Development and Evaluation of a Regional Reanalysis over East Asia

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Introduction

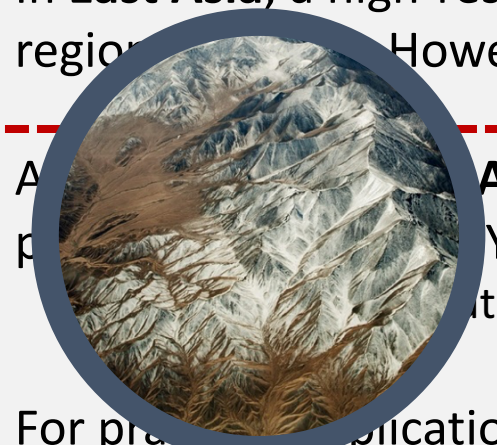
- A reanalysis is **a high-quality climate data set.**
  - produced by assimilating long-time series of observations with a consistent and state-of-the-art NWP model and data assimilation system
  - the best estimate of the state of the atmosphere
  - widespread applications in many research areas

- Most reanalyses have been produced for **the global area.**
  - ECMWF: ERA-15, ERA-40, ERA-Interim, ERA-20CM
  - NCEP: NCEP/NCAR (R1), NCEP/DOE (R2), NCEP CFSR
  - JMA: JRA-25, JRA-55
  - NASA MERRA, NOAA-CIRES (20CRv1 and v2)

- Due to the coarse resolution of global reanalyses, many meteorological organizations started or plan to produce **regional reanalyses with higher resolution.**
  - North America (NARR), Europe (EURO4M), Arctic (ASR)
  - Europe (UERRA) and South Asia in preparation

Introduction

- In **East Asia**, a high-resolution regional reanalysis is required to precisely analyze the regio… However, **no regional reanalysis** has been produced for East Asia.



- A… **Asia Regional Reanalysis (EARR)** was developed for the two-year p… Yang and Kim 2017).
  - …ture, long-term execution of the EARR project

- For pra… plications of reanalysis, **validation is essential**.
  - A… alysis is an estimate of the atmospheric state.

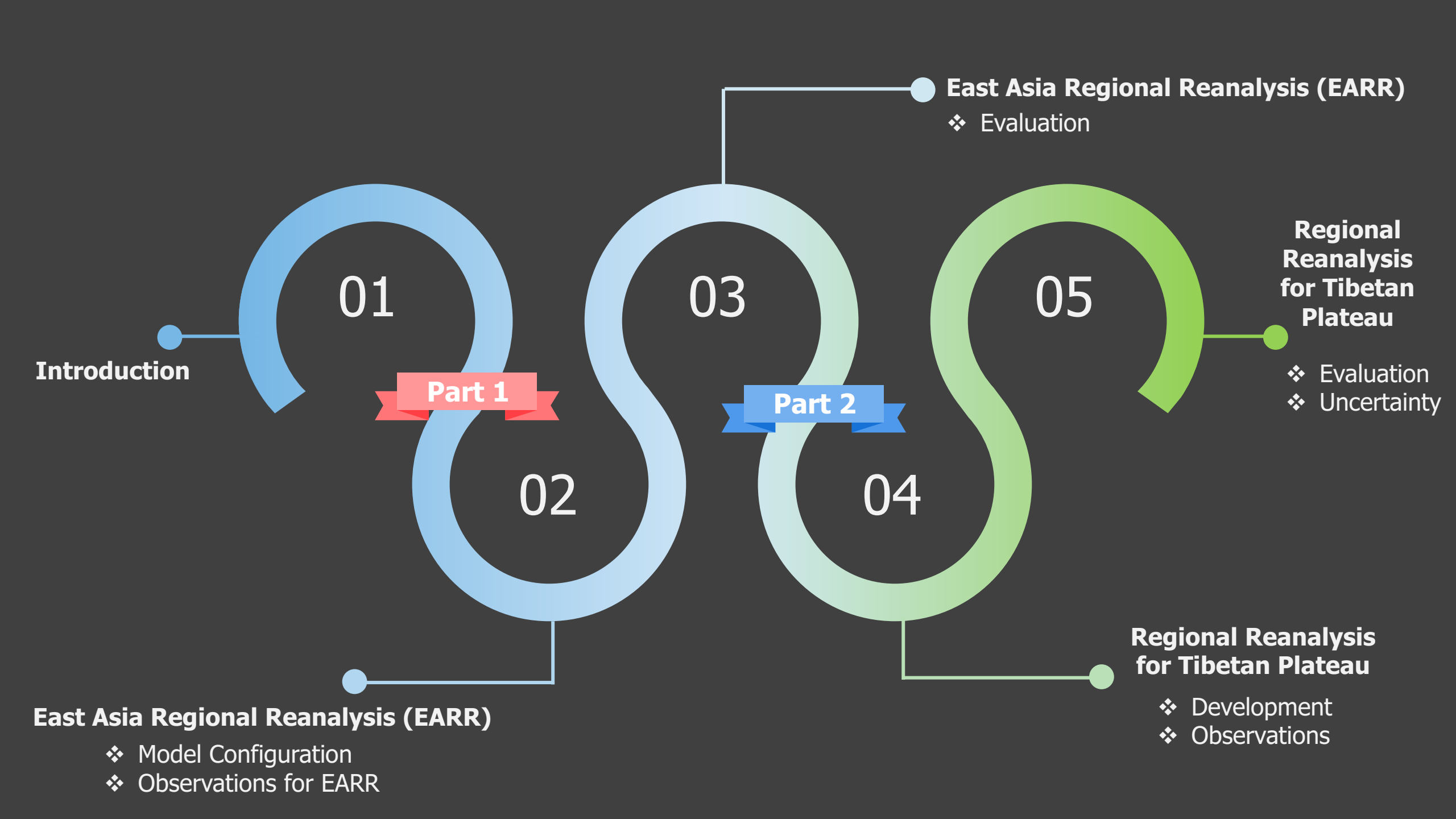
- …**aracteristics and uncertainties of EARR** for the period 2013-2014 are …**gainst ERA-Interim and observation** data.

Part 1

- …e EARR domain does not cover all Tibet region, in order to analyze **Tibetan …au** in greater detail, a regional reanalysis including Tibet region is required.

Part 2

- Therefore, to find out the appropriate reanalysis system before developing it, investigation is needed.


East Asia Regional Reanalysis (EARR)
❖ Evaluation
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Regional Reanalysis for Tibetan Plateau
❖ Evaluation
❖ Uncertainty
Introduction
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02
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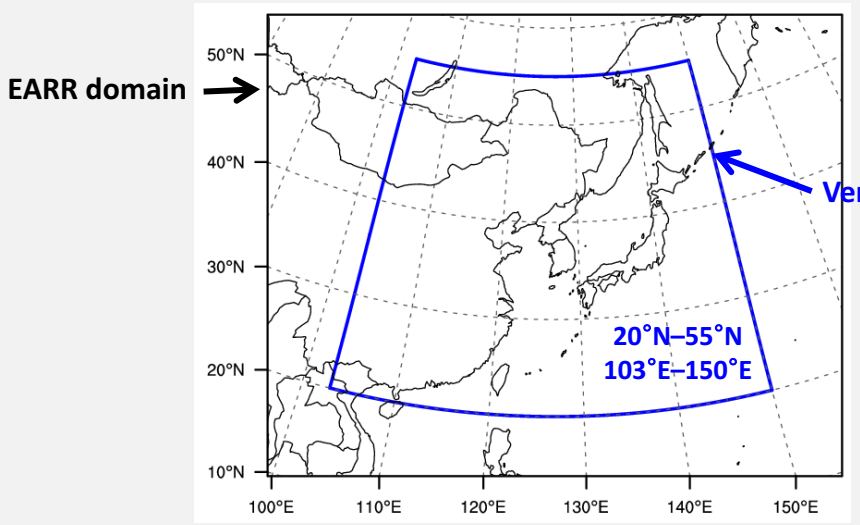
East Asia Regional Reanalysis (EARR)
❖ Model Configuration
❖ Observations for EARR
Regional Reanalysis for Tibetan Plateau
❖ Development
❖ Observations

