Horizon 2020

Call: ERC-2017-COG
(Call for proposals for ERC Consolidator Grant)

Topic: ERC-2017-COG
Type of action: ERC-COG
(Consolidator Grant)

Proposal number: 773051

Proposal acronym: FRAGMENT

Deadline Id: ERC-2017-COG

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How to fill in the forms

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the previous steps in the submission wizard.

1 - General information

Topic	ERC-2017-COG
Call Identifier	ERC-2017-COG
Type of Action	ERC-COG
Deadline Id	ERC-2017-COG

Acronym: FRAGMENT

Proposal title*: FRontiers in dust minerAloGical coMposition and its Effects upoN climaTe

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months*: *60*

Primary ERC Review Panel*: PE10

Secondary ERC Review Panel: (if applicable)

ERC Keyword 1*: *Atmospheric chemistry, atmospheric composition, air pollution*

Please select, if applicable, the ERC keyword(s) that best characterise the subject of your proposal in order of priority.

ERC Keyword 2: *Climatology and climate change*

ERC Keyword 3: *Physical geography*

ERC Keyword 4: *Earth observations from space/remote sensing*

Free keywords: *Dust aerosols; Mineralogy; Physics of emission; Climate; Modelling; Spectroscopy*

Proposal ID **773051** *Acronym* **FRAGMENT**

Abstract*

Soil dust aerosols are mixtures of different minerals, whose relative abundances, particle size distribution (PSD), shape, surface topography and mixing state influence their effect upon climate. However, Earth System Models typically assume that dust aerosols have a globally uniform composition, neglecting the known regional variations in the mineralogy of the sources. The goal of FRAGMENT is to understand and constrain the global mineralogical composition of dust along with its effects upon climate. The representation of the global dust mineralogy is hindered by our limited knowledge of the global soil mineral content and our incomplete understanding of the emitted dust PSD in terms of its constituent minerals that results from the fragmentation of soil aggregates during wind erosion. The emitted PSD affects the duration of particle transport and thus each mineral's global distribution, along with its specific effect upon climate. Coincident observations of the emitted dust and soil PSD are scarce and do not characterize the mineralogy. In addition, the existing theoretical paradigms disagree fundamentally on multiple aspects. We will contribute new fundamental understanding of the size-resolved mineralogy of dust at emission and its relationship with the parent soil, based on an unprecedented ensemble of measurement campaigns that have been designed to thoroughly test our theoretical hypotheses. To improve knowledge of the global soil mineral content, we will evaluate and use available remote hyperspectral imaging, which is unprecedented in the context of dust modelling. Our new methods will anticipate the coming innovation of retrieving soil mineralogy through high-quality spaceborne hyperspectral measurements. Finally, we will generate integrated and quantitative knowledge of the role of dust mineralogy in dust-radiation, dust-chemistry and dust-cloud interactions based on modeling experiments constrained with our theoretical innovations and field measurements.

Remaining characters 0

In order to best review your application, do you agree that the above non-confidential proposal title and abstract can be used, without disclosing your identity, when contacting potential reviewers? ◉ Yes ○ No

Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under Horizon 2020 or any other EU programme(s)? ○ Yes ◉ No

Proposal ID **773051**	*Acronym* **FRAGMENT**

Declarations

1) The Principal Investigator declares to have the explicit consent of all applicants on their participation and on the content of this proposal.*	☒
2) The Principal Investigator declares that the information contained in this proposal is correct and complete.	☒
3) The Principal Investigator declares that this proposal complies with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct).	☒

4) The Principal Investigator hereby declares that *(please select one of the three options below)*:

- in case of multiple participants in the proposal, the coordinator has carried out the self-check of the financial capacity of the organisation on http://ec.europa.eu/research/participants/portal/desktop/en/organisations/lfv.html or to be covered by a financial viability check in an EU project for the last closed financial year.Where the result was “weak” or “insufficient”, the Principal Investigator confirms being aware of the measures that may be imposed in accordance with the H2020 Grants Manual (Chapter on Financial capacity check).	○
- in case of multiple participants in the proposal, the coordinator is exempt from the financial capacity check being a public body including international organisations, higher or secondary education establishment or a legal entity, whose viability is guaranteed by a Member State or associated country, as defined in the H2020 Grants Manual (Chapter on Financial capacity check).	◉
- in case of a sole participant in the proposal, the applicant is exempt from the financial capacity check.	○
5) The Principal Investigator hereby declares that each applicant has confirmed to have the financial and operational capacity to carry out the proposed action. Where the proposal is to be retained for EU funding, each beneficiary applicant will be required to present a formal declaration in this respect.	☒

The Principal Investigator is only responsible for the correctness of the information relating to his/her own organisation. Each applicant remains responsible for the correctness of the information related to him and declared above. Where the proposal to be retained for EU funding, the coordinator and each beneficiary applicant will be required to present a formal declaration in this respect.

According to Article 131 of the Financial Regulation of 25 October 2012 on the financial rules applicable to the general budget of the Union (Official Journal L 298 of 26.10.2012, p. 1) and Article 145 of its Rules of Application (Official Journal L 362, 31.12.2012, p.1) applicants found guilty of misrepresentation may be subject to administrative and financial penalties under certain conditions.

Personal data protection
The assessment of your grant application will involve the collection and processing of personal data (such as your name, address and CV), which will be performed pursuant to Regulation (EC) No 45/2001 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data. Unless indicated otherwise, your replies to the questions in this form and any personal data requested are required to assess your grant application in accordance with the specifications of the call for proposals and will be processed solely for that purpose. Details concerning the purposes and means of the processing of your personal data as well as information on how to exercise your rights are available in the privacy statement. Applicants may lodge a complaint about the processing of their personal data with the European Data Protection Supervisor at any time.

Your personal data may be registered in the Early Detection and Exclusion system of the European Commission (EDES), the new system established by the Commission to reinforce the protection of the Union's financial interests and to ensure sound financial management, in accordance with the provisions of articles 105a and 108 of the revised EU Financial Regulation (FR) (Regulation (EU, EURATOM) 2015/1929 of the European Parliament and of the Council of 28 October 2015 amending Regulation (EU, EURATOM) No 966/2012) and articles 143 - 144 of the corresponding Rules of Application (RAP) (COMMISSION DELEGATED REGULATION (EU) 2015/2462 of 30 October 2015 amending Delegated Regulation (EU) No 1268/2012) for more information see the Privacy statement for the EDES Database).

List of participants

#	Participant Legal Name	Country
1	BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION	Spain
2	AGENCIA ESTATAL CONSEJO SUPERIOR DEINVESTIGACIONES CIENTIFICAS	Spain
3	TECHNISCHE UNIVERSITAT DARMSTADT	Germany

2 - Administrative data of participating organisations

Host Institution

PIC	***Legal name***
999655520	*BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION*

Short name: BSC

Address of the organisation

Street	Calle Jordi Girona 31
Town	BARCELONA
Postcode	08034
Country	Spain
Webpage	www.bsc.es

Legal Status of your organisation

Research and Innovation legal statuses

Public body .... yes
Legal person .... yes
Non-profit .... yes
International organisation .... no
International organisation of European interest ...... no
Secondary or Higher education establishment .... no
Research organisation .... yes

Enterprise Data

SME self-declared status................................. 2011 - no
SME self-assessment .... unknown
SME validation sme....................................... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	Earth Sciences	☐ not applicable
	☒ Same as organisation address	
Street	Calle Jordi Girona 31	
Town	BARCELONA	
Postcode	08034	
Country	Spain	

Principal Investigator

The following information of the Principal Investigator is used to personalise the communications to applicants and the evaluation reports. Please make sure that your personal information is accurate and please inform the ERC in case your e-mail address changes by using the call specific e-mail address:

For Consolidator Grant Applicants: ERC-2017-CoG-applicants@ec.europa.eu

The name and e-mail of contact persons including the Principal Investigator, Host Institution contact are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please save and close this form, then go back to Step 4 of the submission wizard and save the changes.

ORCID ID	0000-0002-4456-0697
Researcher ID	scopus ID 55928817500
Last Name*	Perez Garcia-Pando
First Name(s)*	Carlos
Last Name at Birth	-
Gender*	(●) Male ( ) Female
Title	Dr.
Country of residence*	Spain
Nationality*	Spain
Country of Birth*	Spain
Date of Birth* (DD/MM/YYYY)	25/06/1977
Place of Birth*	Barcelona

Contact address

Current organisation name	Barcelona Supercomputing Center
Current Department/Faculty/Institute/ Laboratory name	Earth Sciences Department
☒ Same as organisation address	
Street	Calle Jordi Girona 31
Postcode/Cedex	08034
Town*	BARCELONA
Phone*	+34934137722
Country*	Spain
Phone2 / Mobile	+34653143417
E-mail*	carlos.perez@bsc.es

Proposal ID **773051** *Acronym* **FRAGMENT** *Short name* **BSC**

Contact address of the Host Institution and contact person

The name and e-mail of Host Institution contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Host Institution, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. Please note that the submission is blocked without a contact person and e-mail address for the Host Institution.

Organisation Legal Name **BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTAC**

First name* **Francesca** Last name* **ARCARA**

E-Mail* **francesca.arcara@bsc.es**

Position in org. *Research Project Manager*

Department *BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONA* ☒ Same as organisation

☒ Same as organisation address

Street Calle Jordi Girona 31

Town BARCELONA Postcode 08034

Country Spain

Phone +34934137774 Phone2/Mobile *+xxx xxxxxxxxx*

Partner organisation

PIC	***Legal name***
999991722	*AGENCIA ESTATAL CONSEJO SUPERIOR DEINVESTIGACIONES CIENTIFICAS*

Short name: CSIC

Address of the organisation

Street CALLE SERRANO 117

Town MADRID

Postcode 28006

Country Spain

Webpage http://www.csic.es

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ......no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person .... yes

Enterprise Data

SME self-declared status.................................2015 - no

SME self-assessment .... unknown

SME validation sme.......................................2007 - no

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	Institute of Environmental Assessment and Water Research	☐ not applicable
	☐ Same as organisation address	
Street	C/ Jordi Girona 18-26	
Town	Barcelona	
Postcode	08034	
Country	Spain	

Proposal ID **773051** *Acronym* **FRAGMENT** *Short name* **CSIC**

Contact address of the partner organisation and contact person

The name and e-mail of Partner Organisation contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Partner Organisation, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. The contact person needs to be added as 'Main Contact' for the Partner Organisation.

Organisation Legal Name **AGENCIA ESTATAL CONSEJO SUPERIOR DEINVESTIGACIONES CIENTIFICAS**

First name* **Xavier** Last name* **Querol**

E-Mail* **xavier.querol@idaea.csic.es**

Position in org. *Senior Researcher*

Department *Institute of Environmental Assessment and Water Research -CSIC* ☐ Same as organisation

☐ Same as organisation address

Street C/ Jordi Girona 18-26

Town Barcelona Postcode 08034

Country Spain

Phone +34 93 4006149 Phone2/Mobile -

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Guillermo	Sanjuanbenito García	programas.europeos@csic.es	+34915681972

Partner organisation

PIC	***Legal name***
999986581	*TECHNISCHE UNIVERSITAT DARMSTADT*

Short name: TECHNISCHE UNIVERSITÄT DARMSTADT

Address of the organisation

Street KAROLINENPLATZ 5

Town DARMSTADT

Postcode 64289

Country Germany

Webpage www.tu-darmstadt.de

Legal Status of your organisation

Research and Innovation legal statuses

Public body .... yes

Legal person .... yes

Non-profit .... yes

International organisation .... no

International organisation of European interest ...... no

Secondary or Higher education establishment .... yes

Research organisation .... yes

Enterprise Data

SME self-declared status................................ 2013 - no

SME self-assessment .... unknown

SME validation sme....................................... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

Department(s) carrying out the proposed work

Department 1

Department name	Institut für Angewandte Geowissenschaften	☐ not applicable
	☐ Same as organisation address	
Street	Schnittspahnstraße 9	
Town	Darmstadt	
Postcode	64287	
Country	Germany	

Contact address of the partner organisation and contact person

The name and e-mail of Partner Organisation contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Partner Organisation, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. The contact person needs to be added as 'Main Contact' for the Partner Organisation.

Organisation Legal Name **TECHNISCHE UNIVERSITAT DARMSTADT**

First name* **Konrad** Last name* **Kandler**

E-Mail* **kandler@geo.tu-darmstadt.de**

Position in org. *Professor*

Department *Institut für Angewandte Geowissenschaften* ☐ Same as organisation

☐ Same as organisation address

Street Schnittspahnstraße 9

Town Darmstadt Postcode 64287

Country Germany

Phone +49 6151 16-23600 Phone2/Mobile -

Other contact persons

First Name	*Last Name*	*E-mail*	*Phone*
Barbara	Köhler	koehler.ba@pvw.tu-darmstadt.de	+49061511657251

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3 - Budget

Participant Number in this proposal	Organisation Short Name	Organisation Country	Total eligible costs/€ (including 25% indirect costs) ?	Requested grant/€
1	BSC	ES	1 449 880	1 449 880
2	CSIC	ES	540 893	540 893
3	TECHNISCHE UNIVERSITÄT DARMSTADT	DE	158 750	158 750
Total			2 149 523	2 149 523

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4 - Ethics issues table

1. HUMAN EMBRYOS/FOETUSES		Page
Does your research involve Human Embryonic Stem Cells (hESCs)?	○ Yes ◉ No	
Does your research involve the use of human embryos?	○ Yes ◉ No	
Does your research involve the use of human foetal tissues / cells?	○ Yes ◉ No	
2. HUMANS		**Page**
Does your research involve human participants?	○ Yes ◉ No	
Does your research involve physical interventions on the study participants?	○ Yes ◉ No	
3. HUMAN CELLS / TISSUES		**Page**
Does your research involve human cells or tissues (other than from Human Embryos/ Foetuses, i.e. section 1)?	○ Yes ◉ No	
4. PERSONAL DATA		**Page**
Does your research involve personal data collection and/or processing?	○ Yes ◉ No	
Does your research involve further processing of previously collected personal data (secondary use)?	○ Yes ◉ No	
5. ANIMALS		**Page**
Does your research involve animals?	○ Yes ◉ No	
6. THIRD COUNTRIES		**Page**
In case non-EU countries are involved, do the research related activities undertaken in these countries raise potential ethics issues?	○ Yes ◉ No	
Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	○ Yes ◉ No	
Do you plan to import any material - including personal data - from non-EU countries into the EU?	○ Yes ◉ No	
Do you plan to export any material - including personal data - from the EU to non-EU countries?	○ Yes ◉ No	
In case your research involves low and/or lower middle income countries, are any benefits-sharing actions planned?	○ Yes ◉ No	
Could the situation in the country put the individuals taking part in the research at risk?	○ Yes ◉ No	

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7. ENVIRONMENT & HEALTH and SAFETY		Page
Does your research involve the use of elements that may cause harm to the environment, to animals or plants?	◯ Yes ◉ No	
Does your research deal with endangered fauna and/or flora and/or protected areas?	◯ Yes ◉ No	
Does your research involve the use of elements that may cause harm to humans, including research staff?	◯ Yes ◉ No	
8. DUAL USE		**Page**
Does your research involve dual-use items in the sense of Regulation 428/2009, or other items for which an authorisation is required?	◯ Yes ◉ No	
9. EXCLUSIVE FOCUS ON CIVIL APPLICATIONS		**Page**
Could your research raise concerns regarding the exclusive focus on civil applications?	◯ Yes ◉ No	
10. MISUSE		**Page**
Does your research have the potential for misuse of research results?	◯ Yes ◉ No	
11. OTHER ETHICS ISSUES		**Page**
Are there any other ethics issues that should be taken into consideration? Please specify	◯ Yes ◉ No	

I confirm that I have taken into account all ethics issues described above and that, if any ethics issues apply, I will complete the ethics self-assessment and attach the required documents. ☒

How to Complete your Ethics Self-Assessment

Proposal ID **773051** *Acronym* **FRAGMENT**

5 - Call specific questions

Academic Training	
Are you a medical doctor or do you hold a degree in medicine? Please note that if you have also been awarded a PhD, your medical degree may be your first eligible degree.	◯ Yes ◉ No
Date of earliest award (PhD or equivalent)* - DD/MM/YYYY	15/12/2005
With respect to the earliest award (PhD or equivalent), I request an extension of the eligibility window, (indicate number of days) [see the ERC 2017 Work Programme and the Information for Applicants to the Starting and Consolidator Grant 2017 Calls].	◯ Yes ◉ No
Eligibility	
Please indicate your percentage of working time in an EU Member State or Associated Country over the period of the grant: Please note that you are expected to spend a minimum of 50% of your total working time in an EU Member State or Associated Country.	100,00
I acknowledge that I am aware of the eligibility requirements for applying for this ERC call as specified in the ERC Annual Work Program , and certify that, to the best of my knowledge my application is in compliance with all these requirements. I understand that my proposal may be declared ineligible at any point during the evaluation or granting process if it is found not to be compliant with these eligibility criteria.*	☒
Data-Related Questions and Data Protection (Consent to any question below is entirely voluntary. A positive or negative answer will not affect the evaluation of your project proposal in any form and will not be communicated to the evaluators of your project.)	
For communication purposes only, the ERC asks for your permission to publish, in whatever form and medium, your name, the proposal title, the proposal acronym, the panel, and host institution, should your proposal be retained for funding.	◉ Yes ◯ No
Some national and regional public research funding authorities run schemes to fund ERC applicants that score highly in the ERC's evaluation but which can not be funded by the ERC due to its limited budget. In case your proposal could not be selected for funding by the ERC do you consent to allow the ERC to disclose the results of your evaluation (score and ranking range) together with your name, non-confidential proposal title and abstract, proposal acronym, host institution and your contact details to such authorities?	◉ Yes ◯ No
The ERC is sometimes contacted for lists of ERC funded researchers by institutions that are awarding prizes to excellent researchers. Do you consent to allow the ERC to disclose your name, non-confidential proposal title and abstract, proposal acronym, host institution and your contact details to such institutions?	◉ Yes ◯ No

The Scientific Council of the ERC has developed a monitoring and evaluation strategy in order to help it fulfil its obligations to establish the ERC's overall strategy and to monitor and quality control the programme's implementation from the scientific perspective. As provided by section 3.10 of the ERC Rules for Submission: a range of projects and studies may be initiated for purposes related to monitoring, study and evaluating the implementation of ERC actions. Do you consent to allow the third parties carrying out these projects and studies to process the content of your proposal including your personal data and the respective evaluation data? The privacy statement on the processing operations of applicants and beneficiaries data for H2020 available on the Participant Portal explains further how your personal data is secured.	(•) Yes ( ) No

Excluded Reviewers

You can provide up to three names of persons that should not act as an evaluator in the evaluation of the proposal for potential competitive reasons.

