Merton College Occam Lecture, Hilary Term 2013

From Excitons to Soot:
the unlikely outcome of a Physics education

Tony Hansen

Merton (Physics) 1969
University of California, Berkeley (Ph.D., Physics, 1977)
Lawrence Berkeley National Lab., Staff Scientist: 1977-2005

Magee Scientific Co. 1986 - -
Tony . Hansen @ MageeScientific . com

MAGEE SCIENTIFIC

2013 Weather Report

SOUTH POLE

Main Menu
Polar Science
Local Information
Local Dept

Local Email
Galley Scroll
Weather
Forecast
Daily Weather Info
Flights
Pax In / Pax Out
SatStat
Phone List & Instructions
Resource Tracking
Station Guide
Station Hours
Leaving the South Pole
ASC

Site Map

Weather for South Pole Station
Today is Monday, February 4th 2:12pm

Temperature
-39.6 °C -39.3 °F
Windchill
-55.8 °C -68.4 °F
Wind
11.7 kts Grid 27
Barometer
675.3 mb (3,294 m/10,806 ft)

If you want to see official met data - click on this link.
If you want to see South Pole Weather FAQ's - click this link.

Done Internet 100%

2013 -56°C windchill

MAGEE SCIENTIFIC

Humility, not Hubris

黑 碳

托尼 汉森

MAGEE SCIENTIFIC

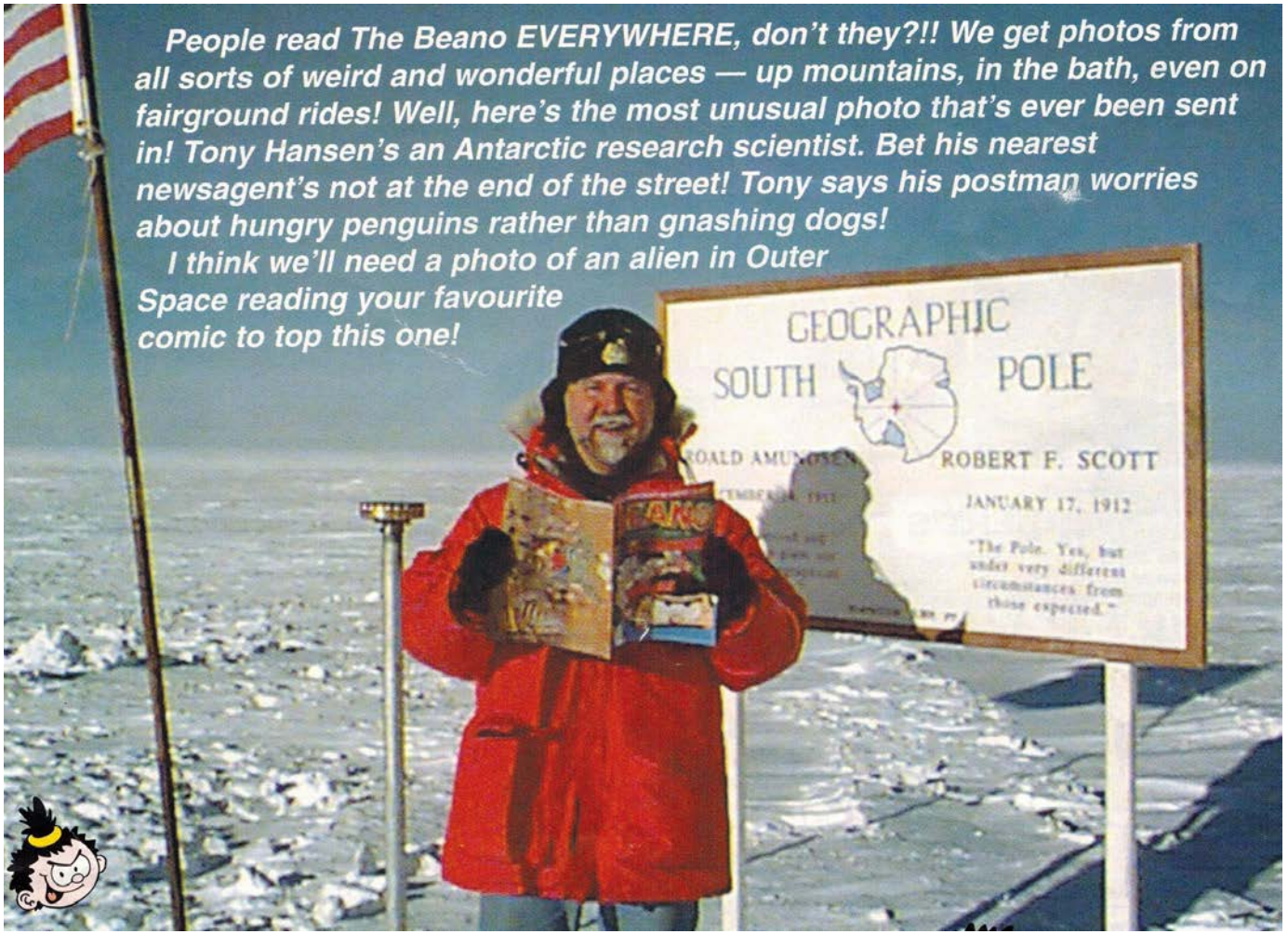
Example of Functional Illiteracy: the Mystery Admonition

MAGEE SCIENTIFIC

1969 Innocence, Potential

MAGEE SCIENTIFIC

1999 Recognition in print



MAGEE SCIENTIFIC

From Excitons to Soot

In Oxford, I studied Solid State Physics under Dr. Baker.
Little did I realize that the Siberian environment of the Clarendon Lab during a winter electricity strike would prepare me for some of my subsequent adventures.

At Berkeley I wrote my Ph.D. thesis on low-temperature solid-state physics: a ‘conventional’ career in academia was expected.

HOWEVER, I wanted to stay in **Berzerkeley**: and found a position at the Lawrence Lab in a newly-formed group, using **Physics** to study the “Black Carbon” air-pollution **soot particle**.

The **WHAT** particle ?????

The Benefit of Classics

The Legend of Icarus contains the concept of being ‘burnt to a cinder’: in our terminology, pyrolyzed. This is, of course, exactly the manner in which soot particles are formed in combustion.

The Classical Greek adjective is **ανθρακιας** = ‘burnt to a cinder’

The Classical Greek verb **αεθαλουν** = ‘to blacken with soot’.

Consequently, while other branches of Physics study leptons, mesons and bosons (‘light’, ‘medium’ and ‘heavy’ particles) …. we study ‘**anthracons**’ (“burnt-to-a-cinder” particles) using an ‘**Aethalometer**’ (measures “blackening with soot”)**.**

The Aethalometer has been the definition of my scientific career.

MAGEE SCIENTIFIC

Career

- 1969-1972: Merton, Physics (J.M. Baker)
- 1972-1977: Univ. Calif. Berkeley, Ph.D. Physics
- 1977-2005: Lawrence Berkeley National Lab.
- 1986 - - - : Private-sector small business
- 1984-1992: Arctic, USSR
- 1996-2013: Antarctic
- 2007 - - - : China, India, Europe
- (Bucket List): “The Third Pole” (Tibet)

MAGEE SCIENTIFIC

Why are air pollution particles important?

- **Public health** – disease & death
- **Climate change** – local, regional and global
- **Precipitation** – reduction of rainfall
- **Visibility** – also, reduction of sunlight for agriculture
- Damage to **cultural heritage** (buildings, monuments, art)
- Impede **high-powered lasers** (‘Star Wars’, U.S. Navy, ..)

1953: Air pollution cancels Arsenal game

MAGEE SCIENTIFIC

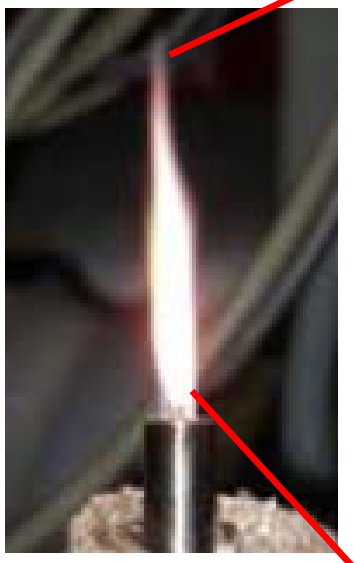
2013: Air pollution closes Beijing Airport

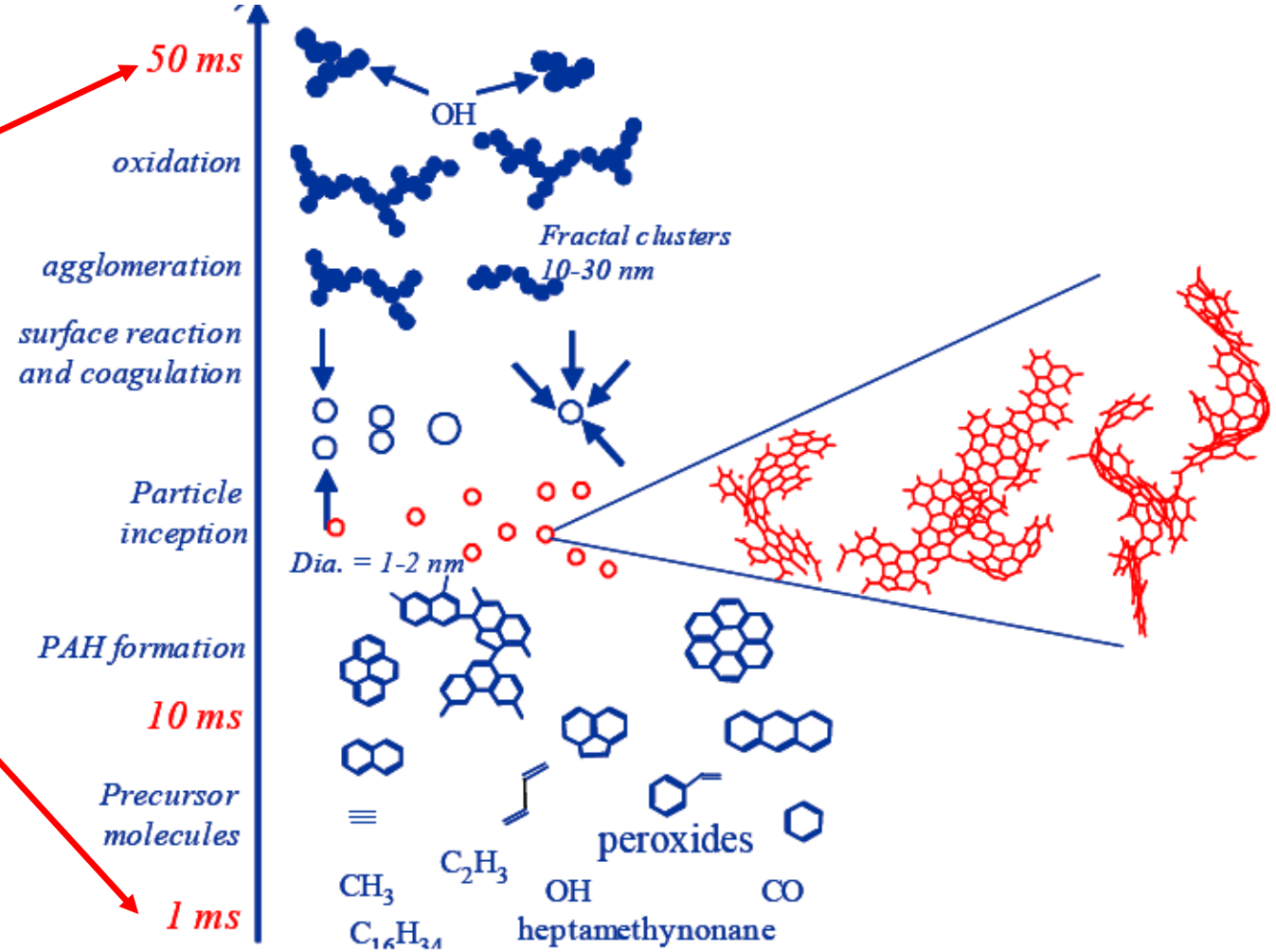
MAGEE SCIENTIFIC

Aerosol Black Carbon : "Soot"

- Formed in all combustion of carbon fuels
- **Small** particle size (typically < 0.3 μm)
- Graphitic microstructure is **black** (~10 m^2/gram)
- **Inert**: removed from the atmosphere only by precipitation and deposition
- **Active Surface** may be porous and covered with chemically-active functional groups and/or **toxics**
- May act as a **condensation nucleus** and change the **optical** and **microphysical** properties of **clouds**.

