Chemical and Physical Properties of Aerosols Measured Onboard the R/V Atlantis during CalNex

NOAA/PMEL Atmospheric Chemistry Group

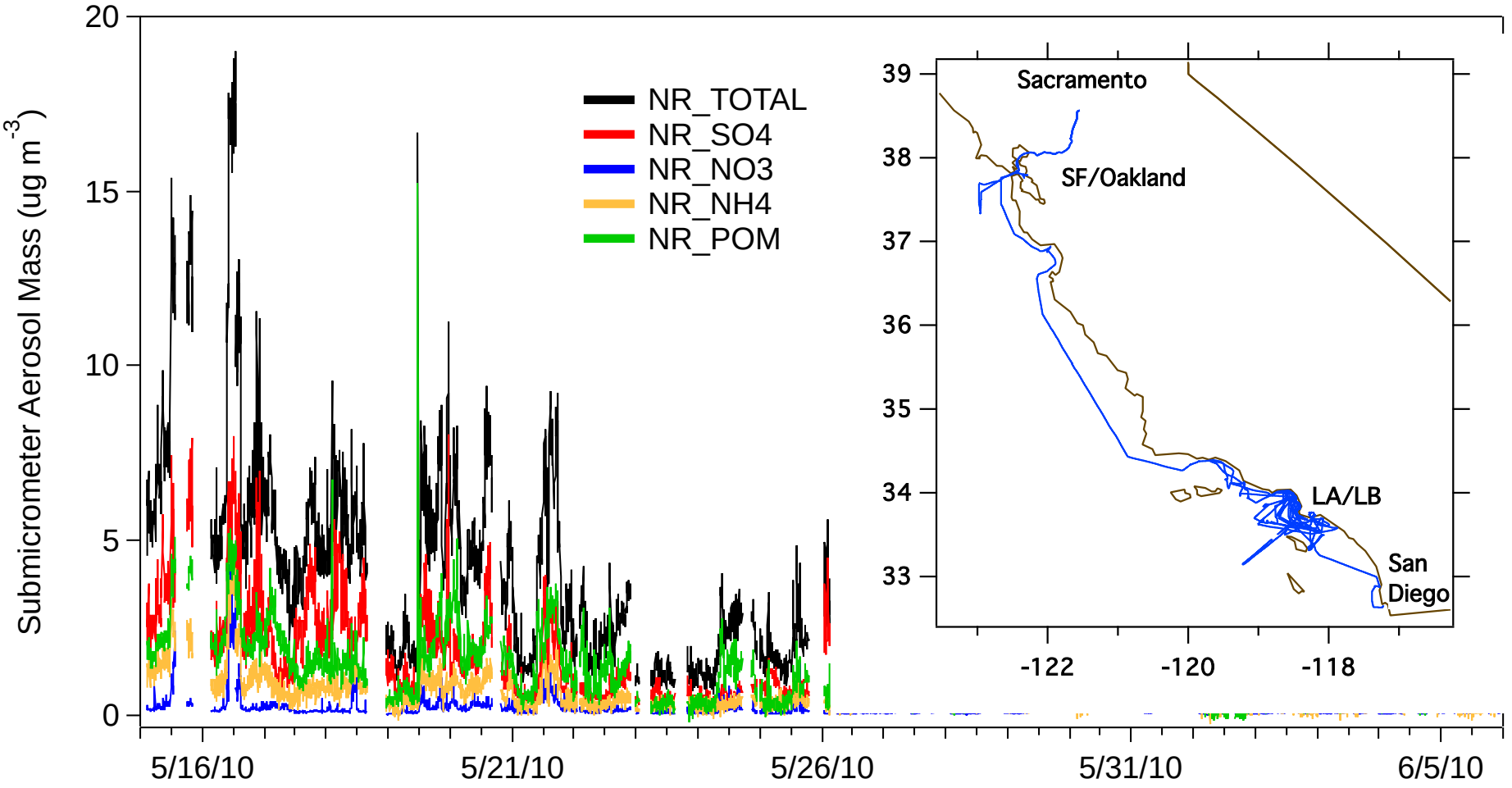
Funded through the NOAA Climate and Air Quality Programs

Data Analysis

- Q-AMS: chemistry
- DMPS-APS: aerosol number size distributions
- Meteorological parameters measured on the ship

  http://saga.pmel.noaa.gov/data/
- Thermo-denuder SMPS system: changes in number size distributions heated to 230°C
- FLEXPART products (Jerome Brioude UofCO & NOAA-ESRL)

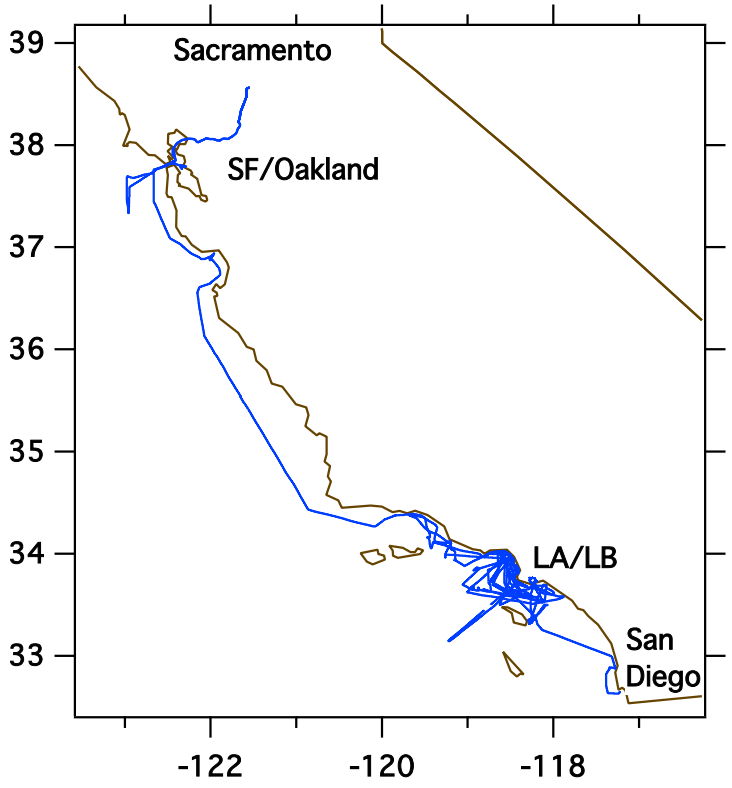
Submicrometer NR Aerosol Mass along the Atlantis Cruise Track



Mean concentration 3.5 ug m^{-3} (0.05 – 19 ug m^{-3})

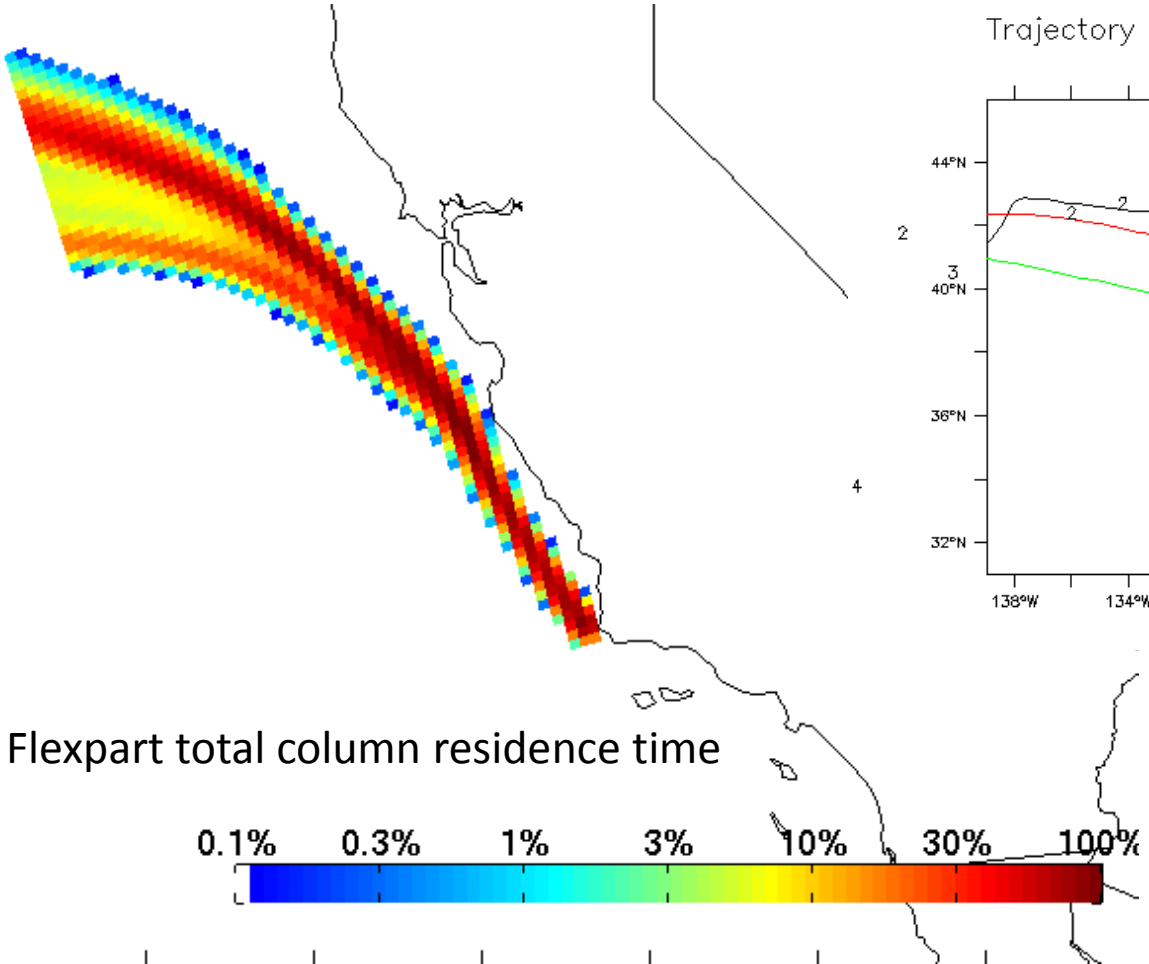
Case Studies

1. Background marine air flow to CA
2. Inland – Sacramento Ship Channel
3. Santa Monica Bay
4. Port of Long Beach/LA

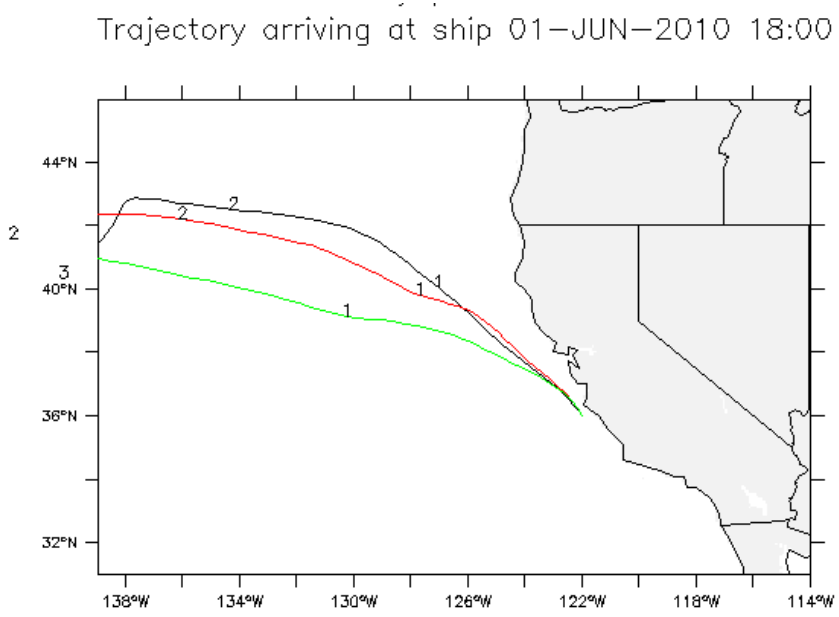


Case Studies

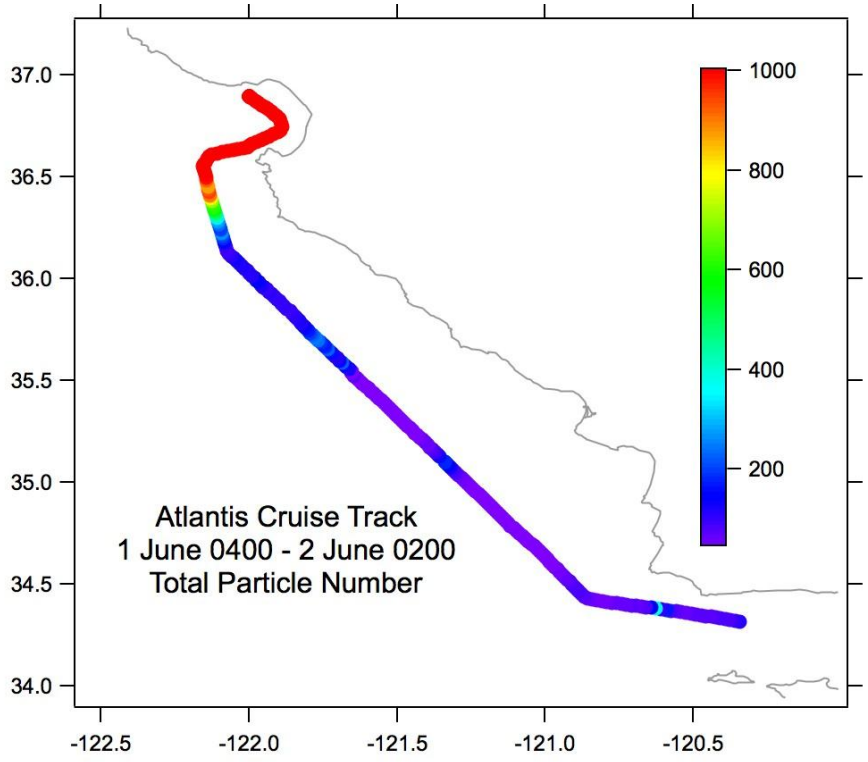
1. Background marine air mass – on shore flow to CA