First Name	
Last Name	
Institution	
Town	
Country	
Webpage	

Extended Open Research Data Pilot in Horizon 2020

If selected, all applicants will participate in the Pilot on Open Research Data in Horizon 2020[1] , which aims to improve and maximise access to and re-use of research data generated by actions.

However, participation in the Pilot is flexible in the sense that it does not mean that **all** research data needs to be open. After the action has started, participants will formulate a Data Management Plan (DMP), which should address the relevant aspects of making data FAIR - findable, accessible, interoperable and re-usable, including what data the project will generate, whether and how it will be made accessible for verification and re-use, and how it will be curated and preserved. Through this DMP projects can define certain datasets to remain closed according to the principle "as open as possible, as closed as necessary". A Data Management Plan does **not** have to be submitted at the proposal stage.

Furthermore, applicants also have the possibility to opt out of this Pilot completely at any stage (before or after the grant signature), thereby freeing themselves retroactively from the associated obligations.

Please note that participation in this Pilot does not constitute part of the evaluation process. Proposals will not be penalised for opting out.

We wish to opt out of the Pilot on Open Research Data in Horizon 2020.	○ Yes	◉ No

[1] *According to article 43.2 of Regulation (EU) No 1290/2013 of the European Parliament and of the Council, of 11 December 2013, laying down the rules for participation and dissemination in "Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)" and repealing Regulation (EC) No 1906/2006.*

ERC Consolidator Grant 2017
Research proposal [Part B1]

FRontiers in dust miner**A**lo**G**ical co**M**position and its **E**ffects upo**N** clima**T**e

FRAGMENT

Cover Page:

- Name of the Principal Investigator (PI): **Carlos Pérez García-Pando**
- Name of the PI's host institution for the project: **Barcelona Supercomputing Center**
- Proposal duration in months: **60 months**

Soil dust aerosols are mixtures of different minerals, whose relative abundances, particle size distribution (PSD), shape, surface topography and mixing state influence their effect upon climate. However, Earth System Models typically assume that dust aerosols have a globally uniform composition, neglecting the known regional variations in the mineralogy of the sources. The goal of FRAGMENT is to understand and constrain the global mineralogical composition of dust along with its effects upon climate. The representation of the global dust mineralogy is hindered by our **limited knowledge of the global soil mineral content** and our **incomplete understanding of the emitted dust PSD in terms of its constituent minerals** that results from the **fragmentation of soil aggregates** during wind erosion. The emitted PSD affects the duration of particle transport and thus each mineral's global distribution, along with its specific effect upon climate. Coincident observations of the emitted dust and soil PSD are scarce and do not characterize the mineralogy. In addition, the existing theoretical paradigms disagree fundamentally on multiple aspects. We will contribute **new fundamental understanding** of the size-resolved mineralogy of dust at emission and its relationship with the parent soil, based on an unprecedented ensemble of **measurement campaigns** that have been designed to thoroughly test our **theoretical hypotheses**. To improve knowledge of the global soil mineral content, we will evaluate and use available **remote hyperspectral imaging**, which is unprecedented in the context of dust modelling. Our new methods will anticipate the coming innovation of retrieving soil mineralogy through high-quality spaceborne hyperspectral measurements. Finally, we will generate **integrated and quantitative knowledge** of the role of dust mineralogy in **dust-radiation, dust-chemistry and dust-cloud interactions** based on modeling experiments constrained with our theoretical innovations and field measurements.

Section a: Extended Synopsis of the scientific proposal (max. 5 pages)

The importance of dust mineralogy

Soil dust aerosols are a key component of the Earth system[1]. Soil dust aerosols created by wind erosion of arid and semi-arid surfaces are amongst the largest contributors to the global aerosol mass load[2] and dominate climate effects over large areas of the Earth[3,4]. Deposition measurements from ice cores and ocean sediments indicate large temporal variations of dust[5-7] occurring on time scales ranging from interannual to decadal as well as glacial to geologic. Dust is not only an indicator of past climate variations but also an integral contributor to climate change[8,9].

Climate perturbations by dust aerosols depend fundamentally upon their physical and chemical properties. 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 [10,11]. The Intergovernmental Panel on Climate Change (IPCC) has identified dust mineralogy as a key uncertainty in the overall contributions of aerosols to radiative forcing[12,13].

Dust perturbs the energy and water cycles by direct radiative forcing[14-19]. The absorption of solar radiation by dust is strongly related to the presence of iron oxides[20-25]. Thermal radiation is also sensitive to mineralogy[26], specifically to abundance of phyllosilicates (clays), quartz and carbonates[27-29].

Dust influences cloud formation and the associated indirect radiative forcing by providing nuclei for liquid and ice clouds[30-38]. The ice nucleation properties of dust depend upon its surface defects[11]. Recent studies have revealed that K-feldspar is the key mineral for ice nucleation[39-43]. The droplet nucleation properties of dust depend upon hygroscopicity, which increases during transport and depends on mineralogy[44-47].

Dust undergoes heterogeneous chemical reactions during transport that increase its hygroscopicity, while altering its optical properties, and the associated radiative forcing[48]. The rates of heterogeneous chemical reactions on the dust surface that form coatings of sulfate, nitrate, chloride, or organics depend strongly on the dust mineralogical composition[49-51]. For example, the uptake of sulfur dioxide by calcite exceeds by at least an order of magnitude uptake by quartz, feldspar and hematite[52-55]. Dust composition also affects the partitioning of semi-volatile inorganic compounds[56], altering their burden and radiative forcing[57].

Earth System Models typically assume that dust aerosols have a globally uniform composition[12,13], neglecting the known local and regional variations in the mineralogical composition of the sources[58-60]. Modeling efforts have focused on constraining dust sources[61-63], emission[64] and PSD[64-67]. While this minimal representation has allowed significant advances in dust and climate research over the past decade, the omission of dust mineralogy impedes further understanding of the dust role in the Earth system.

The challenge of constraining global dust mineralogy

Distinguishing the emitted PSD of individual dust minerals is critical to properly quantifying the climate effect of dust. Even without the complexity of mineralogy, the representation of the total dust PSD at emission is currently challenged by our incomplete understanding of the physics of dust emission and a lack of measurements on global scales[68]. **Coincident observations of the PSD of the emitted dust and parent soil are scarce and do not distinguish the emission of individual minerals[68]; existing theoretical paradigms disagree fundamentally on multiple aspects[68-73].**

While the dust PSD at emission remains uncertain, constraining its mineralogical composition poses additional key challenges[74-77]. Deriving dust mineralogical composition requires global knowledge of soil mineral content. Global atlases of soil mineralogy for modelling the lifecycle of dust aerosols [58-60] are based upon measurements following wet sieving, a technique that disperses (breaks) the mineral aggregates found in the undisturbed parent soil, replacing them with a collection of smaller particles[69,78-82]. During emission, the original, undisturbed aggregates are **fragmented**, but only partially. This results in differences in the PSD, mineralogy and mixing state between the emitted particles derived from the undisturbed soil versus the disturbed (wet-sieved) soil. **The complete lack of experimental studies tackling the size-resolved mineralogy of emitted dust and its relationship with the parent soil hinders our ability to extend and constrain theories of dust emission.**

Soil mineralogy atlases for dust modelling are derived by massively extrapolating an inhomogeneous and limited set of mineralogical analyses of soil samples that are particularly scarce in the arid and semi-arid areas that contain the dust sources[58-60]. Soil mineralogy is derived assuming a relationship with observed soil type that neglects the potentially large regional variations in the mineral content within each soil type. Other key limitations of derived soil mineralogy include the uncertain estimation of iron oxide minerals from qualitative descriptions of soil color, crudely resolved mineral PSDs, and the lack of knowledge of the mixing state of the minerals. **Airborne and spaceborne spectroscopic mapping of soil mineralogy is a promising path to understand the relative abundance of the key dust source minerals with sufficient detail and coverage, but this resource has been virtually unexplored in the context of dust modelling.**

Objectives and ground-breaking nature of FRAGMENT

The overarching goal of **FR**ontiers in dust miner**A**lo**G**ical co**M**position and its **E**ffects upo**N** clima**T**e (FRAGMENT) is to understand, constrain and calculate the global mineralogical composition of dust along with its effects upon climate. **FRAGMENT will fundamentally advance the treatment of dust mineralogy by fulfilling the following objectives (Fig. 1)**:

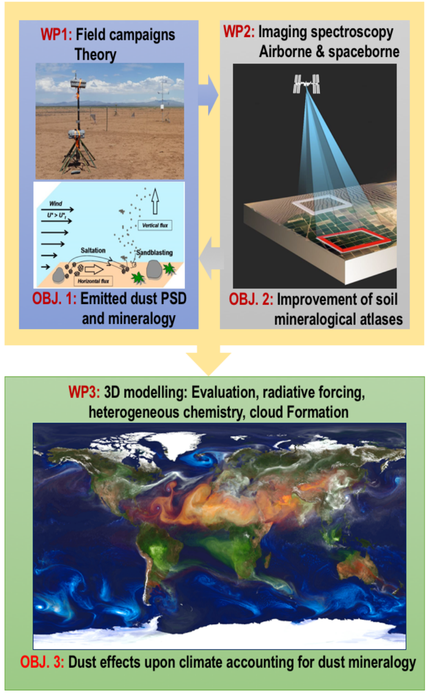


Fig. 1 Conceptual scheme of FRAGMENT. Each of the three objectives (OBJ. 1, OBJ. 2, OBJ. 3) is addressed through their corresponding work packages (WP1, WP2, WP3)

Objective 1: We will contribute **new fundamental understanding** to reduce the large uncertainties in the **emitted dust PSD** by evaluating and extending current theoretical paradigms, based on an unprecedented ensemble of coordinated **measurement campaigns and laboratory analyses**. We will also address for the first time both experimentally and theoretically the **size-resolved mineralogy of dust at emission and its relationship with the parent soil**.

Objective 2: Precise knowledge of dust mineral content requires more detailed and widespread measurements of soil mineralogy. **We will generate integrated and quantitative knowledge regarding the influence of dust mineral composition upon atmospheric radiation, chemistry and clouds** based on modelling experiments constrained with our theoretical innovations and field measurements.

Objective 3: While the impact of dust mineralogy upon climate is potentially large, the interconnection of mechanisms has been neglected in the few models that represent mineral variations. **We will generate integrated and quantitative knowledge regarding the influence of dust mineral composition upon atmospheric radiation, chemistry and clouds** based on modelling experiments constrained with our theoretical innovations and field measurements.

Hypotheses, key scientific questions, and methodology

Objective 1. From the soil to the atmosphere: The emitted PSD and mineralogy of dust

Soil dust particles that travel thousands of kilometers downwind from their source generally have diameters below ~20 μm. However, their direct **aerodynamic entrainment** (emission) is hindered by interparticle cohesion forces that form aggregates of larger sizes[83-85]. The majority of these particles are released through **saltation bombardment**, in which soil aggregates are fragmented by impacts from larger saltating grains, and **aggregate disintegration**, in which saltating aggregates are fragmented upon striking the soil surface[68,70,71,86,87]. Over the last two decades, the theories of Alfaro and colleagues[70,88,89] and Shao[69,90] have provided a framework to predict the emitted dust PSD. Both theories predict more fragmentation of aggregates and thus **smaller emitted particles with increasing wind speed**, in agreement with wind tunnel experiments[88]. However, their practical use in global models is hindered by the **lack of data on input soil properties**. The binding forces of the soil aggregates, the lognormal modes assumed for the emitted dust and the empirical coefficients used by the theories may be soil-specific and therefore not known[73,91]. Also, the undisturbed soil PSD is not available on global scales. To sidestep the lack of measurements, Kok[71] proposed an alternative theory for the emitted PSD, based upon **brittle fragmentation theory** (BFT), whose main assumption is that soil aggregates fragment and release dust following the physics of brittle materials. BFT posits that the **emitted PSD is relatively independent of both the undisturbed soil PSD and the wind speed**. Its application requires knowledge of the dispersed soil PSD, and the side crack propagation length (λ). Kok[71] argues that λ can be approximated as a constant (~12 μm) in agreement with the few available measurements of the emitted PSD, which is both provocative and auspicious for modelling. Later revisions by Kok and colleagues[67,71] suggest that λ may vary between ~10 and ~15 μm depending on soil properties such as aggregate stability. **Given the paucity of measurements, and the apparent contradiction among theories, field observations and wind tunnel experiments, FRAGMENT will conduct field campaigns in distinct source regions to measure the size-resolved dust emission for a range of meteorological and soil conditions in conjunction with an extensive analysis of the underlying soil characteristics. Our aim is to improve our quantitative understanding of the emitted dust PSD.** We aim to answer a number of key questions including: *Does the emitted dust PSD depend on wind speed? How do the contrasting theoretical frameworks compare with observations? Are the lognormal modes, binding forces, and empirical coefficients soil-specific? What is the range of variability of λ? Does λ depend on identifiable and quantifiable soil properties such as* *the dry aggregate stability? How can we account for it? Is the emitted PSD dependent upon emission mechanism (aggregate disintegration vs saltation bombardment vs aerodynamic entrainment)?*

FRAGMENT will not only characterize the emitted dust PSD but also its size-resolved mineralogy through both theory and field campaigns, which to our knowledge has no precedent. In recent studies[74,75,77], we showed that BFT provides an ideal framework to predict the emitted PSD in terms of its constituent minerals because it builds upon relatively abundant dispersed soil data. BFT predicts that the emitted PSD (Fig. 2a) is shifted toward larger diameters compared to the PSD of the dispersed soil (Fig. 2b). The colored areas in Fig. 2b are an example of the bulk mineral fractions within the clay size range (0-2 μm) and the silt size range (2-50 μm) derived from a global atlas of soil type[58,59]. Despite the crude size-dependence of the mineral fractions derived from the soil type atlas, the emitted PSD derived using BFT (Fig. 2a) significantly improves our ability to predict global measurements of the dust mineral composition[74,75,77]. However, the evaluation still highlights significant errors such as the overestimation of quartz and feldspar. **We hypothesize that approximate knowledge of the characteristic PSDs of each mineral in the dispersed soil is key to constraining the global mineralogical composition (Fig. 2c).** Extending BFT with this new dependence upon soil PSD significantly improves our predictions. In this context, **FRAGMENT will conduct unprecedentedly detailed size-resolved mineralogical, chemical and mixing state analysis of the soil and emitted dust to test BFT and our proposed theoretical extensions for individual minerals. We aim to better understand and constrain the evolution of each mineral's PSD from the parent soil to the atmosphere.** The key questions we aim to answer include: *Does the observed size-resolved mineralogy of the soil and the emitted dust support BFT and our proposed extensions? What are the typical dispersed PSDs for each mineral? What is the PSD and mixing state of the different minerals in the emitted dust compared to the dispersed and undispersed soil? What is the best strategy to derive the mineral-specific disturbed PSDs from existing global soil texture and soil mineralogy?*

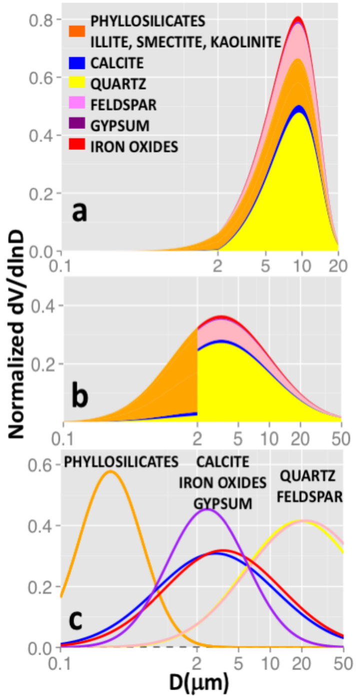


Fig. 2 Example of (a) emitted PSD and mineralogy by BFT; (b) average soil dispersed PSD and mineral fractions; (c) proposed extension of BFT by fitting mineral-specific PSDs.

Methodology (WP1): We will perform a detailed characterization of the soil, emission and meteorology at three distinct regions (Aragón, Spain; Tinfou in Zagora, Morocco; and the Salton Sea, California, US). These regions meet several key criteria: accessibility; variety of soil types, textures, and landforms; local/regional partners for logistical support; and relevance to our diverse theoretical and modelling questions. We will build a mobile measurement platform equipped with active and passive dust samplers along with real-time dust measurement and meteorological instruments. Our measurement platform will obtain (1) the number and size-resolved vertical dust flux along with particle counts and kinetic energy of the saltating particles, and (2) saltation sediment and size-segregated aeolian samples for subsequent laboratory analysis. We will also thoroughly sample the soil accounting for the variance across each measurement site, and we will measure soil moisture variations at 1 cm depth. In the laboratory, we will obtain (1) the PSD of the dry (minimally dispersed) and wet (dispersed) soil and the saltation sediment, (2) the dry soil aggregate stability, and (3) the detailed size-resolved mineralogy, chemistry, morphology and mixing state of the soil and emitted aerosol using XRD, TEM, SEM, EDS, BSED and ICP-MS. The combination of these measurements will allow (1) directly identifying the emission mechanism, while evaluating and refining the three theories to quantify the uncertainty in the emitted PSD, (2) understanding to what extent the emitted PSD is affected by wind speed, soil properties and the emission mechanism, (3) characterize the individual PSD of each soil mineral (Fig. 2c) and its modification during emission (Fig. 2a), (4) precisely evaluating BFT and our proposed extensions for individual minerals, and (5) quantifying the uncertainty of BFT predictions for mineralogy.

