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Green Computing

(A study to measure the Accuracy of ATmega 32 MCU in solving the complicated astronomical equation)

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Abstract: for a long time and solving the equations that have a several trigonometric functions with different angles was a problem for the electronic circuit designer as a matter of circuit complicity, processing time and cost. Examples of these equations are the astronomical equations that used to find the sun position for sun trackers. Solar tracking efficiency based on many important factors, accuracy is one of them. To solve these equations like declination angle and the equation of time a new electronic design has been presented in this paper. This design adopts ATmega32 and real time controller, since all the adopt equations based on time, to implement the electronic circuit design.

Keywords: Astronomical equations, data processing, electronic circuit design, embedded system, microcontroller applications.

Introduction

In order to enhance the productivity of the solar photovoltaic farm, it's required to design an efficient solar tracker. The efficiency of the tracker is a function of its tracking accuracy; power economy, durability; degree of freedom, initial cost and able to communicate with center station for power monitoring and fault diagnosis purposes [1].Sun position is founded based on astronomical equations. Some of these equations are exactly equations and the others are approximately. A study has been accomplished to find the more accurate equation between them to be used by the controller [2].

ATmega 32 Overview

The ATmega32 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega32 achieves throughputs approaching 1 MIPS per MHz allows the system designers to optimize power consumption versus processing speed. The AVR core combines a rich instruction set with 32 general purpose working registers.All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers [3]. Fig.1 shows the pin outs configuration of the ATmega32.

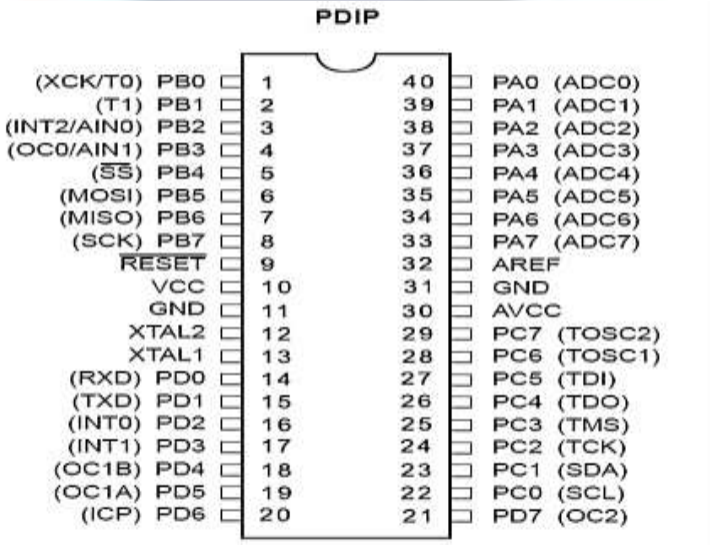

Figure 1. Pin outs ATmega32

The system adopts microcontroller instead of FPGA for many reasons like the cost of the microcontroller is cheaper than the FPGA, easy to program, PDIP pin outs make it easy to install. In comparing the ATmega32 with the other microcontroller like PIC, It has the ability to deal with the trigonometric functions, hyperbolic function, logarithmic function and more. All these function results are float number with accuracy up to six digits.

Equation of Time

Due to factors associated with the earth's orbit around the sun, the earth's orbital velocity varies throughout the year, so the apparent solar time varies slightly from the mean time kept by a clock running at a uniform rate. The variation is called the equation of time (EoT). The equation of time arises because the length of a day, that is, the time required by the earth to complete one revolution about its own axis with respect to the sun, is not uniform throughout the year. Over the year, the average length of a day is 24 h; however, the length of a day varies due to the eccentricity of the earth's orbit and the tilt of the earth's axis from the normal plane of its orbit. Due to the ellipticity of the orbit, the earth is closer to the sun on January 3 and furthest from the sun on July 4 [4] and [5] . Therefore the earth's orbiting speed is faster than its average speed for half the year (from about October through March) and slower than its average speed for the remaining half of the year (from about April through September). The values of the equation of time as a function of the day of the year (NDY) can be obtained approximately from equation 1:

$$\mathrm{EoT} = 0.00037 + 0.43177\cos \mathrm{N} - 7.3464\sin \mathrm{N} - 3.165\cos 2\mathrm{N} - 9.3893\sin 2\mathrm{N} + 0.07272\cos 3\mathrm{N} - 0.24498\sin 3\mathrm{N}$$

where N=(360/365)NDY

But there are more equations described the equation of time will discuss in chapter three. A graphical representation of Equation 1 is shown in Fig.2, from which the equation of time can be obtained directly.

