# Wildfire Smoke Contribution to Surface $PM_{2.5}$ in Halifax, Nova Scotia during the BORTAS-B Experiment

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DALHOUSIE UNIVERSITY *Inspiring Minds*

**National Smoke Forum, Wildland Fire Canada Conference, Halifax, NS, Canada, Oct 10th 2014**


International study led by the University of Edinburgh

Palmer et al., (2013)
Atmospheric Chemistry and Physics
13, p6239


UK Met Office Atmospheric Research Aircraft

- Boreal forest fires burn an average of 2.3 million hectares of Canadian wildland annually (Natural Resources Canada).

- These biomass burning events are a significant source of fine airborne particulate matter with a median aerodynamic diameter less than, or equal to, 2.5 microns ($PM_{2.5}$) and trace gases to the atmosphere.

- In addition to the significant local ecosystem and air quality impacts, it has been demonstrated that wildfire smoke plumes are capable of undergoing significant long range transport (LRT) > chemical transformation en route > forming additional secondary gases and $PM_{2.5}$.

(Crutzen and Andreae, 1990; Cooper et al., 2002; Derwent et al., 2004)

## *Objective of the ground based $PM_{2.5}$ sampling during BORTAS-B*

**To identify and apportion the major sources driving the temporal variability of $PM_{2.5}$ in Halifax, Nova Scotia**

**With a special focus on apportioning the boreal wildfire contribution to $PM_{2.5}$**


**Dalhousie Ground Station (DGS) Location**

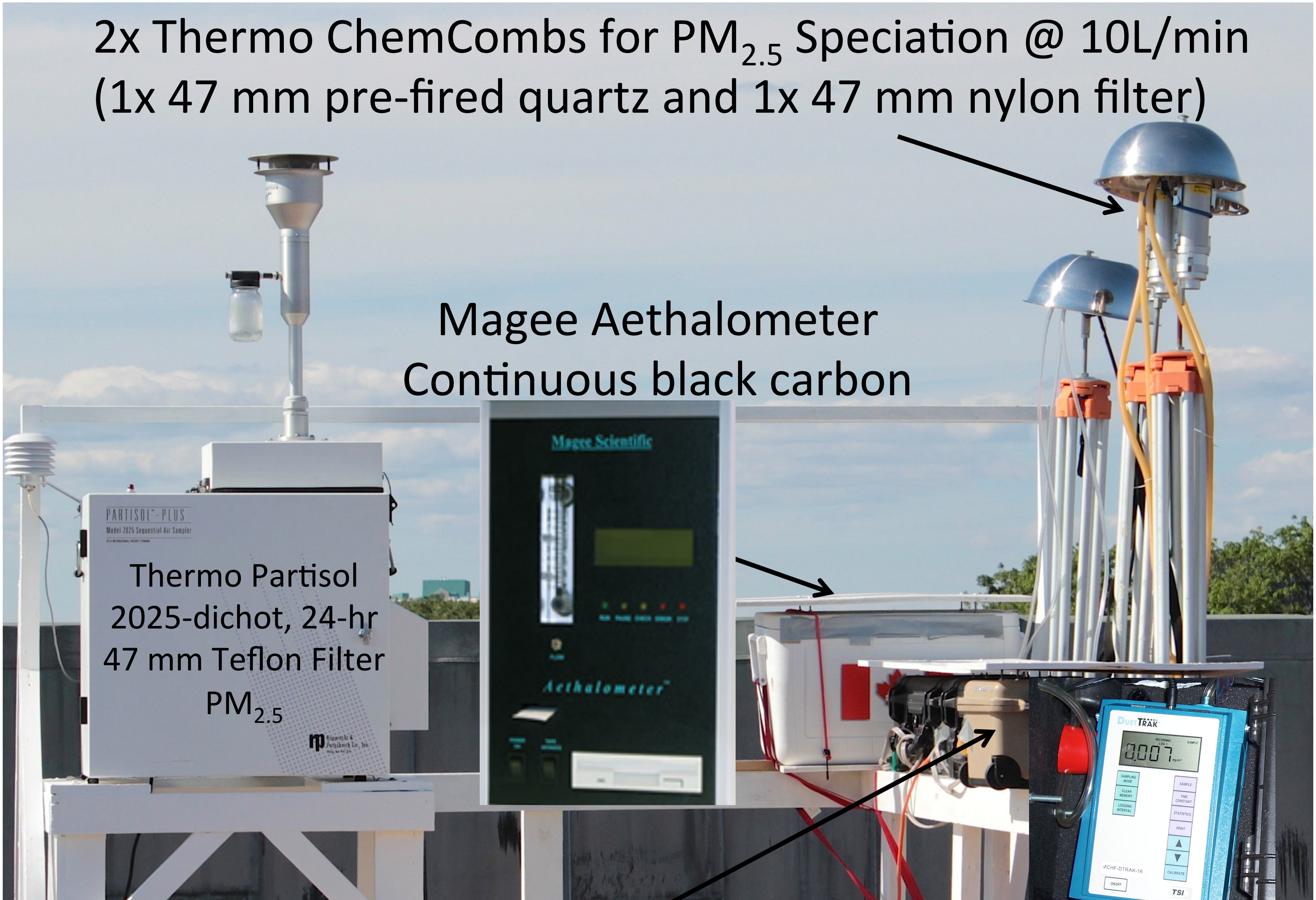
Trace gas species and size resolved particle mass, number and chemical speciation

