The U.S. Perspective in the Monitoring and Assimilation of Aircraft-Based Observations

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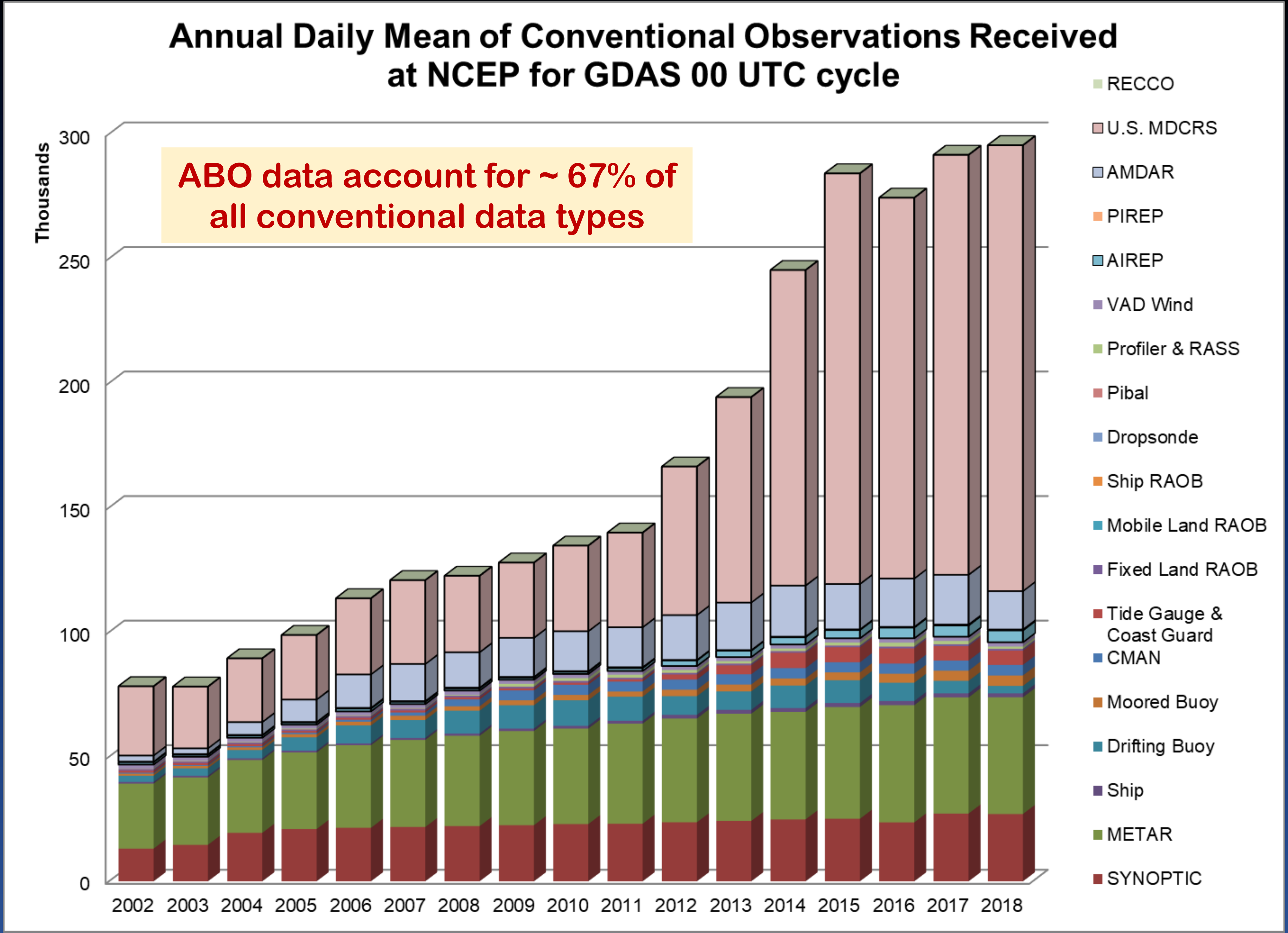
contracted by I. M. Systems Group Inc.

ECMWF / EUMETNET Workshop on Aircraft Weather Observations and Their Use

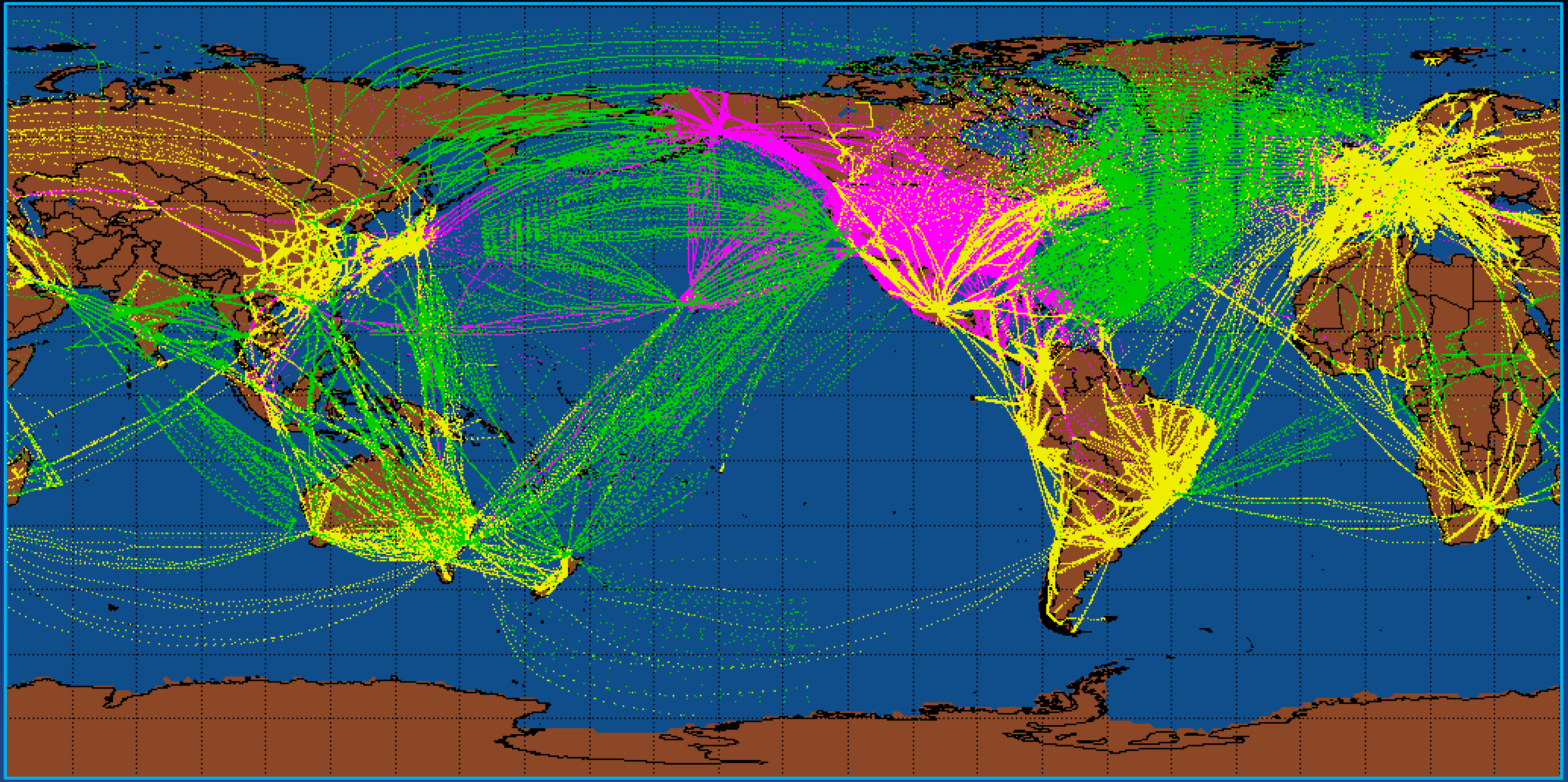
12th February 2020



Annual Daily Mean of Conventional Observations Received
at NCEP for GDAS 00 UTC cycle
ABO data account for ~ 67% of
all conventional data types
Thousands
300
250
200
150
100
50
0
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
RECCO
U.S. MDCRS
AMDAR
PIREP
AIREP
VAD Wind
Profiler & RASS
Pibal
Dropsonde
Ship RAOB
Mobile Land RAOB
Fixed Land RAOB
Tide Gauge & Coast Guard
CMAN
Moored Buoy
Drifting Buoy
Ship
METAR
SYNOPTIC

Available Meteorological Data from Commercial Aircraft

5-day sample from March 2019



Meteorological Data Collection and Reporting System (MDCRS, or U.S. AMDAR)

