Solar Energy Measurements for Ladakh, India

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Abstract

This paper reports on solar radiation data collected by the Ladakh Ecological Development Group (LEDeG) for the Ladakh region of India. The data collection program was designed by the author. Solar data collected using an Eppley 8-48 thermoelectric pyranometer during 1996-98 by LEDeG indicate that the annual average global solar energy on an horizontal plane for the town of Leh during the period was 5530 Whr/m^2/day, and at a 35° south facing tilt the annual average was 6360 Whr/m^2/day. These data confirm that Leh has an excellent solar resource.

Sunshine duration data collected using Campbell-Stokes sunshine recorders for the towns of Kargil and Sumoor (Nubra Valley) were used to estimate the solar radiation at these sites. The estimated average annual values for Kargil and the Nubra Valley (at Sumoor) were 5390 Whr/m^2/day and 5300 Whr/m^2/day, respectively. The differences between these sites and Leh suggest that there is moderate variation in the regional availability of solar energy in Ladakh.

However, although the regional differences in solar energy are relatively small, mountain shading creates large differences in solar access from area to area. Some villages have excellent solar access, with very little mountain shading. Other villages lose 20 to 40% or more of the available solar energy in some months each year due to mountain shading. Therefore, it is critical to evaluate each village or site for solar access before implementing solar related projects in Ladakh.

Key Words: solar, energy, measurement, data, Leh, Ladakh, India

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1. Introduction

Ladakh is located in the northernmost part of India, high in the Himalayan mountains. It is an isolated, high desert region populated primarily by farmers and nomadic herders. The farming depends entirely on irrigation from mountain streams; villages are distributed according to the availability of water. The region is geographically large, with an area of 100,000 sq. km, but sparsely populated (approximately 170,000 people in 239 villages [Maithel, et al., 1998]).

Leh, the main town in the region with a population of approximately 15,000, is located at 34.2° north latitude and at an altitude of 3,500 meters. Its climate is extremely dry (mean annual precipitation of 87 mm per year), and while the summers are mild, the winters are long and cold. Daily low temperatures in Leh of -20°C during winter are not uncommon. [Kawosa, 1988]

Solar technologies are becoming increasingly important in Ladakh. Passive solar heating and photovoltaic lighting systems are the most widely used technologies. Passive solar space heating became possible when glass was first brought into Ladakh in the 1960's, and is now relatively common. Photovoltaic lighting systems were introduced in the late 1980's, and there are now over 5,000 systems installed [Maithel, et al., 1998]. Other solar technologies used in Ladakh to varying degrees include solar water heaters, solar cookers, greenhouses, and solar dryers.

In 1995 the Ladakh Ecological Development Group (LEDeG) initiated a program to evaluate the region's renewable energy resources. The solar data reported here were collected through this program. A more complete summary of LEDeG's renewable energy data collection efforts for the period from 1996 to 1998 can be found in three

reports delivered to LEDeG by the author [Jacobson, 1997; Jacobson, 1998; Jacobson, 1999].

2. Solar Energy Data Collection for Ladakh

The solar data collection program at LEDeG consists of three major components. First, a thermoelectric pyranometer (Eppley 8-48, USA) and an integrator (Comptus, Inc., USA) are used to measure the daily global solar energy on an horizontal plane at Leh. This system was installed in December of 1995, and data have been collected daily since January 1, 1996. The results are presented in Section 2.1. These data are then used in Section 2.2 to estimate the amount of solar energy available on south facing tilted surfaces at Leh.

Second, Campbell-Stokes sunshine recorders (National Instruments, Ltd., India) are used at several stations to collect duration of sunshine data. The stations are at Leh (installed December 1995), Kargil (installed May 1996), Sumoor in the Nubra Valley (installed September 1996), and Nyoma (installed November 1996). The solar radiation and duration of sunshine data collected at Leh with the respective instruments were used to estimate duration of sunshine regression parameters for Ladakh. These parameters and duration of sunshine data were then used to estimate the availability of solar energy at Kargil, the Nubra Valley, and Nyoma. The results are presented in Section 2.3.

