Fourth Atmospheric Motion Vector Intercomparison Study

David Santek[1], Rich Dworak[1],
Steve Wanzong[1], Sophia Reiner[1], Katherine Lukens[2],
Javier García-Pereda[3]

[1]SSEC/Univ. of Wisconsin-Madison
[2]CISESS/Univ. of Maryland
[3]NWCSAF/AEMET

16th International Winds Workshop
09 May 2023

Project Overview

AMVs (Atmospheric Motion Vectors) are produced operationally by several centres throughout the world.

The mains goal of this study are to:

1. To consider both 11.2 μm channel Cloudy AMVs and 6.2 μm channel Clear sky AMVs
2. To compare the different AMV datasets with additional reference wind observations:
   - Aeolus Doppler Wind Lidar (DWL)
   - Commercial aircraft winds observations
3. Define the best options for the calculation of AMVs with new generation geostationary satellites (Himawari-8/9, GOES-R, MTG-I, etc.)

This presentation contains a sample of the intercomparison techniques to highlight differences in AMVs between centres, a summary of the goals achieved, and future considerations.

Participants

BRZ: Brazilian Weather Forecast and Climatic Studies Centre (CPTEC/INPE)

EUM: EUMETSAT

JMA: Japan Meteorological Agency (JMA)

KMA: Korea Meteorological Administration (KMA)

NOA: National Oceanic and Atmospheric Administration (NOAA)

NWC: Satellite Application Facility on Support to Nowcasting and Very Short Range Forecasting (NWCSAF)

⇒ The same six participants as in previous 2018 AMV Intercomparison.

Other institutions were suggested to participate, unsuccessfully.

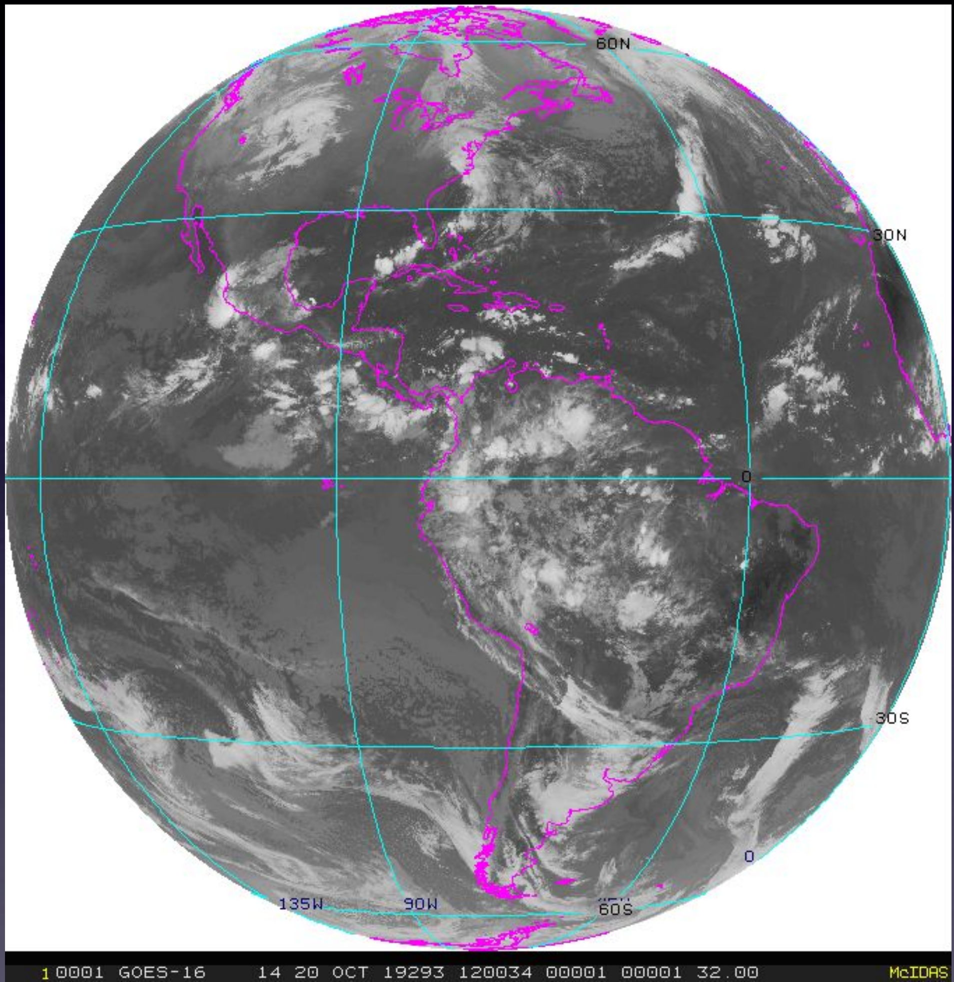
Input datasets

Four different experiments were considered, using:

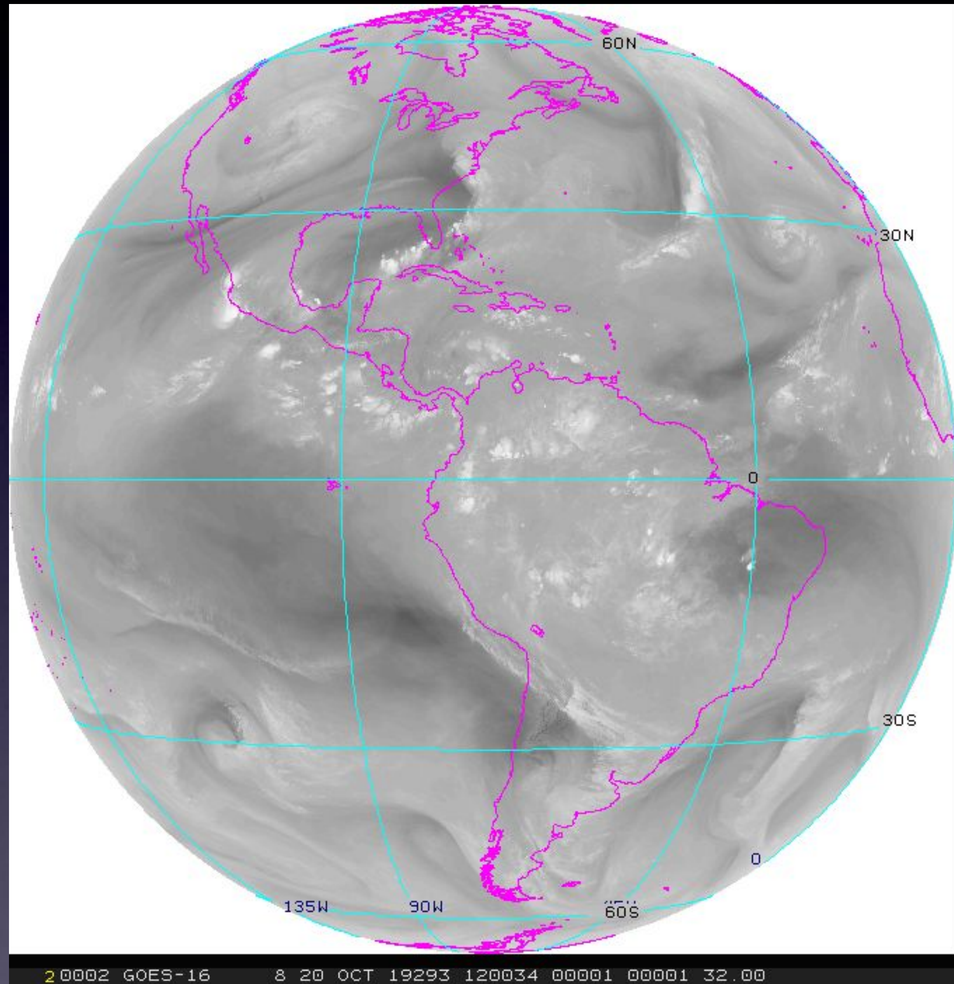
- Four sets of triplets of GOES-16 ABI full disk images from 20 October 2019
- GFS at 03,- 06-, 09,- 12-hour forecasts for wind algorithm first guess
- Corresponding "Cloud products" (derived by NOAA/NESDIS)

Experiment	Config	Time (UTC)	Participants	Reference datasets
1 IR cloudy AMVs	Common	11:50/12:00/12:10	All	Rawinsondes, GFS NWP analysis
2a IR cloudy AMVs	Own	11:20/11:30/11:40	All	Aircraft winds, ADM-Aeolus Mie wind profiles
2b IR cloudy AMVs	Own	11:50/12:00/12:10	All	Rawinsondes, GFS NWP analysis
2c IR cloudy AMVs	Own	18:50/19:00/19:10	All	CALIPSO cloud height
3 WV clear air AMVs	Own	11:20/11:30/11:40	All, except JMA	Aircraft winds, ADM-Aeolus Rayleigh wind profiles
4 WV clear air AMVs	Own	11:10/11:30/11:50	All, except JMA	Aircraft winds, ADM-Aeolus Rayleigh wind profiles

Input datasets



GOES-16 ABI 11.2 µm for 20 October 2019 at 1200UTC



GOES-16 ABI 6.2 µm for 20 October 2019 at 1200UTC

Output dataset

Each centre provided AMV data as text files, with these output parameters:

Column	Variable	Description
1	ID	Identification number
2	LAT[DEG]	Latitude
3	LON[DEG]	Longitude
4	TS[PIX]	Target box size
5	SS[PIX]	Search box size
6	SPD[MPS]	AMV speed
7	DIR[DEG]	AMV direction
8	PRES[HPA]	AMV pressure
9	L	Low-level correction
10	NWSSPD[MPS]	Background guess wind speed
11	NWSDIR[DEG]	Background guess wind direction
12	ALB[%]	Albedo
13	CORR[%]	Correlation
14	T	Brightness temperature
15	PRESSERR[HPA]	AMV pressure error
16	H	Height assignment method
17	QIN[%]	QI without forecast
18	QIF[%]	QI with forecast
19	QIC[%]	Common QI

Notes

1: JMA

Did not generate clear-sky AMVs for Experiments 3 and 4.