Aircraft Meteorological Data Relay (AMDAR) programs

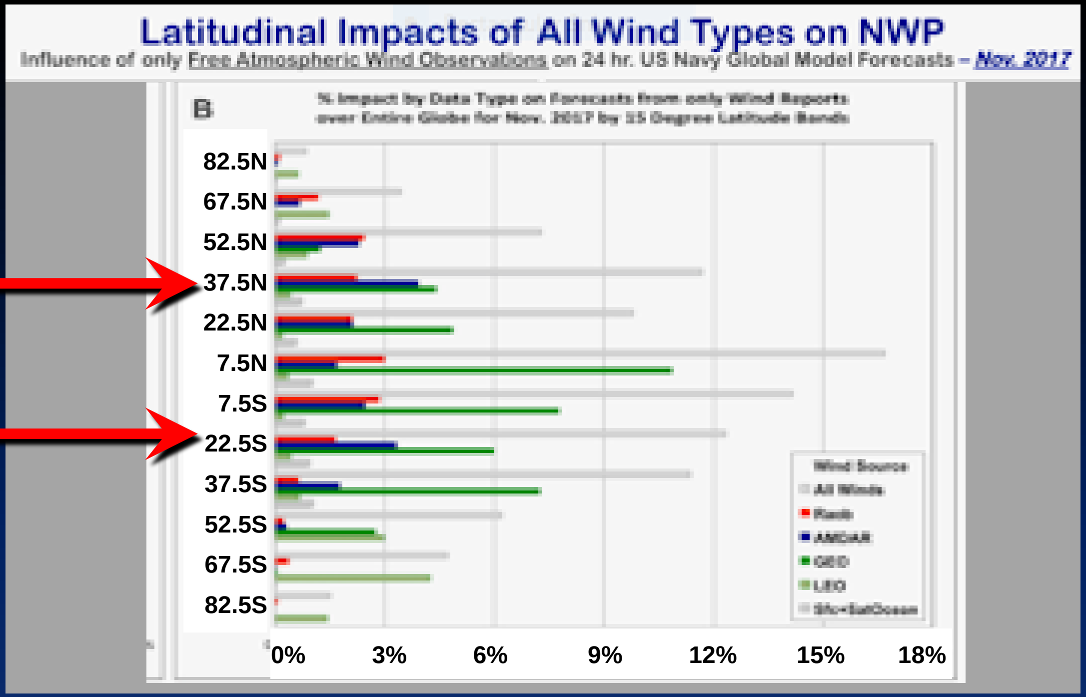
Automated Dependent Surveillance – Contract (ADS-C)

Relative Impact of AMDAR Data to U.S. Navy NWP

as of November 2017

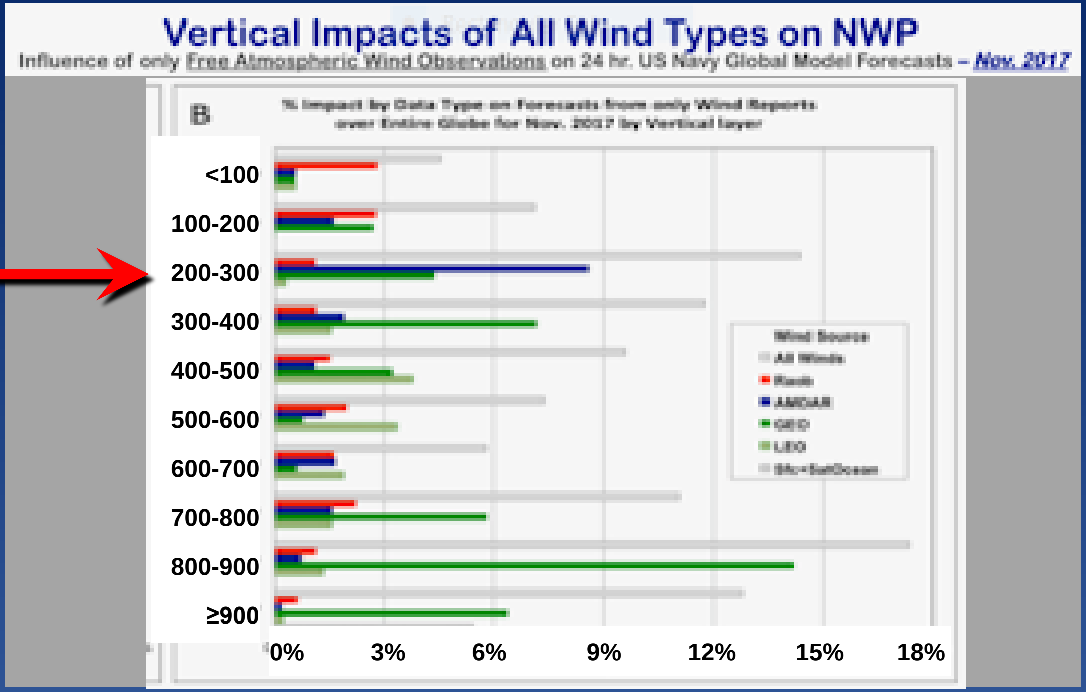
AMDAR is most impactful in
NH mid-latitudes and SH subtropics,
relative to other regions.

Most airports are situated
within the two regions.



AMDAR has the greatest impact of
any observation type at the jet stream level.

Many aircraft occupy this part of the troposphere
at any given time.



Source:

Ralph Peterson (UW / CIMSS), Patricia Pauley (NRL),

WMO AMDAR Observing System Newsletter [Apr. 2019]

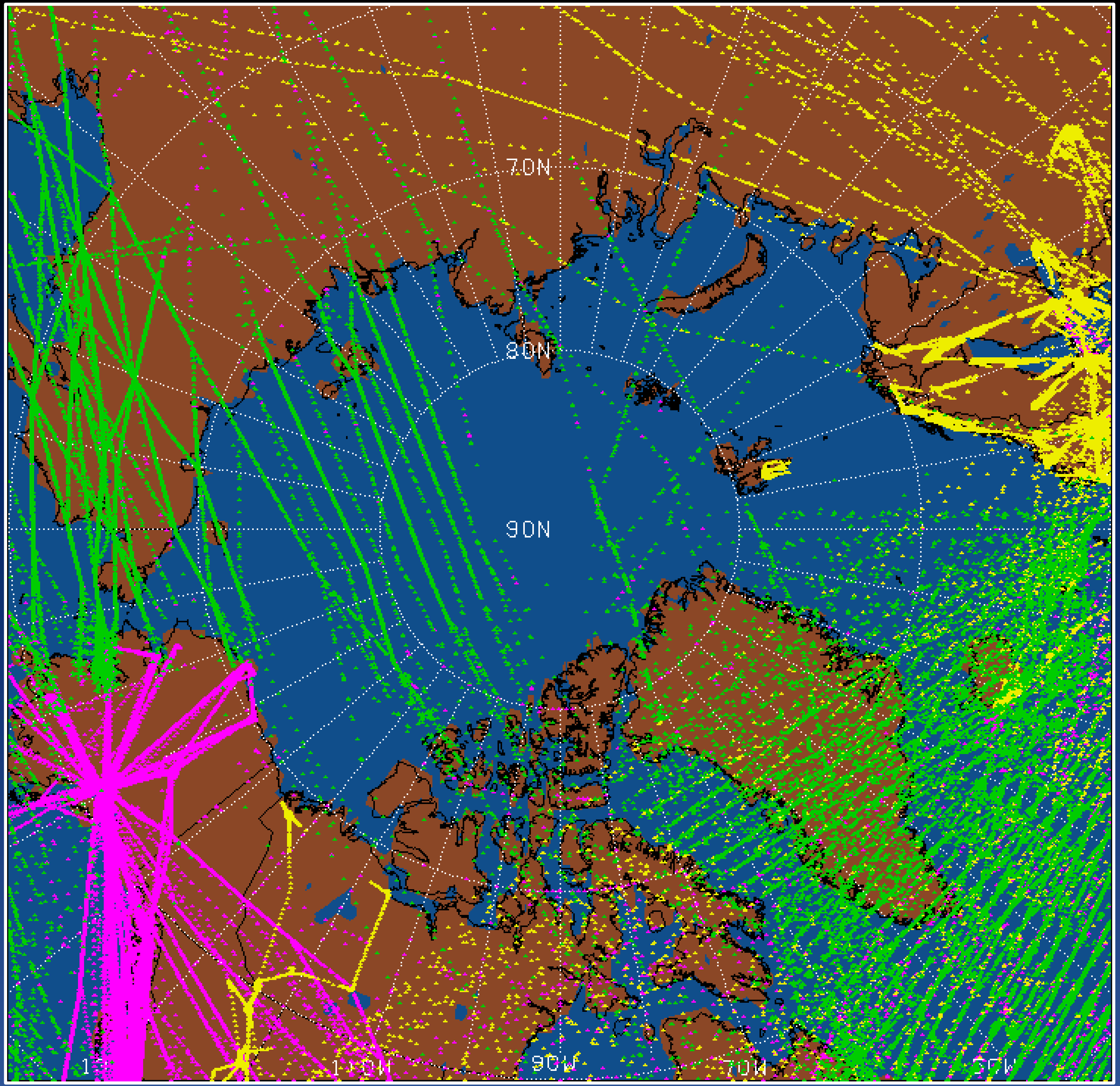
Available Meteorological Data from Commercial Aircraft

5-day sample from March 2019

Considerable ADS-C representation over Greenland, Siberia, and the Arctic Ocean.

Data from Alaska Airlines are prevalent over Alaska.

Profile data available over the N.W. Territories of Canada and over Svalbard.



