Investigating the optimal design for a future constellation of microwave sounding instruments on small satellites using the Ensemble of Data Assimilations method

Katie Lean[1], Niels Bormann[1], Sean Healy[1] and Dirk Schüttemeyer[2]

[1]ECMWF, Reading, United Kingdom, [2]ESA, Noordwijk, The Netherlands

Contact: katie.lean@ecmwf.int

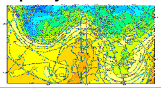
Introduction

Recent advances in technology have allowed the possibility of launching microwave (MW) sounding instruments on small satellites with a performance that is expected to be satisfactory for Numerical Weather Prediction (NWP). In this study, we aim to investigate different potential future constellations of small satellites carrying MW sounding instruments. How much further benefit could be achieved with even better temporal sampling from additional instruments will be established while considering practicalities such as instrument limitations in order to determine an optimal design for global NWP. The impact of these possible constellations will be evaluated by the Ensemble of Data Assimilations (EDA) method. Here we present work from the first, preparatory phase of the 3 key stages of the project:

Preparatory work e.g. adapting observation error model → Develop flexible system to simulate/assimilate small sat radiances → Use the **Ensemble of Data Assimilations** (EDA) to evaluate impact from final list of scenarios

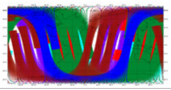
Develop flexible system to simulate/assimilate small sat radiances:

ECMWF NWP analysis → proxy for the 'truth'



interpolate

Observation time and location



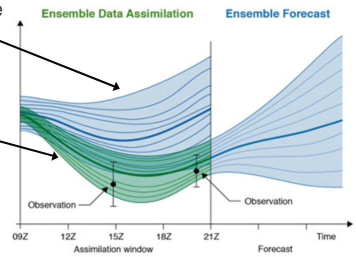
Observation operator RTTOV-SCAT → **Add realistic observation errors** → **Simulated MW sounder radiances**

EDA method overview

The EDA consists of running a finite number of independent cycling assimilation systems, in which observations and the forecast model are perturbed to generate different inputs for each member.

The addition of observations modifies the initial trajectories of the EDA members (blue plume) in the assimilation window and reduces the spread across the members (green plume).

Benefit of additional data is measured by reduction in spread across the members which corresponds to reduction in analysis/forecast uncertainties [1].



Simulated small satellite data are added to real data from an existing observing system. The EDA method has been used for previous ESA and EUMETSAT studies for simulated Aeolus [2] and Radio Occultation [3] data.

Cheaper alternative to traditional Observing System Simulation Experiments (OSSEs) to assess potential of future observing systems

Relating EDA impact to OSE impact

Aim here to provide evidence of links between EDA and Observing System Experiment (OSE) impacts and show EDA method is appropriate to measure relative observation impacts.

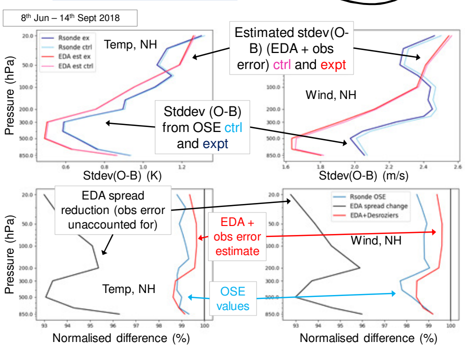
EDA and OSE run in 2 configurations with (1) control: no MW sounding data and (2) experiment: 7x temp and 7x humidity MW sounding instruments

Compare EDA reduction in spread vs. OSE forecast error measured by 12h short-range forecast – radiosonde observations. Need to account for observation error so compare OSE values to equivalent value estimated calculated using EDA spread (assuming uncorrelated observation and background errors):

Short-range forecast error represented by EDA spread

$$\mathrm{STDEV}(O-B) = \sqrt{\sigma_B^2 + \sigma_O^2}$$

Radiosonde observation error provided by Desrozier estimate



Preliminary results show some differences in magnitude and not all vertical structure captured

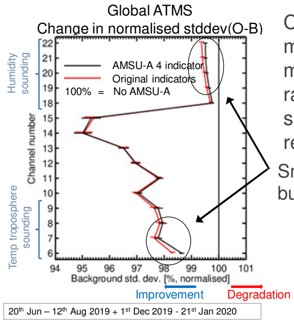
Qualitative similarity in OSE and estimated profiles.

