Dynamic Time Warping Algorithm for Model Calibration

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By

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3B Civil Engineering

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Dear Dr. Haas:

This report, entitled “Dynamic Time Warping Algorithm for Model Calibration” was prepared as my 3B work term report for the Department of Civil and Environmental Engineering at the University of Waterloo.

I was supervised by Dr. Eric Soulis and Dr. James Craig during my work term. I was also employed by the Department of Civil and Environmental Engineering at the University of Waterloo as a research assistant.

The report was written entirely by me and has not received previous academic credits from the University of Waterloo or any other academic institutions. I would like to thank Dr. Soulis and Dr. Craig for introducing me to the world of computational hydrological modelling. I received no help in writing this report.

Sincerely,

Shi Jie Tan

Summary:

Hydrological modeling is an essential tool for simulating hydrologic processes. To ensure the accuracy of a model, the input parameters are typically calibrated, either manually or automatically. One of the most common statistics used in the calibration processes is the Nash Sutcliffe Efficiency Coefficient (NSE). However, the metric is shown to be sensitive to outliers, magnitude bias, as well as time offset bias in time series data.

One method of accounting for this time offset bias is through a similarity search algorithm – dynamic time warping (DTW). DTW uses a nonlinear alignment method to optimally match he indices of the observed and simulated values. R, a statistical programming language and its "dtw" library are used for determining the normalized alignment distance between the two time series data. Four different step patterns were selected for analysis including symmetric, asymmetric, and Rabiner and Juang step pattern. The result from the sample test data - Irondequoit shows that DTW is able to capture the offset in the observed and simulated data but tend to perform some mismatches. Further experiments can be conducted to use the normalized alignment distance as a metric for calibration.

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1.0. Introduction

Hydrological modelling is a powerful tool for simulating the effects of watershed processes. In general, a model is intended to represent a simplified version of the real-world system. It typically consists of various parameters along with its unique characteristics which define the model. The two most fundamental inputs to any hydrological models are rainfall data and drainage area. Other characteristics such as soil properties, soil moisture content and topography are also typically considered. (Gayathri, Ganasri, & S, 2015)

To ensure that the model is indeed accurate, calibration is typically conducted by adjusting the input parameters such that the measured and simulated values match closely. Several established statistics for model evaluation and calibration include the Nash-Sutcliffe Efficiency Coefficient (NSE), percent bias, as well as the root mean squared error & standard deviation ratio (RSR). A novel approach for model calibration is proposed in this report using dynamic time warping – a similarity search algorithm.

2.0. Background

To reduce uncertainty in model simulation, calibration is typically required when evaluating the model. This is achieved by adjusting the input parameters based on the evaluation of simulated and observed data. The procedure begins with a sensitivity analysis followed by a manual or automatic calibration. Standard techniques for model calibration typically include NSE or RSR. A calibration procedure utilizing those two metrics is shown in Figure 1.

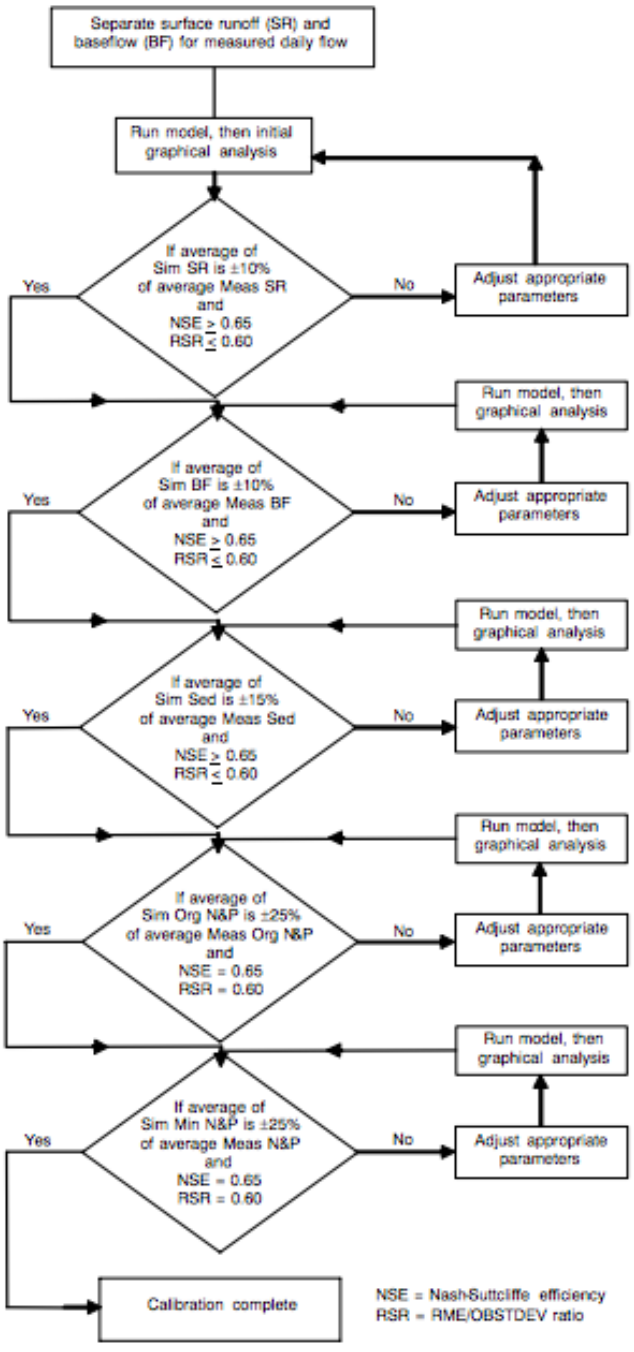

Figure 1. Calibration Procedure (Moriasi, et al., 2007)

3.0. Nash-Sutcliffe Coefficient

NSE is a common regression statistics used for calibrating hydrological models. A formulation and background of the NSE will be provided in this section.

3.1. Formulations

NSE is specifically adapted for evaluating the predictive power of a simulated hydrological model. The formulation is shown in the equation below.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y^{mean})^2}$$

Where Y_i^{obs} corresponds to the *i*th observed value, Y_i^{sim} corresponds to the *i*th simulated value, and $Y_{mean}$is the mean of all the observed data. The summation is used for accounting for all the observed and simulated data where n is the total number of observations.

If the predictions of a linear model are unbiased, the NSE value ranges from 0 to 1. If the predictions of a linear model are biased however, the NSE value can become negative.