2: KMA

AMVs are the same for Experiments 1 and 2b,

as NOAA cloud product was not used in Experiment 1,

and “common” and “own” configurations were exactly equivalent.

3: Geographic coverage

To ensure consistent geographic coverage among the centres,

only AMVs within 6670 km from the satellite subpoint were retained.

4: Pressure range

Only AMVs from 100 to 1000 hPa were considered in comparison statistics.

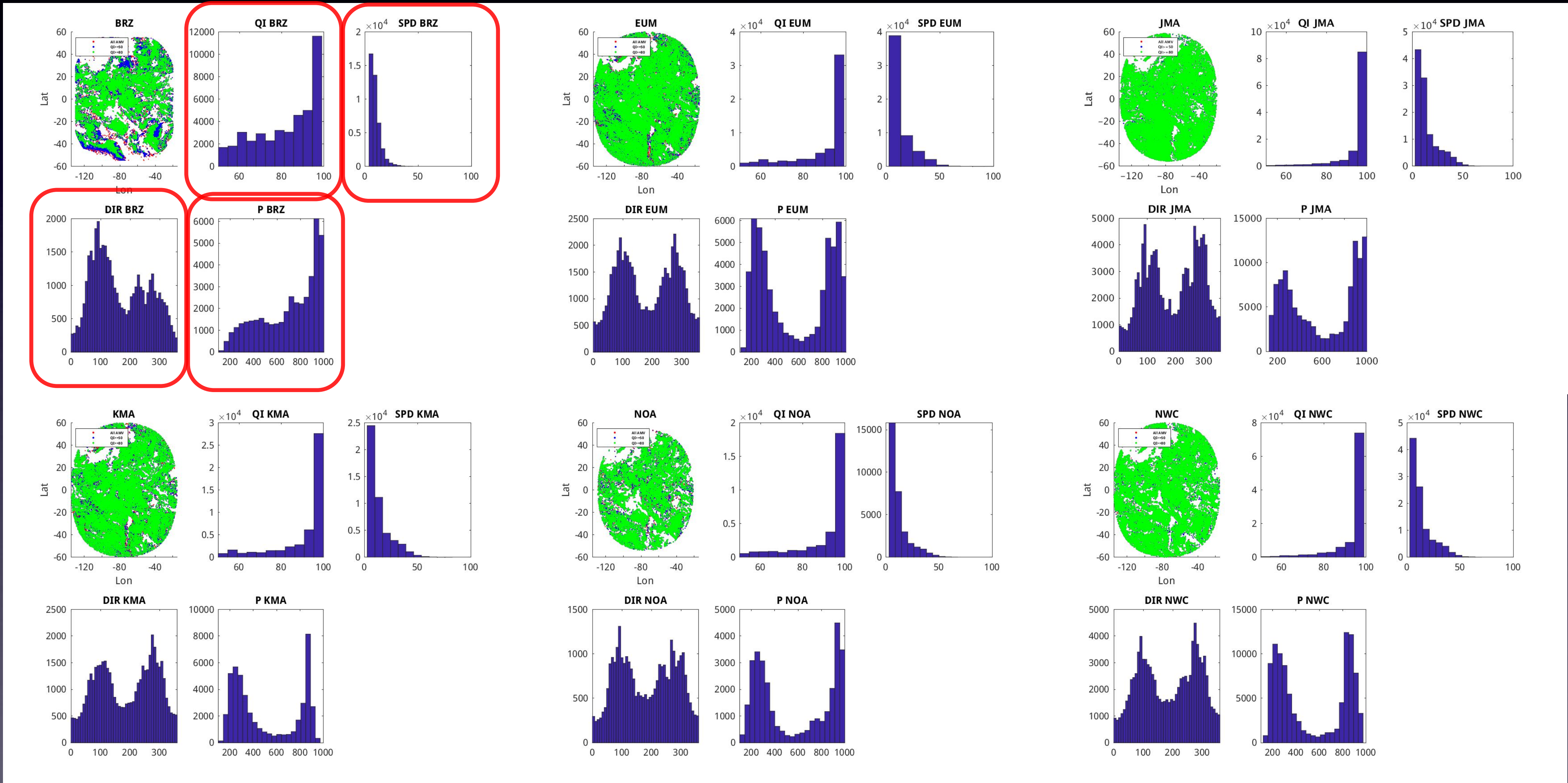
Experiment 1

- AMV producers extract IR11.2 µm cloudy AMVs,
  with the triplet 1150-1210 UTC,
  using their best options for AMV calculation,
  considering <u>prescribed</u> target size, target location,
  search scene size.

- Even though this is similar to experiments
  in previous intercomparisons,
  only EUM, NOA, and NWC
  used the NOAA cloud product.
  This limits comparisons.

Experiment 1

AMV parameter distributions



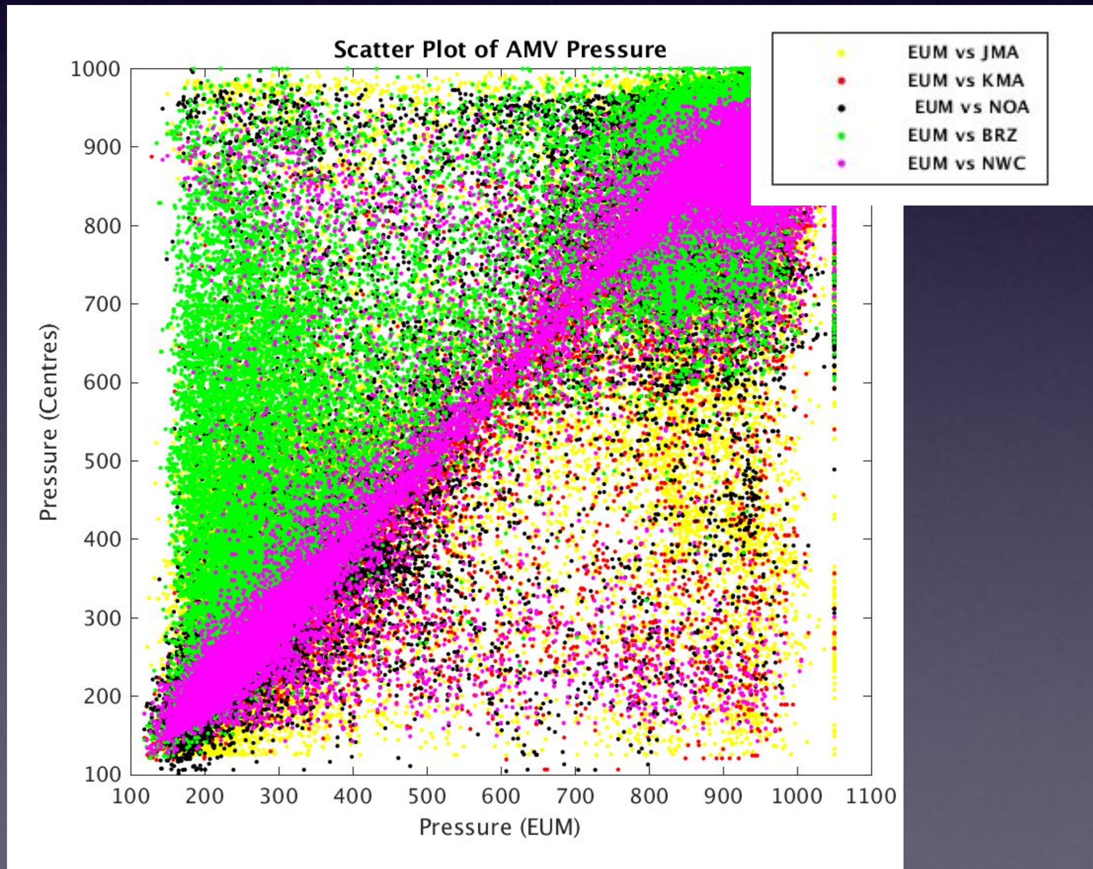
Experiment 1

The distribution of AMV heights is highly variable between the different centres for <u>collocated AMVs</u> due to different AMV height algorithms

Best agreement along diagonal from EUM, NWC, NOA (used NOAA cloud product)

Off diagonal:
BRZ (green), with lower AMVs

KMA (red) and JMA (yellow), with higher AMVs



Experiment 1

Rawinsondes

Table 7-9: Experiment 1: All AMVs (CQI >= 80) comparison to rawinsondes within 150 km. N= number of matches; P bias = pressure bias; P RMS = pressure RMS; Spd bias = speed bias; Spd RMS= speed RMS; Dir bias = wind direction bias; Vec RMS = vector RMS.

Site	N	P bias	P RMS	Spd bias	Spd RMS	Dir bias	Vec RMS
BRZ	3110	-0.13	12.53	-0.45	4.60	-1.41	6.31
EUM	3110	0.01	13.44	-1.41	6.64	0.98	8.35
JMA	5313	0.43	14.48	-0.08	4.64	2.06	6.70
KMA	2653	0.23	12.41	-1.82	6.53	-0.73	8.11
NOA	1760	1.06	13.33	-0.00	4.38	-1.19	6.18
NWC	6187	0.16	12.00	-1.57	5.72	-0.42	7.36

NWP analysis

Table 7-15: Experiment 1: All AMVs (CQI >= 80) compared to background grid: NWP analysis wind. N = total number of AMVs; BFN = number of AMVs with best fit level; VO = mean vector difference; RMSE = root mean square error; VOAF = mean vector difference after best fit; RMSEAF = root mean square error after best fit.

