Aerosols at Mauna Loa Observatory – spring, 2011, versus spring, 2001

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Take-home messages: (I'll send this if you access my e-mail)

1. Aerosols are a major factor in GCM uncertainties
2. Continuing growth in Chinese (and Indian) energy use threatens increases in optically efficient aerosols, especially sulfates, soot, and possibly organics.
3. Our attempt to document these trends derived from 6 week spring sampling programs, 2001 versus 2011, was disappointing because of the highly variable short duration transport phenomena.
4. To see trends of climatically-efficient aerosols at MLO, we must use continuous multi-year measurements, including particle size and composition.
5. We now have cost efficient techniques developed doing at Greenland, 2003 - 2013.
    1. Measure aerosols in 8 size mode, 12 hr time resolution,
    2. Measure mass soft beta ray analysis
    3. 32 elements by synchrotron-induced XRF, to picogram/m^3 detection limits
    4. optical spectrometry 350 nm to 720 nm, every 50 nm (soot), and
    5. (proposed) organic surrogates (IMPROVE protocol)

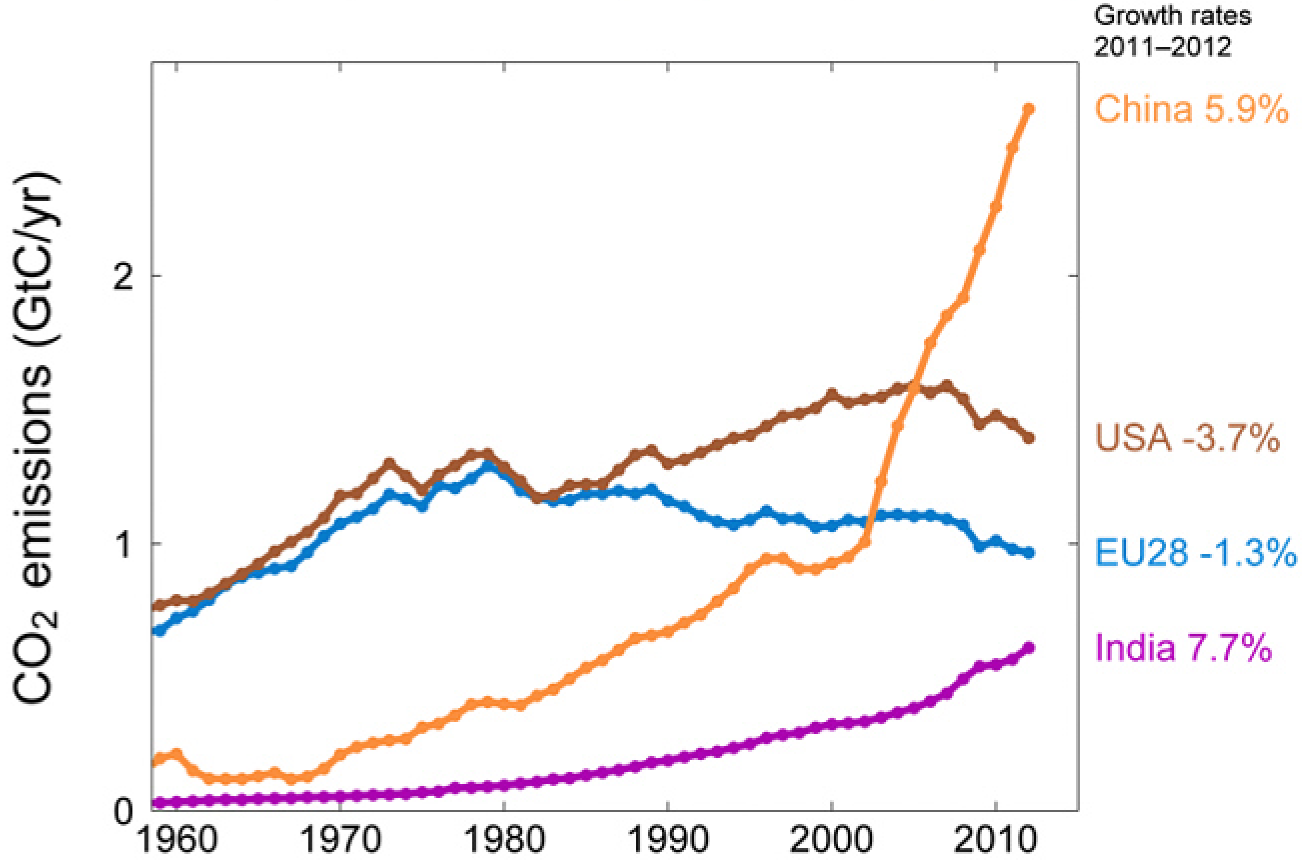
UC Davis and Asian aerosols at MLO

- 1980 6 weeks northern China
    - Mingxing, Winchester, Cahill, and Lixin, *Kexue Tongbao Science Bulletin*. Pp. 51-54 (1981).
  - First size and compositionally resolved dust near Beijing, 4/19/1980
- 1983 9 months, MLO, – 3.5 - 1.0, 1.0 – 0.5, 0.5 – 0.0 µm
    - Braaten and Cahill, Atm., Environment 20:1105-1109 (1986).
  - Finding: Asian dust in spring, size ~ 1 µm diameter
  - Elemental ratio of soil same as Beijing, not local Hawaiian soils
- 1989 – 1999 IMPROVE at MLO, $PM_{2.5}$ 24 hr samples twice a week
  - May 6 – May 23, 1996 3 DRUM 10 to 1.15, 1.15 to 0.34, 0.34 to ~ 0.15 µm
    - Perry, Cahill, Schnell and Harris JGR 104 15 18521 – 818533 (1999)
    - Spring enhancement of soils and industrial pollutants (summarized in this talk)
    - Seen across the US - VanCuren and Cahill JGR 107, D24, 1804 (2002)
- 2001 – March 13 – April 26, **the enormous study ACE Asia**, aircraft, satellites, and UC Davis ground level aerosol measurements, all with 3 hr data, 8 with 8 size, modes 10 to 0.09 µm, including MLO, and 10 with 3 size modes.
    - Seinfeld et al *Bulletin Amer. Meteor. Society*, 85:367-380 (2004)
  - Findings: Comparison to Asian sources,
  - Transport via Taiwan (this talk)
- 2011 - 6 weeks spring and fall, DELTA Group 8 DRUMs, 8 size modes, 10 to 0.09 µm, 3 hr data
  - Findings: Asian trends ???
  - Very fine silicon from power plants (this talk);

GLOBAL CARBON PROJECT

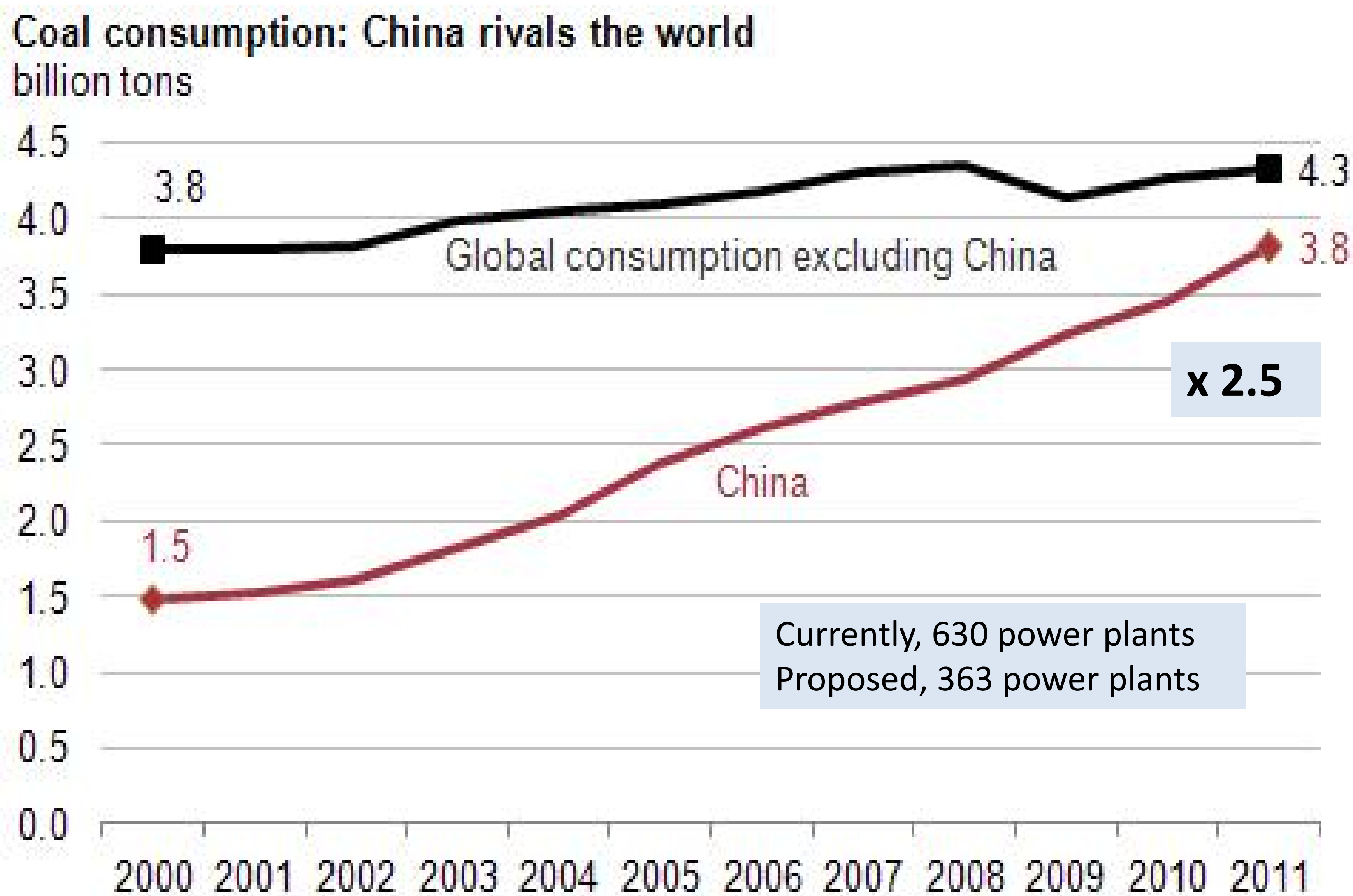
Top Fossil Fuel Emitters (Absolute)

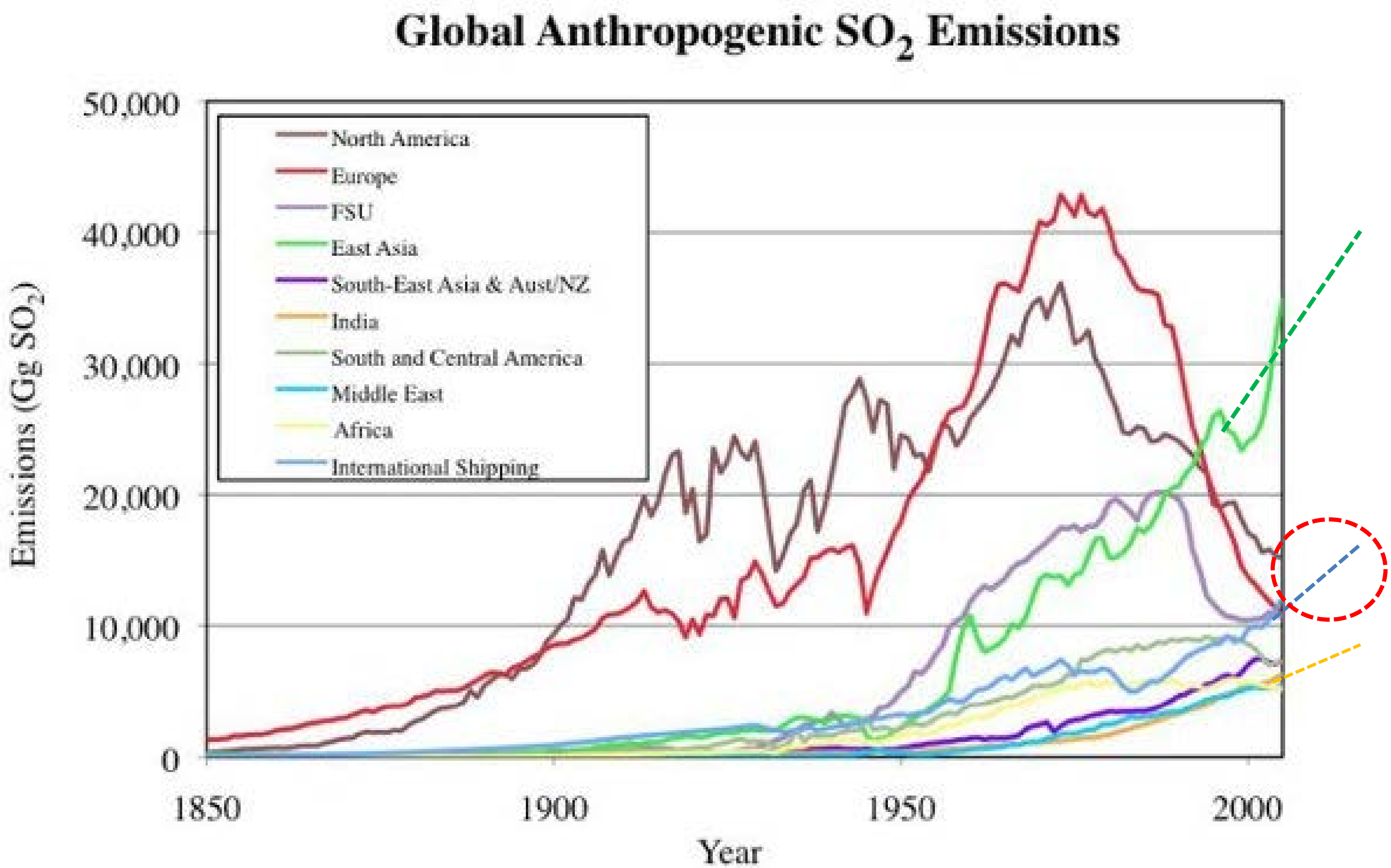
Top four emitters in 2012 covered 58% of global emissions
China (27%), United States (14%), EU28 (10%), India (6%)



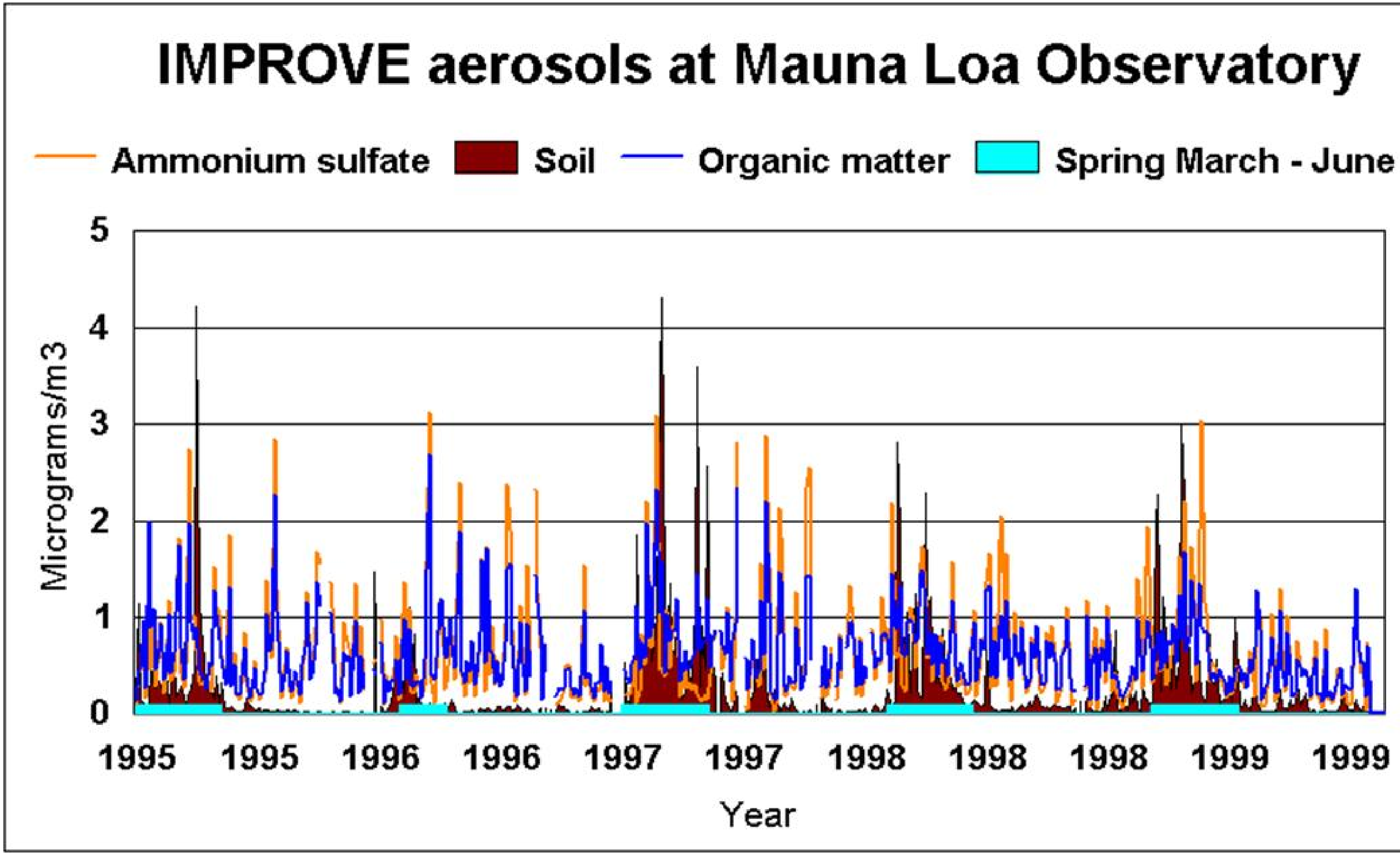
With leap year adjustment in 2012 growth rates are: China 5.6%, USA -4.0%, EU -1.6%, India 7.4%.

