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Núcleo Milenio Paleoclima

Does satellite chlorophyll-a respond to southernmost Patagonian dust? A multi-year, event-based approach

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Key points

We present the first decadal time series of surface dust mass flux in southern Patagonia

The first event-based study in the southwestern Atlantic Ocean shows no evidence for an influence of dust on chlorophyll-a concentrations

Source-inherited low concentrations of bioavailable iron preclude enhancement of primary producers' biomass in proximal open ocean waters

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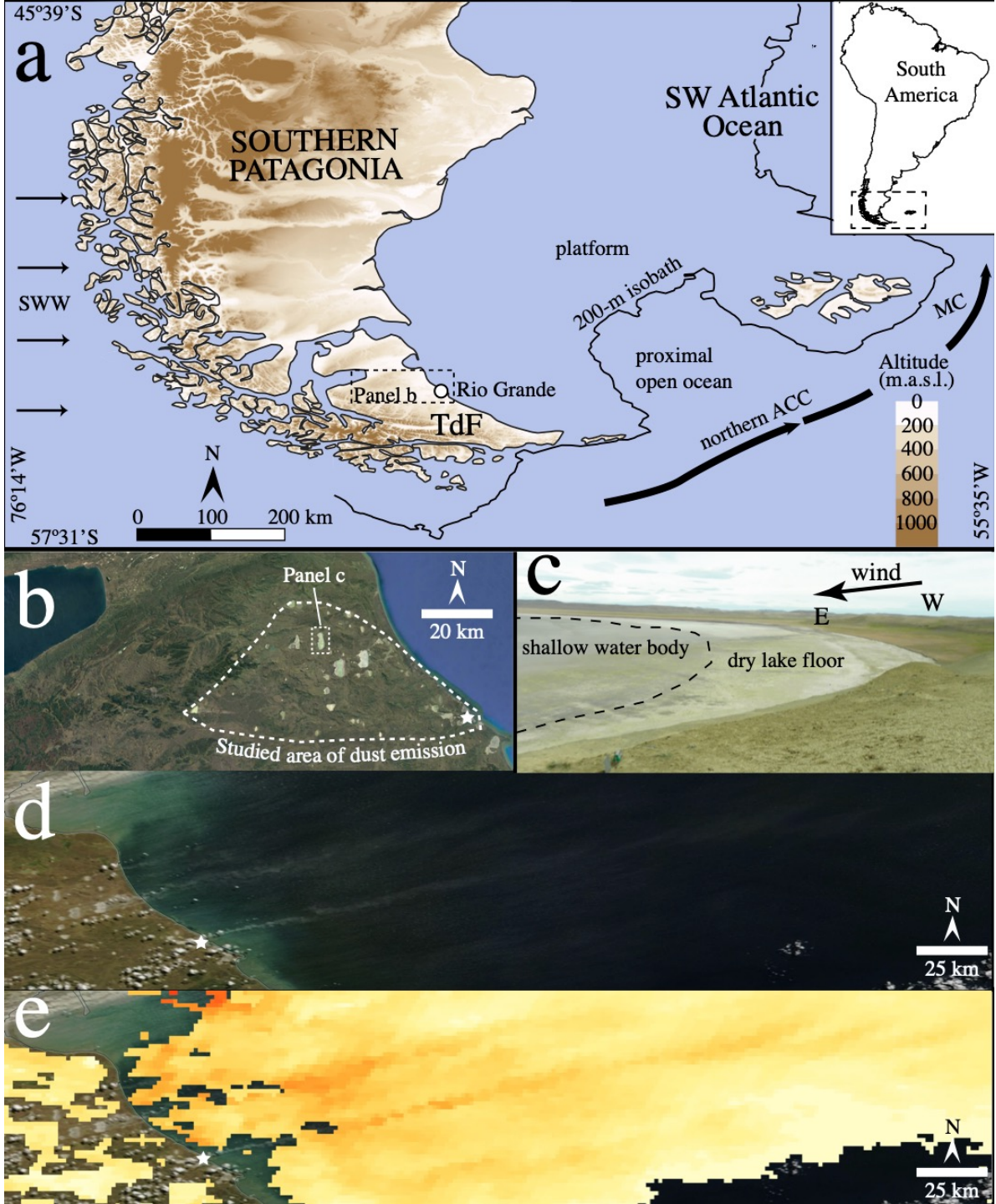
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Introduction

(c) Deflation pan showing a windward dry lake floor and a leeward shallow water body

(d) True color Terra/MODIS image of a dust event on 21 February 2014, where two dust plumes emitted from the study area are identified

(e) These plumes are clearly defined by higher-than-background Aerosol Optical Depth (Terra/MODIS). White star: Rio Grande dust monitoring station.



