Environment Canada Environnement Canada

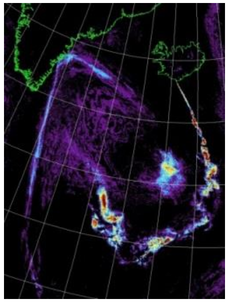
Canada

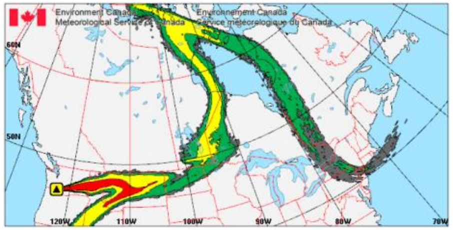
Research and Development Advances at Montréal VAAC since the 2010 Eyjafjallajökull Eruption: Remote Sensing, Transport and Dispersion Modelling, Statistical Validation and Meteorological Data

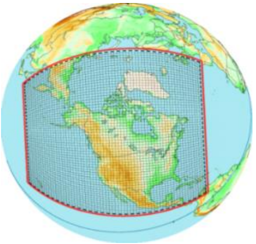
7th International Workshop on Volcanic Ash (IWVA/7)

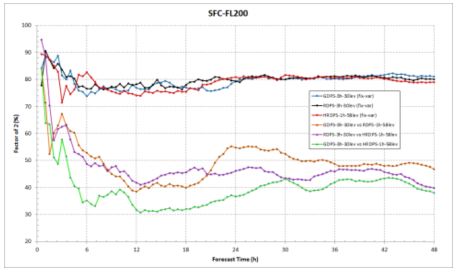
Anchorage, AK, USA, 19-23 October 2015

Alain Malo and Dov Bensimon
Environmental Emergency Response Section
Montréal Volcanic Ash Advisory Centre
Canadian Meteorological Centre Operations
Canadian Centre for Meteorological and Environmental Prediction
Meteorological Service of Canada
Environment Canada







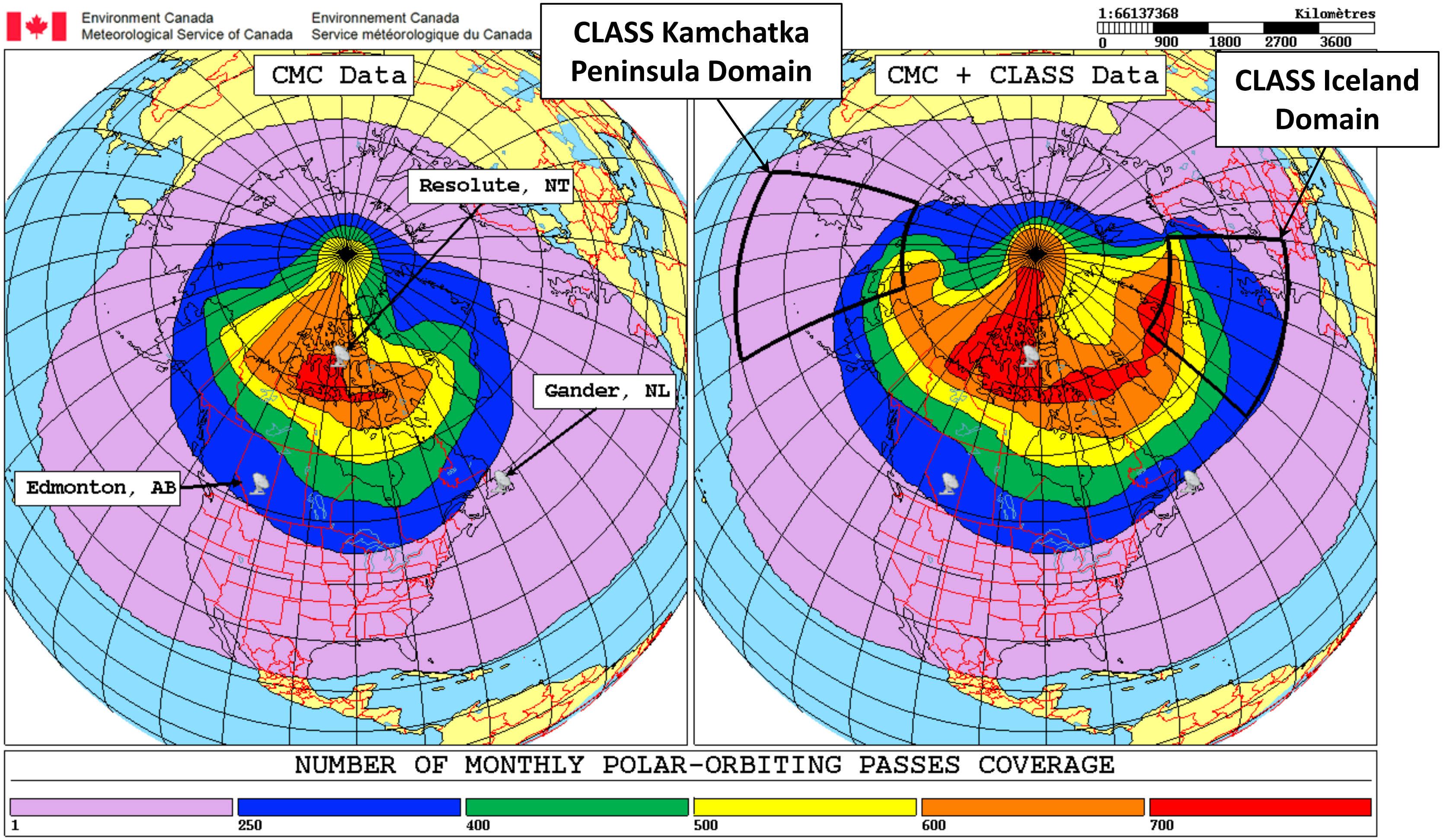


Remote Sensing Data at Montréal VAAC

Satellites	**CMC (Canada, Alaska, Greenland, Northern CONUS)**	**NOAA's CLASS (Kamchatka Peninsula and Iceland)**
Polar orbiting satellites	**AVHRR** • Metop-A/B • NOAA-15/18/19	**AVHRR** • Metop-A/B • NOAA-15/18/19
	MODIS • Aqua/Terra	
Geostationary orbit satellites	• GOES-W • GOES-E	

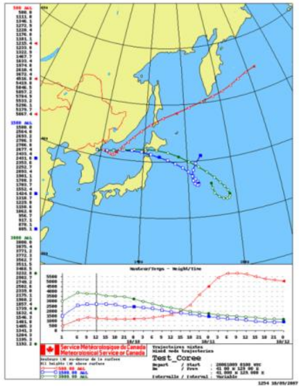
- CMC has initiated procedures to share Canadian data with USGS's VolcView application (http://volcview.wr.usgs.gov/)
  - Collaboration with Dave Schneider (USGS)

Number of Monthly Polar-Orbiting Passes Coverage (November 2014)



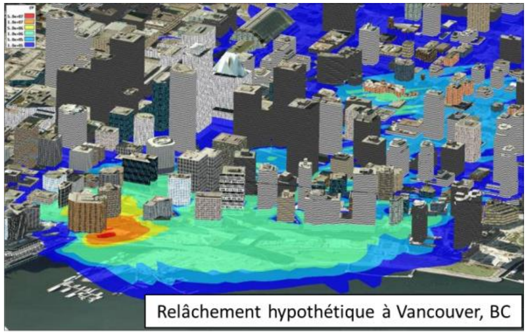
CMC’s Atmospheric Transport and Dispersion Models Suite

- **Trajectory**: Modèle de trajectoires
  - Short/large scale, runs in forward/backward
  - few air parcels moving in the 3D wind field
  - quick estimate of the expected trajectory of an air parcel by the advection transport mechanism
- **MLCD**: *Modèle lagrangien à courte distance*
  - Short scale (< 10 km), runs in forward/backward
  - Driven by NWP data and/or onsite meteorological observations
- **MLDP0**: *Modèle lagrangien de dispersion de particules d’ordre zéro*
  - Large scale (regional, continental, global) > 100 km
  - Runs in forward mode
- **MLDP1**: *Modèle lagrangien de dispersion de particules d’ordre un*
  - Short scale (local, regional) < 100 km
  - Runs in forward mode
- **MLGI**: *Modèle lagrangien global inverse*
  - Large scale (continental, global) > 100 km
  - Runs in backward mode
- **MLDPn**: *Modèle lagrangien de dispersion de particules d’ordre n*
  - Short/large scale
  - Runs in forward/backward
- **CUDM-urbanLS**: Canadian Urban Lagrangian Stochastic Dispersion Model
  - Urban scale, 3D building geometry, driven by a CFD model
  - Runs in forward/backward



Most used operational model

MLDPn will replace MLDP0, MLDP1 and MLGI



Relâchement hypothétique à Vancouver, BC

Environment Canada Environnement Canada

Canada

MLDPn: *Modèle lagrangien de dispersion de particules d’ordre n*

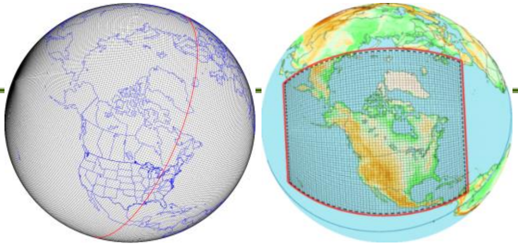
- A new Lagrangian atmospheric transport and dispersion model (ATDM) called MLDPn has been developed
  - 1) to unify the three operational models (namely MLDP0, MLDP1 and MLGI)
  - 2) to combine the advantages and strengths of each model into a single one
  - 3) to simplify code maintenance
  - 4) to improve some algorithms
  - 5) to add several new features for operational use
- The model is currently in its final validation phase and will be fully operational in the coming months.

