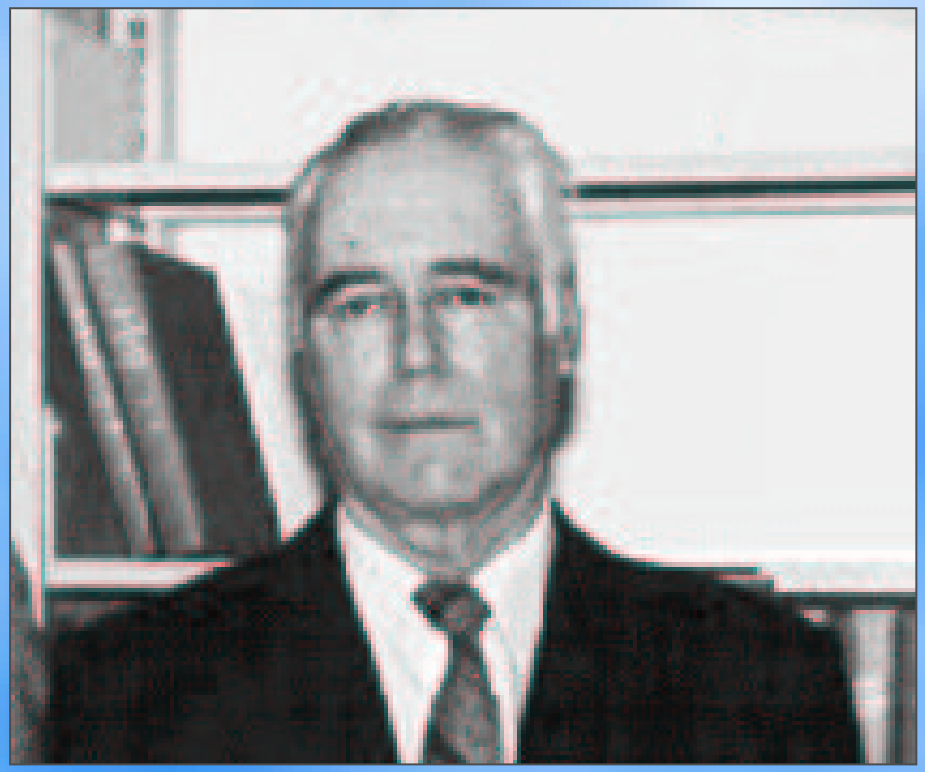
Présentation dédicacée
a André Robert
28 Avril 1929 – 18 Novembre 1993

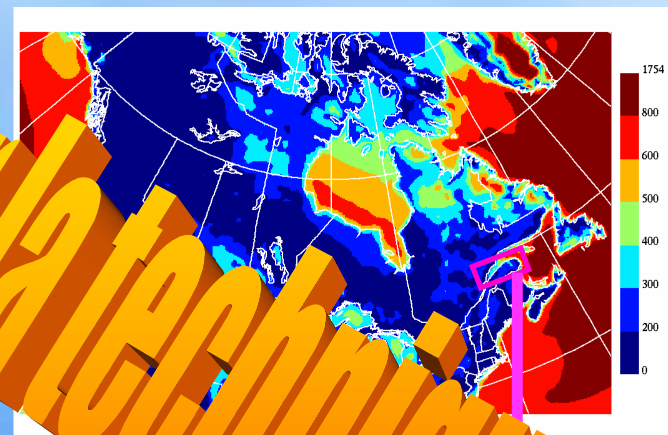


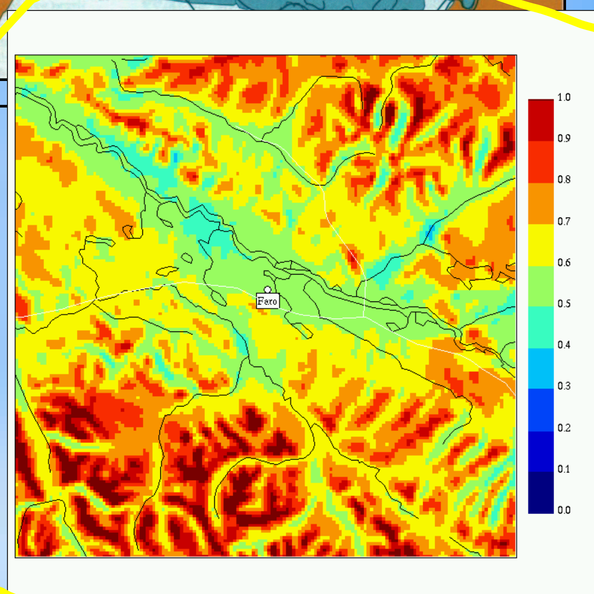
WEST

Atlas Éolien par la technique LAM

Walmsley and … 199…
Meteorological s… rv… ns

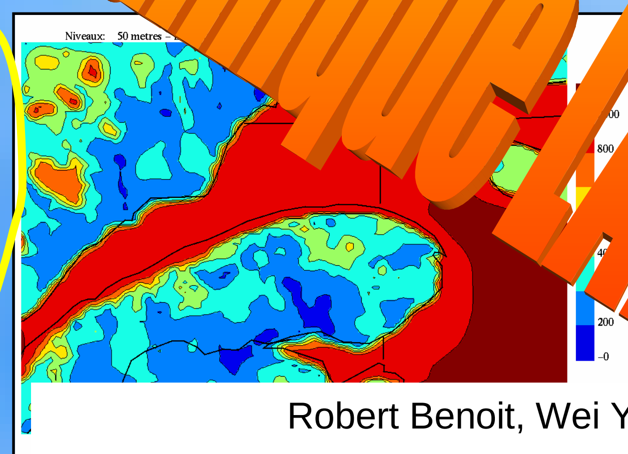
Benoit and Yu, Spring, 2001
CMC operational forecast averaged over 5 years (96-00) grid spacing: 24 km





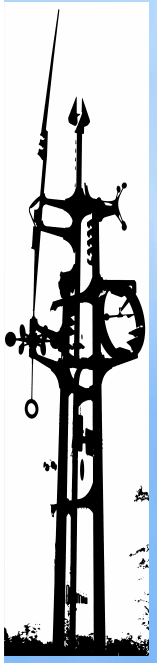
climate

WEST



Benoit et al., Spring, 2003
40 years NCEP data + WEST (meso & micro model) simulations grid spacing: 200 m

Robert Benoit, Wei Yu
et Anne-Laure Simon
Environnement Canada
Dorval Octobre 2003



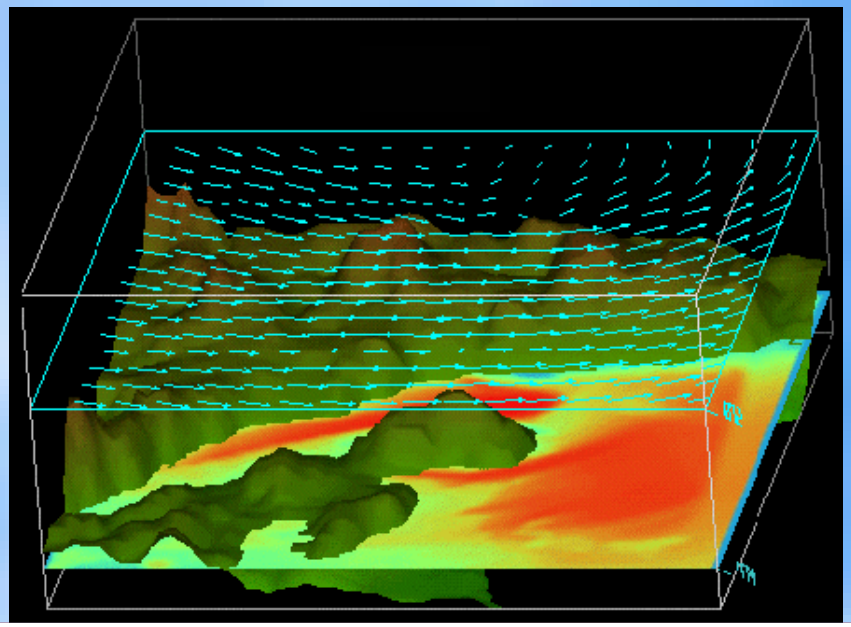
WEST (Wind Energy Simulation Toolkit)

