The New 4D-En-Var Regional Deterministic Prediction System at the Canadian Meteorological Center

Environment Canada Environnement Canada

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1. Introduction

The 4D-Var regional deterministic prediction system (**RDPS**) at the Canadian Meteorological Center (**CMC**) will soon be replaced by the 4D-En-Var scheme, in which the background error covariances are composed of climatological covariances and flow-dependent covariances derived from an Ensemble-Kalman-Filter (**EnKF**) global prediction system. Given that the ensemble forecasts will be produced operationally, the new En-Var approach is computationally less expensive than 4D-Var and it eliminates the need to maintain the tangent-linear/adjoint codes associated with the forecast model (**GEM**). The quality of analyses and forecasts is generally expected to be as good or better than those provided by the currently operational system. Here we present a comparison in forecast skill between 4D-Var and En-Var based on a recent series of tests for the periods (winter) Feb-Mar 2011 and (summer) Jul-Aug 2011. Besides the new assimilation algorithm, several other enhancements are being introduced into the RDPS. As an example, here we show the impact of including ground-based GPS observations.

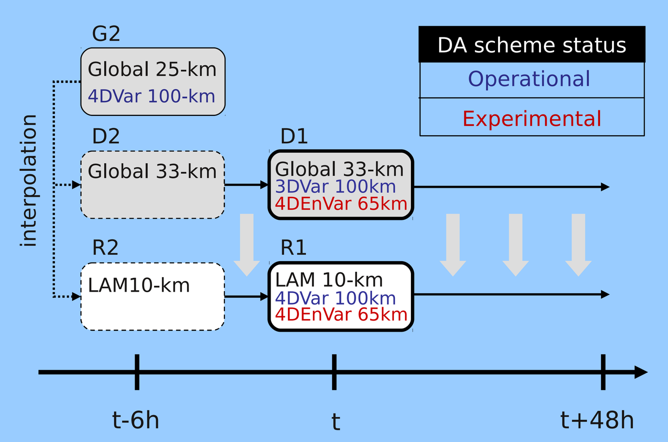

Figure 1. RDPS data assimilation scheme.

Description of the En-Var RDPS

- The RDPS includes a global driver and a limited area model (LAM)
  - Both the driver and LAM include a background check, assimilation step and forecast step, with the driver providing the boundary conditions to the LAM
  - Initial conditions are provided by the CMC operational global analysis system
- 4D dynamic background-error covariances are obtained from the CMC operational global EnKF assimilation/forecast system (192 members at 65 km resolution)
- Covariances used by the RDPS (driver and LAM) are a level-dependent weighted average of dynamic and static (lagged-forecast) covariances
  - Weighting is equal (0.5) below 40 hPa, the dynamic covariance weighting is zero above 10 hPa (scheme reduces to 3D-Var) with a linear transition in-between
- Driver and LAM domains extend up to 0.1 hPa (80 levels, non-uniform distribution)
- Regional En-Var analysis requires 10 min using 320 CPUs (compared to 20 minutes using 2048 CPUs for the currently operational 4D-Var scheme)
  - En-Var increment resolution is 600x300 (compared to 400x200 for 4D-Var)

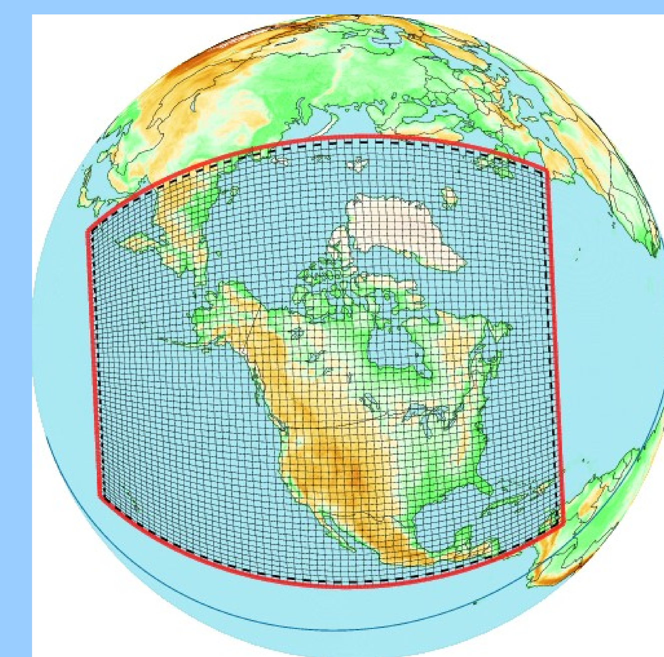

Figure 2. RDPS limited area domain (grid spacing is 10 km in both 4D-Var and En-Var experiments).

