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Non-Hydrostatic Modelling with the Global Environmental Multiscale (GEM) Model

"Workshop on Non-Hydrostatic Modelling"
ECMWF, November 8-10, 2010

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Atmospheric Science & Technology

Content

- History
- New vertical structure
- Vancouver Olympics
- Conclusion

History – The beginning in Canada

- Tanguay, M., A, Robert, R. Laprise, 1990: A Semi-implicit Semi-Lagrangian Fully Compressible Regional Forecast Model, *Mon. Wea. Rev.*, **118**, 1970-1980.

- Semi-implicit semi-Lagrangian
- Height as vertical coordinate (Charney-Phillips)
- Shallow atmosphere
- Limited-area, PS, C-grid
- Acoustic modes were not filtered but distorted
- The rationale was that by removing a constraint on the equation set one would be closer to the exact equations describing the real atmosphere and better physics parameterizations would follow for higher resolution modelling

History – MC2

- Benoit *et al.*, 1997: The Canadian MC2: A Semi-Lagrangian, Semi-Implicit Wideband Atmospheric Model Suited for Finescale Process Studies and Simulation, *Mon. Wea. Rev.*,
- Girard *et al.*, 2005: Finescale topography and the MC2 Dynamics kernel. *Mon. Wea. Rev*.

- Research community in Canada & abroad
- Numerical guidance for the first Mesoscale Alpine Programme (MAP) (Benoit *et al.*, 2002).
- America's Cup for Australia
- Nesting strategy & growing topography

History – MC2 & MAP

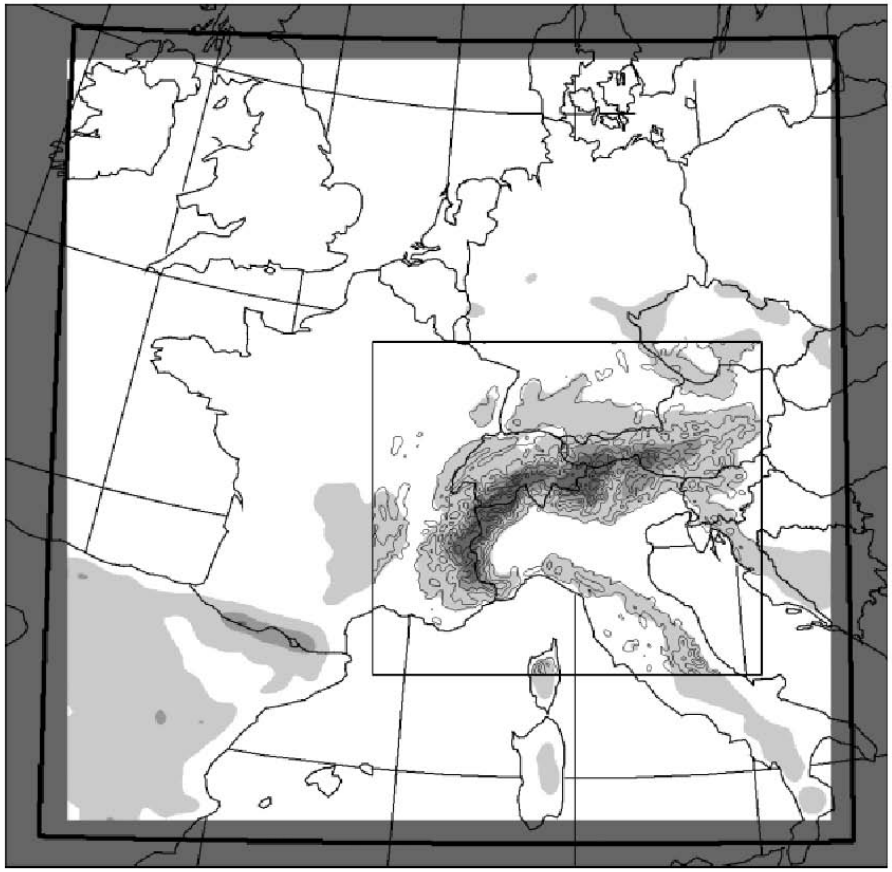
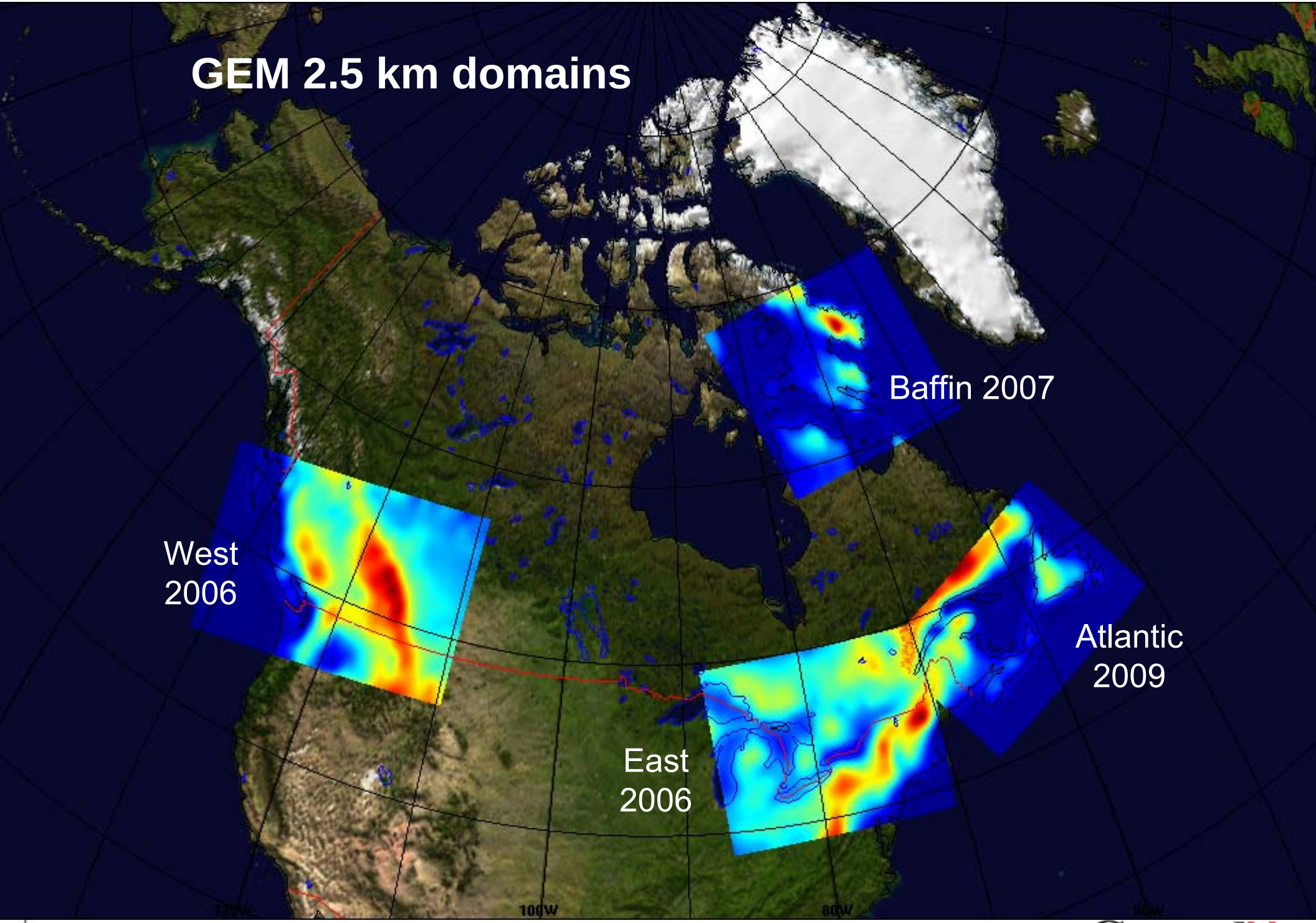


FIG. 2. The computational domain of the SM-14 km, MC2-14 km, and MC2-3 km. The heavy curvilinear outer black rectangle is the actual boundary of the SM. The MC2-14-km domain boundary is the nongrayed-out area, and the MC2-3 km is in the thin inner black rectangle. Topography is plotted in gray shading and contours, for the in MC2-14 km and MC2-3 km (filtered over four grid points), respectively. The political boundaries are also plotted in black lines.

