Development of Environmental Dataset of Taklamakan Desert by TERRA/AQUA MODIS Data

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Abstract: The images of huge fixed type longitudinal sand dunes of eastern Taklamakan Desert acquired with Terra and Aqua MODIS indicate non negligible difference due to influence of solar illumination angles resulting from 70 minutes observation time difference in late Autumn. Analyses of the images of the same sand dunes acquired with Terra MODIS and JERS-1 OPS indicate significant difference due to spatial resolution difference (250 m vs. 18 m). The OPS image shows that when a large longitudinal sand dune grows to a certain size in width then it begins to split. The space and height of huge longitudinal sand dunes in the eastern Taklamkan Desert derived from the OPS image is about 2 km and 120 m in average respectively. The OPS image also clearly shows influences of the Hotien River and Mazartag mountain range on sand dunes of the area. In the north side of the Mazartag mountain range are transversal dunes in the west and compound (pyramidal, transversal and longitudinal) dunes in the eastern part while in the south side are longitudinal dunes. There is a good correspondence between the orientation of the huge fixed type longitudinal sand dunes and the direction of the monthly maximum winds of the sand storm months.
Keywords: Fixed type sand dunes, Monthly maximum winds, Vegetation index, Land cover, Soil water content, DEM, Shade simulated image, Average ground slope, JERS-1 OPS, Landsat MSS, Landsat-7 ETM+.

1. Introduction

There are many reports on Taklamakan Desert including sand dunes. Some of them are geomorphology of wind drift sands (Zhu et al.[1]), large longitudinal sand dunes (Endoh et al.[2]; Tsuchiya and Oguro[3]), Mazartag and sand dunes (Wang et al.[4]), ages of Taklamakan desert (Kanemaki et al.[5]; Endoh et al.[1]; Zhou et al.[6]), geomorphological aspects and influence of the Hotien River (Fujikawa et al.[7]; Jin et al.[8]). Most of the reports on the formation of the desert state that Taklimakan Desert had been formed and developing since the middle Pleistocene.

The purpose of this study is to clarify effects of spatial resolution of observing optical sensors of satellites and apparent features of major sand dunes in the eastern part of Taklamakan Desert and around the Mazartag mountain range from the images acquired with Terra & Aqua MODIS (Moderate Resolution Imaging Spectroradiometer), Landsat MSS (Multi Spectral Scanner) and JERS (Japanese Earth Resource Satellite)-1 OPS (Optical Sensor). Efforts are also made to find the relationship between the maximum monthly wind direction in sand storm seasons and the orientation of the major fixed type longitudinal sand dune and influence of the Hotien River on the sand dune distribution.

2. Image of Average Ground Slope by 1km Mesh DEM

GTOPO30 distributed by EROS Data Center of U.S. Geological Survey in 1993 is a global digital elevation model (DEM) and that was developed to meet the needs of the geospatial data user for regional and continental scale topographic data [9]. Elevations in GTOPO30 are regularly spaced at 30-arc seconds (approximately 1 km). The original GTOPO30 DEM data around of Taklamakan desert and a shade simulated image on Nov. 2, 2002 (13:12 local time) derived from GTOPO30 DEM data indicate in Fig.1(a) and Fig.1(b) respectively. To clarify of the features of Taklamakan desert, moreover, the average ground slope of the desert is computed from GTOPO30 DEM data (Fig.2). The places of interest in this study, i.e., huge longitudinal sand dunes, Mazatrag mountain range, Hotien oasis, Hotien River and Tarim River are indicate in Fig.2.

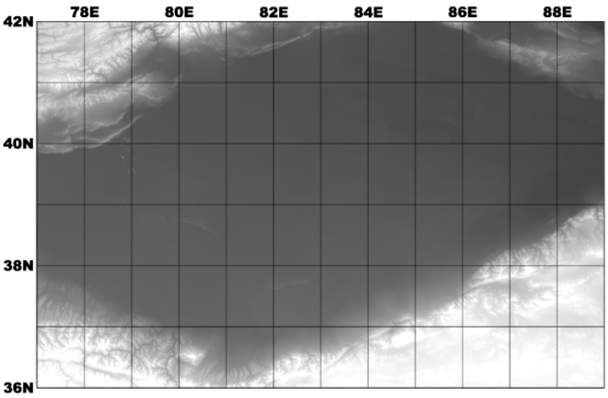


Fig.1(a) Original GTOPO30 DEM image (1 km Mesh).

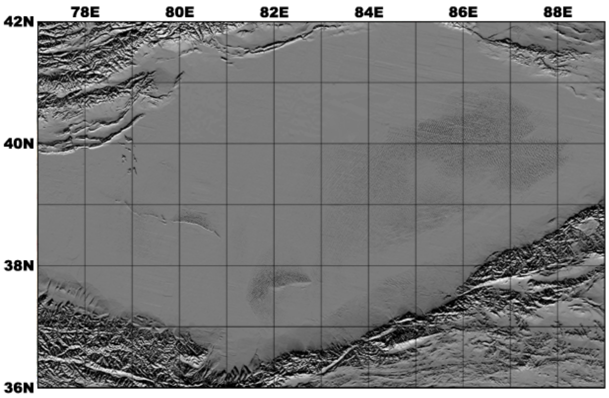


Fig.1(b) Shade Simulated Image (13:12 local time, Nov. 2, 2002).

