Data assimilation over Northern polar region using WRF and WRFDA

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Abstract

In this study, the WRF model and its data assimilation system (WRFDA) are applied to perform analysis and forecast cycles (in a 3-hour interval) over Northern high-latitude region in a 60km horizontal resolution for a 2-year period (2007, 2008). ECMWF's ERA-Interim global reanalysis data (80km resolution) are used as lateral boundary conditions for this regional analysis. It was firstly found that WRF model forecast errors exhibit seasonal variation with largest errors in winter and minimum errors in summer. Therefore, we generated the background error covariance statistics for 4 different seasons to better characterize the WRF model error feature. Our emphasis is to optimize the exploitation of remotely sensed satellite observations such as radiances from microwave sensors (AMSU-A/B and MHS) and GPS radio occultation (GPSRO) refractivity data. Variational bias correction (VarBC) is applied to radiance data during the iteration procedure of assimilation. Some sensitivity experiments were conducted to find optimal configuration. We found that it needs month-long to make VarBC coefficients stable when we start cycling from no knowledge of bias coefficients. Thus, a set of "pre-trained" bias coefficients allows radiance analysis stabilized more quickly. Initial evaluation of 2-year analyses shows better fitting to surface Ps, T2m, u10/v10 observations and upper-air T and Q observations. Some issue was also discovered for upper-air wind and Q2m analysis and potential improvement for future analyses will be discussed. Experience gained from these 60km resolution experiments will guide a 11-year (2000-2010) Arctic System Reanalysis in a higher resolution, which is a collaborated effort among OSU, NCAR, CU and UIUC.

1. Introduction

Harsh environmental conditions in polar regions severely restrict the possibilities for in-situ measurement of the surface and atmospheric state. There is thus a great emphasis placed upon optimizing the exploitation of remotely sensed satellite observations. A collaborated effort is being made to conduct a 11-year (2000~2010) Arctic System Reanalysis (ASR) for better understanding Arctic weather and climate system. The Ohio State University (OSU) is responsible for ASR production for the whole 11-year period. NCAR/MMM team's role in this project is to enhance the robustness of the whole ASR system and optimize the configuration of the WRF model and it data assimilation system (WRFDA) by testing and tuning various aspects of the system. This paper reports the progresses we made so far for ASR, particularly for the WRF data assimilation components. The next section briefly describes the various components of the ASR system. Section 3 depicts the configurations for a two-year (2007-2008) experimental ASR reanalysis, followed by the presentation of the major results in section 4. Some future work is discussed in section 5.

2. ASR system design

Figure 1 illustrates the flowchart of a 3-hr analysis/forecast cycling scheme for the ASR. The entire cycling system components includes: (1) using WPS/REAL, generate initial condition (IC) and lateral boundary condition (LBC) over the ASR domain from the ECMWF's global reanalysis data, ERA-Interim; (2) run the WRF 3-hr forecast, which serves as the background for the WRFDA-3DVAR analysis; (3) update lower boundary condition (e.g., SST, seaice, snow cover etc.) of the 3-hr forecasts from global ICs; (4) perform the WRFDA-3DVAR analysis using the WRF 3-hr forecast as the background; (5) update LBC using the difference of the analysis and background; (6) repeat previous steps for the next cycle. A suite of scripts is used to couple all these components together to permit a continuous ASR production. In the final 11-year production at the OSU, the system will also include a component of land surface data assimilation, which is not the part of our experimental ASR analysis. The observations used in the ASR include the conventional surface (SYNOP, METAR, SHIP, BUOY, QSCAT) and upper air (radiosonde, AIREP, SATOB, Profiler) data in the NCEP 'prepbufr' format, GPS radio occultation (GPSRO), and satellite microwave radiance data in BUFR format. The assimilation time window is ±1.5-hr.

