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Dust Storms in Kazakhstan: Frequency and Division

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Abstract: Dust/sand storm is a common phenomenon in arid and semi-arid regions of Kazakhstan, especially in its southern parts, where areas are covered by a great variety of deserts and are a powerful source of mineral and salt aerosols. We considered the long-term meteorological data and satellite images on dust storms recurrence and their regional division in Kazakhstan. On the basis of generalization and analyses of the numerous cartographic materials, meteorological observations and satellite images, we identified seats of the powerful sources of dust/sand/salt storms. We found areas in Kazakhstan with the highest frequency of dust storms. These are Pre-Aral Karakum and Aralkum deserts; Kyzylkum and Moiynkum deserts; Ryn sands (northern Caspian plain); and southern Pre-Balkhash deserts. The most active source of dust storms is located in sandy deserts or in areas, which have suffered from human activity. Dust storms have a great negative impact on soil conditions and they are particularly dangerous for the environment.

Keywords: Dust storms, soil texture, deserts, Kazakhstan, Central Asia.

INTRODUCTION

A dust event is a meteorological phenomenon common in arid and semi-arid regions and arises when a gust front passes or when the wind force exceeds the threshold value (6m/s) and sand/dust are removed from the dry surface (Squires, 2001; WMO, 2007). According to many, dust storms are the result of turbulent wind systems which raise dust particles into the air reducing visibility to 1000 m or below (Romanov, 1960; Khramov and Mamontova, 1974; Goudie and Middleton, 1992). Dust storm is usually associated with arid and semi-arid areas of temperate, tropical and subtropical latitudes, where the mean annual precipitations are lower than 200-300 mm (Indoitu et al., 2012). Thus drylands, which occupy more than 40% of the earth surface and home for about 1 billion people, are the largest contributors to the global and regional aerosols loading -40-50 % of the annual emission of global aerosols (Squires, 2001).

In central Asia, including Kazakhstan there are huge areas, which are source for the dust, sand and salt storms. The natural factors have a role in the formation of dust/sand/salt storms. The natural factors such as climate aridity, frequent strong wind, scarcity of vegetation, inadequate soil moisture, low relative air humidity, frequent recurrence of soil and atmospheric drought, soil with light texture promotes active development of deflation processes (as a dust storms) in Kazakhstan (NAKZ, 2010; Semenov, 2011). Desertification caused by deflation in Kazakhstan cover dry steppe, semi-desert and desert landscapes (including 205 km^2 of arable land) (Belgibayev, 2001; Dedova et al., 2006). Apart from natural factors, the anthropogenic factors have a significant role in the origin of dust storms. Starting with the intensive development of irrigation in the Aral sea basin at the beginning of 1960s and irrational use of water resources, significant areas of secondary saline soils and anthropogenic solonchak have appeared. These areas are source of salt transfer and these salts have negative affect on the environment and living conditions of local population. White or salt storms are formed as a result of the deflation of the solonchak, salt deposits, and other loose rocks that saturate the air by dust particles. Salt is an indispensable component of dust (Orlovsky and Orlovsky, 2001; Orlova and Seifullina, 2006). Salt/dust transfer and their deposits affect the air and soil surface quality, ground water including drinking water, quality of agricultural and livestock products. By 2000, 42.000 km^2 of the seabed was exposed resulting in a new Aralkum desert (Man-Made Desert) which became powerful source of dust/salt storms during last two decades of the 20th century. The desiccated seafloor is a huge open and often a bare surface rich in salt. The amount of salts from the exposed bottom of the Aral sea reached $15\text{-}75*10^6$ t p/year and raised considerable concerns about human health (Saiko and Zonn, 2000). By other estimate the total amount of deflated material from the exposed bottom of the sea varing from 40 to 150 million tonnes (Micklin, 2010). As well as the deflation process as sand and dust storms are dominant on the vast territory of desert pastures with brown, gray-brown, takyr and sandy soils, which is located in southern Kazakhstan (Medeu, 2010). In Kazakhstan about 14% of all pastures have reached an extreme degree of degradation. Most of these processes are observed in areas of the Aral and Caspian seas and around Balkhash lake (Orlova and Saparov 2009; Medeu, 2010). The northern Caspian sea (Ryn sands), Aral sea region, Syrdarya river delta (Kyzylkum), the southern Pre-Balkhash deserts belong to significant and high degree of land degradation under the influence of grazing (NAKZ, 2010). Pasture degradation is mostly in desert and semi-desert landscapes in Kazakhstan.

For better understanding of soil/land degradation and deflation processes, it is necessary to know the regional divisions of Kazakhstan which are mostly prone to the dust storms. The aim of this study is the detection of dust/sand/salt storms sources, finding the causes, based on consideration and analysis of numerous cartographic materials, data from weather stations and satellite monitoring materials thereby providing the accurate picture of distribution and frequency of dust storms over the Kazakhstan.

STUDY AREA

The Republic of Kazakhstan is one of the rapidly developing and youngest independent countries in the world. Kazakhstan lies between the Siberian Taiga in the north and the central Asia deserts in the south, the Caspian sea in the west and the mountain range of the Tien-Shan and Altay in the east (UNDP, 2002). About 60% of lands in Kazakhstan are flat. Deserts and semi-deserts occupy approximately 50% of the territory, most of them situated in the Turan plain. Arid territories spread from Caspian sea to foothill plains of Zhetysu (Zhongar) Alatau and Tien-Shan mountains. These vast territories have various geological structures and landscape features such as sandy deserts of Ryn, Kyzylkum, Pre-Aral Karakum, Moiynkum, Saryesikatyrau (Fig.1). The northern parts of Kazakhstan are steppes and forest-steppes (Danayev, 2008).