Soot formation in combustion





MAGEE SCIENTIFIC

Emissions of BC are unpredictable

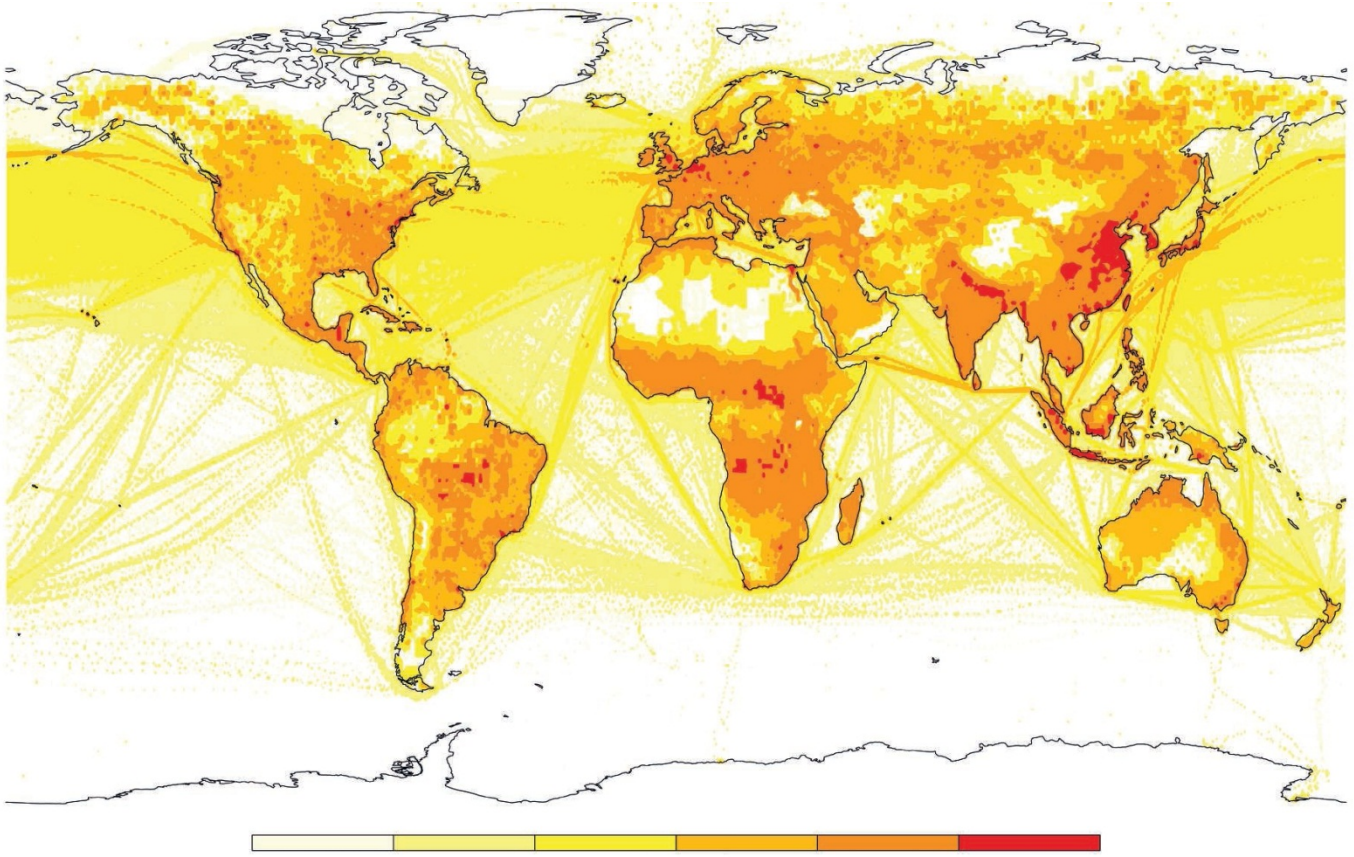
- BC per (kilogram fuel) is **unpredictable * 10^3**

- Quantity of fuel → **CO_2**
- Quality of combustion → **BC**

MAGEE SCIENTIFIC

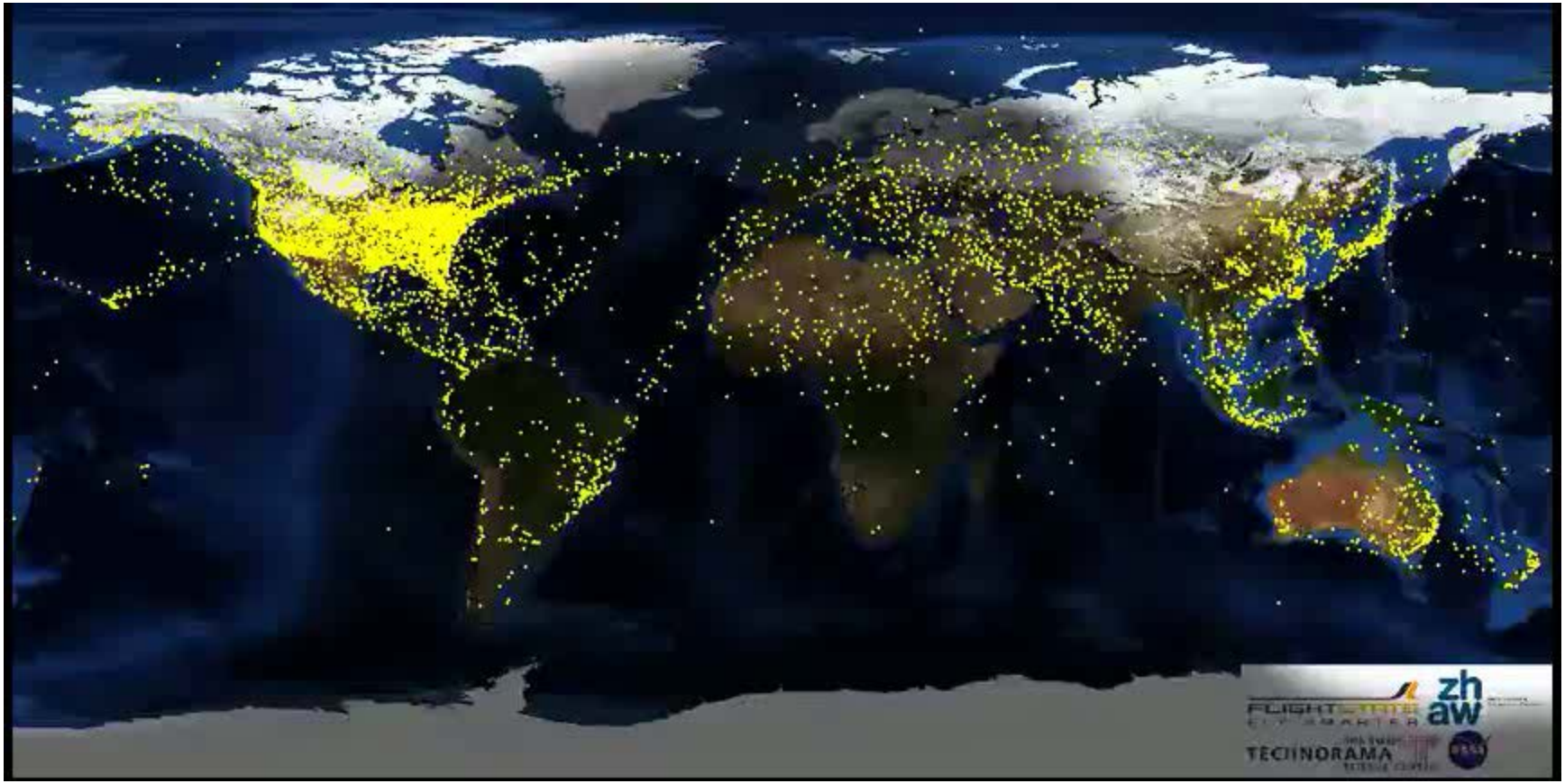
Aerosol Black Carbon : Global Emissions

BC emissions from <u>all</u> sources: fossil + biomass-burning



MAGEE SCIENTIFIC

Aircraft: emissions into the stratosphere



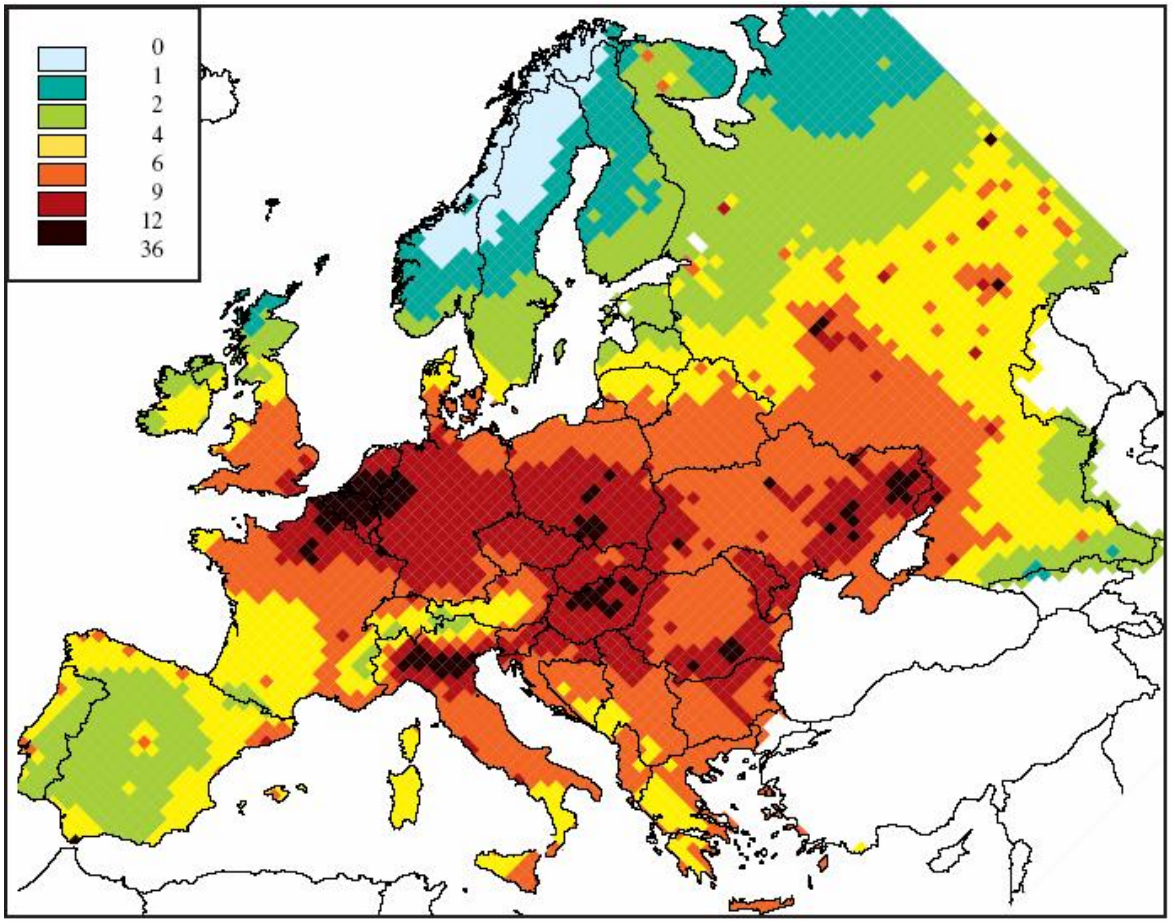
MAGEE SCIENTIFIC

Why are atmospheric aerosols important?

- **Public health – disease & death**
- Climate change – local, regional and global
- Precipitation – reduction of rainfall
- Visibility – also, reduction of sunlight for agriculture
- Damage to cultural heritage (buildings, monuments, art)

MAGEE SCIENTIFIC

Loss of life expectancy in Europe



CAFE Report, EU Commission, 2000

MAGEE SCIENTIFIC

Health impact of Fine Particulates

If two areas of Central and Southern California would *simply meet **existing** Air Quality Standards:*

….. savings $28,000,000,000 per year

- **3,860** fewer premature deaths among those age 30 and older
- **13** fewer premature deaths in infants
- **1,950** fewer new cases of adult onset chronic bronchitis
- **3,517,720** fewer days of reduced activity in adults
- **2,760** fewer hospital admissions
- **141,370** fewer asthma attacks
- **1,259,840** fewer days of school absence
- **16,110** fewer cases of acute bronchitis in children
- **466,880** fewer lost days of work
- **2,078,300** fewer days of respiratory symptoms in children
- **2,800** fewer emergency hospital visits

More premature death in Los Angeles from Air Pollution than Car Accidents

Hall et al., Cal State University Fullerton, Nov. 2008

MAGEE SCIENTIFIC

Aerosol Black Carbon : Global Measurements

WORST : Asia, BC = 10 ~ 100 µg/m³. Exposure of 2 x 10^9 people

MAGEE SCIENTIFIC

Aerosol Black Carbon : Global Measurements

BEST : Antarctica, BC ~ 100 pg/m³. Exposure of 200 people

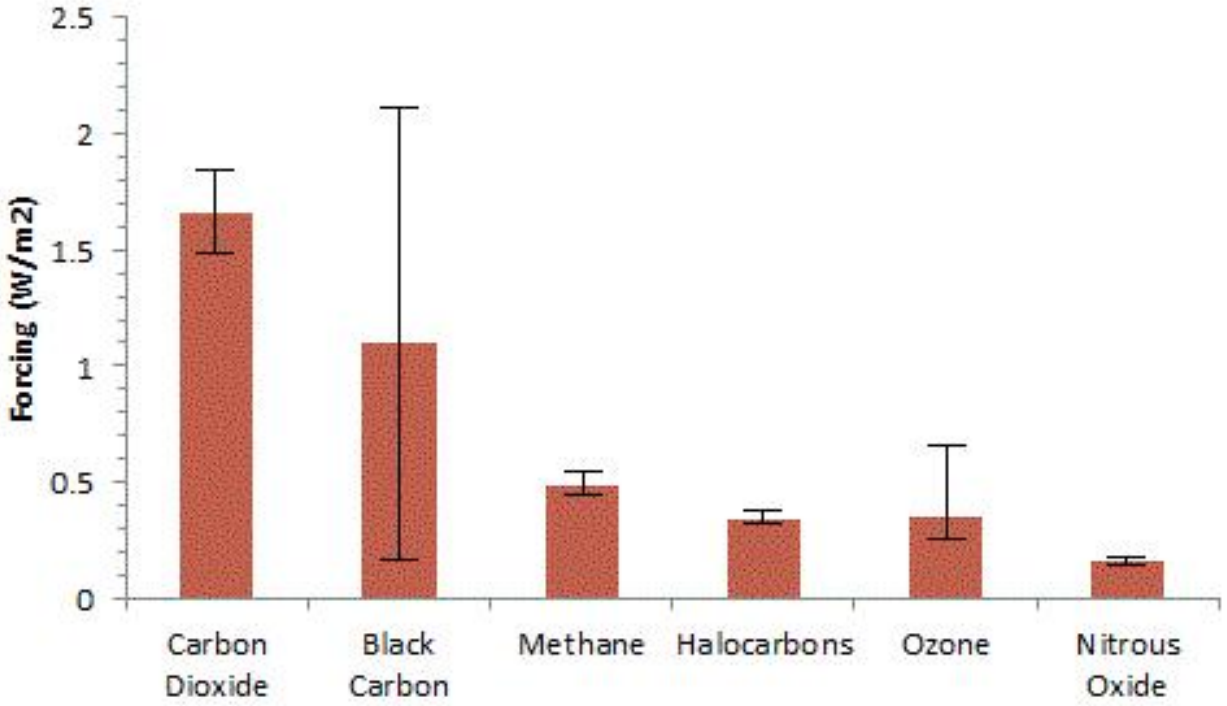
MAGEE SCIENTIFIC

Why are atmospheric aerosols important?