<u>Objective 2:</u> **Global mineral mapping through hyperspectral imaging spectroscopy**

Modeling of dust aerosol mineralogy is based upon maps of soil type and the relation of this variable to soil mineralogy. This relation is inferred using massive extrapolation from a limited amount of soil mineralogical analyses, ancillary information on soil texture and color, and a number of additional assumptions[65]. This limited knowledge together with our incomplete understanding of the emitted dust PSD and its relationship with the PSD of the parent soil precludes accurate assessment of the effects of dust upon climate. **FRAGMENT will improve soil mineralogy atlases for dust modelling using spaceborne and airborne imaging spectroscopy.** Remote spectroscopic mapping of dust source regions is a promising path for measuring the relative abundance of the key dust source minerals with sufficient detail and global coverage.

Over the last two decades, the field of imaging spectrometry has progressed with the development of new instruments, both airborne[92-95] and spaceborne[96-101], and analysis techniques[102-104]. **Recently, FRAGMENT members, including the PI, have proposed to sample the surface mineral composition of Earth dust sources at very high spatial resolution using hyperspectral imaging spectroscopy from the International Space Station (ISS) during a 12-month mission.** The proposed mission, named EMIT, is under review within the NASA Earth Venture Instrument-4 program. EMIT would provide large spectral range (410 to 2450 nm), high signal-to-noise ratio (SNR), high-resolution spatial sampling (≤100 m), and comprehensive near-term coverage of most mineral dust sources. The German EnMAP mission[105] will provide similar spectroscopic measurements after 2019, although it will have a more limited data acquisition capacity[106]. Given the current absence of EMIT and EnMAP retrievals, **FRAGMENT will validate and use existing EO1/Hyperion satellite data[100] for mapping soil mineral abundance, while creating a refined methodological framework to produce higher quality maps when EMIT and EnMAP data become available.** EO-1/Hyperion is a virtually unexplored resource for dust modeling applications. Although its signal-to-noise ratio (SNR) is inferior to that of EMIT and EnMAP, it has shown potential to map basic mineralogy for geological applications[107,108]. Given the limited quality of soil mineralogical atlases, using the global coverage (more than 90,000 scenes) provided by EO1/Hyperion could drastically and immediately improve current estimates.

Deriving surface mineral abundances for dust modelling from spectroscopic measurements introduces challenges that our field measurements will address. For example, current and planned hyperspectral instruments do not retrieve feldspar and quartz, whose absorption features are beyond the measured spectral window. We will combine spectroscopic abundances of other minerals with quartz and feldspar values from current atlases derived from soil type. We will use field campaign measurement to combine grain size information from spectroscopy with atlases mostly based on dispersed soil samples. **Our field campaign at the Salton Sea will collocate high SNR (EMIT-type) retrievals from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)[93] and EO1/Hyperion[100] spectroscopic measurements with detailed mineral- and size-resolved measurements of soil and emitted dust, and perform additional field spectroscopic measurements**. **These combined measurements are unprecedented.** The key questions that we aim to answer include: *How well the surface mineralogical composition retrieved by AVIRIS and EO1/Hyperion compares to field spectroscopy and laboratory measurements of soil samples? How does composition vary as a function of grain size retrieved from spectroscopy? How do we relate mineral abundance and grain size information derived from spectroscopy to mineral abundance and PSD derived from both disturbed and undisturbed soil samples? How does the composition and PSD of the emitted dust collected during the field campaign differ from that of the soil retrieved with spectroscopy? How homogeneous is the composition of the soil as a function of spatial scale? How do we combine existing soil mineralogy atlases with information from spaceborne retrievals?*

Methodology (WP2): During our field campaign at the Salton Sea, we will perform field spectroscopic measurements of the surface both with a point spectrometer allowing sub-meter scale sampling, and a field imaging spectrometer that provides a panorama of the scenes. The collected soil samples will also be measured in the laboratory with spectrometers. These laboratory measurements will provide a direct link to the reflectance measurements of the AVIRIS and EO1/Hyperion through XRD, TEM, SEM and BSED analyses. The heterogeneity at meter- to sub-meter spatial scales (sub-pixel relative to the remote sensing data) will be evaluated and used, along with the samples, to validate and test the remote retrievals of minerals, mineral abundances and grain sizes. All our retrievals will target 10 key minerals that can be obtained from spectroscopy within the spectral window of spaceborne instruments: hematite, goethite, illite, vermiculite, calcite, dolomite, montmorillonite, kaolinite, chlorite, and gypsum. The identification of these minerals and estimation of mineral abundance from the reflectance spectra will be based on the Tetracorder algorithm which has been developed and validated over the 25+ years of the AVIRIS airborne science project[93,102]. With these data, we will study how to combine the mineral abundances and grain sizes derived from spectroscopy with the feldspar and quartz sizes and abundances derived from the soil analyses. Based on the improvements and understanding derived from the detailed comparison at the Salton Sea, we will process both the AVIRIS and EO1/Hyperion archives, which will be used to both evaluate and complement the most recent global mineralogical atlas in terms of mineral abundance and size.

<u>Objective 3:</u> Modelling and effects upon radiation, heterogeneous chemistry and clouds

Dust radiative forcing in nearly all global models varies with environmental properties like surface albedo, along with the dust PSD, but excludes the effect of regional variations in forcing resulting from source variations in soil mineral composition. For particles of a given size, absorption at short wavelengths is most sensitive to the presence of iron oxide minerals within the dust particle[20-25], and at long wavelengths to the presence of phyllosilicates, calcite and quartz[26-29]. **FRAGMENT will enable and evaluate a multiscale atmosphere-chemistry modelling system that includes state-of-the-art dust capabilities with the**

unprecedented constraints on the composition-resolved dust emitted PSD derived from WP1 and WP2. Because iron oxides contribute only a small fraction of the dust mass, their evaluation in a model based upon direct measurements of dust composition is subject to greater uncertainty, compared to more abundant minerals like clays and quartz. However, their absorption dominates even at low abundance. **Our evaluation of iron oxides will include radiance measurements from multiple in-situ and spaceborne instruments. This evaluation will allow stronger constraints upon direct radiative forcing by dust aerosols than is currently possible from models that do not consider aerosol mineralogy.** Dust also affects the partitioning of inorganic aerosol components[56] and undergoes heterogeneous chemical reactions with acidic trace gases that result in the formation of coatings on the dust particle surface, including sulfate[109-112] and nitrate[113-119]. These interactions affect cloud droplet formation by changing both the burden of soluble material and by increasing the hygroscopicity of dust[57,120]. Current models that include dust heterogeneous chemical reactions omit variations in dust mineralogy[121,122]. In the case of cloud droplet formation, only recently has a study assessed the effect of dust composition upon the partitioning of inorganic aerosol components[57]. However, this study neglects heterogeneous chemical reactions, and the underlying soil information consists of only ten points globally. These omissions are potentially important. For example, quartz and feldspar are relatively unreactive toward sulfur dioxide, which contrasts with the high reactivity of calcite[52-55]. Dust is also a key source of ice nuclei in mixed-phase clouds due to its high nucleation efficiency[123-125]. The ice nucleation of dust is mostly controlled by the amount of uncoated K-feldspar[39-43]. **FRAGMENT will investigate the effect of modelled dust mineralogy upon the partitioning of inorganic aerosol compounds and heterogeneous chemistry, along with the subsequent effects upon warm-cloud formation and heterogeneous ice nucleation in mixed-phase clouds, and the associated radiative forcing.** We aim to address a number of questions including: *What is the impact of our new mineral abundance and emitted PSD constraints upon the effects of dust? How large are the effects of regional variations in mineralogy relative to the effect of globally uniform particles? What is the radiative forcing of dust? What is the minimal representation of minerals that needs be considered by Earth System Models to incorporate the largest impacts of dust?*

Methodology (WP3): We will use the Multiscale Online Non-hydrostatic AtmospheRe CHemistry model[126-138] (MONARCH; previously known as NMMB/BSC-CTM), a model designed and developed by the PI of this proposal and his research group that already includes many of the capabilities needed to accomplish the proposed goals. We will first constrain the total dust emission fluxes based on our data assimilation system and derive additional constraints on the emitted PSD and mineralogy by comparing observations to a large number of model experiments, whose parameters are perturbed within their estimated ranges of uncertainty. We will specifically evaluate and further constrain our representation of iron oxide minerals using radiance measurements from multiple instruments based on forward simulations of radiative properties that are especially sensitive to this mineral (e.g., single scattering albedo, color and depolarization ratios), along with mixing assumptions informed by WP1. Based on our constrained model, we will calculate the present-day dust direct radiative forcing, which will be contrasted with the forcing calculated assuming globally uniform particles. We will then explore and evaluate the effects of mineralogy upon the partitioning of semi-volatile inorganic compounds and dust heterogeneous chemistry, along with the associated changes in the burdens of precursor gases, dust, nitrate, sulfate, and ammonium, and the direct aerosol radiative forcing. We will thoroughly evaluate the enhanced model relative to a configuration where the dependencies on composition are neglected; assess the relative importance of the partitioning and heterogeneous chemistry upon the results; and study the role of each mineral with the goal of proposing a minimal mineral representation for climate models. To assess the effects upon clouds, we will incorporate (available) state-of-the-art CCN activation and mineralogy-dependent immersion-freezing nucleation terms into the model. We will evaluate the importance of the partitioning, heterogeneous chemistry and mineralogy upon cloud droplet number concentration (CDNC) and ice nucleating particle (INP) concentration. The evaluation will include satellite data and publicly available compilations of measurements. Finally, this activation framework used in combination with a two-moment cloud microphysics scheme will allow us to calculate the associated (indirect) radiative forcing.

Suitability of the PI and his research team

The achievement of the ambitious goals of FRAGMENT requires a strong cross-disciplinary team working in concert across theory, measurements, spectroscopy and modelling. The expertise of PI and his team members cover all aspects of FRAGMENT. In addition to the PI, the team involves world-class experts on modelling of dust mineralogy (Ron Miller, NASA GISS), aerosol campaigns and analysis (Xavier Querol; Andres Alastuey, CSIC), mineralogy analysis (Konrad Kandler, TUD), and spectroscopy sampling and retrievals (Roger Clark, PSI; Bethany Ehlmann, Caltech; Robert Green; NASA JPL).

Section b: Curriculum Vitae (max. 2 pages)

PERSONAL INFORMATION

Family name, First name: **Pérez García-Pando, Carlos**

Researcher unique identifier: SCOPUS Author ID: 55928817500, ORCID ID: 0000-0002-4456-0697

Date of birth: June 25, 1977

Nationality: Spanish

URL for web site: https://www.bsc.es/es/perez-garcia-pando-carlos
https://pubs.giss.nasa.gov/authors/cperez.html
https://gallery.axa-research.org/en/webdocs/perez-garcia-pando-sand-dust-storms.htm

- **EDUCATION**

12/2005	**PhD in Environmental Engineering** Polytechnic University of Catalonia, Environmental Modelling Laboratory, Barcelona, Spain Summa Cum Laude (Unanimity), Supervisor: Prof. José M. Baldasano
2001	**Industrial Engineer** - Environmental Option Polytechnic University of Catalonia, Industrial Engineering School, Barcelona, Spain
2001	**Ingénieur des Arts et Manufactures** École Centrale Paris, France

- **CURRENT POSITIONS**

10/2016–	**Head of the Atmospheric Composition Group** **AXA Professor on Sand and Dust Storms** **Ramon y Cajal Researcher** Earth Sciences Department, Barcelona Supercomputing Center (BSC), Spain

- **PREVIOUS POSITIONS**

2011-2016	**Associate Research Scientist** NASA Goddard Institute for Space Studies, New York Department of Applied Physics and Applied Math, Columbia University, New York
2009-2011	**Earth Institute Fellow** The Earth Institute at Columbia University, New York NASA Goddard Institute for Space Studies, New York International Research Institute for Climate and Society, New Jersey
2009	**Visiting Scientist (5 months)** NOAA National Centers for Environmental Prediction, Camp Springs, Maryland.
2006-2009	**Research Scientist** **Mineral Dust Group Leader** Earth Sciences Department, Barcelona Supercomputing Center, Spain

- **COMPETITIVE FELLOWSHIPS, AWARDS, PRIZES AND DISTINCTIONS**

2016 – 2030	**AXA Chair on Sand and Dust Storms**. Endowment of EUR 1.7 million awarded by the AXA Research Fund to support my research program at BSC, Spain.
2016 – 2020	**Ramon y Cajal Fellowship** awarded by the Ministry of Economy, Industry and Competitiveness, Spain (I was ranked #1 in Earth Sciences), EUR 210,000.
2014	Co-author of the Best Publication of 2014 at NASA Goddard Institute for Space Studies
2014	Best Science Brief of 2014 at NASA Goddard Institute for Space Studies
2009 – 2011	**Earth Institute Fellowship** (~5% success rate) awarded by the Earth Institute at Columbia University, New York, $110,000.
2009	Mobility grant José Castillejo awarded by the Ministry of Science and Innovation, Spain.
2001 – 2005	PhD Thesis fellowship awarded by the Polytechnic University of Catalonia, Spain.
2007	Poster presentation prize at the 11th International Conference on Harmonisation within atmospheric dispersion modelling for atmospheric purposes.
1998 – 2000	EU Fellowship to obtain the double Spanish-French Engineering degree at the École Centrale Paris, France

- **SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS**

2006 –	**4 Postdocs, 2 PhD, 2 Master Students** Barcelona Supercomputing Center, Spain

2013 – 2016 **1 Postdoc, 1 Master Student**
NASA Goddard Institute for Space Studies, New York

- **ORGANISATION OF SCIENTIFIC MEETINGS**

2012 **Workshop organizer**, "Dust, climate and Health in sub-Saharan Africa" sponsored by the Earth Institute, International Research Institute for Climate and Society, New York
2011 **Co-chair**, World Meteorological Organization SDS-WAS/GESAMP Expert Workshop on "Modelling and Observing the Impacts of Dust Transport and Deposition on Marine Productivity", Malta
2007 **Member of the Steering Committee and local organizer**, "WMO/GEO Expert Meeting on an International Sand and Dust Storm Warning System", Barcelona, Spain

- **INSTITUTIONAL RESPONSIBILITIES**

2016 – **AXA Chair on Sand and Dust Storms**, BSC, Spain
2016 – **Head of the Atmospheric Composition Group**, BSC. Spain

- **COMMISSIONS OF TRUST**

2016 – **Scientific Advisor**, World Meteorological Organization Sand and Dust Storm Warning System Regional Center for North Africa, Europe and Middle East
2014 – 2015 **Evaluator of Research proposals**, NERC, UK / Department of Energy, US
2014 **Member of the expert panel** on extreme events for "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment", as part of the President's Climate Action Plan, US Global Change Research Program (USGCRP)
2012 **Principal Science Advisor**, Atmospheric dust module of the COMET Program, University Corporation for Atmospheric Research (UCAR) and NOAA National Weather Service.
2008 – 2011 **Spanish Representative**, Meningitis Environmental Risk Information Technologies (MERIT), World Health Organization, Geneva, Switzerland
2007 – 2010 **Member of the Steering Committee**, World Meteorological Organization Sand and Dust Storm Warning System Regional Center for North Africa, Europe and Middle East
2007 **Member of the Writing team**, Implementation Plan for an International Sand and Dust Storm Warning System of the World Meteorological Organization
2007 **Editor**, Book of proceedings "WMO/GEO Expert Meeting on an International Sand and Dust Storm Warning System", IOP Conference Series: Earth Environmental Science
2004 – **Reviewer**: Scientific Reports, Nature Geoscience, Biomedcentral Infectious Diseases, Journal of Climate, Geoscientific Model Development, Atmospheric Chemistry and Physics, Tellus B, Theoretical and Applied Climatology, Atmospheric Environment, Geophysical Research Letters, Journal of Geophysical Research, and other

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES**

2016 – Member of the International Cooperative for Aerosol Prediction (ICAP)
2009 – American Geosciences Union
2008 – 2011 Member of the Meningitis Environmental Risk Information Technologies (MERIT)
2004 – 2009 Principal Investigator of the NASA Aerosol Robotic Network (AERONET) in Barcelona.
2004 – 2008 European Geosciences Union

- **MEDIA APPEARANCES:** The Guardian, Astrobiology Magazine, Phys.org, Psychology Today, Voice of America, SciDevNet
- **INSTITUTIONAL HIGHLIGHTS OF MY RESEARCH:** NASA Global Climate Change, NASA Goddard Institute for Space Studies, Earth Institute at Columbia University, International Research Institute for Climate and Society, ECMWF, Barcelona Supercomputing Center
- **AEROSOL-CHEMISTRY MODEL DEVELOPER** BSC-DREAM8b model, MONARCH (NMM/BSC-CTM), NASA Earth System ModelE, Dust forecasts (http://sds-was.aemet.es, http://dust.aemet.es), Air quality forecasts (http://www.bsc.es/caliope/es)
- **MOST RELEVANT COLLABORATORS** Zavisa Janjic (NOAA NCEP, US), Ron L. Miller (NASA, US), Madeleine Thomson (IRI/Columbia University, US), Jan Perlwitz (NASA, US), Natalie Mahowald (Cornell U., US), Paul Ginoux (NOAA GFDL, US), Peter Diggle (Lancaster U., UK), Slobodan Nickovic (Institute of Physics, Belgrade, Serbia), Joe Prospero (U. Miami, US), Yves Balkanski (IPSL, France), Sergio Rodríguez (AEMET, Spain), Emilio Cuevas (AEMET, Spain), Oriol Jorba (BSC, Spain)

Appendix: All on-going and submitted grants and funding of the PI (Funding ID)

On-going Grants

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
AXA Chair on Sand and Dust Storms (long term research program on dust research)	AXA Research Fund	EUR 1.7 million	2016-2030	AXA Chair holder (AXA Professor)	The endowment awarded to the PI is to support his general dust research at BSC but not to fund the specific experimental and modeling activities proposed in this ERC proposal.
ACTRIS PPP Aerosols, Clouds and Trace Gases Research Infrastructure Preparatory Phase Project	H2020	Associated with the PI EUR ~21 k	2017-2019	Contribution to WP7: ACTRIS Strategy and long-term vision	none

Grant applications

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*[2]
EMIT	NASA Earth Venture Instrument-4 program	Total Budget: ~$40 million Directly to the PI: none	2018-2022	Role: Part of the Science Team PI: Robert O. Green, JPL Deputy-PI Natalie M. Mahowald, Cornell Other members of the Science Team include Roger Clark, PSI Paul Ginoux, NOAA Olga Kalashnikova, JPL Ron Miller, NASA Greg Okin, UCLA Bethany Ehlmann, Caltech Luis Gaunter, DLR (PI of the German EnMAP mission) **Role:** Provide advice on the use of surface mineral maps retrieved from spectroscopy for dust modelling	EMIT proposes to sample the surface mineral composition of Earth dust sources using hyperspectral imaging spectroscopy from the International Space Station (ISS) during a 12-month mission. FRAGMENT is **complementary** as it proposes advancing our fundamental knowledge on dust mineralogy based on field campaigns, detailed laboratory analyses and theoretical innovations, which is not addressed in EMIT. Four members of the Science Team of EMIT will collaborate in FRAGMENT (Robert O. Green, Ron Miller, Roger Clark and Bethany Ehlmann)

Previously awarded Grants

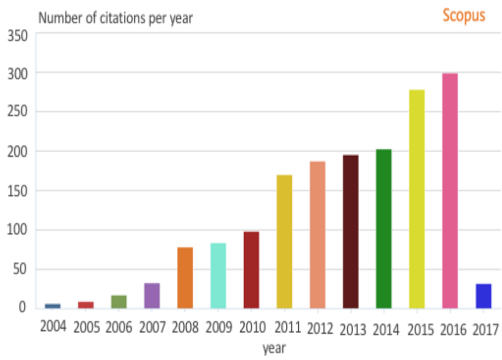
I have participated in 26 Research projects in Spain, EU, and US. Below I highlight the projects where I was Project Director (PD), Principal (PI) or Co-Principal Investigator (Co-PI). Overall the budget I have attracted is ~ **EUR 4 million** (including the AXA Chair Endowment).

