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# User Requirements for Aircraft-Based Observations Over the Next Ten Years

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# Current State of ABO

- **Two basic types of aircraft data available for operational NWP**
  - **AMDAR**—WMO program to provide data specifically for meteorological use
    - FM-42 AMDAR is the traditional ASCII format.
    - AMDAR BUFR template version 7 is currently used for more than 95% of aircraft data.
  - **AIREP**—ICAO program primarily to provide over-ocean flight-level position reports
    - Traditional voice reports use the ASCII AIREP format and have virtually disappeared.
    - Automated ADS reports can be reported in either AIREP format or included in AMDAR.
    - Typically reported by flight number rather than tail number.
- **Most reports include aircraft identifier, latitude, longitude, pressure altitude, temperature, wind direction, and wind speed.**
  - Registration (tail) number is preferred over flight number for QC purposes.
  - AMDAR reports also include flight phase (ascent, descent, level) and a roll angle flag.
  - A subset of AMDAR reports also include humidity.

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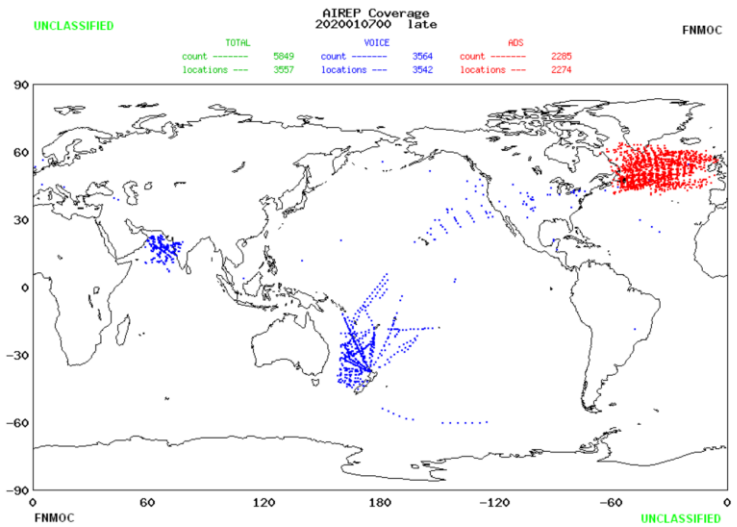


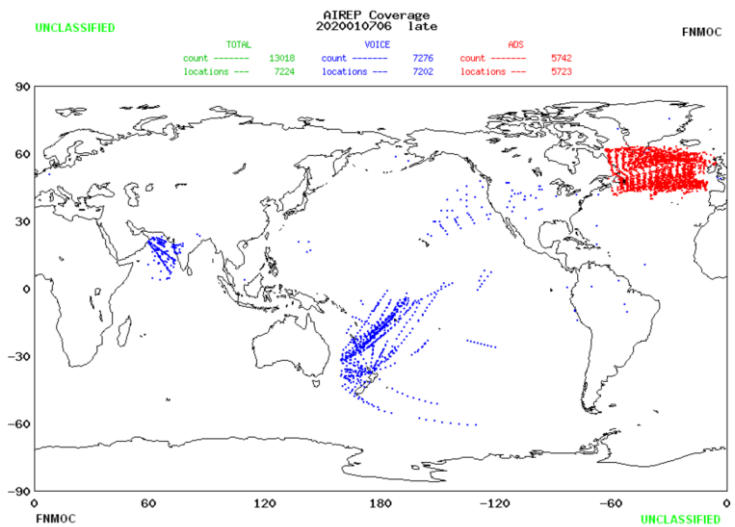


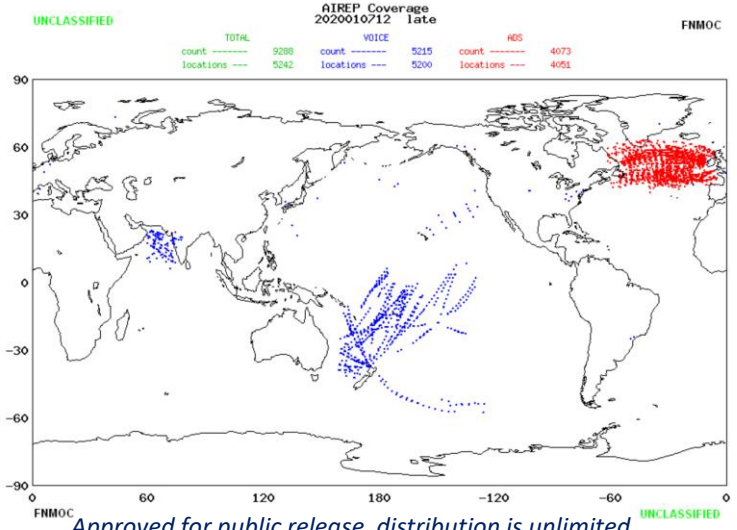


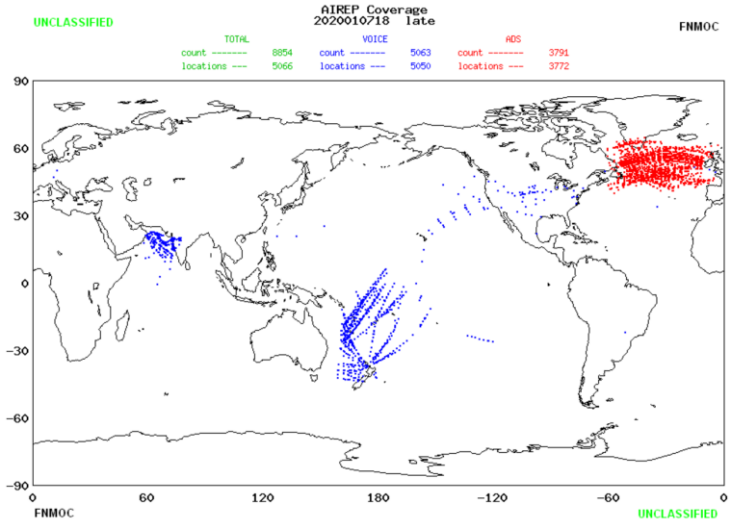


## FNMOC Coverage Diagrams

- Data available for use in NWP in the time window $t_0$-3 hrs to $t_0$+3 hrs, that arrive by $t_0$+8 hrs ("late data cut")
- Aircraft data provided in the ICAO ASCII AIREP format
- Format originally used for voice position reports along oceanic routes at mandatory reporting points, with winds, temperatures, and locations, heavily rounded
- Virtually all AIREPs at present are automated ADS ("Automatic Dependent Surveillance") position reports, with precision similar to AMDAR
- North Atlantic ADS-AIREP reports identifiable because of tail numbers included
- ~3k obs per day assimilated



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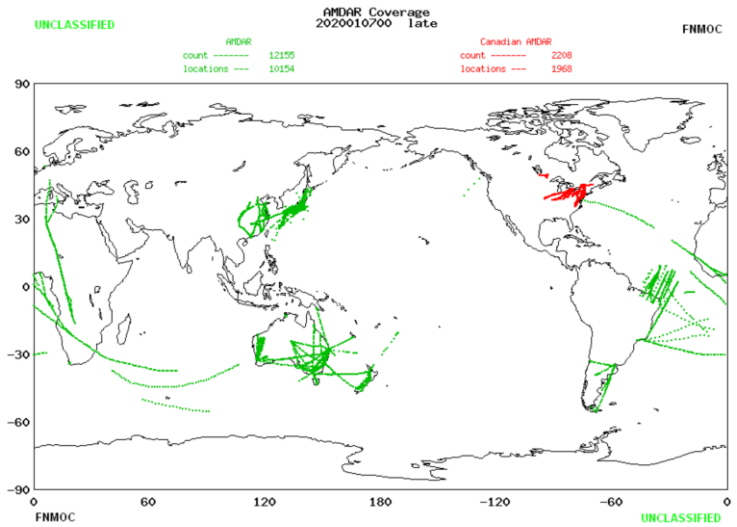