History – Non-hydrostatic GEM-LAM

- Unified modelling system
- Hydrostatic-pressure (GEM)
  - Laprise 1992: The Euler Equations of Motion with Hydrostatic Pressure as an Independent Variable.
- Recent field experiments
  - 10 & 2.5 km windows for the Lunenburg Bay (NS) 2007 Demonstration Project. The goal was to develop a coupled atmosphere/ocean/biology/ chemistry ecosystem model.
  - 15 & 2.5 km windows over the Alps for D-PHASE Operational Period from 1 June to 30 November 2007
  - 1 km window embedded in an expanded West 2.5 km grid for the UNSTABLE 2008 project
  - Special operational forecast cascade to 1 km for the Vancouver Olympic and Paralympic Games. Relocalized in Ontario for G8/G20. A higher resolution urban scale model provided dispersion modelling.


GEM 2.5 km domains
Baffin 2007
West
2006
Atlantic
2009
East
2006
100W
80W

New vertical structure

$$\mu = \frac{\partial p}{\partial \pi} - 1$$

$$\frac{\partial \phi}{\partial \pi} = -\frac{RT}{p}$$

$$\ln \pi = A(\zeta) + B(\zeta)\, s$$

$$s = \ln \pi_S - \zeta_S$$

$$q = \ln(p/\pi)$$

$$\phi_* = -RT_* \left(\zeta - \zeta_S\right)$$

$$\frac{d\mathbf{V}_h}{dt} + f\mathbf{k}\mathrm{x}\mathbf{V}_h + R\overline{T}^{\zeta}\nabla_\zeta\left(Bs+q\right) + \left(1+\overline{\mu}^{\zeta}\right)\nabla_\zeta\phi' = \mathbf{F}_h$$

$$\frac{dw}{dt} - g\mu = F_w$$

$$\frac{d}{dt}\left[\ln\left(\frac{T}{T_*}\right) - \kappa\left(Bs + \overline{q}^{\zeta}\right)\right] - \kappa\dot{\zeta} = \frac{Q}{c_p T}$$

$$\frac{d}{dt}\left[Bs + \ln\left(1+\delta_\zeta Bs\right)\right] + \nabla_\zeta\cdot\mathbf{V}_h + \delta_\zeta\dot{\zeta} + \overline{\dot{\zeta}}^{\zeta} = 0$$

$$\frac{d\overline{\phi'}^{\zeta}}{dt} - RT_*\dot{\zeta} - gw = 0$$

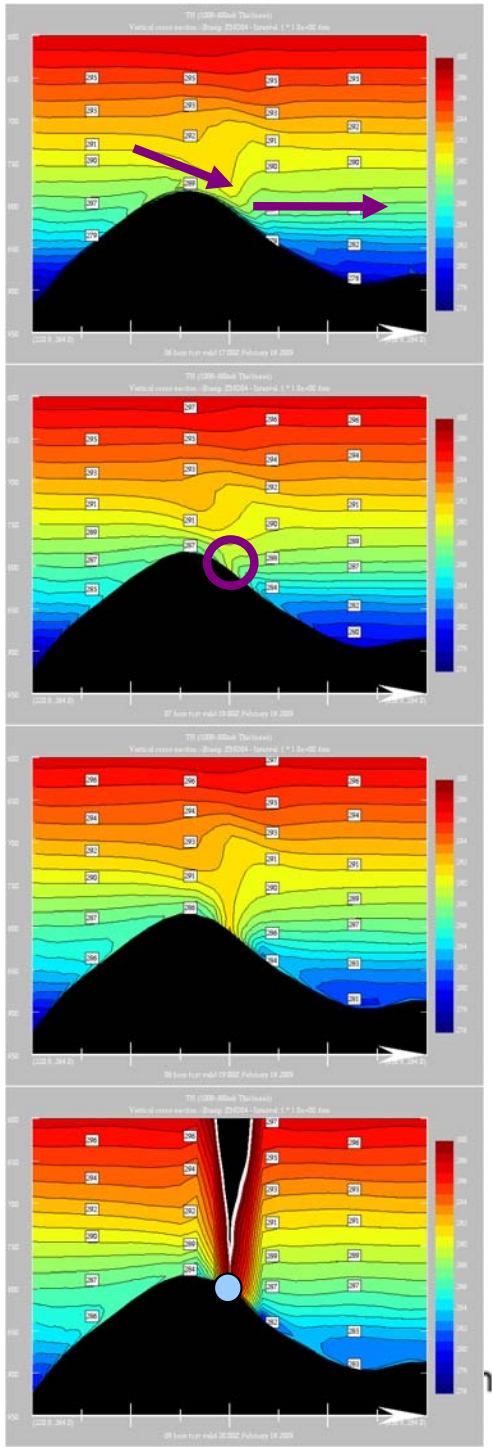
$$1 + \mu - e^{\overline{q}^{\zeta}}\left[\frac{\delta_\zeta q}{\delta_\zeta\left(\zeta + Bs\right)} + 1\right] = 0$$

$$\frac{T}{T_*} + e^{\overline{q}^{\zeta}}\left[\frac{\delta_\zeta\left(\phi'/RT_* + Bs\right)}{\delta_\zeta\left(\zeta + Bs\right)} - 1\right] = 0$$

Charney-Phillips grid

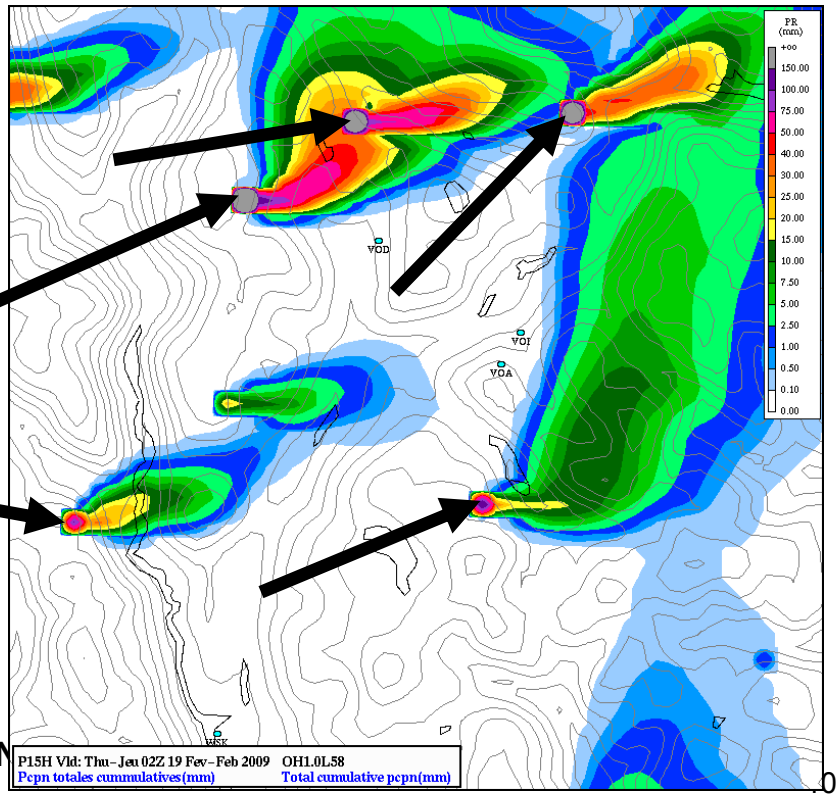
Momemtum levels						Thermodynamics levels
	——	ϕ_T, q_T	——	$\dot{\zeta}_T$	——	$1/2$
				T, w, μ	.....	$3/4$
1	--	$\mathbf{V}_h, \phi, q$	--	------	--	
	——	———	——	$T, w, \mu, \dot{\zeta}$	——	$3/2$
2	--	$\mathbf{V}_h, \phi, q$	--	------	--	
	——	———	——	$T, w, \mu, \dot{\zeta}$	——	$5/2$
...	--	$\mathbf{V}_h, \phi, q$	--	------	--	
	——	———	——	$T, w, \mu, \dot{\zeta}$	——	
$N-1$	--	$\mathbf{V}_h, \phi, q$	--	------	--	
	——	———	——	$T, w, \mu, \dot{\zeta}$	——	$N-1/2$
N	--	$\mathbf{V}_h, \phi, q$	--	------	--	
				T, w, μ	.....	$N+1/4$
	——	s, ϕ_S, q_S	——	$\dot{\zeta}_T$	——	$N+1/2$