1. **PD and Institutional PI**. Department of Energy (DoE DE-SC00671). "Improving the representation of soluble iron in climate models". Collaborative Project between Columbia University, NASA and Cornell University. NASA-Columbia PI: Carlos Pérez García-Pando. Cornell PI: Natalie Mahowald. **$750,000** (10/2011-10/2014).
2. **Co-PI**. NASA ROSES Modeling, Analysis and Prediction Program. "*Contribution to radiative forcing and climate by anthropogenic sources of dust aerosol*". PI: Ron L. Miller. Co-I's from NASA, Columbia University, Geophysical Fluid Dynamics Laboratory and Princeton University. **$1,020,000** (07/2014-07/2016).
3. **Co-PI.** R2O Initiative for the Next Generation Global Prediction System (NGGPS)**,** NOAA. ***"****Implementation and testing of dust models for regional and global forecasting".* PI: Paul Ginoux (GFDL). **$200,000** (2015-2016).
4. **PI**. Earth Institute Cross-Cutting Initiative (CCI). "*Atmospheric aerosol impacts on health in sub-Saharan Africa*". **$45,000** (09/2010-2011).
5. **PI**. Ministry of Science and Technology, Spain. Contract CGL2006-11879/CLI. "*Improvement of the Dust Regional Atmospheric Model (DREAM) for prediction of Saharan dust events in the Mediterranean and the Canary Islands*". **130,000 €**. (10/2006–09/2009).

Section c: Early achievements track-record (max. 2 pages)

After my PhD, I have held research positions as **Group Leader** at the Barcelona Supercomputing Center (BSC, 2006-2009); **Visiting Scientist** the NOAA/National Centers for Environmental Prediction (NCEP, 2009), **Earth Institute Fellow** at the International Research Institute for Climate and Society, Columbia University (IRI; 2009-2011) and the NASA Goddard Institute for Space Studies and Columbia University (NASA GISS; 2009-2011), and **Associate Research Scientist** at NASA GISS (2012-2016). In October 2015, I was **awarded with an AXA Chair of 15 years duration to develop my cross-disciplinary dust research program at the BSC**. The AXA endowment amounts EUR 1.7 million. In 2016 I was also awarded with **Spanish the Ramon y Cajal reintegration fellowship (I was ranked #1 in Earth Sciences)**. I joined BSC as **Head of the Atmospheric Composition Group, where I lead the work of 12 people including senior researchers, postdocs, PhD students and technical support staff.** My research focuses on understanding the physical and chemical processes controlling atmospheric aerosols, and evaluating their effects upon climate, ocean biogeochemistry, air quality and health.

Among my most significant achievements, we can mention 1) my seminal work showing that the inclusion of dust aerosol as a radiatively active substance in numerical weather prediction models can significantly improve weather forecasts over dust affected regions (**Pérez et al. 2006a[15]; 2006b[139]; IF: 3.3; 301 combined citations**); 2) the development of the Multiscale Online Non-hydrostatic AtmospheRe CHemistry model (MONARCH) in collaboration with Zavisa Janjic from NCEP (**Pérez et al., 2011[126]; IF: 5.11; 47 citations; and references therein**), 3) the development of a meningitis incidence model based on climate, dust, population data, and proxies for immunological state or susceptibility, which represented the first contribution of its kind (**Pérez García-Pando et al., 2014[140]; IF: 8.44; 16 citations**); and 4) the development of novel methods to constrain the mineral and chemical composition of dust in models that are the theoretical basis of FRAGMENT (**Pérez García-Pando et al., 2016[77]; IF: 4.2**)



SCOPUS: 56 documents, 1709 total citations by 1154 documents, excluding self-citations 1584, h-index 22
Google Scholar: 2853 citations, h-index 28
Researchgate: 2250 citations, h-index 24

My core area of expertise is atmospheric mineral dust. My work has resulted in **more than 50 peer-reviewed papers, 20 chapters in books, proceedings and reports, more than 150 contributions to conferences/workshops/seminars (26 as invited speaker) and the edition of a book of proceedings.**

Selected peer-reviewed publications. I selected the publications that are more recent and relevant to this ERC proposal. When my name appears both in bold and underlined implies that I was either project PI or group leader of the related publication. The name of my PhD Supervisor (J.M. Baldasano) is underlined. I only introduced 1 publication (#10) from my PhD period due to its relevance and impact.

1. Di Tomaso, E., Schutgens, N. A. J., Jorba, O., & **Pérez García-Pando, C.** (2016) Assimilation of MODIS Dark Target and Deep Blue observations in the dust aerosol component of NMMB-MONARCH version 1.0, Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-206, accepted.
2. Badia, A., Jorba, O., Voulgarakis, A., Dabdub, D., **Pérez García-Pando**, C., Hilboll, A., Gonçalves, M., & Janjic, Z. (2017). Description and evaluation of the Multiscale Online Nonhydrostatic AtmospheRe CHemistry model (NMMB-MONARCH) version 1.0: Gas-phase chemistry at global scale. Geoscientific Model Development, in press. http://www.geosci-model-dev-discuss.net/gmd-2016-141/
3. **Pérez García-Pando, C.**, Miller, R.L., Perlwitz, J.P., Rodríguez, S., & Prospero, J.M., (2016). Predicting the mineral composition of dust aerosols: Insights from elemental composition measured at the Izaña Observatory. Geophysical Research Letters, 43, 10520-10529. **(IF: 4.2)**
4. Perlwitz, J.P.*, **Pérez García-Pando, C*.**, & Miller, R.L.,* (***Equal contribution**) (2015). Predicting the mineral composition of dust aerosols–Part 1: Representing key processes. Atmospheric Chemistry and Physics, 15(20), 11593-11627. **(IF: 5.11; 10 citations SCOPUS)**
5. Perlwitz, J.P., **Pérez García-Pando, C.**, & Miller, R.L. (2015) Predicting the mineral composition of dust aerosols–Part 2: Model evaluation and identification of key processes with observations. Atmospheric Chemistry and Physics, 15(20), 11629-11652. **(IF: 5.11; 4 citations SCOPUS)**
6. Menut, L., **Pérez, C.**, Haustein, K., Bessagnet, B., Prigent, C., & Alfaro, S. (2013). Impact of surface roughness and soil texture on mineral dust emission fluxes modeling. Journal of Geophysical Research: Atmospheres, 118(12), 6505-6520. **(IF: 3.3; 25 citations SCOPUS)**

7. **<u>Pérez, C.,</u>** Haustein, K., Janjic, Z., Jorba, O., Huneeus, N., Baldasano, J. M., Black, T., Basart, S., Nickovic, S., Miller, R.L., Perlwitz, J.P., Schulz, M., & Thomson, M. (2011). Atmospheric dust modeling from meso to global scales with the online NMMB/BSC-Dust model–Part 1: Model description, annual simulations and evaluation. Atmospheric Chemistry and Physics, 11(24), 13001-13027. **(IF: 5.11; 47 citations, SCOPUS)**
8. Seifert, P., Ansmann, A., Mattis, I., Wandinger, U., Tesche, M., Engelmann, R., Mueller, D., **Pérez, C.,** & Haustein, K. (2010). Saharan dust and heterogeneous ice formation: Eleven years of cloud observations at a central European EARLINET site. Journal of Geophysical Research: Atmospheres, 115(D20201). **(IF: 3.3; 44 citations SCOPUS).**
9. Schulz, M., Prospero, J.M., Baker, A.R., Dentener, F., Ickes, L., Liss, P.S., Mahowald, N.M., Nickovic, S., **Pérez**, **C.,** Rodríguez, S., Sarin, M., Tegen, I., & Duce, R.A. (2012). Atmospheric transport and deposition of mineral dust to the ocean: implications for research needs. Environmental science & technology, 46(19), 10390-10404. **(IF: 5.4; 58 citations SCOPUS)**
10. **Pérez, C.,** Nickovic, S., Pejanovic, G., Baldasano, J. M., & Özsoy, E. (2006). Interactive dust-radiation modeling: A step to improve weather forecasts. Journal of Geophysical Research: Atmospheres, 111(D16206). **(IF: 3.3; 140 citations SCOPUS)**

<u>Research monographs</u>

- Editor of the book: WMO/GEO Expert Meeting on an International Sand and Dust Storm Warning System, IOP Conference Series: Earth and Environmental Science Volume 7, Number 1
- Co-author in 2 chapters of Book: Mineral Dust - A Key Player in the Earth System. (Editors P.Knippertz & JB Stuut) Springer Publishing. ISBN 978-94-017-8978-3. www.springer.com/us/book/9789401789776
- Co-author of: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. USGCRP, 2016. http://www.globalchange.gov/health-assessment

<u>Atmospheric aerosol-chemistry model developments</u>

- BSC-DREAM8b model, MONARCH, NASA Earth System ModelE,
- Dust and air quality forecasts (sds-was.aemet.es; dust.aemet.es; www.bsc.es/caliope/es)
- I played a seminal role on the design, creation and successful implementation of the World Meteorological Organization (WMO) Regional Centers on Sand and Dust Storm Prediction in Spain, the only operational forecasting services for airborne dust fully recognized by WMO

<u>26 invited talks in conferences, workshops and seminars. I highlight five recent ones.</u>

- Invited for a keynote talk on dust mineralogy. Goldschmidt Conference, Paris (August 13-18, 2017)
- Modeling Mineral Dust and its Effects upon Climate: Current Status and Challenges (2016) 1st National French Dust Workshop, Paris (Keynote)
- Dust Composition in Climate Models: Current Status and Prospects (2015) American Geophysical Union (AGU) Fall Meeting 2015, San Francisco (Invited)
- Constraining the Dust Mineral Composition in Climate Models (2015) Conference on Airborne Dust, Climate Change, and Human Health, funded by NOAA, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Florida (Invited)
- Can We Inform Reactive Vaccination Strategies for Meningococcal Meningitis in Sub-Saharan Africa Using Dust and Climate Predictors? (2015) Conference on Human Health in the Face of Climate Change: Science, Medicine, and Adaptation. Organized by the "la Caixa" Foundation, BIOCAT, and the New York Academy of Sciences. Barcelona, Spain (Invited)

<u>Prizes, awards and recognitions</u>

- **AXA Chair on Sand and Dust Storms**. Endowment of EUR 1.7 million awarded by the AXA Research Fund to support my research program at BSC, Spain.
- **Ramon y Cajal Fellowship** awarded by the Ministry of Economy, Industry and Competitiveness, Spain (I was ranked #1 in Earth Sciences)
- Co-author of the Best Publication at NASA Goddard Institute for Space Studies (Miller et al., 2014)
- Best Science Brief at NASA Goddard Institute for Space Studies (2014)
- Poster presentation prize at the 11th International Conference on Harmonisation within atmospheric dispersion modelling for atmospheric purposes (2007).
- My work on dust and disease interactions has been highlighted among others by NASA and the European Centre for Medium-Range Weather Forecasts, and covered by international media such as The Guardian

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2) Textor, C., Schulz, M., Guibert, S., Kinne, S., Balkanski, Y., Bauer, ... & Tie, X. (2006). Analysis and quantification of the diversities of aerosol life cycles within AeroCom. Atmospheric Chemistry and Physics 6, 1777-1813.
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ERC Consolidator Grant 2017
Research proposal [Part B2]

Part B2: ***The scientific proposal***

Section a. State-of-the-art and objectives

The importance of dust mineralogy

Soil dust aerosols are a key component of the Earth system[1]**.** Soil dust aerosols created by wind erosion of arid and semi-arid surfaces are amongst the largest contributors to the global aerosol mass load[2] and dominate climate effects over large areas of the Earth[3,4]. Deposition measurements from ice cores and ocean sediments indicate large temporal variations of dust[5-7] occurring on time scales ranging from interannual to decadal as well as glacial to geologic. Dust is not only an indicator of past climate variations but also an integral contributor to climate change[8,9].

Climate perturbations by dust aerosols depend fundamentally upon their physical and chemical properties. 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 [10,11]. The Intergovernmental Panel on Climate Change (IPCC) has identified dust mineralogy as a key uncertainty in the overall contributions of aerosols to radiative forcing[12,13].

Dust perturbs the energy and water cycles by direct radiative forcing[14-19]. The absorption of solar radiation by dust is strongly related to the presence of iron oxides[20-25]. Thermal radiation is also sensitive to mineralogy[26], specifically to abundance of phyllosilicates (clays), quartz and carbonates[27-29].

Dust influences cloud formation and the associated indirect radiative forcing by providing nuclei for liquid and ice clouds[30-38]. The ice nucleation properties of dust depend upon its surface defects[11]. Recent studies have revealed that K-feldspar is the key mineral for ice nucleation[39-43]. The droplet nucleation properties of dust depend upon hygroscopicity, which increases during transport and depends on mineralogy[44-47].

Dust undergoes heterogeneous chemical reactions during transport that increase its hygroscopicity, while altering its optical properties, and the associated radiative forcing[48]. The rates of heterogeneous chemical reactions on the dust surface that form coatings of sulfate, nitrate, chloride, or organics depend strongly on the dust mineralogical composition[49-51]. For example, the uptake of sulfur dioxide by calcite exceeds by at least an order of magnitude uptake by quartz, feldspar and hematite[52-55]. Dust composition also affects the partitioning of semi-volatile inorganic compounds[56], altering their burden and radiative forcing[57].

Dust minerals containing bioavailable iron deposited into ocean waters catalyze photosynthesis by ocean phytoplankton, increasing carbon dioxide uptake and influencing the global carbon cycle[58-60]. The iron content and potential solubility of dust, along with the chemical processes that increase iron bioavailability during atmospheric transport, depend strongly upon mineralogical composition[61,62].

Earth System models typically assume that dust aerosols have a globally uniform composition[12,13]**, neglecting the known local and regional variations in the mineralogical composition of the sources**[63-65]. Modeling efforts have focused on constraining dust sources[66-68], emission[69] and PSD[69-72]. While this minimal representation has allowed significant advances in dust and climate research over the past decade, the omission of dust mineralogy impedes further understanding of the dust role in the Earth system.

The challenge of constraining global dust mineralogy

Distinguishing the emitted PSD of individual dust minerals is critical to properly quantifying the climate effect of dust. Even without the complexity of mineralogy, the representation of the total dust PSD at emission is currently challenged by our incomplete understanding of the physics of dust emission and a lack of measurements on global scales[73]. **Coincident observations of the PSD of the emitted dust and parent soil are scarce and do not distinguish the emission of individual minerals** [73]**; existing theoretical paradigms disagree fundamentally on multiple aspects**[73-78]**.**

While the dust PSD at emission remains uncertain, constraining its mineralogical composition poses additional key challenges[79-82]. Deriving dust mineralogical composition requires global knowledge of soil mineral content. Global atlases of soil mineralogy for modelling the lifecycle of dust aerosols[63-65] are based upon measurements following wet sieving, a technique that disperses (breaks) the mineral aggregates found in the undisturbed parent soil, replacing them with a collection of smaller particles[74,83-87]. During emission, the original, undisturbed aggregates are **fragmented**, but only partially. This results in differences in the PSD, mineralogy and mixing state between the emitted particles derived from the undisturbed soil versus the disturbed (wet-sieved) soil. **The complete lack of experimental studies tackling the size-resolved**

mineralogy of emitted dust and its relationship with the parent soil hinders our ability to extend and constrain theories of dust emission.

