AFAD / WRF Data Assimilation System

Scientific tunings for an operational implementation

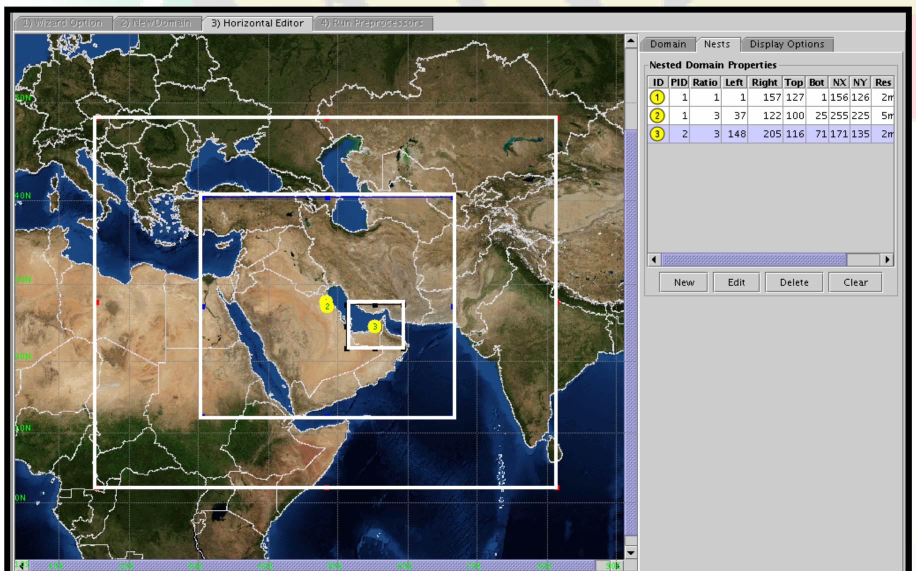
Radi AJJAJI, Ahmad AL KATHERI
and Abdullah DHANHANI
United Arab Emirates Air Force & Air Defense.

Presentation Plan

1. Brief overview about UAE/WRF
2. Data assimilation as implemented in pre-operational mode.
   - Cycling
   - Observations
   - Background Errors Statistics
3. Tuning of UAE/WRF-VAR: Experimental design.
   - Adaptive tuning
   - Outer loops technique
4. Experiments results.
5. Nested WRF-Var: interaction between nests.

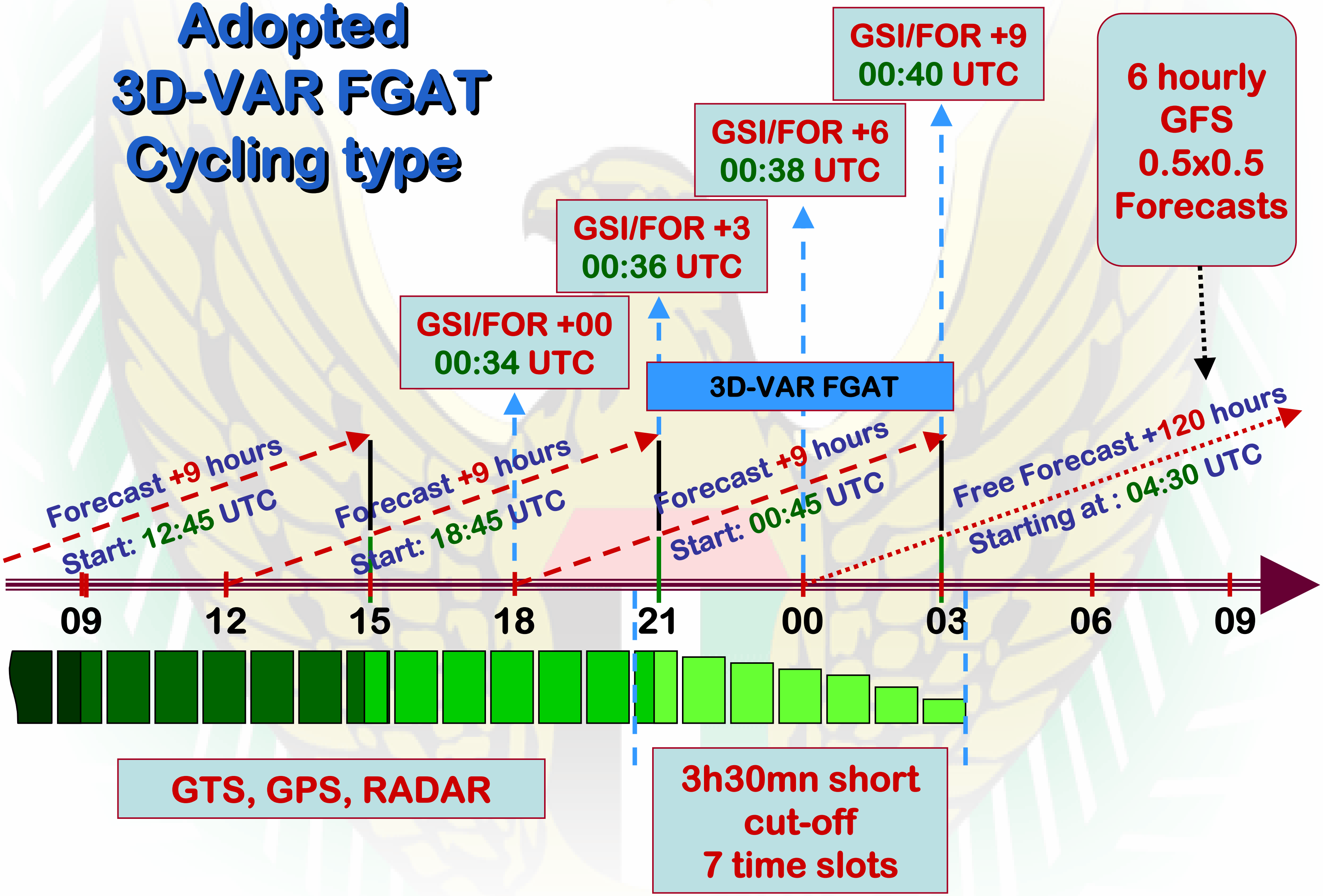
Brief overview about UAE/WRF

WRF 2.2	Domain ‘d01’	Domain ‘d02’	Domain ‘d03’		Domain ‘d01’	Domain ‘d02’	Domain ‘d03’
Grid dimensions	40 km 156 x 126 x 38	13.33 km 256 x 226 x 38	4.44 km 172 x 136 x 38	Radiation	RRTM/Dudhia scheme	RRTM/Dudhia scheme	RRTM/Dudhia scheme
Time step	225 s	75 s	25 s	PBL	YSU scheme	YSU scheme	YSU scheme
Micro-physics	Ferrier*	Ferrier*	Ferrier*	Surface physics	Noah LSM	Noah LSM	Noah LSM
Cumulus scheme	Kain-Fritsch scheme	Kain-Fritsch scheme	Explicit.	Initial and Boundary Conditions.	NCEP GFS/GSI analyses	Two-way nest	Two-way nest