Part 1

East Asia Reanalysis system

- Model configuration
- Observations for EARR
- Evaluation of reanalysis

Model configuration



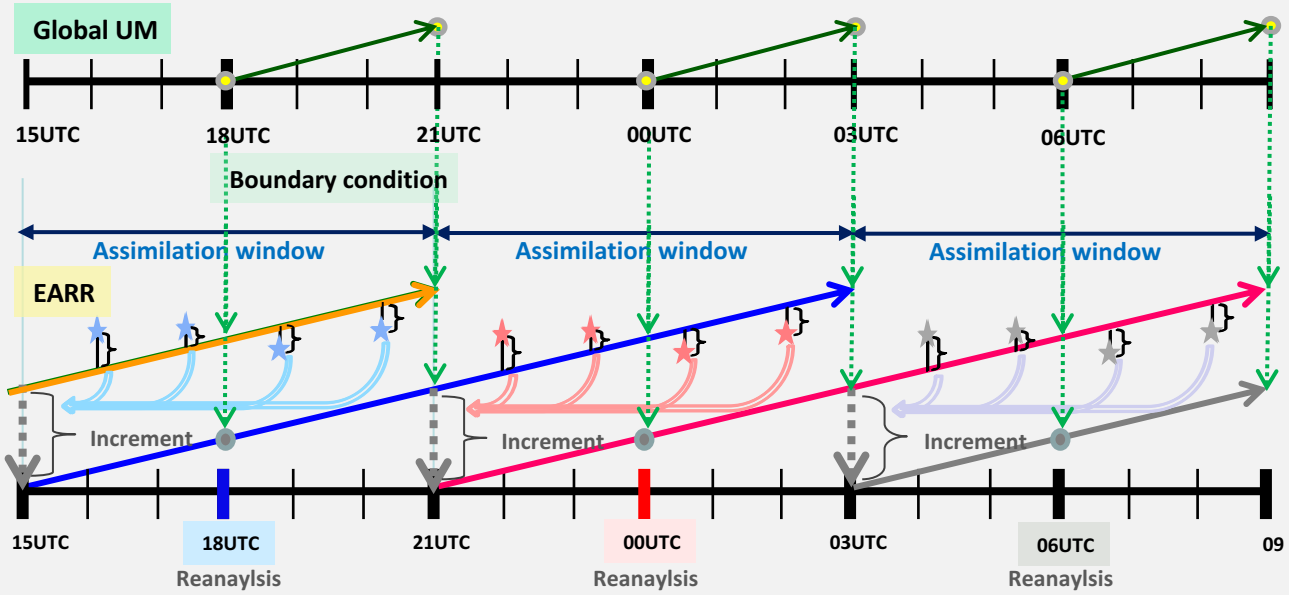
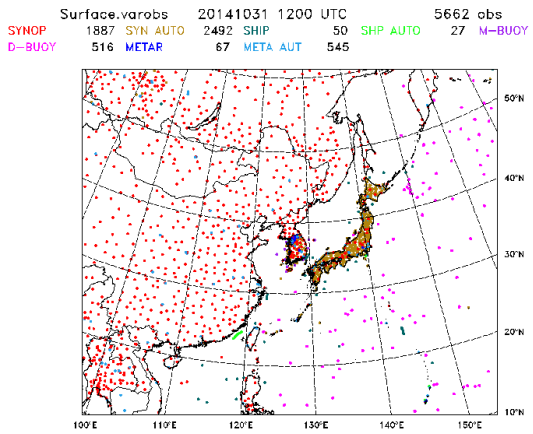
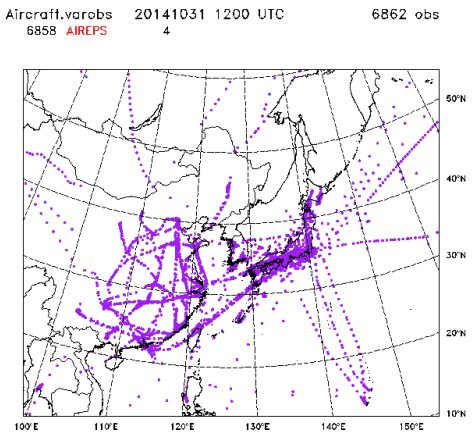


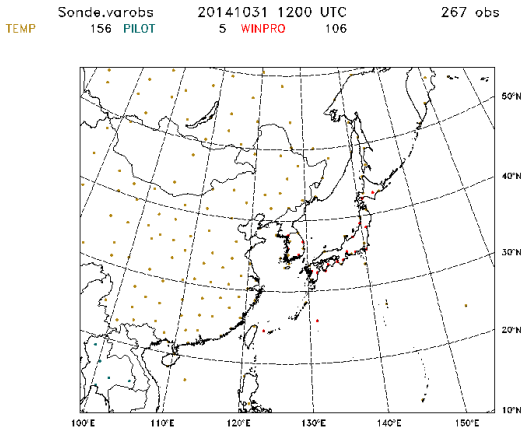
Table 1. Model configuration

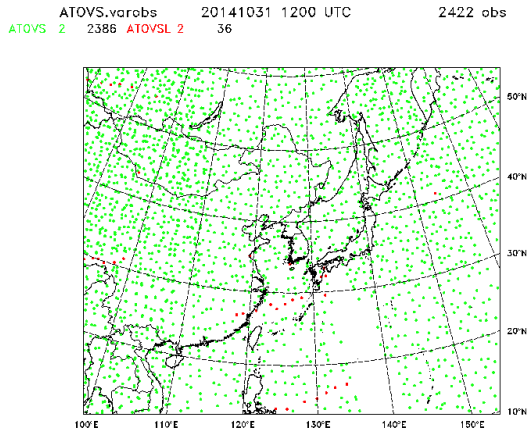
Horizontal Resolution	**12 km** (0.11° × 0.11°, 540 × 432 grid points)
Vertical Levels	70 vertical levels (top ~ 80 km)
Model	**Unified Model** (Davies et al. 2005) at the KMA (v8.2, the KMA operational forecasting system in June 2015)
Lateral boundary condition	Analysis and forecast fields from Global model (25 km) of the UM at the KMA
Data assimilation	**4DVAR** (Courtier et al. 1994, Rawlins et al. 2007)
Spatial discretization	Finite Difference method
Time integration/advection	Semi-implicit time integration and semi-Lagrangian advection scheme
Planetary boundary layer	First-order non-local boundary-layer scheme based on Lock et al. (2000)
Radiation	Edwards-Slingo general 2-stream scheme (Edward and Slingo 1996)
Cumulus convection	Mass flux convection with CAPE closure (Gregory and Rowntree 1990)
Surface	Joint UK Land Environment Simulator (JULES, Best et al. 2011) 4-layer soil model using van Genuchten (1980) soil hydrology
Microphysics	Mixed-phase precipitation scheme (Wilson and Ballard 1999)

Observations









Observation		Description	Variable	Source
SURFACE	SYNOP	Land surface synoptic weather observations	Sfc pressure, wind, temp., humidity	Global Telecommunication System (GTS), KMA, JMA
	METAR	Surface weather observations and reports	Sfc pressure, wind, temp., humidity	GTS, Meteorological Assimilation Data Ingest System (MADIS)
	Ship	Sea surface weather observations by ship	Sfc pressure, wind, temp., humidity	GTS
	Buoy	Sea surface weather observations by buoy	Sfc pressure, wind, temp.	GTS
	BOGUS	Bogus observations generated by national meteorological centres	Sfc pressure, wind	KMA National Typhoon Center (NTC)
Aircraft		Aircraft-based observations reported by the Aircraft Meteorological Data Relay (AMDAR) and Aircraft reports (AIREPs)	Flight-level wind, temp.	GTS, MADIS
Upper air	TEMP	Upper-air observations from radiosonde	Upper-air wind, temp., humidity	GTS, KMA
	PILOT	Upper-air wind profile from pilot balloon or radiosonde	Upper-air wind	GTS
	Wind profiler	Upper-air wind profile from wind profiler	Upper-air wind	GTS, KMA, JMA, Deutscher Wetterdienst (DWD)
ATOVS		Advanced Microwave Sounding Unit (AMSU) and High-resolution Infrared Radiation Sounder(HIRS)	Radiance	UKMO, Regional ATOVS Retransmission Services (RARS)
IASI		Infrared Atmospheric Sounding Interferometer	Radiance	UKMO
AIRS		Atmospheric Infrared Sounder	Radiance	NOAA National Environmental Satellite, Data, and Information Service (NESDIS)
ASCAT		Advanced Scatterometer	Wind	Royal Netherlands Meteorological Institute (KNMI)
AMV		Atmospheric Motion Vector	Wind	GTS, NOAA NESDIS
GPSRO		Global Positioning System Radio Occultation	Bending angle	GTS, NOAA NESDIS, EUMETCast

