Bias Correction in Limited Area Models

Organised by Roger Randriamampianina and held on 31st March 2022

In data assimilation, currently, satellite radiance provides the most extensive input for NWP in global model systems. However, significant efforts are needed to deal with the radiance observation error, in particular observation bias, during assimilation. This is even more true in limited-area model (LAM) systems, where centres often struggle to fully use satellite observations in the data assimilation system, and temporal and spatial coverage is often limited.

The main difficulties for bias correcting satellite radiances in LAM include:

1. Limited number of the sounder observations
2. Non-uniform data sample gathering different atmospheric conditions at different analysis times (for polar-orbiting satellites)
3. A lack of anchor observations that can constrain the bias correction to avoid following model bias
4. In LAMs, most of the time we not interested in the stratosphere. However, many sounding channels that are used in the troposphere also have non negligible sensitivity to the stratosphere.

Global vs Local VarBC

Many NWP centres tackle these difficulties in LAMs by adopting the bias coefficients from a host global model (Météo-France, Japan Meteorological Agency, Canadian Meteorological Centre, Bureau of Meteorology). They assume that

1. the same set of VarBC predictors and the same radiative transfer model is utilized
2. differences between radiance biases detected in global and regional models are not considered significant.

But the biases between global and regional systems can disagree due to different levels of the models' complexity, e.g., differences in the model domain, physics, or bigger resolution gap.

Other centres, particularly where no global model is available, run VarBC in the LAM itself. In this case, the initialization of the coefficients is an important step, along with the way in which the bias correction coefficients are updated for each cycle.

In either case, it is important that channels for which the bias is ill-constrained (e.g. stratospheric channels; infrequently used channels) are not assimilated

Anchor observations

Without sufficient anchor observations, VarBC will tend to adapt towards model climatology and thus bias radiances will support model bias (Eyre, 2016). This is highly undesirable. It is of critical importance to include as many anchor observations as possible in the LAM where VarBC is run. Anchor observations include radiosonde, aircraft and GPSRO – few LAM models assimilate GPSRO at the current time. Although aircraft can be bias corrected in some models, they are able to act as anchor observations in LAM systems without GPSRO.

VarBC initialization

There are two methods of initialization of bias coefficients in the LAM VarBC scheme:

1. Passive mode (Liu et al., 2012; Auligné et al., 2007)
2. Active mode or full mode (Schwartz et al., 2012)

In passive mode, the VarBC coefficients are updated but the observations are not assimilated in the atmospheric analysis. In active mode, the observations are added directly to the analysis at the same time as spinning up the coefficients.

Moreover, the initialization can start from zero bias coefficients (cold start) or using existing coefficient from global or LAM models (warm start). Warm start may be quicker to adapt, but once stabilised, there is no disadvantage to either cold or warm start.

VarBC LAM cycling

The bias coefficients can be updated either consistently with the assimilation cycle (default cycling: e.g. 3hr, depending on the model cycle) or separately at each analysis time (daily cycling: 24hr).

An experiment conducted from 15/10/2015-30/11/2015 during a passive DA cycle; scheme initialized by the warm start method (with N_{bg} set to 2000 – see below). They observe that the 24h cycle outperforms the 3h cycle providing better and more stable bias correction in terms of the mean of OMB and OMA residuals detected for all satellite instruments. The 24h cycle bias coefficients could suffer from insufficient datasets at analysis times when the satellite scans only the edge of the model domain. For example, NOAA-19 covers the domain fully at 12 UTC and provides 200-300 observations, but at 00 UTC, 0-100 observations are available. In this case, 12 UTC is able to constrain the VarBC coefficients much more easily. With daily cycling, it is recommended to remove from the analysis any overpasses where there are very few observations in the domain as the bias corrections will not be well-constrained.

VarBC-LAM adaptivity

The VarBC scheme aims to remove the slowly varying biases before assimilation, and to respond to sudden changes in instrument bias such as recalibration. Therefore, setting the VarBC adaptivity on an appropriate time scale is crucial. When the adaptivity parameters are too slow, the bias correction is impractical as it can take a long time to correct instrument bias changes. On the other hand, for adaptivity that is too fast, the day-to-day features in the NWP model error can be misinterpreted as the instrument bias.

