HIGH-RESOLUTION GLOBAL DUST SOURCE MAP

Mapping Methodology and Results

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INTRODUCTION

- **Global Sand and Dust Storms Source Base Map (G-SDS-SBM)** is made under consultancy engagement with UNCCD.
- Acknowledgements:

UNCCD coordinator of the work was Utchang Kang (ukang@unccd,int);

Bojan Cvetković (Republic Hydrometeorological Service of Serbia; Faculty of Physics, University of Belgrade) provided input data, performed formatting and helped in forming mapping methodology;

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- Goal: to assess globally the capacity of soil surfaces to produce sand and dust storms in case of favorable wind conditions
- **SDS source is *bare topsoil surface susceptible to wind erosion or any surface capable to emit soil particles in favorable wind conditions.***

  Assumption: Areas that include SDS sources have fine soil texture and bare or sparsely vegetated surfaces, which can experience not-frozen and lower soil moisture conditions.

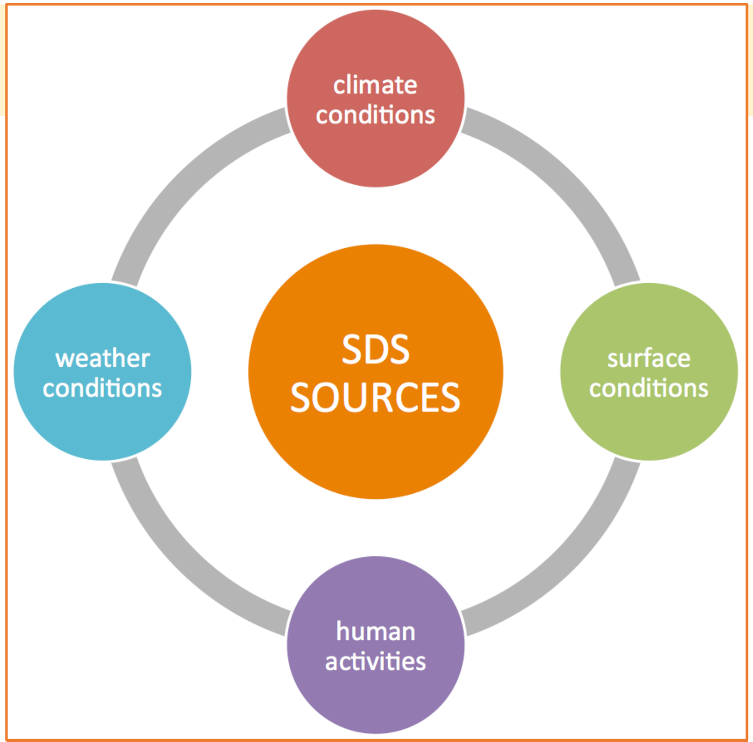
- **SDS source intensity** is capacity of soil surface to emit soil particles under favorable wind conditions.
- **SDS source activity** depends on frequency of high wind.
- SDS sources may be distinguished according to their change in intensity:
  - **permanent** SDS sources: surfaces that have capacity to emit soil particles annually
  - **dynamical** SDS sources: surfaces that have capacity to emit soil particles seasonally or occasionally (during extreme events)

SDS SOURCES: DRIVERS

Drivers that impact SDS sources intensity and activity:

- **Climate conditions**
  aridity, seasonal weather,…
- **Weather conditions**
  extreme wind, drought, …
- **Surface conditions**
  Soil texture, soil moisture, temperature, land cover,…
- **Human activities**
  direct and indirect human impact

Drivers are in mutual interaction.



SDS SOURCES: ANTROPOGENIC

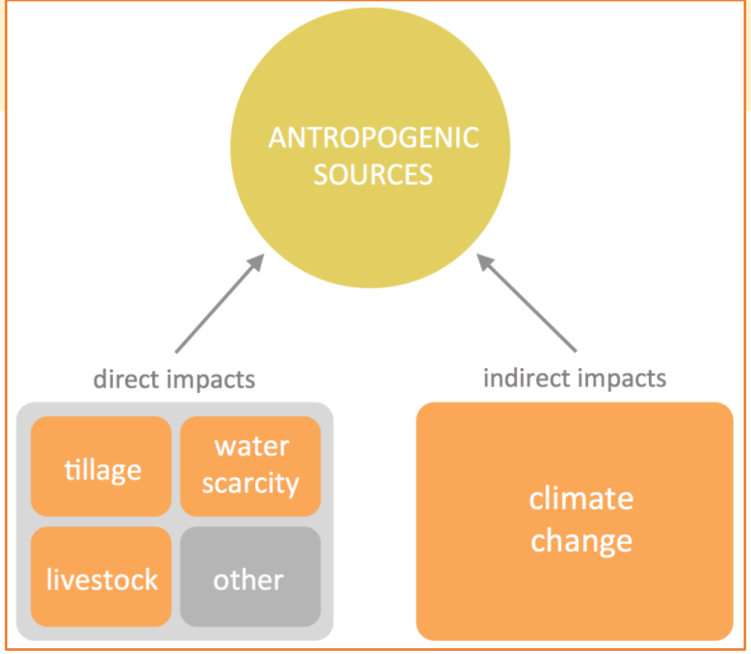
When human activities are predominating driver for SDS sources intensity, these SDS productive areas can be called *anthropogenic sources*.

Direct human impacts

- land cover changes, disturbance of the topsoil and loss of soil structure (agriculture: tillage and livestock breeding),
- use of water for irrigation, hygienic needs (especially for large urban areas) and industry,
- other factors: deforestation, fires, mining, etc.

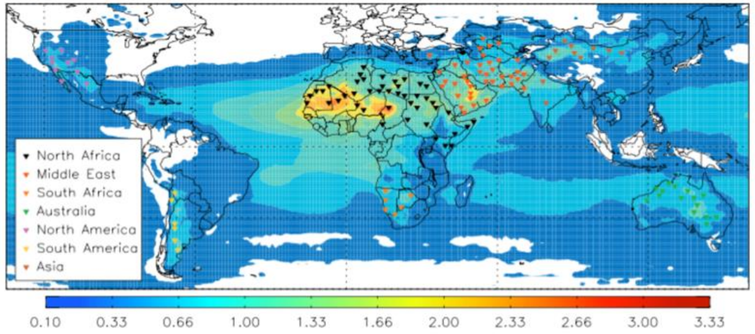
Indirect human impacts

- climate change

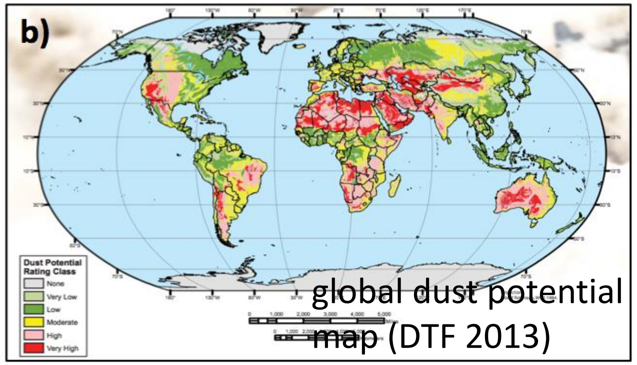


SDS SOURCES: STUDIES

131 hot spots and TOMS AI
a) (Engelstaedter and Washington 2007)

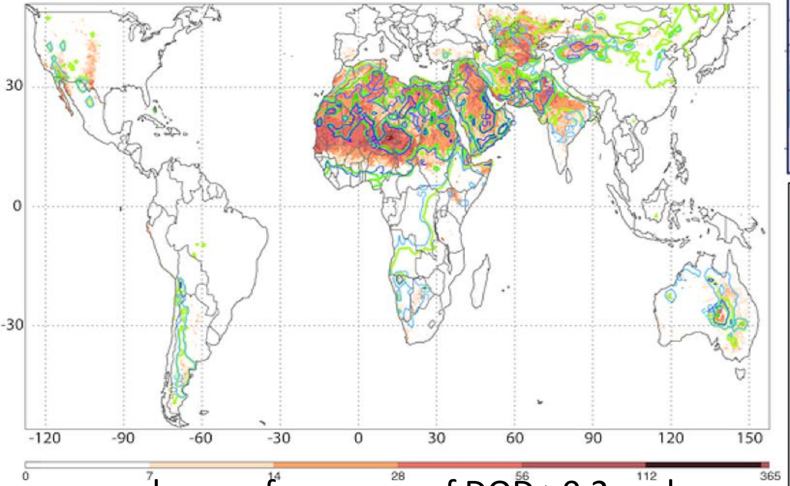


b)



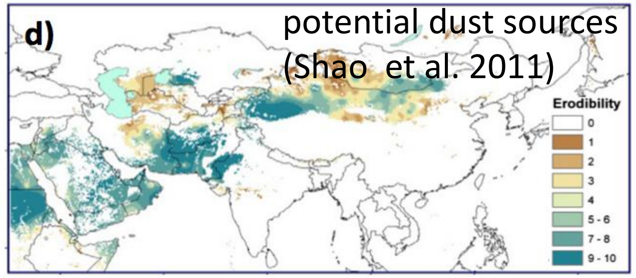
global dust potential map (DTF 2013)

c)



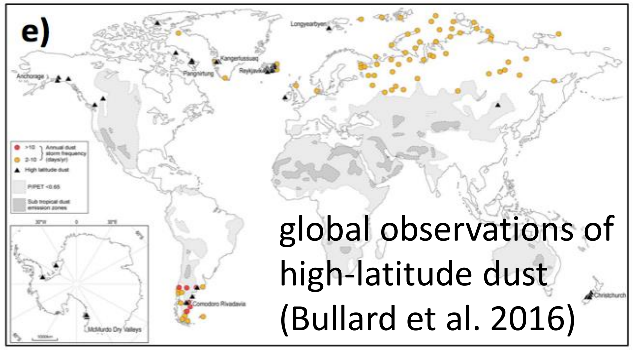
annual mean frequency of DOD >0.2 and TOMS and OMI AI ≥0.5 (Ginoux et al. 2012)

d)



potential dust sources (Shao et al. 2011)

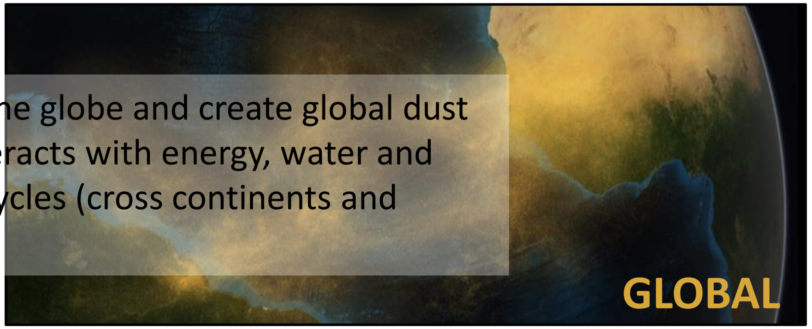
e)



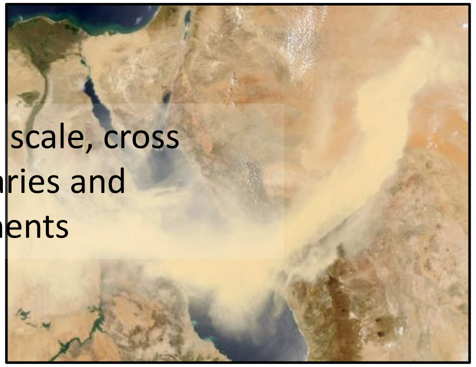
global observations of high-latitude dust (Bullard et al. 2016)

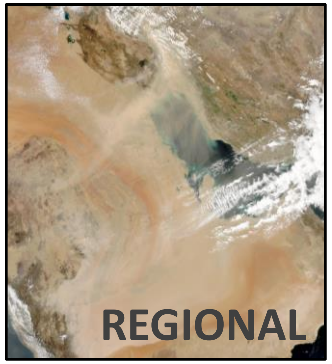
SDS SOURCES: SDS EVENTS

SDS sources contribute to wide range of spatial and temporal scales of SDS (or dust only) events and global dust cycle in general:



global – circle the globe and create global dust cycle which interacts with energy, water and carbon global cycles (cross continents and oceans)

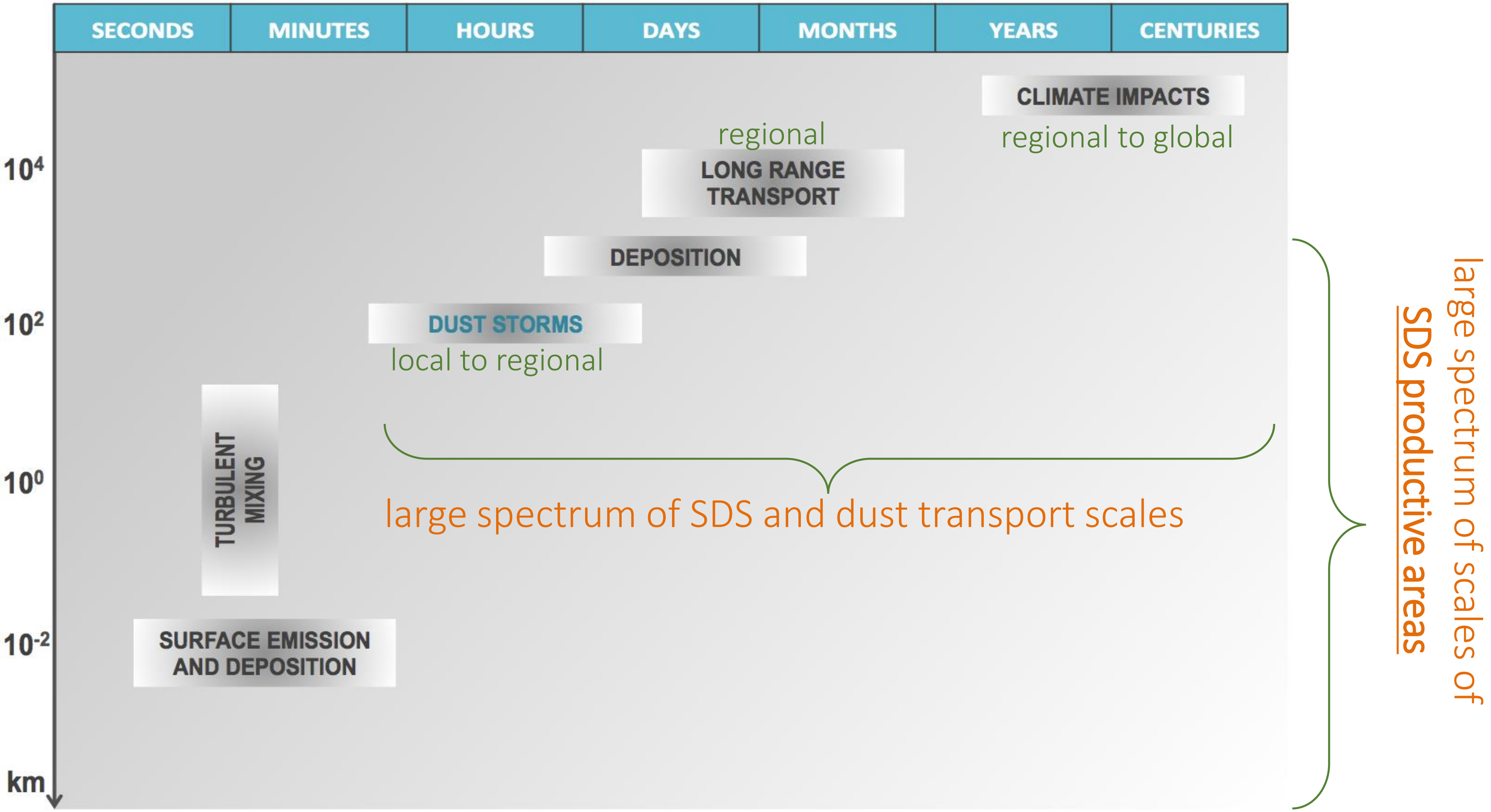




regional – large scale, cross country boundaries and neighbor continents

local – relatively near SDS source

SDS SOURCES: SCALES OF SDS AND SDS SOURCES



GLOBAL MAP NEEDS TO INCLUDE CONTRIBUTION FROM DIFFERENT DRIVERS AND SOURCES OF DIFFERENT SCALES USING UNIQUE METHODOLOGY FOR MAPPING IN ALL AREAS OF THE WORLD.

