Understanding AMV errors using a simulation framework

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Met Office

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Background: Atmospheric Motion Vectors (AMVs)

- Wind retrievals from satellite imagery
  - actually observations of apparent cloud motion

- Method:
  - Feature detection and tracking between consecutive images
  - Height Assignment performed (usually assume AMV represents winds at estimated cloud top height)

- Vertical representivity:
  - Much discussion about whether AMVs are representative of winds at cloud top or in fact representative of winds within cloud.
  - Current NWP observation operators assume AMV represents wind at single height.

- Simulation studies:
  - Several previous studies: is this technique capable of providing useful insights into AMV representivity which give real world improvements?

Motivation: Latest generation of NWP models have very realistic representation of cloud features

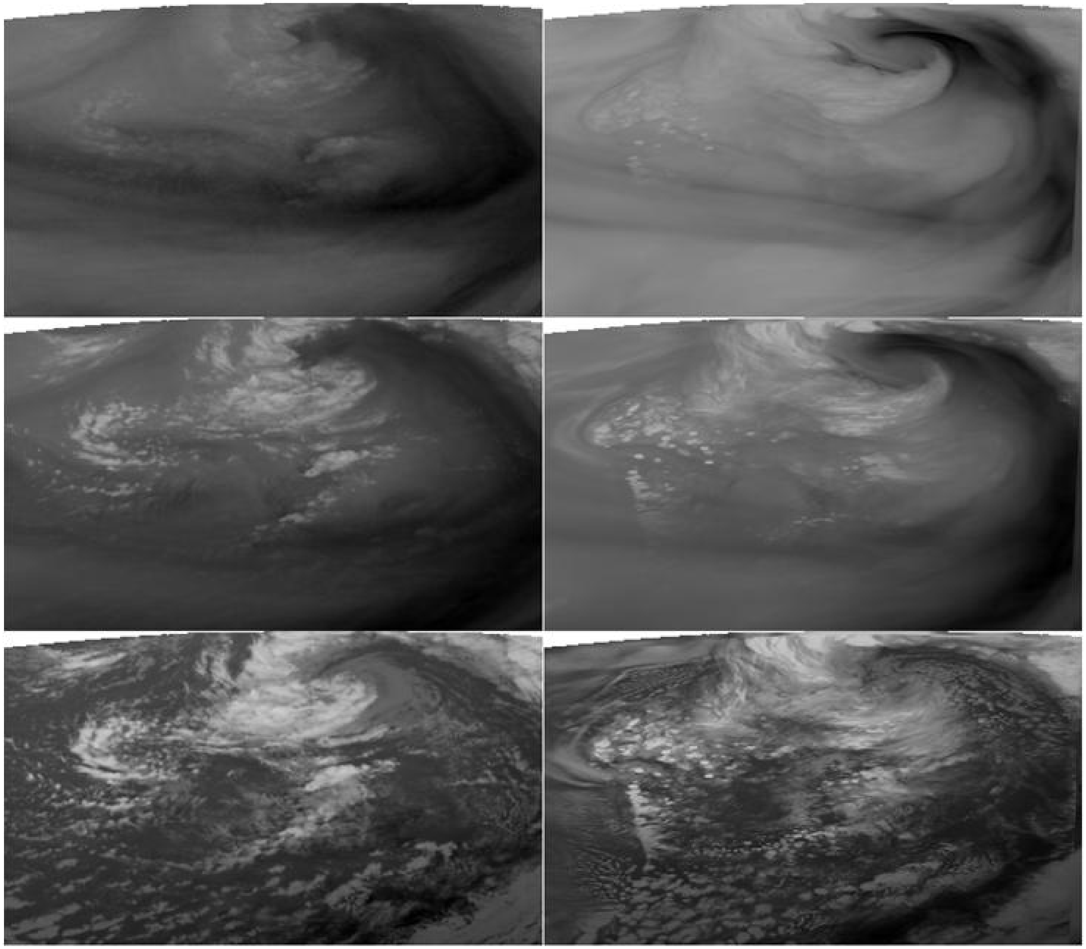
MSG SEVIRI Q. which is real?

Met Office

6.2µm

7.3µm

8.7µm



Robert Tubbs

Aims:

1. Understand vertical representivity of AMVs to help design an improved observation operator for assimilation in NWP models.

2. Compare and contrast simulation study results against standard O-B stats to understand how useful this technique is.

3. Determine if AMV error characteristics depend on cloud type.

Talk outline:

1. AMV error budget
2. Experiment setup
3. How realistic are the experiments?
4. AMV error characteristics
5. Testing different vertical representivity assumptions
6. NWP assimilation trial
7. Conclusions

AMV error budget

AMV error budget

Misfit between AMVs and model background:

AMV vector

obs operator

Background forecast

Misfit O - B

Assigned height (estimated cloud top height)

$$\mathbf{d} = f\,(\varepsilon_y , \varepsilon_H , \varepsilon_{xf} , \varepsilon_{passign})$$

$$\varepsilon_{passign} = g\,(\varepsilon_{instrument} , \varepsilon_{xf} , \varepsilon_{technique})$$

ε_y - tracking error

ε_H - observation operator error
= error in assumptions of vertical representivity

ε_{xf} - background forecast error

$\varepsilon_{passign}$ - error in estimated cloud top

Synthetic AMV error budget

Misfit between synthetic AMVs and model truth:

Errors $\boldsymbol{\varepsilon} = \mathbf{y} - H(\mathbf{x}_t, p_{assign})$

$\boldsymbol{\varepsilon} = f(\varepsilon_y, \varepsilon_H, \varepsilon_{xt}, \varepsilon_{passign})$

$\varepsilon_{passign} = g(\varepsilon_{RTTOV}, \varepsilon_{xt}, \varepsilon_{technique})$

Forecast errors removed

Instrument errors removed

Height assignment errors changed

For simulation study to be useful:

$\varepsilon < \mathbf{d}$

i.e. AMVs should be closer fit to model truth than in O-B (which includes forecast and instrument errors).

Cloud top height estimation techniques are very sensitive to cloud properties:

error characteristics from simulated radiances from model clouds may be different from those for real clouds

Experiment set up

Simulation framework

- Building upon previous AMV simulation studies:
  - Wanzong et al (2006)
  - von Bremen et al (2008)
  - Stewart and Eyre (2012)
  - Hernandez-Carrascal et al (2012)

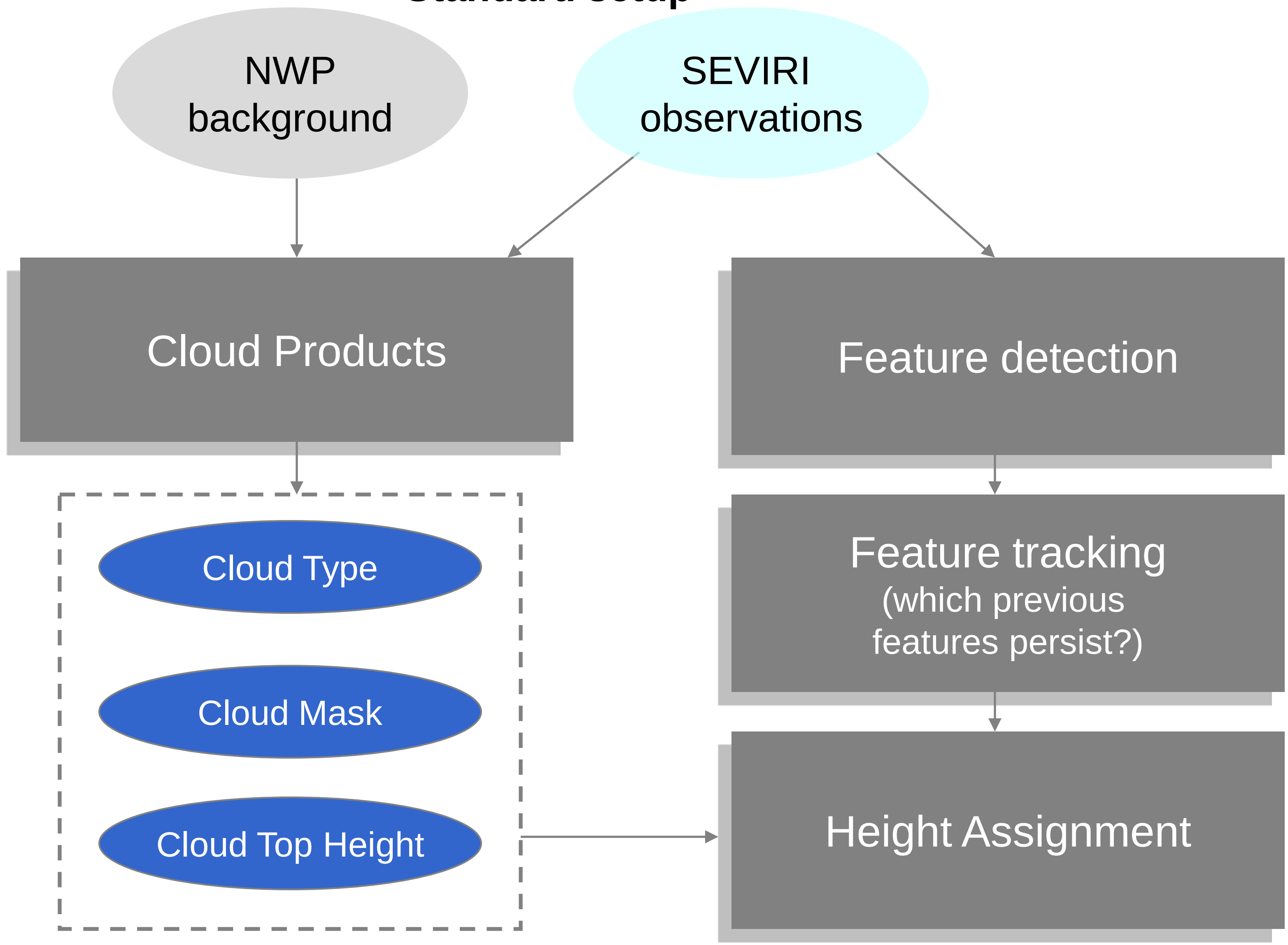
- Met Office UKV model
  - 1.5km grid length NWP model

- RTTOV 11 radiative transfer
  - produces simulated brightness temperatures from model prognostic fields using parameterized treatment of cloud scattering.