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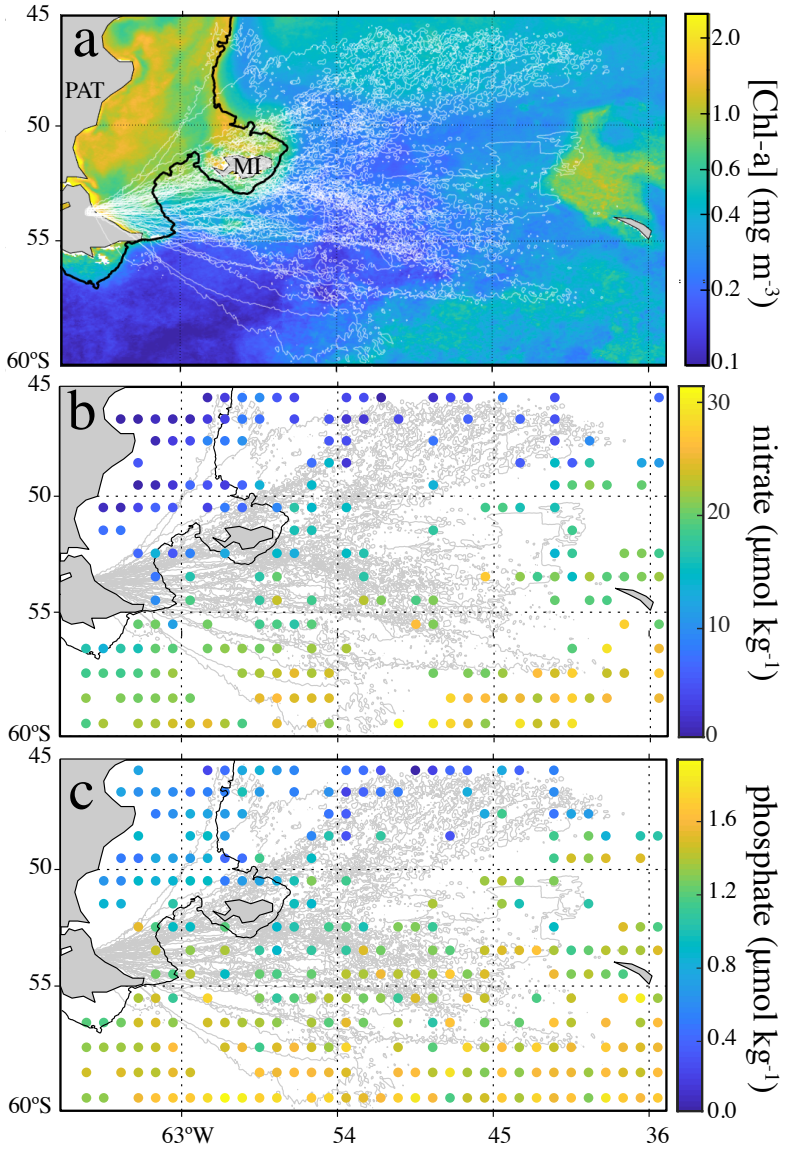
Introduction

