The Canadian RCM : general overview of the model and specific features of the Narccap simulations

Sébastien Biner and Daniel Caya with the contribution
of the climate simulation team at Ouranos

The Canadian RCM (CRCM) history

- Developped at the University of Québec in Montréal during the 1991-2001 period
  - Started as the Ph.D. of Daniel Caya
  - Research assistants and students were added
  - Different versions were released
- Developped, maintained and used by the Ouranos Consortium since 2001

CRCM v4.2.0 (version used for the Narccap simulations)

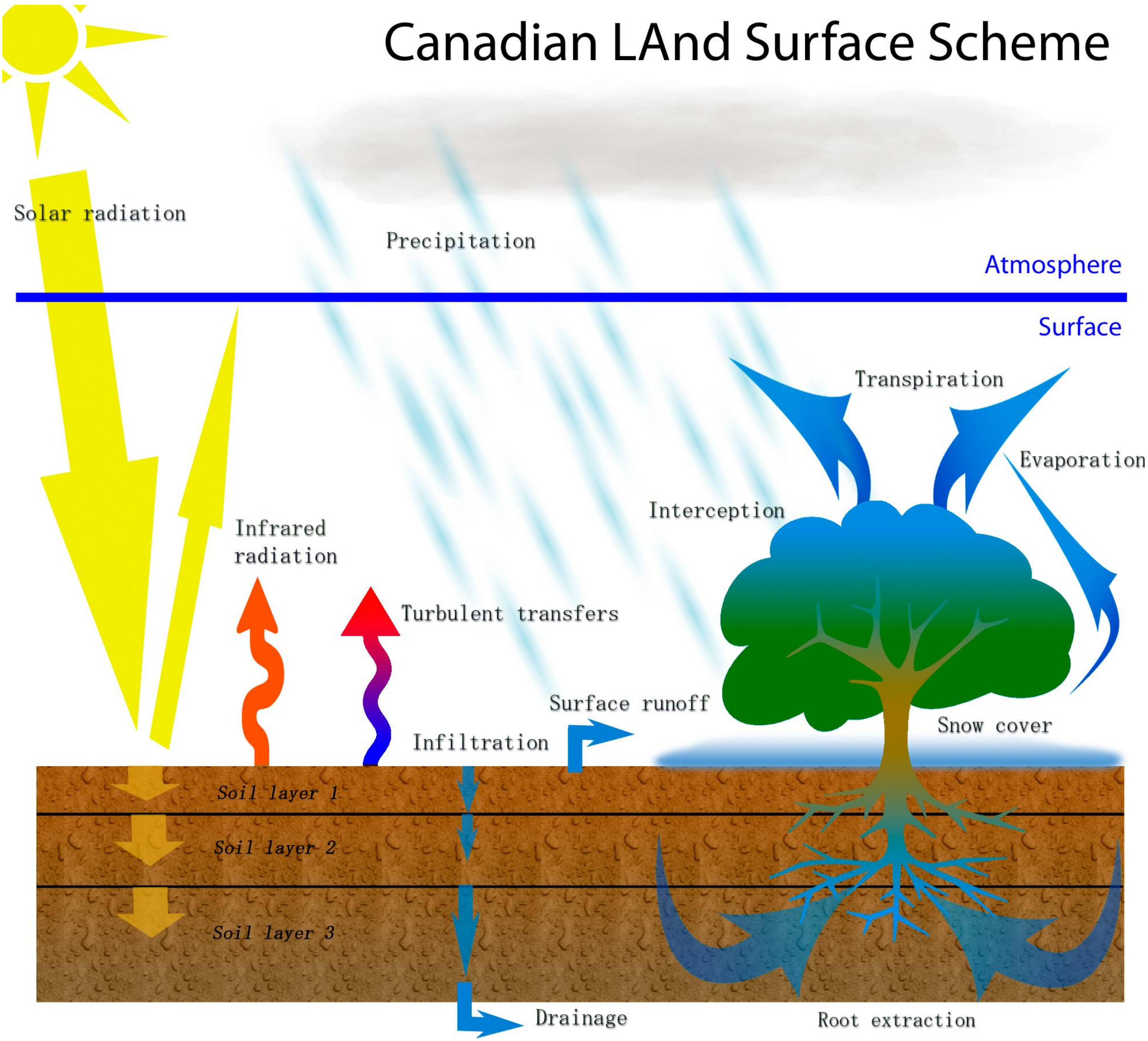
Dynamics
semi-implicit semi-Lagrangian algorithm
Arakawa-C grid on polar stereographic projection
Gal-Chen scaled-height vertical coordinates
Davies nesting on horizontal wind
large-scale nudging (aka spectral nudging)

Physics	
Surface scheme	CLASS 2.7 (3 lyrs) soil: Wilson & Henderson-Sellers 1° veg: GLC2000 1km > 1°
Convection and large scale condensation	Bechtold-Kain-Fritsch sursaturation removal
Radiation	SW Fouquart & Bonnel LW Morcrette
Clouds	diagnostically based on relative humidity excess & conditional stability