The third facet of the solar data collection program consists of shading surveys for 68 of Ladakh's 239 villages. A Solar Pathfinder instrument (Solar Pathways, USA) was used to carry out the surveys, which take approximately 15 minutes at each site to complete. The result is an estimate of the fraction of solar energy lost due to mountain shading for each month of the year. These data are important, as solar energy losses from mountain shading are substantial in some areas. The results are presented in Section 2.4.

2.1 Solar Energy Measurements for Leh, Ladakh

In this section solar radiation data collected at Leh during the period from 1996 to 1998 are presented. The annual average global solar energy on an horizontal plane for

Leh during 1996-98 was 5530 Watt hours per square meter per day (Whr/m^2/day), and at a 35° south facing tilt the annual average was 6360 Whr/m^2/day.

The global solar energy available on an horizontal plane at Leh for 1996 to 1998 are presented in Figure 1. Although there are minor differences between years for the solar energy available in individual months, overall the differences between the three years were relatively minor. The annual average daily solar energy for Leh in 1996 was 5510 Whr/m^2/day, the average for 1997 was 5470 Whr/m^2/day, and the average for 1998 was 5620 Whr/m^2/day. This means that 1998 was about 3% "sunnier" than 1997, while 1996 fell in between. These are small differences by most measures.

An estimate of the solar energy on an horizontal plane for Leh was presented previously in Solar Radiation Over India [Mani and Rangarajan, 1982]. However, these estimates were not based on measured solar data, so it is very useful to compare them to actual measurements. The average data from measurements made by LEDeG from 1996 to 1998 are presented below in Figure 2, along with the estimates made by Mani and Rangarajan. These show that the estimated values are higher than the measured ones for most months. However, additional years of measurements are required in order establish a reliable figure for the solar energy available in the area, as it is possible that the weather during 1996 to 1998 was not representative of the long term trend for the region.

The data collected by LEDeG in 1996-98 result in an annual average of 5530 Whr/m^2/day on an horizontal plane. This is 7% less than the annual average of 5900 Whr/m^2/day predicted by Mani and Rangarajan. It must be pointed out that, despite the fact that they are not based on measured data, the estimates made by Mani and Rangarajan agree remarkably well with LEDeG's measurements.

2.2 Solar Energy on a Tilted, South Facing Surface at Leh

The solar energy on an horizontal plane can be used to estimate the solar energy on a tilted surface using mathematical formulas [Duffie and Beckman, 1991]. A tilt of 35 degrees (°) is common for solar systems in Ladakh, such as solar electric and water heating systems. Occasionally it is desirable to tilt the system at a steeper gradient to

maximize the winter sun. For passive solar heating systems, the tilt is often 90° as the glass is vertical. Estimated values of the solar energy on various tilted surfaces are presented in Table 1.

The data in Table 1 show that the solar energy increases significantly when the tilt is 35° as compared to an horizontal plane. On an annual average the increase is from 5530 $Whr/m^2/day$ to 6360 $Whr/m^2/day$, a difference of 15%. A south facing tilt of 35° at Leh maximizes the total yearly availability of solar energy. Also note that at a 35° tilt the differences between winter and summer time solar energy are decreased substantially.

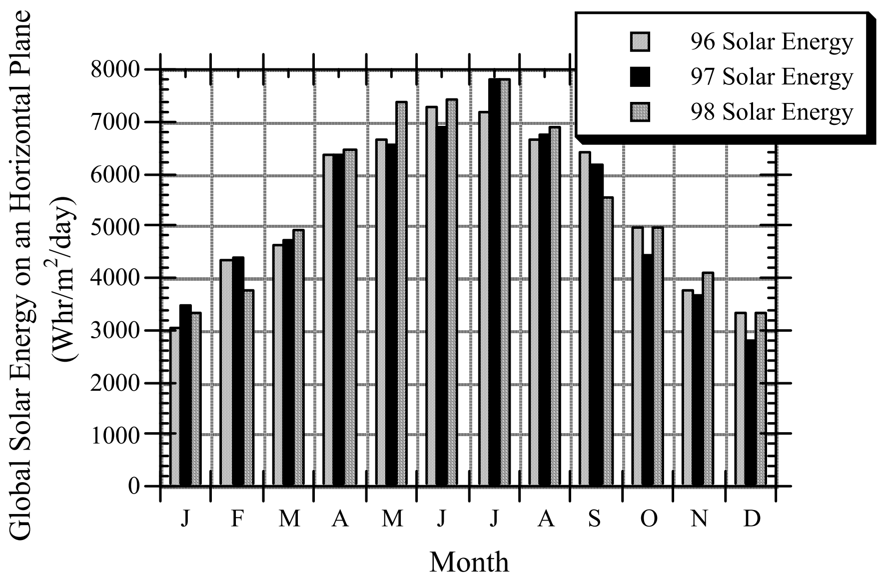

Figure 1. Global Solar Energy on an Horizontal Surface at Leh, Ladakh; Data for 1996 to 1998 (data collected by LEDeG)

