Assimilation of wind information from radiances: AMVs and 4D-Var tracing

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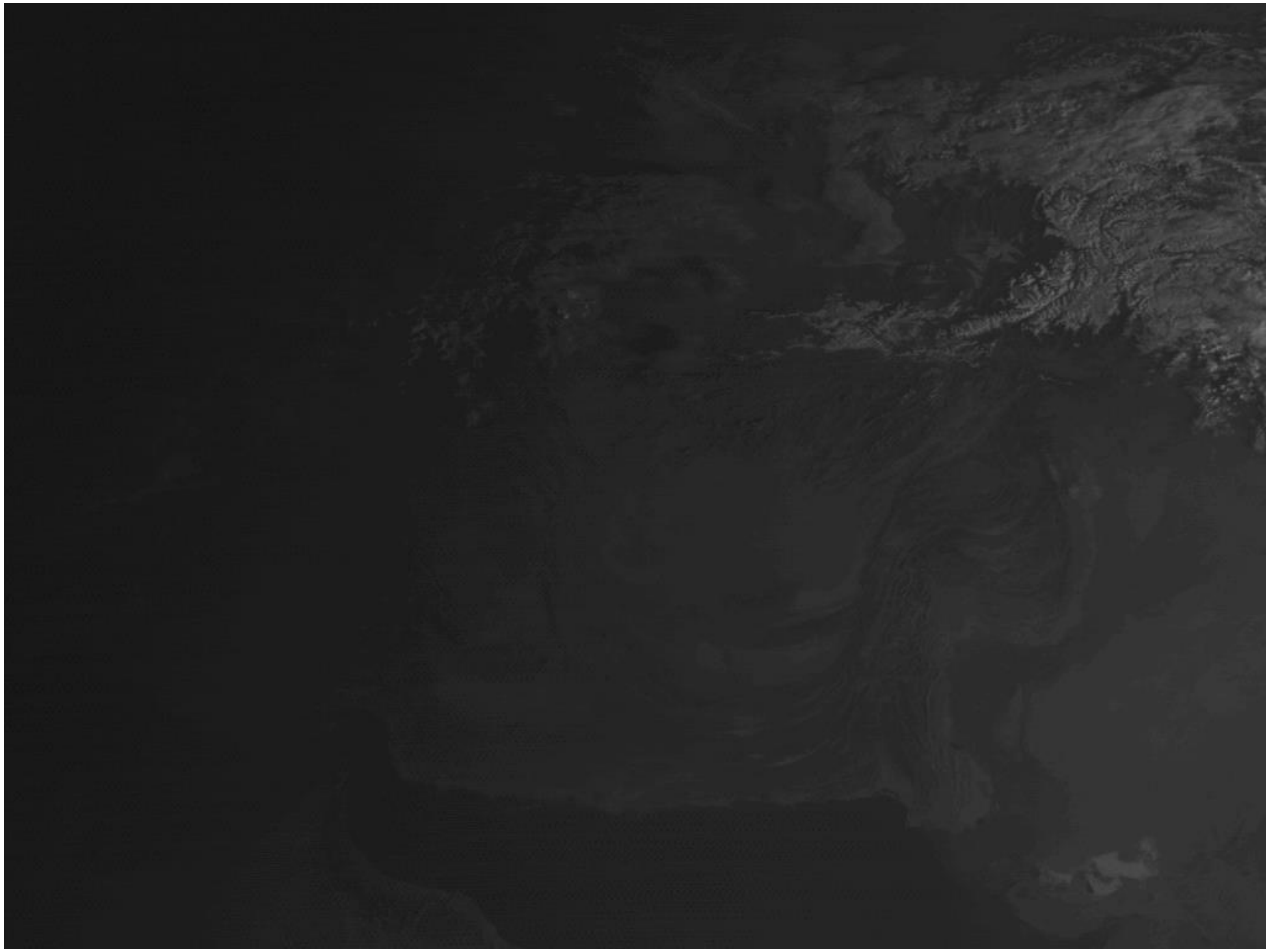
ECMWF Annual Seminar, September 2014

Where does the wind information come from?

In sequence of images – movement of clouds and moisture



Courtesy of EUMETSAT

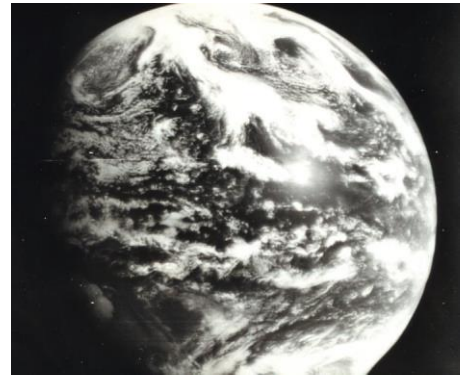
A journey through time

Atmospheric motion vectors are one of the original satellite observations – first produced routinely in the 1970s

TIROS-1 launch

Ted Fujita

Vern Suomi (seated)

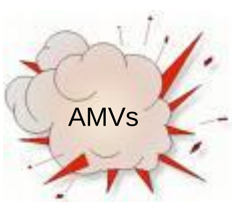


ATS-1 image

1960s	1970s	1980s	1990s	2000s

1960
First TIROS
polar imagery
shows potential

1966
ATS1
geostationary
spin-scan cloud
camera



1979
AMVs from 5
geostationary
satellites for FGGE

Increasing
- -automation
- -image resolution
- -image interval
- -channels (VIS, WV, CO2)

lead to increasing data volume and coverage (x30 in last 15yr)

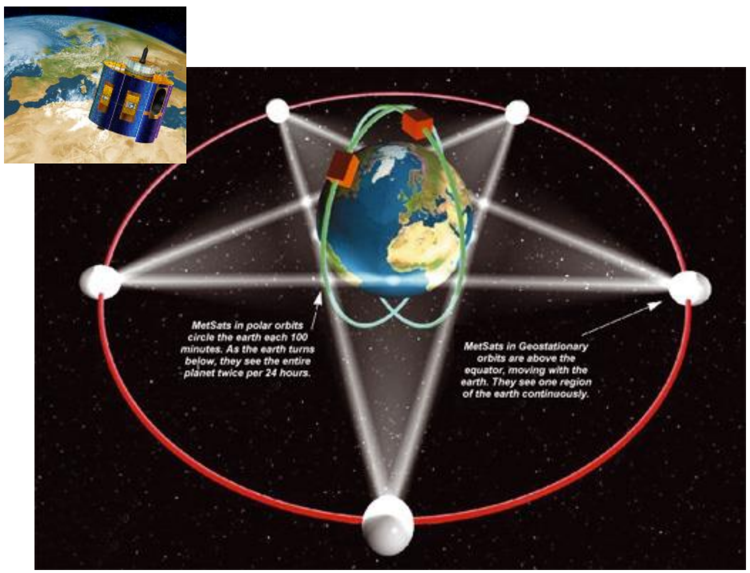
-quality indicators (from 1997)

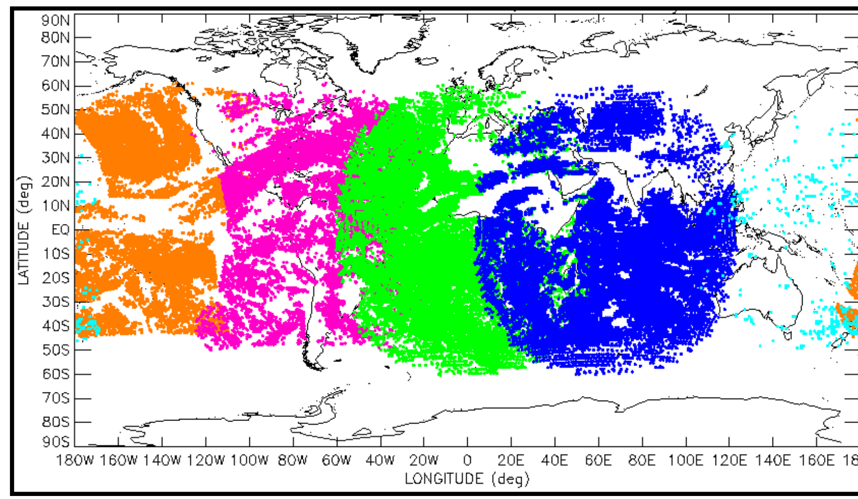
-improving target selection, tracking and height assignment

2002
Routine
production of
polar winds
from MODIS
imagery

Which satellites?

AMVs are produced from geostationary satellite imagery

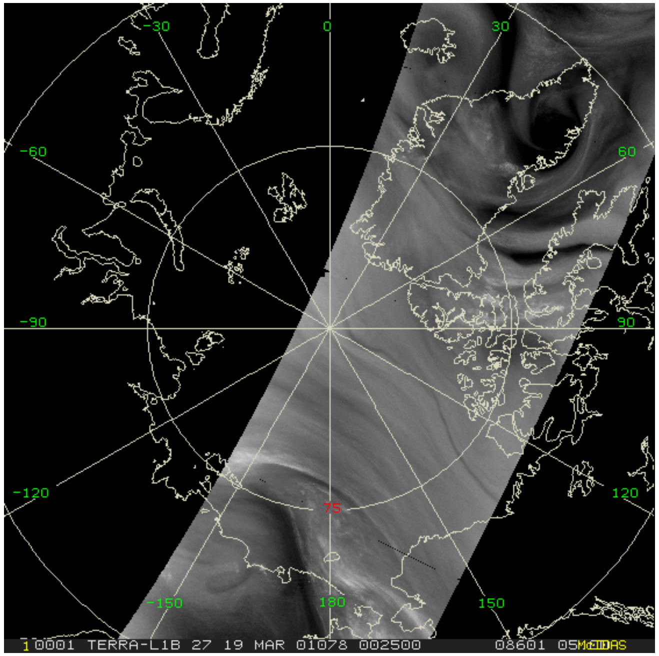


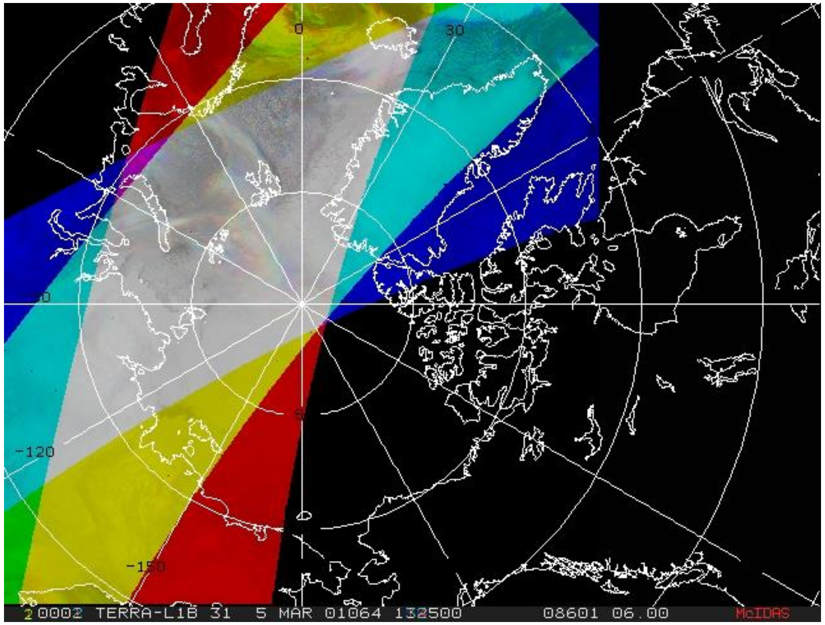


Provide coverage over tropics and mid-latitudes

Which satellites?

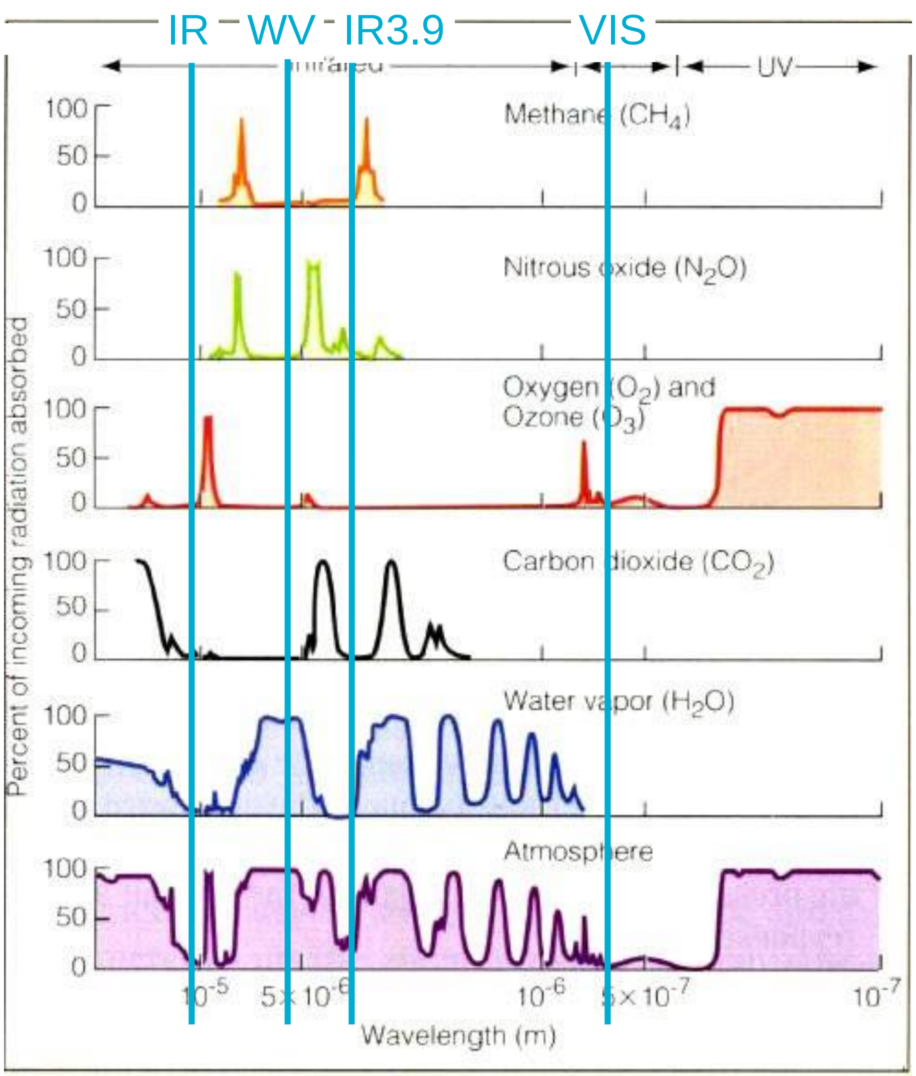
And since 2002 they have been routinely produced from polar-orbitting satellite imagery where the successive overpasses overlap (shown in white) in the polar regions.





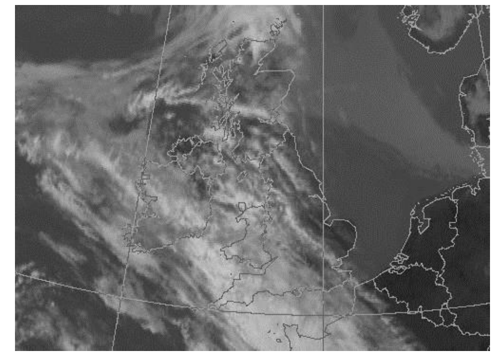
Pictures courtesy of Dave Santek, CIMSS

Channels



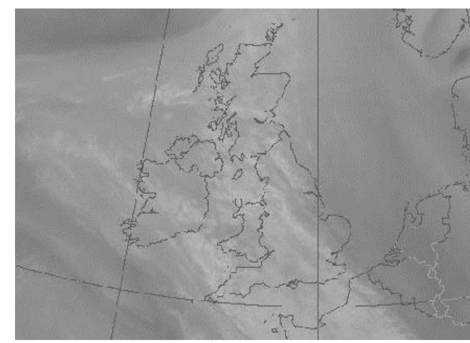
IR window ~ 10.8µm

clouds



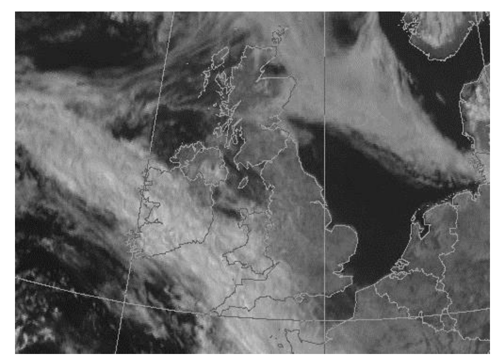
WV absorption~ 6.7µm

clouds and clear sky



VIS ~0.6µm

clouds



Who produces the AMVs?

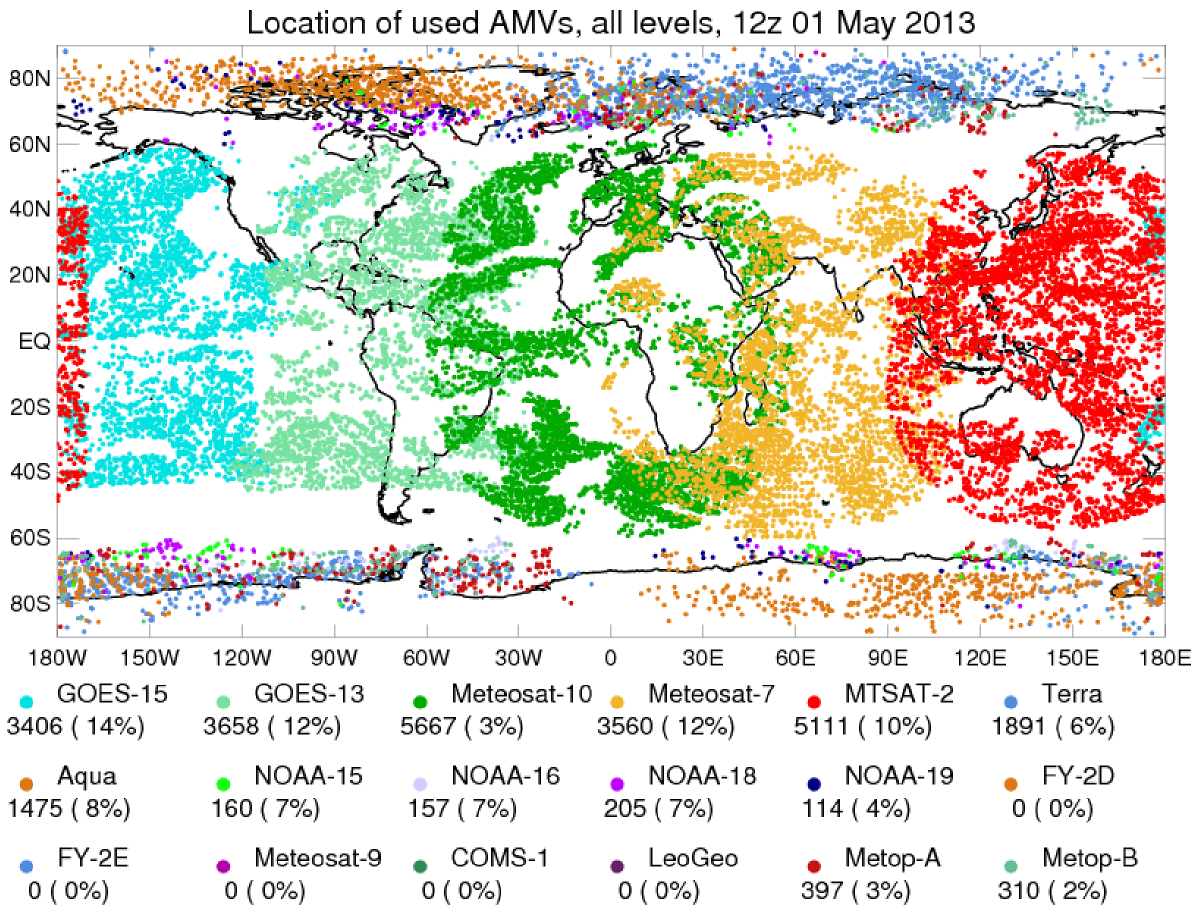
Currently produced by:

- EUMETSAT in Europe (Meteosat-10, Meteosat-7, Metop-A, Metop-B)
- NOAA/NESDIS and CIMSS in the USA (GOES-13, GOES-15, Aqua, Terra, NOAA-15, NOAA-18, NOAA-19, NPP)
- JMA in Japan (MTSAT-2)
- IMD in India (Kalpana, INSAT-3D)
- CMA in China (FY-2D, FY-2E)
- KMA in South Korea (COMS)

Geostationary satellites
Polar satellites

Coverage

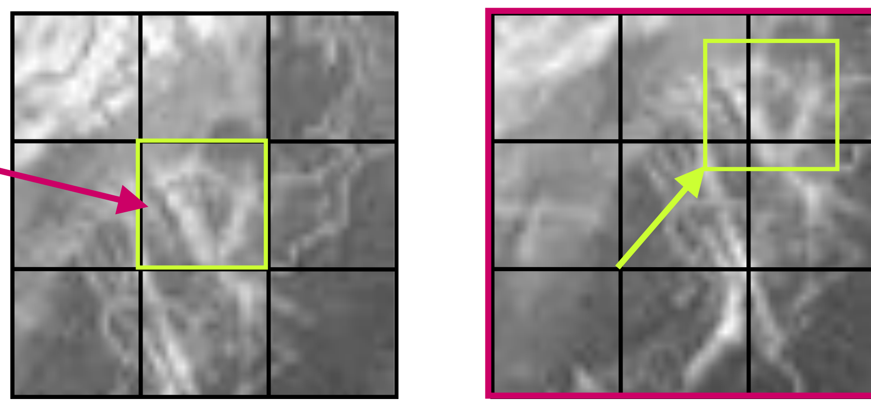
- Together get nearly global coverage – will say more later on filling the gaps....



most geostationary AMVs available hourly

How are AMVs produced?

1. Initial corrections (image navigation etc.)
2. **Tracking** - new location determined by best match of individual pixel counts of target with all possible locations of target in search area.



