Atmospheric Motion Vectors: Past, Present and Future

ECMWF Annual Seminar, Sep 2007
Mary Forsythe
Met Office, Exeter, UK

Thanks to Howard Berger, Chris Velden, Niels Bormann, Claire Delsol, Jo Schmetz, Dave Santek, Nancy Baker, Sakari Uppala, Jaime Daniels, Jörgen Gustafsson, Kris Bedka and Steve Wanzong for providing material for this talk
One of the original satellite observations
But …

They are **not done and dusted**

AND

They are **not obsolete**

During this talk I will demonstrate

Why they are **still useful**

AND

What those in the field are doing to **improve the impact** of atmospheric motion vectors (AMVs) in NWP
Go by many names……

Atmospheric motion vectors (AMVs)

Satellite winds
Satwinds
Cloud track winds
Cloud motion winds
Feature track winds

NOT to be confused with
Scatwinds
Windsat
What are they?

Produced by tracking clouds or gradients in water vapour through consecutive satellite images
AMVs are traditionally produced using geostationary satellite imagery.
Channels

IR window ~ 10.8μm
clouds

WV absorption ~6.7μm
clouds and clear sky

VIS ~0.6μm
clouds
How are they produced?

Initial corrections (image navigation etc.)

- **Target Box / Tracer**
  - 24x24 pixels
  - Pixel – 3 km

- **Search Area**
  - 80 x 80 pixels centred on target box

- **Infrared Imagery**

- **New location determined by best match of individual pixel counts of target with all possible locations of target in search area (use cross-correlation in Fourier domain).**

Need to 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. “
Who produces the AMVs?

Currently produced by:

• EUMETSAT in Europe (Meteosat-9, Meteosat-7)
• NOAA/NESDIS in the USA (GOES-11, GOES-12, Aqua, Terra)
• CIMSS in the USA (NOAA 15-18)
• JMA in Japan (MTSAT-1R)
• IMD in India (Kalpana, INSAT-3a)
• CMA in China (FY-2C, FY-2D)
• CPTEC in Brazil (GOES-10)

Future

• KMI in South Korea (COMS)
What does the data look like?

Real-time visualisation available from http://cimss.ssec.wisc.edu/tropic2/
Hourly GOES-12 IR Cloud-Drift Winds

Sept 13-22, 2003

From Jaime Daniels’ talk at IWW8
Talk Outline

1. Why do we care?
2. The Past – key events
3. The Present – current work
4. The Future – where do we go from here?
Why do we care?

Welcome to
NOBODY CARES
population: 6 billion
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.
What is the impact on forecasts?

- Negative – why are we using it?
- Neutral or mixed impact
- Good, but modest impact
- More impact than any other ob
AMV impact

Operational baseline

1.5

1. AMV denial
2. No Satellite + AMV

18.8

No satellite baseline

8.6

wind at 850 hPa : Sonde obs

control × no_amv
× no_sat ○ no_sat+amv

NH

Tropics

SH

Answer

AMVs improve forecasts, although impact is modest compared to ATOVS radiance data.
Several studies have shown the benefit of AMV data on tropical cyclone track forecasts (Goerss & Hogan, 2006; Soden et al., 2000).

### Forecast track error from a 2007 CIMSS study by Howard Berger

<table>
<thead>
<tr>
<th>Forecast Time (hrs)</th>
<th>12</th>
<th>24</th>
<th>36</th>
<th>48</th>
<th>60</th>
<th>72</th>
<th>84</th>
<th>96</th>
<th>108</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNTRL (km)</td>
<td>82.3</td>
<td>127.3</td>
<td>161.1</td>
<td>191.2</td>
<td>230.8</td>
<td>278.0</td>
<td>322.5</td>
<td>369.0</td>
<td>413.1</td>
<td>450.2</td>
</tr>
<tr>
<td>NO GOES AMV (km)</td>
<td>85.9</td>
<td>133.5</td>
<td>172.2</td>
<td>201.2</td>
<td>234.7</td>
<td>299.5</td>
<td>361.4</td>
<td>413.0</td>
<td>488.0</td>
<td>567.7</td>
</tr>
<tr>
<td>% Improvement</td>
<td>4.3</td>
<td>4.8</td>
<td>6.9</td>
<td>5.2</td>
<td>1.6</td>
<td>7.7</td>
<td>12.0</td>
<td>12.0</td>
<td>18.1</td>
<td>26.0</td>
</tr>
<tr>
<td>Number of Cases</td>
<td>81</td>
<td>79</td>
<td>69</td>
<td>62</td>
<td>55</td>
<td>54</td>
<td>49</td>
<td>45</td>
<td>40</td>
<td>34</td>
</tr>
</tbody>
</table>

