The background of the slide is a vibrant, close-up photograph of green maple leaves. The leaves are in various shades of green, from light lime to deep forest green, and their intricate vein patterns are clearly visible. Several dragonflies are scattered throughout the scene, some in sharp focus and others blurred, suggesting movement. One large dragonfly is prominent on the left side, while a smaller one is visible in the lower right. The overall composition is bright and naturalistic.

**Современные глобальные  
прогностические модели  
атмосферы, используемые в  
метеорологической службе  
Канады**

This hour's hot and cold spots ...

Hot spot in **Canada**: 21.3 °C Ingonish Beach, NS

Cold spot in **Canada**: -19.2 °C Eureka, NU

09.10. 2016 20:40 UTC



# Конец работы над презентацией

This hour's hot and cold spots ...

Hot spot in **Canada**: 18.9 °C Estevan Airport, SK

Cold spot in **Canada**: -18.3 °C Eureka, NU

09.10.16 23:55 UTC



# Начало работы над презентацией

# Канадские модели атмосферы

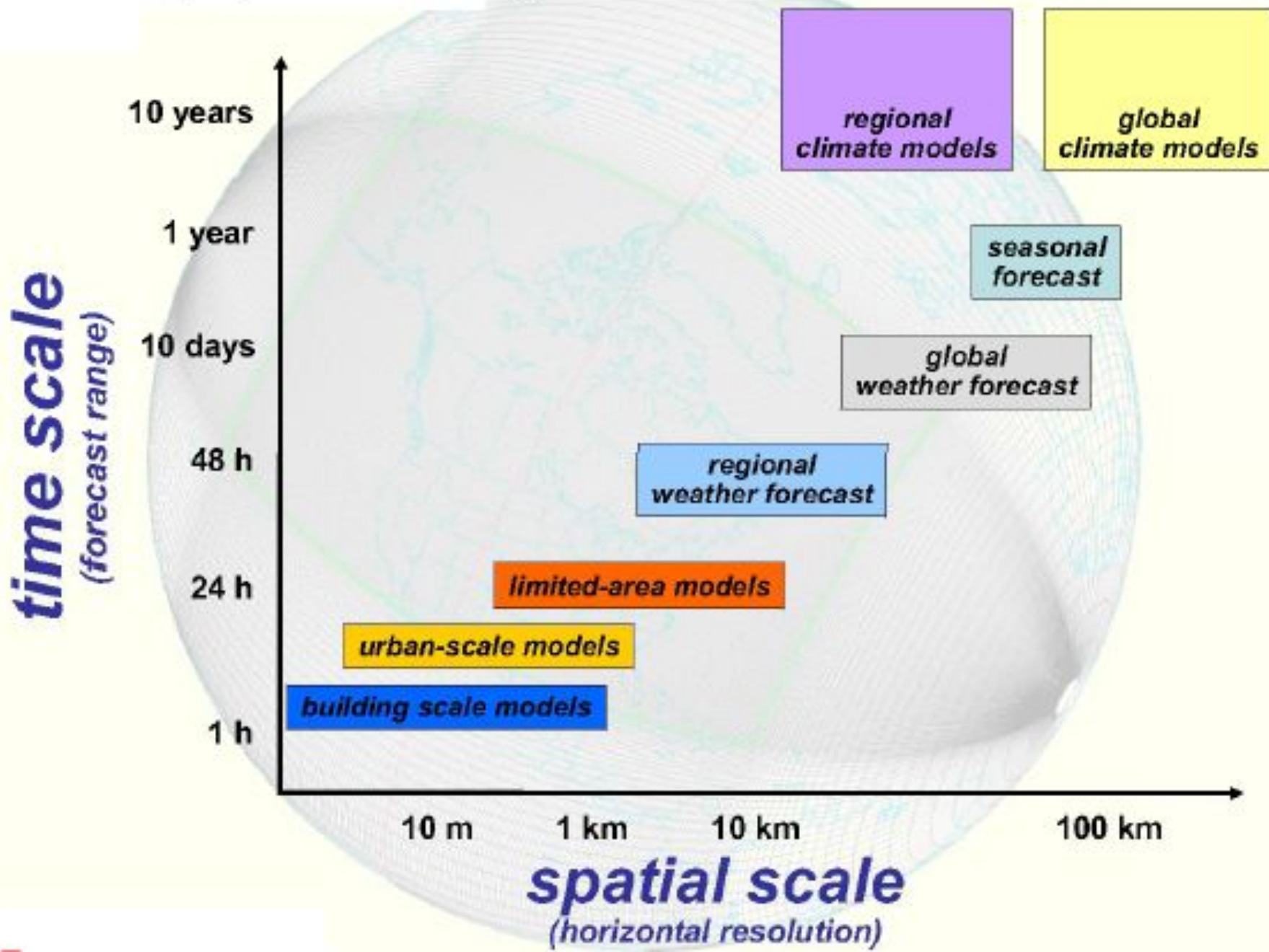
<http://www.ec.gc.ca/meteo-weather/>



AGCM1	<u>The first generation atmospheric general circulation model.</u>
AGCM2	<u>The second generation atmospheric general circulation model.</u>
AGCM3	<u>The third generation atmospheric general circulation model.</u>
AGCM4/CanAM4	<u>The fourth generation and current atmospheric general circulation model.</u>
CGCM1	<u>The first generation coupled global climate model.</u>
CGCM2	<u>The second generation coupled global climate model.</u>
CGCM3	<u>The third generation coupled global climate model.</u>
CGCM4/CanCM4	<u>The fourth generation and current coupled global climate model.</u>