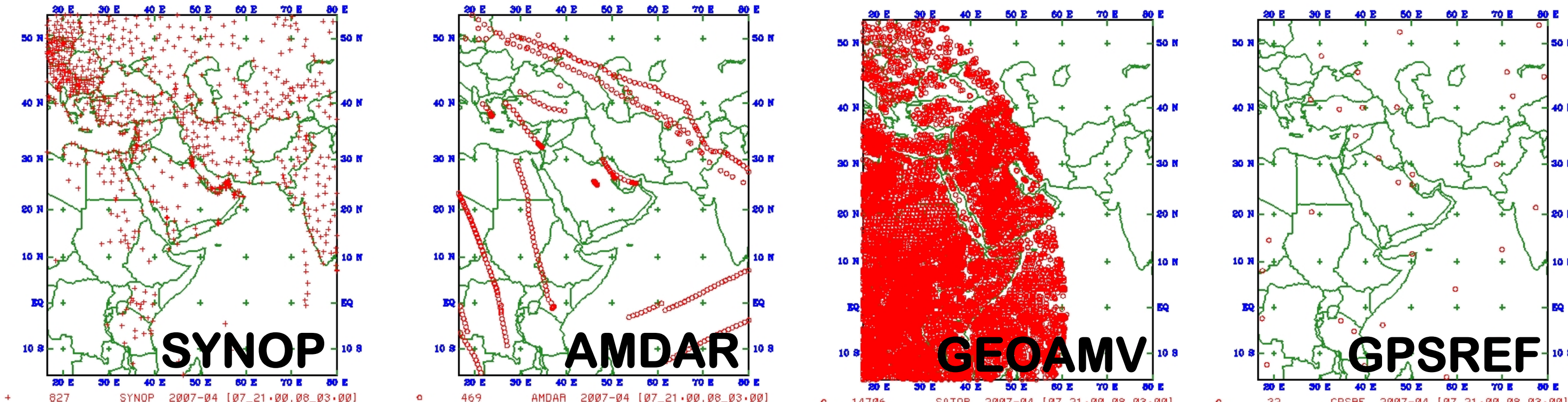


- ❑ **d01:** Middle-East
- ❑ **d02:** Arabian Peninsula
- ❑ **d03:** United Arab Emirates
- ❑ **WPS** is used for LBC interpolation.
- ❑ WRF-VAR is still in parallel suite (for d01, d02 and d03)
- ❑ UAE/WRF outputs on the net:
- ❑ http://www.afmet.ae/main.html