The territory of Kazakhstan is far from oceans and opens for winds from the north. Kazakhstan's climate is continental with uneven distribution of precipitations. Plain areas are generally dry and have precipitation from 100 mm in the southwest up to 400 mm in the north annually. In the mountainous regions, the precipitation ranges between 400 mm and 1600 mm (ADB, 2003; Almaganbetov and Grigoruk, 2008). Average temperature is -18°C in January in the north and -3°C in the south. Average temperature in July increases gradually from 19 °C in the north up to 28-30 °C in the south. Almost the whole territory is windy. Wind speed regime is variable throughout Kazakhstan. Average annual wind speed reaches 4-5 m/s for almost 50% of the area. But the average annual wind speed can reach 6 m/s and even more in some regions of the central parts, coastal areas of Caspian and Aral seas, as well as some areas in the south, south-east and south-west of Kazakhstan (Uteshev, 1959). The flat parts of Kazakhstan have maximum wind speed in spring and autumn seasons, and minimum in summer (Danayev, 2008). Western, northern and north-western cold intrusions are responsible for development of 40% of dust storms. In 22 % cases dust storms are occurring at the periphery of anticyclone and 14 % cases at the exits of the southern cyclones (Romanov, 1960).

MATERIALS AND METHODS

Dust storms appear when some critical thresholds of wind speed, topography and soil structure, unrelated particles are less than 250 microns, high soil dryness, and scarcity of the vegetation cover. These thresholds vary from region to region. Dust storm observations were made at meteorological stations located in particular areas of interest in Kazakhstan. A dust storm starts with a wind speed higher than 6 m/s. A dust storm is considered as strong when the wind speed reaches 10-14 m/s, with visibility between 500 m and 1000 m. Usually, such wind lasts from 3 to 12 hours. The very strong dust storms last for 12 hours or more with a wind speed more than 15 m/s, when visibility decreases up to 50 m or less (Romanov, 1960; Dedova et al., 2006).

For the analyses, we used data of the "Dust storm climatology for Kazakhstan databases". Our database is the

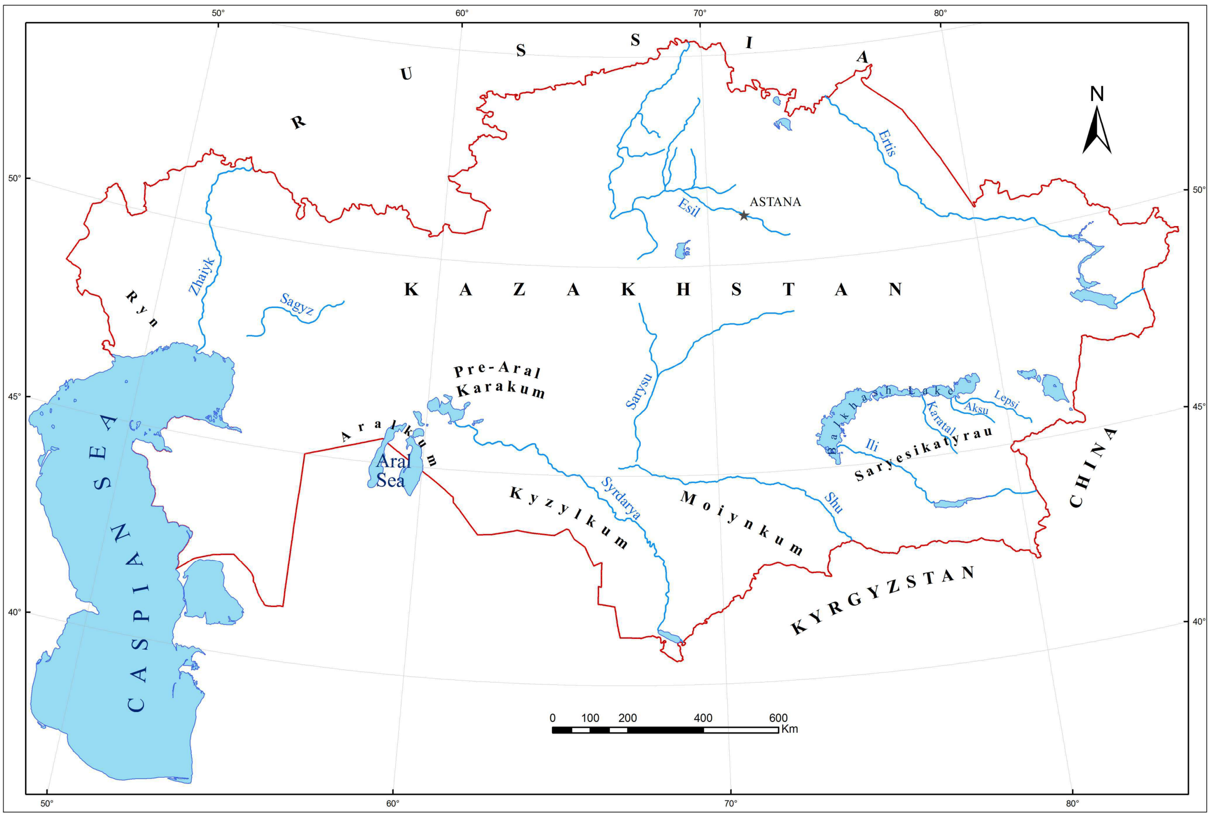

Fig.1. Distribution of sandy deserts in Kazakhstan.

archive data collections contained in the "Reference Books of Kazakhstan climate (2003)". This database contained the monthly average number of days with dust storm for each weather station (30 weather stations) and their frequencies for 39 years. We have analyzed seasonal frequency of dust storms in different regions in Kazakhstan according to average number of days with dust storms in different months for the period 1966-2003. Long-term (many years) variability of the dust storms frequencies was analyzed using data from 1971-2010. For identification of potential sources of dust storms in Kazakhstan, all information about the soil texture on the map of dust storm frequency was studied.

