# A validation of the Yin-Yang global forecast GEM model

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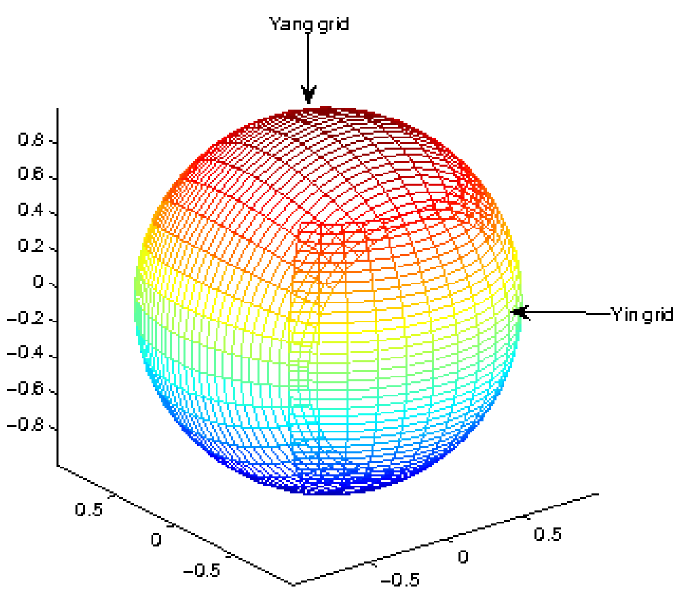
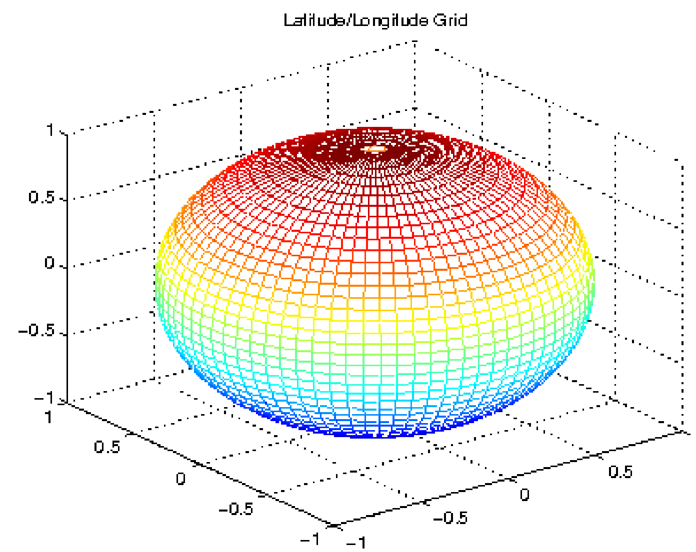
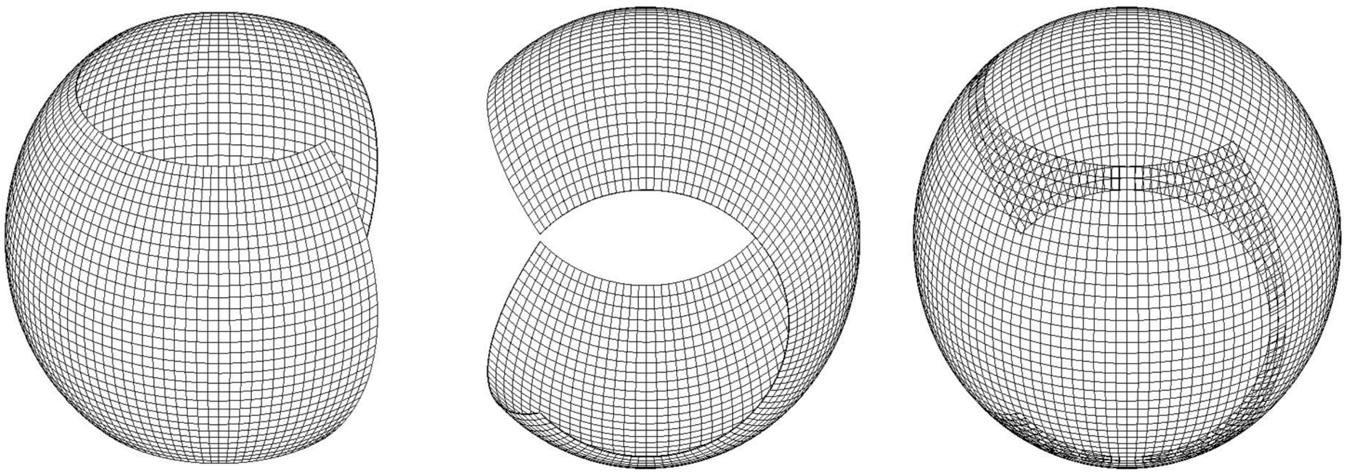
# Outline

- Introduction and motivation
- Model problem and method
- Model Meteorological validation
- Parallel Performance results



# Motivation



- Composite grid
- Pole free
- Each piece is Lat/Lon
- Numerical schemes on Lat/Lon adapted to Yin-Yang
- Schwarz method easily implemented(two-way coupling of 2 LAM models)

# Model problem

$$\frac{d\mathbf{V}_h}{dt} + f\mathbf{k}\times\mathbf{V_h} + RT\nabla_\zeta Bs + \nabla_\zeta \phi' = \mathbf{F^H}, \quad (1)$$

$$\frac{d}{dt}\ln\left(\frac{T}{T^*}\right) - \kappa\left[\frac{d}{dt}(Bs) + \dot{\zeta}\right] = F^T, \quad (2)$$

$$\frac{d}{dt}\left[Bs + \ln\left(1 + \frac{\partial B}{\partial \zeta}s\right)\right] + \nabla_\zeta\cdot\mathbf{V}_h + \frac{\partial\dot{\zeta}}{\partial\zeta} + \dot{\zeta} = 0, \quad (3)$$

$$\frac{T}{T^*} - \frac{\partial\left(\zeta - \phi'/RT^*\right)}{\partial\left(\zeta + Bs\right)} = 0, \quad (4)$$

Vertical coordinate $\zeta = \ln p - Bs$

$B = \left((\zeta - \zeta_{top})/(\zeta_{surf} - \zeta_{top})\right)^r$ ; $s = \ln(p_{surf}/10^5)$

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \frac{1}{\cos^2\theta}\left(U\frac{\partial}{\partial\lambda} + V\cos\theta\frac{\partial}{\partial\theta}\right), \quad (5)$$

$$U = \frac{u\cos\theta}{a}, V = \frac{v\cos\theta}{a}, \quad (6)$$

$$\nabla_\zeta\cdot\mathbf{V}_h = \frac{1}{\cos^2\theta}\left(\frac{\partial U}{\partial\lambda} + \cos\theta\frac{\partial V}{\partial\theta}\right), \quad (7)$$

$$\nabla_\zeta = \frac{a}{\cos\theta}\left(\frac{1}{a^2}\frac{\partial}{\partial\lambda}, \frac{\cos\theta}{a^2}\frac{\partial}{\partial\theta}\right), \quad (8)$$

# Boundary conditions

- vertical:

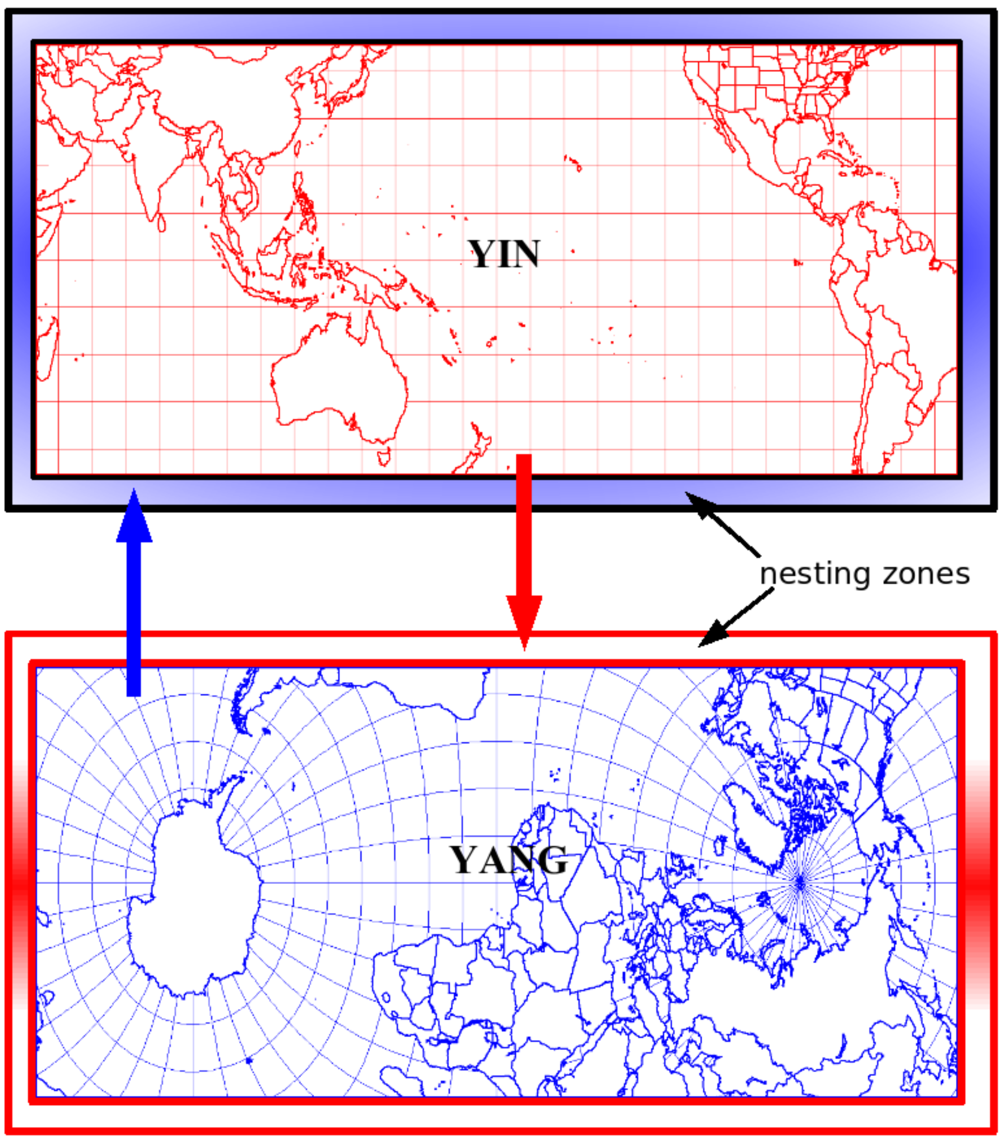
$$\dot{\zeta} = 0 \quad \textit{at} \quad \zeta = \zeta_{surf}, \zeta_{top}. \tag{9}$$

- Horizontal: Dirichlet type
  - Dirichlet type in elliptic solver
  - Dirichlet for all dynamical variables elsewhere

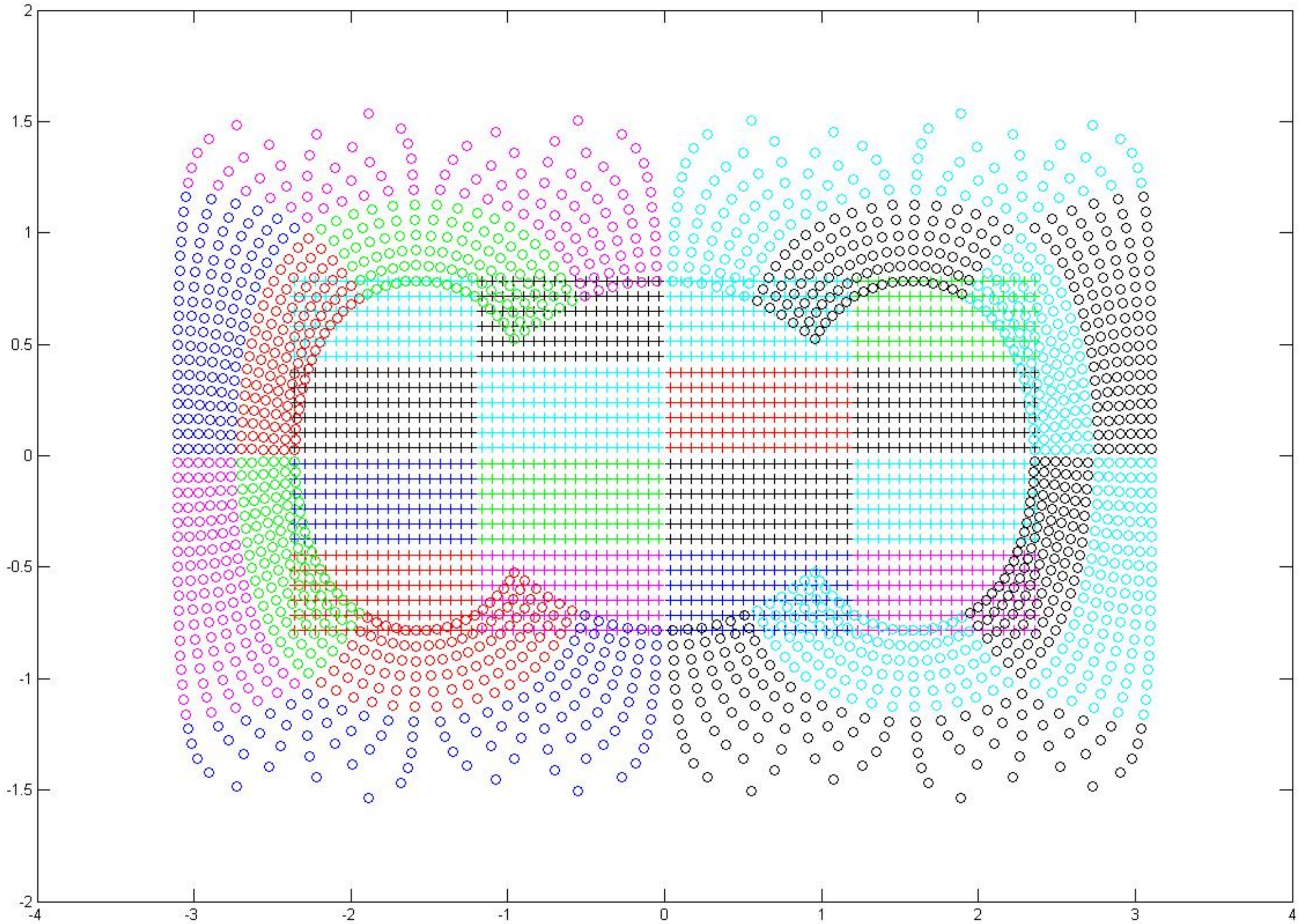
# Domain Decomposition method: Schwarz

- Domain $=$ 2 overlapping sub-domains (YIN/YANG)
- Solve iteratively equations on Sub-domains
  exchange variables at interfaces: Cubic Lagrange interpolation
- On each sub-domain: same local solver with the same time step
  1. The 2 time level semi-Lagrangian method with an implicit time discretization.
  2. Finite differences on horizontal Arakawa-C grid and on vertical Charney-Phillips grid

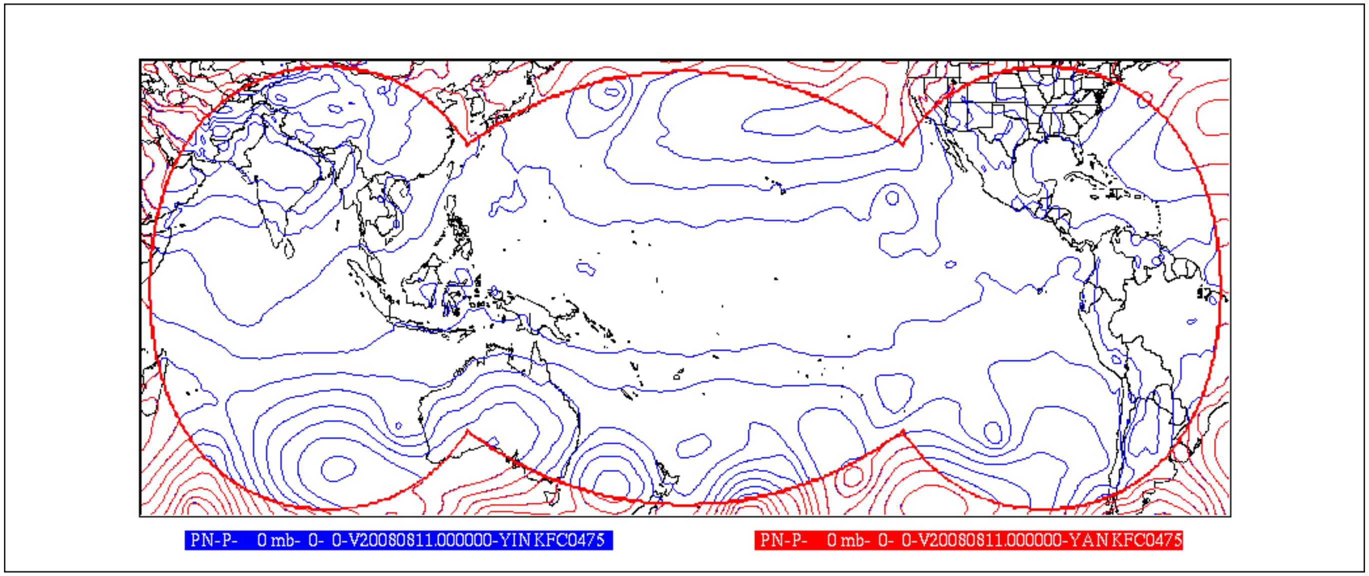
Data Exchange between Yin and Yang subgrids



