**Atmospheric
Chemistry
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Discussions**

Technical Note: Minerals in dust productive soils – impacts and global distribution

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Abstract

Dust storms and associated mineral aerosol transport are mainly driven by meso and synoptic scale atmospheric processes. It is therefore essential that the dust aerosol process and background atmospheric conditions that drive the dust emission and at-

5 mospheric transport be represented with sufficiently well resolved spatial and temporal features. Effects of airborne dust interactions with the environment are determent by the mineral composition of dust particles. Fractions of various minerals in the aerosol are determined by the mineral composition of arid soils, therefore high-resolution specification of mineral and physical properties of dust sources is needed as well.

10 Most current dust atmospheric models simulate/predict the evolution of dust concentration but in most cases they do not consider fractions of minerals in dust. Accumulated knowledge on impacts of mineral composition in dust on weather and climate processes emphasizes the importance of considering minerals in modelling systems. Following such needs, in this study we developed a global dataset on mineral compo-

15 sition of potentially dust productive soils. In our study (a) we mapped mineral data into a high-resolution 30-s grid, (b) we included mineral carrying soil types in dust productive regions that were not considered in previous studies, and (c) included phosphorus having in mind their importance for terrestrial and marine nutrition processes.

1 Introduction

20 Mineral dust is recognized as one of the most abundant aerosols globally (Duce, 1995). While being transported in the atmosphere, dust modifies the Earth's radiation budget. It influences cloud properties and consequently changes atmospheric stability and circulation (e.g. Todd et al., 2007; Hoose et al., 2008). These feedbacks between dust and the atmosphere, if included in numerical atmospheric models could further im-

25 prove weather forecasts and climate simulations (e.g. Nickovic, 2002, 2004; Perez et al., 2006).

From 1990s when a novel concept of incorporating dust concentrations online in atmospheric models was first introduced (Nickovic, 1996; Nickovic and Dobricic, 1996), there was significant improvement in modelling the process of atmospheric mineral aerosol. Most of such models are designed to simulate/predict the time evolution of the dust concentration but do not consider its mineral fractions. Only, some global dust models have included simulation of mineral composition in dust aerosol (Fung et al, 2000; Luo et al., 2005; Hoose et al., 2008) following increased interest of the scientific community to study impacts of minerals upon climate and environment.

In spite of the progress achieved over the last two decades, there are still large uncertainties in dust modelling. Results of different regional models are compared for several days dust event in Bodélé depression region (Todd et al., 2008). A similar study is performed over East Asia (Uno et al., 2006). The degree of uncertainty of dust models is about one order of magnitude for short periods of simulation. Long-term mean global dust emission is less different between the models (Zender et al., 2004), because model over and underestimations over different regions may more or less cancel out. Results of a broad intercomparison of 15 global aerosol models can be found in Huneeus et al. (2011). The identified uncertainties would certainly influence the accuracy of the dust mineral composition as well, if it is incorporated in dust models.

Increasing resolution of atmospheric dust models should, among others, reduce errors of numerical simulations. There are several components of the atmospheric dust process characterized by small-scale nature. Dust emission, as one of them, is related to topographic depressions (Prospero et al., 2002; Ginoux et al., 2001). Engelstaedter and Washington (2007) identified more than hundred dust hotspots at global scale with high annual correlation with gustiness, measure of magnitude of short-lived high wind events that require high resolution model simulation to be properly reproduced. Going further on local scales complexity of sources increases. Dust storms can begin as a process composed of numerous dust plumes emitted from individual point-like sources, spread and merge into a wide dust veil (Lee et al., 2009). Also, dust sources can be only a small fraction of the larger region because most of the region did not experience

erosion. Dust transport driven by a low level wind jet (e.g. Knippertz and Todd, 2007; Washington et al., 2006a, b; Bouet et al., 2007) is another mesoscale process. Furthermore, mineral fractions in dust critically depend on size of dust particles emitted into the atmosphere. For studying long-range transport of dust and minerals embed-
⁵ ded in it, this is sufficient to consider finer longer-life particles originating from clay and silt soils (e.g. Tegen and Lacis, 1996; Nickovic, 2004). Several dust models have been developed over regional domains using higher spatial resolutions (e.g. Nickovic, 2001; Grini et al., 2005; Tegen et al., 2006; Bouet et al., 2007; Washington et al., 2006a, b; Menut et al., 2007) in order to better represent smaller-scale features of the dust
¹⁰ process.