In this paper, we used the numerous cartographic materials (Lobova, 1946; Semenov and Tulina, 1978; Rachkovskaya et al., 2003; Dedova et al. 2006), weather station data and data from the satellite monitoring for detection of strong dust/sand/salt storms centers and their causes. The data of space monitoring in Kazakhstan were analyzed with a NOAA, TERRA and AQUA satellite in order to identify visually the powerful dust storms.

The Arc Map software was used as a main tool to analyze the regional distribution of the dust storm events as well as for preparing the map of dust storms frequency. Using this map, the sources of dust/sand/salt storms, estimate their area and define the relationship between dust storm origin and soil texture with plant communities are identified.

RESULTS AND DISCUSSION

Regional Division of Kazakhstan according to the Dust Storm Frequency

The distribution and frequency of dust storms in Kazakhstan is heterogeneous and spotty and is characterized by large diversity. According to the weather station observations, the high wind speed regime and dust storms are typical for continental climate of almost all over Kazakhstan. The dust storms dynamics in the different regions are indicated in Fig.2. The number of days with dust storms increases from northwest to southeast. In the southern part the number of days with dust storms is high in the sandy deserts and river valleys. The average number of days with dust storms along the Syrdarya and Ili rivers is 28, with maximum of 67; in the southern shore of the Balkhash lake is 30 and 103 respectively (Orlovsky and Orlovsky, 2001). In general, the annual number of days of dust storms is 20-38 in the steppe zone and 55-60 in the desert zone (near the Aral sea and Balkhash lake regions)

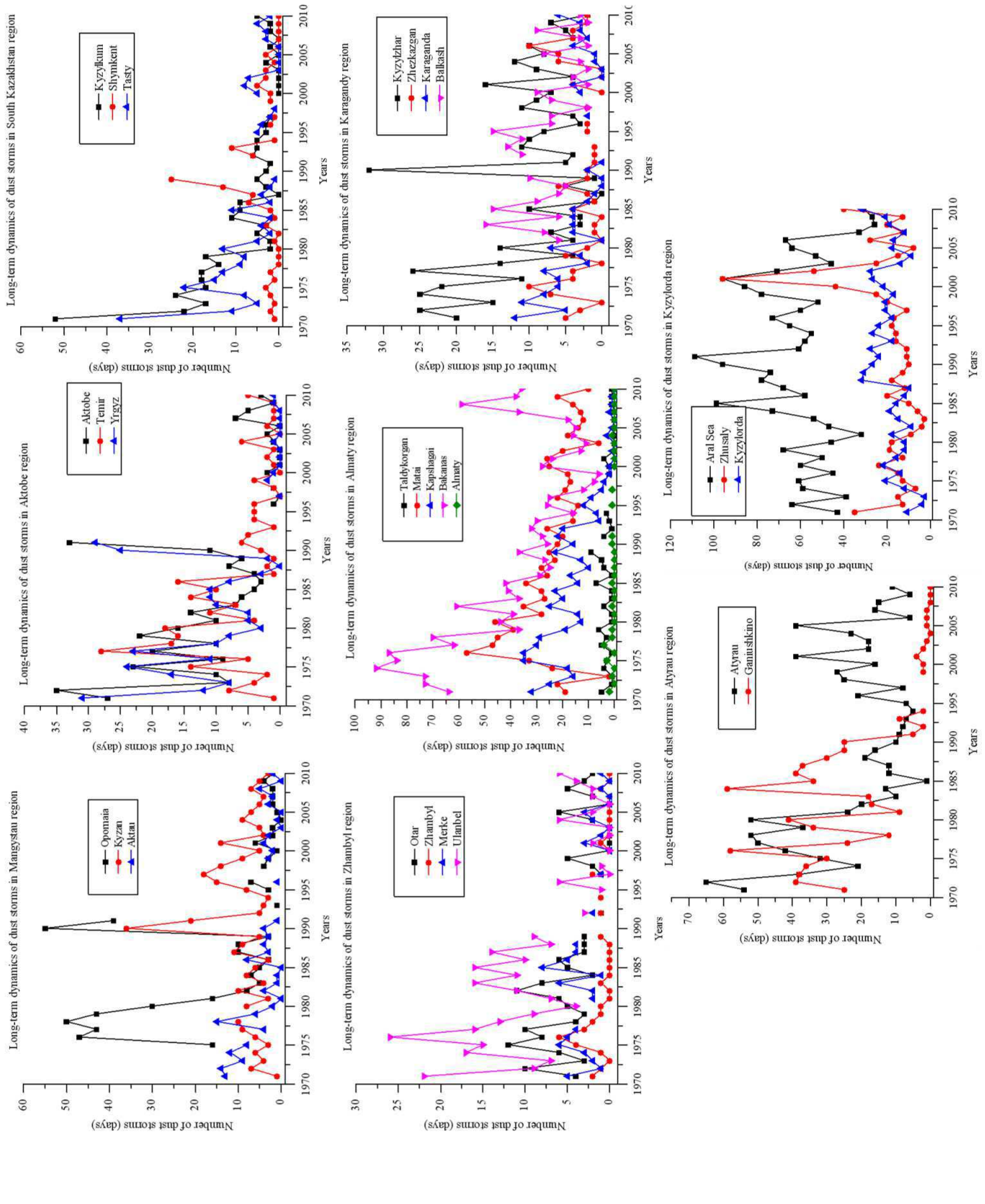

Fig.2. Dust storm dynamics in different regions of Kazakhstan during 1971-2010

(NAKZ, 2005). The sites with dust storms of higher frequency (20 days/year) are situated in areas with higher wind speeds and where soils have light texture which are under intensive use, or in sandy areas with sparse vegetation. Using the long-term meteorological data, numerous cartographic materials, we found the following regions with most frequent dust storms:

a) Pre-Aral Karakum, Kyzylkum and Aralkum deserts. High frequency and long duration dust storms are a feature of arid regions, including the Aral sea and Syrdarys river region. The largest source area for dust storm is the Pre-Aral Karakum (Aral sea weather station) and Kyzylkum deserts, where dust storms occur in 40 to 110 days/year (Fig.2). The most frequent storms are observed in the northern Aral sea region, where their long-term average frequency reaches 36-84 days/year, from 9 to 23 days/year in the eastern Aral sea region, in the southern Aral sea region varies from 6 to 20 days/year (Semenov, 2011). Most parts of the Aral sea region are covered by sands and soils of light texture. Predominance of soil with light texture favors the development of wind erosion processes and formation of aeolian land forms. The average size of sand particles in the region varies from 90-100 to 170-270 microns. These particles are easily transported by wind (Semenov, 2011). Nevertheless, in this region the anthropogenic causes are playing major role in the formation of dust/salt storms. During last two decades of the 20th century the Aralkum desert (Man-Made desert) became active powerful source of dust/salt storms and transfer. The desiccated seafloor is a huge open salt surface and consists mainly of the salt desert (70%) and sand/sand-loamy deserts (20%) (Micklin, 2010). The salt desert is the source of salt-dust storms affecting the entire adjacent regions (Breckle et al., 2012). According to the type of soil/land degradation (salinization, wind erosion) the anthropogenic activity is dominant in the region (NAKZ, 2010; Medeu, 2010).

b) Southern Pre-Balkhash deserts. Meteorological features (temperature and dryness) of the southern Pre-Balkhash deserts and its landscape with sparse vegetation are prone to dust/sand storms, because the winds blow the soil particles from the ground surface very easily (Fedyushina, 1972). The grains size (more than 100 microns) of the sands in most of the areas of this region belongs to easily deflated type of soils (Skotselias, 1995). Dust/sand storms are common events and often happen simultaneously with hot dry winds in the region (Semenov, 2011; Fedyushina, 1972). The number of days with deflation processes (dust/sand storms) in southern Pre-Balkhash

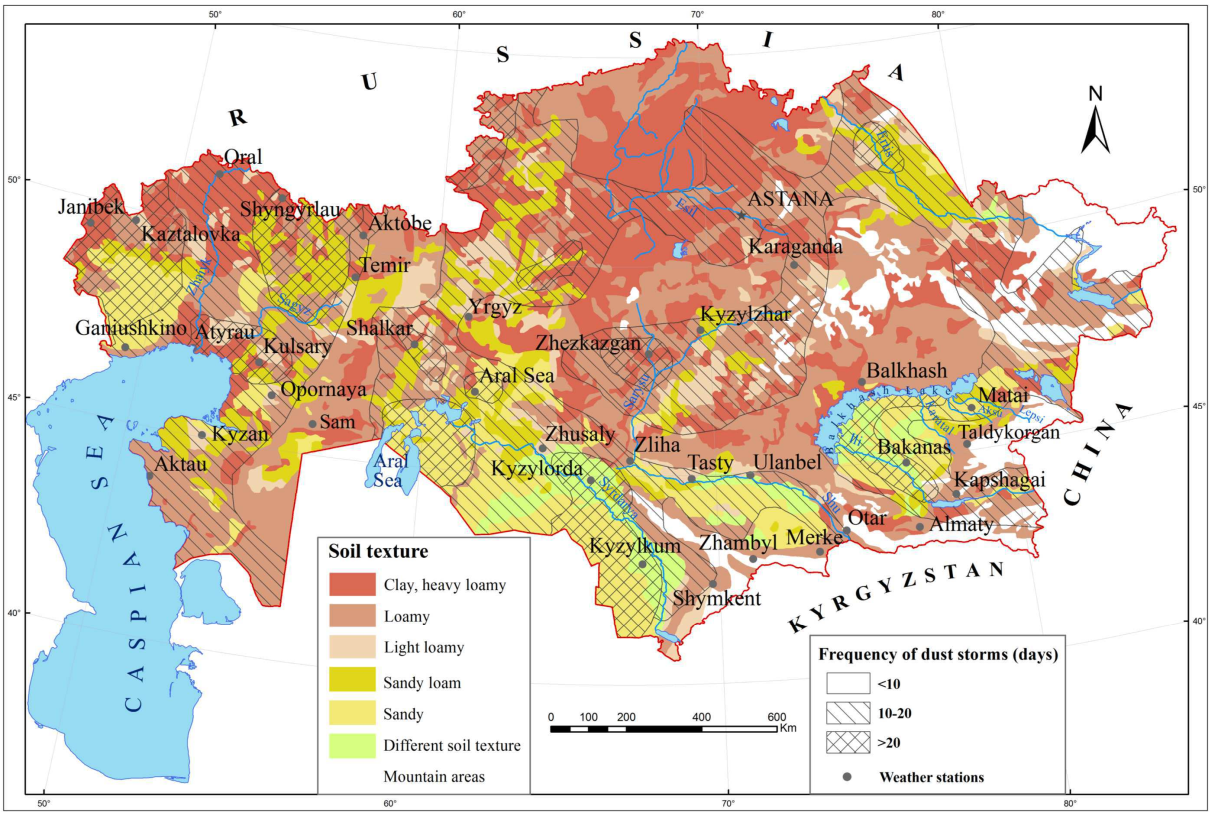

Fig.3. Geographical distribution of soil texture and dust storm frequency in Kazakhstan