A value of 1 corresponds to a perfect match between the modeled and observed data whereas a value of 0 indicates that the model prediction is as accurate as the mean of the observed data. A value of less than 0 indicates that the residual variance is larger than the data variance. Generally, values between 0 and 1 are acceptable (McCuen, Knight, & Gillian, 2006).

Based on the analysis of NSE conducted by McCuen, it was determined that outliers can largely influence the sample values of NSE. Furthermore, the time-offset bias and magnitude bias can negatively affect the accuracy of the metric.

3.2. Time Offset Bias

Time offset bias can arise in hydrological time series data when the rainfall and runoff data are not synchronized. This can be a result of the rain gauge located outside of the watershed or when the rainfall hyetograph is offset from the runoff hyetograph.

The NSE is sensitive to the time offset error. As a result, the numerator of the NSE increases and inflates. To assess the effects of this time offset error, a gamma distribution can be used with a shape parameter of 4.7. The shape parameter is "translated on the time axis to reflect a model that has not been properly calibrated to fit in the time domain but reproduces the magnitudes of the measured hydrograph" (McCuen, Knight, & Gillian, 2006). The result shows that as the offset interval increases, the value of the NSE decreases, meaning the less accurate the metric becomes. Similarly, the smaller the time interval, the less significant the offset is on the NSE.

4.0. Dynamic Time Warping

One method of accounting for the time bias in the time series data as seen in NSE is using a nonlinear alignment metric instead. Dynamic time warping is a type of sequence similarity search algorithms that finds the best match of the two time series using a nonlinear alignment. Figure 2 illustrates the idea of a nonlinear alignment where the index of one series can be matched to a different index in the other series.

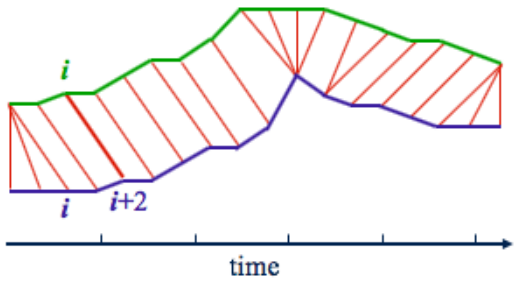

Figure 2. Non-linear Time Warping (Tsiporkova)

4.1. Algorithmic Definitions

The definition of the algorithm is as follows. Given two time series represented in the form of two vectors: $X = (x_1, \dots, x_N)$ and $Y = (y_1, \dots, y_M)$, there exists a local dissimilarity function f between the pairwise elements x_i and y_j.

$$d(i,j) = f(x_i, y_j) \geq 0$$

Where d is the cross-distance matrix between the vectors X and Y. The cross-distance matrix between the two vectors are used as the only input for the algorithm.

To remap the time indices of the two vectors X and Y, warping functions $\emptyset_x$ and $\emptyset_y$ are used to "pick the deformation of the time axes such that the two time series are as close as possible to each other". (Giorgino, 1-25)

$$D(X,Y) = \min d_{\emptyset}(X,Y)$$

Similarly, the average accumulated distortion between the warped time series X and Y can be determined as follows:

$$d_{\emptyset}(X,Y) = \sum_{k=1}^{T} d(\emptyset_x(k), \emptyset_y(k))\, m_{\emptyset}(k)/M_{\emptyset}$$

Where $m_{\emptyset}(k)$ is a per-step weighting coefficient and $M_{\emptyset}(k)$ is the corresponding normalization constant.

4.2. Warping Constraints

Constraints are typically imposed on the warping functions, including monotonicity, continuity, boundary conditions, warping window, and slope constraint.

Monotonicity is set to preserve the ordering of the alignment path such that the features are not repeated. Expressed in terms of the i and j axes, the monotonicity can be formulated as $i_{s-1} \leq i_s$ and $j_{s-1} \leq j_s$. Figure 3 illustrates the idea of monotonicity constraint.

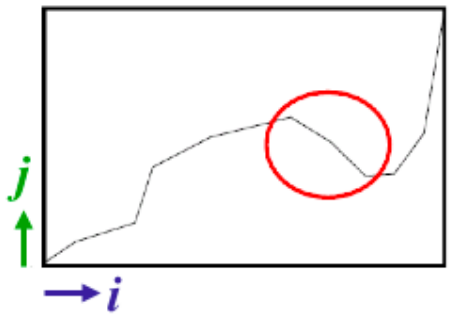

Figure 3. Monotonicity Constraint (Tsiporkova)

The second constraint is continuity such that the alignment path does not jump in time index and that no points are omitted in either of the time series. It can be expressed in terms of $i_s - i_{s-1} \leq 1$ and $j_s - j_{s-1} \leq 1$. Figure 4 illustrates the continuity constraint.

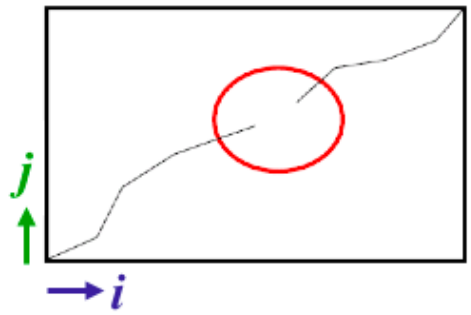

Figure 4. Continuity Constraint (Tsiporkova)

The third constraint is the boundary constraint such that the alignment starts at the bottom left and ends at the top right of the alignment path. It ensures that the alignment does not partially consider one series. It can be formulated as $i_1 = 1$, $i_k = n$, $j_1 = 1$, $j_k = m$. Figure 5 illustrates the idea of boundary constraint.

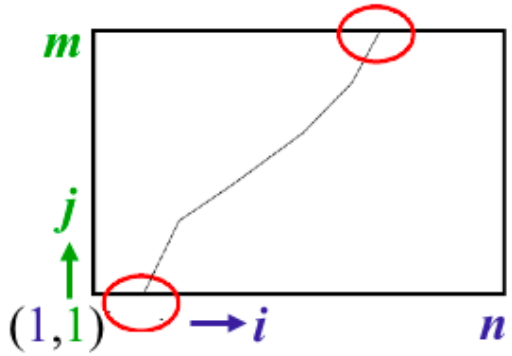

Figure 5. Boundary Constraint (Tsiporkova)

The forth constraint is the warping window such that the alignment does not skip different features or stop at similar features. A window band r is typically defined and expressed as $|i_s - j_s| \leq r$. Figure 6 illustrate this constraint.

