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Increased Density of Assimilated Satellite Radiances in Global 4D-EnVar: The Link between Observation Thinning and Error Variance Inflation

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Motivation

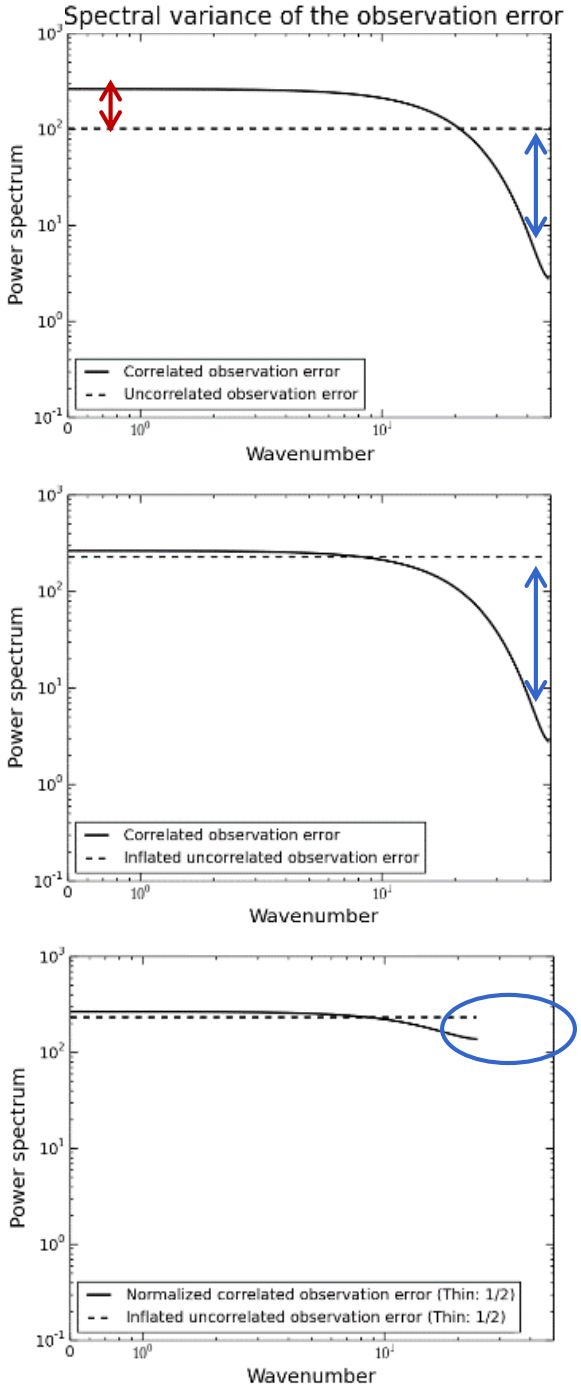
Even though satellite brightness temperature is the observation type with the biggest impact on atmospheric analyses and ensuing forecasts, they are still underused (e.g. ECCC does horizontal thinning at 150 km)

- Brightness temperature errors can have significant spatial correlations:
  - Correlated instrument noise and representativeness error.
  - Correlation from background state used in the observation operator.
- Assimilation algorithms assume spatially uncorrelated obs. errors:
  - Methods to account for spatially correlated observation errors can be impractical if the number of correlated observations is large or if the observations are non-uniformly distributed.
  - Difficult to estimate the real error correlations.
- It is common practice to spatially thin obs. to reduce error correlation between remaining obs., resulting in a loss of small-scale information
- **Goal:** re-assess spatial thinning and variance inflation to extract more information from satellite brightness temperature observations, while still assuming spatially uncorrelated observations in the assimilation

Correlated obs. error

Idealized experiments from Bédard and Buehner, 2019 (accepted in QJRMS):