Source: CDIAC Data; Le Quéré et al 2013; Global Carbon Project 2013

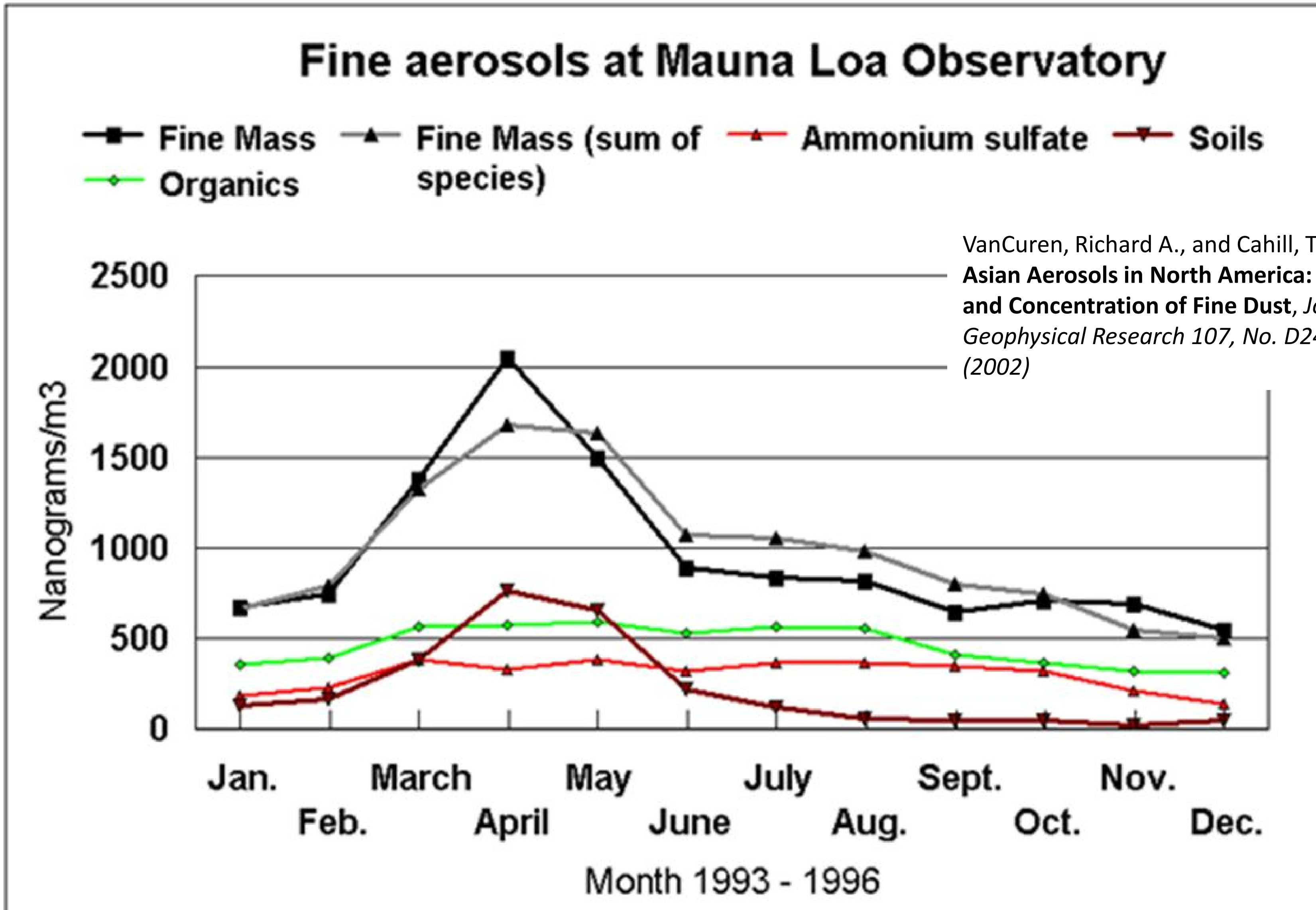

Coal consumption: China rivals the world
billion tons
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3.8
4.3
Global consumption excluding China
3.8
x 2.5
China
1.5
Currently, 630 power plants
Proposed, 363 power plants
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011



Global Anthropogenic SO2 Emissions
50,000
40,000
30,000
20,000
10,000
0
Emissions (Gg SO2)
1850
1900
1950
2000
Year
North America
Europe
FSU
East Asia
South-East Asia & Aust/NZ
India
South and Central America
Middle East
Africa
International Shipping

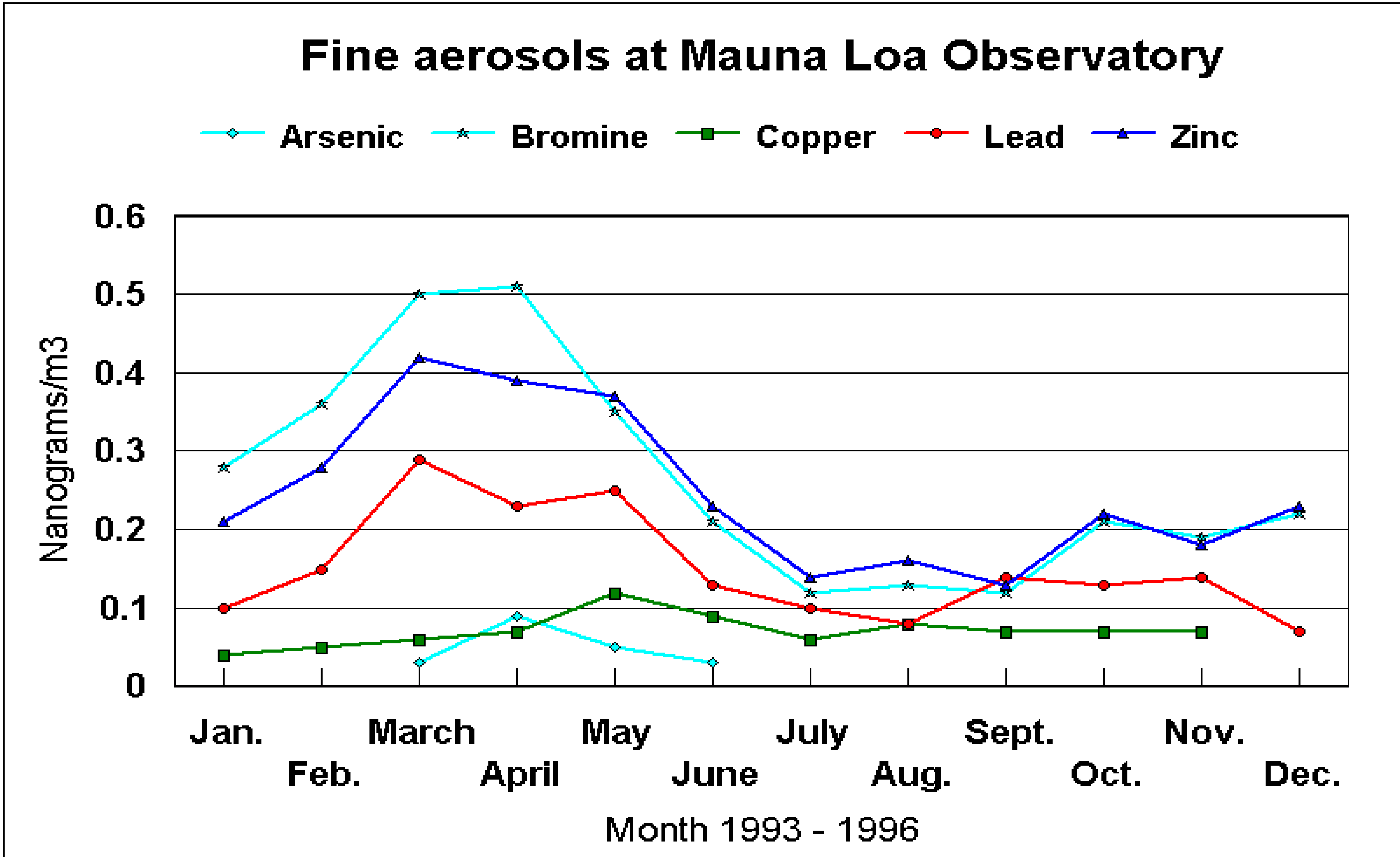

IMPROVE aerosols at Mauna Loa Observatory
Ammonium sulfate
Soil
Organic matter
Spring March - June
5
4
3
2
1
0
Micrograms/m3
1995
1995
1996
1996
1997
1997
1998
1998
1998
1999
1999
Year

Mass and major species

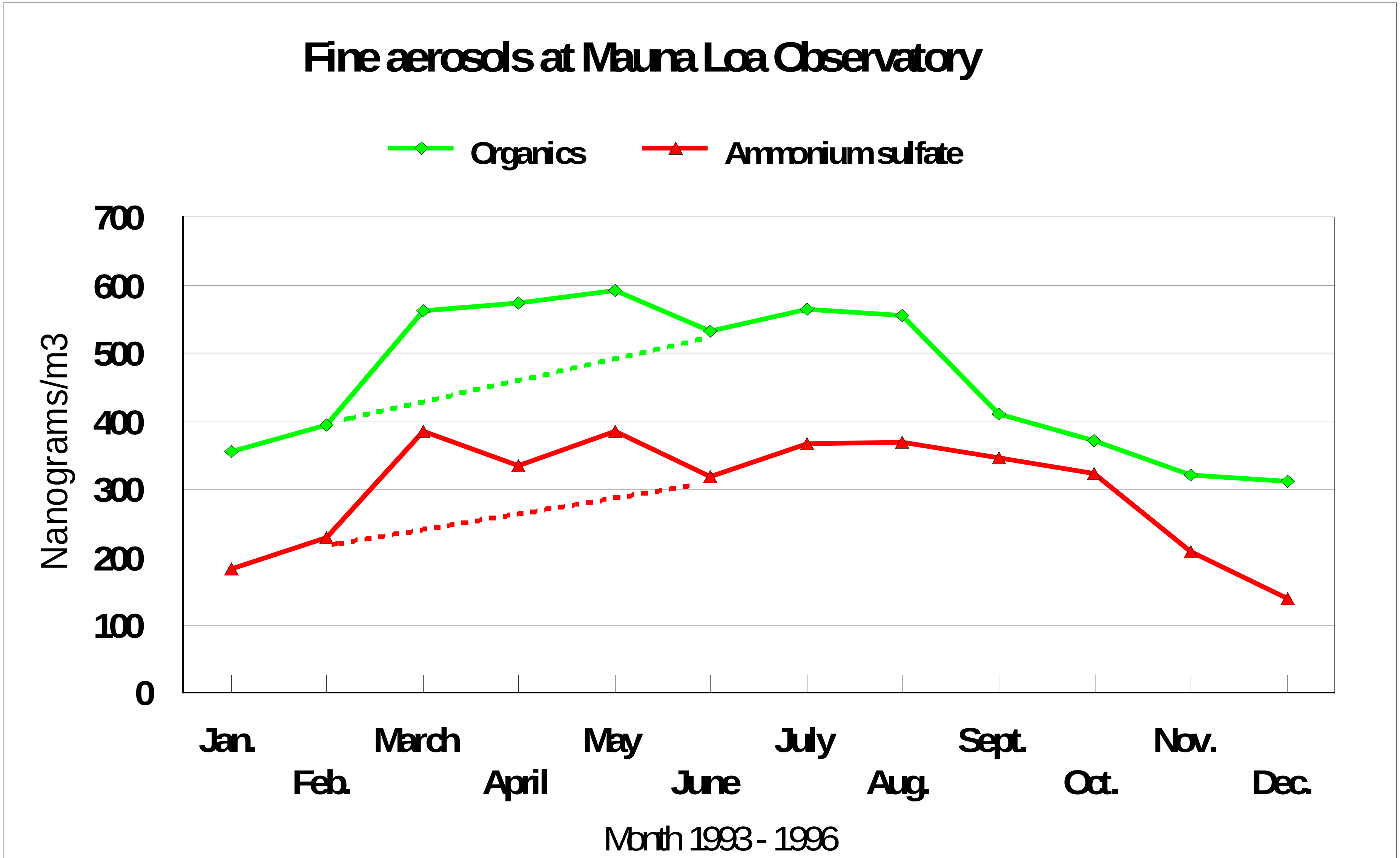


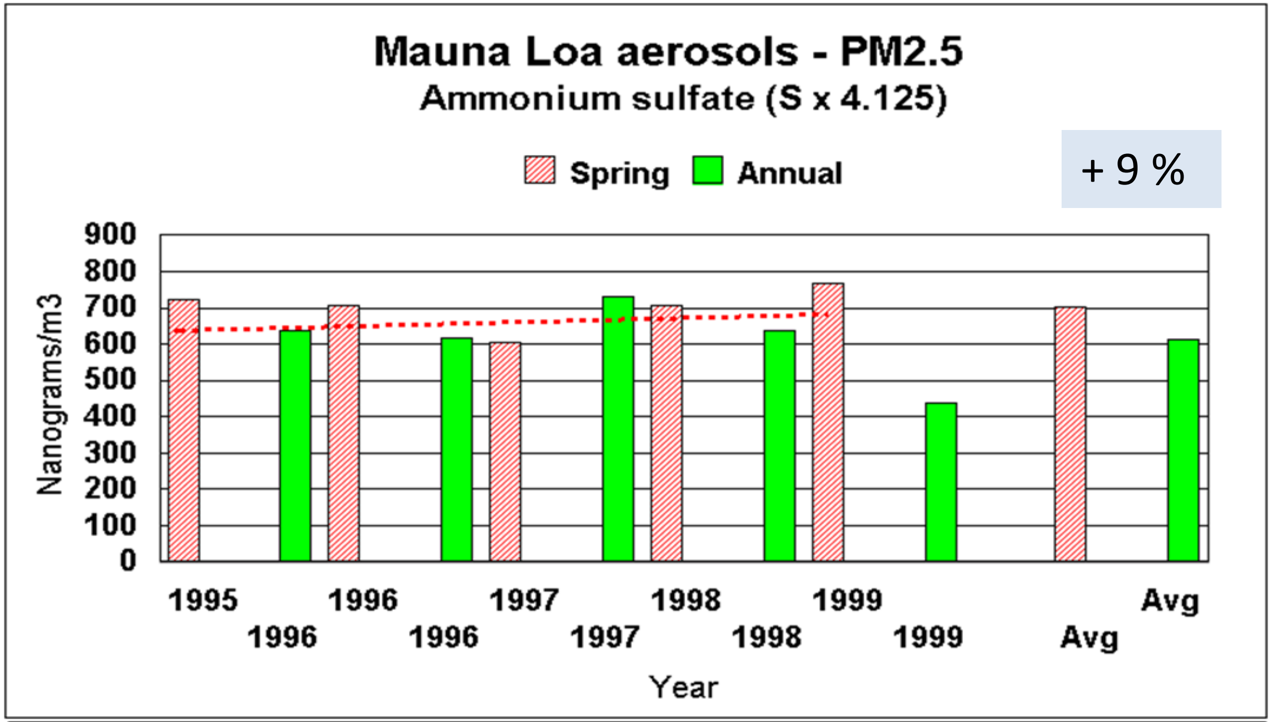
VanCuren, Richard A., and Cahill, Thomas A., **Asian Aerosols in North America: Frequency and Concentration of Fine Dust**, *Journal Geophysical Research 107, No. D24, 4804 (2002)*

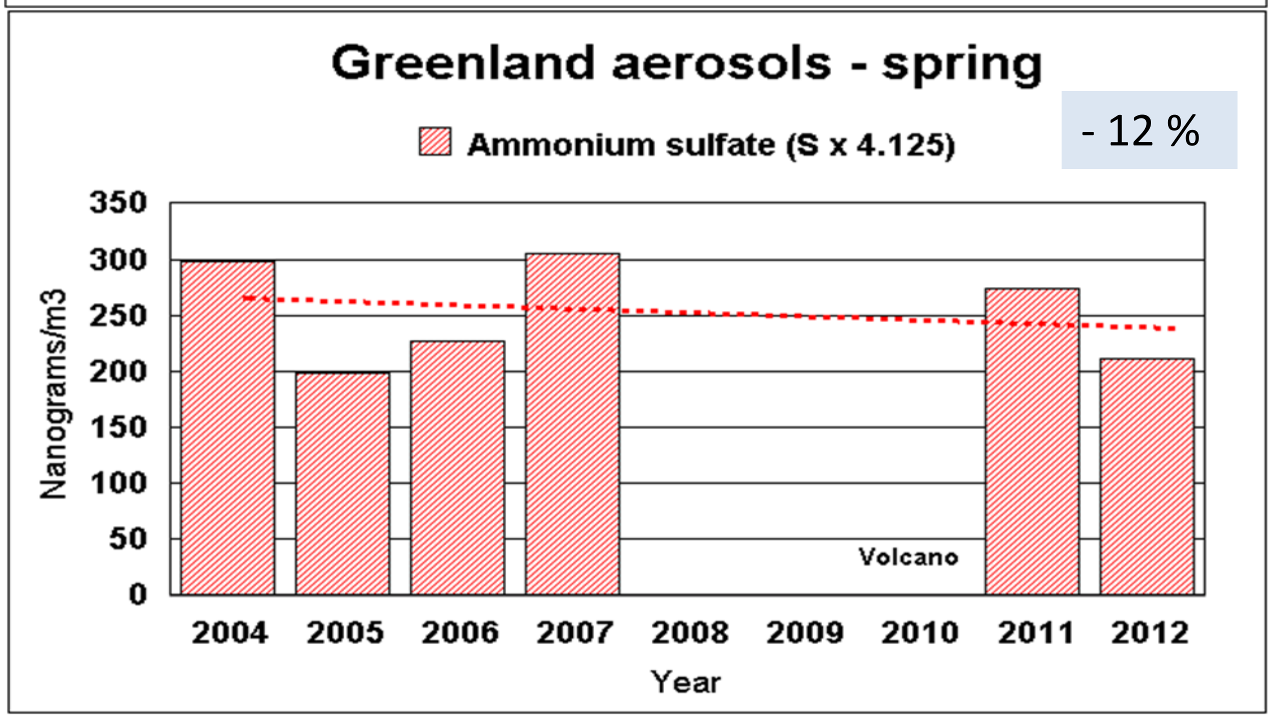
Industrial and urban aerosols



Spring enhancement of sulfates and organics




Mauna Loa aerosols - PM2.5
Ammonium sulfate (S x 4.125)
Spring
Annual
+ 9 %
900
800
700
600
500
400
300
200
100
0
Nanograms/m3
1995
1996
1996
1996
1997
1997
1998
1998
1999
1999
Avg
Avg
Year

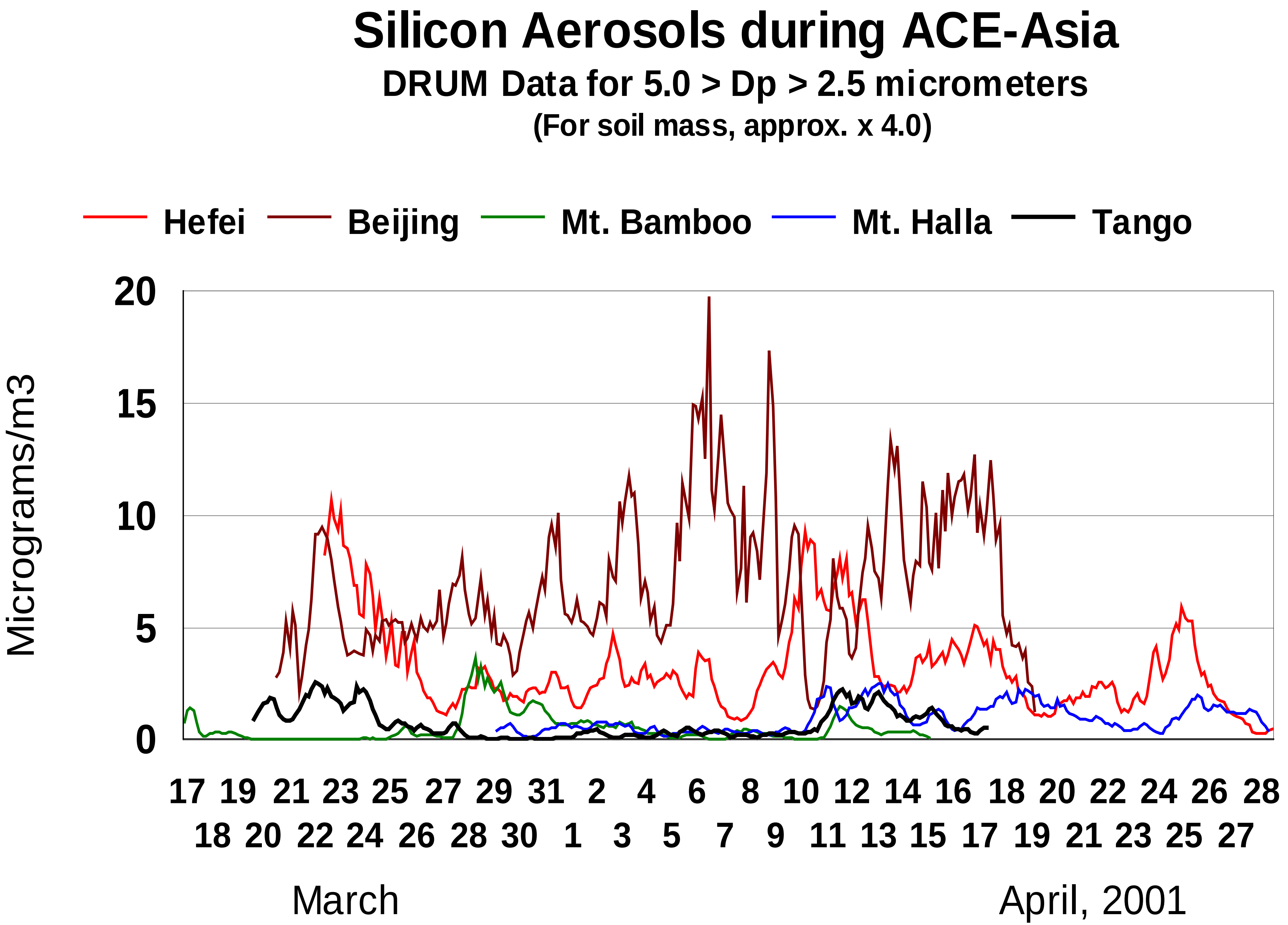

Greenland aerosols - spring
Ammonium sulfate (S x 4.125)
- 12 %
350
300
250
200
150
100
50
0
Nanograms/m3
Volcano
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

