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Single Scattering Albedo derived from Aerosol Optical Thickness Measurement at Ilorin

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Abstract

The seasonal variation of Single Scattering Albedo (SSA) derived from the monthly variations in the Aerosol Optical Thickness (AOT) values obtained from the CIMEL sun photometer in Ilorin (lat. $8^{0}32^{`}$N; long. $4^{0}34^{`}$E) is studied. Single Scattering Albedo for the site was found to range from 0.20 to 0.89 for the period under consideration - January 2003 to December 2004. For the Rain-Harmattan transition months (October and November), the SSA for the month of October was found to range approximately from 0.55 to 0.89. For the month of November, SSA was found to range approximately from 0.25 to 0.54. For the Harmattan months (December and January) and the Rainy months (April, August and September), the SSA was found to range from approximately 0.18 to 0.45. Whereas the AOT for the Harmattan months increased that of the Rainy months was decreasing for most of the months. The average monthly SSA in the Harmattan- Rain transition months (February and March) was found to range approximately from 0.20 to 0.38, depicting an increase in the Aerosol Optical Thickness at this period. These ranges show that the effect of aerosols on the direct radiation of electromagnetic waves is not negligible at the site. Therefore, this could be considered significant to atmosphere at the project site (Ilorin) by characterising it as an absorptive atmosphere.

Key Words: Aerosol Optical Thickness, Single Scattering Albedo, CIMEL.

1. Introduction

Aerosols are suspended solid and liquid particles in the atmosphere and the concentration of aerosols and their sizes, distribution, form and material composition in the atmosphere vary in space and time. Aerosols are either terrestrial i.e. from industrial smoke, forest fire, sand storms, volcanic eruptions, agricultural bush burning or marine in origin (i.e. salt crystals, ocean spray and nuclei of hygroscopic salt), and can be classified by their sizes. Soil aerosols in the atmosphere during the Harmattan season have been a familiar feature of the climate of West African region, forming a substantial portion of the aerosol loading at this time.

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Other sources of aerosols include bush burning (Pinker *et. al*, 2006), anthropogenic aerosols particularly sulphate aerosols from fossil fuel combustion which exist all year round, aerosols from substances such as silica, asbestos, and diesel particulate matter sometimes found in the workplace. Harmattan season soil aerosols are mainly transported by the North Easterly Winds from the Bilma plain (18^0N, 12^0E) in Niger Republic and FayaLargeau (18^0N, 19^0E) in the Chad basin, particularly from the Bodele depression to different parts of the West Africa (Kalu, 1979; Ramanathan *et al*, 2001; Pinker *et al*, 2001; Babatunde *et. al.*, 2005; Falaiye *et. al.*, 2003).

Aerosol optical thickness or depth (AOT/AOD) is the degree to which aerosols prevent transmission of light. (AOT/AOD), denoted by "τ" is also defined as the integrated extinction coefficient over a vertical column of unit cross-section. Single Scattering Albedo (SSA) -ω_0 is the ratio of scattering efficiency to total extinction efficiency. Total extinction efficiency is also called attenuance which is the sum of scattering and absorption observed. Single Scattering Albedo contributes significantly to the behaviour and the nature of the atmosphere. It is important to note that as the value of AOD decreases, the change in Single Scattering Albedo (ω_0) increases, and this shows an inverse proportionality between AOD and the change in ω_0 (Bohren and Huffman, 1983). In this study the values of AOT at 340, 380, 440, 500, 670,870 and 1020 nm measured by the AERONET's CIMEL automatic sun photometer for the period of 3rd January 2003 to 31st December, 2004 was used to calculate the SSA(ω_0).

2. Materials and Methods

The values of AOT measured at 340, 380, 440, 500, 670,870 and 1020 nm was retrieved from the AERONET's CIMEL automatic sun photometer for the period 3rd January 2003 to 31st December, 2004.The SSA (ω_0) was calculated using the Beer-Lambert-Bouguer's equation as given in the equation 1 below. Transmission of the direct solar beam through a vertical slice of the atmosphere can be expressed as the voltage measured at the surface (V) as a ratio of voltage expected at the top of the atmosphere, otherwise known as the calibration constant(V_0). This is not an exact radiometric calibration, but is the value the instrument would record outside the atmosphere, at an Earth-Sun distance of one Astronomical Unit

(AU) and provides a band integrated value of the instrument response multiplied by the solar irradiance.

Atmospheric transmittance depends on the attenuation of extra-terrestrial irradiance by scattering and absorption. When the direct beam is measured over a narrow band-pass (strictly, monochromatic radiation) the Beer-Lambert-Bouguer attenuation law holds and the instantaneous, total optical thickness for that wavelength (τ_λ) can be derived from:

$$V_\lambda = \frac{V_{0\lambda}}{R^2}\exp^{(-\tau_\lambda m)}, \qquad (2.1)$$

where V_λ is the wavelength specific voltage, $V_{0\lambda}$ is the calibration constant for that wavelength, R is the Earth-Sun distance in Astronomical Units at the time of observation of V_λ and; m is the relative optical air mass, which is approximated as the secant of the solar zenith angle (Kasten, 1965).

An expression to compute the Earth-Sun distance, R, is given in Bird and Riordan, 1986. The Single Scattering Albedo SSA (ω_0) is the ratio of the wavelength specific voltage at the surface (V_λ), to the voltage at the top of the atmosphere also called calibration constant ($V_{0\lambda}$). When the direct beam is measured over a narrow band-pass (strictly, monochromatic radiation) the Beer-Lambert-Bouguer's attenuation law holds, hence, the Single Scattering Albedo for that wavelength can be derived from equation 2 after Rollin, 2003:

$$\omega_o = \frac{V_\lambda}{V_{0\lambda}} = \frac{1}{R^2}\exp\left(-\tau_\lambda m\right), \qquad (2.2)$$

where

$$m = \frac{1}{cosz + 0.50572(96.07995 - z)^{-1.6364}}\,. \qquad (2.3)$$

The sun-earth distance is equal to 1 AU, because the calibration constant is measured at an Earth-Sun distance of 1 AU, therefore

$$\omega_o = \exp\left(-\tau_\lambda m\right). \qquad (2.4)$$

2.1 Single Scattering Albedo (SSA)

Single Scattering Albedo, ω_0, is the ratio of scattering efficiency to total extinction efficiency, also called attenuance (i.e. sum of scattering and absorption (k_a + k_s):

$$\omega_o = \frac{\tau_{scat}(\lambda)}{\tau_{ext}(\lambda)}\,. \qquad (2.5)$$

Aerosol single scattering albedo ω_o (the ratio of scattering to extinction) is important in determining aerosol climatic effects, in explaining relationships between calculated and measured radiative fluxes, and in retrieving aerosol optical depths from satellite radiances.