Benáček et. al. (2019) examine 24h cycle adaptivity using the various stiffness parameters used in different NWP models (referred to as N_{bg}): 5000 (NBG5000) as in ARPEGE, 2000 (NBG2000) suggested by Lindskog et al. (2012), and the Cameron & Bell (2016) approach (CAM). CAM is different because N_{bg} is not fixed, but instead a bias halving time (n_h) and a minimum expected number of observations per cycle (N_{min}) are fixed and the adaption rate varies depending on the number of observations actually available in a given cycle. The CAM approach requires significantly fewer observations to reduce 75% of the artificial bias during the 15-day period (average of 50 observations) relative to NBG2000 (120) and NBG5000 (310). However, CAM performed better with a larger N_{min}.

Current experiments at FMI to increase observation usage

In order to make use of small overpasses, this experiment updates bias coefficients only when lots of observations are available (like NOAA-19 at 12 UTC). Other cycles use VarBC from the previous cycle. Results are so far inconclusive. More experiments should be conducted.

Bias correction of passive channels

VarBC only updates bias correction coefficients for the active channels. However, many channels that are not assimilated are used in quality control and cloud detection, especially for hyperspectral infrared sounders. It is important that these passive channels' bias corrections are updated also, whether via VarBC or another method. It's also important to have a mechanism to generate bias corrections for new channels that should be introduced to the assimilation.

Of particular concern is how to initialize low peaking IR channels. There are lots of observations for high peaking channels, but for low channels there are very few observations per cycle. Cold start will never spin up coefficients from those channels.

One proposal to solve the initialization problem for low peaking channels is to find two clear sky days inside the model domain and relax the cloud detection threshold to provide more data, and then warm start the VarBC.

Other methods of adaptive bias correction

Not all centres run VarBC: ECCC have an adaptive bias correction scheme that is not part of 4D-Var, although they do use global coefficients in their LAMs. Coefficients are computed by linear regression from a set of O-A and predictors. The O-A are from 3DVar analysis performed using anchor observations only (i.e. all observations except aircraft, ground based GPS and radiances) using data from a 6.5 days sliding window.

Centre Name	LAM cycles per day	LAM model top	Domain Size	Global Model?
Centre for Climate Research Singapore, Meteorological Service Singapore	8	38.5km	1500km x 1500km	No
NCEP/EMC	12	2-mb	11853x8103	Yes
Météo-France	24	10hPa	1872 km x 1997 km	Yes
Bureau of Meteorology	24	40 km	C3 - 1000x2000km; NAS 4500x5900km; BARRA2 1300x7700km	Yes
Environment Canada	4	0.1hPa (about 65 km)	6350 x 3225 (kmxkm)	Yes
U.S. Naval Research Laboratory	4	Highest-topped domains are 53 km; many domains are 34 km	Smallest domain is 2000x2000 km, largest domain is 15000x10000 km (TC basin)	Yes
MetCoOp	8	10 hPa	2500 x 2500	No
Norwegian Meteorological Institute	8	10 hPa	2000x2000	No
UK Met Office	24	40km	2200 x 2800 (approx)	Yes
NCMRWF	4	80	6000	Yes
Japan Meteorological Agency	8	approximately 22km	4080 km × 3300 km	Yes
NCMRWF	4	40 km	~ 4800 km x 4800 (~4km grid spacing, 1200 x 1200 grid points)	Yes
NIWA	4	NZLAM 80km NZCSM 40 km moving to 80km aklnwp 40km	NZLAM 900x900 points, 35.57x35.57 degrees; NZCSM 1200x1350 points, 16.2x18.225 degrees; aklnwp 744x928 points, 12.15x14.58 degrees; aklnwp 744x928 points, 2.232x2.784 degrees	No