Table 2. The type and source of observations assimilated for EARR

Observations

Part 1. East Asia Regional Reanalysis

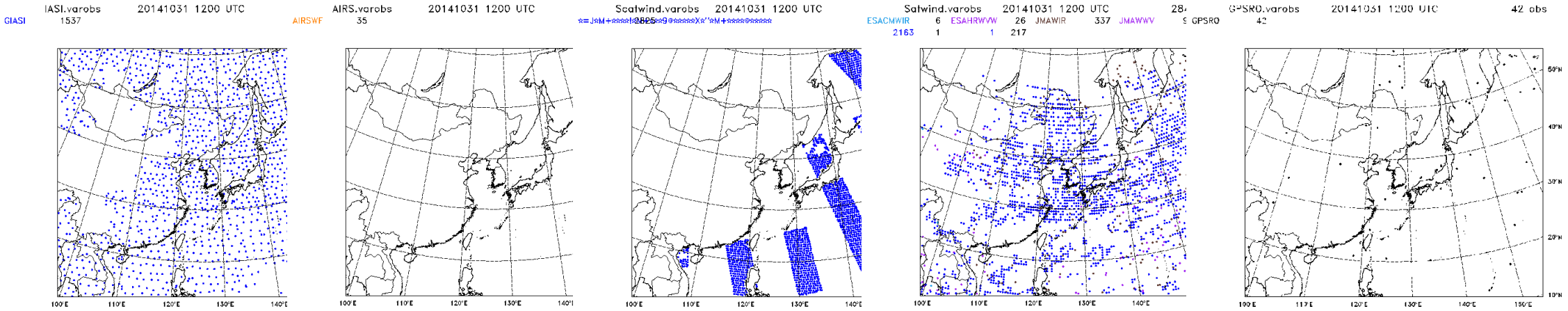


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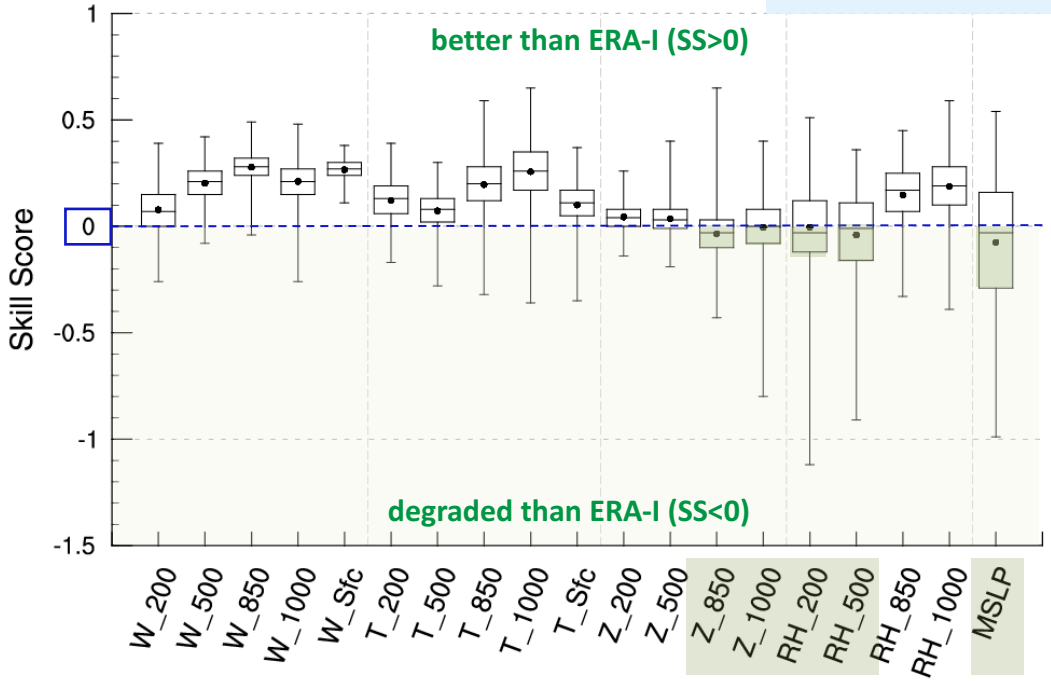
Table 2. The type and source of observations assimilated for EARR

Evaluation – Skill Score

- The skill score reveals how **much the performance of the system is improved** from that of a reference (previous system).
- In this study, **ERA-Interim reanalysis → a reference**
- Skill Score > 0 → EARR performance improved compared to ERA-I.
  Skill Score < 0 → degraded

$$\text{SS (Skill Score)} = \frac{A - A_{ref}}{A_{perf} - A_{ref}} \times 100\% = \frac{RMSE - RMSE_{ref}}{RMSE_{perf} - RMSE_{ref}} \times 100\% = \left(1 - \frac{RMSE}{RMSE_{ref}}\right) \times 100\%$$



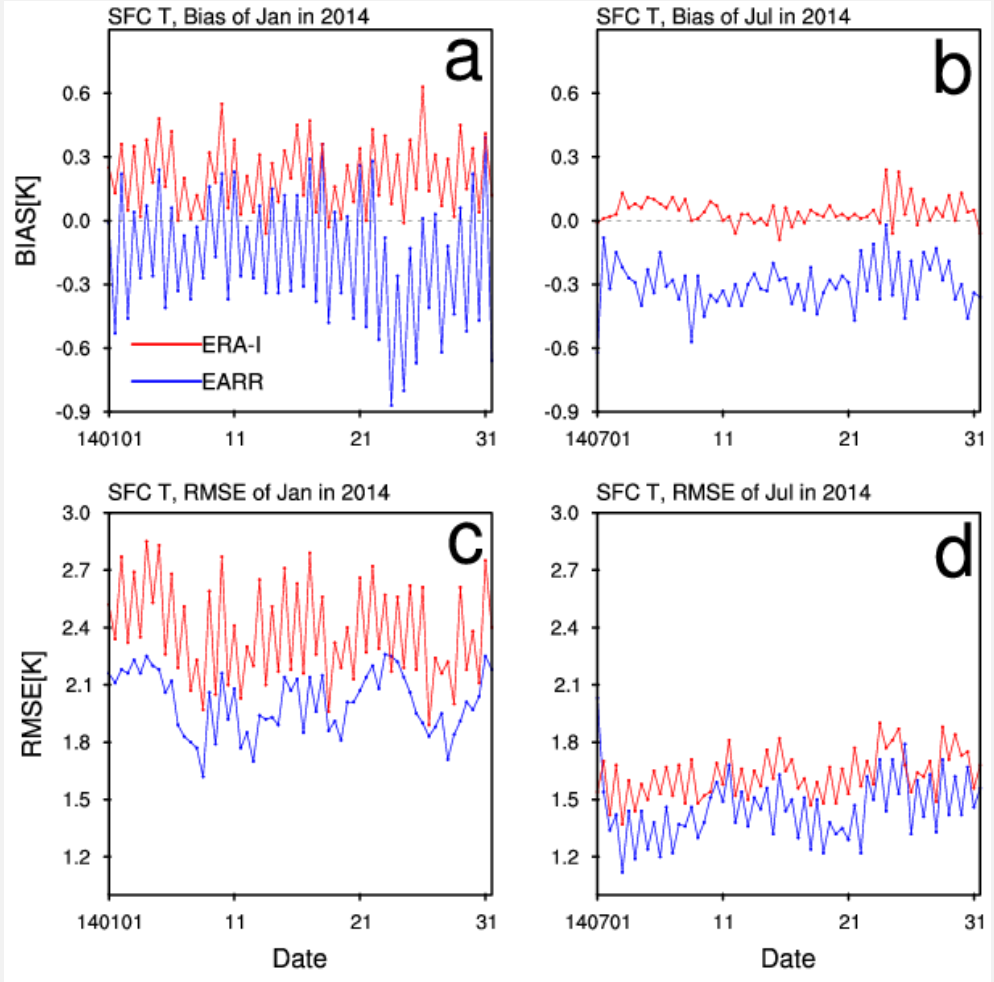
(Yang and Kim 2017, JAMC)

- Averaged skill scores at 00 and 12 UTC for the period 2013-2014.
- Except for MSLP, the geopotential height at 850 and 1000 hPa, and the upper-air relative humidity, **the EARR performance for most variables**, such as wind, temperature, relative humidity, and geopotential height, **is improved compared to ERA-I**.

Evaluation – RMSE

2 m T

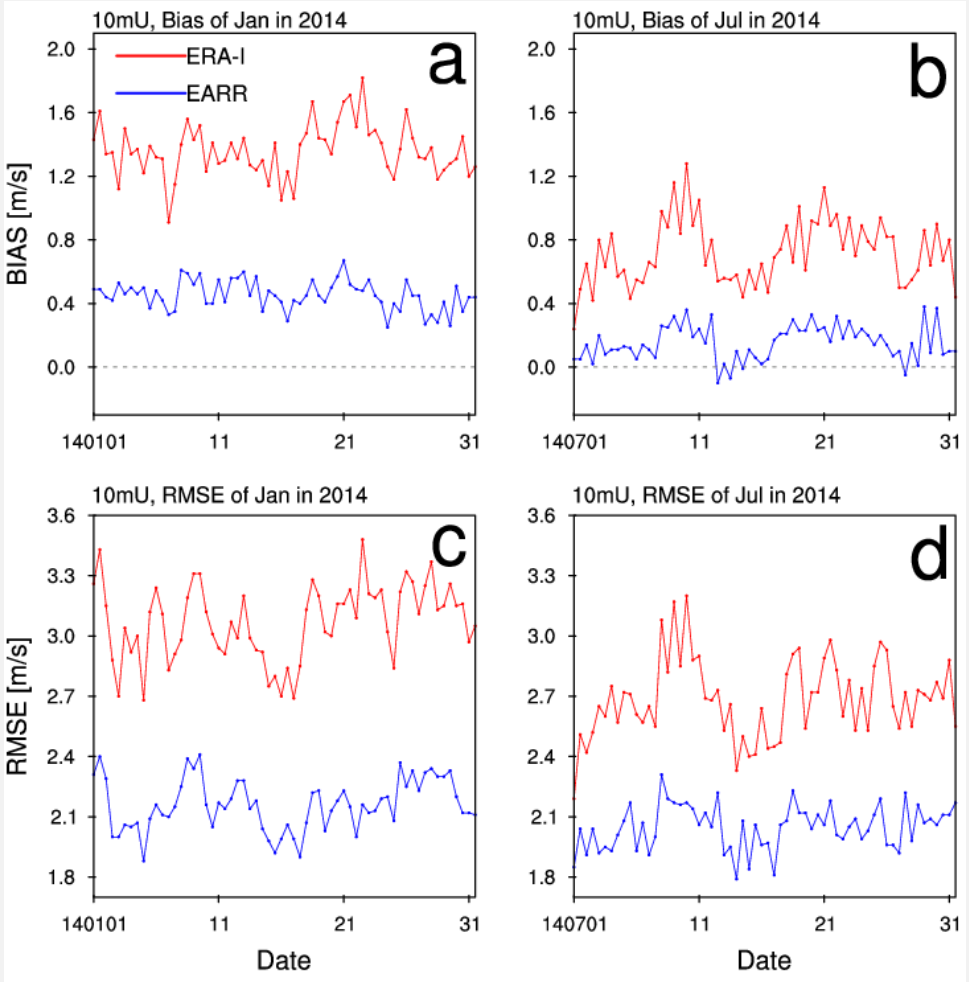
Jan



Jul

10 m U

Jan



Jul

(Yang and Kim 2017, JAMC)