Palmer et al., (2013) ACP 13 p6239

Gibson et al., (2013) ACP 13 p7199

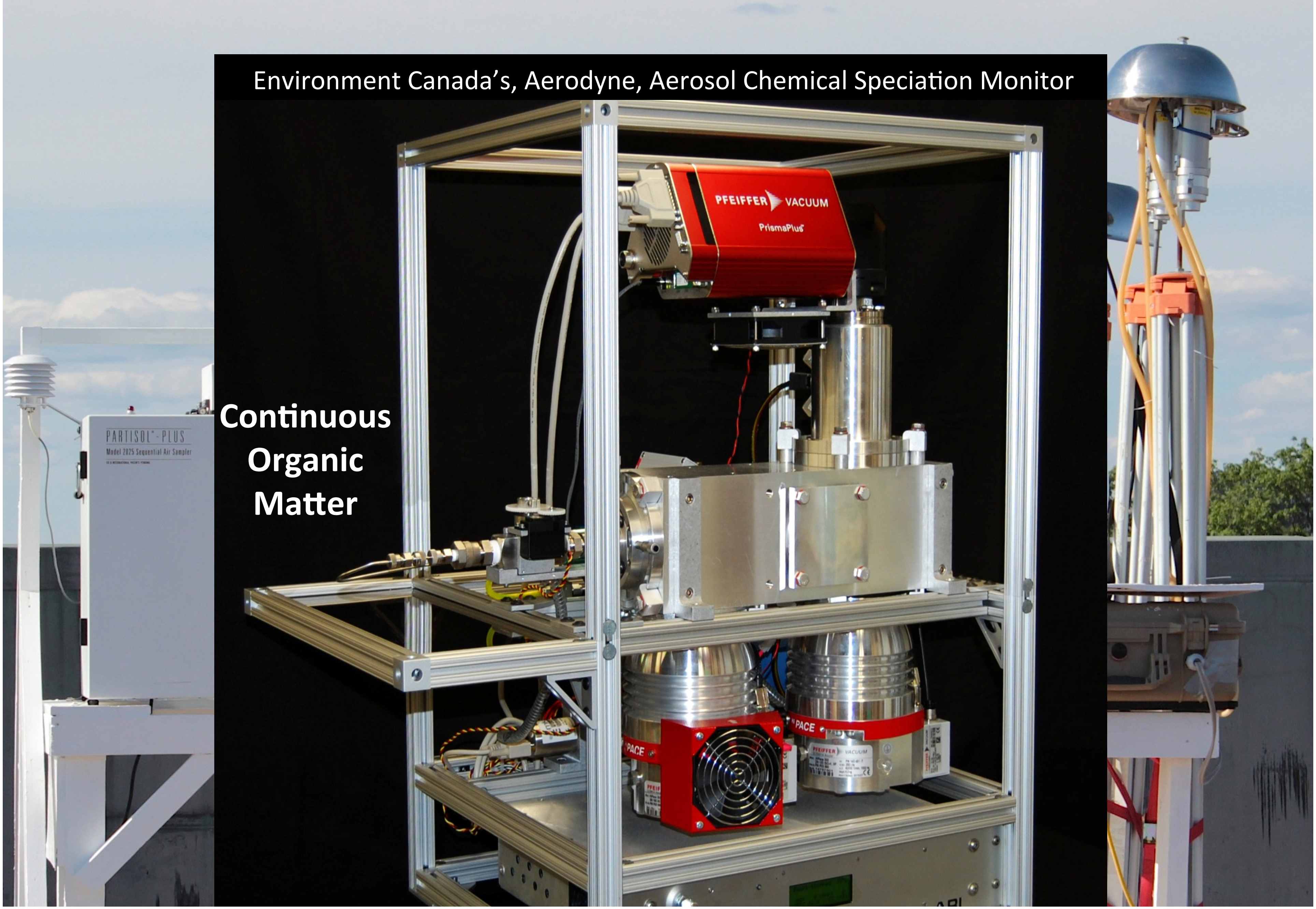
Franklin et al., (2014) 14 p8449

Gibson et al (2014) ACPD 14, p24043

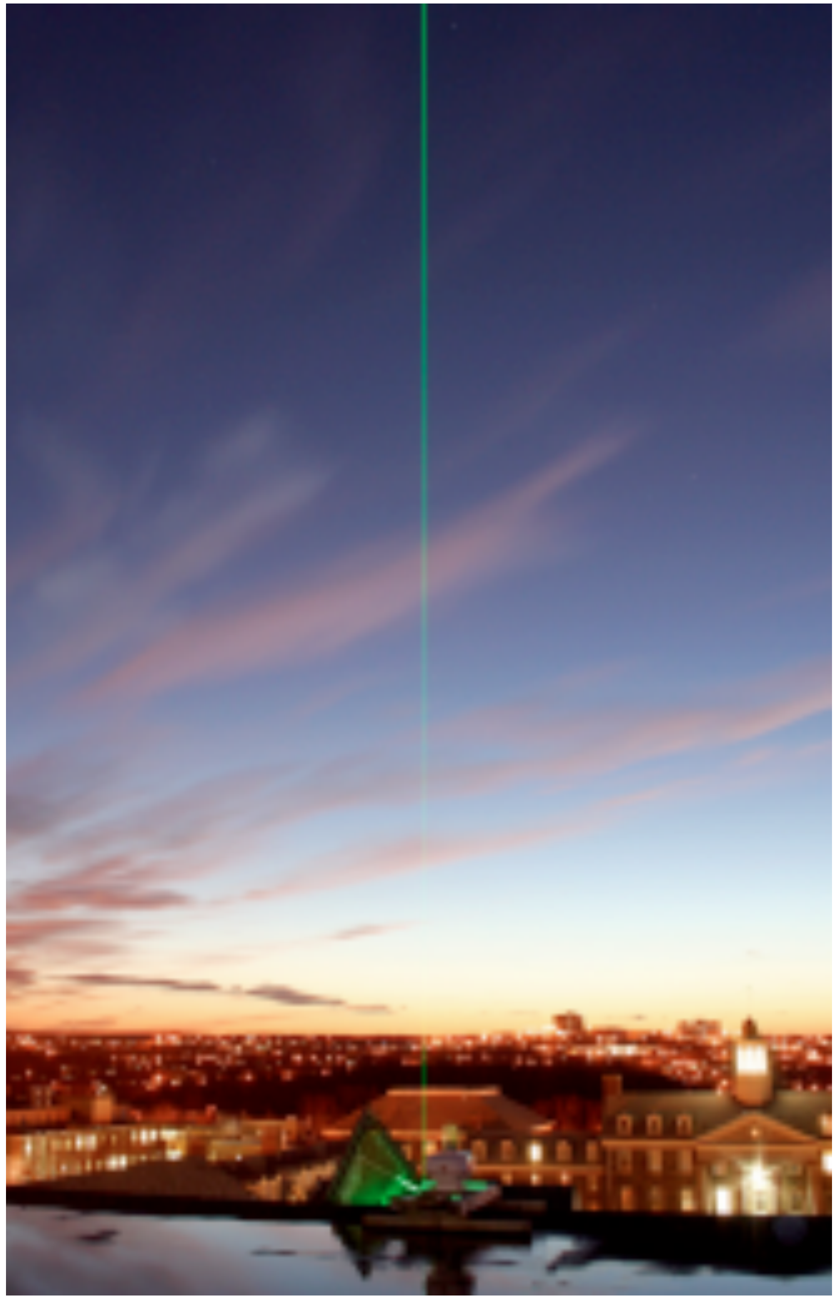


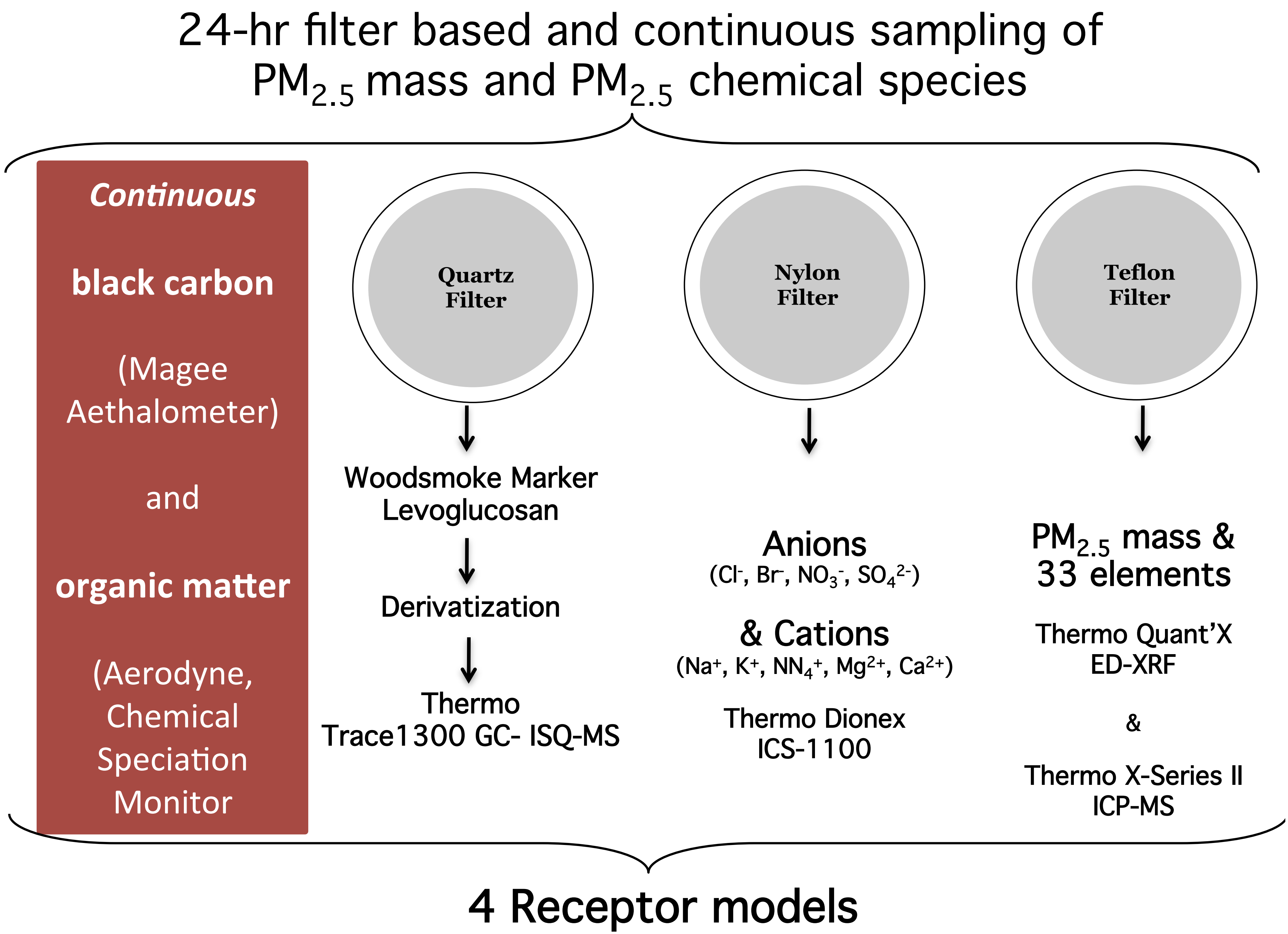

Continuous $PM_{2.5}$ (TSI DustTrak) nephelometer

# Dalhousie Ground Station (DGS)



# Dalhousie Raman Lidar (lower and upper troposphere AOD)





24-hr filter based and continuous sampling of
$PM_{2.5}$ mass and $PM_{2.5}$ chemical species
*Continuous*
**black carbon**
(Magee Aethalometer)
and
**organic matter**
(Aerodyne, Chemical Speciation Monitor)
Quartz Filter
Woodsmoke Marker Levoglucosan
Derivatization
Thermo Trace1300 GC- ISQ-MS
Nylon Filter
Anions
($Cl^-$, $Br^-$, $NO_3^-$, $SO_4^{2-}$)
& Cations
($Na^+$, $K^+$, $NN_4^+$, $Mg^{2+}$, $Ca^{2+}$)
Thermo Dionex ICS-1100
Teflon Filter
$PM_{2.5}$ mass & 33 elements
Thermo Quant'X ED-XRF
&
Thermo X-Series II ICP-MS
4 Receptor models

# Receptor Models Used

## 1. Pragmatic Mass Closure

calculated using molar ratios and enrichment factors of individual chemical species present

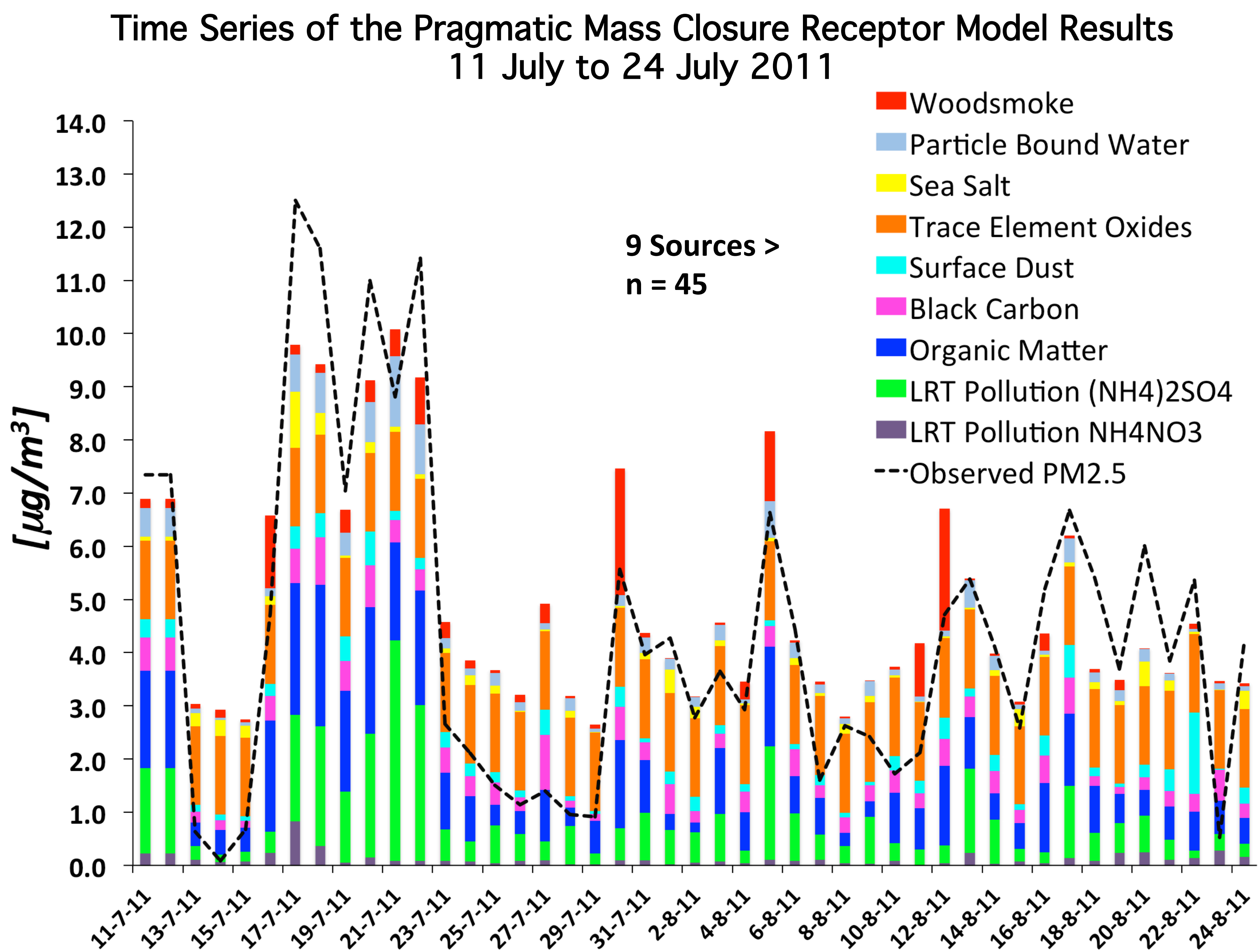
e.g. $NH_4NO_3$ = ($NH_4$*4.44)*0.29 (particle bound water)

*Dabek, E. et al., (2011) Atmospheric Environment. 45 (3) p673*
*Yin, J. et al (2008) Atmospheric Environment, 42 (5) p980*

woodsmoke = levoglucosan x 52 *(Gibson et al., 2013 EGU)*

New enrichment factor

Gibson, M.D., et al. (2014). A comparison of four receptor models used to quantify the boreal wildfire smoke contribution to surface $PM_{2.5}$ in Halifax, Nova Scotia during the BORTAS-B experiment. Atmos. Chem. and Phys. Discussions. 14, pp24043-24086


