Optical analysis of summer-time aerosol events over two southern Canadian sites using ground-based remote sensing techniques

UNIVERSITÉ DE SHERBROOKE

M.L. Karumudi[1]; N. T. O'Neill[1]; A. Saha[1]; D. Daou[1]; S. Zidane[1]; K. B. Strawbridge[2]; B. Firanski[2]; Ihab Abboud[2], Jim Freemantle[1]

[1]Département de Géomatique Appliquée, Centre d'Applications et de Recherches en Télédétection (CARTEL), Sherbrooke, QC, Canada.
[2]Environment Canada, Egbert, ON, Canada.

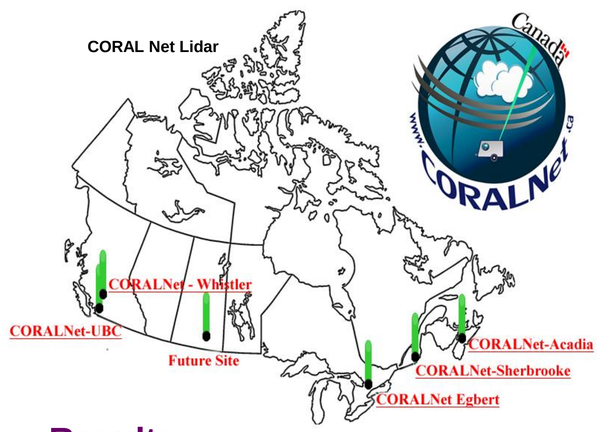
Environnement Canada Environment Canada

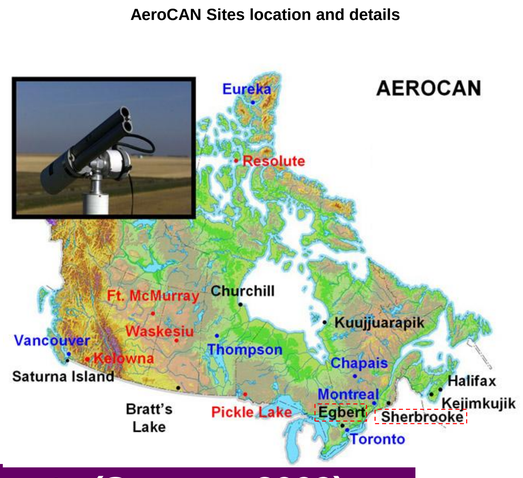
Objective: Over the past several decades a wealth of information from ground-based networks, satellite remote sensing platforms and transport models have helped to better understand aerosol transport pathways over the globe. Sun photometry and Lidar observations were carried out at two southern Canadian stations during the summer 2009. A variety of fine mode (sub-micron) smoke and boundary layer events were analysed using the lidar and sunphotometry data, satellite imagery, emissions data and backtrajectory computations.

Instruments used: CIMEL Sunphotometers (AEROCAN/AERONET network) and CORAL Net Lidars with a focus on the sites at Egbert Ontario and the CARTEL site at Sherbrooke Quebec

Remote sensing imagery products used: MODIS (Aqua and Terra), Aerosol Index (OMI), Fire Locating and Modeling of Burning Emissions (FLAMBE), MISR, CALIPSO.

Models employed: HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model), Global Environmental Multiscale Air Quality model (GEM-AQ) CO-like simulations.





Results:

1. Classification of fine mode events (Summer 2009)

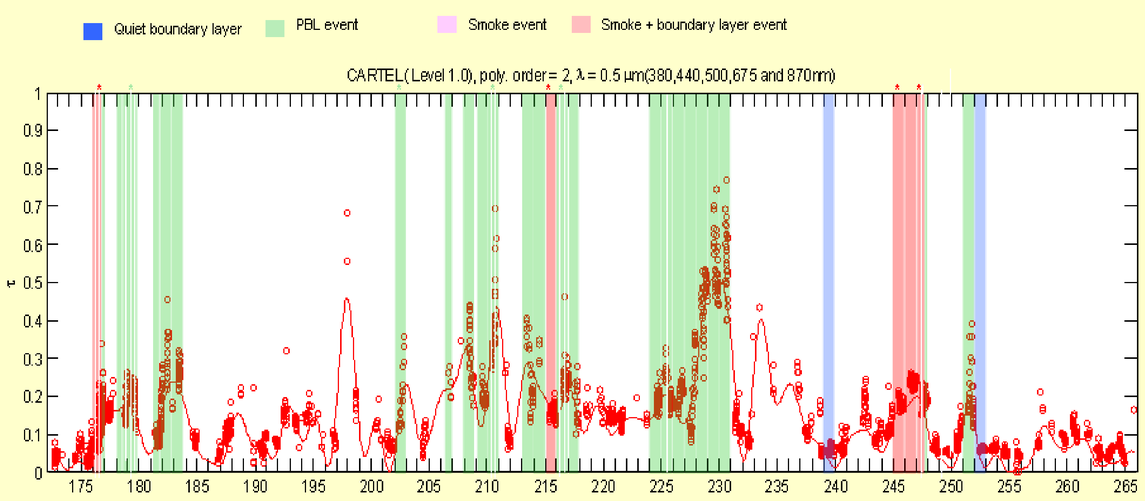


Fig. 1a

Fig. 1b

- Fine mode optical depth variation during the summer of 2009 for the Sherbrooke (CARTEL) and Egbert sites. The coloured overlays represent event classifications determined from the combination of lidar and sunphotometry data, backtrajectories, remote sensing imagery and emissions data. The event averages for a variety of derived parameters are given in the tables below. Note that there are few (pure) smoke events since smoke events were almost always accompanied by significant turbidity variations in the boundary layer.

Class-based statistical analysis for the summer of 2009 events

CARTEL Date	Total(SDA)	Fine(SDA)	coarse(SDA)	Level 1.5 reff,f(Dubovik)	Level 1.5 Sa-Fine mode(500nm)	Trajectory Dept Time(GMT) -Height	Trajectory arrival Time(GMT) -Height	level 1.5 N(Dubovik)	level 1.0 N(SDA)	Event duration(GMT)
25 June	0.27±0.23	0.11±0.04	0.16±0.21	0.13	70.49	2:00-3800m(June 24)	13:00-3100m	1	100	10:00-17:27
	0.3±0.04	0.21±0.02	0.09±0.03						6	20:15-20:35
27 June	0.26±0.07	0.22±0.04	0.04±0.06						11	18:39-20:12,22:57-23:25
28 June	0.29±0.11	0.21±0.02	0.08±0.11						34	10:01-16:48
30 June	0.24±0.03	0.22±0.03	0.02±0.01	0.16±0.01	74.59±5			5	17	22:21-23:36
1 July	0.32±0.07	0.29±0.06	0.02±0.01						23	10:28-12:42
2 July	0.29±0.02	0.26±0.03	0.03±0.02						31	10:03-13:46
21 July	1.87±0.5	0.26±0.06	1.61±0.44	0.32	12.22			1	8	17:09-19:09
25 July	0.29±0.14	0.23±0.04	0.06±0.11						6	15:09-21:53
27 July	0.33±0.07	0.31±0.08	0.02±0.03						29	10:42-21:51