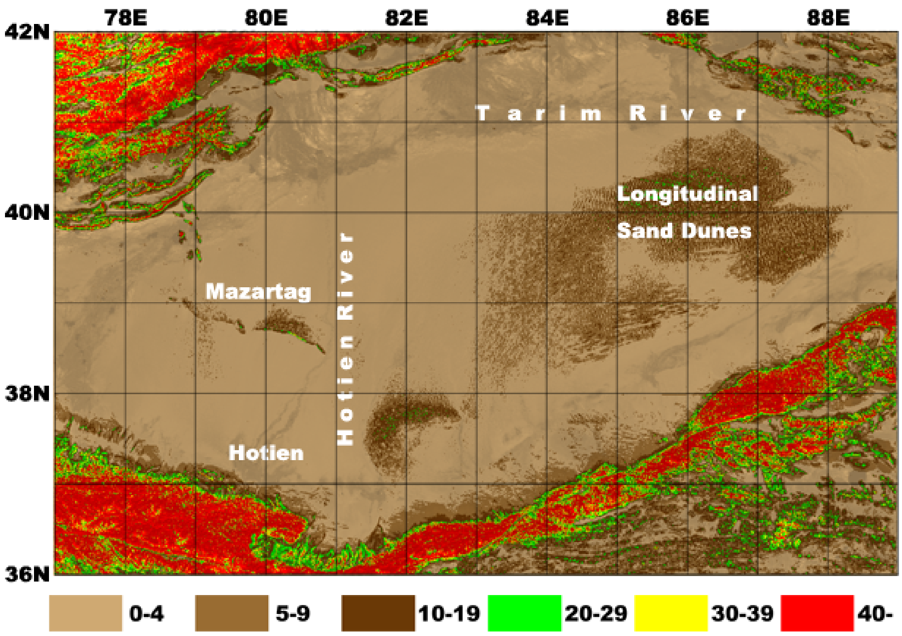


Fig.2 Image of Average Ground Slope computed from GTOPO30 DEM data. Legend Numbers indicate the slope angles in degrees.

3. Images of Terra and Aqua MODIS (250 m spatial resolution)

Two cloud free images of Taklamakan Desert acquired by Terra MODIS at 11:02 (local time) Oct.27, 2001 on a descending orbit (Fig.3(a)) and by Aqua MODIS at 13:12 (local time), Nov.2, 2002 on an ascending orbit (Fig.3(b)) are analyzed. Although well developed sand dunes are recognizable in a large image not clear in the small figure. The analysis indicates that the influence of 70 minutes observation time difference is not negligible. The NE-SW oriented major fixed type longitudinal sand dunes are clearly recognized in the first image with the help of the shadow effect while not so clear in the second image since the direction of the solar beam nearly coincides with the orientation of the longitudinal dunes and shadows do not appear in the image. On the other hand the undulation within the longitudinal sand dunes shows up due to the shadow effect, which gives an impression that sand dunes perpendicularly oriented to the prevailing NE-SW longitudinal dunes exists. It is found that the spatial resolution of the images is not enough to get a detailed structure of the sand dunes.

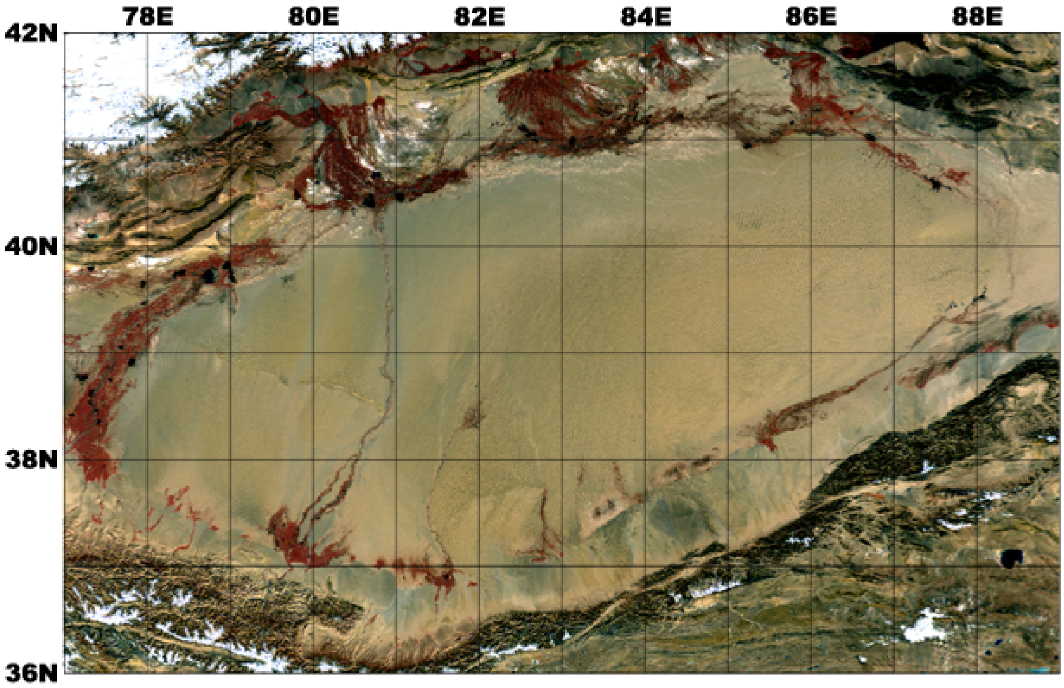


Fig.3(a) Image of Taklamakan Desert acquired with Terra MODIS (11:02 local time, Oct. 27, 2001).

