A posteriori discrimination of aerosol and cloud from satellite retrievals

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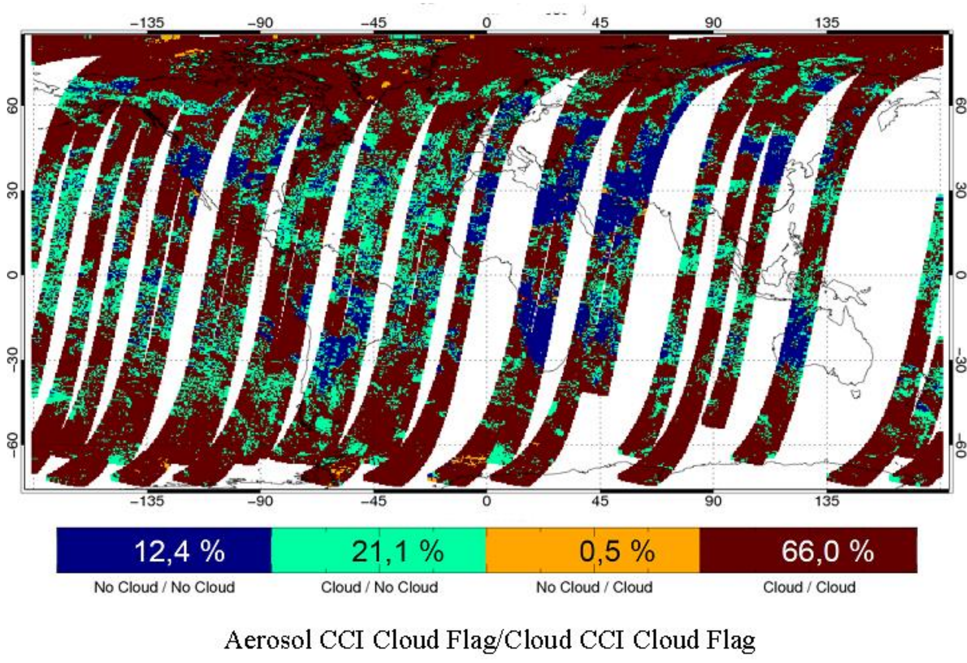
Introduction

Aerosol and cloud have long existed as separate retrieval problems in the satellite remote sensing community, both relying on prior cloud masking to select appropriate pixels.

- Cloud masking is inherently subjective
- Generally, a substantial (and interesting!) fraction of the globe won't be classified as either cloud or aerosol
- Both cloud and aerosol can be retrieved with the same algorithm…



An example AATSR cloud mask from cloud and aerosol CCI show disagreement in 21.6% of cases.

Plot: DLR/DWD

ORAC…

ORAC refers to a group of aerosol and cloud retrieval codes, all using the same basic algorithm.

- Used to stand for “Oxford-RAL Aerosol and Cloud”, now “Optimal Retrieval of Aerosol and Cloud”.
- Also known as “Community Cloud for Climate” – CC4CL – in the cloud_cci project.
- Main variants:
  - Community cloud code
  - Aerosol code
  - IDL development version

See Adam Povey’s poster

ORAC…

- All versions of ORAC are based on optimal estimation
  - All channels fitted by varying all retrieved parameters simultaneously.
  - Aerosol/cloud scattering and absorption modelled using DISORT to provide reflectance/transmission/emission of a scattering layer, which is placed within a “clear-sky” atmosphere (modelled with RTTOV)
- Retrieved parameters:

  Optical thickness, particle effective radius

  Layer height/pressure/temperature (with thermal channels)

  Surface reflectance and temperature (with thermal channels)

