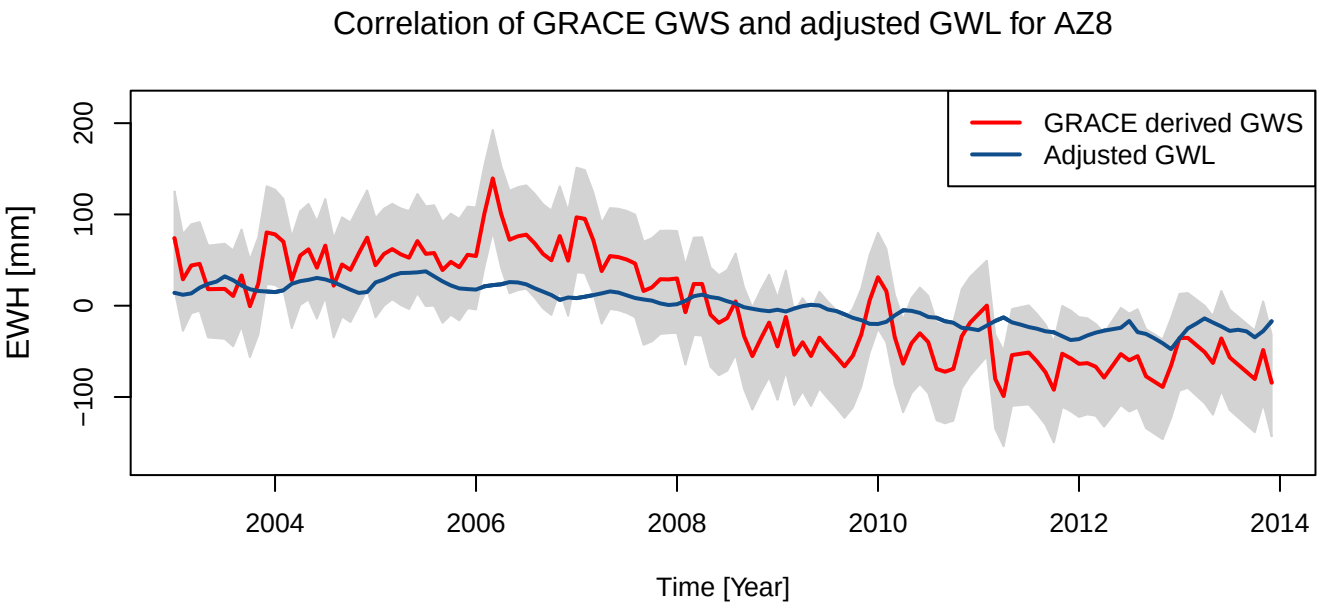

Distribution of mean residuals
Frequency
0
200
400
−100
−50
0
50
100
Mean residual [mm EWH]

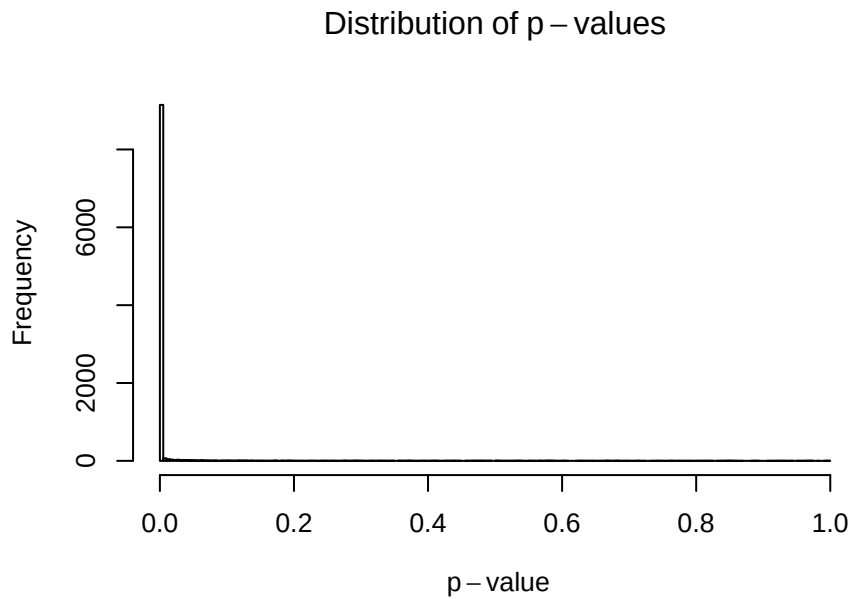

Correlation of GRACE GWS and adjusted GWL for AZ1 – AZ7
GRACE derived GWS
Adjusted GWL
EWH [mm]
200
100
0
−100
2004
2006
2008
2010
2012
2014
Time [Year]

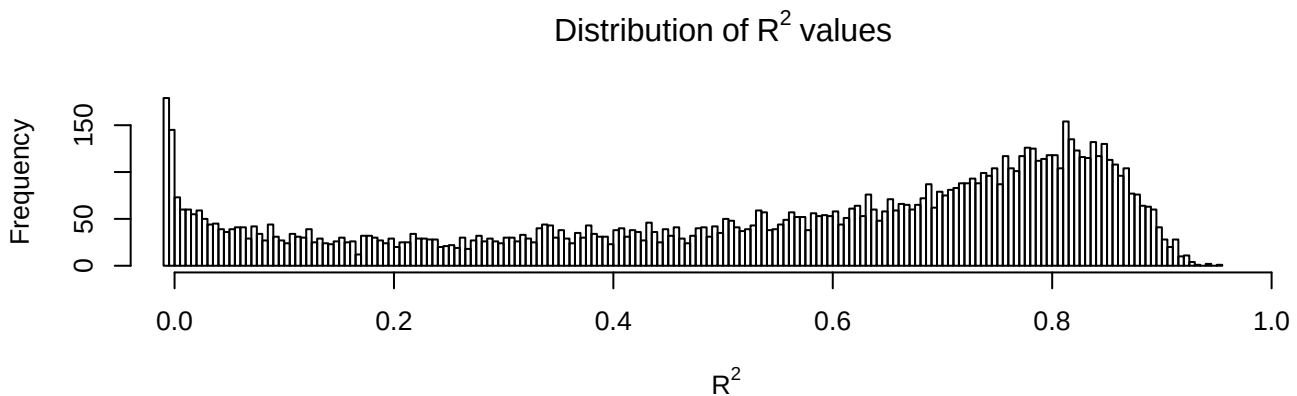

Distribution of p – values
Frequency
6000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value

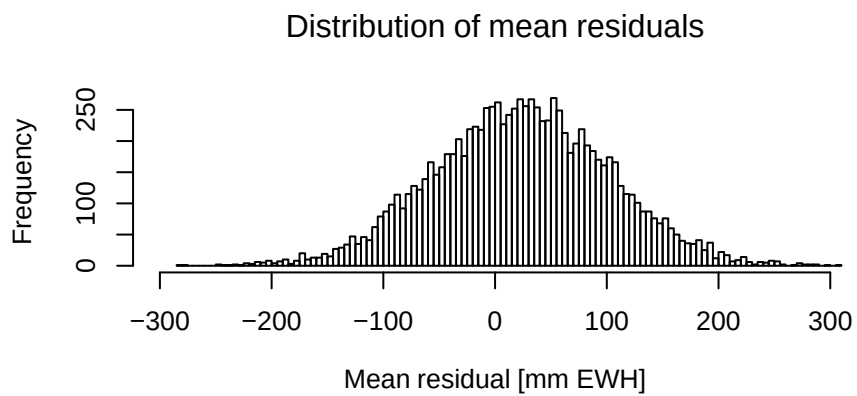

Distribution of R2 values
Frequency
200
100
0
0.0
0.2
0.4
0.6
0.8
1.0
R2

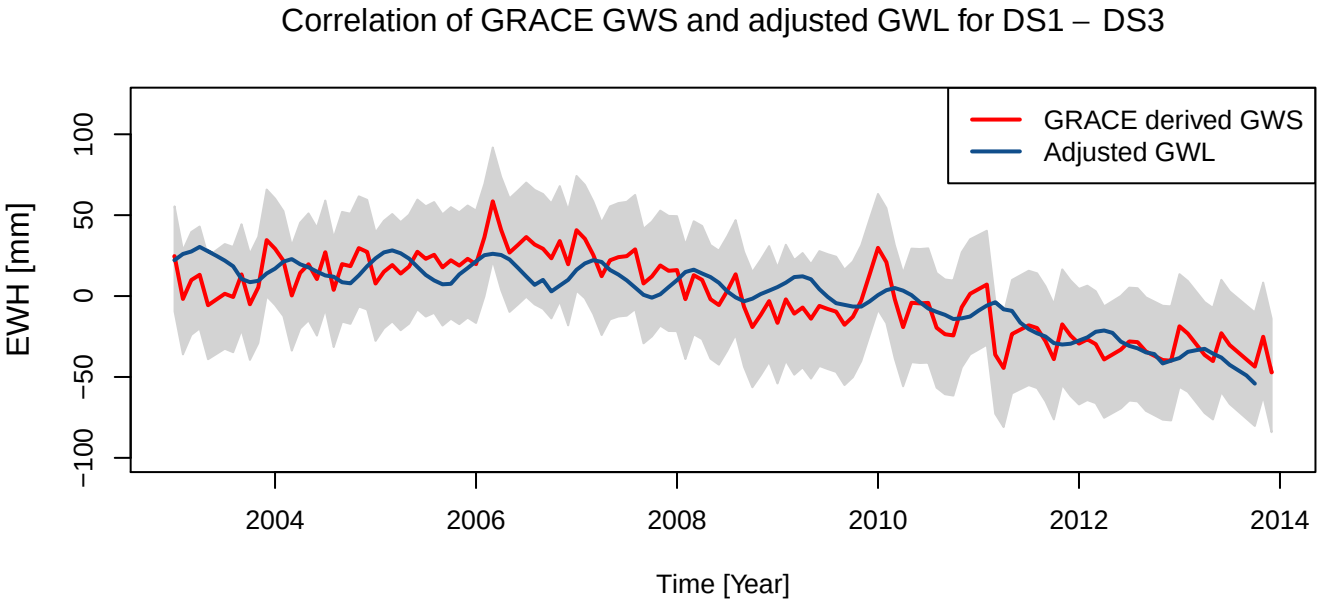

Distribution of mean residuals
Frequency
250
100
0
−300
−200
−100
0
100
200
300
Mean residual [mm EWH]

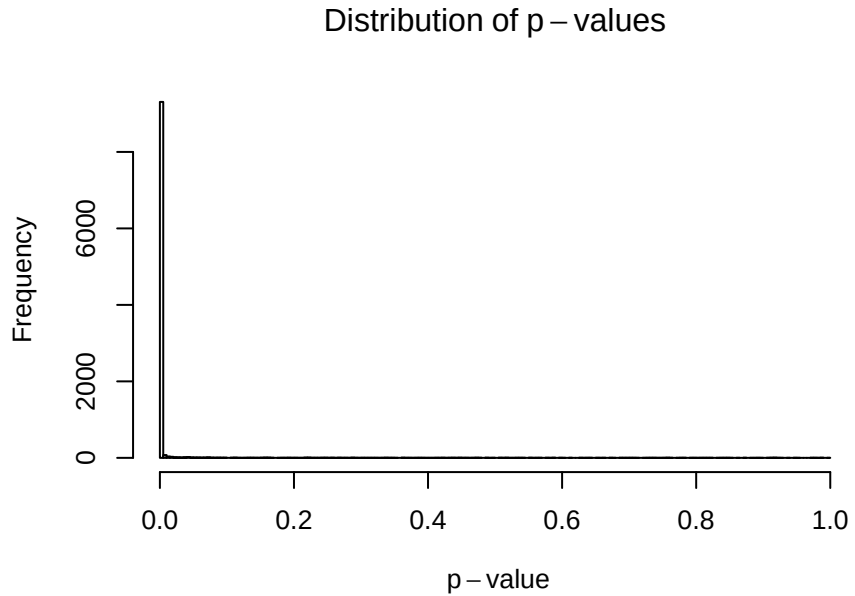

Correlation of GRACE GWS and adjusted GWL for AZ8
GRACE derived GWS
Adjusted GWL
EWH [mm]
200
100
0
−100
2004
2006
2008
2010
2012
2014
Time [Year]

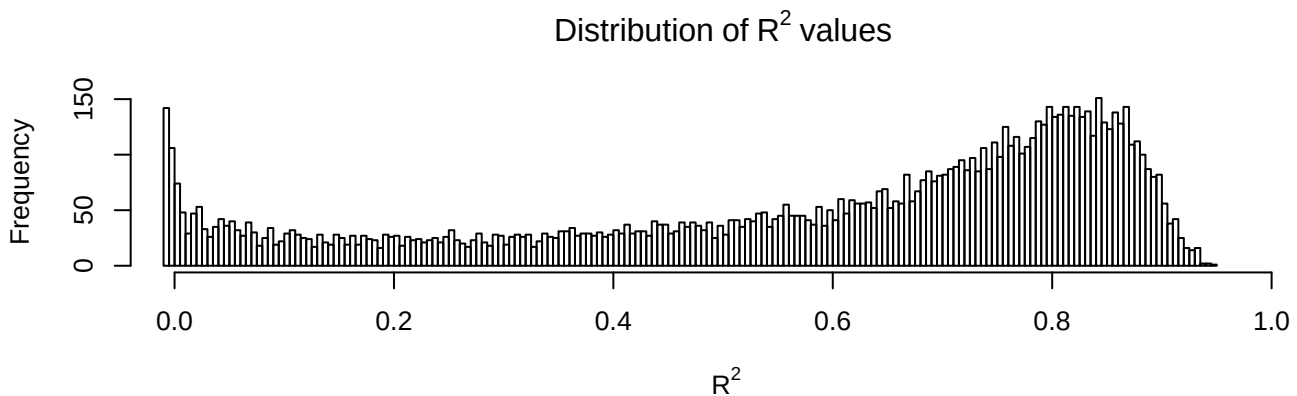

Distribution of p – values
Frequency
6000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value

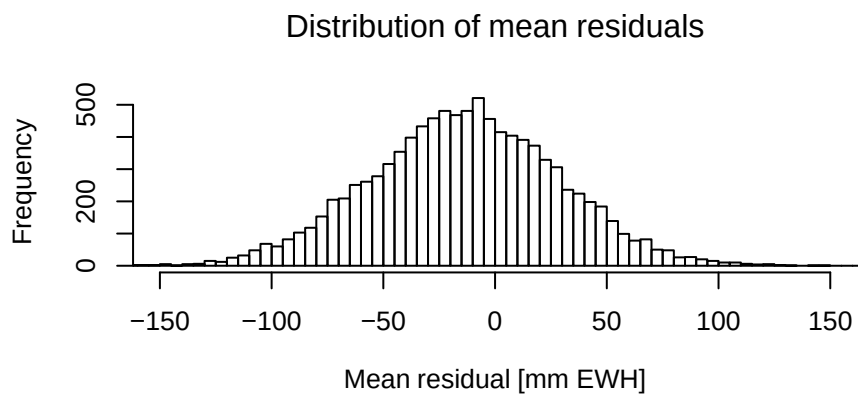

Distribution of R2 values
Frequency
150
50
0
0.0
0.2
0.4
0.6
0.8
1.0
R2

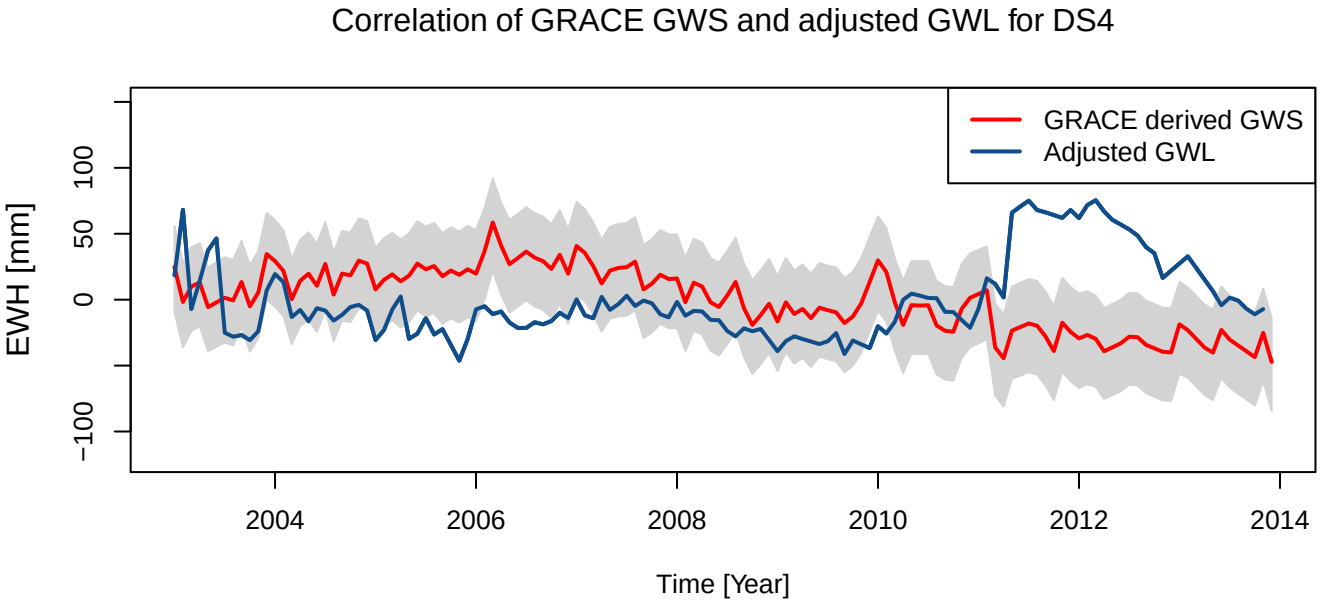

Distribution of mean residuals
Frequency
250
100
0
−300
−200
−100
0
100
200
300
Mean residual [mm EWH]

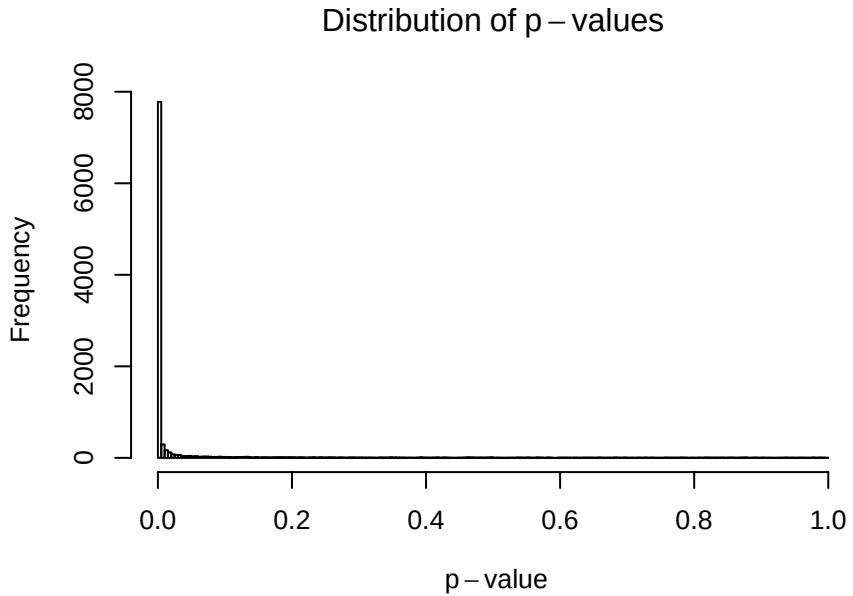

Correlation of GRACE GWS and adjusted GWL for DS1 – DS3
GRACE derived GWS
Adjusted GWL
EWH [mm]
100
50
0
−50
−100
2004
2006
2008
2010
2012
2014
Time [Year]

