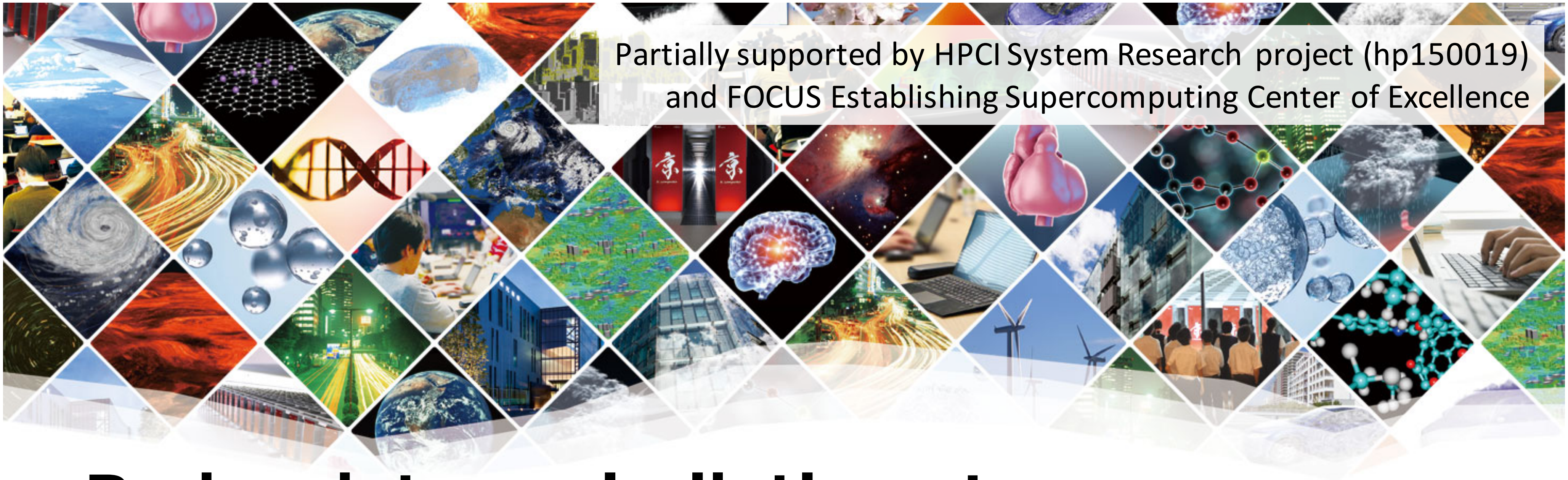

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and FOCUS Establishing Supercomputing Center of Excellence

# Radar data assimilation at sub-kilometer scales: *A case study of Phased-Array Weather Radar Assimilation*

**The 7th EnKF Data Assimilation Workshop**

**26 May 2016**

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Data Assimilation Team

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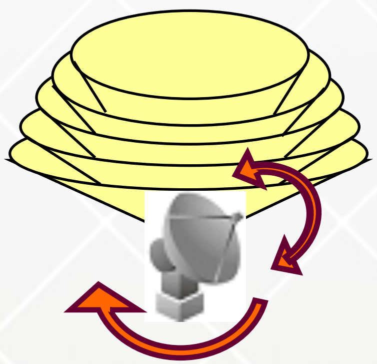
# Motivation

- The resolution of radar observation data can be usually higher than the model resolution; in particular, Phased-Array Weather Radar (PAWR).

- We explore radar data assimilation at 1-km – 100-m model resolution with a 30-s rapid-update cycle using the K computer!

# Phased Array Weather Radar (PAWR)

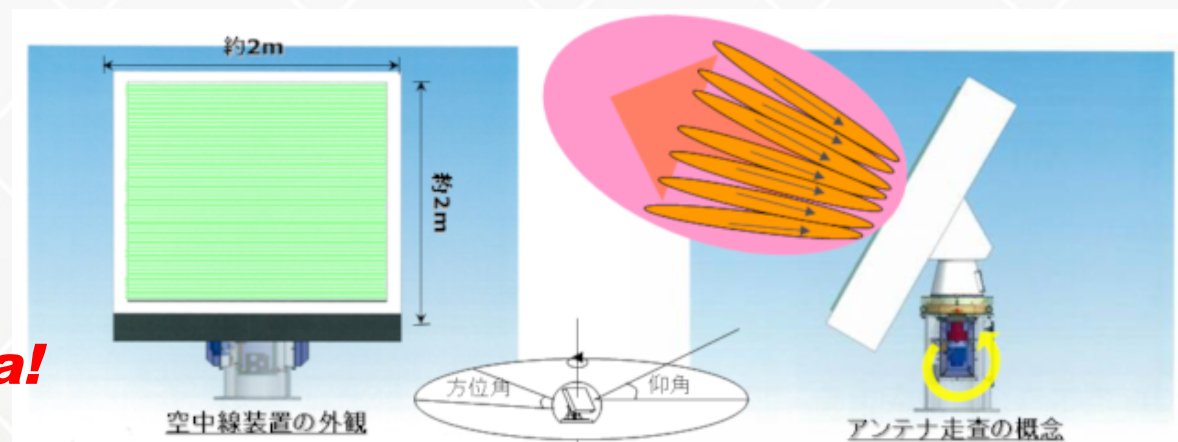
Courtesy of NICT



3-dim measurement using a parabolic antenna (150 m, 15 EL angles in 5 min)

**100x more data!**

10x more data in a 1/10 period




3-dim measurement using a phased array antenna (100 m, 100 EL angles in 30 sec)

# SCALE-LETKF (Lien et al. 2016)

- Model:

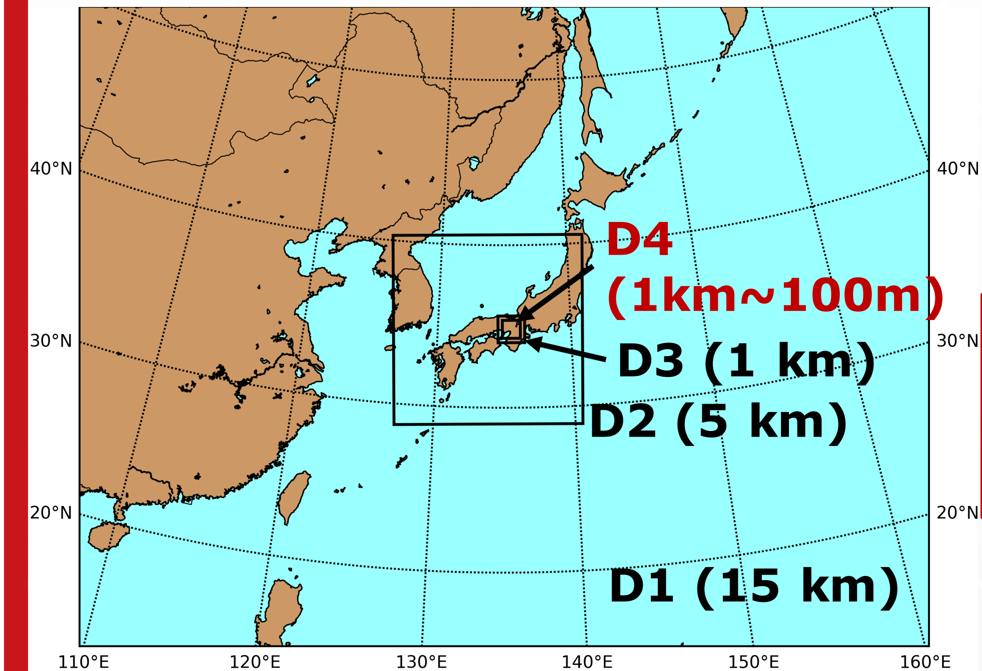
  - Regional model

  - Scalable Computing for Advanced Library and Environment (Nishizawa et al. 2015; Sato et al. 2015)
  - An open-source basic library for weather and climate model.
  - Developed also at RIKEN AICS.

- Data assimilation:

  Local Ensemble Transform Kalman Filter (**LETKF**; Hunt et al. 2007)

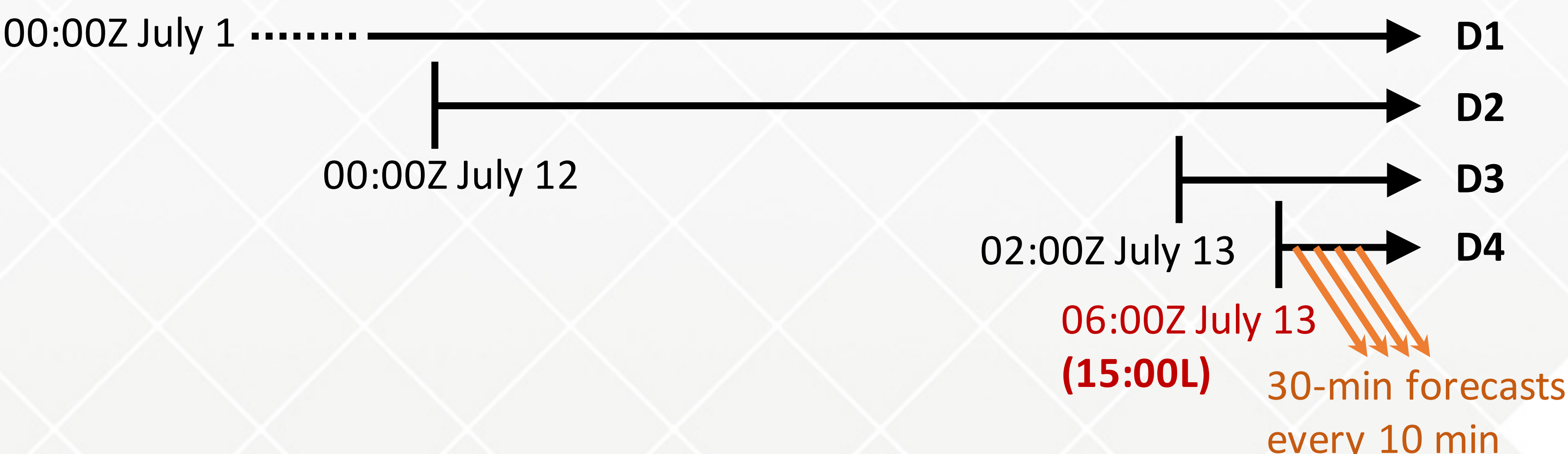
# Experimental settings




| | Resolution | Size | Observation | Cycle length |
|---|---|---|---|---|
| D1 | 15 km | 5760 x 4320 km | PREPBUFR | 6 h |
| D2 | 5 km | 1280 x 1280 km | PREPBUFR | 6 h |
| D3 | 1 km | 180 x 180 km | PAWR | 5 m |
| D4 | 1 km<br>500 m<br>250 m<br>100 m | 120 x 120 km | PAWR | 30 s |

