Met Office

Derivation of AMVs from single-level retrieved MTG-IRS moisture fields

Laura Stewart

Fellows day presentation 17th March 2014

Fellowship introduction

Objectives

- Investigate potential of Meteosat Third Generation – Infrared Sounder (MTG-IRS) to provide information on fine-scale humidity structure through hyper-spectral observations
- Derive Atmospheric Motion Vectors (AMVs) from MTG-IRS retrievals of fine-scale humidity structure
  - understanding error characteristics at different altitudes
  - understanding sensitivity to retrieval processing
  - understanding sensitivity to cloud

Fellowship introduction

Motivation

- AMVs are derived by tracking tracers, such as clouds and water vapour structures, in image sequences from VIS, IR and WV channels
- Assignment of height based on cloud top height or base is typically the main source of error in AMV generation
- MTG-IRS data expected to benefit provision of information on fine-scale humidity structures in the troposphere

→ Potential to derive AMVs from tracking high resolution humidity fields negating need for height assignment

Fellowship introduction

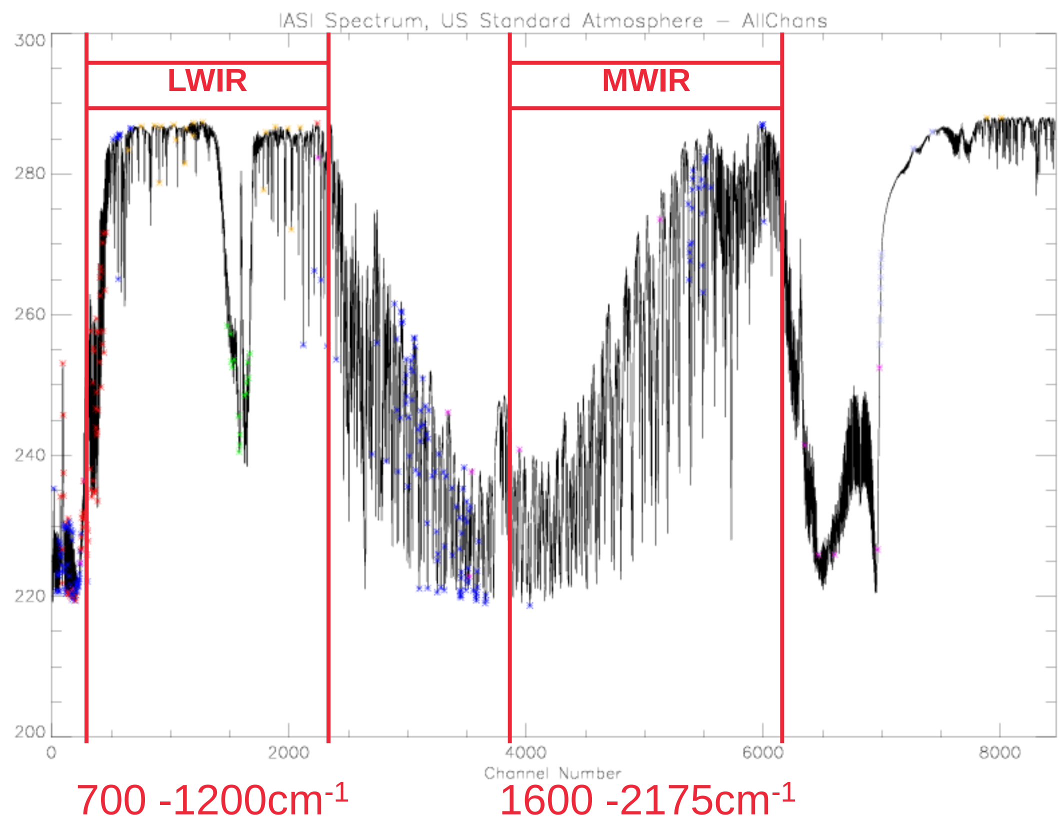
Methodology

- Simulate brightness temperature spectra using Met Office UKV 1.5km model fields and a fast radiative transfer model RTTOV
- Use simulated spectra in a 1D-Var retrieval to generate MTG-IRS like retrievals of specific humidity
- Apply a feature tracking algorithm to track tracers in single-level model and retrieved humidity fields
- Evaluate these derived AMVs against the true model wind field
- Study the effects of cloud and image processing on the quality and quantity of derivable wind information

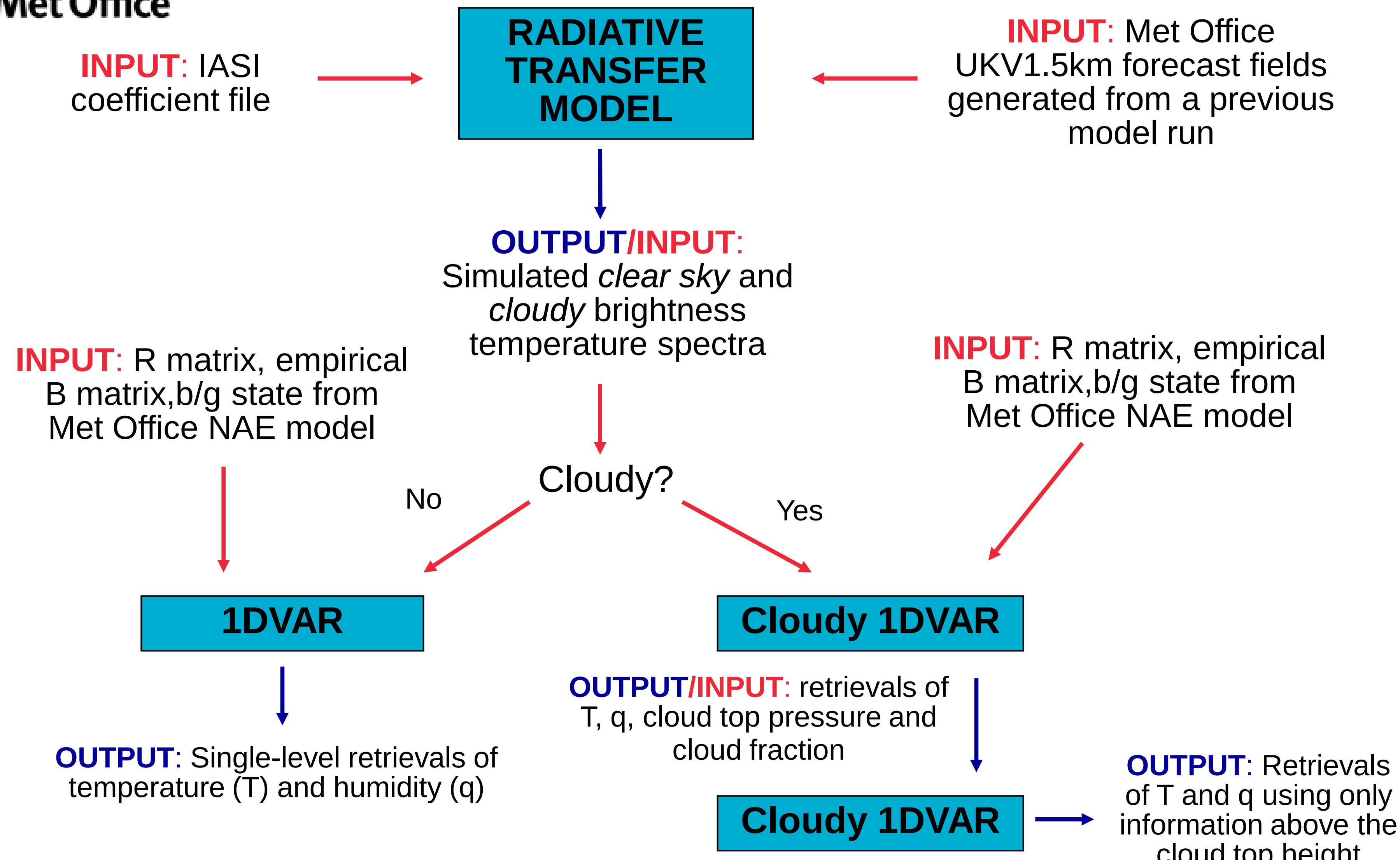
MTG-IRS

- Measurements in LWIR (800 channels 700-1210cm^{-1}) and MWIR (920 channels 1600-2175cm^{-1})
- Spectral resolution of 0.625cm^{-1} (cf IASI 0.25cm^{-1})
- Horizontal resolution ~4km; temporal resolution = 30 min

