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Atmospheric Aerosol Optical Properties and Climate Change in Arid and Semi-Arid Regions

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1. Introduction

In recent years, there has been much attention to the study of atmospheric aerosols in Asia as aerosols generated in this region has significant direct and indirect effect on changing the Earth's climate on a global scale. Aerosols are small particles in the air that originate from a number of different natural and human activities such as ocean spray, dust storms, fires and pollution from fossil fuel combustion. Aerosol particles may be solid or liquid and their sizes range from 0.01 microns to several tens of microns. Scientists have much to learn about how aerosols affect regional and global climate and the direct and indirect radiative forcing of aerosols are still not understood well. In the last decade, scientists from East Asian countries and the world's science communities have organized and conducted many international and regional experiments and projects on aerosol optical properties and the measurement of radiation , for example: NASA AERONET (Aerosol Robotic Network), East Asian Regional Experiment 2005 (EAREX 2005) of the United Nations Environmental Program (UNEP), Atmospheric Brown Cloud (ABC) project, ABC Maldives Monsoon Experiment (APMEX), SKYNET (MEXT Sky Radiometer Network), ADEC (Japan-Sino Joint Aeolian Dust Experiment), ABC-EAREX (ABC East Asian Regional Experiment) and EAST-AIRE (East Asian Study of Tropospheric Aerosols, International Regional Experiment). Figure 1 shows sites of above mentioned networks in East Asia.

The AERONET provides quality-assured data for aerosol optical properties measured by the Sun/sky multi wavelength radiometer over the World. AERONET facility processes and archives these data according to a standardized procedure for the retrieval of aerosol properties. One of the AERONET site at Dalanzadgad of arid region of Mongolia has been operated continuously since 1999 (Tugjsuren N, 2010). Recently, studies on the aerosol monitoring over Eastern Asia using AERONET Sun-photometer acquired aerosol optical thickness and Angstrom exponent measurement have been conducted in the research on Aerosol properties in a Chinese semiarid region (Xia Xiango at al., 2004).

Seasonal and monthly variations of columnar aerosol optical properties over east Asia determined from multi-year MODIS, LIDAR, and AERONET Sun/sky radiometer measurements, (Sang-woo Kim at al., 2006)

The East Asian regional Experiment 2005 (FAREX 2005) project was organized and conducted from March to April 2005 by researches from east Asian countries and others. The regional experiment preceding to FAREX 2005 was the ABC Maldives Monsoon Experiment (ARMEX) conducted from 1 October to 15 November 2004 in the south Asian

region with another ABC supersite at Hanimaadhoo , Maldives. These two regions have large emission sources of anthropogenic aerosols and gases with largely different climates and weather conditions. ARMEX and EAREX targeted detailed study of aerosol characterization in Monsoon transition periods in fall and spring seasons in these regions.
SKYNET is an observation network to understand aerosol-cloud-radiation interaction in the atmosphere. The SKYNET project aims at a better understanding of long-term variability in the radiation budget and atmospheric parameters over the eastern Asia and its attributes based on the analysis of ground-network data. As for this objective, both regional and local analyses are needed to investigate the aerosol effects on climate change. The main instruments consist of a sky radiometer and radiation instruments such as pyronomter and pyrgeometer as a basic site, and a super site has more instruments extended for analyzing atmospheric parameters of aerosol, cloud and radiation. SKYNET has maintained Sky radiometer observation site since 1997 at Mandalgobi of semiarid region of Mongolia, in collaboration with the Chiba University, Japan (Tugjsuren N, 2010).

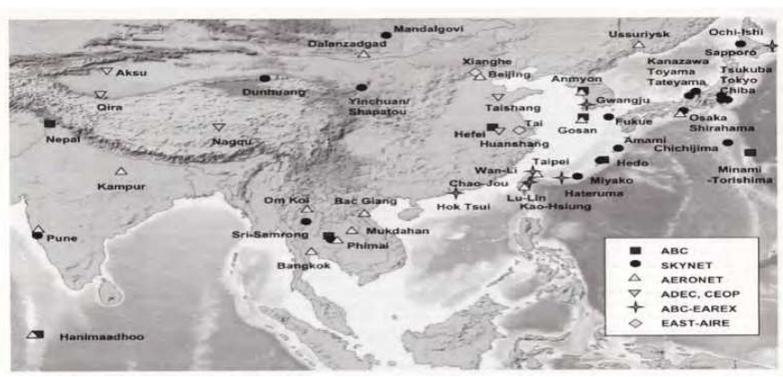


Fig. 1. Site map for projects studying aerosol and radiation measurement in Asia

2. Direct and indirect aerosol radiative effects

Aerosols play dominant role in affecting the energy budget of the Earth climate system by interacting with solar and terrestrial radiation. Aerosols can affect solar radiation budget in two ways; by directly scattering and absorbing solar radiation (this is known as the direct radiative forcing), and also by acting as cloud condensation nuclei thereby influencing the optical properties and life-time of clouds (this is known as the indirect radiative forcing). Aerosols tend to cool the Earth's surface directly beneath them. As most aerosols reflect sunlight back into space, they have a "direct" cooling effect by reducing the amount of solar radiation reaching the Earth's surface. The magnitude of this cooling effect depends on the size and composition of the aerosol particles, as well as the reflective properties of the underlying surface. Aerosols are also believed to have an "indirect" effect on climate by changing the properties of clouds. Clouds with low aerosol concentration and few large water droplets do not scatter light well, and allow much of the sun's light to pass through and reach the Earth's surface. Whereas high aerosol concentrations in clouds creates nucleation points necessary for the formation of many small water droplets. A well known Twomey effect (Twomey et al., 1984) that causes an increase in the cloud optical thickness when aerosols act as cloud condensation nuclei to increase the cloud droplet number and hence to increase the effective cloud droplet radius when the total liquid water path of the

cloud does not change. The decrease of cloud optical thickness and water path partially reduces cloud cooling effect.