MDCRS (U.S. AMDAR)

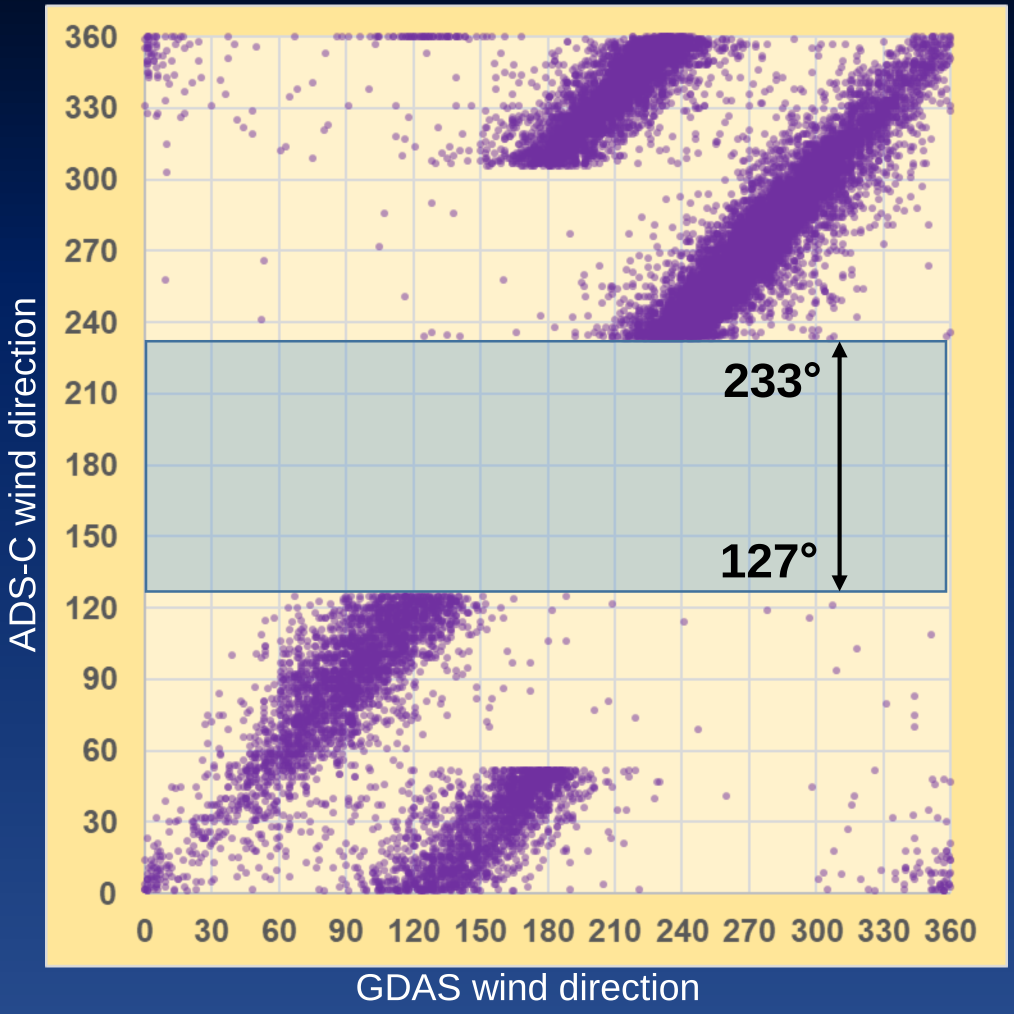
AMDAR programs

ADS-C

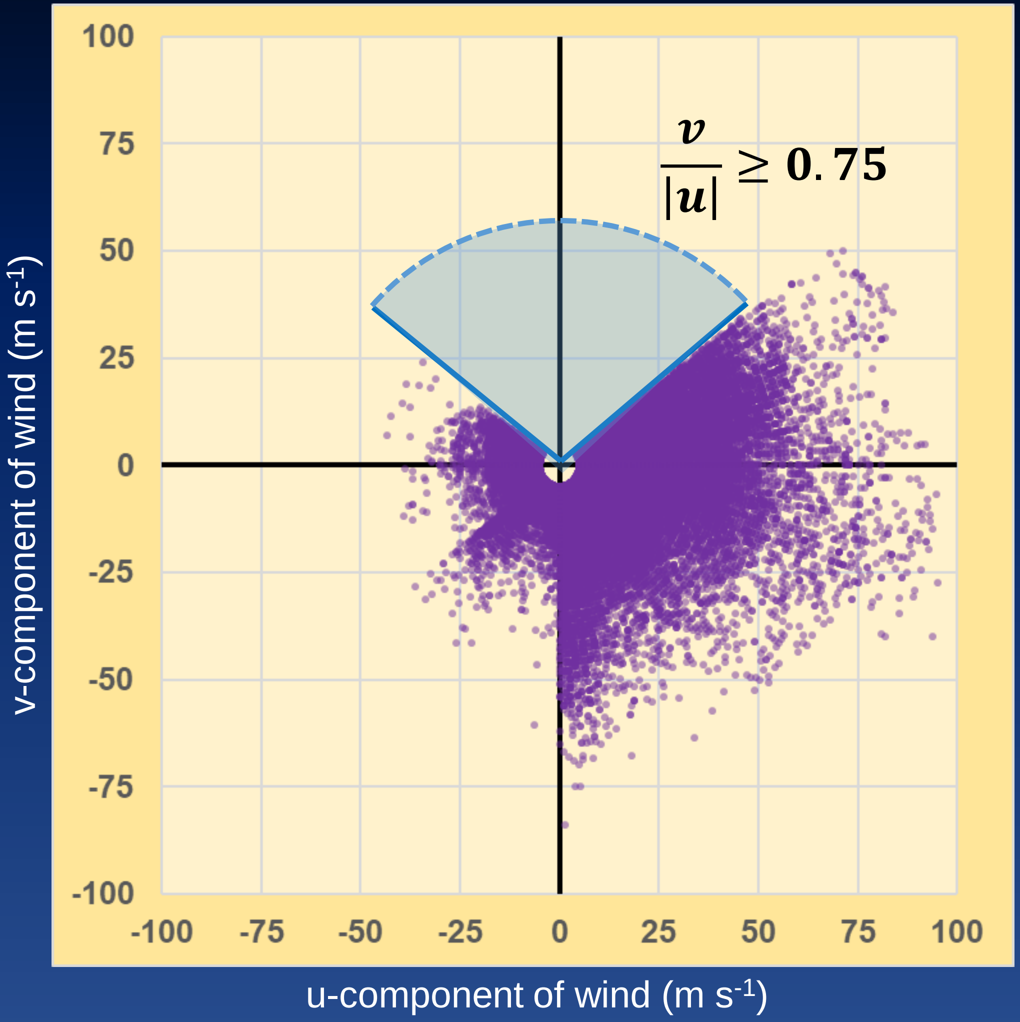
ADS-C wind data from B787s vs GDAS background

5-day sample from March 2019

GDAS vs ADS-C wind direction



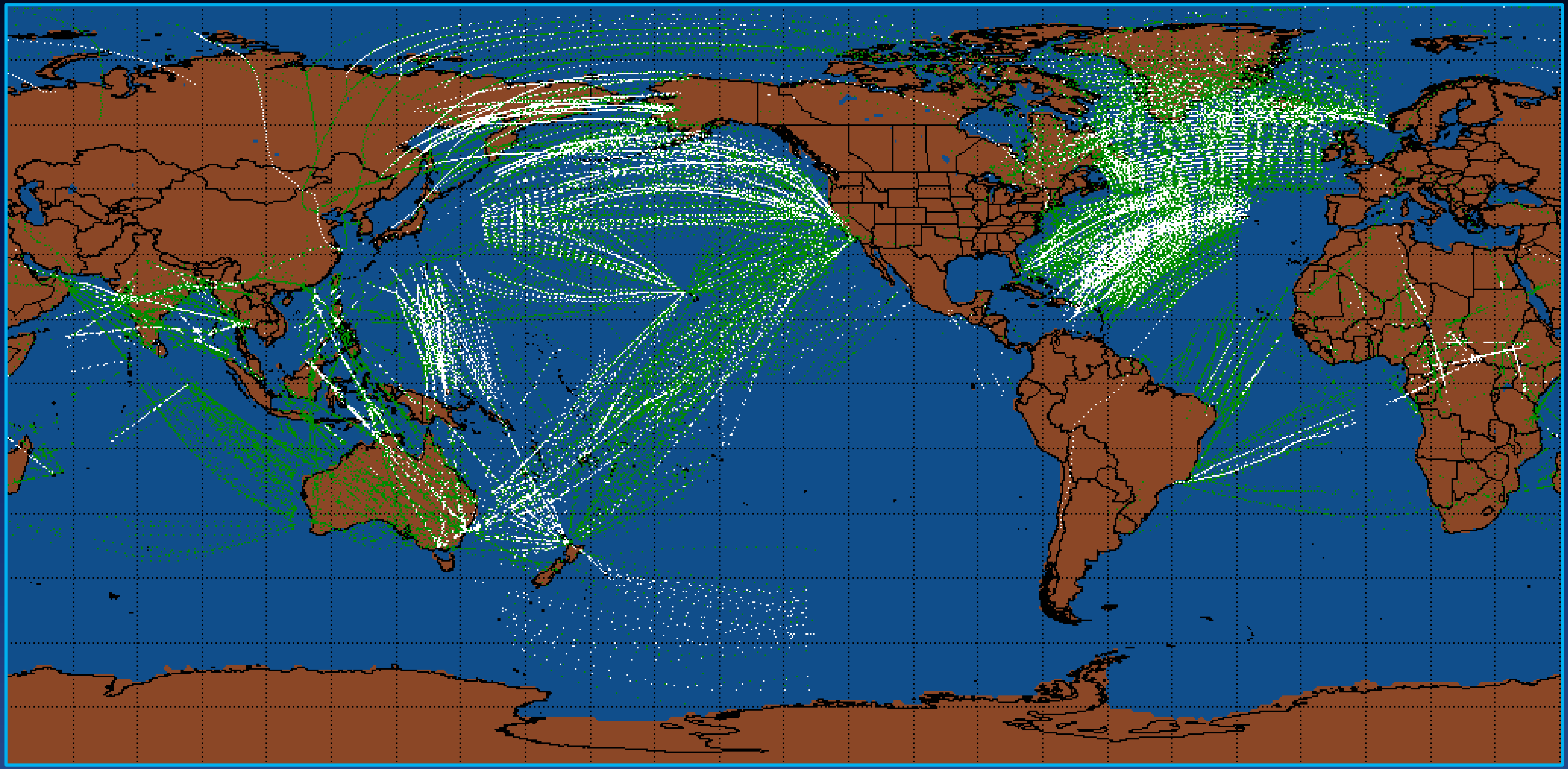
Hodograph of ADS-C wind data



Southerly wind flow, proximal to the aircraft, is not represented!

