Assessing the Impact of Surface Data and Profiler Data on Fog Forecast Using WRF-3DVar: A Case Study on a Dense Fog Event over North China

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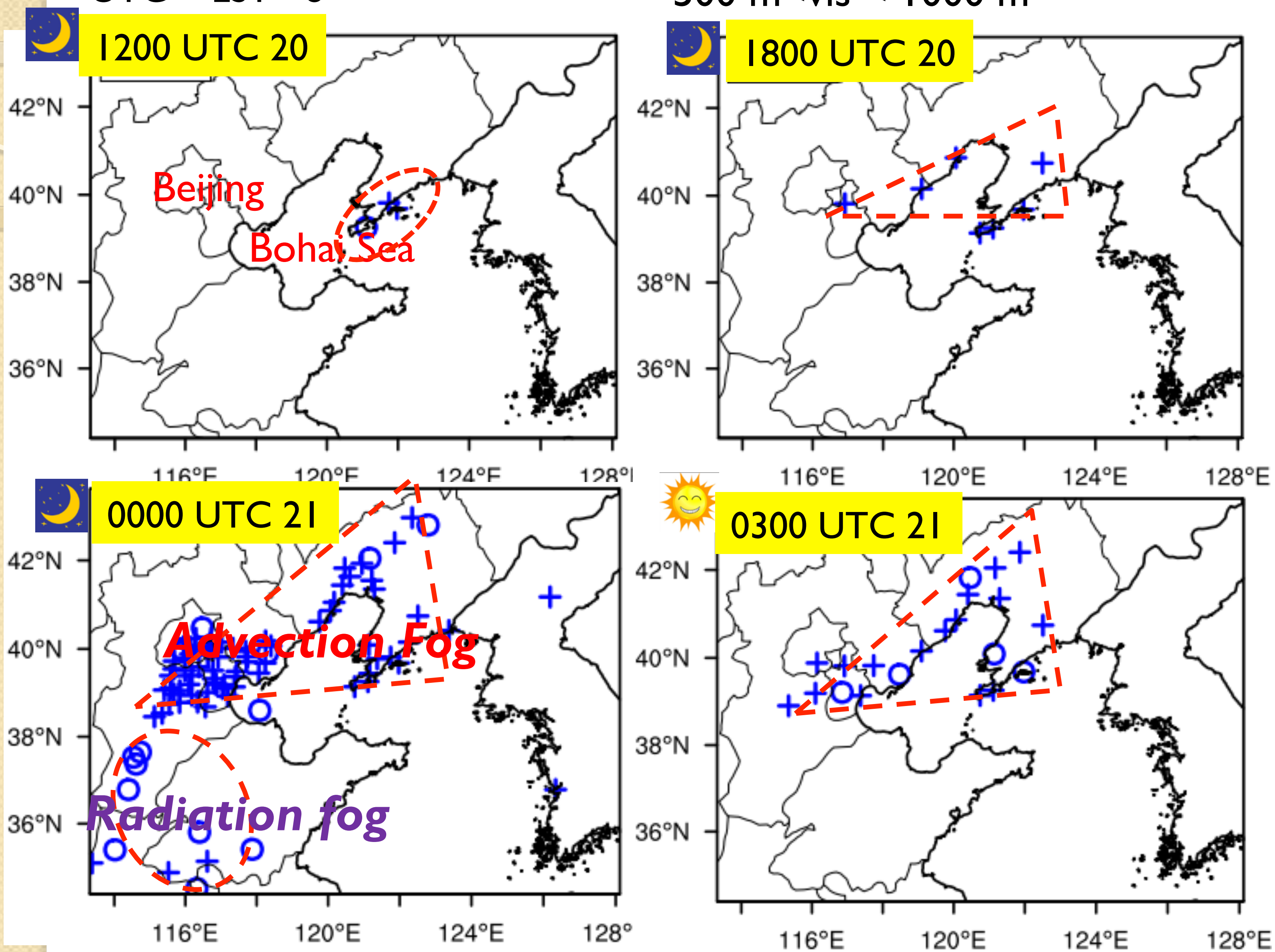
06/17/2015

Surface station visibility obs: ○ vis < 500 m

UTC = LST - 8 + 500 m<vis < 1000 m

Fog: vis < 1000 m

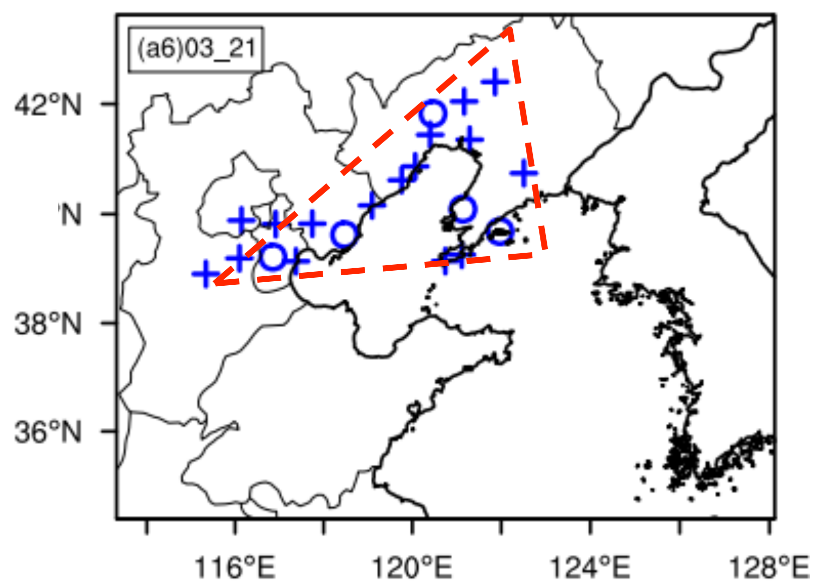


234 flights cancelled

500 flights delayed

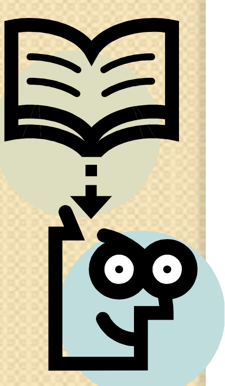
30 000 travelers stranded

*"Dense fog **raided** Beijing "*



Outline

- Background
- Experimental design
- Results
- Analysis
- Summary



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- Fog: horizontal visibility below 1 km due to water or ice droplets suspending in the atmosphere near the surface (Glickman 2000).

- Fog is high impact weather on aviation, marine and land transportation (Gultepe et al. 2007).
  → great need for accurate fog prediction.

- Fog is very sensitive to initial conditions (Hu et al. 2014; Zhou and Du 2010)
  → making the full use of obs to improve model initial conditions is one of the main concerns for accurate fog prediction.

- one of main methods to improve initial conditions of fog predictions: ***DA***

- Studies of DA on fog:

➢ DA techniques

✓ 1-DVAR (Bergot 2005; Muller et al. 2007), EnKF(Remy and Bergot 2010),

✓ 3DVAR(Gao et al. 2010), cycling 3DVAR (Gao et al. 2015)

easy to implement → widely used in the operational system

➢ Obs used by DA

Review of previous studies on fog DA

- Studies of DA on fog:

➢ DA techniques

➢ Obs used by DA:

✓ conventional obs (GTS) (Liang et al. 2009)

✓ AMDAR (Liang et al. 2009) >>> obs only in airports

✓ satellite obs (Gao et al. 2015) >>> loc and time limited

✓ microwave radiometer (Vandenberghe and Ware 2002)

>>> only in field obs experiments and mainly on radiation fog

✓Fog is ***grounded*** cloud and ***PBL*** phenomenon (Gultepe et al. 2007).

