

Use of Aircraft Data in Operational Global Weather Forecasting

EUFAR meeting on aircraft temperature measurement, 11 Nov 2020

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ECMWF

With thanks to Lars Isaksen, Mohamed Dahoui and Mickey Chan

Overview

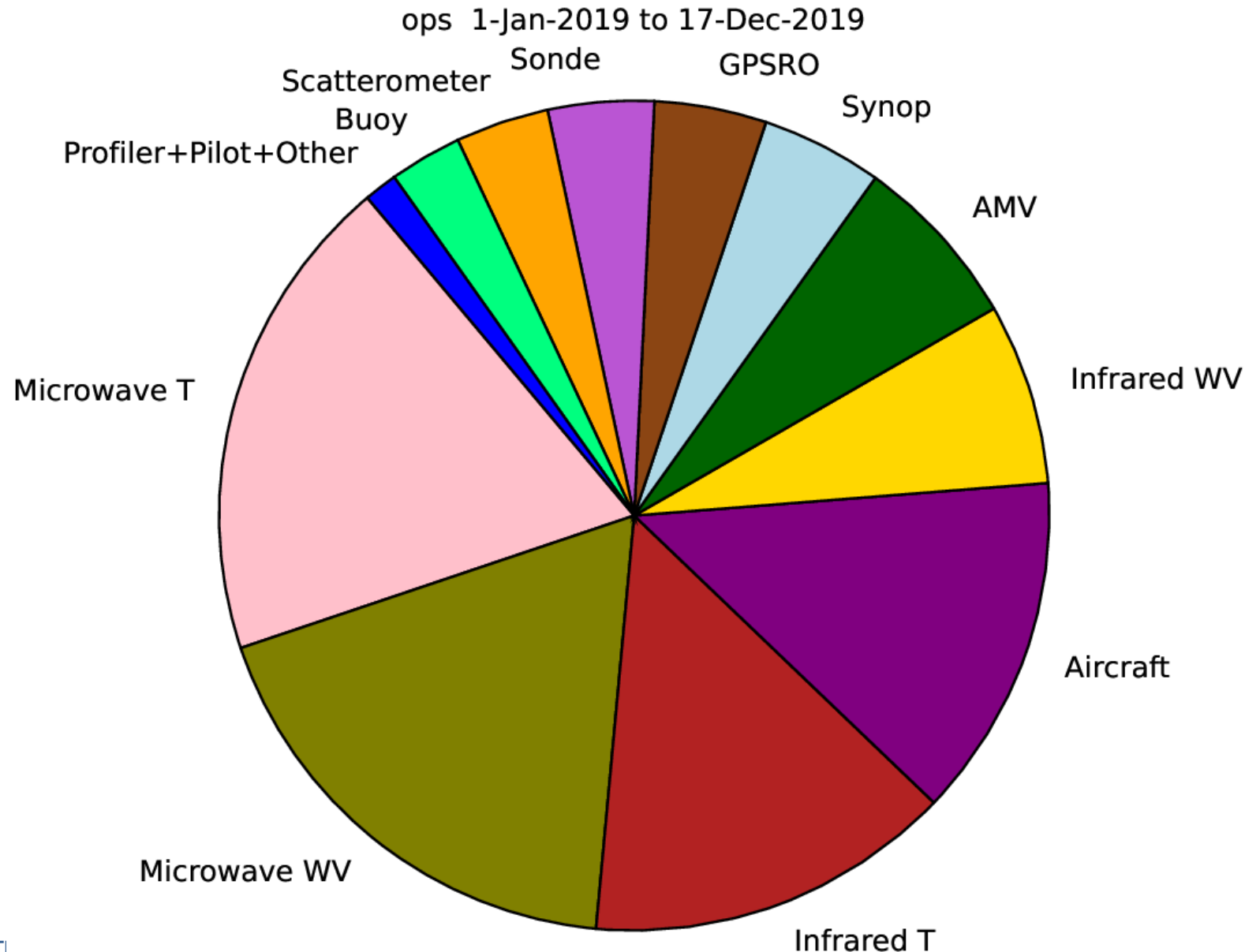
- Introduction
 - Recent work at ECMWF, aircraft impact (OSE and FSOI) and a Quality Control problem
 - Temperature monitoring and biases
 - Biases and 'correcting' them
 - Some plots from <https://www.ecmwf.int/en/forecasts/quality-our-forecasts/monitoring-observing-system#Conventional>
 - Metadata and anonymisation issues
 - Effect of Covid-19 (if time)
 - Summary
- Most aircraft data are 'good'/useful – but this talk will show that there is 'room for improvement'

Highlights over the last few years

- 2014-2015 investigation for EUMETNET about the use of **AMDAR humidity** data and also TAMDAR wind/temperature/humidity **ECMWF Tech Memo 855**
 - March 2016 ECMWF started assimilating AMDAR humidity operationally
- 2017: Reduced horizontal and vertical thinning of aircraft reports
- Late 2017: ECMWF noted “B787 wind problem” – partially addressed by rejecting winds from 550 aircraft
- **Ongoing concerns about the need to bias correct aircraft temperatures**
- ESoWC 2019: try to use online data to map AMDARid to aircraft_type
- Feb 2020: EUMETNET/ECMWF workshop on Aircraft data + Use
- March/April 2020 aircraft numbers drop by 75% (Covid-19)
- May-July 2020 – start using AFIRS, TAMDAR and Mode-S data
 - Also ‘correct’ B787 AIREP/ADS-C winds where possible
- EC/MO/NCEP/BoM paper on impact of Covid-19 submitted to GRL

Impact: FSOI estimate for 2019

- Forecast Sensitivity to Observation Impact (using a dry norm at T+24, verification vs analysis is imperfect, doesn't account for cycling effects)
- Aircraft give about 13% of total impact 😊
- A bit less in NH summer a bit more in NH winter
- Similar to sum of other in situ data (sonde+synop+buoy+ship)
- Large number of reports (830K/day) increasing over the years 😊
- Figure from Alan Geer, ECMWF



