Forecast Sensitivity to Observations Impact (FSOI) by country or region

Forecasting Research

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Contents

Abstract

Forecast sensitivity to observation impact (FSOI) is used to partition observation impacts from the Met Office global numerical weather prediction (NWP) system according to the country or region of origin. Results are considered separately for surface and space-based observations. Satellites operated by the USA and Europe contribute 82% of all space-based FSOI. For surface-based observations, geographic regions are defined using simple combinations of latitude-longitude boxes and impacts are considered with and without aircraft data. In terms of total relative impact, the largest contribution comes from Asia. As expected, the largest impact per (surface) observation comes from Antarctica, followed by South America and Africa. Since the regions are different sizes we also consider the impact per unit of surface area. With aircraft data, there are four regions with equally large FSOI – North America, Central America and Caribbean (NAM CAM Carib); Europe; South America; Asia – whilst Africa and SW Pacific have only around half the impact per area. When aircraft are excluded, there are large reductions in the mean impact per area for NAM CAM Carib and South America due to high proportion of aircraft reports in these regions.

Introduction

Forecast Sensitivity to Observations Impact (FSOI) (Lorenc and Marriott, 2013) is a technique to measure the impact on forecast error due to the assimilation of each individual observation. FSOI is an efficient tool to diagnose observation impacts, since all impacts are produced simultaneously and can easily be aggregated in terms of the different space- and surface-based observing system components.

The Met Office FSOI system uses a global, moist energy norm, calculated from the surface up to 150 hPa. Forecasts are performed at full model resolution (N1280, ~10 km), with the 4D-Var analysis at lower resolution (N320, ~40 km). Forecasts are only considered at lead times of 24 hours. Note that negative FSOI values indicate a beneficial impact, i.e. a reduction in forecast error.

Considering all observation types assimilated (Figure 1 and Appendix b), according to FSOI the largest overall contributions to forecast error reduction come from IASI (13.8% of total impact) and AMSU-A (13.6%). These are followed by geostationary atmospheric motion vectors (AMVs) (10.6%) and aircraft reports (10.5%). Space-based observations contribute 75.9% of the FSOI from 94.3% of the total number of observations. Surface-based observations contribute 24.1% of the FSOI from 5.7% of all observations. Hence we find that the mean impact *per observation* is higher from surface-based observations (surface -1.4×10^{-6} Jkg^{-1}, space -0.26×10^{-6} Jkg^{-1}).

The largest contributions by observing technology (Figure 2 and Appendix c) are from microwave sounders and imagers (29%), followed by hyperspectral IR sounders (27%), and AMVs (12%). Aircraft remain the largest contributor from the surface-based technologies.

In this study, we partition impacts from FSOI according to the country or region of origin of the observation. Impacts are considered for the period 25 September 2018 to 12 January 2019 (operational suite version OS41). For space-based observations it is straightforward to define the origin, since we can use the country or region of the satellite operator or space agency. For surface-based observations we can define geographical regions to represent ownership or the origin of the observation. This involves some approximations as not all observations over the land area of a country are funded by that country.

Only observations operationally assimilated in the Met Office global NWP system are considered in this study. Note that some other observations were available but not assimilated, mainly because they were newly available and not yet adequately assessed.