- Nowcasting SAF (NWCSAF) cloud and AMV products
  - produces AMVs from the simulated satellite imagery.

NWCSAF AMV workflow

Standard setup

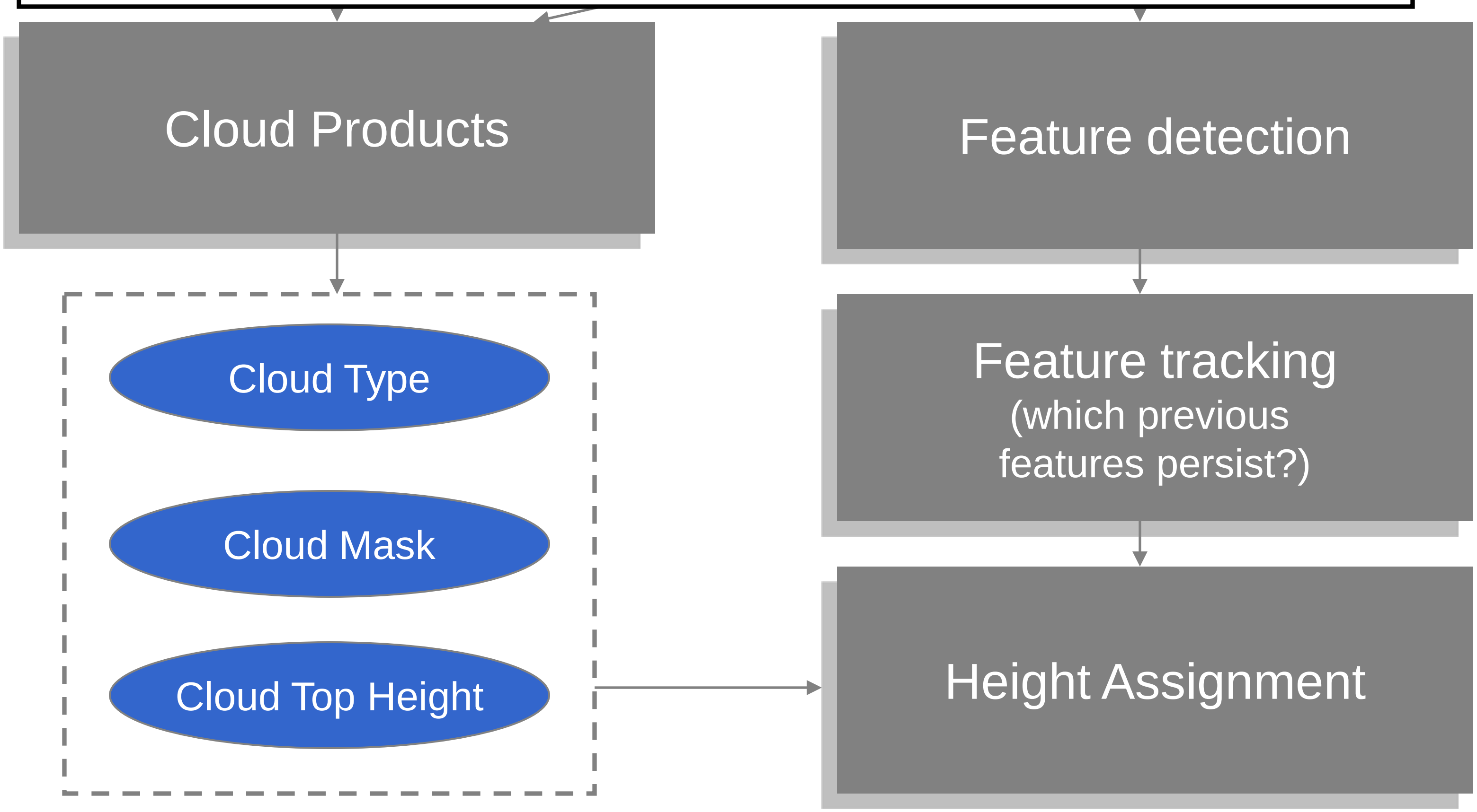


NWCSAF AMV workflow

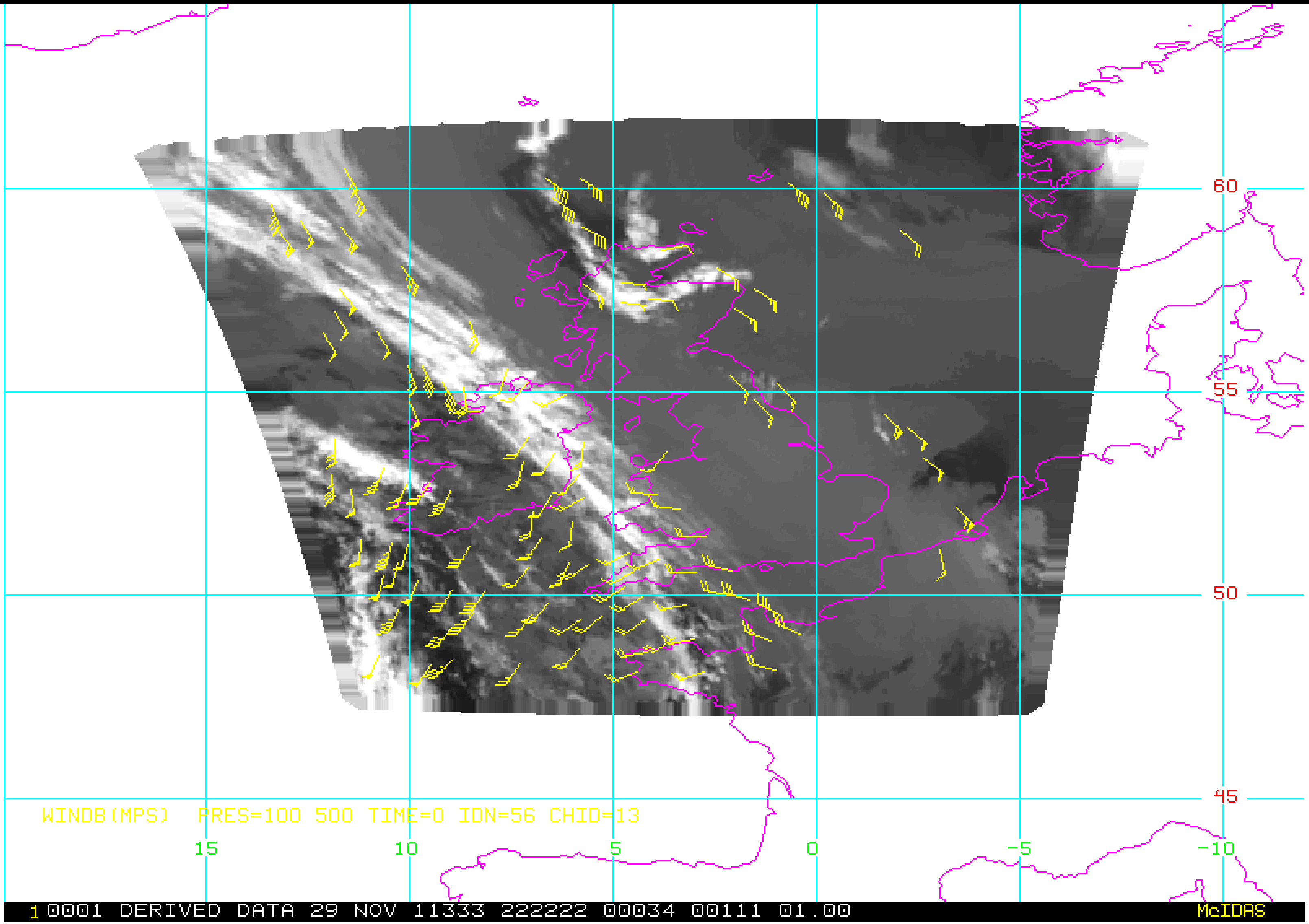
4 week suite: Feb 5th – March 5th 2013

UKV ran daily from 03z to t+22h (PS32 components)