■ surface information

■ PBL structure (T inversion, U/V)

⟹ effective assimilation of surface obs and profiler obs significant for improving the skill of operational forecast of fog

☐Few studies quantitatively explored the impact of *surface data* and *profiler data* on the fog forecast.

Objective of this study

AWS (***A**utomated **W**eather **S**tations*): Rich surface data resource in China
surface T, Q, U/V and P with *high temporal* and *spatial resolutions*
>>>> only be used to do model verification in most studies.

Profiler : U/V profile, high-frequency, at different vertical levels
PBL profiler high vertical resolution below 700 hPa

- Explore the impact of surface data (AWS) and profiler data (PBL profiler) on fog forecast with aspects to *different obs types*, *obs densities* and *distributions*, DA cycling frequency for this case.

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OSSE *(**O**bserving **S**imulated **S**ystem **E**xperiments)* configuration:

- 40-member ensemble simulation with 48-h forecast:
  0000 UTC 20 — 0000 UTC 22 Feb 2007

- one good member → ***Truth*** → ***simulated obs*** *and* ***verification***
  one bad member → ***BG***

  obs = truth + random(0,***obs_err***)

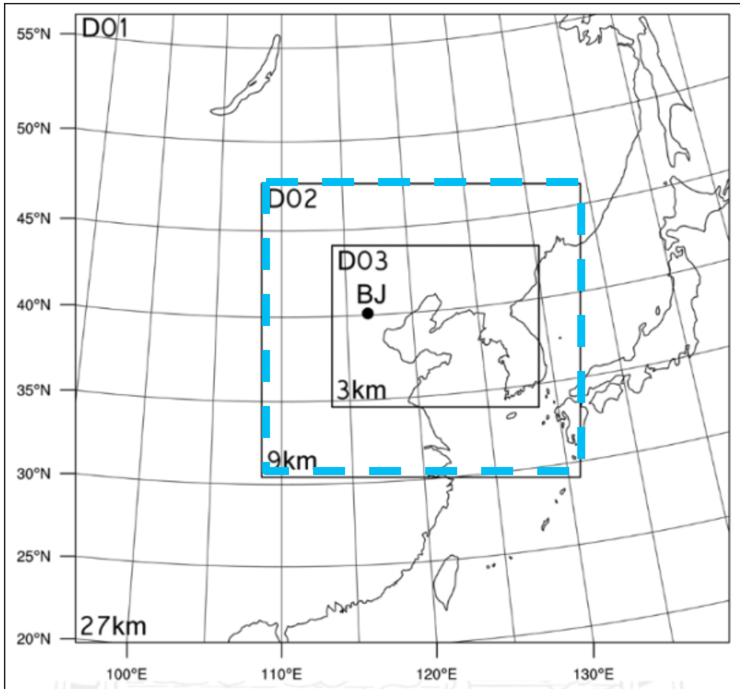
- **BE**: NMC (cv7) T24 - T12
  from 02/01/2007 to 03/12/2007 40 days

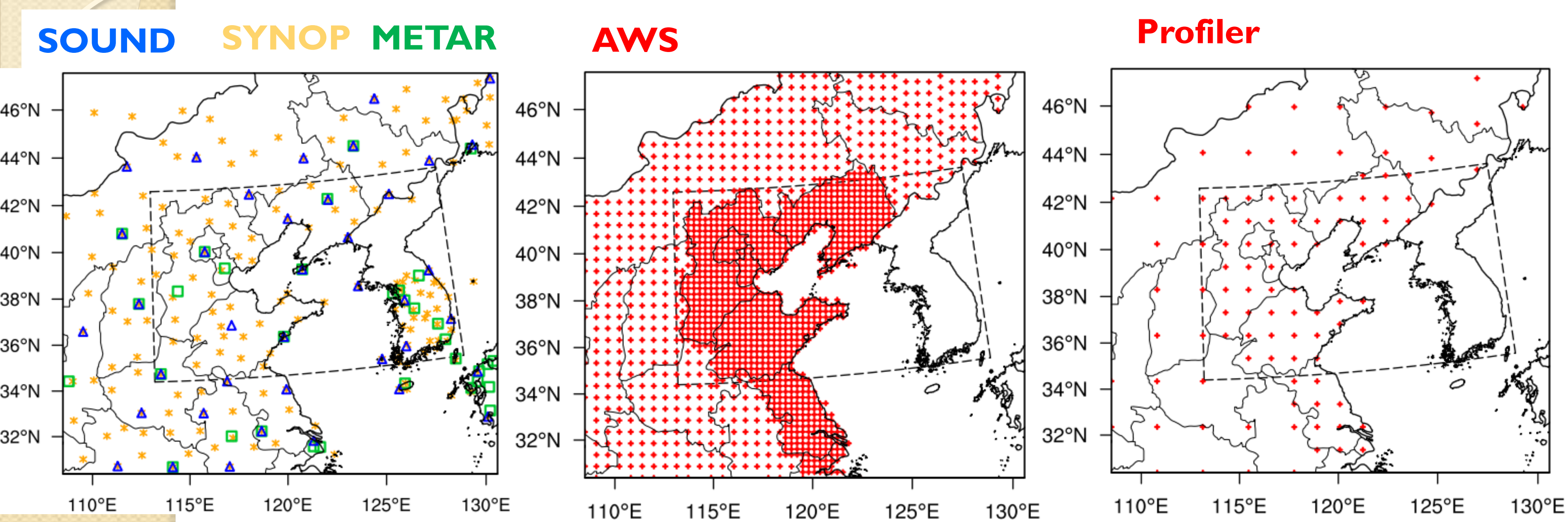
- var_scaling= 1.0 len_scaling= 1.0

- **DA**: D02 and D03

WRF V3.3.1

3-doms
27 km, 9 km, **3** km





Surface data

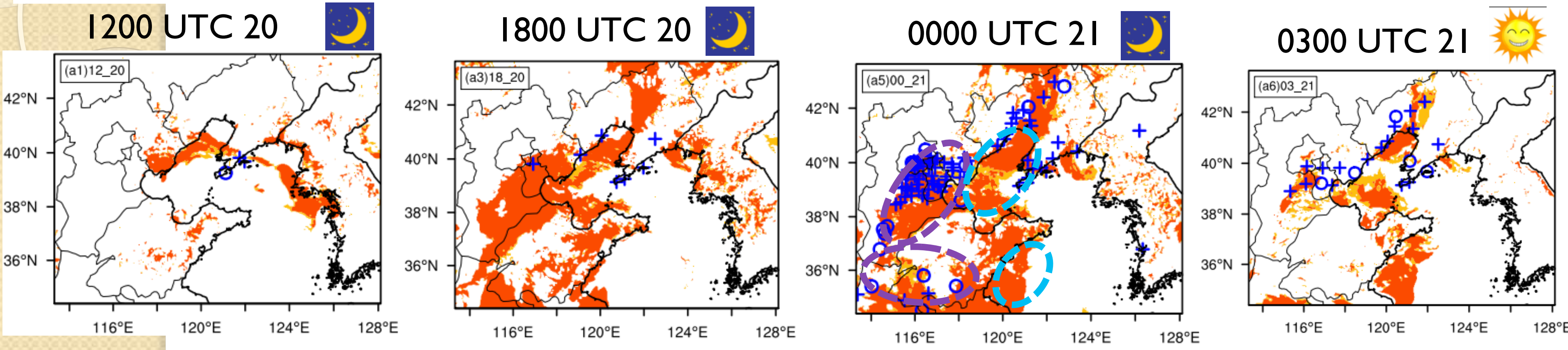
OBS type	SOUND	SYNOP METAR AWS	Profiler
Variables	U/V, T, Q, P	U/V, T, Q, P	U/V
Horizontal density (km)	302	39	164
Vertical resolution	11 levels to 100 hPa	*surface*	45 levels to 700 hPa
Temporal density	12 UTC 02/20	06, 09, 12 UTC 02/20	06, 09, 12 UTC 02/20