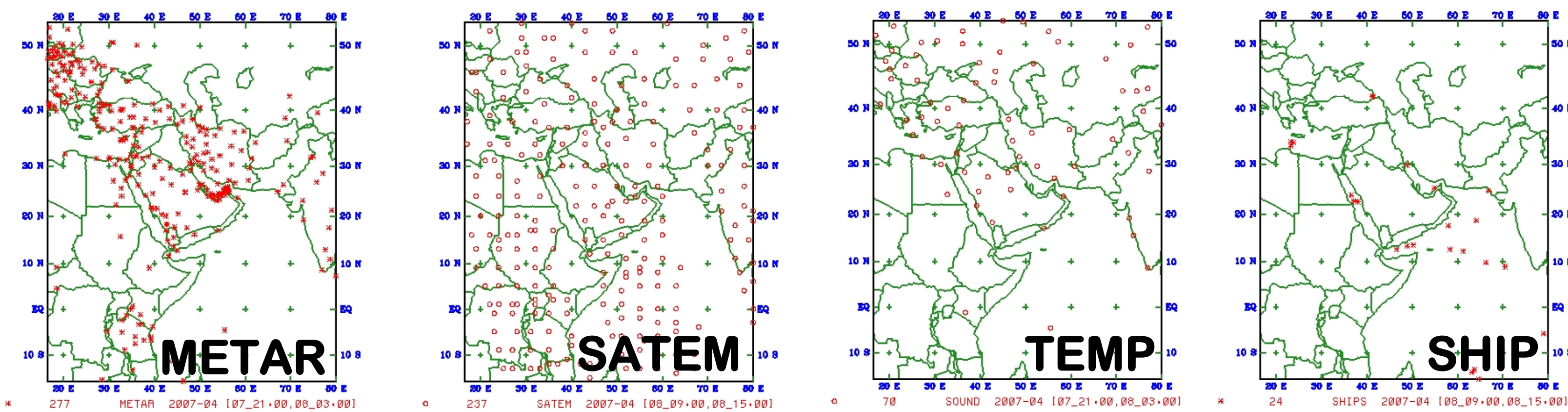
Adopted 3D-VAR FGAT Cycling type



Observational coverage over Middle-East region



~1600 ~300 ~15000 ~20

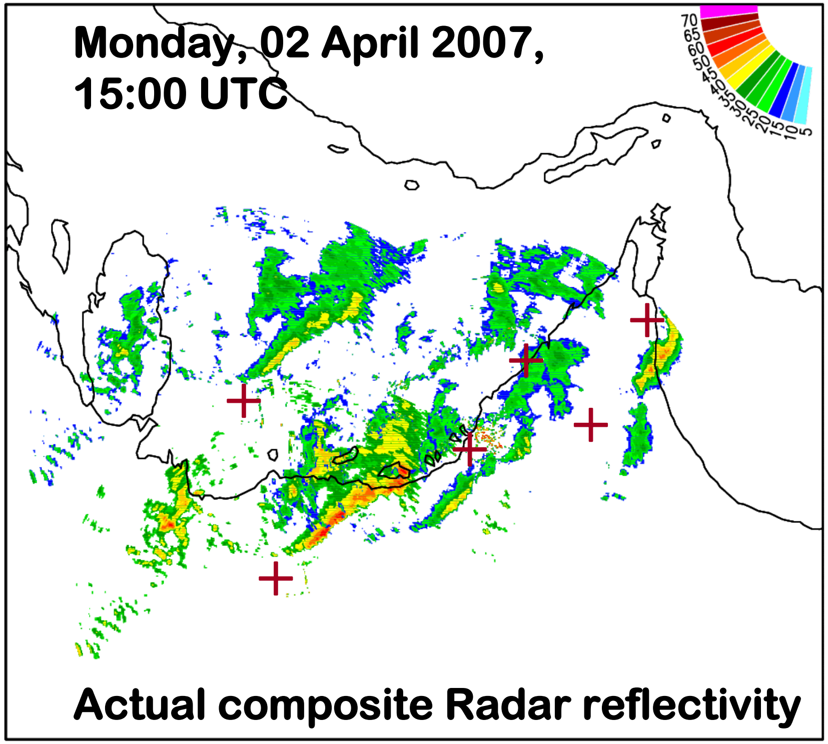


~1000 ~500 ~70 ~80

Numbers are given per FGAT analysis

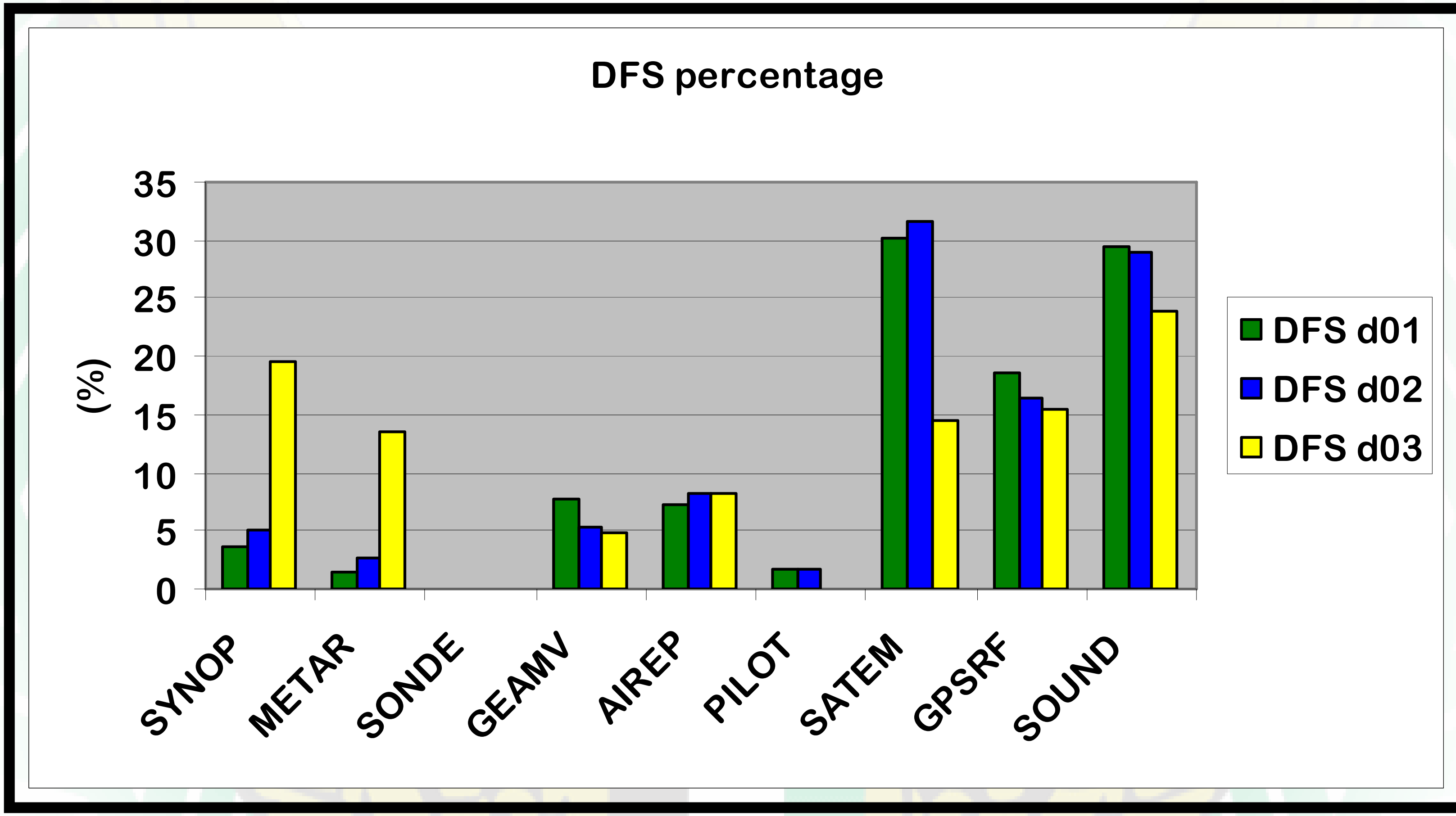
Assimilation of Radar Data

- 6 Doppler Radars (Abu Dhabi, Dubai, Al Ain, Liwa, Delma)
- 1 km horizontal resolution, 11 different elevation angles and 15 minutes frequency.
- Normal/Anomalous Propagation ground clutter corrected by Radar software (Radar Echo Classifier software)
- Mosaic radial velocities, refletivities, precipitation rates in BUFR format.
- BUFR to GRIB/ASCII (super-obbing)
- Raw observations are thinned (1 super obs. / 3 km), then a rejection threshold of 20 dBZ is applied.
- Three dimensional coherence control
- Time distribution coherent with FGAT.
- Multi-radar redundancy check.
- Observations errors depend on the distance to the Radar center.



DWSR-88C, 240 km horizontal range

Degree of Freedom for Signal

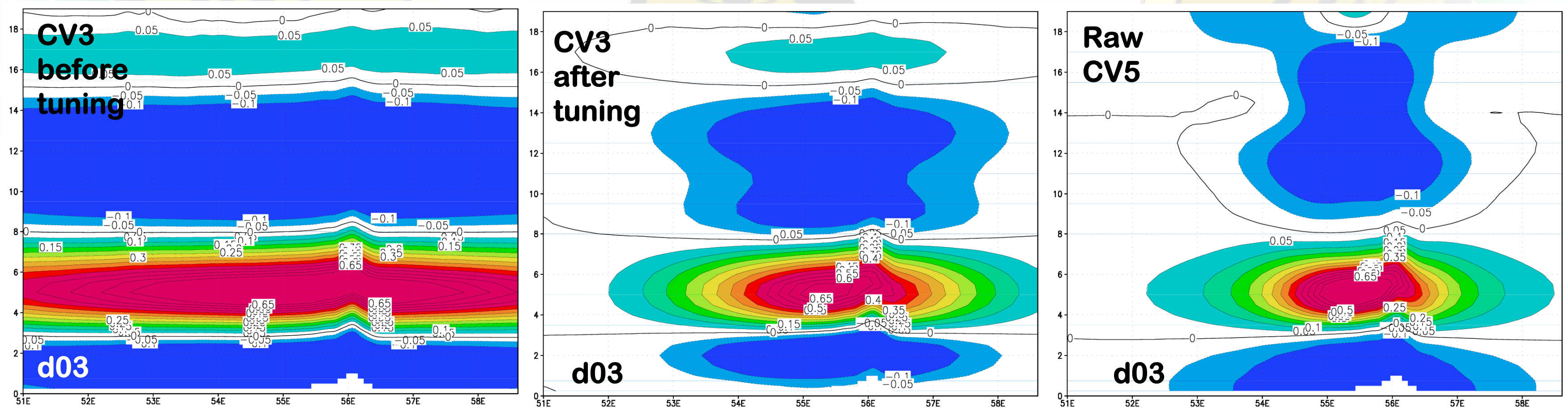


Information content of each individual observation type in AFAD/WRF assimilation system as represented by the DFS estimation.

DFS = Tr (HK) : sensitivity of the analysis to the different observation types.