New Features in MLDPn

- Restart mode useful for extended simulations in time (e.g. Eyjafjallajökull, Fukushima Daiichi)
- Inverse mode to track and identify a possible emitting source
- Handling of a complex emission source term varying in space and time
- User can define a 3D polygon associated with a volcanic cloud (observation)
- Handling of multiple emitting sources
- New dry deposition and wet scavenging schemes developed by Jian Feng available as an option
- Written in C and parallelized using both distributed (MPI) and shared-memory (OpenMP) standards
- **n refers to type of diffusion kernel**
  - 0: order **0**, trajectories calculated according to particle displacement increments
  - 1: order **1**, trajectories calculated according to particle velocity increments
  - m: **m**ixed mode, switch from order 1 (short scale) kernel to order 0 (large scale) kernel based on age of particle criterion
  - w: petroleum/oil spill in **w**ater

Numerical Weather Prediction (NWP) Systems at CMC

- Global Deterministic Prediction System (GDPS)
- Regional Deterministic Prediction System (RDPS)
- High Resolution Deterministic Prediction System (HRDPS)



Global (25 km) and Regional (10 km) NWP model grids

Date	Implementation Feature
3 October 2012	• **RDPS**: increase grid mesh 15 km → **10 km**
13 February 2013	• **GDPS**: increase grid mesh 33 km → **25 km**
18 November 2014	• **HRDPS**: New experimental model with **2.5 km** grid mesh covering most of Canada • **Hourly** meteorological analyses data available from GDPS (before: 6-h)
November 2015	• **HRDPS:** required meteorological variables will be available to drive MLDPn
2016-2017 ???	• **HRDPS** will become fully operational and will replace RDPS

TheJudge: A Statistical Validation Tool

- In order to operationally implement MLDPn, a statistical validation tool called “TheJudge” was developed.

- This innovative tool allows the quantitative comparison and analysis of different numerical simulations based on a wide variety of statistical indicators/metrics.

- Can be used for various applications such as
  - implementation of a new model for operations
  - sensitivity studies
  - uncertainty quantification

- MLDPn was validated successfully against MLDP0 and MLGI. MLDPn produces comparable and valid results to those of MLDP0/MLGI.

TheJudge: Basic Principle

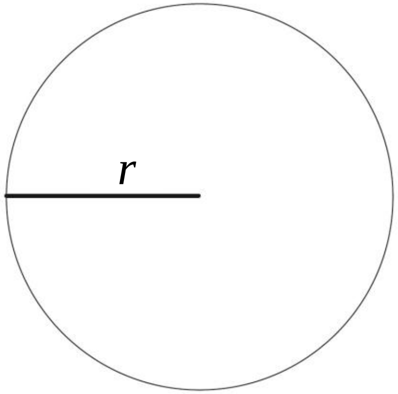
- In the absence of analyses and observations valid over the whole computational model grid, **we vary the seed that initialize the random number generator** used in the stochastic component calculation associated with the turbulent diffusion in the particle displacements.

- This method is applied to create two independent simulations (statistical realisations), thus producing slightly different results.

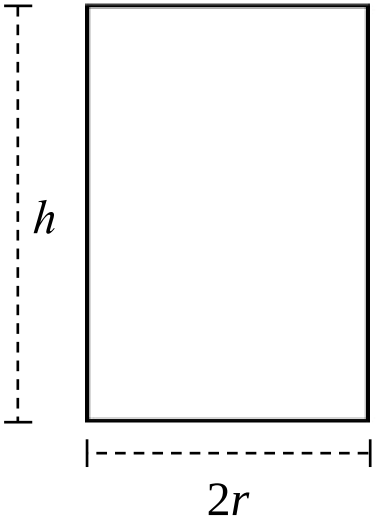
- By comparing these two simulations, we create a ‘**control or reference or benchmark**’ curve that can be used for comparison with the ‘**test**’ curve.

Importance of Considering Different Statistical Indicators

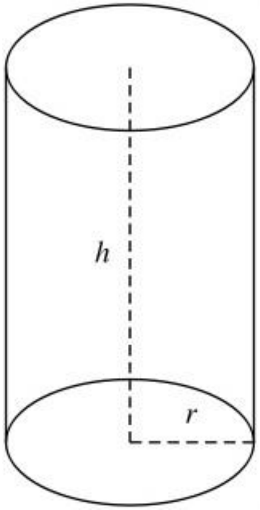
- It is crucial to know the strengths, weaknesses, limitations and bias of each indicator.
- Each statistical indicator provides a unique and different information from others.
- It is necessary to consult many/different indicators before arriving to a final conclusion.



Top view: circle



Side view: rectangle



Tilted view: cylinder

Modelling Setup for Sensitivity Study

INPUT TO DRIVE MLDPn:

- Source: Mount St. Helens, WA, USA (within HRDPS and RDPS domains)
- Date-time of hypothetical release: 23 July 2015 at 00 UTC
- Release duration: 48 h
- Number of Lagrangian particles: 10^6 (~21000 part./h)
- Maximum initial plume height: 12 km AGL
- Vertical distribution of mass: uniform
- Initial seed for random number generator: **fixed**, **variable**
- Different NWP meteorological input forecast fields:
  - **GDPS (25 km)**, **RDPS (10 km)** and **HRDPS (2.5 km)**
  - **3-h** and **hourly** meteorological fields
  - **30** and **58** vertical levels in meteorological fields

OUTPUT FROM MLDPn:

- 48-h forecast air concentrations in 3 aviation flight layers
  - SFC-FL200, FL200-FL350, FL350-FL600
- Computational output horizontal grid mesh: 10 km

Mount St. Helens, WA, USA,
19 May 1982

STATISTICAL ANALYSIS: Use the statistical validation tool TheJudge to make quantitative assessment based on COR, FMS and FA2.

Sensitivity Study

Measure the impact of

- changing from GDPS-3h-30lev to RDPS-1h-58lev.
- changing from RDPS-3h-30lev to HRDPS-1h-58lev.
- changing from GDPS-3h-30lev to HRDPS-1h-58lev.

Current Operational Configuration

Future Operational Configuration

Example:

A: GDPS-3h-30lev-fix vs GDPS-3h-30lev-var

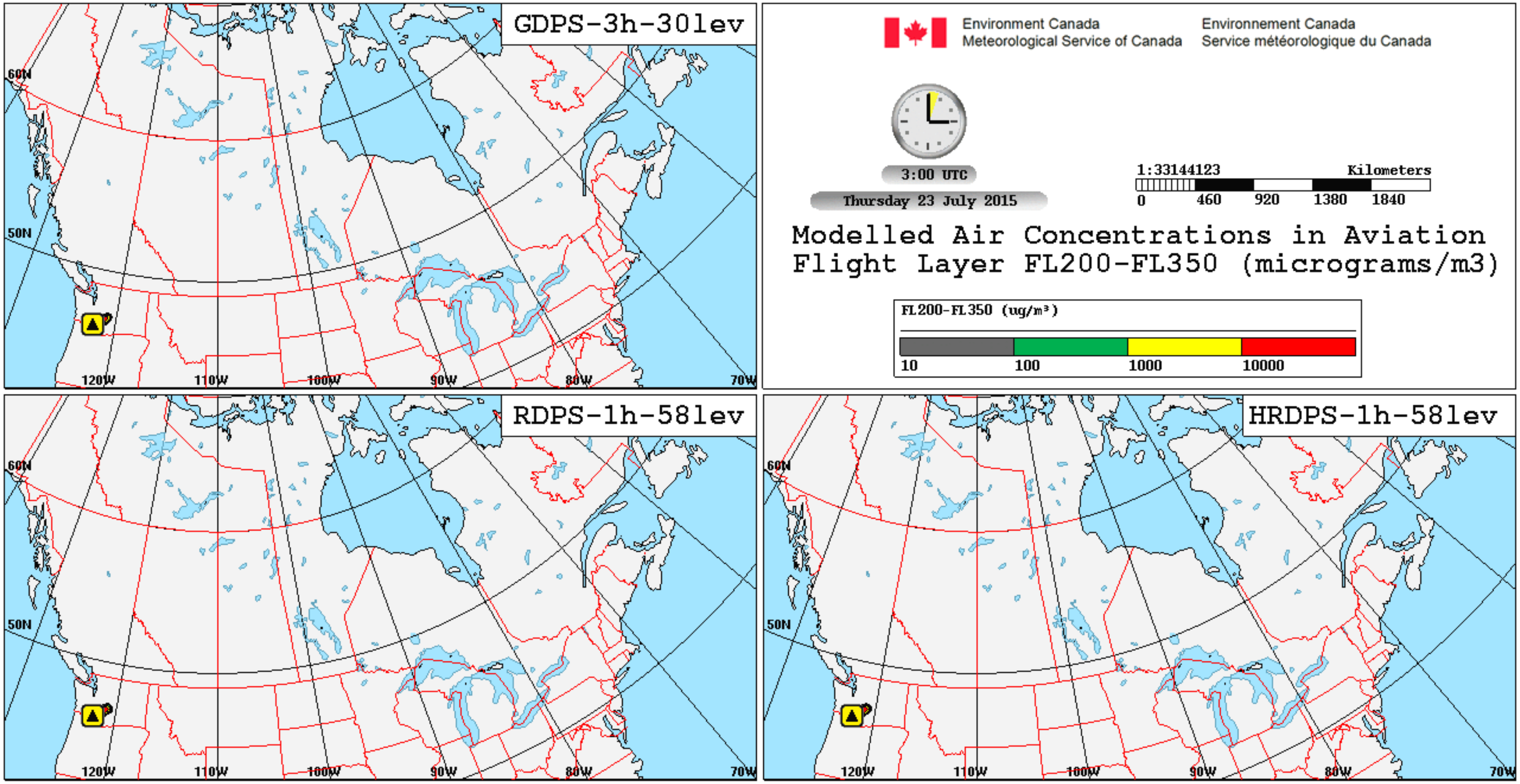
B: RDPS-1h-58lev-fix vs RDPS-1h-58lev-var

← **2 control curves**

C: GDPS-3h-30lev-fix vs RDPS-1h-58lev-fix ← **1 test curve**

- **3 NWP data sets × 2 meteorological time intervals × 2 sets of vertical levels × 2 different seeds = 24 simulations**
- **45 comparisons/curves**
- **243 time series** (for only 3 statistical indicators: COR, FMS, FA2)**!**

MLDPn Simulations



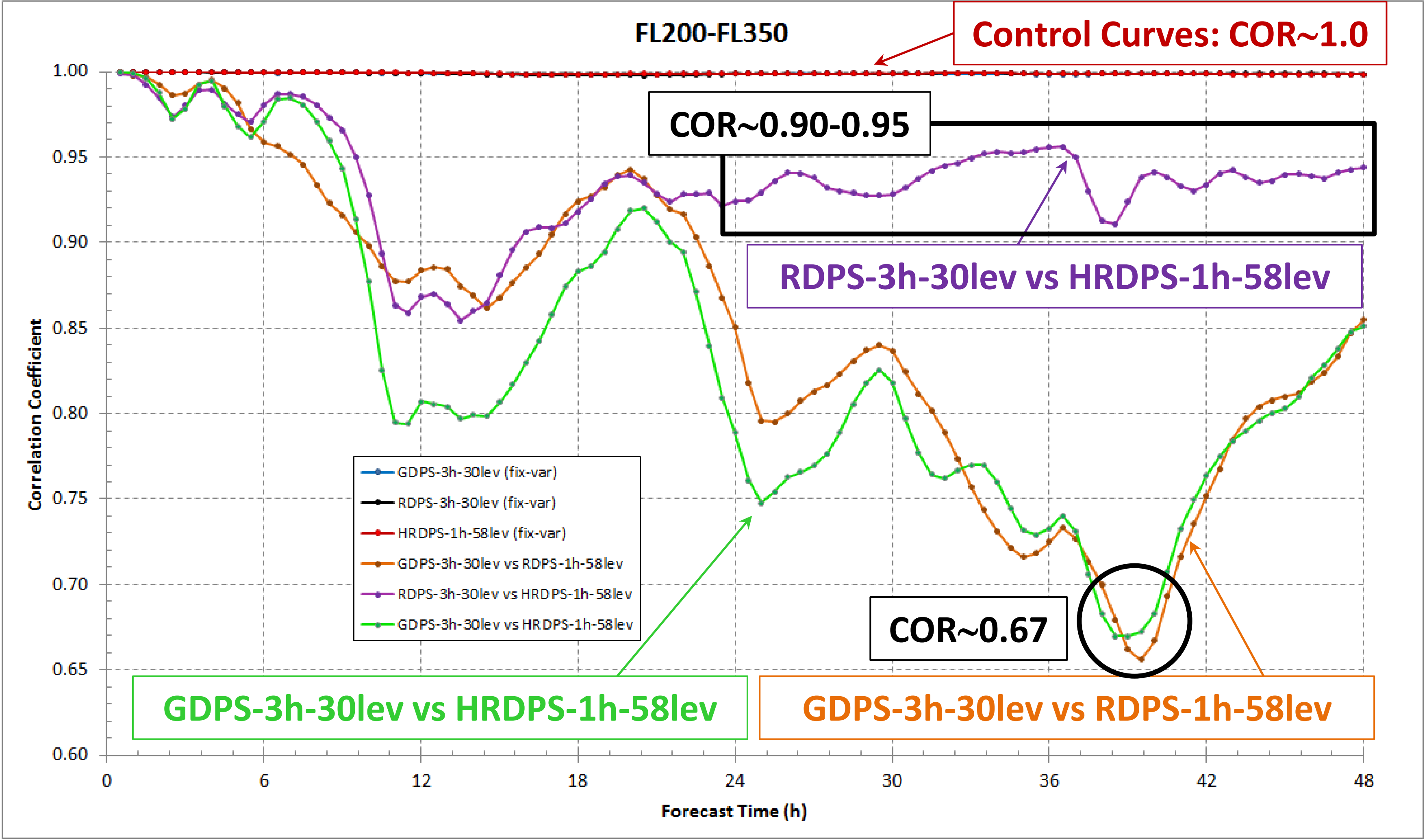
Environment Canada
Meteorological Service of Canada

Environnement Canada
Service météorologique du Canada

3:00 UTC
Thursday 23 July 2015

Modelled Air Concentrations in Aviation Flight Layer FL200-FL350 (micrograms/m3)