- Public health – disease & death
- **Climate change – local, regional and global**
- Precipitation – reduction of rainfall
- Visibility – also, reduction of sunlight for agriculture
- Damage to cultural heritage (buildings, monuments, art)

MAGEE SCIENTIFIC

Climate Change Effects of Aerosols

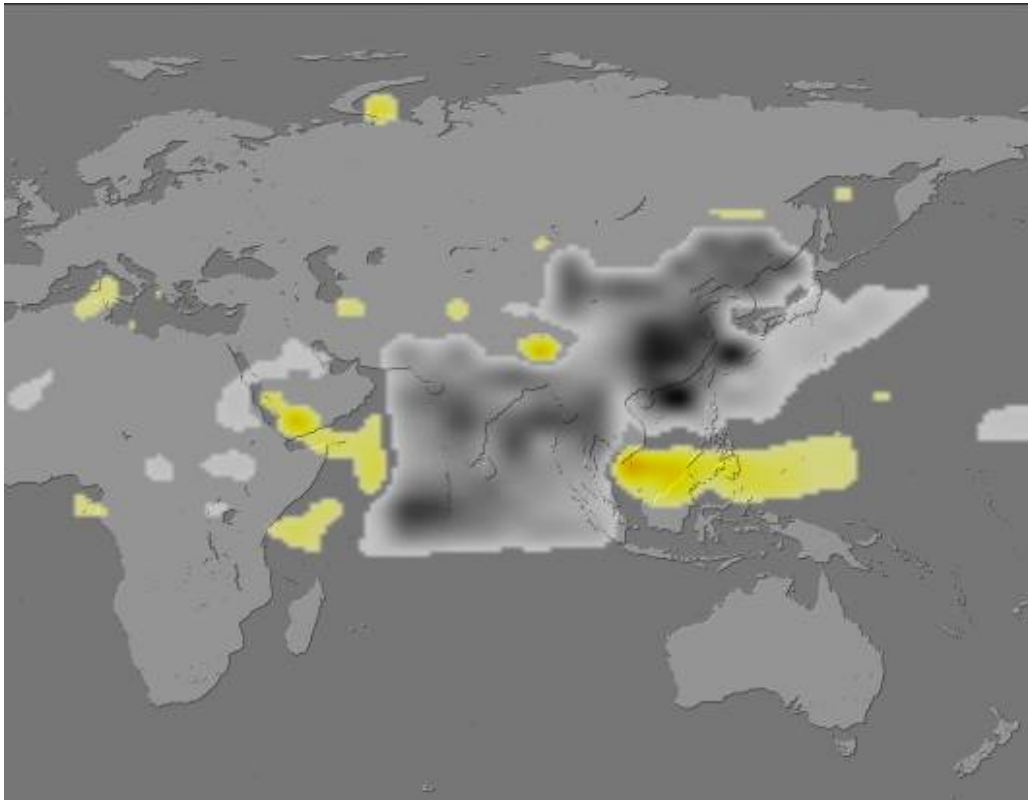


"The best estimate of climate forcing by Black Carbon is 1.1 W m-2. There is a very high probability that Black Carbon emissions have a positive forcing and warm the climate. "Black carbon reduces aerosol albedo, causes a reduction of cloud cover, and reduces cloud particle albedo. All of these effects cause warming."

Bounding the role of Black Carbon in the climate system
T. Bond et al. JGR (2013)

MAGEE SCIENTIFIC

Climate Change Effects of Aerosols



Haze over Asia: **up to 40% of sunlight absorbed.**
Agriculture yields reduced ; local rainfall changed.

Climate Effects of Black Carbon Aerosols in China and India
S. Menon, J. Hansen et al. Science 27 Sep 02: 2250-2253

MAGEE SCIENTIFIC

Aerosol Black Carbon covers continents

Picture taken at ~ 1000 m. altitude over New Delhi, India: early morning.

City is invisible: solar radiation reaching the ground is reducing ~ 5% per decade over the entire country.

~ 12% of Delhi population (> 3 million people) have **respiratory disease**.

MAGEE SCIENTIFIC

Possibility for improvement

Both pictures taken at ~ 1000 m. altitude, early morning.

New Delhi, India

Beijing, China

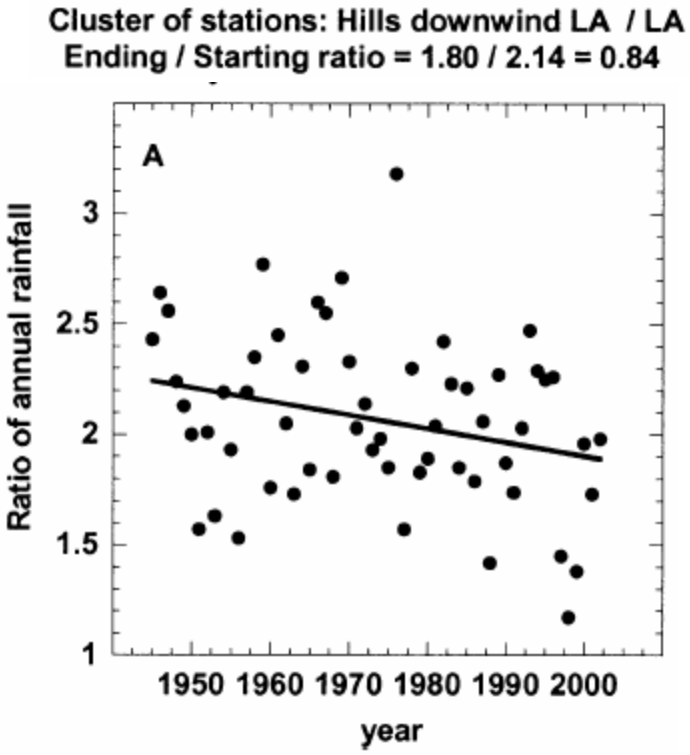
MAGEE SCIENTIFIC

Why are atmospheric aerosols important?

- Public health – disease & death
- Climate change – local, regional and global
- **Precipitation – reduction of rainfall**
- Visibility – also, reduction of sunlight for agriculture
- Damage to cultural heritage (buildings, monuments, art)

MAGEE SCIENTIFIC

Suppression of Precipitation

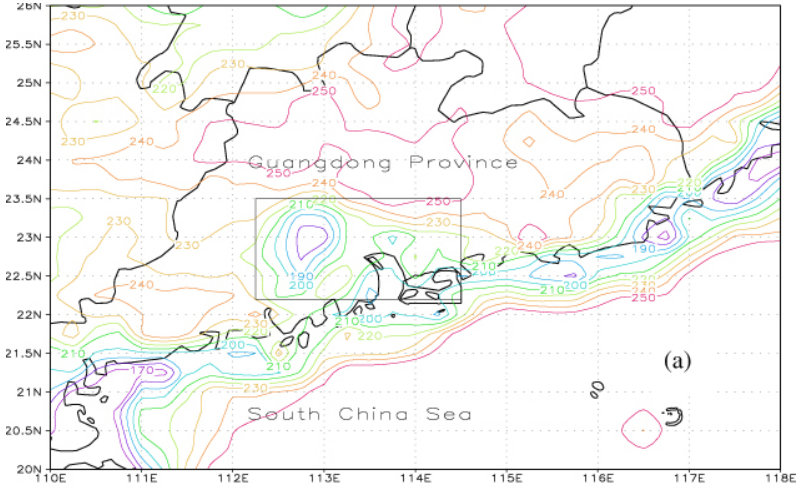


"Urban **air pollution** and industrial air pollution have been shown qualitatively to **suppress rain and snow**. Here, **precipitation losses** over topographical barriers downwind of major coastal urban areas **in California .. that amount to 15%–25% of the annual precipitation are quantified**. …. The evidence includes significant decreasing trends of .. precipitation during the twentieth century in polluted areas in line with increasing emissions during the same period, whereas no trends are observed in similar nearby pristine areas."

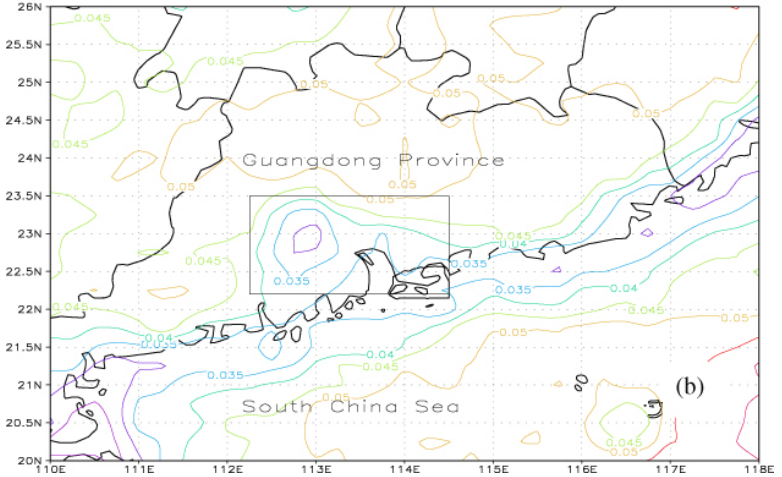
Quantifying Precipitation Suppression Due to Air Pollution
A. Givati and D. Rosenfeld, J. Applied Meteorology 43, 1038-1045, (2004)

MAGEE SCIENTIFIC

Effect on precipitation : South China



Annual precipitation frequency

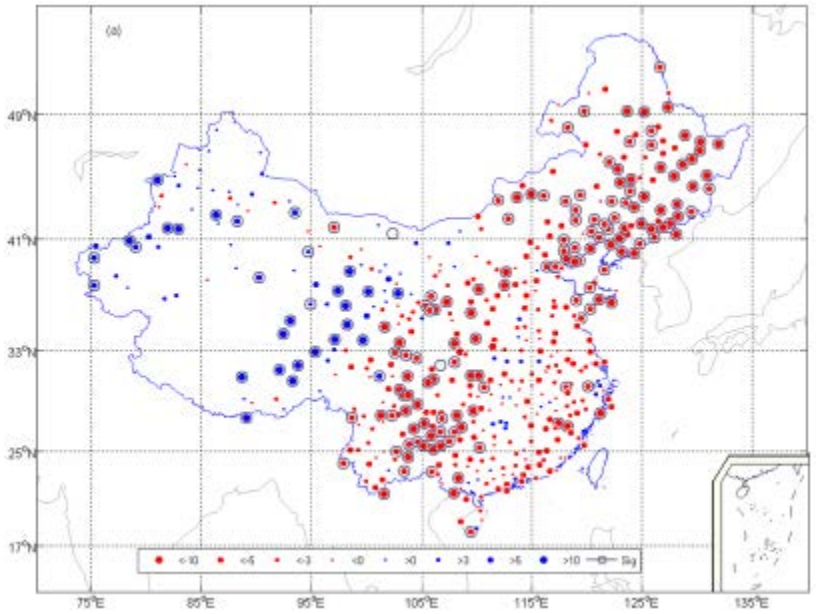


Distribution of weak precipitation

'Urbanization signatures in strong versus weak precipitation over the Pearl River Delta metropolitan regions of China': Weibiao Li et al., Environ. Res. Lett. 6 (2011) 034020

MAGEE SCIENTIFIC

Effect on precipitation in China



" In south-eastern China, …the precipitation days with light rainfall were clearly decreasing in number, while the precipitation days with heavy rain, often inducing floods, have increased in number. "

'Rain-season trends in precipitation and their effect in different climate regions of China during 1961–2008' Yanling Song et al., Environ. Res. Lett. 6 (2011) 034025

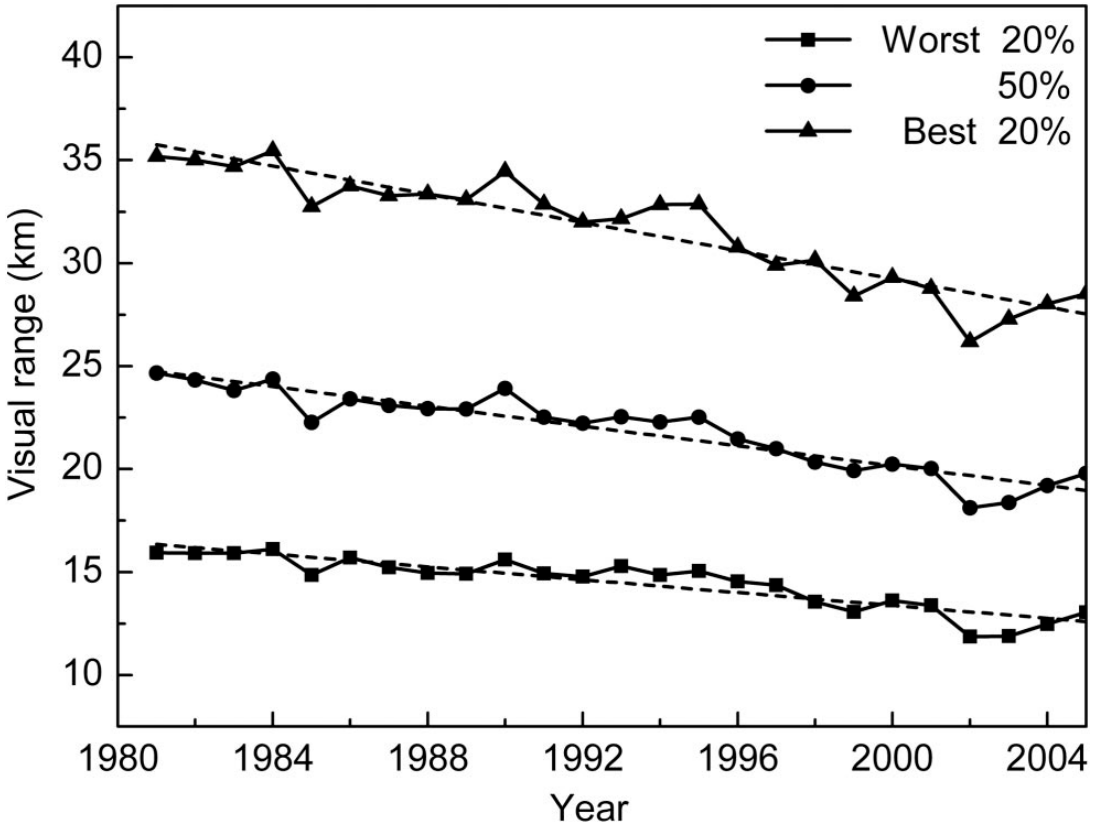
MAGEE SCIENTIFIC

Why are atmospheric aerosols important?