Ensemble size: 100

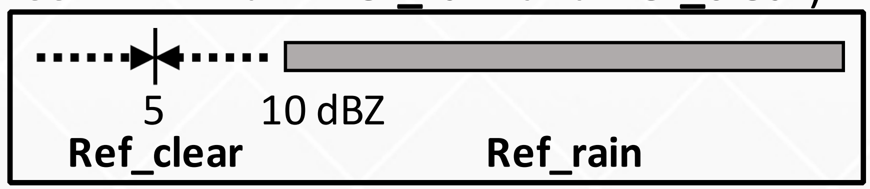
State variables: U, V, W, P, T, Q, Qc, Qr, Qs, Qi, Qg



# Experimental settings

## After a very long process of tuning...............

- Assimilate both reflectivity (**Ref**) and radial velocity (**Vr**) data.
- Radar data QC (Ruiz et al. 2015): remove ground clutter and attenuated data.
- Superob to model resolution (use only the data below 11 km).
- Define **Ref_rain**: raw Ref >= 10 dBZ
  **Ref_clear**: raw Ref < 10 dBZ
- Set all **Ref_clear** (both observation and background) to 5 dBZ. (Similar to Aksoy et al. 2009 but leave a 5-dBZ gap between minimum **Ref_rain** and **Ref_clear**)




- Observation errors: **Ref**: 5 dBZ
  **Vr**: 3 m/s
- Reject data when [y – H(x)] > 10 x obs error
- Reject data when there are too few "raining" (**Ref_rain**) background members: (similar to Lien et al. 2013, 2016 for precipitation assimilation)
  **Ref_rain** obs: require >= 1 (out of 100) background members having **Ref_rain**
  **Ref_clear** obs: require >= 20 (out of 100) background members having **Ref_rain**
- Limit number of observations used per grid (Hamrud et al. 2015): Max = 100
- Relaxation to prior spread (Whitaker and Hamill 2012): α = 0.95
- Covariance localization:
  Horizontal (**Ref_rain** and **Vr**): 4 km
  Horizontal (**Ref_clear**): 2 km
  Vertical (all): 2 km

# 10-min analyses and 30-min forecasts

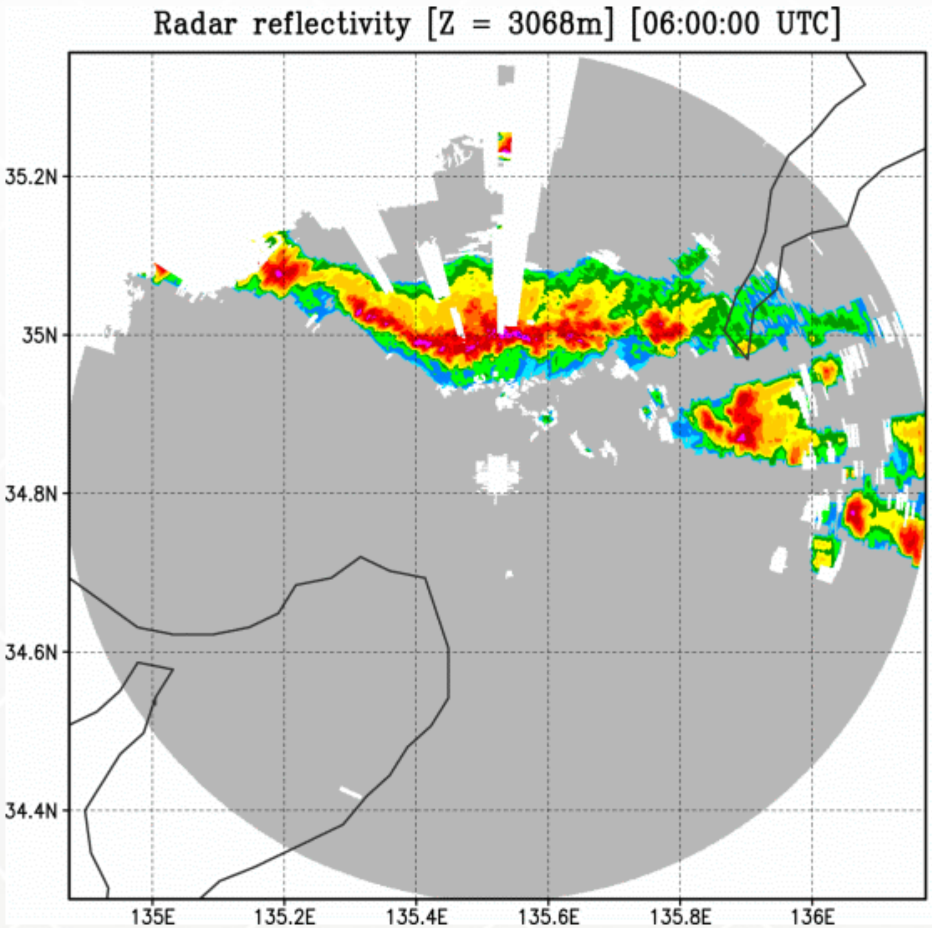
**Obs superobed to the model resolution**

**15:00L – 15:10L : Analysis**

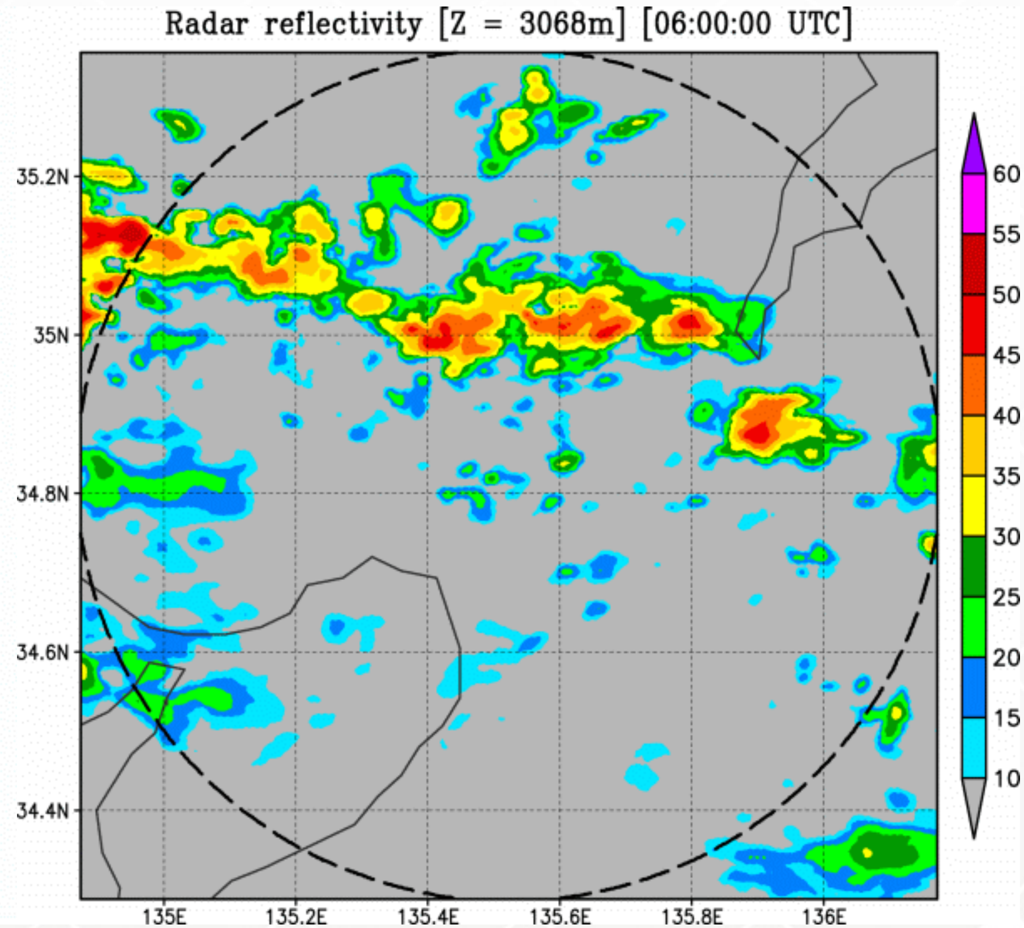
**15:10L – 15:40L : Forecast**

**3-km height**

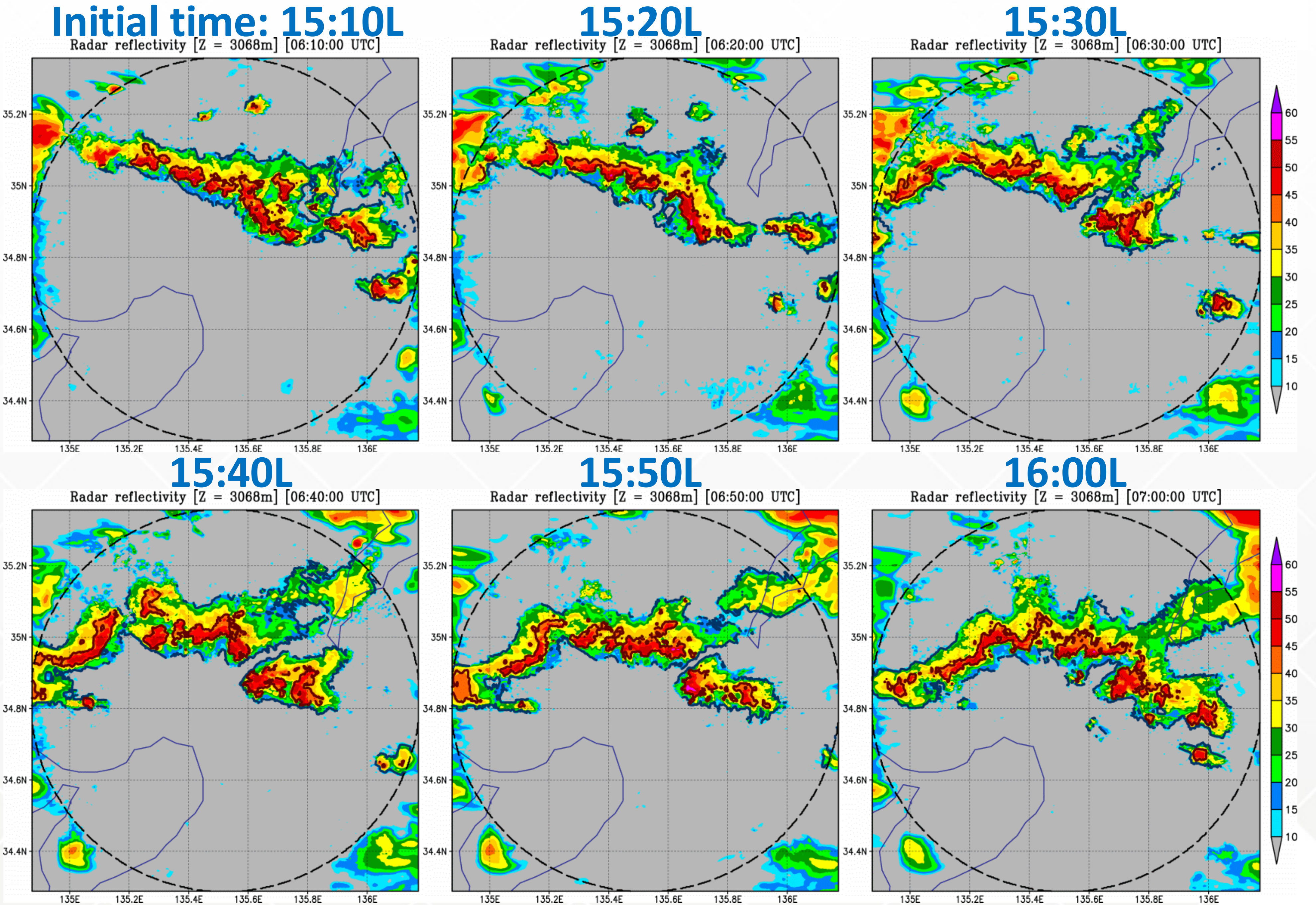
## OBS After QC (Ruiz et al. 2015)