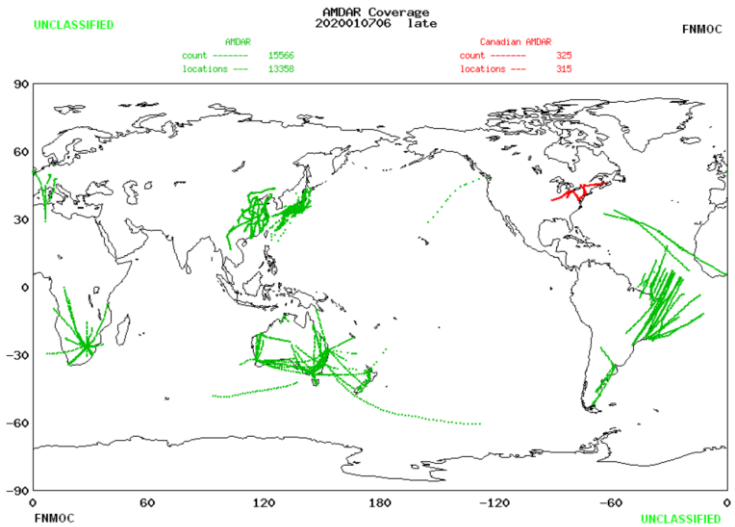


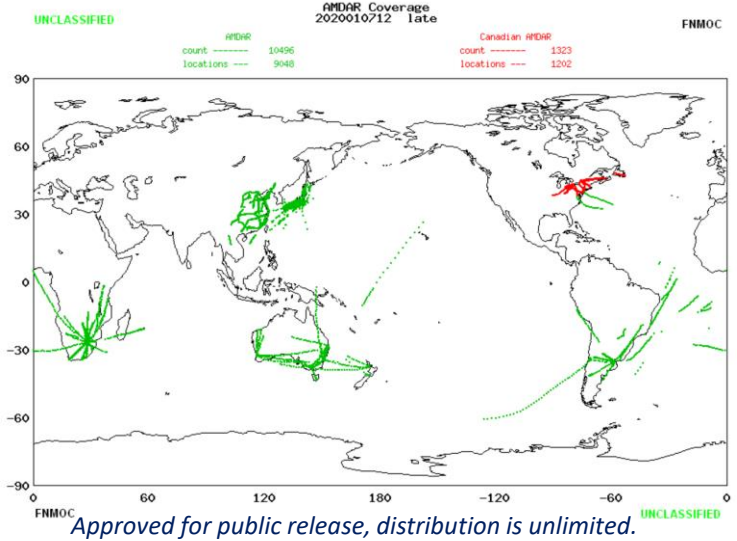


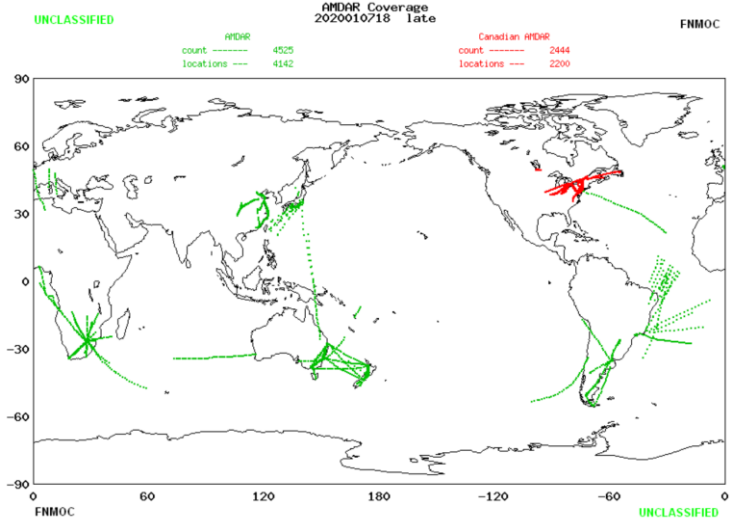


## FNMOC Coverage Diagrams

- Data available for use in NWP in the time window $t_0$-3 hrs to $t_0$+3 hrs, that arrive by $t_0$+8 hrs ("late data cut")
- Aircraft data provided in ASCII AMDAR FM-42 (green) or non-standard BUFR (red)
- FM-42 was the main format used for many years, but most countries have now switched over to BUFR.
- ~21k obs per day assimilated



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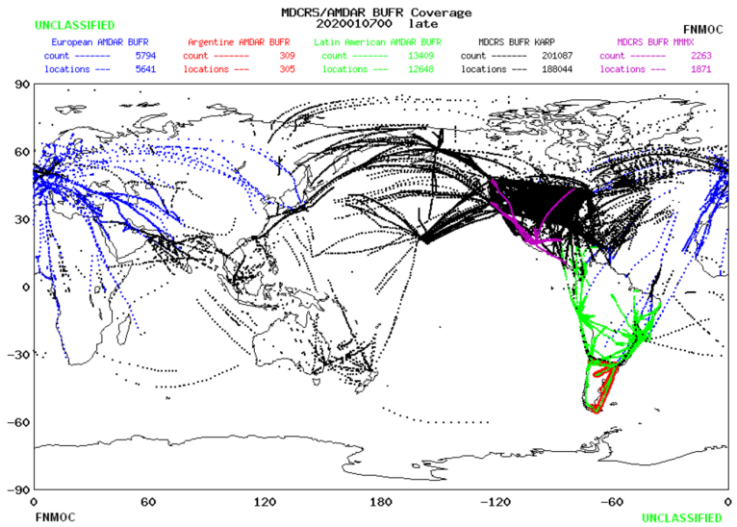