Aerosol single scattering are commonly used to parameterize the slow wavelength dependence of aerosol scattering, absorption, and extinction (Bohren and Huffman, 1983). As AOD decreases, the change in ω_0 increases, thereby showing an inverse proportionality between AOD and ω_0 (Falaiye, 2008).

The SSA is expressed as a fraction and varies between 0 for perfect absorption and 1 for perfect scattering. Realistically, the value of ω_0 is between 0.5 and 1.0 in the visible and UV wavelengths. The use of ω_0 assumes that incoming solar radiation is scattered only once before they reach the earth surface. In turbid atmospheres (AOT > 1.0), the scattering process is complicated by the multiple scattering of radiation by aerosols (Moosmüller and Chakrabarty, 2003). Change of about 0.10 in ω_0 can either cause cooling or warming of the atmosphere depending on the albedo of the underlying surface, aerosol backscattering fraction and so on (Hansen *et al.*, 1974; Bohren and Huffman,1983).

Some studies of $\omega_0$in the visible wavelengths have investigated its spectral dependency with increasing wavelength from 400nm to 700nm (Dubovik *et al.*, 2002). Falaiye (2008) classified the single scattering albedo ω_0 as given below into months and period:

a. Rain- Harmattan transition months- October and November.
b. Harmattan months-December to January.
c. Harmattan-Rain transition months- February and March.
d. Rainy months- April, August and September.

This classification is employed this report.

2.2 Site and Instrumentation

The project site is located at Ilorin, the capital city of Kwara State and lies on latitude $8^0 32^{'}$N and longitude $4^0 34^{'}$E at altitude of 375m above the mean sea level. An albedo of savannah surface is expected at Ilorin because it is a transition zone between the deciduous forest of the south and the savannah of the North. The average monthly temperature is almost uniform throughout the year with a mean of 30.15^0C while the average annual rainfall is about 873mm (Falaiye, 2008).

The prevailing winds in Nigeria, including Ilorin are the south westerly (SW) and North Easterly (NE) trade winds (Falaiye, 2008). The SW winds blow from the Atlantic ocean bringing rain to Nigeria from around April to October. This period is known as the rainy season. The NE wind, a very dry wind, blows across the country between November and March, bringing the Harmattan dust with it and depositing the dust particles according to their size along its path. This period is known as the dry season. The period of the NE winds constitutes the major months of study for aerosols because of its dusty and other peculiar characteristics.

The CIMEL sun Photometer used to measure the Aerosol Optical Thickness is located at the University of Ilorin. This is a 5(five) channel instrument with filters centred around 440/500, 670, 870, 936 and 1020 nm. It has an optical head with two collimators i.e. the solar collimator and sky collimator both with a field of view of 1.2^0 and bandwidth of 10nm full width at half maximum. The optical head has a UV enhanced silicon detector for the sun and a silicon detector for the sky at an operating temperature of between -30^0 to $+60^0$. It measures sun and sky radiance in order to derive the total column water vapour, ozone and the aerosol properties using a combination of spectral filters and azimuth/zenith viewing controlled by a microprocessor.

3. Results and Discussion

The values of AOT obtained at 340, 380, 440, 500, 670, 870 and 1020nm measured by the AERONET (CIMEL) automatic sun photometer for the period of 3rd January, 2003 to 31st December, 2004 was used to obtain the ω_0. The AOT at the different wavelengths are determined using an in built algorithmin the memory of the CIMEL Sun photometer. The data used had been cloud screened and quality assured so as to eliminate spikes due to noise usually caused by cloud obscuration of the solar disk and improper pointing and focus of the sun before being put on the AERONET site for use.

The parameters for determining the ω_0 were given in the equation equations 1 to 4. Several researchers including Bohren and Huffman (1983), Pinker *et al.* (2001), Dubovik *et al.,* (2002), Ramanathan *et al.* (2001) and Moosmueller and Chakrabarty (2003) have shown that scattering is most prominent between 440/500nm which is the middle of the visible wavelength band. Studies have shown that the amount or quantity and size of aerosol in the atmosphere which is described by the Aerosol Optical Thickness (AOT) in the optical sense can also be deduced from the ω_0 (Pinker *et al.,* 2001 and Falaiye *et al.,* 2003b). These variables have been known to greatly affect the yield/output/efficiency of several known solar energy harnessing composite systems such as solar collectors, PV panels, solar driers (Babatunde *et al.*, 2005).

3.1. Daily Variation of SSA

The results of the daily variation of SSA are shown in Figs. 1 – 9. Rain-Harmattan transition months – October 2003, October 2004 and November 2003 (Fig.1 - 3). The SSA in October was found to range from 0.2 to 0.9 in the year 2003 and 0.13 to 0.7 in the year 2004. Whereas the amplitude of variation of the ω_0 is large and wide in October 2003 from the beginning of the month to the end of the month, the amplitude of variation is smaller and closer for October 2004, for this period was found to increase gradually to the highest. The AOT at this period was low which indicates that there was more of direct radiation than scattered in the atmosphere. Hence a solar dryer, a solar PV used at this period will be very effective –higher yield due to reduced amount of aerosols (low AOT; high ω_0) of the atmosphere.

For the month of November (Fig. 3), theω_0 was found to fall in the range from 0.10 to 0.90. The ω_0 was found to be reducing drastically from the higher value (0.9) of October to as low as 0.1 at the end of the month of November. This may be due to an increase in the AOT at this time caused by the intense Harmattan dust being fed into the atmosphere by the incoming North easterly wind resulting into more of diffuse radiation and hence a reduction in the yield from solar PVs' due to accumulation of dust on its surface.

Harmattan months - December and January (Figs. 4 and 5). The ω_0 was found to range from as low as less than 0.10 some days to as high as 0.75 on some days within the month. However, the ω_0 averaged around 0.45 for most of the days in the month, a decrease from the all-time high for most of the days in the previous months under consideration. This therefore implies that we have more of diffuse radiation in the atmosphere at this period caused by the encroachment of Sahara winds from the Sahara deserts bringing along with it a large amount of Harmattan dust and this by implication will mean a further reduction in the yield of any solar energy harnessing system.