SDS SOURCES: MAPPING METHODOLOGIES

Methodologies for SDS source mapping can be distinguished in two groups:

	Data	Advantages	Disadvantages
SDS source mapping from data on SDS occurrence	Observations of SDS (satellite and ground)	good representation (high confidence) of **synoptic overview of major and frequently active SDS source areas** (permanent and seasonal); **recognize global and regional sources that dominate in SDS generation**	spatial and temporal **coverage of observations is not continuous**; lower resolution than mapping resolutions of other soil related parameters; not able to recognize/delineate small scale and occasionally active SDS events; climatological approach (averaging of long term data) gives advantage to natural (permanent and seasonal) and/or larger scale SDS sources; **underestimate SDS sources which are small scale and/or not frequently active**.
SDS source mapping from data on surface conditions	Soil and surface data	contains data on soil characteristics and land use, **can provide high resolution SDS source patterns**, can detect/delineate small scale sources and distinguish SDS source hot spots, **include surfaces with high potential for SDS generation in extreme weather conditions even if they have low activity.**	require relatively **complex combination of information from different sources of data**; because of high spatial variability and not sufficient soil sampling, **quality on soil information may be low which requires implementation of additional information**; does not include information on frequency of SDS generation

SDS SOURCES: MEANING OF THE RESULTS

Results obtained with different methodologies can have different meaning:

	Meaning	Advantages	Disadvantages
SDS source mapping from data on SDS occurrence	Map represents frequency of SDS, assuming that areas with highest frequency are the strongest sources of SDS	Indirectly includes impact of high wind frequency	Does not include surface properties; placement of SDS sources may be biased (dislocated); low resolution
SDS source mapping from data on surface conditions	Map represents SDS sources intensity (capacity of soil surface to emit particles) in case of high wind occurrence	High resolution, gives location SDS sources with different intensity	Does not include high wind frequency, meaning that frequency of real activation of SDS sources is not included
! **Combined surface conditions and atmospheric data**	Includes SDS sources intensity based on surface data and activity of sources based on real wind impacts on SDS sources with defined intensity	Gives high resolution information about SDS sources distribution including their intensity and activity	Global high resolution quality wind data, including local extreme high velocity episodes, does not exist; in climate changing world constant update is needed, because increased frequency of high wind velocity storms

SDS SOURCES: CHOICE OF METHODOLOGY

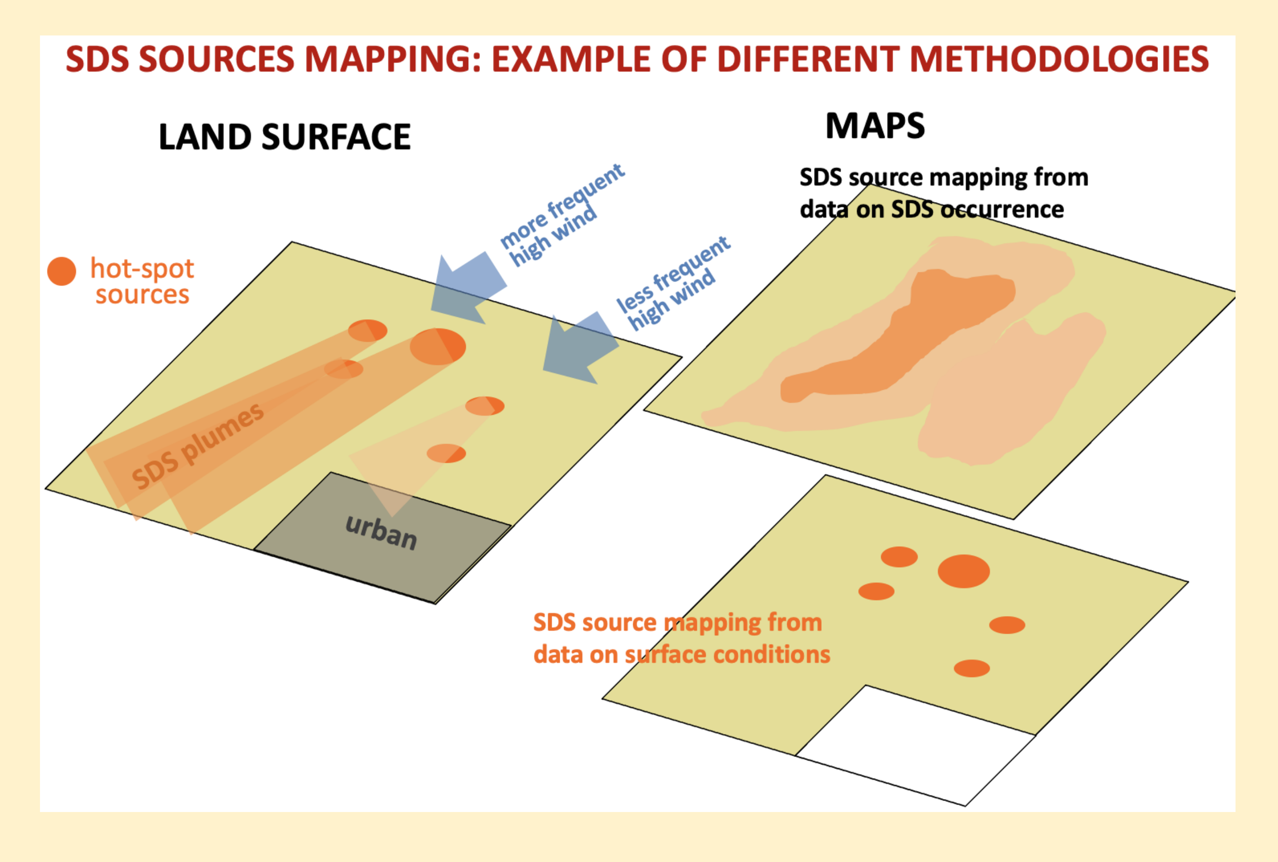
Chosen methodology is **SDS source mapping from data on surface conditions.**

Why this choice of methodology?

- Gives information about specific location of land surfaces that have capacity to emit soil particles in case of high wind conditions
- Gives detail information on SDS sources intensity – distinguish soil surfaces with higher and lesser capacity to contribute to SDS formation
- Can recognize local hot spots – surfaces with high resolution local maximums of SDS sources intensity

Why real wind data are of secondary importance for SDS source mapping?

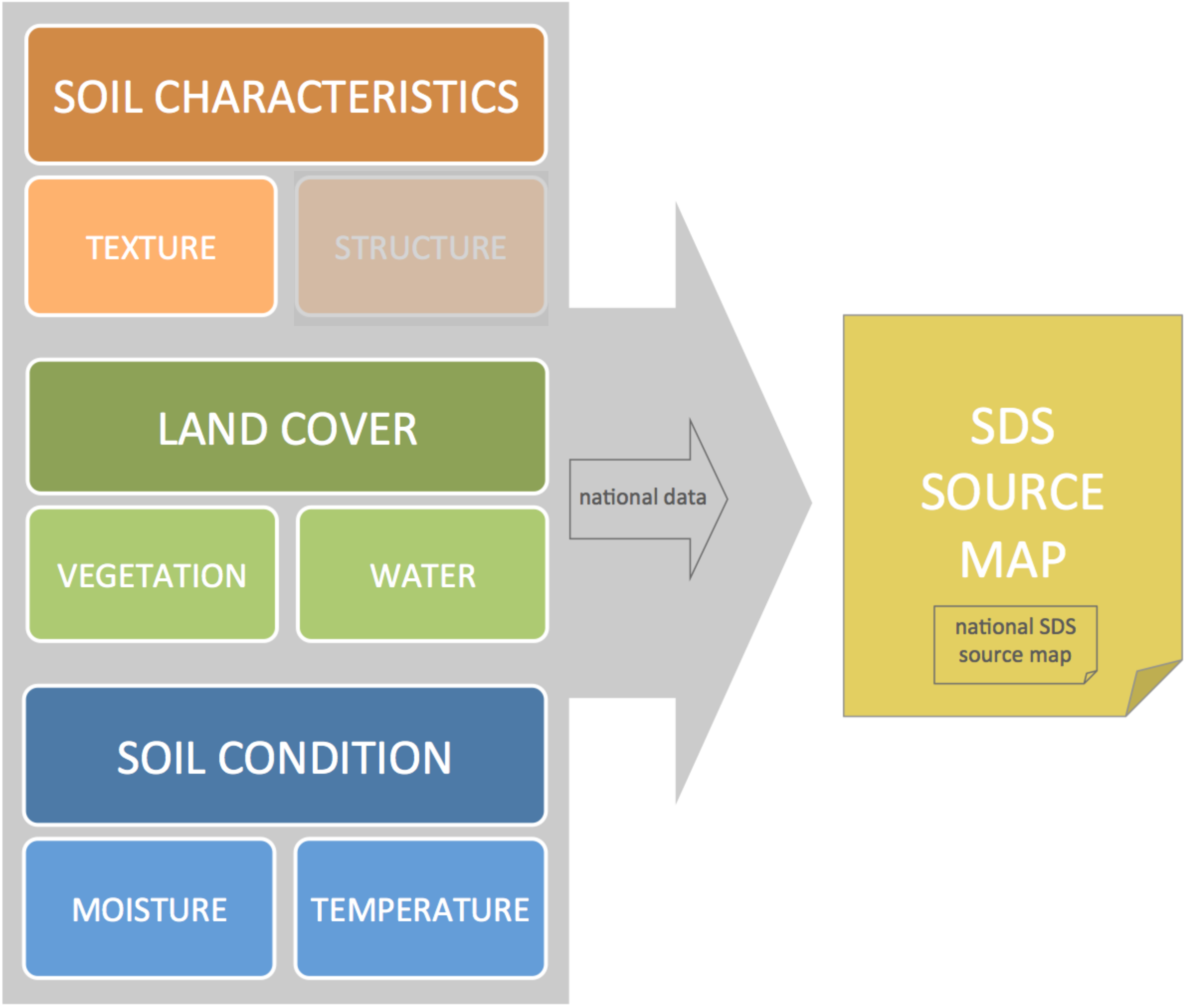
- High wind episodes will happen everywhere in world and if surface with some SDS source intensity exists – it will emit particles
- Inclusion of wind impact may reduce importance of SDS source hot-spots
- No global high resolution wind data (with wind gusts) exists



SDS SOURCES: CLUSTER OF DATA ON SURFACE CONDITIONS

Datasets for mapping:

- **soil characteristics**
  susceptibility of soil surface particles to wind erosion
  (fixed soil properties, but can be variable under stress from direct human impact)
- **land cover**
  surface exposure to wind erosion
  (fixed and variable land cover properties)
- **soil condition**
  moisture and temperature
  (variable soil properties)



Implementation of better quality and more information from national data can improve resolution and accuracy of SDS source map and knowledge on their origin ➔ national SDS source map

G-SDS-SBM: INTRODUCTION

Basic information:

- **Global sand and dust storms source base map (G-SDS-SBM)** represents gridded (geo-referenced) information on the distribution, intensity and variability of sand and dust storms (SDS) sources developed from publically available global datasets.
- The map shows maximum potential of the surfaces obtained from the data **from the last 5 years (2014-2018)** to produce SDS in case favorable wind conditions occur.
- Values of the G-SDS-SBM are **from 0 to 1 – *SDS sources intensity***, where 0 represents that surface has no potential (capacity) to produce SDS, and 1 represents highest SDS source intensity, meaning most productive SDS surfaces in case of high wind conditions.
- **Resolution of the map is 30 arcsec** (about 1km at the Equator) in regular lat-lon grid, projection WGS84.

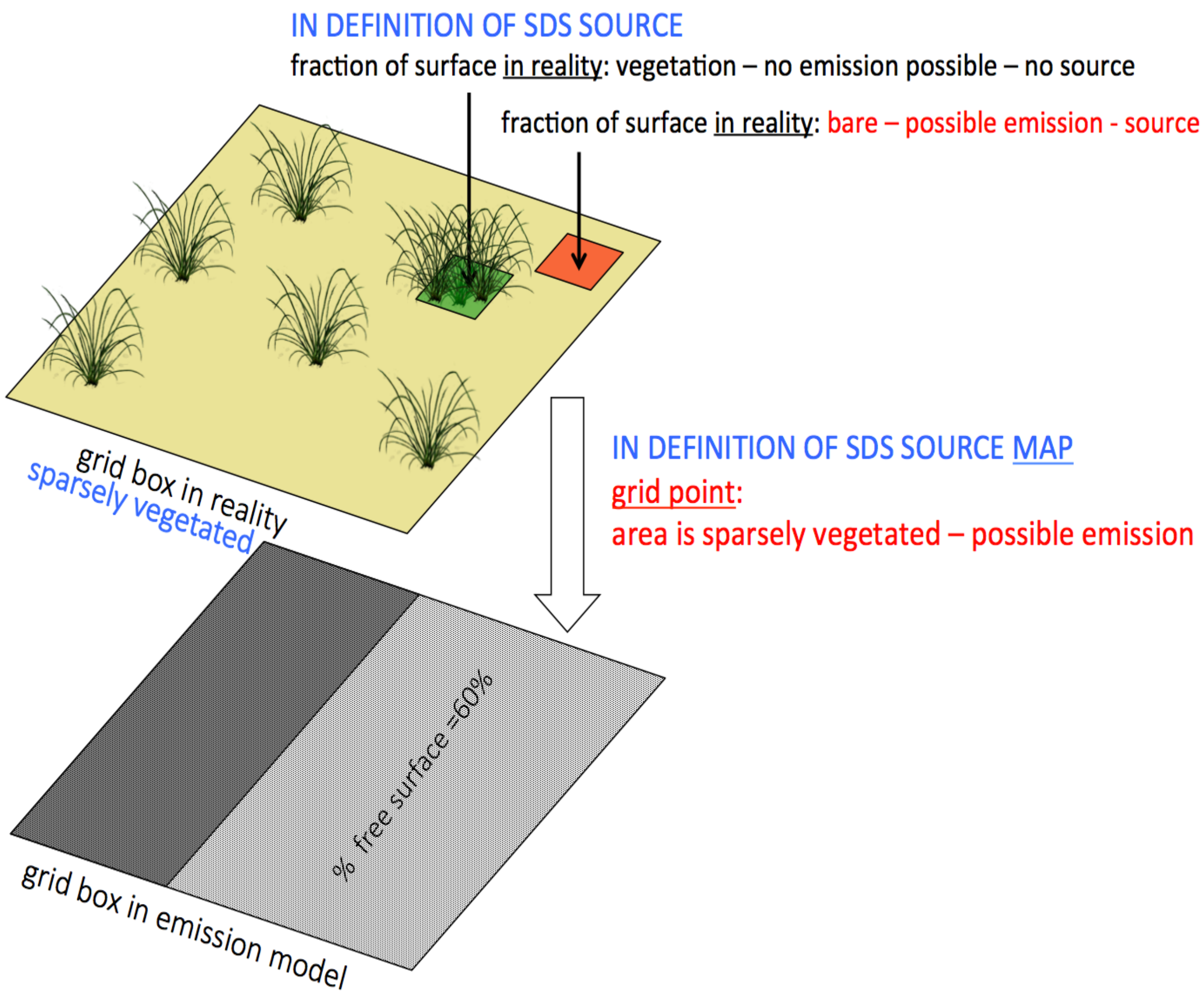
G-SDS-SBM is based on development of four monthly maps:

- **January**, as a month with lowest temperatures and minimum vegetation for northern hemisphere and with opposite conditions on southern hemisphere;
- **April**, as a month when vegetation starts to develop (beginning of the growing season) on the northern hemisphere and when vegetation cover decrease and vanish on southern hemisphere;
- **July**, as a month with highest temperatures and developed vegetation for northern hemisphere and with opposite conditions on southern hemisphere;
- **October**, as a month when seasonal vegetation decreases and vanishes on the northern hemisphere and when vegetation cover starts to develop on southern hemisphere.

