WRFDA-3DVar

Equation

$$J(x) = \frac{1}{2}(x - x_b)^T B^{-1}(x - x_b) + \frac{1}{2}(y - H(x))^T R^{-1}(y - H(x))$$

$J(x)$: Scalar cost function

x : The analysis: what we're trying to find

x_b: Background field

B: Background error covariance matrix

y: Observations

H: Observation operator: computes model-simulated obs

R: Observation error covariance matrix

User provided data:

$J(x)$: Scalar cost function	WRFDA output
x : The analysis	WRFDA output
x_b: Background field	User input
B: Background error covariance matrix	User input
y: Observations	User input
H: Observation operator	Included in WRFDA
R: Observation error covariance matrix	User input

Source of User-provided Data: where do the input files come from?

Symbol	Description	Source
x_b	Background ("first-guess")	real.exe or previous WRF forecast
B	Background error covariances	"gen_be" or default file provided with WRFDA
y	Observations	"obsproc" output or NCEP BUFR files
R	Observation error covariances	

WRFDA Namelist

The WRFDA namelist file includes two parts:

&wrfvar1 / &wrfvar2 / ... &wrfvar22 /	WRFDA namelist options: Running options for WRFDA code
& time_control / &fdda / ... & namelist_quilt /	WRF namelist options: WRFDA needs certain information from the WRF configuration including domain and time settings

Background Options ($\mathbf{x_b}$): What's the format of my background file?

&WRFVAR3

fg_format: Format of the first guess field

fg_format = 1 : ARW regional, default

Background Error Covariance Options ($\mathbf{B}$): What type of background error covariance do I want to use?

&WRFVAR7

cv_options: Background error covariance option

cv_options = 3 : global, default
cv_options = 5 : regional, generated by "gen_be"
cv_options = 5 : regional, generated by "gen_be" with multivariate moisture correlation

Observation Options (y): What's the format of my conventional observations?

&WRFVAR3

ob_format: The format of the conventional and satellite retrieval observation data going into WRFDA

ob_format = 1 : NCEP PREPBUFR (ob.bufr, gpsro.bufr)
ob_format = 2 : ASCII (ob.ascii), default

Observation Options:

```
&WRFVAR
USE_SYNOPOBS =  T,
USE_SHIPSOBS =  T,
USE_METAROBS =  T,
USE_SOUNDOBS =  T,
USE_PILOTOBS =  T,
USE_AIREPOBS =  T,
USE_GEOAMVOBS =  T,
USE_POLARAMVOBS =  T,
USE_BUOYOBS =  T,
USE_PROFILEROBS =  T,
USE_SATEMOBS =  T,
USE_GPSZTDOBS =  F,
USE_GPSPWOBS =  T,
USE_GPSREFOBS =  T,
USE_QSCATOBS =  T,
USE_RADAROBS =  F,
USE_RADAR_RV =  F,
USE_RADAR_RF =  F,
USE_AIRSRETOBS =  T
```

What time window for my observations do I want to use?

&WRFVAR21

time_window_min = "2008-02-05_10:30:00"

&WRFVAR22

time_window_max = "2008-02-05_13:30:00"

Obs between time_window_min and time_window_max are processed

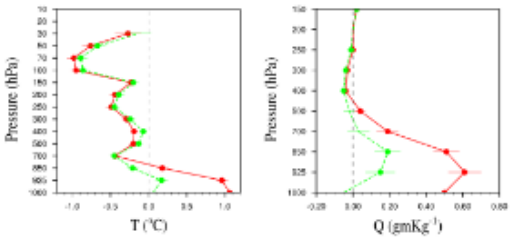
How do I want to handle surface observations?

&WRFVAR11

sfc_assi_options:

sfc_assi_options = 1 (default): The surface observations will be assimilated based on the lowest model level first guess. Observations are not used when the height difference of the elevation of observing site and the lowest model level height is larger than 100 meters

sfc_assi_options = 2: The surface observations will be assimilated based on surface similarity theory in PBL. Innovations are computed based on 10-m wind and 2-m temperature & moisture. (*Please use this option with caution, since the results could be very sensitive*.)