## 250 M (D4)



# 30-min forecasts at 250-m model resolution




Observation: 10 dBZ 40 dBZ

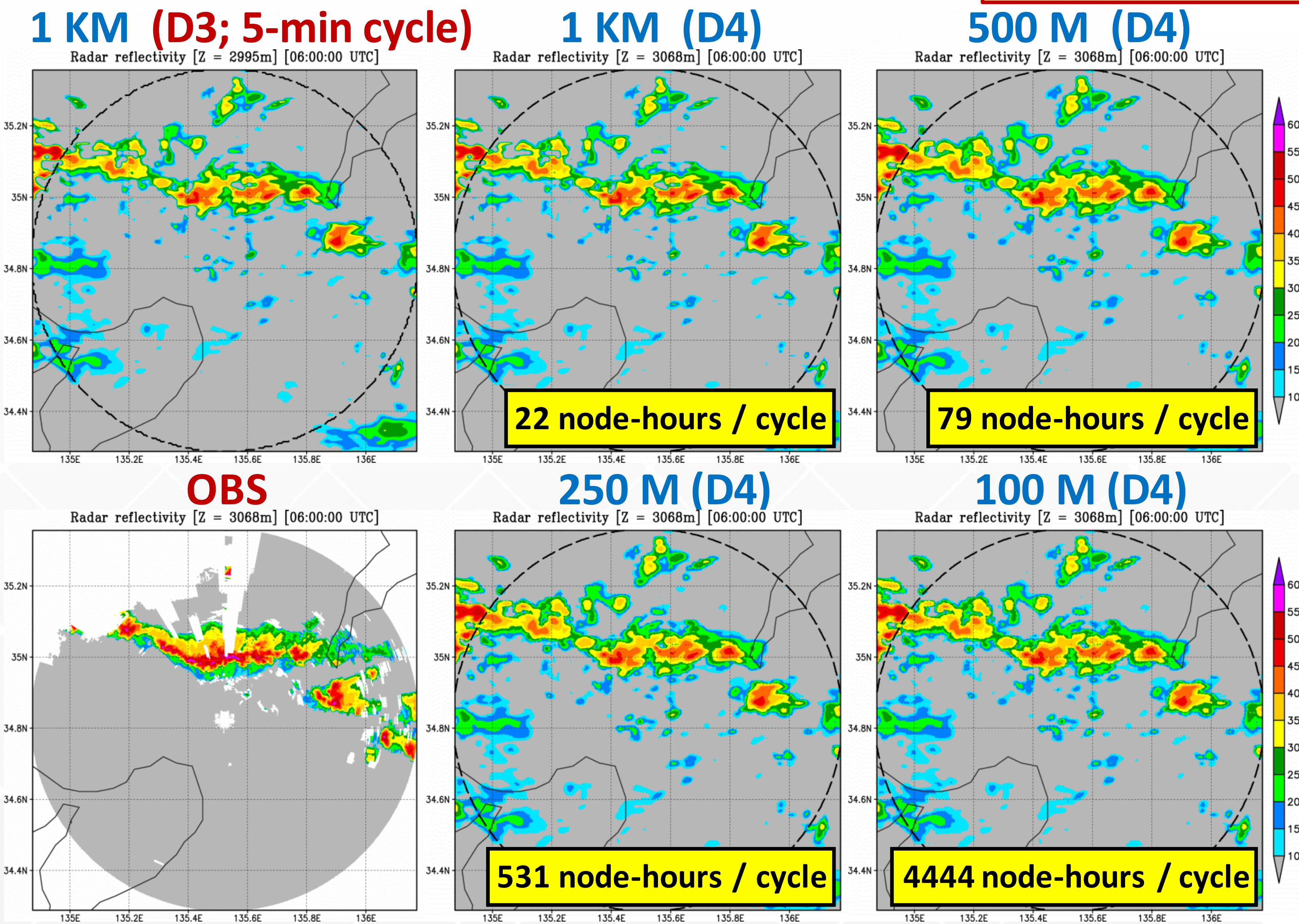
# Resolution dependence

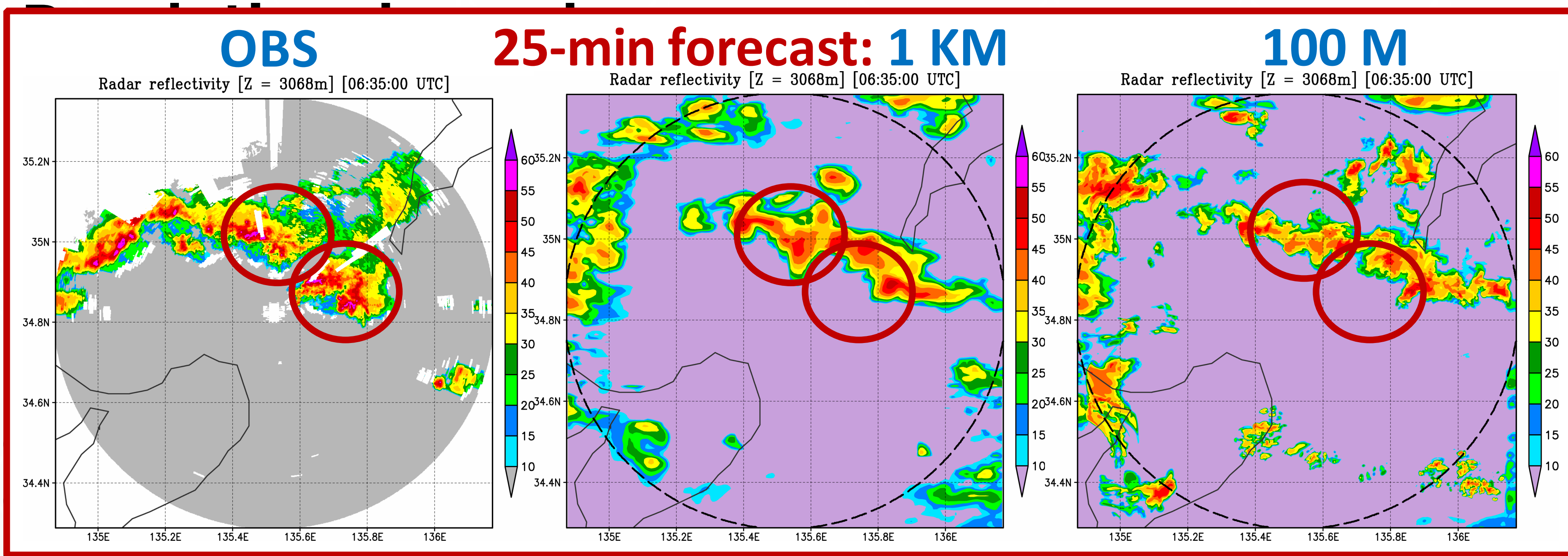
- Compare the 30-min forecast skills at different resolutions:

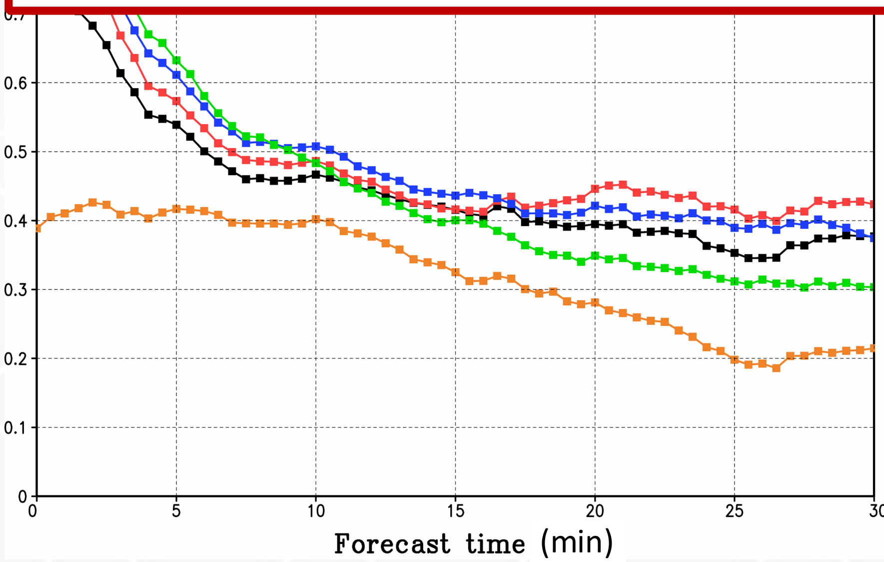
| Experiments | Model resolution | Observation resolution | Cycle length | # forecast cases (every 10 min) |
|---|---|---|---|---|
| **D3_1 KM** | 1 km | 1 km | 5 min | 6 |
| **1 KM** (D4) | 1 km | 1 km | 30 sec | 6 |
| **500 M** (D4) | 500 m | 500 m | 30 sec | 6 |
| **250 M** (D4) | 250 m | 250 m | 30 sec | 6 |
| **100 M** (D4) | 100 m | 100 m | 30 sec | 1 |

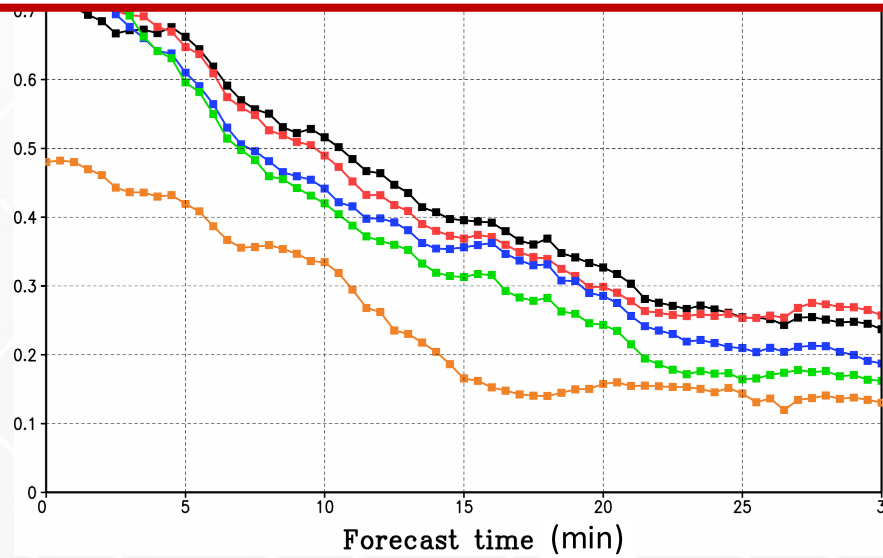
# 10-min analyses and 30-min forecasts at different model resolutions