Background errors

Response to a single temperature observation



- CV5 computed using 1 month WRF outputs for d01, d02 and d03.
- CV3 tuned in such way that single observations experiments increments look like those generated by CV5.
- CV5 variances decreased 10 % to reflect model error variances at 9 hours range.

Adaptive Tuning

d01	u	v	T	p	q
SYNOP	2.10	2.05	1.40	1.59	0.70
METAR	1.82	1.95	1.38	0.73	0.53
TEMP/SFC	2.21	2.00	1.31	1.63	0.64
TEMP	1.77	1.67	1.44		0.90
PILOT	1.63	1.59			
AMDAR	1.31	1.16	0.98		
GEOAMV	2.08	1.60			
Jo total	1.00527		Jb total	1.77	

d02	u	v	T	p	q
SYNOP	2.05	1.89	1.14	1.45	0.69
METAR	1.90	1.79	1.31	0.97	0.68
TEMP/SFC	2.79	1.69	1.35	1.06	1.12
TEMP	1.82	1.72	1.43		0.88
PILOT	1.60	1.59			
AMDAR	1.31	1.20	0.91		
GEOAMV	2.26	1.74			
Jo total	1.00213		Jb total	1.76	

d03	u	v	T	p	q
SYNOP	1.63	1.62	0.88	1.01	0.16
METAR	1.87	1.72	1.00	0.97	0.11
TEMP/SFC	-	-	-	-	-
TEMP	2.18	1.98	1.84		0.98
PILOT	-	-			
AMDAR	1.15	1.34	1.30		
GEOAMV	2.64	1.65			
Jo total	1.00949		Jb total	1.60	

	Thickness	Refractivity	Reflectivity	Radial Velocity
SATEM	1.62			
GPS		0.91		
RADAR			0.95	1.05

- We should inflate background variances by a factor of 1.75
- Attention should be paid to GEAMV error factors: their error is spatially correlated and this correspond to a limitation of the used tuning technique (Chapnik et al.)

Description of the experiments

WRF V2.2	BES	FGAT	OBS. ERR. FACTORS	OUTER LOOPS	GEOAMV	RADAR**
TUNEDCV3	NCEP CV3	YES	NO	1	YES	NO
RAWCV5	NMC CV5	YES	NO	1	YES	NO
ERFCV5	NMC CV5	YES	YES	1	YES	NO
ITS3CV5	NMC CV5*	YES	YES	3*	YES	NO
NOGMV	NMC CV5*	YES	YES	3*	NO	NO
RADARCV5	NMC CV5*	YES	YES	3*	YES	YES
NCEPGSI	Reference = No assimilation, cold start using GSI analyses					

* Variances and length scales are modified during outer loops (feature added in the WRF-VAR source code)

** WRF-VAR code has been modified to output Radar observations contribution to the cost function (in both parallel and serial execution modes). Adaptive tuning procedure (tune.f90) is made working for Radar.

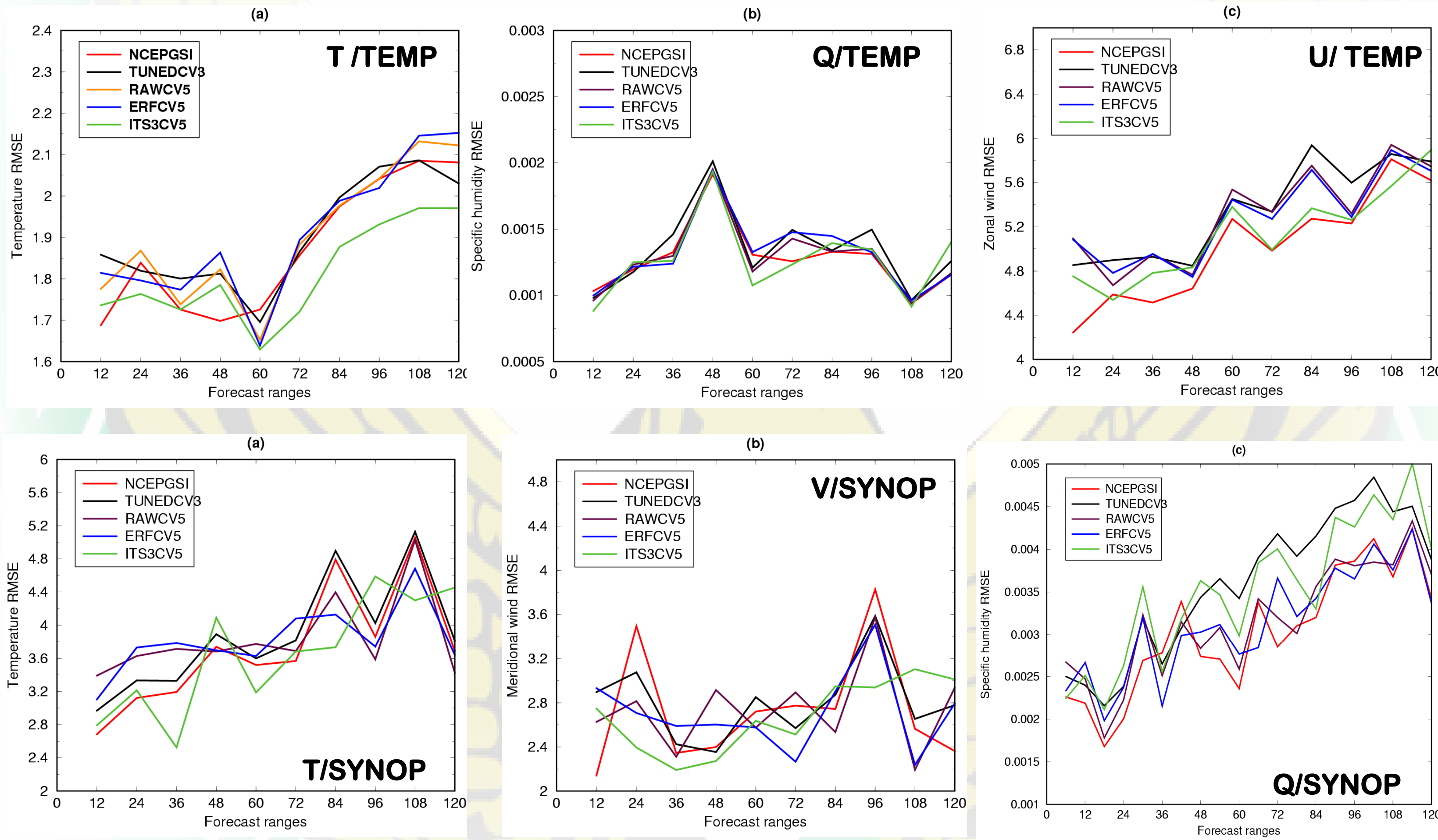
Tuning Background covariances

Variance	Outer loop 1	Outer loop 2	Outer loop 3
PSI	1.75	1.00	0.50
CHI_u	1.75	1.00	0.50
T_u	1.75	1.00	0.50
q/qsg	1.00	1.00	0.50
psfc	1.75	1.00	0.50