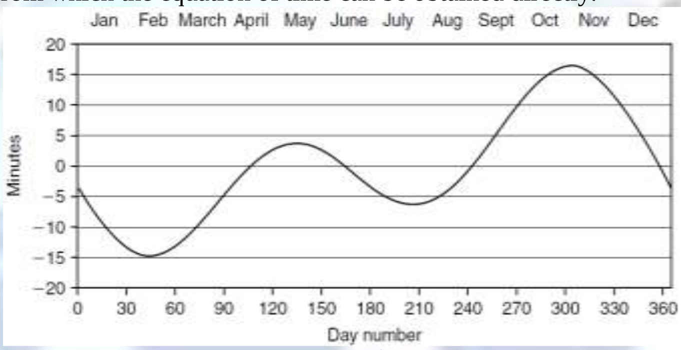

Figure 2Equation of time

Declination Angle, δ

As shown in Fig.3 the earth axis of rotation (the polar axis) is always inclined at an angle of 23.45° from the ecliptic axis, which is normal to the ecliptic plane. The ecliptic plane is the plane of orbit of the earth around the sun.As the earth rotates around the sun it is as if the polar axis is moving with respect to the sun. The solar declination is the angular distance of the sun's rays north (or south) of the equator, north declination designated as positive. As shown in Fig.4 it is the angle between the sun-earth center line and the projection of this line on the equatorial plane. Declinations north of the equator (summer in the Northern Hemisphere) are positive, and those south are negative

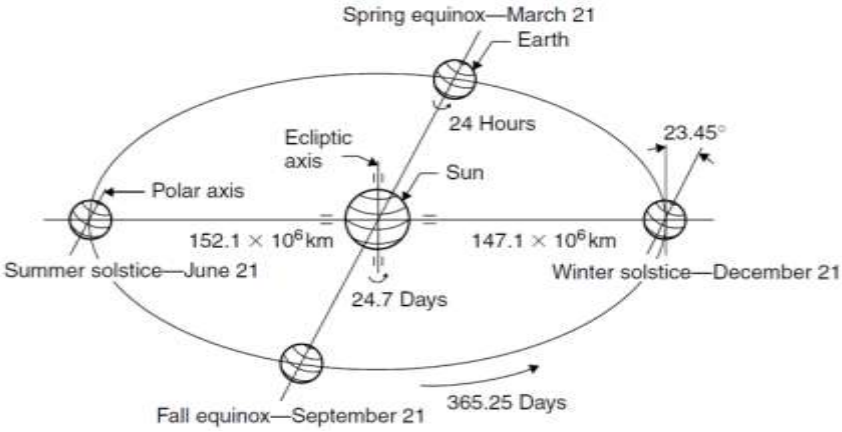

Figure 3 Annual motion of the earth about the sun

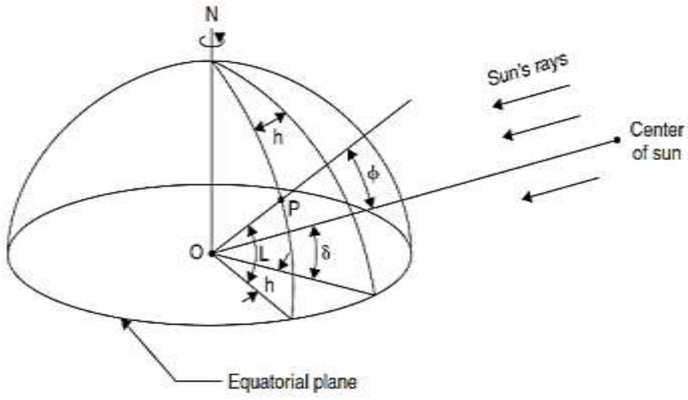

Figure 4: Definition of latitude, hour angle, and solar declination

Fig.5 shows the declination during the equinoxes and the solstices. As can be seen, the declination ranges from 0° at the spring equinox to +23.45° at the summer solstice, 0° at the fall equinox, and -23.45° at the winter solstice [6].