MTG-IRS spectral coverage on a typical IASI spectrum

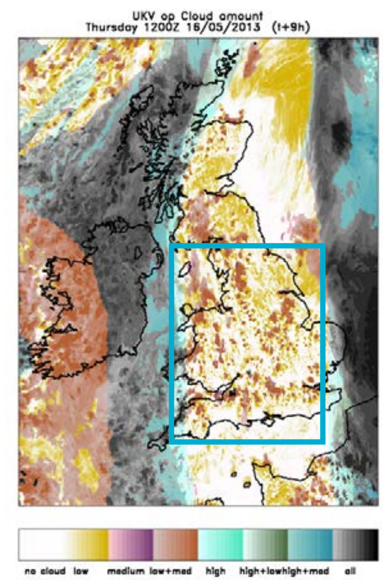


Generating the retrievals

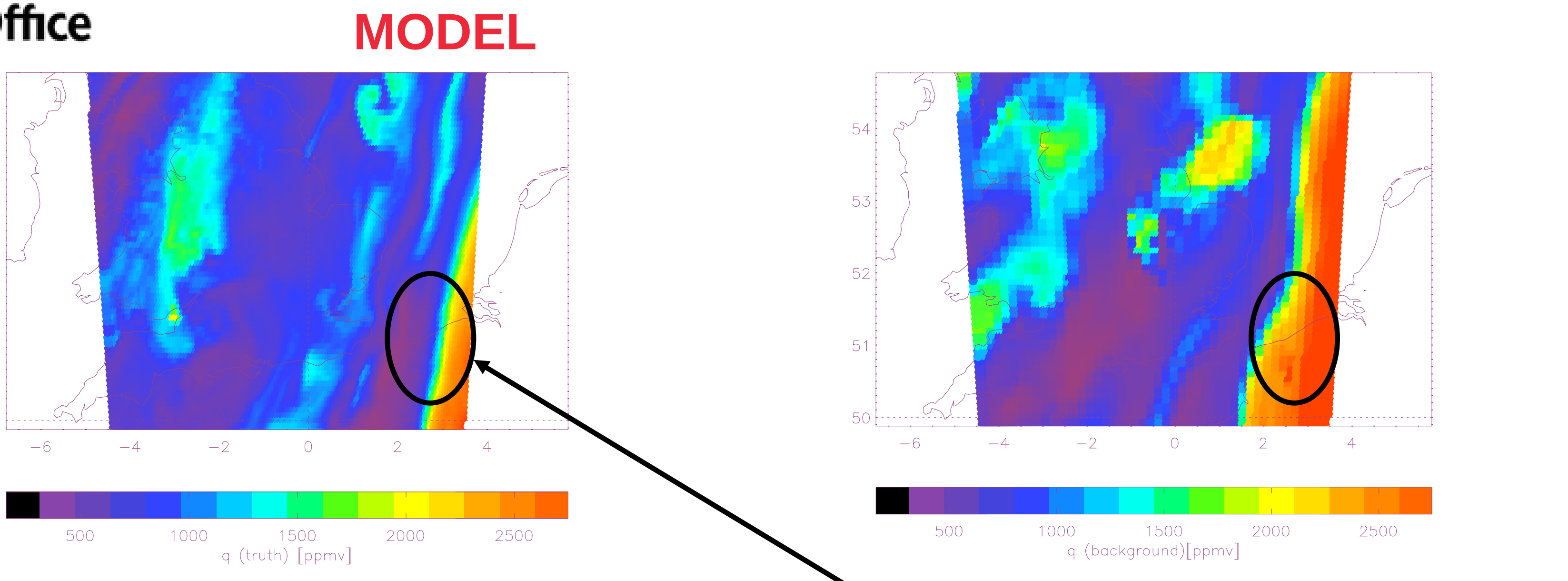


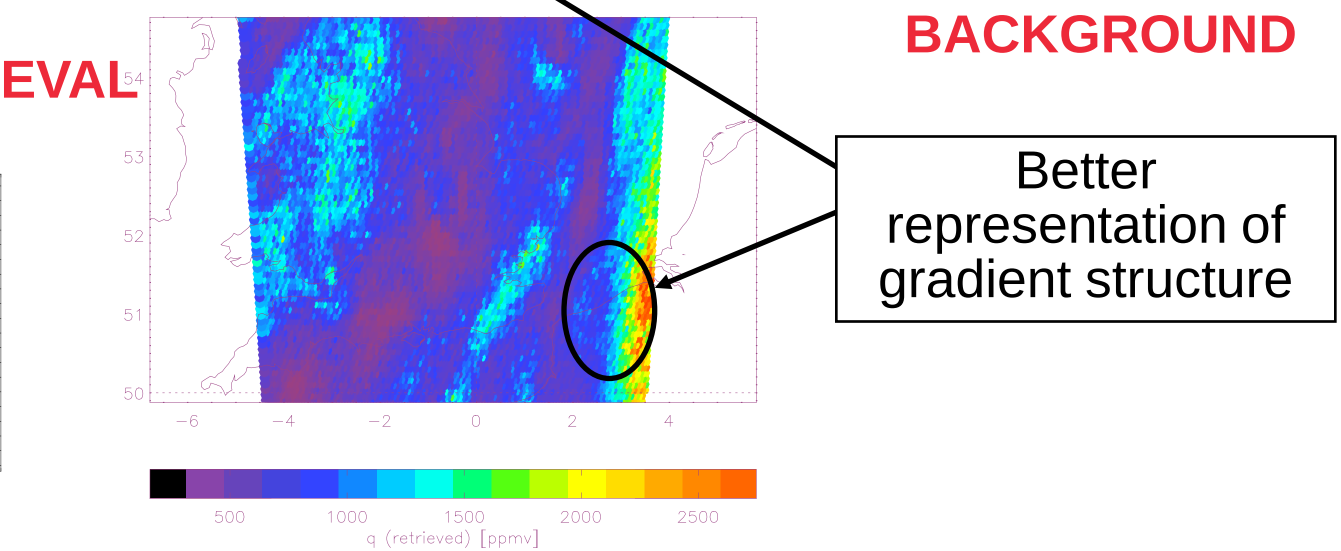
Case study 16th May 2013

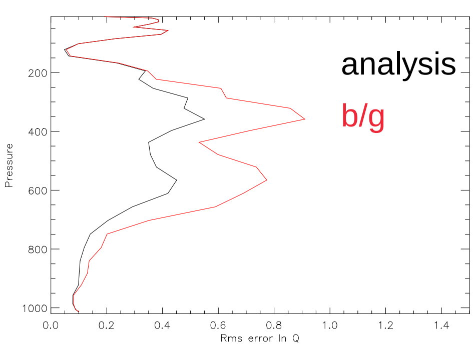
- Domain: England, Wales and English Channel ~[-4,3] degrees lon, [50,55] degrees lat
- Extract UKV model fields at MTG-IRS horizontal resolution -> 133x64 pixel points
- Time window: 06:00 – 09:30
- Conditions: Predominantly clear sky leading to convective cloud cover and showers across the domain
- Model simulations done *with* and *without* cloudy contributions
- Cloud: cloudy radiances = weighted combo of clear-sky radiance and radiance contribution from top of opaque cloud
- Cloud: clouds treated as single layer bodies with spectral properties simulated by the model



Clear-sky humidity retrievals @610hPa



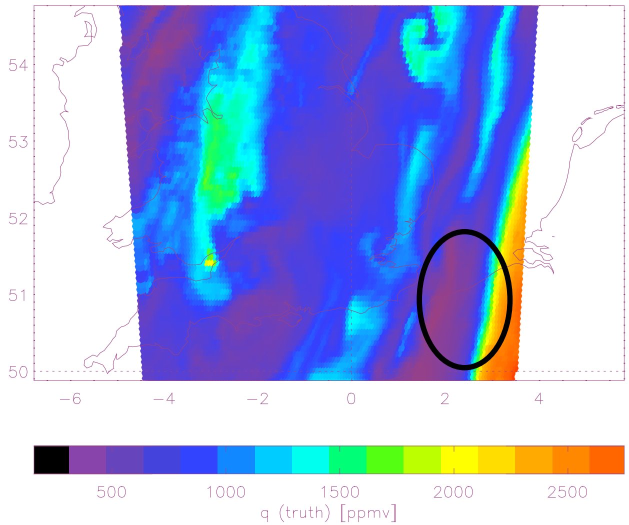




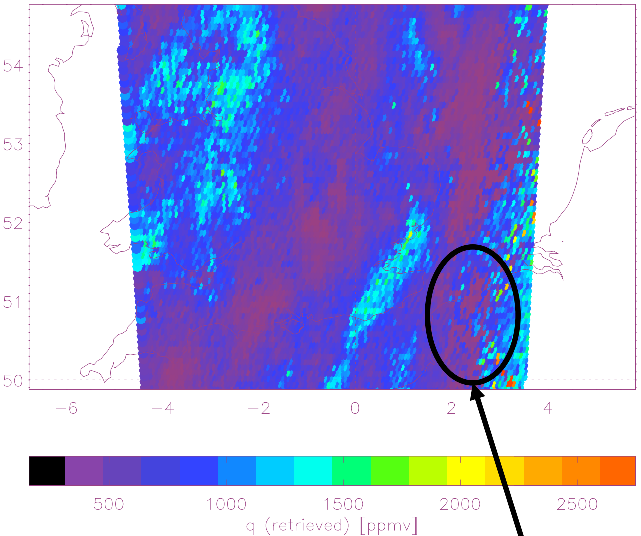
Cloudy humidity retrievals @610hPa

Met Office

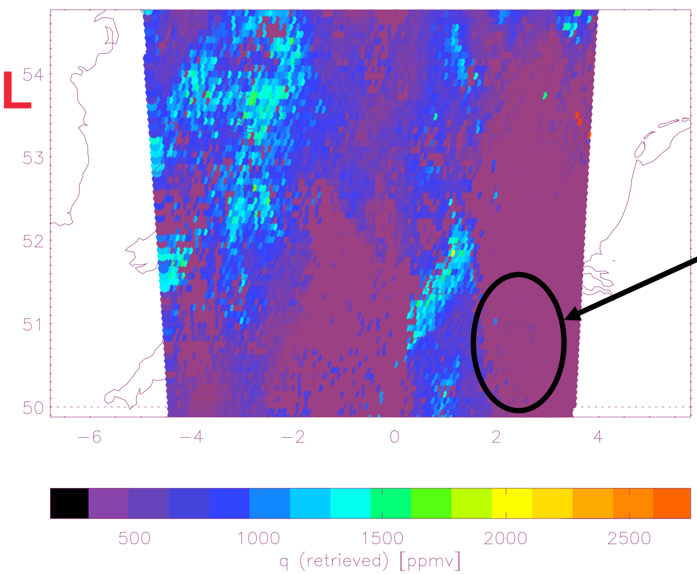
MODEL

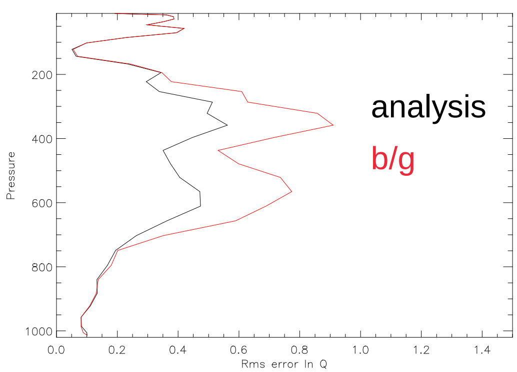


FULL RETRIEVAL



QC RETRIEVAL





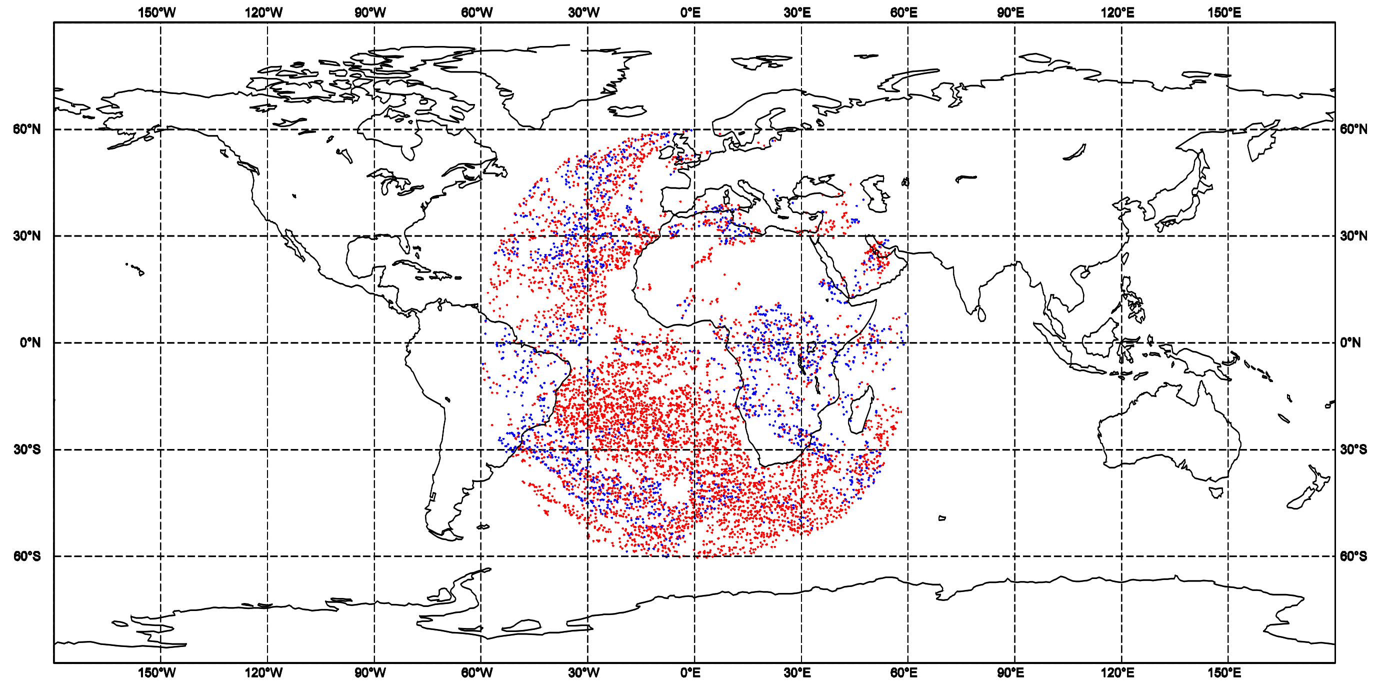
Eliminates any pixels where retrieved CTP > model level