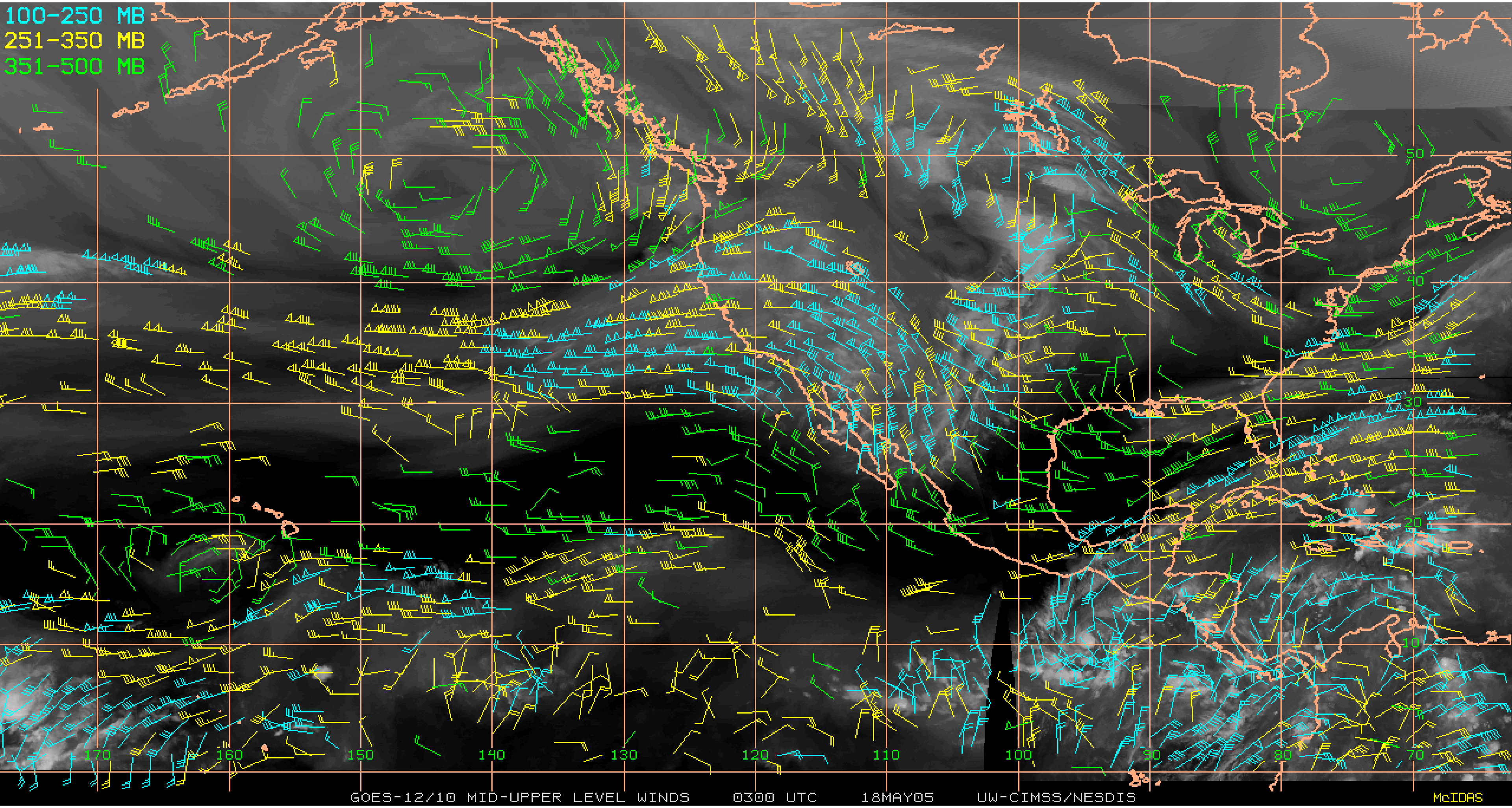
Normally repeat from image 2-> 3 to give a second vector for quality control

3. Assign a **height** to the derived vector

Schmetz & Nuret (1989) stated

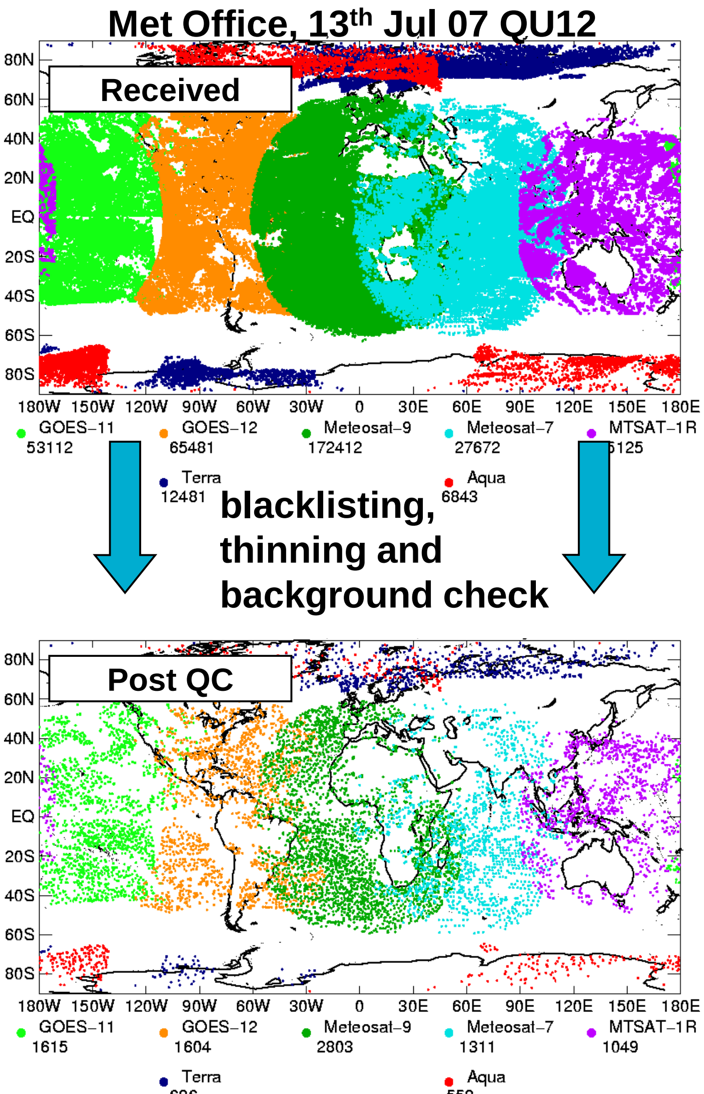
“The AMVs could only give an unbiased estimate of the winds if clouds were conservative tracers randomly distributed within and floating with the airflow. “

What does the data look like?



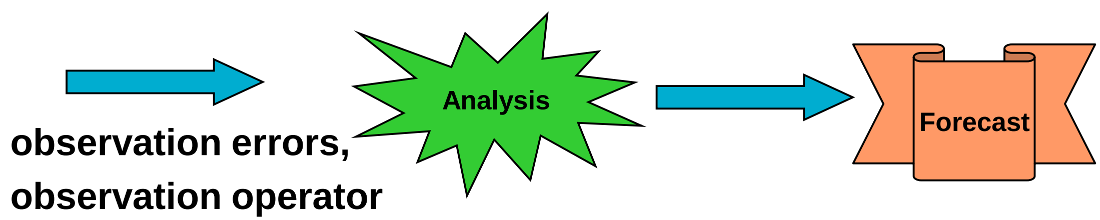
Real-time visualisation available from http://tropics.ssec.wisc.edu

AMV assimilation in NWP



- **Blacklisting**
  - QI thresholds
  - Spatial checks
  - Remove some satellite-channel combinations e.g. CSWV
- **Thinning**
  - One wind per 200 km x 200 km x 100 hPa x 2 hr box.
- **Background check**
  - Remove if deviates too far from background.
- **Observation errors**
- **Observation operator**

For more information see NWP usage pages at:
http://nwpsaf.eu/monitoring/amv/nwp.html



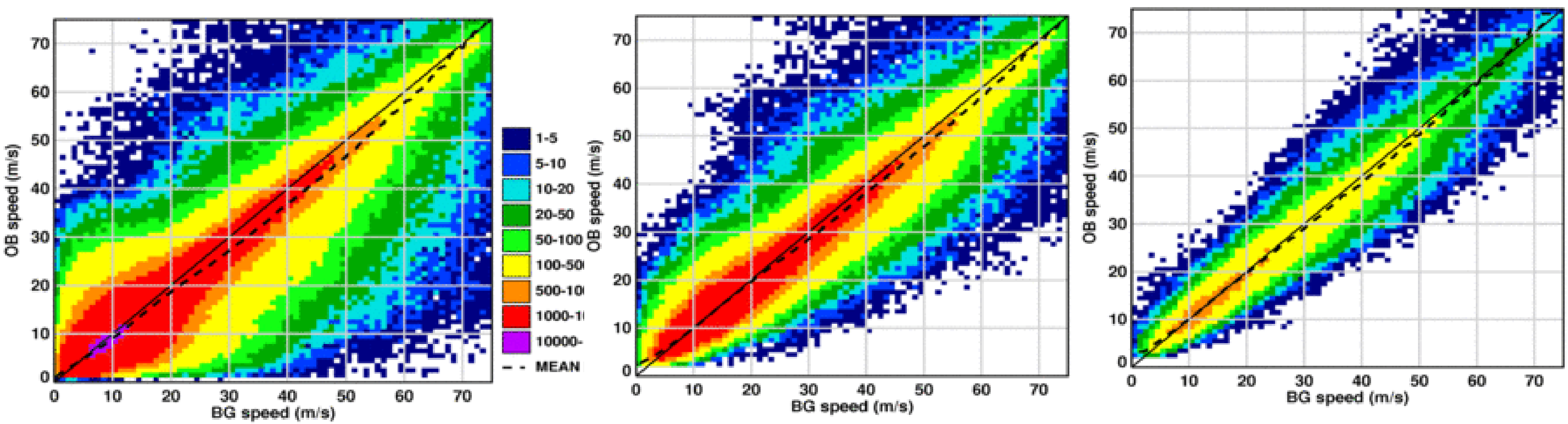
NWP quality control for AMVs

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

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

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

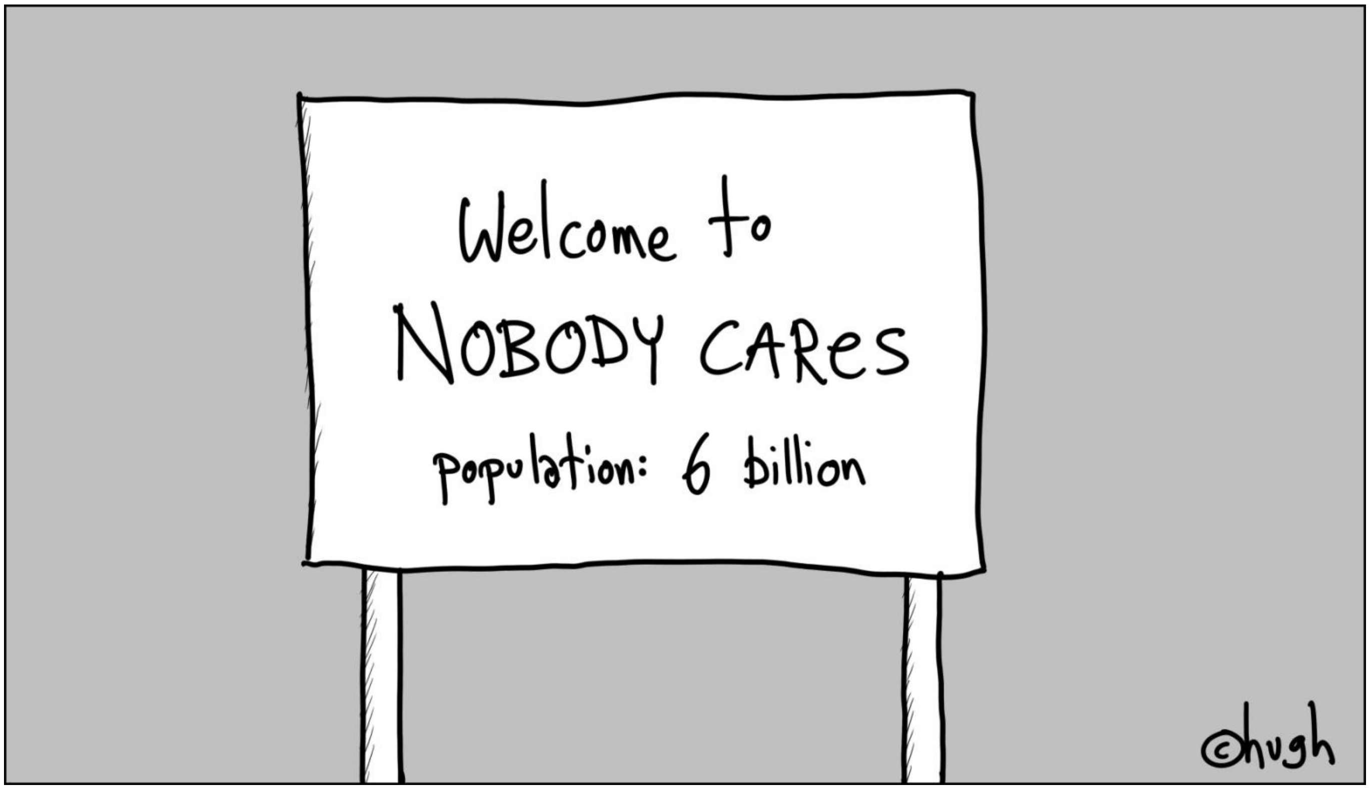
Used (161,247)
stdv = 4.2 m/s



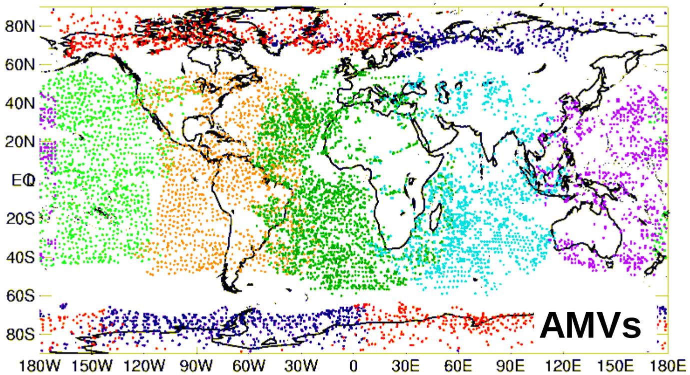
100% **55%** **7%**

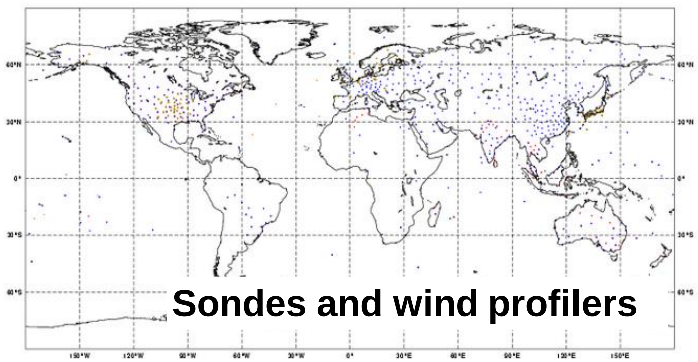
Assimilate only a small percentage of the data

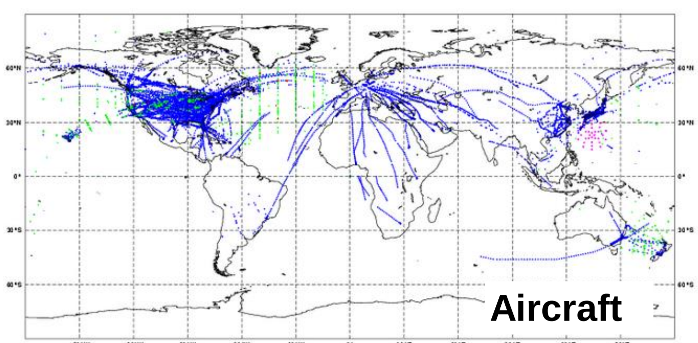
Why do we care?



Why do we care?







For best results, models require information on both the mass field and the wind field.

AMVs are the only observation type to provide good coverage of upper tropospheric wind data over oceans and at high latitudes.

For the AMVs each dot represents a single level wind not a wind profile

Coordinated Study of AMV Impact

Introduction

Two 6 week trial seasons

Period 1: 15 Aug – 30 Sep 2010, NH summer period, 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

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

Study coordinated by James Cotton (Met Office) and Christophe Payan (Meteo France)

(James Cotton)

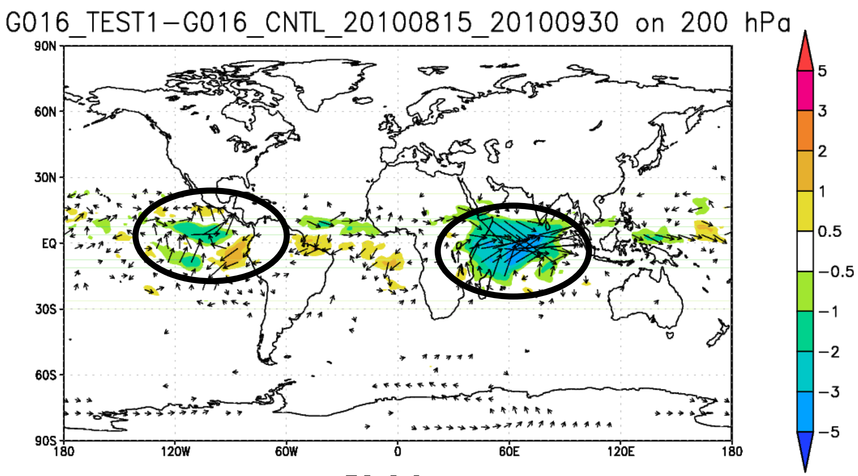
Coordinated Study of AMV Impact

Impact on mean wind analysis at 200/250 hPa

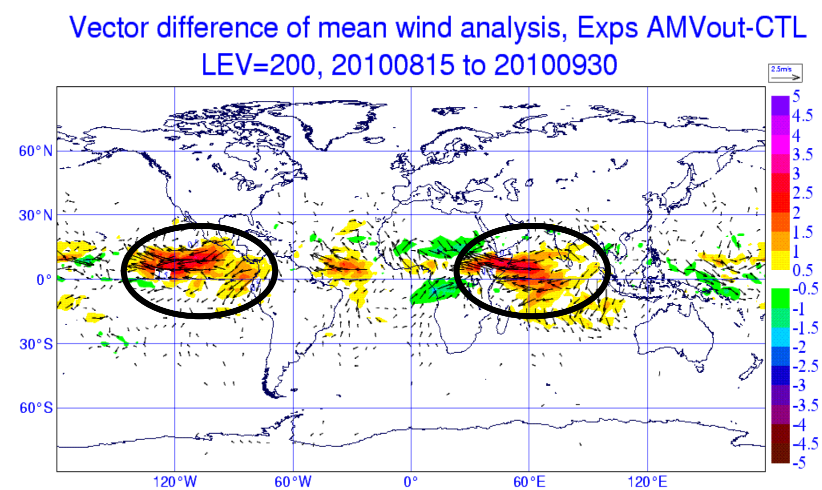
- Concentrated in tropics, particularly (i) Eastern Pacific and (ii) Indian Ocean
- Impact not consistent between centres e.g.

  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

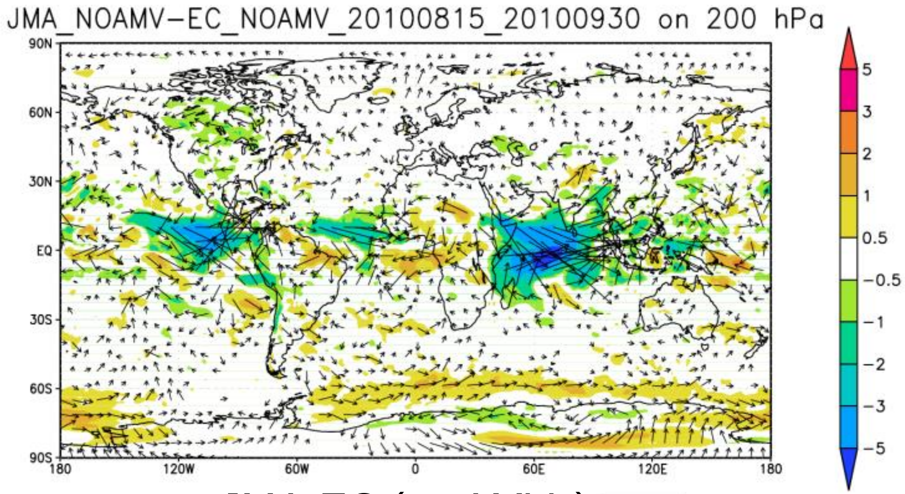
(James Cotton)

Coordinated Study of AMV Impact

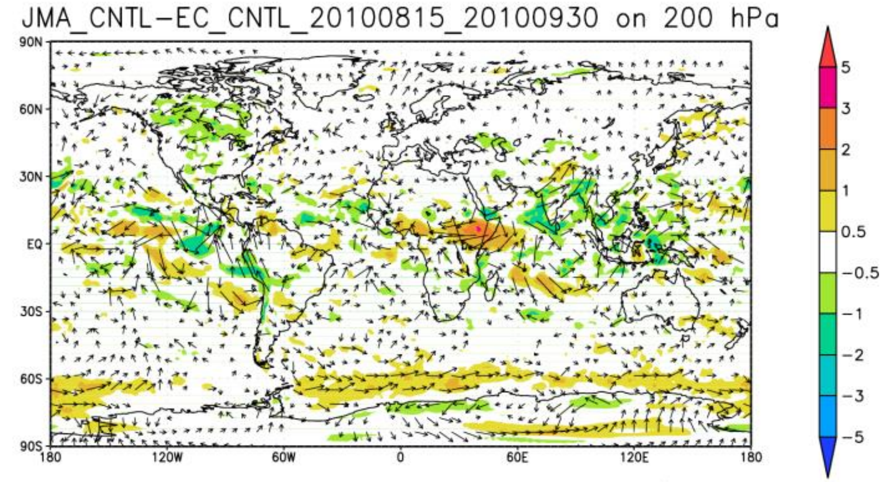
Impact on mean wind analysis at 200/250 hPa

Can we explain the different impacts in the tropics?

- Compare JMA and ECMWF wind analyses with and without AMVs



JMA-EC (no AMVs)



JMA-EC (with AMVs)

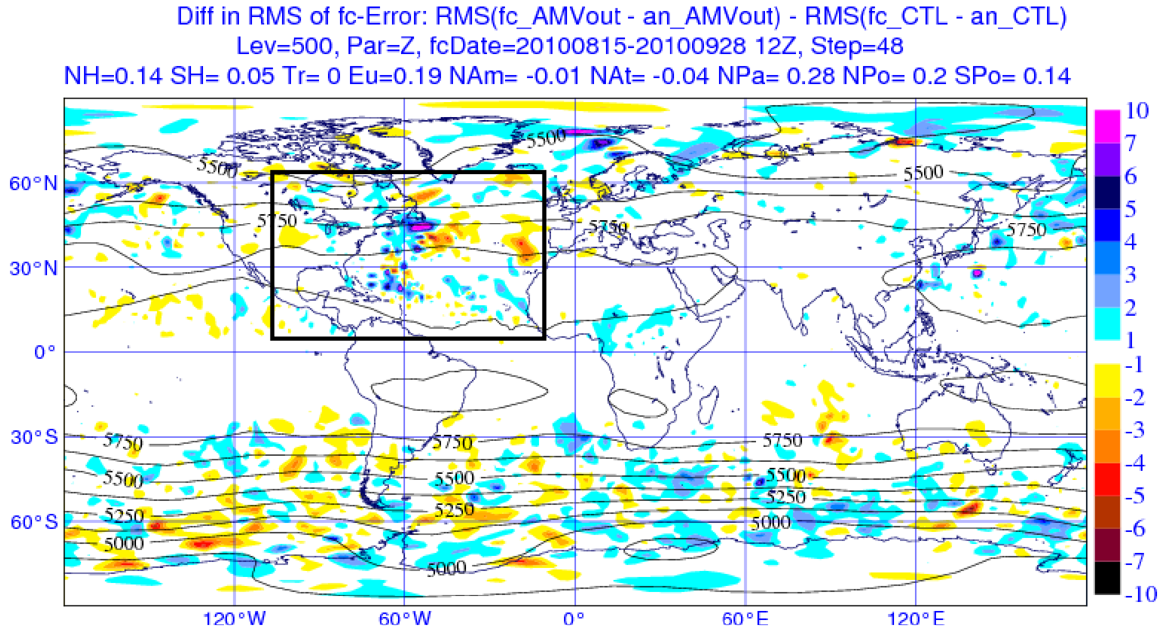
- Overall differences between ECMWF and JMA are significantly smaller in the experiments with AMVs than in the denial experiments
- The differences seen in the AMV denials are likely due to differences in the climatology of the forecast models of the centres
- AMVs act to bring the two systems in better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

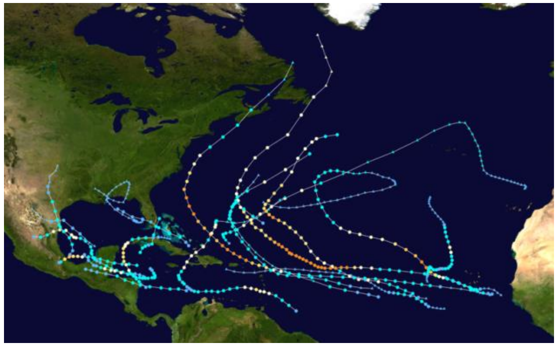
(James Cotton)

Coordinated Study of AMV Impact

Impact on 500 hPa geopotential height T+48 forecast errors (RMS)

- Overall impact rather positive
- Most widespread reductions in RMS found in the extra-topics and polar-regions (verification against own analysis)
- 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.