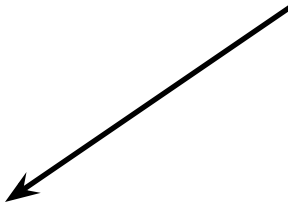
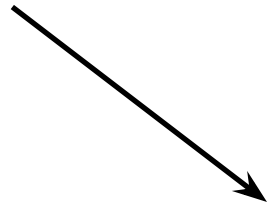
**(Аналоги нашей климатической модели земной системы INMCM4)**

# Modeling Systems and Applications at Environment Canada

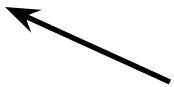


Recherche en Prévision Numérique

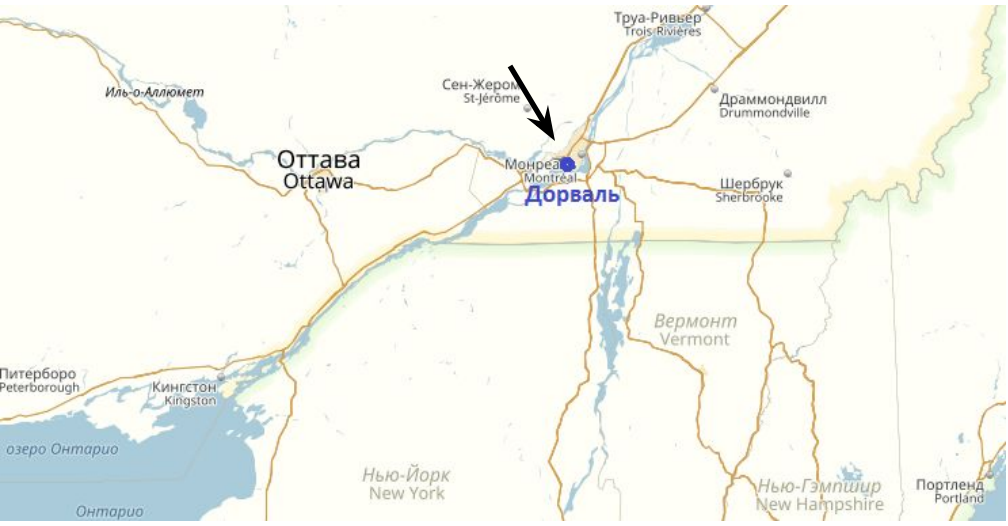
Meteorological Research Branch (MRB)



**Global Environmental Multiscale Model (GEM)**



Canadian Meteorological Centre (CMC)



Находится в Дорвале (Квебек, Канада)

# Развитие численного моделирования в Канаде

## Предшественники

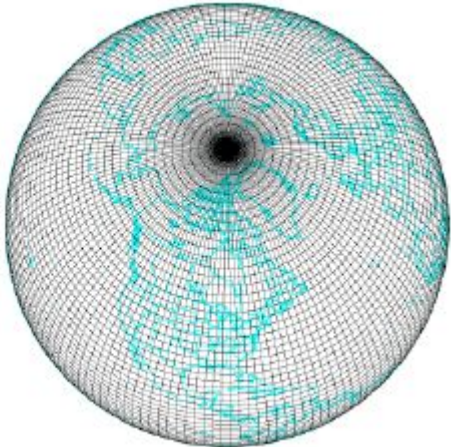
- **GEM**  
Tanguay, M., A, Robert, R. Laprise, 1990: **A Semi-implicit Semi-Lagrangian Fully Compressible Regional Forecast Model**
  - ✓ Полулагранжевая модель
  - ✓ Высота в качестве вертикальной координаты
  - ✓ Модель «пленочной» атмосферы
  - ✓ Ограниченная территория
- Benoit *et al.*, 1997: ***The Canadian MC2: A Semi-Lagrangian, Semi-Implicit Wideband Atmospheric Model Suited for Finescale Process Studies and Simulation – начало численных экспериментов***

