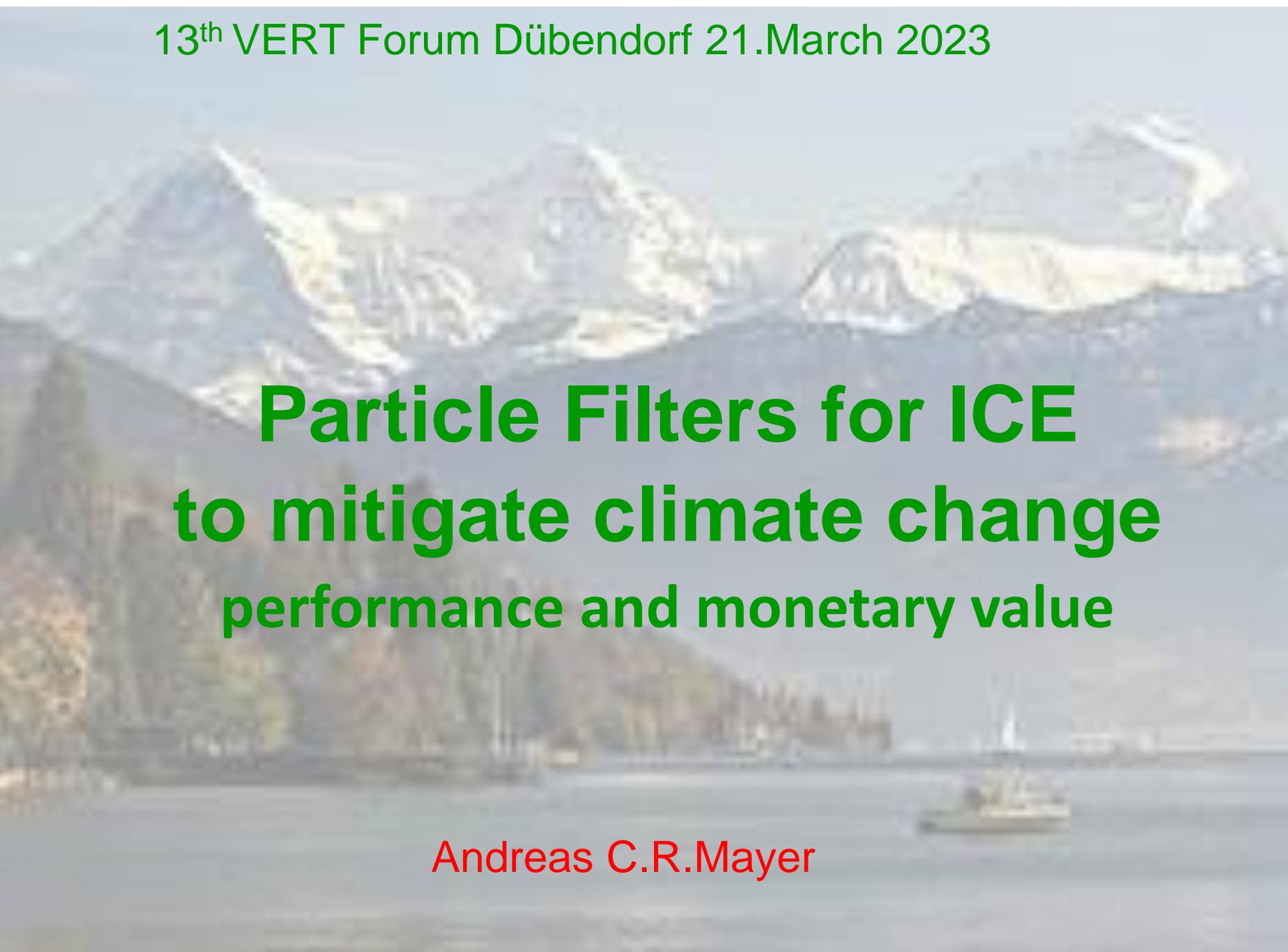


13<sup>th</sup> VERT Forum Dübendorf 21.March 2023



**Particle Filters for ICE  
to mitigate climate change  
performance and monetary value**

Andreas C.R.Mayer

# Global warming: since when do we know?

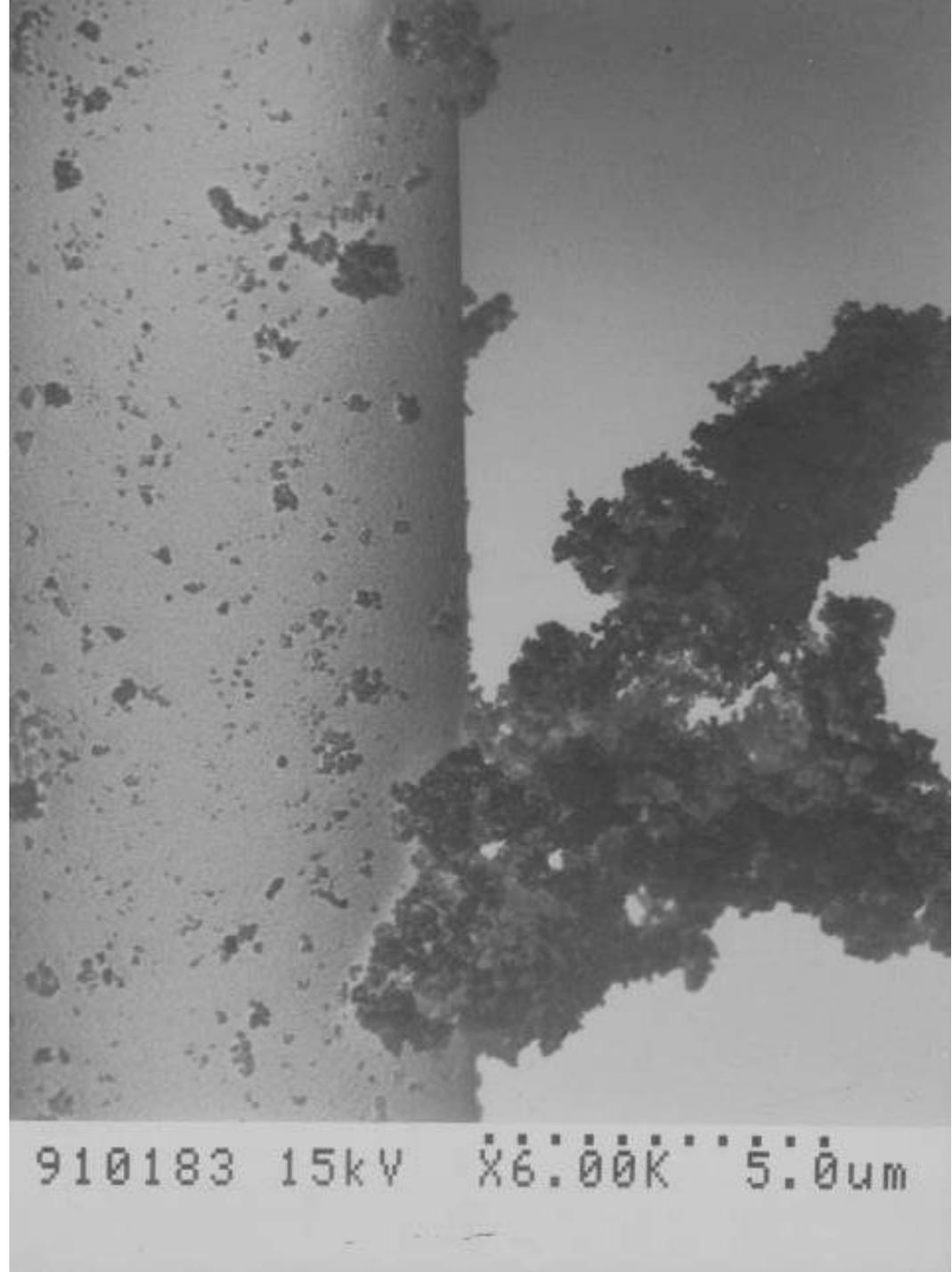
**1856 Eunice Newton Foote**, an amateur scientist, for the first time tested the heat-trapping abilities of different gases. She took several glass cylinders, filled them with gas combinations ranging from very thin air to thicker air, humid air, and air with “carbonic acid,” or what we now call CO<sub>2</sub>. Foote placed the cylinders in the sun to heat up, then in the shade to cool down. When she observed how the temperatures changed, she found that the cylinder with CO<sub>2</sub> and water vapor became hotter than regular air (11° F), and retained its heat longer in the shade. **In other words, wet air and CO<sub>2</sub> were heat-trapping gases.** She published it in the American Journal of Science, saying: What happened inside the CO<sub>2</sub> jar could also happen to our planet. **“An atmosphere of that gas would give to our earth a high temperature.”** she noted

**1824 Joseph Fourier 1824** predicted global warming by mixing gases into the atmosphere

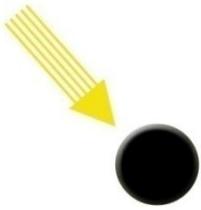
**1895 Svante Arrhenius calculated:** 5-6°C increase by doubling CO<sub>2</sub> content in the atmosphere; based on experimental data of Tyndall he calculated an atmospheric model by hand during several months.