Grid-point Storms



- under light wind conditions (downwind slopes) with strong nocturnal inversions in the valleys
- progressive warming of the lowest model layers leads to static instability at isolated grid points
- GEM v4 (“staggering”) with prognostic thermodynamic level near the surface eliminates the source of instability

15-hr accumulation of the precipitation field (points with accumulation in excess of 150 mm)



An experimental NWP system for the Vancouver 2010 Winter Olympics

- **J. Mailhot, S. Bélair, M. Charron**
- B. Denis, A. Erfani, A. Giguère, N. McLennan, R. McTaggart-Cowan, and J. Milbrandt

EC activities related to VO2010

Experimental NWP system for Vancouver 2010

- add to current CMC operational products
- best possible guidance for Olympic Forecast Team
- forecasters' feedback

Experimental prediction system with 3 components

1. REPS - Regional Ensemble Prediction System (Charron)
2. high-resolution LAM prototype (Mailhot)
   - GEM-LAM model cascade down to 1 km (15km/2.5km/1km)
   - improved physics
3. land surface modeling and assimilation system at microscales (100 m) – (lead S. Bélair)

Development of high-resolution LAM prototype

- Challenges of forecasting for Olympic venues
  - local features (e.g. valley clouds forming fog at mid-mountain - Harvey's cloud in Whistler)
  - terrain-induced flows and strong wind events (gusty winds, visibility)
  - PCP amounts, phase/type (rain/drizzle, freezing rain/drizzle, snow, ice pellets), low cloud base, melting snow levels

- Fit users' specific needs and constraints
  - thresholds for competitions
  - forecasters briefing schedules
    - morning briefing (7h00 local time) – same day forecasts
    - afternoon briefing (12h00 local time) – evening competitions

Forecasting challenges

- Olympic events with sensitive thresholds for decision

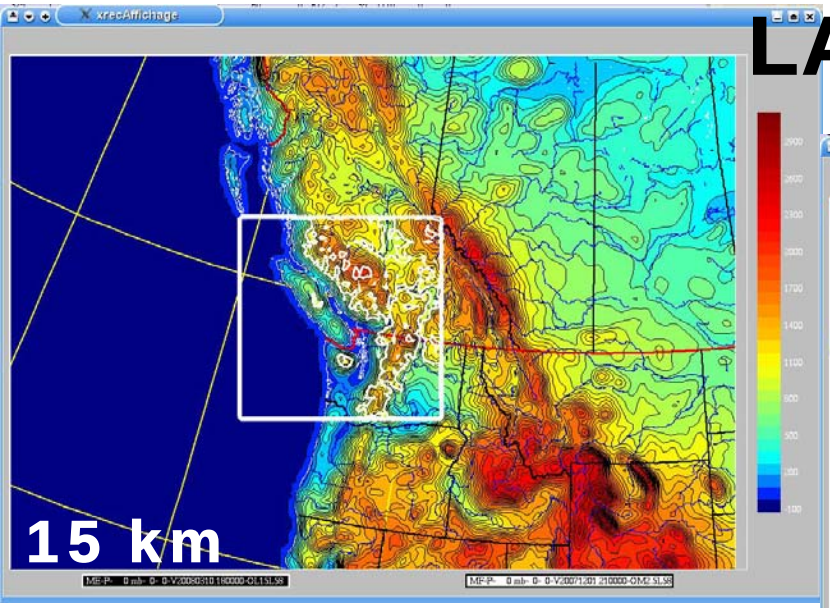
Sport and Weather	New Snow (24 hours)	Wind	Visibility	Rain	Low Temp	High Temp	Wind Chill
Downhill,Slalom, Giant Slalom	> 30 cm	Constant above 17 m/s or gusts > 17 m/s	< 20 m on the entire course>	15mm in 6 hours or less			> -25
	> 15 cm and < 30 cm	Constant 11 m/s to 17 m/s <	20 m on portions of the course	Mixed precipitation			
	➢5 cm ➢2 cm within 6h of an event	Gusts above 14 m/s but < 17 m/s>	>20m but <50m on whole or part of the course				

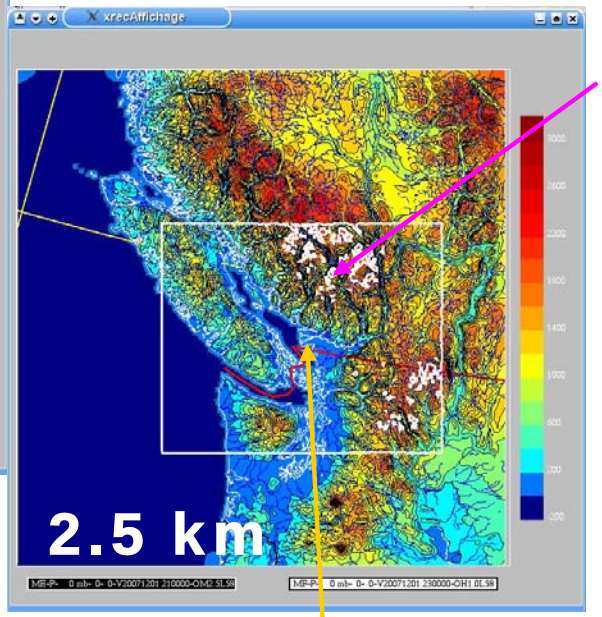
2010 Sports/Weather Threshold matrix;
Red text = Critical Decision point
Orange text = Significant decision point
Green text = Factor to consider

Production of high-resolution LAM forecast

- **3 nested LAM integrations twice daily from 0000 and 1200 UTC GEM Regional forecasts:**