Timeliness is vital! Quite good for aircraft 😊

FSOI statistics for ECMWF operational IFS

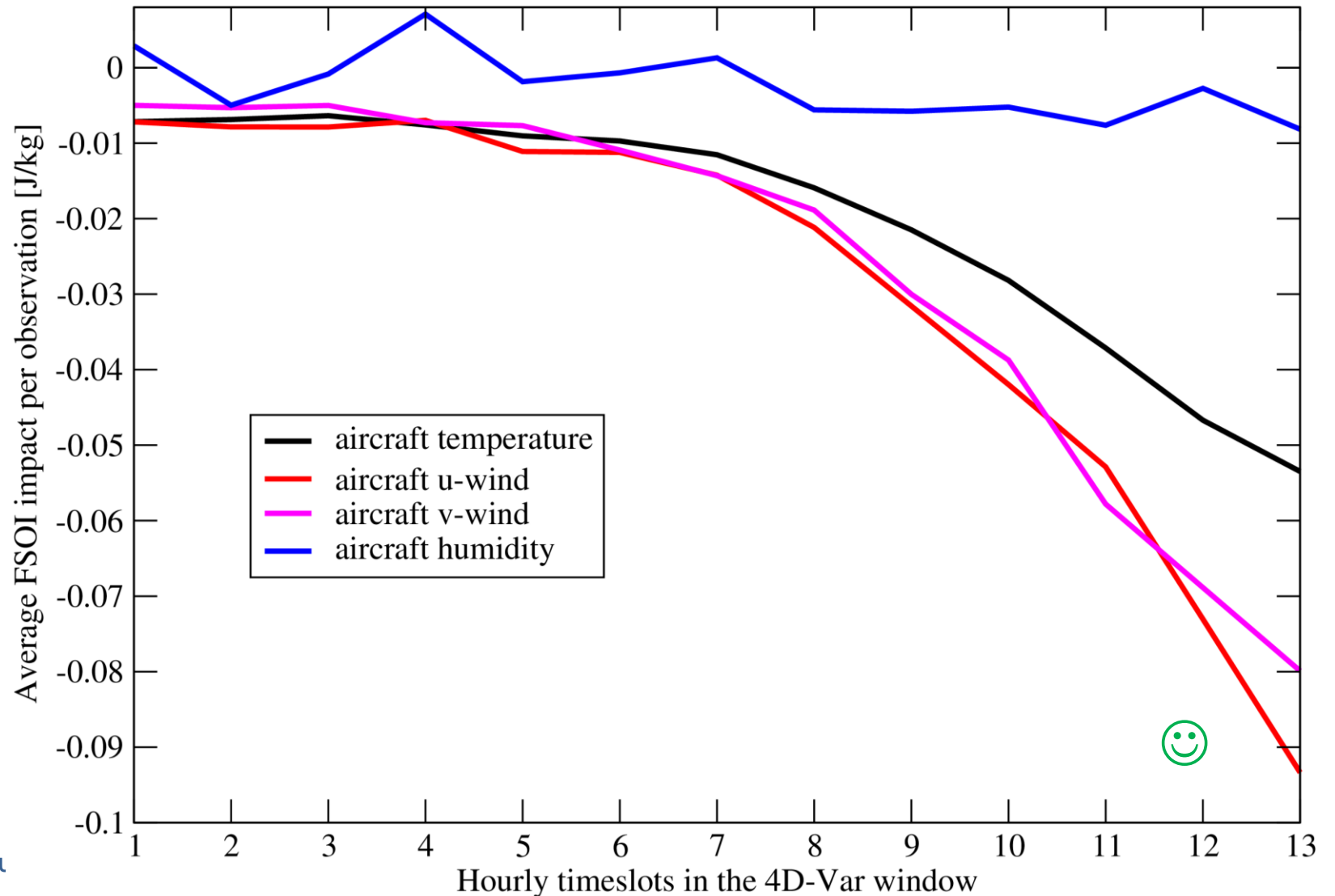
Data from 1-31 October 2019

- ECMWF uses 4DVar with a 12 hour assimilation window

- Observations near the end of the window have more impact on forecast quality! See figure (from TM 855)

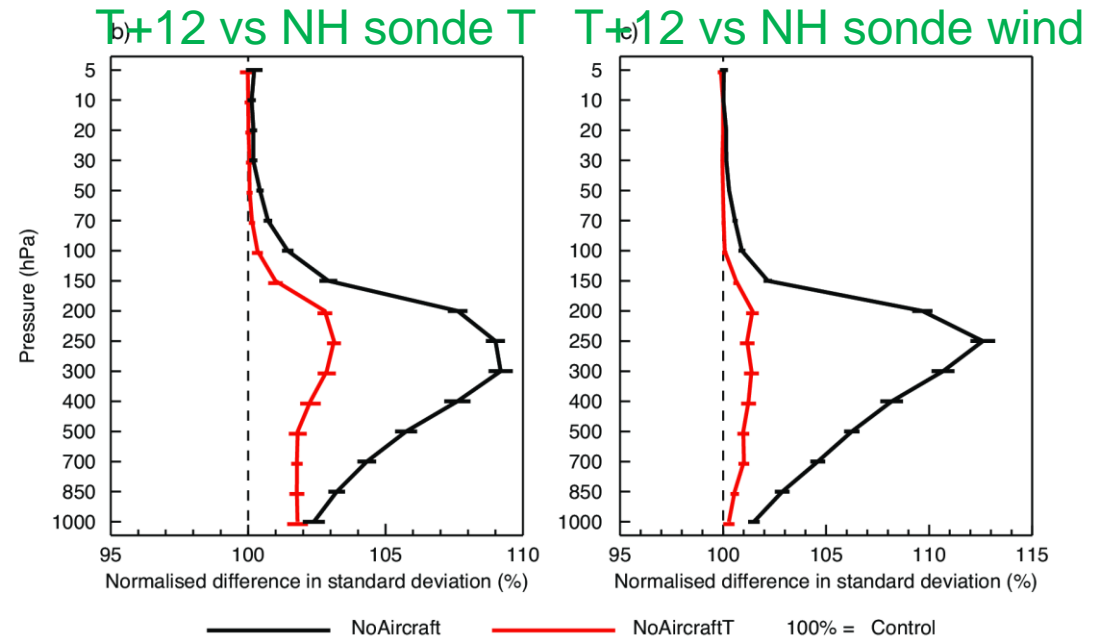
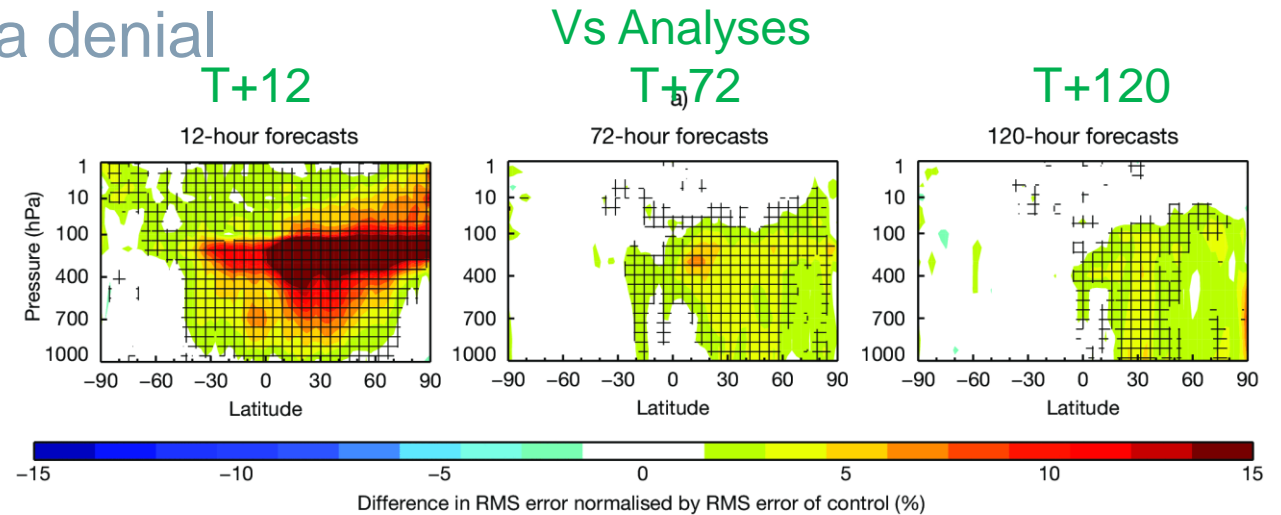
- This is a real effect, shown using satellite OSEs by McNally (2019)