Simulation of mineral fractions in mesoscale dust atmospheric models requires specification of the geographic distribution of minerals in dust-productive soils with high-resolution (Nickovic and Barrie, 2009). In our study, we discuss in Sect. 2 the importance of minerals on different processes, including dust minerals interacting with
¹⁵ atmospheric processes, their role in the marine environment, and impacts of minerals on human health. Section 3 describes a new high-resolution gridded database for minerals in potentially dust productive soils developed to support numerical models simulating atmospheric transport of mineral components in dust. Following Claquin et al. (1999), we concentrate on soil populations of clay and silt and develop a Mineralog-
²⁰ ical Table (hereafter referred as MT) which establishes a correspondence between different dust-productive soil types following FAO74 classification, (FAO-UNESCO, 1974) with mineral fractions of quartz, feldspar, calcite, gypsum, illite, kaolinite, smectite and hematite. We extended MT of Claquin et al. (1999) with three new soil types, Yermosols, Haplic Yermosols and Xerosols, which contain considerable amounts of clay
²⁵ and silt populations in dust productive regions. We furthermore included phosphorus because of its important role in ocean primary production and land fertilization. We finally described in details steps implemented to develop the global database (entitled as GMINER 30) mapped into a 30 s resolution global grid.

2 Impacts of mineral aerosol

Composition of dust minerals affects various processes such as the atmospheric, ocean and terrestrial environments, as well as human health. Including mineral dust transport interacting with the atmosphere in numerical models can improve accuracy of
5 weather forecasts and climate simulations and can contribute to a better understanding of the environmental processes caused by mineral dust. We elaborate below several impacts of dust in which its mineral composition plays an important role.

2.1 Minerals and solar radiation

Mineral dust directly affects the atmospheric radiation (Sokolik and Toon, 1999), and
10 consequently the atmospheric dynamics (e.g. Nickovic, 2002, 2004; Perez et al., 2006; Helmert et al., 2007) by modifying the incoming solar radiation and the outgoing in-frared radiation. As shown in several case studies (e.g. Perez et al., 2006; Todd at al., 2007) the radiative response to high dust load leads to a reduction in surface daytime temperature maximum of several degrees.
15   Response of the solar radiation to dust depends on the dust mineral composition. Mineral composition substantially changes the amplitude of the dust radiative forcing in both solar and infrared spectra (Sokolik et al., 1998; Claquin et al., 1999). As far as radiative impacts caused by mineral composition, differences between the refractive indices of aluminosilicates (illite, kaolinite, smectite and feldspars) are not significant
20 when compared to their natural variability. Claquin et al. (1999) estimated a global distribution of single scattering albedo and ratio of visible to infrared ratio of extinction coefficients as a function of mineral composition, indicating importance of use of this information in atmospheric dust models to appropriately represent the atmospheric radiation balance.

2.2 Minerals and cloud ice nucleation

Dust aerosol affects climate and environment through its influence upon heterogeneous ice nucleation. For example, Klein et al. (2010) found that mineral dust is a dominant constituent in the ice nucleating process in in-situ measurements of aerosol and observed high correlation between observed ice nuclei numbers and simulated dust concentration originating from a major Saharan dust intrusion into Europe. In ice nucleation process, mineralogical structure of dust an plays important role. Clay minerals in dust are particularly efficient for ice nucleation processes shown in field and modelling studies (Chen et al., 1998; Pruppacher and Klett, 1977; Zimmermann et al., 2008, and references therein). Recent studies (e.g. Lohmann and Diehl, 2006; Hoose et al., 2008) parameterize cold cloud formation as a process in which ice nucleation depends on mineral composition in dust.

2.3 Minerals and ocean productivity

Minerals carried by dust particles and deposited over remote ocean regions after long-term atmospheric transport can represent important nutrients for the marine life. Iron, phosphorus and silicon embedded in dust are considered as major potential micronutrients for the ecosystems in remote oceans.

Singh et al. (2008) showed that in a number of major dust deposition episodes over the Arabian Sea, chlorophyll blooming was detected several days later. Cooling of the ocean surface is also noticed along with higher ocean wind speeds during dust events, which can lead to favorable conditions for blooming.