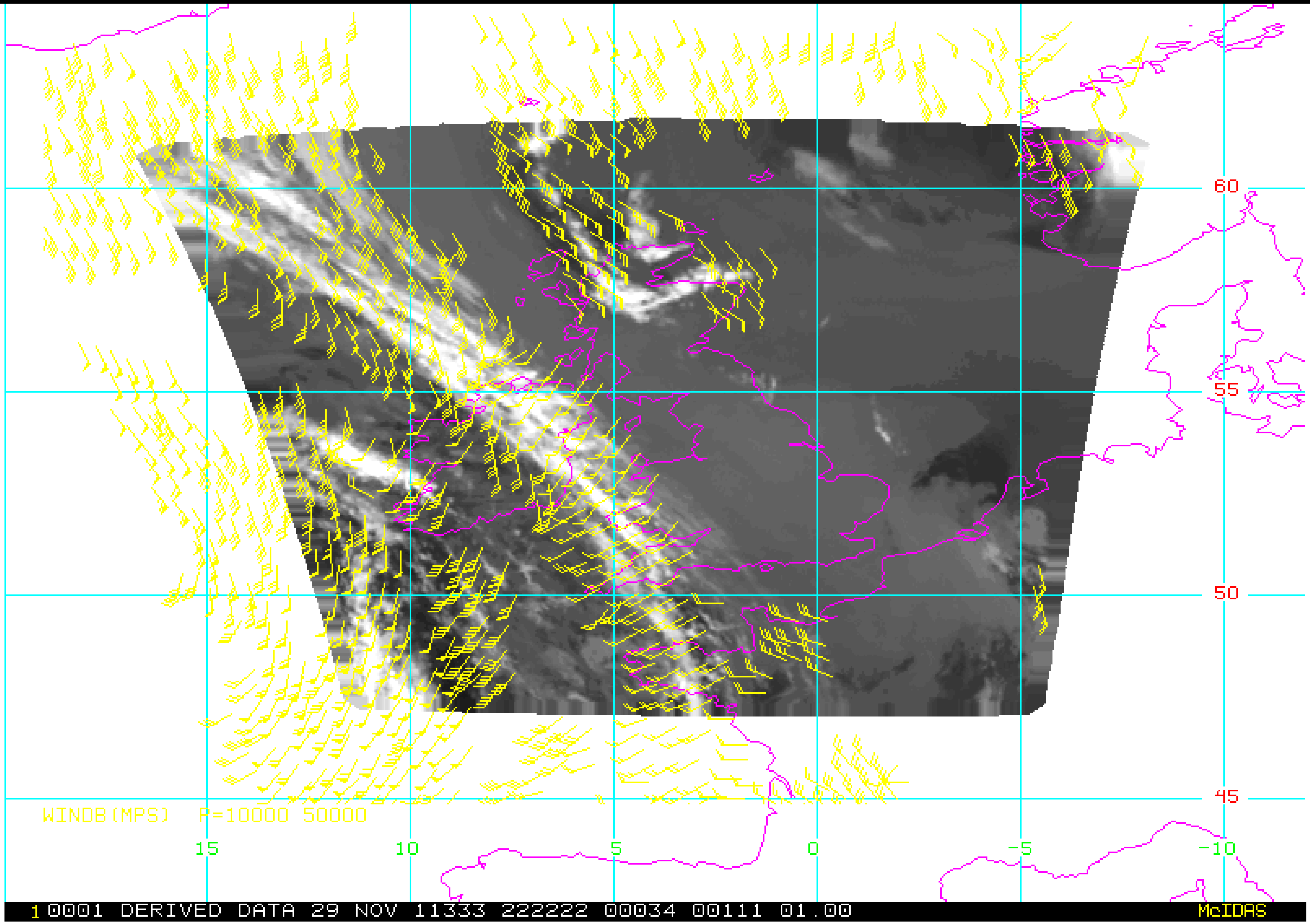
RTTOV11 run on model data at 23:45, 00:00 and 00:15 each day



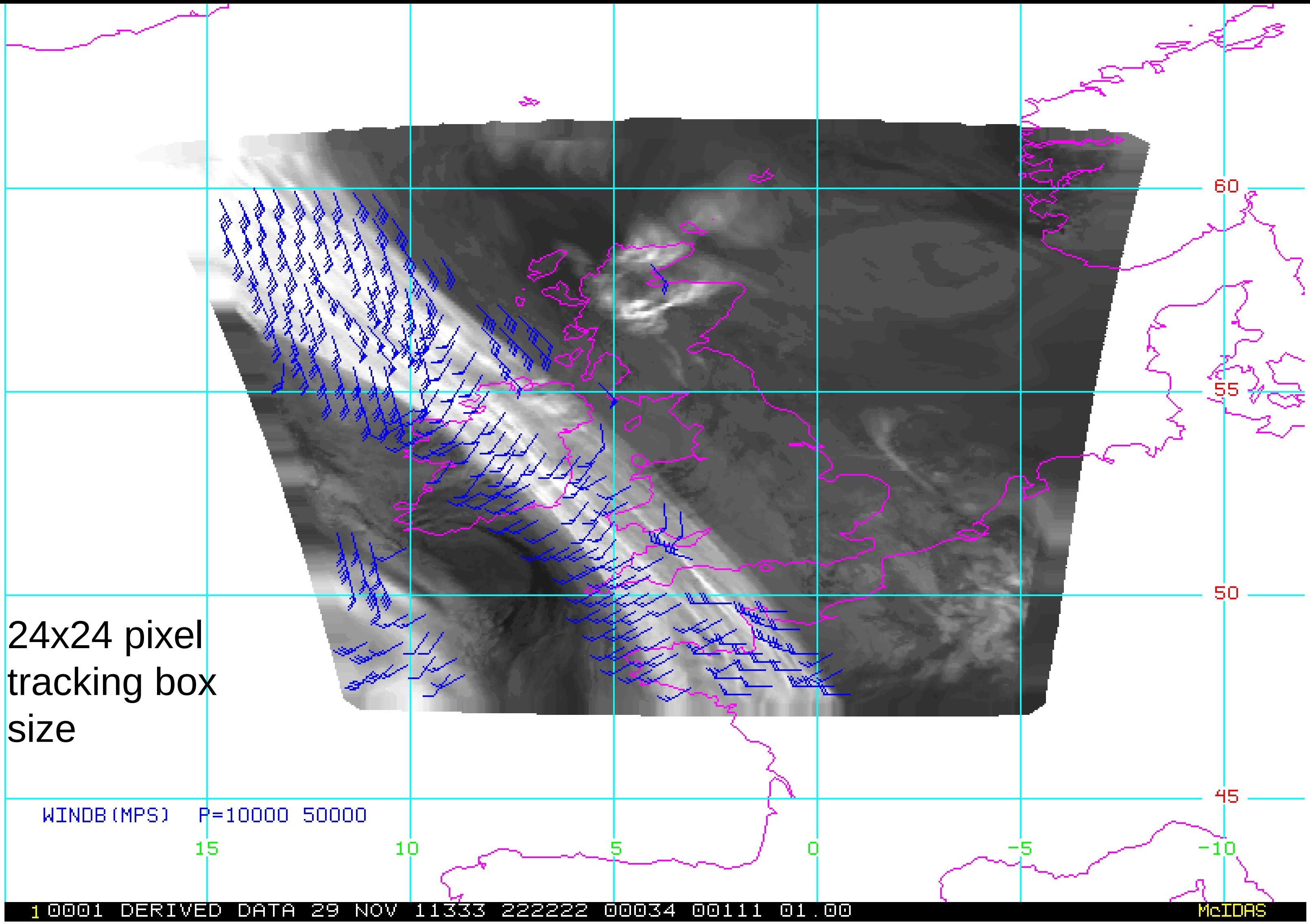
EUMETSAT AMV product



NWCSAF mesoscale AMV product (AEMET)