# Global Environmental Multiscale Model (GEM)

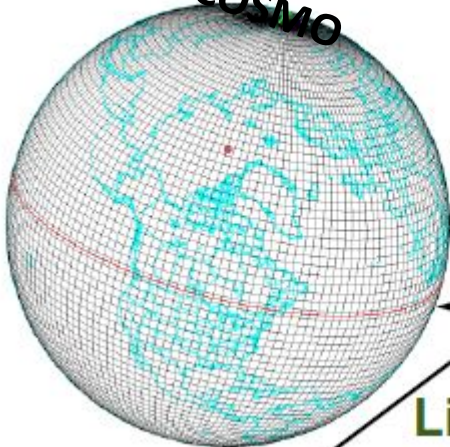
Cemk



Uniform



Kar B  
COSMO

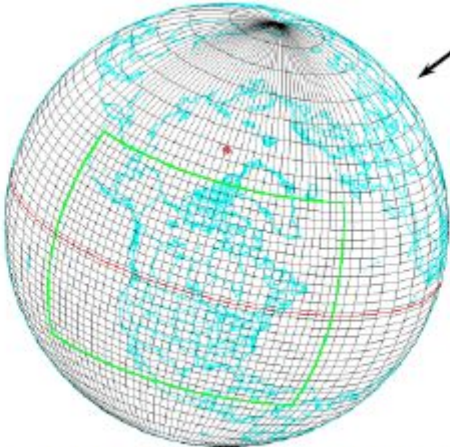


UQAM

Rotated

Limited Area

Variable



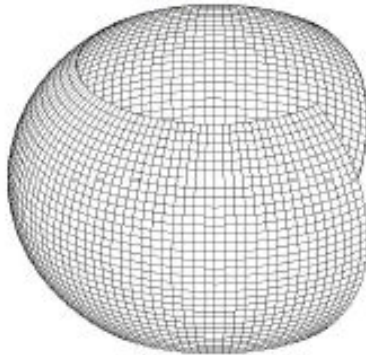
# Еще одна сетка



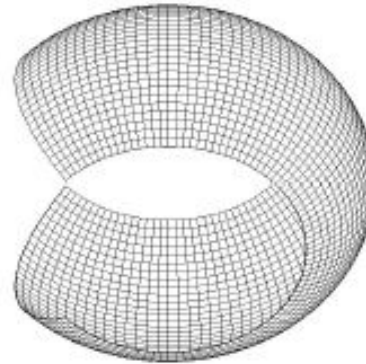
## Composite Grid (Yin-Yang)

- Covering the sphere with two overlapping latitude-longitude patches  $(-\frac{3\pi}{4} \leq \lambda \leq \frac{3\pi}{4}; \frac{\pi}{4} \leq \theta \leq \frac{\pi}{4})$

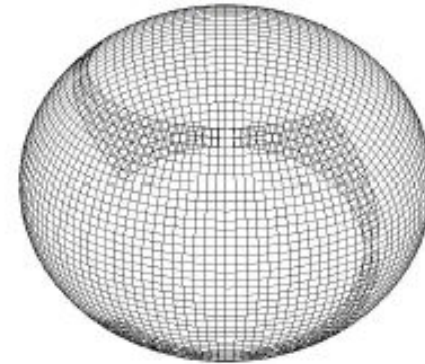
Yang Panel



Yin Panel



Yin-Yang composition





# Вертикальное разрешение

k	hyb	z (m)	$\Delta z$ (m)
...			
32	3.7321E-01	6849.	450.
33	3.9816E-01	6399.	437.
34	4.2401E-01	5962.	426.
35	4.5079E-01	5536.	415.
36	4.7853E-01	5122.	405.
37	5.0722E-01	4717.	394.
38	5.3679E-01	4323.	384.
39	5.6725E-01	3940.	374.
40	5.9861E-01	3566.	365.
41	6.3089E-01	3201.	354.
42	6.6390E-01	2846.	340.
43	6.9721E-01	2506.	309.
44	7.2888E-01	2198.	281.
45	7.5897E-01	1916.	254.
46	7.8721E-01	1663.	231.
47	8.1378E-01	1432.	209.
48	8.3864E-01	1223.	190.
49	8.6186E-01	1033.	172.
50	8.8342E-01	861.	155.
51	9.0341E-01	706.	142.
52	9.2202E-01	564.	128.
53	9.3912E-01	436.	116.
54	9.5491E-01	321.	105.
55	9.6940E-01	216.	95.
56	9.8278E-01	121.	81.
57	9.9425E-01	40.	

8

57 levels (current)