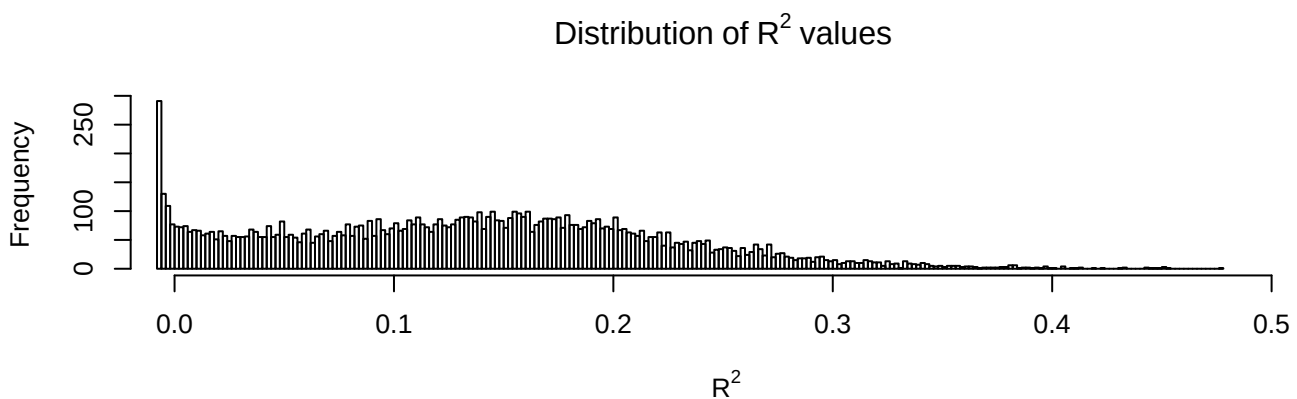

Distribution of p – values
Frequency
6000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value

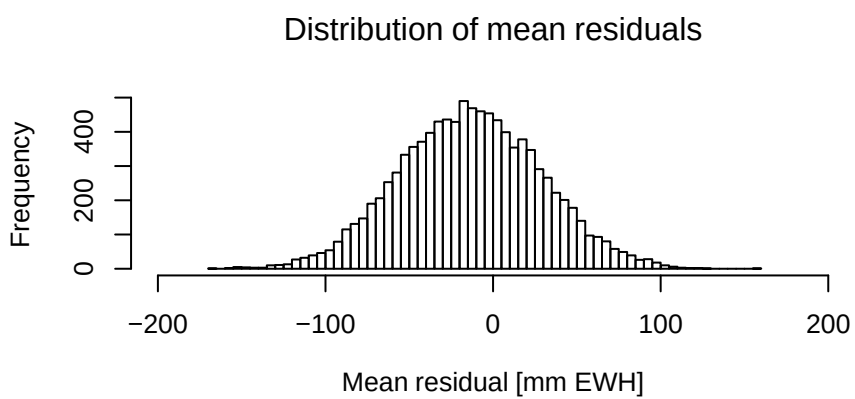

Distribution of R2 values
Frequency
150
50
0
0.0
0.2
0.4
0.6
0.8
1.0
R2

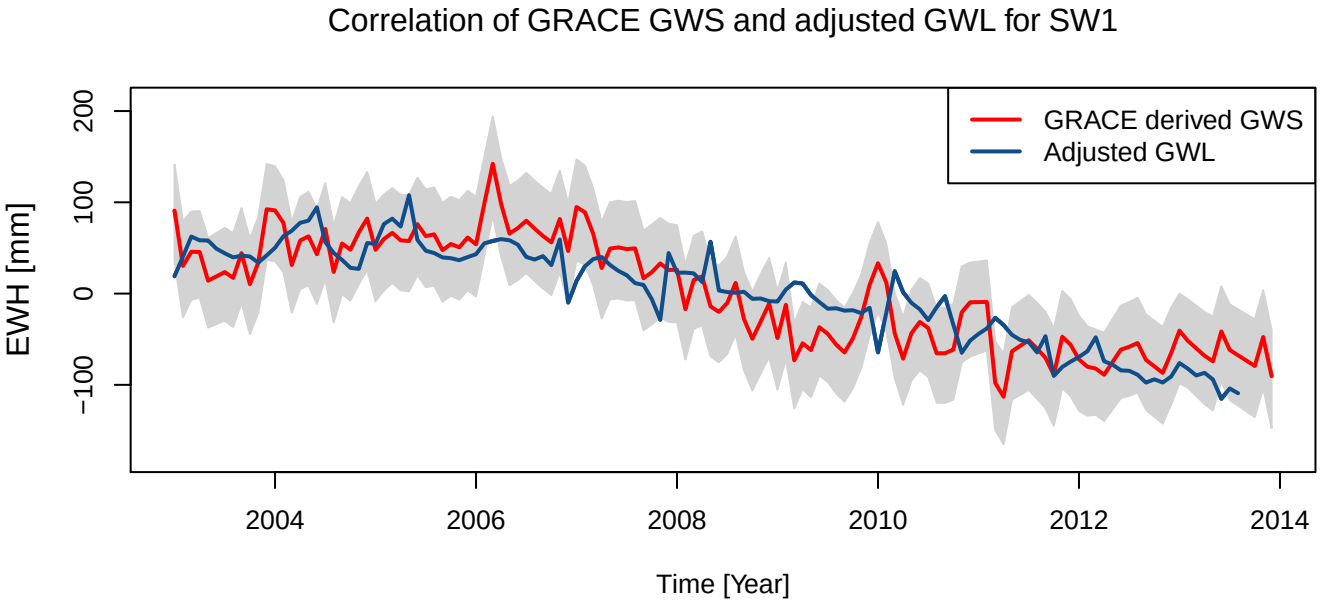

Distribution of mean residuals
Frequency
500
200
0
−150
−100
−50
0
50
100
150
Mean residual [mm EWH]

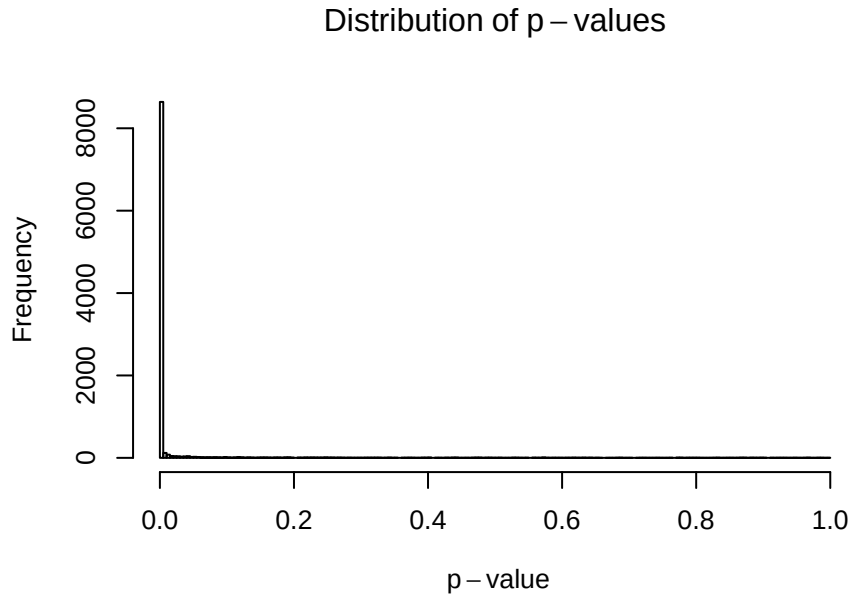

Correlation of GRACE GWS and adjusted GWL for DS4
GRACE derived GWS
Adjusted GWL
EWH [mm]
100
50
0
−100
2004
2006
2008
2010
2012
2014
Time [Year]

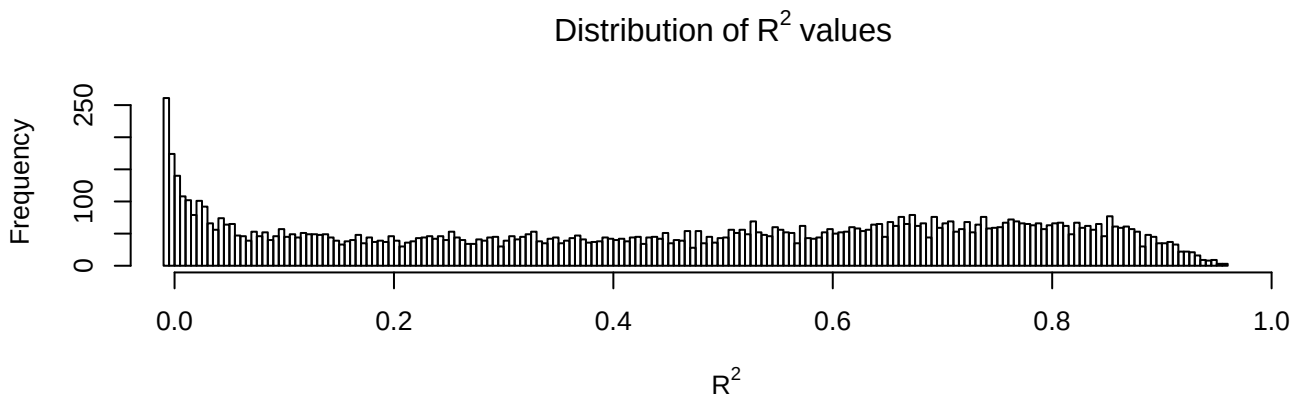

Distribution of p – values
Frequency
8000
6000
4000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value


Distribution of R2 values
Frequency
250
100
0
0.0
0.1
0.2
0.3
0.4
0.5
R2


Distribution of mean residuals
Frequency
400
200
0
−200
−100
0
100
200
Mean residual [mm EWH]


Correlation of GRACE GWS and adjusted GWL for SW1
GRACE derived GWS
Adjusted GWL
EWH [mm]
200
100
0
−100
2004
2006
2008
2010
2012
2014
Time [Year]


Distribution of p – values
Frequency
8000
6000
4000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value


Distribution of R2 values
Frequency
250
100
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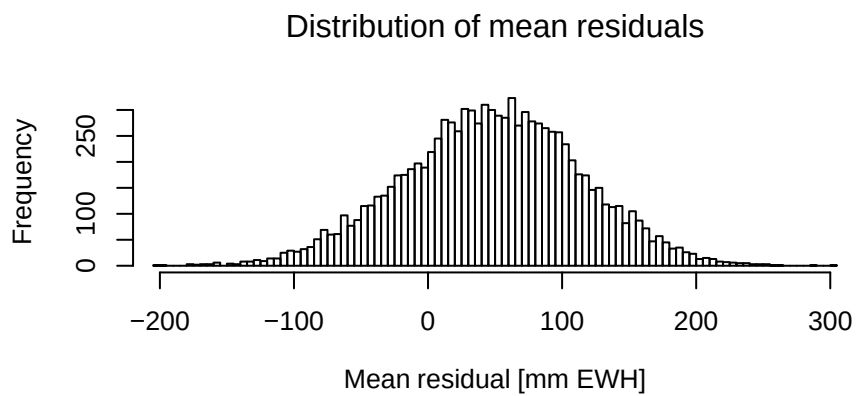
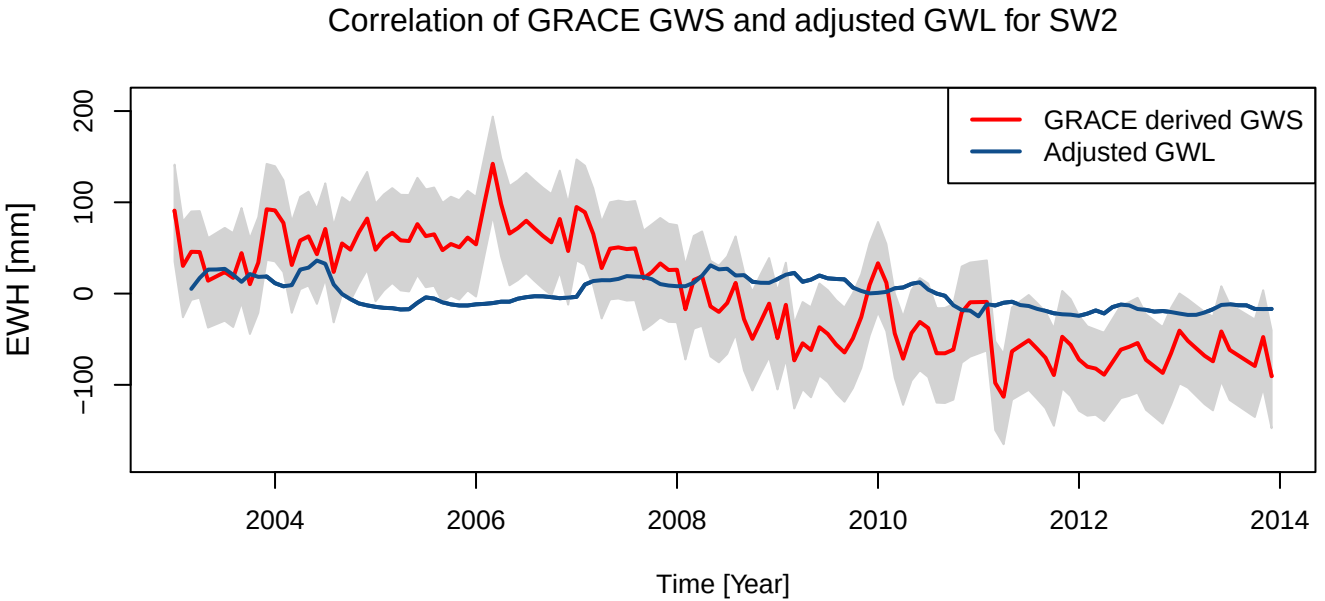
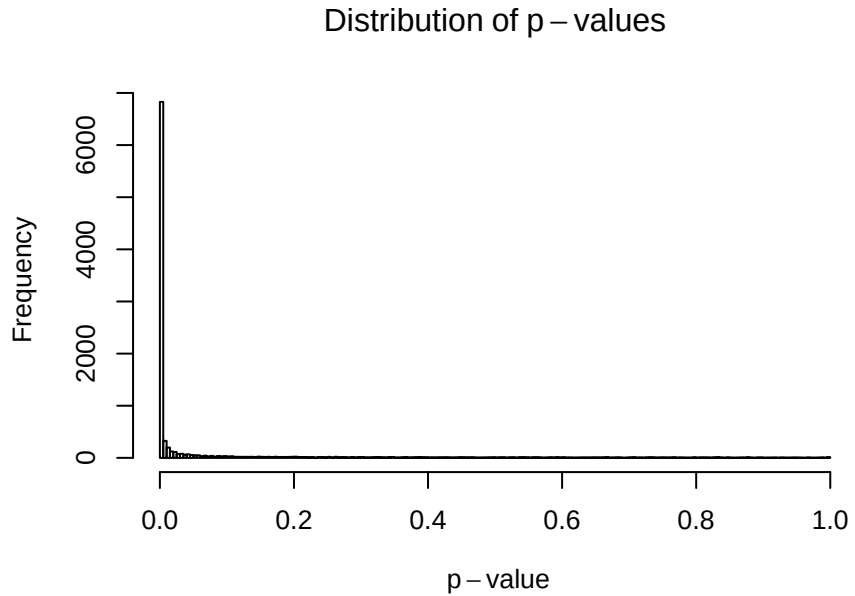
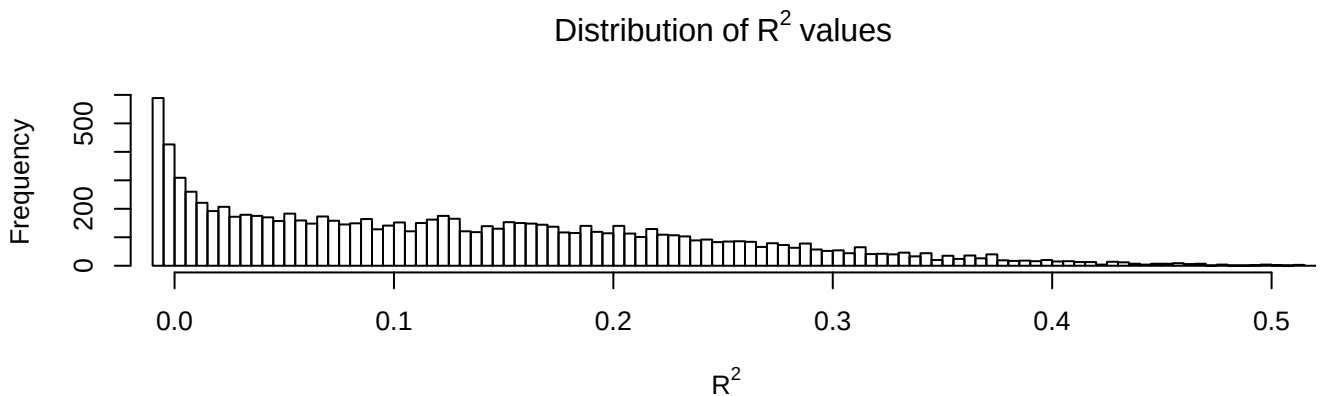
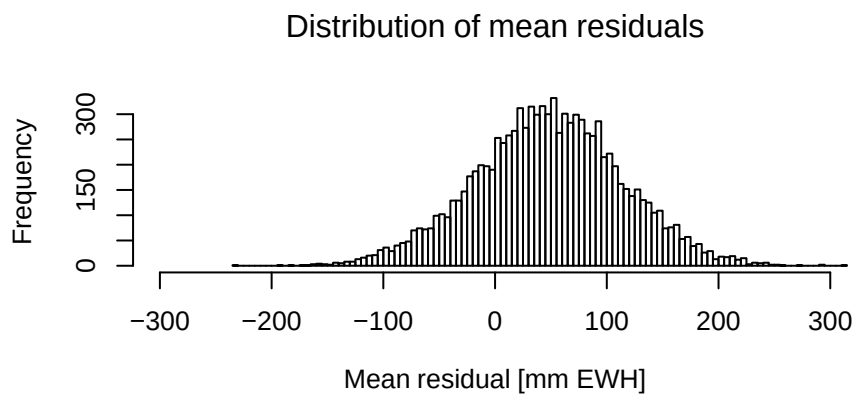
0.0
0.2
0.4
0.6
0.8
1.0
R2

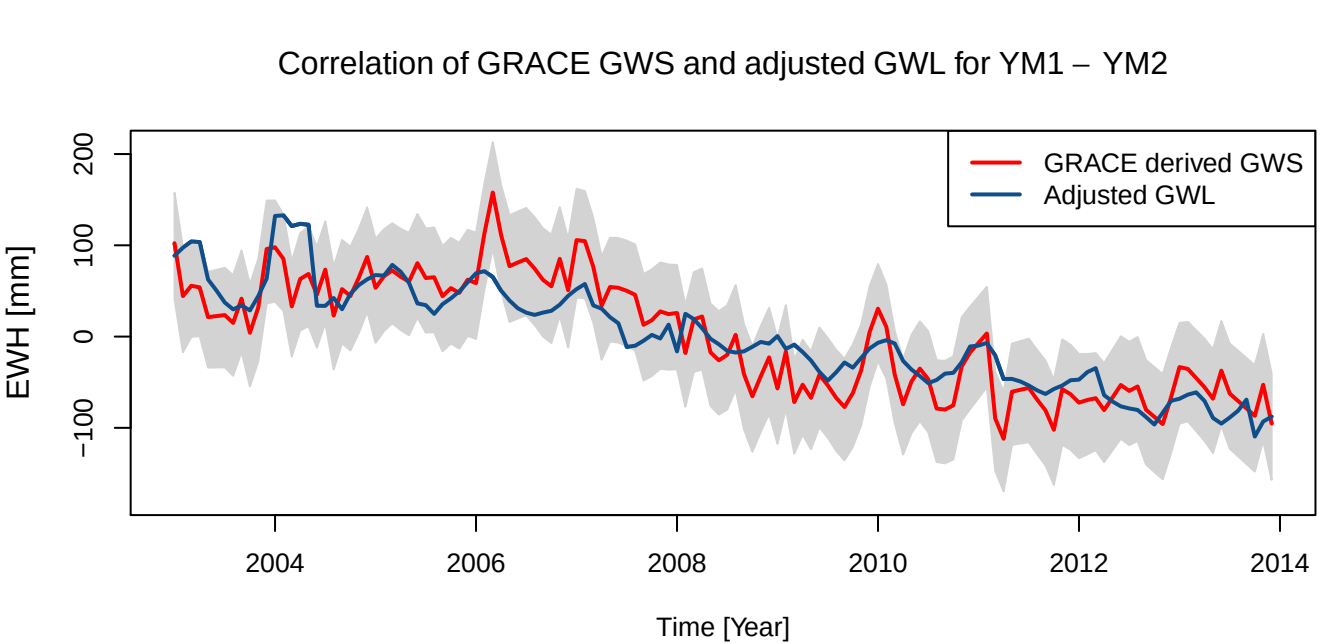

Distribution of mean residuals
Frequency
250
100
0
−200
−100
0
100
200
300
Mean residual [mm EWH]