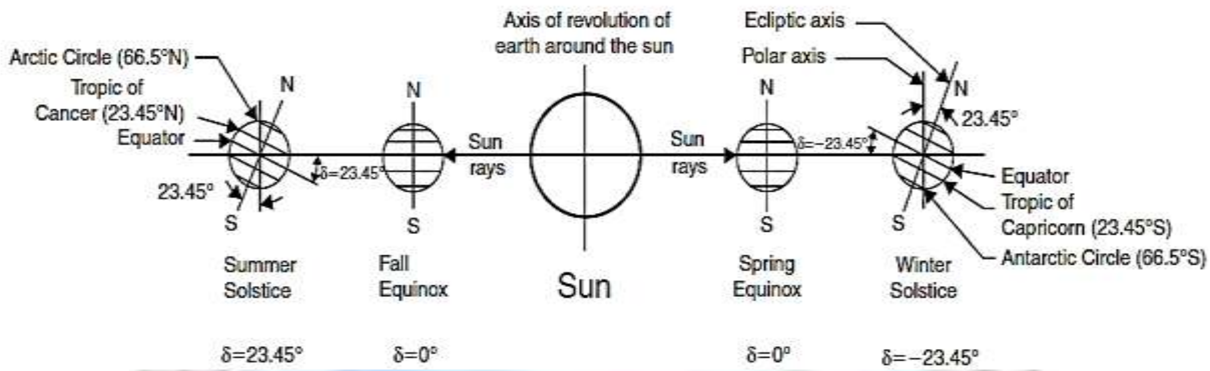

Figure 5: Yearly variation of solar declination

The variation of the solar declination throughout the year is shown in Fig.6. The declination, δ, in degrees for any day of the year (N) can be calculated by the Spencer formula:

$$\delta = 0.33281 - 22.984\cos N + 3.7872\sin N - 0.3499\cos 2N + 0.03205\sin 2N + 0.1398\cos 3N + 0.07187\sin 3N$$

where $N = (360/365)NDY$
(2)

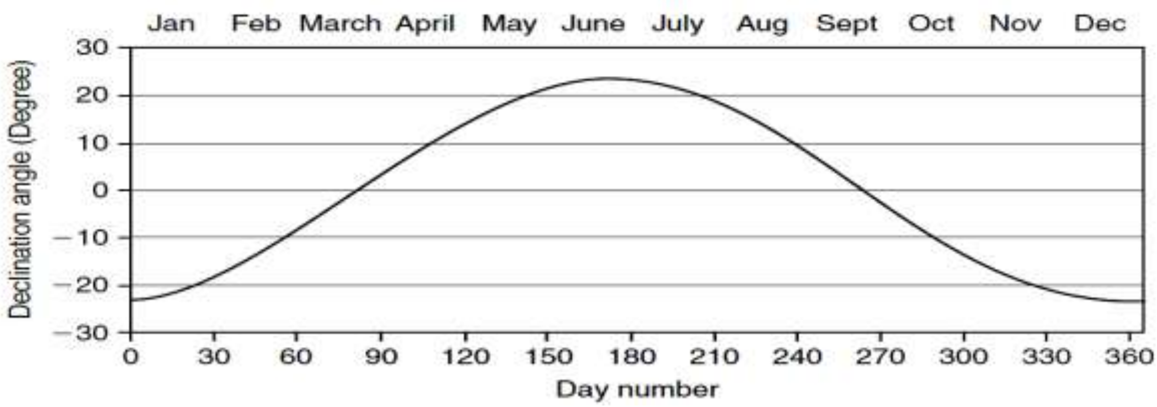

Figure 6: Declination of the sun

As shown in Fig. 5, the Tropics of Cancer (23.45°N) and Capricorn (23.45°S) are the latitudes where the sun is overhead during the summer and winter solstice, respectively. Another two latitudes of interest are the Arctic (66.5°N) and