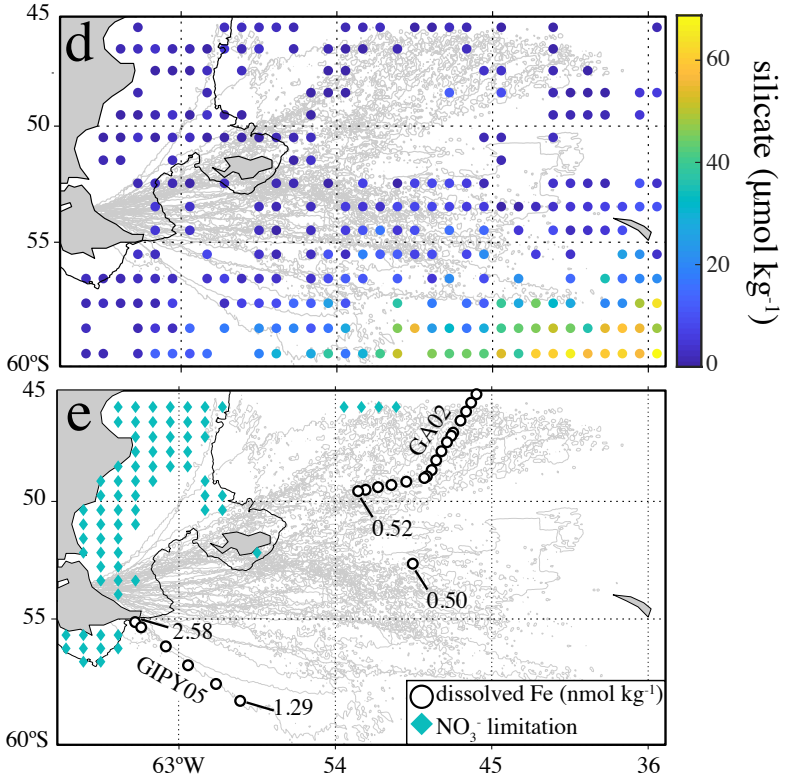
White/grey contours correspond to modeled 5 µg m^{-3} isolines of total dust deposition for 32 dust events (mostly during austral summer). Austral summer (JFM) concentrations of:

(a) chlorophyll-a (low platform vs. high open ocean)

(b,c,d) major macronutrients, <10 m depth, 1º-grid cell means (high NO_3^- & PO_4^{3-} platform vs. low macronutrients open ocean)

(e) Dissolved Fe measurements (<10 m below sea level). Dots with no tag <0.49 nmol kg^{-1}. Cyan diamonds represent areas where nitrate is modeled to be the limiting nutrient (vs. Fe), with Fe the limiting nutrient elsewhere (Song et al., 2016). Fe-limited open ocean.





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Methods

(A) Combine two datasets to model dust emission by individual events:

1) Surface visibility data (in situ): meteorological station. Parameter: dust-related visibility reduction (hourly resolved).

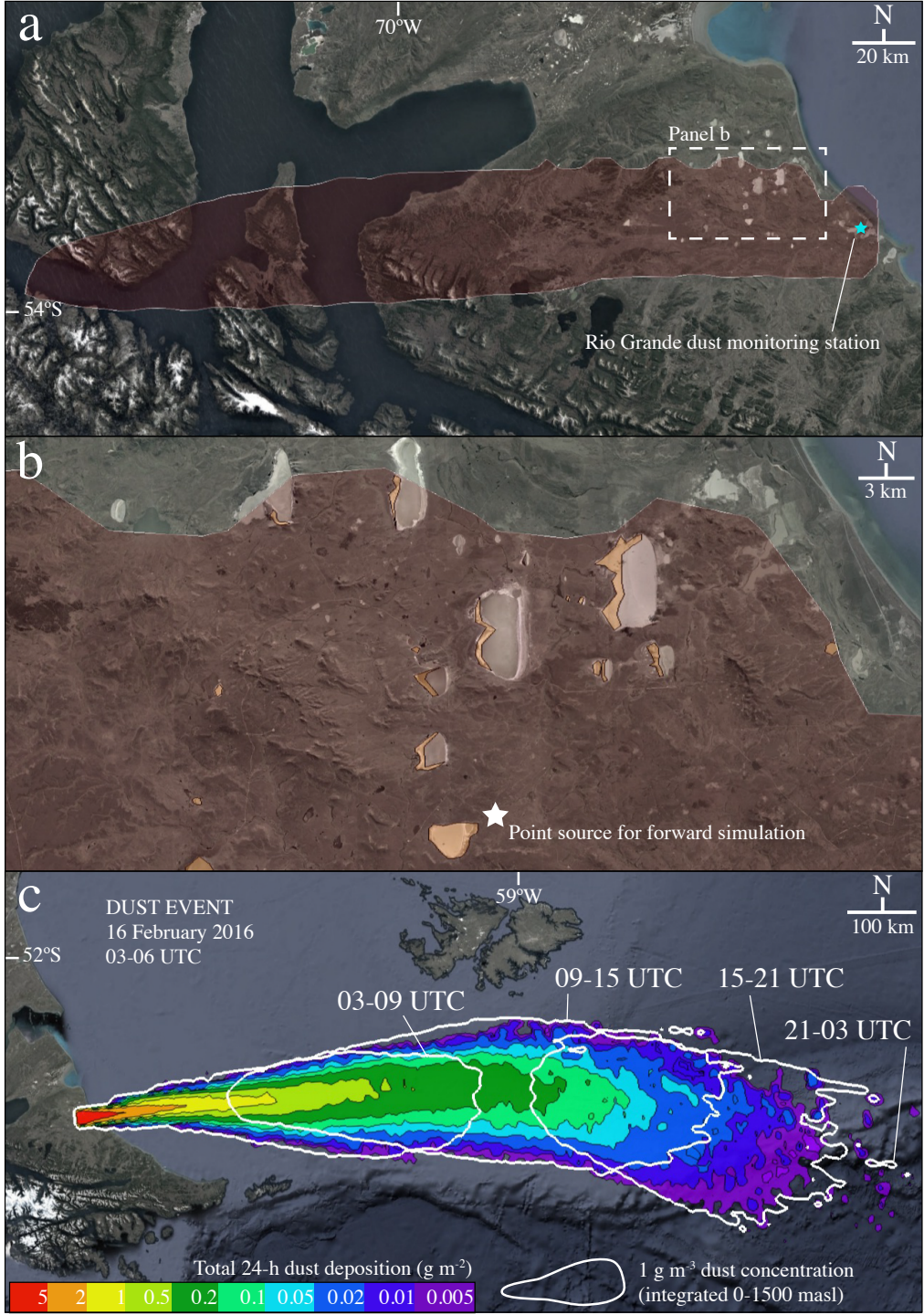
2) Dust sampling: passive collectors. Continuous dust mass collection, resolution: 38 days in average, coverage: 10 years.

