Systematic Observations Financing Facility

Eleventh Steering Committee
19-21 May 2025

ECMWF SOFF Impact Experiments: A scientific case for scaled-up SOFF investments

Decision 11.2

Systematic Observations Financing Facility

Weather and climate data for resilience

Decision 11.2: ECMWF SOFF Impact Experiments: A scientific case for scaled-up SOFF investments

The SOFF Steering Committee

Welcomes the SOFF impact experiments undertaken by European Centre for Medium-Range Weather Forecasts (ECMWF) in collaboration with the World Meteorological Organization (WMO) to quantify how new Global Basic Observing Network (GBON) observations reduce uncertainty in short-range weather forecasts.

Notes that the experiments provide

- The strongest scientific evidence to date demonstrating targeted investments in GBON infrastructure in under-observed regions dramatically improve forecast accuracy, both locally and globally.
- Rigorous, comparable metrics for demonstrating the impact of SOFF investments, providing a strong evidence base for the need for scaled-up SOFF investments.

Requests the SOFF Secretariat to

- Widely communicate the results of the study, including with potential additional contributors to the SOFF UN fund
- Widely communicate the results of the study in its engagement with the United Nations Framework Convention on Climate Change (UNFCCC) process and the 30th Conference of the Parties of the UNFCCC (COP30) Presidency.
- Reach out to potential public and private partners and philanthropies, in collaboration with ECMWF and WMO, and jointly prepare a proposal for a potential third phase of SOFF Impact work with a focus on the importance of SOFF-supported data for Artificial Intelligence forecasting.
- Present this proposal for consideration at the 12th Steering Committee meeting.

Purpose of this Document

This document presents a summary prepared for the SOFF Steering Committee of the results of the second phase of SOFF impact studies. The European Centre for Medium-Range Weather Forecasts (ECMWF) in coordination with WMO and the SOFF Secretariat designed and ran eight tailored scenarios simulating the impact of expanding the number of reporting Global Basic Observing Network (GBON) stations.

The ECMWF SOFF experiments provide the strongest scientific evidence to date that targeted investments in GBON infrastructure in under-observed regions dramatically boost forecast accuracy—both locally and globally, providing a clear case for scaled-up SOFF investments.

The full scientific report will be prepared by ECMWF and finalized in 2025.

Table of contents

Executive Summary

Accurate weather forecasts save lives and livelihoods. Yet, vast areas of the globe remain blind spots in the global observing system. To effectively address these blind spots and guide SOFF investments, the SOFF Steering Committee initiated science-based impact assessments. WMO partnered with the European Centre for Medium-Range Weather Forecasts (ECMWF), an intergovernmental organization that is both a research institute and a 24/7 operational service producing global weather predictions for its Members, co-operating States and a broader community.

ECMWF first conducted a review of scientific literature on the role of observations in improving forecast skill (Decision 9.2). This review confirmed that surface-based observations significantly improve forecast accuracy, especially in data-sparse regions.

In the second phase, ECMWF designed and ran eight tailored scenarios simulating the impact of expanding Global Basic Observing Network (GBON) surface, upper-air and marine stations. These scenarios explored forecast improvements from adding observations in Least Developed Countries (LDCs), Small Island Developing States (SIDS), Lower Middle-Income Countries (LMICs), and closing regional gaps such as in Africa and the Pacific. The scenarios represent different funding pathways for SOFF.

ECMWF applied the Ensemble of Data Assimilations (EDA) technique to quantify how new observations reduce uncertainty in short-range forecasts – providing rigorous, comparable metrics for demonstrating the investment impact.

The ECMWF SOFF experiments provide the strongest scientific evidence to date that targeted investments in GBON infrastructure in under-observed regions can dramatically improve forecast accuracy – both locally and globally. This evidence provides a clear case for scaled-up SOFF investments.

The main results of the scientific experiments can be summarized as follows:

- **The more data, the larger the impact.** Forecast accuracy improves in direct proportion to new observations.
- **Greatest benefits for Africa.** The largest improvements are observed from adding observations in Africa. Forecast uncertainty reduces by over 30% in high-impact regions.
- **Investments in the Pacific SIDS are important.** Forecast uncertainty reduction up to 20% in this data-sparse and important region for global weather prediction.
- **Data from upper air stations deliver the largest benefits in the tropics**. Upper-air observations are especially important in the tropics for constraining atmospheric profiles.

- **SOFF expansion to all ODA countries gives the biggest return.** The expansion scenario to Lower-Middle Income Countries and all ODA countries shows the largest improvement in forecast accuracy.
- **GBON marine data yield limited gain unless station density increases**. However, marine data are relevant for observational completeness, for local use, and represent a proportionally small investment.
- **Local investments generate global benefits.** As weather does not respect borders, forecast improvements propagate across regions.

The results from these scientific experiments provide a robust foundation for future SOFF investment decisions. The experiments also point to potential future studies, including a possibly third phase of impact studies, potentially undertaken in partnership with ECMWF and the private sector with a focus on applying ECMWF's new Artificial Intelligence Forecasting System (AIFS). Initial discussions with partners also emphasize the importance of a “two-way-street" for SOFF countries, ensuring countries have access to improved forecasting capacities resulting from SOFF investments. This will democratize cutting-edge forecasting capacity across developing countries and further unlock the value of observational data.

ECMWF Impact Experiments

1. Context

The SOFF Steering Committee, through Decision 6.8, endorsed and approved funding SOFF Impact Reports based on scenarios of GBON implementation. Impact in this study refers to the improvement in forecast skill resulting from increased investment in observations. It has been proven that the value of improved forecast skill translates directly to safety and numerous socio-economic benefits[1]. WMO has engaged the European Centre for Medium-Range Weather Forecasts (ECMWF), one of the World Meteorological Centres and member of the SOFF Advisory Board, to prepare the assessments for the reports. The study was conducted in two phases. The first phase (Decision 9.2) provided a literature review and assessment of our current knowledge on forecast skill improvement and impact of improved GBON networks. Phase one also identified the scenarios for SOFF-tailored further research and experiments in phase two. The objective of phase two of the impact studies is to further develop an understanding of the impact of SOFF investments on forecast skill. This document is the output of the experiments completed during phase two.

1.1. Quantifying the importance of observations

All monitoring and prediction of weather start from the collection and global exchange of observations. This data provides the only direct source of information about the atmosphere. Weather is inherently global, and to understand and predict weather and climate patterns, observations covering the entire globe need to be made available to the global monitoring and prediction model systems. The WMO Integrated Global Observing System (WIGOS) comprises both satellite- and surface-based observations. Spaceborne observations offer global coverage, capturing data from every part of the Earth. However, the information that satellites provide is “indirect” and it usually requires the application of sophisticated inverse methods to retrieve useful information about the atmospheric state from the raw measurements. Calibrating and supplementing satellite data with directly measured surface and upper-air data is essential in this context.

Despite the global coverage provided by the variety of satellite observing systems used in operational numerical weather prediction (NWP), phase one of this study confirmed that surface-based data, including both surface and upper-air in situ observations, remain a crucial component of WIGOS. In addition to improving the initial conditions required to produce accurate forecasts, they also have important additional roles in both

[1] Mark R. Rosenzweig and Christopher R. Udry: Assessing the Benefits of Long-Run Weather Forecasting for the Rural Poor: Farmer Investments and Worker Migration in a Dynamic Equilibrium Model; NATIONAL BURAU OF ECONMIC RESEARCH Working Paper No. 25894, Cambridge, MA, May 2019.

forecast verification and in constraining the bias corrections applied to satellite radiance measurements.

Surface-based observations directly measure critical weather parameters such as temperature and humidity, but are limited by the availability of observation stations, particularly in remote and underdeveloped areas. Currently, there are large data gaps in surface-based weather observation networks, negatively affecting the quality of weather forecasts globally. Closing these data gaps is essential for the world to be better prepared, to better understand and therefore more effectively adapt to a changing climate.