EXP	N	BFN	VO	RMSE	VOAF	RMSEAF
BRZ	25626	5099	3.21	4.11	2.82	3.75
EUM	45874	14522	4.19	6.24	3.47	5.72
JMA	105057	33858	3.54	5.43	3.14	5.18
KMA	40954	13816	4.11	5.93	3.30	5.32
NOA	25944	8788	3.09	3.94	2.46	3.36
NWC	95461	31020	3.36	4.37	2.70	3.75

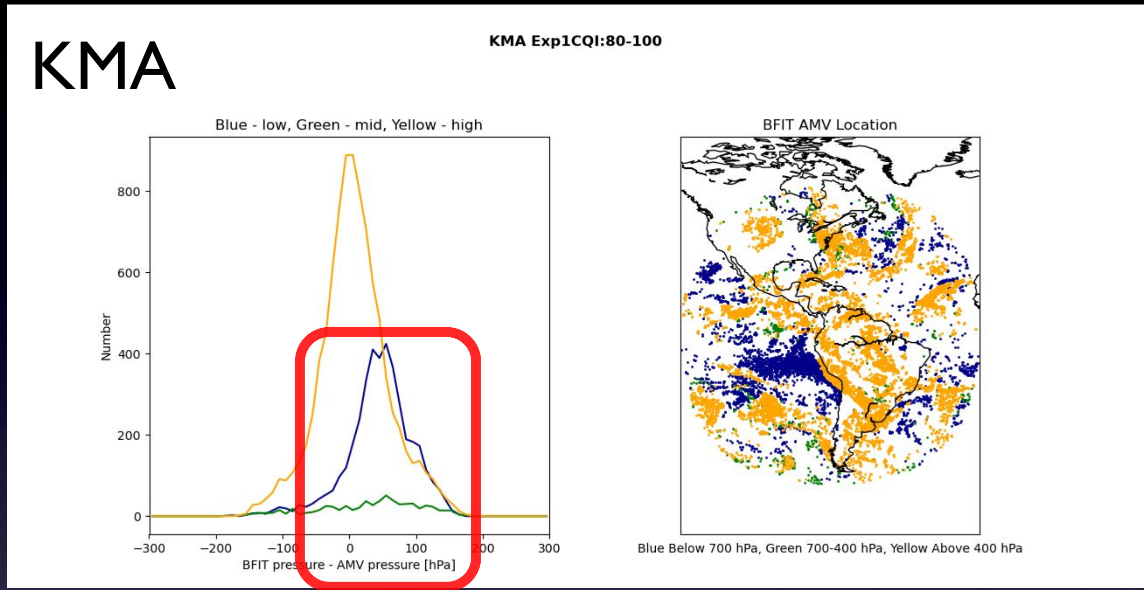
Experiment 1

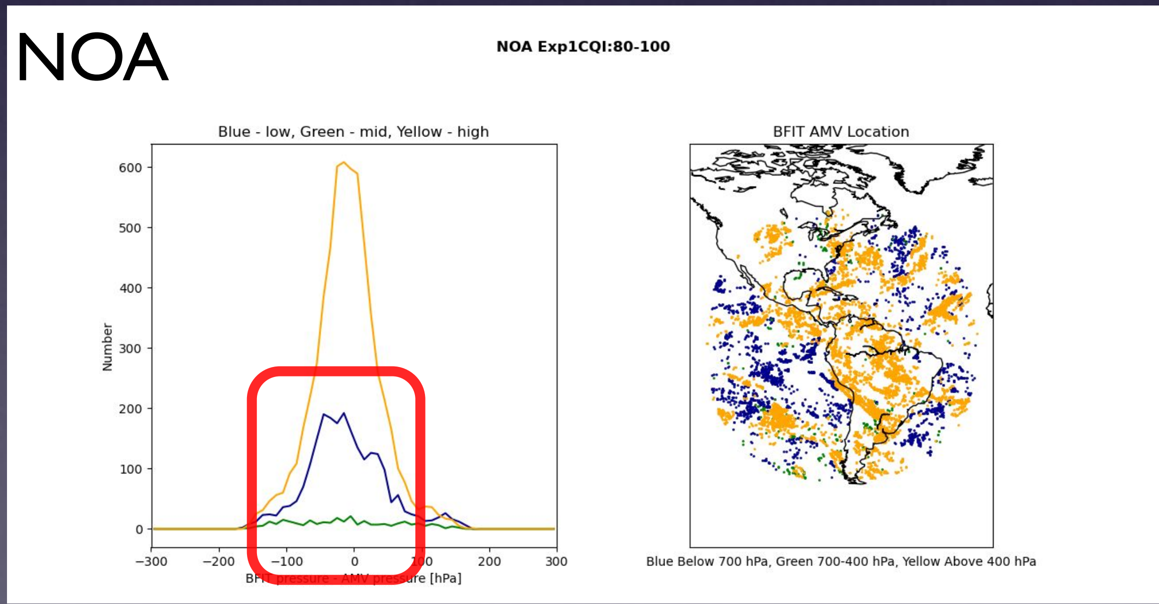
Best Fit Analysis
AMV pressure is adjusted to
best fit the vertical profile of winds

Some examples:

KMA: Low AMVs (blue) are adjusted downward

NOA: Low AMVs (blue) are adjusted upward





Experiment 2

- AMV producers extract IR11.2 µm cloudy AMVs,
  with a triplet of images,
  using their best options for AMV calculation,
  considering a centre-specific operational configuration
  (target size, target location, search scene size).

- Optionally, use the NOAA cloud product.
  However, only EUM, NOA, and NWC used it.

Experiment 2

<u>Three different image triplet times</u>

2a: 11:20/11:30/11:40 UTC for comparison with
Aircraft winds and Aeolus Doppler wind lidar wind profiles

2b: 11:50/12:00/12:10 UTC for comparison with
rawinsondes and NWP analysis winds

2c: 18:50/19:00/19:10 UTC for comparison with
CALIPSO satellite cloud height data

Experiment 2b

Rawinsondes

Table 8-17: Experiment 2b: All AMVs (CQI >= 80) comparison to rawinsondes within 150 km. N= number of matches; P bias = pressure bias; P RMS = pressure RMS; SpdBias = speed bias; SpdRMS= speed RMS; DirBias = wind direction bias; VecRMS = vector RMS.

Site	N	P bias	P RMS	Spd bias	Spd RMS	Dir bias	Vec RMS
BRZ	3033	0.13	14.21	0.22	4.61	-0.81	6.80
EUM	3047	0.49	14.38	-0.37	5.84	2.75	7.85
JMA	5057	0.24	13.93	-0.01	3.83	0.45	5.39
KMA	2653	0.23	12.41	-1.82	6.53	-0.73	8.11
NOA	1971	0.77	13.45	0.01	4.48	-1.96	6.08
NWC	4679	0.61	14.35	0.55	5.35	3.62	6.87

NWP analysis

Table 8-23: Experiment 2b: All AMVs (CQI >= 80) compared to background grid: NWP analysis wind. N = total number of AMVs; BFN = number of AMVs with best fit level; VO = mean vector difference; RMSE = root mean square error; VOAF = mean vector difference after best fit; RMSEAF = root mean square error after best fit.

EXP	N	BFN	VO	RMSE	VOAF	RMSEAF
BRZ	25843	5357	3.22	4.11	2.79	3.71
EUM	45173	13432	4.26	6.31	3.57	5.81
JMA	94720	35004	2.34	3.00	1.94	2.60
KMA	40954	13816	4.11	5.93	3.30	5.32
NOA	28056	9281	3.13	3.98	2.48	3.37
NWC	91483	26317	2.96	3.91	2.39	3.31

Experiment 2b

Common Quality Indicator (CQI) evaluation

EUM
No gross error check before Quality Control
(Also in KMA)

CQI	N	BFN	VO	StdDev	RMSE	VOAF	RMSEAF
0-9	3014	53	58.94	43.03	72.98	58.84	72.97
10-19	1210	103	35.87	40.06	53.77	35.50	53.73
20-29	1351	133	16.55	24.99	29.98	16.08	29.88
30-39	2441	411	11.19	19.23	22.25	10.56	22.10
40-49	2282	355	8.85	14.26	16.78	8.26	16.61
50-59	3425	534	7.72	9.00	11.86	7.08	11.57
60-69	3608	623	6.00	5.88	8.41	5.39	8.05
70-79	4671	947	5.64	5.36	7.78	4.98	7.36
80-89	6775	1363	4.99	4.86	6.97	4.41	6.58
90-100	38863	12069	4.14	4.61	6.19	3.42	5.66

CQI
Provides a measure of AMV quality (0 to 100%)