Soil mineralogy atlases for dust modelling are derived by massively extrapolating an inhomogeneous and limited set of mineralogical analyses of soil samples that are particularly scarce in the arid and semi-arid areas that contain the dust sources[63-65]. Soil mineralogy is derived assuming a relationship with observed soil type that neglects the potentially large regional variations in the mineral content within each soil type. Other key limitations of derived soil mineralogy include the uncertain estimation of iron oxide minerals from qualitative descriptions of soil color, the crudely resolved mineral PSDs, and the lack of knowledge of the mixing state of the minerals. **Airborne and spaceborne spectroscopic mapping of soil mineralogy is a promising path to understand the relative abundance of the key dust source minerals with sufficient detail and coverage, but this resource has been virtually unexplored in the context of dust modelling.**

Objectives

The overarching goal of **FR**ontiers in dust miner**A**lo**G**ical co**M**position and its **E**ffects upo**N** clima**T**e (FRAGMENT) is to understand, constrain and calculate the global mineralogical composition of dust along with its effects upon climate. **FRAGMENT will fundamentally advance the treatment of dust mineralogy by fulfilling the following objectives (Fig. 1)**:

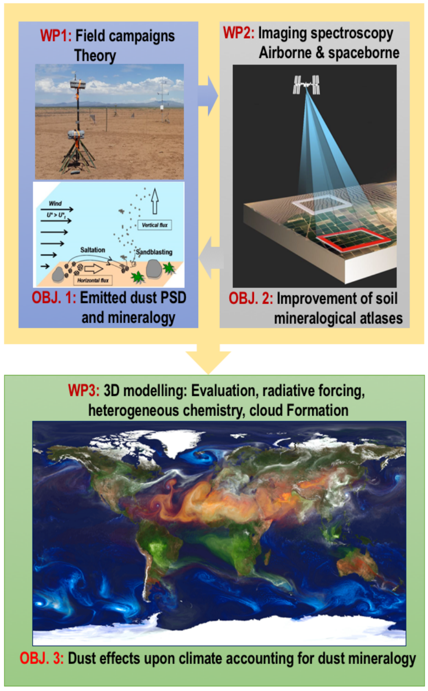


Fig. 1 Conceptual scheme of FRAGMENT. Each of the three objectives (OBJ. 1, OBJ. 2, OBJ. 3) is addressed through their corresponding work packages (WP1, WP2, WP3)

<u>Objective 1:</u> We will contribute **new fundamental understanding** to reduce the large uncertainties in the **emitted dust PSD** by evaluating and extending current theoretical paradigms, based on an unprecedented ensemble of coordinated **measurement campaigns and laboratory analyses**. We will also address for the first time both experimentally and theoretically the **size-resolved mineralogy of dust at emission and its relationship with the parent soil**.

<u>Objective 2:</u> Precise knowledge of dust mineral content requires more detailed and widespread measurements of soil mineralogy. **We will generate integrated and quantitative knowledge regarding the influence of dust mineral composition upon atmospheric radiation, chemistry and clouds** based on modelling experiments constrained with our theoretical innovations and field measurements.

<u>Objective 3:</u> While the impact of dust mineralogy upon climate is potentially large, the interconnection of mechanisms has been neglected in the few models that represent mineral variations. **We will generate integrated and quantitative knowledge regarding the influence of dust mineral composition upon atmospheric radiation, chemistry and clouds** based on modelling experiments constrained with our theoretical innovations and field measurements.

<u>Hypotheses and key scientific questions addressed by FRAGMENT</u>

<u>Objective 1.</u> From the soil to the atmosphere: The emitted PSD and mineralogy of dust

Soil dust particles that travel thousands of kilometers downwind from their source generally have diameters below ~20 µm. However, the direct **aerodynamic entrainment** (emission) of these particles is hindered by interparticle cohesion forces that form aggregates of larger sizes[88-90]. The majority of these particles are released through **saltation bombardment**, in which soil aggregates are fragmented by impacts from larger saltating grains, and **aggregate disintegration**, in which saltating aggregates are fragmented upon striking the soil surface[73,75,76,91,92]. Over the last two decades, the theories of Alfaro and colleagues[75,93,94] and Shao[74,95] have provided a framework to predict the emitted dust PSD. Alfaro's **dust production model** (DPM) parametrizes the emitted PSD as three lognormal modes, whose relative proportions depend upon the bonding energy of the soil aggregates and the kinetic energy of the saltators impacting the soil. The DPM predicts more fragmentation of aggregates and thus **smaller emitted particles with increasing wind speed**, in agreement with wind tunnel experiments[93]. Shao calculates the emitted PSD as a weighted average of the PSD measured for undisturbed and the disturbed soil. The weighting factor depends upon two empirical coefficients and the wind speed, and also predicts smaller particles with increasing wind speed in agreement with the same tunnel experiments[93]. However, the practical use of these theories in global models is hindered by the **lack of data on input soil properties**: the binding forces, lognormal mode parameters and empirical coefficients may be soil-specific and therefore not known[78,96], and the undisturbed soil PSD is not available on global scales. To sidestep the lack of measurements, Kok[76] proposed an alternative theory for the emitted PSD, based upon **brittle**

fragmentation theory (BFT), whose main assumption is that soil aggregates fragment and release dust following the physics of brittle materials. BFT posits that the **emitted PSD is relatively independent of both the undisturbed soil PSD and the wind speed**, at least partly eliminating the need for a detailed understanding of the soil interparticle forces. Its application requires knowledge of the dispersed soil PSD, and the side crack propagation length (λ), whose dependencies are uncertain[72,77]. Kok[75] argues that λ can be approximated as a constant (~12 μm) based on the few available measurements of the emitted PSD. The theory correctly predicts not only the observed power law in the 2-10 μm, but also the relative reductions of the PSD below 2 μm and above 10 μm. (Note that the theory is not applicable for aerodynamically lifted dust, for very cohesive soils, or for dust larger than ~20 μm, whose emission is not always due to fragmenting impacts.) The agreement of BFT with measurements is both provocative and auspicious for modeling. Whereas other prevailing theories[74,75] predict that the emitted PSD depends upon wind speed and undisturbed soil properties, in BFT, the emitted PSD is relatively independent of both factors. Later revisions by Kok and colleagues[72,76] suggest that the range of invariance may be confined to diameters below ~5μm (above that value the limited experimental data show more scatter), and that λ, rather than being a constant, may vary between ~10 and ~15μm depending on soil properties such as aggregate stability. However, this framework still defends and assumes that the emitted PSD is independent of wind speed[78].

Given the paucity and incompleteness of measurements, and the apparent contradiction among theories, field observations and wind tunnel experiments, **FRAGMENT will conduct field campaigns in distinct source regions to measure the size-resolved dust emission for a range of meteorological and soil conditions in conjunction with an extensive analysis of the underlying soil characteristics. Our aim is to improve our quantitative understanding of the emitted dust PSD. To our knowledge, the variety and completeness of our proposed characterization is unprecedented.**

We aim to answer a number of key questions including: *Does the emitted dust PSD depend on wind speed? How do the contrasting theoretical frameworks compare with observations? Are the lognormal modes and binding forces in the DPM and the empirical coefficients in Shao's theory soil-specific? What is the range of variability of the BFT parameter λ? Does λ depend on identifiable and quantifiable soil properties such as the dry aggregate stability? If yes, how can we account for it? Is the emitted PSD dependent on the emission mechanism (aggregate disintegration vs saltation bombardment vs aerodynamic entrainment)?*

FRAGMENT will not only characterize the emitted dust PSD but also its size-resolved mineralogy through both theory and field campaigns, which to our knowledge has no precedent. Global soil mineralogy atlases for dust-cycle modelling[63-65] are based upon measurements following wet sieving, which disperses the aggregates found in the soil. In recent studies[79,80,82], we showed that BFT provides an ideal framework to predict the emitted PSD in terms of its constituent minerals because it builds upon relatively abundant dispersed soil data. BFT predicts that the emitted PSD (Fig. 2a) is shifted toward larger diameters compared to the PSD of the dispersed soil (Fig. 2b). That is, the fragmentation of mineral aggregates, specially phyllosilicates, during saltation preserves a greater fraction of mass at silt sizes compared to the breaking of aggregates during dispersion of the soil prior to analysis[78]. The colored areas in Fig. 2b are an example of the bulk mineral fractions within the clay size range (0-2 μm) and the silt size range (2-50 μm) derived from a global atlas[61,62] and fitted to a monomodal PSD based upon measurements of a disturbed soil[76]. Despite the crude size-dependence of the mineral fractions derived from the soil type atlas, the emitted PSD derived using BFT (Fig. 2a) significantly improves our ability to predict global measurements of the dust mineral composition[78,79,81]. However, the comparison still highlights significant errors such as the significant overestimation of quartz and feldspar. **We hypothesize that approximate knowledge of the characteristic PSDs of each mineral in the dispersed soil is key to constraining the global mineralogical composition.** Based on the bulk content of each mineral in the clay and silt size ranges and on several assumptions, we fitted mineral-specific dispersed PSDs (Fig. 2c shows an example for one soil type). Our fitting matches qualitatively the expected soil particle sizes for each mineral. For example, feldspar and quartz feature larger median diameters in the soil than other silt minerals such as calcite. Extending BFT with this new dependence upon soil PSD significantly improves our predictions (not shown). For example, the overestimation of quartz and feldspar

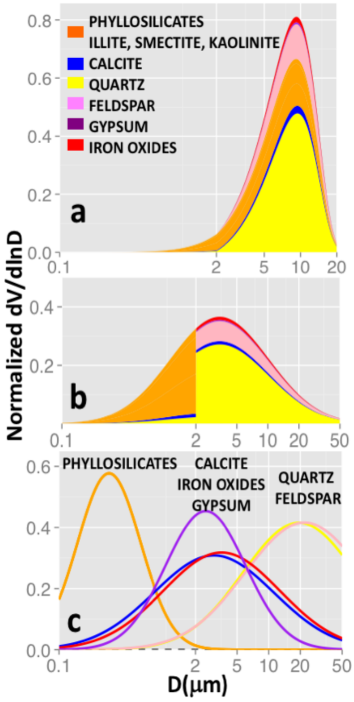


Fig. 2 Example of (a) emitted PSD and mineralogy by BFT; (b) average soil dispersed PSD and mineral fractions; (c) proposed extension of BFT by fitting mineral-specific PSDs.

in downwind measurements is reduced because its distribution within the dispersed soil and the emitted dust is shifted towards larger diameters (with shorter particle lifetimes) compared to other minerals. **FRAGMENT will conduct unprecedentedly detailed size-resolved mineralogical, chemical and mixing state analysis of the soil and emitted dust sampled during the field campaigns to test BFT and our proposed theoretical extensions for individual minerals. We aim to better understand and constrain the evolution of each mineral's PSD from the parent soil to the atmosphere, focusing upon minerals such as hematite and feldspar that are key for radiation and ice nucleation, respectively.**

The key questions we aim to answer include: *Does the observed size-resolved mineralogy of the soil and the emitted dust support BFT and our proposed extensions? What are the typical dispersed PSDs for each mineral? What is the PSD and mixing state of the different minerals in the emitted dust compared to the dispersed and undispersed soil? What is the best strategy to derive the mineral-specific disturbed PSDs from existing global information of soil texture and soil mineralogy?*

<u>**Objective 2:**</u> **Global mineral mapping through hyperspectral imaging spectroscopy**

Modeling of dust aerosol mineralogy is based upon maps of soil type and the relation of this variable to soil mineralogy. This relation is inferred using massive extrapolation from a limited amount of soil mineralogical analyses, ancillary information on soil texture and color, and a number of additional assumptions[65]. This limited knowledge together with our incomplete understanding of the emitted dust PSD and its relationship with the PSD of the parent soil precludes accurate assessment of the effects of dust upon climate. To address this challenge, **FRAGMENT will improve current estimates of soil-surface mineralogy for dust modelling using spaceborne and airborne imaging spectroscopy. Remote spectroscopic mapping of dust source regions is a promising path for measuring the relative abundance of the key dust source minerals with sufficient detail and global coverage.** Over the last two decades, the field of imaging spectrometry has progressed with the development of new instruments, both airborne[97-100] and spaceborne[101-107], and analysis techniques[108,109]. The launch of EO-1/Hyperion[105] by NASA and of CHRIS[106] on Proba-1 by ESA are significant landmarks in the progression of the technology. The future is also promising. **Recently, FRAGMENT members, including the PI, have proposed to sample the surface mineral composition of Earth dust sources at very high spatial resolution using hyperspectral imaging spectroscopy from the International Space Station (ISS) during a 12-month mission.** The proposed mission, named EMIT, is under review within the NASA Earth Venture Instrument-4 program. EMIT would provide large spectral range (410 to 2450 nm), high signal-to-noise ratio (SNR), high-resolution spatial sampling (≤100 m), and comprehensive near-term coverage of most mineral dust sources. EMIT would supersede current space multispectral measurements from Landsat, ASTER, and SENTINEL, and create a paradigm shift by allowing the production of an accurate near-global database of surface mineralogy that exceeds, by six orders of magnitude, the mineralogical analyses that underpin the current mineralogical atlases. The German EnMAP mission[110] will provide similar spectroscopic measurements after 2019, although it will have a more limited data acquisition capacity[111].

Given the current absence of EMIT and EnMAP retrievals, we will use existing EO-1/Hyperion satellite data[105], a virtually unexplored resource for dust modeling, while we evaluate and refine our analysis methods in anticipation of the coming missions. Hyperion's signal-to-noise ratio (SNR) is inferior to that of EMIT and EnMAP, but has shown potential to map basic mineralogy for geological applications[112,113]. Given the poor quality of soil mineralogical atlases, using the 90,000 scenes provided by EO1/Hyperion globally could drastically and immediately improve current estimates. **FRAGMENT aims to demonstrate the value of EO1/Hyperion for mapping soil mineral abundance for dust aerosol modeling, and create a methodological framework to produce higher quality maps when EMIT and EnMAP data become available.** We will improve current retrievals by examining issues of spectral and spatial scaling, including subpixel detection, and quantification. Deriving surface mineral abundances for dust modelling from spectroscopic measurements introduces challenges that our field measurements will address. For example, current and planned hyperspectral instruments do not retrieve feldspar and quartz, whose absorption features are beyond the measured spectral window. We will combine spectroscopic abundances of other minerals with quartz and feldspar values from current atlases derived from soil type. We will use field campaign measurements to combine grain size information from spectroscopy with atlases mostly based on dispersed soil samples. **One of our field campaigns will be conducted in the Salton Sea (California), a region prone to wind erosion, where high-quality retrievals from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) are available (Fig. 3). The campaign will collocate airborne and spaceborne spectroscopic measurements with detailed mineralogically resolved measurements of soil and emitted dust, and additional field spectroscopic measurements**.

The key questions that we aim to answer include: *How well is the surface mineralogical composition retrieved by AVIRIS (high SNR) and Hyperion (lower SNR) compared to field spectroscopy and laboratory measurements of soil samples? How does composition vary as a function of grain size retrieved from spectroscopy? How do we relate mineral abundance and grain size information derived from spectroscopy to mineral abundance and PSD derived from both disturbed and undisturbed soil samples? How does the composition and PSD of the emitted dust collected during the field campaign differ from that of the soil retrieved with spectroscopy? How homogeneous is the composition of the soil as a function of spatial scale? How do we combine existing soil mineralogy atlases with information from spaceborne retrievals?*

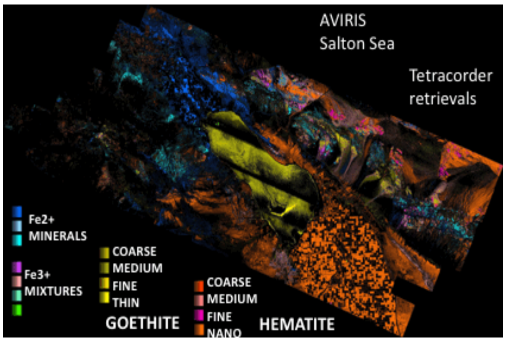


Fig. 3 Iron mineralogy retrievals in the Salton Sea with AVIRIS using the Tetracorder algorithm

<u>Objective 3:</u> Modelling, evaluation and effects upon radiation, heterogeneous chemistry and clouds

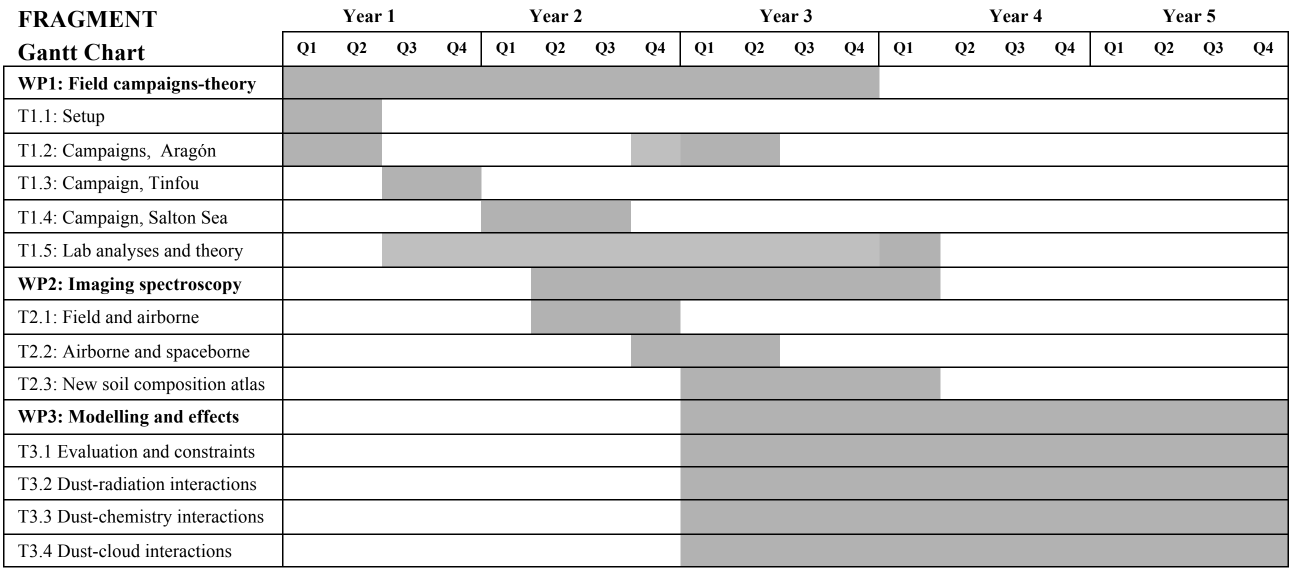
Emitted dust is transported throughout the atmosphere where it affects the energy and water cycles by radiative interactions[14-29] and interacts with both warm and mixed-phase clouds[30-43]. Dust radiative forcing in nearly all global models varies with environmental properties like surface albedo, along with the dust PSD, but excludes the effect of regional variations in forcing resulting from source variations in soil mineral composition. For particles of a given size, absorption at short wavelengths is most sensitive to the presence of iron oxide minerals within the dust particle[20-25], and at long wavelengths to the presence of phyllosilicates, calcite and quartz[26-29]. **FRAGMENT will enable and evaluate a multiscale atmosphere-chemistry modeling system that includes state-of-the-art dust capabilities with unprecedented constraints on the size and composition-resolved dust emission. We will constrain the total dust emission fluxes through data assimilation techniques and derive additional constraints on the emitted PSD and mineralogy by comparing observations to a large number of model experiments perturbed within the estimated ranges of uncertainty.** Because iron oxides contribute only a small fraction of the dust mass, their evaluation in a model based upon direct measurements of dust composition is subject to greater uncertainty, compared to more abundant minerals like clays and quartz. However, their absorption dominates even at low abundance. **Our evaluation of iron oxides will include radiance measurements from multiple in-situ and spaceborne instruments. This evaluation will allow stronger constraints upon direct radiative forcing by dust aerosols than is currently possible from models that do not consider aerosol mineralogy.**