Overall reductions in EDA spread compare favourably with OSE forecast error reductions. However, no obvious one-to-one correspondence.

Adaptation of observation error model

Data from small satellites will be assimilated in the all sky framework. To account for different representativeness of clouds in observations and model, observation error increases in presence of cloudy signals from observation or model [4]. Cloud indicators in current scheme for MW temp sounders use a scattering index or liquid water path estimate derived from the 23.8 and 31.4 GHz channels which will be unavailable on the small satellites.

52.8GHz suitable alternative cloud indicator



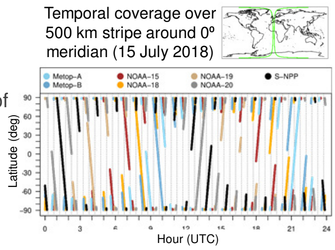
Cloud indicator based on 52.8GHz provides measure of the cloud signal in observation and model equivalents, calculated using clear-sky radiative transfer calculations. Tests using AMSU-A show current impact of all sky use is well reproduced.

Small, significant degradation in some ATMS channels but medium-range impacts of change remain neutral

Low frequency AMSU-A channels are not currently assimilated so full potential impact from loss of channels not assessed here

Choosing potential constellations

Temporal coverage over 500 km stripe around 0º meridian (15 July 2018)



7 satellite polar constellation coverage sparser in tropics/mid-lat

10 different scenarios will be tested. Choice of different scenarios motivated by 2 key areas:

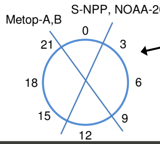
What is the optimal number/orbit type?

To better increase sampling frequency:

- Different orbital planes?
- Mixture of polar/low inclination (particularly for better tropical/mid-latitude coverage)?

Humidity (~183GHz) only or with additional temperature (~55GHz) sounding channels?

- Improved dynamical information due to higher temporal sampling
- Increased sampling reduces effective noise for temperature sounding



Orbital planes of JPSS and Metop programs provide baseline representing complementary backbone for testing optimal constellation of small satellite MW data.

Other considerations include instrument performance limitations e.g. higher instrument noise

Next steps

Development of the simulation/assimilation system is ongoing. Parallel activities conducted by ESA, Janet Charlton Research Systems, Fluctus, Informus and In-Space Missions will determine the satellite distribution for each scenario and provide orbital parameters for the model to observation location interpolation step at ECMWF. The final scenarios will be agreed and EDA experiments will begin.

References

[1] Isaksen, L., Bonavita, M., Buizza, R., Fisher, M., Haseler, J., Leutbecher, M., Raynaud, L., Dec 2010. Ensemble of data assimilations at ECMWF, *ECMWF Tech Memo. No 636.*

[2] Tan, D. G. H., Andersson, E., Fisher, M., Isaksen, L., 2007. Observing-system impact assessment using a data assimilation ensemble technique: Application to the ADM-Aeolus wind profiling mission. *Quart. J. Roy. Meteor. Soc. 133, 381390.*

[3] Harnisch, F., Healy, S. B., Bauer, P., English, S. J., 2013. Scaling of GNSS Radio Occultation Impact with Observation Number Using an Ensemble of Data Assimilations. *Mon. Wea. Rev. 141, 43954413.*

[4] Geer, A. J., Bauer, P., 2011. Observation errors in all-sky data assimilation. *Q. J. R. Meteorol. Soc. 137, 2024–2037.*