30 second cycle LETKF assimilation of dual PAWR observations to short-range convective forecasts

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Goal: High-resolution, rapid-update cycle assimilation of radar data

- **High Resolution**: Targeting 100m horizontal resolution — observe detailed structure of convection and small-scale features

- **Rapid Update Cycling** — Performing rapid-update of high resolution grids every 30 seconds — reasonable assume linear evolution at convective scales

- **Assimilate PAWR**: Optimize the use of high spatial-temporal resolution data from Phased Array Weather Radar (PAWR), which allows to observe the detailed structure of convective storms

*Improve short-range forecasts of severe convective storms*
Phased Array Weather Radar / Introduction

Parabolic antenna

150m every 5 mins

100x more data!
10x more data

Transmits fan beam

2m x 2m (antenna)

3D reflectivity and Doppler radial velocity at 100m on 100 elevation angles every 30 seconds

Phased Array Weather Array

Kobe

Suita (Osaka)

X band radar (3.1 cm wavelength)
Phased Array Weather Radar / Reflectivity

Reflectivity of convective band system observed by Suita (Osaka) PAWR on 13 July 2013

Every 30 seconds means PAWR captures rapidly developing convective cell

Phased Array Weather Radar / Dual Coverage

**Suita:**
Operational since May 2012

Covering Osaka, Kobe and Kyoto
Kobe: Operational since summer 2014

Suita: Operational since summer 2012

Dual coverage over Kobe region

Advantages: X-band radars suffer from attenuation by intervening precipitation and wet radome (absorb radiation), so failure by one radar system can be covered by another.
GOAL: Assimilate observations from both radars to improve short-range forecasts

- Ensure **consistency** between radar data
- An **effective QC** that removes sidelobes echoes, ground clutter and contamination
- A sophisticated NWP model that is **designed and tuned** to perform rapid-update cycling at high resolution (up to 100m)
Model and Experiment Setup
SCALE-LETKF

Scalable Computing for Advanced Library and Environment (Nishizawa et al. 2015; Sato et al. 2015)

An open-source basic library for weather and climate simulation.
Developed by Computational Climate Science Research Team, RIKEN R-CCS.

SCALE-RM: A regional NWP model based on SCALE.

LETKF

Based on Hunt et al. 2007

Widely used method suitable for parallel computing — with K supercomputer we can run with high efficiency

SCALE-LETKF

(LIEN ET AL. 2017)
Severe Convective System: 11 Sept 2014

Osaka PAWR observations

08:00 JST

08:10

08:20

08:40

Isolated convective system initiated very rapidly (minutes) within dual coverage region

Kobe PAWR Ref.

Suita (Osaka) PAWR Ref.

Rainfall intensity up to 50 mm/hr – severe convective events targeted by rapid-update system
**SCALE-LETKF / Experiment design**

**Ensemble size:** 100

State variables: U, V, W, P, T, Q, Qc, Qr, Qs, Qi, Qg

**Reflectivity and Doppler radial velocity**
(Obs err = 5dBZ, 3m/s)

<table>
<thead>
<tr>
<th>Level</th>
<th>Resolution (km)</th>
<th>Size (km)</th>
<th>Observation Type</th>
<th>Cycle Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>15</td>
<td>5760 x 4320</td>
<td>PREPBUFR</td>
<td>6 h</td>
</tr>
<tr>
<td>D2</td>
<td>5</td>
<td>1280 x 1280</td>
<td>PREPBUFR</td>
<td>6 h</td>
</tr>
<tr>
<td>D3</td>
<td>1</td>
<td>300 x 300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D4</td>
<td>1 km, 250m, 100m</td>
<td>180 x 180</td>
<td>PAWR (Ze + Vr)</td>
<td>30 s</td>
</tr>
</tbody>
</table>

**START Cycling**
00:00 JST Sept 1

00:00 Sept 10

02:00 Sept 11

08:00 Sept 11

30-min forecasts (from ensemble mean)
Data Processing
PAWR: Quality Control

- Good QC is critical - side lobe echoes, ground clutter are big problems for PAWR due to broad beam

- Two QC algorithms available for PAWR observations

- QC algorithm specifically developed for Suita PAWR. Previously used in PAWR studies (e.g. Maejima et al. 2015)
- Considers 4 parameters:
  - Texture of reflectivity patterns
  - Radial velocity
  - Ze correlations with time
  - Ze vertical gradient
- Good at removing attenuated rain and ground clutter but range sidelobes can remain an issue

Option 2 – NICT QC
- Under continual development by NICT (National Institute for Communications Technology)
- Part of long-term strategy to obtain QC’ed observations in *realtime* – assimilate new PAWR data every 30 seconds
- Includes sidelobe removal feature
PAWR: Super observations