Dust also affects the partitioning of inorganic aerosol components[56] and undergoes heterogeneous chemical reactions with acidic trace gases that result in the formation of coatings on the dust particle surface[114-125], including sulfate—by uptake of sulfur dioxide or reacting with sulfuric acid—, and nitrate—by uptake of nitric acid, dinitrogen pentoxide, nitrate radical or nitrogen dioxide. These interactions affect cloud droplet formation by changing both the burden of soluble material and by increasing the hygroscopicity of dust[126]. Current models that include dust heterogeneous chemical reactions omit variations in dust mineralogy[127,128]. In the case of cloud droplet formation, only recently has a study assessed the effect of dust composition upon the partitioning of inorganic aerosol components[57]. However, this study neglects heterogeneous chemical reactions, and the underlying soil information consists of only ten points globally. These omissions are potentially important. For example, quartz and feldspar are relatively unreactive toward sulfur dioxide, which contrasts with the high reactivity of calcite[52-55]. Dust is also a key source of ice nuclei in mixed-phase clouds due to its high nucleation efficiency[129-131]. The ice nucleation of dust is mostly controlled by the amount of uncoated K-feldspar[39-43], although Na-plagioclase feldspars and quartz may also play a more prominent role than previously thought[43]. **FRAGMENT will investigate the effect of modeled dust mineralogy upon the partitioning of inorganic aerosol components and heterogeneous chemistry, along with the subsequent effects upon warm-cloud formation and heterogeneous ice nucleation in mixed-phase clouds. We will provide quantitative understanding of the effects of mineralogical composition, based upon existing schemes for heterogeneous chemistry and warm and mixed-phase cloud formation, using our new constraints on the emitted PSD and mineralogy.**

We aim to address a number of questions including: *What is the impact of our new emission constraints upon the climate effect of dust? How large are the effects of regional variations in mineralogical composition relative to the effect of globally uniform particles? What is the present-day radiative forcing of dust? What is the minimal representation of minerals that needs be considered by Earth System Models to incorporate the largest impacts of dust on climate?*

Section b. Methodology

In order to achieve the ambitious goals of the project, FRAGMENT gathers a strong cross-disciplinary team working in concert across theory, measurements, laboratory analyses, spectroscopy and modelling. We will perform an unprecedented ensemble of field campaigns and laboratory analyses designed to test our theoretical hypotheses, generate novel fundamental and quantitative knowledge, and reduce the uncertainty on the emitted dust PSD and mineralogy (WP1). We will improve soil mineralogical atlases for dust modelling using field, airborne and spaceborne hyperspectral imaging spectroscopy (WP2). On the modelling side, we will investigate the influence of the dust PSD and mineralogy upon atmospheric radiation, chemistry and clouds using emission constraints provided by our theoretical innovations, field data, updated soil atlases and other available laboratory data and observations (WP3). How FRAGMENT will assess the effects of dust mineralogy upon climate is depicted in Fig. 1. Below we provide a Gantt chart illustrating the project schedule including the WPs and related tasks.



WP1. Field campaigns, analyses and theory

In the field experiments, we will test and develop theories linking the parent soil to the emitted dust in terms of PSD and mineralogy. We will perform a detailed characterization of the soil, emission and meteorology at three distinct regions (**Aragón**, Spain; **Tinfou, Zagora**, Morocco; and the **Salton Sea**, California, US) to confront theory, evaluate our hypotheses and answer key questions of this proposal. These regions meet several key criteria: **accessibility**; **variety** of soil types, textures, and landforms; **local/regional partners** that will help with the logistics for the campaigns; and **relevance** to respond to our diverse theoretical goals and questions.

Task 1.1. Setup of a mobile measurement platform and field procedures

We will build a mobile measurement platform consisting of a central tower and four peripheral towers equipped with active and passive dust samplers along with real-time dust measurement instruments. There will be an additional tower for meteorological measurements. The size-resolved suspended dust flux will be derived using optical spectrometers and multistage cascade impactors collocated at two heights on the central tower, based on the gradient method[132,133]. The optical spectrometers (GRIMM) will provide online measurements of the PSD of dust number concentration between 0.25 and 30 µm with time resolution of 1-6 s. The collocated multistage cascade impactors (modified DEKATI) will actively collect the suspended dust in five stages from 0.1 to 30 µm, which will allow calibrating the optical counters, testing the consistency of the independent mass and number measurements, and obtaining size-segregated samples for subsequent mass, chemistry, mineralogy and microscopy analysis (see Task 1.5). Additional passive sampling of the suspended dust will be performed at the five towers with sets of catchers at four different heights. While passive sampling is inefficient for collecting small suspended particles[134], its role is to accumulate enough mass during low emission events to allow an extensive and diverse set of laboratory analyses (see Task 1.5). Our focus is the emitted PSD and mineralogy, but identification of saltation is key to properly assess the applicability and limitation of emission theories. To this end, saltation sediment will be collected at the bottom of each tower using a modified version of the Cox sand catcher[135,136]. The precise history of the saltation events along with the time-resolved particle counts and kinetic energy will be obtained with *Sensit*[137] saltation sensors. (In Task 1.5 we describe how we will identify the occurrence of saltation.) The meteorological tower will be equipped with five cup anemometers and four temperature sensors at various heights to measure the wind speed and temperature profile, along with a relative humidity (RH) sensor and a wind vane. The wind and temperature profiles will be used to calculate wind friction velocity, soil roughness length and other parameters required to determine the vertical mass fluxes based on the gradient method[132,133]. While the wind speed will be available every 10 s, the proper determination of the vertical fluxes requires the wind friction velocity to be integrated over the major time scales of turbulence[133].

We will perform a stratified-random sampling of the soil, where 1 cm deep scoop samples are collected at locations that capture the variance of soil properties across each measurement site[138]. We will account for the potential effect of soil moisture on aggregation. Soil moisture variations at 1 cm depth will be measured using Time-domain Reflectometry sensors, whose applicability to wind erosion studies in arid environments has been proven if proper calibration is applied[139,140]. RH close to the surface will be also used to assess potential aggregate bonding, which has been argued to increase with RH except within the range ~40-60%, where it paradoxically decreases with RH[141].

Task 1.2: Multiannual measurement campaigns in Aragón, Spain

Aragon is a dry region subject to wind erosion by strong Cierzo winds throughout the year[142]. Its proximity to Barcelona (two hours by car) will facilitate the testing and fine-tuning of our instrumentation and field procedures and allow multiannual measurements at reduced cost. Our team includes local collaborators from the Estación Experimental de Aula Dei - CSIC, who have extensive experience in wind erosion measurements[142] in the region, and will assist with logistics and specific plot selection. Our first preparatory campaign will occur between March and April of the first year, with additional campaigns during the second and third years.

Task 1.3 Measurement campaign in Tinfou, Zagora, Morocco

Located in North Africa, Tinfou is located 35 km southeast of the city Zagora and surrounded by sources that produce massive and frequent dust storms[143]. Morocco is not only easily accessible from Spain, but is also safe and does not share the current and near-future security concerns of most other North African countries. We have confirmed local support by collaborators from DLR[144] (partnering with the Moroccan IRESEN[145]), who maintain a dust surface concentration measurement site in Zagora for solar radiation research. Our soil and emitted PSD measurements tailored for Tinfou will complement the detailed airborne data of the PSD, mineralogical composition, shape and optical properties obtained during the Saharan Mineral Dust Experiment (SAMUM) I campaign[143,146-149]. (Detailed mineralogical analyses of SAMUM-I data were contributed by a partner of this ERC proposal[143].) Another key feature is that dust transported from this region typically affects the Izaña Observatory on Tenerife Island, in the Canary Islands. Measurements at this location offer a continuous decadal record of size-resolved dust concentration and elemental composition[150]. Our colleagues at the Izaña Observatory will provide size-resolved dust samples from their daily routine measurement program for extensive mineralogical analysis. Our campaign at Tinfou will extend over ~3 months during the summer and fall of the first year.

Task 1.4 Measurement campaign in the Salton Sea region, California, US

The Salton Sea region has multiple environments for dust emission, including dry, ephemeral washes, interdune areas, and exposed lake sediments[151]. Most importantly, field sampling in this region allows direct comparison with existing airborne (AVIRIS) and spaceborne (EO1/Hyperion) hyperspectral imaging spectroscopy measurements that will be used to improve atlases of soil mineralogy for dust modelling. Our campaign will include additional field spectroscopic measurements along with the extensive emission and soil sampling. We will have local support in WP2 from our collaborators at Caltech and the NASA Jet Propulsion Laboratory. We plan to perform uninterrupted measurements for ~6 months during spring and summer of the second year. The spectroscopic measurements and methods are detailed in WP2 (Tasks 2.1 and 2.2).

Task 1.5 Laboratory analyses, theory and hypothesis-testing

We will derive the PSD of the dry (minimally dispersed) and wet (dispersed) soil and the saltation sediment using sonic sieving and a laser diffraction particle analyzer. The combination of this information with the *Sensit* saltation data and the meteorological data will allow identification of the emission mechanism. Whether dust emission is caused by saltation will be determined on the basis of saltation particle counts and wind friction velocity. The contributions of saltation bombardment and aggregate disintegration will be distinguished by contrasting the minimally dispersed and fully dispersed PSDs of the soil and saltation sediment. For bombardment, the saltation sediment PSD is barely changed by dispersion, because the saltators are sand particles that resist disintegration. In contrast, aggregate disintegration is characterized by saltating aggregates that fragment upon striking the surface. In this case, the PSD of the saltation sediment will be greatly modified by dispersion, and the difference between the dispersed PSDs of the saltation sediment and the soil will be small. The dry aggregate stability[152], i.e., the resistance of soil aggregates to breakdown from physical forces, will be characterized based on the mean weight diameter of the minimally dispersed soil PSD along with the percentage of aggregate disintegration after various levels of sonic energy applied[153]. By combining these data, the vertical size-resolved dust flux (or emitted PSD), meteorological measurements and soil moisture, we can **(1) directly identify the emission mechanism, while evaluating and refining the three theories to quantify the uncertainty, (2) understand to what extent the emitted PSD is affected by wind speed, soil properties and the emission mechanism, and (3) tackle the first set of questions formulated in Objective 1.**

We will use size-segregated aeolian samples from the field multistage cascade impactor, and size-segregated soil and aeolian subsamples generated in the laboratory to obtain the size-resolved composition, chemistry, morphology and mixing state of the soil and emitted aerosol. We will subject the soil samples and the passive aeolian samples to high-resolution size separation using a non-commercial laboratory cascade impactor. We will also obtain dispersed soil subsamples within the standard clay and silt size ranges for comparison to soil mineralogical datasets. All the samples and subsamples will be analyzed for:

- Mineralogical composition by a powder XRD Bruker D8 A25 Advance X-ray diffractometer θ-θ.
- Nano and micro-sized particle morphology and mineralogy by electron microscopy single particle analyses. Samples will be collected in parallel on carbon adhesive and on transmission electron microscopy (TEM) grids for different analysis paths. All samples will be subject to automated scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDS), yielding particle and average chemical information. This will quantify the size-resolved mineralogical composition for about 1000 – 2000 particles per sample and size class. (In conjunction with vertical fluxes, detailed compositional fluxes will be determined.)
- A more in-depth analysis of single particles by TEM and backscatter electron diffraction (BSED) will yield information on crystal structure and mineralogical composition. This detailed analysis will be applied in particular to the feldspar component and to the iron compounds, which are key to ice nucleation and radiation, respectively. Combining the more general SEM and detailed BSED approach will lead to a more precise quantification of the amount and size of feldspar (potentially active ice nuclei) relative to their abundance and size in the soil. SEM in conjunction with TEM will yield information on the dust spectral absorption properties by determining the iron mineral phase information. Also, mixing state information for the iron phases will be determined, which considerably impacts the optical properties.
- Elemental composition, by means of acid-digestion and subsequent analysis by Inductively Coupled Plasma-Mass Spectrometry for trace elements, X-ray fluorescence for silicon, and atomic emission spectrometry for major elements.

The detailed size-resolved mineralogy and mixing state analyses will allow us to characterize more accurately the individual PSD of each soil mineral (Fig. 2c) that is used to calculate its emitted PSD. The comparison of the soil and emitted dust in terms of PSD, mineralogy and mixing state will allow precise evaluation of BFT and our proposed extensions for individual minerals, while responding to the remaining questions in Objective 1. The soil sampling in the Salton Sea region will be particularly extensive to allow thorough comparison with the field, airborne and spaceborne spectroscopic measurements (details in WP2). We will quantify the uncertainty of BFT predictions through our detailed size-resolved characterization of the soil minerals. The limited size resolution of current soil databases that distinguish only clay and silt sizes hinders our ability to extend BFT to individual minerals.

<u>WP2: Improving soil mineralogical atlases using imaging spectroscopy</u>

Global knowledge of soil mineralogy is essential to upscaling the knowledge generated in WP1 to calculate dust mineralogy, but current atlases are far from perfect. The most complete dataset available[65] characterizes the clay (0-2 μm) and silt (2-63 μm) size ranges of FAO soil types (units) in terms of abundance of 12 key minerals important for dust-climate interactions, i.e., quartz, feldspar, illite, smectite, kaolinite, chlorite, vermiculite, mica, calcite, gypsum, hematite and goethite. While this dataset represents a substantial improvement compared with previous versions[63,64], it is based upon barely 700 soil descriptions that sample only 55% of the FAO soil units. Moreover, the mineralogical samples do not cover many regions that are prolific dust sources, and the distribution of records within sampled regions is very inhomogeneous. Given the limited direct measurements of soil mineral content, a global atlas is created by relating mineralogy to the more widely characterized soil type. A number of additional assumptions are made to overcome the lack of information. For example, hematite and goethite abundances are inferred from soil color[154,155]. Based upon anecdotal (and conflicting) evidence, hematite is assumed to be present only at clay sizes, with goethite at both clay and silt sizes[156-158]. WP2 will take up the challenge of improving soil mineralogy estimates for dust modeling using available airborne and spaceborne imaging spectroscopy and mineral detection methods[107,113]. While the value of imaging spectroscopy to mineral mapping has been demonstrated for geological applications, we intend to use this resource for the first time in the context of dust modeling by improving global atlases of soil mineralogy (as described in Task 2.3). We emphasize that the methods derived from this investigation will inform processing of high-quality spectroscopic measurements from coming spaceborne missions (e.g. EMIT, EnMAP).

Task 2.1 Hyperspectral mineral mapping of the Salton Sea region

data are key because (1) they provide a direct link to the reflectance measurements of the airborne and spaceborne sensors (see Task 2.2); (2) the reflectance data corresponding to the sampled area can also be linked to the laboratory measurements of composition by XRD and the detailed mineralogical and morphological analyses of the soil and aeolian samples from Task 1.5; (3) the heterogeneity at meter- to sub-meter spatial scales (that are sub-pixel relative to the remote sensing data) can be evaluated and used, along with laboratory measurements, to validate and test the remote retrievals of minerals, mineral abundances and grain sizes. Over the study area, we will survey the composition at sub-meter scale with spectroscopic techniques. Our collaborators at Caltech will contribute their existing instruments. An ASD FieldSpec3 point spectrometer will acquire data over regular 20 m x 20 m grids throughout the study region, taking data each 1 m^2. A field imaging spectrometer will be used to obtain a panorama of the scenes from a topographic high (or ladder) and, if small scale variability is observed, image directly over the sample sight. A quadcopter with VNIR camera, sensitive to variation in iron mineralogy and wetness, will be used to acquire a sub-meter basemap for mapping variability. Samples will also be measured in the Caltech lab with VNIR and MIR spectrometers to link soil composition to the XRD, TEM, SEM and BSED analyses. We aim to acquire a comprehensive understanding of the relationship between the spectroscopic retrievals and the laboratory analyses of the soil and aeolian samples, putting emphasis on mineral abundances, grain sizes and mixing state. Our retrievals will target 10 key minerals that can be obtained from spectroscopy within the spectral window of the spaceborne instruments: hematite, goethite, illite, vermiculite, calcite, dolomite, montmorillonite, kaolinite, chlorite, and gypsum. The identification of these minerals and estimation of mineral abundance from the reflectance spectra will be based on the Tetracorder algorithm which has been developed and validated over the 25+ years of the AVIRIS airborne science project[98,107,159-161]. Tetracorder uses multiple algorithms, including spectral fitting procedures, to identify minerals, and derives relative abundance of minerals (through spectral feature strength). Tetracorder retrieves grain sizes for some minerals, including hematite and goethite, from the depth and shape of the absorption features. Finer discrimination of mineral chemistry and particle grain sizes is possible with more reference spectra. Because feldspar and quartz are undetected by spaceborne spectroscopy, we will also study how to combine the mineral abundances and grain sizes derived from spectroscopy with the feldspar and quartz abundances and soil texture derived from the laboratory soil analyses. This task will be key to properly combining the spaceborne retrievals with the soil mineralogy atlas.

