cosmic dust and the
the oceanic cycle of iron

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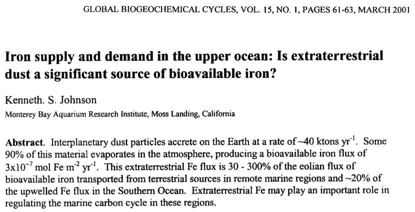

GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 15, NO. 1, PAGES 61-63, MARCH 2001

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CRITICAL REVIEW

Cosmic dust in the earth's atmosphere†

John M. C. Plane*

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This review discusses the magnitude of the cosmic dust input into the earth's atmosphere, and the resulting impacts from around 100 km to the earth's surface. Zodiacal cloud observations and measurements made with a spaceborne dust detector indicate a daily mass input of interplanetary dust particles ranging from 100 to 300 tonnes, which is in agreement with the accumulation rates of cosmic-enriched elements (Ir, Pt, Os and super-paramagnetic Fe) in polar ice cores and deep-sea sediments. In contrast, measurements in the middle atmosphere – by radar, lidar, high-flying aircraft and satellite remote sensing – indicate that the input is between 5 and 50 tonnes per day. There are two reasons why this huge discrepancy matters. First, if the upper range of estimates is correct, then vertical transport in the middle atmosphere must be considerably faster than generally believed; whereas if the lower range is correct, then our understanding of dust evolution in the solar system, and transport from the middle atmosphere to the surface, will need substantial revision. Second, cosmic dust particles enter the atmosphere at high speeds and undergo significant ablation. The resulting metals injected into the atmosphere are involved in a diverse range of phenomena, including: the formation of layers of metal atoms and ions; the nucleation of noctilucent clouds, which are a sensitive marker of climate change; impacts on stratospheric aerosols and O_3 chemistry, which need to be considered against the background of a cooling stratosphere and geo-engineering plans to increase sulphate aerosol; and fertilization of the ocean with bio-available Fe, which has potential climate feedbacks.

Introduction

The solar system is full of dust: if all the dust in the inner solar system (*i.e.* between the sun and Jupiter) were compressed together it would form a moon 25 km in diameter.[1] The main sources of dust are collisions between asteroids (the asteroid belt lies between the orbits of Mars and Jupiter), and the sublimation of comets (which are balls of dust-laden ice) as they approach the sun on their orbits through the solar system.[2,3] Fresh dust trails produced by comets which crossed the earth's orbit recently (within the last 100 years or so) are the origin of meteor showers such as the Perseids and Leonids.[4] Dust particles from long-decayed cometary trails and the asteroid belt give rise to a continuous input of sporadic meteoroids, which provides a much greater mass flux on average than meteor showers.[2,3]

This review addresses an apparently simple question: what is the magnitude of the cosmic dust input to the earth's atmosphere? Table 1 shows that even very recent estimates of the Interplanetary Dust Particle (IDP) input vary from 5 to 270 t d^{-1} (tonnes per day). Zodiacal cloud observations and spaceborne dust detection (dark blue shading in Table 1) indicate a daily input of 100–300 t d^{-1}, which is mostly in agreement with the accumulation rates of cosmic elements in polar ice cores and deep-sea sediments (grey shading). In contrast, measurements in the middle atmosphere (light blue shading) – by radar, lidar, high-flying aircraft and satellite remote sensing – indicate that the input is only 5–50 tonnes.

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† Part of the atmospheric chemistry themed issue.


John M. C. Plane

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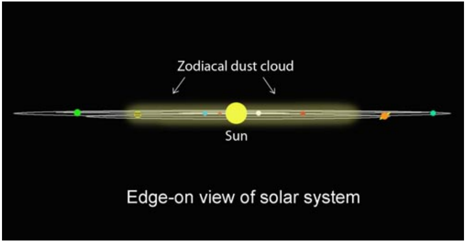
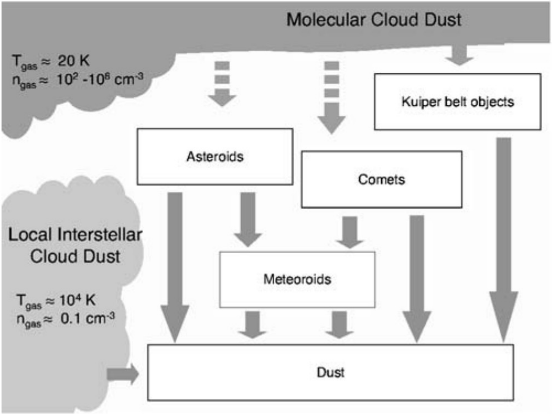
ZODIAKAL LIGHT