28 July	0.25±0.03	0.23±0.03	0.02±0.01	0.16±0.01	78.88±2.71			3	7	13:03-15:39
29 July	0.49±0.19	0.37±0.1	0.12±0.16						32	10:37-18:54
1 Aug	0.3±0.1	0.24±0.08	0.06±0.06	0.15±0.01	77.53±0.83			3	32	10:46-23:22
2 Aug	0.65±0.15	0.32±0.03	0.33±0.17						4	10:41-13:54
3 Aug	0.16±0.02	0.15±0.02	0.01	0.17±0.01	76.04±9.62	18:00-5500m(July 29)	19:00-2100m	9	64	10:29-23:20
4 Aug	0.35±0.1	0.24±0.04	0.11±0.1	0.15±0.01	73.66±0.93			2	52	10:34-23:10
5 Aug	0.24±0.03	0.22±0.03	0.02±0.02	0.13±0.03	55.33±3.8			2	7	17:24-18:54
12 Aug	0.24±0.05	0.21±0.02	0.03±0.03	0.14	69.81			1	14	21:03-23:05
13 Aug	0.26±0.05	0.24±0.04	0.02±0.02	0.13±0.01	69.6±1.06			2	22	10:39-16:23,19:53-20:27
14 Aug	0.24±0.02	0.22±0.02	0.02±0.01	0.16±0.01	73.85±3.32			5	37	14:23-23:06
15 Aug	0.31±0.06	0.29±0.07	0.02	0.16±0.01	77.25±7.03			6	25	17:23-23:01
16 Aug	0.5±0.06	0.45±0.07	0.05±0.07	0.18	86.97±6.05			3	40	12:05-22:49
17 Aug	0.56±0.08	0.55±0.08	0.01	0.19±0.01	90.73±3.88			7	38	13:24-22:48
18 Aug	0.58±0.09	0.56±0.09	0.02±0.02	0.19±0.01	88.52±1.79			4	28	11:42-19:07
27 Aug	0.16±0.18	0.06±0.01	0.1±0.19	0.19±0.01	79.85±8.22			4	40	12:43-22:19
2 Sep	0.19±0.01	0.18±0.02	0.01	0.15±0.01	71.63±3.57	15:00-4000m(Aug 29)	15:00-3100m	12	67	11:02-22:35
3 Sep	0.25±0.01	0.24±0.01	0.01	0.15±.01	69.92±2.47	8:00-3000m(Aug 29)	12:00-3100m	12	68	11:03-22:33
4 Sep	0.21±0.03	0.2±0.02	0.01±0.01	0.15±0.01	73.99±4.32	20:00-5500m(Aug 28)	12:00-3000m	8	35	11:04-17:33
	0.22±0.01	0.2±0.01	0.02						13	20:18-21:56
8 Sep	0.3±0.07	0.28±0.07	0.02±0.01	0.15±0.01	73.29±2.27			4	10	13:31-20:01
9 Sep	0.07±0.01	0.06	0.01±0.01	0.17±0.01	75.58±5.12			10	69	11:10-22:22

