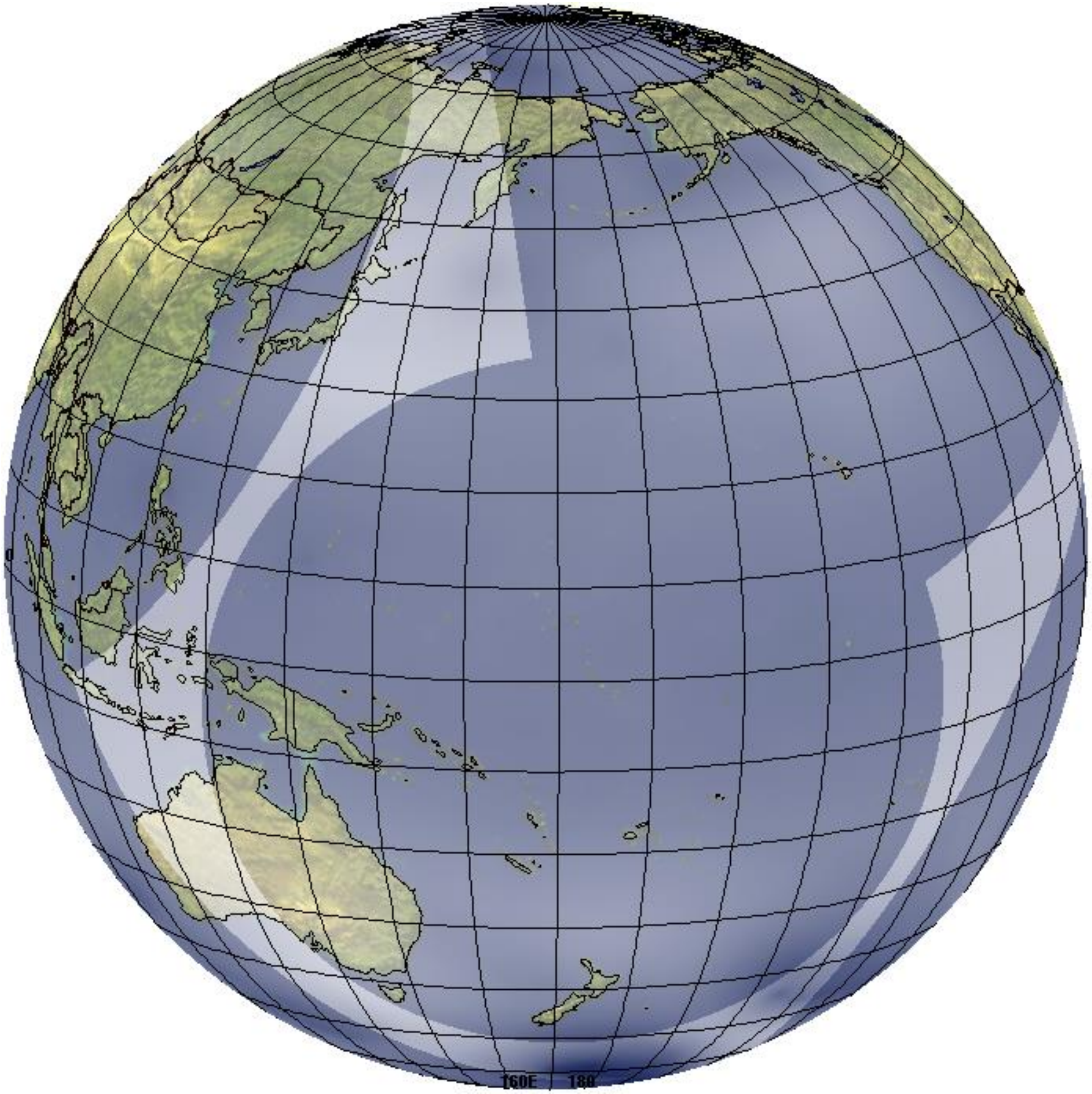
# The operational GDPS-YY 25Km

Abdessamad Qaddouri &Vivian Lee



# Collaborators

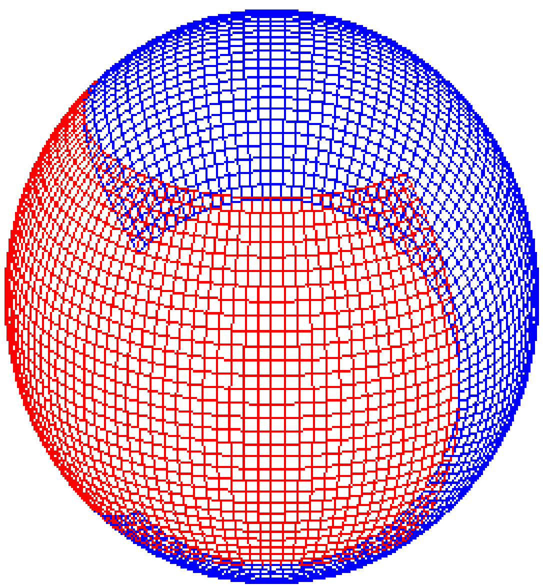
Michel Desgagné, Claude Girard, André Plante, Monique Tanguay, Stéphane Gaudreault,  Michel Roch, Ron McTaggart-Cowan, Michel Valin, Stéphane Chamberland, Martin Charron, Jean Côté …

# Outline

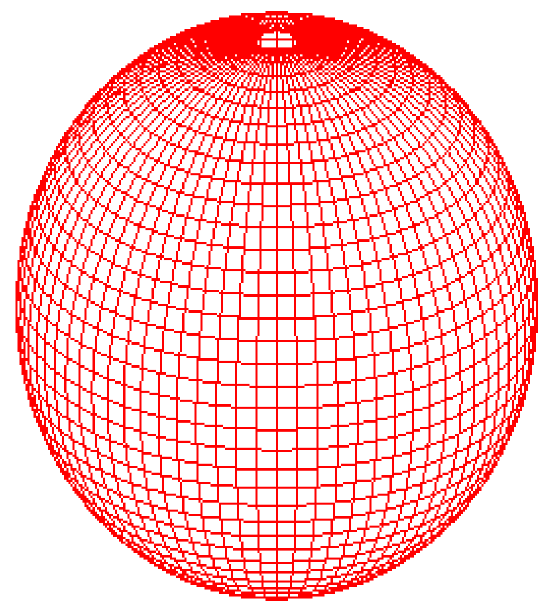
- Why do we have to change the grid?
- Domain decomposition method used for GEM model on Yin-Yang grid.
- Blended variables in the overlap zone
- Some Results
- List of differences (GU25 vs GY25)