- T126 28-Levels
- GFS and assimilation (SSI) run from July 28th - October 28th 2005
- Control: All operational observations assimilated
- Experiment: GOES IR/WV AMVs removed
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, but less so than some other observations e.g. ATOVS radiances

4. Can be important for improving tropical cyclone track forecasts
The Past
The Past

1960
- First TIROS polar imagery shows potential
- Ted Fujita

1966
- ATS-1 launch

1979
- AMVs from 5 geostationary satellites for FGGE

1980s
- Increasing automation, image resolution, and channels (VIS, WV) lead to increased data volume and coverage

1990s

2002
- Routine production of polar winds from MODIS imagery

© Crown copyright 2007
Increasing data volumes

Number extracted in a typical 12z update run in June of each year

1998
Geostationary
Meteosat-7
Meteosat-5
GOES-8
GOES-9
GMS-5
INSAT
Polar
None

2007
Geostationary
Meteosat-9
Meteosat-7
GOES-11
GOES-12
MTSAT-1R
INSAT-3a
Kalpana
FY-2C
Polar
Terra
Aqua
NOAA-15
NOAA-16
NOAA-17
NOAA-18

x30 in 10 years
Key changes

Satellite imager improvements

- **Shorter image intervals** (15 min for Meteosat Second Generation, 5-10 min shown to be optimal for cloud tracking)
- **Improved pixel resolution** (1 km, although 3-4 km more typical)
- **More channels** e.g. WV, IR3.9, CO₂ – useful for tracking and height assignment (semi-transparency corrections).

Derivation improvements

- Fully automated production enables higher density datasets (spatial and temporal).
- Move to BUFR format – more information sent with each wind including quality indicators (from 1997)
- Improved methods of target selection, tracking and height assignment.

Other developments

- **Polar winds** (from 2002)
Polar AMV data

• AMVs can be derived from polar-orbiting satellite imagery where the successive overpasses overlap (shown in white) in the polar regions.

• Produced from:
  • MODIS IR and WV imagery on Terra and Aqua since 2002
  • AVHRR IR imagery on NOAA 15-18 since 2007

• Main difficulty is timeliness – 3.5-7 hour lag time.

Pictures courtesy of Dave Santek, CIMSS
Polar AMV data

- Provide the main source of tropospheric wind information over the polar regions.
- Complementary coverage to the geostationary AMV data
Forecast error evolution Aug 14th, 2004
500 hPa geopotential height
Polar wind summary

- Impact trials show modest positive impact on forecast skill, most impact is in the polar regions.

- MODIS winds are assimilated operationally at more than 8 NWP centres.

Recent development
Timeliness improvement through use of direct broadcast stations (since 2006).
The Past: summary

1. AMVs were first produced routinely in the **1970s**.

2. Since then the **data has continued to improve and expand** through use of newer satellite imager instruments (higher resolution, more channels) and better AMV derivation.

3. **Polar AMVs** are the latest milestone in the AMV history and have proved a useful contribution to the observing system.
The Present
Can we improve the impact of AMVs in NWP?

Probably

One of main difficulties is that the errors are complicated and are spatially and temporally correlated.

Largest source is thought to be the height assignment.
Why do we care about height error?

The error in vector due to the height error can be significant, particularly in regions of high vertical wind shear.

Can also understand how a systematic height error can result in a systematic speed bias.
Vector is derived by tracking a target that contains many pixels

**First challenge** is to decide which pixels should be used for the height assignment

REMINDER

New location determined by best match of individual pixel counts of target with all possible locations of target in search area (use cross-correlation in Fourier domain).
Choice of pixels – what can go wrong….

Example courtesy of Jörgen Gustafsson, EUMETSAT
Second challenge is to decide what level (or layer) is most representative of the cloud motion?

Mostly the AMVs are assigned the pressure of the cloud top except …

some low level AMVs which are assigned an estimate of cloud base.

