Environment Canada Environnement Canada

Canada

A Case Study of Atmospheric Transport and Dispersion of PyroCb Smoke: Implications for Volcanic Ash Modelling

2nd IUGG-WMO Workshop on

Ash Dispersal Forecast and Civil Aviation

World Meteorological Organization

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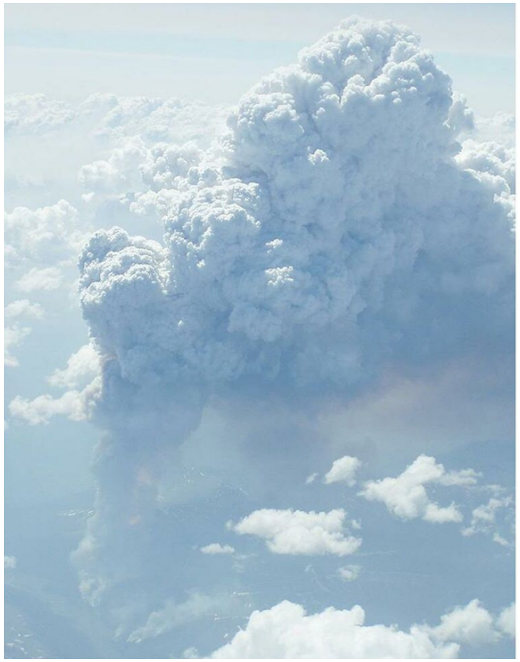
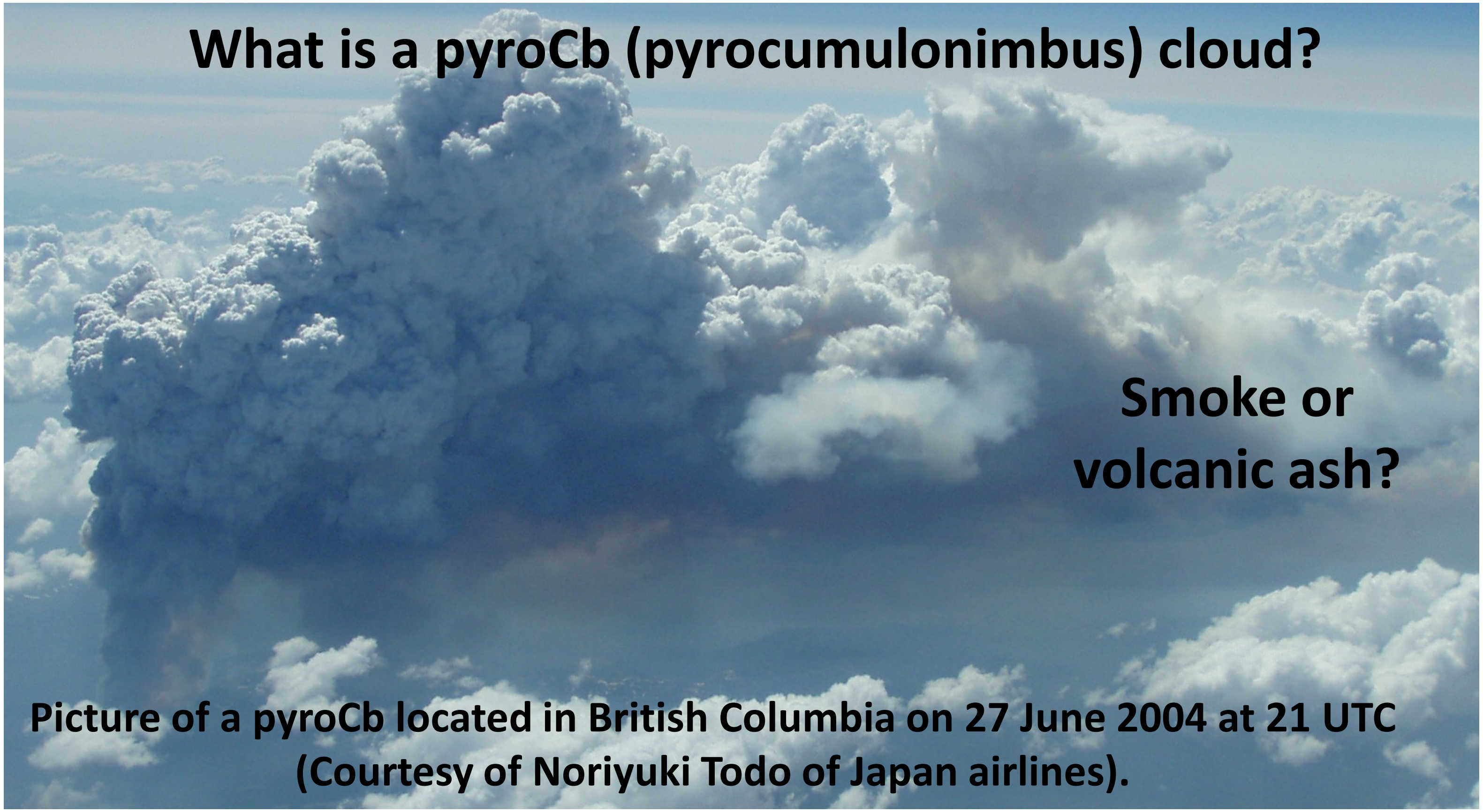


Outline

- Pyrocumulonimbi
- Description of ATDM MLDP0
- Operational case study:
  - PyroCbs in Northern Alberta, Canada, 10-11 July 2012
  - Qualitative validations of MLDP0, based on satellite imagery
- Summary and conclusion