1.2. Results of phase 1

A review of existing studies found that adding surface-based observations significantly impacts forecast accuracy, especially in areas with sparse data coverage. Some of the key messages from this review include:

- **There is a high impact of additional surface-based observations, especially in data sparse areas.** Despite being fewer in number compared to satellite data, surface-based observations have a strong influence on forecast accuracy in many regions.
- **Surface-based observations create local, regional and global benefits.** When a new observation is used its impact will, at first, be local, but as weather systems move, the impact moves with them so that each day the area benefiting from the original observation becomes larger.
- **Both surface land and upper air stations are important.** While both are critical elements of the global observing system, the relative importance of surface land versus upper-air observations varies across studies. More studies suggest that upper air observations have more impact, and there is a tentative acceptance that upper air observations have more impact than near-surface observations.
- **In general, adding one new surface-based observation in a data sparse region has more impact than adding a similar new surface-based observation in a data-rich region.** There is evidence that reducing data gaps in Africa (in particular regions such as East Africa, the Rift Valley, and the Horn of Africa), parts of the Pacific and Atlantic Oceans, the Arctic Ocean and Antarctica, significantly improve forecast accuracy.
- **More scientific studies on the impact of surface-based observations are required.** Most studies in the literature explore satellite data impact, and studies on surface-based data are more limited. Existing studies on the impact of additional observations do not provide the level of granularity required to fully guide SOFF investment priority decisions.

2. Scope and methodology of Impact Experiments

2.1. Ensemble of Data Assimilations (EDA) methodology

To assess the potential impact of additional surface-based observations, ECMWF applied an Ensemble Data Assimilation (EDA) method which has been applied by researchers to estimate the impact of new satellite observing systems (e.g., Lean *et al.*, 2025). This is an ensemble method based, in this study, on 10 perturbed members that provides a *theoretical* estimate of the "error bars" for the NWP analyses (initial conditions) and short-range forecasts, both with and without simulated datasets. The EDA "spread" is used to estimate these error bars. The "spread" is simply the standard deviation of an ensemble of atmospheric states about the mean of the ensemble. If the EDA spread is reduced as result of assimilating a new dataset, this indicates that the new dataset is expected to improve the statistical uncertainty – or error bar – of the analysis and/or short-range forecasts.

To assess different scenarios of SOFF investment and expansion, the following scenarios were developed for this study:

- Baseline: Current observing system (shown in Figure 1 based on June 2023).
- Ensemble of Data Assimilations Scenarios: Adding simulated surface land, upper-air and marine observations for different country groupings (LDCs, SIDS, LMIC, all ODA eligible countries, FCS) and regions (Africa, Pacific), representing different funding expansion pathways for SOFF.
- Observation System Experiments Scenarios: Simulating the absence of surface land and upper-air observations.

Based on these EDA scenarios, the simulations investigate how the uncertainty is reduced when new data is added to the NWP system. The observed change is a result of the information provided by the new observations. The EDA provides a relative, rather than an absolute, measure of the observation impact, and it is usually considered most reliable for analyses and short-range (12-hour forecasts) error statistics when integrated over large spatial areas. The reliability in the short-range impact is because the EDA is primarily designed to provide spatially varying, short-range error covariance information for use in ECMWF's operational four-dimensional variational (4D-Var[2]) system. The 4D-Var is the system used at ECMWF to combine a short-range forecast with observations to produce the best possible estimate of the current state of the atmosphere. It has been used successfully at ECMWF for this purpose since 2010. However, at longer forecast ranges (day 5), the EDA does not capture the forecast error growth, and the ensemble spread values are too low (Lean et al., 2025).

The baseline control scenario assimilates all satellite and in-situ observations that were used operationally in June 2023 and includes no simulated data. The combined number of real in situ and satellite observation values assimilated in the baseline control experiment is greater than 30 million per day.

To the current observing system or baseline, new simulated observations (surface [S], upper air [UA] and/or marine) were added for each scenario as described in Table 1. For each scenario, the reduction in forecast uncertainty is computed using the EDA spread values.

Table 1. Different types of scenarios used for the study which are added to added to the baseline.

Scenario	Country groupings	Data type
SC 1	LDCs + SIDS	S + UA
SC 2	LDCs + SIDS + LMICs	S + UA
SC 3	All ODA + SIDS	S + UA
SC 4	LDCs + SIDS	S + UA + Marine
SC 5	FCS	S + UA
SC 6	Pacific	S + UA
SC 7	Africa	S + UA
SC 8	All ODA + SIDS	UA only

[ODA = Official Development Assistance; LDC = Less Developed Country; LMIC = Low- and Middle-Income Countries; SIDS = Small Island Developing State; FCS = Fragile and Conflict Affected Situations] [S=Surface Stations; UA=Upper Air stations]

2.2. Assimilation of simulated data

Simulated observations are generated from ECMWF's high resolution, operational four-dimensional variational[2] (4D-Var) analyses at a frequency meeting GBON requirements for surface (hourly), radiosondes (six-hourly) and buoys (hourly). The 4D-Var provides the initial conditions for a new forecast. Overall, it has been demonstrated that the statistical characteristics of simulated data generated in this way are similar to real observations.

Simulated datasets for this study are subjected to the same quality control procedures as real observations. The only exception is for surface winds over land, which are not currently assimilated in the operational ECMWF system but have been tested in the study. Noise added to the simulated data is assumed to be spatially and temporarily uncorrelated.

2.2.1 Surface observations

Figure 1 and Figure 2 illustrate the data points of the real and simulated surface and upper-air datasets used in in this study. Figure 1 shows the observational network according to the baseline scenario in June 2023, without added simulated observations in the upper panel and the additional stations added in SC 3, which represents the most comprehensive set of new observations included (all ODA + SIDS) in the lower panel.

[2] 4D-Var is the system used at ECMWF to combine a short-range forecast with observations to produce the best possible estimate of the current state of the atmosphere. This then provides the initial conditions for a new forecast.

These figures illustrate how the new observations being tested complement the existing, real observation network. Figure 1 lower panel highlights the important gaps filled, in particular in Africa, as compared to the June 2023 baseline.