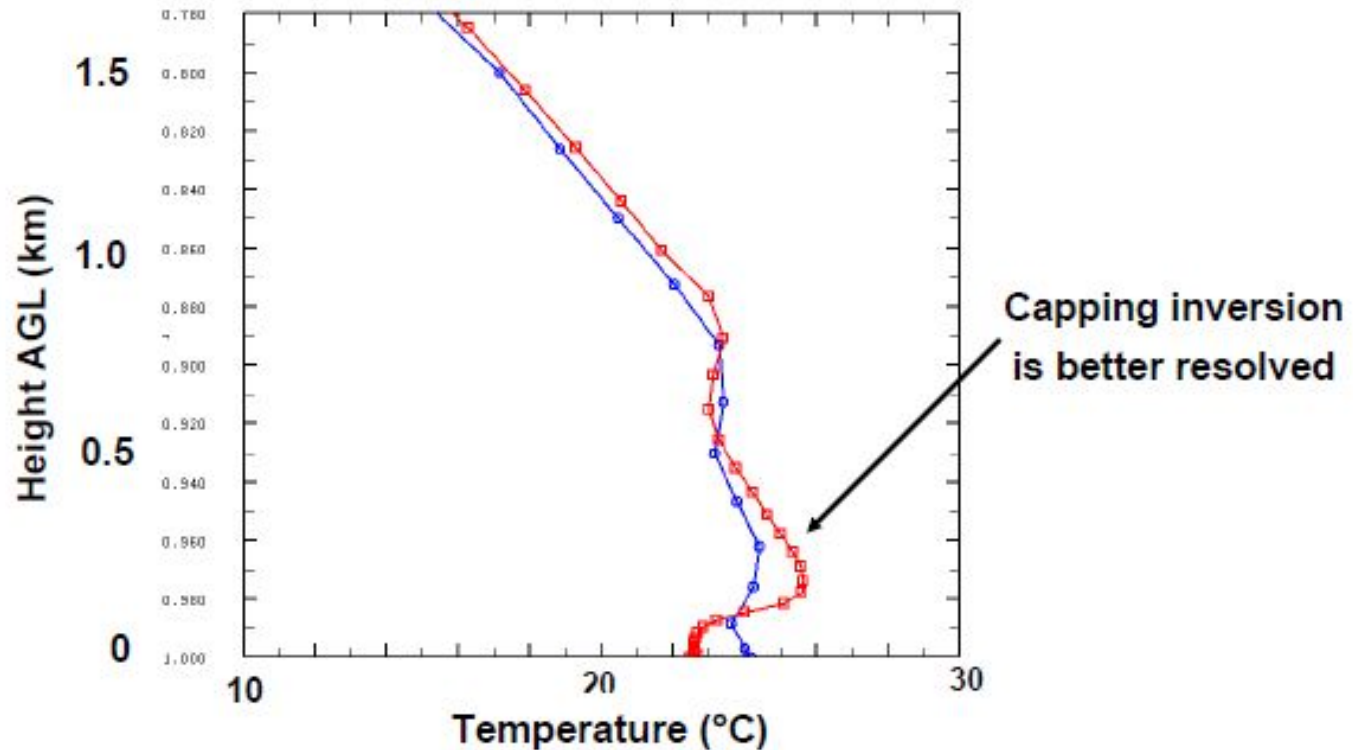
k	hyb	z (m)	$\Delta z$ (m)
...			
47	8.5323E-01	1103.	130.
48	8.6939E-01	973.	117.
49	8.8416E-01	855.	105.
50	8.9762E-01	751.	94.
51	9.0983E-01	657.	84.
52	9.2086E-01	573.	75.
53	9.3080E-01	498.	66.
54	9.3972E-01	432.	59.
55	9.4770E-01	373.	52.
56	9.5481E-01	321.	46.
57	9.6112E-01	276.	40.
58	9.6672E-01	235.	35.
59	9.7166E-01	200.	31.
60	9.7600E-01	169.	27.
61	9.7982E-01	142.	24.
62	9.8316E-01	118.	21.
63	9.8607E-01	97.	18.
64	9.8860E-01	80.	15.
65	9.9080E-01	64.	13.
66	9.9270E-01	51.	11.
67	9.9434E-01	39.	10.
68	9.9575E-01	30.	8.
69	9.9696E-01	21.	7.
70	9.9799E-01	14.	6.
71	9.9888E-01	8.	5.
72	9.9963E-01	3.	

25

72 levels (testing)

# Эксперименты с вертикальным разрешением

Example of Model Soundings  
(pre-storm environment)



57 levels (current)

72 levels (testing)

# Система уравнений

Задание вертикальных координат

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

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

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

$$s = \ln \pi_s - \zeta_s$$

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

$$\phi_* = -RT_*(\zeta - \zeta_s)$$

Граничные

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

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

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

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

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

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

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

where  $\zeta = \ln p - Bs$  is a log-hydrostatic-pressure type coordinate with  $p$  the pressure,  $B = [(\zeta - \zeta_{\text{top}})/(\zeta_{\text{surf}} - \zeta_{\text{top}})]$  the metric term,  $s = \ln p_{\text{surf}} - \zeta_{\text{surf}}$  the mass variable that depends only on the horizontal,  $T$  the temperature,  $\phi = \phi^* + \phi'$  the geopotential,  $\phi^*(\zeta) = -RT^*(\zeta - \zeta_{\text{surf}})$ ,  $T^* = \text{const}$  and  $\mathbf{V}_h$  the horizontal wind.  $R$  is the gas constant and  $\kappa = R/c_p$ , where  $c_p$  is the specific heat at constant pressure. The coordinate system permits a switch-controlled choice between the hydrostatic primitive equations and non-hydrostatic Euler equations. See Girard *et al.* (2010) for additional details.

→ Уравнение движения

→ Негидростатика  
Уравнение притока тепла

→ Уравнение неразрывности

→ Уравнение для геопотенциала

Далее идет дискретизация (пространственная и временная)



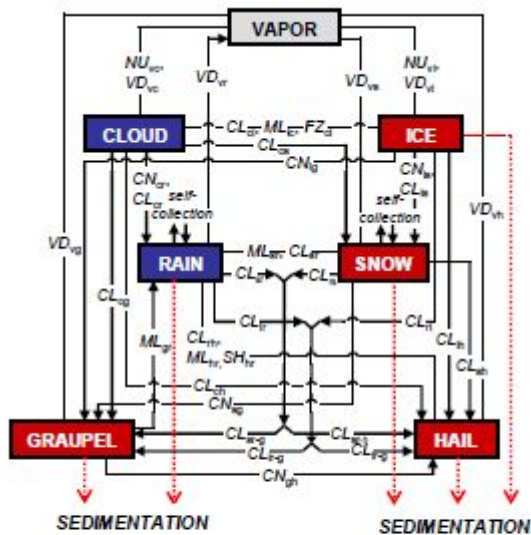
Конечно-разностный метод решения системы

# Параметризац

ИИ

- Негидростатическая модель (уровни до 10 гПа). Количество точек сетки в области интегрирования 560 x 494 (2005)
- Рельеф и растительность задается на основе глобальных баз данных с высоким разрешением (Геологическая служба США)
- 4 типа поверхностей: земная поверхность и разного рода растительностью (Interactions between Soil-Biosphere-Atmosphere, открытая вода, морской лед, ледники и деловые щиты)
- Турбулентность в граничном слое считается через коэффициенты турбулентности
- Используется схема микроконденсации (Kong and Yau, 1997)
- Учет гравитационных волн
- A shallow convective scheme (Kuo-Transient), to represent overshooting cumulus cloud activity (see Bélair et al., 2005)

• И др.