Deficiency of iron limits the primary marine productivity and can lead to high-nutrient low-chlorophyll marine conditions (e.g. Mahowald et al., 2009). Although the iron input to the ocean by rivers is large, it affects only biota of the coastal zones. On the other hand, deposition of mineral dust in remote oceans after a long-range transport is considered as an important probable source of iron in these regions. Mahowald et al. (2010) show that iron input to the ocean not only increase ocean productivity but

that this increase represents carbon-dioxide sink, which has a global worming offsetting effect. It is assumed that the availability of iron to the photosynthetic marine microorganisms depends on the iron aerosol solubility. Iron in desert soils is almost non-soluble but some cruse-based observations indicate that solubility increases during the aerosol transport (Baker and Jickells, 2006). Factors such as mineralogy of sources, atmospheric (photo-) chemical processing and particle size features are among the most frequently proposed hypotheses (Baker and Croot, 2008). Journet et al. (2008) indicated that iron solubility is linked with the mineralogical composition of aerosol. According to their study, the most bioavailable fraction of iron in dust are clay minerals containing relatively low iron content but more than 90 % of it in a soluble form, rather than the iron oxides (e.g. hematite) characterized by high iron content (50–80 %). The atmospheric processing of iron on its path from sources to remote oceans is however still poorly understood (Mahowald et al., 2009; Okin et al., 2011).

Phosphorus is another marine nutrient embedded in mineral dust that enters into the ocean through the atmospheric deposition. Although amounts received by deposition are much smaller than through river and marine upwelling inputs, this input still might be a significant source of phosphorus in oligotrophic parts of the ocean. Atmospheric phosphorus exists almost entirely in the form of aerosols due to low volatility of phosphorus compounds (Mahowald et al., 2005). Both iron and phosphorus inputs influence the nitrogen flux to the ocean. In the presence of sufficient amounts the growth of non-diazotrophic organisms might be stimulated (Okin et al., 2011).

Finally, dissolved silicon arriving into the ocean with dust, provides a major control on the growth of siliceous phytoplankton in the open sea regions. As in case of iron and phosphorus, the riverine input is the major source of silicon in the coastal zones, but the atmospheric deposition of silicon carried by soil dust is the most important supplier of this element in the remote sea (Tegen and Kohfeld, 2006).

2.4   Minerals and health

Airborne dust can significantly influence human health. Middleton et al. (2008) reported that there is increased number of patient hospitalizations during dust storm days in Cyprus. Liu et al. (2009) estimated impacts of inter-continental transport of aerosols on premature mortality and found that nearly 380 thousands premature deaths per year globally are associated with exposure to fine aerosols transported inter-continentally dominated with dust. Yoshida et al. (2008) found that inhaled desert dust causes adverse effects on mouse male reproductive function. They hypothesize that humans might experience similar effects.

Iron-catalyzed free radical generation is known to be an important factor enhancing acute lung inflammation (Prospero, 1999) and it is also a major carcinogenic factor (Fubini and Arean, 1999). In the lungs exposed to mineral aerosol, probability of oxidative damage is high because of the high oxygen concentration and the presence of catalytically active iron in atmospheric particulates. Iron in the lung can be used for microbial growth and replication, resulting in more virulent and persistent infections (Turi et al., 2004). The rate of the reaction between oxygen and the ferrous iron in the goethite mineral present in dust is particularly high (Schoonen et al., 2006).

Meningococcal (epidemic) meningitis in the Sahel, one of the most serious diseases in Africa, with high mortality rate, is highly correlated with dusty weather. How dust eventually triggers the meningitis epidemics yet remains unclear. Thompson et al. (2009) identified dust-related mechanisms as possible epidemic activators, including the impact of dust particles on the fluid dynamics of airborne transmission of the bacteria, the impact of dust on preceding viral infection, or the activation of the meningococcal bacteria through the high iron content of dust particles.

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3 Global distribution of minerals

Soil fractions that contain fine particles (silt and clay with particle size less then 0.002 mm and between 0.002 and 0.05 mm, respectively, according to USDA Soil Texture Classification system) are easily lifted from the Earth surface and then transported
5 downwind. During their residence in the atmosphere, wind-born dust can significantly influence the environment. Long range transport and deposition far from the source are driven by the atmospheric processes. Atmospheric-dust models do simulate such processes, but generally do not consider mineral composition in dust, mainly because of the lack of detailed information on geographic distribution of mineral fractions in dust
10 soil sources. Necessary condition for including mineral composition in models is to provide a gridded database of mineral composition in dust productive soils.