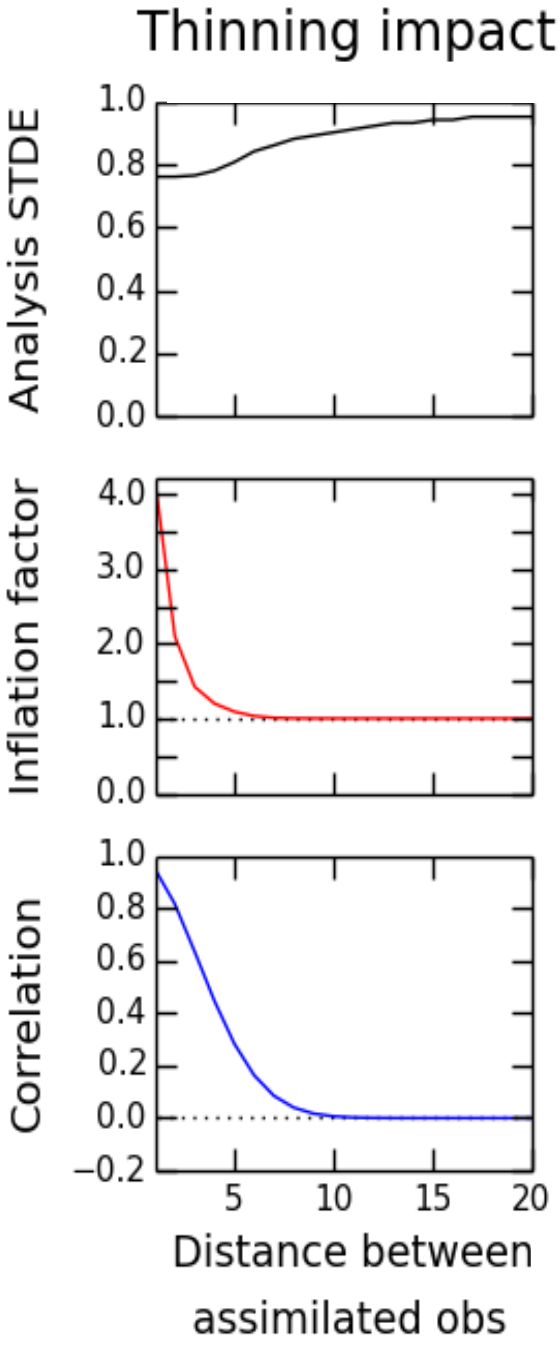
- Positively correlated errors have more energy at the large scales:
  - The spectrum is similar to red noise.
- Simply neglecting the error correlations can degrade the resulting analysis by overfitting large scales and underfitting small scales.
- Inflation allows correctly fitting the scales at which background error has the most energy (large scales), but further neglects small scales.
- Thinning reduces spatial error correlation between the remaining observations (spectrum more flat), but information on the small scales is lost.



Thinning impact with optimally inflated diagonal R matrix

From idealized experiments (Bedard and Buehner, 2019):

- Optimal inflation ≈ 1 when correlation ≤ 0.2 (Liu and Rabier, 2002).
- With optimally inflated diagonal R, the analysis error is smallest when using all obs. (no thinning).
- Without inflation, the analysis is degraded when correlation > 0.2 (not shown).



Experimental framework

Assimilation experiments are performed in a near-operational context to assess the impact of reducing thinning applied to brightness temperature observations.

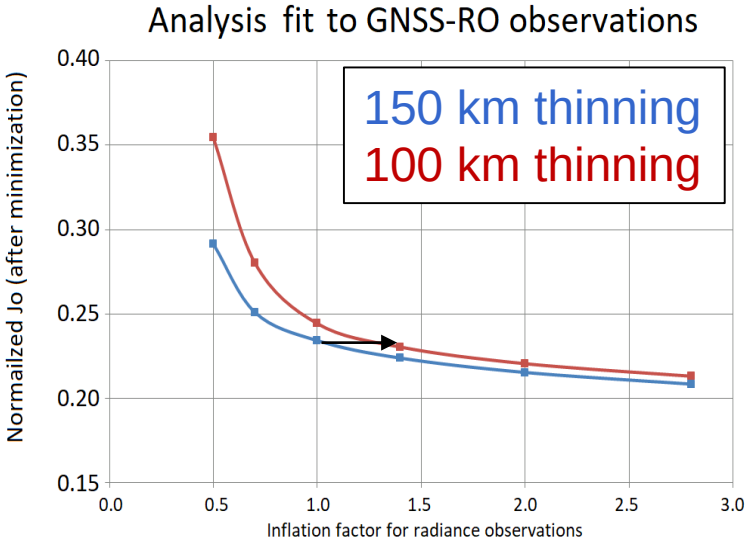
- 39 km global deterministic prediction system:
  - 3D-EnVar data assimilation algorithm using 256 ensemble members.
  - Spatially diagonal observation error covariance matrix (R).
- Tests performed on radiance obs. (MW and IR imagers and sounders):
  - Different thinning (150 km vs 100 km).
  - Different observation error variance inflations (0.5, 0.7, 1.0, 1.4, 2.0, 2.8).
- Tests performed over 2.5 months period (2016/06/15 to 2016/08/31):
  - All operationally assimilated observations are used.
- Forecasts are evaluated against Era5 analyses:
  - Evaluation against radiosondes not statistically significant.