- Perform superobbing of observations to match model resolution
- Observations are converted to 3D cartesian grid, QCéd and superobbed is performed
- At 250m we can retain detailed structure of storm

Osaka raw observations (100m) after QC (Ruiz et al. 2015) and 250-m superobing for LETKF

Images by Guo-Yuan Lien
Single PAWR Assimilation
Cycling starts 08:00 on 11 Sept 2014

Assimilating observations from Suita PAWR at 250m

Analysis closely matches observations - Individual convective cells (intensity and structure) represented in the model analysis

SCALE-LETKF well-tuned (localization, obs error)
Single PAWR Assimilation (Osaka)

SCALE-LETKF Anal. (250m)  SCALE-LETKF Anal. (100m)  Observations (100m)

08:10 (after 10 mins cycling)  08:10 (after 10 mins cycling)  08:10

08:20

08:30

dbz

08:30
Assimilating PAWR from single PAWR at high resolution (up to 100m) have shown we can improve analyses and short range forecasts (e.g. Maejima et al. 2017).
Dual PAWR Assimilation
Severe convective storm on 20/8/16 which developed rapidly into intense convective rain event that brought heavy rainfall over Osaka

- Initialized and developed with dual coverage region

- Both Suita and Kobe radars featured range sidelobes (error feature) in observations (common issue for PAWR)
PAWR consists of stronger side lobes (transmit unwanted radiation in unwanted direction) – means more ground clutter compared to conventional radars.

- PAWR emits electronic beams in the EL direction. These are transmitted as fan beams.
- PAWR consist of stronger side lobes (transmit unwanted radiation in unwanted direction) – means more ground clutter compared to conventional radars.
- Can affect quality of data.
Dual PAWR Assimilation: Sidelobe errors

Osaka PAWR

Reflectivity @ 2km

1730

Sidelobe echoes appear beyond storm

20 August 2016

Kobe PAWR

Reflectivity @ 2km

1730

Sidelobe extending away from radar
Dual PAWR Assimilation: Sidelobe errors

Osaka PAWR

20 August 2016

Reflectivity @ 2km

Sidelobe echoes

Superob (1km resolution)

After QC (Ruiz et al 2015)

Sidelobe remains in observations
Goal: To improve analyses and forecasts with the assimilation of dual PAWR observations

Experiment 1 (Control)

“SINGLE” PAWR (Osaka)

Assimilate Osaka Ref + Vr

Experiment 2

“DUAL” PAWR (Osaka + Kobe)

Assimilate Osaka + Kobe radial velocity (Vr) separately but combine Reflectivity (Ze)

- Within dual-coverage region, assimilate larger Ze value – assuming that echo with larger value is less attenuated
- Perform simple spatial smoothing of reflectivity field to reduce large differences caused by combining Ze – each grid assigned with 80% of observed value and 20% of surrounding grid values
**Dual PAWR Assimilation: 1km Experiments**

**“SINGLE” (Osaka Only) Ref. Analysis (z=2km)**

- Start D4 cycling at 17:10
- Initialize 30 min forecasts @ 18:00

Sidelobe echoes present in analyses

Increase in reflectivity in DUAL

**“DUAL” (Osaka + Kobe) Ref. Analysis**
Dual PAWR Assimilation: Rain Intensity (mm/hr) Forecasts

Surface Rainfall Intensity forecasts initialized @ 18:00

- **DUAL** achieved higher rain intensity in 30 minutes forecasts
- Highest rain intensity located on northern side
- Issues with location and structure of convection remain – improve with better QC
- Improved tuning of SCALE-LETKF, observations

![Map of Surface Rainfall Intensity Forecasts](image-url)
Current Tasks

1) Investigate the **impact of sidelobe echoes** to forecasts

- Large feature that remains – major issue of PAWR observations is sidelobe echoes
- Currently we don’t have QC that reliably removes this feature
- Understand the impact of sidelobe error to forecasts

2) **Improve NICT QC** - Enable assimilation of dual PAWR at higher resolution (250m, 100m)

- Update/improve tuning NICT QC – current version doesn’t adequately remove sidelobe errors.
- Once improved QC, run higher resolution experiments with dual-PAWR
Summary

- 30 second update and high resolution DA performed with SCALE-LETKF and PAWR observations has shown to improve analyses and forecasts.

- Preliminary DUAL-PAWR experiments have shown some improvements in rain intensity forecasts at lower resolution (1km) compared to single PAWR experiments, but improvements in current QC (Ruiz et al. 2015 and NICT QC) needed to remove large error features (sidelobes), clutter that negatively impact forecasts.

- Current activities include investigating impact of range sidelobe echo to forecasts and improving QC.

- Higher resolution (250m, 100m), rapid-update cycling experiments using Kobe and Suita PAWR observations planned next with improved QC.