April 17, 2010

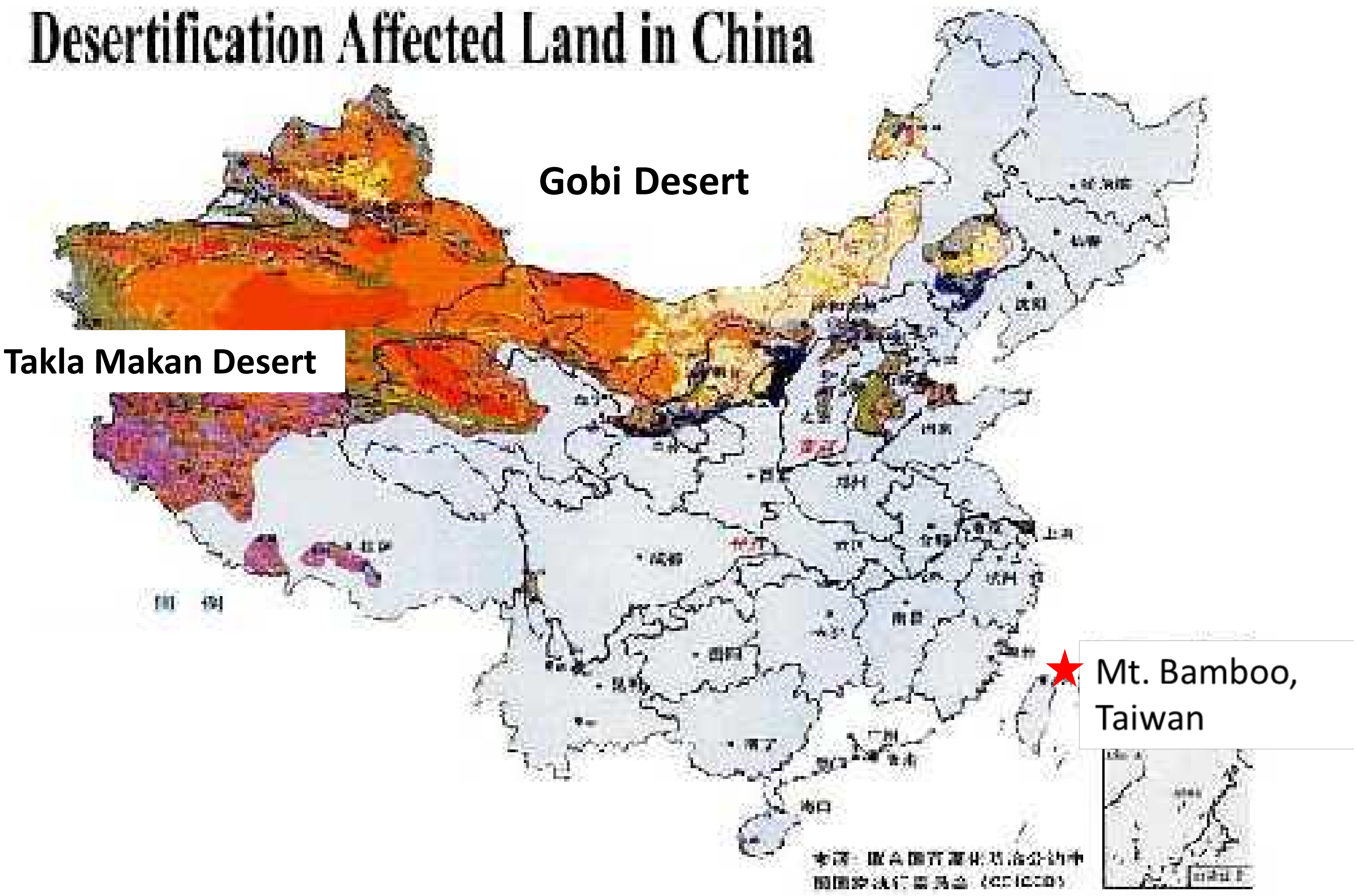
Results of 1980 - 1999

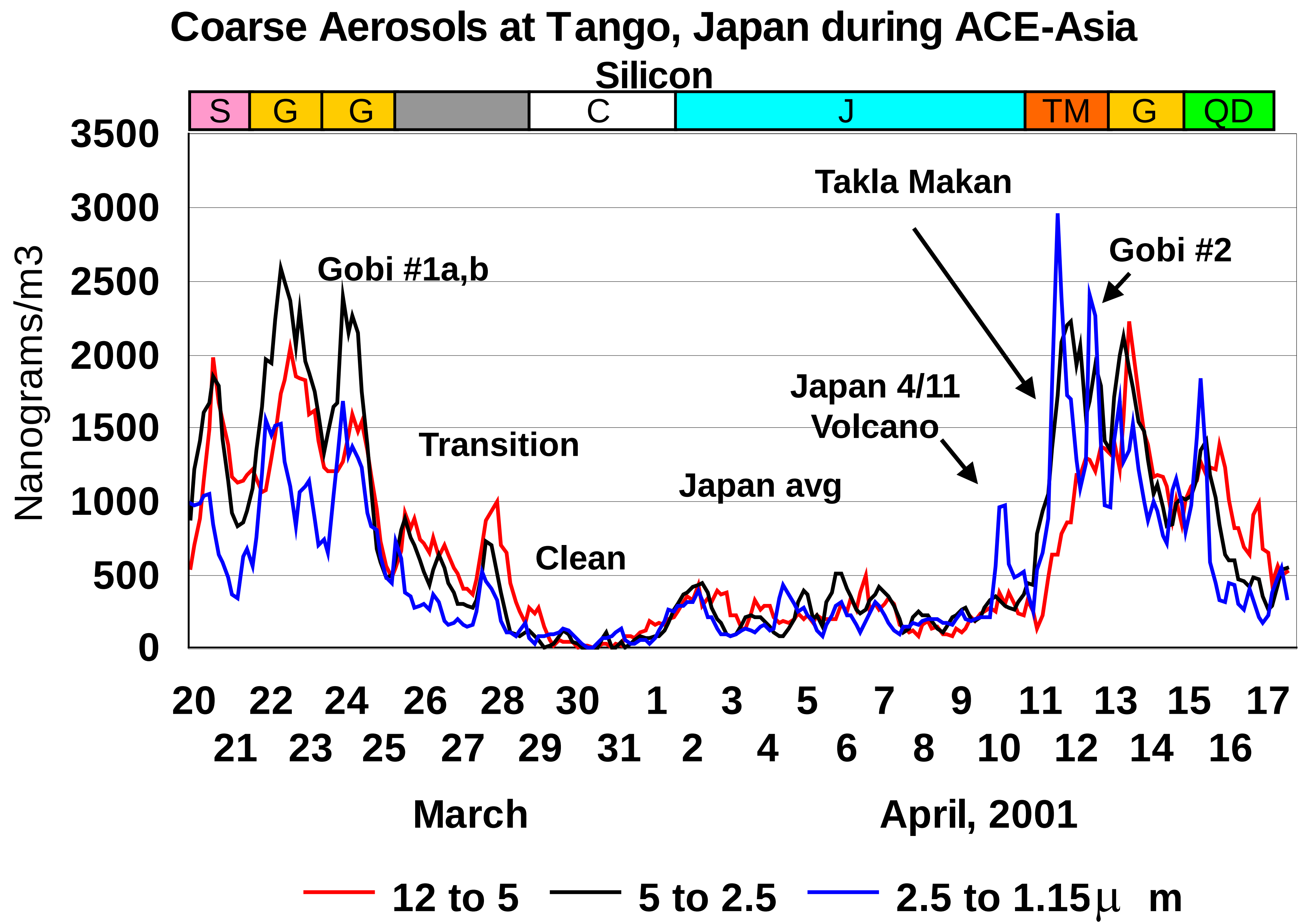
- Soil dust
  - Overwhelmingly Asian, not local soil
  - Overwhelmingly spring transport
  - Highly variable year to year
  - Is ~ 1 µm diameter, but extends down to 0.5 µm
  - Correlated with anthropogenic toxics
  - Occurs at MLO on both downslope (night) and upslope (day) winds
- Sulfates and organics
  - Spring enhancement but mostly an annual impact

Aerosol sampling sites – UC Davis in ACE-Asia

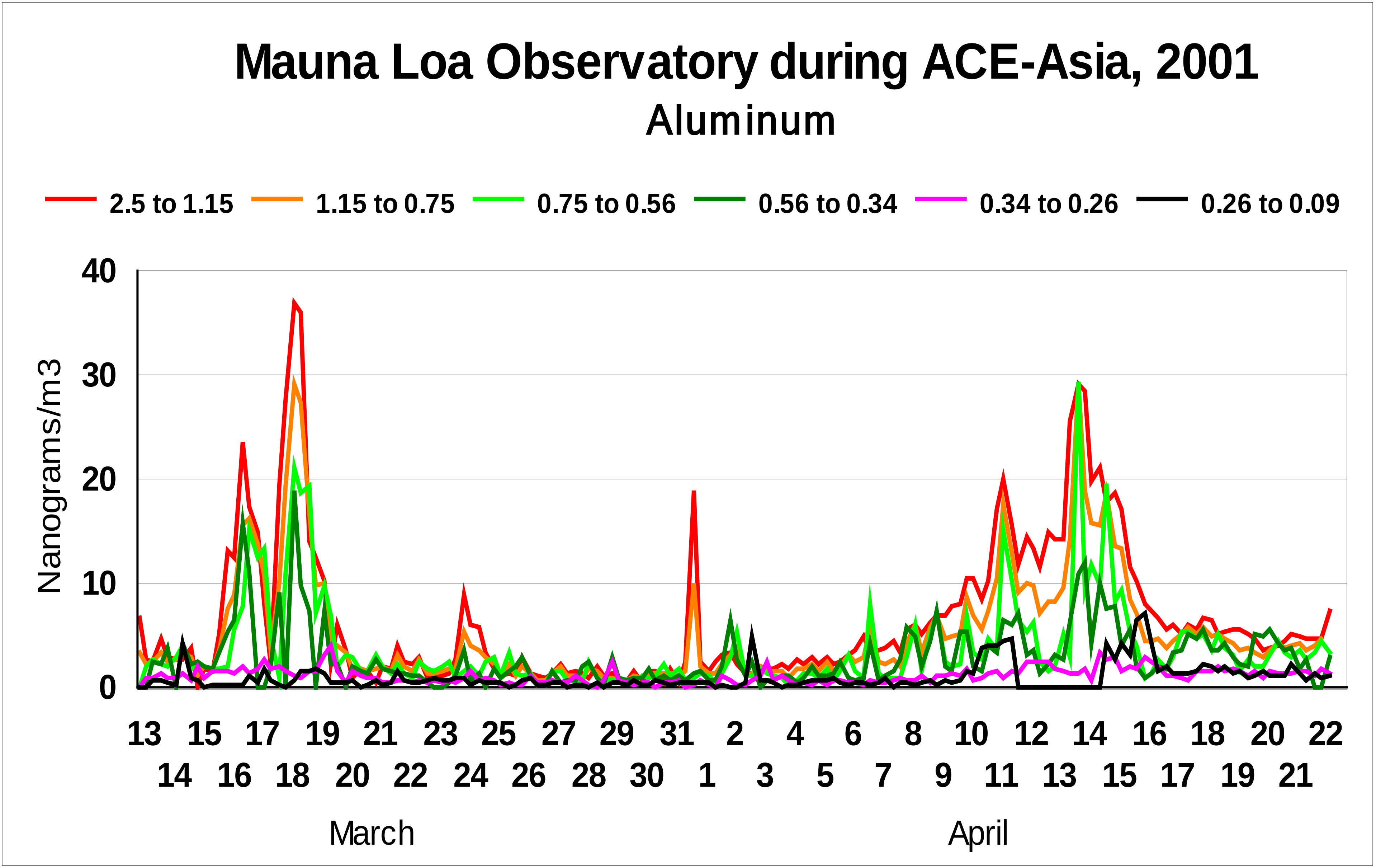


Silicon Aerosols during ACE-Asia
DRUM Data for 5.0 > Dp > 2.5 micrometers
(For soil mass, approx. x 4.0)
Hefei
Beijing
Mt. Bamboo
Mt. Halla
Tango
Micrograms/m3
20
15
10
5
0
17 19 21 23 25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26 28
18 20 22 24 26 28 30 1 3 5 7 9 11 13 15 17 19 21 23 25 27
March
April, 2001


Desertification Affected Land in China
Gobi Desert
Takla Makan Desert
Mt. Bamboo,
Taiwan

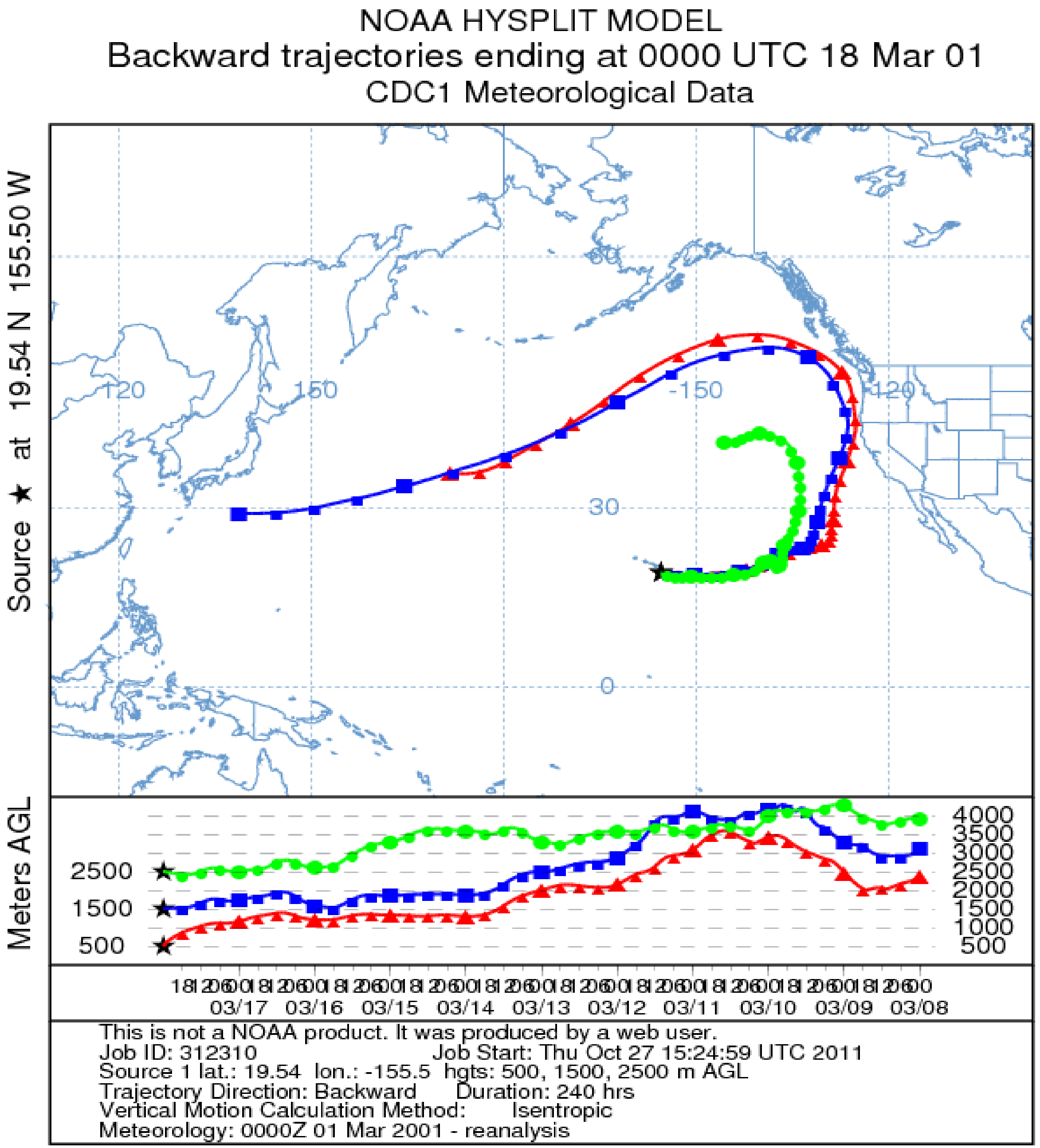


Coarse Aerosols at Tango, Japan during ACE-Asia
Silicon
S
G
G
C
J
TM
G
QD
Nanograms/m3
3500
3000
2500
2000
1500
1000
500
0
Takla Makan
Gobi #2
Gobi #1a,b
Japan 4/11
Volcano
Transition
Japan avg
Clean
20
22
24
26
28
30
1
3
5
7
9
11
13
15
17
21
23
25
27
29
31
2
4
6
8
10
12
14
16
March
April, 2001
12 to 5
5 to 2.5
2.5 to 1.15μ m