(B) Use HYSPLIT 4 to model particle trajectories.

1) Backward dispersion simulation for a 3-hour dust event with point-source emission from the BSNE collector at the monitoring station (Figure a).

2) Mapping of dust sources within the contour defined by backward dispersion (Figure b)

3) The forward dispersion simulation (Figure c)



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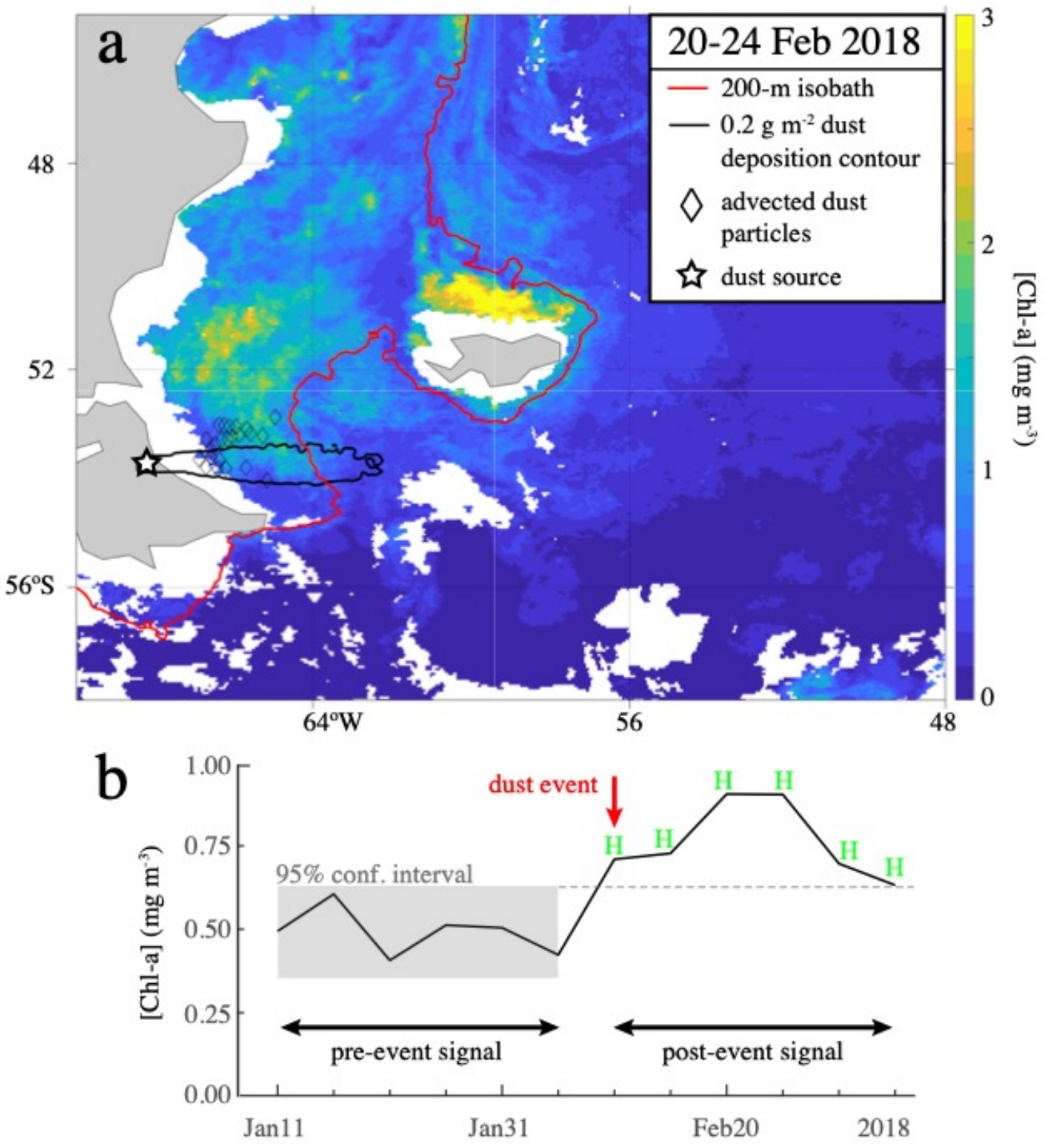
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Methods