Experimental design

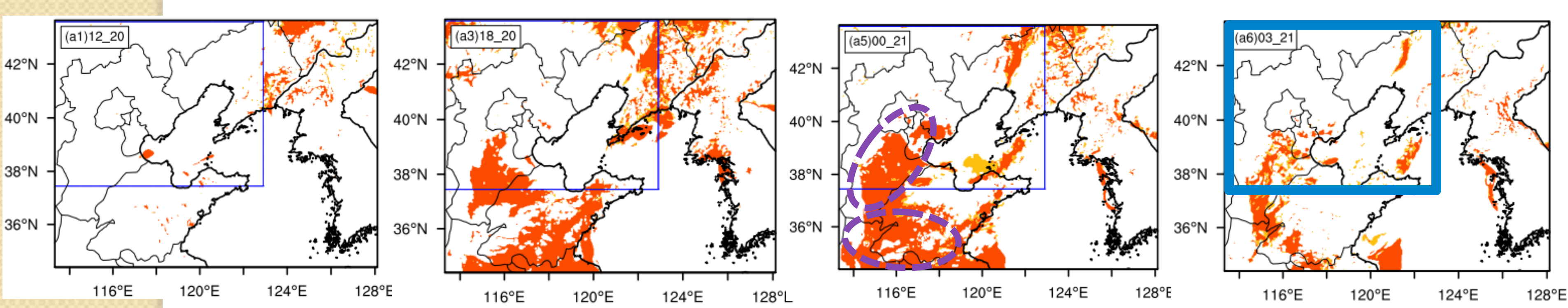
3-h cycling

Date	2/20			
UTC	06	09	12	
PFL	WRF + PFL	WRF + PFL	WRF + *SND* +PFL	15-h WRF FCST →
SFC	WRF + SFC	WRF + SFC	WRF + *SND*+ SFC	15-h WRF FCST →
BOTH	WRF + SFC + PFL	WRF + SFC + PFL	WRF + *SND* + SFC+PFL	15-h WRF FCST →

Truth



Background



Radiation Fog

Advection Fog

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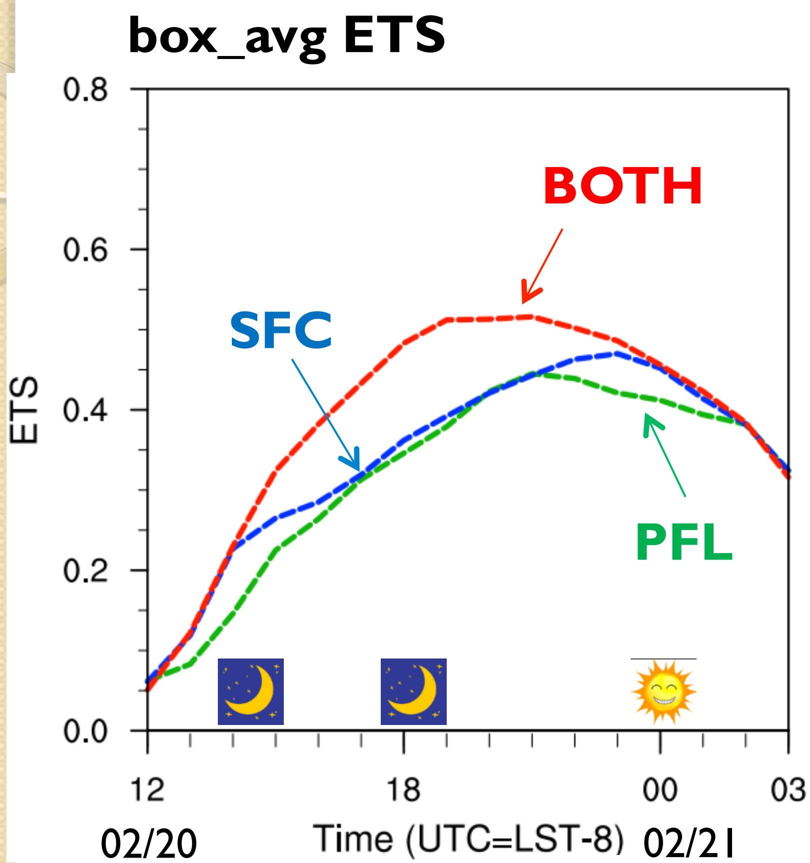
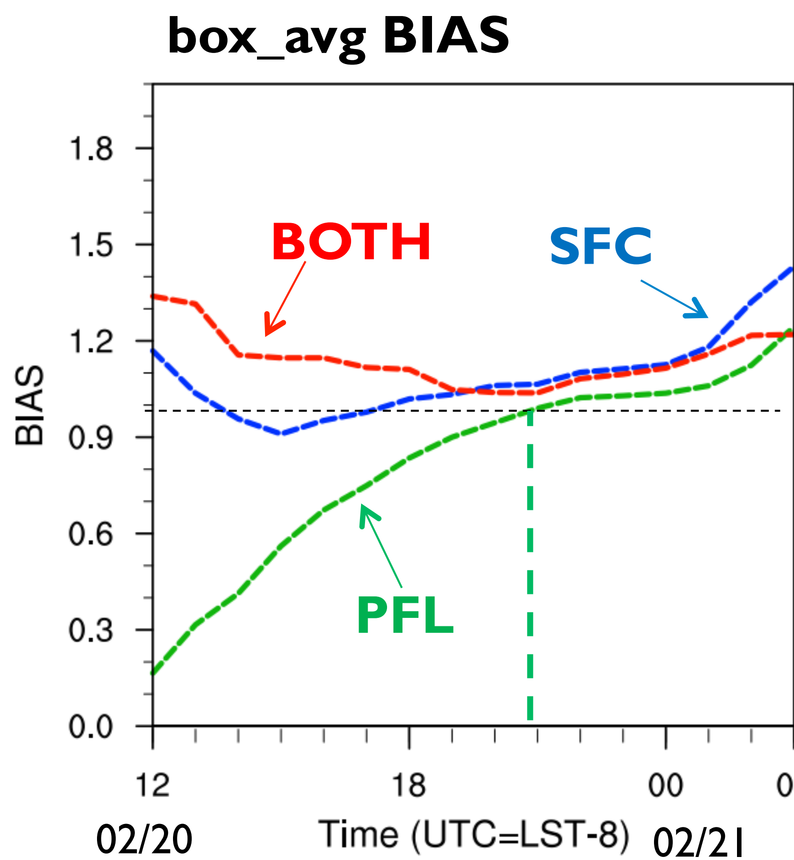
Results