Evaluation – Comparison of Monthly Mean

Jan 2014

SFC T

SFC U

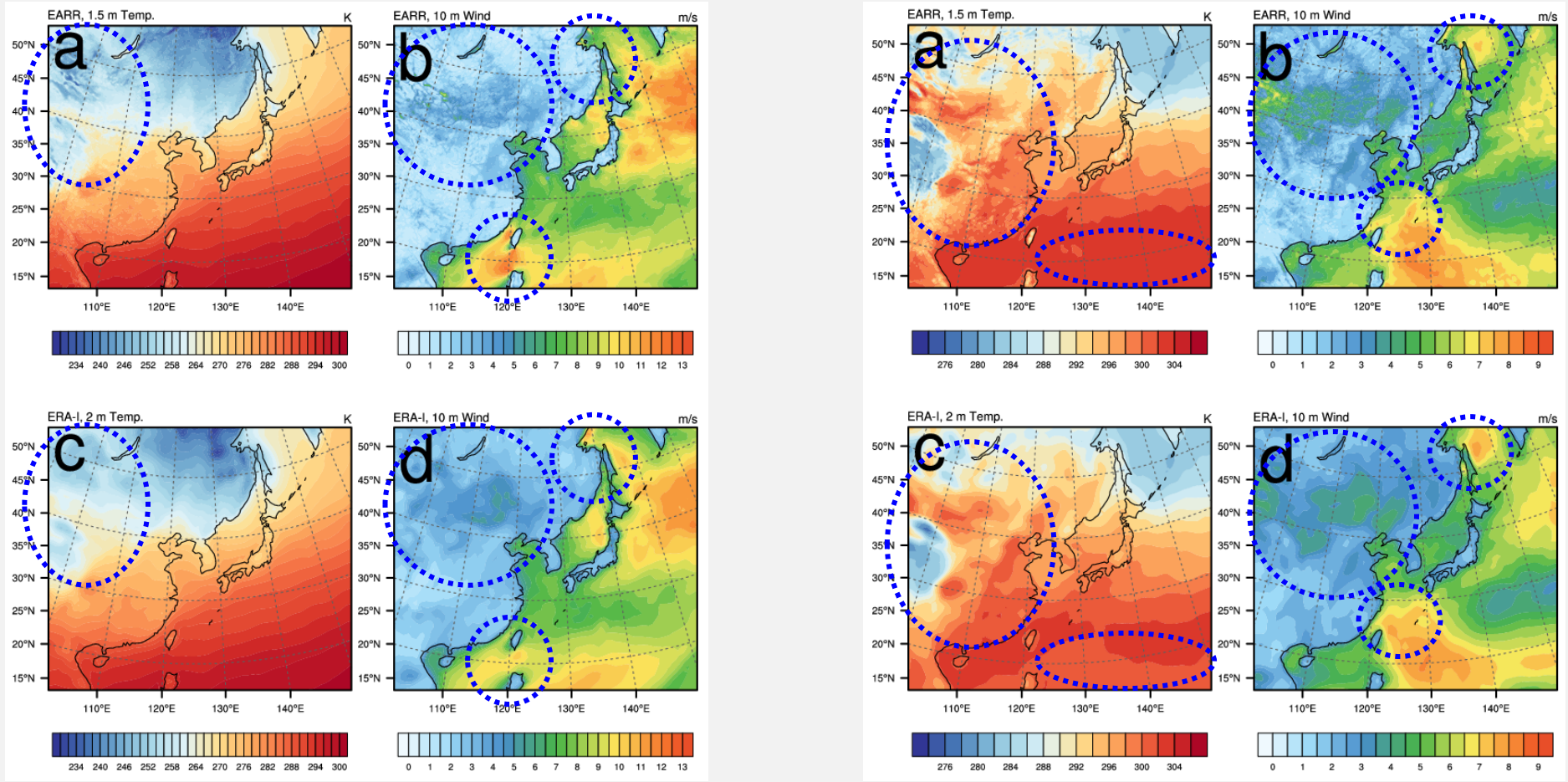
Jul 2014

SFC T

SFC U

EARR

ERA-I



(Yang and Kim 2017, JAMC)

Conclusion

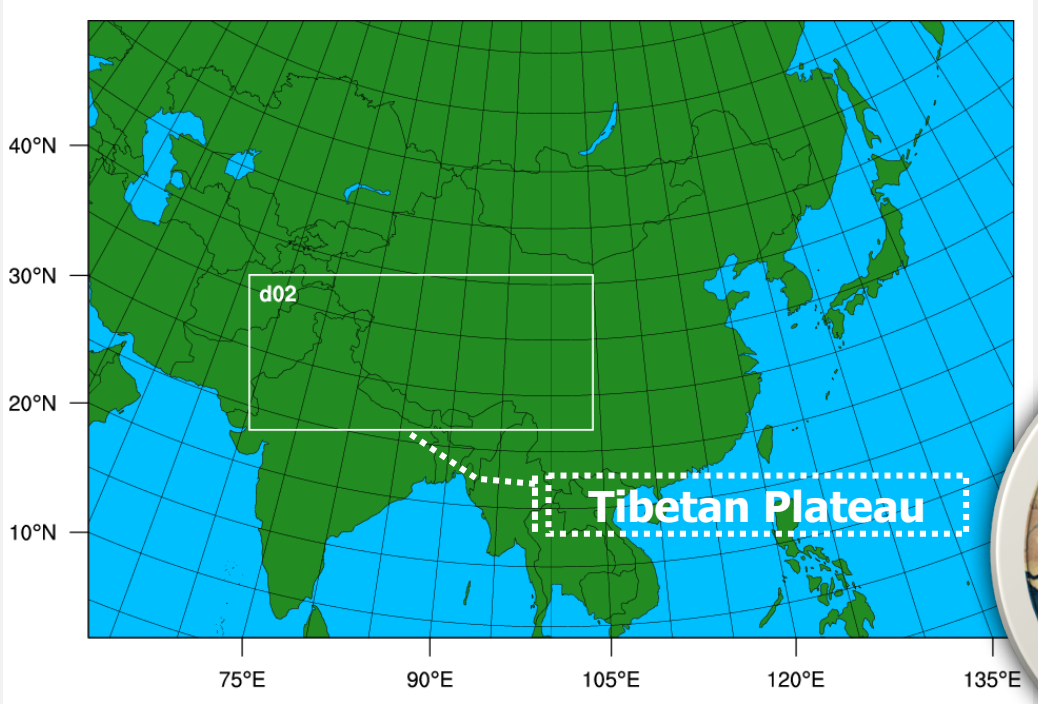
- In this study, **the East Asia Regional Reanalysis (EARR) was developed for the period 2013-2014** and characteristics of the EARR were examined compared to ERA-Interim (ERA-I) reanalysis.
- Compared to the ERA-I, in terms of skill scores, the EARR performance for wind, temperature, and geopotential height improved except for MSLP, the lower-air geopotential height, and the upper-air relative humidity.
- Based on the results of various evaluation tools, it is found that EARR simulates near-surface variables better than ERA-I.
- Therefore, although special care needs to be taken when using the upper-air relative humidity from EARR, **the near-surface variables of the EARR are found to be more accurate than those of ERA-I**.
- More analysis will be conducted after EARR is produced for a longer period.

Part 2

A regional reanalysis for Tibetan Plateau

- Development
- Evaluation
- Future plan

Part 2. A Regional Reanalysis for Tibetan Plateau



	EnKF or Hybrid	ERA-I
Grid spacing	30 km	80 km
Assimilation Window	6 h	12 h
Assimilation	EnKF or hybrid	4D-Var
Model	WRF (v3.7.1)	IFS (Cy31r2)

- Grids: 300 x 200 grid points
- ERA-Interim reanalysis used as I.C. and B.C.
- Period: 2 months (Jan and Jul in 2013)
- Assimilated obs: **Conventional obs.**

- To find the most appropriate and cost-efficient assimilation method, **hybrid data assimilation method is developed.**

- A regional reanalysis including Tibetan Plateau based on the two assimilation methods (EnKF and hybrid) for assimilating observations is produced and investigated for the period of two months.

Development - Hybrid

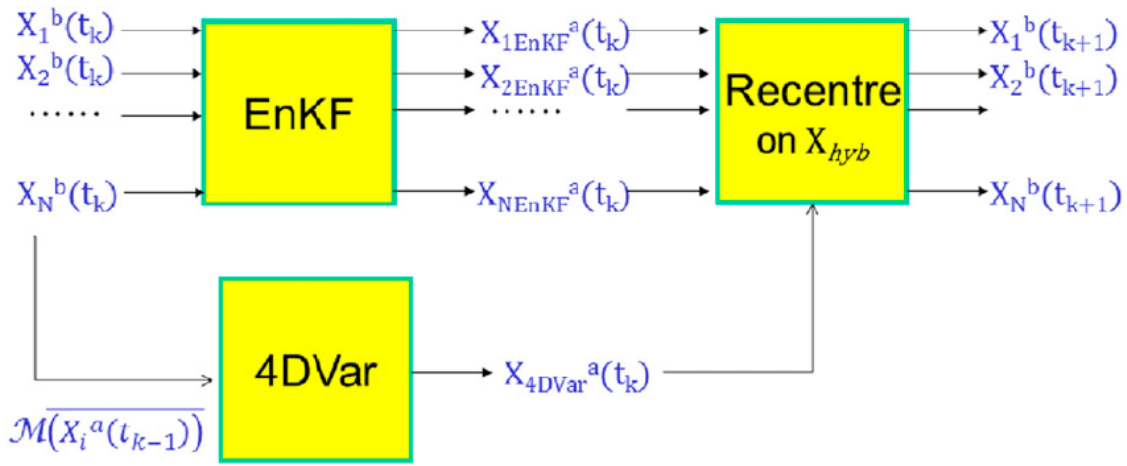


FIG. 4. Schematic of the hybrid gain EnDA.