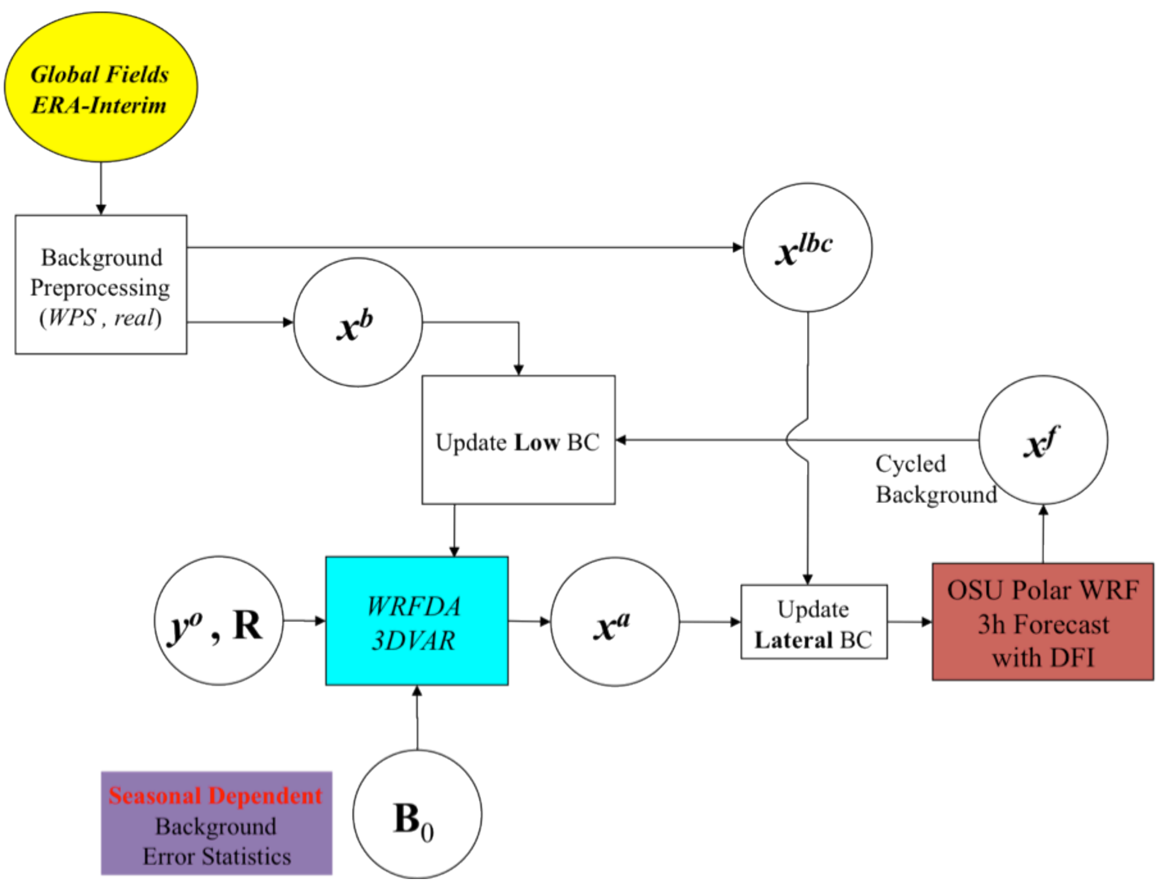

Figure 1. Flowchart of the ASR cycling analysis/forecast scheme

3. Configurations for two-year ASR experiments

Several experiments were conducted for a two-year period (Jan. 2007 - Dec. 2008) to test the robustness of the whole ASR system and evaluate various aspects of its analysis performance. Figure 2 shows the model domain used for the two-year ASR experiments. We adopted a single domain configuration with a reduced horizontal resolution of 60km so that we can obtain the results of several two-year long experiments with a feasible computational cost in a relatively short time. The 71 vertical levels with a model top at 10hPa were used. The Polar WRF V3.2.1 from OSU was used. The physical options used include: WSM5 microphysics, Grell 3d ensemble cumulus scheme, MYJJ 2.5 PBL scheme, NCEP/NCAR unified NOAH LSM, short-wave and long-wave RRTMG radiation scheme, fractional sea-ice, gravity-wave drag (GWD) and digital filter initialization (DFI).