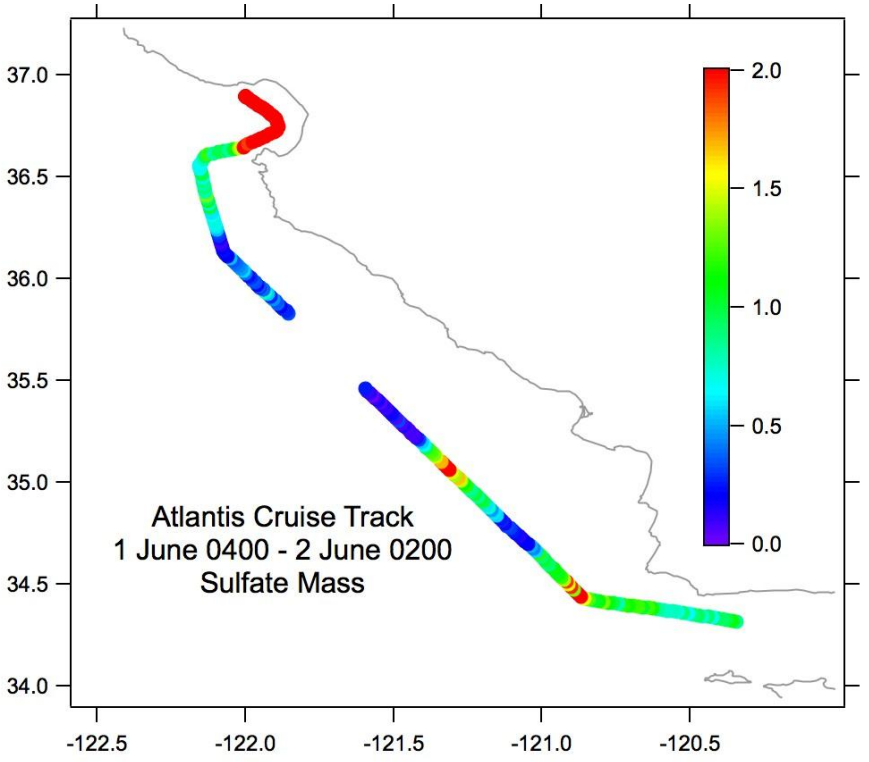
Flexpart total column residence time



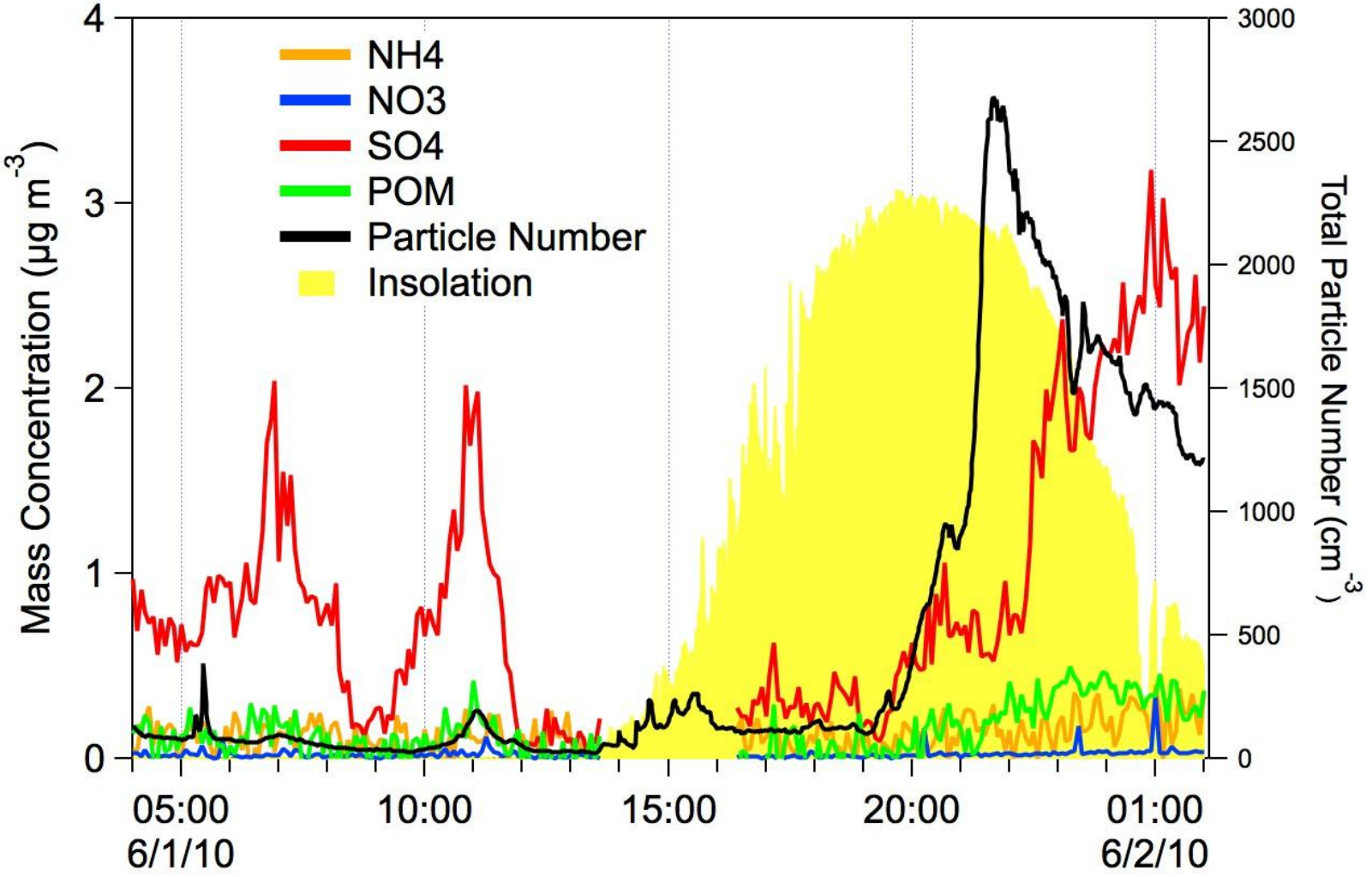
Hysplit back trajectory



Particle Number (cm^{-3})



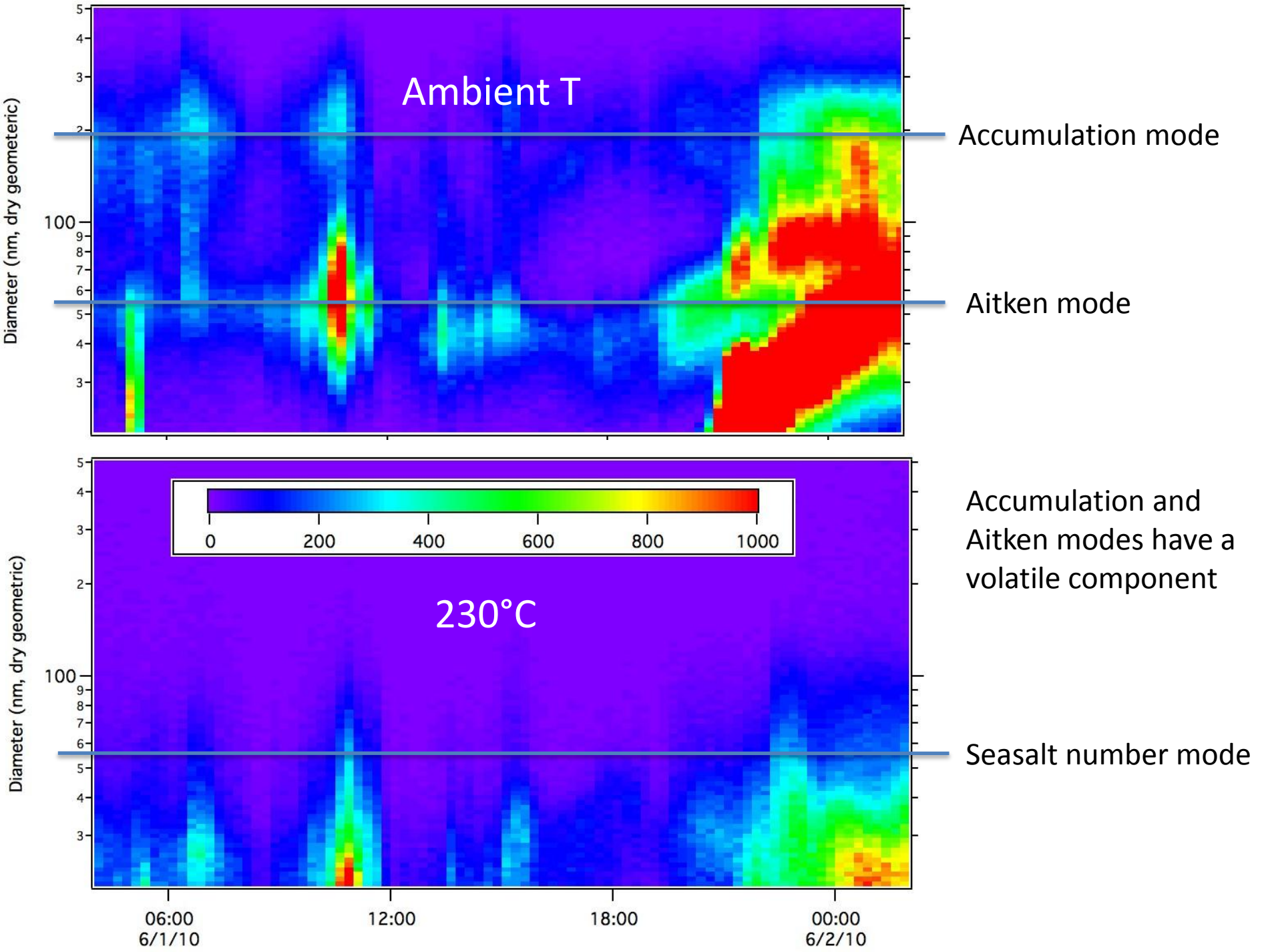
Sulfate Mass (ug m^{-3})

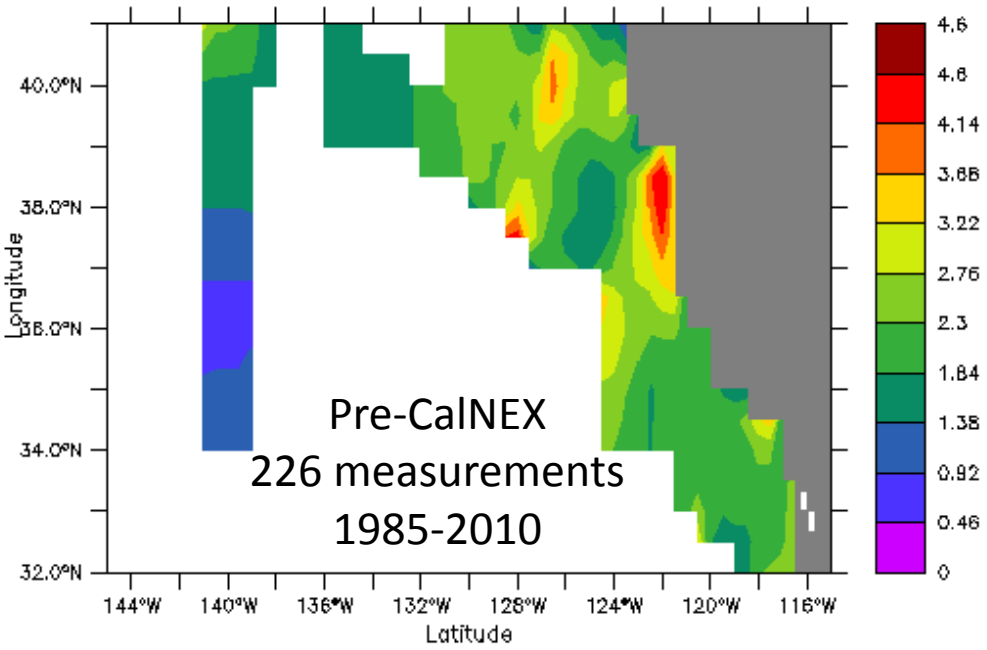


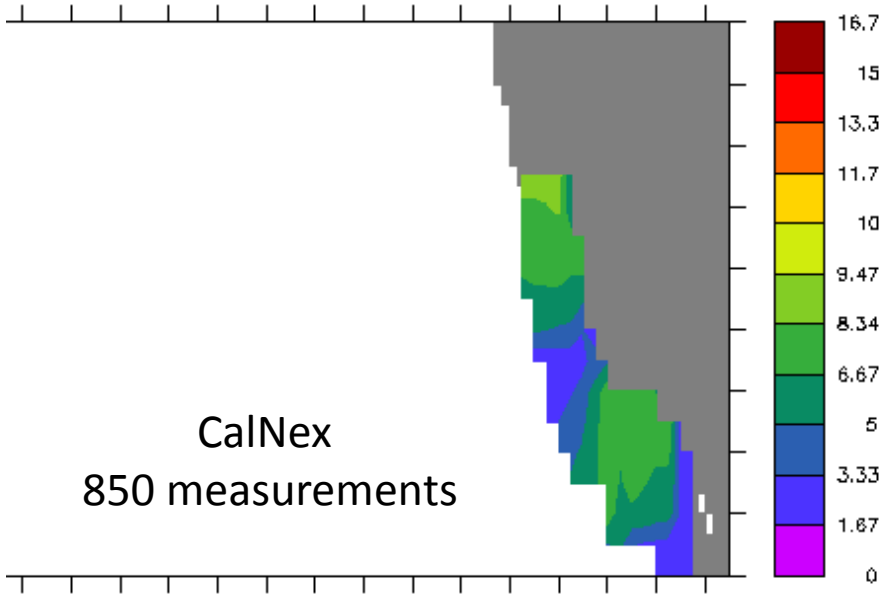
Very low organic aerosol concentrations.