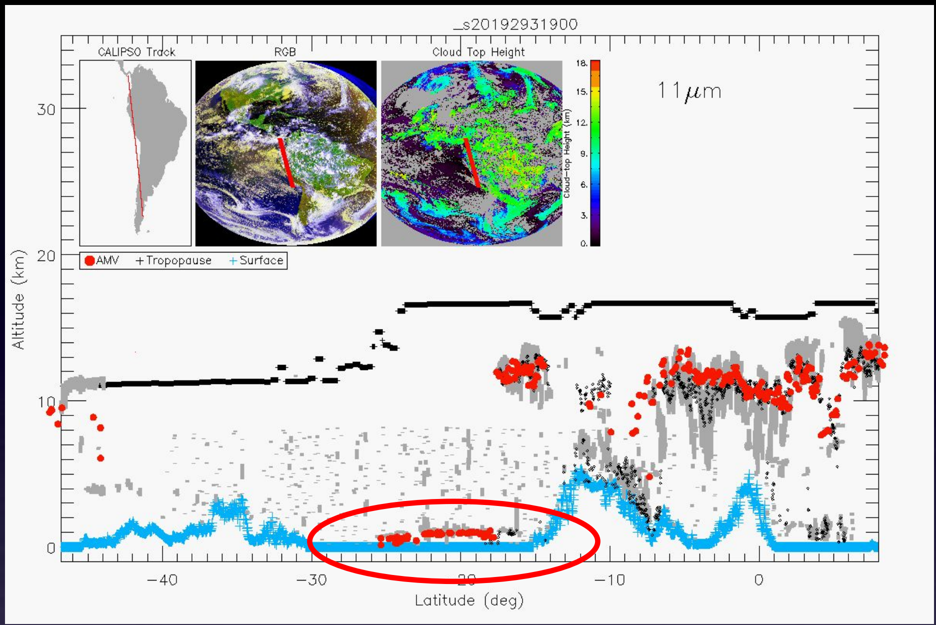
NWC
Gross error check before Quality Control
(Also in BRZ, NOA)

CQI	N	BFN	VO	StdDev	RMSE	VOAF	RMSEAF
0-9	0	0	-	-	-	-	-
10-19	3	1	8.87	3.00	9.37	6.83	8.35
20-29	47	12	6.69	3.91	7.75	5.45	6.96
30-39	77	6	5.47	3.70	6.61	5.12	6.37
40-49	169	31	5.30	3.84	6.54	4.65	6.06
50-59	697	158	4.64	3.53	5.83	3.96	5.22
60-69	1395	283	4.49	3.28	5.56	3.93	5.13
70-79	2555	618	4.08	3.08	5.11	3.43	4.51
80-89	6097	1449	3.68	2.79	4.62	3.12	4.09
90-100	85386	24868	2.91	2.53	3.86	2.33	3.25

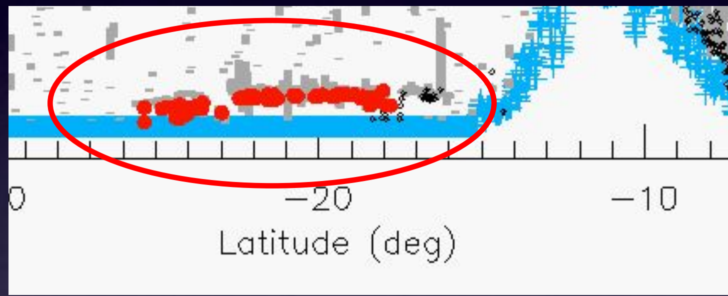
CALIPSO
Experiment 2c

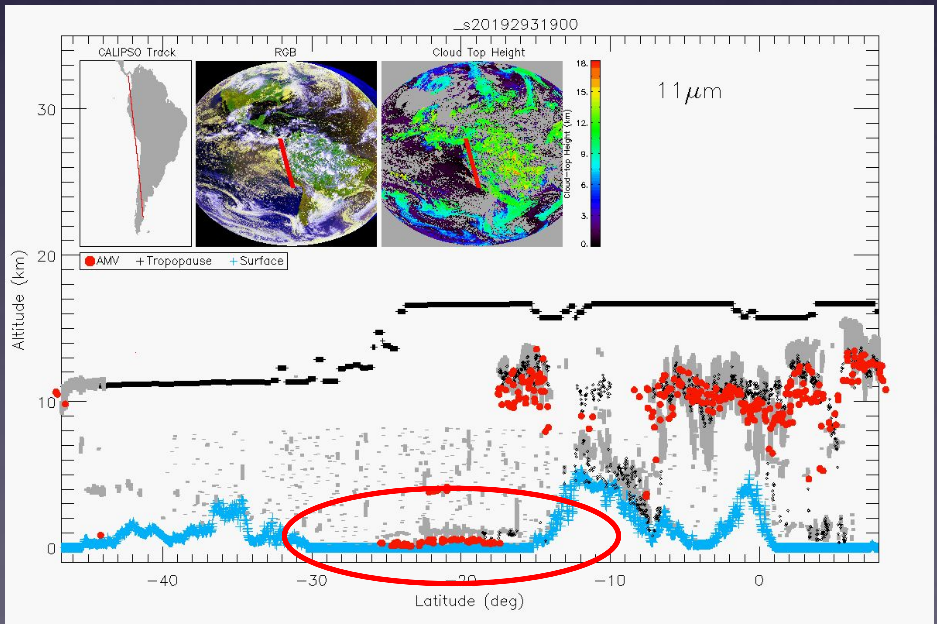
- CALIPSO is a line-of-site measurement, so there are few collocations with AMVs
- Therefore, this evaluation is qualitative as illustrated in the following figures
- Results in agreement with the Best Fit analysis
- AMVs generally:
  - Near the cloud base for high-level clouds
  - Within the cloud or below cloud base for low clouds

Experiment 2c: Low clouds

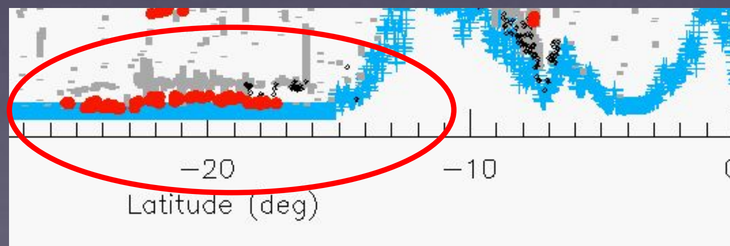


KMA

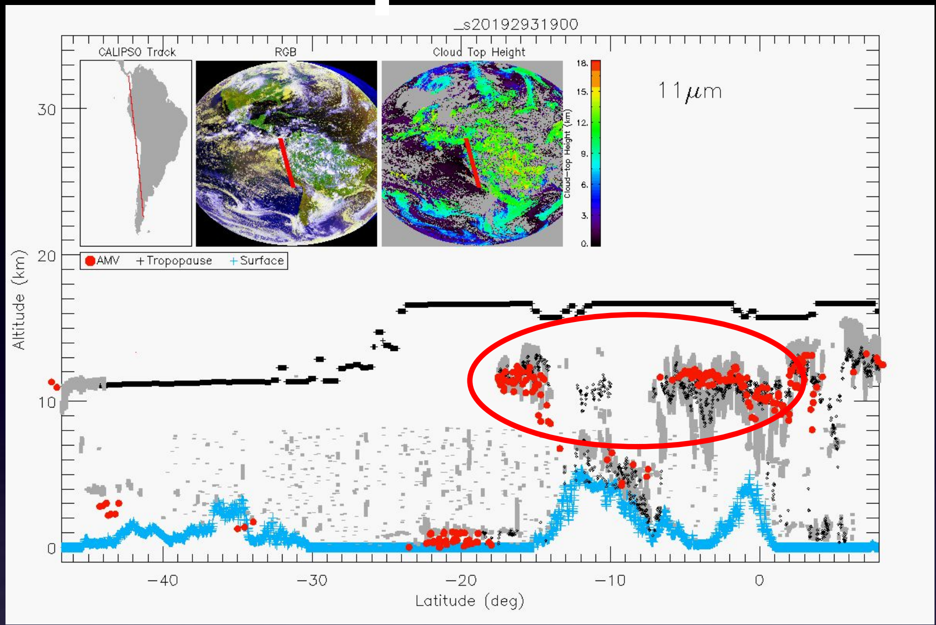




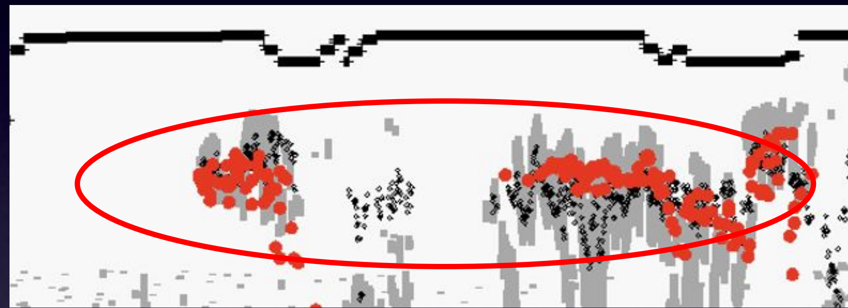
NOA

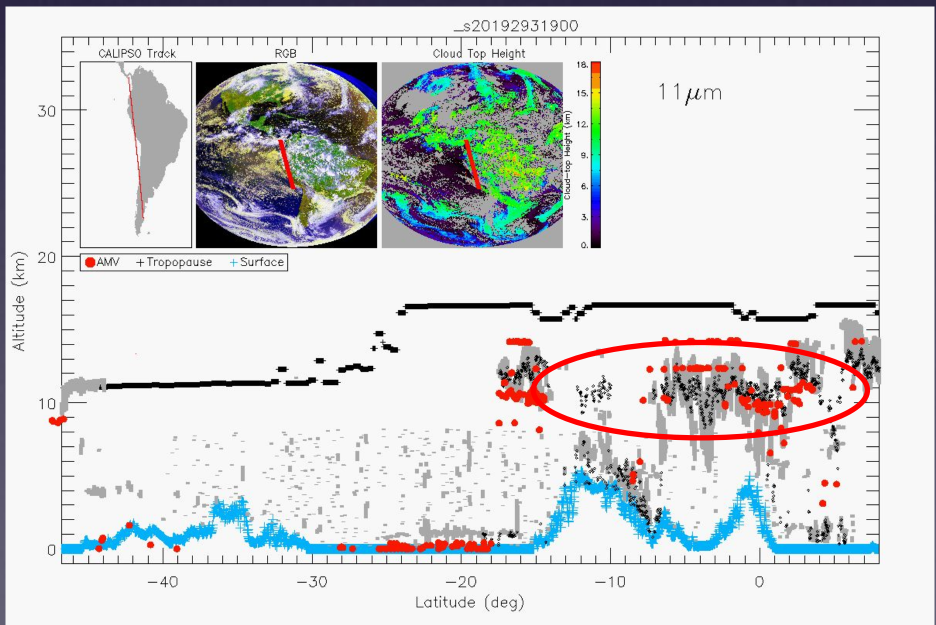


Experiment 2c: High clouds



EUM





BRZ

Experiment 3

Clear sky WV winds 10-minute interval

- AMV producers extract WV 6.2 µm clear sky AMVs, with the triplet 1120-1140 UTC (10-minute interval), using their best options for AMV calculation, considering a centre-specific operational configuration (target size, target location, search scene size).