# Soot Particles a double Risk because of

- very small <100 nm
  - surface > 100 m<sup>2</sup>/g
  - carrying toxics
  - persistent in organism
  - carcinogenic
  - **black colour**
- long life toxic aerosol  
weeks to month up to 3500 m  
(→ Jungfrauoch-Laboratory)

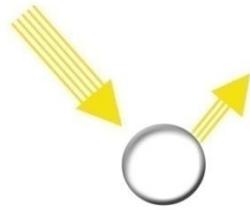


### Warming Effect of Black Carbon Aerosols



“Low albedo”

### Cooling Effect of Organic & Sulfate Aerosols



“High Albedo”

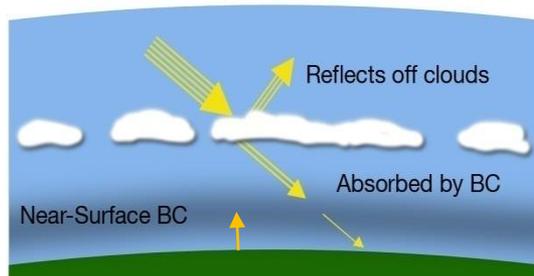
### Multiplying Effect When Mixed Together



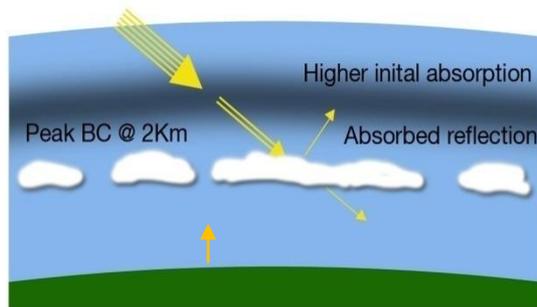
“Very Low Albedo”

## Higher in atmosphere

Traditional View: Peak Black Carbon Close to Surface



New Findings: Peak Black Carbon at 2Km



Science Daily, United Nations Environment Program Nov 2008

# Global Warming by BC-Particles in Air

Proportional to particle mass  
strongly depending on

- **reflection properties**  
(Diesel high, Wood low)
- **mixing properties with water droplets** (internal, external mix)
- **In-cloud effects like ice formation** Z.A.Kanji VERT Forum 2021
- **residence time**

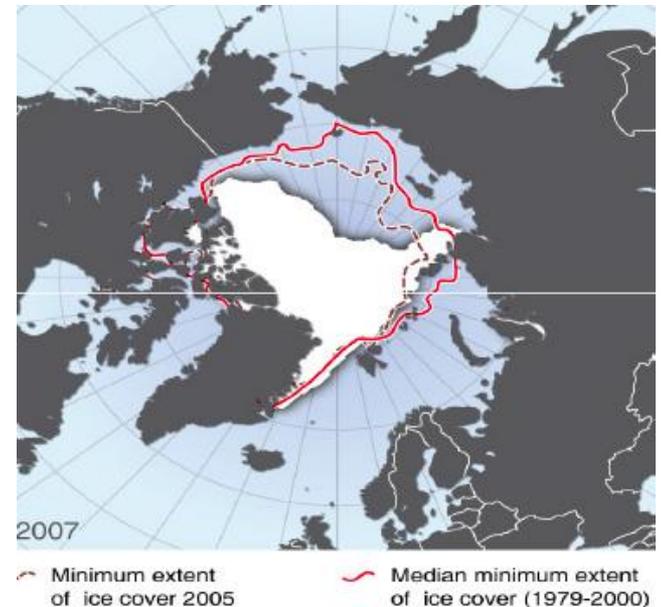


# Polar Regions and Glaciers in Himalayas Anden, Alps

Climate changing effects  
up to 4 times higher than  
in Central Europe



BC on snow  
decreases  
albedo,  
turning to  
water..  
further  
lowering  
albedo



Journal of Geophysics Res.2007

Source: UNEP/GRID Arendal & EPA

# Jacobson Fossil 2002 – ETH-NPC 2002

**Control of fossil-fuel particulate black carbon and organic matter,  
possibly the most effective method of slowing global warming**

Mark Z. Jacobson

Department of Civil and Environmental Engineering, Stanford University, Stanford,  
California 94305-4020, USA

Email: [Jacobson@stanford.edu](mailto:Jacobson@stanford.edu)

Tel: (650) 723-6836

*Journal of Geophysical Research*, in press.

Submitted Oct. 8, 2001; Revised Feb. 4, 2002; Accepted April 12, 2002.