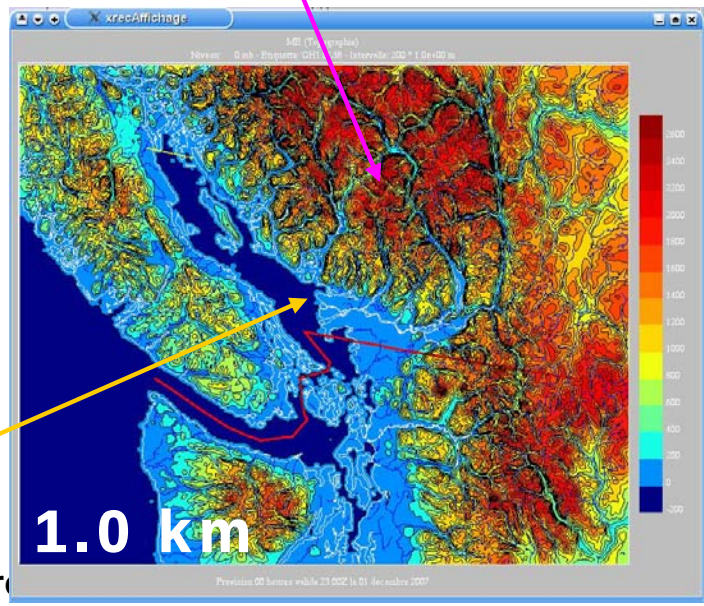
LAM-15 km → 2.5 km → 1 km





Whistler

Vancouver



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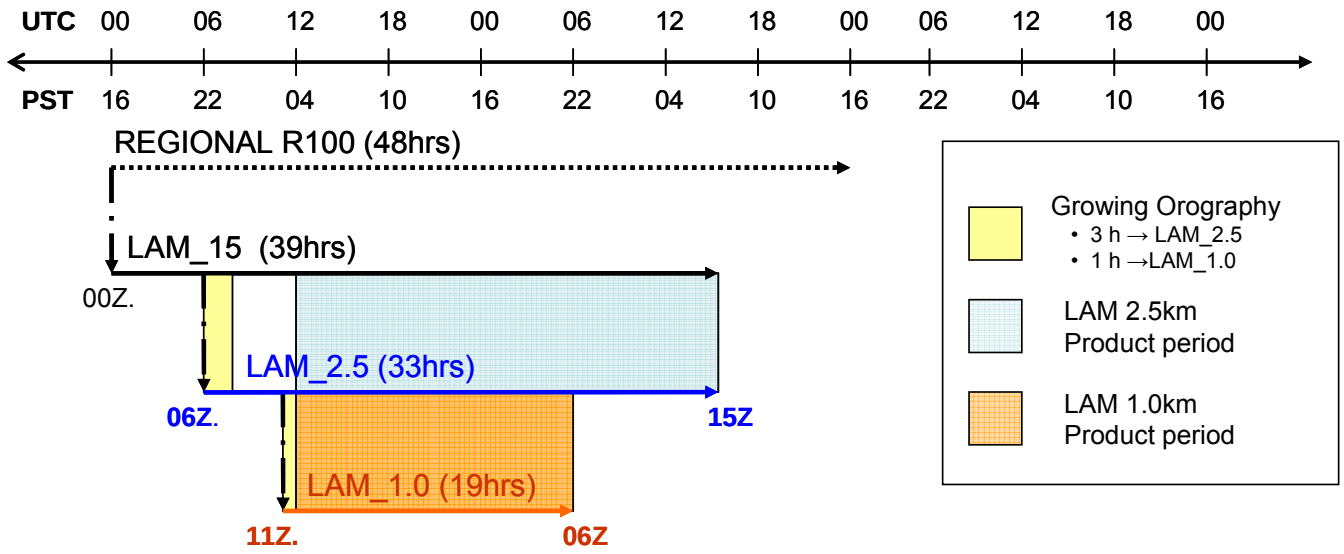
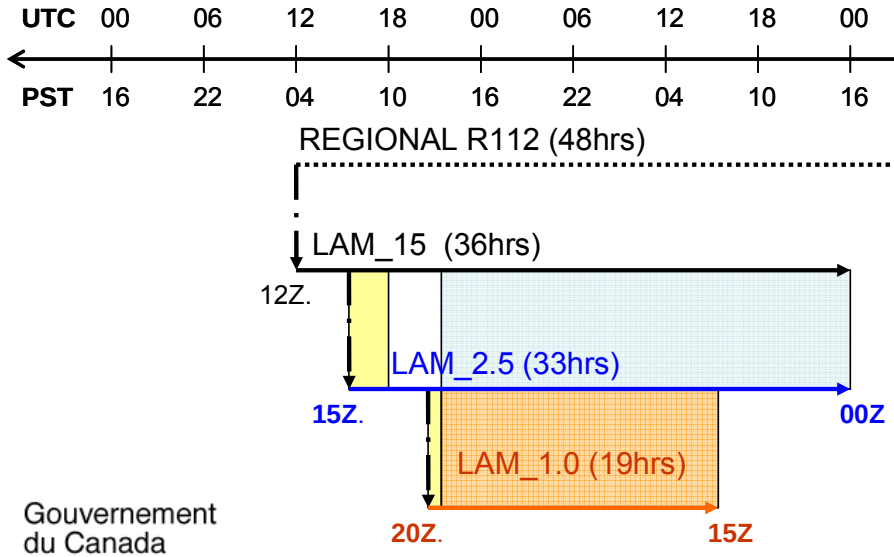
High-resolution LAM prototype





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New features and products

- **Improved physics**
  - geophysical fields (orography, surface roughness,…) using new database at 90-m res
  - CCCma_rad radiation scheme (solar + infrared)
  - Milbrandt-Yau double-moment bulk microphysics (with a prognostic snow/liquid ratio for snow density)

- **New model diagnostic outputs**
  - visibility reduction due to hydrometeors (fog, rain, and snow)
  - cloud base, melting level, snow base
  - solid-to-liquid ratio for snow density
  - diagnostics of surface wind gusts and wind variances (speed + direction)

Final adjustments

Latest available program libraries:

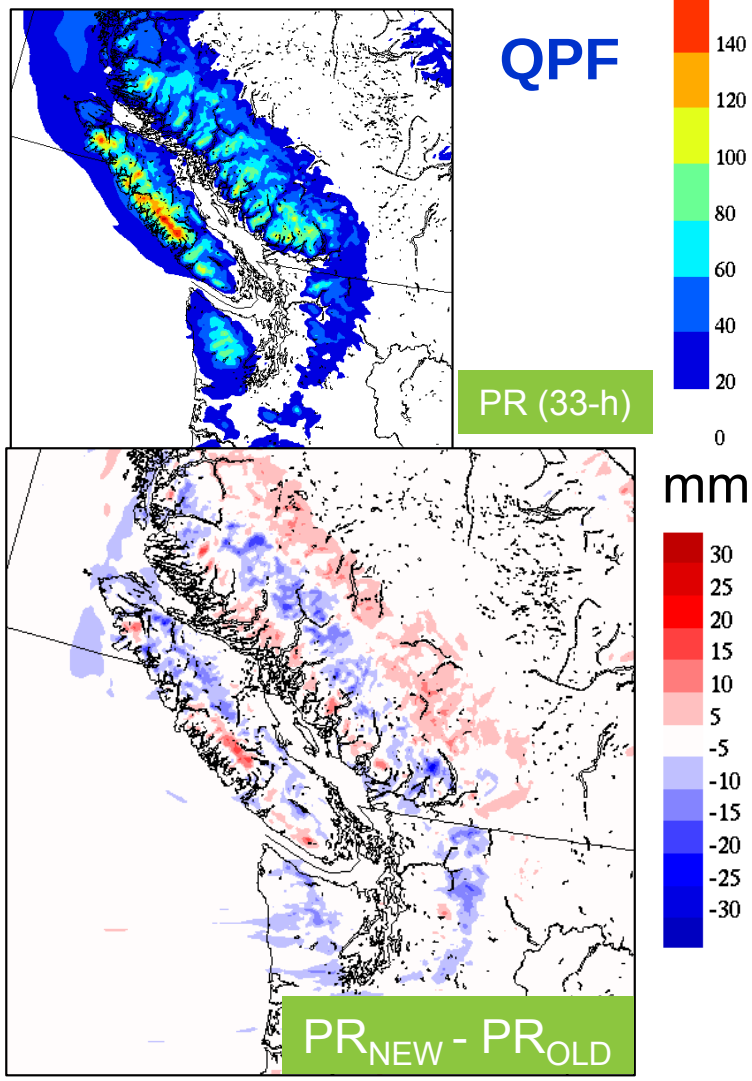
1. **Dynamic (GEM v_4.0.6):**
   - vertical “staggering” (Charney-Phillips):

     solved intermittent grid-point storm problem;
   - “growing” orography:

     reduction of “shocks / extrapolations” during the nesting adjustment process;

2. **Physics (PHY v_5.0.4):**
   - “fine-tuning” of the double-moment bulk microphysics (mostly for snow).