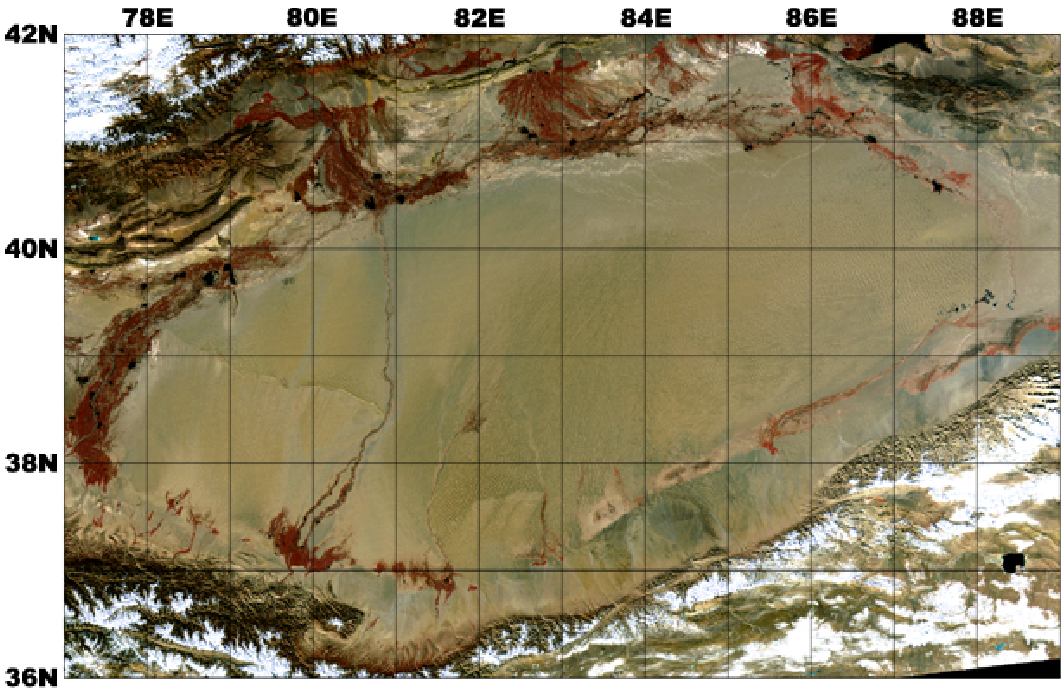


Fig.3(b) Image of Taklamakan Desert acquired with Aqua MODIS (13:12 local time, Nov.2, 2002).

4. Images of Vegetation Indices by Terra MODIS (250 m spatial resolution)

The images of NDVI (Normalized Difference Vegetation Index) computed by Eq.(1) and SAVI (Soil Adjusted Vegetation Index) computed by Eq.(2) of Taklamakan Desert computed from Terra MODIS at 11:02 (local time) Oct.27, 2001 show in Fig.4(a) and Fig.4(b) respectively. Although well developed farm lands in the oases and grasslands around the rivers are recognizable in both vegetation index images not clear at the small grasslands in the desert. The analysis indicates that the difference of vegetation index is not negligible in the desert.

$$NDVI = (NIR\ Band + Red\ Band) / (NIR\ Band - Red\ Band). \quad (1)$$

$$SAVI = (1 + L) * (NIR\ Band + Red\ Band) / (NIR\ Band - Red\ Band + L) \text{ where } L = 0.5 \text{ (Soil Adjusted Coefficient)}. \quad (2)$$

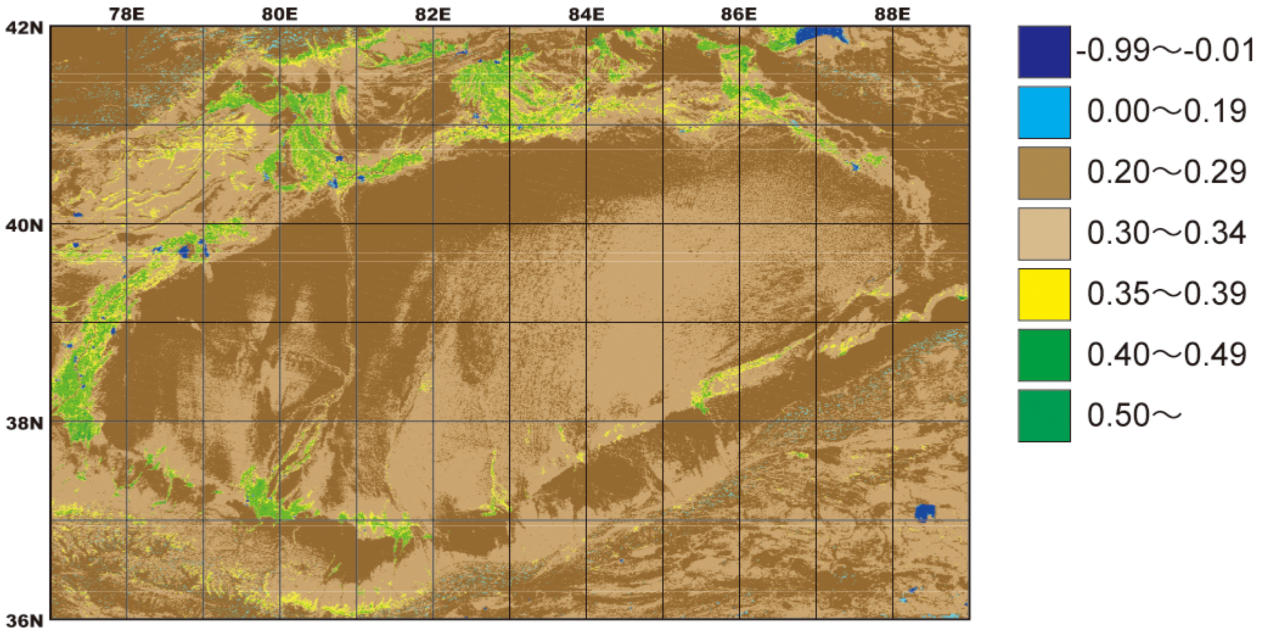


Fig.4(a) Image of NDVI (Normalized Difference Vegetation Index) computed from Terra MODIS (11:02 local time, Oct. 27, 2001).