2. Time-mean upper-air and precipitation scores

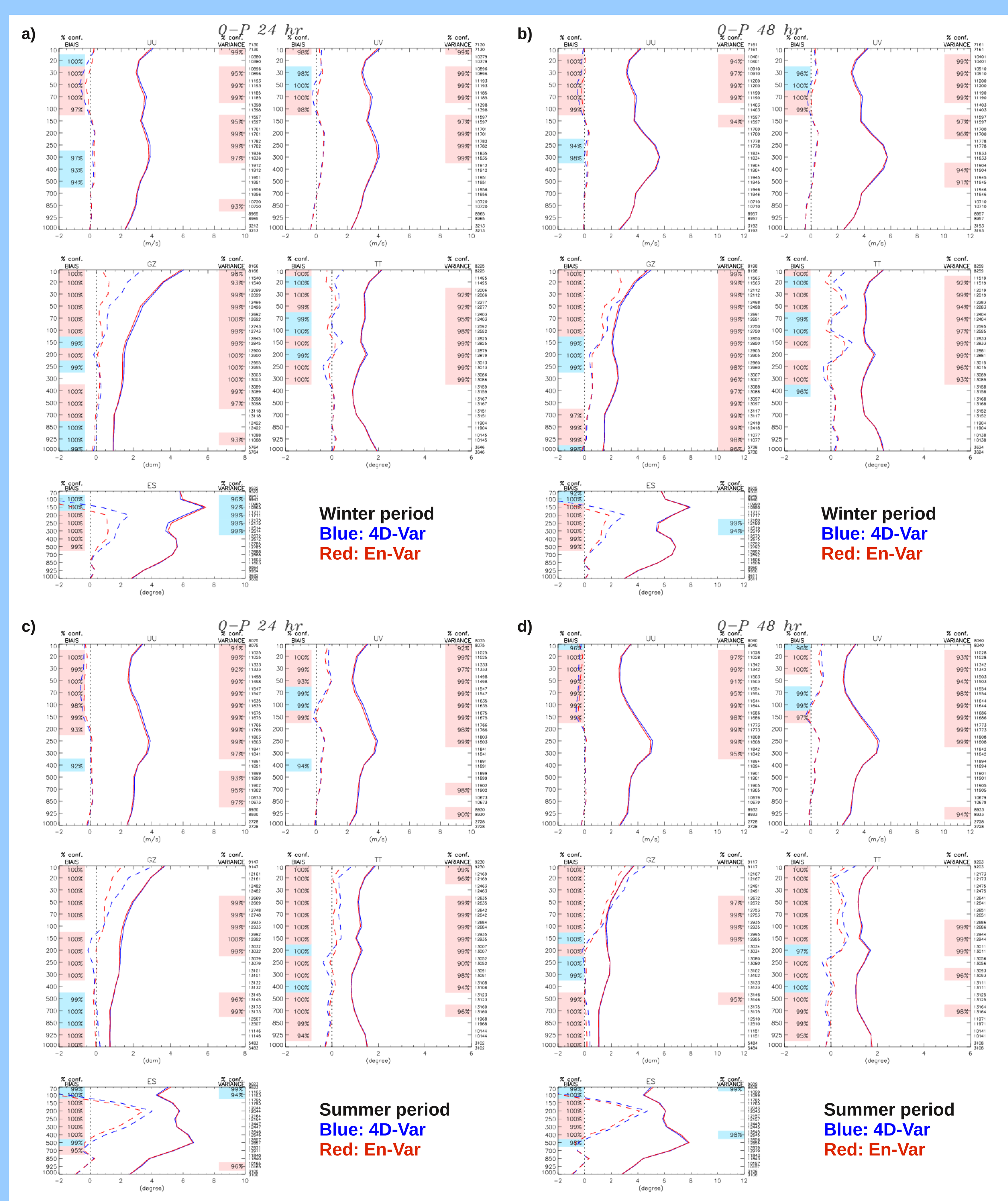

Figure 3. Mean forecast scores over North America against radiosonde data at lead times **(a)**, **(c)** 24 h and **(b)**, **(d)** 48 h averaged over ~118 cases (every 12 hours) for **(a)**, **(b)** winter 2011 and **(c)**, **(d)** summer 2011 based the (blue) 4D-Var and (red) En-Var analysis system for (UU) zonal wind, (UV) wind modulus, (GZ) geopotential height, (TT) temperature and (ES) dew-point depression. Dashed (continuous) curves correspond to the mean (standard deviation). Colored boxes on the left (right) of each plot show the confidence interval, 