- Public health – disease & death
- Climate change – local, regional and global
- Precipitation – reduction of rainfall
- **Visibility – also, reduction of sunlight for agriculture**
- Damage to cultural heritage (buildings, monuments, art)

MAGEE SCIENTIFIC

Reduction in visibility in South China



'Visual Range Trends in the Yangtze River Delta Region of China, 1981–2005' : Lina Gao et al., JAWMA 61 (2011) p. 843

MAGEE SCIENTIFIC

Optical Analysis of Aerosol Particles

Analytical Methods:

1. **Optical absorption**
2. Optical scattering

Sample Preparation:

1. None – analyze *in-situ* suspension
2. **Collect aerosol particles**
   a. **Filter** – interception on fibers
   b. Impactor – deposition on surface
   c. Impinger – collect into liquid

MAGEE SCIENTIFIC

Underlying Principle – Absorption

Beer's Law : $I = I_0 \, e^{-(k \cdot D)}$

I_0 is incident intensity; I is transmitted intensity

D is total density of material traversed;

k is absorption coefficient.

Measure I and I_0 ; use known value of k ; determine D

→ measure amount of absorbing material

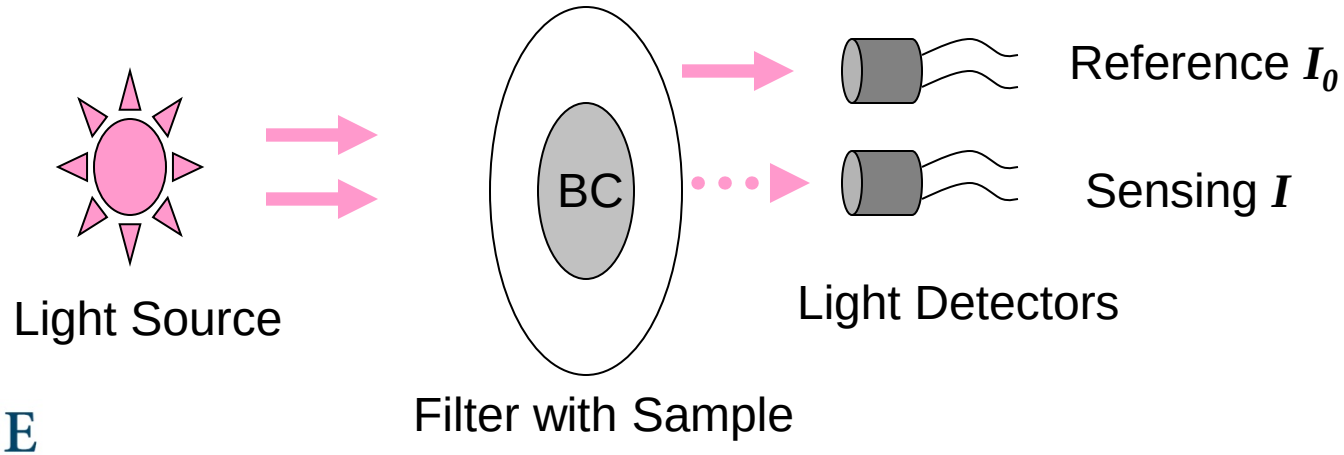
Note ! – *k* is function of wavelength λ ;

***D* may be mixture of materials with varying absorption spectra**

MAGEE SCIENTIFIC

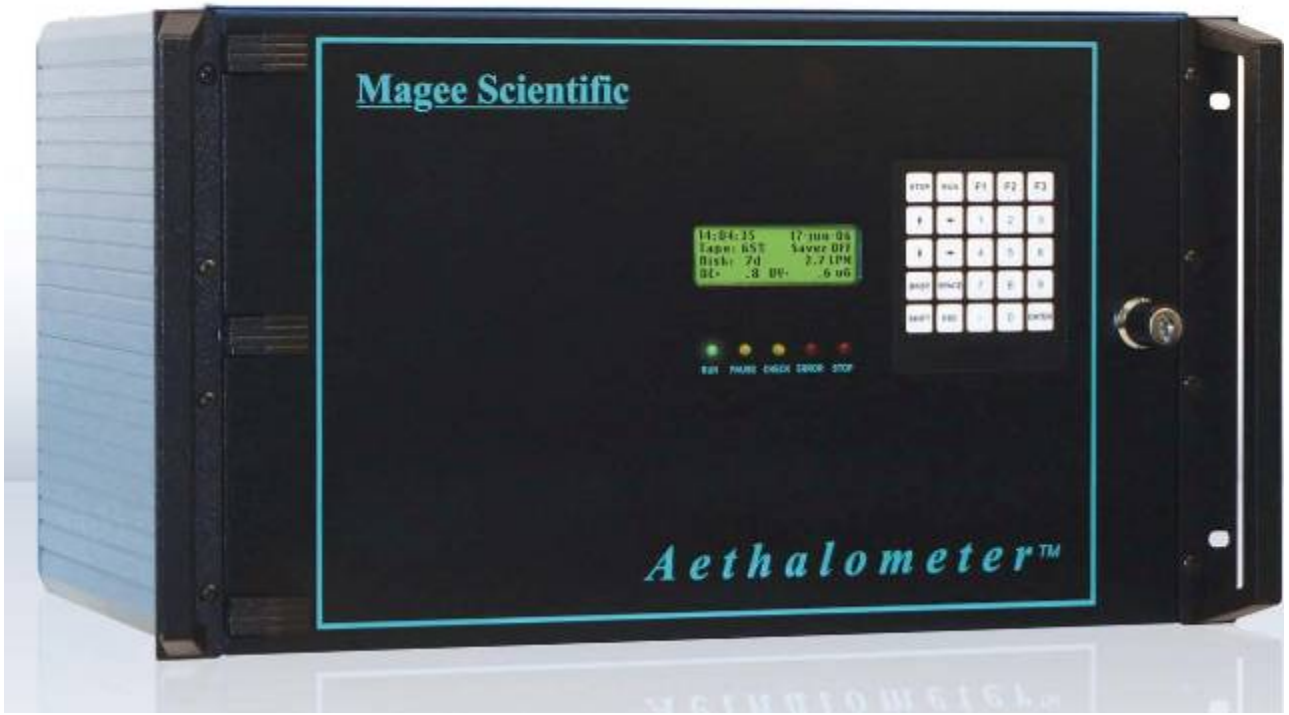
Advantages / Attributes of Optical Analysis

- Instantaneous
- Non-destructive
- Mobile / Portable
- Added dimension - *time*
- Added dimension - *wavelength*



MAGEE SCIENTIFIC

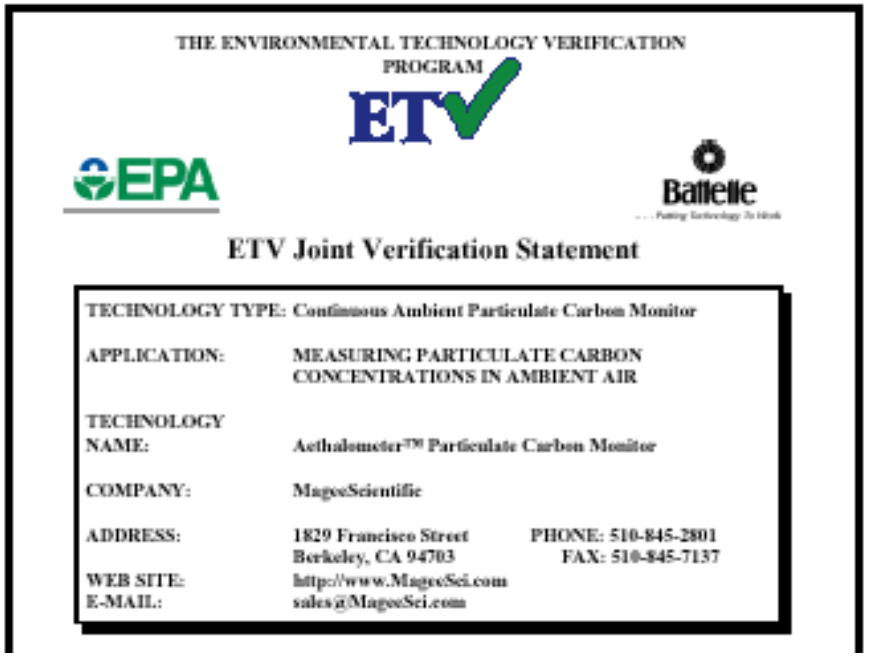
Analytical Instrument : *Aethalometer* ™



19-inch rack mount chassis

MAGEE SCIENTIFIC

Formal approval in USA and China



THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

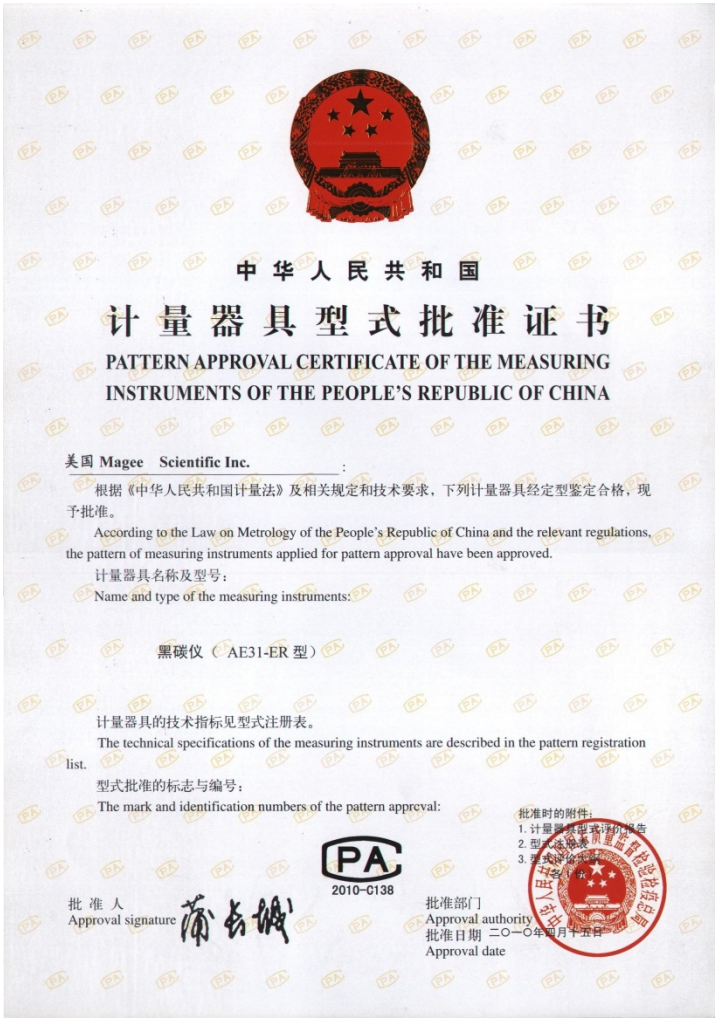
ETV

EPA

Battelle

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Continuous Ambient Particulate Carbon Monitor	
APPLICATION:	MEASURING PARTICULATE CARBON CONCENTRATIONS IN AMBIENT AIR	
TECHNOLOGY NAME:	Aethalometer™ Particulate Carbon Monitor	
COMPANY:	MageeScientific	
ADDRESS:	1829 Francisco Street Berkeley, CA 94703	PHONE: 510-845-2801 FAX: 510-845-7137
WEB SITE:	http://www.MageeSci.com	
E-MAIL:	sales@MageeSci.com	



中华人民共和国

计量器具型式批准证书

PATTERN APPROVAL CERTIFICATE OF THE MEASURING INSTRUMENTS OF THE PEOPLE'S REPUBLIC OF CHINA

美国 Magee Scientific Inc.：

根据《中华人民共和国计量法》及相关规定和技术要求，下列计量器具经定型鉴定合格，现予批准。

According to the Law on Metrology of the People's Republic of China and the relevant regulations, the pattern of measuring instruments applied for pattern approval have been approved.

计量器具名称及型号：

Name and type of the measuring instruments:

黑碳仪（ AE31-ER 型）

计量器具的技术指标见型式注册表。

The technical specifications of the measuring instruments are described in the pattern registration list.