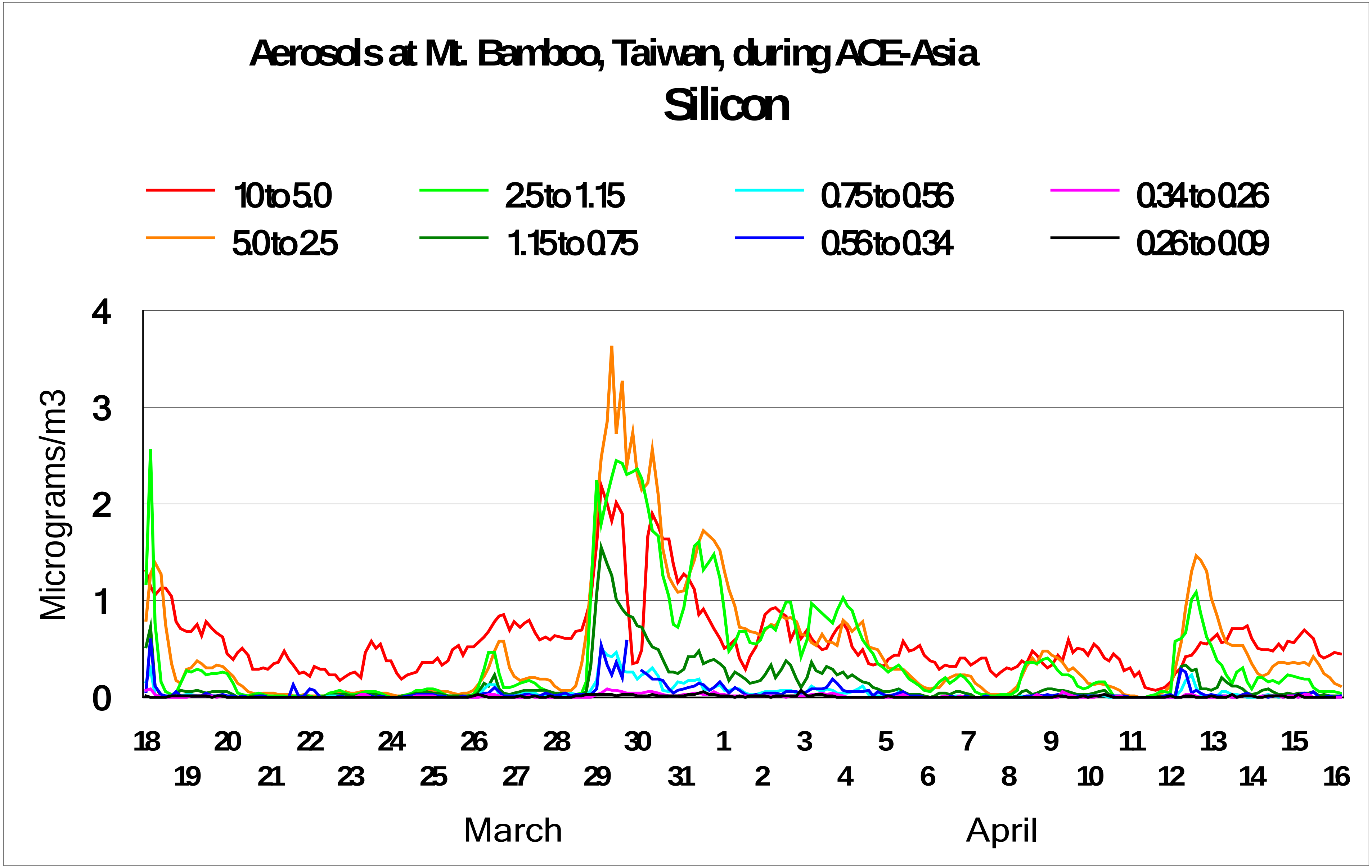


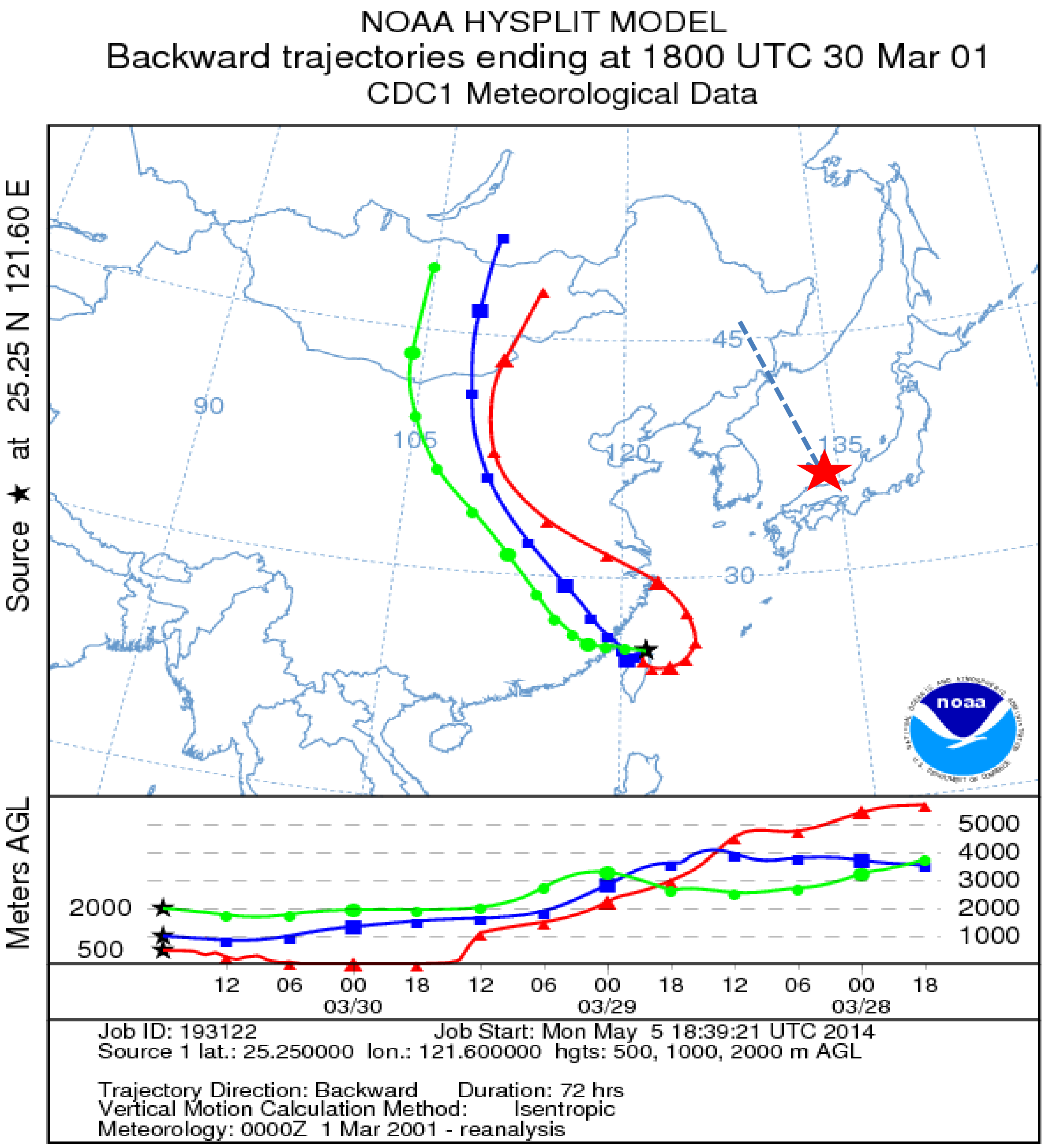
Mauna Loa Observatory during ACE-Asia, 2001
Aluminum
2.5 to 1.15
1.15 to 0.75
0.75 to 0.56
0.56 to 0.34
0.34 to 0.26
0.26 to 0.09
Nanograms/m3
0
10
20
30
40
13 15 17 19 21 23 25 27 29 31 2 4 6 8 10 12 14 16 18 20 22
14 16 18 20 22 24 26 28 30 1 3 5 7 9 11 13 15 17 19 21
March
April

Soil trajectories have Asian sources; Note that they always arrive from elevated trajectories descending to MLO

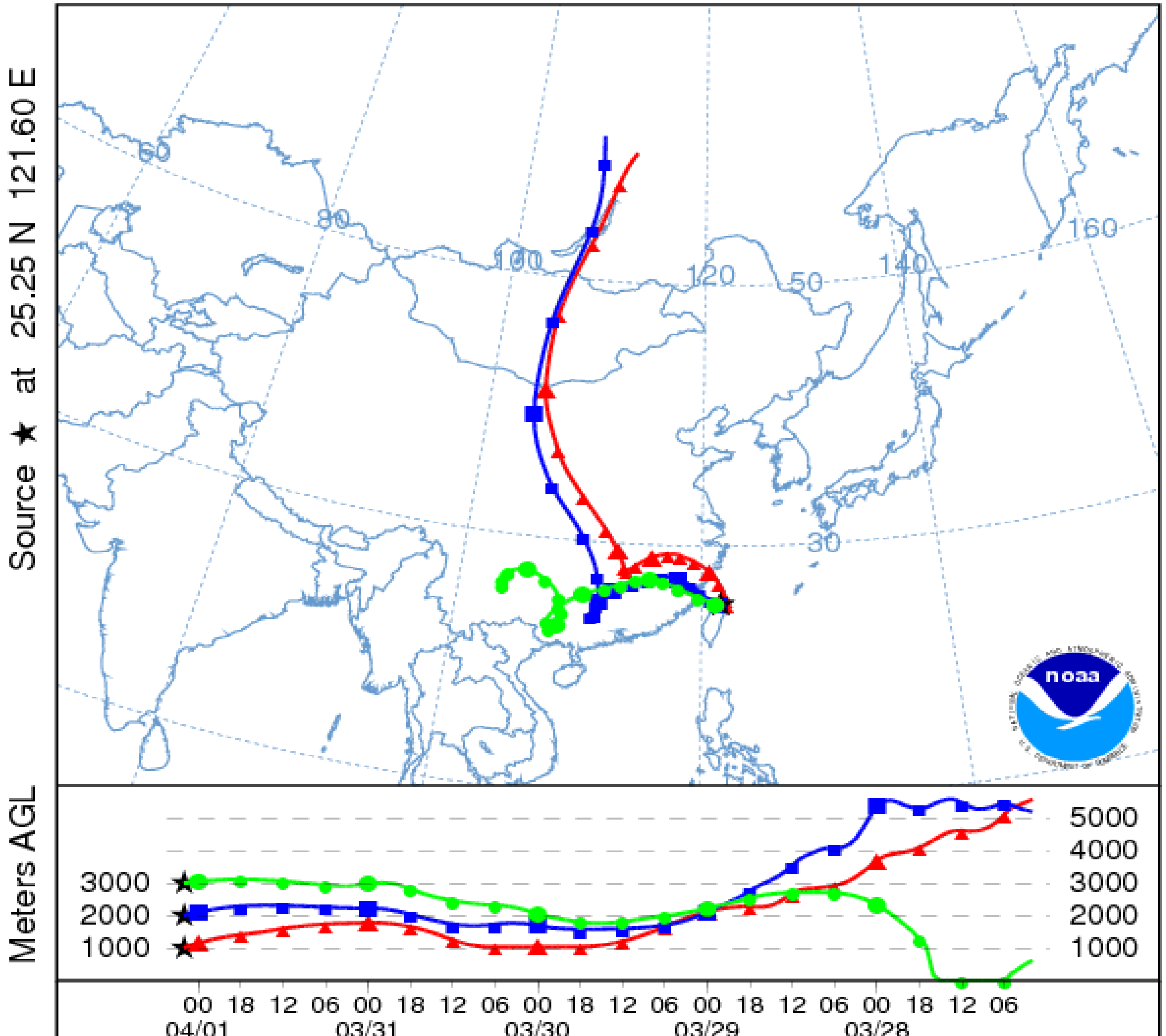


Taiwan is on the transport trajectory



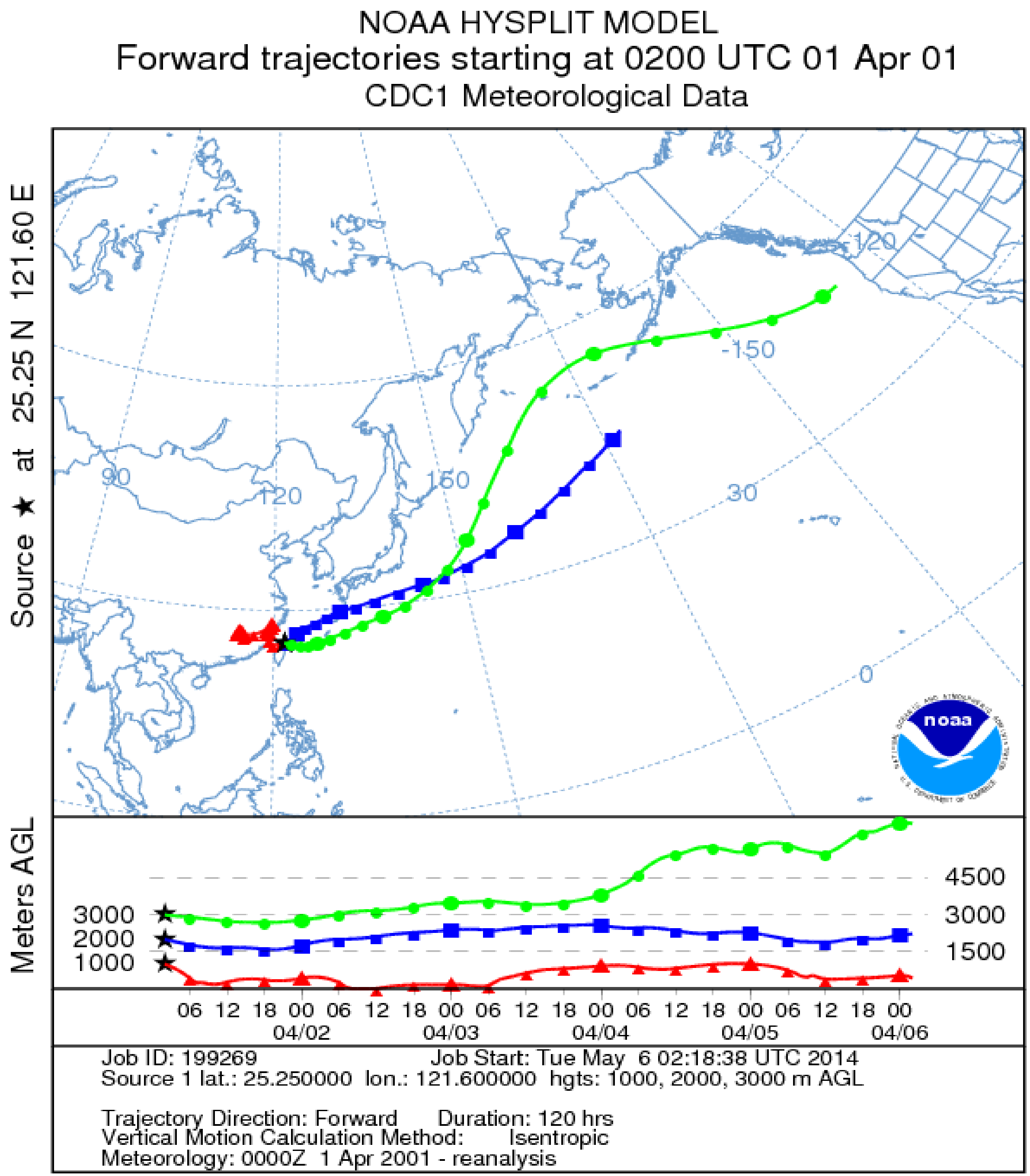

NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 30 Mar 01
CDC1 Meteorological Data
Source ★ at 25.25 N 121.60 E
90
105
120
135
45
30
noaa
Meters AGL
2000
500
5000
4000
3000
2000
1000
12 06 00 18 12 06 00 18 12 06 00 18
03/30
03/29
03/28
Job ID: 193122 Job Start: Mon May 5 18:39:21 UTC 2014
Source 1 lat.: 25.250000 lon.: 121.600000 hgts: 500, 1000, 2000 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Isentropic
Meteorology: 0000Z 1 Mar 2001 - reanalysis

NOAA HYSPLIT MODEL
Backward trajectories ending at 0200 UTC 01 Apr 01
CDC1 Meteorological Data

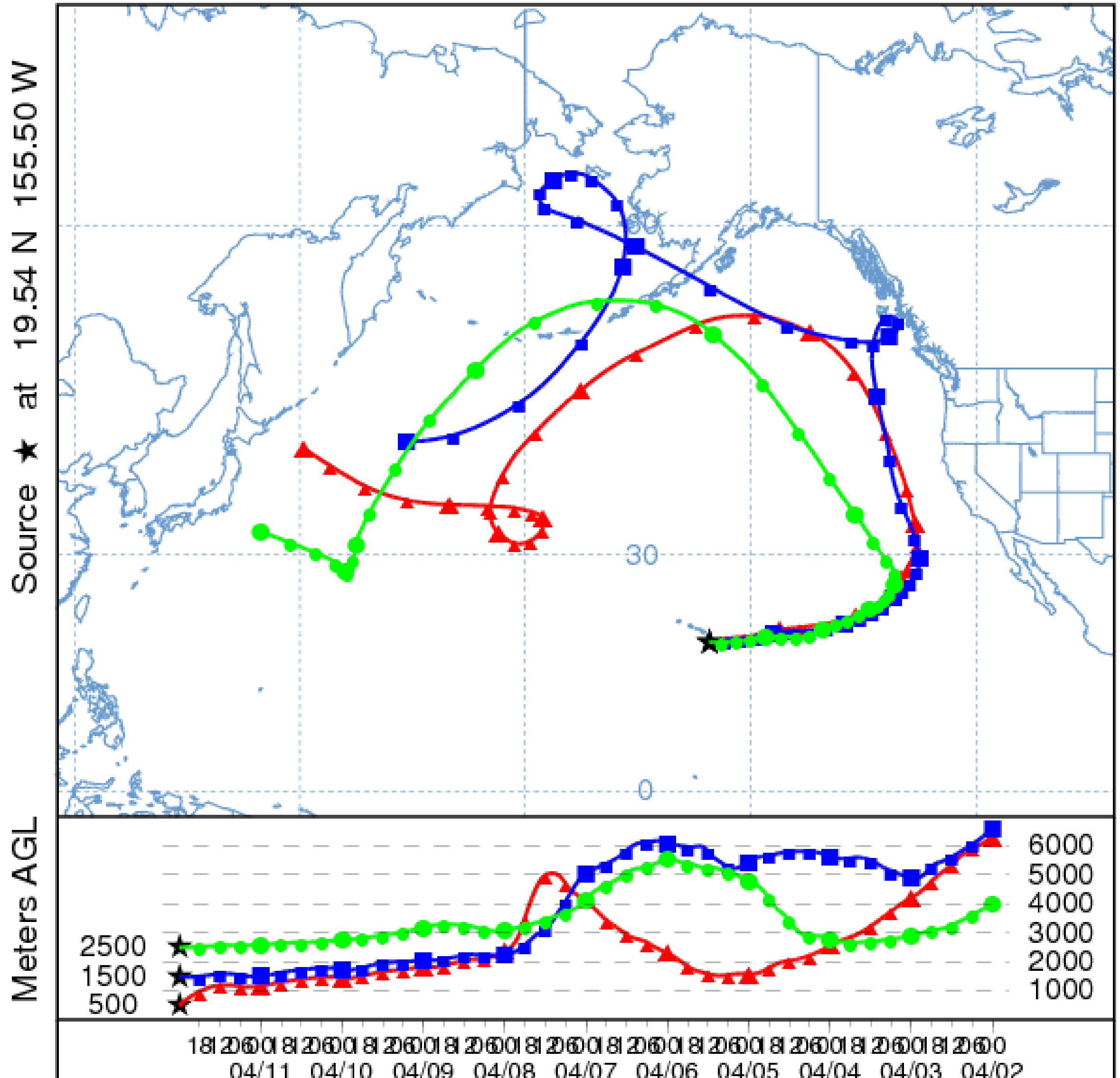


Job ID: 199334 Job Start: Tue May 6 02:22:05 UTC 2014
Source 1 lat.: 25.250000 lon.: 121.600000 hgts: 1000, 2000, 3000 m AGL

Trajectory Direction: Backward Duration: 120 hrs
Vertical Motion Calculation Method: Isentropic
Meteorology: 0000Z 1 Apr 2001 - reanalysis


NOAA HYSPLIT MODEL
Forward trajectories starting at 0200 UTC 01 Apr 01
CDC1 Meteorological Data
Source ★ at 25.25 N 121.60 E
90
120
150
-150
-120
60
30
0
Meters AGL
3000
2000
1000
4500
3000
1500
06 12 18 00 06 12 18 00 06 12 18 00 06 12 18 00 06 12 18 00
04/02
04/03
04/04
04/05
04/06
Job ID: 199269
Job Start: Tue May 6 02:18:38 UTC 2014
Source 1 lat.: 25.250000 lon.: 121.600000 hgts: 1000, 2000, 3000 m AGL
Trajectory Direction: Forward
Duration: 120 hrs
Vertical Motion Calculation Method: Isentropic
Meteorology: 0000Z 1 Apr 2001 - reanalysis