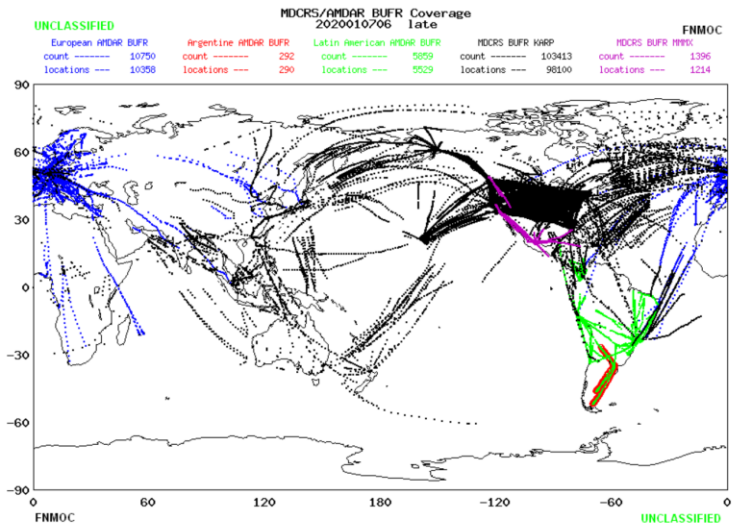


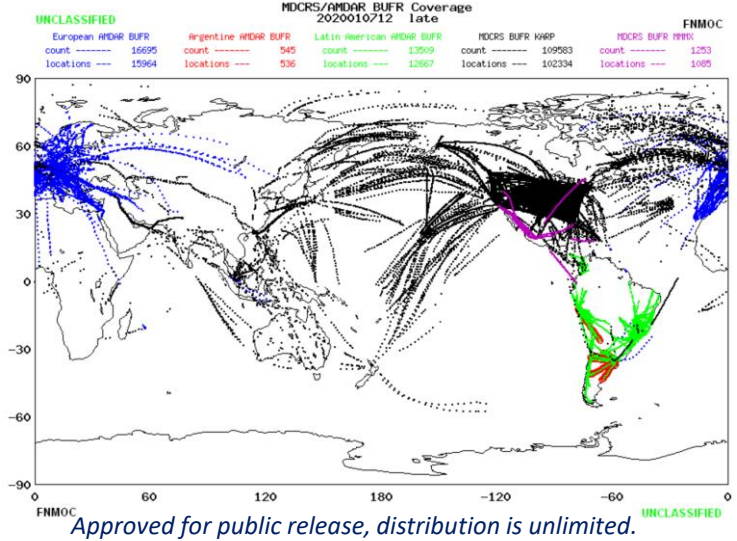


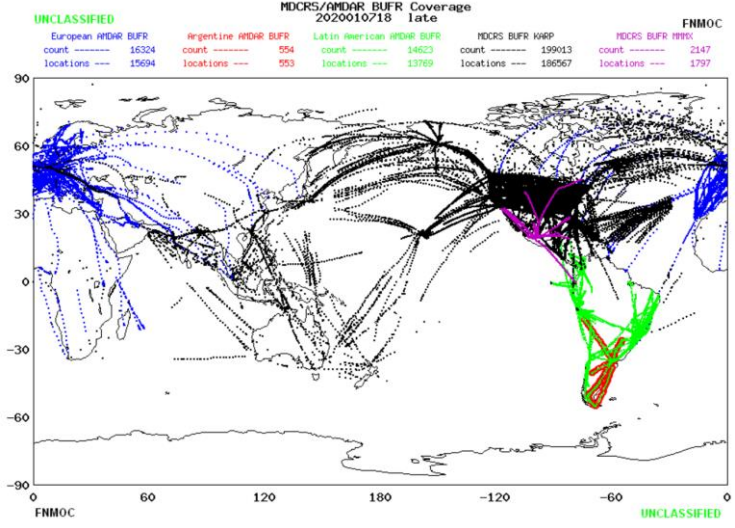


## FNMOC Coverage Diagrams

- Data available for use in NWP in the time window $t_0$-3 hrs to $t_0$+3 hrs, that arrive by $t_0$+8 hrs ("late data cut")
- Aircraft data provided using the AMDAR BUFR template version 7
- ~97% of aircraft observations used in NWP
- Large geographic differences
  - Land vs ocean
  - NH vs SH
- Temporal differences
- ~1M obs per day assimilated



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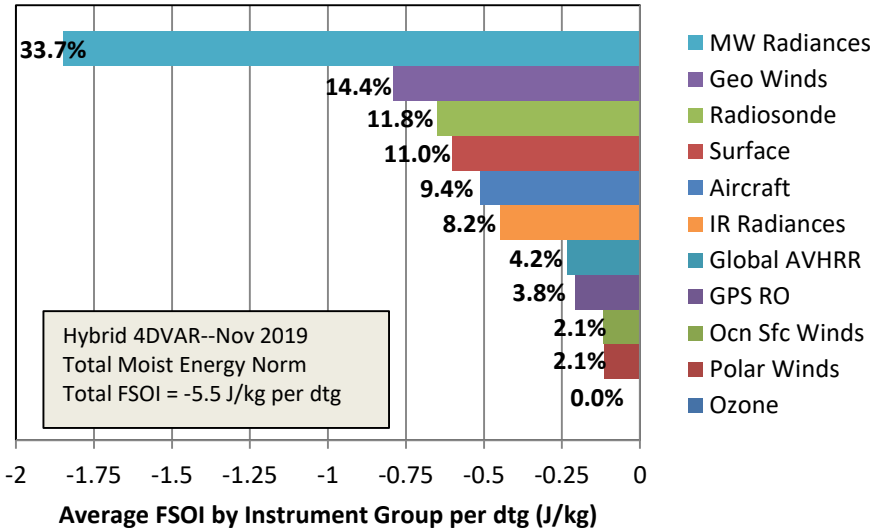
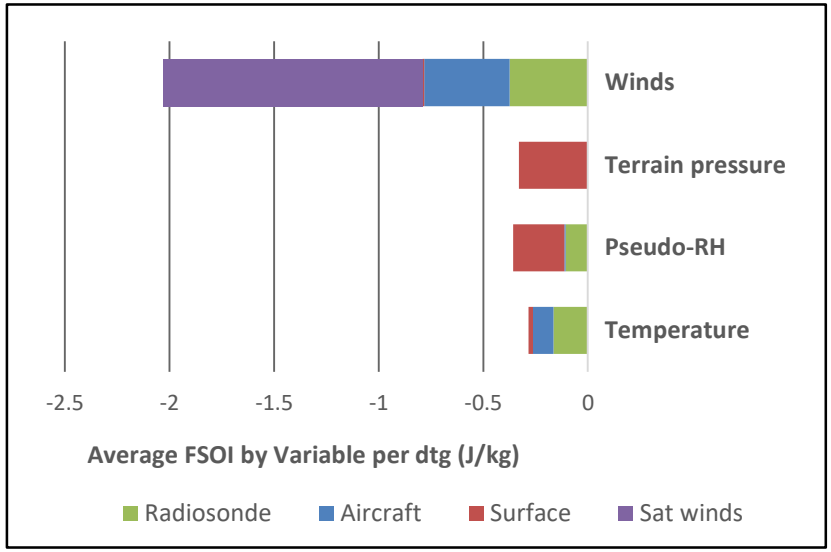
# Current State of ABO




FSOI = Forecast System Observation Impact, a measure of the error reduction in 24-hr forecasts associated with assimilated observations, here using the U.S. Navy's global NWP system (*Baker and Daley (QJRMS, 2000); Langland and Baker (Tellus, 2004)*)

Satellite radiances: **60.5%** of the assimilated observations yield **41.9%** of the error reduction
Satellite-derived winds: **24.0%** of the assimilated observations yield **22.8%** of the error reduction
Conventional data (radiosonde, surface, aircraft): **12.7%** of the assimilated observations yield **32.2%** of the error reduction

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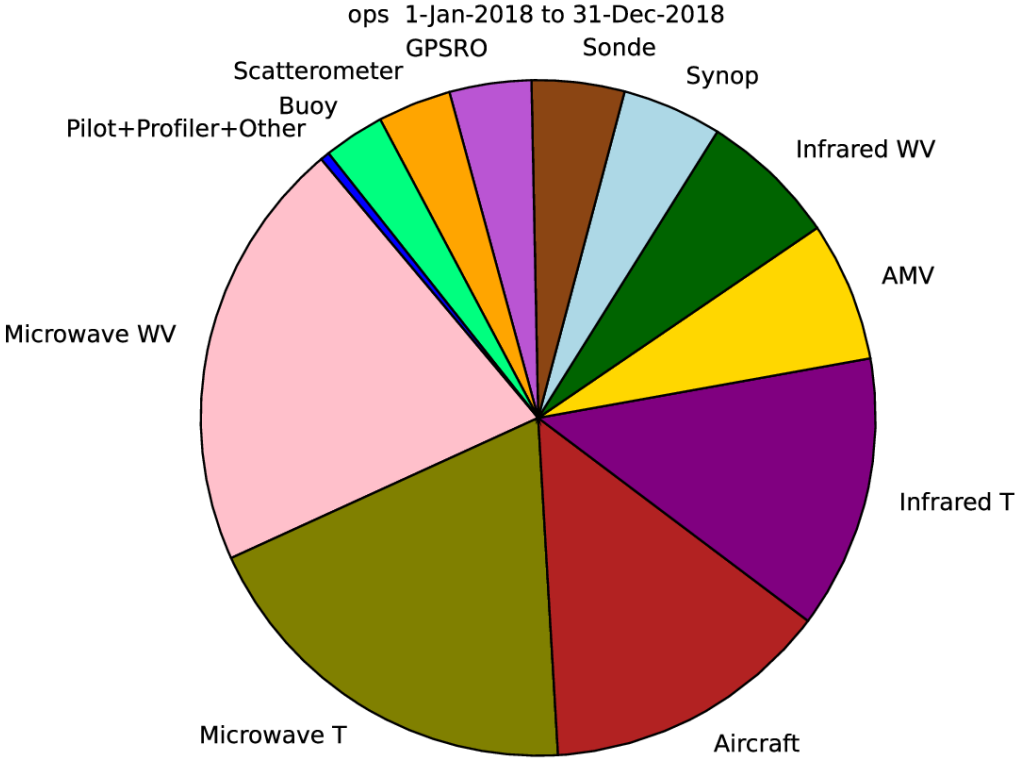
# Current State of ABO




## FSOI for the ECMWF system for 2018

- Based on a dry energy norm
  - FSOI in the U.S. Navy system is based on a moist energy norm.
- The impact of various observing systems depends on the details of data usage and is different than in the U.S. Navy system.
  - Radiances play a greater role
  - Satellite winds play a smaller role
- Aircraft data give 13-14% of the error reduction.
  - Flight-level temperatures are used in the ECMWF system but not in the U.S. Navy system.