Obs superobed to the model resolution






Experiments are performed with the same localization settings while also using the same observation number limit

1 KM
500 M
250 M
100 M

D3_1 KM (5-min update cycle)

# Resolution dependence
## (obs limit = 100)

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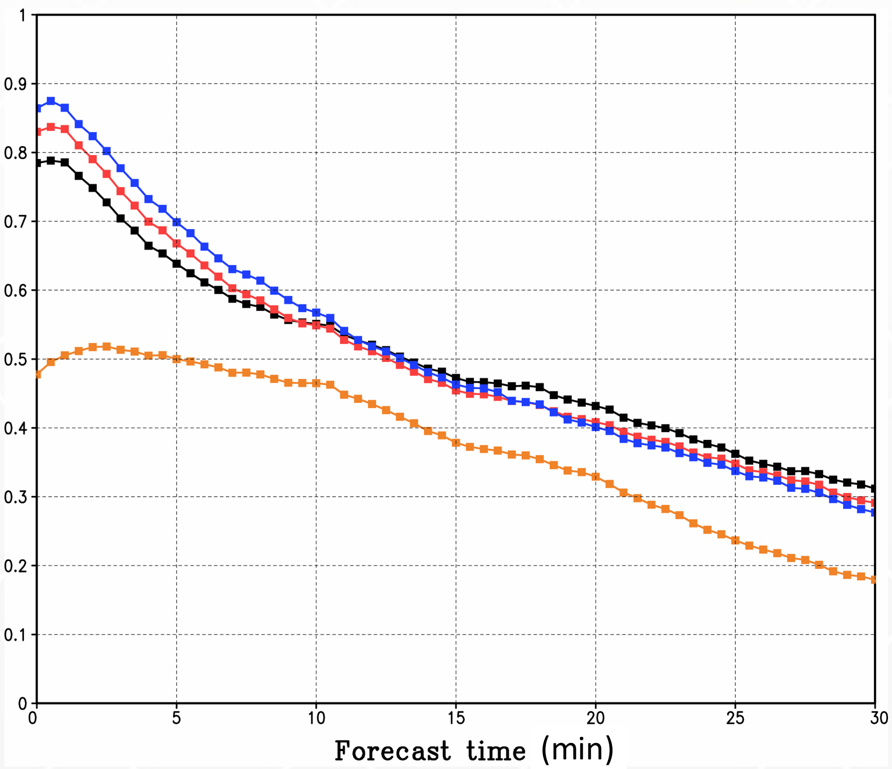
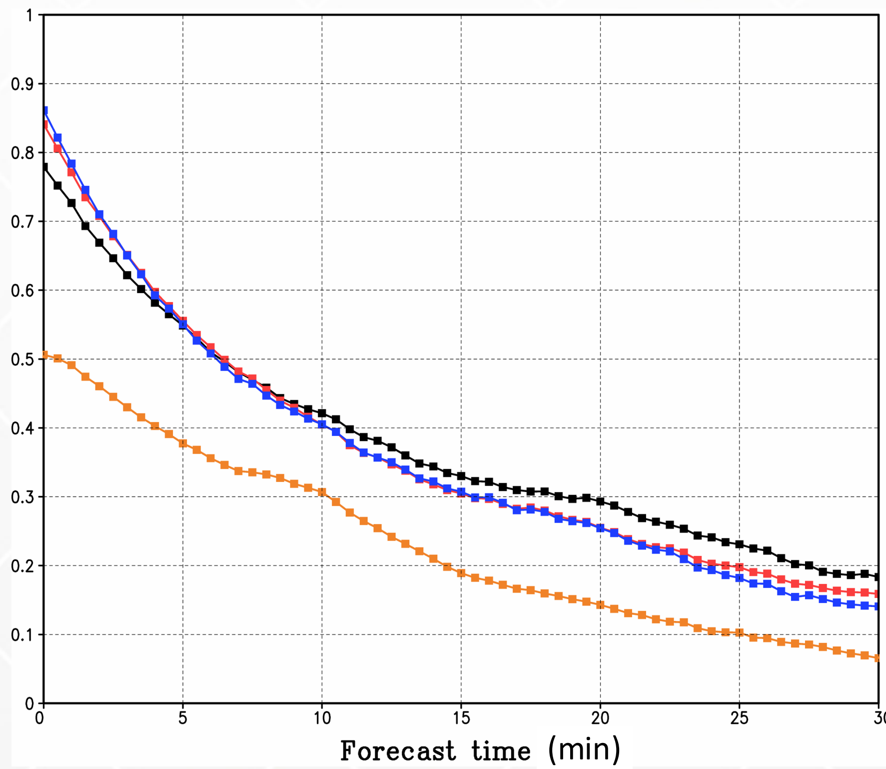
## Threat scores

(0610Z - 0700Z; **6 forecasts**)

**[10 dBZ]**




**[30 dBZ]**




**1 KM** **D3_1 KM (5-min update cycle)**

**500 M**

**250 M**

# Observation number limit (Hamrud et al. 2015)

- Limit the number of observations assimilated per grid point for each combination of different report types (e.g., radiosonde) and variables (e.g., U-wind).
  - Observations spatially closest to the analyzed grid point are selected.
- In their system (i.e., ECMWF global model):
  - Maximum observation number per grid (NOBS) = **30**
  - Advantages:
    - Save the computational time.
    - Significantly increase the forecast scores in the Northern Hemisphere (3-5% anomaly correlation metric).
- Modifications in our study:
  - Observations with smallest “localization-modified observation errors” are selected.
  - Optimal NOBS = **100** by sensitivity experiments at 250-m resolution.

# Impact of obs number limit (250 m)

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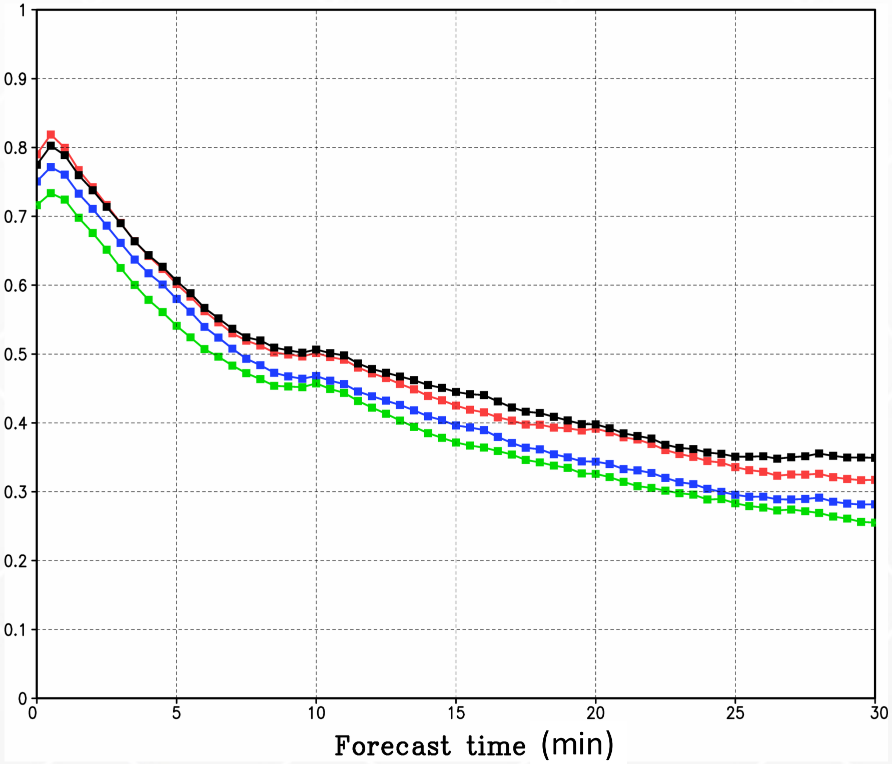
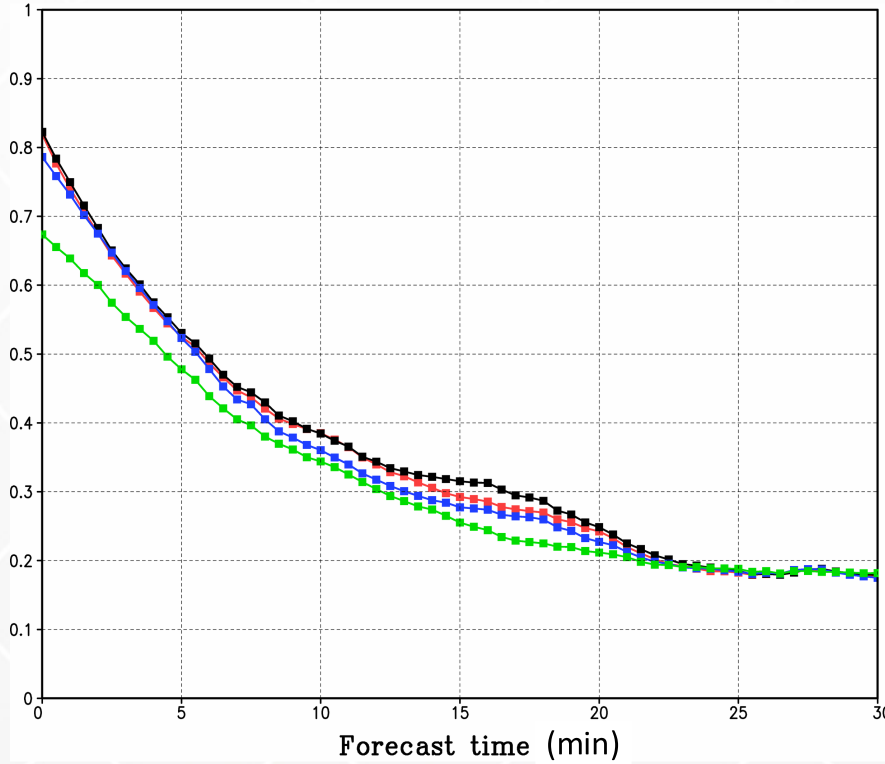
## Threat scores

(0610Z - 0620Z; **2 forecasts**)