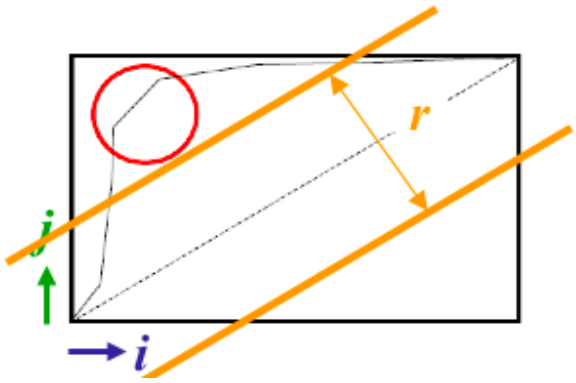

Figure 6. Window Constraint

Lastly, the sloping constraint can be implemented such that the alignment path does not become too deep or shallow. This effectively prevents short parts of the sequence matched with long parts

of the sequence. The constraint can be formulated as $(j_{sp} - j_{s0}) / (i_{sp} - i_{s0}) \leq p$ and $(i_{sq} - i_{s0}) / (j_{sq} - j_{s0}) \leq q$. Figure 7 illustrates the slope constraint.

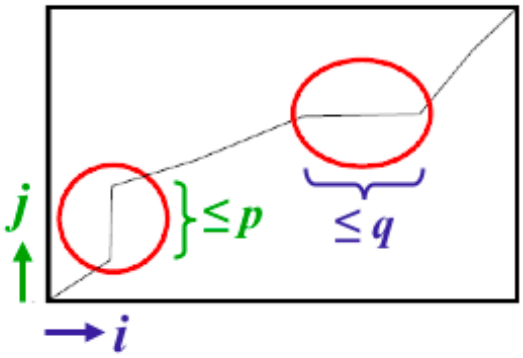

Figure 7. Slope Constraint (Tsiporkova)

4.3. Step Patterns

Step patterns compute the transition between the matched pairs and the corresponding weights. The step patterns specify $\emptyset(k+1)$ given the previous time steps $\emptyset(k)$ and $\emptyset(k-1)$ (Giorgino, 1-25).

The algorithms used in computing the step patterns are based on the method of dynamic programming where every time the algorithm is implemented, it references the solutions of subproblems that have already been computed. Four common step patterns can be used for computing the algorithms: symmetric 1, symmetric2, asymmetric and Rabiner and Juang's step pattern. The formulas for the step patterns are as follow:

Symmetric 1:

$$g[i,j] = \min (g[i-1,j-1] + d[i,j], g[i,j-1] + d[i,j], g[i-1,j] + d[i,j])$$

Symmetric 2:

$$g[i,j] = \min\left(g[i-1,j-1] + 2 \times d[i,j], g[i,j-1] + d[i,j], g[i-1,j] + d[i,j]\right)$$

Asymmetric:

$$g[i,j] = \min\left(g[i-1,j] + d[i,j], g[i-1,j-1] + d[i,j], g[i-1,j-2] + d[i,j]\right)$$

Rabiner and Juang:

$$g[i,j] = \min\left(g[i-2,j-1] + d[i-1,j] + d[i,j],\ g[i-2,j-2] + d\,[i-1,j] + d[i,j],\right.$$
$$\left. g[i-1,j-1] + d[i,j],\ g[i-1,j-2] + d[i,j]\right)$$

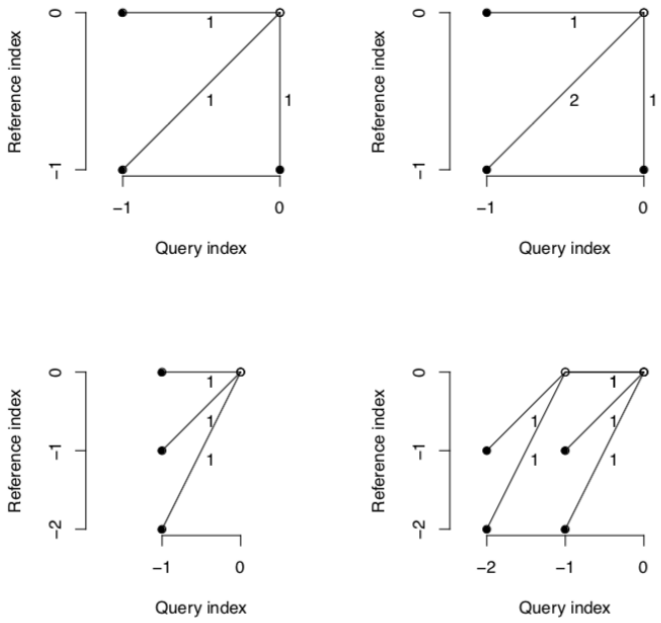

Figure 8. Four Step Patterns. From Left to Right and Top to Bottom: Symmetric 1, Symmetric 2, Asymmetric, Rabiner and Juang (Giorgino, 1-25)

Figure 8 shows the graphical form of the four step patterns where the horizontal axis represents the query index and the vertical axis represents the reference index.

5.0. Dynamic Time Warping Implementation

The implementation of dynamic time warping using the sample hydrological data as well as the results will be discussed in this section. The script is provided in Appendix 1 for further reference.

5.1. Procedure

The "dtw" library from R is used for analysis. The basic syntax is as follows:

$$dtw(x, y, dist.method = "Euclidian" , step.pattern = symmetric2)$$

Where a distance method, step pattern and window band can be selected.

All four types of step patterns were applied to the data sets and four alignment functions were defined: "alignment.rj", "alignment.as", "alignment.s1", "alignment.s2". To compute the average distance along the warping curve, the alignment distance was further normalized. Lastly, the step pattern with the lowest overall alignment distance was selected as the optimal alignment distance.

5.2. Data Analysis

A sample time series data set Irondequoit was used for analysis. The data set is provided in Appendix 2 for reference. The graph of the simulated vs observed hydrographs is plotted in Figure 9 as shown below. The simulated hydrograph corresponds to the black line and the observed hydrograph corresponds to the red line. As shown, the simulated hydrograph tends to follow the same trends as the observed data. The observed hydrograph however also shows much greater fluctuations than the simulated hydrograph.

Figure 10 shows the dynamic time warping effect on the simulated and observed plot. As expected, the peak of the simulated data also tends to match with the peak of the observed data. However, it can be observed in some instances, the peaks of the observed time series are matched to the farther

peaks of the simulated time series instead of the closer peaks. According to human intuition, those are perceived as mismatches.

