Sensitivity of Hurricane Intensity and Structures to Vertical Resolutions in HWRF

Da-Lin Zhang and Lin Zhu

Department of Atmospheric & Oceanic Science
University of Maryland

Xuejin Zhang

NOAA/AOML/Hurricane Research Division

Motivation

- Lindzen and Fox-Rabinovitz (1989)

$$\Delta Z = \frac{f}{N}\Delta X$$

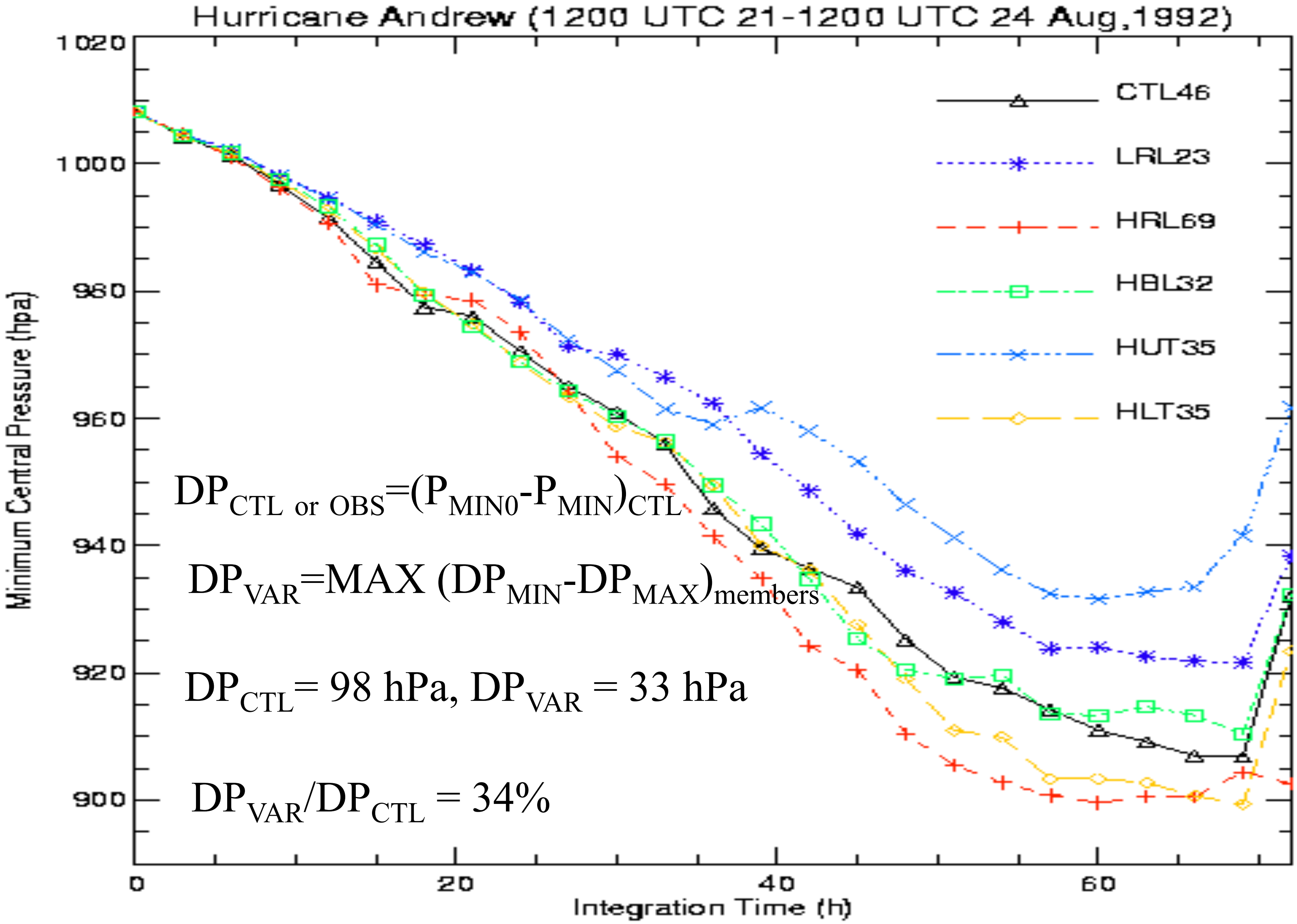
- Pecnick and Keyser (1987)

For gravity wave:

$$\Delta Z = m\Delta X$$

- Person and Warner (1991) studied frontal rainbands/CSI, and noted the development of spurious gravity waves when the horizontal and vertical resolutions are inconsistent.

Time series of P_{MIN} (Zhang and Wang 2003)



$DP_{CTL\ or\ OBS}=(P_{MIN0}-P_{MIN})_{CTL}$

$DP_{VAR}=MAX\ (DP_{MIN}-DP_{MAX})_{members}$

$DP_{CTL}= 98$ hPa, $DP_{VAR} = 33$ hPa

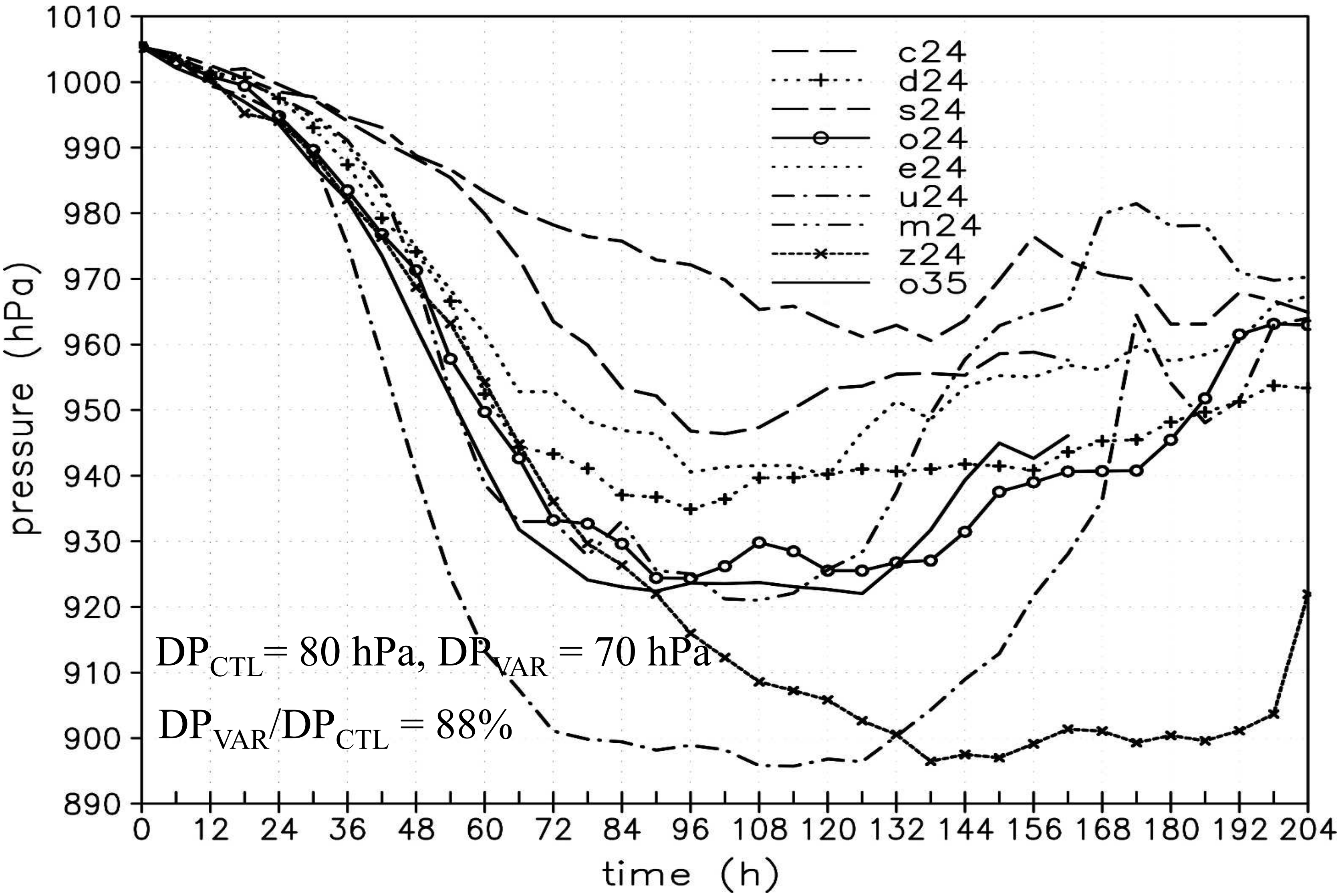
$DP_{VAR}/DP_{CTL} = 34\%$

MM5, $\Delta x = 6$ km, model top at 50 hPa, the Lin et al. (1983) microphysics

Conclusions from Zhang and Wang (2003)

- Hurricane intensity and structures are very sensitive to vertical resolution and its vertical distribution ($DP_{VAR}/DP_{CTL} = 34\%$, $\Delta V_{MAX} \sim 30\ m\ s^{-1}$, when vertical resolution increases from 23 to 69 levels);
- Increasing vertical resolution tends to simulate a stronger storm in terms of central pressure and 3D winds;
- Increasing the vertical resolution in the low troposphere is more efficient in intensifying a hurricane than that in the upper troposphere.

Time series of P_{MIN} (Kimball and Dougherty 2006)



MM5, Δx = 5 km, model top at 100 hPa, the Reisner graupel scheme, idealized Initial conditions with no mean flow

Conclusions from Kimball and Dougherty (2006)

- Results confirm those from Zhang and Wang (2003);
- A well-resolved outflow layer is found to be necessary for proper storm intensification, while a well-resolved inflow layer does not necessarily correspond to an intense storm.
- Weak storms develop when too few levels are assigned to the upper layer.

Previous work suggests

- Hurricane intensity and inner-core precipitation structures are very sensitive to vertical resolution and its distribution;
- Guidelines for vertical resolution distribution in hurricane models need to be developed in order to improve hurricane intensity forecasts.

The Goals of this project:

- To improve our understanding of the impact of vertical resolution on hurricane intensity forecasts with different datasets;
- To see to what extent hurricane intensity forecasts by HWRF are sensitive to vertical resolution and its vertical distribution;
- To examine to what extent we can optimize the distribution of vertical resolution for the finest grid size of 3 km in HWRF.

Experimental Design

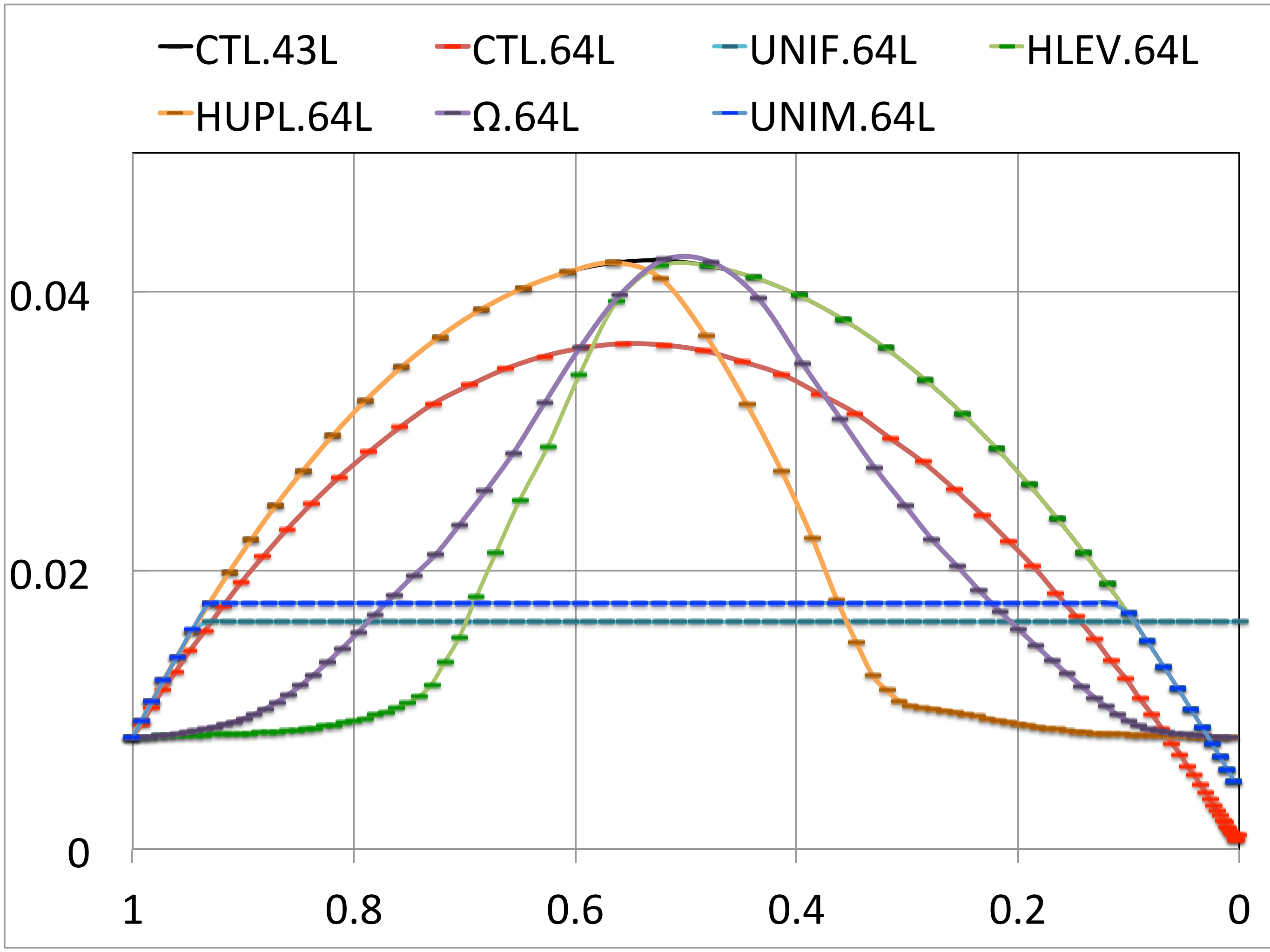
- Operational HWRF, 27/9/3km, CTL.43L, model top at 50 hPa; a fixed surface layer, 126-h forecasts
- Group 1 runs deal with different vertical resolutions in the lower, middle and upper troposphere, and uniform resolution in the layers above $\sigma = 0.9$.
- Group 2 runs deal with different vertical resolutions while keeping the near-parabolic shape of the σ-distribution similar to that in CTL.43L.