***WEST** is a 100% Canadian wind energy analysis and forecasting software. It includes:*

- *Statistics package to compress the historical observation (upper air ballon) data*
- *Surface property generator*
- *NWP (Numerical Weather Prediction) type operational mesoscale model*
- *Microscale model*
- *Post-analysis package*
- *specially designed for use by industries due moderate computer requirement.*

Mesoscale

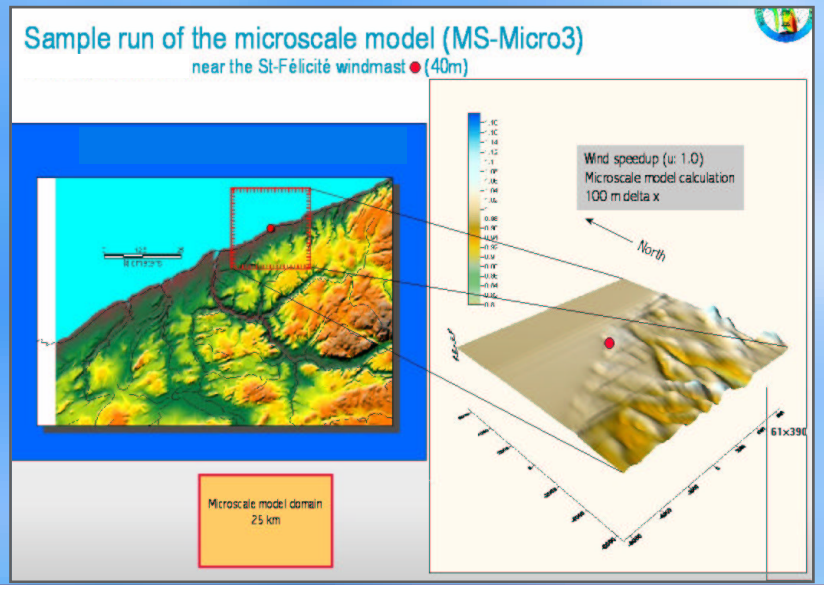
- fully compressible Navier-Stokes equations
- 3D, **time-dependent**
- accurate and efficient solution of flow
- Limited Area
- self-nesting capability (250--> 50 …-->5 ... km)



Microscale

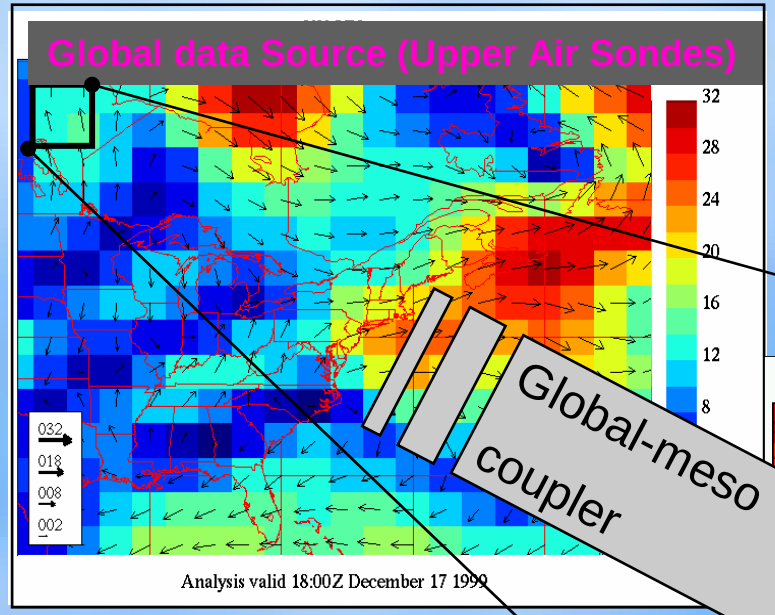
3D **steady-state** surface boundary-layer flow model

- Mixing-length turbulence closure
- Horizontal domains of order 100 m to 10 km
- Terrain slopes less than 0.3 to 0.5
- Inputs:
  - DEM and land-use
  - Wind statistics at a given height agl:
    - joint frequency table for speed and direction
    - from the set of mesoscale simulations



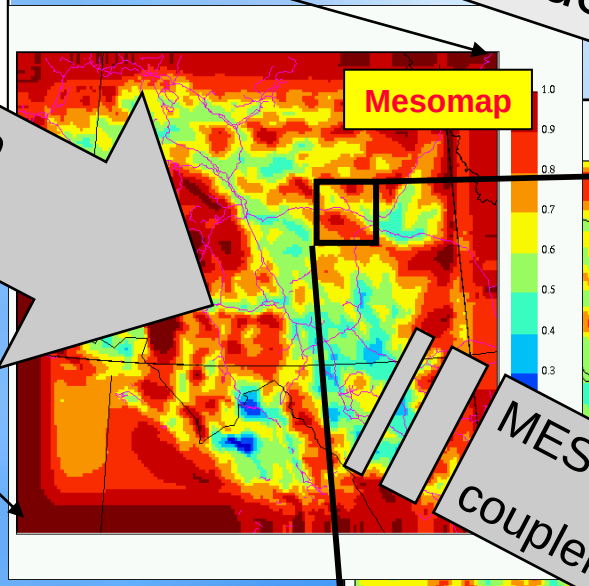
WEST

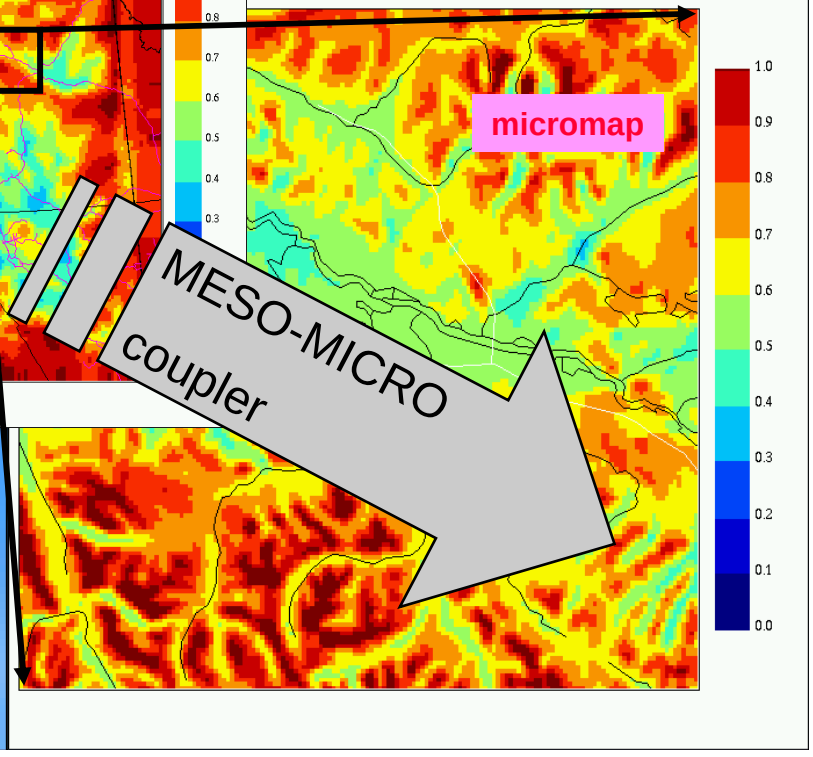
Statistical-dynamical downscaling



2-step spatial refinement 3D Atmospheric Models

Global-meso coupler





MESO-MICRO coupler

Large number of time samples
Climate:

- Past
- Future (clim change)

…
Compress statistically

Climate Classification … two options

- EOLE
  - Geostrophic time series for one global cell
    - 0 m and 1500 m ASL
  - Equi-angular (16) and equi-frequency-speed bins
  - Sign of shear
  - ~200 states with distinct frequencies (weights)
  - Ancillary params to 5000 m ASL
  - Initialize LAM for each state:
    - hydrostatic + geostrophic wind, level by level, zero initial topography
  - Constant Lateral BCs: geostrophic drag (Ekman) at low levels
- MonteCarlo
  - Use full atmospheric states (3D weather analyses)
  - Replace classification with random “representative” sample (~300 members)
  - Unsuccesful attempt to use advanced classification tools
    - EOFs, r.diag
    - … further work needed!
  - Regular NWP initialization of the LAM
  - Equal frequencies

Time dimension in meso/micro-scale model

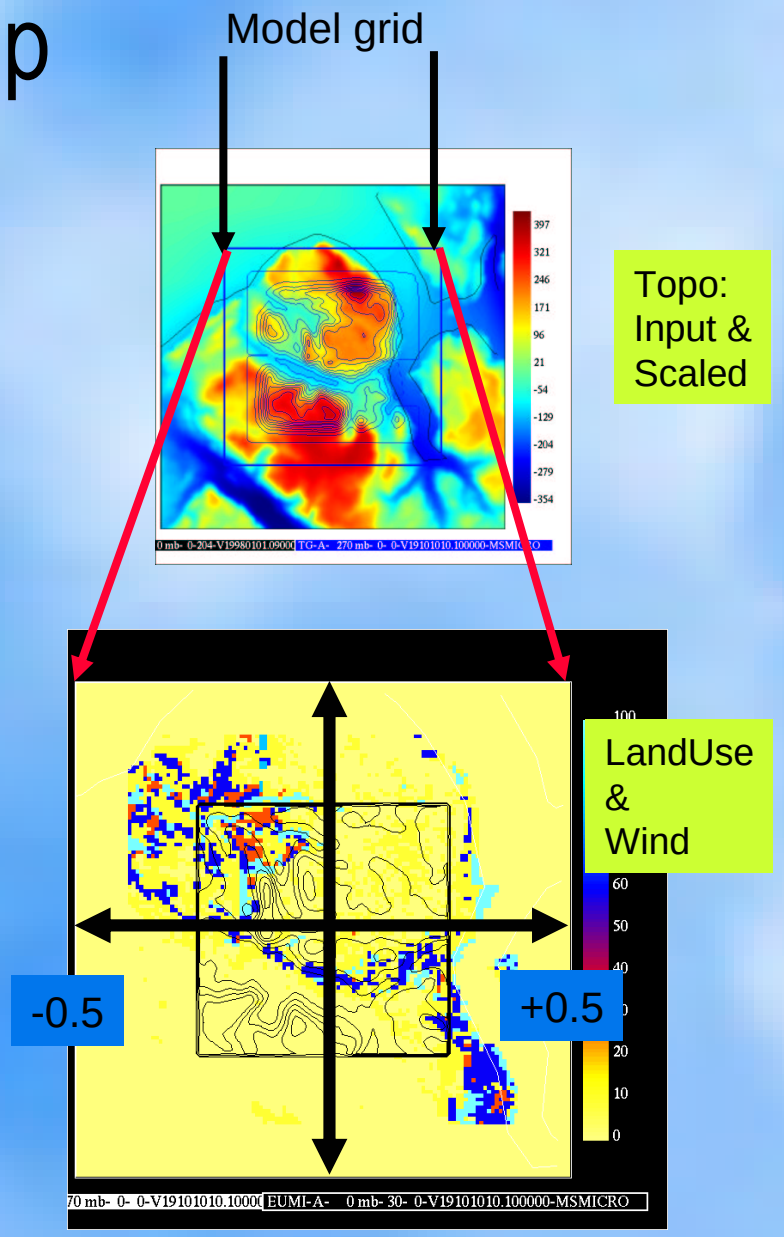
- 2 modes of operation for the **Meso**:
  1. Weather forecast mode
     - Clock is significant
     - Full initial state (eg a weather map)
     - All physical processes are on
       - IR and solar
       - Ground heating/cooling
     - Up/downslope density currents
     - More time steps (eg 1 day)
  2. Lower Flow (< 5 km agl) adaptation to terrain
     - Final time not significant
     - Simplified initial state (eg strait isobars)
     - Turn off some physical effects: sun, ground heating, etc
     - Achieve pseudo-equilibrium
     - Less (and longer) time steps (eg 9 hours)
- Possible to measure sensitivity to each mode
- 2nd mode = usual practice for WEST wind maps
- **Micro**: *full* steady-state (no time stepping)
- Cost & complexity: MESO >>> MICRO
- An efficient alternative to Regional Climate Models (RCMs) to obtain local low-level wind climate distributions

Typical LAM setup

- Dynamics
  - 5 km; Nx, Ny~ 150; lid=20 000 m
  - 120 s timestep (twice longer than usual…no fast UL flow); Total steps=270 (9 h)
  - 28 levels; 10 under 1500 m
  - Diffusion: del4, no top sponge
  - Halo: 3 pnts
  - Nest: 13 total = 5 (blend) + 8 (topography)
  - Topo: Grid cell mean or some smoothing (~4Δx)
- Physics
  - Dry
  - No radiation
  - No GWD
  - No surface heat flux
  - Land-sea mask
  - CLEF blyr
  - Roughness: vegetation-based, NO subgridscale nor Silhouette scheme

Typical Micromodel setup

- Δx=150 m
- Topo,roughness input:
  - 205 x 205 grid
  - room for all model rotations
- N=128 transform (=model) grid
  - Non-dimensional edge=1
  - x=-0.5 to x=+0.5
- Outer scale x=0.4 (flat outside this)
- Inner scale x=0.3 (free inside that)
- Wind output from central quarter, N=64 (~10 km edge)