ECMWF

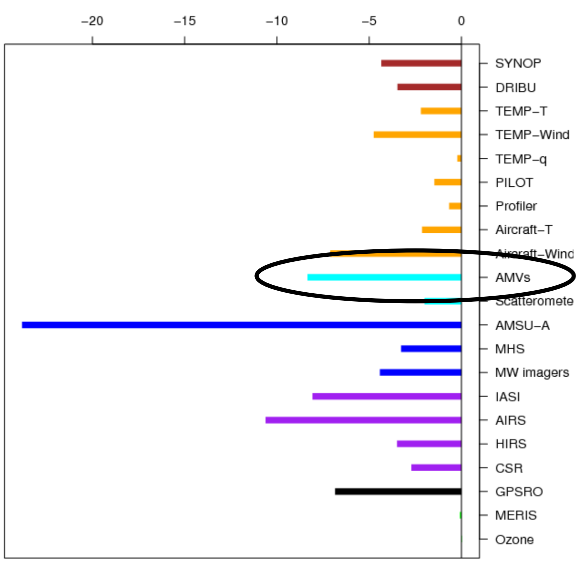
Blue/purple colours represent where the forecast RMS in the reference experiment (containing the AMVs) is smaller than in the denial experiment i.e. **positive impact**

(James Cotton)

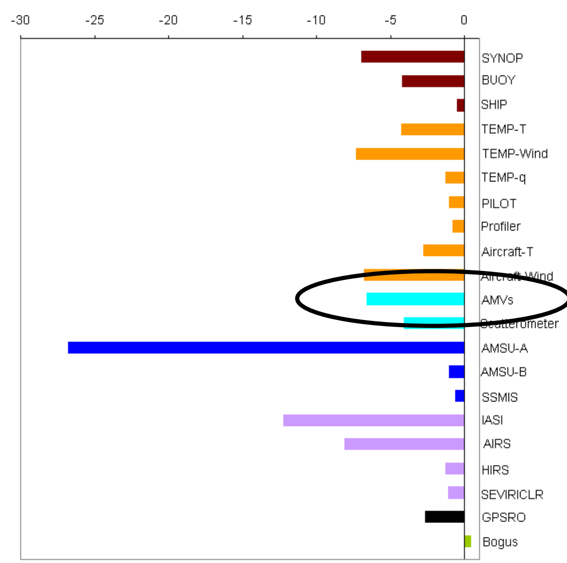
Coordinated Study of AMV Impact

Forecast sensitivity to observations (FSO)

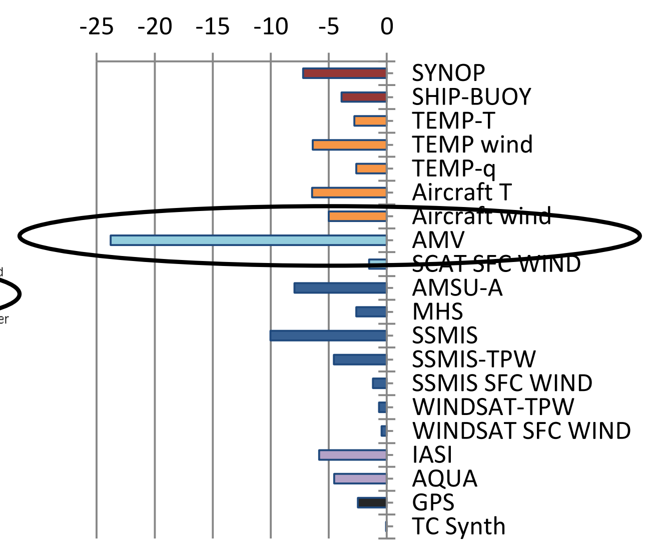
- Adjoint-based FSO method gives estimate of the contribution of each observation towards reducing the 24-hour forecast error
- Top level results agree fairly well for ECMWF, Met Office, MF – **AMV FSO of 7-11%**.
- Markedly different for NRL – AMV FSO of 23%. Due to differences in AMV assimilation (e.g.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



ECMWF



Met Office



NRL

(James Cotton)

Coordinated Study of AMV Impact

Conclusions

- Positive forecast impact across all NWP centres – especially in upper troposphere, demonstrated by fit to radiosonde profiles, time series of forecast error and FSO results.

- Big impact on the tropical mean wind analysis

- Bigger impact seen for centres using 3D-Var or fewer other observations, and for NRL whose FSO statistics show a different impact from several 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

- FSO statistics further indicate significant relative importance of AMVs in the global observing system

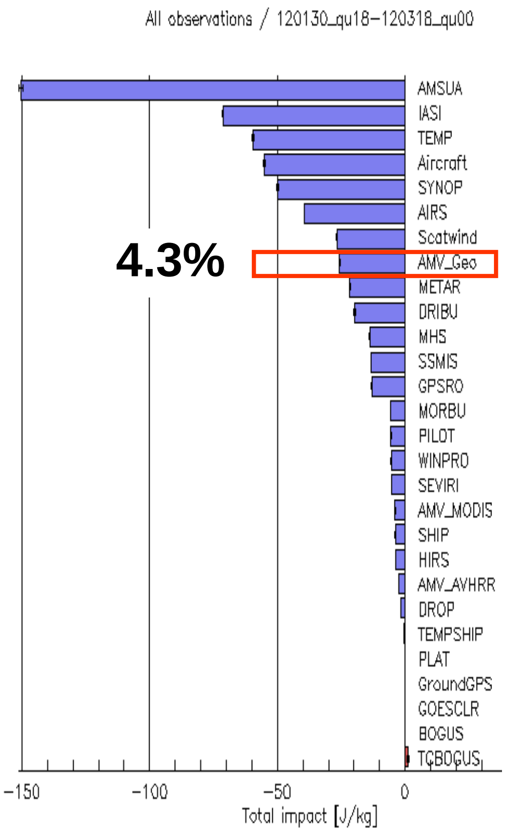
Final report at http://cimss.ssec.wisc.edu/iwwg/Docs/windsdenial-synthesisV1-1.pdf

(James Cotton)

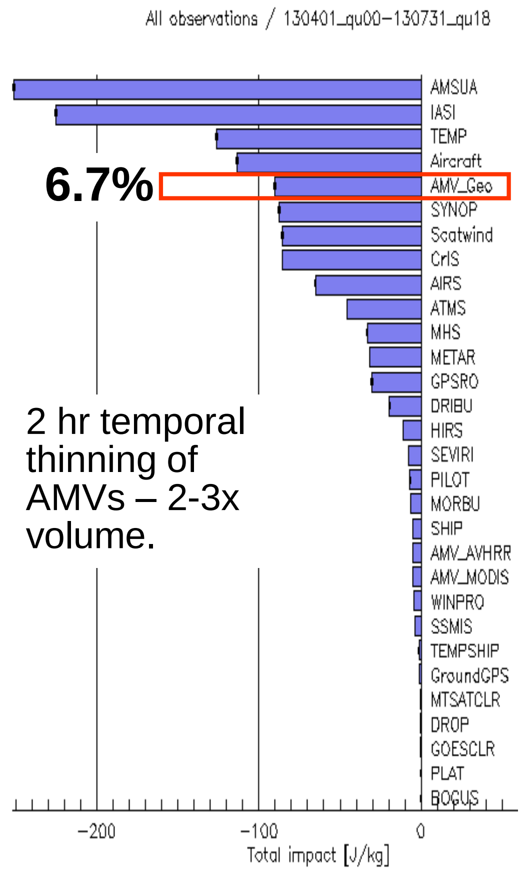
Impact on 24-hr forecast error - FSO

- Increasing FSO as increase AMV data assimilated at Met Office

Jan-Mar 2012

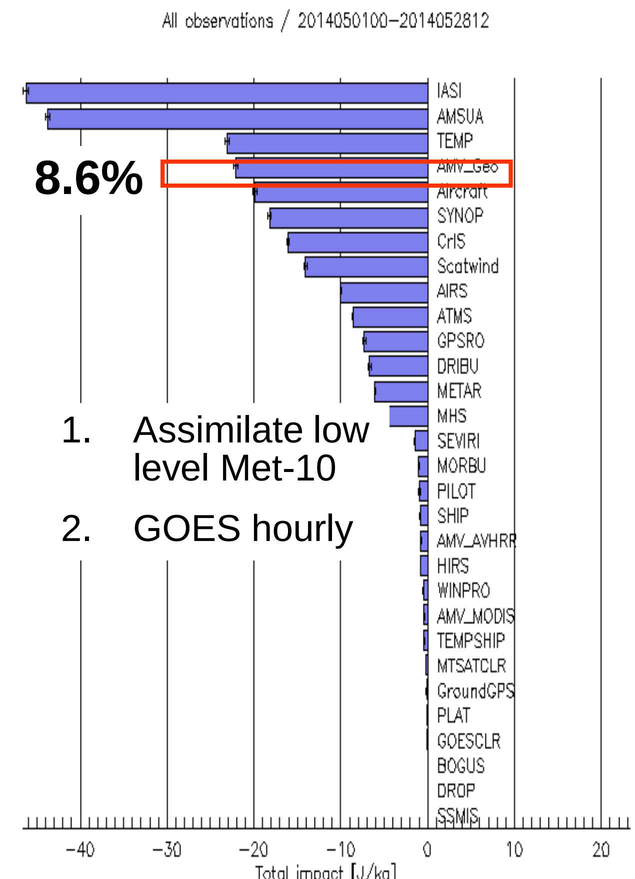


Apr-July 2013



2 hr temporal thinning of AMVs – 2-3x volume.

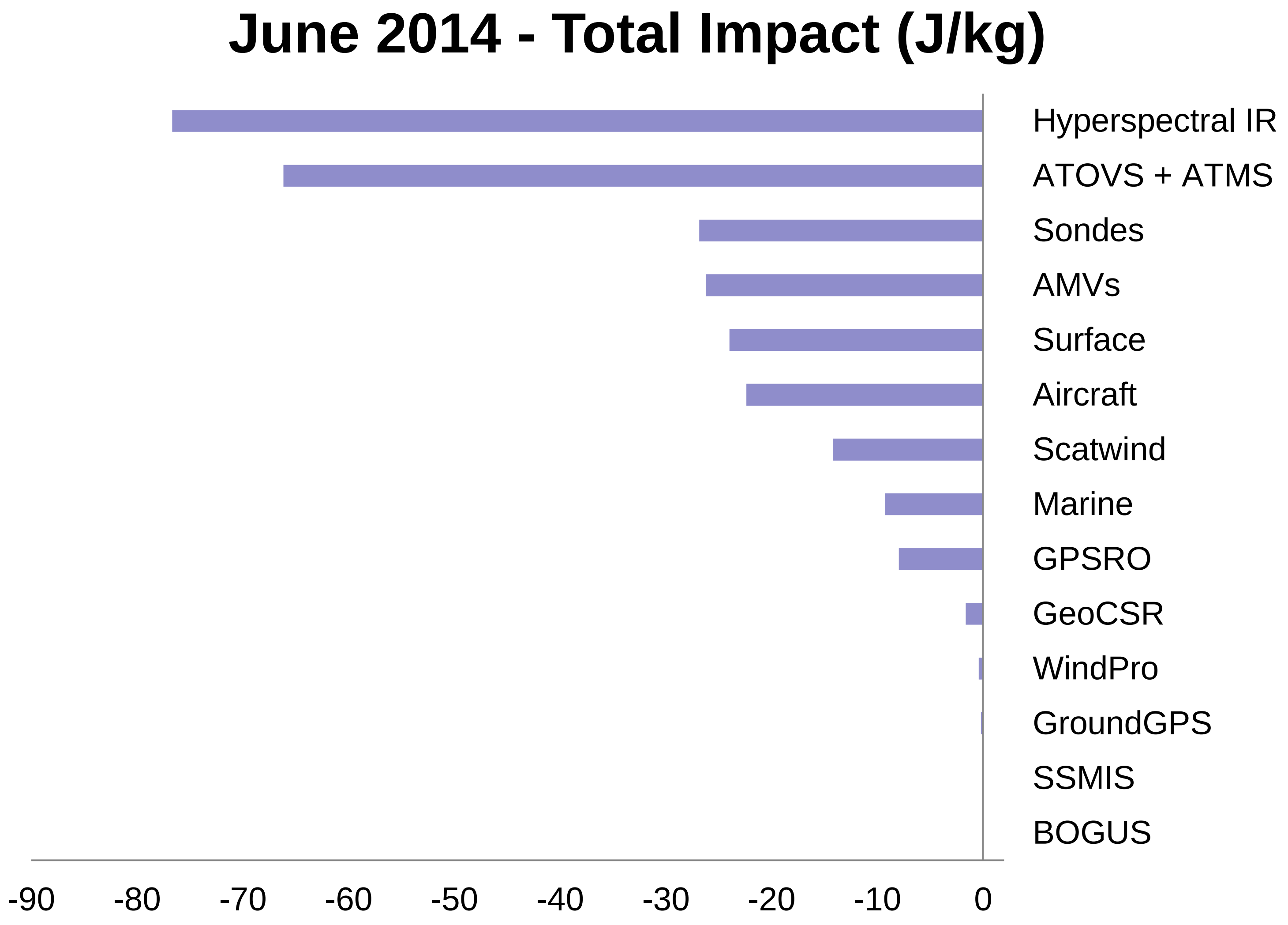
May 2014



1. Assimilate low level Met-10
2. GOES hourly

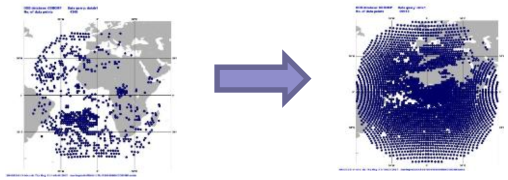
Contributions to the total observation impact on a moist 24-hour forecast-error energy-norm, surface-150 hPa (from Richard Marriot and James Cotton)

Impact on 24-hr forecast error - FSO

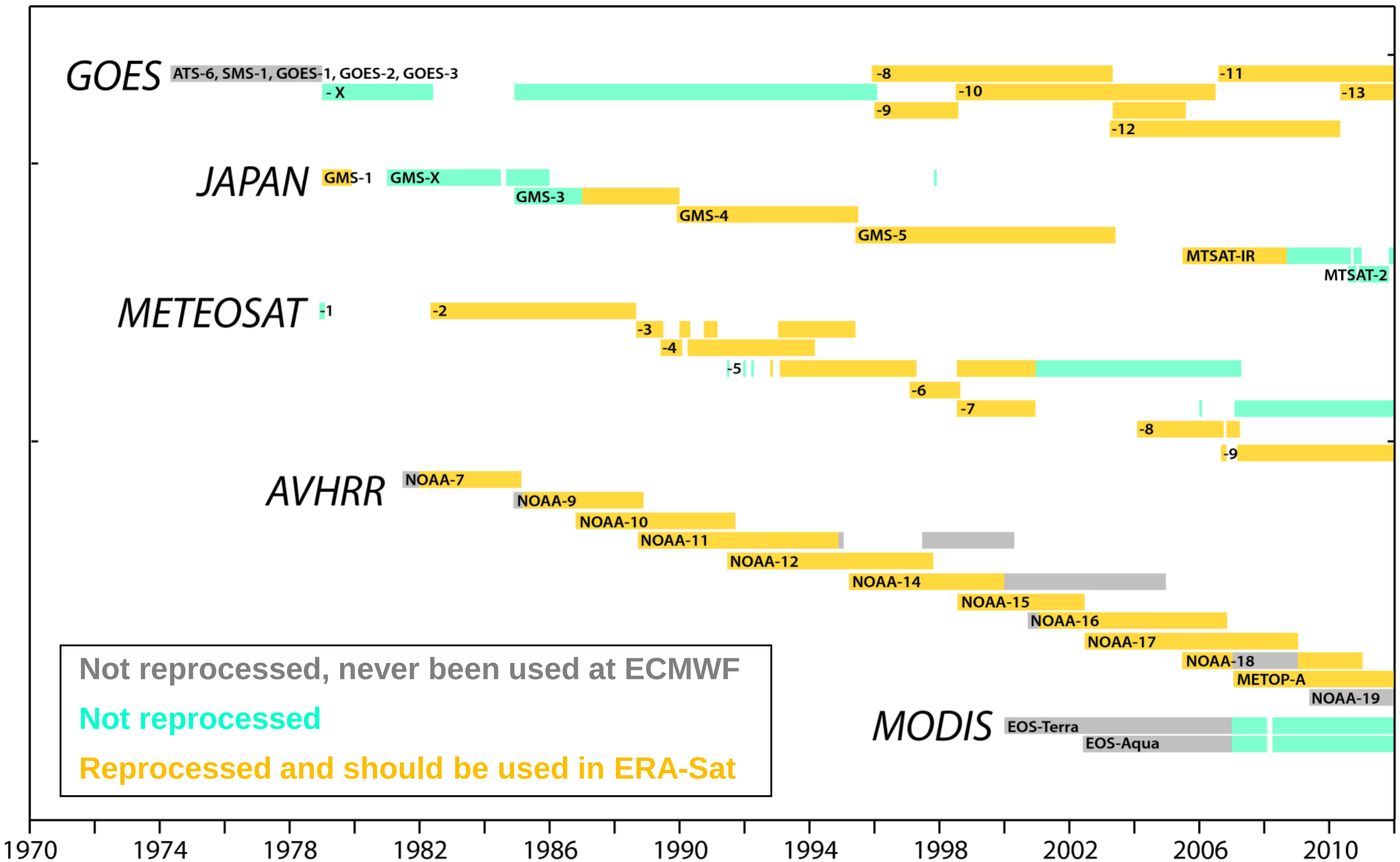


(James Cotton)

Reprocessed AMVs for reanalysis



Quality of reprocessed data is much improved.



Thanks to reprocessing efforts in the AMV community, a large amount of reprocessed AMV data are available

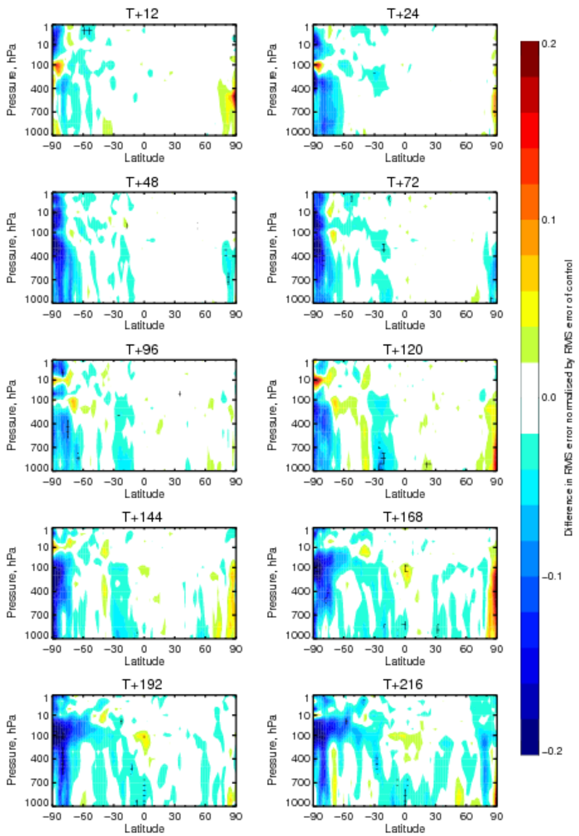
(Carole Peubey)

Reprocessed AMVs for reanalysis

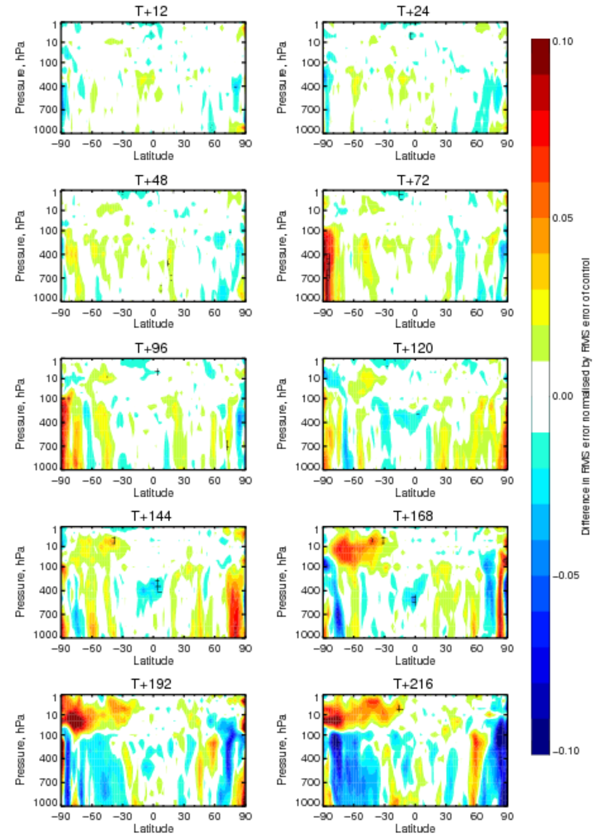
Met Office

Difference in forecast RMSE (VW) *BLUE= POSITIVE IMPACT*

1983: "NOAA7" *minus* "no NOAA7"



2009: "NOAA18" *minus* "no NOAA18"



→ Difficulty to get improvement over a dense observational network?