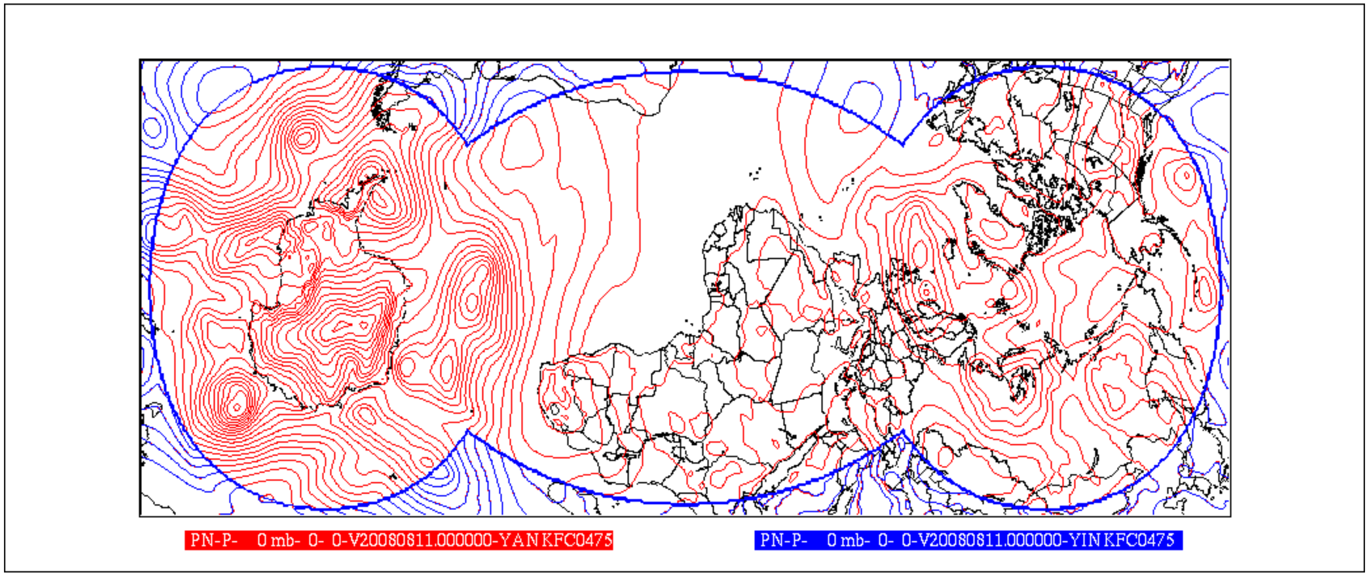
# Communication Pattern



# PN field seen in each native grid




Subgrid Yin




Subgrid Yang

# Temporal discretization

( see, Côté and Staniforth 1988 Mon. Wea. Rev. and also Yeh at al. 2002 Mon. Wea. Rev.)

- On each subdomain for each prognostic variable $F$

$$\frac{dF}{dt} + G = 0 \tag{10}$$

- Time discretization and weighted $G$ terms along trajectory

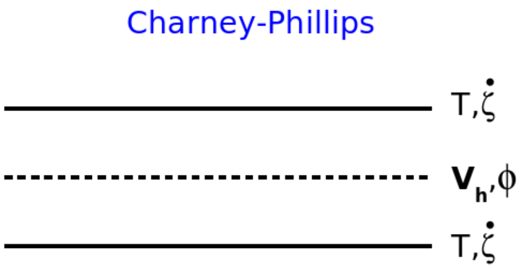
$$\frac{F - F^-}{\Delta t} + \left[ (\frac{1}{2} + \epsilon) G + (\frac{1}{2} - \epsilon) G^- \right] = 0. \tag{11}$$

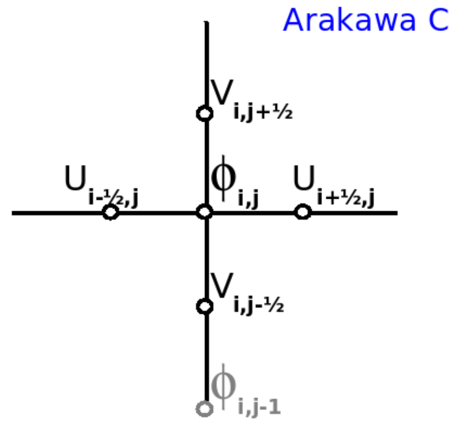
- Approximate solution for a trajectory calculation

$$\begin{aligned} \frac{d\mathbf{r}}{dt} &= \mathbf{V_h}(\mathbf{r}, \zeta, \mathbf{t}) & \frac{d^2\mathbf{r}}{dt^2} &= -\mathbf{r}\frac{\mathbf{V_h^2}}{\mathbf{a^2}} \\ \frac{d\zeta}{dt} &= \dot{\zeta}(\mathbf{r}, \zeta, \mathbf{t}) & \frac{d^2\zeta}{dt^2} &= 0, \end{aligned} \tag{12}$$

# Spatial discretization

( see, Girard et al. 2010 submitted Mon. Wea. Rev. and also Girard et al. 2010 CMC report)




- Vertical: finite differences on staggered Charney-Phillips grid

$$\frac{d\mathbf{V}_h}{dt} + f\mathbf{k}\times\mathbf{V_h} + R\overline{T}^{\zeta}\nabla_\zeta Bs + \nabla_\zeta\phi' = \mathbf{F^H}, \tag{13}$$

$$\frac{d}{dt}\ln\left(\frac{T}{T^*}\right) - \kappa\left[\frac{d}{dt}\left(\overline{B}^{\zeta}s\right) + \dot\zeta\right] = F^T, \tag{14}$$

$$\frac{d}{dt}\left[Bs + \ln\left(1+\delta_\zeta\overline{B}^{\zeta}s\right)\right] + \nabla_\zeta\cdot\mathbf{V}_h + \delta_\zeta\dot\zeta + \overline{\dot\zeta}^{\zeta} = 0, \tag{15}$$

$$\frac{T}{T^*} + \left[\frac{\delta_\zeta\left(\zeta - \phi'/RT^*\right)}{\delta_\zeta\left(\zeta + Bs\right)}\right] = 0, \tag{16}$$

- Horizontal: finite differences on staggered Arakawa C grid

# 3D Elliptic boundary value problem on Yin-Yang grid

( see, Qaddouri et al. 2008 Appl. Num. Math. and also Qaddouri $17^{th}$ DDM 2008)

- Linear set of equations reduce to EBVP

$$\triangle_\zeta P + \frac{\gamma}{\kappa\tau^2 RT^*}(\delta_\zeta^2 + \overline{\delta_\zeta}^\zeta)P = AP = R_E, \qquad (17)$$

where $P = \phi' + RT^* Bs$

- Iterative solution

$$\begin{aligned} AP^{(1),k} &= R_E^{(1)} \quad \text{on } \Omega_1, & AP^{(2),k} &= R_E^{(2)} \quad \text{on } \Omega_2, \\ B_1^{(1)}P^{(1),k} &= B_1^{(1)}P^{(2),k-1}, \quad \text{on } \delta\Omega_1, & B_1^{(2)}P^{(2),k} &= B_1^{(2)}P^{(1),k-1}, \quad \text{on } \delta\Omega_2 \end{aligned}$$

where: $B_l =$ Identity operator

- Other interface operator : future parallel implementation

# Digital Filter and High-order diffusion

- Diabatic digital filter[1] with a 6 hour span.
- Scale selective hyper-Laplacian[2] $\nabla^6$ applied to momentum variables and temperature.


1. Fillion, L., H. L. Mitchel, H. R. Ritchie and A. N. Staniforth, 1995: The impact of a digital filter finalization technique in a global data assimilation system, *Tellus*, **47A**, 304-323.