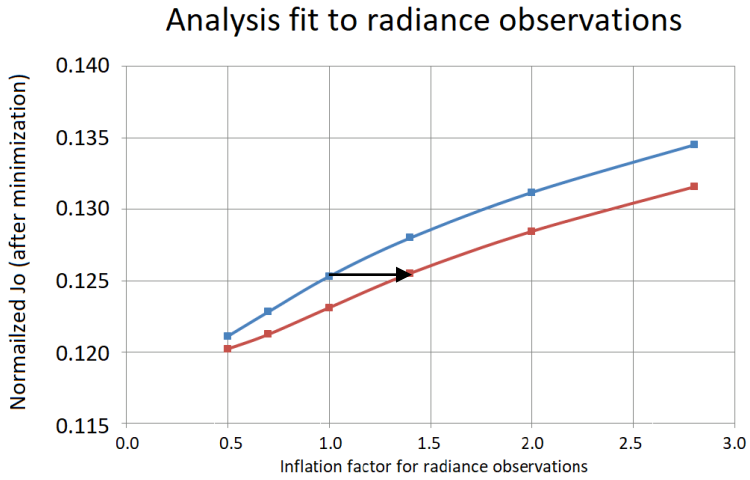
Impact of reduced thinning

- With reduced thinning, the number of assimilated radiance obs. is increased.
- With reduced thinning, observation error variance has to be inflated for radiances to keep a similar analysis fit to obs. (radiances and other obs. families).

# profile / cycle	150km	100km	% Increase
AIRS	10.5k	15.8k	51%
CRIS	11.4k	18.3k	61%
IASI	23.2k	34.7k	50%
CSR	57.2k	97.3k	70%
AMSU-A	65.5k	110.2k	68%
MHS	33.6k	69.8k	108%
ATMS	15.9k	35.1k	120%
SSMIS	16.6k	36.8k	122%

* Some families of observations are sensitive to the thinning algorithm geometry.





Impact from thinning and inflation

Forecast evaluation against Era5:

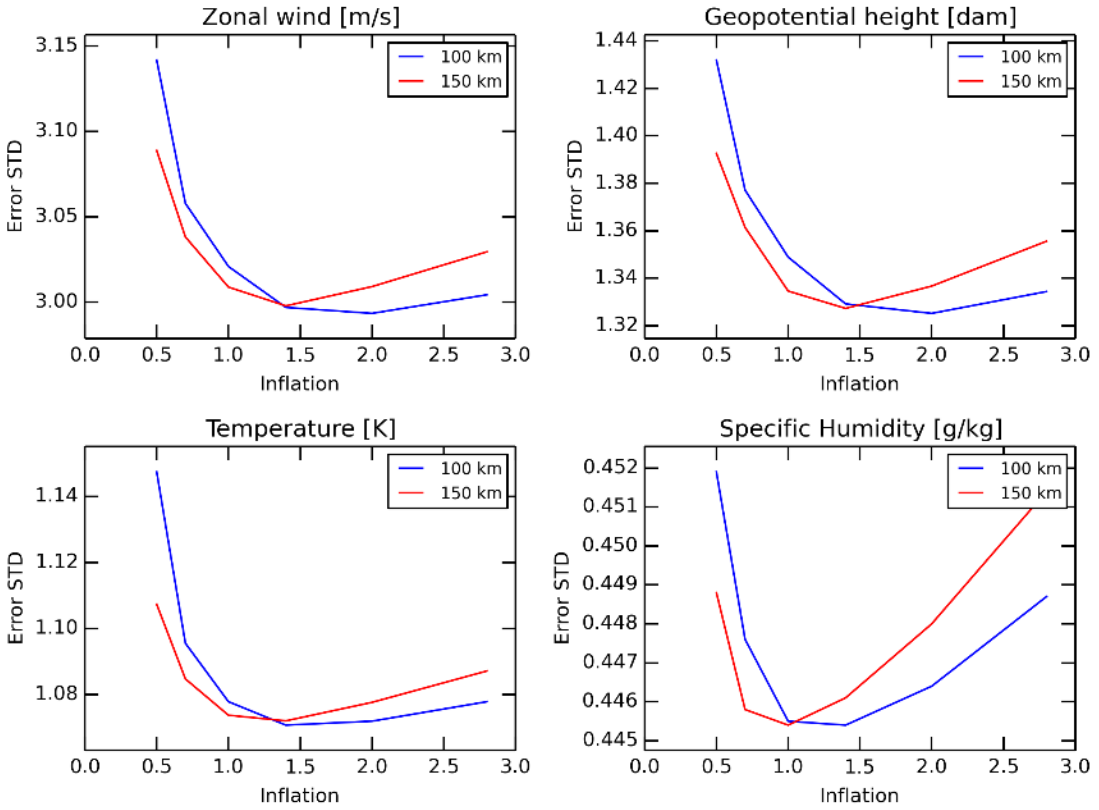
- Vertically averaged temperature (from 1000 to 1 hPa) @ 48 h (world):

