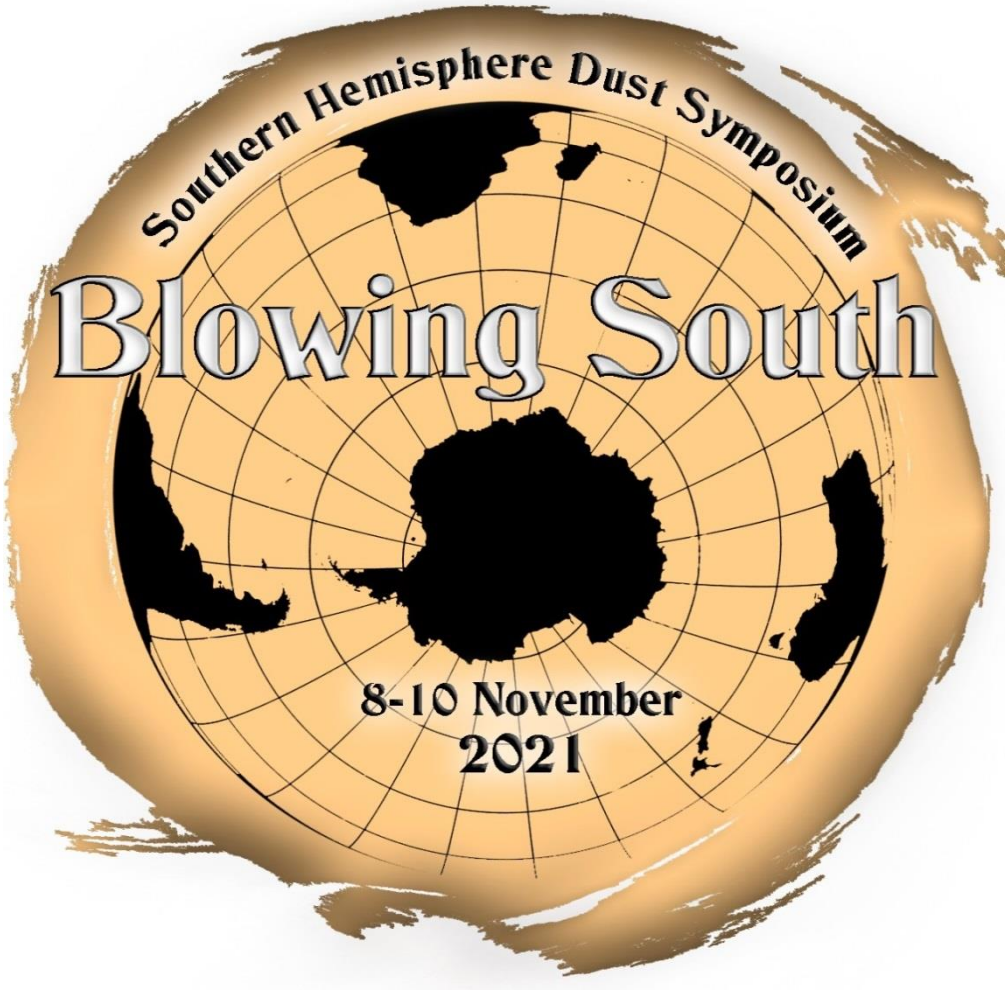

Proceedings of the Blowing South: Southern Hemisphere Dust Symposium

1st International Edition
On line event – 8-10 November 2021

We are pleased to present the Proceedings of the Blowing South: Southern Hemisphere Dust Symposium. A free online event, organized between November 8 and 10, 2021.

This symposium was designed to bring together international scientists working on the observation and modeling of the present-day and paleo dust cycle in the Southern Hemisphere, across temporal and spatial scales, including both feedback with climate and impact on society.

The talks were intended to discuss the latest advances and share the main scientific questions of the community, providing an opportunity to discuss recent and on-going work on these critical issues, and to expand on pre-existing collaborations that in certain areas of research and in certain regions are still quite limited.

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INDEX (in order of appearance in the programme)

KEYNOTE SPEAKER

Examining the drivers of Australasian dust emissions: Contrasting the behaviour of the warm-arid and cold-wet Southern Hemisphere dust sources through time

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The controls on dust emissions include vegetation cover, sediment moisture content, grain size, windiness and sediment availability. Vegetation cover and sediment moisture content are related to aridity and, for that reason aridity, has been traditionally regarded as the major control on variability in dust emissions through time. While aridity is unequivocally linked to dust emissions over short time scales (events to annual timescales), the role of aridity as the key driver of dust emissions over millennial time-scales is less certain. In addition, different dust source regions (i.e. different climatic/geomorphic settings) may respond distinctively to changes in these parameters through time. For example, they could be more or less sensitive to aridity or to sediment availability. Global dust source regions can be broadly divided into warm-arid dust sources (like Australia), and cold-climate/high latitude dust sources (such as New Zealand) and, at face value, these could be expected to respond very differently to the changes in boundary conditions that influence dust emissions. Using records of dust emissions reconstructed from Australia and New Zealand as examples, I will examine the question as to what drives dust emissions across these different landscapes. In doing so I will explore whether dust sources respond consistently to unidirectional changes in key parameters, such as aridity or sediment supply, or whether they show a more complex response to variability. In doing so I will also examine the question as to what dust flux records tell us about palaeo-environmental conditions.

The age of dust—A new hydrological indicator in arid environments?

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Dust plays important roles in the environment, and there has been much interest in the formation, provenance, and age of the world's dust deposits. Ongoing debates are concerned with the importance of glacial grinding versus eolian abrasion and fluvial transport in the formation of silt-sized particles. Short-lived uranium-series isotopes afford new insights because they can be used both for provenance fingerprinting and for constraining the integrated age of chemical and physical weathering and subsequent transport and storage of sediments.Here we present trace element and Sr, Nd, and U-series isotope analyses from a number of Australian dusts and suspended river sediments remobilized during floods a year later. The inferred ages of the Australian dust appear to be linked to aridification and the loss of inland megalakes 30–120 k.y. ago. This provides preliminary evidence that the age of dust may provide a new hydrological indicator in arid environments.

Sulphur as a proxy for Southern Hemisphere westerly wind strength on sub-Antarctic Macquarie Island

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Reconstructions of past Southern Hemisphere westerly wind (SHW) behaviour are often inconsistent due to variations in methods used, and factors associated with study site locations. Sub-Antarctic islands, such as Macquarie Island, are ideally suited to studies of past SHW variability. They are located at latitudes where surface winds are strongest, and their climates, water chemistry and ecology are primarily governed by the westerlies. The SHW affect lakes through sea spray aerosol (SSA) inputs, and previous studies demonstrated that salinity, as measured by electrical conductivity (EC) in lake water, is the primary driver of water chemistry. A relationship between salt-sensitive biological indicators (e.g., diatoms and testate amoebae) and EC has been established, and used to infer variability in past SHW strength. Stronger winds lead to greater production of SSA over the ocean and therefore deposition in lakes, leading to higher measured EC in water. Thus, diatom/testate amoebae-EC inference models can be used to reconstruct past SHW strength variability. However, this is a relatively indirect method. Direct relationships between chemical indicators of SSA deposition and wind strength, and their potential to reconstruct past SHW variability on Macquarie Island have not been tested; for example (geo)chemical indicators such as sulphur (S) in lake sediment records. To establish the relationship between SSA and wind strength, we used a combination of in-situ aerosol monitoring over 14 months, and simple models of SSA production and lake water balance. A hydrochemical survey of 40 lakes found that most, while dilute, had a similar ionic signature to seawater, with upwind lakes in the west having higher EC than those in the east. Of the major seawater ions, $SO4^{2-}$ was most likely derived from marine aerosols. Other ions indicated additional processing (Cl^{-}, Na^{2+}) or contribution from non-marine sources such as catchment erosion (Mg^{2+}, Ca^{2+}, K^{+}). Based on this and other geochemical analyses, S was considered the most appropriate geochemical tracer as a proxy for wind to reconstruct SHW strength at Macquarie Island over the last ca. 1800 years. S was measured in sediment cores from two lakes (Lake Tiobunga and nearby unnamed lake) near the western edge of the Macquarie Island plateau using µ-x ray fluorescence core scanning, bulk subsample total S (%) and δ34S analysis. Bulk S variations in both lake records were broadly similar and δ34S indicated a marine source of S throughout. Higher S concentrations indicated stronger SHW between 550–950 CE and 1250–1450 CE, lower S suggested weaker winds in between. Sedimentation rates in both lakes slowed from 1450–1900 CE. The unnamed lake was heavily impacted by the introduction of rabbits when Macquarie Island was discovered in 1810 CE, limiting interpretation of changes since. While the presence of a non-climate signal is difficult to exclude in Lake Tiobunga, there was an increasing trend in S since the mid-20th century, consistent with observational data of strengthening SHW. Work is underway to extend the record further back in time, and investigate past changes in the SHW and relationship to precipitation across the mid-high latitudes of the Southern Hemisphere.

Reconstruction of atmospheric mineral dust and volcanic ash deposition in the Falkland Islands from a peat record

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Accurate reconstructions of past variations in long-range transport of dust and subsequent deposition to the remote Sub-Antarctic and Southern Oceans are central to our ability to understand the Earth system processes that drive changes of marine productivity and atmospheric carbon cycle in this region critical for the global climate. In this contribution, we present a terrestrial record of volcanic ash and mineral dust deposition in the western South Atlantic Ocean using a 4 m-long peat core sampled in the Falkland Islands (Malvinas) covering the Late Glacial and Holocene periods. The main objectives of this study are to identify and quantify changes in dust sources and accumulation rates using geochemical fingerprinting.

An age-depth model was established based on thirteen radiocarbon dating. A basal age of 15.2-15.7 cal kyr BP was found for the peat core corresponding to the approximate starting time of peatland development reported in the Falkland Islands and giving a time resolution of 50-130 years. Peat samples were characterised for their ash content, elemental and isotopic (Nd) composition. Dust accumulation rates were estimated based on the variations of the concentration of conservative elements (REE). To identify the number and timing of statistically significant changes in the different datasets a changepoint modelling approach was used.

A statistical analysis performed on the geochemical dataset evidenced that the lithogenic elements are immobile within the peat profile indicating that dust deposition record is well preserved in the peat deposit. Five ash-rich layers with an enrichment in K are identified as tephra layers. They matched the timing of the largest explosive eruptions of volcanoes of Andean Southern and Austral Volcanic Zones i.e. eruptions of the Reclus (14.76 ± 0.18 kyr cal BP), Monte Burney (9.45± 0.64 kyr cal BP and 4.25 ± 0.52 kyr cal BP), Hudson (7.68 ± 0.14 kyr cal BP and 3.75-3.95 kyr cal BP) and Aguilera (3.12 ± 0.14 kyr cal BP) volcanoes. Excluding tephra layers, five main phases of dust deposition were identified based on changes of REE ratios suggesting variations in dust nature and/or source. The chemical composition (REE ratios and Nd isotopic composition) of the peat is compared to the signature of local geological material (rocks, sand, sediments) and South American dust sources published in the literature. It shows that the contribution of local sources is negligible and that mineral dust mostly derived from the long-range transport of Patagonian dust with a "mafic-like" geochemical signature distinguishable from other source areas in Southern South America which have a more "crustal-like" signature (Central Western Argentina, Puna and Altiplano regions). Dust accumulation rates calculated from the peat record were four times higher during the Late Glacial period compared to the beginning of the Holocene and only showed little variations during the Holocene. Altogether, these results fill an important gap in the geographical distribution of dust records available in the Southern Hemisphere.

Holocene dynamics of the Southern Hemisphere westerly winds: A depositional dust record from the Falkland Islands (Islas Malvinas)

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Recent intensification and southwards migration of the Southern Westerly Wind (SWW) belt has been identified as a key mechanism in controlling Southern Ocean carbon fluxes and global climate. Despite the importance of the SWW, our ability to predict their future behaviour is limited by a lack of agreement between palaeo-archives used to reconstruct the belt's Holocene dynamics. This disagreement is particularly prevalent across centennial to millennial timescales. Differences between South Atlantic records have been attributed to the indirect nature of past wind strength proxies and a sampling bias towards continental southern South America, where the Andes mountain range can confound results. Recent reconstructions have sought to address this disagreement by conducting studies on sub-Antarctic islands, free from confounding continental influences and located in the core of the SWW belt. Here we utilise inorganic (dust) flux, Itrax core scanning, rare earth element (REE) composition and HYSPLIT modelling from a 13,500 year peat record of South Atlantic SWW intensity and air-mass circulation from the Falkland Islands (Islas Malvinas). We find increased dust deposition and variability from 1700-5500 cal yr BP, signalling intensification of the SWW and possible teleconnections to the El Niño–Southern Oscillation during the mid-Holocene. Patagonia acts as a consistent distal dust source during this period, indicating no large latitudinal movements in the wind belt. Additionally, we capture two possible volcanic eruptions in our record, likely from Mt Hudson, at ~4000 and ~9800 cal yr BP, offering a snapshot of air mass circulation at these times. Multiple independent proxies directly measuring wind-blown transport, HYSPLIT modelling, and high-resolution radiocarbon dating allow this record to act as a reliable South Atlantic datapoint in accurately constraining the behaviour of the SWW belt and increasing our understanding of Holocene South American dust emissions.

Wind-blown dust and salt-spray concentrations reveal long-term correspondence between Southern Hemisphere Westerly wind intensity and temperature over the Southern Ocean

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The circumpolar belt of Southern Hemisphere Westerly winds (SHW) has strengthened and contracted closer to the Antarctic coast in recent decades, bringing about significant environmental changes throughout the southern high latitudes. These include rapidly warming temperatures on the Antarctic Peninsula, enhanced Agulhas leakage, increased basal melting of ice-shelves, reduced precipitation supply to the southern continents, and a reduction in the carbon-sink capacity of the Southern Ocean. Despite their crucial role, evolution of the winds over centennial-scales is currently poorly constrained, limiting our ability to

predict their impacts under future climates. To address this problem, we collected a series of new palaeoenvironmental records from peatlands and lakes on Sub-Antarctic islands that are located close to, or within, the core SHW belt and are therefore most sensitive to changes in wind-behaviour. Proxies for changes in wind-behaviour have until recently remained indirect, reliant on convoluted assumptions to relate a measurable variable (e.g., precipitation) to wind conditions. Using ITRAX-XRF scanning and bulk sample ICPMS to track minerogenic inputs into these new records we have begun to map and estimate fluxes of both localised and long-distance transported dust, as a direct proxy for past wind conditions. While they provide a direct link to wind-behaviour, taken alone these reconstructions are prone to uncertainties caused by stochastic changes in the availability of dust in source regions and changes in the hydrology of the archives as they develop. To provide multi-proxy cross-validation we developed a novel, independent biological proxy, based on the sensitivity of microbes (testate amoebae and diatoms) to changes in the concentration of salt-spray aerosols deposited inland by the wind. Using this multi-proxy approach, we combine our records from Marion Island and South Georgia to separate changes in wind intensity from latitudinal migration. These records for the Atlantic sector of the Southern Ocean, demonstrate correspondence between Southern Hemisphere Westerly wind intensity and temperature, spanning both recent decades and the Holocene.