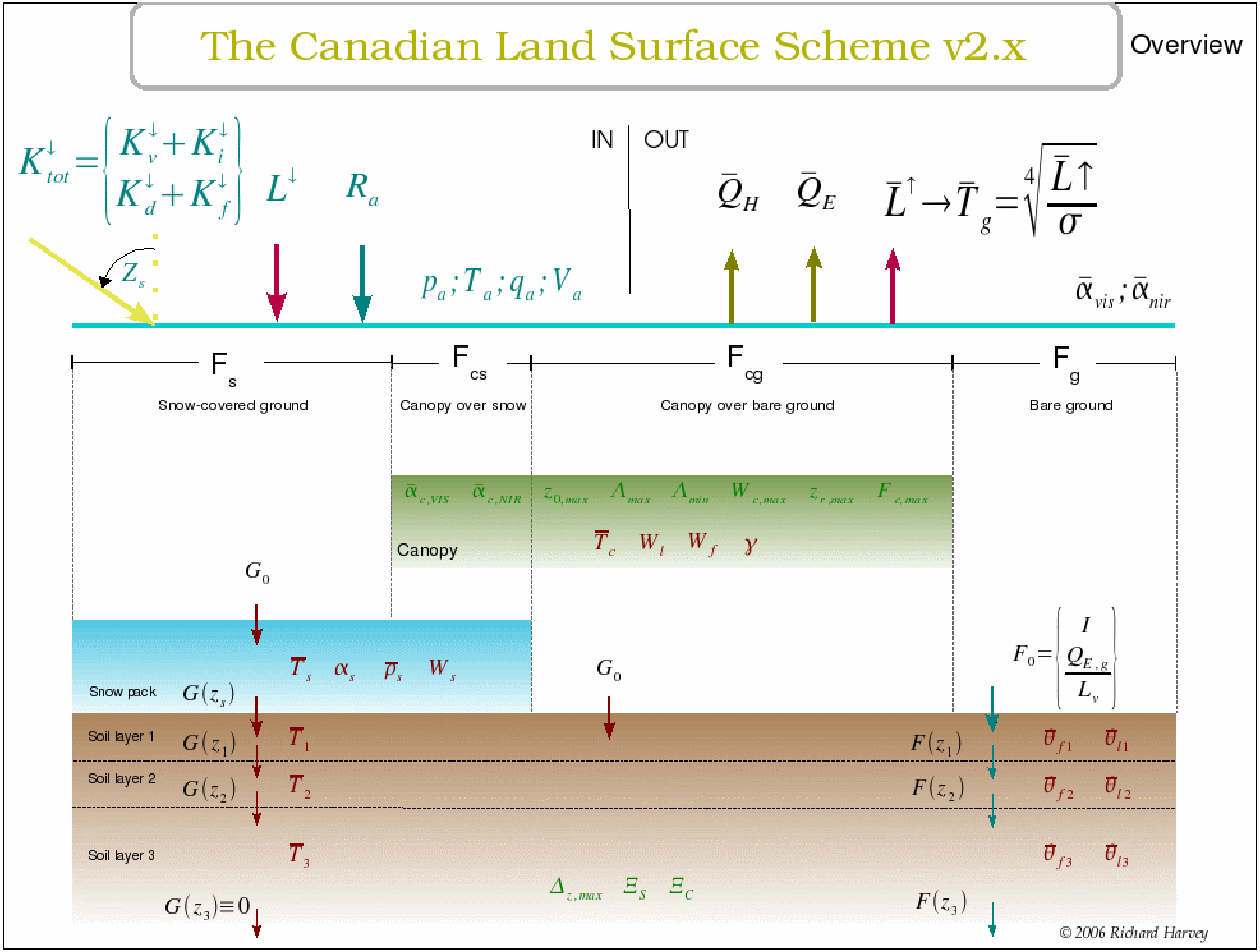
Key features

- CLASS surface scheme
- Large-scale nudging

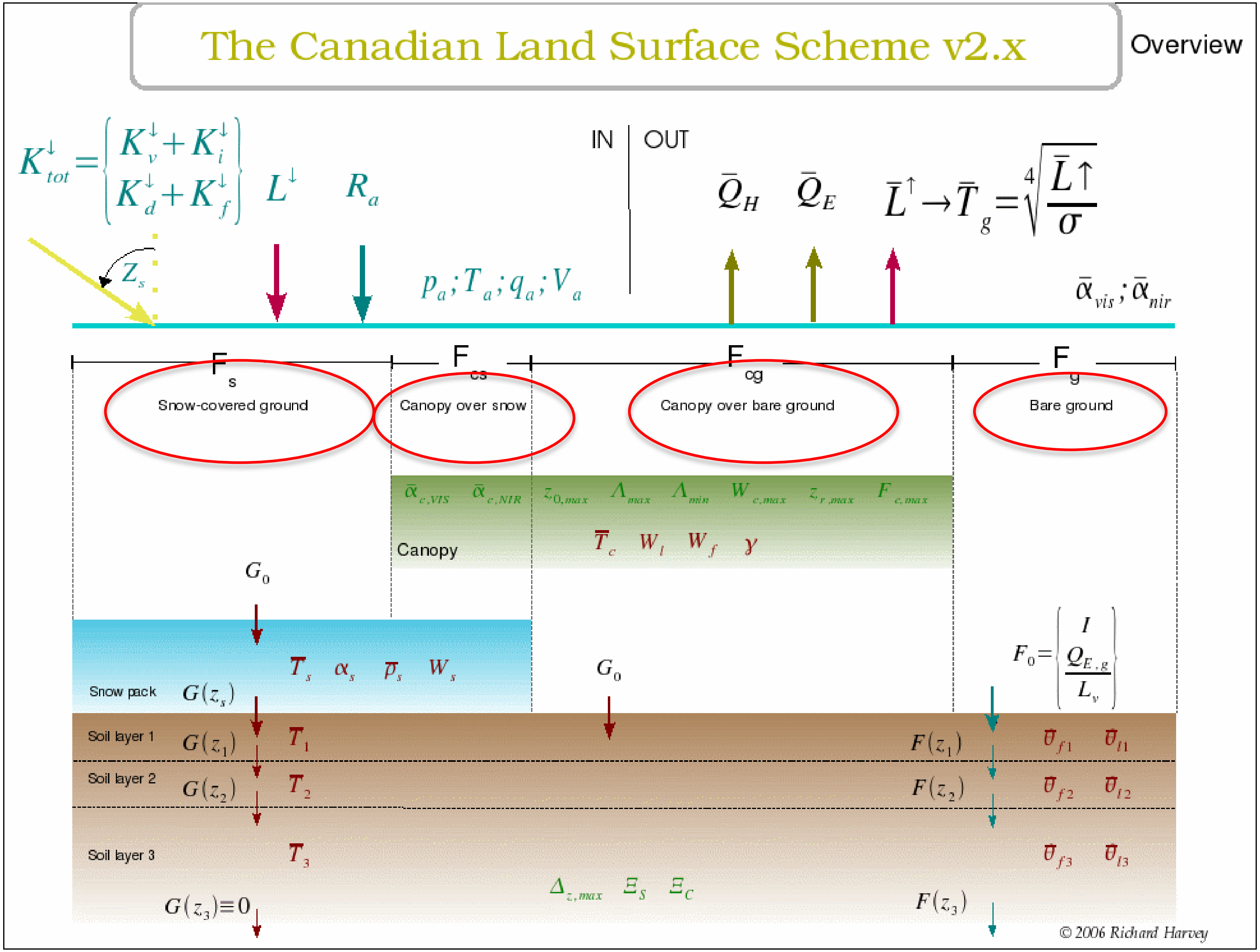
Canadian LAnd Surface Scheme



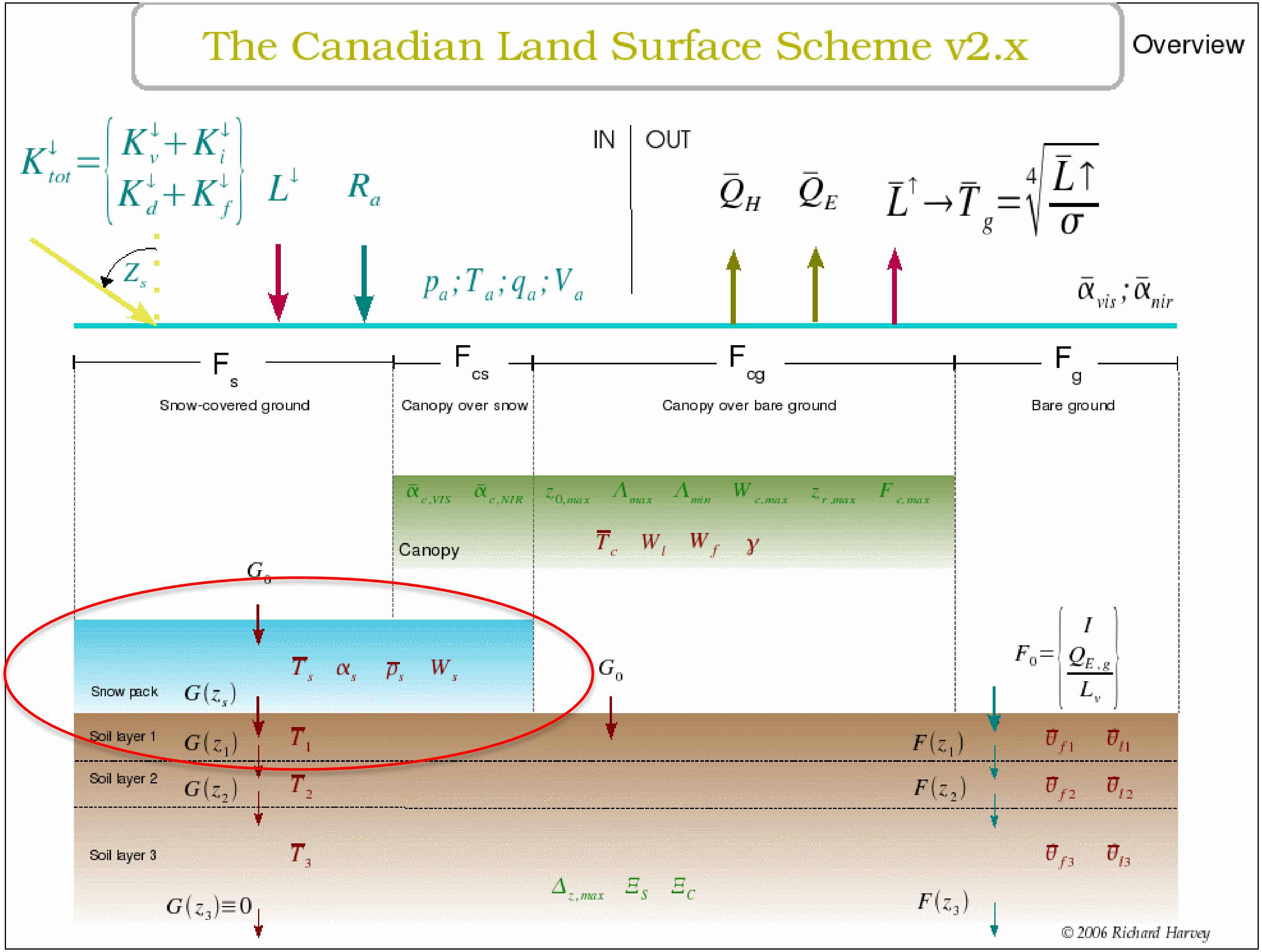
2nd generation surface scheme with 3 soil layers



Each cell is divided in 4 sub-regions



Sowpack treated as explicit 4th layer

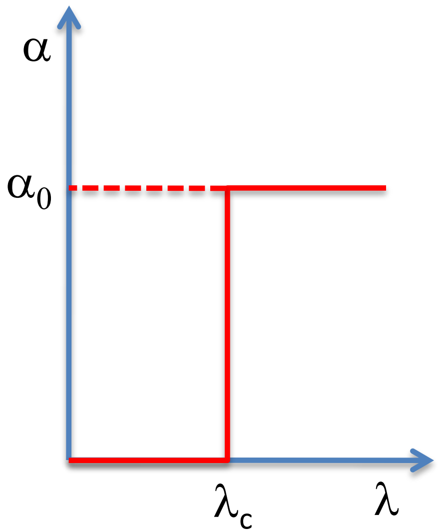


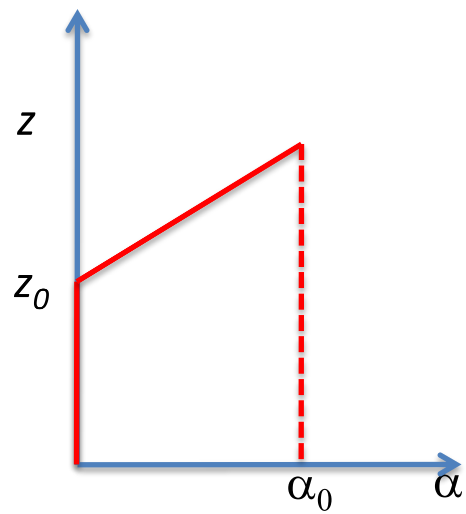
Large-scale Nudging.