型式批准的标志与编号：

The mark and identification numbers of the pattern approval:

PA 2010-C138

批准时的附件：

批 准 人
Approval signature

批准部门
Approval authority

批准日期 二〇一〇年四月十五日
Approval date

MAGEE SCIENTIFIC

New model : constant R&D required

MAGEE SCIENTIFIC

Typical air-quality monitoring stations

- Measurements at single fixed point
- Analyze temporal patterns to determine source contributions
- **Different** locations can have **different** temporal patterns

London

Germany

China

MAGEE SCIENTIFIC

Tibet : 5200 m. ASL

Picture courtesy of J. J. Cao, Xi'an, China

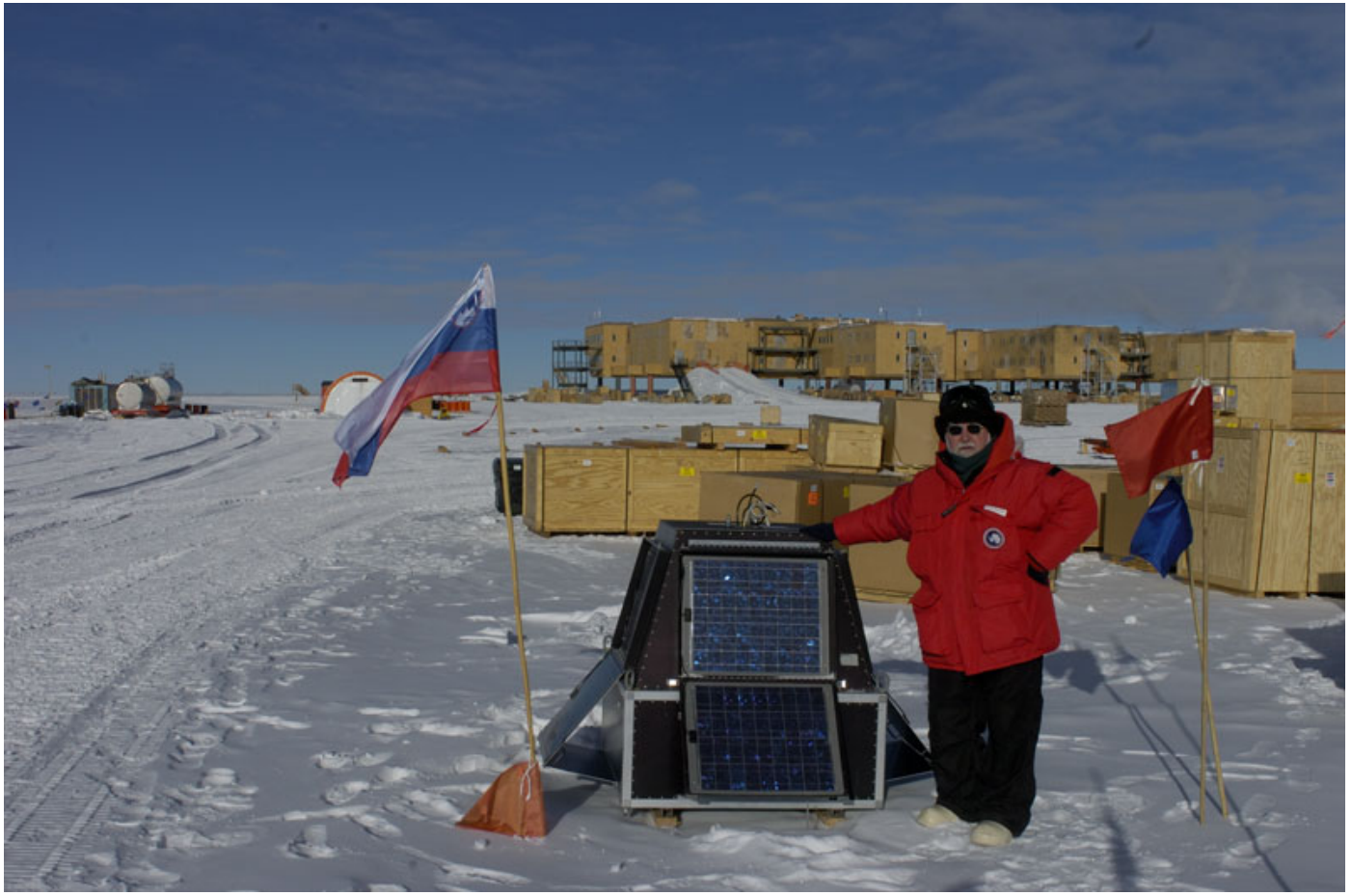
MAGEE SCIENTIFIC

Mojave Desert, California : +45°C

Picture courtesy of E. Winegar, California

MAGEE SCIENTIFIC

South Pole, Antarctica : -55°C



MAGEE SCIENTIFIC

Measurement of **Vertical Distribution** of BC

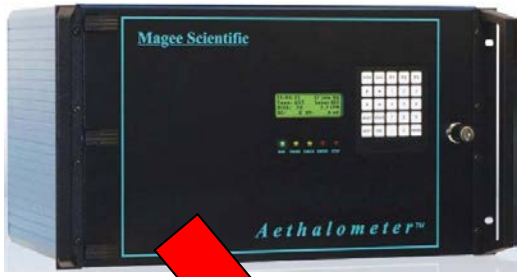
- BC emission factors can be **very different** (factor **10^6**) **:** emissions depend on **quality of combustion**
- BC not directly related to CO_2 emission
- Climate forcing depends on **both CO_2 and BC ….** and the **Vertical Profile** is critically important
- Local BC concentrations that affect public health can be **highly variable** **….** and the **Local Variations** are critically important

- BC emissions can not be predicted: must be measured
- Studies of **Climate Forcing** require **more data in all dimensions** -

BC (x, y, Z, t)

MAGEE SCIENTIFIC

"Micro" Aethalometer : same principle



.. but smaller size

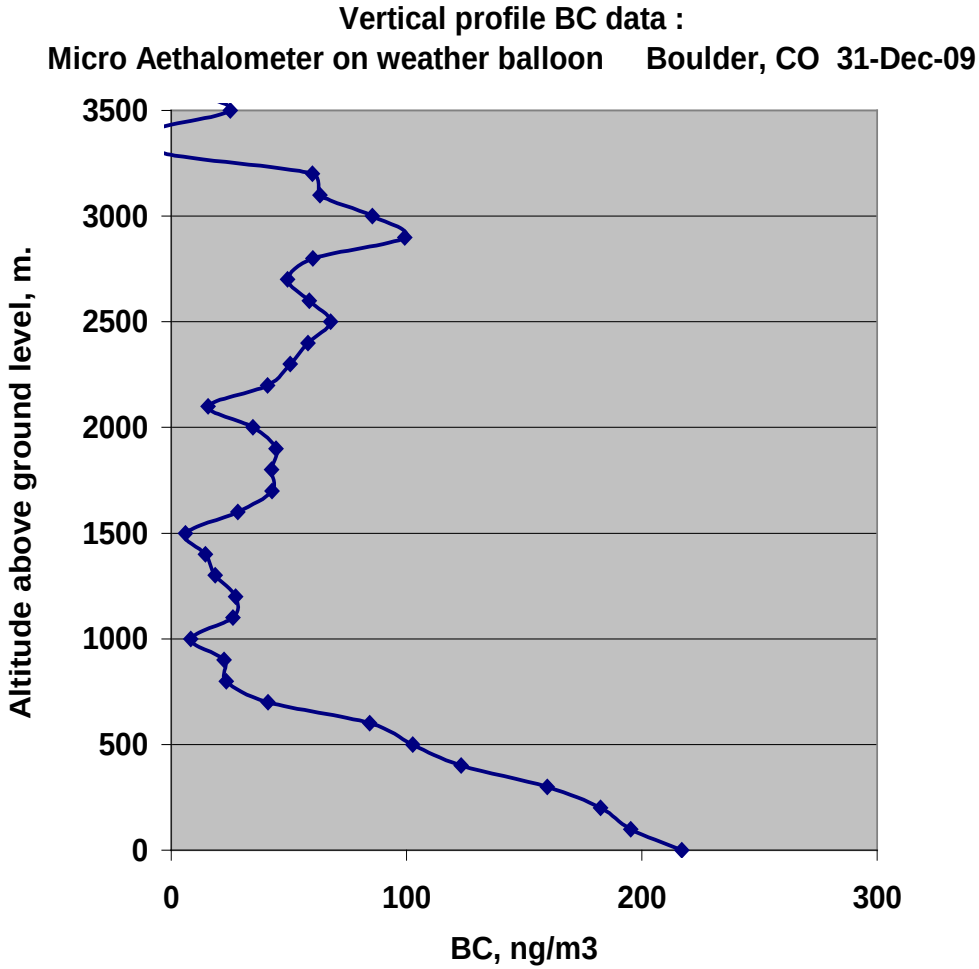
Weighs 250 g.

MAGEE SCIENTIFIC

Vertical Profiling Measurements - $

Weather Balloon

Courtesy of R. C. Schnell, NOAA/GMD, Boulder, CO, USA

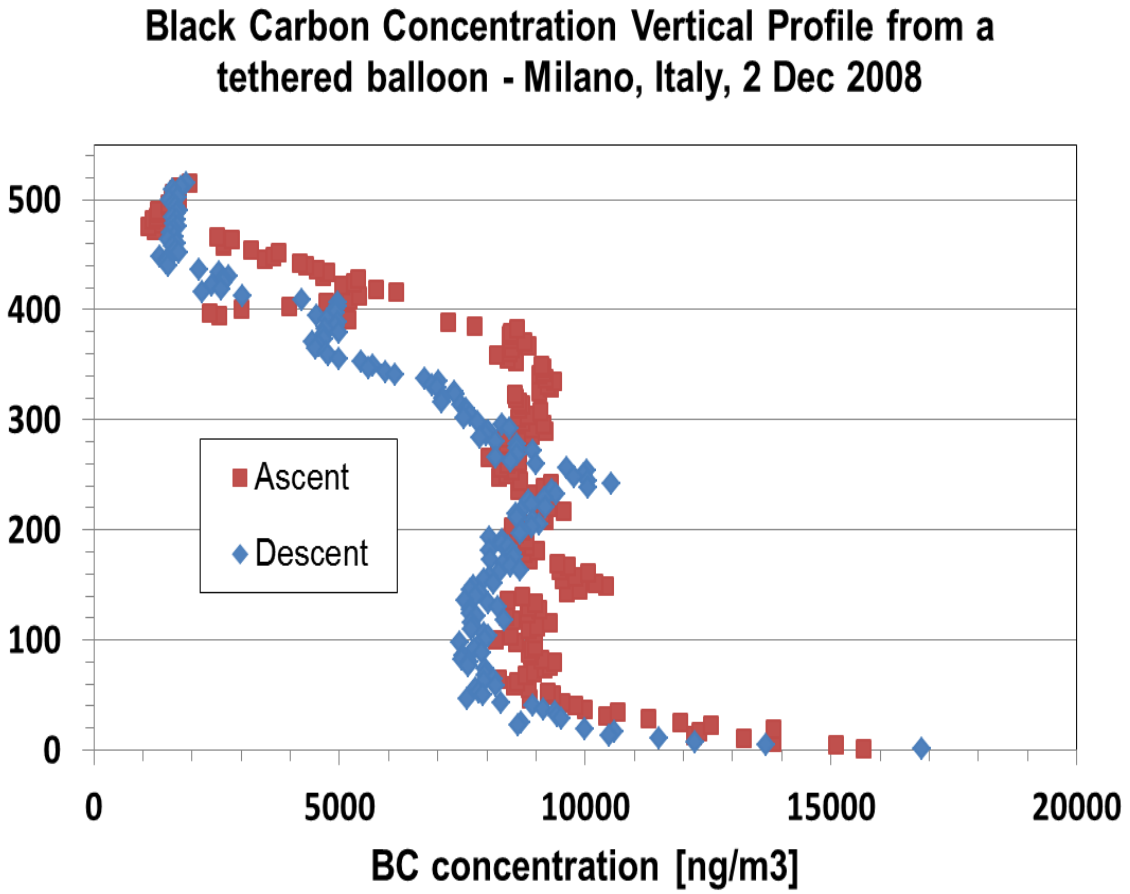


MAGEE SCIENTIFIC

Vertical Profiling Measurements - $$

Tethered Balloon

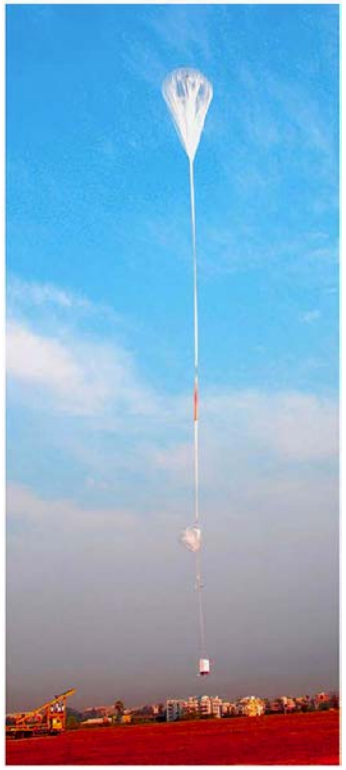
L. Ferrero, G. Močnik et al., Sci. Total Environ. 409, 2824 (2011)