Typical AMV use at the Met Office

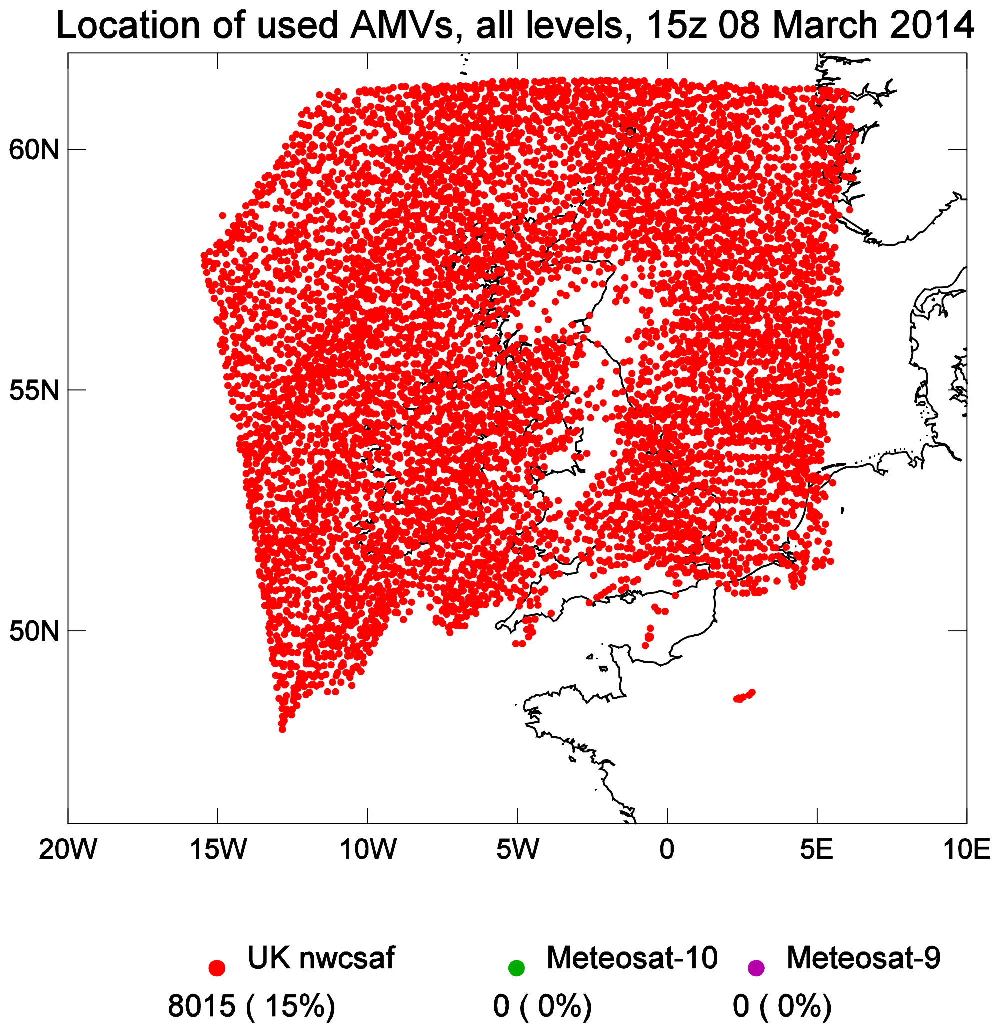
MSG IR10.8

MSG WV 7.3

Data Coverage: Satwind (13/3/2014, 0 UTC, qg00)
Total number of observations assimilated: 6899
\CLRED\EUMETSAT MSG IR 10.8 (5335) \CLGREEN\EUMETSAT MSG HRVIS (0) \CLCYAN\EUMETSAT MSG VIS 0.8 (0) \CLBLUE\EUMETSAT WV 7.3 (1564)

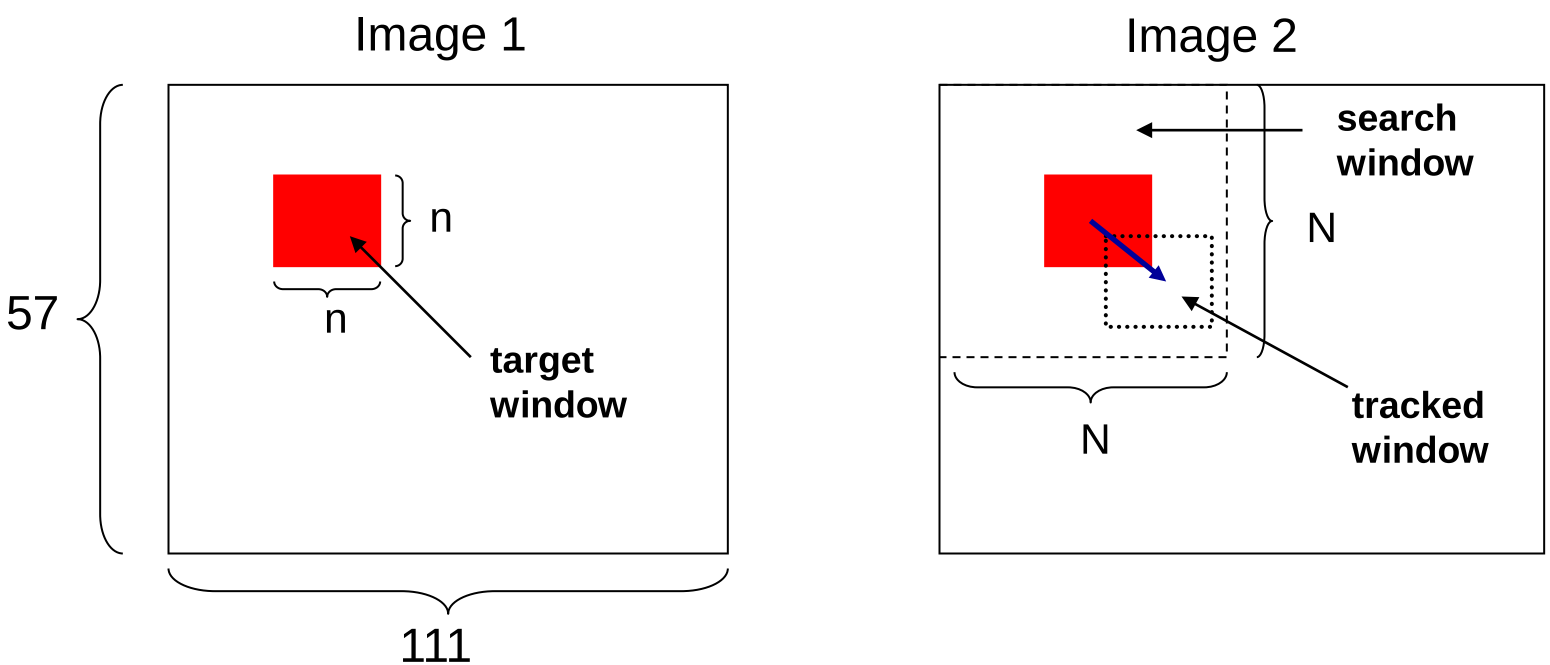


Typical AMV use at the Met Office



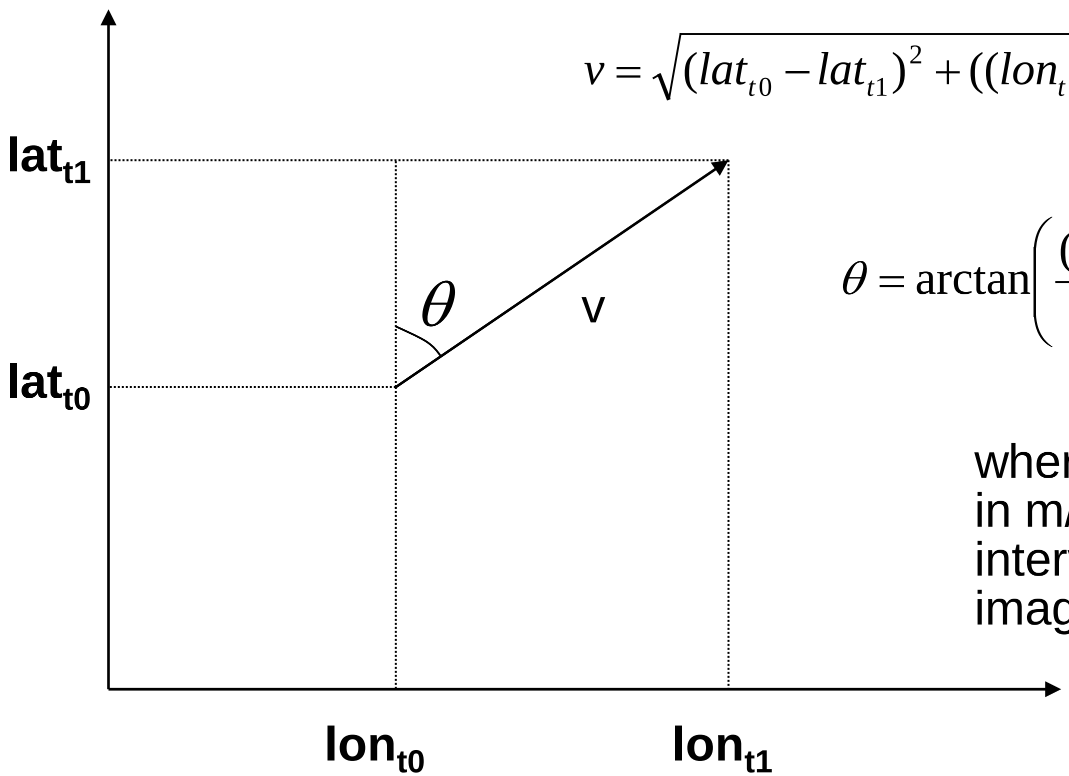
Feature tracking algorithm

- Modified CPTEC tracking software
- Time interval between images = 30 minutes
- Target window size = 6x6, 8x8, 10x10, 12x12
- Euclidean distance technique used for target matching



Feature tracking algorithm

- Each target window generates one AMV
- Speed and direction of each AMV are calculated using the displacement in the target and tracked images



$$v = \sqrt{(lat_{t0} - lat_{t1})^2 + ((lon_{t0} - lon_{t1})\cos(lat_{t0}))^2} \times \frac{RT}{DT}$$

$$\theta = \arctan\left(\frac{(lon_{t0} - lon_{t1})\cos(lat_{t0})}{(lat_{t0} - lat_{t1})}\right)$$

where RT is angular speed in m/s and DT is the time interval between the two images in hours

‘Good’ AMVs?