COR Time Series for Air Concentrations in Layer FL200-FL350



Control Curves: COR~1.0

COR~0.90-0.95

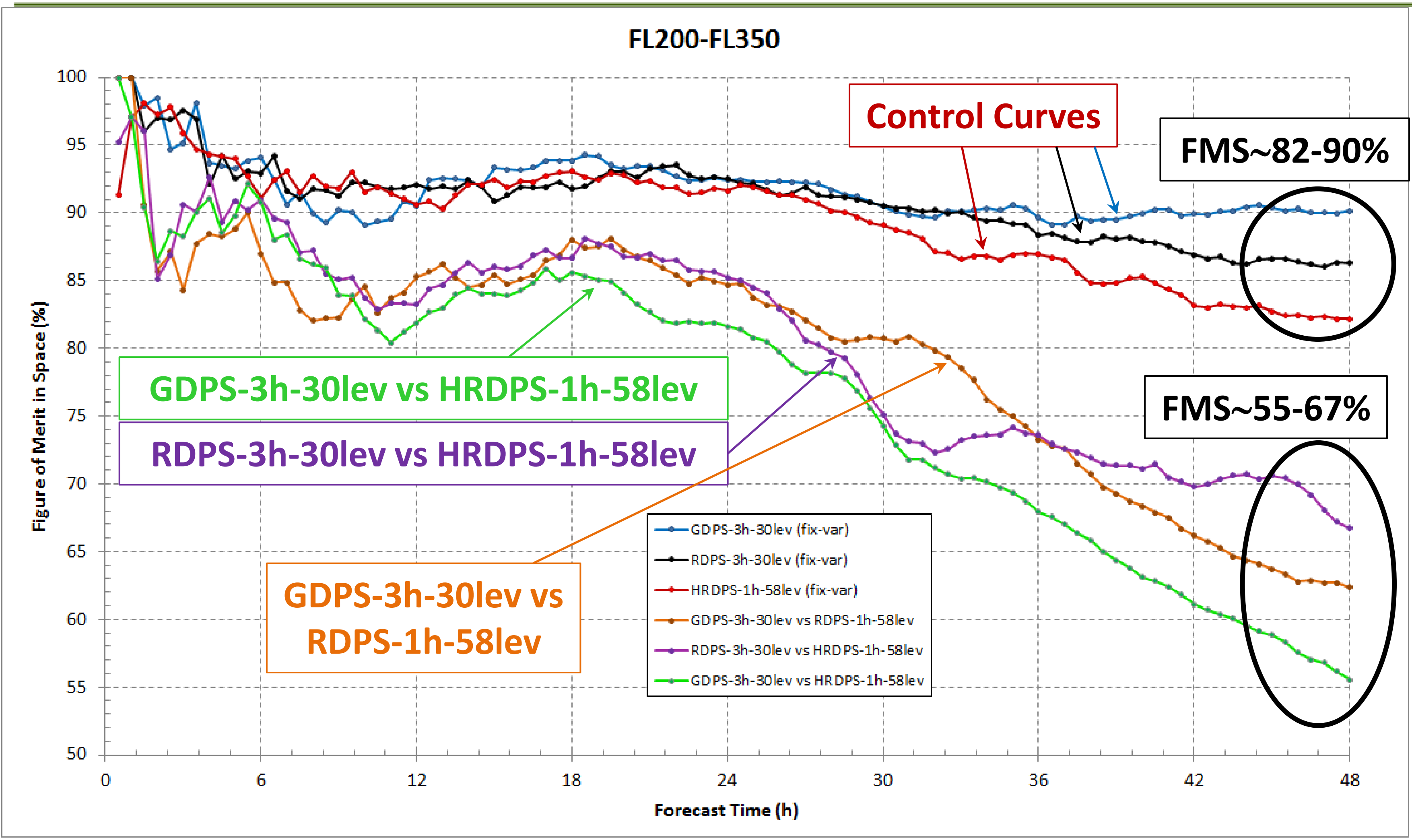
RDPS-3h-30lev vs HRDPS-1h-58lev

COR~0.67

GDPS-3h-30lev vs HRDPS-1h-58lev

GDPS-3h-30lev vs RDPS-1h-58lev

FMS Time Series for Air Concentrations in Layer FL200-FL350



Control Curves

FMS~82-90%

GDPS-3h-30lev vs HRDPS-1h-58lev

RDPS-3h-30lev vs HRDPS-1h-58lev

FMS~55-67%

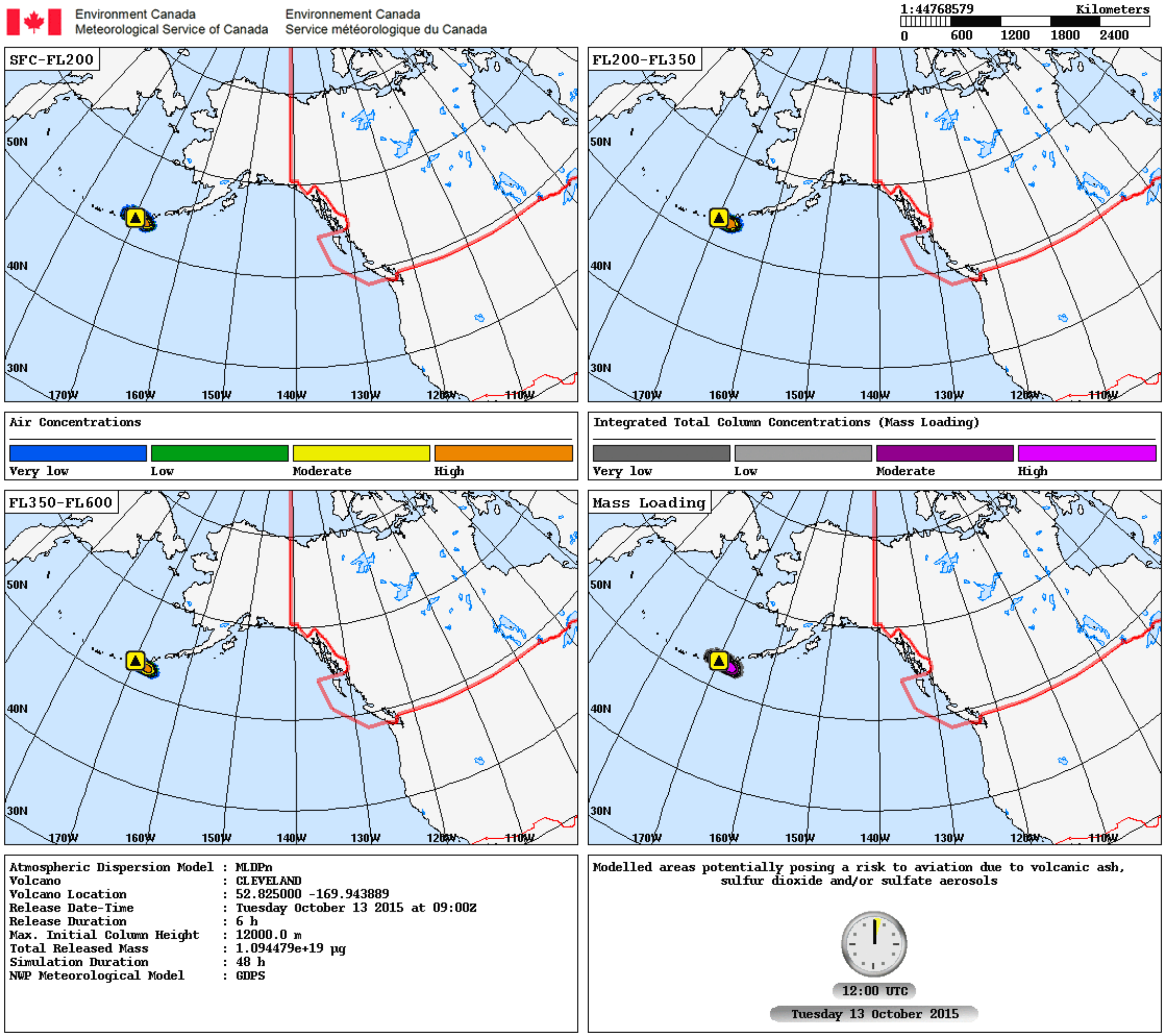
GDPS-3h-30lev vs RDPS-1h-58lev

Sensitivity Study: Preliminary Results

- Modelled air concentrations are very sensitive to the choice of NWP model, including temporal resolution and number of vertical levels in the driving meteorological fields.

New VAAC Layout for Automatic and Hypothetical Simulations

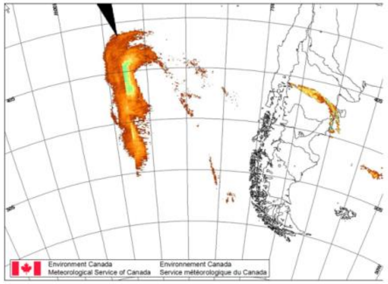
http://meteo.gc.ca/eer/vaac/index_e.html



Atmospheric Dispersion Model : MLDPn
Volcano : CLEVELAND
Volcano Location : 52.825000 -169.943889
Release Date-Time : Tuesday October 13 2015 at 09:00Z
Release Duration : 6 h
Max. Initial Column Height : 12000.0 m
Total Released Mass : 1.094479e+19 µg
Simulation Duration : 48 h
NWP Meteorological Model : GDPS

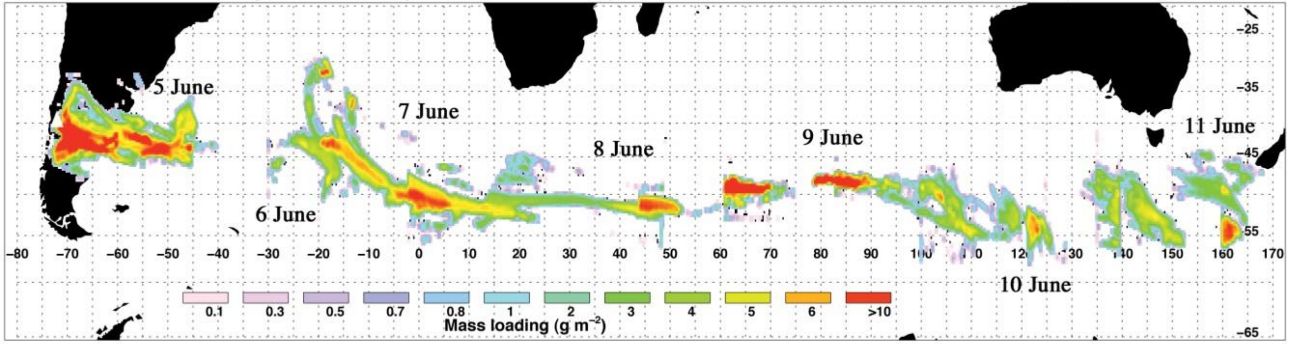
Modelled areas potentially posing a risk to aviation due to volcanic ash, sulfur dioxide and/or sulfate aerosols