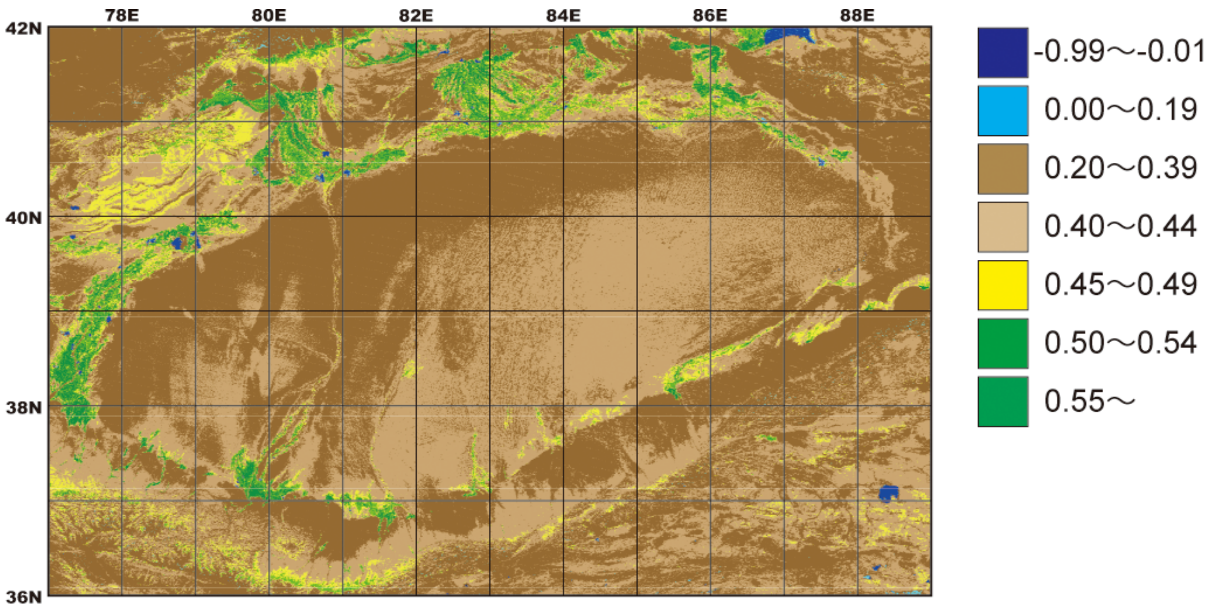


Fig.4(b) Image of SAVI (Soil Adjusted Vegetation Index) computed from Terra MODIS (11:02 local time, Oct. 27, 2001).

5. Detailed Analyses of Hotien Oasis Area by Landsat-7 ETM+ (30 m spatial resolution)

The Images of NDVI, Land cover and Soil Water Content around Hotien Oasis area in the southern Taklamakan Desert computed from Landsat-7 ETM+ (May 4, 2001) show in Fig.5. The analyses indicate that 1) The sand, pebble, stone, rock, soil, farm land, rivers and reservoirs are classified well in the land cover image, 2) The well developed farm lands in the oases and grasslands around the rivers are recognizable in NDVI (Normalized Difference Vegetation Index) image, 3) The small reservoirs and ponds in the oasis are detected with soil water content image. To protect the sand derived from the desert the poplar trees are planted in regular intervals along the road and the irrigation channels at the boundaries of the Cotton Field (Fig.6).