Fine-tuning of microphysics



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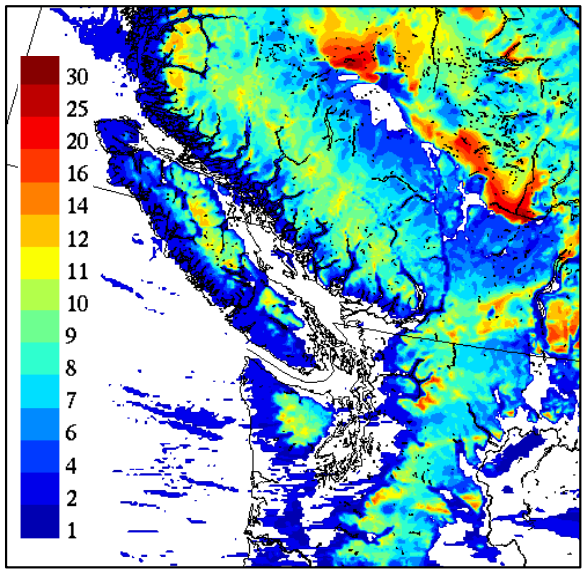
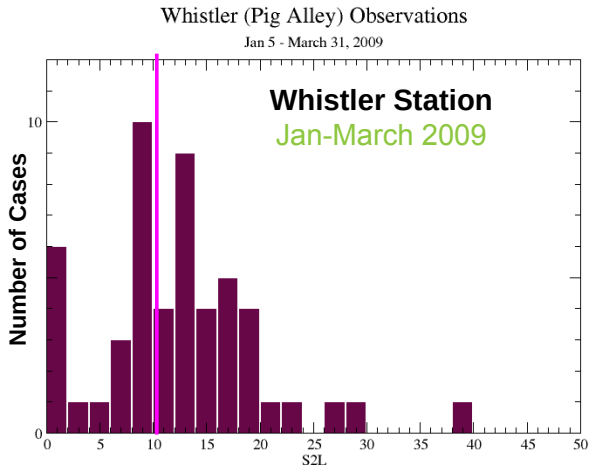
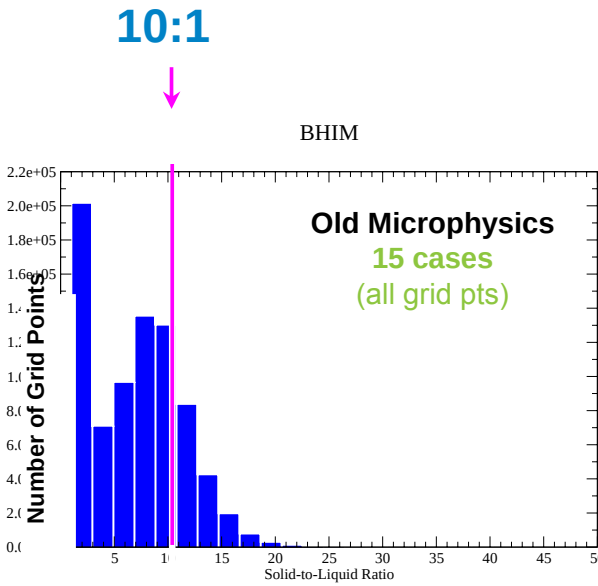
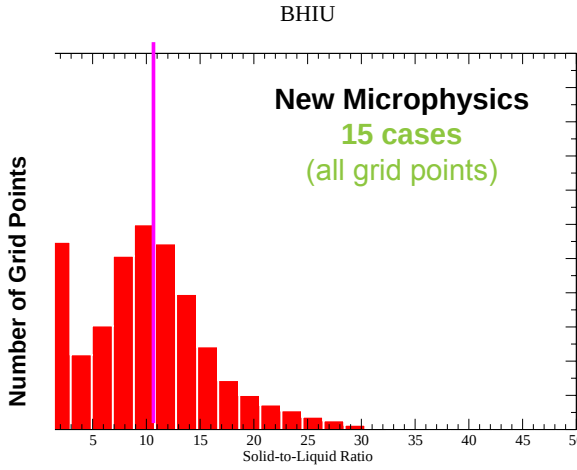
Solid-to-Liquid Ratio









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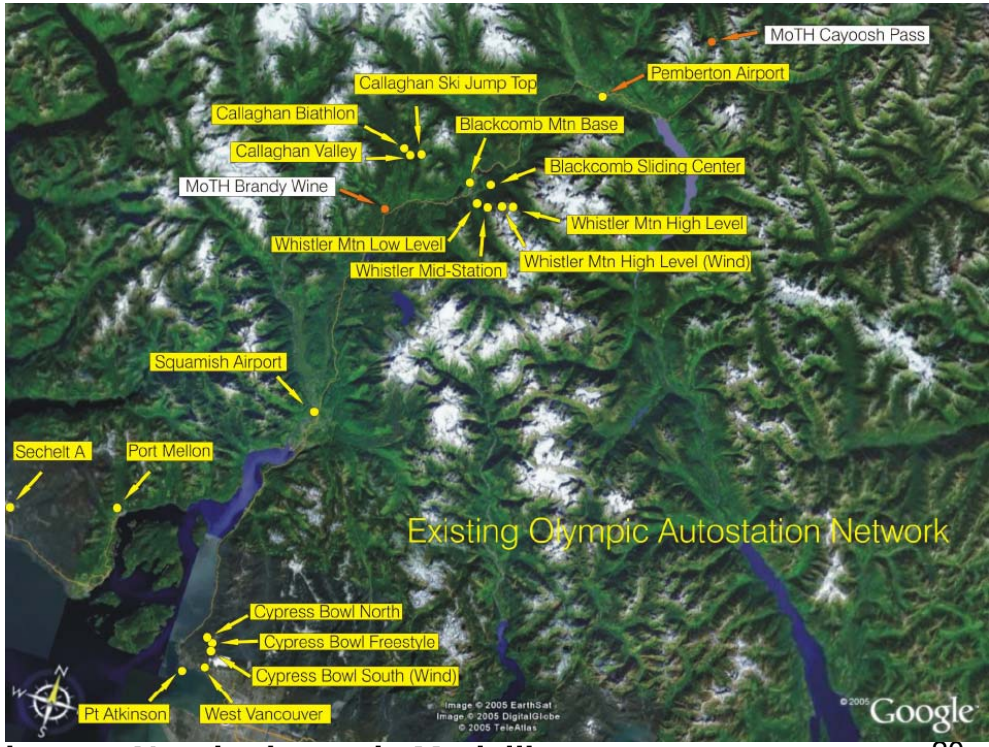
Verifications for VO2010

- **Olympic Autostation Network (OAN) consists of**
  - ~ 40 standard and special surface observing sites (hourly or synop available on GTS)
  - (relatively) large number of surface stations
  - concentrated in small region
- **Verifications based on a set of 15 cases (winters 2008/9)**
  - representative of “bad” weather conditions for the area
  - frontal passages, heavy snow, change of PCP phases, valley clouds, strong wind gusts,…



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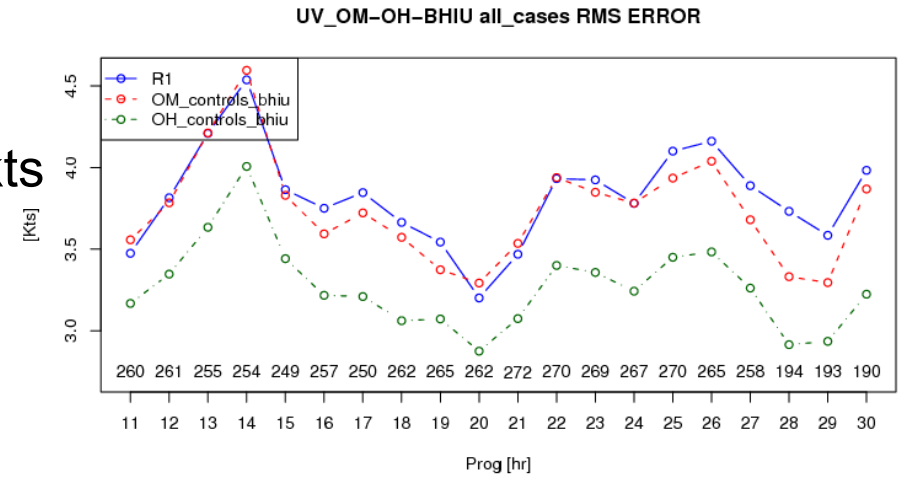
Evaluation – Near-surface winds and temperature

Average of 15 Cases

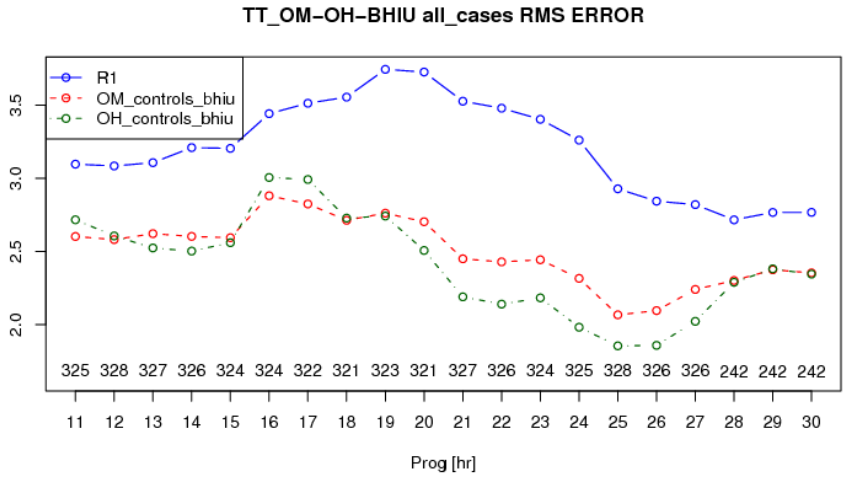
REG-15 km
2.5 km
1 km

Wind Speeds (10 m)