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# Future User Requirements

- **Perspective: global operational NWP**
- **More observations**
  - Improved coverage
  - Additional variables
- **Improved quality of observations**
  - Temperature biases
  - Gross errors in winds
- **Improved documentation**
  - Additional metadata
  - Overall documentation

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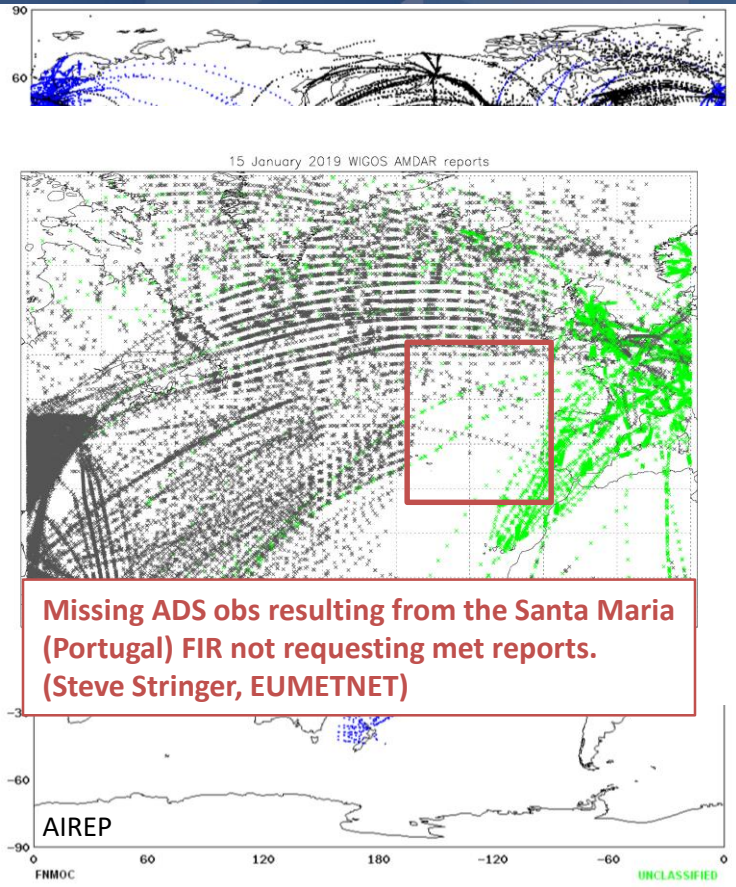
# Future User Requirements—More Observations

- **Improved ADS coverage**
  - ADS reports are useful but are no substitute for AMDAR
    - ADS obs are primarily at flight level—no high-resolution ascent/descent profiles.
    - Some ADS obs have had wind quality issues.
  - Even so, ADS reports do provide useful coverage at fligh level and have a beneficial impact for winds similar to flight-level AMDAR on a per-ob basis. (Flight-level temperature is not currently used in the U.S. Navy's global model.)
  - **Increased coverage might be possible if all Flight Information Regions (FIRs) requested and provided meteorological reports.**

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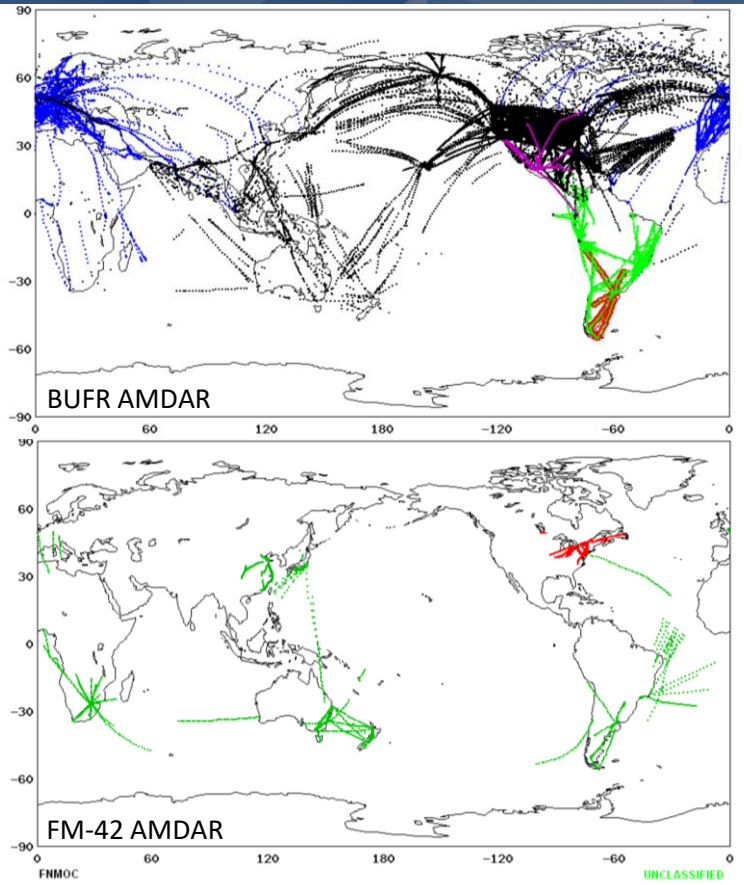
# Future User Requirements—More Observations

- **Improved AMDAR coverage**
  - **More data should be provided in data-sparse regions, especially in the tropics and Southern Hemisphere.**
    - The WICAP initiative, a collaboration between WMO and IATA, is establishing regional AMDAR programs in each WMO regional association.
    - Some countries/airlines might require financial subsidies. (AeroMexico and LATAM data are subsidized at present. Papua New Guinea data were short-lived because of funding issues.)