(C) Build [Chl-a] time series before and after each one of the 32 dust events considered in this study (each 1-14 hs long, spanning >6 yr). One example:

1) Map of [Chl-a] for 20-24 February 2018. The black diamonds represent the final position of dust particles after advection by satellite ocean currents from the day of the dust event to 20 February 2018.

2) Time series for [Chl-a] uncorrected for post-depositional dust particle advection due to surface ocean currents. All six 5-day mean values after dust deposition plot above the 95% confidence interval of the pre-event signal, so they are classified H for “high”.



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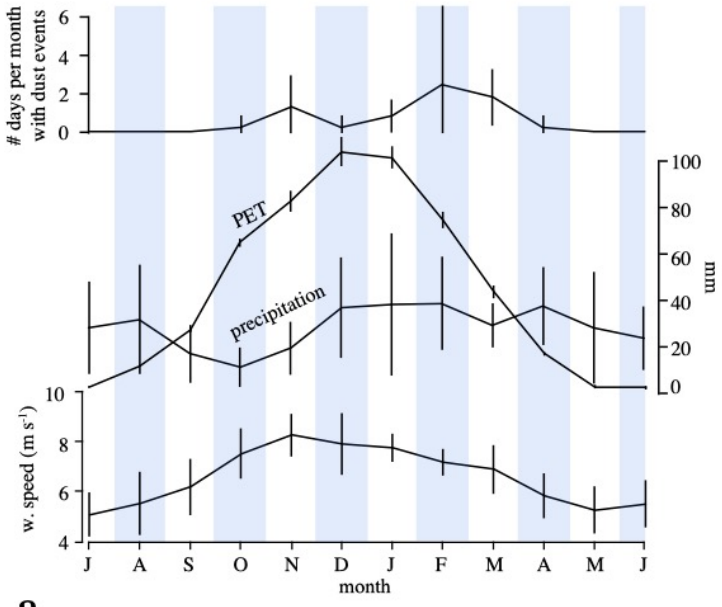
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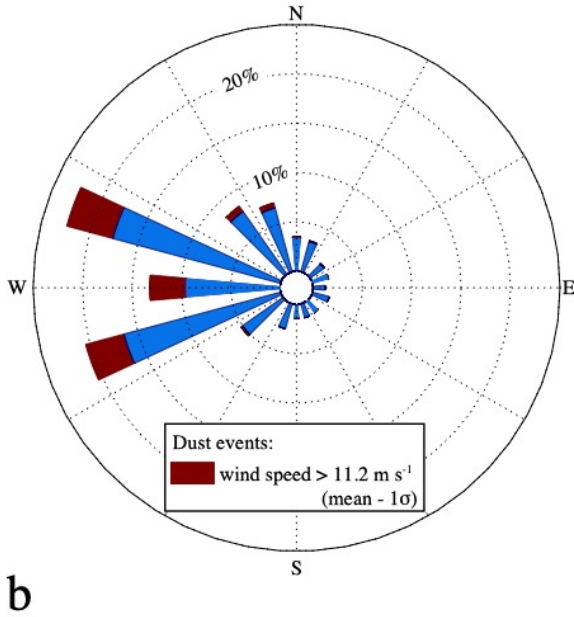
Results

