The atmospheric iron cycle in EC-Earth

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I. Extended Abstract

The ocean is known to act as an atmospheric carbon dioxide (CO_2) sink. About a quarter of the CO_2 emitted to the atmosphere since the industrial revolution, has been captured by the ocean [1]. The capacity of the ocean to capture CO_2 highly depends on ocean productivity which relies upon bio-available iron (Fe) for photosynthesis, respiration and nitrogen fixation [2]. Fe is in fact considered to be the limiting nutrient in some remote regions of the ocean known as high-nutrient low-chlorophyll (HNLC) [3]. Understanding and constraining the bio-available iron supply to the ocean is thus fundamental to be able to project future climate.

Fe supply reaches the oceans mainly from rivers as suspended sediment. However, fluvial and glacial particulate Fe is restricted to near-coastal areas. Therefore, the dominant input of iron to open ocean surface is the deposition of atmospheric mineral dust emitted from arid and semiarid areas of the world. Another contributor to atmospheric Fe supply that is not always accounted for in models, is combustion, which main sources are anthropogenic combustion and biomass burning.

Just a fraction of the deposited Fe over ocean can be used by marine biota as nutrient (bio-available). The assumption that soluble Fe can be considered as bio-available will be used here [4]. Freshly emitted Fe-dust is known to be mainly insoluble. Observations, modelling and laboratory studies suggest that the solubility of Fe-dust increases downwind of the sources due to different processes [5] [6]. On the other hand, although the total burden of emitted combustion Fe is known to be smaller than Fe-dust, combustion Fe at emission may be more soluble [7].

The dust Fe content, speciation and ability to dissolve depends upon mineralogy. Earth System Models (ESMs) typically assume that dust aerosols have a globally uniform composition, neglecting the known local and regional variations in the mineralogical composition of the sources. In fact, dust aerosols are a mixture of different minerals, whose relative abundances, particle size distribution (PSD), shape, surface topography and mixing state influence their effect upon climate.

In this work we aim to improve our understanding of the atmospheric delivery of bio-available Fe to the ocean by implementing and constraining Fe emissions and a Fe solubilization atmospheric mechanism in a state-of-the art ESM, EC-Earth. EC-Earth is collaboratively developed by European research
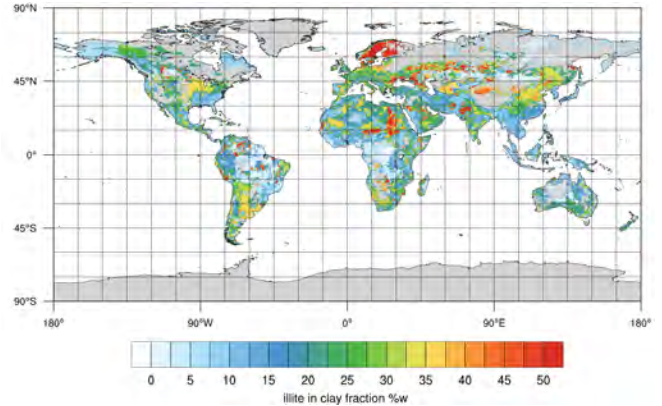

Fig. 1. Illite in clay fraction [%] in Claquin mineralogical dataset.

centers from 10 different countries including the Barcelona Supercomputing Center (BSC) [8]. All our developments will be implemented in the atmospheric chemistry module of EC-Earth: the Tracer Model 5 (TM5) [9].

A. Iron emissions

Relying on the hypothesis that both dust and combustion aerosols are the major sources of bio-available Fe deposited over open ocean surface, emissions coming from those sources need to be properly assessed in the model.

1) Fe-dust emissions: We will implement a soil mineralogical dataset (see Figure 1) [10] [11] and improve and apply an extended version of brittle fragmentation theory (BFT) [12] to represent the emitted PSD of each mineral in each grid cell of the model. Dust Fe content will be then calculated based on standard chemical formulas for each mineral [13] (Nickovic et al. (2013))

2) Fe-combustion emissions: Current emission inventories applicable to present and future time periods do not provide explicitly iron species. A common assumption is used here in which iron emissions are estimated based on other combustion species as black carbon (BC) or organic carbon (OC).

In this work scaling factors, which are based on experimental data [14], of total Fe emissions to those of BC (Fe:BC) and OC (Fe:OC) for each of the emission sectors in the IPCC-AR5 inventory [15] are used.

B. Atmospheric processing of Fe

TM5 simulates aqueous-phase chemistry in aerosol water and cloud droplets as described in [16]. The atmospheric
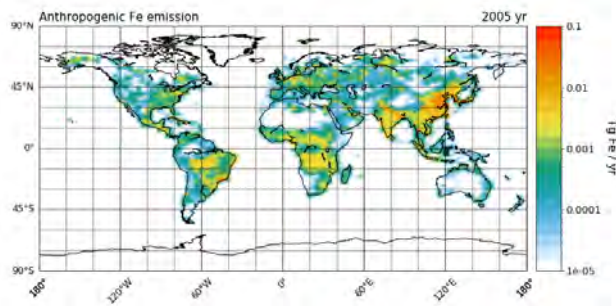
Fig. 2. Combustion Fe emissions [$(TgFe)/yr$] for the year 2005 for one of our simulations.

processing mechanism of iron is treated as a kinetic process accounting for 1) a proton-promoted and 2) an oxalate-promoted.

For the proton-promoted mechanism, the dissolution rate of minerals in aerosol and cloud water is calculated by applying an empirical parameterization [17], taking the saturation degree of the solution, the type of mineral as well as the reactivity of Fe species and the ambient temperature into account. The ligand-promoted dissolution scheme follows what has been experimentally proposed by other studies [18] and directly depends on oxalate concentration.

C. Planned work and expected outcome

Time-slice experiments for the present-day and future climate scenarios will be carried out. Our goal is to understand and compare the responses and regional variations of soluble Fe deposition under different periods, with different anthropogenic emissions, and quantify the contribution of the different sources to the soluble Fe deposition.

Present-day simulations will be evaluated with available compilations of total Fe deposition and concentration measurements.

This study will allow to do fully coupled simulations that account for the effect of bioavailable Fe variations upon the carbon and nitrogen cycles (currently ESM base the determination of the soluble Fe deposited over ocean on climatological information). The implementation of a explicit mineralogy for dust in EC-Earth will also allow a more detailed exploration of other effects of dust on climate.

II. ACKNOWLEDGMENT

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Elisa Bergas-Massó received her BSc degree in Physics with a mention in fundamental physics from Universitat de Barcelona (UB) in 2018. She completed her MSc degree in Meteorology in the same university in 2019. While doing the MSc degree, she did an internship in the Atmospheric Composition group of the Earth Sciences department of the Barcelona Supercomputing Center (BSC) working on mineral dust emission. Since September 2019, in the scope of a Ph.D., she has focused her work on the iron cycle and its implementation in climate models.