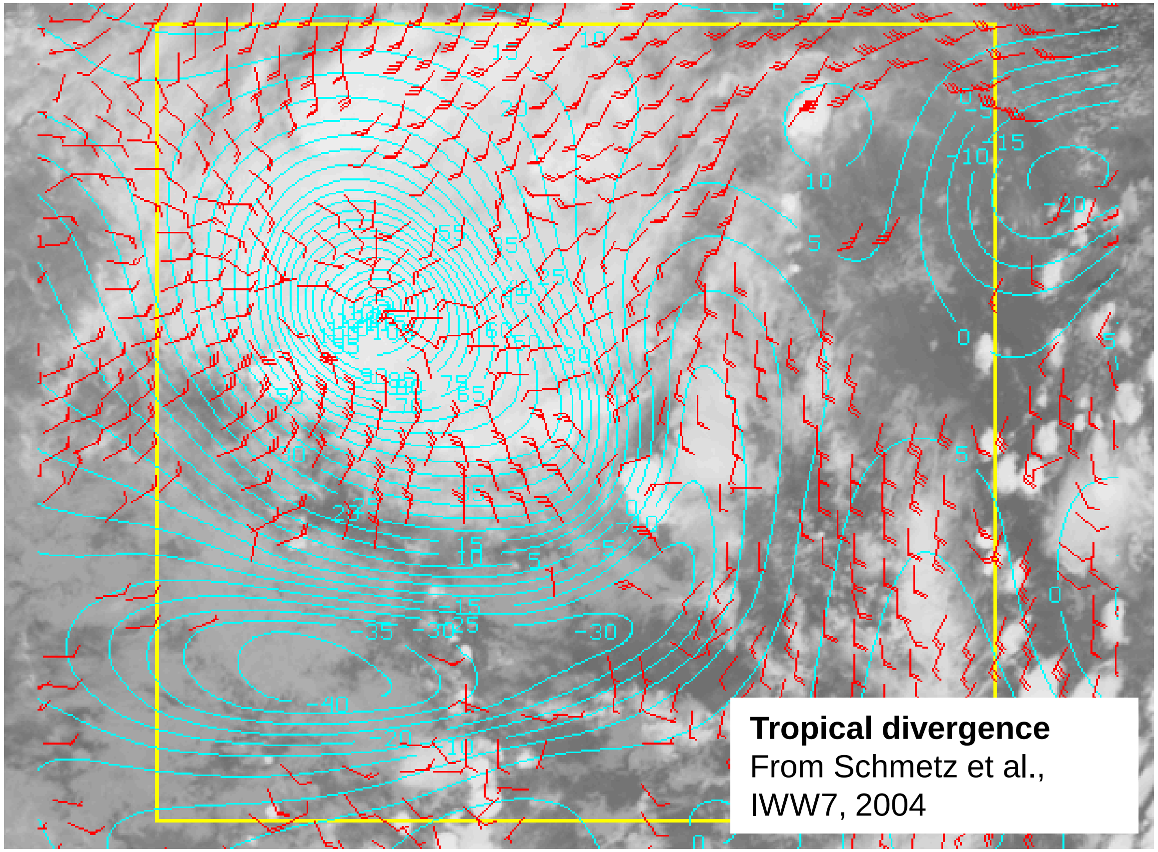
- Bigger impact seen for earlier datasets when fewer other observations available. Important to reprocess older datasets (e.g. Pre-1995 GOES).
- But still see good impact from more recent datasets e.g. GOES-11/12.

(Carole Peubey)

Met Office

Other uses of AMVs

AMVs can be used either directly or by deriving fields including vorticity and divergence for use in nowcasting, validation/verification and climate studies.



Tropical divergence
From Schmetz et al., IWW7, 2004

Summary of why we care

1. Access to information on mass and wind field is important.
2. AMVs provide global wind coverage and can be the only source of tropospheric wind data over some areas of ocean and at high latitude
3. Positive impact on forecast accuracy
4. Can be useful for improving tropical cyclone track forecasts
5. Useful for climate research primarily as input to reanalyses

Recent advances and challenges

1. Understanding the errors
2. Height assignment
3. Observation errors
4. Closing the gap
5. High resolution winds

International Winds Working Group (IWWG)

WORK TOGETHER

IWWG - formal working group of CGMS - forum to discuss and coordinate research and developments.
Biennial Workshops, IWW12 held June, 2014 in Copenhagen, Denmark

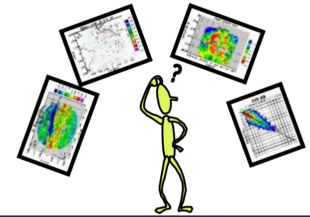
Key Collaborative Projects

1. NWP SAF analysis reports of monthly O-B monitoring (every 2 years)
2. NWP winds impact study (2011-12)
3. Inter-comparison of AMV derivation schemes (1. 2006, 2. 2012-14)
4. Simulated data studies (ECMWF - 2011-12, University of Reading – 2011-14)
5. Access to portable AMV derivation software (via NWC SAF) to support research efforts
6. High resolution winds wiki page

Web page: **http://cimss.ssec.wisc.edu/iwwg/iwwg.html**

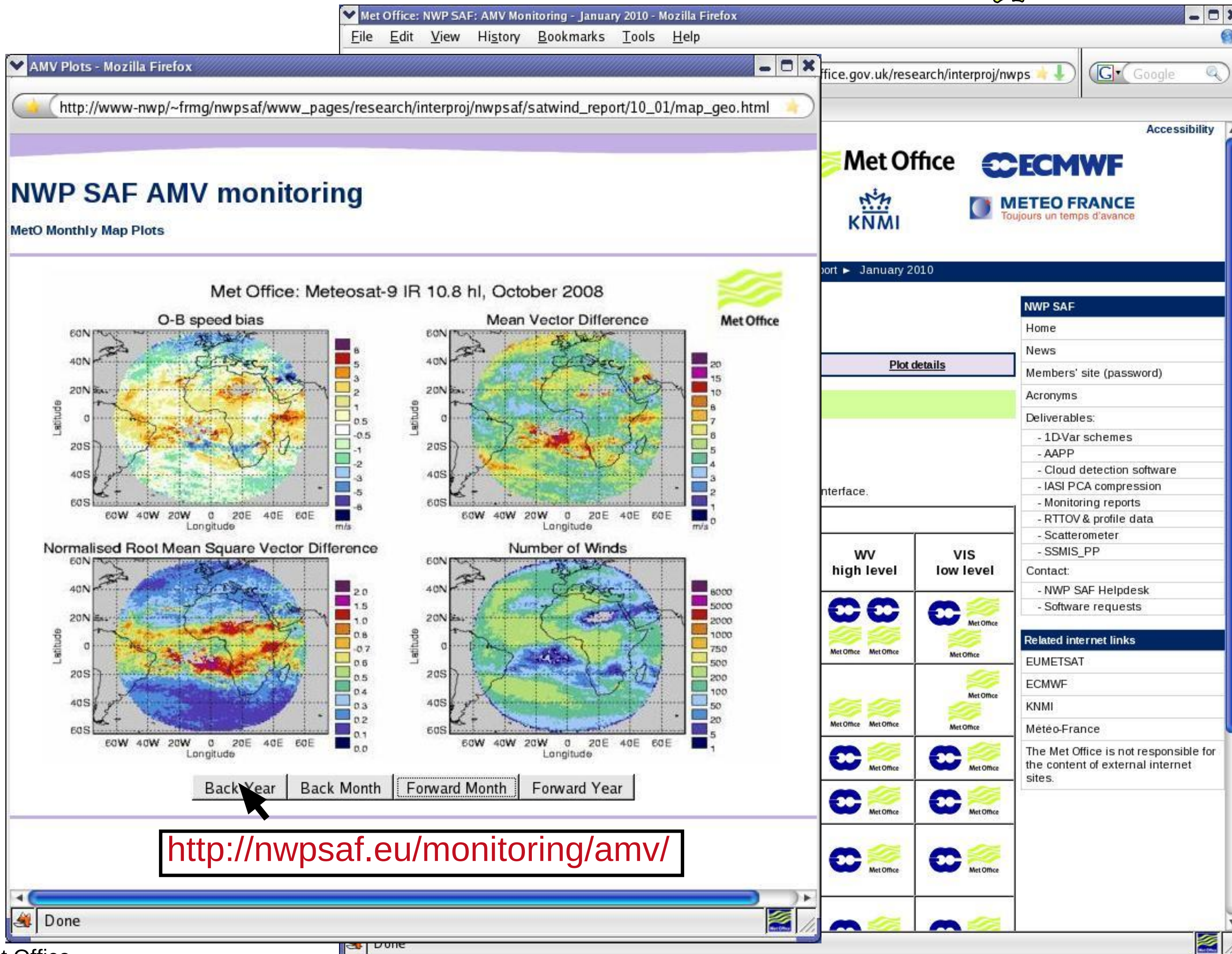
1. Understanding the errors

NWP SAF AMV Monitoring



AMVs have complicated errors.

Rolling 3 year archive of monthly O-B monitoring plots (Met Office and ECMWF)



(James Cotton)

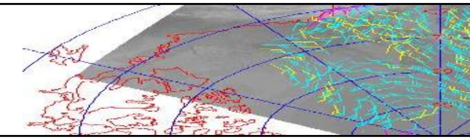
1. Understanding the errors

NWP SAF AMV Monitoring – Analysis Reports

O-B plots versus Met Office and ECMWF backgrounds - attempt to separate error contributions:

Differences suggest dependency on model error

Similarities suggest problems with AMVs (or shared model errors)

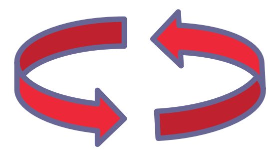


28 datasets, 2 NWP, 4 plot types, separated by channel, height... **= LOTS of plots!**

To exploit this resource requires a thorough investigation – *Analysis Reports*

- Published every 2 years
- Core is record of features identified in the monitoring
- Attempt to diagnose the cause of observed differences
- Use to improve AMV derivation and treatment in NWP models

Understand



Improve

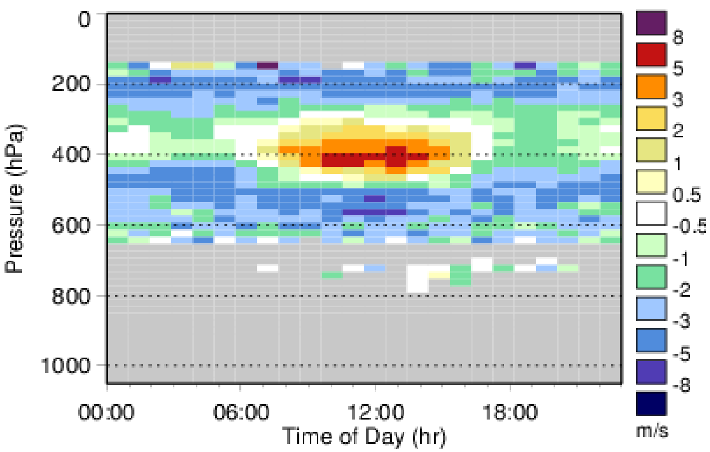
To investigate use:

- Plots of O-B statistics
- Comparisons to model best-fit pressure
- Comparisons with other cloud top pressure products (e.g. MODIS, Calipso …).
- Analysis of AMVs overlain on imagery

Met Office

1. Understanding the errors

NWP SAF AMV Monitoring – Analysis Report example

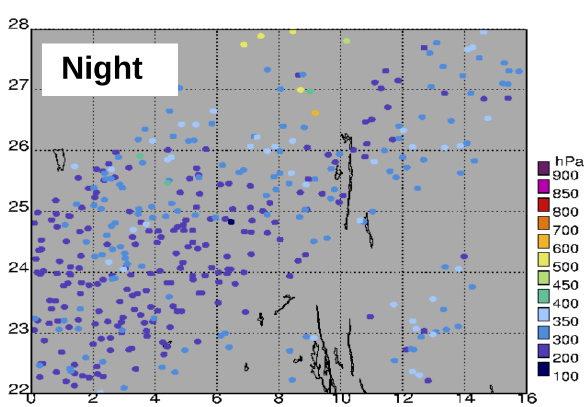


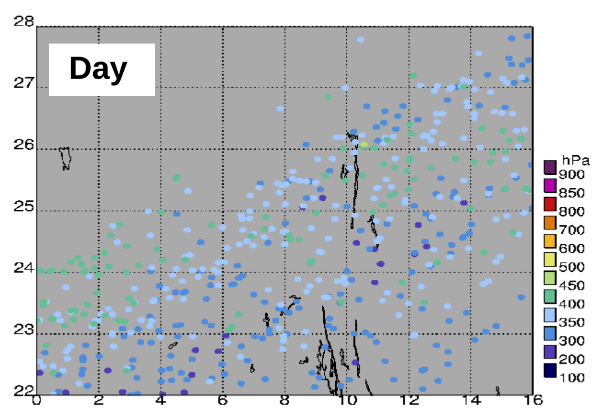
Hovmöller plot of O-B speed bias by time of day for Meteosat-9 IR 10.8 AMVs, Feb 2009 (HA=CO_2 slicing)

- Fast bias localised at ~400 hPa below the sub-tropical jet over the Sahara at 20-30N
- Diurnal pattern – present only during daytime
- Assigned heights are higher during night-time, more consistent with other cloud top pressure products and model best-fit pressure.

What is causing bad heights during daytime?

- *Possibly due to inadequate representation of diurnal temperature range of desert surface.*
- *Likely due to interpolation between T+12 and T+18 forecasts. Recommend - use 3 hour (or better) intervals*





 Meteosat-9 IR 10.8 AMV height assignment for (a) 2100-0300 UTC and (b) 0900-1500 UTC on 16 February 2009

2. Height assignment

Height assignment thought to be biggest source of error

AMV height errors can be due to:

i) Choice of pixels to use for height assignment

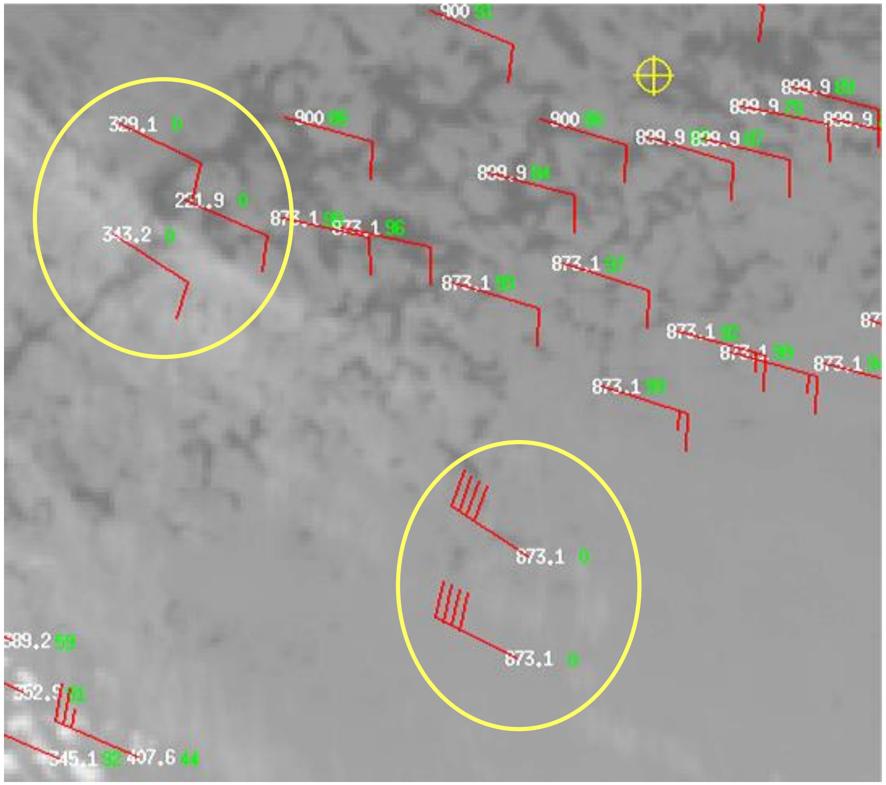
ii) Appropriateness of using cloud top or cloud base estimates

→ AMV specific problems

iii) Limitations of cloud top/base pressure methods — Can learn from cloud community

2. Height assignment

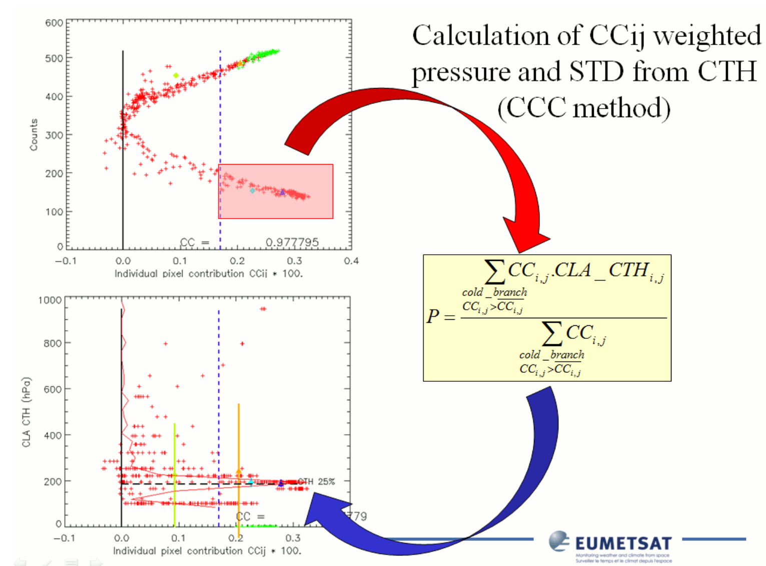
i. Choice of pixels – what can go wrong….



Example courtesy of Jörgen Gustafsson, EUMETSAT

Vector is derived by tracking a target that contains many pixels

CCC approach



Pixel contribution to the cross correlation coefficient, CCij, is used to select the pixels that contribute most to the tracking

Borde et al, 2014, JAOT, 31, 33-46

2. Height assignment

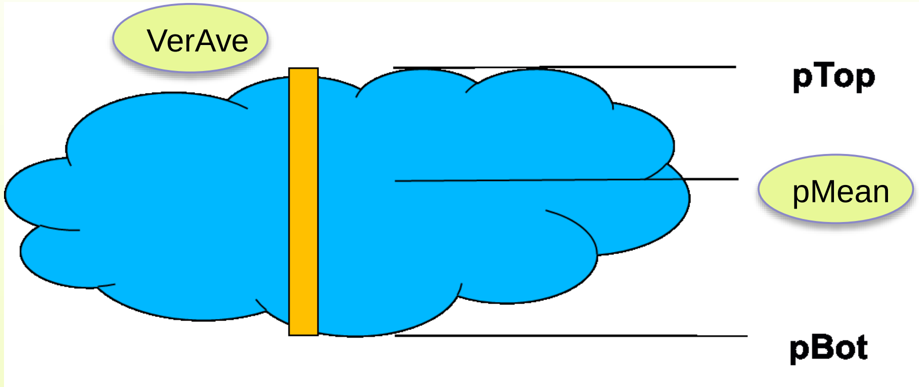
ii. Level or layer

Are the AMVs representative of the motion of the cloud top, cloud base, some level within the cloud or should they be treated as layer winds?

Several recent studies aimed to investigate this problem…

Folger & Weissman, 2014, JAMC
Lean et al., 2014
Salonen, IWW12 talk
Hernandez-Carrascal & Bormann, 2014, JAMC, 53, 65-82
Velden & Bedka, 2009, JAMC, 48, 450-463
Weissman et al., 2013, JAMC, 52, 1898-1877

Model simulation framework - derive AMVs from sequences of images simulated from high-resolution model fields. “Truth“ is known. Comparison of derived AMVs with model wind and cloud field allows better characterisation of AMVs.



pMean – weighed mean of model levels within the cloud, weights proportional to ice (or liquid water) content.

Sometimes clouds are deep: variants **pMCap**, **VerAveCap** – capped at 100 hPa

Locations are independent of pressure assigned during derivation.

From Hernandez-Carrascal IWW12 talk

2. Height assignment

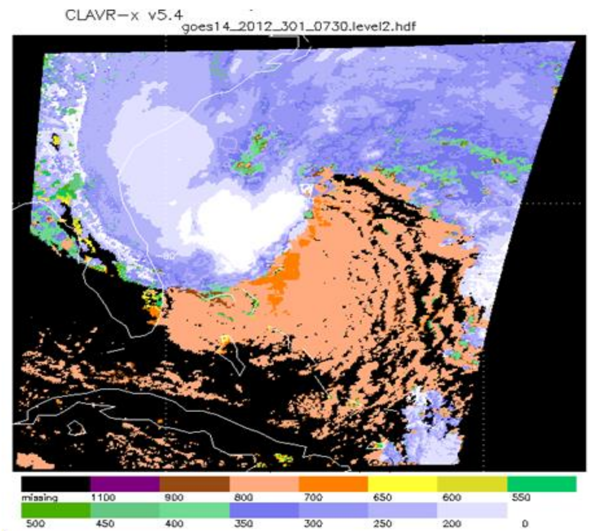
iii. Cloud top pressure method

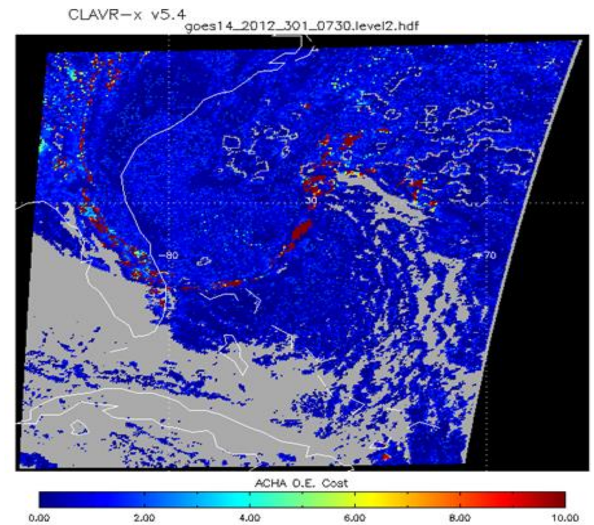
i) Choice of pixels to use for height assignment
ii) Appropriateness of using cloud top or cloud base estimates
} AMV specific problems

iii) Limitations of cloud top/base pressure methods – learn from cloud community

Increasingly moving towards direct use of pixel-based cloud schemes developed by cloud community

- Benefit from latest developments
  - 2-layer cloud schemes *(e.g. Watts et al, 2011, Geophys. Res.)*
  - better handling of heights of cloud edges *(see below)*
- Information on height error and cost – useful for identifying where height assignment is more problematic





Cloud height retrievals tend to fail near cloud edges – often where AMVs are located.

Cirrus cloud heights vary little over large spatial scales, can use retrievals for thicker cloud to constrain heights of thinner cloud in same region.