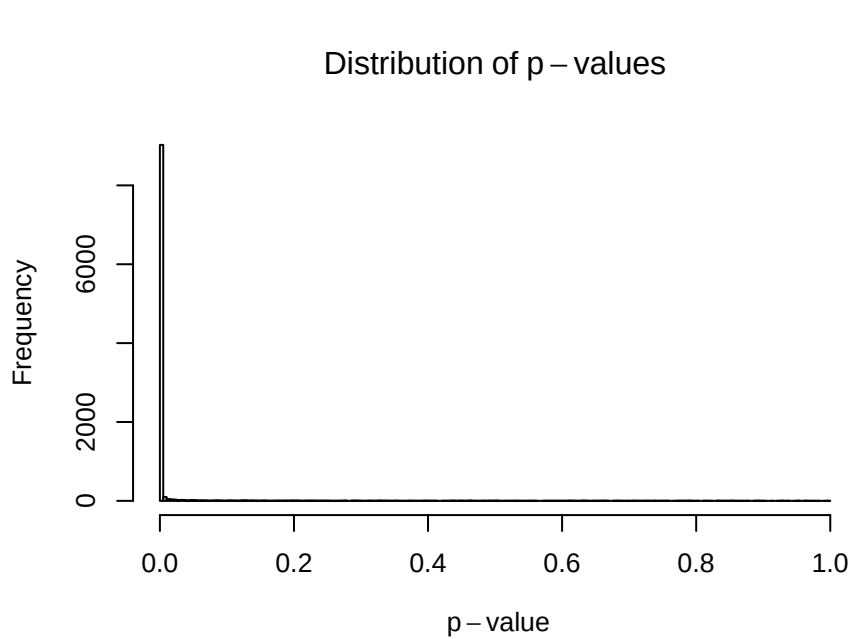

Correlation of GRACE GWS and adjusted GWL for SW2
GRACE derived GWS
Adjusted GWL
EWH [mm]
200
100
0
−100
2004
2006
2008
2010
2012
2014
Time [Year]

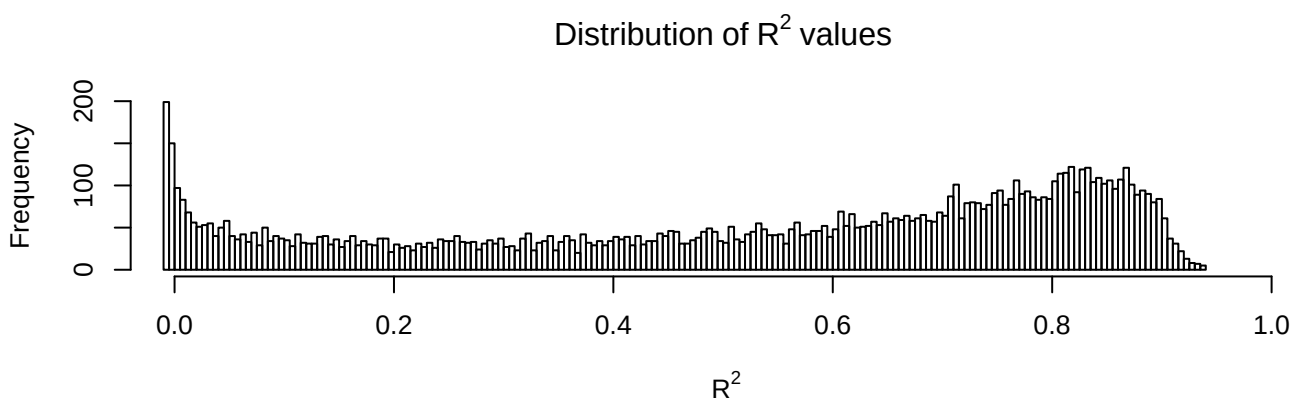

Distribution of p – values
Frequency
6000
4000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value

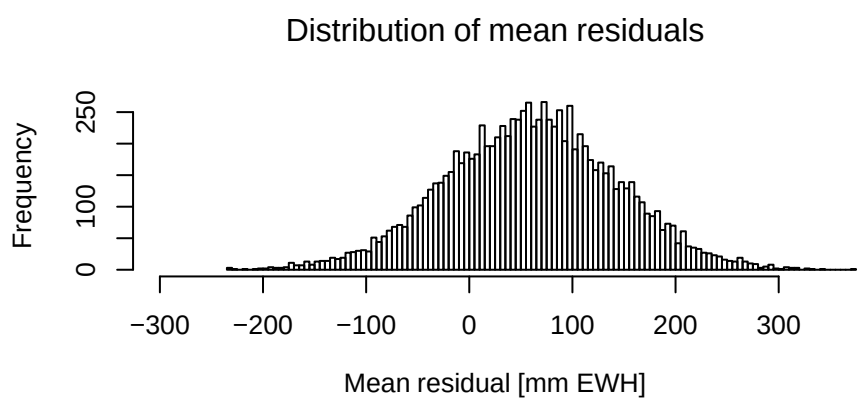

Distribution of R2 values
Frequency
500
200
0
0.0
0.1
0.2
0.3
0.4
0.5
R2

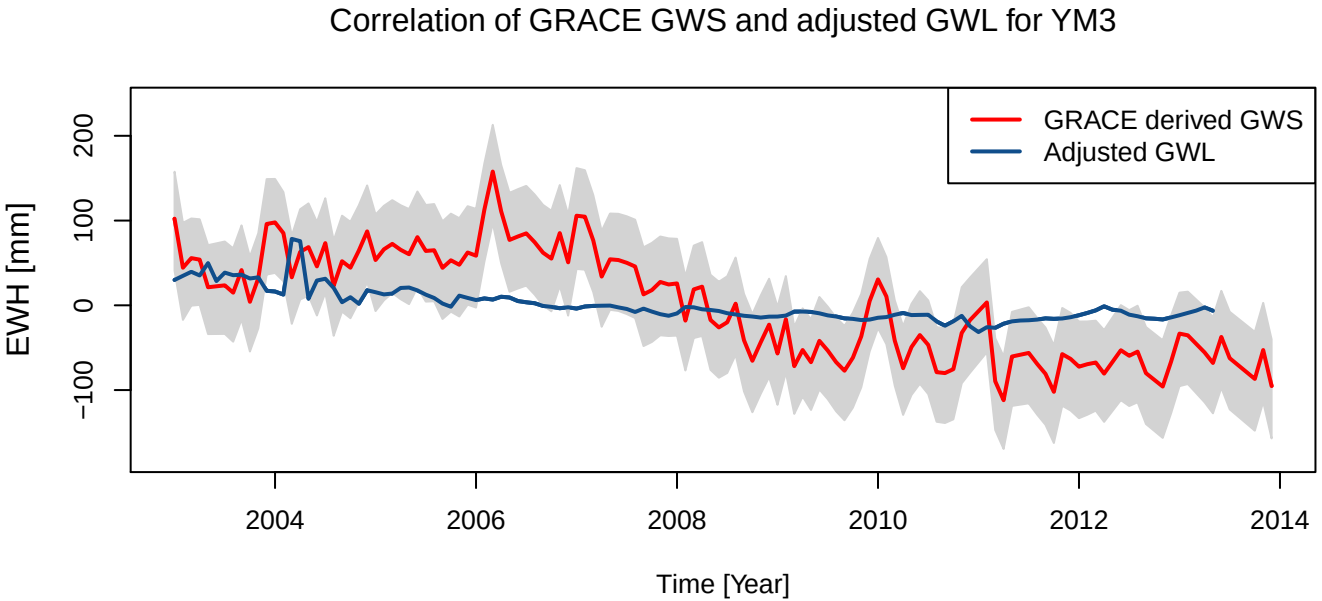

Distribution of mean residuals
Frequency
300
150
0
−300
−200
−100
0
100
200
300
Mean residual [mm EWH]

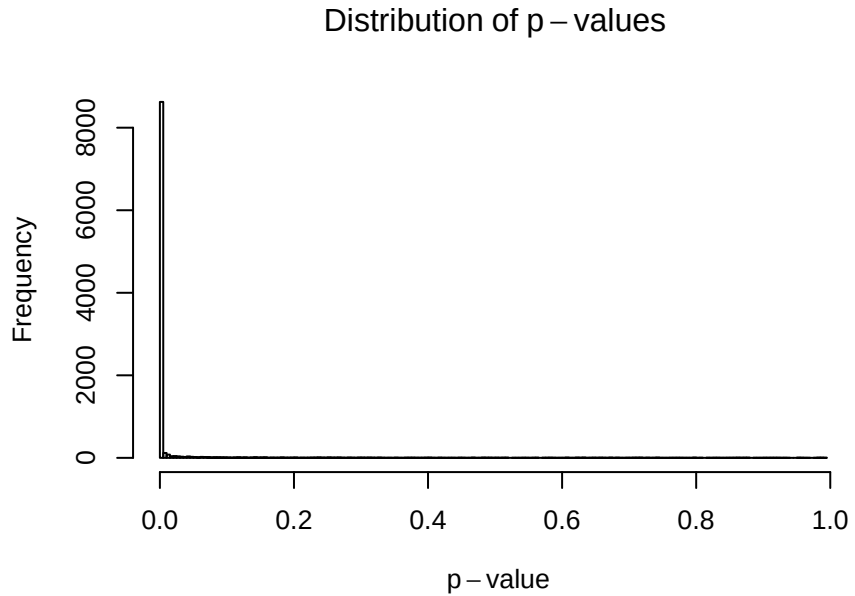

Correlation of GRACE GWS and adjusted GWL for YM1 – YM2
GRACE derived GWS
Adjusted GWL
EWH [mm]
200
100
0
−100
2004
2006
2008
2010
2012
2014
Time [Year]

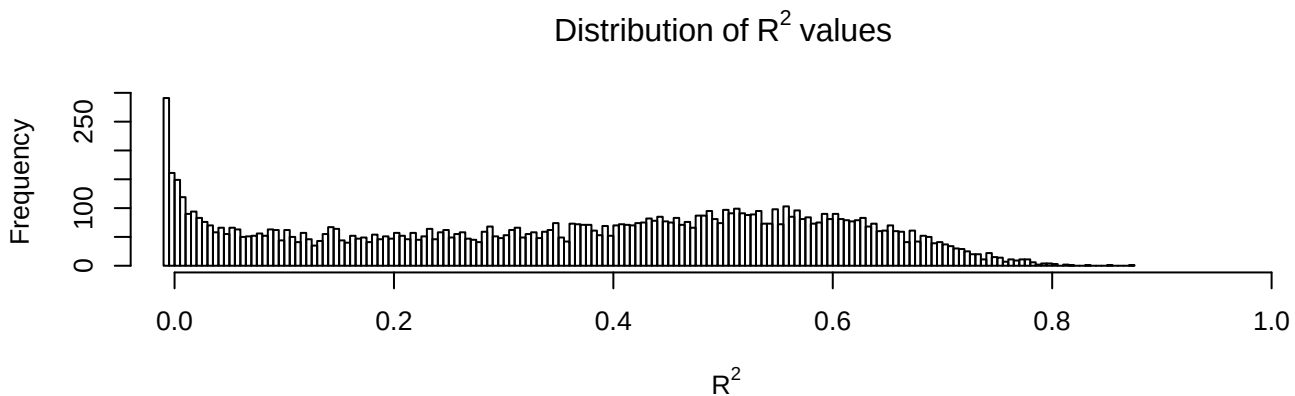

Distribution of p – values
Frequency
6000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value

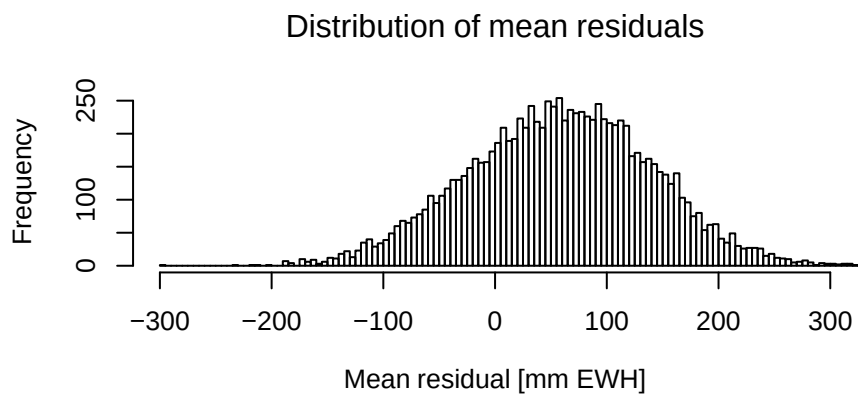

Distribution of R2 values
Frequency
200
100
0
0.0
0.2
0.4
0.6
0.8
1.0
R2


Distribution of mean residuals
Frequency
250
100
0
−300
−200
−100
0
100
200
300
Mean residual [mm EWH]

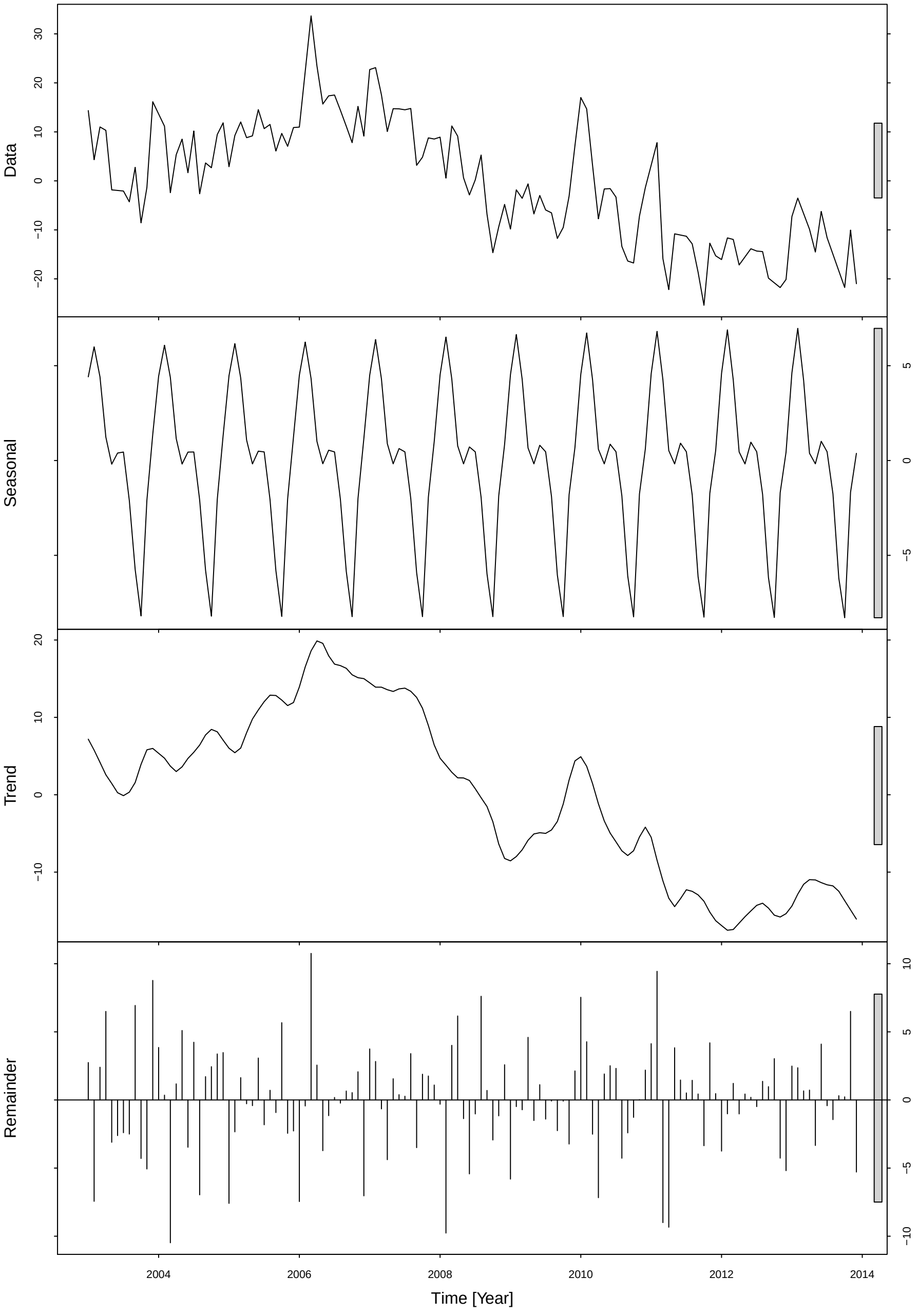

Correlation of GRACE GWS and adjusted GWL for YM3
GRACE derived GWS
Adjusted GWL
EWH [mm]
200
100
0
−100
2004
2006
2008
2010
2012
2014
Time [Year]


Distribution of p – values
Frequency
8000
6000
4000
2000
0
0.0
0.2
0.4
0.6
0.8
1.0
p – value

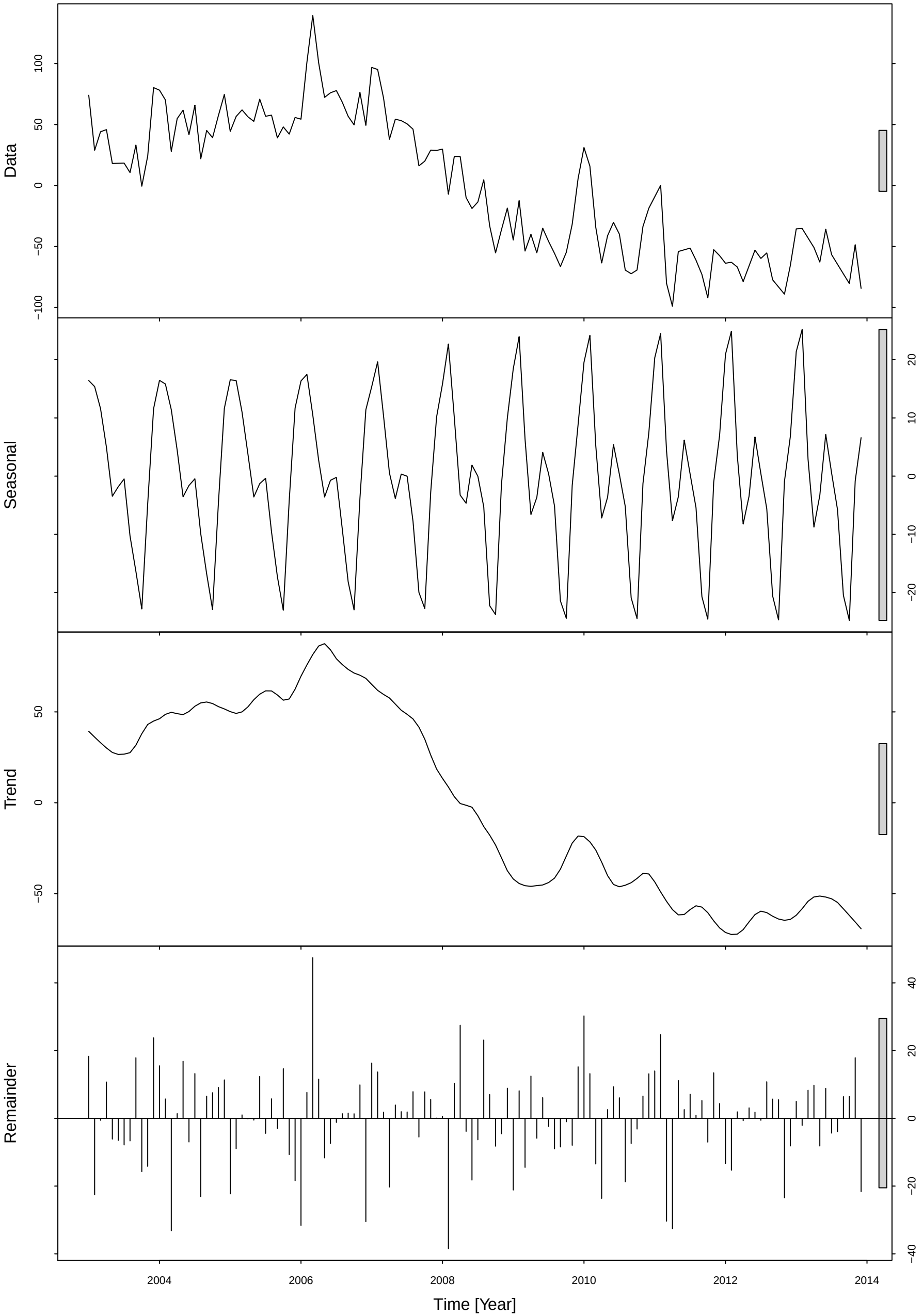

Distribution of R2 values
Frequency
250
100
0
0.0
0.2
0.4
0.6
0.8
1.0
R2


Distribution of mean residuals
Frequency
250
100
0
−300
−200
−100
0
100
200
300
Mean residual [mm EWH]

