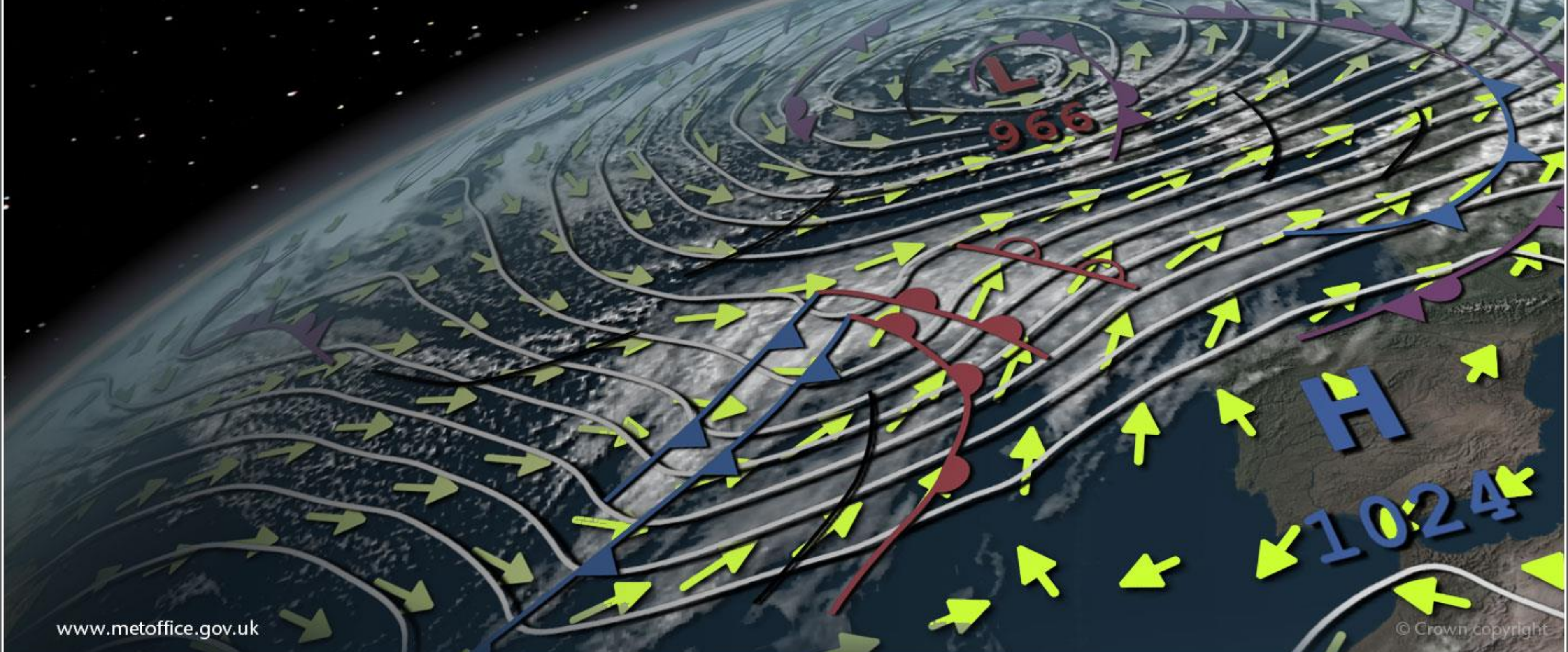
AMVs in the Tropics: use in NWP, data quality and impact

James Cotton, Mary Forsythe, Francis Warrick (Met Office)
Kirsti Salonen, Niels Bormann, Katie Lean (ECMWF)

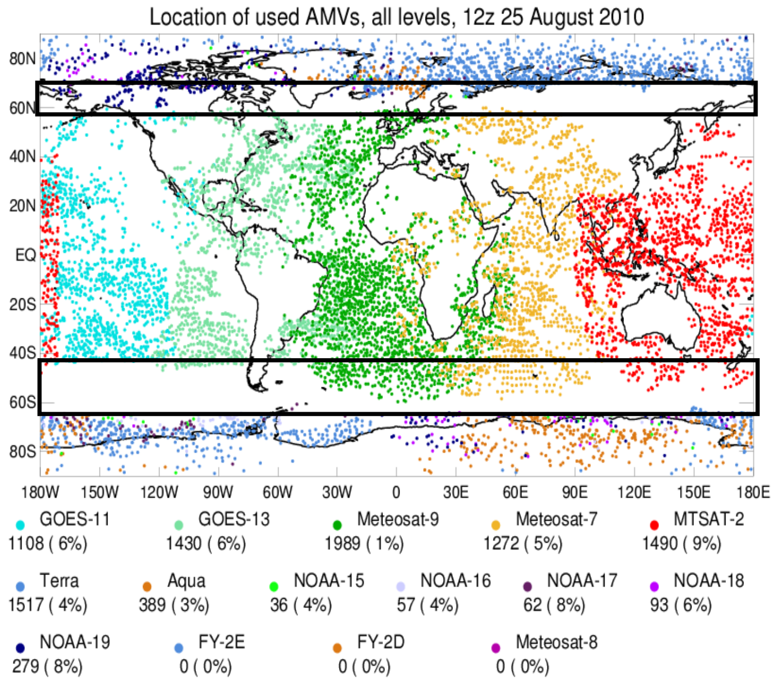
Joint ECMWF/ESA Workshop on ‘Tropical modeling, observations and data assimilation’, 7-10 November 2016

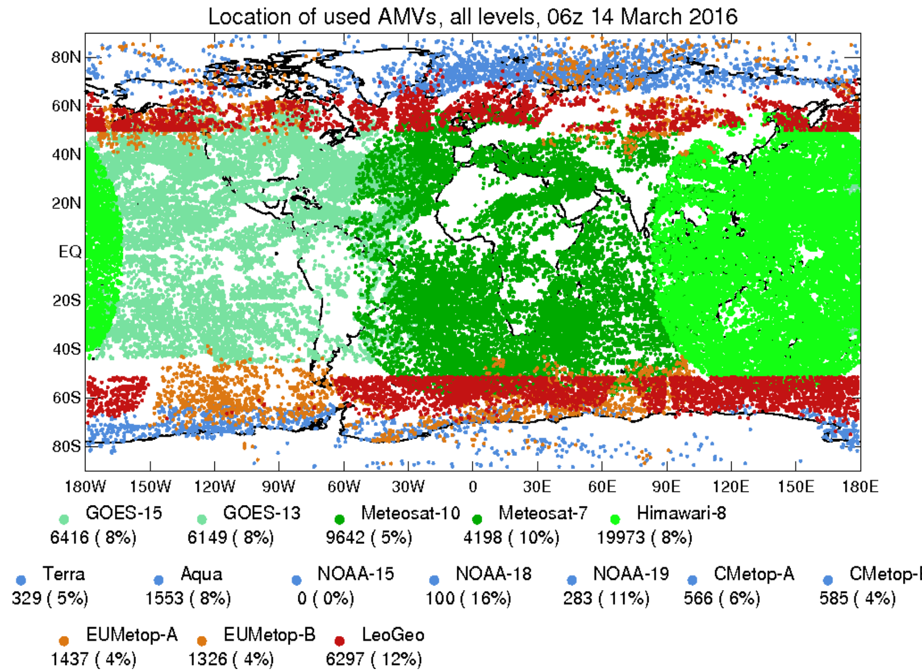


Contents

- AMV use at Met Office
- Data quality in the tropics
- Quality control and errors
- Coordinated impact study - tropics
- Recent data denial study

AMV coverage – from 2010 to 2016





Thinning: 200-km x 100-hPa x 2-hours

Tropics – 5 Geo's: Meteosat-7, Meteosat-10, GOES-13/15, Himawari-8

Others: Meteosat-8 (future IODC), INSAT-3D, FY-2E/G, COMS-1..

Data quality in the tropics

O-B Monitoring

NWP SAF AMV monitoring provides a long-term archive of obs minus background (O-B) statistics and *Analysis Reports*; http://nwpsaf.eu/monitoring/amv/index.html

- Met Office and ECMWF backgrounds

General trend observed for mid level (400-700 hPa) and upper level (above 400 hPa) AMVs

- AMVs that are faster than the model (positive speed bias) in the tropics
- AMVs that are slower than the model (negative speed bias) in the extra-tropics