- Require: correlation coefficient between target and tracked window to be greater than some level-dependent threshold

$$cor = \frac{\sum_k \sum_l (T_{k,l} - \bar{T})(S_{k,l} - \bar{S})}{\sqrt{\sum_k \sum_l (T_{k,l} - \bar{T})^2} \sqrt{\sum_k \sum_l (S_{k,l} - \bar{S})^2}} > 0.7$$

- Require: sufficient contrast within the target window
- Require: wind speed to be less than maximum value of background wind, i.e, v < 15m/s @ 656hPa
- Require: quality indicator from automated quality control (AQC) scheme to be greater than some threshold

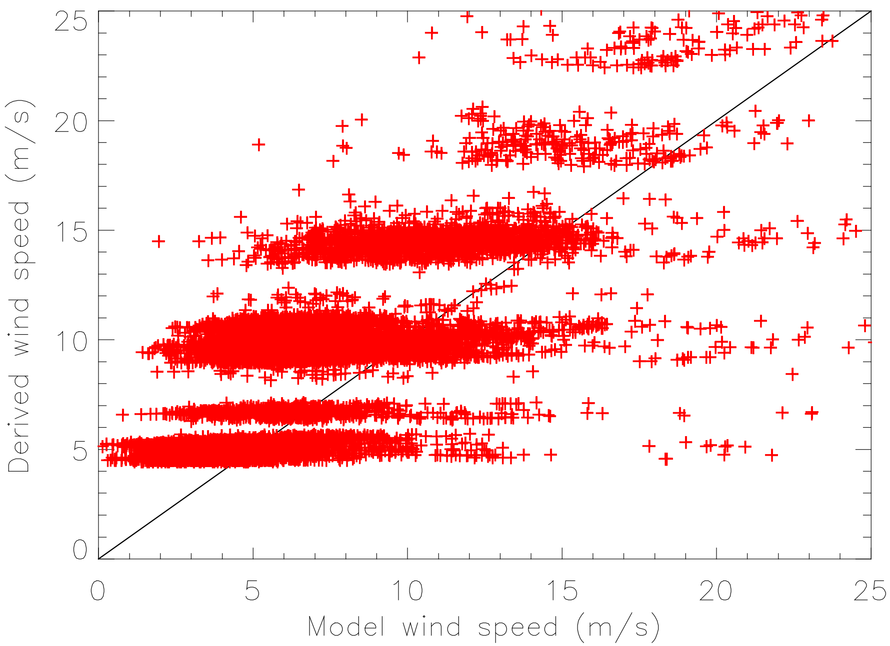
$$QI = \Phi_{direction} + \Phi_{velocity} + \Phi_{vector} + \Phi_{spatial} > 0.5$$

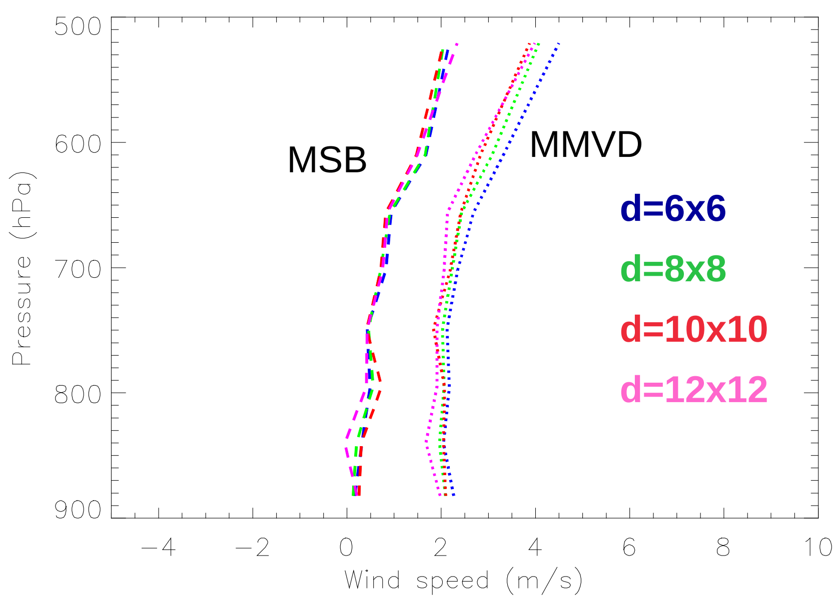
Tracking model humidity fields

- An indicator of the best we could expect the tracking to perform, eg, using the smoothest field
- Track features at 8 RTTOV tropospheric pressure levels between 882hPa and 521hPa (1.15km – 5.27km)
- Using target box sizes n=6x6, 8x8,10x10,12x12 on a 133x64 pixel grid
- 6 triplets of sequential images used, eg. images at 07:00, 07:30 and 08:00 form triplet
- Evaluate errors in derived winds through comparison with the true model winds
- Calculate mean tracked wind (v), mean speed bias (MSB) and mean magnitude vector difference (MMVD)

Tracking model fields

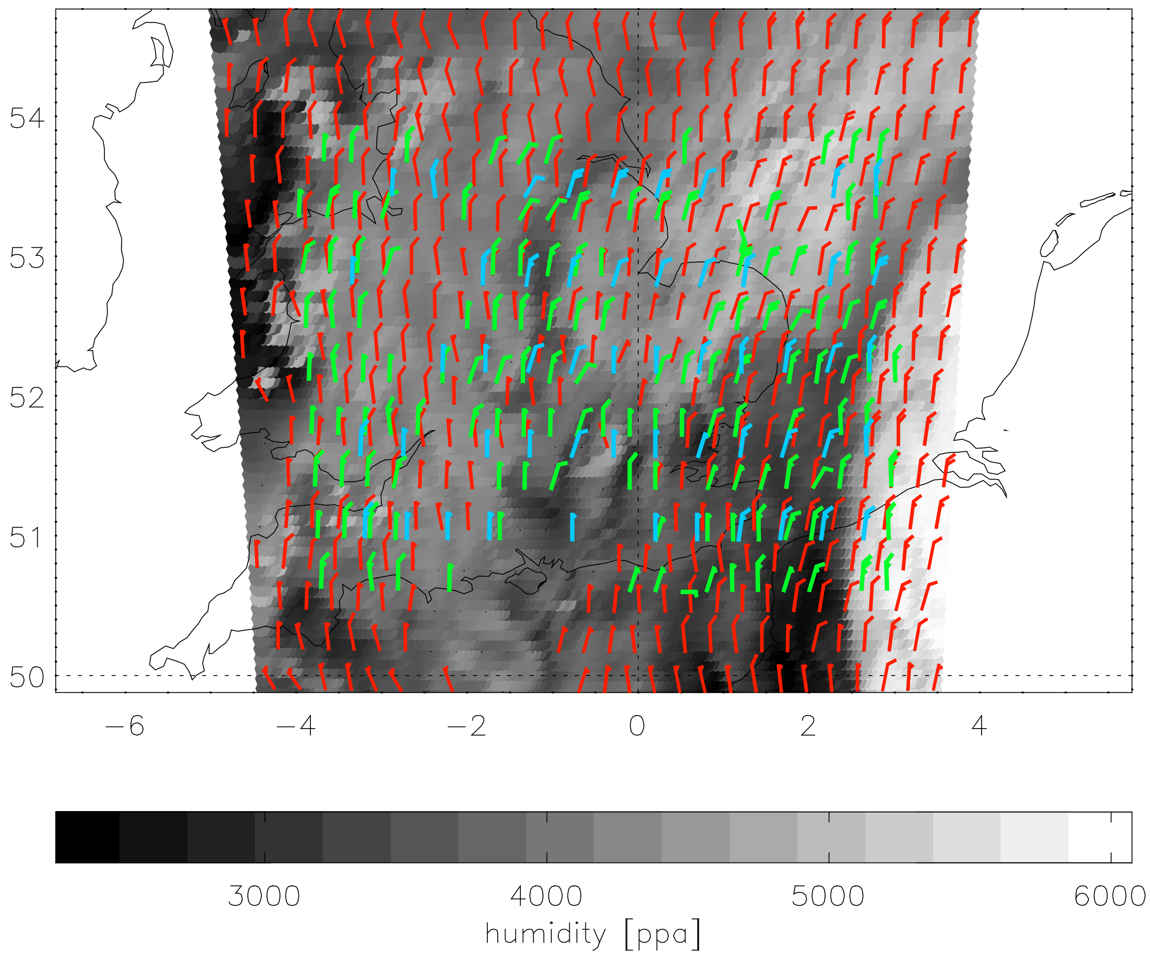
- 15,431 winds derived over time window
- Derived winds typically overestimate wind speed
- Bias is a function of wind speed: 0.3m/s for winds < 5m/s, 3.28m/s for winds between 15-20m/s





- With bias correction, biases comparable to those seen operationally
- Little variation in error with target box size - largest target box is marginally best
- Increase in MSB and MMVD with height

Tracking model fields



Winds at 795hPa

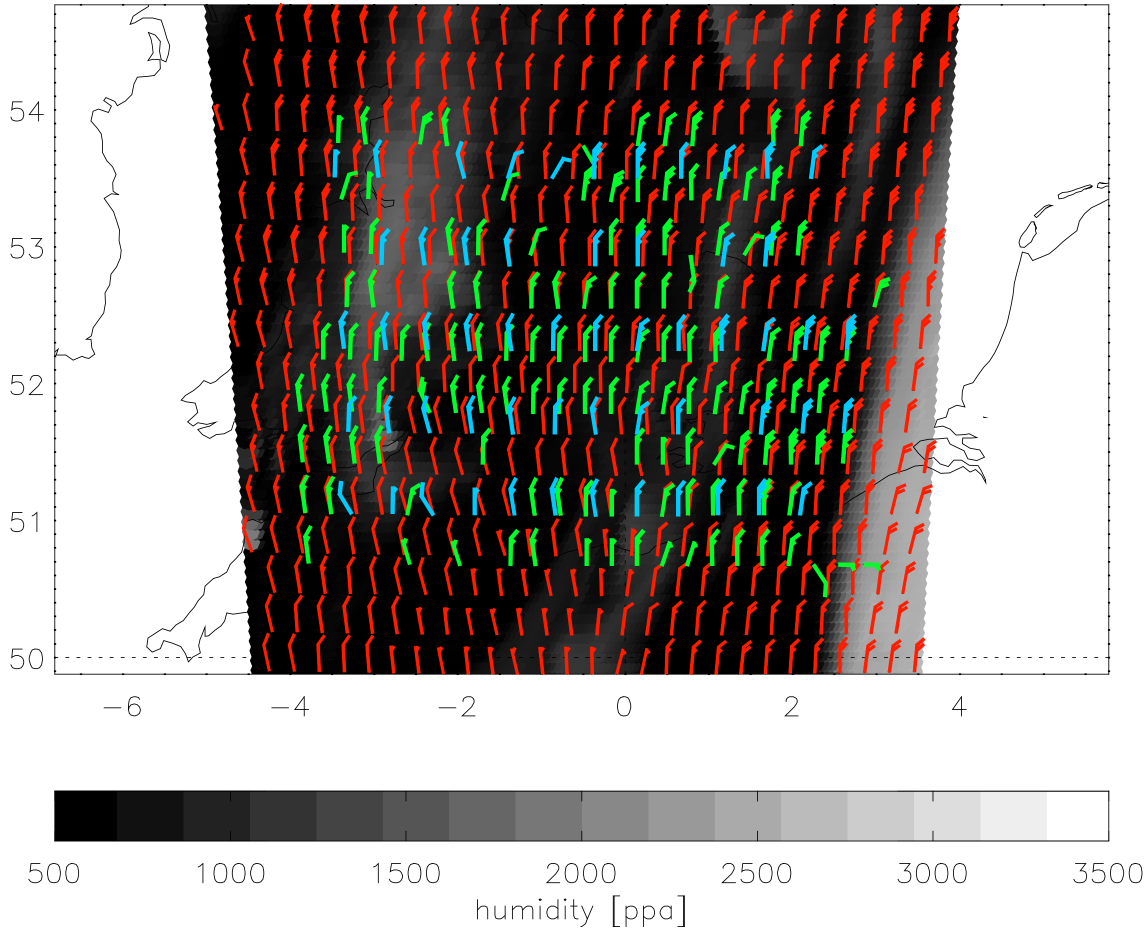
Truth tracked winds d=6x6

Truth tracked winds d=10x10

Model wind field

0-2.5m/s	**No barb**
2.5m/s	**Short barb**
5m/s	**Long barb**

Tracking model fields



Winds at 610hPa

Truth tracked winds d=6x6

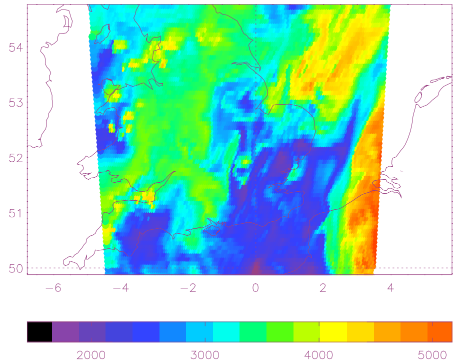
Truth tracked winds d=10x10

Model wind field

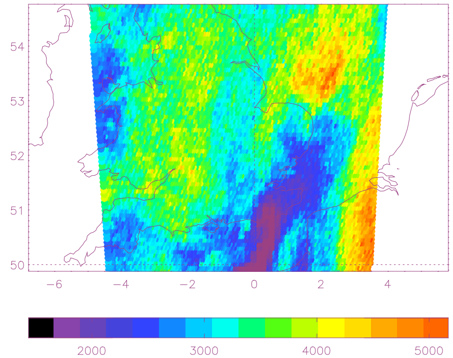
0-2.5m/s	**No barb**
2.5m/s	**Short barb**
5m/s	**Long barb**