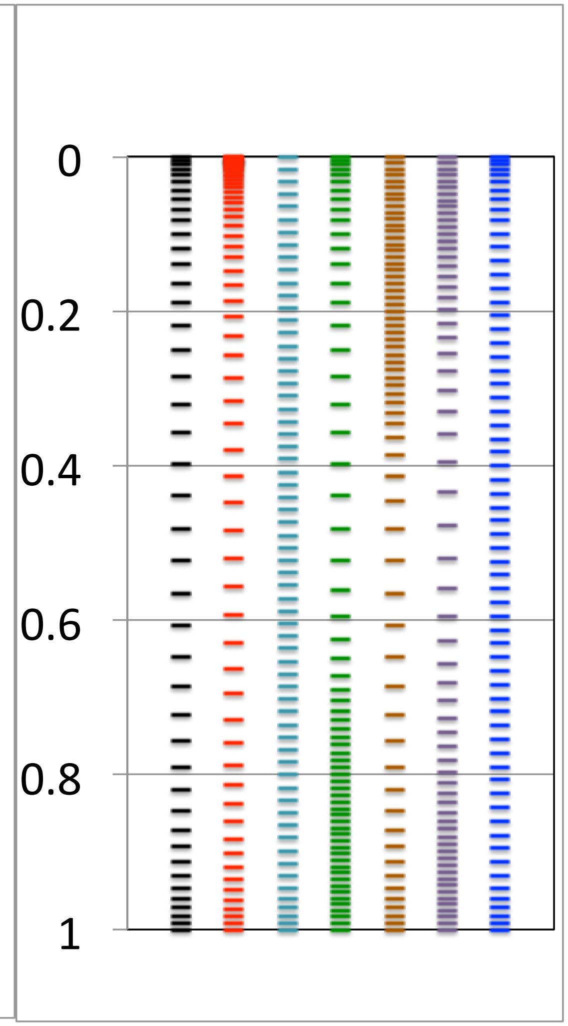
Real-data and idealized-data tests

- 12 real-data cases during 2009-2012:
  i) cold start; and ii) warm start;
- Idealized simulations with a bogus vortex under i) no mean flow, ii) mean flow, and iii) vertical wind shear

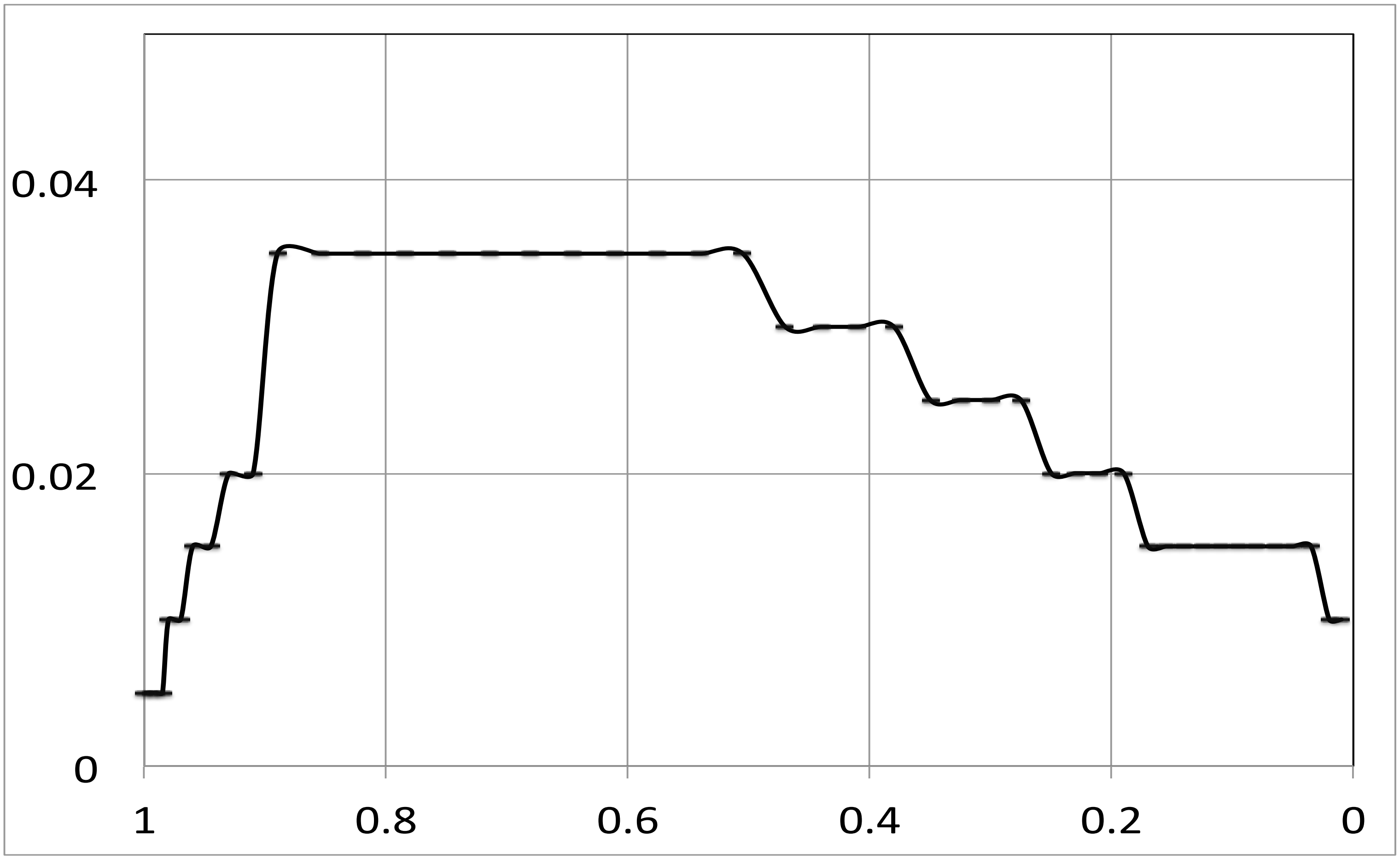
Group 1

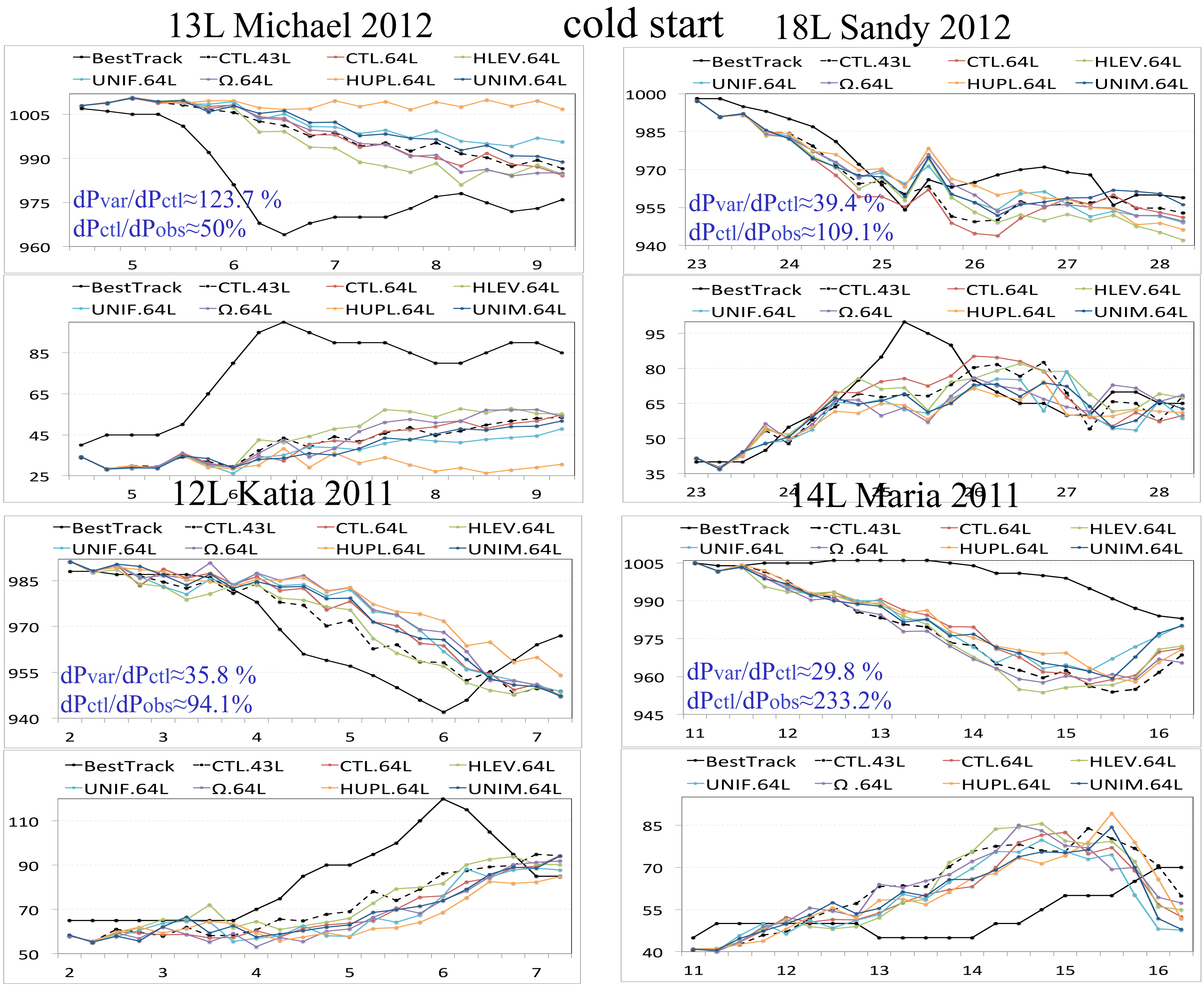
UNIF: uniform above 0.9; UNIM: uniform midlevels;
HLEV: high resolution low-levels; HUPL: high resolution upper-levels.



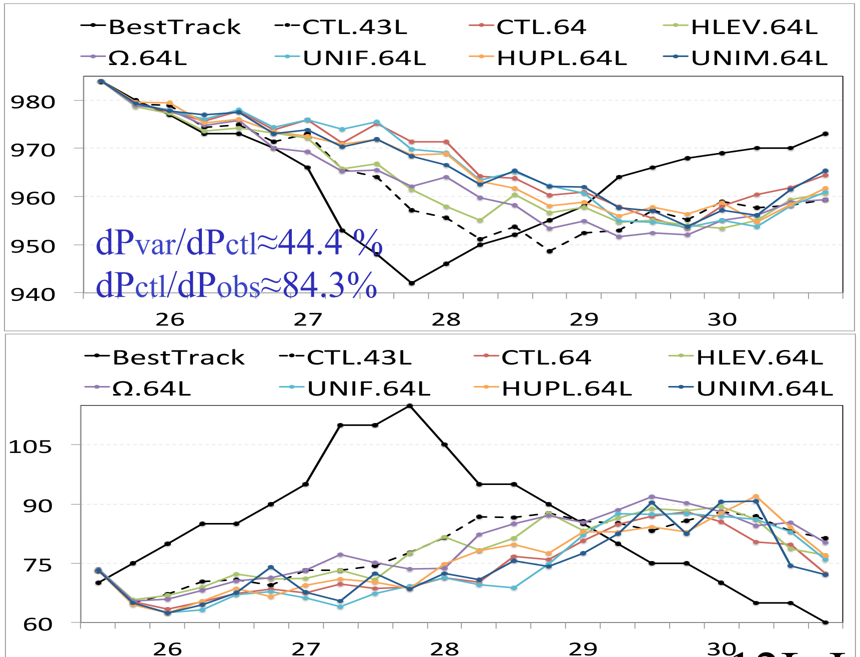


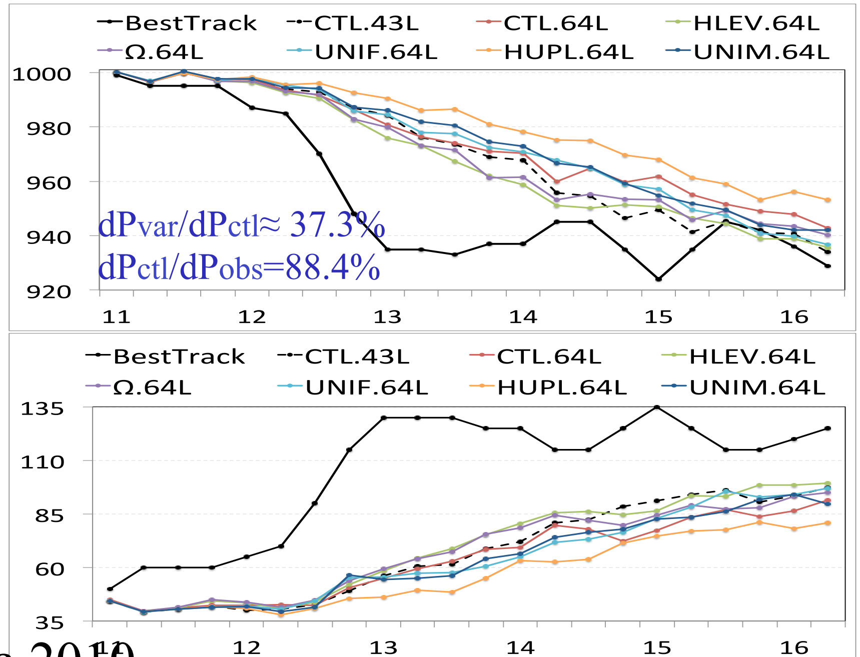
Vertical resolution and its vertical distribution used by Zhang & Wang (2003), Liu et al. (1997), and Kimball and Dougherty (2006)



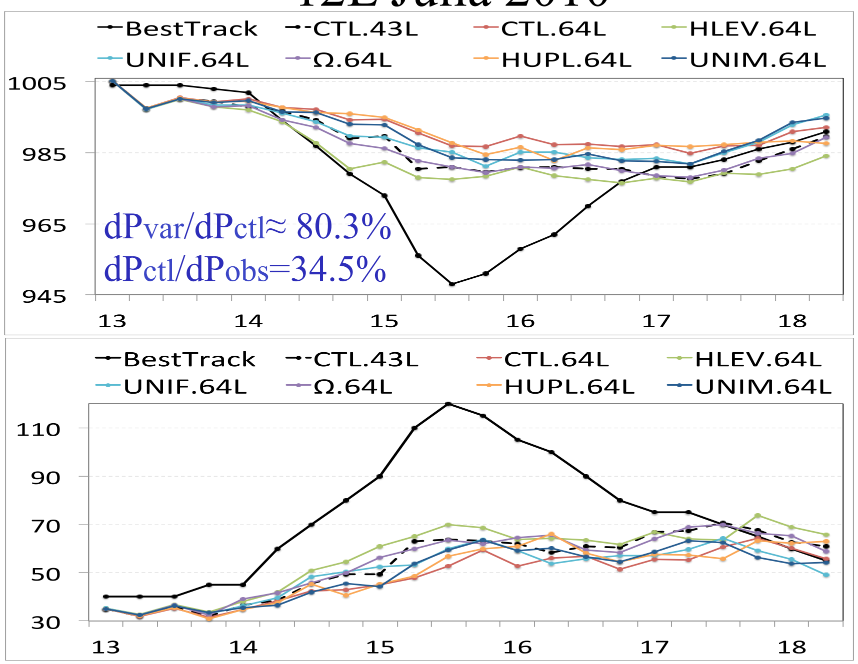

13L Michael 2012
cold start
18L Sandy 2012
12L Katia 2011
14L Maria 2011
BestTrack
CTL.43L
CTL.64L
HLEV.64L
UNIF.64L
Ω.64L
HUPL.64L
UNIM.64L
dPvar/dPctl≈123.7 %
dPctl/dPobs≈50%
dPvar/dPctl≈39.4 %
dPctl/dPobs≈109.1%
dPvar/dPctl≈35.8 %
dPctl/dPobs≈94.1%
dPvar/dPctl≈29.8 %
dPctl/dPobs≈233.2%