[Followed work by Fritz Hasler in the 1980s that showed that movement of marine trade wind cumulus was best correlated with the top of the marine boundary layer (cloud base)].

BUT

Should we really consider them as layer-average winds?
Third challenge is to calculate the cloud top pressure or estimate a cloud base pressure.

Two main approaches for cloud top pressure:

1. EBBT (equivalent black-body temperature)

Compares the measured brightness temperature to forecast temperature profiles from an NWP model to find the level of best-fit.

   **Advantage:** available everywhere

   **Disadvantage:** Will put semi-transparent or sub-pixel cloud too low due to radiance contributions from below the cloud.
2. Multi-channel – CO$_2$ slicing and WV intercept techniques

\[
\begin{align*}
R_{CO2/wv} - R_{CS}^{cs} & = E_{CO2/wv} \left[ R_{CO2/wv}^{bcd} (P_c) - R_{CO2/wv}^{cs} \right] \\
R_{IR} - R_{IR}^{cs} & = E_{IR} \left[ R_{IR}^{bcd} (P_c) - R_{IR}^{cs} \right]
\end{align*}
\]
Cloud base pressure

• estimated using the mean and standard deviation of the cloud cluster temperatures.

One final check applied by some producers…

Inversion correction

• If an inversion is present in the forecast profile and the AMV is low level then relocate the AMV to the level of the minimum temperature of the inversion.
In summary:

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

iii) Limitations of cloud top/base pressure methods

Can learn from cloud community

AMV specific problems
How do we improve the impact of AMVs in NWP?

AMV community meets biennially at the *International Winds Workshops (IWW)*

Most NWP centres have one person (if lucky) working on the AMVs – need to work together

1. Improve AMV data (reduce errors in $u$, $v$ and $p$)
2. Harmonise AMV processing between data producers
3. Improve AMV quality information provided with data
4. Improve assimilation strategy

To do this we need to improve our understanding of the AMVs and their errors
How can we investigate AMV errors?

1. O-B statistics studies (e.g. NWP SAF) and comparisons to sondes and aircraft winds

2. Comparisons to rawinsonde/model best-fit

3. Comparisons with other cloud top pressure products (e.g. MODIS, Calipso ...). Also consideration of other cloud properties (e.g. optical depth).

4. Analysis of AMVs overlain on imagery

Vector Difference, $i = \sqrt{(ObU - BgU_i)^2 + (ObV - BgV_i)^2}$

© Crown copyright 2007
NWP SAF AMV monitoring

NWP SAF – Numerical Weather Prediction Satellite Application Facility
A EUMETSAT-funded initiative

AMV Monitoring
Displays comparable AMV monitoring output from different NWP centres to help identify and partition error contributions from AMVs and NWP models.

Intended to stimulate discussion and to lead to improvements in AMV derivation and AMV use in NWP.

Analysis reports produced every 2 years.

http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report
Example, Sahara region

Meteosat-9 IR 10.8
O-B speed bias, Feb 2007
400-700 hPa

Mid level fast speed bias in winter

Associated with low height bias in best-fit statistics
EBBT puts high semi-transparent cloud too low. But why CO2 slicing not used more?

- Investigations at EUMETSAT highlighted problems in inversion regions, where can be more than one solution to CO₂ slicing.

- An amended decision strategy went operational on 22⁰ March 07 leading to reduction, but not elimination, of the fast speed bias over the Sahara.
CGMS-34 recommended activities

1. Inter-comparison of AMV operational algorithms using a common data set from MSG (all AMV producers).

2. Comparison of AMV height assignments with new measurements from instruments on the A-train (e.g. cloud lidar).

3. AMVs derived from simulated imagery – proposed plan involving ECMWF and EUMETSAT/CIMSS
Idea: Derive AMVs from sequences of images simulated from high-resolution model fields (clear and cloudy).

Advantage: “Truth“ is completely known. Comparison of derived AMVs with model wind field should allow better characterisation of AMVs and their errors.

Aspects that could be investigated:
1. Height assignment.
2. Which height should be estimated (cloud top/base/...?)
3. Observation operators for cloudy and clear AMVs.
4. EUMETSAT’s divergence product.
5. Influence of calibration/radiance biases.