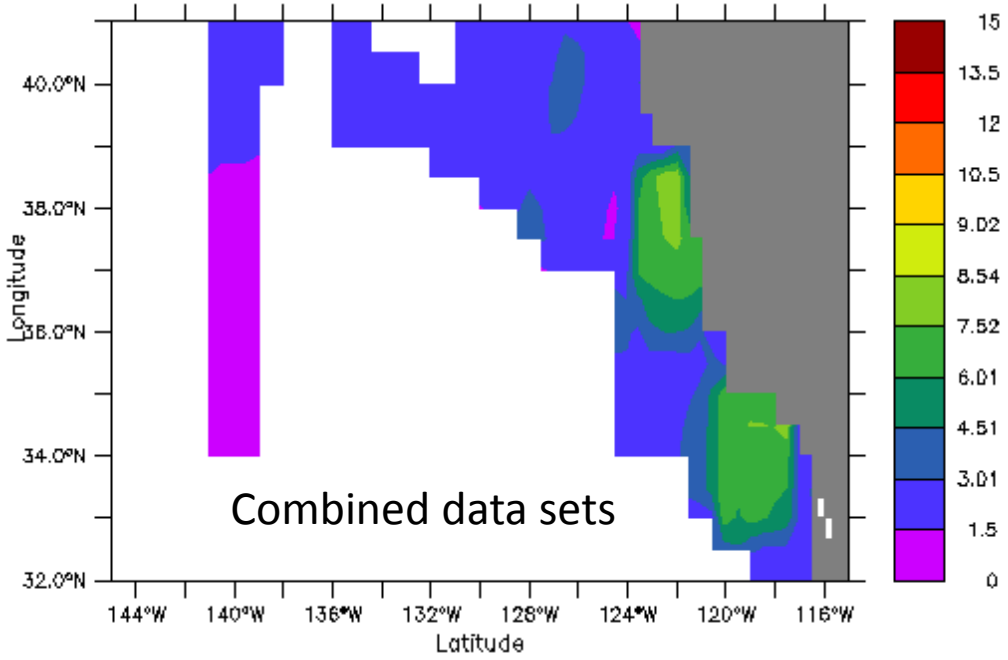
Very acidic submicrometer sulfate aerosol ($NH_4^+/SO_4^=$ MR <<1).

Burst of small particles (high number low mass) in afternoon.


Ambient T
Accumulation mode
Aitken mode
Diameter (nm, dry geometeric)
230°C
0
200
400
600
800
1000
Accumulation and Aitken modes have a volatile component
Seasalt number mode
Diameter (nm, dry geometric)
06:00
6/1/10
12:00
18:00
00:00
6/2/10







Seawater DMS Concentrations
May-October
http://saga.pmel.noaa.gov/dms/

Sulfur Transport to CA
5 day DMS lifetime, 35% onshore flow
2.3e8 gS/day (Bates & Cline, 1985)

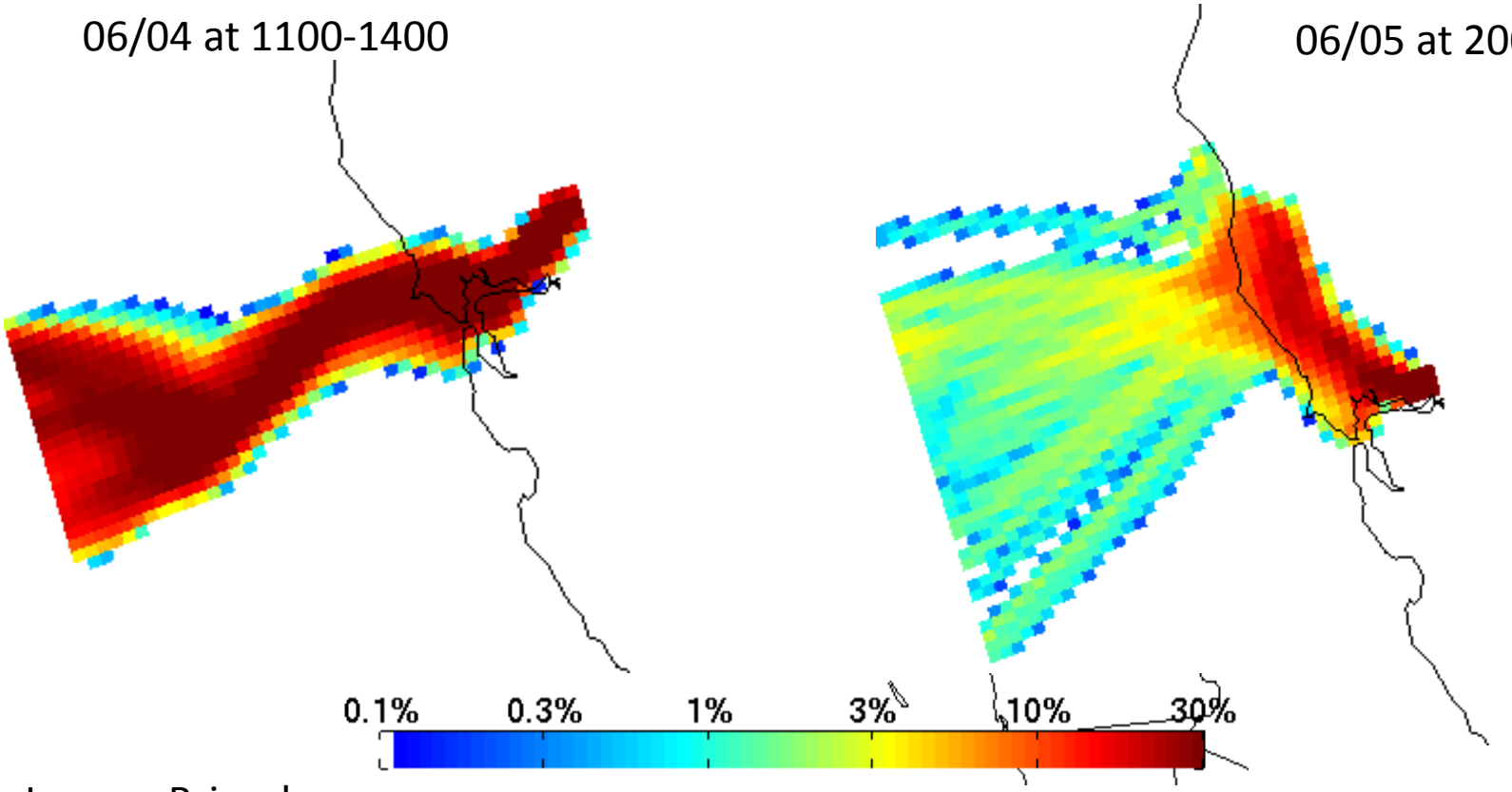
US West Coast Shipping, 0.5% S Fuel
0.13e8 gS/day (Eric Williams, CSD)

Case Study 2
Sacramento Ship Channel
June 4-6, 2010

Surface residence time plots

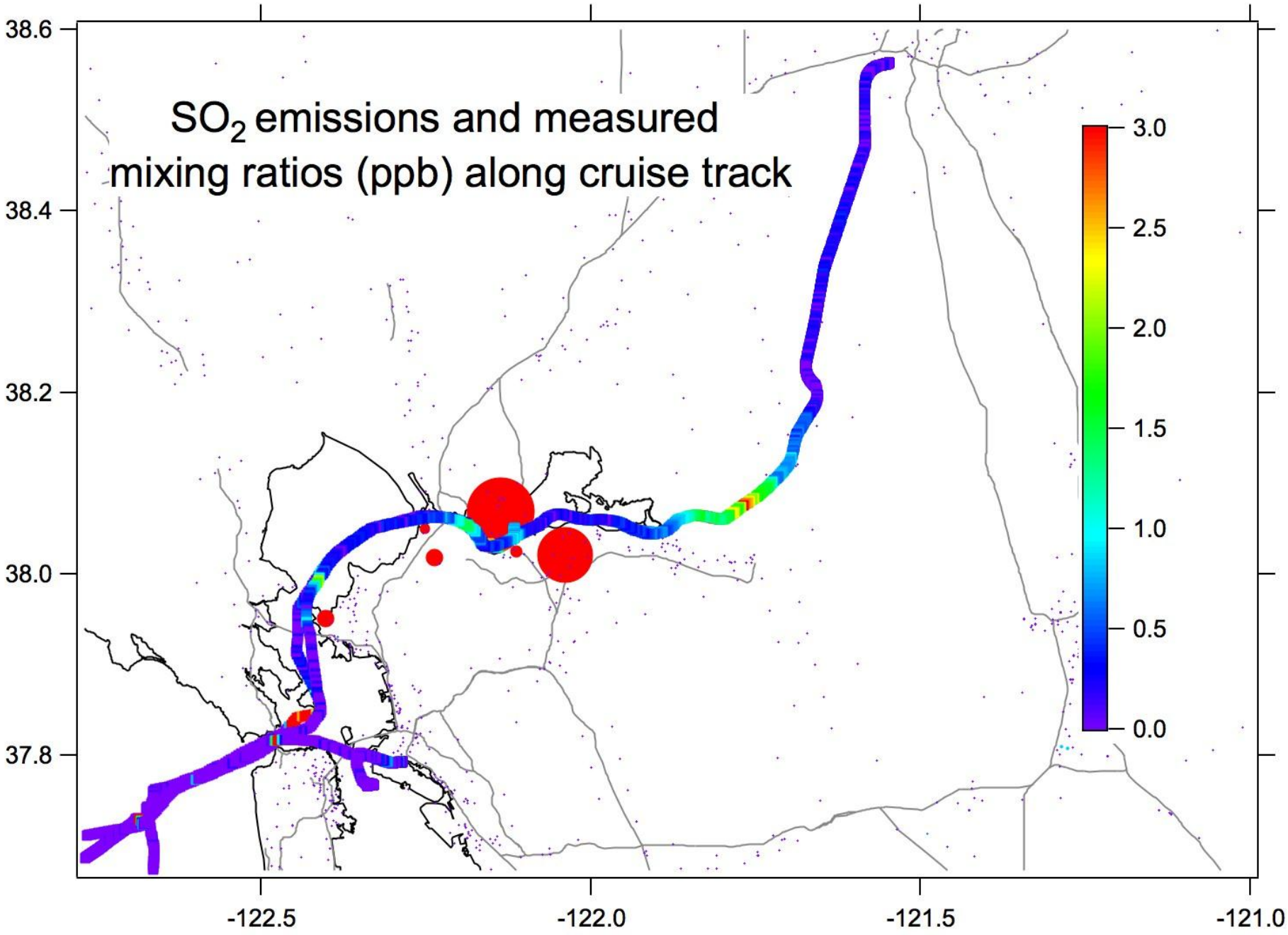
06/04 at 1100-1400

06/05 at 2000-2300



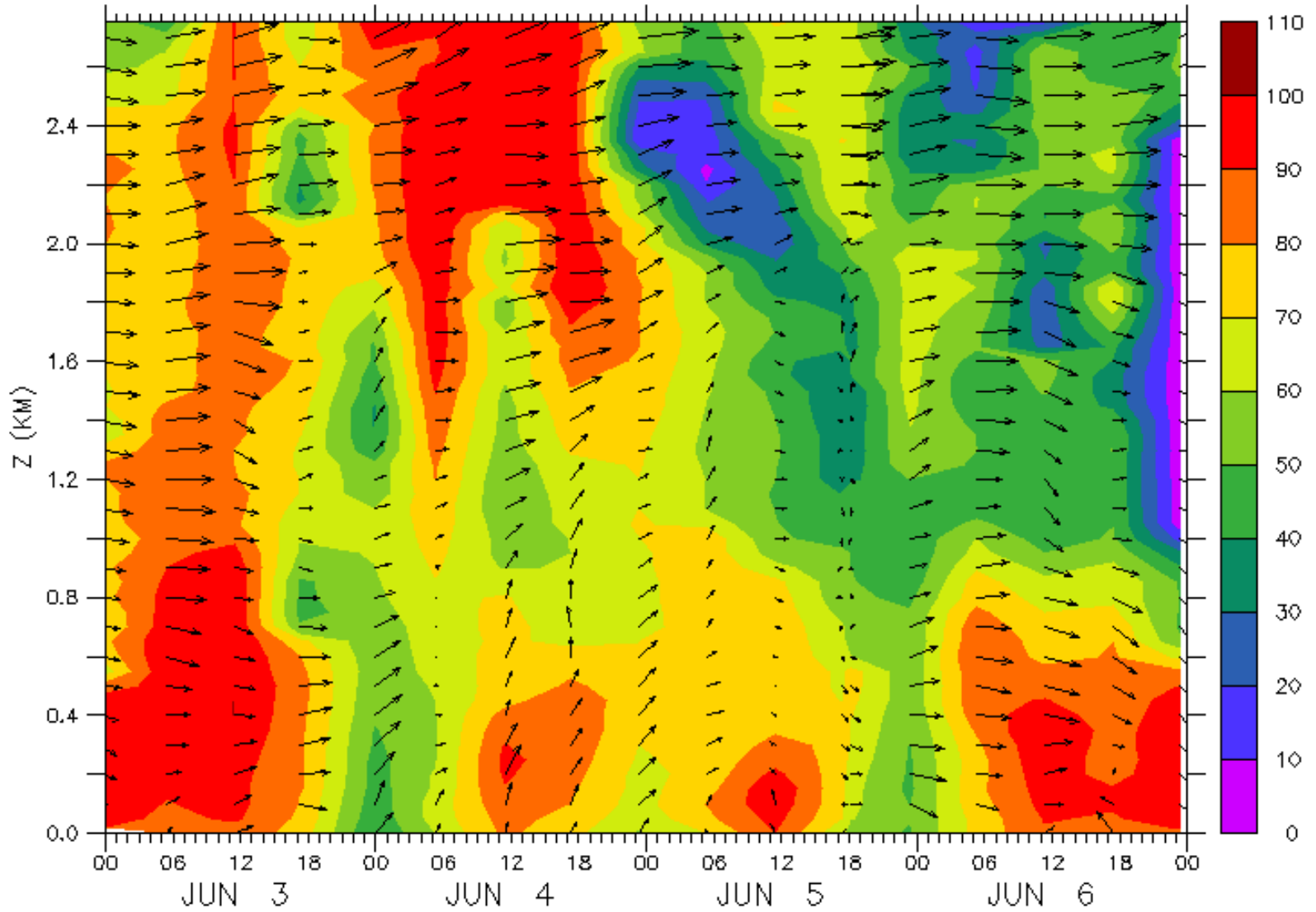
Jerome Brioude

http://www.esrl.noaa.gov/csd/metproducts/flexpart/static_pages/atlantisimage.html