From talk by Andrew Heidinger, IWW12 on GOES-R methodology

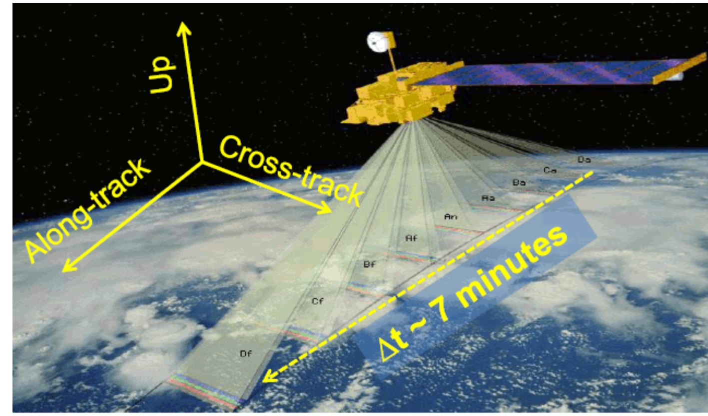
2. Height assignment

iii. Cloud top pressure method

An alternative approach – stereo heights

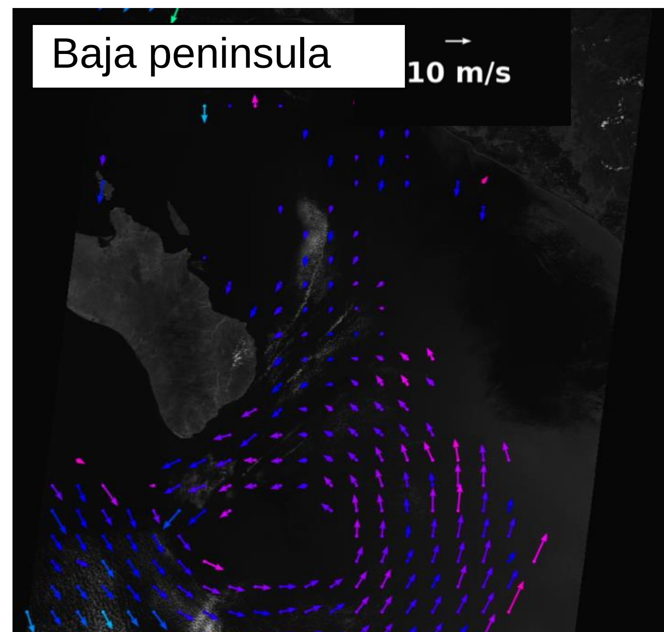
MISR - multi-angle radiometer on polar platform. Similar derivation to traditional AMVs, but use stereo height assignment – NRT data just released

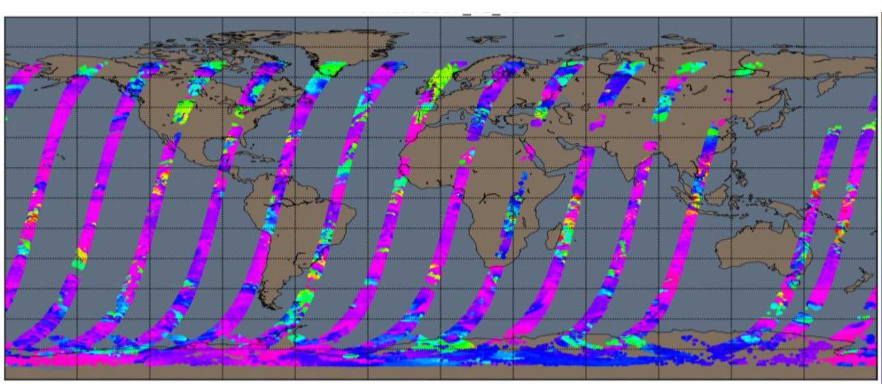
- Improved pixel resolution (275 m,17.6 km target size) - capture rapidly evolving scenes (eye of hurricane)
- DWD and NRL shown benefit in NWP despite narrow swath.



Follow-on MISR missions have been proposed

Potential to use stereo heights from Sentinel-3 and dual-GEO





Images from Kevin Mueller's talk, IWW12, 2014

3. Observation errors

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 Error² + Error in u/v due to error in height²)

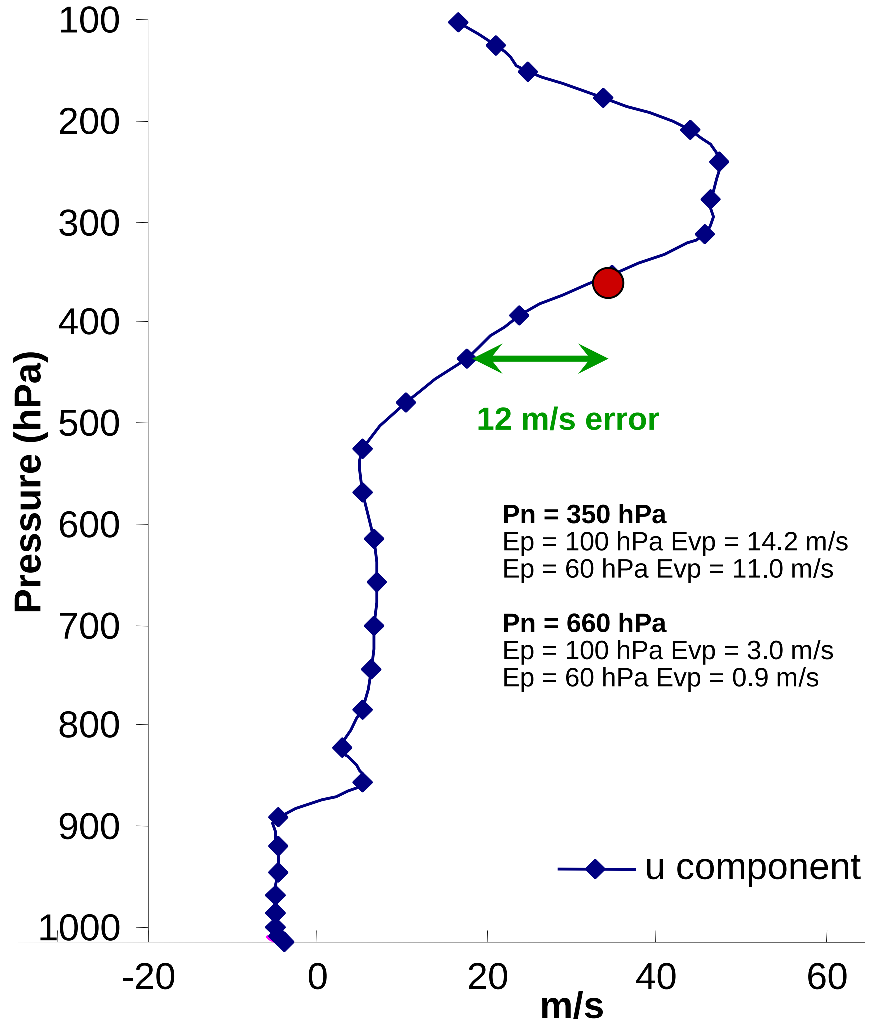
For this we need an estimate of:

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

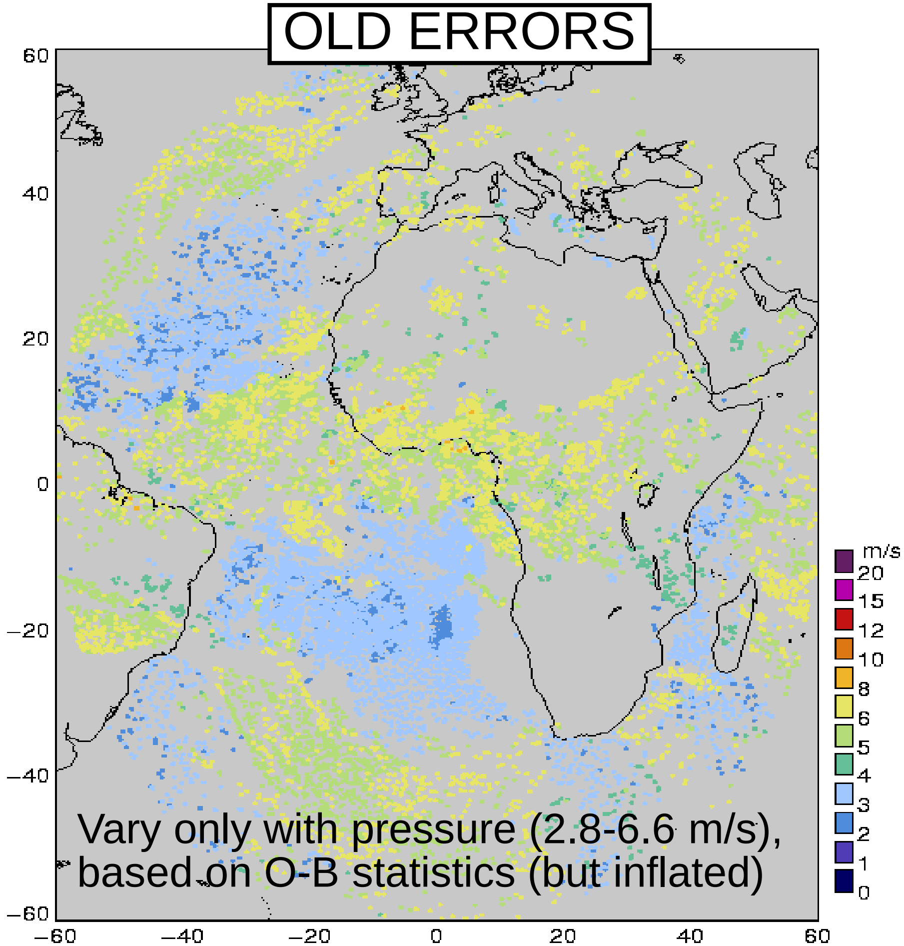
Ideally from data producers

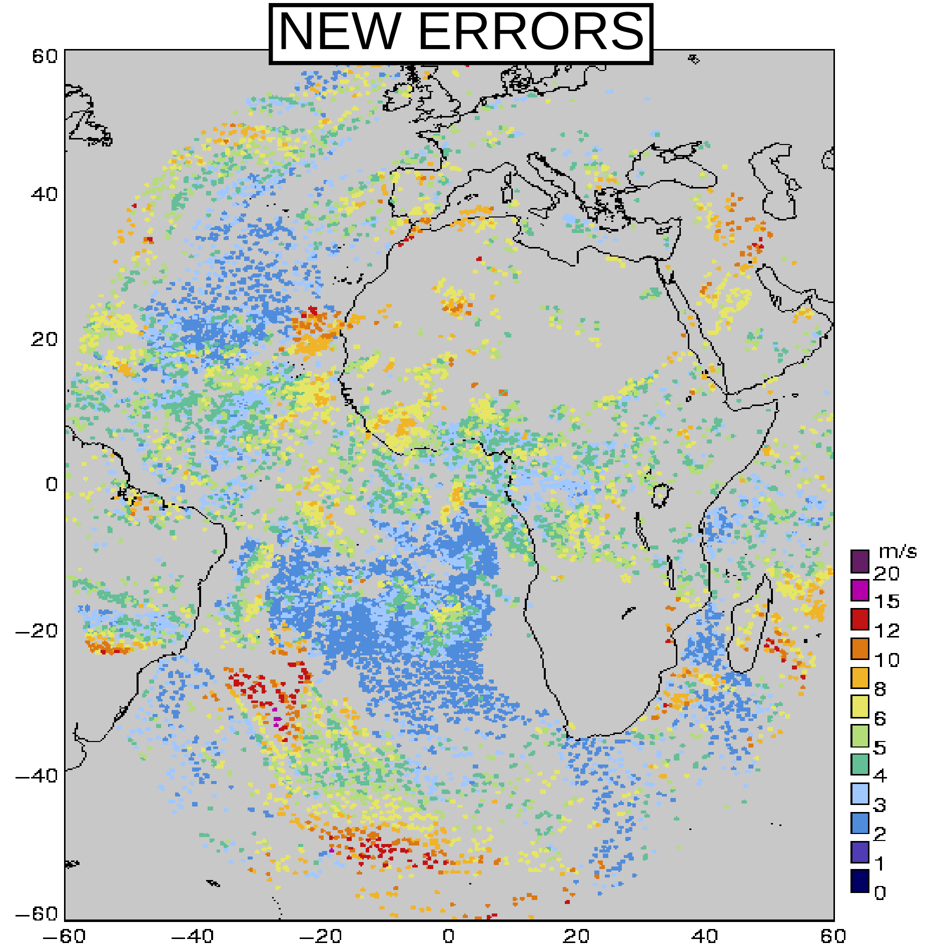
Until then estimate Ep using best-fit pressure stats as a guide.
See Forsythe & Saunders, IWW9, 2008; Salonen et al, 2014, submitted to JAMC

Currently assume uncorrelated errors



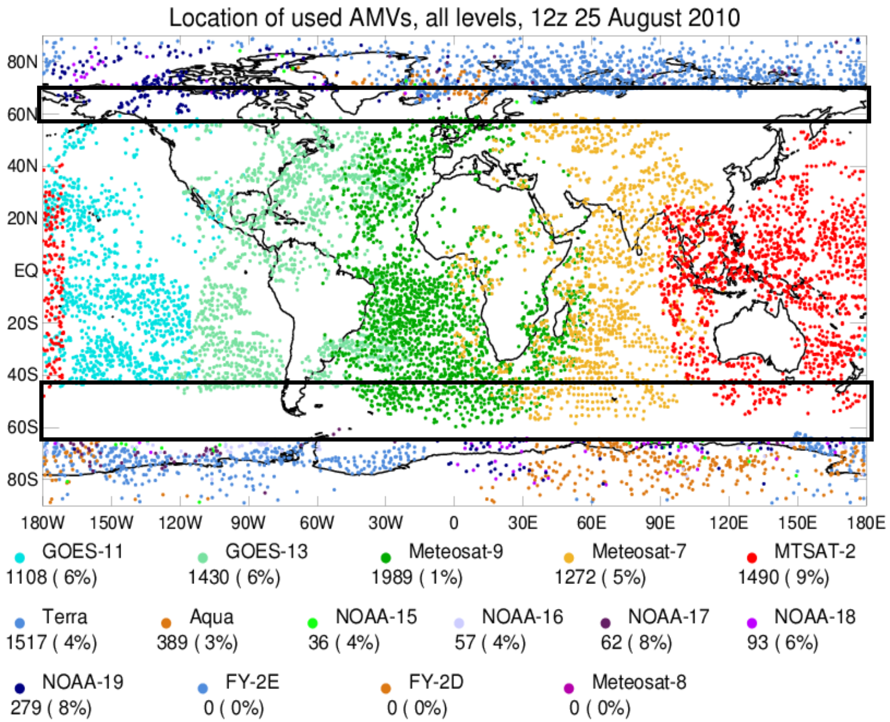
3. Observation errors



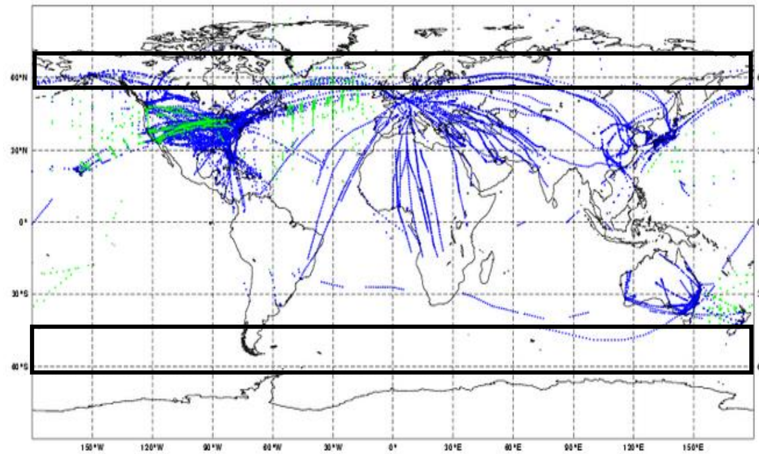


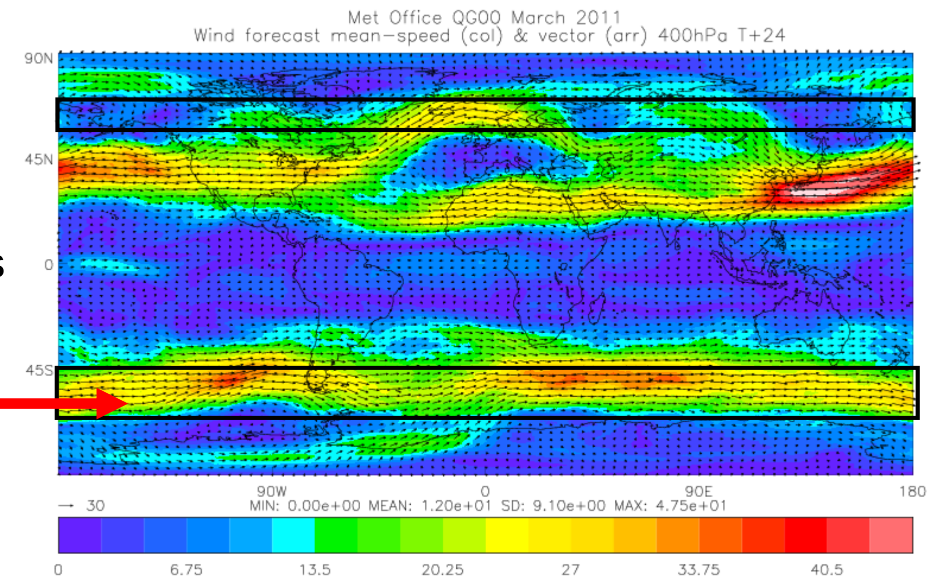
Benefit seen in assimilation experiments at the Met Office and ECMWF

4. Closing the Gap...



Aircraft



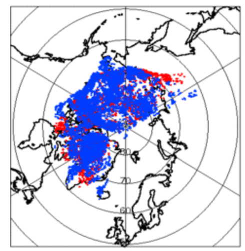


- Key baroclinic areas void of wind observations
- Lack of other wind data in AMV data voids
- Useful for constraining polar front jets

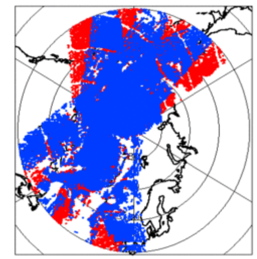
4. Closing the Gap...

i. Polar winds from image pairs

Metop triplets



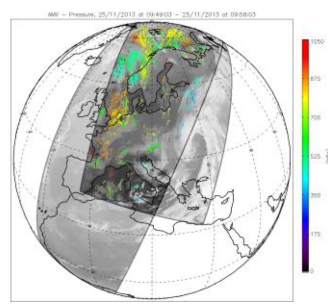
Metop pairs

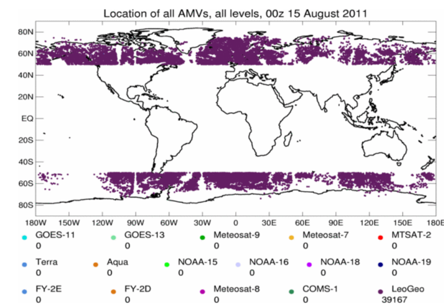


ii. Polar winds from mixed LEO/LEO

e.g. Dual Metop-A/B (EUMETSAT),

LeoGeo (CIMSS)





iii. Highly elliptical orbit

e.g. Polar Communications & Weather (PCW)

Canadian mission for 2 satellites in highly elliptical “TUNDRA” orbit with ABI-like imager (2021?)

iv. Also MISR and Aeolus, but narrow swath

5. High resolution AMVs

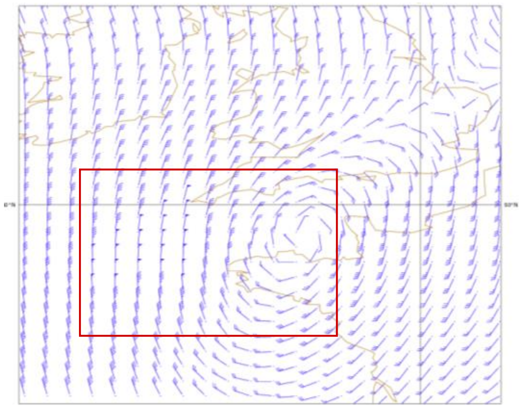
Why are we interested?

- Current AMV products capture broad-scale to synoptic-scale flow.
- NWP moving to higher spatial resolution

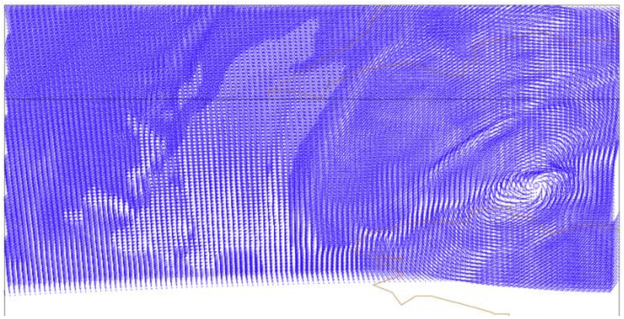
e.g. Met Office	global	17 km
	UK	1.5 km

- Can see information available on smaller scales in the imagery.
- Spatial and temporal resolution improving with future instruments e.g. GOES-R, Himawari-8 etc. Also rapid scan (5 min from Meteosat-9) or for severe weather.
- Can we derive more useful AMV information for nowcasting or assimilation in high resolution models? Particularly to help with forecasting high impact weather events.