2. Qaddouri A.,and V.Lee 2008: Solution of the implicit formulation of high order diffusion for the Canadian Atmospheric GEM model. Proc. 2008 Spring Simulation Multiconf., High Performance Computing Symp., J.A. Hamilton, Jr. et al. (eds), Soc. For Modeling and Simulation Internat., Ottawa, Canada, 2008, pp 362-367

# Physical parameterization (Same as in the operational global model)

1. the ISBA land surface scheme for the surface layer effects (Bélair *et al.*, 2003a,b)
2. Geleyn boundary layer cloud scheme (Geleyn,1987)
3. Kuo transient shallow convection scheme (Kuo, 1974)
4. the Kain-Fritsch deep convection scheme (Kain and Fritsh,1993)
5. the Bougeault-Lacarrère turbulent mixing length scheme (Bougeault and Lacarrère, 1989)
6. the radiative transfer scheme from Li and Barker (Li and Barker, 2005)
7. the non-orographic gravity wave drag scheme by Hines (Hines, 1997a,b)
8. the inclusion of a methane oxidation parameterization scheme (same scheme used in ECMWF model)
9. the ozone climatology based on ozonesonde and satellite measurements from Fortuin and Kelder (Fortuin and Kelder, 1998)

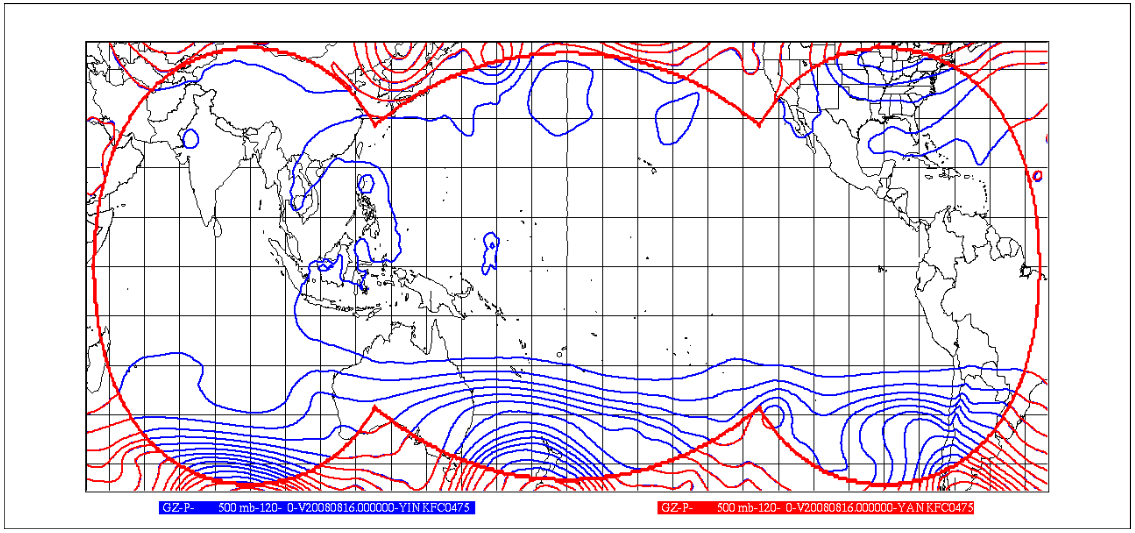
Strategies for improving the scalability of the UM in response to changing computer architectures.

Paul Selwood, Nigel Wood et al.

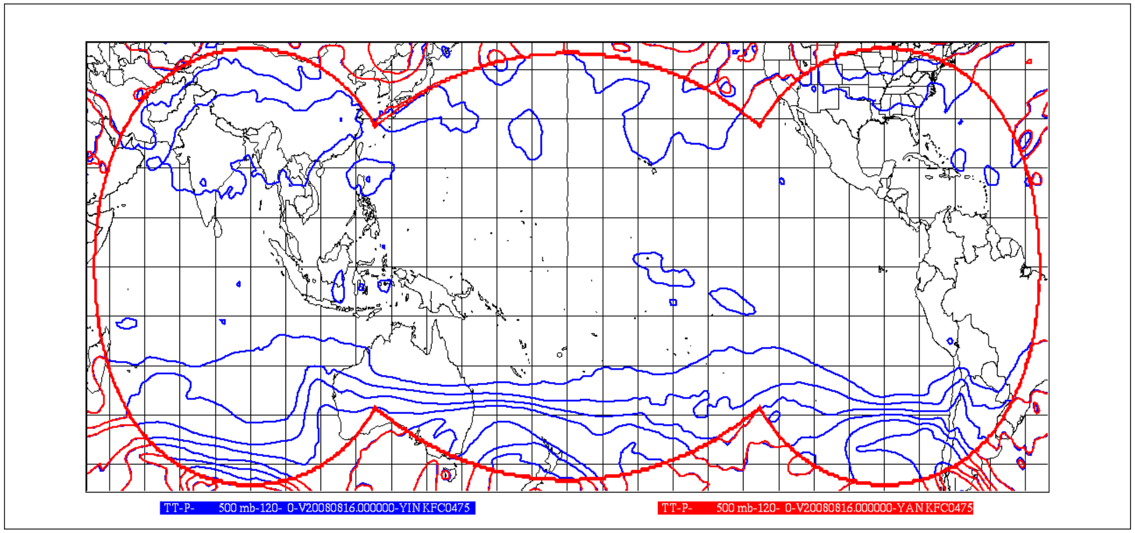
- Yin-Yang grid

*This avoids pole problems, but instead there is the overlap of the two quasi-hemispheric grids. Issues are then how to couple the two grids in an accurate (and conservative) way and determine whether there is, and if so how to control, spurious wave propagation near the overlap region*.

# No Spurious wave propagations near the overlap region




GZ at 500mb, 120 hour forecast blue=yin,red=yang




TT at 500mb, 120 hour forecast blue=yin,red=yang

# Numerical results

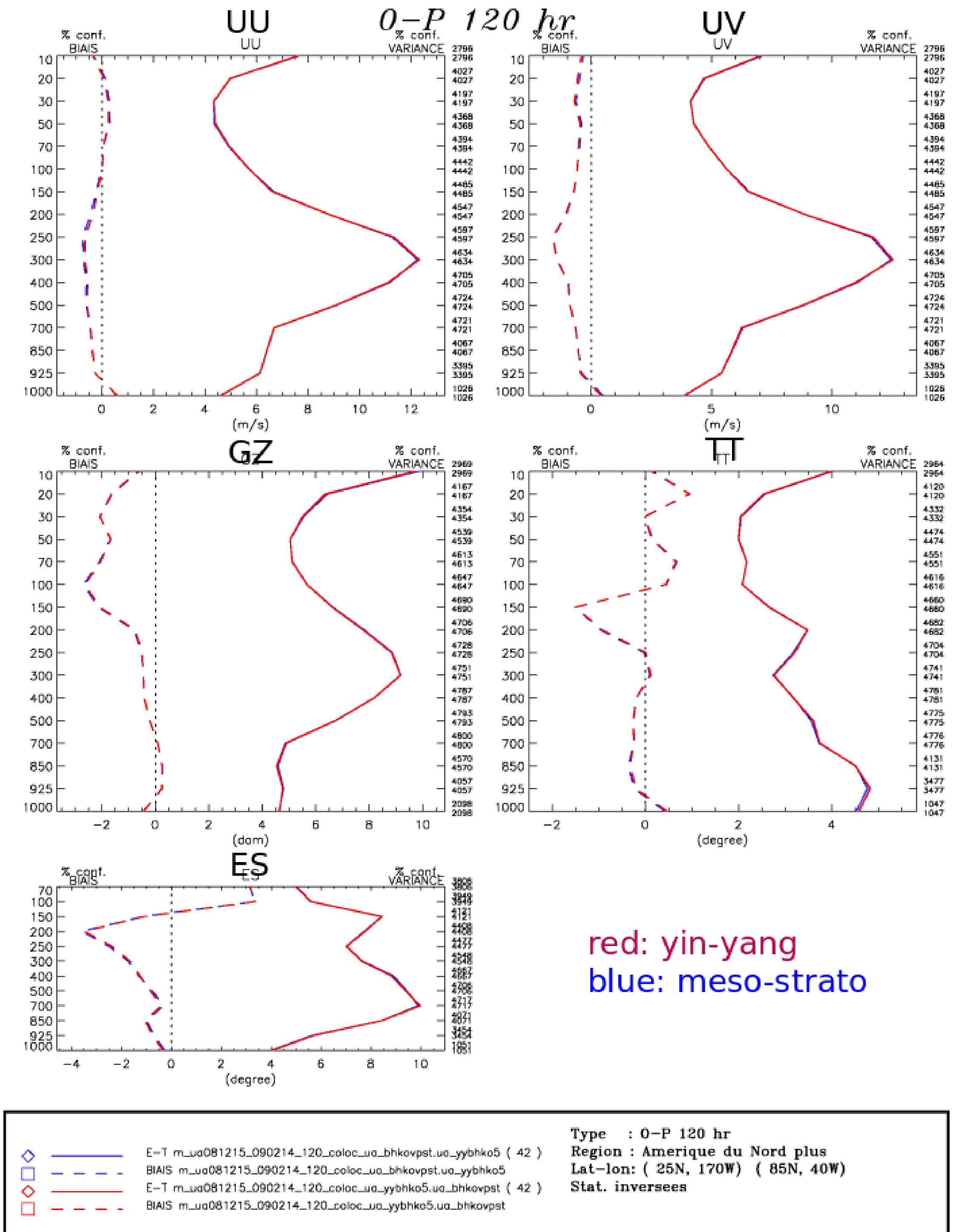
- Objective evaluation of 5 day forecasts against observations (radiosondes).
- Verification is done for a set of 42 winter and 42 summer integrations initialized with analysis of 2008.
- Two configurations with the same model: Yin-Yang$(600 \times 200 \times 80) \times 2$ and Lat/Lon$(800 \times 400 \times 80)$.