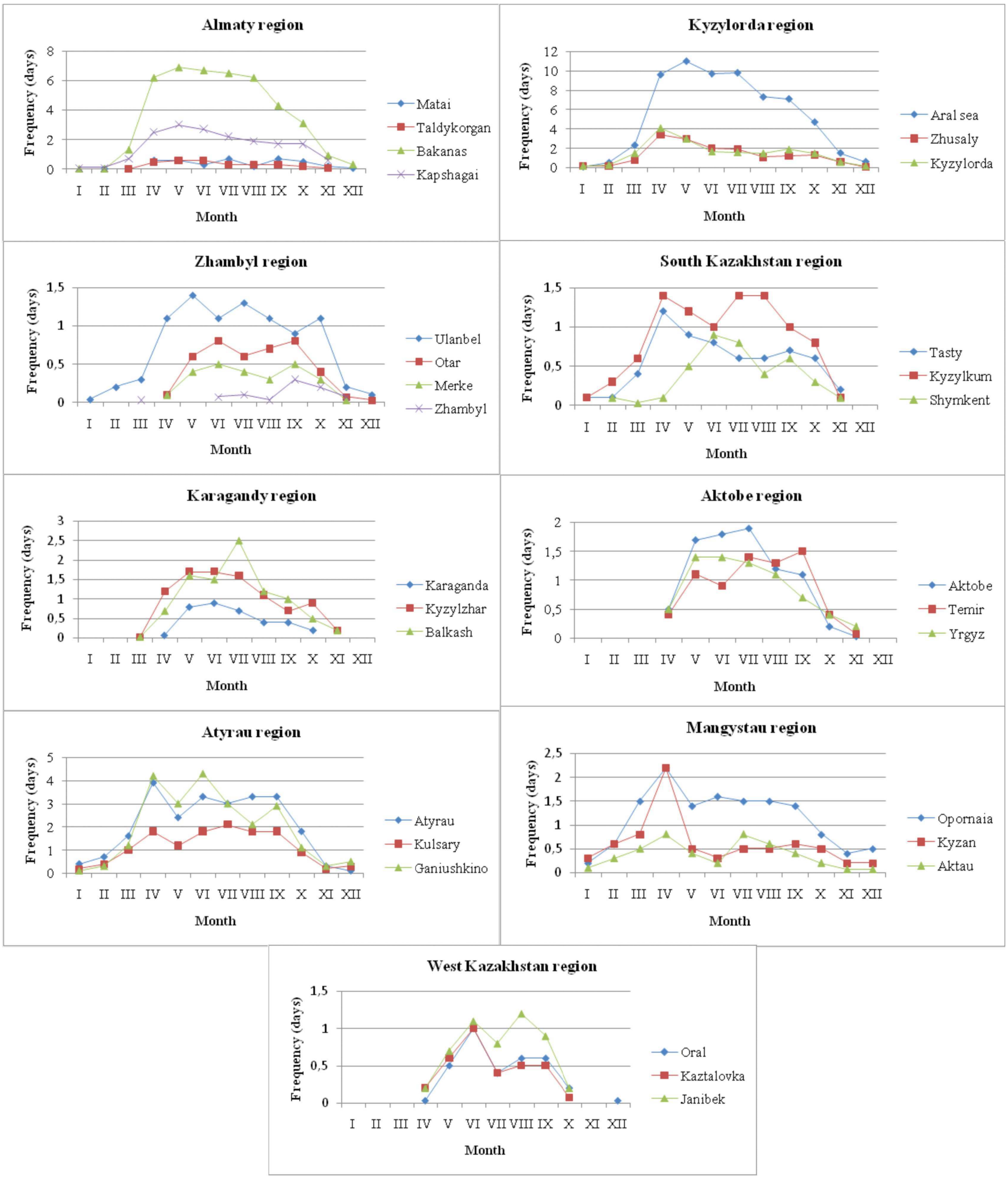

Fig.4. Seasonal frequency of dust storms in different regions of Kazakhstan for the period of 1966-2003.

deserts reaches 30-40 days (Taukum Desert), in the Ili river deltas and valley and on the southern coast of Balkhash lake, which decreases to 10-20 days in Saryesikatyrau desert. There are large number of dust/sand storms in the Bakanas station (Fig.2-3), because there takyr-like soils contain silty sand sediment, clay particles and have mostly fine structure. The takyr-like soils are distributed in most areas of Bakanas and Akdala ancient dry delta plains, along the left bank of Karatal river (Asanbayev and Faizov 2007). Consequently, in this region natural landscape has a major role in the origin of dust/sand storm. In addition, natural landscapes disturbance in the southern Pre-Balkhash deserts is dominant (NAKZ, 2010; Medeu, 2010). However, sandy deserts of southern Pre-Balkhash region is subjected to intensive human activity. In 1970s, after creation of the Kapshagai water reservoir and intensive use of water from Ili, Karatal and Lepsi rivers (for irrigation, electric energy production) led to the decrease in water level in Balkhash lake. As a result, considerable part of land in coastal area of Balkhash lake has undergone soil salinization and degradation, respectively, reducing and regulating river flow level of Ili and Karatal which led to the drying of many lakes, including salty lakes in deltas of these rivers (Skotselias, 1995; Belgibayev, 2001; Kudekov, 2002). As a consequence, the new sources of soil deflation and sources of dust/sand storms have appeared in the southern Pre-Balkhash deserts that led to high concentration salts in the atmospheric flows. These salts cause deterioration of pastures, reduction of biodiversity, salinization and desertification of soils.

Strong and Very Strong Dust Storms

Strong and very strong dust storms (more than 4 days) cover large areas of mostly western Kazakhstan and Atyrau oblasts (region); part of Aktobe and Karaganda oblasts, the northern half of the right bank Ertis river in the Pavlodar oblast; Ili river valley, Sam sands, Kyzylkum sands in the territory of Syrdarya river ancient delta, and two areas in the Shu river valley (Fig.5). These areas are used for agricultural or industrial production, additionally, such factors as high wind speed (exceeding 8-10 m/s) and light-textured soils (soil particle size less than 250 microns), dryness of soils and sandy deserts with sparse vegetation resulting in strong dust storms (Semenov, 2011). According to composed map of the territory strong and very strong dust storms are determined. Due to the variable frequency, the dust storms covering the areas are further divided into 4 groups by following frequencies: 518525 km^2 (19%) is >4 days, 141175 km^2 (5%) is 3.1-4 days, 1444561 km^2 (53%) is 1.1-3 days, and 613445 km^2 is <1 day (23%). The frequency of very strong dust storms which lasts more t han 12 h is 2.5-4 %, is observed in the following weather stations: Shyngyrlau, Kyzylkum, Sam, Aral Sea, Shalkar.