- NWP centres need observations as early as possible



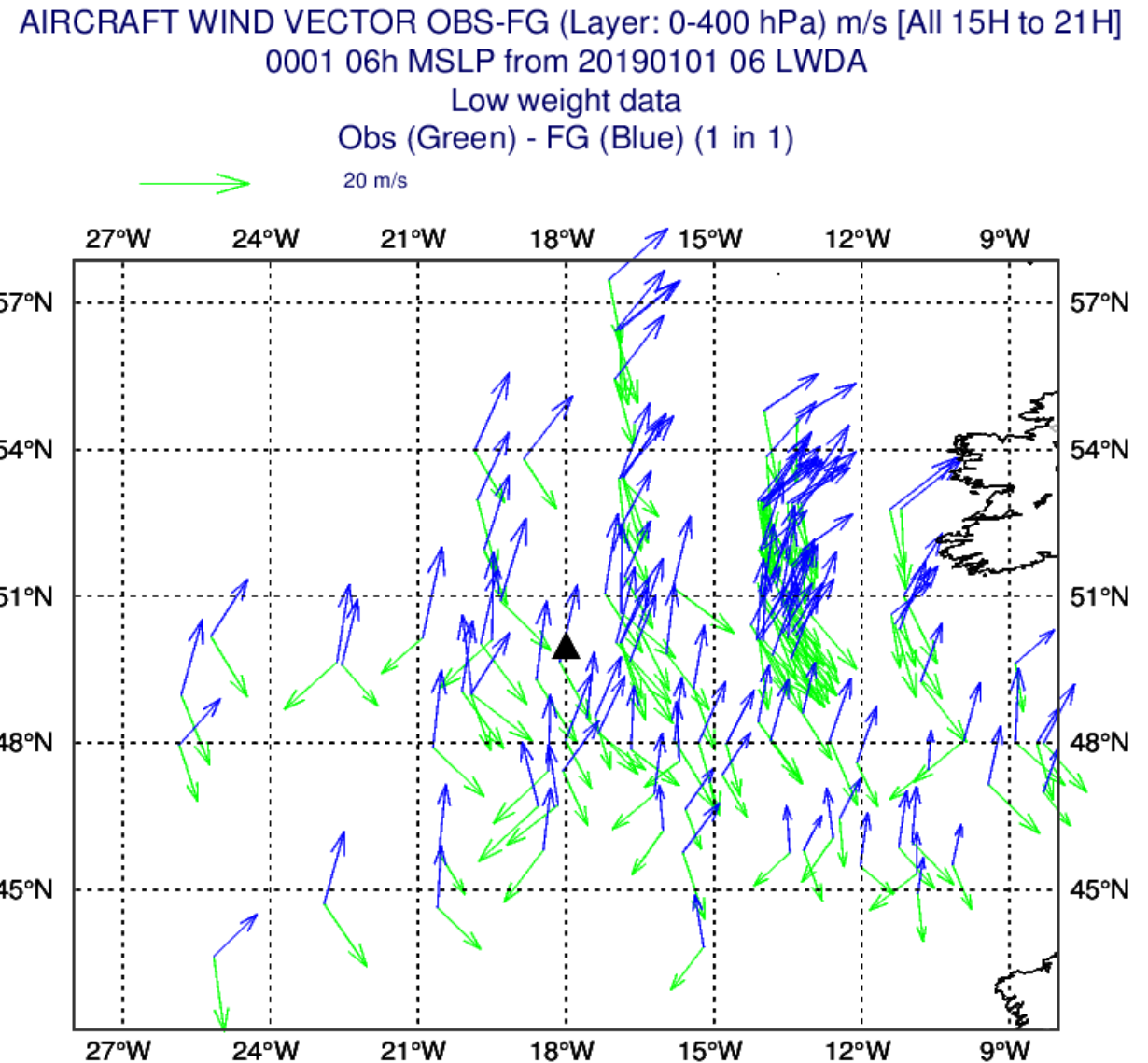
Impact from aircraft data denial

- OSE: Observing System Experiment
 - ECMWF IFS, 3 months in 2019
 - Control – all data
 - NoAircraft: top plot and black line in b,c)
 - NoAircraftT(emperature), red line in b,c)
-
- Biggest impact is ~250 hPa in NH almost 10% worse vs sonde T, 13% vs sonde wind
 - Most of the impact (even on T) comes from the aircraft winds
-
- Ingleby et al (2020, submitted to GRL)



B787 wind problem

- Quasi-intermittent problem with wind direction (sign of v) for a subset of B787 winds! Those from ADS-C (US but some European) Nasty QC problem 😞 😞
- More data blacklisted in short-term (550+ identifiers) – throws out good data too
- Frustrating problem
- First experiment “correcting” (~dealiasing) v -winds was worse in tropics – results better when restricted to AIREP and ADS-C (separated from AMDAR)
- We have very little metadata on aircraft: 😞 😞 type, airline and processing are N/A except that we know type for two subsets (2018)



Aircraft temperature biases

- Ballish and Kumar (BAMS, 2008), Petersen (BAMS,2016): aircraft biased warm by 0.3-1.0K
- Drüe et al (QJRMS, 2008): bias as fn(aircraft type)? Just part of story?
- De Haan et al (2020, in prep.): later presentation
- Use of VarBC to “correct” the data: ECMWF: Isaksen et al (2012, Newsletter), NCEP: Zhu et al (2015, MWR)
 - Typical fn each aeroplane: $\text{Constant} + c_1 * \text{ascent rate} + c_2 * \text{descent rate}$
 - VarBC works somewhat better for satellite data than in situ observations – primarily due to much larger data volume for a satellite data channel than for one aeroplane
- VarBC – Is it the best method?
 - Better if NWP centres don't have to bias correct data

October 2020 ECMWF mean bias correction by type*

Type (EU)	Num	AvCorr	Type (US)	Num	AvCorr
A318_AFR	1233	-0.57	A321_DAL	876	-0.40
A319_AFR	2229	-0.52	A320_DAL	2044	-0.35
....				
A340	6252	0.60	B763_UPS	334298	0.66
B777	71590	0.83	B712_DAL	11317	0.76
A333_DLH	7103	0.87	B748_UPS	48776	0.94
B772_BAW	3412	0.93	B789_UAL	16036	0.97
B77W_AFR	8254	1.13	B788_UAL	8796	1.06
			B787	129128	1.09

*Type information is incomplete but comes from either a) US/EU AMDAR programs or b) ESoWC 2019 study (with M Chan, M Dahoui) matching flightradar24 to AMDAR tracks. NOT used in ECMWF VarBC, which uses aircraft identifier, ascent rate and O-B.