Summary of Differences

| | Global meso-strato | Yin-Yang meso-strato |
|---|---|---|
| Mode | Global | Two-way coupled LAM |
| Vertical Lid Sponge | Number of levels = 6 Implicit factorized del-2 horizontal, coefficient=50000, mf=10 | Number of levels = 6 Explicit 9 point filter, coefficient=.1 |

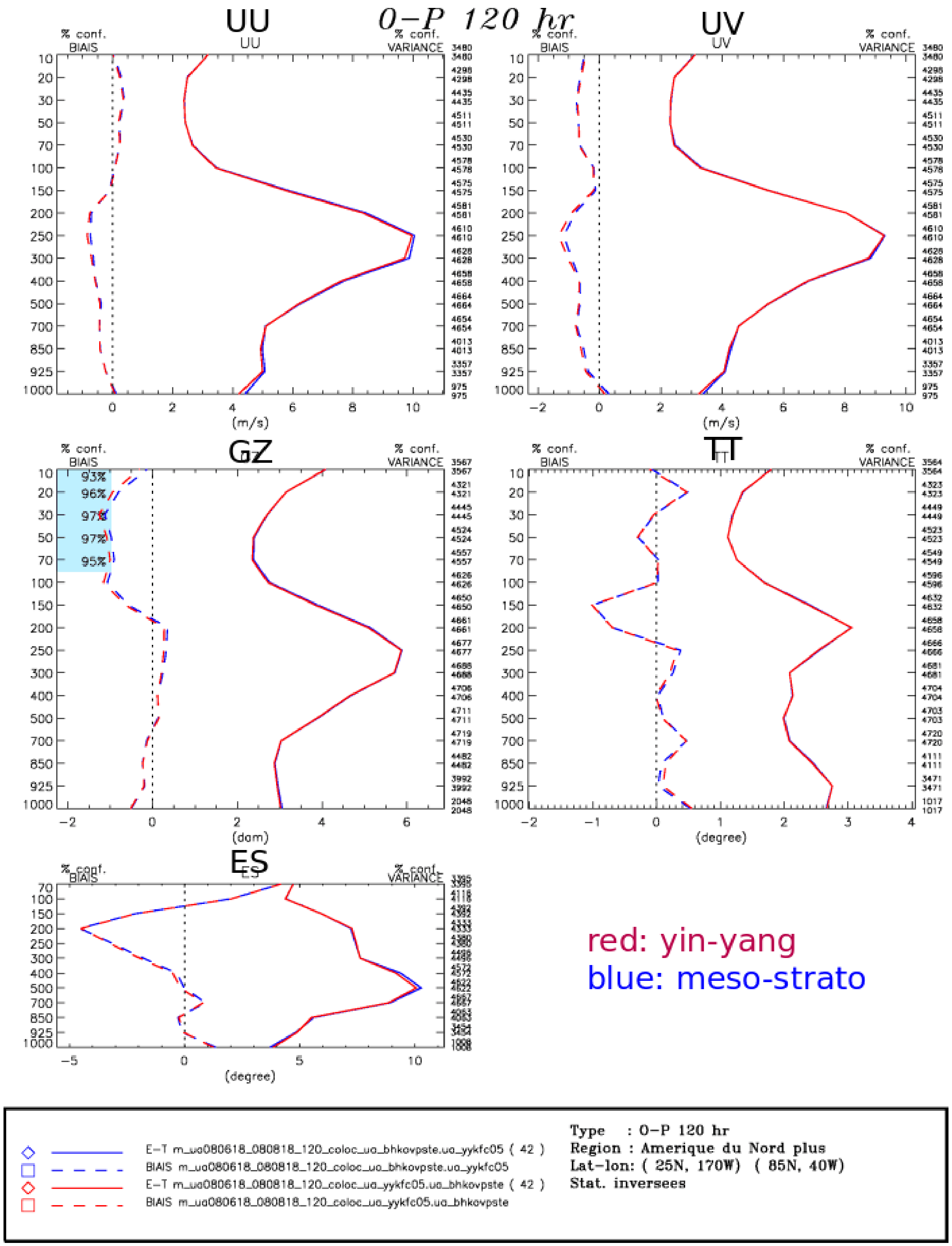
# Objective Evaluation for Winter Cases (5 day forecasts)

**North America**: Kfc trigger=.05, Hzd Diff Coef = .04



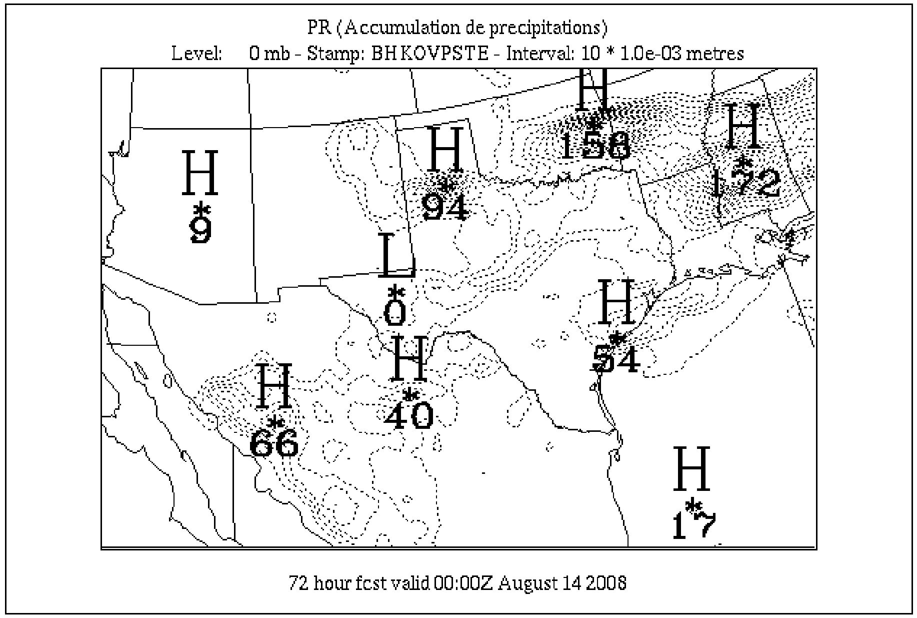
# Objective Evaluation for Summer Cases (5 day forecasts)

