GLOBAL SAND AND DUST STORMS SOURCE BASE MAP

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**SLIDE 01: Title slide**

- everything on the slide

**SLIDE 02: Technical information**

- everything on the slide

**SLIDE 03: SDS sources: Definitions**

Here are introduced some definitions important for understanding following work:

SDS source is defined as a bare topsoil surface susceptible to wind erosion or any surface capable to emit soil particles in favorable wind conditions. Areas that include SDS sources have fine soil texture and bare or sparsely vegetated surfaces, which can experience not-frozen and low soil moisture conditions.

Capacity of soil surface to emit soil particles under favorable wind conditions is named here SDS SOURCE INTENSITY. We consider here that if SDS source exists if it has some values of SDS source intensity. If SDS source intensity is 0, source does not exist.

SDS sources stay inactive if there is there is no wind, strong enough to provoke emission of particles from the surface. During the windy conditions SDS sources, meaning the surfaces that have some SDS source intensity, become active. SDS SOURCES ACTIVITY depends on frequency of high wind conditions.

SDS sources intensity may change during the year, in some periods they have SDS source intensity zero (meaning they do not exist), and in some periods they can reach high intensity values. So, they can be divided in two groups, according to their change in intensity: PERMANENT SDS sources and DYNAMICAL SDS sources. Permanent sources are the ones that have capacity to emit soil particles, meaning to contribute to SDS formation, during the whole year. Dynamical SDS sources are sources that change their intensity during the year, and appear only seasonally or occasionally. We distinguish here occasionally from seasonally, because there are SDS sources that appear seasonally on regular basis, and the ones that appear occasionally appear only during extreme events, like drought, heat waves in cold areas, etc.

**SLIDE 04: SDS sources: Drivers**

Drivers that impact SDS sources intensity and activity are: climate conditions, weather conditions, surface conditions and human activities. They are all in mutual interaction.

Climate is one of the main drivers that caused formation of permanent SDS sources in desert areas. Extreme aridity followed by the periods with high winds left desert areas with removal of vegetation or water bodies and long-term exposure to erosion, which consequently led to formation of SDS sources. Climate conditions also affect seasonal change of SDs sources intensity, which is mainly related to the seasonal change of vegetation and snow cover, moisture and temperature. Seasonal winds cause seasonal activity of sources.

Weather conditions are distinguished from climate conditions, because extreme weather deviates from usual climate behavior. This driver consider impact of extreme events on SDS sources intensity, such are drought, heat waves, storms with extreme winds, etc.

Surface conditions are closely related to climate and weather conditions, but can be also impacted by human activities. This driver includes land cover type, soil properties, soil temperature and moisture.

Human activities became very important driver that impact SDS sources intensity because of the human direct and indirect impacts that also can change other drivers. This is explained in more details on the next slide.

**SLIDE 05: SDS sources: Anthropogenic**

Because of the increasing importance of human impact on SDS activity, and assessment that large part of the total atmospheric dust transport is caused by human activities (ten years ago assessment was 25% from total amount), but also much more on local level, it is important to introduce in terminology ANTHROPOGENIC SOURCES. Because it is hard to separate exactly what are only-man made sources or combination of drivers, such sources will be defined as:

When human activities are predominating driver for SDS sources intensity, these SDS productive areas can be called *anthropogenic sources*.

But, we can recognize what are possible human impacts on formation of such sources, and divide them in DIRECT impacts and INDIRECT impacts. Direct impacts consider change of land cover, like removal of natural vegetation and disturbance of the topsoil structure related to agricultural activities, water scarcity that caused drying of lakes and rivers and reduction of soil moisture, deforestation, fires, mining, etc. Indirect human impact that comes from climate change can amplify droughts and even increase permanently aridity of the area, intensify storms with high wind conditions, etc. Impact of climate change worldwide became so strong it is comparable with natural drivers. It is hard to distinguish what is caused by climate change and what is from direct human impacts. Usually it is combination of drivers that are n mutual interaction.