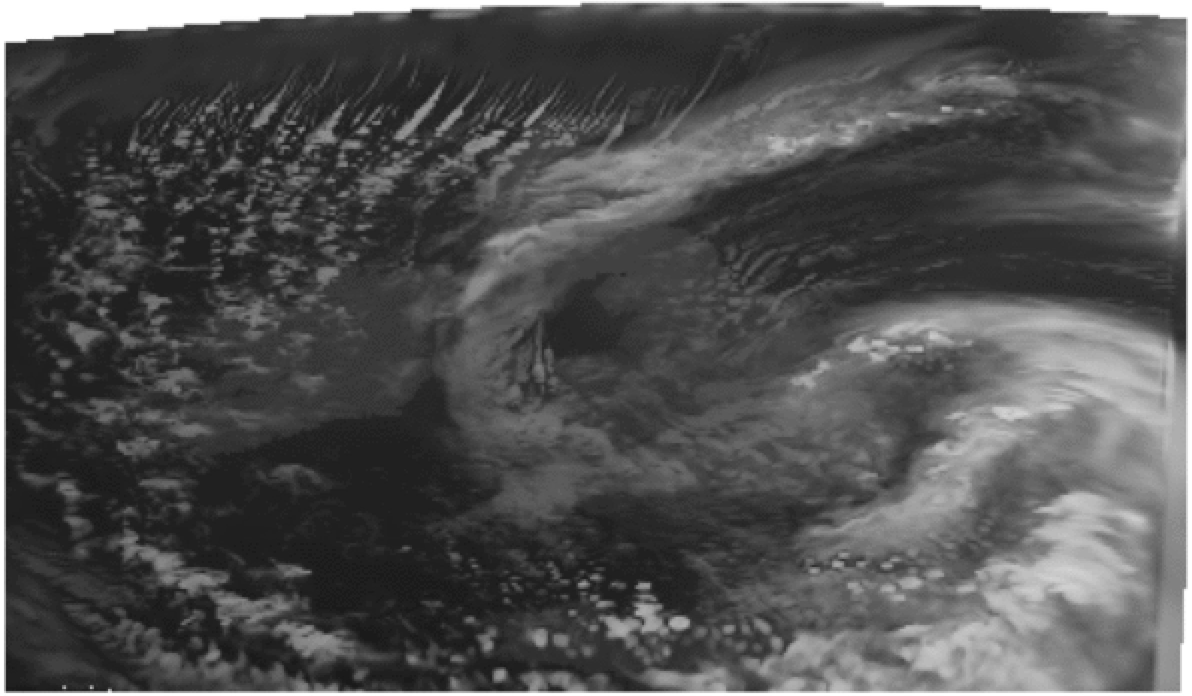


Synthetic high resolution AMVs



24x24 pixel tracking box size

Trial period: simulated brightness temperatures

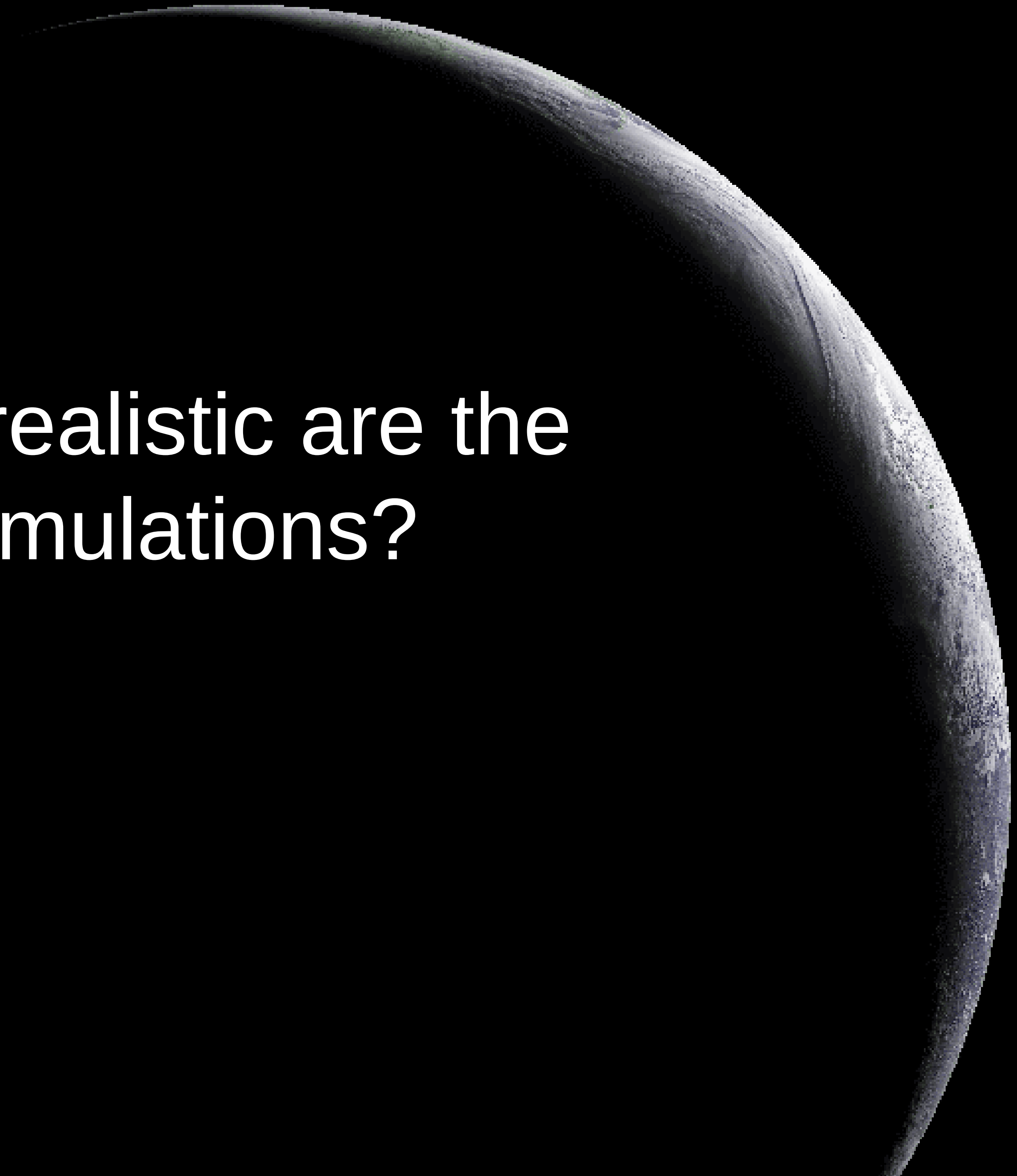


Wide range of meteorological situations sampled:

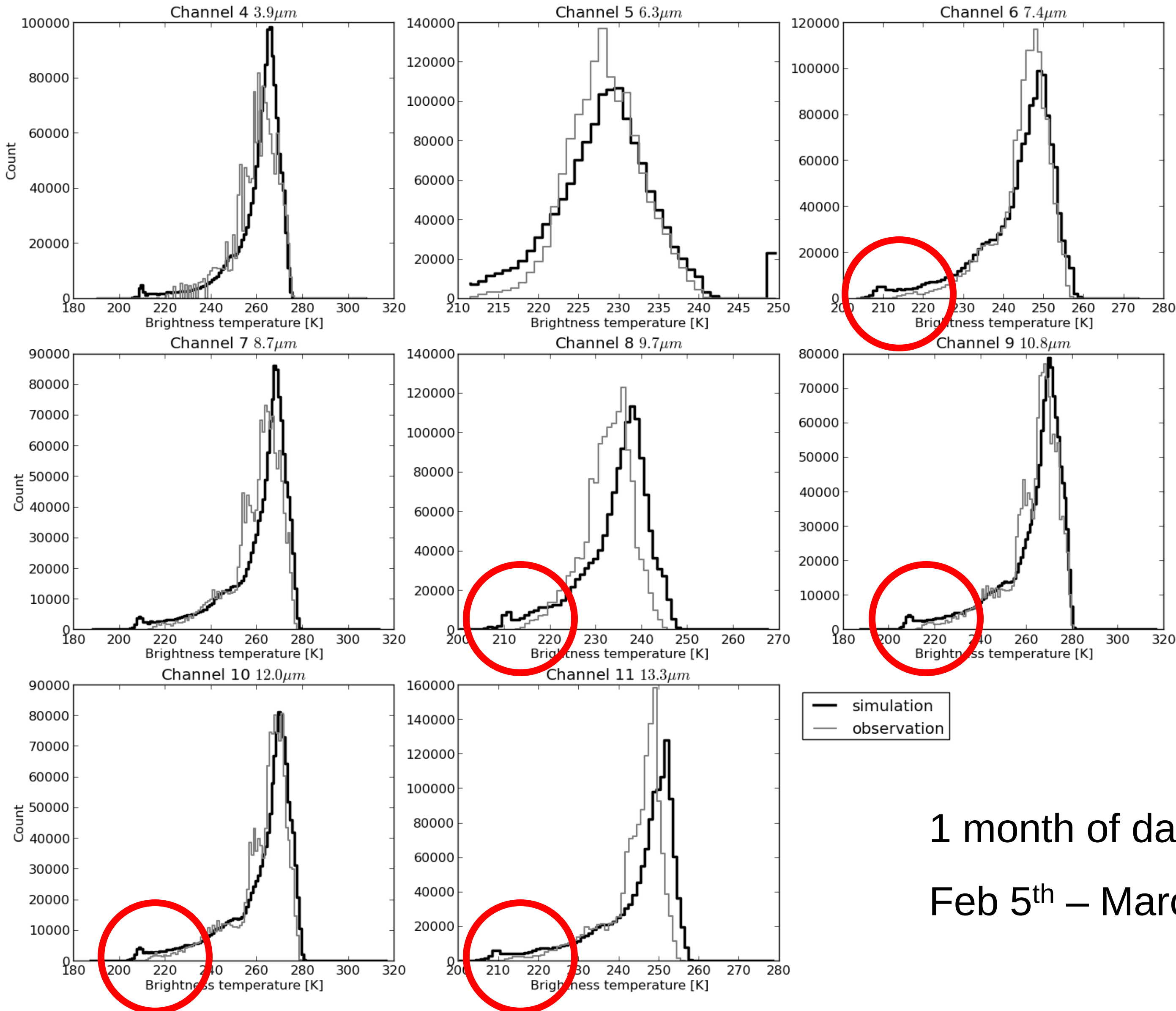
-maritime convection, frontal cloud, thin cirrus, stratocumulus over inversion etc

-6 weeks: long period of study compensates for relatively small domain

How realistic are the simulations?



Realism of simulated brightness temperatures



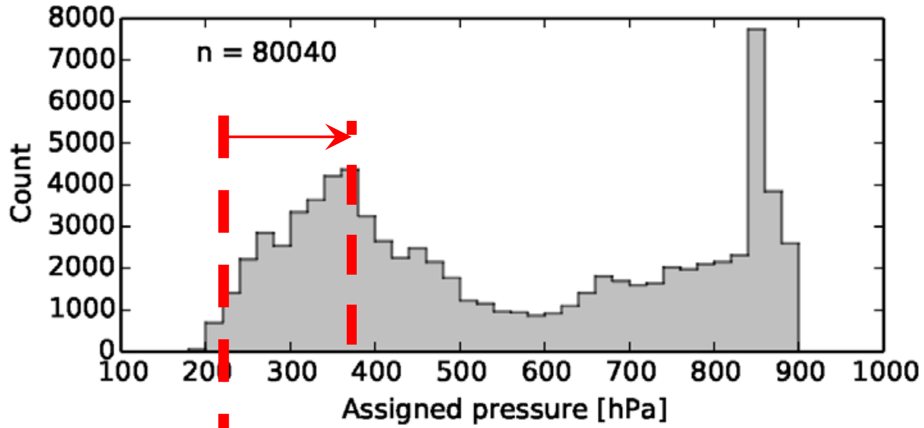
Tendency for more cold pixels in simulations

(cirrus)

1 month of data:

Feb 5th – March 5th, 2013

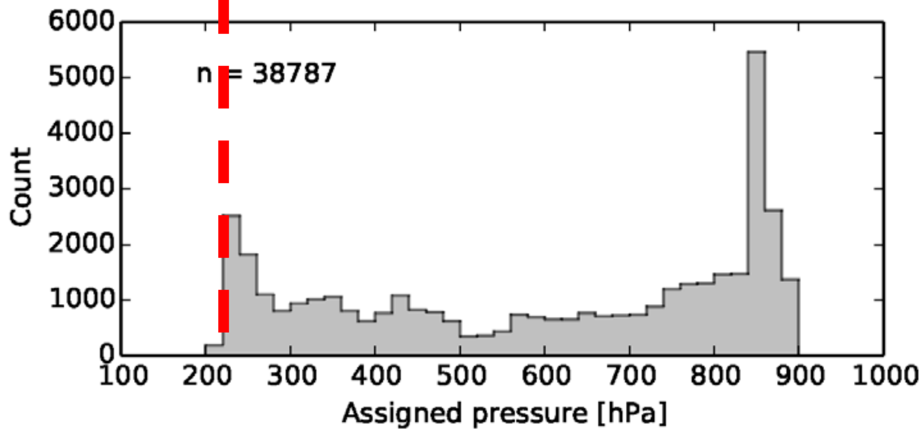
Realism of simulated AMVs: distribution of assigned heights



Real AMVs

Not as many AMVs from upper level clouds in simulations

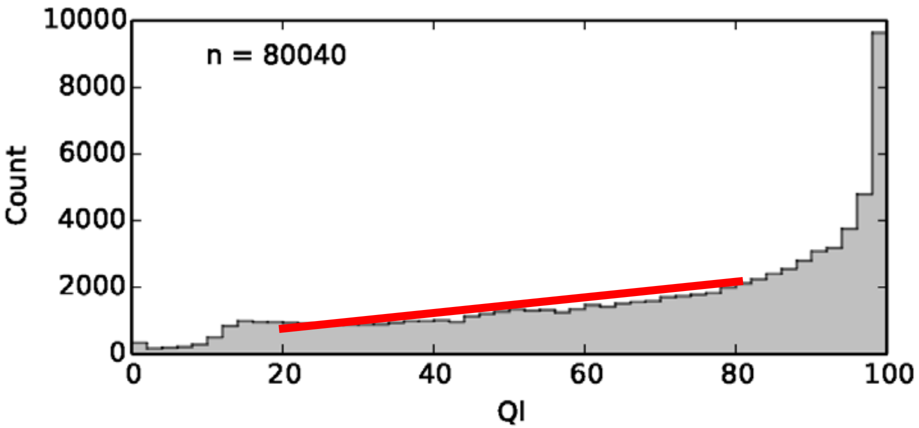
Cirrus peak too high



Synthetic AMVs

Realism of simulated AMVs: distribution of QI values

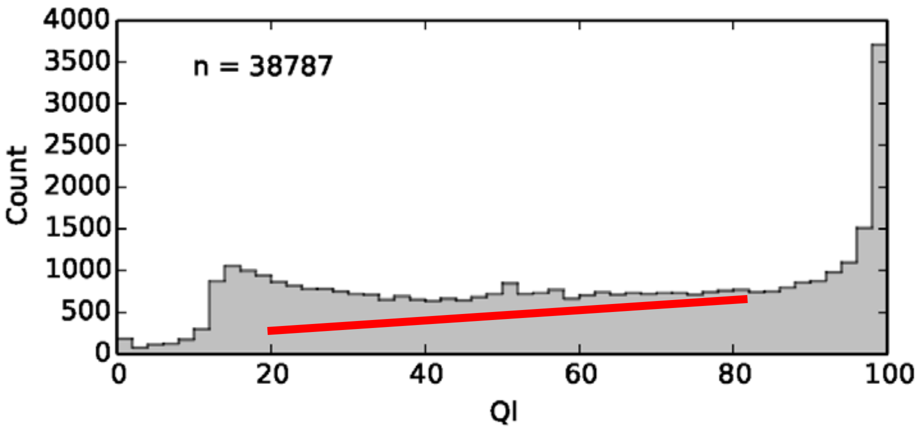
Used QI **without** model background consistency check



Real AMVs

More AMVs with low QI values in simulated dataset

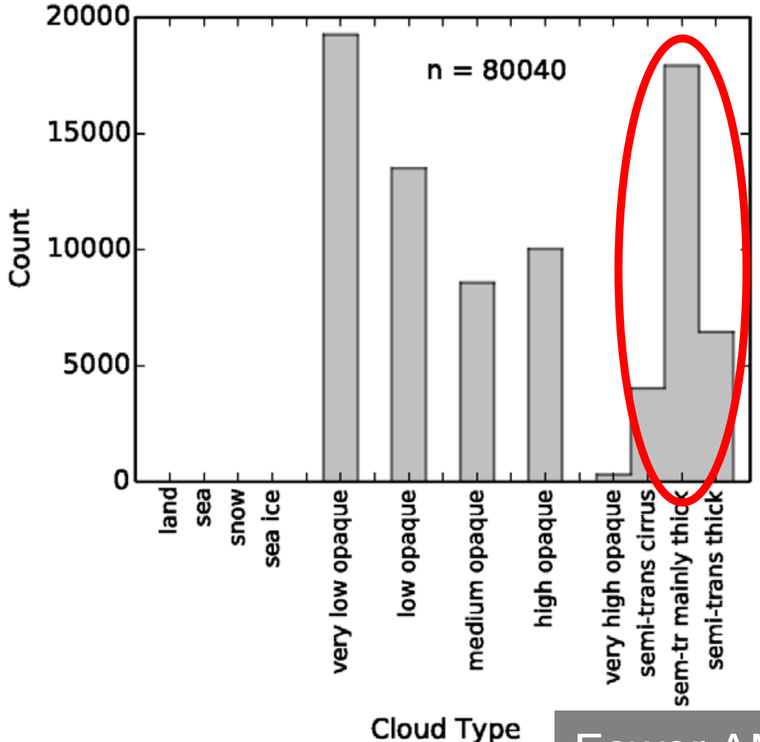
= increased tracking errors?



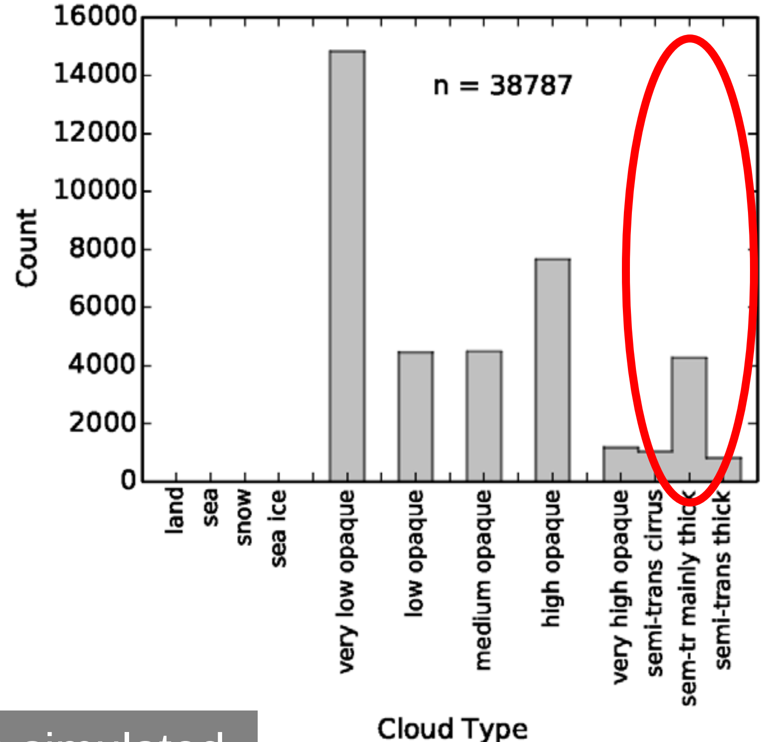
Synthetic AMVs

Realism of simulated AMVs: distribution of cloud types

Real AMVs



Synthetic AMVs



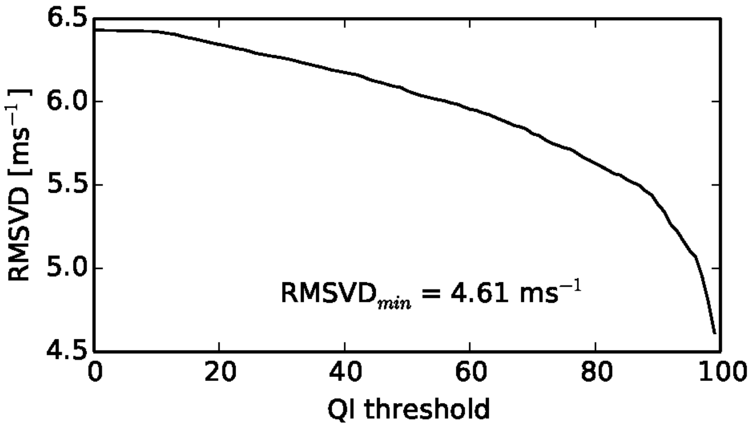
Fewer AMVs in simulated dataset, particularly from thin cirrus clouds.

