SOSE: SENSITIVITY OBSERVING SYSTEM EXPERIMENT

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ABSTRACT A new method is presented to define the observational requirements (quality and quantity) for a future observing system to improve forecasts of extreme weather. We use sensitivity structures to correct the (incorrect) forecast initial state with a constraint that these structures do not conflict with existing observations. As a result, our computed analysis corrections do not affect the total analysis error but do improve the forecast. The corrected analyses are used to simulate future observations. We focus on real extreme events that were badly forecast operationally, which cannot be done in an OSSE. Moreover, unlike in OSSEs, in SOSEs the simulation of all observing systems is not required.

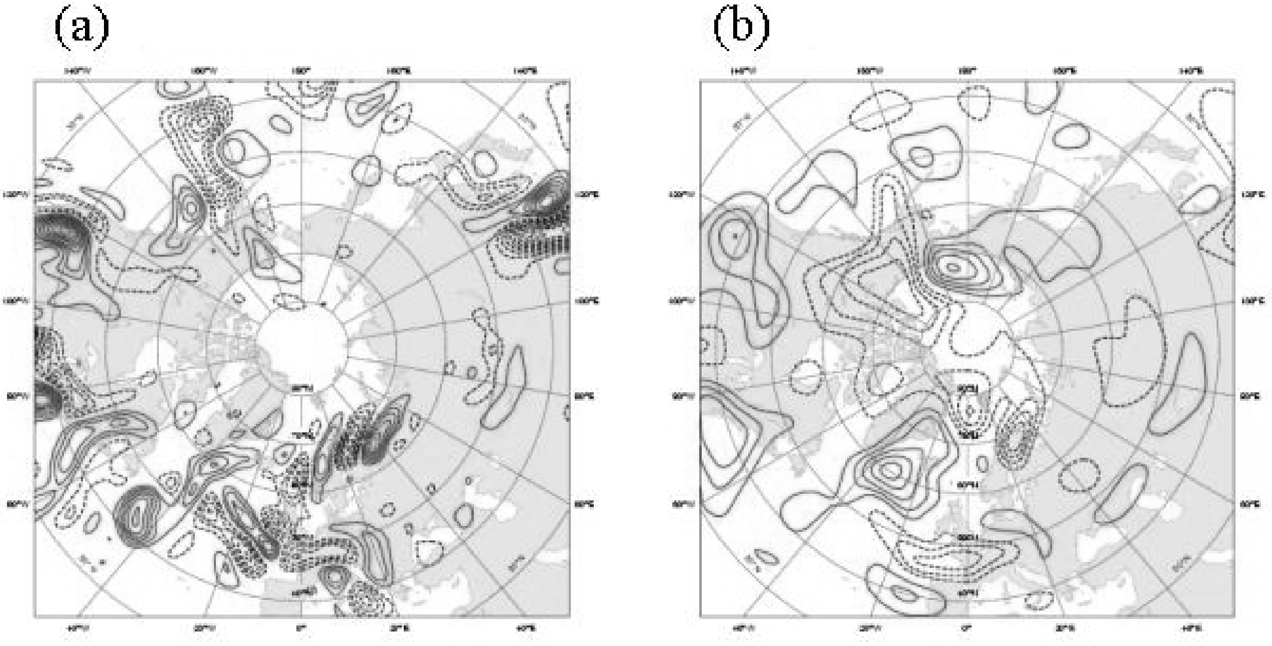


Figure 1. Sensitivity structures for temperature at 500 hPa that improve a 2-day ECMWF forecast. The norm for initial analysis change computation (see text) is either constrained by Total Energy (a) or by the B-matrix (b).

1. INTRODUCTION

Many resources are spent on new observation types complementing the meteorological Global Observing System (GOS), or its Climate equivalent GCOS. The potential value of these observations for weather and climate analyses depends on:

- The information content of the new observing system and its fundamental ability to complement the G(C)OS in describing the atmospheric circulation and mass field;
- The ability of the (future) data assimilation system (DAS) to exploit this new information;

The first requirement is prime, the second could be a pitfall when testing the new observations in existing DASs. These are often not well tuned to exploit new data types, and extended trials are needed to test the consistency of the new data with the forecast model and analysis scheme characteristics.