- AMV height assignment determined by data producers

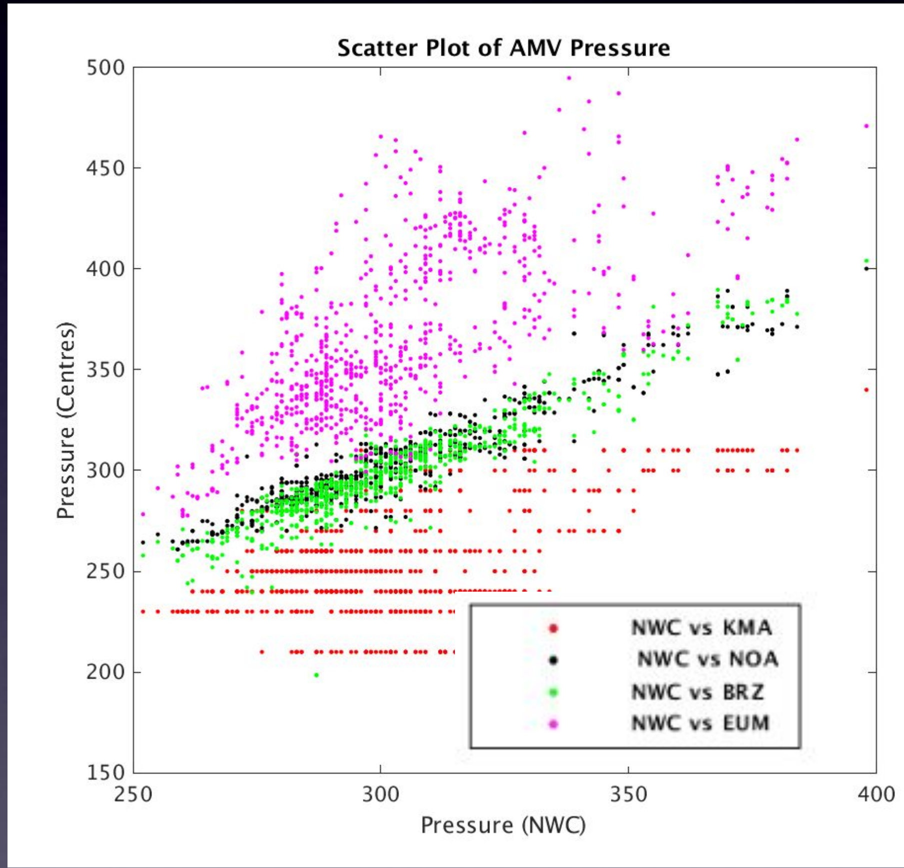
- This dataset is used for validation against Aircraft winds and Aeolus Doppler wind lidar wind profiles

Experiment 3

Scatter plot of AMV pressure with NWC as the reference

On diagonal:
NWC vs NOA
NWC vs BRZ

Off diagonal:
NWC vs EUM (magenta)
- EUM AMVs too low
NWC vs KMA (red)
- KMA AMVs too high



Experiment 4

Clear sky WV winds 20-minute interval

- AMV producers extract WV 6.2 µm clear sky AMVs, with the triplet 1110-1150 UTC (20-minute interval), using their best options for AMV calculation, considering <u>a centre-specific operational configuration</u> (target size, target location, search scene size).

- AMV height assignment determined by data producers

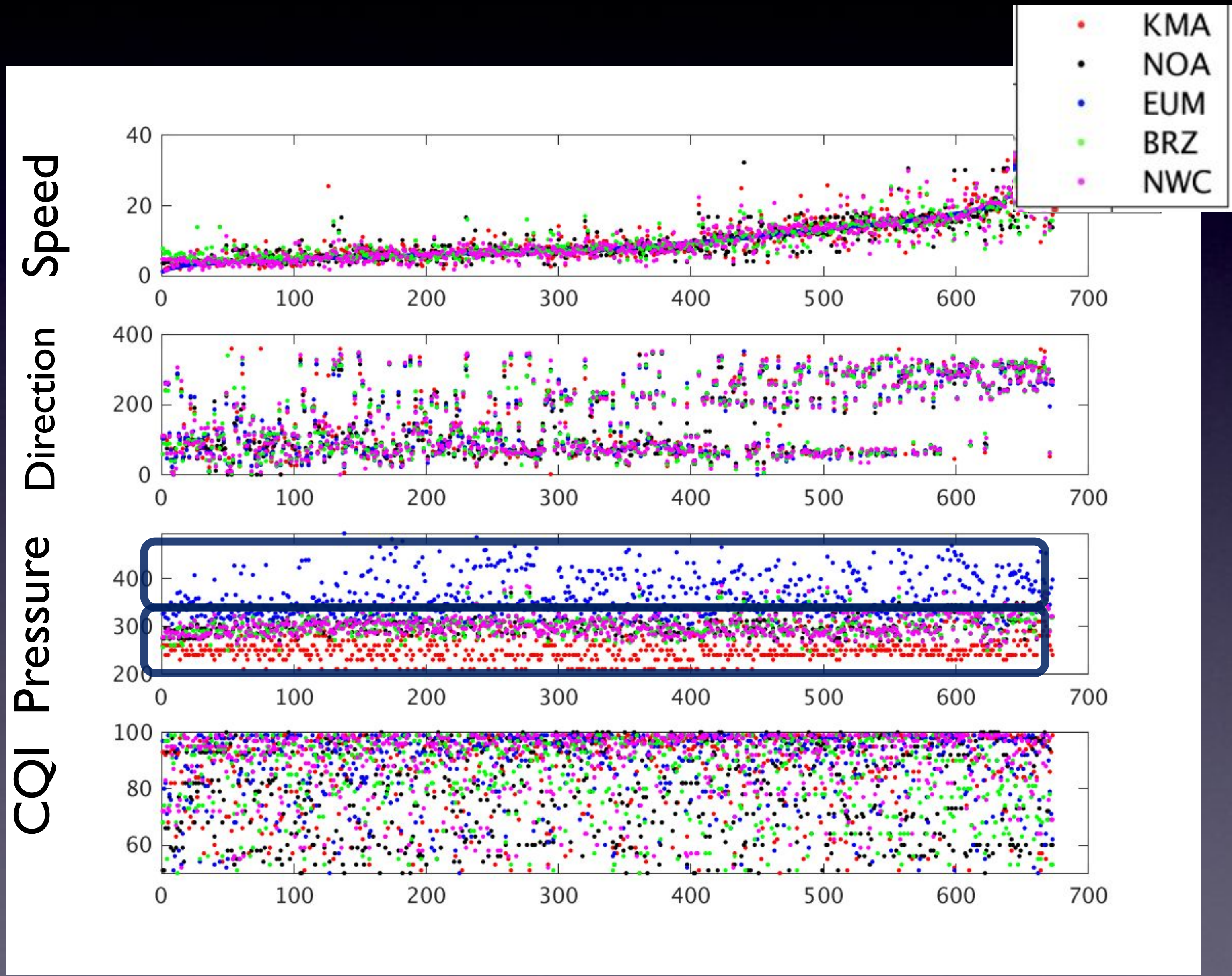
- This dataset is used for validation against Aircraft winds and Aeolus Doppler wind lidar wind profiles

Experiment 4

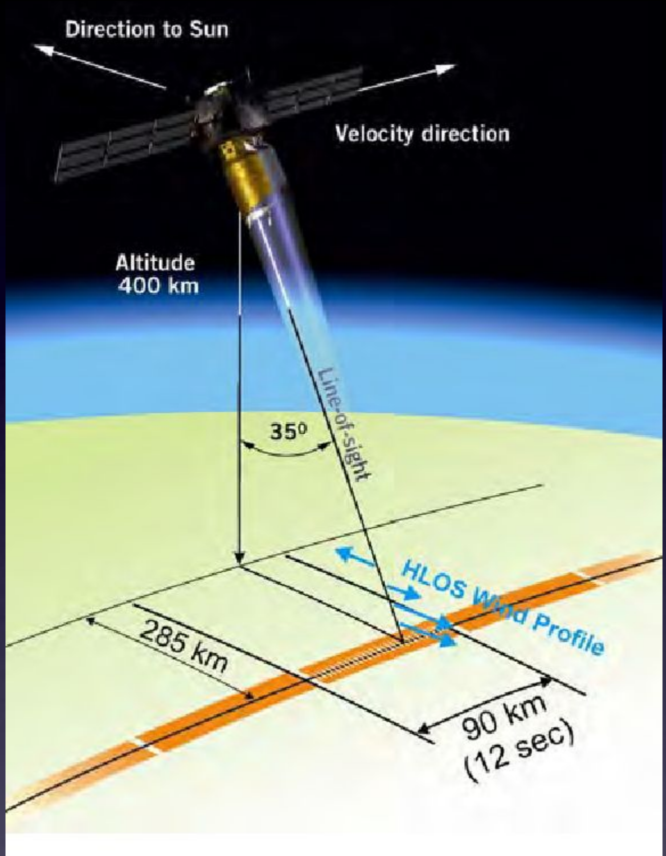
As seen in Experiment 3:

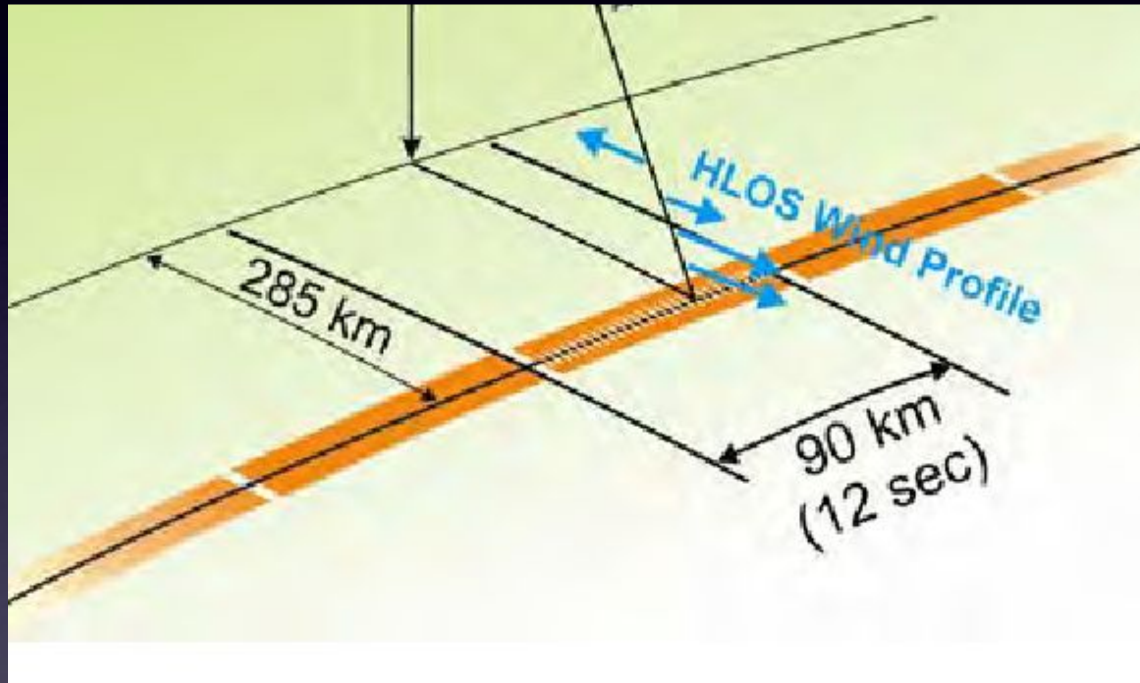
NWC vs EUM (blue)
EUM AMVs too low

NWC vs KMA (red)
KMA AMVs too high



Comparison to Aeolus winds
Experiments 2a, 3, 4



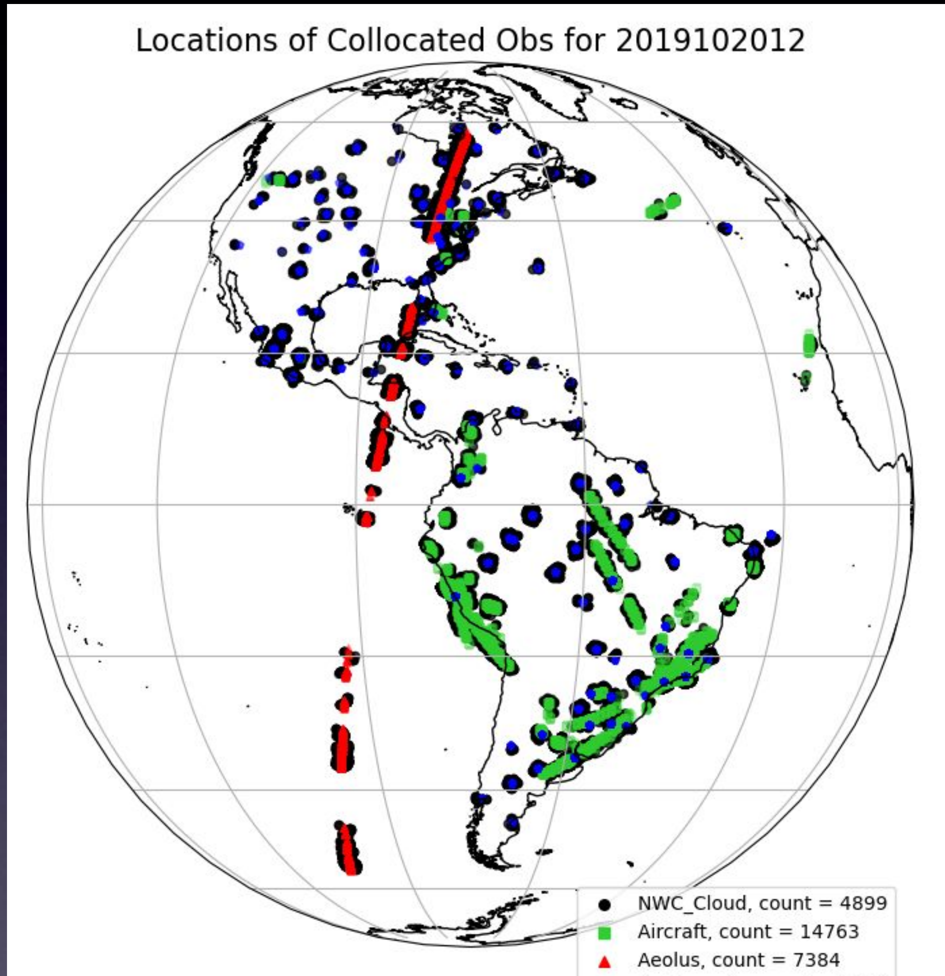


Aeolus: Doppler wind lidar (DWL) instrument. Single line-of-sight instrument, which results in the Horizontal Line of Sight (HLOS) component of the wind.

Mie: Particle scattering (aerosols and clouds)
Rayleigh: Molecular scattering (cloud free)

Aeolus: Mie with cloudy AMVs

Experiment 2a



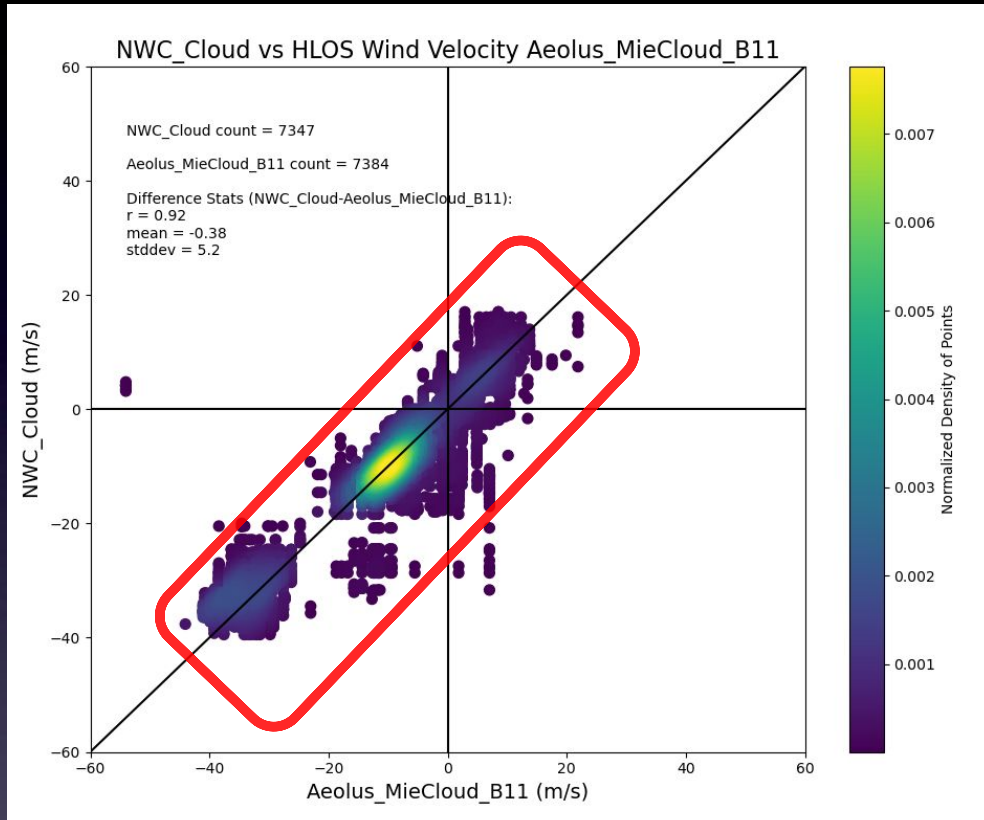
Collocations of AMVs with Aeolus (red), aircraft wind reports (green), rawinsondes (blue, not used)