Time Series of the Pragmatic Mass Closure Receptor Model Results
11 July to 24 July 2011
Woodsmoke
Particle Bound Water
Sea Salt
Trace Element Oxides
Surface Dust
Black Carbon
Organic Matter
LRT Pollution (NH4)2SO4
LRT Pollution NH4NO3
Observed PM2.5
9 Sources >
n = 45
[μg/m3]
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
11-7-11
13-7-11
15-7-11
17-7-11
19-7-11
21-7-11
23-7-11
25-7-11
27-7-11
29-7-11
31-7-11
2-8-11
4-8-11
6-8-11
8-8-11
10-8-11
12-8-11
14-8-11
16-8-11
18-8-11
20-8-11
22-8-11
24-8-11

# 2. Absolute Principal Component Scores

Multivariate factor analysis based approach

Thurston, G.D., et al., (1985) Atmospheric Environment, 19 (1) p9

Guo, H. et al., (2004) Environmental Pollution, 129 (3) p489

Bruno, P., et al., (2001) Fresenius J. of Analytical Chemistry, 371 p1119

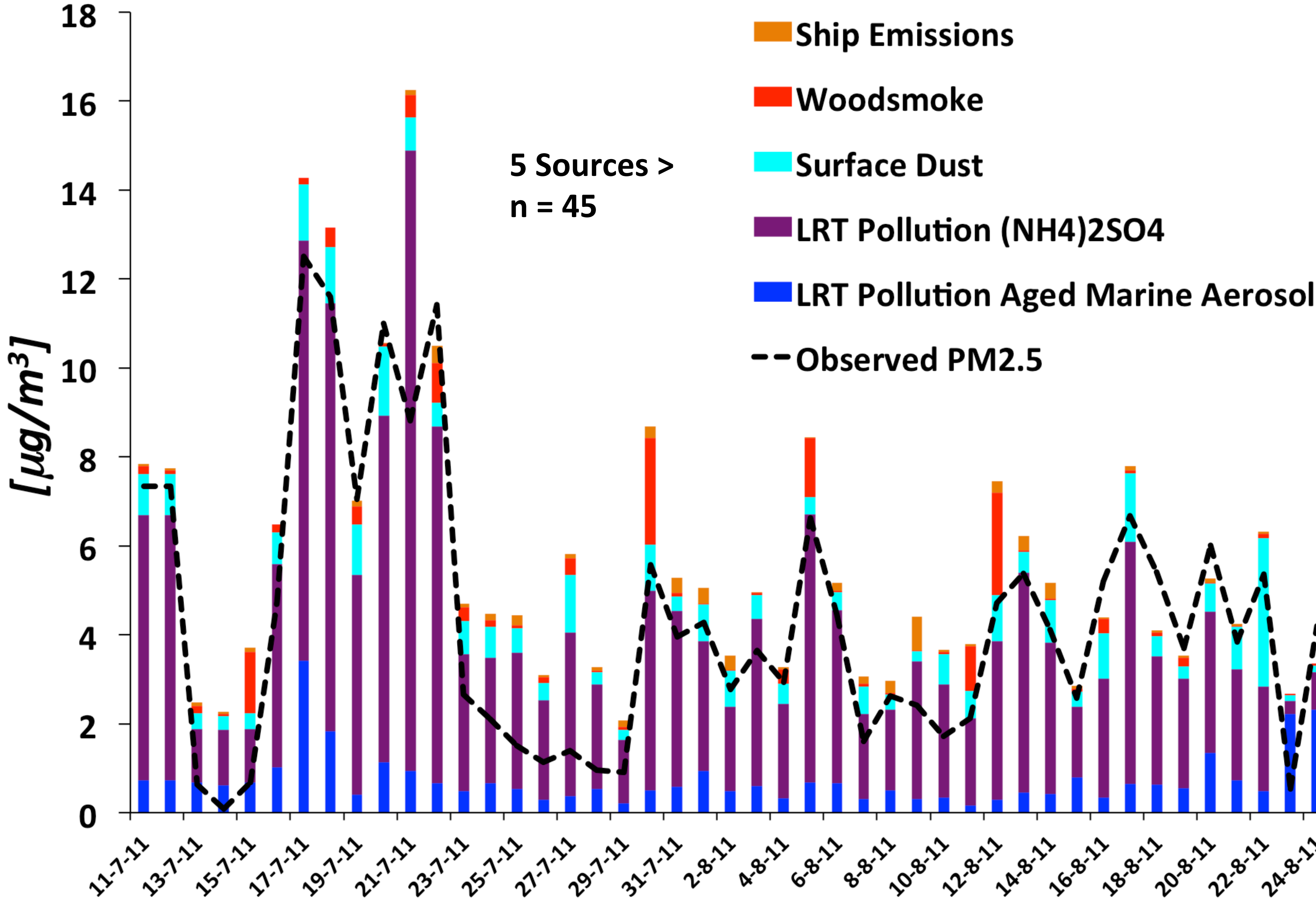
Gibson, M.D., et al. (2014). Atmos. Chem. Phys. Disc. 14, p24043

# Absolute Principal Component Scores (APCS) and Positive Matrix Factorization

User has to **determine the $PM_{2.5}$ source** within factor profiles from ***a priori* knowledge of source chemical markers**, e.g.

- Boreal forest wild fire smoke = high factor scores for **levoglucosan**, black carbon and K
- Secondary Ions (Long-range Transport), OM, $NH_4^+$, $NO_3^-$, S and $SO_4^{2-}$
- LRT Pollution marine aerosol mix = $NO_3^-$, $Mg^{2+}$ and $Na^+$
- Ship emissions = Ni and V
- Surface dust = Al, Fe, Si and Ca

## Time Series of the Absolute Principal Component Scores Receptor Model Results
## 11 July to 24 July 2011



# 3. USEPA Chemical Mass Balance

Multivariate least squares source profile model.

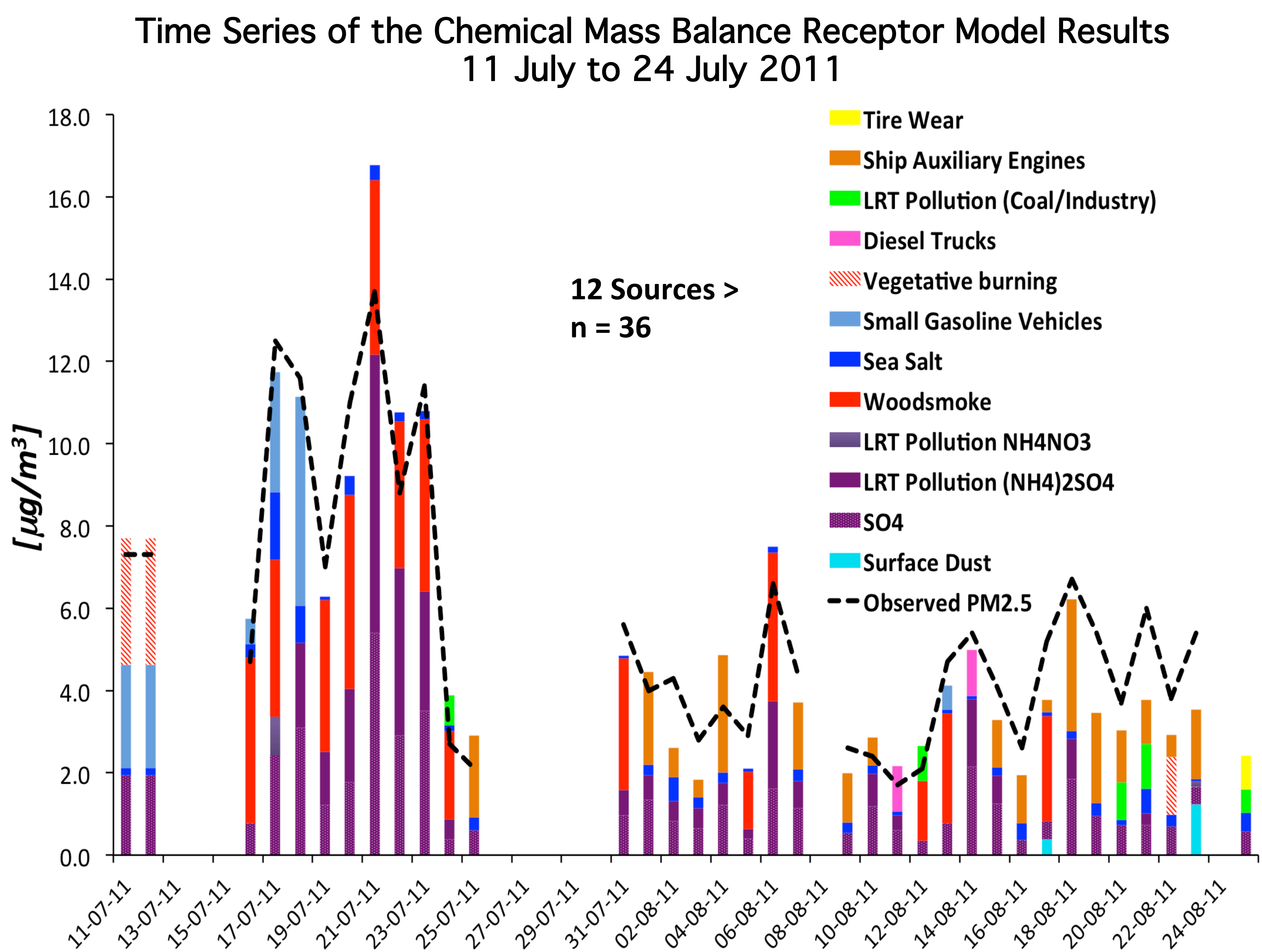
Identifies the source of $PM_{2.5}$ by matching chemical species in the sample with those in known source profiles

Followed by determining the relative source contribution to $PM_{2.5}$

Ward, T.J., et al. (2012). $PM_{2.5}$ source apportionment in a subarctic airshed - Fairbanks, Alaska. *Aerosol and Air Quality Research* 12, 536-543.

Ward, T.J., et al. (2006). The 2003/2004 Libby, Montana $PM_{2.5}$ source apportionment research study. *Aerosol Science and Technology* 40, 166-177.