90% and above, corresponding to the lower bias (standard deviation), i.e. **red boxes imply a significant improvement brought by En-Var**, compared to 4D-Var. The number of radiosonde observations is given on the right-hand side of each plot.

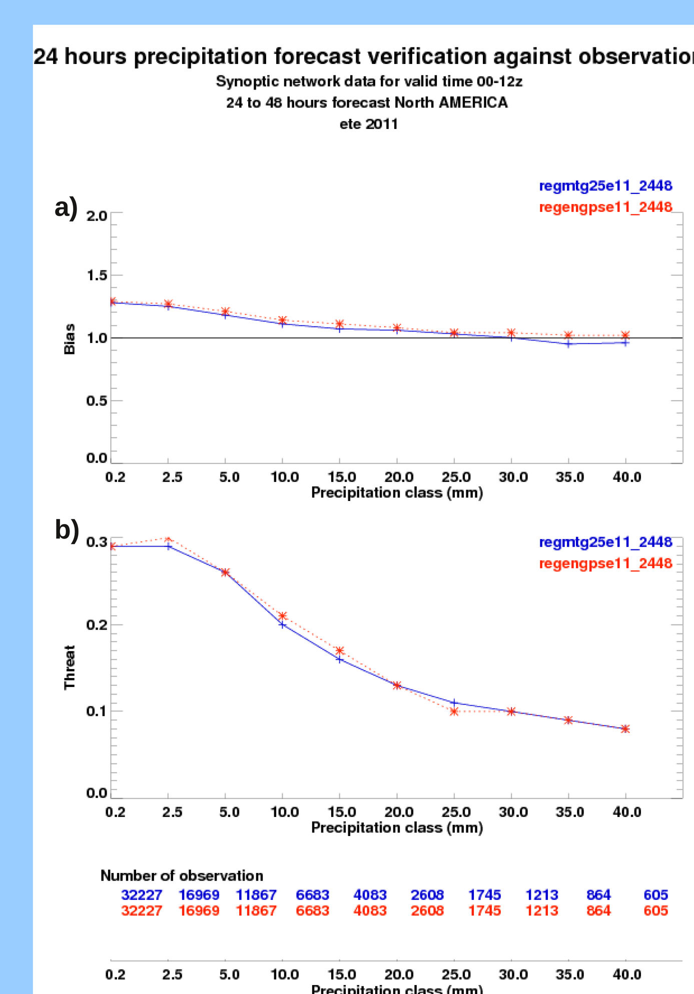

Figure 4. Mean forecast precipitation scores over North America against the SYNOP network during summer period for lead times 24-48 h corresponding to (blue) 4D-Var experiment and (red) En-Var experiment: **(a)** bias and **(b)** threat score (higher threat score is better). The number of observations for each precipitation class is shown at the bottom of the figure.