G-SDS-SBM: MAPPING AND MAJOR CONCERNS

Priority in detecting SDS sources

- soil texture information
- free surface % (without vegetation, snow/ice cover, water bodies and non frozen soil)

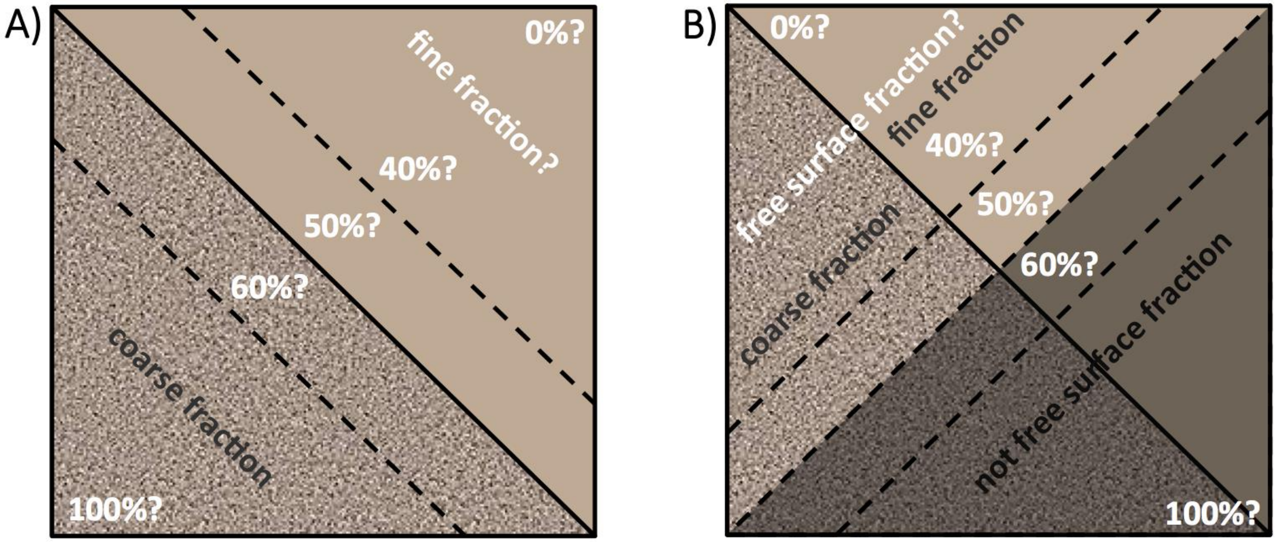


Challenge in soil texture information (picture A)

- Soil texture data are low quality on global level, because not enough measurements or quality national data were not included in global datasets

Challenge in definition of free surfaces (picture B)

- High variability of vegetation and snow cover, soil temperature and water bodies extent
  - ➔ Requires implementation of information on seasonal variability of free surfaces
  - ➔ Need to related percentage of free surface with satellite data!

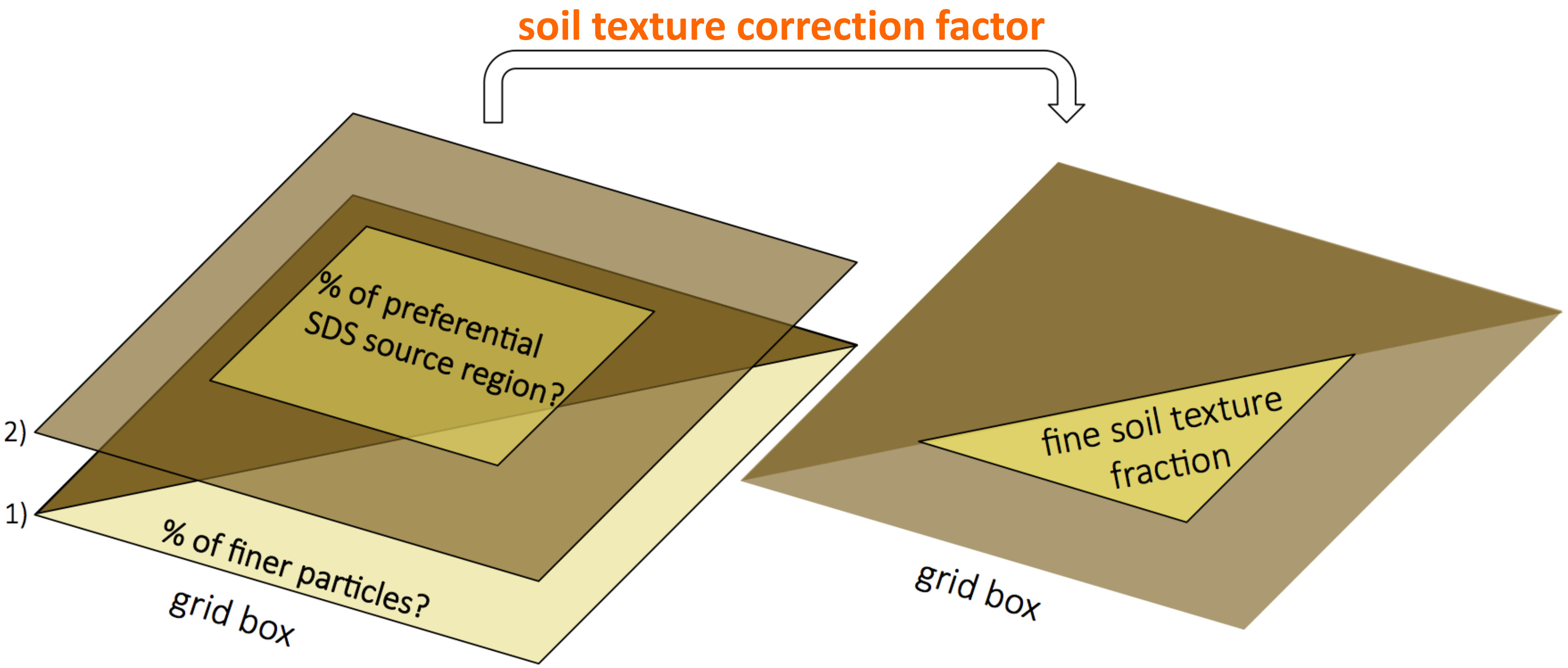


G-SDS-SBM: SOIL TEXTURE (1)

How is derived improved soil texture information for SDS source detection

- from soil texture databases is estimated fine particles content (layer 1);
- increased fine texture content in areas with high probability for high alluvium content, and reduced in areas with low probability (layer 2)

topsoil fraction of soil texture that is susceptible to wind erosion



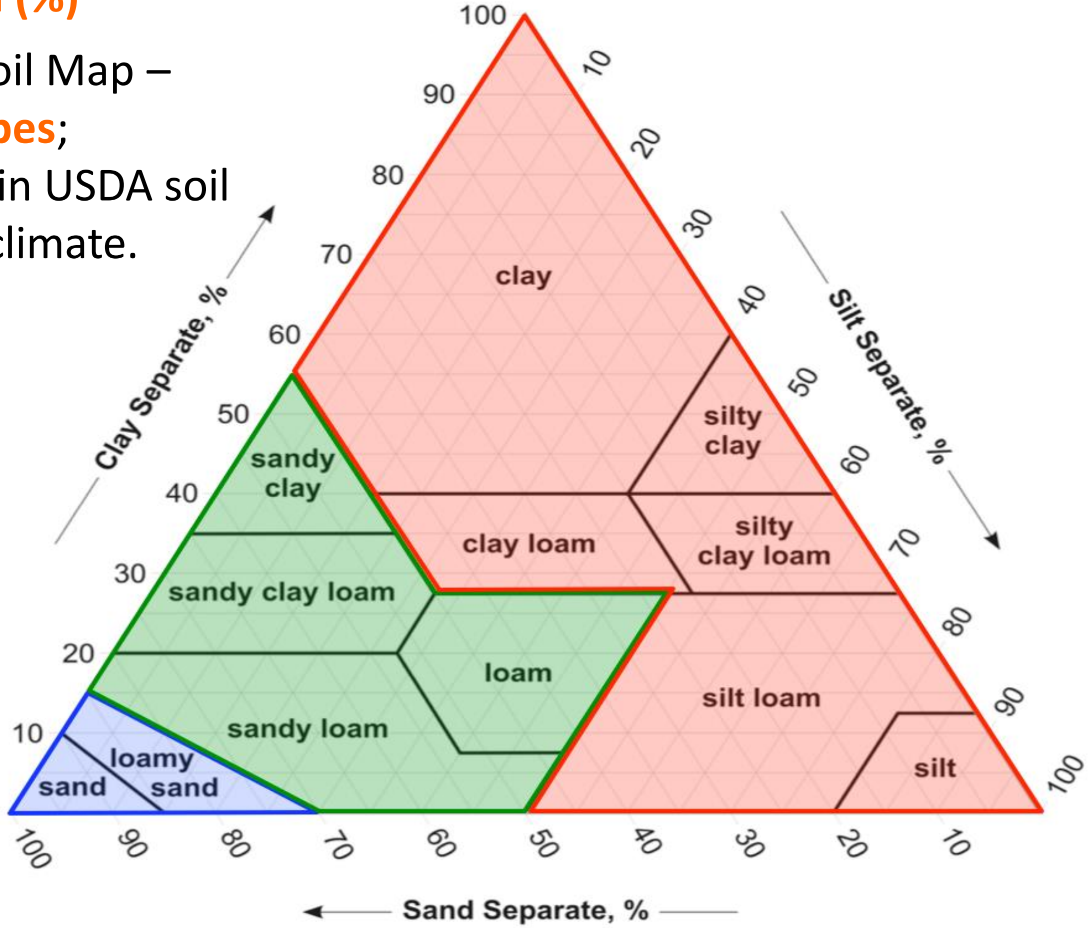
G-SDS-SBM: SOIL TEXTURE (2a)

Obtaining fine particles content of topsoil

AVAERAGE of two databases for soil texture were used:

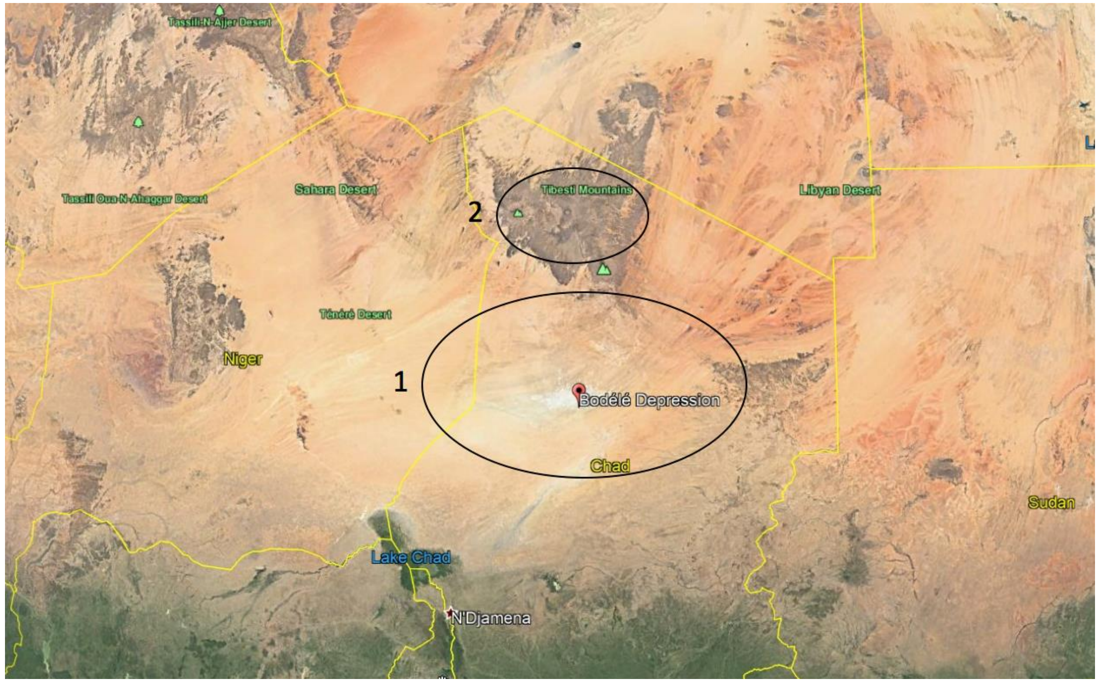
- **ISRIC** (International Soil Reference and Information Centre) World soil Information database that provides SoilGrids (soil global gridded information), at 30 arcsec resolution provides global sets for mass **fraction of clay, silt and sand (%)**
- **STATSGO-FAO** (Natural Resources Conservation Service US General Soil Map – Food and Agriculture Organization) database of **USDA soil texture types**; combination of US 30arcsec and for the rest of the world FAO 2 arcmin USDA soil database that is usually used in numerical modeling of weather and climate.

NOTE: USDA soil texture types in STATSGO-FAO are translated to fraction of clay, silt and sand in %, using ISRIC database and changing by minimum percent of soil texture fraction to correspond to USDA soil texture type in STATSGO-FAO map in case the criteria is not already met.

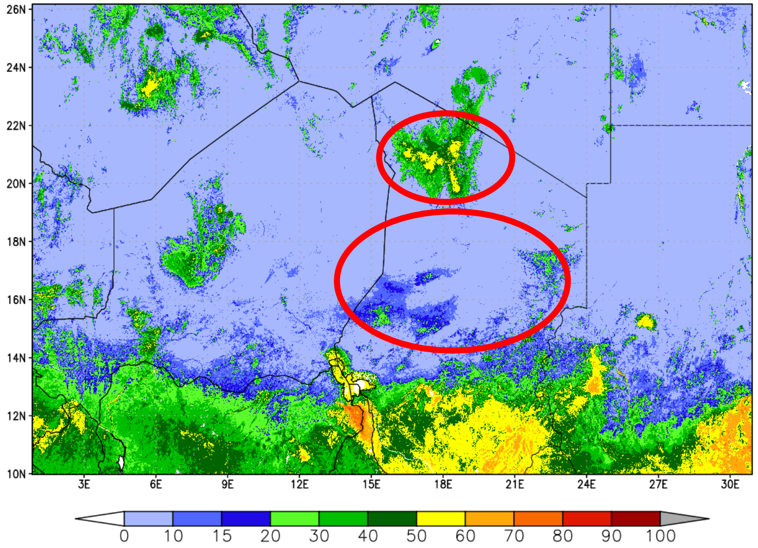


G-SDS-SBM: SOIL TEXTURE (2b)

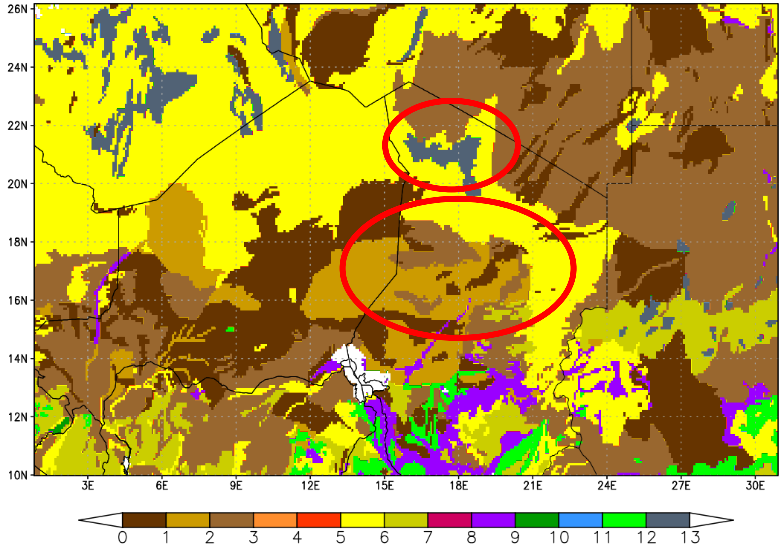
Example explaining the reason for using of combination of two soil texture databases: Bodele d.



Google Earth image of the selected domain:
1. Bodele depression, 2. Tibesti mountains.



Fine particles (clay+silt) content in top soil from ISRIC database (%).