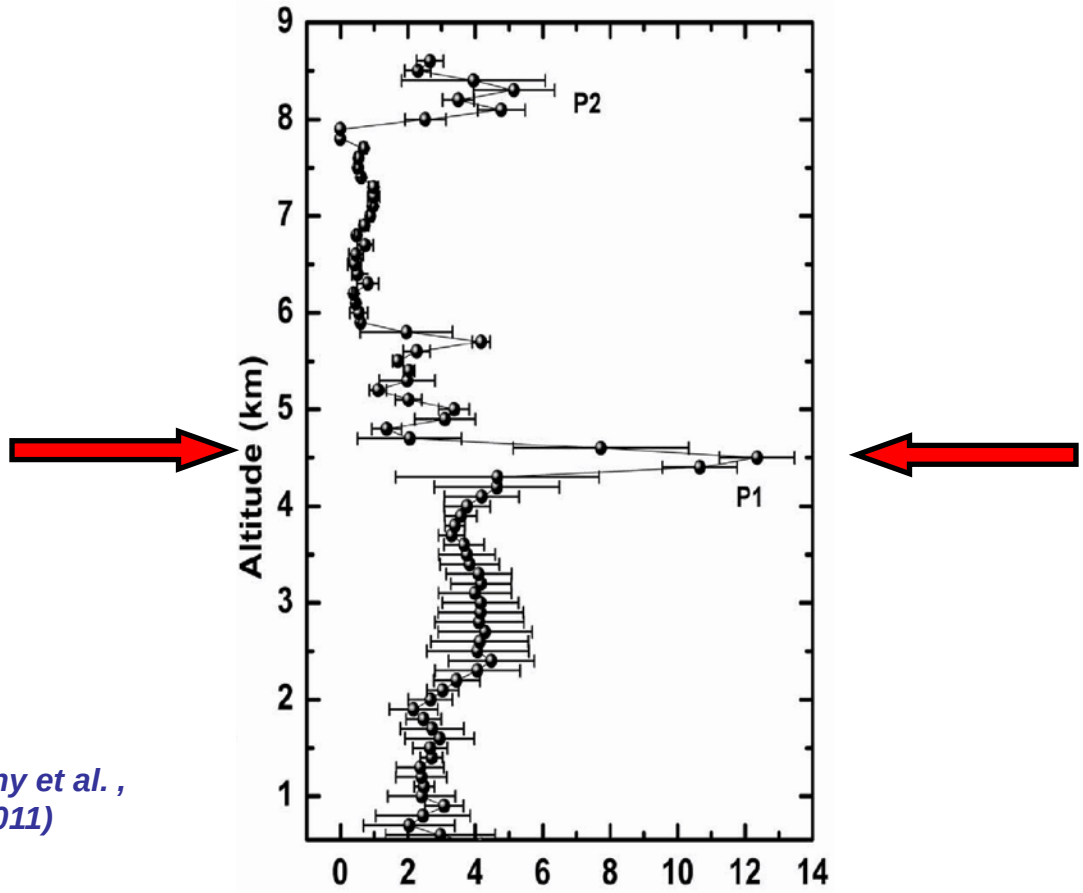


MAGEE SCIENTIFIC

Vertical Profiling Measurements - $$$

Heavy-Lift High-Altitude Balloon





S. Suresh Babu, K. Krishnamoorthy et al. , Geophys. Res. Lett. 38, L08803 (2011)

MAGEE SCIENTIFIC

Where does this high-altitude BC go to ...?

Picture courtesy of J. J. Cao, Xi'an, China

MAGEE SCIENTIFIC

… to Tibet, where glaciers are melting ?

Picture courtesy of J. J. Cao, Xi'an, China

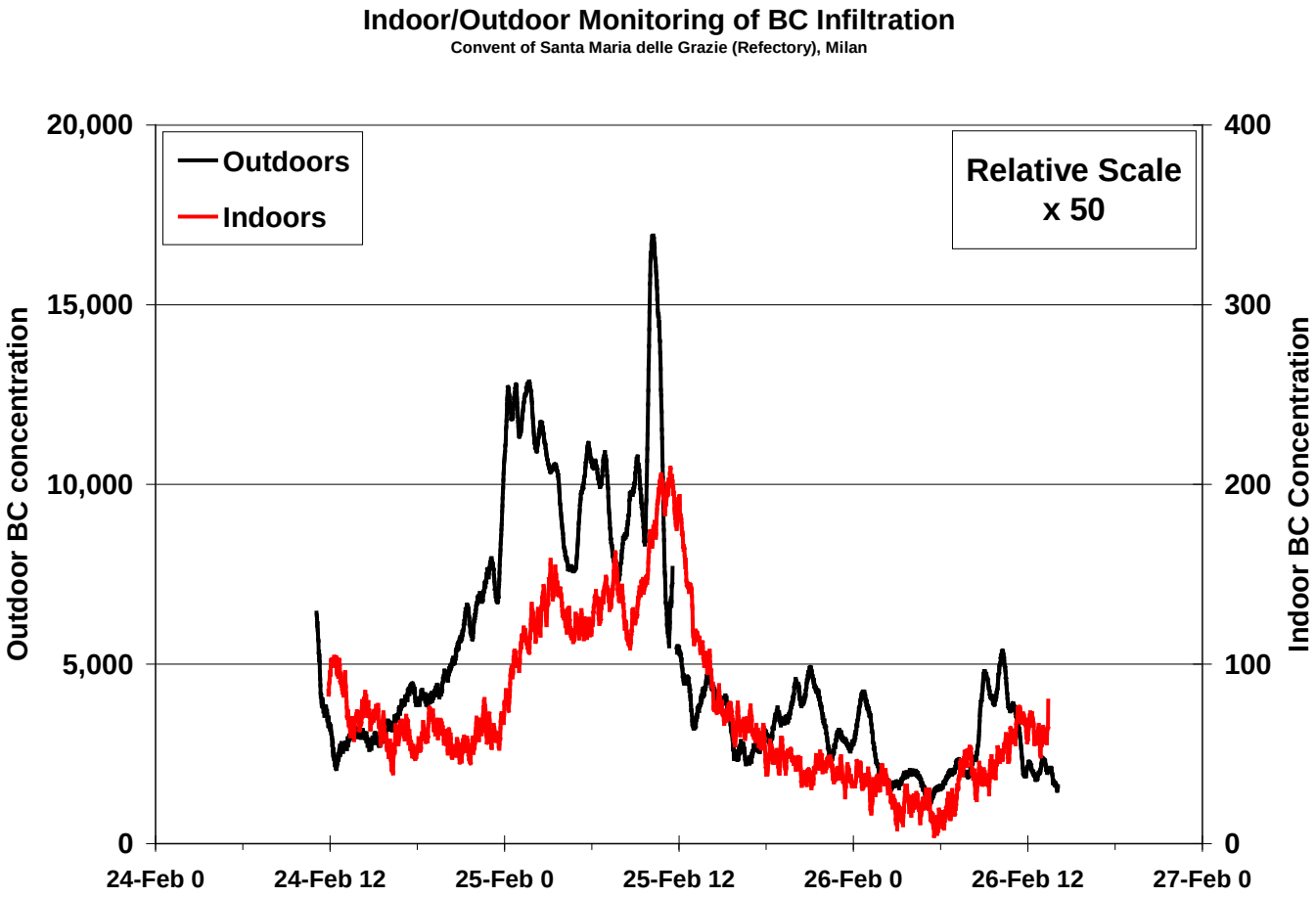
MAGEE SCIENTIFIC

Why are atmospheric aerosols important?

- Public health – disease & death
- Climate change – local, regional and global
- Precipitation – reduction of rainfall
- Visibility – also, reduction of sunlight for agriculture
- **Damage to cultural heritage (buildings and art)**

Pollution monitoring at the ‘Last Supper’

Griša Močnik



Data courtesy of Dane Westerdahl, Cornell University

MAGEE SCIENTIFIC

I didn’t talk about laser weapons …

- … ask me afterwards

Advantages / Attributes of Optical Analysis

- Instantaneous → ***real-time data***
- Non-destructive
- Mobile / Portable / Personal
- Added dimension - ***wavelength***

MAGEE SCIENTIFIC

Spectral analysis

From Black&White to Color

MAGEE SCIENTIFIC

Europe : Renewable fuels : wood

- Wood/biomass is a '**sustainable fuel'** (from CO_2 perspective)
- Burning biomass is a **major energy source in rural areas**
- Quality of combustion varies greatly : high-efficiency central heating *vs.* individual wood-stoves

MAGEE SCIENTIFIC

Spectral Absorption Analysis

- Most Aethalometer models offer analysis at **7 wavelengths**:

  370, 470, 520, 590, 660, 880 and 950 nm

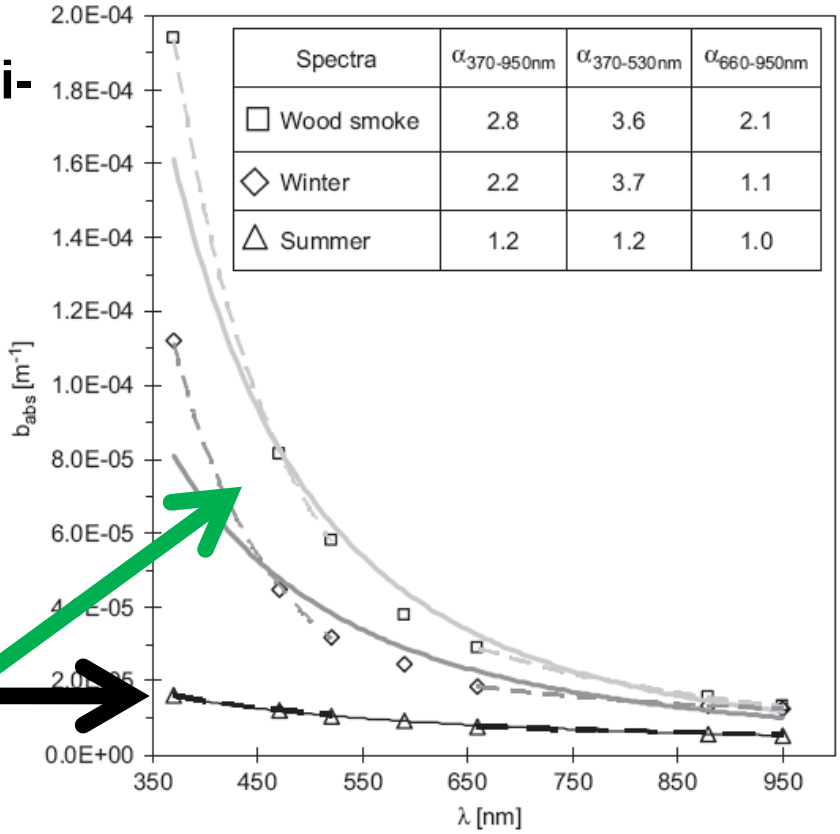
- "Black" materials absorb uniformly across the spectrum: the 880 nm analysis is quantitative for 'Black Carbon'.

- Other species – aromatic organic compounds – sometimes called **"Brown Carbon"** - can show increased absorption at shorter wavelengths.

MAGEE SCIENTIFIC

Biomass vs. diesel smoke – wavelength dependence

- **measure absorption b_{abs} with multi-wavelength Aethalometer**
- **for pure black carbon: $b_{abs} \sim 1/\lambda$**
- **general Angstrom exponent: $b_{abs} \sim 1/\lambda^{\alpha}$**



diesel: $\alpha \approx 1$

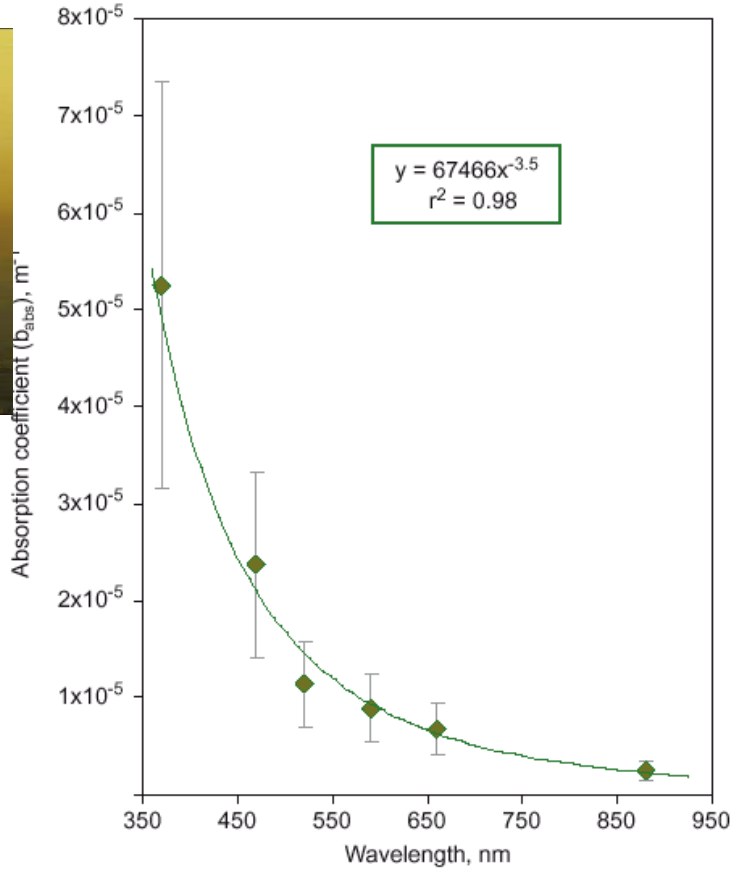
biomass: $\alpha \approx 2$ and higher

J. Sandradewi et al., A study of wood burning and traffic aerosols in an Alpine valley using a multi-wavelength Aethalometer, Atmospheric Environment (2008) 101–112

MAGEE SCIENTIFIC

Absorption spectrum of biomass smoke - Europe

Haze of biomass smoke over Paris



'Ambient measurements of light absorption by agricultural waste burning organic aerosols'

O. Favez, S. C. Alfaro, et al.,
J. Aerosol Science 40, 613 (2009)

MAGEE SCIENTIFIC

Attributes of Optical Analysis

- Instantaneous → ***real-time data***
- Added dimension – ***time & day***

  may permit identification of sources by examining temporal patterns.
- Added dimension – ***wavelength***

  may permit identification of smoke from **biomass** and **coal** combustion.
- It's ***Physics***

MAGEE SCIENTIFIC

Summary : Applications

- **Black Carbon has serious effects on Health and Climate**
- **BC is highly variable and must be measured**
- **It may be possible to identify different sources of BC**

$$BC\ (x, y, z, t, \lambda)$$

MAGEE SCIENTIFIC

Good Policy must be based on Good Data

Good science <u>can</u> make a difference

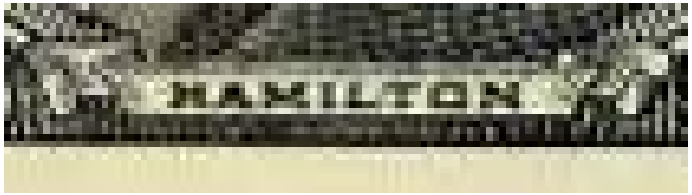
MAGEE SCIENTIFIC

Aethalometer™ development

- 1977 : optical absorption method developed
- 1979 : Aethalometer concept developed; research prototype
- 1980 : first field test, first publication
- 80's : measurements at remote locations
- 1986 : **start business in garden shed**
- 90's : recognition of public health importance
- 00's : recognition of climate change forcing
- **2001** : US EPA "ETV" approval
- 2007 : incorporate; **move out of shed**; open mfg. subsidiary in Europe
- **2010** : China – official "Pattern Approval"
- 2011: U.S. Report to Congress on Black Carbon
- 2012: major publication (***JGR***): BC =~ 60% of CO_2 climate forcing
- 2012: business doubles
- 2013 : more than **1500** instruments worldwide.