Up to 90% of visible light is reflected back to space by such clouds without reaching the Earth's surface. Indeed, if there were no aerosols in the atmosphere, there would be no clouds. It is very difficult to form clouds without aerosol particles acting as "seeds" for the formation of clouds. As aerosol concentration increases within a cloud, the water in the cloud gets spread over many more particles, each of which is correspondingly smaller. We have yet to accurately appraise the respective impacts of naturally caused aerosols and those caused by human activities on the climate. Aerosols are produced naturally, from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels and the alteration of natural surface cover, also generate aerosols. Moreover, we do not precisely know in which regions the amount of atmospheric aerosol is increasing, diminishing, and remaining constant. The emission of anthropogenic aerosol is usually based on conversions of government statistics of energy used by various industries (Streets D.G et al., 2009). Aerosols are continuously transported by atmospheric motions and are largely removed by cloud and precipitation processes thus the amount of aerosols in a unit volume of atmosphere is frequently changing. Aerosol particles larger than 1 micrometer in size are produced by windblown dust and sea salt from sea spray and bursting bubbles. Aerosols smaller than 1 micrometer are formed mostly from condensation processes such as conversion of sulfur dioxide (SO_2) gas to sulfate particles and from formation of soot and smoke during combustion. As volcanoes erupt, they blast huge smoke clouds into the atmosphere. These clouds are made up of particles and gases, including sulfur dioxide. Millions of tons of sulfur dioxide gas from a major volcanic eruption can reach the stratosphere. There, with the help of water vapor, sulfur dioxide converts to tiny persistent sulfuric acid (H_2SO_4) aerosols. These aerosols reflect radiation from the sun, thereby preventing the sun's rays from heating the Earth's surface. Aerosols play dominant role in affecting the energy budget of the Earth climate system by interacting with solar and terrestrial radiation. Aerosols tend to cool the Earth's surface directly beneath them. As most aerosols reflect sunlight back into space, they have a "direct" cooling effect by reducing the amount of solar radiation reaching the Earth's surface. The magnitude of this cooling effect depends on the size and composition of the aerosol particles, as well as the reflective properties of the underlying surface. Global dimming and brightening phenomena have been studied using data of surface radiation networks.

Wild et al. (2005) found that surface solar radiation in most parts of the world experienced a reversal trend from "dimming" to "brightening" in early 1990s. Also, Shi et al. (2008) observed similar situation in China in the beginning of 1990s. These studies showed that the surface solar solar radiation is increasing in the European region , while the Asian region still suffers a decrease in the surface solar radiation due to increasing anthropogenic aerosols.

Rei Kudo et al. (2010) measured surface solar radiation under the clear sky conditions from 1975 to 2008 by measuring optical thickness and single scattering albedo. Their findings show that surface solar radiation at numerous locations decreased until the mid-1980s (global dimming), and increased after the decline (global brightening). During this study, they observed that optical thickness increased until the mid-1998s, then decreased until the late 1990s, and was almost constant in the 2000s. Single scattering albedo was low until the late 1990s, then increased, and was almost constant in the 2000s. The magnitude of the brightening was 12.7 Wm^{-2}, of this, 8.3 Wm^{-2} was due to a decrease of optical thickness, and the remaining 4.4 Wm^{-2} was due to an increase of single scattering albedo.

Volcanic eruptions are thought to be responsible for global cooling as it has been observed that there is cooling for a few years after a major eruption As volcanoes erupt, they blast huge smoke clouds into the atmosphere. These clouds are made up of particles and gases, including sulfur dioxide. Millions of tonnes of sulfur dioxide gas from a major volcanic eruption can reach the stratosphere. There, with the help of water vapor, the sulfur dioxide converts to tiny persistent sulfuric acid (H_2SO_4) aerosols. These aerosols reflect radiation from the sun, thereby preventing the sun's rays from heating the Earth's surface. In the case of major eruptions, injection of volcanic dust into the stratosphere may affect the climate globally as well as regionally due to the large amount of volcanic aerosols that remain in the stratosphere for years. The extent of the cooling depends on the force of the eruption and, possibly, on its location relative to prevailing wind patterns. After formation, the aerosols are mixed and transported by atmospheric motions (Budyko et al., 1986). In the Northern Hemisphere, a quick change in monthly average surface air temperatures has been observed after major volcanic eruptions and the effects last a few years. The average temperature decrease over the first year is about 0.3-0.4 ^{0}C. Short term surface temperature effects were observed over the northern United States after Mt. St. Helen erupted. The importance of sulfuric aerosol which is formed by the conversion of sulfur dioxide in volcanic gas to sulfuric acid in evaluating the stratosphere was first established in the 1980-1990's. During the last 100 years, many volcanoes erupted on the planet Earth. The eruption of Mt. Pinatubo in Philippines on 15 June 1991 was regarded as an extraordinary activity in the 20th century. Disk-shaped ash clouds with diameters of up to 600 km were observed by GMS-4 at one hour intervals, as they dispersed at altitudes of 20-30 km in the stratosphere, which were above dense typhoon clouds. The amount of sulfur dioxide injected into the stratosphere was about 15 to 30 MT by the 1991 eruption of Mt. Pinatubo, compared with 7 to 20 MT of sulphur dioxide by the 1982 El Chichon eruption (in southern Mexico) and about 50 MT by the 1883 Krakatoa eruption. The potential effect of volcanic eruptions on global climate may be huge, but careful studies are required to determine the exact impact as the climatic dynamics are complicated by the greenhouse effect due to the increases of carbon dioxide in the air.

Asian dust particles have significant effect on the radiative budget of the earth-atmosphere system through the scattering and absorption of solar and long wave radiation and acting as condensation nuclei to form cloud. During the past thirty years, the physical, chemical and optical properties, as well transport mechanism of the Asian dust have been intensively investigated. Recently, a number of lidar groups in East Asia have coordinated a lidar network for the observation of dust during Spring in order to understand their three-dimensional spatial distribution and temporal variation in Asia. Dust storms can also generate large amounts of aerosol in the troposphere. Usually, dust aerosols are produced in arid and semi-arid areas on Earth and transported by the atmosphere to be later deposited over land or ocean and influence the primary formation and deep ocean sediments. The radiative effect of the dust layer still remains to be assessed. Every year during spring, a number of dust storms occur in the Gobi desert in southern and western Mongolia and northern or northwestern China. Large amounts of soil and sand particles uplifted from this area are transported to Japan, Korea and the North Pacific region by prevailing westerly wind. Dust storms may have contributed to the desertification of the southern and western Mongolia and northwestern China during recent decades. Due to the large spatial and temporal extent of desert dust in the atmosphere, interactions of desert dust with clouds and land surface can have substantial climatic impacts. The absorption or diabatic heating of Asian dusts can cause the evaporation of cloud droplets and reduce cloud water path.

Clearly desertification is a historical phenomenon, and not a phenomenon of present times. Desertification is a global problem, not only because of the vast areas of drylands, which occupy about one third of the earth's surface. The deserts of central Asia are located in the temporal belt of the continental climate (Fig.2).