06L Danielle 2010   cold start   11L Igor 2010

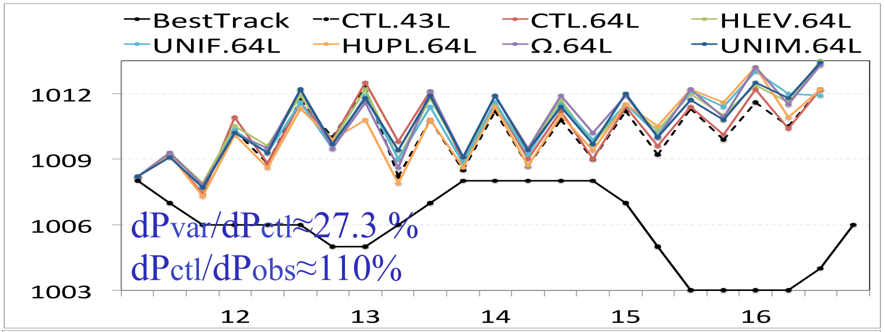


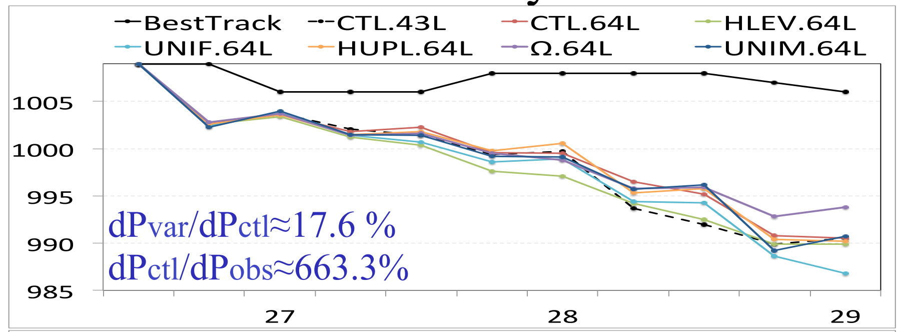


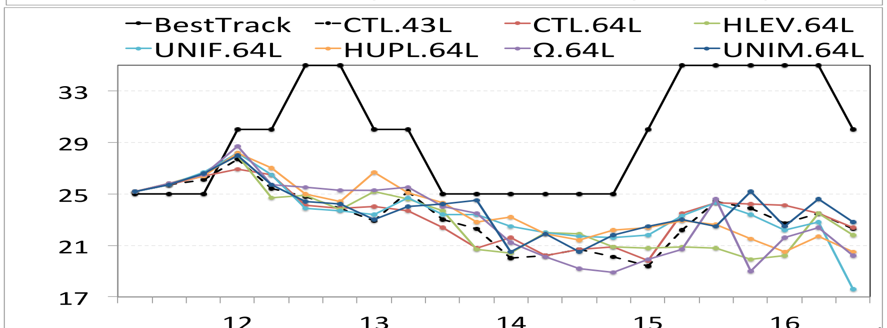
12L Julia 2010

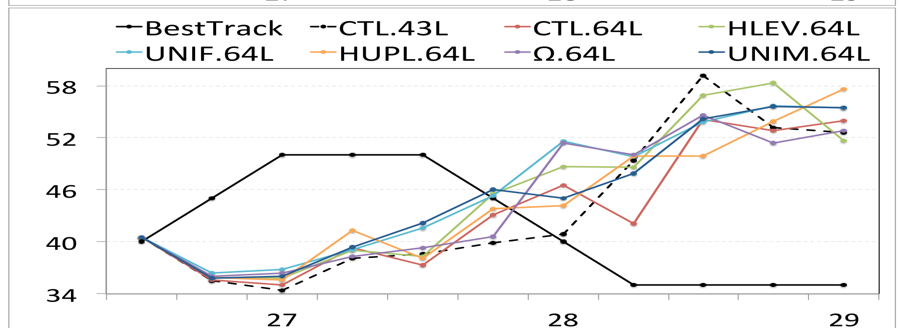


02L Ana 2009 cold start 05L Danny 2009

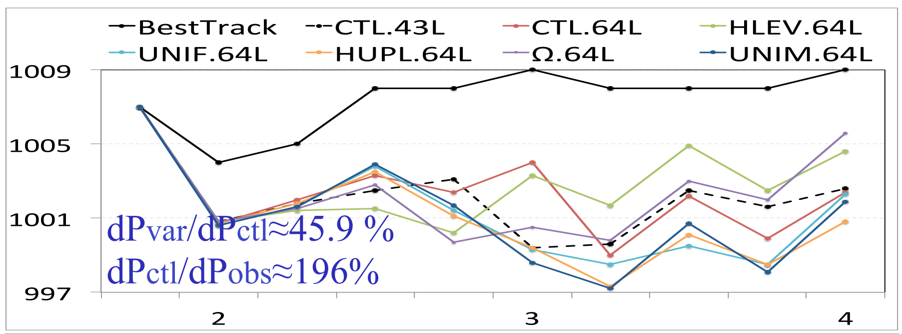


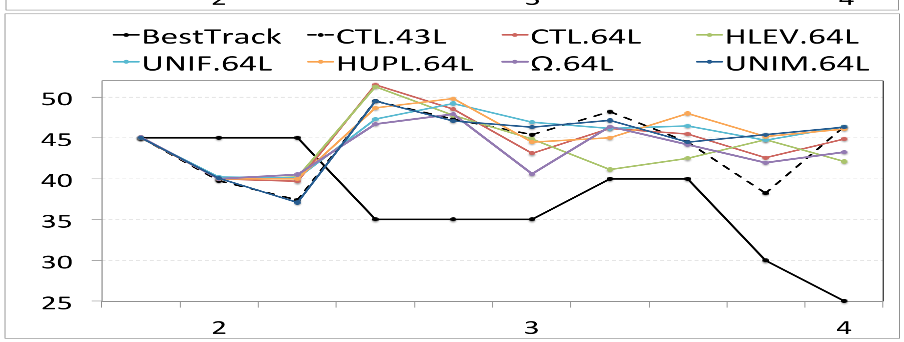


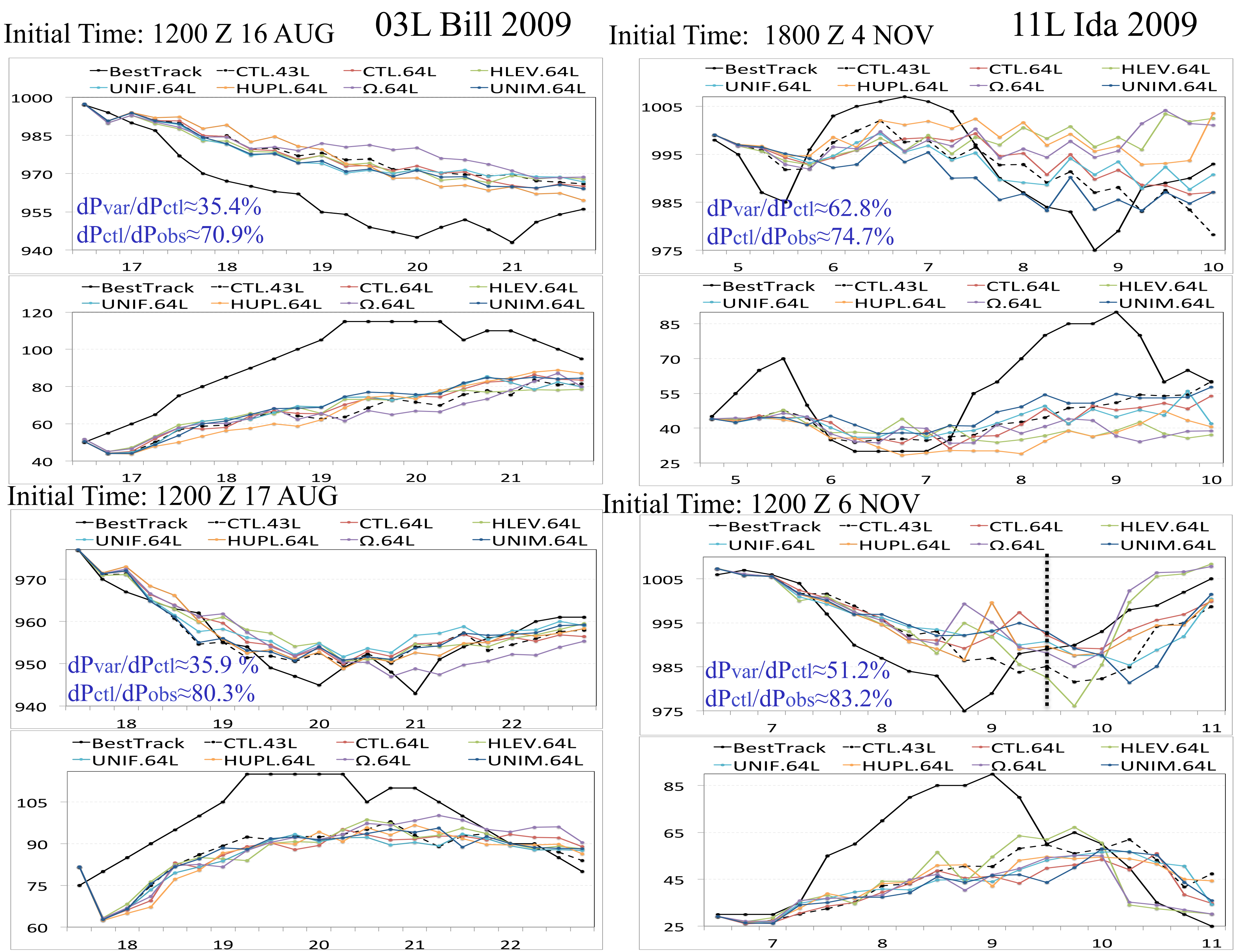




06L Erika 2009

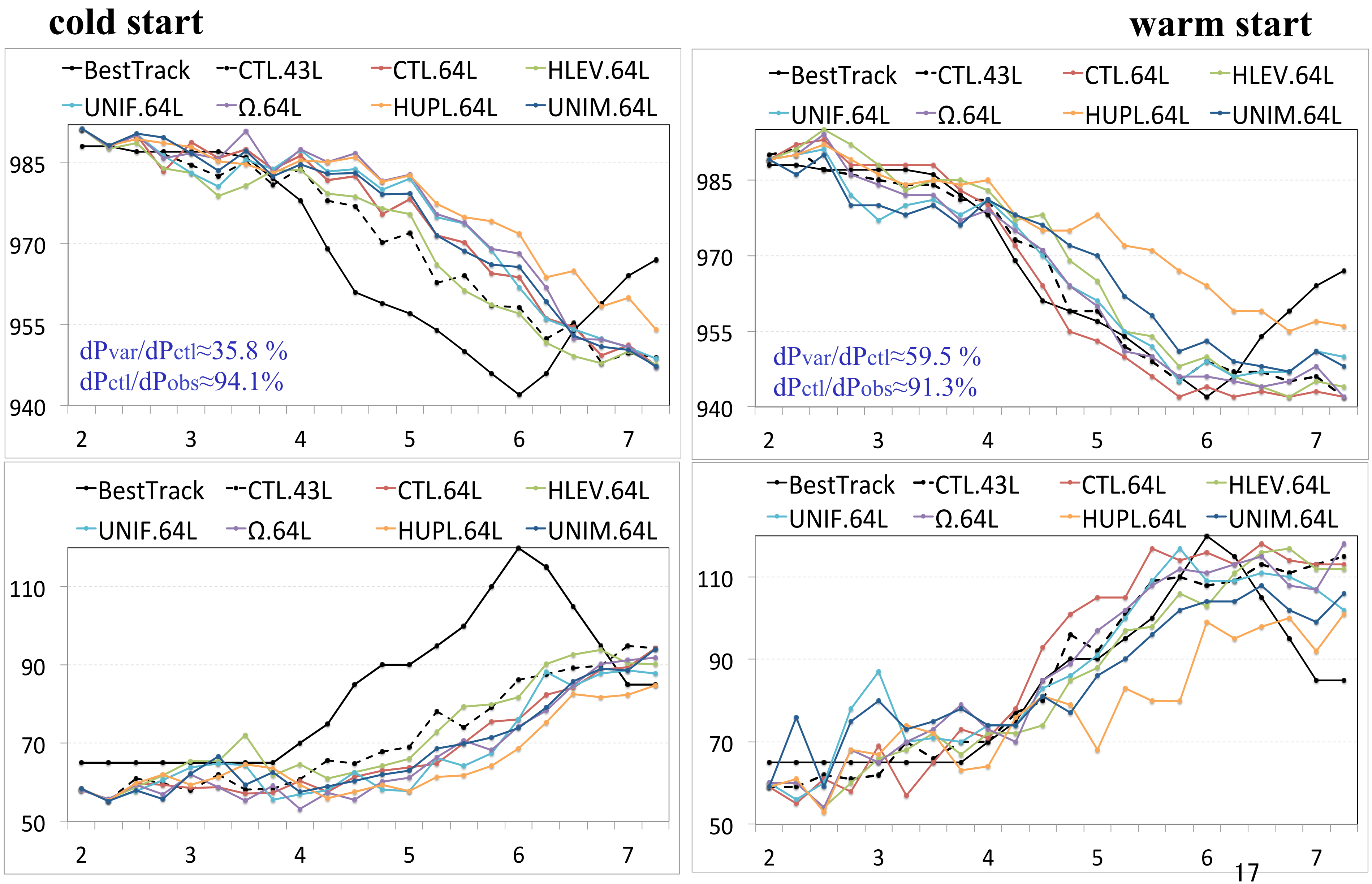






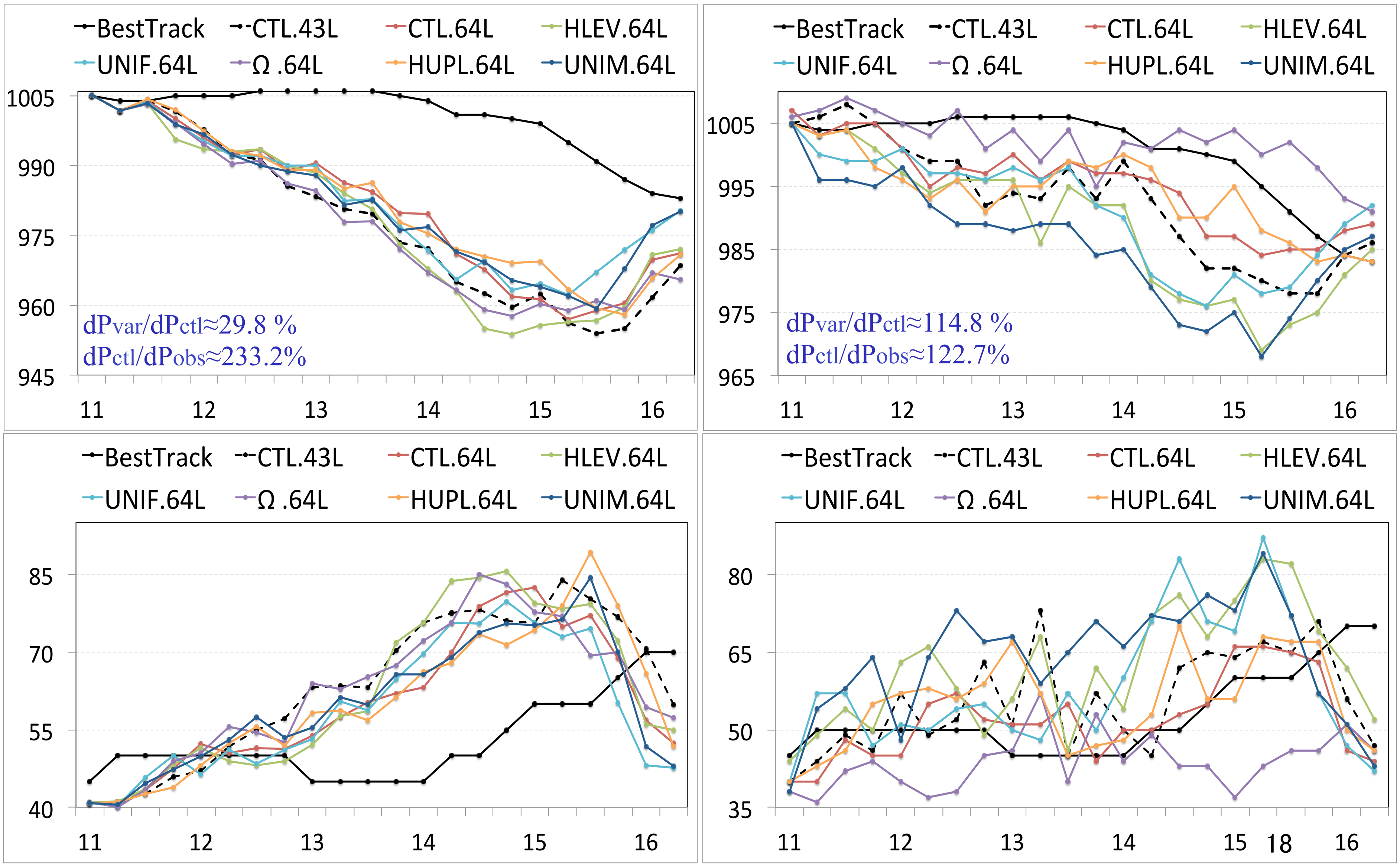
03L Bill 2009
11L Ida 2009
Initial Time: 1200 Z 16 AUG
Initial Time: 1800 Z 4 NOV
Initial Time: 1200 Z 17 AUG
Initial Time: 1200 Z 6 NOV
BestTrack
CTL.43L
CTL.64L
HLEV.64L
UNIF.64L
HUPL.64L
Ω.64L
UNIM.64L
dPvar/dPctl≈35.4%
dPctl/dPobs≈70.9%
dPvar/dPctl≈62.8%
dPctl/dPobs≈74.7%
dPvar/dPctl≈35.9 %
dPctl/dPobs≈80.3%
dPvar/dPctl≈51.2%
dPctl/dPobs≈83.2%