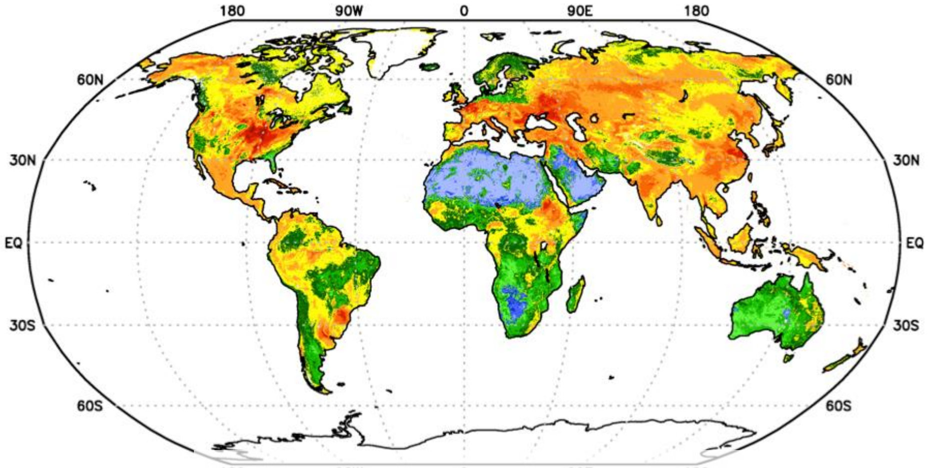


Soil texture types from STATSGO-FAO database

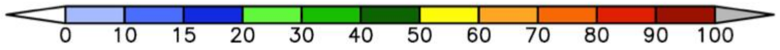
1	sand	silt+1.5clay<15
2	loamy sand	15≤ silt+1.5clay silt+2clay<30
3	sandy loam	7≤clay<20 silt+2clay≥30 sand>52
6	loam	7≤clay<27 28≤silt<50 sand≤52

G-SDS-SBM: SOIL TEXTURE (2c)

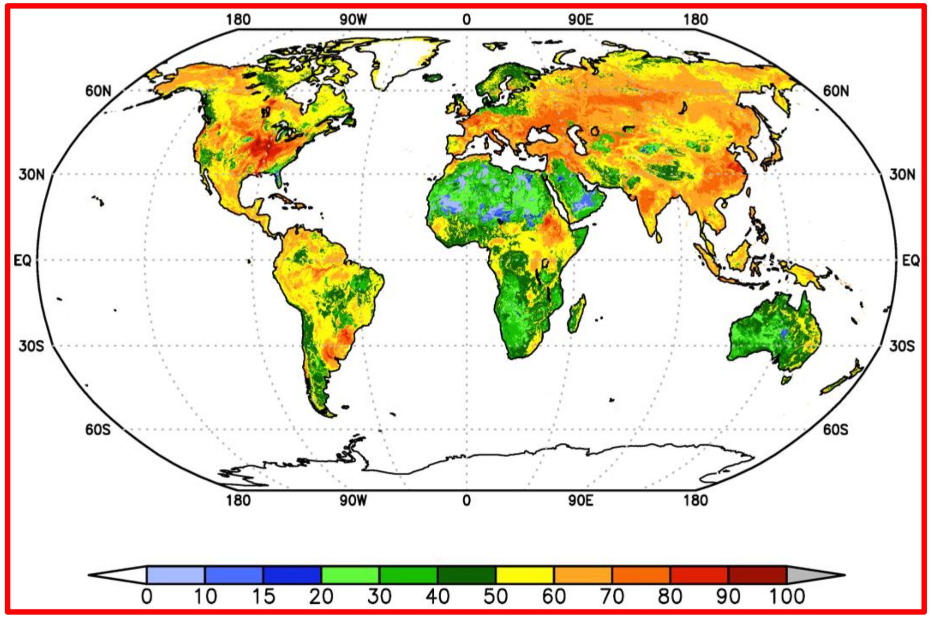
Global soil texture data



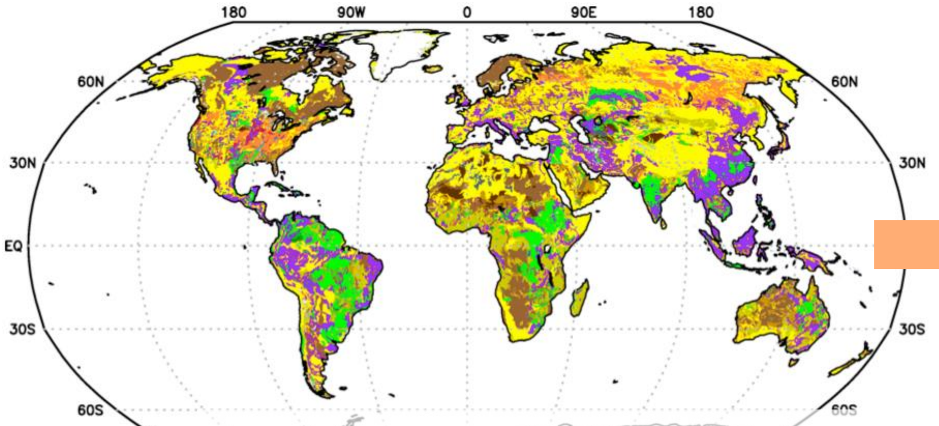
ISRIC soil texture, clay+silt in %



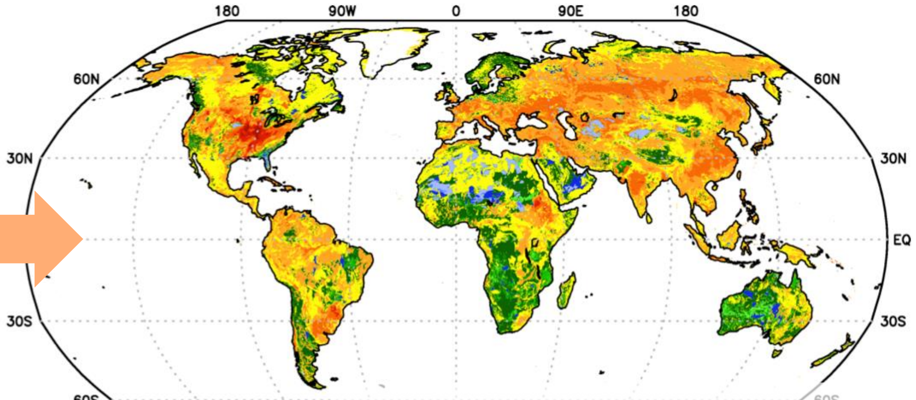
These two datasets are averaged.



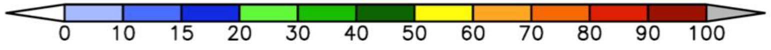
Average value of ISRIC soil texture values and converted STATSGO-FAO soil texture; in the image is clay+silt in %



STATSGO-FAO soil texture categories (1-12) and bedrock in grey



STATSGO-FAO soil texture converted in % of clay/silt/sand; in the image is clay+silt in %.



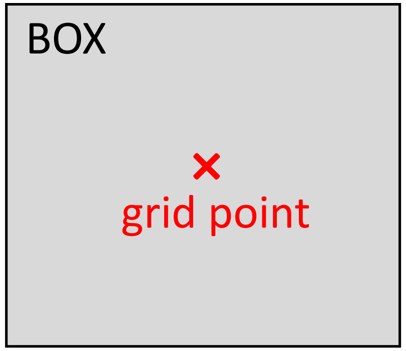
G-SDS-SBM: SOIL TEXTURE (3a)

Approach applied for increasing contribution from topographical pits

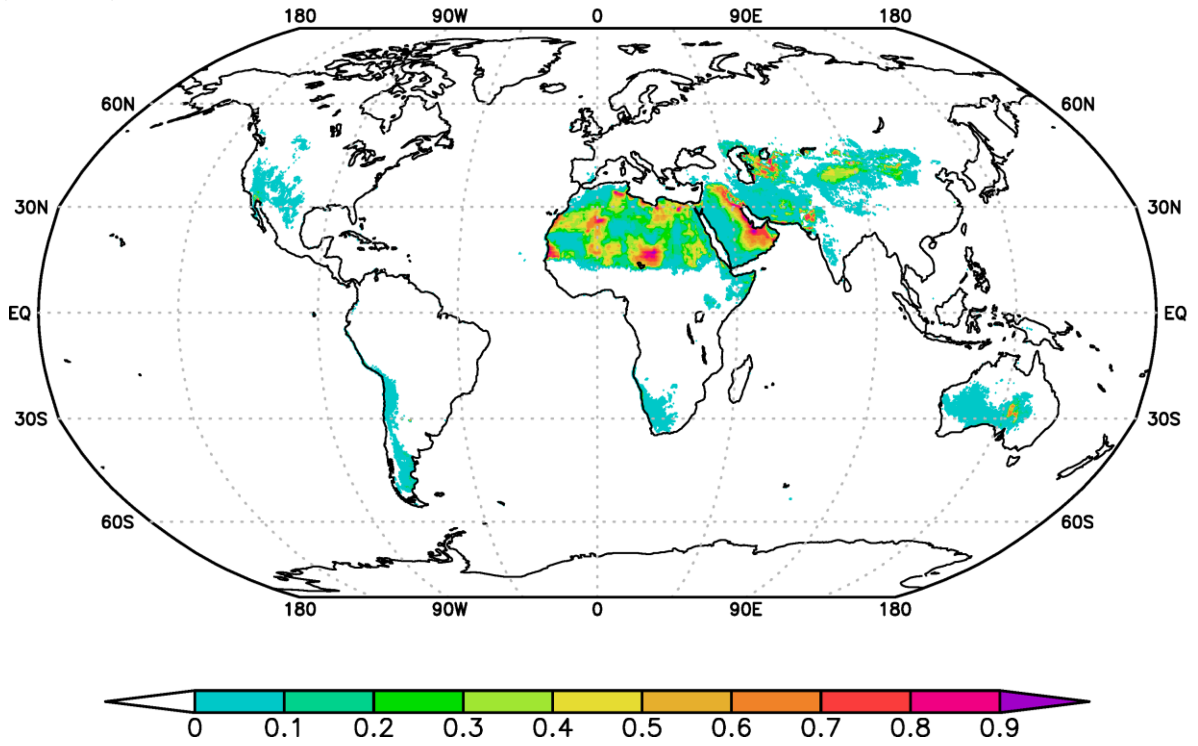
Adopted approach: S-function according to Ginoux et al. (2001)

$$S = \left(\frac{Z_x - Z_i}{Z_x - Z_n}\right)^5$$

- Z_x is maximum value in the box
- Z_n is minimum value in the box
- Z_i is value in ×
- S has values from 0 to 1, and higher values distinguish topographical pits (have high probability to contain alluvium)



Original S-function in Ginoux et al. (2001) is derived on 1° resolution, with box size of 10°x10° for calculation of S-function.

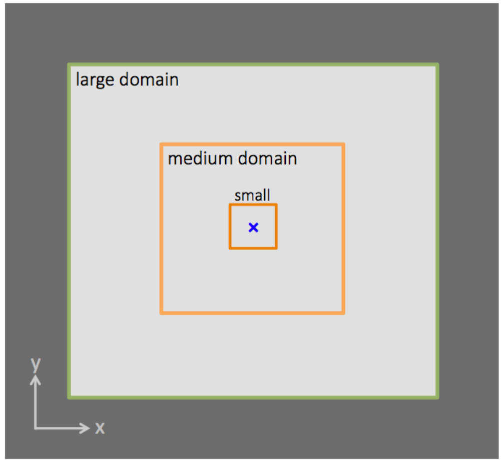


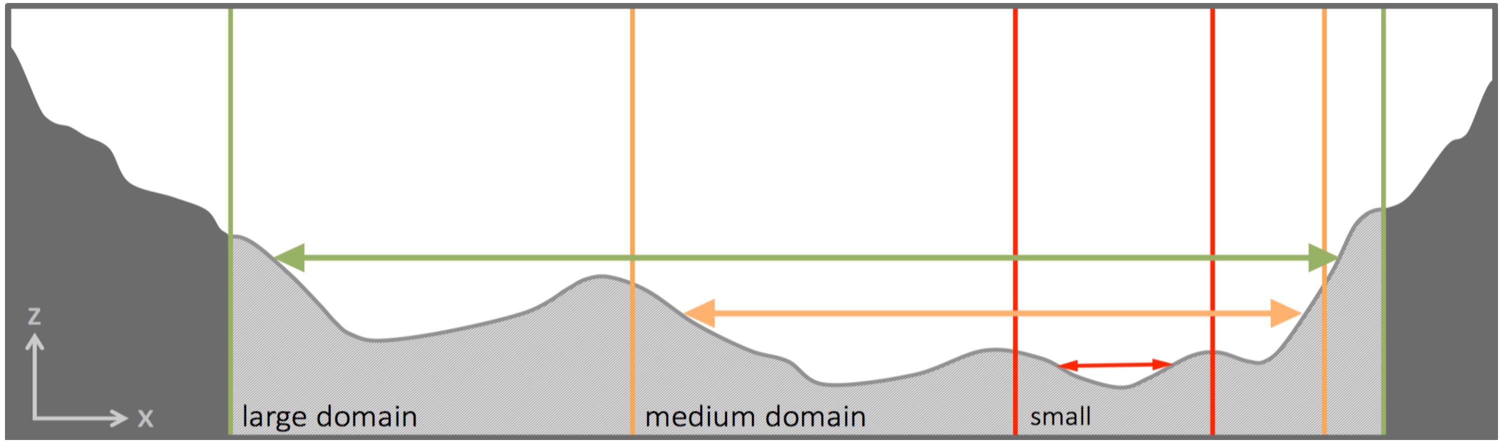
S-function (Ginoux et al. 2001) masked with low annual precipitation threshold - proved to correspond well with satellite data

G-SDS-SBM: SOIL TEXTURE (3b)

Development of soil texture correction factor

The idea:
Results from different box sizes (large to small) can recognize different scales of topographical lows (large to small).

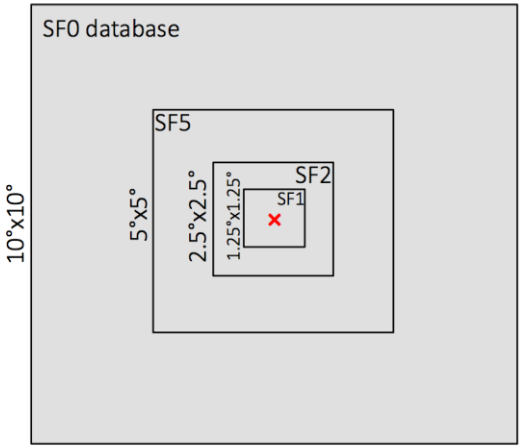




Chosen box sizes and resolution for calculation:

On global level ensemble of four S-function datasets are calculated on 1/120° (30 arcsec) resolution:

- SF0 (box = 10°x10°)
- SF5 (box = 5°x5°)
- SF2 (box = 2.5°x2.5°)
- SF1 (box = 1.25°x1.25°)



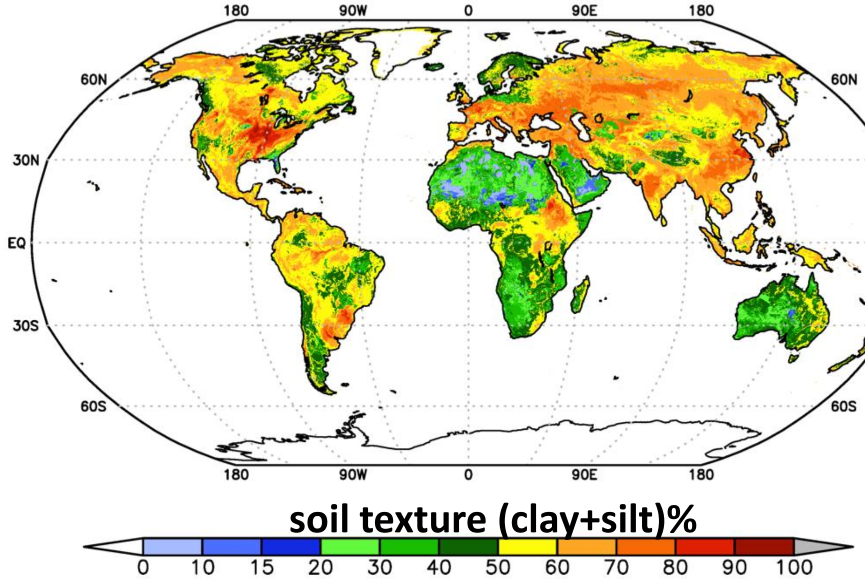
Adopted S-function value:
Average of 4 values is used as final S-function value, which is used for definition of correction factor:
$SF = (SF0+SF5+SF2+SF1) / 4$

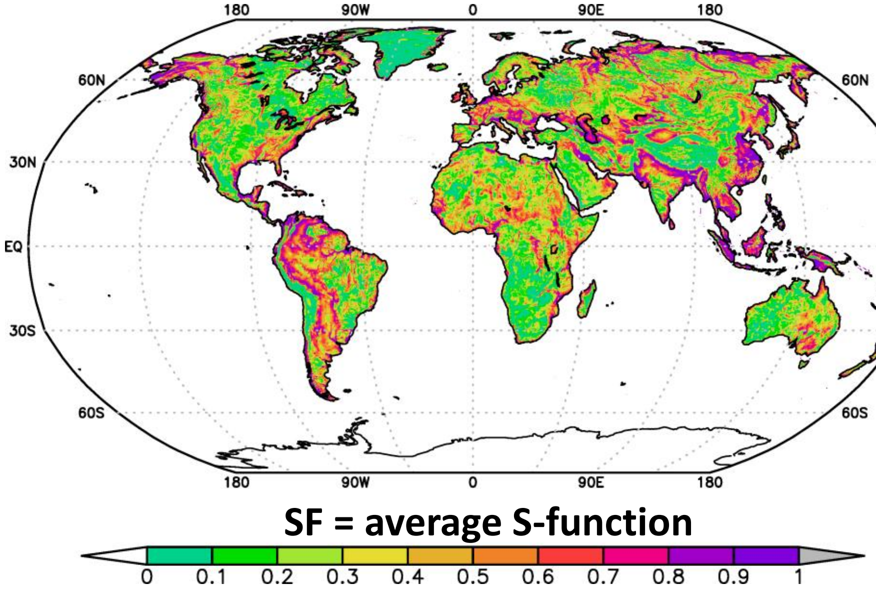
Correction factor:
assumption 1. $FP : FPTOT = FP_C : CSTOT_C$
assumption 2. $CSTOT_C = 0.5 (FPTOT + SF)$
$FP_C = FP \times 0.5 (1 + SF/FPTOT) = FP \times CF$