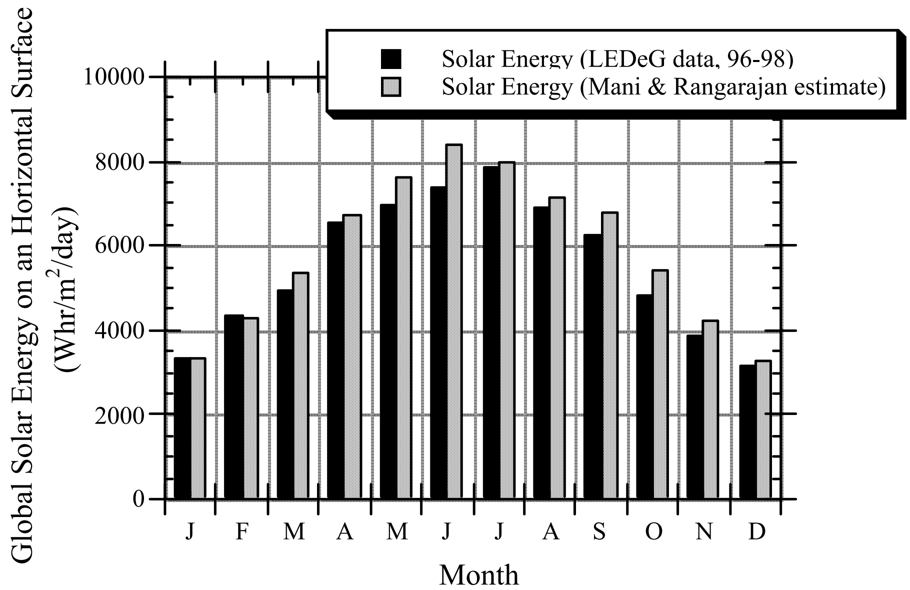

Figure 2. Average Daily Global Solar Energy on an Horizontal Surface at Leh, Ladakh; Combined data for 1996 to 1998 compared with estimates made by Mani and Rangarajan (1982)

Table 1. Global Solar Energy on Tilted, South Facing Surfaces at Leh
(horizontal data from 1996-98, measured by LEDeG)

Month	Horizontal	20 deg. tilt	35 deg. tilt	50 deg. tilt	90 deg. tilt
	($Whr/m^2/day$)	($Whr/m^2/day$)	($Whr/m^2/day$)	($Whr/m^2/day$)	($Whr/m^2/day$)
January	3310	4580	5270	5660	5140
February	4330	5490	6040	6270	5200
March	4930	5580	5750	5640	4070
April	6550	6960	6800	6320	3770
May	6960	7060	6600	5870	3040
June	7380	7350	6730	5840	2810
July	7830	7850	7240	6310	3020
August	6920	7200	6900	6290	3490
September	6250	6970	7080	6820	4550
October	4840	5920	6380	6510	5180
November	3900	5370	6160	6600	5900
December	3190	4590	5370	5840	5430
Annual Avg.	5530	6240	6360	6160	4300

2.3 Estimated Solar Energy at Kargil, Nubraand Nyoma

Duration of sunshine data for Leh, Kargil, the Nubra Valley (at Sumoor), and Nyoma are presented in Table 2. The solar energy at these sites can be estimated from the duration of sunshine data. See Appendix A for formulas for the estimates. The estimates for Kargil and Nubra are more accurate than the estimate for Nyoma, as very little data is available for Nyoma. The estimates for all of the sites will improve in time with more data.

