Comparison of two pairs of momentum control variables in WRFDA for convective-scale data assimilation

Juanzhen Sun\textsuperscript{1}, Hongli Wang\textsuperscript{1}, Wenxue Tong\textsuperscript{2}, Xiangyu Huang\textsuperscript{1}, and Dongmei Xu\textsuperscript{2}

\textsuperscript{1}National Center for Atmospheric Research
\textsuperscript{2}Nanjing University of Information Science and Technology
Outline

• Motivation of the study
• Comparing error characteristics
• Impact on precipitation forecast
• Summary and conclusions
Common options for momentum control variables

1. x and y components of velocity: $u$ and $v$
2. Stream function and velocity potential: $\psi$ and $\chi$
3. Vorticity and divergence: $\zeta$ and $\delta$

- WRFVAR uses the option 2
- Other DA systems that use this option: NCEP GSI, MetOffice 3/4DVar

Considerations for choosing control variables

- Gaussian distribution
- Small cross-correlation
- Computation efficiency
- Ease in defining balance
Relationships between the momentum control variables

\[ \psi : \text{Stream function} \]
\[ \chi : \text{Velocity potential} \]

\[ \nabla^2 \psi = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \zeta \]

Vorticity

\[ \nabla^2 \chi = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \delta \]

Divergence

In this study, we focus on the two pairs of momentum control variables: \( \psi \chi \) and \( uv \)
Possible issues in using $\psi \chi$ as control variables for limited-area convective-allowing NWP

- Produce analyses that possess large-scale motions of the background field and ignore the small-scale information in the observation (Xie and MacDonald 2011)
- Have to deal with a complicated boundary value problem for the conversion (Xie and MacDonald 2011)
- Slow spinup that causes difficulty for high frequency cycling

Questions to be answered through this study

• How do the two options compare in terms of their error property and hence analyses?

• What is the impact on precipitation forecast?
Error correlations computed using the NMC method (24h-12h)

**Data:** Realtime WRF forecasts, June-July 2012  
**Resolution:** 3km  
**Domain:** 2/3 of CONUS  
**Lat:** 24~49  
**lont:** -116 ~ -74

<table>
<thead>
<tr>
<th></th>
<th>psi</th>
<th>chi</th>
<th>t</th>
<th>ps</th>
</tr>
</thead>
<tbody>
<tr>
<td>psi</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>chi</td>
<td>-0.1326816</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>0.07656949</td>
<td>0.06037489</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ps</td>
<td>0.11058880</td>
<td>-0.04465158</td>
<td>-0.11587265</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>u</th>
<th>v</th>
<th>t</th>
<th>ps</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v</td>
<td>-0.00981649</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>0.00306958</td>
<td>0.01183282</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ps</td>
<td>-0.00020944</td>
<td>-0.04180923</td>
<td>-0.11587265</td>
<td>1</td>
</tr>
</tbody>
</table>
Gaussian Distribution?
Comparison of length scales

CV5: Generate BES using WRFDA utility GEN_BE CV5 (ψ and χ_u)
CV_uv: Generate BES using a new option in GEN_BE (u and v)
Comparison of error STD

**NMC:** Calculating STD without using GEN_BE

**CV5:** Generate BES using WRFDA utility GEN_BE CV5 ($\psi$ and $\chi_u$)

**CV_Uv:** Generate BES using a new option in GEN_BE ($u$ and $v$)
UV vs. $\psi \chi$ – single obs test

Comparing the two increments along x-direction on obs. level

U increment using CV5 BES

U increment using CV_uv
UV vs. $\psi \chi$ – real data test

V increment from CV5

V increment – CV_uv

(g) v 850 hPa

(h) v 850 hPa
Averaged FSS score for 7 Cases over 29 convective forecasts in the Front Range region

ROI = 10 km

Threshold=1mm

Threshold=2.5mm
Initialization Time: 2008080900

Stage 4 Rainfall (mm/hr) validated at 2008080904

1 Hour Precipitation (mm) validated at 2008080904

3DVar CV5 validated at 2008080904

3DVar CV_uv validated at 2008080904
Summary

1. Using two-month warm season 3km data over a limited-area domain, we have found

   - $uv$ and $\psi\chi$ all have Gaussian error distributions

   - $u$ and $v$ have less correlation than $\psi$ and $\chi$

   - $u$ and $v$ have larger variances and smaller length scales than $\psi$ and $\chi$; the reduction of the length scale is more pronounced at the high-frequency modes

   - Single observation and real data test showed analyses with CV$_{uv}$ BES resulted in $u/v$ increments that are smaller scale and higher magnitude

2. Improved precipitation forecasts with CV$_{uv}$ analyses are demonstrated, especially beyond 8-9 hours