CGMS-37 WMO-WP-04
v1, 30 September 2009
Prepared by WMO
Agenda Item: II/6
Discussed in WG II

SATELLITE NEEDS OF THE WMO SAND AND DUST STORM WARNING ADVISORY AND ASSESSMENT SYSTEM (SDS-WAS)

This Working Paper discusses the needs of the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) concerning current and future satellite products. The Paper reviews the exiting products of different satellite operators, describes the importance of use of the satellite parameters in improving the monitoring and prediction of the sand and dust storm atmospheric process, and indicates what are the gaps in providing dust-relevant products to the SDS-WAS community.

Action/Recommendation proposed:

CGMS is invited to keep the SDS-WAS community informed, through the WMO Secretariat, on current and planned products relevant for the detection of the sand and dust process in the atmosphere.

SATELLITE NEEDS OF THE WMO SAND AND DUST STORM WARNING ADVISORY AND ASSESSMENT SYSTEM (SDS-WAS)

1 STATUS OF THE WMO SAND AND DUST STORM WARNING ADVISORY AND ASSESSMENT SYSTEM (SDS-WAS)

In June 2008, the sixtieth WMO Executive Council (EC-60) welcomed the SDS-WAS initiatives to assist Members to gain better access to services related to sand and dust storm prediction and warning advisories through capacity building and improved operational arrangements. EC-60 also welcomed the establishment of two SDS-WAS regional nodes: the Northern Africa - Middle East – Europe (NA-ME-E) Node hosted by the Regional Centre in Spain, and the Asia Node hosted by the Regional Centre in China. Both regional nodes will be responsible for collecting, archiving and disseminating predictions from those research and operational models that have the capacity to model sand and dust storms. Establishment of more regional nodes in the future is also considered.

In the second half of 2008, the SDS-WAS Implementation Plan 2009-2013 was drafted and discussed by regional steering groups of the two SDS-WAS nodes. The Plan will be presented to the Commission for Atmospheric Science (CAS) in November 2009, and the Executive Council in 2010. Because of some operational aspects anticipated by the SDS-WAS implementation, cooperation is being established between the WMO Commissions for Basic Systems (CBS) and for Atmospheric Sciences (CAS) to ensure transition of certain SDS-WAS activities from research to operational forecasting.

In November 2008, the SDS-WAS Steering Committee for the NA-ME-E Node met for the fist time to discuss the way forward for the SDS-WAS implementation in its region of responsibility. It was recommended that in the second half of 2009 the dust-related monitoring data and forecast products from various regional node partners be exchanged daily. Spain as the host country for the node activities is establishing a dedicated portal for that purpose. Potential contributors to SDS-WAS activities in RA VI (Europe) include France, Germany, Great Britain, Greece, Israel, Spain, DLR, ECMWF, and ESA.

In October 2009, the Korean Meteorological Administration (KMA) and the Atmospheric and Environmental Research Institute of Seoul National University are hosting and organizing the WMO SDS-WAS Asia/Central Pacific Node Workshop in Seoul, Korea. The key objective of the workshop is to discuss implementation of the WMO SDS-WAS Asia Node where the satellite observations represent key information for dust model validation and data assimilation.

2 AVAILABLE SATELLITE PARAMETERS RELEVANT FOR SDS

The most relevant parameters observed by satellite for sand and dust storm (SDS) are the quantitative or semi-quantitative aerosol index (AI) and the aerosol optical thickness (AOT). The AI is physically related to AOT. These parameters can be used to identify the spatial distribution and strength of SDS.

Aerosol Index (AI)

The quantitative index is obtained from the difference of brightness temperatures (BT) of 10.8 μm and 12.0 μm channels. This method is called the dual channels difference method (DCD) or brightness temperature difference method (BTD). SDS is identified by the area where the brightness temperature difference $BT_{10.8\mu m} - BT_{12.0\mu m}$ is negative.

If the satellite measured BT is available for three channels (8.7 μm, 10.8 μm and 12.0 μm), the BT difference $BT_{8.7\mu m} - BT_{10.8\mu m}$ yields the SDS strength. The strong SDS is indicated by a positive BT difference while a weak one is revealed by a negative BT difference of these two channels. Therefore, the brightness temperatures measured by three channels (8.7 μm, 10.8 μm and 12.0 μm) can be used to detect SDS extent and intensity. The SEVIRI imager of Meteosat-9 located over Africa has 12 channels including the 8.7 μm, 10.8 μm and 12.0 μm channels. However this kind of imager will not be available on geostationary satellites over Eastern Asia and the west Pacific region before 2014-2015.

One semi-quantitative aerosol index is the Infra-red Difference Dust Index (IDDI). The IDDI is a record of the reduction in brightness temperature of the Earth-atmosphere system due to the presence of aerosols, and is constructed from Meteosat Infrared channel data. In order to use the IDDI as a means of measuring atmospheric dust, the reduction of BT due to the presence of cloud must be identified and either masked or removed, and the diurnal variation of the IDDI due to the change of surface temperature must also be removed.