The estimated values for the daily average solar energy on an horizontal plane at Leh, Kargil, Nubra, and Nyoma are presented in Figure 4. These results show moderate differences between the sites during the period of record, and noticeable differences from month to month. The annual average daily solar energy at Leh is 5530 $Whr/m^2/day$, while the estimated annual average for Kargil and Nubra are 5390 $Whr/m^2/day$ and 5300 $Whr/m^2/day$, respectively. On an annual basis, the solar energy at Kargil and Nubra are 2.5% and 4% less than at Leh. The limited data for Nyoma indicate that it receives more sun that Leh. However, this analysis is based on just two full years of data for Kargil and Nubra and less than one year of data for Nyoma. A number of years are needed to make firmer statements about regional variations in solar energy. Moreover, potential errors

associated with estimating solar energy from duration of sunshine data contribute uncertainty to these comparisons.

Table 2. Monthly Average Daily Sunshine Duration for Sites in Ladakh

	Leh	Kargil	Nubra	Nyoma
	data for 1-96 to 12-98	data for 5-96 to 12-98	data for 10-96 to 11-98; missing 6-98	data for11-96 to 12-96 & 3-98 to 12-98; missing 1-97 to 2-98
Month	(hours/day)	(hours/day)	(hours/day)	(hours/day)
Jan	5.8	5.1	5.3	n/a
Feb	6.6	5.8	4.7	n/a
Mar	5.8	6.1	5.2	7.6
Apr	8.0	7.1	6.9	8.8
May	8.4	8.2	8.0	9.9
June	8.9	8.1	7.1	10.8
July	10.1	8.7	9.4	11.1
Aug	9.3	7.3	8.1	7.3
Sept	8.9	8.3	7.1	6.9
Oct	7.8	7.0	6.9	8.8
Nov	7.8	6.1	6.3	6.8
Dec	6.8	4.8	4.9	6.7

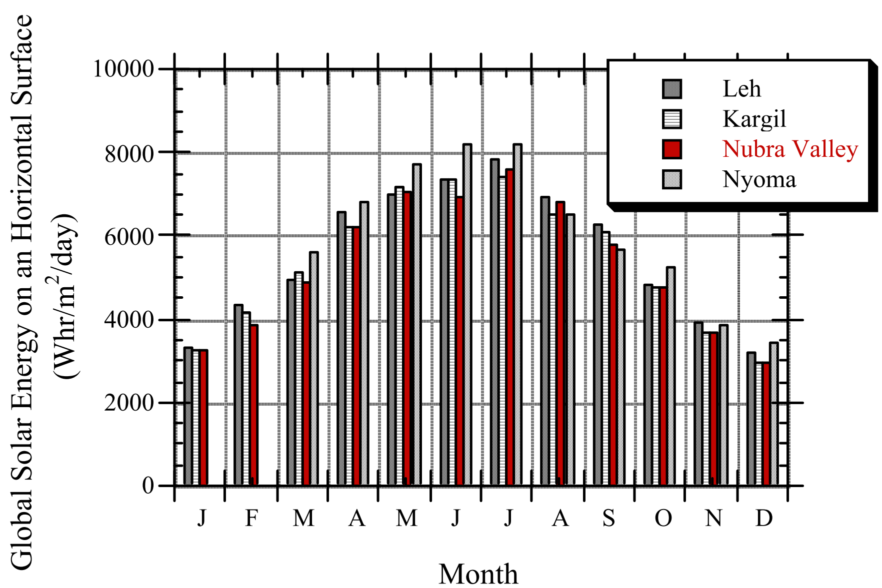

Figure 4. Average Daily Solar Energy on an Horizontal Surface for Leh (measured), Kargil (estimated), the Nubra Valley (est.), and Nyoma (est.)

2.4 Solar Energy Lost to Shading in Ladakh

Despite the analysis in the previous section, not all villages in Ladakh have approximately equal access to solar energy. While regional variations in solar energy are moderate, mountain shading[1] results in large differences in the level of solar access from village to village. A survey of 68 Ladakhi villages indicates average losses of 10% of the available solar energy each year to shading. Moreover, some villages have excellent solar access, while others lose 20 to 40% or more of the available solar energy in some months each year due to mountain shading. During the winter the shading losses are the greatest, as the sun is low in the sky. The data show that while 63% of the villages surveyed lose less than 20% of the available solar energy in the month with the most shading, 31% of villages lose 21 to 40% of the solar energy and 5% of villages lose more than 40%. See Figure 5. One village surveyed lost 100% of the available solar energy for 4 months each winter due to mountain shading. These data demonstrate that it is critical to evaluate each village or site for shading before implementing solar related projects in Ladakh.