Brownlee, 2016, Elements



solar system contains many smaller particles, from meteors to dust
most particles are concentrated near the ecliptic plane
zodiakal light: solar light scattered at these particles

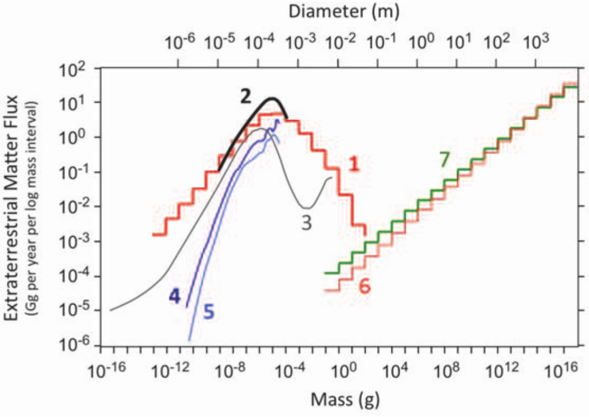
WHERE DOES THE DUST COME FROM?



Mann, 2006, Astron. Astrophys. Rev.

sources of dust: collisions of larger objects, comet's tails, extrasolar matter

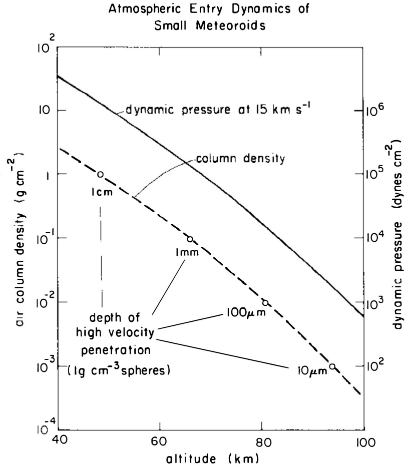
SIZE DISTRIBUTION



Peucker-Ehrenbrink, 2016, Elements

mass flux to earth is dominated by particles smaller than 1 mm (cosmic dust), and by rare impacts of very large meteors

WHAT HAPPENS TO COSMIC DUST?



Brownlee, 1985, Ann. Rev. Earth Plan. Sci.

typical particle entry speed > 10 km s^{-1}

most smaller particles completely evaporate between 80 and 40 km height

ablated material largely re-condenses as ’metoric smoke particles’

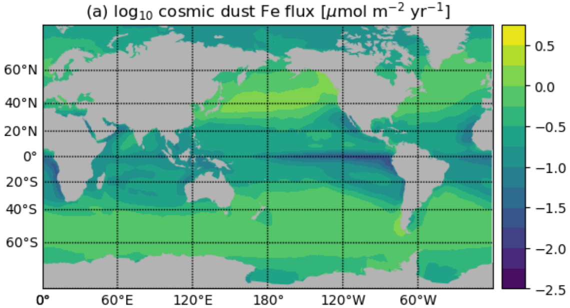
SOME SURVIVING MATERIAL

Cosmic spherules from the 1873-1876 Challenger expedition
Taylor 2016, Elements

slightly larger particles survive as partially molten material

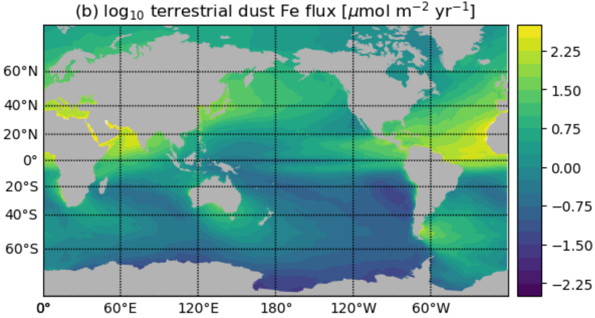
often found in deep-sea sediments as ’cosmic spherules’

COSMIC DUST DEPOSITION



cosmic dust: calculated from meteor ablation; chemical reactions and transport through the atmosphere (Dhomse et al. 2013)
largest deposition in subtropics; relatively homogeneous

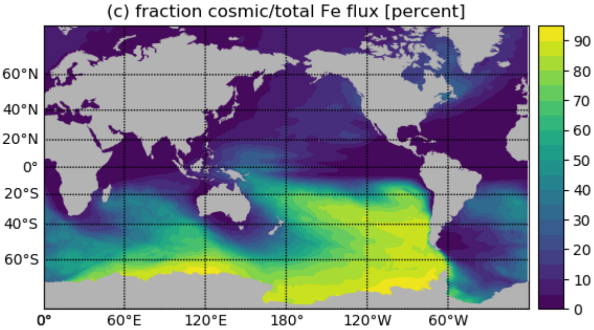
TERRESTRIAL DUST DEPOSITION



terrestrial dust: dust deposition from Albani et al., 2016, assuming Fe is 3.5% of total, and soluble fraction of dust Fe 2%