Modification of a prognostic variables *X* with the following equation :

$$X^{+}_{RCM} = (1-\alpha)X_{RCM} + \alpha X_{LBC}$$

Where X_{RCM} is the value of *X* from the RCM, X_{LBC} is the value of *X* from the LBC and α is a function of the length scale λ and the altitude *z*.





Only the fields higher than altitude z_0 and with scale larger than λ_c are affected by the large-scale nudging.

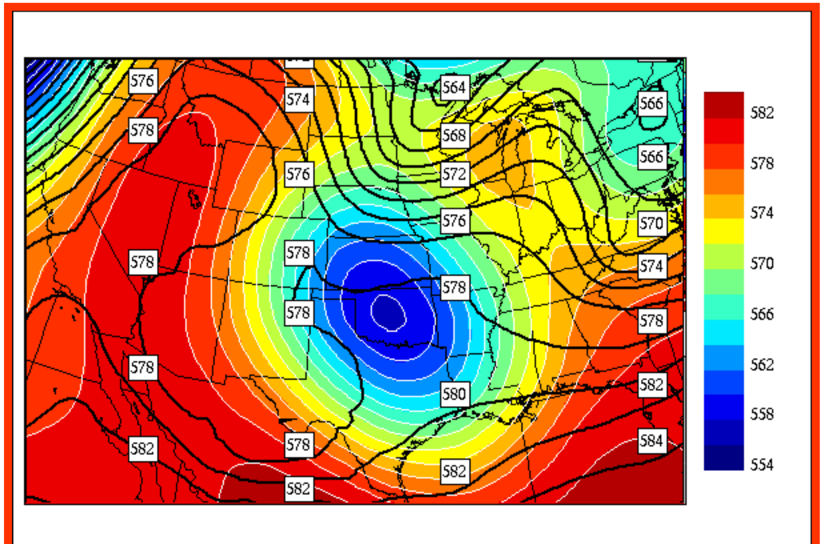
Tyically, λ_c=1400km, z_0=500 hPa and *X*=horizontal wind
α_0=0.05 (I.e. e folding time of 48h)

Large-scale Nudging.

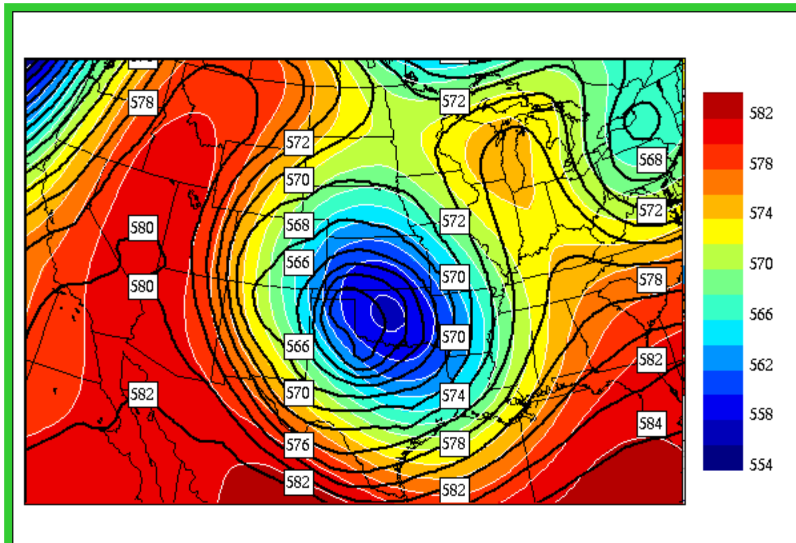
Motivations to use LSN

•Prevents the development of large discrepencies between the LBC and the RCM

Without LSN



With LSN



CRCM(blacklines) and NCEP(color) analysis GZ 500 hPa [dam] on 22 May 1988 at 12Z (i.e. 180 h of simulation)

Large-scale Nudging.

Motivations to use LSN

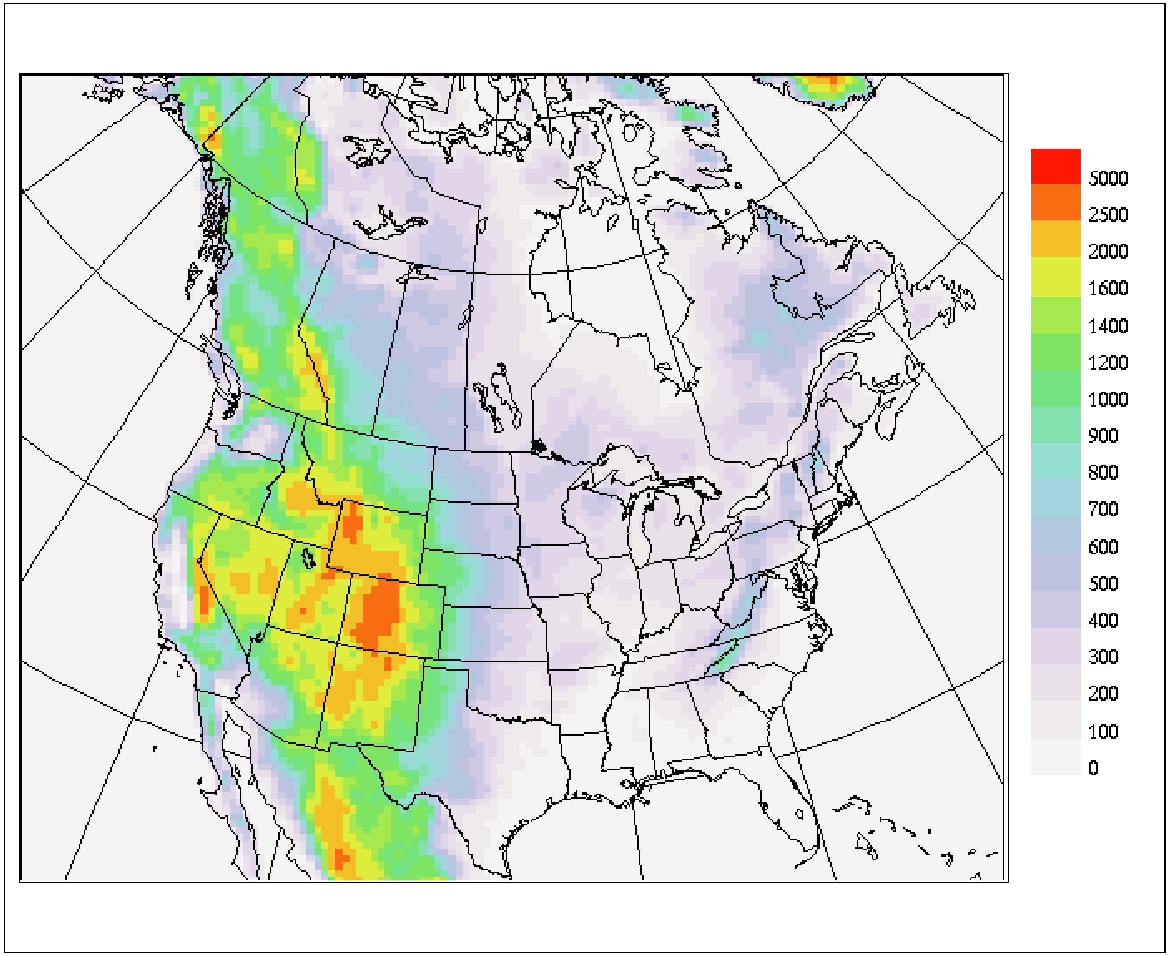
•Prevents the development of large discrepencies between the LBC and the RCM

•Reduction of the mismatch between the RCM and the LBC at the outflow boundary

•Reduction of the sensitivity of a simulation to the domaine size and configuration

•Side effects seem minimal up to now(*c.f.* Alexandru *et al 2009,* MWR)

Set-up for the Narccap simulations



- CRCM version 4.2.0
- 160x135 computation grid
- 10 points Davies nudging on the perimeter
- 140x115 diagnostic grid (grid of the NetCDF files)
- Polar stereographic grid with 50 km resolution @ 60deg. N
- 900s time-step

Other specific questions

- Soil initialisation?
- Spin-up length?