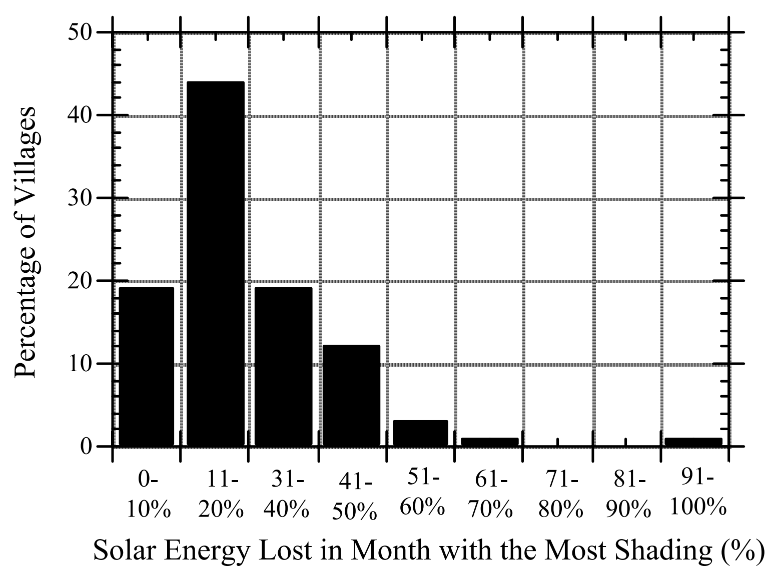

Figure 5. Solar Energy Losses for Villages in Ladakh During the Month with the Most Shading

[1]Note that mountain shading is in addition to possible site specific shading from trees, buildings, etc.

3. Conclusions

Solar data collected during 1996-98 indicate that the annual average global solar energy on an horizontal plane for Leh during the period was 5530 Whr/m^2/day, and at a 35° south facing tilt the annual average was 6360 Whr/m^2/day. These data confirm that Leh has an excellent solar resource. The estimated annual average daily solar energy on an horizontal plane available at Kargil was 5390 Whr/m^2/day and for the Nubra Valley it was 5300 Whr/m^2/day. These data indicate that on an annual basis the regional variations in solar energy in the Ladakh region are moderate. However, mountain shading creates large differences in solar access from area to area. Some villages have excellent solar access, with very little mountain shading. Other villages lose 20 to 40% or more of the available solar energy in some months each year due to mountain shading. Therefore, it is critical to evaluate each village or site for solar access before implementing solar related projects in Ladakh.

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References

Duffie, J.A., and Beckman, W.A., *Solar Engineering of Thermal Processes, Second Edition*, John Wiley & Sons, USA, 1991.

Jacobson, Arne, *Renewable Energy Resource Data Collection in Ladakh, India: A Summary of Data Collected and Other Work Completed in 1996*, LEDeG, 1997.

Jacobson, Arne, *Renewable Energy Resource Data Collection in Ladakh, India: A Summary of Data Collected in 1997*, LEDeG, 1998.

Jacobson, Arne, *Renewable Energy Resource Data Collection in Ladakh, India: A Summary of Data Collected in 1998*, LEDeG, 1999.

Kawosa, M.A., Remote Sensing of the Himalaya, Natraj Publishers, Dehra Dun (Uttar Pradesh), India, 1988.

Maithel, Malhotra, Prasad, and Singh, Renewable Energy Plan for Ladakh Region, New Delhi: Tata Energy Research Institute, 1998.

Mani, A. and Rangarajan, S., Solar Radiation Over India, Allied Publishers Private Ltd., New Delhi, 1982.

Appendix A. Estimation of Solar Energy from Duration of Sunshine Data[2]

The solar energy data and the duration of sunshine data for Leh for 1996 and 1998 can be used to estimate regression parameters for sunshine recorders in Ladakh's climate type. This is done based on the following equation:

$$\frac{\bar{H}}{\bar{H}_o} = a + b*(\frac{\bar{n}*S}{\bar{N}})$$

where:	$\bar{H}$	=	monthly average daily global solar energy on an horizontal surface at Leh (Whr/m^2/day, Table 1)
	$\bar{H}_o$	=	maximum possible monthly average daily global solar radiation on an horizontal surface (Whr/m^2/day, Table A.1)
	a	=	y-intercept parameter for sunshine recorder regression
	b	=	slope parameter for sunshine recorder regression

[2]The equations presented in this section are from Duffie and Beckman [1991].