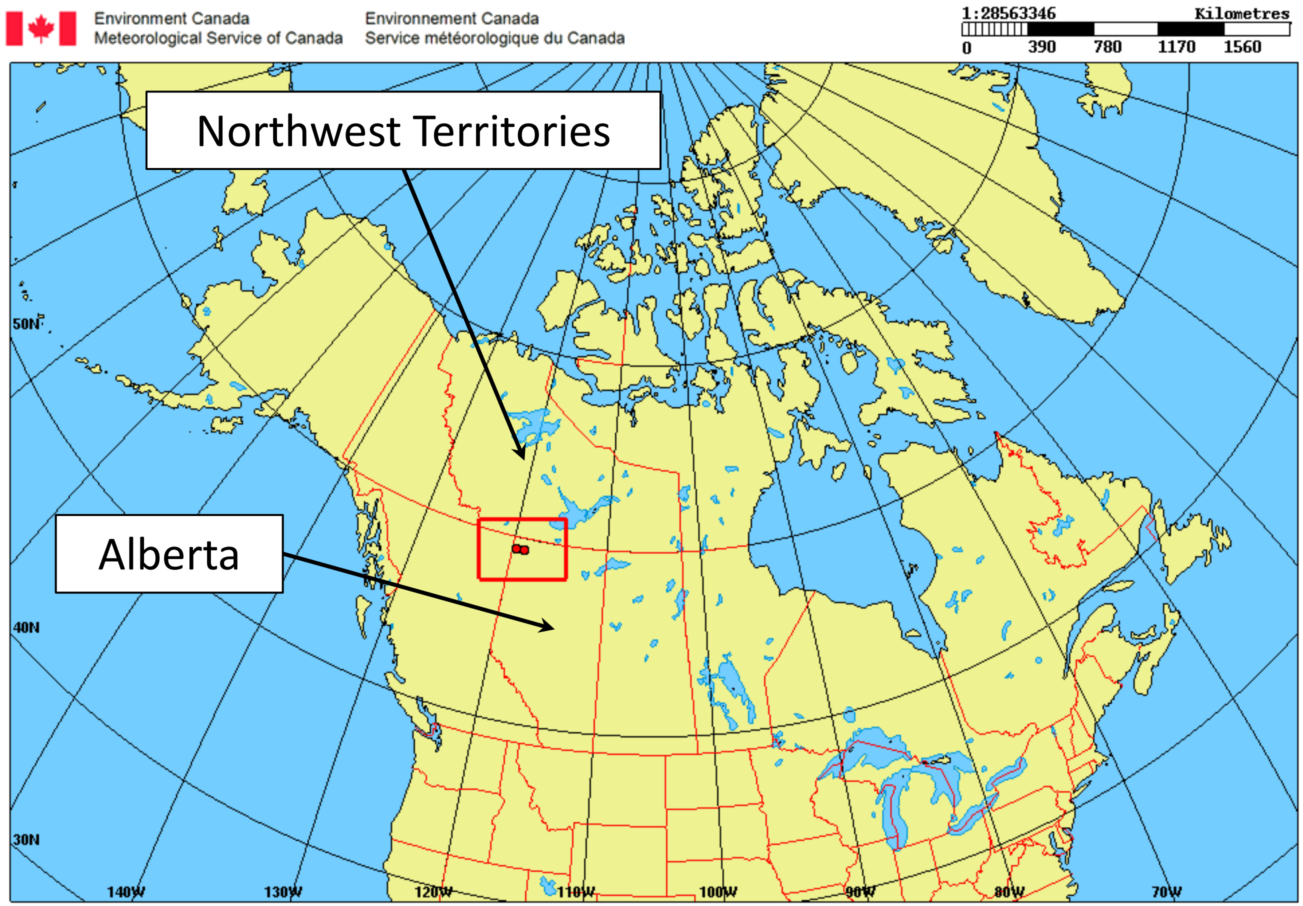
Smoke Transport from PyroCbs vs Volcanic Ash



Picture of a pyroCb located in British Columbia on 27 June 2004 at 21 UTC (Courtesy of Noriyuki Todo of Japan airlines).

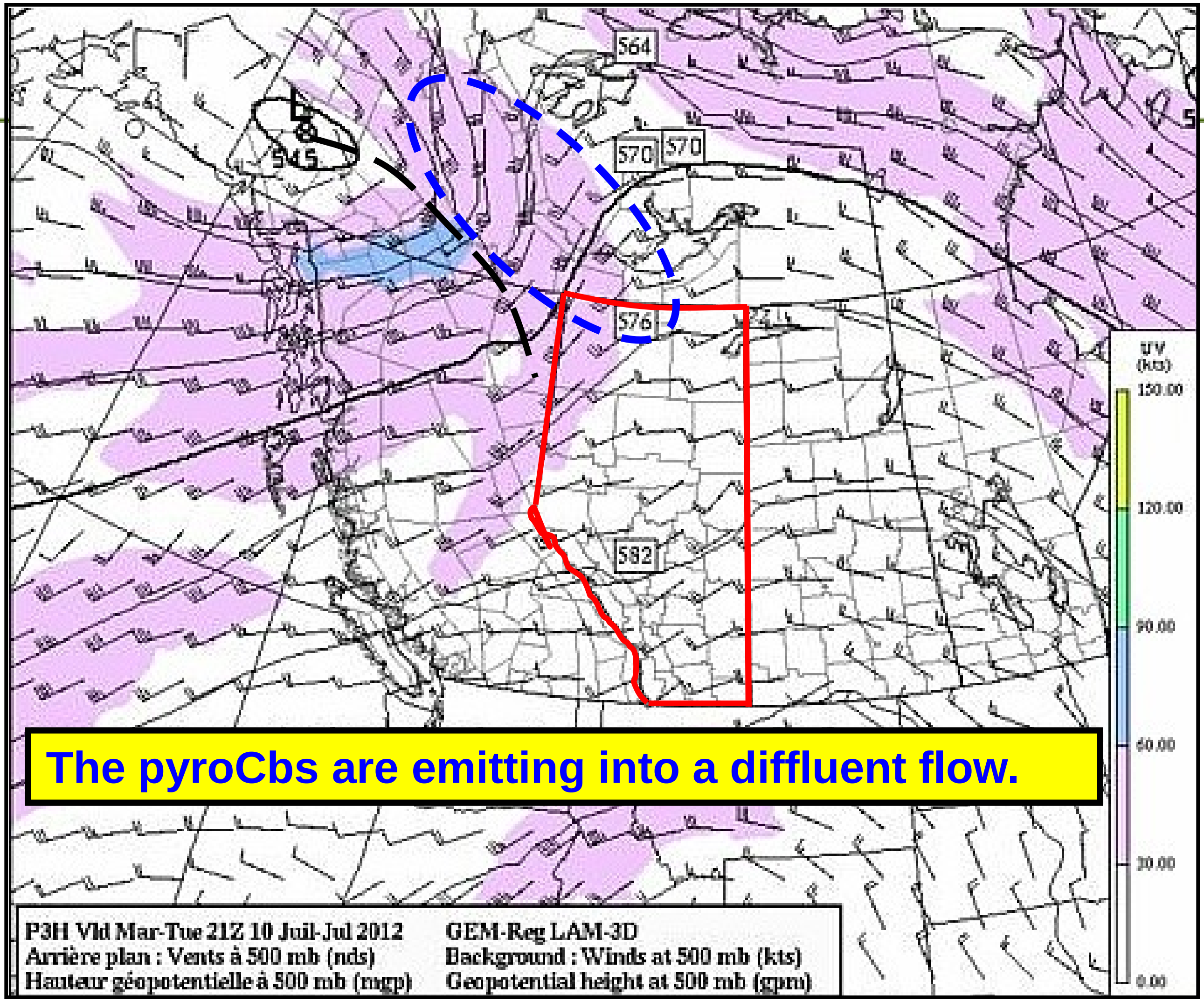
VAAC Montréal occasionally receives AIREPs of “VA” that is actually smoke.