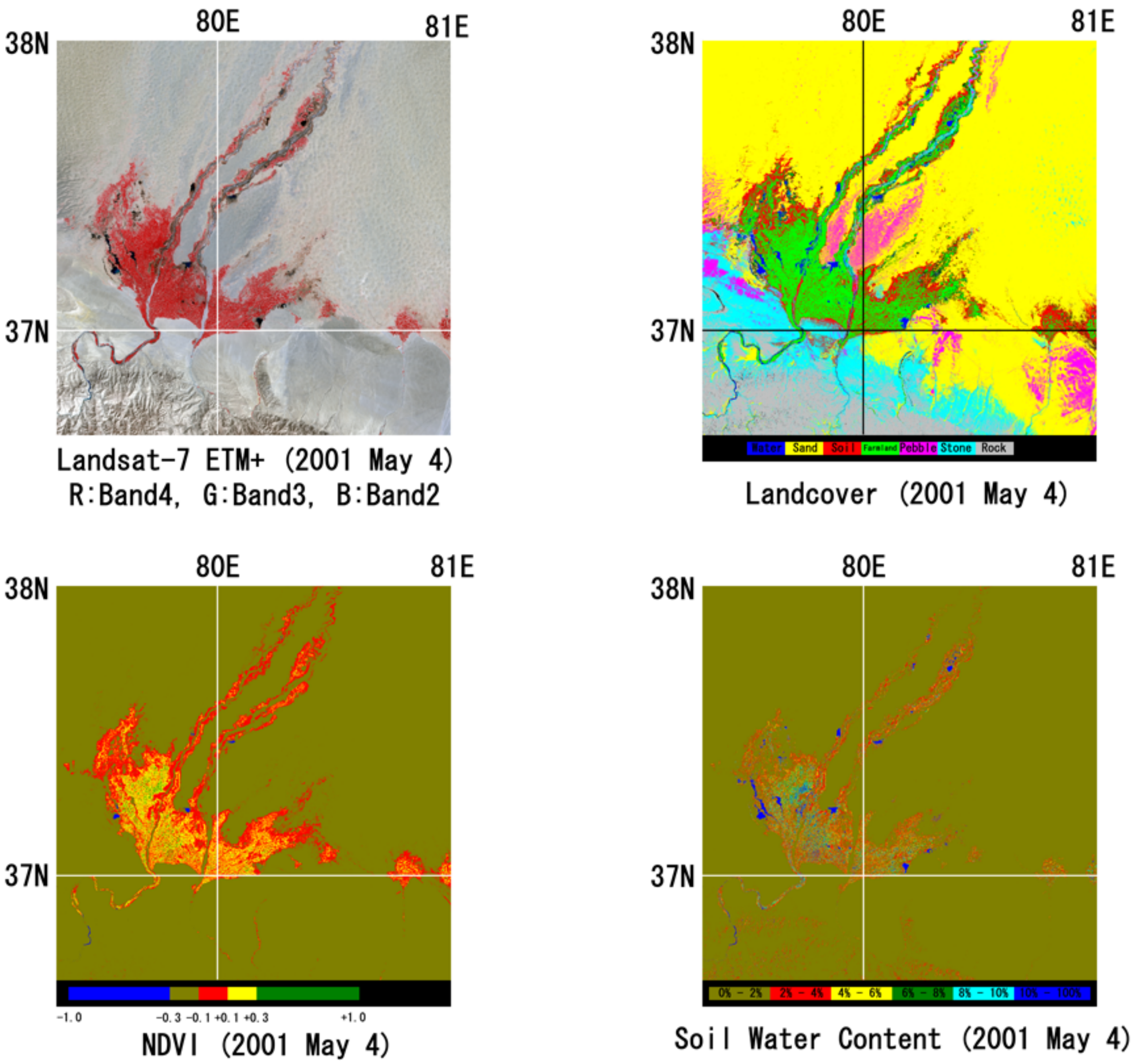


Fig.5 Detailed analyses of the Hotien Oasis Area by Landsat-7 ETM+ (May 4, 2001).

Fig.6 Forest to protect the sand (left), Irrigation channels (middle) and Cotton Field (right) around of the Hotien Oasis Area.

6. Structure of the Huge Fixed Type Longitudinal Sand Dunes and Effect of the Spatial Resolution of the Sensors

Fig.7 is an image of JERS-1 OPS taken on Nov. 4, 1992 over the eastern Taklamakan Desert to the west of the lower Tarim River. With 18 m spatial resolutions the image shows detailed structure of huge fixed type longitudinal sand dunes. SPOT HRV (High Resolution Visible) images (20 m spatial resolution) taken on Jan. 20, 1989 and April 21, 1993 indicate identical feature, which proofs the stability of sand dunes. Fig.8 is a picture of a dune taken from the eastern bank of the Tarim River. Fig.7 shows that the sand dune grows SW-ward or downstream gradually and when it grows too large then it splits into two. To see the growth rate of the dune width and influence of spatial resolution of the sensors four 40 km length lines are drawn perpendicularly to the longitudinal sand dunes at 20 km interval (AB = BC = CD =20 km) as are shown in Fig.7. Similar grids are drawn on the images of Landsat MSS and Terra MODIS and number of dunes along the four lines and average spacing of the dunes obtained from respective images are shown in Table 1. Number of dunes is influenced by the spatial resolution of images. The JERS-1 OPS image indicates that dune width increases from line A to C (40 km) by 1.3 times then stops growth. The width and the length of a single largest dune is about 2.85 km and 40 km respectively like a small mountain range.

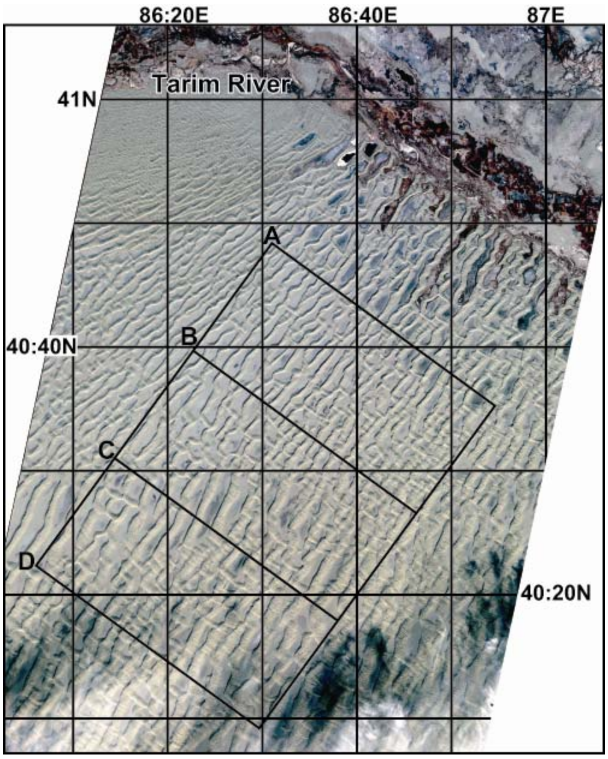


Fig.7 JERS-1 OPS image of longitudinal sand dunes of the eastern Taklamakan Desert to the west of the lower Tarim River (Nov. 4, 1992).