Geographic coverage of ADS-C data

5-day sample from March 2019



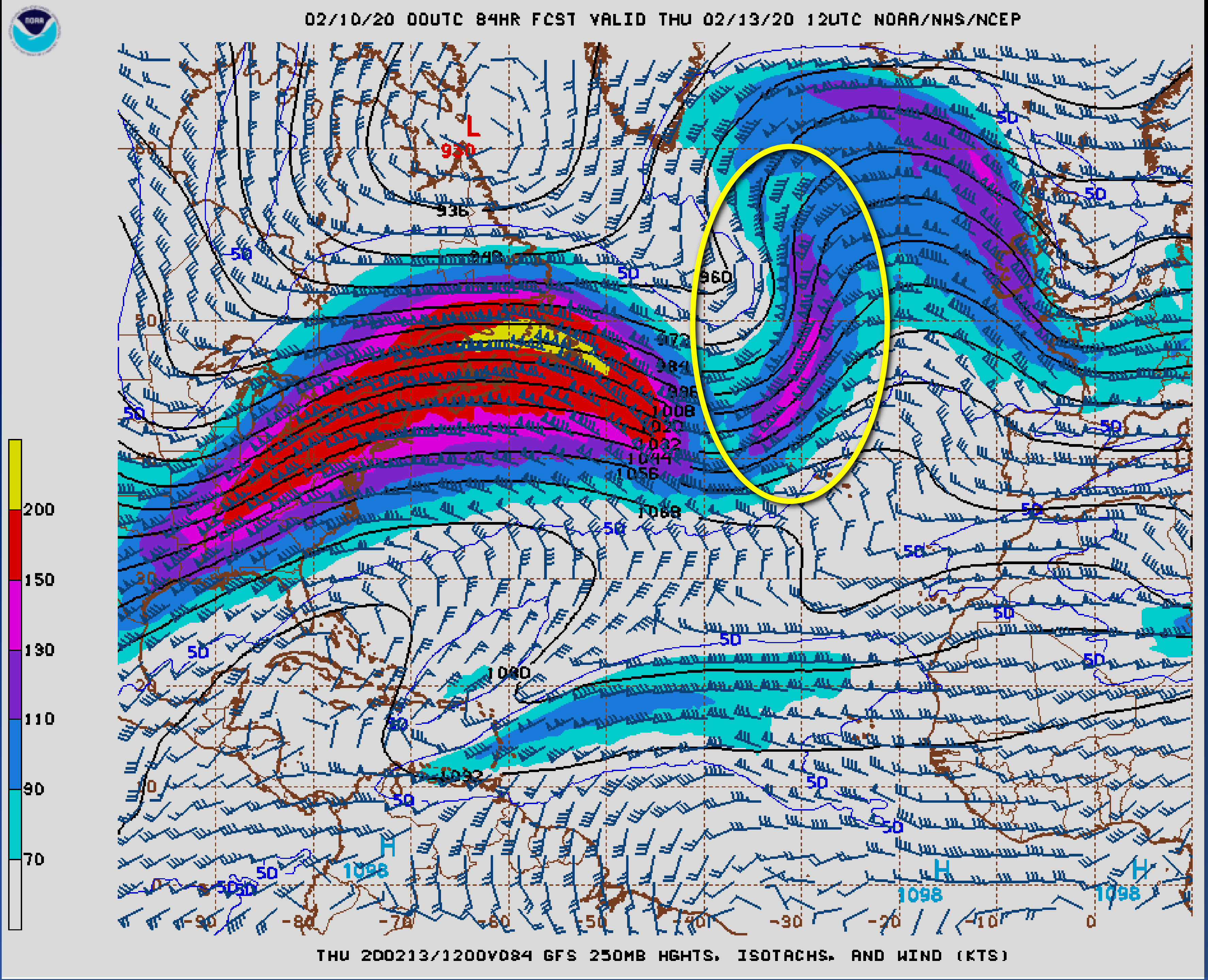
Approximately 15% of all ADS-C data originate from B787s.

GFS 250-hPa wind forecast

depicting 12 UTC
13 February 2020,

initialized 00 UTC
10 February 2020

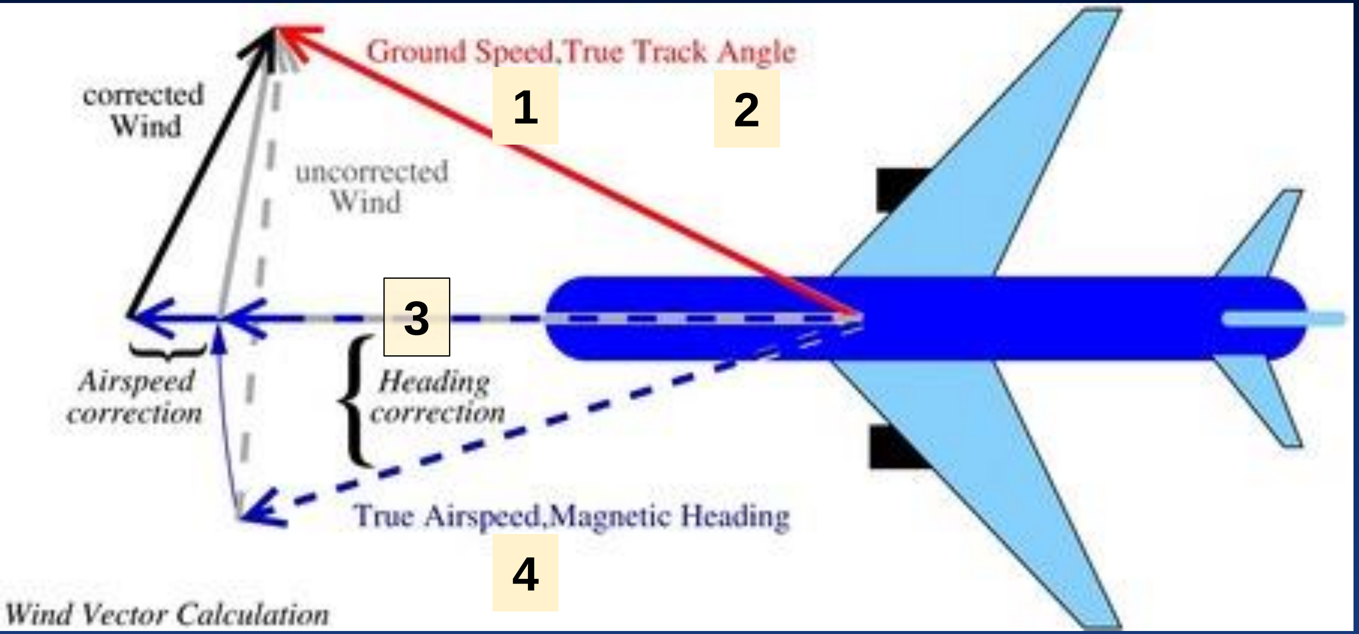
Unrepresentative ADS-C wind data are likely to be reported over the North Atlantic.



source: https://mag.ncep.noaa.gov

Method for Recovering Erroneously Reported Wind Data

Recalculate the wind vector using motion vectors relative to the ground and air, as is done with Mode-S radar tracking of aircraft.



Source: KNMI https://mode-s.knmi.nl/index.html

From some aircraft, ADS-C data messages directly report: **1**) ground speed, **2**) true track angle, and **3**) true aircraft heading. **4**) True airspeed can be determined from a relation of observed temperature to the local Mach number ($V_{acft} = M\sqrt{\gamma RT}$).

Assuming only the sign of the *v*-component is in error, the orientation of the vector is readily corrected.