PyroCbs in Northwestern Alberta, Canada: 10 July 2012



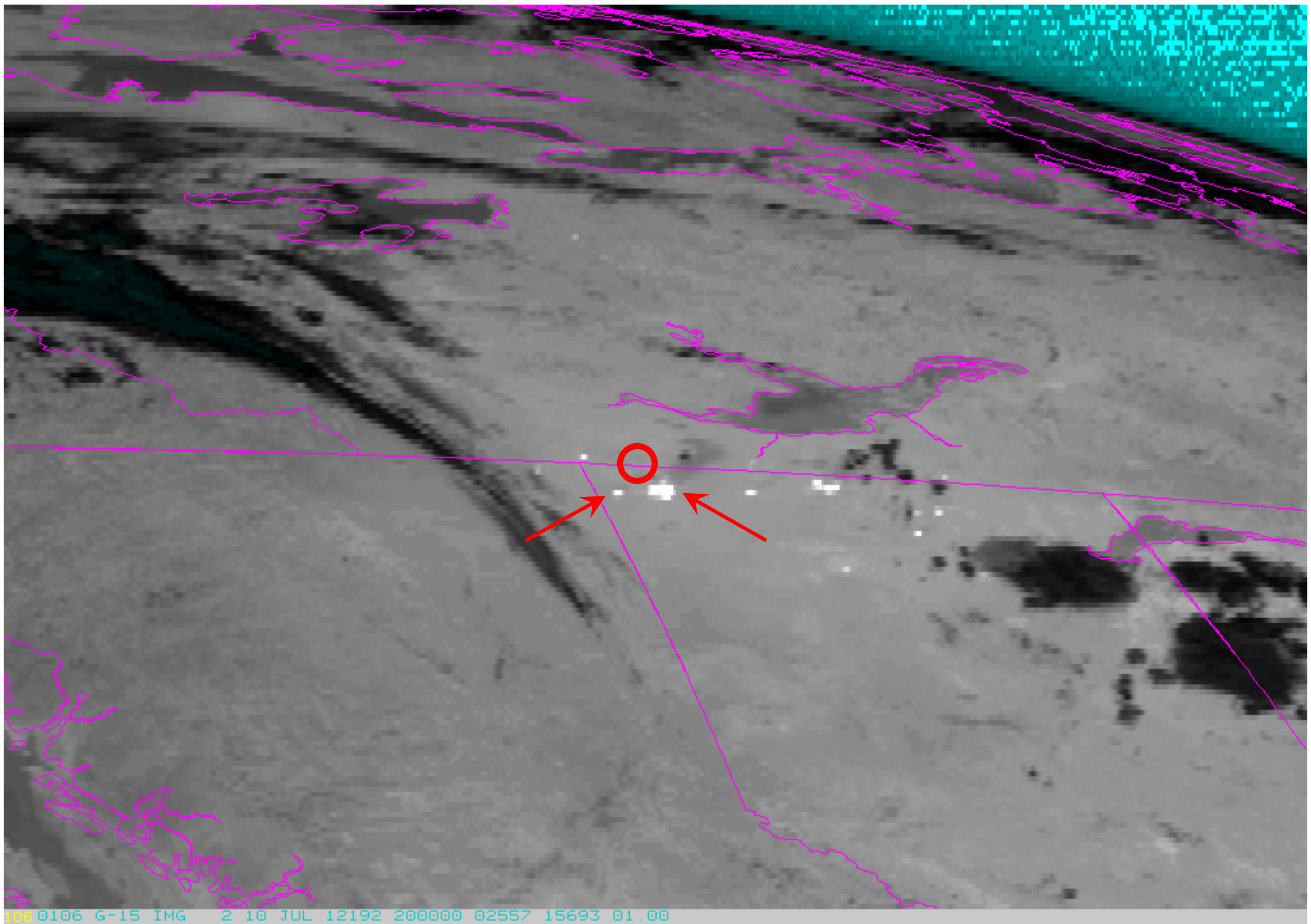
2 distinct pyroCbs (~50 km apart)

Wind at 500 mb (~5.5km), 10 July 2012, 21 UTC



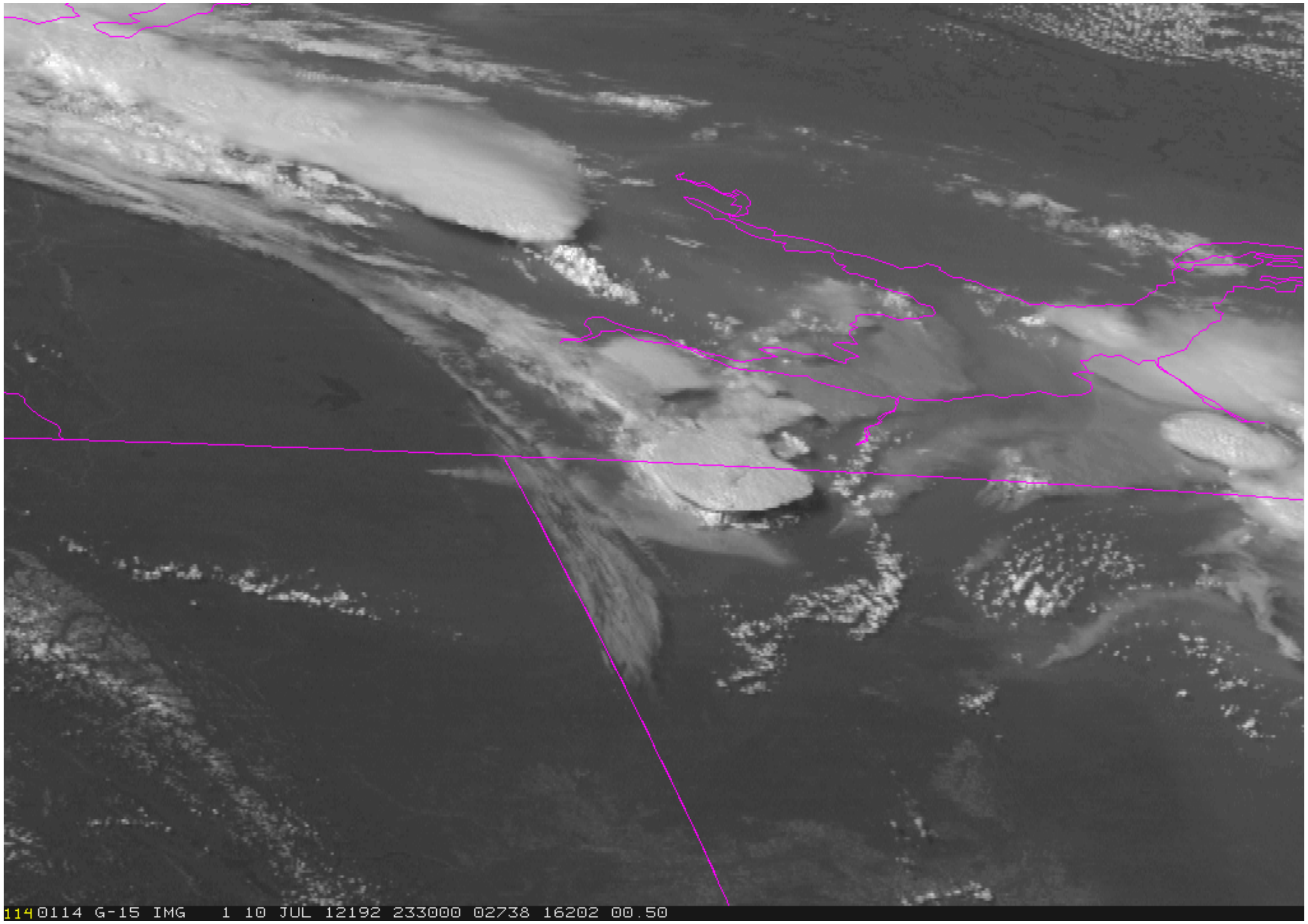
GOES-15 short-IR 3.9µm: 10 July 2012, 20 UTC