3.1 Dust productive soils

In order to identify FAO soils that are dust productive, we first identified which soil types occupy the majority of arid regions at the global scale. We spotted such regions us-
15 ing the following Olson land cover categories (Olson, 1994a, b) of the USGS global dataset: low sparse grassland (only considered in China and Mongolia), bare desert, semi desert, sand desert, semi desert shrubs and semi desert sage. Global distributions of these land cover types include all major dust productive areas (Engelstaedter and Washington, 2007).
20   Next step was to determine which FAO soil types are most representative in selected bare and arid regions. We remapped the FAO 2 min data (FAO-UNESCO, 1992) into the 30 s grid in order to use the same grid as the one of the USGS land cover. By overlapping these two matrixes, we obtained fractions of soil types in selected land cover categories, and most of the area, approximately 99 %, is dominated by soil types
25 presented in Fig. 1, where fractions of particular soils, range between 0.1 and 23 % of the total area. Soil types listed in Fig. 1 are assumed to be dust productive.

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3.2 Mapping mineral fractions

Following Claquin et al. (1999), we selected eight minerals, quartz, feldspars, illite, kaolinite, smectite, calcite, gypsum and hematite, for which their fractions will be specified for different soil types. We summarize below arguments used in Claquin et al. (1999) to select the eight minerals.

The clay phyllosilicates group (illite, kaolinite and smectite) represents the most abundant chemical weathering minerals in sedimentary rocks. Tectosilicates (quartz, feldspar), based on silicates, together with phyllosilicates, constitutes approximately 90 % of the Earth crust. Because of the aluminum presence in phyllosilicates and feldspars, these two groups absorb less infrared radiation than quartz. Finally, phyllosilicates in comparison with tectosilicates have larger surface-to-volume area and are therefore more chemically reactive.

Carbonates were considered in Claquin et al. (1999) because of their important role in direct and indirect effects to the solar radiation, Carbonates have a low infrared absorption between 8 and 12 μm; they are also highly soluble making the carbonates-carrying aerosol favourable to influence the precipitation acidity, to act as cloud condensation nuclei and therefore to contribute to indirect radiative effects.

Gypsum originates mainly from (paleo-) lacustrine sources and has moderate absorption in the infrared spectrum. The importance of lacustrine sources for dust emission was emphasised by Tegen et al. (2002) and in their study lacustrine sources are introduced as a separate soil texture class. For example, the Bodélé depression, one of the largest worldwide dust source is consists of fine lacustrine sediments deposited by paleo lake Chad in the Holocene.

Mineral fractions are distributed over clay and silt size populations as shown in Table 1. Note that calcite, quartz and hematite appear in both. Following proposal from Claquin et al. (1999) hematite and goethite are considered together with common name hematite. From Fig. 1 it is obvious that 24 soil types selected in Claquin et al. (1999) (marked in orange in Fig. 1) occupy the major part of potentially dust productive area;

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the three additional soil types appear with high percentage: Yermosols (10 %), Podzoluvisols (9 %), HaplicYermosols (5.5 %) as well.

In order to determine effective fractions of minerals in soils, percentages of clay and silt populations has to be specified. Since there is no such global data for specific soils, these fractions are evaluated using hybrid STATSGO-FAO soil map (US Department of Agriculture, 1994) available in a 30 s resolution for USDA 12 soil texture classes. Clay and silt percentages in soil texture classes are specified following Tegen at al. (2002) and Shirazi et al. (2001). Overlapping hybrid STATSGO-FAO and FAO data we calculated mean global values of clay and silt population for the soil types from Fig. 1. The results are shown in Fig. 2. Yermosols (Y) and HaplicYermosols (Yh) contain 12 % and 14 % of clay and 31 % and 32 % of silt, respectively. High content of silt and clay in these two soils qualify them to be included in further analysis. Podzoluvisols are considered as dust non-productive soils having relative low fractions in clay (5 %) and silt (10 %), and are therefore excluded from the further analysis.

The mineral composition for HaplicYermosols (Yh) is assumed to have the same mineral composition as Haplic Xerosols (Xh), following analogy proposed in Claquin et al. (1999), and mineral composition for Yermosols (Y) is assumed to be equal to the mean of fractions of the Y group, i.e. of Yk, Yh, Yl, Yy and Yt. Xerosols (X) occupy only 0.3 % of potentially dust productive area, (Northwest Africa and Central Asia), but have average of 19 (%) for clay and 40 (%) for silt population and could therefore influence the composition of mineral aerosol. We also added X with its mineral composition obtained as a mean of mineral content of other soils of the Xeroslols group (i.e. Xk, Xh, Xl, Xy) already present in Claquin et al. (1999). Global distribution of soil types introduced by Claquin et al. (1999) and additional three soil types, Y, Yh and X are presented in Fig. 3.