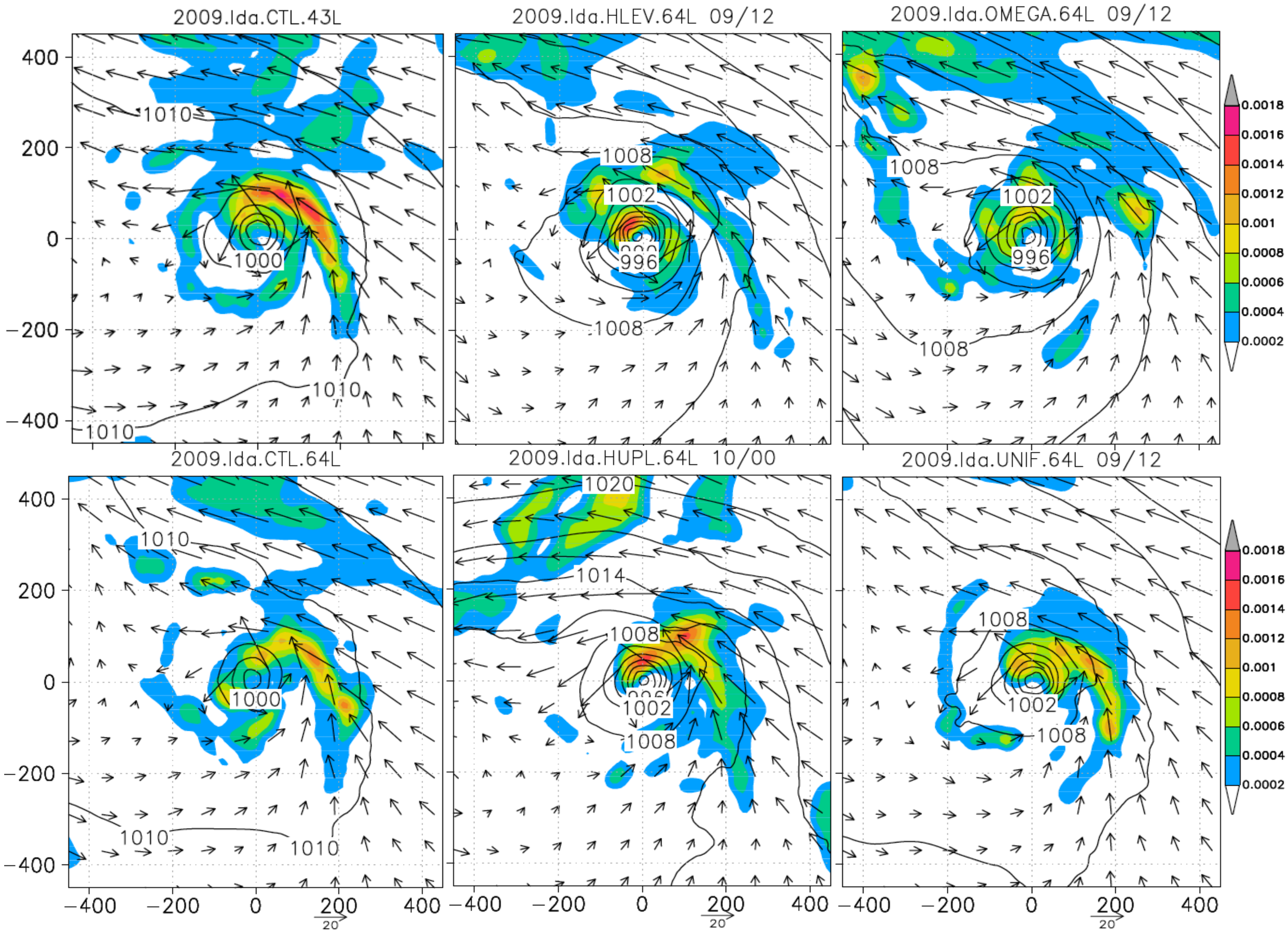
12L Katia 2011 – an intensifying storm



14L Maria 2011 – a slow-intensifying storm

cold start **warm start**

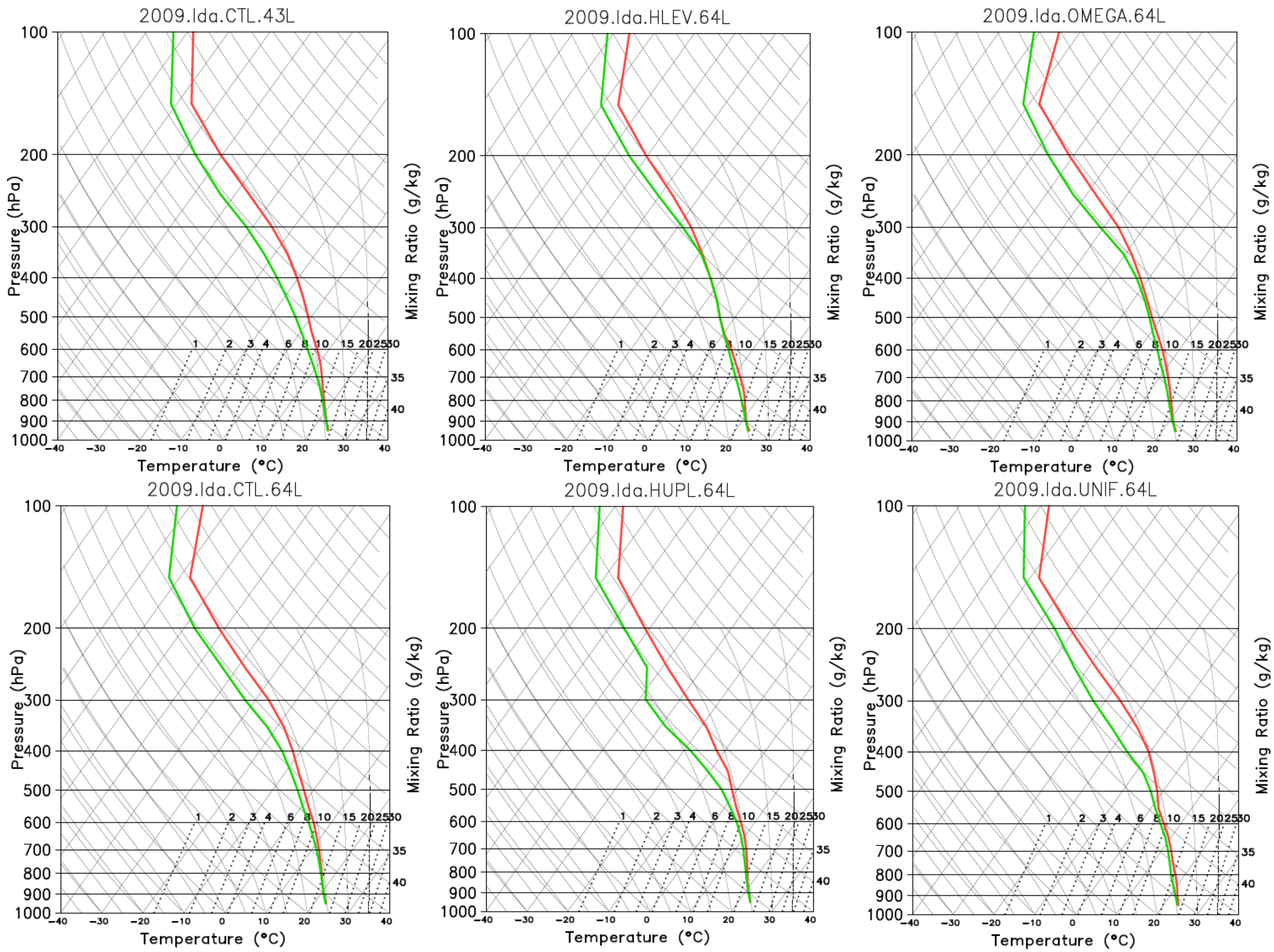




Total Condensates (shaded), MSLP (contoured) and horizontal flow vectors at 900 hPa taken for Ida (2009) at 1200 Z 9 NOV (see dotted lines in slide 16).

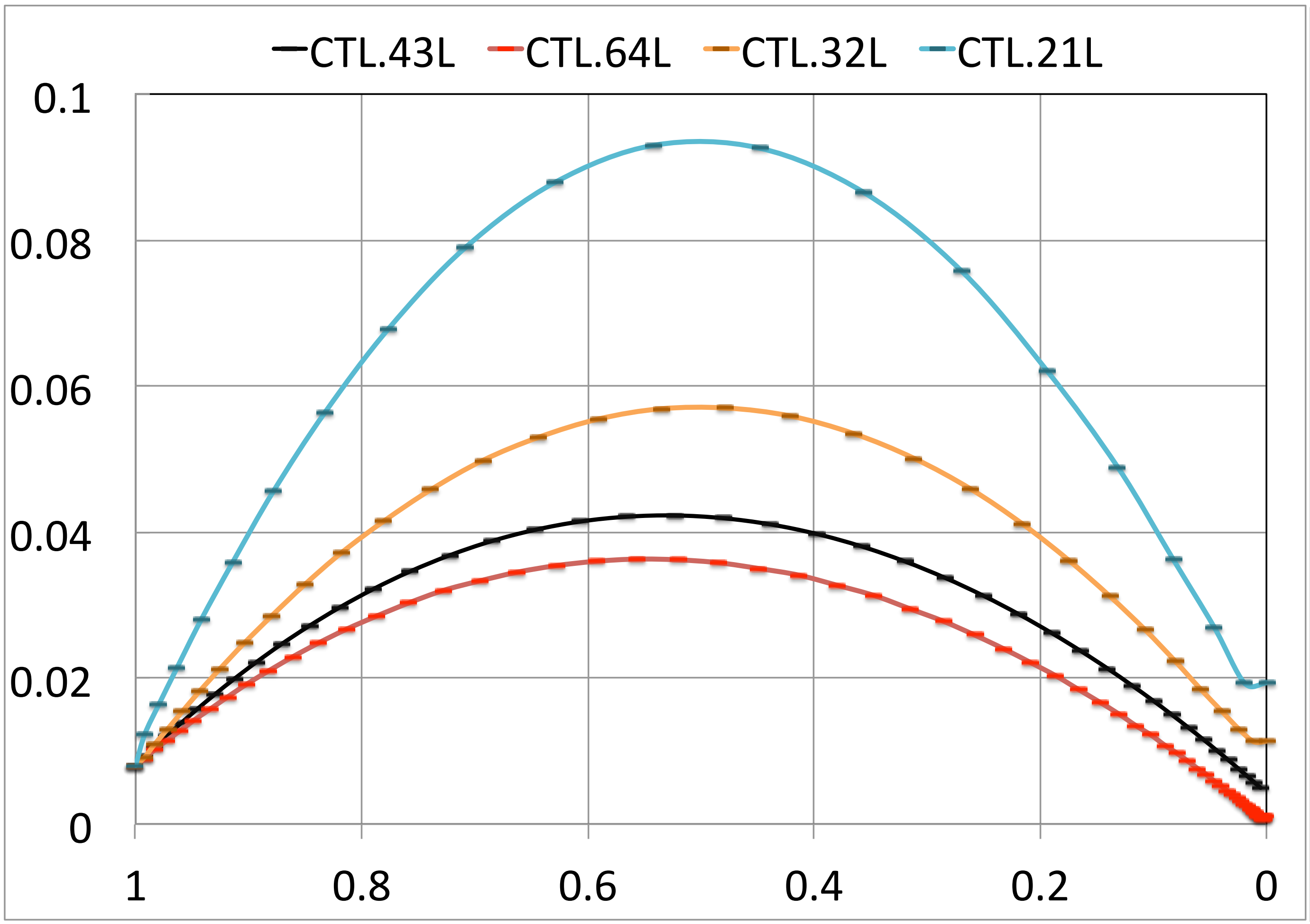
Summary from Group 1 runs

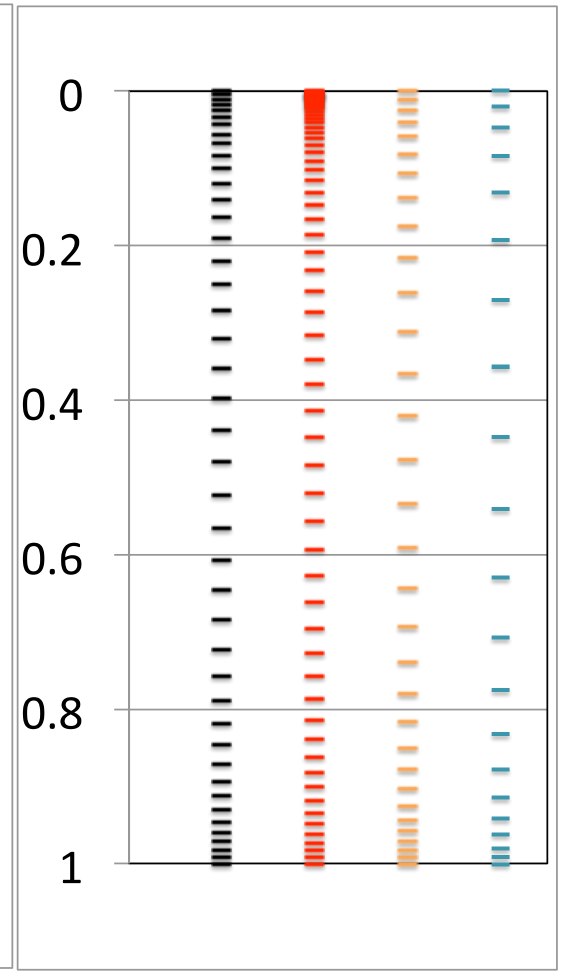
- Hurricane intensity forecasts are sensitive to vertical resolution distribution (with DP_{VAR}/DP_{CTL} = 30 – 50% and higher);
- In general, increasing the lower-level resolution tends to produce stronger storms;
- Increasing the vertical resolution from 43 to 64 levels does not necessarily result in significant changes in storm intensity, and in some cases it gives weaker intensity.
- Too high resolution near the model top in the current HWRF appears to be unnecessary;