Antarctic (66.5°S) Circles. As shown in Fig. 5, at winter solstice all points north of the Arctic Circle are in complete darkness, whereas all points south of the Antarctic Circle receive continuous sunlight.
The opposite is true for the summer solstice. During spring and fall equinoxes, the North and South Poles are equidistant from the sun and daytime is equal to night time, both of which equal 12 h [1] and [7].

Error Estimation Formulas

To compare, in matter of accuracy between several equations describe the same variable has approximated equations that based on statistical approximation, it's required to compare between the max error, the mean square error, the sum of the square error and the average of the square error as shown in equations 3,4,5 and 6.

- $\text{Max Absolute Error}(\mathbf{MAE}) = \text{MAX}|e_i| \quad 1 \leq i \leq 365$ (3)
- $\text{Mean Square Error}(\mathbf{MSE}) = (Y_{ai} - Y_{si})^2$ (4)
- $\text{Summation of Square Error}(\mathbf{SSE}) = \sum_{i=1}^{365}(Y_{ai} - Y_{si})^2 = \sum_{i=1}^{365} e^2$ (5)
- $\text{Average Absolute Error}(\mathbf{AAE}) = \frac{\sum_{i=1}^{365}|e^2|}{365}$ (6)

The result of the equations that describe the declination angle and the equation of time have been compared with the astronomical values that published by the [8] and [9] to calculate the accuracy of these equations andto find the best of them to use it later in the main design.

Equations Accuracy Estimation

A. Formulas describe the declination angle

There are many equations describe the declination angle, the research discus these equation briefly to evaluate the most accurate form of them. Table 1 lists five of them with AAE, MAE and SSE. Fig.7 shows the absolute error in declination equations compare with real values over one year (2012) [8].

Table1: Approximation Formulas for the Declination Angle

Formula	MAX	SSE
$\delta 1 = 23.45 \text{ x } \sin[(360/365)(NDY + 284)]$	1.1142	93.98
$\delta 2 = 23.45 \text{ x } \sin[(360/365)(NDY - 80)]$	1.8648	282.81
$\delta 3 = \sin^{-1}\{0.39795 \cos[0.98563(NDY - 173)]\}$	1.2303	124.12
$\delta 4 = 23.47 \sin[(360/365)(NDY + 284)]$	1.1215	95.45
$\delta 5 = 0.33281 - 22.984 \cos N + 3.7872 \sin N - 0.3499 \cos 2N + 0.03205 \sin 2N - 0.1398 \cos 3N + 0.07187 \sin 3N \text{ where } N = (360/365)NDY$	0.2967	12.93

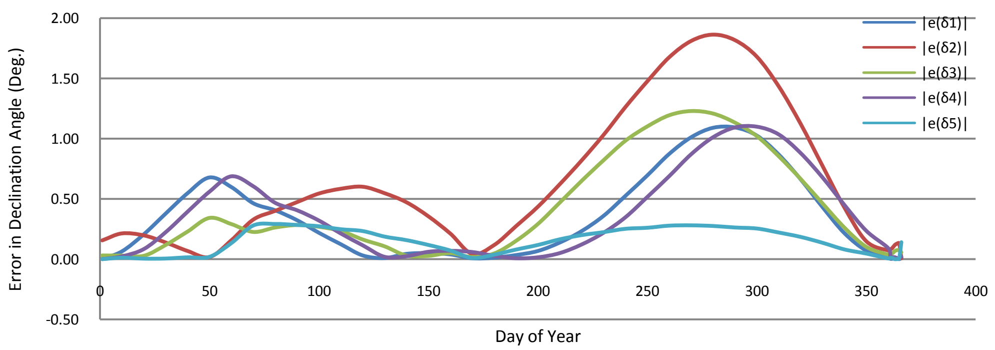

Figure 7: The absolute error for declination equations

B. Formulas Describe the Equation of Time

The values of the equation of time as a function of the day of the year (N) can be obtained approximately from the equations listed in Table 2 AAE, MAX and SSE have been calculated to find the most accurate equation. Fig.8 shows the absolute error for EoT equations comparing with real values over one year (2012) [9].