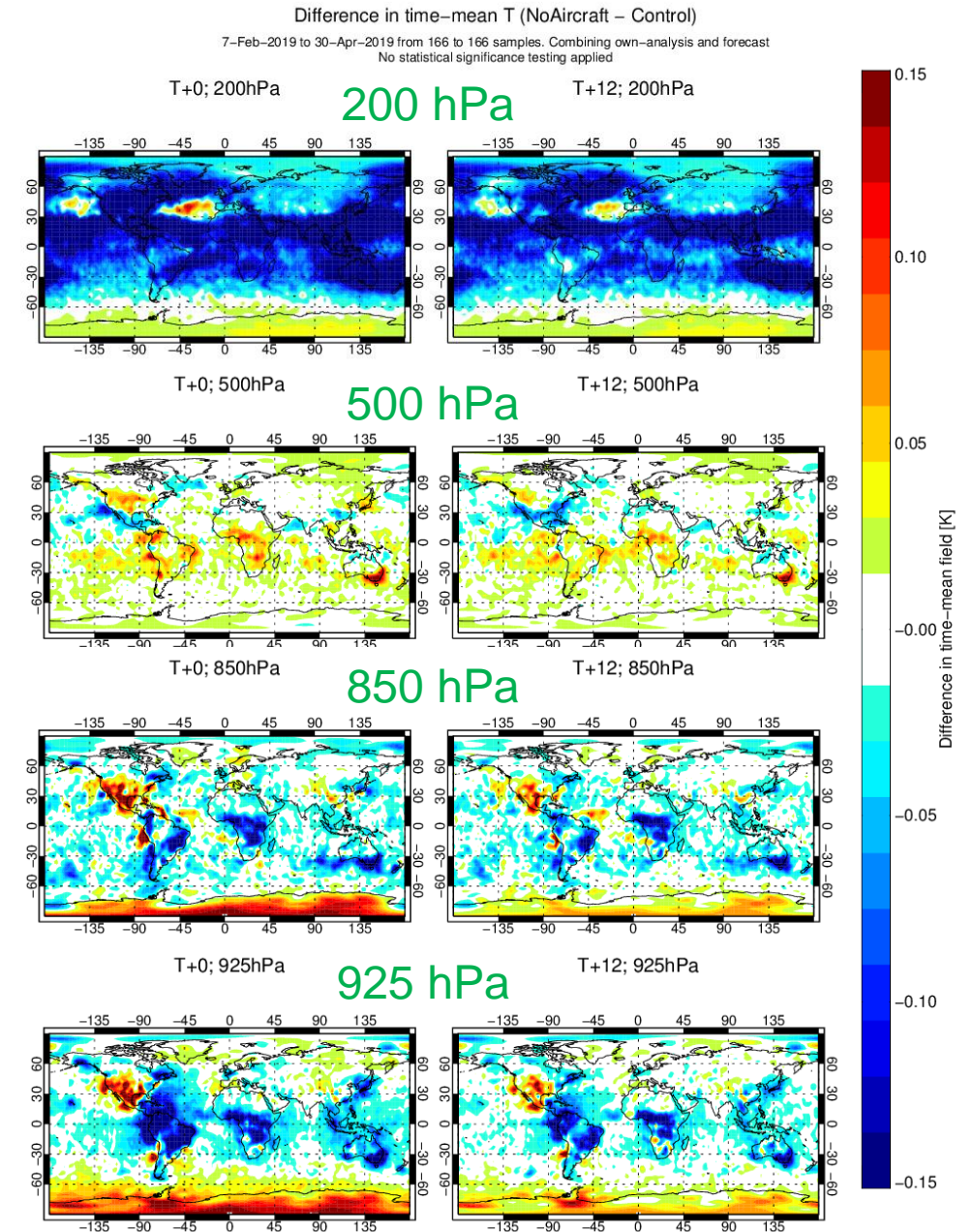
Bias is linked to aircraft type (even if the details aren't clear)

Bias correction methods are useful but imperfect

- Eyre (2015, QJRMS) in the presence of model biases NWP bias correction schemes work best when there is a large proportion of “anchor” observations
- For temperature radiosondes and GPS-RO form the anchor observations: up to end of 2019 these data sources were ~constant whereas the data needing bias correction (satellite soundings and aircraft data) was increasing
 - In 2020 the number of aircraft reports crashed and GPS-RO increased significantly
- Even with VarBC assimilation of aircraft data causes a residual bias (next slide)
 - ‘Weak constraint’ 4DVar has sometimes confused aircraft bias with model bias – especially above airports with lots of reports
- Can something be done to improve aircraft temperatures “at source”?
 - Current accuracy is good enough for airlines but not for NWP and climate

OSE with no aircraft data

- Mean differences between NoAircraft and Control (T+0 and T+12)
- Largest, most widespread difference at 200 hPa (top) – as expected
- Magnitude ‘only’ 0.15° - but a problem, despite VarBC
- More localised impacts at lower levels
- Interaction with model bias at low levels in tropics?



Plots from ECMWF
monitoring web pages.
Data for January 2020
Mainly for flight levels.

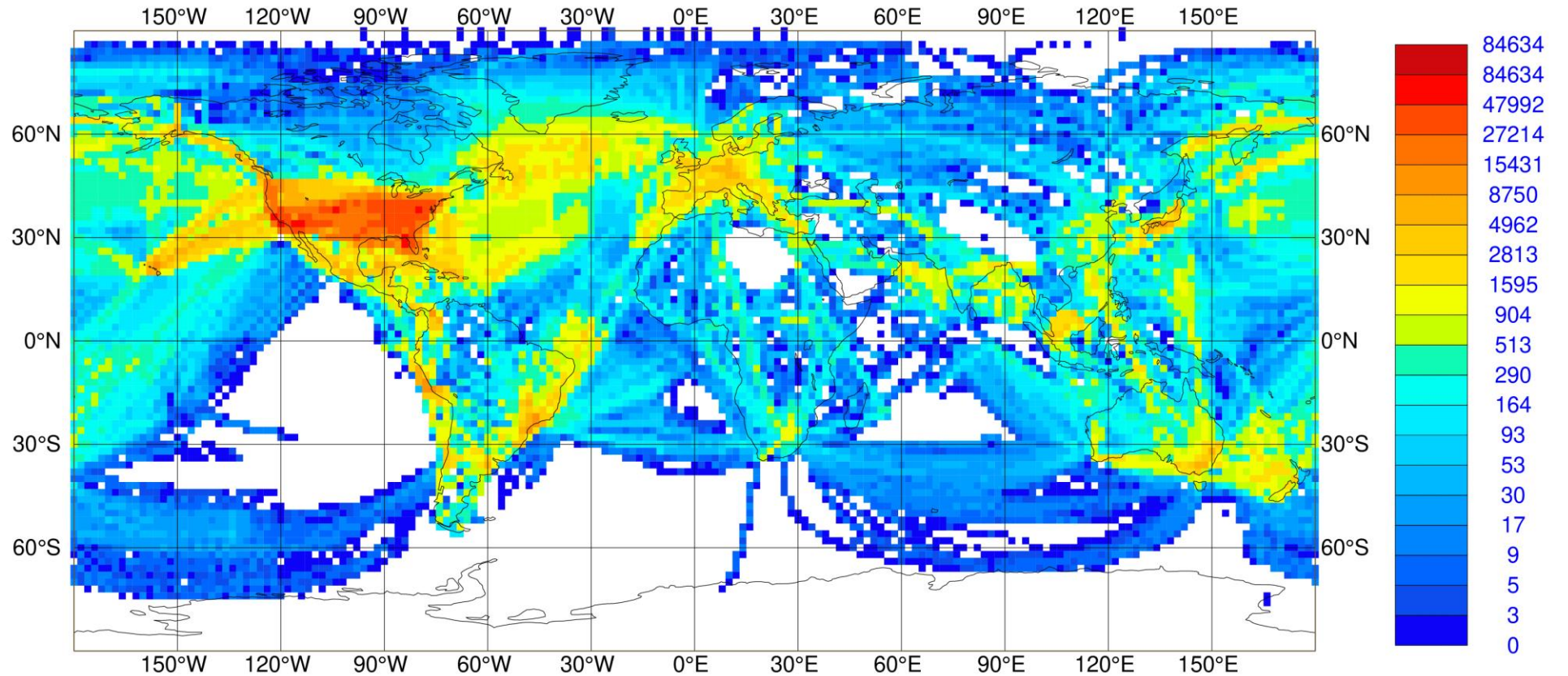
TEMP FROM AMDAR
NUMBER OF OBSERVATIONS PER GRID SQUARE (USED)

