

APPENDIX 4

TECHNOLOGY AND PROCESSES FOR DUST AND SANDSTORM MONITORING, FORECASTING AND EARLY WARNING

1.1 MONITORING INDICATORS

What follows is an annotated list of indicators but it must be remembered that not all will be relevant to all situations. Some though have special value as input for modeling and forecasting. A basket of indicators is probably required to give the best outcome.

“Horizontal Visibility” can be considered as an effective indicator. This is because the visibility observation and analysis have been used in classifying and reporting [Middleton and al, 1986; Natsagdorj et al., 2003] DSS in almost all the countries at least since the last 50 years. Another important thing is that the value of horizontal visibility has a relationship with surface dust concentration, and can then provide a proxy for dust distributions almost in real time. Rapid data access (four times each day) and an efficient communication system (e.g., GTS) exist in almost all the countries. This is very useful for validating the DSS FS output. WMO has been using visibility classifying the DSS until the present-day. The only problem for visibility network is that all the existing visibility data comes from the naked eye, not from an instrument.

“Total suspended particle (TSP)” is another proxy indicator for DSS FS & EWS. TSP is classed as a proxy indicator mainly because TSP is not a pure dust aerosol concentration indicator. TSP over continental Asia can actually be divided into five general categories: (1) soil dust aerosol and associated species (consisting of oxides of Al, Si, K, Ca, Ti and Fe, and trace elements), (2) particulate sulfates, (3) aerosol nitrates, (4) ammonium products, and (5) carbonaceous material [Solomon et al., 1989; Zhang et al., 2002; Zhang et al., 2001]. One cannot be simply attribute the observed TSP to the dust contributions and the associated DSS event. The other four types of particulate contribute to the observed TSP. Another problem for TSP is that no real-time TSP data can be obtained by instruments at this moment. Once there is a DSS outbreak, a High Volume Air Sampler can be employed for TSP measurement and DSS sampling.

“Particulates with diameter smaller than 10 μm (PM_{10})” It has been listed as one of the indicators for air quality evaluation in every country; also it is a main indicator to estimate the impact of suspended particulate matter on human health. A major characteristic of DSS in North East Asia is its color. The color of PM_{10} sample collected from the middle and east of the PRC, the Republic of Korea, and Japan is darker than TSP sample. The color is a clue as to the source area. Currently, β -ray dust mass monitor is employed to PM_{10} measurement in PRC.

This indicator is also somewhat useful, but it is less important than TSP. It is not only because the contribution to the PM_{10} loading are from five types of particulate, but also because the soil dust particles associated with DSS include lots of particles with a diameter larger than 10 μm dust particles. This would give a gross underestimate, especially in severe or very severe DSS events. **But the PM_{10} data can be obtained in real-time in the proposed network stations, a merit over TSP.**

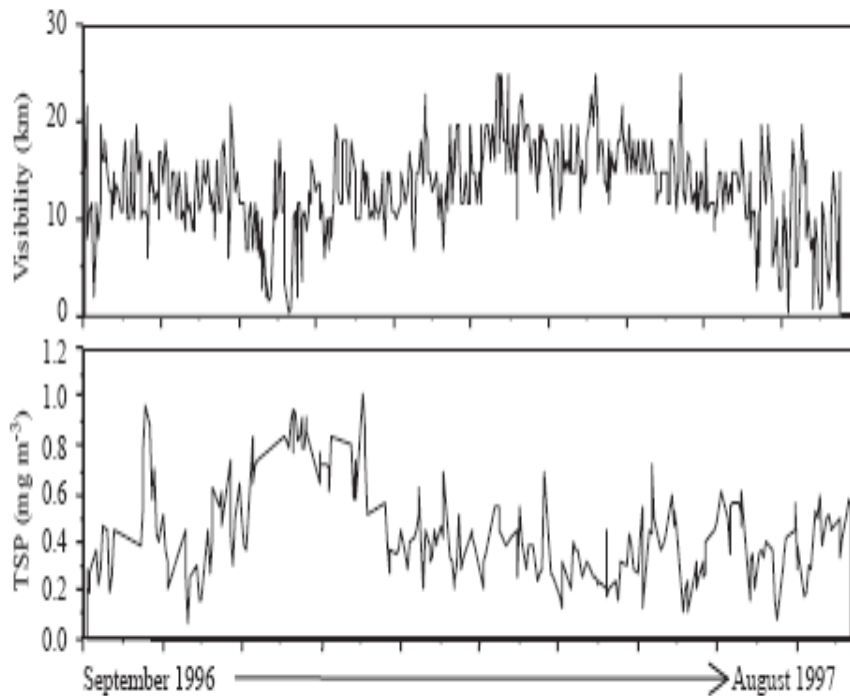


Figure A4.1 Time Series of TSP and Visibility (14:00 observation) in Xi'An from September 1996 to August 1997 [Zhang et al., 2002].