- Time-mean verification scores against radiosonde observations generally show improved forecast skill in the En-Var experiments compared to 4D-Var
- The En-Var analysis typically fits radiosonde data better than 4D-Var (not shown), mostly because the synoptic-hour En-Var analysis is a direct result of the minimization procedure, while in 4D-Var the same quantity is actually a 3-h nonlinear forecast based on the true analysis, valid 3 hours earlier
- Forecasts of the principal meteorological variables based on En-Var generally exhibit more skill at all lead times relevant for the RDPS, i.e. 12-48 hours
  - See predominance of red boxes over blue boxes in Figure 3, both in summer and winter
- En-Var precipitation forecast scores are as good as or better than with 4D-Var in most regions of North America (see Figure 4)
  - Initial tests with En-Var showed a deterioration in precipitation scores for some regions, however this has been largely corrected through the addition of another observation type which provides a further constraint at the surface (see Section 3)

3. Impact of ground-based GPS data

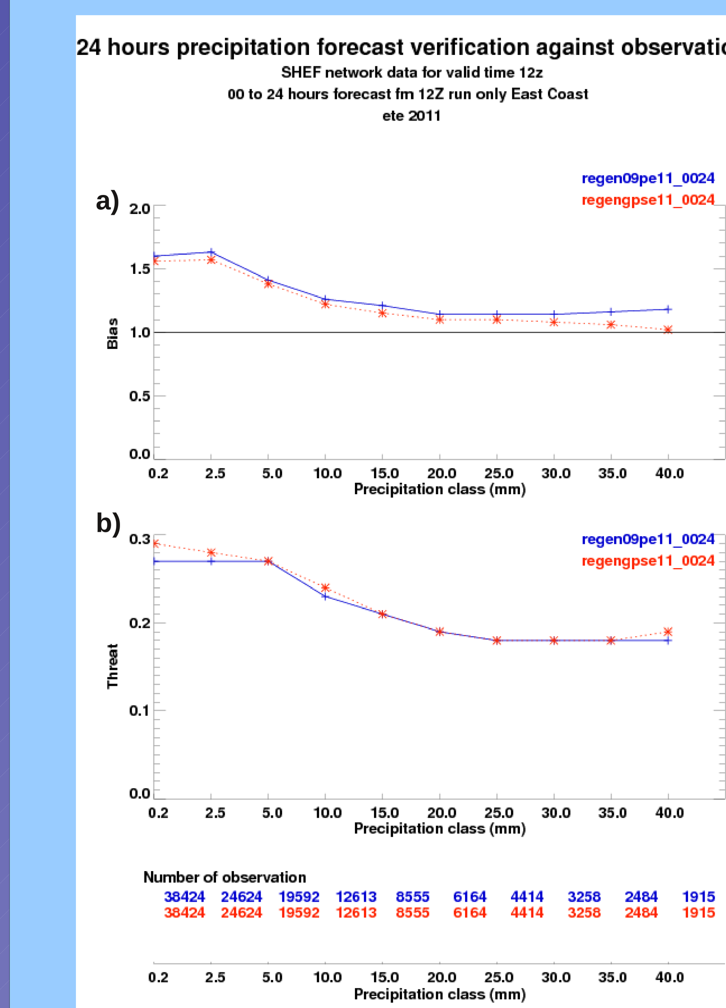

Figure 5. Mean forecast precipitation scores over North America against the SHEF network during summer period for lead times 0-24 h corresponding to an En-Var experiment (blue) excluding and (red) including ground-based GPS observations: **(a)** bias and **(b)** threat score (higher threat score is better). The number of observations for each precipitation class is shown at the bottom of the figure.

- Before ground-based GPS observations were included, En-Var based forecasts exhibited anomalously moist conditions (and a corresponding deterioration in precipitation scores) during summer over the south-east United States (not shown)
  - Deterioration was particularly apparent for analyses valid at 12Z
- **Addition of ground-based GPS data lead to a reduction in moisture in this region and improved the scores** (Figures 5 and 6) for lead times 0-24 h
  - Improvement is seen in analyses valid both at 00Z and 12Z, but particularly at 12Z
  - Impact disappears at lead times 24-48 h but is clearly beneficial at earlier times
- See Poster 777: Assimilation experiments with ground-based GPS observations in the Environment Canada Global and Regional Deterministic Prediction Systems by S. Macpherson *et al.* (JCSDA Poster Session, Wed., 2:30-4:00 PM)