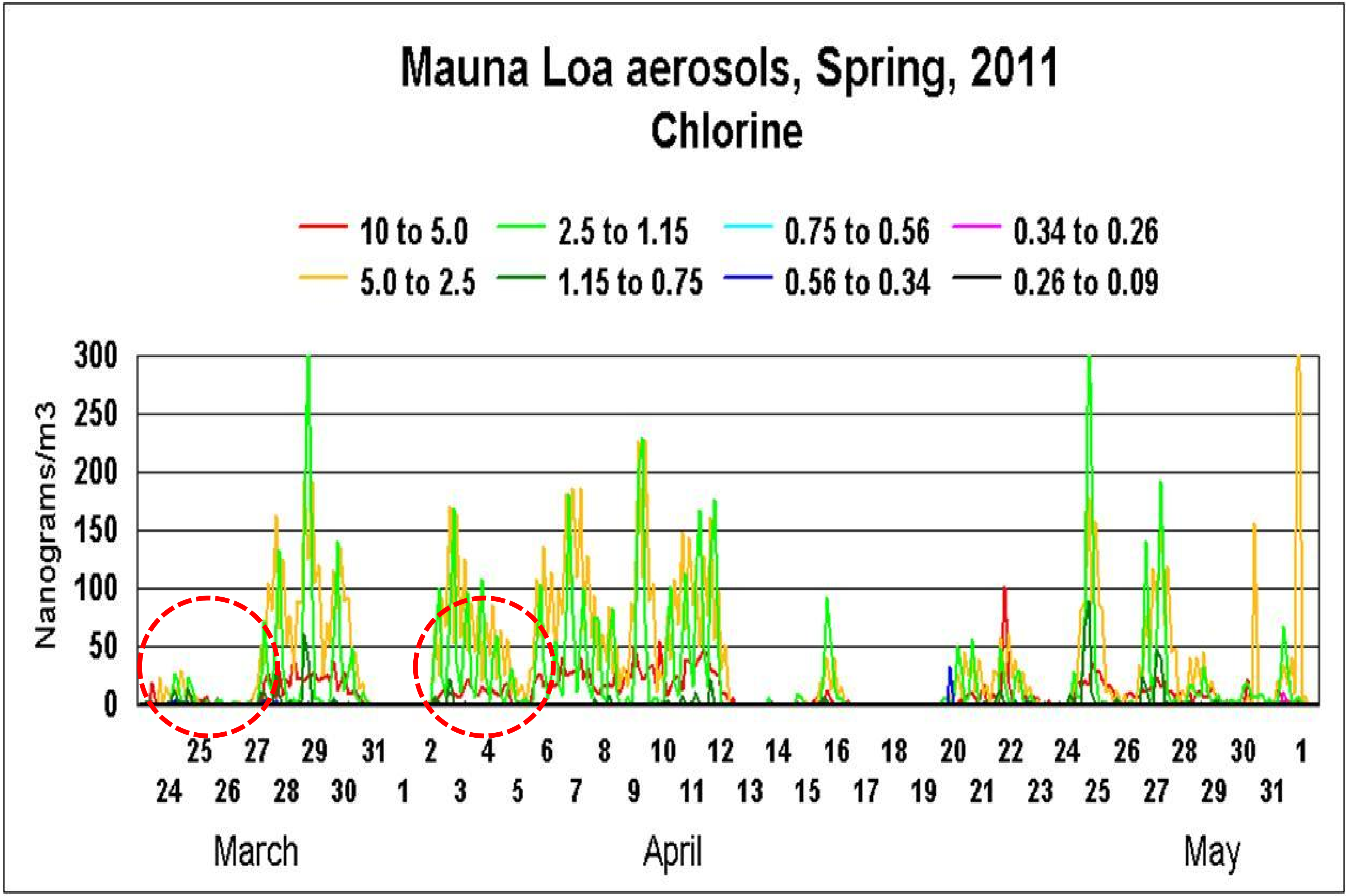
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 12 Apr 01
CDC1 Meteorological Data

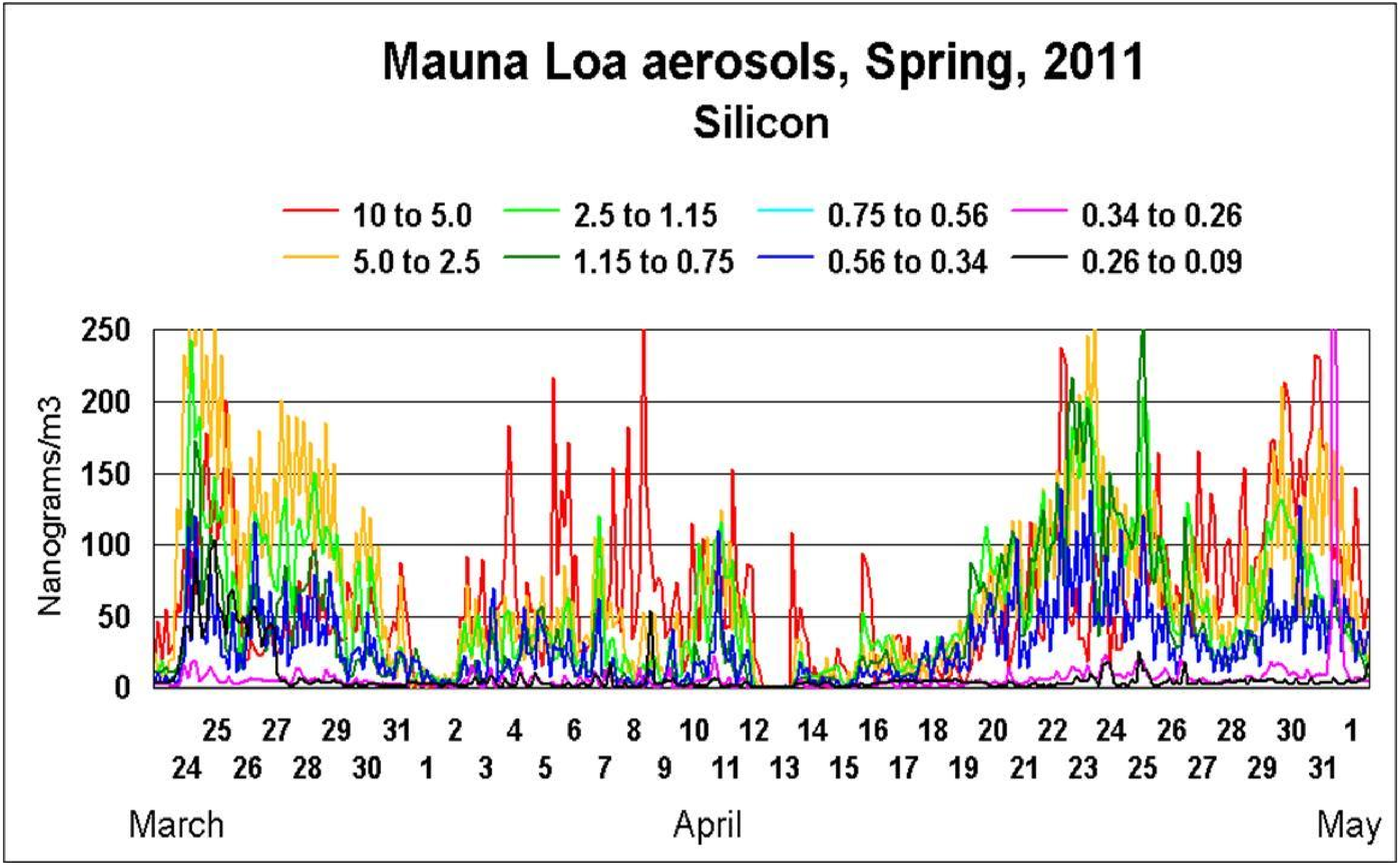


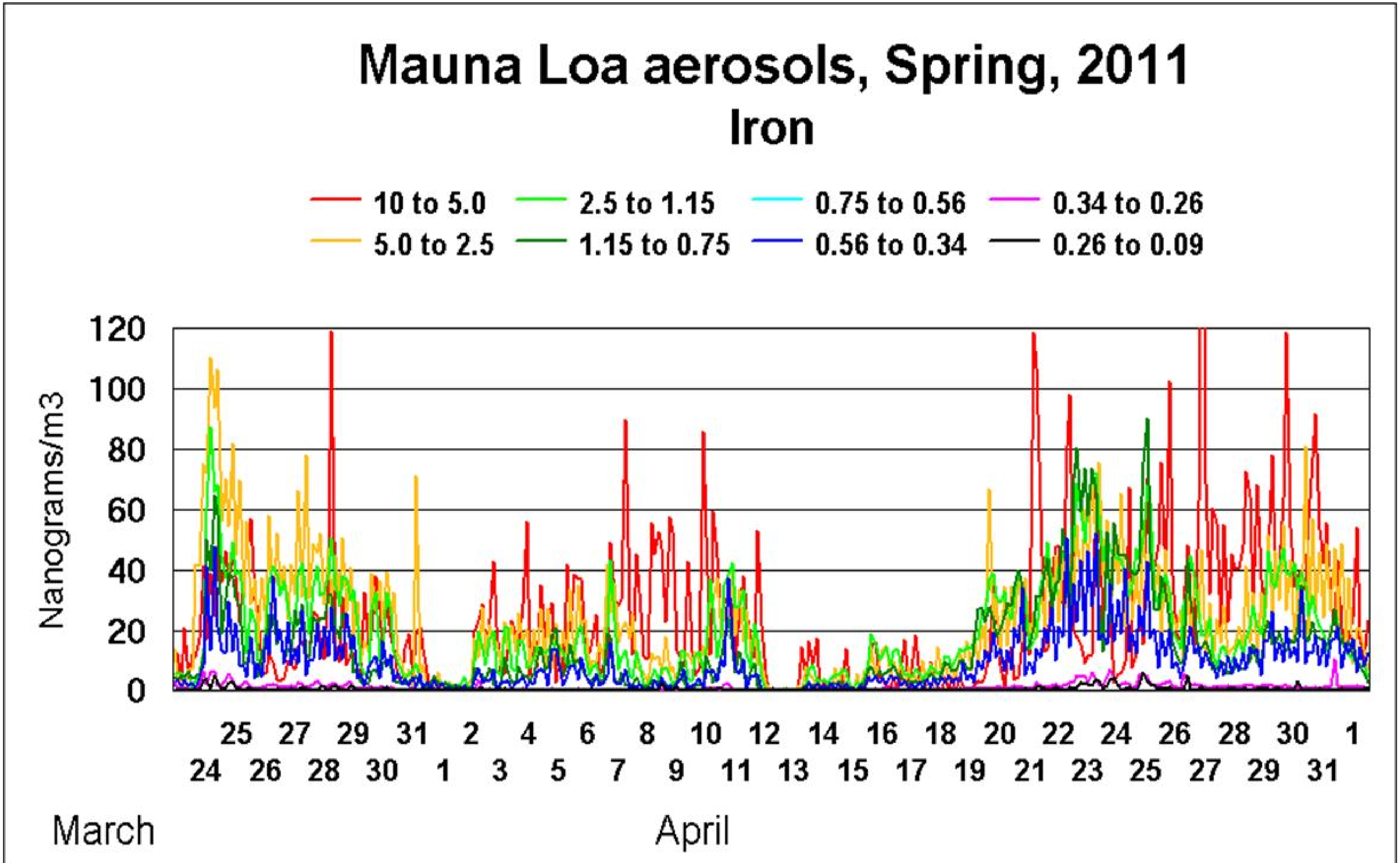
This is not a NOAA product. It was produced by a web user.
Job ID: 332325 Job Start: Thu Oct 27 15:36:52 UTC 2011
Source 1 lat.: 19.54 lon.: -155.5 hgts: 500, 1500, 2500 m AGL
Trajectory Direction: Backward Duration: 240 hrs
Vertical Motion Calculation Method: Isentropic
Meteorology: 0000Z 01 Apr 2001 - reanalysis

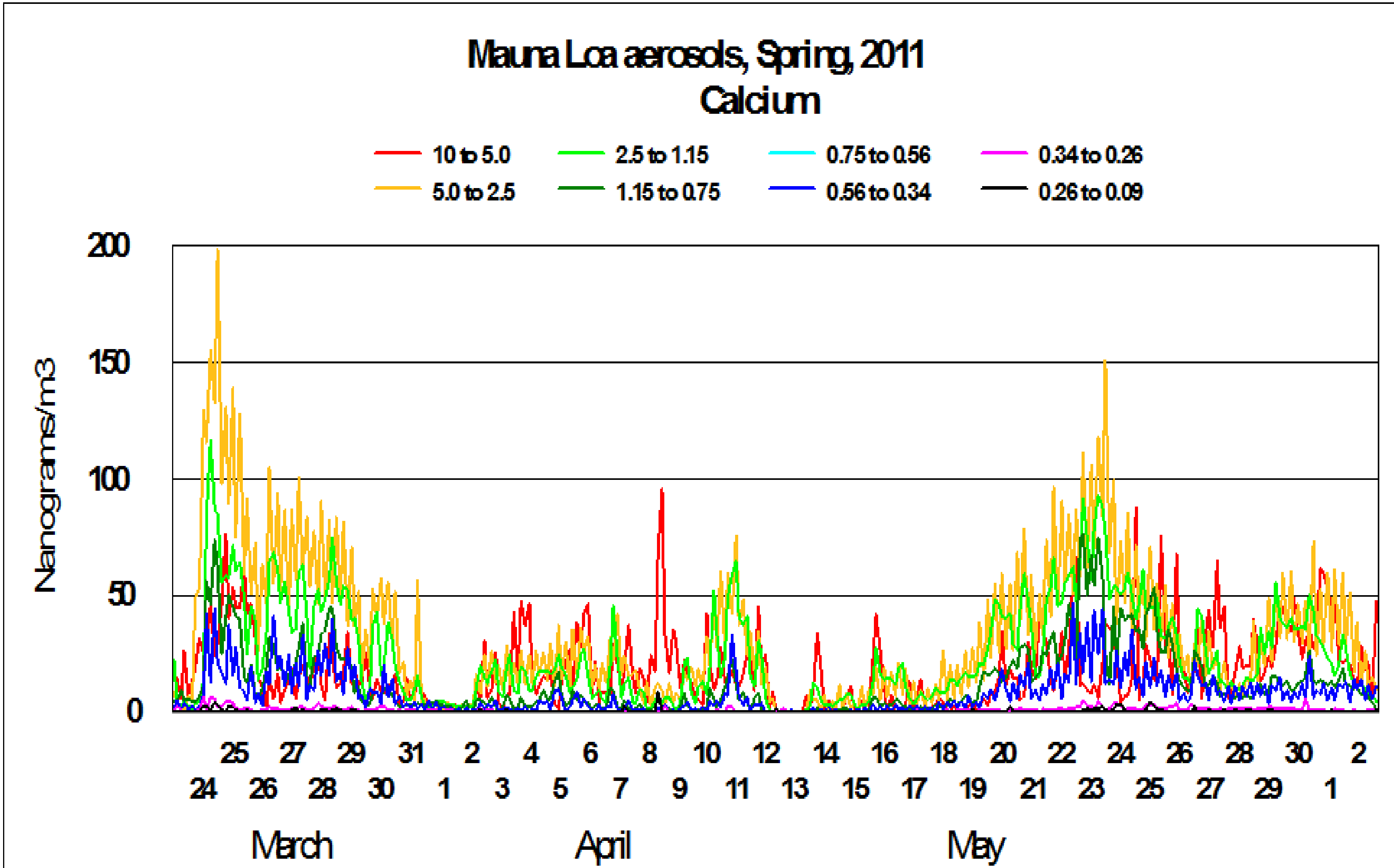
Results of ACE-Asia 2001

- Established spatial variability of soil, sulfur, and anthropogenic toxics sources in China
- Measured drop off as aerosols passed over East Asian islands
- Tracked a soil event from the Gobi desert to MLO via Taiwan

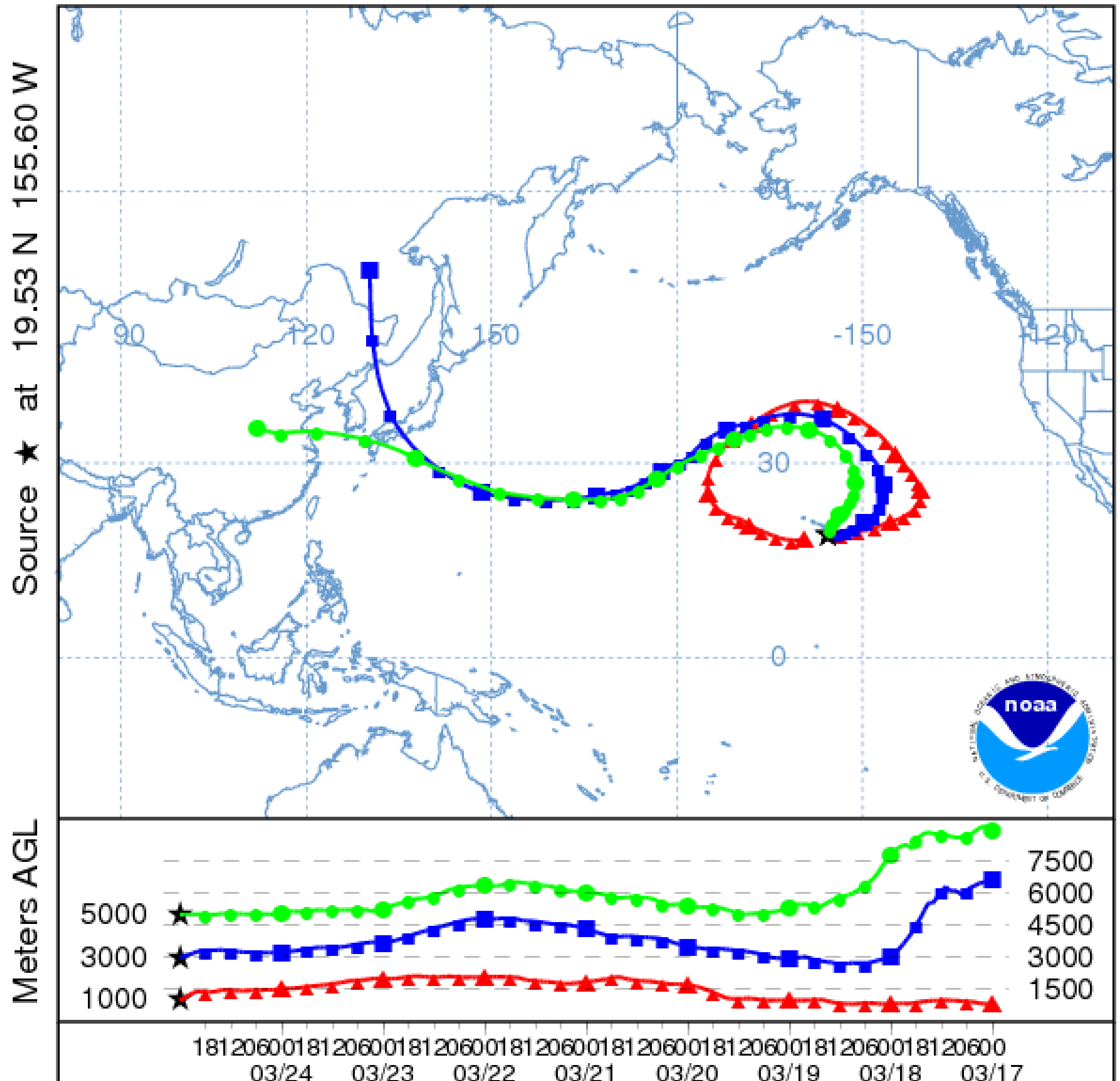

Mauna Loa aerosols, Spring, 2011
Chlorine
10 to 5.0
2.5 to 1.15
0.75 to 0.56
0.34 to 0.26
5.0 to 2.5
1.15 to 0.75
0.56 to 0.34
0.26 to 0.09
Nanograms/m3
300
250
200
150
100
50
0
25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 1
24 26 28 30 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
March
April
May