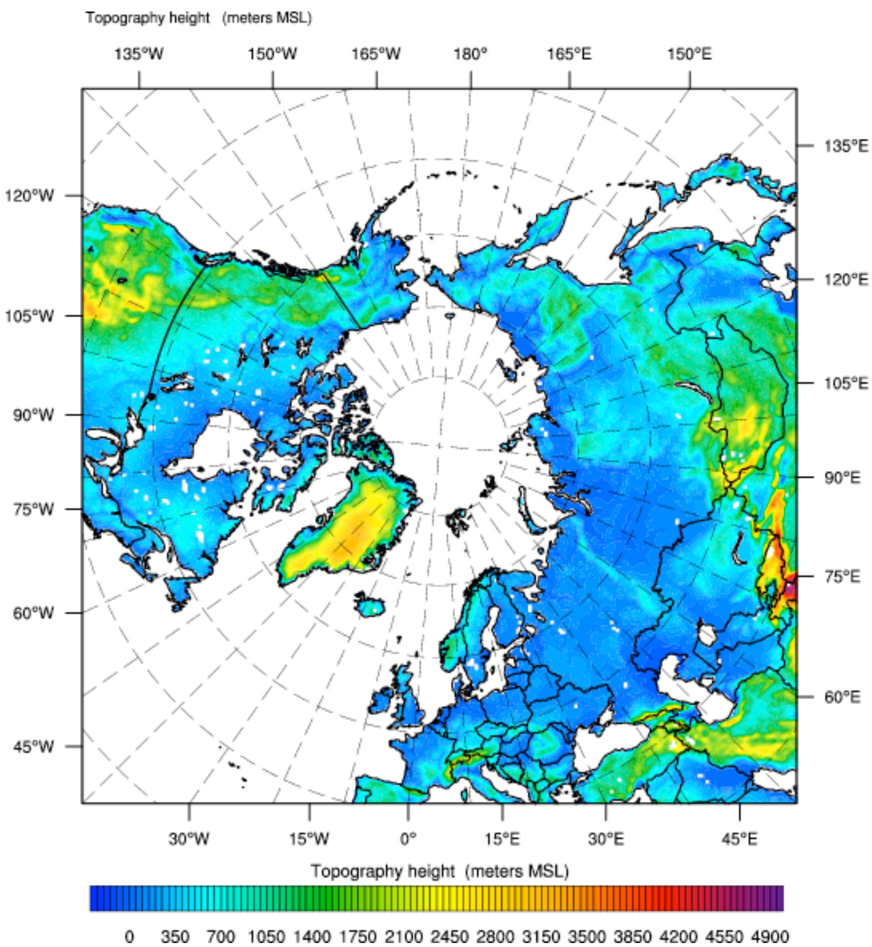

Figure 2. Model terrain over the ASR test domain.

Prior to cycling ASR experiments, it is necessary to obtain the statistics of the background error covariances using the 'NMC' method (Parrish and Derber, 1992). It was found that WRF model forecast errors exhibit seasonal variation with largest errors in winter and minimum errors in summer (not shown). Therefore, we generated the background error covariance statistics for 4 different seasons to better characterize the WRF model error feature and used them for all the experiments.

4. Results

The ASR system, as described in section 2, was proved to be very robust. There is no failure during the entire two-year period of continuous cycling (after a number of bug-fixes and enhancements) and the system performance looks stable with reasonable seasonal variation. A number of experiments were conducted to test and evaluate different aspects of the system. Here we only describe the main findings from the various results.

4.1 Positive impact of GPSRO data

Several improvements (e.g., improved quality control and data vertical coordinate) were achieved during the system enhancement to allow a clear positive impact from GSPRO data. Figure 3 shows root-mean-square error (RMSE) of the ASR 3-hr forecasts verses the ERA-interim reanalysis for the first month (January 2007) of two-year test period. The positive impact by assimilating GPSRO data can be clearly seen for temperature, wind, and geopotential height fields.