Harmattan- Rain transition months - February and March (Figs. 6 and 7).Though there were a few days of ω_0 that are as low as 0.1, the ω_0 for most of the days in these months, averages and oscillates about 0.4 to 0. 55. This shows a slight increase from the ω_0 obtained in the previous month. However, there is a decrease in AOT which is caused by the onset of the rainy reason. At the beginning of the rainy session, we have more of Rayleigh scattering occurring in the atmosphere than Mie scattering due to very light aerosol burden and the South westerly wind bearing water vapour with it cleaning out the atmosphere from heavy dust particles. We can therefore safely assume that there is an increase in the amount of incoming solar flux hence an expected increase in the yield of solar energy harnessing systems should be expected at this period.

Rainy months - April and September (Figs 8 and 9). The daily values ofω_0 was found to range from less than 0.1 to 0.5 for March; 0.15 to 0.7 for April and 0.25 to 0.8 for September. However the ω_0 was closer to the median (0.45) of the range for all of the months considered in the rainy months. Expectedly there is a decrease in AOT value because most of the aerosols present in the atmosphere have been washed out by the rain which is now more consistent and falling frequently. The result of this being that the atmosphere is very clean and clear except for pockets of clouds here and there which if not obscuring the solar disk will give an increased amount of incoming solar fluxes and by implication a marked increase in the yield of solar energy harnessing systems.

3.2 Monthly Variation of ω_0

The average of all the daily variation of ω_0 for each of the month under consideration was computed and plotted as shown in figures 10 and 11 for the year 2003 and 2004 variations respectively. As can be seen from the monthly presentations (Figs 10 and 11) October present the highest monthly ω_0 ranging from 0.55 to 0.9 for all the wavelength range, ω_0 values in November ranges from 0.25 to 0.55 for all the wavelength, ω_0 values in December and January ranges from less than 0.2 to 0.45, the ω_0 values for February and March ranges from 0.2 to 0.38. The ω_0 increased slightly in the rainy month of April ranging from 0.35 to 0.47 and then stabilising in the range 0.2 to 0.45 till August before it rose again in the range 0.4 to 0.62 in September. The wide amplitude observed in the daily variational pattern has disappeared in the monthly variations as shown in figures 1 and 2.

4. Conclusion

The estimated ω_0 for Ilorin was found to range from 0.20 to 0.90 for the period under consideration – January 2013 to December 2004. For the Rain-Harmattan transition months (October and November), the ω_0 for the month of October was found to range approximately from 0.55 to 0.89 which shows that at this period the AOT was low which indicates that there was more of direct solar radiation passing through the atmosphere hence, solar PV used at this period is expected to be very effective due to reduced amount of aerosols in the atmosphere. However for month of November, ω_0 was found to fall to a range approximately from 0.25 to 0.55 which indicates an increase in the AOT at this time due to the increase intensity of the incoming North Easterly wind which results into more of diffuse radiation and hence an expected reduced yield of solar PVs'.

For the Harmattan transition months (December and January), the $\omega_0$fell further to a range approximately from 0.18 to 0.45 which also means more of diffuse radiation and will thus give a reduced yield for any solar energy harnessing system. An increase in the value of ω_0 was observed in the Harmattan- Rain transition months (February and March). The ω_0 was found to range approximately from 0.20 to 0.35showing an increase in AOT. At this period there is a decrease in the amount of incoming solar flux due to the increase in the value of AOT and more of diffuse radiation. This is expected to be reflected as a decrease in the yield of solar PVs'.

For the Rainy months (April, August and September), the ω_0 was found to range from 0.18 to 0.45. This shows a decrease in AOT resulting into an increase in the amount of incoming solar flux due basically to the washout of dust in the atmosphere by the heavy rains. Since we have more of direct solar flux to impinge on surfaces at this period there is expected to be an increase in the yield of solar PVs'.

The value of the ω_0 at this period was found to have the same range as that obtained for the Harmattan transition months of December and January. These ranges show that the effect of aerosols on the direct radiation of electromagnetic waves is not negligible or small at the site deriving from the fact that change in ω_0 by as much as 0.1 can either cause cooling or warming of the atmosphere and here we have experienced a wide swing in the value of ω_0 from as low as 0.18 to as high as 0.89 through a single season. These swing will definitely have a marked effect on the performance of any solar energy harnessing system particularly Solar PVs'. The atmosphere at Ilorin has been characterised as absorptive for most time of the season (January to December), hence the use of Solar PV's are expected to produce very high yield.