Positive bias in tropics

- Often more pronounced for WV channel winds

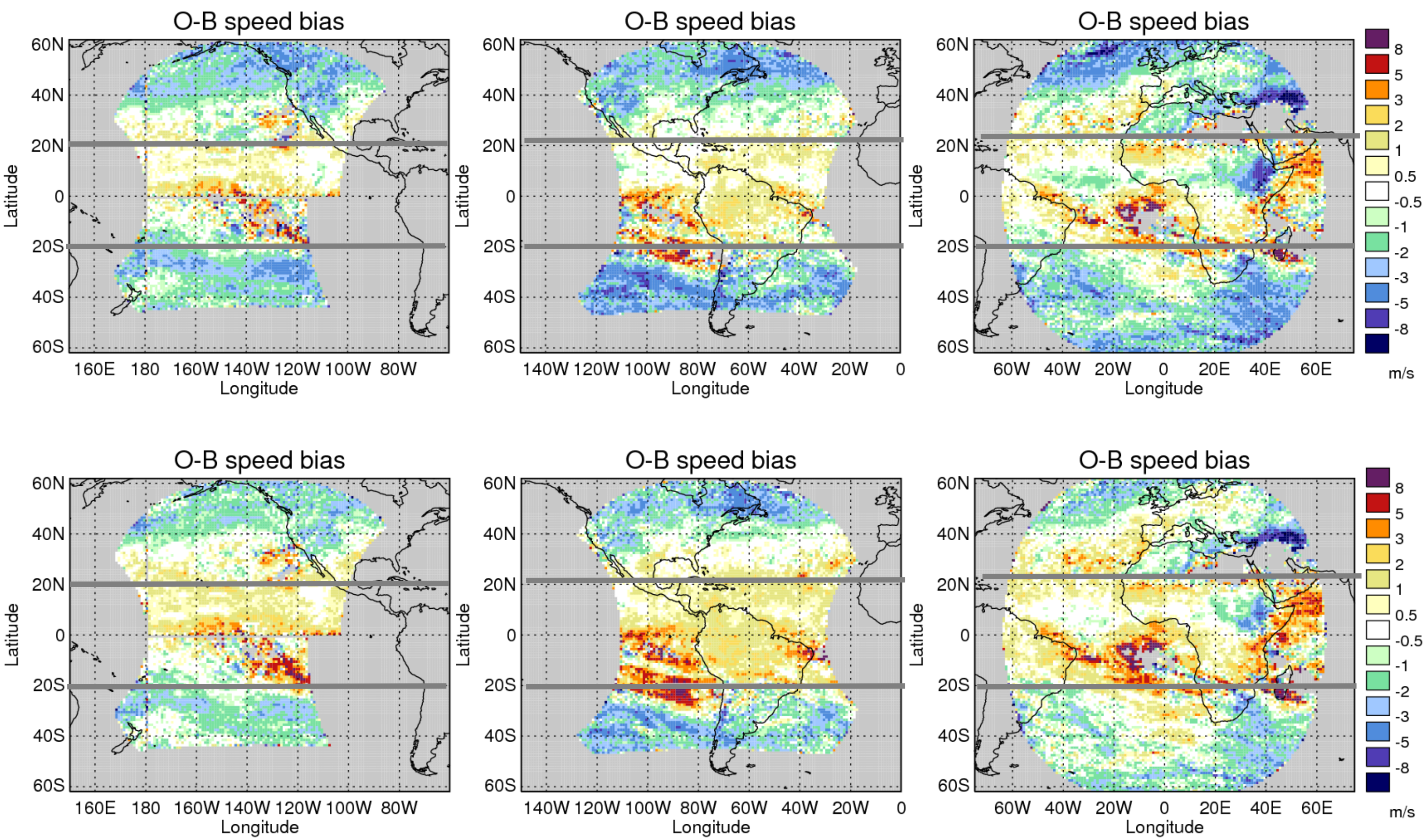
High Level O-B, Sept 2016

Met Office

GOES-15 NESDIS | **GOES-13** NESDIS | **Meteosat-10** EUMETSAT

IR

Cloudy WV



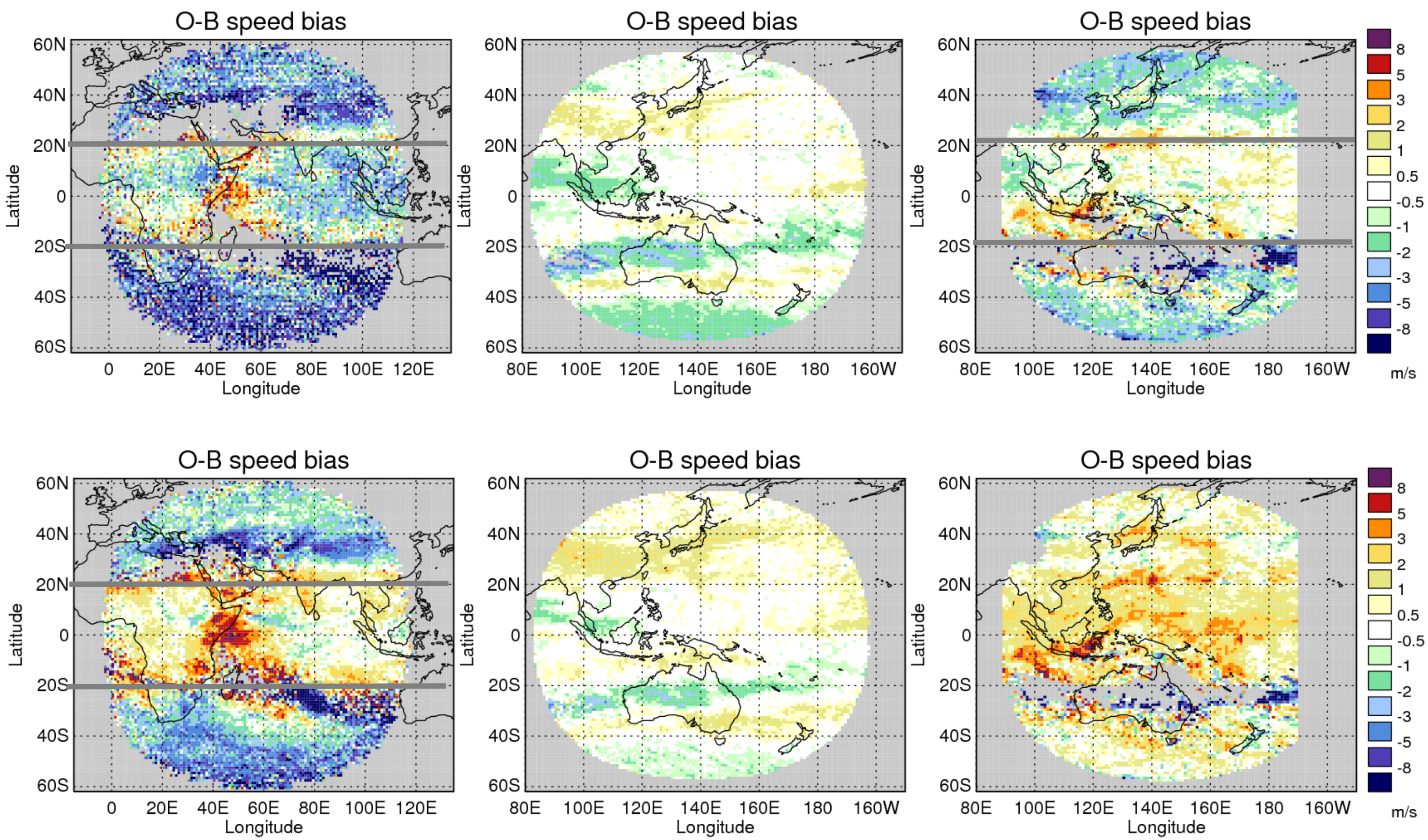
High Level O-B, Sept 2016

Met Office

Meteosat-7 EUMETSAT | **Himawari-8** JMA | **MTSAT-2 (Sept 2015)** JMA

IR

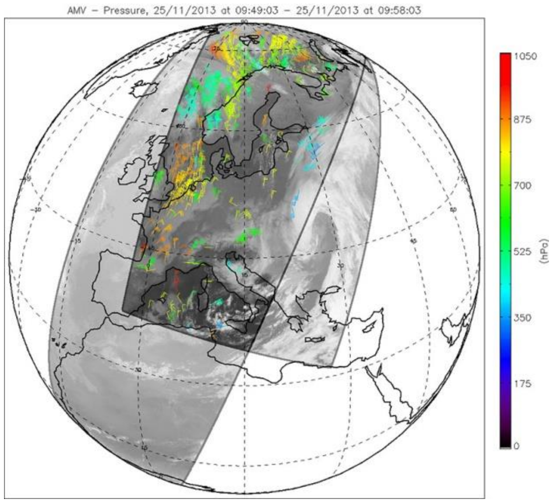
Cloudy WV

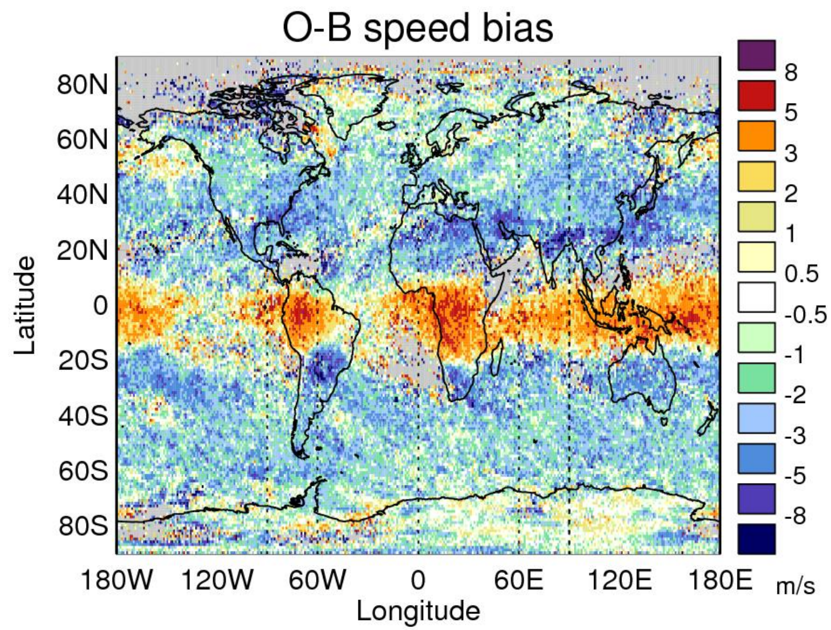


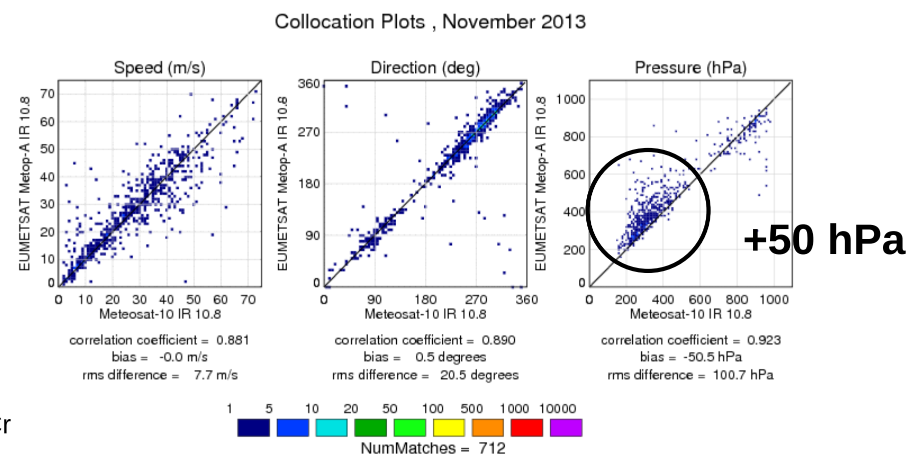
Dual Metop-A/B IR

High Level O-B, March 2016

EUMETSAT







- Dual Metop - image pairs from consecutive Metop-A/B swaths, ~50 mins apart
- No WV/CO_2 for height assignment of semi-transparent clouds (limited use of IASI)
- Height bias vs. MSG
- Bias position moves with ITCZ

EUMETSAT Study

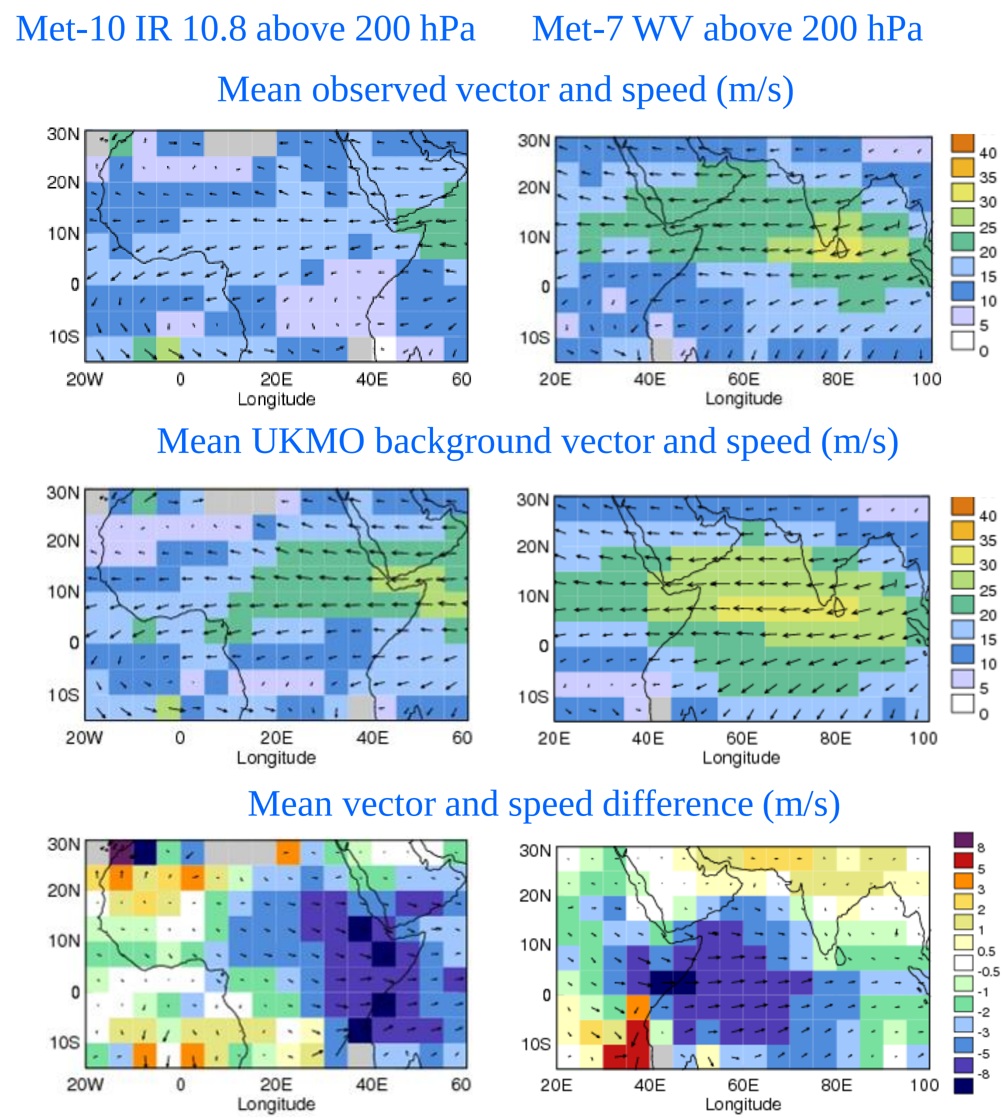
"AMV Speed Biases in the Tropics"

EUMETSAT (ITT) proposed study, tasks include

- Explore in more detail the potential scientific explanations of AMV speed biases in tropics (convection, diurnal cycle of tropospheric humidity, semi-transparent clouds, horizontal and vertical wind shears, gravity waves, ICTZ position...etc.).
- Investigate whether AMVs are really representative of local winds or linked to other atmospheric phenomena in tropics (growing of convective cells, gravity waves).
- Draw specific conclusions on AMVs extraction in tropical areas and general recommendations to improve the quality and the use of the AMV products in such region.

Negative speed bias in TEJ

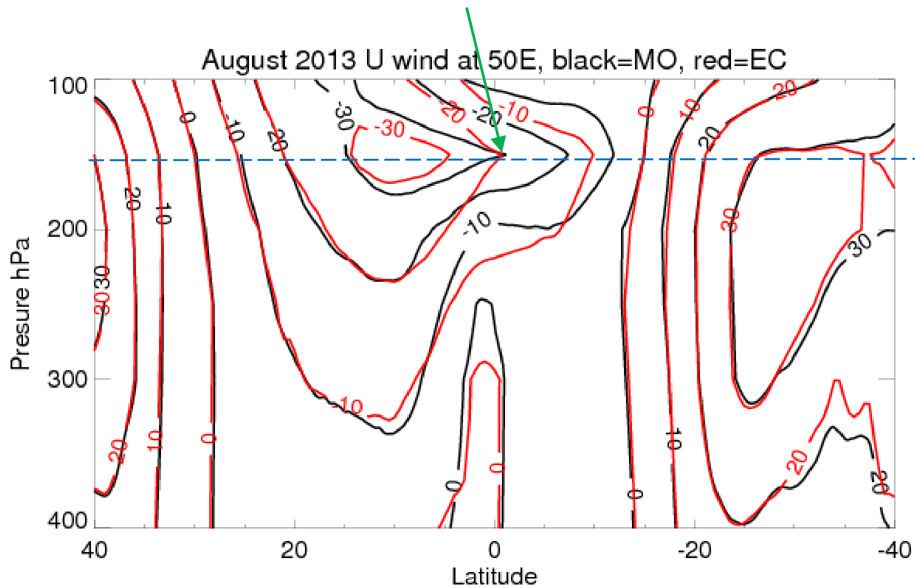
- Negative speed bias for Met-7 and MSG in high-troposphere of the tropics between June-Sept
- Coincides with Tropical Easterly Jet
- Bias more prominent for MetO than ECMWF

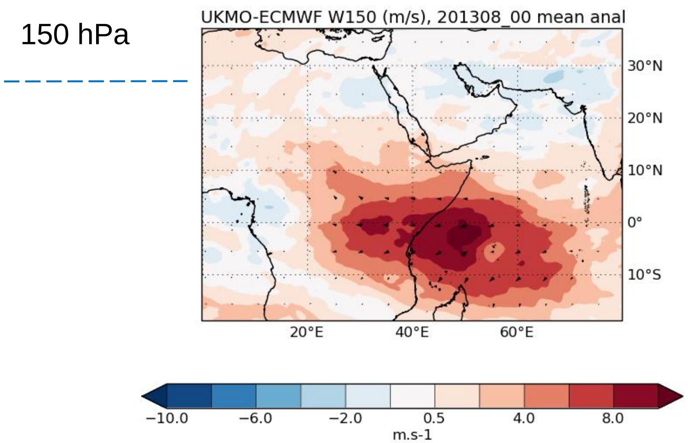


e.g. August 2013

Negative speed bias in TEJ

UKMO – ECMWF Analyses





Cross section of the mean zonal (U) wind component at 50° E: Met Office analysis (black) and ECMWF analysis (red).