Mauna Loa aerosols, Spring, 2011
Silicon
10 to 5.0
2.5 to 1.15
0.75 to 0.56
0.34 to 0.26
5.0 to 2.5
1.15 to 0.75
0.56 to 0.34
0.26 to 0.09
Nanograms/m3
250
200
150
100
50
0
25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 1
24 26 28 30 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
March
April
May


Mauna Loa aerosols, Spring, 2011
Iron
10 to 5.0
5.0 to 2.5
2.5 to 1.15
1.15 to 0.75
0.75 to 0.56
0.56 to 0.34
0.34 to 0.26
0.26 to 0.09
Nanograms/m3
0
20
40
60
80
100
120
25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 1
24 26 28 30 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
March
April


Mauna Loa aerosols, Spring, 2011
Calcium
10 to 5.0
5.0 to 2.5
2.5 to 1.15
1.15 to 0.75
0.75 to 0.56
0.56 to 0.34
0.34 to 0.26
0.26 to 0.09
Nanograms/m3
200
150
100
50
0
25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 2
24 26 28 30 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 1
March
April
May

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 25 Mar 11
GDAS Meteorological Data



Job ID: 160337 Job Start: Wed May 7 23:36:23 UTC 2014
Source 1 lat.: 19.530000 lon.: -155.600000 hgts: 1000, 3000, 5000 m AGL

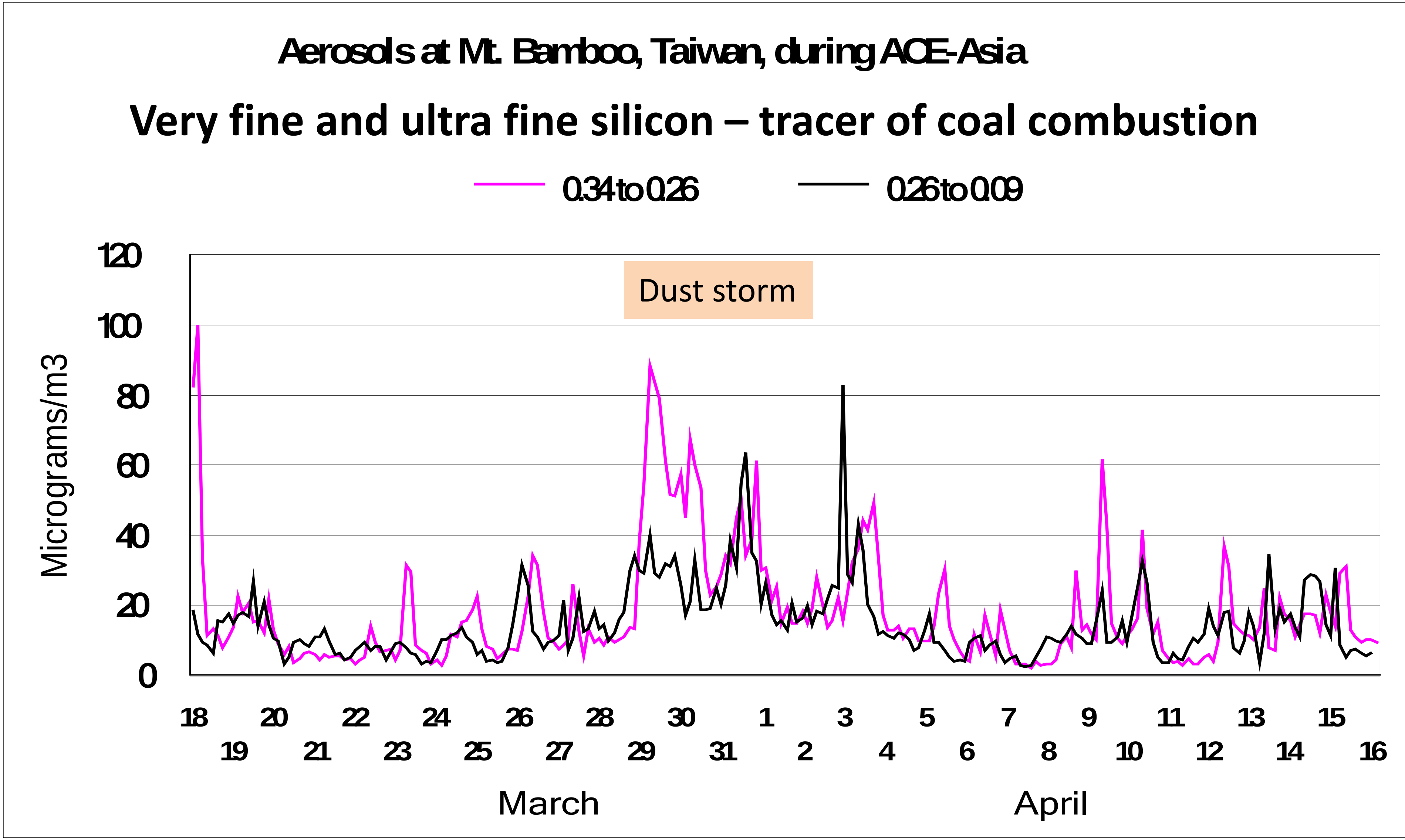
Trajectory Direction: Backward Duration: 192 hrs
Vertical Motion Calculation Method: Isentropic

Ratio of aerosols –
6 weeks at Mauna Loa Observatory – Spring 2011 versus spring 2001

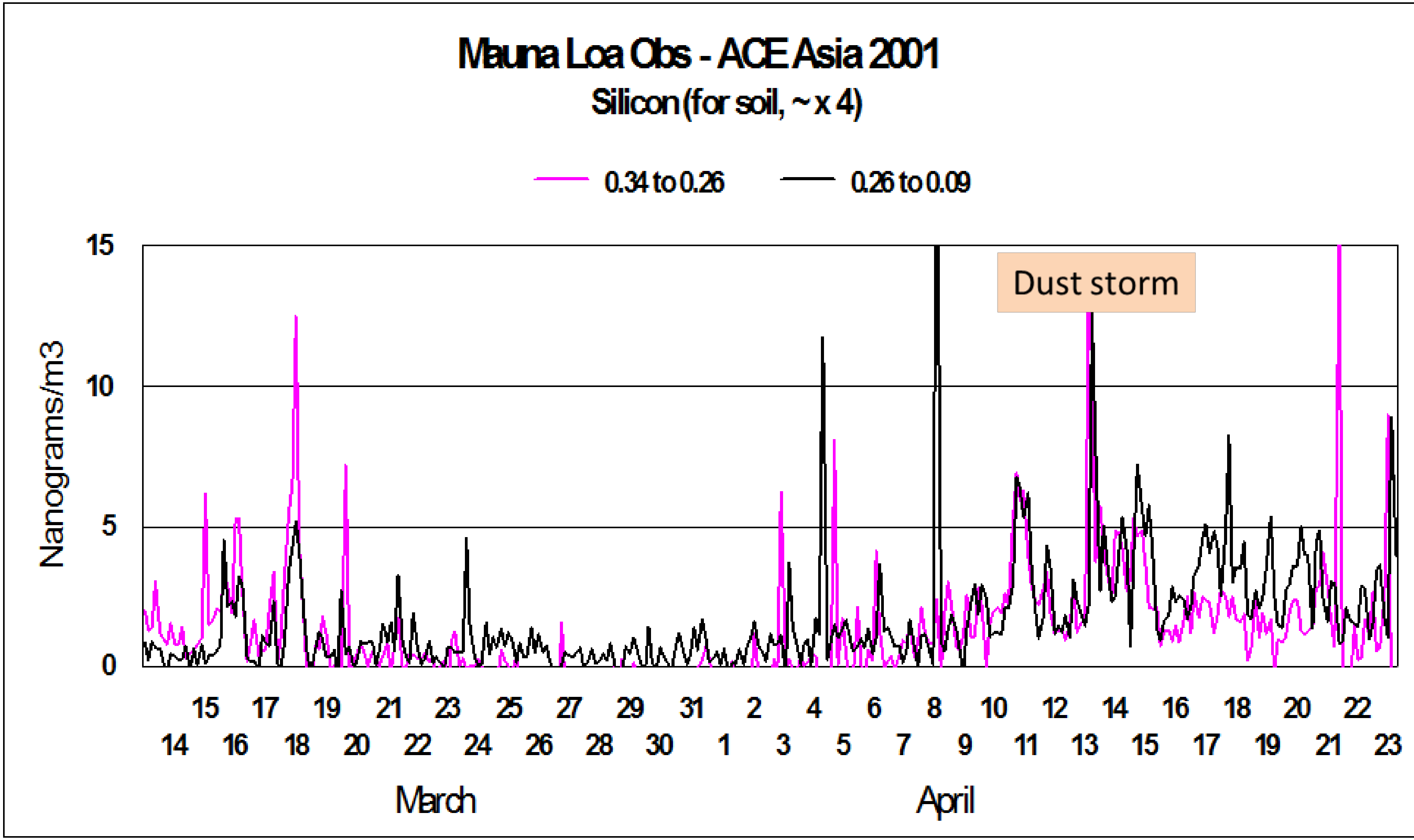
PM2.5	Soil	Al, Si, K,	Amm.	Salt	metals							
	With oxides	Ca, Mn, Fe	SO4	NaCl	**V**	**Cr**	**Ni**	**Cu**	**Zn**	**Se**	**Br**	**Pb**
	ng/m^3		ng/m^3	ng/m^3	ng/m^3	ng/m^3	ng/m^3	ng/m^3	ng/m^3	ng/m^3	ng/m^3	ng/m^3
2001	299.4		535	11.5	0.05	0.12	0.40	0.58	1.91	0.06	0.23	0.9
2011	325.7		1245	18.0	0.12	0.07	0.41	1.26	1.62	0.44	1.13	5.9
Ratio, 2011/2001	**1.28**		**2.33**	**1.56**	**2.49**	**0.60**	**1.04**	**2.17**	**0.86**	**7.28**	**4.89**	**6.26**
Error	**± 0.28**											

- Notable:
  - Soil and sea salt only modestly enhanced
  - Ammonium sulfate ~ Chinese coal use, up x 2.5
  - Cars increased by about a factor of 10, but lead 40% from coal

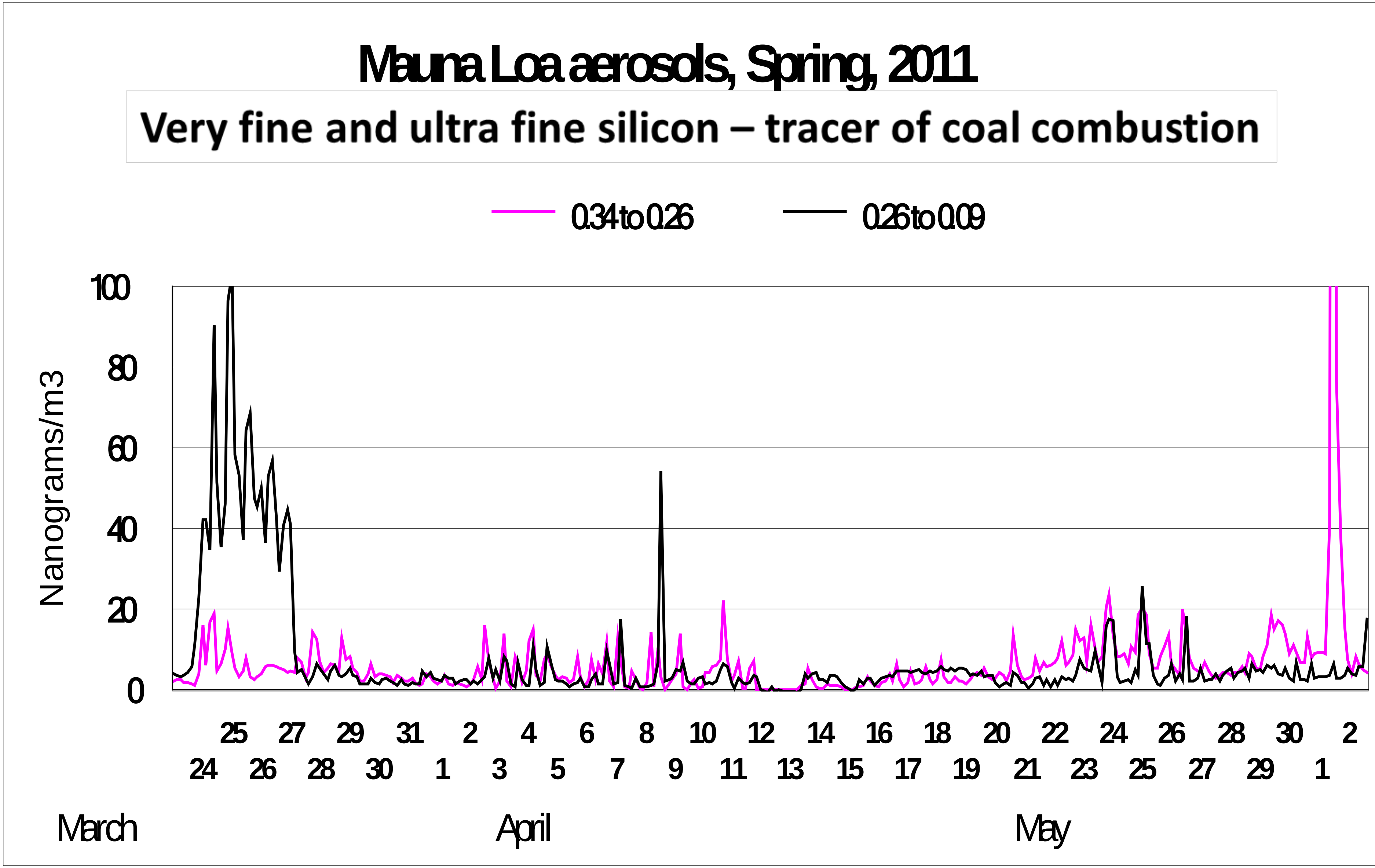
Very fine silicon – a proven tracer of coal combustion

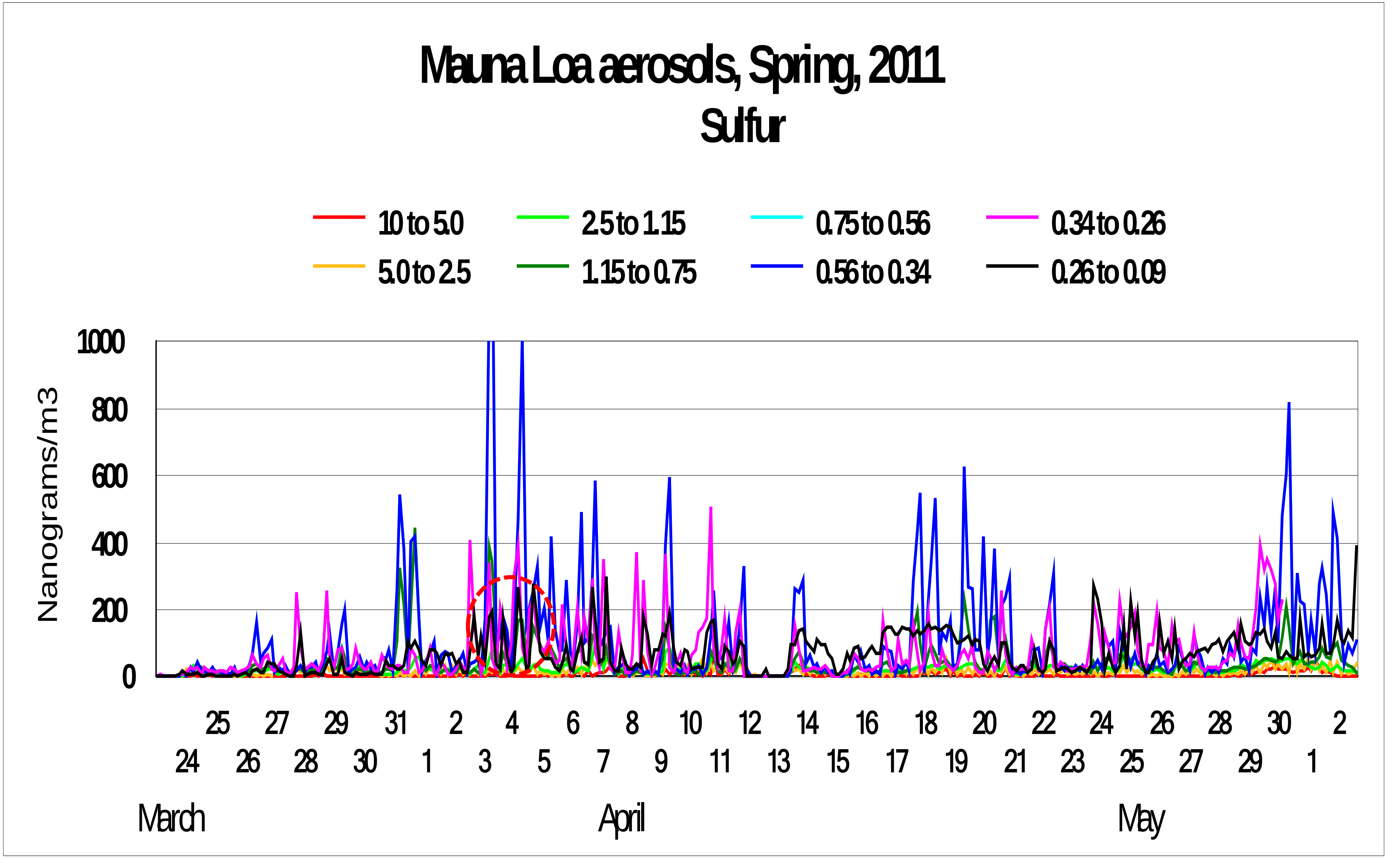


The very fine silicon coal tracer at MLO

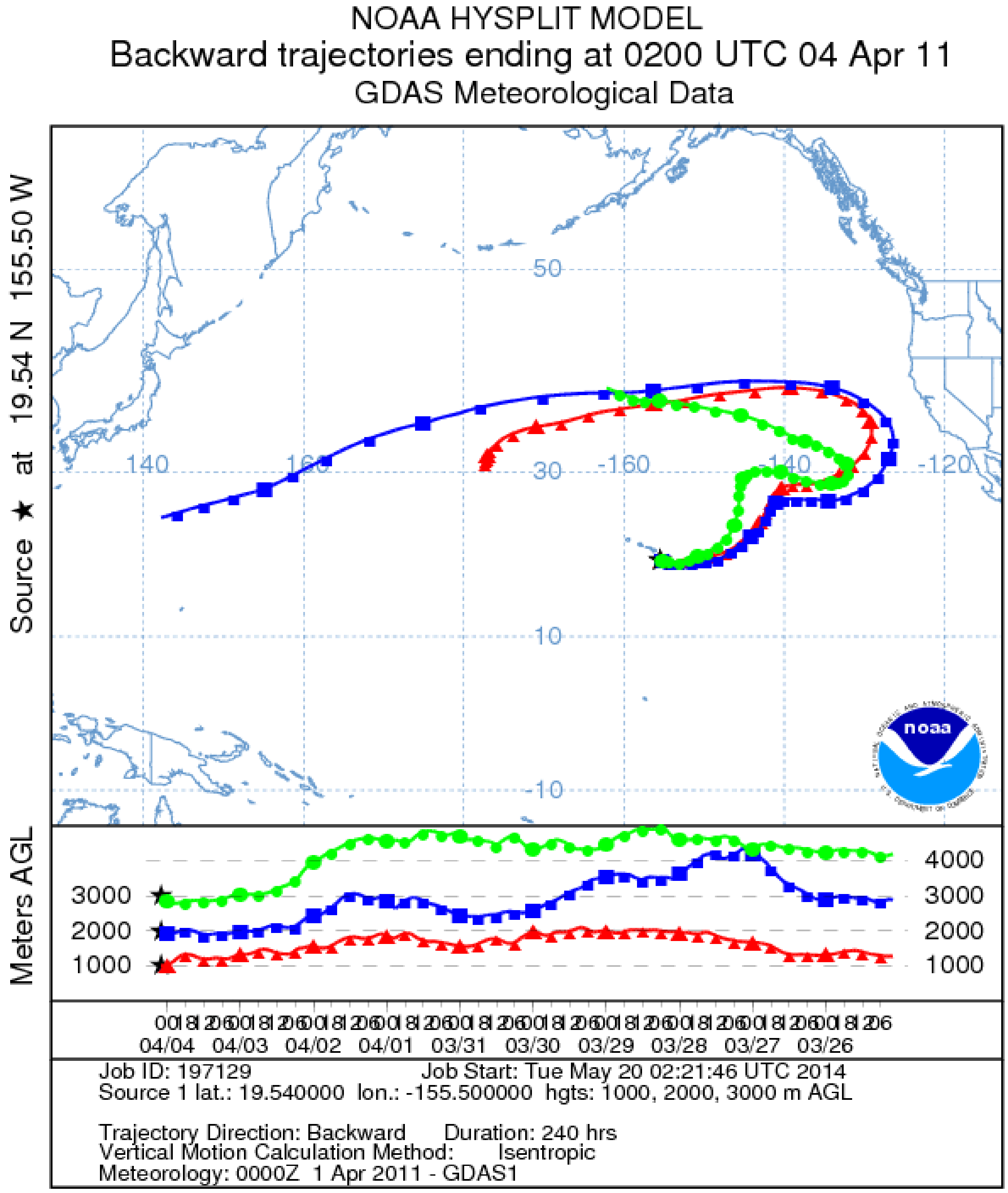


Note: SO_2 scrubbers, increasingly used in China, remove the silicon, too.