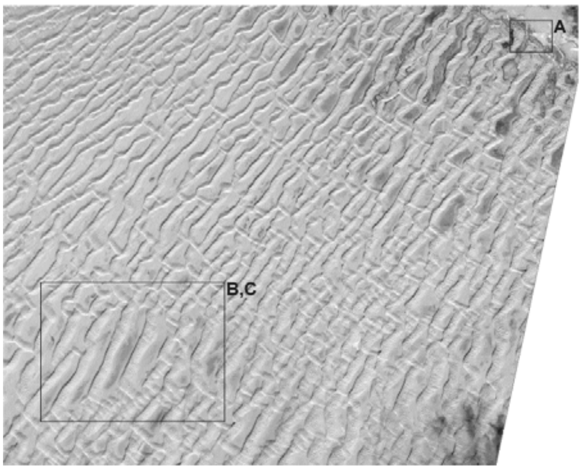
Fig.8 A sand dune taken from the eastern bank of the Tarim River.

Table 1. Number (N) and space (S km) of Sand dunes along 40 km length lines, A, B, C and D drawn at 20 km interval on the image of JERS-1 OPS, Landsat MSS and Terra MODIS.

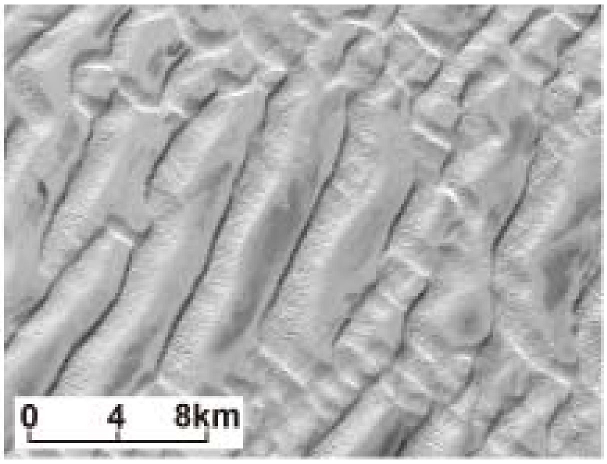
	JERS-1 OPS (18m)	Landsat MSS (80m)	Terra MODIS (250m)
	N / S km	N / S km	N / S km
A	24 / 1.67	24 / 1.67	19 / 2.22
B	23 / 1.74	23 / 1.74	19 / 2.22
C	18 / 2.22	18 / 2.22	18 / 2.35
D	18 / 2.22	18 / 2.22	18 / 2.35

7. Detailed Structure of the Fixed Type Longitudinal Sand Dunes

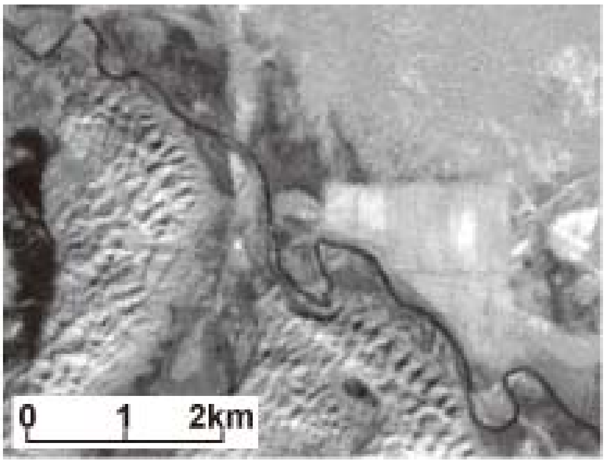
Fig.9(b), the enlarged image of the dune indicated by letter A in Fig.9(a) of JERS-1 OPS stereo pair images (Sep. 8, 1993) shows that smaller sand dunes are superimposed on a huge dune, while Fig.9(c) , enlarged image of the part indicated with letter B in Fig.9(a) shows that the top of the dune is flat. A similar feature is found in the dunes of another place. Endoh et al. (1995) based on their survey along the Desert Highway reports that south of 40:15N there are huge longitudinal sand dunes called draas, on some of which barchan type sand dunes are superimposed. This situation continues until around 39:00N. The topography of the sand dunes estimated from the stereo pair images of JERS-1 OPS is shown in Fig.9(d). The height of well-developed sand dunes ranges from 100 to 180 m with the average of 120 m.



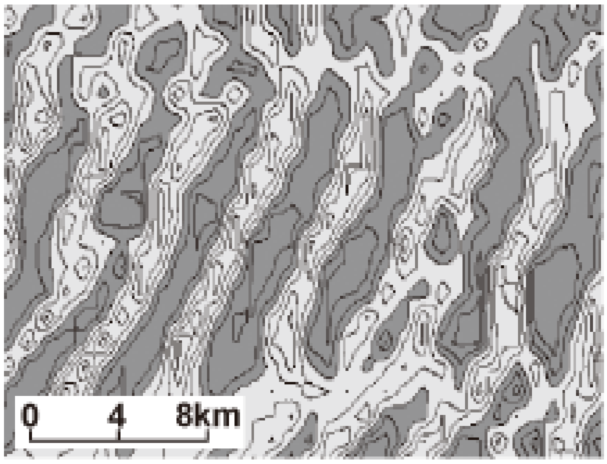
(a) Enlarged image of Fig.7



(c) Enlarged image of the part B in Fig.9(a)



(b) Enlarged image of the part A in Fig.9(a)



(d) Result of stereo pair image analysis (20 m intervals) of the part B in Fig.9(a).