ABO Data Assimilation at NCEP

Global Data Assimilation System (GDAS) configuration

- Finite-Volume Cubed-Sphere dynamical core (FV3) with 13-km horizontal grid spacing
- 4-D Hybrid Ensemble Variational assimilation scheme
  - Observations are assimilated along a time-based trajectory of sequential *X, Y, Z* background fields
- Application of a temperature bias correction is specific to each contributing aircraft
  - corrections to ascent/descent data vary by the rate of vertical motion
  - corrections to cruise level data are largely derived from radiosonde and GPS radio occultation climatologies
- Assimilation of AIREP, AMDAR, and ADS-C observations; no assimilation of PIREP data

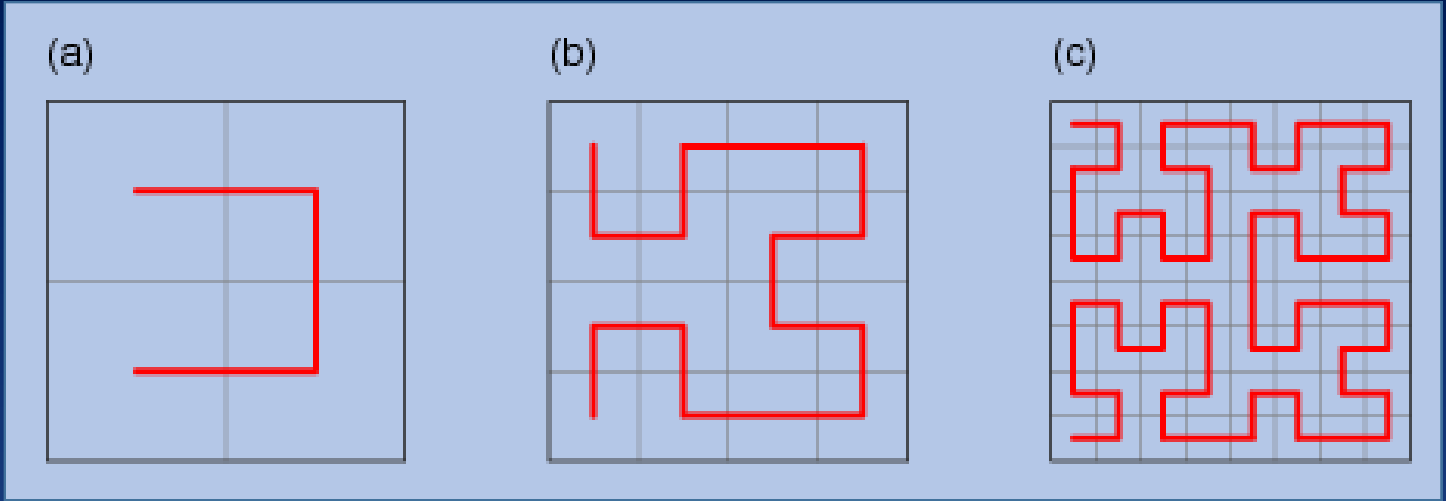
Future developments

- Down-weighting of aircraft data in high density areas, as determined through application of Hilbert curve projection
- Correction of grossly erroneous wind vectors through application of available aircraft relative motion data
- Global assimilation of TAMDAR data (currently assimilated in Rapid Refresh regional modeling system)

Application of Hilbert Curve projection

Courtesy of Purser and Su, at NCEP/EMC

Developed by David Hilbert (1891), a “curve” discretely and isometrically samples a 2-D, 3-D, or 4-D dataset onto a 1-D parameter. It can be thought of as the limit of the sequence whose first three stages are shown below in the case of a simple 2D square. A density distribution in the plane maps to a proportionate parameter-density of the “curve”.

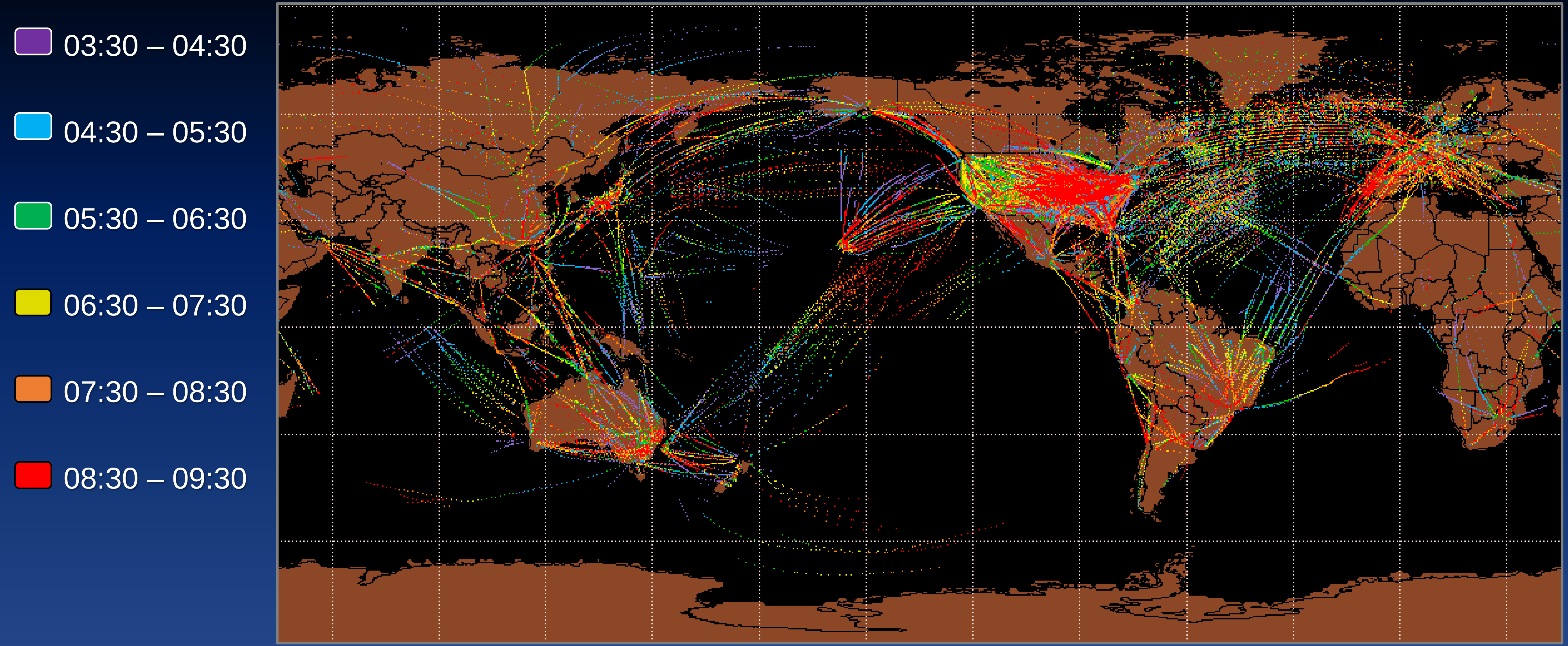


Depending on the model area of responsibility, the computing cost for assimilation can become excessive where many homogeneous reports are frequently and closely generated.

Moreover, any tendency of high bias or a systematic error across these reports can result in a degradation of model skill; the Hilbert curve projection allows efficient density estimation and is used toward assigning a lowered assimilation weight to dense ABO reports.

ABO Data Available for 06 UTC model cycle, 10-12 km layer

5-day sample from March 2019



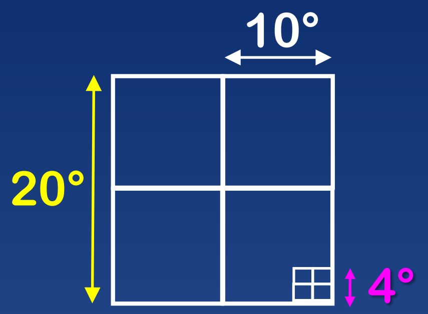
ABO report density varies widely across the world, and across time.

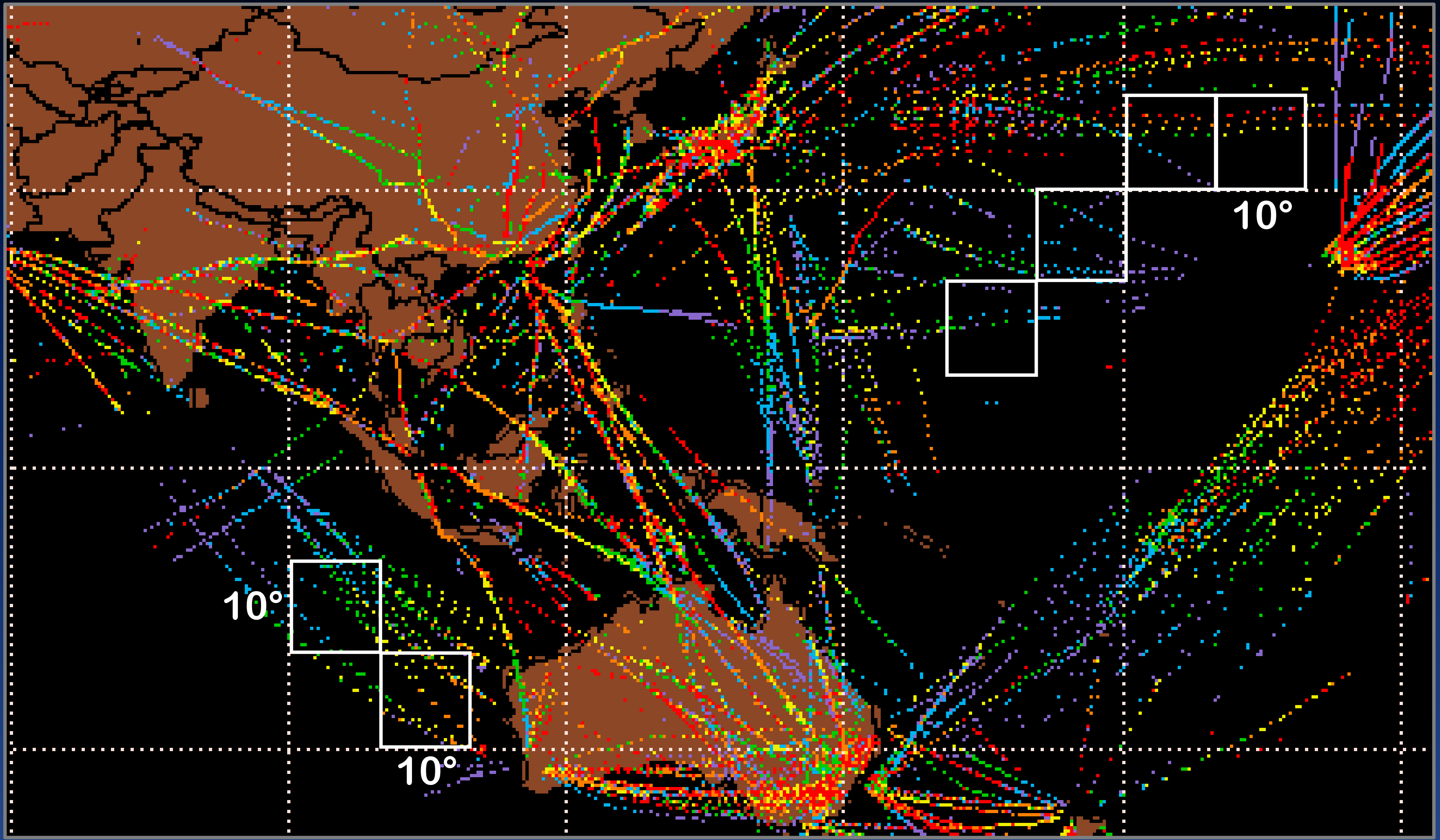
ABO Data Available for 06 UTC model cycle, 10-12 km layer

5-day sample from March 2019

- 03:30 – 04:30
- 04:30 – 05:30
- 05:30 – 06:30
- 06:30 – 07:30
- 07:30 – 08:30
- 08:30 – 09:30

Hilbert curve parameters:
200 km × 200 km × 2 km × 1 hr





The Hilbert curve projection traces a singular report available within a specified cuboid.