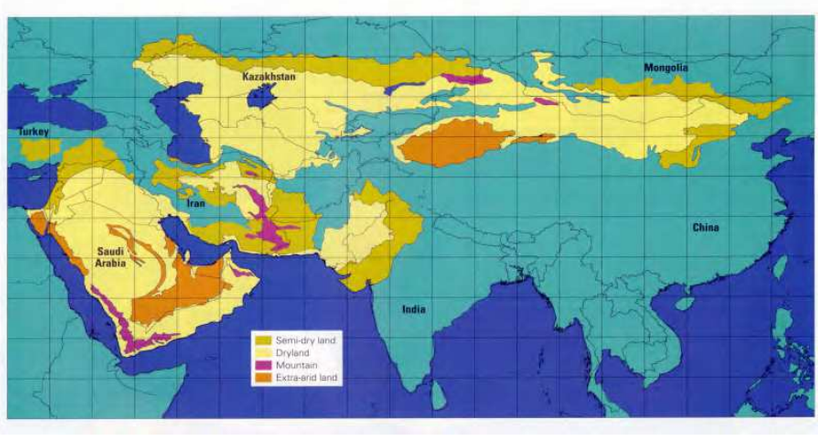


Fig. 2. Regional map of semiarid lands and drylands of Asia (Source: Nikolai Kharin and Ryutaro Tateishi and Hussein Harahsheh)

The main cause of desertification is the diminishing state of vegetation and plant coverage and increase in bare land, which in its turn elevates the air temperature, and affects biodiversity and ecological sustainability negatively. Presently 10-20 % of world dry lands is affected by desertification (Millenium Ecosystem Assessment, 2005). Desertification assessment must take into consideration the local conditions of the study area. These conditions should be investigated through field observations, with the help of remote sensing tools. The type and degree of desertification can be interpreted from the results of such investigations. Vegetation cover degradation is considered to be the main form of desertification. The soils of deserted lands are particularly sensitive to changes in the physical environment and in vegetative cover. Crop cultivation is one of the important factors contributing to soil erosion. The total land area of Mongolia is 156.5 million hectares and cultivated land occupies 1.35 million hectares of the total land area. Our calculations show that over the past 30 years, an average of 35-50 tons of soils have been lost from each hectare of cultivated land due to erosion (Tugjsuren N., Takamura T., 2003). Destruction of vegetation in sandy desert contributes to the development of wind. As known, the velocity of wind and the wind regime determines the intensity of wind erosion. For wind velocity $v>6$ m/s, sand particles can be blown aloft, and clay particles are moved by $v>10$ m/s. The significantly dry climate, low soil fertility and sparse vegetation cover of arid and semi-arid regions, make desertification a key issue of environmental concern. As a result of Mongolian desertification researches have concluded that 77.2 % of total territory was affected by desertification at low, medium and strong levels (Tugjsuren N., Enkhjargal G., 2010).

3. Climate change trends in arid and semi-arid region (on the example of Mongolia)

Arid and semi-arid areas comprise about 30% of earth surface. Changes in climate and climate variability will likely have a significant impact on these regions. Worldwide climate

change and global warming have affected the humidity and warmth, circulation and balance of matters in the troposphere, causing significant changes in the climate, strength, frequency of occurrences, thus has become one of the challenges faced by humanity. Current features of the climatic changes differ from fluctuations that took place over few hundred thousand years in the world history by its frequency, and have significantly changed in the last few hundred years, raising issues of capacity to adapt to such changes. Researchers have warned that more than 2.0 ^{0}C change in the world's outer surface mean air temperature would bring serious damages to the world ecosystem. However, in the last 100 years (from 1906 to 2006) the air temperature has increased by 0.74 ^{0}C , thus reaching one third of the peak change, and their studies over many years have determined that such increase in temperature will accelerate in the future. The April 2007 report, produced by the Intergovernmental Professional Committee on Climate Change, concludes that 90% of climate changes are caused by negative human activities. The climate is extremely continental with low precipitation in arid and semi-arid regions in southern and western Mongolia and northern and northwestern China. Summer is hot, dry and cloudless. Average summer temperature is +20^{0}C, average winter temperature is -26^{0}C and average rainfall is between 200-220 mm in arid and semi-arid regions of Mongolia. Winter lasts from November to late April. Although winter is cold with lot of snowfalls, it also has many sunny days. Studies show that the climate of arid and semi-arid regions has been significantly changing in the past 70 years (Report on the state of the environment of Mongolia , 2008).

Trends in temperature changes. The results of continuous study on Mongolia's climate reveal that on average the air temperature on surface from 1940 to 2009 has become warmer by 2.1^{0}C throughout the whole territory (Figure 3); by 1.9-2.3^{0}C in mountainous regions; and 1.6^0-1.7^{0}C in Gobi and steppe regions. The warmer climate was observed in all seasons; however, the colder seasons had temperature increases of 3.6^{0}C and spring and fall seasons had temperature increases of 1.8^0-1.9^{0}C. In the summer season, the temperature increase was 1.1^{0}C (Report on the state of the environment of Mongolia, 2008). Rapid increases in the air temperature in warmer seasons and no significant increases in the level of precipitation are the main reasons for dryness in arid and semi-arid regions of Mongolia.

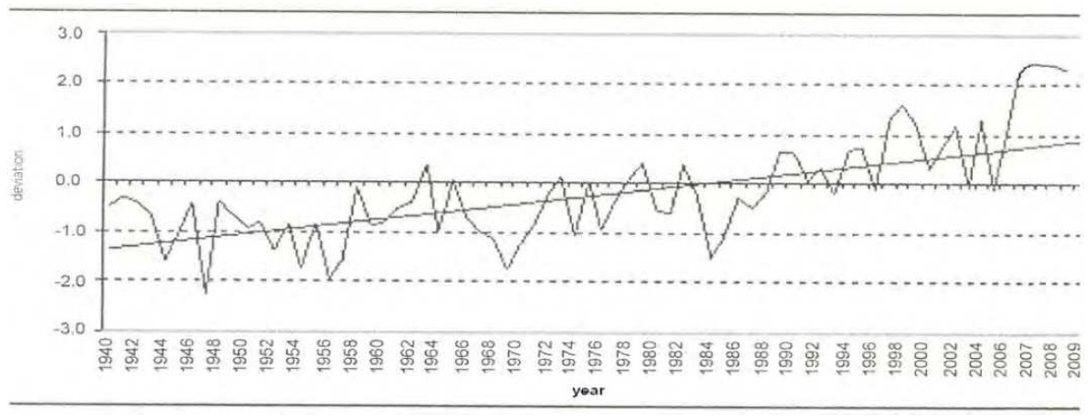


Fig. 3. Annual mean air temperature trend during 1940-2009 in Mongolia

For instance, Mongolia's mean air temperature is expected to increase on average by 1.4-1.5^{0}C in the years 2010-2039, and the total annual precipitation is estimated to be reduced by 4.0% in the years 2010-2039 (Report on the state of the environment of Mongolia, 2008). One

of the important effects is an indirect effect through change in the earth's surface temperature and general circulation. The large scale general circulation is changed when the surface of the region is cooled by aerosols through direct and indirect surface forcing.

Trends in precipitation changes. The changes and trends in the precipitation throughout Mongolian territory were determined by seasons, and by period from 1940 to 2009. The annual precipitation of Mongolia is determined by warmer seasons level of precipitation, which makes up about 70% of the total precipitation. For instance, 92% of the annual precipitation falls in warmer seasons and less than 3% falls in winter season. Besides precipitation, changes in the features of summer time rain has also occurred. The percentage of mild rain has reduced and from 1980s, the percentage of thunderstorms has increased by 20% in arid and semi-arid regions. Changes in the climate has caused changes in the total transpiration, balance in the soil humidity and land ecosystem, thus leading to increase in transpiration speed of 2-3 mms/per annum in arid regions. In other words, in 50 years the total transpiration will be increased by 100 mms and the transpiration in arid regions will be most accelerated. In the past 70 years, annual total precipitation has dropped by 7% or 16 mms in arid and semi-arid regions of Mongolia. Precipitation has dropped by 8.7-12.5% in the central and Gobi regions, and rose by 3.5-9.3% in the eastern and western regions; while precipitation has increased by 5.2-10.7% in fall and winter, and dropped by 9.1-3.0% in spring and summer (Report on the state of the environment of Mongolia, 2008). The drop in annual and summer season precipitation was observed mainly in the central region, eastern side of the western region, in the middle of the Gobi region, and center of the eastern region (Figure 4).