Another semi-quantitative aerosol index is obtained from the Ozone Monitoring Instrument (OMI) on board the NASA polar-orbiting satellite Aura. The OMI aerosol index (OMI-AI) is a measure of the difference of the wavelength dependent backscattered UV radiation between the atmospheres with and without the aerosols. The OMI-AI can be obtained globally once a day with a horizontal resolution of $0.25° \times 0.25°$. However, it has difficulty to detect low-level aerosols below 2 km and is only available in a processed form after three days. There is no direct follow-on to the Aura/OMI mission, but there is a potential for using comparable capabilities of GOME-2 on Metop, OMPS and VIIRS on NPP/NPOESS.

Aerosol Optical Thickness (AOT)

The aerosol optical thickness (AOT) observed from satellites can be used to detect atmospheric aerosols.

- The AOT can be obtained from the Moderate Resolution Imaging Spectro-radiometer (MODIS) instrument on board the TERRA (EOS AM – 1) and AQUA (EOS PM – 1) satellite at 550 nm spectral band and thermal –IR Dust index (TDI) with MODIS BTs at 3.7, 9.7, 11 and 12 μm bands.

- The NASA algorithm MODIS-AOD (Aerosol Optical Depth) yields AOT at 3 visible wavelengths and aerosol size parameters. However, this cannot retrieve the data over bright surfaces such as a desert area.

- The NASA algorithm MODIS-DeepBlue, can retrieve AOT and Angstrom coefficient over highly reflecting land surface (desert and urban area) with the radiance measured at 412, 490, 670 nm.

Each MODIS instrument has a design life of five years, though it has been in operation for a much longer time. When combined with comparable follow-on instruments, these instruments would provide a decadal data set for comprehensive SDS research.

Aerosol Optical Depth (OD)

- The OMI-OD algorithm, based on Aura OMI instrument data, provides the aerosol extinction and absorption optical depth (OD). The OMI-OD is so sensitive to aerosols mixed with clouds or above clouds or ice/snow that accurate OD can only be retrieved under clean-sky conditions. It does not work over highly reflective surface.

- The IODI (Infra-red Optical Depth Index) can be retrieved from 10.8 μm channel. Theoretically this method is similar to the IDDI. However the IODI is not affected by the changes of surface temperature and surface emissivity.

Some useful space-based instruments for the measurement of aerosol properties are listed in Table 1.

3 CURRENT AND FUTURE USE OF SATELLITE PRODUCTS IN SDS-WAS

The physical meanings of both the quantitative and the semi-quantitative aerosol indexes are theoretically related to the atmospheric vertical aerosol optical thickness (AOT) so that there are apparent relationships among the satellite AOTs, the height of dust layer, the concentration of dust, and the visibility on land. However, there are some gaps for these various products at different spatial and temporal scales. In order to fill these gaps the various index values and satellite products can be reconstituted with the results of radiative simulation of SDS numerical models.

The combination of satellite observations with operational SDS numerical models requires the consideration of the time interval of observations, geographical coverage, horizontal resolution and the delay of availability of the data. For SDS data assimilation, the frequent observations delivered by geostationary satellites provide a valuable flexibility.

Even though there are many satellite products relevant to SDS, their capabilities are varying significantly with the composition of aerosol, height of the aerosol layer, atmospheric temperature and moisture, cloudiness, characteristics of land surface related to emissivity and bidirectional reflectance distribution function. Because the accuracy of many SDS satellite products is estimated from a theoretical approach or globally averaged results, it is worthwhile to redefine the accuracy of satellite SDS products with considerations of regional aerosol characteristics and seasonal changes of surface characteristics over a main target area.

For operational applications, it is important to consider the expected duration of the satellite operational phase, the stability of its status, and the possibility of follow-on satellites. The SDS products from geostationary satellite have been developed for a long time and enhanced significantly in recent years. The capability of geostationary satellites to perform stable and continuous observation with a time-interval of 15 or 30 minutes leads to more opportunities in satellite products assimilation. In the cases of research satellite instruments with special purposes such as CALIPSO/CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), Terra/MISR (multi-angle imaging spectro-radiometer), Aura/OMI (Ozone Monitoring Instrument) etc., the products can be used for validation of other products from geostationary satellites. Additionally these products can be used for the development of SDS algorithms for the instruments of next generation satellites. Hyper-spectral resolution sensors which are important for environmental monitoring as well as meteorological purpose (AIRS on EOS-Aqua), IASI on Metop, CrIS on NPP and NPOESS, etc.) should be used to investigate the composition of aerosol, because they have capabilities to detect molecular absorptions and emissions.