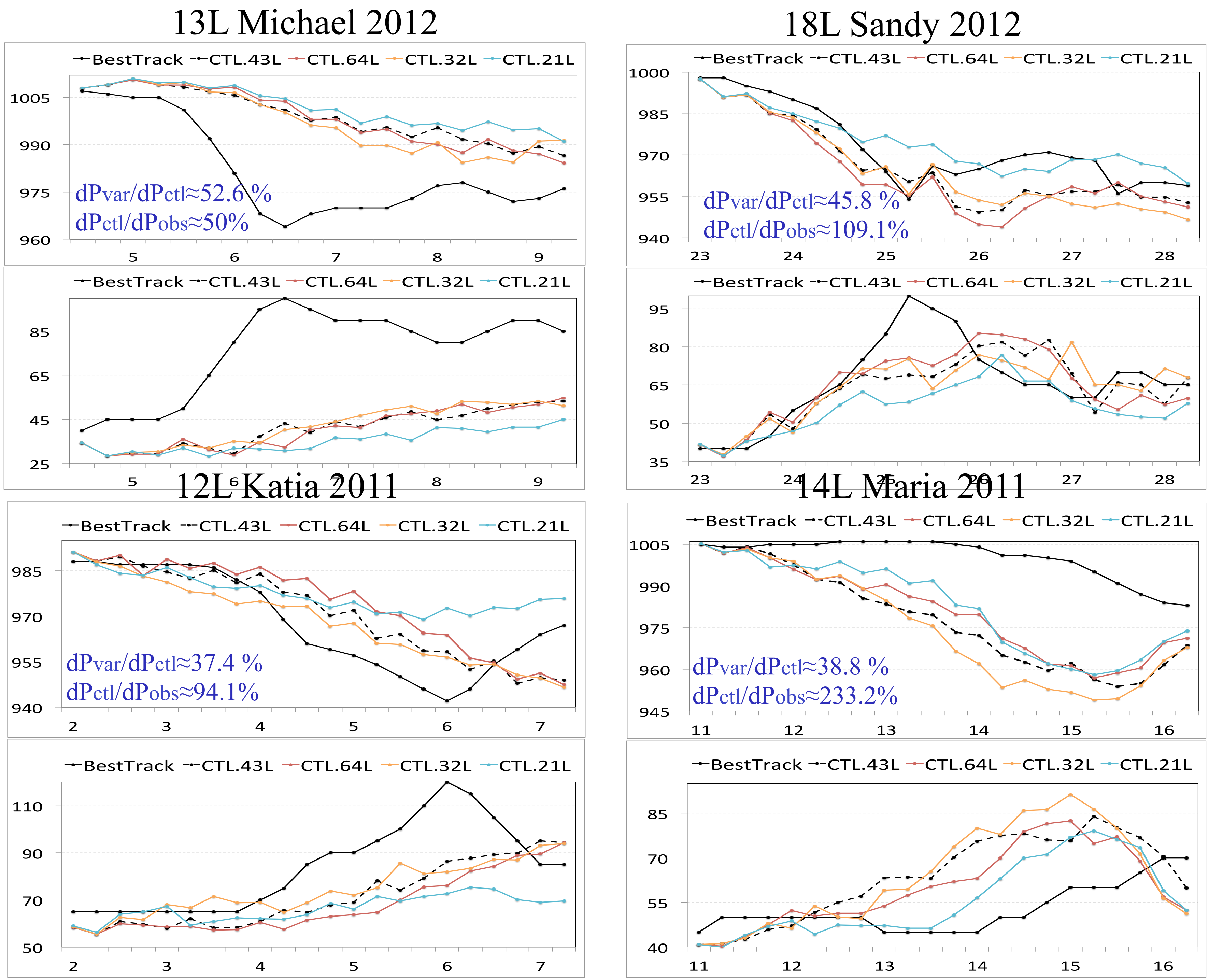


Area-averaged (54 km x 27 km) eyewall soundings taken at 1200 Z 9 NOV from Group 1 runs (see dotted lines in slide 17).

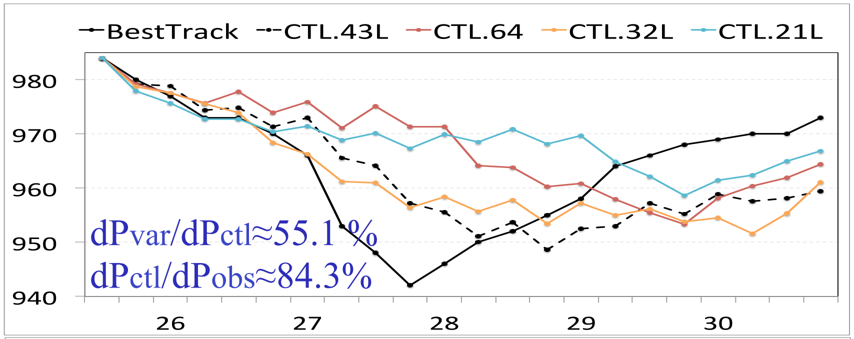
Group 2

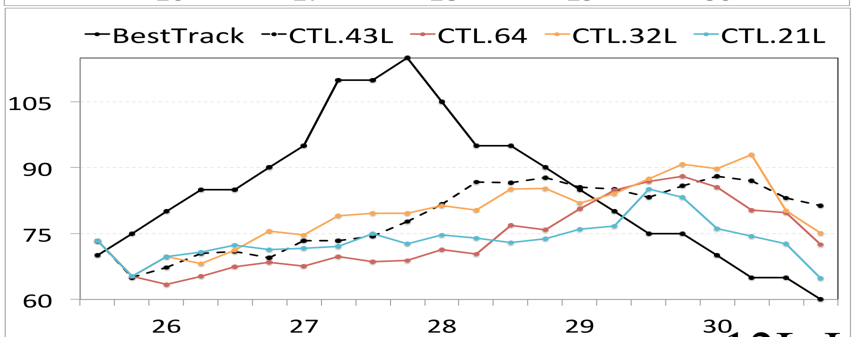

CTL.43L
CTL.64L
CTL.32L
CTL.21L
0.1
0.08
0.06
0.04
0.02
0
1
0.8
0.6
0.4
0.2
0


0
0.2
0.4
0.6
0.8
1

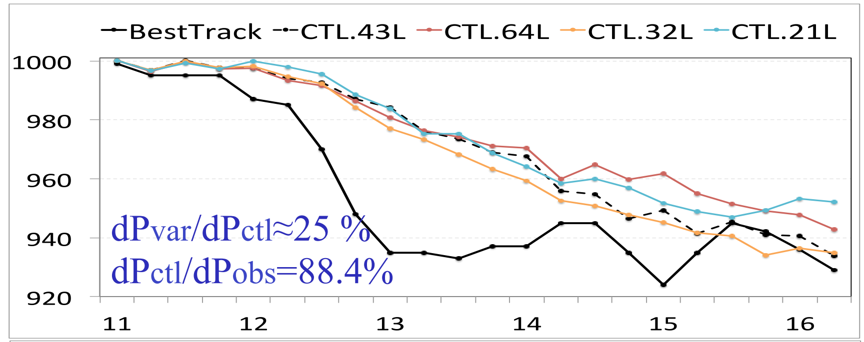

13L Michael 2012
18L Sandy 2012
12L Katia 2011
14L Maria 2011
BestTrack
CTL.43L
CTL.64L
CTL.32L
CTL.21L
dPvar/dPctl≈52.6 %
dPctl/dPobs≈50%
dPvar/dPctl≈45.8 %
dPctl/dPobs≈109.1%
dPvar/dPctl≈37.4 %
dPctl/dPobs≈94.1%
dPvar/dPctl≈38.8 %
dPctl/dPobs≈233.2%