- Large model differences in equatorial E. Africa and W. Indian Ocean
- Mean Met Office analysis up to 10 m/s faster than ECMWF
- Negative AMV O-B likely has contribution from model error

Quality Control and Errors

Overview

AMVs are treated as wind observations at a single pressure level. Height assignment (HA) remains dominant source of error

Errors in HA can be handled via :

- *a-priori* blacklisting of known problem areas with large systematic errors (Cotton and Forsythe, 2012)
- down-weighting observations through specification of situation-dependent observation errors (Forsythe and Saunders, 2008; Salonen and Bormann, 2013)
- bias correcting *mean height errors* - in regional models (Lean et al., 2015) and global models (Salonen and Bormann, 2016)

Met Office new QC – inversion height correction and 'dry layer' QC (Cotton et al., 2016)

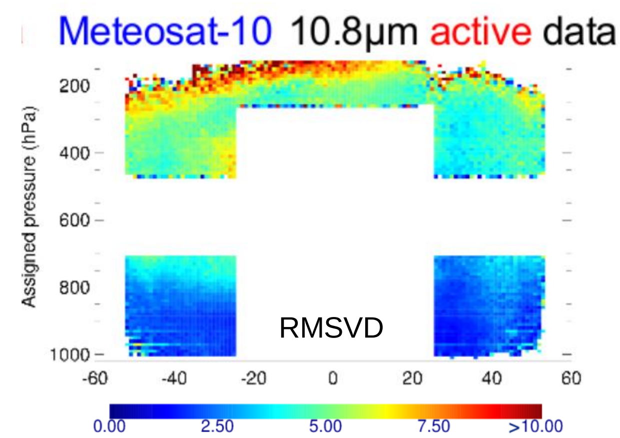
Geographical Selection

Katie Lean, Kirsti Salonen (ECMWF)

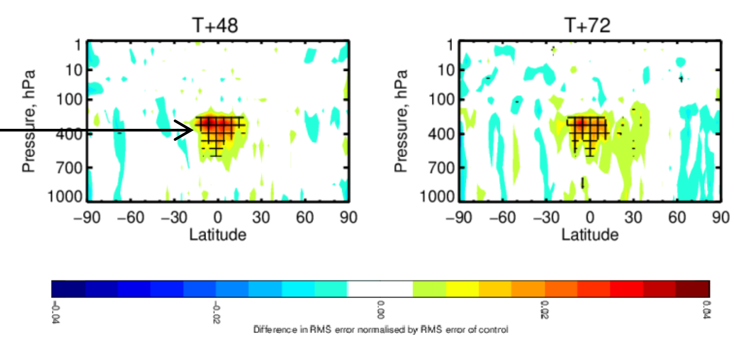
AMVs in tropics can be screened prior to assimilation and/or have tighter quality indicator (QI) thresholds

e.g. ECMWF blacklisting

- Meteosat-10 IR and WV winds below 250 hPa in the tropics (25N-25S)
- Himawari-8 IR winds below 300 hPa in the tropics (25N-25S)
- Dual Metop-A/B winds equatorwards of ± 40°



Attempts to relax blacklisting in tropics for MSG led to degraded forecast scores (Salonen and Bormann, 2016)



Normalised difference in wind forecast RMS error for day 2 and 3

Individual observation error scheme

A good specification of the observation error is essential to assimilate in a near-optimal way

Two independent sources

Error in vector

- Linked to accuracy of tracking step

Error in height

- Linked to accuracy of height assignment
- More problematic if large vertical wind shear

Total u/v error = √ (u/v Error^2 + Error in u/v due to error in height^2)

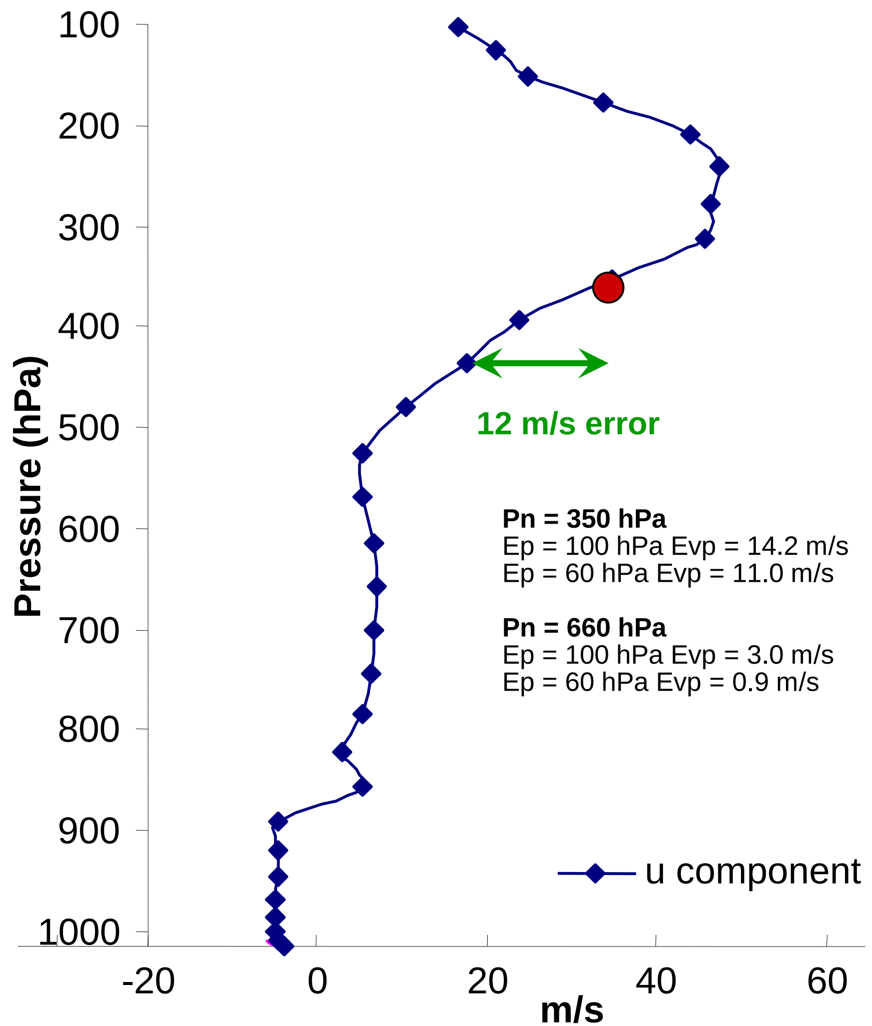
For this we need an estimate of:

1. u and v error (Eu and Ev)
2. height error (Ep)

Ideally from data producers

Until then estimate Ep using best-fit pressure stats as a guide.
See Forsythe & Saunders, IWW9, 2008; Salonen et al, 2014, JAMC

Currently assume uncorrelated errors

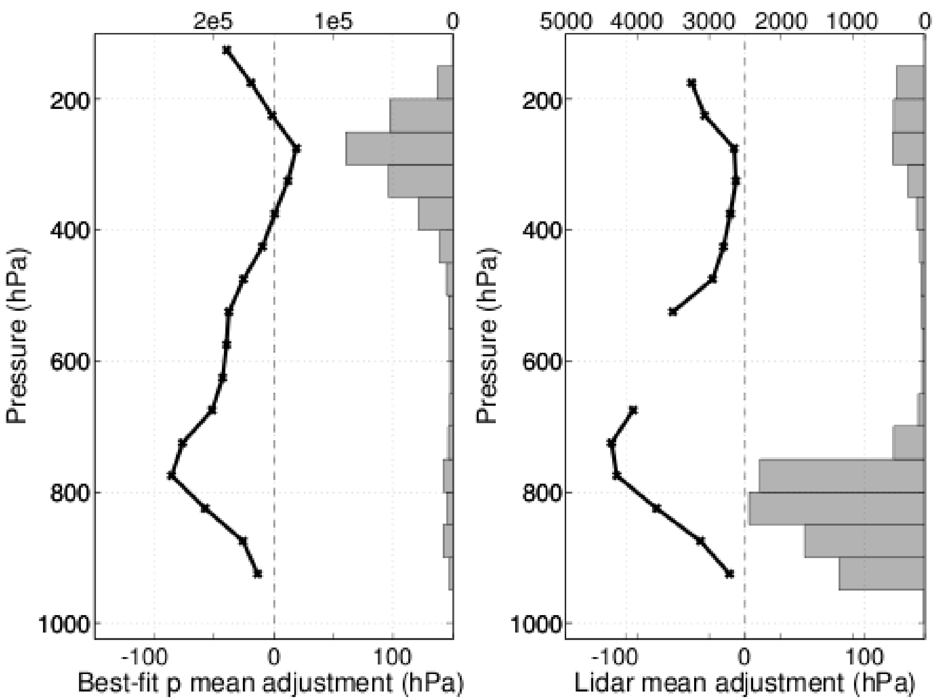


Estimating Systematic Height Errors

Kirsti Salonen, Niels Bormann (ECMWF)

Met Office

Best-fit Pressure | Lidar



AMV height higher than level of best-fit

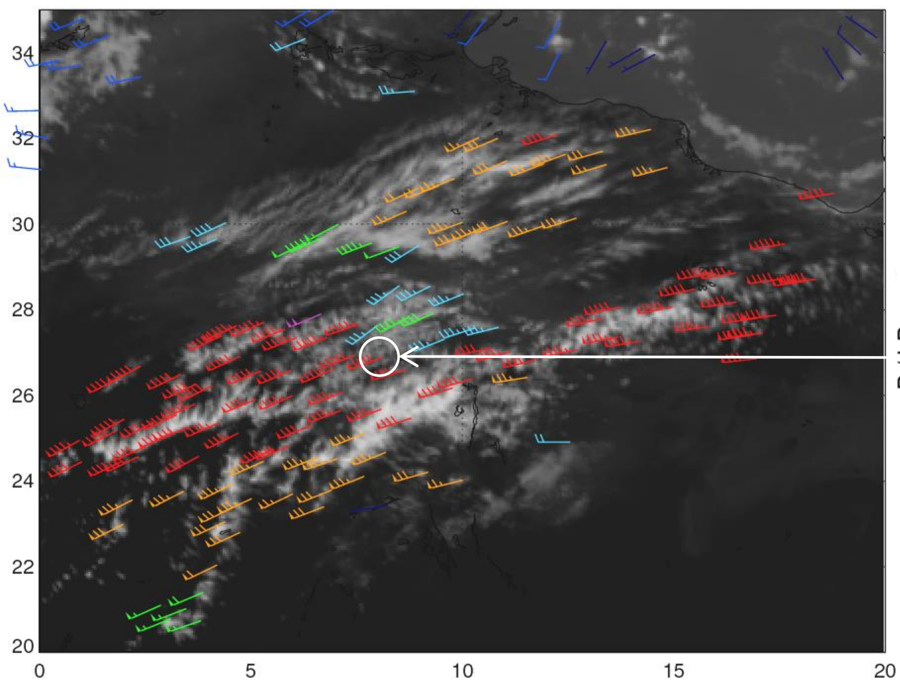
GOES-15 IR

- AMV height error estimates similar for both methods
- Can be used to re-assign to more representative level
- Preliminary DA experiments show encouraging results for impact on forecast scores
- Mixed results for O-B fit (AMV fit slightly degraded, other winds improved)