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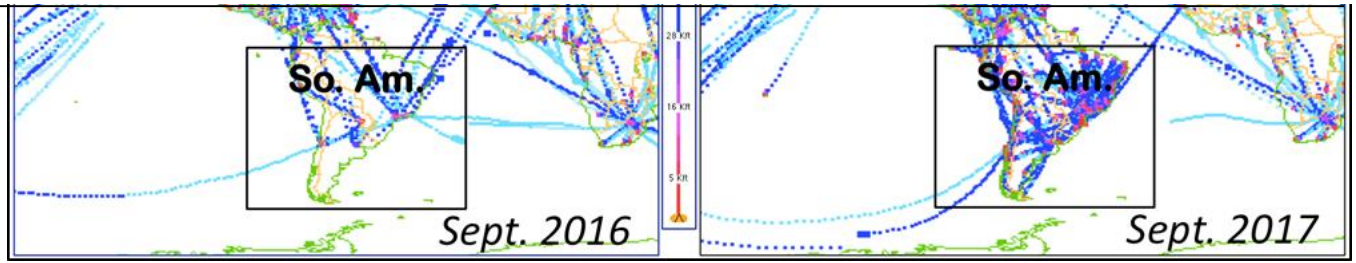
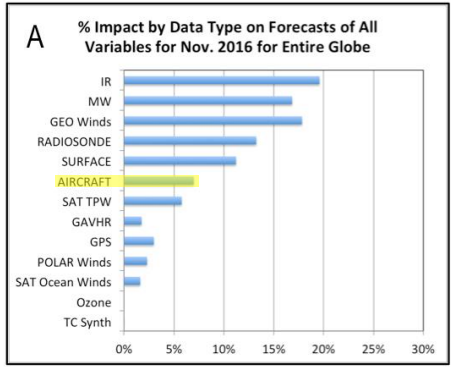
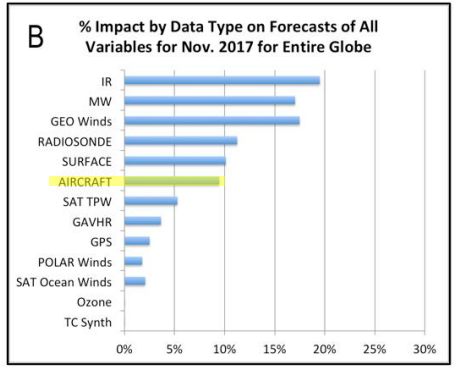
# Impact of Increased Aircraft Observations in South America

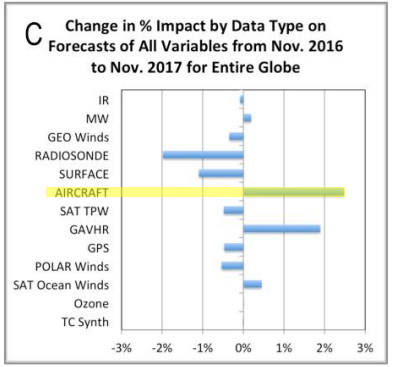


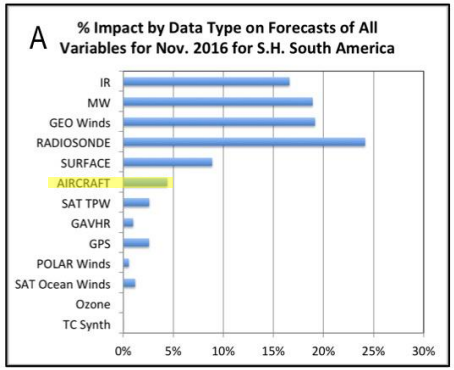

Comparing Nov 2016 to Nov 2017, AMDAR observations increased by over 18%. The error reduction in 24-hr forecasts had the greatest change for aircraft data.

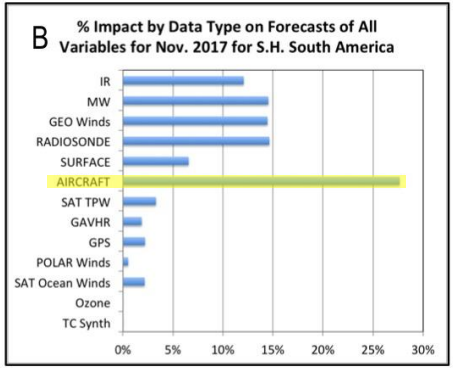
Looking at the contribution to the global error reduction from the South American region, the large increase in AMDAR observations led to a huge increase in impact.

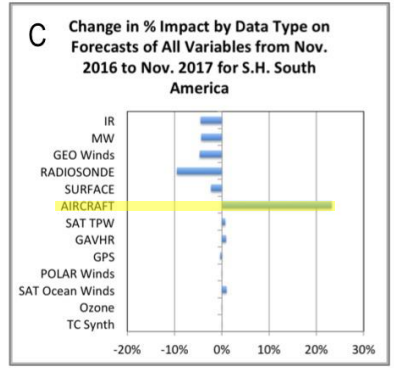



*Petersen, R.A., and P.M. Pauley, 2018: What a difference a year makes: The impact of enhanced AMDAR reporting over South America. WMO AMDAR Newsletter, April 2018.*

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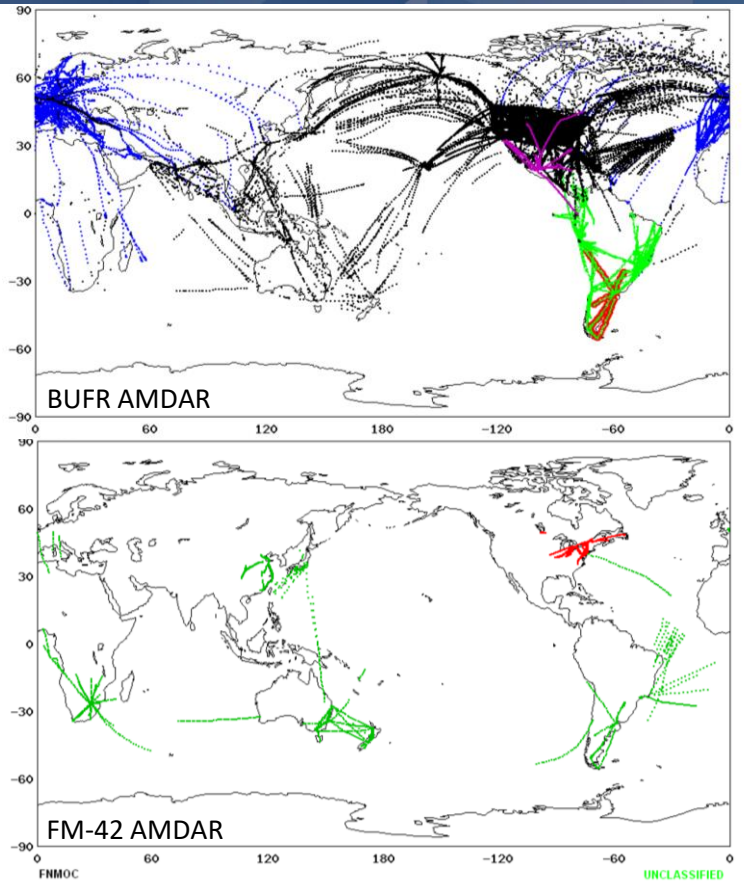
# Future User Requirements—More Observations

- **Improved AMDAR coverage**
  - **More data should be provided in data-sparse regions, especially in the tropics and Southern Hemisphere.**
  - **Increasing ascent/descent profiles at night could possibly be attained by increased participation by package carriers or the use of UAVs.**
  - **Timeliness can also affect coverage. Improving data latency can make the difference between obs being used or being unavailable for use.**
    - Ideally, observations should be available within minutes.