Decomposed GRACE derived GWS, Azraq Basin



Decomposed GRACE derived GWS, Amman−Zarqa Basin



Decomposed GRACE derived GWS, Dead Sea Basin

Data

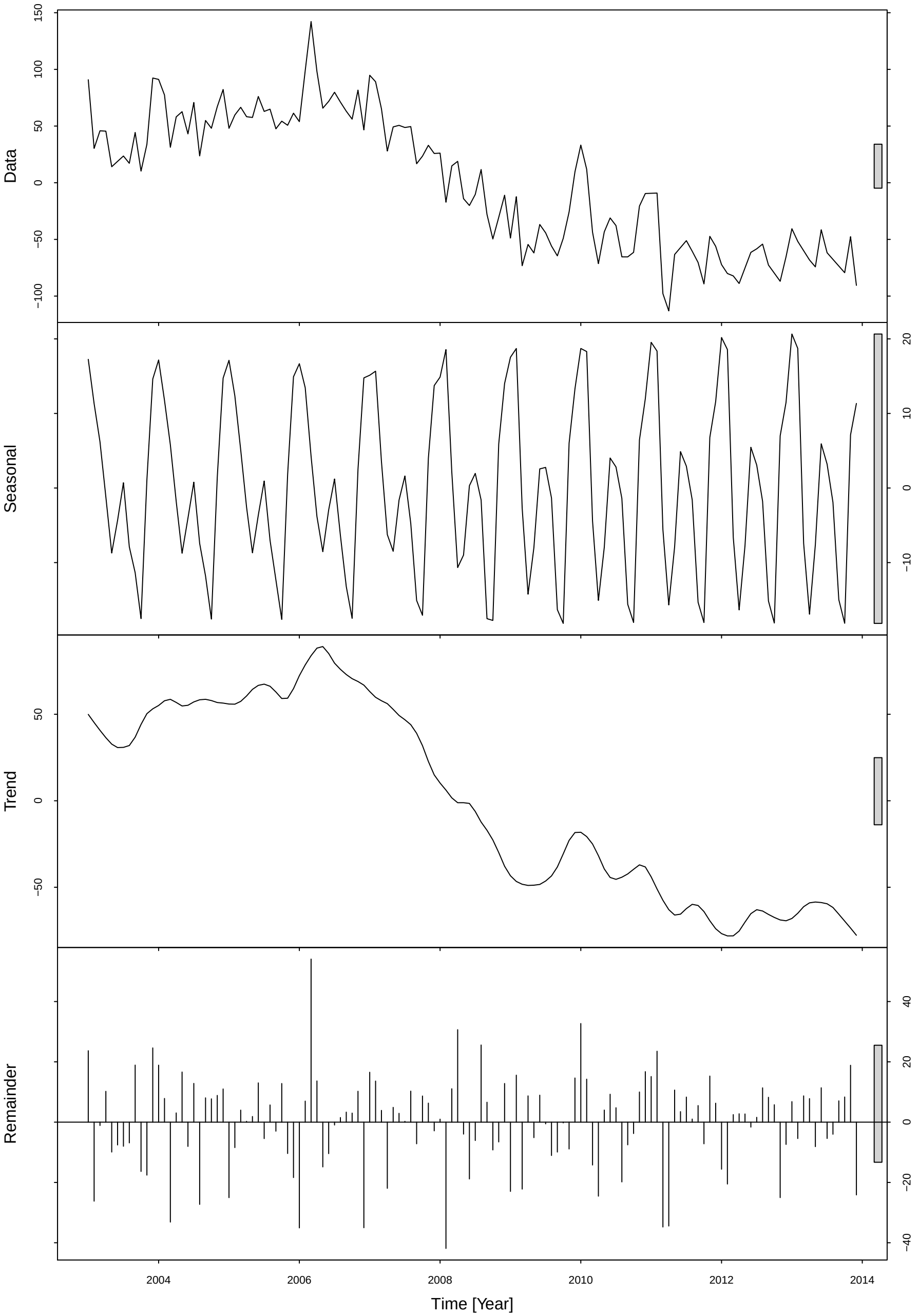
Seasonal

Trend

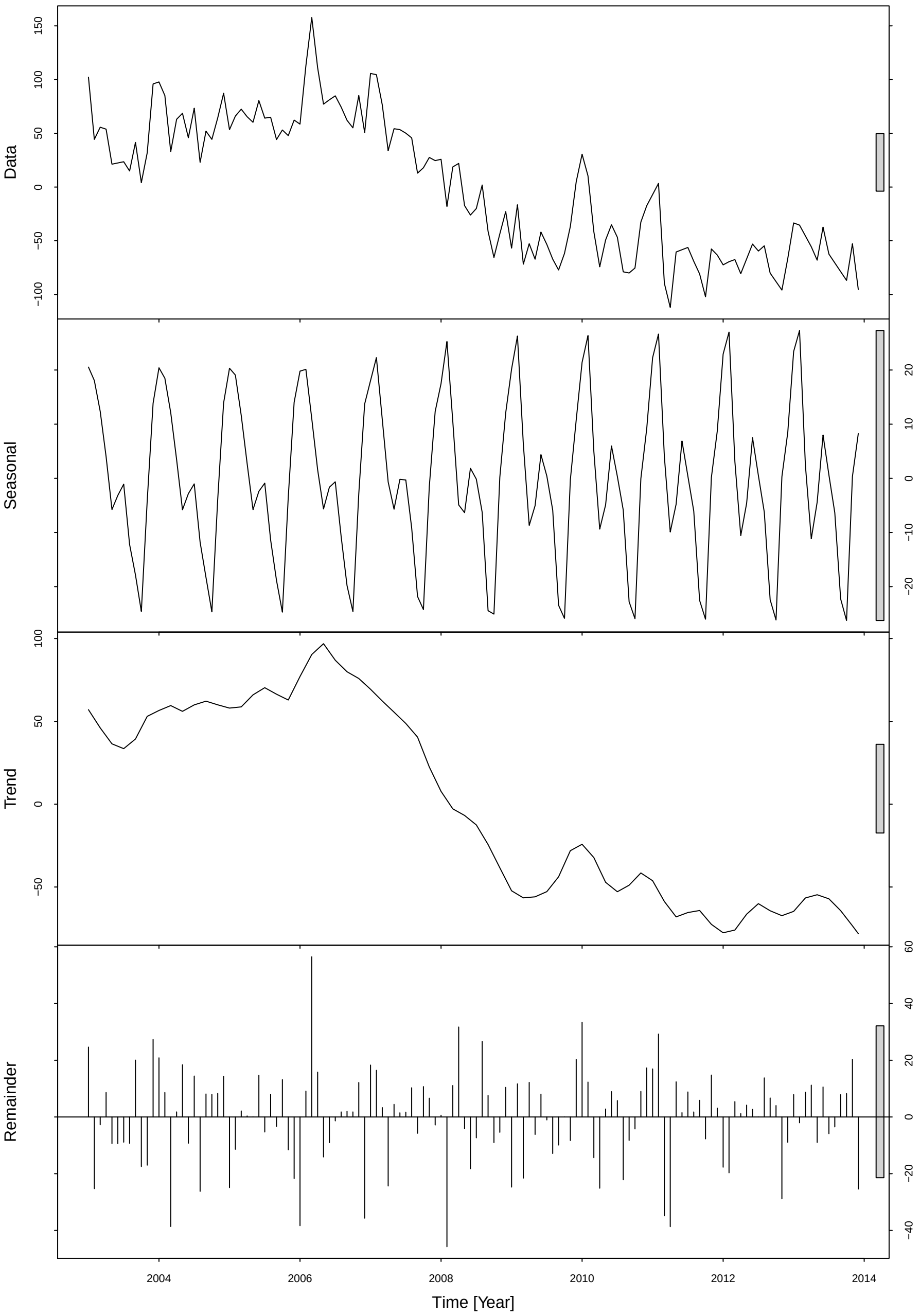
Remainder

Time [Year]

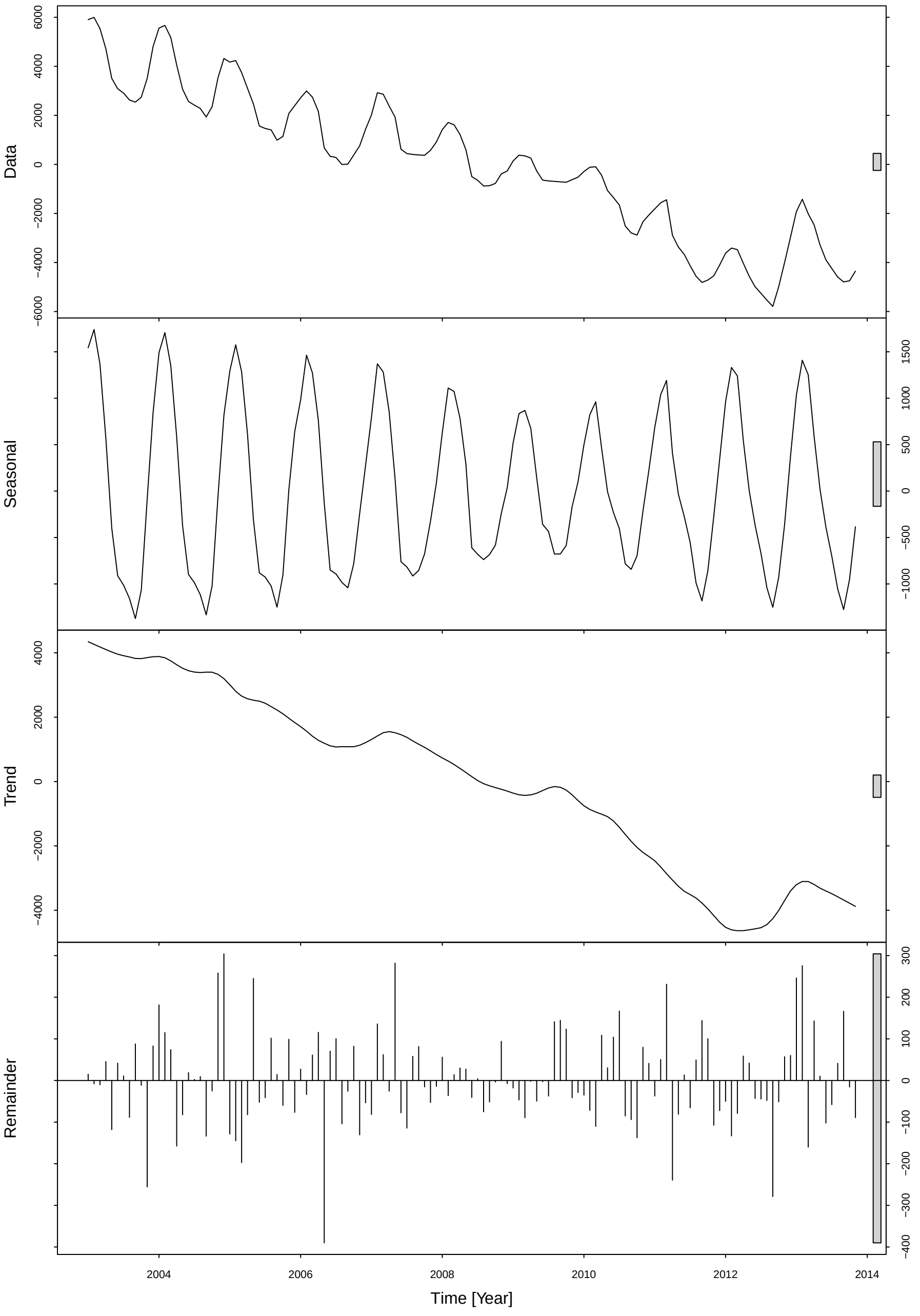
Decomposed GRACE derived GWS, Side Wadis Basin



Decomposed GRACE derived GWS, Yarmouk Basin



Decomposed averaged groundwater level of AR1−AR4



Decomposed groundwater level of AR5

Data

Seasonal

Trend

Remainder

Time [Year]

Decomposed averaged groundwater level of AZ1−AZ7

Data

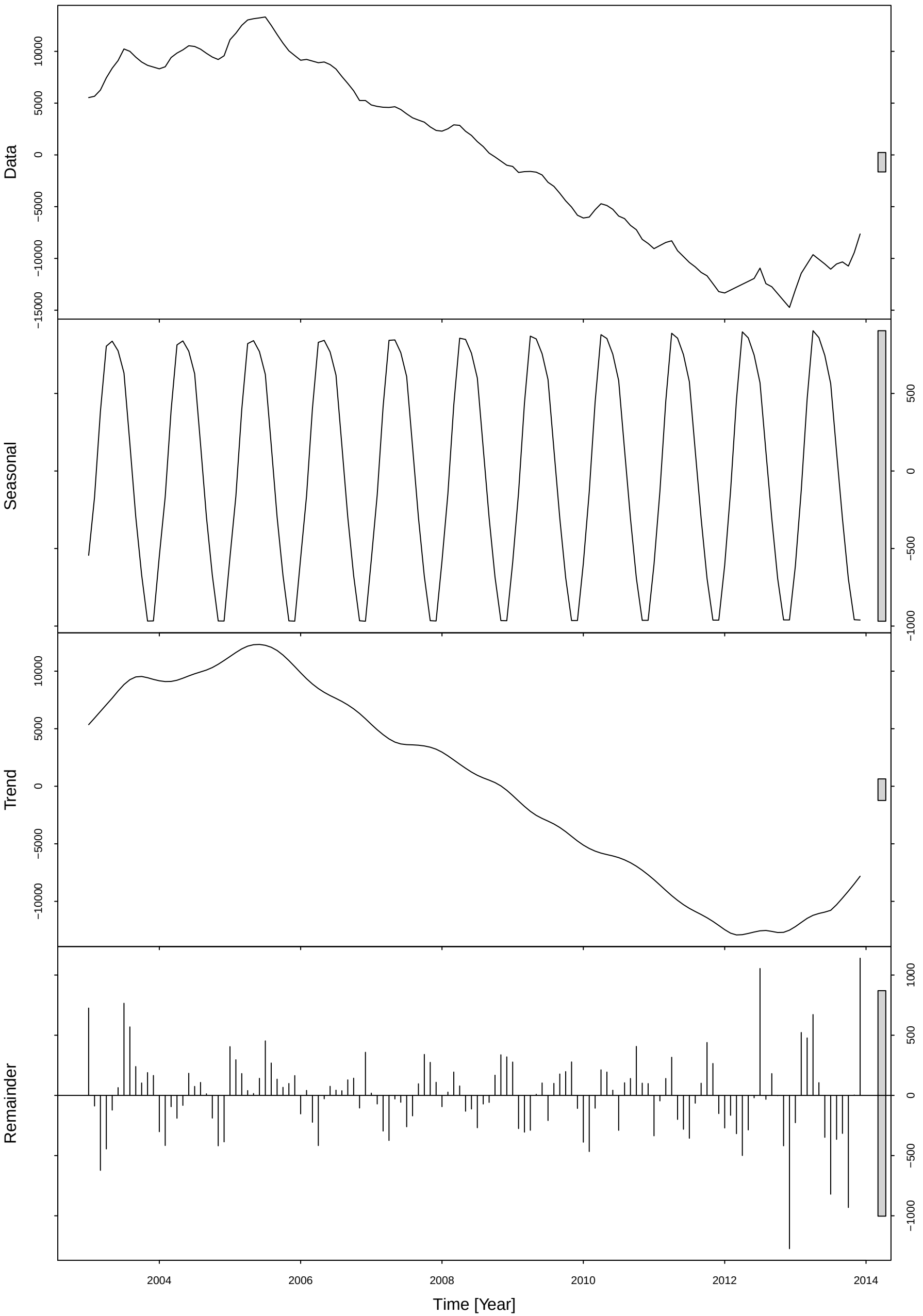
Seasonal

Trend

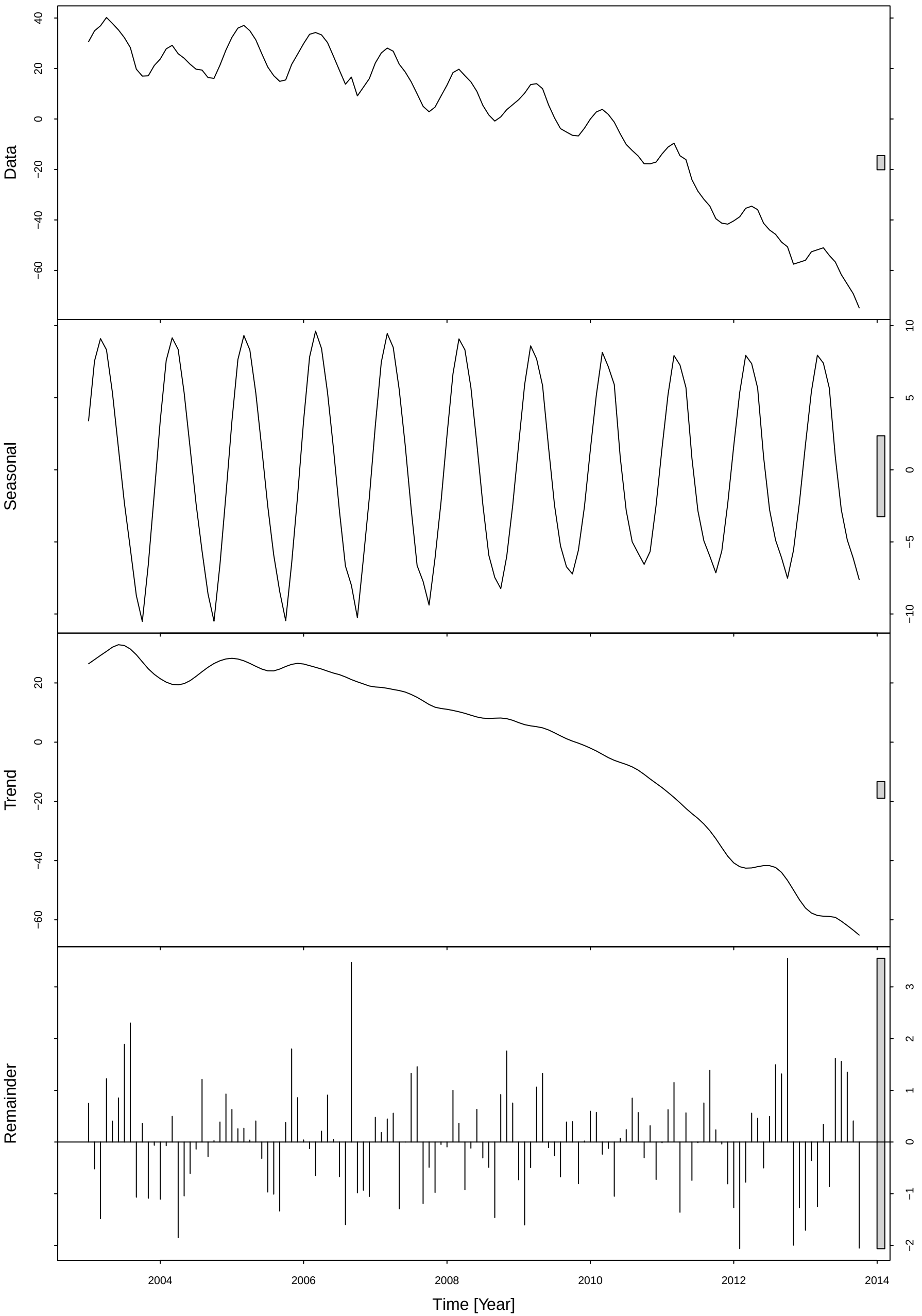
Remainder

Time [Year]