*Gibson, M.D., et al. (2014). A comparison of four receptor models used to quantify the boreal wildfire smoke contribution to surface PM2.5 in Halifax, Nova Scotia during the BORTAS-B experiment. Atmos. Chem. and Phys. Discussions. 14, pp24043-24086*



Time Series of the Chemical Mass Balance Receptor Model Results
11 July to 24 July 2011
[µg/m³]
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
12 Sources >
n = 36
Tire Wear
Ship Auxiliary Engines
LRT Pollution (Coal/Industry)
Diesel Trucks
Vegetative burning
Small Gasoline Vehicles
Sea Salt
Woodsmoke
LRT Pollution NH4NO3
LRT Pollution (NH4)2SO4
SO4
Surface Dust
Observed PM2.5
11-07-11
13-07-11
15-07-11
17-07-11
19-07-11
21-07-11
23-07-11
25-07-11
27-07-11
29-07-11
31-07-11
02-08-11
04-08-11
06-08-11
08-08-11
10-08-11
12-08-11
14-08-11
16-08-11
18-08-11
20-08-11
22-08-11
24-08-11

# 4. USEPA Positive Matrix Factorization

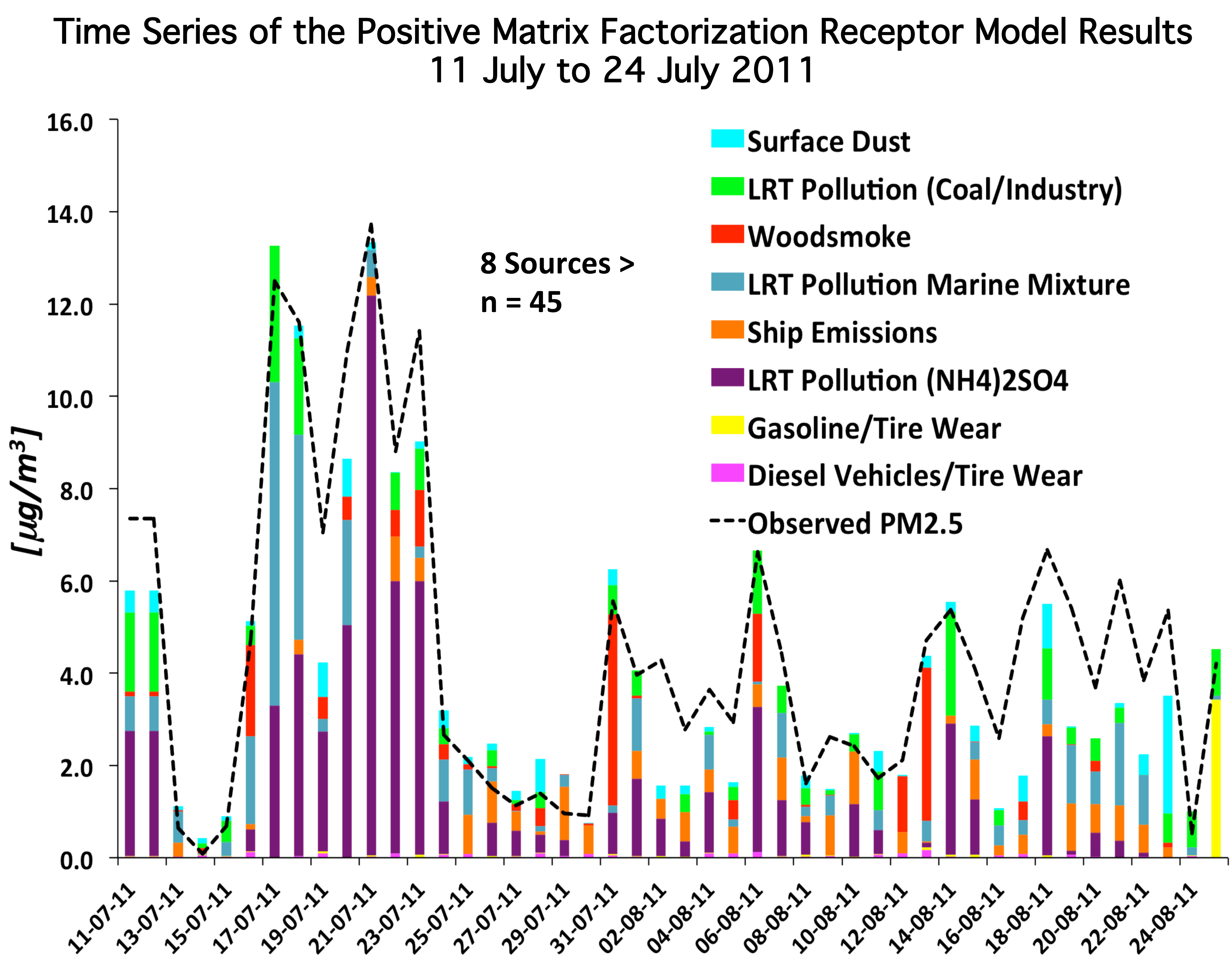
Multivariate factor analysis based approach

prevents "non-negative" mass contributions

Gibson, M.D., et al. (2014). A comparison of four receptor models used to quantify the boreal wildfire smoke contribution to surface $PM_{2.5}$ in Halifax, Nova Scotia during the BORTAS-B experiment. Atmos. Chem. and Phys. Discussions. 14, pp24043-24086

Gibson, M.D., et al. (2013). Identifying the sources driving observed $PM_{2.5}$ temporal variability over Halifax, Nova Scotia, during BORTAS-B. *Atmos. Chem. and Phys. 13, pp7199-7213*.

Jeong, C.-H., et al. (2008). Influence of biomass burning on wintertime fine particulate matter: Source contribution at a valley site in rural British Columbia. *Atmospheric Environment* 42, 3684-3699.


Time Series of the Positive Matrix Factorization Receptor Model Results
11 July to 24 July 2011
8 Sources >
n = 45
Surface Dust
LRT Pollution (Coal/Industry)
Woodsmoke
LRT Pollution Marine Mixture
Ship Emissions
LRT Pollution (NH4)2SO4
Gasoline/Tire Wear
Diesel Vehicles/Tire Wear
Observed PM2.5
[µg/m3]
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
11-07-11
13-07-11
15-07-11
17-07-11
19-07-11
21-07-11
23-07-11
25-07-11
27-07-11
29-07-11
31-07-11
02-08-11
04-08-11
06-08-11
08-08-11
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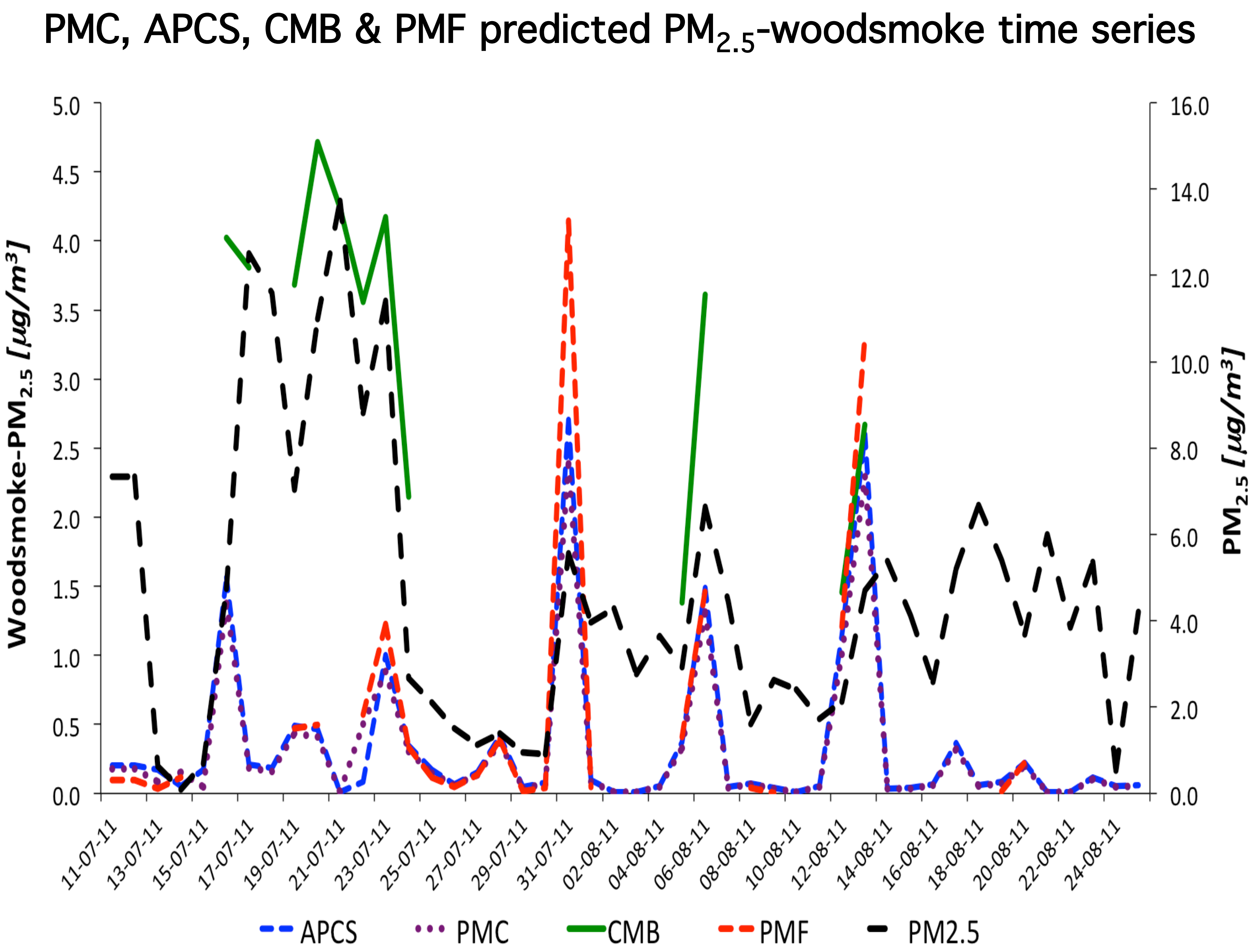
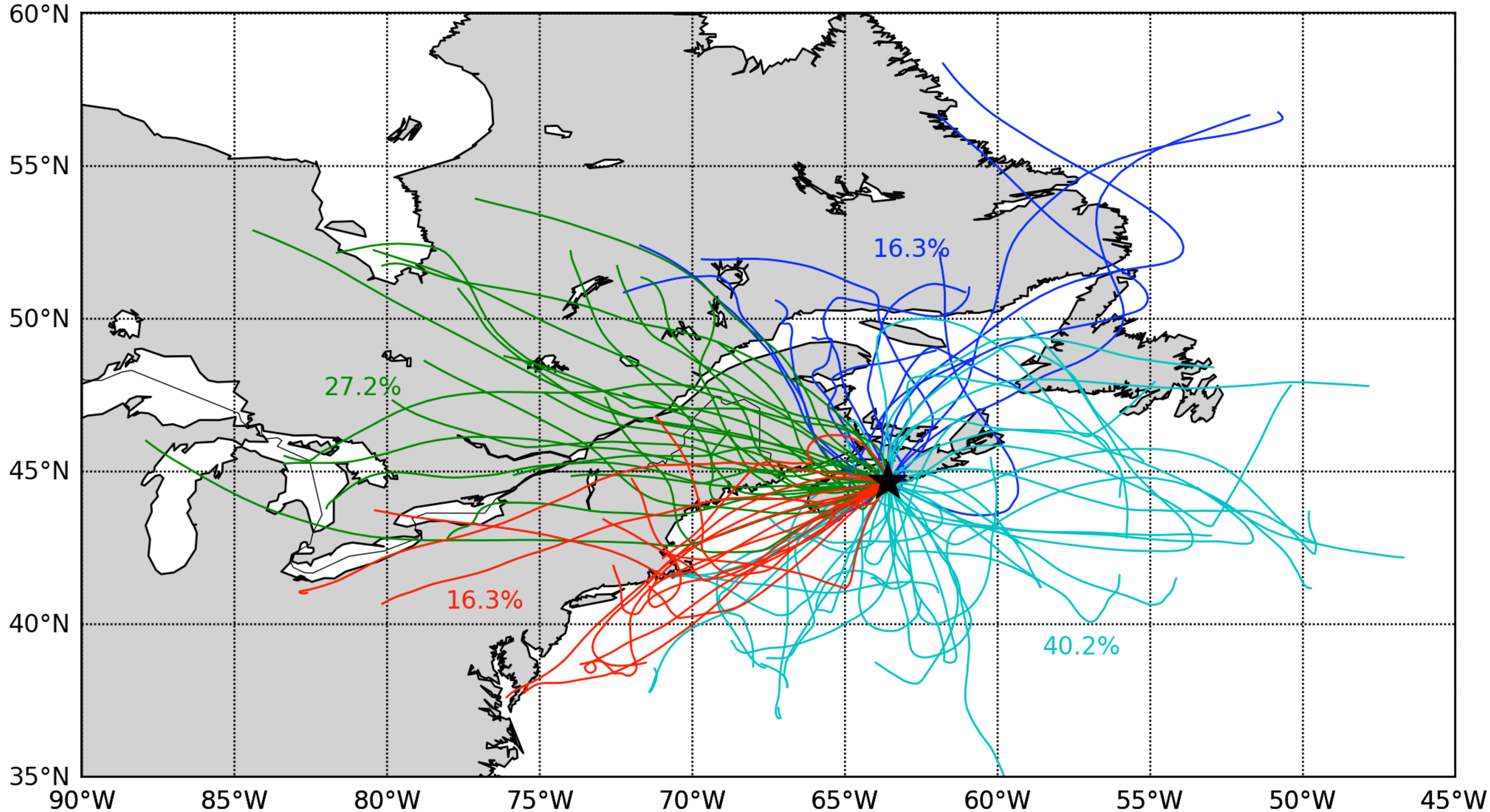
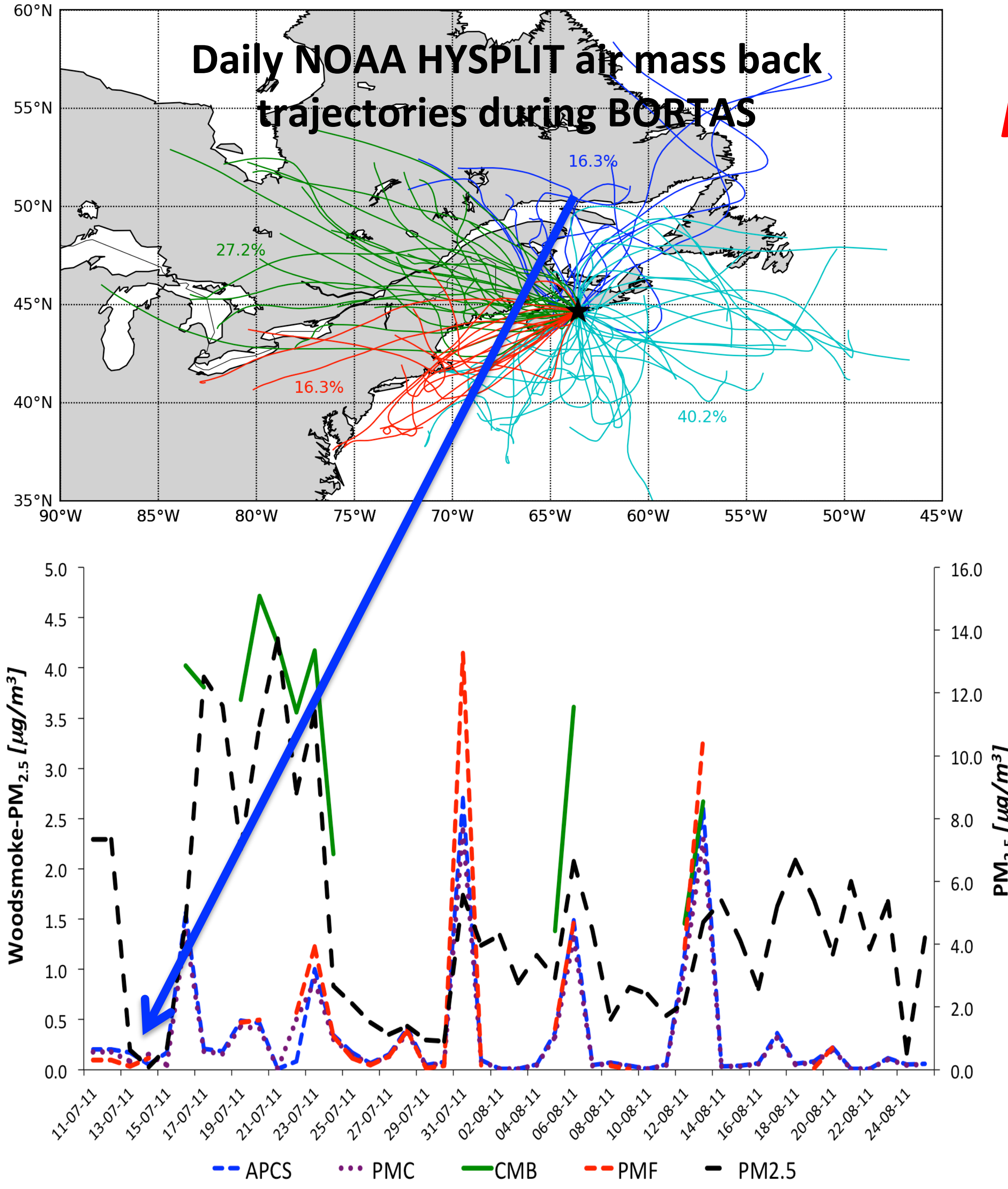
12-08-11
14-08-11
16-08-11
18-08-11
20-08-11
22-08-11
24-08-11