Task 2.2 AVIRIS and EO1/Hyperion retrievals

The field spectroscopic data and the soil samples will be used to evaluate and constrain retrievals from both AVIRIS and EO1/Hyperion satellite imagery in the Salton Sea. AVIRIS, flown by NASA Jet Propulsion Laboratory (JPL) at an altitude of ~20 km, represents the state-of-the-art airborne hyperspectral system[98,162] covering the 0.4–2.5 μm spectral range with 224 bands at approximately 10 nm spectral resolution with a SNR of ~500:1. Over the years, AVIRIS has acquired important volumes of data, particularly in the southwestern US (Fig. 4a) including the Salton Sea region (Fig. 3). (Near-future spaceborne missions like EMIT and EnMAP will incorporate a similar high-quality hyperspectral system.) Hyperion is a satellite hyperspectral sensor covering the 0.4 to 2.5 μm spectral range with 242 spectral bands at approximately 10 nm spectral resolution and 30 m spatial resolution from a 705 km orbit[163,164] with a SNR of ~50:1 in the visible. Hyperion´s archive includes more than 90,000 scenes globally (Fig. 4b). Based on the improvements and understanding derived from the detailed comparison in the Salton Sea we will process both archives. We will select the usable dust source area scenes (free of clouds and aerosol), obtain the un-resampled radiance data and sun-look calibration data, update the spectral and radiometric calibration[98], apply an atmospheric correction[165,166], screen the data for vegetation and average the low vegetation spectra, and finally obtain the mineral abundances based on the Tetracorder algorithm.

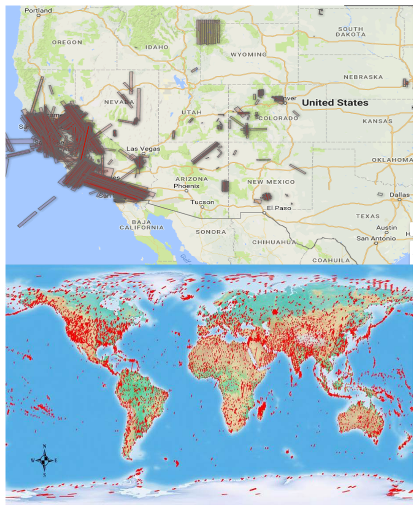


Fig. 4 Coverage of AVIRIS (US) and EO1/Hyperion (global) scenes.

Task 2.3 Improvement of current soil mineralogical atlases

All the processed scenes from AVIRIS and Hyperion will be aggregated to the spatial resolution of the soil mineralogy atlas using a point-counting procedure. The uncertainty of the abundant Hyperion retrievals will be estimated in regions of colocation by comparison to the higher-quality AVIRIS retrievals. The globally distributed Hyperion-processed scenes (Fig. 4b) will be used to both evaluate and complement the global mineralogical atlas in terms of mineral abundance and size based on the knowledge acquired in Tasks 2.1 and

2.2. Even if Hyperion´s amount of data exceeds by orders of magnitude the soil data that underpin the current atlas, some extrapolation based on soil texture and soil type will still be needed. Our new global maps will also include a measure of the uncertainty in the mineral abundances.

WP3: Evaluating, constraining and quantifying the effects of dust mineralogy

WP3 is devoted to modeling the effects of mineralogy upon radiation, the partitioning of semi-volatile compounds, heterogeneous chemistry and clouds using the new fundamental understanding of the emitted dust PSD and size-resolved mineralogy and mixing state generated in WP1 and the improved estimates of the global soil mineral abundances derived from WP2.

Model: To accomplish our proposed goals, we will use the Multiscale Online Non-hydrostatic AtmospheRe CHemistry model[167-177] (MONARCH; previously known as NMMB/BSC-CTM), a model designed and developed by the PI of this proposal and his research group at BSC, in close collaboration with partners at other institutions such as NOAA, NASA and University of California, Irvine. The model provides regional daily dust forecasts for Northern Africa, Middle East and Europe through the WMO Regional Centers for dust prediction hosted by BSC[178,179], and contributes with global forecasts to the International Cooperative for Aerosol Prediction (ICAP) Multi Model Ensemble. MONARCH contains advanced chemistry and aerosol packages, and is coupled online with the Non-hydrostatic Multiscale Model (NMMB)[180,181], which allows for running either global or high-resolution (convection-allowing) regional simulations. The NMMB has evolved from the WRF-NMM regional model, facilitating easy implementation of the extensive array of cloud microphysics schemes available in WRF. In recent projects, the dust-cycle component of MONARCH[167,168] was upgraded with (1) a global-scale 10 km resolution mapping of dust sources based on MODIS Deep Blue[182] (2) multiple choices for the dust emission scheme[66,183,184], (3) a drag partition correction for the wind speed threshold for dust emission (based on a static roughness length for arid regions derived from ASCAT and PARASOL retrievals[185] and a dynamic roughness length for semi-arid and cultivated regions derived from MODIS LAI), (4) the ability to run the model with separate mineral tracers using a soil mineralogy atlas, whose emitted PSDs are based on our hypothesized extension of brittle fragmentation theory[79,80,82], and (5) a dust (and aerosol) data assimilation system based on the Local Ensemble Transform Kalman Filter (LETKF)[177]. As part of a separate project and in order to link the research performed with MONARCH to the EC-Earth Earth System model[186] developments at BSC, the aerosol package is currently being updated to include a revised version of the M7 aerosol microphysics[187] used in EC-Earth´s chemistry package (TM5)[188]. In the original M7 dust can be internally mixed in the soluble accumulation and coarse modes, and externally mixed through insoluble accumulation and coarse modes. M7 considers the formation of new sulfate particles by nucleation of sulfuric acid, condensation of sulfuric acid onto existing particles, water uptake and intra- and inter-modal coagulation. To better characterize the dust PSD, we are incorporating a super-coarse mode.

Task 3.1 Modelling dust mineralogy: experiments, evaluation and additional constraints

In this task, we will perform global simulations of the dust cycle to test the retrieved soil mineral abundances and the predicted emitted PSDs. In a first step, we will minimize the errors in the spatial and temporal variability of the total dust fluxes. We note that only the total fluxes (not the emitted PSD) will be corrected. Our goal is to allow a (more) independent test of the mineral abundance maps and the emitted PSDs. For instance, dust models typically rescale the predicted global emission by bringing the dust cycle into optimal agreement with observations[69]. The evaluation of regional (and seasonal) variations in the dust cycle is then used as an independent test of the quality of the model. For our purposes, we will obtain spatially and temporally-resolved rescaling factors by assimilating dust optical depth (DOD) retrievals over land[182]. Data assimilation methods can be used not only to correct dust loading[189,190], but also to constrain (correct) dust emission[191-194]. We will use a fixed-lag Kalman smoother based on our LETKF data assimilation system[178], which is in essence a Kalman filter that iteratively estimates emissions, allowing for retrospective corrections of emissions from observations later in time. The dust emission ensemble will be generated by perturbing the three dust emission schemes available in the model. Suitable spatial and temporal scales of correlation of the perturbations will be estimated. Because this inversion procedure is computationally expensive it will disregard mineralogy, given that its effect upon extinction is small compared to the effect of the dust mass and PSD. Our assimilation will specifically use available DOD from MODIS Deep Blue at 10 km resolution (already generated and provided by our colleague Paul Ginoux from NOAA). Once the total fluxes are optimized we will evaluate the modeled mineral fractions with an augmented version of our recent global compilation of mineral fraction measurements by size[80].

Using the corrected total dust fluxes and our predicted total dust PSD, we will run and evaluate multiple simulations that include sub-regional perturbations of the relative abundance and emitted PSD of each mineral within ranges uncertainty estimated in WP1 and WP2. To reduce the number of runs, perturbations will be generated based latin hypercube sampling (LHS)[195] within the most prominent dust sources only. LHS samples across a multi-dimensional parameter uncertainty space while retaining good coverage within any single parameter uncertainty range. The evaluation of these simulations with available mineral fraction observations will provide further constraints in the mineral abundances and emitted PSDs of each mineral. These calculations will take into account the effect of mineralogy upon dust chemistry, which has an effect upon the hygroscopic properties and therefore the lifetime of dust. Dust chemistry is treated in Task 3.3.

Task 3.2: Mineralogy in dust-radiation interactions: further constraints and assessment

In this task, we use radiance measurements to evaluate and constrain the hematite fraction of dust aerosol particles. With our estimate of the mineral composition of dust aerosols, we will derive the corresponding direct radiative forcing. For dust particles of a given size, absorption at solar wavelengths is most sensitive to the presence of iron oxide minerals. Because iron oxides contribute only a small fraction of the particle mass, their evaluation in models based upon direct measurements of dust composition are subject to greater uncertainty, compared to more abundant minerals like clays and quartz. Because of the strong influence of iron oxides upon shortwave absorption, radiance measurements by satellites and ground-based measurements offer a complementary means for evaluating and constraining the model. We will specifically evaluate our representation of iron oxide minerals using radiance measurements from multiple instruments.

Based on model output, we will run and evaluate forward simulations of retrieved radiative properties that are especially sensitive to this mineral. We will use observations of single scattering albedo (ssa) at several wavelengths in addition to lidar color and depolarization ratios, which are independent of the dust load, but depend upon refractive index and PSD. We will use (1) AERONET[196], which provides PSD and ssa at several wavelengths; (2) recent PARASOL retrievals[197,198], which provide ssa at 550 nm, effective radius and variance for two modes; (3) OMI OMAERUV, which provides ssa near the ultraviolet wavelengths[199], where hematite is an especially strong absorber; and (4) CALIPSO lidar providing the color ratio of backscatter at 1064 and 532 nm along with 532 nm depolarization ratios[200] that have unique dependencies upon dust composition and size[201-203]. In order to avoid contamination by other aerosols, we will screen for dust using high AOD, a large fraction of non-spherical particles, the spectral dependence of ssa and the PSD. For the forward simulations of radiative properties, we will use a spheroid model with the same distribution of aspect ratio as used in AERONET and PARASOL retrievals, and we will form the index of refraction according to the Maxwell-Garnet mixing rule and mixing assumptions derived from WP1. Distinguishing the effect of the hematite fraction and PSD will be based on the lidar color ratio and spectral variations of the ssa that provide varying sensitivity to size and mineral composition. Also, depolarization at 532 nm is almost uniquely sensitive to the real part of the refractive index (rather than size), for which hematite has a substantially larger value compared to the other minerals.

Using our best model representation, we will calculate the present-day dust direct radiative forcing considering both shortwave and longwave forcing[29,81]. To this end, we will implement the treatment of the radiative effects of each mineral within MONARCH. We will use the previous assimilation and evaluation to guide this calculation, including mixing rules and representation of non-spherical effects. We will calculate the resemblance of a minimal calculation (based on dust cores internally mixed with iron oxides) to the full calculation of forcing derived from explicit consideration of all the minerals. This minimal representation is far less expensive than consideration of all the minerals and internal mixtures, which is valuable for guiding Earth System model development or for simulations where only the radiative forcing is of interest, and the explicit simulation of each individual mineral other than hematite is unnecessary. We will also investigate the effect of calcite, quartz and phyllosilicates at thermal wavelengths. Finally, we will calculate the regional forcing resulting from globally uniform particles, whose composition is a global average of the regionally varying mineral content. This will be contrasted with the forcing calculated with regionally varying composition. This contrast will quantify the error of regional forcing that results from assuming globally uniform composition, as nearly all models currently assume. These calculations will omit the effect of dust mineralogy upon heterogeneous chemistry, which is treated in Task 3.3.

Task 3.3: Mineralogy in the partitioning of semi-volatile compounds and heterogeneous chemistry: developments, evaluation and assessment

Using our best estimates for dust emission, emitted PSD and mineralogy, we will explore and evaluate the effects of mineralogy upon the partitioning of semi-volatile inorganic compounds and dust heterogeneous chemistry, along with the associated changes in the burdens of precursor gases, dust, nitrate, sulfate, and ammonium, and the direct radiative forcing for the combination of aerosol species. For this task, only minor model developments will be required. We will complement the M7 aerosol microphysics and EQSAM thermodynamic equilibrium model[204] with the full set of (known) dust heterogeneous reactions (including the uptake of sulfure dioxide, HNO_3, H_2SO_4, N_2O_5, NO_3, NO_2, O_3, H_2O_2, HO_2, and OH), using the Kinetic PreProcessor (KPP) package[205] available within our model infrastructure. EQSAM calculates the gas/liquid/solid equilibrium partitioning of semi-volatile inorganic compounds, where K, Ca, Mg, and Na are considered as chemically active components and assumed to exist in the form of mineral salts. The amount of these individual crustal species will be obtained at each model grid box from the elemental composition of each mineral weighted by mineral amount. For the heterogeneous chemistry, the mineral-specific uptake coefficients will be taken from the literature[206].

We will thoroughly evaluate the enhanced model relative to a configuration where the dependencies on composition are neglected. (To account for the uncertainties in the uptake coefficients, we will evaluate multiple simulations that comprise a perturbed physics ensemble.) We will explore the relative importance of partitioning and heterogeneous chemistry upon the results, and study the role of each mineral with the goal of proposing a minimal mineral representation for climate models. For the evaluation, we will use measurements available at regions near or downstream of dust sources[207-212]. (Additional literature research will be carried out to augment this compilation.) The evaluation will also include data from the Clean Air Status and Trends Network (CASTNet), the Interagency Monitoring of Protected Visual Environments network (IMPROVE), and the European Monitoring and Evaluation Programme (EMEP).

A specific study will be performed using a high-resolution (~3 km) regional domain of MONARCH covering Northern Africa, Europe and the Eastern Atlantic Ocean. In this case our evaluation will be complemented with data provided by the CSIC: detailed aerosol chemical composition measurements at the Izaña Observatory in Tenerife and the Spanish observation network available since 2002. Izaña, located in the sub-tropical Atlantic downwind of African dust sources, is characterized by frequent dust episodes and dust mixing with industrial pollutants[211]. We will also be able to link the aerosol chemical composition measurements with the size-resolved mineralogy analyses at Izaña, and the characterization of emission and mineralogy (from WP1) and the extensive airborne data provided by the SAMUM I campaign at Tinfou, which is a source region that frequently affects Izaña. The Spanish network includes remote background, regional background and urban background stations that experience dust intrusions from Northern Africa, and mixing with anthropogenic pollutants[213].

Finally, we will extend our calculation in Task 3.3 to obtain the present-day dust and total aerosol direct radiative forcing considering the effects of mineralogy both upon radiation and the partitioning semi-volatile compounds and heterogeneous chemistry. This will be contrasted with the forcing calculated both using a minimal representation of minerals and without regionally varying composition.

<u>Task 3.4: Mineralogy in dust-cloud interactions: developments, evaluation and assessment</u>

This task will be devoted to calculating the effects of dust upon liquid and mixed-phase clouds and the associated (indirect) radiative forcing, using our constrained dust mineralogical composition along with existing cloud droplet and ice activation and microphysics schemes. (We note that developing new microphysics schemes is beyond the scope of FRAGMENT.) Dust mineralogy indirectly affects cloud condensation nuclei (CCN) activity by impacting the coating of dust particles by soluble materials and by changing the burden of inorganic aerosols (see Task 3.3). In mixed-phase clouds, K-feldspar particles are considered to dominate the concentration of ice nucleating particles (INP) downwind of dust sources[39].

To assess the effects of mineralogy upon clouds we will update and use the two-moment cloud microphysics scheme of Morrison and Gettelman (M&G)[214], which predicts the number concentrations and mixing ratios of cloud droplets and cloud ice to simulate indirect aerosol effects and cloud-aerosol interactions. The updates refer only to the CCN activation and inmersion-freezing nucleation terms that form cloud droplets and ice crystals.

For the CNN activation, we will follow the recent study of Karydis and colleagues[57]. We will incorporate the *unified activation parameterization* that considers both the inherent hydrophilicity from adsorption and the acquired hygroscopicity during aging[57,126,216,217]. Adsorption is considered mineralogy-independent and is applied to the insoluble modes. For the soluble modes, the scheme combines the adsorption of the insoluble dust particles and the absorption due to the hygroscopicity of the soluble coatings. The cloud droplet number concentration (CDNC) is obtained from the CNN spectrum computed for the maximum supersaturation[218,219], which depends on the in-cloud updraft velocity[220]. Karydis[57] calculates that the adsorption activation of insoluble aerosols upon CDNC is more important than the effect of dust chemistry on the absorption via the partitioning of semi-volatile aerosol compounds. was specified based upon only of ten points globally. We will reproduce this study using our constrained dust emission, emitted PSD and mineralogy, while considering the effect of heterogeneous chemistry and its dependencies upon mineralogy. We will investigate the importance upon CDNC of the partitioning, heterogeneous chemistry and mineralogy relative to the mineralogy-independent adsorption. This activation framework used in combination with the M&G microphysics will also allow calculating the associated radiative forcing. For model evaluation, we will use MODIS-derived CDNC, cloud fraction and optical thickness[221,222] and publicly available compilations of CCN[223] and CNDC[57] observations.

To calculate INP concentration, we will follow the recent studies of Atkinson and colleagues[39], who provide a mineralogy-dependent active site parameterization that is mostly sensitive to K-feldspar based on laboratory measurements. This empirical scheme follows a singular approximation where the time dependence of nucleation is neglected and particle-to-particle variability is considered the major factor that explains the observed spectrum of INP concentrations, in agreement with many laboratory studies. In a recent modeling study[224], the parameterization was able to reproduce 70% of the observations of INP in terrestrial locations within 1.5 orders of magnitude, which is a significant improvement over other empirically-based schemes that do not account for mineralogy[130,225]. Among other things, the results show particularly large overestimation of INP in marine locations affected by K-feldspar. Possible explanations are the uncertainties in the emitted PSD and in the effect of atmospheric processing both on its scavenging[226], and/or by affecting its INP ability[227]. We will reproduce this study using our constrained dust emission, emitted PSD and mineralogy. We will repeat this study using our constrained dust emission, emitted PSD and mineralogy. We will consider the effect of mineralogy, partitioning of semi-volatile compounds and heterogeneous chemistry on the solubility and scavenging of K-feldspar and test whether assuming a reduced INP ability for the K-feldspar contained in the insoluble modes reduces the overestimation in remote regions. For the evaluation of INP we will use the BACCHUS INP Database[228]. Also in this case, this activation scheme in combination with the M&G microphysics will finally allow calculating the associated radiative forcing.