Information from Bormann et al., IWW8

Met-8 6.2μm simulated from T2047 (~10 km) global model run using RTTOV-Cloud.
NWP quality control for AMVs

Extract all AMVs valid from 9z – 15z

460641
Extract all AMVs valid from 9z – 15z

1. Blacklisting
   • Apply QI thresholds
   • Spatial and temporal checks
   • Remove some satellite-channel combinations
Extract all AMVs valid from 9z – 15z

1. Blacklisting
   • Apply QI thresholds
   • Spatial and temporal checks
   • Remove some satellite-channel combinations

2. Thinning
   • one wind per 200 km x 200 km x 100 hPa box.

3. Background check
   • Remove if deviates too far from background.

Assimilate only a small percentage of the data: 9626 / 2%
NWP quality control for AMVs

Met-9 TR IR winds, above 400 hPa, July 2007

All received (985,236)  
\[\text{rms} = 4.9 \text{ m/s}\]

QI\(>80\) (646,134)  
\[\text{rms} = 4.1 \text{ m/s}\]

Used (6,598)  
\[\text{rms} = 2.6 \text{ m/s}\]

Current thinning and quality control strategy is very wasteful.
Observation errors

At most centres vary only with pressure (at Met Office: 2.8-6.6 m/s) – based on O-B statistics (but inflated).

Observation operator

Treated as point observations in space and time (although neither are true).
1. Can we learn more about the impact of AMVs in NWP?

2. Can we use what we learnt from the O-B monitoring, best-fit pressure statistics and other investigations to help improve our blacklisting and errors?

3. Should we develop a new observation operator to treat the winds as layer observations?

4. Is there a better way to handle spatial error correlations than thinning and inflated errors?
NRL are using an adjoint approach (see Nancy Baker’s talk) to identify where the data has most good/bad impact.

Adjoint investigations

101–300 hPa NAVDAS ADJ SatWind U–comp Mean Observation Impact [*1000]
30–Day SATWIND_51 MET07 IR, VT 2007062300–2007072200
Min, Max: −2.31, 4.742 Mean: 0.00175, SDEV: 0.206, Sum: 0.01914

© Crown copyright 2007

Positive impact
Negative impact

 Courtesy of Nancy Baker (NRL) and Howard Berger (CIMSS)
Improving the AMV assimilation

1. Can we learn more about the impact of AMVs in NWP?

2. Can we use what we learnt from the O-B monitoring, best-fit pressure statistics and other investigations to help improve our blacklisting and errors?

3. Should we develop a new observation operator to treat the winds as layer observations?

4. Is there a better way to handle spatial error correlations than thinning and inflated errors?
Observation errors

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

Current observation errors vary only with pressure.

New approach
Take into account…..
• Errors are variable and becoming better understood.
• Height assignment error often dominates, but is not a problem in regions of low wind shear.

AMV error = Error in vector + Error in vector due to error in height

For this we need an estimate of:
1. Vector error
2. Height error

Ideally from data producers
Until vector error estimate provided by producers, we can estimate based on the model-independent quality indicator.

**Example**

At QI=80, Vector error=2.3 m/s
Height error estimate (Ep)

We may be able to use best-fit pressure statistics as a guide to generate height errors as a function of satellite / channel / height assignment method and pressure level.

Can look at observed - model best-fit pressure distributions (black curves).

1. Fairly Gaussian
2. Mostly unbiased

In cases with larger height bias can consider spatial blacklisting.

Elsewhere can use rms of distribution as proxy for the height error (this will contain a contribution from the error in best-fit).
Error in vector due to error in height (Evp)

\[ Evp = \sqrt{\sum W_i (v_i - v_n)^2} \]

where \[ W_i = e^{-\frac{(p_i - p_n)^2}{2E_p^2}} \frac{dP_i}{\sum W_i} \]

- \( E_vp \) = Error in vector due to error in height
- \( E_v \) = Vector error
- \( E_vp \) = Error in vector due to error in height

Example

Total Error = \( E_v + E_vp \)

\[ = 2.3 + 1.6 \]

\[ = 3.9 \text{ m/s} \]

\( P_n = 350 \text{ hPa} \)
\( E_p = 100 \text{ hPa} \)
\( E_v = 14.2 \text{ m/s} \)
\( E_v = 14.2 \text{ m/s} \)