SO_2 emissions and measured mixing ratios (ppb) along cruise track
38.6
38.4
38.2
38.0
37.8
-122.5
-122.0
-121.5
-121.0
3.0
2.5
2.0
1.5
1.0
0.5
0.0

YEAR : 2010

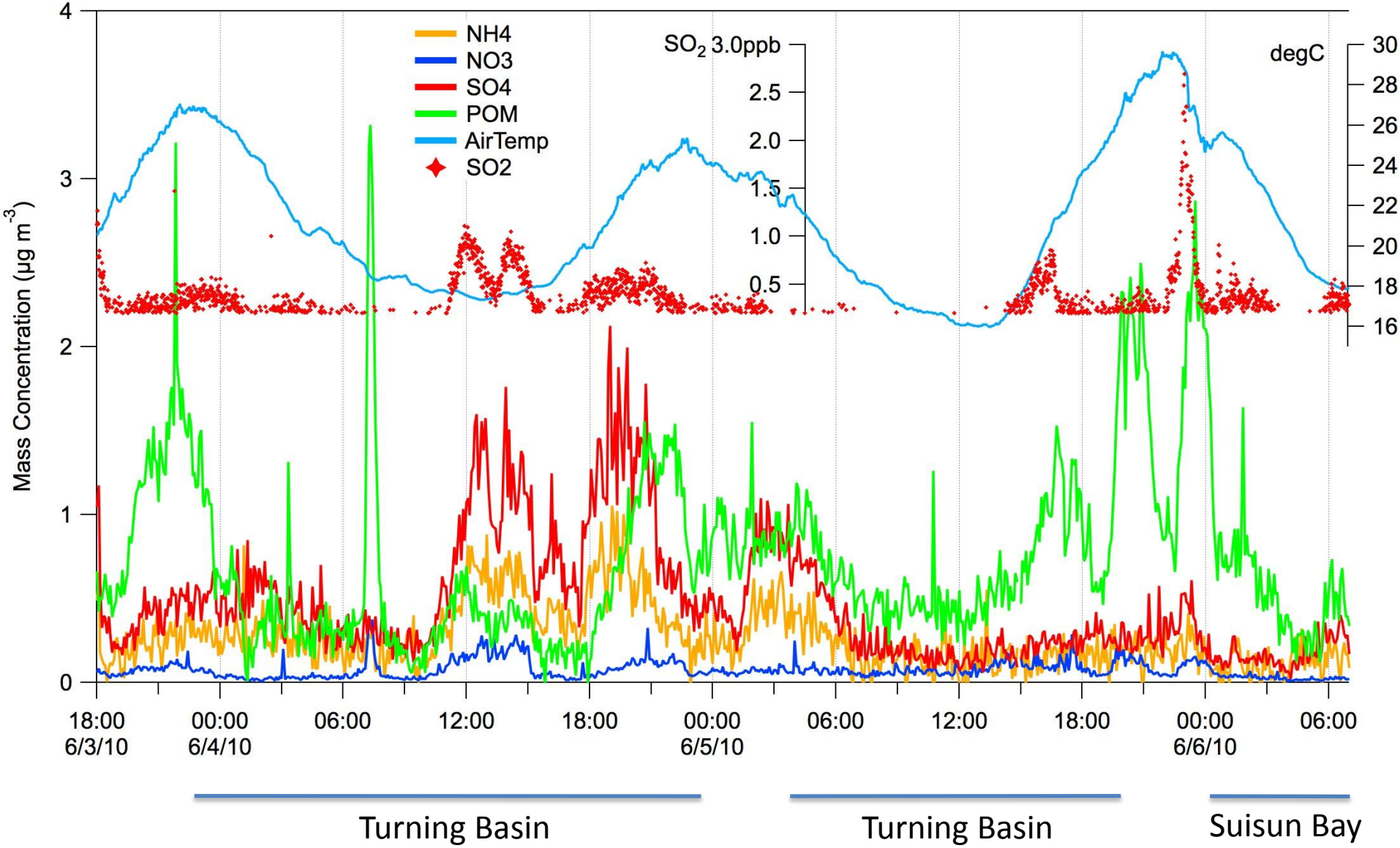
DATA SET: CALNEX_rsond_all

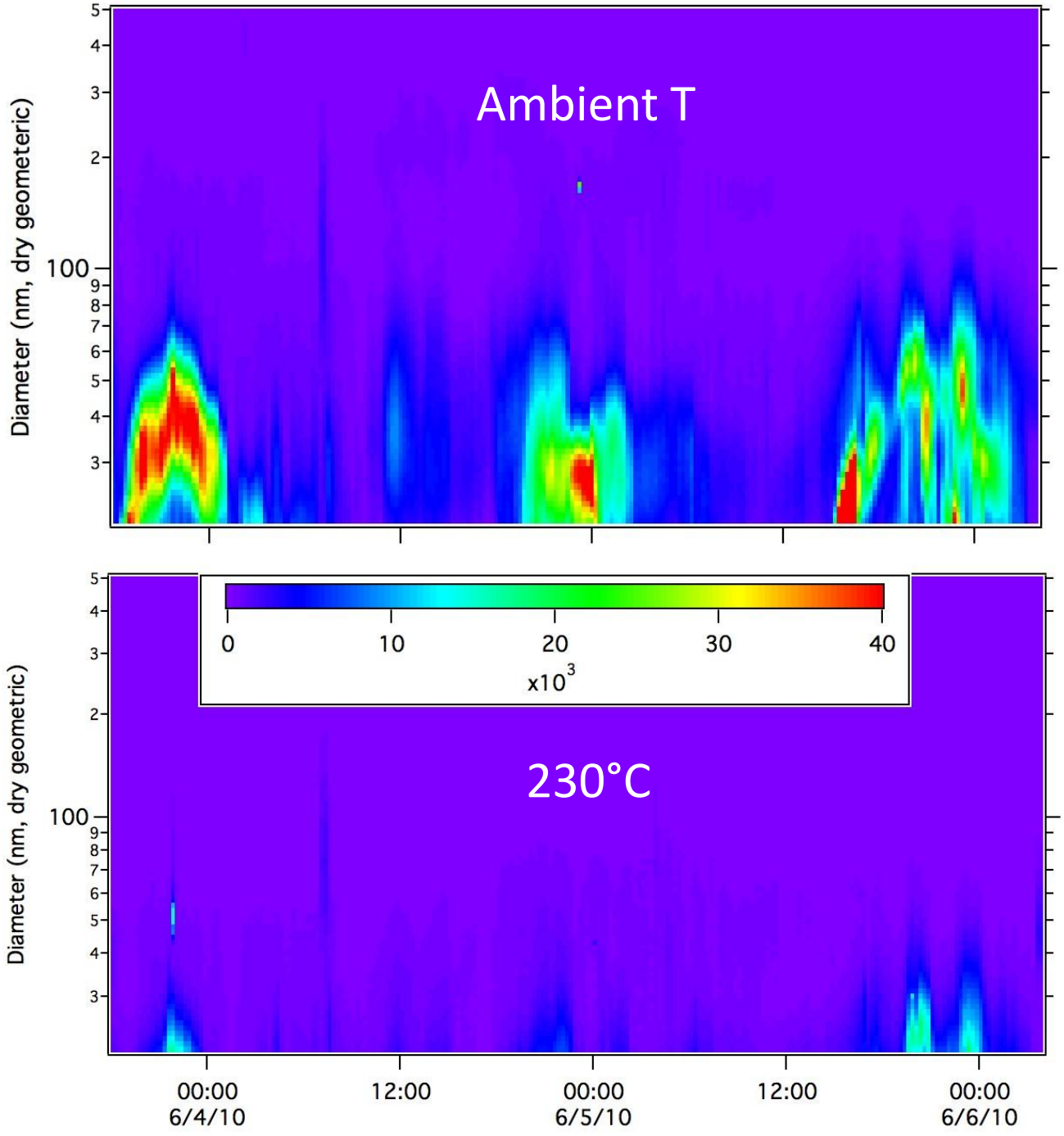


Relative Humidity, %, and Horizontal Winds

→ 20.0

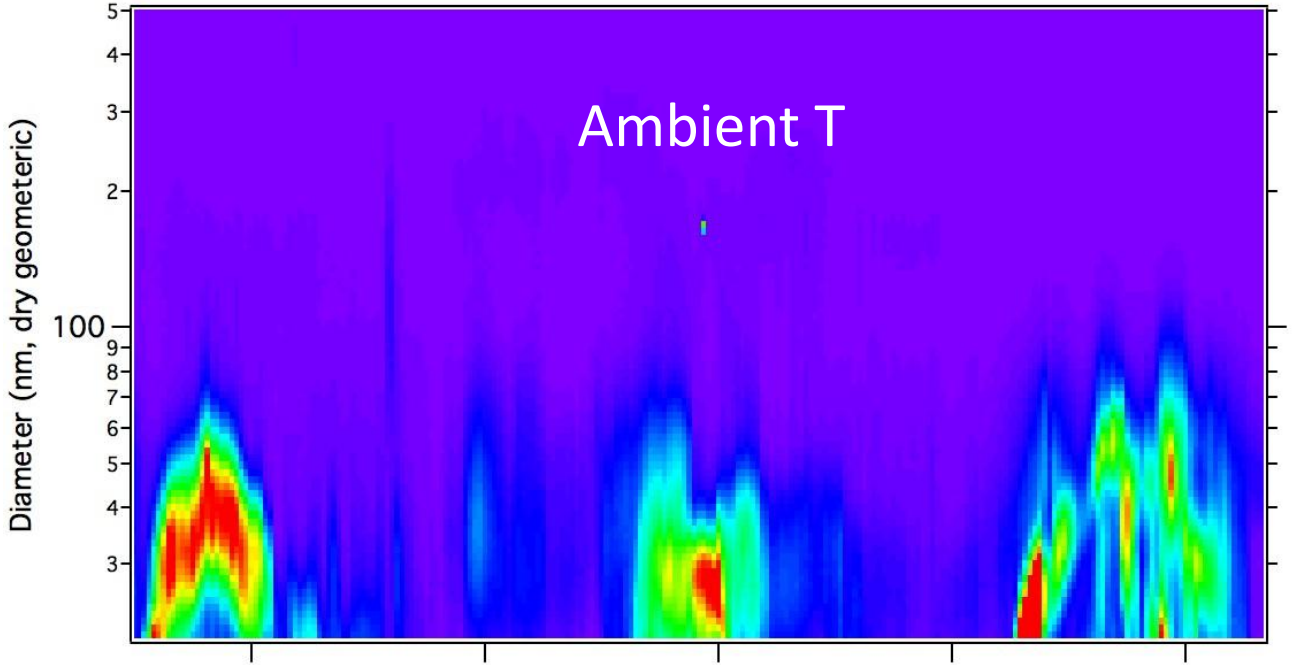
Sacramento Ship Channel

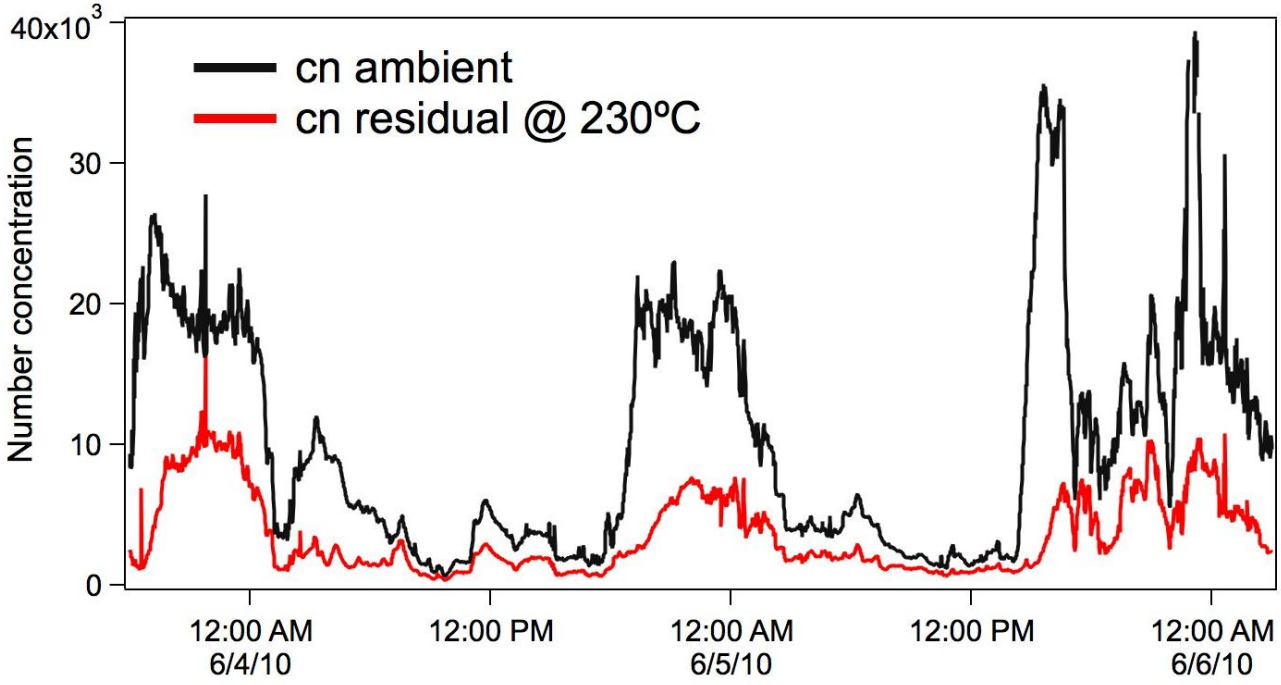




Mid-day local time aerosol nucleation events

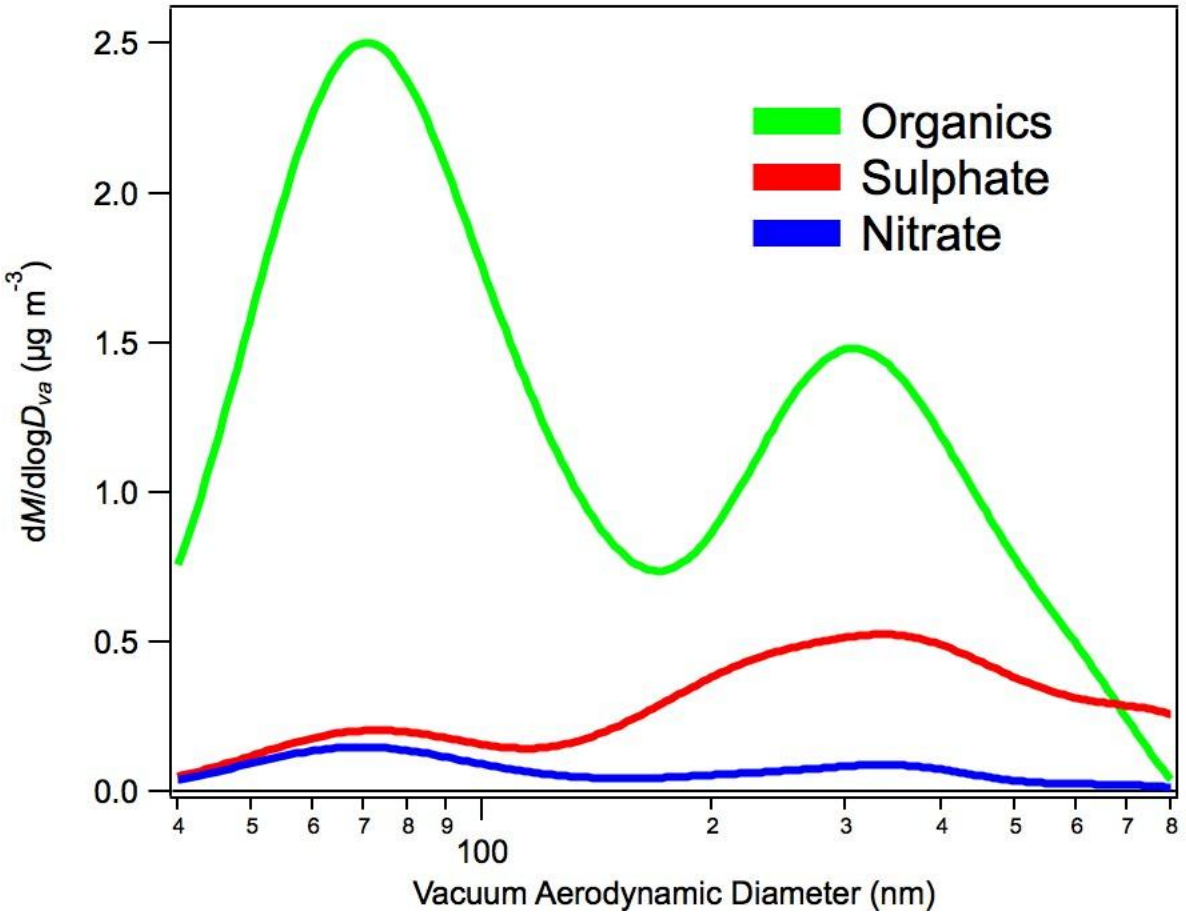
Aerosol size reduced upon heating





Mid-day local time aerosol nucleation events

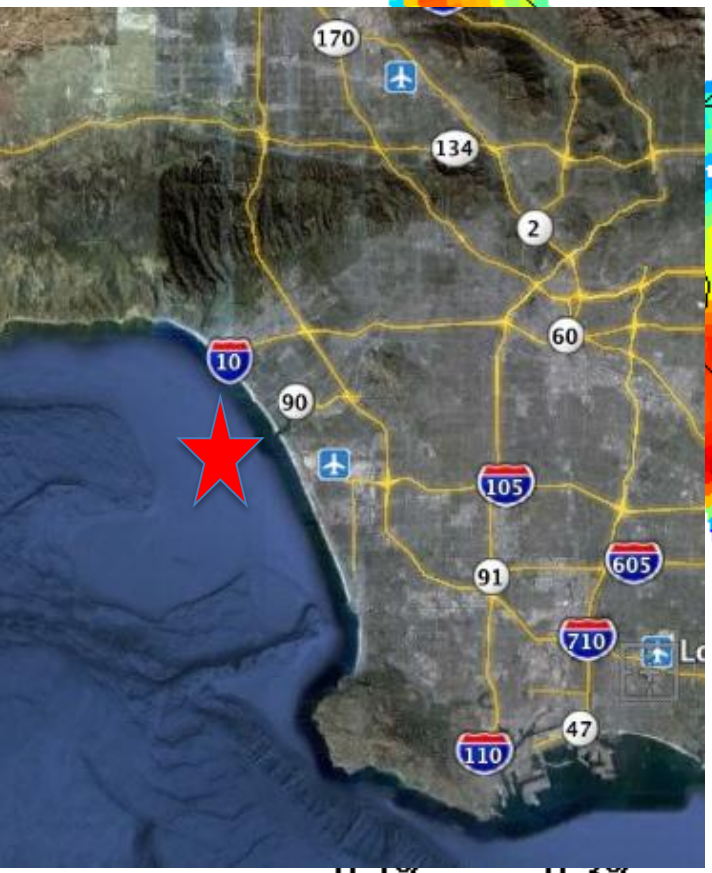
Mass size distribution 3 June 2010, 1930-2330