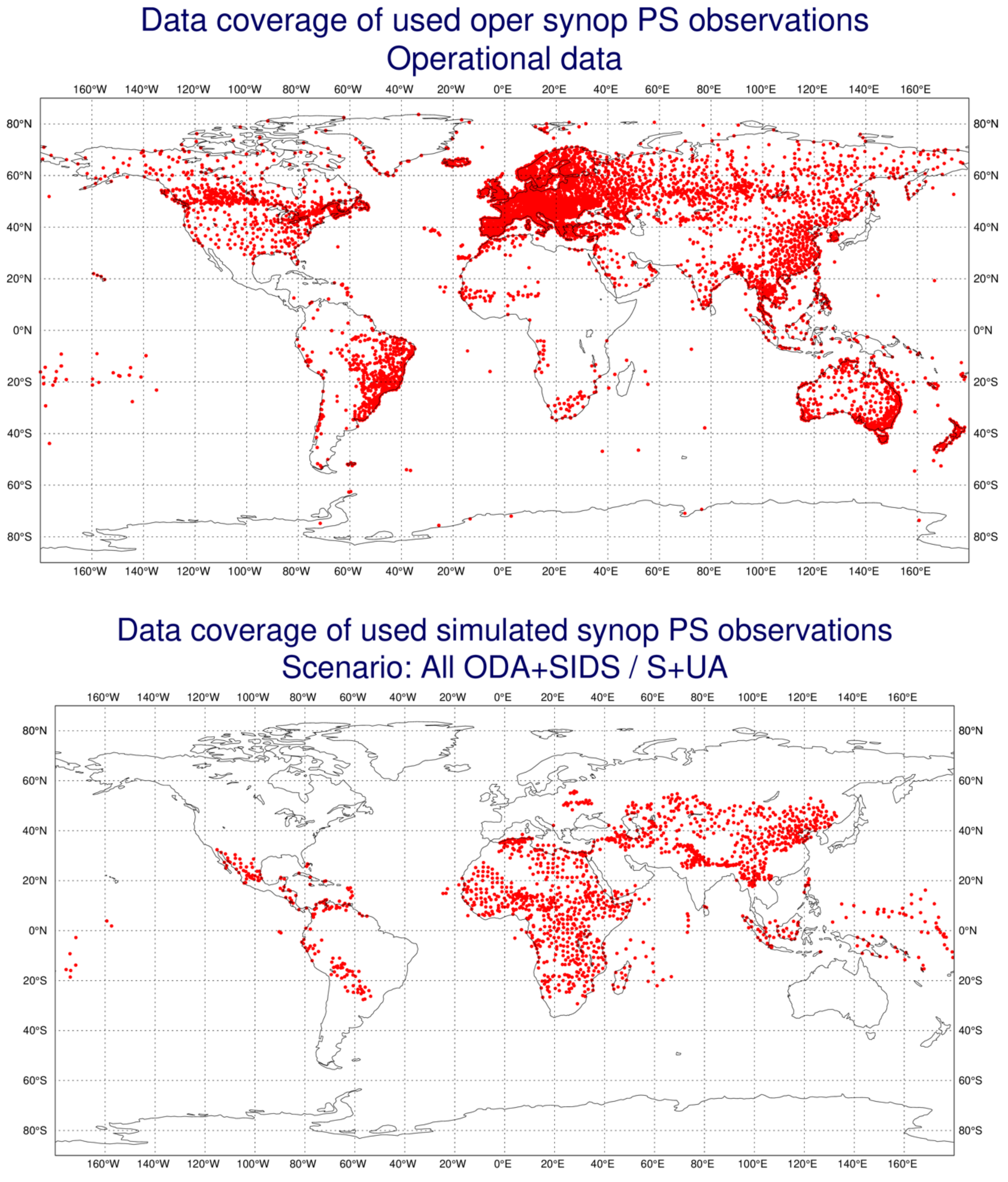
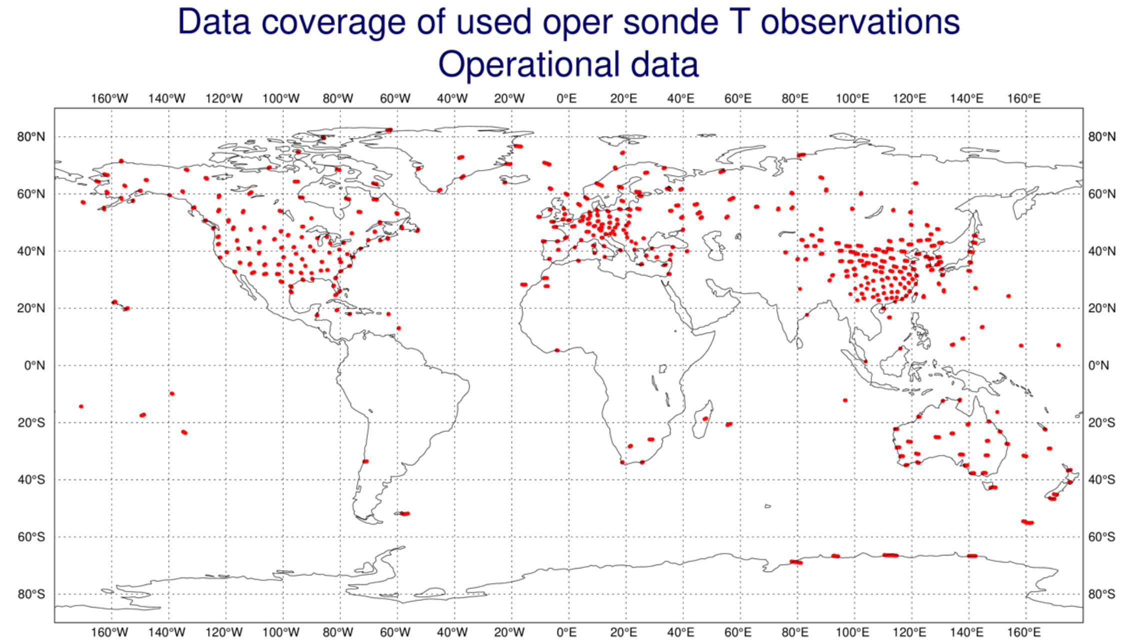


Figure 1. Spatial coverage of surface pressure measurements used in a 12-hour assimilation window on June 1, 2023. Real surface observations are shown in the upper panel and the simulated observations used in SC 3 (All ODA+SIDS / S+UA) are given in the lower panel. The spatial coverage of SYNOP (surface synoptic observations) that are near real-time surface observations of several parameters (i.e. temperature, pressure, wind speed and direction, humidity) made by staffed and automated weather stations.

2.2.2 Upper Air observations

Figure 2 demonstrates the spatial coverage of radiosondes measurements used in a 12-hour assimilation window on June 1, 2023. Radiosondes are a major source of in-situ profile data used in NWP, providing observations of several meteorological parameters by means of a small ballon-borne instrument package. The parameters measured by radiosondes are geopotential height, wind speed and direction, temperature, and humidity as a function of pressure (or height) More details on the sensors and how they are assimilated into the ECMWF system can be found in [Pauley P. and B. Ingleby, 2022]. Figure 2 lower panel demonstrates the simulated observations used in SC 3 (All ODA+SIDS / S+UA)



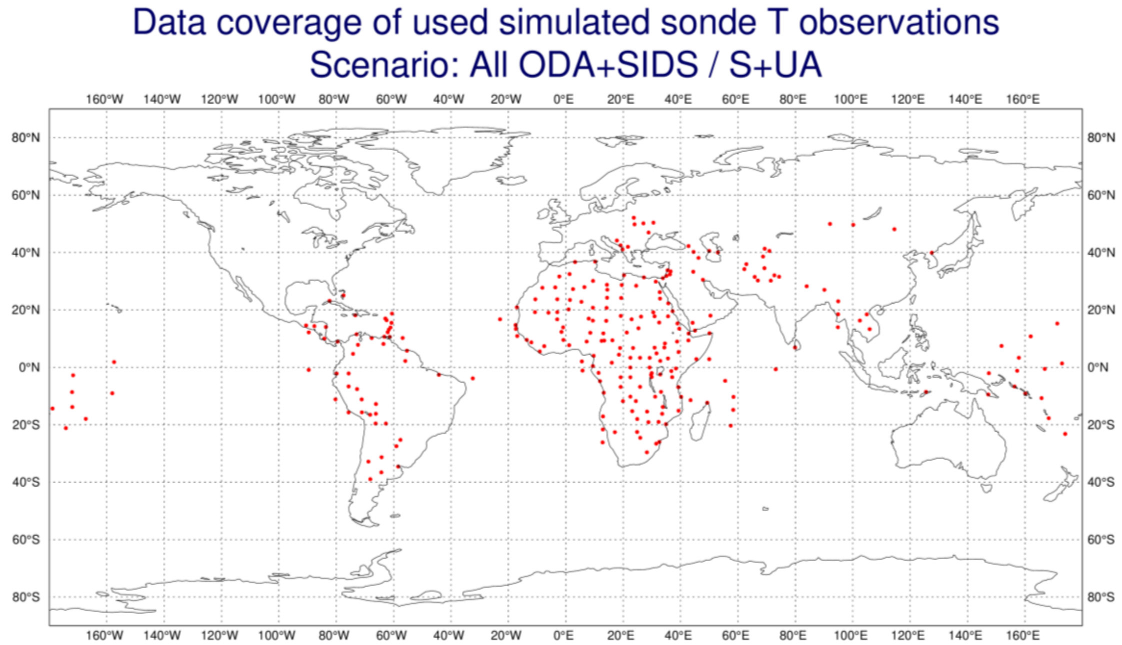


Figure 2. Spatial coverage of radiosondes measurements used in a 12-hour assimilation window on June 1, 2023. Real radiosonde observations are shown in the upper panel and the simulated observations used in SC 3 (All ODA+SIDS / S+UA) are given in the lower panel. Note, the slight horizonal drift in the location of real radiosondes, but not seen with the simulated data. The simulated radiosondes are assumed to have a fixed location in this study.

3. Results and implications for SOFF Investments

3.1. Impact of increased observations

One of the main results of the study is that the reduction in uncertainty is directly related to the number of additional observations added to the system. Table 2 outlines the number of surface, upper-air and marine stations added for each of the 8 scenarios and includes an estimate of the compliance cost. Considering that the highest number of additional simulated observations results in the largest forecast uncertainty improvements, the improvements are also directly correlated with cost of compliance. For example, the scenario with the greatest number of observations (SC 3) shows the largest improvements in uncertainty and the highest annual compliance cost. Conversely, SC 6 – the Pacific scenario – provides the smallest improvements when assessed over large areas and has the lowest annual compliance cost.