Tracking clear-sky retrieval humidity fields

- Demonstrated success in tracking simulated model fields at MTG-IRS resolution
- MTG-IRS humidity retrievals well-represent the humidity structures and gradients present in the model fields…however retrievals are noisier
- Previous work has shown that the noisiness of retrievals inhibits the amount of derivable wind information



Model



Retrieval

Gaussian multi-scale representation

- Smoothing technique previously used for feature tracking in SEVIRI WV channels
- Typically used in image analysis to study contribution of different frequencies to the structure of an image
- Gaussian blur L(x,y) of an image I(x,y) is given by the convolution of the image with a 2D Gaussian kernel G(x,y)

$$L(x,y) = G(x,y) * I(x,y)$$

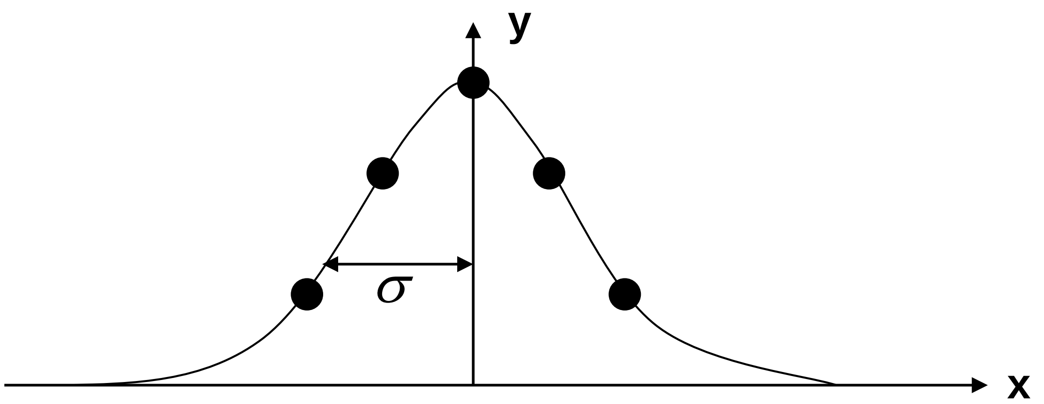
where

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-(x^2+y^2)/2\sigma^2}$$

(x,y) is distance from kernel centre

σ^2 is the variance

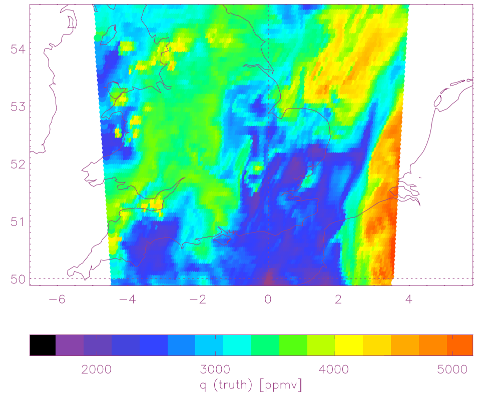
Gaussian multi-scale representation

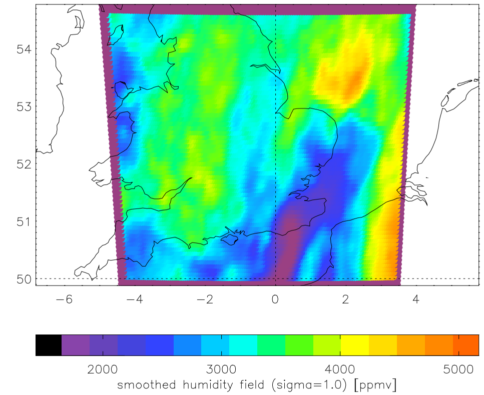


- Choose σ^2 such that the noise is reduced without smoothing away fine-scale features and strong gradients
- σ^2 dictates the spread of the Gaussian function and hence the level of smoothing/range of frequencies removed
- Kernel size dictates the number of points on the Gaussian function to use in the smoothing

Tracking smoothed clear-sky retrievals

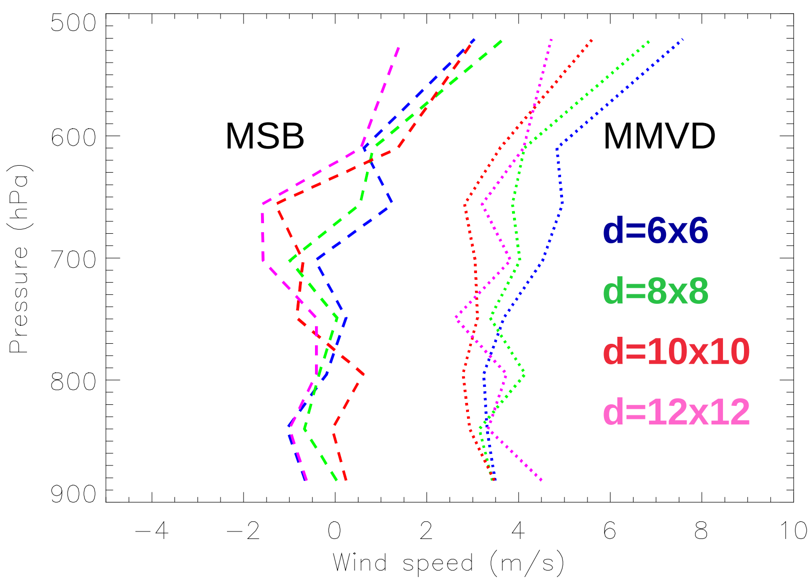
Truth





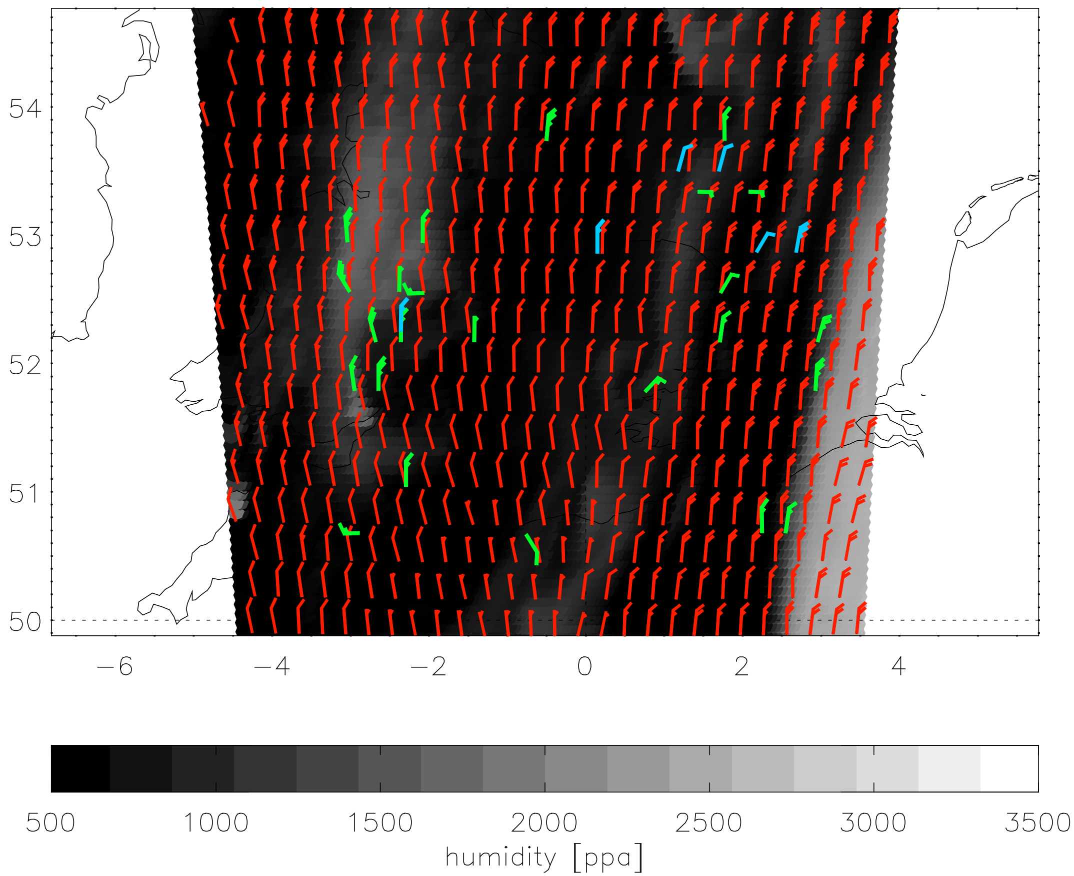
Smoothed Retrieval

Sigma=1



- 2267 winds derived over the time window
- As before derived winds overestimate the wind speed
- More variation with target box size – 10x10 target box size gives best results
- Errors are approximately 1-1.5m/s larger than those when tracking model fields

Tracking smoothed clear-sky retrievals



Winds at 610hPa

Truth tracked winds d=6x6

Truth tracked winds d=10x10

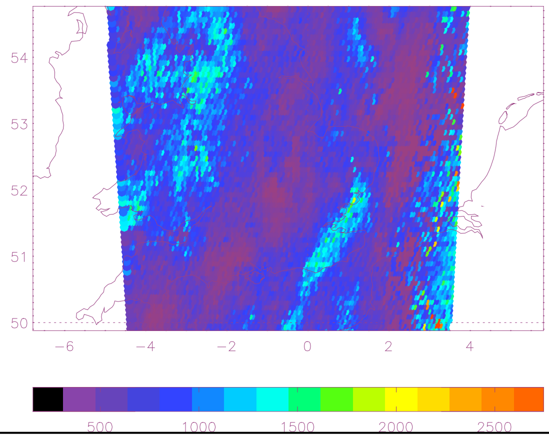
Model wind field

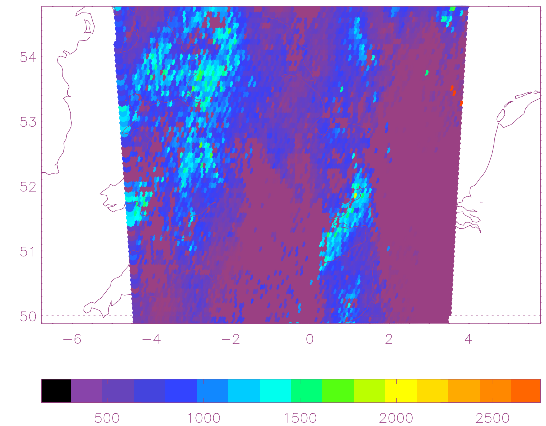
0-2.5m/s	**No barb**
2.5m/s	**Short barb**
5m/s	**Long barb**

Tracking cloudy retrieval humidity fields

- Cloudy retrievals are generated from a dual 1D-Var process:
  - the first 1D-Var retrieves cloud top pressure and cloud fraction
  - the second 1D-Var retrieves humidity fields using only information from channels sensitive above the retrieved cloud top
- Retrieval information below the cloud top is largely propagated from the background field
- Two approaches to tracking in cloudy retrievals
  - Mask out retrieval information below the cloud top and track using the remaining discontinuous information
  - Track in the full retrievals and then perform quality control on the derived winds to eliminate those generated at points below the cloud top