(courtesy of Dan Lindsey, NOAA/NESDIS/RAMMB)

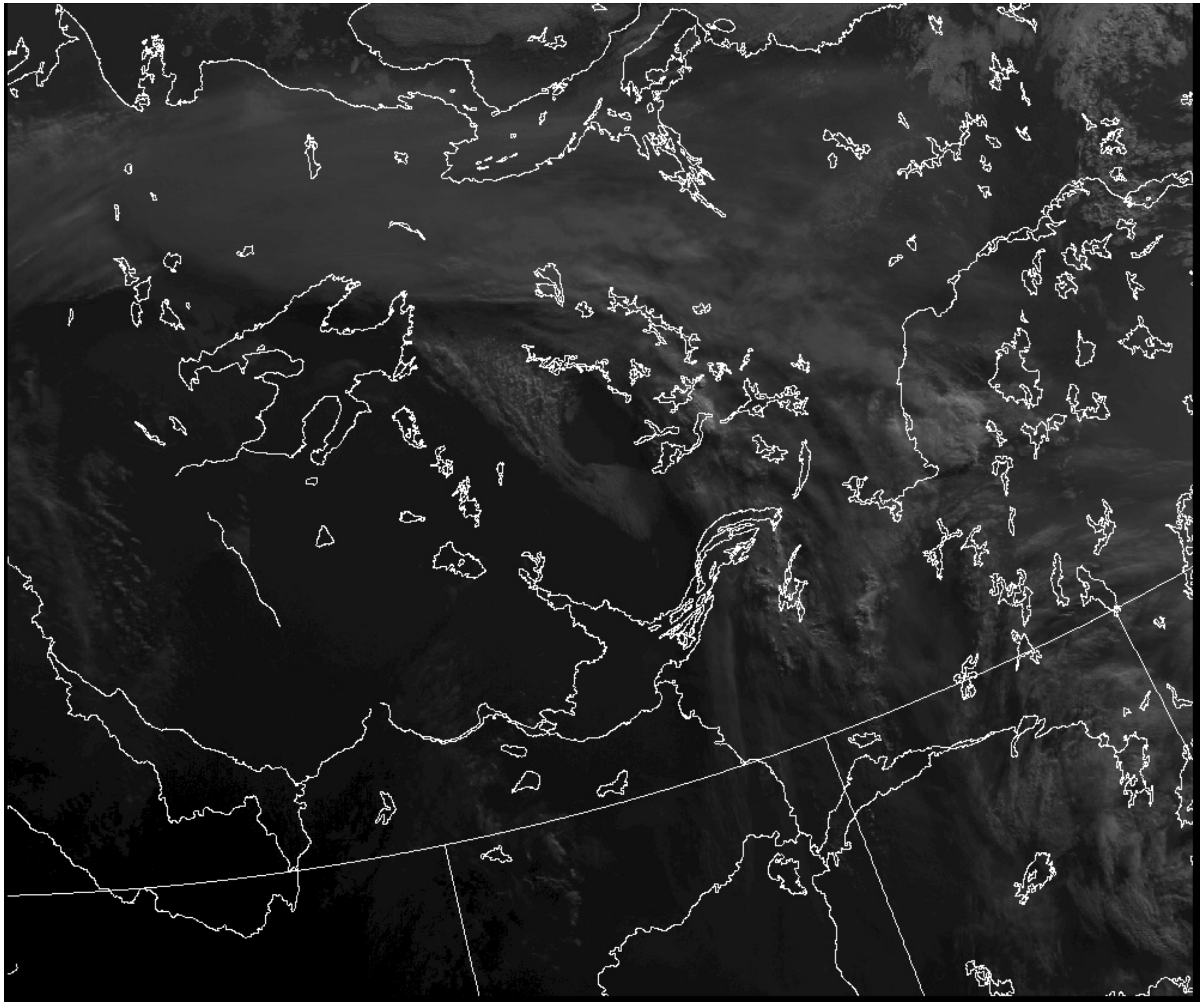


GOES-15 Visible Animation: 10-11 July 2012

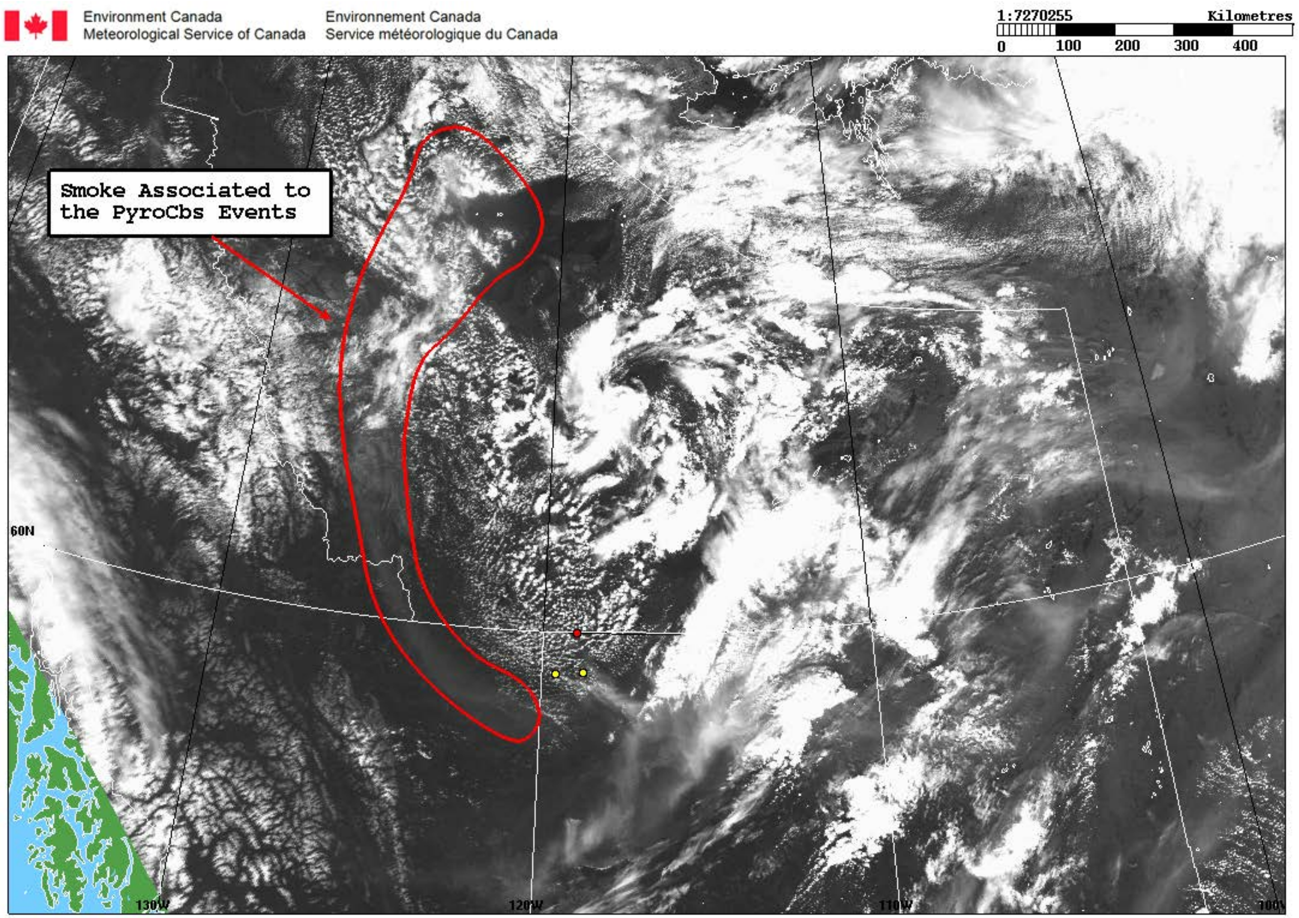
(courtesy of Dan Lindsey, NOAA/NESDIS/RAMMB)