Atmospheric Transport Modelling at Global Scale: 15-Day Simulation at Puyehue – Cordón Caulle, Chile, 4-19 June 2011 – Support Provided to other VAACs

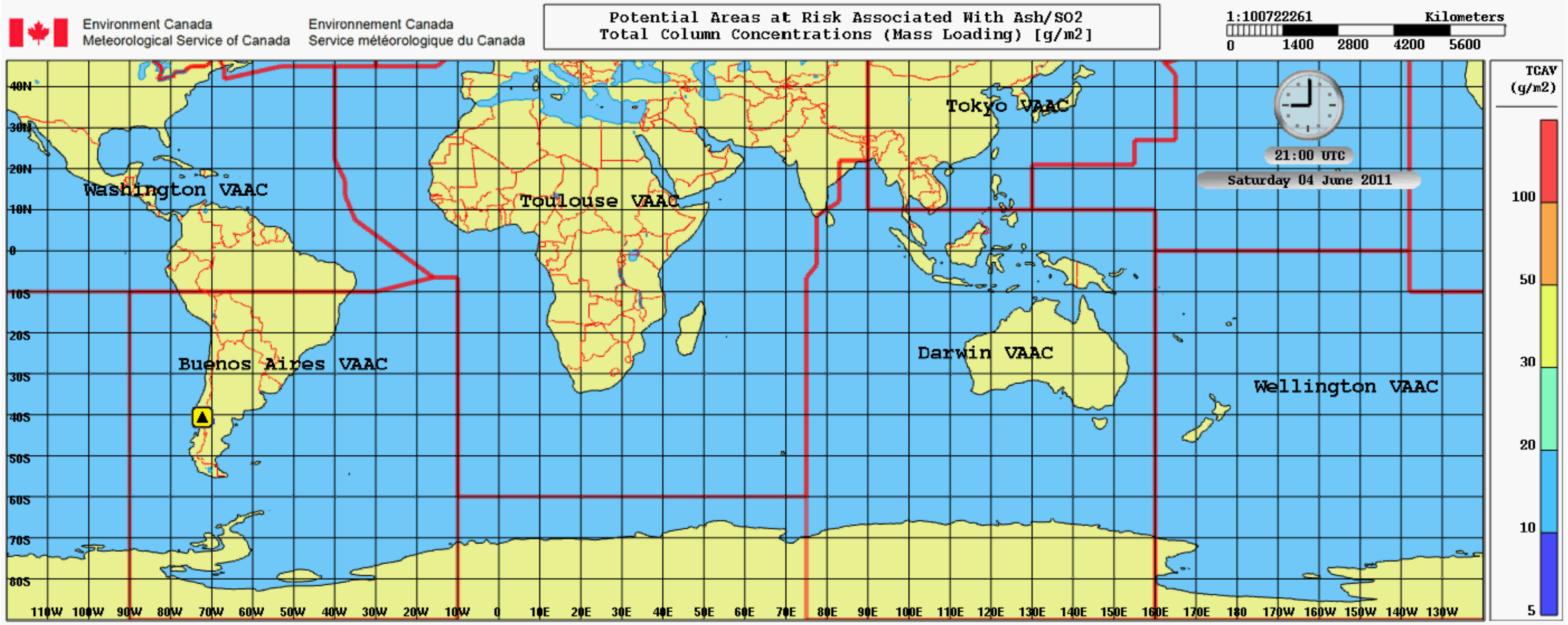


Volcanic ash detected on 14 June, based on satellite data using a combination of infrared channels. This is a composite from 2 satellites: NOAA-19 (valid 2112 UTC, left portion) and NOAA-18 (valid 1938 UTC, right portion). It shows fresh volcanic ash in the atmosphere being emitted by the eruption at Cordon Caulle in Chile. The large volcanic cloud over the Pacific originated from the 4 June eruption and has travelled around the globe over a 10-day period.

Image produced at VAAC Montreal with the Terascan software and data retrieved from the NOAA CLASS web site.

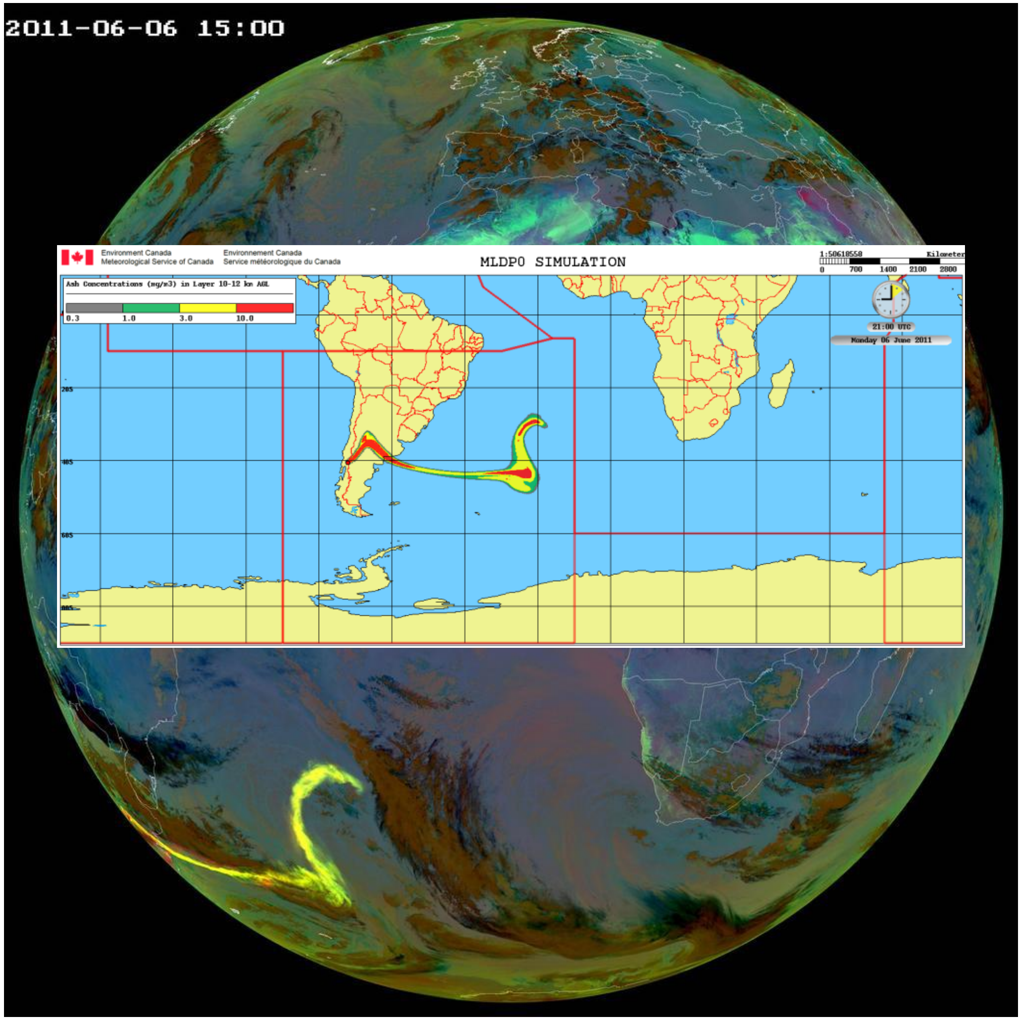


MODIS Ash Mass Loading Retrievals. ▲ Puyehue–Cordon Caulle Eruption. 4–10 June, 2011. Dr Fred Prata, NILU. Email: fred.prata@nilu.no