Global model 40 km



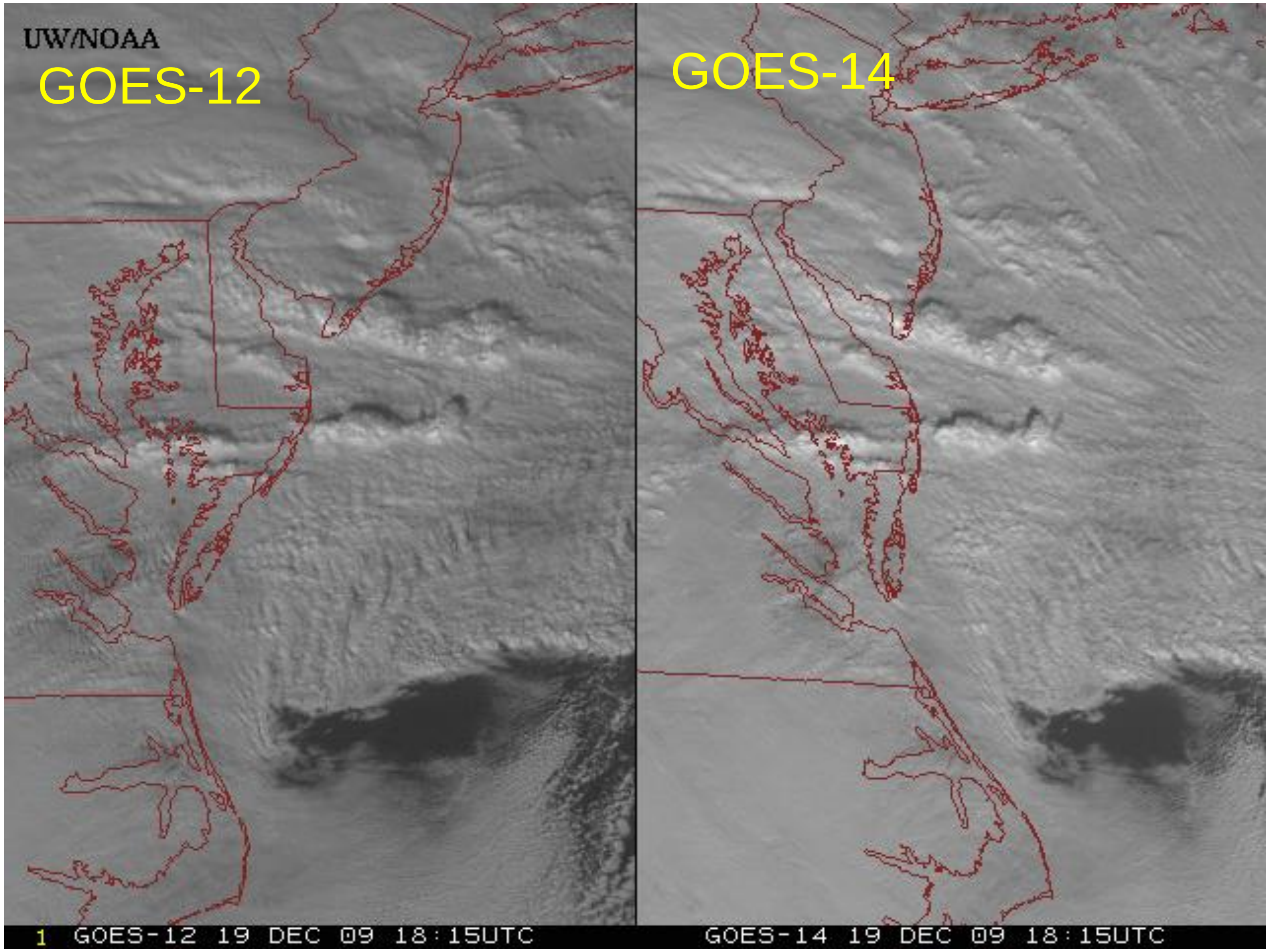
UK 4km



Examples of wind field resolution from Met Office models operational in 2010

5. High resolution AMVs

A look ahead to capability with GOES-R

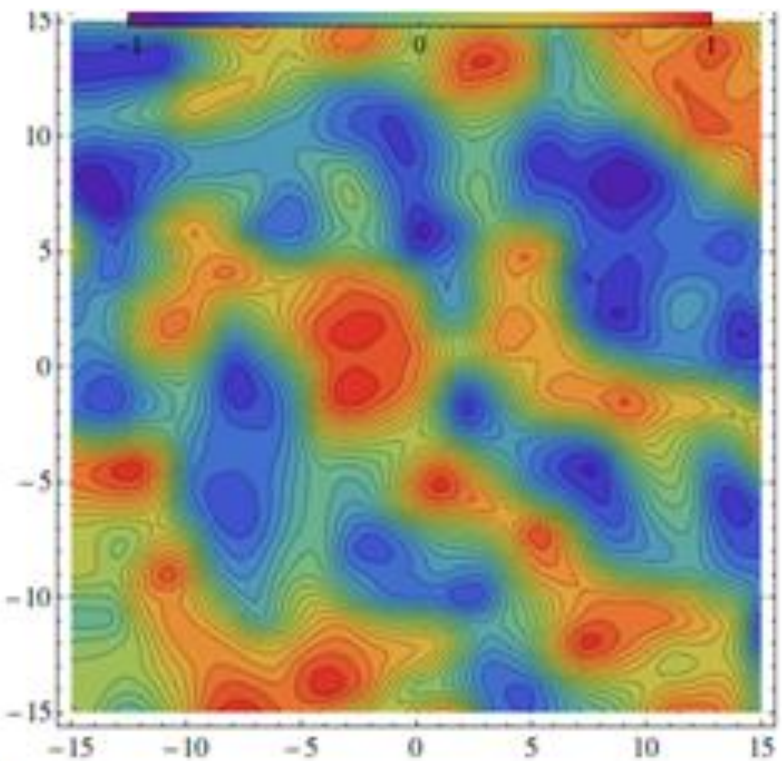


Visible data from the GOES-14 NOAA Science Test – 1 min imagery, *from Jaime Daniels, NESDIS*

5. High resolution AMVs

Tracking – becomes trickier

Use smaller targets and shorter imager intervals to derive high resolution AMV datasets reflecting the motion of smaller scale features of the flow.

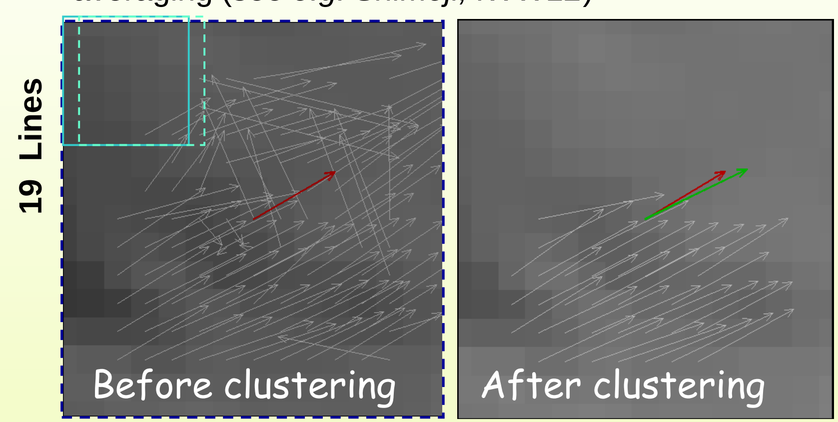


Example correlation surface with 5x5 pixel targets.
BUT more noise - many peaks ->
Information included in target feature is not enough to determine wind vector accurately

From Kazuki Shimoji's IWW12 talk

Need to reduce noise

- clustering (e.g. Nested tracking developed at NESDIS)
- use information from correlation surface to filter out poorly constrained cases.
- averaging (see *e.g. Shimoji, IWW12*)



From Jaime Daniels

5. High resolution AMVs

Other tricky bits

AMVs

- More sensitive to satellite image registration errors (but navigation systems are improving).
- Cannot resolve slower winds well with shorter image intervals.
- Current quality indicators tuned to large-scales - penalize spatially varying, accelerating wind features

NWP

- In NWP smaller scales tend to change fast and represent only modest energy conversion. The quantity and coverage of observations to initialise and evolve these scales is a daunting challenge. Inadequate coverage could compromise the analysis of the larger scales.
- AMVs have correlated errors in space and time. To alleviate problems, data is thinned (or superobbed) and errors inflated. But if thin too much, we will lose the mesoscale information of interest

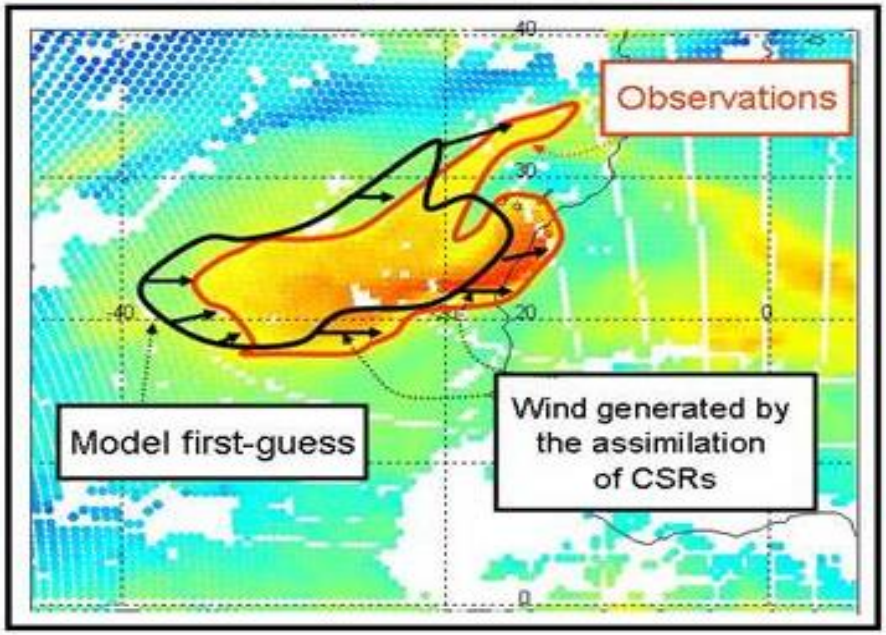
Wiki page on IWWG web page to foster collaboration

https://groups.ssec.wisc.edu/groups/iwwg/activities/high-resolution-winds-1/high-resolution-winds

Recent advances and challenges: summary

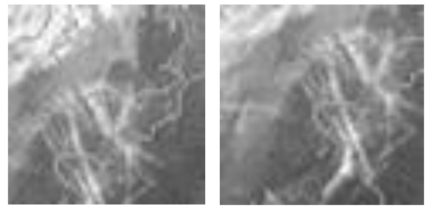
1. Working together within IWWG community to address key areas.
2. Recent efforts to improve the quality and coverage of the data including:
   - Understanding the errors
   - Closing the data coverage gap
   - Improving AMV height assignment
3. Greater benefit of AMVs in NWP should be possible through:
   - Improvements to data (better feature tracking, height assignment)
   - More information on quality and representivity
   - Improved coverage (spatially and temporally)
   - Improvements to assimilation strategy
4. Interest in high resolution AMV products, but many challenges.

4D-Var Tracing



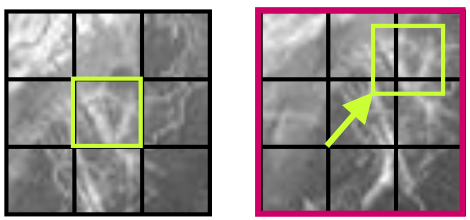
For more information on following slides see Peubey and McNally, 2009, QJRMS and EUMETSAT fellowship reports by Cristina Lupu

AMVs versus direct radiance assimilation

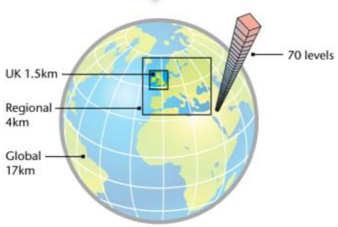


In both cases start with a sequence of images

AMVs



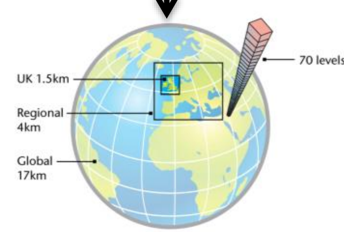
Derive AMVs from displacement of target



Assimilate AMV winds in NWP

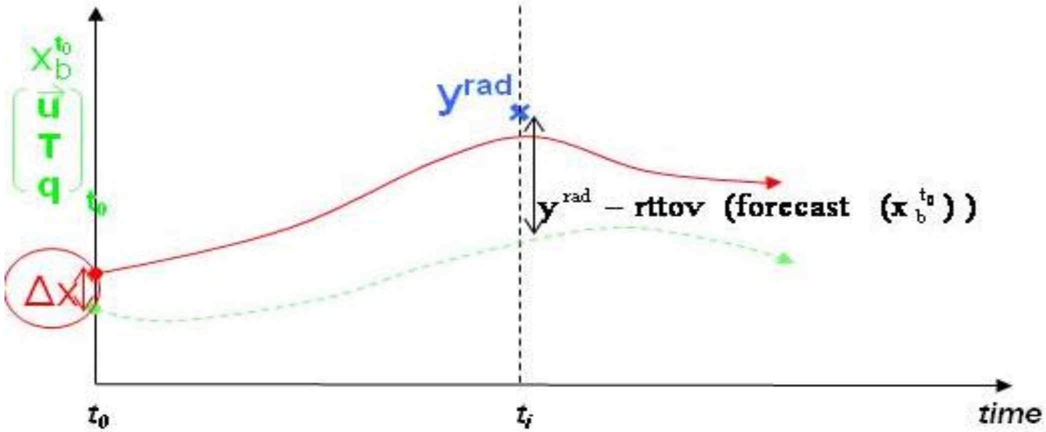
Radiances

Assimilate thinned radiances directly



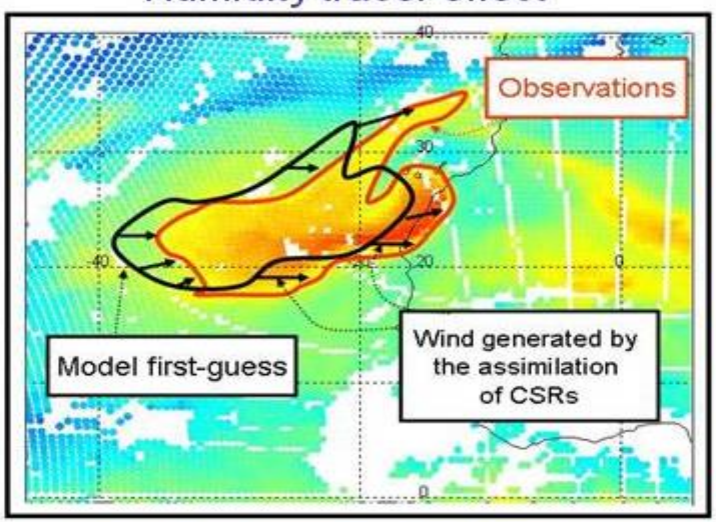
Wind information obtained through the 4D-Var tracer effect

Indirect forcing of the wind field through passive tracing



To fit the time and spatial evolution of humidity or ozone signals in the radiance data, 4D-Var has the choice of creating constituents locally or advecting constituents from other areas. The latter is achieved with wind adjustments.

Humidity tracer effect

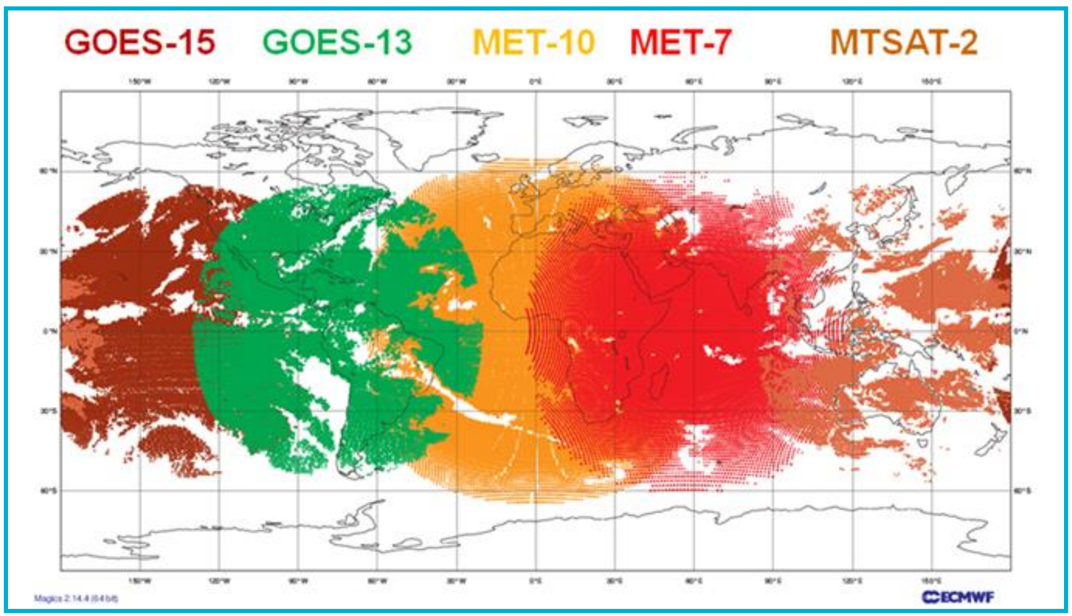


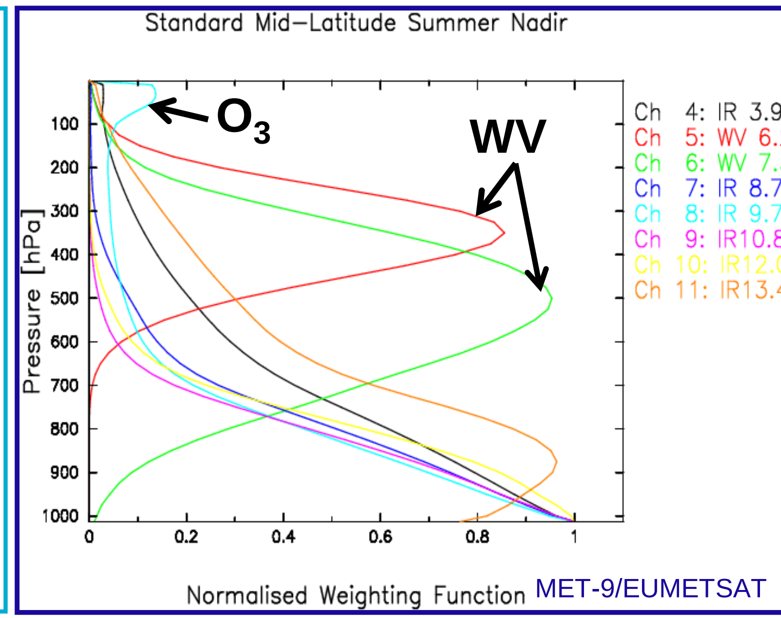
(Carole Peubey)

Wind adjustments from radiance observations

Potential to extract wind information from assimilation of all radiance observations – focus on the high temporal frequency geostationary radiances in this talk.

- *Tracking WV (mid-upper troposphere) or O_3 (lower stratosphere) features;*



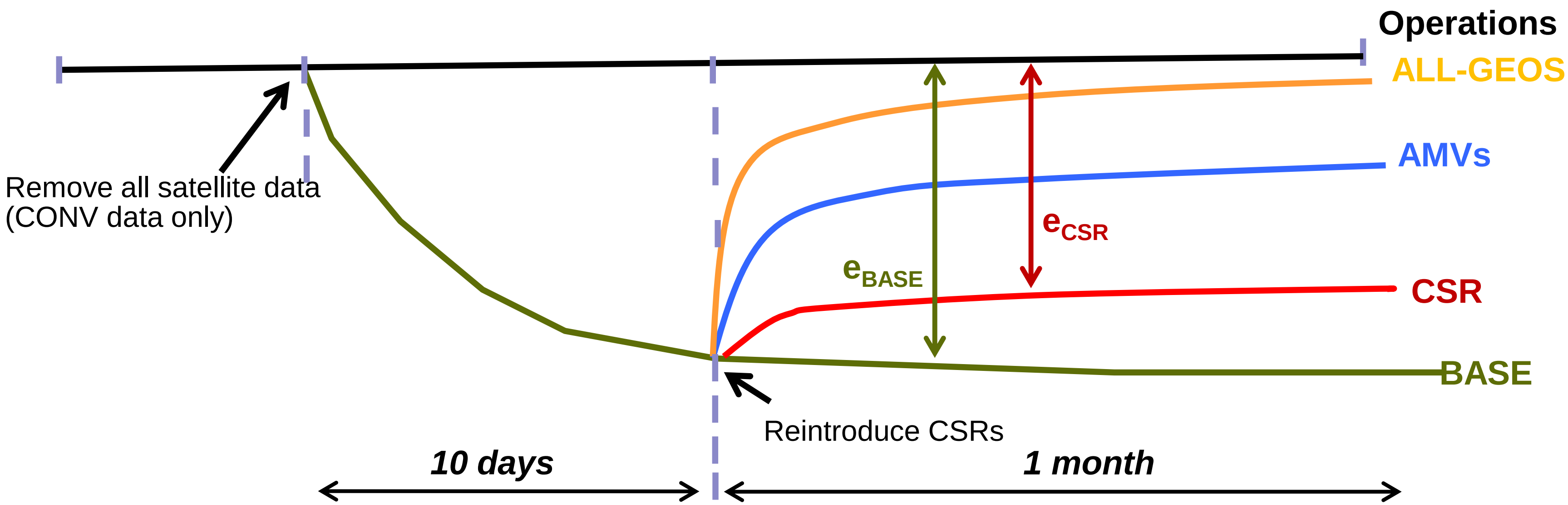


(Cristina Lupu)

Impact of CSRs on wind analyses

CSR= MET-9 only, 2 WV channels, peaking 300 and 500 hPa

AMV= MET-9 only, all AMV data assimilated in operations (IR, WV and visible)



(Carole Peubey)

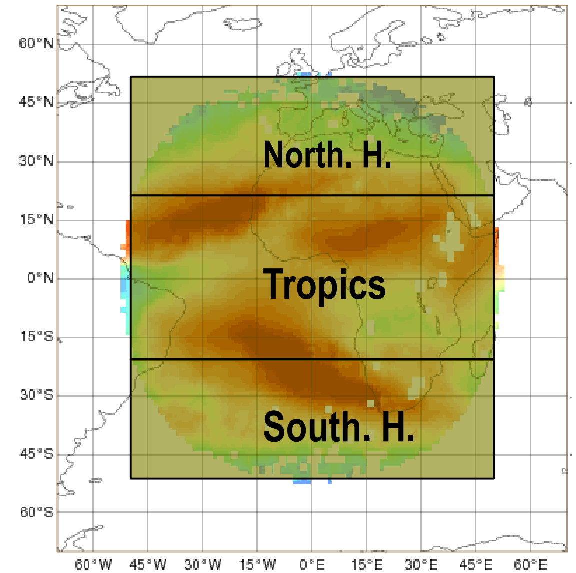
Wind analysis scores

Wind analysis errors are calculated as departures from the ECMWF operational analysis, considered as the best estimate of the true wind field:

$$RMSE_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\left(u_i - u_i^r\right)^2 + \left(v_i - v_i^r\right)^2\right]}$$

For each experiment the analysis error is compared to that of Base to provide a “Wind analysis score”:

$$\Delta RMSE = \frac{\sum_{j=1}^{m}\left(RMSE_j - RMSE_j^{Base}\right)}{\sum_{j=1}^{m} RMSE_j^{Base}}$$

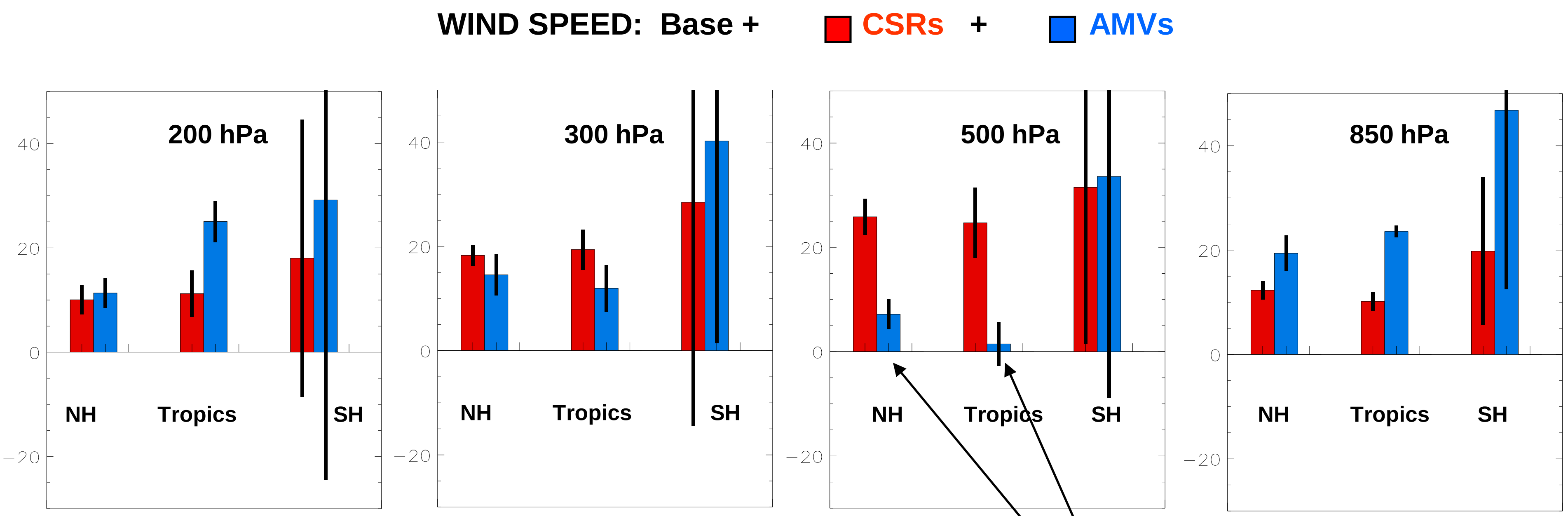


Analysis score = 0% no improvement over the base
Analysis score = 100% no error with respect to the operational analysis