# Why do we have to change the grid?

GY grid



GU grid



# GU25 /GY25

**Lat-Lon grid  GU25**

- 1024x800 grid-points
- 2 singular points
- High resolution near poles: 39km/0.05km
- Reached the limits of scalability for GEM model
- Needs special treatment near poles

**Yin-Yang Grid GY25**

- 1287x417x2 grid-points
- No singular points
- Grille spacing quasi-uniform: 25km/17.2km
- Scales well for GEM model
- Needs special treatment in the overlap regions.

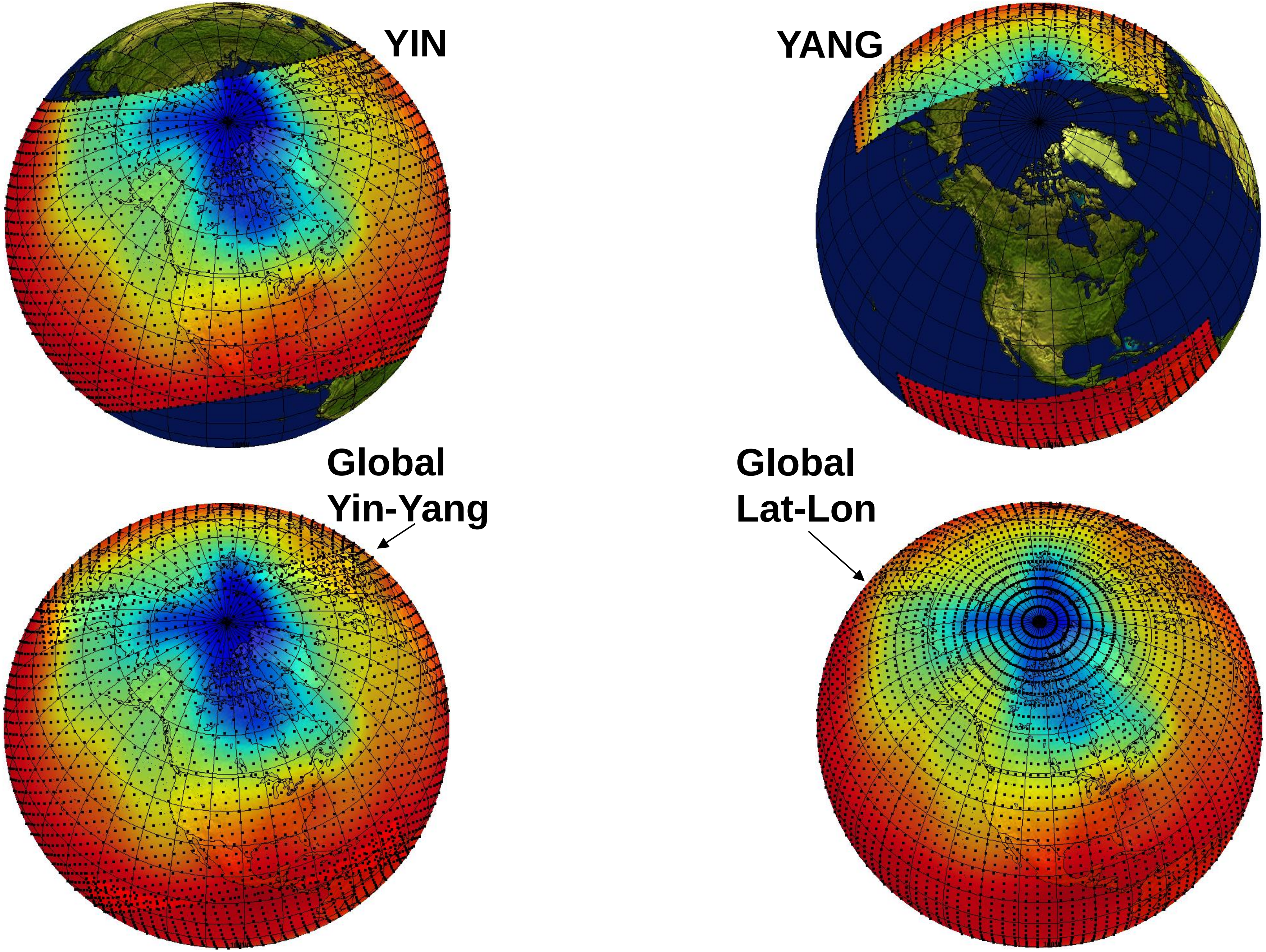
# Timings

**GU 25km – v4.7.0-rc5**

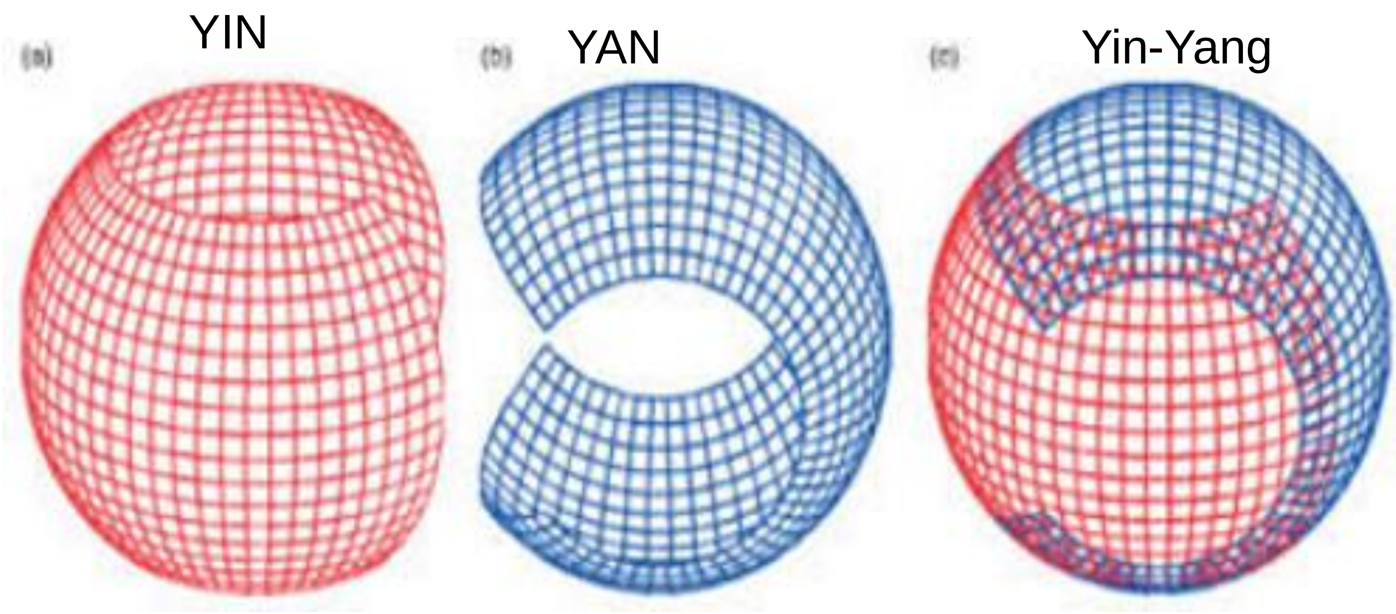
| PE Topo<br>Npx x Npy x OpenMP | # of Nodes | Timing (minutes) |
|---|---|---|
| 2x29x8 | 15 | 66 |
| 2x29x16 | 29 | 51 |
| **2x40x16 (Operations)** | **40** | **41 (I/O on 40 nodes)** |

**GY 25km – v4.7.0-rc5**

| PE Topo<br>Npx x Npy x OpenMP **( x2)** | # of Nodes | Timing (minutes) |
|---|---|---|
| 27x15x1 | 26 | 53 |
| 20x12x2 | 30 | 51 |
| **20x16x2** | **40** | **43 (I/O on 1 node)** |
| **27x15x2** | **51** | **37** |
| **27x16x4** | **108** | **28** |


YIN
YANG
Global
Yin-Yang
Global
Lat-Lon

# GY25 for global Forecast




$$\Omega = \{45^0 - 3\delta \le \lambda \le 315^o + 3\delta;\ -45^0 - \delta \le \theta \le 45^o + \delta\}; \delta = 2^0$$

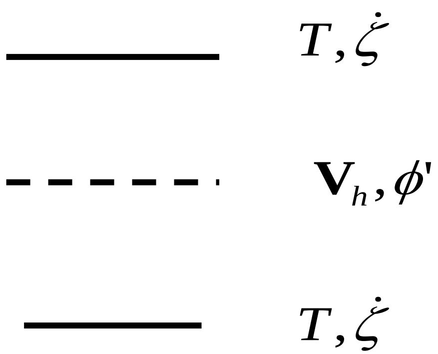
The global forecast is based on the two-way nesting method between 2-limited area models;