Soil initialization

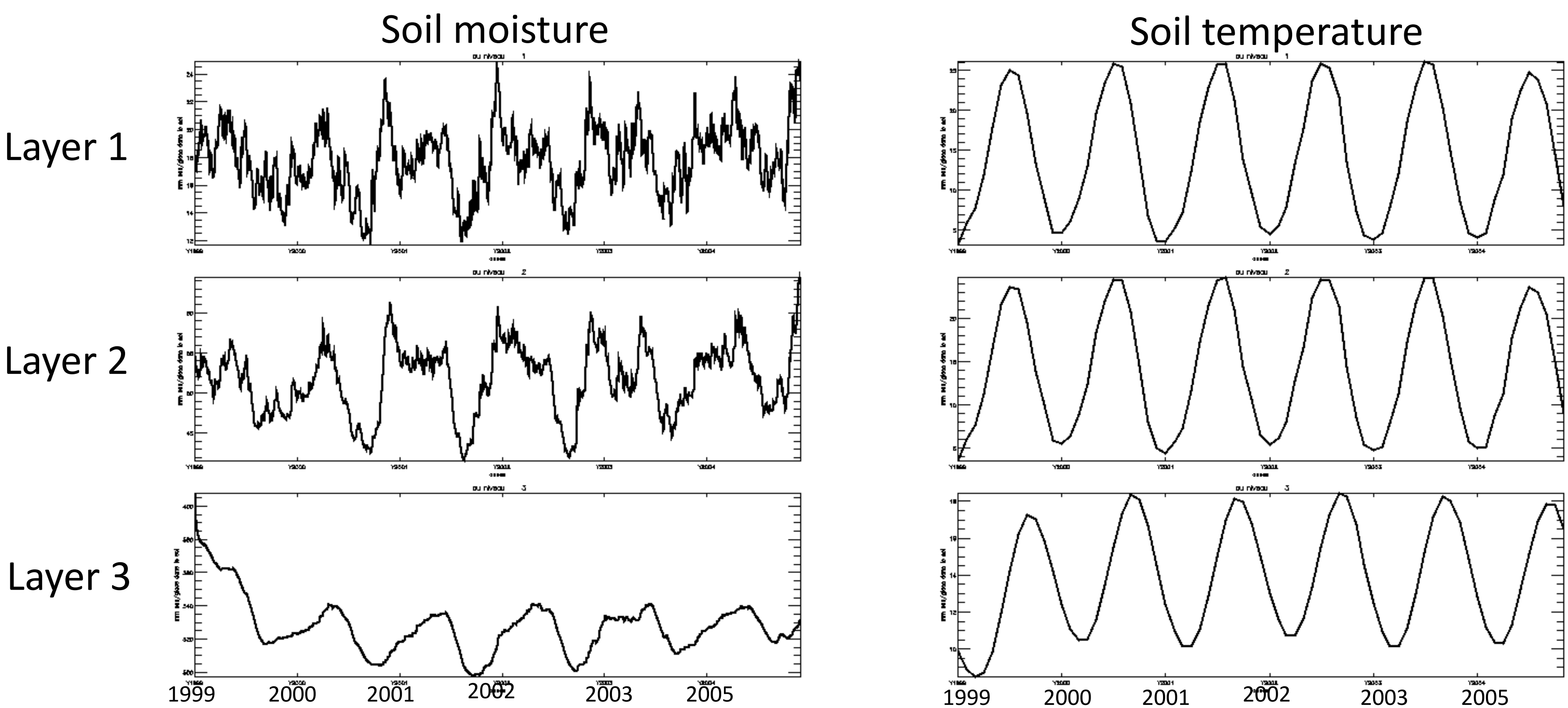
- Some soil variables are prognostic and only need to be initialized (*e.g.* soil moisture, temperature, snow cover, …)
- Some soil variables are prescribed with different update frequencies (*e.g.* SST, Sea ice, Root depth, ozone, …)

Details :

- Deep soil variables obtained from a 3 year simulation of the Canadian GCMiii
- Topography and Ground Cover are taken from 1/6x1/6 deg US Navy datset
- Vegetation fields : GLC2000 dataset interpolated on 1x1 deg grid
- SST and Sea ice :
    - Using reanalysis LBC : lake and ocean use the AMIP2 values
    - Using a given GCM for LBC : ocean uses the GCM values and Lake uses a lake model with flux correction.
- Other variables : initialized by a climatology of the Canadian GCMiii

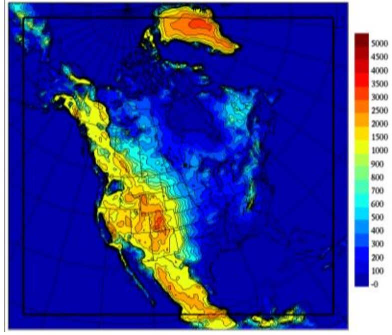
Spin-up period

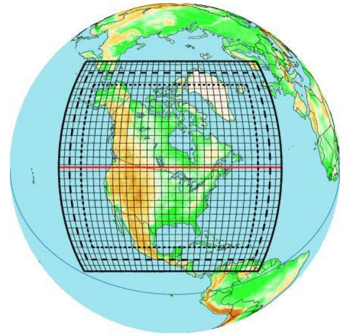
- We use 3 years of spin-up
- Order of time taken for the deepest soil layer to reach steady state.



Time evolution of soil moisture (left) and temperature (right) for the three soil layer over a region covering apporximatively the contiguous USA (courtesy of Dominique Paquin)