PMC, APCS, CMB & PMF predicted PM2.5-woodsmoke time series
Woodsmoke-PM2.5 [μg/m3]
PM2.5 [μg/m3]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
11-07-11
13-07-11
15-07-11
17-07-11
19-07-11
21-07-11
23-07-11
25-07-11
27-07-11
29-07-11
31-07-11
02-08-11
04-08-11
06-08-11
08-08-11
10-08-11
12-08-11
14-08-11
16-08-11
18-08-11
20-08-11
22-08-11
24-08-11
APCS
PMC
CMB
PMF
PM2.5

# Daily NOAA HYSPLIT air mass back trajectories during BORTAS

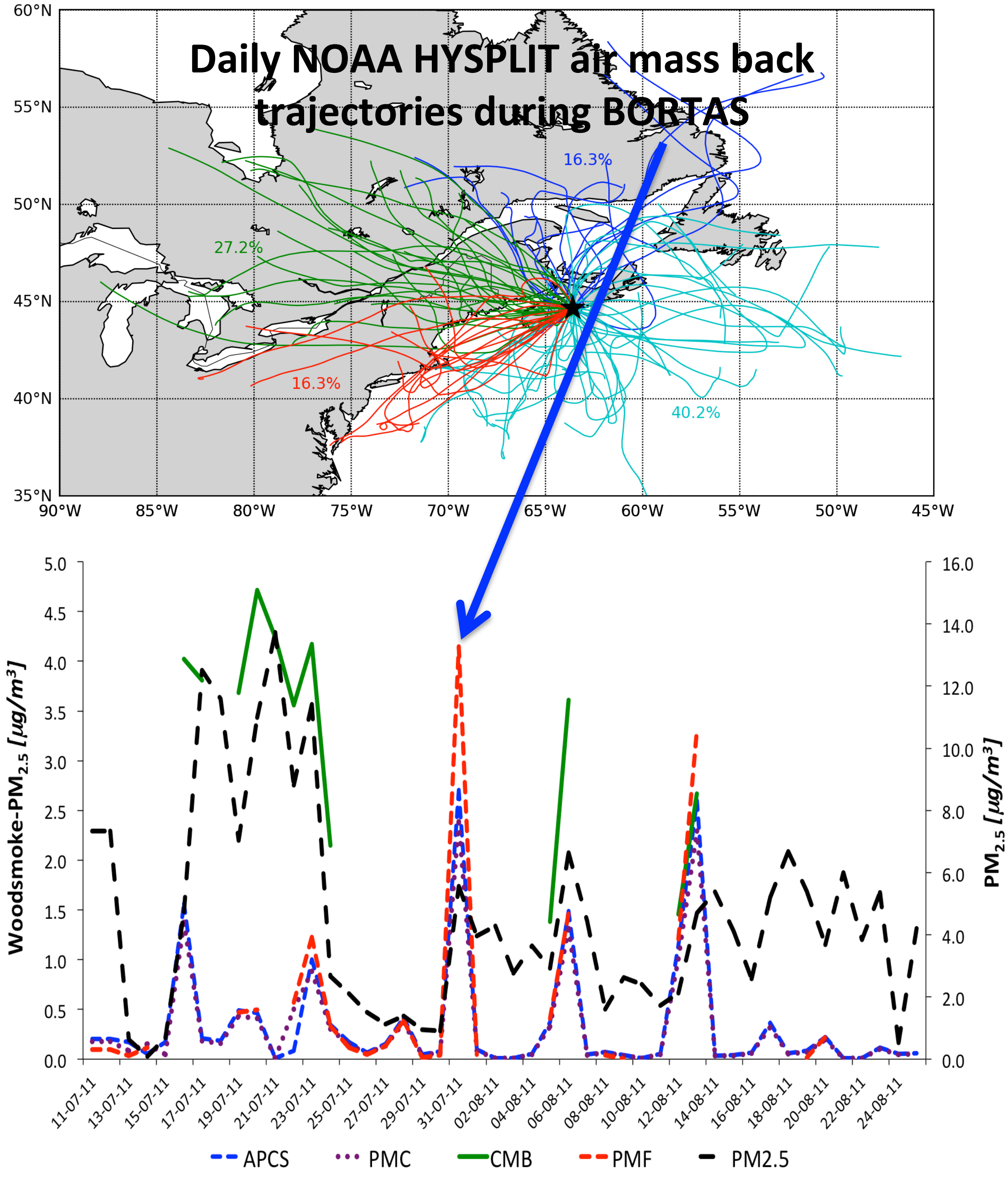
## (http://ready.arl.noaa.gov/hysplit-bin/trajtype.pl?runtype=archive)