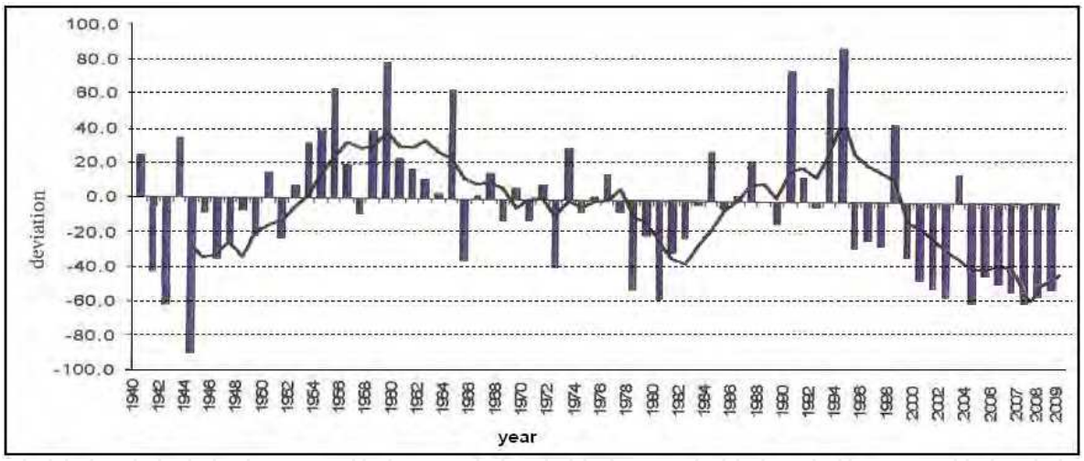


Fig. 4. Annual total precipitation in Mongolian territory

This trend of precipitation in arid and semi-arid regions can be explained by competing effects of natural and anthropogenic aerosols. By some researcher (Jianping Huang., 2008), a semi-direct effect may be the dominating factor of dust aerosol-cloud interaction over arid and semi-arid areas in East Asia, and contribute to the reduction of precipitation via a significantly different mechanism as compared to that in Africa. Certainly, further research is needed to verify it.

4. Aerosol optical properties in arid and semi-arid regions

To accurately study aerosol distribution and composition, continuous observations are required through satellites, networks of ground-based instruments and dedicated field

experiments. The AERONET is global ground-based network of Sun/sky automated radiometers supported by NASA's Earth Observing System (EOS) and other international research institutions. AERONET Sun-photometer has been used to measure solar radiation and aerosol properties in the arid Gobi desert region of Mongolia, Dalanzadgad (43.57722°N, 104.41917°E and 1470m above the sea level) since February 1997. We have analyzed Aerosol Optical Thickness (AOT), and derived Angstrom exponent acquired by an AERONET Sun-photometer at Dalanzadgad (Tugjsuren N., Batbayar J., 2008). Monthly means computed from quality-assured daily means, seasonal trends were presented and discussed. Spring and early summer has the maximum seasonal average AOT and minimum seasonal average appears in winter of 2002-2003. Average monthly Angstrom exponents indicates that aerosol mixtures of both coarse and fine mode particles, and especially dust aerosols were dominant in spring in Dalanzadgad. One of the main problems of the regional climate understanding is atmospheric aerosol variability. The atmospheric aerosols have a complicated non-uniform structure, characterization and optical properties. Thus ground based continuous monitoring of their physical and optical properties are necessary. The AERONET provides quality-assured data for aerosol optical properties measured by the Sun/sky multiwavelength radiometer over the World. AERONET facility processes and archives these data according to a standardized procedure for the retrieval of aerosol properties. This chapter addresses the aerosol optical properties over arid and semi-arid regions of Mongolia using data obtained from representative sites of the Global AERONET Sun-photometer and SKYNET Sky radiometer measurements (Tugjsuren N., Batbayar J., 2008, 2010).

SKYNET is an observation network to understand aerosol-cloud-radiation interaction in the atmosphere. SKYNET has maintained Sky radiometer observation site since 1997 at Mandalgobi (45.711°N, 106.265°E and 1393 m above the sea level) of semi-arid region of Mongolia, in collaboration with the Chiba University. This site has been equipped mainly with a sky radiometer and radiation instruments for continuous measurements of atmospheric parameters such as aerosol, cloud and radiation. The SKYNET project aims at a better understanding of long-term variability in the radiation budget and atmospheric parameters over eastern Asia and its attributes based on the analysis of ground-network data. As for this objective, both regional and local analyses are needed to investigate the aerosol effects on climate change. SKYNET data at Mandalgobi site provide us with valuable information of the Earth's and atmospheric parameters. The data are also important for extracting precise knowledge on the Earth's atmosphere, as well as on physical processes of aerosol-cloud-radiation interactions. Accurate information of aerosol optical properties determined by analyses using data collected by the sky radiometer of SKYNET network has been involved research activities in the semi-arid region of Mongolia. These efforts have allowed an opportunity to obtain comprehensive information of aerosol optical properties that will be helpful to recognize the aerosol effects on regional climate change and future climate scenarios. The data used in the present study are from the Sky radiometer observations at Mandalgobi for spring, 2007. The data observed at Mandalgobi site are compiled and archived in the SKYNET server in Chiba University. The data provided from SKYNET server of Chiba University have been treated with data quality control procedure. We used Level 2.0 data including retrieved parameters such as Aerosol optical thickness (τ), Angstrom Exponent (α) and Single scattering albedo (ω) at wavelengths of 500nm from SKYNET archives at Chiba University (http://atmos.cr.chiba-u.jp).The results of the analysis for monthly and seasonal mean AOT and Angstrom exponent and size distribution

over Mongolian arid and semi-arid regions are presented in the research Tugjsuren N., Batbayar J, 2005, 2006, 2008, 2010.

Annual variations of aerosol optical properties. The AERONET retrieval for AOT (τ) is performed at four wavelengths (λ) 340, 500, 870 and 1020nm, and the Angstrom exponent ($\alpha_{500\text{-}870}$) is evaluated at 500 and 870nm for the Dalanzadgad site in Mongolia. The monthly averages of aerosol optical thickness at 500nm(τ_{500}), and Angstrom exponent ($\alpha_{500\text{-}870}$) are summarized in Table 1 (Tugjsuren N., Batbayar J, 2008).