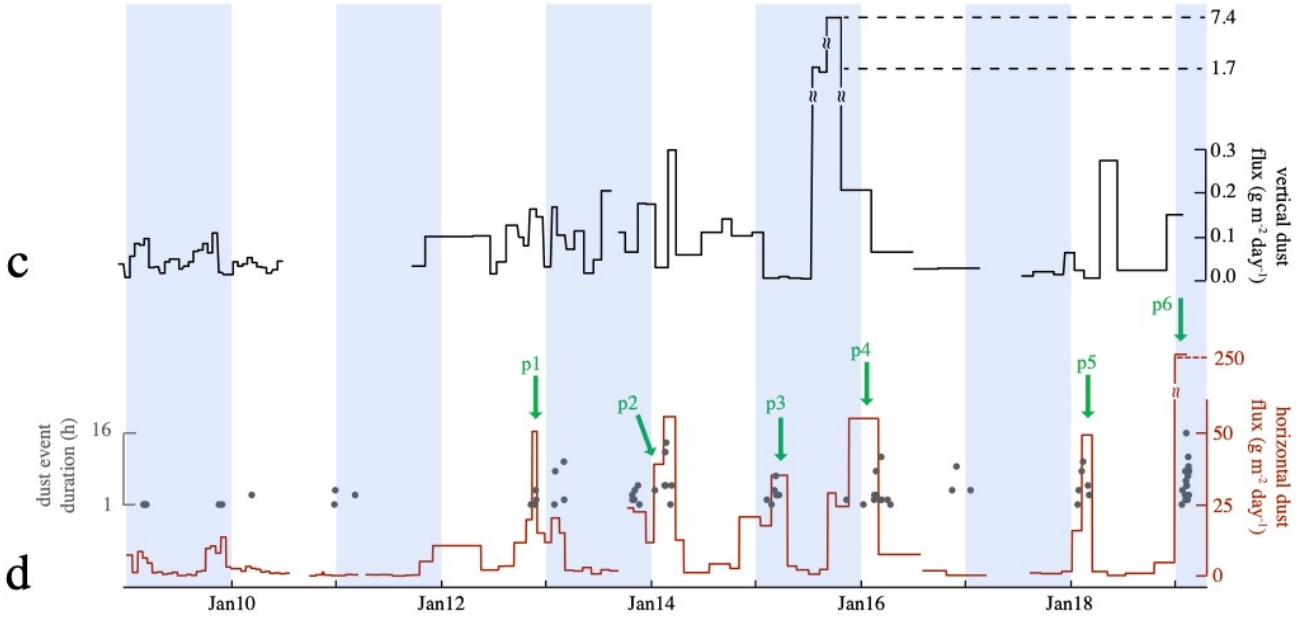
(a) Monthly means for days per month with ≥1 hs reduction in visibility due to dust (Jan ’09-Feb ’19), precipitation, potential evapotranspiration (PET, Penman-Monteith) and wind speed (January 2009-December 2018). Error bars are 1σ. Peak in dust activity after many months of accumulated water deficit (PET-precip).

(b) Direction of wind (hourly) between 29 December 2008 and 20 February 2019. Wind speed during dust events is mostly W-SW to W-NW, >11.2 m s^{-1}.

(c) Vertical and (d) horizontal dust fluxes measured at the dust monitoring station (red line), and visibility reduction events due to dust (i.e., dust events, black dots). The 32 dust events that fall inside peaks in horizontal dust mass flux marked with green arrows were modeled in terms of particle trajectories and deposition.