– Operational system with current thinning could benefit from more observation error variance inflation (for winds, GZ and temperature).

– Reduced thinning, without obs. error variance inflation can degrade forecasts.

– Reduced thinning experiments can provide improved forecasts if obs. error variance is inflated accordingly.

– Separate tuning for humidity sensitive channels may be useful.

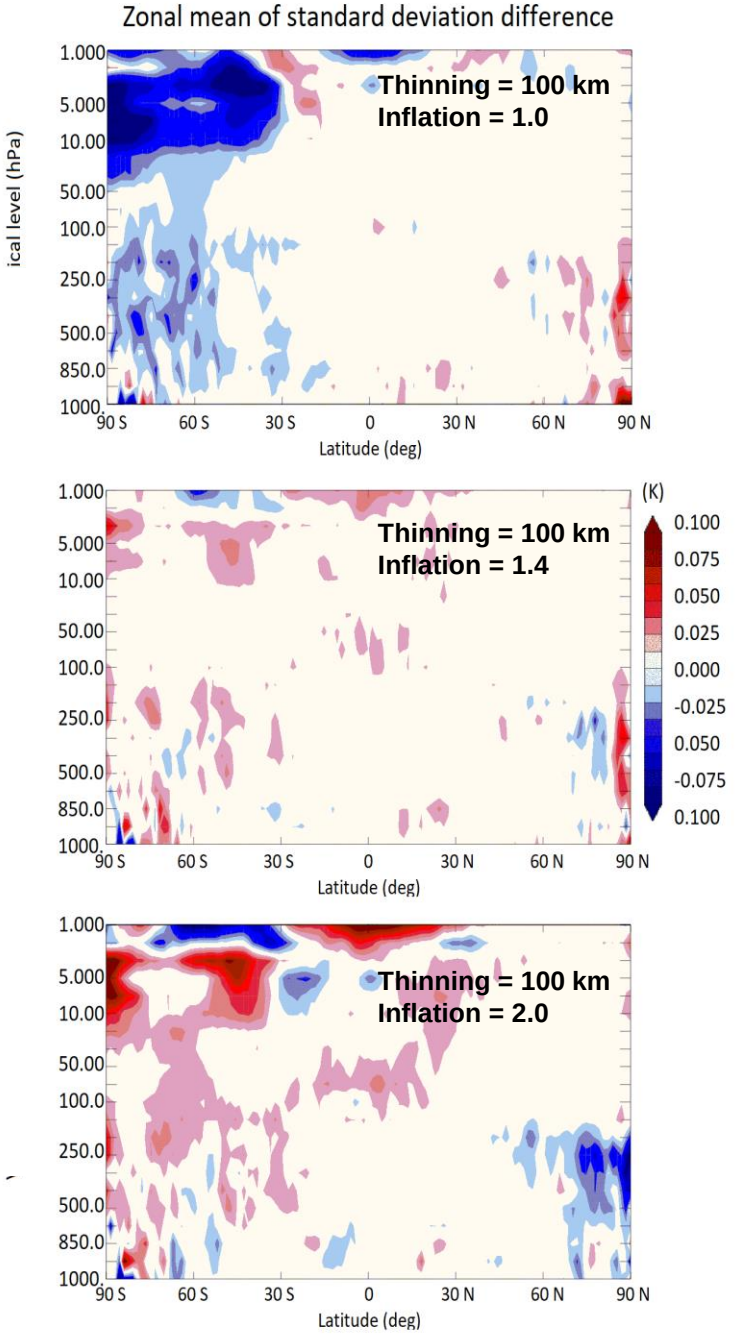


Impact on forecasts: zonal distribution.