**Radiative Forcing Equivalence Ratio per Unit Mass  
BC / CO<sub>2</sub> : 640'000 – 830'000 : 1**



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Hearing Summary

## HEARING ON BLACK CARBON AND GLOBAL WARMING

Rep. Henry A. Waxman

Chairman, Committee on Oversight and Government Reform

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October 18.2007 – 5 leading researchers incl.M.Jacobson

- **BC is the second leading cause of Global Warming**
  - BC is of particular importance in the Arctic (Albedo-Reduction)
  - BC comes from Diesel engines and fires – wild and domestic
  - Decreasing BC emissions will **immediately slow GW**
  - Decreasing BC emissions will improve public health
  - Opportunities to decrease emissions **exist now**
- Obama-Administration: EPA must propose measures, re-define the role of BC-particles and adjust limit values to the state of the science

# Jacobson 2009

On my question whether the numbers of CO<sub>2</sub>/BC equivalence ratio might have changed since 2002: the result of new research is in the range of that in the 2002 paper, rather higher close to 1 Mio:1

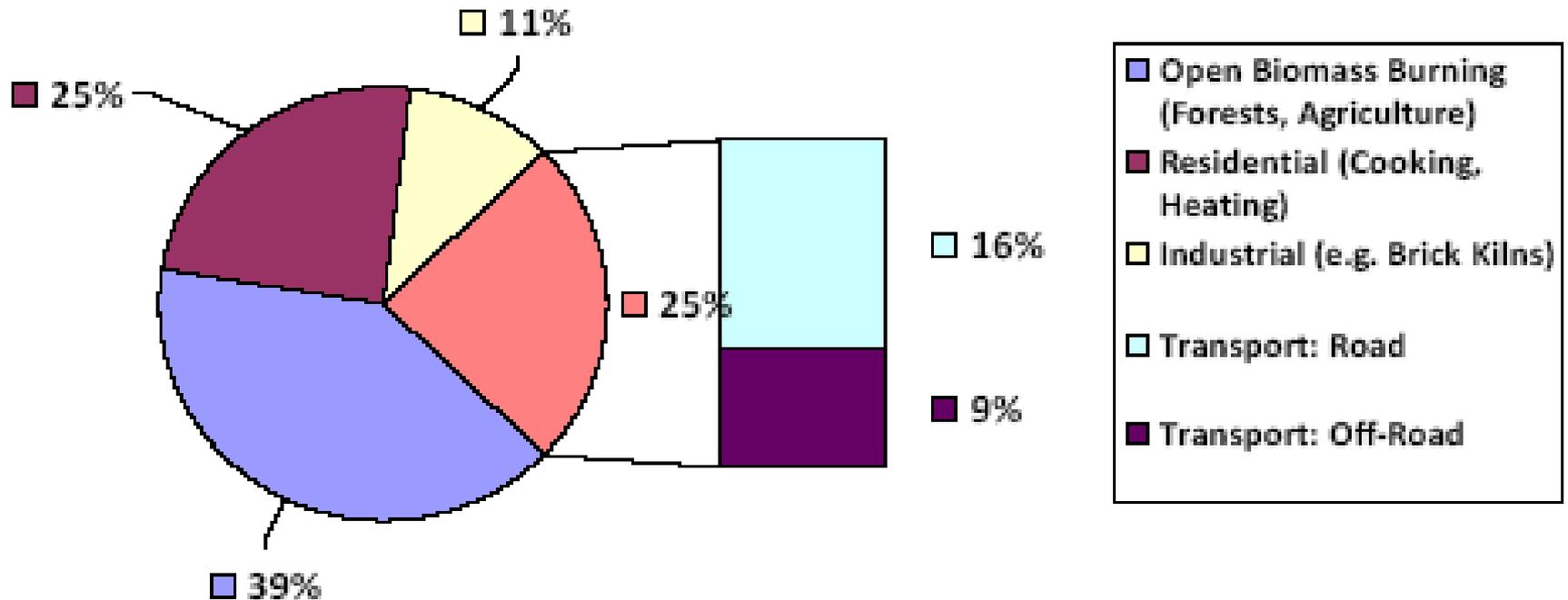
**360,000-840,000:1** ratio of ff BC warming per unit ambient mass in the atmosphere to that of CO<sub>2</sub>

**or 120,000-280,000:1** for ff BC+OM to that of CO<sub>2</sub>)

Confirmed by Hansen (NASA), Seinfeld, Chung, Bond, Ramanathan, Carmichael, Swiss Ad Hoc Expert Group 2023, Baltensperger (PSI)

# Sources of BC-Particles

Figure 1: Global Sources of Black Carbon (*Bond, ICCT Black Carbon Workshop, January 5, 2009*)



# BC blackening the North Pole comes from Europe – acc. to NASA



Abb. 3: Entstehungsgebiete und Verbreitungsrichtungen von Rußpartikeln auf der Nordhalbkugel