Where data reports are less frequent and spaced apart, all such data are then fully weighted for assimilation.

ABO Data Available for 06 UTC model cycle, 10-12 km layer

5-day sample from March 2019

- 03:30 – 04:30
- 04:30 – 05:30
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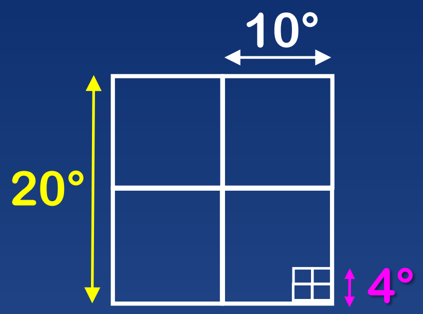
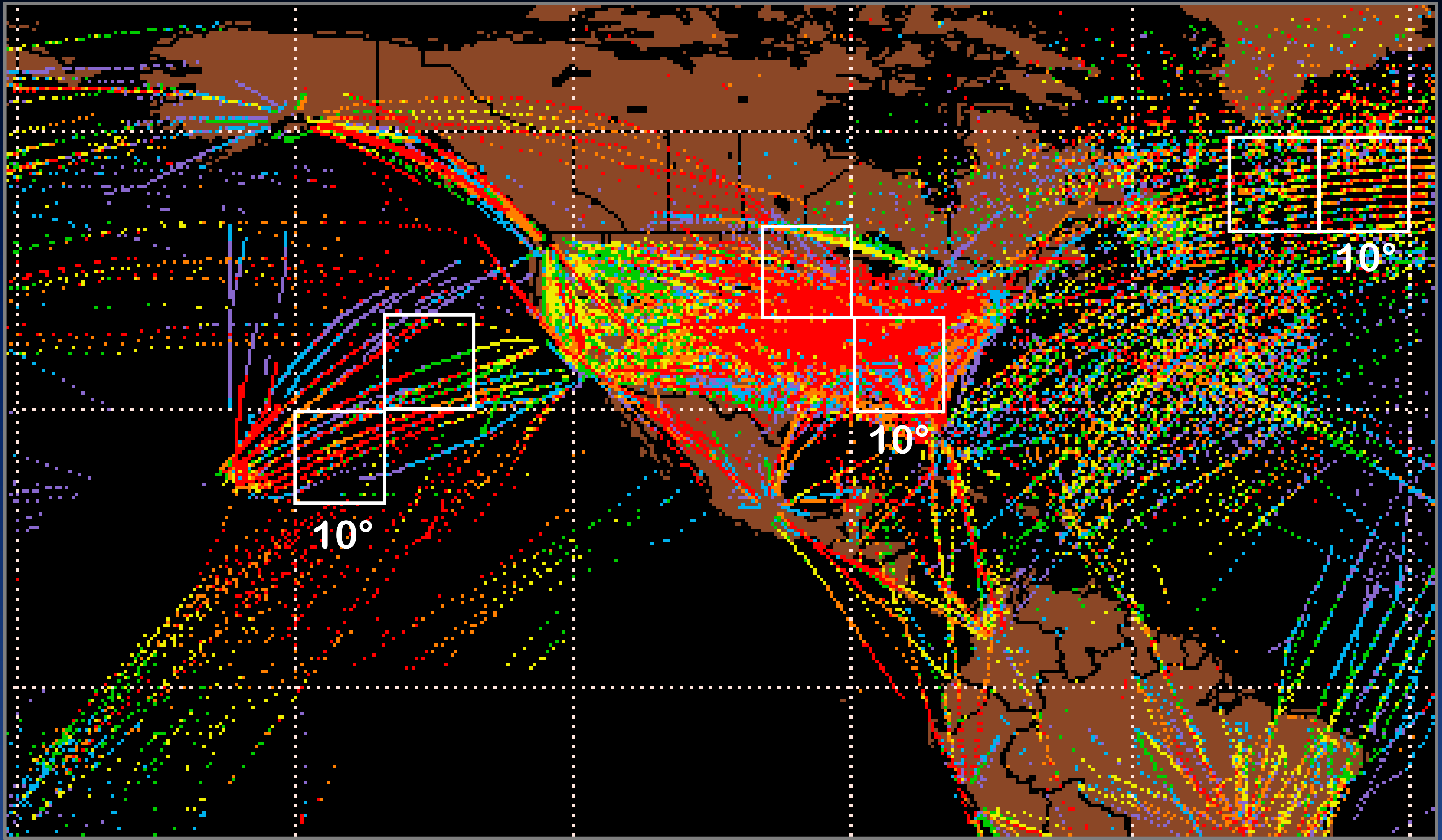




Where ABO reports are more frequent and/or closely spaced, data are assigned a lower weight for assimilation.

Interactive Resource for ABO Data Monitoring

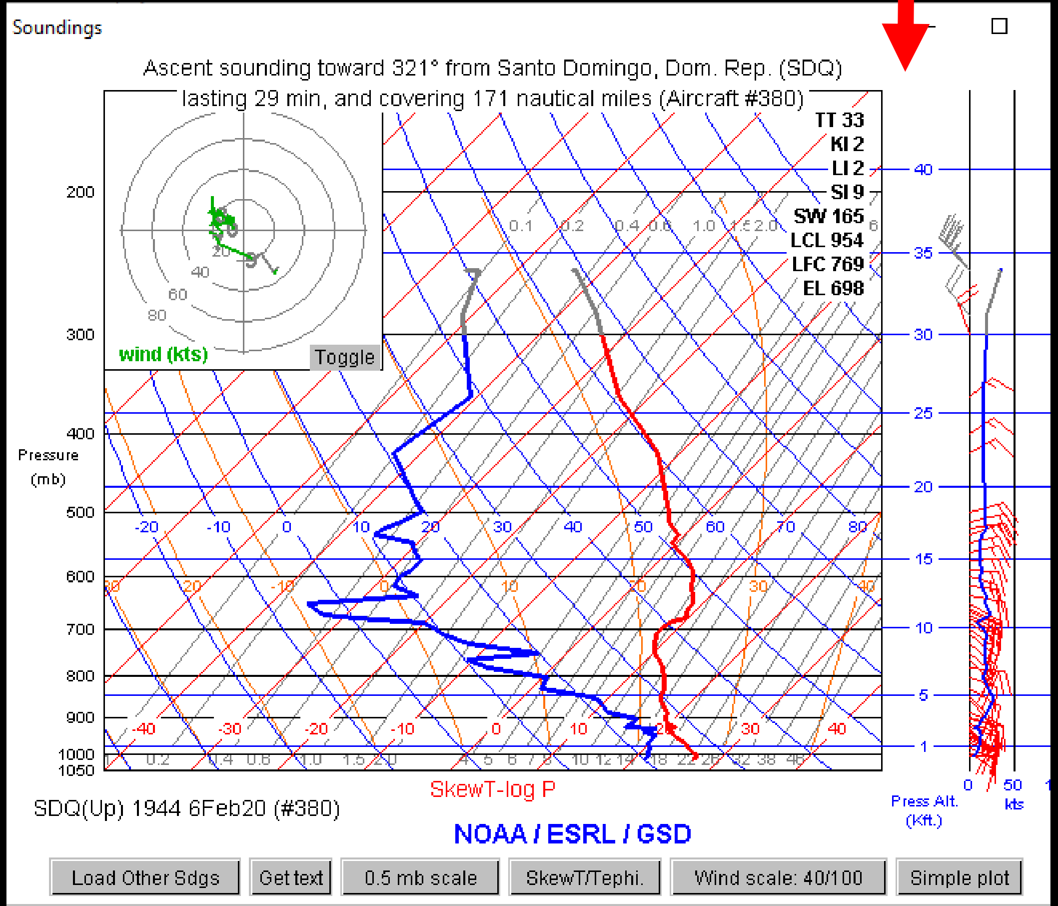
Sortable 7 day statistics for all AMDAR reporting more than 200 times in the last 7 days, world wide.