Qaddouri and Lee 2011 Q.J.R.Meteorol.Soc.137:1913-1926

# Domain decomposition method

- On each panel (Yin/Yang)
  - A system of forced primitive equations is solved with a local solver based on Implicit semi-Lagrangian time discretisation.
  - Boundary conditions are passed by cubic-Lagrange interpolation (non-matching grids)
  - Implicit discretisation: 3D-elliptic problem is solved by the iterative Schwarz method

# Forced primitive Equations
# Spatial discretization

Charney Phillips Grid



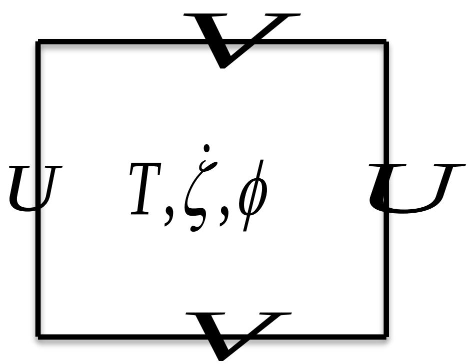

$$\frac{d\mathbf{V}_h}{dt} + f\mathbf{k}\mathrm{x}\mathbf{V}_h + R\overline{T}^{\zeta h}\nabla_{\zeta}(Bs) + \nabla_{\zeta}\phi' = \mathrm{F}^{\mathrm{H}}$$

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

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

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

Arakawa C Grid




Girard et al. 2014 Mon.Wea.Rev..,142,3,1183-1196

# Time Iterative Solver

$$\frac{\mathrm{d}F_{\mathrm{i}}}{\mathrm{dt}} + G_{\mathrm{i}} = 0$$

$$\frac{F_i^A}{\tau} + G_i^A = \frac{F_i^D}{\tau} - \beta G_i^D \equiv \mathrm{R}_i; \quad \tau = \Delta t / 2$$

Linearisation

$$L_i \equiv \left( \frac{F_i^A}{\tau} + G_i^A \right)_{lin}; \qquad N_i \equiv \frac{F_i^A}{\tau} + G_i^A - \left( \frac{F_i^A}{\tau} + G_i^A \right)$$