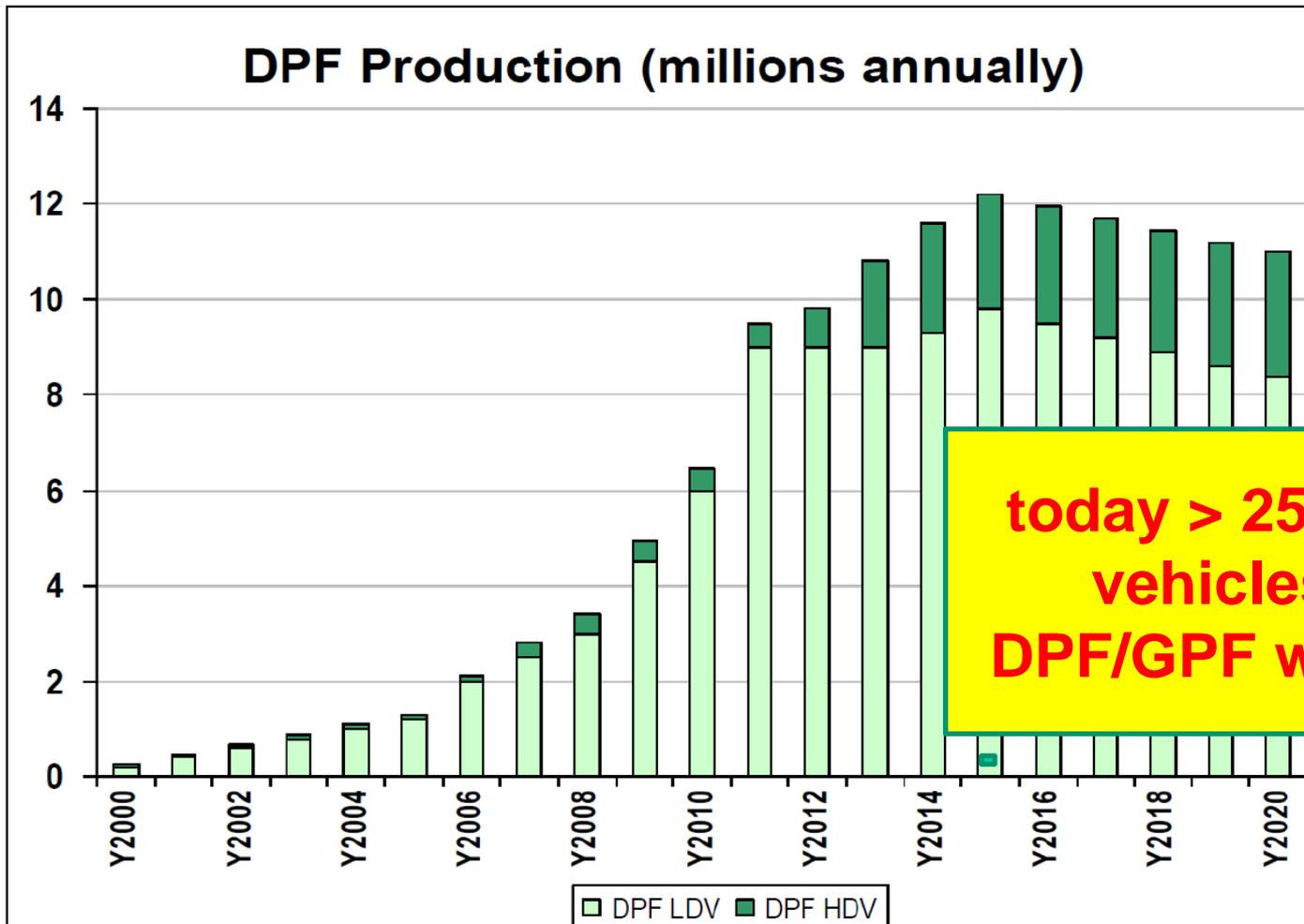
## Woher kommt der Ruß in der Arktis?