\( P_n = 660 \text{ hPa} \)
\( E_p = 80 \text{ hPa} \)
\( E_v = 12.8 \text{ m/s} \)
\( E_v = 12.8 \text{ m/s} \)

\( E_p = 60 \text{ hPa} \)
\( E_v = 11.0 \text{ m/s} \)
\( E_v = 11.0 \text{ m/s} \)

\( E_p = 100 \text{ hPa} \)
\( E_v = 3.0 \text{ m/s} \)
\( E_v = 3.0 \text{ m/s} \)

\( E_p = 80 \text{ hPa} \)
\( E_v = 1.6 \text{ m/s} \)
\( E_v = 1.6 \text{ m/s} \)

\( E_p = 60 \text{ hPa} \)
\( E_v = 0.9 \text{ m/s} \)
\( E_v = 0.9 \text{ m/s} \)
Observation errors – new approach examples

OLD ERRORS

NEW ERRORS
How good are the new errors?

Should see a positive correlation with O-B rms

**BUT** O-B RMS will contain a contribution from background error.

Fairly encouraging result
New observation errors – impact experiment

Small impact – Met Office NWP index of +0.2 (compare with 1.5 for all AMVs).

But running with own estimates of vector and height errors (may benefit from further tuning). Would expect more impact if error estimates provided by producers with each wind.
Improving the AMV assimilation

1. Can we learn more about the impact of AMVs in NWP?
2. Can we use what we learnt from the O-B monitoring, best-fit pressure statistics and other investigations to help improve our blacklisting and errors?
3. Should we develop a new observation operator to treat the winds as layer observations?
4. Is there a better way to handle spatial error correlations than thinning and inflated errors?
AMVs are produced by tracking all the pixels in the target, although only some will dominate in the cross-correlation.

The cloud or WV feature also has a finite thickness, in case of CSWV can be 100’s hPa thick.

Should we therefore represent them as layer observations?

**Observation Operator**

**BUT** not trivial

- Placement of layer operator
- Width of layer operator
- Shape of layer operator

Investigations ongoing at CIMSS (Velden & Bedka)

*Improved Representation of Satellite-Derived Atmospheric Motion Vectors by Attributing the Assigned Heights to Tropospheric Layers (draft)*
Improving the AMV assimilation

1. Can we learn more about the impact of AMVs in NWP?

2. Can we use what we learnt from the O-B monitoring, best-fit pressure statistics and other investigations to help improve our blacklisting and errors?

3. Should we develop a new observation operator to treat the winds as layer observations?

4. Is there a better way to handle spatial error correlations than thinning and inflated errors?
Spatial Error Correlations

Study by Bormann et al., 2003 (MWR, 131, 706-718) using a 1-yr dataset of AMV-radiosonde collocation pairs showed statistically significant spatial error correlations for distances up to ~800 km.

BUT

NWP systems assume uncorrelated error to reduce computation.

To alleviate problems, data is thinned and errors inflated.

New techniques to allow for correlated error are being considered at some centres (e.g. ECMWF), which would allow data to be used at higher resolution.
AMVs for mesoscale applications

By tracking smaller targets and using small imager intervals it is possible to derive high resolution AMV datasets reflecting the motion of smaller scale features of the flow.

Applications:

1. Tropical Cyclone studies
2. Input to convective initiation nowcasting
3. Assimilation in mesoscale NWP models

From Velden et al, 2005
(Top) GOES-12 VIS imagery of Hurricane Isabel on 12 Sep 2003.
(Bottom) Low level AMVs in Isabel’s eye derived from 3-min interval VIS imagery

© Crown copyright 2007
AMVs for mesoscale applications

By tracking smaller targets and using small imager intervals it is possible to derive high resolution AMV datasets reflecting the motion of smaller scale features of the flow.

Applications:

1. Tropical Cyclone studies
2. Input to convective initiation nowcasting
3. Assimilation in mesoscale NWP models

From Bedka and Mecikalski, 2005

Mesoscale AMVs overlaid on GOES-12 VIS imagery centred on developing convection over NE Kansas. Green - 1000–700 hPa, blue - 700–400 hPa and purple - 400–100 hPa. Blue arrows highlight mid tropospheric diffluence in the vicinity of the mature convection.
AMVs for mesoscale applications

By tracking smaller targets and using small imager intervals it is possible to derive high resolution AMV datasets reflecting the motion of smaller scale features of the flow.