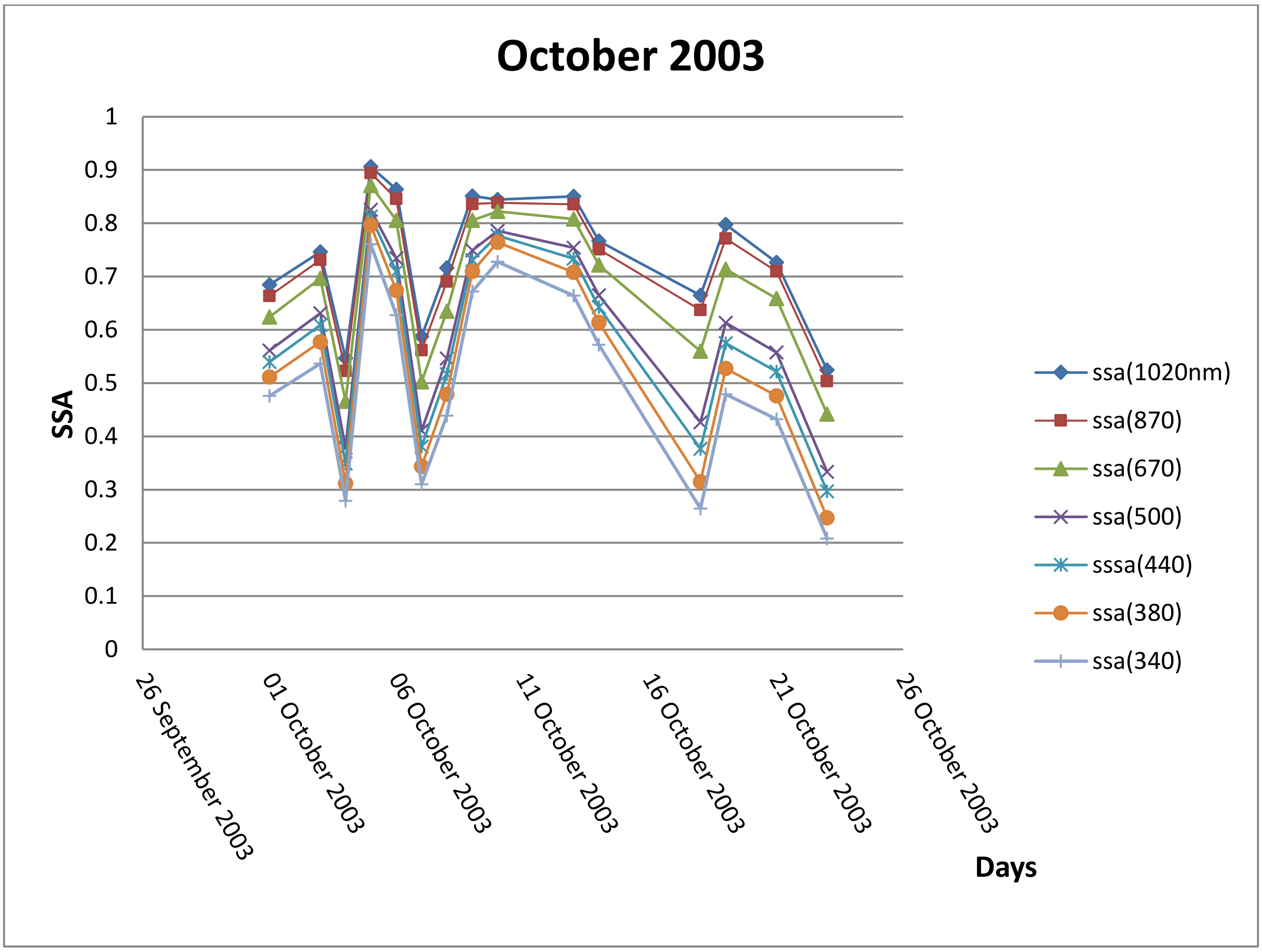

Fig. 1: Monthly variation of SSA in October 2003.

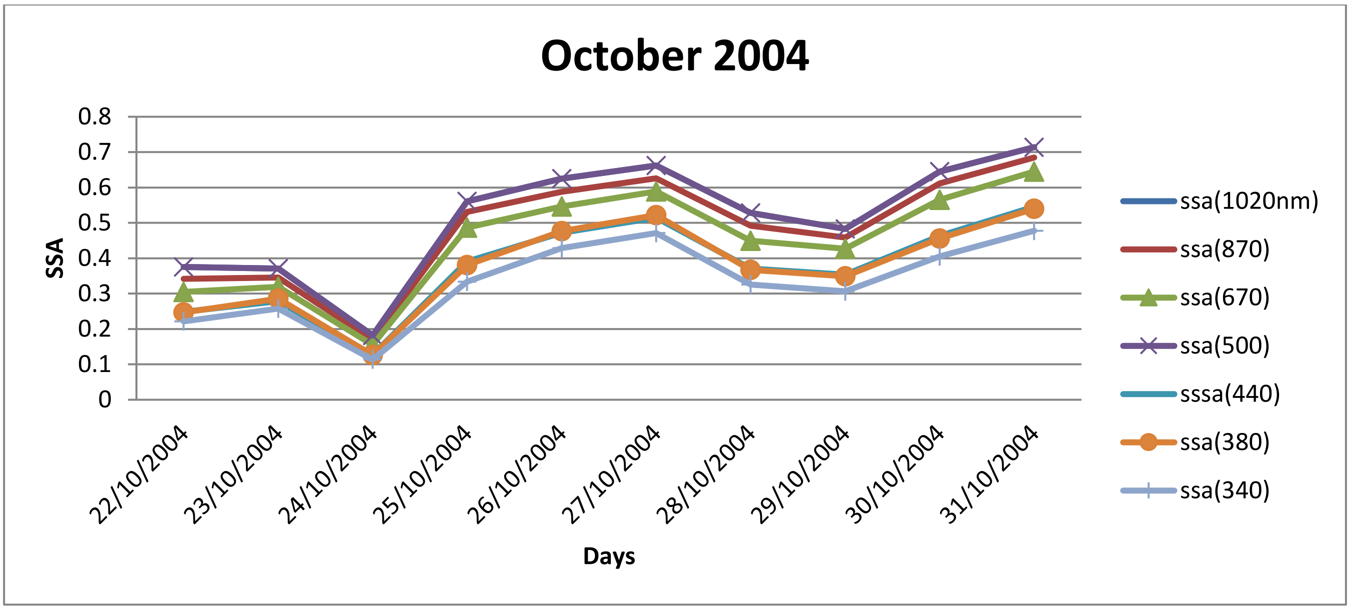

Fig. 2: Daily Variation of SSA for October 2004.