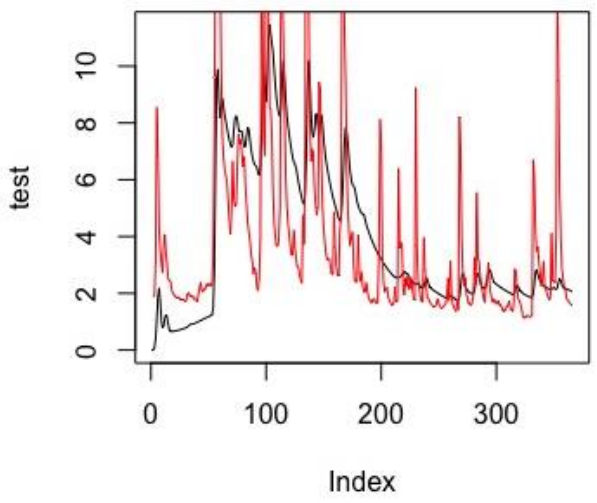

Figure 9. Simulated vs Observed Hydrographs (Observed and Simulated Data in Red and Black)

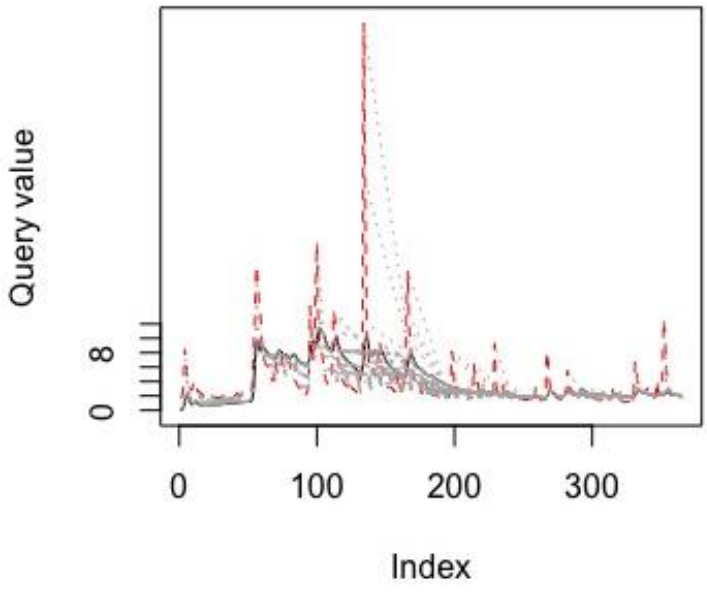

Figure 10. Simulated vs Observed Hydrographs with Dynamic Time Warping Effect

Figure 11 clearly shows the path of the alignment of the two time series data with the query index (simulated values) on the horizontal axis and the reference index (observed values) on the vertical axis. It can generally be observed that the algorithm performs well with the alignment path approximately linear. This indicates a relatively low alignment distance cost.

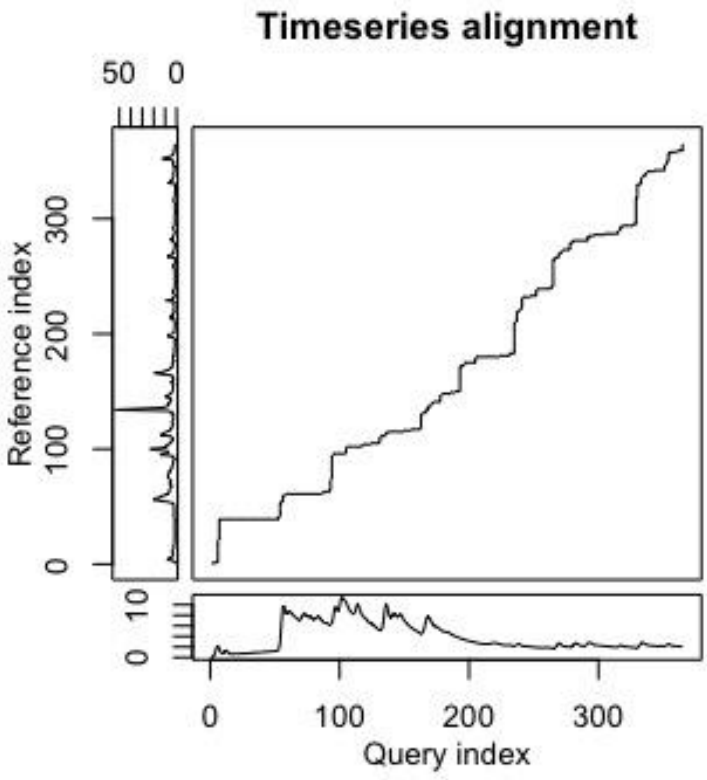

Figure 11. Time Series Alignment

6.0. Conclusion

Hydrological modelling is an essential tool for modelling hydrologic processes. Calibration is typically used for ensuring the accuracy of the model. Typically, the NSE and RSR are used during the calibration procedure. One shortcoming of NSE as discussed in this report is time offset bias as a result of the linear alignment. To potentially improve this, a similarity search algorithm –

dynamic time warping can be used for optimally matching the indices of the observed and simulated data based on the shortest distances. It can be observed from the results that dynamic time warping is able to capture the offset in the time series data but tend to perform some mismatches. Further experiments should be conducted to use dynamic time warping's normalized alignment distance as a metric for calibrating the model and potentially improve the calibration process.

References:

Gayathri, D., Ganasri, P., & S, D. (2015). A Review on Hydrological Models. *Elsevier*, 1001-1007.

Giorgino, T. (1-25). *Computing and Visualizing Dynamic Time Warping Alignments in R: The dtw Package* . Padua: National Research Council of Italy.

McCuen, R., Knight, Z., & Gillian, C. (2006). Journal of Hydrologic Engineering. *Evaluation of the Nash-Sutcliffe Efficiency Index*.

Moriasi, D. N., Arnold, J. G., Liew, M. W., Bingner, R. L., Harmel, R. D., & & Veith, T. L. (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *2007 American Society of Agricultural and Biological Engineers*, 885-900.