Aeolus: Mie with cloudy AMVs

Experiment 2a

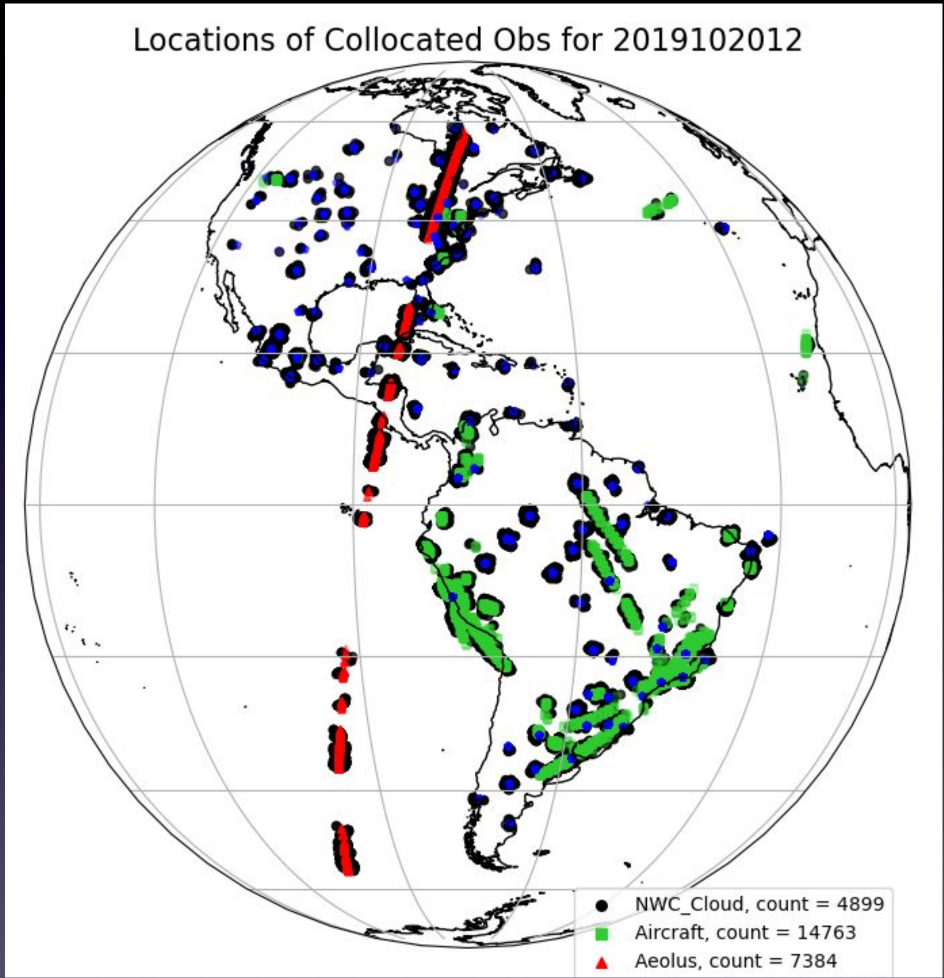
Aeolus does not measure total wind, only that component perpendicular to the orbit path: Horizontal Line of Site (HLOS)

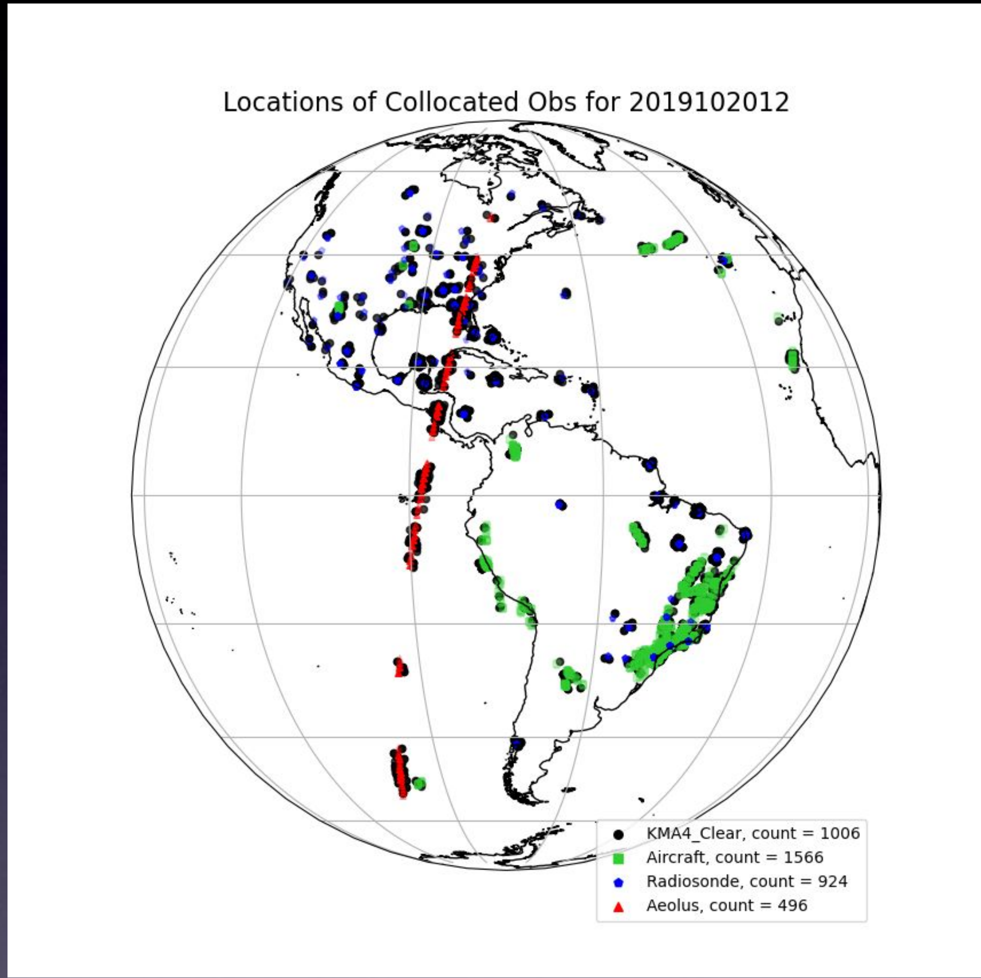
AMV winds are converted to HLOS-equivalent (as though viewed by Aeolus)



Site	N AMVs	N Aeolus	Mean	StdDev	RMSE
BRZ	1061	1075	1.40	4.03	4.26
EUM	4554	4570	0.19	6.56	6.56
JMA	9017	9043	-0.11	4.55	4.55
KMA	3576	3605	-0.28	5.06	5.07
NOA	2746	2754	-0.43	4.31	4.33
NWC	7347	7384	-0.38	5.20	5.21