Suitability of the PI and his research team

The achievement of the ambitious goals of FRAGMENT requires a strong cross-disciplinary team working in concert across theory, measurements, spectroscopy and modelling. The expertise of PI and his team members cover all aspects of FRAGMENT.

The PI will be supported by 2 experienced researchers and 2 postdocs who are part of the PI's research group at BSC. Dr. Oriol Jorba and Dr. María Gonçalves are aerosol-chemistry modelling experts and main co-developers of the MONARCH model that is used in WP3. They will both contribute to the model developments and assist the PI in guiding 3 recruited postdocs working on Tasks 3.2 (effects on radiation), 3.3 (effects on chemistry) and 3.4 (effects on clouds), respectively. Dr. Enza di Tomaso is the main developer of the data assimilation system of MONARCH and will focus on Task 3.1. Dr. Sara Basart is a dust modelling expert with large experience in model evaluation. She will conduct the model evaluation in Task 3.1 and assist the project team in the remaining evaluation tasks within WP3. FRAGMENT will also recruit 1 postdoc who will focus on WP2 (spectroscopy).

IDAEA-Consejo Superior de Investigaciones Cientificas (IDAEA-CSIC) will assist the PI in conducting the field campaigns and the laboratory work (WP1). BSC is a modeling and supercomputing facility and IDAEA-CSIC is a laboratory facility. Both are located in the same street in Barcelona and are frequent partners in proposals given their complementary facilities and proximity. Technische Universität Darmstadt (TUD) will collaborate by performing the detailed nano and micro-sized particle morphology and mineralogy analyses (Task 1.5).

The team involves world-class experts on modelling of dust mineralogy (Dr. Ron Miller, NASA GISS), aerosol campaigns and analysis (Dr. Xavier Querol; Dr. Andres Alastuey, IDAEA-CSIC), mineralogy analysis (Dr. Konrad Kandler, TUD), and spectroscopy sampling and retrievals (Dr. Roger Clark, PSI; Dr. Bethany Ehlmann, Caltech; Dr. Robert Green; NASA JPL). Dr. Bethany Ehlmann is an expert in the acquisition and processing of remotely acquired visible/infrared data from the earth and other planets, geological fieldwork, and multiple laboratory techniques. She will contribute her existing field spectroscopic instruments and laboratory facilities to survey the surface's composition during the campaign in the Salton Sea (Task 2.1). Dr. Roger Clark is an expert in identification and mapping minerals on the Earth and on other planets. He invented the Tetracorder system which is used in WP2 to retrieve mineral abundance and grain size from reflectance data. WP2 also counts also with the collaboration of Dr. Robert Green (NASA Jet Propulsion Laboratory) who is the PI of the proposed EMIT mission. Dr. Clark will contribute to Tasks 2.2 and 2.3. Dr. Green has been AVIRIS Experiment Scientist from 1989 to present and Science team member for 4 spaceborne and 5 airborne imaging spectrometers instruments. He will provide guidance on the use of AVIRIS and EO1/Hyperion data.

Section c. Resources

Cost Category			**Total in Euro**
Direct Costs	**Personnel**	PI	155,971
		Senior Staff	92,030
		Postdocs	569,168
		Students	195,000
		Other	164,800
	i. Total Direct Costs for Personnel		**1,176,966**
	Travel		124,500
	Equipment		152,152
	Other goods and services	Consumables	156,000
		Publications (including Open Access fees)	30,000
		Other	5,000
	ii. Total Other Direct Costs		**462,652**
A – Total Direct Costs (i + ii)			1,639,618
B – Indirect Costs (overheads) 25% of Direct Costs			409,905
C1 – Subcontracting Costs (no overheads)			100,000
C2 – Other Direct Costs with no overheads			
Total Estimated Eligible Costs (A + B + C)			**2,149,523**
Total Requested EU Contribution			**2,149,523**

Request for additional funding above EUR 2 000 000 for	**Justification**
(b) the purchase of major equipment	**149,523 € for purchase of major durable equipment: instrumentation for the proposed field campaigns, and infrastructure for model post-processing and storage. Details are given below.**

Duration of the project in months:	**60**
% of working time the PI dedicates to the project over the period of the grant:	**60%**

Budget justification per institution and category

<u>**Barcelona Supercomputing Center (BSC, Host Institution). Total requested: 1,449,880 €**</u>

Personnel (884,336 €):

The main fraction of the budget will go for personnel cost. Specifically, the <u>PI</u> will devote 60% of his time to the proposal. He will be supported by <u>2 experienced researchers</u> who are part of the PI's research group at BSC: Dr. Oriol Jorba and Dr. María Gonçalves who are aerosol-chemistry modelling experts and main co-developers of the MONARCH model. They will both contribute to the model developments in WP3 and assist the PI in guiding the 3 postdocs who will focus on Tasks 3.2, 3.3 and 3.4 (see next).

<u>Postdocs:</u> We request full support for 3 postdocs during 3 years to develop Tasks 3.2 (effects on radiation), 3.3 (effects on chemistry) and 3.4 (effects on clouds), respectively. We also request full support for 1 postdoc for 2 years to work on WP2 (imaging spectroscopy and improvement of soil mineralogical maps). We request partial support for 2 postdocs who are currently part of the PI's research group at BSC. Dr. Enza di Tomaso is the main developer of the data assimilation system of MONARCH and will focus on Task 3.1. Dr. Sara Basart is a dust modelling expert with large experience in model evaluation. She will conduct the model evaluation in Task 3.1 and assist the project team in the remaining evaluation tasks within WP3.

<u>PhD Student:</u> We request full support for 1 PhD student during 4 years to focus on WP1. The student will help preparing and conducting the field campaigns, and perform the analyses of the emitted PSD and the soil in the IDAEA-CSIC laboratory facilities (Tasks 1.1, 1.2, 1.3, 1.4, 1.5). The student will be co-advised by the PI and

Xavier Querol from IDAEA-CSIC. The PhD thesis will combine measurements and theory to tackle the uncertainties in the emitted dust PSD.

Other personnel: This will be devoted to support 4 months of salary of a project manager that will specifically assist the PI in the preparation and coordination of the field campaigns and all the administrative tasks related to these.

Travel (110,500 €): In addition to the usual travel costs necessary for the PI and his team to participate in international events to present project results, FRAGMENT involves travel costs for the participation in the field campaigns in the three regions (Salton Sea, USA; Tinfou, Morocco and Aragon, Spain). The travel costs for the field campaigns in Aragón foresee costs for car rental, lodging and daily allowances. The travel costs for the field campaign in Tinfou, Morocco as well as in Salton Sea include also flight tickets, in addition to car rental, lodging, and daily allowances.

Equipment (24,068 €): BSC has world-class high performance computing facilities (MareNostrum IV, 1.5 Petaflops/s) where all FRAGMENT simulations and data processing will be performed at no cost for the project. The number of simulations and derived output will be large. We request support for post-processing and storage infrastructure: 2 large-memory FatNode and 30 HPC disks of storage x 3TB.

Other goods and services (66,000 €): Publications in peer reviewed journals, registration fees for international conferences (including Open Access fees for those publications that cannot go with the Green Route), and dissemination (FRAGMENT website, newsletters, brochures). Other: This includes the truck rental and transport costs of the instrumentation for the field campaigns in Aragón, Tinfou and Salton Sea (including shipping costs). This will cover also the costs for the obligatory financial certificates on the financial reports to the European Commission.

Subcontracting costs (100,000 €): Collaborators Dr. Bethany Ehlmann (California Institute of Technology, Caltech), Roger Clark (Planetary Science Institute, PSI) will be subcontracted for contributions in WP2. The team at Caltech will contribute their existing field spectroscopic instruments and large laboratory facilities to survey the surface's composition during the campaign in the Salton Sea (Task 2.1) and help with the data processing of the field data. Dr. Clark will contribute to Tasks 2.2 and 2.3. Both researchers will collaborate with the PI and the postdoc recruited for WP2.

IDAEA-CSIC Partner Institution. Total requested: 540,893 €

IDAEA-CSIC will assist the PI in conducting the field campaigns and the laboratory work. BSC is a modeling and supercomputing facility and IDAEA-CSIC is a laboratory facility. Both are located in the same street in Barcelona and are frequent partners in proposals given their complementary facilities and proximity.

Personnel (197,631 €): Senior Staff: this will cover the time devoted to the project by Dr. Xavier Querol, Dr. Andrés Alastuey, and Dr. Fulvio Amato. They will prepare the mobile measurement platform, contribute to the field campaigns, and guide the laboratory work (WP1). Dr. Querol and the PI will co-advice the PhD student recruited by BSC to work on WP1. Other personnel: In addition, they we request support for an engineer during 4 years, who will support the field campaigns and the laboratory work.

Travel (7,000 €): Covers travel to international conferences.

Equipment (128,084 €): We request support to purchase instrumentation needed to accomplish the goals of WP1. 2 GRIMM dust monitors (optical particle counters) that will permit determining the number flux of particles; 2 DEKATI DLPI+ cascade impactors that will permit collecting particles on 25 mm collection substrates into multiple (configurable) size fractions for chemical and mineral characterization; 2 Sensit saltation sensors; 1 Gil Sonic Ultrasiever 5 mobile towers with specific configurations; fully instrumented meteorological tower from Campbell Scientific.

Other goods and services (100,000 €): We estimate ~1150 samples and size-segregated subsamples of the soil, sediment and emitted dust that will be analyzed with diverse techniques (Task 1.5). The budget will cover both the laboratory chemical consumables and the analysis costs.

Technische Universität Darmstadt (TUD). Total requested: 158,750 €

Dr. Konrad Kandler from TUD will collaborate by performing the detailed nano and micro-sized particle morphology and mineralogy analyses (Task 1.5). **Personnel (95,000 €):** PhD Student: a PhD student will help in preparing the field campaigns with respect to sampling and direct reading techniques. The major task will be the analysis and data evaluation of the acquired samples by electron microscopy techniques. The student will be co-advised by the Konrad Kandler and the PI. The PhD thesis will focus on the relationship of the soil and the emitted PSD in terms of mineralogy and mixing state.

Travel (7,000 €): Covers travel to international conferences and travel for FRAGMENT meetings at BSC.

Other goods and services (25,000 €): Includes the consumables of the electron microscope and the acquisition and preparation on the sampling substrates.

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Commitment of the host institution for ERC Calls 2017[1, 2, 3]

The Barcelona Supercomputing Center, BSC, which is the applicant legal entity,

confirms its intention to sign a supplementary agreement with
<<Carlos Perez Garcia-Pando>>

in which the obligations listed below will be addressed should the proposal entitled
<<Fragment>> : << FRontiers in dust minerAloGical coMposition and its Effects upon climaTe>

be retained.

Performance obligations of the *applicant legal entity* that will become the beneficiary of the H2020 ERC Grant Agreement (hereafter referred to as the Agreement), should the proposal be retained and the preparation of the Agreement be successfully concluded:

The *applicant legal entity* commits itself to hosting *[and engaging]* the *principal investigator* for the duration of the grant to:

a) **ensure that the work will be performed under the scientific guidance of the *principal investigator* who is expected to devote:**
- *in the case of a Starting Grant at least 50% of her/his total working time* to the ERC-funded project (action) and spend at least 50% of her/his total working time in an EU Member State or Associated Country;
- *in the case of a Consolidator Grant at least 40% of her/his total working time* to the ERC-funded project (action) and spend at least 50% of her/his total working time in an EU Member State or Associated Country;
- *in the case of an Advanced Grant at least 30% of her/his total working time* to the ERC-funded project (action) and spend at least 50% of her/his total working time in an EU Member State or Associated Country.

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[1] A scanned copy of the signed statement should be uploaded electronically via the Participant Portal Submission Service in PDF format.
[2] The statement of commitment of the host institution refers to most obligations of the host institution, which are stated in the H2020 ERC Model Grant Agreement (MGA). The H2020 ERC MGA is available on the ERC website at http://erc.europa.eu & http://ec.europa.eu/research/participants/portal/desktop/en/funding/reference_docs.html.
The reference to the time commitment of the Principal Investigator is stated in the ERC Work Programme 2017.
[3] This statement (on letterhead paper) shall be signed by the institution's legal representative and stating his/her name, function, email address and stamp of the institution.

b) **carry out the work to be performed, as it will be identified in Annex 1 of the Agreement, taking into consideration the specific role of the *principal investigator*;**

c) **enter — before signature of the Agreement — into a '*supplementary agreement*' with the *principal investigator*, that specifies the obligation of the *applicant legal entity* to meet its obligations under the Agreement;**

d) **provide *the principal investigator* with a copy of the signed Agreement;**

e) **guarantee the *principal investigator's* scientific independence, in particular for the:**

   i) **use of the budget to achieve the scientific objectives;**

   ii) **authority to publish as senior author and invite as co-authors those who have contributed substantially to the work;**

   iii) **preparation of scientific reports for the project (action);**

   iv) **selection and supervision of the other *team members* (hosted *[and engaged]* by the *applicant legal entity* or other legal entities), in line with the profiles needed to conduct the research and in accordance with the *applicant legal entity's* usual management practices;**

   v) **possibility to apply independently for funding;**

   vi) **access to appropriate space and facilities for conducting the research;**

f) **provide — during the implementation of the project (action) — research support to the *principal investigator* and the team members (regarding infrastructure, equipment, access rights, products and other services necessary for conducting the research);**

g) **support the *principal investigator* and provide administrative assistance, in particular for the:**

   i) **general management of the work and his/her team**

   ii) **scientific reporting, especially ensuring that the team members send their scientific results to the *principal investigator*;**

   iii) **financial reporting, especially providing timely and clear financial information;**

   iv) **application of the *applicant legal entity's* usual management practices;**

   v) **general logistics of the project (action);**

   vi) **access to the electronic exchange system (see Article 52 of the Agreement);**

h) **inform the *principal investigator* immediately (in writing) of any events or circumstances likely to affect the Agreement (see Article 17 of the Agreement);**

i) **ensure that the *principal investigator* enjoys adequate:**

  i) **conditions for annual, sickness and parental leave;**

  ii) **occupational health and safety standards;**

  iii) **insurance under the general social security scheme, such as pension rights;**

j) **allow the transfer of the Agreement to a new beneficiary ('portability'; see Article 56a of the Agreement).**

k) **take all measures to implement the principles set out in the Commission Recommendation on the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers[4] - in particular regarding working conditions, transparent recruitment processes based on merit and career development – and ensure that the *principal investigator*, researchers and third parties involved in the project (action) are aware of them.**

For the host institution (applicant legal entity):

Date

...01/02/2017...................

Name and Function

Mateo Valero. ; BSC Director.

Email and Signature of legal representative

Mateo.valero@bsc.es. ; ....

Mateo Valero
Director

Stamp of the host institution (applicant legal entity)

Barcelona
Supercomputing
Center
Centro Nacional de Supercomputación

IMPORTANT NOTE: In order to be complete all the above mentioned items are mandatory and shall be included in the commitment of the host institution.

[4] Commission Recommendation 2005/251/EC of 11 March 2005 on the European Charter for Researchers and on a Code of Conduct for the Recruitment of Researchers (OJ L 75, 22.3.2005, p. 67).

Juan Carlos I, Rey de España

i en nom seu el **y en su nombre el**

Rector de la Universitat Politècnica de Catalunya

atès que, d'acord amb les disposicions i circumstàncies que preveu la legislació vigent,

considerando que, conforme a las disposiciones y circunstancias previstas por la legislación vigente,

Carlos Pérez García-Pando

que va néixer el dia 25 de juny de 1977, a Barcelona (Barcelonès), de nacionalitat espanyola, Enginyer Industrial el 2001, per la Universitat Politècnica de Catalunya, ha superat els estudis de doctorat al

nacido el día 25 de junio de 1977, en Barcelona (Barcelonès), de nacionalidad española, Ingeniero Industrial en 2001, por la Universitat Politècnica de Catalunya, ha superado los estudios de doctorado en el

DEPARTAMENT DE PROJECTES D'ENGINYERIA

dins el PROGRAMA D'ENGINYERIA AMBIENTAL, i ha fet constar la seva suficiència en aquesta Universitat, amb la qualificació d'Excel·lent "Cum Laude", el dia 15 de desembre de 2005, expedeix aquest

dentro del PROGRAMA DE INGENIERÍA AMBIENTAL, y ha hecho constar su suficiencia en esta Universidad, con la calificación de Sobresaliente "Cum Laude", el día 15 de diciembre de 2005, expide el presente

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con carácter oficial y validez en todo el territorio nacional, que faculta al interesado para disfrutar los derechos que a este título otorgan las disposiciones vigentes.

Barcelona, 17 de gener de 2006

Barcelona, 17 de enero de 2006

La persona interessada	**El rector**	**El cap del Servei de Gestió Acadèmica**
Carlos Pérez García-Pando	Josep Ferrer Llop	Ramon Martí Maranillo

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UNIVERSITAT POLITÈCNICA DE CATALUNYA

(Denominació de la Unitat Estructural Gestora)

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Revers del títol de DOCTOR per la
UNIVERSITAT POLITÈCNICA DE CATALUNYA
expedit el dia 17 de gener de 2006, a favor del Sr.
Carlos Pérez García-Pando
que va superar els estudis de doctorat segons el Reial decret 778/1998 al
DEPARTAMENT DE PROJECTES D'ENGINYERIA
i ha fet constar la seva suficiència el dia 15 de desembre de 2005,
amb la qualificació d'Excel·lent "Cum Laude".

Reverso del título de DOCTOR por la
UNIVERSITAT POLITÈCNICA DE CATALUNYA
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Carlos Pérez García-Pando
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DEPARTAMENT DE PROJECTES D'ENGINYERIA
y ha hecho constar su suficiencia el día 15 de diciembre de 2005,
con la calificación de Sobresaliente "Cum Laude".

El cap del Servei de Gestió Acadèmica

Ramon Martí Maranillo

RCM-FNMT Mod. 41/00