Thank you

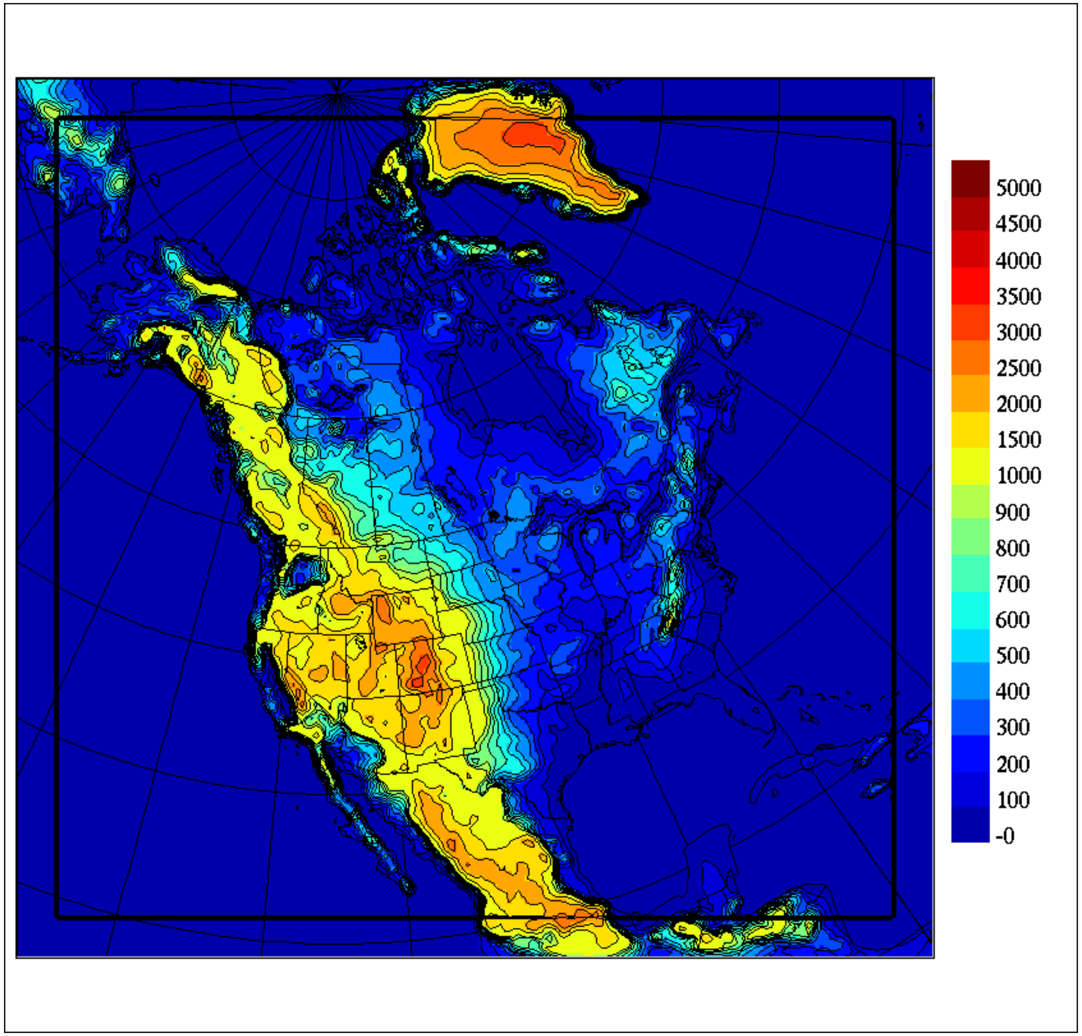




	CRCM4 (v4.2.3) 201x193, 29L, @45km	CRCM5 (v3.3.0) 178x158, 53L, @0.5°	CRCM5C (v3.3.0) 178x158, 53L, @0.5°	CRCM5V (v3.3.0) 180x158, 35L, @0.5°
Surface scheme	CLASS 2.7 (3 lyrs) soil: Wilson & Henderson-Sellers 1° veg: GLC2000 1km > 1°	ISBA (2lyrs) soil: USDA 1km AGRC 10km FAO 1° veg: USGS 1km	CLASS 3.4 (3 lyrs, no mosaïc) organic soil snow (Brown) soil: Wilson & Henderson-Sellers 1° veg: USGS 1km	CLASS 2.7 (3 lyrs) soil: Webb (1993) Veg : Wilson & Henderson-Sellers
Convection and large scale condensation	Bechtold-Kain-Fritsch sursaturation removal	Kain-Fritsch Sundqvist	Kain-Fritsch Sundqvist	Zhang-McFarlane sursaturation removal
Radiation	SW Fouquart & Bonnel LW Morcrette	RRTM correlated-K	RRTM correlated-K	RRTM correlated-K
Clouds	diagnostically based on relative humidity excess & conditional stability	based on relative humidity with vertically varying threshold	based on relative humidity with vertically varying threshold	statistical cloud scheme
Spectral nudging	yes	no	no	no

CRCM_4.2.3

- semi-implicit semi-Lagrangian algorithm
- Arakawa-C grid on polar stereographic projection
- Gal-Chen scaled-height vertical coordinates.
- nesting follows Davies over the sponge zone (9-grid points)
- large-scale nudging (*Biner et al*. 2000) is applied over the entire domain for horizontal wind over 500 hPa
- physical parameterization follows AGCM3, including CLASS_V2.7 surface scheme (3 layers), but moist convection follows Bechtold-Kain-Fritsch
- 201x193 grid points (182 x 174)
- 45 km true at 60 N.
- 29 vertical levels
- Dt 900 sec.
- Pilot ERA40 at 2.5 deg and AMIPII 1 deg



Histoire : 1991 - 2001

Regional Climate Modelling circa 1991

<u>NCAR RegCM: F.Giorgi</u>

- Road-tested MM4

  Δt = 5 min, Δx = 60 km

- Adapted μ-scale Physics
- Ensemble of 5-day sim.

<u>CRCM-β: D. Caya, PhD</u>

- Novel NH-SI-SL Dyn.

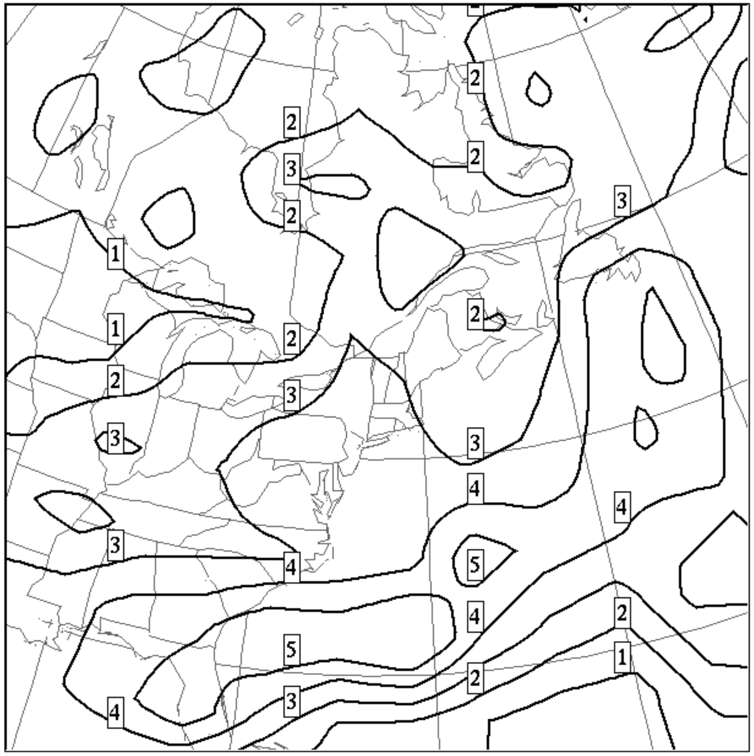
  Δt = 20 min, Δx = 45 km

- Integral GCMii Physics
- 2-month continual sim.

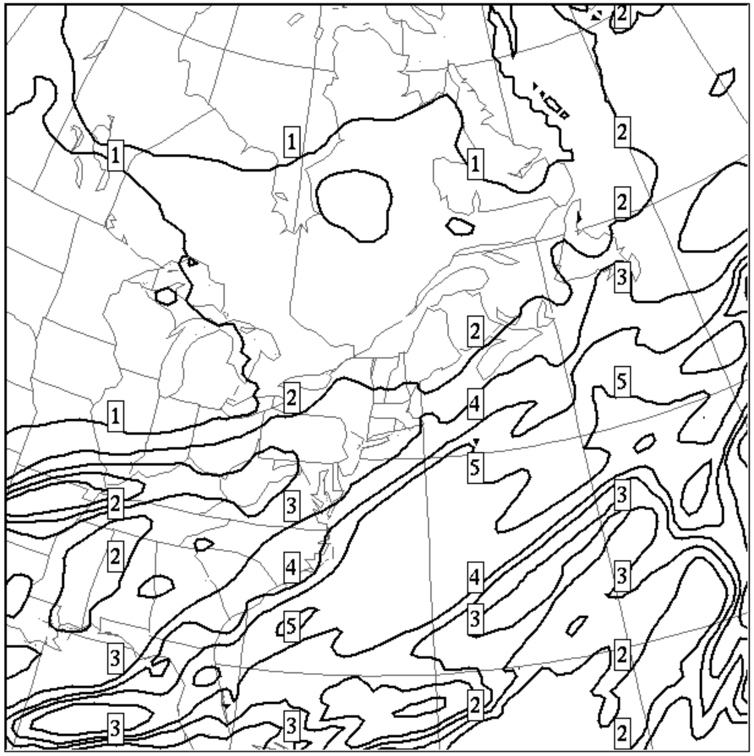
1994

A single January mean precipitation (mm da^{-1})

T32 GCMii



45-km CRCM-β



CRCM-β (Caya and Laprise, 1999 MWR)