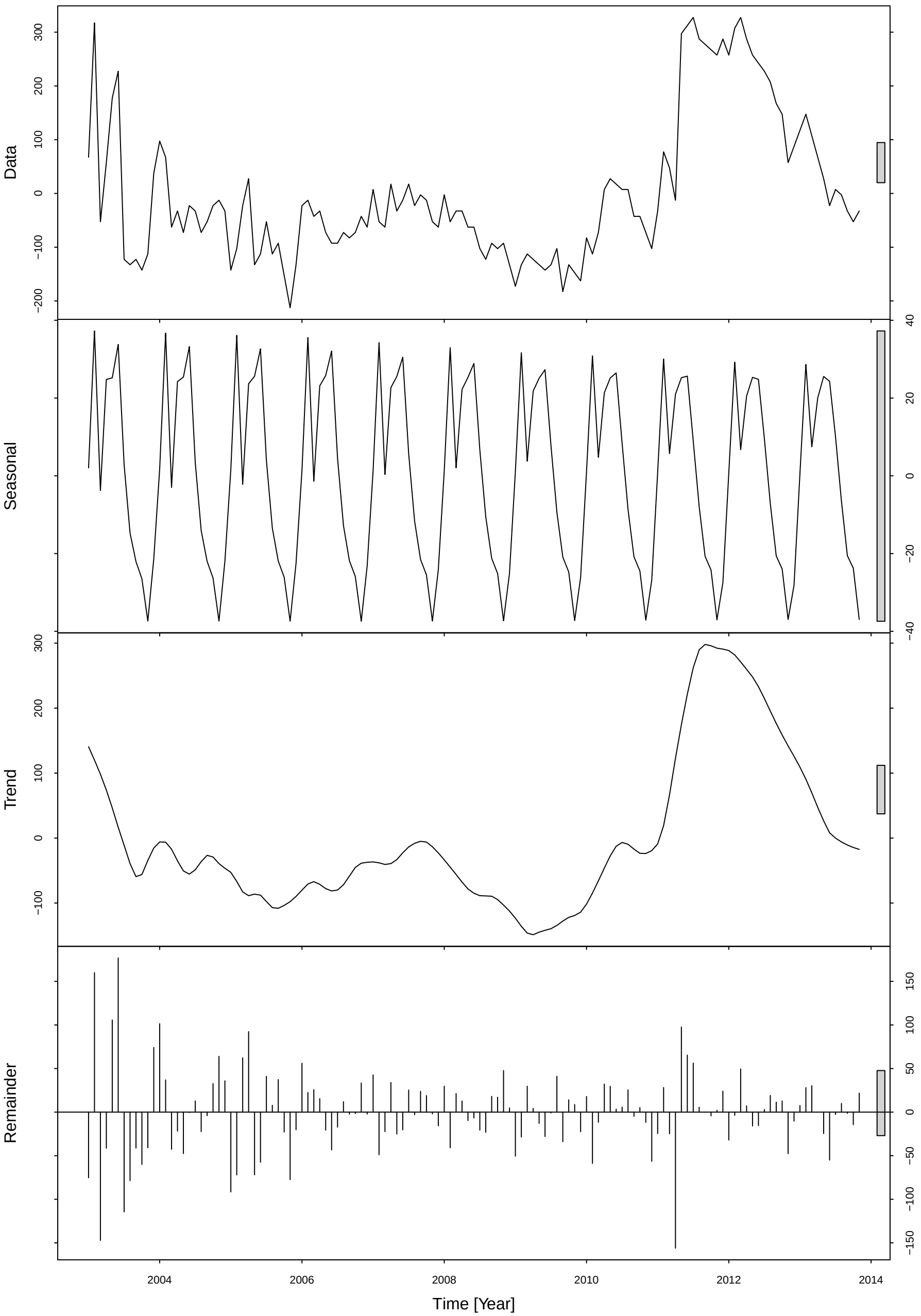
Decomposed groundwater level of AZ8



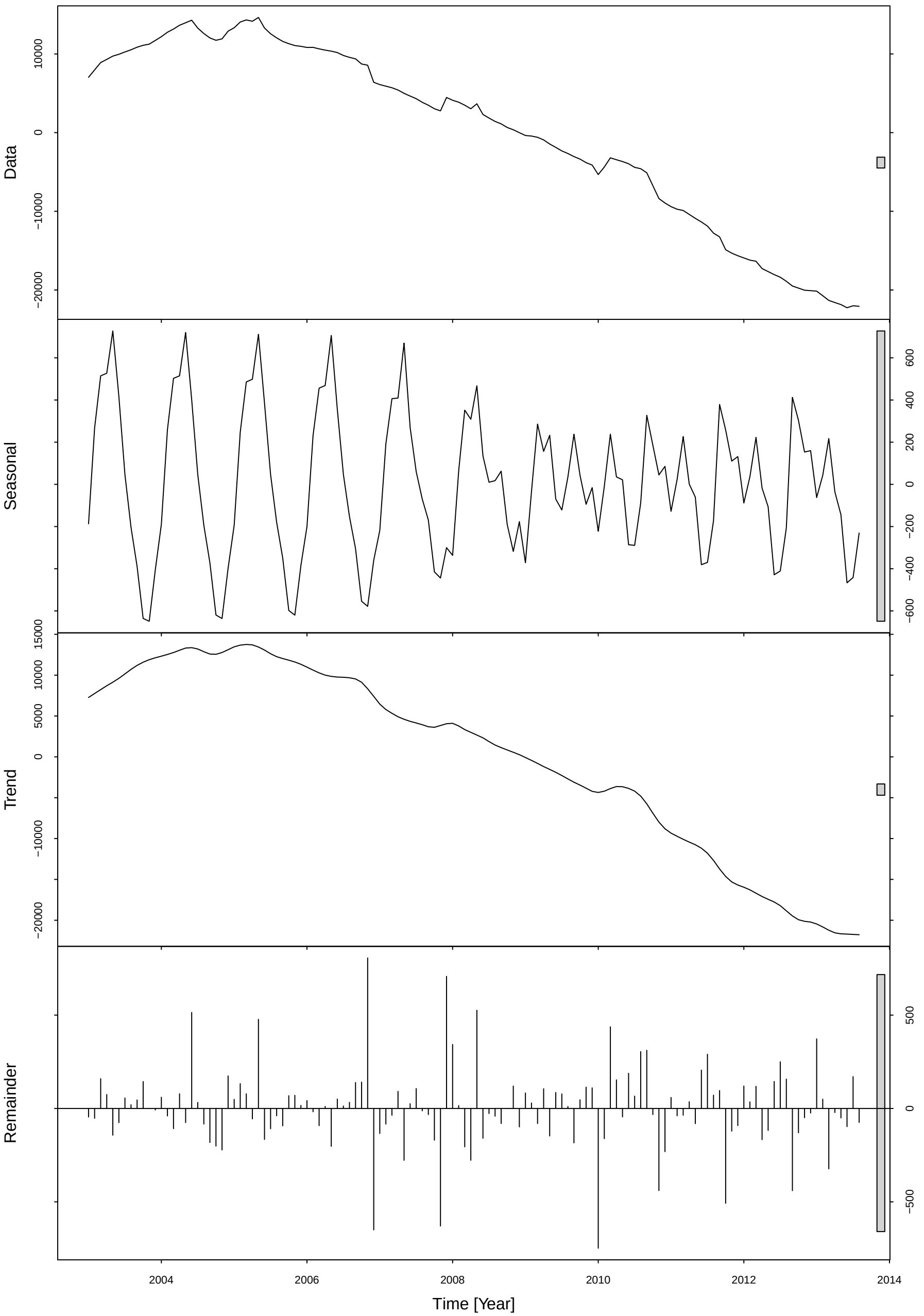
Decomposed averaged groundwater level of DS1−DS3



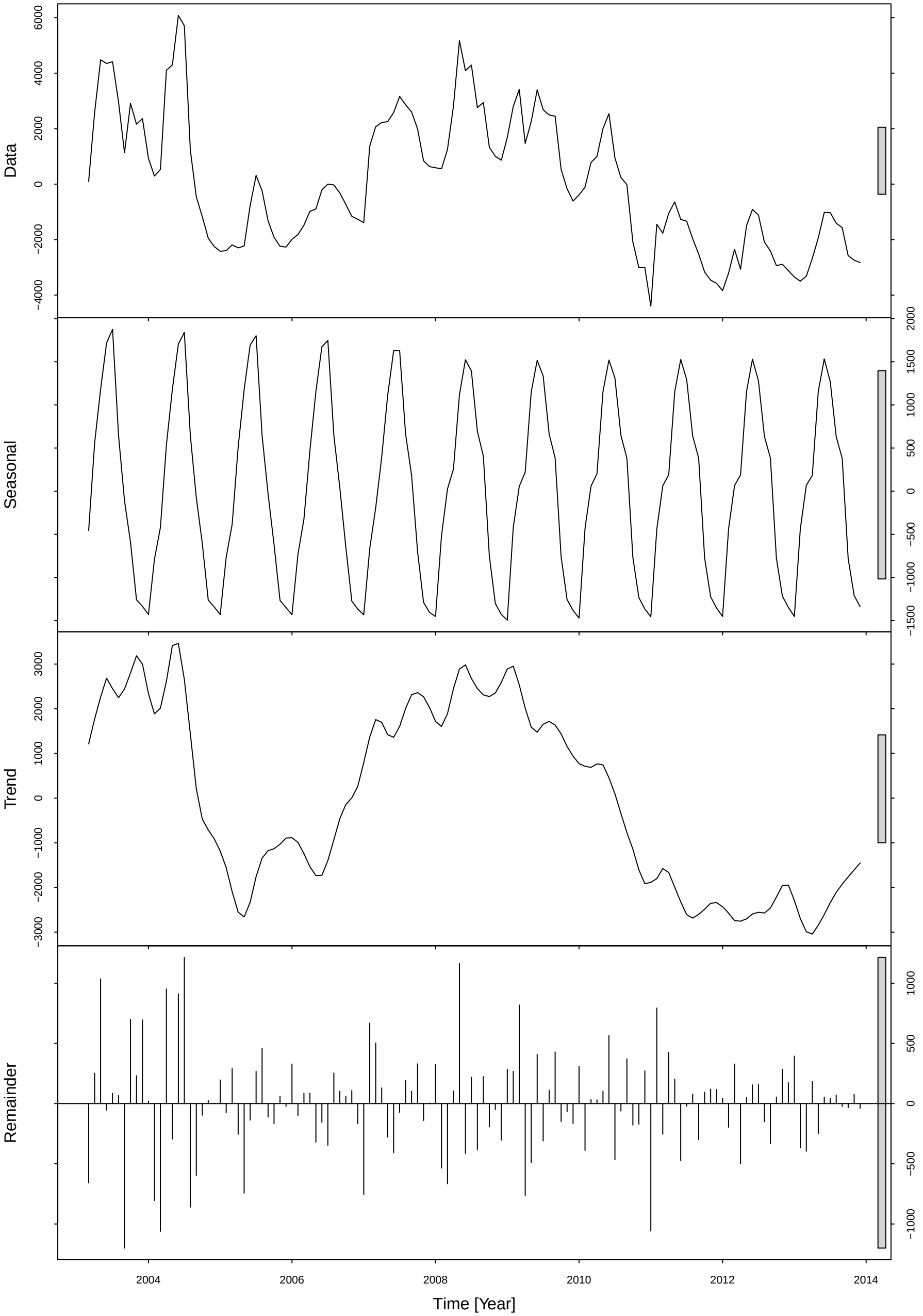
Decomposed groundwater level of DS4



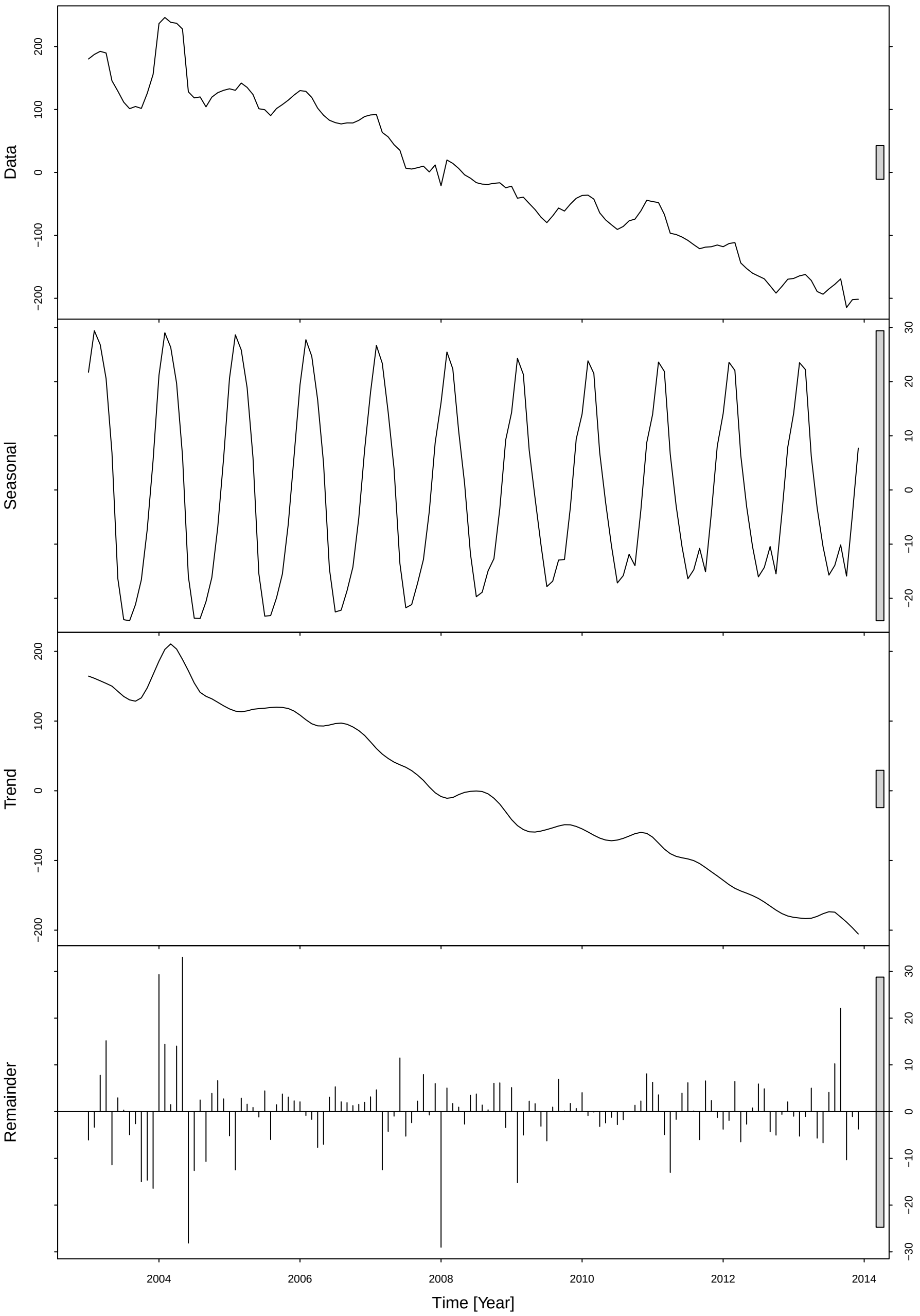
Decomposed groundwater level of SW1



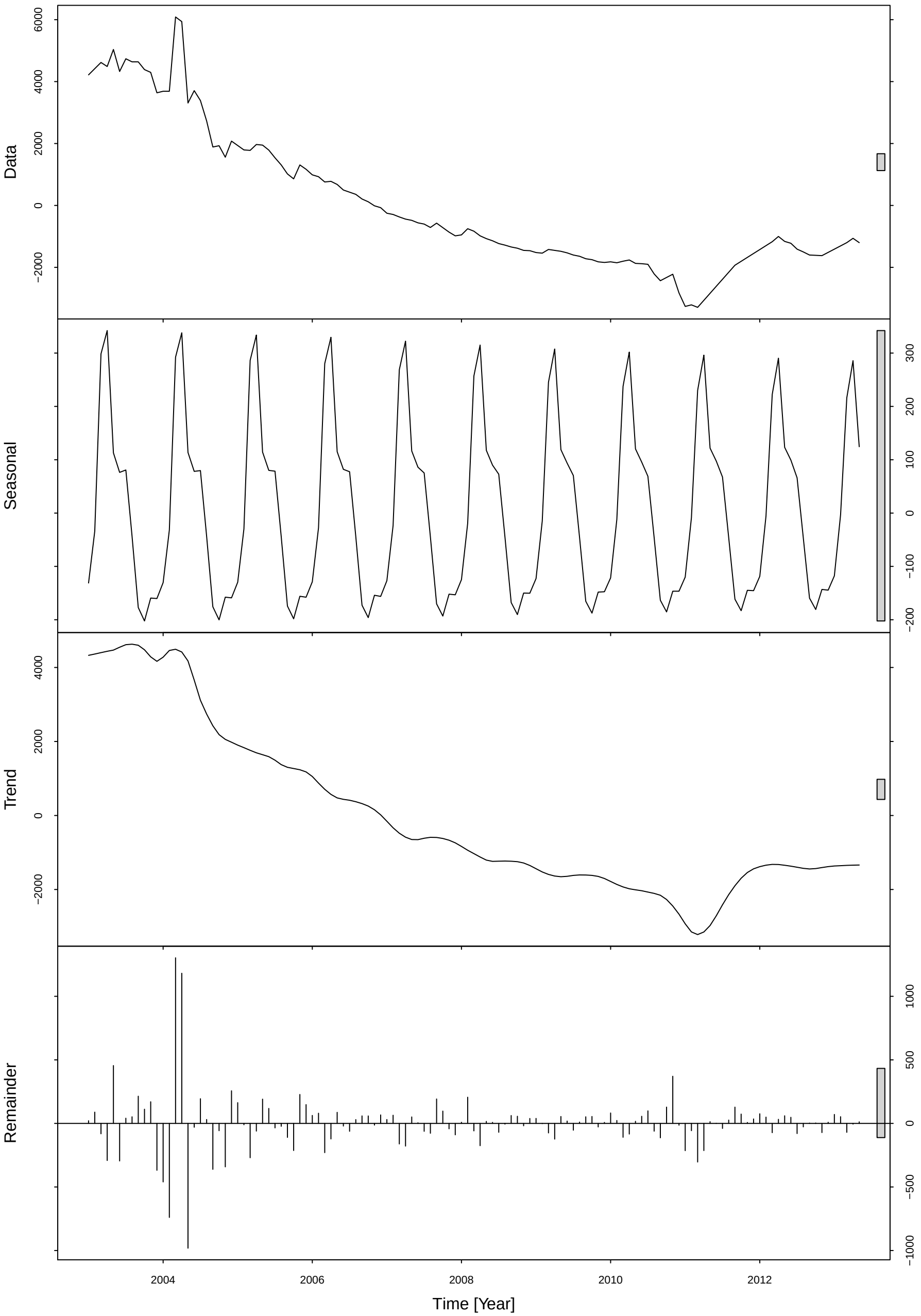
Decomposed groundwater level of SW2

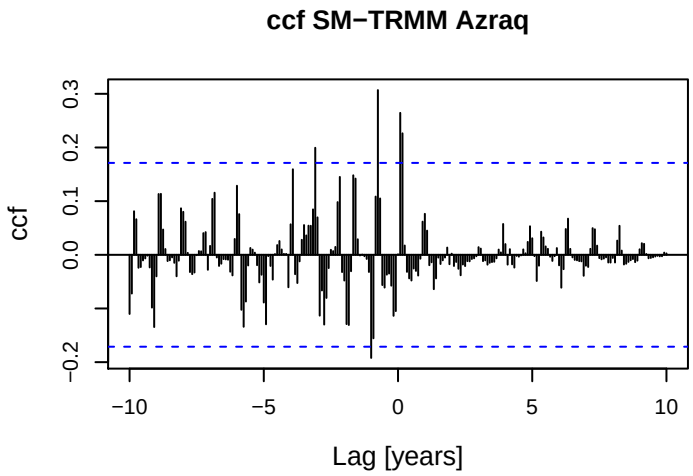


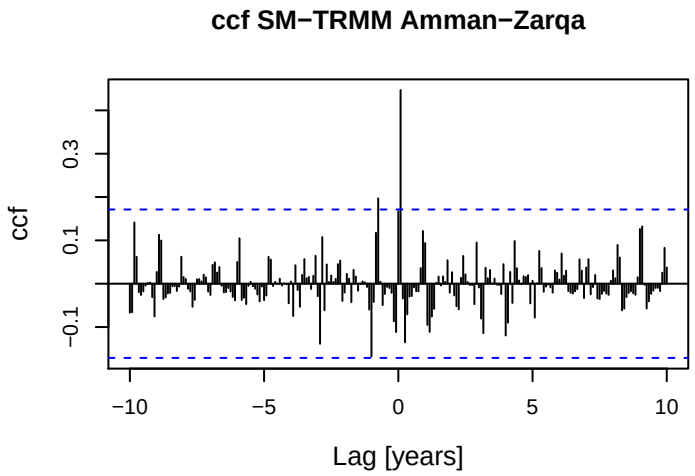
Decomposed averaged groundwater level of YM1−YM2