Aircraft data minus GFS 3-h forecast.

abs(bias_T) > 2°C shown in red
std_T > 2°C shown in red
abs(bias_S) > 2 m/s shown in red
std_S > 5 m/s shown in red
abs(bias_D) > 7° shown in red (when S > 10 m/s)
std_D > 30° shown in red (when S > 10 m/s)
rms_W > 7 m/s shown in red (vector wind difference, when heading is known)
abs(bias_RH) > 10% shown in red
std_RH > 20% shown in red

For the period 2020-02-01 02:00:00 to 2020-02-07 21:59:59
(Click on a column header to sort by that column)
(Click on a GSD_ID to get a time series in a separate window)

GSD_ID	N_T	avg_T	bias_T	std_T	N_S	avg_S	bias_S	std_S	bias_D	std_D	rms_W	N_RH	avg_RH	bias_RH	std_RH	model	airline		
.	.	.	.	.	.	.	.	.	.	.	.	V	.	.	.	.	.		
11006	1273	-16.9	-0.0	1.0	1273	23.9	0.1	2.9	-1	8	4.0	1273	46.3	4.1	20.1		SW		
10997	1269	-16.2	-0.1	0.9	1269	24.8	0.1	2.6	-0	6	3.9	1269	45.0	-2.5	15.7		SW		
11058	1263	-15.5	-0.2	1.1	1263	24.9	0.2	3.0	-0	7	4.0	1263	47.6	-0.2	17.8		SW		
10998	1257	-15.2	2.0	1.1	1257	25.7	0.2	2.8	1	6	3.8	1256	35.5	-10.6	14.5		SW		
11184	1247	-17.1	0.2	1.1	1247	25.5	0.1	3.1	-0	6	4.4	1246	61.3	0.5	27.4		SW		
11921	1226	-21.8	-0.1	1.0	1226	25.4	0.1	2.7	-1	6	3.7	1224	39.9	-6.1	15.9		SW		
11246	1221	-17.7	-0.1	1.2	1221	24.8	0.2	3.2	1	8	4.7	1221	57.1	2.9	20.3		SW		
11050	1212	-18.4	-0.1	0.9	1212	23.7	-0.3	2.8	0	6	3.8	1205	53.3	-3.6	17.7		SW		
11182	1205	-15.2	-0.1	1.0	1205	17.9	-0.1	2.4	-0	6	3.4	1205	41.7	0.5	15.4		SW		
11249	1200	-15.5	0.0	1.1	1200	17.4	0.0	2.3	-0	6	3.1	1200	39.9	-1.6	15.5		SW		
11009	1242	-8.3	-0.1	0.9	1242	16.0	0.1	2.3	0	7	3.2	1192	33.2	-3.8	11.8		SW		
11060	1196	-13.6	-0.0	0.9	1196	20.7	0.3	2.5	-1	6	3.5	1183	51.1	-2.4	20.7		SW		
11911	1183	-16.4	-0.1	1.1	1183	23.4	-0.0	3.1	-2	7	4.4	1183	46.6	-1.1	13.8		SW		
10804	1181	-15.4	0.1	1.2	1181	19.9	0.0	2.9	-1	8	3.9	1181	67.7	28.1	57.0		SW		
11207	1178	-21.6	0.1	1.1	1178	23.2	0.1	2.8	1	7	4.0	1177	46.0	6.4	31.6		SW	2020-02-01 02:06:00	2020-02-07 20:52:00
11066	1183	-15.4	-0.1	1.4	1183	20.7	0.0	2.8	0	7	3.9	1176	39.5	-0.7	23.1		SW	2020-02-01 02:00:00	2020-02-07 21:52:00
11083	1176	-16.5	-0.1	1.1	1176	24.9	0.1	2.8	-1	6	3.9	1176	48.5	-3.6	21.1		SW	2020-02-01 02:36:00	2020-02-07 21:59:00
11419	1175	-19.0	0.1	0.9	1175	23.8	0.1	2.6	0	6	3.6	1175	43.5	0.9	14.3		SW	2020-02-01 02:00:00	2020-02-07 21:59:00
10992	1267	-17.5	-0.1	1.1	1267	22.0	-0.2	2.8	-0	7	4.0	1173	38.0	-3.1	14.9		SW	2020-02-01 02:24:00	2020-02-07 21:58:00
11049	1179	-16.4	-0.1	1.2	1179	24.0	-0.4	2.6	-0	7	3.8	1166	48.1	-4.4	16.7		SW	2020-02-01 02:00:00	2020-02-07 21:13:00
11179	1166	-15.0	0.2	1.3	1166	21.5	0.1	2.9	-1	7	4.1	1166	48.2	0.9	18.0		SW	2020-02-01 02:38:00	2020-02-07 21:59:00
11296	1164	-19.3	1.4	1.3	1164	26.9	0.1	3.5	0	7	4.8	1163	43.6	-3.7	20.4		SW	2020-02-01 02:00:00	2020-02-07 21:59:00



Source: https://amdar.noaa.gov, NOAA/OAR Earth Science Research Laboratory / Global Services Division

Additional Acknowledgements

NOAA/NWS/NCEP/EMC Aircraft Data Assimilation Team

- Jim Purser, Yanqiu Zhu, Xiujuan Su, Dagmar Merkova, Andrew Collard

Collins Aerospace (formerly Rockwell Collins)

- Alan Williard, Jeannine Hendricks

NWS / Office of Observations

- Curtis Marshall – Program Manager for ABOs and for MesoNet

Thanks to ECMWF and to EUMETNET for organizing and hosting this workshop.

Thank you for observing!

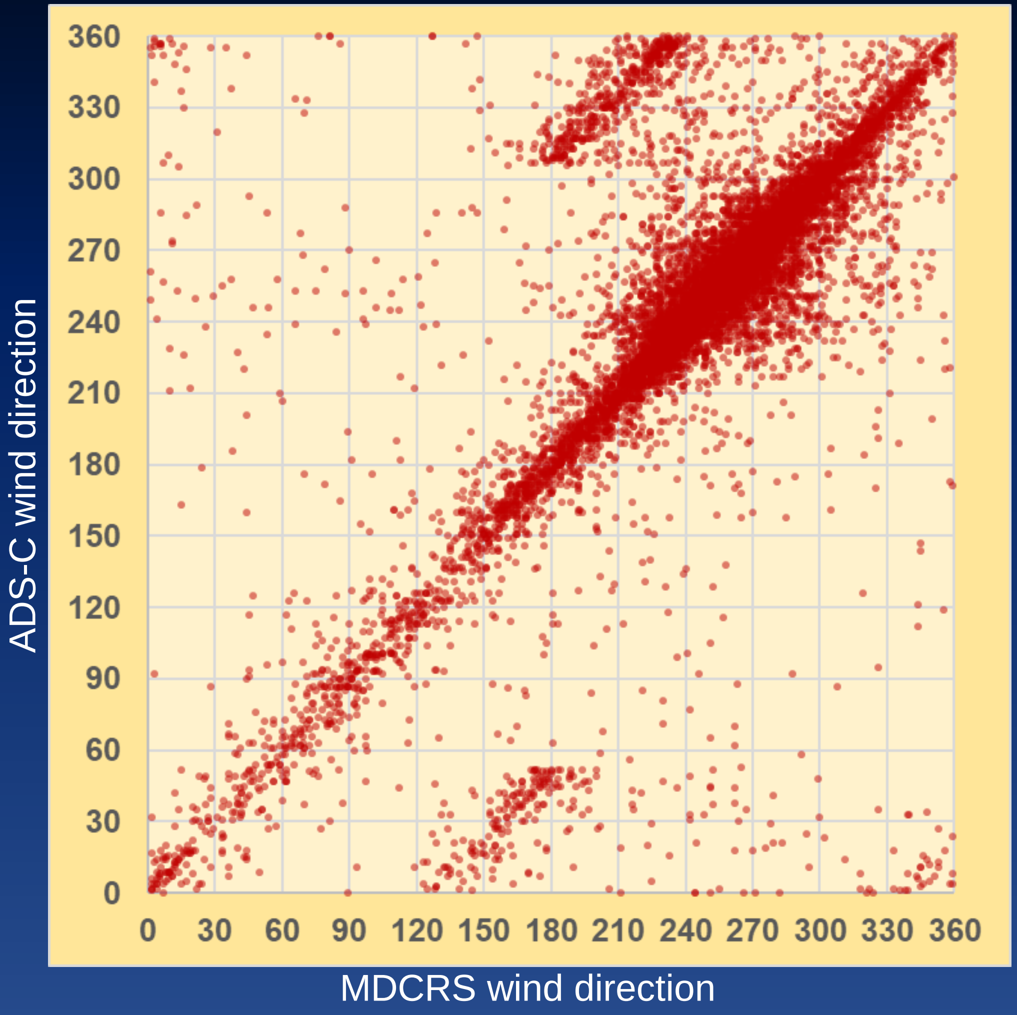
Questions or comments?