A greater consistency of observations and DAS is generally achieved in Observing System Experiments (OSE) or Observing System Simulation Experiments (OSSE), but for different reasons. The assimilation of existing observing systems is already tuned for beneficial analysis impact, whereas simulated (future) observing systems do often not fully capture the real observation error characteristics. However,

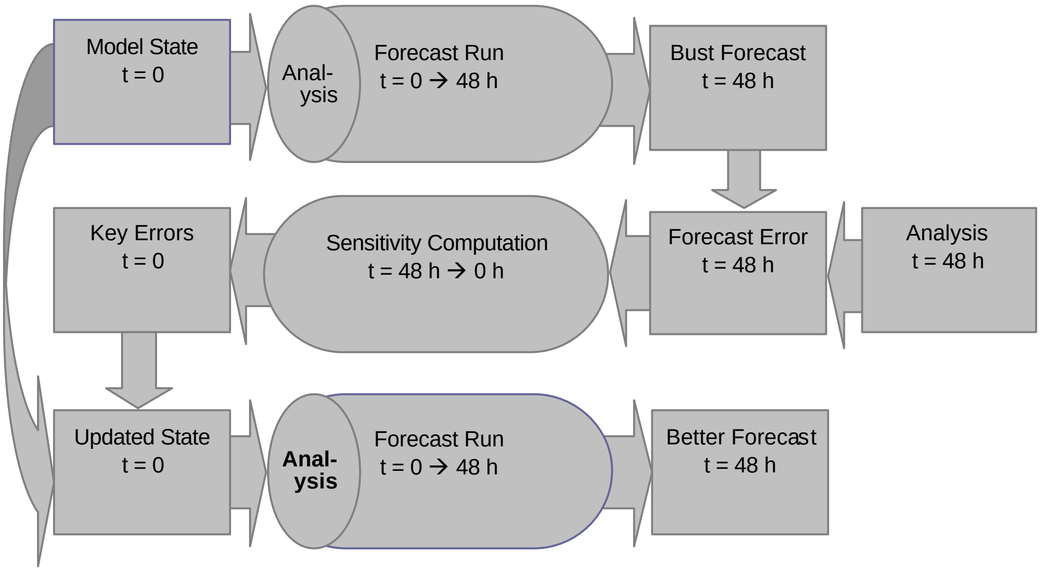


Figure 2. Background state sensitivity experiment. The updated analysis (bold) provides the SOSE pseudo truth.

OSSE calibration should guarantee the appropriate observing system impact (e.g., Marseille et al., 2000; Matsutani et al, 2004).

OSSE test the analysis and forecast impact of future and thus non-existing observing systems, whereas OSE test the impact of existing observing systems. OSE thus provide real impact of real observations in a given data assimilation system. The OSE are used to further test and improve the assimilation of certain data types, and to test the relevance of the different existing components of the GOS (WMO, 2004). Gaps in the GOS, for example the lack of wind profile data over the oceans, tropics, and Southern Hemisphere (SH), can be filled by new observing systems, like DWL. OSE cannot test the expected impact of such observations, since no existing observing system provides these data. OSE or Observation System Replacement Experiments, OSRE, could for example be used respectively to test the impact of existing wind profile observations over Northern Hemisphere land or how these may be replaced by another observing system (Cress et al, 1999). Although indicative, it is however a priori not clear how exactly to extrapolate these results to the case of more uniform and complete wind profile coverage over the globe. To overcome this problem OSSE may be conducted, realistically simulating the atmosphere, all existing and newly expected observing systems, and thus conditioning the appropriate sensitivity of the given DAS to these different observation types (Marseille et al, 2000). It may be clear that OSSE require many human resources.

We investigate another and simpler methodology to infer the potential benefit of a future observing system, and limit ourselves to cases of NWP forecast busts or failures. We aim at defining the observational requirements (quality and quantity) for a DWL to improve forecasts of extreme weather with focus on extreme events that were badly forecast operationally. To assess the added value of a DWL we generate synthetic wind profiles with a coverage that resembles possible future instrument designs and network scenarios. The main challenge remains in the combined NWP assimilation of real conventional observations and synthetic DWL observations. Strictly speaking, the simulation of synthetic lidar data requires the true atmospheric state but which is unknown. Alternatively, we use sensitivity structures to correct the (incorrect) forecast initial state. Sensitivity computations are performed operationally at ECMWF as a diagnostic tool to trace back forecast errors to rapidly growing errors in the forecast initial state. We investigate the realism of these sensitive structures, based on both the total energy (TE) and background error covariance matrix (B) norm for the perturbations in the initial analysis (Barkmeijer et al, 1999), as depicted in figure 1. Initially, we use the OSSE results that have the unique property of the true atmospheric state to be known, thus facilitating the interpretation of the tests (section 2). As such, the realism of the sensitivity structures and the methodology is confirmed.