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# Future User Requirements—More Observations

- **Availability of Mode-S data**
  - Mode-S data in the vicinity of airports are very dense and are not at present shared on the GTS.
    - There are approximately 1M AMDAR reports per day worldwide. The potential number of Mode-S reports for the UK alone is about 6M.
    - Many users will want to greatly thin or superob these data.
  - **Should all Mode-S data be pushed to the GTS and let subscribers select which bulletins they want?**
  - **Should all Mode-S data be placed on a server that lets subscribers select a subset?**
  - **Should a subset of Mode-S data be placed on the GTS with the full dataset available from a server?**
  - **What format should be used for Mode-S data?**

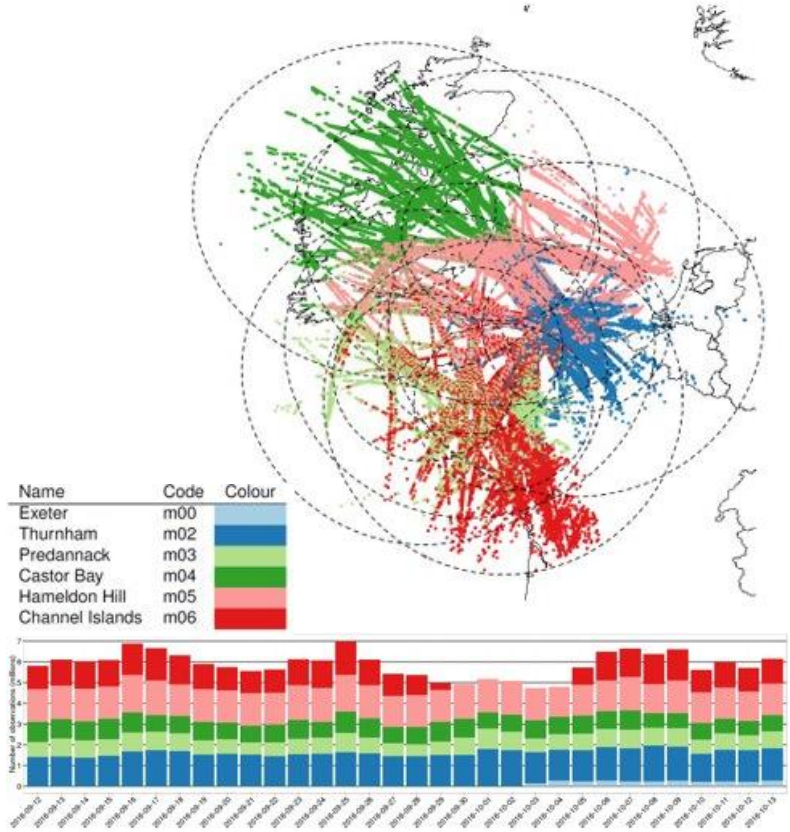


Figure courtesy of Ed Stone, UK Met Office

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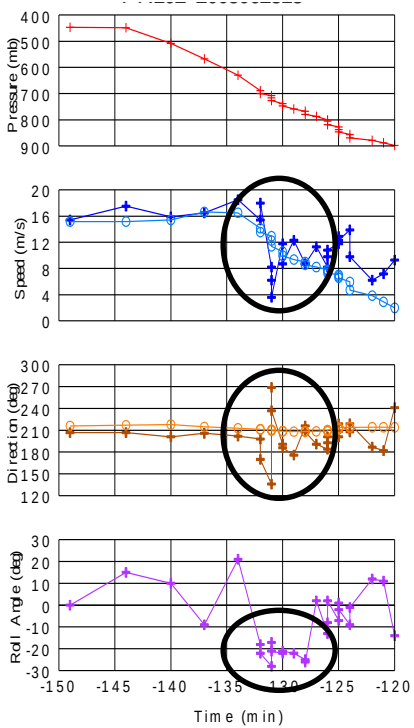
# Future User Requirements—More Observations

- **Future use of data from UAVs**
  - UAVs hold promise for providing meteorological observations for NWP, especially in otherwise difficult-to-observe situations. However, data quality from UAVs is highly variable and depends on the type of aircraft and its instrumentation.
  - **UAVs need to have platform-dependent identifiers, preferably following current practice for commercial aircraft observations.**
  - **Metadata in UAV observations must include airframe type at a minimum, and possibly avionics/ground station type, as well as windfinding type (e.g., GPS vs. magnetic compass).**
  - **UAV data shared on the GTS should be in a WMO-approved format, preferably BUFR.**




Aircraft winds have errors when the aircraft is maneuvering

Wind speed varies from 4 to 12 m/s

Wind direction varies from 130° to 270°

Aircraft is maneuvering Large roll angles

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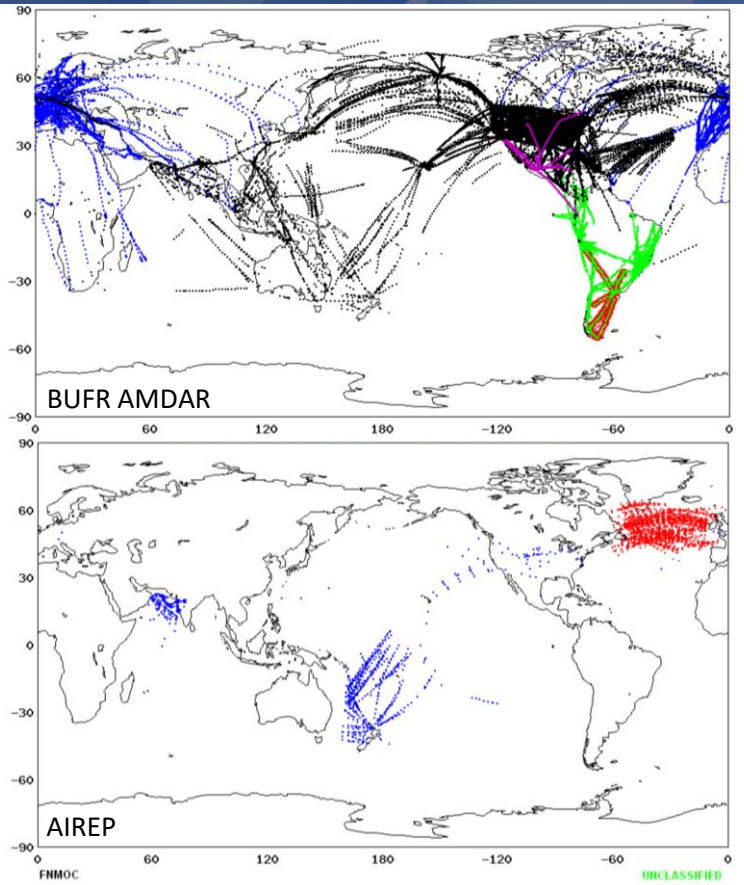
# Future User Requirements—More Observations

- **Reduced duplication**
  - Observations from a particular aircraft can be received in multiple formats—AMDAR, AIREP, ADS-C, ADS-B, and Mode-S—and in some cases with different identifiers.
  - **To the extent possible, observations from the same aircraft should use the same identifier regardless of formatting, in order to facilitate the removal of duplicate/redundant data.**
    - For example, at present most AIREPs use flight number, while AMDAR uses an encoded tail number.
    - The provision of ADS reports in BUFR using the same aircraft identifiers used for AMDAR is encouraged, at least for aircraft reporting AMDAR.

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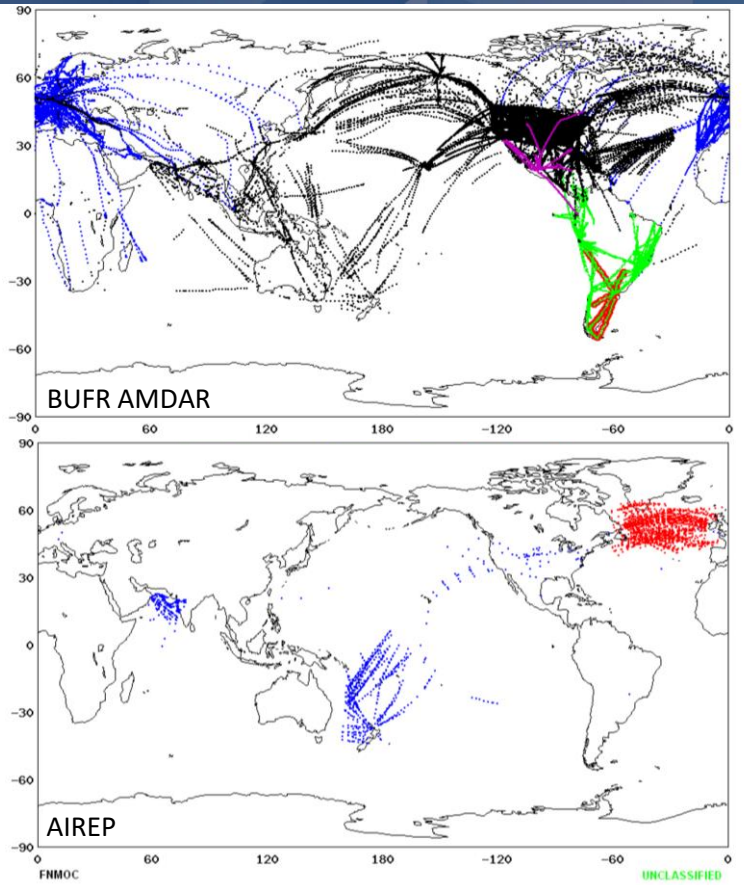
# Future User Requirements—More Observations

- **Reduced duplication**
  - To the extent possible, observations from the same aircraft should use the same identifier regardless of formatting, in order to facilitate the removal of duplicate/redundant data.
  - As Mode-S data become more widely available, any compensating decrease in AMDAR data should be discussed and agreed upon with data users.