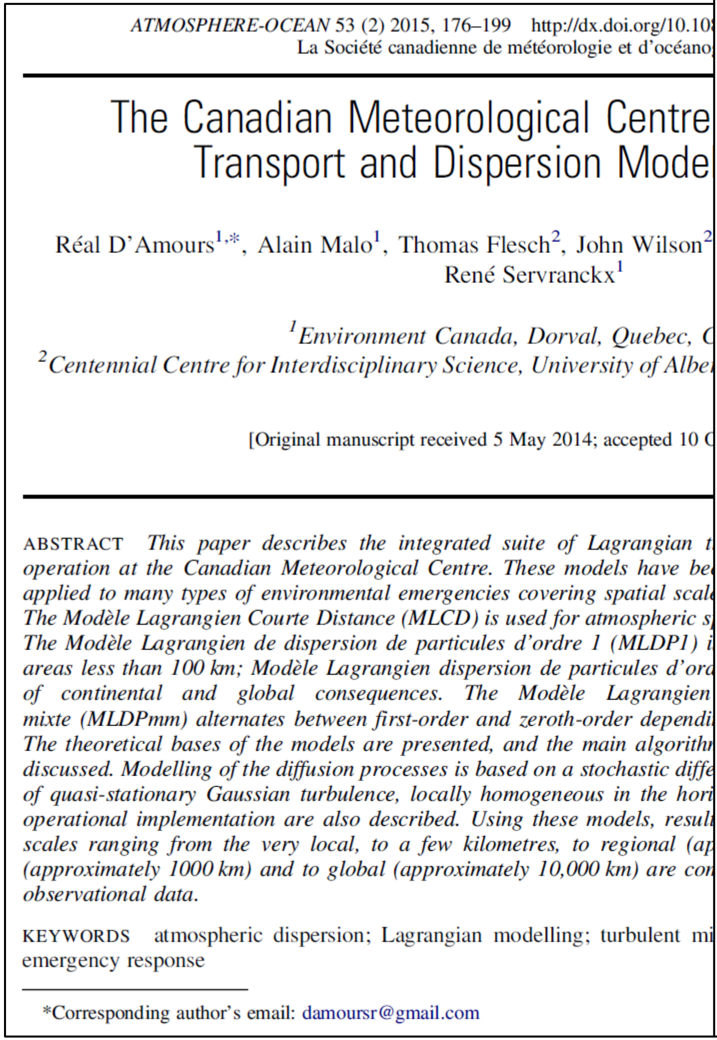


Potential Areas at Risk Associated With Ash/SO2
Total Column Concentrations (Mass Loading) [g/m2]

SEVIRI MSG Satellite Imagery, 6 June 2011 at 15 UTC
vs
Modelled Concentrations in Layer 10-12 km



Recent Papers Published in Atmosphere-Ocean and Journal of Environmental Radioactivity



ATMOSPHERE-OCEAN 53 (2) 2015, 176–199 http://dx.doi.org/10.10
La Société canadienne de météorologie et d'océano

The Canadian Meteorological Centre
Transport and Dispersion Mode

Réal D'Amours[1,*], Alain Malo[1], Thomas Flesch[2], John Wilson[2]
René Servranckx[1]

[1]*Environment Canada, Dorval, Quebec, C*
[2]*Centennial Centre for Interdisciplinary Science, University of Albe*

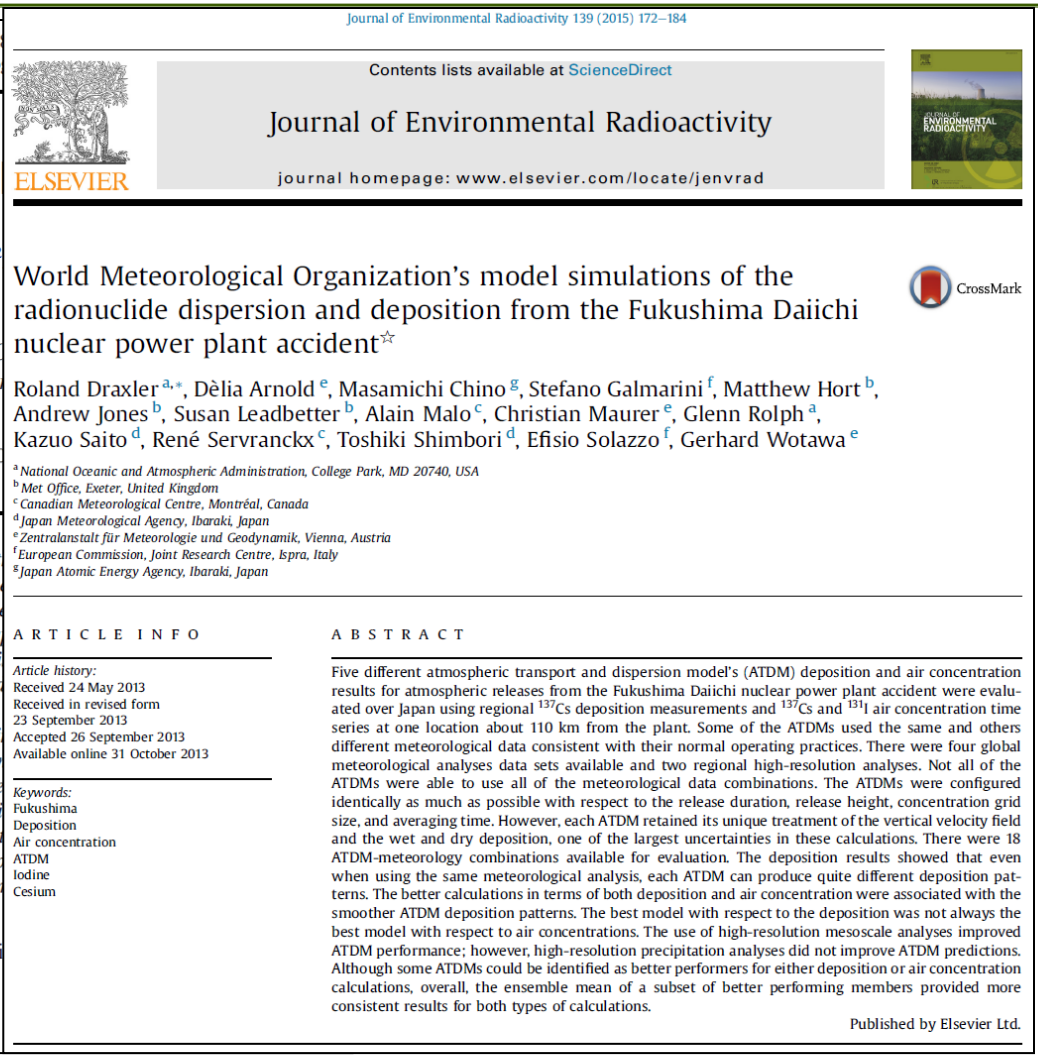
[Original manuscript received 5 May 2014; accepted 10 C

ABSTRACT *This paper describes the integrated suite of Lagrangian t*
operation at the Canadian Meteorological Centre. These models have be
applied to many types of environmental emergencies covering spatial scal
The Modèle Lagrangien Courte Distance (MLCD) is used for atmospheric s
The Modèle Lagrangien de dispersion de particules d'ordre 1 (MLDP1) i
areas less than 100 km; Modèle Lagrangien dispersion de particules d'or
of continental and global consequences. The Modèle Lagrangien
mixte (MLDPmm) alternates between first-order and zeroth-order dependi
The theoretical bases of the models are presented, and the main algorith
discussed. Modelling of the diffusion processes is based on a stochastic diffe
of quasi-stationary Gaussian turbulence, locally homogeneous in the hori
operational implementation are also described. Using these models, resul
scales ranging from the very local, to a few kilometres, to regional (ap
(approximately 1000 km) and to global (approximately 10,000 km) are co
observational data.