**SLIDE 06: SDS sources: Studies**

There are many studies that describe global distribution of SDS sources. Some of them are presented in these pictures. Usually global distribution is defined using data on SDS observations and not directly detecting of sources itself.

Main SDS productive sources areas are situated in so called “dust belt” on the northern hemisphere (North Africa, Middle East, Central Asia). Other notable SDS productive areas are in south-west part of USA, southern part of South America, south Africa, and Australia.

Knowledge about global SDS is improving constantly, and it became important also to detect SDS affected areas outside usual SDS productive areas, like in mid-and high altitudes. Such sources are mainly dynamical, meaning they appear in some seasons or during extreme weather events.

**SLIDE 07: SDS sources: SDS events**

These are some examples of SDS and airborne dust transport that originated from SDS sources.

Global transports originate from the global most productive SDS sources from which severe winds uplifted and injected dust in higher atmosphere, where it entered free atmospheric circulation that is capable to carry dust over large distances, as well as over oceans.

Regional transport of dust may be in form of high altitude dust transport or in form of severe SDS, which spread from surface to higher altitudes in the atmosphere. These also originate from relatively large scale sources or clusters of smaller SDS sources in dry and high wind conditions. Transport may be from continent to continent or cross countries border transport.

Severe local SDS may additionally originate from nearby relatively small scale sources, but may have severe effects.

What is considered as large scale source (what looks to us as large dust productive area) usually consists of hotspots bulk (many hotspots distributed with high density over some area) that emit SDS plums individually and they then merge in large SDS.

Duration of SDS is directly related to spatial scaled of affected area.

**SLIDE 08: SDS sources: SDS and SDS sources scales**

Here are represented time and space scales of different SDS and consequently produced high altitude dust transport processes in the upper atmosphere. Duration and distance of transport are directly related, as already mentioned. Longer duration means longer distance of impact.

There is a large spectrum of scales of SDS events, but also a large spectrum of scales of SDS productive areas. But, it is important to have in mind that SDS productive areas can consist from cluster of SDS sources of smaller scales. They do not have to be homogeneously large areas with the same SDS source intensity, but it can have large spatial variability.

Considering all the above, decision is to make SDS base source map on high resolution (30sec=1/120deg, about 1km at the equator). We target to define high resolution global SDS base source map, that can recognize all spectrum of source sizes: from small scale sources, even the ones not frequently active, to large scale SDS productive areas with their complex structure of SDS source intensity.

It is important to mention and remember that SDS mapping must consider also areas which are less productive but can affect air quality significantly, and may reduce visibility.

**SLIDE 09: SDS sources: Mapping methodologies**

Methodologies for SDS source mapping can be divided in two groups. First one is SDS source mapping based on SDS observations, using satellite data and/or ground data on visibility, pm10, etc. advantage of this approach is that it can recognize most active SDS source areas, and major global and regional sources. But, because it relies on SDS observations, which are not consistent in space and time, this approach underestimates SDS sources that are not frequently active. Also, precise placement of source areas, especially small-scale hot-spots, can not be well represented. Second type of methodology is SDS source mapping from data on surface conditions. This methodology uses soil and surface data, and can produce high resolution SDS source patterns, with recognition of SDS sources hot-spots within SDS productive area. But, this approach requires complex combination of input datasets, and depends on quality of soil data.

For this work was chosen approach for mapping based on SDS source mapping from data on surface conditions, because it will provide more accurate high resolution spatial distribution of sources.

**SLIDE 10: SDS sources: Meaning of results**

Applying different methodologies for SDS source mapping will give results that are in certain agreement in patterns, as expected. But real meaning of the results is different.

Mapping from SDS occurrence will give map of SDS ACTIVITY, and not exactly placement of source areas, but it is assumed maximum are in the same regions. This approach indirectly includes high wind frequency, and thereby SDS sources activity, but real SDS sources intensity can not be exactly assessed, because of no surface data. Also, it gives results on lower resolution.