Table 2 Approximation Formulas for the Equation Of Time

Formula	MAX	SSE
$EoT1 = 9.87\sin 2B - 7.53\cos B - 1.5\sin B$ where B=360(NDY-81)/365)	0.4353	106.71
$EoT2 = -9\sin[2(NDY-1)] - 5$ for $NDY \leq 100$ $EoT2 = 5\sin[((NDY-100))/0.395] - 1$ for $100 < NDY < 242$ $EoT2 = 18.6\sin[(NDY-242)/0.685] - 2.5$ for $NDY \geq 242$	0.3987	67.21
$EoT3 = 12 + [0.123\sin X - 0.0043\cos X + 0.1538\sin 2X + 0.0608\cos 2X$ where $X = (NDY-1)(360/365.242)$	0.5618	166.67
$EoT4 = 0.00037 + 0.43177\cos N - 7.3464\sin N - 3.165\cos 2N - 9.3893\sin 2N + 0.07272\cos 3N - 0.24498\sin 3N$ where $N = (360/365)NDY$	0.3049	63.86

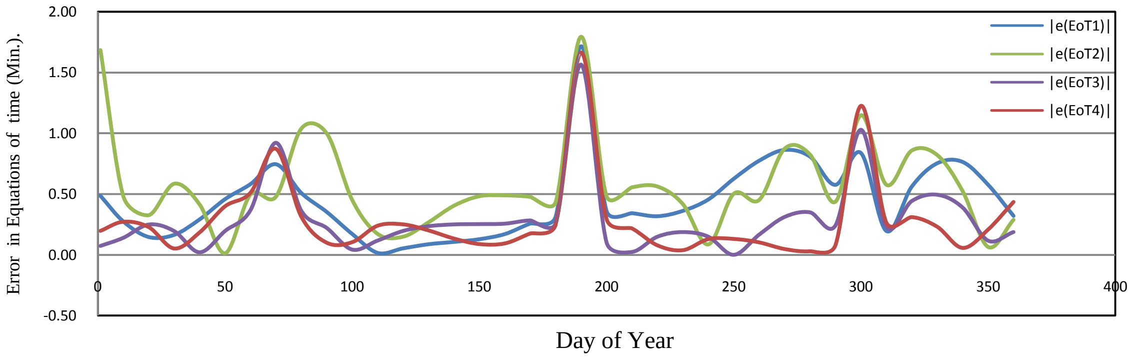

Figure 8: The absolute error for EoT equations

Circuit Implementation

The system adopts the most difficult equations describe the declination angle and equation of time, equation δ5 Table.1 and EoT4 Table.2 to measure the accuracy of the used microcontroller. Table.3 shows the error between the measured values of the equation 1 and 2 by computer and ATmega32 every 10 days. Fig.9 shows the simulation circuit which consists of ATmega32, real time controller (RTC) and LCD screen. The microcontroller read time and date periodically from the RTC via I2C protocol and calculate the declination angle and the equation of time as shown in the figure. Programming of the ATmega 32 has been done by using Flowcode AVR version 4. This program makes software for AVR microcontroller is easier, especially for the beginner.