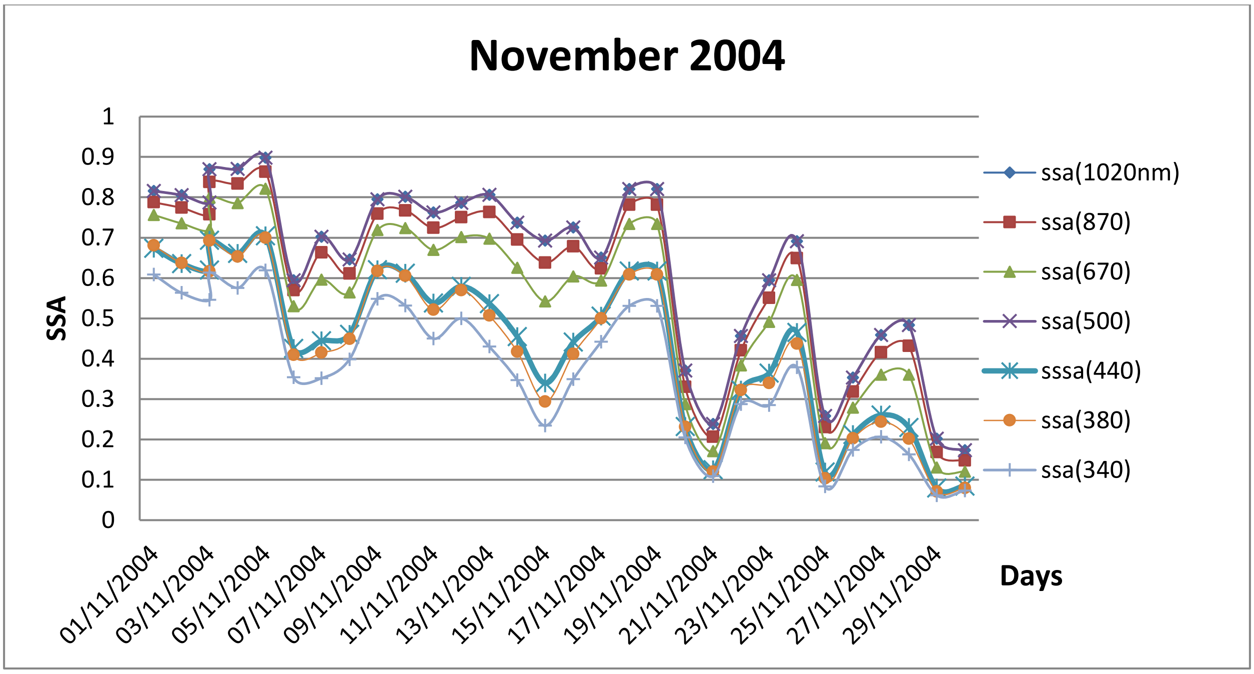

Fig. 3: Daily Variation of SSA for November 2004.

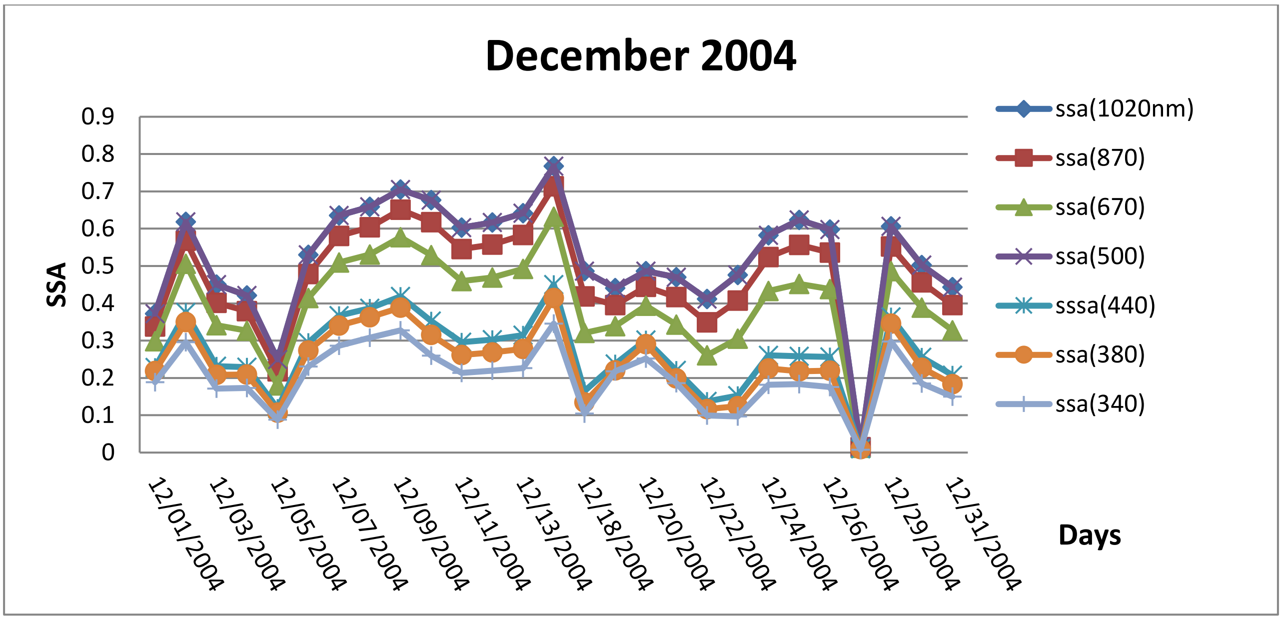

Fig. 4: Daily Variation of SSA for December 2004.