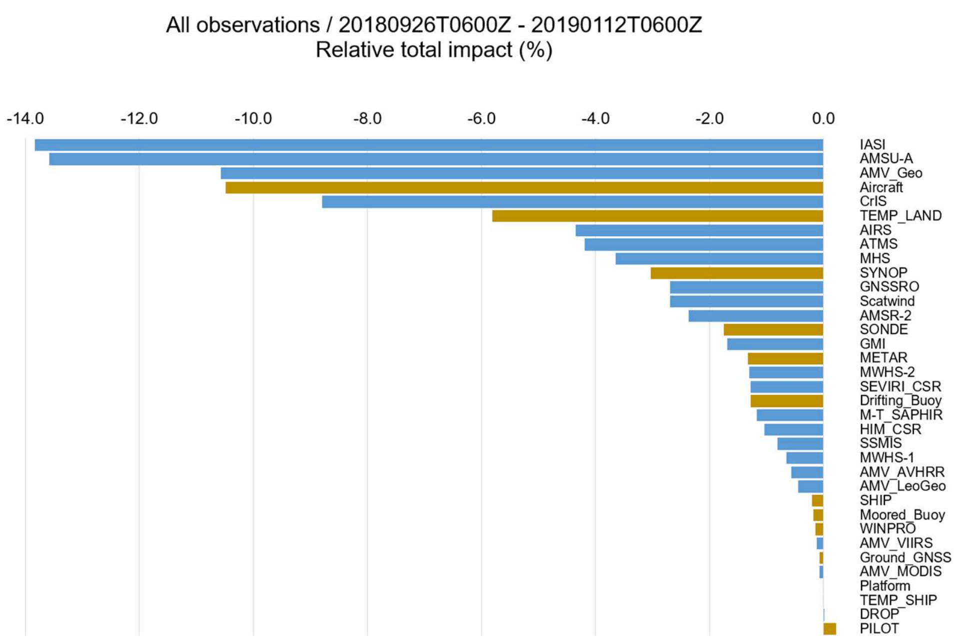

Figure 1. Relative FSOI for all observations assimilated in the Met Office global NWP system. The impact is expressed as the percentage of the total impact on 24 hr forecast error. Space-based observations are coloured blue, whilst surface-based observations are coloured gold. The observation type acronyms are explained in Appendix b.

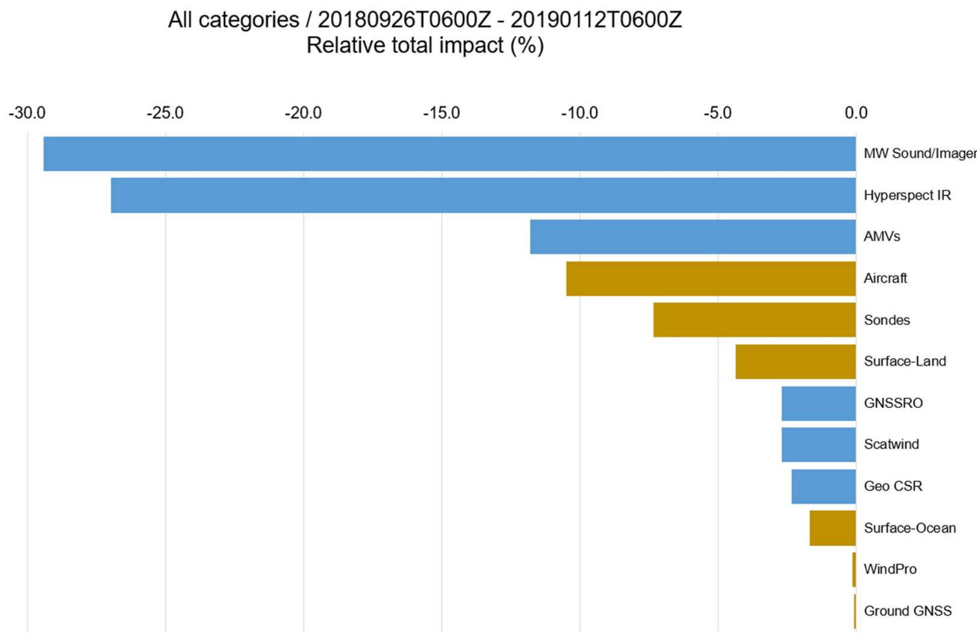

Figure 2. Relative FSOI for all observation technologies assimilated in the Met Office global NWP system. The impact is expressed as the percentage of the total impact on 24 hr forecast error. Space-based observing technologies are coloured blue, whilst surface-based observing technologies are coloured gold. The acronyms are explained in Appendix c.