Centre	Does LAM take VarBC coefficients from the global model?	Does your LAM run VarBC?	If your LAM runs VarBC, what is the cycling?	Do you compute coefficients for passive channels in VarBC?
Centre for Climate Research Singapore, Meteorological Service Singapore	No	Yes	VarBC updates every assimilation cycle	No
NCEP/EMC	No	Yes	VarBC updates every assimilation cycle	Yes
Météo-France	For some instruments	For some instruments	VarBC updates every assimilation cycle	Yes
Bureau of Meteorology	Yes	Moving towards VarBC	VarBC updates every assimilation cycle	No
Environment Canada	Yes	No		No
U.S. Naval Research Laboratory	No	No	N/A	No
MetCoOp	No	Yes	VarBC updates every 24 hours separately for each cycle	Yes
Norwegian Meteorological Institute	No	Yes	VarBC updates every 24 hours separately for each cycle	Yes
UK Met Office	No	Yes	VarBC updates every assimilation cycle	No
NCMRWF	Yes	No		
Japan Meteorological Agency	No	Yes	VarBC updates every assimilation cycle	No
NCMRWF	No	Moving towards VarBC	We were using VarBC, but noticed some spurious signals when we assimilate the radiances. We have stopped using	No

			radiances in the LAM and now assimilating only conventional and Radar observations	
NIWA	No	No		

Centre	Predictors used in LAM BC scheme	Do all predictors vary in VarBC?	Same predictors as global?
Centre for Climate Research Singapore, Meteorological Service Singapore	Constant;850-300hPa thickness;200-50hPa thickness;Tskin;TCWV;Scan Position Terms;Orbital predictors for SSMIS;	All predictors vary in VarBC	
NCEP/EMC	Constant;Scan Position Terms;Viewing Angle Terms;lapse rate, surface emissivity;	All predictors vary in VarBC	Yes
Météo-France	Constant;Scan Position Terms;Viewing Angle Terms;1000-300hPa thickness;850-300hPa thickness;200-50hPa thickness;Tskin;TCWV;Orbital predictors for SSMIS;	All predictors vary in VarBC	It's a subset
Bureau of Meteorology	Constant;Scan Position Terms;850-300hPa thickness;200-50hPa thickness;Orbital predictors for SSMIS;	Some predictors are static and can only be changed manually	Yes
Environment Canada	Constant;Scan Position Terms;Viewing Angle Terms;1000-300hPa thickness;200-50hPa thickness;10-1hPa thickness;50-5hPa thickness;	All predictors vary in VarBC	Yes
U.S. Naval Research Laboratory	N/A;	Some predictors are static and can only be changed manually	There are some differences
MetCoOp	Constant;Viewing Angle Terms;1000-300hPa thickness;200-50hPa thickness;Land or Ice Mask;	All predictors vary in VarBC	It's a subset
Norwegian Meteorological Institute	Scan Position Terms;Viewing Angle Terms;1000-300hPa thickness;850-300hPa thickness;200-50hPa thickness;Constant;Land or Ice Mask;power 2 and power 3 of viewing angle (over land);	All predictors vary in VarBC	
UK Met Office	Constant;Scan Position Terms;850-300hPa thickness;200-50hPa thickness;	Some predictors are static and can only be changed manually	It's a subset
NCMRWF			

Japan Meteorological Agency	Constant;Viewing Angle Terms;Tskin;orbit flag terms;	All predictors vary in VarBC	There are some differences
NCMRWF	200-50hPa thickness;850-300hPa thickness;Scan Position Terms;Constant;	All predictors vary in VarBC	Yes
NIWA	Constant;Scan Position Terms;850-300hPa thickness;200-50hPa thickness		

Centre	Biggest barriers to an effective VarBC system for your LAM?	Any other comments about VarBC in your LAM?
Centre for Climate Research Singapore, Meteorological Service Singapore	Availability of few radiosonde observations to anchor bias correction.	Inherited from Met Office global model and cycled through LAM before cold start.
NCEP/EMC	How often to update the coefficient in the hourly 3D-EnVar assimilation system? The 1-hour time window makes the polar orbit data coverage is very poor. This is the big challenge I am facing now.	N/A
Météo-France		For GEO satellites, we run VarBC in the LAM. But for LEO satellites, at the latitudes of the AROME France domain, we consider there are not enough samples to correctly estimate the bias and therefore the VarBC coefficients. Therefore we take the VarBC coefficients of the global model for those satellites. Considering the fact that VarBC should correct for observation bias and Radiative Transfer bias, we consider this is a reasonable assumption.
Bureau of Meteorology	For C3, the small domain and large amounts of land mean a lack of anchor obs and many patchy overpasses. We also have 7 domains.	For these reasons we are currently using global coeffs, but the model top is low which is also not ideal. We will soon have some obs that are not used in the global model (AHI CSR at full resolution; MHS at high resolution). Maybe we can use global coeffs for some obs effectively and then they will anchor the new ones. We are also considering using the Australia-wide analysis, NAS, to provide bias correction coefficients for the C3 domains. With this aim we are going to