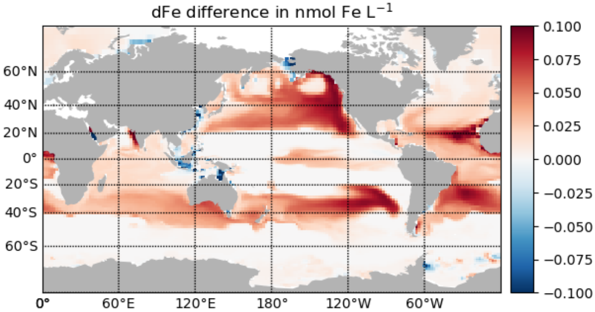
largest deposition downwind of deserts; variation over five orders of magnitude

CONTRIBUTION OF COSMIC DUST



cosmic dust contributes more $> 50\%$ to total soluble iron flux in parts of Southern Ocean

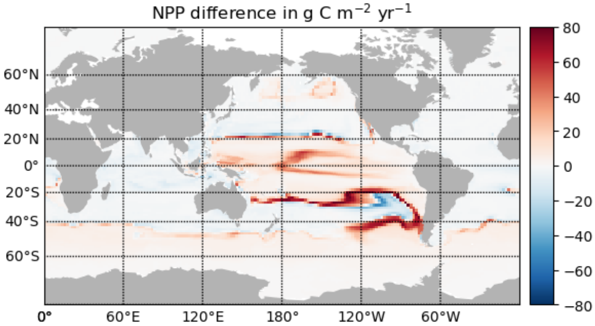
HOW DOES IT AFFECT FE?



difference in DFe between a model run with/without cosmic dust

largest increases where cosmic dust is large and Fe is not limiting
overall, changes are small

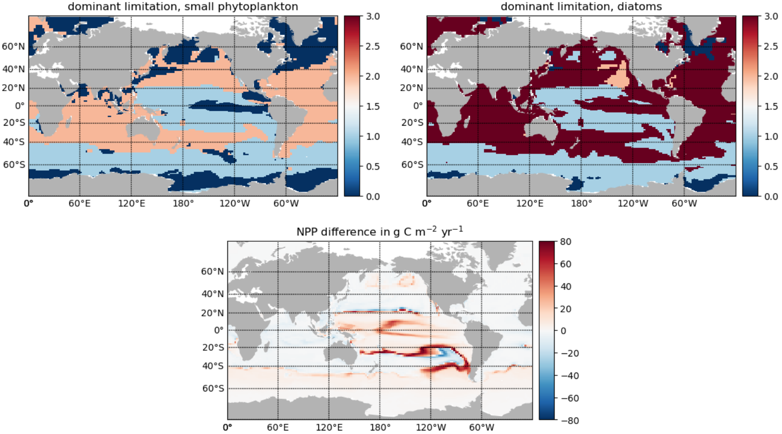
HOW DOES IT AFFECT PRIMARY PRODUCTION?



difference in NPP between a model run with/without cosmic dust

global NPP increases by 2%, export by 0.9%

AND WHY THERE?



largest where boundaries between Fe and N-limited regions shift

THIS IS ONE MODEL. HOW ABOUT OTHERS?

	sources [10^9 g Fe yr^{-1}]				
model	dust	sediment	hydro	cosmic	resid time [yr]
REcoM	317	271	50	12	69
BEC	1223	4825	988		8.1
PISCES	1826	1485	631		11.5/15.7

(grey: old numbers from Tagliabue et al. 2016, need to check)

effect is small because upwelling contributes most Fe in the Southern Ocean

how much of the upwelled iron derives ultimately from cosmic dust differs between models

similar results obtained in BEC, with shorter residence times; PISCES to come soon

SUMMARY AND OPEN ENDS

- cosmic dust is a significant contribution to soluble Fe deposition in Southern Ocean
- some uncertainty in the relative cosmic dust contribution from uncertainties in terrestrial dust input (especially solubility)
- effect on dissolved Fe < 0.1 nM
- Southern Ocean effect on NPP rather small, because dust is a relatively minor contribution here to Fe supply, compared to vertical upwelling/mixing, shelves, . . .
- global effect on NPP in % range
- residence time important
- isotopes?