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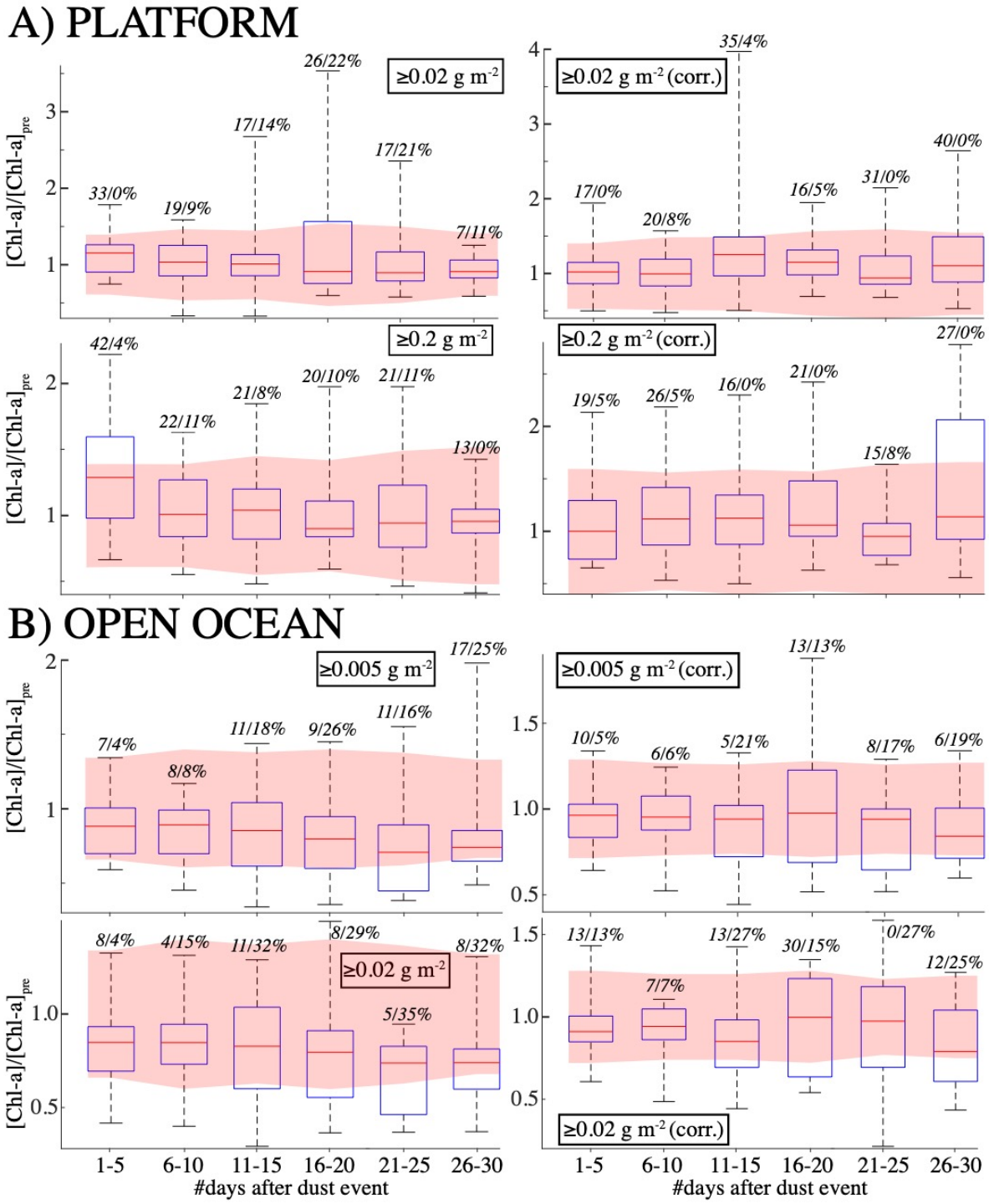
Results

Results summary: satellite [Chl-a] in southernmost Patagonia.

We plot (a) platform and (b) open ocean area-averaged [Chl-a] for 5-day periods after dust deposition, normalized to the pre-event mean, within dust deposition contours of 0.005, 0.02 and 0.2 g m-2, with and without correction (corr.) for post-depositional particle advection due to currents.

On each box, the central red mark represents the median, the bottom and top blue edges indicate the 25th and 75th percentiles, respectively, and the whiskers extend to the most extreme data points. Data points separated more than 3σ from the mean were previously discarded. The pink area represents the mean 95% confidence interval around the pre-event means. The percentages correspond to the fraction of dust events that classify as high (H)/low (L), with H + L + E (i.e., equivalent) = 100%.

No evidence of a role of dust deposition on [Chl-a].