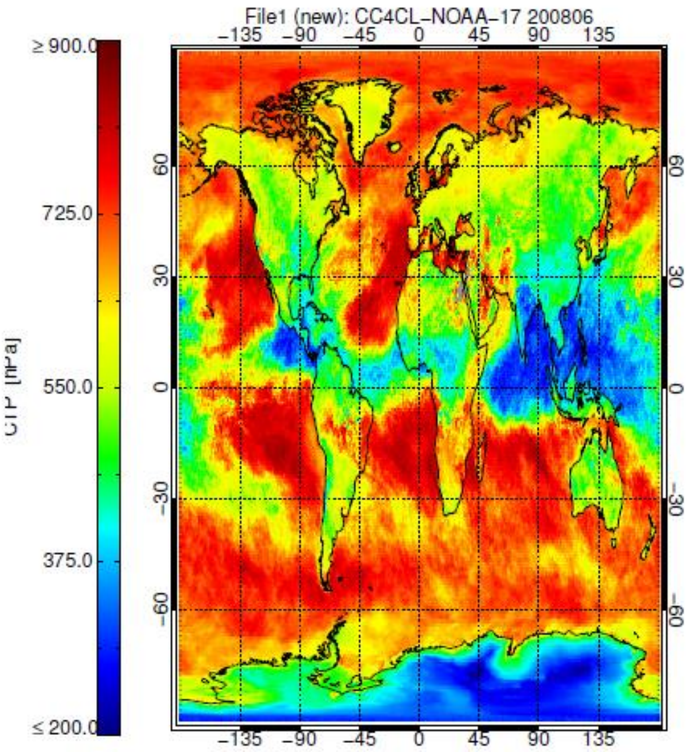
  Aerosol type/cloud phase determined a posteriori

See Thomas et al. (2009) in Kokhanovsky and de Leeuw, “Satellite remote sensing over land”

ORAC…Community cloud code

Code base developed for cloud_cci and applied to MODIS, AVHRR and (A)ATSR:

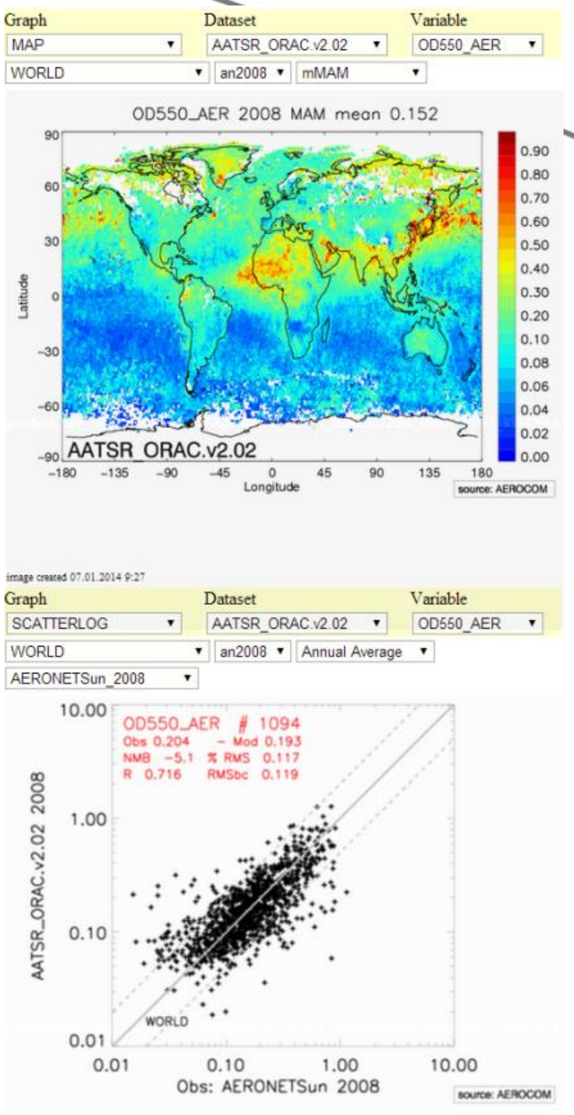
- Available via an online code repository for collaborative development – see http://proj.badc.rl.ac.uk/orac
- Fully coded in Fortran 2003



ORAC…Aerosol code

Code used for aerosol_cci and applied to (A)ATSR (and previously to SEVIRI):

- Main retrieval code in Fortran, with IDL preprocessing
- Provides a choice of two surface BRDF treatments allowing for multi-view instruments to be utilised
- Can be configured to utilise thermal channels, producing a combined aerosol/surface temperature retrieval