Space-based impacts

Space-based observations are partitioned according to the satellite operator or space agency:

USA: Terra, Aqua, NOAA-15, NOAA-18, NOAA-19, NOAA-20, Suomi-NPP, GOES-E, GOES-W, F-17, Coriolis

Europe: Metop-A, Metop-B, Meteosat-8, Meteosat-11

Japan: Himawari-8, GCOM-W

China: FY-3B, FY-3C

India: Scatsat-1

USA-Taiwan: COSMIC

India-France: Megha Tropiques

USA-Japan: GPM

LeoGeo: LeoGeo AMV

For space-based observations, the largest contributors to forecast error reduction are the USA (43%) and Europe (39%) (Figure 3) and these provide by far the largest number of observations assimilated (Figure 5). In terms of the mean impact per observation, the largest contribution is from the LeoGeo Atmospheric Motion Vectors, which don't belong to a single agency/country since they are winds derived from composites of different geostationary and polar imagers. The highest impact per observation (Figure 4) from a single country is Japan, which is largely due to Himawari-8. The next highest impact is from USA-Taiwan (i.e. COSMIC radio occultation observations). Impacts per observation for other countries are quite similar to each other.

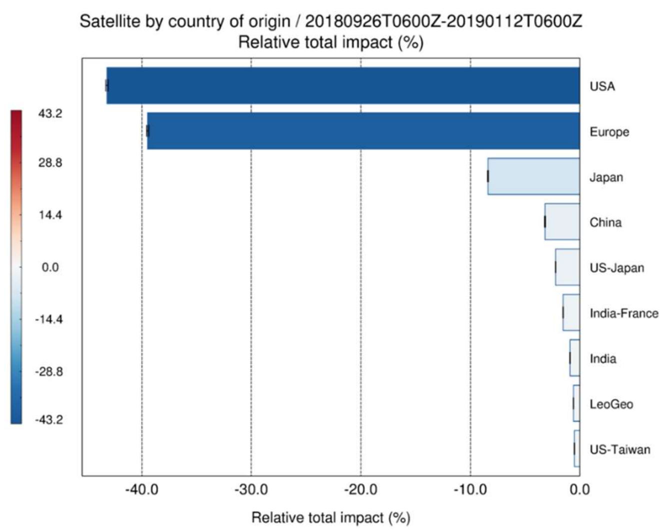

Figure 3. Relative FSOI for space-based observations aggregated by satellite operator. The impact is expressed as the percentage of the total "space-based impact" on 24 hr forecast error. The list of satellites included within each category is given in the main text.

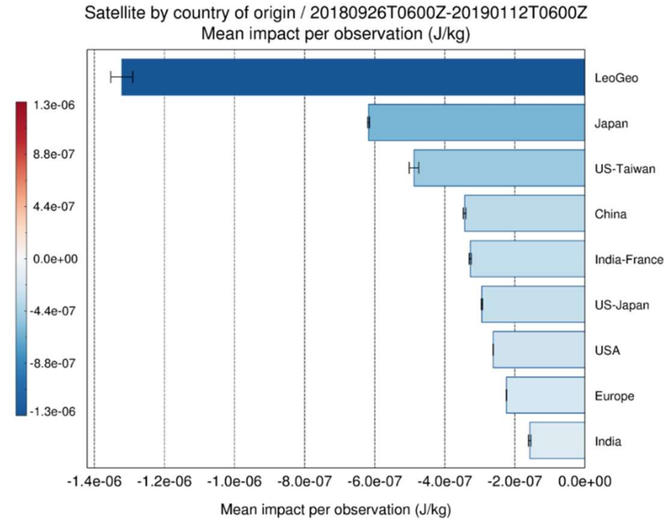

Figure 4. Mean impact per observation for space-based observations aggregated by satellite operator.

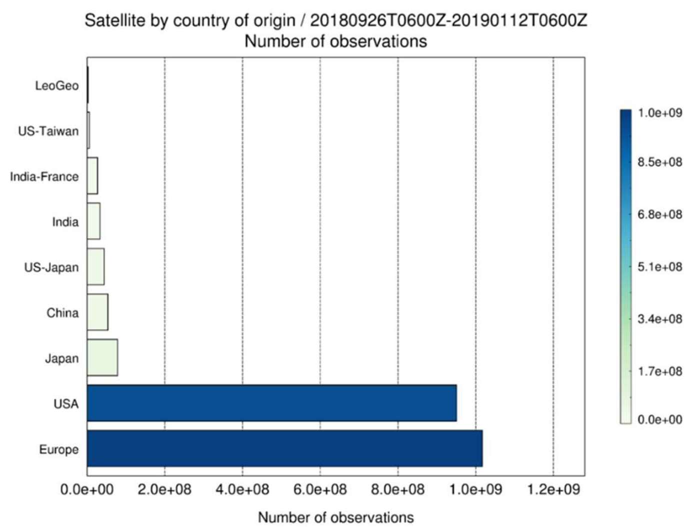

Figure 5. Number of space-based observations assimilated, aggregated by satellite operator.