**North America**: Kfc trigger=.05, Hzd Diff Coef = .04

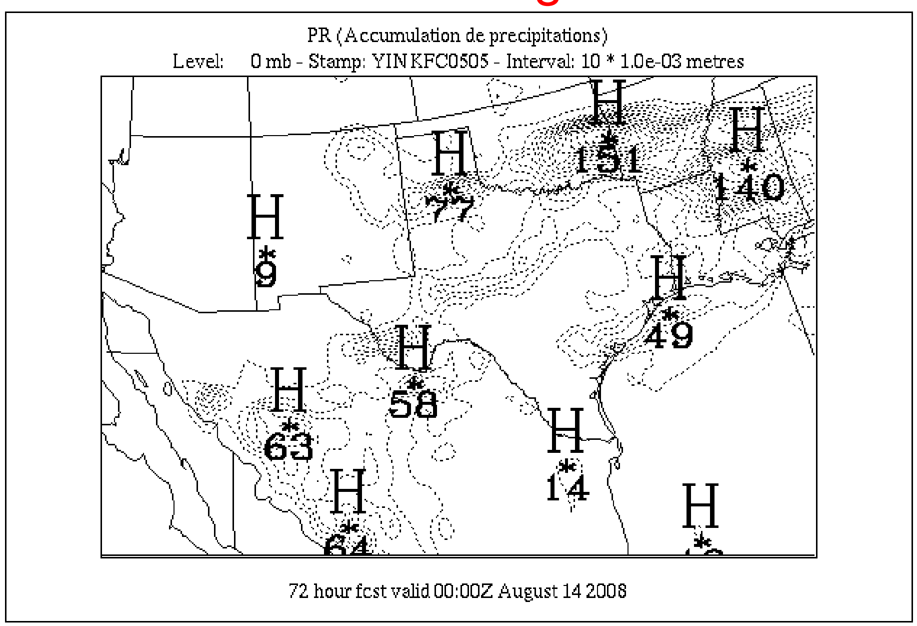


Accumulated Precipitation after 72 hrs Kfc trigger= .05

global

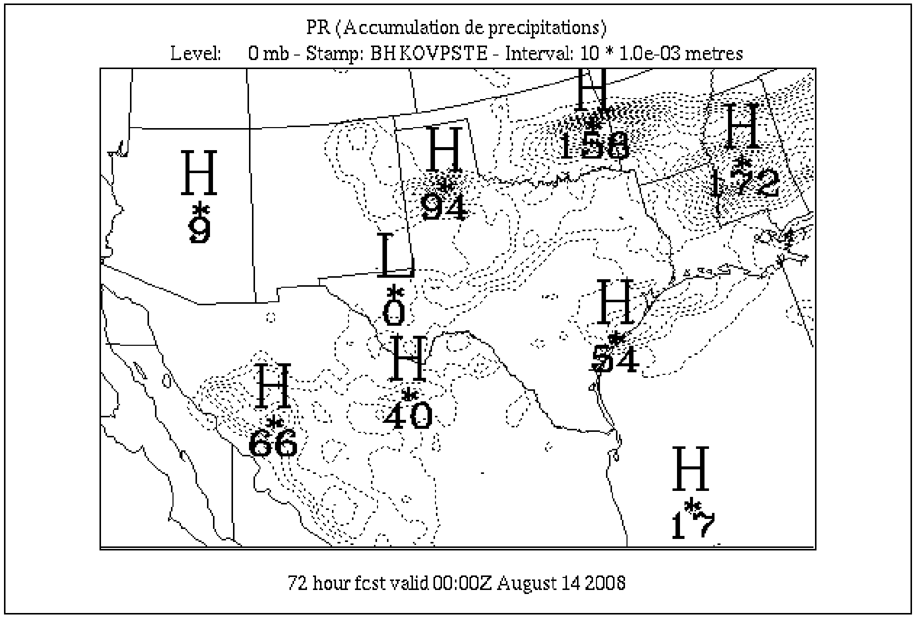



Yin-Yang



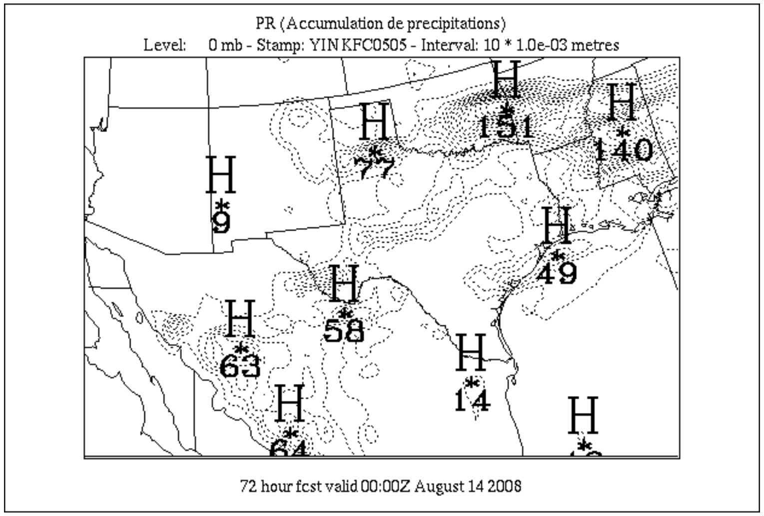
# Accumulated Precipitation after 72 hrs

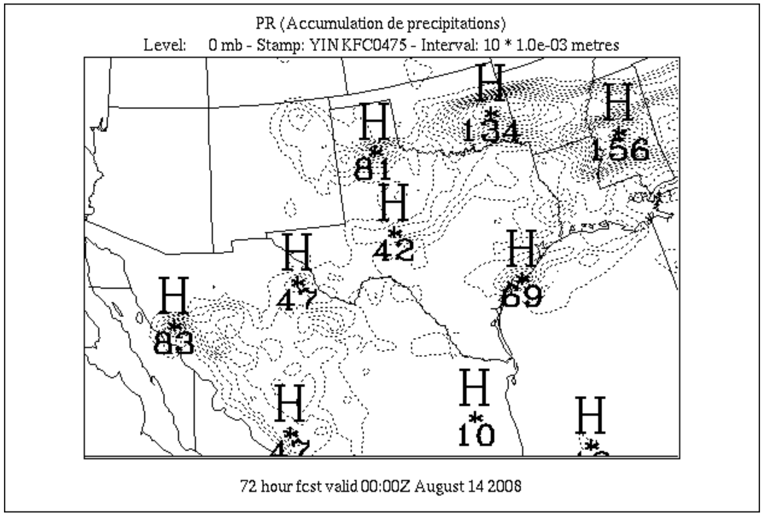
## global,Kfc trigger= .05




## Yin-Yang

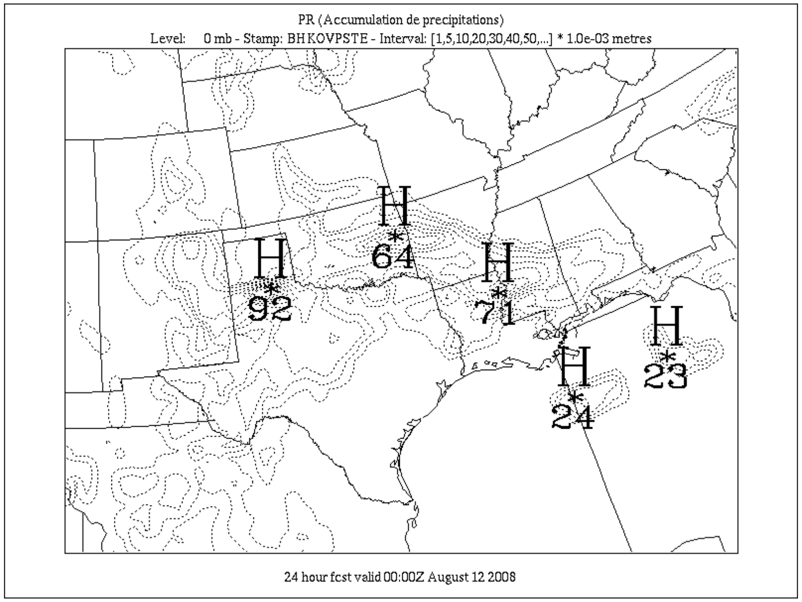
## Kfc trigger= .05,Kfc trigger= .0475

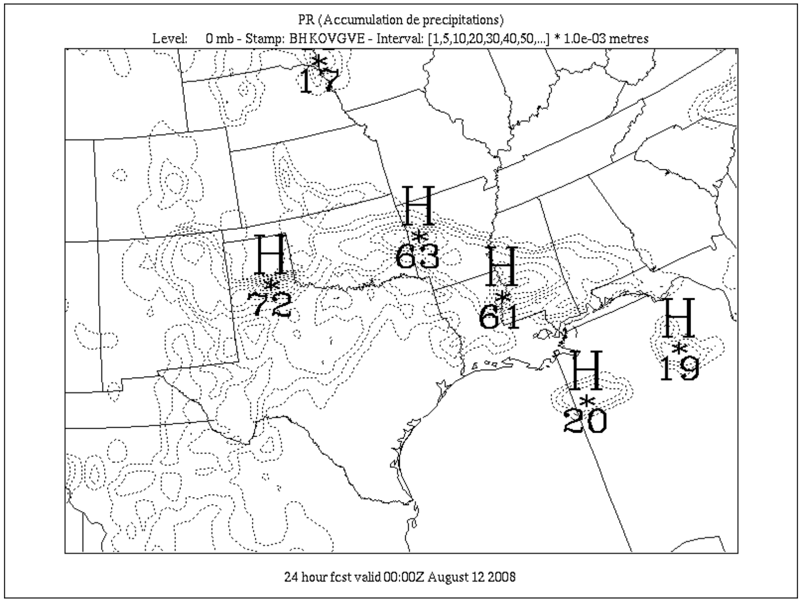


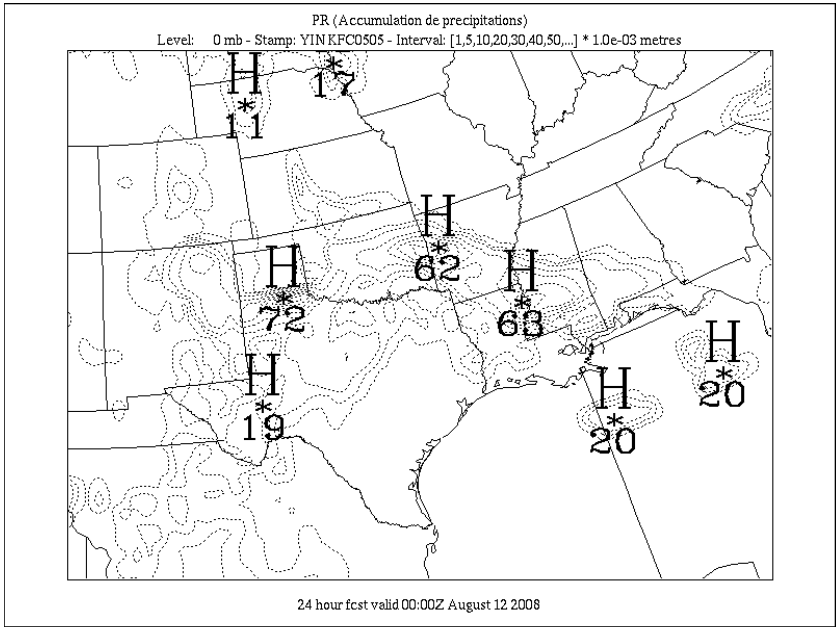
Accumulated Precipitation after 24 hrs Kfc trigger= .05