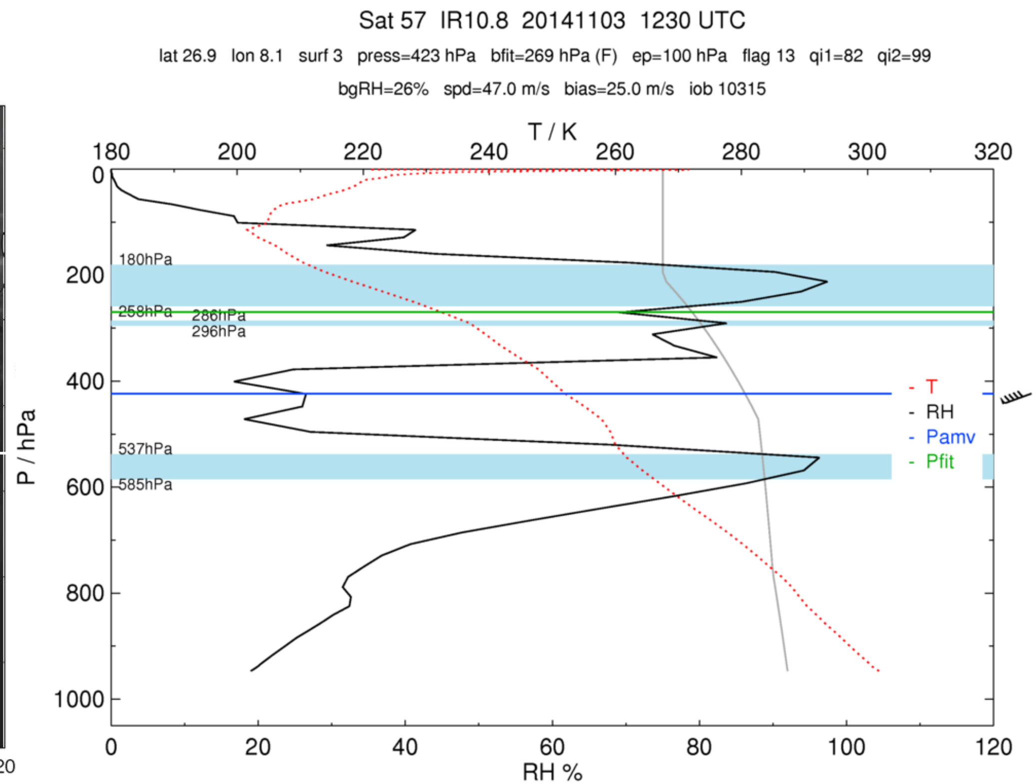
Dry Layer QC

MSG IR10.8 AMVs at 12:30 UTC, 3 Nov 2014

AMV Speed



QI2 > 80



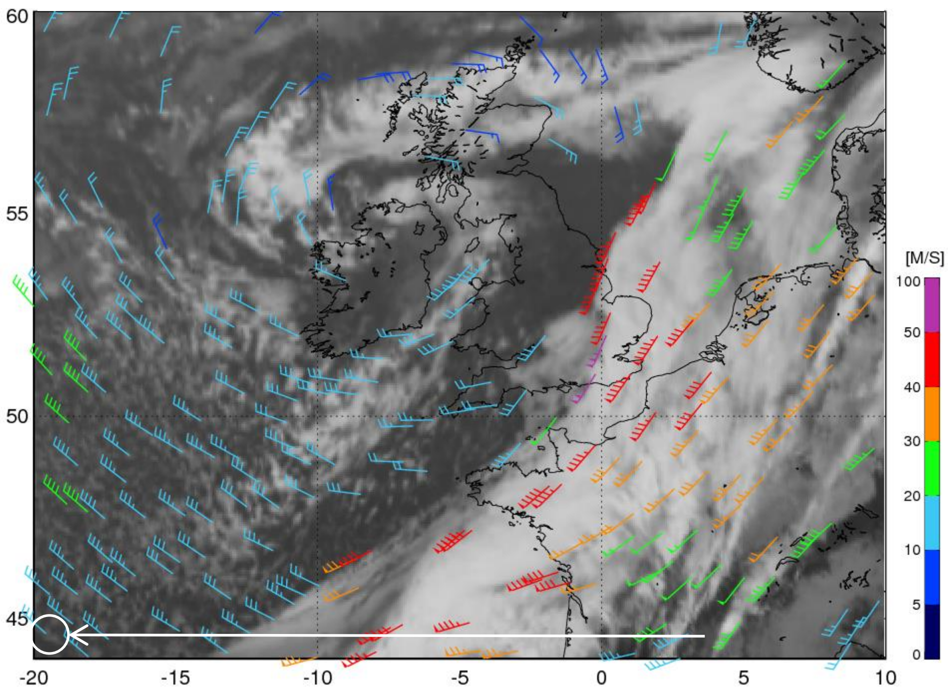
P=423 hPa, V=47 m/s, O-B=+25 m/s, BgRH=26%

AMV assigned in dry slot between 2 moist layers. Large speed bias

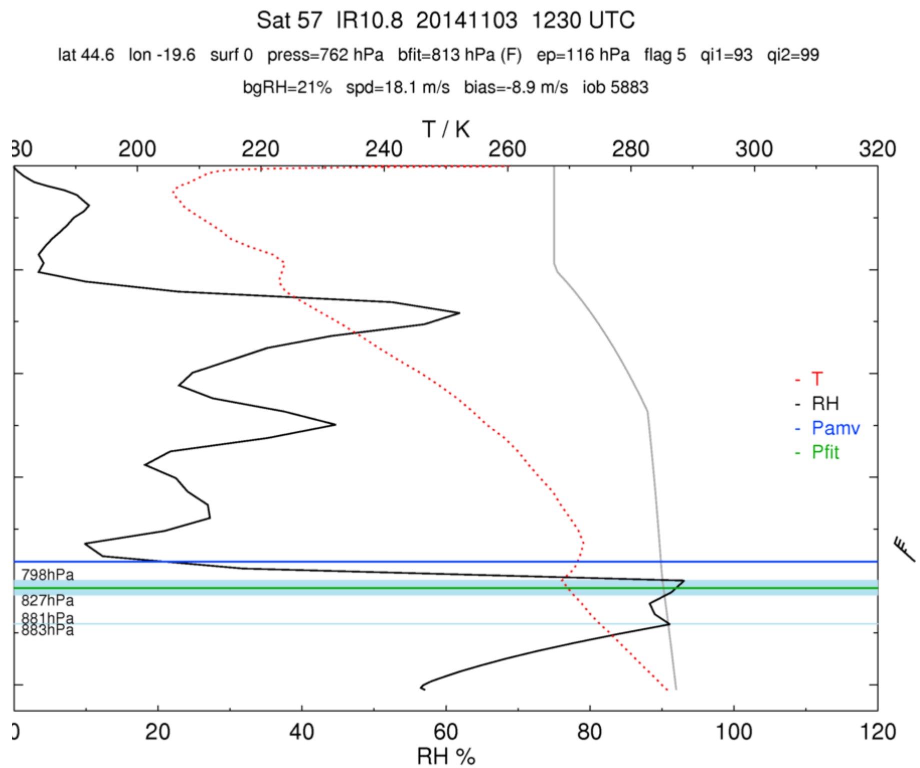
Inversion Correction

MSG IR10.8 AMVs at 12:30 UTC, 3 Nov 2014

AMV Speed



QI2 > 80



P=762 hPa, V=18 m/s, O-B=-9 m/s, BgRH=21%

Assigned ½ way up from inversion base. Same speed, large bias, bg RH 21%.

New Quality Information

Francis Warrick

Many AMV producers moving to use of pixel-based cloud schemes developed by the cloud community, in some cases providing additional information

Cloud optical depth ✓

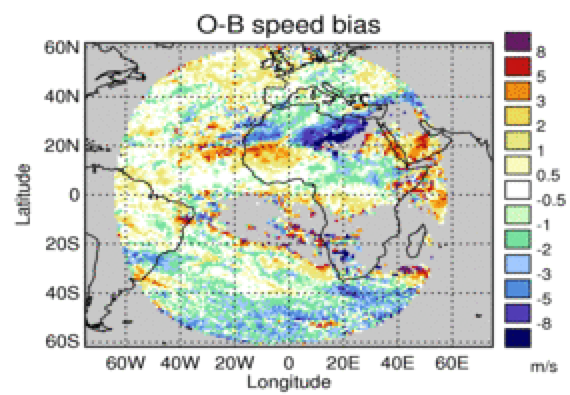
Median pressure error ✓

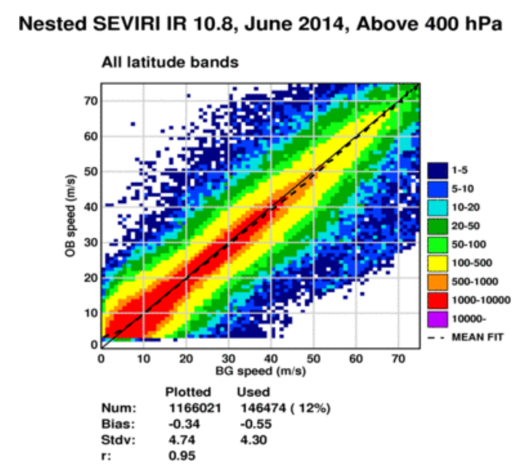
Scene cloud type

OE cost?

- Help understand AMV errors
- Potential to filter out poor data
- Feed estimated height error into observation error scheme
- Potential also for height reassignment or layer representation

OD > 0.75





Met Office

Collaborative AMV Impact Study (2012)

Coordinated Study of AMV impact in NWP

James Cotton(1), Christophe Payan(2), Richard Marriott(1), Nathalie Saint-Raymond(2), Niels Bormann(3), Kirsti Salonen(3), Koji Yamashita(4), Nacy L. Baker(5), Pat Pauley(5), Rolf Langland(5), Liang Xu(5), Ron Gelaro(6), Dagmar Merkova(7), Alexander Cress(8), Yooonjae Kim(9), Eunhee Lee(9), Eunha Sohn(9), Chu-Yong Chung(9)

(1) UMKO, (2) Meteo France, (3) ECMWF, (4) JMA, (5) NRL, (6) GMAO, (7) Tellus Applied Science, (8) DWD, (9) KMA

11th International Winds Workshop, Auckland, New Zealand, 20-24 February 2012

Coordinated study of NWP winds impact

Study Details

Expand on an earlier preliminary study from 2008/09 by selecting two longer trial seasons (6 weeks) and coordinating a more consistent approach to producing verification results.

Period 1: 15 Aug – 30 Sep 2010, captures all major Atlantic hurricanes

Period 2: 1 Dec 2010 – 15 Jan 2011, NH winter period

Test options:

1. AMV denial (Periods 1 and 2)
2. Scatterometer denial (Period 1)
3. Polar AMV denial (Period 2)
4. Sensitivity study (Period 1)

Results from 8 NWP centres

Here we focus on AMV results

	No AMV	No Scat	No Polar	Sensitivity
DWD	✓ ✓	✓	✓	
ECMWF	✓ ✓	✓	✓	✓
GMAO				✓
JMA	✓ ✓	✓	✓	✓
KMA	✓ ✓			
MF	✓ ✓		✓	✓
NRL	✓ ✓	✓	✓	✓
UKMO	✓ ✓	✓		✓

Coordinated study of AMV impact

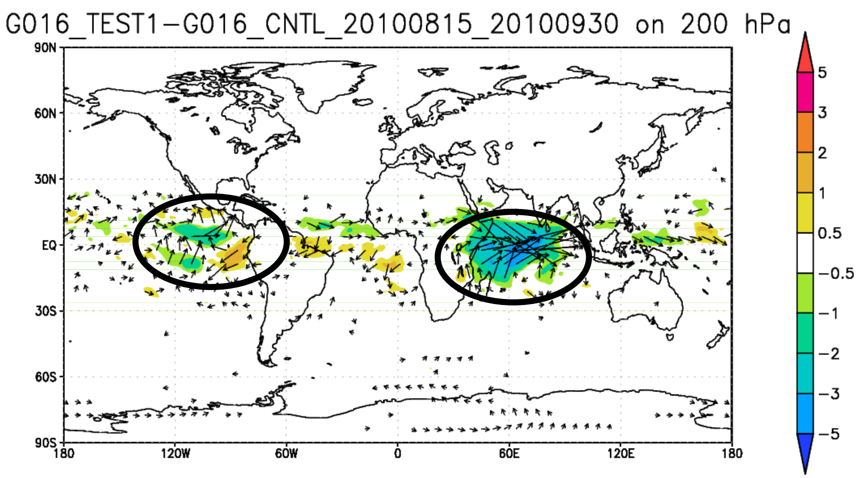
A few highlights

Impact on mean wind analysis at 200/250 hPa

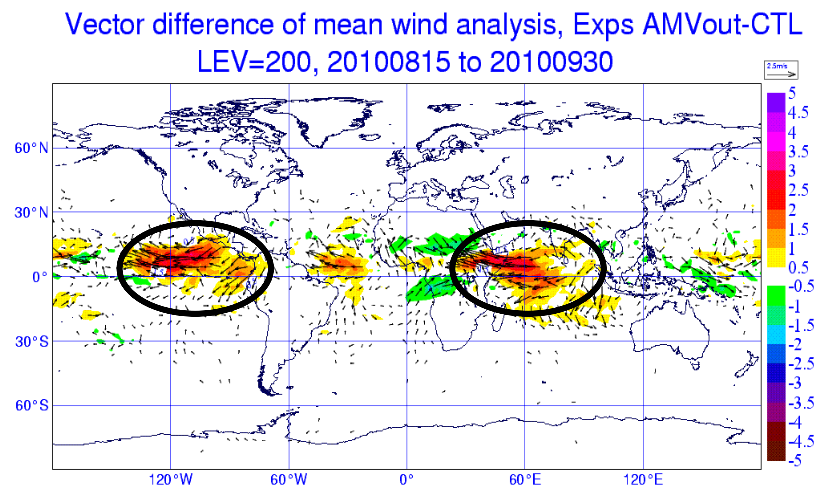
- Concentrated in tropics, particularly (i) Eastern Pacific and (ii) Indian Ocean
- Impact not consistent between centres e.g.

  During Period 1 there is a predominantly Easterly mean flow in the tropics.

  The inclusion of the AMVs tends to enhance the strength of the easterly flow at DWD, JMA and NRL, but reduce it at ECMWF and MF



JMA



ECMWF

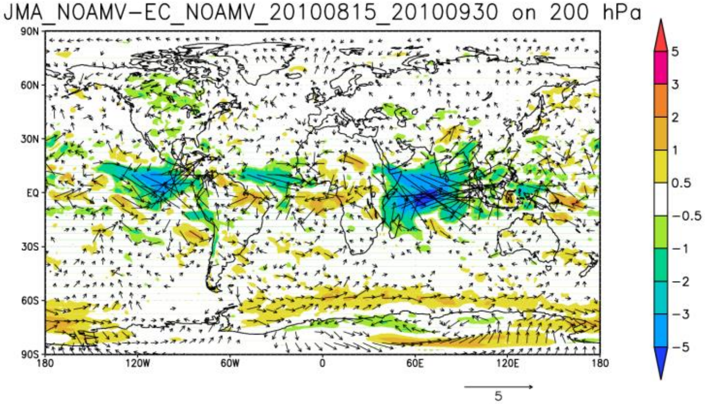
Denial –Control: green/blue represent where the analysis is faster as a result of assimilating AMVs

Coordinated study of AMV impact

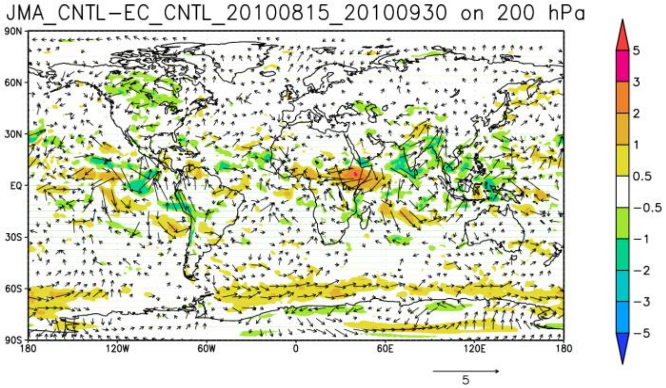
A few highlights

Can we explain the different impacts in tropics?