Tsiporkova, E. (n.d.). *Dynamic Time Warping Algorithm for Gene Expression Time Series.*

Appendix A:

```
library("dtw")
# specify library path
.libPaths()

# load the sample data
setwd("/Applications/DTW/")
hy <- read.csv("Irondequoit_Hydrographs.csv")

# process the data
Hydro.sim <- hy[,c(5)]
Hydro.obs <- hy[,c(6)]

Hydro.length <- length(Hydro.sim)

ref <- window(Hydro.obs, start = 1, end = 366)
test <- window(Hydro.sim, start = 1, end = 366)

# plot observed vs simulated data
plot(test, col = 'black',type ='l')
lines(ref,col = 'red')

# step patterns
alignment <- dtw(test, ref, keep=TRUE)

# plot
dtwPlotTwoWay(alignment)
dtwPlotThreeWay(alignment)

# find normalized distance
ratio <- alignment$normalizedDistance
print(ratio)
```

Appendix B:

time	date	hour	precip [mm/day]	Irondequoit [m3/s]	Irondequoit (observed) [m3/s]
0	2000-01-01	00:00.0	---	0	
1	2000-01-02	00:00.0	0.056154	0.0120349	1.8689
2	2000-01-03	00:00.0	3.80124	0.0930514	1.9255
3	2000-01-04	00:00.0	12.9496	0.394727	3.1432
4	2000-01-05	00:00.0	0.608368	1.05276	8.5517
5	2000-01-06	00:00.0	0	1.86501	6.881
6	2000-01-07	00:00.0	0.234571	2.18695	4.2475
7	2000-01-08	00:00.0	0	1.71816	3.5679
8	2000-01-09	00:00.0	1.89163	1.05952	3.0865
9	2000-01-10	00:00.0	4.48134	0.772944	2.7184
10	2000-01-11	00:00.0	2.09898	0.855347	3.5679
11	2000-01-12	00:00.0	0	1.10502	4.0776
12	2000-01-13	00:00.0	8.00024	1.25319	3.3697
13	2000-01-14	00:00.0	3.41527	1.14197	3.0016
14	2000-01-15	00:00.0	0	0.89601	2.4919
15	2000-01-16	00:00.0	0.17071	0.722163	2.4352
16	2000-01-17	00:00.0	0.989827	0.661968	2.4352
17	2000-01-18	00:00.0	0.388864	0.655252	2.1238
18	2000-01-19	00:00.0	0.607175	0.659432	1.9822
19	2000-01-20	00:00.0	5.47332	0.665045	1.9255
20	2000-01-21	00:00.0	4.62339	0.672017	1.9255
21	2000-01-22	00:00.0	0.057493	0.680245	1.8123
22	2000-01-23	00:00.0	0	0.689631	1.8689
23	2000-01-24	00:00.0	0.32191	0.700097	1.8689
24	2000-01-25	00:00.0	0.39982	0.711574	1.8123
25	2000-01-26	00:00.0	5.55843	0.723996	1.7556
26	2000-01-27	00:00.0	3.68739	0.737299	1.8123
27	2000-01-28	00:00.0	0.815723	0.751423	1.7556
28	2000-01-29	00:00.0	0	0.76631	1.7556
29	2000-01-30	00:00.0	2.16756	0.781905	1.699
30	2000-01-31	00:00.0	9.21333	0.800392	1.8123
31	2000-02-01	00:00.0	1.99685	0.828074	1.9822
32	2000-02-02	00:00.0	1.33349	0.867792	2.0105
33	2000-02-03	00:00.0	0.114555	0.900368	1.9255
34	2000-02-04	00:00.0	0.17071	0.909766	1.8689
35	2000-02-05	00:00.0	0.970349	0.911684	1.9255
36	2000-02-06	00:00.0	0.497207	0.921934	1.8123
37	2000-02-07	00:00.0	0.22911	0.939642	1.784
38	2000-02-08	00:00.0	0	0.959772	1.8123

39	2000-02-09	00:00.0	0	0.980104	1.699
40	2000-02-10	00:00.0	0.285265	1.00042	1.9255
41	2000-02-11	00:00.0	2.44265	1.02035	2.1521
42	2000-02-12	00:00.0	0	1.03987	2.3786
43	2000-02-13	00:00.0	0.22911	1.05948	2.1238
44	2000-02-14	00:00.0	5.77659	1.07957	2.0388
45	2000-02-15	00:00.0	4.85096	1.09993	2.1521
46	2000-02-16	00:00.0	0.22911	1.12004	2.1238
47	2000-02-17	00:00.0	1.18708	1.13969	2.2653
48	2000-02-18	00:00.0	1.82536	1.15903	2.3503
49	2000-02-19	00:00.0	7.6669	1.17835	2.2653
50	2000-02-20	00:00.0	0.22911	1.19781	2.322
51	2000-02-21	00:00.0	0	1.21712	2.2653
52	2000-02-22	00:00.0	0	1.23573	2.3503
53	2000-02-23	00:00.0	0	1.4882	3.2564
54	2000-02-24	00:00.0	0.114555	2.772	7.7022
55	2000-02-25	00:00.0	2.6651	6.30764	14.2717
56	2000-02-26	00:00.0	0.64382	9.56401	20.1899
57	2000-02-27	00:00.0	0.514375	9.89025	18.6891
58	2000-02-28	00:00.0	7.43325	8.86539	14.0451
59	2000-02-29	00:00.0	0	8.18535	13.5071
60	2000-03-01	00:00.0	0.341419	8.53066	9.7976
61	2000-03-02	00:00.0	2.79649	8.86039	7.5323
62	2000-03-03	00:00.0	2.42014	8.55045	6.796
63	2000-03-04	00:00.0	0	8.265	6.343
64	2000-03-05	00:00.0	0	8.06492	6.1447
65	2000-03-06	00:00.0	0	7.82703	5.9182
66	2000-03-07	00:00.0	0	7.6022	5.2386
67	2000-03-08	00:00.0	0.177249	7.40944	4.5873
68	2000-03-09	00:00.0	0	7.24326	4.0776
69	2000-03-10	00:00.0	9.93868	7.13641	4.9838
70	2000-03-11	00:00.0	0.570529	7.2494	6.6544
71	2000-03-12	00:00.0	11.4625	7.76072	5.2952
72	2000-03-13	00:00.0	1.74984	8.1767	5.0687
73	2000-03-14	00:00.0	0	8.2469	5.1253
74	2000-03-15	00:00.0	0.341419	8.10413	6.4562
75	2000-03-16	00:00.0	2.64526	7.80305	7.6172
76	2000-03-17	00:00.0	13.1978	7.67895	7.2491
77	2000-03-18	00:00.0	0	7.74112	7.419
78	2000-03-19	00:00.0	0	7.68309	6.881
79	2000-03-20	00:00.0	0	7.42115	6.4562