11 July 2012
NOAA-19/AVHRR Visible at 1106 UTC



12 July 2012
NOAA-19/AVHRR Visible at 1931 UTC



Background Image: NOAA-19 AVHRR-HRPT Visible Valid 12 July 2012 at 1931 UTC

Description of MLDP0

(Modèle Lagrangien de Dispersion de Particules d'ordre 0)

- Main operational model
- MLDP0 replaced CANERM (Eulerian model) April 2009

- 3D Lagrangian particle model
- 0^{th} order: Random displacements in the vertical
  - Trajectories calculated based on increments in the particle displacements
  - Turbulence effects modelled according to a vertical diffusion coefficient
  - Accounting for density gradient correction term
- Horizontal diffusion: 1^{st} order Langevin equation (Mesoscale fluctuations for meandering)

- Off-line model
- Driven by full 3D meteorological fields from CMC's GEM (Global & Regional) NWP system
- Sophisticated emission scenario module controlling source through release rate over time
- Physical processes :
  - Radioactive decay
  - Wet scavenging
  - Dry deposition
  - Gravitational settling (Stokes' law)
- Forward and adjoint (inverse) modes
- Averaged concentrations (**x**, t) over a grid and vertical layers

- Running architectures: Linux, AIX
- Run time (wall clock time): ~ 7 min. (72-h forecast / AIX)

$$dz = \left(\underbrace{\frac{\partial K}{\partial z}}_{\text{diffusion drift term}} + \underbrace{\frac{K}{\rho}\frac{\partial \rho}{\partial z}}_{\text{density gradient correction term}} + \underbrace{w_s}_{\text{mean synoptic vertical motion}} - \underbrace{w_g}_{\text{gravitational settling velocity}} \right) dt + \underbrace{(2K)^{1/2} dW}_{\text{random displacement}}$$

$$d\xi_i \,,\, dW \in N(0, \sqrt{dt}), \quad \text{incremental Weiner process}$$

$$\mathbf{x} = (x, y), \quad \mathbf{U} = (u_s, v_s), \quad \mathbf{u}^m = (u^m, v^m), \quad i = u, v$$

$$d\mathbf{x} = (\mathbf{U} + \mathbf{u}^m) dt$$

$$du_i^m = \underbrace{-\frac{u_i^m}{\tau_L^m} dt}_{\text{deterministic term}} + \underbrace{\left(\frac{2\sigma_m^2}{\tau_L^m} \right)^{1/2} d\xi_i}_{\text{stochastic term}}$$

Multiple Simulations Using the Operational Configuration

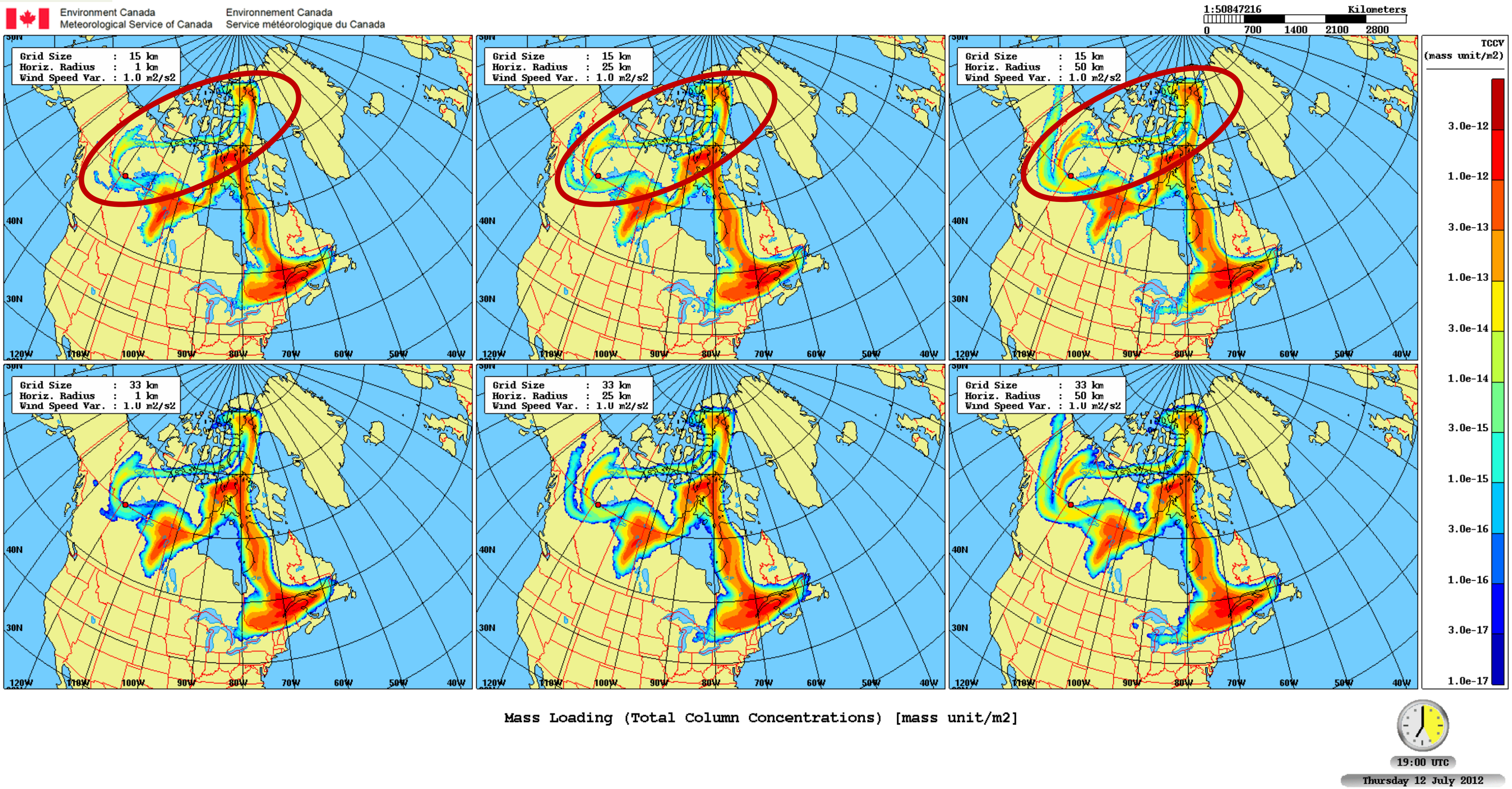
PARAMETERS	VALUES HELD CONSTANT
Source Location	60º N, 119º W (Northern Alberta)
Release date and time	10 July 2012 at 2200 UTC
Release duration	1 h
Mass release rate	1 mass unit/h
Simulation duration	122 h
Nb. of Lagrangian particles	10^6
Max. initial plume height	12 km AGL
Vertical distribution of mass	Uniform
NWP Model	GEM-RDPS at 10 km grid mesh
NWP Data	Analyzed meteorological fields at 6 h intervals
Nb. of selected vertical levels	25 eta levels
Physical processes	Wet scavenging and dry deposition