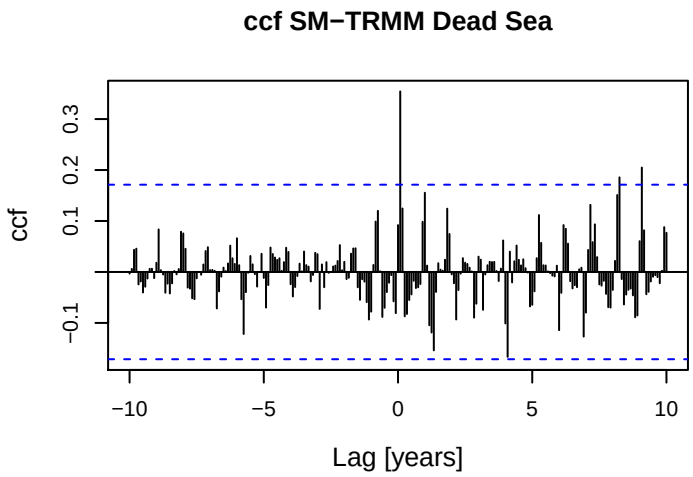


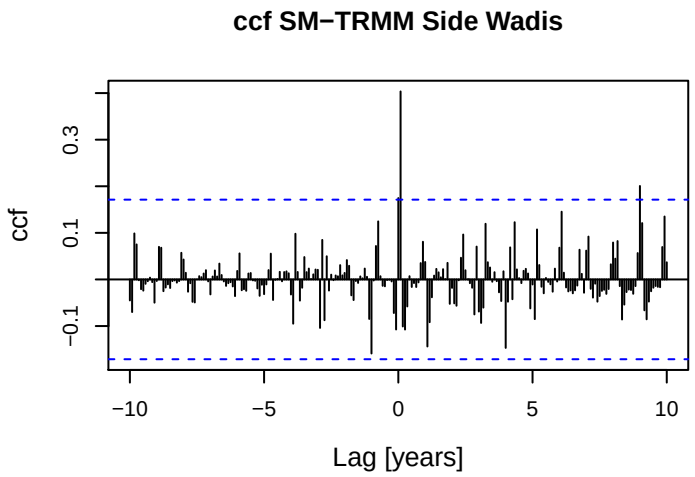
Decomposed groundwater level of YM3

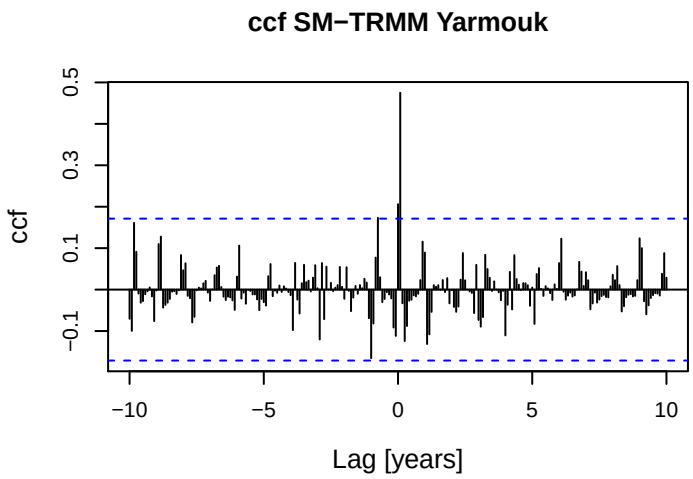


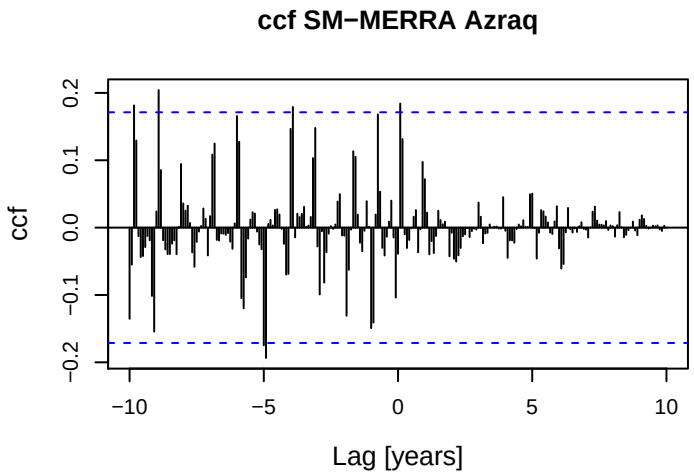

ccf SM−TRMM Azraq
ccf
0.3
0.2
0.1
0.0
−0.2
−10
−5
0
5
10
Lag [years]

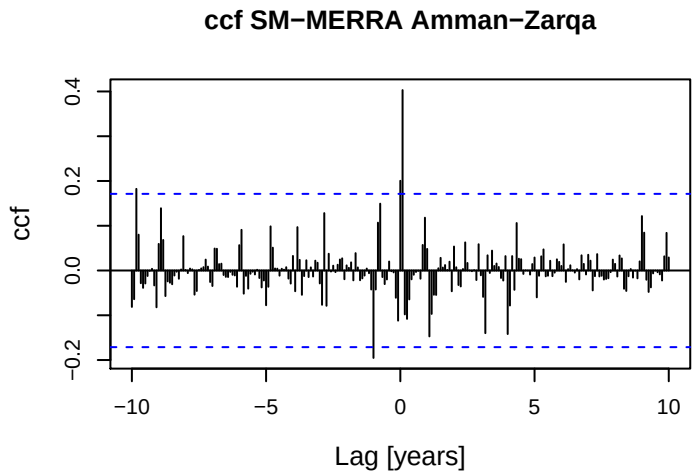

ccf SM−TRMM Amman−Zarqa
ccf
0.3
0.1
−0.1
−10
−5
0
5
10
Lag [years]

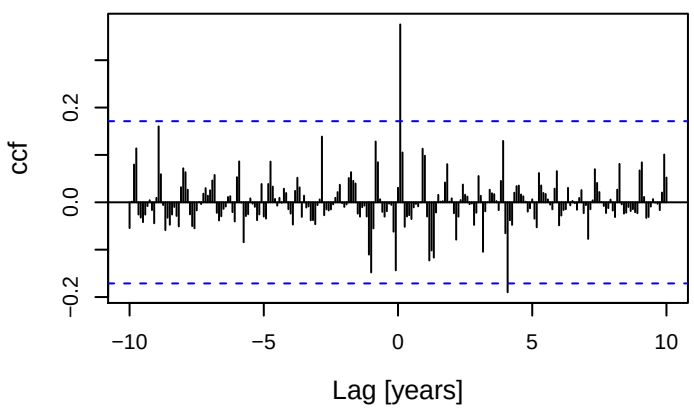

ccf SM−TRMM Dead Sea
ccf
0.3
0.2
0.1
−0.1
−10
−5
0
5
10
Lag [years]

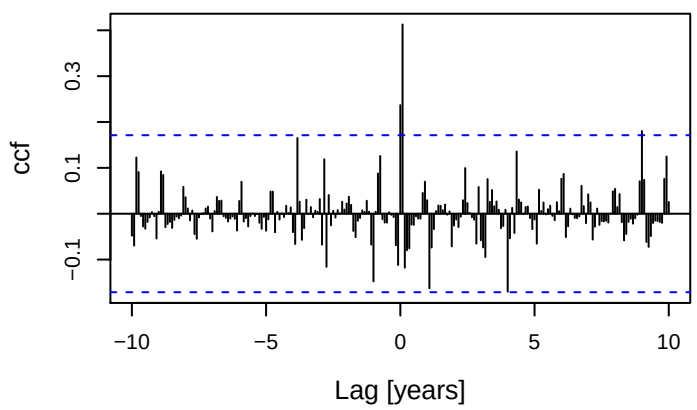

ccf SM−TRMM Side Wadis
ccf
0.3
0.1
−0.1
−10
−5
0
5
10
Lag [years]

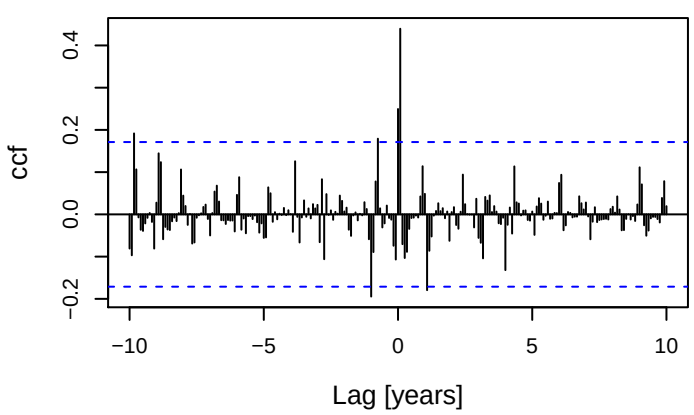

ccf SM−TRMM Yarmouk
ccf
0.5
0.3
0.1
−0.1
−10
−5
0
5
10
Lag [years]


ccf SM−MERRA Azraq
ccf
0.2
0.1
0.0
−0.1
−0.2
−10
−5
0
5
10
Lag [years]

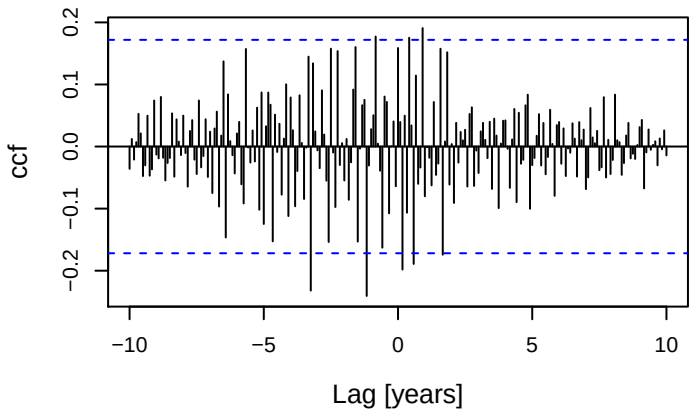

ccf SM−MERRA Amman−Zarqa
ccf
0.4
0.2
0.0
−0.2
−10
−5
0
5
10
Lag [years]


ccf SM−MERRA Dead Sea
ccf
0.2
0.0
−0.2
−10
−5
0
5
10
Lag [years]

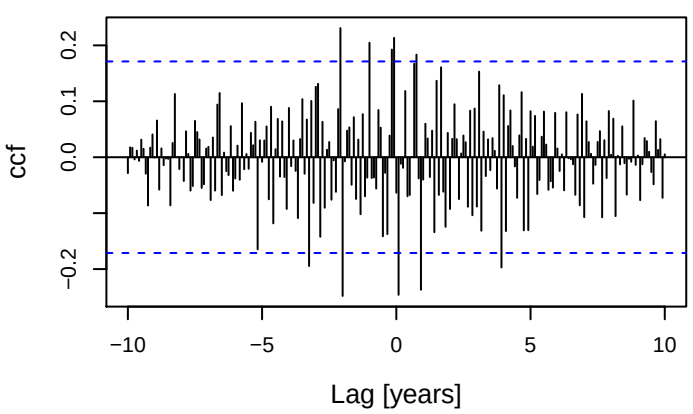

ccf SM−MERRA Side Wadis
ccf
0.3
0.1
−0.1
−10
−5
0
5
10
Lag [years]


ccf SM−MERRA Yarmouk
ccf
0.4
0.2
0.0
−0.2
−10
−5
0
5
10
Lag [years]