Hansen und seine Kollegen haben auch gezeig flächen der Arktis vorwiegend aus Europa stam Rußemissionen aufgrund der herrschenden Wi gel entweder über Sibirien oder direkt in die A Zwar gelangen Rußpartikel auch aus Nordame doch der größte Anteil aller Rußpartikel im a Drittel aufgrund der Stärke und Richtung der V dellierungen und Messungen im Gange, um d Rußemissionen auf die Arktisregion noch bess

# DPF-Installations in Europe

+GPF from 2017

China, India,  
Israel, Iran  
Latin America  
USA HDV  
are following

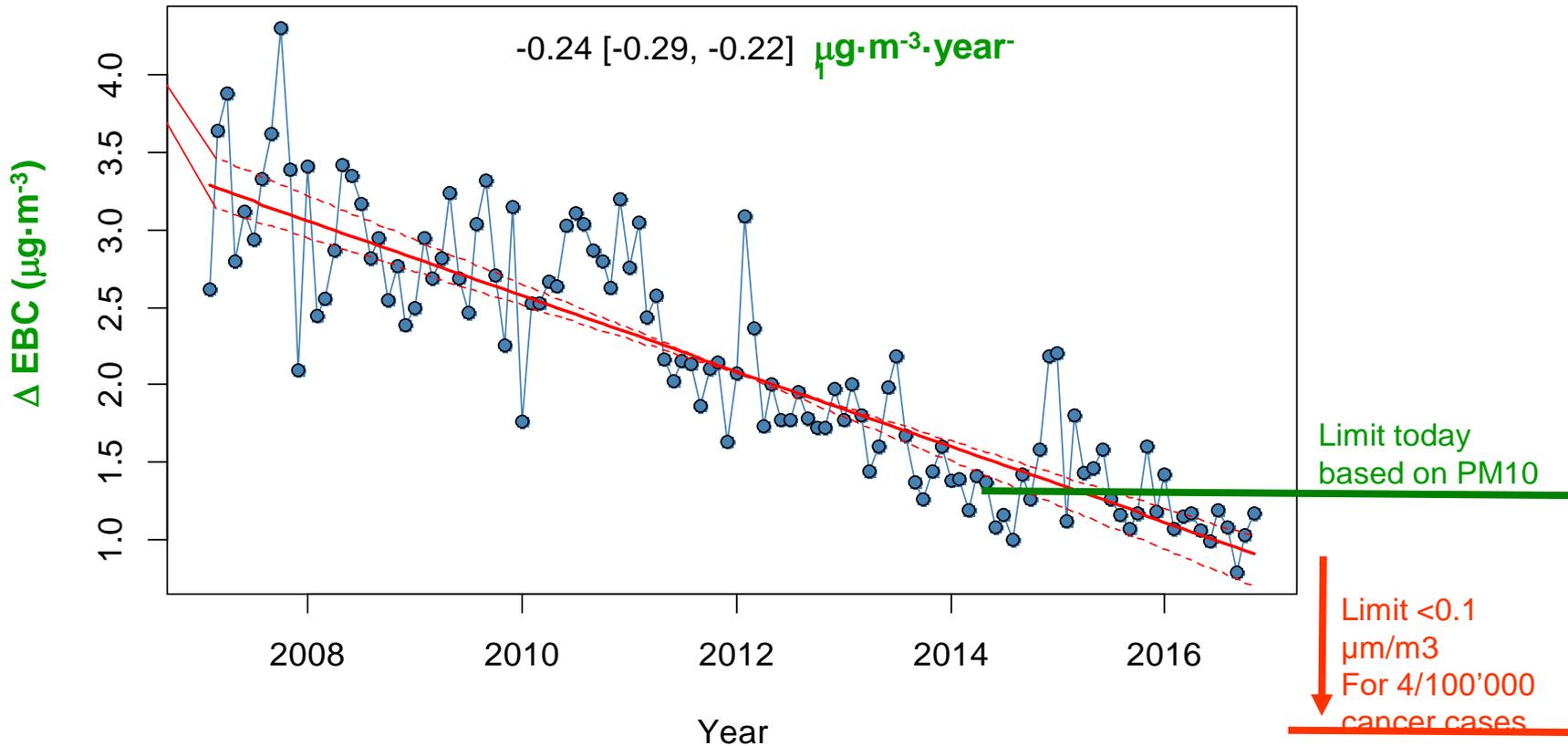


# How a Vehicle Tailpipe can look after 85'000 km City Driving



# and the Result: Cleaning the Air by DPF in Switzerland

## Monitoring BC at the motorway crossing Härkingen



# What is the contribution of all our Particle Filters today? Sharm el Sheigk 2022

We assume emission level Euro 3, i.e. 0.05 g/km for the diesel passenger car without filter

Lifetime 10 years, 200,000 km, i.e. emission →  
→ 10 kg soot per car lifetime, 100 kg per truck

In total, approx. 250 million Diesel particle filters have been sold so far, in the current fleet probably 150 million particle filters are effectively working

With a filtration efficiency of almost 100%, the emission of a overall mass of soot of 1.5 million tonnes of soot was saved by passenger cars; for trucks, the same amount is added, i.e. a total of 3 million tons of soot.

With a Soot/CO<sub>2</sub> equivalent of only 100'000:1, this would be equivalent to the effect of 300 billion tons of CO<sub>2</sub> over 10 years (lifetime of this fleet), i.e. 30 billion tons per year.