At what time is my analysis valid?

$$\mathbf{J(x)} = \frac{1}{2}(\mathbf{x} - \mathrm{x_b})^{\mathrm{T}}\mathrm{B}^{-1}(\mathbf{x} - \mathrm{x_b}) + \frac{1}{2}(\mathrm{y} - \mathrm{H}(\mathbf{x}))^{\mathrm{T}}\mathrm{R}^{-1}(\mathrm{y} - \mathrm{H}(\mathbf{x}))$$

&WRFVAR18

analysis_date = "2008-02-05_12:00:00" (should be the same time as in your first-guess file)

How much output information do I want?

&WRFVAR1

print_detail_grad:

print_detail_grad = .false.(default)

print_detail_grad = .true. Output cost function and gradient values of every observation type each iteration into standard output files (rsl.out)

Before You Run

$$J(x) = \frac{1}{2}(x - x_b)^T B^{-1}(x - x_b) + \frac{1}{2}(y - H(x))^T R^{-1}(y - H(x))$$

Check input files:

- Background ($\mathbf{x_b}$): $DAT_DIR/rc/2008020512/wrfinput_d01
  - NETCDF format
  - For cold-start mode, ($\mathbf{x_b}$) is generated by WRF "real.exe"
  - For cycling mode, ($\mathbf{x_b}$) is generated by WRF from a previous cycle's forecast
- Background Error Statistics ($\mathbf{B}$): $DAT_DIR/be/be.dat
  - Binary format
  - Generated by "gen_be" for this specific test case domain
- Observations ($\mathbf{y}$, $\mathbf{R}$) : $DAT_DIR/ob/2008020512/ob.ascii (conventional obs only)
  - ASCII or PREPBUFR format
  - Generated by OBSPROC from obs.2008020512, included in the tar file of the test data.
- Prepare a WRFDA namelist containing runtime options

Symbol	Description	WRFDA names
x_b	Background ("first-guess")	./fg
B	Background error covariances	./be.dat
y	Observations	./ob.ascii OR ./ob.bufr
R	Observation error covariances	./ob.ascii OR ./ob.bufr
N/A	User-defined run-time options (namelist)	./namelist.input
N/A	Land-use table	./LANDUSE.TBL
N/A	WRFDA executable	./da_wrfvar.exe

After running you'll find:

- **cost_fn** (cost function)
- **grad_fn** (Gradient of cost function)
- **gts_omb_oma_01** (point-by-point O, O-B, O-A information, etc.)
- **namelist.output** (Complete namelist)
- **statistics** (domain-wide O-B and O-A statistics)
- **wrfvar_output** (Analysis x,the input to the WRF model)

O: Observation, A: Analysis, B: Background (first-guess)

cost_fn and grad_fn

- Contains values of the cost function and its gradient.
  - If calculate_cg_cost_fn =.false., only the initial and final values of the cost and gradient functions are output as follows:

cost_fn

Outer Iter	EPS	Inner Iter	J	Jb	Jo	Jc	Je	Jp	Js	Jl
1	0.100E-01	0	24322.148	0.000	24322.148	0.000	0.000	0.000	0.000	0.000
1	0.100E-01	21	16141.945	1847.293	14294.652	0.000	0.000	0.000	0.000	0.000

grad_fn

Outer Iter	EPS	Inner Iter	G	Gb	Go	Ge	Gp	Gs	Gl
1	0.100E-01	0	543.846	0.000	543.846	0.000	0.000	0.000	0.000
1	0.100E-01	21	4.767	60.783	60.970	0.000	0.000	0.000	0.000

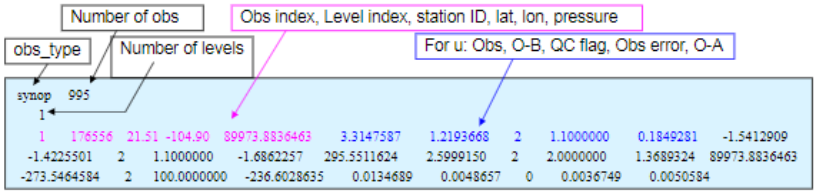
b: background term
o: observation term
c: JcDFI term
e: alpha term
p: radiance variational bias correction term
s: skin temperature or cloud cover term
l: lateral boundary conditions control variable (4dvar only)

  - If calculate_cg_cost_fn =.true., the cost function and its gradient at each iteration will be computed and written into **cost_fn** and **grad_fn**.