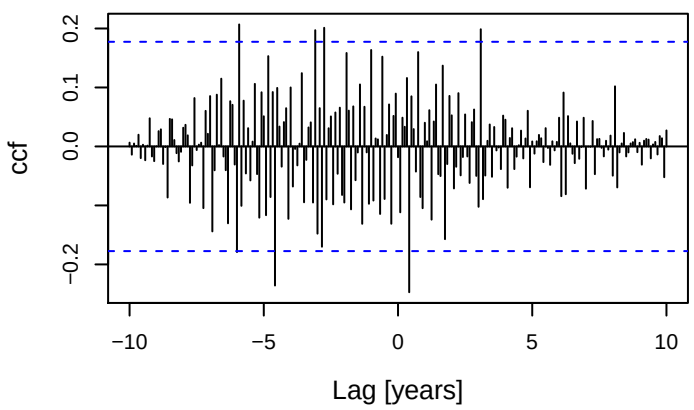
ccf GWL−TRMM Azraq, AR1−AR4



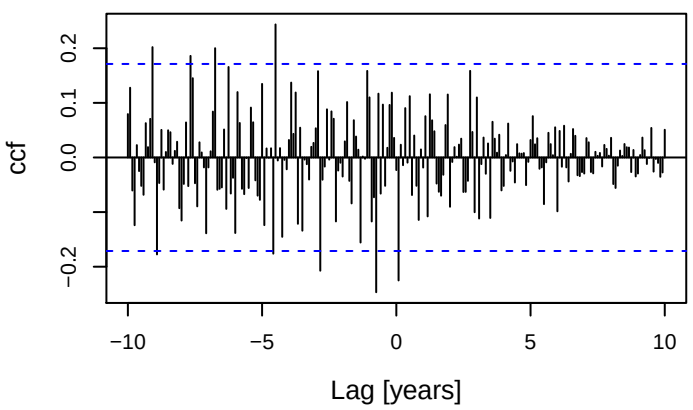
ccf GWL−TRMM Azraq, AR5



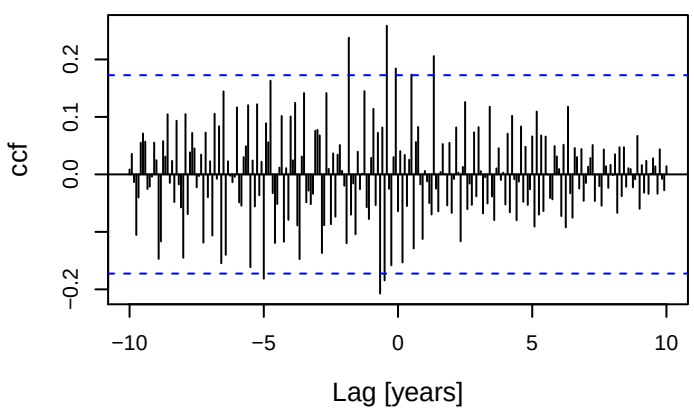
ccf GWL−TRMM Amman−Zarqa, AZ1−AZ7



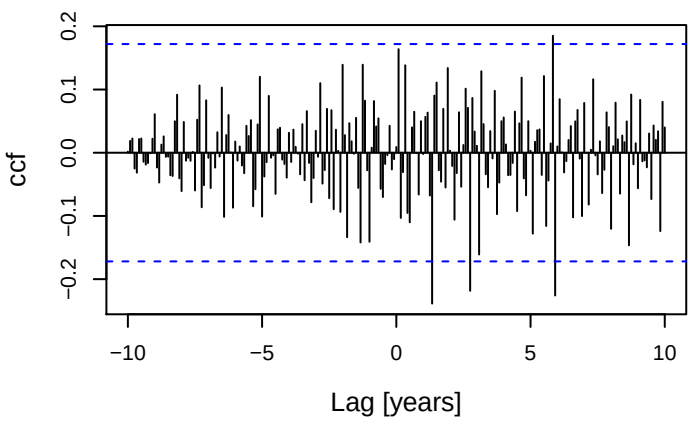
ccf GWL−TRMM Amman−Zarqa, AZ8



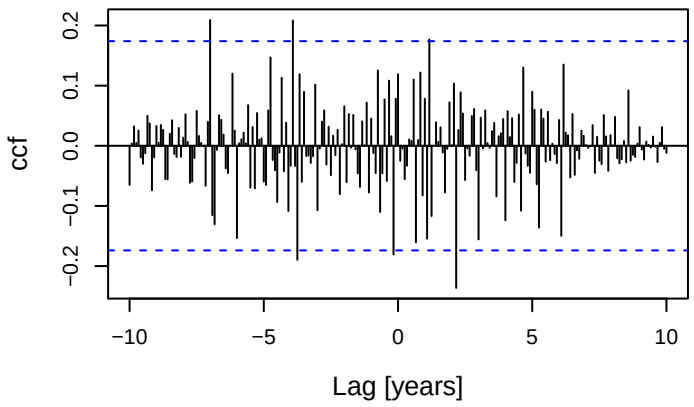
ccf GWL−TRMM Dead Sea, DS1−DS3



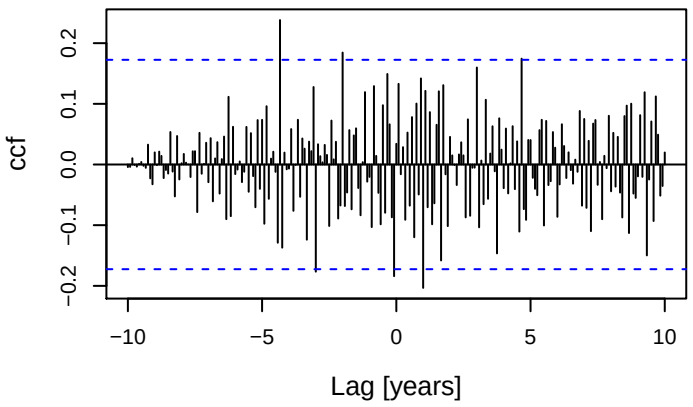
ccf GWL−TRMM Dead Sea, DS4



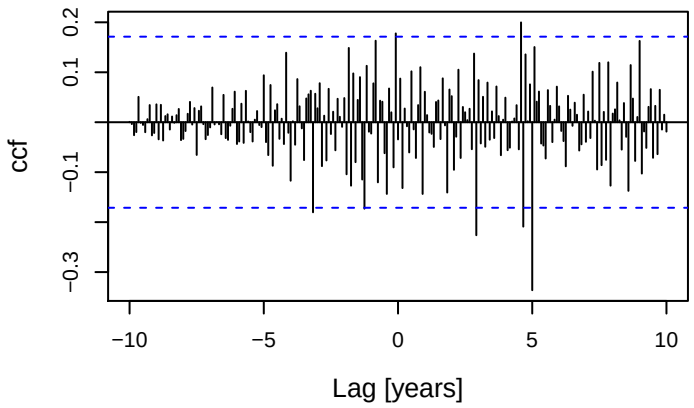
ccf GWL−TRMM Side Wadis, SW1



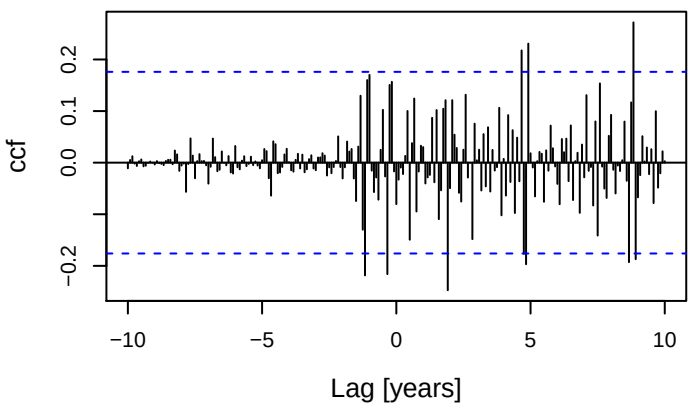
ccf GWL−TRMM Side Wadis, SW2

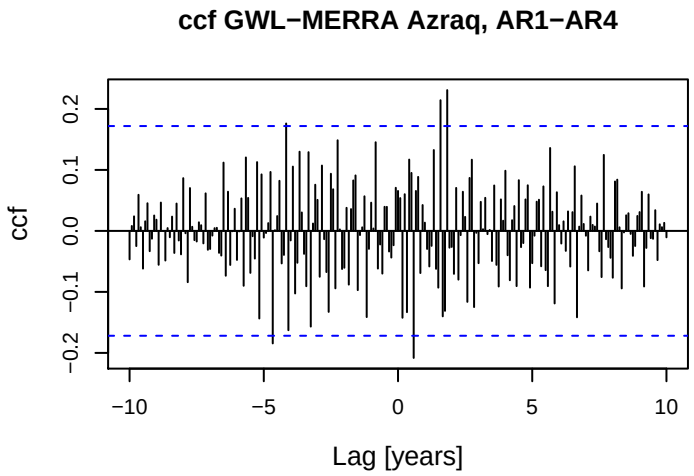


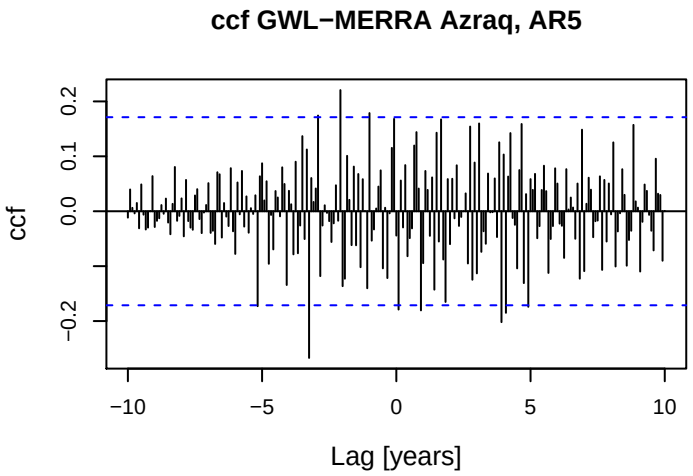
ccf GWL−TRMM Yarmouk, YM1−YM2

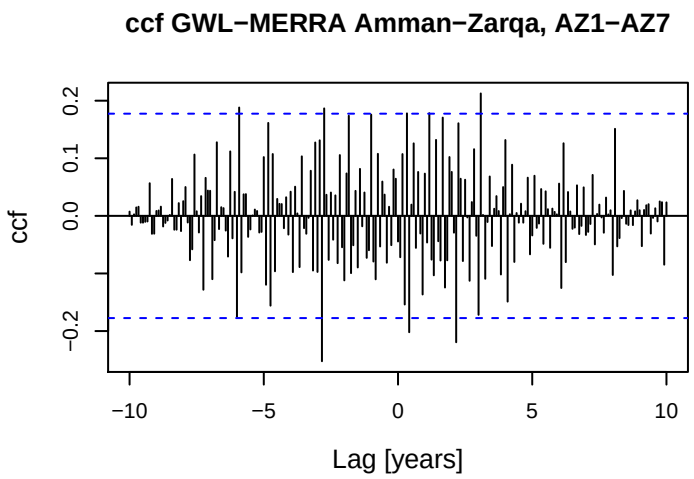


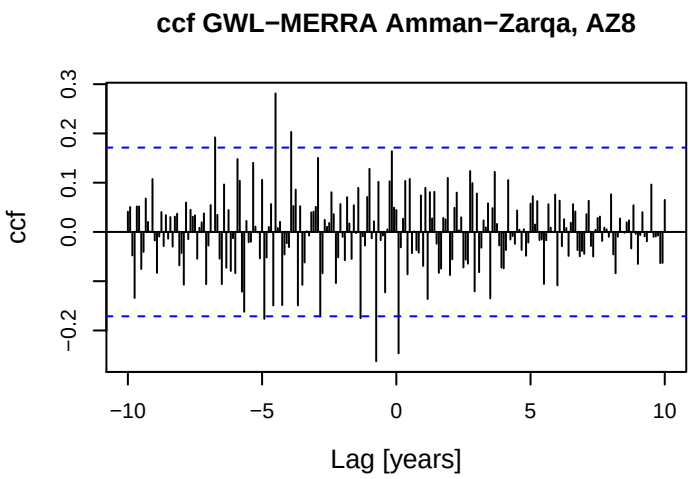
ccf GWL−TRMM Yarmouk, YM3

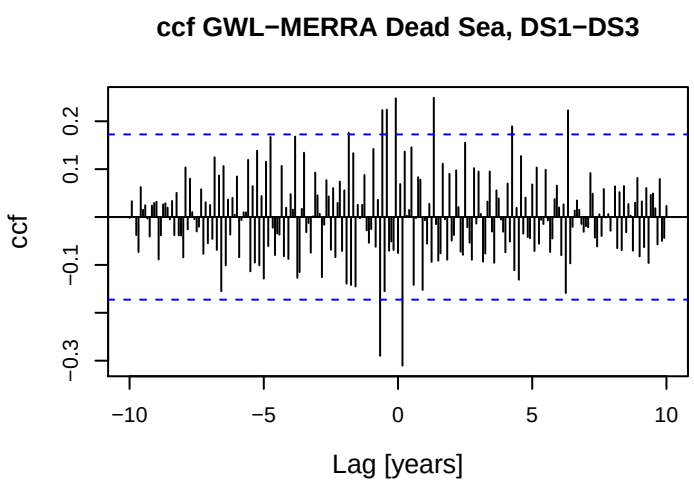


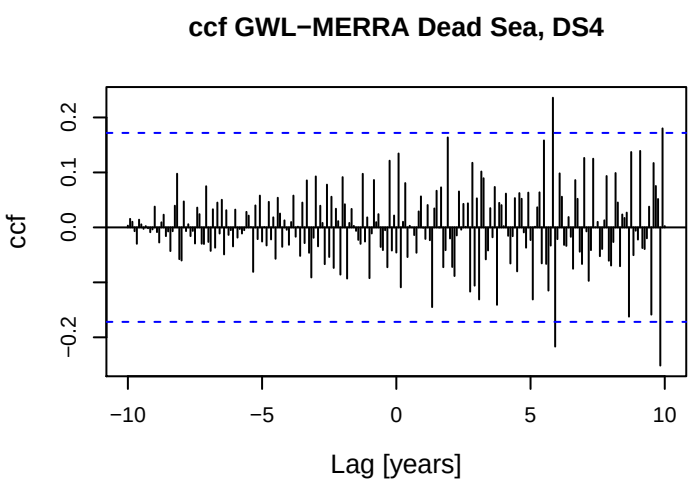

ccf GWL−MERRA Azraq, AR1−AR4
ccf
Lag [years]

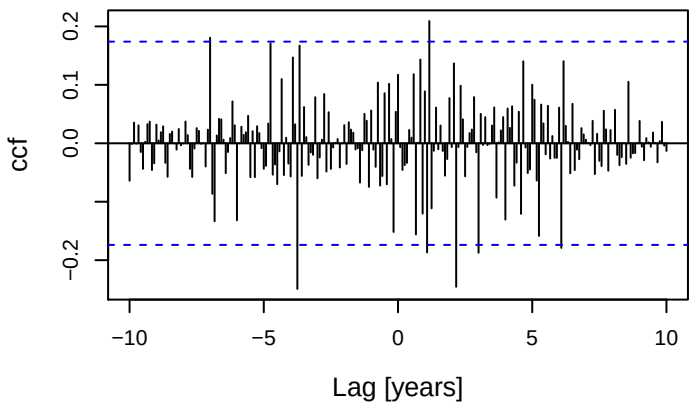

ccf GWL−MERRA Azraq, AR5
ccf
Lag [years]

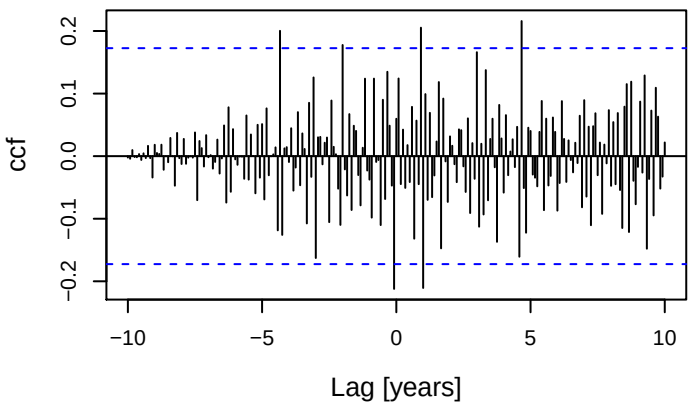

ccf GWL−MERRA Amman−Zarqa, AZ1−AZ7
ccf
Lag [years]

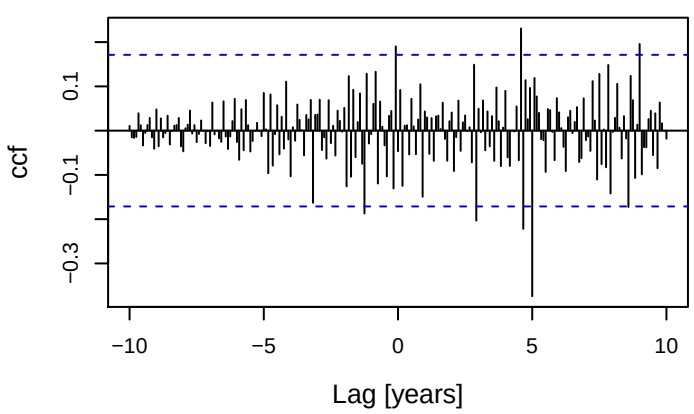

ccf GWL−MERRA Amman−Zarqa, AZ8
ccf
Lag [years]

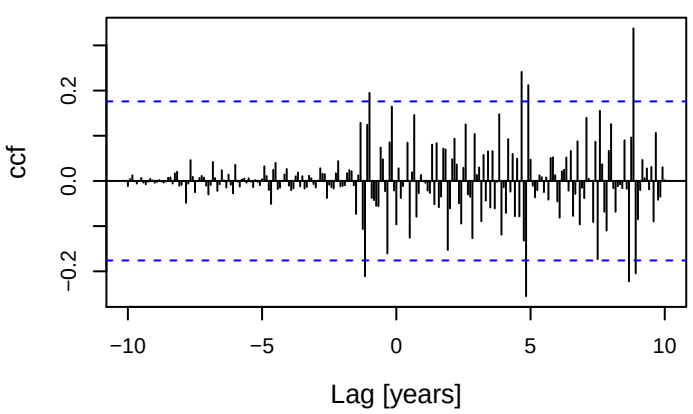

ccf GWL−MERRA Dead Sea, DS1−DS3
ccf
Lag [years]

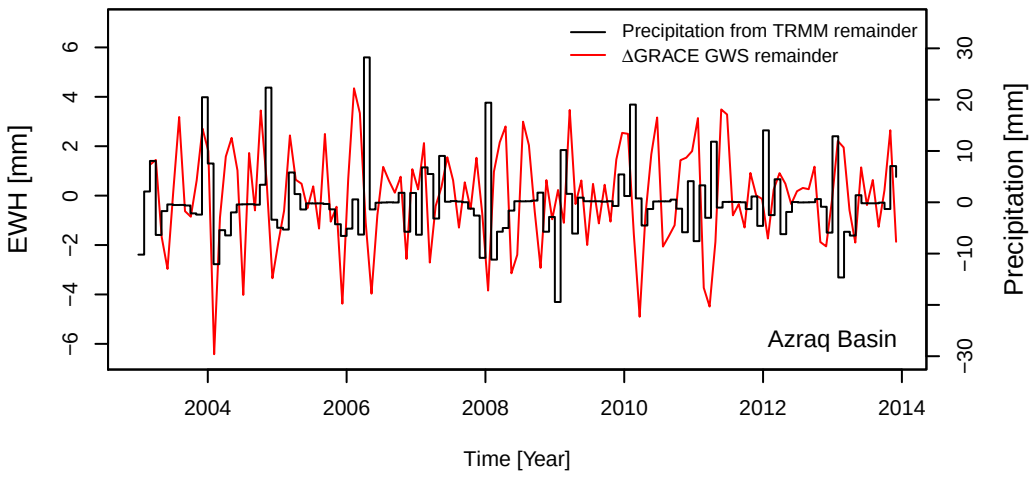

ccf GWL−MERRA Dead Sea, DS4
ccf
Lag [years]

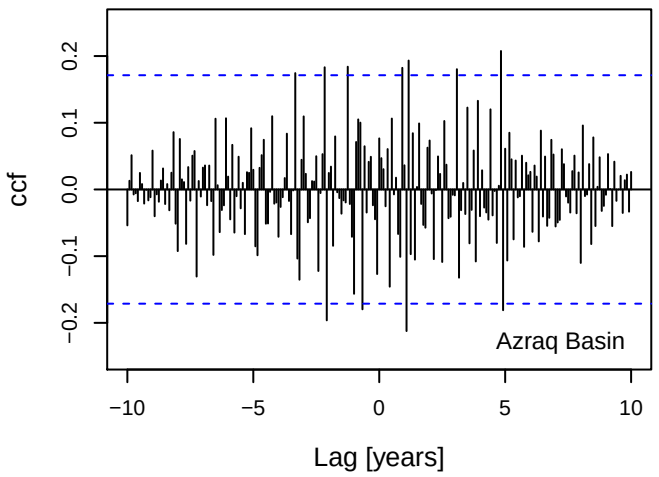

ccf GWL−MERRA Side Wadis, SW1
ccf
Lag [years]


ccf GWL−MERRA Side Wadis, SW2
ccf
Lag [years]


ccf GWL−MERRA Yarmouk, YM1−YM2
ccf
Lag [years]


ccf GWL−MERRA Yarmouk, YM3
ccf
Lag [years]


Precipitation from TRMM remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Azraq Basin
Time [Year]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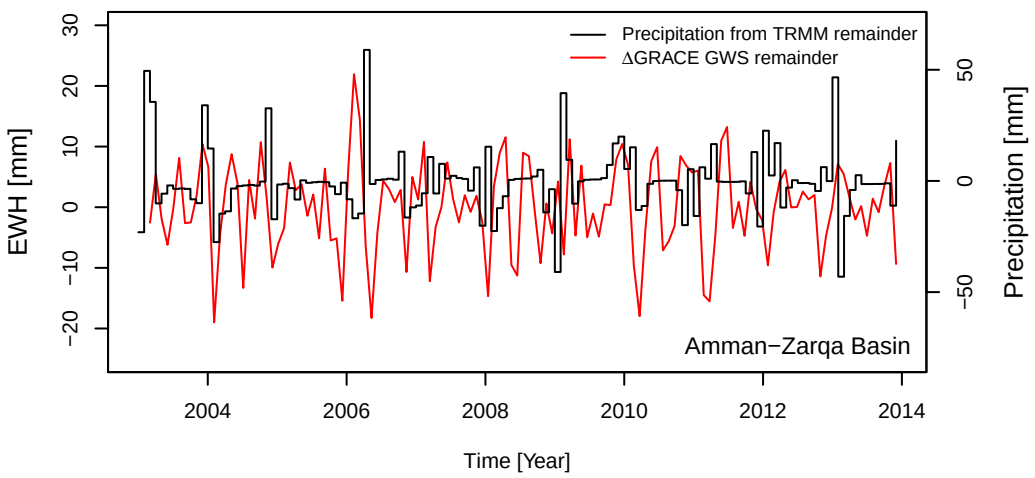
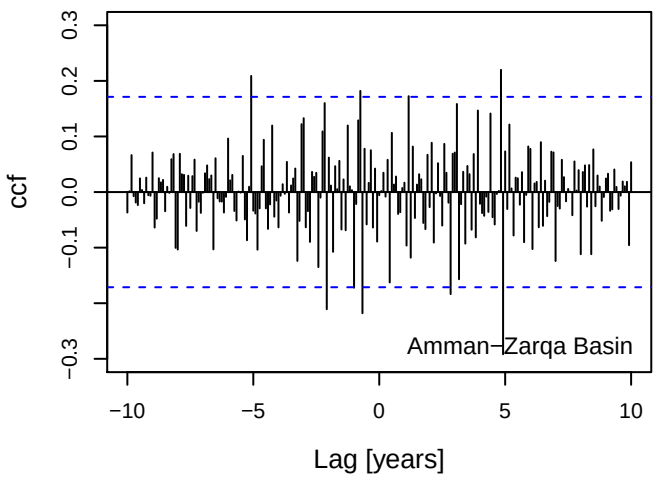
Azraq Basin
Lag [years]


Precipitation from TRMM remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Amman−Zarqa Basin
Time [Year]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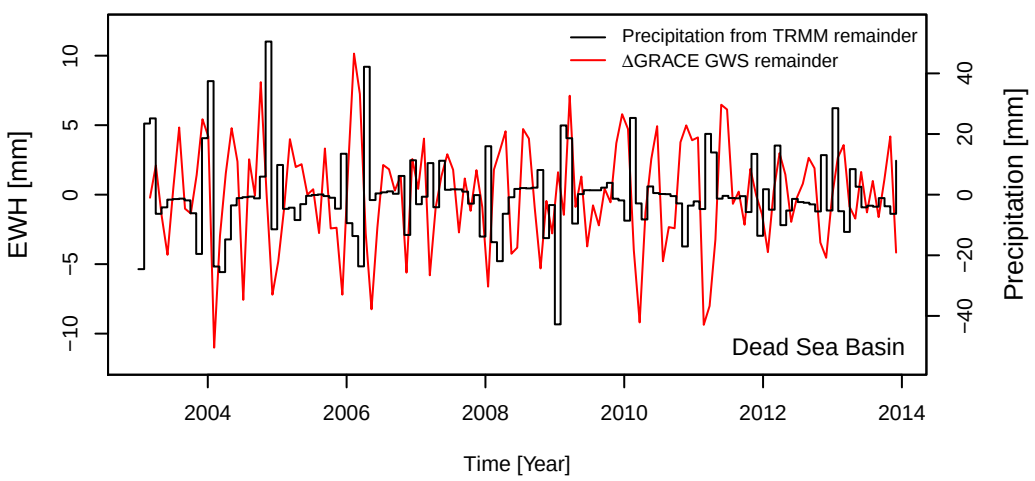
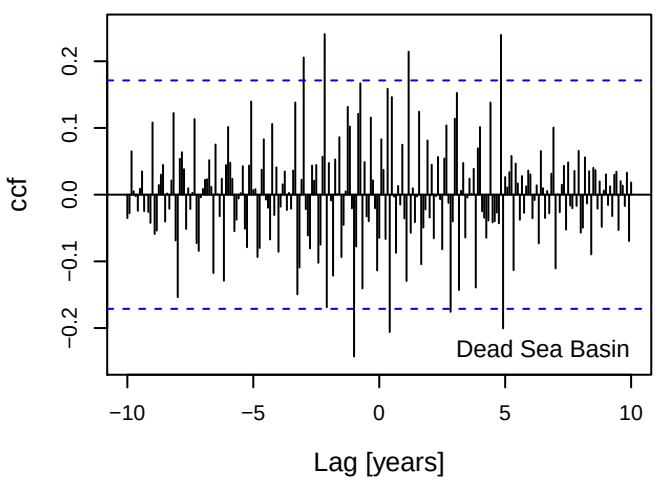
Amman−Zarqa Basin
Lag [years]