Table 2. The scenario definitions, observation numbers and expected annual compliance cost.

Scenarios		Number of surface stations (improved+new)	Number of upper-air stations (improved+new)	Number of marine stations	Expected annual compliance cost (USD)
SC 1	LDCs+SIDS | S+UA	617	135		43,597,290.8

Scenarios		Number of surface stations (improved+new)	Number of upper-air stations (improved+new)	Number of marine stations	Expected annual compliance cost (USD)
SC 2	LMICs+LDCs+SIDS | S+UA	1069	194		66,031,504.6
SC 3	All ODA+SIDS | S+UA	1709	259		93,403,055.6
SC 4	LDCs+SIDS | S+UA+marine	617	135	145	44,087,790.8
SC 5	FCS | S+UA	576	110		36,620,792.4
SC 6	Pacific | S+UA	117	19		6,7527,94.8
SC 7	Africa | S+UA	703	137		45,385,709.2
SC 8	All ODA+SIDS | UA only		259		61,388,829.0

As the reduction in uncertainty is largest where the density of new, simulated observations is greatest, the observed improvements are largest over land (Figure 3). Focusing on SC 1 for the surface, Figure 3 shows a spatial map of the percentage change in the surface pressure analysis uncertainty, when compared with the control experiment (100×(scenario – control)/control).

The plots are noisy at small scales, particularly in regions where we have not added extra observations, but there are large areas with the large spread reductions (blue areas, with spread reductions > 10 %). The largest signal – meaning the largest reduction in statistical uncertainty or EDA spread – is for Africa, where the analysis uncertainty is reduced by more than 10 % over much of the continent, with some improvements exceeding 30 %. However, there are also strong improvements in the Indian ocean and Pacific where new observations are also introduced. In general, the improvements greater than 10 % in Africa, the Indian Ocean and the Pacific are statistically significant at the 95 % level, as indicated by the diagonal “hatching” shown in the figure.

The improvements in surface pressure uncertainty shown in Figure 3 are large. To provide some context, the spread increases (or the degradation in the analysis uncertainty) from an experiment where *real surface observations* on land are removed from the baseline control experiment are shown in Figure 4. The spread increases arising from removing these observations can exceed 30 % in data rich areas of North America, Europe, Asia and Australia. The spread increases are generally smaller in Africa, reflecting that fewer surface observations are being removed there but, more positively, also indicating that improvements can be made in this region.

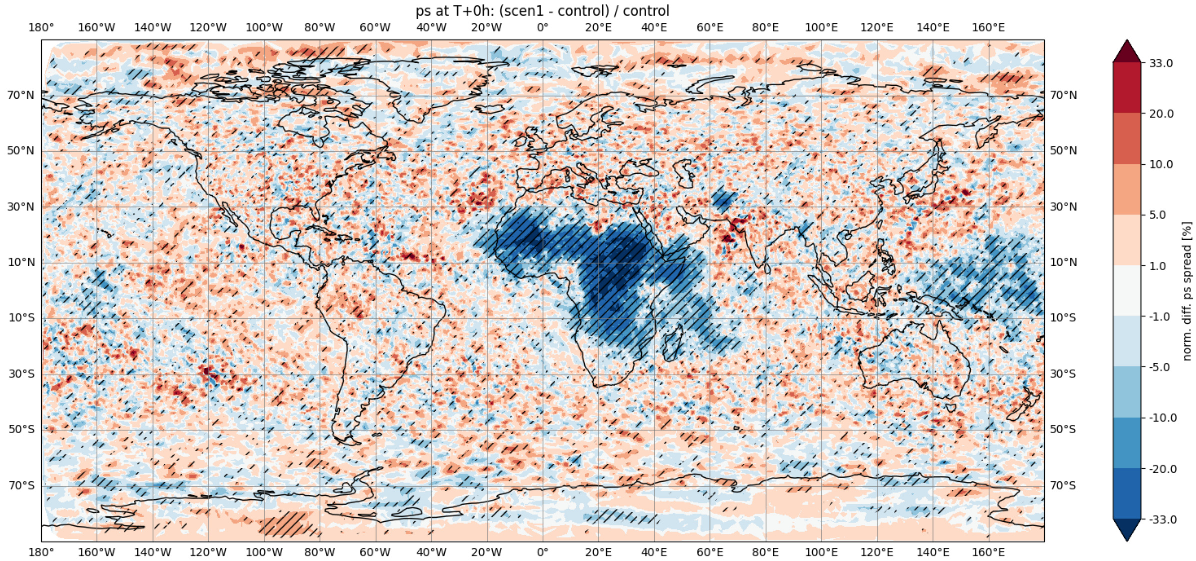


Figure 3. The percentage reduction in the surface pressure analysis uncertainty for SC 1, when compared with the control experiment for June 1-30, 2023. Negative values (blue shading) indicate the regions where the surface pressure analysis uncertainty for SC 1 is improved when compared to the control experiment. The diagonal lines superimposed on the shading indicate regions where the improvement is statistically significant at the 95 % level.

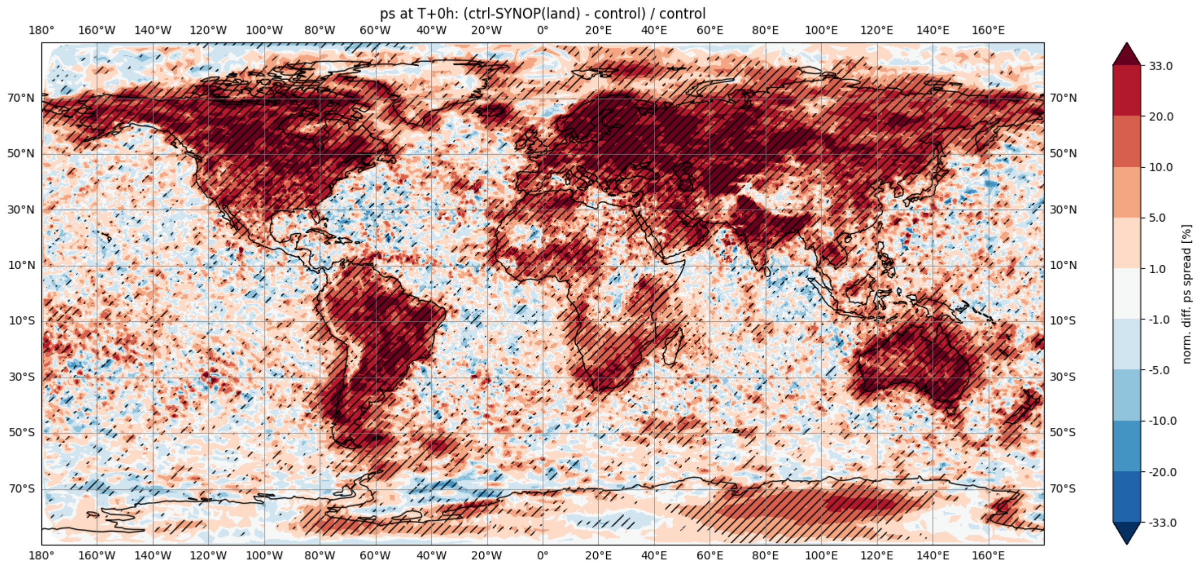


Figure 4. A spatial map of the surface pressure analysis uncertainty increases when real surface observations on land are removed from the control experiment, for June 1-30, 2023. The diagonal lines superimposed on the shading indicate regions where the change in EDA spread is statistically significant at the 95 % level.

3.2. Impact by station type

3.2.1 Impact of surface observations on surface parameters

One objective of the study was to develop a better understanding of the relative impact of surface vs upper-air stations. GBON requirements are set for both surface and upper-air observations, however to date relatively few funding mechanisms support countries with the infrastructure and human capacity for upper-air measurements. To investigate this relative impact, the study compared the reduction of uncertainty between SC 3 and SC 8. These two scenarios share the same upper-air network, but SC 8 does not include surface observations (Table 1). Figure 5 (top panel) shows the distribution of surface stations used in SC 3, and (lower panel) compares SC 3 surface pressure spread reduction with SC 8. It is clear that the surface observations make substantial contribution to combined surface plus upper-air uncertainty improvements. The uncertainty values improved by over 10 % across much of Africa, and more generally there is a strong correlation between improvements > 10 % and the locations of the additional surface observations for the 12h forecast types investigated.