Maps derived from methodology that is chosen for this work, SDS source mapping from data on surface conditions, provides information on SDS SOURCE INTENSITY, which represents real source distribution. It is possible to have it on high resolution. But, information on frequency of SDS sources activation in not included. Anyway, capacity of soil surfaces to produce SDS is addressed with this map.

Best choice for risk assessment for impact of SDS, would need combined approach that relies on SDS source intensity map and atmospheric data. It would give the information about SDS sources that contribute the most to detected SDS negative impact in the region of interest. But this is currently not possible to do on high resolution globally, because needed data are not available for this assessment, and should be further addressed on national or local level.

**SLIDE 11: SDS sources: Choice of methodology**

So, considering extensive analysis of pros and cons of different methodologies. For the purpose of SDS source mapping is chosen, as already mentioned, SDS source mapping from data on surface conditions.

(on the slide are listed main reasons for this choice)

Frequent question is why wind data are not included, but they are actually of secondary importance because if the surface has some SDS source intensity (SDS source exists) strong will happen for sure, in some areas more frequently in some less, but this SDS source area will be activated. For example, SDS sources near populated areas are not frequently active, can be ones per year or in several years, but they can affect millions of people (like in Phoenix, Tehran, etc.). So, even these sources have much lower activity but high intensity, and damage much higher than very active sources in desert areas. So, real risk assessment from SDS requires much complex approach than just inclusion of wind data. Also, as mentioned before, for global mapping, no suitable wind datasets exist.

**SLIDE 12: SDS sources: Example**

Here is simply presented an example, a scheme, that explains main difference from these two approaches in mapping. On the left is and example of land surface area with distinguished hot-spot sources. High wind is more frequent over some sources and over some less. Sources emit dust plumes downwind. On the right (upper picture) is presented map that can be derived from, for example, satellite data on SDS occurrence. And on the lower picture is presented map that can be derived from surface data. Since our main goal is to assess SDS sources, we can see why our choice of methodology is second one.

**SLIDE 13: SDS sources: Cluster of data**

Datasets needed for mapping of SDS sources using surface data are listed here. Soil characteristics represent susceptibility of soil surface particles to wind erosion. On short periods these are fixed soil properties, but can be variable under stress from direct human impact. They include, most importantly soil texture information, that gives information on top soil particle size distribution, which is very important for emission and formation of SDS.

Land cover data are fixed and variable properties of surface conditions and include information on surface exposure to wind erosion, like is there water, snow or ice cover, or vegetation cover.

Soil condition data are variable soil properties: soil moisture and temperature.

Implementation of better quality of surface data and additional data from national data can improve resolution and accuracy of SDS source map and knowledge on their origin, meaning that improvement of quality of data is possible in national SDS source maps.

**SLIDE 14: G-SDS-SBM: Introduction**

Now we are representing how Global sand and dust storms base map is created.

(all information are on the slide)

The reason why only these four months are selected is to save on computing time, assuming that cycle of SDS source intensity change during the year will be well represented on global level using data for these months (explained further on the slide).

**SLIDE 15: G-SDS-SBM: Mapping and major concerns**

Here, in more details, is presented what is considered in SDS mapping.

Top priority is to map areas with sufficient fine soil texture and free surfaces. SDS productive soil texture, as already discussed, is the one that have sufficient clay and silt content. Silt is most efficient to contribute to SDS, and clay and sand less. Free surfaces are the ones that have low moisture, not frozen, do not have vegetation, snow or ice cover, water bodies.

Major concerns are that soil texture information for the whole globe is of low quality because there were not enough measurements in some areas (especially deserts) and/or quality national data were not included in global datasets. This means that percentage of finer and coarser fraction in not well represented, and mapping is very sensitive to this parameter.