Centre	Biggest barriers to an effective VarBC system for your LAM?	Any other comments about VarBC in your LAM?
		add GNSS-RO to NAS. However, there's still a lot of land in the domain. Our regional reanalysis BARRA-2, uses VarBC, but the domain is large, so hopefully this is OK.
Environment Canada	As our bias correction coefficients come from the global system, there is always the concern that the difference in model bias may be a problem. Ideally, we shoud compute our bias correction in the LAM but then there is a problem with polar orbiters because of their sporadic coverage in the LAM domain.	We run different LAMs with an assimilation system at EC. Here I give you information for our HRDPS (High Resolution Deterministic forecast System) which is the best system in terms of horizontal resolution (around 2.5km, remember that Canada is a large domain) Assimilation of radiances was recently implemented in this system. Please note that, as discussed in our latest email, we don't use VarBC. We compute our coefficients by linear regression from a set of O-A and predictors. The O-A are from 3DVar analysis performed using anchor observations only (i.e. all observations except aircraft, ground based GPS and radiances). We use data from a 6.5 days sliding window. Research is ongoing to replace the 3DVar analysis with a 3D-EnVar analysis. Some channels (AMSUA 13-14 and ATMS 14-15) are still corrected with static coefficients that are updated from time to time. This is something we want to change in the future.
U.S. Naval Research Laboratory	We currently do not use radiances operationally in the LAM (COAMPS); this is a feature supported for research runs only. Biggest challenge is that our center may need to start a LAM domain anywhere in the world at any point in time with 0 notice.	Questions 11 and 12 don't apply to the LAM, as we don't run with radiances operationally. The global model (NAVGEM) utilizes VarBC.
MetCoOp	Incomplete sampling of all view angles at many analysis times	
Norwegian Meteorological Institute	Mainly for IR, but also valid for MW for low peaking channels. This can be challenging due to cloudiness, meaning not enough observations to be used for coefficients update.	

Centre	Biggest barriers to an effective VarBC system for your LAM?	Any other comments about VarBC in your LAM?
UK Met Office		Scan bias has both static and varying components. Background error for coefficients is formulated to target a bias halving time of 8 days for most instruments, 30 days for SEVIRI radiances. Using global bias information in some way is still something we would like to investigate.
NCMRWF		
Japan Meteorological Agency	Observation data are limited in time and area.	VarBC in the JMA meso-scale NWP system is described here. https://doi.org/10.2151/jmsj.2021-076
NCMRWF	VarBC system for the polar satellites always poses problems mainly because coverage is confined to alternate 6 hourly assimilation cycles.	
NIWA	1) Our SatRad bias correction, recalculated every cycle from a 3 week rolling archive of Bstat files, works well. 2) Using VarBC would increase the complexity of our suites as would we have to run two sets of OPS tasks: one with VarBC and one with SatRad bias correction so that we could update the scan and OPS only channel biases in the VarBC file. 3) It is not clear that VarBC will perform better than SatRad.	I am going to try out VarBC in the NZLAM and will use some sort of period averaged method to update our VarBC file (either a rolling archive of VarBC files or exponential running means) to overcome the problems associated with using the UKMO's method of updating the VarBC file. At some point I will implement transferring the large scale analysis from the NZLAM to the NZCSM_DA. I will then experiment with more frequent DA cycles in the NZCSM_DA. I would like to run both the NZLAM and NZCSM_DA using Stu Webster's L118_78km vertical grid (or maybe an L118_80km variant of it) which is L70_40km like near the surface and L70_80km like near the top as this would probably improve explicit convection. Unfortunately L118_78km is not currently supported for DA by the Met Office.