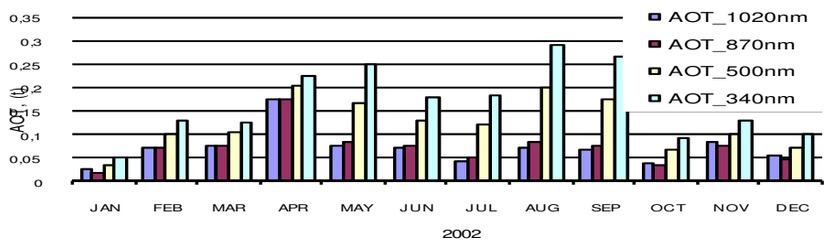
Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
						2002						
$\tau_{0.00nm}$	0.04	0.10	0.10	0.22	0.17	0.13	0.12	0.20	0.17	0.07	0.10	0.07
$\alpha_{500\text{-}870nm}$	1.54	1.13	0.76	0.58	1.40	1.28	1.93	1.71	1.85	1.98	1.08	1.00
						2003						
$\tau_{0.00nm}$	0.06	0.08	0.15	0.13	0.25	0.43	0.10	0.07	0.06	0.05	0.06	0.03
$\alpha_{500\text{-}870nm}$	1.29	1.19	1.00	1.19	1.23	1.47	1.24	1.50	1.37	1.53	1.93	1.74

Table 1. The monthly averages of Aerosol optical thickness, τ_{500nm}, and Angstrom exponent, $\alpha_{500\text{-}870nm}$

Average monthly value of AOT at 500 nm greater than 0.15 was in April-May and August-September of 2002 and in March, May-June of 2003. The maximum values observed were 0.22 in April 2002 and 0.43 in June 2003. Furthermore, highest values of average monthly AOT were 0.22 and 0.20 in April and August 2002 respectively and 0.25 and 0.43 in May and June 2003 respectively. The Angstrom exponent provides a rough measure of aerosol particle size. In general, the small values of Angstrom exponent (α) indicate the large particles, and the large values represent small particles. The mean monthly Angstrom exponents values observed were mostly in the range 1.0-1.93 during 2002-2003. However, low values in the range 0.58-0.76 were in March and April of 2002 which indicates that dust aerosol were dominant in Dalanzadgad in spring (March-April). The mean monthly AOT at four wavelengths (λ) 340, 500, 870 and 1020nm for 2002-2003 are illustrated in Figure 5. According to spectral dependence for annual variation of AOT (τ) in the ultraviolet and visible wavelengths (λ_{340}, λ_{500}) have maximum values in spring (April-May), late summer and early autumn (August-September) and minimum values in the middle of winter (January) of 2002 and maximum values in late spring, early summer and minimum values in winter of 2003. At the near infrared wavelengths (λ_{870} and λ_{1020}) 870, 1020nm, AOT maximum values was in middle spring (April) and minimum in middle winter (January) of 2002. AOT annual variation trend of near infrared wavelengths (λ_{870} and λ_{1020}) showed similar trend with AOT of ultraviolet and visible wavelengths (λ_{340}, λ_{500}) during 2003. Indeed, AOT maximum value at ultraviolet and visible wavelength (λ_{340} and λ_{500}) appears 0.43 and 0.61 respectively, in early summer (June) and decreases to a minimum in the winter (December) then increases again to spring and early summer in the all visible and near infrared wavelengths.

The Angstrom exponent (evaluated at 500 and 870nm) variation during 2002-2003 is presented in Fig. 6. The mean monthly minimum value of Angstrom exponent ($\alpha_{500\text{-}870}$) within the range 0.58-0.76 appears in spring (March and April) of 2002, it indicates background conditions dominated by coarse mode (dust aerosols) aerosols. Moreover, mostly fine aerosol particles except spring season in 2002-2003.

a)



b)

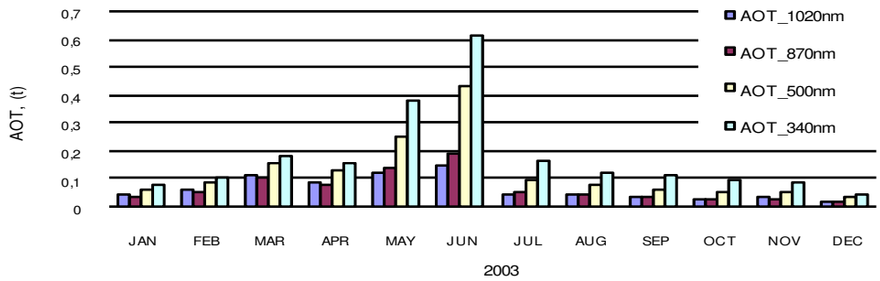


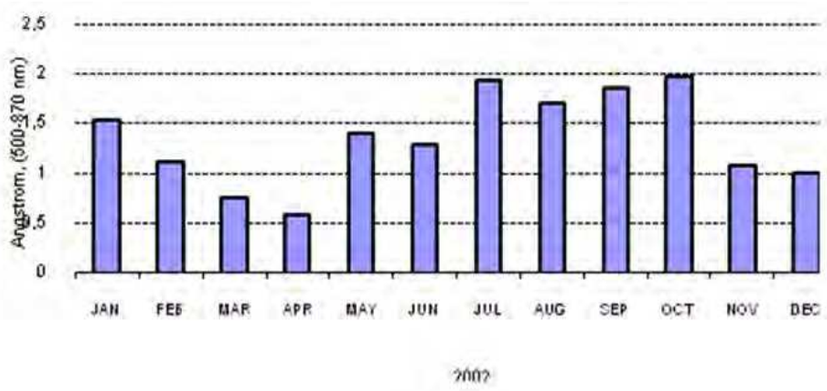
Fig. 5. Monthly mean aerosol optical thickness (AOT) at 440nm, 500nm, 870nm, 1020nm for the 2002 (a) and 2003 (b) at Dalanzadgad AERONET site.

AOT and Angstrom exponent dependence. The scatter plots of Angstrom exponent $\alpha_{500\text{-}870}$ versus aerosol optical thickness, τ_{500} for each season are shown in Figure 7. As shown on these scatter plots, there seems similar corelation between Angstrom exponents, $\alpha_{500\text{-}870}$ and AOT, τ_{500} for range 0.0-0.3 of AOT for four seasons. Particularly, the Angstrom exponent ranges 0.1- 3.6 for τ_{500}< 0.3. Mostly broad spread observed of Angstrom exponent for 0.0-3.2 to 0.6 of AOT in spring and summer season. Moreover, narrow spread of Angstrom exponent for 1.0-2.0 appears in range 0.5-1.5 of AOT in summer and autumn.

Aerosol size distributions. Seasonal averages of aerosol volume size distribution parameters at Dalanzadgad AERONET Sun-photometer site are summarized in Table 2. The second and forth columns represents effective radius, R_{eff}, third, fifth columns are columnar volume, C_v for fine and course mode particles respectively, and sixth is total columnar volume of particles, C_v. As shown in this table aerosol effective radius, R_{eff} (in μm) and columnar volume of particles per unit section of atmospheric column, C_v ($\mu m^3/\mu m^2$) by two aerosol fine and course modes.