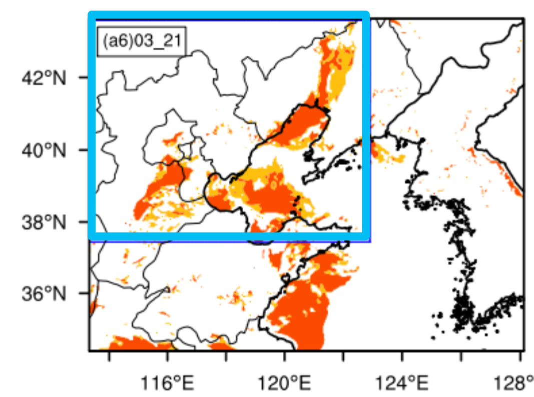


6.6 %

Exp	PFL	SFC	BOTH
ETS	0.316	0.337	0.383

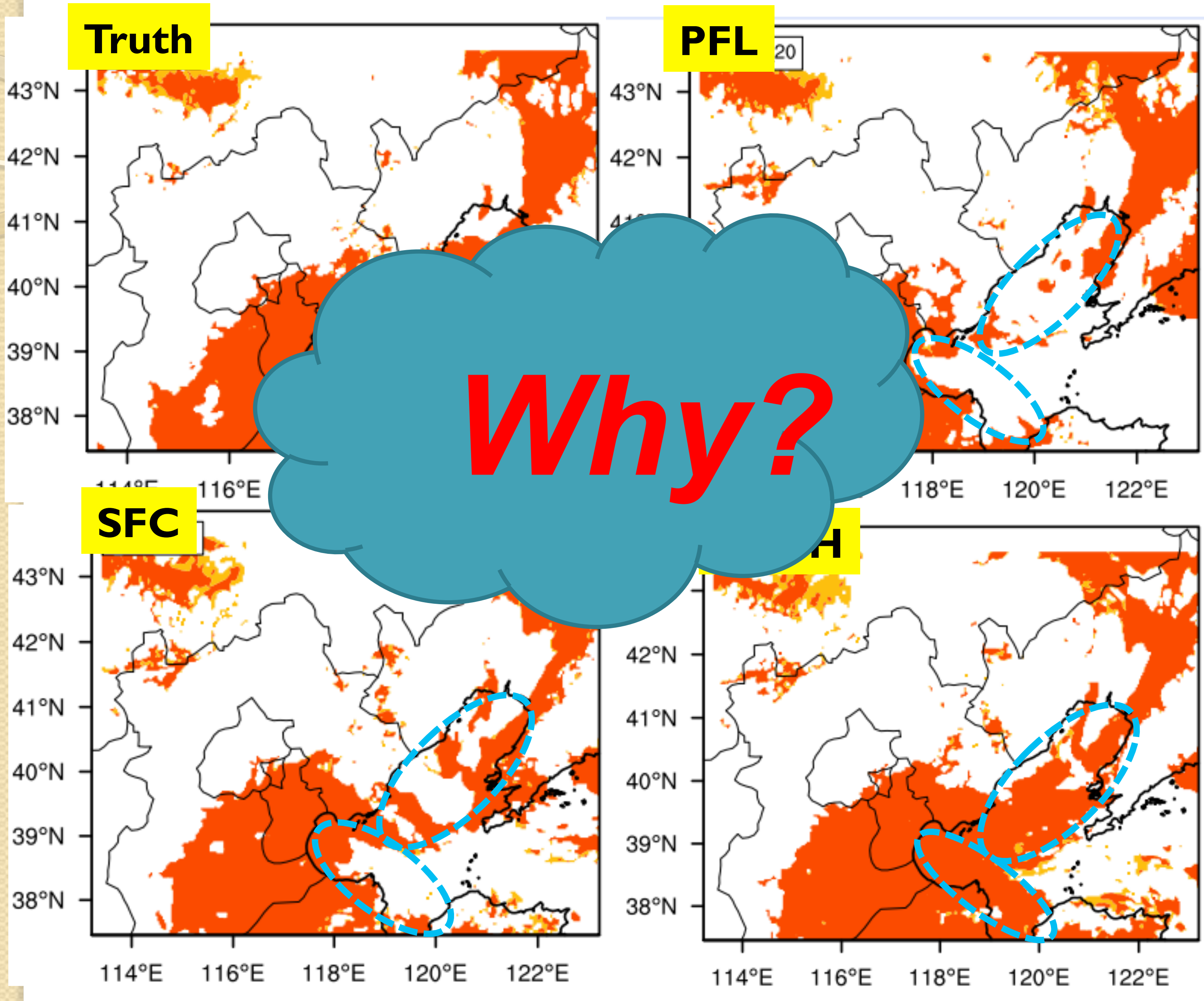
temporal_avg

21.2 %



Results

Fog coverage （**shading**） (***vis < 1 km***) at the first model level at 1800 UTC 20 Feb 2007 (6 h forecast).