Dissolved titanium as a tracer for dust input in the Southern Hemisphere

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The deposition of atmospheric dust from continental sources is a major input path of trace elements into the open ocean and may be the major controlling factor on primary productivity in the Southern Ocean, potentially through the dissolution from particles of the limiting nutrient iron. However, dust deposition to the open ocean is still poorly constrained and restricted to few direct observations and estimates based on model outputs. Currently tracers for dust deposition include, dissolved Aluminum and more recently the use of thorium isotopes to determine the supply of dust particles to the surface ocean. In this presentation, we will use dissolved titanium data obtained from the South Pacific Gyre and the Atlantic sector of the Southern Ocean to estimate dust fluxes to these regions and examine the underlying uncertainties and assumptions used in this approach. Comparison to the other tracers commonly employed shows the importance of chemical kinetics and lability (bioavailability/scavenging) on the residence time and thus the ability of such approaches to accurately determine long term average deposition rates or integrate over short term episodic inputs (e.g. seasonal winds, volcanic ash, bushfire ash, rain events).

Impact of desert and volcanic aerosol deposition on phytoplankton in the Southern Indian Ocean

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The Southern Ocean is known to be the largest High Nutrient Low Chlorophyll (HNLC) area of the global ocean, where algal development is mainly limited by iron (Fe) deficiency, except in few naturally Fe fertilized areas (e.g. around Kerguelen plateau). The availability of different nutrients is unevenly distributed in this area. Thus, northwards the polar front, nitrogen and phosphorus (N and P) concentrations are high, but the scarcity of silicon (Si) limits the growth of diatoms (HN-Low Si-LC area). Further North, the Southern Indian Ocean is characterized by macronutrient limitation and low primary production (LNLC).
In these areas, atmospheric input could play a major role in the nutrient supply of primary producers. The main aim of this study is to assess the biological response of local phytoplankton communities to a deposition of two types of natural aerosols: desert dust and volcanic ash. Preliminary trace-metal clean laboratory experiments enabled us to quantify the abiotic dissolution of main macro- and micronutrients in dry and wet deposition mode of different natural aerosols of these types that yield us to choose Patagonia dust and ash from the Icelandic volcano Eyjafjallajökull for our experiment at sea.
We set up a series of on-board trace-metal clean microcosm experiments in the contrasted biogeochemical conditions of the Southern Indian Ocean with addition of realistic amounts of dust and ash of respectively 2 and 25 $mg.L^{-1}$. Experiments ran over 48 hours to evaluate the triggered primary production, cell abundances, and community structure through pigment assessment. Parallel experiments with nutrient addition (dFe, DIP, DIN and dSi) enabled us to determine which element(s) dissolved from the aerosols was responsible for the enhanced algal growth.
The highest CO_2 fixation rate of 50 $mg.m^{-3}.day^{-1}$ was found at the natural Fe fertilized Kerguelen plateau station. Dust, ash and Fe addition triggered primary production, and CO_2 fixation doubled in these treatments. At the different HNLC stations (high N - low Si and high N - high Si), Fe and aerosol addition induced increased CO_2 fixation. In the northern LNLC stations, algal growth was stimulated by nitrogen

addition as expected, but Fe, Si and/or aerosol addition also triggered a biological response from Synechococcus cyanobacteria and pico- and nanoeukaryotes.
Noteworthy, in most experiments the two contrasted aerosol types (desert dust and volcanic ash) at particle charges which varied over more than an order of magnitude triggered very similar biological responses in all of the sampled areas, even with distinct elementary and mineral compositions (e.g. the Icelandic volcano ash is 64 % amorphous and contains roughly twice the amount of Fe, P, Mn and Zn compared to the Patagonian desert dust which is only 48 % amorphous).

Atmospheric trace metal deposition in the oceans south of Southern Africa

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Atmospheric deposition of aerosols can supply important micronutrients (trace metals) to surface oceanic waters and through this supply, enhance marine phytoplankton primary productivity. Various previous cruises have sampled trace metal aerosols over the Southern Ocean (SO) during summer, but data during the winter months is still missing. This is despite that most of the dust emissions from Southern Africa occurs during the drier winter and spring months. Hence, we conducted a sampling expedition during winter (July to August) and spring (October to November) in 2019 from South Africa towards the southwestern Indian Ocean and southeastern Atlantic Ocean. Since the impact of aerosols on marine biogeochemistry depends on the solubility of the aerosols' particulate phases, we report the total composition and fractional solubility of atmospheric trace metals (Al, Fe, Mn, Cu, Co, Pb and Zn). For the latter we conducted two-stage leaching experiments (Milli-Q water and a 25% acetic acid leach). The mean total concentration (±SD) in ng m^{-3} were 2388 ± 2494 (Fe), 197 ± 129 (Al), 295 ± 280 (Mn), 13.6 ± 17.3 (Cu), 1.8 ± 2.2 (V) and 26 ± 16 (Zn), at five stations in winter, and 165 ± 71 (Al), 48 ± 21 (Fe), 1.2 ± 0.6 (Mn), 10 ± 20 (Cu), 40 ± 20 (Zn) and 0.6 ± 0.3 (V), at seven stations in spring. The fractional solubility in Milli-Q water ranged from 0 to 31 % for Fe, 2 to 30 % for Al, 0.2 to 23 % for V and 2.1 to 80% for Zn, 1 to 84% for Co, 0 to 45% for Cu and 0 to 47% for Mn. The labile fraction in the 25% acetic acid leach ranged from 0.5 to 41 % for Fe, 9 to 48 % for Al, 0.1 to 88 % for Mn, 25 to 72 % for Zn and 3.3 to 39 % for Co. Backward trajectories showed that some aerosols were from southern African sources, especially those collected closer to the continent, while the higher latitude samples originated either from South America or Antarctica. Here, we present one of the few studies that collected aerosols and determined the fractional solubility during winter and spring.

Aeolian dust and bioactive trace metals concentrations over the Indian Ocean

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Aeolian dust is one of the major sources of macro and micro nutrients to surface water of open oceanic region. Subsequent to their deposition, they can impact on surface water biogeochemical processes, including primary productivity. It is thus important to quantify atmospheric composition and fluxes of dust and associated trace metals (which also act as micronutrients) over the marine region. In this context, we are reporting here Aeolian dust and associated trace metal concentration in aerosols collected along Meridional transit over the Indian Ocean (starting from southern coast of India to 13°S). Aerosol samples have been collected during two cruises SSD-48 (starting from Chennai port; 6.55°N, 82.30°E of western Bay of Bengal up to Central Indian Ocean Basin (CIOB); 13.7°S 74.68°E) during April-May 2018 and SSD-62 (starting from Mormugao port; 15.37°N, 73.84°E of eastern Arabian Sea up to CIOB; 13.56°S 75.56°E) during June-

July 2019 which coincide with Austral Winter. Total 33 samples were collected on PALLFLEX®™ tissue quartz filters using a high volume samplers (TISCH Environmental) during the two cruises. Subsequently all sample were acid digested by using HF and HNO_3 with Savillex vials in a clean lab. Trace metals (Mn, Cu, Cd, Pb) were analyzed using (Attom ES HR-ICP-MS) and major element (Al, Fe) were analyzed by (AGILENT-710 Axial ICP-OES).
We estimated dust abundance (ug/m^3) using Al concentration, presuming Al value similar to upper continental crust (8.04%). Our data suggest the Arabian Sea receive higher amount of dust (14.6 ± 9.7 µg/m^3) during monsoon (June-July) as compared to the Bay of Bengal (10.2 ± 9.7 µg/m^3). Major sources of this dust over the Arabian Sea include Middle East and northern Africa region surrounding the Arabian Sea. Compared to the Northern Indian Ocean (NIO), equatorial Indian Ocean receives relatively lower dust (3.6 ± 0.4 µg/m^3) during SW-monsoon and (8 ± 5.8 µg/m^3) spring inter-monsoon. In CIOB region the air parcels are dominantly from Australia and Indonesian region which brings aeolian dust to these regions during SW-Monsoon and have relatively higher dust (4.3 ± 1.6 µg/m^3) as compared to spring inter-monsoon (1.8 ± 1 µg/m^3) months. Higher dust concentration during SW-monsoon coincide with Austal winter when the western Australia receives high concentration of dust compare with other seasons. Other than Mn, CIOB region receives lower amount of crustal derived trace metals (like Fe) compared to NIO. During our study period almost similar Mn concentration is found over the NIO and CIOB region. The Enrichment factor (EF) of Mn shows higher values over CIOB in contrast to those collected over the NIO indicating relatively more anthropogenic influence, possibly from the Indonesia and Australia. EF of Cu, Cd and Pb were found >10 suggesting anthropogenic influence for enrichment of theses metals.

Does the deposition of aeolian dust on the sea favor primary productivity?

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In the coast of the Patagonia, Argentina, strong winds from the western sector carry large amounts of dust into the sea. In previous studies it was observed that dust contains nutrients that, on certain occasions, could favor the development of primary producers. However, so far there are no direct measurements that allow corroborating the effect of dust on organisms in the marine environment. Within the framework of the Pampa Azul Initiative, during November 2017, a series of experiments were carried out on board the Oceanographic Vessel Puerto Deseado to address the effect of dust on primary productivity *in situ*. The goal was to study the effect of the deposition of aeolian dust in the sea on the uptake of nitrogen sources carried out by the primary producers. Through a series of Niskin bottles, 20 liters of surface seawater (5 m-deep) was collected and then filtered through a 200 µm net and divided in two parts. To one of these parts 0.05 mg L^{-1} of dust was added, while the other part was left as a control. These two parts were kept in incubation after the addition of $^{15}NH_4Cl$ and $Na^{15}NO_3$. Samples were taken to measure the concentration of nitrate and ammonium, and the uptake of nitrate and ammonium at three intervals of time: 0 h, 24 h and 48 h. Dust used in the experiments was collected weeks ago by means of passive collectors located on the ground. Although the addition of dust increases the concentration of nitrate and ammonium in seawater; it reduced the uptake of nitrogen sources and therefore, the primary productivity. Some possible causes of these results will be discussed in the presentation.

Influence of dust on the microbial food web in Nuevo Gulf (Patagonia, Argentina)

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Patagonia is recognized as a major dust source in the Southern Hemisphere originated from rivers basins, glacial activity, salt lakes or natural events such as volcanic eruptions. Additionally, dust associated with anthropogenic sources (e.g., agriculture, livestock or mining industry) was detected over this region using satellite data or in situ measurements. The aim of this project was to study the effect of dust on the microbial food web in Nuevo Gulf (Patagonia, Argentina). The experiment was carried out during the austral spring 2018, using nine outdoor microcosms incubated in situ close to the coast. Microcosms were filled with one of three treatments: Control contained seawater without dust addition, Dust 1 received low concentrations of dust (0.05 mg L^{-1}) and Dust 2 were enriched with high concentrations of dust (1 mg L^{-1}). The experiment lasted six days. Initial seawater was characterized by low inorganic nutrient concentrations suggesting an oligotrophic condition. Dust 2 treatment led to an increase in nitrate + nitrite and ammonium concentrations in the microcosms. In general, nitrate + nitrite concentrations decreased steadily over time in all treatments indicating nutrient uptake by phytoplankton and bacteria. The concentration of ammonium gradually decreased in all microcosms until Day 3 and then increased towards the end of the experiment. Significantly higher ammonium concentration was observed in Dust 2 which was on average two times higher than in Control and Dust 1 treatments. Silicic acid concentration peaked in all mesocosms on Day 1 and then declined reaching the lowest values on Day 5. Phosphate concentration showed a decreasing trend in all microcosms, constituting ~30-40% of the initial values at the end of the experiment. DIN:DIP ratios <16 in all microcosms suggested nitrogen limitation during the experiment. Additionally, DSi:DIN ratios <1 indicated likely Si co-limitation at the end of the experiment in Dust 2 treatment. Heterotrophic bacteria showed a similar trend in all treatments increasing from the start to the middle of the experiment and then decreased towards Day 5. In general, picocyanobacteria abundance decreased steadily over time in all treatments and reached the lowest values on Day 5. A similar trend was observed in relation to picoeukaryote abundance in Dust 2 treatment. In Control and Dust 1 treatments picoeukaryote abundance peaked at Day 3 and then declined close to initial values on Day 5. Our results indicate that dust was both nitrate + nitrite and ammonium sources. Changes in DIN:DIP and DSi:DIN ratios observed over the course of the experiment reflected changes in the autotrophic-to-heterotrophic picoplankton biomass ratio, suggesting stronger nutrient limitation in Control and Dust 1 treatments.

Dust emission from the agricultural fields in the semi-arid Free State, South Africa, and the influence of crusts and soil cover

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The agricultural areas in the semi-arid Free State province in South Africa are the biggest sources of dust emission in the country. This emission of dust can cause land degradation which can eventually lead to a reduction in crop yield. The suspended dust from this region also has the potential to reach the densely populated Gauteng area, where it can have a negative effect on human health. The dust season takes place in early winter and spring, but the amount of observed dust events differs greatly from year to year. This temporal variation indicates that there is a strong influence of soil and surface characteristics on the erodibility of the surface. Therefore, it is necessary to understand the processes that drive the dust emission from these bare and crusted agricultural lands. This study presents a combination of experimental small-scale measurements with the Portable In-Situ Wind Erosion Laboratory (PI-SWERL), field monitoring measurements, and UAV image analyses on a maize, groundnut, sunflower, and fallow field. The PI-SWERL measurements showed a significant difference between the emission from crusted and loose surfaces (0.49 mg s^{-1} m^{-2} and 2.34 mg s^{-1} m^{-2}, respectively, at a friction velocity of 0.56 m s^{-1}). The emission of loose surfaces is mainly controlled by the presence of clay and silt (R^2 = 0.68), whereas the emission from crusted surfaces showed a strong correlation with the presence of abraders (R^2 = 0.76). The horizontal sediment flux was measured by using masts with Big Spring Number Eight (BSNE) samplers. The horizontal sediment flux was then compared to the vegetation cover, which was obtained by UAV image analysis. The data showed a general negative exponential relationship between the vegetation cover and the horizontal sediment flux. The horizontal sediment flux on the fallow fields was therefore relatively high, which is an indication of the abrasion taking place on these crusted areas. These abraders are likely originating from adjacent fields and minimizing this input of particles could minimize emission from crusted surfaces. This external influence should be taken into account when modeling emissions from crusted surfaces or developing guidelines for agricultural practices.