4 CURRENT GAPS AND PROPOSED EXTENSION OF SATELLITE PRODUCTS

The combination of satellite products and SDS numerical model output is still at its initial stage. Satellite SDS observation over East Asia and the Western Pacific is currently unstable, and the accuracy of numerical predictions is still insufficient by lack of expertise in this field.

With the generations of geostationary satellites currently available in the region (MTSAT-1R and -2, FY-2C to FY-2G) and with COMS that will be operated by KMA for seven years, the usage of 5-channel imagers will continue until at least 2014. (http://cgms.wmo.int/Satellites.html). It is expected that satellite application for SDS can become operational over East Asia and the West Pacific with the advanced imagers of the next generation.

The near-real time validation of dust numerical models used for the SDS-WAS requires comparisons against satellite observations. Aerosol optical thickness calculated by the model can be compared with the semi-quantitative aerosol index from satellites such as IODI of MTSAT-1R or AOD of MODIS. A better comparison can be made between model simulated brightness temperatures and the satellite observed ones.

Table 1. Instruments on board of satellites can be used to investigate the aerosol properties

Instrument/ Algorithm	Near Real time	Quantitative / Qualitative	Resilience of satellite data	Spatial coverage	Spatial resolution	Temporal resolution
2 IR channels methods	Yes	Qualitative	Operational Geostationary satellite system for 6 years (until 2015)	Geostationary satellite MTSAT-1R disc (140E) (60S-60N, 80E-160W)	4 km at SSP[§3]	30 minutes
MTSAT-1R IDDI like	Yes	Semi-quantitative aerosol index	Operational Geo-satellite system for 6 years (until 2015) MTSAT-1R since July 2005	Geostationary satellite MTSAT-1R disc (140E) (60S-60N, 80E-160W)	4 km at SSP	30 minutes
MTSAT-1R IODI	Yes	AOT of IR channel	Operational Geo-satellite system for 6 years (until 2015) MTSAT-1R since July 2005	Geostationary satellite MTSAT-1R disc (140E) (60S-60N, 80E-160W)	4 km at SSP	30 minutes
Aerosol Optical Thickness	Yes	AOT over ocean	Operational Geo-satellite system for 6 years (until 2015)	Over ocean only (52°N~17°N, 114°E~150°E)	1°x1°	Daily mean
MODIS	more than 2 days (Possibly in the future)	AOT at 3 vis wavelengths Aerosol size parameters	Research instrument on NASA Polar satellites Terra since December 1999 Aqua since May 2002[§1]	Polar satellite 2 VIS, 4 IR images per a day with Terra and Aqua	Depends on channel, 1 km	Daily coverage
OMI	No?	Semi-quantitative aerosol index	Aura platform No clear follow-up after Aura (GOME on METOP?)	Polar satellite Global daily coverage	0.25° x 0.25°	Daily coverage
MISR	No	Level 2 AOT including over land	Terra platform Since December 1999 No follow up	Polar satellite Narrow swath	18 x 18 km^2	Global coverage every 7 to 9 days

Instrument/ Algorithm	Near Real time	Quantitative / Qualitative	Resilience of satellite data	Spatial coverage	Spatial resolution	Temporal resolution
AIRS	Probably Yes	Infrared AOD	Aqua platform since May 2002	Polar satellite	15 x 15 km^2	Daily coverage
ATSR AATSR	With 24 hours delay	Vis AOD Qualitative dust detection from IR	ENVISAT/ERS since 1991 until 2011	Polar satellite Narrow swath	1 x 1 km^2	Global coverage every 3 days
MODIS	No	AOT at 550nm and Thermal-IR Dust Index (TDI)	Terra since December 1999 Aqua since May 2002	4 images per day in IR with Terra and Aqua	10km	Daily coverage
FY-2C(10/04) FY-2D(12/06) FY-2E(--/09)	Probably	Qualitative Sand/dust storm detection; Semi-quantitative AOD (550nm) and visibility.	Since October 2004 (Operational retrieval at the National Satellite Meteorological Center of China)	Geostationary satellite FY 2C (Feng Yun) [§2] 86.5E 105E 123.5E VIS 6 bits, IR 10 Bits	IR bands: 5 x 5 km VIS 1.25 km	15 min
MODIS-DeepBlue	Probably	Quantitative AOT and Angstrom coefficient	Research instrument on NASA satellites Aqua since May 2002 (MYD04_L2, Collection 5)	See above	~10 x 10 km^2	1minute - <1hour
CALIPSO	1 month		Cloud-Aerosol Lidar with Orthogonal Polarization	Extremely narrow swath		

§1: No direct follow –on although OMPS,VIIRS on NPP/NPOESS or GOME-2 on Metop may offer a relevant capability.

§2: Asian and Pacific region centered at 105°E. Data may be useful for Global geo-composites.

§3: SSP : sub-satellite point

MTSAT-1R products (http://mscweb.kishou.go.jp/product/product/index.htm)