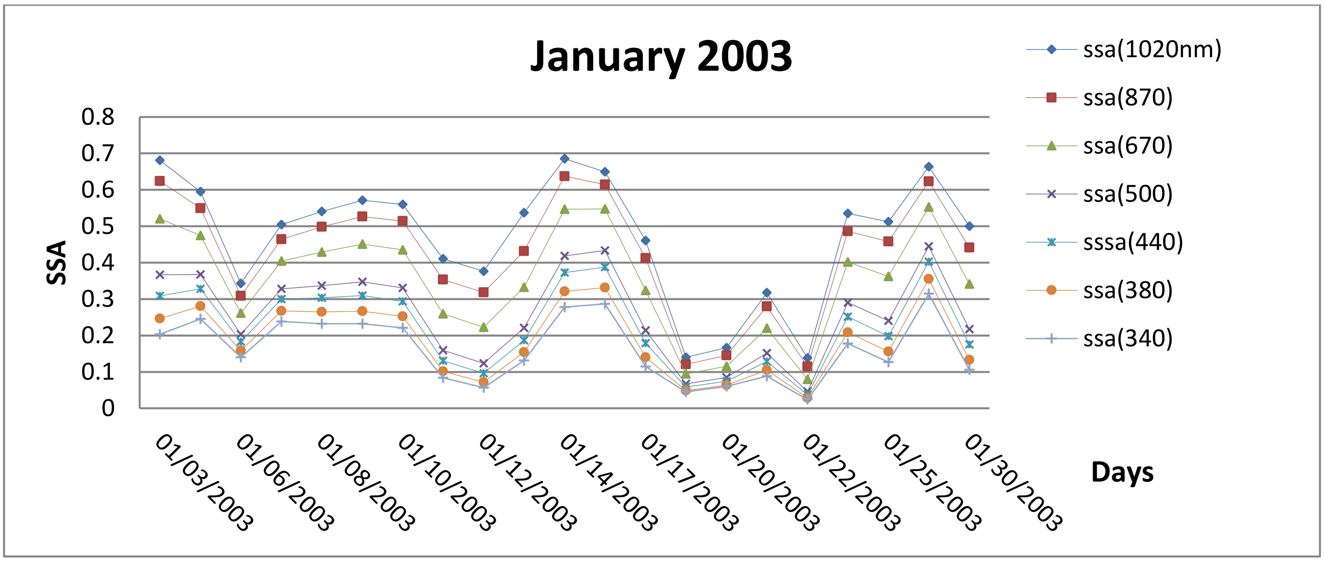

Fig. 5: Daily Variation of SSA for January 2003

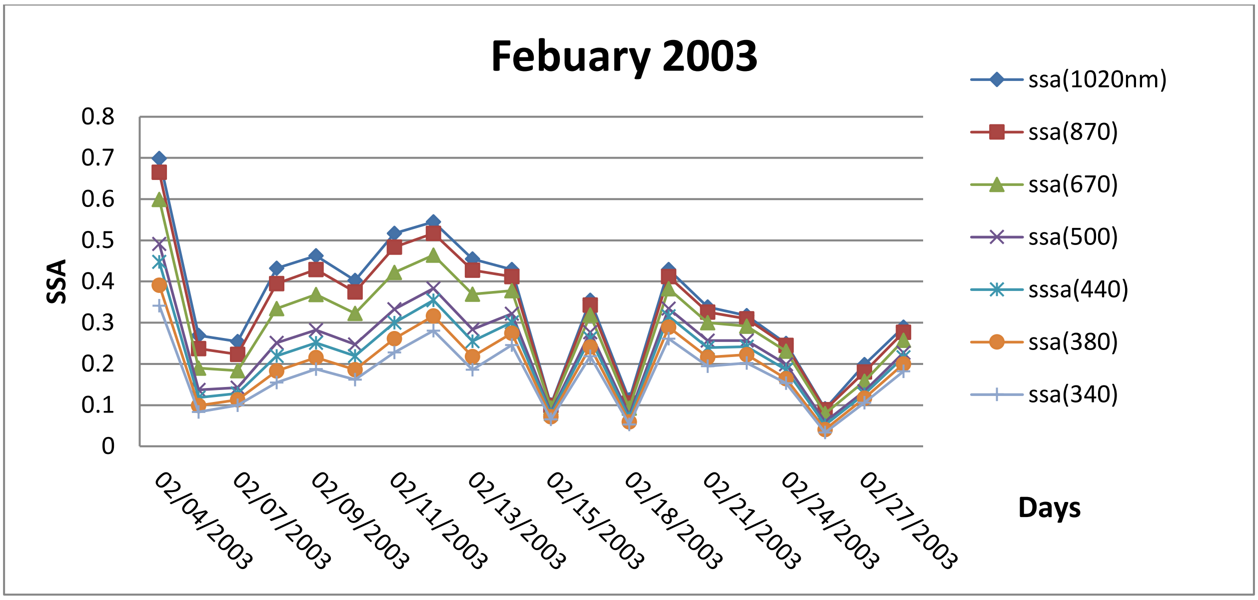

Fig. 6: Daily Variation of SSA for February 2003

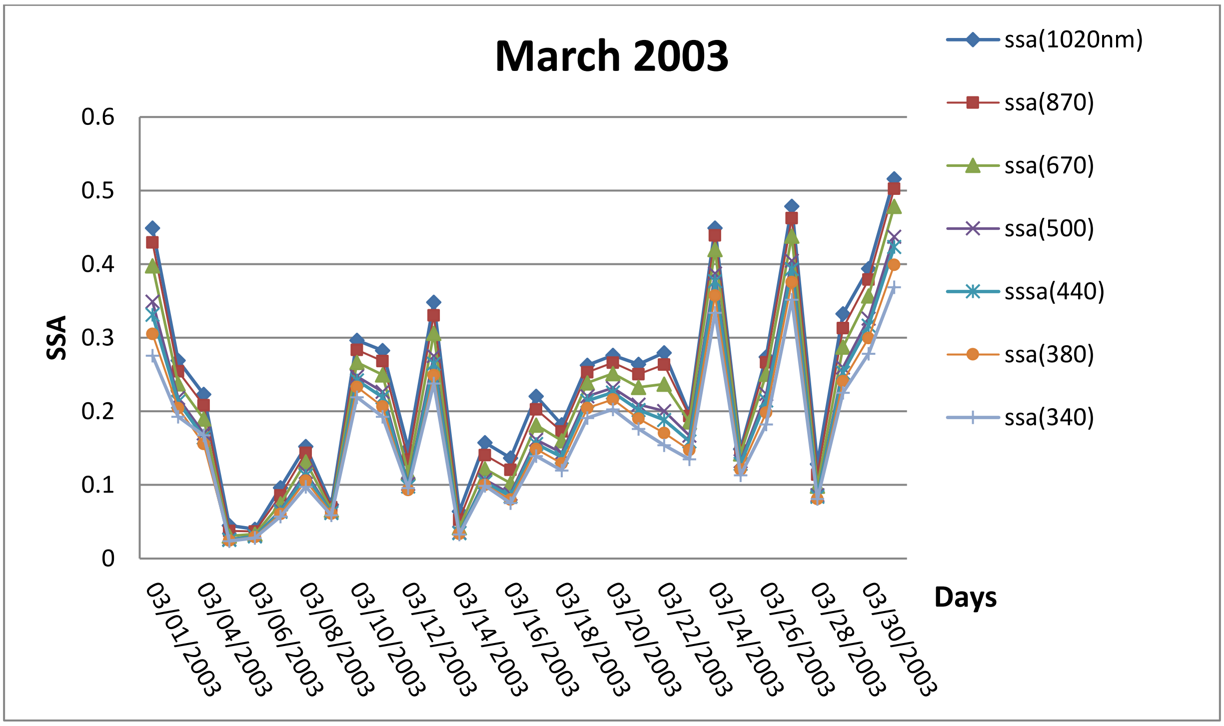

Fig. 7: Daily variation of SSA for March 2003.