**[10 dBZ]**




**[30 dBZ]**




**NOBS = 30 : Second best results**

**NOBS = 100 : Best results**

**NOBS = 500**

**NOBS = ∞**

# Impact of obs number limit - #OBS (250 m; 1st cycle)

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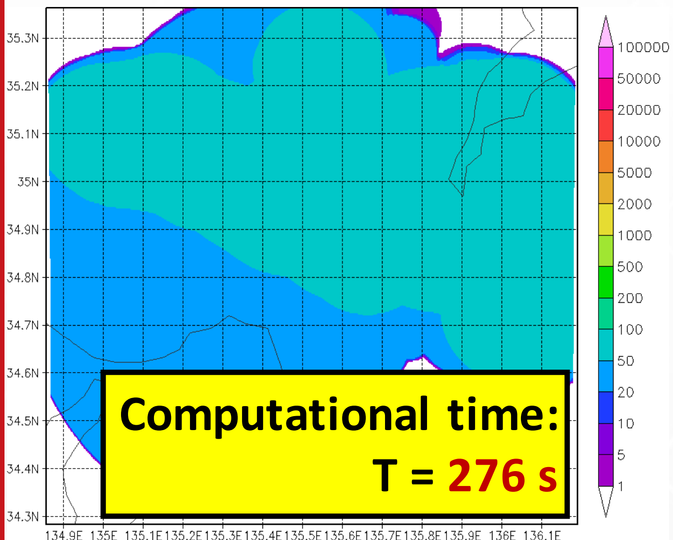
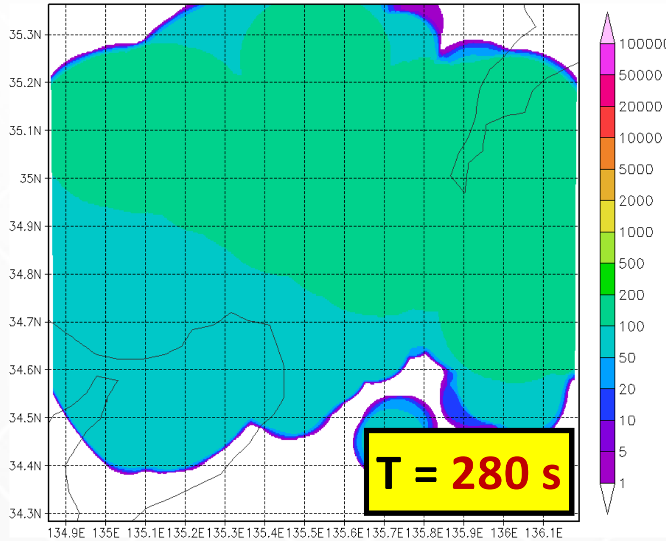
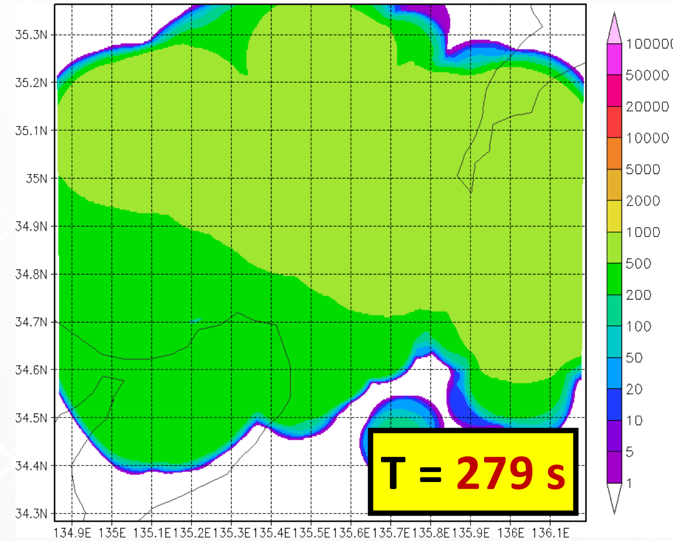
## NOBS = 30



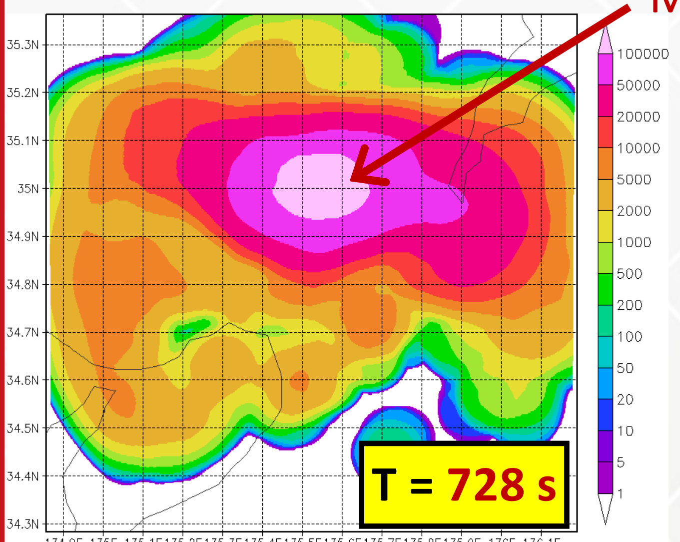

## NOBS = 100




## NOBS = 500




## NOBS = ∞



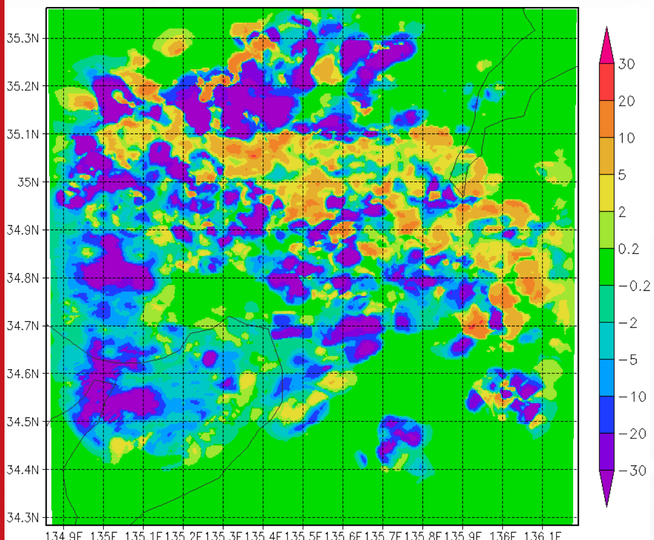

More than 100,000 observations !

Localization cut-off area for **Ref_rain** and **Vr**

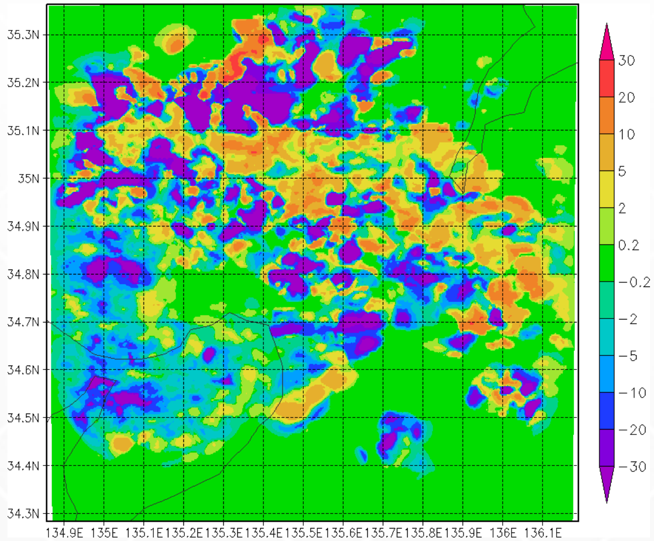
| | | |
|---|---|---|
| Covariance localization: | | |
| Horizontal (**Ref_rain** and **Vr**): | 4 km (cut-off radius 14.6 km) |
| Horizontal (**Ref_clear**): | 2 km (cut-off radius 7.3 km) |
| Vertical | (all): | 2 km (cut-off radius 7.3 km) |

# Impact of obs number limit - Increment Ref (dBZ) (250 m; 1st cycle)

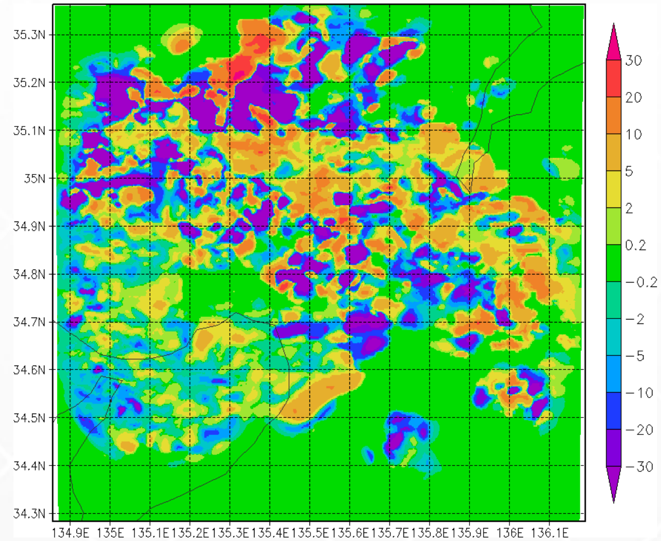
## NOBS = 30



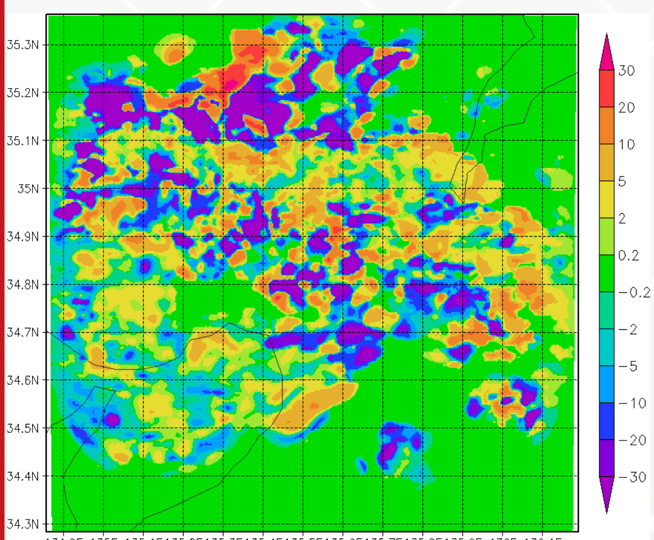

## NOBS = 100




## NOBS = 500




## NOBS = ∞




Very similar !