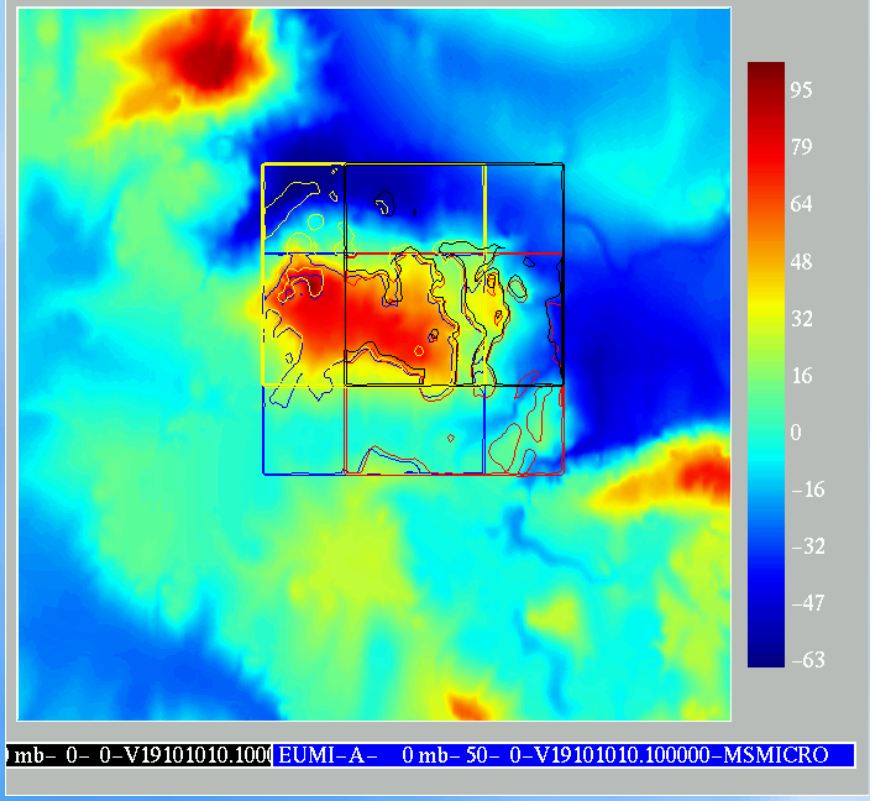


Meso-Micro Coupler

- Strong response to ground forcing
- Important to align well the micro grids
- Anchor on the mesogrid due to wind coupling
- Define
  - σ =fractional overlap of the "central quarters"
  - α =nondimensional distance between consecutive microdomain centers (in units of meso Δx)
- Meso/Micro splitter and aggregator
- Minimize double counting of effects:
  - Perturbation topo
  - Prefer input wind well-above surface layer
- Inputs:
  - Meso grids of mean wind speed, directional frequencies and topo/roughness
  - Microscale topo&landuse on meso domain
  - Matching table betw meso/micro LU indexes
- Outputs (Microscale aggregated) :
  - Wind Speed
  - Wind Energy
- Typical run: over a full LAM domain every 1 or 3rd points
  - → 3000-10000 micromodel runs…~1 sec each on LINUX
  - σ ~ 0.3 ; α = 1 or 3
  - Example later in presentation

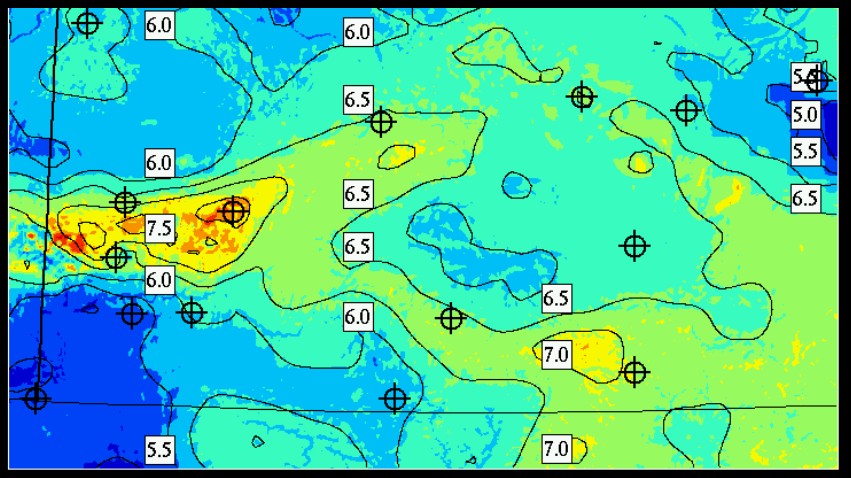
Basic 2 x 2 Microdomains Array

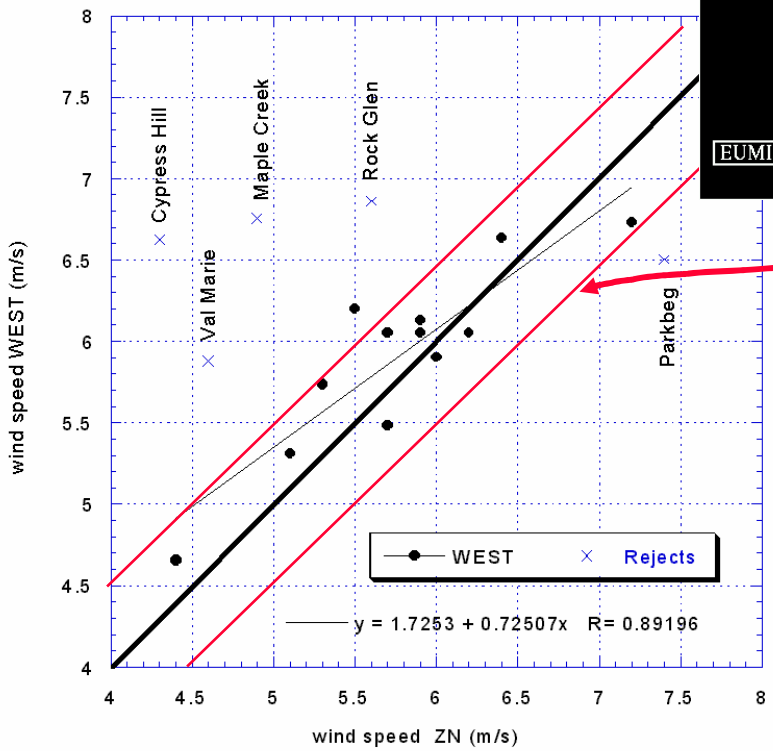
Speeds on Topographic Perturbation



Validation of WEST over SW Saskatchewan

Wind speed climate: meso & micro





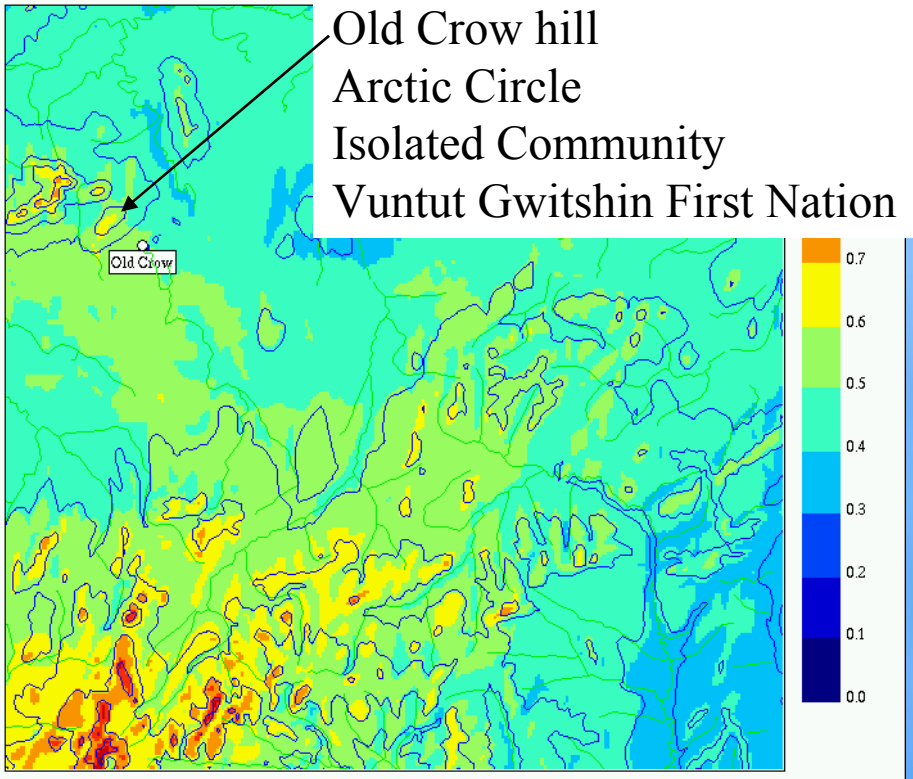
- Error level: ~ 0.5 m/s just MESO
- Just above WE industry requirement
- Rejects: potential to identify