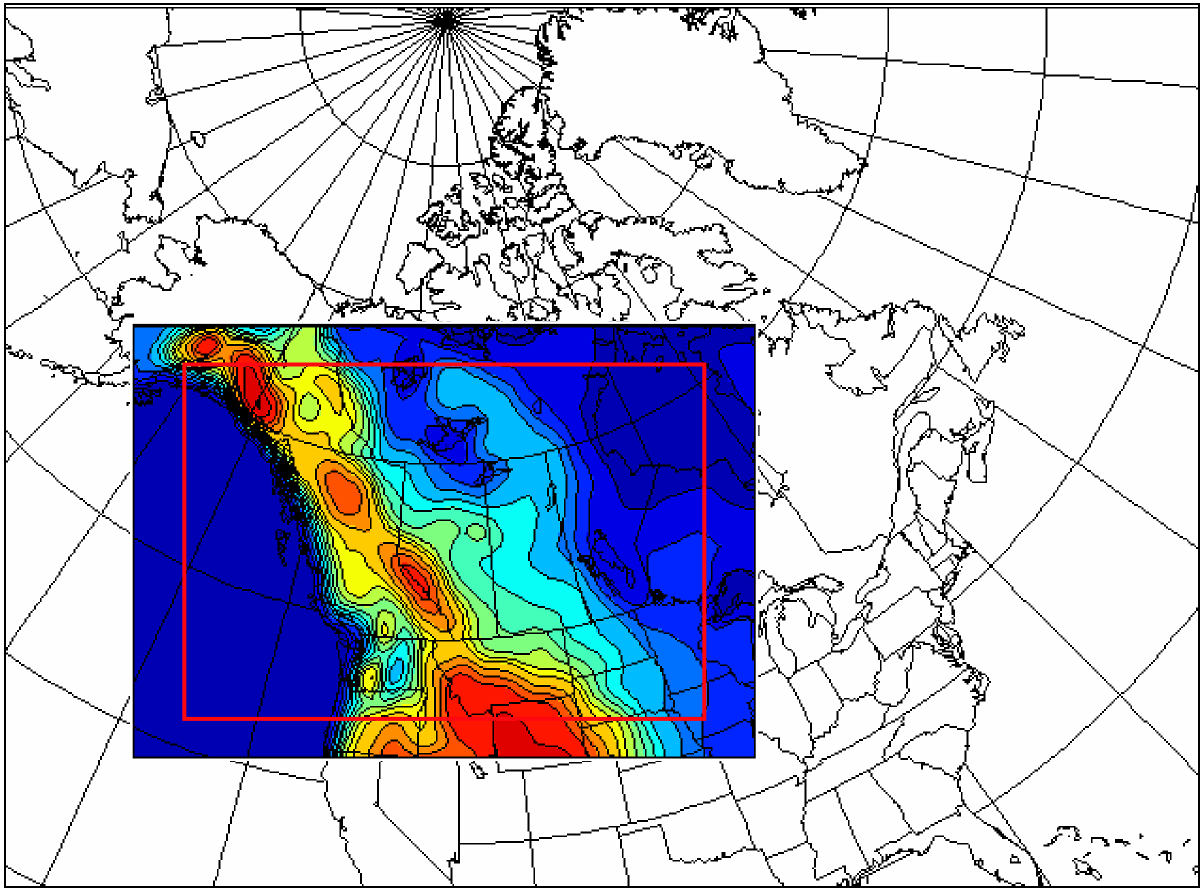
Outcome:

- No penalty for NH with use of SI-SL
- SL acceptable for climate simulations
- GCMii Physics (almost) acceptable at 45 km
- No climate drift in long simulation with nested RCM
- Plausible fine-scale details in RCM simulation

en 1996

CRCM-I (1/3)

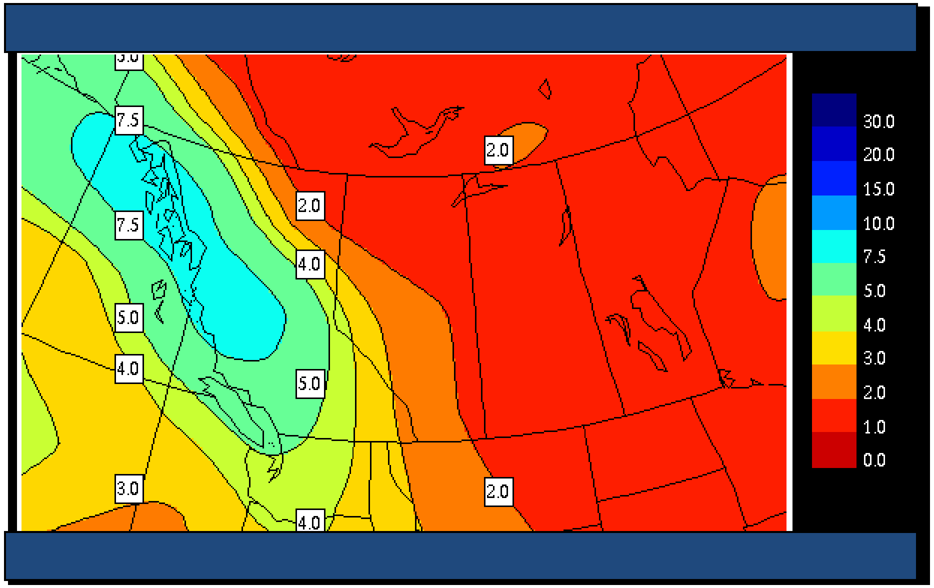
First “Policy” Run



- •101 x 71 @ 45 km
- •19 levels to 29 km
- •2 X 5 years
- •1x and 2x CO_2

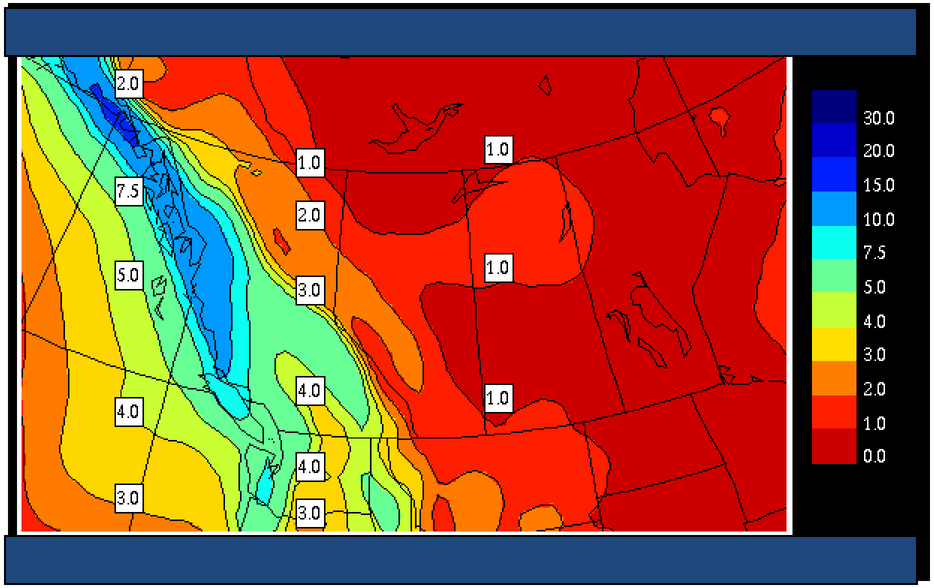
- •Atm: GCMii driven
- •Ocean: Results from GCMii mixed layer and thermodynamic sea-ice

- •No Lakes



GCMii @ T32

5-year mean 1xCO_2
Winter precipitation
(mm da^{-1})



CRCM-I @ 45 km

CRCM-I (3/3)

(Laprise et al., 1998, Atmos.-Ocean)