Precipitation from TRMM remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Dead Sea Basin
Time [Year]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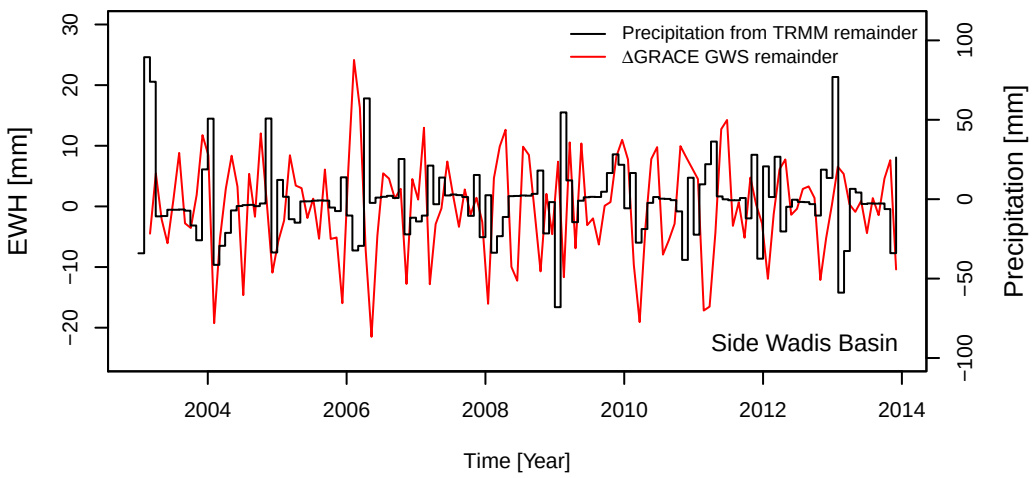
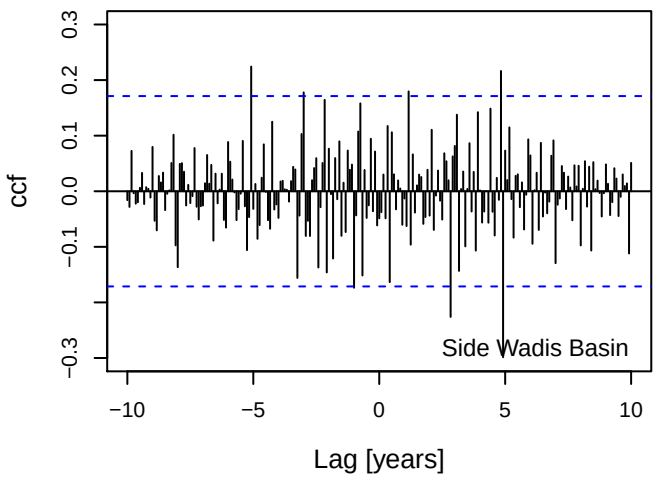
Dead Sea Basin
Lag [years]


Precipitation from TRMM remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Side Wadis Basin
Time [Year]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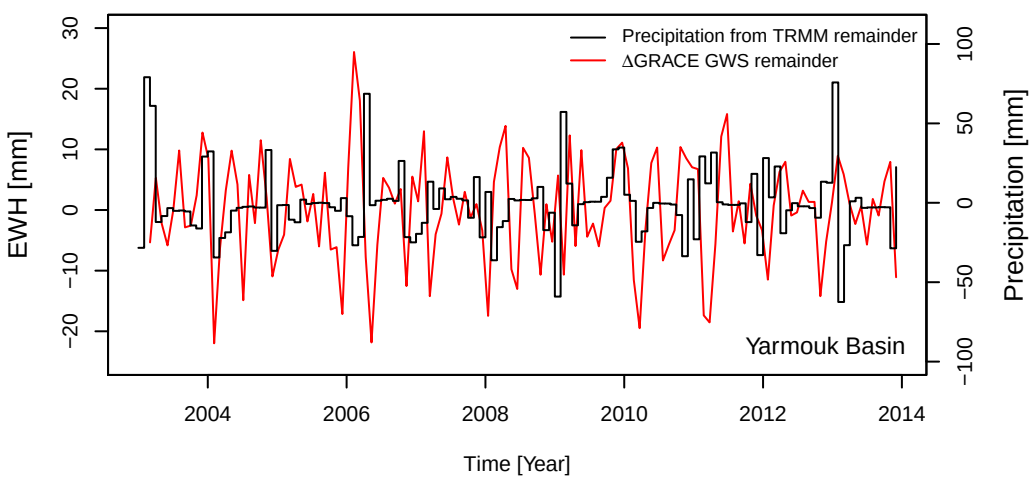
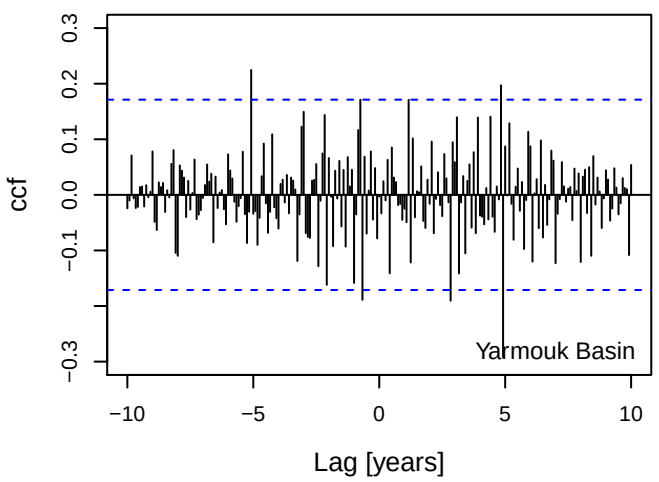
Side Wadis Basin
Lag [years]


Precipitation from TRMM remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Yarmouk Basin
Time [Year]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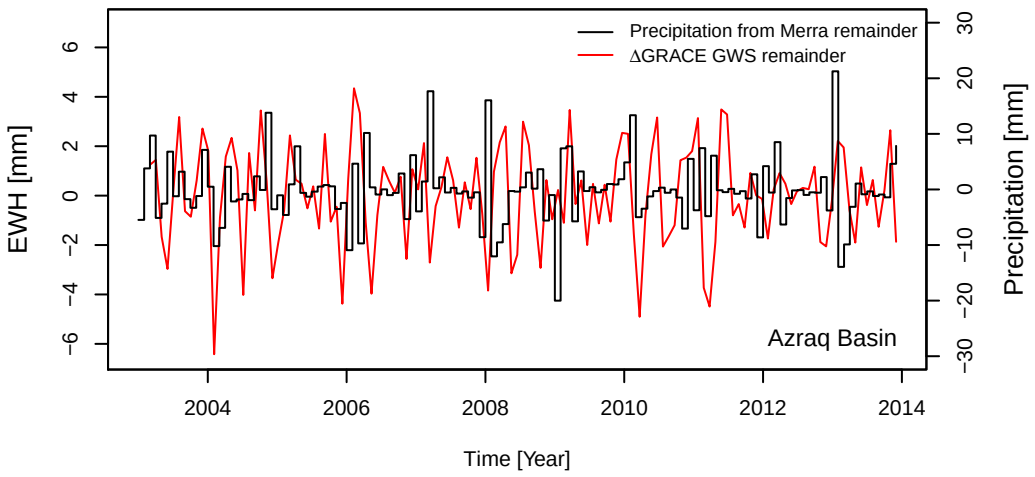
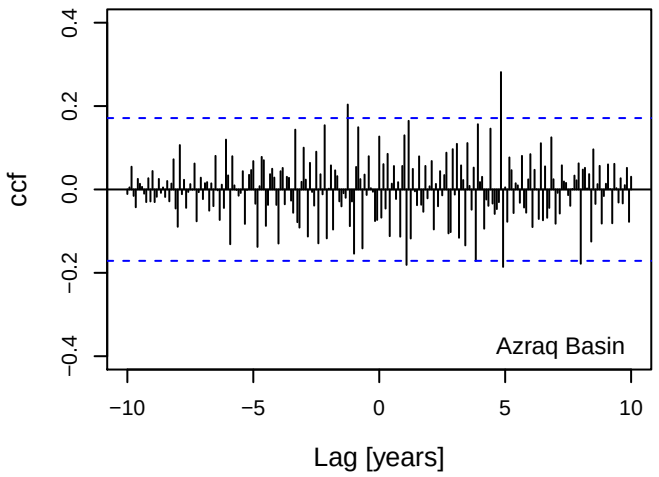
Yarmouk Basin
Lag [years]


Precipitation from Merra remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Azraq Basin
Time [Year]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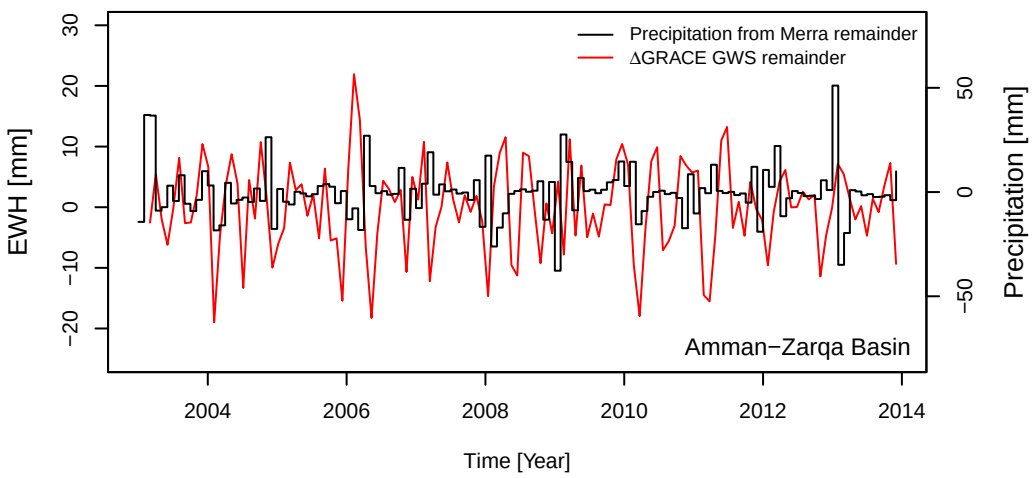
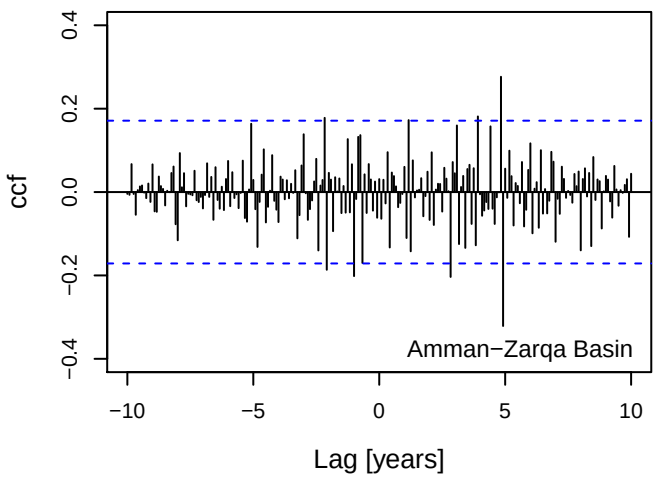
Azraq Basin
Lag [years]


Precipitation from Merra remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Amman−Zarqa Basin
Time [Year]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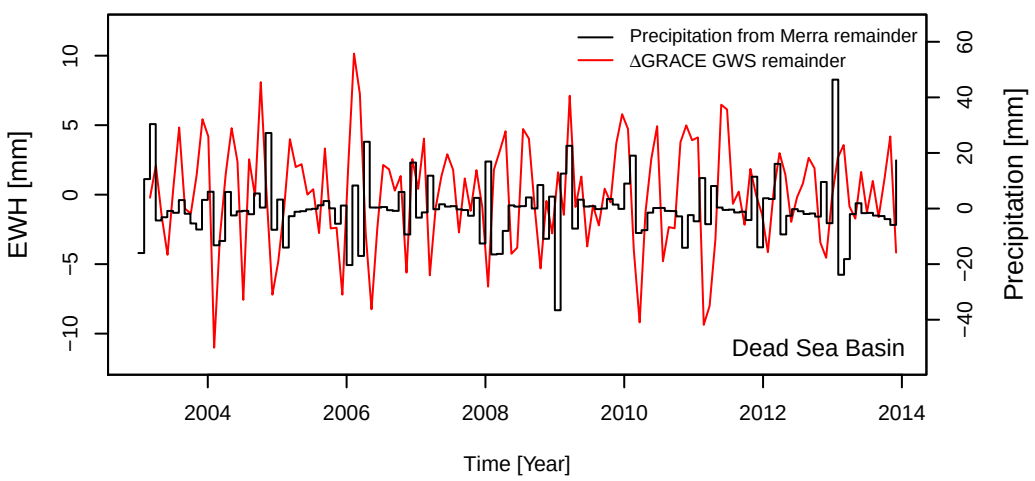
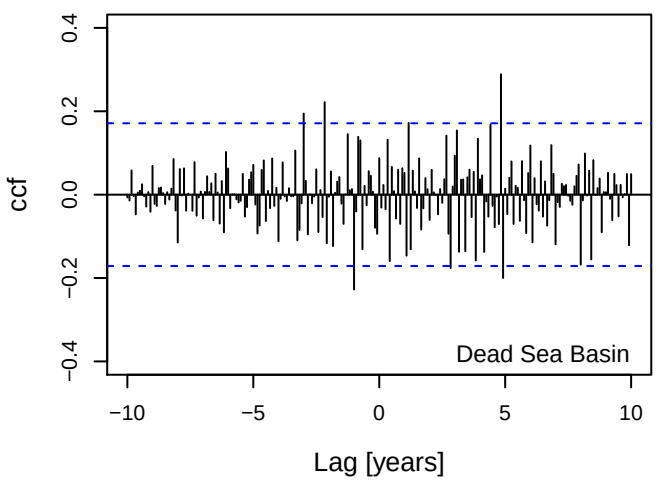
Amman−Zarqa Basin
Lag [years]


Precipitation from Merra remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Dead Sea Basin
Time [Year]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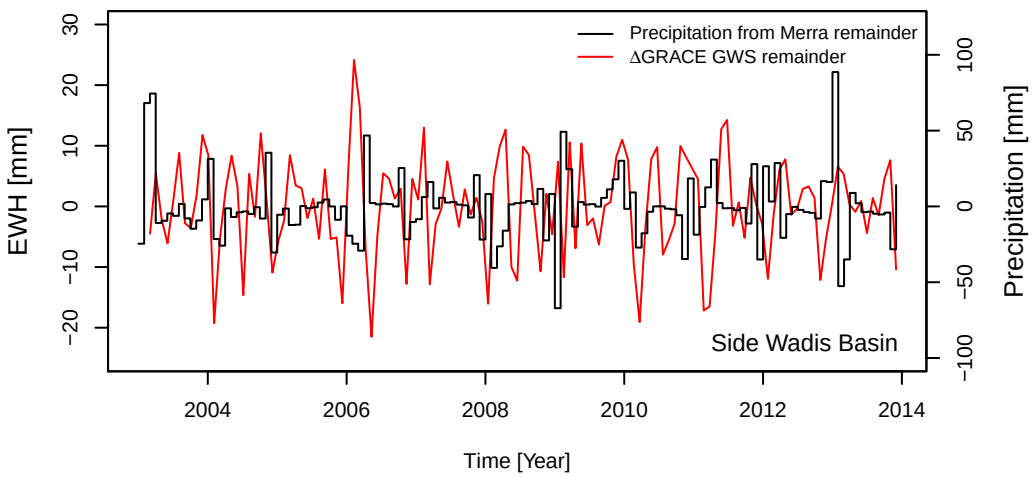
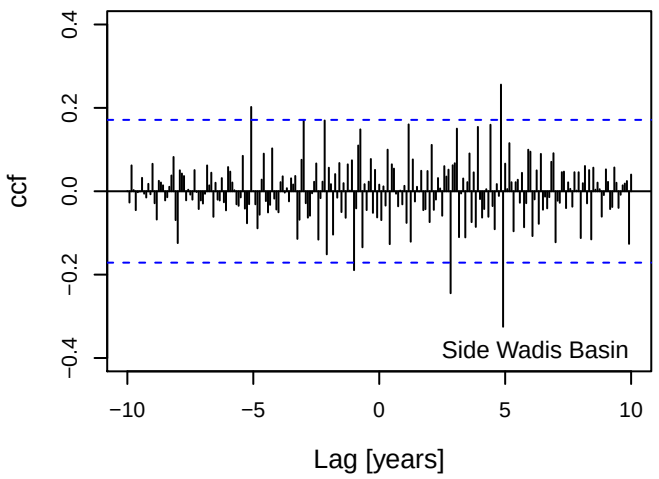
Dead Sea Basin
Lag [years]


Precipitation from Merra remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Side Wadis Basin
Time [Year]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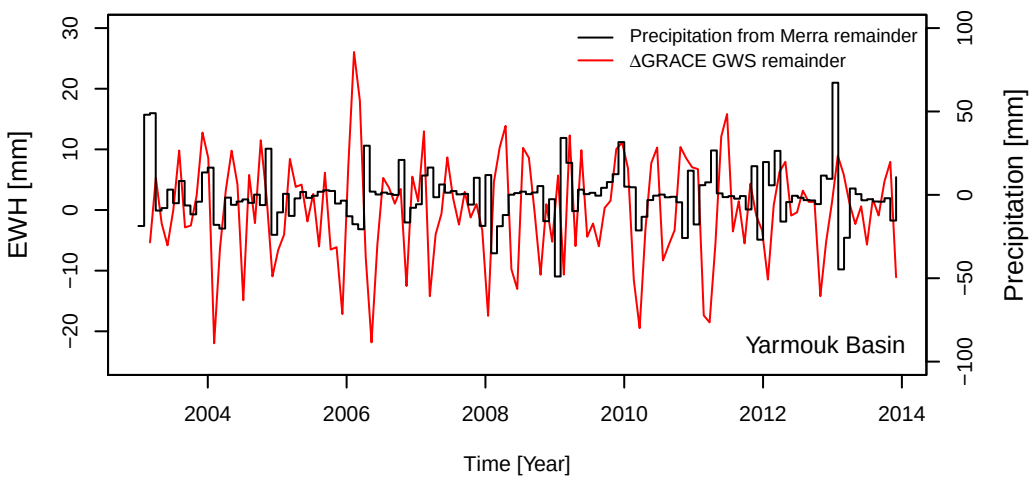
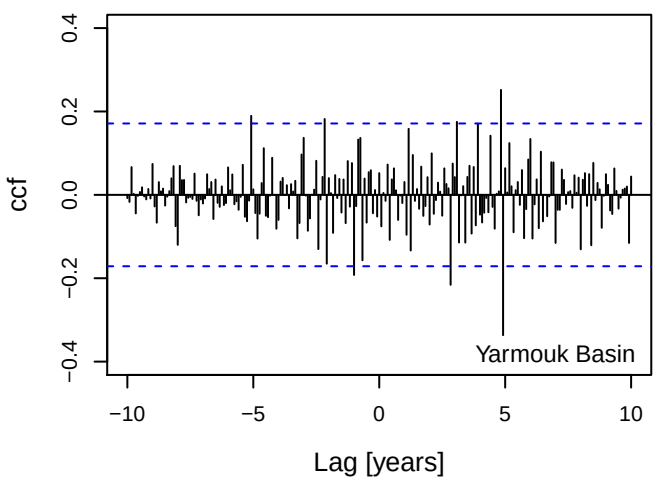
Side Wadis Basin
Lag [years]


Precipitation from Merra remainder
ΔGRACE GWS remainder
EWH [mm]
Precipitation [mm]
Yarmouk Basin
Time [Year]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Yarmouk Basin
Lag [years]