80	2000-03-21	00:00.0	0.114555	7.18007	6.8243
81	2000-03-22	00:00.0	0.497207	7.16064	5.8049
82	2000-03-23	00:00.0	0	7.50972	5.1253
83	2000-03-24	00:00.0	0	7.85508	4.5024
84	2000-03-25	00:00.0	0.114555	7.75861	4.1343
85	2000-03-26	00:00.0	0	7.40229	3.8511
86	2000-03-27	00:00.0	0.056154	7.06792	3.3697
87	2000-03-28	00:00.0	0.378064	6.82682	3.1148
88	2000-03-29	00:00.0	1.78775	6.65143	2.6901
89	2000-03-30	00:00.0	0.056154	6.53514	2.8883
90	2000-03-31	00:00.0	0	6.49133	2.7184
91	2000-04-01	00:00.0	0	6.41409	2.2087
92	2000-04-02	00:00.0	2.52612	6.25018	2.0954
93	2000-04-03	00:00.0	9.0937	6.1513	2.5485
94	2000-04-04	00:00.0	14.9884	6.43745	3.936
95	2000-04-05	00:00.0	0.976888	7.53016	14.4133
96	2000-04-06	00:00.0	0.347958	9.12687	11.355
97	2000-04-07	00:00.0	0	9.68308	7.3624
98	2000-04-08	00:00.0	10.9927	9.05375	6.8527
99	2000-04-09	00:00.0	11.8616	8.74408	16.5087
100	2000-04-10	00:00.0	3.9661	9.62457	23.2481
101	2000-04-11	00:00.0	1.59703	10.985	12.516
102	2000-04-12	00:00.0	6.44523	11.4528	8.58
103	2000-04-13	00:00.0	0	11.1143	8.4384
104	2000-04-14	00:00.0	0	10.8172	7.5889
105	2000-04-15	00:00.0	0	10.4836	5.5501
106	2000-04-16	00:00.0	0	9.88845	4.4741
107	2000-04-17	00:00.0	0.056154	9.31925	3.9927
108	2000-04-18	00:00.0	2.60078	8.8648	3.6812
109	2000-04-19	00:00.0	0	8.54295	3.6529
110	2000-04-20	00:00.0	0	8.34031	3.8511
111	2000-04-21	00:00.0	16.2963	8.22453	5.0404
112	2000-04-22	00:00.0	1.57661	8.49106	13.8469
113	2000-04-23	00:00.0	1.10508	9.58092	12.8275
114	2000-04-24	00:00.0	0	10.1976	10.902
115	2000-04-25	00:00.0	0	9.60713	8.2968
116	2000-04-26	00:00.0	0	8.83733	6.2297
117	2000-04-27	00:00.0	0	8.27335	5.097
118	2000-04-28	00:00.0	0	7.89744	4.4741
119	2000-04-29	00:00.0	0	7.59324	4.0776
120	2000-04-30	00:00.0	0	7.30836	3.6812
121	2000-05-01	00:00.0	1.99685	7.04025	3.3414

122	2000-05-02	00:00.0	4.92155	6.79985	3.3414
123	2000-05-03	00:00.0	0	6.6241	4.2192
124	2000-05-04	00:00.0	0	6.53988	3.6246
125	2000-05-05	00:00.0	0.892439	6.41842	3.2564
126	2000-05-06	00:00.0	0	6.18706	2.9166
127	2000-05-07	00:00.0	0	5.94075	2.9166
128	2000-05-08	00:00.0	0	5.72183	2.6618
129	2000-05-09	00:00.0	0	5.52859	2.4636
130	2000-05-10	00:00.0	4.54832	5.3516	2.3503
131	2000-05-11	00:00.0	2.64552	5.19456	4.7572
132	2000-05-12	00:00.0	22.9344	5.14403	3.7378
133	2000-05-13	00:00.0	26.6153	5.5395	7.9004
134	2000-05-14	00:00.0	7.11406	7.02736	53.8019
135	2000-05-15	00:00.0	0.949004	9.2244	31.998
136	2000-05-16	00:00.0	0	10.1978	12.063
137	2000-05-17	00:00.0	0.17071	9.48933	8.1836
138	2000-05-18	00:00.0	3.28911	8.41902	6.6544
139	2000-05-19	00:00.0	7.09488	7.71461	7.0792
140	2000-05-20	00:00.0	9.37683	7.48602	6.9376
141	2000-05-21	00:00.0	0.497207	7.77046	5.6917
142	2000-05-22	00:00.0	0	8.28852	5.1253
143	2000-05-23	00:00.0	1.31177	8.31686	4.7572
144	2000-05-24	00:00.0	13.3871	7.86573	5.0404
145	2000-05-25	00:00.0	5.02997	7.64289	9.4295
146	2000-05-26	00:00.0	0	8.00098	9.1746
147	2000-05-27	00:00.0	0	8.29439	6.5412
148	2000-05-28	00:00.0	0	7.97456	5.0687
149	2000-05-29	00:00.0	0	7.44168	4.3042
150	2000-05-30	00:00.0	0	6.99982	3.7661
151	2000-05-31	00:00.0	4.3217	6.68076	3.398
152	2000-06-01	00:00.0	0.056154	6.42254	3.1998
153	2000-06-02	00:00.0	3.46381	6.18729	3.1715
154	2000-06-03	00:00.0	0	5.96777	3.2281
155	2000-06-04	00:00.0	0	5.7617	2.9449
156	2000-06-05	00:00.0	0	5.56771	2.6901
157	2000-06-06	00:00.0	3.02521	5.38626	2.6618
158	2000-06-07	00:00.0	0.497207	5.22339	4.8705
159	2000-06-08	00:00.0	0.056154	5.0838	3.5962
160	2000-06-09	00:00.0	1.7482	4.94517	2.9733
161	2000-06-10	00:00.0	0	4.79339	2.7184
162	2000-06-11	00:00.0	3.7646	4.64421	2.6051