Horizontal and vertical fluxes of particulate matter during wind erosion on arable land in the province La Pampa, Argentina

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A detailed analysis of horizontal and vertical PM fluxes during wind erosion has been conducted, based on measurements of PM10, PM2.5 and PM1.0 concentrations at windward and leeward positions on a measuring field. The three fractions of PM are differently influenced by the increasing wind and shear velocities of the wind. The measured concentrations of the coarser fractions of the fine dust, PM10 and PM2.5, increase with wind and shear velocity, whereas PM1.0 concentrations show no clear correlation to

the shear velocity. The share of PM2.5 on PM10 is depending on the measuring height and wind speed and varies between 4 to 12 m s-1 in 1 m height ranging from 25 to 7 % (average 10%), and in 4 m height from 39 to 23 % (average 30%). Although general relationships between wind speed, PM concentration, and horizontal and vertical fluxes could be found, the contribution of the measuring field was very low, as balances of incoming and outgoing fluxes show. Consequently, the measured PM concentrations are determined by a variety of sources, as traffic on unpaved roads, cattle drives, tillage operations and wind erosion, and thus representing all components of land use and landscape structure in the near and far surroundings of the measuring field. Our results may rather reflect factors from the landscape scale than being influenced by field-related variables. The used measuring devices to monitor PM concentrations showed differences of up to 20%, which led to considerable deviations when determining total balances. Differences up to 67% between the calculated fluxes prove the necessity of a previous calibration of the used devices.

Highlights of the study on aeolian dust emitted from agricultural soils of Argentina

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Although some precedents exist, strong research on wind erosion in Argentina started around 1995. The first works focused on the measurement of wind erosion. Some mass flux profile models turned out not to be mathematically feasible to calculate the horizontal mass transport, hence producing important biases. Even when using the models that can represent better the mass distribution with height, such as exponential functions or linear interpolation, we found differences of up to 50% in the calculated mass transport depending on the sampling set up. Considering this, soil losses measured in loessic soils from central Argentina were up to 1.5 kg m^{-2} day^{-1} (or 27 Mg ha^{-1} $year^{-1}$). Generally, much lower values were measured in other soil types across the country. Mean threshold wind speed was 7.5 m s^{-1} for loessic soils, but generally higher for other soil types in more arid and windy regions. After studying wind erosion, work was oriented towards dust or particulate matter less than ten microns in diameter (PM10) emitted from agricultural soils and from other wind-erosion prone surfaces in rural areas. Very sandy surfaces such as unpaved roads were found to emit less dust per unit of transported mass, but to emit much more absolute quantities because horizontal mass transport was much higher than on soils. Using concentration gradients, average potential PM10 vertical emission for loessic soils from central Argentina was estimated to be between $2x10^{-4}$ g m^{-2} s^{-1} and $8x10^{-4}$ g m^{-2} s^{-1}. According to our findings, abrasion predominates in sandy surfaces, and lifting of loose particles prevails in finer surfaces. Higher emission values were observed for loamy textures due to the overlapping of abrasion, lifting, and fragmentation of aggregates during saltation. Aggregates that move most actively by saltation on loamy-textured soils are, on average, 110 microns in diameter. We also observed that around 250 metres of bare surface are needed for the development of a dust plume from full fragmentation of the saltating soil aggregates on a loamy sand soil. Particles that we have consistently found to actively contribute to the emission of dust are up to around 62.5 microns, because particles in this size range are much more affected by vertical forces than bigger ones. On average, 12% of these particles were found to be lost by vertical movement over a distance of 200 meters. The highest PM10 emission rates under field conditions were observed when relative humidity was below 20% and the air temperature was higher than 30°C, especially when the wind speed exceeded 8 m s^{-1}. Interaction between climate, soil and tillage produces high variability of dust emission. Dust is generally enriched in chemical elements as compared to the bulk soil. Nutrient content in PM10 from eroded sediment from these soils was found to be up to 60 g/kg C, 5 g/kg N, 900 mg/kg S; and up to 250 mg/kg Ca and Mg. C y N are transported

higher than Ca and Mg, especially on less structured surfaces, and S showed a more homogenous distribution with height.

PM10 emission from feedlots in soils with different texture: Cattle trampling effect

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Cattle feedlot surfaces can be an important aerosol source, but they have barely been studied. The action of the hooves on the loose, dry layer of soil and manure creates ideal conditions for particulate matter (PM) emissions. The feedlot system was considered as a set of surfaces that could potentially be affected by the processes of wind erosion and dust emission due to the direct effect of cattle trampling on the surface and the different activities related to commercial feedlot The objectives of this work were: a) to quantify the soil loss (Q) and the consequent emission of PM10 (FvPM10) from different surfaces within the feedlot: unpaved roads (UR), cropland (C) and cattle pen (CP); and b) to evaluate the cattle trampling effect in UR, C and CP on Q and FvPM10. Three cattle feedlots in a N-S transect were selected from the Pampas Semiarid Region (PSR) with different soil textures: Trenel (FT), Santa Rosa (FSR) and General Acha (FGA). On each surface (C, UR, CP), the effect of animal trampling was assessed at three levels of disturbance: a) no disturbance (D0, soil samples without cattle trampling effect), b) low disturbance (DL, soil sample affected by low cattle trampling effect) and c) high disturbance (DH, soil sample affected by high cattle trampling effect). In a wind tunnel, erosion events were simulated at 10.5 m s^{-1} (μ*: 0.26 m s^{-1}) during 5 min. A low animal trampling effect was simulated by 10 tramples of cow hoof and a high animal trampling effect was simulated by 60 tramples of cow hoof. The results showed that Q and FvPM10 were UR > C > CP and that the cattle trampling effect was generally directly proportional to Q and FvPM10 ($p < 0.05$). The highest Q and FvPM10 observed in the UR were due to a combination of high sand content, low organic matter, high EF and low aggregation that produces a highly erodible surface. The C surfaces, despite having a better aggregation, showed low dry aggregate stability and were moderately prone to wind erosion. On the contrary, CP are surfaces with a high proportion of organic material which enhances the formation of macro-aggregates (>6.4 mm) that are structurally stable and less prone to suffer wind erosion. Emissions from CP represented less than 5% of the total emissions from all the surfaces of each feedlot while in UR represented more than 60%. PM10 emission efficiency (calculated as FvPM10/Q) of the different surfaces (UR, CP and C) ranged between 10-6 and 10-4. In general the FvPM10/Q was higher in the feedlot with the finest soil texture (FT) than in the other two feedlots with coarser soil (FSR and FGA). Regarding the type of surface, emission efficiency from UR was lower than from C and CP surfaces. CP presented the lowest values of Q and FvPM10, but it showed high RE so it could be considered a continuous source of wind-derived emission of PM10 due to the effect of permanent trampling.

Carbon enrichment in particulate matter is affected by the interaction between soil type and management

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Coarse textured soils, with low soil organic carbon (SOC) content, like those of the Pampas, are prone to be eroded by the wind. It is known that wind erosion of these soils, which largely depends on management practices and climatic conditions, can modify the physico-chemical composition of the uppermost layer. Little is known on how such changes may affect the composition and enrichment of the particulate matter (PM). Because of this, three soils of the Pampas, spanning from sandy- to sandy loam texture, and with low- (LC), medium-(MC) and high (HC) cultivation intensities, were sampled in two consecutive 10-year periods: a more humid and a dryer than the normal for the region. For each soil and in all dates, PM was separated by a sorption-based laboratory procedure. Samples were investigated for granulometry, organic C and mineral (Si-O of quartz and O-H of clay minerals) and organic (C-H of aliphatics, C=O of carboxylic acids, aldehydes, amides and aromatics, and C-O-C of polysaccharides) functional groups. Results show that PM composition does not differ between soils. This can be explained by the frequent turnover of the uppermost layer due to tillage, constituting a reload of new particles. However, C enrichment of PM of LC and HC, mainly associated with that of C-H groups of plant debris and C-O-C of polysaccharides of microbial origin, was higher than in MC. This can be explained by the dominance of quartz sand grains, side-by-side arranged with fresh and loose organic matter in LC, that determine the ease with which fine sized clay and silt and low-density fresh debris, accumulated in PM. The accumulation of C in PM of HC was related to its presence in polysaccharides as part of fine-sized microaggregates. The better aggregation of MC may explain why C accumulated in lower proportion in its PM. With time and in all sites, PM impoverished in C and enriched in clay, as shown by the increase in the clay+silt/C ratio. This was explained by SOC impoverishment after the dryer period, which was related to the decrease of the labile C-H groups, probably caused by the low residue input followed by its rapid oxidation during the dryer phase. LC impoverished the most, probably due to its low SOC stock mainly composed by C-H groups. The clay enrichment in PM was probably a consequence of the deterioration of soil structure due to frequent tillage. In MC and HC, clay accumulation in PM was significant only when frequent tillage operations were performed during the dryer phase. In LC, clay enrichment occurred even during the moister period, and may be explained by the worse physical conditions of this soil. However, PM of LC and HC prevailed as the most C enriched ones along the time, according to its composition rich in C-H and C-O-C groups easily transported by the wind. The decrease with time of the proportion of C in PM would affect its distribution in the ecosystem.

Are sodium-rich dust inputs from shrinking lakes diminishing southern South American soil fertility?

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Dry lake beds exposed by shrinking water bodies in arid regions constitute sodium (Na)-rich mineral dust emission hotspots that may potentially affect agriculture. While several studies have proposed this link based on the dispersive properties of Na, no mass balance has so far been attempted. We modeled 13 years of dust emission from Mar Chiquita (MC), the most extensive saline lake in South America, which has experienced recent shrinking in response to climate variability and anthropogenic water diversion in the upper tributaries. Based on the chemistry of dust, we found that on average between 2005-2017, ~15-150 mg m^{-2} of MC-derived soluble Na was deposited 300 km from the source in August plus September, the

season of strongest MC dust emissions. We compared these values against exchangeable Na stocks measured on agricultural soils at 13 sites across the Pampean plains, with differing rainfall regimes and water holding capacity. We found that infiltrated rainfall water in equilibrium with Na from deposited dust has a low to non-existent short-term, seasonal sodification risk, except in close proximity to the MC dust source (<50 km) where this risk might be severe. However, dilution during the rest of the year, combined with losses of Na, imply that long-term dust-related rises in exchangeable Na are probably negligible at all studied sites, except close to the dust source where deposition rates are maximum. Under scenarios of enhanced salt-rich dust emissions from shrinking lakes in the 21st century, attention should be paid to soils close to MC and to salt-rich dust sources worldwide, in order to prevent the occurrence of degradation processes related to Na enrichment. However, only by accurate mass balancing of the atmospheric inputs to the soils can this effect be correctly gauged.

Low source-inherited iron solubility limits fertilization potential of South American dust

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In regions where atmospheric processing is weak due to low anthropogenic emissions, fertilization of iron-limited oceans by mineral dust aerosols strongly depends on iron solubility at the sources. Southern South America (SSA) is one of the most pristine environments, and the main contributor of dust to the southern oceans, in turn the most sensitive ocean basin to iron fertilization. Thus, the present-day lack of fertilization of the southern oceans by SSA dust is hypothesized to reflect low iron bioavailability inherited from the sources. However, a dearth of geochemical studies of active dust sources in SSA prevents testing this hypothesis. To remedy this, we conducted the first systematic sampling of active dust sources in SSA, which we combined with previous sampling of wind-borne dust close to the sources. Iron leaching experiments showed that the fertilization potential of SSA dust is low compared to dust from other regions. Based on characterizations of grain size, size-resolved mineralogy, elemental chemistry and iron speciation, we found that variability in labile iron of present-day dust-emitting surface sediments and close-to-source dust is dictated by multiple factors, being enhanced by high clay contents, small grain size and higher proportions of paramagnetic versus magnetic iron, irrespective of iron oxidation state. The independence of the most labile, water-soluble iron on grain size may imply that we currently underestimate the role of coarse glaciogenic dust as a supplier of bioavailable iron during ice ages, during which enhanced supply of dust-borne bioavailable iron to the southern oceans is observed.

Dust cycle in Antarctica: insights from Holocene East Antarctic firn/ice core records and atmospheric dust measurements at Concordia Station

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Mineral dust deflated from the continents of the Southern Hemisphere can be transported long-distance to central East Antarctica. After deposition onto the polar plateau, dust buried in snow, firn and ice layers can be studied through ice cores and can be used to document past atmospheric circulation variability and past climate conditions at the source. Over the last years, an increasing amount of evidence revealed that the dust cycle in Antarctica is much more complex than expected. Important regional differences exist between (1) high-altitude sites of the central East Antarctic plateau, displaying the lowest dust deposition fluxes on Earth; (2) marginal locations close to the Transantarctic Mountains, that are sensitive to regional climate changes; (3) low-elevation coastal sites, which represent a key area to assess the atmospheric dust export to the Southern Ocean but are still poorly studied. We provide here a comprehensive overview of the atmospheric dust cycle in these three environments of the Antarctic, paying particular attention to central East Antarctic sites and to the Holocene dust transport variability deduced from dust grain size changes registered in the SOLARICE ice core. Recent optical atmospheric dust measurements performed all year round at Concordia Station in the framework of the OPTAIR project will be shown and used to refine the interpretation of paleo-data.

Mineral dust in the snow pits of the East Antarctic International Ice Sheet Traverse (EAIIST): preliminary results and perspectives

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The East Antarctic International Ice Sheet Traverse project (EAIIST, 2017-2022) surveyed a large region of the East Antarctic plateau, including areas of megadunes and wind glazed surfaces, between the French-Italian Concordia station (75°S, 123° E), and the US South Pole station (90° S). The scientific objectives of EAIIST are to study the icy terrain of the Antarctic continent in its driest places. These areas are largely unexplored and unknown and offer unique and extraordinary morphological characteristics. During the survey six sites were selected to sampling in the snow pits and with shallow cores. The samples were then transported to the EuroCold Lab. of the University Milano Bicocca in Italy, where dust concentration, grain size distribution and optical properties were measured. The analysis shows that the particle size increases from the Megadune Accumulation site to the Wind Crust site with intermediate values for AGO5, Paleo and Megadune Erosion. A volcanic event was also recognized in all the sites analyzed. It can be useful for reconstructing the accumulation rate in the different sites and it can be an important stratigraphic marker for correlations. Once the volcanic event has been dated, we will also interpret the data with the analysis of shallow ice cores taken on the same sites as well as making a comparison with the chemical analyzes.