(Courtesy of Bonavita et al. 2015, MWR)

$$\overline{\mathbf{x}}^a_{\text{Hybrid}} = \alpha \mathbf{x}^a + (1-\alpha)\overline{\mathbf{x}}^a, \quad (18)$$

$$\mathbf{X}^a_{\text{Hybrid}} = \mathbf{X}^a + \overline{\mathbf{x}}^a_{\text{Hybrid}} \mathbf{v}^{\mathrm{T}}. \quad (19)$$

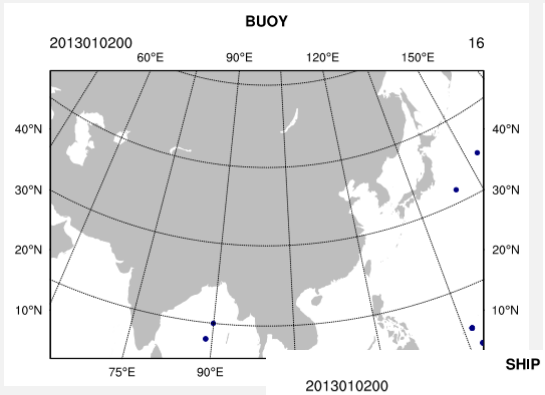
The vector $\mathbf{v} = (1\,1\,\ldots\,1\,1)^{\mathrm{T}}$ is a column of k ones used to add the mean to each column of $\mathbf{X}^a$, resulting in the final analysis ensemble having the hybrid-derived analysis as its mean. Finally, as with the standard LETKF, we update the single grid point at the center of the local region with the hybrid solution. For both hybrid methods, α is chosen empirically based on the ensemble size (k) and observation coverage (l).

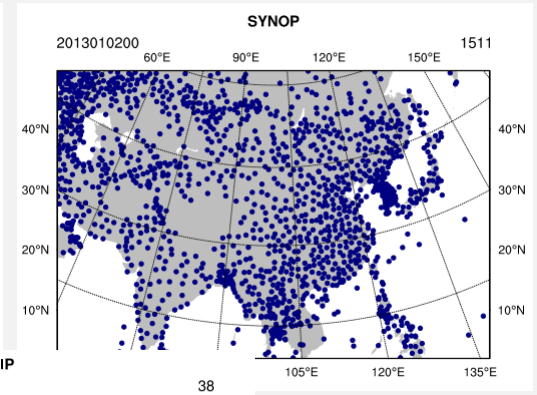
(Courtesy Penny 2014, MWR)

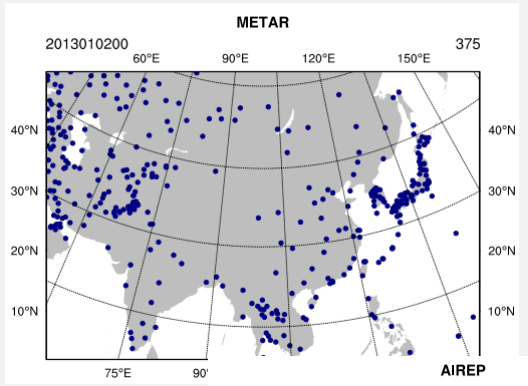
$$X^a_{Hyb} = \alpha \overline{X}^a_{EnKF} + (1-\alpha) X^{f(6h)}_{ERA-I}, \ where \ \alpha = 0.5$$

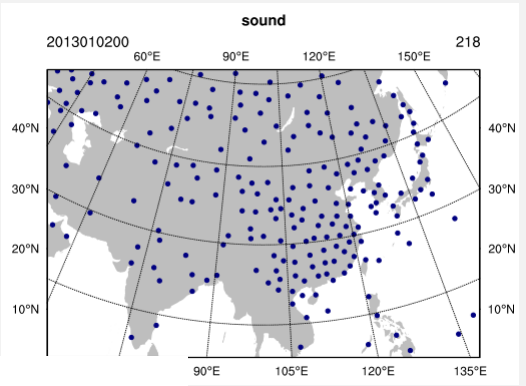
Development - observations

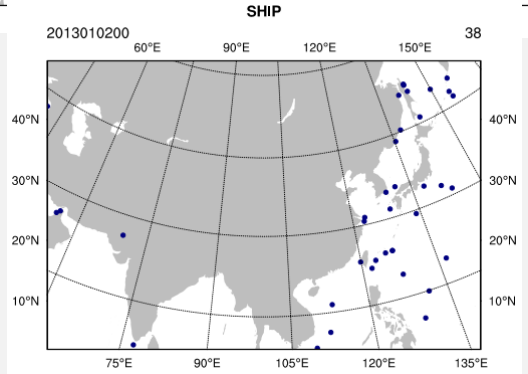
Part 2. A Regional Reanalysis for Tibetan Plateau