• Compare JMA and ECMWF wind analyses with and without AMVs



JMA-EC (no AMVs)



JMA-EC (with AMVs)

- Overall differences between ECMWF and JMA are significantly smaller in the experiments with AMVs than in the denial experiments
- The differences seen in the AMV denials are likely due to differences in the climatology of the forecast models of the centres
- AMVs act to bring the two systems in better agreement

Niels Bormann, Koji Yamashita

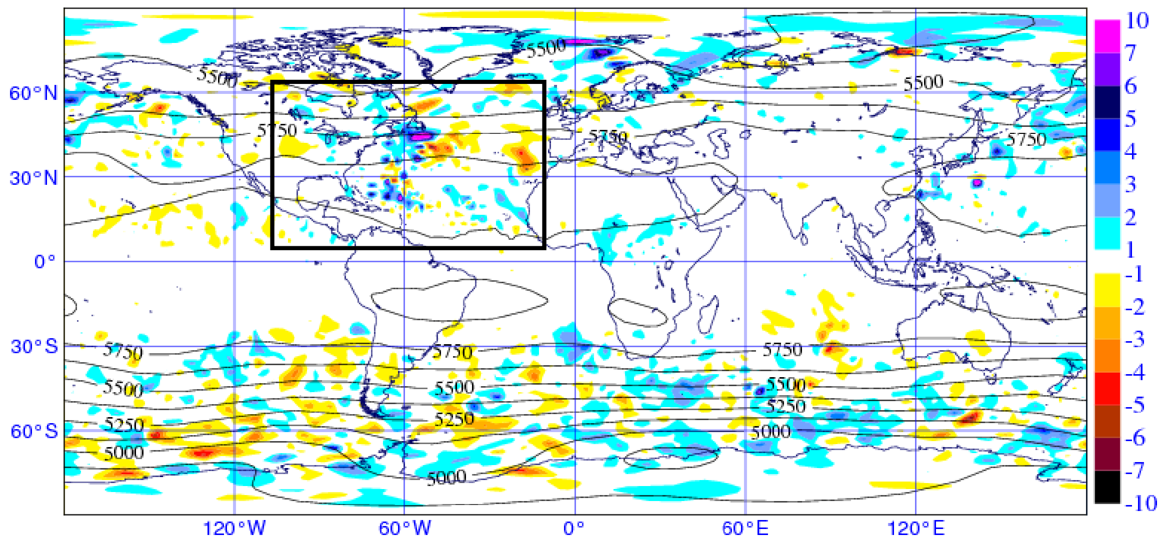
Coordinated study of AMV impact

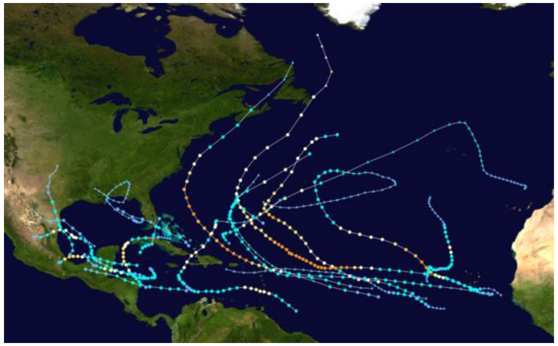
A few highlights

Impact on 500 hPa Geopotential Height T+48 forecast error (RMS)

- Overall impact rather positive
- Most widespread reductions in RMS found in the extra-topics and polar-regions in particular
- Several centres (ECMWF, MF, DWD, JMA, UKMO) in period 1 show a largely positive impact on Z500 in region of North Atlantic storm tracks e.g.

Diff in RMS of fc-Error: RMS(fc_AMVout - an_AMVout) - RMS(fc_CTL - an_CTL)
Lev=500, Par=Z, fcDate=20100815-20100928 12Z, Step=48
NH=0.14 SH= 0.05 Tr= 0 Eu=0.19 NAm= -0.01 NAt= -0.04 NPa= 0.28 NPo= 0.2 SPo= 0.14





ECMWF

Blue/purple colours represent where the forecast RMS in the reference experiment (containing the AMVs) is smaller than in the denial experiment i.e. positive impact

Recent Met Office Denial Study

Observing System Experiments (OSEs)

- A coordinated set of OSE's designed to give us a snapshot of impacts from PS37 observations and to analyse the consistency with Forecast Sensitivity to Observations Impacts (FSOI).

The following set of data denial experiments have been run:

Exp	**Data Denied**
Expt 1	No IR data (no IASI, CrIS, AIRS, HIRS or SEVIRI)
Expt 2	No MW data (no AMSU/MHS, ATMS, SSMIS, AMSR-2, Saphir, FY-3C)
Expt 3	No MW Humidity (no MHS, ATMS18-22, FY-3C, Saphir, SSMIS 9-11 & 12-16, AMSR-2)
Expt 4	No MW Imagers (no AMSR-2, SSMIS 12-16)
Expt 5	No Adv IR sounder humidity channels (AIRS, CrIS and IASI) and no HIRS 11,12
Expt 6	No AMVs
Expt 7	No GNSSRO
Expt 8	No Scat
Expt 9	No TEMPs
Expt 10	No Ground based GNSS

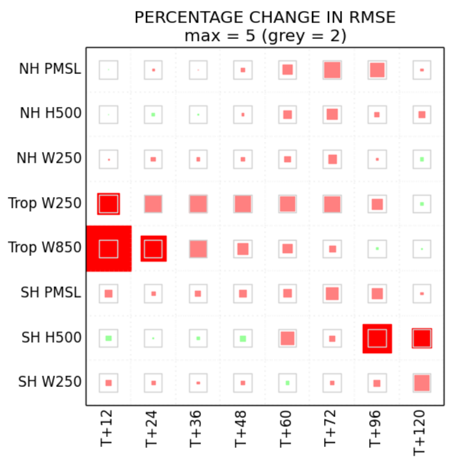
Baseline is a PS37 N320 control from 12 Nov - 15 Jan 2015/16

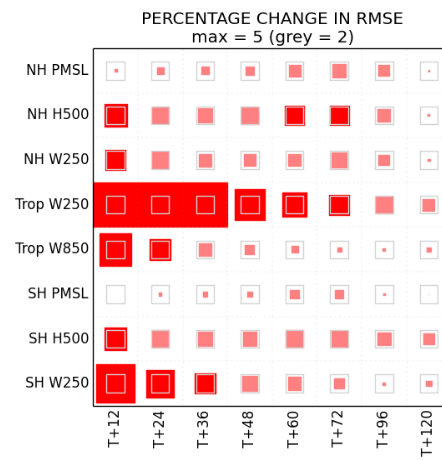
Impact Scorecards – Fc RMS Error

Vs Observations

Vs ECMWF Analysis

No AMV





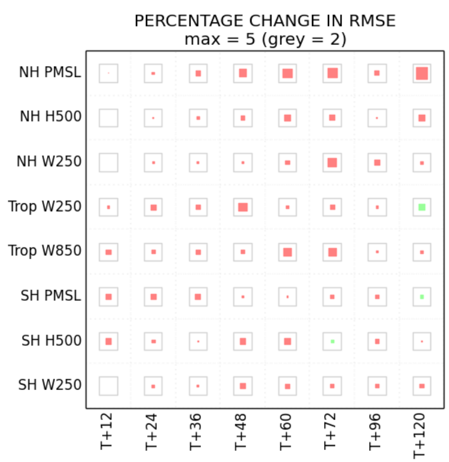
Upper level winds in tropics

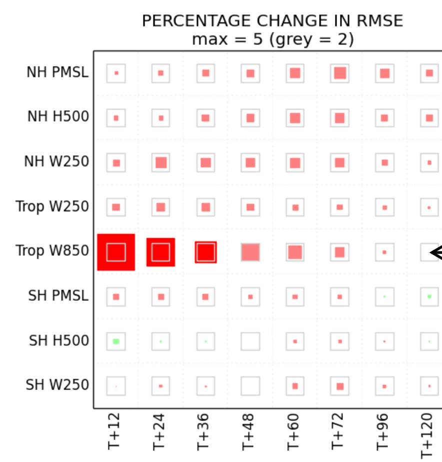
No Scat

NH

TR

SH





Low level winds in tropics

Lead time

Summary

- NWP needs wind data to represent the divergent comp. of the flow properly
  - particularly important in the tropics and for smaller scales..
  - but not likely to be captured with current spatial thinning of ~200-km
- Dependant on work in cloud community to improve CTH information
- Work to address AMV errors (HA) is ongoing, but more to understand – are tropical AMVs representative of local winds? (EUM ITT)
- AMV data have tended to have a positive speed bias in tropics
- AMVs have strong impact on the tropical mean wind analysis in the upper troposphere and reduce bias between models
- Beneficial impact on forecast RMS errors, particularly for short-range wind forecasts in the tropics
- Future AMV products will include additional quality information from the derivation

Thank you for listening

Questions?

References

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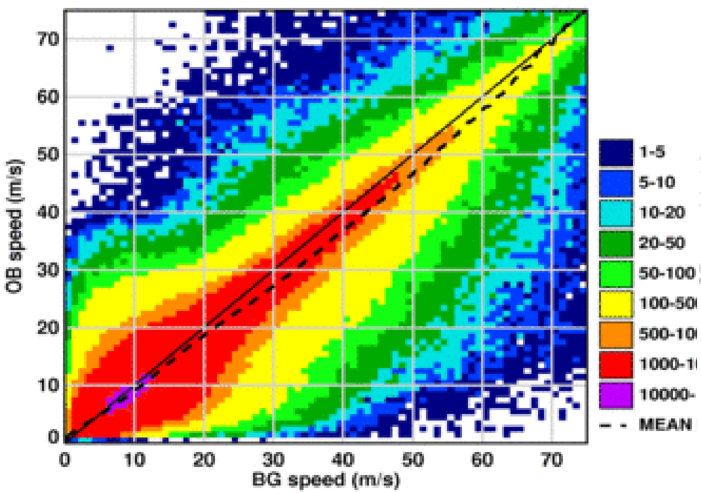
Spare Slides

NWP quality control for AMVs

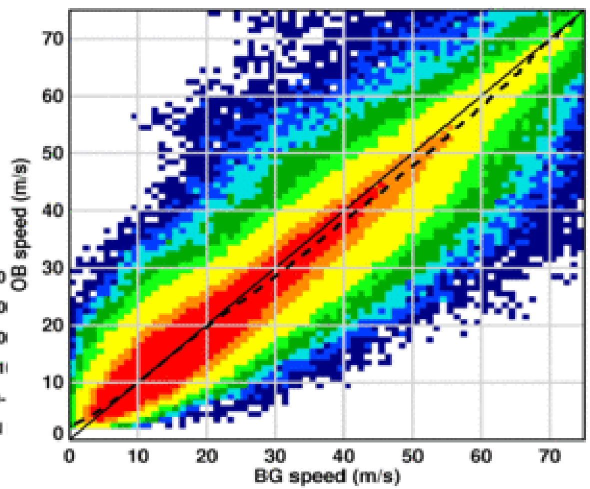
Met-9 NH IR winds, above 400 hPa, August 2014

All received (2,291,797)
stdv = 6.5 m/s



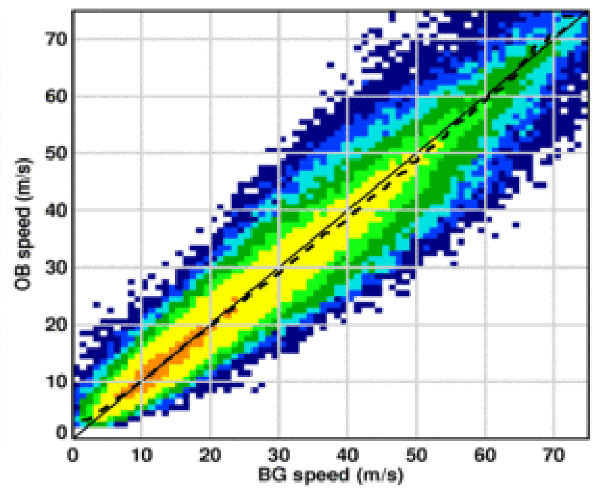
100%

QI1>80 (1,257,157)
stdv = 4.9 m/s



55%

Used (161,247)
stdv = 4.2 m/s



7%

Assimilate only a small percentage of the data

Dual Metop-A/B IR

(Warrick, 2016)

AVHRR viewing geometry playing a role?