Length scale	Outer loop 1	Outer loop 2	Outer loop 3
PSI	1.00	0.50	0.25
CHI_u	1.00	0.50	0.25
T_u	1.00	0.50	0.25
q/qsg	1.00	050	0.25
psfc	1.00	0.50	0.25

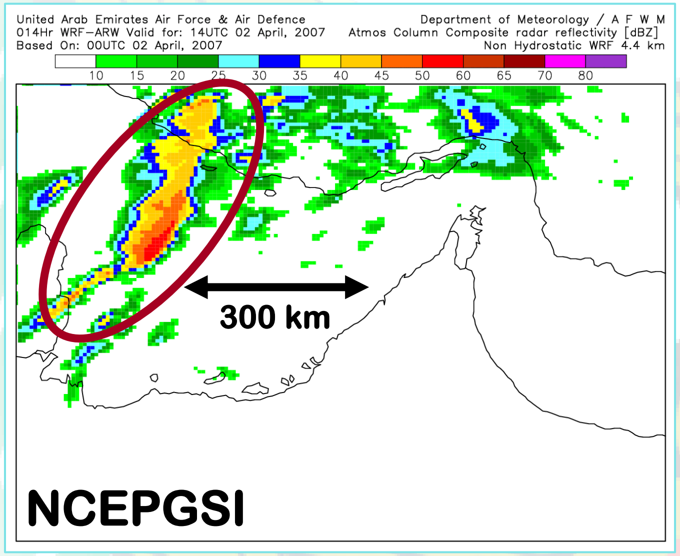
- Variances are increased (1.75) in the first outer loop in order to fit more the observations. Length scales are maintained (1.00) to spread the information at a maximum radius.
- In the second and third outer loops, more confidence in the guess (Var. factor = 1.00) , and only small scales are analyzed (L.S. factor = 0.50, 0.25)

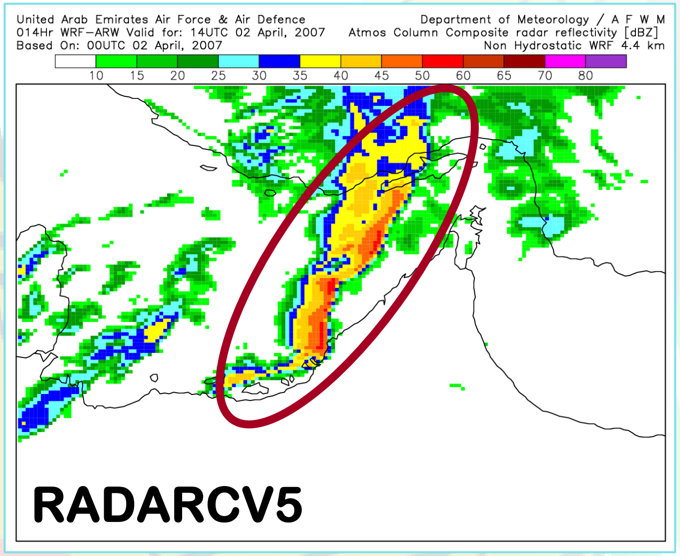
Experiments results

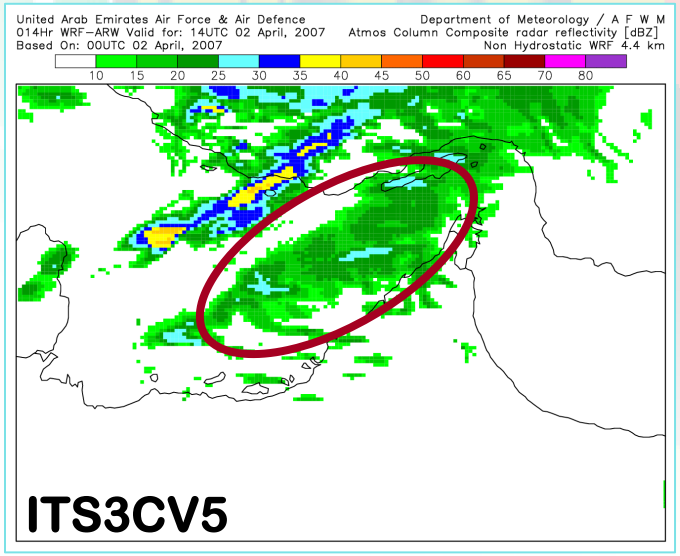


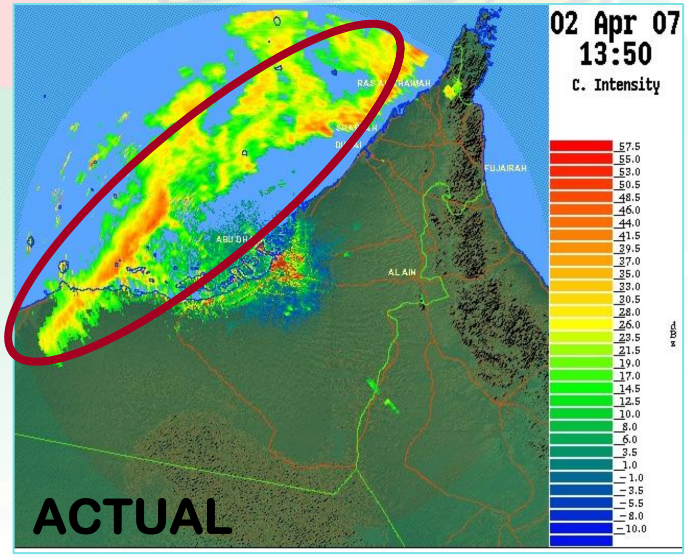
- ❑ **CV5, Adaptive tunings, 3 outer loops with different BES scaling performs quite well.**
- ❑ **General bad performance at the beginning of the forecast.**