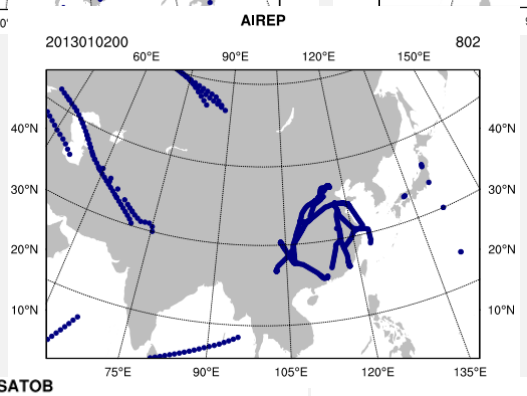


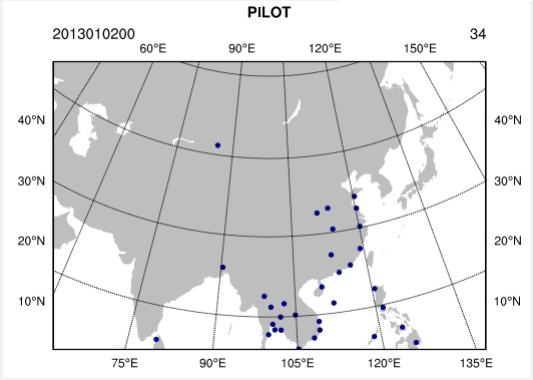


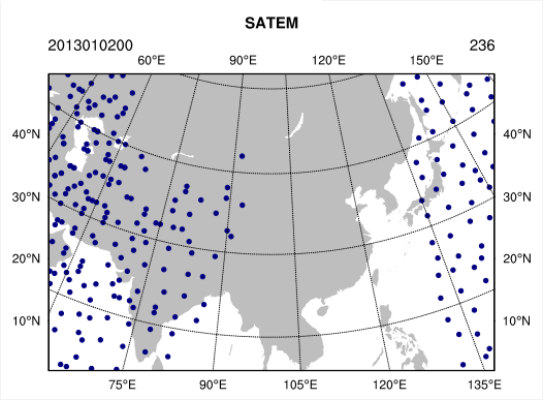


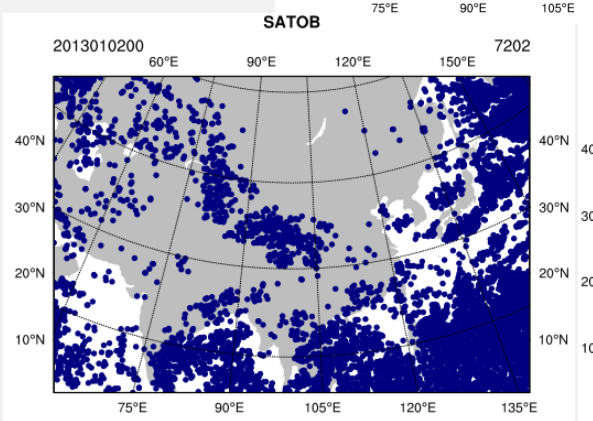


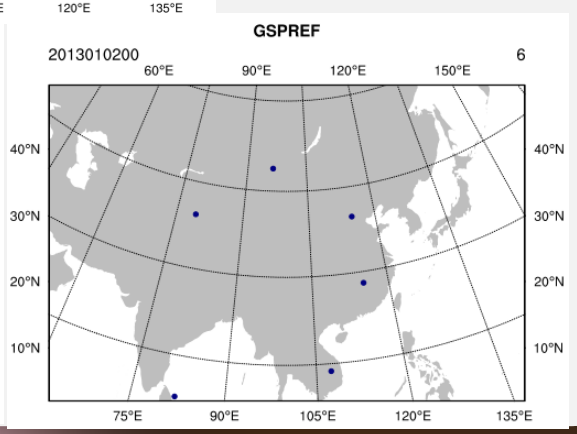






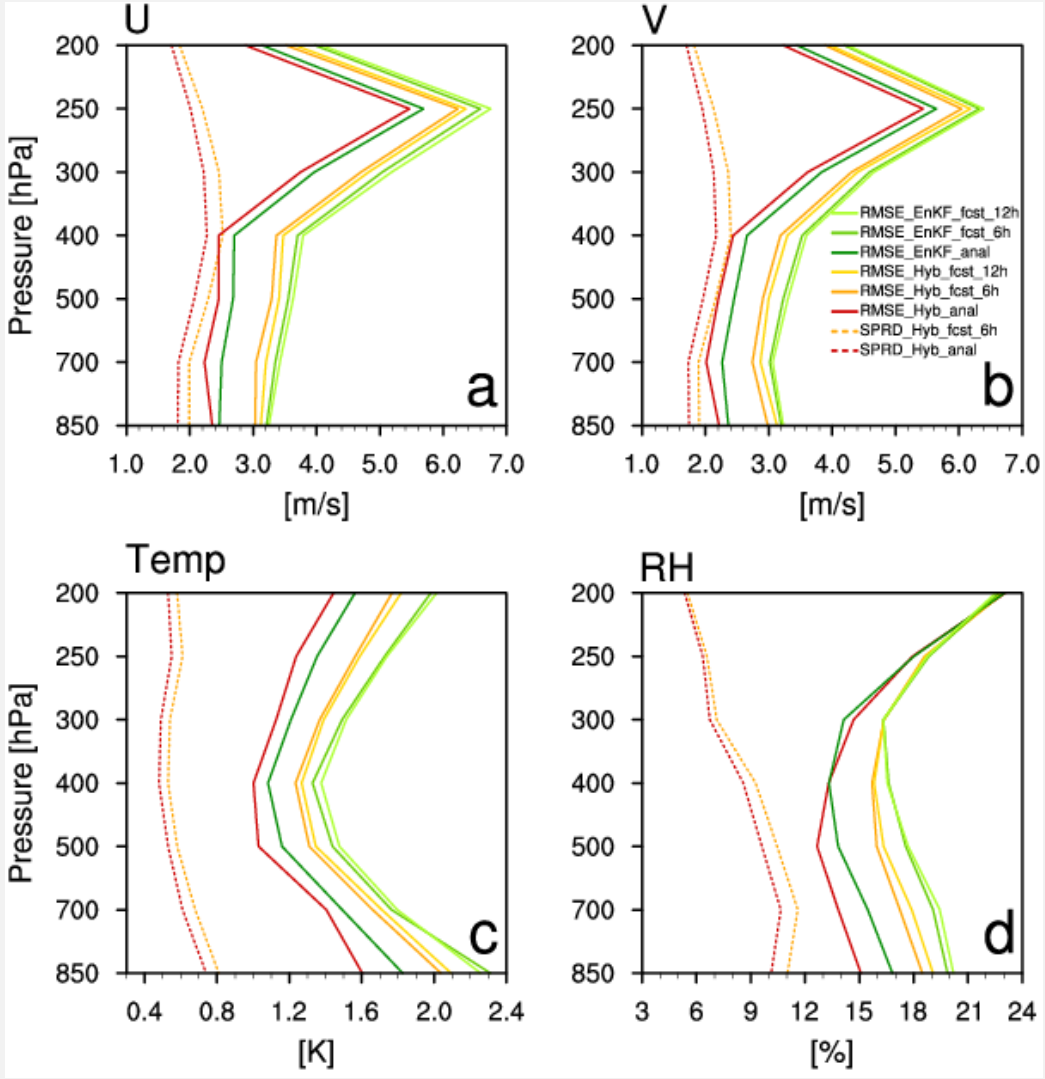






Evaluation (Hybrid vs EnKF)

RMSE and Spread (1month-Jan/2013)



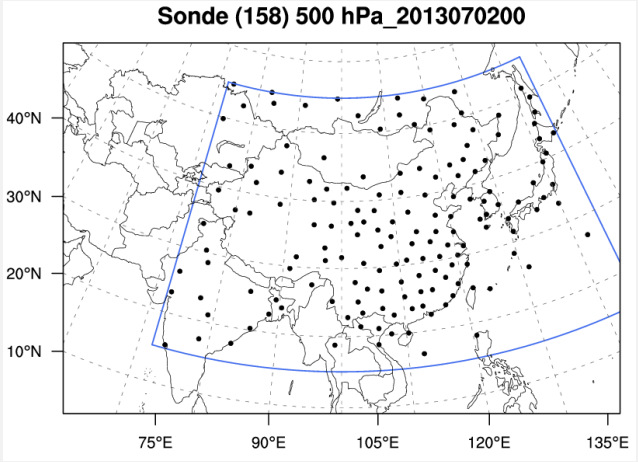
EnKF

- RMSE_EnKF_fcst_12h
- RMSE_EnKF_fcst_6h
- RMSE_EnKF_anal

Hybrid

- RMSE_Hyb_fcst_12h
- RMSE_Hyb_fcst_6h
- RMSE_Hyb_anal
- SPRD_Hyb_fcst_6h
- SPRD_Hyb_anal

- Verification Period: 2013/Jan/02 12Z – 2013/Jan/31 12Z (every 12 h)
- Verification Measures: RMSE against Radiosonde



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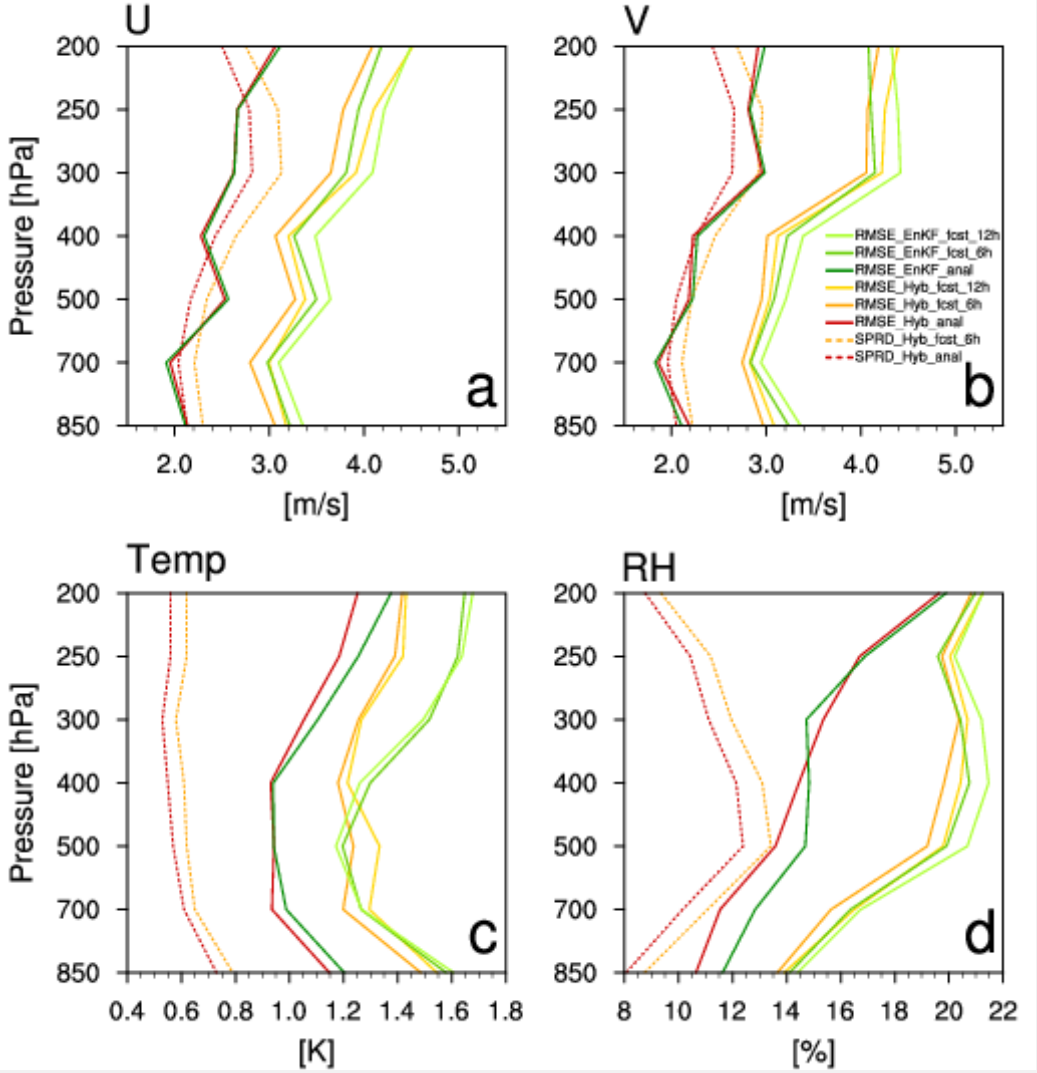

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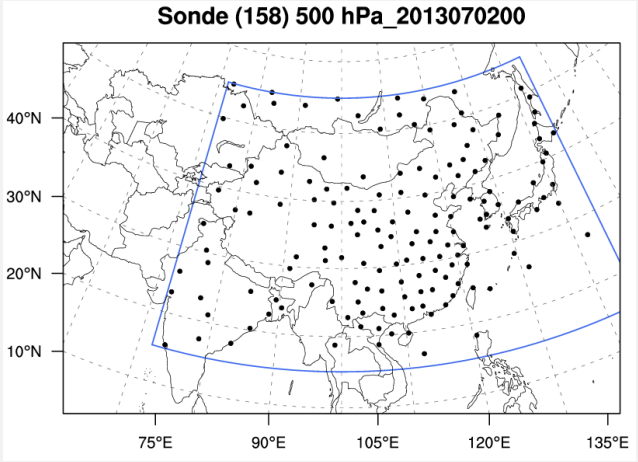