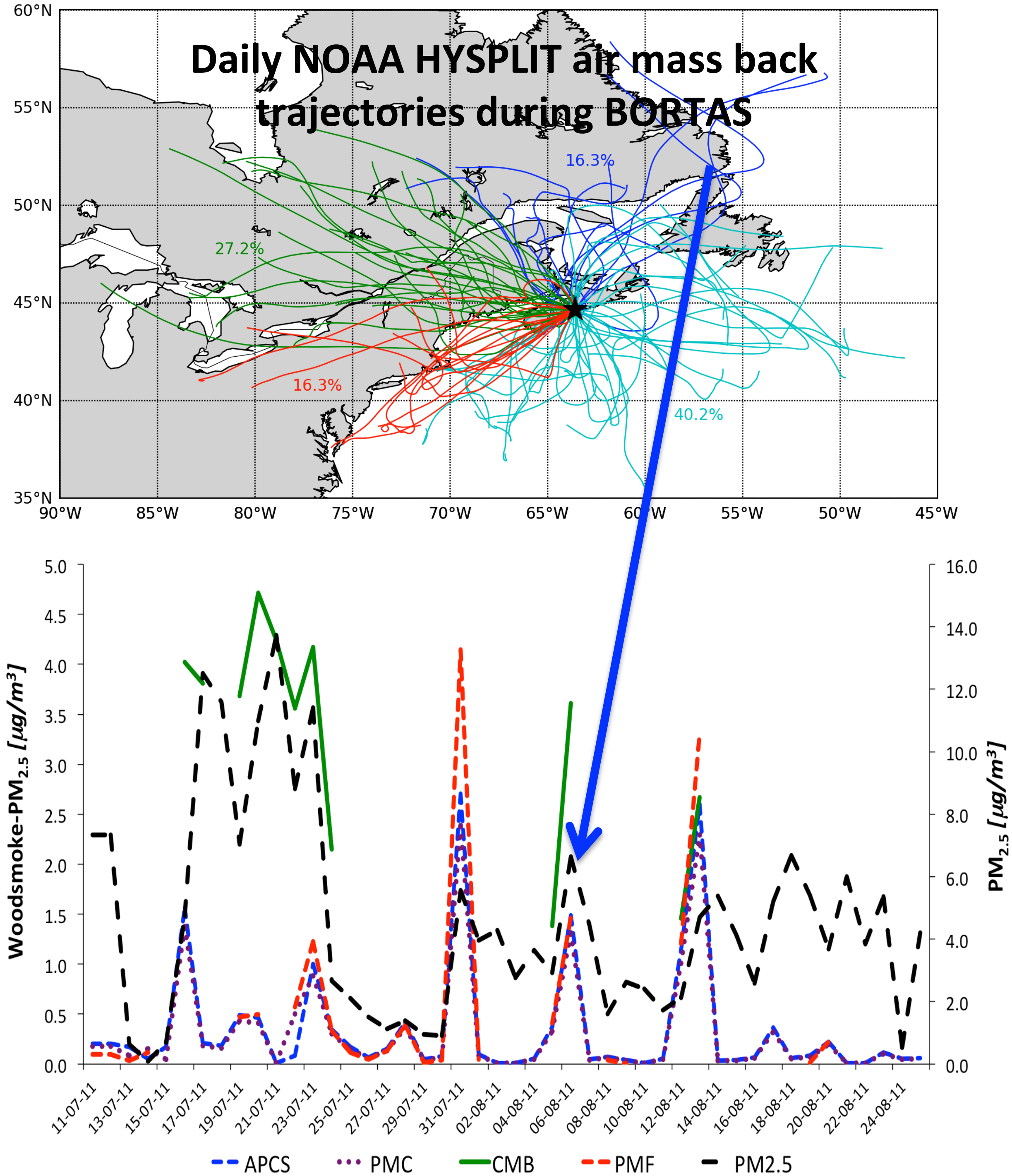



# *No Upwind Fire activity*

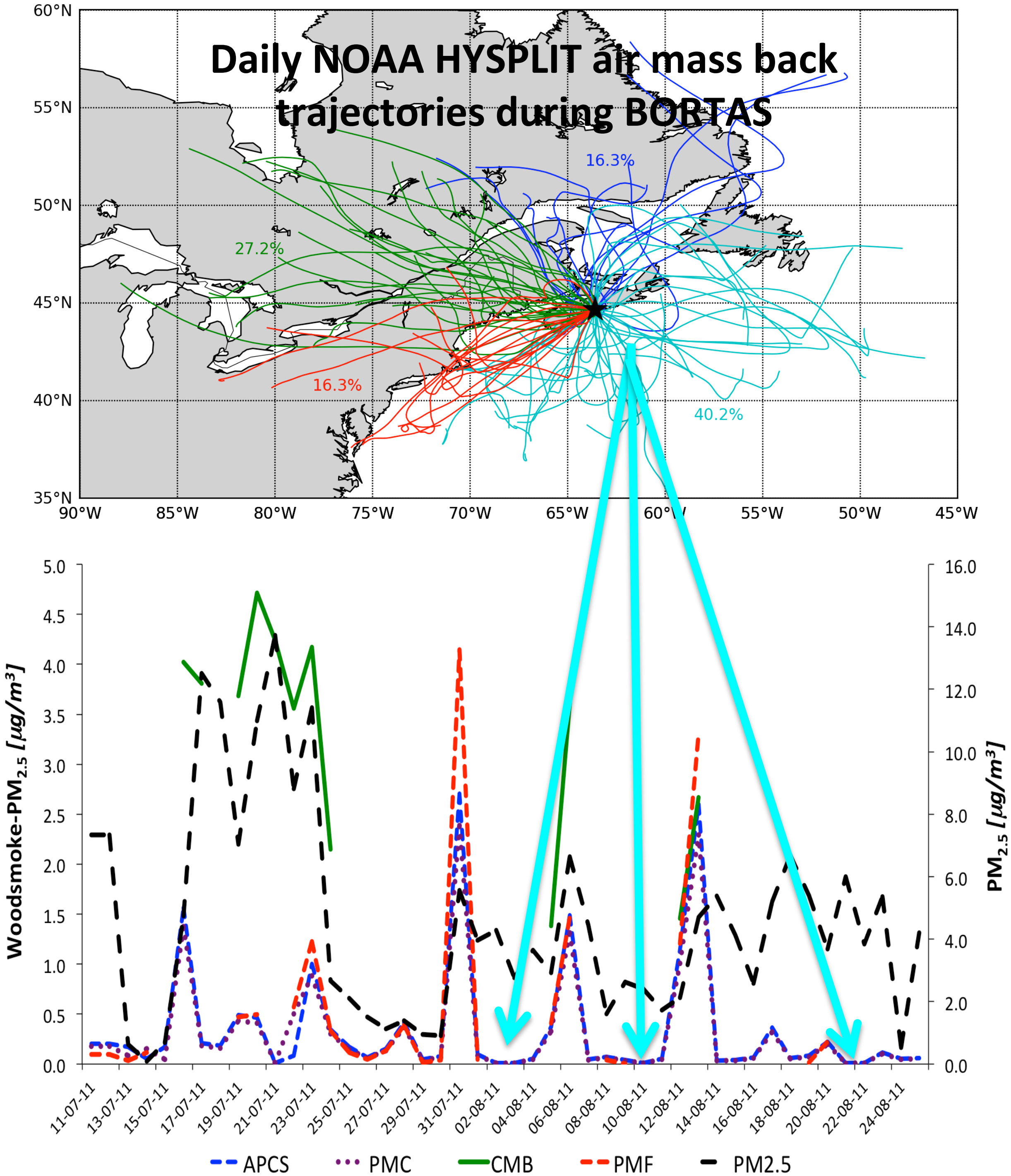
**Northerly airflow from clean source regions characterized by low $PM_{2.5}$ mass and low woodsmoke mass contributions**




**These woodsmoke spikes were associated with NE airflow that crossed Newfoundland and Cape Breton, en route to Halifax**

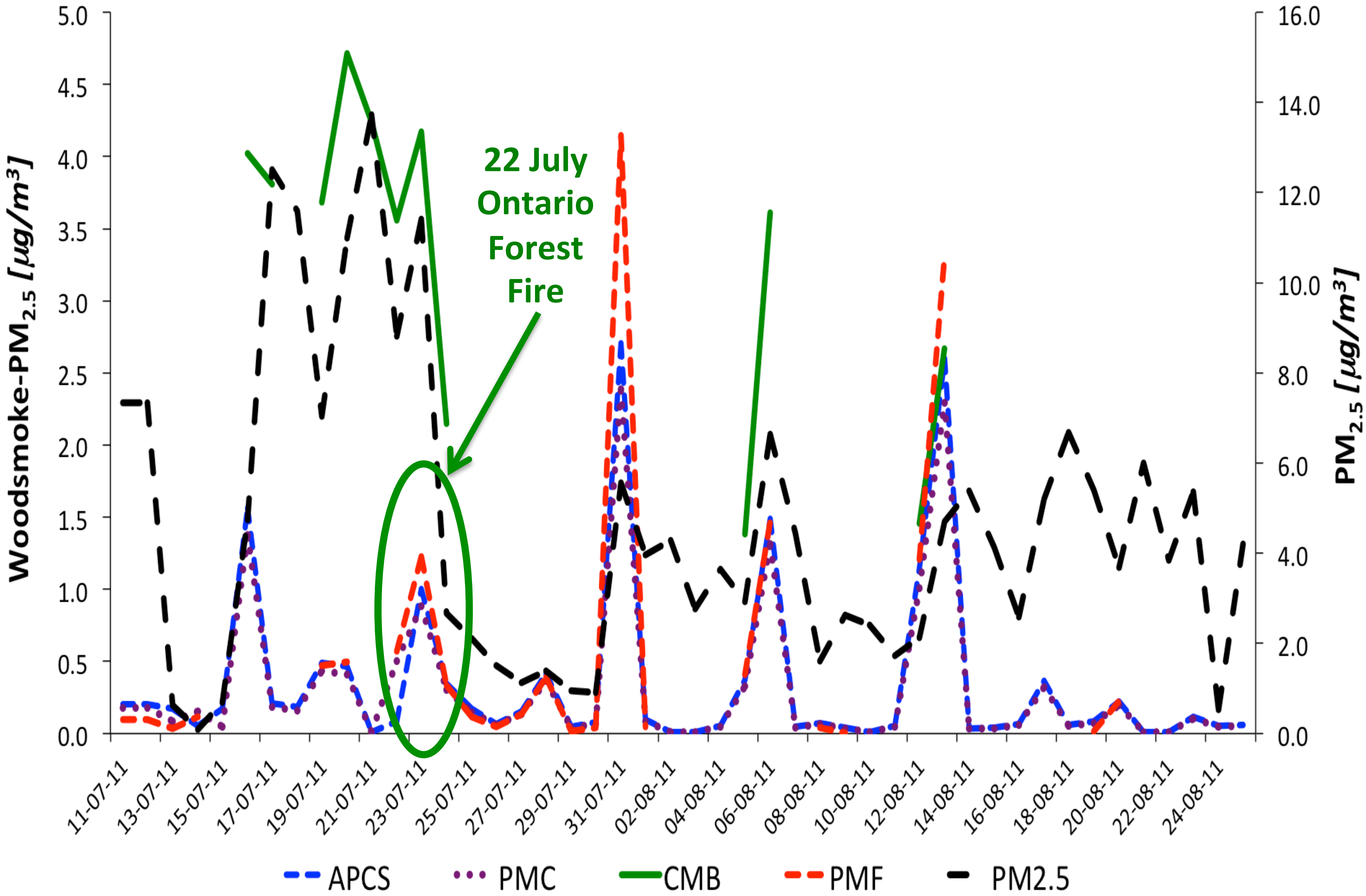



**These woodsmoke spikes were associated with NE airflow that crossed Newfoundland and Cape Breton, en route to Halifax**