KEYWORDS atmospheric dispersion; Lagrangian modelling; turbulent mi
emergency response

---

*Corresponding author's email: damoursr@gmail.com



Journal of Environmental Radioactivity 139 (2015) 172–184

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

ELSEVIER

World Meteorological Organization's model simulations of the radionuclide dispersion and deposition from the Fukushima Daiichi nuclear power plant accident☆

CrossMark

Roland Draxler[a,*], Dèlia Arnold[e], Masamichi Chino[g], Stefano Galmarini[f], Matthew Hort[b], Andrew Jones[b], Susan Leadbetter[b], Alain Malo[c], Christian Maurer[e], Glenn Rolph[a], Kazuo Saito[d], René Servranckx[c], Toshiki Shimbori[d], Efisio Solazzo[f], Gerhard Wotawa[e]

[a] *National Oceanic and Atmospheric Administration, College Park, MD 20740, USA*
[b] *Met Office, Exeter, United Kingdom*
[c] *Canadian Meteorological Centre, Montréal, Canada*
[d] *Japan Meteorological Agency, Ibaraki, Japan*
[e] *Zentralanstalt für Meteorologie und Geodynamik, Vienna, Austria*
[f] *European Commission, Joint Research Centre, Ispra, Italy*
[g] *Japan Atomic Energy Agency, Ibaraki, Japan*

ARTICLE INFO

Article history:
Received 24 May 2013
Received in revised form
23 September 2013
Accepted 26 September 2013
Available online 31 October 2013

Keywords:
Fukushima
Deposition
Air concentration
ATDM
Iodine
Cesium

ABSTRACT

Five different atmospheric transport and dispersion model's (ATDM) deposition and air concentration results for atmospheric releases from the Fukushima Daiichi nuclear power plant accident were evaluated over Japan using regional ^{137}Cs deposition measurements and ^{137}Cs and ^{131}I air concentration time series at one location about 110 km from the plant. Some of the ATDMs used the same and others different meteorological data consistent with their normal operating practices. There were four global meteorological analyses data sets available and two regional high-resolution analyses. Not all of the ATDMs were able to use all of the meteorological data combinations. The ATDMs were configured identically as much as possible with respect to the release duration, release height, concentration grid size, and averaging time. However, each ATDM retained its unique treatment of the vertical velocity field and the wet and dry deposition, one of the largest uncertainties in these calculations. There were 18 ATDM-meteorology combinations available for evaluation. The deposition results showed that even when using the same meteorological analysis, each ATDM can produce quite different deposition patterns. The better calculations in terms of both deposition and air concentration were associated with the smoother ATDM deposition patterns. The best model with respect to the deposition was not always the best model with respect to air concentrations. The use of high-resolution mesoscale analyses improved ATDM performance; however, high-resolution precipitation analyses did not improve ATDM predictions. Although some ATDMs could be identified as better performers for either deposition or air concentration calculations, overall, the ensemble mean of a subset of better performing members provided more consistent results for both types of calculations.

Published by Elsevier Ltd.

Acknowledgments

Contributor	Field of Expertise
Philippe Barnéoud	Modelling, Validation, VAAC, RSMC
Biljana Bekcic	Modelling, VAAC, RSMC
Najat Benbouta	Urban Modelling
Dov Bensimon	Ops Training, Outreach, VAAC, RSMC, CTBTO
Pierre Bourgouin	Section Head
Nils Ek	Inverse/Urban Modelling, Validation, VAAC, RSMC
Jean-Philippe Gauthier	Modelling, GUI
Éric Legault-Ouellet	Validation, GUI
Alain Malo	Modelling, Validation, VAAC, RSMC
Guillaume Marcotte	Source Term Estimation, Chemical Specialist
Gilles Mercier	Aquatic/Urban Modelling, CTBTO
Serge Trudel	Remote Sensing, GUI
Jian Feng	Dry Deposition and Wet Scavenging Schemes
Réal D’Amours	Modelling, Validation, CTBTO
René Servranckx	Remote Sensing, RSMC

Thank you!

- Dov Bensimon, M. Sc. Operational meteorologist and Montréal VAAC manager

  Dov.Bensimon@ec.gc.ca

  +1 514 421-5296

- Alain Malo, M. Sc. Physicist – Research, Development and Operations

  Alain.Malo@ec.gc.ca

  +1 514 421-4626

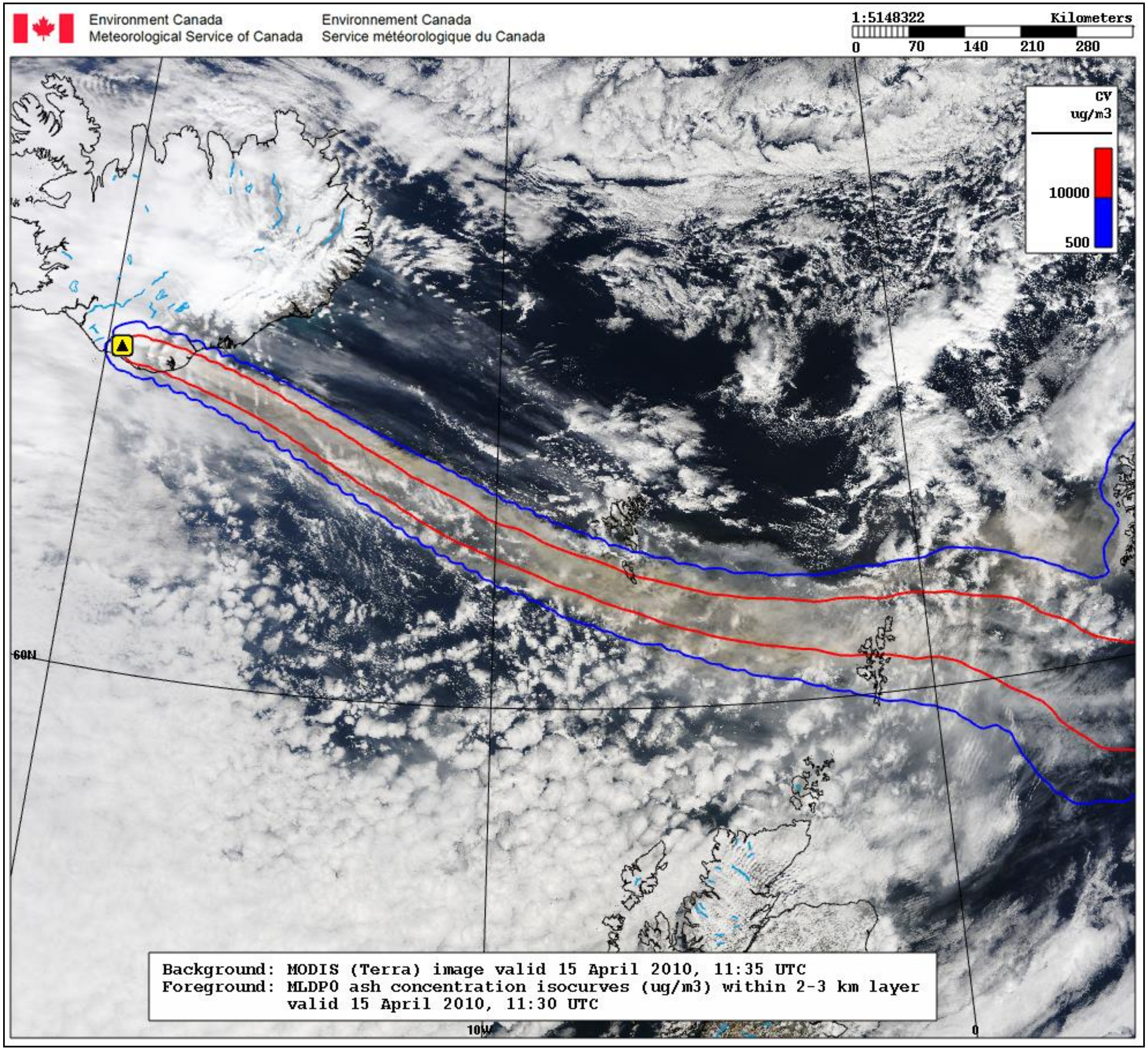
Supplementary Slides

Selected Publications

- **D'Amours, R.**, **Malo, A.**, Flesch, T., Wilson, J., **Gauthier J.-P.**, **Servranckx, R.**, 2015, “The Canadian Meteorological Centre's Atmospheric Transport and Dispersion Modelling Suite”, *Atmosphere-Ocean*, **53** (2), 176–199, doi:10.1080/07055900.2014.1000260
- Katata, G., Chino, M., Kobayashi, T., Terada, H., Ota, M., Nagai, H., Kajino, M., Draxler, R., Hort, M. C., **Malo, A.**, Torii, T., Sanada, Y., 2015, “Detailed source term estimation of the atmospheric release for the Fukushima Daiichi Nuclear Power Station accident by coupling simulations of an atmospheric dispersion model with an improved deposition scheme and oceanic dispersion model”, *Atmospheric Chemistry and Physics*, **15** (2), 1029–1070, doi:10.5194/acp-15-1029-2015
- Draxler, R., Arnold, D., Chino, M., Galmarini, S., Hort, M., Jones, A., Leadbetter, S., **Malo, A.**, Maurer, C., Rolph, G., Saito, K., **Servranckx, R.**, Shimbori, T., Solazzo, E., Wotawa, G., 2015, “World Meteorological Organization's Model Simulations of the Radionuclide Dispersion and Deposition from the Fukushima Daiichi Nuclear Power Plant Accident”, *Journal of Environmental Radioactivity*, **139**, 172–184, doi:10.1016/j.jenvrad.2013.09.014
- **D'Amours, R.**, **Malo, A.**, **Servranckx, R.**, **Bensimon, D.**, **Trudel, S.**, **Gauthier, J.-P.**, 2010, “Application of the atmospheric Lagrangian particle dispersion model MLDP0 to the 2008 eruptions of Okmok and Kasatochi volcanoes”, *Journal of Geophysical Research*, **115** (D00L11), 1–11, doi:10.1029/2009JD013602
- Guffanti, M., Schneider, D. J., Wallace, K. L., Hall, T., **Bensimon, D. R.**, Salinas, L. J., 2010, “The aviation response to a widely dispersed volcanic ash and gas cloud from the August 2008 eruption of Kasatochi, Alaska, USA”, *Journal of Geophysical Research*, **115** (D00L19), 1–9 doi:10.1029/2010JD013868
- **Feng, J.**, 2009, “A size-resolved model for below-cloud scavenging of aerosols by snowfall”, *Journal of Geophysical Research*, **114** (D08203), 1–8, doi:10.1029/2008JD011012
- **Feng, J.**, 2008, “A size-resolved model and a four-mode parameterization of dry deposition of atmospheric aerosols”, *Journal of Geophysical Research*, **113** (D12201), 1–13, doi:10.1029/2007JD009004
- **Feng, J.**, 2007, “A 3-mode parameterization of below-cloud scavenging of aerosols for use in atmospheric dispersion models”, *Atmospheric Environment*, **41** (32), 6808–6822, doi:10.1016/j.atmosenv.2007.04.046