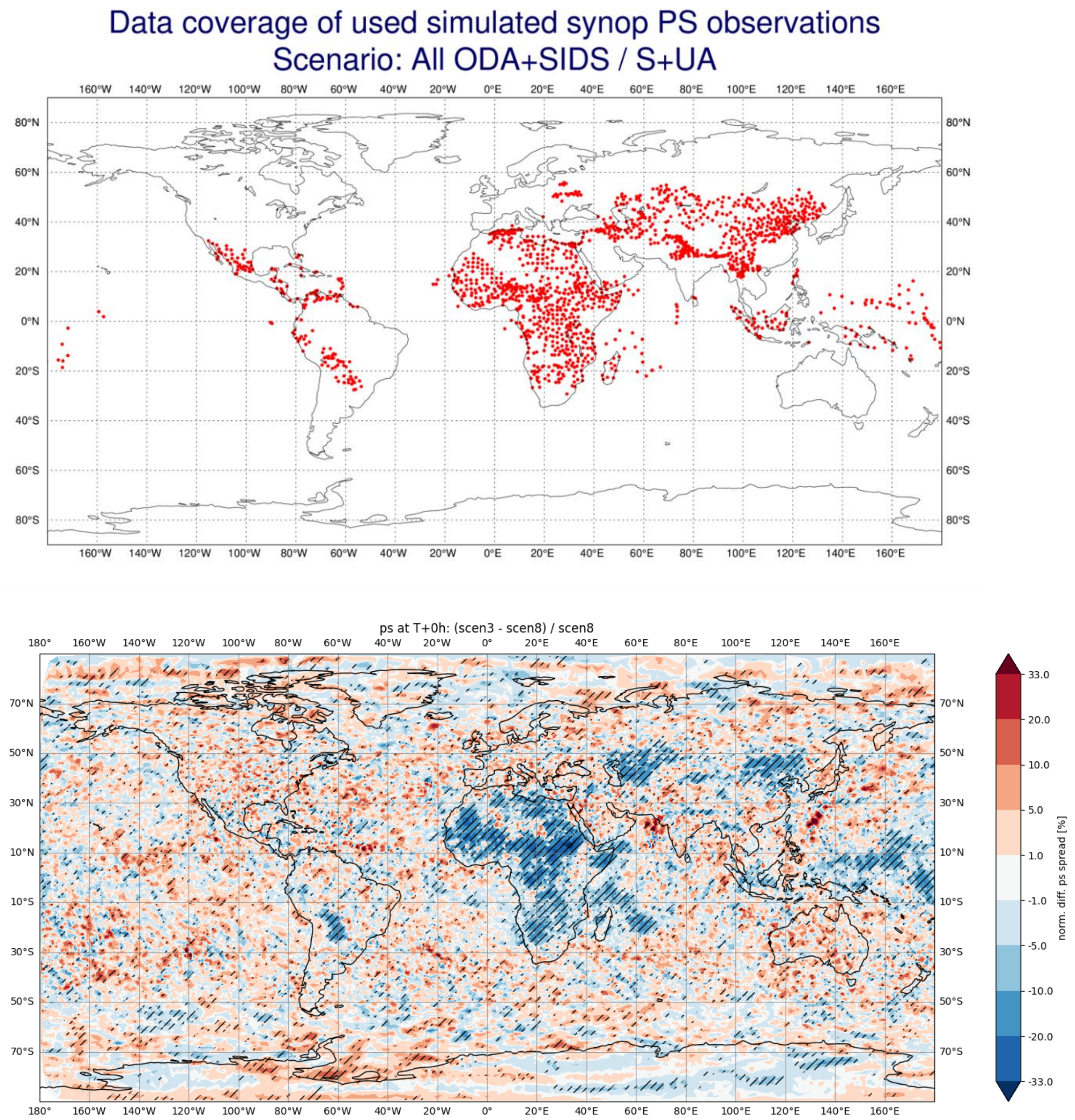


Figure 5. Upper panel: the map of surface observations used in SC 3. Lower panel: The reduction in surface pressure analysis uncertainty for SC 3 when compared with the SC 8 for June 1-30, 2025. This illustrates the impact of surface network in assimilated in SC 3 but not included in SC 8.

3.2.2 Impact of Upper Air stations

When assessing the impact of upper air observations, presenting vertical profiles of spread changes integrated over spatial areas (e.g. Northern Hemisphere, Southern Hemisphere etc.) provides additional information about the impact. Figure 6 shows the percentage changes in temperature and zonal wind spread for short-range 12-hour forecasts on a set of fixed pressure levels in the atmospheric column from near the surface (1000 hPa) up to around 35 km above the surface (5 hPa).

Improvements are seen over the entire vertical profile for both variables. The largest forecast uncertainty improvements are in the tropics, with reductions of 2 % or greater for both variables, and for all scenarios except SC 6, which is the smallest proposed change to the observing system and which focuses on the Pacific (Table 2). SC 3 provides the largest improvements in forecast uncertainty mainly because it is the largest proposed change to the observing system. The impact of the surface observations on the upper-air parameters can be seen by comparing SC 3 and SC 8. In the tropics, the surface observations provide small improvements the temperature uncertainty estimates up to around 300 hPa.

Figure 7 illustrates how observation number affects the uncertainty estimates on a given pressure level. It shows the EDA spread estimate for short-range forecasts of zonal wind at 850 hPa in the tropics, versus the number of new upper-air sites in the tropics. The uncertainty improvements are roughly linear in additional site number, and there is no indication of “saturation of observation impact” with this range of observation numbers. Saturation of observation impact is usually interpreted as the limit where adding new observations appears to have negligible additional benefit, indicating a diminishing return on investment.