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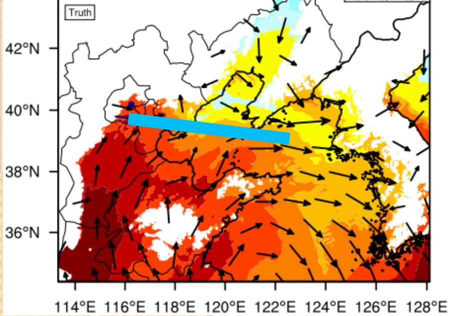
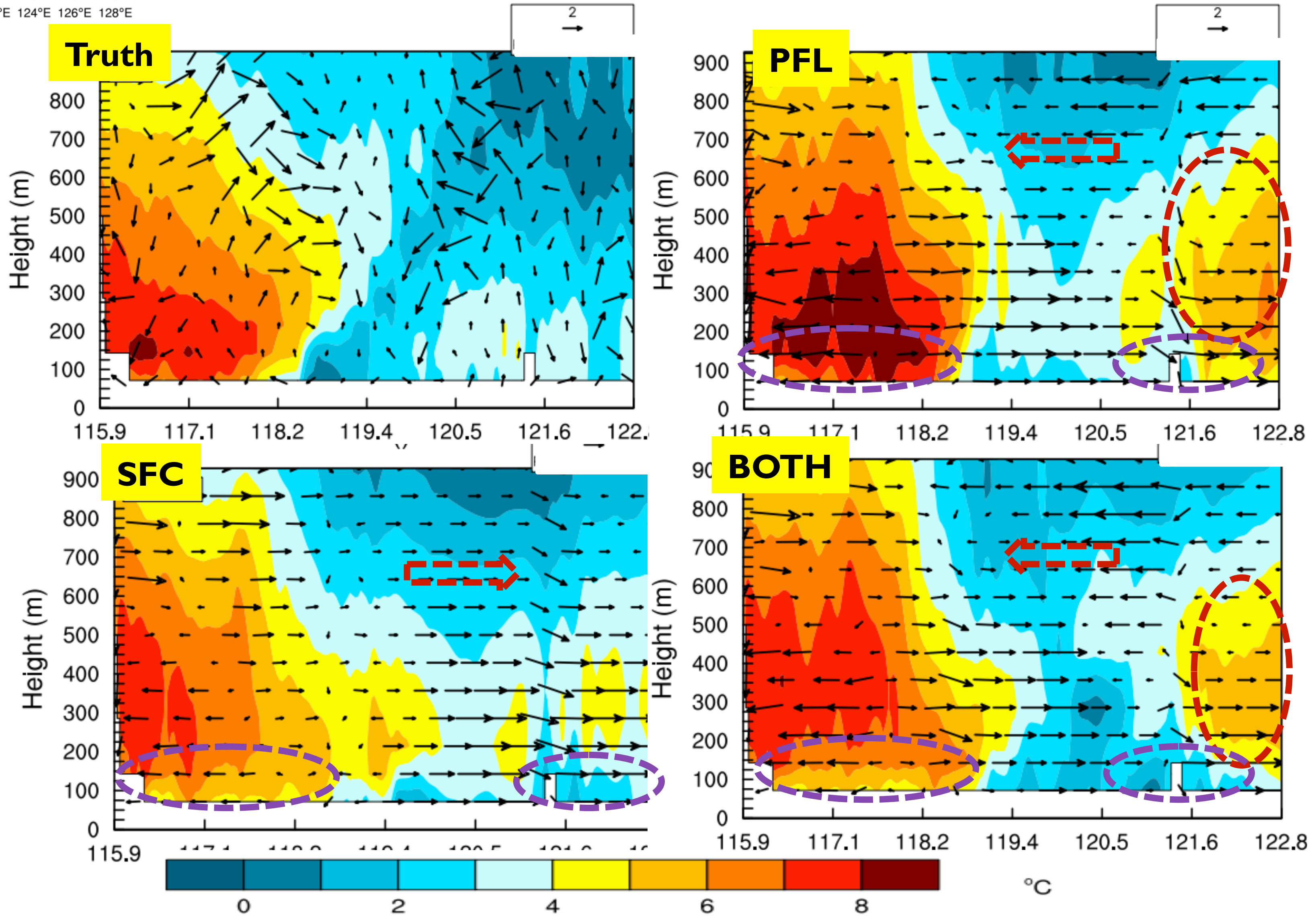
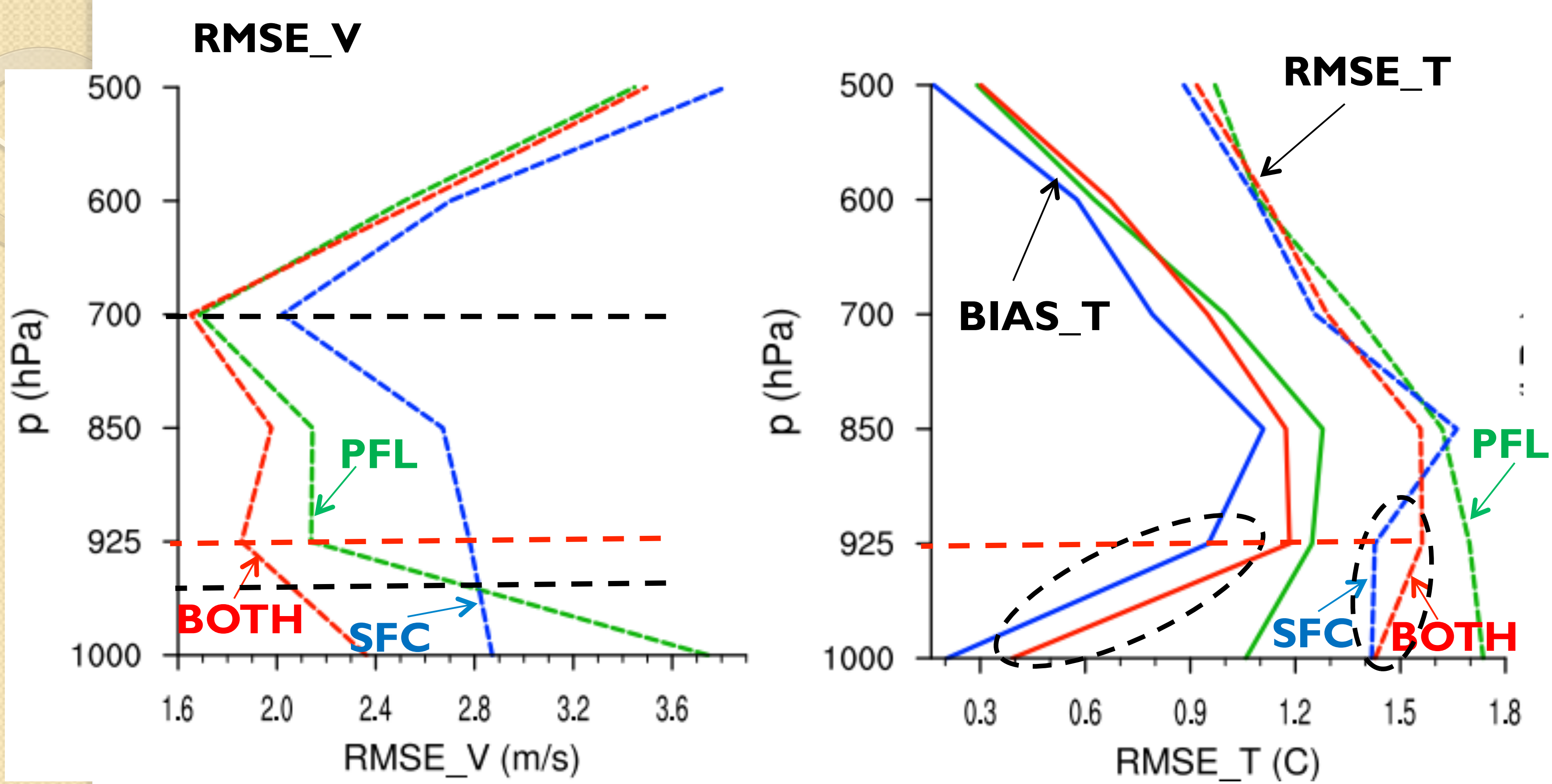


Shading: T
Vector: U/V/W

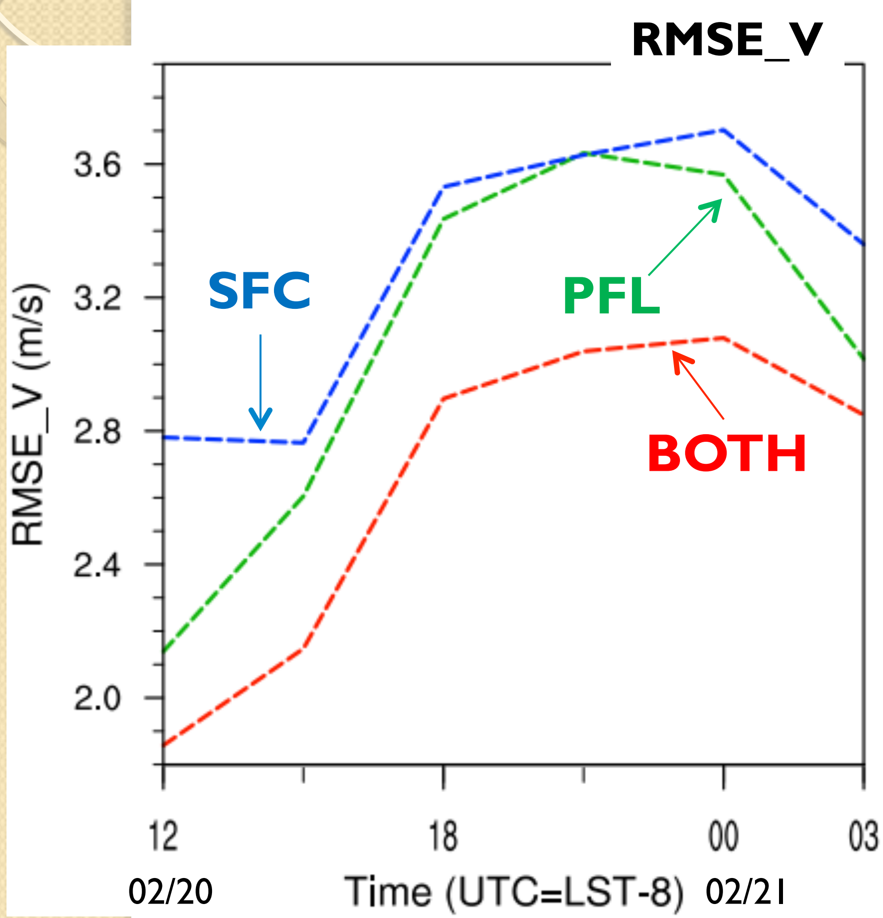
at 1200 UTC 20 Feb 2007 (*the last cycle*)