*Do jter=1,2   (Crank Nicholson)*

*Do iter=1,2  (Non-linear)*

$$\left(L_i\right)^{iter,\,jter} = \left(R_i\right)^{jter} - \left(N_i\right)^{iter-1,\,jter}; \qquad \left(N_i\right)^{0,1} = N_i\left(\mathbf{r}, t - \Delta t\right)$$

$$i = 1, \dots, Neq$$

*end do*

*end do*

Côté et al. 1998 Mon.wea.Rev., 126, 1373-1395

# Elliptic problem $P \equiv \phi' + RT_*\left(Bs + q\right)$

$$\nabla_\zeta^2 P + \frac{\gamma}{\kappa\tau^2 RT_*}\left(\delta_\zeta^2 P + \overline{\delta_\zeta P}^\zeta - \varepsilon\left(1-\kappa\right)\overline{P}^{\zeta\zeta}\right) = R$$

Vertical boundary conditions: Mixed type

$$\left[\frac{\gamma}{\kappa\tau^2 RT_*}\left(\delta_\zeta P - \varepsilon\overline{P}^\zeta\right)\right]_T = -\left(L''_\theta\right)_T \qquad \left[\frac{\gamma}{\kappa\tau^2 RT_*}\left(\delta_\zeta P + \kappa\overline{P}^\zeta\right)\right]_S = -\left(L''_\theta\right)_S + \frac{\phi_S}{\tau^2 RT_*}$$

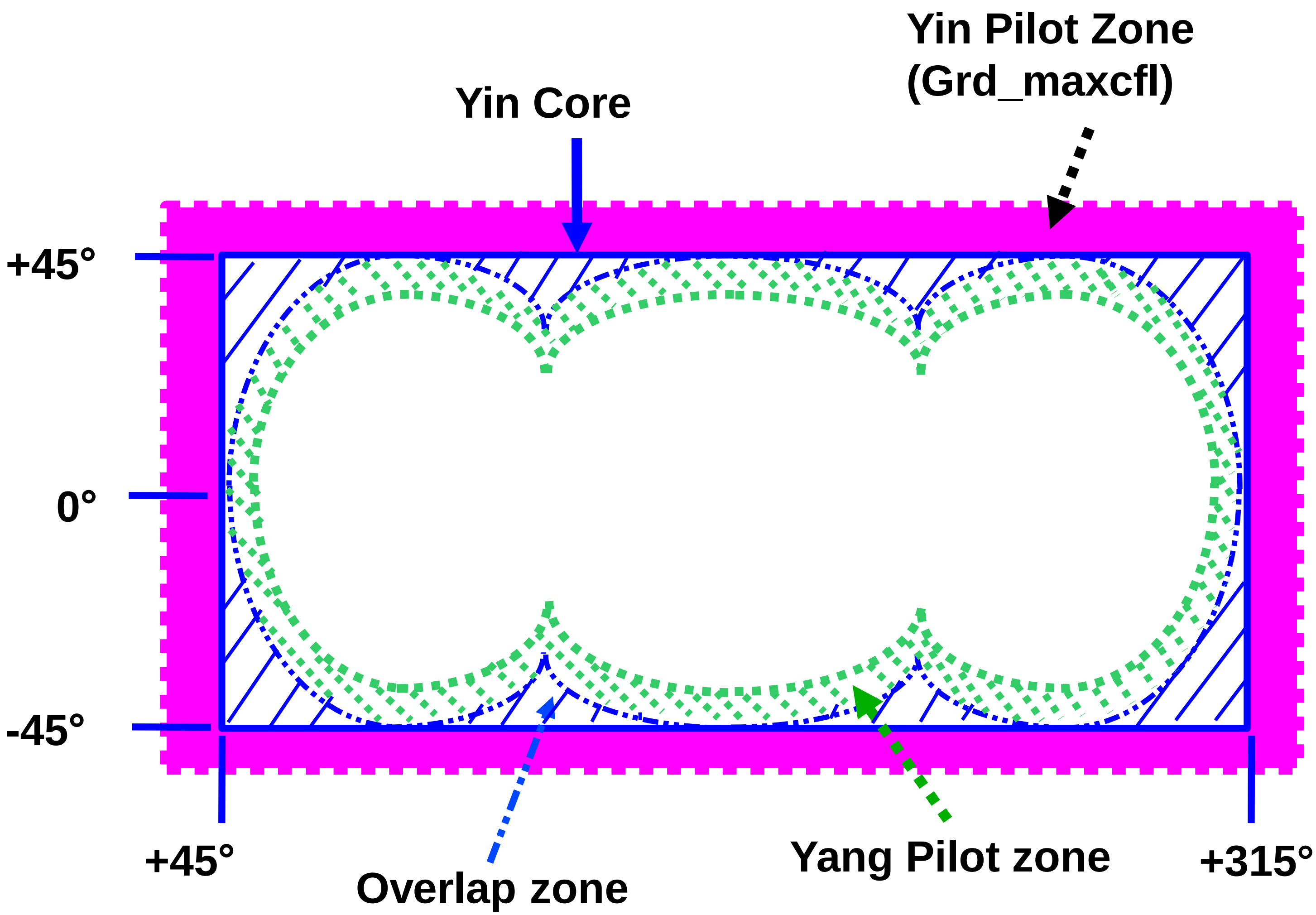
Horizontal boundary conditions: Dirichlet type

The others variables are calculated by back-substitution from P.

# Semi-Lagrangian on GY grid

- 1-Extend each panel (Yin, Yang) by a halo (size depends on CFL_max),
- 2-Interpolate from other panel to the halos the fields and (u,v,$\dot{\zeta}$ ) from previous time-step,
- 3-Do Semi-Lagrangian time integration as usual in each panel. Goto 2

Qaddouri et al. 2012 Q.J.R.Meteorol.Soc.138:989-1003



Yin Pilot Zone
(Grd_maxcfl)
Yin Core
+45°
0°
-45°
+45°
Overlap zone
Yang Pilot zone
+315°