DATA PERIOD = 2020-01-01 21 - 2020-02-01 09

EXP = 0001, LEVEL = 0.00 - 400.00 HPA

Min: 0 Max: 81693 Mean: 17379.8 Total: 8516100.0

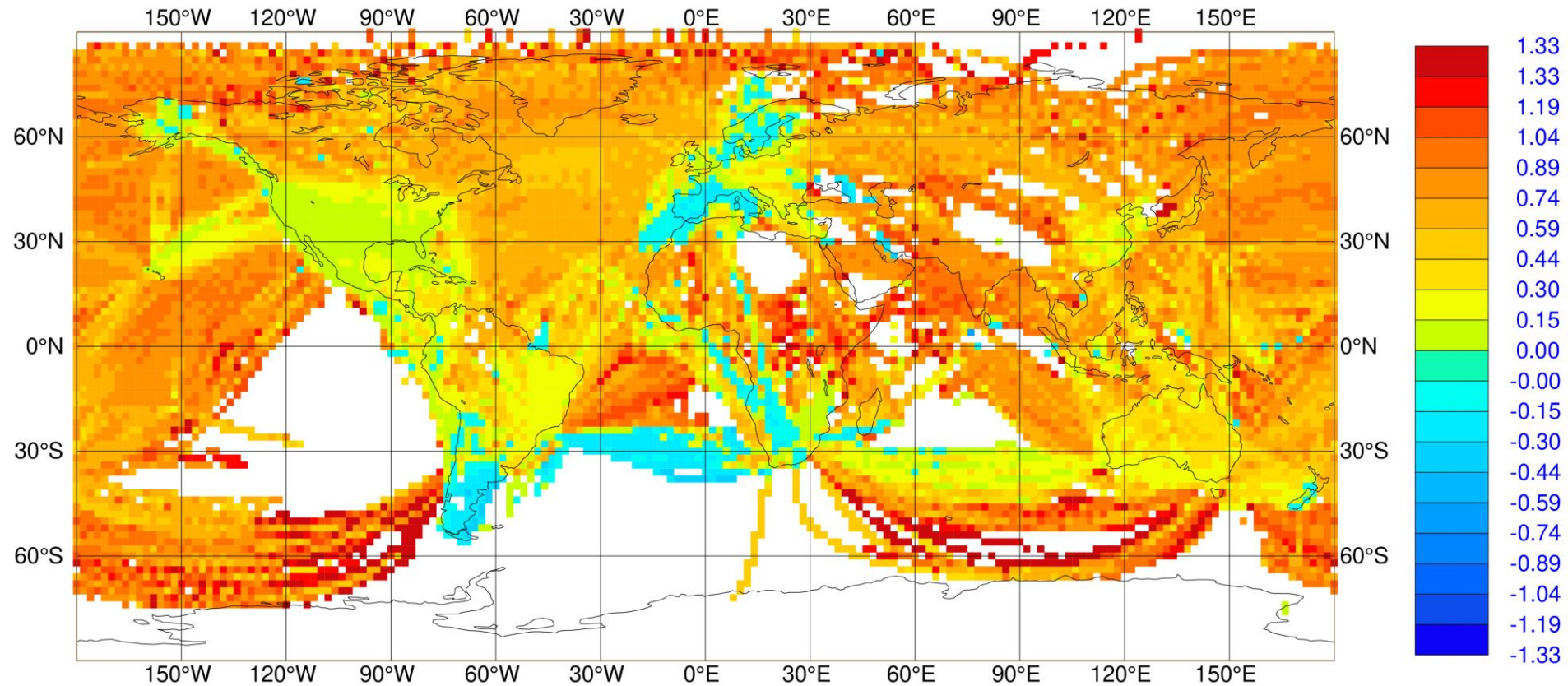
GRID: 2.00x 2.00



Interesting patterns,
Differences in magnitude
and sign.
Deserves investigation.

TEMP FROM AMDAR
MEAN BIAS CORRECTION [K] (USED)
DATA PERIOD = 2020-01-01 21 - 2020-02-01 09
EXP = 0001, LEVEL = 0.00 - 400.00 HPA
Min: -0.638 Max: 2.137 Mean: 0.253
GRID: 2.00x 2.00