Case Study 3

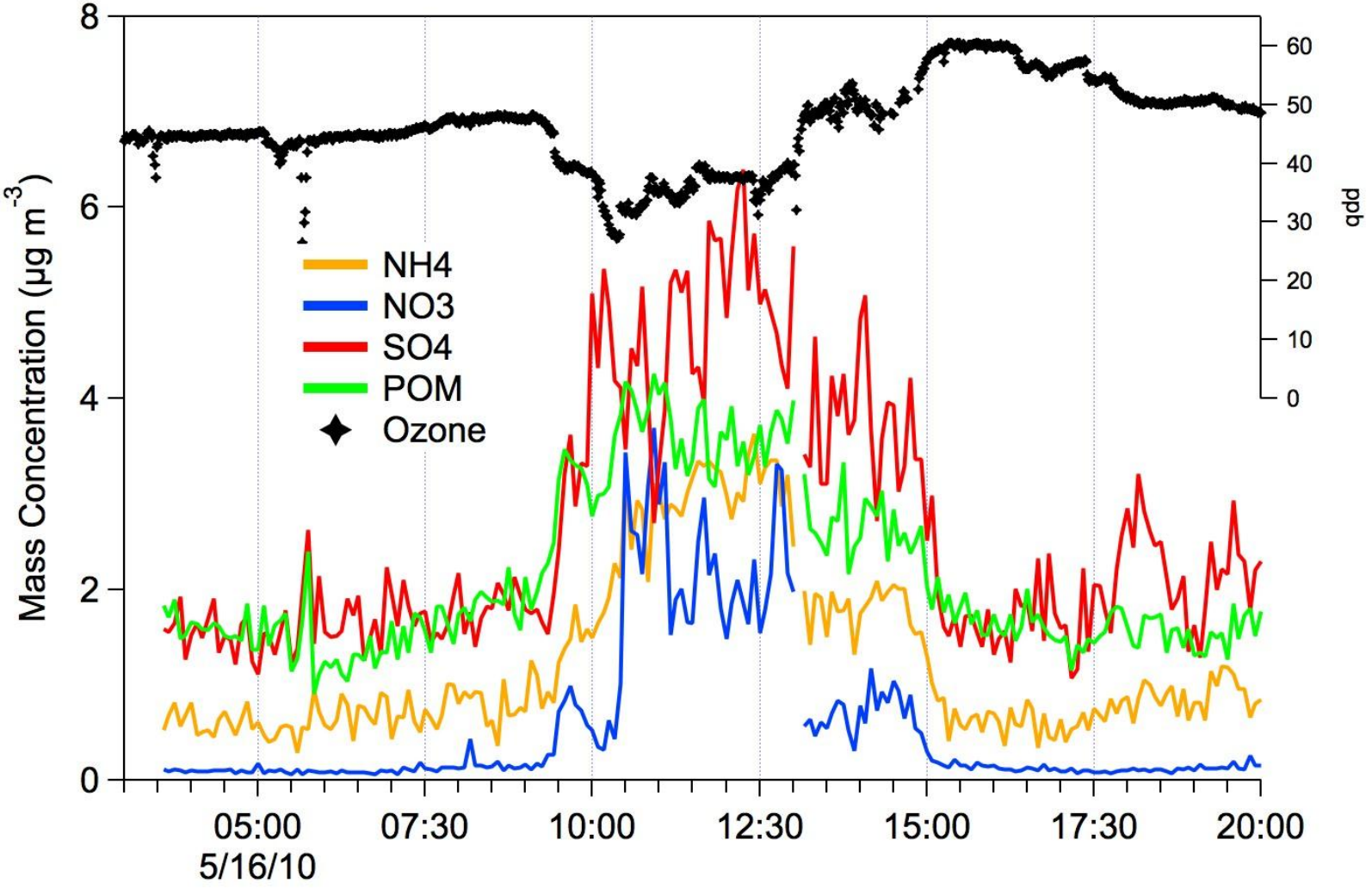
Santa Monica Bay #1

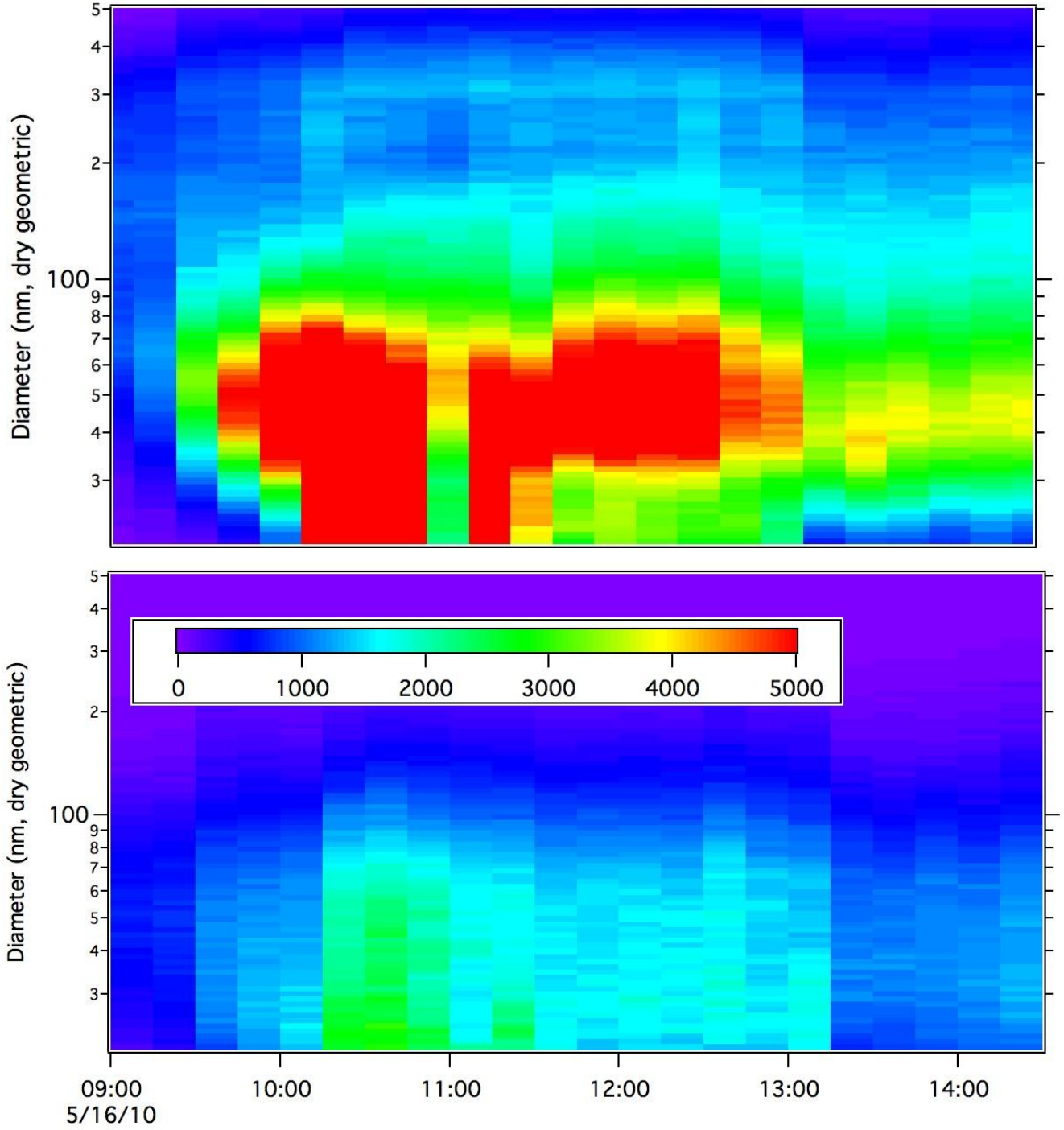
16 May 2010



Santa Monica Bay #1

Sunday, 16 May 2010, pre-dawn plume

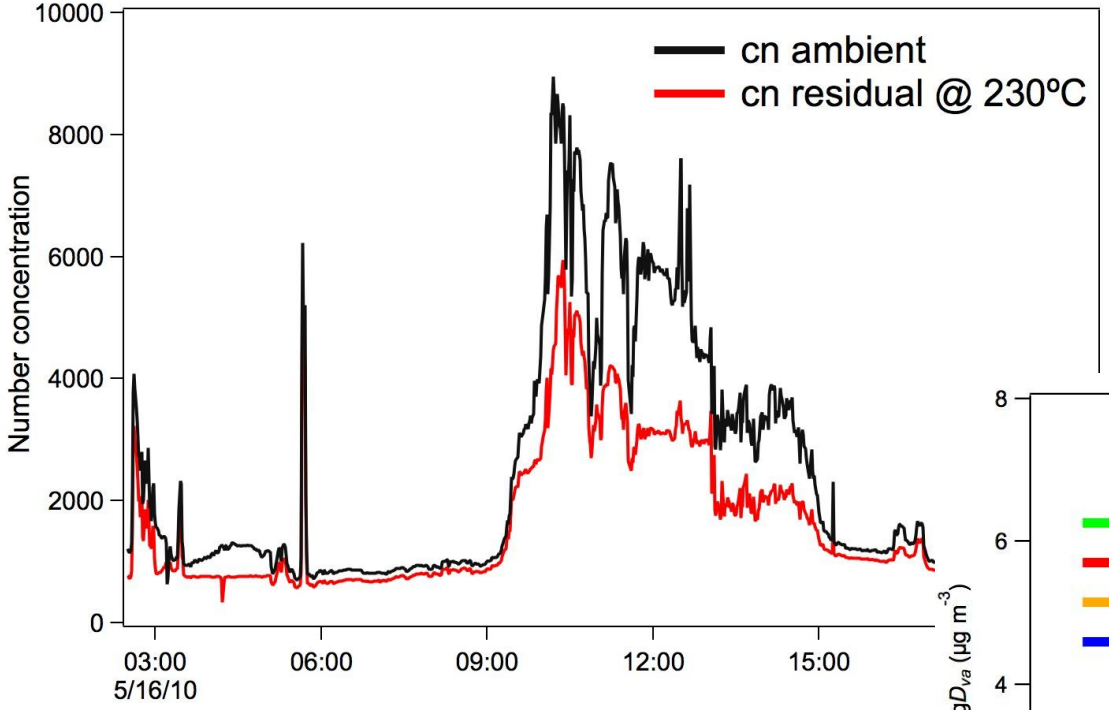


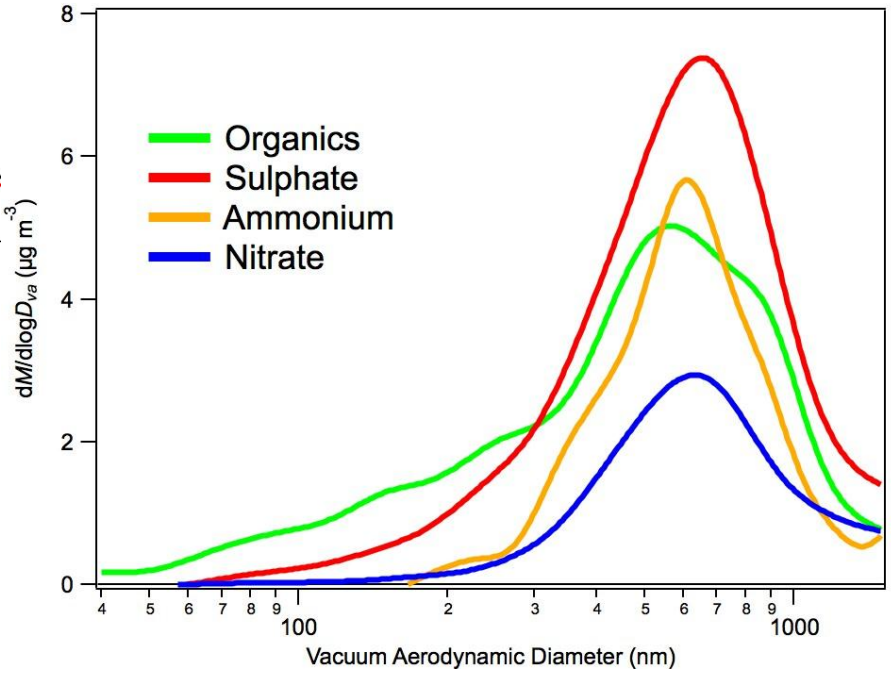


Number distribution dominated by Aitken and Nuclei mode particles.