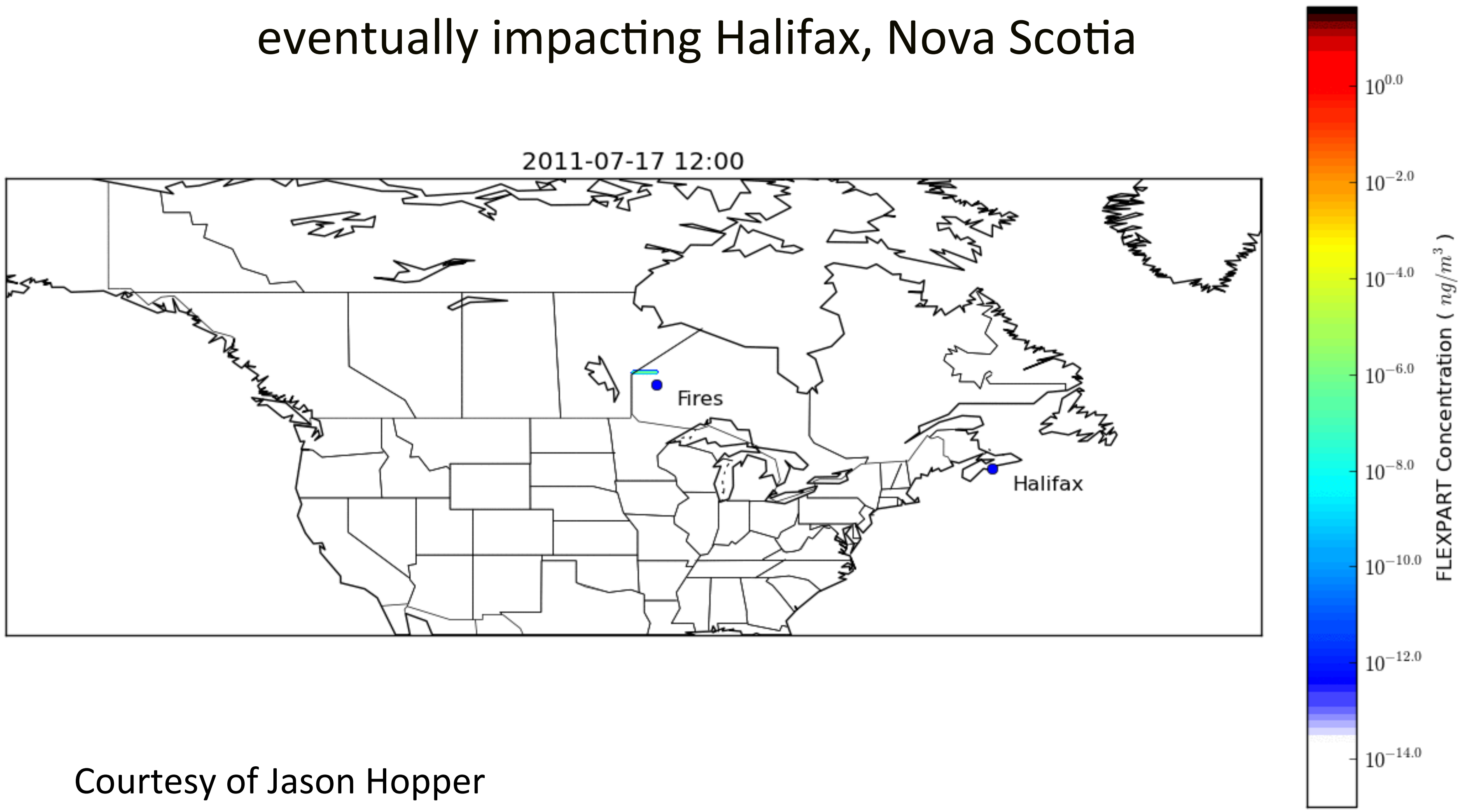



**Marine air flow resulted very low $PM_{2.5}$-woodsmoke contributions**

# Ontario boreal forest fire woodsmoke event

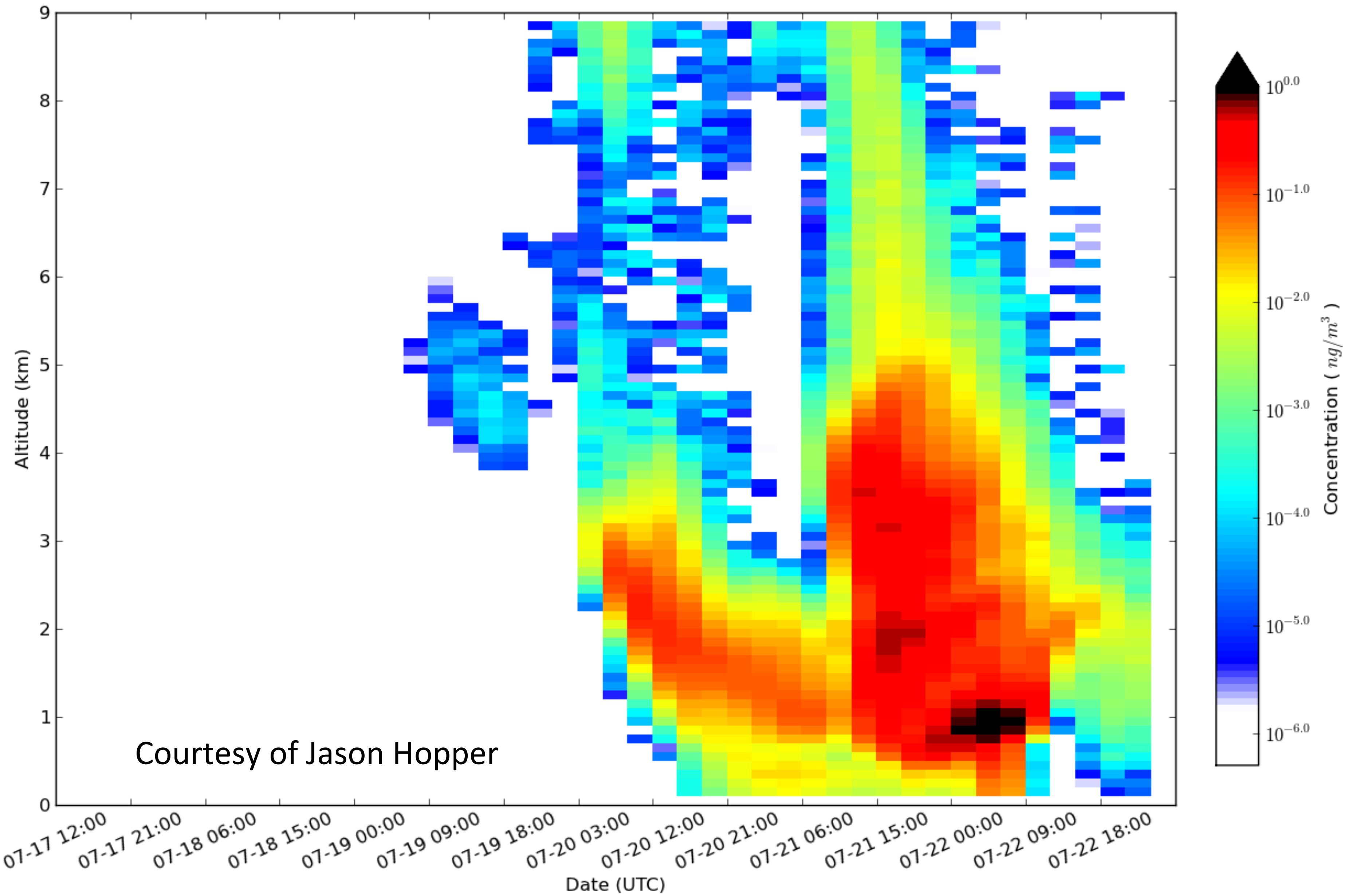


# FLEXPART 5-DAY Air Parcel Forward Trajectory Model
# 17 July to 22 July 2011
# Air parcel crosses large forest fire in Northern Ontario, eventually impacting Halifax, Nova Scotia