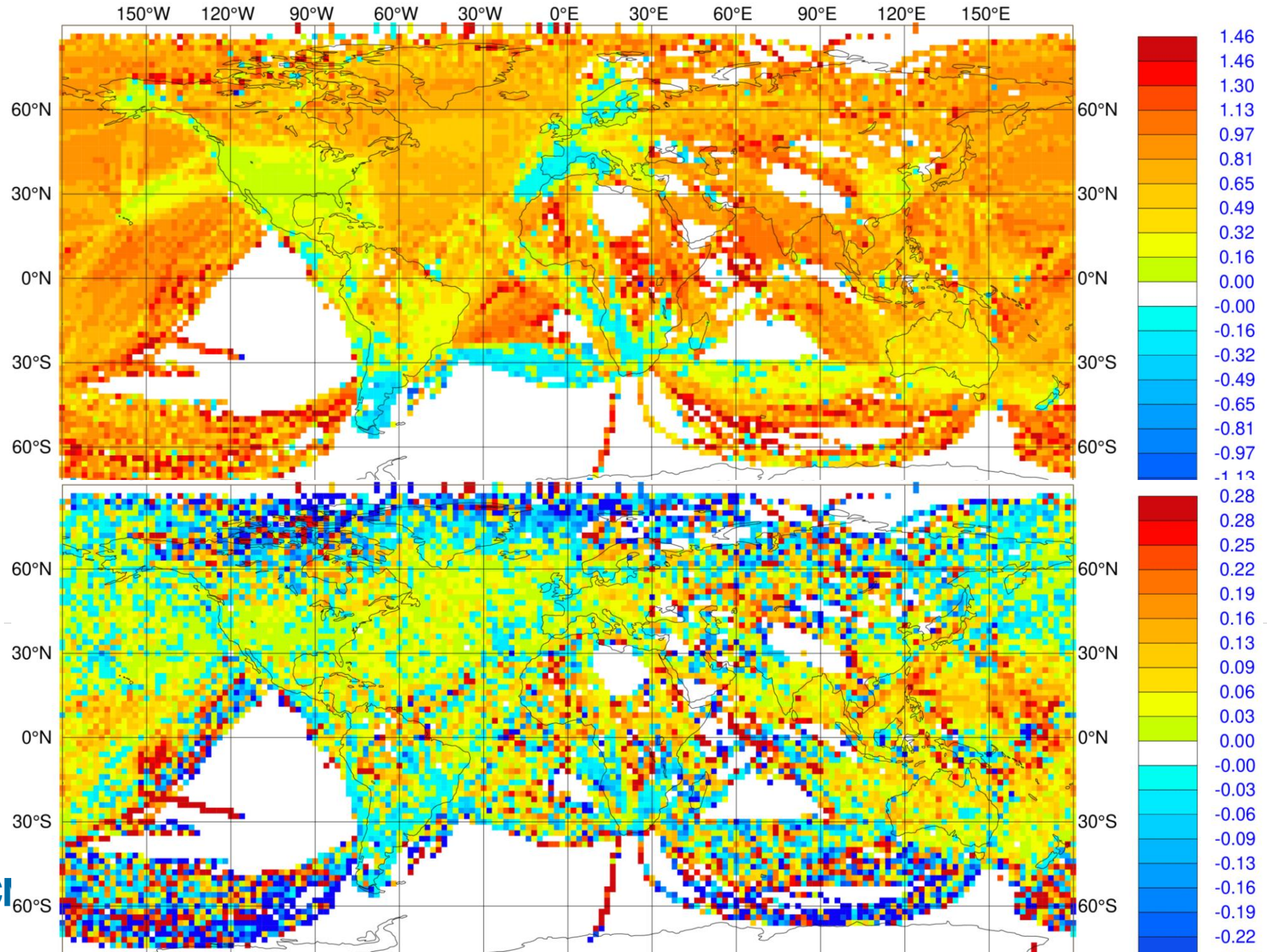
0.253



- Mean(Obs-Analysis)
- Top plot: uncorrected global mean 0.271

- Bottom plot: corrected global mean 0.018

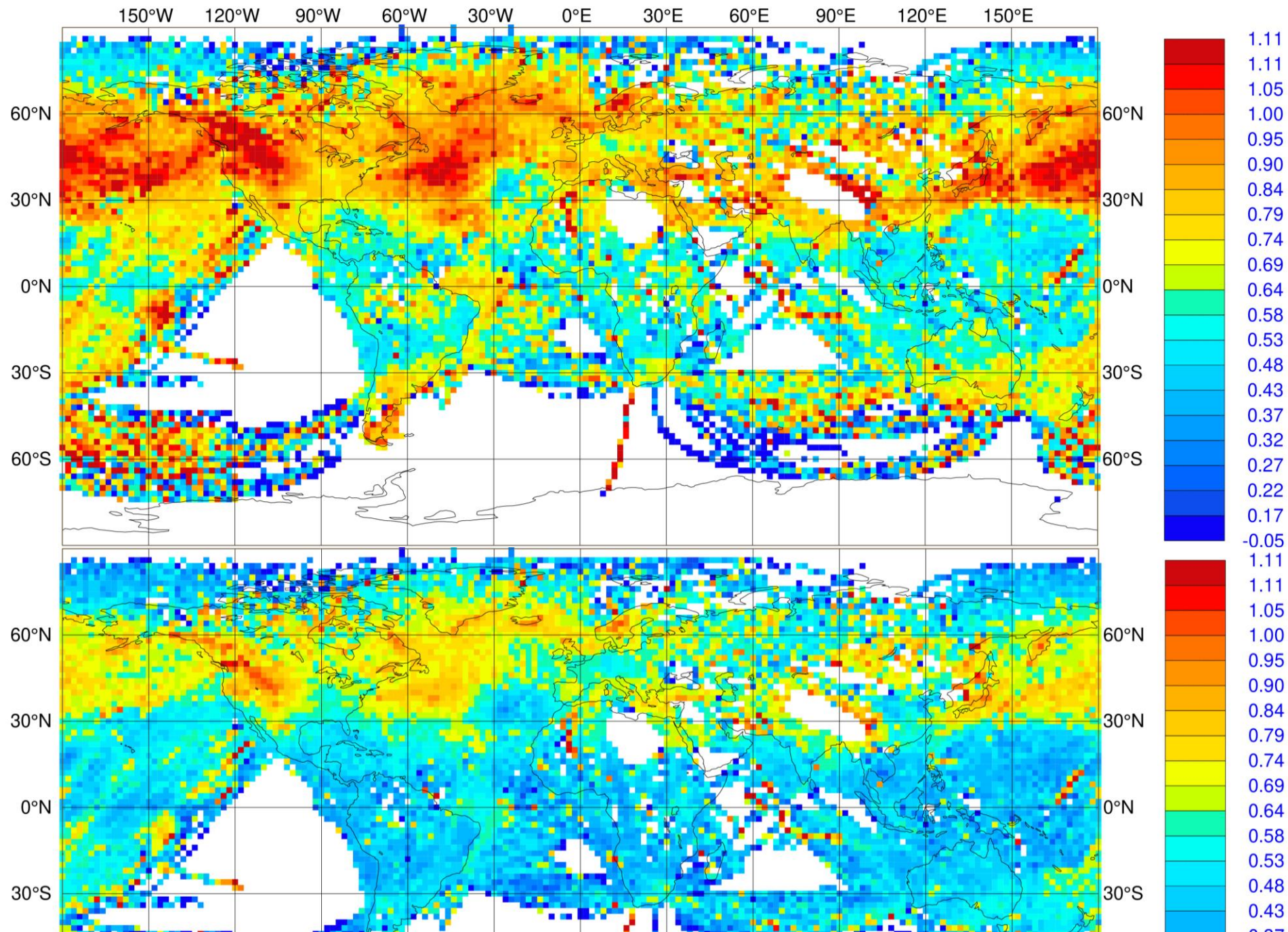
- VarBC 'works' – means we can assimilate biased data



SD(O-B) top and
SD(O-A) bottom

Largest SDs in a)
cyclogenesis regions,
b) E of Himalayas &
c) over Rockies
Also large SD(FSOI),
not shown, except for
Rockies – mountain
waves? (Diffs
reduced less over
Rockies.)

Can see occasional
suspicious tracks!



Bias correction at mid-levels –
also shows marked geographic
dependence.