The SOSE (see figure 2) uses these sensitivity structures to define a pseudo truth that

- Improves the 2-day forecast,
- Has realistic spatial structures,
- Is compatible with the existing (real) observations.

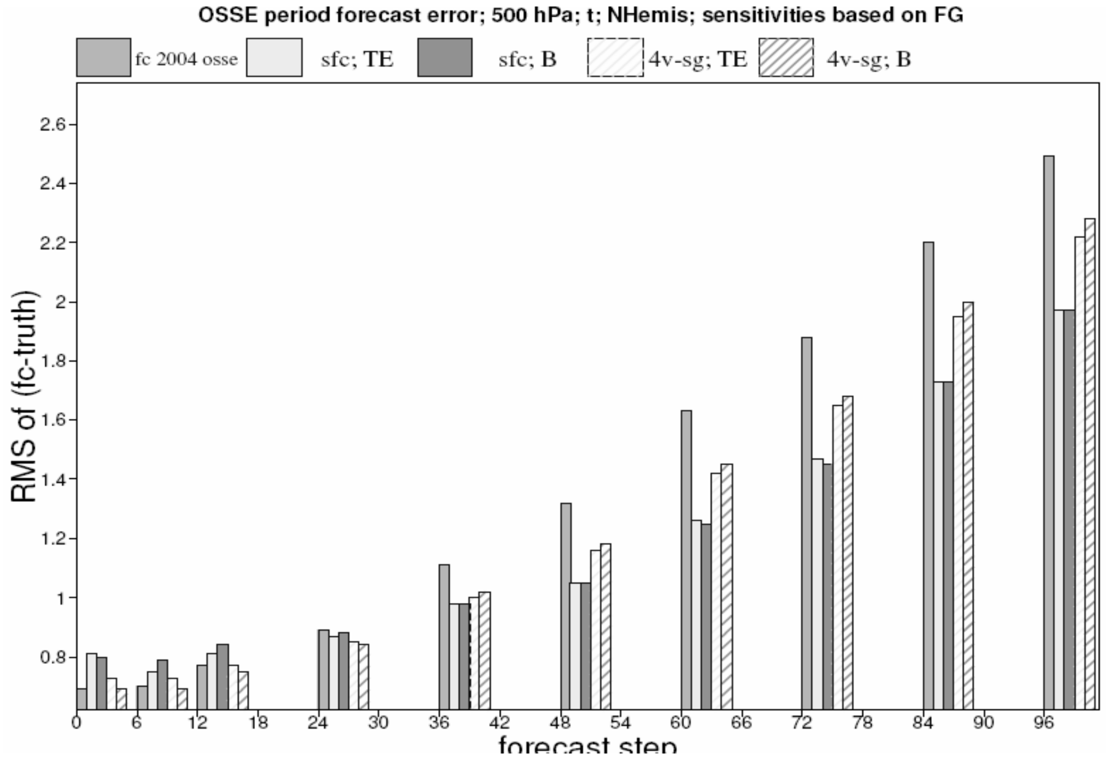


Figure 3. Temperature error evolution averaged over 15 days in the OSSE (1st column), with common analysis sensitivities by TE norm (2nd white column) and B norm (3rd grey column) and with SOSE analysis sensitivities by TE norm (4th white column) and by the B norm (last hashed column).