Surface-based impacts

For surface-based observations we partition impacts by geographical regions using combinations of latitude-longitude boxes (Figure 6). Regions are based loosely on the 6 WMO regions (http://www.wmo.int/pages/prog/dra/regional_offices.php) but restricted to mainly include land areas only. Antarctica is added as a 7th region. Region 4, North America, Central America and the Caribbean is abbreviated to “NAM CAM Carib”.

Notes on the region boundaries:

- Africa includes Mauritius to the east
- Asia includes the Maldives to the south
- NAM CAM Carib includes Saint-Paul Island, most of the Aleutian Islands, and Alert station in the Arctic

Partitioning using latitude and longitude should be a reasonable approach for “stationary” surface-based reports, but less useful for “mobile” reports. For this reason we exclude drifting buoys (1.3% of total impact from *all* observations) and ship reports (0.2% of total impact) as the location of each of these observations bears little relation to the country that operates these systems. Aircraft data (10.5% of total impact from *all* observations) also cross between regions, however there are a large proportion of flights within a region which can be considered to belong to that region.

Since aircraft are one of the largest contributors to FSOI, surface-based impacts are presented with aircraft data included (Table 1) and aircraft data excluded (Table 2) from the observing system.

The ranking of the relative FSOI for each region is fairly similar when aircraft data are included or excluded (Figure 7). In both cases the largest contribution comes from Asia. When aircraft data are excluded, the regions which increase their impact share are Asia, SW Pacific, and Antarctica. For Europe there is little change in the relative impact. The regions which see the largest drop in impact share when aircraft data are excluded are South America and NAM CAM Carib. These are the two regions for which aircraft data make up the highest proportion of surface observations (see Figure 8).

In terms of the mean impact per observation, the ranking of the regions is the same with and without aircraft data included (Figure 9). The highest impact per surface-based observation comes from Antarctica, followed by South America and Africa. Unsurprisingly these correspond to the regions with the lowest number of surface-based observations (Figure 8). Similarly we find that the regions with the lowest mean impact per observation, Europe and NAM CAM Carib, are those with the highest number of surface-based observations.

Lastly, because the 7 regions are not of equal size we can consider the mean impact per unit of surface area (Figure 10). In this case the presence of aircraft data does have a large effect on the ranking of the regions.

When aircraft data are included, there are 4 regions with similarly large mean impacts: NAM CAM Carib, Europe, South America, and Asia. Africa and SW Pacific have around half the impact per unit of surface area compared to the leading regions.

The regions which see the largest drop in mean impact per unit area when aircraft data are excluded are South America and NAM CAM Carib. This again highlights the importance of aircraft data to the impact from these two regions. With aircraft excluded, the region with the largest mean impact per unit area is Asia.