# Impact of obs number limit - #OBS (250 m; 1st cycle)

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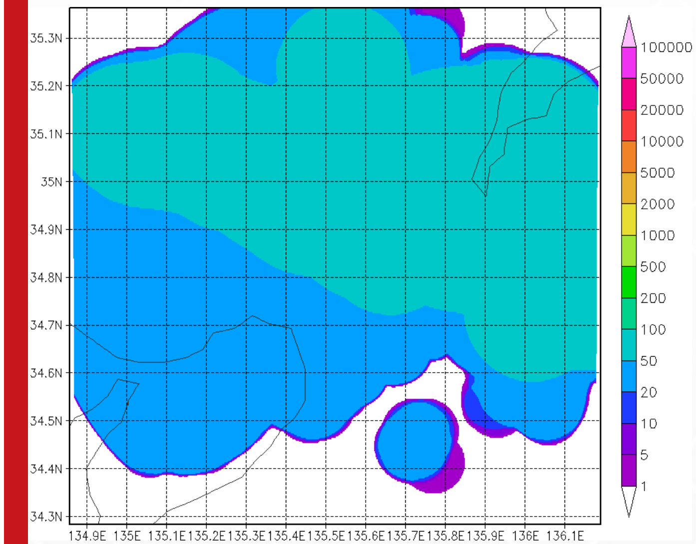
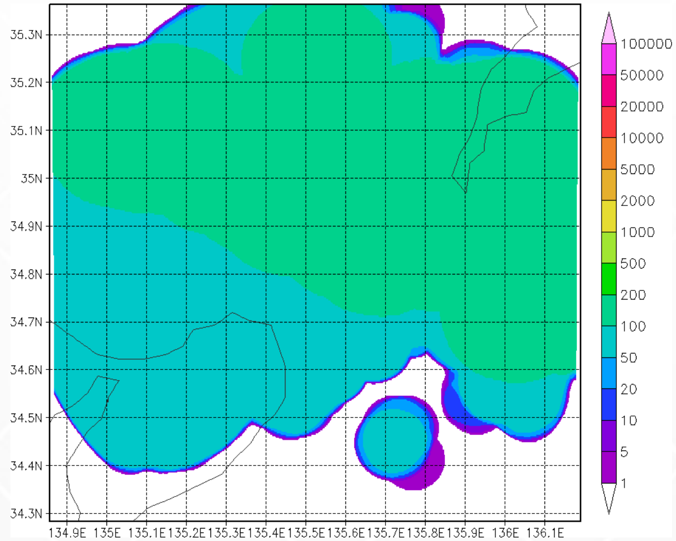
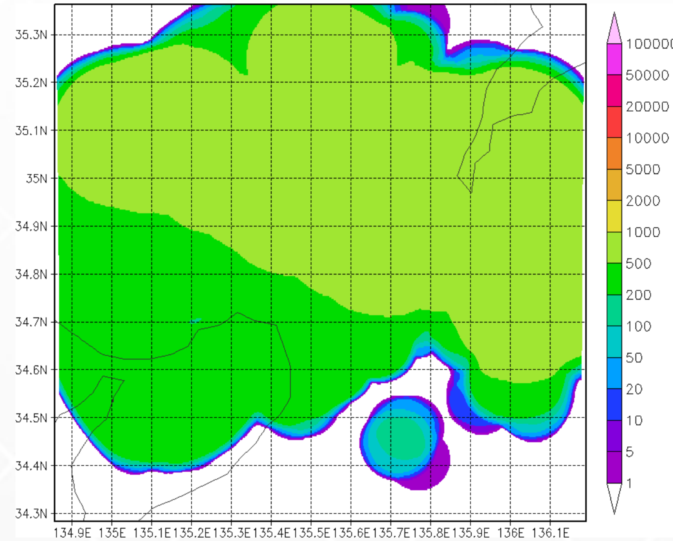
## NOBS = 30



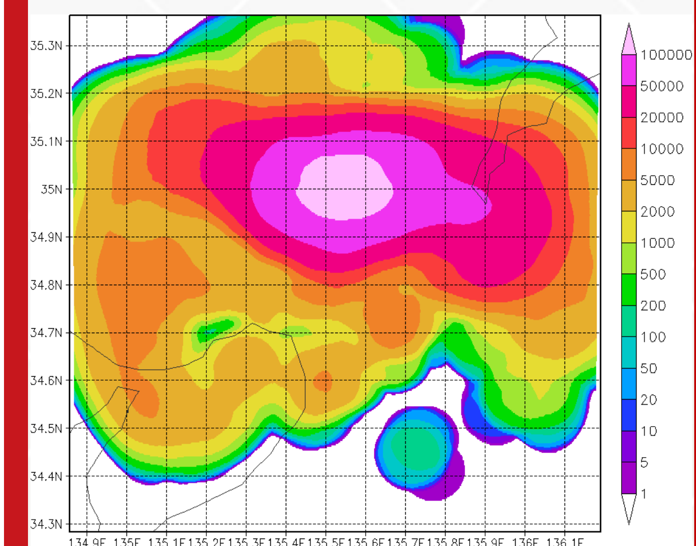

## NOBS = 100



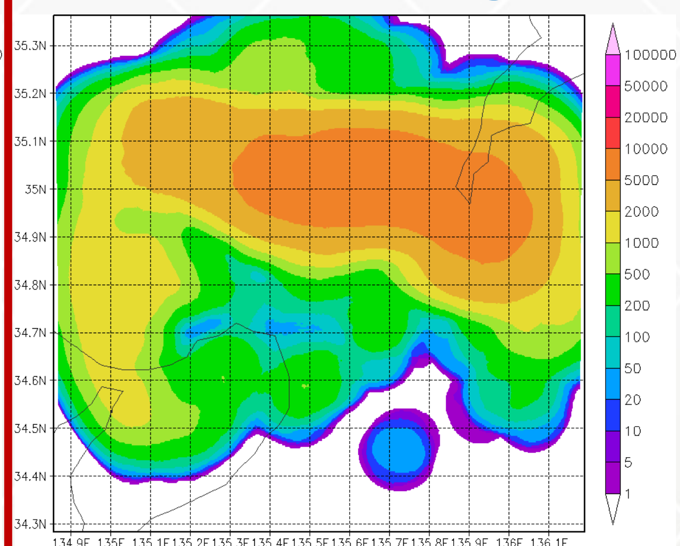

## NOBS = 500



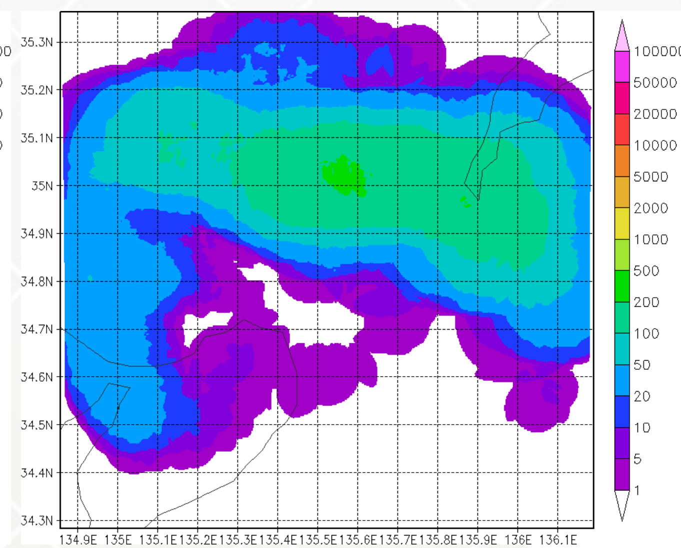

## NOBS = ∞




## 1 km thinning




## 4 km thinning



# Impact of obs number limit - Increment
# Ref (dBZ) (250 m; 1st cycle)

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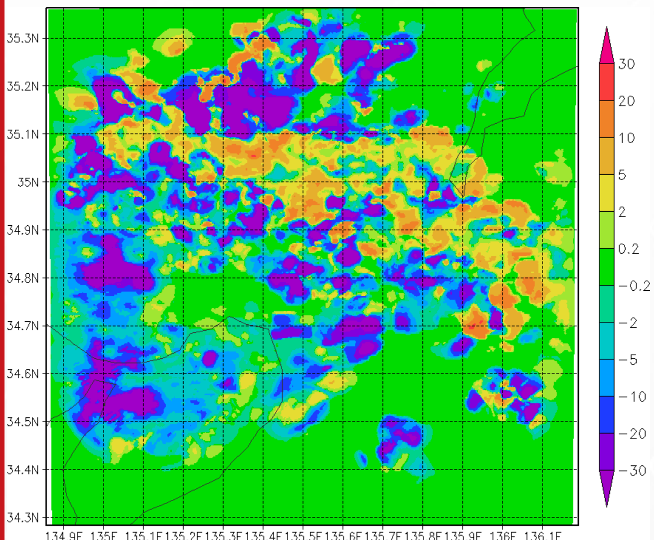
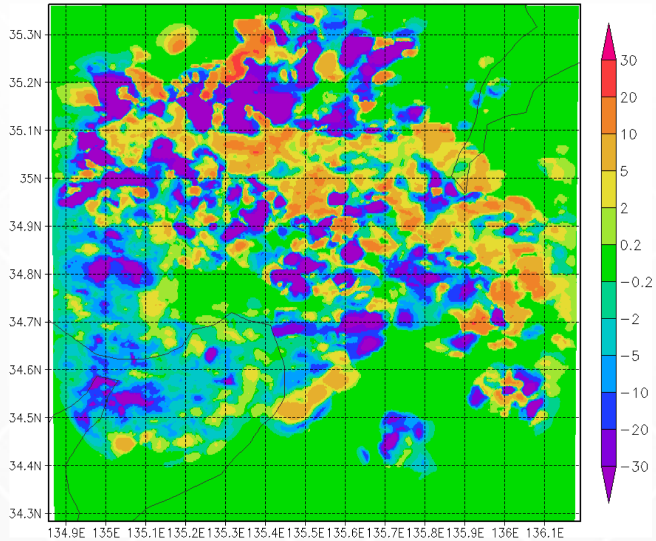
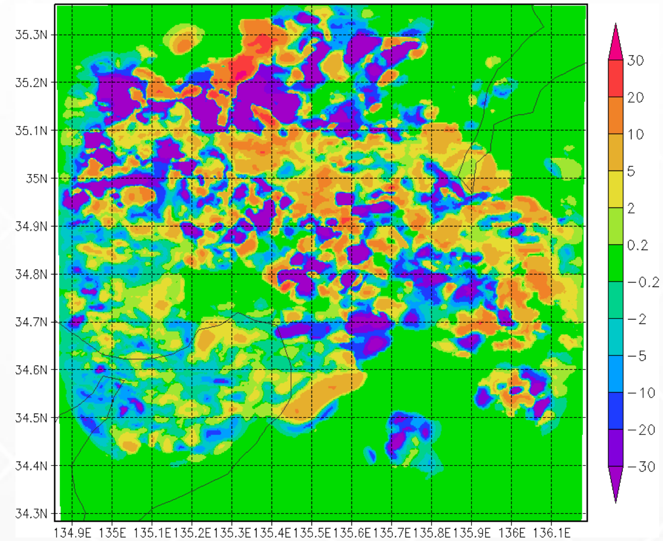
## NOBS = 30