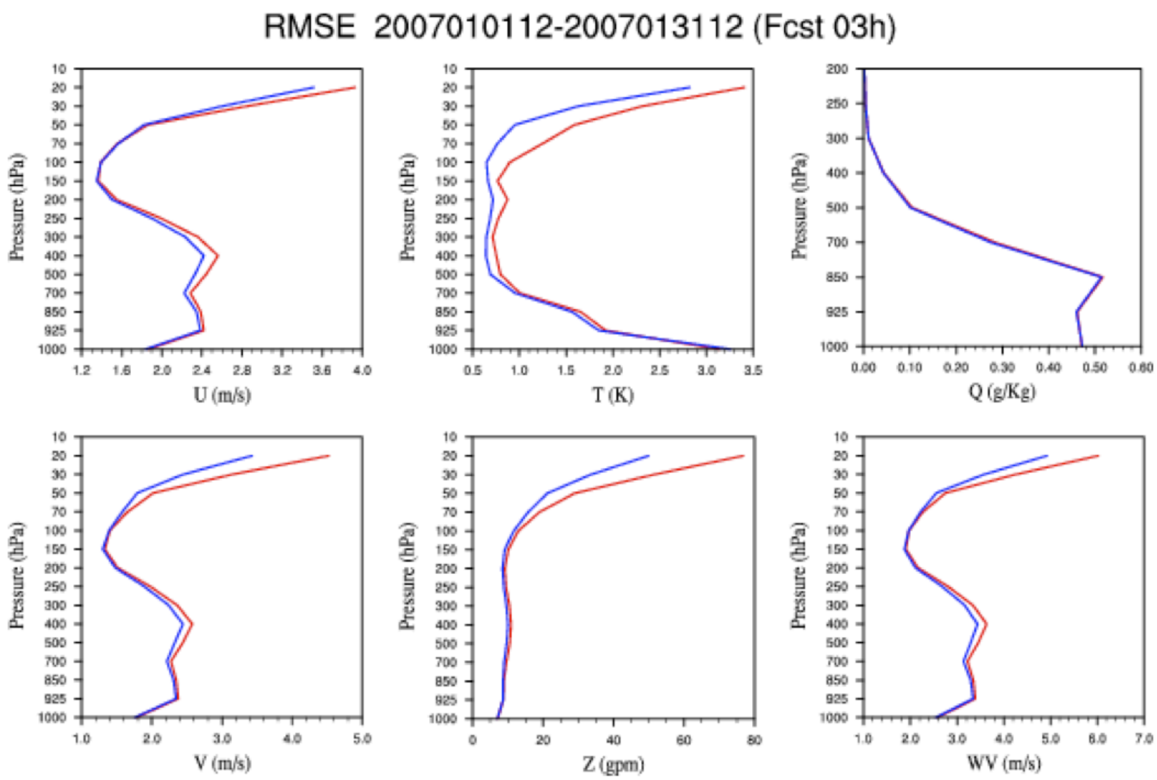

Figure 3. Root-mean-square error (RMSE) of the ASR 3-hr forecasts verses the ERA-interim reanalysis during a one-month test period in January 2007. Six panels are the RMSE for u/v wind component, temperature (T), geopotential height (Z), specific humidity (Q), and wind vector

(WV), respectively. Red curves are for the experiment only assimilating prepbufr data, and blue curves for the experiment assimilating both prepbufr and GPSRO data.

4.2 Importance of radiance monitoring

The ASR domain covers a quite large portion of ocean, where there is very coarse coverage of conventional observations. We expect that satellite radiance data can better constrain the ASR analysis with their good coverage over ocean. Even though radiance data assimilation capability is available in the WRFDA system (Barker et al., 2011), it was never been applied to the reanalysis with the year-long continuous cycling experiments, which requires much more careful attention on the data quality and treatment of radiance bias correction during a long period. Table 1 provides a list of available microwave radiance data during different period since 2000. There are a total 12 sensors from 7 satellites and each needs to pay careful attention for channel selection, quality control and bias correction and represent a significant amount of work.

Table 1. Microwave radiance data used in the ASR.

	AMSU-A	AMSU-B	MHS
NOAA-15	X	X	
NOAA-16	X	X	
NOAA-17		X	
NOAA-18	X		X
NOAA-19	X		X
METOP-2	X		X
EOS-2 (Aqua)	X		

To facilitate the channel selection for those many sensors, we developed a method within the WRFDA system to monitor radiance data quality (prior to data assimilation cycling experiments) over the ASR domain during the entire lifetime of each sensor, using the ERA-Interim as the reference. Figure 4 illustrates time series of bias (Figure 4a) and standard deviation (after bias correction) (Figure 4b) statistics of observed minus the CRTM-calculated brightness temperatures for METOP-2 AMSU-A channels 5~9, which was generated from a WRFDA monitoring run over the ASR domain for a period of ~20 months (April 2007 – December 2008). The monitoring run used ERA-Interim reanalysis as the reference field and started from no knowledge of bias correction coefficients. It is evident from the time series of standard deviation that it needs spin-up time for bias correction to reach appropriate values. Also note that bias of different channel exhibits to different extent seasonal variation, generally with minimum in summer and maximum in winter. Monitoring is also a powerful tool to identify bad channels. For instance, METOP-2 AMSU-A channel 7 (blue curve) had increasing standard deviation from

July 2008, which was known to suffer from increasing instrument noise and was turned off by data assimilation systems in the NWP centers. This implies that a pre-assimilation monitoring is crucial to identify and exclude bad sensors/channels/periods for applications with long run, such as reanalysis in this project.