Six hydrometeor categories:

2 liquid: *cloud, rain*

4 frozen: *ice, snow, graupel, hail*

For each category  $x = c, r, i, s, g, h$ :

$$N_x(D) = N_{0x} D^{\alpha_x} e^{-\lambda_x D}$$

Prognostic variables

$q_x, N_x$  (12)

**Current MY2 scheme:**



**SNOW**

$$\rho_s = f(D_s)$$

$$V = a_s D^{bs}$$



**GRAUPEL**

$$\rho_g = 400 \text{ kg m}^{-3}$$

$$V = a_g D^{bg}$$



**HAIL**

$$\rho_h = 900 \text{ kg m}^{-3}$$

$$V = a_h D^{bh}$$

**Modified MY2 scheme:**



**SNOW**

$$\rho_s = f(D_s)$$

$$V = a_s D^{bs}$$



**GRAUPEL**

$\rho_g$  is predicted

$$V = a_g(\rho_g) D^{bg(\rho_g)}$$



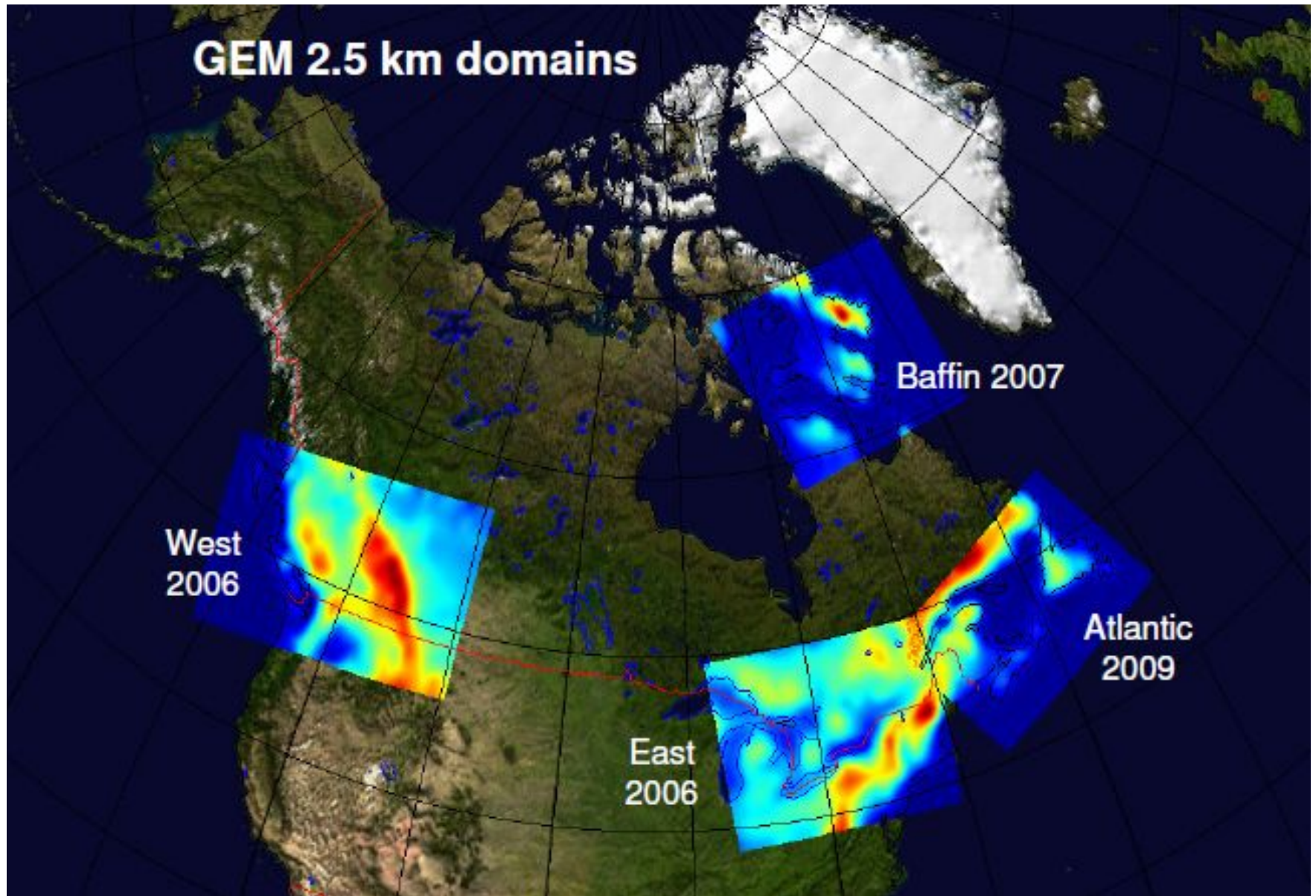
**HAIL**

$$\rho_h = 900 \text{ kg m}^{-3}$$

$$V = a_h D^{bh}$$

**SMOOTHER TRANSITION**  
between categories

# Области

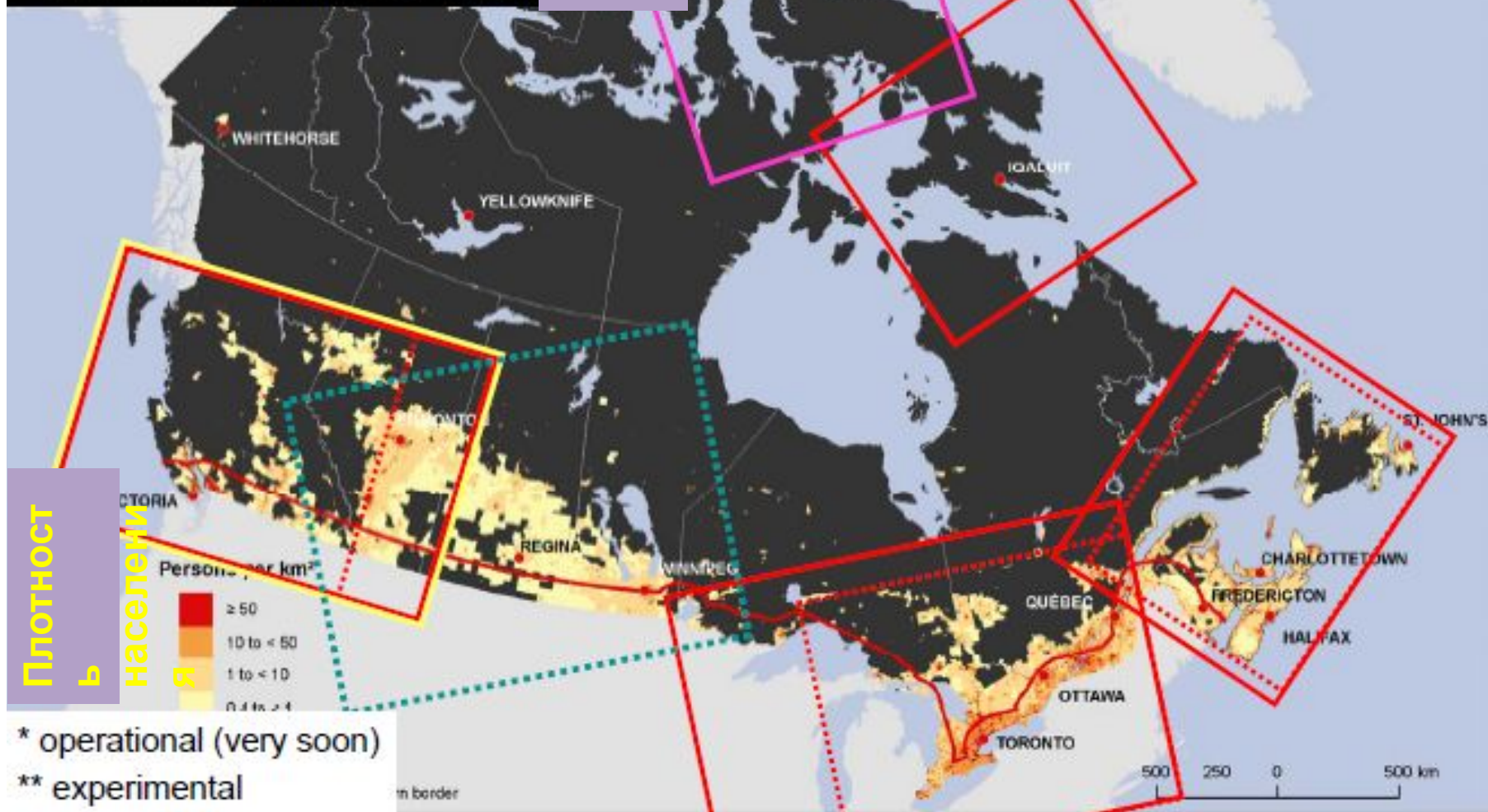


(на август 2012)

- 4 “full-time” grids
- 1 “seasonal” grid
- $\Delta z = 2.5 \text{ km}$
- west domain\* is 2 x 42 h
- other domains\*\* are 1 x 24-h
- downscaled from GEM-10 km