The Seasonal Distribution and Duration of Dust Storms

Kazakhstan is a large region with variable geographical and climatic features, therefore dust storms activities vary on annual and inter-annual scales. In general dust storms in Kazakhstan are common in the spring and summer seasons. According to average number of days with dust storms in different months for the period 1966-2003, two peaks were found; April-June and August-September (less in October) (Fig. 4). Due to the drastic rise in the temperatures and high wind speed in the spring, the southern desert surfaces suffer from rapid evaporation of precipitation, which together with strong winds favors the development of dust storms. The Kyzylkum, Pre-Aral Karakum and Southern Pre-Balkhash deserts are the main regions of Kazakhstan, where dust storms are common, especially during April-October and April through August respectively (Aral Sea and Bakanas weather stations).

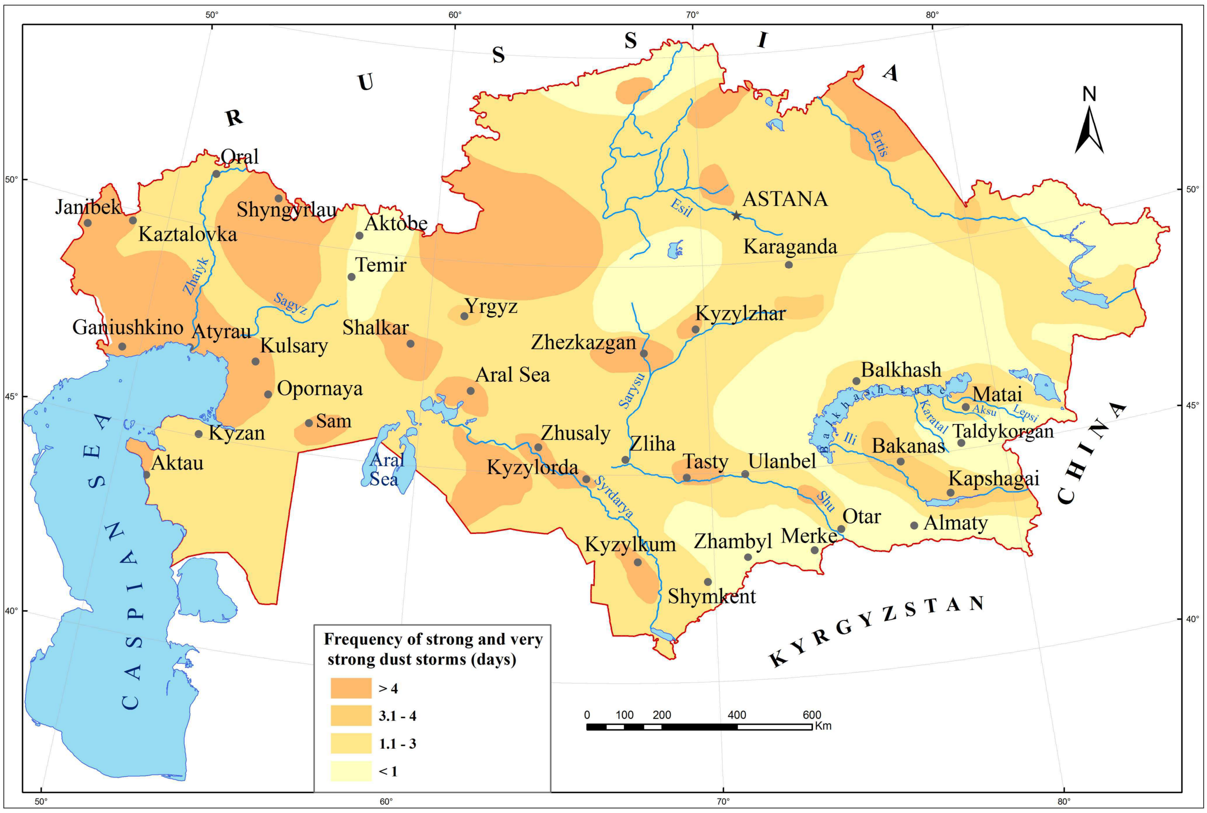

Fig.5. Distribution of strong and very strong dust storms in Kazakhstan

The frequency of dust storms which lasts more than 3 hours is rather high in all weather stations (except foothill weather stations) and varies within 12-30% (Table 1). More prolonged dust storms lasting between 1-3 and 9 hours, represent 10-32% of the total dust events during the year. The frequency of dust storms with duration 1-9 hours increases in areas with light soil texture.

The Relationship of Dust Storm Origin and Soil Texture

The soil texture is an important feature which determines the soil surface resistance to the wind erosion (soil deflation). According to the soil map of Kazakhstan there are following kinds of soil texture: sandy, sandy loamy, light loamy, loamy, clay and heavy loamy, and layered soils of different composition (Fig.3). In order to find the potential sources of dust storms, all soils are divided into 2 classes. The light-textured soils (sandy and sandy loam) belong to the first class and all other kinds of soil belong to the second. The sandy and sandy loam kinds are severely prone to the deflation processes (Fig.3). The plant community has a role in the formation of dust/sand storms. Depending on soil texture, chemistry of soils and pedogen rocks, communities of species of certain ecology are formed. Communities with similar ecology are grouped in so-called edaphic variants (Rachkovskaya et al. 2003). Edaphic variants of deserts conditioned by soil texture such as vast sandy massifs Ryn, Kyzylkum, Karakum, Moiynkum and Southern Pre-Balkhash deserts (Taukum, Saryesiktyrau) belong to psammophytic variants of plant communities. Also there are sandy deserts in the Aral and Northern Caspian regions. The communities are formed on the sandy soils and sands. The analysis of the map of Edaphic variants of deserts in Middle Asia (Rachkovskaya et al. 2003) show that the psammophytic variants of vegetation are vulnerable for dust/sand storms. In addition, the data on the location of the soil with light texture in the areas with strong dust storms based on the available data was analysed. The centers of dust storms of high repeatability (> 20 days/year) are situated in areas with soil of light texture and high wind speed (Fig.3). Such areas are also used intensively in the agricultural or industrial development as they are located in regions of sandy deserts with sparse vegetation or sometimes barren dunes. According to Fig.3 the highlighted areas with strong dust storms are found in the regions of light-textured soils or sands. Such kinds of soils with psammophytic plant community are source for rising of the fine aerosol in the atmosphere streams, which are clearly detected by the satellite monitoring systems.