Resolution differences will limit maximum impact to ~60% (NH,TR) - 80% (SH)

(Cristina Lupu)

Impact of CSRs on wind analyses



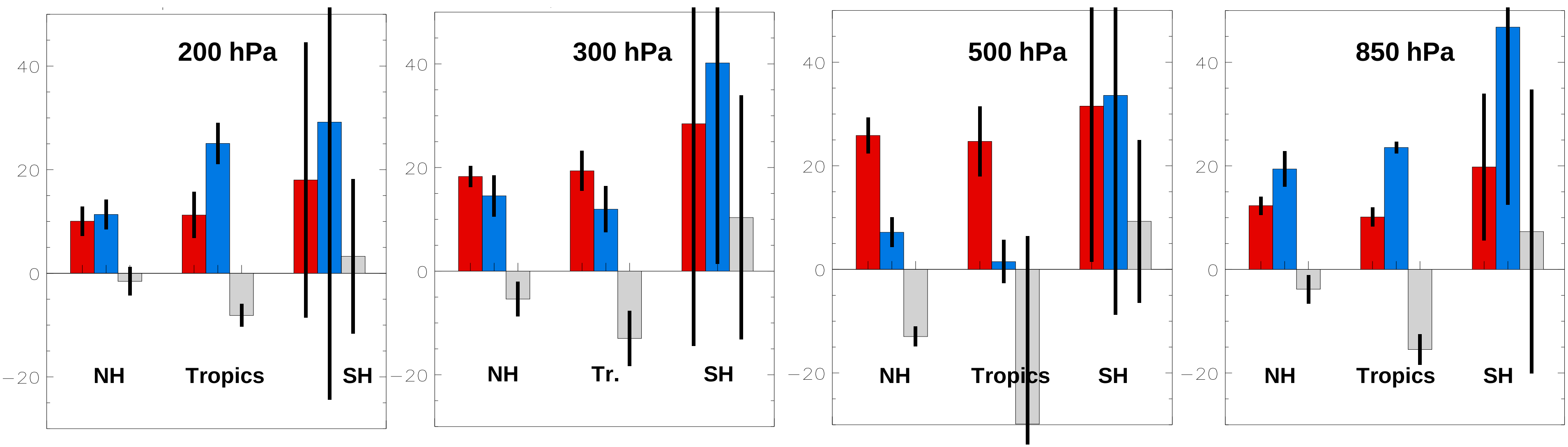
=> CSRs have a larger impact on wind analysis compared to AMVs at 300 hPa and 500 hPa, but less at 200 hPa and 850 hPa

fewer AMVs at 500 hPa

(Carole Peubey)

Impact of CSRs on wind analyses

WIND SPEED: Base + CSRs + AMVs + Clear-Sky AMVs

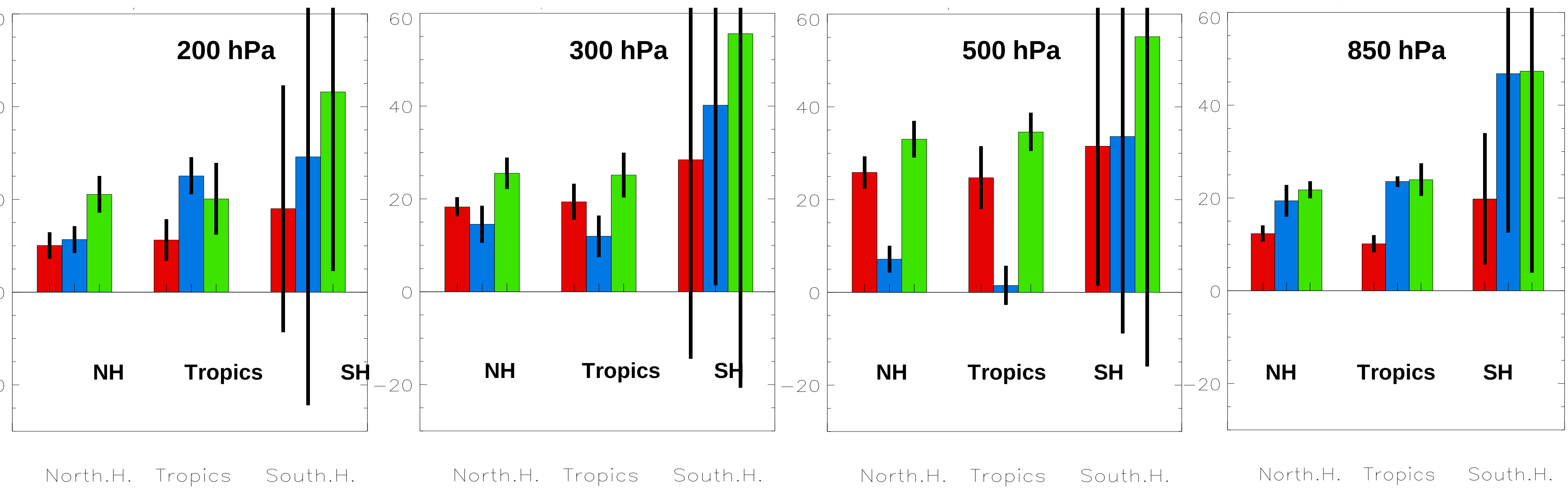


=> Negative impact of the clear-sky AMVs (treated as point-like observations in the model)

(Carole Peubey)

Impact of CSRs on wind analyses

WIND SPEED: Base + CSRs + AMVs + All radiances in MET-9 disk - CSRs



→ CSRs impact on wind slightly less than that of all other radiances inside MET-9 disk at 300 and 500 hPa

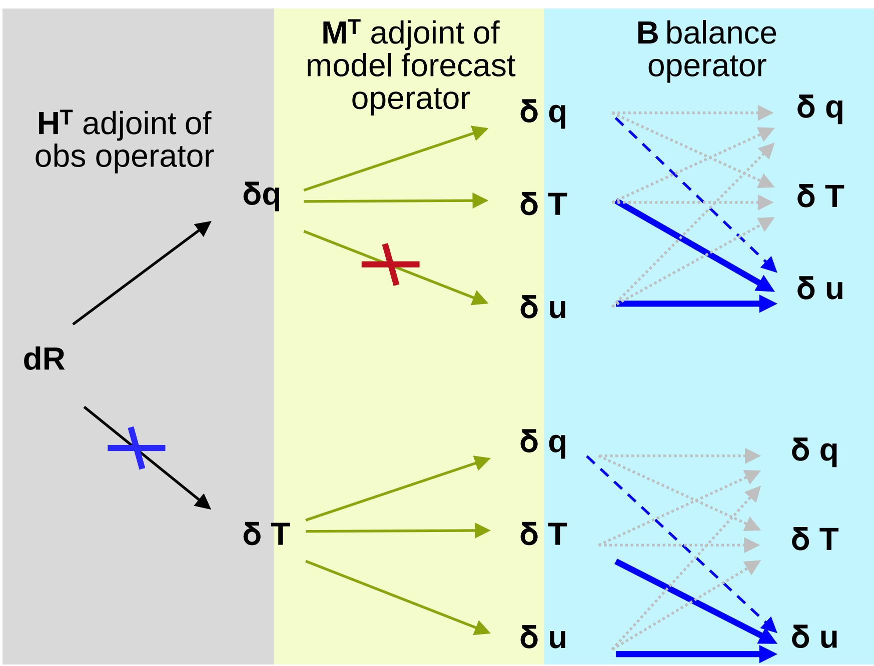
(Carole Peubey)

Identifying the mechanisms of the CSR impact on winds

Radiances can impact the wind analysis through 3 different ways:

1. cycling (model dynamics and physics)
2. error correlations between wind and mass variables (balance)
3. 4D-Var (tracer effects)

$$\nabla J(\mathbf{x}(t_0) = \mathbf{B}^{-1}[\mathbf{x}(t_0) - \mathbf{x}_b(t_0)] + \mathbf{M}^{\mathrm{T}}\mathbf{H}^{\mathrm{T}}\mathbf{R}^{-1}[HM(\mathbf{x}(t_0) - \mathbf{y}]$$



The 4D-Var minimisation process can be regarded as a series of transformations of the observation departure, applying successively the operators: $\mathbf{R}^{-1}$, $\mathbf{H}^{\mathrm{T}}$, $\mathbf{M}^{\mathrm{T}}$, **B;**

<u>SEVIRI CSR Experiments</u>:

Full 4D-Var

No δT

No tracer effect

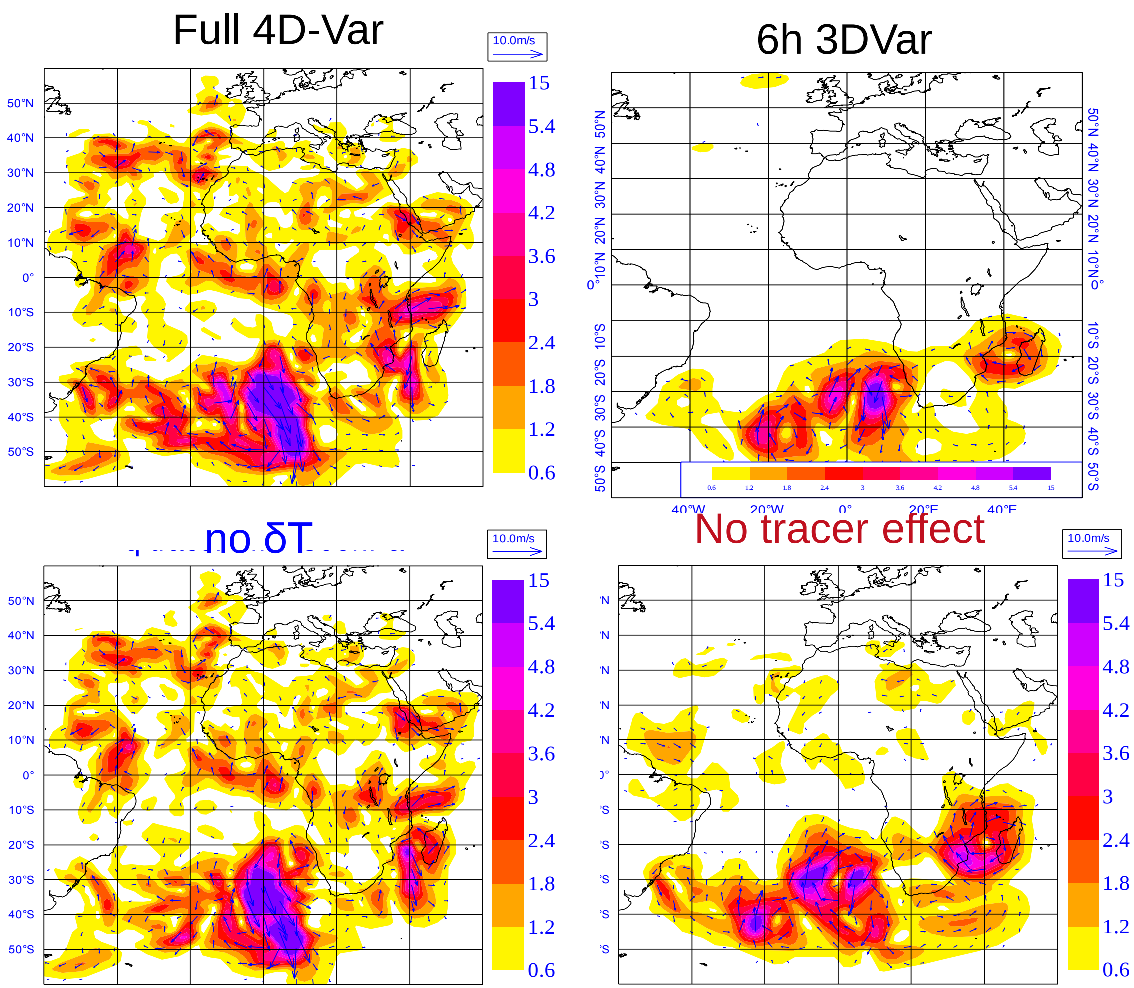
No tracer effect, no δT

3D-Var

(Carole Peubey)

Identifying the mechanisms of the CSR impact on winds

First CSR-generated wind increment – 300 hPa



Little wind information via temperature.

Big impact of removing tracer effect.

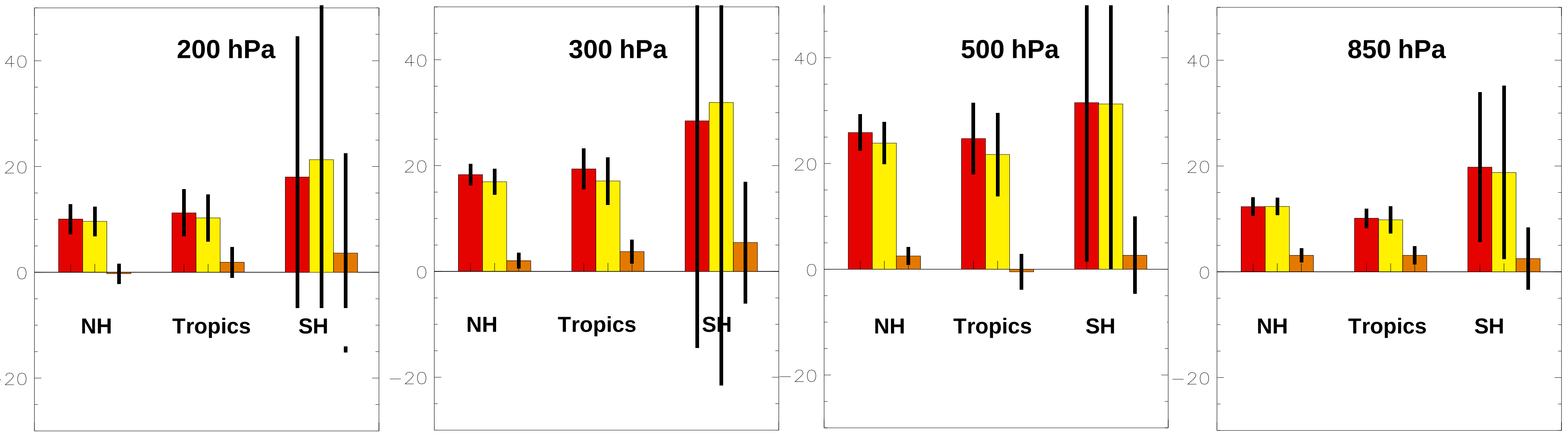
Some remaining impact from balance constraints (no tracer effect and 3D-Var very similar)

Other processes have very little impact on the wind increment

(Carole Peubey)

Identifying the mechanisms of the CSR impact on winds

WIND SPEED: Base + CSRs for full 4D-Var, no δT, no tracer effect, no δT

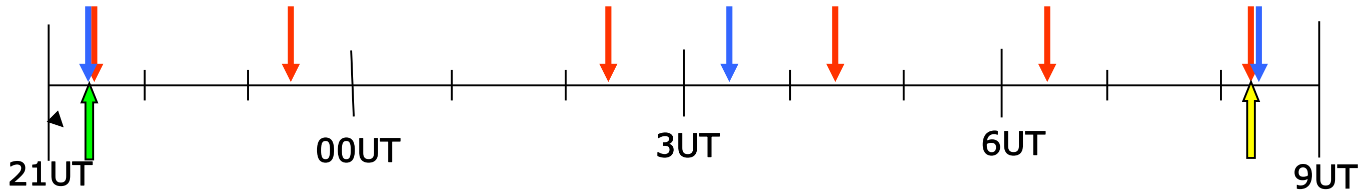


→ with cycling alone (no tracer effect, no δT), CSRs do not have a significant impact on winds

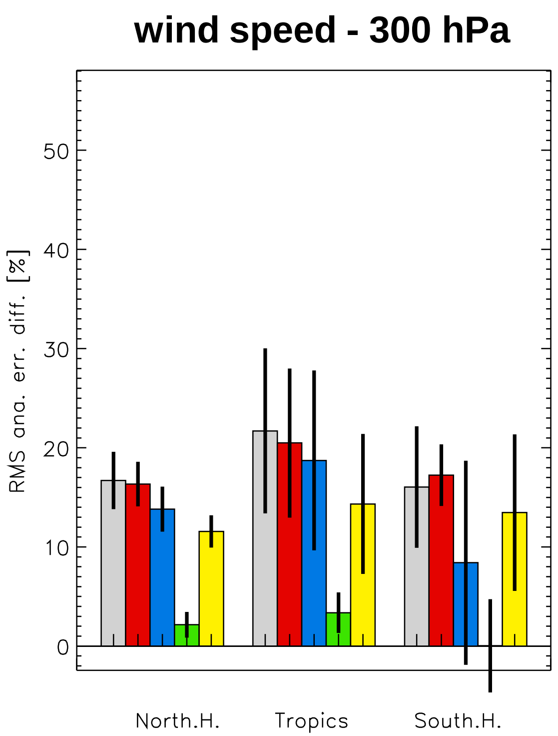
→ Most of the CSR impact on wind seems to come from the humidity tracer effect

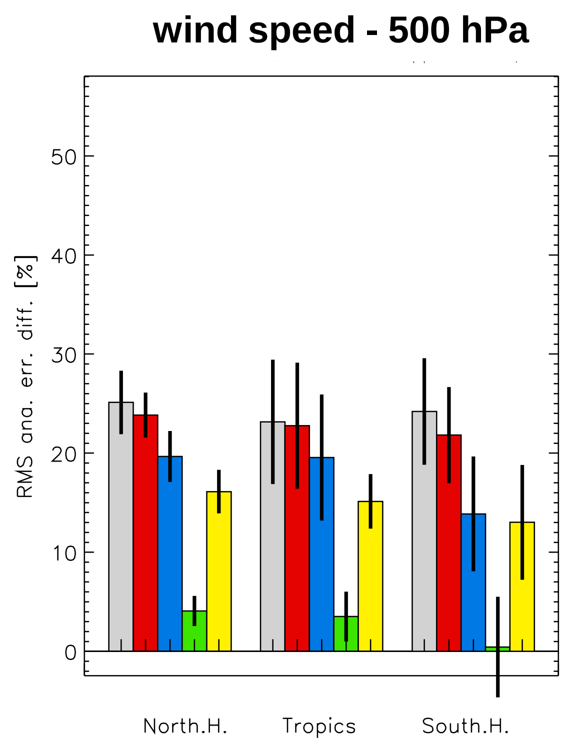
(Carole Peubey)

Importance of observation frequency



Base + CSRs	12 im./window	6 im./window	3 im./window
	single im. at 1st slot of window		single im. at last slot of window





Having the image at the end of the window gives better scores than having it at the beginning of the window

(Carole Peubey)

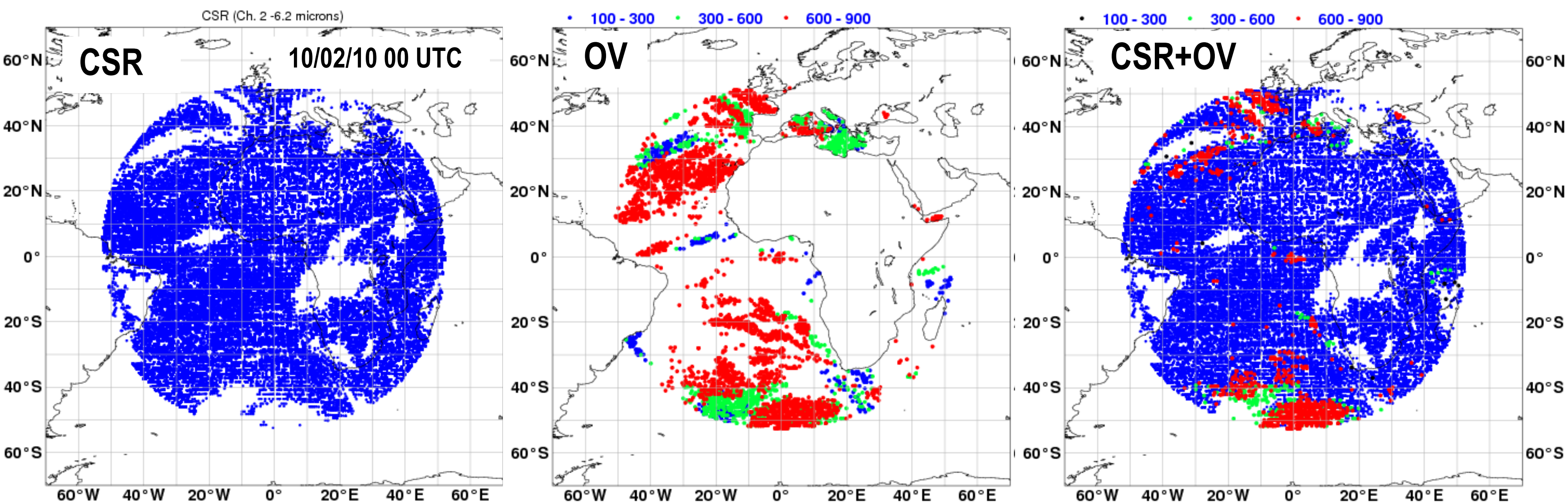
Impact of cloud-affected radiances

Much recent effort on assimilating cloud-affected radiances – often dynamically interesting areas, but challenging.