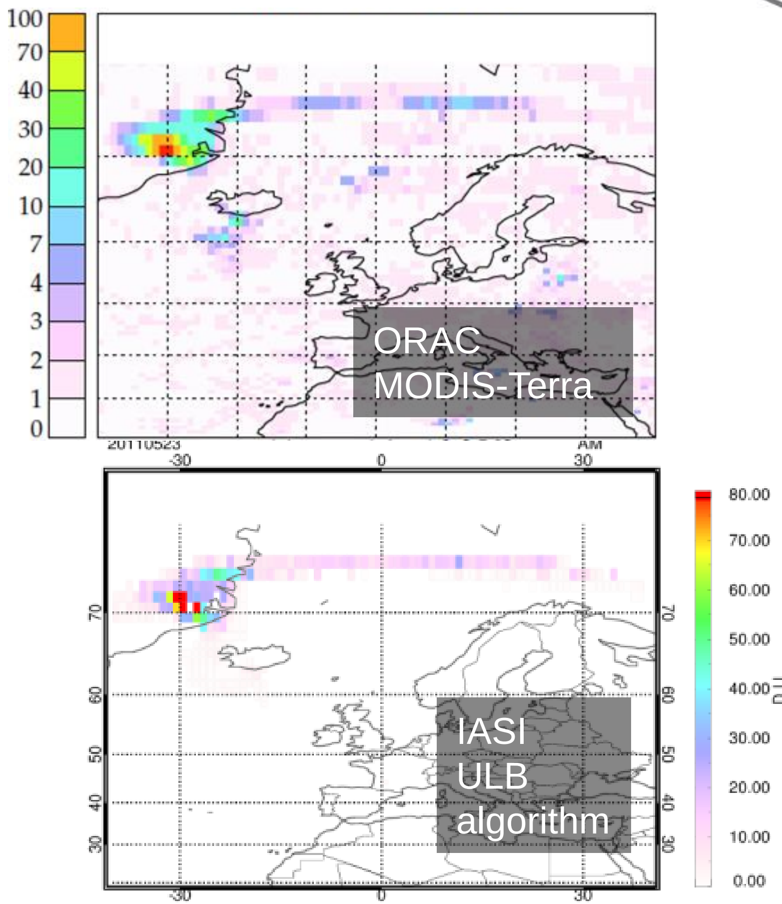


ORAC aerosol_cci product on AEROCOM

ORAC… IDL development version

This is a test-bed code which is much more flexible, but much slower than the Fortran versions:

- Written in IDL, but utilises Fortran modules for radiative transfer (e.g. RTTOV)
- Provides BRDF surface, online radiative transfer, dual cloud-layer capability and the ability to retrieve trace gases (thus far SO_2 and H_20).



SO2 from Grimsvötn 23/05/2011

A posteriori scene identification

- OE retrieval provides statistics on the quality of the fit
  - In particular the retrieval cost is directly related to the conditional probability of the retrieved state given the measurement (for a particular set of assumptions):

$$J = -2 \ln P(\mathbf{x}|\mathbf{y})$$

- Can we use this information to distinguish between cloud and aerosol (and different cloud/aerosol types)?