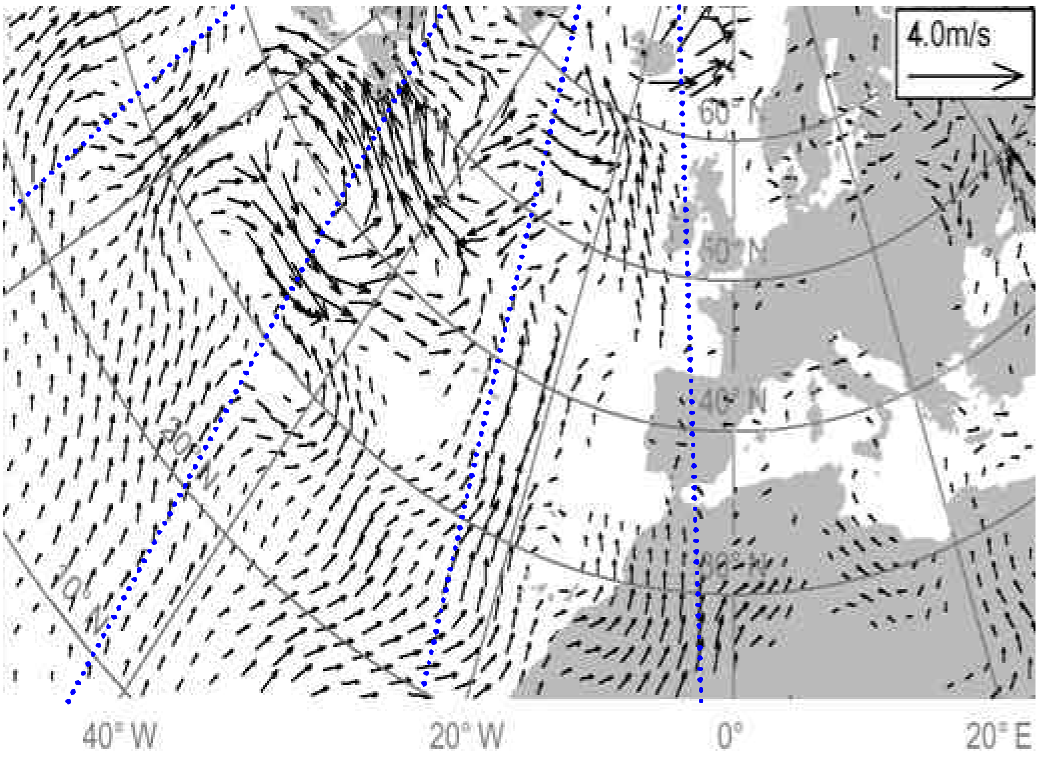


Figure 4. ADM-Aeolus DWL sampling of the SOSE perturbations.

We sample these structures from space by DWL for a number of design and network scenarios and assess their potential to reduce forecast failures. The method could also be adopted for other observing systems, like, e.g., GPS.

2. SENSITIVITY STRUCTURES

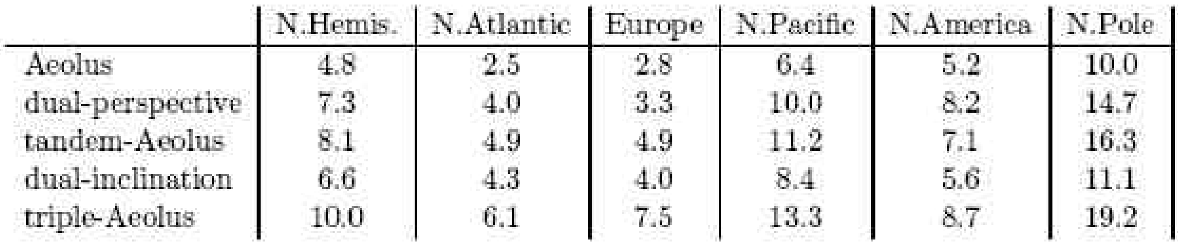
The sensitivity structures displayed in figure 1 show rather different spatial characteristics and amplitudes. The spatial characteristics and amplitudes, however, determine the required density of sampling (quantity) and required quality of the new observing system, respectively. Figure 3 shows TE and B-matrix norm analysis perturbations do reduce the 2-day forecast error by about 50%.

The different TE and B structures give equal reduction in forecast error. However, the analysis perturbations do not reduce the analysis error, but rather amplify it, in particular for temperature (see also Isaksen, 2003). This may furthermore indicate that the perturbations are in conflict with the conventional observations, and, consequently, with synthetic DWL observations simulated from these perturbations.