Visual Identification of Dust Storms Based on the Satellite Monitoring Data

The geo-information analyses involving the satellite imagery will enable to consider the natural dust storms in combination with the soil characteristics. Observation from space makes it possible to reveal the main sites of salt/dust cloud formation, their size and main directions of salt/dust

Table 1. Frequency (%) of dust storms of various variations

Station	Duration, h									
	1	1-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	>24
Shyngyrlau	18.5	23.7	24.0	19.8	9.1	2.5	1.1	0.6	0.5	0.2
Oral	36.5	27.8	22.4	8.1	3.2	1.4			0.3	0.3
Atyrau	9.8	26.6	29.9	20.5	8.9	1.8	1.1	0.7	0.5	0.2
Aktobe	38.9	25.8	19.8	11.5	3.0	0.8		0.2		
Shalkar	16.7	23.7	23.8	17.8	10.2	3.4	1.4	0.8	0.6	1.6
Yrgyz	37.6	21.4	20.8	12.8	4.2	1.4	0.8	0.2	0.6	0.2
Sam	19.2	25.4	29.1	12.7	7.2	3.0	1.6	1.2	0.3	0.3
Ulanbel	48.1	32.1	15.8	2.5	0.9	0.2	0.2			0.2
Zhambyl	43.0	32.6	16.0	5.6	1.4	0.7	0.7			
Kyzylzhar	30.3	27.2	23.6	10.8	5.4	1.4	0.9	0.2		0.2
Karaganda	55.0	25.3	12.6	5.3	1.7	0.1				
Zhezkazgan	30.0	26.7	23.9	12.7	5.9	0.2	0.2	0.2		0.2
Balkhash	72.4	17.4	3.1	4.1	1.0	2.0				
Aral Sea	20.7	27.8	26.8	12.9	6.0	3.2	0.4	1.1	0.2	0.9
Zhusaly	17.2	27.0	26.0	18.1	7.4	1.7	0.7	0.5	0.4	1.0
Kyzylorda	11.3	23.1	30.4	23.5	8.9	1.5	0.5	0.1	0.2	0.5
Tasty	25.4	31.3	24.0	11.9	6.0	0.6	0.6	0.2		
Kyzylkum	21.2	23.9	24.0	12.9	10.5	3.8	1.4	0.6	0.8	0.9
Shymkent	46.8	31.4	15.0	4.2	0.9	0.4	0.9			0.4
Bakanas	32.3	29.4	21.9	10.1	4.4	1.2	0.4	0.1	0.1	0.1
Matai	29.5	29.0	25.6	11.4	3.6	0.7	0.1		0.1	
Taldykorgan	66.2	27.6	6.2							

transportation (Grigoriev and Lipatov, 1979; Zakarin et al., 2001). The climatic conditions of Kazakhstan indicate that dust storms occur mostly during spring and autumn periods. We selected cases of severe dust storms in the potentially dangerous deflation areas of Kazakhstan (Fig. 6-7). In Fig. 6 some cases of strong dust storms can be seen; these areas are potentially dangerous for the development of deflation. The strong dust storms in the Betpakdala desert during October of 2005 is depicted in Fig. 6 (A). Dust storms (Fig. 6B) were caused by strong long-term winds observed in northern Caspian sea with 300-350 km in length. The satellite monitoring system recorded extra-strong salt/dust removal of the eastern (May 16) and western (September 1) directions in the Aral sea (Fig. 6(C). In addition, the eastern shore of the Aral sea and Amudarya delta region is a source of the powerful salt/dust removals. The analysis of the satellite images demonstrated that in August 2011, the dried bottom area of the Aral sea was 57.529 km^2. The area of waterbodies was 2317 km^2, 4411 km^2 and 3243 km^2 for Eastern, Western and small Arals respectively (Kozhoridze, 2012). As a result there was a drop in Aral sea level, new dry areas became active hotspots of salt/dust storm outbreaks (Wiggs et al., 2003; Galaeva and Idrysova, 2007; Indoitu et al., 2012). Aeolian erosion carried the white dust storms from the dried bottom of the Aral sea, which is one of the strongest foci of dust/sand/salt storms in the central