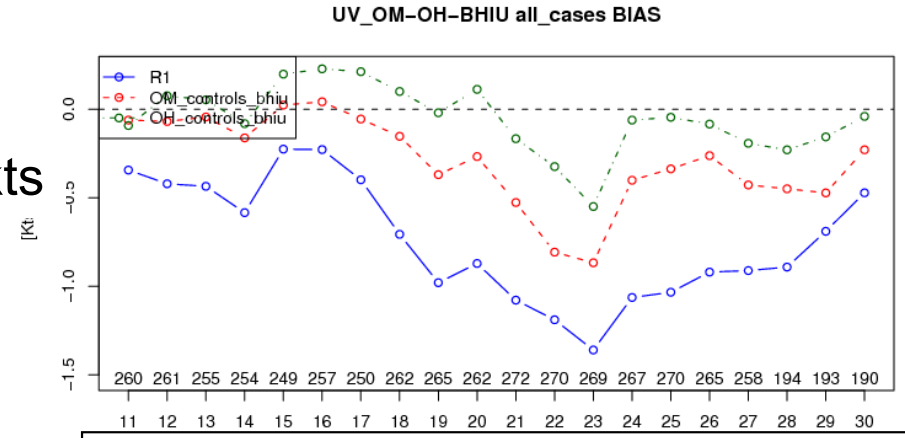
kts

Temperature (2 m)

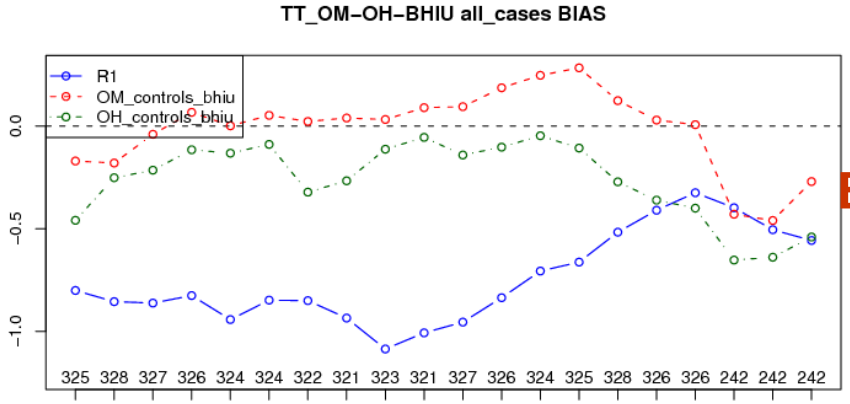


°C

RMS



kts



°C

BIAS

Significant improvements at 1 km for winds and temperatures (also 2.5 km) with respect to operational regional REG-15 km model

Customized output package

Customized output package

- Based on Olympic forecasters' feedback
  - products
  - display format,...
- Easy display (jpeg images)
- Comprehensive list of model outputs
  - 2D maps, time series at stations
  - vertical soundings & cross-sections
- Products available for evaluation by support desk & briefings

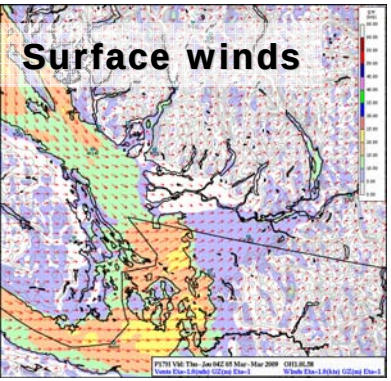
Customized output package

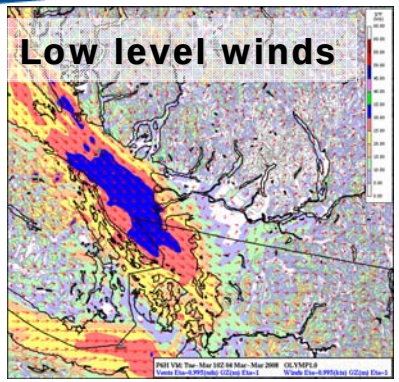
List of model outputs (2D maps, time series at stations, vertical soundings and cross-sections):

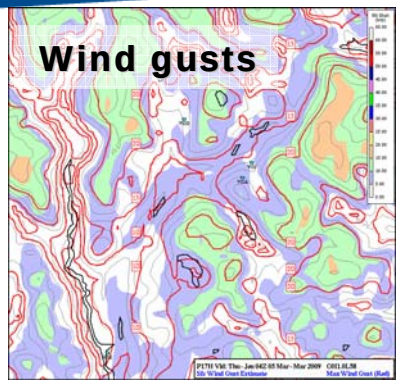
2D MAPS:

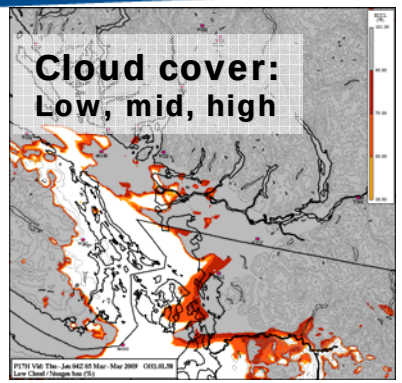
- Screen-level potential temperature θ
- Screen-level relative humidity (relative to liquid phase)
- 10-m winds
- Wind gusts (gust estimates, minimum and maximum values)
- Standard deviations of 10-m wind speed and direction
- Accumulated precipitation types (liquid/freezing/snow/frozen)
- Precipitation accumulation (liquid / solid / total)
- Precipitation rate (liquid / solid / total)
- Snow/liquid ratio {S2L}
- Cloud cover (high/ mid/ low + total)
- Cloud base height
- Visibility (through fog, rain, snow, plus total)
- Freezing level (m - 0°C isotherm level)
- Snow level (m – lowest level with non-zero snow rate)
- Wind chill factor