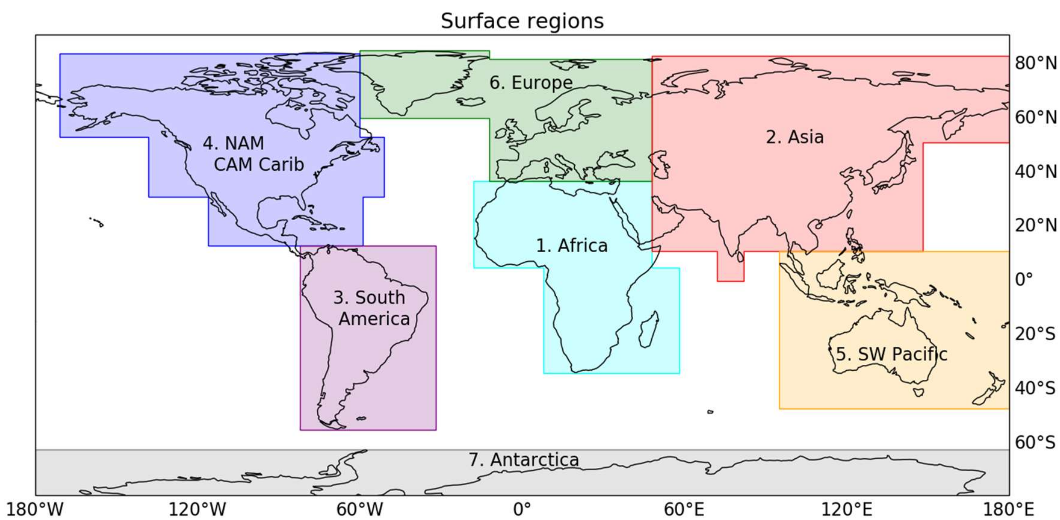

Figure 6. Map of regions used for partitioning surface-based impacts. This is to illustrate the latitude and longitude boxes used to construct each region. Note the map projection is misleading in terms of the size of each region so actual surface areas are given in Table 1.

Region	Surface Area (million km^2)	Mean impact per ob (x10^{-6} Jkg^{-1})	Number of obs	Total impact (Jkg^{-1})	Relative total impact (%)	Mean impact per million km^2
1 – Africa	47.0	-3.50	4820511	-16.9	10.6	-0.36
2 – Asia	64.2	-1.97	21904361	-43.1	27.1	-0.67
3 – South America	36.7	-3.74	6795447	-25.4	16.0	-0.69
4 – NAM CAM Carib	45.6	-0.77	43887279	-33.7	21.2	-0.74
5 - SW Pacific	55.2	-2.19	9819759	-21.5	13.6	-0.39
6 – Europe	21.7	-0.42	35588470	-14.9	9.4	-0.69
7 – Antarctica	27.8	-5.18	651599	-3.4	2.1	-0.12

Table 1. Surface-based FSOI statistics by region, including aircraft observations.

Region	Surface Area (million km^2)	Mean impact per ob (x10^{-6} Jkg^{-1})	Number of obs	Total impact (Jkg^{-1})	Relative total impact (%)	Mean impact per million km^2
1 – Africa	47.0	-2.30	3475486	-8.0	9.1	-0.17
2 – Asia	64.2	-1.61	18312443	-29.5	33.5	-0.46
3 – South America	36.7	-3.60	2860948	-10.3	11.7	-0.28
4 – NAM CAM Carib	45.6	-0.58	25129164	-14.7	16.7	-0.32
5 - SW Pacific	55.2	-1.75	7848482	-13.8	15.6	-0.25
6 – Europe	21.7	-0.28	30290171	-8.5	9.7	-0.39
7 – Antarctica	27.8	-5.11	645258	-3.3	3.7	-0.12

Table 2. Surface-based FSOI statistics by region, excluding aircraft observations. Note that the relative impacts without aircraft data are scaled so they still sum to 100%.