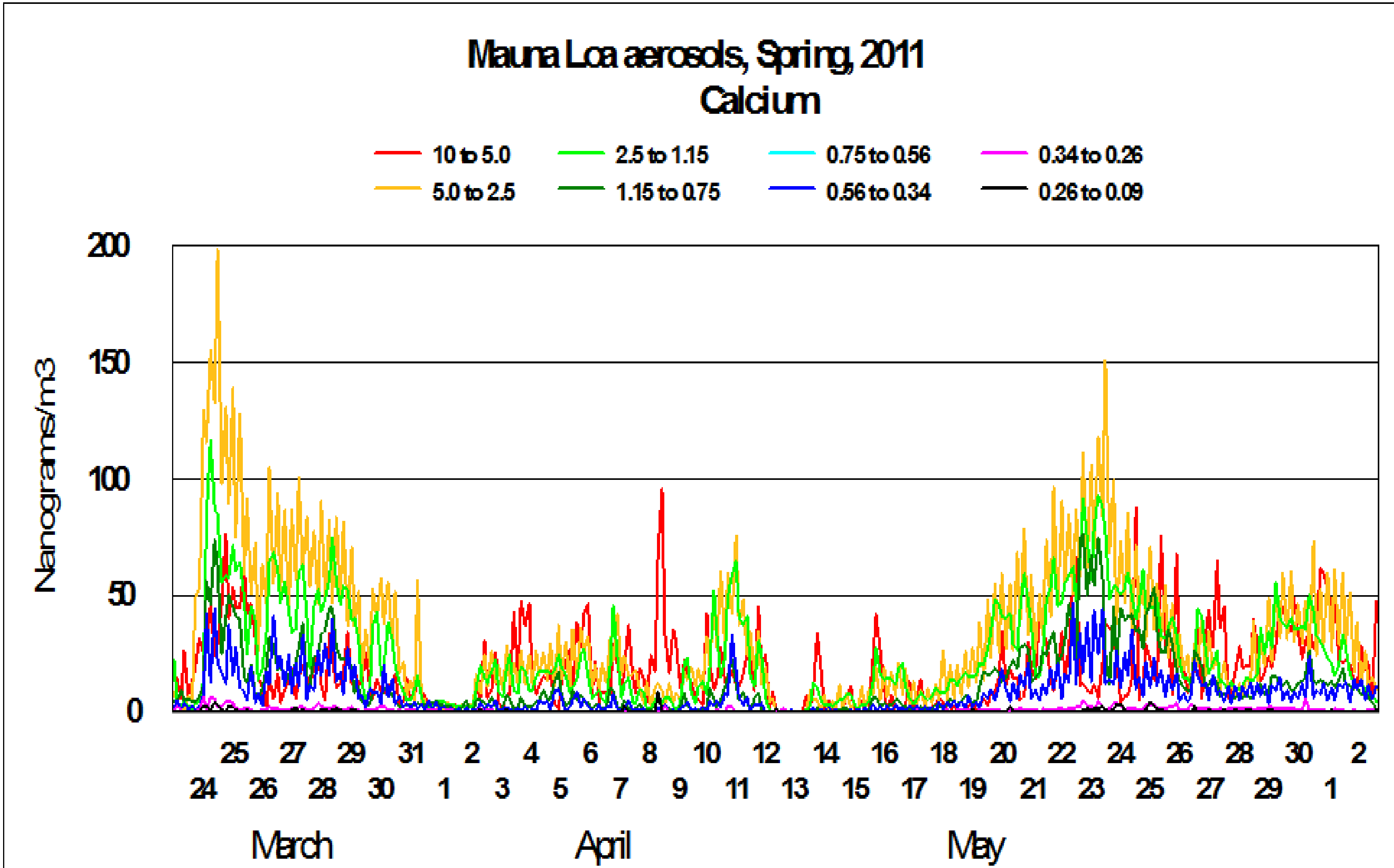




Mauna Loa aerosols, Spring, 2011
Sulfur
10 to 5.0
5.0 to 2.5
2.5 to 1.15
1.15 to 0.75
0.75 to 0.56
0.56 to 0.34
0.34 to 0.26
0.26 to 0.09
Nanograms/m3
1000
800
600
400
200
0
25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 2
24 26 28 30 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 1
March
April
May

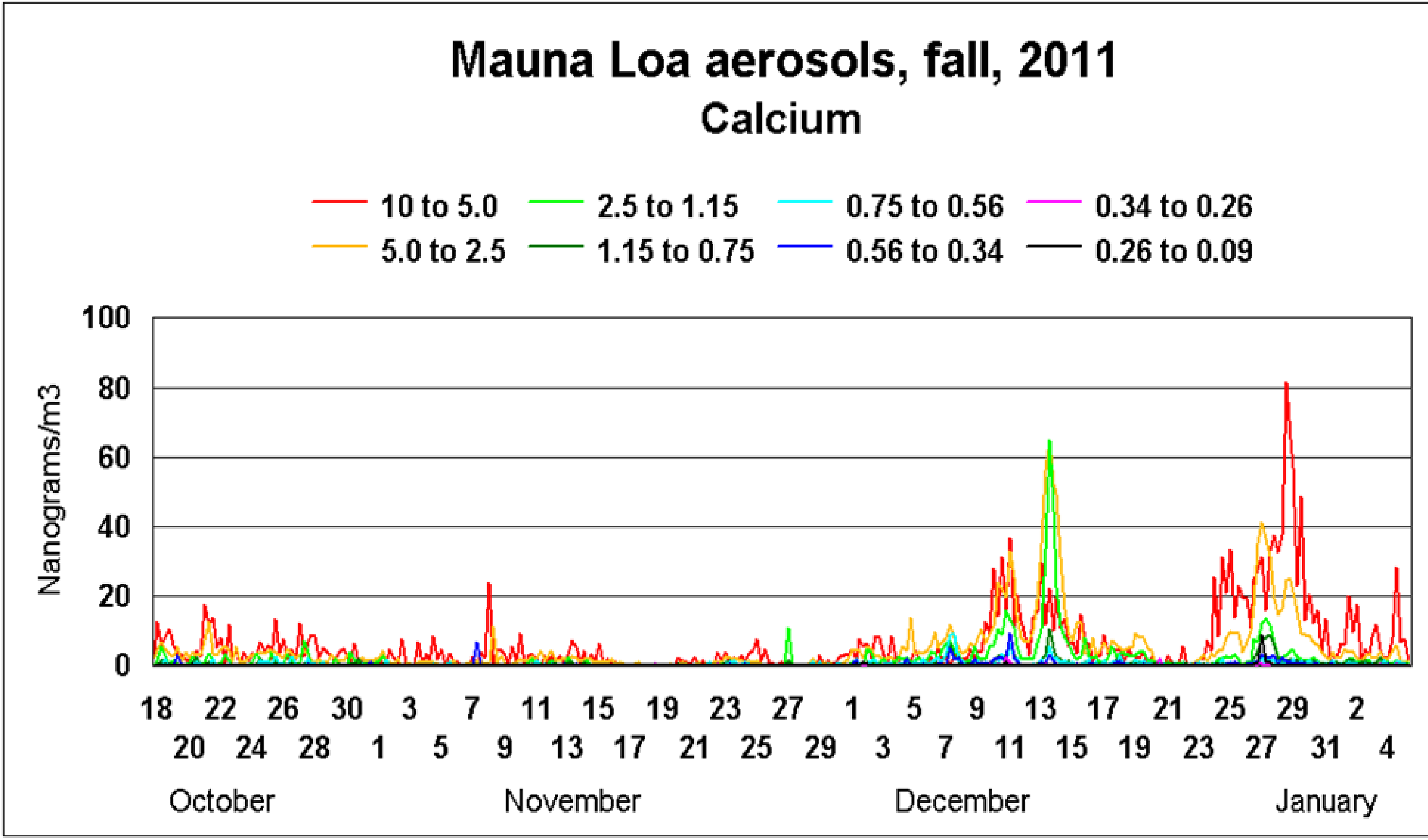

NOAA HYSPLIT MODEL
Backward trajectories ending at 0200 UTC 04 Apr 11
GDAS Meteorological Data
Source ★ at 19.54 N 155.50 W
50
30
10
-10
140
160
-160
-140
-120
Meters AGL
4000
3000
2000
1000
04/04
04/03
04/02
04/01
03/31
03/30
03/29
03/28
03/27
03/26
Job ID: 197129
Job Start: Tue May 20 02:21:46 UTC 2014
Source 1 lat.: 19.540000 lon.: -155.500000 hgts: 1000, 2000, 3000 m AGL
Trajectory Direction: Backward
Duration: 240 hrs
Vertical Motion Calculation Method: Isentropic
Meteorology: 0000Z 1 Apr 2011 - GDAS1

Spring, 2011



Mauna Loa aerosols, Spring, 2011
Calcium
10 to 5.0
5.0 to 2.5
2.5 to 1.15
1.15 to 0.75
0.75 to 0.56
0.56 to 0.34
0.34 to 0.26
0.26 to 0.09
Nanograms/m3
200
150
100
50
0
25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 2
24 26 28 30 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 1
March
April
May

Comparison to fall; note the scale change.



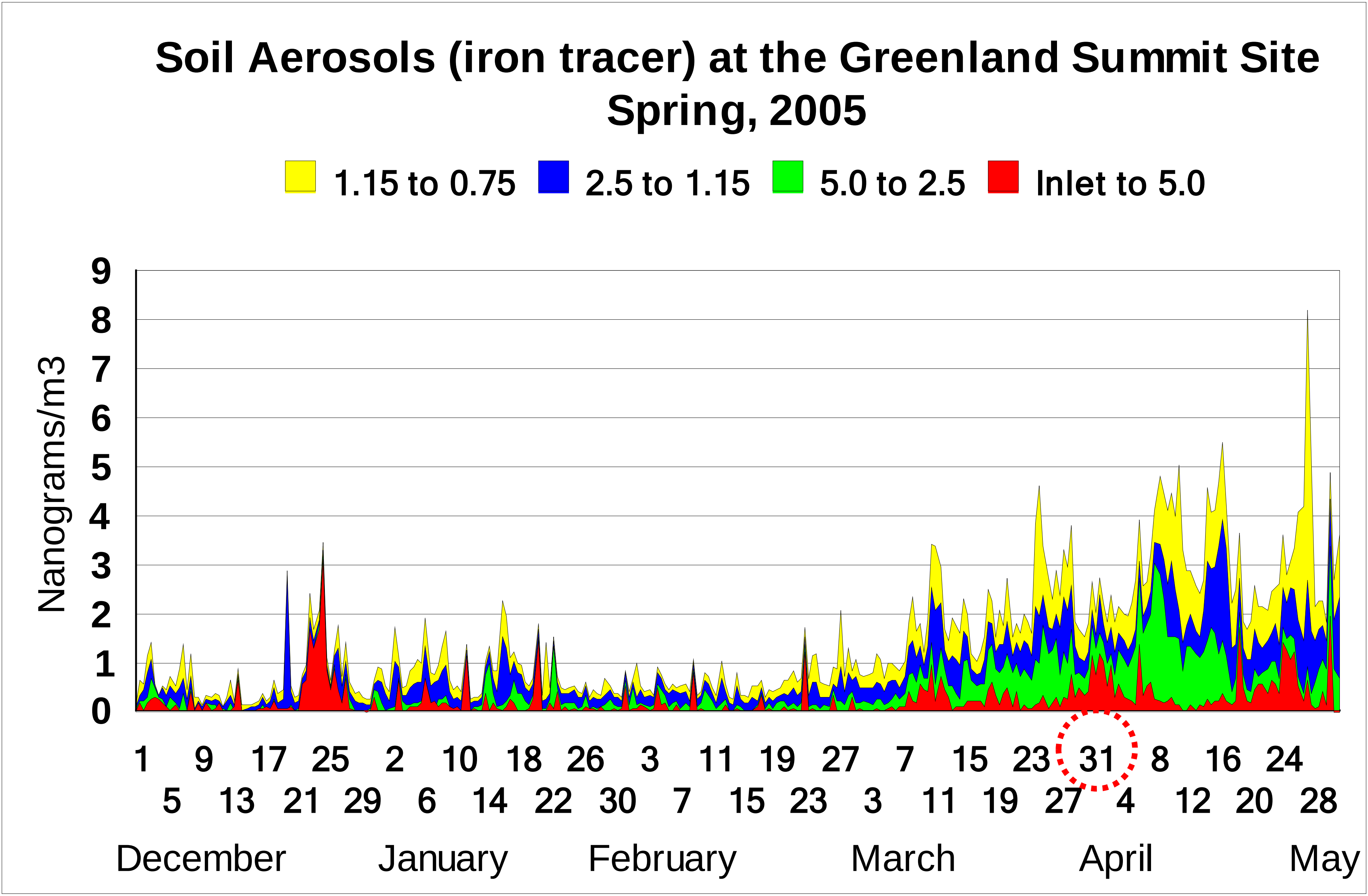
Results of 2011 to 2001 comparison

- Seasonal variability make six week studies unable to accurately measured annual increases
- Need an continuous study to see aerosol trends
- Very fine silicon (tracer of coal combustion) ~ 15% at MLO versus Taiwan

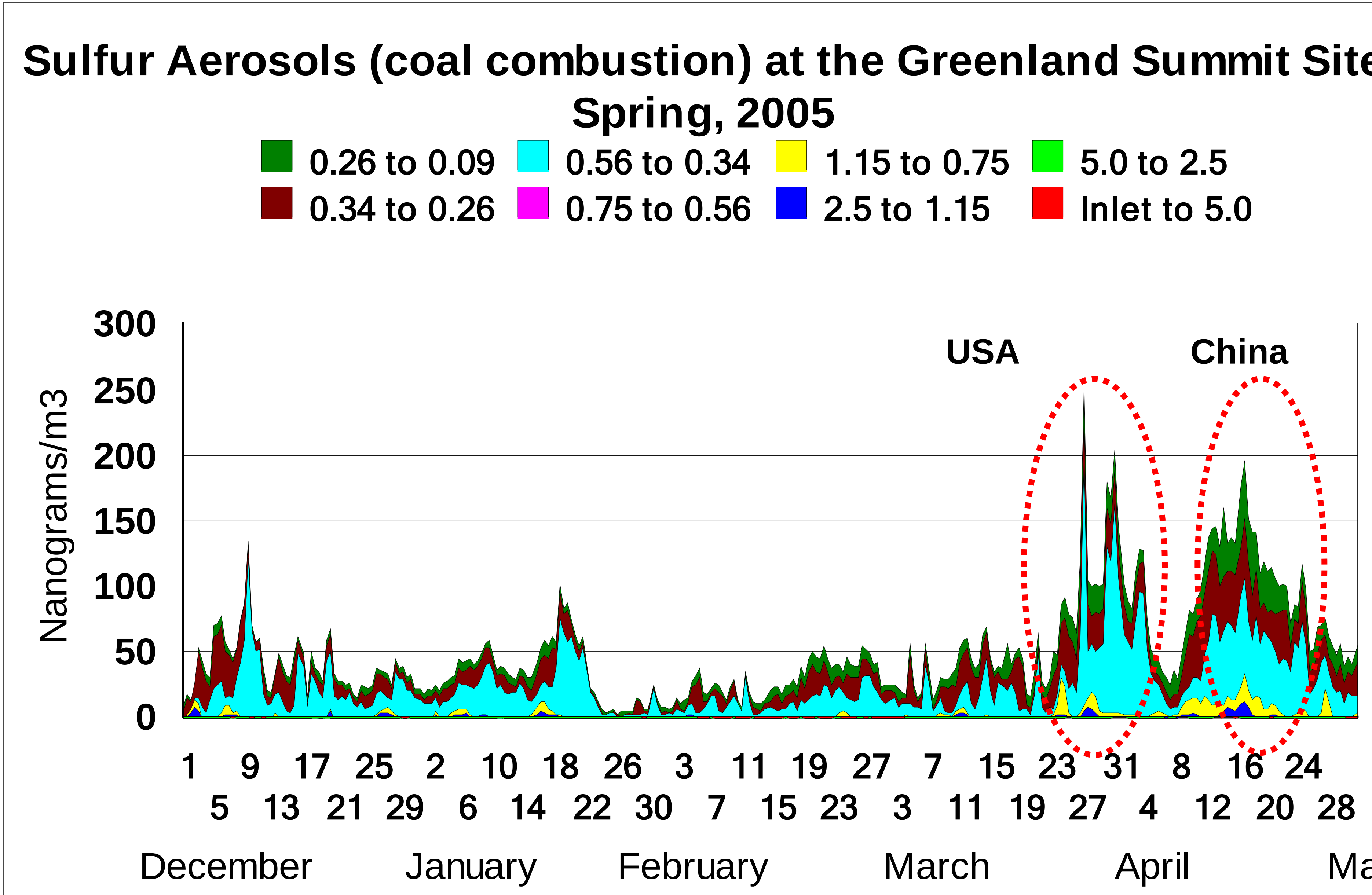
Trends in aerosols for global climate studies

- **Urgent need to track aerosols at MLO**
  - Continuous measurements (12 hr resolution) of size resolved (10 to 0.09 µm) mass, optical scattering and absorption , sulfates, organics, soot, trace metals,….
- Techniques perfected at Greenland, 2003 to 2013, in much more challenging conditions
  - U. California, Davis, with UC Merced, Desert Research Institute, and U. Alaska, Fairbanks
  - Cost – circa $45,000/year