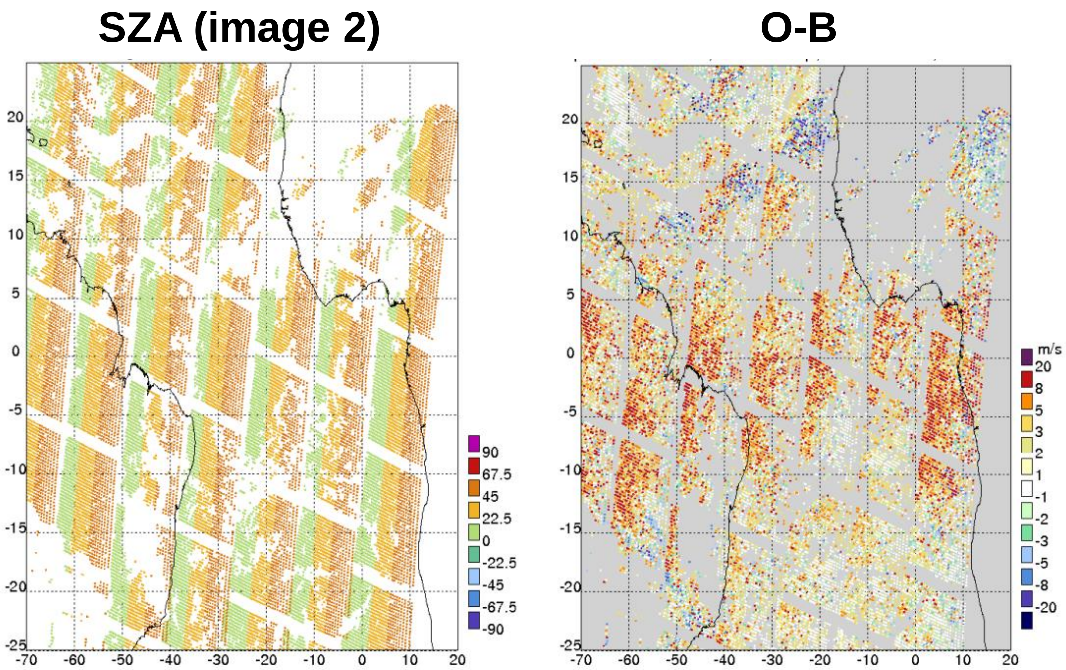
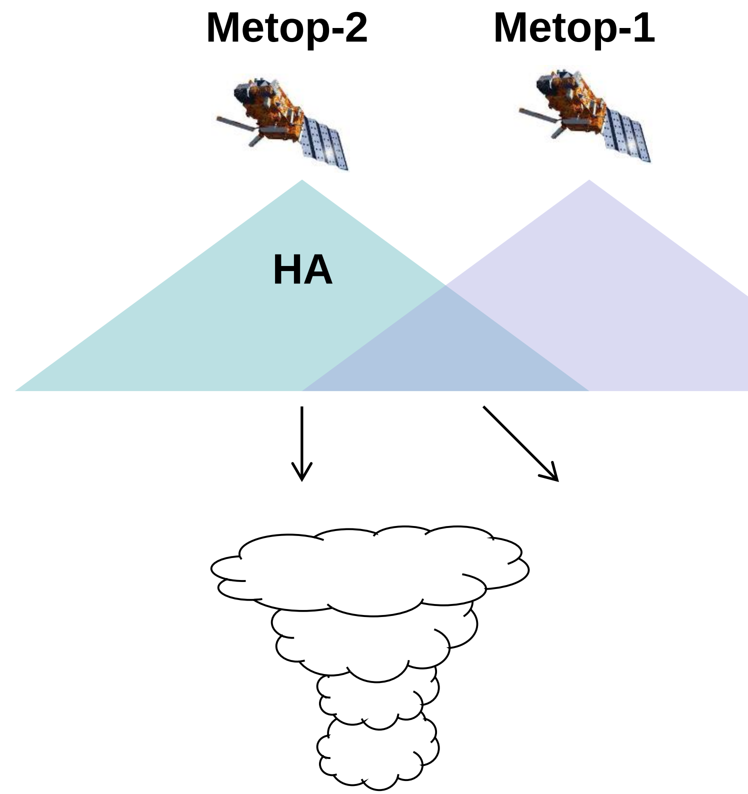


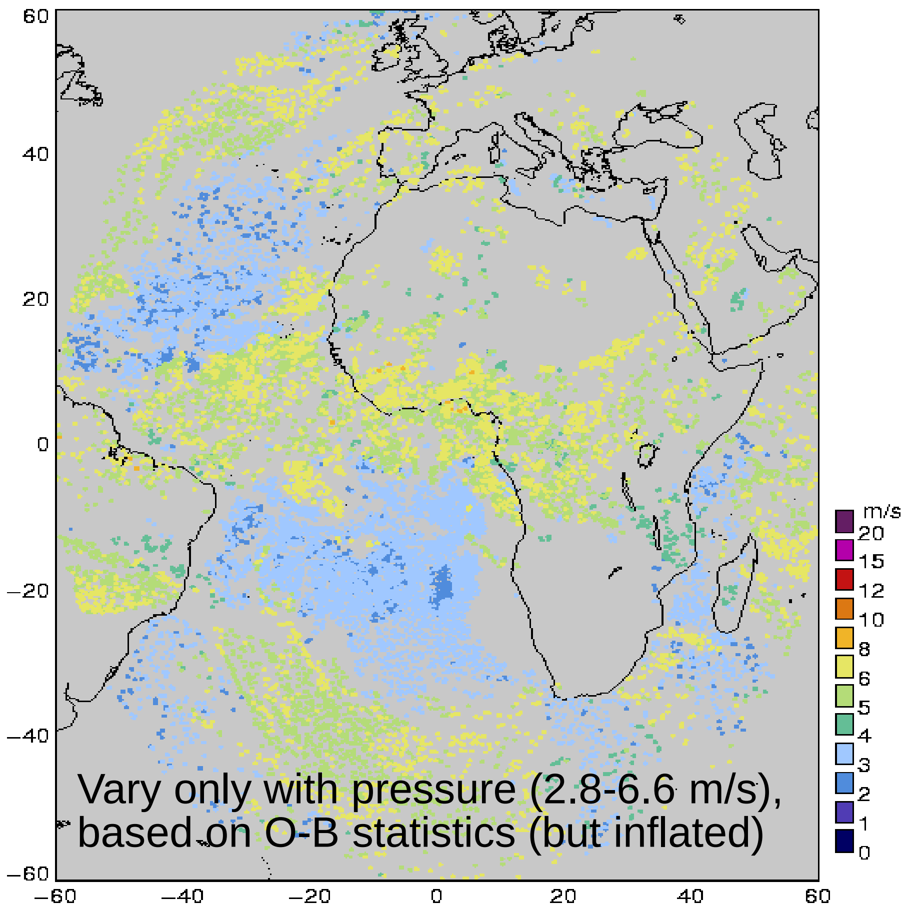
Figure 18: Properties of Dual-Metop AMVs from 0900 to 1500 UTC, 15/3/16.



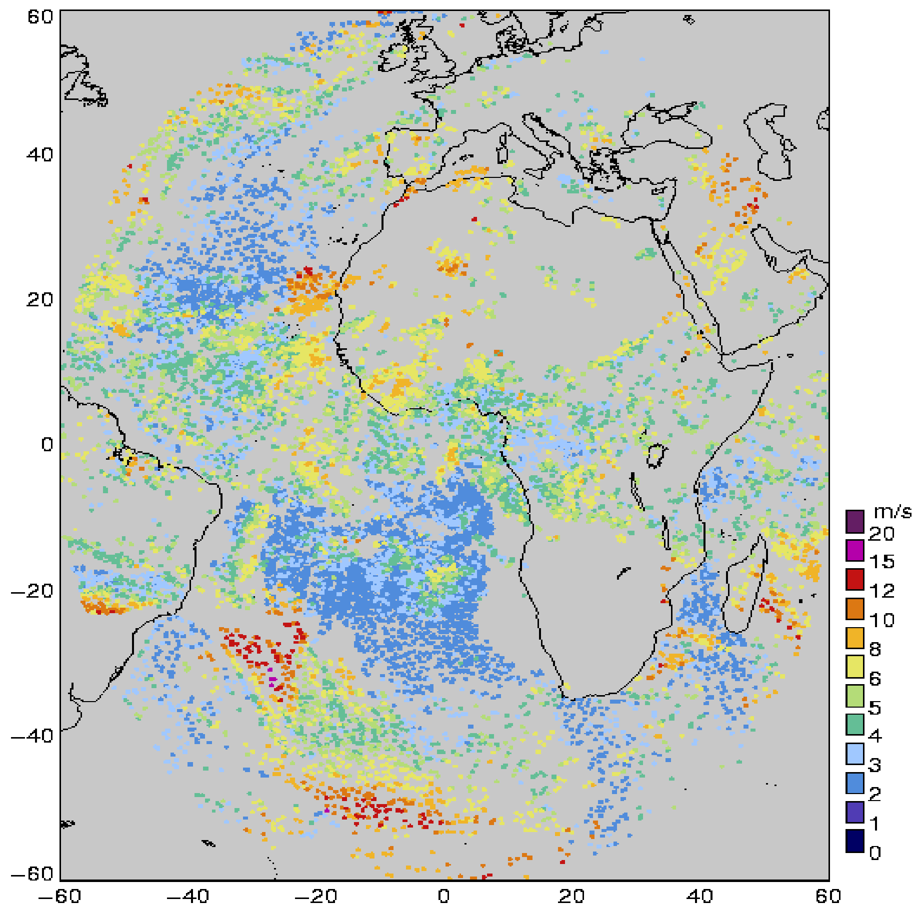
- In ITCZ, bias shows strong dependence on satellite zenith angle (SZA)
- AMV quality worse when HA done from low SZA?

Observation errors

Old Errors



New Errors

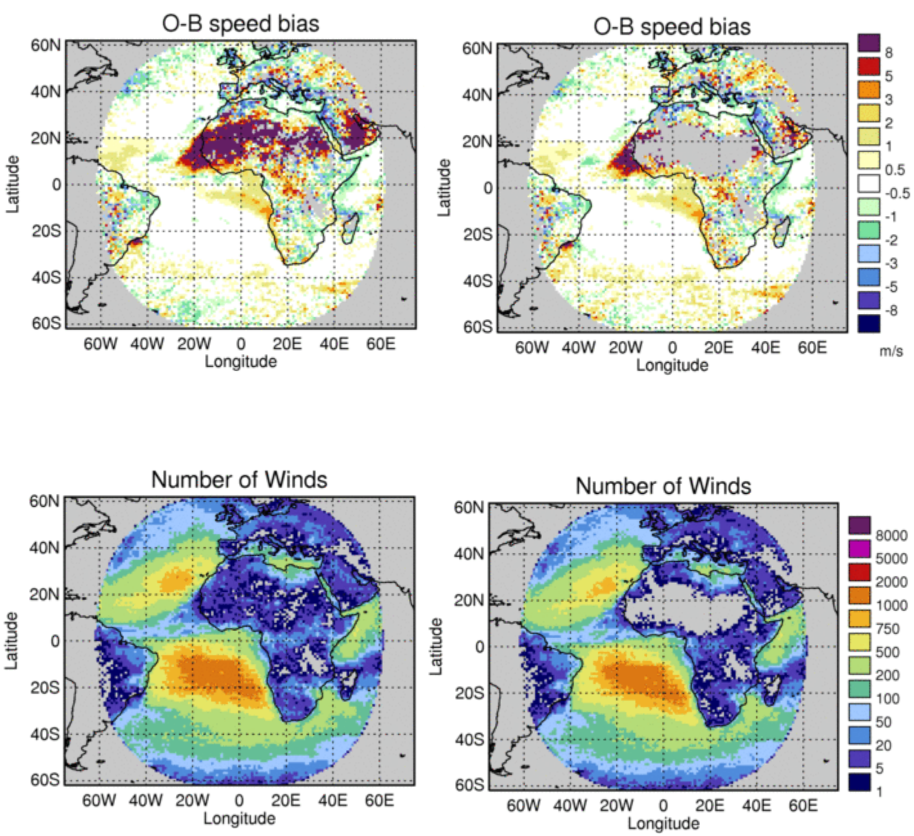


Benefit seen in assimilation experiments at the Met Office and ECMWF

Dry Layer QC

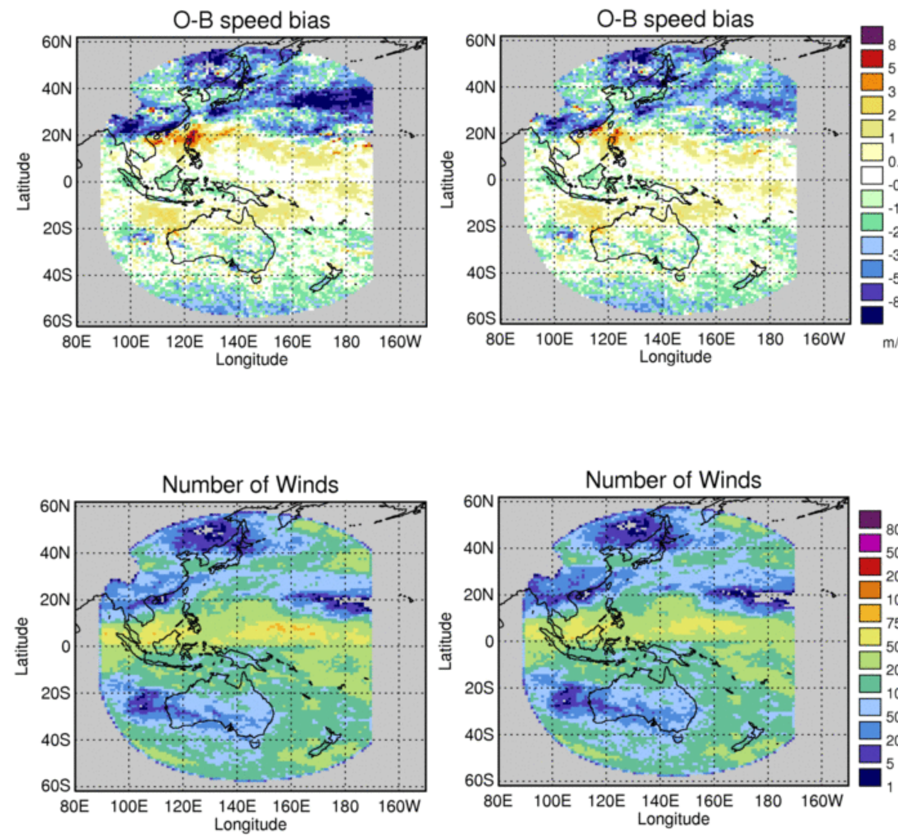
Jan 2015: QI2 > 80

QI2 > 80 | + Dry Layer Flag



MSG IR10.8 below 700 hPa

QI2 > 80 | + Dry Layer Flag



MTSAT-2 IR above 400 hPa

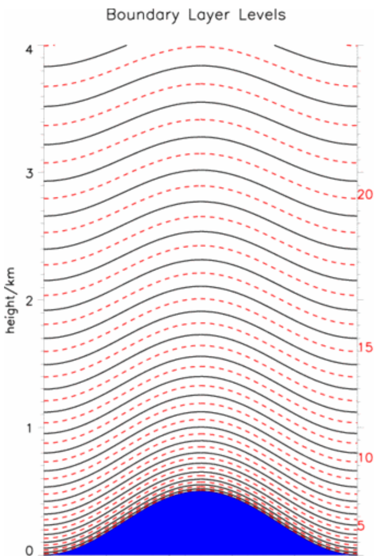
Why an Inversion Correction?