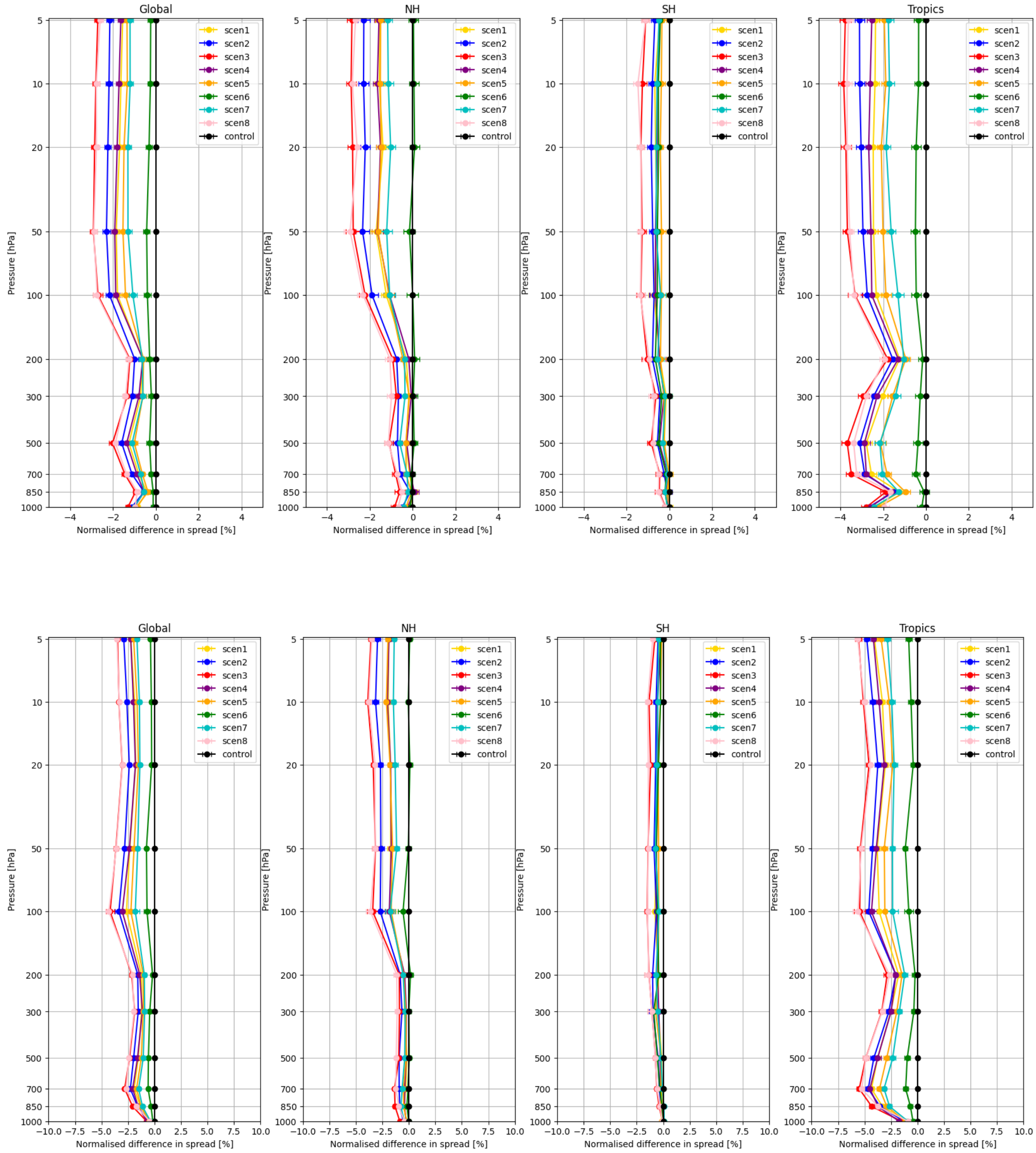


Figure 6. The percentage temperature (upper panel) and zonal wind (lower panel) spread reductions for 12-hour forecasts, relative to the control experiment given on fixed pressure levels. The spread changes are given globally and integrated over the northern hemisphere extra-tropics (NH), southern hemisphere extra-tropics (SH) and Tropics.

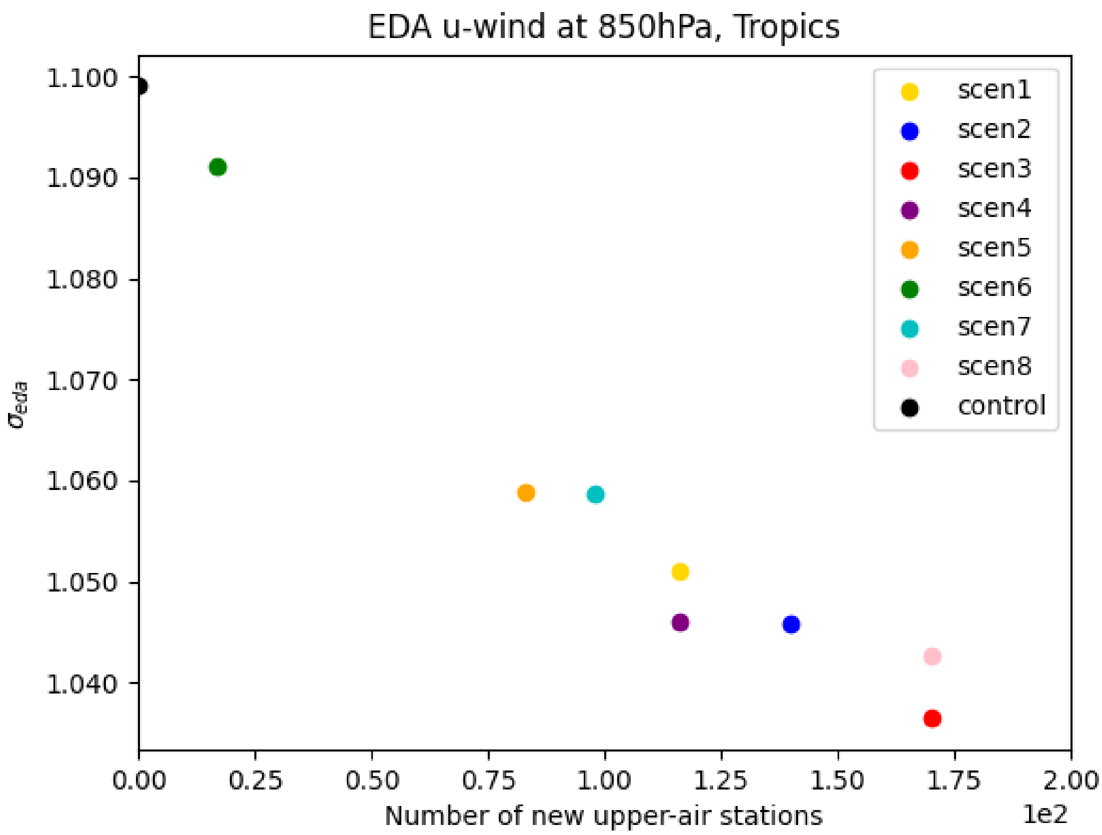


Figure 7. The change in short-range forecast uncertainty for the zonal wind (〖m s〗 ^(-1)) at 850 hPa in the tropics, plotted as a function of the number of new upper-air observation sites in the tropics.

3.2.3 Impact of marine stations

Figure 8 shows the locations of the additional marine observations introduced in SC 4 (upper panel) and compares the surface pressure uncertainty improvements for SC 4 against those obtained in SC 1. The improvements can be seen in locations of the new marine observations, reducing spread by around 5-10 % where the new observations are introduced. However, the observation density and spatial coverage new marine observations SC 4 mean that, overall, the spread reductions shown in this comparison appear to be relatively modest when compared with the large spread reductions obtained over land (e.g, Figure 3). This also reflects the small number of additional stations and therefore relatively small additional investment required.

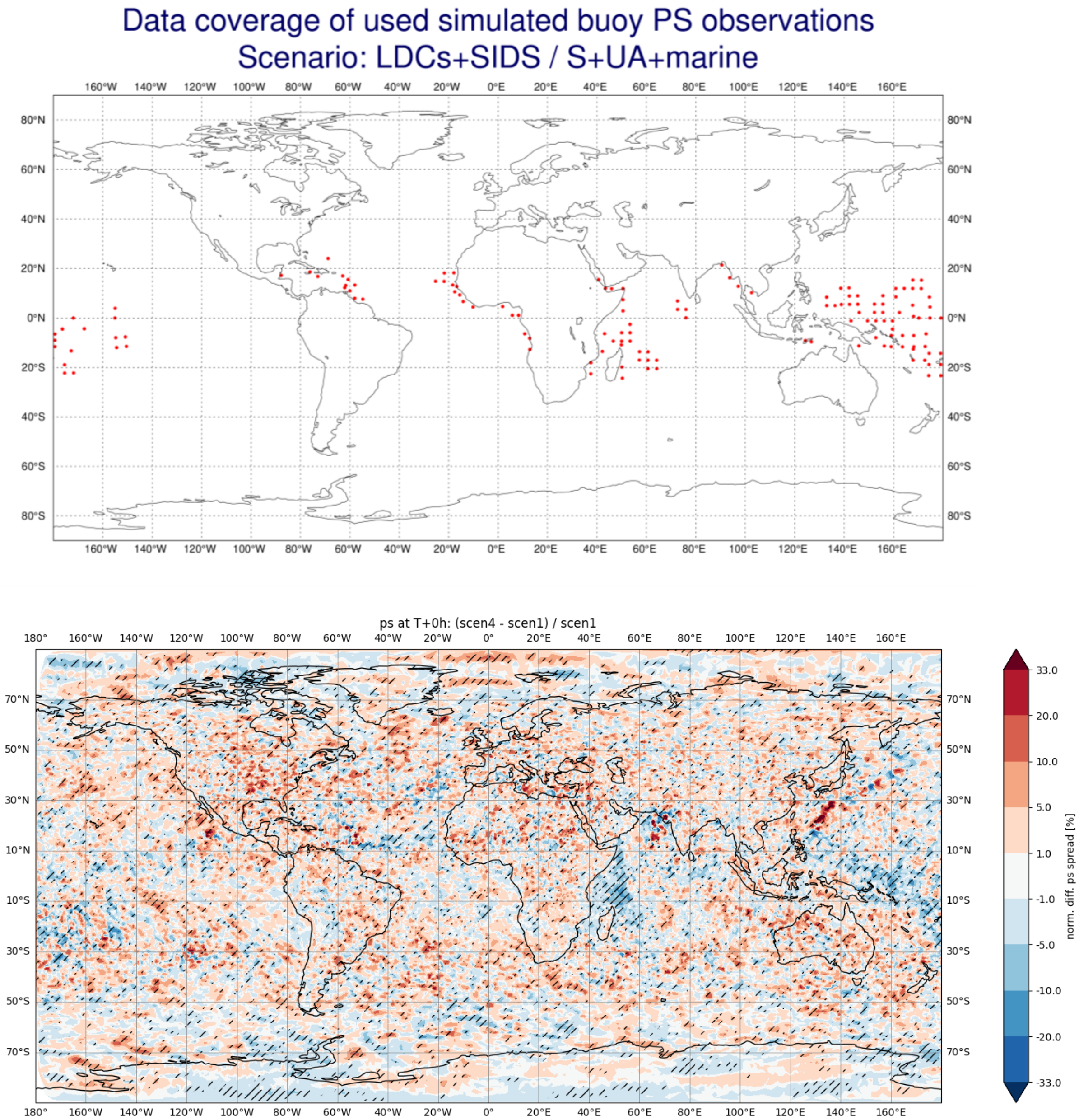
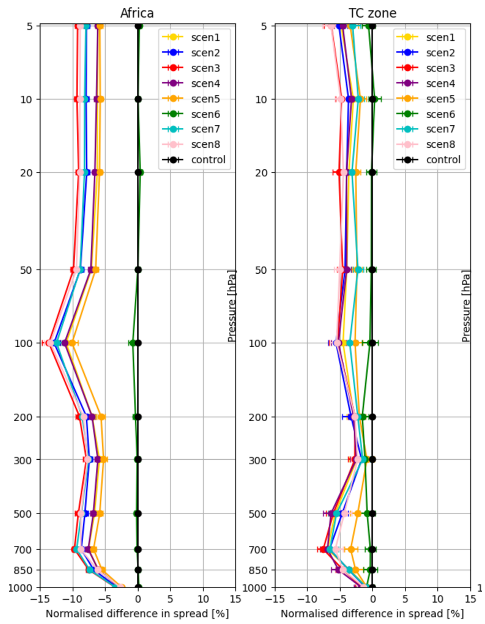