From Table 2, we have seen that aerosol volume size distribution in seasonal pattern at Dalanzadgad has effective radius (R_{eff}) in the range 0.141-0.154 for fine mode and 1.506-2.268 for course mode during 2002-2003. The columnar volume of particles (C_v) ranges from 0.005 to 0.030 and 0.014-0.111 for fine and course mode respectively. Hence, in this table, larger effective radius (1.918-2.268) of course mode occurred in summer and autumn seasons, while large columnar volume (0.111) observed in spring season of this period. The large columnar volume in spring associated with strong wind occurrence season and dry period over this arid region.

a)



b)

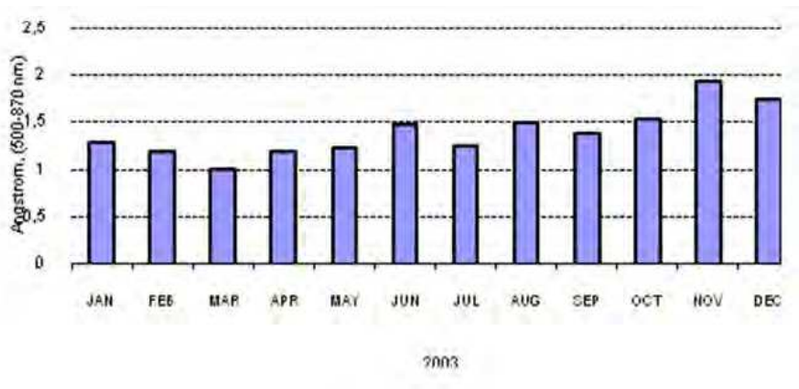


Fig. 6. Monthly mean Angstrom exponent at 500-870 nm for the 2002 (a) and 2003 (b) at Dalanzadgad AERONET site.

	Fine mode		Coarse mode		Total
	R_{eff} (μm)	C_v ($\mu m^3/\mu m^2$)	R_{eff} (μm)	C_v ($\mu m^3/\mu m^2$)	C_v ($\mu m^3/\mu m^2$)
			2002		
Winter	0.141	0.009	1.597	0.024	0.054
Spring	0.148	0.015	1.506	0.111	0.125
Summer	0.141	0.020	2.030	0.029	0.050
Autumn	0.140	0.029	2.268	0.020	0.048
Year	0.142	0.018	1.850	0.051	0.069
			2003		
Winter	0.152	0.006	1.575	0.027	0.032
Spring	0.149	0.015	1.644	0.026	0.041
Summer	0.154	0.030	2.124	0.024	0.053
Autumn	0.146	0.005	1.918	0.014	0.019

Table 2. Seasonal averages of aerosol volume size distribution parameters at Dalanzadgad AERONET Sun-photometer site; Reff is the effective radius (in μm) and Cv is the columnar volume of particles per unit cross section of atmospheric column

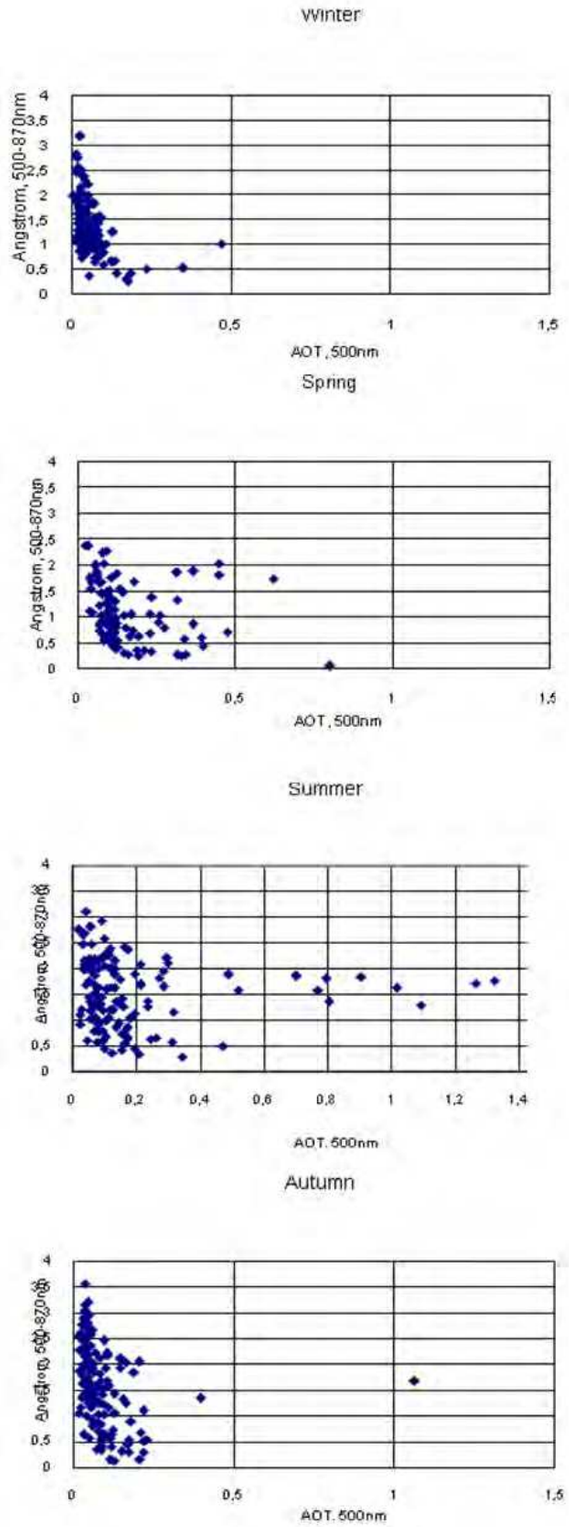


Fig. 7. Scatterplots of daily mean Angstrom exponent, $\alpha_{500\text{-}870}$ versus aerosol optical thickness, τ_{500} for each season at Dalanzadgad AERONET site.

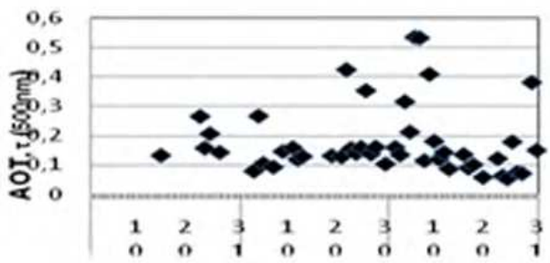
Table 3. below summarizes statistical characteristics of the aerosol optical properties in Mandalgobi semi-arid region. It gives us the opportunity to evaluate the background characteristics of aerosol optical thickness (τ), Angstrom exponent (α) and Single scattering albedo (ω) in semi-arid region of Mongolia.The optical thickness is of mean values of τ (500nm) around 0.17-0.18 and standard deviation of 0.04 to 0.07. The Angstrom exponent ranges 0.78 to 1.28 with standard deviation 0.18- 0.42 and single scattering albedos are around 0.94-0.99 at 500nm with standard deviation 0.02-0.03 (Tugjsuren N., Batbayar J, 2008, 2010).