The worldwide yearly emission of CO<sub>2</sub> today is 35-40 billion tonnes.

**According to this highly simplified calculation, we would have achieved an effect with our particle filter action that is in the order of magnitude of the annual human made supply of CO<sub>2</sub> to the atmosphere 😊**

# But this ist not realistic

Since residence time of soot particles in the atmosphere is much shorter than of CO<sub>2</sub>. While CO<sub>2</sub> might stay 20 years or more, soot aerosols may be cleaned out of the atmosphere by rain or become ineffective by hydrophylic coating or internal mixing so their residence time might be weeks to months in our countries

Residence time ratio 240 :1

→ Jacobson's equivalence factor  $500'000: 240 = 2083$

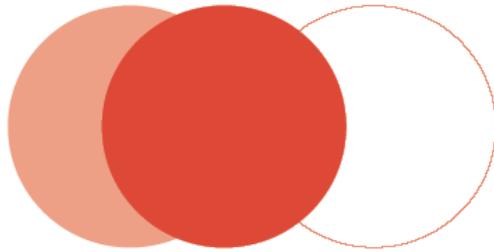


Table 1. Global Warming Potentials (GWP) drawn from the IPCC 4th Assessment Report

	GWP20	GWP100	GWP500
<b>Black carbon</b>	<b>1600</b>	<b>460</b>	<b>140</b>
Methane	72	25	7.6
Nitrous oxide	289	298	153
Sulfur oxides	-140	-40	-12
Organic carbon	-240	-69	-21
Carbon dioxide	1	1	1

Note: The methodology used for black carbon was also used for organic carbon and sulfur oxides. Values for black carbon, organic carbon and sulfur oxides were not published by the IPCC and are not official estimates.

# Study by Alantic Consulting 2009

Table 1: Relative Global Warming Potential of a selection of key emissions

Emission	Global Warming Potential <sup>D</sup> Relative to CO <sub>2</sub>	
	20 Year Period	100 Year Period
CO <sub>2</sub>	1	1
Methane	72	25
Nitrous Oxide (NO <sub>x</sub> )	289	298
Black Carbon	2200	680

# again Jacobson 2009

**Table 4.** The 20- and 100-Year Surface Temperature Response Per Unit Emission Functions and the 100-Year Surface Temperature Response Per Unit Mass for Fossil-Fuel Soot, Biofuel Soot and Gases, Black Carbon in Both, and Methane<sup>a</sup>

X	20-Year STRE	100-Year STRE	100-Year STRM
BC+POC in FS	2400–3800	1200–1900	$4.9\text{--}11 \times 10^5$
BC in FS	4500–7200	2900–4600	$1.05\text{--}2.4 \times 10^6$
BC+POC in BSG	380–720	190–360	$3.6\text{--}9.9 \times 10^4$
BC in BSG	2100–4000	1060–2020	$3.5\text{--}9.7 \times 10^5$
Methane	52–92	29–63	21–45

CO<sub>2</sub> (Figure 1), a result consistent with similar analyses of climate response [*Jacobson*, 2002b, 2004a, 2006] and radiative forcing [*Jacobson*, 2000, 2001b; *Chung and Seinfeld*, 2002; *Ramanathan and Carmichael*, 2008] of particles containing black carbon.

# Equivalence Factors

	ICCT, M. Walsh 6/2009	Atlantic Cnsultants 2009	VERT 2012	STRE M.Jacobson 2009
BC (engine soot)	<b>1600</b>	<b>2200</b>	<b>1440</b>	<b>2400-7200</b>
CO <sub>2</sub>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>

→ We continue with 2083

# Realistic Impact of soot avoided by particle filters

During DPF lifetime 10 years: **3 million tons soot**  
x equivalence factor 2083 equals **6,2 billion tons CO2**  
**Per year: 0.6 billion tons** avoided mainly in Europe

CO2- emission of EU per year: 4,06 billion tons (2019)  
CO2-Emission of Germany per year: 700 million tons

**Global Warming Impact avoided by DPF  
compared to CO2 Europe: 15%**

**This means that with the DPFs, without waiting for the IPCC decisions, we have already effectively mitigated the rise in temperature since year 2000; without DPFs it would already be significantly hotter.**

**In fact, Jacobson expects the effect of soot to warm the atmosphere by 1.7°C and recommends that U.S. Congress focus primarily on this simple and immediately effective remedy**

We have submitted this to conference participants but the IPCC at Sharm el Sheikh has not taken notice of this  
Saying that there still doubts on the inventory  
(have we time for doubts?)