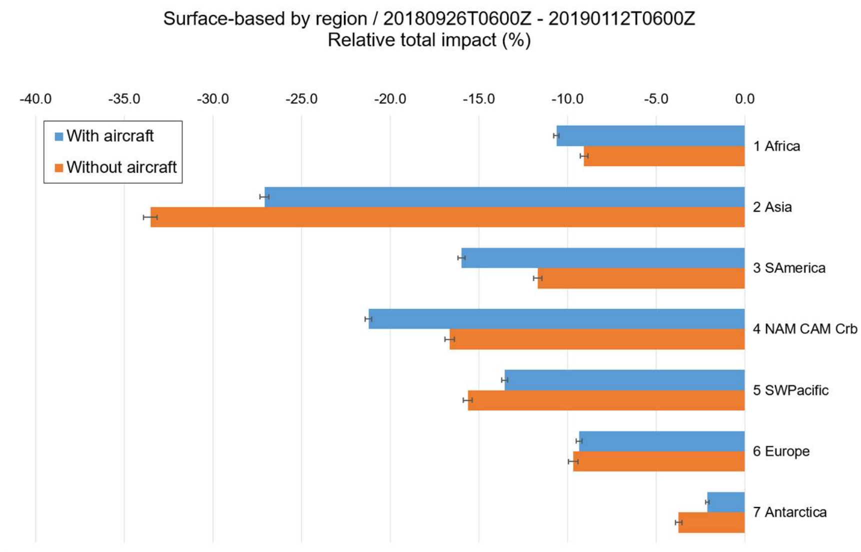

Figure 7. Relative FSOI for surface-based observations aggregated by region. Impacts are shown with aircraft reports included (blue bars) and excluded (orange bars). The impact is expressed as the percentage of the total "surface-based impact" on 24 hr forecast error, where for each observing system (with and without aircraft) the relative impacts sum to 100%.

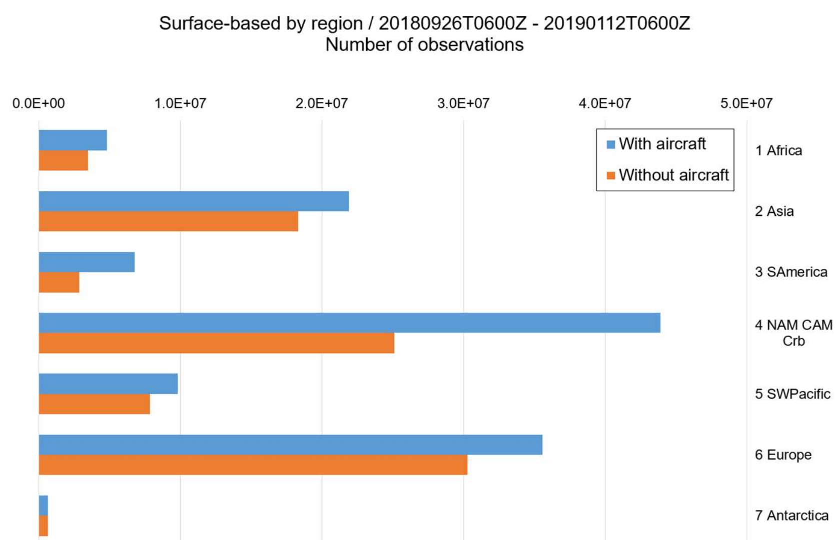

Figure 8. Number of surface-based observations assimilated, aggregated for each region. Numbers are shown with aircraft reports included (blue bars) and excluded (orange bars).

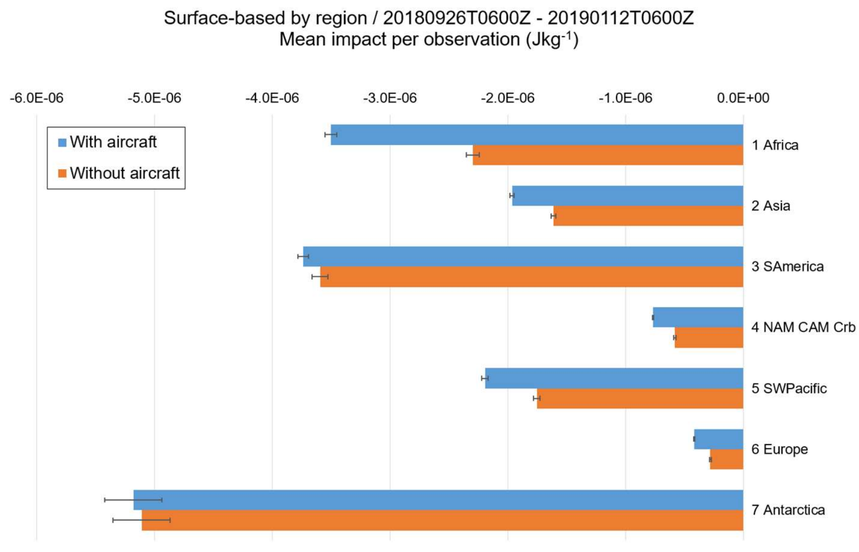

Figure 9. Mean impact per observation for surface-based observations aggregated by region. *Impacts are shown with aircraft reports included (blue bars) and excluded (orange bars).*