-fewer trackable features

Error characteristics of AMVs: real v simulations

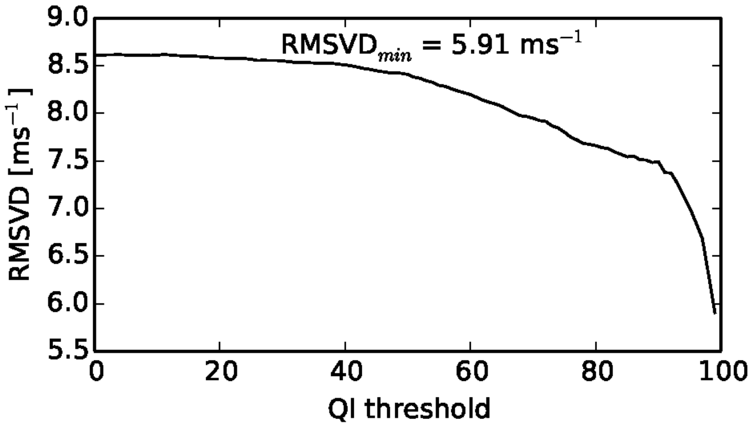
Error as function of QI threshold

Used QI **without** model background consistency term



Real AMVs

QI is a provides a good estimate of AMV errors.

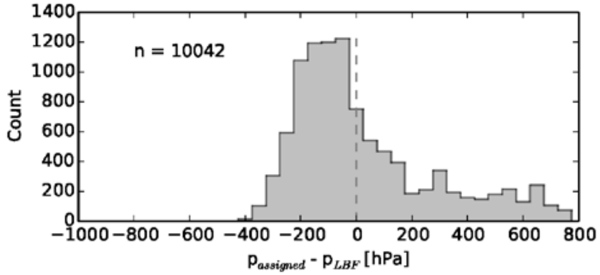


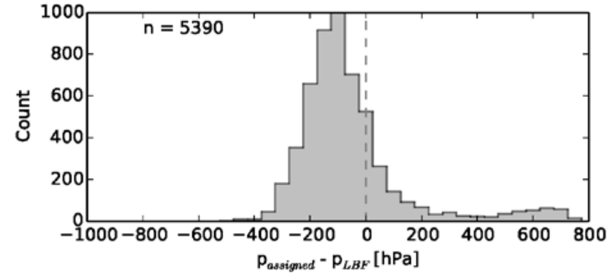
Synthetic AMVs

Level of best fit stats:

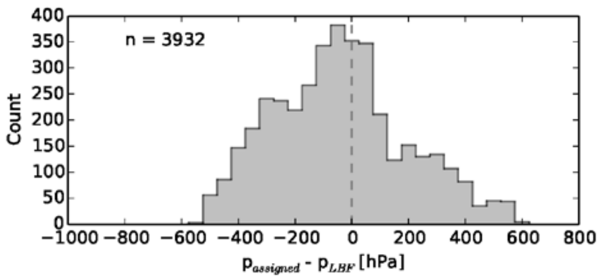
real v simulated

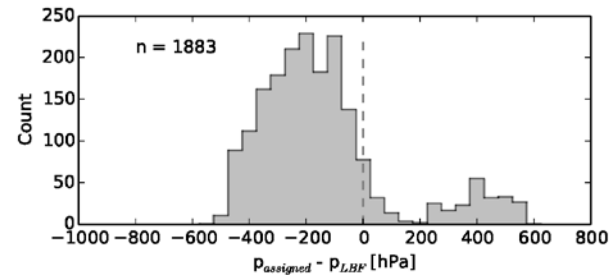
low



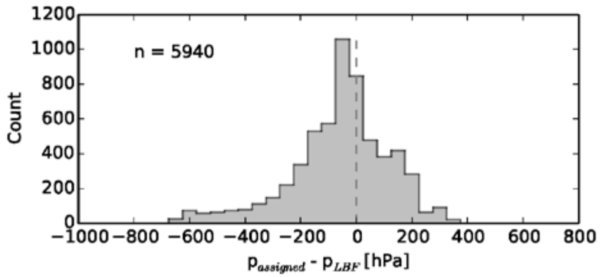


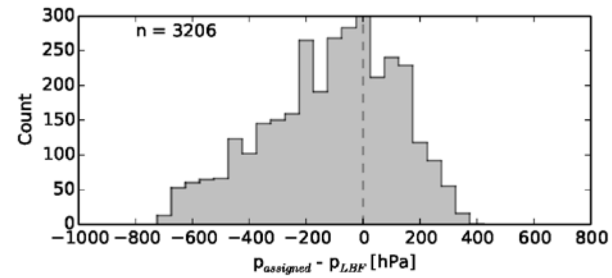
medium



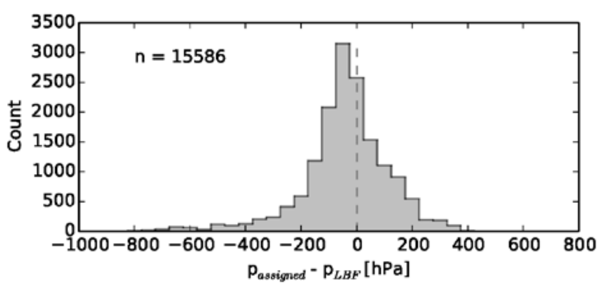


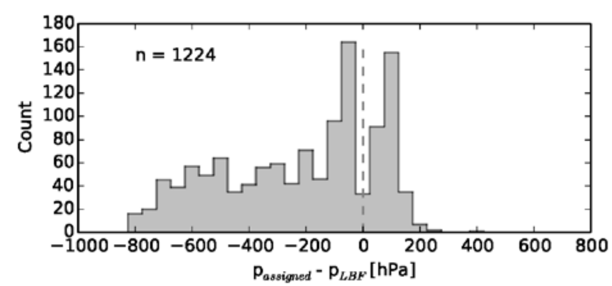
high





semi-transparent

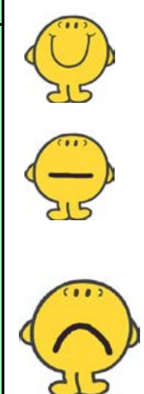




Misfit between AMV and model: simulated v O-B

QI>80

Cloud category	Simulated		Real	
	RSMVD $[ms^{-1}]$	**Bias** $[ms^{-1}]$	**RMSVD** $[ms^{-1}]$	**Bias** $[ms^{-1}]$
Low opaque	**3.97**	-1.66	4.69	**-0.56**
Medium opaque	5.67	-2.94	**5.34**	**-1.08**
High opaque	9.95	-3.73	**6.54**	**-2.50**
High semi-transparent	13.53	-7.64	**5.88**	**-1.27**



includes forecast error and instrument error

Q. Why are the simulated errors so large?

Due to increased height assignment errors or tracking errors?

Misfit between AMV and model **at level of best fit**

QI>80

Errors **at level of best fit**:

Cloud category	Simulated		Real	
	RSMVD [ms^{-1}]	**Bias** [ms^{-1}]	**RMSVD** [ms^{-1}]	**Bias** [ms^{-1}]
Low opaque	**1.37**	-0.19	1.55	**-0.05**
Medium opaque	**1.41**	-0.15	1.63	**-0.06**
High opaque	2.43	0.07	**2.12**	**0.04**
High semi-transparent	**1.98**	**-0.16**	2.19	0.20

Strongly suggests that height assignment errors are increased for simulated high clouds.

If increased error in simulated AMVs was due to increased tracking error: wouldn't expect to find a good fit at any level.

If increased error in simulated AMVs was due to increased height assignment error: expect there would be some height which gives a good fit.

Synthetic AMV error budget

Real 'O-B'	Simulated 'Obs-Truth'
$\mathbf{d} = \mathbf{y} - H(\mathbf{x}_f , p_{assign})$	$\boldsymbol{\varepsilon} = \mathbf{y} - H(\mathbf{x}_t , p_{assign})$
$\mathbf{d} = f(\varepsilon_y , \varepsilon_H , \varepsilon_{xf} , \varepsilon_{passign})$	$\boldsymbol{\varepsilon} = f(\varepsilon_y , \varepsilon_H , \varepsilon_{passign})$
$\varepsilon_{passign} = g(\varepsilon_{instrument} , \varepsilon_{xf} , \varepsilon_{technique})$	$\varepsilon_{passign} = g(\varepsilon_{RTTOV} , \varepsilon_{technique})$

For simulation study to be useful:

$$\varepsilon < \mathbf{d}$$

We have shown:

- **ε < d for low clouds: simulation study is useful.**
- **ε > d for high clouds:**
  - primarily due to increased $\varepsilon_{passign}$, most likely from $\varepsilon_{technique}$
  - simulation study results for these clouds not useful.

Vertical representivity assumptions

ε_H

Synthetic AMV error budget

Real 'O-B'

$\mathbf{d} = \mathbf{y} - H(\mathbf{x}_f , p_{assign})$

$\mathbf{d} = f(\varepsilon_y , \varepsilon_H , \varepsilon_{xf} , \varepsilon_{passign})$

$\varepsilon_{passign} = g(\varepsilon_{instrument} , \varepsilon_{xf} , \varepsilon_{technique})$

Simulated 'Obs-Truth'

$\boldsymbol{\varepsilon} = \mathbf{y} - H(\mathbf{x}_t , p_{assign})$

$\boldsymbol{\varepsilon} = f(\varepsilon_y , \varepsilon_H , \varepsilon_{passign})$

$\varepsilon_{passign} = g(\varepsilon_{RTTOV} , \varepsilon_{technique})$

Observation operator, H:

- Maps model state into quantity equivalent to AMV observation.
- Requires you to make an assumption about what an AMV represents

  e.g. assumption A: AMV represents wind at cloud top height.