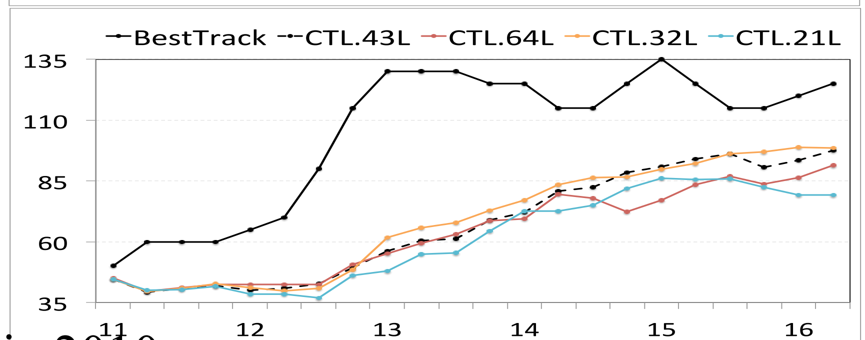
06L Danielle 2010



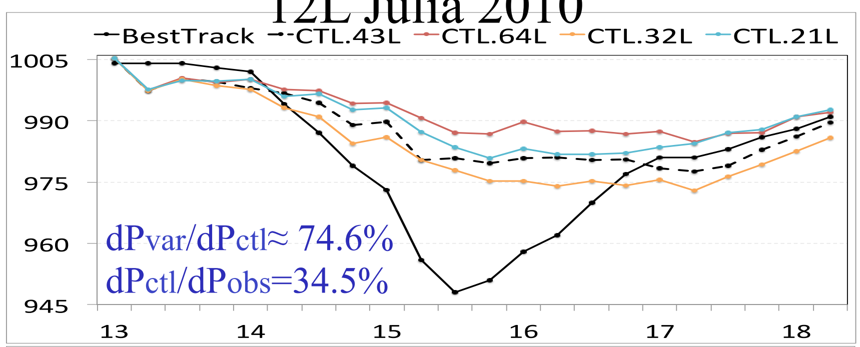


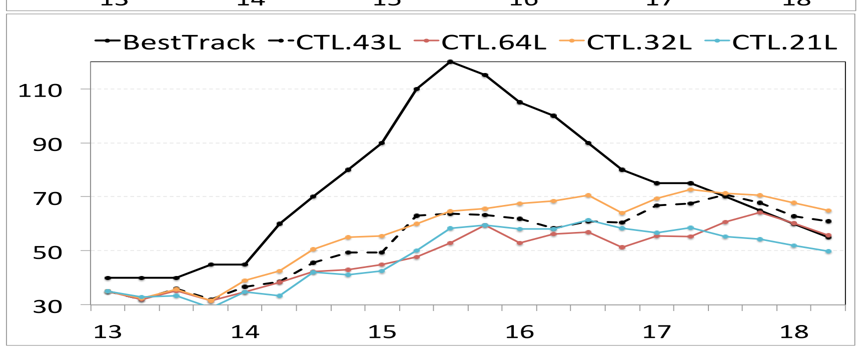
11L Igor 2010



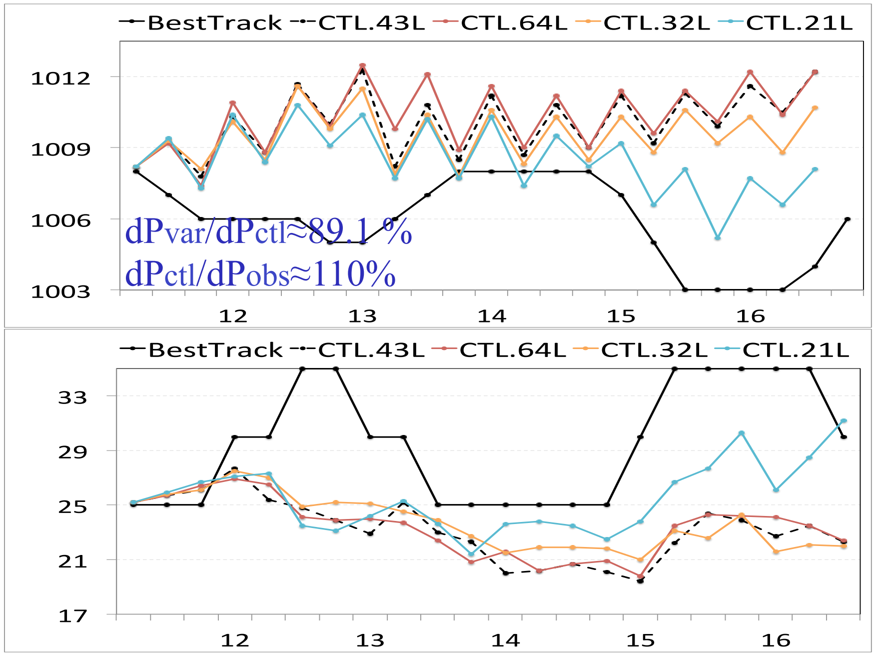


12L Julia 2010

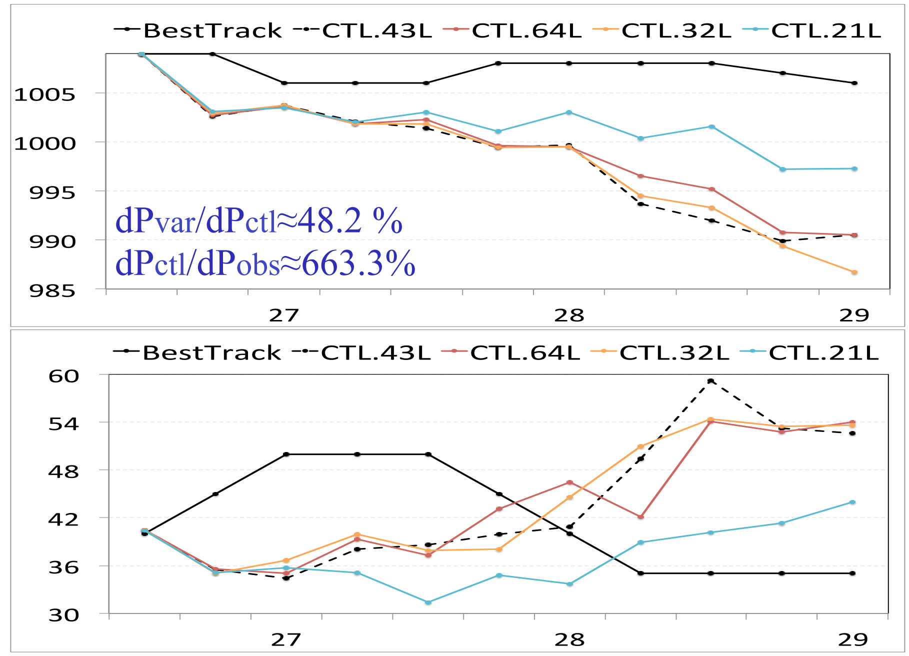




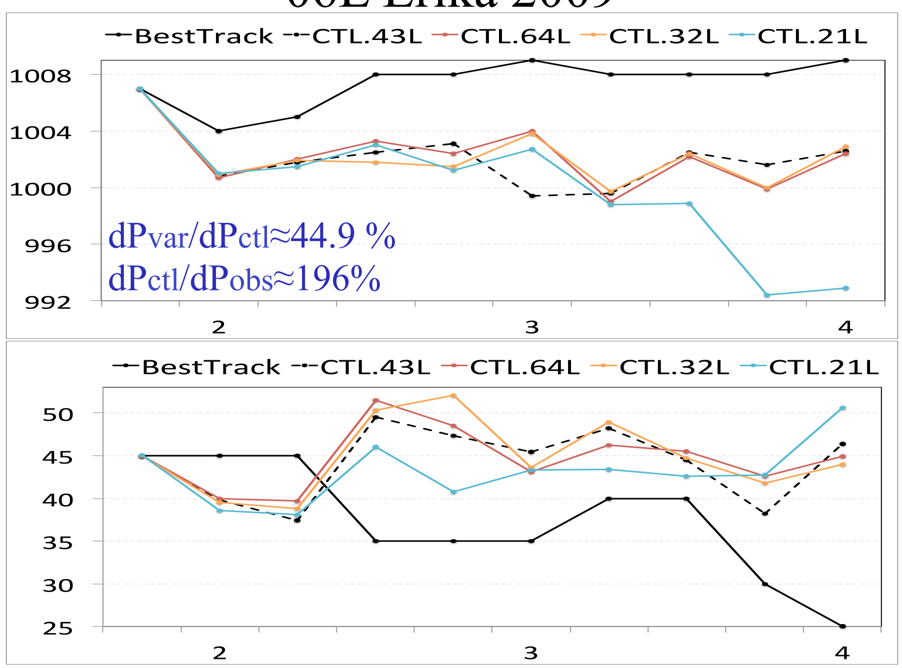
02L Ana 2009



05L Danny 2009

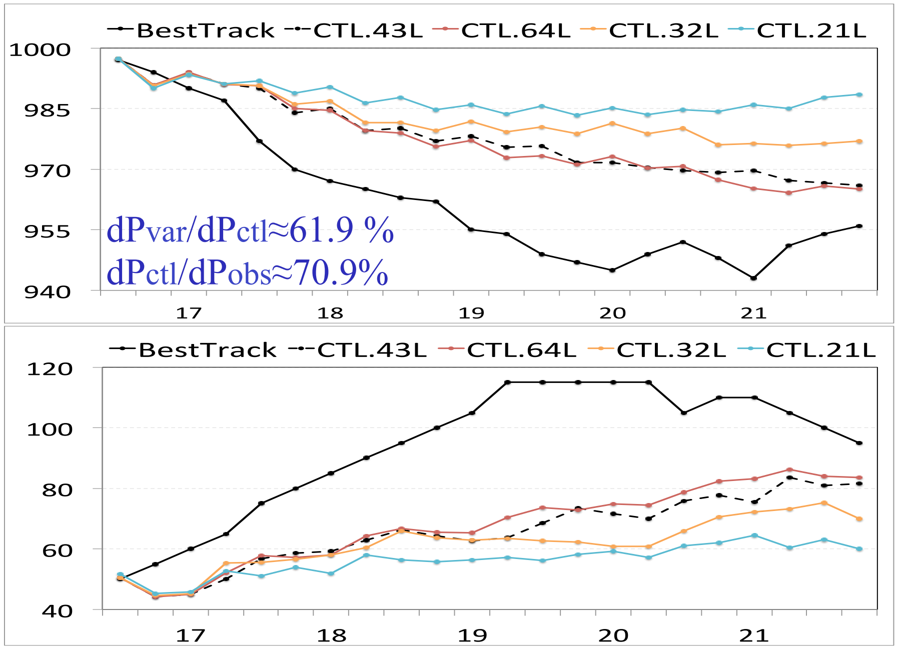


06L Erika 2009

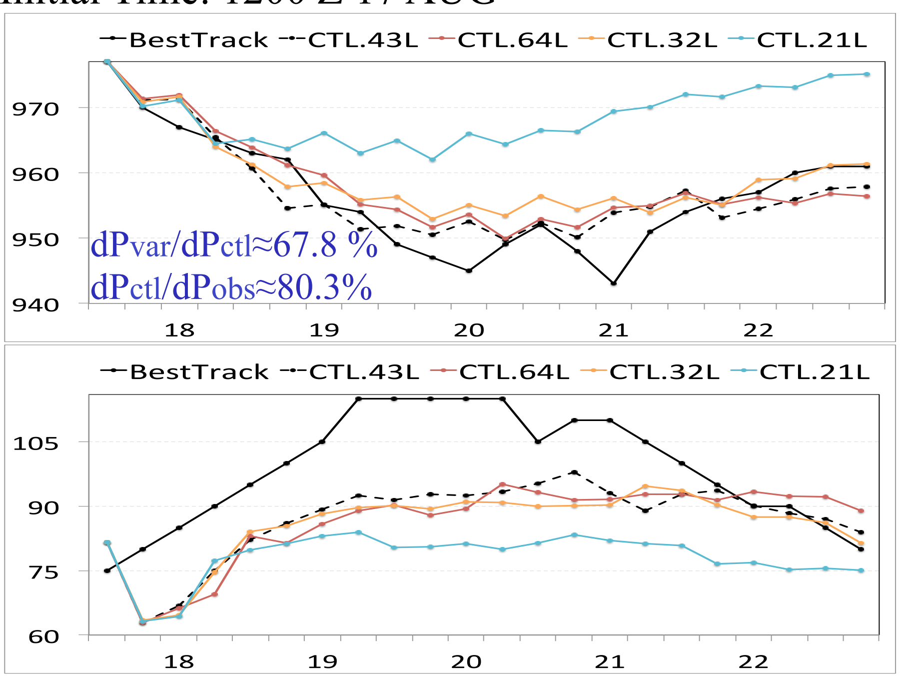


03L Bill 2009

Initial Time: 1200 Z 16 AUG

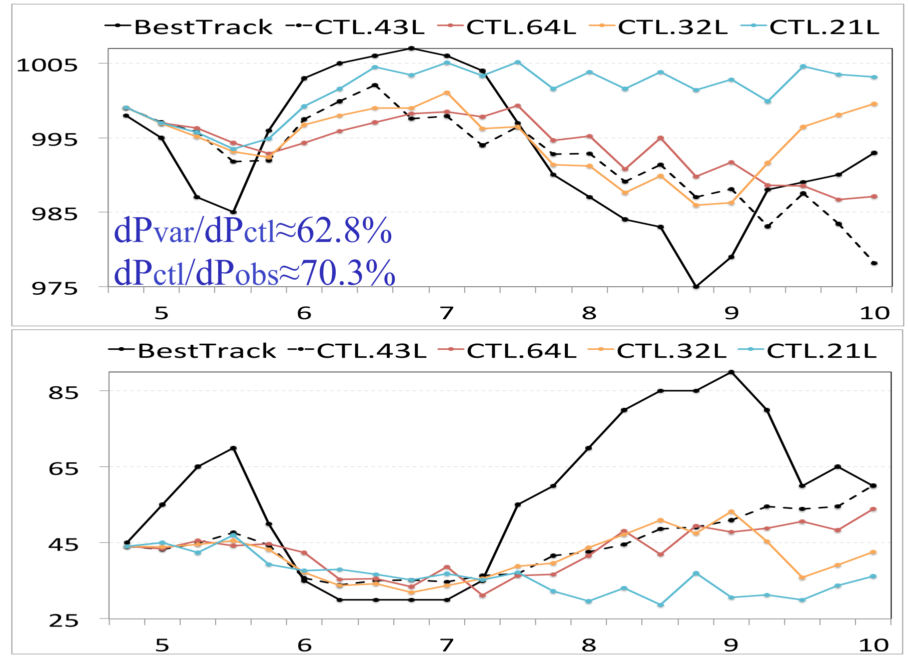


Initial Time: 1200 Z 17 AUG

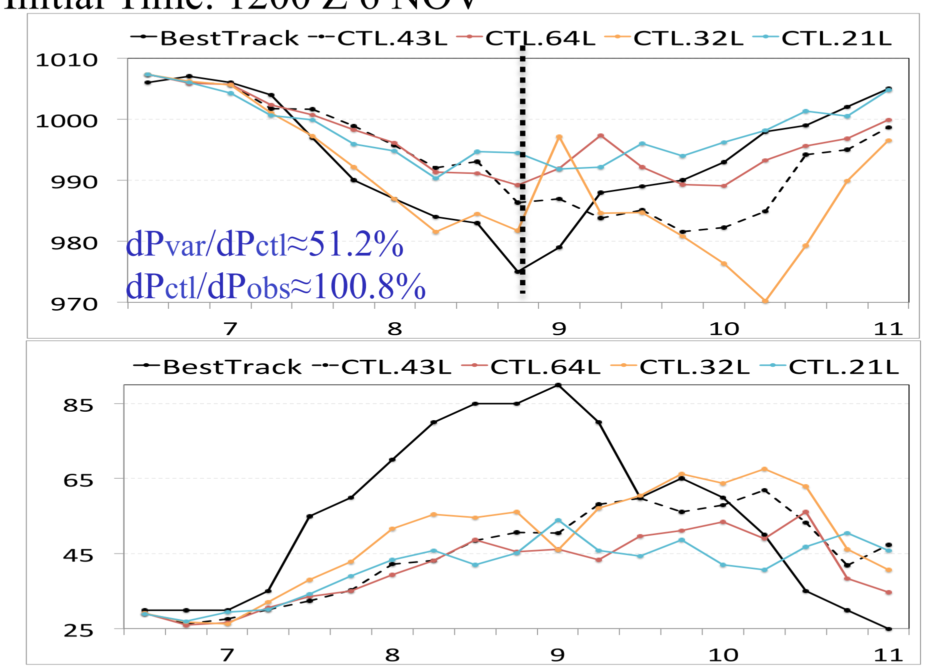


11L Ida 2009

Initial Time: 1800 Z 4 NOV