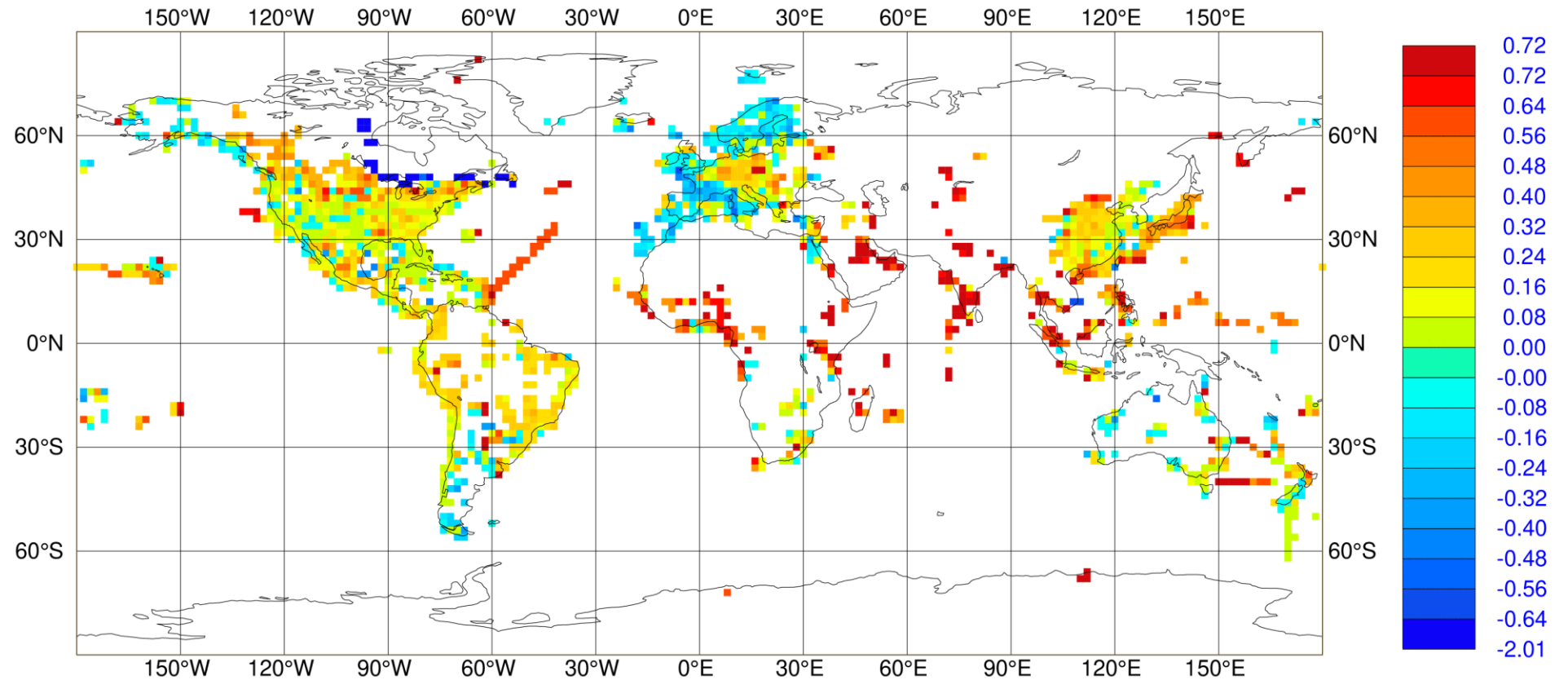
Also some suspicious tracks.

TEMP FROM AMDAR
MEAN BIAS CORRECTION [K] (USED)
DATA PERIOD = 2020-01-01 21 - 2020-02-01 09

EXP = 0001, LEVEL = 400.00 - 700.00 HPA

Min: -1.928 Max: 2.146 Mean: 0.114

GRID: 2.00x 2.00



Anonymisation etc

- Airlines+pilots didn't want users to know actual identifiers*, this has led to a lack of metadata (aircraft type, airline)
- Each AMDAR program has its own anonymisation system (eg F-GSQH becomes EU1006)
- But that same aircraft may also report via ADS-C and Mode-S – so it has three identifiers (we don't know the link between them)
- *flightaware, flightradar24 have changed the game – can we get airlines to admit that anonymisation is out-of-date?

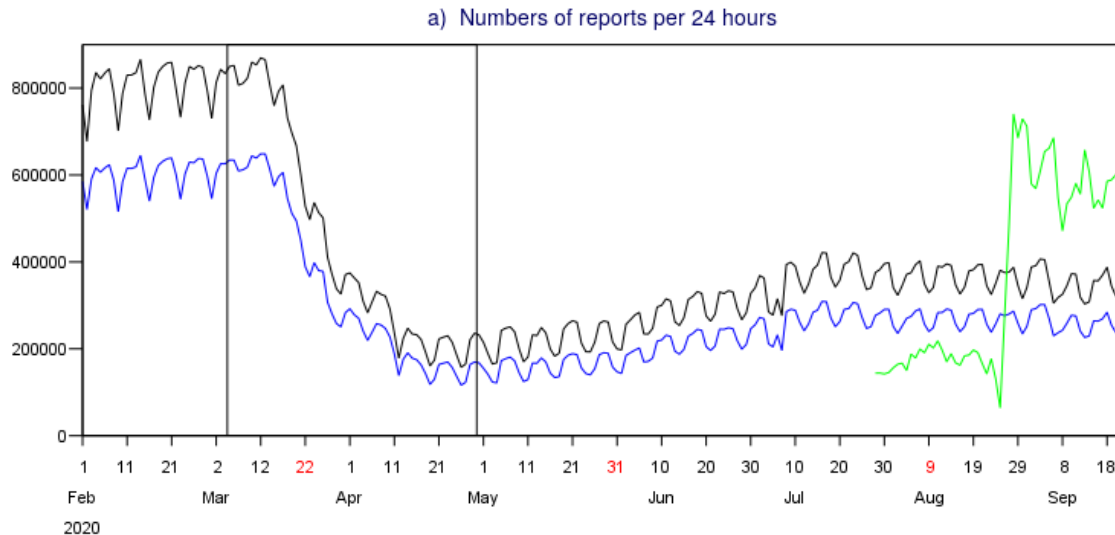
- NWP systems want identifiers/metadata for a) duplicate checking/thinning, b) bias correction, c) monitoring and rejection of aircraft with major problems, d) warning systems (eg fewer buoys today – contact the person responsible)
- ECMWF warning system currently monitors aircraft by region – would be good to monitor by airline and aircraft type as well

Metadata – the ideal?

- Aircraft type (A320, B777 etc)
- Airline
- Turns and/or turbulence
- Aircraft velocity
- Observation source (AMDAR, ADS-C etc)
- Avionics system and version
- Instruments used (make etc, table used for N declination)
- Ascent/descent rate
- Departure+arrival airports (or flight id)
- Tail number or ICAO serial number
- AMDAR program
 - From discussions with Pat Pauley, Alexander Cress and others, Nov 2019

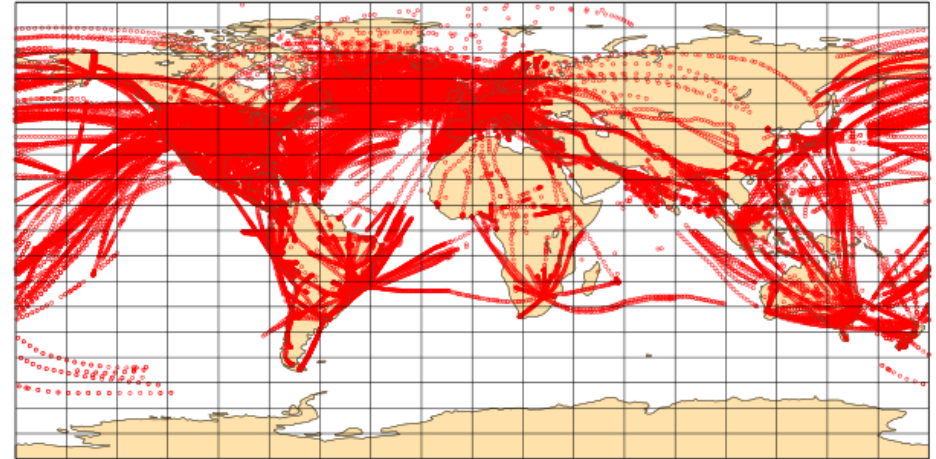
Impact of Covid-19 (1)