Forecast evaluation against Era5:

(ref: Thinning = 150 km, Inflation = 1.0)

- Temperature @ 48 h (World):
  - Reducing spatial thinning without further inflating observation error variance degrades the forecasts (blue contours).
  - Small improvements (≤ 0.1 K) are achieved when reducing spatial thinning while inflating the obs. error variances (red contours).
  - **Impacts mostly noticeable in the Southern extratropical and tropical regions.**

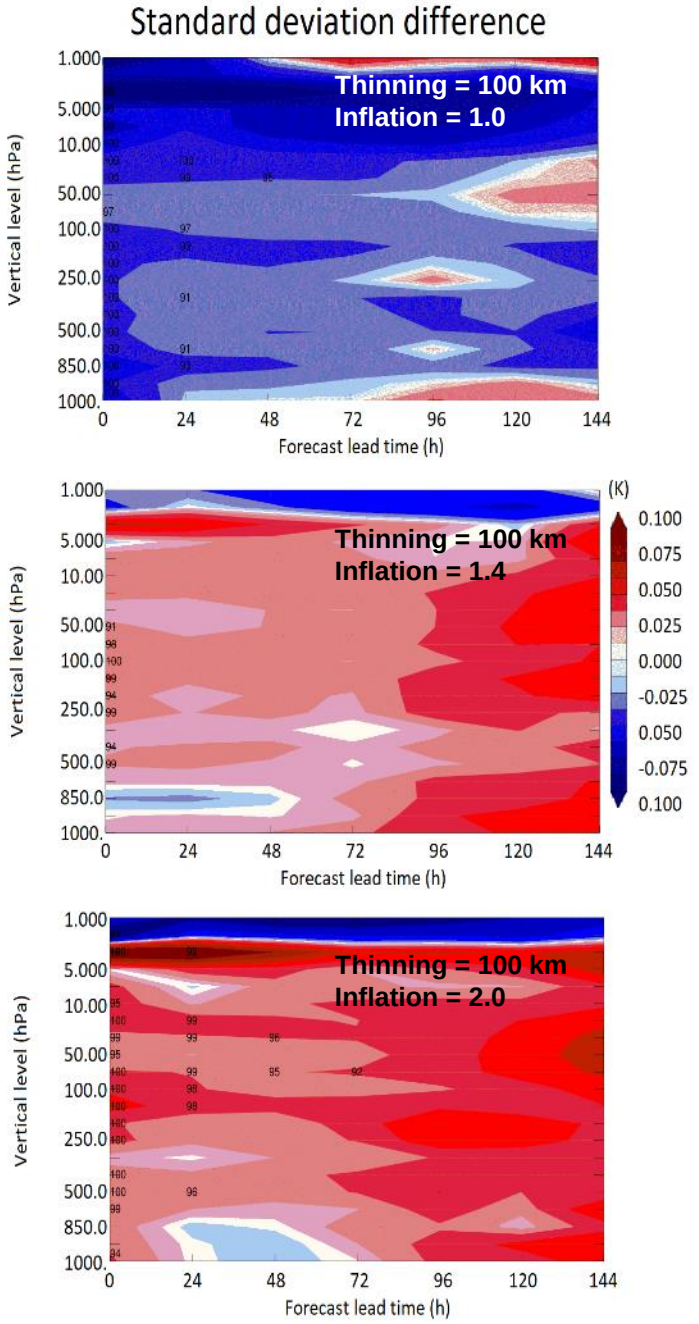


Impact on forecasts as a function of lead time

Forecast evaluation against Era5:

(ref: Thinning = 150 km, Inflation = 1.0)

- Temperature (Southern extratropics):
  - Reducing spatial thinning without further inflating observation error variance degrades the forecasts (blue contours).
  - Small improvements (≤ 0.1 K) are achieved when reducing spatial thinning while inflating the obs. error variances (red contours).
  - **Differences are statistically significant for forecasts up to 72 h.**
  - Deteriorations in upper levels
    - Potentially need to re-assess inflation for AMSU-A channels 13-14 and ATMS channels 14-15.



Take Home Messages

Using a diagonal R matrix sacrifices small scales:

- Both inflation and thinning can be used to give correct weight to large scales, but underweights the small scales (when observation error is correlated)
- Thinning reduces spatial error correlation between the remaining obs. (spectrum more flat), but information on the small scales is lost
- With optimally inflated diagonal R, the analysis is degraded with thinning and it is best to keep most or all the obs.

Experimental results in a near operational context are consistent with results from idealized experiments.

Observation error variance inflation needs to be increased when reducing spatial thinning distance to avoid overfitting large scales:

- Small (but statistically significant) improvements can be achieved by reducing spatial thinning of satellite radiance observations from 150 km to 100 km, especially in the Southern extratropical and tropical regions.