From IWW3 Schmetz et al. (1996)

- Important that low level winds are assigned within boundary layer as directional variations can increase rapidly above the capping inversion.
- (Low) clouds travel with wind at cloud-base which is usually within atmospheric boundary layer (ABL)

Most GEO AMVs already account for inversion situations, but there remain potential benefits to doing within NWP

- Full vertical model resolution (more levels within ABL to resolve inversion)
- Highest temporal resolution and update frequency (e.g. 3-hrly x4 /day, rather than 6-hrly x2 /day)
- Consistent with model characteristics



Schmetz et al. (1996), Low-Level Winds from High-Resolution Visible Imagery, *Proceedings of Third International Winds Workshop*, 1996.

Coordinated study of AMV impact

Some Conclusions

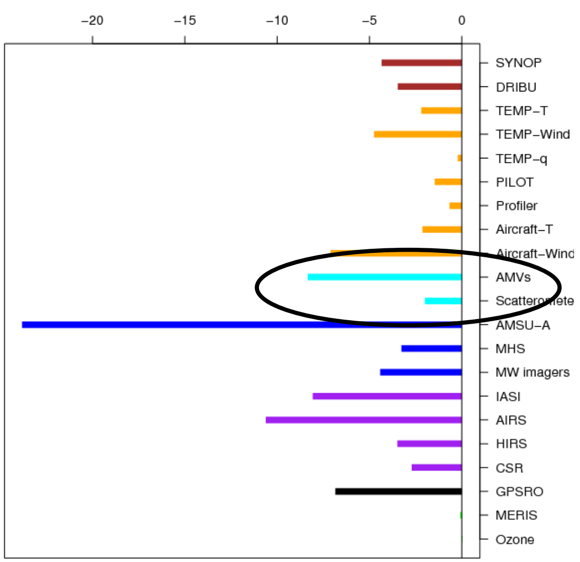
- Nearly all centres showed a strong impact from AMVs on the tropical mean wind analysis in the upper troposphere
- Differences in the tropical wind fields are considerably smaller when AMVs are assimilated compared to the AMV denial case.
- The AMVs act to bring the two systems in closer agreement and would suggest that the AMVs provide an accurate source of wind information in these areas.
- Largest impact on short-range wind forecasts (out to T+24) is also seen in the tropics at high level (fit to radiosonde winds)
- Larger impact often seen for centres who use 3DVAR or fewer other observations,
- No geographical regions where the AMVs are performing consistently poorly among several centres. Suggests regions of negative impact are mainly system-dependent (QC, thinning, assimilation scheme, forecast model, etc), rather than AMV-dependent

Coordinated study of AMV impact

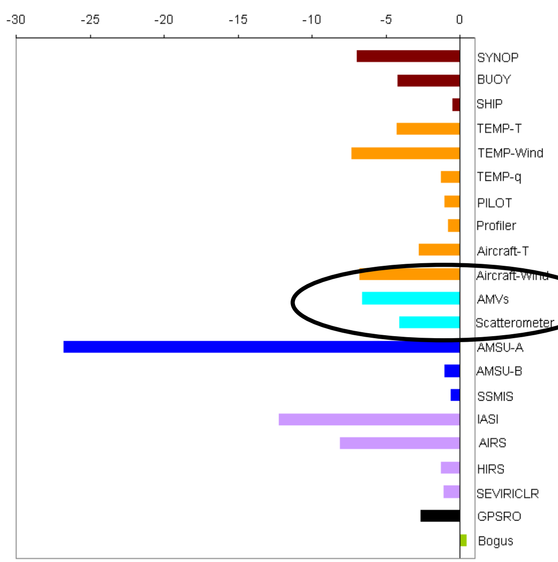
A few highlights

Forecast sensitivity to Observations (FSO)

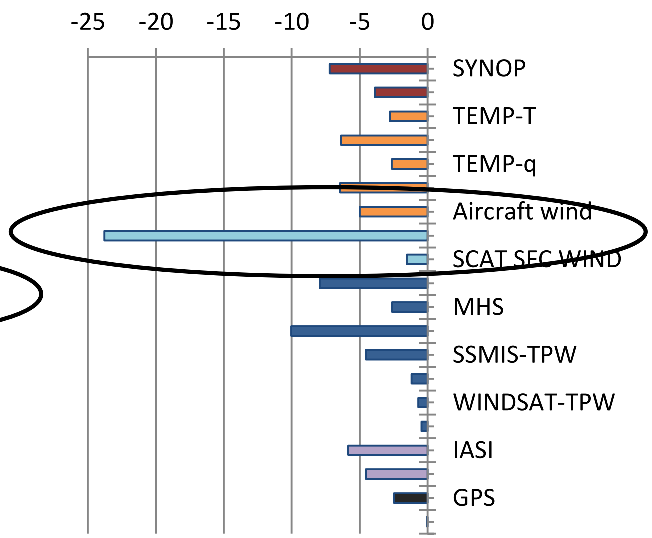
- Adjoint-based FSO method gives estimate of the contribution of each observation towards reducing the 24-hour forecast error
- Top level results agree fairly well for ECMWF, Met Office, MF – AMV FSO of 7-11%
- Markedly different for NRL – AMV FSO of 23%. Due to differences in AMV assimilation (e.g. superobs) or is the NAVDAS system able to extract wind information more effectively than temperature information?



ECMWF



Met Office



NRL

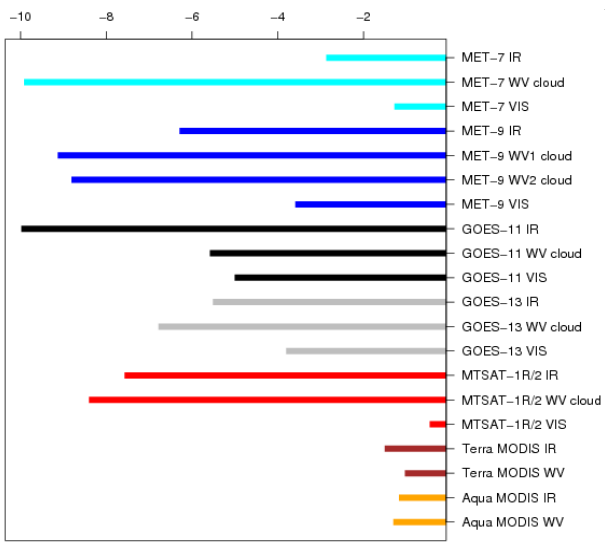
Coordinated study of AMV impact

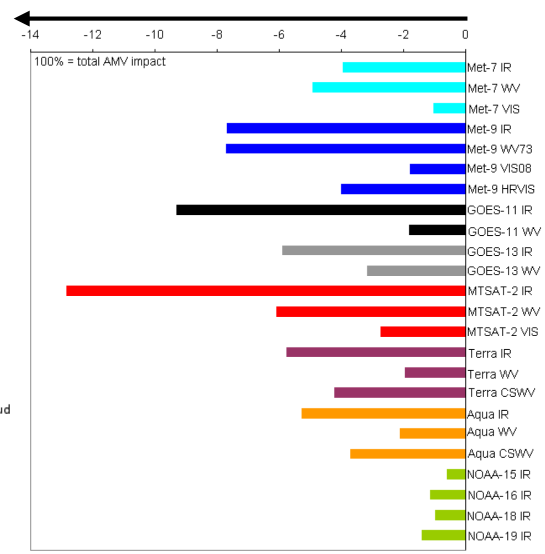
A few highlights

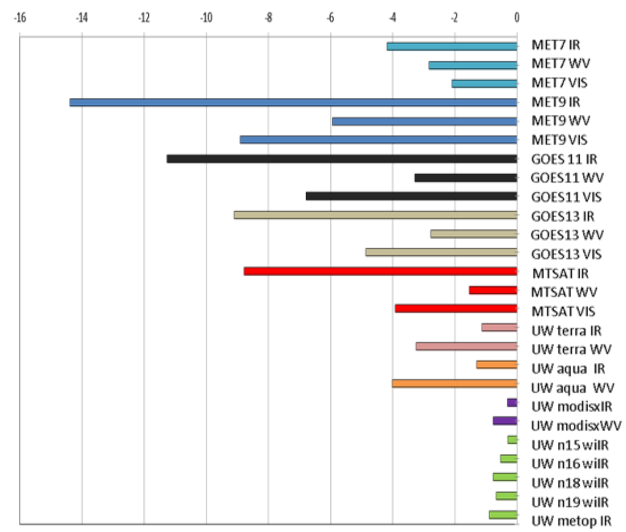
Total AMV FSO by satellite/channel combination

- All combinations contribute positively
- Total impacts closely related to the number of observation assimilated
- Difference in impact from geostationary WV winds: largest contributions for ECMWF, smallest for NRL

reduction in forecast error







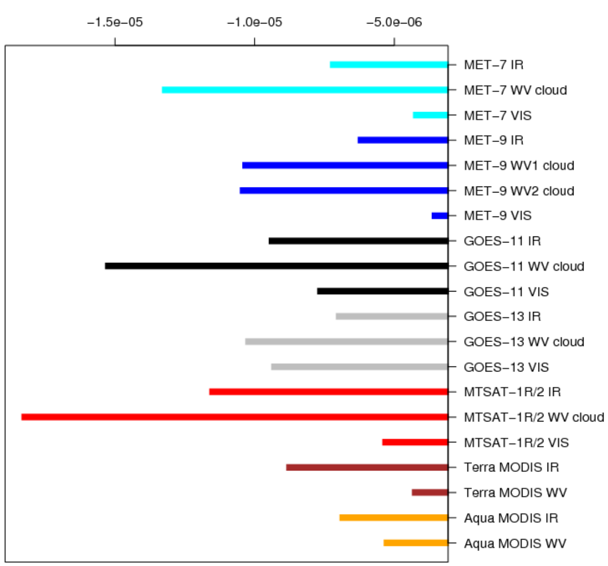
ECMWF | Met Office | NRL

Coordinated study of AMV impact

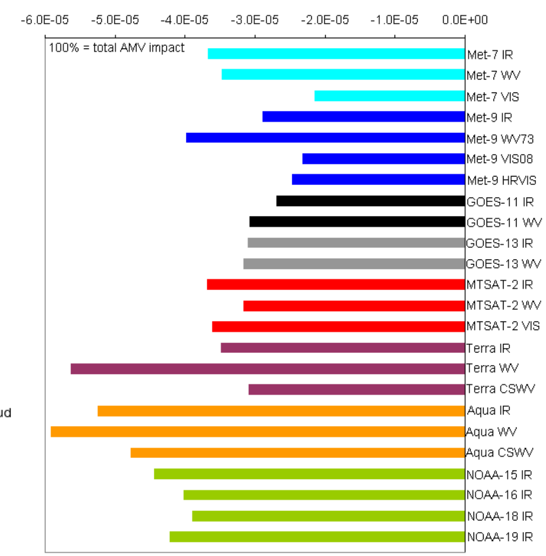
A few highlights

Mean FSO per observation

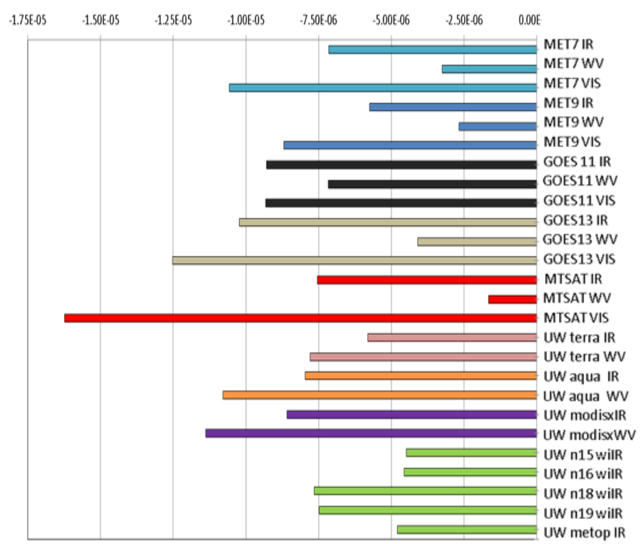
- Met Office shows more uniform impact per observation
- For ECMWF the largest contribution per observation comes from the geostationary cloudy WV winds, smallest tends to be from visible
- Opposite tends to be true for NRL - largest impact per geostationary superob is from the visible winds and the smallest from the WV
- Polar wind differences: Met Office shows strong impact, small impact for ECMWF