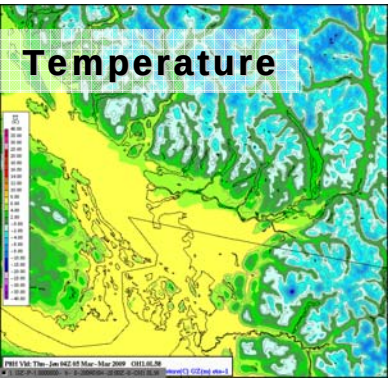
LAM-Olympic model outputs

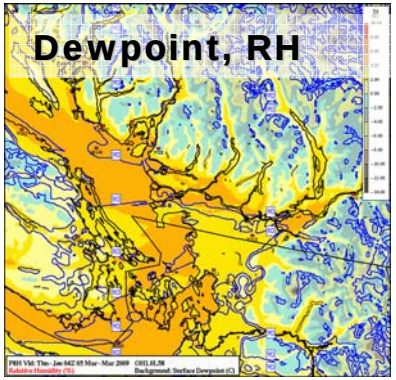


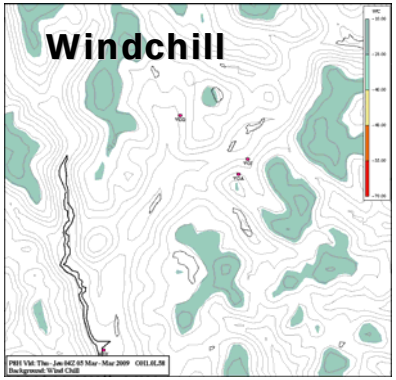


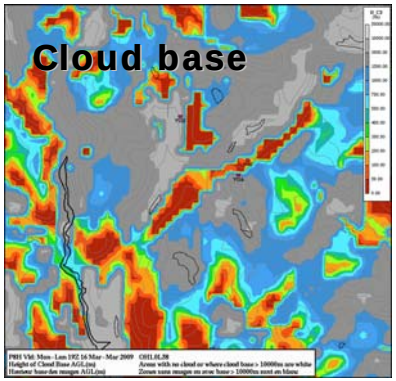


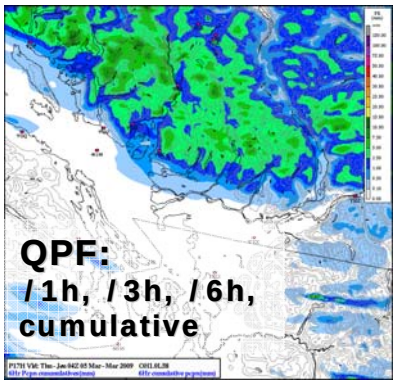


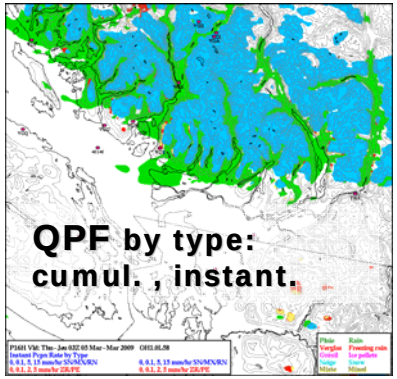


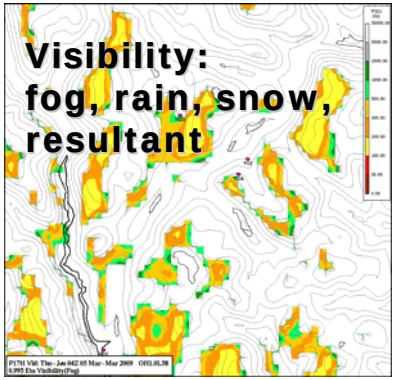












2D maps (1 km)

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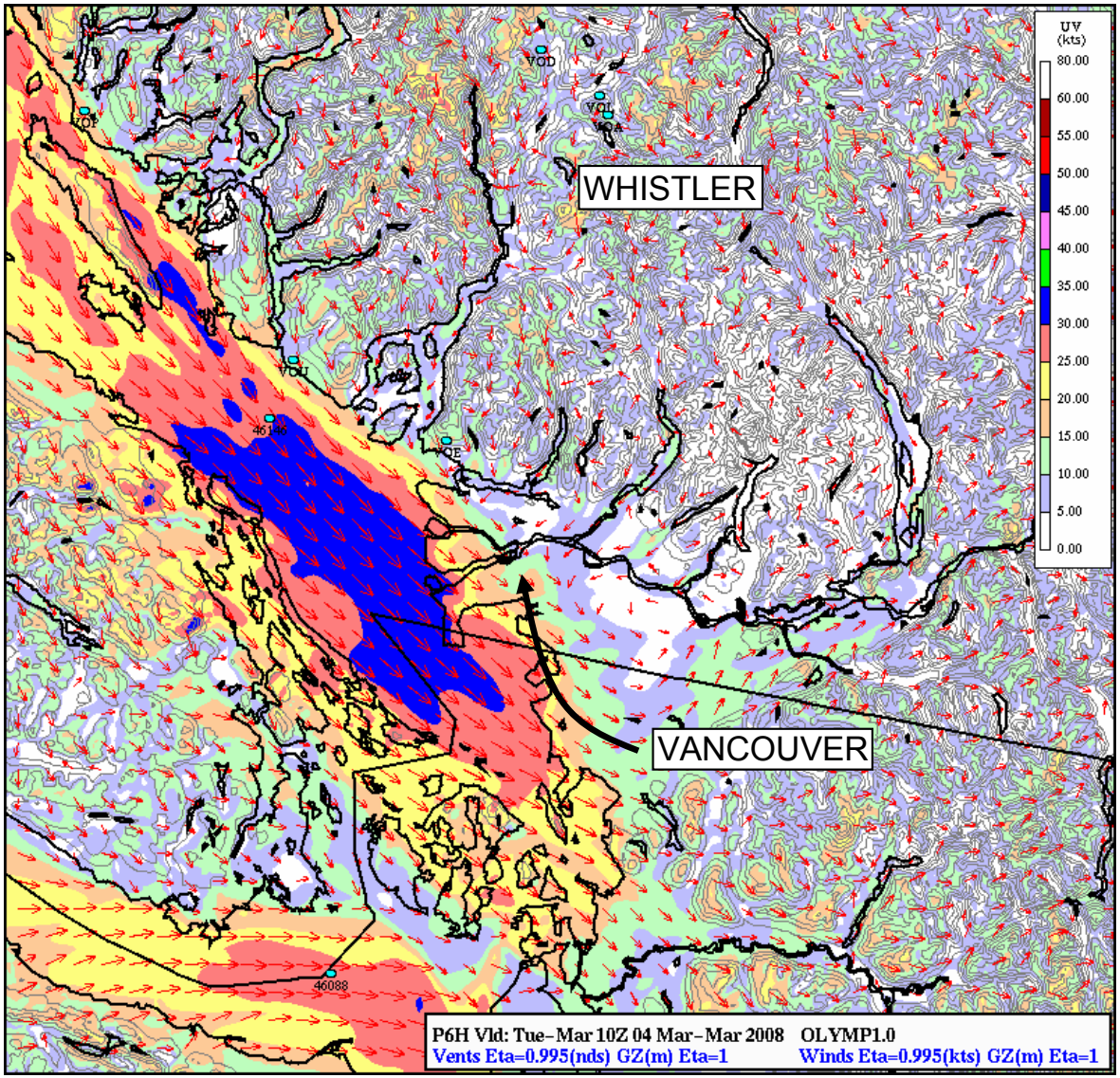
High-resolution forecasts

Low-level wind speed and direction

1-km LAM model

6-h run valid at 10Z 4 March 2008



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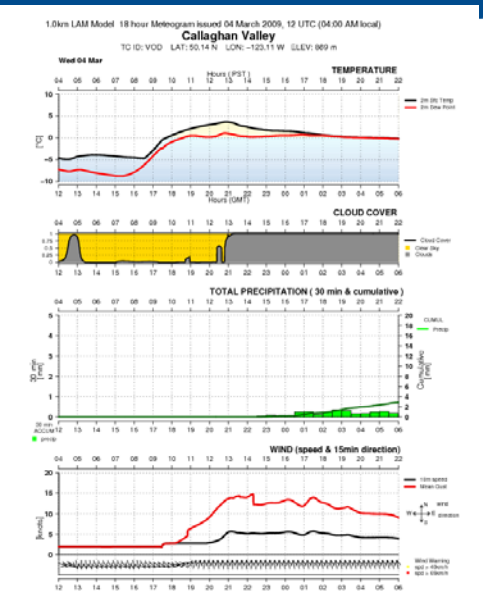
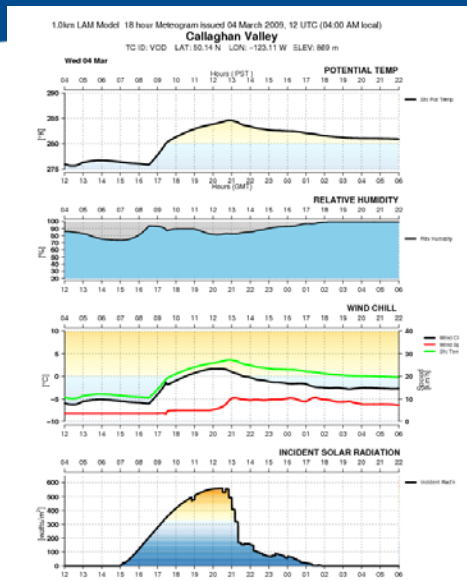
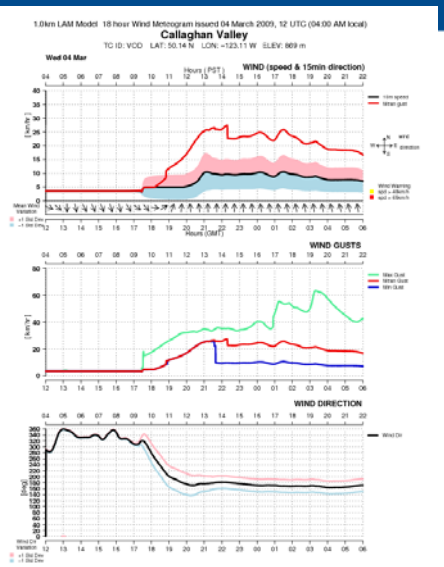
LAM-Olympic model outputs