Table1: Statistical analysis of events over CARTEL

Egbert Date	Total(SDA)	Fine(SDA)	Coarse(SDA)	Level 1.5 reff,f(Dubovik)	Level 1.5 Sa-Fine mode(500nm)	Trajectory Dept Time(GMT)-Height	Trajectory Arrival Time(GMT)-Height	level 1.5 N(Dubovik)	level 1.0 N(SDA)	Event duration(GMT)
25 June	0.57±0.65	0.29±0.05	0.28±0.66	0.14	76.64			1	42	10:44-14:53
27 June	0.17±0.04	0.17±0.04	0.00	0.16±0.01	61.28±5.36	8:00-3500m(June 26)	12:00-2200m	4	103	10:35-16:23
28 June	0.32±0.03	0.32±0.03	0.00	0.18	72.99			1	17	20:48-22:44
4 July	0.07±0.01	0.07±0.01	0.00	0.17±0.01	71.63±3.14			5	83	17:03-23:50
9 July	0.27±0.06	0.27±0.05	0.01±0.01	0.16	63.42±4.21			2	16	21:39-22:44
10 July	0.38±0.26	0.26±0.04	0.11±0.24	0.13±0.01	62.19±1.23			2	40	20:33-23:51
11 July	0.29±0.06	0.28±0.05	0.01±0.01						7	15:51-16:21
17 July	0.28±0.05	0.28±0.05	0.00	0.16±0.01	70.94±4.87			4	14	18:21-19:11
20 July	0.27±0.06	0.24±0.03	0.03±0.05	0.17	61.71			1	31	18:55-19:56,21:18-22:56
21 July	0.91±1.15	0.28±0.06	0.63±1.17	0.16	66.21±3.42			3	4	15:09-16:48
22 July	0.97±0.53	0.28±0.05	0.69±0.53						20	14:54-23:33
24 July	0.48±0.45	0.25±0.04	0.23±0.46						8	17:03-21:06
28 July	0.37±0.1	0.31±0.05	0.06±0.11						46	18:00-23:20
29 July	1.72±0.62	0.24±0.05	1.48±0.59						13	18:24-22:41
31 July	0.28±0.07	0.25±0.02	0.03±0.08	0.17±0.02	61.03±6.74			4	19	12:45-13:21, 15:26-16:18
2Aug	0.27±0.16	0.27±0.16	0.00	0.19±0.02	59.3±3.77	6:00-6000m(July 30)	15:00-4300m	4	101	12:13-17:21,20:09-23:50
3 Aug	0.55±0.77	0.2±0.06	0.35±0.72	0.17	61.61	20:00-2000m(July 27)	15:00-2400m	1	36	11:02-16:54
4 Aug	0.7±0.16	0.7±0.16	0.01	0.18	88.29±0.33			2	65	11:33-23:05
5 Aug	0.19±0.07	0.18±0.06	0.01±0.04	0.15±0.01	61.37±9.3	18:00-5000m(Aug 3)	14:00-6500m	2	138	11:04-23:47
6 Aug	0.16±0.02	0.16±0.02	0.00	0.18±0.02	56.58±6.04	12:00-3500m(Aug 3); 18:00-6500m(Aug 1)	14:00-3400m,21:00-8000m	8	199	11:13-23:48
7 Aug	0.17±0.04	0.16±0.03	0±0.03	0.18±0.01	61.73±10.23	3:00-3700m(July 26)	12:00-3700m	3	119	11:06-19:00
8 Aug	1.32±0.55	0.22±0.04	1.1±0.53						30	14:21-17:54
9 Aug	0.29±0.03	0.29±0.02	0.00						11	18:18-19:00
14 Aug	0.29±0.07	0.29±0.07	0.00	0.16	67.64±2.45			6	70	17:09-23:33
15 Aug	0.37±0.09	0.37±0.09	0.00	0.15	72.58±2.4			2	92	13:33-20:42
16 Aug	0.57±0.09	0.57±0.09	0.00	0.18±0.01	85.82±2.36			6	152	11:39-22:57
17 Aug	0.38±0.04	0.38±0.04	0.00	0.19±0.02	85.66±2.01			2	64	11:20-15:15
25 Aug	0.28±0.06	0.25±0.04	0.03±0.05	0.14	59.86±4.43			3	28	14:52-18:21
1 Sep	0.16±0.03	0.15±0.03	0±0.01	0.16±0.01	65.96±3.41	12:00-2000m(Aug 28)	15:00-2500m	6	120	13:54-22:30
2 Sep	0.22±0.02	0.22±0.02	0.00	0.15±0.01	66.69±2.53	18:00-2000m(Aug 28)	16:00-2500m	8	149	13:54-22:27
3 Sep	0.14±0.02	0.14±0.02	0.00	0.16±0.01	60.48±3.85	23:00-4500m(Aug 28)	14:00-2500m	9	163	13:03-22:26
4 Sep	0.23±0.11	0.18±0.03	0.05±0.11	0.16±0.01	63.05±2.75	12:00-4500m(Aug 29)	18:00-3100m	4	134	14:45-22:23
6 Sep	0.17±0.04	0.16±0.02	0.01±0.03	0.16±0.01	62.12±8.66	23:00-4700m(Aug 31)	18:00-2900m	4	116	14:27-22:24
8 Sep	0.23±0.02	0.23±0.02	0.00	0.17±0.01	67.28±8.92			6	25	14:18-15:48
9 Sep	0.32±0.12	0.26±0.03	0.05±0.12	0.18±0.01	77.82±7.2			5	35	12:48-13:39, 14:26-15:39
18 Sep	0.04±0.01	0.04±0.01	0	0.21±0.01	66.98±6.06			5	89	15:57-22:21
19 Sep	0.04±0.01	0.04±0.01	0	0.21±0.01	76.34±15.18			11	117	13:48-22:22
20 Sep	0.05±0.01	0.04	0±0.01	0.19±0.02	71.36±24.70			7	135	14:28-22:21
22 Sep	0.61±0.16	0.43±0.1	0.18±0.14						38	14:57-21:54