Fig.9 Detailed structure of the fixed type longitudinal sand dunes observed by JERS-1 OPS stereo pair images (Sep. 8, 1993).

8. Influences of Hotien River, Mazartag and Sand Dunes around Mazartag

The influence of the Hotien River flowing across the desert from south to north on the sand dunes and the morphological feature of its basin areas are seen in Fig.10 of JERS-1 OPS (Oct. 31, 1993). Longitudinal sand dunes of NE-SW orientation are recognized to the east of the river. Mazartag (mountain range) extends westward for about 230 km from the middle of the Hotien River. Although not high (mostly less than 200 m (see Fig.11), its influence on sand dunes is significant. Since there are two gaps in the range as is seen in Fig.12 of Landsat MSS (Oct. 4, 1975) local people call the eastern, middle (very short) and western parts Mazartag, Rustag and Choqquatag respectively. In Uygur language “Tag” means mountain. In the north of Mazartag are compound sand dunes of huge pyramidal, transversal and short longitudinal sand dunes. Height of large pyramidal sand dunes estimated from the stereo pair images ranges from 100 to 150 m.

In the north of Choqquatag (western part) are well developed transversal sand dunes. Both the height and length of the dunes increase toward the Choqquatag. The average space of the transversal dunes along the line A, B, C and D indicated in Fig.13 of JERS-1 OPS (Dec. 30, 1992) are measured on the images of JERS-1 OPS, Landsat MSS and Terra MODIS and shown in Table 2. The height, width and average space of sand dunes increase toward Choqquatag (western Mazartag mountain range). The height of the dunes estimated from stereo pair images is from 50 to 100 m near the Choqquatag while at the places of A and C the height is mostly less than 50 m. To the south of the mountain ranges are longitudinal sand dunes and most of them are lower than 30 m.

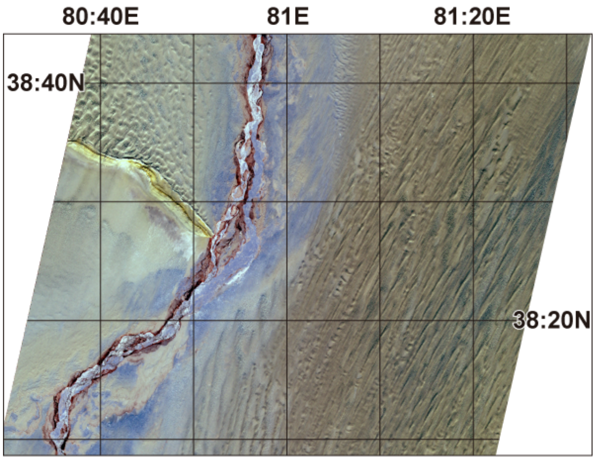


Fig.10 JERS-1OPS image of the Hotien River and eastern Mazartag mountain range area (Oct. 31, 1993).

Fig.11 Picture of eastern edge of Mazartag taken from South side.

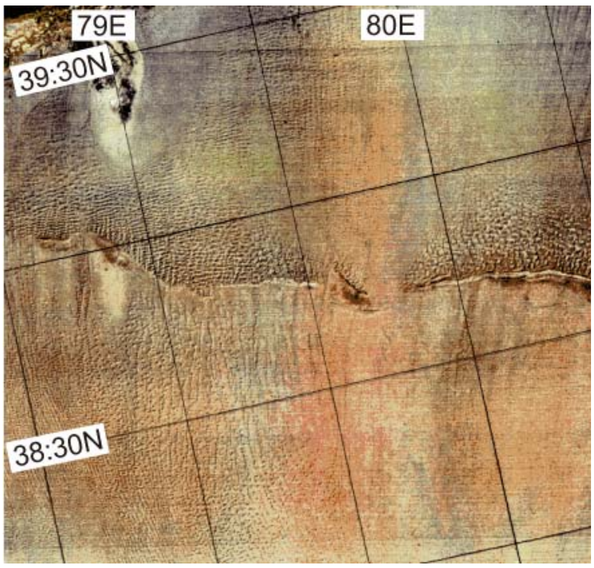


Fig.12 Landsat MSS image of Mazartag mountain range area (Oct. 4, 1975).