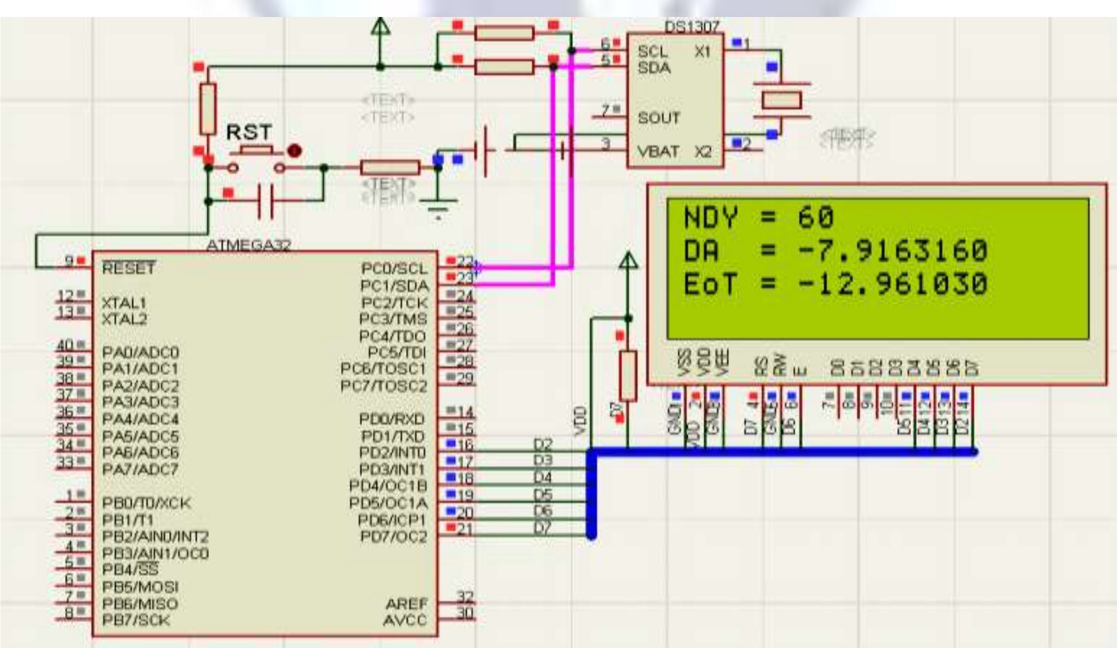

Figure 9: Circuit Simulation

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Fig. 10 shows the flowchart for the used program to produce the HEX file. This file is uploaded to the ATmega32 in the Proteus simulation software to display the DA, and EoT values. These values have been compared with result of the same equations via computer, and then the mean square error has been calculated for each value.

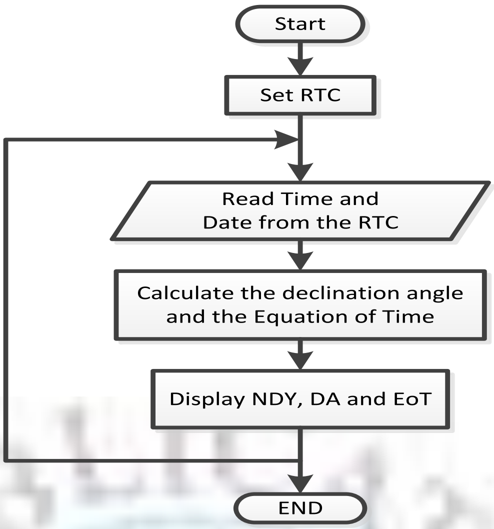

Figure 10: Software Flowchart

Conclusion and Result

Solving of complicated functions like Astronomical equations with accuracy as shown in Table.3 reflects a good apptinounity to electronic designers especially for solar tracking system. Such accuracy is more than enough since the maximum error for declination angle is (0.5521245 deg.) and (6.78082x10-10 minute) for the equation of time.