Year/Months	N	τ	σ_τ	α	σ_α	ω	σ_ω
March, 2007	5	0.18	0.07	1.28	0.42	0.94	0.03
April, 2007	18	0.17	0.04	1.27	0.31	0.99	0.02
May, 2007	24	0.18	0.05	0.78	0.18	0.96	0.03

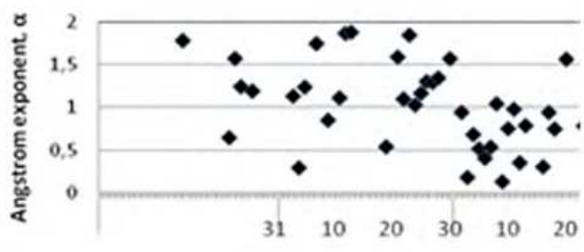
Table 3. Statistical characteristics of aerosol optical properties at Mandalgobi semi-arid region, Mongolia

Figure 8. illustrates the daily average aerosol optical thickness (a), Angstrom exponent (b), single scattering albedo (c) and standard deviations of daily τ_a(500nm) (d) for the period from March to May in 2007 at Mandalgobi
SKYNET site. From Figure 8a the daily average aerosol optical thickness values at 500 nm are higher in the second half of the spring season than first half. The aerosol optical thickness values are generally, between 0.05 and 0.20, however in some cases this values has been exceed. The monthly variation of the daily average aerosol thickness showed a maximum value of 0.53 in the first decade of May. Thus, daily mean values of τ_a(500nm) over Mandalgobi show the spring seasonal peaks in May 2007. In the majority of cases the computed standard deviations of daily τ_a(500nm) range below 0.07, however, occasionally this value is exceeded (Figure 8d).
Figure 7b presents the daily average values of Angstrom exponent, α for Mandalgobi site. The Angstrom exponent values showed significant variability with values from 0.13 to 1.89 while AOT values are between 0.05 and 0.60 and large day to day variation in the study period can be observed.
Furthermore, the optical observation data collected in Mandalgobi SKYNET site provides single scattering albedo data for this study. Daily average single scattering albedo ω, at 500nm, range from 0.87 to 0.99 (Figure 8c). However, values of single scattering albedo in the range between 0.95 and 0.99 are observed mostly. These values are close to values in a clean region. The single scattering albedo obtained in this region at 500nm is similar to 0.95 in Nagasaki (Nakajima et al., 1989). But some values of single scattering albedo as well as 0.87 and 0.89 obtained sometime during this period are similar to 0.89 in Dunhuang (Kim, D.H. et al., 2005). The frequency of occurrence distributions for aerosol optical thickness τ, and Angstrom exponent α are presented in Figure 8. The frequency histograms of τ (500nm) for Mandalgobi site demonstrate the majority of values (75%) are less than 0.20 (Figure 8a) and other values (25%) are around 0.30-0.60. The most frequently occurring values of aerosol optical thickness τ (500nm) are about 0.20 for this site in spring 2007.The Angstrom exponent frequency for Mandalgobi site shows relatively broader distributions. The frequency histogram has higher Angstrom exponent's peak frequency around between 0.7 and 1.3 (Tugjsuren N., Batbayar J, 2006, 2008, 2010)

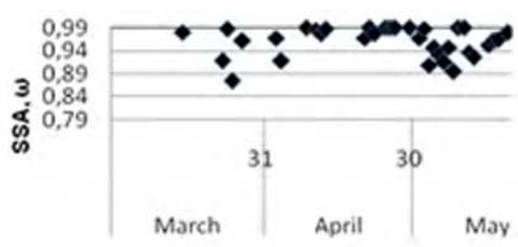
a)



b)



c)



d)

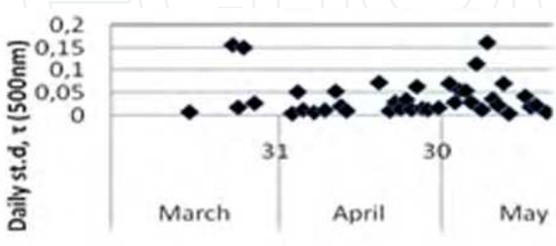


Fig. 8. Daily mean values of aerosol thickness at 500nm (a), Daily mean values of Angstrom exponent (b), Daily mean values of single scattering albedo (c), Daily standard deviations of τ (500nm) (d) for Mandalgobi site (45.711°N, 106.265°E).

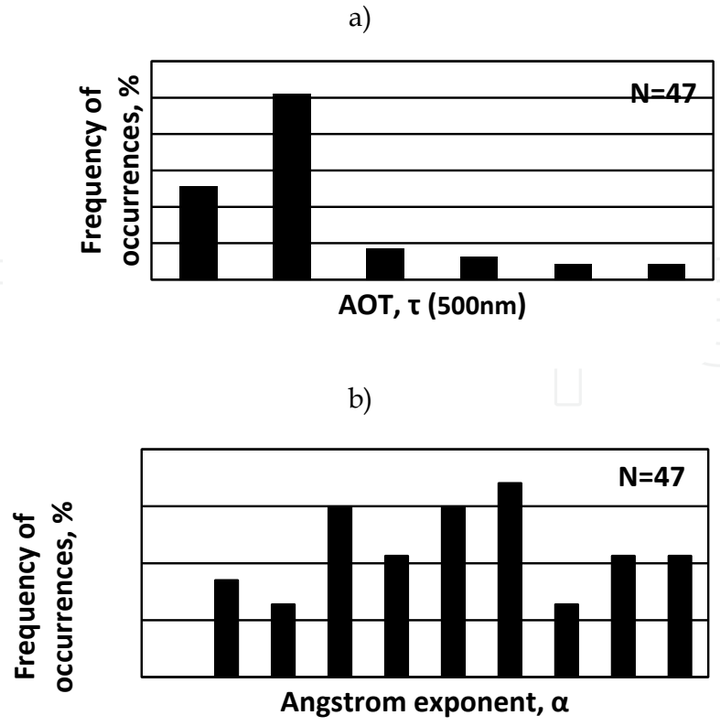


Fig. 9. Frequency of occurrences of aerosol optical thickness at500nm (a) and Angstrom exponent, α (b) for Mandalgobi site.

The scattergrams of Angstrom exponent, αversus aerosol optical thickness, τ (500nm) for spring, 2007 are shown in Figure 9.