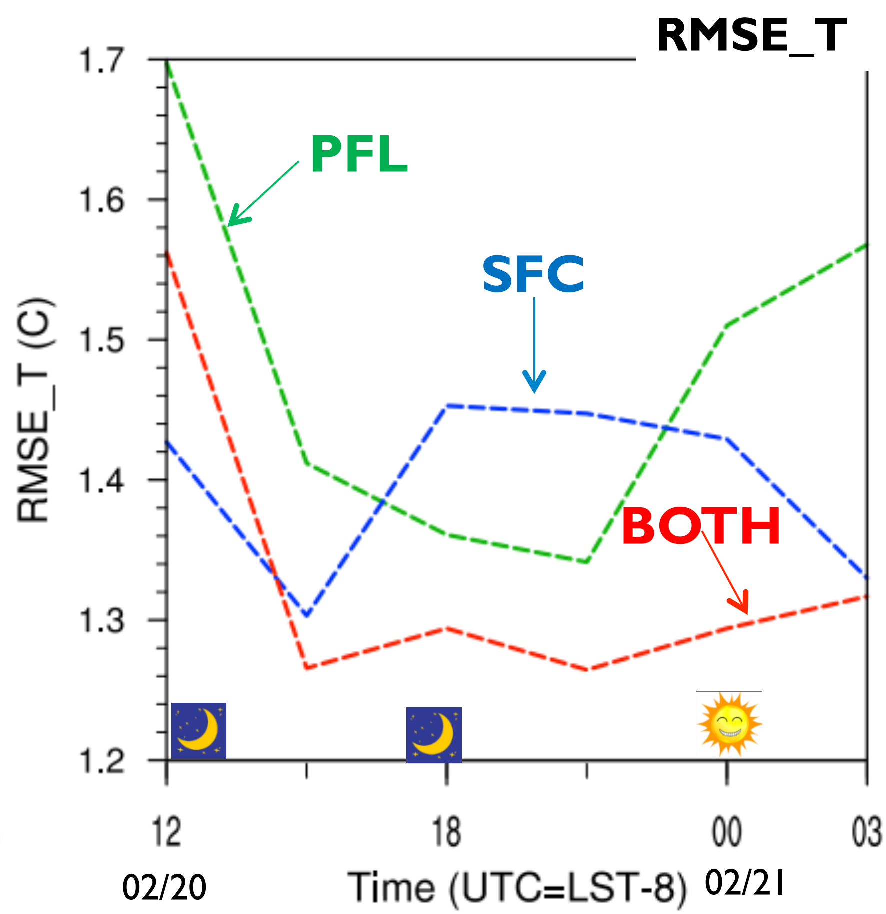


Analysis RMSE over D03 at 1200 UTC 20 Feb 2007 (the last cycle)



Forecast RMSE *at 925 hPa* over D03





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Summary

- ✓ Compared with ***PFL***, ***SFC*** can improve the fog forecast with increasing the ETS by ***6.6%***. This is because that SFC has better near-surface wind and moisture fields and more stable stratification. It indicates that data with higher *horizontal density* and more *variables at the surface* (surface obs) has more impact on fog forecast than that of obs with only *wind information* but high *vertical resolution* (profiler).

- ✓ Compared with ***SFC***, ***BOTH*** made the fog forecast significantly improved with ***13.6 %*** increase of ETS. This is because that the better U/V vertical structure at PBL leads to better dynamically balanced fields of U/V, T and Q. It indicates that the combination of both surface data and profiler data are extremely necessary to improve the skill of fog forecast for this case.

Future work:

- Conduct experiments withholding T and Qv to examine the impact of *wind* vs *T and Qv* in surface obs on fog forecast

- Examine the impact of obs densities, obs distributions and the DA cycling frequency on fog forecast

- Conduct real data experiments

Thank You

Extra Material

- 40-member ensemble simulation with 48-h forecast:
  0000 UTC 20 — 0000 UTC 22 Feb 2007

- initial ensemble generated with WRF-3DVar randomly sampling the background error covariance from a fixed covariance model
- The standard deviations of the initial ensemble
  - 0.3 g/kg for water vapor mixing ratio
  - 3 m/s for wind
  - 1.2 K for air temperature

- **Obs = *truth* + random(0,*obs_err*)**

- ***Obs_err:***

- Surface obs: SYNOP, METAR, AWS
  u/v= 1 m/s, **T**= 1 degree, **Q** = 1 g/kg, **P** = 1 Pa

PROFL_UHF:
(PBL profiler)

h(1)= elev + **100 m**

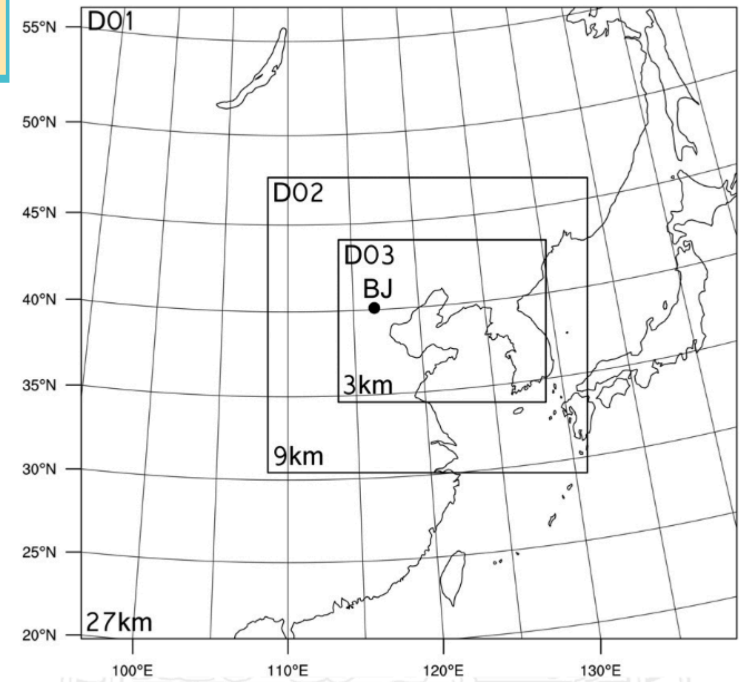
h(x)=h(1) + k * **60 m**

h(x) < **3000 m**
(~700 hPa)

Pressure (hPa)	**1000**	**925**	**850**	**700**	**500**	**400**	**300**	**250**	**200**	**150**	**100**
Wind (m/s)											
SOUND	1.1	1.1	1.1	1.4	2.3	2.8	3.3	3.3	3.3	3.0	2.7
PROFL	1.0	1.0	1.2	1.2	/	/	/	/	/	/	/
T(K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Q(g/kg)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P(Pa)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Experimental design

Dom	D01: 159*153 (**27 km**) D02: 232*214 (**9 km**) D03: 448*343 (**3 km**)
e_vert	40 levels (**7 levels below 1 km**)
p_top	50 hPa
Microphysics	WSM 6-class graupel
Longwave	RRTM
Shortwave	Dudhia
Surface layer	QNSE surface layer
Land surface	Thermal diffusion scheme
Boundary layer	**QNSE**
Cumulus	Kain-Fritsch (only for D01 and D02)