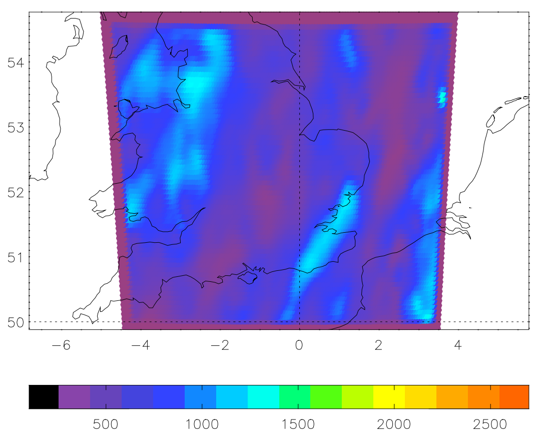
Tracking cloudy retrieval humidity fields

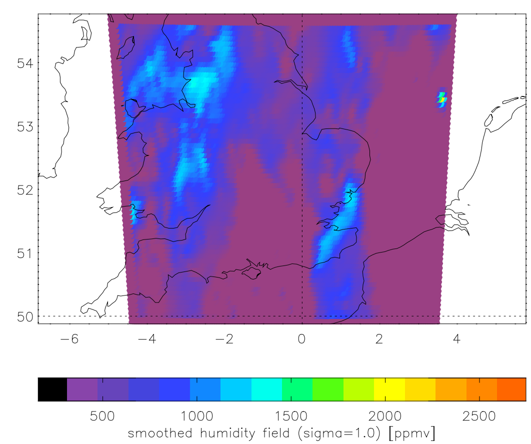




Full retrieval: track using all available information (even that below the cloud top)

Masked retrieval: mask retrieval information below the cloud top (set humidity to nominally zero)



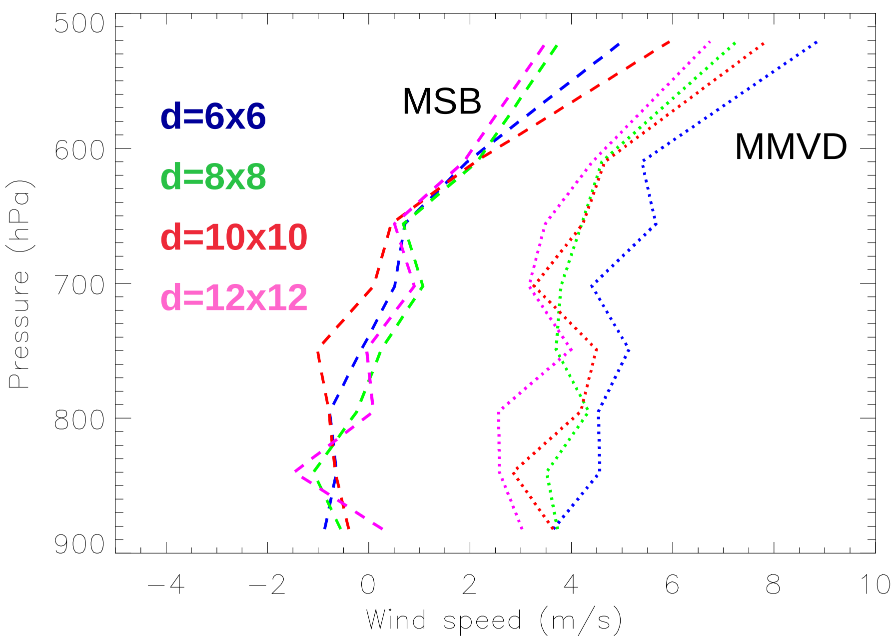


Tracking smoothed cloudy retrievals

Approach 1: Mask pixels below the retrieved cloud top

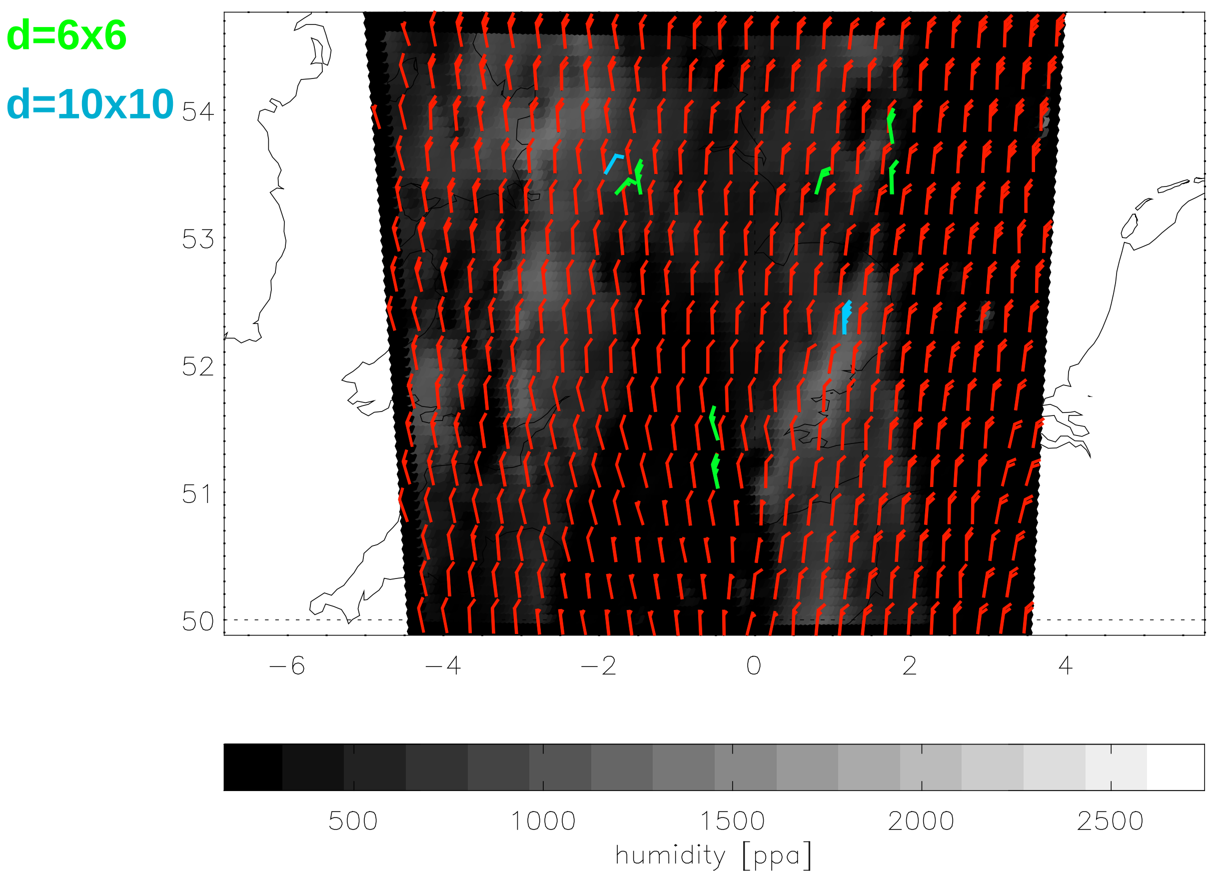
Level	% pixels available
882hPa	26
840hPa	31
795hPa	37
749hPa	43
702hPa	50
656hPa	56
610hPa	60
521hPa	70

- 1038 winds derived over the time window (compared to 2267 for clear-sky case)
- Errors below 600hPa comparable with those seen for clear-sky case
- Above 650hPa, errors are noticeably larger



Tracking smoothed cloudy retrievals

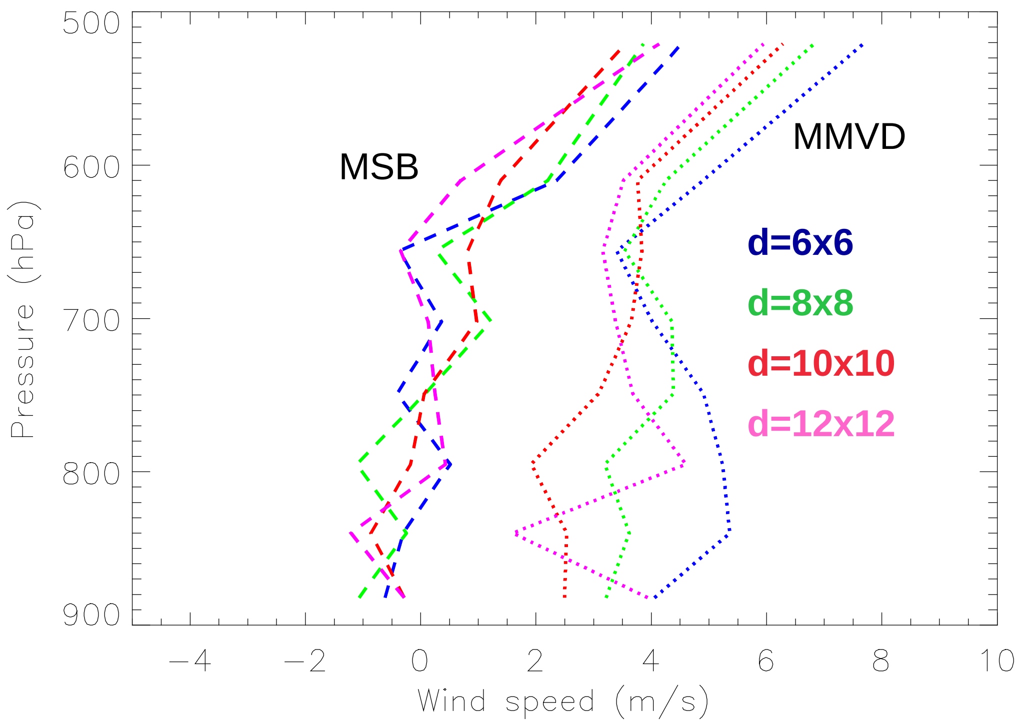
Approach 1: Mask pixels below the retrieved cloud top



- Very few winds even at 610hPa
- Below 749hPa, almost no quality wind information
- Below 700hPa, fewer than 50% of pixels available for tracking
- Discontinuity of information inhibits wind derivation