$\bar{n}$	=	monthly average daily sunshine duration at Leh (hours/day, see Table 2)
S	=	shading correction factor (Table A.2)
$\bar{N}$	=	maximum possible monthly average daily sunshine duration at Leh (hours/day, see Table A.1).

The regression values for Leh based on data from 1996-98 are as follows:

a	=	0.38
b	=	0.43

These values can be used to estimate the monthly average daily solar energy for the other sunshine recorder stations in Ladakh using the data provided in Tables A.1 and A.2 and the duration of sunshine data from Table 2. The values for $\bar{N}$ and $\bar{H}_o$ are based on the latitude of the sites, and the shading correction factors in Table A.2 are based on shading surveys at the measurement sites. Note that the regression values are used without any attempt to account for potential climate differences (e.g. humidity levels) between Leh and the other locations in Ladakh. This may result in some error, particularly for Kargil.

As an example of a calculation, the amount of solar energy for Sumoor (Nubra Valley) in December of 1998 can be estimated as follows:

$$\bar{H}_{\text{Sumoor Jan}} = \bar{H}_o * (a + b * (\frac{\bar{n} * S}{\bar{N}})) = (5130 \text{ Whr/m}^2) * [0.38 + 0.43 * (\frac{5.3 * 1.11}{10.0})]$$

$$= 3200 \text{ Whr/m}^2\text{/day}$$

The final answer is rounded to two significant figures. This is done due to account for uncertainties in several of the measured values.

Table A.1. Maximum Duration of Sunshine and Maximum Solar Energy for Solar Data Recording Stations in Ladakh

Month	$\bar{N}$, Leh	$\bar{N}$, Kargil	$\bar{N}$, Nubra	$\bar{N}$, Nyoma	$\bar{H}_o$, Leh, Lat =34.2	$\bar{H}_o$, Kargil, Lat =34.5	$\bar{H}_o$, Nubra, Lat =34.7	$\bar{H}_o$, Nyoma, Lat =33.2
	(hours/ day)	(hours/ day)	(hours/ day)	(hours/ day)	(Whr/m^2/ day)	(Whr/m^2/ day)	(Whr/m^2/ day)	(Whr/m^2/ day)
Jan	10.0	10.0	10.0	10.1	5220	5160	5130	5410
Feb	10.8	10.8	10.8	10.8	6600	6550	6520	6770
Mar	11.8	11.8	11.8	11.8	8330	8290	8270	8460
Apr	12.8	12.9	12.9	12.8	10010	9990	9970	10070
May	13.8	13.8	13.8	13.7	11110	11110	11110	11120
June	14.3	14.3	14.3	14.2	11530	11540	11540	11500
July	14.0	14.1	14.1	14.0	11300	11300	11300	11290
Aug	13.2	13.3	13.3	13.2	10420	10400	10400	10460
Sept	12.2	12.2	12.2	12.2	8910	8880	8860	9020
Oct	11.1	11.1	11.1	11.2	7100	7050	7020	7260
Nov	10.2	10.2	10.2	10.3	5540	5480	5450	5730
Dec	9.8	9.7	9.7	9.8	4830	4770	4740	5030

Table A.2. Shading Adjustment Factors for Solar Data Recording Stations

Month	Shading Factor	Shading Factor	Shading Factor	Shading Factor
	Leh	Kargil	Nubra	Nyoma
Jan	1.01	1.12	1.11	1.04
Feb	1.04	1.09	1.11	1.03
Mar	1.04	1.06	1.09	1.02
Apr	1.03	1.03	1.05	1.01
May	1.02	1.04	1.02	1.01
June	1.03	1.05	1.03	1.01
July	1.03	1.03	1.02	1.01
Aug	1.03	1.03	1.04	1.01
Sept	1.04	1.06	1.09	1.02
Oct	1.01	1.09	1.11	1.02
Nov	1.01	1.12	1.10	1.03
Dec	1.01	1.13	1.09	1.04