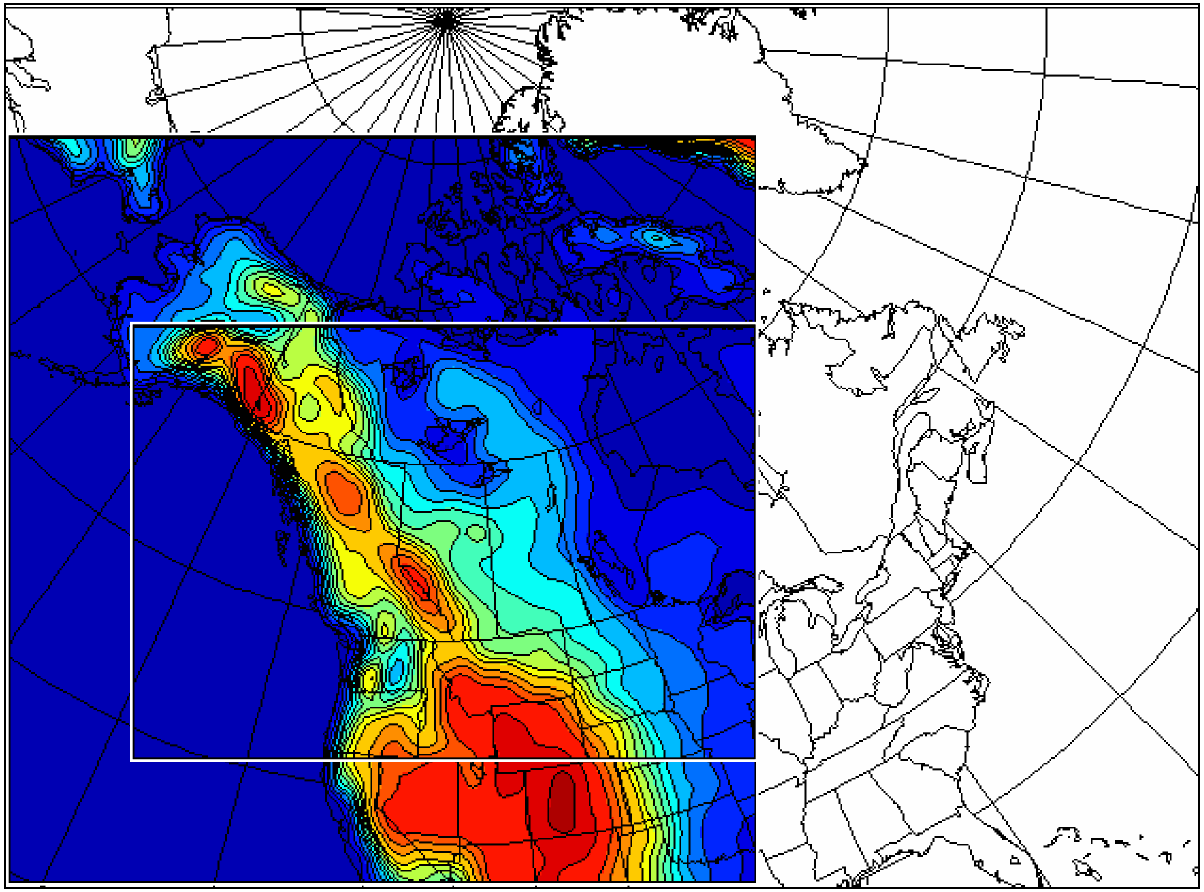
<u>Take home message:</u>

- Stable integration over 5 years of 1x and 2x CO_2
- Increased spatial definition of climate features and climate-change signal
- NO increased of temporal variability (variance)
- Different distributions for some variables (pcp)
- Systematic biases of GCM are passed on to RCM
- Need to improve GCMii physics at CRCM resol.
  - Moist convection (in summer)
  - Cloud cover diagnostics

en 1999

CRCM-II

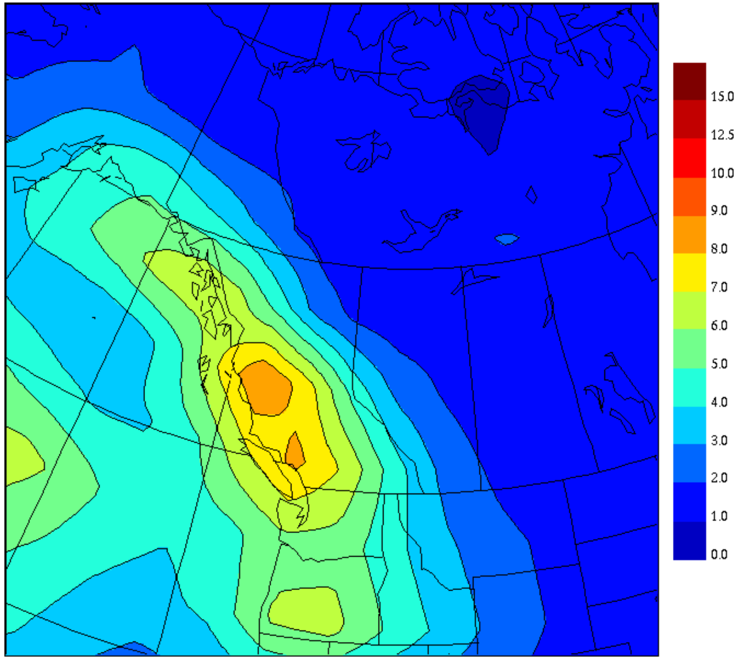
Second “Policy” Run



- •120 by 120 @ 45 km
- •3 time-slices of 10 yrs
- •Transient CO_2 and aerosols scenario

- •Atm: CGCM2 driven
- •Ocean: Results from CGCM2 dynamical ocean and sea-ice

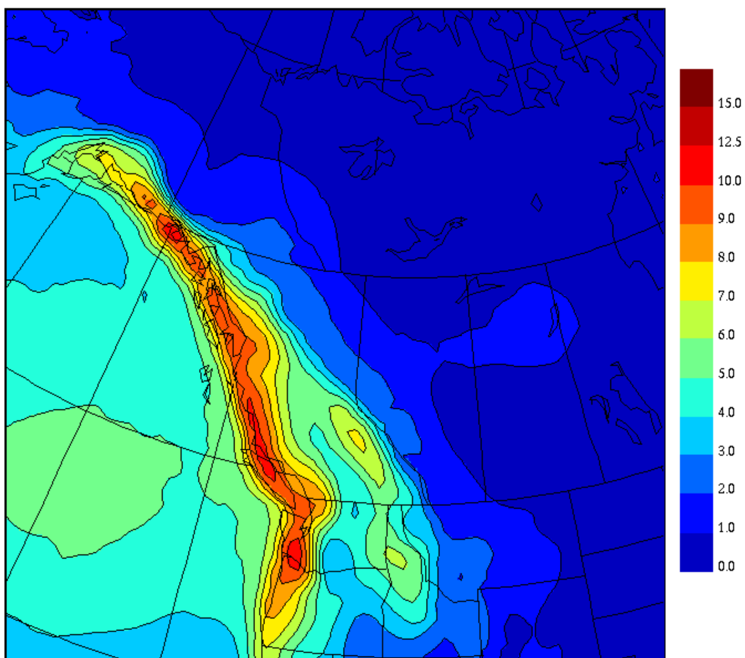
- •No Lakes



CGCM2 @ T32

10-year mean (1xCO_2)
Winter precipitation
(mm da^{-1})

CRCM-II @ 45 km



CRCM-II (3/3)
(Laprise et al., Clim. Dyn., 2003)

Improvements upon CRCM-I

- Moist convection of Kain and Fritsch (1990)
- Modified diagnostic clouds
- Implicit T_g prognostic equation
- SSTs and sea ice interpolated from CGCM2-simulated dynamical ocean and sea ice
- Transient CO_2 and aerosols as in CGCM2

Physics still requires attention

- Bechtold's version of Kain-Fritsch better
- Clouds and Stratiform precipitation
- Surface processes

Le consortium Ouranos est créé en 2001

550 Sherbrooke ouest,
Montréal, au centre-ville,
18^{e}-19^{e} étage, 1600 m^{2}

Partenaires fondateurs:

- 8 ministères provinciaux
- Hydro-Québec
- Service Météorologique du Canada
- Autres partenaires probables

+ 4 Universités

Financement:

- Environ 9M/an en support financier, technique et scientifique, sans inclure les fonds de recherche universitaires

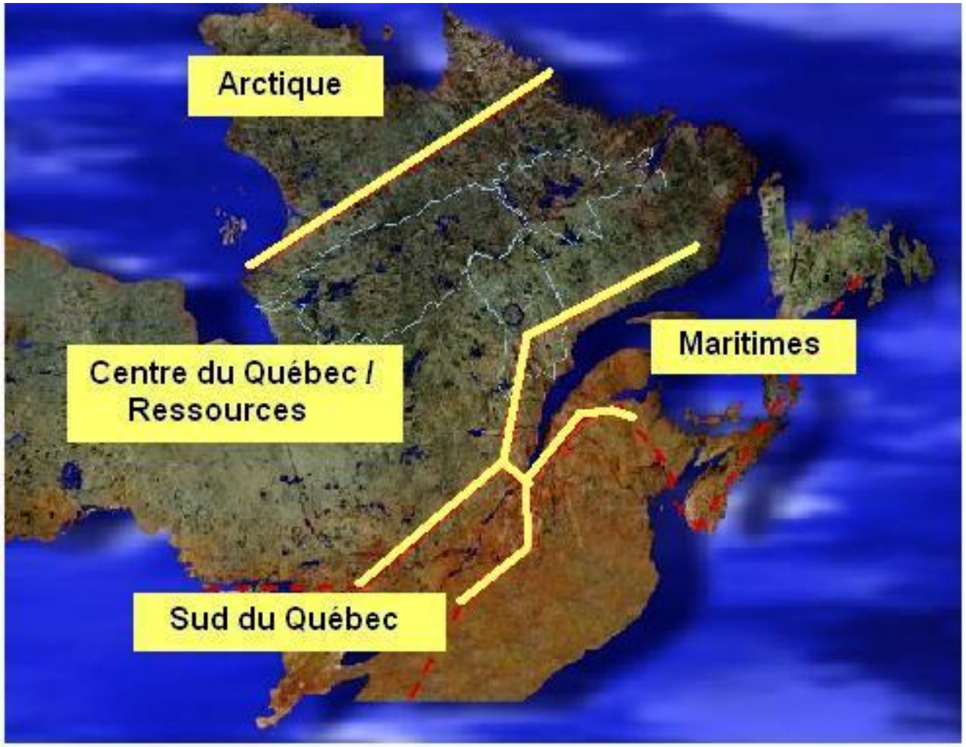
Vision:

- Un lieu d'échange et de formation pour des climatologues, hydrologues, géographes, économistes, sociologues…
- Une masse critique de spécialistes des changements climatiques...
- Un nœud multi-universitaire, multi-partenaire, multi-disciplinaire…