List of minerals in the MT is extended with phosphorus because of its importance for the primary marine food production. Atmospheric phosphorus exists almost entirely in the form of aerosols due to the low volatility of phosphorus compounds (Mahowald et al., 2005). Although only 10 % of phosphorus in mineral dust aerosol is bioavailable

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(Jickells and Spokes, 2001; Mahowald et al., 2005), it may play an important role in biological response of the marine ecosystem when dust is deposited into the ocean. Okin et al. (2004) linked phosphorus concentrations to the top 20 cm of 12 soil categories of the United States Department of Agriculture National Resource Conservation Service (USDA) soil taxonomy. To be consistent with the MT, we matched USDA soil orders and FAO soil classes that we assumed are potentially dust productive (Fig. 1) and we used information about typical bulk density of soils from Rawls (1983). Data about phosphorus content is available only for general soil classes and is not considered separately for clay and silt populations. We assumed that all soil types that belong to the same group have the same phosphorus content. Obtained the results are in given in percentages common for both clay and silt populations.

By compiling data from the steps described above, we present in Table 1 percentages of 9 minerals found in silt and clay population for 27 FAO soil types listed in the order of appearance in Fig. 1. Based on mineral fractions in Table 1, we create a global 30 s gridded dataset of mineral composition entitled GMINER 30. Data are organized in geographic sub-domains (tiles) as used for the USGS topography dataset (http://eros.usgs.gov/ecms/images/common/gtopo30/tiles.gif); in our study we use only tiles north of −60° S. In total, the database consists of 324 files (27 tiles × 12 minerals in silt and clay) and it is available on: http://www.seevccc.rs/GMINER30/.

For practical implementation of GMINER 30 data in an atmospheric-dust model, effective mineral fractions have to be specified by multiplying a fraction of particular mineral with its corresponding soil population fraction. In the example shown in Fig. 4 we calculated distribution of effective mineral contents using GMINER 30 fractions multiplied by clay/silt contents from hybrid STATSGO-FAO data set.

Silicates have the highest content if compared with the other considered minerals (Fig. 4a–e). Quartz content (Fig. 4a) is larger than 12 % over almost all the area where selected soil types are found (Fig. 2) with high contents (over 30 %) on every continent. Illite, kaolinite and smectite (Fig. 4b–d), which are present only in clay population, generally have concentrations up to 12 %. An exception is illite in Middle East where there

are values over 20 % and localized maximums over 25 %. Maximums of kaolinite and smectite concentrations are found over the same areas, i.e. in Eastern Africa, Western India and East Australia. Kaolinite reaches the maximum over 16 %, while the smectite maximum is over 28 %. Surface content of feldspar (Fig. 4e), is characterized by strong

5 gradients, especially in central Sahara, with maximum values over 16 % surrounded by areas with values lower than 2 %. Asia is the continent with highest feldspar content, with maximum between 24 and 28 %. Carbonate mineral calcite (Fig. 4f) is present in both, silt and clay population. Content is generally bellow 6 %. Higher values can be found in South Africa, Mediterranean coast of Africa, South Australia, Arabia and

10 Middle East. Iron oxides (Fig. 4g) content is lower in comparison with previously mentioned minerals, with the content bellow 3 % at global scale. Sulphate mineral gypsum (Fig. 4h) is present only in the silt population with amounts bellow 1 % almost in all areas of appearance. Smaller areas with maximum above 2 % are located in Africa, Arabia and Asia. Phosphorus (Fig. 4i) has much smaller amounts compared to other

15 presented minerals not exceeding 0.07 %.

Area covered in GMINER 30 and in Figs. 3 and 4 is not necessarily dust productive. Next step is mapping it with dust mask. Dust-atmospheric models use different approaches in mapping dust source regions. It is a common practice that first guess in defining dust productive areas is based on USGS Global Land Cover Data (Nickovic et

20 al., 2001; Walker et al., 2008). This usually implies a selection of land cover types that are barren and arid, and thus potentially dust productive. Another way is to assume that such regions coincide with arid regions receiving a long-term average of precipitation lower than a threshold (Claquin et al., 1999). Mask of dust productive areas can be further refined by defining dust preferential sources based on topographic features

25 of the terrain (Ginoux et al., 2001), hydrology model (Tegen et al., 2002), geomorphological features (Zender et al., 2003), different satellite observations (Prospero et al., 2002) and it can be also seasonally dependent (Tegen et al., 2002).