Internal report Jan 2003 includes other areas: Gaspe, Lake Ontario (coastlines)

Yukon windmaps: Zooms

Colour: microscale model (200m mesh) 30m agl

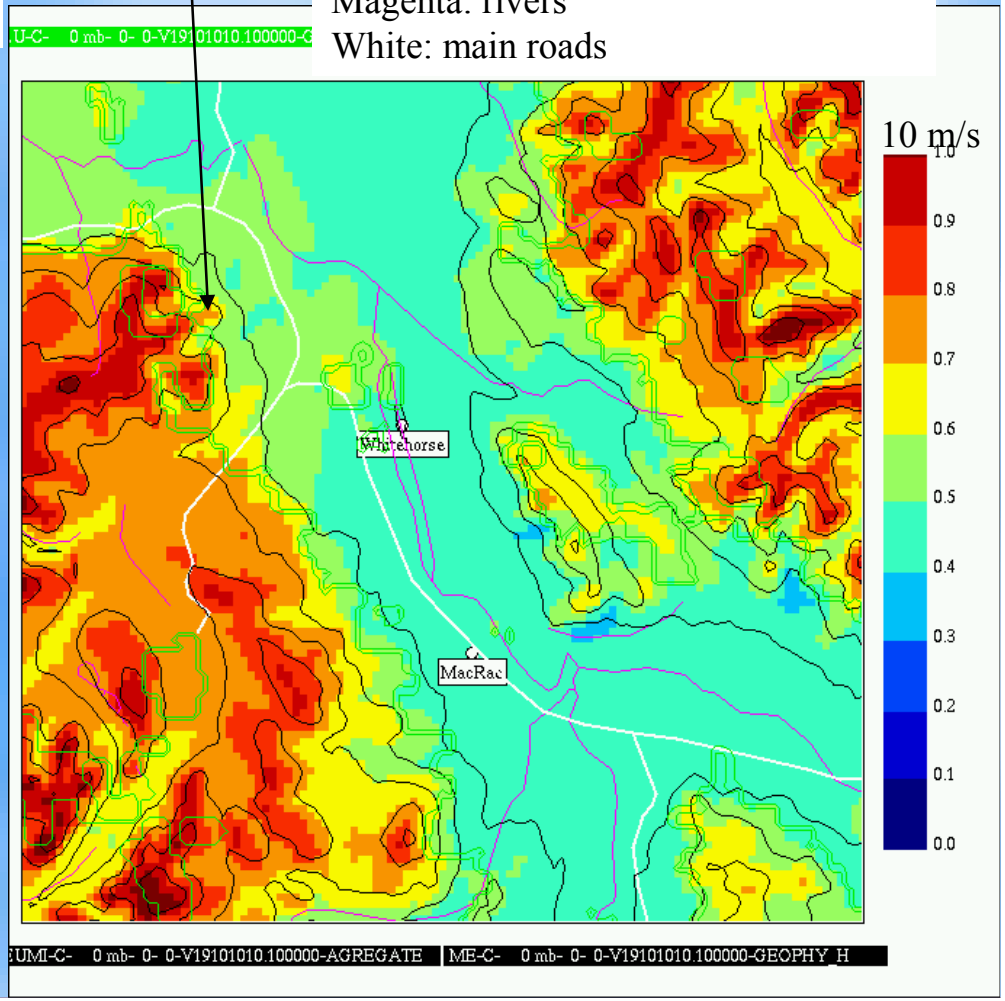
Old Crow hill
Arctic Circle
Isolated Community
Vuntut Gwitshin First Nation



Green: rivers
Blue: topography

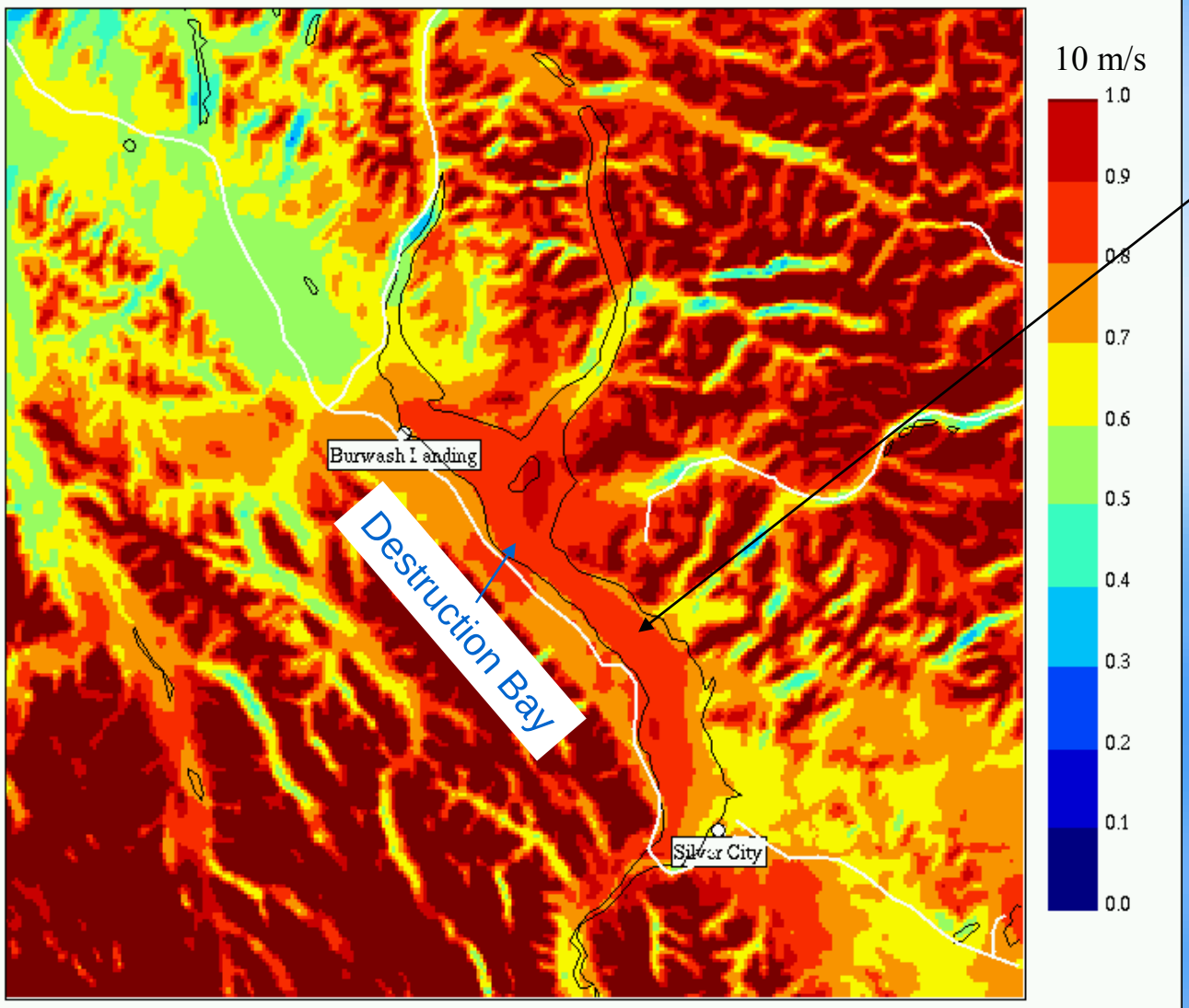
Whitehorse area
Haeckel Hill 2 Wind Turbines

Black lines: topography (200m incr)
Green: land use
Magenta: rivers
White: main roads