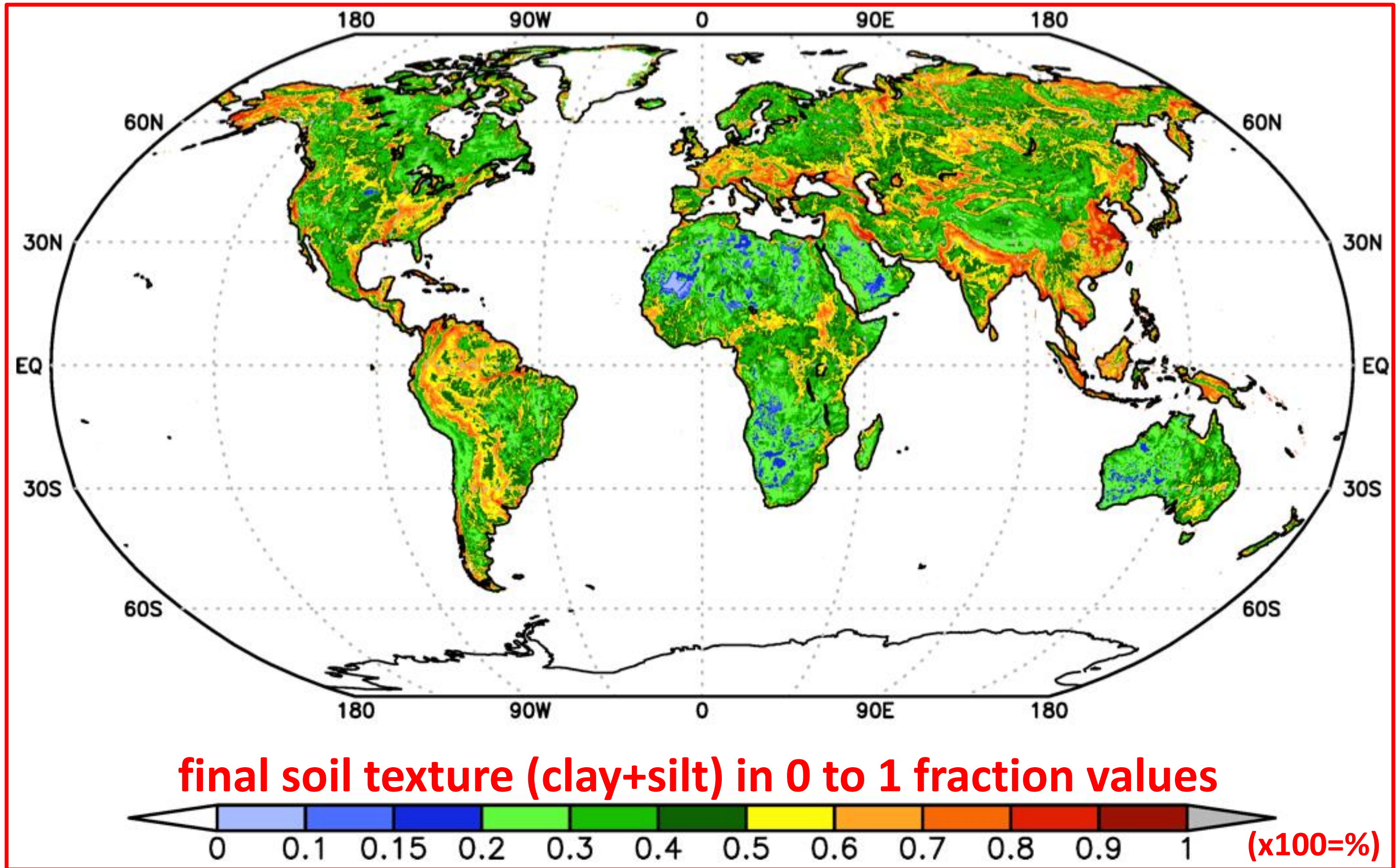
(FP is caly/silt content, FPTOT is clay+silt, index C is “corrected”)

G-SDS-SBM: SOIL TEXTURE (3c)

Corrected global soil texture database for SDS source mapping



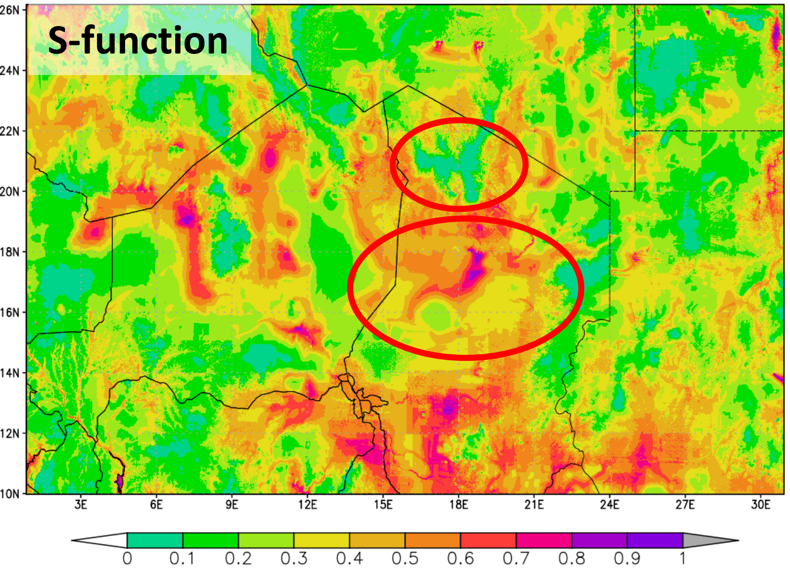


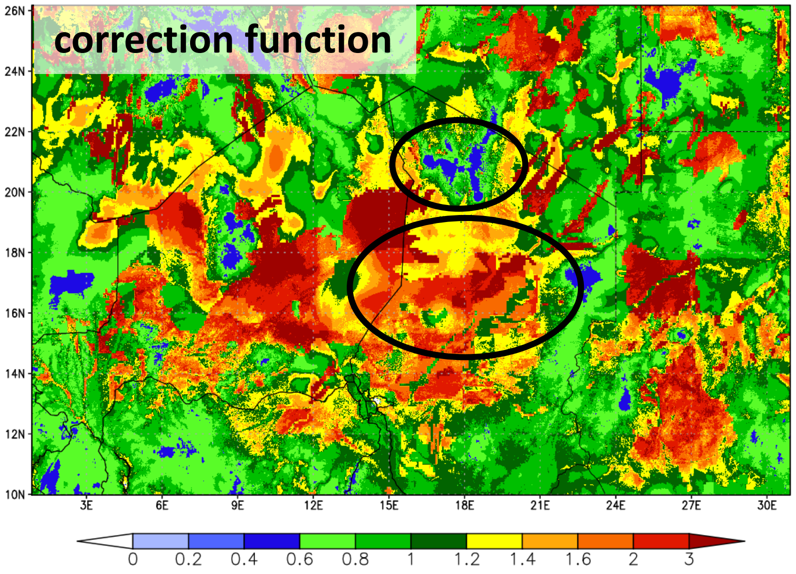


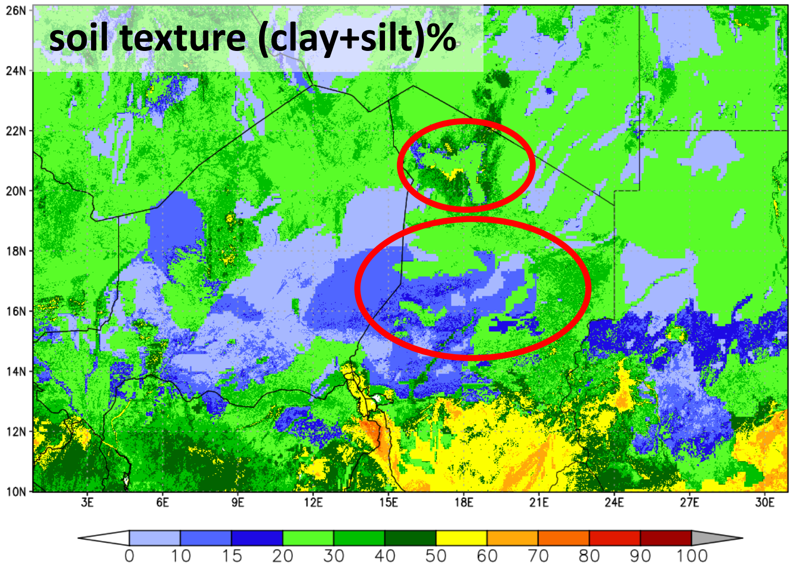
NOTE: soil texture data were missing in some areas of dried water bodies and melted glaciers, and were filled in with nearest value.

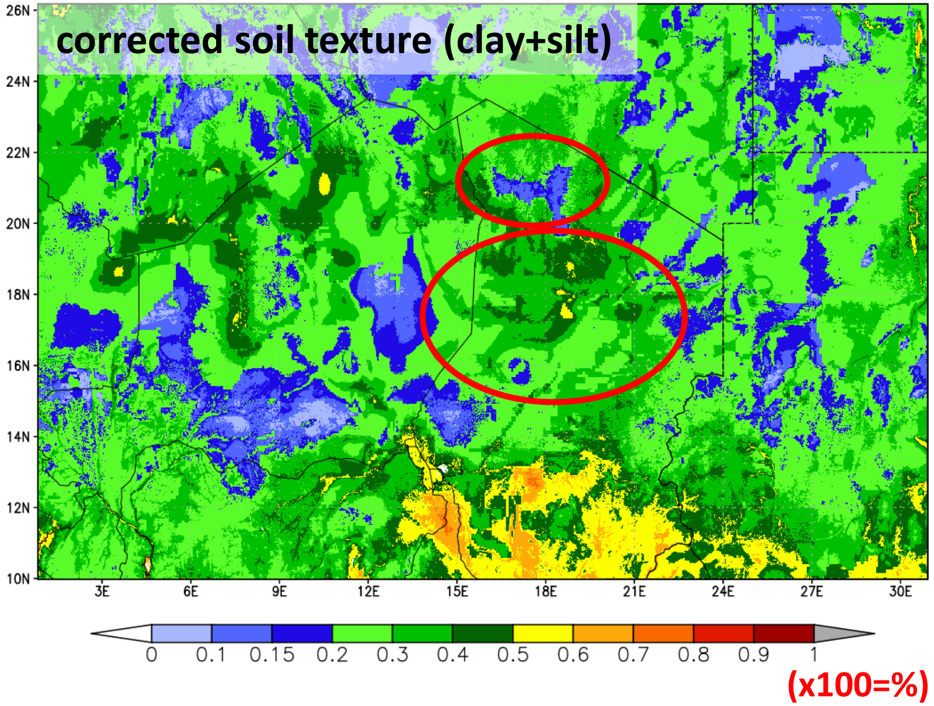
G-SDS-SBM: SOIL TEXTURE (3d)

Example for corrected global soil texture database for SDS source mapping: Bodele d.









G-SDS-SBM: SOIL MOISTURE AND TEMPERATURE

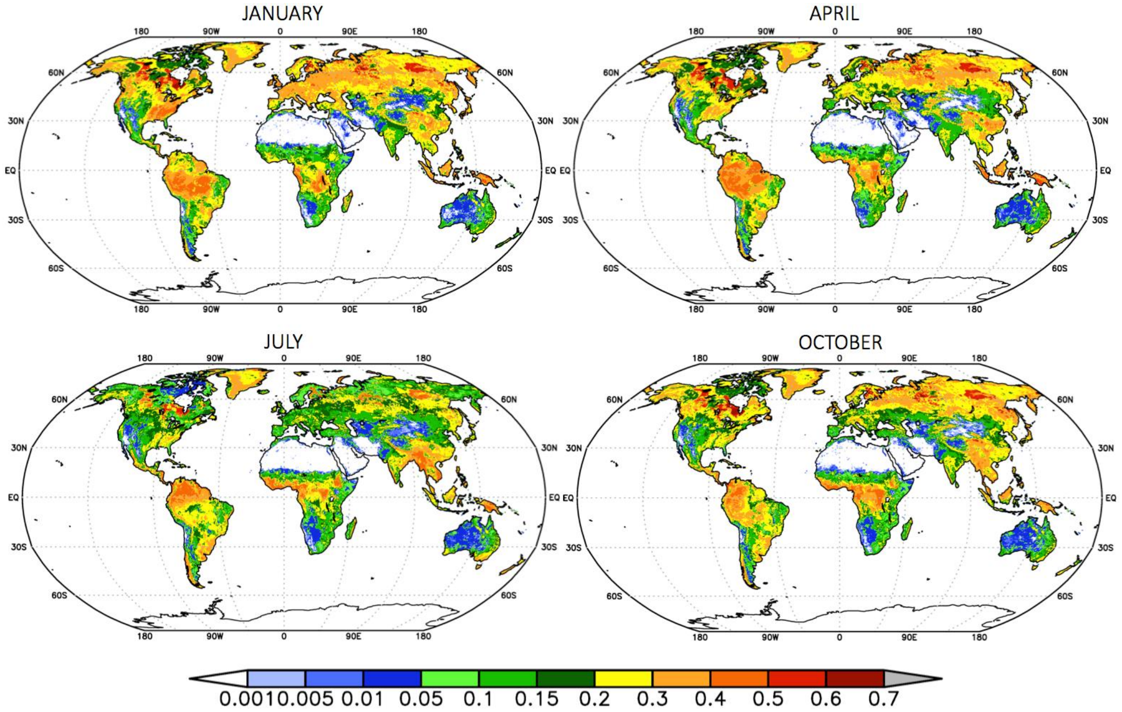
- ECMWF analysis on 0.25° resolution, for each day for 00 and 12 UTC for Jan., Apr., July and Oct. for the **period 2014-2018** for the top soil layer. Data were transformed to 30 arcsec resolution by assigning the “nearest point” value, meaning that in grid box 0.25^{o} x0.25^{o} data on 30 arcsec resolution have the same values as value representative for that grid box in original files.

Soil moisture data

For each month from this 5-years period is derived **minimum value**.

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.

Soil moisture is used to define SMF (soil mositure factor).

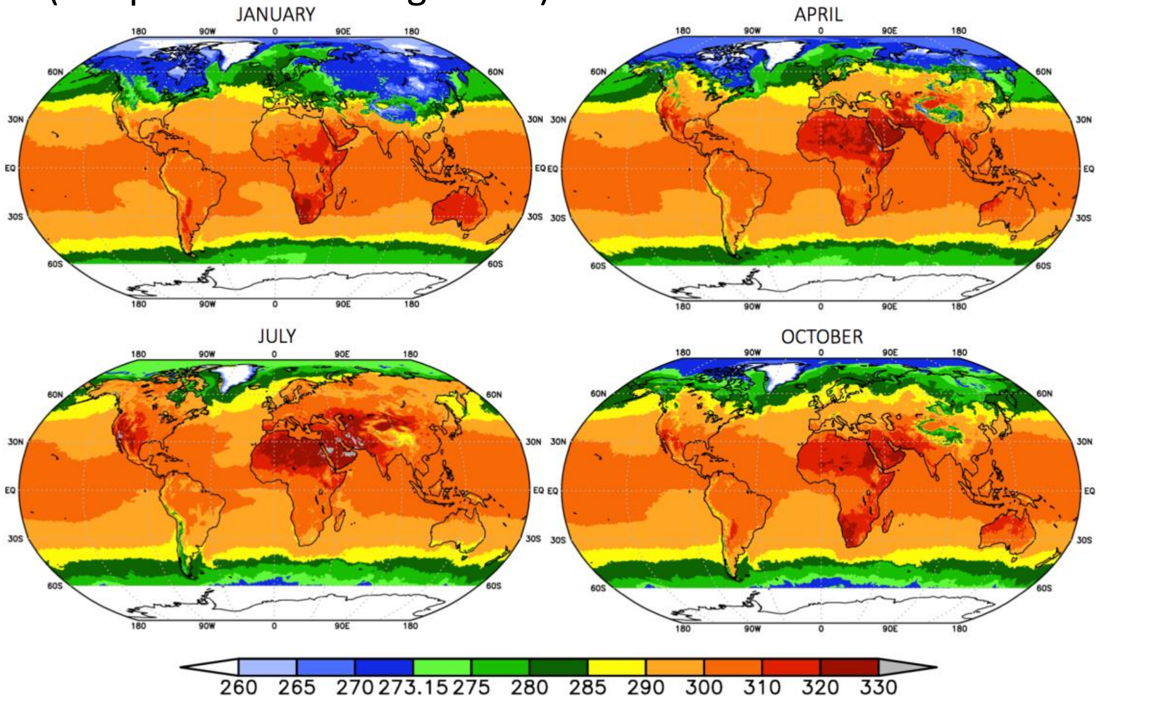


Soil temperature data

For each month from this 5-years period is derived **maximum value**.