Table 3: Error Estimation

	Declination Angle	EoT
SSE	7.2116786	6.84939E-10
MAX	0.5521245	6.78082E-10
AAE	0.19491	1.85119E-11

Table 4: Error Estimation for the ATmega32 Calculations

Date	NDY	Declination Angle			Equation of time		
		Computer	ATmega32	MSE	Computer	ATmega32	MSE
1-Jan	1	-23.070062	-23.0673	7.629E-06	-3.119469	-3.119469	0
10-Jan	10	-22.148272	-22.071327	0.0059205	-7.027629	-7.027629	0
20-Jan	20	-20.506578	-20.295431	0.0445831	-10.638991	-10.638991	0
30-Jan	30	-18.262014	-17.88885	0.1392514	-13.164252	-13.164252	0
9-Feb	40	-15.480567	-14.948941	0.2826262	-14.401303	-14.401303	0
19-Feb	50	-12.244009	-11.586222	0.4326837	-14.299081	-14.299081	0
29-Feb	60	-8.647491	-7.9163172	0.5346151	-12.961029	-12.961029	0
10-Mar	70	-4.796746	-4.0536952	0.5521245	-10.628436	-10.628436	0
20-Mar	80	-0.804982	-0.1079762	0.4858171	-7.646245	-7.6462456	3.6E-13
30-Mar	90	3.210447	3.81718462	0.3681305	-4.416386	-4.4163866	3.6E-13
9-Apr	100	7.131493	7.62324762	0.2418226	-1.345402	-1.3454026	3.6E-13
19-Apr	110	10.842881	11.2151242	0.138565	1.206373	1.20637326	6.76E-14
29-Apr	120	14.2355	14.4999262	0.0699212	2.967388	2.96738826	6.76E-14
9-May	130	17.209612	17.3871822	0.0315312	3.784114	3.78411426	6.76E-14
19-May	140	19.67778	19.7910902	0.0128392	3.634029	3.63400296	6.78082E-10
29-May	150	21.567444	21.6346932	0.0045225	2.621874	2.62187426	6.76E-14
8-Jun	160	22.82305	22.8552672	0.0010379	0.960895	0.96089526	6.76E-14
18-Jun	170	23.407683	23.4097782	4.39E-06	-1.057514	-1.0575146	3.6E-13
28-Jun	180	23.304157	23.2791502	0.0006253	-3.101373	-3.1013736	3.6E-13
8-Jul	190	22.515515	22.4702882	0.0020455	-4.838213	-4.8382136	3.6E-13
18-Jul	200	21.064942	21.0153632	0.0024581	-5.973384	-5.9733846	3.6E-13

28-Jul	210	18.995083	18.9684452	0.0007096	-6.282948	-6.2829486	3.6E-13
7-Aug	220	16.36679	16.4002622	0.0011204	-5.638467	-5.6384676	3.6E-13
17-Aug	230	13.257333	13.3922632	0.0182062	-4.021873	-4.0218736	3.6E-13
27-Aug	240	9.758124	10.0312922	0.0746209	-1.52942	-1.5294206	3.6E-13
6-Sep	250	5.972038	6.40595122	0.1882807	1.635551	1.63555106	3.6E-15
16-Sep	260	2.01038	2.60522022	0.3538349	5.180658	5.18065806	3.6E-15
26-Sep	270	-2.01038	-1.2807922	0.5322984	8.752183	8.75218306	3.6E-15
6-Oct	280	-5.972038	-5.1586932	0.6615298	11.970494	11.9704946	3.6E-13
16-Oct	290	-9.758124	-8.9295012	0.6866157	14.470259	14.4702596	3.6E-13
26-Oct	300	-13.257333	-12.487487	0.5926629	15.94168	15.9416806	3.6E-13
5-Nov	310	-16.36679	-15.721305	0.4166509	16.168255	16.1682556	3.6E-13
15-Nov	320	-18.995083	-18.517944	0.2276616	15.056325	15.0563256	3.6E-13
25-Nov	330	-21.064942	-20.769347	0.0873764	12.652083	12.6520836	3.6E-13
5-Dec	340	-22.515515	-22.380801	0.0181479	9.142804	9.14280436	1.296E-13
15-Dec	350	-23.304157	-23.279675	0.0005994	4.840875	4.84087536	1.296E-13
25-Dec	360	-23.407683	-23.422868	0.0002306	0.151516	0.15151636	1.296E-13

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