Figure 8: Upper panel: locations of marine observations used in SC 4. Lower panel: The analysis surface pressure uncertainty reductions comparing SC 4 with SC 1, for June 1-30, 2023. Blue shading indicates that the marine observations in SC 4 are reducing the surface pressure analysis uncertainty when compared with SC 1.

3.3. Impacts by region (localized impacts)

Seven of the eight scenarios represent a very considerable enhancement of the surface-based and/or upper-air observing systems in Africa (reflecting the number of LDCs and ODA-eligible countries on the continent). As a result, the analysis and forecast uncertainty is reduced significantly over most of the continent in each of these scenarios. The improvements are evident both for key surface parameters, such as surface pressure, 2m temperatures, 2m humidity and 10m wind, and for upper-air profiles of temperature, humidity and vector wind, from near the surface up to 5 hPa (35 km). However, in addition we also find some potentially important uncertainty improvements in the tropical North Atlantic, in an area known as the “main development region” (MDR) for Tropical Cyclone (TC) genesis. This is usually defined as the region within 6–18°N and 20–60°W.

The EDA results for Africa and the MDR region are shown in Figure 9. The improvements for the MDR do not mean that TC forecasts will be improved as a result of the suggested observation changes being tested. However, they do show that many of the scenarios have the potential to significantly improve the analyses and short-range forecasts for the MDR region. This is a potentially significant result that needs further investigation.



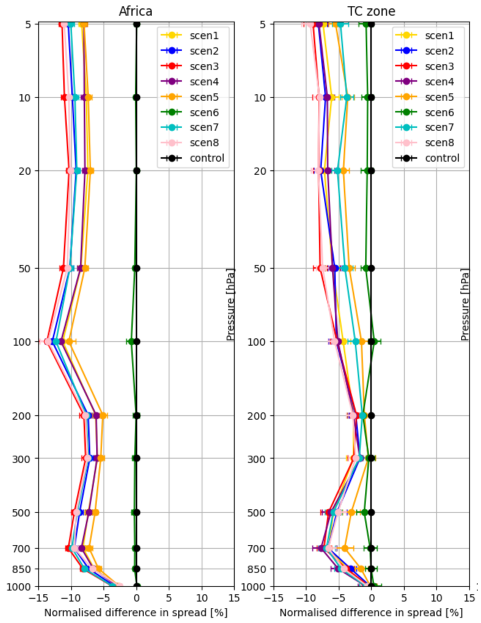


Figure 9. Zonal wind spread reductions for 12-hour forecasts for the Africa region (left) and main development region ("TC zone") (right). Similar spread reductions are found for temperature, humidity and meridional wind.

3.4. Impact of SOFF expansion scenarios

Figure 7 illustrates how the upper-air uncertainty estimates improve for 850 h Pa zonal winds, as more upper-air observation sites are added in tropics. In particular, comparing SC 1, SC 2 and SC 3 we see continued improvements in the upper-air scores as more countries are added to the simulation. These upper-air results are complemented with the additional improvements in surface pressure analyses shown in Figure 10, where SC 2 and SC 3 are compared with SC 1. It should be emphasised that SC 1, shown in Figure 3, would represent a good improvement to the global observing system, but there would be additional benefits from the more comprehensive observation networks in SC 2 and, more obviously, SC 3 in the regions where new observations are added. For example, in SC 3, we see additional improvements, > 10 %, in regions of South America and Northern and Southern Africa.

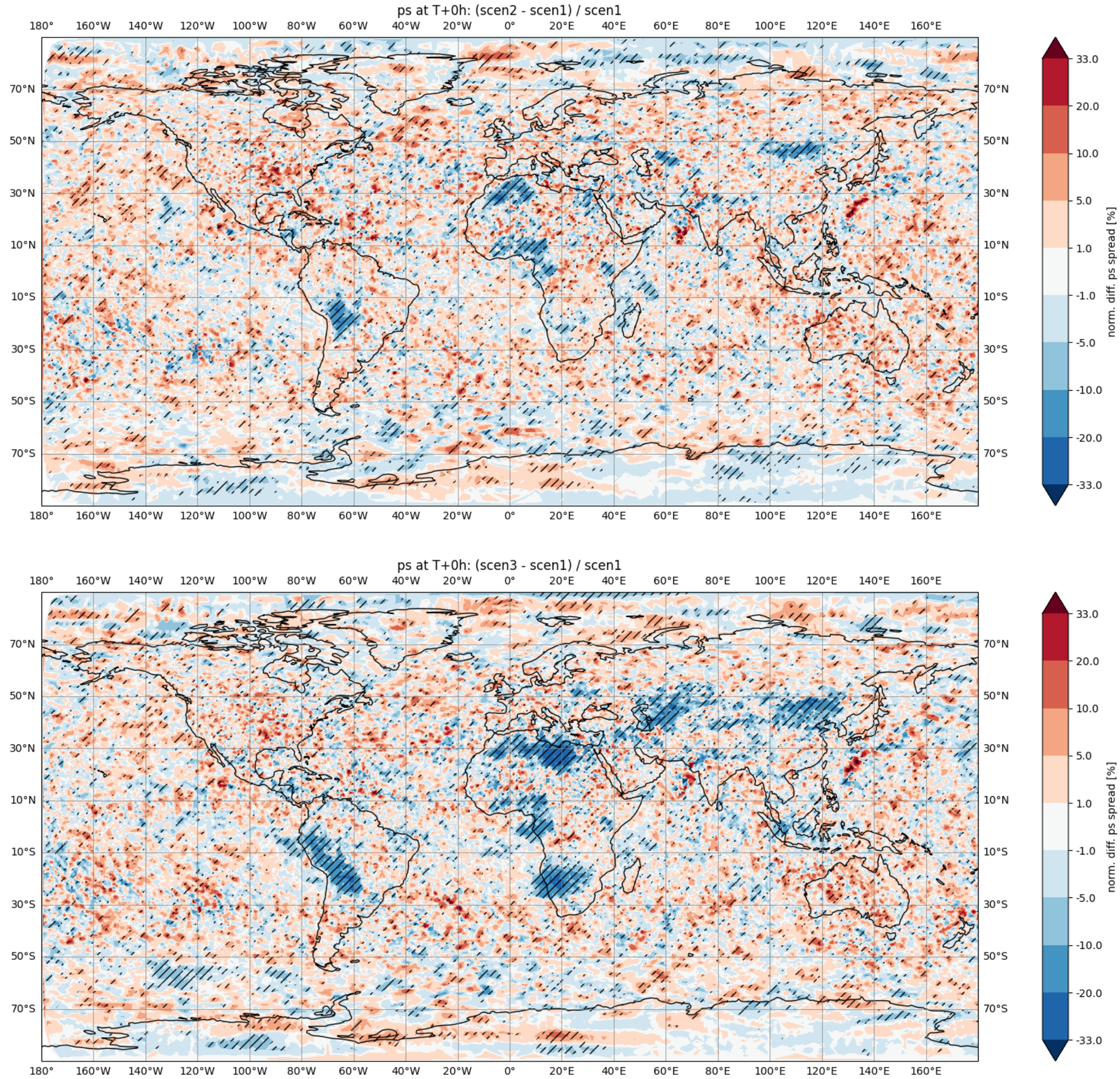


Figure 10. The additional surface pressure analysis uncertainty improvements when SC 2 is compared with SC 1 (upper) and when SC 3 is compared with SC 1(lower).