Tracking cloudy smoothed retrievals

Approach 2: Use all retrieval points and apply QC after feature tracking



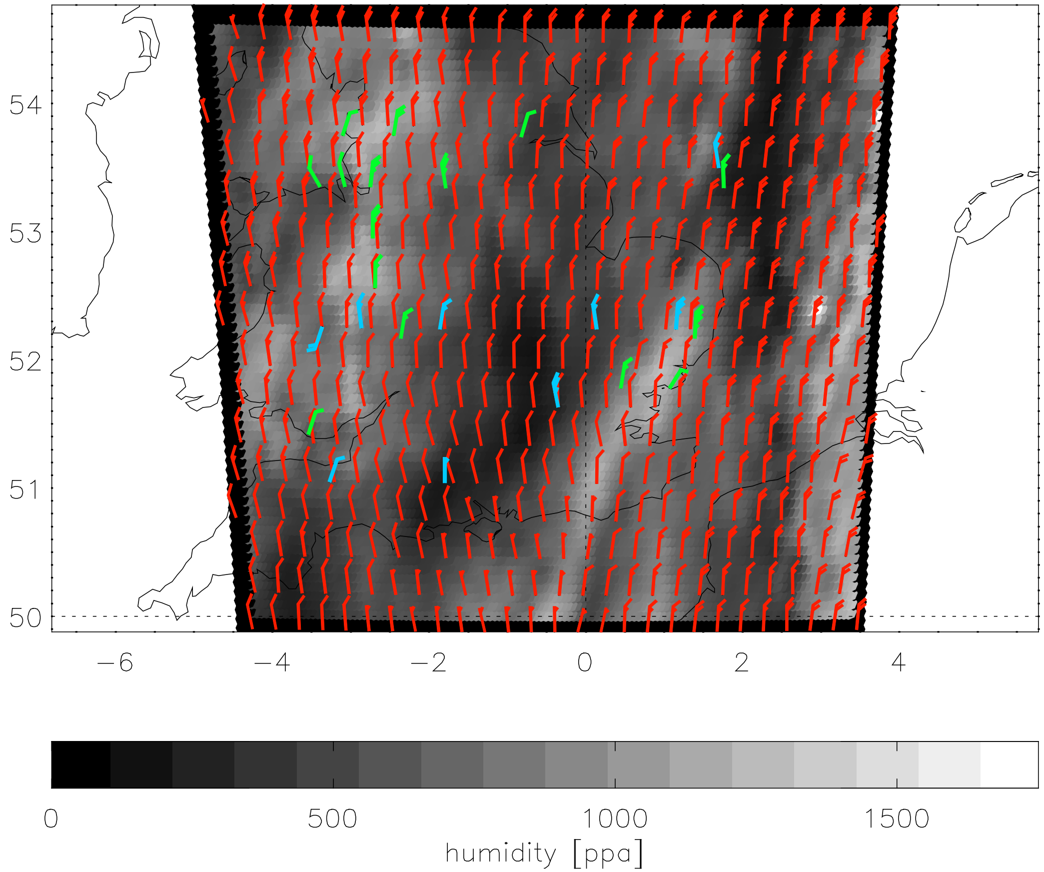
- Use all available retrieval information
- 1312 winds derived over the time window (26% improvement on Approach 1)
- Large variability in errors with target box size especially at lower levels
- A larger target box is often preferable

Tracking cloudy smoothed retrievals

Approach 2: Use all retrieval points and apply QC after feature tracking

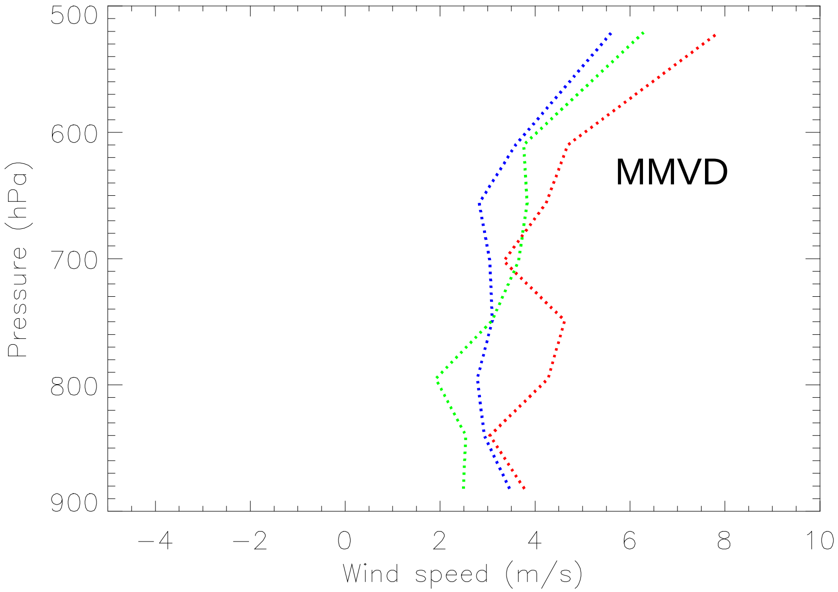
d=6x6

d=10x10



- More continuous field for tracking
- Improvement in number and quality of derived winds
- More comparable with clear-sky case

Comparison



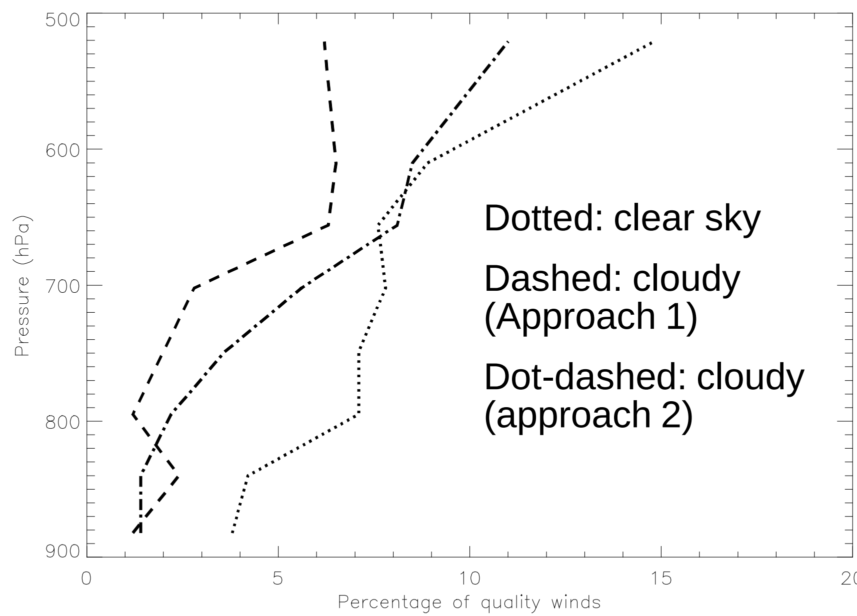
Clear sky retrievals

Cloudy retrievals (Approach 1)

Cloudy retrievals (Approach 2)

Approach 2 outperforms Approach 1 on nearly all levels: smaller MMVD and increased number of winds

	# winds (all levels)
Model	15431
Clear-sky	2267
Cloudy (A1)	1038
Cloudy (A2)	1312



Comparison

	MSB (below 700hPa)	MMVD (below 700hPa)	MSB (700-400hPa)	MMVD (700-400hPa)
Model	-0.35 -0.26	2.86 2.06	1.06 0.74	3.73 2.64
Clear-sky	-0.43 -0.31	4.52 3.31	0.81 0.15	5.98 3.87
Cloudy (A1)	-2.00 -1.54	5.84 4.00	1.34 0.87	6.83 4.73
Cloudy (A2)	-2.06 -1.64	5.35 3.51	0.92 0.50	5.92 4.15

Using all winds (m/s)

Using winds derived from 10x10 and 12x12 target boxes (m/s)

Summary

- Feature tracking in model humidity fields provides a very good representation of the true wind field
  - Demonstrates the applicability of the tracking algorithm

- Feature tracking in retrieval humidity fields is inhibited by noise
  - Use Gaussian multi-scale representation for smoothing
  - Smoothed clear-sky retrieval fields generate fewer winds than model fields but good quality wind info available on all levels

- Generation of quality wind from feature tracking in cloudy retrievals is dependent on the QC treatment of cloud
  - Eliminating all points below the retrieved CTP (Approach 1) resulted in very little quality wind information in the mid to low troposphere
  - Using all cloudy retrieval points and applying the QC after the tracking (Approach 2) resulted in more wind information and improved wind quality
  - The errors in the derived winds (using Approach 2) were largely comparable with those seen operationally

Take home messages…

- Feature tracking in retrieved humidity fields at MTG-IRS resolution appears feasible under clear-sky and cloudy conditions
- Tracked winds are still subject to the quality control needed for traditionally derived winds, ie. neighbour checking, correlation and contrast thresholds
- Smoothing the retrieval fields can improve the quality and quantity of wind information derivable
- Using all of the retrieval information (even under the presence of clouds) is preferable to eliminating cloud affected pixels before the feature tracking
- Potential for this work to be extended and look further at the impact of non-advective motion (ie, where humidity is not a passive tracer) and the treatment of winds as representative of a layer of movement rather than a single point observation

Questions and answers

Comparison metrics

- Simulation study allows for direct comparison with UKV model winds

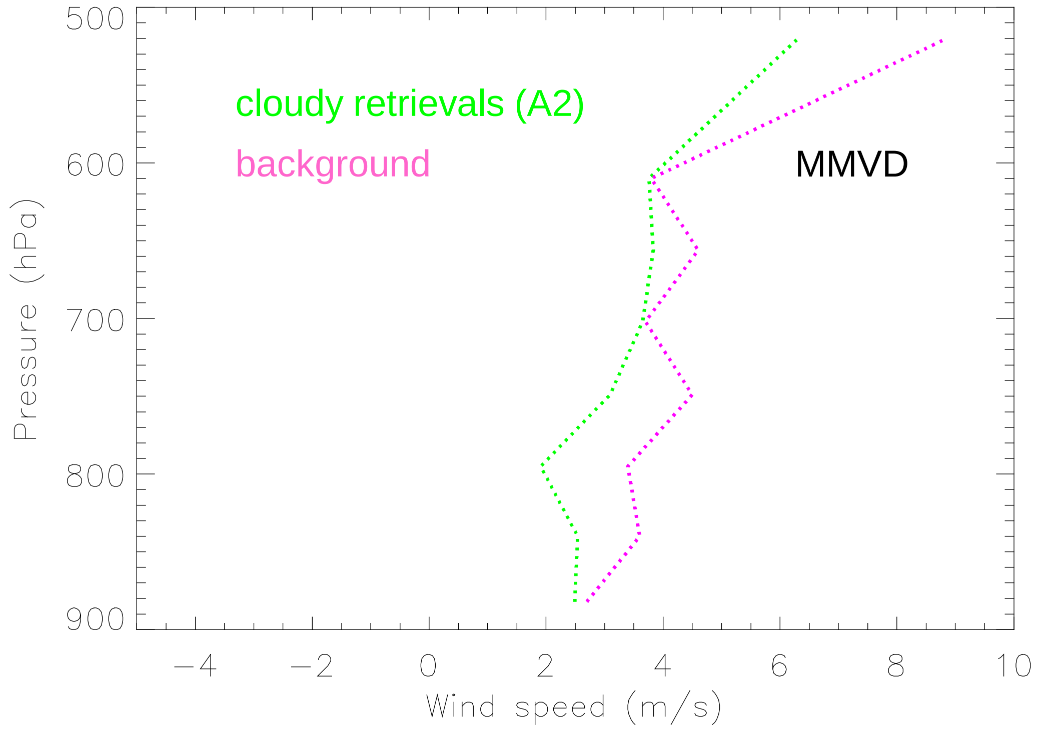
$$MSB = \frac{1}{N}\left(\sqrt{u_T{}^2 + v_T{}^2} - \sqrt{u_D{}^2 + v_D{}^2}\right) \equiv \frac{1}{N}\left(V_T - V_D\right)$$

$$MMVD = \frac{1}{N}\sqrt{V_T{}^2 + V_D{}^2 - 2V_T V_D \cos\left|\theta_T - \theta_D\right|}$$

where u_T, v_T, V_T, θ_T relate to the true winds

u_D, v_D, V_D, θ_D relate to the derived winds

Comparison against tracking background fields



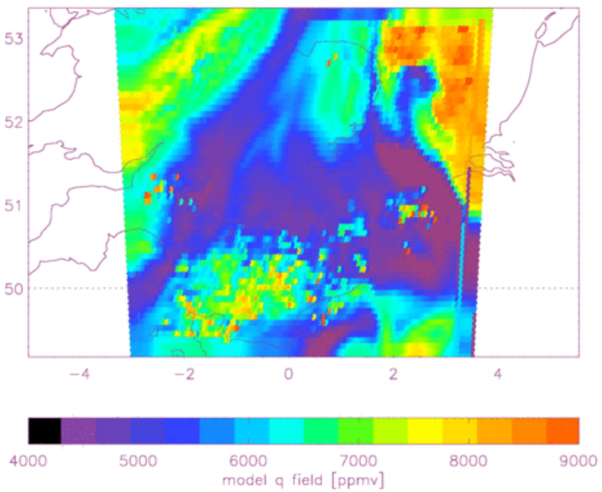
- Background information implicitly used in feature tracking cloudy retrievals (approach 2)
- Tracking in cloudy retrievals (approach 2) is an improvement on tracking the background at all levels
- Number of winds derived is less than half that when using cloudy retrievals; very little wind information in mid to high troposphere