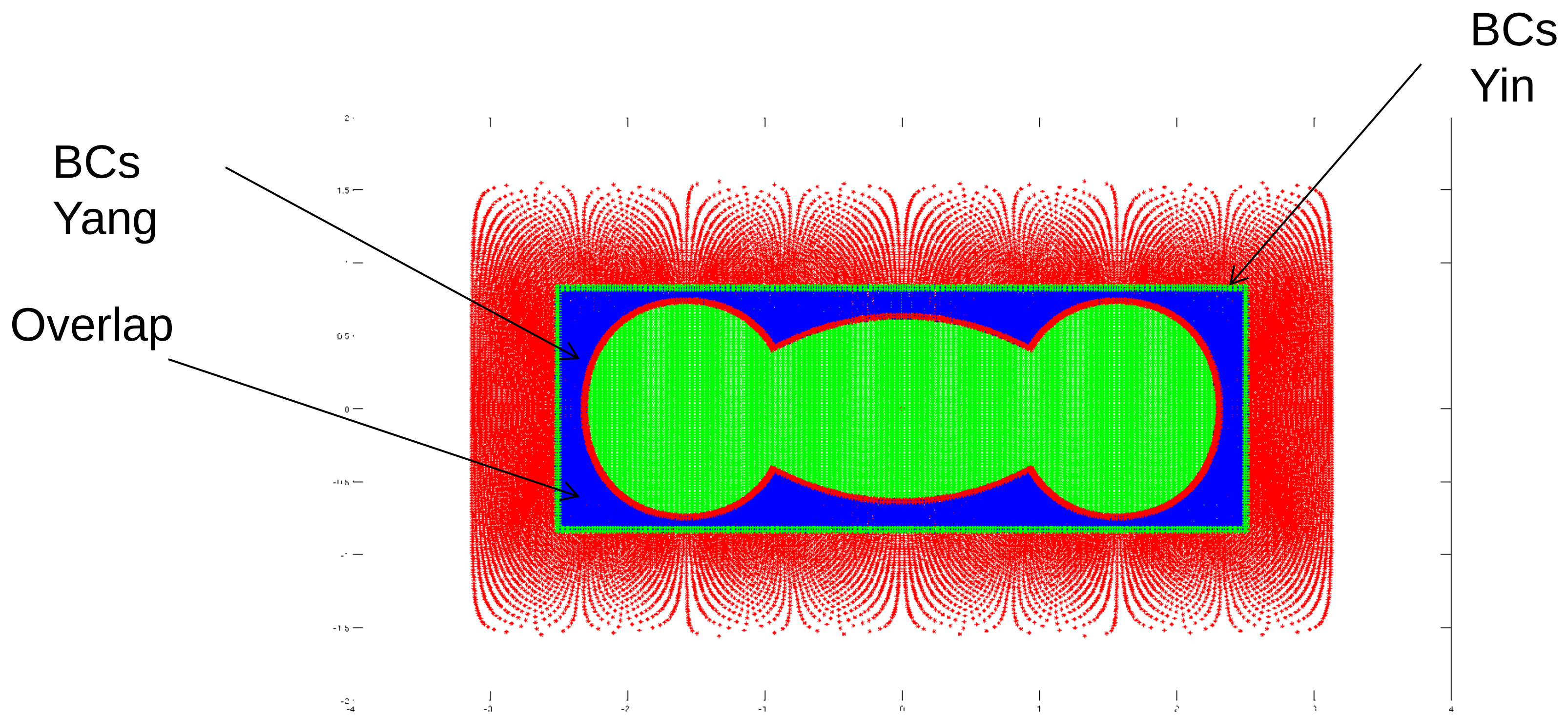
# Elliptic problem on GY grid with Schwarz method

- Global solution is obtained by solving iteratively 2 elliptic sub-problems ( Yin/Yang)
  - 1) receive Boundary conditions (BCs) from the other panel; solve local elliptic problem.
  - 2) if boundary conditions converge, stop; else send BCs to other panel ; goto 1

Note : we use 2 degrees as overlap to increase convergence.

Qaddouri et al. 2008 Appl.Numerical.Math.,58,4,459-471

# Iterative Schwarz method : GY grid




GDPS_YY 25Km : only 4 iterations are needed  for convergence
with 2 degrees overlap

# Why are there differences in the overlap?

- At each time step, the value of all the dynamical fields are prescribed by the other panel in its piloting region.

- The local solution of each panel includes the overlap region needed for the convergence of the elliptic problem.

- The two LAM solutions in the overlap can evolve independently (even though we assure a global convergence in the elliptic solver).

- Small and sharp differences may arise between the two panel point values in the overlap region ( due to some schemes that have threshold parameters).

# Solution: Flow relaxation scheme (blending)

- To eliminate the sharp differences, the point values in the overlap region are relaxed toward the value of the other panel at the end of dynamical time step (before physics).

$$\frac{\partial \mathrm{F}^{\mathrm{l}}(\mathrm{x},\mathrm{t})}{\partial t} = k(x)\left\{F^{l}(x,t) - F^{3-l}(x,t)\right\},\ = 1,2$$