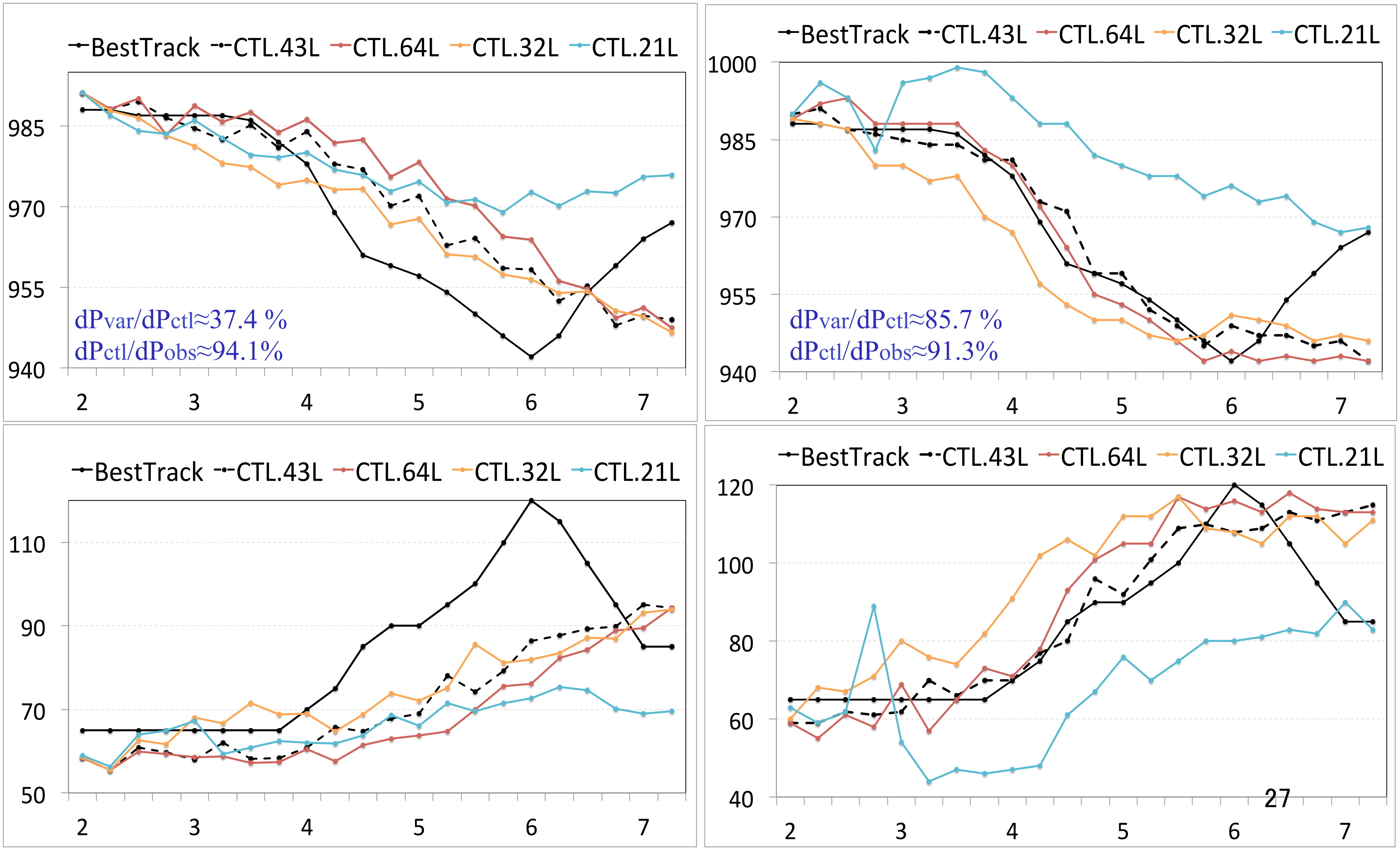


Initial Time: 1200 Z 6 NOV



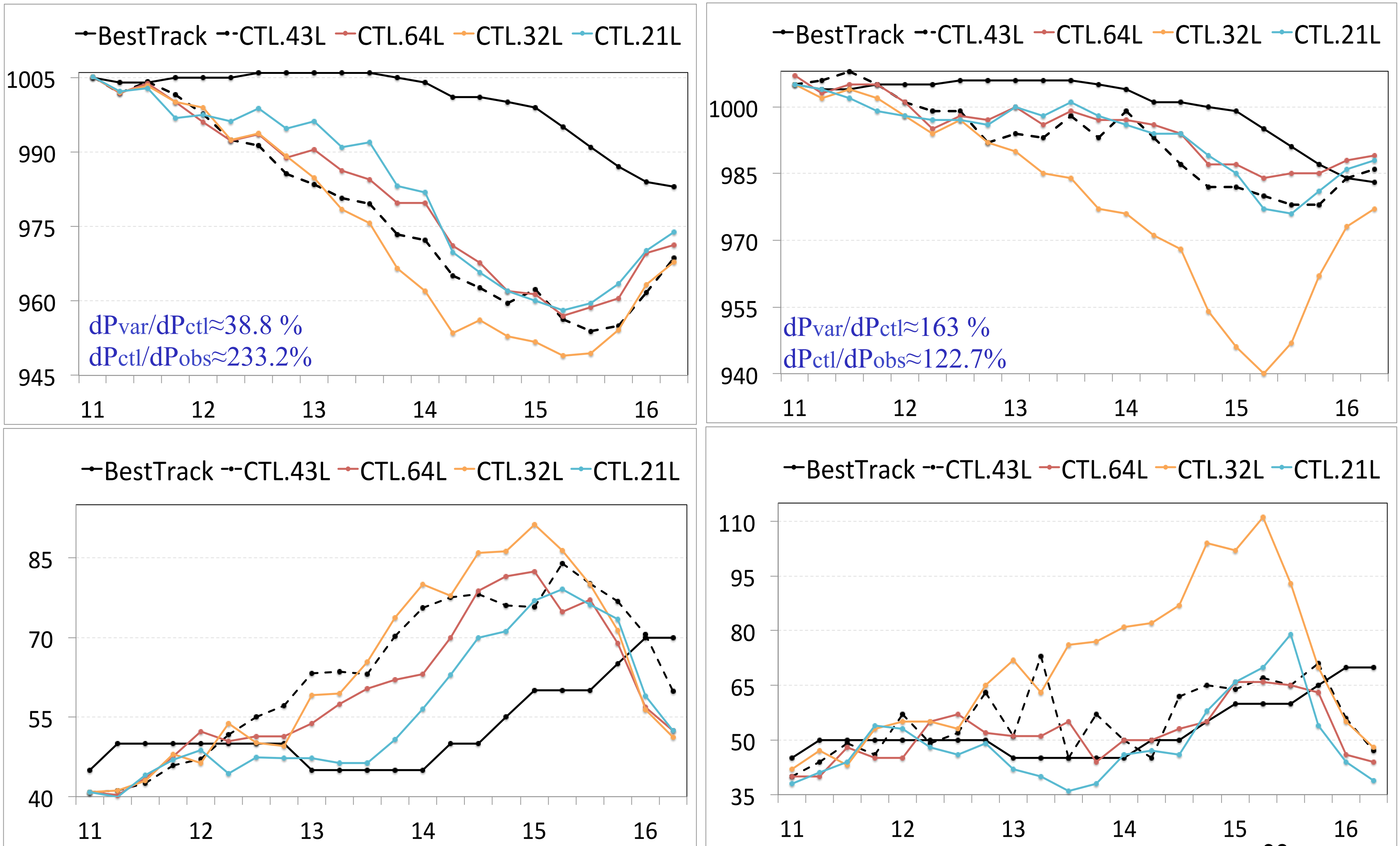
12L Katia 2011

cold start **warm start**



14L Maria 2011

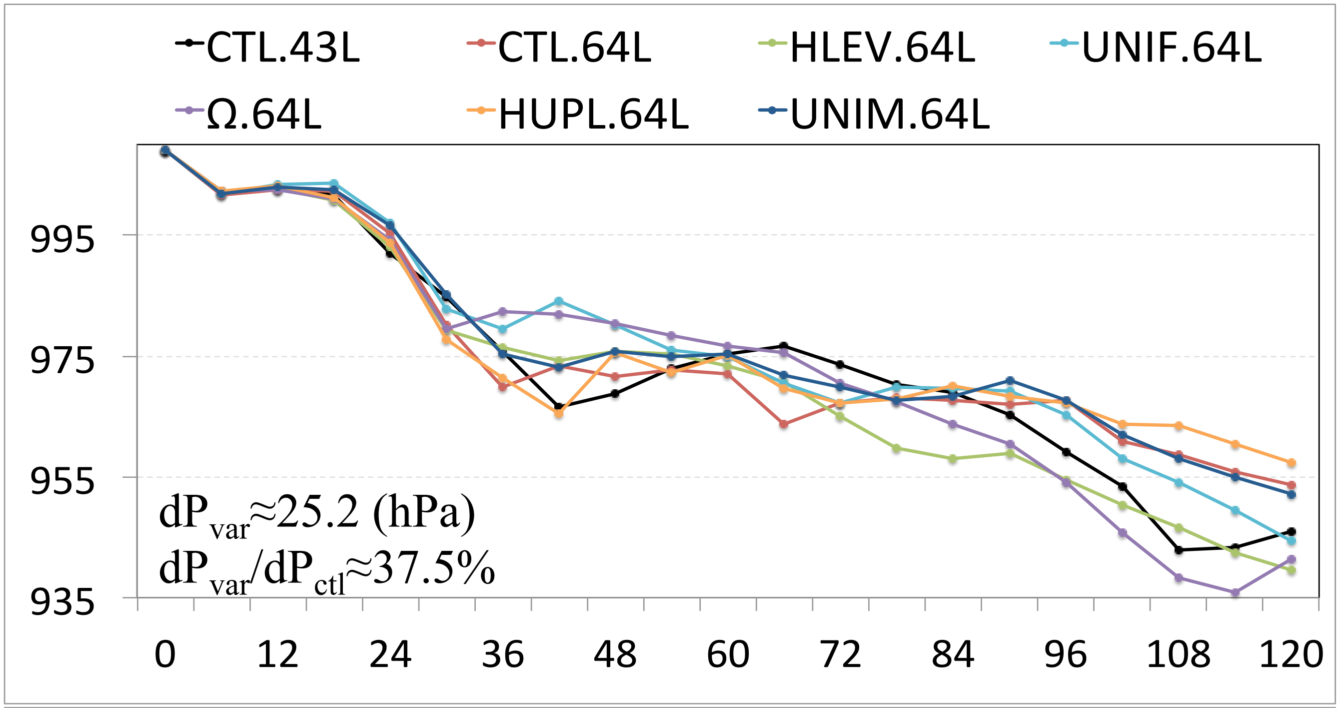
cold start **warm start**

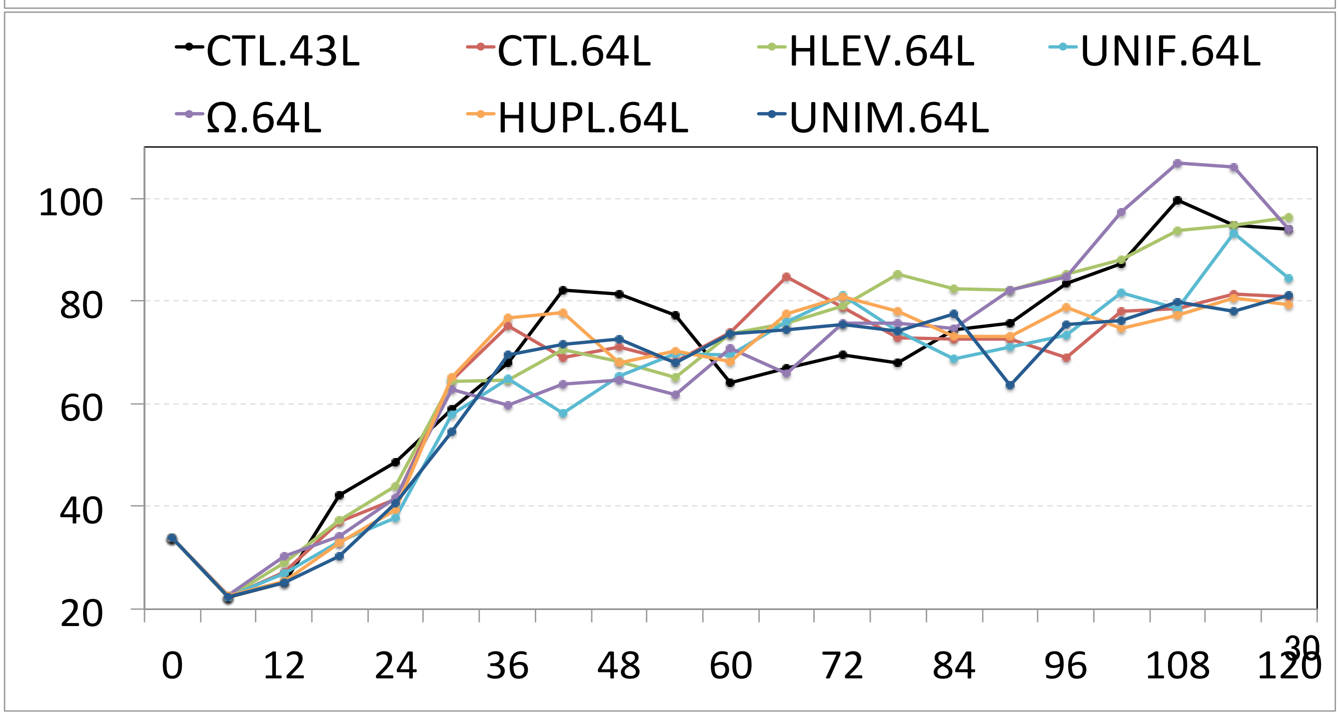


Summary of Group 2 runs

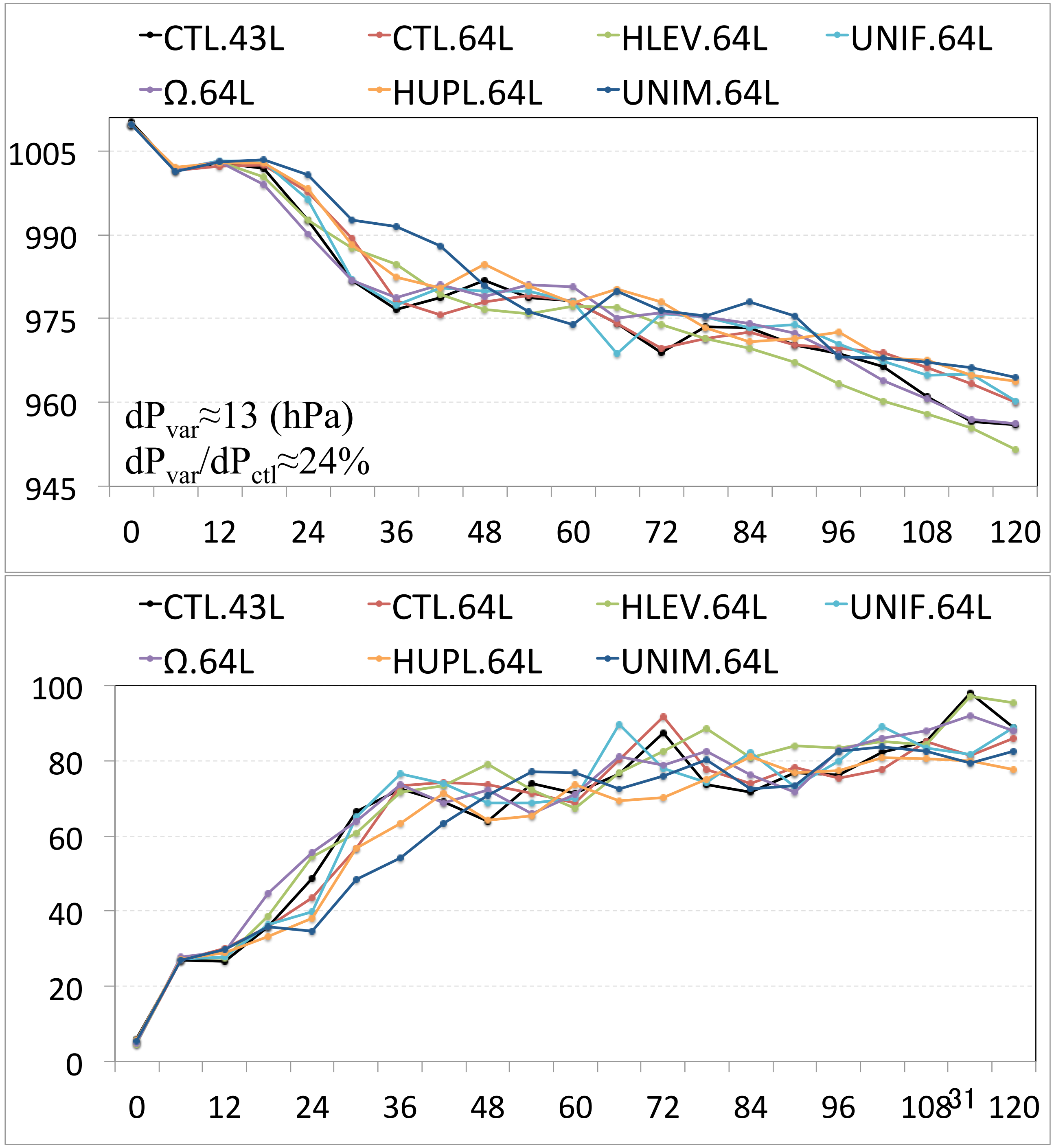
- The CTL.32L and CTL.43L runs tend to produce stronger storms for intensifying storms, whereas both CTL.64L and CTL.21L runs produce weaker storms;
- Results suggest that an optimized vertical resolution may occur between 32 and 43 levels with a near-parabolic shape, given the current HWRF configuration;