Santa Monica Bay #1

Sunday, 16 May 2010, pre-dawn plume





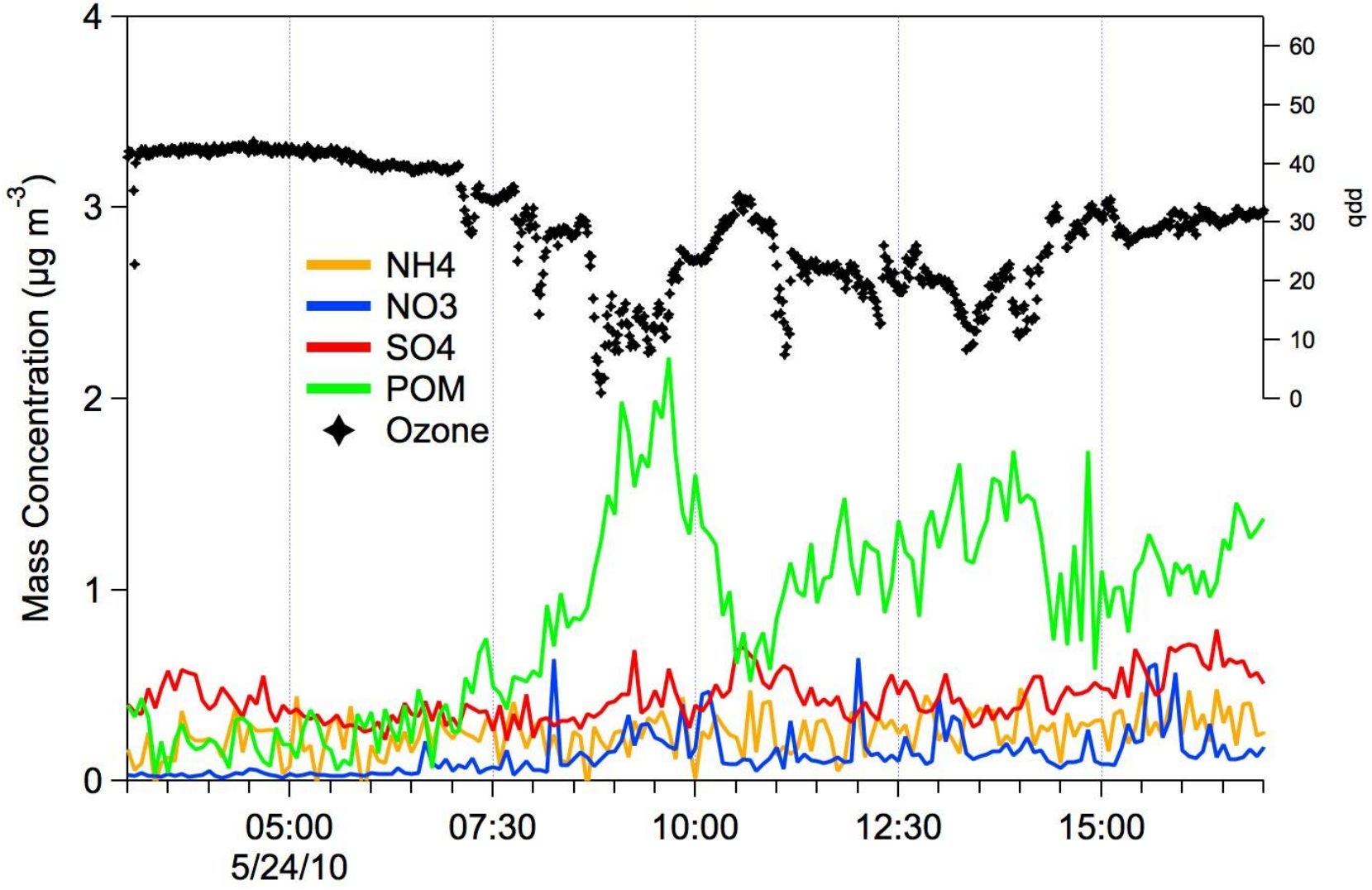
Santa Monica Bay #2

24 May 2010, Off the airport

0.1% 0.3% 1% 3% 10% 30%

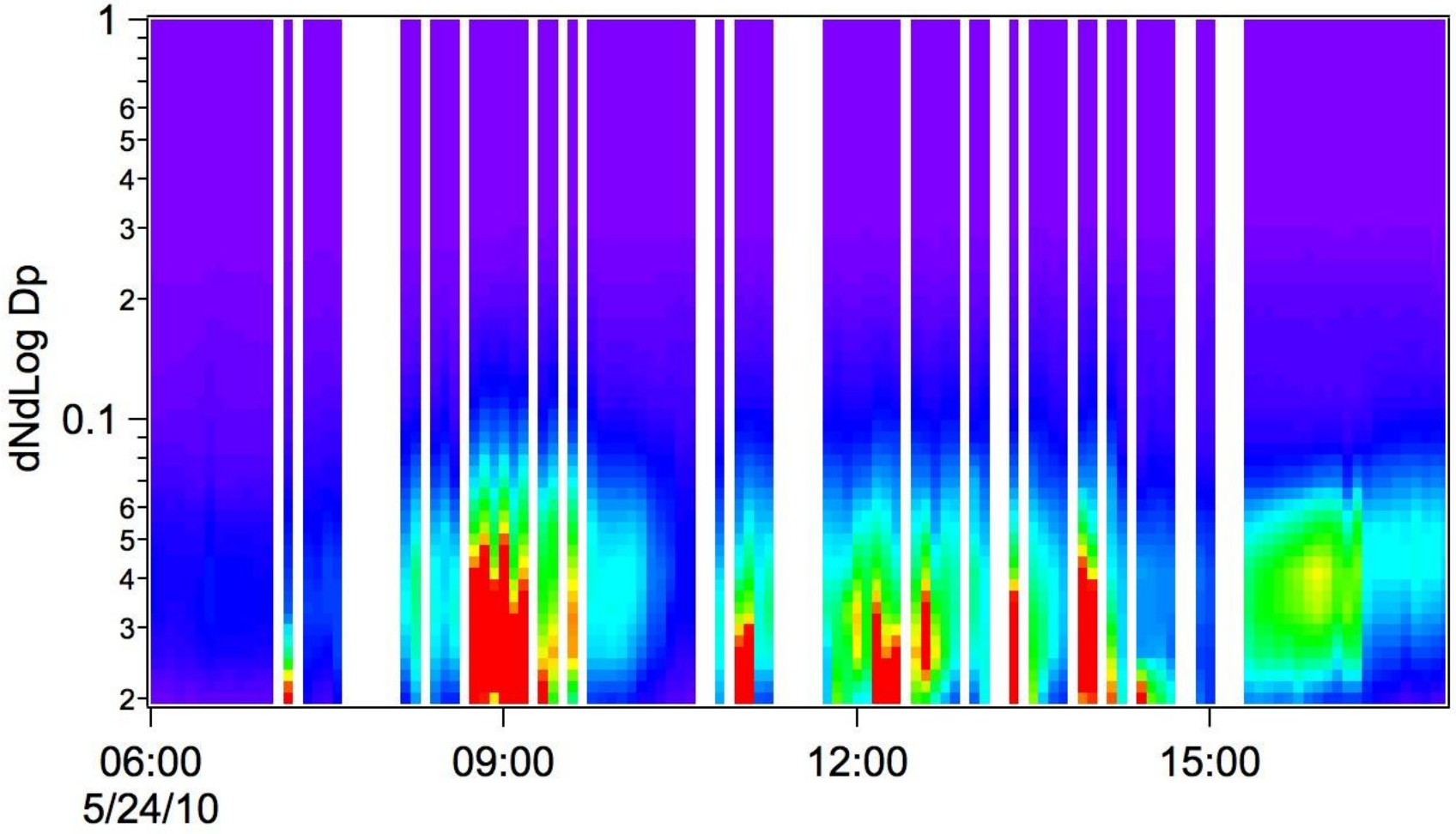
Santa Monica Bay #2

24 May 2010, Off the airport



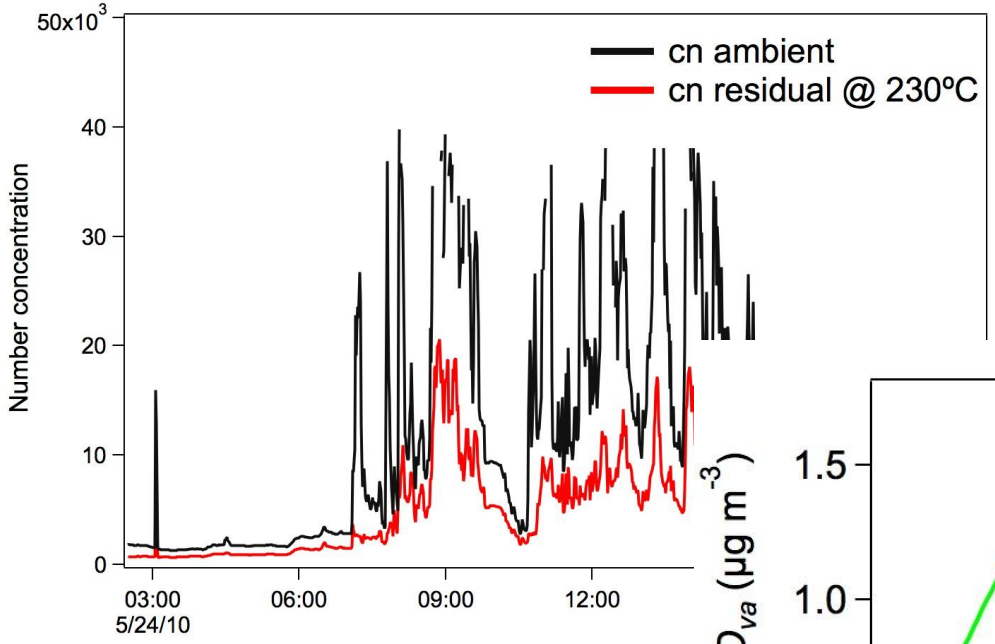
Santa Monica Bay #2

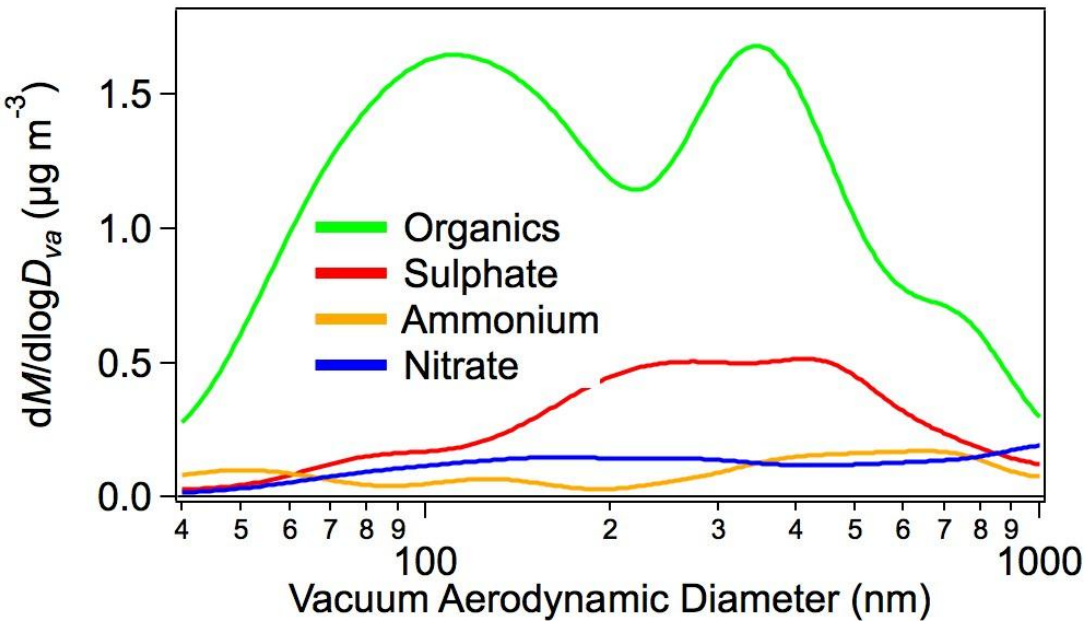