Applications:

1. Tropical Cyclone studies
2. Input to convective initiation nowcasting
3. Assimilation in mesoscale NWP models

BUT spatially and temporally correlated error so hard to use data at full resolution.

Routine 5 minute interval rapid scan winds over Europe (Meteosat-8) from 2008
Derived products from AMVs

AMVs can be used to derive various fields including vorticity and divergence.

EUMETSAT are producing a tropical divergence product from the Meteosat-9 WV 6.2 AMVs.

Scale of features only 300-500 km. (AMVs thinned in 2° by 2° boxes).

Could be used for nowcasting and validation.

Tropical divergence
From Schmetz et al., IWW7, 2004

Evolution of divergence pattern
13 May 2004
0815 – 2115
From Schmetz et al., IWW8, 2006
• EUMETSAT have reprocessed old satellite imagery to produce higher quality and higher resolution AMVs to support reanalysis projects e.g. ERA-40.

6th Feb 1989
Reprocessed: 96615

Original: 4345

From Claire Delsol, ECMWF

From Sakari Uppala, ECMWF

Meteosat
Reprocessed winds

• CIMSS are producing a 20-year AVHRR polar AMV dataset for assimilation in future reanalyses to help address the Arctic wind field errors in NCEP/NCAR and ECMWF reanalysis products (Dworak et al., 2006, IWW8).
The Present: summary

1. Current AMV assimilation is wasteful and quite crude.

2. Strategies to improve the assimilation include:
   - Individual errors
   - Observation operator changes to treat as layer
   - Allowance for spatially correlated error in VAR

3. We would benefit from:
   - Harmonisation of AMV derivation methodology
   - More information on AMV quality sent with each wind e.g. vector and height errors.

4. Various investigations (e.g. NWP SAF AMV monitoring, simulated data study) should continue to teach us more about the AMVs and their errors potentially leading to improvements in the AMV data.

5. AMVs can also be used for mesoscale studies, derived products and reanalysis.
The Future
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.
Maintaining the AMV observations

Ideally minimum of

- 5 geostationary
- 2 polar

Maintain good channel range on imagers (IR, VIS, WV, CO₂).

One concern is lack of a WV channel on polar imagers after MODIS until at least 2016.
Other wind observations for the future

Doppler Wind Lidar Winds

**Timescale:** 2009

ADM-Aeolus 3 year mission (ESA)

Provide *wind profiles*

Expect positive impact on forecast quality (Tan and Andersson, 2005; Stoffelen et al., 2006)

**BUT**

1. Limited horizontal coverage
2. Only cross-track component of wind
Other wind observations for the future
Hyperspectral sounder winds

**Timescale:** 2015-2020

- Advanced IR sounders on future geostationary platforms will have more and sharper weighting functions.
- Can use the sounder data to derive high vertical resolution moisture analyses in clear sky areas.
- Wind profiles can be derived by applying AMV tracking techniques to sequences of moisture analyses on different levels.
- Resulting winds should have more reliable heights than traditional AMVs.
Can also get wind information by assimilating cloud/moisture information in 4D-Var, but need to represent cloud well and horizontal and temporal resolution limited by analysis. Therefore AMVs likely to remain useful for many years.
AMV assimilation versus radiance assimilation

Can also get wind information by assimilating cloud/moisture information in 4D-Var, but need to represent cloud well and horizontal and temporal resolution limited by analysis. Therefore AMVs likely to remain useful for many years.
1. Wind observations will remain important for NWP.

2. Future tropospheric wind data likely to be provided by sondes, aircraft, wind profilers, AMVs, Doppler Wind Lidar and potentially hyperspectral sounder winds.

3. Direct assimilation of cloudy radiances may one day make AMVs redundant, but this is unlikely to happen for many years.
1. AMVs were first produced in real-time in the 1970s, but since this time the data volume, coverage and quality has markedly increased.

2. Impact experiments show benefit to forecast accuracy and hurricane track forecasts.

3. A major limitation is the complicated and spatially correlated errors. It is important to consider what AMVs are representative of and to go back to fundamentals to understand error characteristics.

4. Greater benefit of AMVs in NWP should be possible through:
   - Improvements to data
   - More information on quality and representivity
   - Improvements to assimilation strategy

Any Questions?