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.

Soil temperature and moisture is used to define TFR (temperature freezing factor).

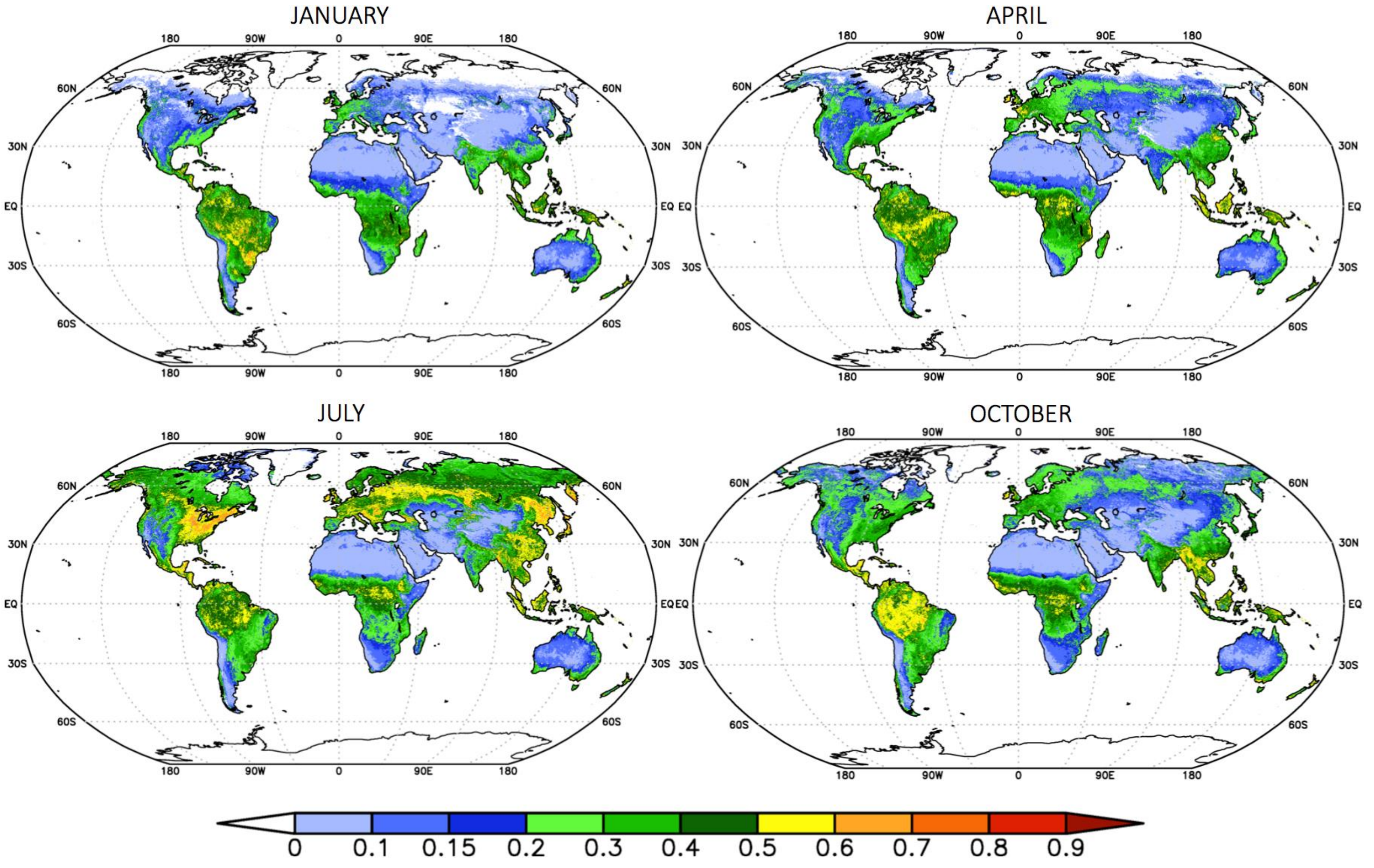


G-SDS-SBM: BARE LAND FRACTION (1)

MODIS EVI data

- MODIS EVI data are derived for months January, April, July and October for every year in the period **2014-2018**.
- Data are from MOD13A3 dataset on 1km resolution.
- For each month from this 5-years period is derived **minimum positive value**.
- **Bare land fraction is defined from EVI_{min} for each month.**

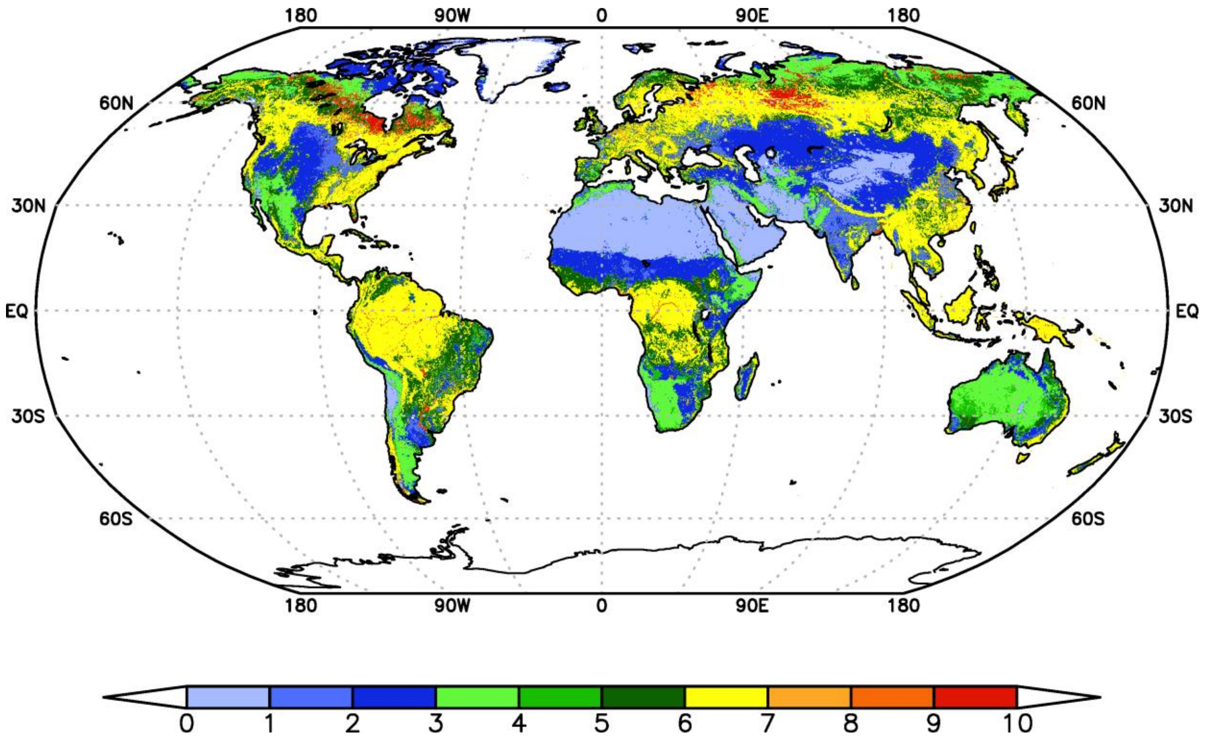
Using minimum positive value instead of average can represent **maximum possible bare land fraction for each grid point** that may happen in present and probably near future climate.



G-SDS-SBM: BARE LAND FRACTION (2)

MODIS land cover data

- MODIS land cover data product MCD12Q1 Version 6, variable LC-Type1 – IGBP classification
- Annual dataset on 1km resolution; was not available until 2018; used data for 2012-2016 (maximum extension of 1-4 types).
- Used for recognition of type of sources and to support EVI parameterization of bare land fraction



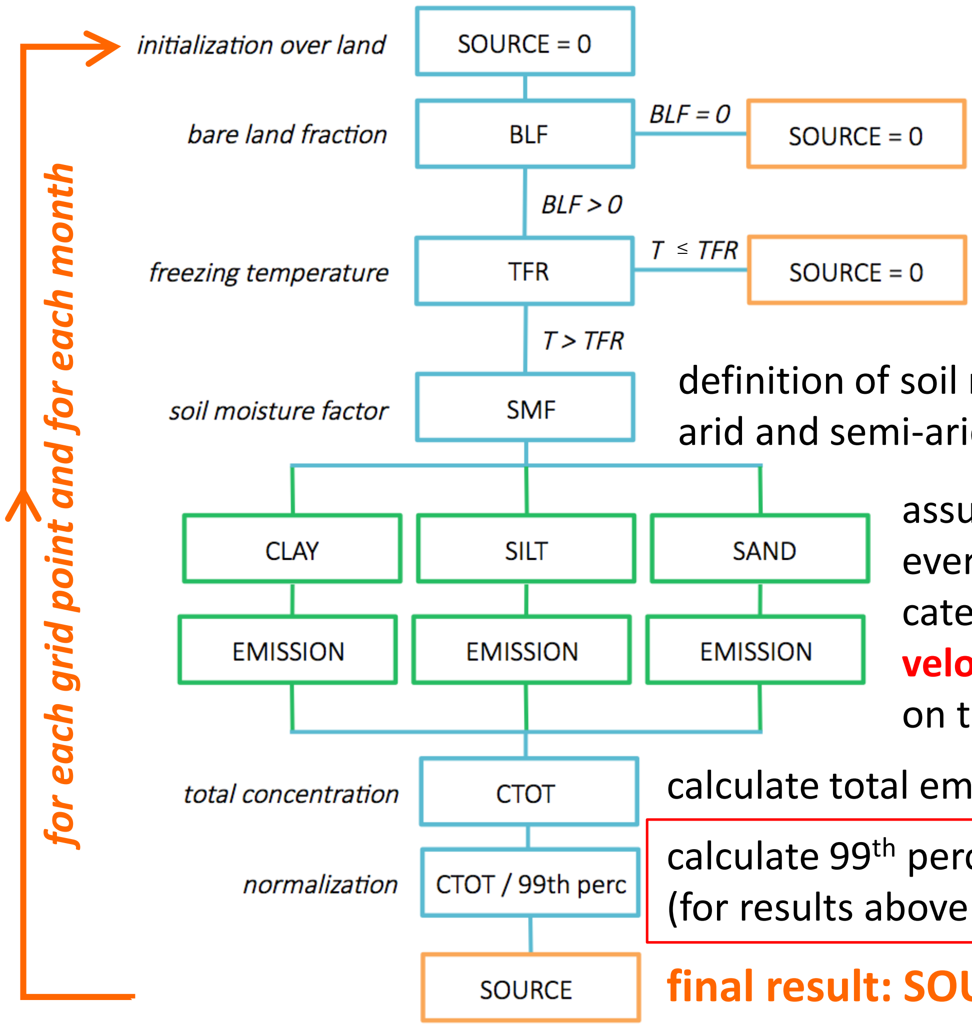
MODIS land cover types, simplified map obtained from data 2012-2016:
1) barren or sparsely vegetated,
2) cropland and cropland / natural vegetation mosaic,
3) grasslands,
4) open shrublands,
5) closed shrublands, 6) woody savannas and savannas,
7) forests, 8) urban and built-up, 9) water, 10) permanent wetlands.

Land cover types 1) - 4) can be SDS productive.

MODIS data are used to determine BLF (bare land fraction).

G-SDS-SBM: ALGORITHM (1)

Calculation of SDS sources intensity: emission scheme applied



definition of bare land fraction (look at previous slide)

definition of soil freezing temperature depending on the soil moisture (look at net slide)

definition of soil moisture factor for emission reduction outside arid and semi-arid areas (look at next slide)

assumption: strong wind that can produce SDS can happen everywhere: run emission scheme for each particle size category (clay, silt, sand) **under assumption that friction velocity is 1m/s**, including impact of soil moisture depending on the clay content (Fecan et al. 1999) and SMF

calculate total emitted concentration (clay+silt+sand)

calculate 99th percentile of all values and scale with it (for results above 1 is assigned value 1)

final result: SOURCE = SDS source intensity

Sources with maximum value 1:

- *top 1% intensity of all global SDS sources.*

TXF (soil texture factor) is factor for contribution of particle categories:

- TXF=0.17 for clay
- TXF=1 for silt
- TXF=0.05 for sand

Emission function:

$$SC_i \sim SINF_i \times \left[1 - \left(\frac{U_{*t\,i}}{U_*}\right)^2\right] U_*^2$$

$SINF_i = BLF_i \, x \, TXE_i \, x \, SMF_i$

(Nickovic et al. 2001)

G-SDS-SBM: ALGORITHM (2)

Explanation of additional parameterizations in the emission scheme

BLF (bare land fraction):

If land cover type gives an information that surface is bare or sparsely vegetated (types 1-4), or it can be bare or sparsely vegetated in some seasons (seasonal and occasional SDS sources), excluding urban and build-up areas

➡ value of EVI over these regions provide further information about fraction of bare surface:

- lower threshold for EVI is set to 0.02, to exclude possible "false" signals from small positive values;
- from 0.02 to 0.03, BLF is linearly increasing to 100%, and stays 100% for all EVI values bellow or equal to 0.1; for EVI values from 0.1 to 0.15, BLF is decreasing from 100% to 0%;
- especially for "barren" land cover type, values of BLF are set to 100%, disregarding the EVI values.

TFR is T threshold, depends on soil moisture:

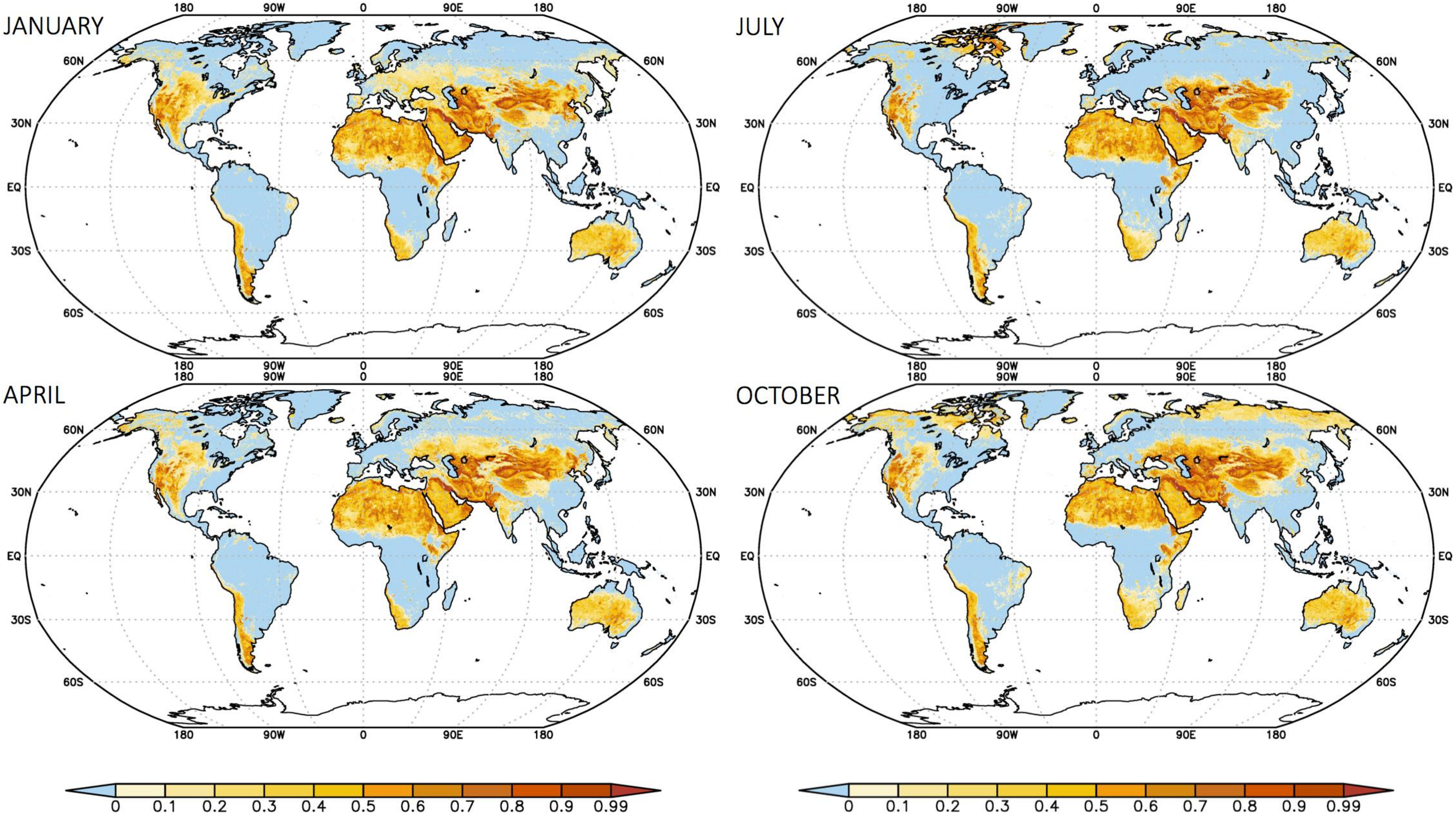
- If the soil is drier (less than 0.2) it is assumed that TRF is 260K:
- If soil moisture content is equal or above 0.2, TFR increases as SMC increases up to value 272K for SMC 0.4, which is near the maximum SMC for most of the soils.
- If input soil temperature is above determined threshold TFR, soil is not frozen and is possible to produce particles emission.
- If input soil temperature is equal or lower than TFR, soil particles emission is not possible.