3.5. Impact of comprehensive upper-air only versus a mixed surface/upper-air

The EDA simulations enable the comparison of a comprehensive upper-air only network change for all ODA-eligible countries (SC 8), with a slightly more modest combined upper-air and surface scenario limited to LDCs, SIDS, and LMICs (SC 2). These have a roughly equivalent investment cost and represent two different pathways for funding expansion for SOFF.

Figure 11 shows the surface pressure uncertainty differences, with blue shading showing areas where the SC 2 uncertainty is lower and, conversely, red shading showing where the SC 8 uncertainty is lower. This figure compares the impact of direct observations of surface pressure in SC 2 with the surface pressure information retrieved from upper-air observations in SC 8. SC 2 has a better surface pressure analysis than SC 8 in the regions where surface pressure stations have been added. However, the more comprehensive upper-air network in SC 8 produces a better surface pressure analysis in regions where SC 8 has additional radiosondes, but SC 2 has neither radiosondes nor surface observations. The clearest example of this in Figure 11 is the large degradation (red shading), greater than 10%, in North Africa, centred around 15°N and 15°E. Similar degradations are also apparent in Southern Africa and South America, where additional upper-air observations are assimilated in SC 8. These results would suggest that investment in both surface and upper-air stations in a smaller number of countries is generally better than upper-air stations only in a larger number of countries.

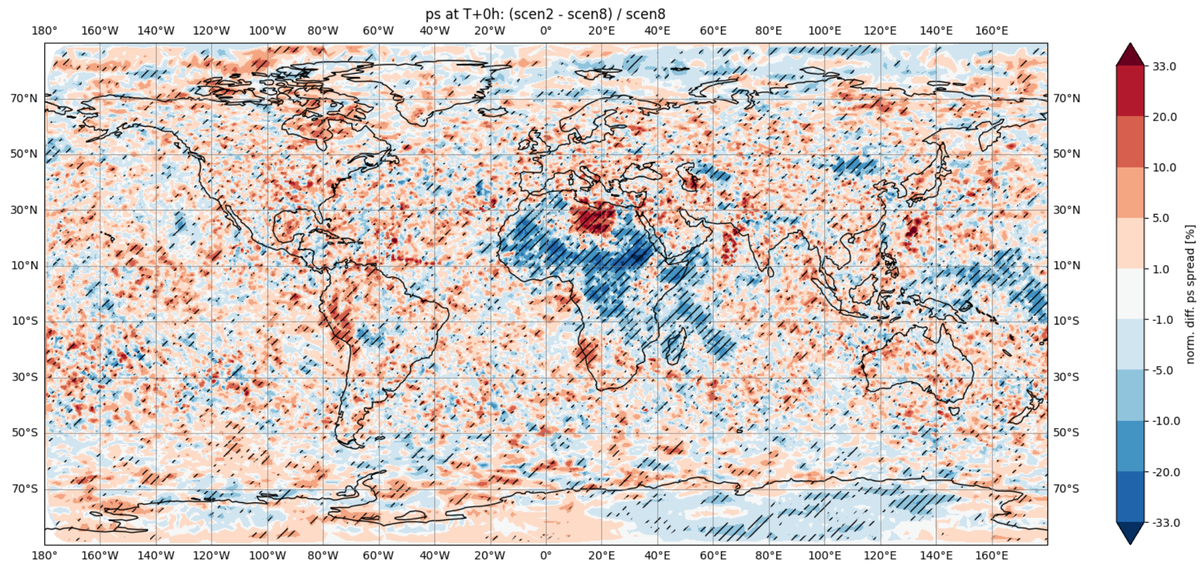


Figure 11. The percentage difference in surface pressure analysis uncertainty comparing scenario 2 with SC 8. Blue shading indicates that SC 2 has a smaller surface pressure uncertainty than SC 8.

4. Next steps

4.1. Investigating longer-range forecasts

As discussed above, the EDA provides useful information for analyses and short-range forecast uncertainty, but validity of this method for longer forecast ranges is questionable because it fails to reproduce realistic forecast error growth.

In contrast, the ECMWF ensemble prediction system (ENS) provides *reliable* forecast uncertainty information with realistic error growth for the medium-range. The ENS system is initialised using a combination of both the EDA output plus additional perturbations based in singular vectors. (The singular vectors are currently required to ensure realistic error growth, but the long-term goal is for the ENS system to be initialised with just the EDA). It may be possible to estimate the medium-range forecast impact of new observations using the current ENS system. This would be done by comparing medium-range ENS spread estimates produced with EDA perturbations and singular vectors generated both with and without the new simulated datasets. This approach has not been tried before, and the work would be proof of concept. The generation of simulated data would be the same, but it would require running both the ECMWF EDA and ENS systems (or, perhaps, a more efficient AI based ENS "emulator"), and it would certainly require longer experiments to achieve statistically significant results for the medium-range. However, in principle it would generalise the results provided in this study.

Alternatively, the medium-range impact could be assessed in a more conventional observing system simulation experiment (OSSE), although OSSEs are not currently performed at ECMWF.

4.2. Further investigation of tropical cyclone genesis

The experiments demonstrate that the additional observations in Africa would result in important uncertainty improvements in the tropical North Atlantic, in an area known as the "main development region" (MDR) for Tropical Cyclone (TC) genesis. Due to the importance globally for TC genesis, one area for future investigation would be assessing the impact of removing all currently available observations from the MDR region to assess their impact on TC forecasts. The ENS approach above could be used to investigate the reduction in medium-range forecast for TC forecasts over a full season.

4.3. Impact study with Artificial Intelligence (AI) Forecasting System

ECMWF just launched its open-source Artificial Intelligence Forecasting System AIFS single forecast model. For the first time, the model has been implemented using the *Anemoi* framework. *Anemoi* consists of Python-based open-source components, enabling users to run the software themselves. The SOFF Secretariat and ECMWF are exploring opportunities to engage the private sector to run the open-source code of the AIFS model using simulated SOFF data (including synthetic radiosondes) to determine the improvement of forecasts if SOFF (Global Basic Observation Network) were to be achieved.

Linked to this work, ECMWF and other partners are interested in the "democratization" of forecasting and making machine learning more available to developing countries. Early discussions with ECMWF and private partners have proposed to develop 'Forecast-in-a-Box' which will bring the opportunities for edge-computed weather forecasting, allowing users to run the entire weather prediction workflow on the infrastructure of their choice. These workflows can be customised to the users' particular requirements, the products and plots they want to produce, and improve efficiency by producing the data close to the downstream data usage.

References

Lean, K., Bormann, N., Healy, S., English, S., Schüttemeyer, D. & Drusch, M. (2025) Assessing forecast benefits of future constellations of microwave sounders on small satellites using an ensemble of data assimilations. *Quarterly Journal of the Royal Meteorological Society*, e4939.

Pauley P, Ingleby B (2022) Assimilation of in-situ observations. In: Park SK, Xu L (eds) Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications (Vol. IV). Springer. Pages 293-371 in https://link.springer.com/book/10.1007/978-3-030-77722-7