Yukon windmaps: Zooms

Colour: microscale model (200m mesh) 30m agl



Kluane Lake area
Prospect Turbine Site
Kluane First Nation

Black lines: lakes
White: main roads

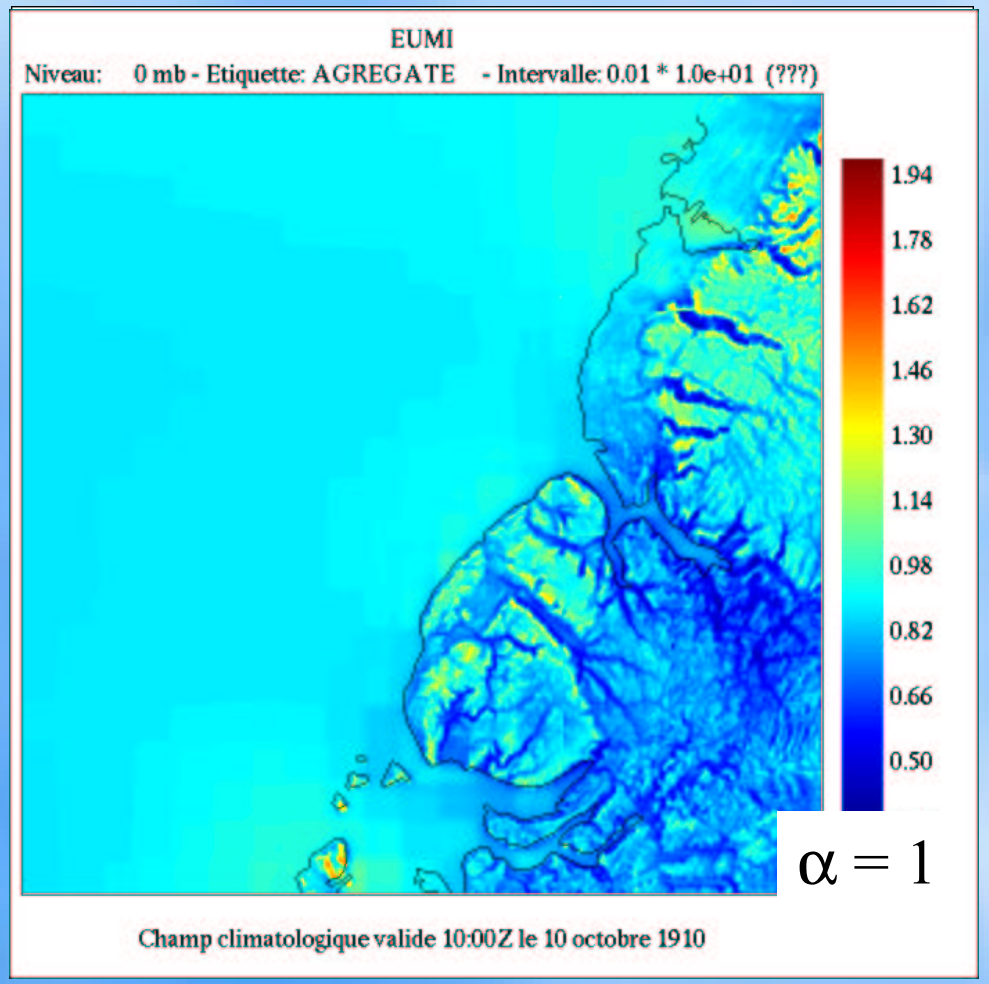
Preliminary Validation of the Yukon Windmaps (30 m agl)

Location	Observed	WEST Meso	Notes
Valleys	~ < 4	~ 4	
Destruction Bay	6	9	Tower near lakeshore escarpment
Paint Mt	5	4.5	Projected to 30 m
Bear Crk	6	6	
Tagish	4+	5	
Faro Sheep	4.6	5	
Lendrums	4.5	4.5	
Haeckle Hill	6 – 6.5	7	

Thanks to JPPinard et al !
Paper in prep for Atm-Oc

MMC Coupling aspects in coastal areas

- Flat response of micromodel when no topo or landuse gradient across domain (ocean)
- Tends to generate flat tiles near coastline
- Reduced with $\alpha = 1$



Applying WEST for new Wind Atlas of Canada

- Canada far behind U.S. and Europe in operationalizing its wind atlas
- coast to coast: uniform quality, role of Environment Canada
- Spatial resolution:
  - 5 km meso mesh (=Level 1)
  - 100-200 m micro mesh
- 1st version complete Late 2003 – Early 2004
- Web-based results:
  - maps & graphics : **public**
  - Gridded numerical results : **consultants**
- EC/NRCAN Partnership
  - EC: WEST Technology , Atlas generation and Web site prototype
  - NRCAN and Geomatics Canada:
    - providing high quality topography and LandUse national databases for the microscale model
    - Hosting of the Wind Atlas in the Atlas of Canada
- role of industry, private sector consultants:
  - Quality control & Grid refinement
  - WEST Level 2 and/or alternate microscale
- Much progress during last 6 months … almost ready to go into production
- Atlas: ~ 5 M$ product value from user point of view
- Atlas favorise installation de l'electricite eolienne au pays
- Consequence future:
  - besoin de prevision de puissance eolienne ciblees a microechelle sur plusieurs sites
  - → nombreux clients de donnees du CMC

LAM-MOS power prediction study @ AWTS

6 MOS stations in a 100 km radius

GEM (CMC's regional operational model)
Resolution: 24 km
Forecast horizon: 48 hours (twice a day)
Time lag: +2 hrs

LAM (Mesoscale model)
Resolution: 5 km (151 x 151 x 40)
Forecast horizon: 48 hours (twice a day)
Time lag: +1.5 hrs (16 PCs)
Retained outputs: U, V, T, etc.

UMOS 1
Statistical correction
Outputs: U, V, S, T, etc.

MsMicro (Microscale model)
Resolution: 50 m
3D dynamic boundary layer model
Outputs: U, V

Power plant measurements
U, V, T, and P (power generation)
Manufacturer's power curve or
"plant power curve"

UMOS 2
Statistical model for power generation

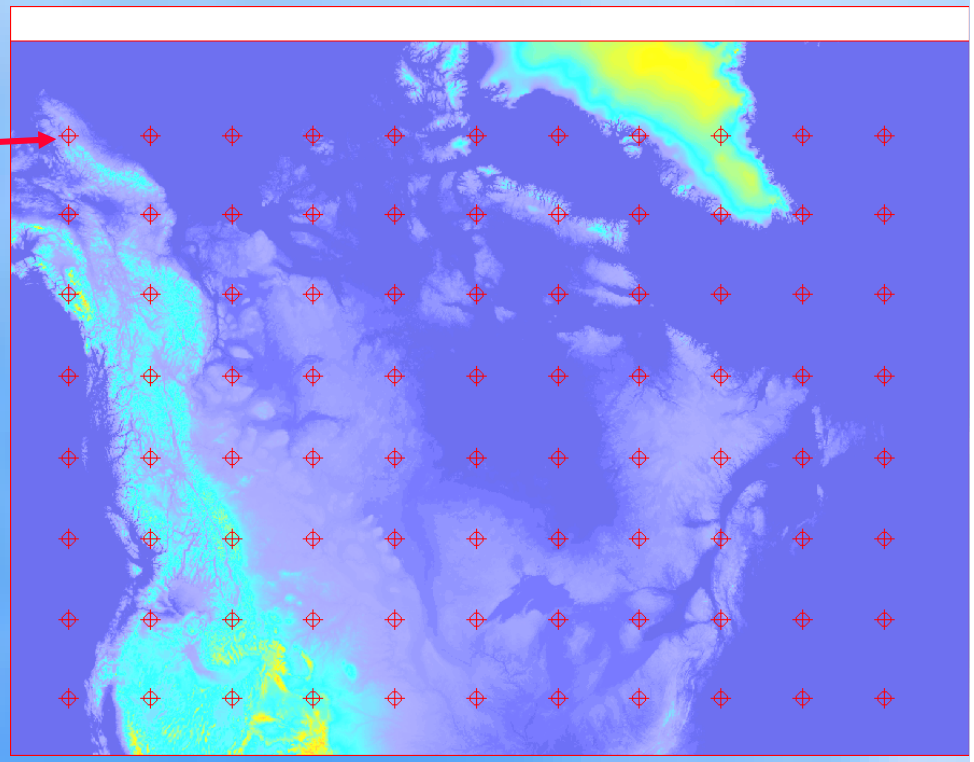
Predicted power production for the next 44 hours