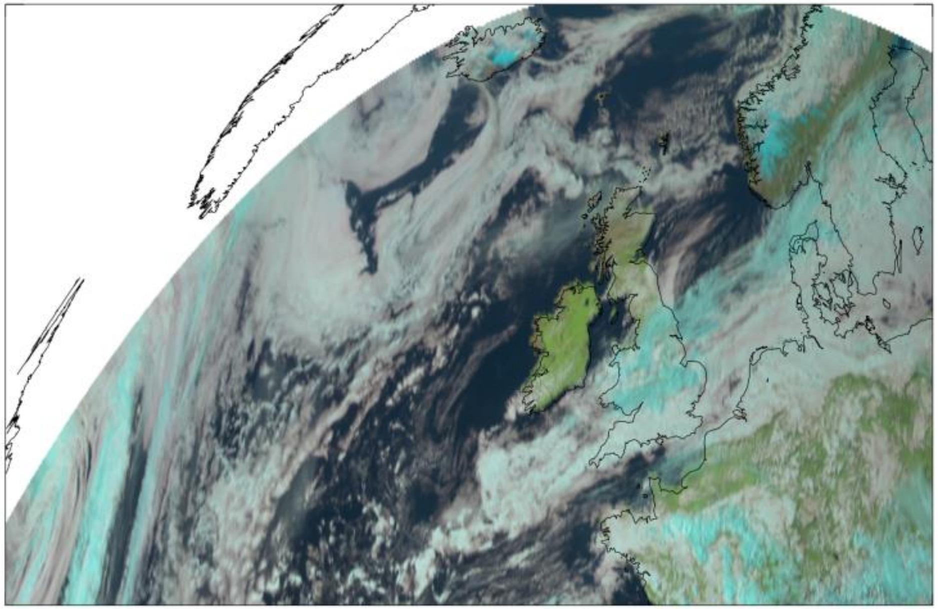
The $\chi 2$ test

- Measurement cost function:

$$J_m = [\mathbf{y} - \mathbf{f}(\mathbf{x})]\ \mathbf{S}_y^{-1}\ [\mathbf{y} - \mathbf{f}(\mathbf{x})]$$

  will be a random sample from a normal distribution with a standard deviation of 1, with degrees of freedom equal to the number of measurements, *m*.
- Thus, it should follow a χ^2 distribution with *m* degrees of freedom and each J_m value can thus provide a probability that the retrieval is consistent with the measurement
- *Assumes that the covariance matrix,* $\mathbf{S}_y$*, is an accurate representation of the uncertainty in the system and that the forward model,* $\mathbf{f}(\mathbf{x})$*, is a good representation of the physics of the measurement.*
- Similar argument can be applied to the a priori cost.

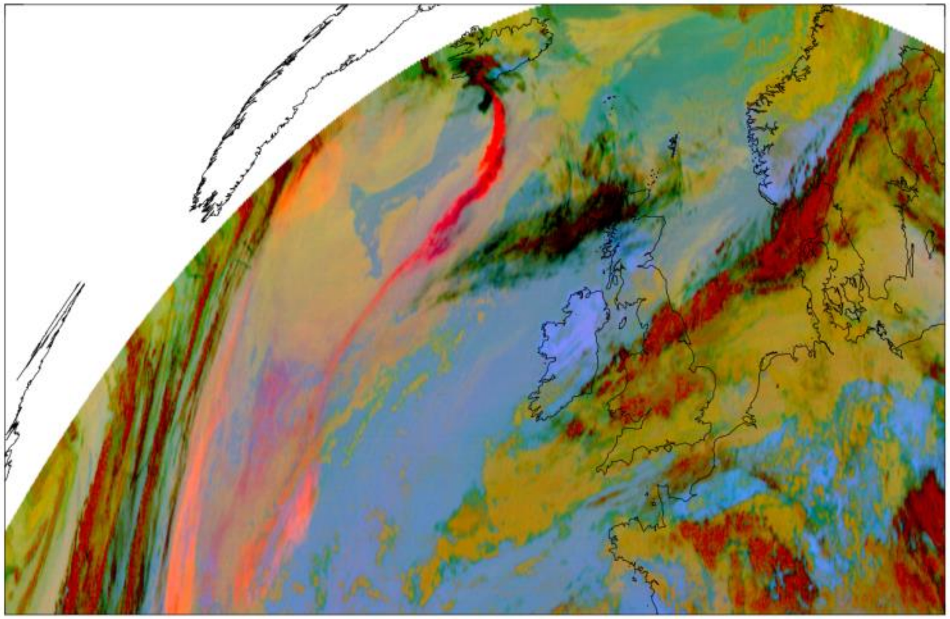
Application to a SEVIRI scene



Eyjafallajökull scene from 8 May 2010

- All SEVIRI channels fit
- Optical depth, effective radius, cloud top height and surface temperature retrieved
- Ice and liquid water cloud, ash and maritime aerosol used