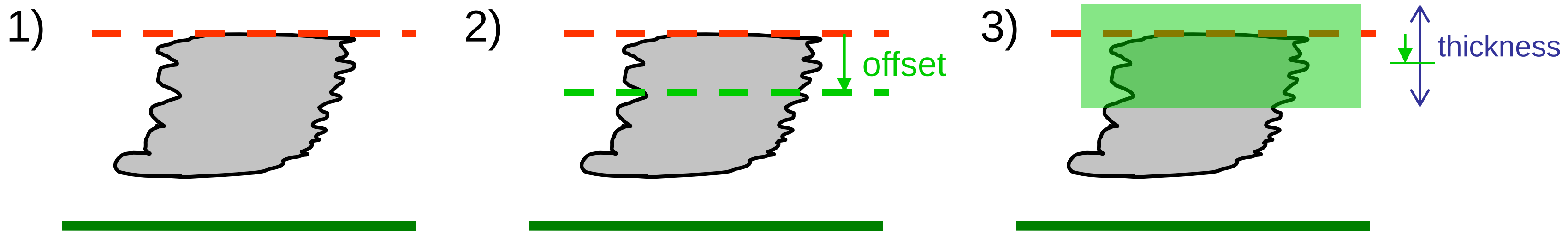
  assumption B: AMV represents mean wind in 100hPa layer beneath cloud top.

Helps understand vertical representivity of AMVs:

- change H, and see how **d** and ε change.
- indicates if error in observation operator, ε_H is increased or decreased.

Vertical representivity of AMVs

- All AMV observation operators used in NWP data assimilation assume AMVs are representative of winds at cloud top height.
- Several studies have shown that AMVs are more representative of winds within a layer beneath the cloud top.
- Hernandez-Carascal and Bormann (2014) showed that much of the benefit of the layer averaging could be gained by simply lowering the assigned height.
- Here, we compare 3 vertical representivity assumptions:
  1. AMVs representative of winds at cloud top height (control)
  2. AMVs representative of winds at single height beneath cloud top.
  3. AMVs representative of winds in layer beneath cloud top.



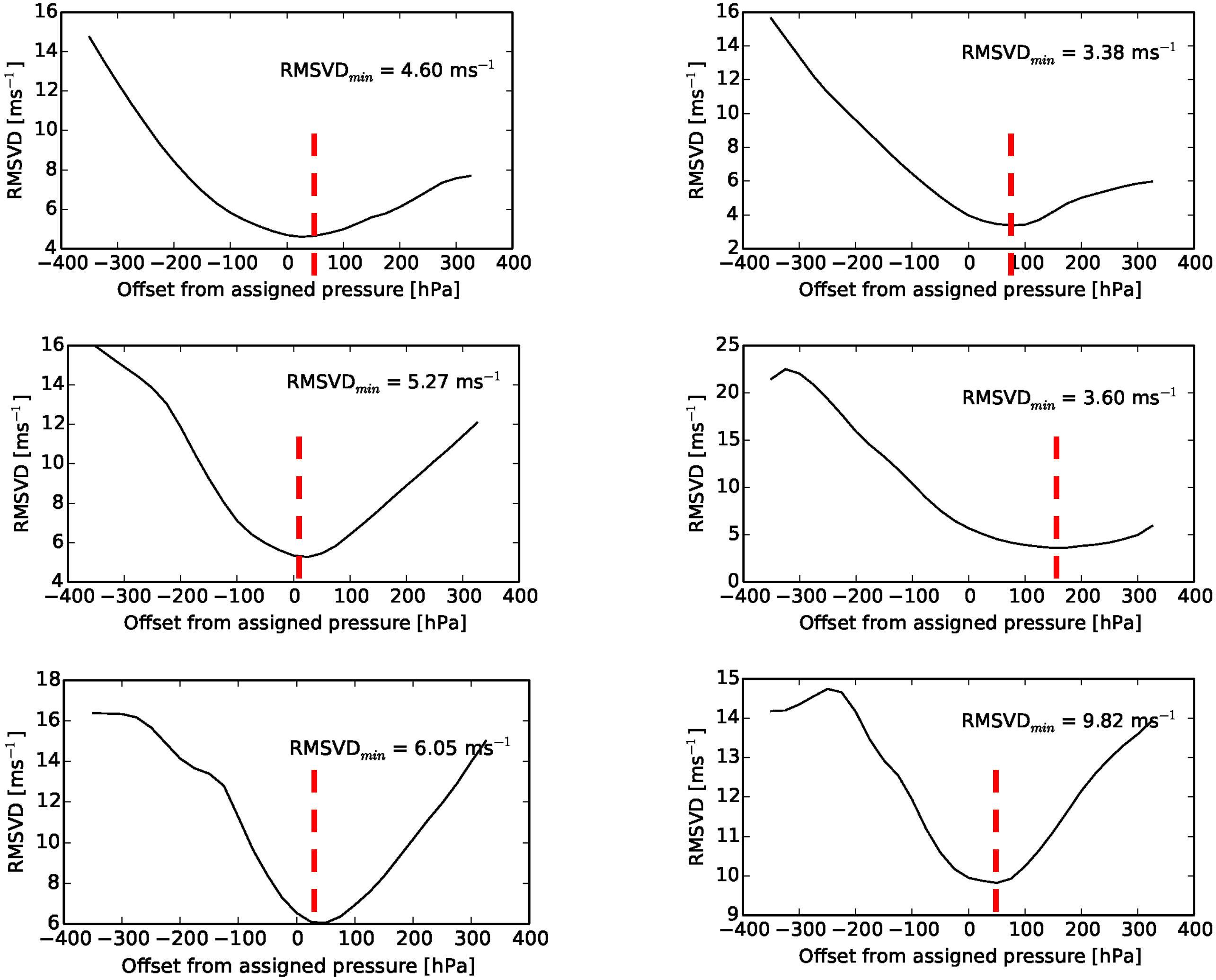
Vertical representivity: single level beneath assigned height
real v simulated

- Finding optimal offset for lower assigned height

Low opaque

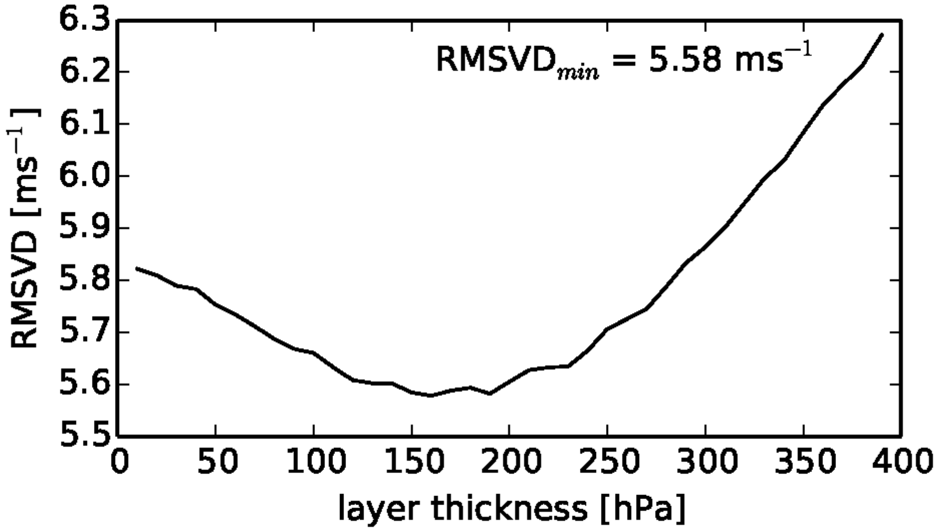
Medium opaque

High opaque



Vertical representivity: layer mean beneath assigned height

- Vary layer thickness and find which thickness gives minimum RMSVD



Semi-transparent high clouds

For layer centre 30hPa below assigned height.

Vertical representivity: layer mean beneath assigned height
real v simulated

- Optimal offset and layer thickness found from Feb 5th – Mar 5th 2013 real data

Cloud category	Offset [hPa]	Layer thickness [hPa]
Low	40	450
Medium	10	275
High opaque	40	250
High semi-transparent	30	150

i.e. layer centred beneath cloud top gives optimal fit to AMVs.

Improved fit using new vertical representivity assumptions

QI>80

Results from Feb 5th – Mar 5th, 2013 (real data) :

Cloud category	At assigned RSMVD [ms^{-1}]	At assigned Bias [ms^{-1}]
Low opaque	4.69	-0.56
Medium opaque	5.34	-1.08
High opaque	6.54	-2.50
High semi-transparent	5.88	-1.27

- Optimal layer gives best fit for all categories.
- Slow bias in upper level AMVs is almost completely removed

Improved fit using new vertical representivity assumptions

Results from Oct 14th – Nov 2nd, 2013 (real data):