Another expected problem is with mapping of free topsoil surfaces. In some parts of the world there is high variability of vegetation and snow cover. Also, there is seasonal drying of water bodies. Also, in regions with very cold winters it is possible that surface is frozen and not capable to emit particles in favorable with conditions. So, for example, there can be large variability of free surface information (picture B), especially seasonally, but also because of increased severe weather frequency under climate change impact. It is important to mention that many water bodies are drying constantly (Aral sea), many agricultural land is abandoned and stayed barren (or only sparsely vegetated).

In former lakebeds, that are dried relatively “recently” (because climate change impact and water scarcity) there is no soil data!!! But, these data are filled with nearest point value.

**SLIDE 16: G-SDS-SBM: Soil texture (1)**

Significant effort was done in order to improve soil texture information to improve soil texture information on global level for the purpose of SDS source mapping.

This is done by creating soil texture correction function. It is assumed that applying this correction function on soil texture data would give better representation of soil surface particles susceptibility to wind erosion. Actually, to highlight those areas giving them higher weight.

**SLIDE 17: G-SDS-SBM: Soil texture (2)**

For initial soil texture information (clay, silt and sand percentage) two databases are used: ISRIC that gives percentages of each category, and STATSGO-FAO that gives information about 12 USDA soil texture types given on the pisture (not exact percent of each category). First STATSGO-FAO categories are translated to percent of clay, silt and sand (total of these three is 100%), using ISRIC database and correction for each category according to defined thresholds clay, silt and sand contents.

Average of these two databases is then calculated. This represents final initial soil texture dataset, on which will be applied soil texture correction factor.

These two databases are chosen because they showed certain advantages (or disadvantages) in different regions.

**SLIDE 18: G-SDS-SBM: Soil texture (3)**

The idea for defining soil texture correction factor comes from S-function from Ginoux et al. (2001). This function is calculated in point but using information from the box around that point. It has a meaning to distinguish topographical lows (pits), and assumes that in these areas is high probability to have alluvium, which consists of fine particles content.

Originally it was calculated on coarse resolution but well represented major global sources, and results agreed well with satellite data that show SDS occurance.

**SLIDE 19: G-SDS-SBM: Soil texture (4)**

Using this S-function is developed soil texture correction factor.

S-function is calculated globally on 30 arcsec resoltuion. Ensemble of four sets of S-functions is calculated, using different box sizes. Results derived from large box sizes recognize large scale topographical lows (pits), and results from smaller box sizes recognize smaller scale pits. Final S-function value for defining correction factor is obtained as average of these four datasets, which means that equal importance (weight) was given to large, medium and small scale pits that have high probability to have high content of fine particles.

Correction factor is calculated under assumption that representative value of fine texture content is average of S-function and fine (clay+silt) initial soil texture content.

Correction factor is applied on clay content and silt content. Sand content is the rest, to fill up to 100%.

**SLIDE 20: G-SDS-SBM: Soil texture (5)**

Here are represented data: left upper – fine texture content (clay+silt) as average of two soil texture databases; left lower – s-function obtained as average of four datasets; and on the right is the fine soil texture content after correction factor is applied.

**SLIDE 21: G-SDS-SBM: Soil moisture**

Soil moisture data are derived from ECMWF for each month, for each day in 00 and 12 UTC, for the period 2014-2018. Minimum value for each month was retrieved as input for mapping (presented in the picture).

Using minimum soil moisture content instead of average can represent maximum possible dryness for each grid point that may happen in present and probably near future climate.

**SLIDE 22: G-SDS-SBM: Soil temperature**

Soil temperature data are also derived from ECMWF for each month, for each day in 00 and 12 UTC, for 2014-2018. Maximum value for each month was retrieved as input for mapping (presented in the picture).

Using maximum soil temperature instead of average can represent **maximum possible not-frozen conditions for each grid point** that may happen in present and probably near future climate.