PARAMETERS	VALUES VARIED
Grid mesh [km]	15, 33
Initial horizontal column radius [km]	1, 25, 50
Horizontal wind velocity variance for mesoscale fluctuations (σ_v^2) [m^2/s^2]	0.0, 0.1, 0.5, 1.0

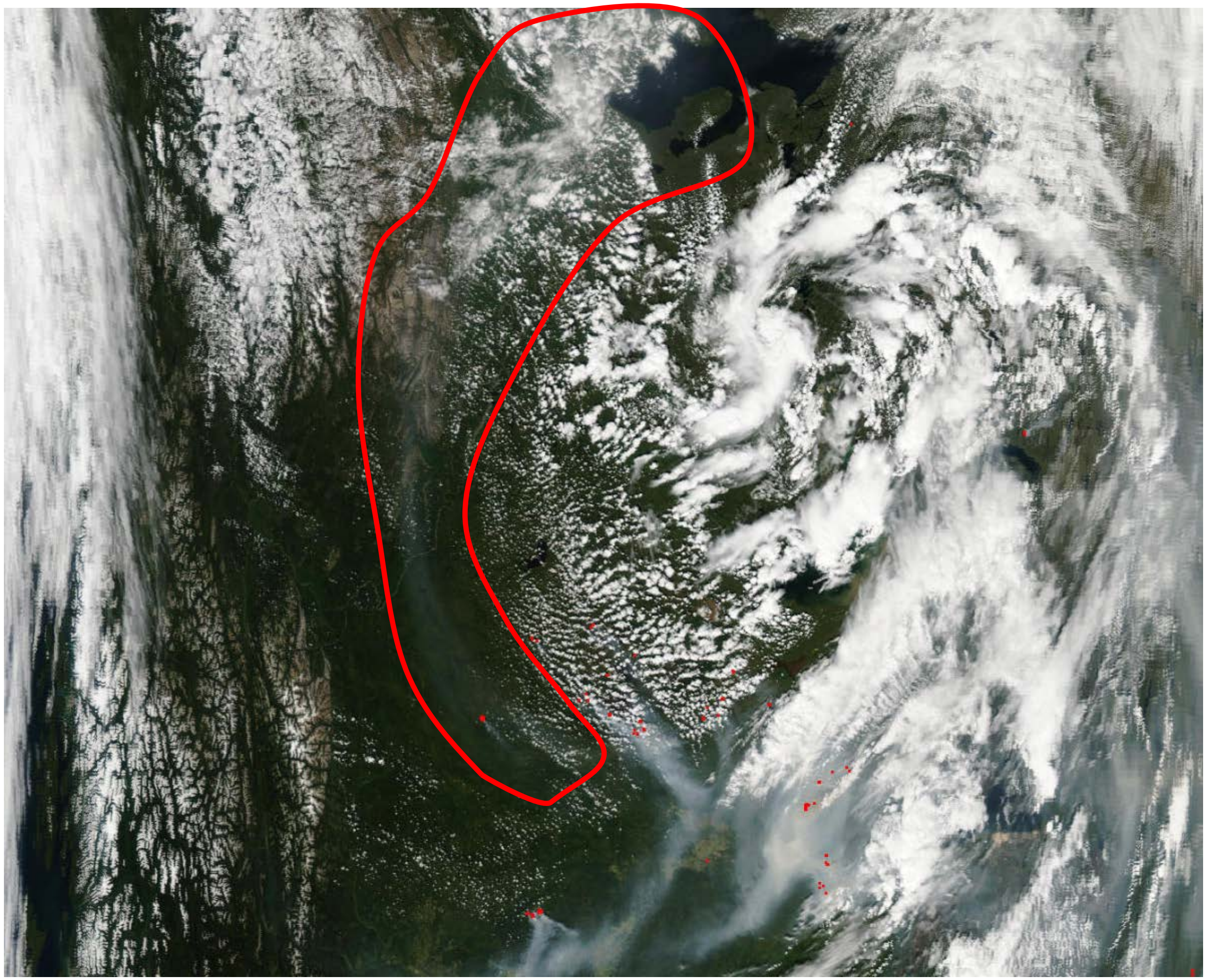
→ **24 simulations**

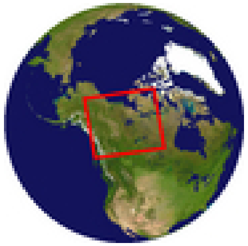
MLDP0 Mass Loading 12 July 2012, 1900 UTC: Increasing Horizontal Diffusion