- LANDUSE data: Beijing_30s (D03)
- NCEP FNL data: 1deg*1deg

WRF V3.3.1

0600 UTC 02/20 (DA) → 0900 UTC 02/20 (DA) → 1200 UTC 02/20 (DA) → FCST

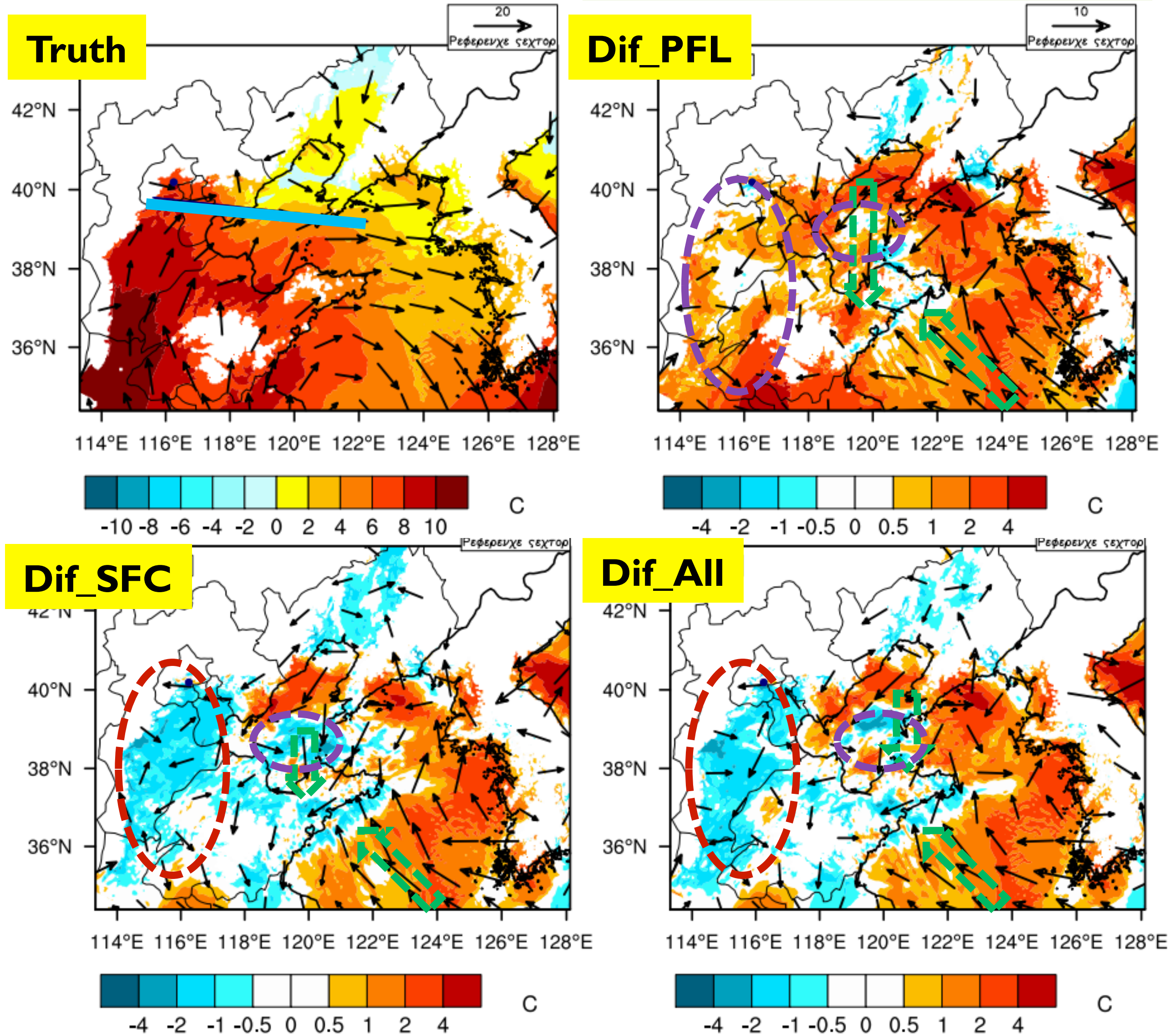
Dif = Exp (analysis) – Truth

Shading: T
Vector: U/V

at 1000 hPa

over D03

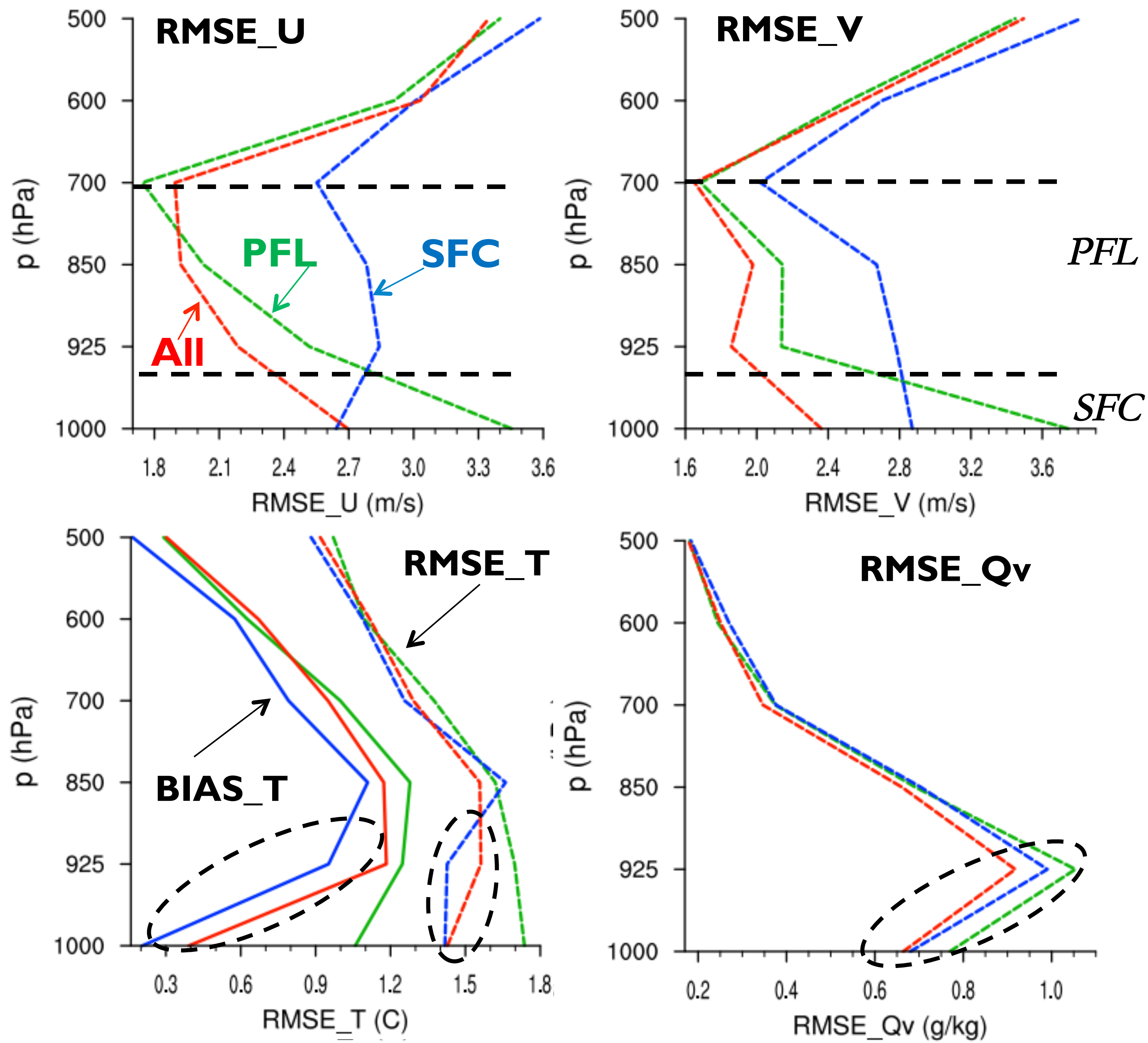
at 1200 UTC 20 Feb 2007 *(initial time)*