Radar reflectivities impact

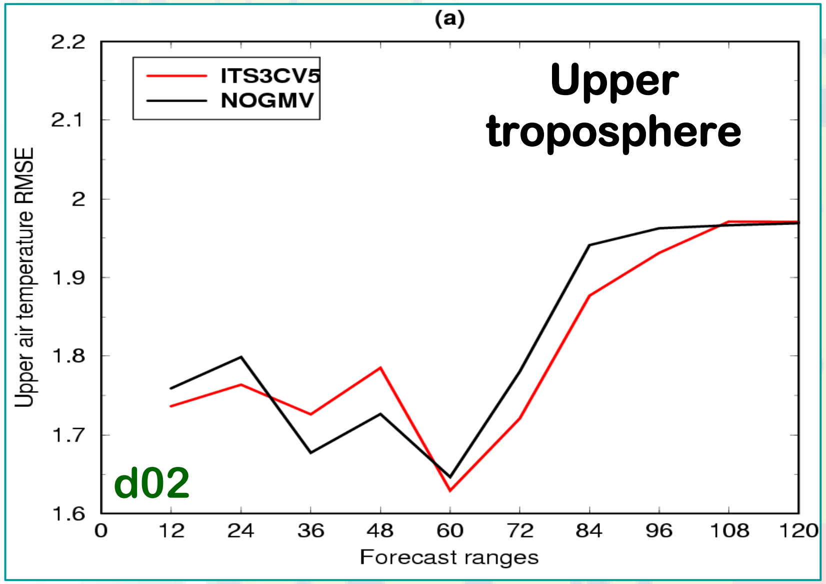


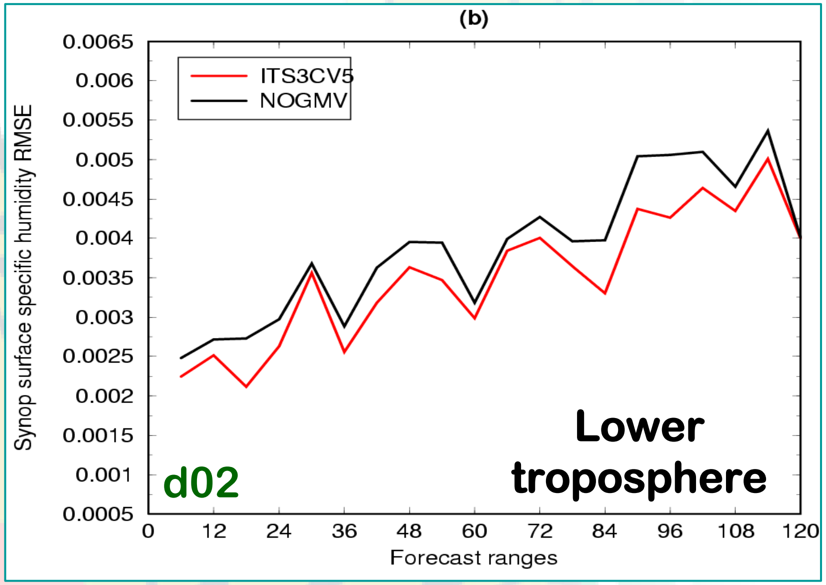






Geostationary Atmospheric Motion Vectors impact





- METEOSAT 8 data (5 times denser that METEOSAT 7)
- IR winds: with QI > 85
- Vis winds: below 700 hPa and QI > 70
- WV cloudy: above 400 hPa and QI > 85
- Thinning: 1 observation per grid box
- The reduction in RMS is denoting high quality METEOSAT 8 AMVs.

Interaction between nests in WRF VAR.

- Introduce, in a coherent manner, large and longer scales in the small scale analysis.
- Deal with the LBC issue in 3D-Var and provide information from observations outside the nest domain.
- Avoid costly multiple outer loops per nest.
- Introduce progressively high resolution observations

Nested WRF 3D-Var: 1st Scenario

$$J_k(\delta x) = \frac{1}{2}(\delta x)^T B_k^{-1}(\delta x) + \frac{1}{2}(H_k \delta x - d)^T R_k^{-1}(H_k \delta x - d)$$

$$d = y - \mathrm{H}_k\left(x_{a_{k-1}}^{L \to H}\right)$$

$$\delta x = x - x_{b_k}$$

$J_k(\delta x)$: Incremental cost function for nest k

x_{b_k} : First Guess for nest k

B_k : Background errors for nest k

H_k : Observation operator inside nested domain k

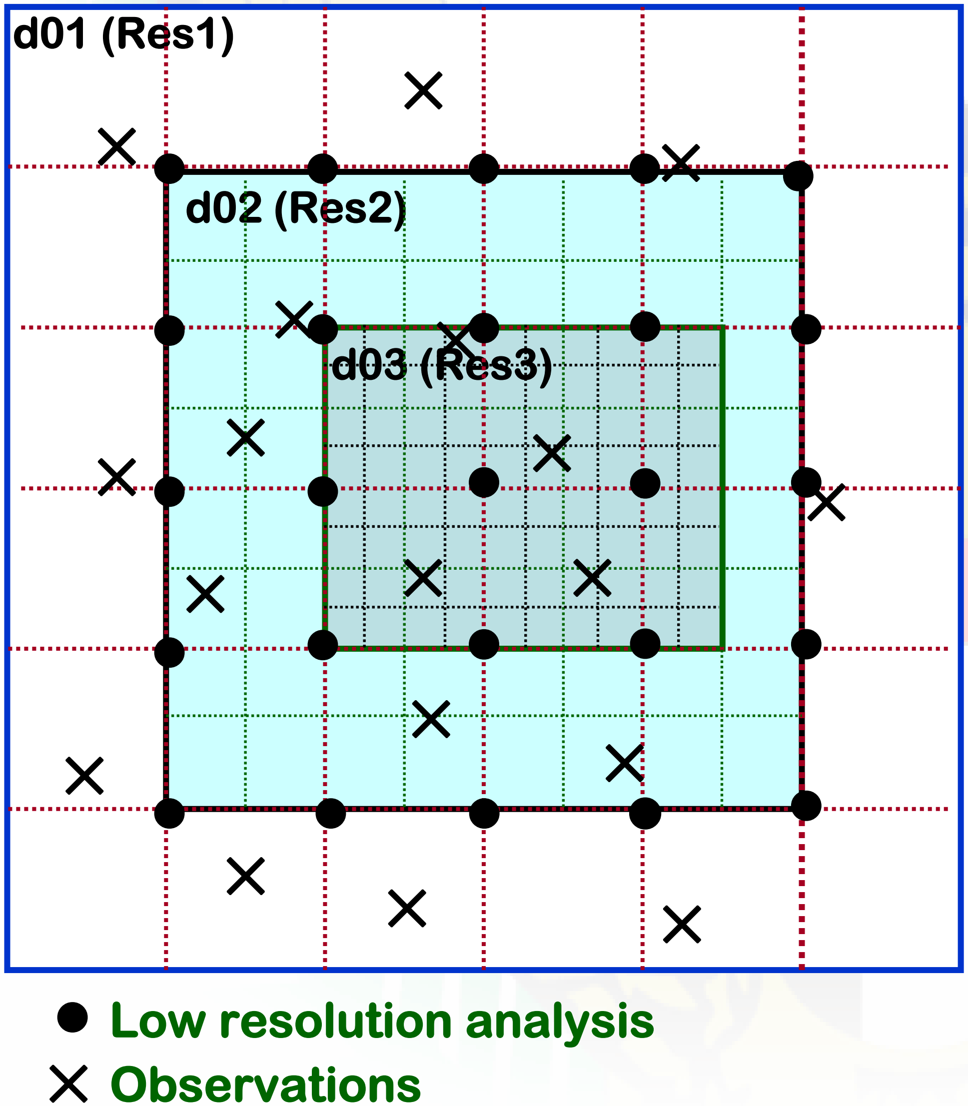
H_k : The non linear observation operator

y_k : Observation vector inside nested domain k

R_k : error covariances of observations inside nest k

$x_{a_{k-1}}^{L \to H}$: Analysis in nest $k-1$ interpolated to nest k grid.