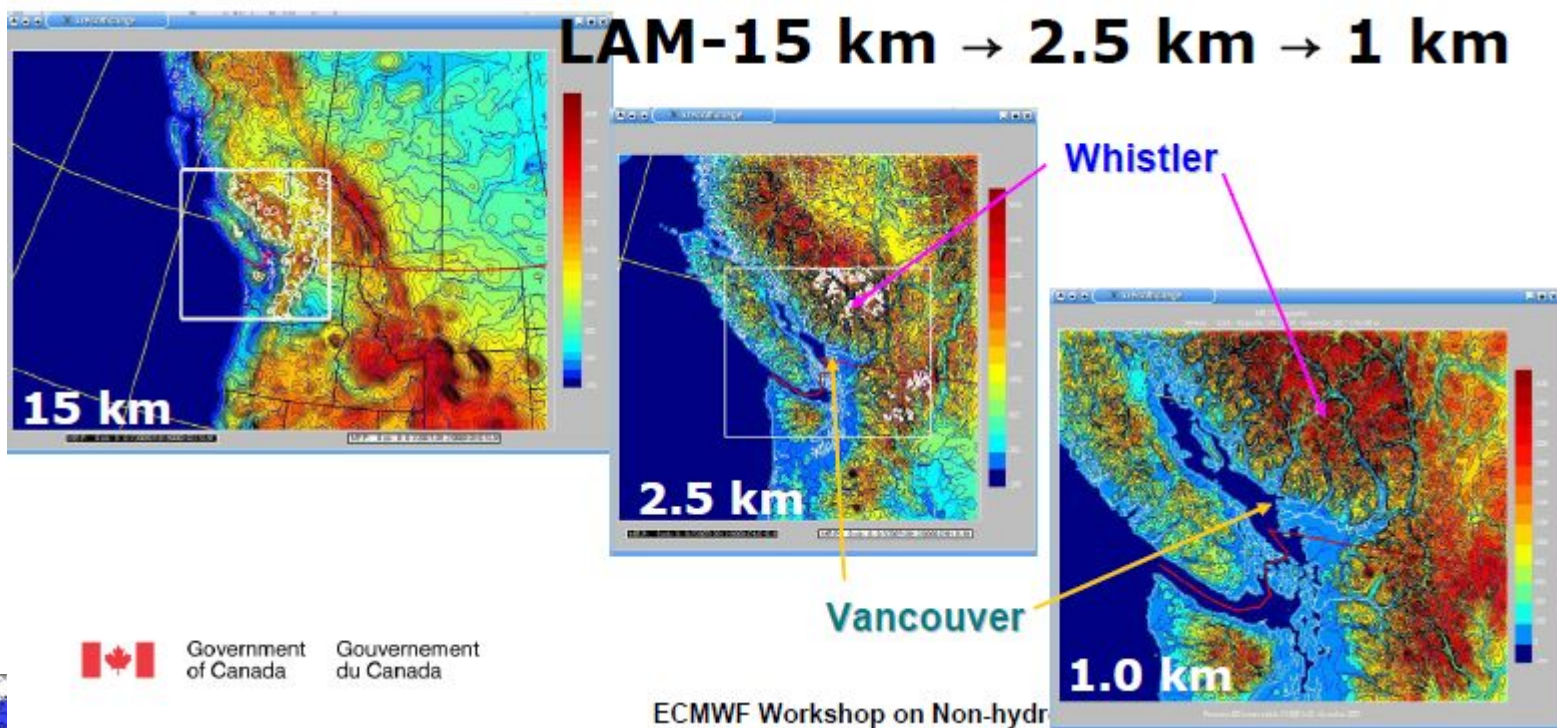
15 (?)

Population density, 2006  
by Dissemination Area (DA)



В 2016 году вся территория Канады должна быть переведена на 2.5-

LAM-15 km → 2.5 km → 1 km



Передача граничных условий от моделей с  
грубым разрешением моделям с более  
высоким разрешением – как в COSMO  
Откуда берутся изначальные граничные  
условия (?)

Области интегрирования GEM:

континентальный домен (синий, шаг 15 км),  
региональный домен (салатовый, шаг 15 км)

+



# Эксперименты с увеличением разрешения до

**1 км:**

- 2008 г. - 1-й эксперимент в провинции Альберта (видимо, пробный)
- 2010 – зимняя олимпиада/паралимпиада в Ванкувере
- 2014 – зимняя олимпиада/паралимпиада в Сочи
- 2015 – панамериканские игры в Торонто