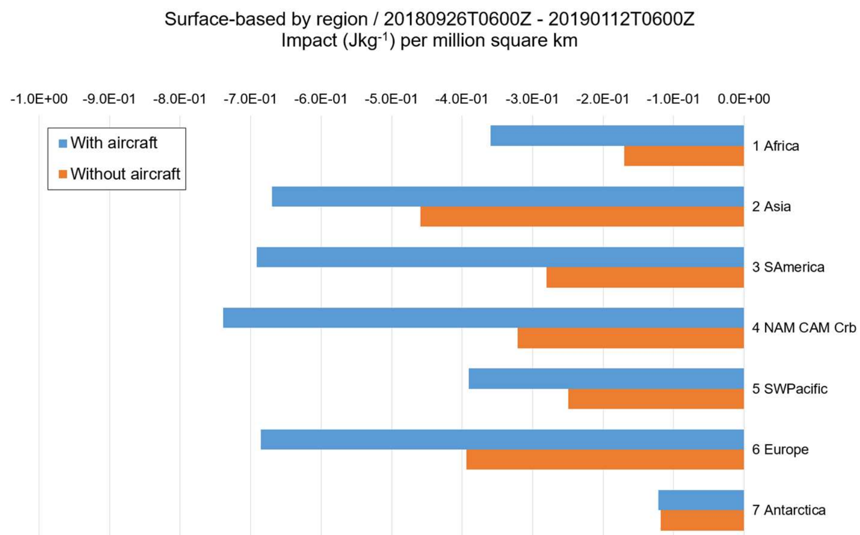

Figure 10. Mean impact of surface-based observations per surface area of each region. Impacts are shown with aircraft reports included (blue bars) and excluded (orange bars).

Conclusions

Satellites operated by agencies in the USA and Europe are clearly the largest contributors to forecast error reduction for space-based observations, together making up 82% of all space-based FSOI. Excluding LeoGeo winds, the largest impact on a per observation basis is from Japan, largely due to Himawari-8 being one of only two Japanese satellites assimilated.

For surface-based observations the impacts are considered with and without aircraft data. The regions which see the biggest change in impact when aircraft data are excluded are South America and NAM CAM Carib, as these are the regions for which aircraft data make up the highest proportion of surface observations.

In terms of total relative impact, the largest contribution comes from Asia and the overall rankings are similar with and without aircraft data.

It is somewhat unsurprising that the largest impact on a per observation basis comes from Antarctica. It is found that the regions with the highest mean impacts per observation (Antarctica, South America and Africa) are also the regions that have the lowest number of surface-based observations.

The presence of aircraft data is important when we consider the mean impact per unit surface area of each region. When aircraft are included, NAM CAM Carib, Europe, South America, and Asia all have similarly large mean FSOI per unit area, whilst Africa and SW Pacific have around half the impact. When aircraft excluded, we find the region with the largest mean impact per unit area is Asia.

This study has taken a simplified approach to partitioning surface-based impacts using latitude-longitude boxes. The accuracy of the statistics could be improved by instead using the individual call signs or station identifiers associated with the reports to more accurately assign each observation to the country which the observation “belongs” to. Creating the control files for such a study would be a far more labour intensive task than that undertaken here however.

References

Lorenc, A. C. and Marriott, R. T. (2013) Forecast sensitivity to observations in the Met Office Global numerical weather prediction system. *Q. J. R. Meteorol. Soc*., **140**, 678, pp 209-224

Appendix: acronym lists

a) Space agencies

CMA – China Meteorological Administration

EUMETSAT – The European Organisation for the Exploitation of Meteorological Satellites

JMA – Japan Meteorological Agency

CNES – Centre National d'Etudes Spatiales (France)

NASA – The National Aeronautics and Space Administration (USA)

NOAA – The National Oceanic and Atmospheric Administration (USA)

b) Observation types in Figure 1

Aircraft – Aircraft Meteorological Data Relay (AMDAR) and Aircraft Report (AIREP) from commercial aircraft.

AIRS – Atmospheric InfraRed Sounder on the Aqua satellite, operated by NASA.

AMSR-2 – Advanced Microwave Scanning Radiometer-2 on the GCOM-W satellite.