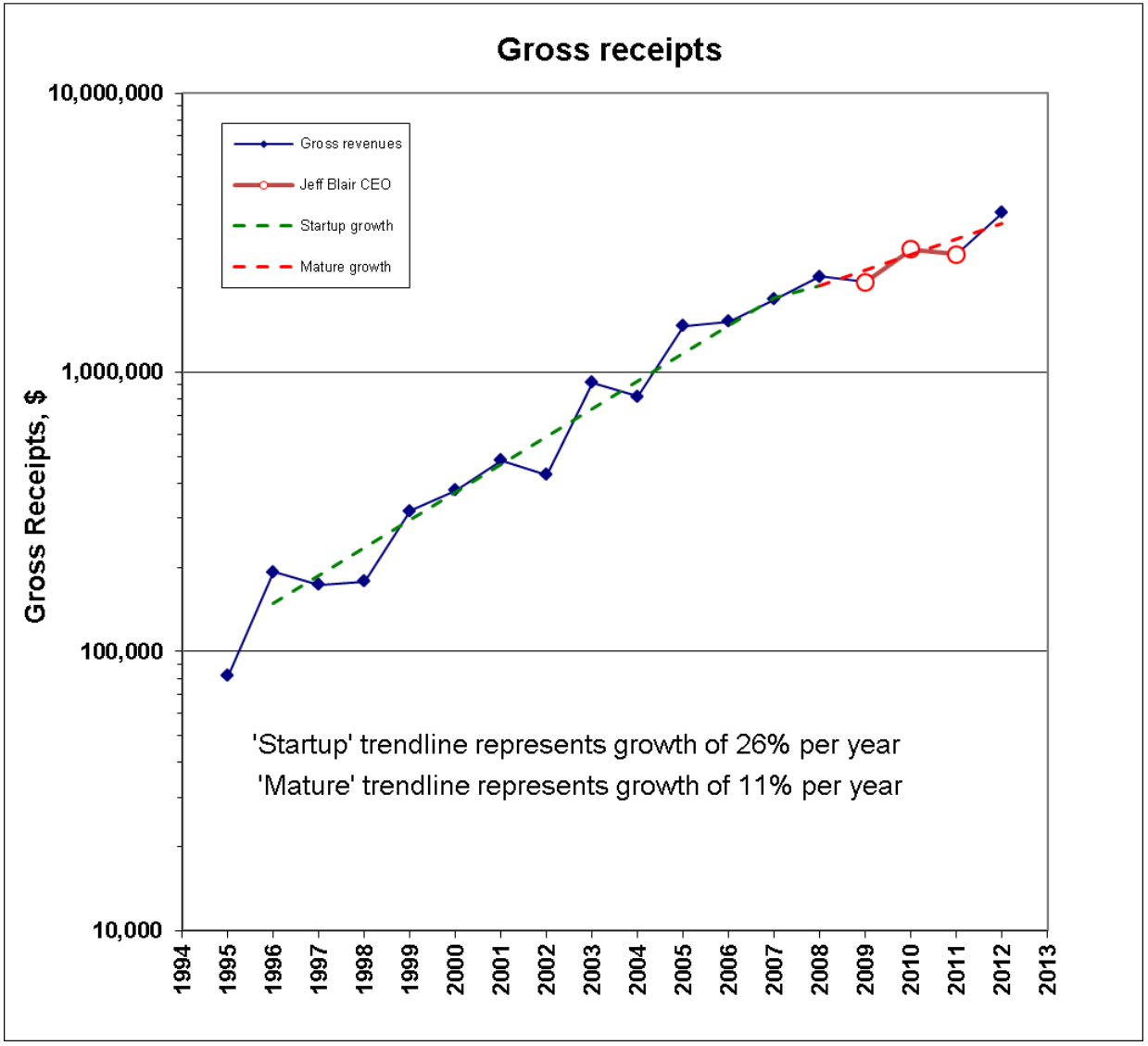
MAGEE SCIENTIFIC

Business: The Hamiltonian re-defined



MAGEE SCIENTIFIC

Business growth



MAGEE SCIENTIFIC

Science can take you on an adventure

- **CFC's can reach Antarctica … hence the 'Ozone Hole'**
- **What about Black Carbon?**
- **"How can you know until you go there and get data ?**

MAGEE SCIENTIFIC

It’s a Very Long Flight to New Zealand

MAGEE SCIENTIFIC

It’s a Long Flight from NZ to Antarctica

MAGEE SCIENTIFIC

No Frills: “Self-Unloading Cargo”

MAGEE SCIENTIFIC

Welcome to *The Ice*

MAGEE SCIENTIFIC

Overnight transit through McMurdo

MAGEE SCIENTIFIC

Connecting flight to Pole

MAGEE SCIENTIFIC

The End of the Earth … "**Destination Zulu**"

90°S ; - 40°C ; 9500 - 11400 feet altitude

MAGEE SCIENTIFIC

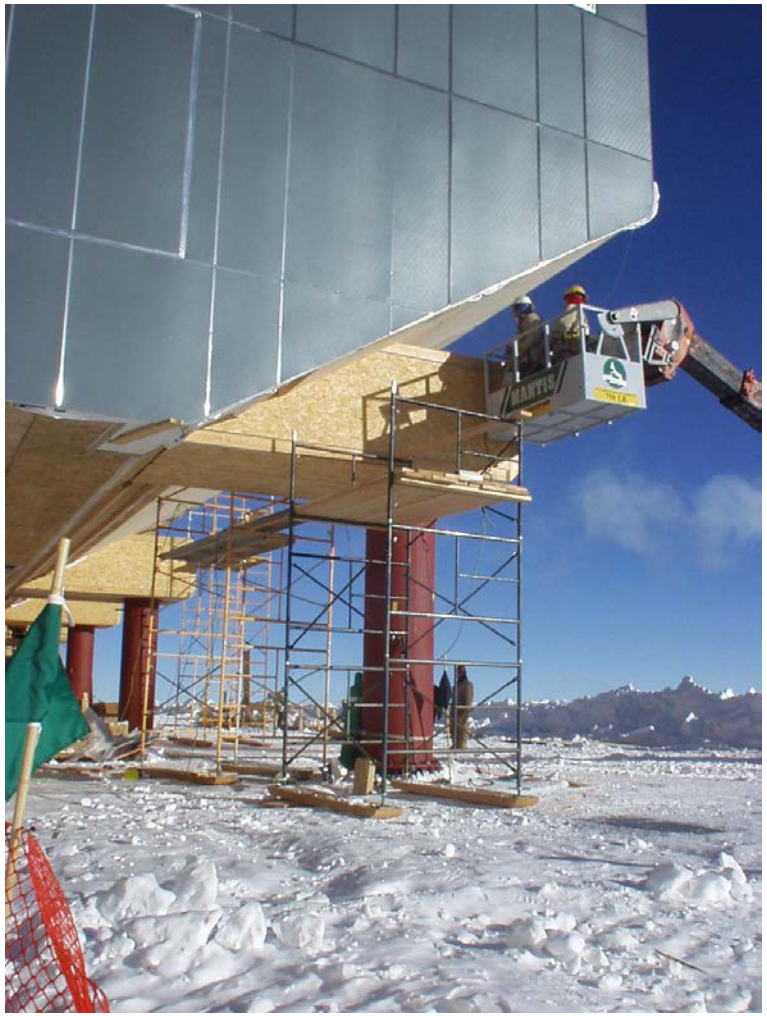
The old station was buried under snow

1996

MAGEE SCIENTIFIC

A new station had to be built

2006



MAGEE SCIENTIFIC

Installing 1-inch plywood at - 40°

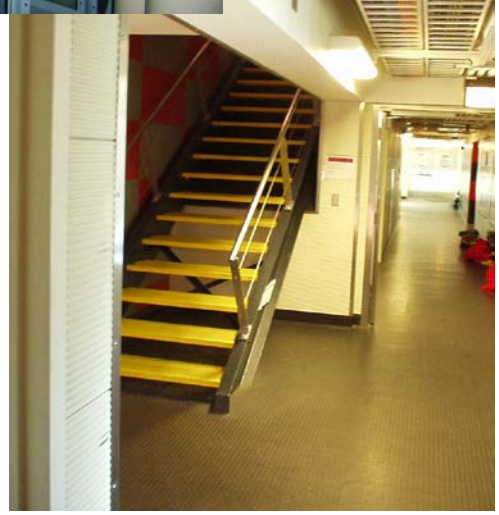
2006

MAGEE SCIENTIFIC

The finished station is VERY impressive

MAGEE SCIENTIFIC

Inside, it's *fabulous*

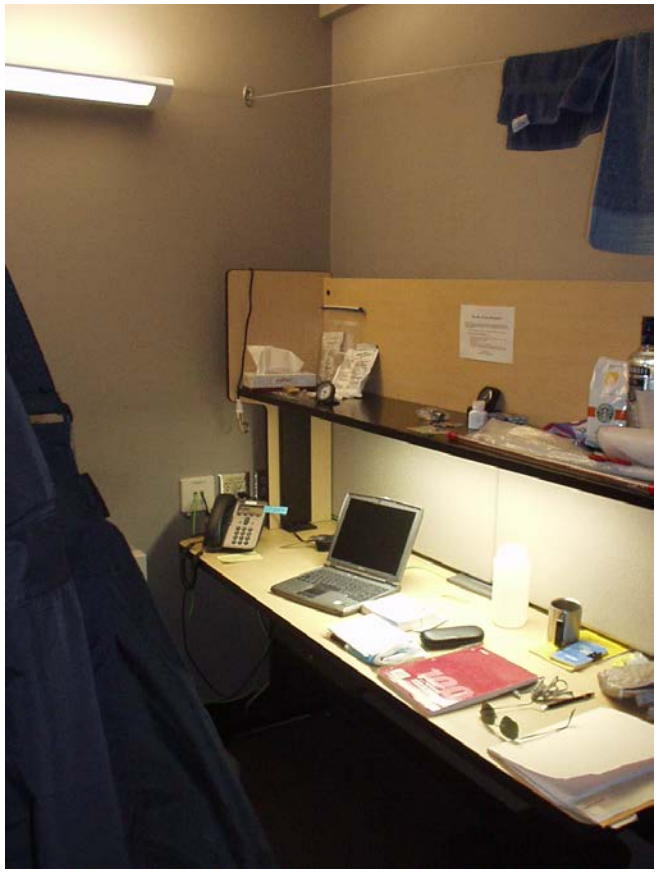


MAGEE SCIENTIFIC

Excellent food ..

MAGEE SCIENTIFIC

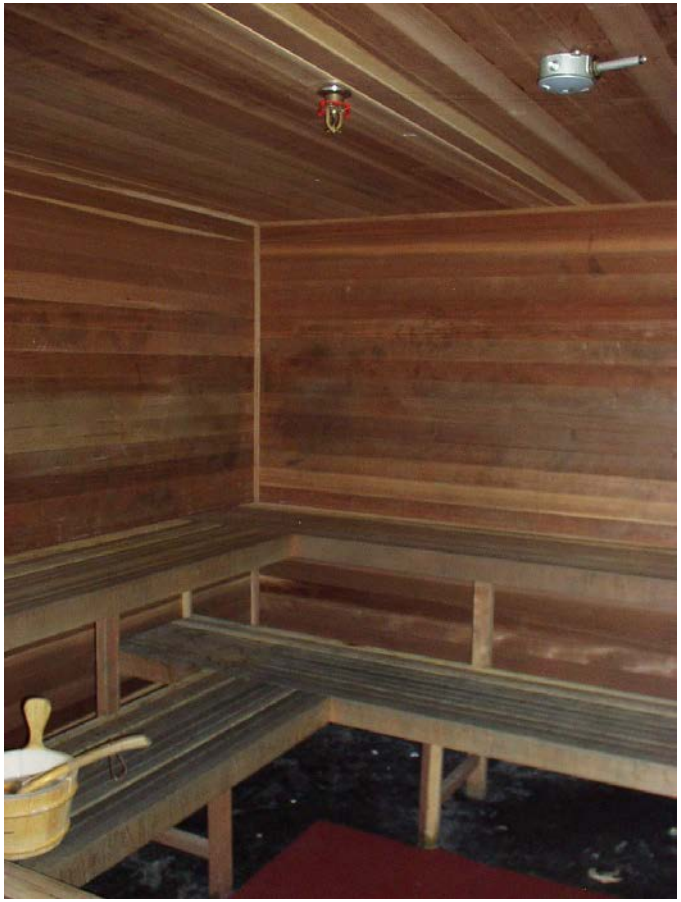
A comfortable room



with Ethernet and VoIP phone ! (when the satellite is up)

MAGEE SCIENTIFIC

An unadvertised door …… a sauna



MAGEE SCIENTIFIC

Outside, however, it's still - 40°

Ice, more **Ice**, Madness, Hypothermia, even more **Ice**

Attacked by imaginary birds

Spool-henge: a megalithic relic

MAGEE SCIENTIFIC

It’s a thousand miles to the coast ..

MAGEE SCIENTIFIC

Next fuel: 1000 miles

MAGEE SCIENTIFIC

Next accommodation: 1000 miles

MAGEE SCIENTIFIC

Next toilets: 1000 miles

MAGEE SCIENTIFIC

Next armchairs: 1000 miles

MAGEE SCIENTIFIC

Entrance to the Lost City of Cryopolis ?