“Dust aerosol loading” can be considered as the best indicator for DSS regional monitoring and early warning network observations, because the higher dust concentration observed especially in depositional regions of DSS exhibits the transported dust associated with DSS from the source regions. If the spatial distribution of dust aerosol concentration predicted by FS can be compared and adjusted quickly and efficiently with an observed distributions of dust concentration from the regional network stations, a new initial condition will then be used into the rolling forecasting, which is extremely important for the accuracy in forecasting. Unfortunately no dust concentration data can be quickly and efficiently transferred to the existing DSS FS and cannot be established in the near future. This is mainly because to obtain the dust aerosol concentration, it takes several days or weeks to conduct the required chemical analysis.

The limitation of these two indicators is that there is no feasible way to get the data in real time. This limitation reduces their value in forecasting.

For the DSS source countries, the most frequently used indicators and technologies in DSS monitoring are meteorological data, soil and vegetation status, visibility and, where available, PM_{10} , TSP, and LIDAR although the last mentioned indicators are not very effective under conditions of severe DSS events. These air quality indicators form the core of monitoring programs in both Japan and the Republic of Korea. But knowing what data to collect is only the first step. Collecting it in a way that allows cross-region comparison is another.

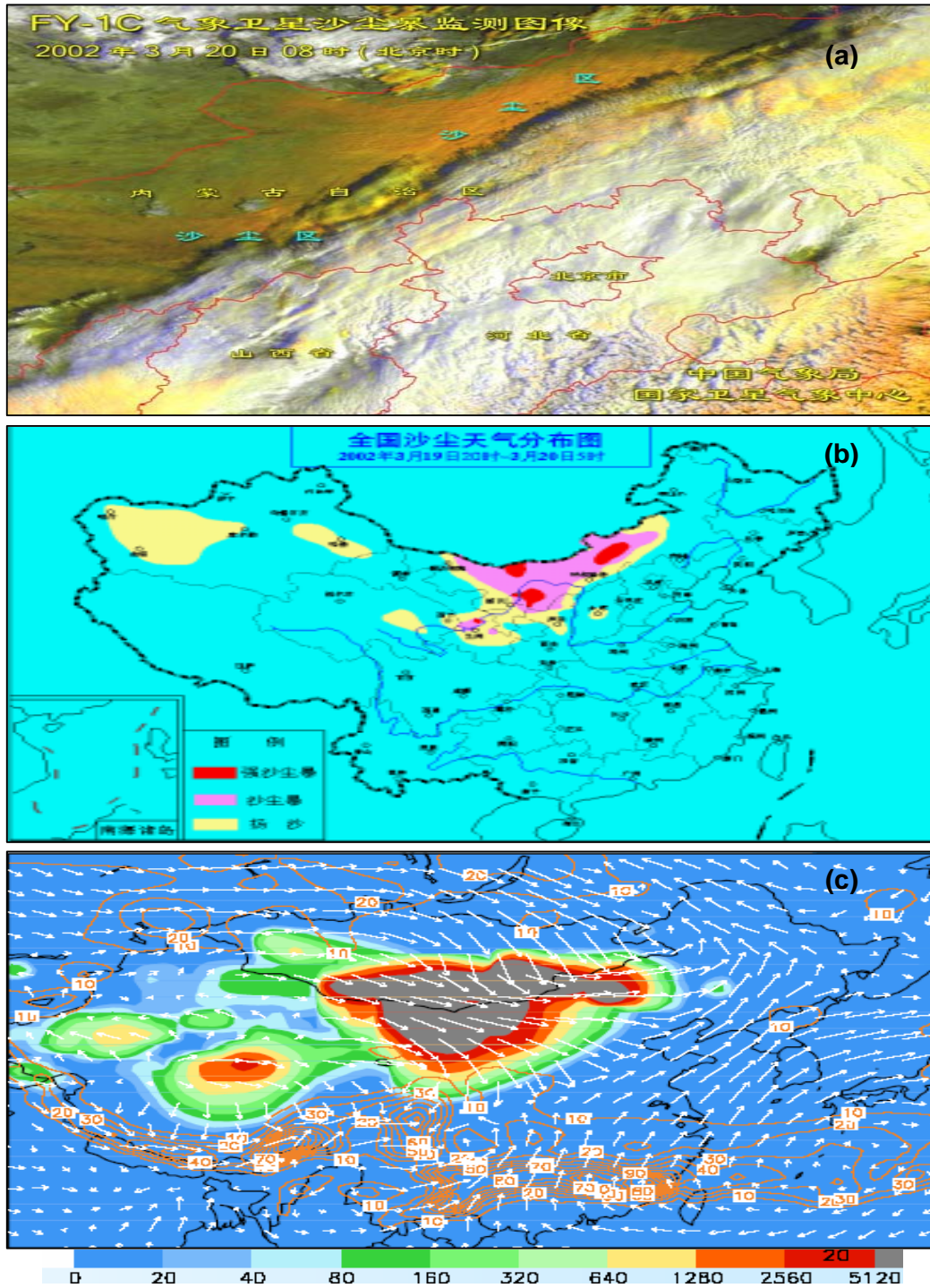


Figure A4.2 Spatial Distribution of DSS provided new dust initial condition for accurate forecasting. (a) DSS distribution retrieved from FY-1C satellite at CMA (08:00 BST, 20 March 2002); (b) DSS distribution reported on the basis of horizontal visibility in the PRC (20:00BST, 19-March to 05:00, 20 March 2002); (c) FS estimated surface concentration of dust aerosol ($\mu\text{g m}^{-3}$) and observed wind and rain (02:00 BST, 20 March 2002) in the PRC

So it is clear that because of the different needs in the DSS source areas and the DSS receiving areas and different ways to model DSS outbreaks, it is desirable to collect data from a basket of indicators (Table A4.1)

Table A4.1 Summary of the Data Required as Input for Various Models

Class of Indicator	Purpose & role	Specifications