$\sigma_v^2 = 0.0, 0.1, 0.5, 1.0 \ m^2/s^2$

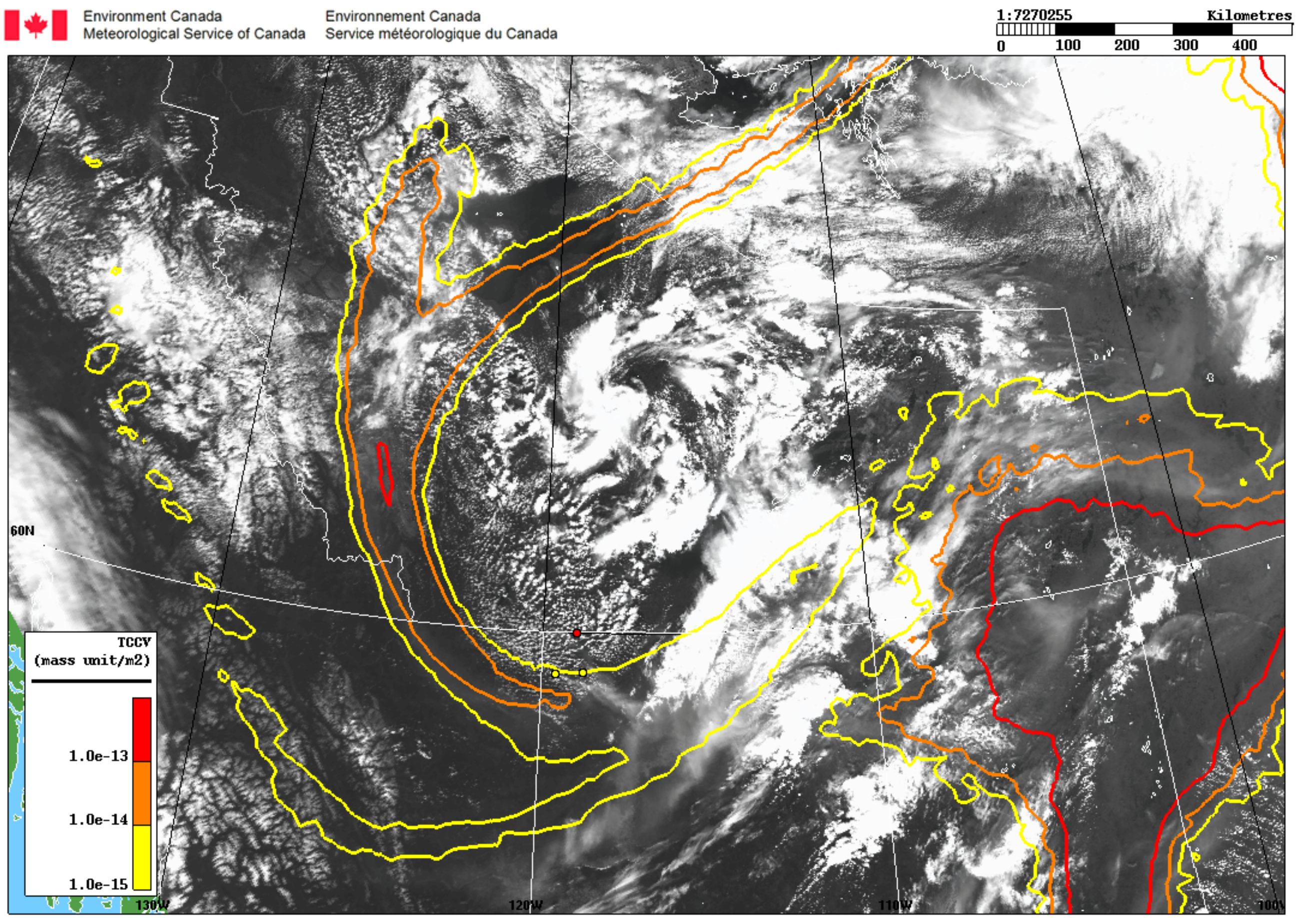


Aqua/MODIS Visible
12 July 2012, 2035 UTC





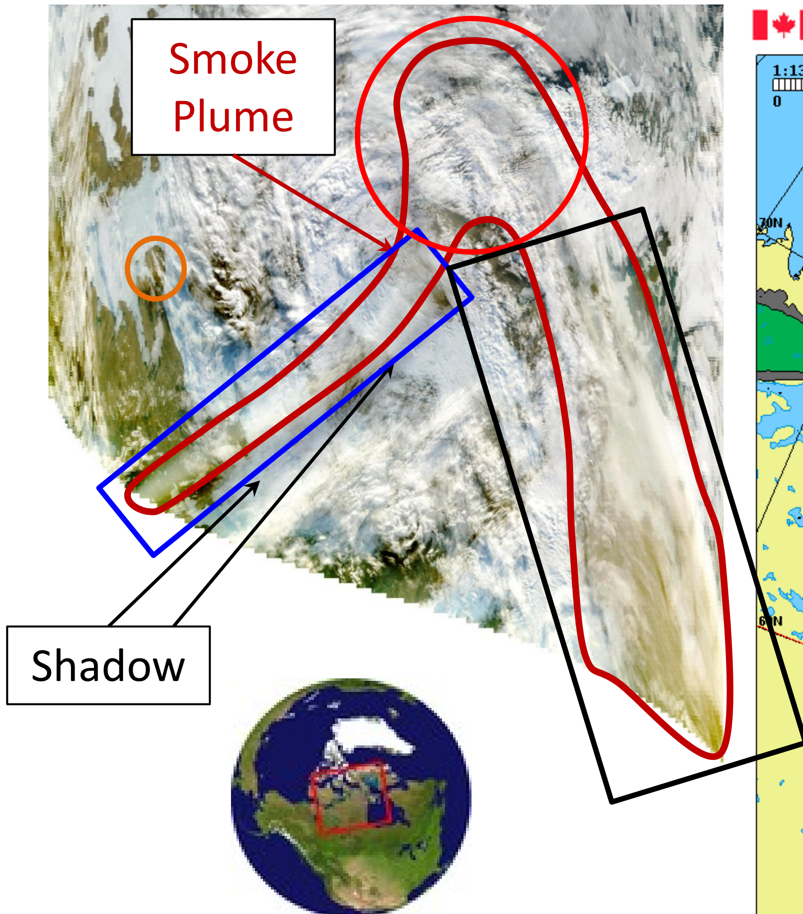
12 July 2012
NOAA-19/AVHRR Visible at 1931 UTC vs MLDP0 Mass Loading at 1900 UTC

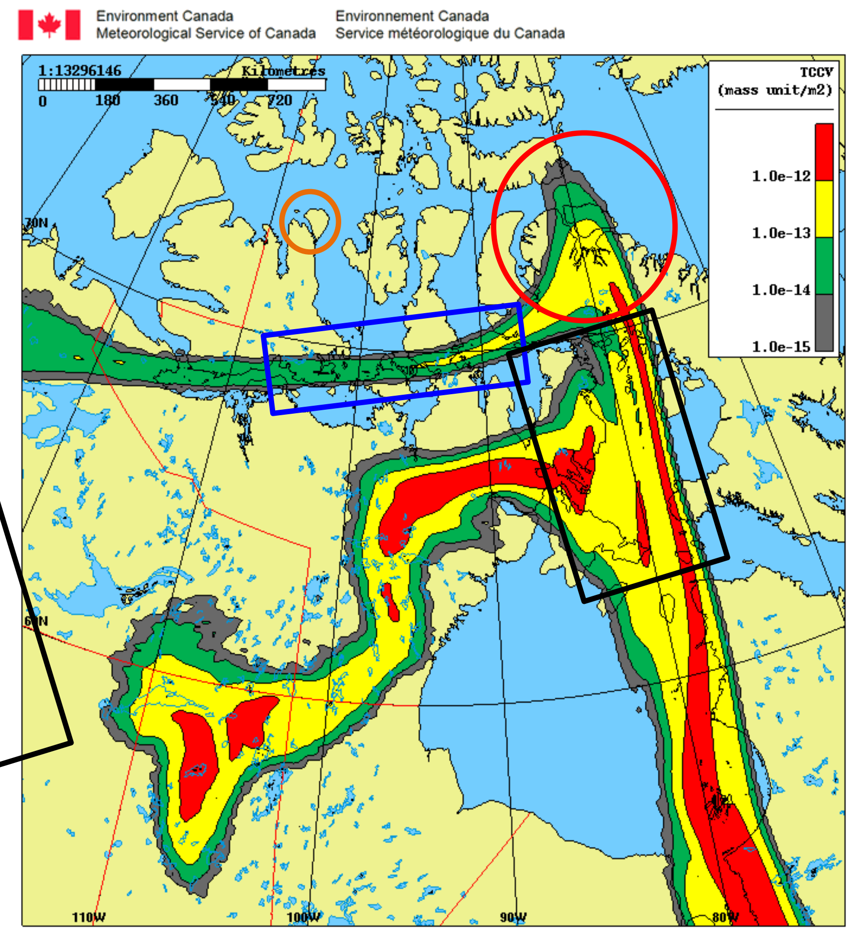


Background Image: NOAA-19 AVHRR-HRPT Visible Valid 12 July 2012 at 1931 UTC

Foreground Image: MLDP0 Mass Loading Valid 12 July 2012 at 1900 UTC
 - Mesh: 15 km, Radius: 25 km, Variance: 0.5 m2/s2