- No change is made when the two panel solutions are in agreement

H C Davies 1976 Q J Roy Met Soc 102 405-418

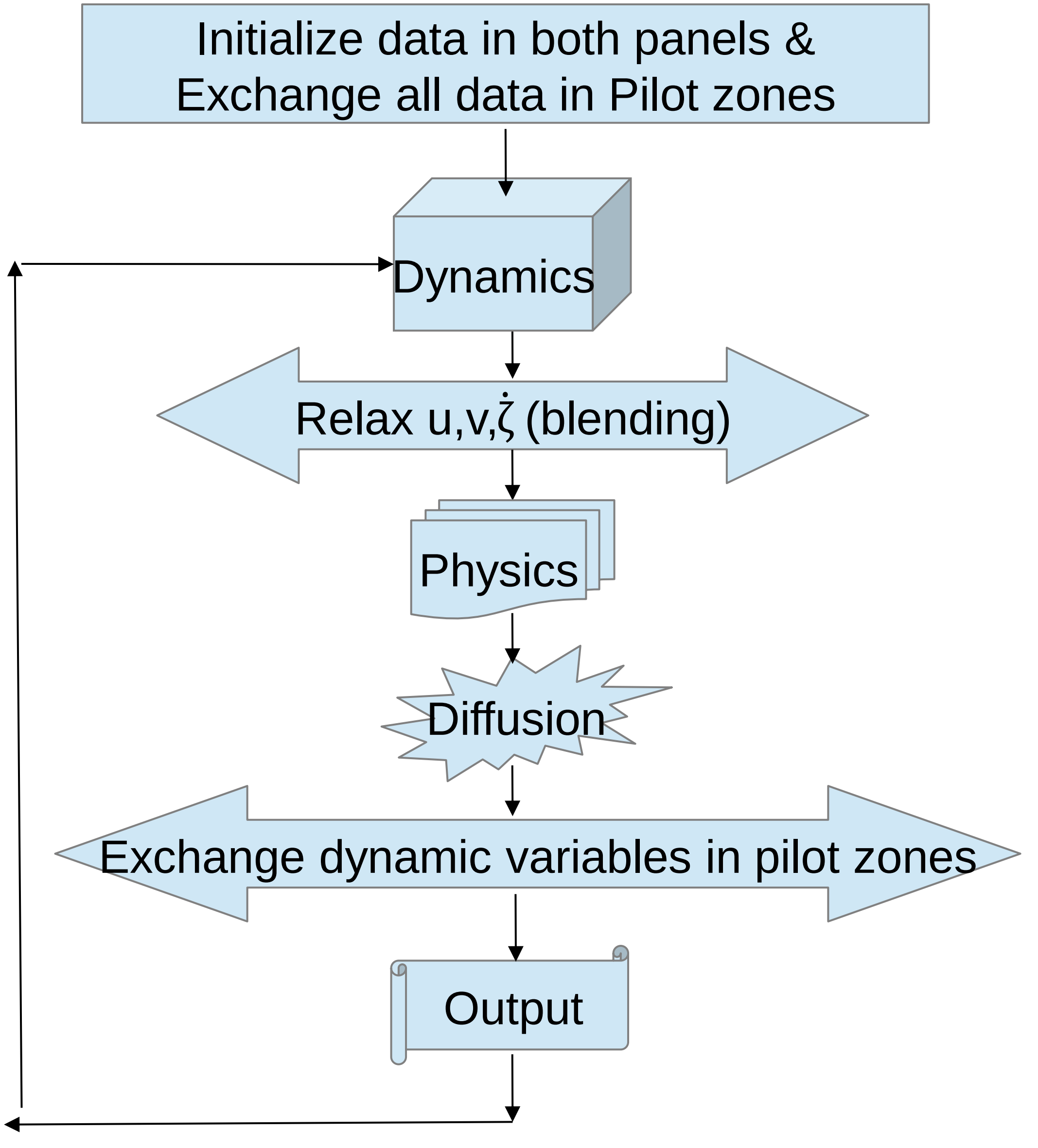
# Solution: Flow relaxation scheme (blending)

- $k(x)$ constant

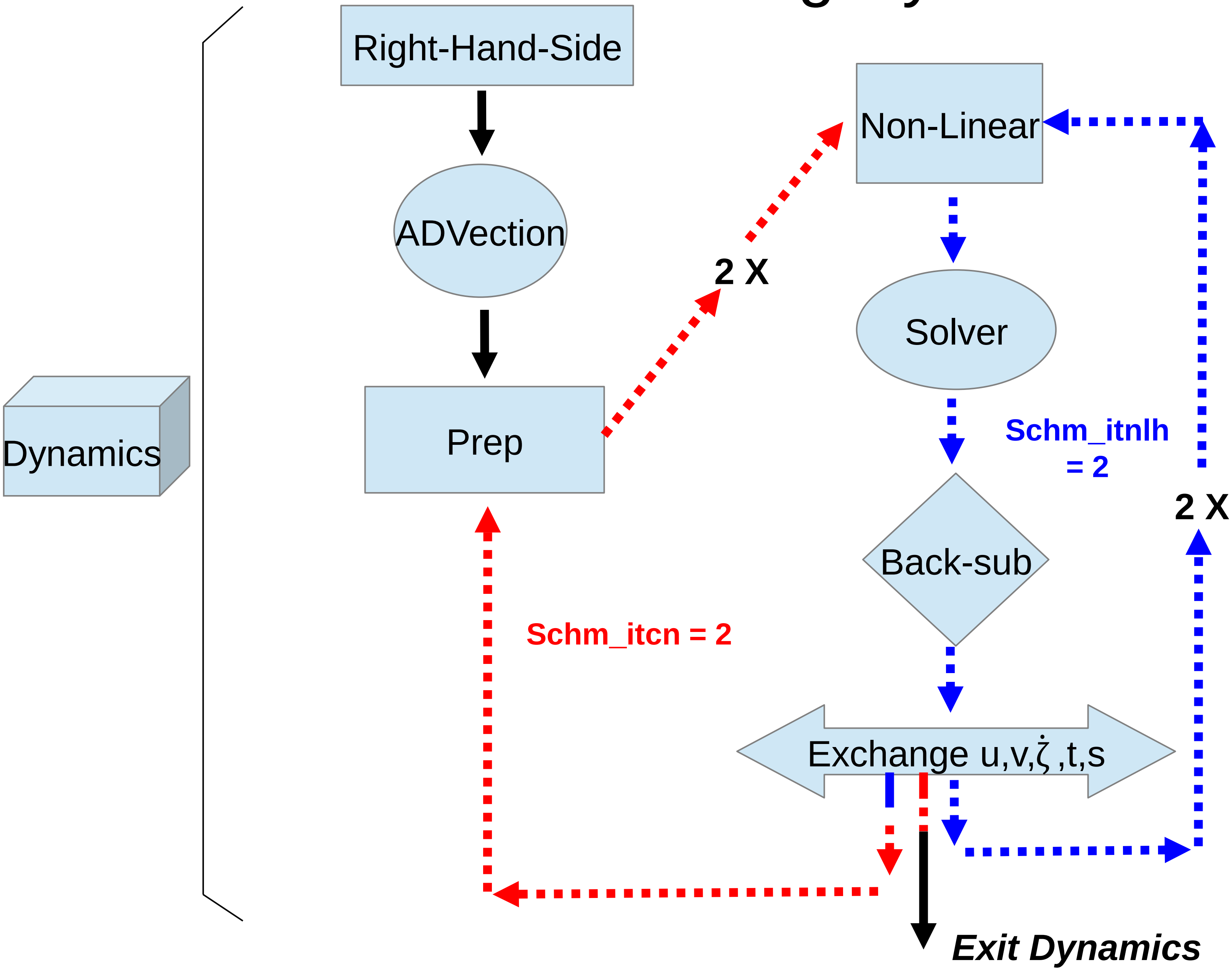
$$F_r^l(x,t) = 0.5 * \left\{ F^l(x,t) + F^{3-l}(x,t) \right\}, \; l = 1,2$$