Global-Meso Coupler

- Couple the gridded climatic data (Reanalyses) to the LAMs
- Mosaic approach
- Same principles as the Meso-Micro Coupler
- Ensure gridpoints sharing between adjacent LAMs
  - Minimize flow differences due to
  - Surface forcings
  - Splitting/merging operations
- Center LAMs on individual Global gridpoints ($\Delta x \sim 250$ km)
- Define overlap (σ'). Minimum ~0.3 to cover 2 adjacent nestings
- Practical maximum ~ 0.6. (cost proportional to σ'^2)
- Atlas = aggregate of all LAMs
- Minimize spatial distortion of Atlas
  - Project Global grid on a coordinate system with mapscale very close to 1 over Canada

Layout of mesoscale domains

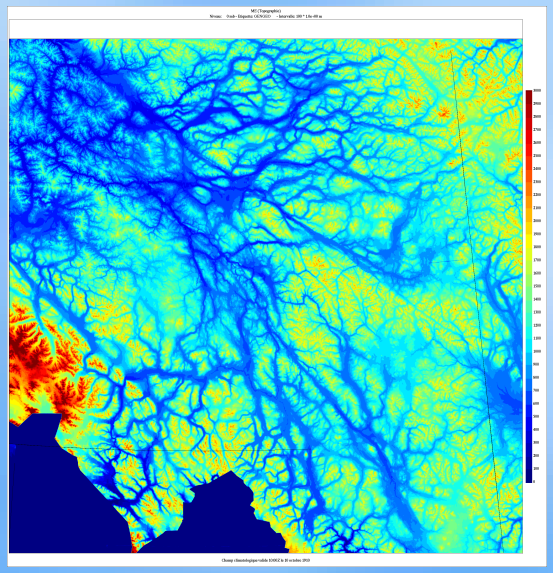
- Centroids of the meso-domains
  - Sample strategy:
  - 11x8 = 88 centroids
  - Each mesodomain @ 5km mesh
- 5km seamless geophysics for the meso
  - Shown=topography
- Wind Atlas Climate problem size:
  - ~ 20 000 flow realizations
  - Will be executed under a regional priorization scheme
  - E.g. Northern Territories and Southern Canada first, then less populated parts

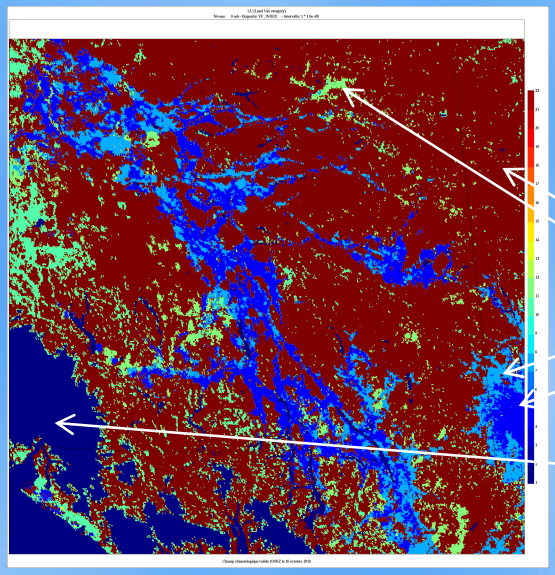


Hi-res Terrain & Land-use for the microscale

- Topography
  - 1:250 000 elevation rasters (DEMs, CDED) NRCAN
  - National coverage
- Land-use (veg class.) → roughness
  - USGS satellite classification: 1-km global
  - NRCAN vector veg themes 1:250 000
- Others: eg BTM, USGS, Corine
- Micro-flows: Tributary on quality of these datasets

1:250 000 rasters=80 m grids





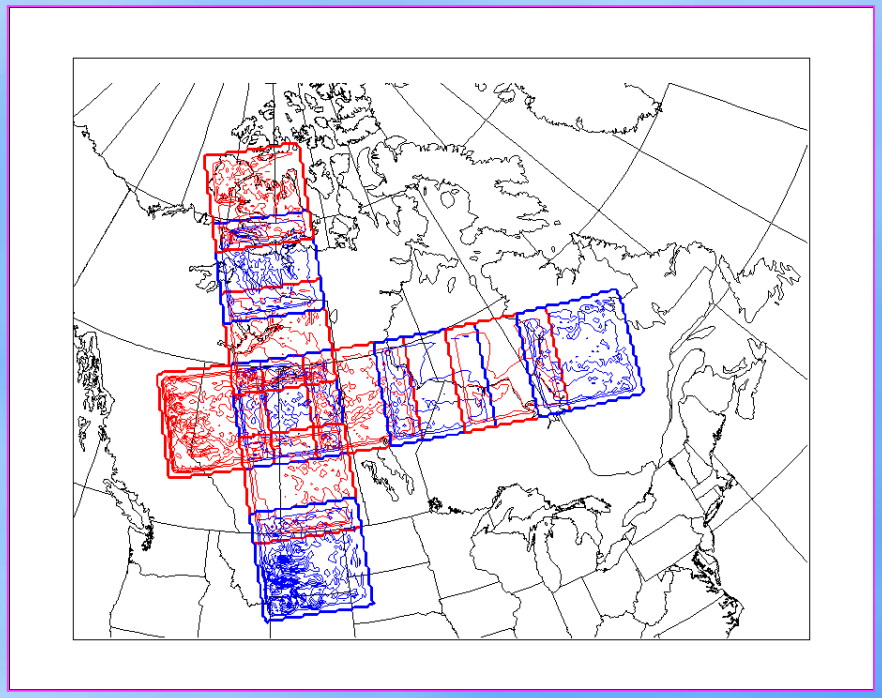
Southern Yukon

22 tundra
11deciduous shrubs
7 deciduous trees
5 evergreen trees
……

1 water ??? Vs ICE

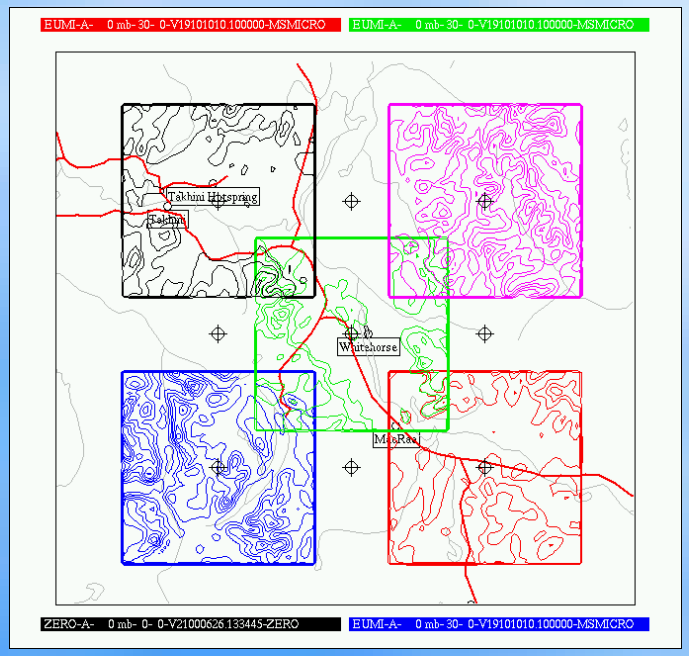
Maximum quality: Achieving seamless results