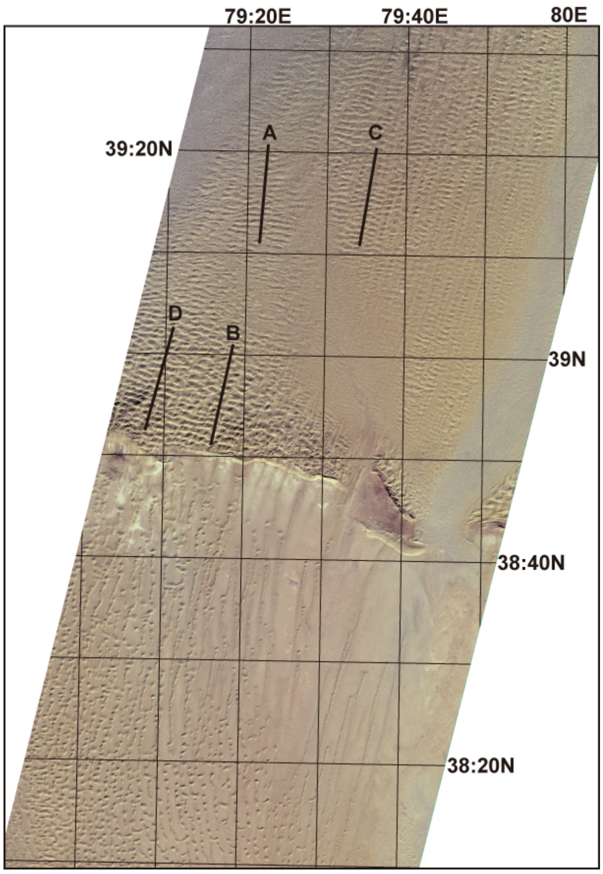


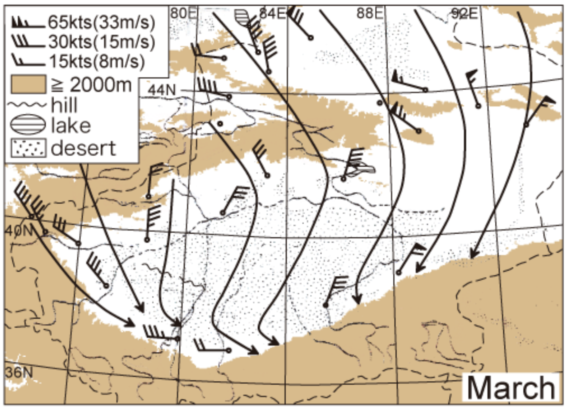
Fig.13 JERS-1 OPS image of western Mazartag (Choqquatag) area (Dec. 30, 1992).

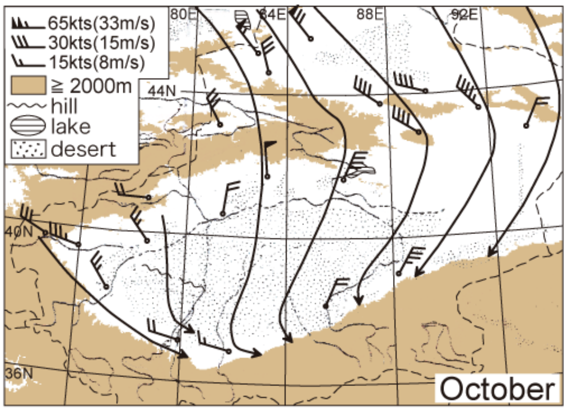
Table 2. Average space of transversal sand dunes obtained from JERS-1 OPS, Landsat MSS and Terra MODIS images.

	JERS-1 OPS (18m)	Landsat MSS (80m)	Terra MODIS (250m)
A	0.95	0.95	1.42
B	1.10	1.10	1.32
C	0.95	0.95	1.42
D	1.10	1.10	1.42

9. The Direction of the Maximum Monthly Wind vs. Orientation of Major Fixed Type Sand Dunes

To see the relation between the orientation of the longitudinal sand dune and strong wind causing sand storms the monthly maximum winds of March, April and October the so called months of sandstorms for 10 years (1961-1970) are plotted and shown in Fig.14 together with the virtual streamlines. It is found that there is a good correspondence between the direction of the maximum winds of the sand storm season and the orientation of the huge fixed type longitudinal sand dunes. The direction of the maximum monthly wind of March and April well coincides with the main wind direction of the months shown by Yoshino [10].





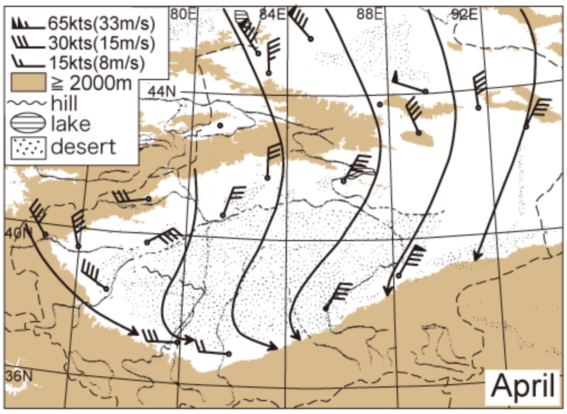


Fig.14 The maximum monthly winds in knot of March, April and October, the months of sand storm for10 years (1961-1970) and virtual stream line. Since the observation is not simultaneous October the term virtual is used.

10. Concluding Remark

The foregoing analyses lead to the following conclusion. The images of JERS-1 OPS with capability of stereoscopic observation and spatial resolution of 18 m can give fairly detailed information on the geometrical features of sand dunes. In spite of the fact that fairly large amount of sand is transported during sandstorms the large sand dunes stay without changing the shape and location in the desert area. In this connection it is interesting to notice the statement by Zhu et al.[1] that the height of the sand dunes reflects the length of time for their formation. It seems that continuity condition for the sand transport is nearly satisfied and steady state is attained in the analyzed places in the time span of hundred years.

Appendix

Alphabetical expression of Uygur names is not standardized like Taklimakan (Taklamakan), Hotien (Hotan), Kelia(Keria), Cele(Qira) etc. Mazartag mountain range is called under 3 names by local Uygur people since there are 2 gaps. The eastern, middle (very short) and western parts are called Mazartag, Rustag and Choqquatag respectively. Tag means mountain in Uygur language.

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