Nested WRF 3D-Var: 1st Scenario



- 3D-Var analysis over d01.
- Compute innovations in domain d02 using d01 analysis.
- 3D-Var analysis over d02 based on d02 first guess
- 3D-Var analysis over d03 with the same technique
- Large scale information is introduced inside the small scale analysis through the innovations.
- Necessitate minor changes in the code.

Nested WRF 3D-Var: 2nd Scenario

$$J_k(\delta x) = \frac{1}{2}(\delta x)^T B_k^{-1}(\delta x) + \frac{1}{2}(H_k \delta x - d)^T R_k^{-1}(H_k \delta x - d)$$

$$d = y - \mathrm{H}(x_{b_k})$$

$$\delta x = x - x_{a_{k-1}}^{L \to H}$$

$J_k(\delta x)$: Incremental cost function for nest k

x_{b_k} : First Guess for nest k

B_k : Background errors for nest k

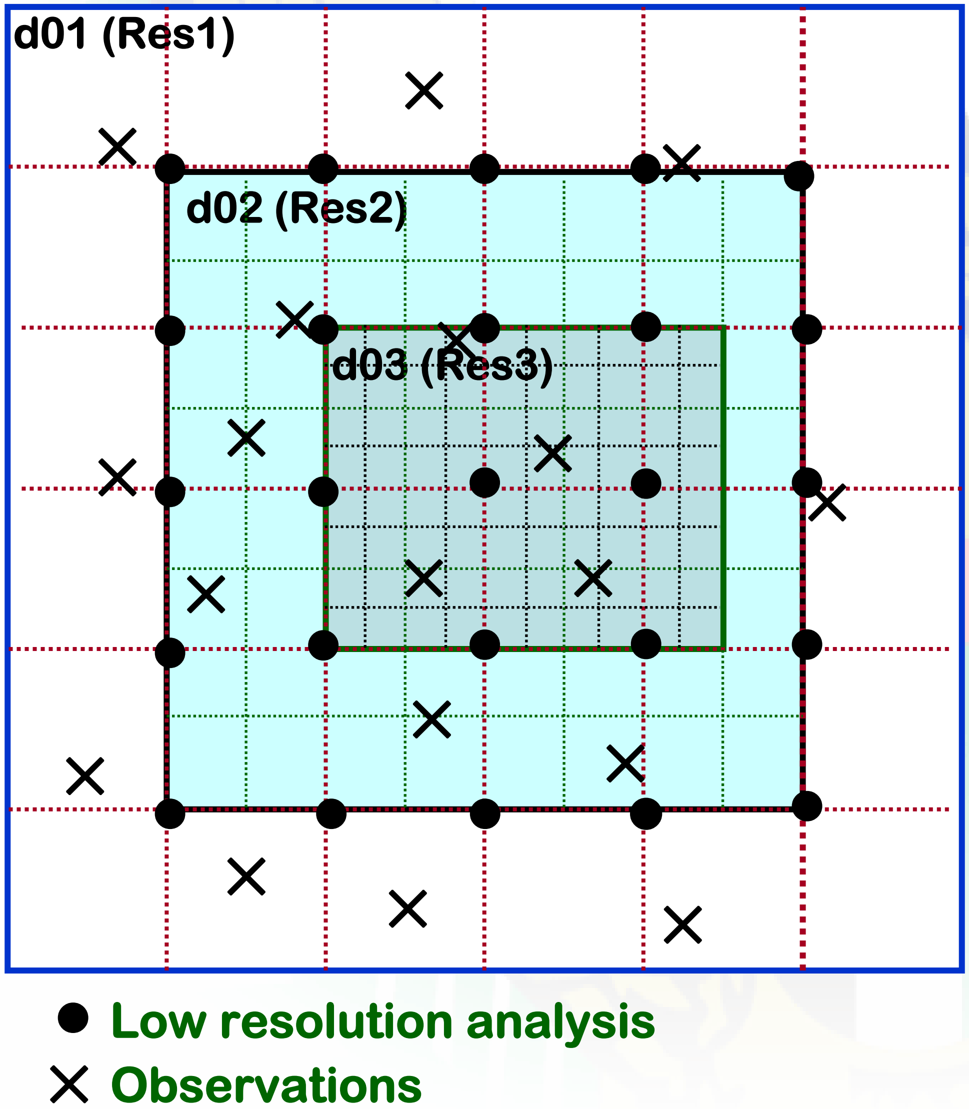
H_k : Observation operator inside nested domain k

y_k : Observation vector inside nested domain k

R_k : error covariances of observations inside nest k

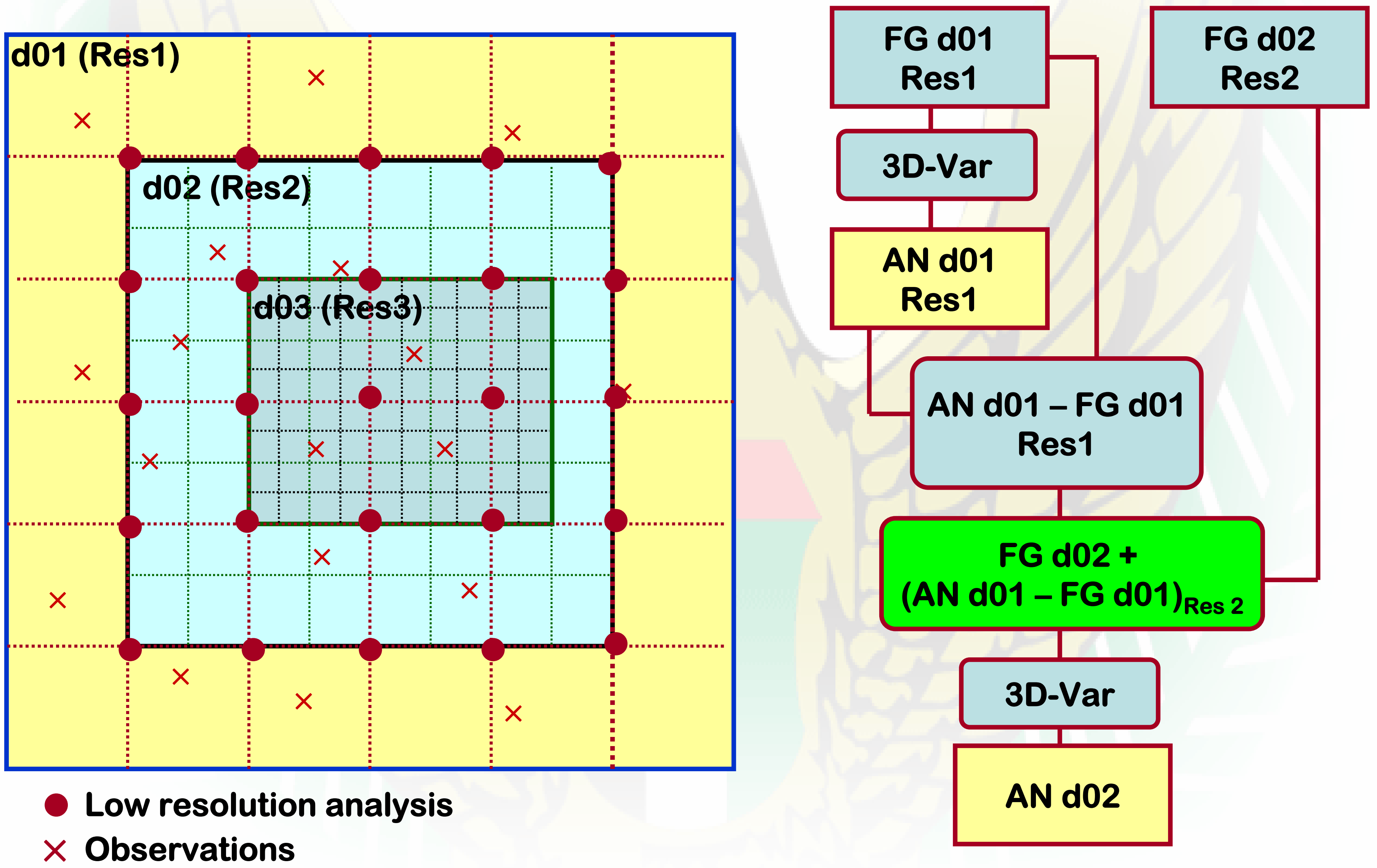
$x_{a_{k-1}}^{L \to H}$: Analysis in nest $k-1$ interpolated to nest k grid.