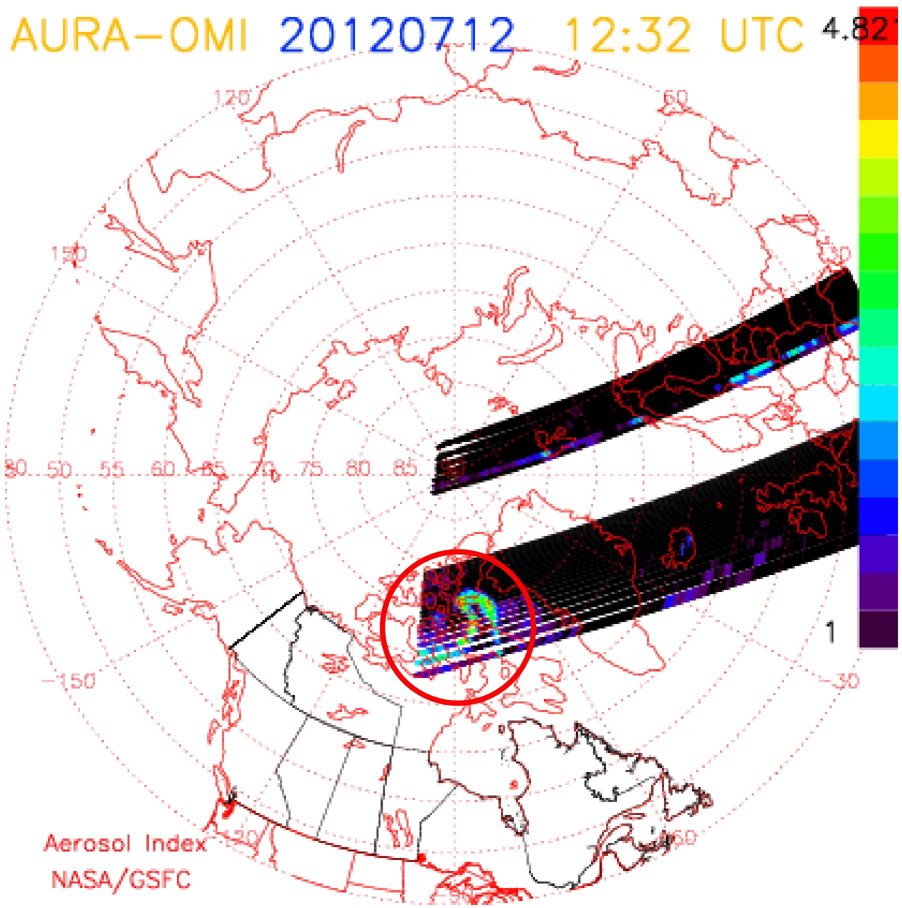
12 July 2012
Aqua/MODIS Visible at 0915 UTC vs MLDP0 Mass Loading at 0900 UTC

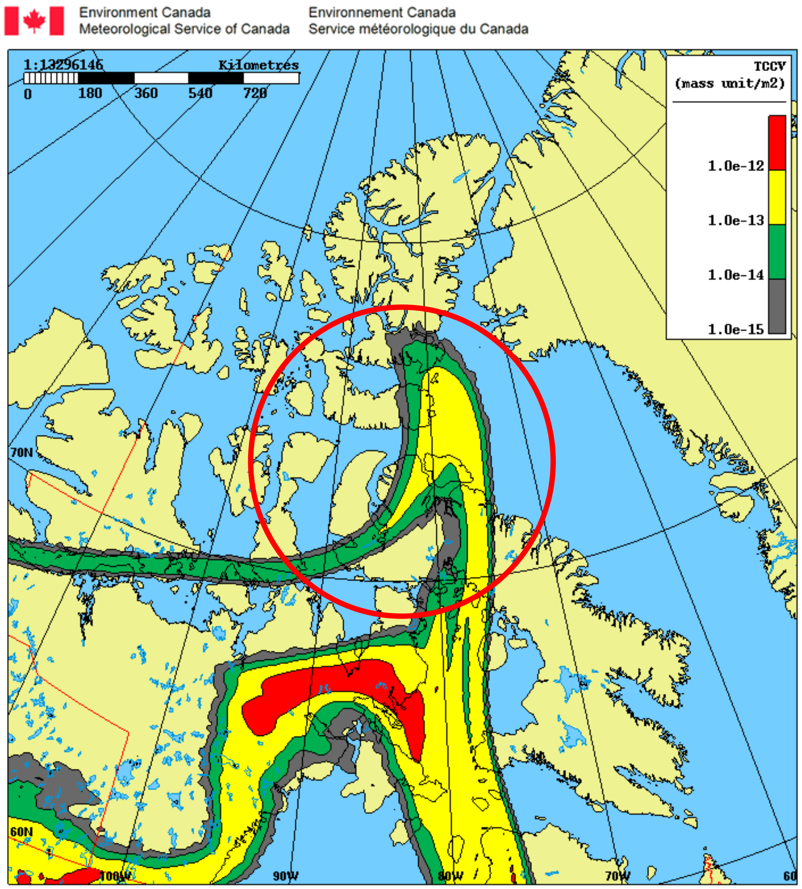




MLDP0 Mass Loading Valid 12 July 2012 at 0900 UTC

12 July 2012
AURA/OMI Aerosol Index at 1232 UTC vs MLDP0 Mass Loading at 1300 UTC





MLDP0 Mass Loading Valid 12 July 2012 at 1300 UTC

Courtesy of Mike Fromm, NRL

Uncertainties, Approximations, Unknowns and Sources of Error: Similar to Volcanic Eruptions

1. Source Term
   - Location and number of emission fires (pyroCbs)
   - Emission date-time for each fire
   - Emission duration for each fire
   - Mass emission rate as function of time
   - Initial plume geometry (height, radius and vertical distribution of mass within the emission column)
   - Nature and properties of pollutant (buoyancy plume vs. dense gas plume)
   - Particle size distribution

2. NWP Meteorological Data

3. Atmospheric Transport and Dispersion Model MLDP0

Summary and Conclusions

- PyroCb smoke presents many of the same challenges to ATD modelling as volcanic ash.
  - Uncertainties in the source term are a major issue.
- An operational case study was done on smoke from pyroCbs.
- A number of ATDM parameter combinations yielded similar results.
  - *e.g.* Reducing resolution increases numerical diffusion in concentration outputs – same effect obtained by increasing the wind variance.
  - Similar results were obtained at high and low resolution.

This case confirms yet again:

- Source geometry is a crucial modelling input.
- Higher resolution does not necessarily mean better results!
- Remote sensing data is an essential and necessary component.

The End