The role of Southern Africa in explaining the East Antarctica dust fingerprint during interglacial times

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Mineral dust is a natural tracer of atmospheric composition and climate variability, yet little is known about the Southern Hemisphere (SH) dust cycle during the last climatic periods. Major efforts have attempted to solve the 'puzzle' of the origin of the potential source areas (PSAs) that contribute dust to the Southern Ocean (SO) and East Antarctica (EA). Multiple studies have unequivocally demonstrated the main dust contributor is Southern South America (SSA). However, there is still no consensus about secondary contributions from other PSAs, including Australia, New Zealand and local Antarctic sources. Moreover, lesser still is the knowledge about other land masses around the Antarctic continent, such is the case of the hyper-arid areas of Southern Africa (SAF), that despite being a very important dust source, its role as a dust supplier to different environments of the SH has been significantly underestimated. Here we present a comprehensive geochemical characterization of the SAF region. On the basis of Sr-Nd-Pb isotope ratios and rare earth element concentrations analyzed in sediments collected along the major dust-producing areas in the Namibian coast (Kuiseb, Omaruru and Huab riverbeds and the Namibia sand sea area), this study demonstrates for the first time that, together with PSAs in Southern South America (Patagonia, Puna-Altiplano Plateau), Southern Africa appears as a secondary dust source to the South Atlantic sector of the SO and EA during interglacial times.

REE-based reconstruction and quantification of dust flux provenances in East Antarctica over the Last Glacial-Interglacial Transition

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To elucidate the atmospheric circulation changes in the past and present climate, the determination of dust provenance in eolian deposits - i.e., sediment or ice cores - is paramount. Antarctic ice cores have revealed

the tight interplay between dust flux to the Southern Hemisphere and the climate. However, so far, the unambiguous identification of Antarctic dust sources and their evolution through time remain limited due to the substantial amounts of dust usually required by geochemical analyses. Here, using an in-depth statistical modeling specifically developed for Rare Earth Elements (REE) patterns from dust samples collected in ice cores (Epica Dronning Maud Land - EDML)[1] and from potential source areas (PSAs) over the Southern Hemisphere, we identified and quantified the source evolution of atmospheric depositions in E. Antarctica over the Last Glacial-Interglacial Transition (LGIT). Strontium, Nd and Pb isotopic data are also compared with our REE results. We showed that many sources are involved in the dust mixing reaching EDML with, as shown before, Patagonia as the most important source followed by Australia, Southern Africa (SAF), New-Zealand (NZ) and Puna-Altiplano plateau. During the Last Glacial Maximum (LGM), dust reaching EDML is mostly from glacier driven sources (Patagonia and NZ) while Holocene is characterised by larger relative contributions from desertic source regions (SAF and Australia). We could also relate the evolution of dust provenance and flux to document climatic transitions within PSAs and at a larger scale within the Southern Hemisphere. This work provides major implications for the reconstruction of atmospheric paleocirculation and paleoclimate.

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Giant dust in a tropical Andean glacier as a proxy of deep convection over the Altiplano

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Recent studies have considered giant dust particles larger than 20 µm in diameter in ice, obtaining interesting results in particular related to the relationships existing between these particles and the atmospheric patterns responsible for their deflation, transport, and deposition. In the Altiplano, a semi-arid plateau in the southern tropical Andes, a deeper understanding of past atmospheric patterns related to precipitation is a high priority topic in paleoclimatology, particularly to support the adaptation of local communities to the projected reduction in water availability. In this presentation I share one of the latest findings relating giant dust particles deposited on top of a tropical Andean glacier and seasonal atmospheric processes in the Bolivian Altiplano, in particular deep convective precipitation (Lindau et al., 2021). These findings are the result of joint efforts to analyze the dust record in an ice core from Nevado Illimani (Bolivia), involving the Centro Polar e Climático (Brazil), Institut de Recherche pour le Développement and Institut des Géosciences de l'Environnement (France), EUROCOLD (Italy), and Climate Change Institute (US). In June 2017, we drilled a 24 m core at an altitude of 6350 m above the sea level on the saddle between the two Nevado Illimani summits. We dated the core by annual layer counting based on seasonal oscillations of dust, calcium, and stable water isotopes. The very pronounced seasonal variations in these proxies allowed for the development of a precise chronology, which covers the period from 1999 to 2017. During austral summer (wet season), we observed an increase in the relative proportion of giant dust particles, in association with oscillations of stable isotope records. Convective activity is known to significantly affect the isotopic composition of tropical precipitation as intense regional convection leads to more isotopically depleted precipitation. Given the size of these particles and the dust geochemical and mineralogical fingerprint, we confidently associate the giant particles with local and regional convective activity. This is corroborated by regional meteorological data. The interpretation of giant particles and stable isotope records suggests that downdrafts due to convective activity promote turbulent conditions capable of suspending giant particles in the vicinity of Nevado Illimani. Giant particles and stable isotopes, when considered together, can be therefore used as a new proxy for obtaining information about deep convective activity in the past. Thus, we show for the first time that climatic processes control the presence of giant dust

particles in Andean ice and demonstrate the great potential of giant particle records which are strongly influenced by meteorological processes at high altitude continental glaciers. Analysis of a longer ice core would be desirable in the future to investigate the relationships between giant dust particle deposition, atmospheric deep convection, and periodic climatic phenomena (La Niña).

Towards evaluating the impacts on Namibian mineral dust on the regional ecosystems: new data on composition and long-range transport

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The west coast of southern Africa is a crossroad of diverse aerosols of distant and local origins that play a role in the present and future climate, and could be affected by its changes. Besides being the transport region of major forest fires occurring in Central Africa in the austral dry season (August to October), southern Africa accounts for approximately 5% of the global annual emissions of mineral dust, as major recognized sources in Arabia and the deserts of East Asia. The largest sources are in Namibia, mostly ephemeral dry riverbeds along the Namibian coastline and the Etosha Pan desert. Depending on their physical (size, viscosity) and chemical (hygroscopicity, oxidation state) properties, these aerosols could have a number of impacts on the local and distant biogeochemical cycles. They could affect the regional fog formation and its potential in redistributing and providing nutrients and pollutants to ecosystems, while also acting on its lifetime by light-scattering and absorption. Previous work has also suggested that the transport of mineral dust could impact the productivity of both the Namibian coastal and that of the Southern Ocean. In this work, we present the results of the first long-term dataset of the aerosol chemical composition at an observatory on the coast of Namibia, facing the south-eastern Atlantic Ocean. Aerosol samples in the mass fraction of particles smaller than 1 and 10 µm in aerodynamic diameter were collected between 2016 and 2017 at the ground-based Henties Bay Aerosol Observatory (HBAO; 22°6′ S, 14°30′ E; 30 m above mean sea level). Samples were analyzed by X-ray fluorescence, ion chromatography and Inductively Coupled Plasma Mass Spectrometry to determine the elemental and the water-soluble composition of mineral dust from the Namibian sources that would determine their impacts during transport. During the observational period, the occurrence of mineral dust was episodic. Overall, 19 episodes of mineral dust were identified during the 2 years of sampling. The average mass ratio of Si/Al was 3.7 ± 1.0 in 2016 and 3.4 ± 0.8 in 2017, lower than the average values of 4 to 4.6 expected in global soils and crustal rock. Our average values are consistent with those obtained for particles less than 10 µm in diameter by Eltayeb et al. (1993) in the central Namib and consistent for mineral dust aerosols generated in a laboratory experiment. The average Fe/Al ratio was 0.74 ± 0.19 in 2016 and 0.76 ± 0.18 in 2017. The analytical results are interpreted by the modelling of dust export and deposition by the COSMO MUSCAT chemical transport model with improved dust source parameterization.

Is it dust, or what?

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For a synopsis of aerosol composition directed at natural aerosol sources, chemical aerosol data taken over the Southern Ocean and adjacent land stations have been collected from research cruises, Island stations and coastal stations spanning the years from 1983 to 2020. Besides sea salt and marine biogenic components, the data cover the typical crustal elements Calcium, Magnesium, and Potassium (CMP). With concurrent sodium data non-sea salt fractions of these elements have been calculated. The air mass origin of each sample was analyzed with hourly ten-day back trajectories. For each trajectory the number of travel hours from the nearest continent to the sampling point was calculated. With that air mass information samples were selected from the database which were taken at least five days downwind of the nearest continent. Nevertheless, these samples exhibited significant amounts of CMP. With a comparison of seasonal and geographic distributions of CMP and biogenic aerosol components such as Methylsulfonic acid the question is discussed to which extent the enrichment of nominally crustal elements may be due to a sea spray origin of CMP.

The importance of high-latitude dust for global climate through its role in ice nucleation in clouds

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The amount of ice and liquid water in clouds in the mid-high latitude oceans, including the Southern Ocean, is key to global climate [1]. However, the concentration of ice-nucleating particles in these clouds is poorly defined. This limits our capacity to predict how these clouds will change in a warming world resulting in substantial uncertainties in ice cloud-feedbacks. For example, modelling studies demonstrate that the amount the planet will warm for a doubling of carbon dioxide is predicted to increase by 1.5 K when the supercooled water content of oceanic clouds is corrected. High-latitude dust and the biological components they contain are thought to be important ice-nucleating particles in these climatically important cloud systems. Hence, characterising the sources and seasonality is critically important for reducing uncertainty in climate projections. In this talk I will summarise modelling work demonstrating the sensitivity of Southern Ocean clouds to ice-nucleating particles and also present results for the ice nucleating ability of high latitude dusts (from the Northern Hemisphere).

[1.] Murray, B. J., K. S. Carslaw, and P. R. Field (2021), Opinion: Cloud-phase climate feedback and the importance of ice-nucleating particles, Atmos. Chem. Phys., 21(2), 665-679, doi:10.5194/acp-21-665-2021.

Constraining dust-driven immersion freezing in climate models using spaceborne retrievals

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Clouds and dust aerosols impact the Earth's thermostat and precipitation. There is increasing evidence that dust aerosols frequently control cloud glaciation, modifying clouds' radiative effect and response to global warming. For realistic climate change projections, it is crucial to improve the simulated pathway between dust immersion freezing and cloud glaciation. However, current freezing schemes, which extrapolate laboratory results to larger atmospheric scales, are poorly constrained. Based on spaceborne observations of cloud-phase and aerosols, we explore whether dust-driven immersion freezing can be improved in a climate model so that the climate impact of dust ice-nuclei can be estimated more accurately. Combining an aerosol model reanalysis with spaceborne retrievals of cloud phase, we estimated the global co-variability between mineral dust aerosol and cloud glaciation. Relying on a spaceborne lidar, a lidar-radar synergy, and a radiometer-polarimeter synergy, we also locate and quantify the hemispheric and seasonal contrast in cloud-phase. Finally, we use these estimations to refine the dust-driven droplet freezing in a climate model. Our results show that observations of cloud-top phase contrasts may be used to evaluate dust-driven droplet freezing in climate models.

In the extratropics, the average frequency of ice cloud increases by +5% to +10% for higher mineral dust mixing-ratios on a day-to-day basis. For similar mixing-ratios of mineral dust, we found that the ice frequency can still vary between latitudes, especially between Hemispheres and between mid- and high-latitudes. By using only retrievals for which satellite products agree on cloud-phase, we find that the cloud-phase transition from liquid to ice occurs within a narrower temperature range. This suggests that individual products tend to classify too many clouds as liquid for temperatures below -30°C and too many as ice for temperatures above -10°C. At −30°C, the hemispheric and seasonal contrasts — relative to the Southern Hemisphere and boreal spring, respectively — lie between +21% to +39% for individual cloud-phase products and between +52% to +75% for a combination of products. We use these contrasts to tune the dust ice-nuclei efficiency in the model, limiting their effect during clean conditions. Consequently, the model agrees better with the estimated cloud-top-phase contrasts, resulting in a dust-driven glaciation effect of 0.14 ± 0.13 W m^{-2} in the Northern Hemisphere, which is lower than previously assumed.

Aeolian remobilization of volcanic ash: physical processes, particles and deposits in Southern volcanic terrains

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Although major dust emission sources in the Southern Hemisphere have been associated with deserts, salt lakes, and anthropogenic sources, recent studies on volcanic terrains have also recognised the significant contribution of ash deposits to aeolian processes in this region. In particular, due to the high volcanic activity in South America, combined with strong prevailing winds towards the East-Southeast, the Andes Range and the Patagonian steppe have been blanketed with vast deposits of loose particles, highly susceptible to be remobilised. Recent eruptions of Hudson (1991), Chaitén (2008), Cordón Caulle (2011-2012), and Calbuco (2015) volcanoes in Chile have emitted large amounts of material leading to intermittent, but long-lasting, aeolian processes, aggravating and prolonging the impacts on exposed communities. Compared to other sources of aeolian material though, the application of dust emission schemes and sediment transport models requires some specific adaptations to describe the aeolian remobilisation of volcanic ash. The wide-ranging timescales over which ash-remobilisation occurs (syn-eruptive to millennia after the eruption) are controlled by poorly-constrained factors, such as the availability of loose material and the change in compaction of the volcanic deposit over time, both of which make the erosion of volcanic deposits different to that of mineral sand and dust. Taking the 2011-2012 eruption of the Cordón Caulle eruption as a case study, we here present a comprehensive analysis of aeolian processes of volcanic ash. We specifically study the associated deposits, the size and morphology of the particles, and the timescale of the horizontal mass flux decay. Our results show that a specific grain size range, from < 0.4 to 500 microns, with 15-40% of material ranging from 63 – 125 microns, perfectly coincides with the grain sizes that minimise the wind threshold friction velocity for saltation. We further identify that a two-phase exponential decay describes the timescale of mass flux of airborne material. The first phase is characterised by a fast decay timescale and high mass fluxes associated with the initial input of a large volume of loose particles into the system. The second phase, with a slow decay timescale and low mass fluxes, is associated with soil stabilization processes and, most importantly, with the effects of supply-limited processes. We conclude that, in volcanic regions affected by small to moderate eruptions, characterized by an almost instantaneous injection of a large volume of material followed by the subsequent depletion of particles and rapid compaction processes, the availability of wind-erodible particles plays a major role on aeolian mass fluxes. We propose a simple and reproducible empirical model to describe the mass flux decay of remobilised ash in this supply-limited environment. This approach represents an innovative strategy to link field measurements of multi-sized and supply-limited deposits with saltation erosion theory.