# Our Conclusions (at EU-JRC 2009)

- Retrofit of all Diesels with DPF – works immediately
- Transfer Retrofit Technology worldwide
- GPF Retrofit SI engines
- Stop wood burning
- Establish a monetary soot compensation value

# Establish Soot Credits for Emission Trading !



**assuming 80 EUR per ton CO2 (EEX CO2 2022):**

**One kg not emitted Soot**

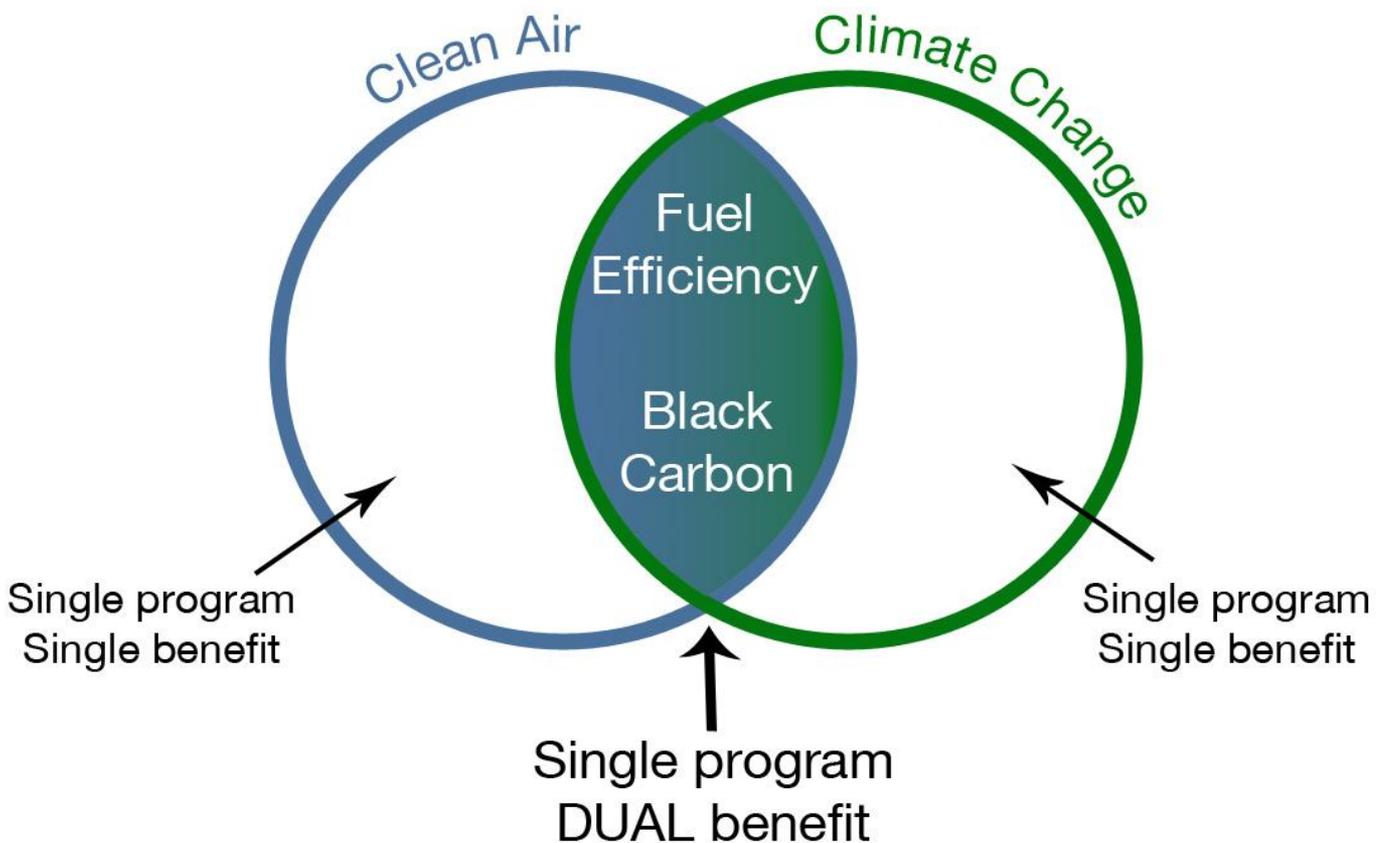
**deserves a credit of 166 Euro**

**→ 1'660 Euro per LDV DPF retrofitted**

**→ 16'600 Euro per HDV DPF retrofitted**

**→ plus health benefit**

# *The Solution is the Diesel Particle Filter*











# Overall Radiative Forcing due to Black Carbon and other Aerosols and Gases compared to CO<sub>2</sub>

Global mean radiative forcing for the year 2000, relative to 1750

Source: IPCC, 2007