163	2000-06-12	00:00.0	16.3564	4.54381	4.1909
164	2000-06-13	00:00.0	11.5735	4.63714	4.644
165	2000-06-14	00:00.0	26.618	5.18977	13.7336
166	2000-06-15	00:00.0	1.55783	6.15094	19.3687
167	2000-06-16	00:00.0	13.135	7.282	11.5816
168	2000-06-17	00:00.0	1.28127	7.82406	9.4861
169	2000-06-18	00:00.0	0.285265	7.67052	6.5412
170	2000-06-19	00:00.0	0.277942	7.28812	4.9554
171	2000-06-20	00:00.0	0.114555	6.73936	4.1343
172	2000-06-21	00:00.0	1.0265	6.2978	3.6812
173	2000-06-22	00:00.0	8.09709	6.0006	3.936
174	2000-06-23	00:00.0	0.497207	5.83236	4.1626
175	2000-06-24	00:00.0	0.93997	5.77802	3.0016
176	2000-06-25	00:00.0	1.23146	5.68346	2.4352
177	2000-06-26	00:00.0	3.61648	5.47123	2.4069
178	2000-06-27	00:00.0	6.32335	5.24905	2.4069
179	2000-06-28	00:00.0	0	5.08059	4.0493
180	2000-06-29	00:00.0	1.71159	4.97424	2.7184
181	2000-06-30	00:00.0	9.10927	4.87703	2.4069
182	2000-07-01	00:00.0	0	4.7956	2.7467
183	2000-07-02	00:00.0	0	4.80126	2.237
184	2000-07-03	00:00.0	1.29138	4.76499	2.0388
185	2000-07-04	00:00.0	5.22704	4.59976	2.0671
186	2000-07-05	00:00.0	0	4.42124	2.3786
187	2000-07-06	00:00.0	0	4.29088	2.0671
188	2000-07-07	00:00.0	0	4.18413	1.8689
189	2000-07-08	00:00.0	0	4.06942	1.7556
190	2000-07-09	00:00.0	0.626684	3.95508	1.6707
191	2000-07-10	00:00.0	2.10552	3.84982	1.6707
192	2000-07-11	00:00.0	0	3.75311	1.784
193	2000-07-12	00:00.0	0	3.66209	1.8123
194	2000-07-13	00:00.0	0	3.57522	1.699
195	2000-07-14	00:00.0	1.48248	3.49208	1.6424
196	2000-07-15	00:00.0	2.015	3.41249	1.7273
197	2000-07-16	00:00.0	3.87287	3.33638	3.4546
198	2000-07-17	00:00.0	0.341419	3.26366	8.1269
199	2000-07-18	00:00.0	0	3.19414	7.0226
200	2000-07-19	00:00.0	0	3.12751	3.3414
201	2000-07-20	00:00.0	0	3.06346	2.3786
202	2000-07-21	00:00.0	0.114555	3.00186	2.0388
203	2000-07-22	00:00.0	1.40419	2.94266	2.1238
204	2000-07-23	00:00.0	0	2.88574	2.2087
205	2000-07-24	00:00.0	0	2.831	1.8689

206	2000-07-25	00:00.0	0	2.77832	1.7556
207	2000-07-26	00:00.0	0	2.72756	1.6707
208	2000-07-27	00:00.0	0	2.67861	1.5857
209	2000-07-28	00:00.0	0	2.63138	1.5857
210	2000-07-29	00:00.0	11.1649	2.58967	1.699
211	2000-07-30	00:00.0	0.285265	2.56505	2.2087
212	2000-07-31	00:00.0	3.80324	2.56491	1.699
213	2000-08-01	00:00.0	14.9793	2.55891	1.699
214	2000-08-02	00:00.0	5.85183	2.5462	6.3996
215	2000-08-03	00:00.0	2.28212	2.57521	3.5962
216	2000-08-04	00:00.0	18.72	2.60762	3.7945
217	2000-08-05	00:00.0	0	2.62753	3.6812
218	2000-08-06	00:00.0	0.22911	2.71252	2.237
219	2000-08-07	00:00.0	11.9758	2.76607	1.9255
220	2000-08-08	00:00.0	0.056154	2.71996	2.5485
221	2000-08-09	00:00.0	3.64691	2.70221	2.2653
222	2000-08-10	00:00.0	1.28445	2.68772	2.6335
223	2000-08-11	00:00.0	0.741239	2.60606	2.1521
224	2000-08-12	00:00.0	3.13788	2.5102	2.1804
225	2000-08-13	00:00.0	1.16672	2.44112	2.5485
226	2000-08-14	00:00.0	0	2.39615	2.1521
227	2000-08-15	00:00.0	0.855794	2.35921	1.8689
228	2000-08-16	00:00.0	9.32737	2.32786	1.7556
229	2000-08-17	00:00.0	4.06371	2.31663	9.2313
230	2000-08-18	00:00.0	0.17071	2.33712	3.6529
231	2000-08-19	00:00.0	0.497207	2.34693	2.5202
232	2000-08-20	00:00.0	0	2.30684	2.1804
233	2000-08-21	00:00.0	0	2.24548	1.8972
234	2000-08-22	00:00.0	0	2.19437	1.7273
235	2000-08-23	00:00.0	20.4324	2.17562	1.699
236	2000-08-24	00:00.0	5.69042	2.23903	3.9644
237	2000-08-25	00:00.0	0	2.42408	2.8317
238	2000-08-26	00:00.0	0	2.5564	2.2653
239	2000-08-27	00:00.0	0	2.48669	1.8689
240	2000-08-28	00:00.0	0	2.33934	1.8123
241	2000-08-29	00:00.0	0	2.23451	1.699
242	2000-08-30	00:00.0	0	2.18158	1.6424
243	2000-08-31	00:00.0	0	2.14903	1.5857
244	2000-09-01	00:00.0	0	2.1192	1.5291
245	2000-09-02	00:00.0	0	2.09016	1.5291
246	2000-09-03	00:00.0	0.32191	2.06188	1.5291
247	2000-09-04	00:00.0	0.626684	2.03436	1.6424
248	2000-09-05	00:00.0	0	2.00759	1.8123
249	2000-09-06	00:00.0	0	1.98157	1.6424
250	2000-09-07	00:00.0	0	1.95627	1.5291

251	2000-09-08	00:00.0	0	1.93162	1.4725
252	2000-09-09	00:00.0	2.06327	1.9076	1.4725
253	2000-09-10	00:00.0	1.09979	1.88418	1.5291
254	2000-09-11	00:00.0	3.26852	1.86154	1.5857
255	2000-09-12	00:00.0	5.06696	1.84089	1.6424
256	2000-09-13	00:00.0	10.5589	1.8292	1.8972
257	2000-09-14	00:00.0	1.9407	1.83997	2.5485
258	2000-09-15	00:00.0	5.80414	1.8773	1.7273
259	2000-09-16	00:00.0	4.06365	1.90193	3.1432
260	2000-09-17	00:00.0	0	1.89621	1.9822
261	2000-09-18	00:00.0	0	1.8779	1.6424
262	2000-09-19	00:00.0	0	1.84264	1.5008
263	2000-09-20	00:00.0	1.14106	1.79786	1.4442
264	2000-09-21	00:00.0	4.90715	1.76105	1.3592
265	2000-09-22	00:00.0	2.9409	1.73846	1.7273
266	2000-09-23	00:00.0	25.6802	1.75099	1.4158
267	2000-09-24	00:00.0	16.6137	1.8808	8.2119
268	2000-09-25	00:00.0	0	2.23115	6.7677
269	2000-09-26	00:00.0	3.70993	2.62624	3.8228
270	2000-09-27	00:00.0	0.911949	2.70043	2.7184
271	2000-09-28	00:00.0	0.771755	2.48801	2.2653
272	2000-09-29	00:00.0	0	2.26974	2.5485
273	2000-09-30	00:00.0	0	2.14413	1.9822
274	2000-10-01	00:00.0	0	2.08477	1.8123
275	2000-10-02	00:00.0	0	2.05036	1.6424
276	2000-10-03	00:00.0	0	2.02324	1.6141
277	2000-10-04	00:00.0	2.61146	1.99993	1.5857
278	2000-10-05	00:00.0	2.50391	1.98418	1.6707
279	2000-10-06	00:00.0	10.6286	1.99966	1.8972
280	2000-10-07	00:00.0	8.98529	2.09976	3.2564
281	2000-10-08	00:00.0	3.79223	2.34202	2.2937
282	2000-10-09	00:00.0	0	2.61696	5.5501
283	2000-10-10	00:00.0	0.569746	2.69776	3.1998
284	2000-10-11	00:00.0	1.20465	2.56127	3.1148
285	2000-10-12	00:00.0	0	2.37583	2.6335
286	2000-10-13	00:00.0	0	2.25778	2.2653
287	2000-10-14	00:00.0	0	2.20293	2.0388
288	2000-10-15	00:00.0	0.22911	2.17207	1.8123
289	2000-10-16	00:00.0	11.2624	2.16737	1.6707
290	2000-10-17	00:00.0	0.334097	2.25196	2.4069
291	2000-10-18	00:00.0	8.54225	2.488	2.4069
292	2000-10-19	00:00.0	0	2.7108	3.0865
293	2000-10-20	00:00.0	0	2.80539	2.3786
294	2000-10-21	00:00.0	0	2.77396	2.0105