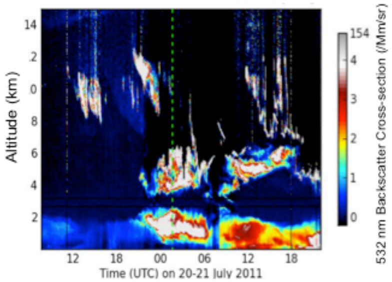



Courtesy of Jason Hopper

# FLEXPART Model of the Ontario forest fire smoke concentration directly above Halifax – 20 July to 22 July 2011

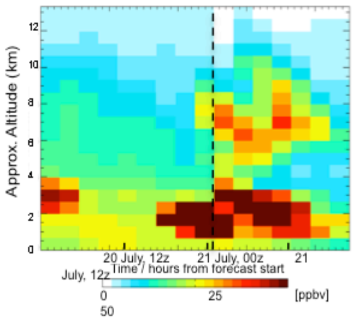


# Comparison of simultaneous observations



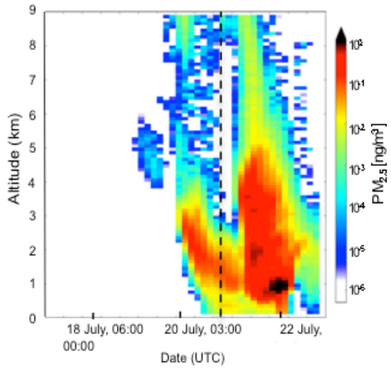

a) Lidar back scatter cross section DGS, 20/21 July 2011

a) Lidar backscatter cross section DGS, 20/21 July 2011



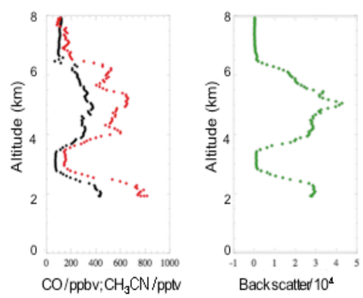

b) GEOS-5 predicted CO at the DGS 20/21 July, 2011

b) GEOS-5 CO forecast at the DGS 20/21 July, 2011




c) FLEXPART vertical $PM_{2.5}$ profile, DGS, 21 July 2011

c) FLEXPART vertical $PM_{2.5}$ profile, DGS, 21 July 2011

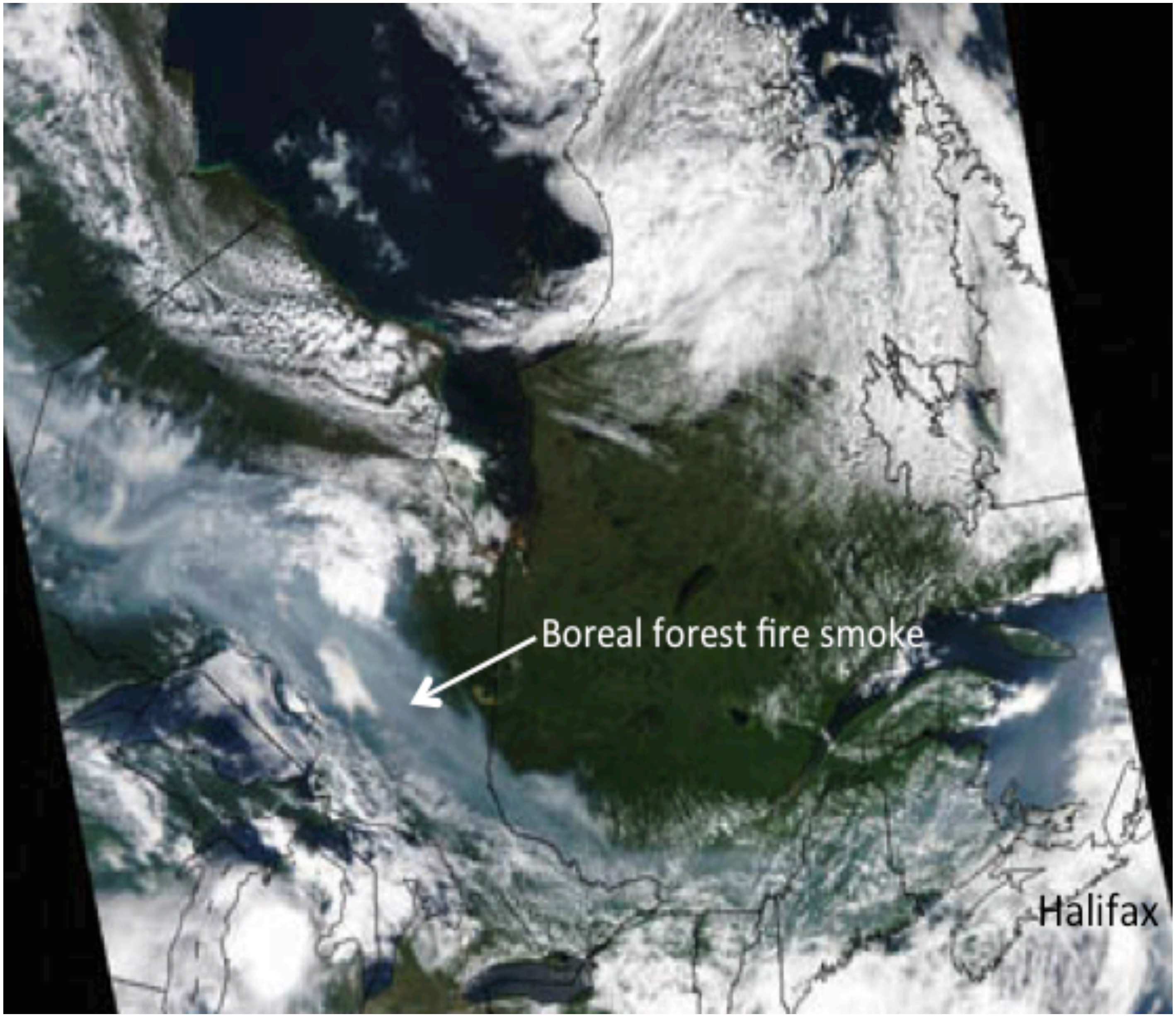



d) Spiral aircraft profiles over the DGS, 21 July 2011

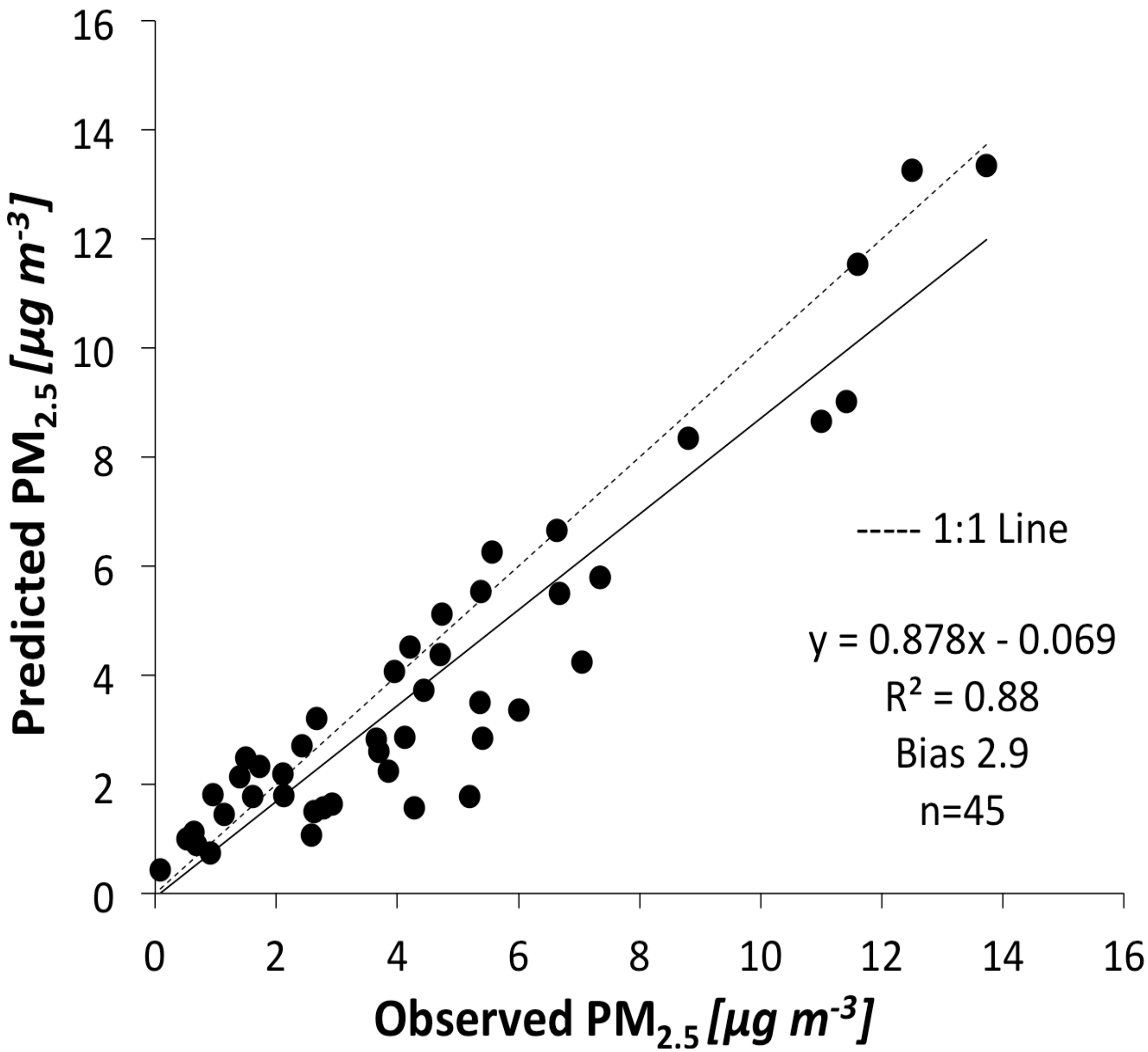
d) Spiral aircraft profiles over the DGS, 21 July 2011.

*Vertical dashed lines in a), b) and c) indicate the time of the spiral aircraft profiles in d)


5-day HYSPLIT air mass back trajectory arriving at 12:00 UTC overlaying the fire hot spot map for 28 July 2011



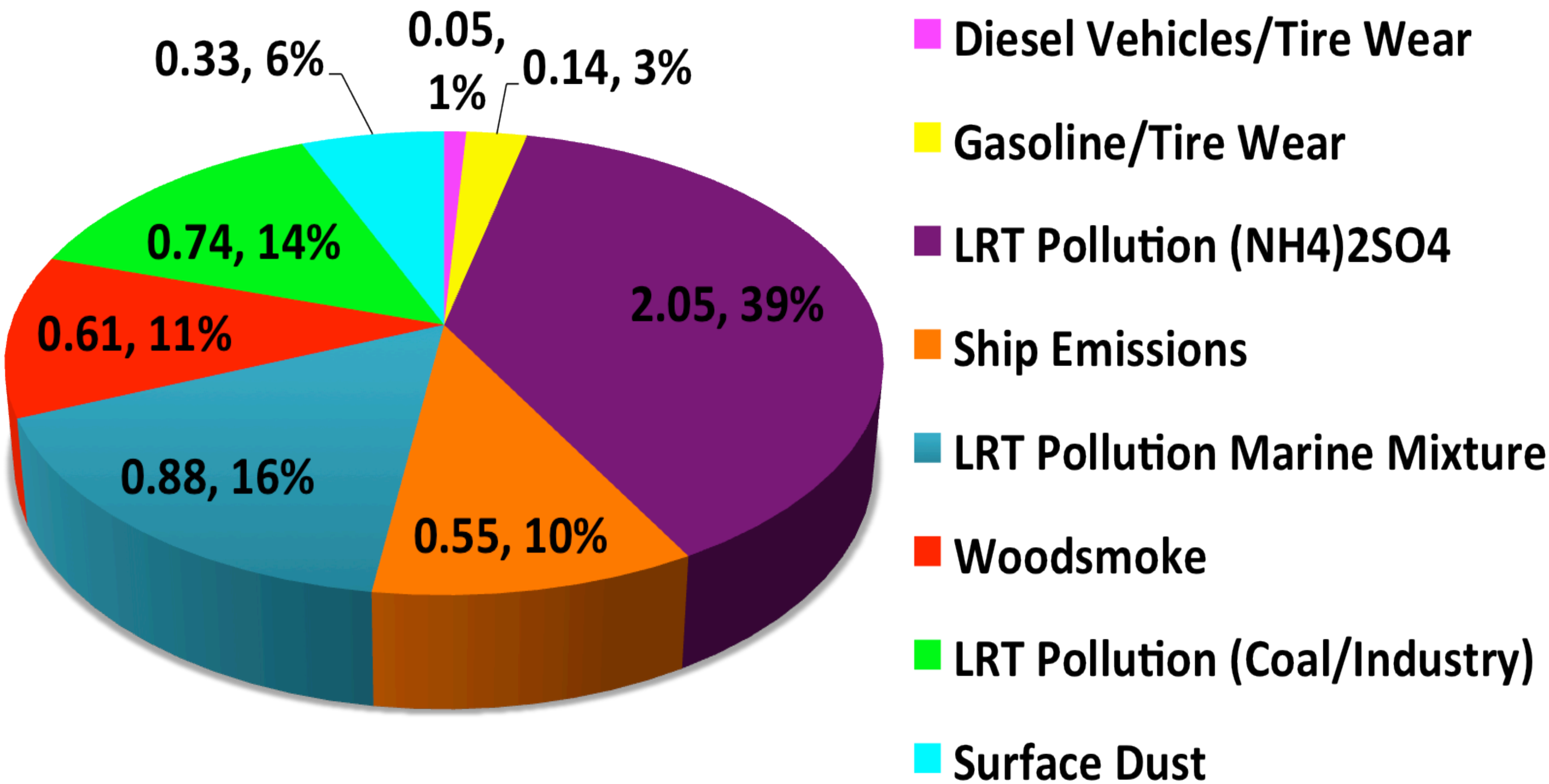
NASA AQUA MODIS true colour satellite image at 18:00 UTC on 18 July 2011 clearly showing boreal forest fire smoke from Northern Ontario advecting over Halifax, Nova Scotia




Positive Matrix Factorization (PMF) predicted versus observed $PM_{2.5}$

**$PM_{2.5}$ source apportionment by Positive Matrix Factorization**

*data labels = mass ($\mu g/m^3$), % relative contributions*




**8 Sources Apportioned** **Total LRT 69%**

# Summary

- Between 5 and 12 Sources identified by the four receptor models
- Only PMF can predict total $PM_{2.5}$ mass concentrations below 2.0 $\mu g/m^3$.
- Positive Matrix Factorization performed the best of the four receptor models.
- The use of a woodsmoke chemical marker such as levoglucosan is critical when carrying out $PM_{2.5}$ source apportionment studies of that include woodsmoke.
- The study has demonstrated the utility of using satellites, chemical transport models, aircraft, air mass trajectories to support in situ measurements of size-resolved $PM_{2.5}$ species
- All of the receptor models provide further insight into the main sources driving the temporal variability of $PM_{2.5}$ in Halifax during BORTAS-B project.

# Next Steps
# Tube Furnace Combustion Product Source Profiling Experiments to Verify the Receptor Modelling Results

# Acknowledgements


- Professor Paul Palmer (BORTAS lead) University of Edinburgh, School of GeoSciences for funding project consumables *via* Philip Leverhulme Prize


Photo courtesy of James Kuchta


Thanks for listening!
Banamex
OREGON
NIKE