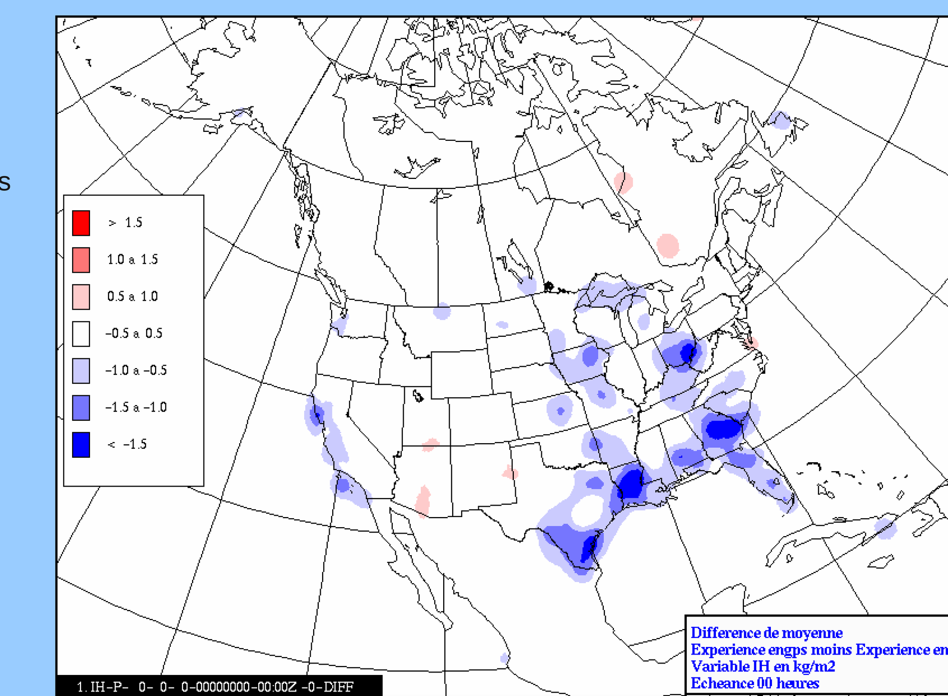

Figure 6. Difference in time-mean increments (En-Var minus 4D-Var) valid at 12Z of the vertically-integrated water vapor [kg/m^2] during the summer period. Blue (red) shading corresponds to positive (negative) values, i.e. blue shading indicates dryer conditions in the En-Var increments).