295	2000-10-22	00:00.0	0	2.6211	1.8123
296	2000-10-23	00:00.0	0	2.47519	1.6707
297	2000-10-24	00:00.0	0.056154	2.39083	1.784
298	2000-10-25	00:00.0	0	2.34767	1.7273
299	2000-10-26	00:00.0	0	2.31733	1.6141
300	2000-10-27	00:00.0	0	2.28748	1.699
301	2000-10-28	00:00.0	0.497207	2.25802	1.7273
302	2000-10-29	00:00.0	0	2.22905	1.5857
303	2000-10-30	00:00.0	0	2.20081	1.5574
304	2000-10-31	00:00.0	0	2.17344	1.4725
305	2000-11-01	00:00.0	0	2.14688	1.3875
306	2000-11-02	00:00.0	0	2.12102	1.3592
307	2000-11-03	00:00.0	0.114555	2.09574	1.4158
308	2000-11-04	00:00.0	1.04823	2.07107	1.5574
309	2000-11-05	00:00.0	0.341419	2.04736	1.5574
310	2000-11-06	00:00.0	0	2.02487	1.7273
311	2000-11-07	00:00.0	0	2.00267	1.5008
312	2000-11-08	00:00.0	0	1.97997	1.4158
313	2000-11-09	00:00.0	1.38506	1.95771	1.3592
314	2000-11-10	00:00.0	9.32945	1.95253	1.5574
315	2000-11-11	00:00.0	1.78166	2.01318	2.86
316	2000-11-12	00:00.0	0	2.17349	2.775
317	2000-11-13	00:00.0	0.935501	2.28918	2.1521
318	2000-11-14	00:00.0	1.74984	2.23802	1.8123
319	2000-11-15	00:00.0	0	2.1283	1.7273
320	2000-11-16	00:00.0	0	2.06454	1.6141
321	2000-11-17	00:00.0	0.22911	2.03601	1.4442
322	2000-11-18	00:00.0	0.22911	2.00545	1.1893
323	2000-11-19	00:00.0	0	1.97285	1.1327
324	2000-11-20	00:00.0	0.22911	1.94643	1.1327
325	2000-11-21	00:00.0	1.0849	1.92518	1.1893
326	2000-11-22	00:00.0	1.2602	1.90573	1.2176
327	2000-11-23	00:00.0	1.48245	1.88676	1.1893
328	2000-11-24	00:00.0	0.114555	1.86827	1.161
329	2000-11-25	00:00.0	0.17071	1.85023	1.1893
330	2000-11-26	00:00.0	12.0114	1.85692	1.2176
331	2000-11-27	00:00.0	9.03435	1.98244	6.7111
332	2000-11-28	00:00.0	0.22911	2.34146	6.0315
333	2000-11-29	00:00.0	1.42629	2.74785	4.1626
334	2000-11-30	00:00.0	3.07185	2.8391	3.4546
335	2000-12-01	00:00.0	0	2.67382	3.6246
336	2000-12-02	00:00.0	1.597	2.52953	3.1148
337	2000-12-03	00:00.0	0	2.44506	2.6901
338	2000-12-04	00:00.0	0	2.36664	2.2653
339	2000-12-05	00:00.0	1.1777	2.30069	2.5485
340	2000-12-06	00:00.0	0.17071	2.25871	3.1148
341	2000-12-07	00:00.0	0.285265	2.23275	2.2653
342	2000-12-08	00:00.0	0.667917	2.21121	2.1238
343	2000-12-09	00:00.0	0.056154	2.19021	1.9822
344	2000-12-10	00:00.0	0	2.1697	1.8689

345	2000-12-11	00:00.0	0.455974	2.1497	1.7556
346	2000-12-12	00:00.0	6.10984	2.13512	1.9255
347	2000-12-13	00:00.0	0.893633	2.14046	4.1059
348	2000-12-14	00:00.0	14.9543	2.17445	2.4352
349	2000-12-15	00:00.0	0	2.19056	2.4352
350	2000-12-16	00:00.0	0	2.15695	2.3786
351	2000-12-17	00:00.0	9.19535	2.13007	4.0776
352	2000-12-18	00:00.0	0.64382	2.19539	12.7142
353	2000-12-19	00:00.0	0.114555	2.39099	9.4861
354	2000-12-20	00:00.0	0.341419	2.51725	5.5218
355	2000-12-21	00:00.0	0	2.43719	3.8794
356	2000-12-22	00:00.0	0	2.30269	2.8317
357	2000-12-23	00:00.0	0	2.22154	2.5485
358	2000-12-24	00:00.0	0.17071	2.18842	2.1238
359	2000-12-25	00:00.0	0.39982	2.17	2.1238
360	2000-12-26	00:00.0	0.056154	2.15198	1.8123
361	2000-12-27	00:00.0	0.72173	2.13434	1.7556
362	2000-12-28	00:00.0	0.892439	2.11706	1.699
363	2000-12-29	00:00.0	0.114555	2.10013	1.6424
364	2000-12-30	00:00.0	1.63827	2.08354	1.5857
365	2000-12-31	00:00.0	3.30078	2.06728	1.5857
366	2001-01-01	00:00.0	1.31174	2.05133	1.5291