SMF is the reducing factor for particles emission in case soil moisture content (SMC) is above 0.15:

- Soil moisture increase threshold friction velocity for emission (depending also on the clay content, Fecan et al. 1999) this parameterization is based on the observations for arid and semi-arid soils - for wetter soil surface additional reduction factor needed.
- SMF includes additional restriction on emission: if the SMC is higher than 0.15, SMF decreases from value 1 (100%), according to formulae 0.15/SMC, meaning that for wet soils it decreases up to third of efficiency compared to dry soils.
- No upper threshold for SMC for emission is defined, because in high wind conditions soil surface can dry fast and emit some particles.

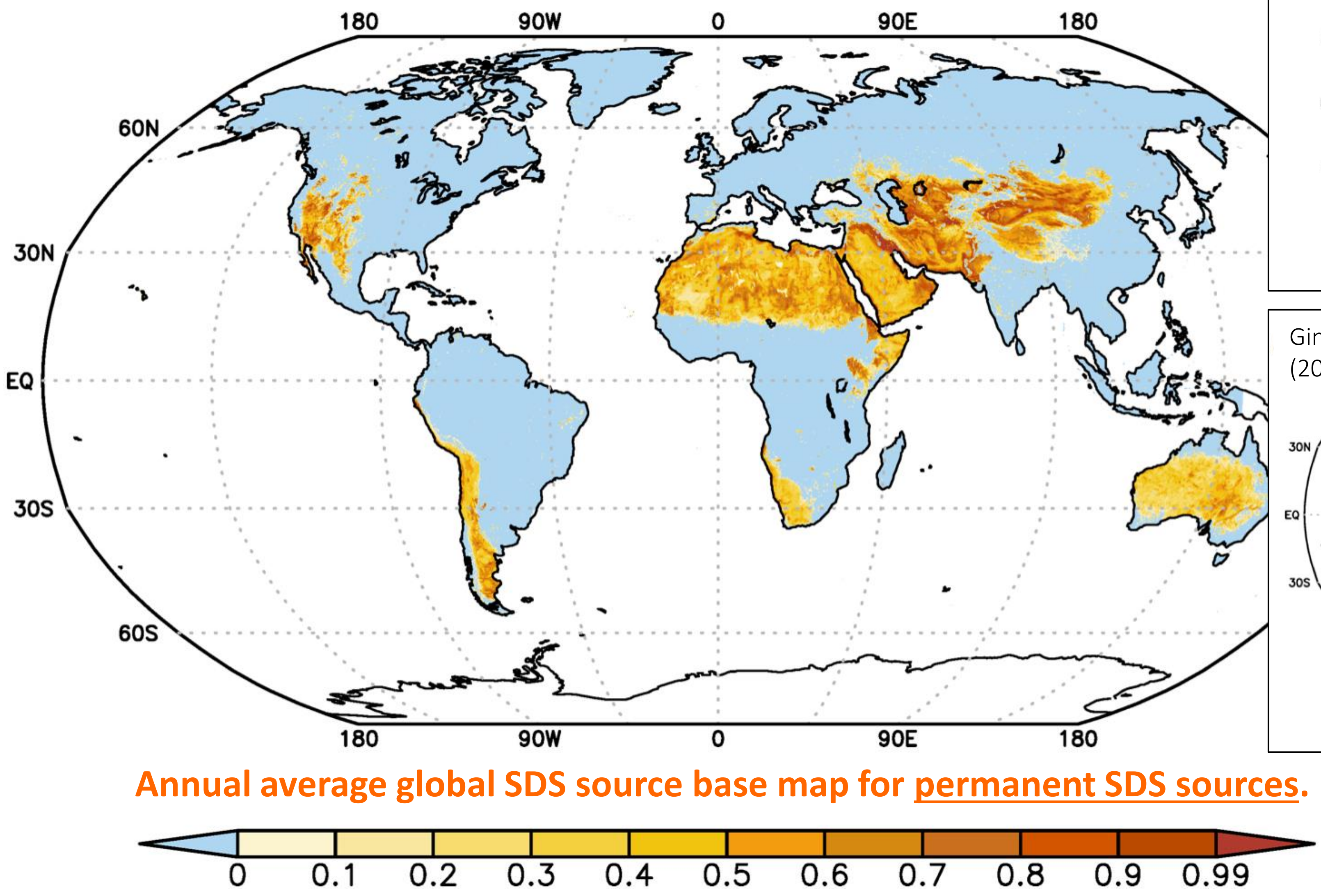
G-SDS-SBM: RESULTS (1)

G-SDS-SBM: MONTHLY

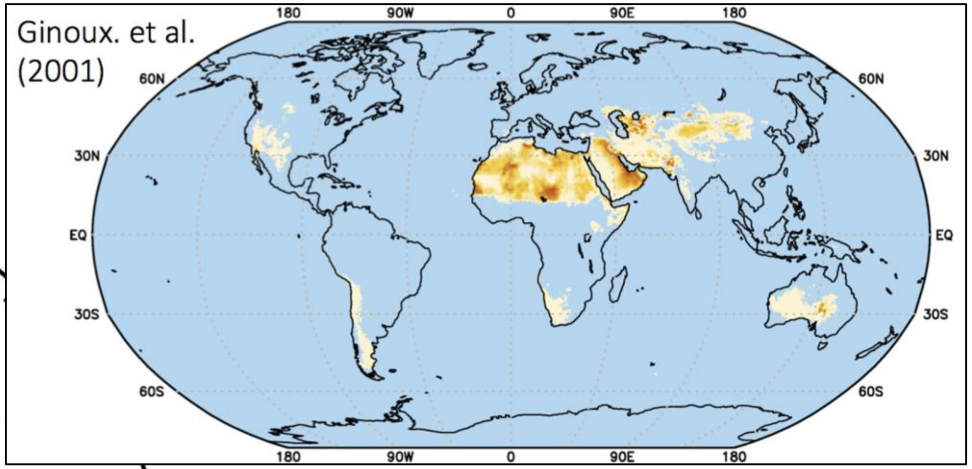


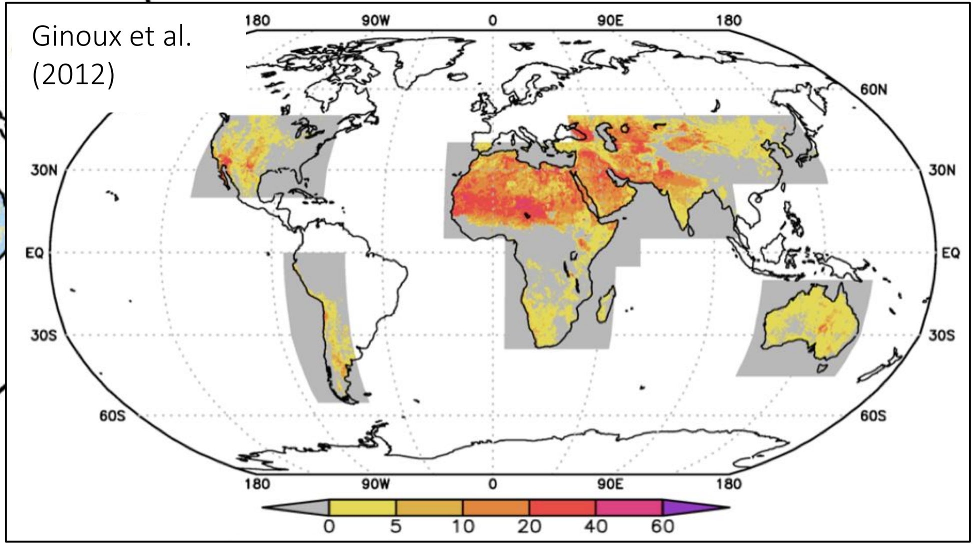
G-SDS-SBM: RESULTS (2)

G-SDS-SBM: ANNUAL



Annual average global SDS source base map for permanent SDS sources.

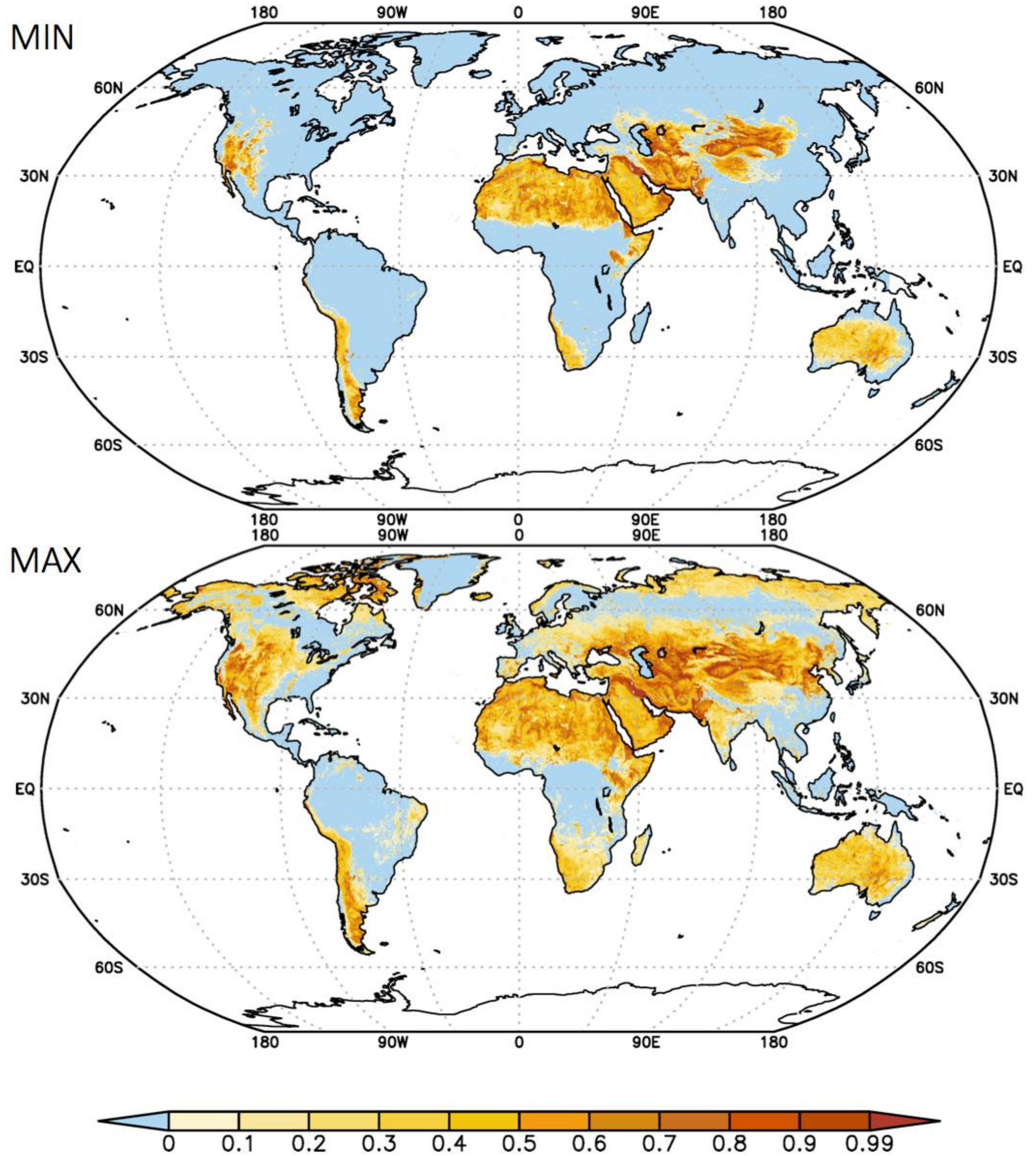




Permanent sources are considered here as sources that have intensity value above 0 in all months.

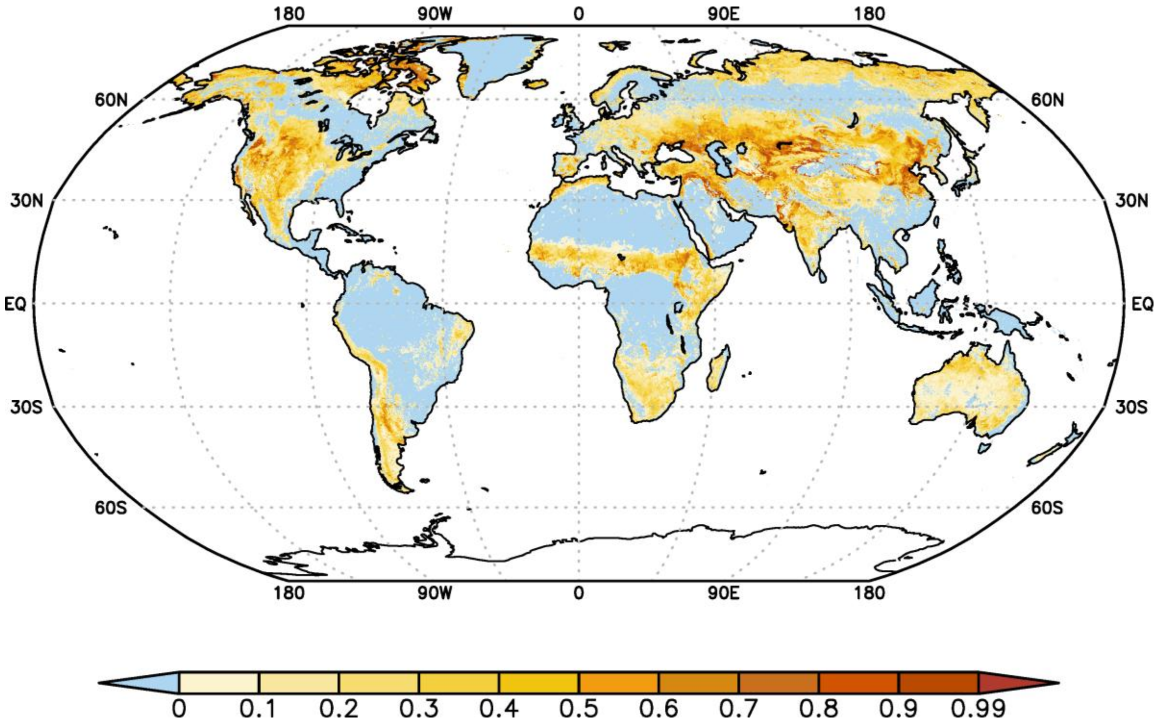
G-SDS-SBM: RESULTS (3)