Water vapour as a passive tracer

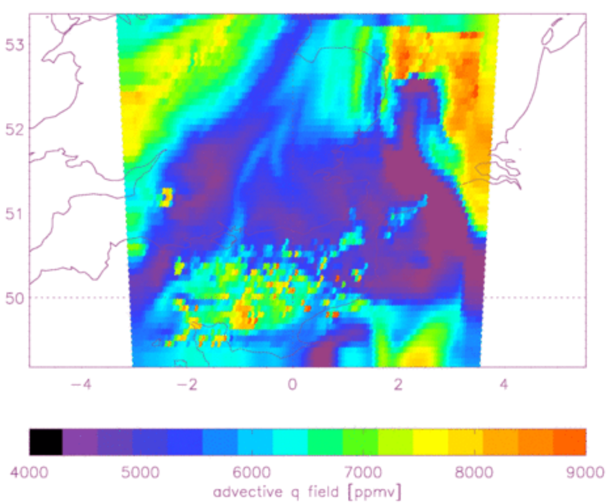
- How much of the change in humidity over the time step is attributable to wind flow? Does this vary between model levels?
  - Calculate the advective component of the humidity field resulting from the model winds by applying a semi-Lagrangian scheme for passive advection
  - Compare against the model field at the next time step
  - Calculate relative change of specific humidity due to not advective motion, identifying potential convective changes over model levels

Water vapour as a passive tracer @ 795hPa

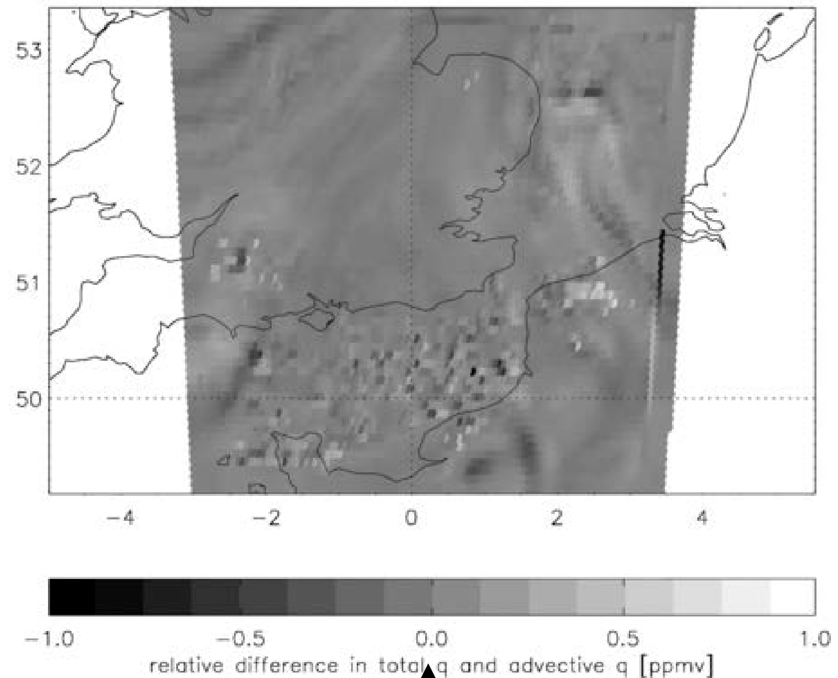
Model field Q



Advective field Q^A



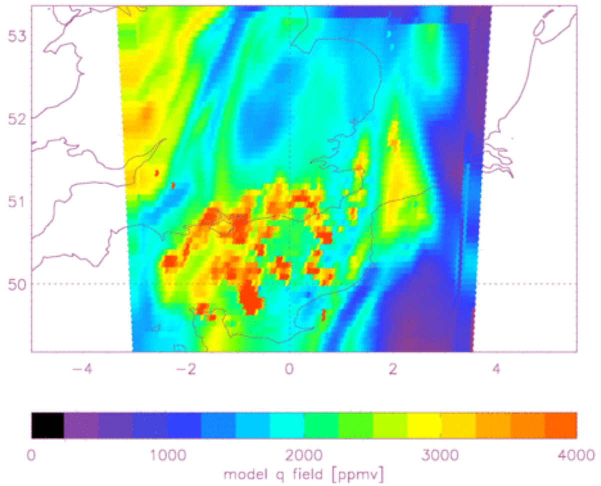
Relative change in humidity not due to advective motion $(Q-Q^A)/Q$



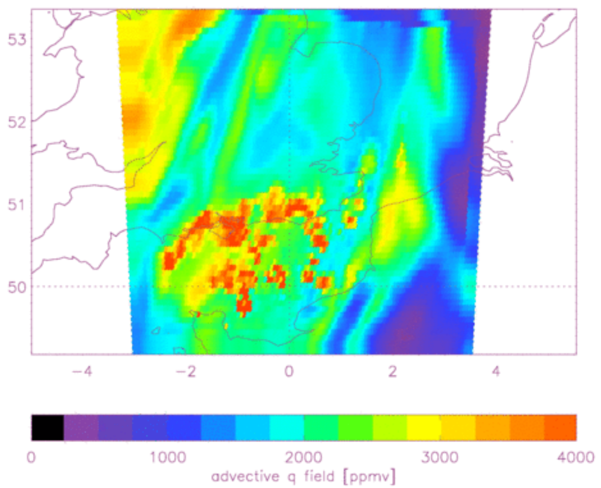
Values close to zero represent predominantly advective flow

Water vapour as a passive tracer @ 656hPa

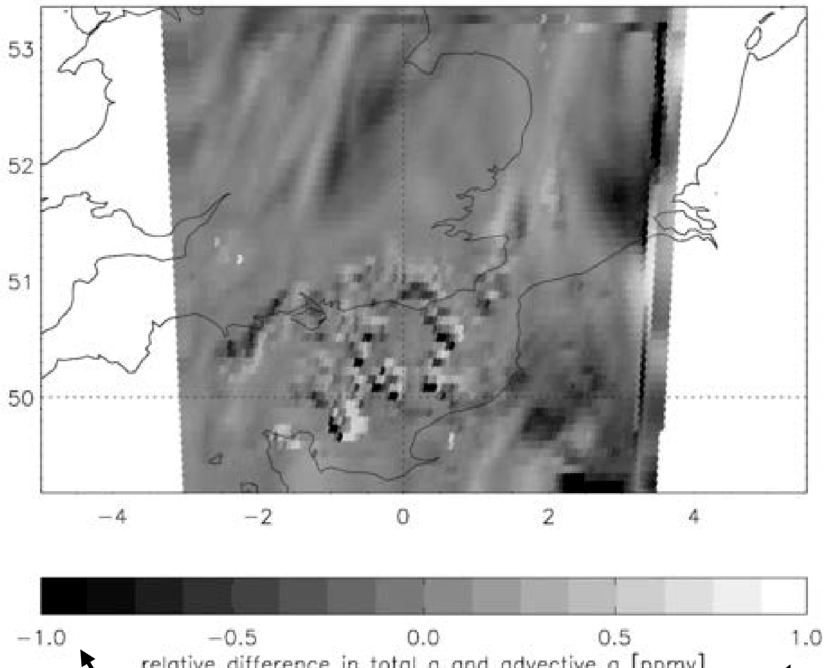
Model field Q



Advective field Q^A



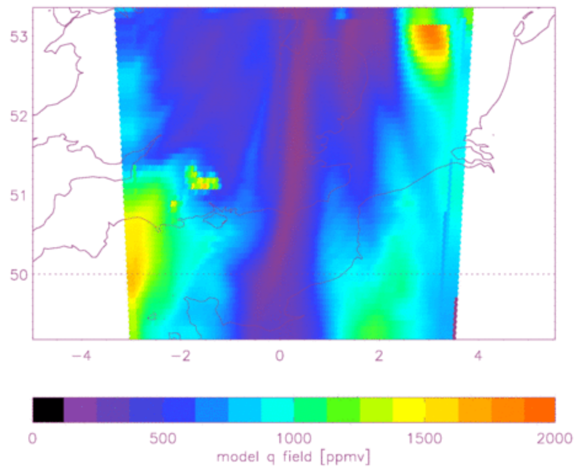
Relative change in humidity not due to advective motion $(Q-Q^A)/Q$



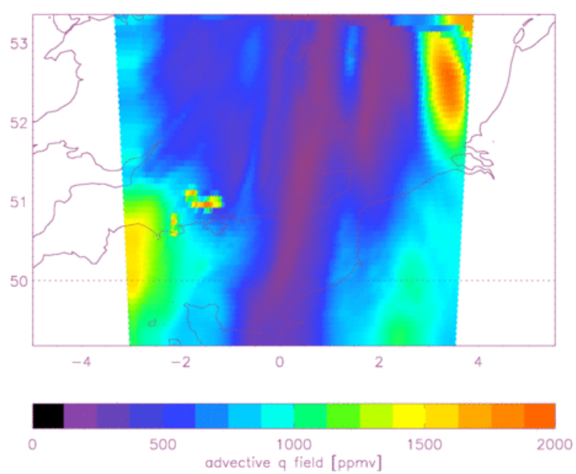
Values far from zero suggest a non-advective component of humidity flow

Water vapour as a passive tracer @ 512hPa

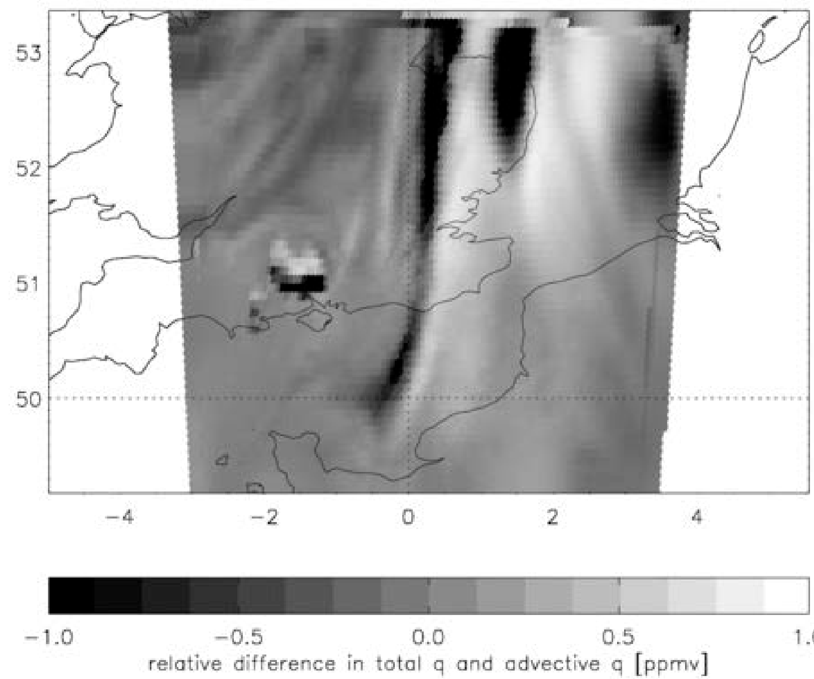
Model field Q



Advective field Q^A



Relative change in humidity not due to advective motion $(Q-Q^A)/Q$



Non-advective contributions to humidity flow appear larger at higher pressure levels

Water vapour as a passive tracer