Group 1
Idealized runs
No mean flow

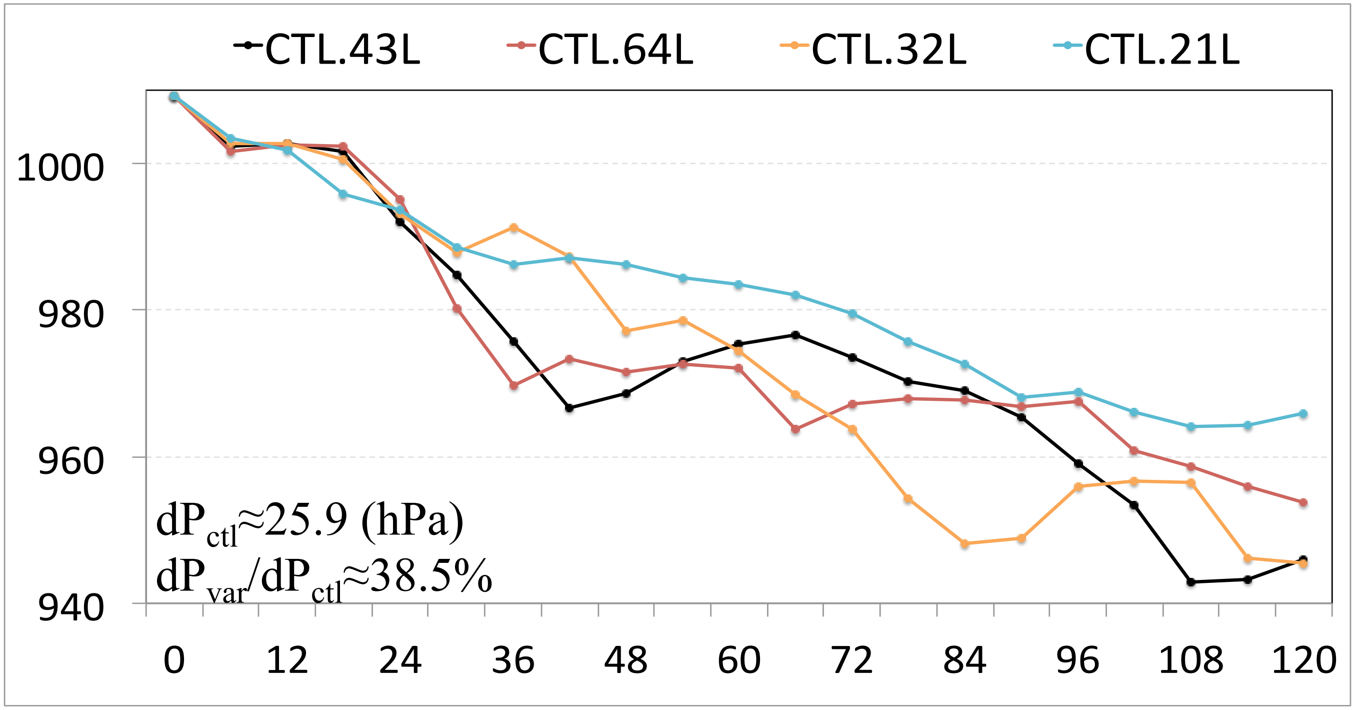


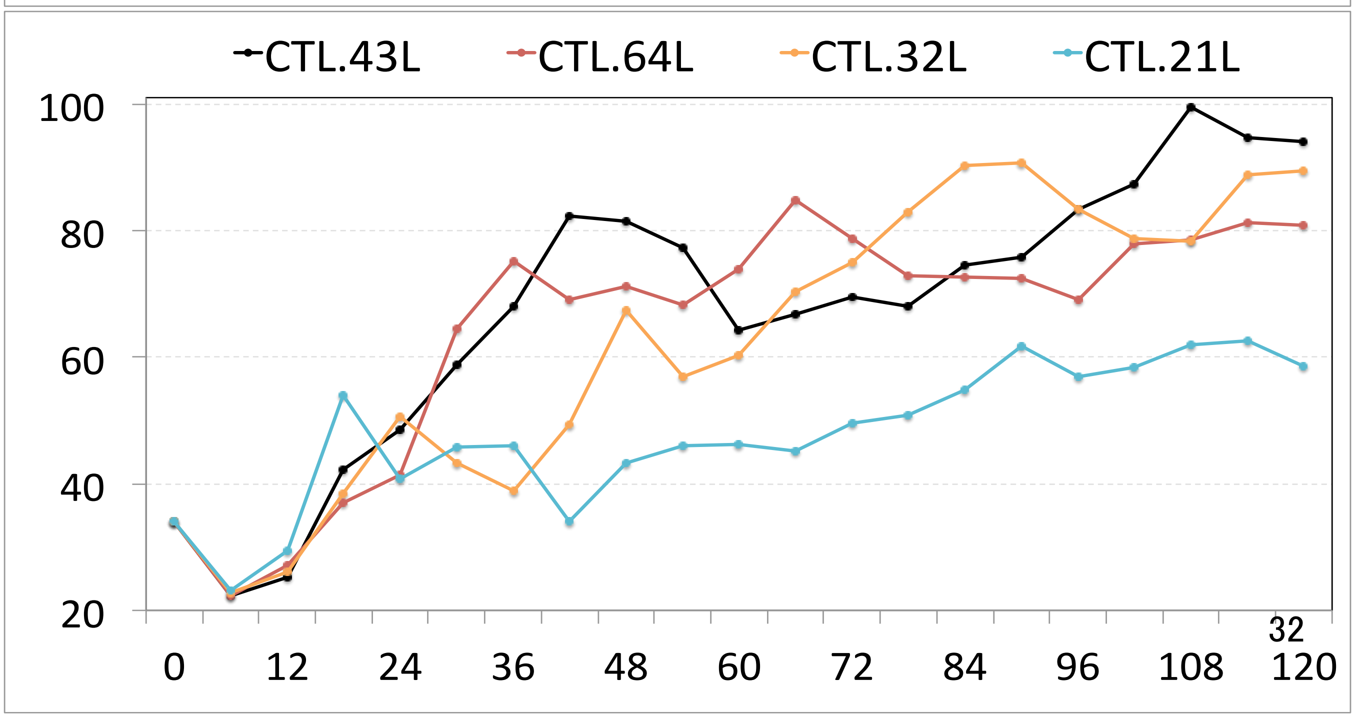


Group 1
Idealized runs with mean flow -3 m/s

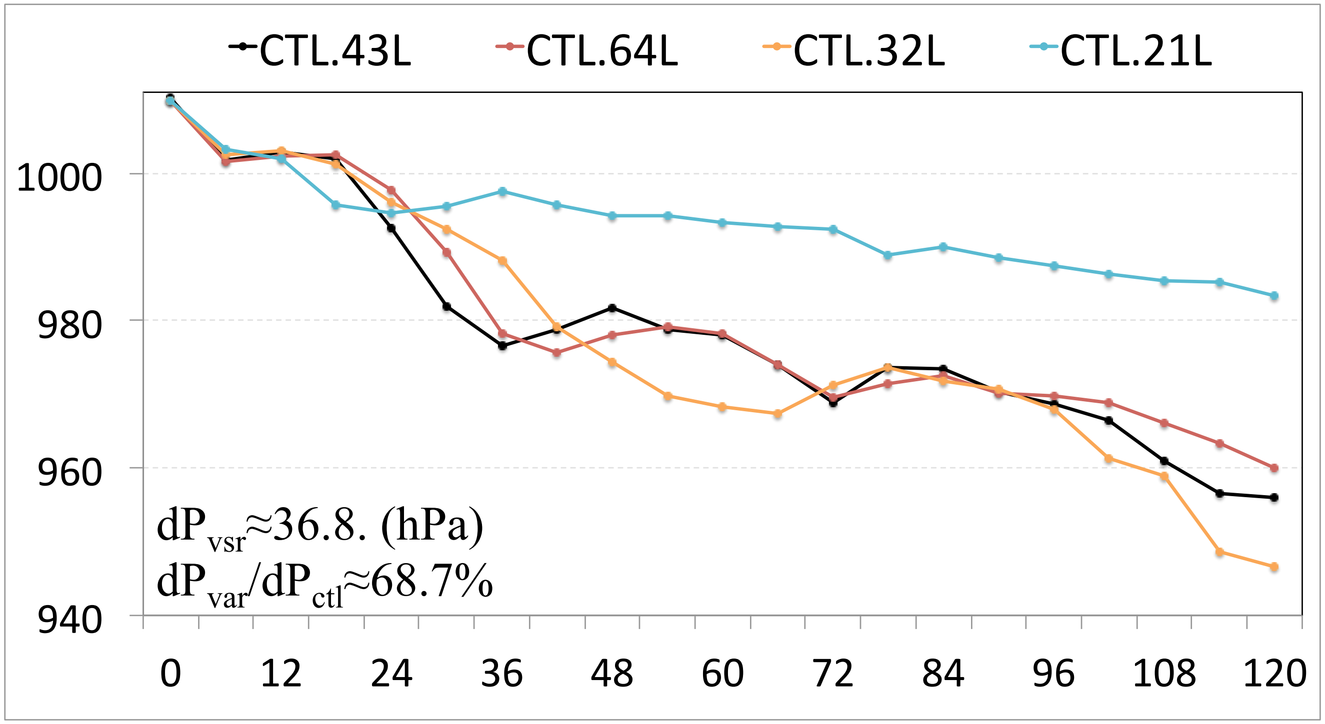


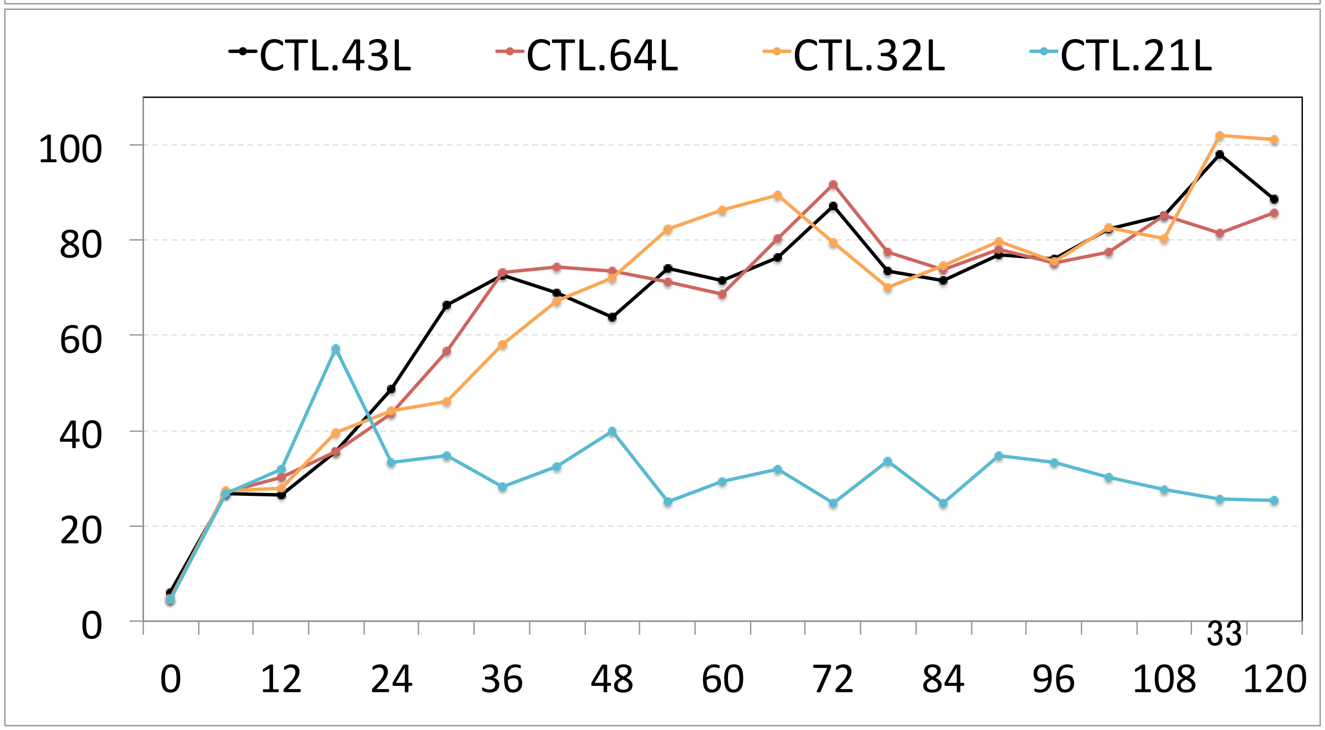
Group 2
Idealized runs
No mean flow





Group 2
Idealized runs
mean flow -3 m/s





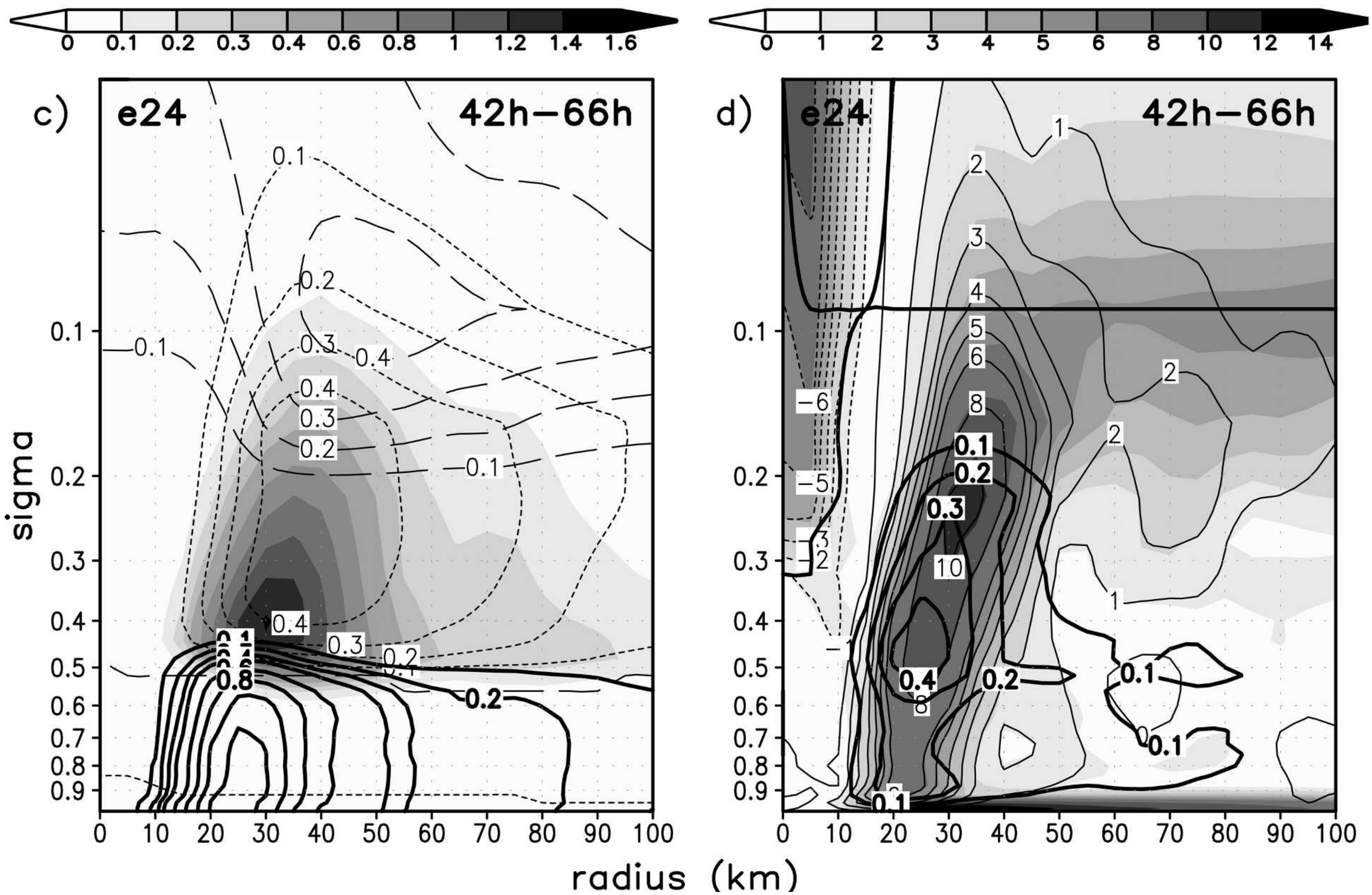
Summary of idealized runs

- Results confirm those obtained from the real-data runs;

Future Work

- Complete the idealized runs under vertical wind shear;
- Diagnosis will be performed to gain insight into why decreasing the vertical resolution from 64 to 43 and then to 32 levels produces stronger storms;
- Diagnostic will be carried out to understand why weaker storms tend to be significantly over-predicted by all sensitivity runs;
- Develop an optimized vertical resolution and its vertical distribution for the current HWRF configuration.

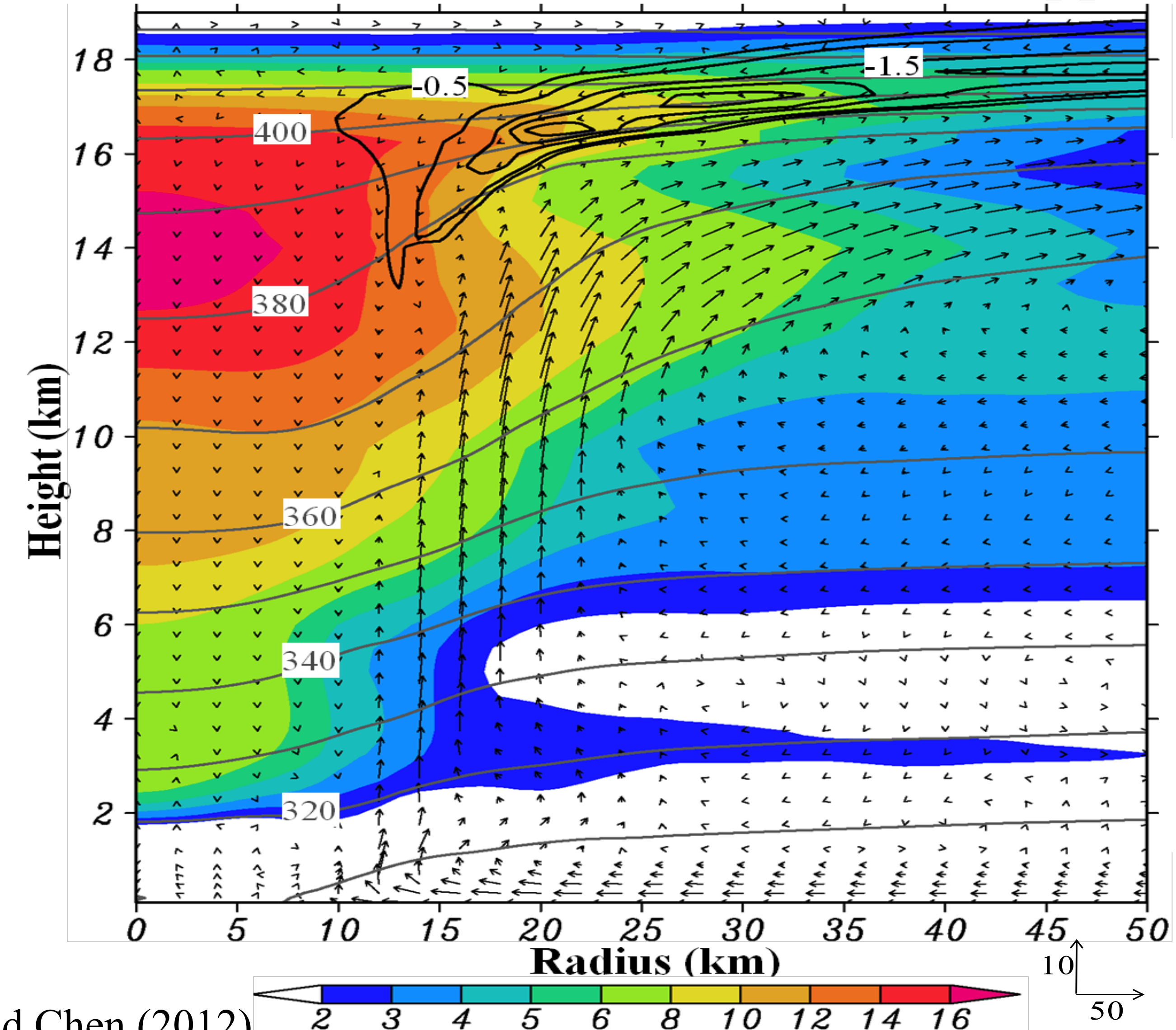
Why insensitive to higher resolution in the upper levels?



Model top at 100 hPa

From Kimball and Dougherty (2006)

The Lin's microphysics scheme appears to be more sensitive to vertical resolution in the upper levels



Zhang and Chen (2012)