- Mid-March to Mid-April numbers of AMDAR+AIREP dropped by 75%
- Long-haul very badly hit, cargo less so
- Back to almost 50% by July but numbers declining again
- ECMWF started using Mode-S winds over Europe (green line below) – only about 5% of those available

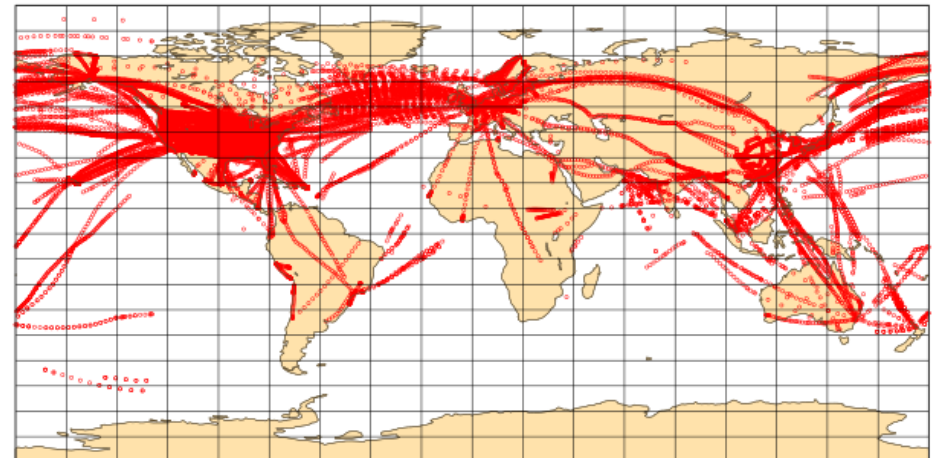


2020

b) 2020-03-04 0900-2100 UTC 325329 reports

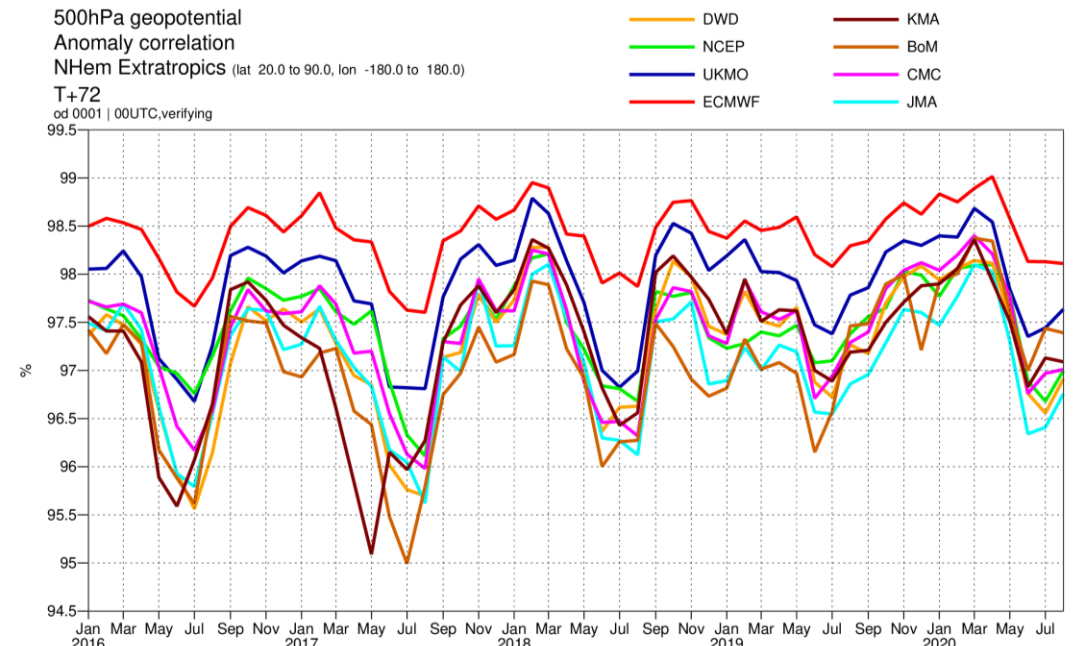
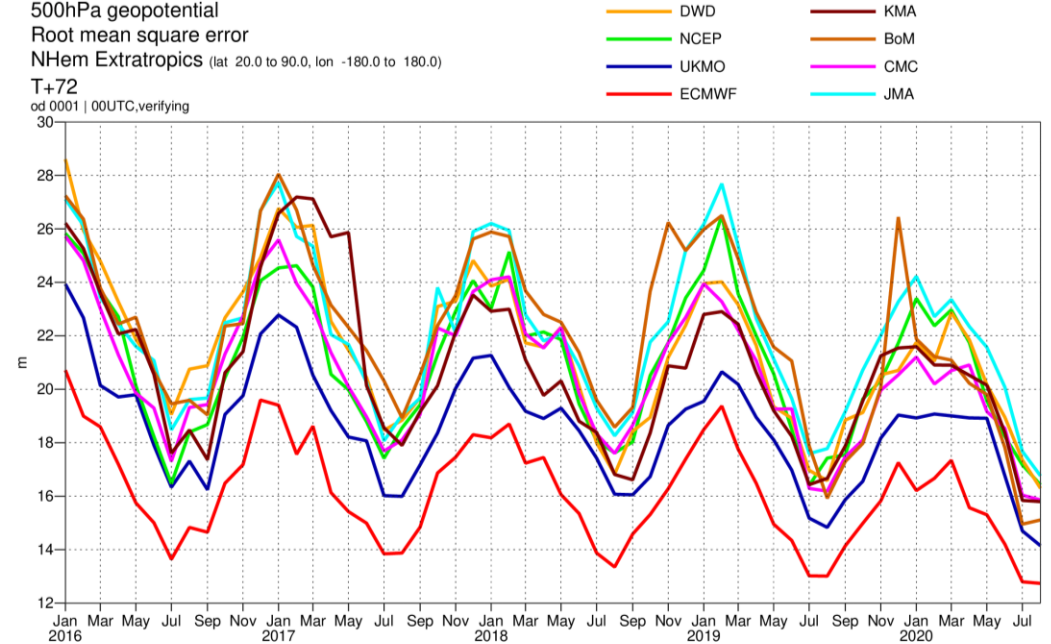


c) 2020-04-29 0900-2100 UTC 89941 reports



Impact of Covid-19 (2)

- No clear effect on forecast scores
- Also looked at 250 hPa winds at T+24
- A) Not complete loss – still 25%
- B) Extra satellite data in 2020: Aeolus winds and radio occultation (COSMIC-2 + Spire)
- C) Other upgrades to forecast system
- D) Year-to-year variations in skill anyway
- E) We don't have a control, with 'normal' aircraft data – sure that that would have been even better
- Ingleby et al (2020, submitted)



Summary

- Aircraft data are valuable for NWP! And mostly good quality.
 - Winds give more impact than temperatures
 - Timeliness is important (generally good)
- B787 wind problem – very frustrating issue
 - Partially corrected at ECMWF now (Boeing working on fix)
- Temperature biases, aircraft too warm on average but fn(aircraft_type)
 - NWP bias correction is imperfect and gets worse as % “anchor obs” reduces
 - Can bias be fixed at source in longer term?
- We want better metadata (aircraft type etc)
 - Attempt using flightradar24 to deduce aircraft type and airline, partial success