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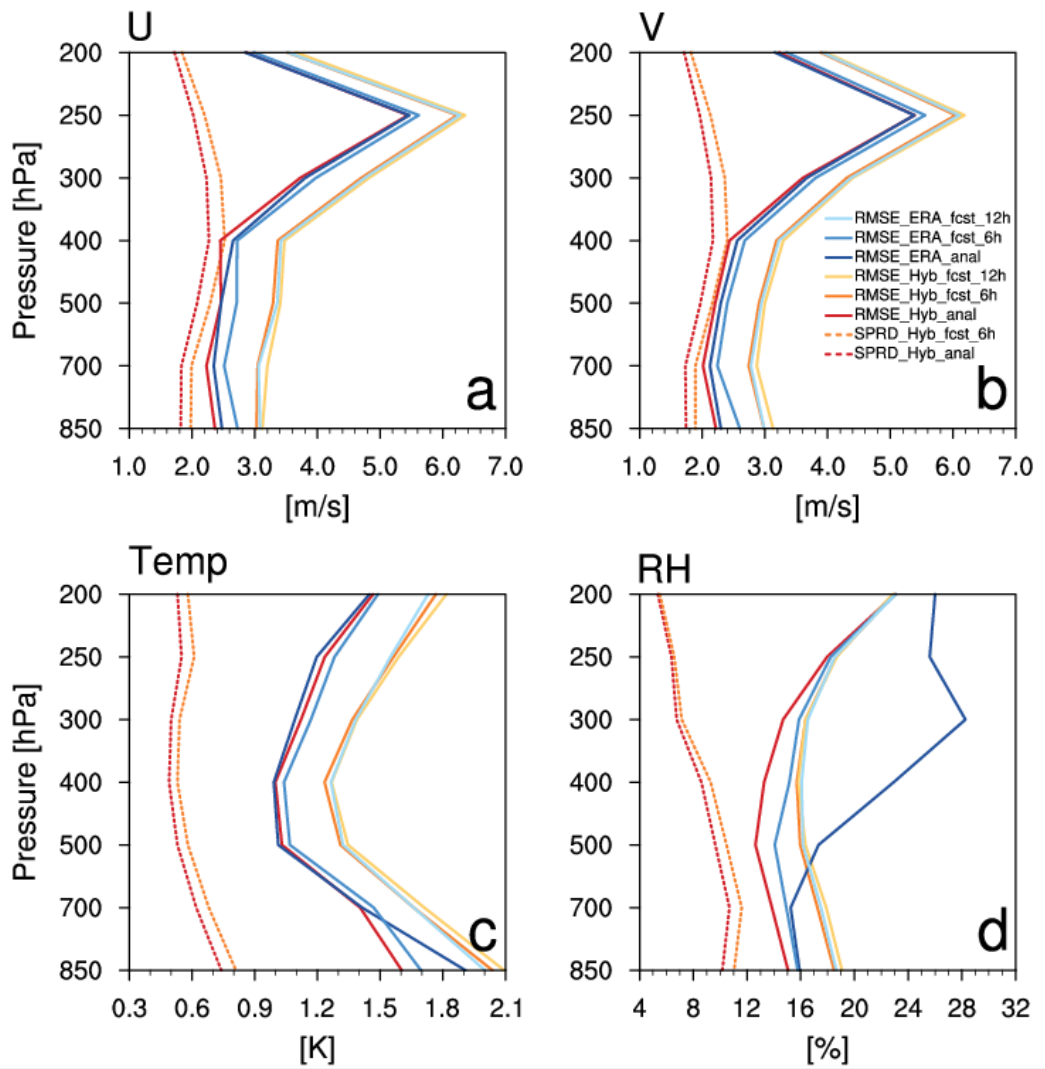

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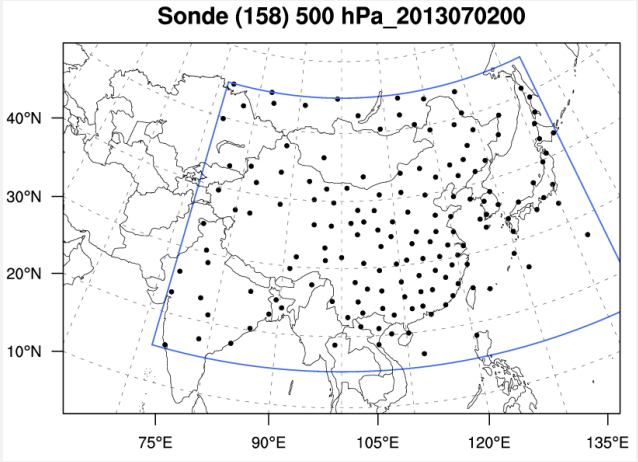

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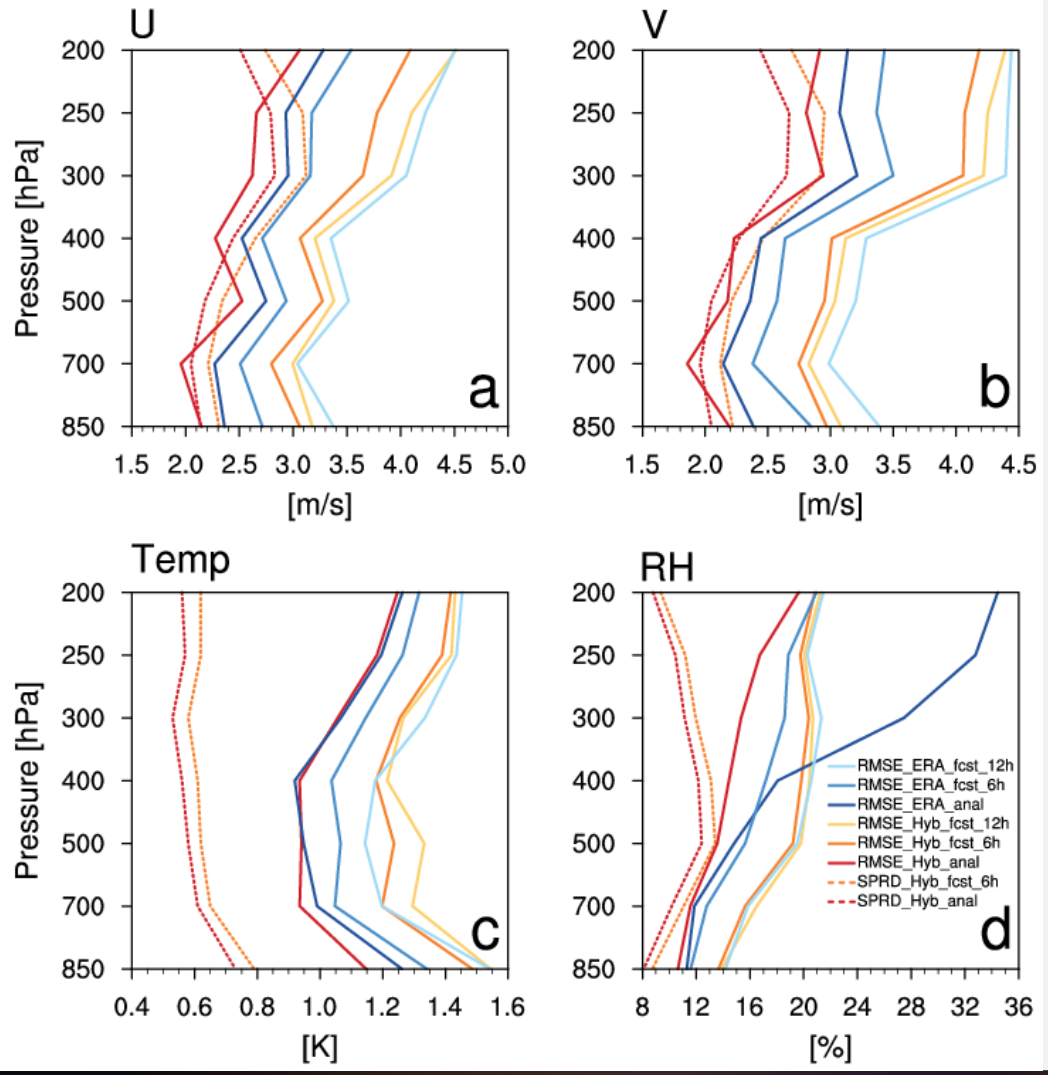
Part 2. A Regional Reanalysis for Tibetan Plateau

RMSE and Spread (1month-Jul/2013)