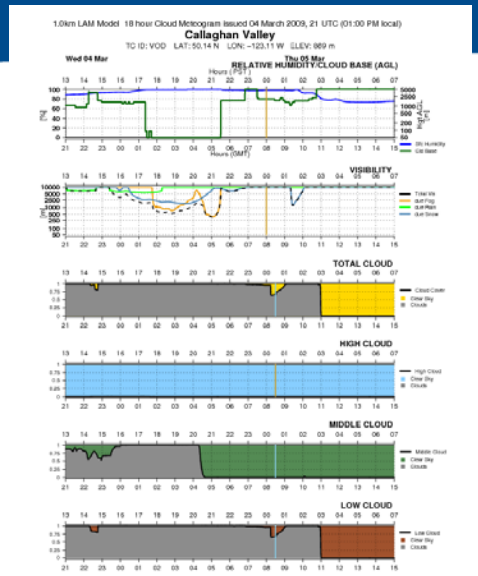
General Wx



TT, TD etc.

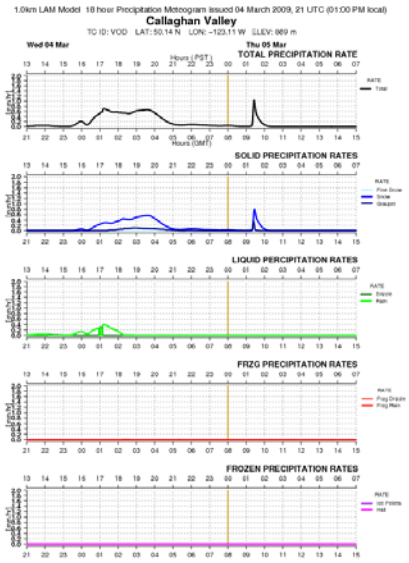


Wind and Gusts

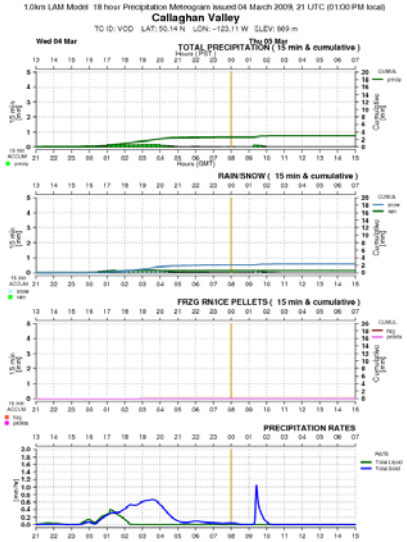


Clouds and vis.

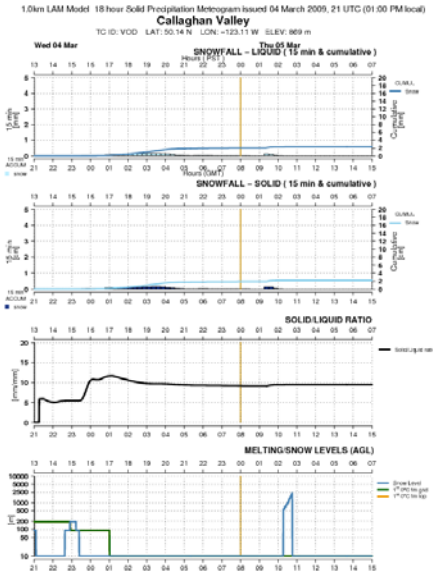
Meteograms (1 km)



PCP Rates



Precipitation



Snow

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High-resolution forecasts

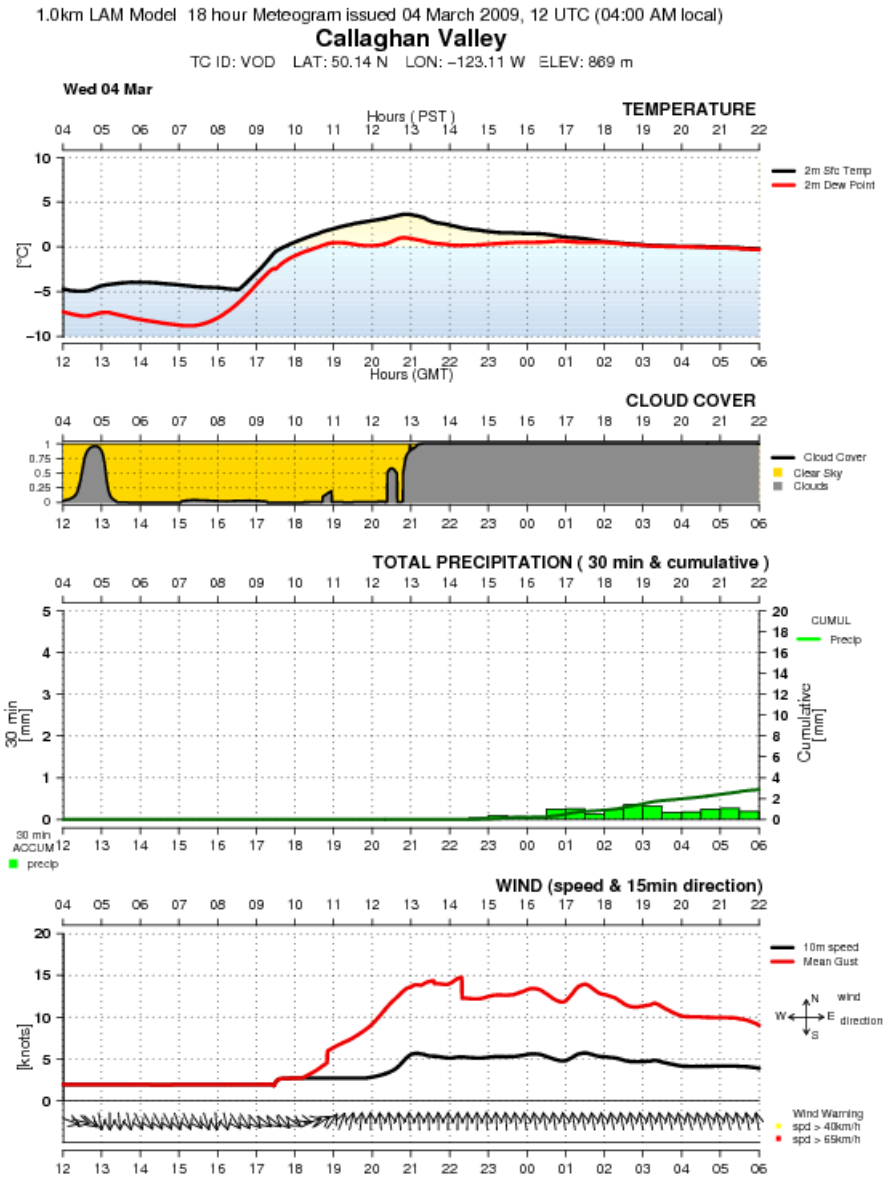
General Wx:

Callaghan Valley (VOD)

Low-level temperature, cloud cover, total precipitation, and wind speed and direction

1-km LAM model

18-h meteogram from 12 UTC 4 March 2009



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Conclusion

- LAMs 2.5 km part of guidance tools
  - Widely used, removing them would lead to complaints.
- Learning ladder for resolution
- Olympics configuration ported to LAM 2.5 km
- Number of windows & frequency?
- Expected to become fully operational
- European Center for Short-Range Weather Forecasting?

Questions?

Merci!

Thank You!