Surface characteristics data	Very important as model inputs (Boundary conditions & fundamental data for dust emission estimate)	Grid data: 0.5 degree (or 50km) mesh at worst, ideally 0.1 degree (or 10km) mesh or finer
Point data (Monitoring data)	For data assimilation : Effective but not essential (does not necessarily improve the accuracy of forecasts)	Temporally: Need for real-time data The number of sites: The more, the better, but efficiency will change: (Ratio of number vs. efficiency) 1 -> 10 sites critical 10 -> 100 efficient 100 -> 1000 less efficient
	For each model validation , and for model developments of forecasting, early warning and assessment of likely impact of taking a remedial measure such as afforestation; very important	Temporally: No need of real-time data (monthly OK) The number of sites: Even a small number is useful: 10-20 in PRC, 5-10 in Mongolia would be enough for the first step

Point data (monitoring data)

Measurements	Priority	For validation and model improvement	For assimilation
LIDAR	High	Direct comparison is impossible (Needs conversion between concentrations and extinction coefficient) *Can get vertical profiles	Not directly available
Horizontal velocity	Medium	Useful to validate meteorological model simulations	Available (For meteorological model)
Visibility	Low	Direct comparison is impossible (Needs conversion between concentrations and visibility)	Not directly available

Surface characteristics data

Landuse/Vegetation	All of these are essential data for accurate simulation of DSS
Soil texture	
Soil moisture status	
Snow cover	

The scope of other indicators that should be considered in DSS monitoring in the future is set out below as follows:

- (a) Meteorological
 - Wind velocity, direction
 - Air turbidity
 - Visibility
 - Atmospheric stability parameters
 - Snow coverage
- (b) Soil
 - Texture
 - Moisture
 - Temperature
 - Bare soil
- (c) Vegetation Coverage
- (d) Relief
 - Slope
 - Aspect
 - Elevation
- (e) Socio-economic
 - Unpaved road network
 - Open mining area

1.2 GROUND SURFACE MONITORING: ITS ROLE AND EFFECTIVENESS

Dust and sandstorms are atmospheric phenomena and are often classified as hazardous weather events. However, they are ground-initiated and ground-generated in source regions, ground-enhanced along their transport path. They are air-driven storms but it is the interaction between the atmosphere and the ground surface that is the key to DSS outbreak and impacts. The ground surface conditions and the ecological environmental of the source regions and along the transport route are very important.