4. Meteorological evaluation

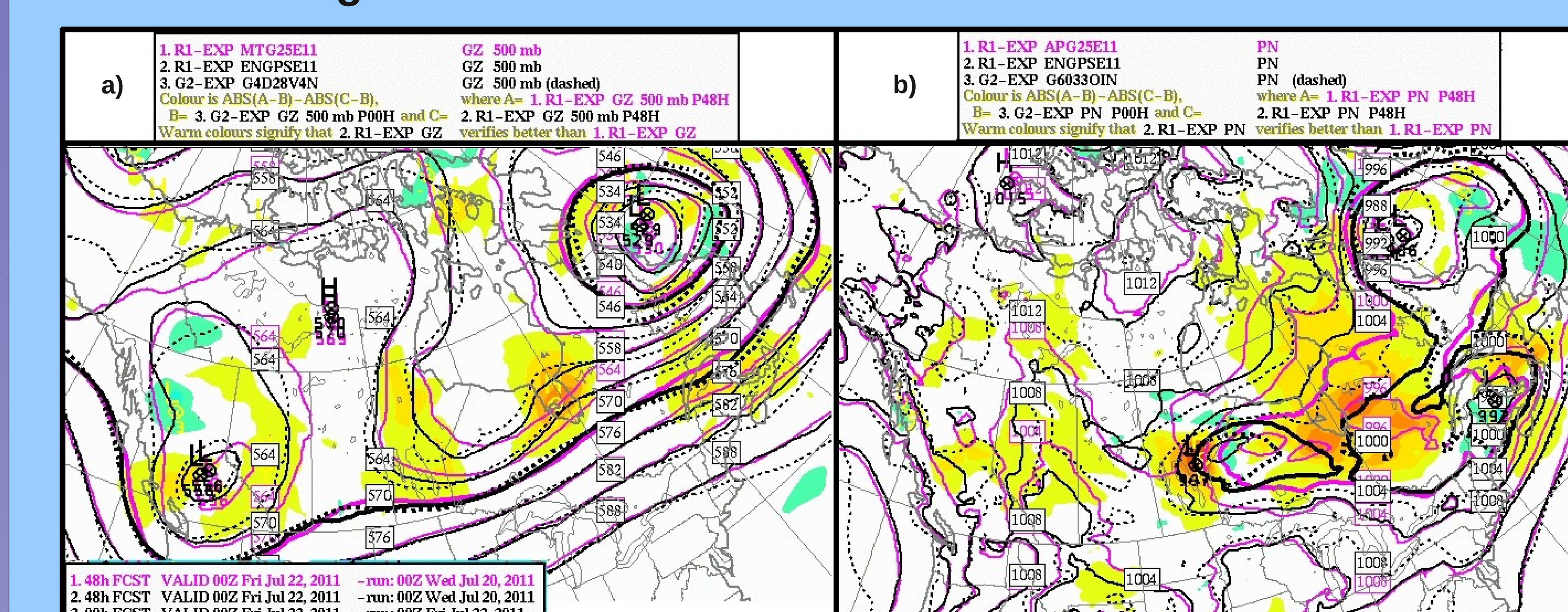

Figure 7. A summer case. Contours of **(a)** geopotential height GZ [dam] at 500 mb and **(b)** sea-level pressure PN [mb] valid at 00Z July 22, 2011 based on (magenta) 48-h forecast from 4D-Var experiment, (black continuous) 48-h forecast from En-Var experiment and (black dashed) verifying analysis. The verifying analysis comes from the operational global prediction system (4D-Var) which assimilates more observations than the regional system due to a longer cut-off time. **Regions where the En-Var based** (4D-Var based) **forecast is closer to the verifying analysis are shown in yellow through red** (cyan through blue).

- A meteorological evaluation was performed by CMC operations staff (Figures 7 and 8)
- 4D-Var and En-Var regional forecasts were compared with the operational global analysis valid at the same time (the global analysis has a longer cut-off time, i.e. more observations than the regional experiments)
- Comparing 4D-Var and En-Var to each other, the forecasts were markedly different in 20% of the winter cases and 16% of the summer cases.
  - Of these, there were 2-4 times as many cases where En-Var was better than 4D-Var
- Improvements were seen most frequently in the Atlantic region.
- 4D-Var and En-Var forecasts were fairly similar in the Pacific and Arctic regions in summer.
- Inverted troughs in the American mid-west were usually represented better by 4D-Var.
- Quantitative precipitation forecast scores are similar between 4D-Var and En-Var
- En-Var forecasts of the location and strength of Hurricane Irene were somewhat more accurate than 4D-Var forecasts (Figure 8)