Aeolian remobilisation associated with the recent explosive activity of Sabancaya volcano in southern Peru

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Explosive volcanic eruptions can produce large amounts of pyroclastic material that represent a threat to exposed communities and the environment. In particular, very fine volcanic ash (or volcanic dust; diameter < 63 µm) are commonly dispersed by the wind over wide regions, impacting human and livestock health as well as important economic systems, including air traffic. Whilst volcanic eruptions are often short lived and associated with discrete events, many volcanoes, such as Sabancaya in southern Peru, undergo stages of repeated explosive eruptions over time periods of years to decades. Simultaneously, continuous aeolian remobilisation of loose volcanic particles takes place around the volcano, favoured by dry and windy conditions combined with small amounts of vegetation. These processes represent a long-lasting secondary hazard that extends the impact of the primary sedimentation from the volcanic plume (primary ash fallout). In order to document aeolian processes associated with a long-lasting cycle of explosive eruptions, we conducted a field campaign at Sabancaya in July-August 2018. We first identified and categorised aeolian remobilisation phenomena based on high-definition videos and an appropriate classification for lithometeors adapted to volcanic ash. The most intense remobilisation phenomena encountered in the field are ash storms during which large quantities of ash are lifted to heights > 100 m by strong turbulent winds, reducing the visibility to less than 1 km. Additional PM10 measurements illustrate the intermittent nature of aeolian remobilisation and suggest that the concentration of very fine particles in suspension increases as the day progresses, due to diurnal changes in conditions such as the increasing surface temperature and wind speed. Furthermore, we have separately sampled primary fallout deposits and airborne remobilised material, and subsequently analysed the density, size and morphology of the collected particles. Although our field observations suggest intensive reworking of volcanic ash deposits at Sabancaya, the physical distinction between primary and remobilised particles is ambiguous, with only slight morphological differences. This emphasises the importance of combining field observations with a real-time sampling approach in these complex erosive terrains where both aeolian remobilisation and the emission of fresh pyroclastic material occur simultaneously.

Ensemble modelling of wind-induced resuspension of volcanic ash in Patagonia

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Resuspension and dispersal of volcanic ash by wind can cause negative effects on human health, flora, fauna, air and ground transportation, agricultural-livestock activity, goods, infrastructure works, services, and tourism. In particular, the possible effects on health include respiratory problems, gastrointestinal problems, ocular irritation, complaints in the skin and intoxication of animals. Moreover, the air traffic can be interrupted due to the presence of volcanic ash in suspension and the ground traffic can be affected by visibility reduction. Numerical modelling can be a useful tool for reducing the impacts of volcanic ash resuspension. Considerable progress has been made in the last years with regard to deterministic modelling of resuspension that includes the development of specific model strategies for dealing with this problem. The next step in this discipline is the generation of ensemble simulations to represent the uncertainty associated with different initial conditions and physical settings. The goal of this work is to generate an ensemble of volcanic ash resuspension simulations by perturbing critical source parameters and meteorological inputs to take into account different sources of uncertainty. The modelling system is based on the coupling between the atmospheric dispersal and deposition model FALL3D and the WRF-ARW

(Weather Research and Forecasting–Advanced Research) model. Our case study is the resuspension of the fallout deposit generated by the 2011 Cordón Caulle eruption which was remobilized by strong postfrontal winds. The atmospheric and land-surface fields are provided by the WRF-ARW with 18 km of horizontal resolution. In order to characterize the emission source area, we used tephra fallout deposit data based on field measurements of particle grain size distribution and density from both proximal and distal samples and an isopach map. Ensemble simulations are compared with deterministic results and the satellite images of the event. Finally, to quantify the impact, an analysis of the results is carried out using statistical metrics (e.g., the ensemble mean and spread) and categorical metrics. The results of this work show meaningful improvements in the current methodologies of resuspension simulations. The new developments presented here will enable an improvement of ash resuspension forecasting and will be available in future releases of the FALL3D model.

Impacts associated with aeolian remobilisation of volcanic ash: are they so different from those related to mineral dust?

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Explosive volcanic eruptions typically eject large amounts of ash into the atmosphere that eventually accumulate on the Earth's surface. However, the cycle of volcanic ash does not stop there. When specific conditions are met, ash can be remobilised by wind and re-entrained into the atmosphere for years to decades and even thousands of years after an eruption has ended. Although the occurrence of this phenomenon was reported in the first half of the 20th century, little attention has been devoted to it because of its complexity and, today, our knowledge is still incomplete. Nonetheless, the recent eruptions of Eyjafjallajökull (2010, Iceland) and Cordón Caulle (2011, Chile) volcanoes have highlighted again the impact of remobilised ash on communities and the environment, generating a renewed interest among the volcanological community. The Argentinian Patagonia is one of the three main geographical regions in the world, together with Alaska and Iceland, where this phenomenon has been reported. Remobilisation of ash associated with deposits from the eruptions of Hudson (1991), Chaitén (2008), Cordón Caulle (2011) and Calbuco (2015) volcanoes have been observed during and after the eruption. In this work, we review the impacts associated with the aeolian remobilisation of these deposits in the Argentinian Patagonia, as well as the methodologies employed to assess them. In addition, we compare these impacts with those reported in the existing literature for mineral dust in order to establish similarities and differences between them. We expect this work to promote discussion on how volcanic ash and mineral dust researchers can collaborate to raise awareness around these hazardous processes and together contribute to improving strategies to mitigate the associated impacts.

KEYNOTE SPEAKER

Contributions to the study of southern hemisphere Late Pleistocene climatic variability through the characterization of South American dust sources and the related sedimentary deposits

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The need to increase knowledge in aspects related to the climatic conditions prevailing over the southern hemisphere (SH) during the last glacial-interglacial periods, boosted the interest of the scientific community to investigate the physicochemical/isotopic characteristics of sediments deflated from southern South America (SSA) and to recognize them in key sedimentary deposits of the region (e.g., Pampas, Patagonian shelf, Southern Ocean; Antarctica). Due to its geographic position, SSA represents a key area that could help to unravel some questions related to past climatic changes. In particular, the region has the most significant loess deposits in the SH and this proximal aeolian dust record witnesses the importance of wind erosion affecting different latitudinal and topographic areas in the "arid diagonal" of SSA, and could shed light on the past atmospheric circulation over the SH. Furthermore, a huge amount of this aeolian material has been transported to remote areas, taking both essential micronutrients to the ocean and a fingerprint representing a particular SSA region, useful to trace back the origin of dust in paleo-climatic archives recovered from the Southern Ocean and Antarctica. During the last 20 years, we gained insight into aspects related to modern/past dust dynamics in the region, characterizing its textural, chemical/isotopic compositions and contributing to the interpretation of how the atmospheric circulation over the region could have changed during the last climatic cycles. In this talk, I present a review of these research activities showing the main results obtained by our group and pointing out future perspectives that could help the scientific community working on this issue to improve the state-of-the-art related to the role of the SH in the context of global future climate change scenarios.

KEYNOTE SPEAKER

Late Cenozoic record of South American loess: tectonic and paleoclimatic implications

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The sedimentary dynamics of southern South America loess is a key issue to understand and discuss Quaternary paleoenvironmental and paleoclimatic reconstructions as well as the dust impact on atmospheric dynamics and biogeochemical cycles, a matter of debate and ongoing research. The loess record is widely extended east of the Andes covering ample areas of the Chaco-Pampean plain along with several intermountain valleys of Sierras Pampeanas (NW Argentina). In the Pampean plain, three major cycles of loess accumulation have been identified. The first occurred during the late Miocene (~11Ma-6 Ma) followed by a second cycle between <6Ma and >3.3 Ma. The third cycle of loess accumulation began in the mid-Pliocene (~<3.3 Ma) and continued during the Quaternary up to the Present. The resulting loess sedimentation sequences have been related to tectonic events during the late Miocene and the mid-Pliocene.

The common features of the sequences are the presence of paleosols, and the dominance of reworked loess facies (loess-like deposits); primary loess facies are much more common in the late Quaternary record. The mineralogical composition of the loess sequences is mostly volcaniclastic with variations through time and space (e.g. volcanic lithics vs volcanic mineral content. Hence, loess deposits are synorogenic related to episodes of Andean uplift. Besides, the loess-paleosol sequences indicate an episodic sedimentation process interpreted as the result of Neogene-Quaternary climatic changes (glacial-interglacial conditions). In the NW mountain valleys of Sierras Pampeanas, known from several contributions, the loess-paleosol sequences with a reported thickness of up to 40 m represents an early-late Pleistocene record of high resolution to reconstruct paleoenvironmental and paleoclimatic conditions.
At present, both the Andean piedmont and the intermontane valleys of Sierras Pampeanas along with the Chaco-Pampean plain are blanketed by a late Quaternary aeolian cover consisting of dune fields in the western areas, and sand sheet-loess mantles eastwards. The dune fields cover the distal sectors of several alluvial megafans developed at the Andean piedmont; these major landforms are key geomorphological setting of high sedimentary availability to analyze the provenance of aeolian particles. Studies under progress across these settings indicate active aeolian/ fluvial interaction including several stages of sediment transport, the reworking of older sedimentary units, and redeposition. In the NW of Argentina, the geomorphological and sedimentological settings surrounding the NW mountain valley loess-paleosol sequences remain to be studied in detail. The sources areas of the deposits are considered to be located NW-N of the valleys. However, large intermountain tectonic basins are located immediately west covered by fine fluvial sediments from rivers that drain the Andes and the Puna plateau. These settings must be explored as other potential sources of the mountain loess.
Hence, a detailed geomorphological and sedimentary analysis is needed to provide an accurate context for sampling strategies in studies focused on dust sources as well as paleoenvironmental and palaeoclimatic reconstructions.

Composition and origin of the sand fraction of surface sediments of the Pampean region: A review and a conception

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In order to improve the knowledge of the composition and sources of the Pampean sediments, a review of the mineralogical information available in the literature was carried out. According to the data, there is a clear compositional differentiation between the loessic sediments of the South Pampa and those of the North Pampa. Quantitative differences are not only observed between the main components of the light and heavy sand fractions, but also between the mineralogical varieties of the main species in both fractions. Moreover, a detailed analysis of sand mineralogy data from soils in the Rolling Pampa and its proximal sectors have shown great vertical and spatial heterogeneity, allowing the identification of different "mineralogical models" as well as the delimitation of several "mineralogical zones". In this sense, the Rolling Pampa appears as a geographical, pedological and mineralogical transition area between those two large areas of the Pampean Region.
This mineralogical heterogeneity would be related to volcanic-pyroclastic contributions coming from different sources in the Andean mountain range, as well as contributions from a diversity of igneous, metamorphic and sedimentary rocks from other sources located around the region. Although in the South Pampa the particles supply from the Tandilia and Ventania ranges are not very significant, in the North Pampa the particles from the Córdoba and San Luis Pampean ranges appear very important in the constitution of the loessic sediments. Here also the contribution of ashes and dust from the northern sector of the Central Volcanic Zone and from the Puna would seem to have a significant importance that has not yet been adequately measured. On the other hand, the sediments in the Rolling Pampa are characterized and differentiated from other sectors by containing varied proportions of minerals transported by the river systems of the Argentine Mesopotamian region, which would have been moved by the wind from the

floodplains during periods of low water levels and perhaps from the continental platforms in times of marine regressions.
In this context, in addition to the eolian transport of particles carried out by various wind systems, a previous approach of clasts through various fluvial systems to the margins of the region is also relevant. The contribution produced by the Desaguadero-Salado system and the Negro and Colorado rivers in southern Pampa, as well as the notorious transport made by the Paraná river and its tributaries in the Chaco and eastern Pampa have been evaluated by several authors. Nevertheless, and according to our analysis, the role of rivers draining the Córdoba and San Luis Pampean Ranges seems to be more important than is usually considered in the conformation of the loessic sediments of northern Pampa.
In summary, the available mineralogical information indicates a great complexity of the sedimentological processes in the Pampean region, and suggests the need for a more open conceptualization and deeper and more refined studies regarding the composition, origin and distribution of these sediments.

Paleoenvironmental changes in southern South American dust sources recorded by clay minerals of the Pampean loess

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Clay minerals are among the most ubiquitous minerals on earth's surface. Different climatic conditions produce different clay minerals that can be recorded in the geologic archive providing insights into past weathering scenarios. However, in southern South America, scarce information is available from clay mineral assemblages found in aeolian sediments, such as loess deposits. Moreover, there is a lack of studies employing clay minerals for paleoclimatic reconstruction at dust sources and loess deposits. Therefore, we explore the clay mineral composition of modern dust source areas in southern South America and within the pampean loess to gain insight into paleoenvironmental conditions prevailing during the late Pleistocene-early Holocene in the region. We find that clay minerals recovered from the loess deposits are of an allochthonous origin, implying their formation at the 'arid diagonal', then blown away, and deposited downwind in the Pampas without post-depositional changes, hence shedding light on the weathering conditions at the dust sources during the last glacial/interglacial transition.

Geochemistry of aeolian sediments recorded at Pampean Loess for the last glacial-interglacial transition: implications for provenance and climate variability

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High-resolution studies of paleorecords located close to the dust source areas of South America are relevant for increasing the knowledge of past climatic conditions in the Southern Hemisphere. In this sense, the Pampean loess archives can offer explicit records of dust source, wind transport and deposition in the region, providing new insights that may be used to better understand the role of dust in future climate change

scenarios. In this work, we studied the provenance of three loess sequences, distributed along the Pampean loess belt deposited during the Marine Isotope Stage (MIS 3) period up to the early Holocene. Isotopic (Sr, Nd and Pb) and geochemical (REE) studies were performed in different grain-size subpopulations of loess records in order to compare the results with the geochemical signature of the main potential dust source areas within the Arid Diagonal of southern South America. Our data indicated that Nd and Pb are powerful provenance proxies that together allow the differentiation of potential dust sources fingerprints. The geochemical signature from the Pampean loess has a mix-source composition indicating that multiple regions of the Arid Diagonal supplied aeolian sediments to the Pampean Plain, including southern central-west Argentina and the Puna-Altiplano region. We also observed that increased mass accumulation rates at the Pampean Plain are associated with greater deposition of fine sediments together with the activation of Puna-Altiplano sources. We suggest that sediment stocks accumulated during the previous wet phase allowing greater dust activity during the subsequent arid climatic phase at the Puna-Altiplano.