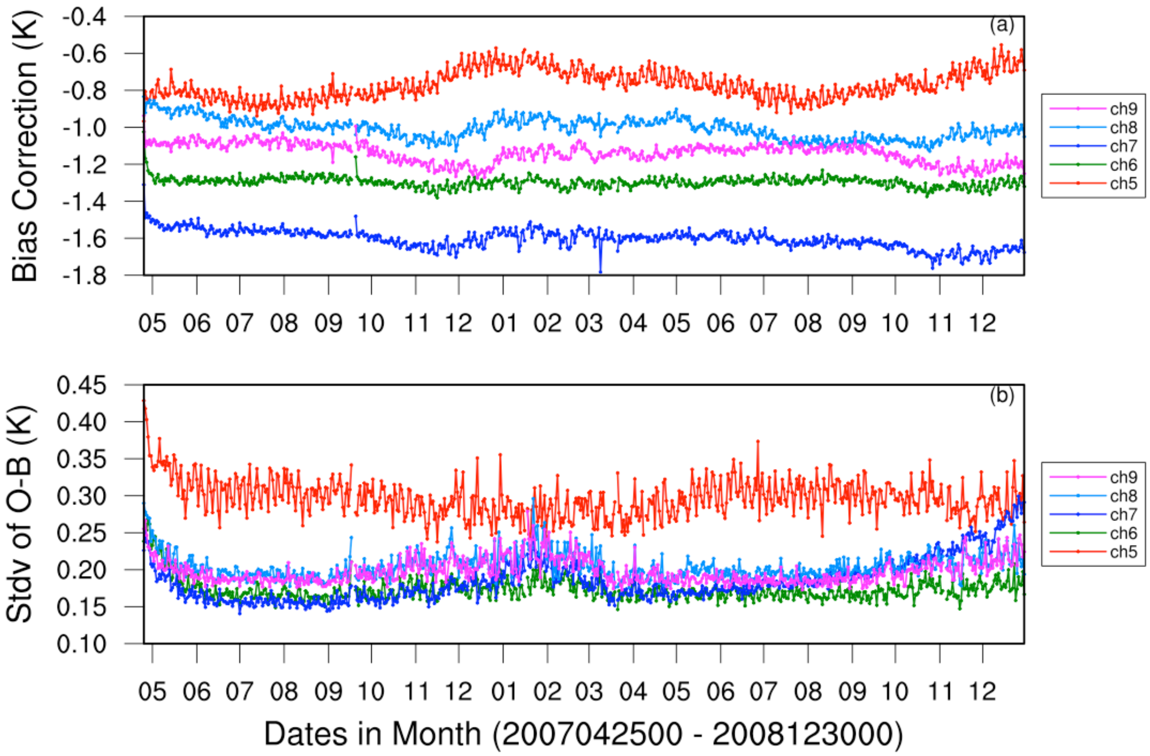

Figure 4. Time series of (a) bias and (b) standard deviation statistics of observed minus CRTM-calculated brightness temperatures for METOP-2 AMSU-A channels 5~9, which was generated from a WRFDA monitoring run over the ASR domain. The reference field used in the monitoring is ECMWF's ERA-Interim reanalysis.

With careful channel/sensor selection, we indeed obtained a clear positive impact by assimilating radiance data in addition to the conventional and GPSRO observations during a two-year test period of 2007 and 2008 (not shown). The impact was particularly evident for upper-air wind field, and at the asynoptic times when usually no radiosonde observations are available.