EXTRA

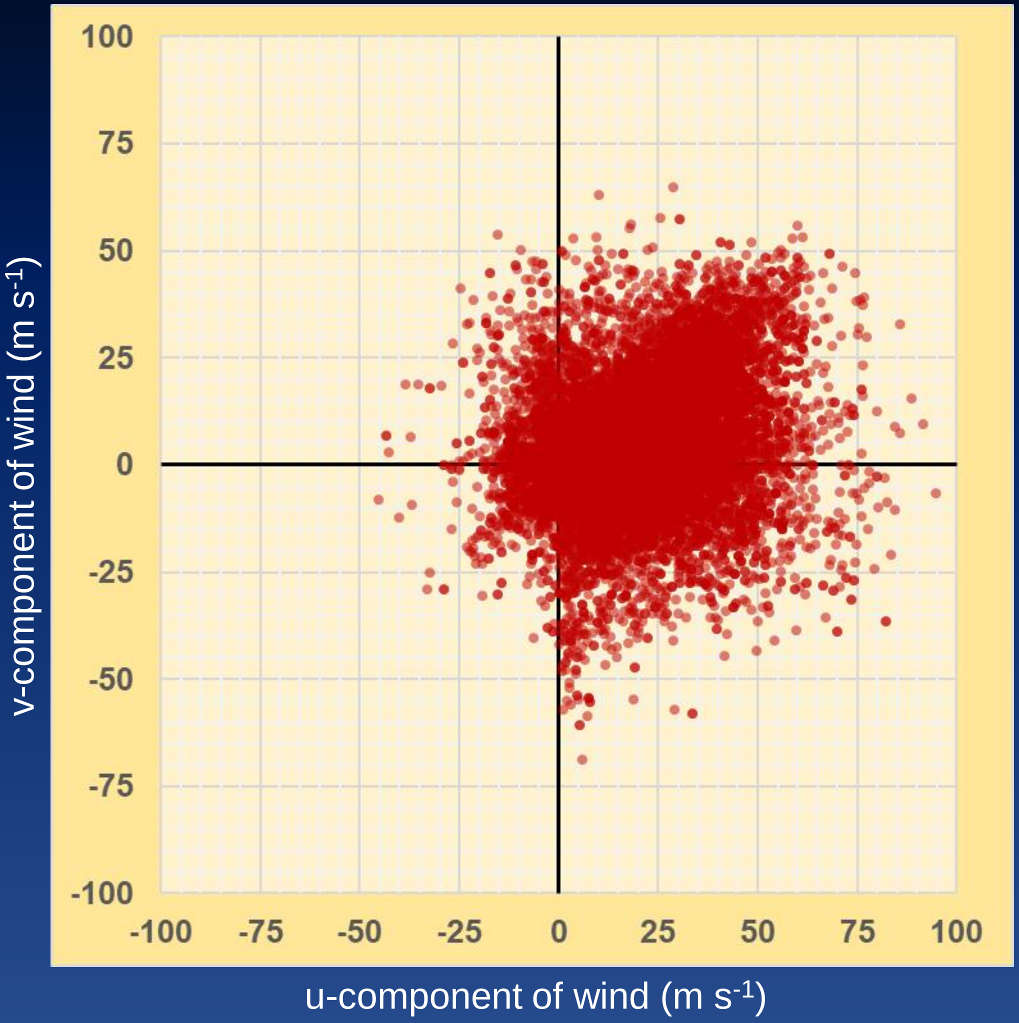
ADS-C wind data from MDCRS-participating aircraft

5-day sample from March 2019

MDCRS vs ADS-C wind direction



Hodograph of ADS-C wind data

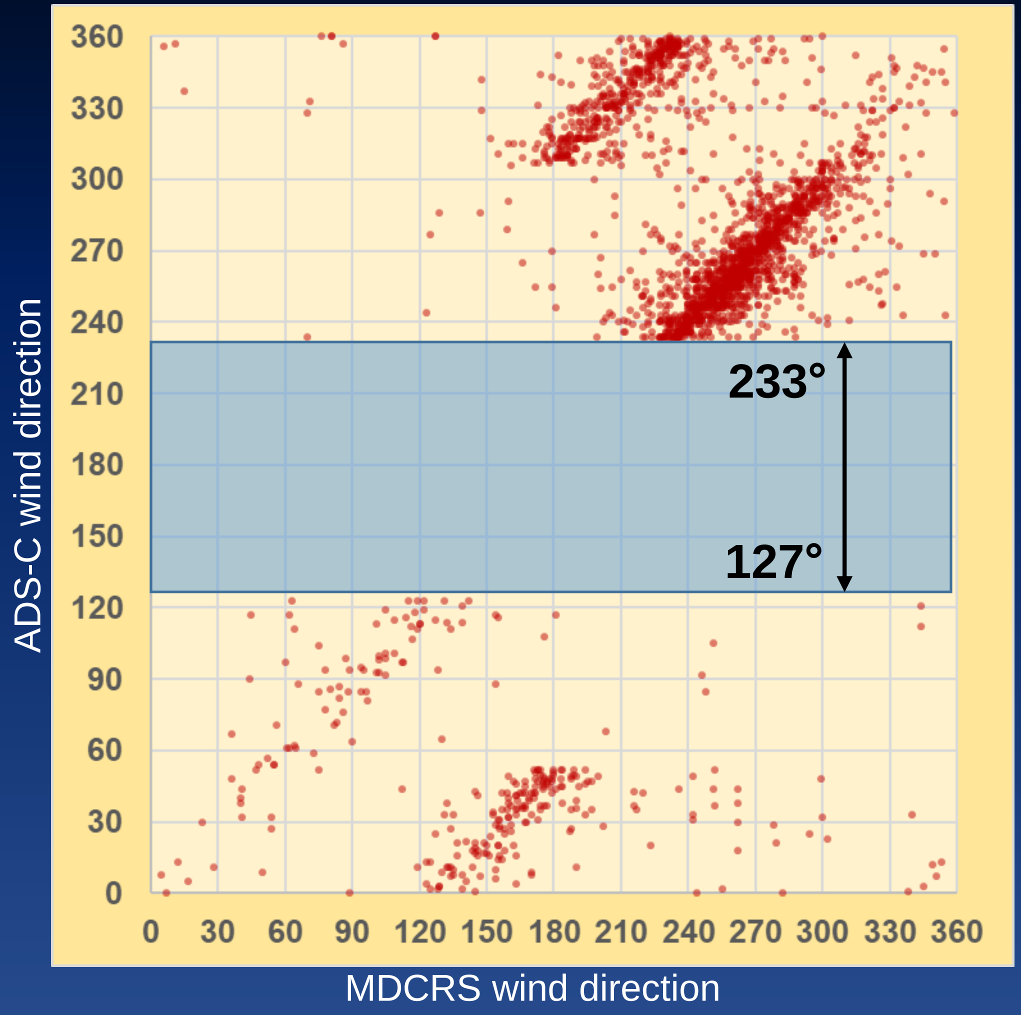


Some ADS-C observations are poorly correlated with MDCRS

ADS-C wind data from MDCRS B787 aircraft

5-day sample from March 2019

MDCRS vs ADS-C wind direction



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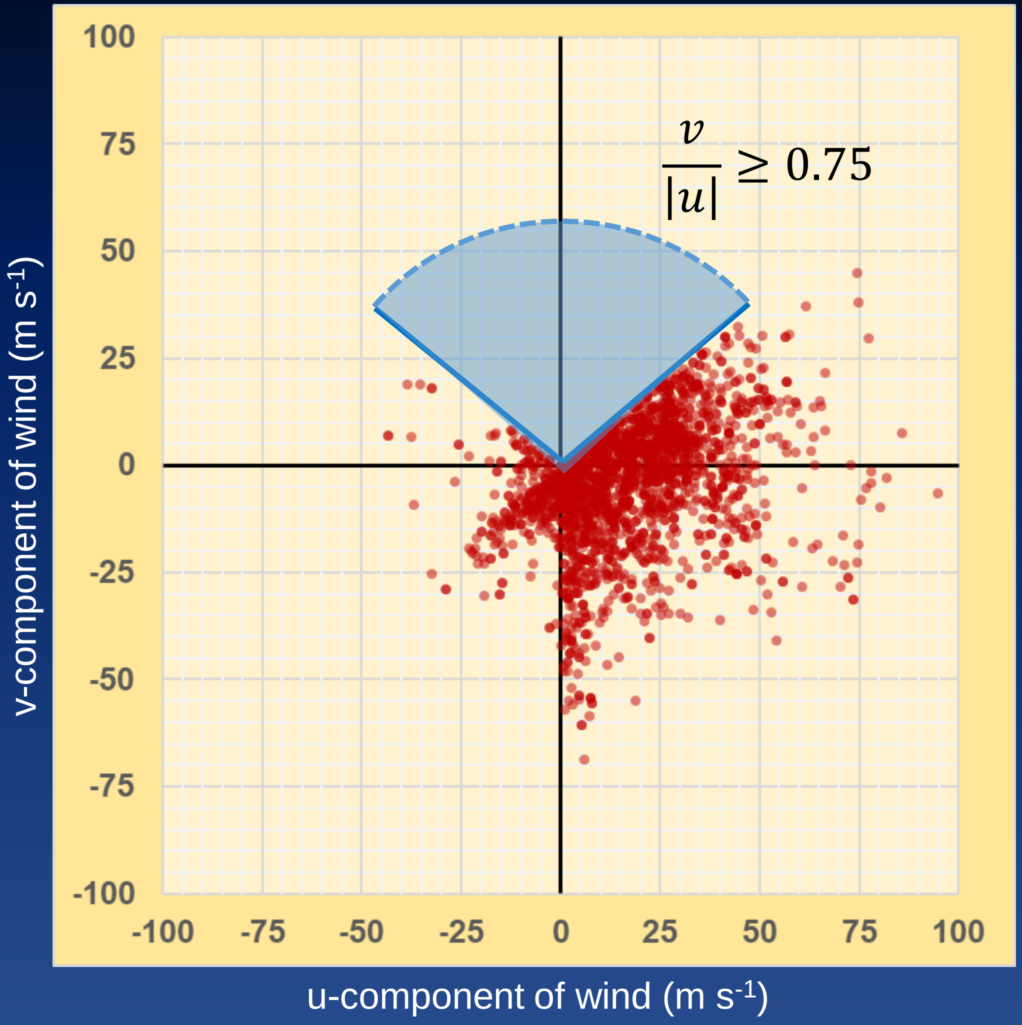

Available Meteorological Data from TAMDAR network

5-day sample from March 2019