Minimum LGM Dust Deposition on the South American Loess and its Possible Relationship with a Coeval Maximum in Antarctica

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We present a regional study of the Pampean loess in South America based on a detailed analysis of three sections across the core of the Pampas. High-resolution luminescence dating resulted in a new chronology that covers a period from Marine Isotope Stage 3 to the early Holocene. Reliable estimations of mass accumulation rates (MARs) for loess were used to infer the temporal dust flux variation during the last glacial/interglacial transition in southern South America (SSA). Minimum MARs in each section were identified for the Last Glacial Maximum (LGM), contrasting with high dust fluxes observed in more distal Southern Atlantic Ocean (SAO) and East Antarctica. We hypothesize that the power of the Pampean loess as a sink of dust was reduced during the LGM, allowing long-range transport of SSA dust to SAO and East Antarctica. This hypothesis is consistent with proxy data and models suggesting drier conditions in the Pampas during the LGM, which would have shut down loess accumulation. It is also consistent with isotopic evidence that points to northern Patagonia and southern central-western Argentina as main contributors of dust to East Antarctica during glacials, given that the prevailing regional wind system implies that dust emitted from these regions would have necessarily passed through the Pampas in its way to the SAO and East Antarctica. Forthcoming Nd, Sr, and Pb isotope results for the Pampean loess will allow further testing of this hypothesis.

Unraveling mineral dust sources for the Western Amazon Basin during the last 7.5 kyrs B.P.

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Satellite images allow us to visualize massive dust plumes crossing the Atlantic Ocean from the Sahara Desert towards the Amazon Basin. It is expected that these plumes have an important contribution to the fertilization of the rainforest, through the dry deposition of (micro) nutrients. Some authors claim a vital teleconnection between those environments, with changes in the Sahara Desert spatial coverture possibly reflecting in the forest expansion/retraction. However, for efficient dust atmospheric transport, certain settings should meet both in source and sink, and also, in the atmospheric mechanism. Therefore, during the Holocene, considering different atmospheric transport conditions, different aridity levels in South America and Africa, and volcanic activity, it is not clear if the same pathways for dust have occurred similarly as the present. To investigate the effectiveness and the geographic range of the Sahara dust through time, we have analyzed a sediment core (~7.5 kyrs B.P.) retrieved from Pata Lake, Central-Western Amazon, aiming to detect if a persistent Saharan dust signal does exist using $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotope ratios as fingerprints of dust provenience. Our results and interpretations, contrarily to the modern scenario, showed that along the mid-to-late Holocene, dust reaching this part of the Amazon basin had diverse sources regions accounting with contributions from the Andean region, the Northern and Southern Africa, and probably some volcanic activity. Therefore, Sahara's dust impact cannot be generalized as the main source of dust for the totality of the Amazon rainforest.

Southern Hemisphere westerly wind dynamics across the Pleistocene-Holocene transition as seen from the Falkland Islands, South Atlantic

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The Southern Hemisphere westerly wind belt (SHW) is a major feature of Southern Hemisphere, mid-latitude climate that is closely linked with the ventilation and draw down of CO_2 in the Southern Ocean. Past changes in the strength and position of this wind belt are poorly resolved, particularly across the Pleistocene-Holocene transition – a time period associated with rapid fluctuations in global temperatures and atmospheric CO_2 levels. Here, we use dust geochemistry, particle size measurements and palaeoecological analyses from a peat sequence in the Falkland Islands, South Atlantic, to describe changes in the SHW between 16.0-6.5 ka (thousand years before C.E. 1950). Wind strength was low prior to and during the Antarctic Cold Reversal (14.9-13 ka), intensified between 13.15-12.00 ka as temperatures increased and then weakened, reaching minima between 12-11 ka during the Early Holocene Thermal Maximum. Northerly air masses became more dominant from 12.0-10.2 ka and wind strength remained low until our record is affected by a storm surge of tsunami ca. 7.84 ka. We interpret these data as a shift in the core

latitude of the SHW; from north of 51 °S prior to and during the Antarctic Cold Reversal, at ~51 °S before the onset of the Holocene, and moving South of 51 °S during the peak of the Early Holocene Thermal Maximum and into the Holocene (11.5-7.84 ka). This suggests that the position of the core wind belt was coupled with atmospheric temperatures through the Pleistocene-Holocene transition.

Current Challenges and Recent Advances in Understanding the Paleoclimatic Dust Cycle

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Mineral dust particles are the most important atmospheric aerosols by mass. They affect the climate system in various ways, scattering and absorbing solar and terrestrial radiation, influencing cloud formation, and providing micronutrients to remote ecosystems. However, unlike greenhouse gases, their spatial distribution is heterogeneous and their effect therefore regionally distinct. In addition, dust residence time in the atmosphere is strongly linked to the hydrological cycle. Because of these complexities, a large uncertainty remains associated with the net effect of dust on the paleoclimate system.
Surface dust deposition fluxes have been measured in ice cores, marine sediment cores, loess, lake sediment cores, and peat cores. Dust fluxes from each of those paleoclimatic archives features different time span, resolution, uncertainties, and limitations.
Paleoclimatic dust simulations are particularly challenging because of the dearth of information available to tune climate models in various paleoclimatic settings (e.g. vegetation cover, wind strength and direction, wet vs. dry deposition etc.). Although we can compare simulated dust deposition at locations where dust fluxes have been measured in paleoclimatic archives, large uncertainties remain for particles sizes, transport pathways, and source locations.
In this talk, I will review recent advances in our understanding of the dust cycle in the past, identify the main challenges currently facing the observational and modeling dust communities, and discuss strategies to improve interaction between the observational and modeling communities.

ClimAG-Krigger: A new (paleo)Climatology-oriented toolbox for Anisotropic Global Kriging interpolation

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Data-model comparisons are common when addressing (paleo)climate questions. Many applications require deriving continuous surface fields of scalar variables from a set of irregularly distributed data points, typically for model validation against data or data-derived model input as initial or boundary conditions. While various interpolation techniques and interfaces exist, few can simultaneously: (1) interpolate across local to global spatial scales, (2) perform anisotropic interpolation using the spatial structure derived from the data instead of an assumed one, and (3) explicitly derive uncertainty in the interpolated fields due to both data density and measurement error. We present a standalone interpolation toolbox including a graphical user interface (GUI), which is aimed at the general earth science community. It uses a kriging algorithm whose distance metric is the geodesic on an oblate spheroid, be it the WGS-84 reference ellipsoid for

applications on the surface of the Earth, or an equivalent ellipsoid with varying radii for interpolation on vertical levels above the surface. While kriging algorithms exist that perform interpolation on such non-Euclidean distances, they do not provide a check for conditionally negative semi-definiteness (CNSD) of the variogram matrix, which is a requisite for the kriging method. Since mathematical theory of kriging on spheroids or ellipsoids has not yet provided a set of authorized variance-distance functions, we incorporated a numerical check for CNSD condition for each data realization and variance-distance modeling scheme. The GUI will allow the user a high degree of customization. Preliminary results are promising, with robust results for isotropic interpolation. The derivation of CNSD variogram matrices for anisotropic interpolation remains the major challenge of the project. When completed, ClimAG-Krigger will provide the community with an easy-to-use, robust tool for anisotropic global kriging that will be specifically tailored for (paleo)climate applications. In particular for this symposium, applications to global dust deposition since the Last Glacial Maximum will be discussed.

Effect of iron from dust fluxes in the Glacial Southern Ocean

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During cold climate periods such as the Last Glacial Maximum (LGM, approximately 20 thousand years before present), ice sheets occupied most of North America and Europe, producing lower sea level than in modern times, and atmospheric carbon was also lower than today. One mechanism proposed to link low atmospheric carbon to glacial periods is an increase in the sinking of organic carbon from the surface Southern Ocean and its accumulation in deep waters. This could have happened through iron, an important nutrient for phytoplankton production that is mostly missing in that region. If iron levels were higher in the LGM, then more phytoplankton would grow, sequestering carbon from the atmosphere, and sinking it to deep waters as dead matter. In this work we use a global ocean model to study differences between the iron cycles of preindustrial times and the LGM. Atmospheric iron fluxes were estimated from reconstructed surface dust fluxes. We find that an increase of atmospheric dust flux to the ocean raised ocean iron in the LGM's Southern Ocean, increasing productivity and sinking sequestered atmospheric carbon as organic matter. However, we also find that lower sea level in the LGM exposed continental shelves, decreasing the iron flux coming from marine sediments, acting against the other effect.

Comparative view of the iron solubility impacts on ocean carbon stored during the Last Glacial Maximum and Holocene

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Ice and sediment cores have provided important information about the natural variability of atmospheric CO_2, which has ranged between 180-280 ppm during glacial and interglacial periods, respectively. The ocean has been one of the main reservoirs, and in particular, recent studies have shown that the biological pump would be responsible for at least a quarter of this difference. In addition, one of the factors responsible for the variation in CO_2 concentration is the iron supply to the surface ocean. As a result, an increase in wind dust fluxes during cold periods, such as the Last Glacial Maximum (LGM, 26-19 ky BP), promotes significant biogeochemical activity by altering primary production and affecting the export and sequestration of carbon. Although the entire ocean is concerned, in certain areas, such as the High Nutrient Low Chlorophyll (HNLC) regions, phytoplankton production is more sensitive to the availability of iron.

However, both the deposition of the dust and the solubilization of the iron transported by the dust particles are not homogeneous between basins, affecting the biological uptake of CO_2.
Here, we used a carbon-centric Earth System Model of Intermediate Complexity, cGENIE, to quantify the effect of iron solubility in the biological pump, i.e. the difference between 80 and 100 ppm of atmospheric CO_2 under different Earth's conditions. We worked with empirical data, and CMIP5 model simulations of surface dust flux reconstructions for LGM and Holocene (12-8 ky BP) climatic conditions for this research. Since the solubility of iron is not well known both today and during the past, different solubility fields were created, and four levels of iron dissolution were tested at the global and regional levels to establish the main zones and conditions linked to the drawdown of CO_2.

KEYNOTE SPEAKER

Biogeochemical impacts of dust deposition in the ocean

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Huge amount of particles originating from desert area reach the ocean surface each year. The fate of these pulses of particles and the nutrients they can deliver to the water column is of high importance regarding marine biogeochemistry and carbon cycle. Our knowledge are still fragmented regarding actual fluxes and dust impacts in different part of the ocean, in particular in the Southern Hemisphere. However, during the last decade, the processes involved at the air-sea interface and below the sea surface have become better quantified and understood. I will present recent findings regarding these processes, the search for their parameterization and the link we can make between experimental and modelling approaches.

Simulating Size-resolved Atmospheric Dust Transport to Dronning Maud Land, Antarctica

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Long-range transported mineral dust stored in Antarctic ice cores is an indicator of climate variability in the Southern Hemisphere over interannual to orbital timescales. These dust particles are transported to Antarctica through synoptic atmospheric circulation patterns and therefore can be used as a proxy for past atmospheric circulation variability. However, the characteristics and variability of these dust transport pathways are not well-understood and are crucial for interpreting changes in dust deposition recorded in Antarctic ice cores. This study models present-day dust transport to a high elevation ice core site in Dronning Maud Land (DML; 74°60′S, 0°6′E), Antarctica, where a new 1000 year old ice core was recently drilled as part of the Isotopic Constraints on Past Ozone Layer in Polar Ice (ISOL-ICE) program. This presentation will showcase ice core observations and dust trajectory modeling results over the "observation era" (1979-2016). Results from the simulations are used to investigate dust deposition variability on seasonal to decadal timescales in the new ISOL-ICE ice core.
Investigation of the ice core dust record shows a strong positive trend in dust mass concentration between 1979 and 2016, and change point analysis reveals shifts in the dust concentration in the late-1980s and mid-2000s. The coarse particle percentage, a proxy of particle size distribution (PSD), shows a similar positive trend over the same period with shifts in values detected in the late-1980s and early-2010s.
The FLEXible PARTicle dispersion model (FLEXPART) is utilised to conduct backward modeling of dust transport to the ice core site with the novel approach of varying dust PSD in the simulations constrained by particle size observations from the new ice core record. We determine the spatial variability and sensitivity of dust transport pathways to various conditions such as seasonality, dust PSD, geopotential height, and regional-to-hemispheric scale zonal and meridional winds. Model results show that less than 20% of dust back trajectories originate from sub-Antarctic landmasses, predominantly from South America, south of 45°S. Additionally, DML is more sensitive to South America emissions of fine dust particles (0.8-2 μm) compared to coarse dust particles (2-5 μm) by at least a factor of 5, with varying emission sensitivity hot

spots depending on the particle size. Overall initial results suggest that while dust emission sensitivities show changes relative to varying conditions, dust transport trajectories do not vary significantly and systematically with different conditions.
Findings from this study will improve interpretation of present-day Antarctic dust deposition variability and its relation to present-day atmospheric circulation variability. Establishing this relationship in turn leads to an increased understanding of atmospheric circulation variability over decadal to centennial timescales and therefore helps improve climate prediction in the Southern Hemisphere.

The impact of millennial scale climate change on the subantarctic Pacific during the last glacial

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During Marine Isotope Stage 3 (MIS-3) warming events know as Antarctic Isotope Maxima are thought to be linked to abrupt slowdowns of Atlantic Meridional Overturning Circulation (AMOC). Across the South Atlantic and Indian Oceans, sediment core reconstructions have shown that these warming events are associated with decreases in lithogenic dust flux, a weaker biological pump and increased deep ocean ventilation. In contrast, changes in the Pacific Ocean during warming events remain largely unknown. Here we present 230Th-normalised reconstructions of lithogenic and biogenic particle flux in the southwest Pacific (TAN1106-28, 2798m). Fluxes of lithogenic material, iron, excess barium, chlorins and organic carbon are strongly correlated (r2 = > 0.8 p = < 0.01) across MIS-3 in this record and decrease during warming events. This tight correlation suggests variability in biogenic flux in this region is driven by variability in Fe fertilization, as has been observed in the South Atlantic and Indian Oceans. In support of this hypothesis, biogenic fluxes are more strongly correlated with Fe flux than with lithogenic flux in this record. We propose that during MIS-3 warming events a decrease in glacially derived lithogenic material from New Zealand weakens the biological carbon export in this region. These observations of AIM warming associate millennial-scale change highlight the importance of subantarctic iron flux on the carbon cycle in the subantarctic Pacific Ocean during MIS-3.

Dust and fire, two distinct sources of essential nutrients (N, Fe) to the atmosphere?