Initial formulation only for overcast (OV) scenes with cloud fraction > 0.99 (limited numbers pass this test, ~8000 in one month) - based on scheme developed for AIRS and IASI at ECMWF

(McNally 2009, QJRMS, 135)

CSR, OV, CSR+OV and AMVs from SEVIRI were each added to a NOSAT baseline experiment. T511L91 (12-hour 4D-Var) , 10th February – 10th March 2010

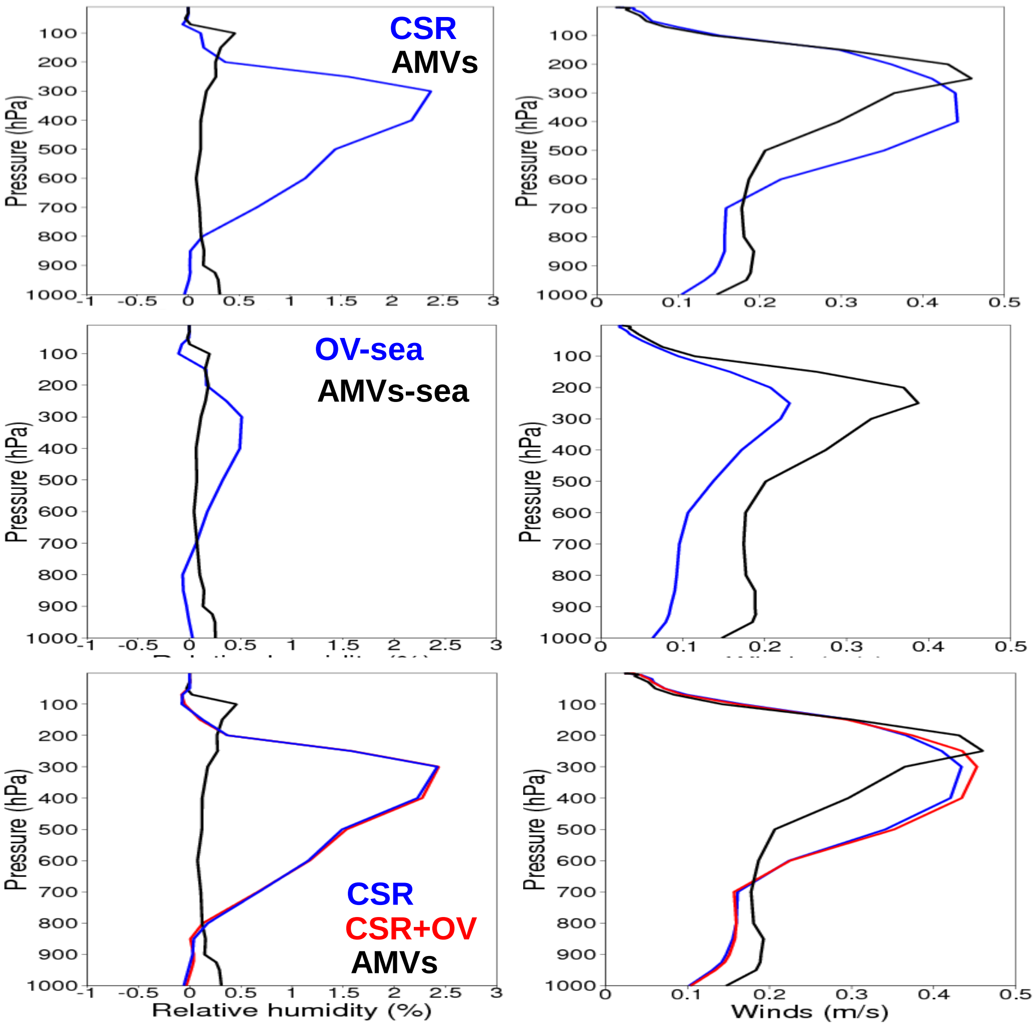


(Cristina Lupu)

Met Office

Impact of cloud-affected radiances

RMS of relative-humidity and wind speed increment differences with respect to the NOSAT exp, averaged inside Met-9 disc over 1-month



CSR and **AMV** impact is complementary

CSR@500hPa

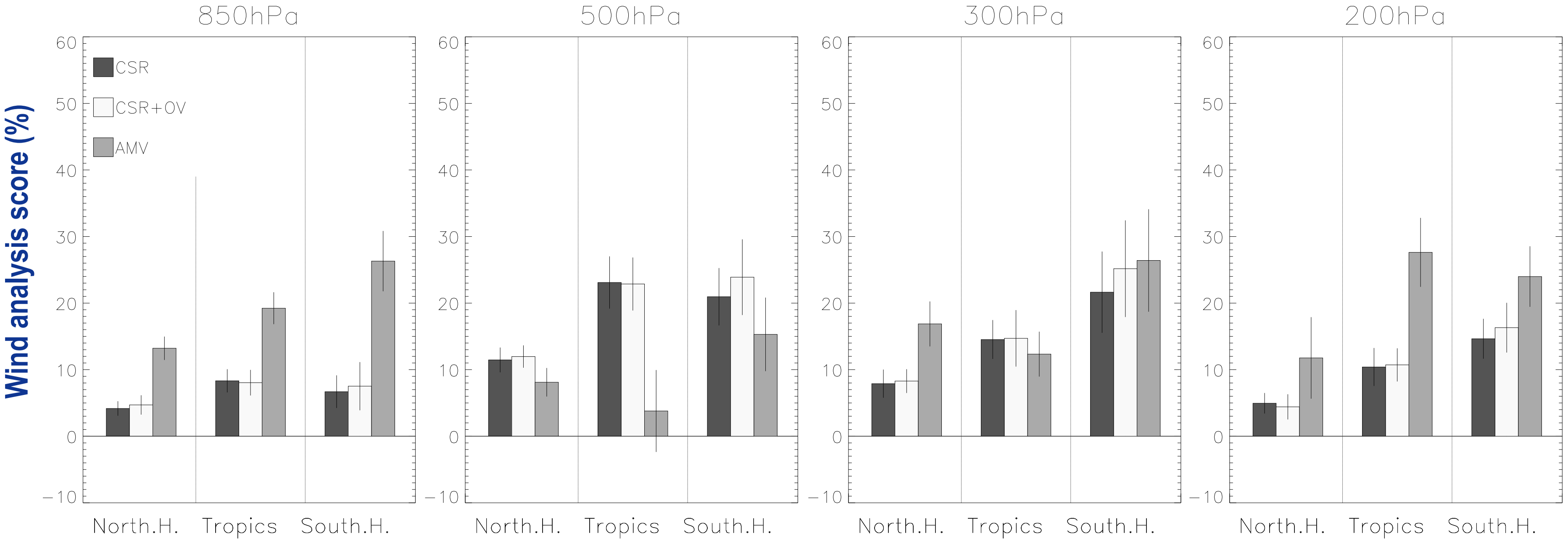
AMVs@200 and 850 hPa

OV and **AMVs** impact show very good agreement with a maximum impact in the upper troposphere (250-300 hPa).

CSR+OV and **CSR** wind speed increments are very similar in structure; a larger magnitude with a maximum at 300 hPa is obtained from CSR+OV

(Cristina Lupu)

Impact of cloud-affected radiances



Some benefit from overcast radiances in SH particularly. Still less than AMVs at 200 hPa and 850 hPa, but fewer observations assimilated.

OV – assimilated since June 2012

(Cristina Lupu)

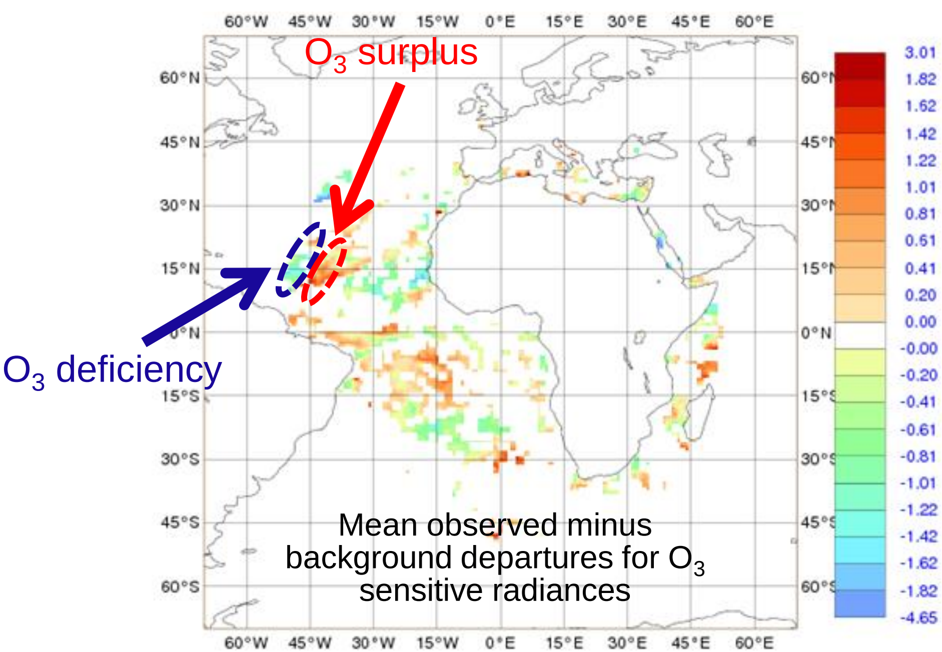
O_3 sensitive CSR impact on winds

SEVIRI CSR 9.7 µm channel sensitive to O_3 concentration in the upper-troposphere and lower-stratosphere

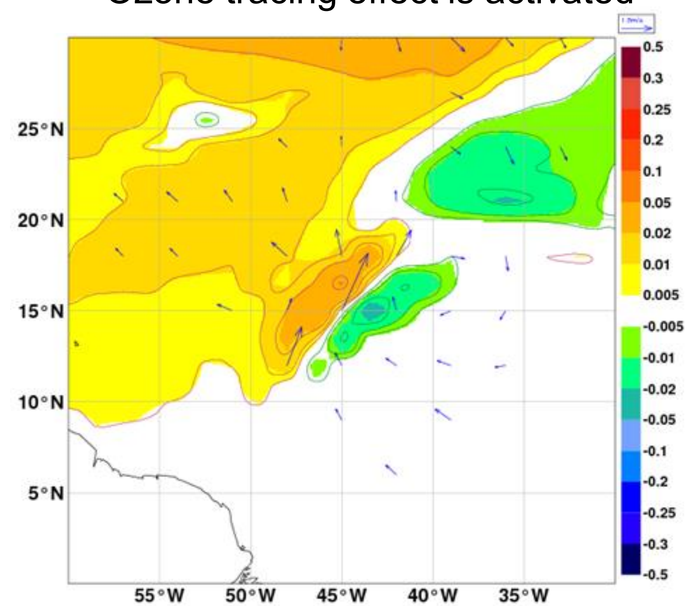
Ozone feature tracing analogous to the ***Humidity tracing effect***

The fitting of ozone sensitive radiances within the 4D-Var analysis can be achieved by instigating ozone advecting wind increments.

Relative to *baseline with only conventional observations + scat + GPSRO*, found very small impact on wind analysis in the upper troposphere - max 2% improvement in the Tropics@150hPa

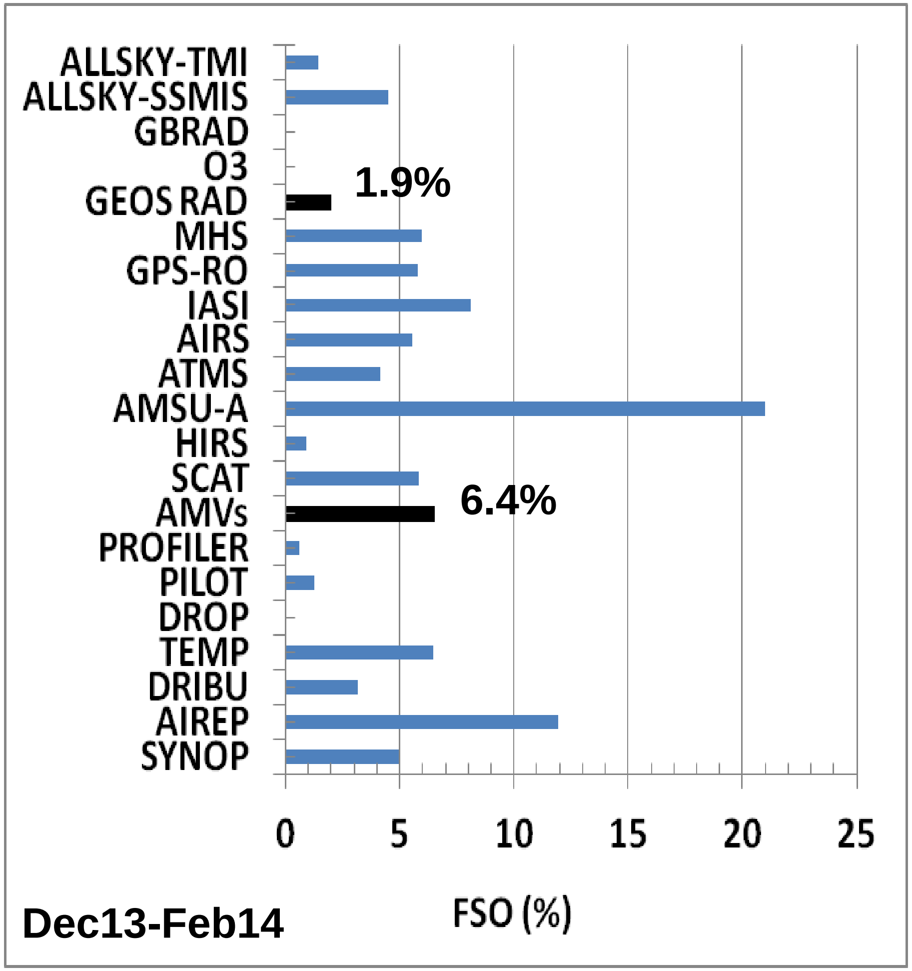


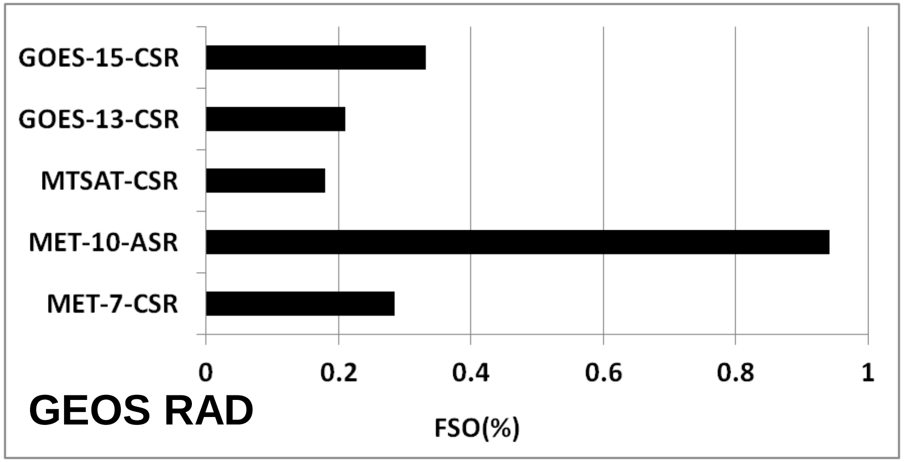
"Ozone tracing effect is activated"

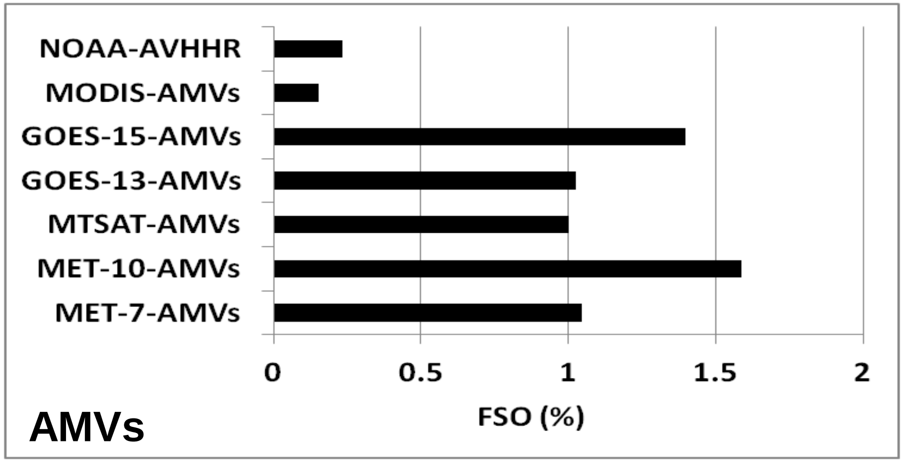


(Cristina Lupu)

FSO impact of geostationary radiances







(Cristina Lupu)

4D-Var tracing: Summary

Mechanism

• Model cycling alone does not allow much positive impact of CSRs on winds → need 4D-Var
• Dominant effect is humidity-tracer advection – wind field adjusts in order to fit observed humidity features via minimization of the 4D-Var cost function.

Types

• Positive impact of CSRs on analysis wind field, complementary to AMVs, biggest impact at 300 and 500 hPa (AMVs more impact at 200 hPa and 850hPa).
• Extending to cloudy data is a challenge. See some additional benefit from assimilation of all-sky radiances in overcast scenes.
• Application to O_3 sensitive radiances - potential to constrain winds in the lower stratosphere, but impact small so far.

Frequency

• Frequent images matters. Much larger benefit from images at the end of the assimilation window as enables the assimilation process to use humidity as an advected tracer from which info about flow can be extracted.

(Carole Peubey and Cristina Lupu)

Met Office

A look ahead

Future requirements for wind data in NWP

NWP model will always need wind data to represent the divergent component of the flow properly.

Particularly important

1. in Tropics
2. for small-scale features of flow

Latter only likely to get more important as model resolution improves.

Therefore need to maintain/improve wind component of global observing system.

Preferably have good horizontal, temporal and vertical coverage

AMV assimilation versus radiance assimilation

Met Office

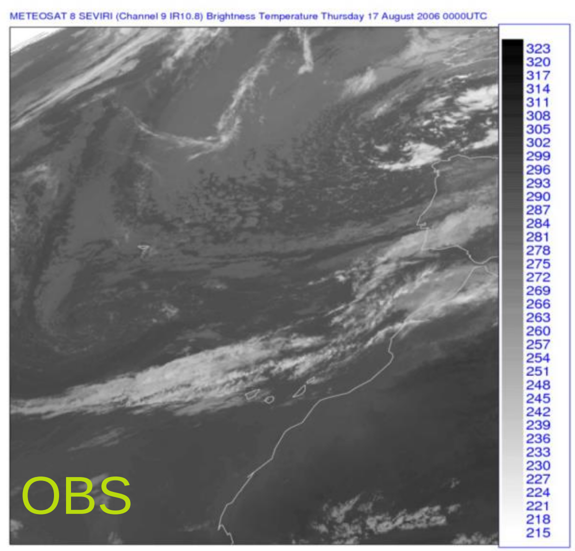
Can extract wind information by assimilating cloud and moisture information in 4D-Var.

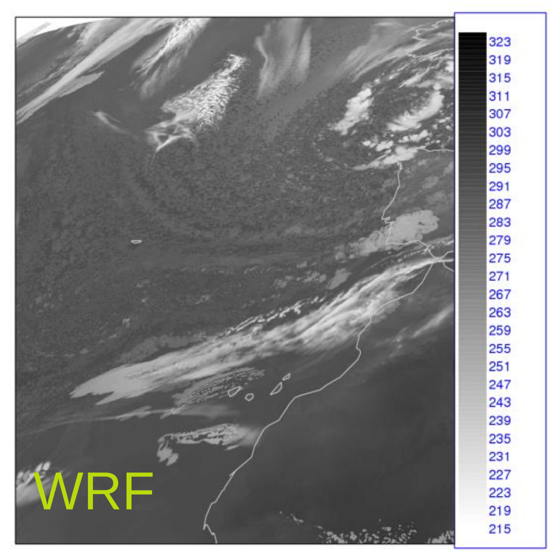
Assimilation of clear sky radiances already shown to improve wind analysis and is recommended approach for clear sky areas (clear sky AMVs not assimilated).

Direct assimilation of cloudy radiances could, in theory, improve on current AMV techniques in allowing for development and dynamical coupling of features. Is it likely that radiance assimilation will ultimately replace AMVs?

Challenging….

- Highly non-linear operators with respect to cloud variables
- Requires adequate representation of model cloud
- Mismatched cloud locations in models and observations
- Handling of multi-layer cloud
- More situation and cloud-specific background error formulations
- Resolution of analysis in space and time
- Spatial and temporal density of assimilated radiance data (5-10 min image interval optimal for cloud tracking in AMV derivation)
- Choice of DA – 4D-Var may be better at extracting dynamical information than some ensemble approaches





AMV assimilation versus radiance assimilation

Met Office

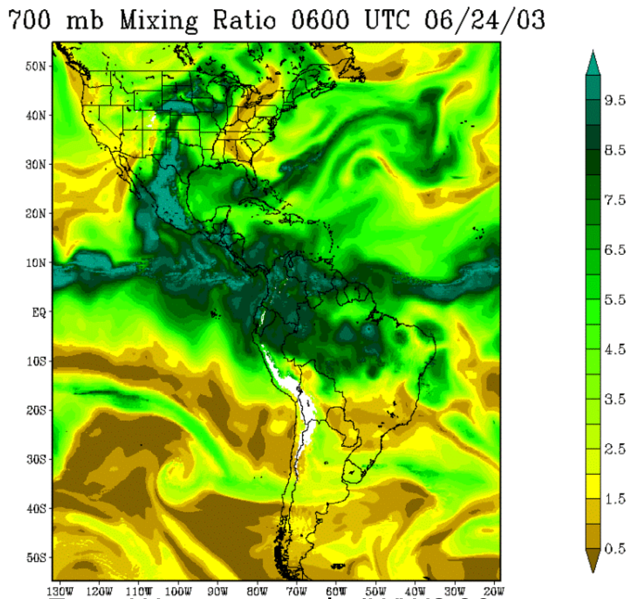
How best to handle geostationary hyperspectral IR sounders? MTG-IRS planned for 2021 (30 min return time, 4 km resolution)

Option 1:

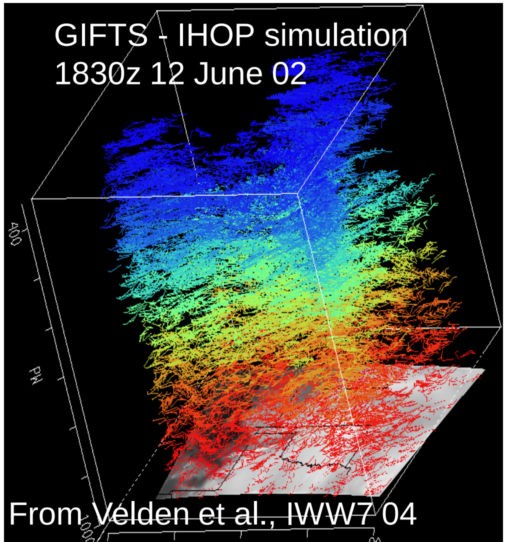
- Assimilate the radiances directly.

Option 2:

- Use sounder data to derive moisture analyses on different levels.
- Wind profiles can be derived by applying AMV tracking techniques to these sequences of moisture analyses on different levels. No need for direct height assignment.
- Approach demonstrated with simulated data, required smoothing of the humidity images See Laura Stewart's EUMETSAT Fellowship reports and earlier work at CIMSS (see right).



From Wanzong et al., IWW8 06



From Velden et al., IWW7 04

Talk Summary

1. AMVs were first produced in real-time in the 1970s; since this time the coverage and quality has markedly increased.
2. Impact experiments and FSO scores show benefit to forecast accuracy
3. A major limitation is the complicated and spatially correlated errors. NWP SAF monitoring and simulated data studies can teach us more about what AMVs are representative of and help to better understand error characteristics.
4. This in turn should enable greater benefit of AMVs in NWP through improvements to the AMV derivation and assimilation strategy.
5. Extraction of wind information from radiance assimilation via 4D-Var tracing effect has been demonstrated. CSRs provide complementary information to AMVs, potential for ASRs in the future?
6. Wind information from geostationary satellites (as AMVs or via radiance assimilation) is likely to be an important source of wind data for NWP for many years.

Any Questions?