Application to a SEVIRI scene



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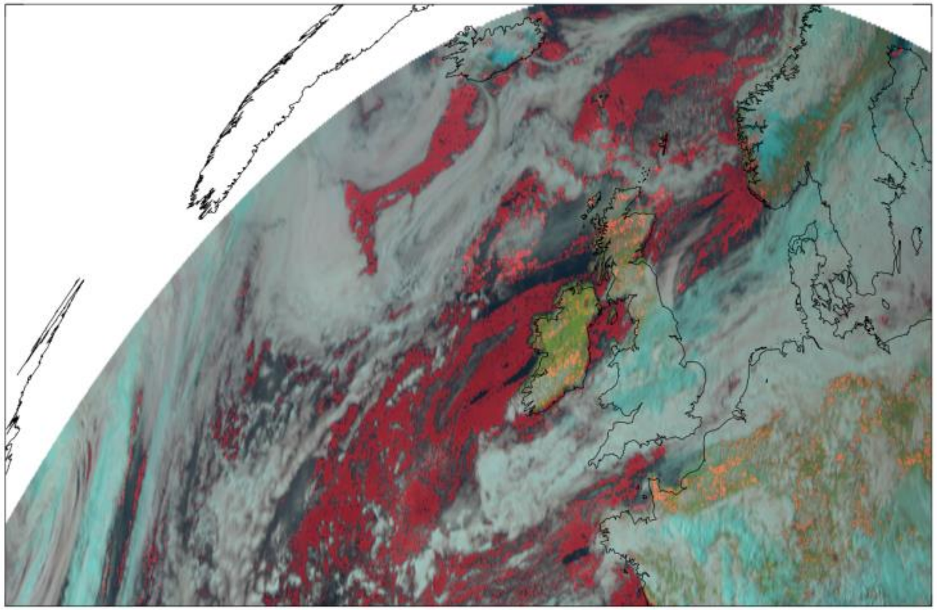

Probability for aerosol

Eyjafallajokull scene from 8 May 2010

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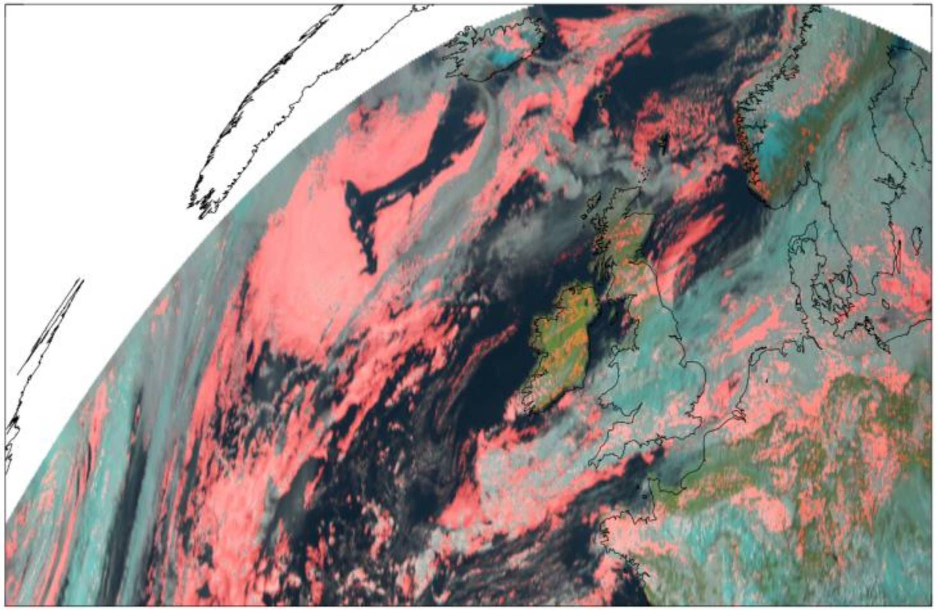
Application to a SEVIRI scene