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Results

mimicks source-inherited solubility

mimicks enhanced solubility due to atmospheric/oceanic processes

Table 1. Total iron (Fe_{TOT}), H_20- and HNO_3-soluble iron (DFe_w and DFe_{acid}) and iron speciation (Fe^{2+} vs. Fe^{3+}) of dust samples.

sample lab name	BSNE peak #[1]	Fe_{TOT} ± 1σ (wt%)[2]	DFe_w ± 1σ (wt%)[2]	DFe_{acid} ± 1σ (wt%)[2]	Fe^{2+} (%, vs. Fe^{3+})[3]
RG-BSNE59	1	2.83 ± 0.02	0.00165 ± 0.00001	0.148 ± 0.001	n.d.
RG-BSNE74	2	2.77 ± 0.01	0.00140 ± 0.00001	0.188 ± 0.001	n.d.
RG-BSNE82	3	3.137 ± 0.004	0.00420 ± 0.00003	0.183 ± 0.001	19
RG-BSNE89	4	3.23 ± 0.03	0.00295 ± 0.00002	0.173 ± 0.001	16*
RG-BSNE99	5	3.01 ± 0.02	0.00079 ± 0.00001	0.207 ± 0.001	15-21*
RG-BSNE104	6	3.12 ± 0.02	0.00176 ± 0.00001	0.207 ± 0.001	13-22*

[1]See peak numbering in Figure 5d.

[2]With respect to total sample. For details see Table S3 (Fe d) of the Supporting Information

[3]CP collector samples analyzed for the same time period (

global: 1-7 wt%

global: 10^{-5}-6.3 wt%

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Discussion

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Dust Fe-bearing mineralogy

Surface (i.e., first 2-10 nm) speciation of Fe in dust particles indicates a predominance of oxidized Fe(III). XPS results are consistent with Fe(II)-O and Fe(III)-O chemical bondings, especifically (hydr)oxides and silicates as the main Fe-bearing phases. This is consistent with low Fe solubility in deionized water. It is also consistent with the predominantly non-glacial origin of surface materials that emit dust in the study area (Villarreal & Coronato, 2017), which has been shown to be associated with higher Fe(III) than Fe(II) (Shoenfelt et al., 2017).

Source-inherited dust-Fe is insoluble in southernmost Patagonia

Proximal open ocean waters constitute a HNLC region during summer. Available surface dissolved Fe measurements offshore of the 200-m isobath are scarce between 45-60ºS and average 0.23 nmol kg^{-1}. These observations, together with biogeochemical modeling results (Song et al., 2016), are consistent with Fe being a limiting nutrient for phytoplankton growth, although it is possible that silicate may be a co-limiting macronutrient.

It is estimated that <0.008 nmol L^{-1} of dissolved Fe is added to open ocean waters through deposition of unprocessed dust, potentially raising background surface ocean values from ~0.22 nM to ~0.23 nM. This is insufficient to generate algal blooms in this region ([Chl-a] > 1 mg m^{-3}), which require at least 0.5 nM along the full mixed layer depth for at least three days (Boyd et al., 2010). However, small inputs of Fe may have a resolvable effect on satellite [Chl-a]. The fact that we do not see any response indicates that unprocessed dust iron deposition to the open ocean has an effect too small to be instrumentally resolved, or alternatively, that iron limitation relief cannot be achieved until a threshold value in Fe is reached.

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Discussion

How much could dust-Fe solubility be potentially enhanced in southernmost Patagonia?

An upper bound of ~0.4 nM may potentially be added in open ocean waters, raising oceanic surface dissolved Fe concentration from ~0.2 nM to ~0.6 nM. Nonetheless, it is highly unlikely that processing of dust may raise Fe solubility for two reasons: (1) emissions of SO_2 to the atmosphere derived from oxidation of DMS may not be sufficient to generate observable changes in NPP (Meskhidze et al., 2005), and (2) southernmost Patagonia is scarcely populated and local anthropogenic emissions of SO_2 are negligible.

Effects on the shelf

Assessing the reasons for the lack of a response of phytoplankton biomass to dust deposition over Patagonian shelf waters is challenging due to a lack of data on dust macronutrient concentrations and surface Fe concentrations on the shelf. In order to properly gauge the fertilization potential of dust in the Patagonian shelf, Fe determinations in dust should be complemented by similar macronutrient characterizations (Paparazzo et al., 2018).

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