24 May 2010, Off the airport



Santa Monica Bay #2

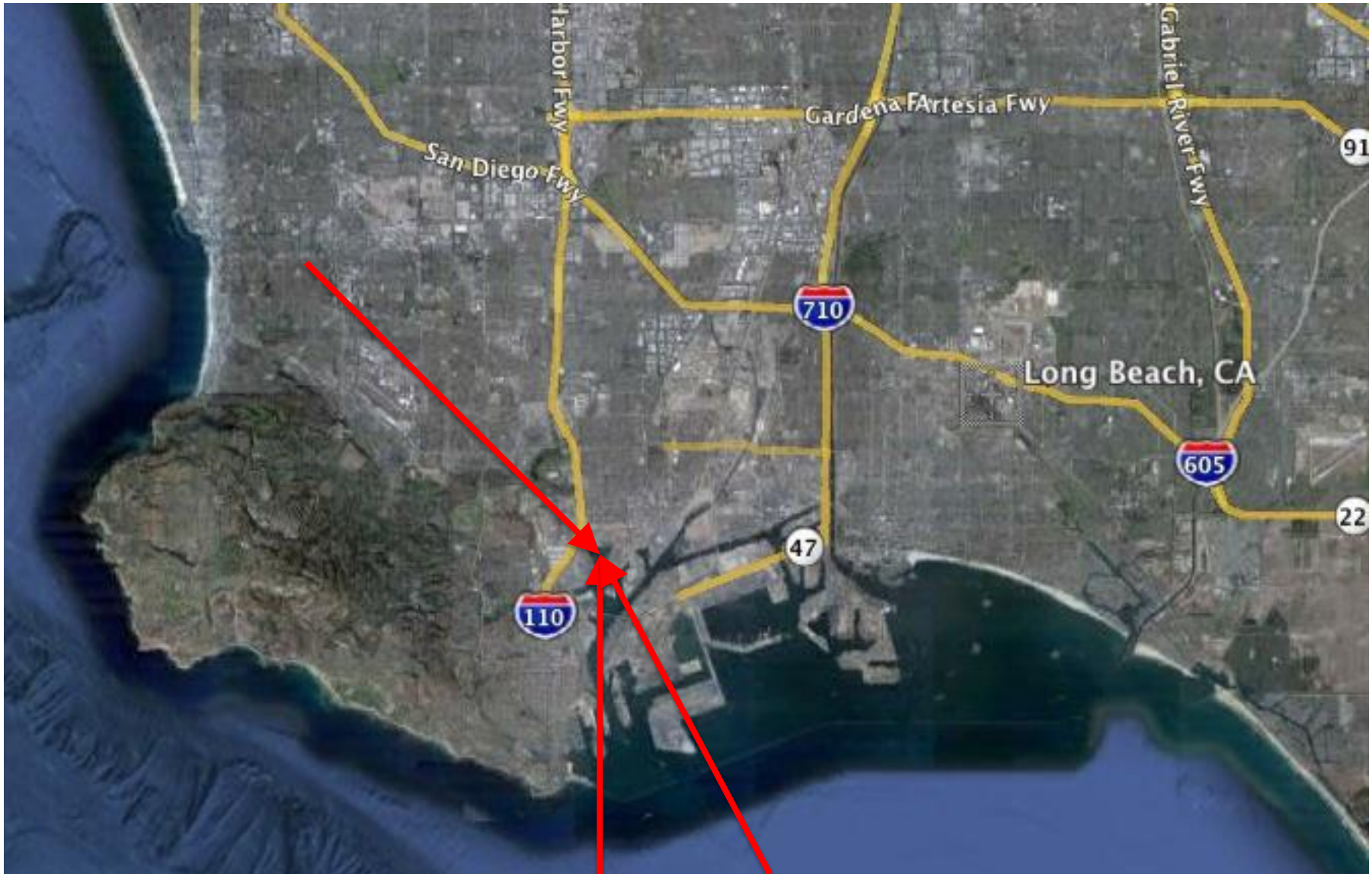
24 May 2010, Off the airport





Case Study 4

Port of Long Beach/LA



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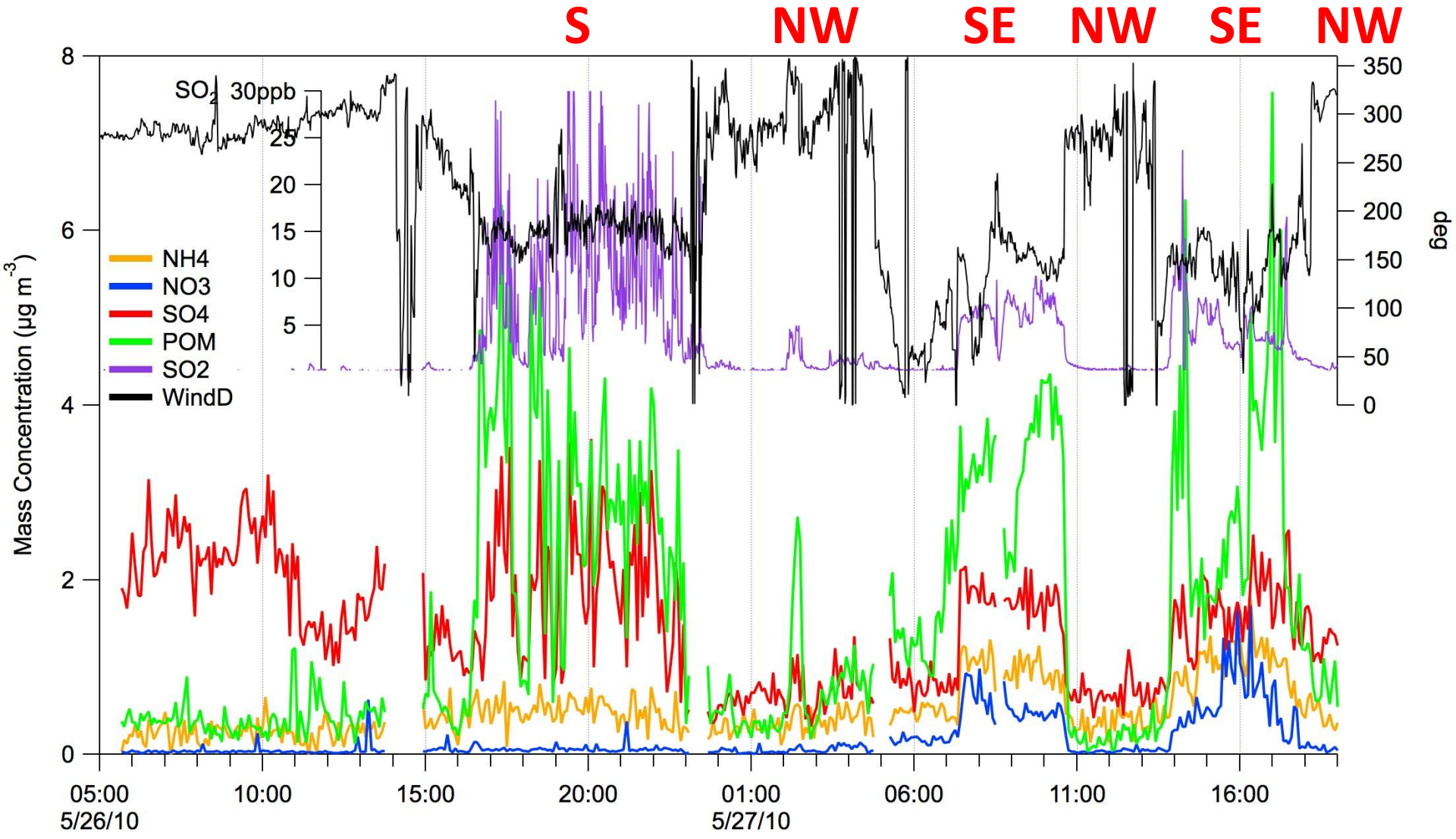

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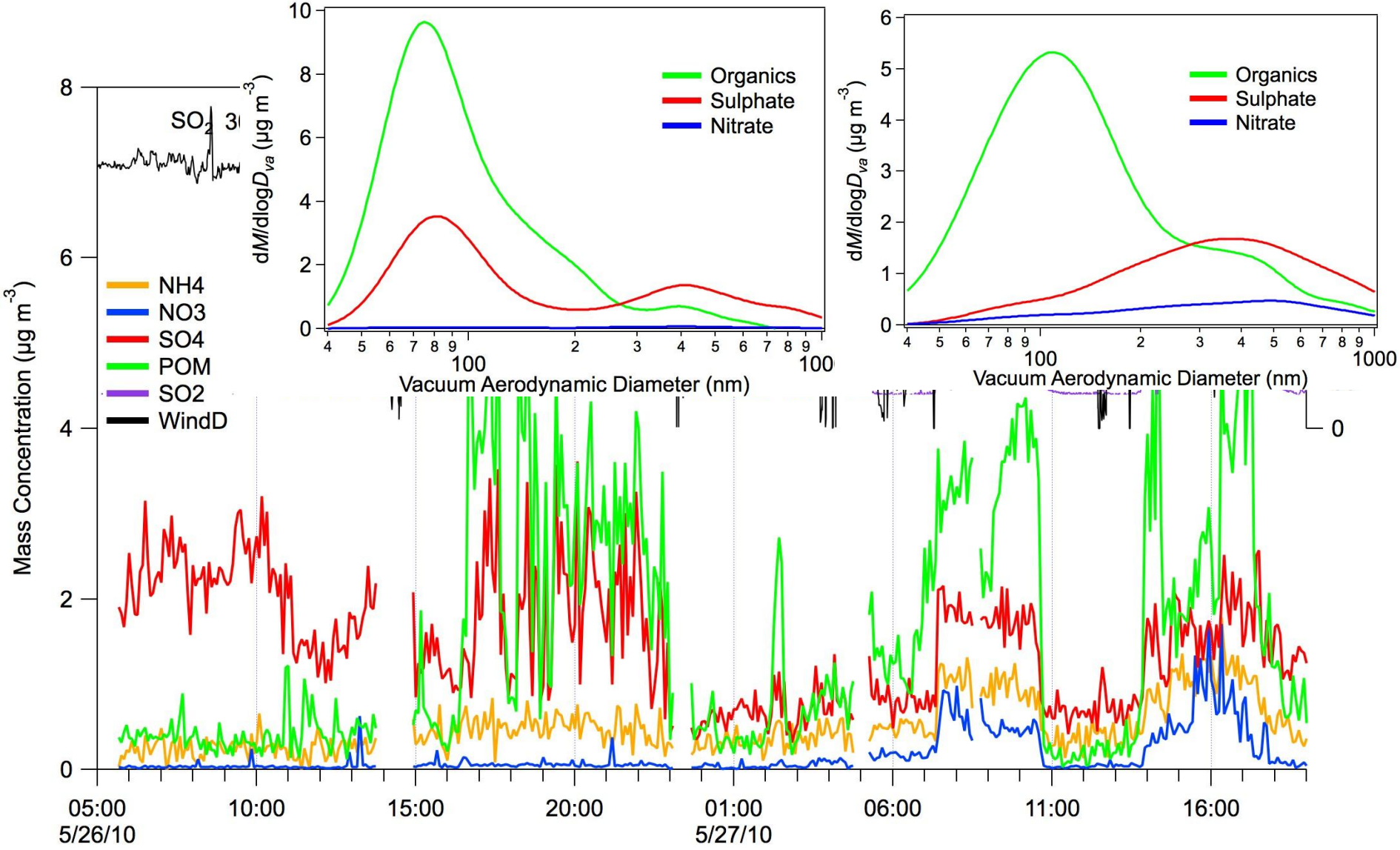