Left:Global Uniform, Right: Global Variable



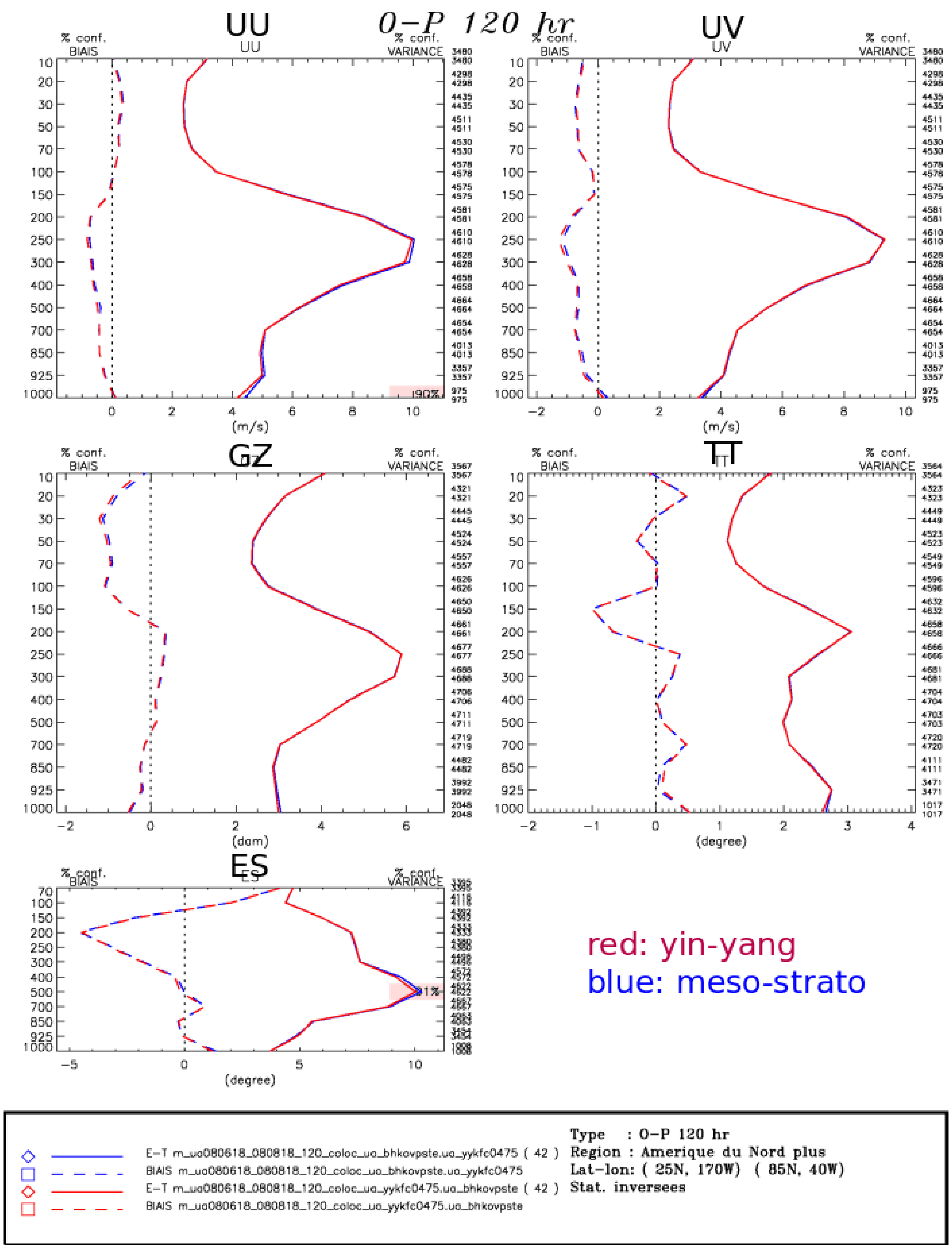




Yin

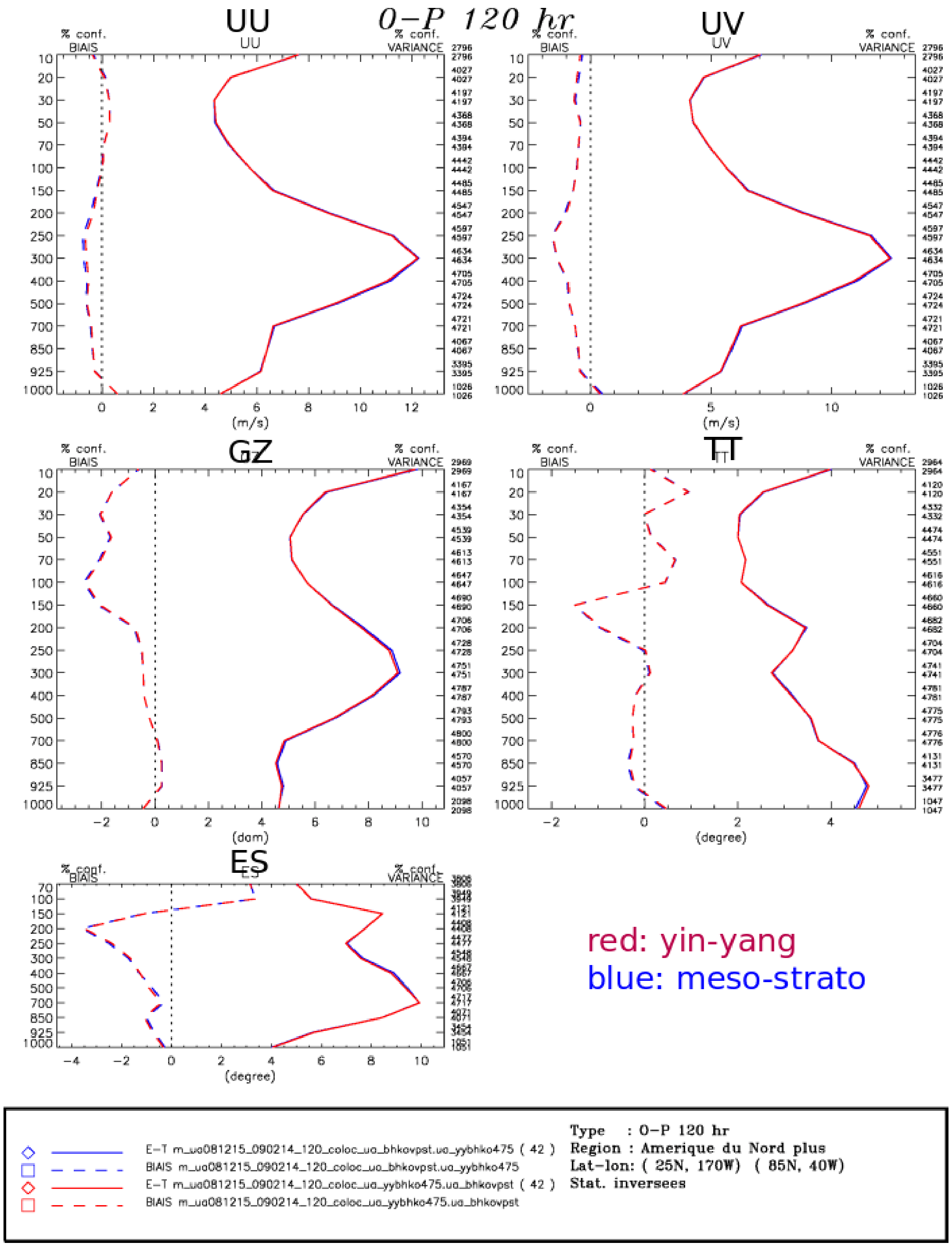


Objective Evaluation for Summer Cases (5 day forecasts)