Table2: Statistical analysis of events over Egbert

- These derived parameters (all referenced to 500 nm wavelength) include the total AOD, the fine and coarse mode optical depths, effective fine mode particle radius and extinction to backscatter ratio (lidar ratio) of fine mode particles (from the Dubovik inversion), trajectory departure and arrival times (for smoke events), the event duration and the event classification.
The Dubovik inversions were Level 1.5. "N" refers to the number of data points employed in the averaging for a given event

2. Case study; plume height retrievals from MISR and CALIOP

In this section we demonstrate a specific (interesting) example of how we determined the source of a particular event at Egbert

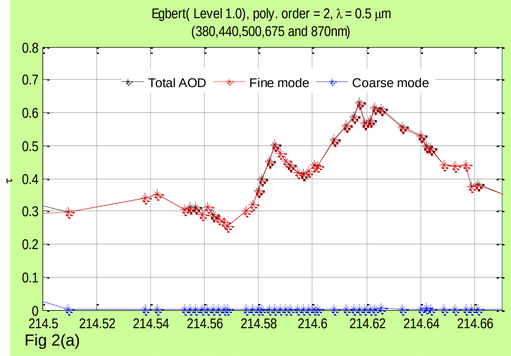


Fig 2(a)

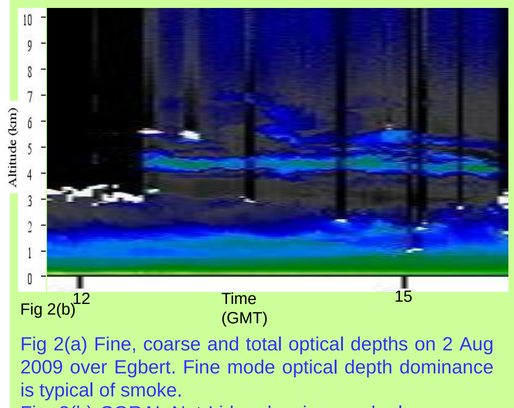


Fig 2(b)

Fig 2(a) Fine, coarse and total optical depths on 2 Aug 2009 over Egbert. Fine mode optical depth dominance is typical of smoke.
Fig. 2(b) CORAL Net Lidar showing smoke layers over Egbert corresponding to fine mode optical depth in Fig. 2(a).

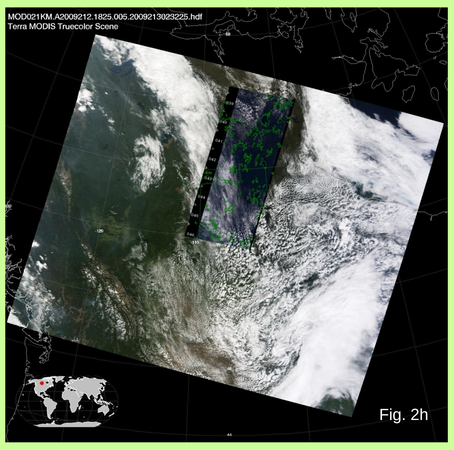


Fig. 2h

Fig 2(h) shows the MISR image (Orbit 51164) within MODIS Terra image (7/31/2009 18:25UTC)