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The recent increase in the occurrence and intensity of fire events worldwide lead scientists to questions the previously underestimated contribution of pyrogenic emissions to the atmospheric loading of bio-essential nutrient. In the Southern Hemisphere, atmospheric transport and deposition of dust and fire emissions is a major pathway for supplying vital nutrients such as iron (Fe) to remote and anemic marine ecosystems in the Southern Ocean. However, these aeolian sources are characterised by highly episodic and hardly predictable emissions, making the acquisition of representative field observations difficult. The resulting paucity of field measurement available across the Southern Hemisphere prevent accurate model representation of the impact of dust and fire aerosols atmospheric nutrient deposition on Southern Ocean marine ecosystems and the associated feedback on the carbon cycle. In this study, we present results from an ongoing continuous monitoring of aerosols composition, origin and transport at the kunanyi time-series sampling station, in Hobart, Tasmania (Australia). This time series dataset (2016-early 2020) enabled the characterisation and comparison between dust- and fire-dominated aeolian emissions at the sampling station. Our results revealed a striking increase in the atmospheric loading of total and bioaccessible Fe during fire episodes at kunanyi, as well as other potentially (co-)limiting nutrient including nitrate, NO_3^-; ammonium, NH_4^+; and manganese, Mn. Interestingly, no enrichment in aeolian Fe and Mn was observed during fire events compared to dust events and compared to the averaged upper Earth crust, suggesting a prevailing lithogenic origin, rather than pyrogenic, for Fe and Mn even during fire episodes. This observation together with high bulk mineral dust emission estimates during fire events at kunanyi, indicated that a large fraction of soil is entrained alongside fire plumes likely due to the action of strong pyro-convective winds. Concentrations of lead (Pb) and vanadium (V), two metals commonly associated with anthropogenic pollution, were high in fire-impacted aerosols from kunanyi. While V seemed to have a prevailing crustal origin (EFV<10), significant lead enrichment (EFPb>10) may indicate, as previously suggested, the re-suspension of historical unleaded petrol signature in soil during pyro-convection. Finally, we found very distinct characteristics between the signatures of past fires which occurred close to kunanyi (proximal fires) and kilometers away from the station (distal fires). Total Fe and mineral dust loading decreased at increasing distance from the fire emissions source due to gravitational settling of dust entrained by pyro-convection. However, atmospheric processing during the aeolian transport resulted in higher bioaccessible Fe concentration and fractional Fe solubility in aerosols associated with distal fire emissions. Atmospheric transport also seemed to play a key role in transforming pyrogenic nitrogen oxides into the secondary nitrogen aerosols, resulting in increased NO_3^- and NH_4^+ loading down the fire plume transport path. As future projections (2060–2079) suggest that climate change may increase the risk of intense fires worldwide (Jones et al., 2020), atmospheric time-series monitoring stations like kunanyi are key to apprehend future impact on atmospheric composition and marine ecosystems.

Lithogenic particle flux to the subantarctic Southern Ocean: a multi-tracer estimate using sediment trap samples

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The delivery of lithogenic material from atmospheric dust to remote regions of the Southern Ocean is thought to be a key source of micronutrients, particularly iron, essential for phytoplankton growth. Here, we present a time series of lithogenic flux estimates from 2010 to 2019 using sinking particles collected by sediment traps deployed at 1000 m at the Southern Ocean Time Series (SOTS) mooring station in the subantarctic Southern Ocean (140ºE, 47ºS). Lithogenic flux estimates were made based on aluminium, titanium, iron and thorium concentrations in sinking particles and showed good agreement with one another. A multi-tracer flux estimate was calculated using an average of all individual tracer flux estimates in order to reduce biases associated with each element's reactivity in seawater. This mean lithogenic flux exhibited a

strong seasonality, with two peaks in late spring and in summer. The magnitude of our multi-tracer lithogenic flux was comparable to previous single season sediment trap-based fluxes reported in the Southern Ocean and to ^{230}Th-normalised lithogenic fluxes from core-top sediments at the same study location.
A lack of lithogenic tracer enrichment in our samples compared to the average upper continental crust values indicated that lithogenic material dominates iron supply in this region. Sinking particle samples from SOTS showed similar Fe enrichment to aerosols collected over southern marine regions around Australia, suggesting that Australian dust may be the primary lithogenic source to sinking particles collected at SOTS. Evidence of lead (Pb) enrichment in sediment trap samples at 1000 m highlighted a non-negligible contribution from anthropogenic particles, a source which could represent a secondary Fe supply to the samples. Therefore, we concluded that aeolian emissions from Australia likely compose the primary source of lithogenic particles to the subantarctic Southern Ocean south of Australia. This hypothesis was further supported by the seasonality in that the maximum lithogenic particle flux at 1000 m depth in late spring was preceded by seasonal atmospheric aerosol loading maxima (from aerosol optical depth and satellite reanalysis modelled dust deposition) that occurred during the Australian dust storm season in spring.
While carbon export at 1000 m showed good correlation with surface chlorophyll concentrations at SOTS across the study period, there was no clear linear relationship between lithogenic sinking fluxes at 1000 m and marine productivity in this subantarctic region of the Southern Ocean. These findings prompt further work to quantify the relationship between atmospheric supply of trace nutrients and productivity responses in the subantarctic Southern Ocean, while providing a new upper limit estimation of dust deposition to subantarctic waters south of Australia.

Using thorium isotopes to quantify dust deposition to the Southern Ocean

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Wind-borne lithogenic aerosols (‘dust’) have long been considered a major source of iron and other micronutrients to remote ocean regions. Iron is important as it is the limiting micronutrient for phytoplankton growth, particularly in the Southern Ocean. However, recent evidence indicates that the relationship between dust deposition and increased ocean productivity is not clear cut, with the modern evidence of correlations proving to be surprisingly sparse. Uncertainty in this component of the carbon cycle could lead to issues with climate models, as dust deposition to the ocean is projected to grow in the future with increasing land-use changes.
This study aims to quantify the deposition of dust to the oceans to Australian sector of the Southern Ocean, as a means to estimate the flux of iron from lithogenic aerosols. Our approach utilises the radioactive decay disequilibrium of thorium isotopes in seawater as a proxy to quantify the input of the lithogenic component of dust. This method has a great advantage over similar methods as thorium isotopes can provide information on the lithogenic input (232Th), and the residence time of thorium in seawater (230Th). Comparable geochemical methods rely on estimations of the residence time of an element within the water column which can be a significant source of uncertainty.
We will present data from samples collected from previous GEOTRACES voyages, including at the Southern Ocean Time Series site to the south of Tasmania (140° E, 47° S) which have been collected over a span of three years. Previous estimates of the dust flux have been conducted at this site over a span of 20 years using sediment, sediment trap, and aerosol measurements, along with modelling studies. Preliminary results indicate that these prior studies underestimate the dust flux to this region.

Phytoplankton community response to the deposition of wildfire aerosols

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During the 2019-2020 Australian fire season, vast areas of bushland were burned, and large smoke plumes were emitted into the atmosphere. Driven by south-westerly winds, those plumes were transported over great distances and supplied iron-bearing pyrogenic aerosols, such as black carbon (BC), to remote oceanic regions downwind of Australia, resulting in widespread phytoplankton blooms observed in the iron-limited Pacific Southern Ocean (Tang, Llort et al., 2021). Here we present a more in-depth analysis of the phytoplankton response to the deposition of BC and dust. Based on satellite ocean colour, satellite reanalysis products and in-situ profiling float measurements, we studied anomalies in the resident phytoplankton community in response to aerosol-derived pyrogenic and mineral iron. We observed notable increases in phytoplankton growth (chlorophyll and carbon biomass), photochemical efficiency (decreased fluorescence per unit chlorophyll), intra-cellular pigmentation (chlorophyll per unit carbon) as well as apparent shifts in the phytoplankton community structure (spectral backscatter slope, Chl-a size distribution) in the bloom region. Each of these changes coincided with highly anomalous BC deposition fluxes (>1400% relative to climatological values). We further found that physiological anomalies persisted for six months after the initial aerosol-stimulated response. The prolonged response was presumably supported by iron recycling and atmospheric supply of mineral iron. We conclude that soluble iron in pyrogenic aerosols played a major role in fertilising the iron-limited Pacific Southern Ocean and that the broad expanse of the resulting phytoplankton blooms extended the recirculation of nutrients.

KEYNOTE SPEAKER

Late Quaternary paleoclimate records of southern-hemisphere drylands derived from deep-marine sediment archives

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In this presentation I will discuss paleo-environmental records from offshore the western parts of the three inhabited austral continents. Based on the grain-size distributions of the terrigenous sediment fractions in deep-marine sediment records, we have been able to reconstruct the proportions of wind-blown- and river-flown sediments throughout the geological past. The records from the northwestern Australian continental slope1,2 go furthest back in time: 5.3Myr and describe a history of varying monsoon intensity in this part of the world. The record from Walvis Ridge3, offshore Namibia, contains a stratigraphy of 300kyr and shows a consistent alternation of relatively dry interglacials as opposed to wet glacials. Very similar patterns were recognised in the sediment records obtained on the northern Chilean continental slope4 throughout the past 120kyr and which were interpreted as equatorial displacements or expansions of the rain-bearing southern westerlies during glacial stages.

KEYNOTE SPEAKER

Southern South America dust activity in relation to long range transport to Antarctica and the Southern Ocean

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Southern South America (SSA) has been identified as a major source of dust found in East Antarctica snow at temporal scales ranging from the Pleistocene glaciations to the present. In addition, this dust activity has been proposed as a possible source of nutrients to Southern Ocean ecosystems and may have been a major factor in the regulation of atmospheric carbon dioxide. Current understanding of dust activity, the export and long-range transport of dust from SSA is limited despite it is a recurrent phenomenon. Much of what we know about this activity and its impacts is provided by modeling studies. Except limited ice and sediment core evidence, there are very few observational based assessments with appropriate time resolution and spatial scale that can corroborate or provide constraints to these modeling efforts. At the same time, satellite time series of aerosol observations over the region and spanning twenty years are already available. This is a valuable source of information that can help to fill the gaps in understanding as well as supporting modeling efforts. This presentation will provide an overview of dust activity in SSA as seen by satellite observations with focus on the Patagonia desert, its major sources of dust and patterns of activity as well as a discussion on its long-range transport towards Antarctica.

Regional and local mineral dust activity over South America

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The overall production of mineral dust in South America has been estimated to be about 2.3-2.6% of the global production. Whereas most of the studies have historically been focused on the largest desert dust regions in North Africa, the Middle East and China, South America has received scarce attention, especially on the characterisation of sources at a local scale. A satellite-based analysis is conducted to characterise mineral dust sources at both regional and local scales. The regional analysis is based on MODIS Deep Blue Collection products (MOD04L2-MYD04L2) of Aerosol Optical Depth (AOD) and Angstrom Exponent (α) between 2015 and 2019 at 10 km horizontal resolution. The local-scale characterisation is carried out using the MODIS MAIAC product (MCD19A2), which employs a multi-angle algorithm for retrieving AOD at 1 km horizontal resolution. High values of AOD along with low values of α are associated with mineral dust sources (AOD-α method). A sensitivity test for a range of α values is performed. The above approach is complemented with geological evidence and also contrasted with the computation of the Dust Optical Depth (DOD), as formulated by Anderson et al. (2005). Significant mineral dust sources are identified in the Atacama Desert (Northern Chile), the Sechura Desert (Northern Peru), West-Central Argentina and the Argentinian Patagonia. In both the Atacama and the Sechura Deserts, mineral dust sources are primarily associated with coastal dunes and wind erosion features. In West-Central Argentina, mineral dust sources

are dominated by partially dried lakes and dunes developed on distal alluvial fans, whereas, in the Argentinean Patagonia, these are mostly associated with dried lakes. A very distinctive seasonality is identified in the Atacama Desert and the Argentinean Patagonia. Higher event frequencies, AOD and DOD, are computed throughout the austral summertime in both regions, accompanied by a wide range of **α** values (0.0-1.4). This suggests multiple sources with a dominant presence of mineral dust. On the contrary, wintertime is characterised by lower AOD and DOD, and high **α** values (>1.0), suggesting fine-particle dominance. AOD values and frequencies of dust events during summer are about one order of magnitude higher in the Atacama than the Argentinean Patagonia. In fact, the Atacama Desert presents over 20 mid-intensity dust outbreaks during the austral summer with area-averaged AOD > 0.5 and **α** < 1.0. Unlike the Atacama and Patagonia, West-Central Argentina exhibits a less evident seasonality. In this region, dust activity is observed most of the year, with minimum AOD and DOD values during autumn. On the other hand, the Sechura Desert presents significant mineral dust activity (frequency of dust events) throughout the year. However, AOD and DOD reach higher magnitudes during summer, in a similar order of magnitude to those observed during summertime in the Atacama Desert. Implications for solar energy production, air quality, and modelling validation applications are discussed.

Atmospheric deposition in the Atacama Desert: Mineral contribution and colonization of microorganisms in the hyperarid core

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The Atacama Desert has been indicated as the most arid and oldest desert in the world. The aridity in this ecoregion has prevailed for more than 10 million years and this lack of water and, consequently, the low rate of water erosion, has favored the accumulation of material for a long period of time in this desert. Due to this absence of soils leaching, it is more likely that a contribution of key and significant matter to the Atacama surface will occur through the contribution of deposited atmospheric particles, and that said contribution is driven by the existing local wind systems. This mass influx has been proved as a major source of salts but organic compounds, nutrients and microorganisms' contents in deposited dust remain as an open question. Considering that to the west of the Atacama, the Humboldt Current provokes a high biological production in the Pacific Ocean, and the presence of vegetated soils eastwards of this desert in the Altiplano, an important biological load in the atmospheric particles suspended from soils and the ocean is very probable. To answer these questions, the objective of this work was to evaluate the contribution of aeolian transport and deposition of atmospheric material in the Atacama Desert, with a focus on the biological hotspots and temporal dynamics of organic matter and nutrients contained in the dust. To accomplish this, 15 passive dust collectors were set in a west-east transect around 23.5 ºS, covering different areas of the Atacama, represented by 5 study sites. To control environment variables, temperature and humidity of soil was controlled, along with speed and direction of winds. From preliminary results in the central part of the transect in the Yungay area (Central Depression), a deposition rate of 8,262 g m^{-2} yr^{-1} was calculated and a total organic carbon (TOC) content of 2,2 mg g^{-1} was obtained from a vegetated point within the hyper arid core of the Atacama Desert. These TOC results are higher than those found in hyperarid Yungay soils probably due to vegetation presence and the local mobilization of organic matter because of wind action. Nevertheless, the arrival of organic compounds and microorganisms may be affected and oxidized by the chemical reactivity of surface soils in the Atacama due to the photochemically production of secondary aerosols and the fog water supply.