ECMWF



Met Office



NRL

Coordinated study of AMV impact

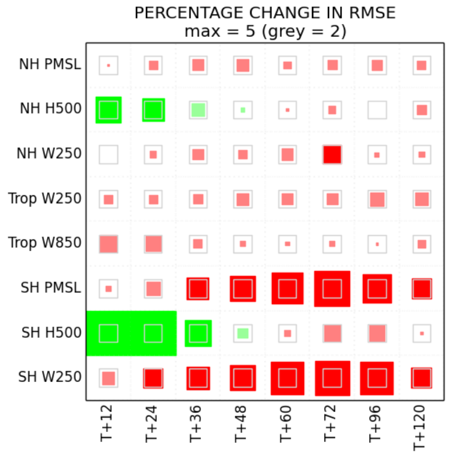
Conclusions

- Probably for the first time have been able to demonstrate a consistent level of positive forecast impact from AMVs across all NWP centres – especially in high level extra tropics
- Nearly all centres see a strong impact on the tropical mean wind analysis
- Larger impact often seen for centres who use 3DVAR or fewer other observations, and for NRL whose FSO statistics suggest quite a different impact from the various components of the observing system
- No geographical regions where the AMVs are performing consistently poorly among several centres. Suggests regions of negative impact are mainly system-dependent (QC, thinning, assimilation scheme, forecast model, etc), rather than AMV-dependent
- In addition to the classic denial study, the FSO stats further indicate significant relative importance of the AMVs in the global observing system context

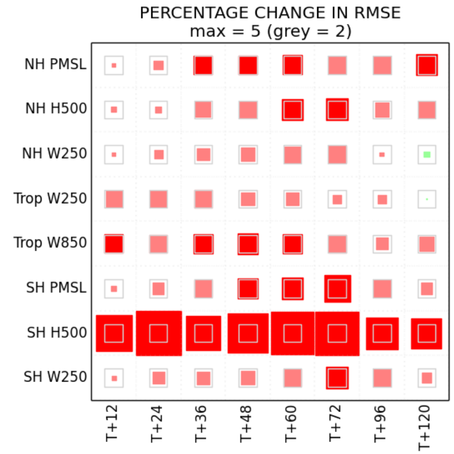
Impact Scorecards

Versus Observations

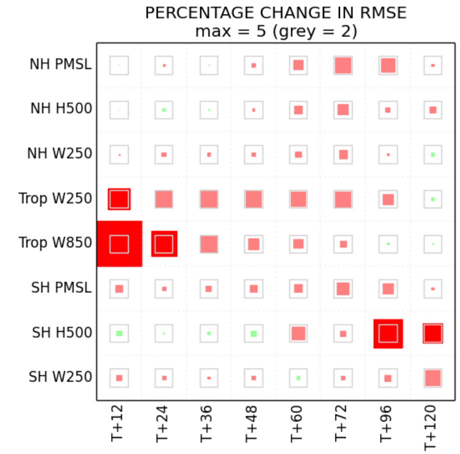
No IR



No MW



No AMV

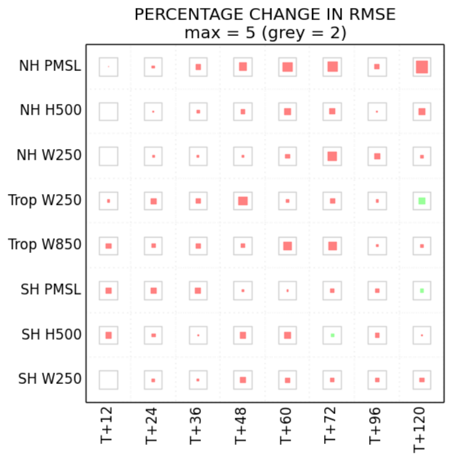


No Scat

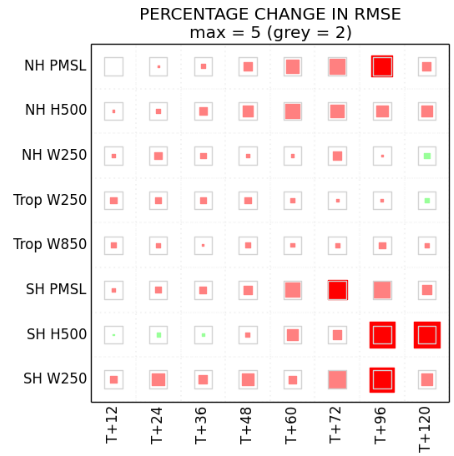
NH

TR

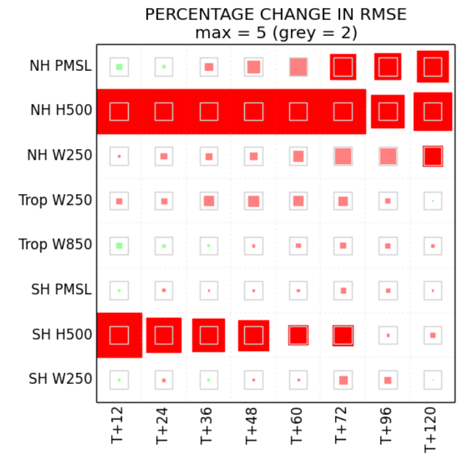
SH



No GNSSRO



No Sonde

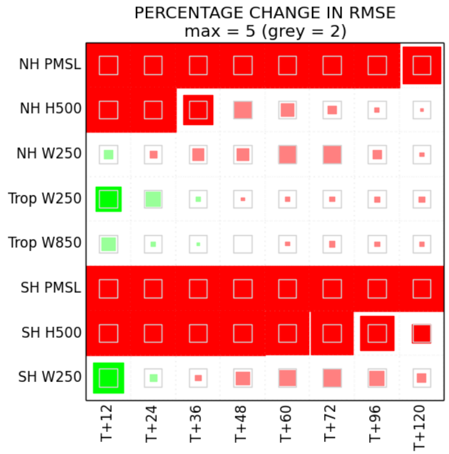


Lead time →

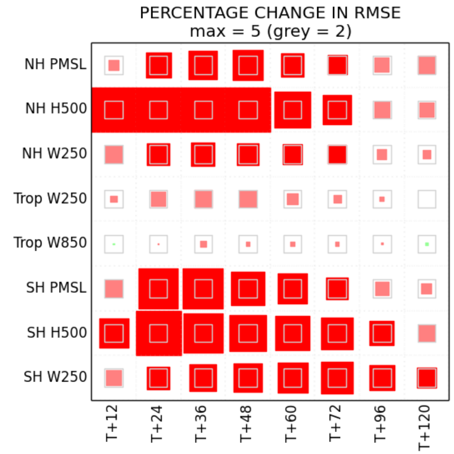
Impact Scorecards

Versus Own Analysis

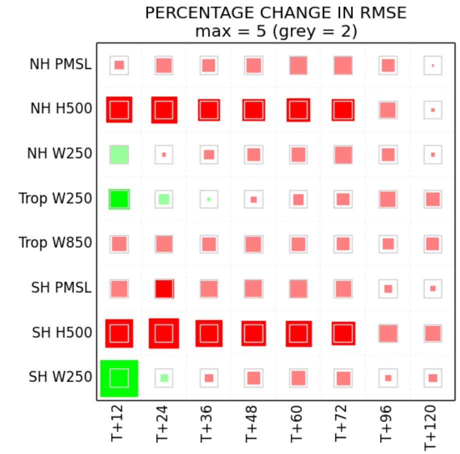
No IR



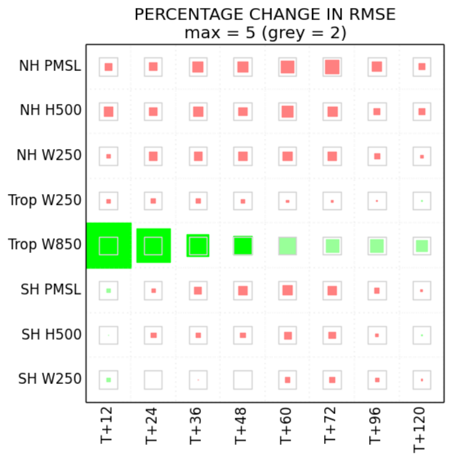
No MW



No AMV



No Scat



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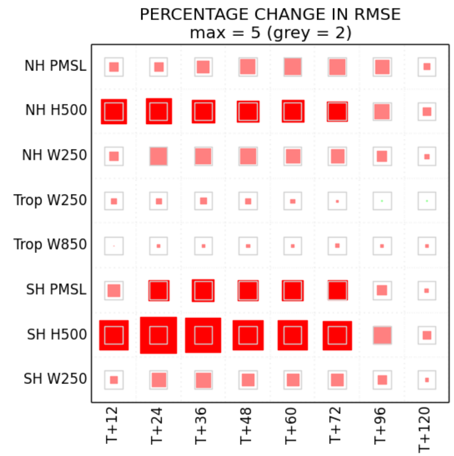

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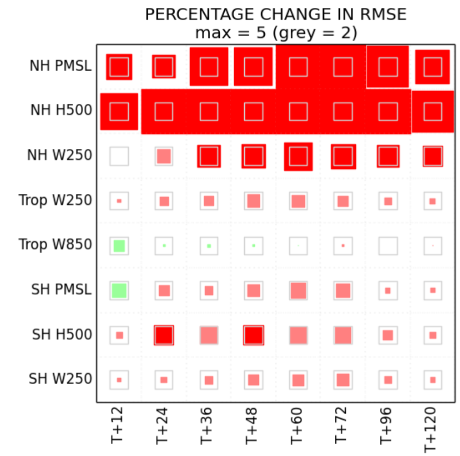
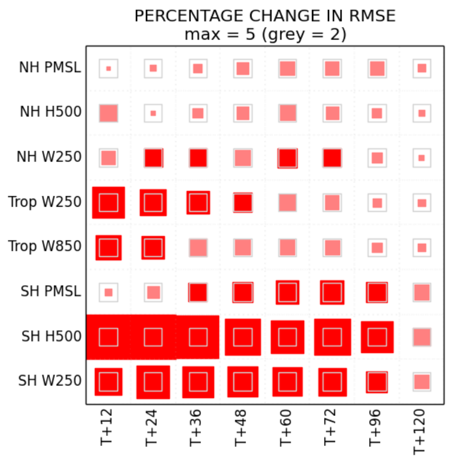


Met Office

Impact Scorecards

Versus ECMWF Analysis

No IR



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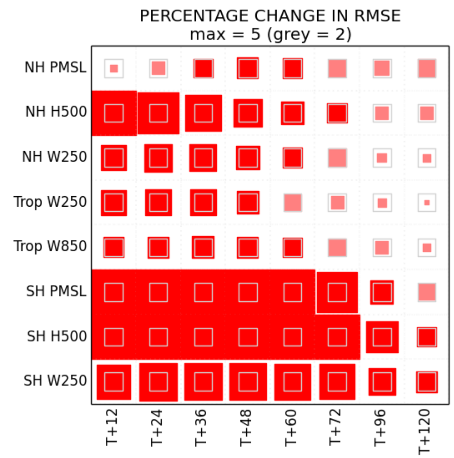
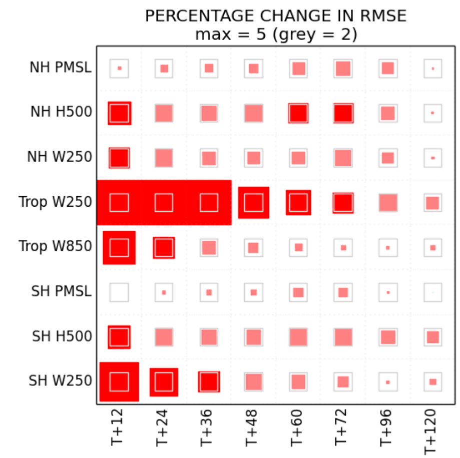
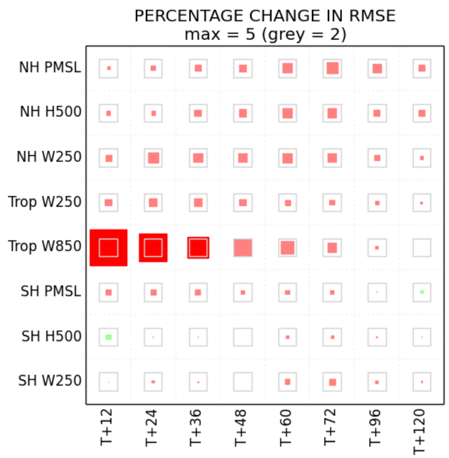


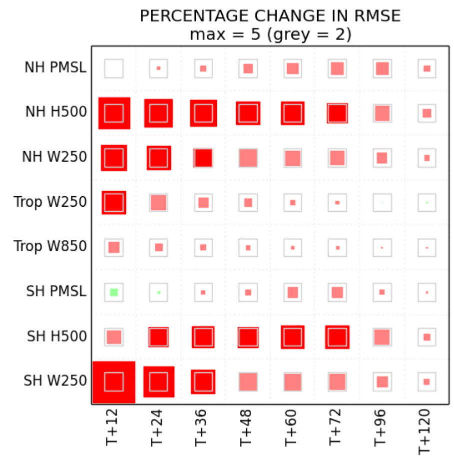
No AMV



No Scat



No GNSSRO



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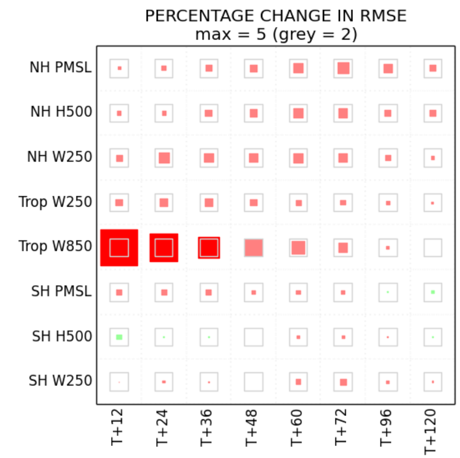

OSE Impact Summary

- All data denial experiments behave as expected
- Complimentarity
  - Radiances impact H500, PMSL
  - AMV/Scat winds impact winds (and H500)
  - Sonde main impact northern hemisphere
  - Radiances large impact in southern hemisphere
- Discrepancy
  - Scatwinds W850 in tropics, show opposite impact verifying against own analysis (-ive) vs. ECMWF analysis (+ive)

- Improved analysis of water vapour to make optimal use of temperature sounding channels