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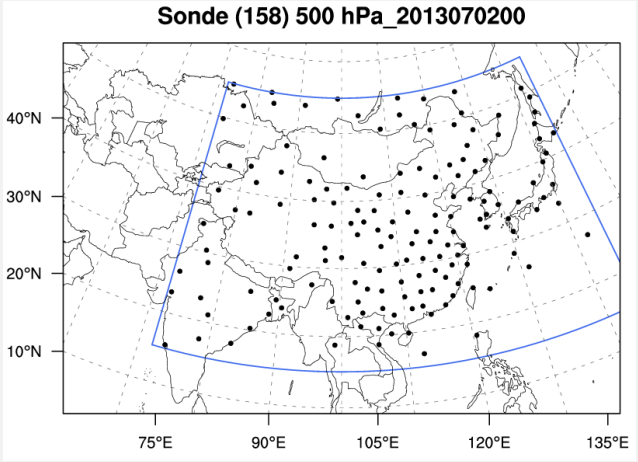
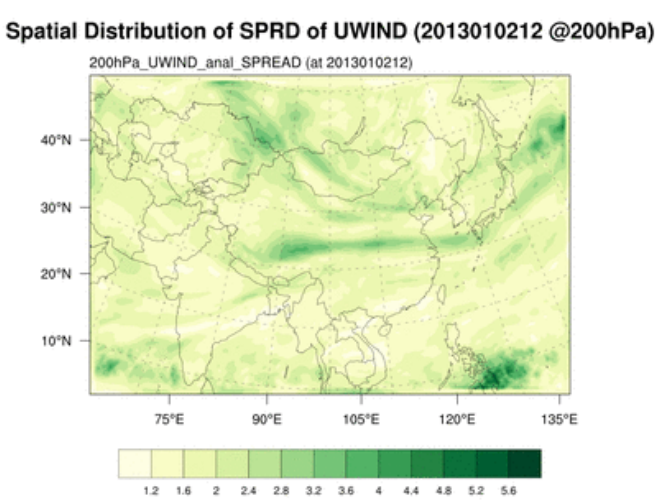
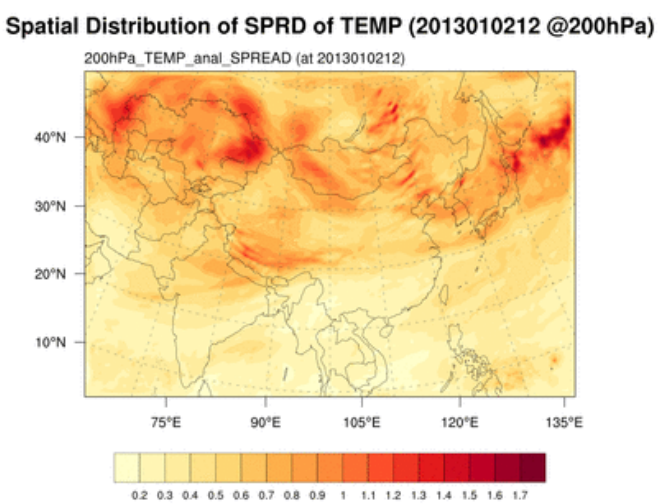
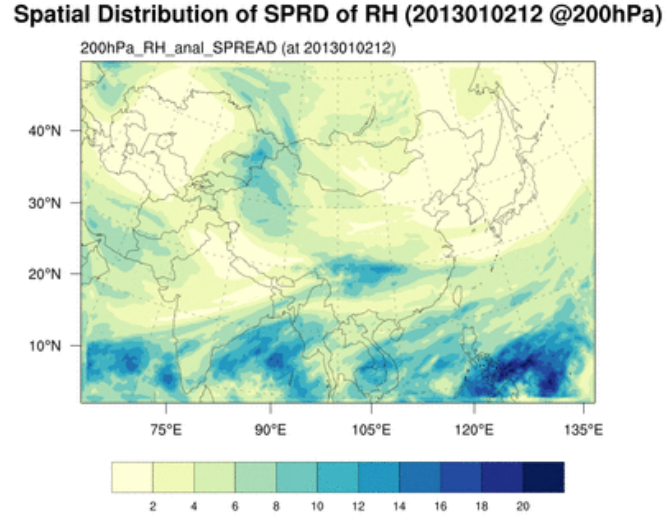
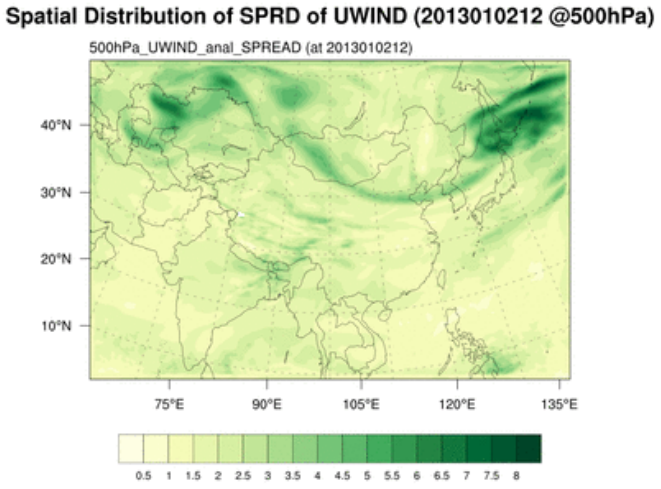
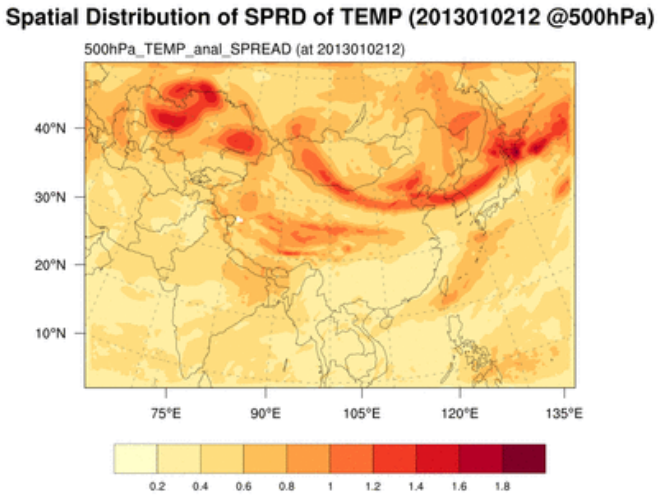
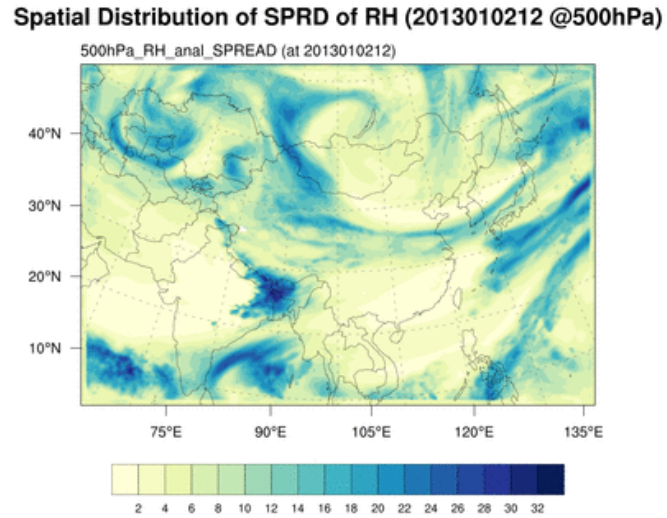
- Verification Period: 2013/Jul/02 12Z – 2013/Jul/31 12Z (every 12 h)
- Verification Measures: RMSE against Radiosonde



Spatial dist. of spread

Part 2. A Regional Reanalysis for Tibetan Plateau

	U-Wind	TEMP	RH
200 hPa			
500 hPa			

- Based on the two assimilation methods (EnKF and hybrid), a regional reanalysis including Tibetan Plateau are produced for the period of two months (Jan and Jul in 2013).

- It is found that the **hybrid method** with EnKF and 6 h forecast of ERA-I can simulate **more accurate reanalysis than EnKF method**.

- **The accuracy of 12 h forecast fields from hybrid method is comparable to one from ERA-I**, although all the satellite observations are not assimilated for the hybrid method.

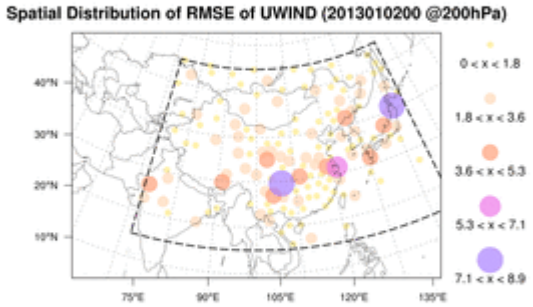
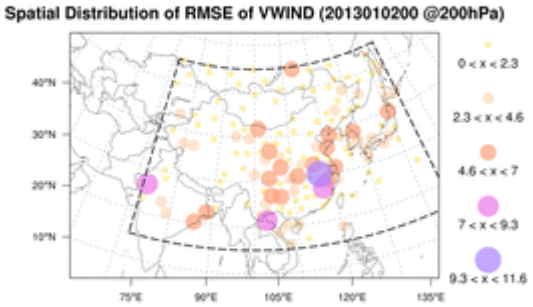
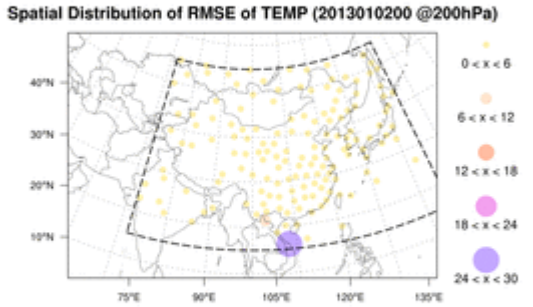
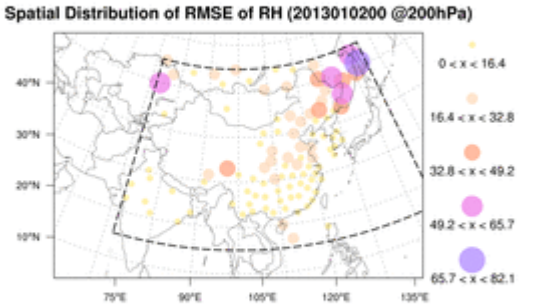
- Thanks to the ensemble based method, **ensemble spread can be provided as information on the uncertainty of reanalysis** to users of reanalysis for each time.

Future plan

- **The nested domain with higher resolution (10 km) for Tibetan Plateau will be produced** based on the hybrid assimilation method for three months in 1998 and 2008, respectively.
- The reanalysis produced will be verified **against independent observations obtained from observation experiment** in Tibetan Plateau for those two periods.
- **The satellite observation data could be assimilated additionally** to improve the quality of a regional reanalysis.
- A Tibetan Plateau regional reanalysis will be produced **for a long period of time**, after the reanalysis system is developed.

Spatial dist. of RMSE

Part 2. A Regional Reanalysis for Tibetan Plateau

	U-Wind	V-Wind	TEMP	RH
200 hPa				
500 hPa