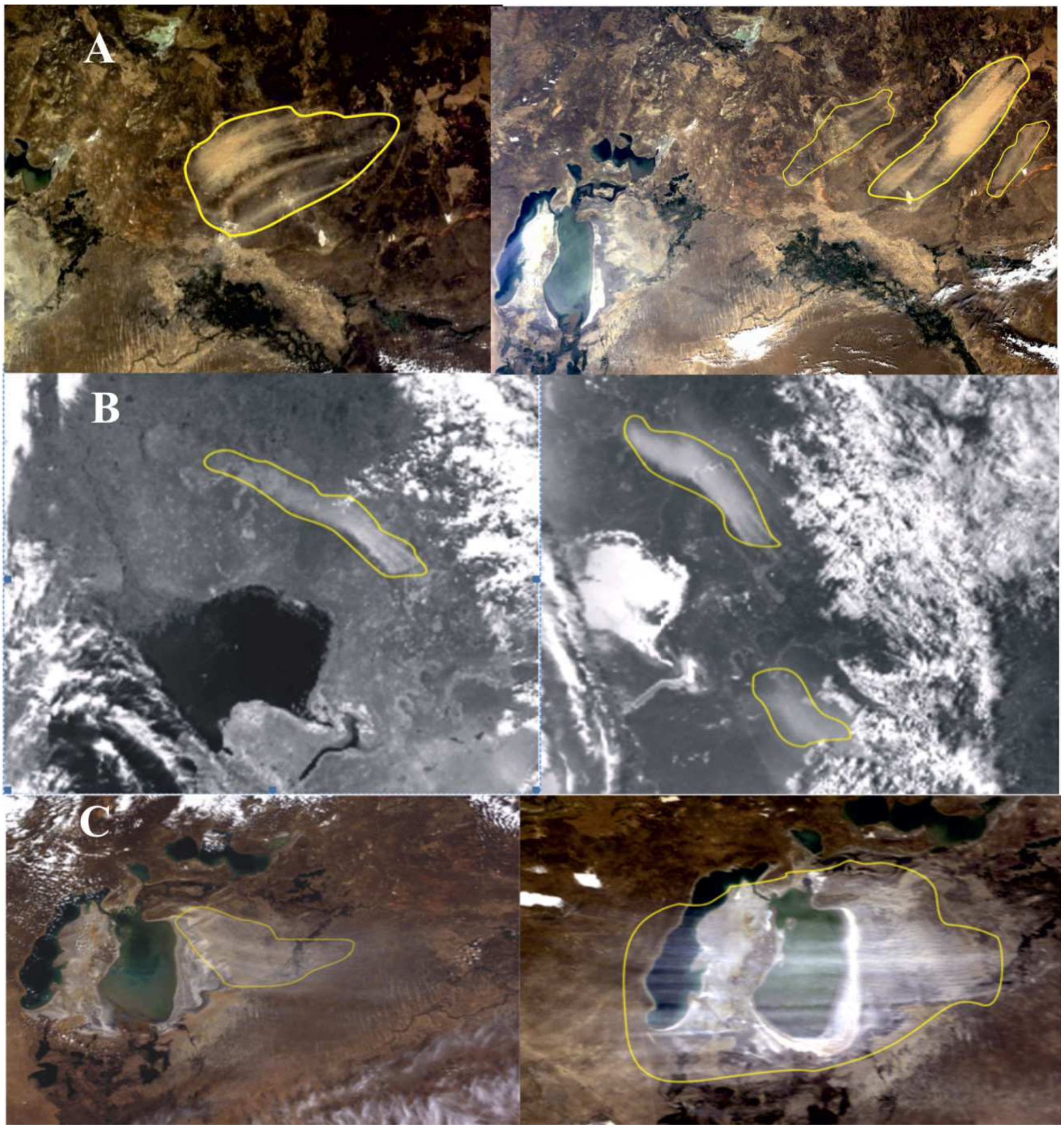

Fig.6. Dust storms: (A) to the west and east from the Zhezkazgan city (central Kazakhstan) on 5-6th October 2005; (B) to the north from the Caspian Sea on 9th April 2003; (C) in the Aral Sea on 16th May and 1st September 2006

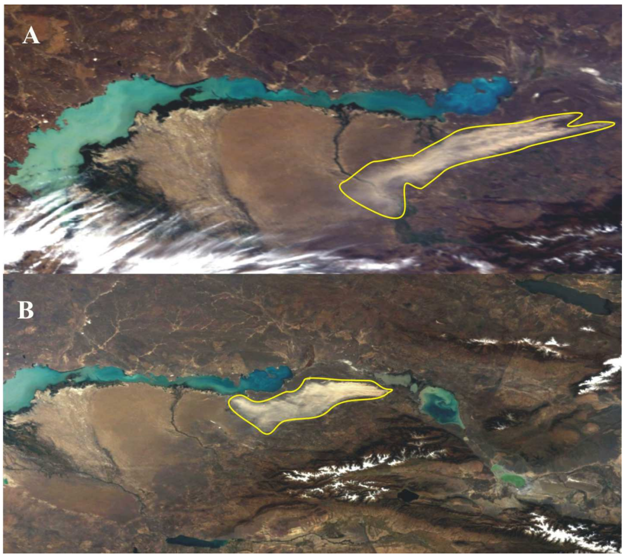

Fig.7. Dust storms: **(A)** to the south from the Balkhash Lake on 4th September 2006; **(B)** in the Balkhash-Alakol region on 1st October 2004.

Asia. The dust/sand storms recorded in the Balkhash and Balkhash-Alakol regions are presented in Fig.7. All these images confirm that the determined regions are intensive dust/sand/salt sources in Kazakhstan.

CONCLUSIONS

Dust storm is one of the most dangerous weather phenomenon, which appears if wind speed, soil conditions and vegetation cover are favorable for it. They are distributed in Kazakhstan unevenly, depending on the geological structure, wind speed and soil texture with plant community.

1 In Kazakhstan apart from natural environmental factors, the anthropogenic pressure increased their effect seriously during the last 50 years. All these have destroyed the environment and led to serious and rapid soil/land degradation.
2 The dust storm intensity depends particularly on the soil properties. The light-textured soils (sandy loam and sandy) with psammophytic variants of plant communities are most affected by deflation processes, and they are the main sources of the micro-fine aerosol particles in atmospheric currents.
3 The areas, which are most prone to the dust/sand/salt storms are following: Pre-Aral Karakum and Aralkum deserts; Kyzylkum and Moiynkum deserts; Ryn sands (northern Caspian plain); and southern Pre-Balkhash deserts. Dust/sand/salt storm sources lead to the degradation of pastures and agricultural fields, impoverishment of biodiversity and soil salinization. The complex analyses of the dataset from meteorological stations, maps and satellite monitoring gave us possibility for the prediction of global, regional and local climate changes.

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