Analysis RMSE

over D03

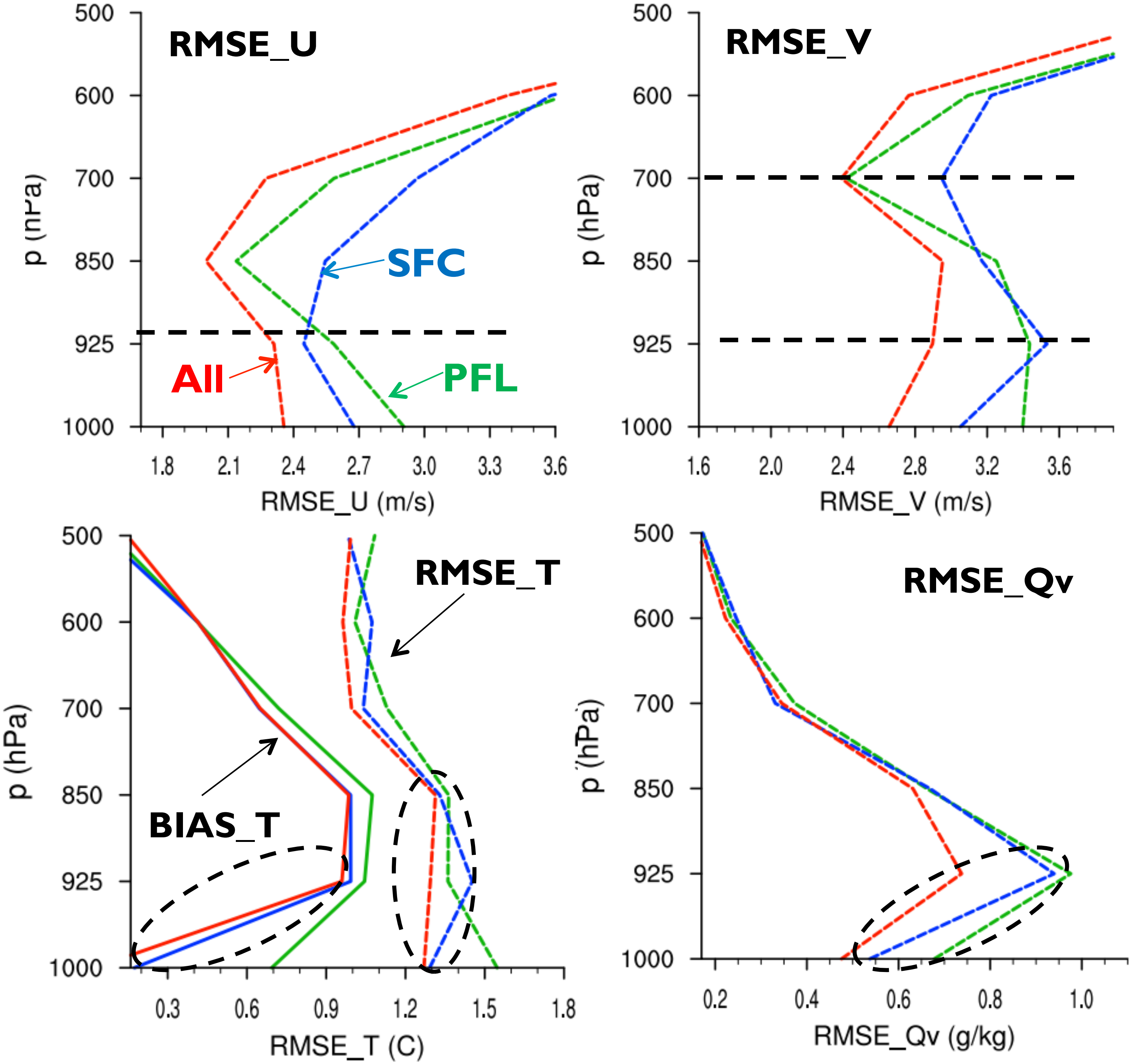
at 1200 UTC 20 Feb 2007



Forecast RMSE

over D03

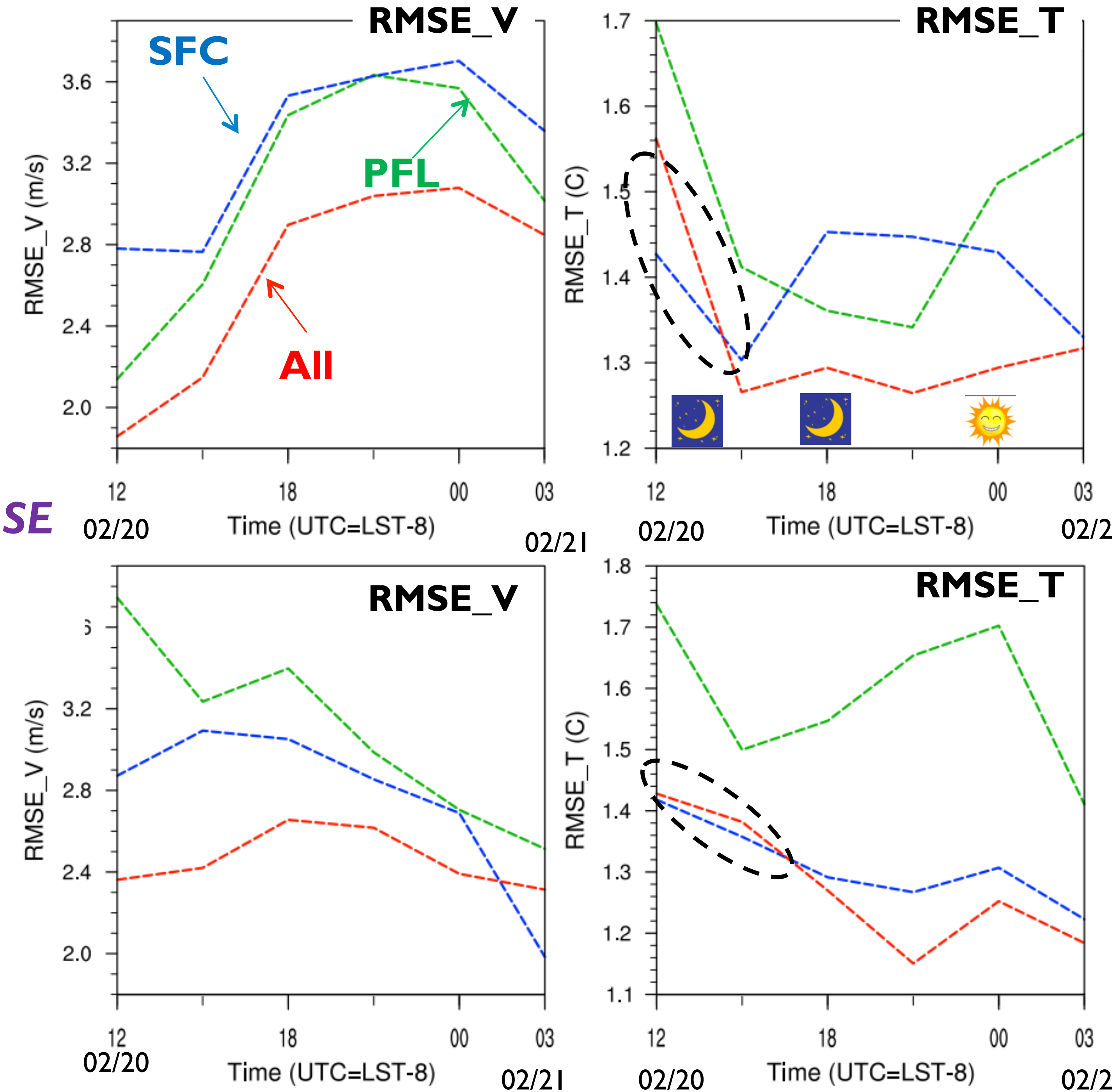
at 1800 UTC 20 Feb 2007 (6 h forecast)



925 hPa

Forecast RMSE

over D03



1000 hPa