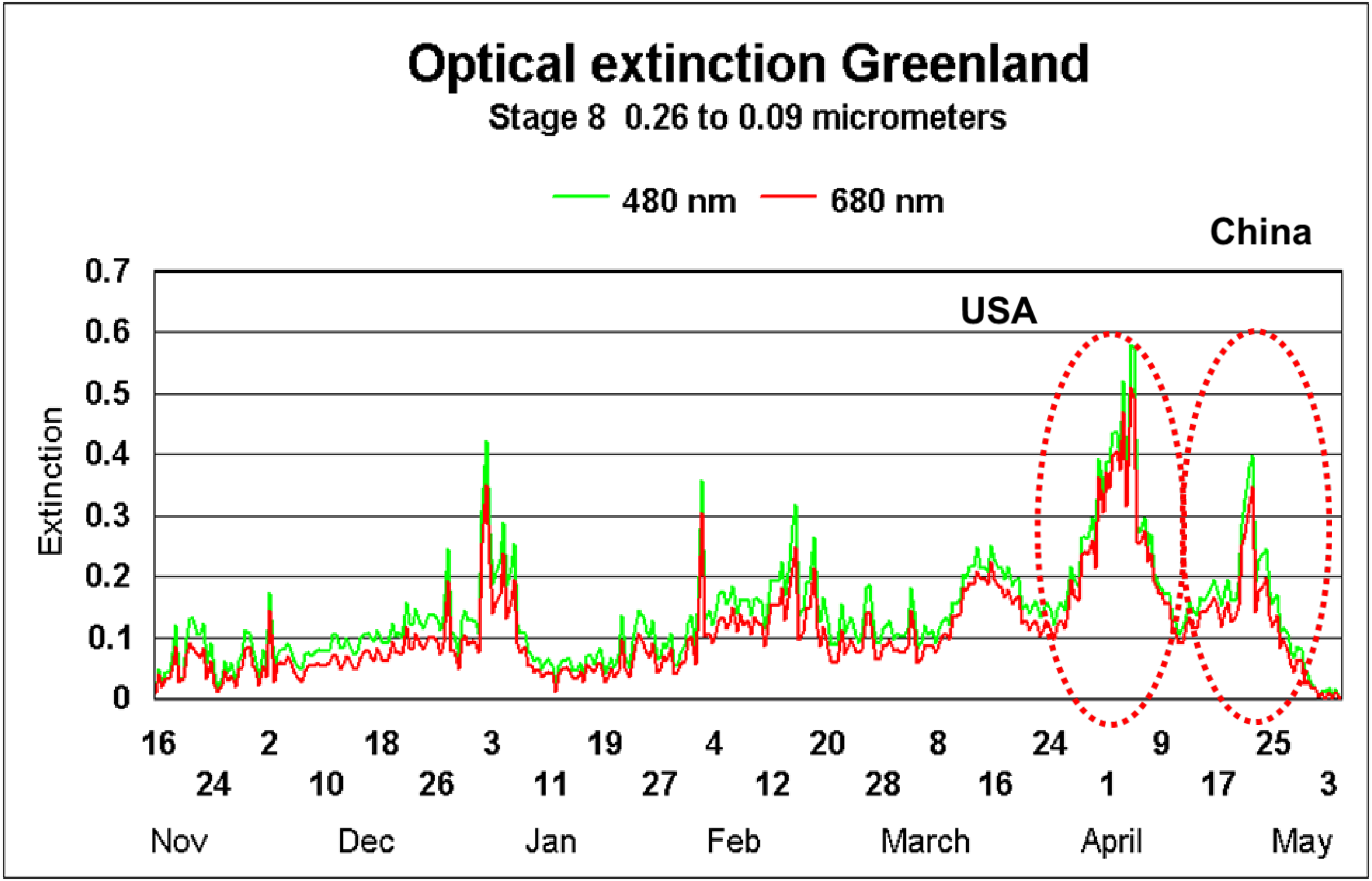
Continuous sampling – inlet at surface, but DRUM in tunnel under 3 m of snow



Soil signature allows deposition calculations while identifying current anthropogenic impacts at Summit



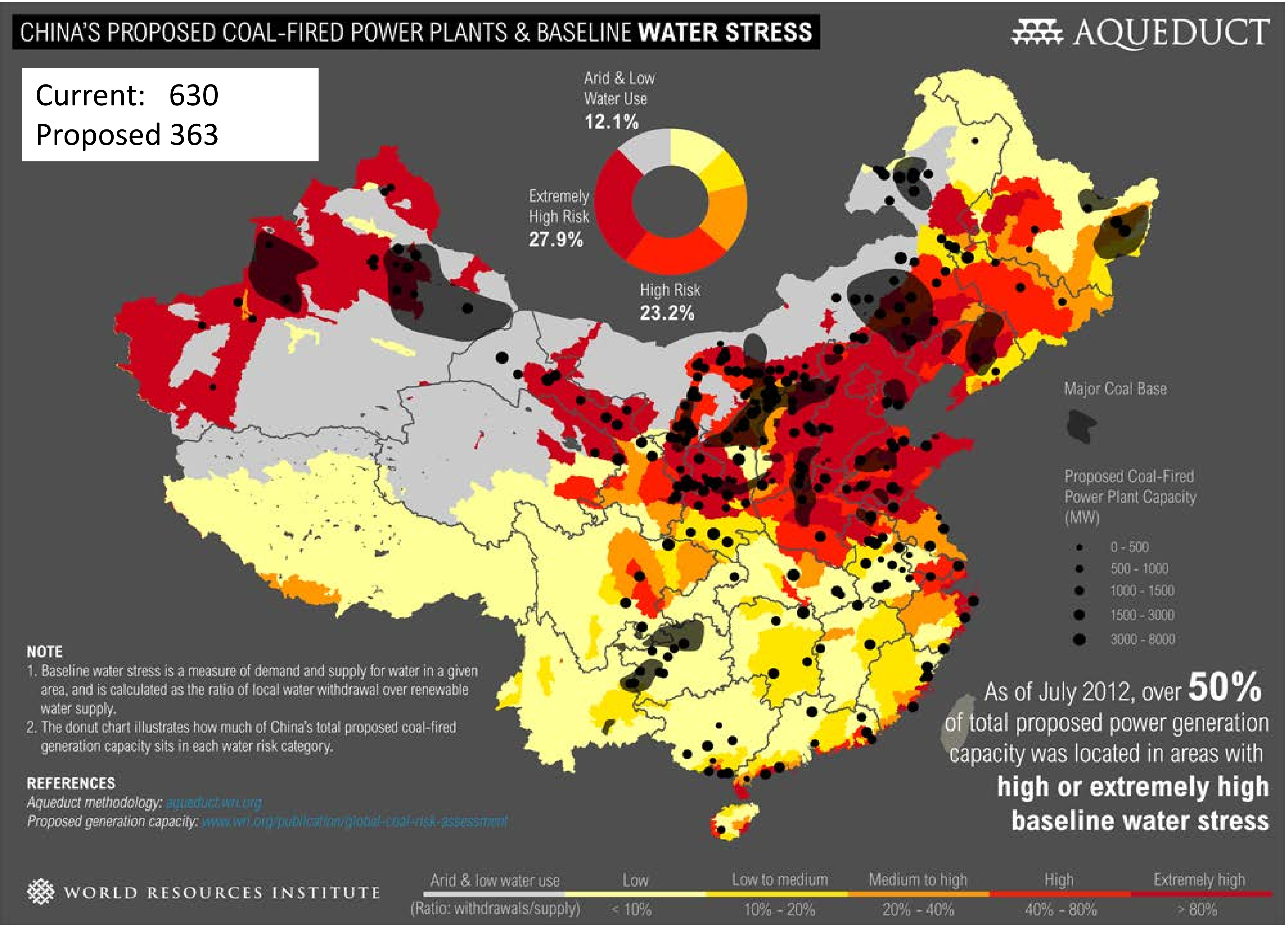
Optical extinction every 50 nm 350 nm to 720 nm



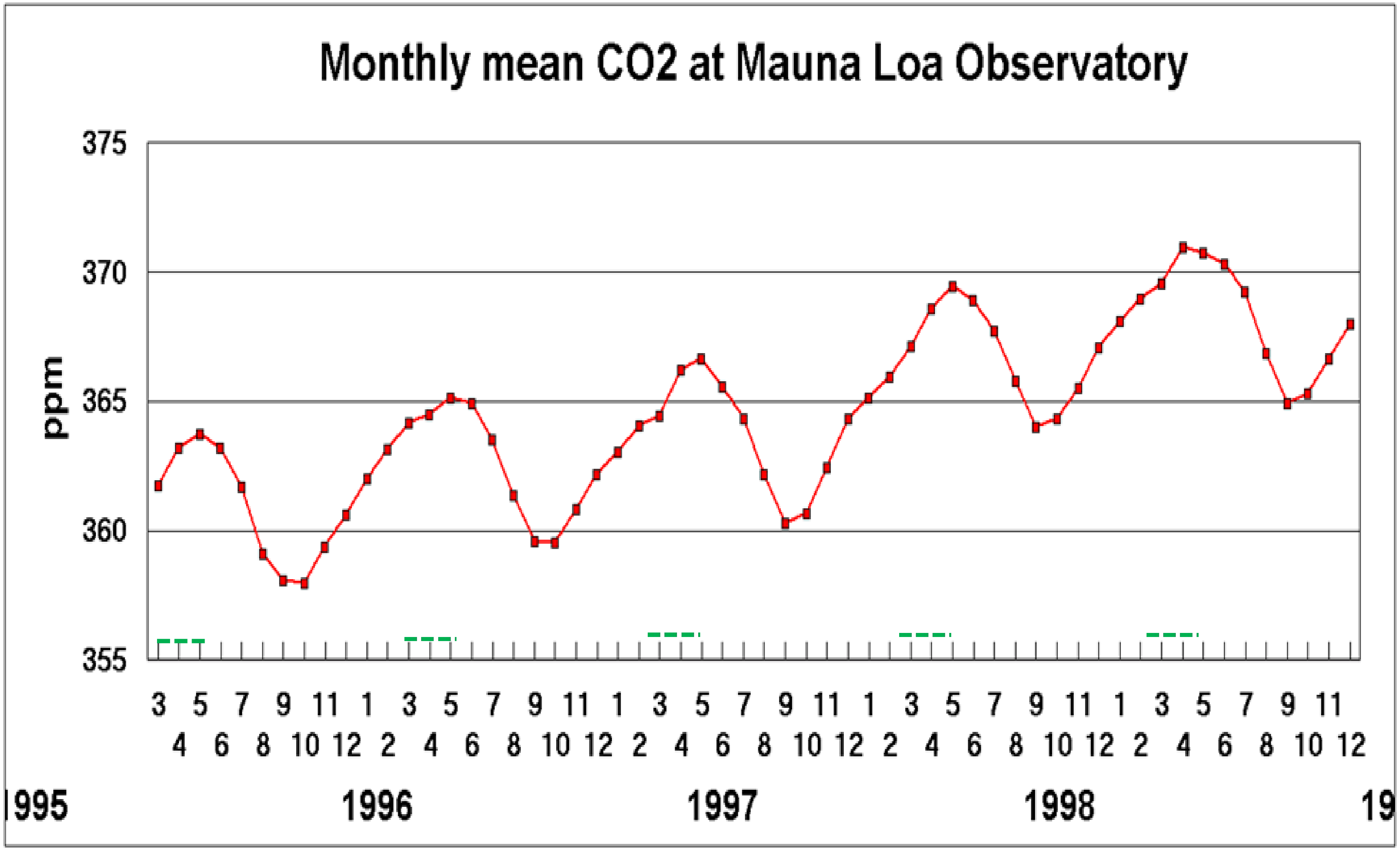
Acknowledgements

- Thanks to
  - all the MLO director and staff that supported this work for all those years
  - Prof. Kevin Perry, Dr. Steve Cliff and Dr. Yongjing Zhou who performed the S-XRF at the Advanced Light Source, Lawrence Berkeley NL (DOE supported)
  - NOAA READY for HYSPLIT (what would I do without it!)
  - NSF Polar programs for the Greenland program

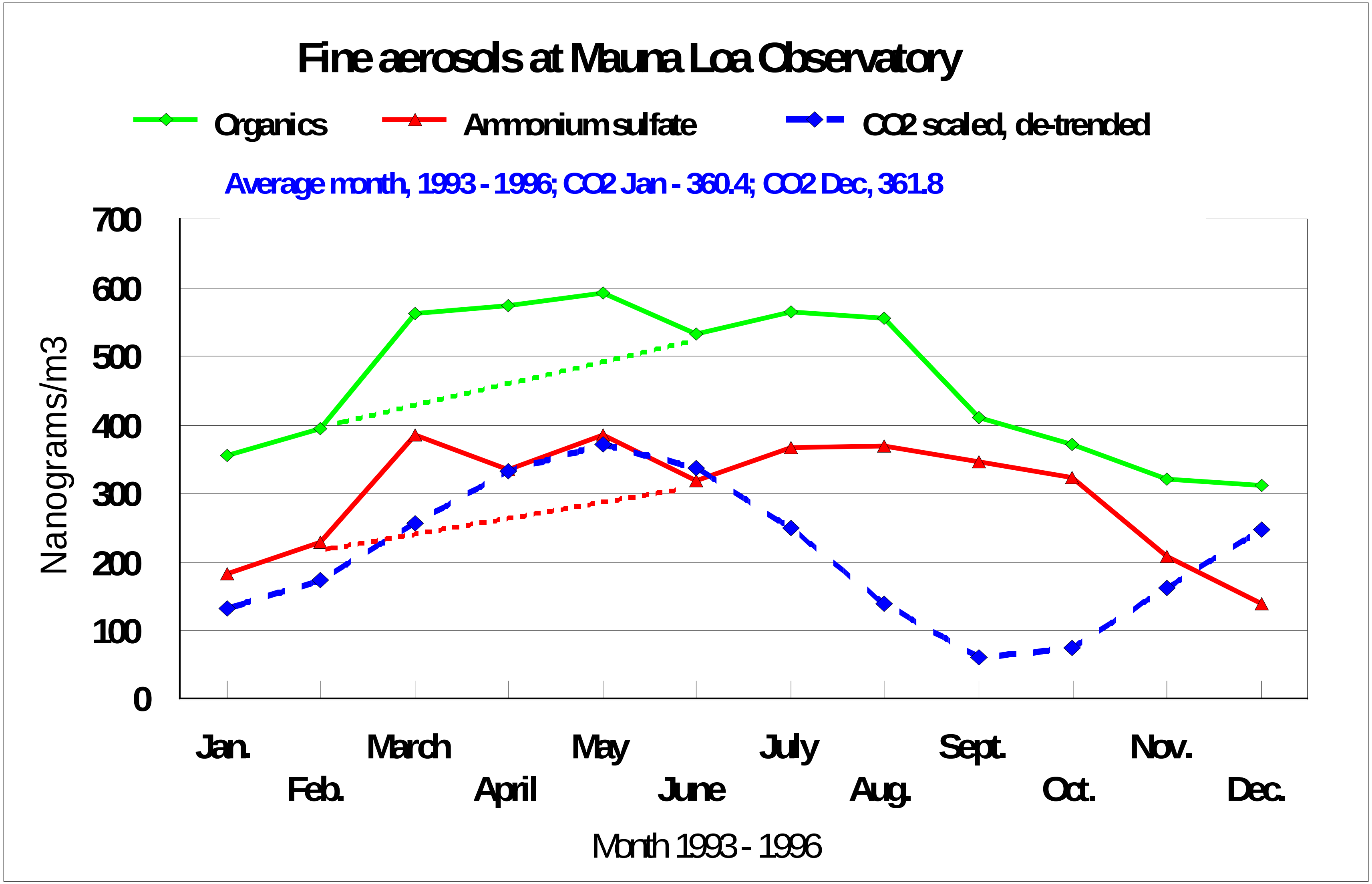
Current: 630
Proposed 363

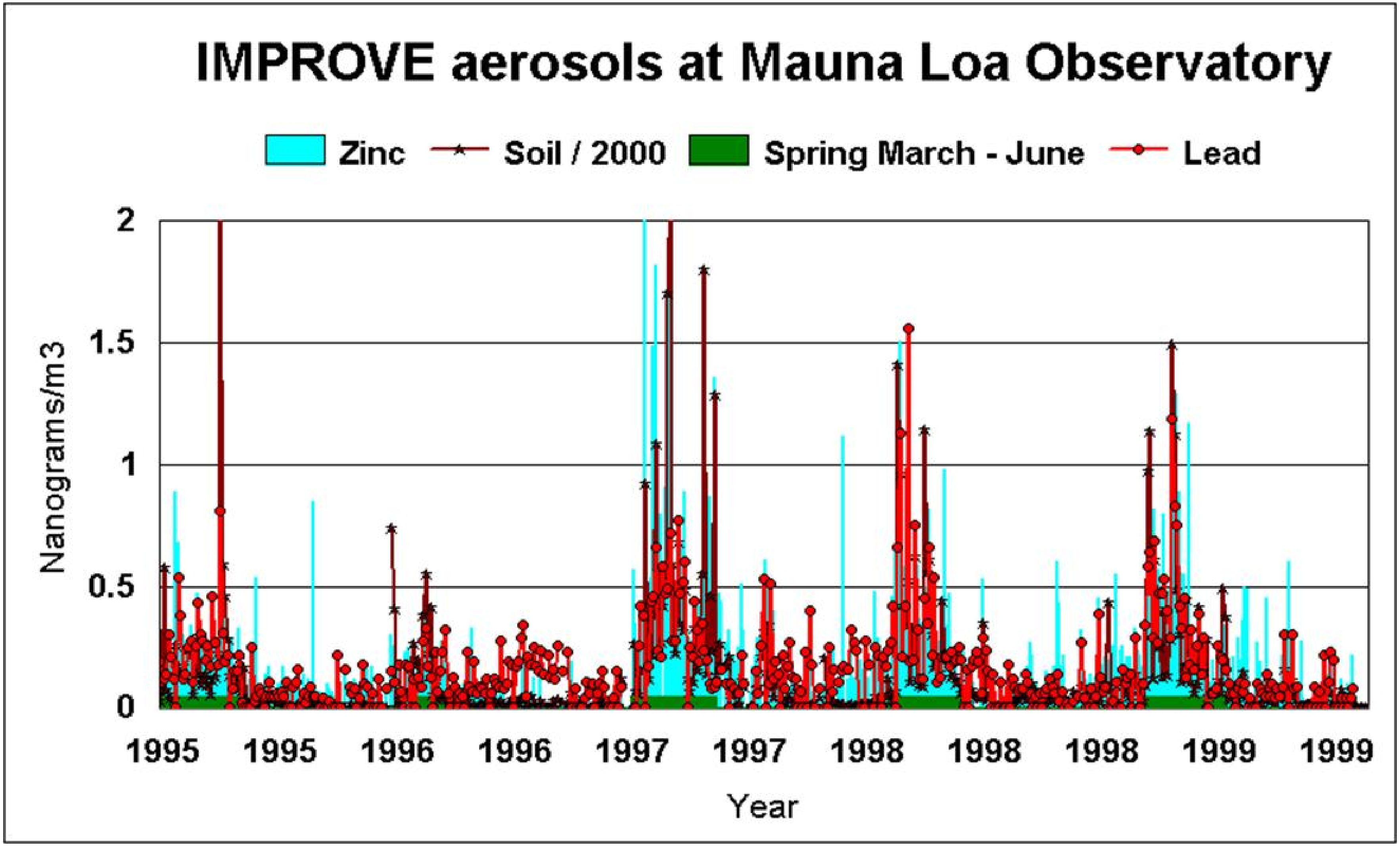


For a comparison.....



Comparison with CO2




IMPROVE aerosols at Mauna Loa Observatory
Zinc
Soil / 2000
Spring March - June
Lead
Nanograms/m3
2
1.5
1
0.5
0
1995
1995
1996
1996
1997
1997
1998
1998
1998
1999
1999
Year