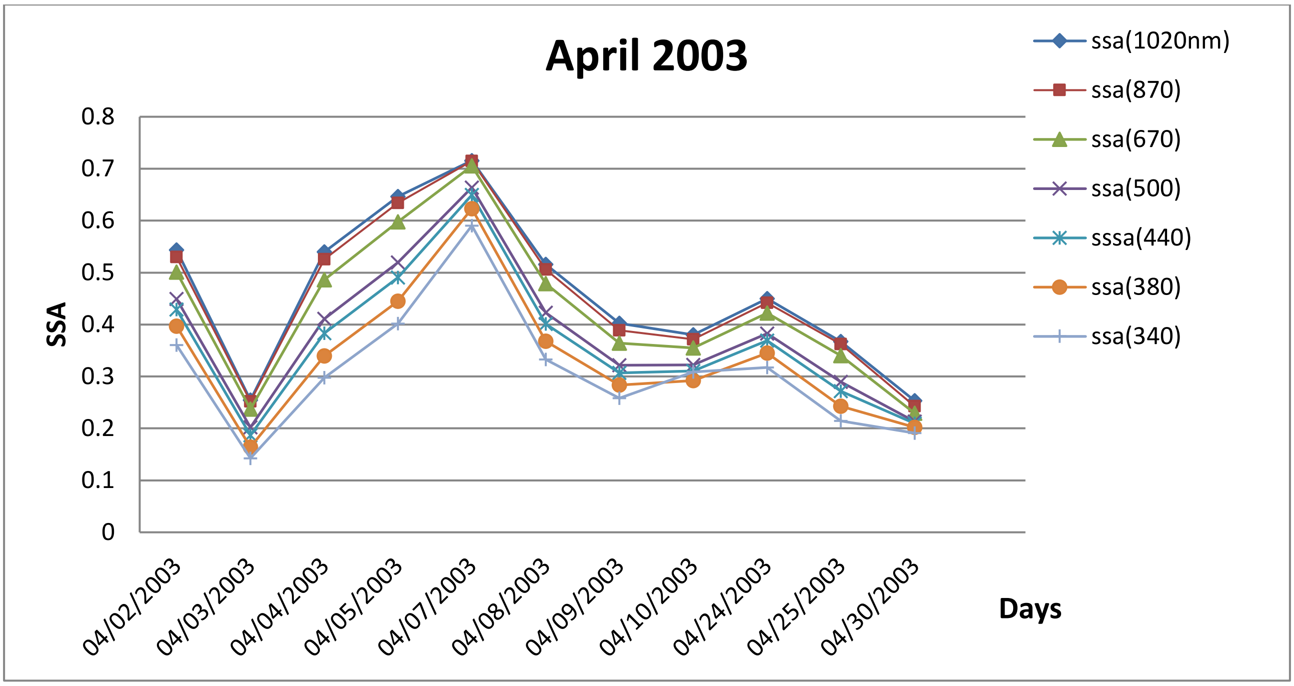

Fig. 8: Daily Variation of SSA for April 2003

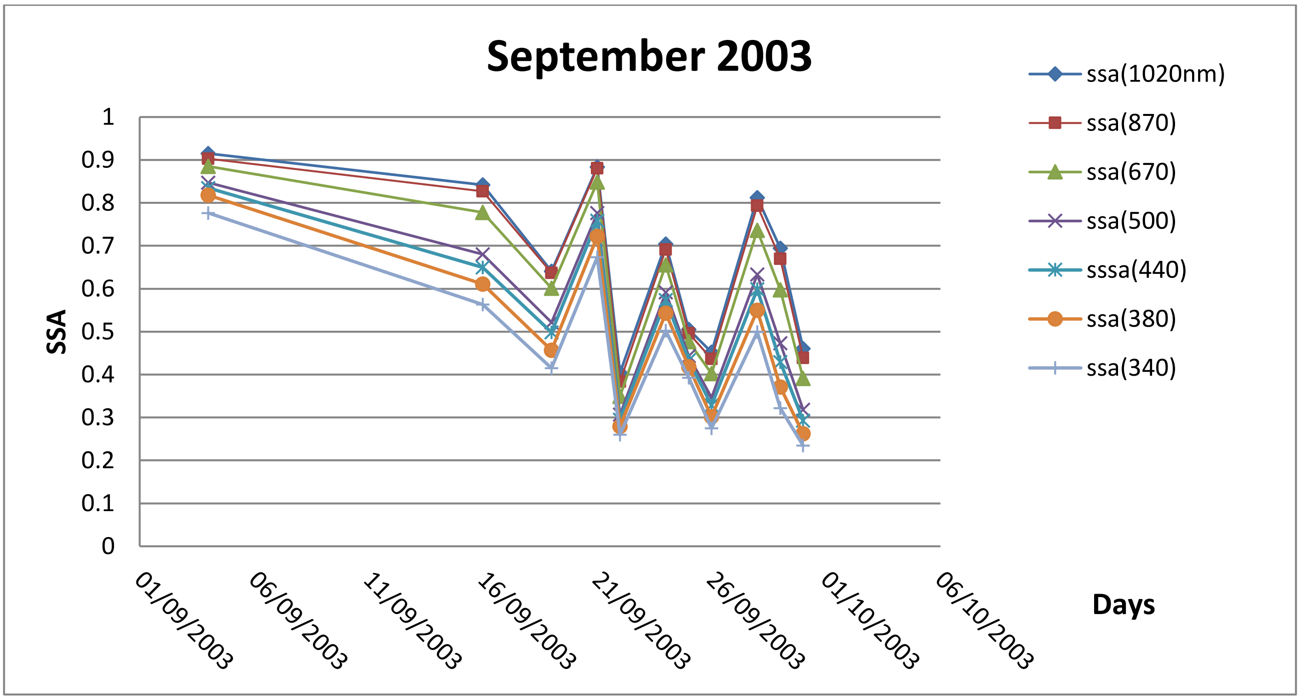

Fig. 9: Daily Variation of SSA for September 2003

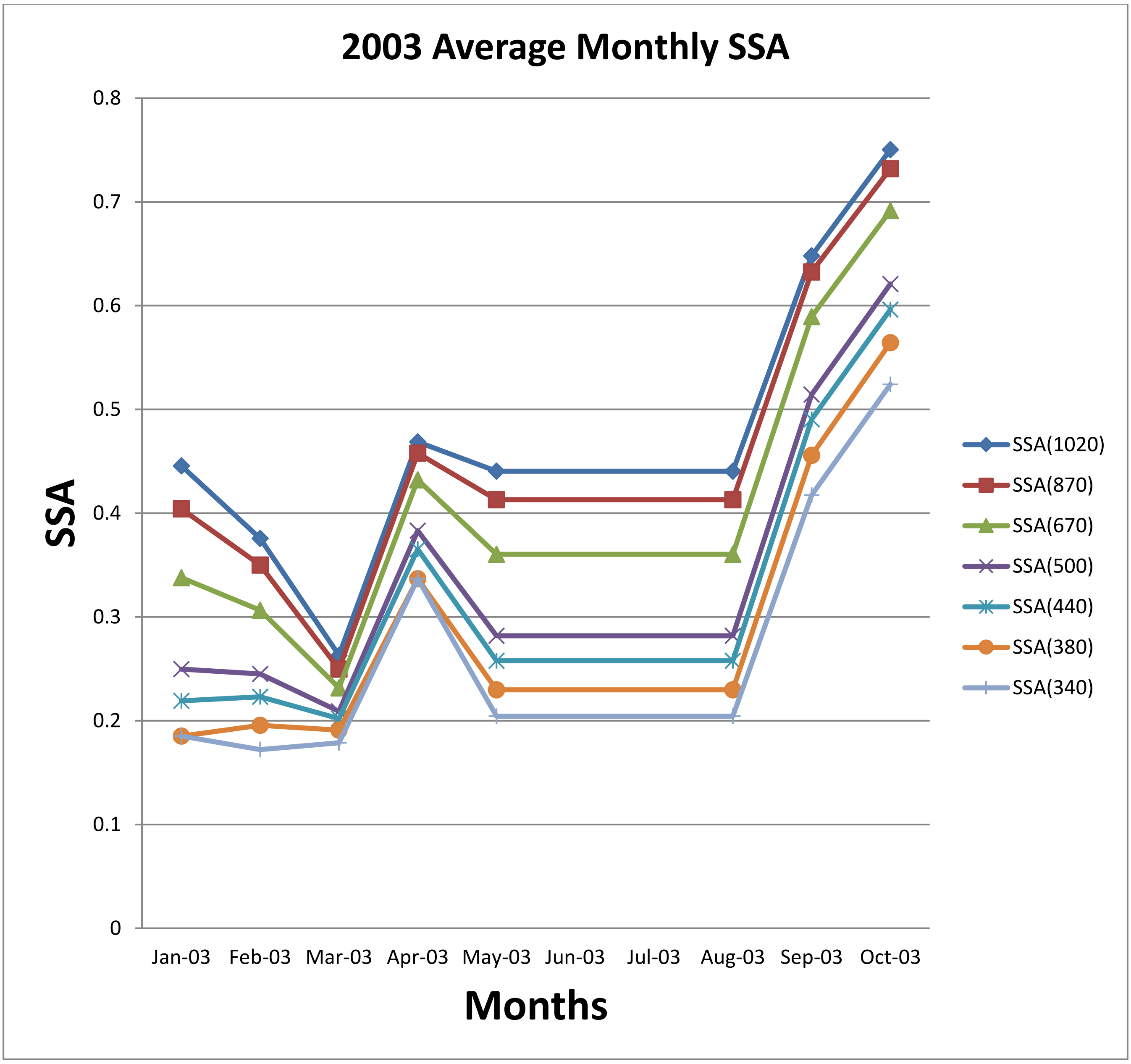