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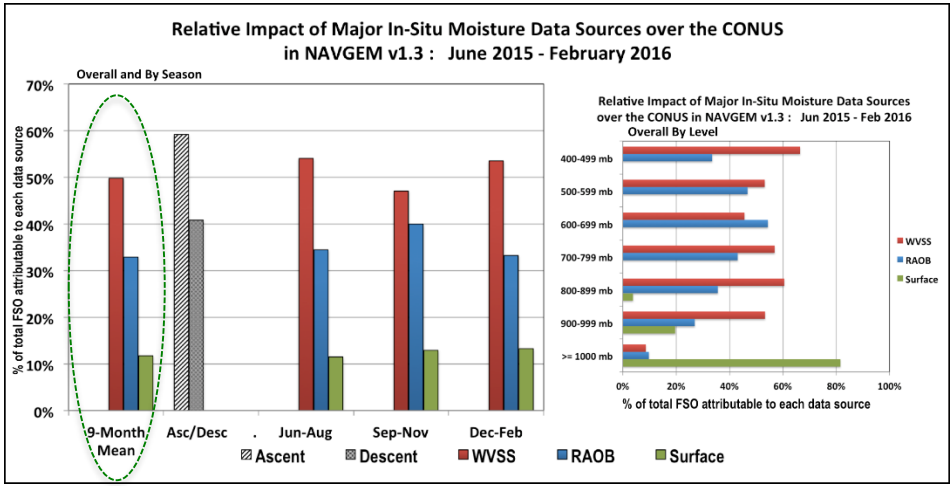
# Future User Requirements—Additional Variables

- **Additional variables—Humidity**
  - Humidity data using the WVSS-II laser-diode system is available on UPS and Southwest Airlines aircraft.
  - The WVSS-II humidity data can be as or more important than radiosonde humidity regionally.
  - UPS has shown the importance of humidity profiles in local fog forecasting. (*Petersen et al., 2016, BAMS*)
  - **Equipping more aircraft with the WVSS-II system should be considered, especially for long-haul aircraft that provide profiles in data-sparse regions.**




The contribution to the global FSOI was computed for the CONUS region to better examine the impact of WVSS-II humidity from the ~125 equipped aircraft. Because of the asynoptic nature of aircraft data and multiple profiles per day from a single aircraft, the error reduction in 24 hr forecasts in the U.S. Navy global NWP system associated with aircraft humidity is greater than that for radiosonde humidity overall and in most layers in the vertical. (*R.A. Petersen and P.M. Pauley, 2018: Assessing the complimentary impact of atmospheric wind observations from satellites and aircraft at global and regional scales. EUMETSAT 2018 Meteorological Satellite Conference, Talinn, Estonia, 17-21 Sept 2018.*)

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# Future User Requirements—Additional Variables

- **Other additional variables**
  - **Improved automated turbulence reports (including its absence) are important for turbulence nowcasting and for validating turbulence forecasts. Airframe-independent measures of turbulence could also be assimilated into numerical models.**
  - **Chemical measurements could also be used for validation. Accurate ozone measurements might be a candidate for assimilation.**

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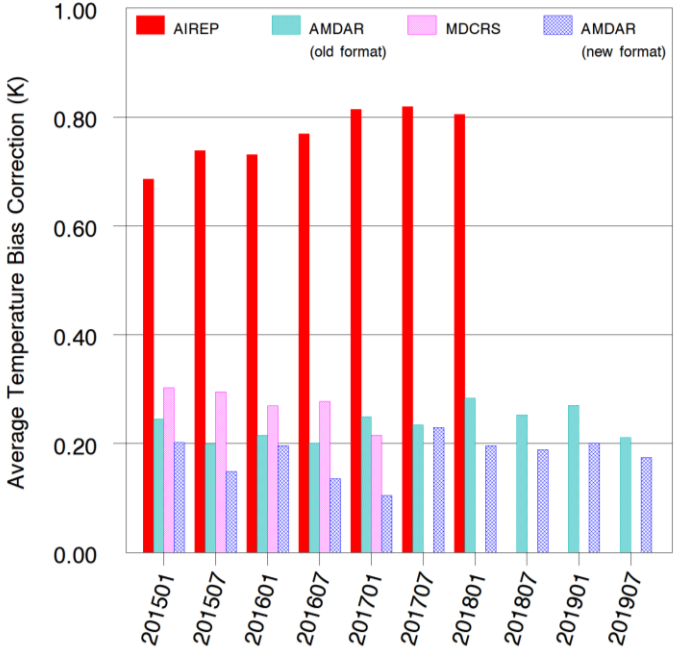
# Future User Requirements—Improved Quality

- **Improved data quality—Temperature**
  - Aircraft temperature observations are known to be biased, especially at flight levels.
  - Biases typically range between 0.5K and 1.0K.
  - Bias correction is used with some success to mitigate these biases, but only works well if there are sufficient "anchoring obs" that are not bias corrected.
  - **Temperatures are subjected to large corrections to convert total air temperature to static air temperature. If either the algorithm used to compute the correction or the instrumentation and its placement could be improved, bias correction might be unnecessary. This would be useful if even a subset of aircraft had the improved algorithm and could be considered anchoring obs and so exempted from bias correction. These obs should be tagged in some way.**




Average bias correction applied at ECMWF in ERA5. The use of AIREP temperatures was stopped in 2018, and the format for MDCRS data was changed to use the AMDAR BUFR template version 7 ("new format") in 2017. AMDAR averages are larger for pressures less than 300 hPa, but with a lot of variability (SD ~0.4K).

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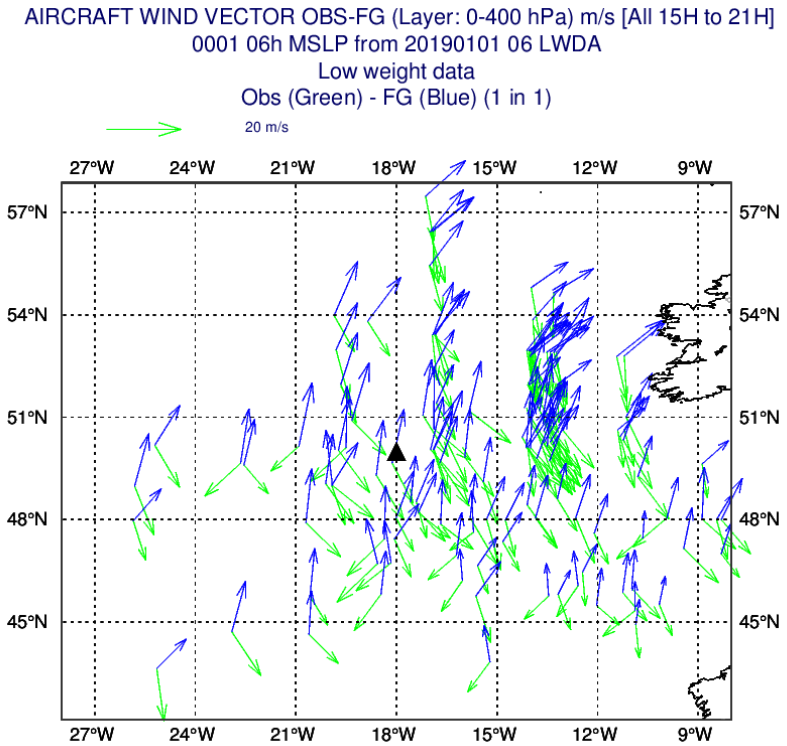
# Future User Requirements—Improved Quality