**SLIDE 23: G-SDS-SBM: Bare land fraction (1)**

To define bare land fraction are used MODIS data. MODIS EVI were retrieved for four months for the period 2014-2018. Minimum positive value of EVI for each month was used (shown in the picture).

Using minimum positive value instead of average can represent maximum possible bale land fraction for each grid point that may happen in present and probably near future climate.

If EVI is positive and less or equal to 0.1, bare land fraction is 100%. As EVI value is increasing from 0.1 to 0.15, bare land fraction is decreasing from 100% to 0%.

**SLIDE 24: G-SDS-SBM: Bare land fraction (2)**

MODIS land cover data are used to support bare land fraction mapping from EVI data, because of shallow water, dark soils, and surfaces of mixed colors that can have small EVI but actually can not be SDS productive.

**SLIDE 25: G-SDS-SBM: Algorithm**

Here is presented algorithm of data processing. Simple layering of different data is not possible because of the complex connections between input parameters. So, parameterization of emission was applied to simulate particles emission uder conditions defined with input parameters. Emission is calculated for each particle size category. It is assumed that friction wind velocity is 1m/s, which corresponds to strong wind during intense SDS. Total emitted concentration is then normalized (scaled) to values 0 to 1. Dividing the total emitted concentration with value of 99th percentile does it. Obtained values that are higher than 1 (emission higher than 99th percentile) have assigned value 1.

This way is done calculation of SDS sources intensity, with values form 0 to 1.

Algorithm is applied on every land point, and for each month.

**SLIDE 26: G-SDS-SBM: Monthly**

Here are the results: monthly maps of SDS sources that represents SDS sources intensity, meaning capacity of soil surfaces to produce SDS. have in mind that weakest (small intensity) sources probably do not produce SDS, but rather “blowing dust” events.

Many different versions of SDS source maps can be derived from these results. Examples are on following slides.

**SLIDE 27: G-SDS-SBM: Annual**

This is the map of annual sources - sources that have some intensity during the whole year (permanent SDS sources). And corresponds to previously mentioned maps derived from different SDS studies. Major parts are situated in “dust belt”, Australia, etc.

**SLIDE 28: G-SDS-SBM: Maximum and minimum**

Minimum and maximum values for SDS sources intensity derived from monthly data.

Comparing these two maps, we can see how large is variability of SDS sources intensity, related to change of weather conditions and, consequently, change of bare land fraction.

**SLIDE 29: G-SDS-SBM: Dynamical sources**

Here is presented difference between maximum and minimum values of SDS sources intensity, so this map shows dynamical sources – sources that change their intensity during the year.

**SLIDE 30: G-SDS-SBM: Overview**

On this image are distinguished clearly permanent and dynamical sources. Also, sources with higher maximum intensity are highlighted.

**SLIDE 31: G-SDS-SBM: Simple**

This is an example of SDS source map where in simple way are presented different information on sources.

Knowing the land cover types, we can distinguish cropland areas and grassland areas that can be exposed to human impact because of agricultural practice (unsustainable tillage, grazing,..). Under “other” type are considered other bare of sparsely vegetated areas that have SDS source intensity. That can be desert areas, dried lakes and rivers, land exposed because of glacier retreatment, because of fires, mining, etc.

Also, further are distinguished higher intensity SDS sources from lower intensity, and higher intensity are divided in permanent and dynamical (seasonal /occasional). Usually we use “seasonal” for all dynamical sources.

For example, if areas under grassland and cropland types show higher intensity permanent category, these areas are alarm for exposure for land degradation. “Other” permanent higher intensity sources already degraded or in process of severe degradation and loss of surface composition due to wind erosion. Also, seasonal higher intensity cropland areas must implement SLM practices considering that weather conditions under climate change will be drier and with more extreme events that increase vulnerability of these areas.

**SLIDE 32: G-SDS-SBM: Few additional notes**

(all relevant is written on the slide)

Additionally is worth to mention, that full methodology is described in details in the Report.