- Several tests have been conducted ; the solution of relaxing only the winds (u,v) and generalized vertical velocity $\dot{\zeta}$ in the overlap region has been proven the best.

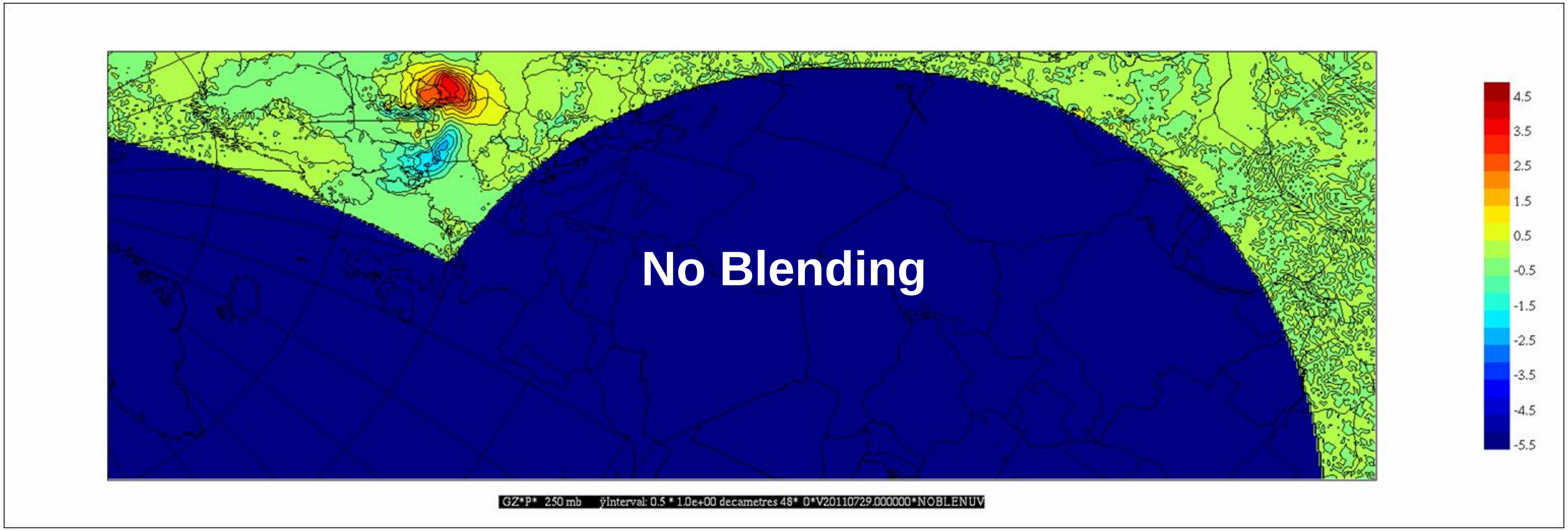
# Flow of GEM GY grid

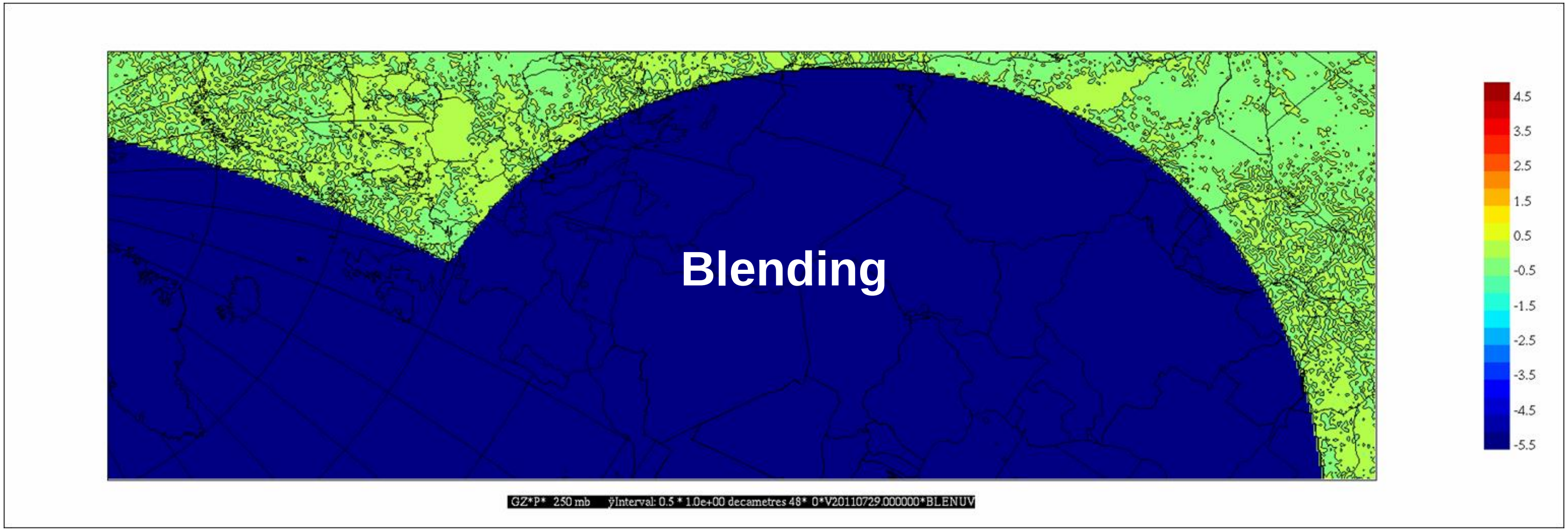


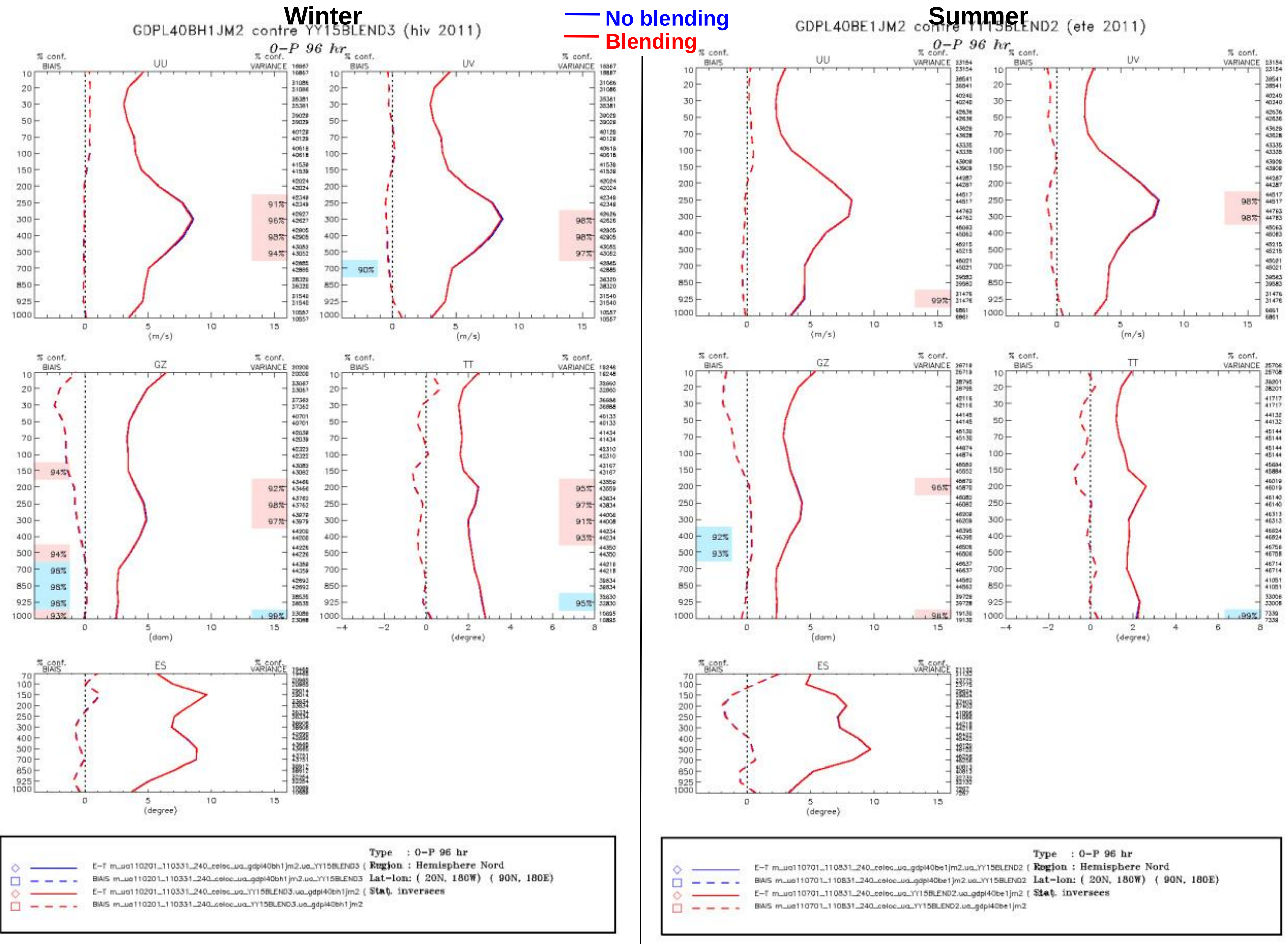
# Flow of GEM Yin-Yang Dynamic core



# Overlap zone





Winter
Summer
No blending
Blending
GDPL40BH1JM2 contre YY15BLEND3 (hiv 2011)
GDPL40BE1JM2 contre YY15BLEND2 (ete 2011)
0-P 96 hr
UU
UV
GZ
TT
ES
% conf. BIAIS
% conf. VARIANCE
(m/s)
(dam)
(degree)
Type : 0-P 96 hr
Region : Hemisphere Nord
Lat-lon: ( 20N, 180W) ( 90N, 180E)
Stat. inversees

# Differences between GU and GY

| GY (proposed) | GU (current) |
|---|---|
| GEM version 4.7.0 | GEM version 4.6.1 |
| Yin-Yang Grid | Global Lat-lon |
| Blending in Overlap Zone | |
| Advection using trapezoid wind average and cubic interpolation for trajectories | Advection using mid-point wind average and linear interpolation for trajectories |
| Explicit horizontal diffusion | Implicit horizontal diffusion |
| Vspng_zmean = False | Vspng_zmean = True |
| Psadj = True | Psadj = False |
| Geophysical fields created on each Yin and Yang grid individually | Geophysical fields created on global lat-lon |
| Output fields on 'U' grid | Output fields on 'Z' grid |
| No thermo level above momentum level (# of Thermo = # of Momentum) | Thermo level above momentum level (#of Thermo = # of Momentum+1) |
| Diagnostic level Winds and Temperature are not written out at 1.0 hyb. Instead: Winds are written at 10 meters Temperature at 1.5 meters | Diagnostic level Winds and Temperature are written out at 1.0 hyb |
| Scabality allows faster timings | Scalability limit reached |

# Merci Thank you