GMINER 30 provides information about mineral composition existing in the most of areas identified as dust productive identified by dust source mask definitions mentioned above. Choice of dust mask is not considered here since it is out of the scope of our study.

4   Summary and conclusions

There is increased attention of the scientific community on the issue of dust mineral composition interactions with the environment. Recent Joint Workshop of GESAMP and the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) on Modelling and Observing the Impacts of Dust Transport/Deposition on Marine Productivity (WMO, 2011) emphasized the importance of *"...use of high-resolution soil mineralogical maps for modelling dust production and simulating 3-D transport and transformation of different minerals as a result of atmospheric processing, including the process of Fe-solubility..."*. (http://www.wmo.int/pages/prog/arep/gaw/documents/ReportofThirdGESAMPWG38.pdf)

However, due to lack of sufficiently resolved information on mineral content in sources, current dust numerical models either poorly or not at all, simulate how mineral fractions evolve and transform during the atmospheric transport. The aim of our study was to improve this situation by providing information on geographic distribution of mineral content in arid soils well described at the global scale. For that purpose we developed a database of soil minerals mapped in a 30 s grid (GMINER 30). GMINER 30 is based on Mineral Table specified by Claquin et al. (1999), which we have upgraded by inclusion of three additional FAO soil types (Yermosols, HaplicYermosols and Xerosols) found to exist in major dust productive areas. We also supplemented the Table with phosphorus soil fraction due to its impacts on marine bioproductivity and land fertilization. When applied in atmospheric dust models, the information from GMINER 30 can be used to specify emissions of mineral fractions and should be limited only to grid points of a particular dust model declared as potentially dust-productive.

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In our study, we did not consider a group of soils and associated minerals typical for agricultural areas that could be significant seasonal source of dust. This will be a subject of future work, as well as a development of a dust atmospheric model with included simulation of mineral fractions.

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Table 1. Fractions of clay and silt minerals in selected soil types.

| FAO soil types in arid regions	Fractions of clay minerals normalized to 100 %						Fractions of silt minerals normalized to 100 %					clay & slit
	Illite	Kaolinite	Smectite	Calcite	Quartz	Fe-oxide	Feldspar	Gypsium	Calcite	Quartz	Fe-oxide	Phosphorus
Lithosols (I)	40	20	29	4	7	1	40	1	6	53	1	0.049
CalcicYermosols (Yk)	57	13	16	11	3	2	7	1	14	78	2	0.031
Yermosols (Y)	34	31	24	6	5	1	32	2	8	59	1	0.031
HaplicYermosols (Yh)	20	54	22	1	3	2	24	1	1	73	2	0.031
LuvicYermosols (Yl)	45	20	20	7	7	2	23	1	5	70	2	0.031
CalcicXerosols (Xk)	57	13	16	11	3	2	7	1	14	78	2	0.034
CalcaricRegosols (Rc)	42	39	9	4	7	3	19	1	3	75	3	0.049
CambicArenosols (Qc)	16	66	5	1	11	4	14	1	1	82	4	0.04
EutricRegosols (Re)	32	53	10	1	5	2	38	1	1	59	2	0.049
OthicSolonchaks (Zo)	31	6	46	11	7	1	43	6	22	31	1	0.034
GypsicYermosols (Yy)	27	18	40	8	7	0	26	6	16	57	0	0.031
LuvicXerosols (Xl)	45	20	20	7	7	2	23	1	5	70	2	0.034
FerralicArenosols (Qf)	23	48	23	1	5	1	15	1	1	84	1	0.04
HaplicXerosols (Xh)	20	54	22	1	3	2	24	1	1	73	2	0.034
Rock (RO)	50	9	26	1	14	1	6	1	1	92	1	–
CalcaricFluvisols (Jc)	22	9	46	11	12	0	39	2	30	31	0	0.03
LuvicArenosols (Ql)	10	78	3	1	9	3	22	1	1	70	5	0.04
Chromic Vertisols (Vc)	16	27	48	4	5	4	62	1	3	31	4	0.079
EutricFluvisols (Je)	18	23	55	1	3	1	10	1	2	86	1	0.03
Salt (SA)	39	4	26	29	1	1	1	26	93	5	1	–
TakyricYermosols (Yt)	21	51	21	3	5	1	80	1	4	16	1	0.031
OrthicSolonetz (So)	37	32	17	6	7	2	23	1	4	71	2	0.022
GleyicSolonchaks (Zg)	16	32	24	21	5	0	28	15	20	51	0	0.034
Xerosols (X)	37	26	24	7	5	2	20	2	9	70	2	0.031
GypsicXerosols (Xy)	27	18	40	8	7	0	26	6	16	57	0	0.034
TakyricSolonchaks (Zt)	25	33	24	10	6	0	66	1	12	22	0	0.034
AlbicArenoslos (Qa)	21	53	21	0	4	1	15	1	0	84	1	0.04
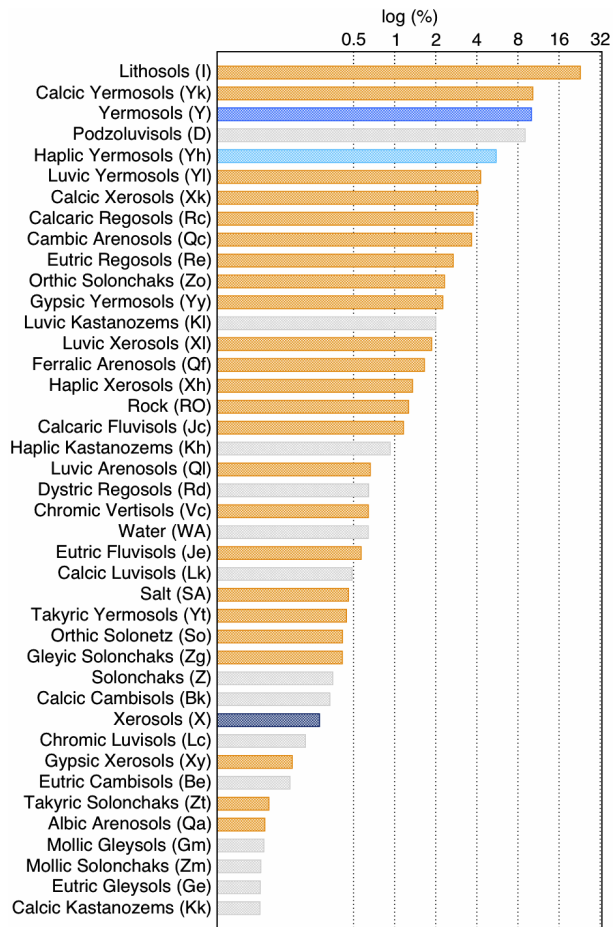
Fig. 1. Fractions of most frequent soil types that cover in total 99 % area of arid and bare regions on globe. In orange are soil types introduced in MT by Claquin et al. (1999), in blue new added soil types in MT, in grey soil types not included in MT.