Eyjafjallajökull, Iceland: 15 April 2010

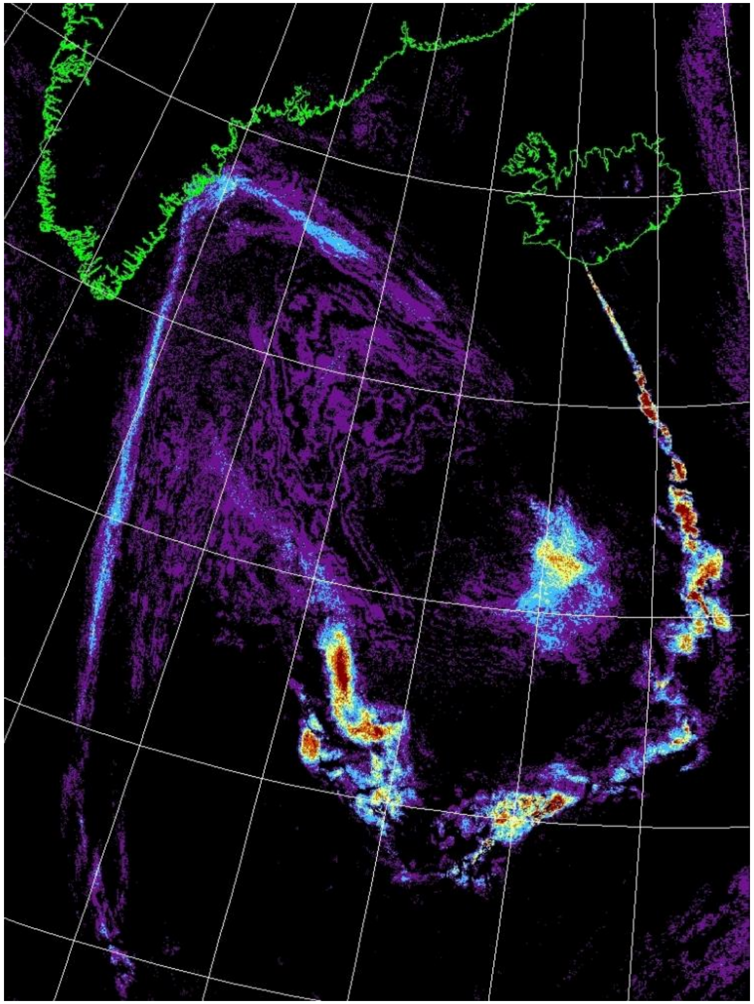
© Alamy



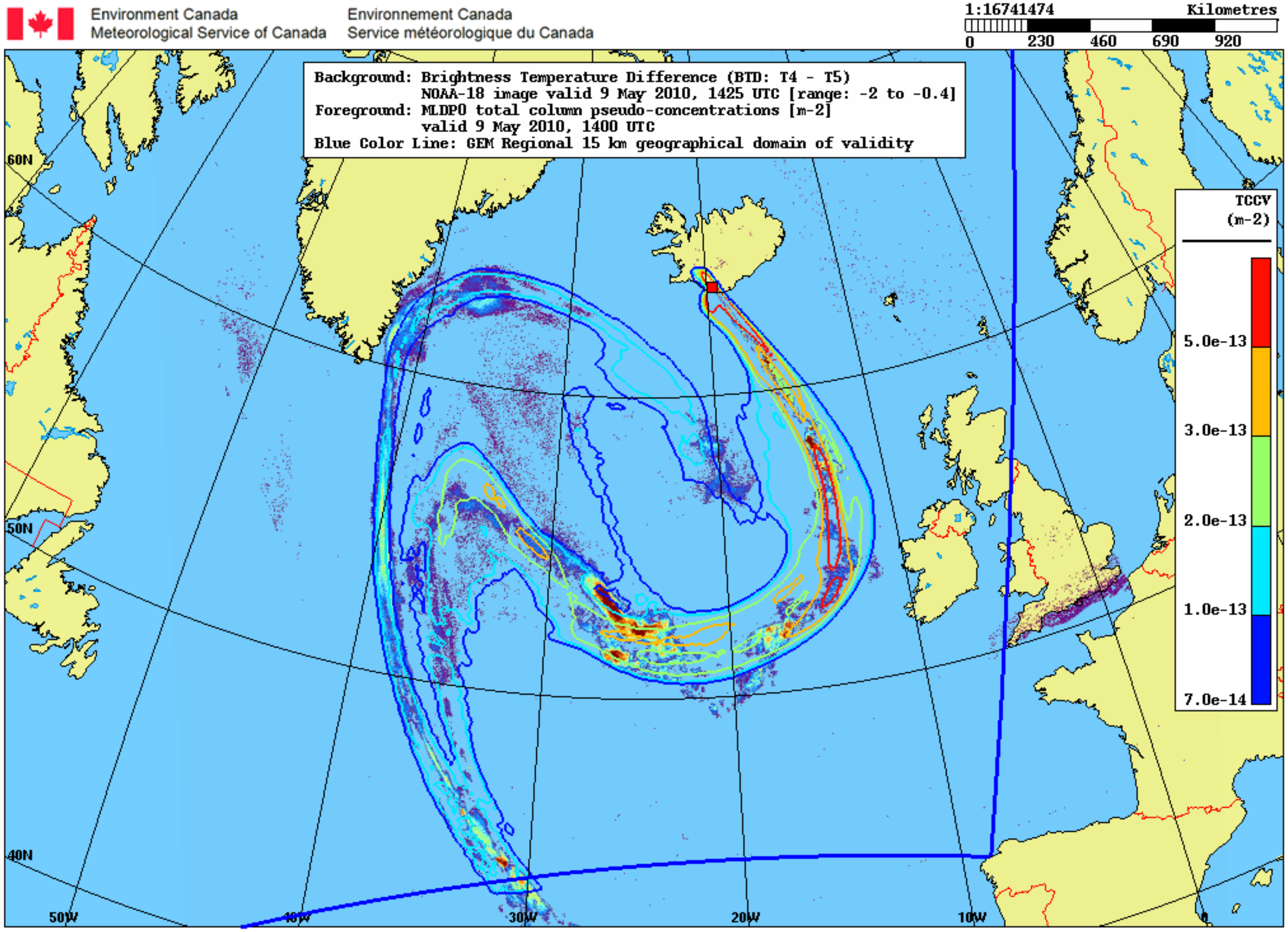
Background: MODIS (Terra) image valid 15 April 2010, 11:35 UTC
Foreground: MLDP0 ash concentration isocurves (ug/m3) within 2-3 km layer
valid 15 April 2010, 11:30 UTC

Eyjafjallajökull, Iceland: 6-9 May 2010

Brightness Temperature Difference (BTD) in Infrared
AVHRR NOAA-15 Valid 9 May 2010 at 1758 UTC



Eyjafjallajökull: MLDP0 Quantitative Verification Against DTB AVHRR ($T_4 - T_5$) Satellite Imagery



Background: Brightness Temperature Difference (BTD: T4 - T5)
NOAA-18 image valid 9 May 2010, 1425 UTC [range: -2 to -0.4]
Foreground: MLDP0 total column pseudo-concentrations [m-2]
valid 9 May 2010, 1400 UTC
Blue Color Line: GEM Regional 15 km geographical domain of validity