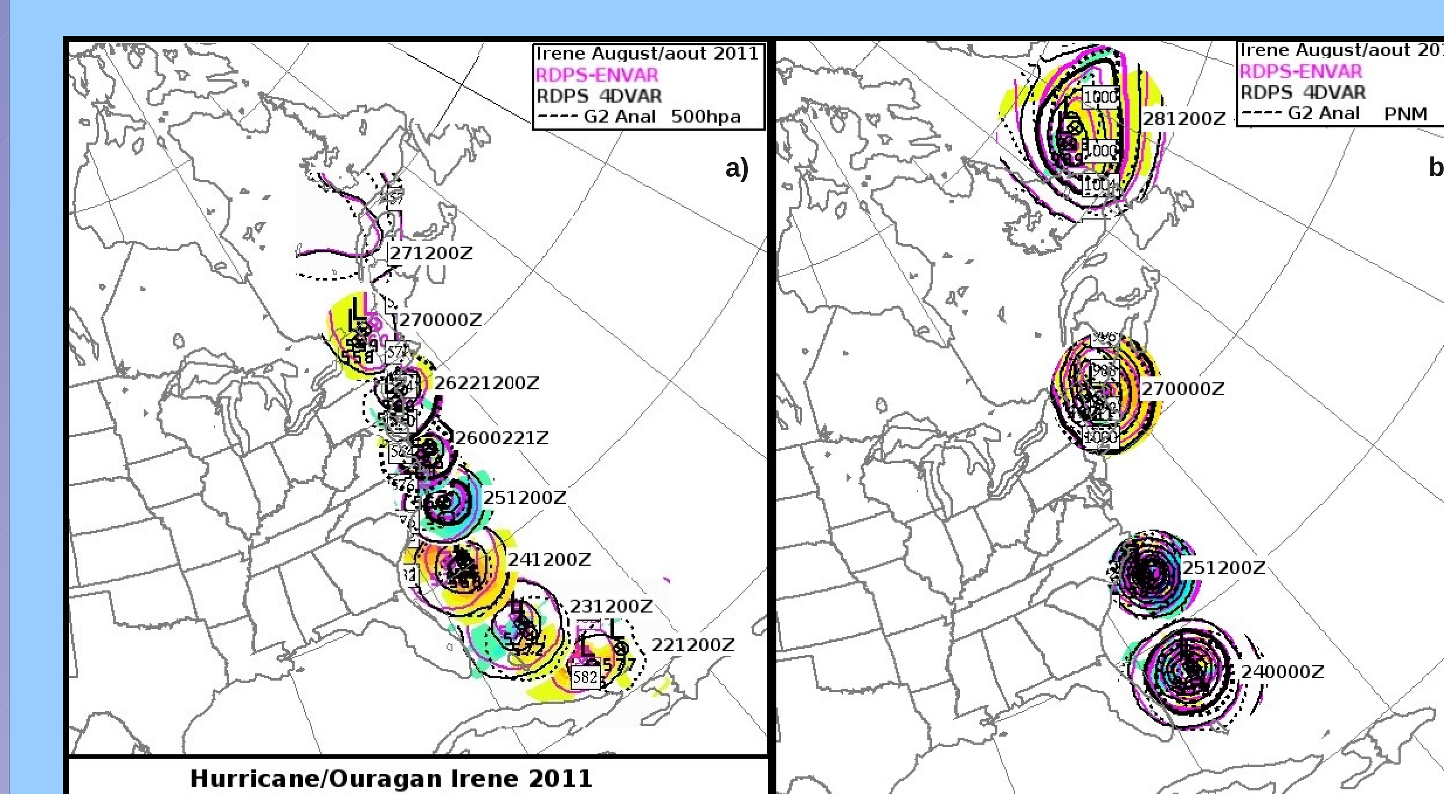

Figure 8. Development of Hurricane Irene, Aug 22-27, 2011. Contours of **(a)** geopotential height GZ [dam] at 500 mb and **(b)** sea-level pressure PN [mb] based on (magenta) 48-h forecasts from 4D-Var experiment, (black continuous) 48-h forecasts from En-Var experiment and (black dashed) verifying analyses. The verifying analyses come from the operational global prediction system (4D-Var) which assimilates more observations than the regional system due to a longer cut-off time. **Regions where the En-Var based** (4D-Var based) **forecasts are closer to the verifying analyses are shown in yellow through red** (cyan through blue).

5. Future outlook

- Operational implementation of the new RDPS En-Var system is expected for fall 2014
- The system implemented will have further enhancements, i.e.
  - Covariances will be provided by 256 ensemble members at 50 km resolution instead of 192 members at 66 km resolution
  - Initial analysis input at t-6 h will come from a new 15 km En-Var global assimilation system rather than the currently operational 25 km 4D-Var system
  - RDPS increment resolution will increase from 600x300 (shown here) to 800x400
- Furthermore, in the global system, the digital filter will be replaced by the incremental analysis update (IAU) approach
- Final tests are currently underway

6. References

- Buehner, M., J. Morneau and C. Charette, 2013: Four-dimensional ensemble-variational data assimilation for global deterministic weather prediction. *Nonlin. Processes Geophys.*, **20**, 669-682.
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