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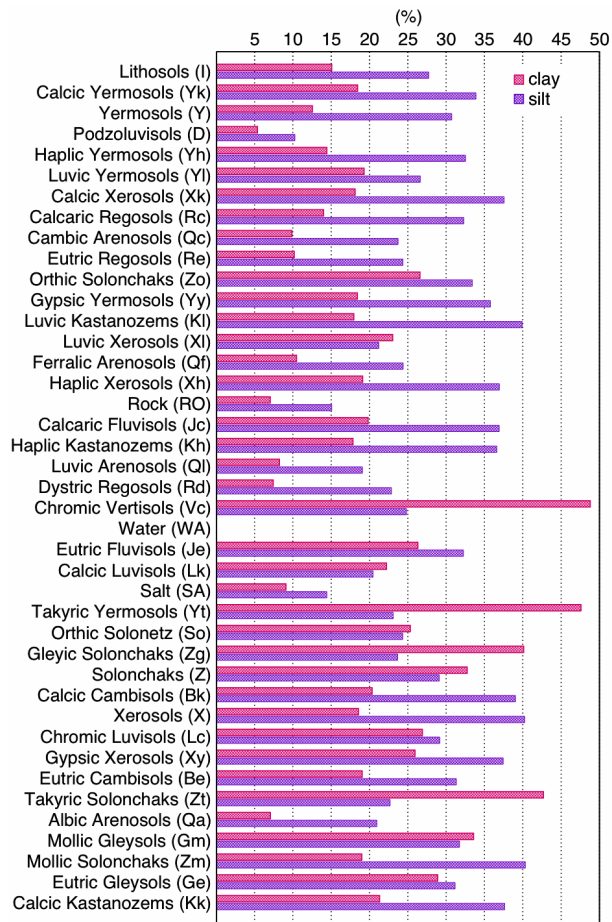Full Screen / Esc

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Fig. 2. Global mean fractions of clay and silt in soil types listed in Fig. 1.