- **Improved data quality—Winds**
  - A subset of aircraft have displayed gross wind errors, often in wind direction:
    - ADS reports from Gulfstream aircraft that report “engineering” direction rather than “meteorological” direction.
    - Wind reports from B787 aircraft that have large direction errors in ADS reports but not in AMDAR reports. (ATAN2 error?)
  - **Gross wind errors should be corrected by updates to the avionics. While such updates are being rolled out, metadata (e.g., airframe/avionics type) should be provided to allow users to identify aircraft susceptible to known errors.**



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# Future User Requirements—Improved Documentation

- **Additional metadata—WIGOS identifiers and OSCAR/Surface**
  - The WMO is moving toward using WIGOS identifiers for all "surface"-based platforms, including not only land surface stations, ships, and buoys, but also radiosonde stations, aircraft, and radars. These will be catalogued in OSCAR/Surface, together with relevant metadata.
  - WIGOS identifiers are much longer than currently used identifiers; even the local identifier can use up to 16 characters. Accommodating WIGOS identifiers will require much work by NWP centers.

| WIGOS Identifier Series (number) | Issuer of Identifier (number) | Issue Number (number) | Local Identifier (characters) |
|---|---|---|---|
| 0 01 125 | 0 01 126 | 0 01 127 | 0 01 128 |
| 4 bits = 2 digits | 16 bits = 5 digits | 16 bits = 5 digits | 128 bits = 16 chars (a-z), (A-Z), (0-9) |
| Only series "0" has been defined; identifies observing stations | WMO Program or Country/National Identifier | Typically zero for WMO Programs & WMO Co-Sponsored Programs; can range from 0-65535 for national schemas | For WMO Programs & Co-Sponsored Programs, typically the "legacy" WMO Identifier; can be (up to) any 16 char string for national schemas |
| 0 | 20001 | 0 | 72662 |

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  - WIGOS identifiers are much longer than currently used identifiers; even the local identifier can use up to 16 characters. Accommodating WIGOS identifiers will require much work by NWP centers.
  - **To minimize disruption, the use of current aircraft identifiers (encoded registration/tail numbers) as the WIGOS local identifier is encouraged. This would enable continuity with existing reject/accept lists in use at NWP centers.**
  - **New aircraft should continue to use the existing schema for aircraft identifiers as long as practical. Ideally, identifiers would be unique and would use no more than eight characters for encoded registration/tail numbers and eight characters for encoded flight numbers. This would allow NWP centers more time to adapt their code to WIGOS identifiers.**
  - **Would the issuer of identifier segment use the WMO program value of 20005 or would it use country codes for the country of origin?**

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# Future User Requirements—Improved Documentation

- **Additional metadata—Data source**
  - At present, ADS and AMDAR data processed in the U.S. by ARINC use the same BUFR template but are disseminated on the GTS using separate bulletins. However, many NWP centers do not retain the bulletin name in their observation processing. Without the bulletin name, the data source (ADS or AMDAR) is no longer identified. This can be important when errors such as the B787 gross wind errors are present in ADS reports but not AMDAR reports.
  - **To simplify distinguishing between ADS and AMDAR reports, the data source should be included as a BUFR variable in the observations.**
  - **As previously stated, the same identifier should be used for ADS and AMDAR observations from the same aircraft.**

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# Future User Requirements—Improved Documentation

- **Additional metadata—WIGOS identifiers and OSCAR/Surface**
  - **What metadata should be included in observations vs. catalogued in OSCAR/Surface?**
    - Chris Hill (NCEP): In addition to aircraft ID, the country registration, airframe model, the array of sensor types (e.g. temperature, humidity, wind, EDR, gas or particulate concentration) and their measuring capabilities (e.g. value range, accuracy, and hysteresis) would all become referenced - as is already done with most other observing platforms.
    - Pat Pauley (NRL): The airframe type and maybe avionics type should be included in the observations, drawing an analogy with radiosonde type and instrument type. Other less frequently used metadata as available should be catalogued in OSCAR/Surface (when implemented).
    - Bruce Ingleby (ECMWF): The airframe type, the airline, the data source (e.g., ADS-C or AMDAR) and ideally the avionics used should be included in the report and other less frequently used metadata should be available in OSCAR/Surface.

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# Future User Requirements—Improved Documentation

- **Overall documentation**
  - Basic documentation about aircraft observations is given in the "WMO Guide to Aircraft Observations" (https://library.wmo.int/doc_num.php?explnum_id=4120).
    - Focus on programmatic elements (e.g., data formats, OSCAR/Surface, WMO-related activities)
  - Ideally, there should be an authoritative new publication that explains the different data sources, their strengths and weaknesses, and the acronyms involved from a data user's perspective.

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Questions?

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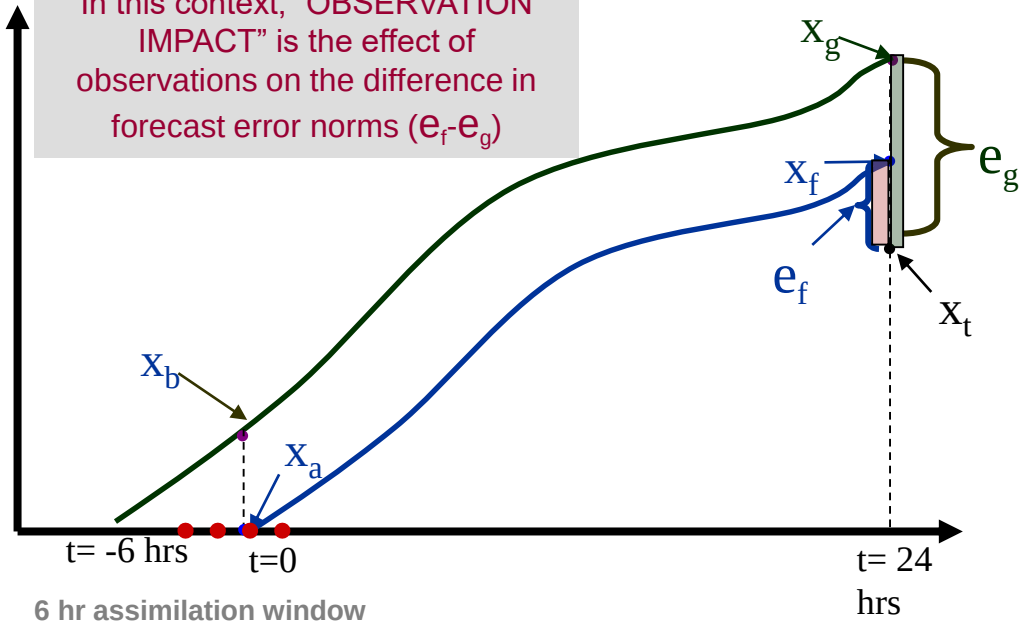
# Observation Impact Methodology

Observations move the forecast from the **background trajectory** to the **trajectory starting from the new analysis**

In this context, "OBSERVATION IMPACT" is the effect of observations on the difference in forecast error norms ($e_f$-$e_g$)




*Langland and Baker (Tellus, 2004), Gelaro et al (2007), Morneau et al. (2006)*

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