MAGEE SCIENTIFIC

Stop daydreaming, get back to work !
Designated project location … right *there*

2006

If the equipment has to go into an ice pit

2006

MAGEE SCIENTIFIC

Then **we** will have to **dig** the pit

2006

MAGEE SCIENTIFIC

Where are all the young guys ??

2006

MAGEE SCIENTIFIC

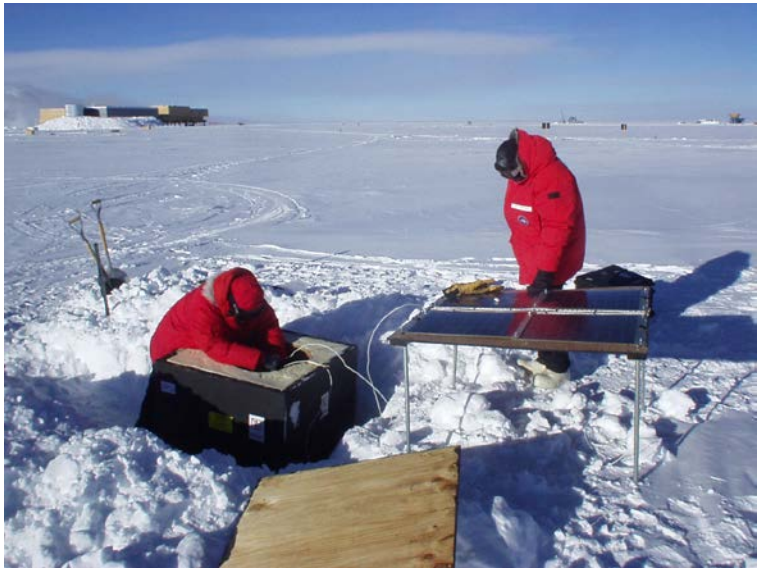
Installation using the ‘Armstrong Method’

2006

MAGEE SCIENTIFIC

Attach the cables, close the lid

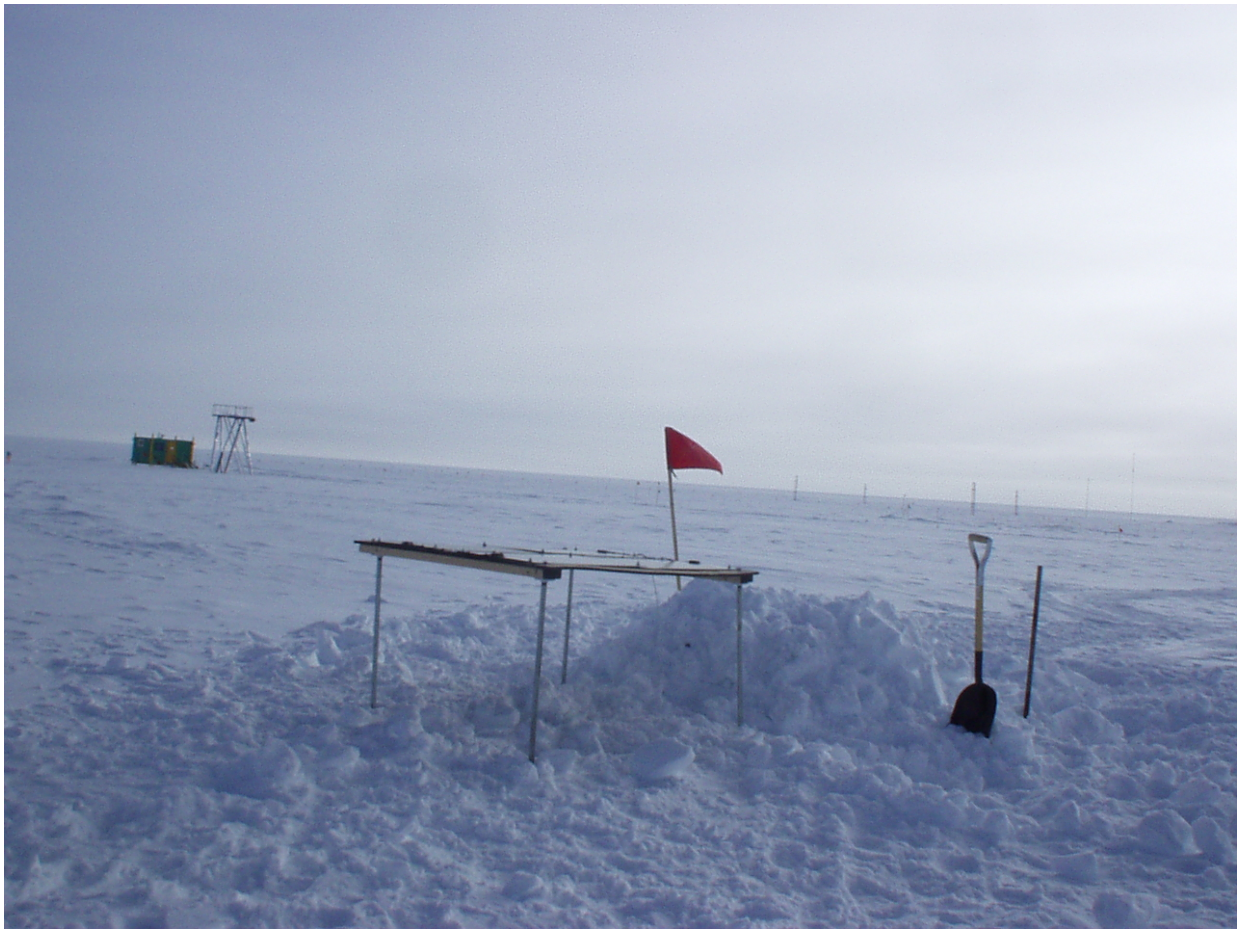
2006



MAGEE SCIENTIFIC

Cover with snow, wait 1 year

2006



MAGEE SCIENTIFIC

All adventures come to an end ..

MAGEE SCIENTIFIC

Take those last pictures

MAGEE SCIENTIFIC

Pack bags, walk out to the flight line

MAGEE SCIENTIFIC

Wait (at -40°) until they let us board

Back to sea level .. back to the World .. back

But after *The Ice* gets into you

1996

.. you're never the same ..

2003

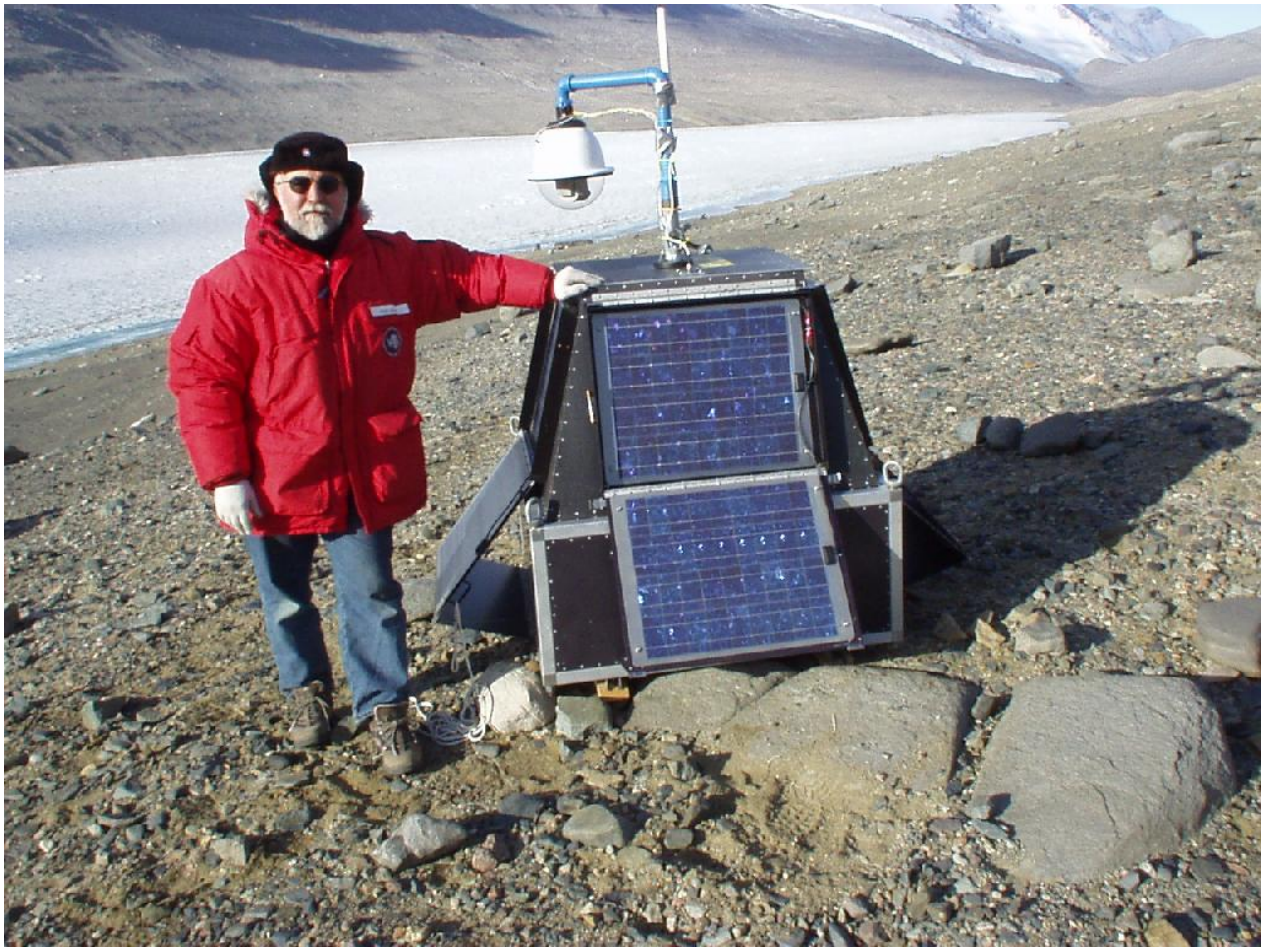
MAGEE SCIENTIFIC

It affects everyone ..

MAGEE SCIENTIFIC

The things you made with your own hands …

2004



MAGEE SCIENTIFIC

.. can take you to places you can't imagine.

2006

MAGEE SCIENTIFIC

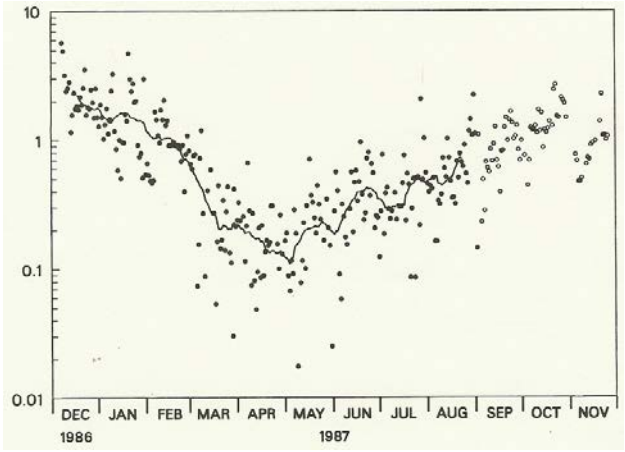
.. and the planet will spin beneath your feet.

2013

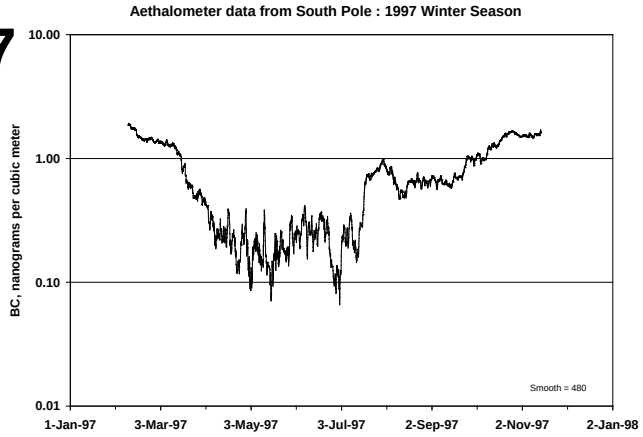
MAGEE SCIENTIFIC

Scientific result : BC annual cycle at Pole

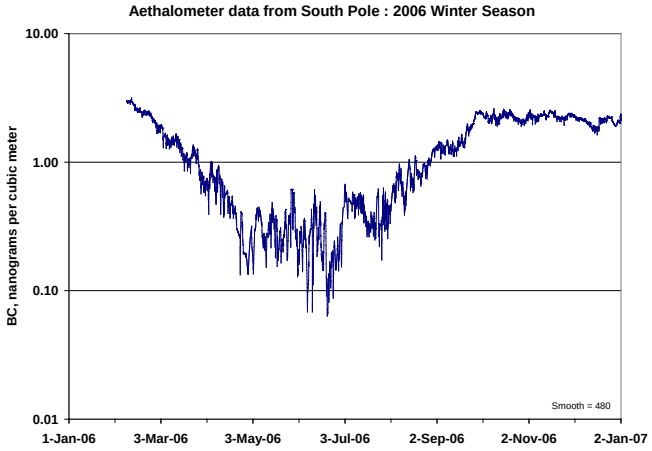
1987



1997



2006



2013 ?

MAGEE SCIENTIFIC

1972 What did this young man ….

MAGEE SCIENTIFIC

1264 … learn …

MAGEE SCIENTIFIC

2013 … and take to the end of the earth ?

MAGEE SCIENTIFIC

2013

MAGEE SCIENTIFIC

What did it require?

MAGEE SCIENTIFIC

Thank you for your attention,

MAGEE SCIENTIFIC

If you have any questions ….

MAGEE SCIENTIFIC

… the answers will come in 22 seconds.

MAGEE SCIENTIFIC

End of presentation

For further information, please write to me:

Tony.Hansen @ MageeScientific.com

MAGEE SCIENTIFIC