Dust concentration in San Jorge Gulf and adjacent shelf (Patagonia, Argentina)

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Patagonia is the major source of aeolian dust into the southern part of the Atlantic Ocean and Argentinean shelf. However, to the best of our knowledge there are no direct measurements in these regions. The objective of this study is to analyze, for the first time, the spatial distribution of dust concentration in San Jorge Gulf and adjacent shelf (43ºS-48ºS). Dust concentration was measured on 74 stations on an oceanographic survey conducted on board of the R/V Puerto Deseado between October 28th and November 8th of 2017. Measurements were conducted with a particle counter (PCE-PCO 1) and the concentration of particles in the air (particles per liter: p/l) was evaluated in six classes of particle sizes: 0.3 µm, 0.5 µm, 1.0 µm, 2.5 µm, 5.0 µm and 10 µm (size distribution around the mean of each is Gaussian and parameters are standardized in ISO 21501-4:2018). Additionally, data of relative humidity and air temperature were obtained. Particle concentrations varied inversely to particles sizes: the highest concentration was observed for smaller particles and the lowest concentration was observed for bigger particles (mean concentration for 0.3 µm: 18,500 p/l; 0.5 µm: 7030 p/l; 1.0 µm: 1750 p/l; 2.5 µm: 390 p/l; 5.0 µm: 80 p/l; 10 µm: 44 p/l). The highest concentration of particles was measured between 46ºS and 48ºS, while the lowest concentration was measured between 43ºS and 45ºS.

Determination of provenance of aerosols by isotopic analysis and atmospheric modeling in the Atlantic and Southern Ocean

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Mineral dust in the atmosphere exerts considerable influence on climate, biogeochemical processes, air quality and is a key player in understanding past changes in the general circulation, biogeochemical cycles, and, consequently, climatic regimes. Tracing potential source regions of aerosols/dust is a key factor in understanding the atmospheric circulation regimes. In this context, Sr and Nd isotopes in continental fine sediments have been used as tracers (or fingerprints) of dust found in deep ice cores retrieved from the Antarctic ice sheets. To demonstrate the ability of radiogenic isotopes as dust fingerprints we have conducted atmospheric sampling at sea during oceanographic cruises carried out in the summer of 2010, 2011, and 2012 by the Brazilian Antarctic Program. The cruises covered from the Southern Hemisphere subtropics towards the sub-Antarctic region along the Argentine continental shelf and through the Drake Passage and Bellingshausen sea, where aerosols were collected. We aimed at comparing the radiogenic isotope signature of the collected aerosols with their most likely sources in the corresponding continental mainland with databases as described in the literature for the isotope ratios $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$. We compared our onboard data with inventories for Patagonia, Australia, and Antarctica. Additionally, atmospheric modeling by HYSPLIT 4.0 was used as a tool to determine the influence of the continental airmasses over our collected particulate material. In this work, we tested the hypothesis that the radiogenic isotope fingerprinting of aerosols over the Southwestern Atlantic Ocean can be explained by corresponding

continental sources. In total, the origins of aerosols were attributed to: (1) the Patagonian semi-desert over the Argentine continental shelf; and (2) a mix of dust sources from Patagonia, Australia, and rock outcrops existing in the Antarctic continent. Over the Drake Passage and Bransfield Strait/Bellingshausen sea/Antarctica, an influence of multiple continental dust sources is likely to exist such as Patagonia, Australia, and Antarctic rock outcrops from ice-free areas (e.g.: Fyfe Hills Rocks, Dry Valleys, Bunger Hills and Adelie Land), where higher ratios of $^{87}Sr/^{86}Sr$ (i.e., ~0.712) were found together with very negative εNd(0) values (i.e., ~-36).

Modern dust deposition over the South Atlantic Ocean from seafloor surface sediments

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Mineral dust is a major component of sediment input to the remote open ocean. About ten percent of all global dust emissions comes from Southern Hemisphere sources. The main Southern Hemisphere sources include Australia, South America and southern Africa, but also inter-hemispheric transport from the Northern Hemisphere contributes significantly to the Southern Hemisphere dust budget, as well as New Zealand. In the South Atlantic, the majority of the total dust deposition originates from South American sources. However, in-situ measurements of dust deposition over the Southern Hemisphere oceans are scarce and there is a great need for an expanded geographical coverage of direct observations of dust deposition. We present grain size data and ^{230}Th-normalised deposition fluxes of seafloor surface sediments covering the entire South Atlantic Ocean. These sediments not only contain mineral dust, but also contributions from fluvial and hemipelagic sediments. By using end-member modelling we aim to disentangle the dust signal from these sediments to reveal dust grain size, and in combination with the ^{230}Th-normalised fluxes determine the specific dust deposition fluxes to the South Atlantic, which can be used to calibrate and validate model simulations.

High latitude dust sources in Antarctica produce severe air pollution

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The Arctic and Antarctic regions include large areas of High Latitude Dust (HLD) sources, from where dust is transported long distances. The first estimates are that all high latitude dust sources cover > 500,000 km^2 and contribute to at least 5 % of global dust budget. HLD was recognized as an important climate driver in Polar Regions in the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate in 2019.
Active dust sources have been monitored in Iceland as well as in the Southern Hemisphere. Several important ice-free areas in Antarctica (e.g., Seymour Island, Cape Lamb on Vega Island, Terrapin Hill) are located in the Eastern Antarctic Peninsula region. The largest of these ice-free areas can be found on the Ulu Peninsula, James Ross Island. In situ measurements from the James Ross Island showed that the air is polluted by local dust sources, as well as due to long-range transport from Patagonia. The PM10 concentrations in Antarctica were higher than those in natural areas of the Northern Europe in 2018. The highest hourly aerosol concentrations of 57 μg m^{-3} for particulate matter (PM10) were detected during high wind speed events that exceeded 10 ms^{-1}, which is also a threshold level for activating local mineral material

sources. Mean (median) mass concentrations of the PM10 were 6.4 ± 1.4 (3.9 ± 1) μg m^{-3}, while the PM2.5 was 3.1 ± 1 (2.3 ± 0.9) μg m^{-3} for the whole measurement period in January-March 2018. Preliminary results from the summer campaign in 2021 showed that dust concentrations were significantly higher than in 2018, exceeding daily PM10 of 40 μg m^{-3}. This confirms that Antarctica is an important HLD source and more observations are needed. Antarctic dust has significant impacts on snow and local glaciers as well as the air quality and potentially clouds and surrounding oceans. This study presents unique long-term dust measurements of PM0.3-10 in Antarctica.

Transport of Patagonian mineral dust to Antarctica: Modeling of trajectories during the last decade (2010-2019) using HYSPLIT

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In Antarctica, mineral dust plays an important role in the Earth system both directly, through influencing the earth's energy balance by scattering and absorbing radiation, and serving as nuclei for cloud formation, and indirectly, through fertilizing ecosystems upon deposition (impacting ecological communities and their evolution). Moreover, the atmospheric mineral dust loading produces changes in the chemical and physical composition of the atmosphere. Several modeling studies and in situ observations have shown that dust in Antarctica originates primarily from Australia, Patagonia, and New Zealand, varying their contribution depending on the location in the Antarctic region. This study examines the synoptic transport mechanism and circulation patterns of trajectories reaching Antarctica beginning in three Patagonia locations, chosen based on their dust activity. These locations are North Patagonia (44°S, 67°W), Colhué Huapi Lake (45.5°S, 68.5°W) and Great San Julián Depression (49°S, 69°W). To determine the synoptic mechanism and circulation patterns that drive transport to Antarctica, 10-day trajectories are calculated using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model forced with meteorological fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 global atmospheric reanalysis. Trajectories are considered starting at 0, 100 and 1000 m above ground level every 6 hours from 2010 to 2019 at each location. Seasonal and interannual variability of trajectories is analyzed and characterized in conjunction with ERA5 meteorological fields to detect favorable circulation patters of transport to Antarctica. Results will be presented displaying main mechanisms of Patagonian dust transport to Antarctica and their inter- and intra-annual variability for the last decade.

First glance at 5 Million years of dust input to the South Pacific

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Atmosphere-ocean-cryosphere interactions and teleconnections between high and low latitudes play an important role in past and future climate change, and the Subantarctic Southern Ocean provides the major link between Antarctica and the low latitudes. In the Southern Ocean, atmosphere-ocean interactions are believed to control sea ice cover, Antarctic Icesheet dynamics, upper ocean stratification, biological nutrient utilization, and exposure rates of deep water. In this context, dust records are a key climatic variable, as direct agent in the climate system (through affecting biological productivity and the carbon cycle and the radiative energy balance) and as indirect proxy of atmospheric processes, such as shifts in major wind systems (Westerlies).
High-resolution down-core dust records from the Pacific Southern Ocean based on conventional piston cores covering the past ~1Ma indicate 2-3 times higher dust deposition rates in glacial periods compared to interglacial periods, coupled with higher export productivity. Longer sediment records based on IODP drilling were previously not available from the South Pacific in contrast to the Atlantic and Indian sectors of the Southern Ocean.
IODP Expedition 383, sailed in the summer of 2019, set out to fill this gap and drilled a sequence of six sites in the central South Pacific, the eastern South Pacific and the Chilean Margin – a total of 3 kilometers of sediments, spanning from the Miocene to the Holocene.
In this presentation, we will give an overview of the recovered sediment cores and introduce early results of the dust input, based on shipboard data, XRF scanning, and some early ICP-OES and constant flux proxy work. Our records from the central South Pacific focus on the Plio-Pleistocene history of dust input at orbital time-scales and provide an important counterpart to the South Atlantic dust records from ODP Site 1090.

Radiometric dating confirms >450,000 years of climate-lithogenic flux connection at the Eastern Weddell Gyre/ACC boundary

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We present results on lithogenic fluxes and productivity indicators for sediment core PS63/146-2 from 55.32°S, 23°E, 4800 m water depth. Using the 230Thex CRS-dating method (Geibert et al. 2019), it was possible to date this core by absolute age constraints, entirely independent of any correlation with other records. The reconstructed lithogenic fluxes show a striking similarity to glacial-interglacial oxygen isotope fluctuations. Preserved fluxes of biogenic opal and excess barium reveal how marine productivity responded to the changing environmental conditions. The origin of the lithogenic material at this location can currently not be determined with certainty. Possible sources are dust, glacial erosion, physical processes on continental shelves responding to sea level, drift with icebergs or sea-ice, and others. Whatever process is determining the lithogenic input at this location, it is very closely connected to glacial-interglacial cycles.

Systematic changes in South Pacific dust provenance during the last two glacial cycles

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The Earth's change from glacial to interglacial state is inherently coupled with variations in atmospheric CO2 concentrations [1]. Increased supply of the micronutrient iron (Fe) is considered to have promoted bioproductivity in the Southern Ocean, thus contributing to the reduction of atmospheric CO_2 during glacial periods [2, 3, 4]. The Southern Hemisphere dust cycle has been identified as an important supplier of Fe to the glacial Southern Ocean [3, 4, 5], but relatively little is known about sources and pathways of different dust source contributions during past glacial-interglacial cycles. Here, we use the geochemical fingerprint of the lithogenic dust fraction extracted from marine sediment core PS75/056-1 to generate a time series of dust provenance for the remote subantarctic South Pacific. We measured the rare earth element and radiogenic isotope compositions (Sr, Nd and Pb) of the lithogenic <5 µm fraction of 108 sediment samples and used the Bayesian mixing model MixSIAR to quantify changes in dust provenance over the past 260,000 years. Our results show that the major sources of dust to the subantarctic South Pacific are Australia/New Zealand and South America. The highest contributions of South American dust (up to ~75%) correspond with relatively low iron fluxes [4, 5] and finer grain size of the dust fraction [6] following peak interglacial conditions. During the latter part of the glacial cycle, the proportion of Australian/New Zealand dust increases to 40 – 50% in correspondance with increasing iron input [4, 5] and a coarsening of the dust fraction [6]. However, peak glacial intervals show a relative increase in South American dust when dust grain sizes were relatively coarse. Our findings imply that the two sources of far-travelled dust both contributed to the increased glacial supply of Fe to the subantarctic South Pacific. The high representation of South American dust during the glacial intervals indicates that the circumpolar transport of the coarser dust particles may not have been driven by increased emissions from a more proximal source alone, but also involved an overall strengthening of the westerly winds. [1] Lüthi et al. (2008) Nature 453, 379–382. [2] Martin (1990) Paleoceanography 5, 1–13. [3] Martínez-Garcia et al. (2014) Nature 476, 312–315. [4] Lamy et al. (2014) Science 343, 403–407. [5] Shoenfelt et al. (2018), PNAS 115, 11180–11185. [6] van der Does et al. (2021), QSR 263, 106978.

Marine sedimentary insights into a uniquely Pacific early Holocene dust peak at ~10 ka

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Marine sedimentary records of dust flux variability provide important constraints on the strength and position of the westerlies and nutrient delivery to the surface ocean across changing climatic conditions. In the Southern Hemisphere, discrepancies between Pacific and Atlantic dust flux records and Antarctic ice cores shed light on spatial variations in dust emissions, provenance, and transport through time. Here we compare a suite of ^{230}Th-normalized Southern Ocean dust flux records spanning the past 25 kyr and highlight the occurrence of significant early Holocene South Pacific dust flux peak at ~10 ka. We caveat the precise timing of the ~10 ka dust peak due to the inherent difficulties in constraining sediment core

chronologies in the carbonate-poor sediments of the Southern Ocean. Maximum expression of the ~10 ka peak is identified in PS75-93-1 (60.87°S, 169.55°W), where dust fluxes approach 65% of the Last Glacial Maximum (LGM) values at this site. Expression of the ~10 ka peak is more muted at the more eastern PS75-56-1 (55.16°S, 114.79°W), where dust fluxes reach 55% of the LGM flux. Distinct shifts in the Th/Ti ratios of western South Pacific sediments indicate a major shift in the dominant dust provenance at this time. The lack of a similar peak in either South Atlantic or EPICA dust flux records suggest that the 10 ka increase in dustiness arises from a uniquely Pacific dust source, such as Southeast Australia, where local lake records indicate enhanced aridity during this interval. Within age model uncertainty, this early Holocene increase in South Pacific dustiness appears to coincide with, and may be responsible for, a major shift in dust provenance and an increase in the 1-5 um dust fluxes recorded in the Taylor Glacier ice core record as well. Although Southern Ocean biologic productivity tends to vary out of phase on either side of the polar front, the ~10 ka dust peak correlates with increased productivity (indicated by excess barium fluxes) in Pacific sediment cores both north and south of the front. This correlation suggests that both regions of the Pacific Southern Ocean may be sensitive to dust-borne Fe fertilization during the early Holocene conditions. Our results highlight the value of increased spatial resolution in Pacific Southern Ocean dust flux reconstructions in order to improve our understanding of Southern Hemisphere dust dynamics and their role in global biogeochemical cycling.