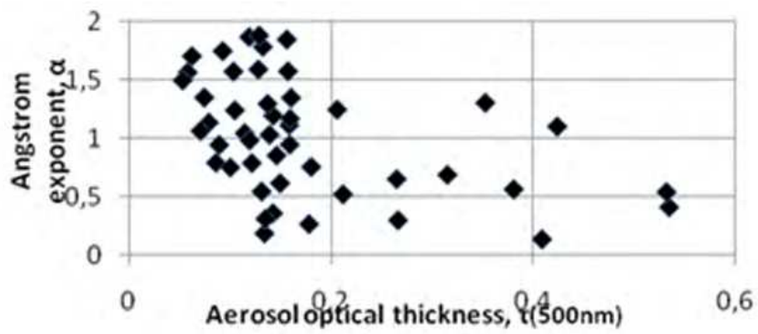


Fig. 10. Scattergram of Angstrom exponent versus and aerosol optical thickness in spring, 2007 for Mandalgobi site.

As shown on these scattergrams, semi-arid region has a wide range of Angstrom exponent values (0.13-1.89) at low aerosol optical thickness (0.05-0.20). It shows a reasonable trend of increasing values of Angstrom exponent, α as τ (500nm) decreases over study site. There is most large variation in aerosol optical thickness values when Angstrom exponent values are smaller than about 0.8 in spring season. Lastly, the analysis of the aerosol optical properties should be continued with more continuous observational data and to elaborate and improve

the analyses for different seasons and more optical and physical parameters such as volume size distributions and refractive index.

5. Concluding remarks and discussions

Aerosols have many ways to change the regional climate. Observed long term trends of temperature, cloud properties, precipitation and so on important to be interpreted as the direct and indirect aerosol radiative effects. In order to characterize aerosol optical properties in arid region, we analyzed ground measured aerosol optical thickness, Angstrom exponent and size distribution data obtained from AERONET Sun-photometer site at arid region of Mongolia. As a result, spring and early summer has the highest seasonal average AOT and minimum seasonal average appears in winter and mean monthly Angstrom exponent values occurred mostly in the range 1.0-1.93. However, low values of Angstrom exponent appears within the range 0.58-0.76 in spring. Hence, average monthly Angstrom exponents indicates that aerosol mixtures of both coarse and fine mode particles, especially dust aerosols are dominant in spring (March, April).According to spectral dependence of annual variation of AOT in the ultraviolet and visible wavelengths (λ_{340}, λ_{500}) have maximum values occurred in spring, late summer and early autumn and minimum values in winter. At the near infrared wavelengths (λ_{870} and λ_{1020}) 870, 1020 nm showed similar trend with AOT of ultraviolet and visible wavelengths (λ_{340}, λ_{500}). AOT maximum value at ultraviolet and visible wavelengths (λ_{340}, λ_{500}) appears 0.43 and 0.61 respectively, in early summer and decreases to a minimum in the winter then increases again to spring and early summer in the all ultraviolet, visible and near infrared wavelengths. The aerosol volume size distribution in seasonal pattern at arid region is that the effective radius (R_{eff}), ranges 0.141-0.154 for fine mode and 1.506-2.268 for course mode. Also the result showed that larger effective radius (1.918-2.268) with course mode occurred in summer and autumn seasons, while large columnar volume (0.111) was observed in spring season. The large columnar volume in spring is associated with strong wind occurrence season and dry period over this arid region. Aerosol optical properties (aerosol optical thickness, Angstrom exponent, and single scattering albedo) over semi-arid region were analyzed for spring season, using measurements of the Skyradiometer Network (SKYNET). The aerosol optical thickness values are generally, between 0.05 and 0.20, however some cases has reached up to 0.73 in spring. Mandalgobi site has large Angstrom exponent ranging between 0.13 and 1.89 due to fine particles. And there also exist dust particles with Angstrom exponent values around 0.13-1.00. The single scattering albedo values mostly range from 0.95 to 0.99. But dust concentration in the atmosphere is mostly very high during spring season in arid and semi-arid regions.

The Asian dust particles produce significant perturbation on the earth surface. We found that during normal daytime the direct solar radiation was much larger than diffused sky radiation, except during sunrise and sunset, and at noontime the direct solar radiation flux was 3.5-4.0 time larger than diffused sky radiation in arid and semi-arid regions. But, for dust day of spring, the diffuse sky radiation always appeared larger than the direct solar radiation. Because there was no cloud during that time, this solar radiation perturbation certainly was due radiation by the large amounts of dust particles suspended in the troposphere. Smaller particles fall more slowly in the atmosphere and decrease the amount of rainfall. In this way, changing aerosols in the atmosphere can change the frequency of cloud occurrence, cloud thickness, and rainfall amounts. If there are more aerosols, scientists expect more cloud drops to form. Since the total amount of condensed water in the cloud is

not expected to change much, the average drop must become smaller. This has two consequences - clouds with smaller drops reflect more sunlight and such clouds last longer, because it takes more time for small drops to coalesce into drops that are large enough to fall to the ground. Both effects increase the amount of sunlight that is reflected to space without reaching the surface. It is thought that aerosol cooling may partially offset expected global warming that is attributed to increases in the amount of carbon dioxide from human activities. Cloud radiative properties are strongly affected by the relative contributions, which are dependent on wavelength, of in-cloud aerosols, water vapor, cloud droplets as well as ice particles. The probable adverse impact on humanity due to aerosol cooling effect from increased dust particles in the atmosphere will be recognized when greenhouse effect decreases as a result of the concerted effort by countries around the world. There is probability that in the near 5-8 years, decreasing greenhouse effect will be felt as a result of the measures undertaken by the international communities. Aerosols have many pathways to change the regional climate. For one of the main cause of warming in arid and semi-arid regions, may be, related to the dust aerosol warming effect through the absorbing of solar radiation. Certainly, further research is needed to verify it. For further detailed studies of the radiative effects by real aerosols, the importance of closure experiments is highly suggested. Furthermore, for prediction of feature climate changes, it is needed to evaluate the direct and indirect radiative forcing by anthropogenic aerosols.

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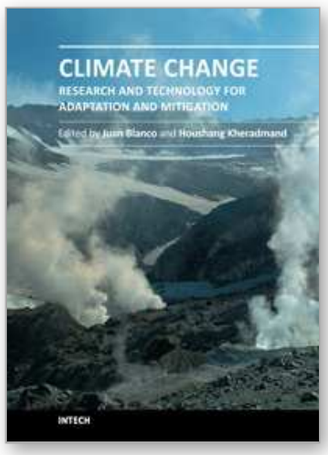
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This book provides an interdisciplinary view of how to prepare the ecological and socio-economic systems to the reality of climate change. Scientifically sound tools are needed to predict its effects on regional, rather than global, scales, as it is the level at which socio-economic plans are designed and natural ecosystem reacts. The first section of this book describes a series of methods and models to downscale the global predictions of climate change, estimate its effects on biophysical systems and monitor the changes as they occur. To reduce the magnitude of these changes, new ways of economic activity must be implemented. The second section of this book explores different options to reduce greenhouse emissions from activities such as forestry, industry and urban development. However, it is becoming increasingly clear that climate change can be minimized, but not avoided, and therefore the socio-economic systems around the world will have to adapt to the new conditions to reduce the adverse impacts to the minimum. The last section of this book explores some options for adaptation.

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