✓ WRFDA tools: plot_cost_grad_fn.ncl

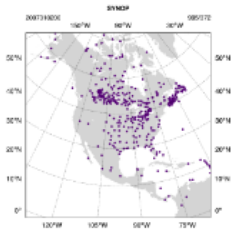
gts_omb_oma_01

- Contains complete point-by-point, detailed observation information.



- Measured quantities for each observation type vary:

synop: u, v, t, p, q	polaramv: u, v
metar: u, v, t, p, q	gpspw: tpw
ship: u, v, t, p, q	sound: u, v, t, q
geoamv: u, v	sonde_sfc: u, v, t, p, q
airep: u, v, t	profiler: u, v
pilot: u, v	buoy: u, v, t, p, q
satem: thickness	airsr: t, q
qscat: u, v	gpsref: ref



✓ WRFDA tools: plot_gts_omb_oma.ncl
✓ WRFDA tools: plot_ob_ascii_loc.ncl

statistics

- Contains domain-wide O-B and O-A information:

Diagnostics of OI for synop

var	u (m/s)	n	k	v (m/s)	n	k	t (K)	n	k	p (Pa)	n	k	q (kg/kg)	n	k
Number:		331			332			355			330			361	
Minimum(n,k):	-8.4007	363	0	-8.4086	878	0	-8.7006	882	0	-390.7893	931	0	-0.4165E-02	719	0
Maximum(n,k):	8.0456	886	0	8.1898	630	0	7.7302	421	0	471.9343	944	0	0.8168E-02	787	0
Average :	-0.0621			-0.1385			-0.1178			20.1177			-0.1625E-03		
RMSE :	2.5021			2.1355			3.1978			108.1518			0.3629E-03		

Diagnostics of AO for synop

var	u (m/s)	n	k	v (m/s)	n	k	t (K)	n	k	p (Pa)	n	k	q (kg/kg)	n	k
Number:		331			332			355			330			361	
Minimum(n,k):	-4.2296	172	0	-8.0783	683	0	-8.9005	883	0	-472.9290	931	0	-0.4152E-02	719	0
Maximum(n,k):	8.8540	886	0	8.7990	630	0	8.8192	421	0	392.4096	944	0	0.8058E-02	1	0
Average :	-0.0847			-0.1355			-0.1293			1.1728			0.1647E-04		
RMSE :	1.8850			1.8955			2.1990			101.3819			0.3998E-03		

Minimum of gridded analysis increments

Lvl	u	i	j	v	i	j	t	i	j	p	i	j	q	i	j
1	-1.8935	17	32	-1.8865	36	14	-6.8626	20	36	-314.7470	44	1	-0.1451E-02	18	33
2	-11.8476	16	33	-12.0870	36	14	-5.8242	21	36	-311.2889	44	1	-0.1458E-02	18	33

Maximum of gridded analysis increments

Lvl	u	i	j	v	i	j	t	i	j	p	i	j	q	i	j
1	1.0760	41	8	1.0739	28	13	1.4994	34	20	197.0381	28	2	0.1401E-02	39	8
2	1.4844	40	8	1.6180	28	13	1.4471	7	20	198.8169	28	2	0.1891E-02	39	8

Mean of gridded analysis increments

Lvl	u	v	t	p	q
1	-0.0327	0.0932	-0.1477	17.7414	-0.1047E-03
2	-0.0051	0.0738	0.0116	17.2803	-0.8066E-04

RMSE of gridded analysis increments

Lvl	u	v	t	p	q
1	0.7846	0.6040	1.0120	72.0411	0.1258E-03
2	0.7995	0.6483	0.9189	71.2814	0.1476E-03

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- **WRFDA Code Flow**