3. RESOLVE CONFLICT OF SENSITIVITY STRUCTURES WITH REAL OBSERVATIONS

Figure 2 depicts an approach that does prevent the above inconsistency. By computing a first guess perturbation rather than an analysis perturbation, we keep the capability to improve a 2-day forecast. If we presume that the most significant first guess perturbations are in observation-sparse areas, then a subsequent analysis should still reduce the 2-day forecast error. Figure 3 indeed indicates that half of the capability to reduce the 2-day forecast error is kept in the perturbed analyses which are based on perturbed first guess and all existing observations. The perturbed analysis is pushed to the observations in data dense areas and maintains the first guess sensitivity structures in data sparse areas. The assimilated perturbations thus match with the conventional observations and at the same time maintain (part of) the forecast error reduction capability. Moreover, the analysis error is not any more degraded on average, in particular for the B norm. Moreover, spatial frequency and vertical profile analyses show that B norm sensitivities thus obtained are very similar to common analysis increment structures and the OSSE analysis errors. As such, the B norm SOSE structures are selected as pseudo truth for DWL scenario simulation.

4. IMPACT



	N.Hemis.	N.Atlantic	Europe	N.Pacific	N.America	N.Pole
Aeolus	4.8	2.5	2.8	6.4	5.2	10.0
dual-perspective	7.3	4.0	3.3	10.0	8.2	14.7
tandem-Aeolus	8.1	4.9	4.9	11.2	7.1	16.3
dual-inclination	6.6	4.3	4.0	8.4	5.6	11.1
triple-Aeolus	10.0	6.1	7.5	13.3	8.7	19.2

Table 1: Forecast impact of different DWL scenarios as a percentage of the maximum achievable 2-day forecast impact on 500 hPa geopotential height.

DWL impact has been tested for the ADM-Aeolus scenario, a dual perspective scenario, i.e., like ADM but providing two orthogonal views, a tandem Aeolus scenario with double coverage, a tandem Aeolus scenario with dual inclination such that some dual perspective information is acquired at high latitudes of 50-70 degrees, and a triple Aeolus scenario, i.e., single perspective, but threefold coverage as compared to Aeolus. Both analysis and forecast impacts were analysed, and both in the areas with extreme forecast error and in the areas with common forecast error. Impacts in all these areas were consistent and comparable in relative terms. Table 2 shows the 500 hPa 2-day forecast improvements of geopotential height. We conclude

☞ Tandem-Aeolus performs clearly better than dual-perspective; increased coverage preferable over improved local observation of two wind components ;

☞ The performance of Tandem-Aeolus is less than twice the performance of Aeolus; similar for Triple Aeolus ;

- ☞ Triple Aeolus is twice as performant as single Aeolus; better over Europe.

A more detailed analysis of the impact can be found in Marseille et al (2006).

5. CONCLUSIONS AND OUTLOOK

OSSE tests show that the SOSE B norm perturbations do reasonably match the “true” analysis error structures, indicating that these analysis perturbations are realistic in spatial scale and amplitude. Moreover, the SOSE B norm perturbations provide more balanced mass/wind structures and smallest analysis error in the temperature field.

The perturbed analyses are input to synthesising the DWL observations. Several DWL scenarios are tested for their ability to sample the realistically simulated analysis perturbations, and thereby improve the 2-day forecasts. The OSSE work has resulted meanwhile in a satisfactory procedure, and is applied on real cases of 2-day forecast failure in order to test the DWL ability to reduce such forecast errors. By testing several DWL scenarios a synthesis of requirements on wind profile quality and quantity has been obtained.

The ability of and requirements for other observing systems to do the same may obviously be tested by the same methodology. The methodology complements OSE and OSSE, since the former by definition cannot test the impact of new complements to the GOS, and the latter requires careful calibration and observation simulation.

A drawback of the approach presented here is that forecast failures are implicitly attributed to observations in a single time window. However, we know that analyses depend strongly on the first guess, incorporating information of all past observations. Cycling of the SOSE method should really be envisaged in this respect. A second consideration is that the only objective of the sensitivity method is to improve the 48-hour forecast, while a posteriori analyses over the full forecast range are available. However, we note from figure 3 that the sensitivity structures do improve other forecast ranges as well. By SOSE cycling we thus achieve further forecast improvements as well. Results on SOSE cycling will be presented at the ADM-AEOLUS workshop from 26-28 September in ESTEC Noordwijk, the Netherlands.

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