4.3 Impact of improved surface analysis

One improvement made for the ASR is the revision of surface data assimilation scheme in the WRFDA system. The original WRFDA system has a conservative use of surface data, and surface observations (u10, v10, t2m, q2m, and surface pressure) were rejected when the difference of the model terrain and observation elevation is larger than 100m. This led to the rejection of a significant amount of valuable surface data, particularly over mountainous areas, which cover a large portion of the ASR domain. We revised surface assimilation scheme by relaxing the "100m-check", quality control threshold, and tuning observation errors as well as applying terrain correction for t2m and surface pressure observations, which resulted in a substantially better fitting of the ASR analyses to surface observations.

Figure 5 depicts the two-year (2007, 2008) time series of the relative reduction of root-mean-square error of the ASR reanalysis with respect to the ERA-Interim reanalysis, i.e., [RMSE(ERA-Interim)-RMSE(ASR)]/RMSE(ERA-Interim), when verifying against SYNOP surface observations. It can be seen that the ASR analyses have more than 10% smaller RMSE on average than the ERA-Interim for all variables and represent a much better fitting to surface observations.

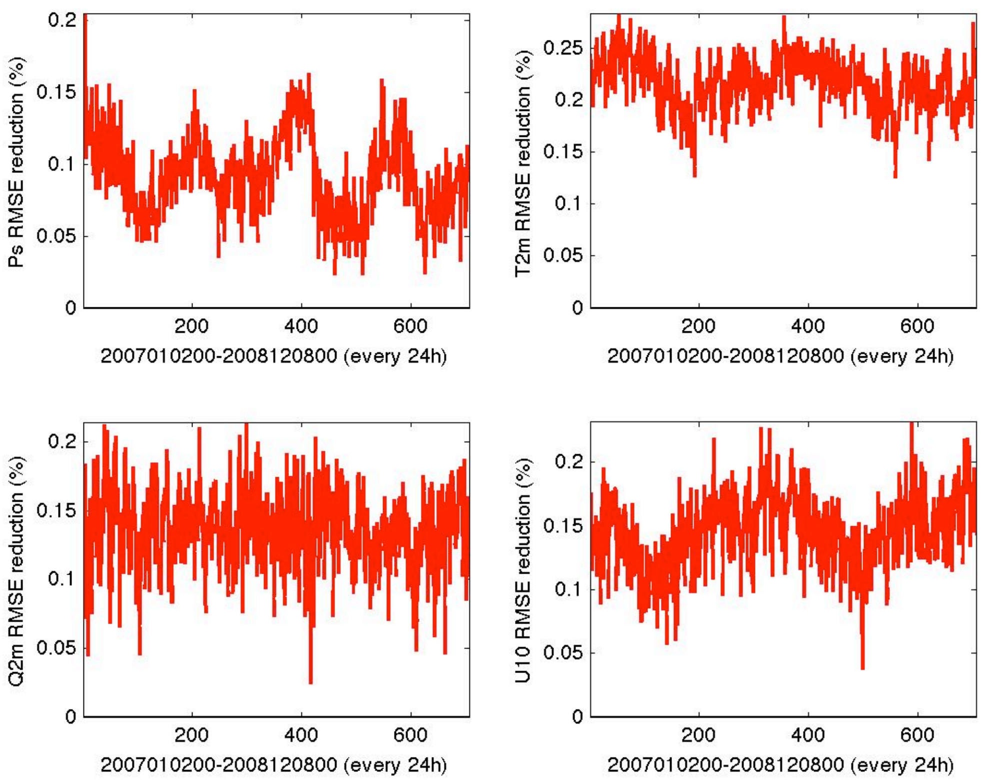

Figure 5. Two-year (2007, 2008) time series of the relative reduction of root-mean-square error of the ASR reanalysis with respect to the ERA-Interim reanalysis, when verifying against SYNOP surface observations. Four panels are for surface pressure (Ps), temperature (T2m) and specific humidity (Q2m) at 2-meter, and u-wind component at 10-meter (U10), respectively.

5. Future work

It should be mentioned that Q2m observations are currently assimilated with their raw values, while T2m observations are assimilated with terrain-corrected values. This could cause some inconsistency between T2m and Q2m analyses. Q2m analysis could be further improved by assimilating some kind of value-corrected Q2m observations. The background error covariances are currently obtained through a domain-averaged statistics, which could be improved by introducing latitude-dependent statistics in the future. We will further improve the system and conduct testing in a higher resolution.

Acknowledgements

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