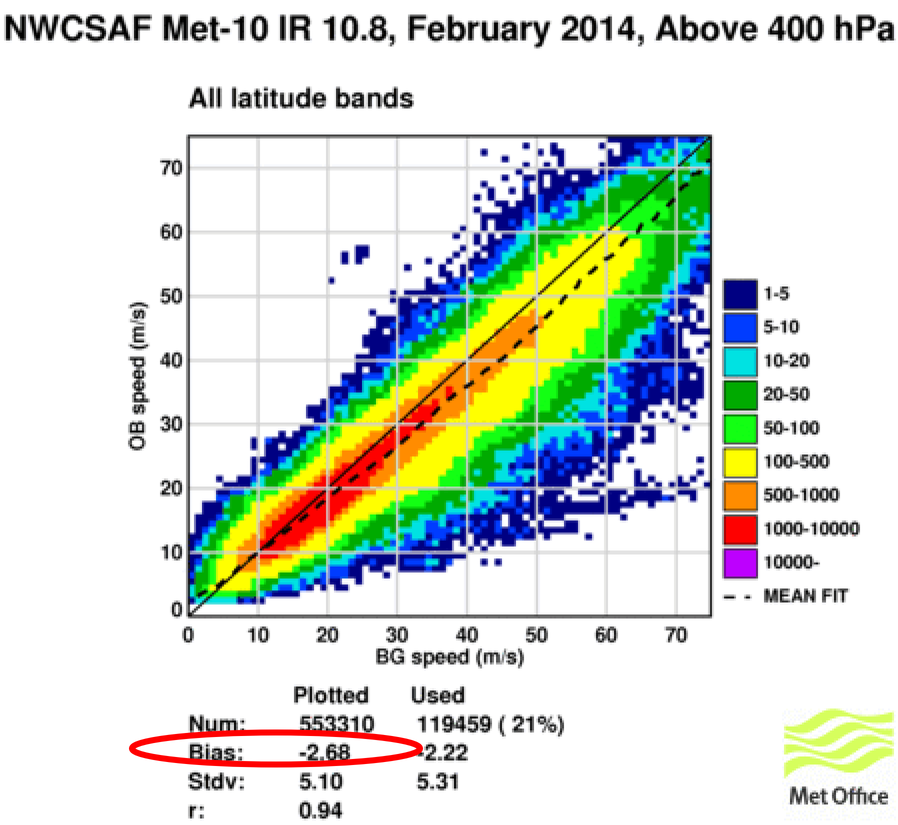
QI>80

Independent trial period using same optimal offset, thickness paramaters derived from previous case study.

Cloud category	At assigned		Lower assigned		Optimal layer	
	RSMVD [ms^{-1}]	**Bias** [ms^{-1}]	**RMSVD** [ms^{-1}]	**Bias** [ms^{-1}]	**RMSVD** [ms^{-1}]	**Bias** [ms^{-1}]
Low opaque	4.29	-1.41	4.18 (2.6%)	-0.99	**3.67 (14.5%)**	**-0.33**
Medium opaque	6.86	-1.23	6.77 (1.3%)	**-0.89**	**6.09 (11.2%)**	-1.42
High opaque	8.85	-2.95	7.66 (13.4%)	-0.13	**6.96 (21.4%)**	**-0.12**
High semi-transparent	8.57	-3.02	7.45 (13.1%)	-1.41	**7.05 (17.7%)**	**-1.04**

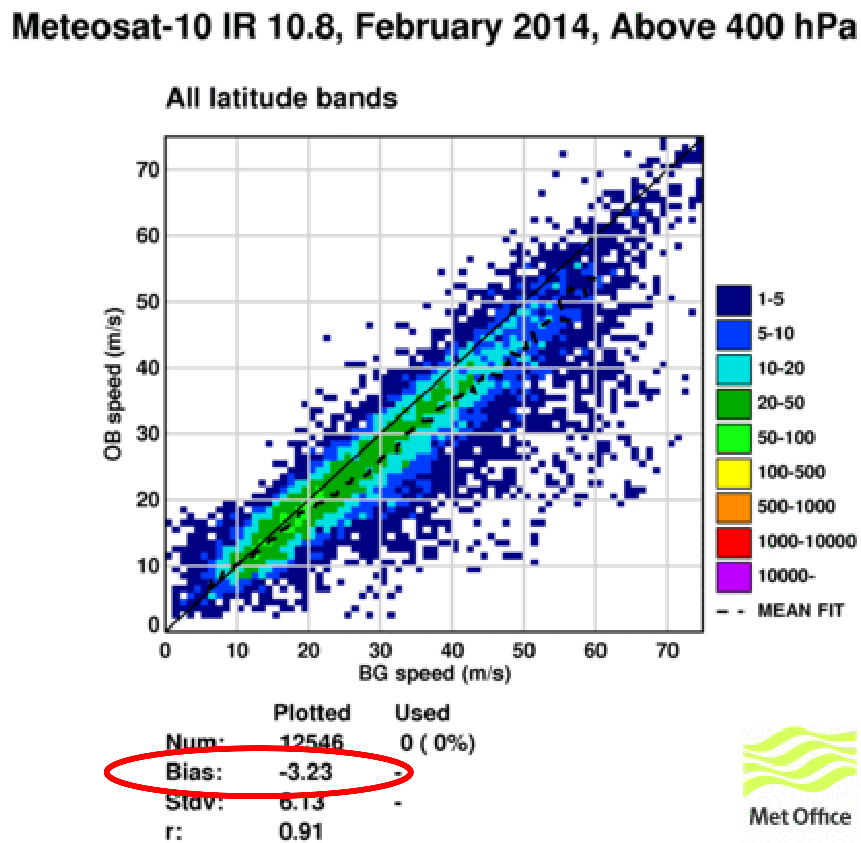
- Results indicate that improvement from using layer mean is robust.
- Slow bias still significantly reduced in independent trial period.

Removal of slow bias



NWCSAF AMVs

(standard assigned height)



EUMETSAT AMVs

(only within NWCSAF domain)

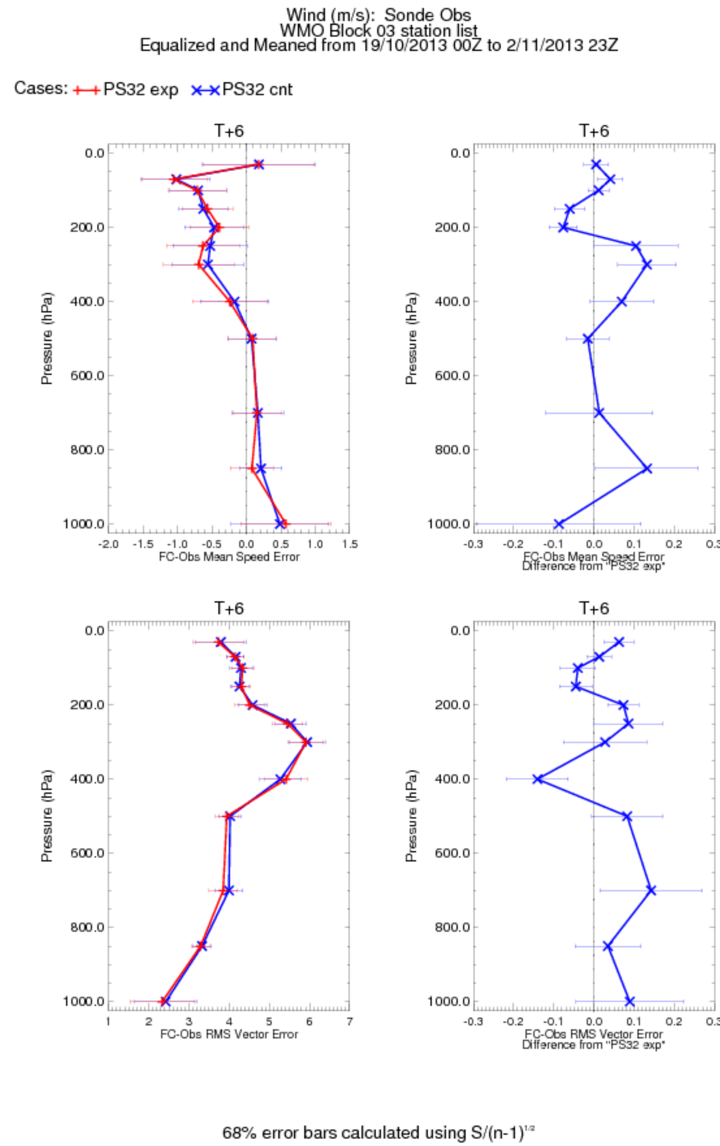
NWP assimilation trials using a lower assigned height

- Results demonstrated that lowering assigned height by around 40hPa gives an improved fit to the model background.

- Easy-win : no changes required to observation operator

- NWP assimilation trial setup:
  - 2 weeks Nov 2013.
  - UKV 3d VAR, 3 hour cycling.
  - Lowered all assigned heights by 40hPa

- +ve impact on tropospheric winds during t+0 – t+12h
- broadly neutral for other variables.



NWCSAF AMVs at Met Office

- Met Office now produces mesoscale AMVs operationally using NWCSAF AMV package.

- NWCSAF AMVs operationally assimilated into UKV model (>400hPa only).

- Lower assigned heights of NWCSAF AMVs now operational in UKV.

- Plans:
    - to start testing a layer average observation operator.
    - retune observation errors in assimilation based on cloud top height and cloud type.
    - new O-B stats monitoring package developed during this fellowship to be run in real time at Met Office.

Conclusions

- **On vertical representivity of AMVs:**
  - Presented further evidence that AMVs representative of layer mean wind with layer centre slightly below cloud top.
  - Slow bias in upper level AMVs almost completely removed by either lowering assigned height or by comparing against optimal layer mean wind.
  - Demonstrated improved usage of AMVs:
    - Lower assigned height ~40hPa: easy win
      - significantly reduced slow bias
    - Layer mean wind:
      - gives closest fit between AMVs and model.
    - Robust results confirmed in independent trial period.
  - Cloud type dependence of AMV error stats: evidence that cloud type is a predictor of AMV error characteristics
- **On utility of simulation study technique:**
  - Model simulations are getting more and more realistic.
    - Synthetic AMVs from **low** and **medium** height clouds had similar error characteristics to real AMVs
  - Simulations of clouds are still imperfect:
    - Synthetic AMVs from **high cloud** suffered from large height assignment errors: results not representative of real AMVs
  - In this study of cloudy AMVs, the simulation technique did not yield any more useful results that could not be found from standard O-B stats.
  - Simulation studies still very useful for simulating future observing systems.
    - Need to be aware of limitations of technique when drawing conclusions from results.