Nested WRF 3D-Var: 2nd scenario



- ❑ 3D-Var analysis over d01.
- ❑ d02 analysis is based on d01 analysis as background
- ❑ d02 innovations are computed using d02 First Guess.
- ❑ 3D-Var analysis over d03 with the same technique
- ❑ Large scale information is introduced inside the small scale analysis through the background term.
- ❑ Adaptive tuning for B_k to be coherent with the used background (low resolution analysis).
- ❑ Necessitate minor changes in the code.

Nested WRF 3D-Var: 3rd scenario



Conclusion about the different scenarios

- Larger and longer scales information are introduced in the nest
- Only small scales are kept from the guess.
- Provide implicitly information from observations outside the nest as well as data near the boundary inside the domain.
- No need for more than 1 outer loop per domain since, for example the, 3D-Var analysis on domain d03 is an implicit third outer loop.
- Less expensive when compared to the use of multiple outer loops per domain.
- Corresponding experiments are ongoing.

Summary & Conclusion

- WRF-VAR is successfully implemented in the UAE/WRF operational suite taking advantage of :
  - Multiple nests
  - Local BES
  - FGAT
  - Outer loops technique
  - Adaptive tuning technique.
  - Radar data assimilation
- Certain weaknesses were noticed and planned to be processed in the near future:
  - Initialization (digital filters)
  - Surface analysis.
- Experiments dealing with the interaction between nests in assimilation mode are being performed.

Extra slides

Nested WRF 3D-Var: 4th scenario

$$J_k(x) = \frac{1}{2}\left(x - x_{b_k}\right)^T B_k^{-1}\left(x - x_{b_k}\right) + \frac{1}{2}\left(H_k(x) - y_k\right)^T R_k^{-1}\left(H_k(x) - y_k\right) + \frac{1}{2}\left(x - x_{a_{k-1}}^{L\to H}\right)^T A_{k-1}^{-1}\left(x - x_{a_{k-1}}^{L\to H}\right)$$

$J_k(x)$: Cost function for nest k

x_{b_k} : First Guess for nest k

B_k : Background errors for nest k

H_k : Observation operator inside nested domain k

y_k : Observation vector inside nested domain k

R_k : error covariances of observations inside nest k

$x_{a_{k-1}}^{L\to H}$: Analysis in nest $k-1$ interpolated to nest k grid.

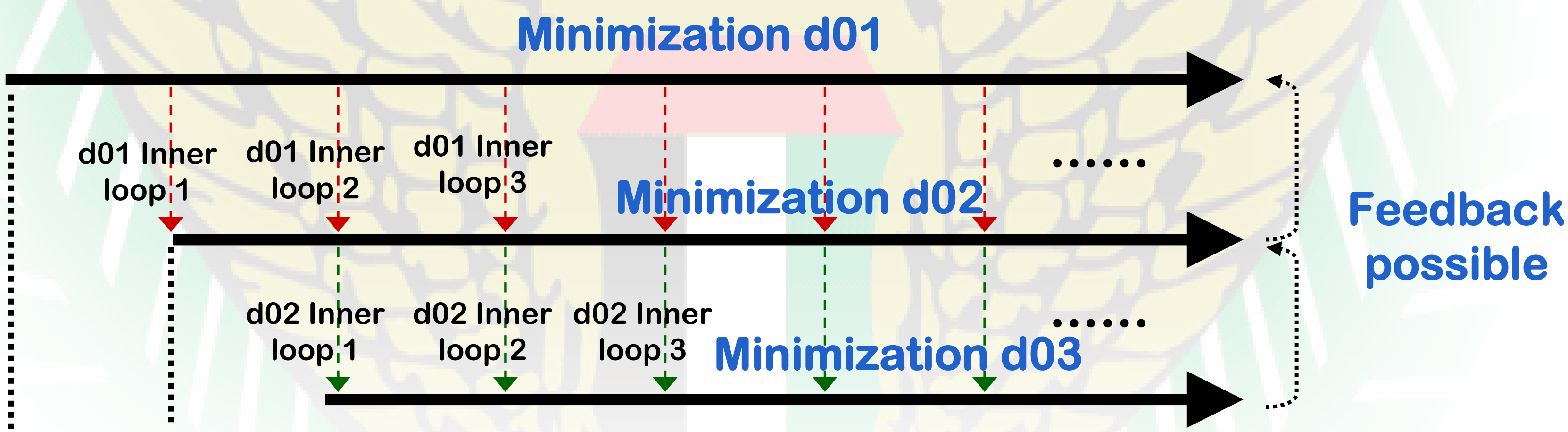
$$A_{k-1}^{-1} = B_{k-1}^{-1} + H_k^T R_k^{-1} H_k^T$$

B_{k-1} : Background errors covariances for nest $k-1$ (parent) interpolated to nest k grid.

Nested WRF 3D-Var: 4th scenario

- Large scales taken from the parent nest
- Small scales taken from the WRF forecast (First guess).
- Use progressively high resolution observations (Adapted thinning, Radar, …etc)
- Nest k-1 information could be introduced into nest k during the minimization process at the level of inner loops in the following manner:

Let's suppose that we have 3 nested domains d01, d02 and d03



Intuitively convergence is guarantied because the increments tend to stabilize with the number of inner loops