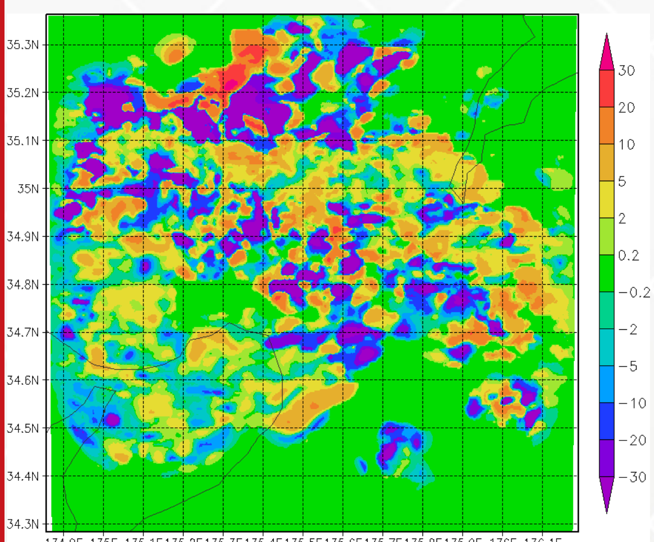

## NOBS = 100



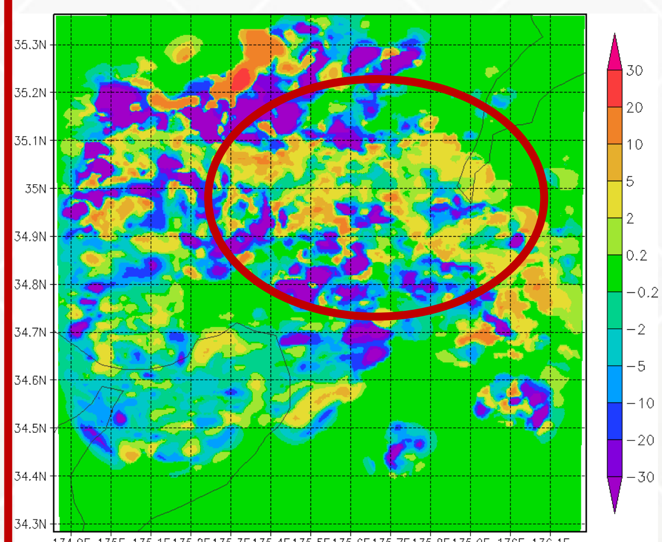

## NOBS = 500



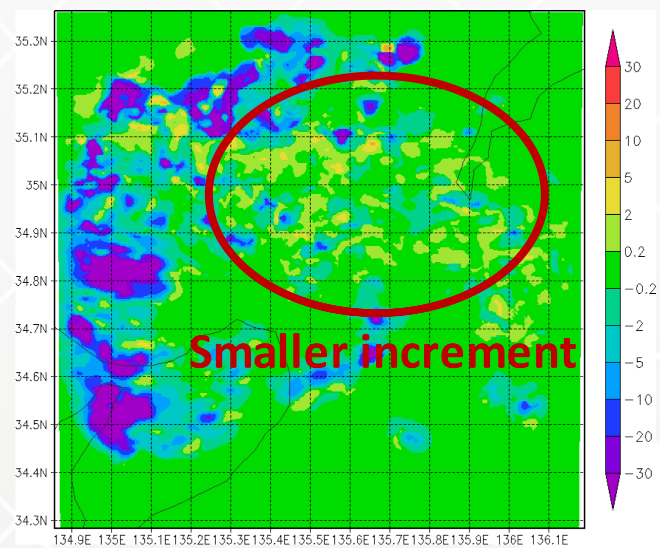

## NOBS = ∞




## 1 km thinning




## 4 km thinning



# Impact of obs number limit (250 m)

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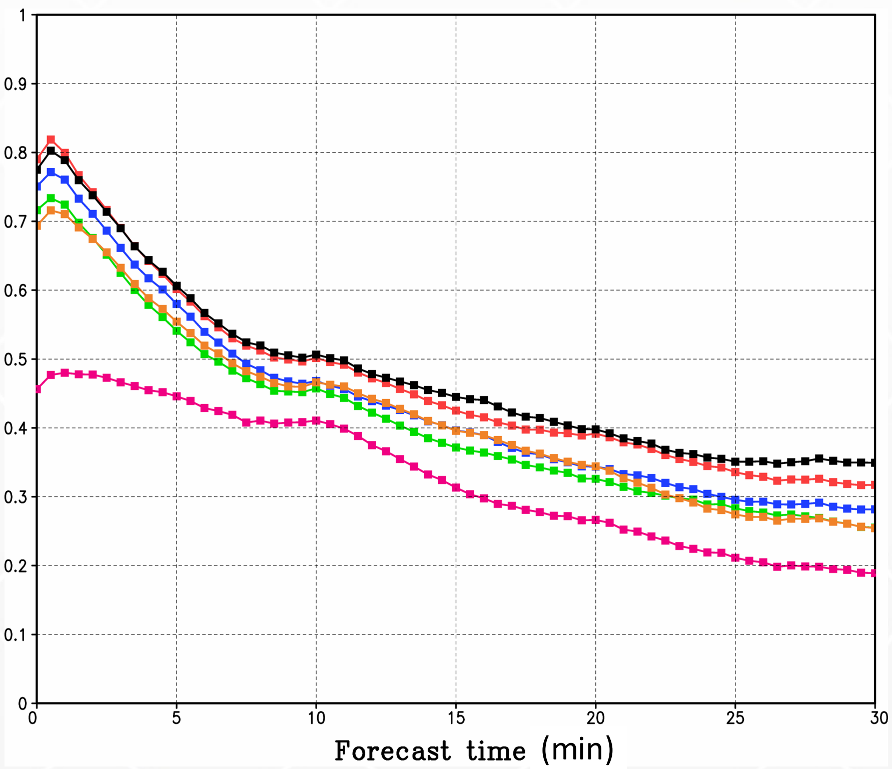
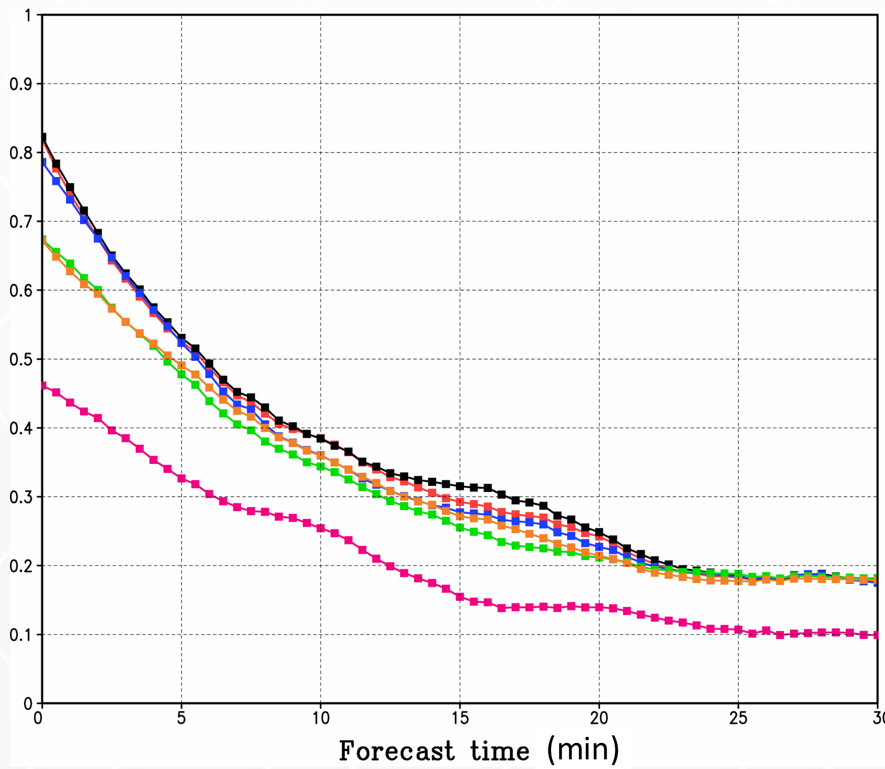
## Threat scores

(0610Z - 0620Z; **2 forecasts**)

**[10 dBZ]**




**[30 dBZ]**




**NOBS = 30**
**NOBS = 100**
**NOBS = 500**
**NOBS = ∞**

**1 km thinning (NOBS = ∞ )**
**4 km thinning (NOBS = ∞ )**

# Impact of covariance inflation methods

- Relaxation to prior perturbation (**RTPP**; *Zhang et al. 2004*) vs. Relaxation to prior spread (**RTPS**; *Whitaker and Hamill 2012*)
- In the LETKF:

**RTPP**: $$\mathbf{W} \leftarrow (1-\alpha)\mathbf{W} + \alpha\mathbf{I}$$

**RTPS**: $$\mathbf{W} \leftarrow \left(\alpha\frac{\sigma^b - \sigma^a}{\sigma^a} + 1\right)\mathbf{W} = \left(\alpha\sqrt{\frac{\mathbf{X}^b\mathbf{X}^{bT}}{(k-1)\mathbf{X}^b\widetilde{\mathbf{P}}^a\mathbf{X}^{bT}}} - \alpha + 1\right)\mathbf{W}$$

α = 0.95

# Impact of relaxation method
# (1 km; obs limit = 100; alpha = 0.95)

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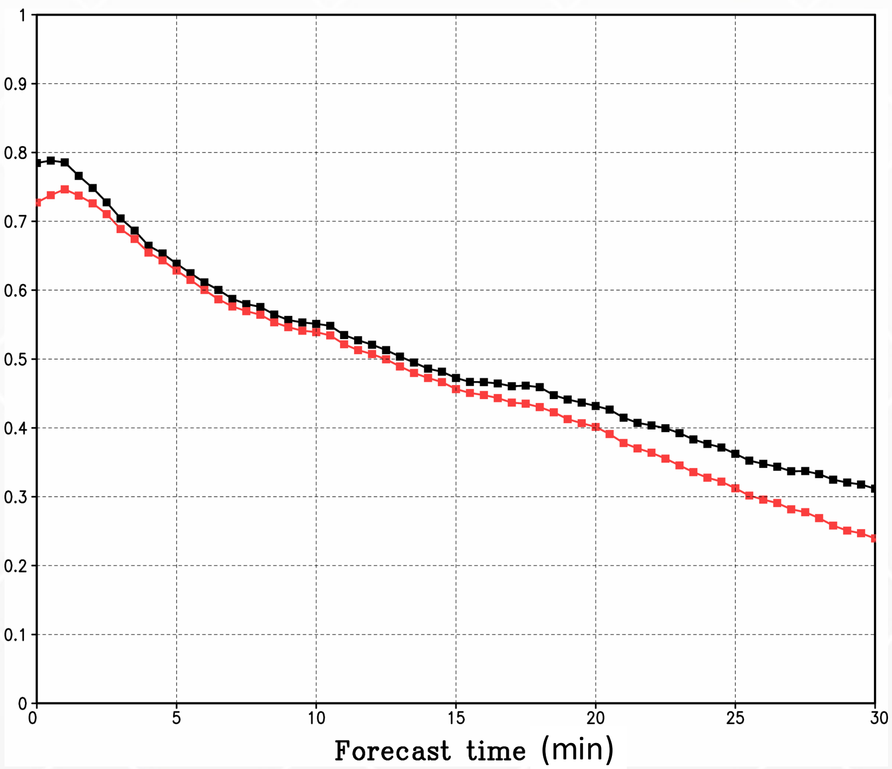
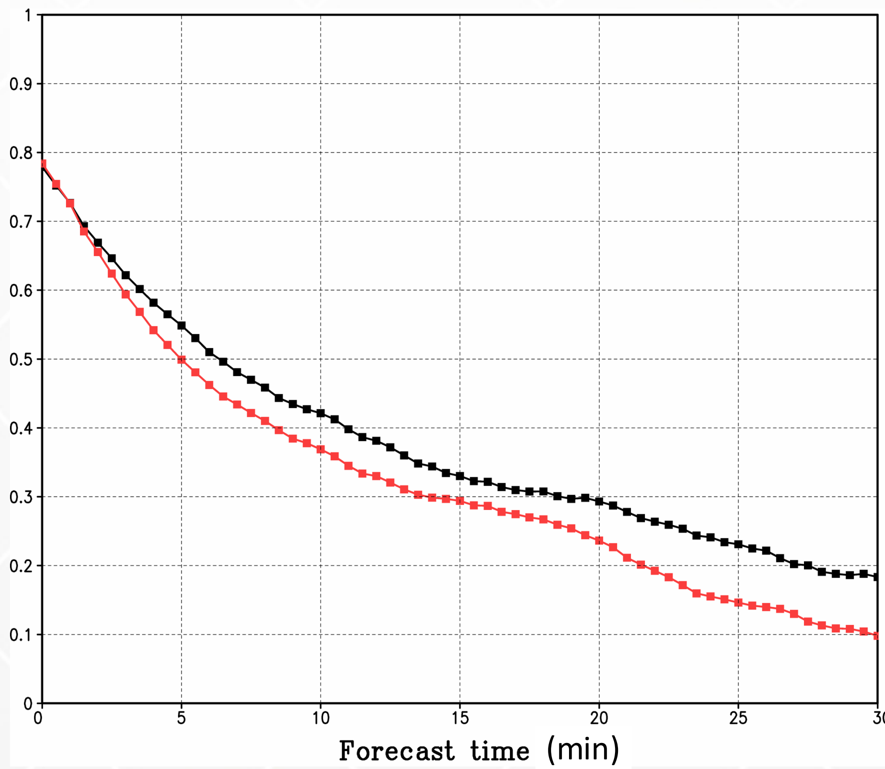
## Threat scores