OURANOS


1994
1999
sécheresses, canicules
Saguenay (1996), 26 millions
d'eau et 9 millions de tonnes de
Le Grand Verglas (1998),1,5 millions
d'abonnés affectés, jusqu'à 30 jours sans électricité
© La Maison de La Presse, Chicoutimi

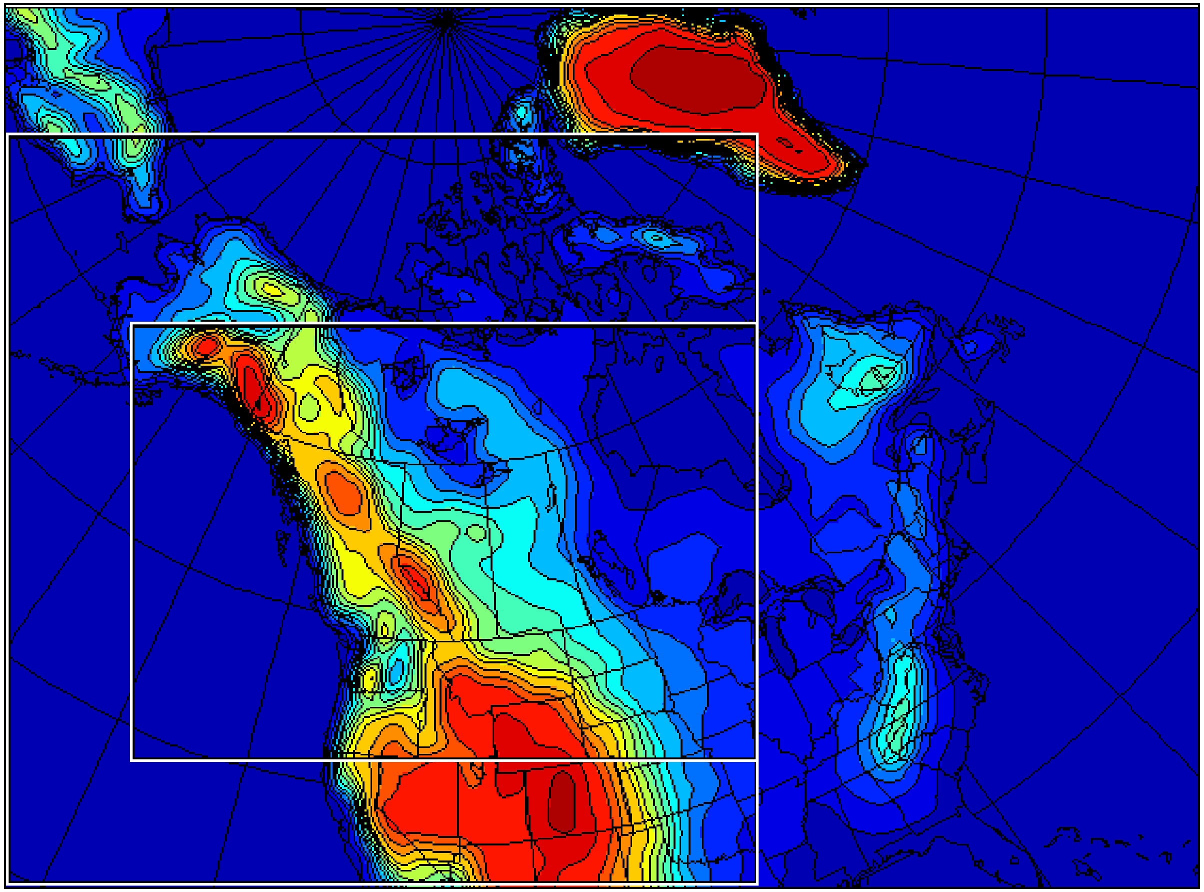
Les principaux projets à Ouranos



Simulations climatiques à Ouranos

- **MRCC-2 piloté par réanalyses**
  - NCEP RA1 @ ~500km (1975-1999)
- **MRCC-2 piloté par GCM couplé**
  - Modèle canadien CGCM2 @ ~500km (is92a 1968-1995)
  - Modèle canadien CGCM2 @ ~500km (is92a 2039-2064)
- **Validation**
  - Observation de surface sur grille (Observations: T_{abri}, pcp)
  - Intégrations spatiale sur bassins versants (avec Hydro-Québec) Ruissellement (avec Hydro-Québec)
  - …
- **Évaluation de l'incertitude**

CRCM-III



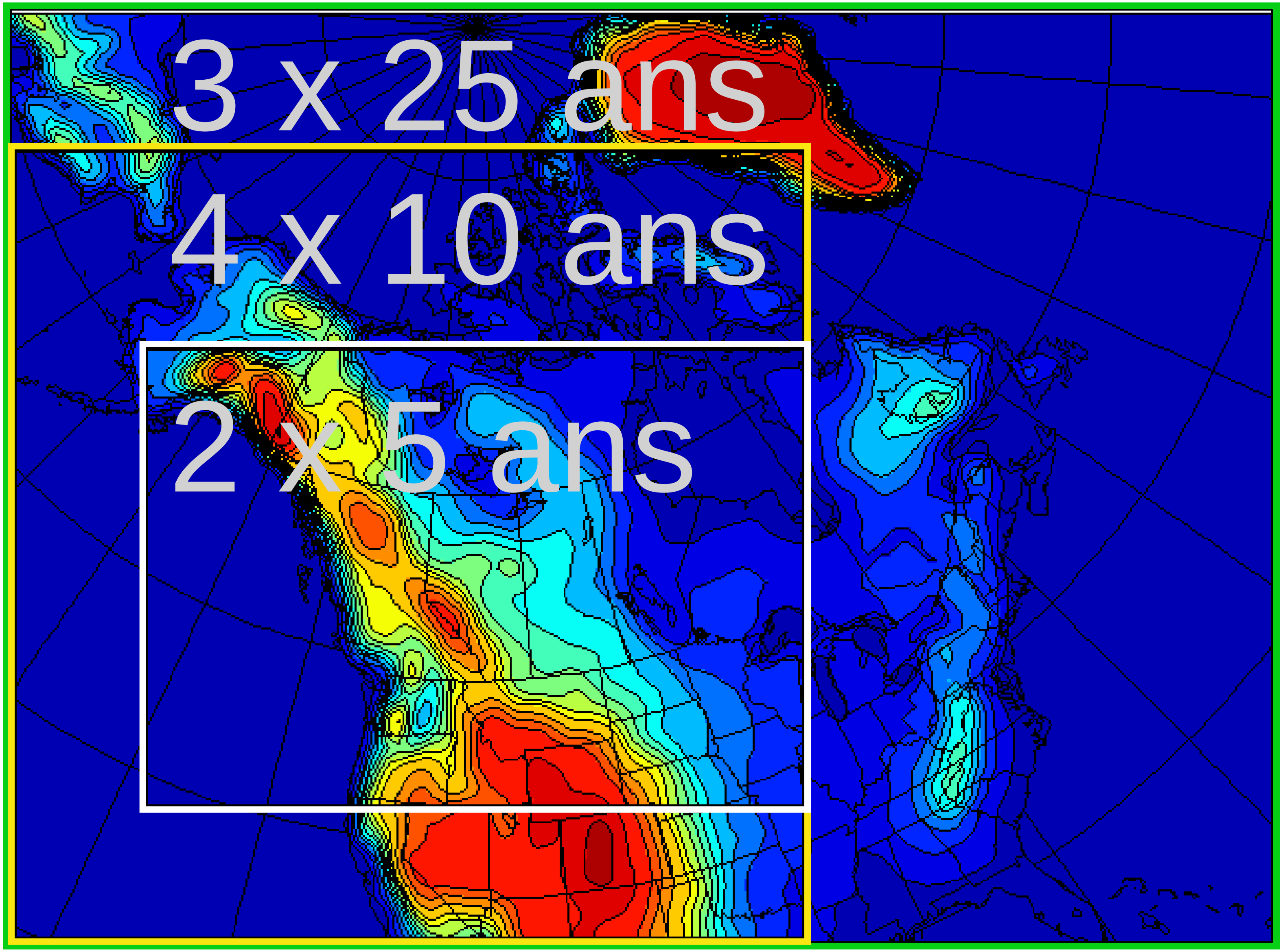
"Pan-Canadian"

- 193 x 145 @ 45km
9,000 km x 6,500 km

- Driven by CGCM2
- Driven by NCEP

- Mixed-layer lakes

Les domaines MRCC


3 x 25 ans
4 x 10 ans
2 x 5 ans

Domaine NARCCAP