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

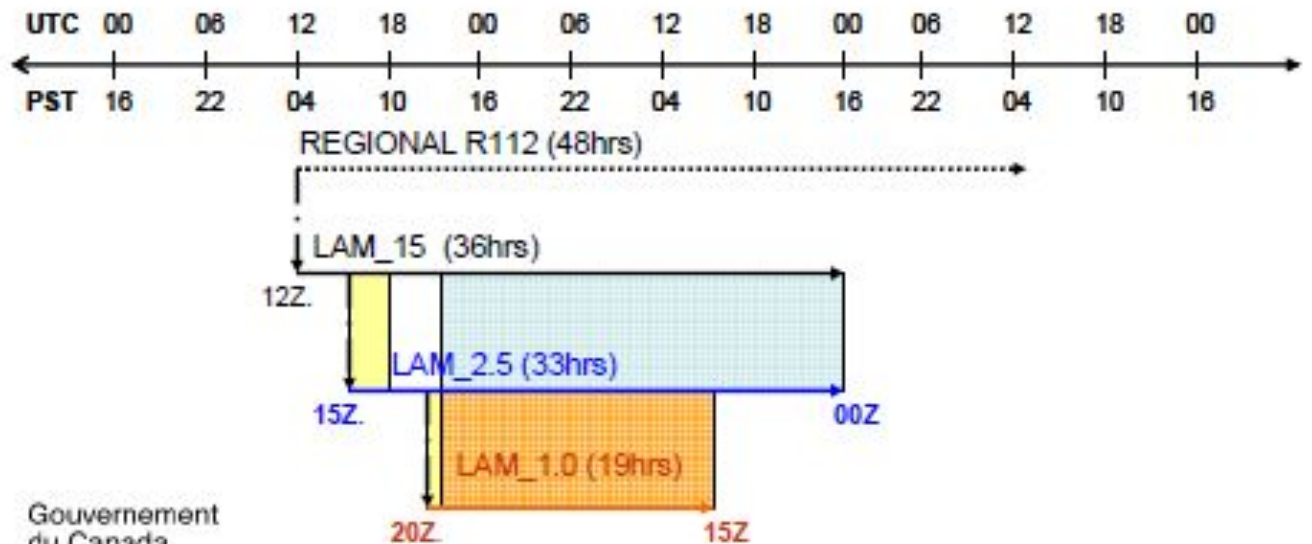
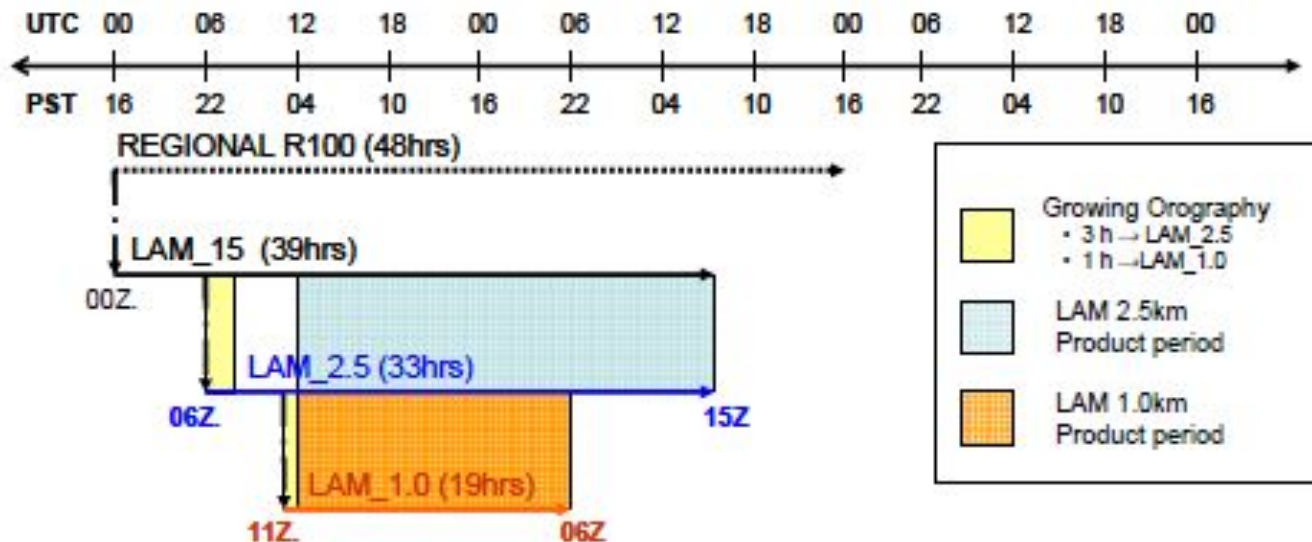


Government of Canada

Gouvernement du Canada

Canada

# Заблаговременность



Government of Canada

Gouvernement du Canada



# Источники/Литература

- <http://www.ec.gc.ca/meteo-weather/>
- [https://en.wikipedia.org/wiki/Global\\_Environmental\\_Multiscale\\_Model](https://en.wikipedia.org/wiki/Global_Environmental_Multiscale_Model)
- [https://www.cmascenter.org/conference/2013/abstracts/zhang\\_sensitivity\\_simulated\\_2013.pdf](https://www.cmascenter.org/conference/2013/abstracts/zhang_sensitivity_simulated_2013.pdf)
- [http://www.yorku.ca/pat/research/dsills/papers/MP11/Erfani\\_et\\_al\\_2005.pdf](http://www.yorku.ca/pat/research/dsills/papers/MP11/Erfani_et_al_2005.pdf)
- [https://www.eol.ucar.edu/projects/ceop/dm/model/cmc/E\\_GEM\\_t10.pdf](https://www.eol.ucar.edu/projects/ceop/dm/model/cmc/E_GEM_t10.pdf)
- <http://www.newton.ac.uk/files/seminar/20120824153016001-153260.pdf>
- [http://srnwp.met.hu/workshops/Offenbach\\_2013/22Milbrandt-20130514-Offenbach.pdf](http://srnwp.met.hu/workshops/Offenbach_2013/22Milbrandt-20130514-Offenbach.pdf)
- <http://www.ecmwf.int/sites/default/files/elibrary/2010/15129-workshop-non-hydrostatic-modelling-global-environmental-multiscale-gem-model.pdf>

A close-up photograph of several autumn leaves scattered on a dark, textured wooden surface. The leaves display a variety of colors, including bright yellow, vibrant orange, deep red, and some green, indicating the transition of seasons. The lighting is bright, highlighting the intricate vein patterns on the leaves. The text "Спасибо за внимание!" is overlaid in a light blue, sans-serif font across the center of the image.

*Спасибо за внимание!*