Remote sensing has value in DSS monitoring in two main ways:

- Real-time monitoring in spatial distribution of DSS by remote sensing
- Ground surface conditions and ecological environmental assessment in the source regions and depositional regions by remote sensing

Low-resolution remote sensing data can be used to retrieve the spatial distribution of DSS, aerosol optical depth and aerosol index when a DSS event occurs. The satellite data and models that have potential for DSS monitoring are shown in Table A4.2.

The monitoring should focus on the source region, the transport path and the deposition areas. Low resolution remote sensing data can be used to identify the outbreak, extent, density, and visibility during the DSS events.

1.3 REMOTE SENSING FOR DSS REAL TIME MONITORING

Remote sensing has an important role for ground surface conditions and ecological conditions assessment in the source regions and along the transport path. Tables A4.2 to A4.4 show the attributes of the various satellites in common use.

Remote sensing has great potential for DSS monitoring but DSS events are not stationary and change is rapid. For real-time monitoring at regional scale, high resolution satellite data

will not fit the purpose due to the narrow swath width (60-180km) and low temporal resolution (16 -26 days). Also high-resolution data is expensive. High resolution data can be used in limited key DSS source areas, where DSS occurs more frequently and has more serious effect.

Table A4.2 Satellite Data and Models for DSS Monitoring

Satellite	GMS/VISSR	NOAA AVHRR	MODIS
Frequency of visit	Hourly	Twice a day	Twice a day
Resolution	5 km	1.1km	250m, 500m, 1km
Swath (coverage)	1/3 of the earth surface	2000km	2330km
Selected wavelength	Visible, infrared	1.6µm 11µm 12µm	1.628-1.652µm 3.66-3.84µm 10.78µm 11.28µm
Selected bands	All bands	Channel 3A, 4 and 5	Channel 6, 20, 31, 32
Models for best observation	No	$NDDI = a \cdot e^{(b \cdot v_{ch3})} \cdot (ch4 - ch5) / ch4$	Not available, can use same model as NOAA data
Data cost	Free, material cost	Free, material cost	Free, material cost
Station cost (RMB)	200,000	200,000	3,000,000
Output	Hourly monitoring	Daily Monitoring 1. Comparable dust intensity index 2. Visibility 3. Monitoring the source, transportation, diffusion and deposit of dust sandstorms 4. Albedo* 5. Optical Depth**	Daily Monitoring 1. Comparable dust intensity index 2. Visibility 3. .Monitoring the source, transportation, diffusion and deposit of dust sandstorms 4. Albedo* 5. Optical Depth**
Comments	Limited by cloud cover	Limited by cloud cover	Limited by cloud cover

* Albedo: Percentage of light reflectivity (radiance), white =100% Albedo

** The optical depth model is available but the model validation is a difficult to conduct. It needs highly restricted conditions. The model is ready to serve the research purpose but cannot meet the requirements in operation. It is a valuable parameter for DSS monitoring, but it is not sufficiently precise for quantitative analysis. It needs further research and supporting instruments.

Table A4.3 List of DSS Indicators Derived from Satellite

Satellite name	DSS indicators	Usage status
NOAA	Vegetation cover Land surface temperature Wind DSS location, movement Land cover type	operational
MODIS	Land cover type Aerosol thickness, size distribution	experimental
SeaWifs	Aerosol thickness, size distribution	experimental
Landsat	Vegetation cover Sandy sources Relief Land cover type	operational
SPOT	Vegetation cover Land cover type Sandy sources Relief	operational