AMSU-A – The Advanced Microwave Sounding Unit-A on the Metop series of satellites operated by EUMETSAT, and the NOAA-X series of satellites operated by NOAA.

AMV_AVHRR – Atmospheric Motion Vectors (AMVs) (wind vectors) derived from sequences of satellite images from the AVHRR on the Metop series of satellites operated by EUMETSAT, and the NOAA-X series of satellites operated by NOAA.

AMV_Geo – Atmospheric Motion Vectors (AMVs) (wind vectors) derived from sequences of geostationary satellite images.

AMV_LeoGeo – Atmospheric Motion Vectors (AMVs) (wind vectors) derived from composites of low earth orbit and geostationary images.

AMV_MODIS – Atmospheric Motion Vectors (AMVs) (wind vectors) derived from sequences of satellite images from the MODIS on the Aqua and Terra satellites, operated by NASA.

AMV_VIIRS – Atmospheric Motion Vectors (AMVs) (wind vectors) derived from sequences of satellite images from the VIIRS on Suomi NPP, operated by NASA.

ATMS – Advanced Technology Microwave Sounder on the Suomi NPP and NOAA-20 satellites, operated by NASA.

CrIS – Cross-track Infrared Sounder on the Suomi NPP and NOAA-20 satellites, operated by NASA.

Drifting_Buoy – Drifting buoys.

DROP – Radisonde that is dropped from a plane.

GMI – GPM Microwave Imager on the GPM Core Observatory, operated by NASA.

GNSSRO – Global Navigation Satellite System (GNSS) radio occultation

Ground_GNSS – Ground-based Global Navigation Satellite System (GNSS) measurements of Zenith Total Delay (ZTD).

HIM_CSR – Clear sky radiances from the Himawari series of satellites operated by JMA.

IASI – The Infrared Atmospheric Sounding Interferometer on the Metop series of satellites operated by EUMETSAT.

METAR – Aviation weather report, typically from airports.

MHS – Microwave Humidity Sounding on the Metop series of satellites operated by EUMETSAT, and NOAA-18/19 operated by NOAA.

Moored_Buoy – Moored buoys.

M-T_SAPHIR - Sondeur Atmospherique du Profil d'Humidite Intertropicale par Radiometrie, on the Megha-Tropiques satellite operated by CNES.

MWHS-1 – Micro-Wave Humidity Sounder-1 on the FY-3B satellite, operated by CMA.

MWHS-2 – Micro-Wave Humidity Sounder-2 on the FY-3 series of satellites, operated by CMA.

PILOT – Pilotsonde, balloon with only measurements of wind speed and direction.

Platform – Reports from fixed platforms or oil rigs.

Scatwind – 10m ocean surface wind vectors (ambiguous) from scatterometers and passive microwave.

SEVIRI_CSR – Clear sky radiances from SEVIRI on the Meteosat Second Generation satellites.

SHIP – Ship reports.

SONDE – Radiosonde reports in BUFR code.

SSMIS – Special Sensor Microwave - Imager/Sounder on DMSP-F17 satellite.

SYNOP - surface synoptic observations.

TEMP_LAND – Radiosonde reports made over land in TEMP code.

TEMP_SHIP – Radiosonde reports made from ships in TEMP code.

WINPRO – Wind profilers.

c) Observing technology in Figure 2

Aircraft – as in Appendix b.

AMVs – Atmospheric Motion Vectors.

Geo CSR – Clear sky radiances from geostationary imaging satellites.

GNSSRO – as in Appendix b.

Ground GNSS – as in Appendix b.

Hyperspectral IR – Hyperspectral infrared sounders (AIRS, IASI, CrIS).

MW Sound/Imager – Microwave sounders and imagers (ATOVS, ATMS, M-T SAPHIR, MWHS-1/2, AMSR-2, SSMIS, GMI).

Scatwind – as in Appendix b.

Sondes – Radiosondes (TEMP LAND, TEMP SHIP, dropsondes, PILOT).

Surface-Land – Land-based surface observations (SYNOP, METAR).

Surface-Ocean – Ocean-based surface observations (Moored buoys, drifting buoys, ships, platforms)

WindPro – Wind profilers.

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