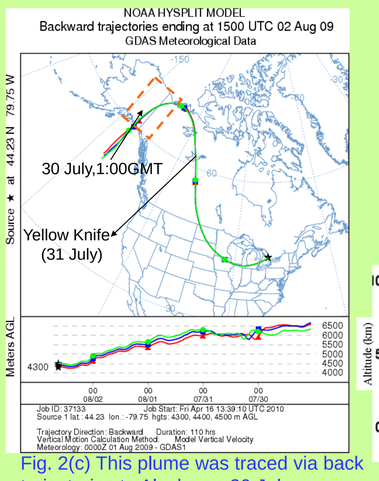


Fig. 2(c) This plume was traced via back trajectories to Alaska on 30 July

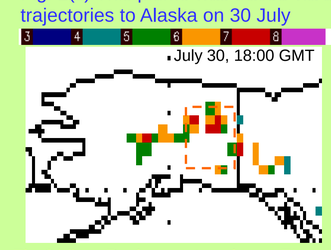


Fig.2(d) Red rectangle; FLAMBE emissions area responsible for the smoke plumes of this Case study (c.f. Fig. 2(c))

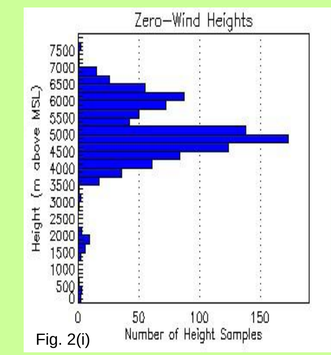


Fig. 2(i)

Fig. 2(i) shows MODIS plume profiles over Yellowknife on 31 July suggesting that the plume observed at ~ 4.5-5km and ~ 6km is consistent with the back trajectory heights on 31July(in Fig. 2c).

Fig. 2(e) CALIOP orbit trajectory corresponding to Fig. 2f and Fig. 2g

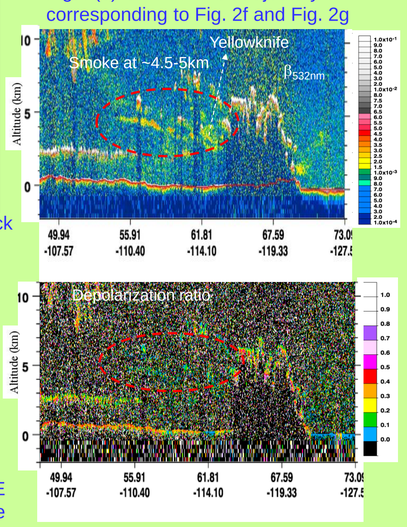


Fig 2(f): CALIPSO 532nm Total Attenuated Backscatter, $Km^{-1}Sr^{-1}$ and depolarization ratio; 2009-07-31 20:12:30.3 to 20:25:59.0, Version 3.01 (the distance of nearest approach to Yellowknife was ~21 km). The high backscatter coefficient and low depolarization ratio values are suggestive of smoke layers at 4-5km (c.f. the MISR analysis of Fig. 2(g)).

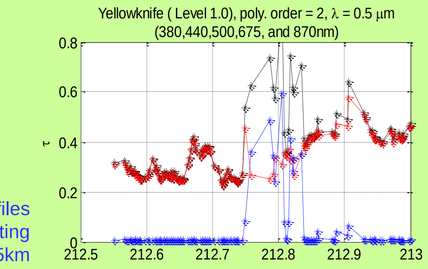


Fig.2(j) Fine mode optical depth dominance on 31July.

3. Application of our aerosol classification results; columnar versus surface indicators of fine mode aerosol (τ_f vs PM2.5)