Aeolus: Rayleigh with clear sky AMVs

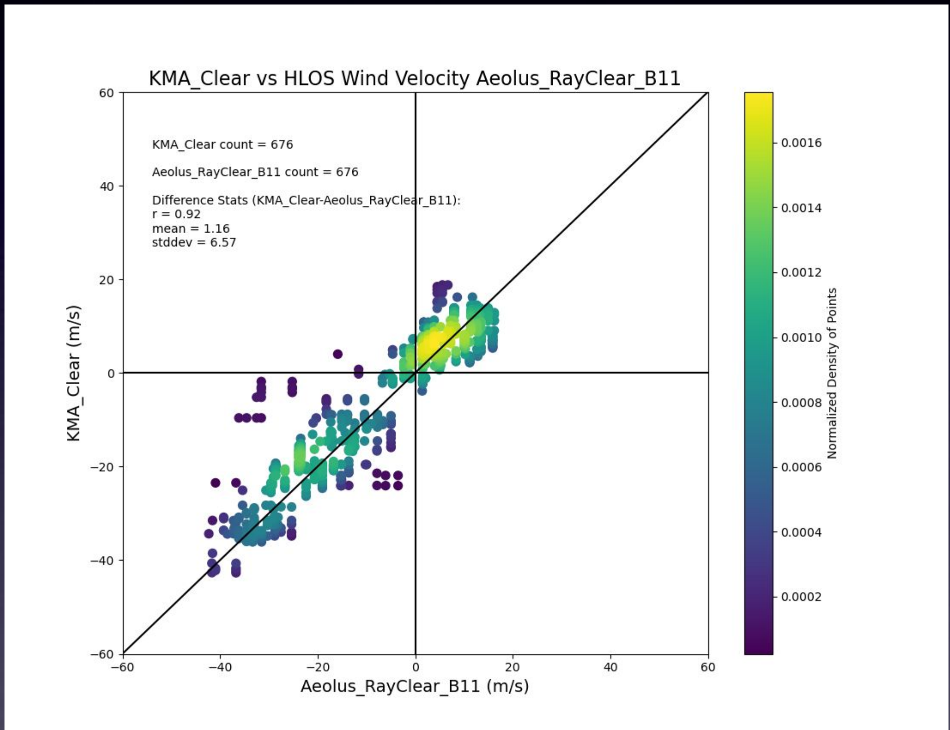




KMA: 10-minute time interval AMVs

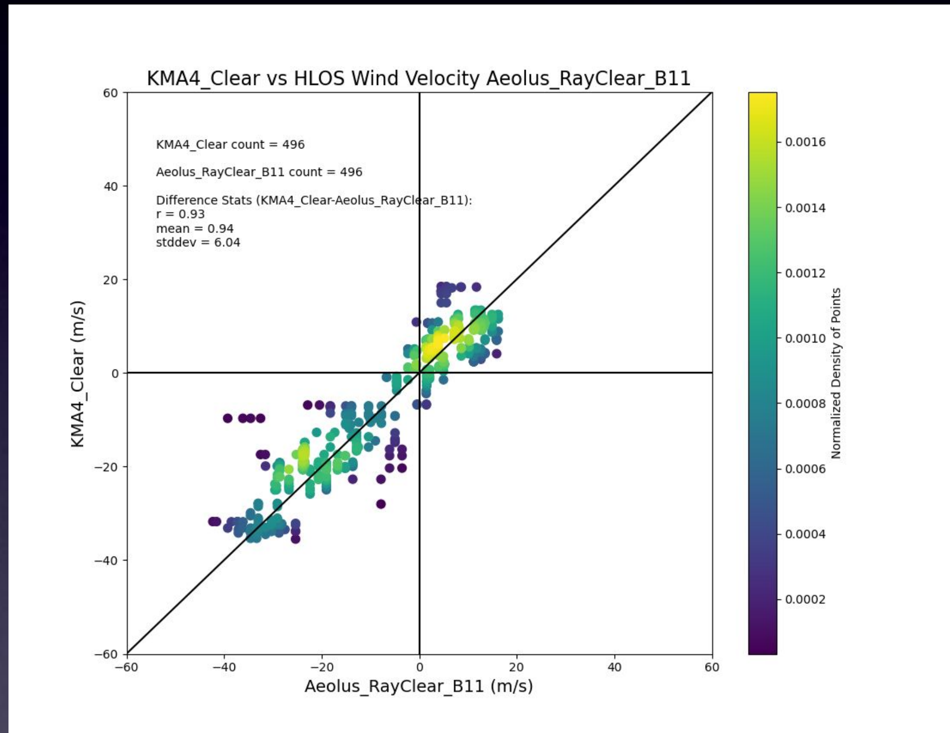
KMA: 20-minute time interval AMVs

Aeolus: Rayleigh with clear sky AMVs



KMA: Experiment 3
10-minute time interval AMVs

HLOS-equivalent AMV wind vs
Rayleigh clear



KMA: Experiment 4
20-minute time interval AMVs

HLOS-equivalent AMV wind vs
Rayleigh clear

Aeolus: Rayleigh with clear sky AMVs

Experiment 3

10-minute time interval AMVs

Site	N AMVs	N Aeolus	Mean	StdDev	RMSE
BRZ	347	347	-1.25	5.56	5.70
EUM	325	325	0.47	7.89	7.90
JMA	-	-	-	-	-
KMA	676	676	1.16	6.57	6.67
NOA	11	11	-0.21	4.06	4.06
NWC	552	552	-1.28	4.64	4.81

Experiment 4

20-minute time interval AMVs

Site	N AMVs	N Aeolus	Mean	StdDev	RMSE
BRZ	552	552	-1.28	4.64	4.81
EUM	260	260	-0.26	6.60	6.60
JMA	-	-	-	-	-
KMA	496	496	0.94	6.04	6.11
NOA	9	9	-1.42	4.33	4.56
NWC	259	259	-0.36	4.55	4.57

10-minute vs 20-minute time interval

Improved RMSE with a longer time interval for WV clear sky AMVs

This confirms previous research

Comparison to Aircraft winds
Experiments 2a, 3

Experiment 2a Cloudy AMVs

Site	N AMVs	N aircraft	Mean	StdDev	RMSE
BRZ	1311	2141	0.04	3.46	3.46
EUM	4191	6430	1.54	6.59	6.77
JMA	5899	9702	-0.05	3.77	3.77
KMA	4492	6738	-0.14	8.31	8.31
NOA	2722	4576	0.78	4.24	4.32
NWC	8765	14760	0.88	4.28	4.37

Experiment 3 Clear sky AMVs

Site	N AMVs	N aircraft	Mean	StdDev	RMSE
BRZ	351	425	2.25	3.80	4.41
EUM	325	325	0.47	7.89	7.90
JMA	-	-	-	-	-
KMA	1626	2131	2.12	6.16	6.51
NOA	100	137	-1.06	4.70	4.82
NWC	778	947	0.89	4.89	4.97

Cloudy vs Clear sky AMVs

More cloudy AMVs than Clear sky AMVs

RMSE generally worse for Clear sky AMVs (KMA an exception)

Overall Summary

- The different AMV algorithms are becoming more similar, resulting in better agreement in the AMVs as compared to each other and to rawinsondes and NWP analysis
- New comparisons of the AMVs to Aeolus and aircraft winds are consistent with those against rawinsondes and NWP analysis
- Some operational configurations are converging to the prescribed configuration (f.ex. KMA)
- Main drivers in variability: the number of AMVs and the height assignment.

Conclusions

Brazil (CPTEC/INPE)

- The performance of the BRZ AMV algorithm has improved due to all changes in the AMV algorithm

- Comparison against all reference winds is very similar to the best AMV centres

- Investigate: The use of its “NWP coherency filtering” brings the AMVs in too close agreement with the background wind field, removing interesting AMVs (real observations different to the NWP forecast wind)

- Investigate: Check differences in AMV height assignment, and no AMVs with speed > 45 m/s

Conclusions
JMA

- The JMA algorithm is unchanged since the previous AMV intercomparison, and so results are rather similar

- Investigate: more random distribution in the AMV height; for example, many AMVs are located in high levels while the rest of centres locate them at low levels (is the satellite image really showing a high feature for the JMA height?)

Conclusions
NOAA

- Investigate: AMV vertical distribution:
  There are very few AMVs in middle levels,
  which is in disagreement with the other centres

- Investigate: Very few clear sky AMVs
  compared to other centres

Conclusions
EUMETSAT

- This study indicates that EUMETSAT
may not use a gross error check before the Quality control

- Investigate: The use of a gross error check may improve
the overall quality of AMVs

Conclusions

KMA

- Results have degraded with respect to the previous AMV intercomparison, possibly caused by the new "CCC height assignment method", which depends on the quality of the Cloud products used

- Investigate: Consider keeping the previous height assignment methods (EBBT and IR/WV intercept) until a better evaluation of the Cloud products used

- Investigate: The use of a gross error check may improve overall quality of AMVs

Conclusions

NWCSAF

- NWCSAF AMV algorithm is unchanged since the previous AMV intercomparison.
- It agrees well with other centres in terms of parameter distributions and statistics, especially when using the CQI and own configuration.
- Investigate: Depending on the image time interval, the number of clear sky AMVs varies by 50%, which is unlike other centres.

Questions?

Discussion:
Possible additional analyses

- Some AMV algorithms can have an important dependency on the NWP winds (f.ex. BRZ).
  ⇒ Evaluate and statistically quantify.

Algorithms should identify situations
where AMVs are correct, but deviate from NWP winds!

Discussion:
Possible additional analyses

- Collocated AMVs from different centres can have very different AMV heights (as seen in the scatter plots).
  ⇒ Attempt to determine how this pressure variability
  is possible through examining the tracer feature,
  the presence of cloud layers, etc.,
  and evaluate which options can be better.

These tasks could be evaluated with the same datasets
in an Extension to this "AMV intercomparison study"

Any other suggestions for this?

Discussion: Considerations for new-generation satellites

- Removing AMVs using a gross error check results in all AMVs with improved quality (CQI score).

<u>However, using the NWP background wind for this should be avoided!</u>

- Some options for this from different AMV producers:

⇒ NOA: Some cloud types screened out.
Some pressure limits for some cloud types

⇒ NWC: Correlation > 80%, Pressure error < 150 hPa,
No orographic influence, Near AMVs with similar speed/dir
For the two subAMVs in the same AMV:
- Speed diff < 10 m/s, Dir diff < 20°, Pres diff < 50 hPa

<u>Should all AMV centres define a gross error check before Quality control?</u>

Discussion: Considerations for new-generation satellites

- AMV datasets from the different centres have had some homogenization, considering their cloudy AMV outputs and the comparison against several reference wind datasets.
  ⇒ This has been reached using the CQI,
  and the - unrequested - convergence
  of part of the datasets toward a common configuration.

Any other options for further homogenization?

⇒ Consider here f.ex. the best configurations for global and regional models defined by NWP community
(Link with Working Groups discussions)

⇒ And the "Common QI module" and "new AMV BUFR"
(for those AMV centres who still haven't)

Discussion: Considerations for new-generation satellites

- AMV datasets from the different centres have had some homogenization, considering their cloudy AMV outputs and the comparison against several reference wind datasets.
  ⇒ This has been reached using the CQI,
  and the - unrequested - convergence
  of part of the datasets toward a common configuration.

  There are also requests for;
  ⇒ High resolution quality indicators for regional/mesoscale
  ⇒ "Tracking error" related to "Correlation surface"
  (Link with Working Groups discussions)

Discussion: Considerations for new-generation satellites

- The better AMV agreement has been reached despite differences in algorithms, especially in the AMV height assignment.
  ⇒ The <u>CALIPSO comparison and Best Fit analysis</u> show that more work needs to be done.

<u>AMV producers should evaluate both elements in the Report, for possible changes in their height assignment processes.</u>

Discussion: Considerations for new-generation satellites

- Even without substantial results in this study
  from the water vapor AMVs
  nor the different time intervals between images,
  it is important to consider these for future studies,
  since they tie into what we expect from future satellites
  (additional satellite channels,
  higher temporal resolution between images).

Discussion: Considerations for new-generation satellites

<u>Related to this, which additional elements are considered important for any future intercomparisons?</u>

<u>Some suggestions:</u>

⇒ Additional channels (e.g., visible, shortwave IR)

⇒ Including polar AMVs, with the latest and future polar orbiting satellites (JPSS VIIRS, EPS-SG METimage)

⇒ AMVs from hyperspectral IR retrievals (3D winds)

- Potentially better height assignment for clear sky winds

Discussion: Considerations for new-generation satellites

Related to this, which additional elements are considered important for any future intercomparisons?

Some suggestions:

⇒ Encourage participation from research institutes, to see how new technology compares to the operational algorithms:

- Using image doublets instead of triplets (QC issues)
- New height assignment techniques (e.g., stereo)
- Machine learning, optical flow
  (with issues: data thinning, correlated errors)

Thank you for your attention!

Full results of "Fourth AMV Intercomparison study" available at (374 page report!):
http://cimss.ssec.wisc.edu/iwwg/Docs/CIMSS_AMV_Comparison_2021_Report_02Nov2022.pdf

For any other questions: Dave Santek <dasantek@wisc.edu>
Javier García-Pereda <jgarciap@aemet.es>