G-SDS-SBM: MAXIMUM AND MINIMUM



G-SDS-SBM: DYNAMICAL

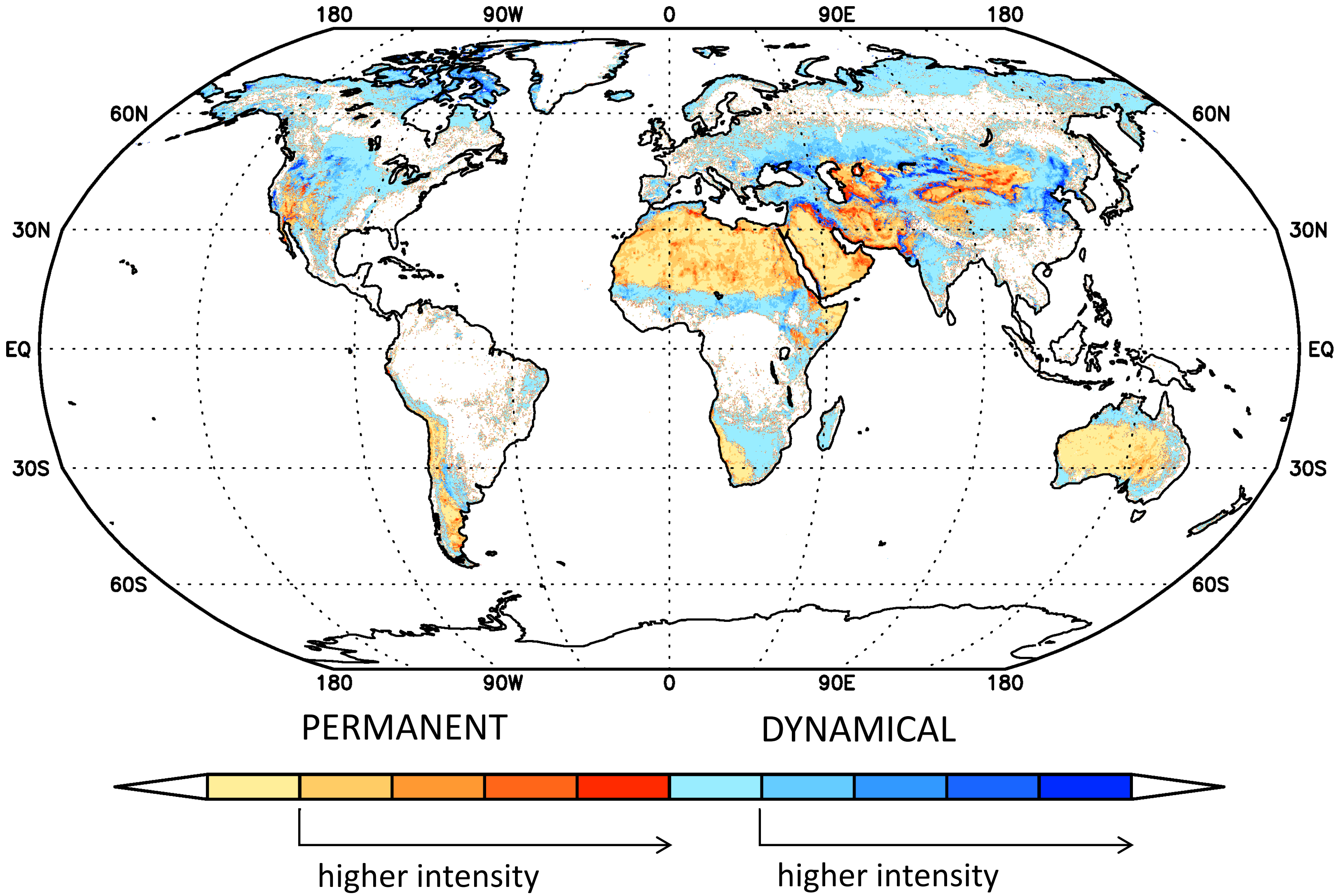
Difference of maximum and minimum SDS source intensity values **shows <u>dynamical component of sources intensity</u> – change intensity during the year.**
Sources that appear/disappear during the year: **seasonal and occasional** (occasional appear during favorable extreme weather conditions).



G-SDS-SBM: RESULTS (4)

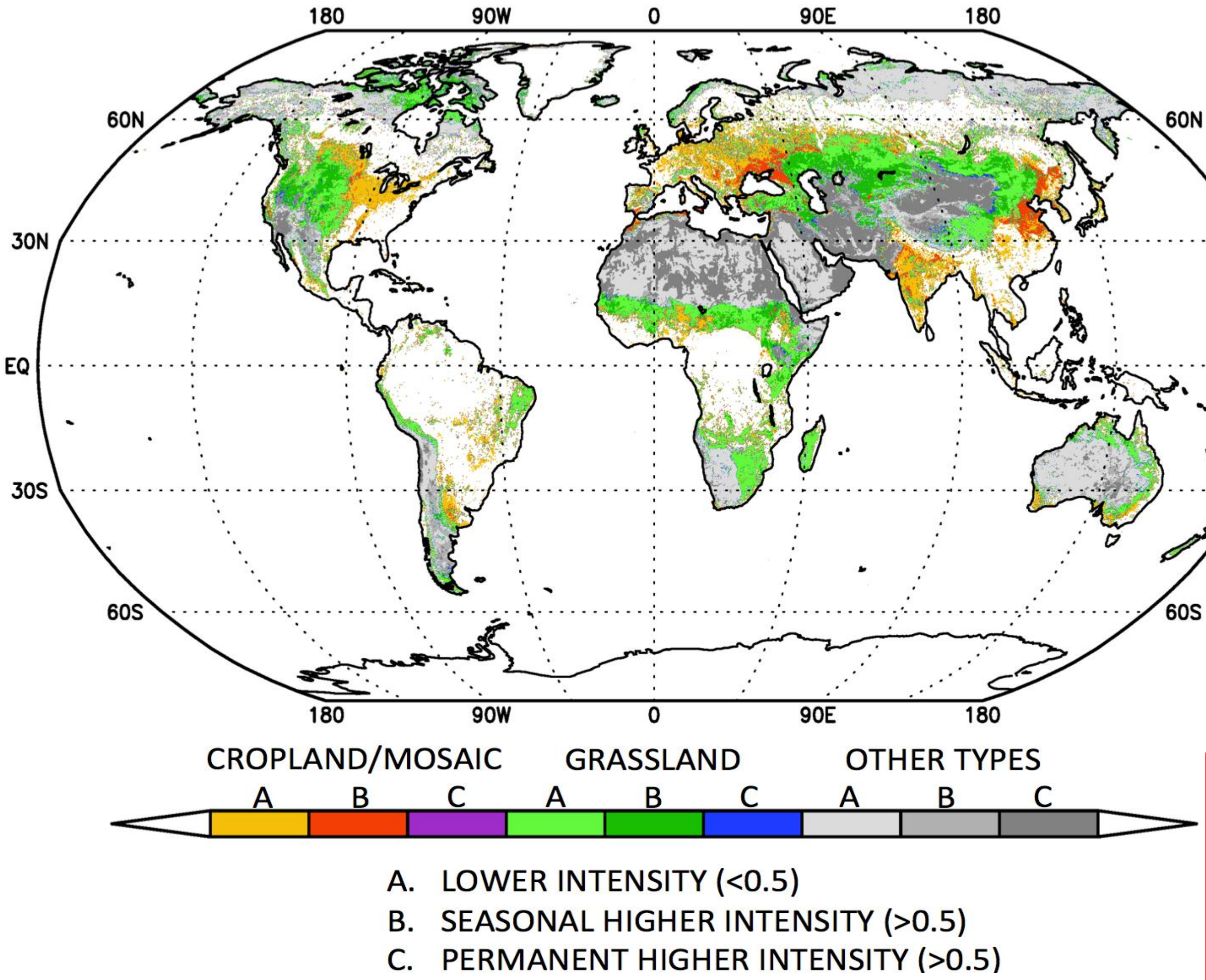
G-SDS-SBM: SIMPLE VIEW (a)

Distinguished permanent and seasonal/occasional sources,
with focus on sources with higher SDS source intensity (higher than 0.5).



G-SDS-SBM: RESULTS (5)

G-SDS-SBM: SIMPLE MAP

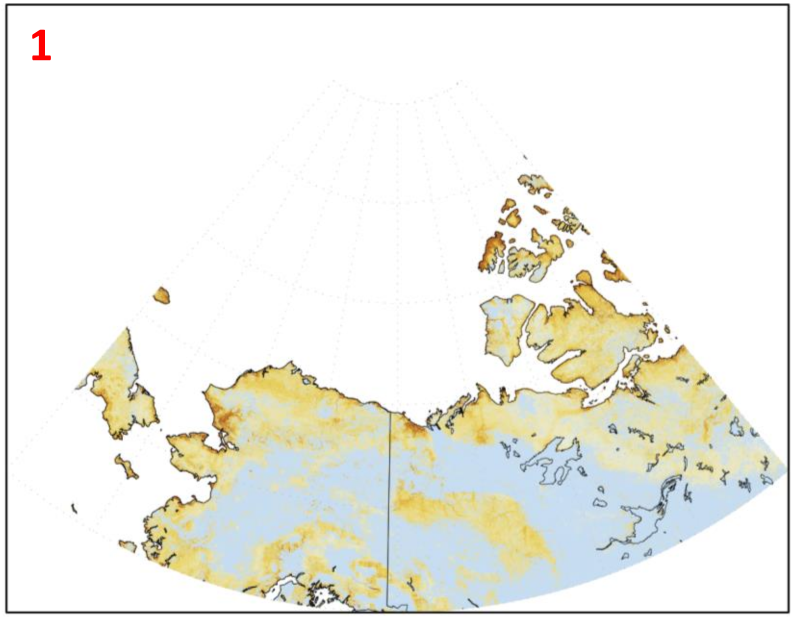


SIMPLE map:

- simple representation od SDS sources intensity (divided in 2 types: lower and higher intensity)
- <u>distinguish permanent intensity sources and seasonal/occasional SDS sources</u>
- show type of sources (<u>cropland, grassland and other</u> barren of sparsely vegetated surfaces)
- **First guess where degradation is possible because of negative human impacts**

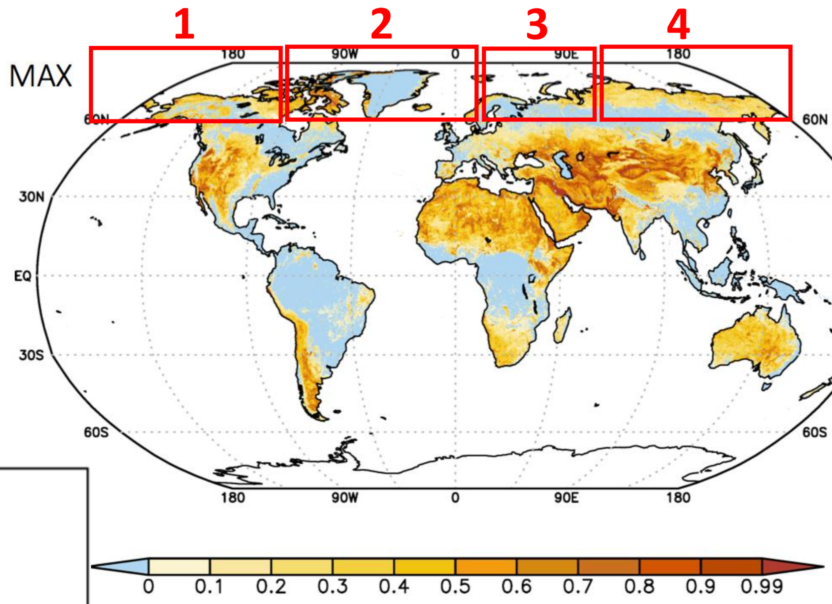
"Permanent" here means as sources with constant intensity. "Seasonal" includes seasonal and occasional sources.

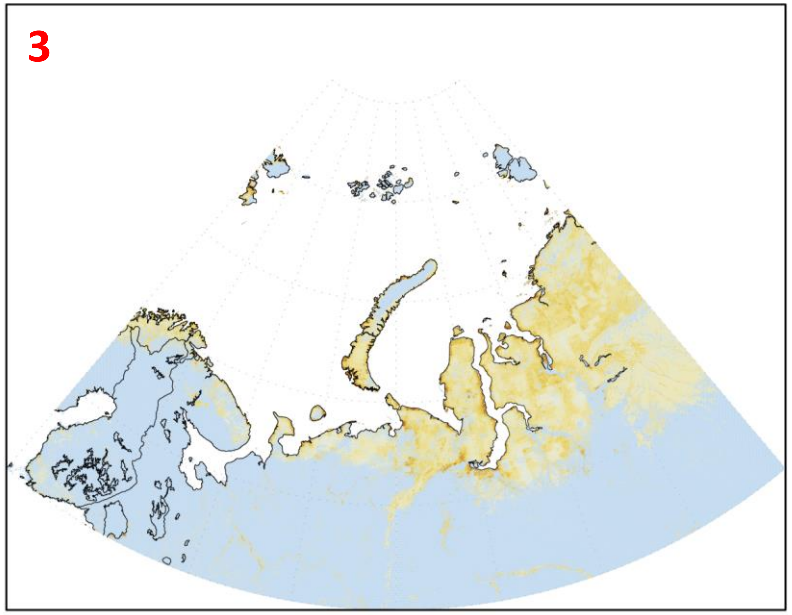
G-SDS-SBM: RESULTS (6)

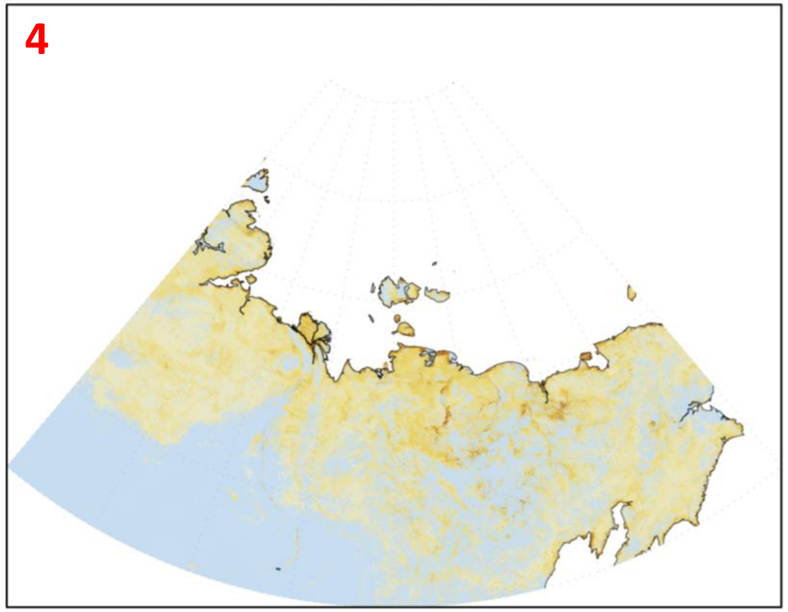


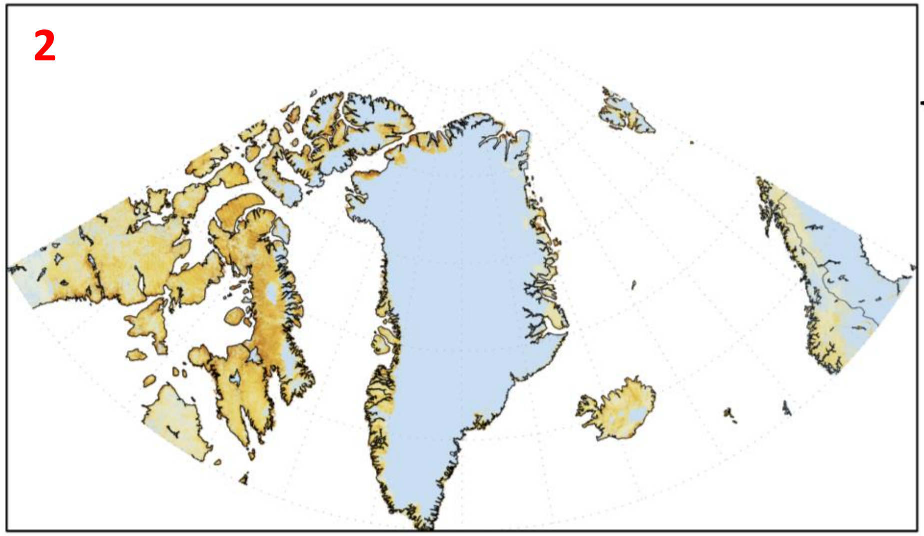
G-SDS-SBM: HIGH-LATITUDE SOURCES

latitude > 60°N









These sources mainly appear seasonally or during extreme weather (heat waves, drought).

G-SDS-SBM: ADDITIONAL NOTES

- **Quality of global SDS source base map** depends on quality and availability of global input data and current knowledge that provided parameterizations used in algorithm
- **G-SDS-SBM includes climate change impact:** methodology enabled recognition of soil surfaces that may have capacity to act as SDS sources under extreme weather conditions, which are increasing in climate changing world
- Largest **uncertainty in results** if for SDS sources with low intensity
- **Spatial inconsistency of data** appears because of resolution of input data and numerical approaches
- For SDS source **risk assessment** is needed to include information on exposure of population downwind of SDS sources, negative human impacts, etc.
- **Improve on nation level:** using national data and information, including additional observations and field studies, and high resolution coupled atmospheric-SDS modeling is possible to derive more accurate SDS sources map, assessment of their frequency of activation and impact area.

Use of the G-SDS-SBM approach in numerical dust transport modeling:

- Dust source map is not fixed information, nor it is fixed on seasonal or monthly level.
- Infromation on BLF needs to be updated monthly.
- Information on soil temperature and moisture regurarly updated from the atmospheric part of the model.
- Only fixed infromation is on soil texture.