On the mesoscale domains



- Terrain-adapted flow pattern
  - Here: Just for westerly inital isobars
  - Atlas: whole climate
- Isotachs shown for 6 x 5 domains, at 50 m agl
- Global-Meso Coupler
- Domains overlap= 30%
  - ~minimum
- Further development before Atlas production…
  - Reduce lte, v differences

…and the microscale domains



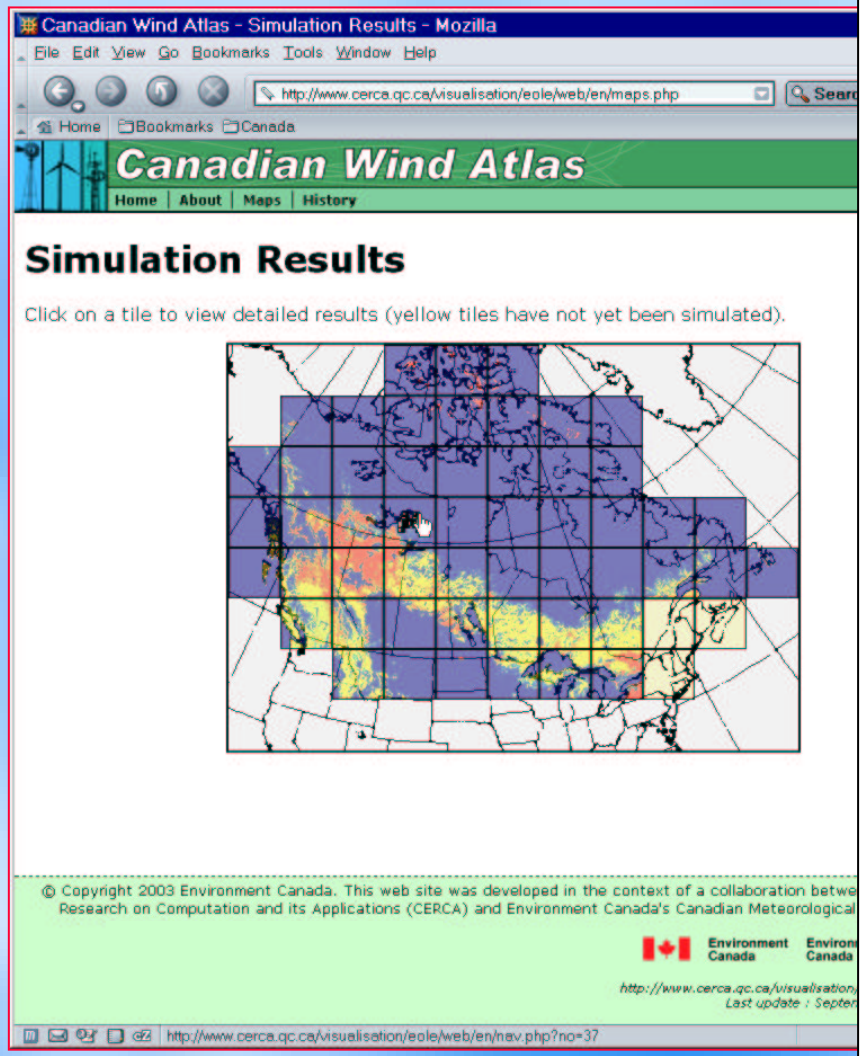
=individual meso gridpoint

Meso-micro Coupler
Colored boxed=
individual micromodel runs

Computing the Wind Atlas Database

- Computing task:
  - **Major Cost is the meso part:**
    - ~100x200 flows for the meso part
    - Could increase significantly if larger overlap needed
  - Micro part:
    - impressive
    - 1000-10000 microdomains per mesodomain
    - but cheap to compute
- Disk Archive::
  - DISK: 8600MB/mesodomain
  - Overall: **Close to 1 TeraByte**. 755 GB (2 time samples)
- Linux Cluster
  - ~ 10 Pentium 4- 2.4 GHz
  - ~100 days of wall-clock … or more
- EC supercomputer:
  - IBM Power4 (Regata) 800 cpu at the CMC
  - A few days/weeks (wall-clock), if access to a large chunk of the machine is granted (Special Agreement needed)

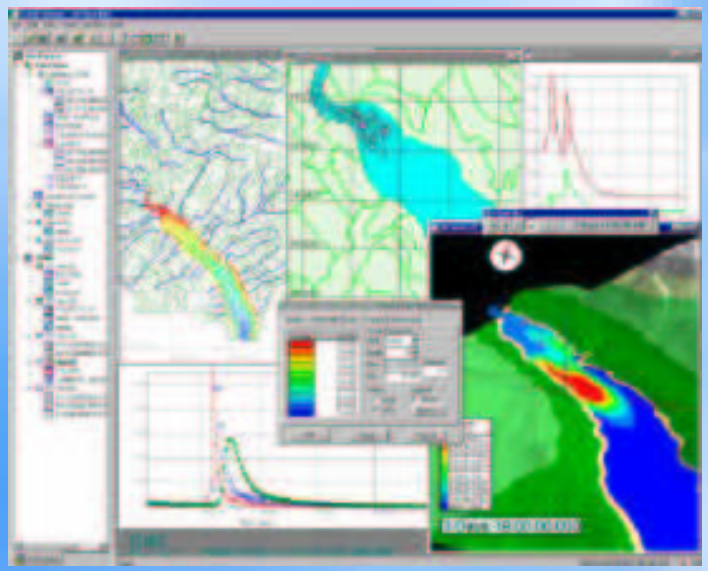
Website of the Wind Atlas



- **Goal is a public-domain web-based Wind Atlas**
  - –Prototype almost completed in Montreal Engineering School (Polytechnique)
    - •Fully portable
    - •Canned Graphics
  - –Aim at transfering the prototype to Geomatics Canada early 2004 (National Atlas)
- **Maps Database:**
  - –Large set of maps
  - –By Region, Parameter (windspeed, windrose freq)
  - –Meso, Micro or Both
  - –Option to export map content in Georeferenced form (eg MID/MIF, …)
- **Fluid Modelling Database**
  - –For wind energy consultants
  - –Allows redo of the microscale part
  - –And further meso downscaling: eg 5km down to 1 or 2 km, on a smaller piece of land
  - –May require a “tape”/“media” service, depending on data volume

WEST system: licensing to private sector

- **WEST** wind mapping system developed under UNIX/Linux
- Full **WEST** Porting to Windows XP Pro:
  - ~ 9 months, from July 2003
  - Meso engine port almost completed by now (9/2003)
  - Embedded in a full GIS environment: EnSIM (NRC-Canada)
  - Annual license basis
- Interim license for Linux Users (until early 2004)
  - Per project basis
- Hardware level: scalable cluster approach
- Licenses
  - definition being worked out at EC now
  - User Support team being assembled



Remaining challenges for the “Atlas”

- UV differences across LAM overlaps
- Minimize overlap ratio (0.3 – 0.6)
- Initialization of the LAM-mosaic:
  - Geostrophic initialization tolerable or …
  - Revert to MonteCarlo (set of 50 km national f’casts)
- If Geostrophic, then Upgrade Geostrophic Classification scheme
- Upgrade the NRCAN topography
- Obtain the NRCAN landuse & interface to geophysics generator
- Complete the website prototype
- Execute the Atlas calculation !!!!!!!!

Merci pour votre attention