**North America**: Kfc trigger=**.0475**, Hzd Diff Coef = .04



Objective Evaluation for Winter Cases (5 day forecasts)
**North America**: Kfc trigger=**.0475**, Hzd Diff Coef = .04




red: yin-yang
blue: meso-strato

## Setup for Performance Tests

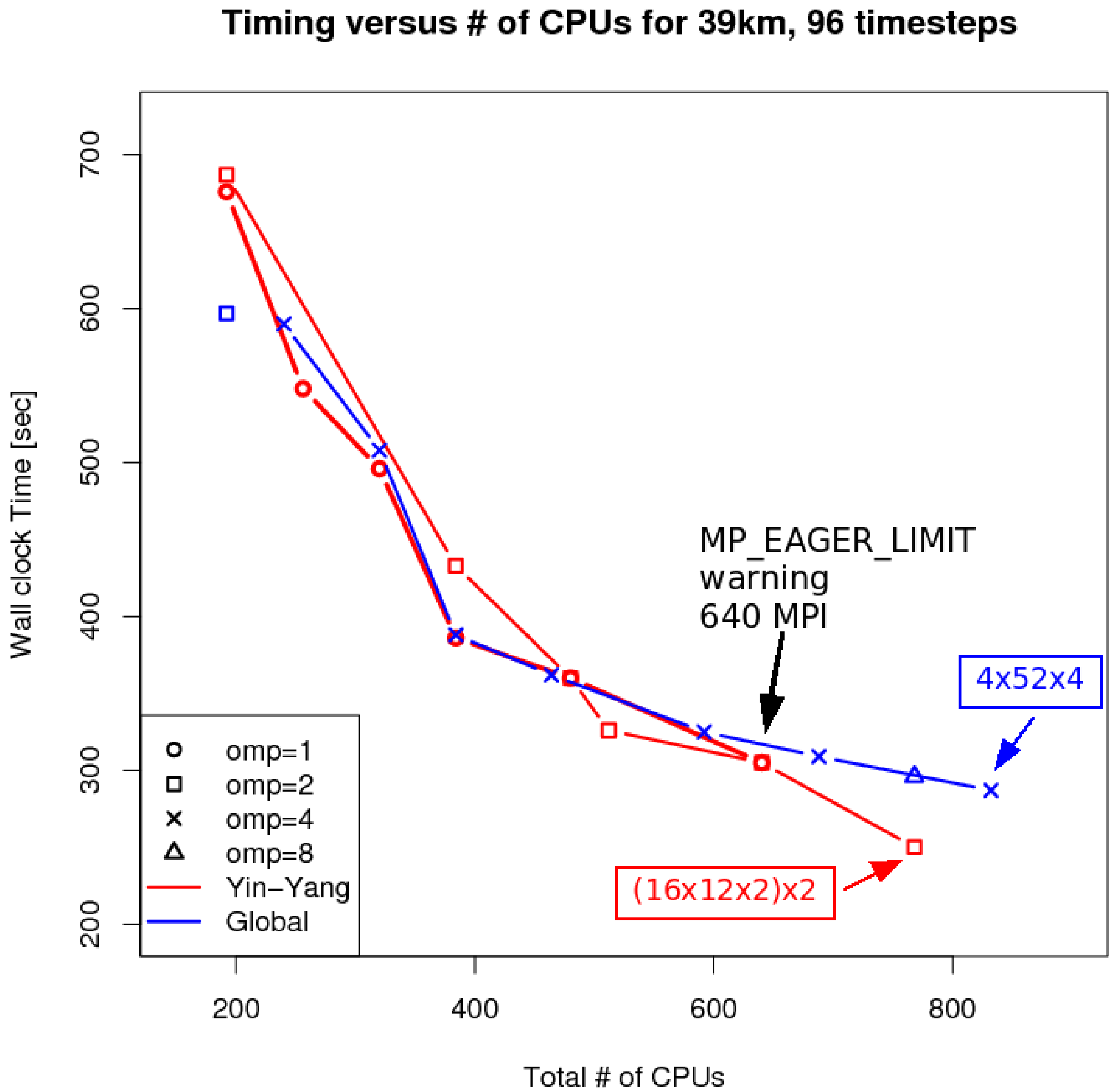
- equivalent resolution at the equator
- both uses FFT: constraint on the choice of points along X
- Yin-Yang: Number of points along X = 3 $\times$ number of points along Y
- Difficult to use the same processor topology for both

## Performance Results: Yin-Yang versus Global

FFT, $\Delta\tau$ = 720 sec, 39km resolution at the equator

**Global setup: 1024 x 512 x 80L**

**Yin-Yang setup: 799 x 267 x 80L** (overlap=2°, cfl=5)

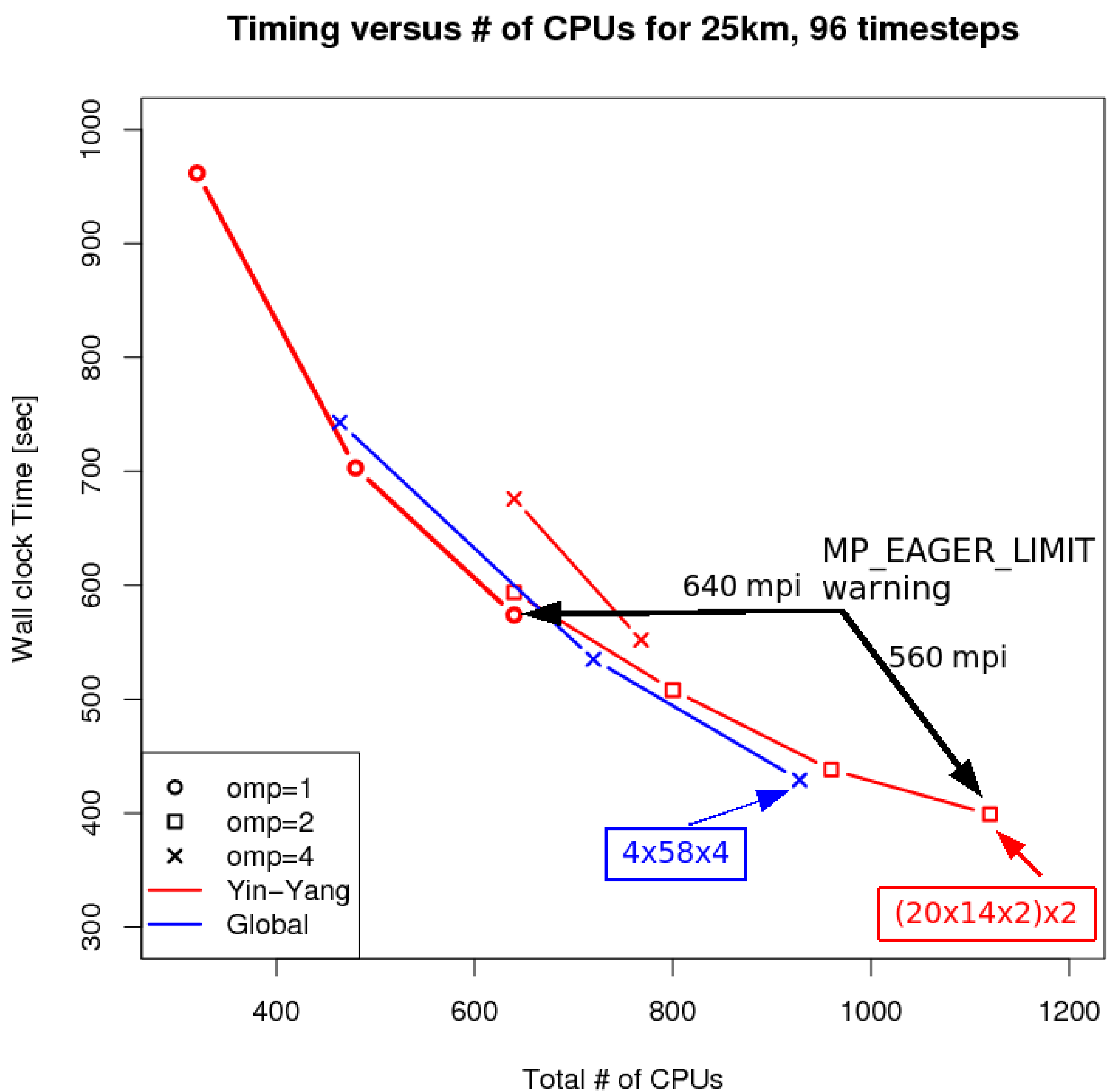


## Performance Results: Yin-Yang versus Global

FFT, $\Delta\tau$ = 450 sec, 25km resolution at the equator

**Global setup: 1600 x 800 x 80L**

**Yin-Yang setup: 1279 x 427 x 80L** (overlap=3°, cfl=5)



## Breakdown of timings: 25km

| Mode | PE Topo | NEST | BAC | SOL | ADV | PHY | TOT | CPUs |
|---|---|---|---|---|---|---|---|---|
| Global | (2x58x4) | N/A | 8 | 57 | 204 | 278 | 743 | 464 |
| Yin-Yang | (20x12x1)x2 | 52 | 25 | 130 | 147 | 215 | 703 | 480 |
| Global | (4x45x4) | N/A | 6 | 37 | 143 | 208 | 535 | 720 |
| Yin-Yang | (20x10x2)x2 | 38 | 20 | 104 | 101 | 130 | 508 | 800 |
| Global | (4x58x4) | N/A | 6 | 35 | 113 | 143 | 429 | 928 |
| Yin-Yang | (20x14x2)x2 | 31 | 19 | 77 | 80 | 93 | 399 | 1120 |

Legend:

PE Topo - processor topology (Npex X Npey X OpenMP)
NEST - exchange of boundary conditions
BAC - Back Substitution
SOL - Solver
ADV - Advection
PHY - Physics
TOT - Total Wallclock
CPUs - Total Number of CPUs used

## Future steps

- Add optimized interface Schwarz conditions in elliptic problem solution.
- Use iterative local elliptic solver instead of direct one.
- Replace implicit hyper-diffusion by a fast explicit one.
- Optimize trajectory calculations.
- Eliminate one Nest(BCS) call.

## Thank-you !

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