Summary

1. Background marine air mass – on shore flow to CA, most likely aerosol mixed into the MBL from the FT. Background concentration of ≈2 μg/m^3 of acidic sulfate.
2. Inland – Sacramento Ship Channel. New particle production each day mainly organic mass on a non-volatile core. Sulfate mass hours downwind of major point sources.
3. Santa Monica Bay – seabreeze bringing highest aerosol mass concentrations measured during the experiment. Organic/sulfate/nitrate on non-volatile core.
4. Port of Long Beach/LA – S flow (SO2, organic mass), NW flow (low aerosol mass concentration), SE flow (elevated organic, sulfate, nitrate, ammonium mass concentrations)

Summary of CalNex Emission Factor Data

Ship type	g NO_2 /kg fuel	g SO_2 /kg fuel	g CO /kg fuel	Speed, knots	# ships
Container ships	78.4±34.7 (23)	7.1±6.5 (21)	4.3±6.5 (23)	8.1 – 20	18
Freighters	64.0±24.8 (3)	3.6±3.7 (3)	2.5±2.1 (2)	5.7 – 11.4	3
Tankers	62.2±6.7 (2)	7.2±9.4 (2)	2.2±3.2 (2)	11.7 – 14.7	2
Vehicle carrier	57.0±13.7 (3)	7.2±7.2 (3)	7.6±11 (3)	7.4 – 18.1	1
Cruise ships	55.7±5.6 (5)	0.5±0.3 (5)	0.7±1.0 (5)	11.1 – 20.6	3
High-speed (ferries)	33.7±13.2 (12)	0.1±0.4 (11)	2.9±3.7 (11)	7.0 – 30.1	6
Anchored ships	26.4±16.1 (21)	4.0±6.8 (21)	6.9±9.4 (21)	0	12

Summary of Houston Emission Factor Data

Ship type	g NO_2 /kg fuel	g SO_2 /kg fuel	g CO /kg fuel
Container ships	59.8±20.8 (9)	30.4±16.6 (6)	9.8±6.4 (10)
Freighters	87.0±29.6 (11)	20.4±15.6 (11)	7.0±3.5 (10)
Tankers	79.2±23.4 (12)	27.3±17.4 (9)	16.7±15.3 (9)

SO_2 Emissions from Commercial Marine Vessels

1. Mission

Mission	Avg. SO_2 EF	fuel %S	Max SO_2 EF	fuel %S
CalNex 2010	4.4 (±5.7)	0.2	28	1.4
TexAQS 2006	15.5 (±16.7)	0.78	70	3.5

Current ARB regulations cap marine fuel S at 1.5% for MGO; 0.5% for MDO

- **Our data indicate 100% compliance with regulation**

2. Biogenic vs Commercial Marine Vessel Sulfur Sources off the California Coast

DMS emission and import (Bates and Lamb, GBC, 1992): 7.1e6 mol/day
(Assume: 5 day (summer) DMS lifetime; average wind speed; 35% onshore)

Import of DMS sulfur = 2.3e8 gS /day

US west coast ship SO_2 emissions for 2002: 80,200 metric tons (Corbett, 2004)
(Assume: CA fraction of coast = 0.62; all emissions reach shore; fuel S = 2.7%)

Import of CMV sulfur = 0.68e8 gS /day (0.13e8 gS/day with 0.5% S fuel)

- New ARB regs take place in 2012 ➔ fuel S < 0.1%
- North American Emission Control Area regs take place in 2012 ➔ fuel S <1%
  in 2015 ➔ fuel S <0.1%

Sulfur Dioxide Emissions from Ships During CalNex 2010

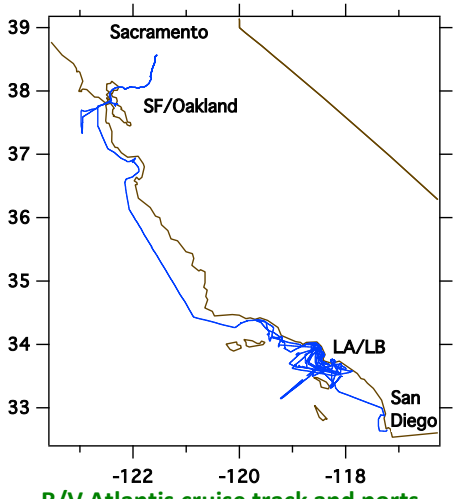
Eric Williams NOAA/ESRL/CSD

BACKGROUND

- Marine Notice 2009-4; 25 Jun 2009 requires cleaner fuels in 24 NM zone
  - MGO at < 1.50 % fuel-S
  - MDO at < 0.5 % fuel-S
- Applies to all engines and boilers

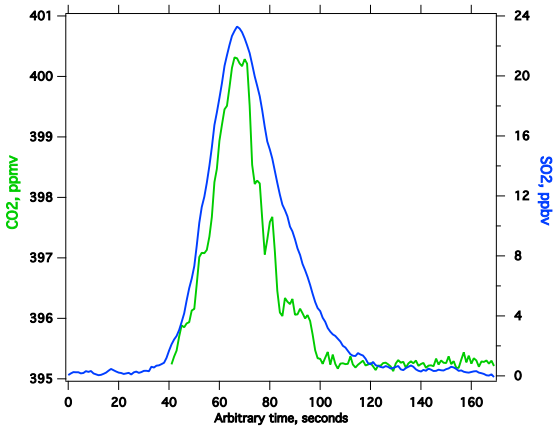
CalNex study May-Jun 2010

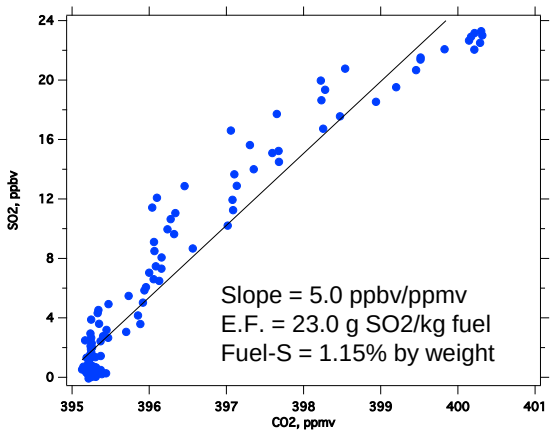
- R/V Atlantis: NOAA-chartered
- Gas-phase and aerosol measurements
- Marine vessel emissions was a focus



R/V Atlantis cruise track and ports

Exhaust Plume from tanker Taipan





MEASUREMENTS

- Highly correlated CO2 and SO2
- CO2 is measure of fuel burned
- SO2 only from fuel-S content

ANALYSIS

- Calculate slope of SO2 vs CO2
- Slope * 4.6 = Emission factor
- Emission factor/20 = % fuel-S

CalNex 2010 Emission Factor Data

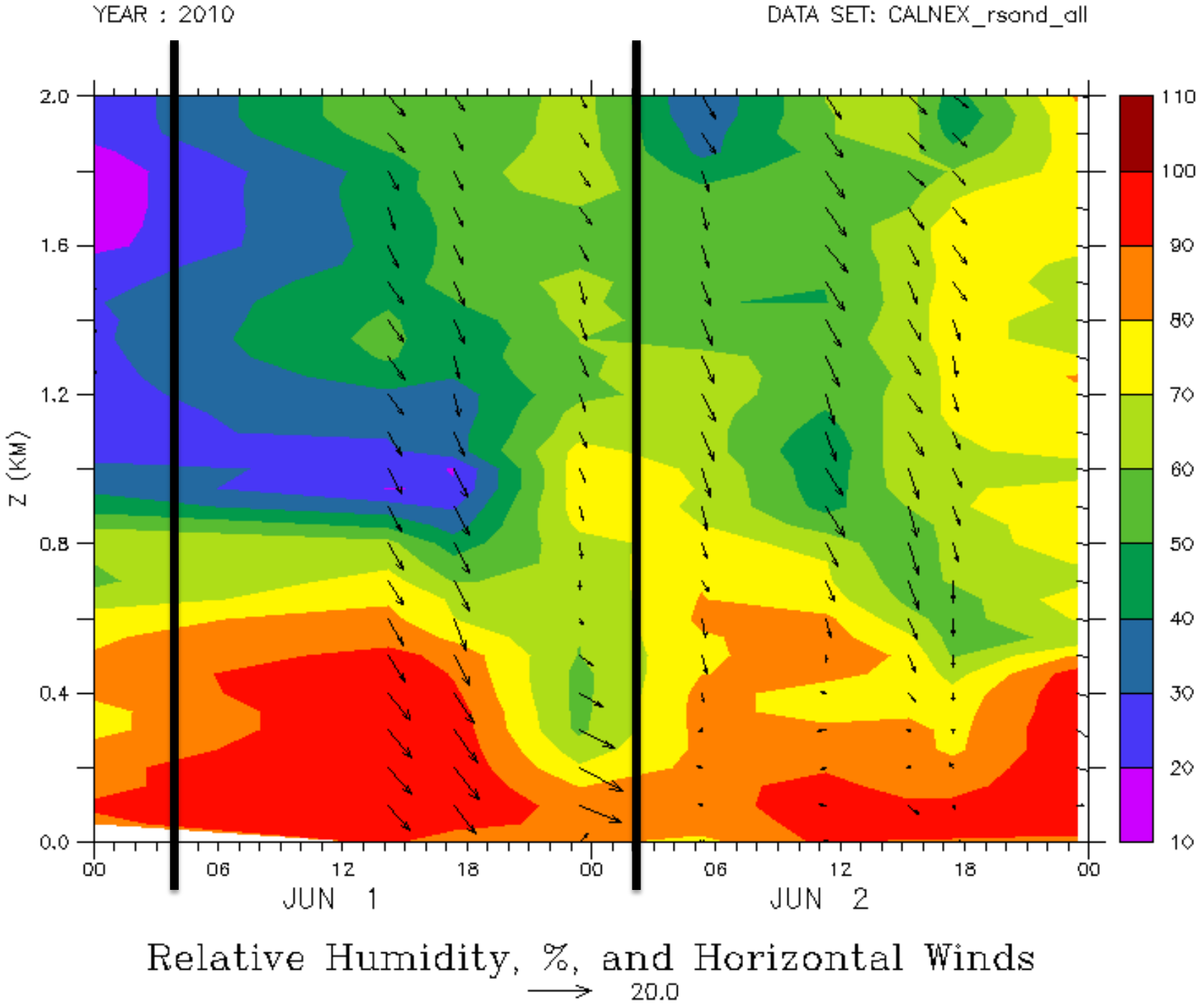
Ship type	g SO_2 /kg fuel	%fuel-S
Container ships	7.1±6.5 (21)	0.36
Freighters	3.6±3.7 (3)	0.18
Tankers	7.2±9.4 (2)	0.36
High-speed (ferries)	0.1±0.4 (11)	0.01
Anchored ships	4.0±6.8 (21)	0.20
STUDY MAXIMUM	28.4	1.42
STUDY MEDIAN	0.69	0.03

Houston 2006 Emission Factor Data

Ship type	g SO_2 /kg fuel	% fuel-S
Container ships	30.4±16.6	1.52
Freighters	20.4±15.6	1.02
Tankers	27.3±17.4	1.37
STUDY MAXIMUM	70.4	3.52
STUDY MEDIAN	6.39	0.32

SUMMARY and FINDINGS

- To date 123 ship plume analyses are done
- Data show compliance with 1.5% fuel-S limit
- More than 80% compliance with 0.5% limit
- Our data measure all emissions from the stack – main engine, aux engine, boilers
- Our data cannot distinguish what fuel types – HFO, MDO, MGO – are in use
- Median fuel-S is X10 lower for CalNex than for Houston


YEAR : 2010
DATA SET: CALNEX_rsond_all
Z (KM)
2.0
1.6
1.2
0.8
0.4
0.0
00
06
12
18
00
06
12
18
00
JUN 1
JUN 2
110
100
90
80
70
60
50
40
30
20
10
Relative Humidity, %, and Horizontal Winds
20.0