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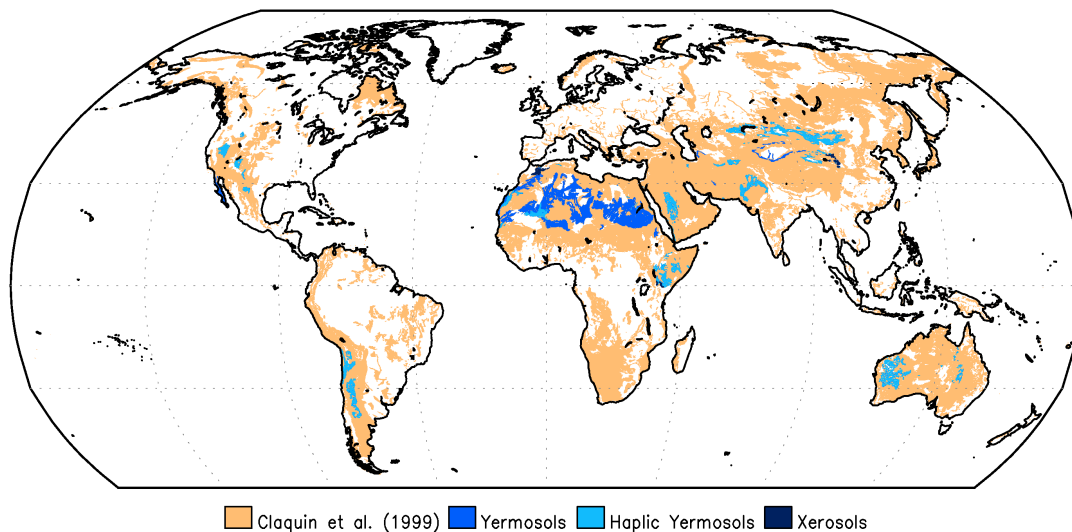
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Fig. 3. Global distribution of soil types selected by Claquin et al. (1999) with three new selected soil types, Yermosols, Haplic Yermosols and Xserosols.

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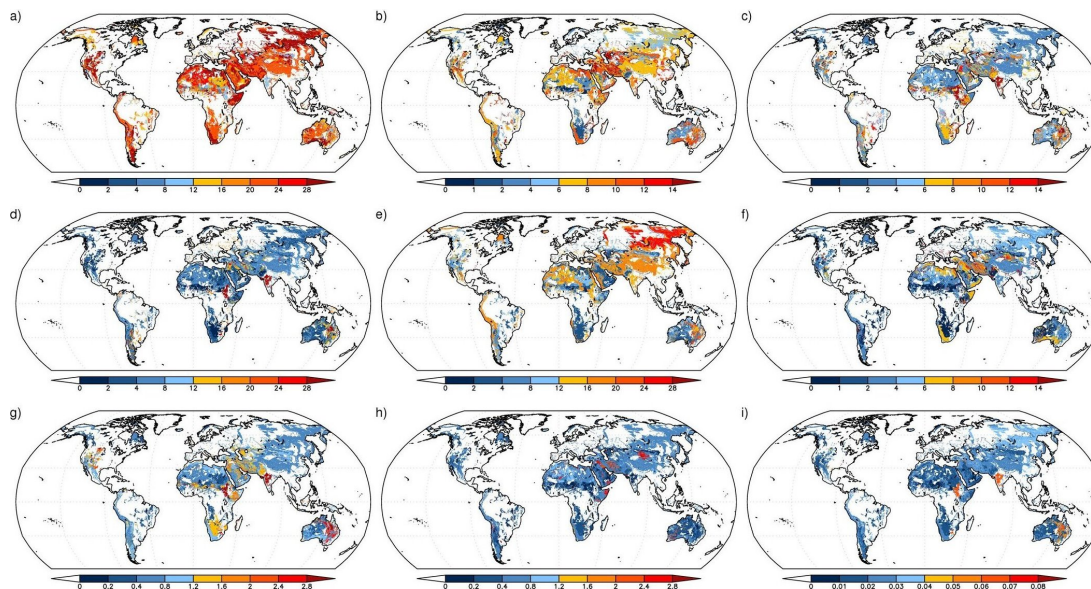Printer-friendly Version

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Fig. 4. Global distribution of effective minerals content in %, for **(a)** quartz, **(b)** illite, **(c)** kaolinite, **(d)** smectite, **(e)** feldspar, **(f)** calcite, **(g)** hematite, **(h)** gypsum and **(i)** phosphorus. For minerals that are present in both, clay and silt, values are summed.

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