Fig. 10: Chart of the average monthly SSA in 2003.

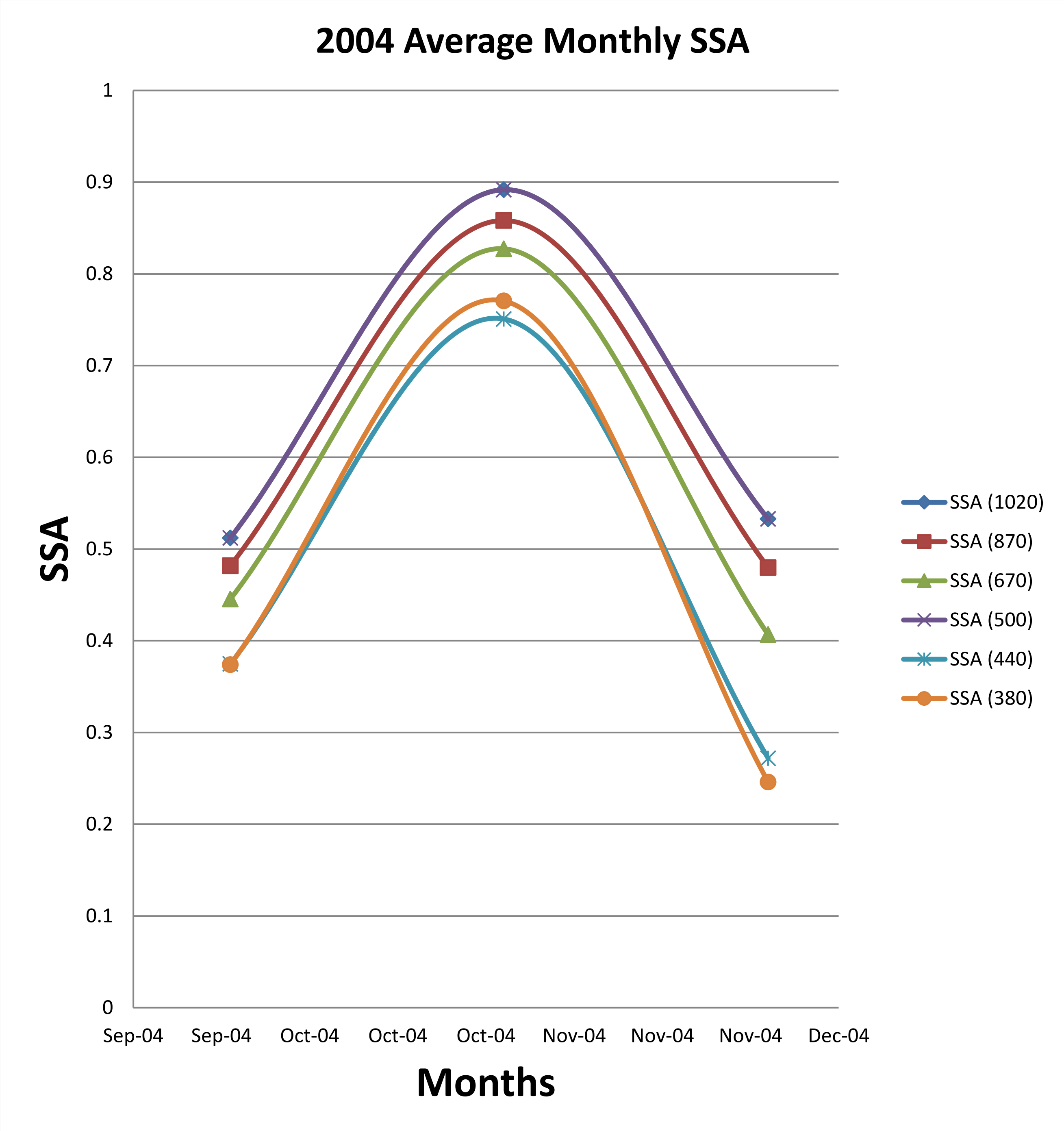

Fig. 11: Plot of the average monthly SSA of 2004.

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