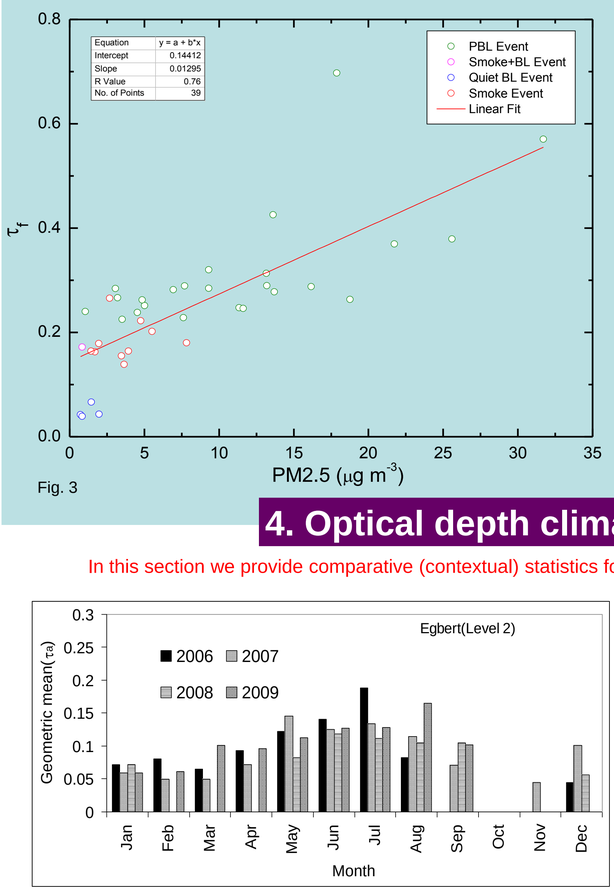


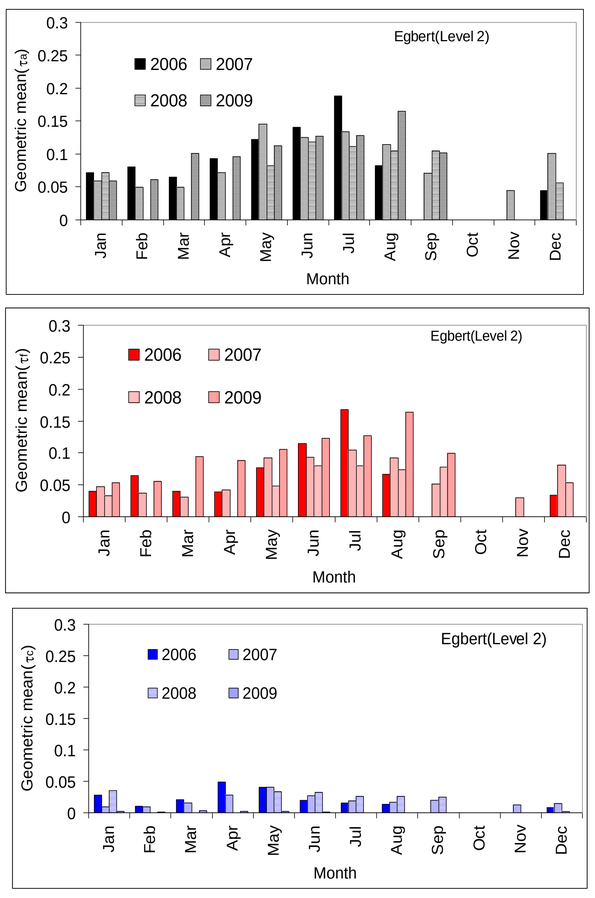
Fig. 3

Fig. 3 shows the correlation between tau_f vs PM2.5 over Egbert for different classes of events corresponding to Fig. 1b. The utility of the aerosol classification (in terms of improving the classification results for PBL events) is inconclusive. Further work will include a larger data ensemble and division of τ_f into columns above and below the boundary layer.

Symbol Glossary	
τ_f	Fine mode aerosol optical depth
τ_c	Coarse mode aerosol optical depth
τ_a	Total optical depth
Sa	Lidar ratio
$r_{eff,f}$	Fine mode effective radius

4. Optical depth climatology (2006-2009)

In this section we provide comparative (contextual) statistics for the 2009 aerosol classification analysis



➢Fig. 4. Yearly variation of monthly (geometric) means for fine, coarse and total aerosol optical depth (at 500 nm). Notable features are the increase in fine mode optical depth during the summer months due to smoke and pollution aerosols and an apparent increase in coarse mode optical depth during the late winter and spring (much of which can probably be attributed to spring-time Asian dust).

Acknowledgements: The *authors are thankful* to CFCAS (Canadian Foundation for Climate and Atmospheric Science), NSERC (National Sciences & Engineering Research Council) and CFI (Canadian Foundation for Innovation) for *financial support* . Technical assistance from the NASA AERONET project and Environment Canada is also gratefully acknowledged.