**Table A4.4 Remote Sensing for Ground Surface Conditions Monitoring
(an Example from PRC)**

Satellite	NOAA AVHRR	MODIS	SPOT VEGETATION	SPOT	LANDSAT TM
Frequency of visit	Twice a day	Twice a day	One day globe coverage	1-4 days	16 days
Resolution	1.1km	250m, 500m, 1km	1.15km	2.5m, 5m, 10m, 20m	15m, 30m
Swath	2000km	2330km	2250km	60km*60km,	180km*180km
Vegetation coverage monitoring	Band 2,1	Band 2, 1 NDVI VI IR/R SQRT IR/R TNDVI	Provide one day synthesis vegetation index image and 10 day synthesis vegetation index image	Band 3,2 NDVI VI IR/R SQRT IR/R TNDVI	$NDVI = \frac{(IR-R)}{(IR+R)} = \frac{(TM4-TM3)}{(TM4+TM3)}$ $VI = IR-R = TM4-TM3$ $IR/R = TM4/TM3$ $SQRT IR/R = \sqrt{TM4/TM3}$ $TNDVI = \frac{\sqrt{TM4 - TM3}}{\sqrt{TM4 + TM3} + 0.5}$
Selected bands for soil moisture	4, 5	4,5,6,7,8,9	SWIR band: Leaf surface water content	No	Band 6
Selected bands for snow cover	4, 5	MODIS Standard Snow Products MOD10 MOD33	All bands	All bands	All bands
Cost estimation	Free, material cost	300RMB/orbit	Annual fee 110,000 RMB	12000RMB/scene	5000 RMB/scene
Comments	Last winter snow cover monitoring is the most important for DSS monitoring	Regular monitoring from summer to next spring	VEGETATION NDVI data can be downloaded from www.vgt.vito.be	5 years monitoring circle, focus on source region	5 years monitoring circle, focus on source region

Notes: **VI**: Vegetation Index. $VI > 1$, is the boundary of vegetation or non vegetation. **NDVI**: Normalized Difference Vegetation Index. $NDVI > 0.15$, is the boundary of vegetation or non vegetation. This is a more precise and commonly used indicator for vegetation. **TNDVI**: Transformed Normalized Difference Vegetation Index. If this model is used, then no negative value will appear in the image no matter whether there is vegetation or other targets in the image with higher reflectivity on red band than Infrared band. The input for these models must be the reflectivity, not the digital number of the images.

A framework of how remote sensing technology might be integrated into DSS Monitoring and Early Warning in PRC is shown in Figure A4.3.

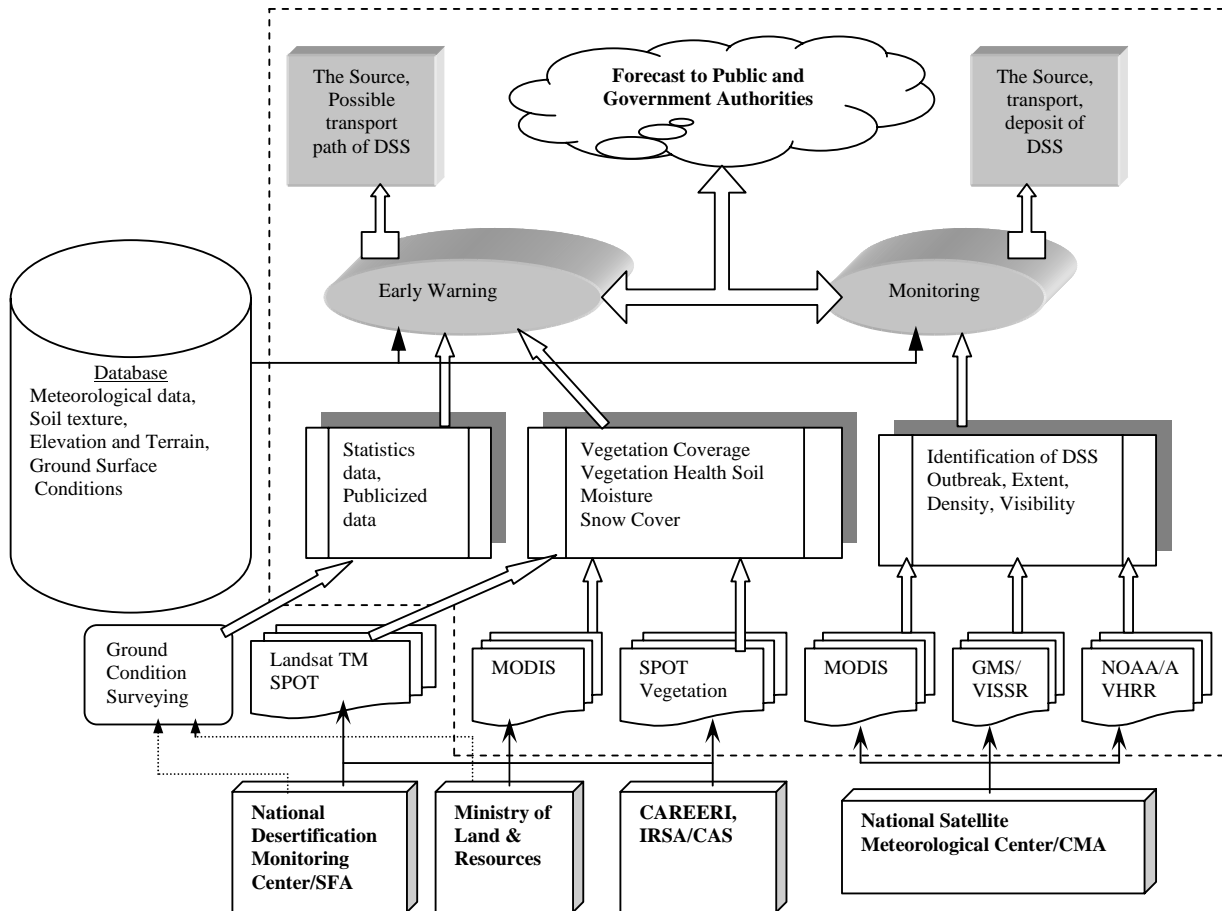
For DSS monitoring purposes the most suitable remote sensing satellites are:

1. NOAA. AVHRR data successfully has been used for environmental studies and monitoring at the regional scale. The advantage of NOAA data is its availability at every 6 hour interval and at 5 bands 0.58 - 0.68, 0.725-1.1, 3.55-3.93, 10.3-11.3, 11.5-12.5 mkm over the large area. Also NOAA data is cheap and is very useful for long term monitoring. All participating countries have a NOAA receiving station.
2. MODIS provide comprehensive coverage in spectral and spatial contexts in comparison with NOAA data. Spatial resolution of 250, 500 and 1000 m in 36

wavebands in the spectral range from 0.4 to 14 mkm. Temporal resolution is 1-2 days.

Another suitable tool for DSS is the Microwave sensor. Microwave RS has one very good advantage of cloud transparency observation. In most of cases DSS especially those caused by cyclone, coincides with cloud. This sensor gives us the possibility to monitor even in the case of cloud cover. Microwave RS has been successfully used for soil moisture and precipitation monitoring, both important indicators of DSS.

Figure A4.3 Framework on Remote Sensing for DSS Monitoring and Early Warning (an Example from PRC)



Geostationary satellites that provide data every 30 minutes have been mostly used for weather forecasting. Also, combined and integrated use of multi-sensors of different satellites could be useful.

- Using GMS satellite data, every hour monitoring during the DSS season, principally from February to June¹.
- Using NOAA AVHRR satellite data for DSS, soil moisture, vegetation monitoring, and every day monitoring during the DSS season, principally from February to June.
- Using SPOT VEGETATION for vegetation monitoring, every ten days during non DSS season, every one day during DSS season, principally from February to June.
- Using MODIS for vegetation monitoring and soil moisture monitoring every day during the DSS season, principally from February to June.

The assessment should forecast the source region, the possible transport path and the deposition areas before the DSS outbreak. The statistical data and the data from the ground condition surveying results (not the original surveying data, database, detailed maps) should delineate the areas with poor ecological environment and those with poor vegetation coverage. Using such a database, and statistical data from ground surveys even low-resolution remote sensing data at regular (10 days intervals) can monitor vegetation cover and vigor in the potential DSS outbreak areas and along the likely transport path. In addition, soil moisture status, snow cover and other surface characteristics of value to modelers can be used to support the early warning efforts.

The framework of remote sensing technology for ground surface conditions and ecological environment assessment is shown in Figure 4.3 The satellite data used for DSS monitoring and their functions in DSS monitoring and the ground surface conditions and the ecological environment assessment of the source region and transport path are shown in Table A4.4 and Box A4.1.

Box A4.1 Suggested Applications for Remote Sensing in DSS Forecasting and Early Warning

- Use NOAA AVHRR satellite data for soil moisture, snow cover monitoring before the DSS season from September to February.
- Use MODIS for vegetation monitoring, soil moisture estimation, snow cover monitoring regularly before the DSS season from September to February.
- Use SPOT VEGETATION for vegetation coverage, health condition monitoring, every ten days during non DSS season, from September to February.
- Use Landsat TM or SPOT images for vegetation monitoring and ecological environment assessment only in sensitive source regions and along the transport path. It should be conducted on a 5-year cycle, mainly relying on the project results and output of SFA and Ministry of Land Resources.
- Use elevation data or topographical map to delineate the possible transport path and store in the database.

¹ Sometimes DSS occur at other seasons. Less frequent monitoring occurs over the whole year.