(0610Z - 0700Z; **6 forecasts**)

**[10 dBZ]**




**[30 dBZ]**




**Relaxation to prior spread (RTPS)**

**Relaxation to prior perturbation (RTPP)**

# Impact of relaxation method
# (1 km; obs limit = 100; alpha = 0.95)

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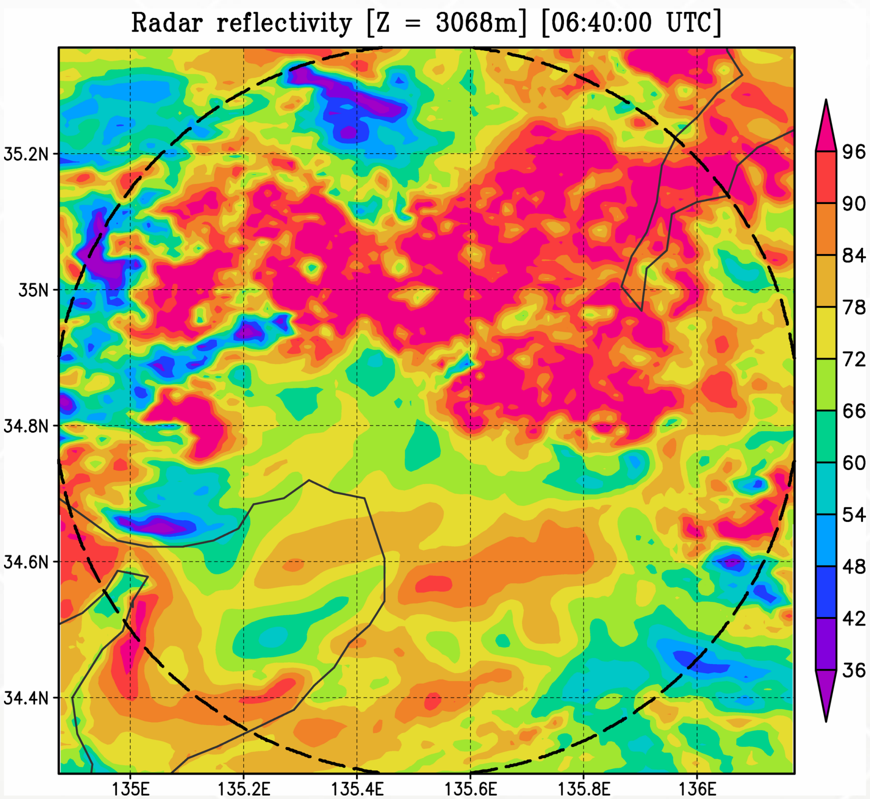
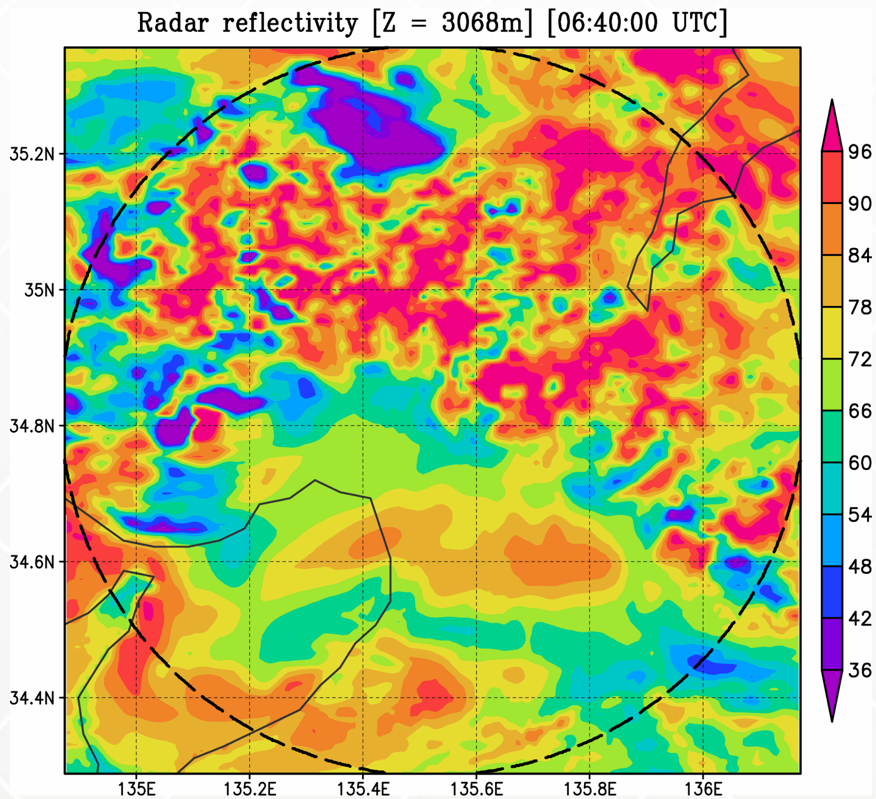
3-km height relative humidity:
**Analysis at 15:40L**

**RTPS**




**RTPP**

**Too noisy and too dry**



# Impact of relaxation method (1 km; obs limit = 100; alpha = 0.95)

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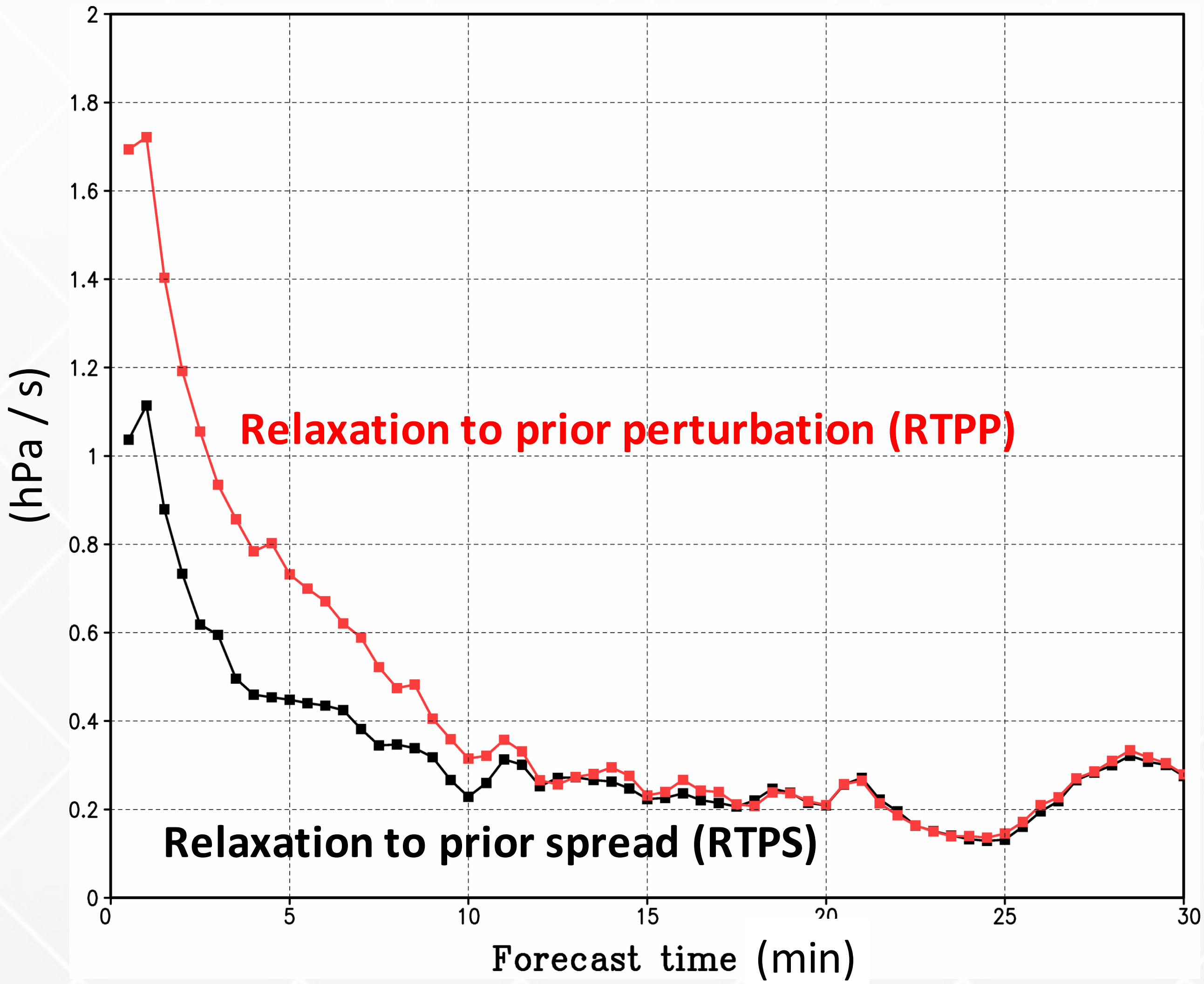
Imbalance measured by domain-averaged |dPs/dt|

**30-min forecast started from 15:40L**



# Summary

- **The sub-kilometer radar data assimilation using the LETKF can work!**
  - Higher resolution assimilation up to 100 m leads to a better fit to observation, *although the benefit does not last beyond 10 minutes in our current experiments.*
  - The 30-second update cycle is advantageous over the 5-minutes update cycle.
- **Optimal settings are suggested:**
  - Observation number limit (*Hamrud et al. 2015*)
  - Relaxation to prior spread (RTPS) (*Whitaker and Hamill 2012*)
- **Potential drawbacks:**
  - The model may not be well tuned in the sub-kilometer resolution.
  - No consideration of model errors:
    - e.g., “Additive noise” method (*Dowell and Wicker 2009*)