Probability for water cloud

Eyjafallajokull scene from 8 May 2010

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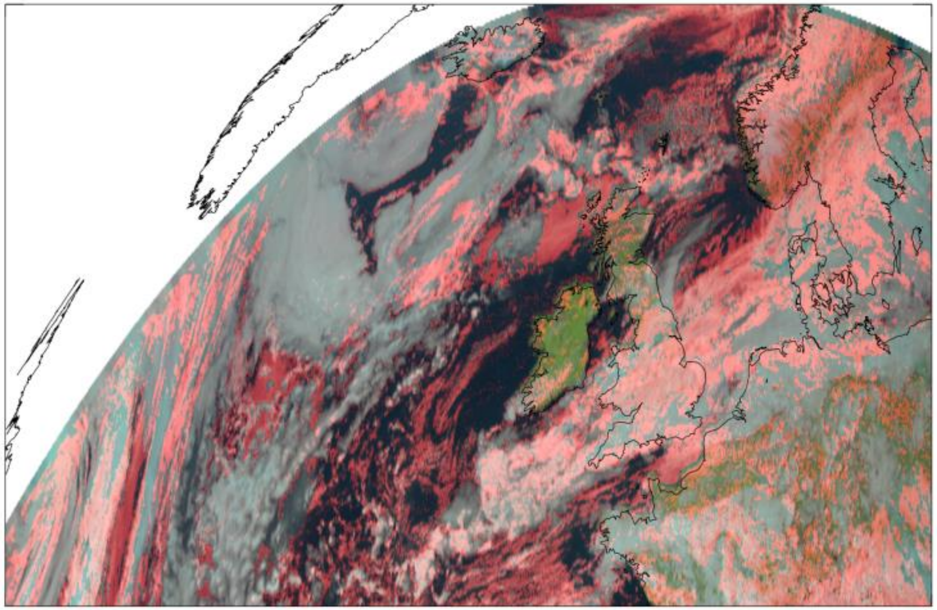
- Optical depth, effective radius, cloud top height and surface temperature retrieved
- Ice and liquid water cloud, ash and maritime aerosol used

Application to a SEVIRI scene

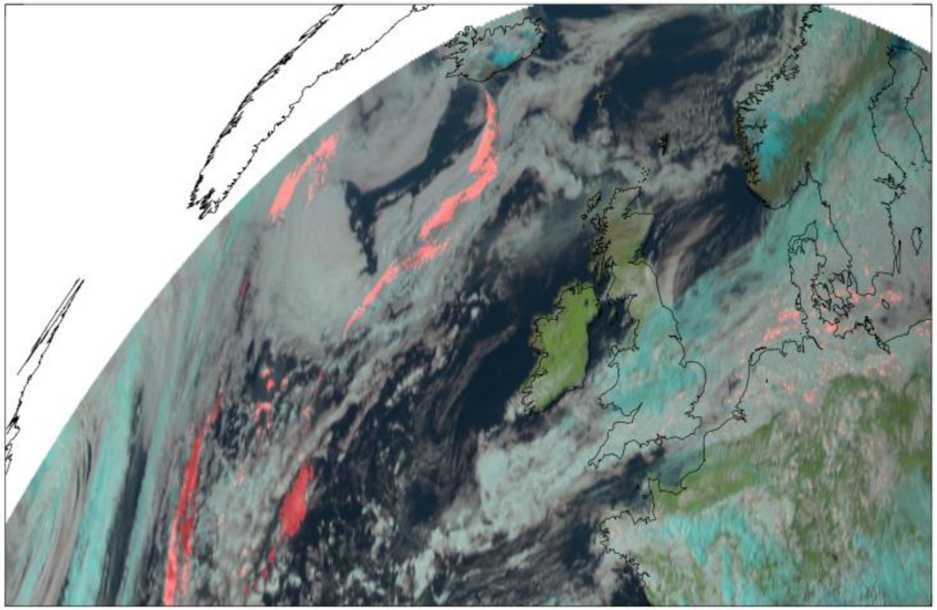


Probability for ice cloud

Eyjafallajokull scene from 8 May 2010

- All SEVIRI channels fit
- Optical depth, effective radius, cloud top height and surface temperature retrieved
- Ice and liquid water cloud, ash and maritime aerosol used

Application to a SEVIRI scene

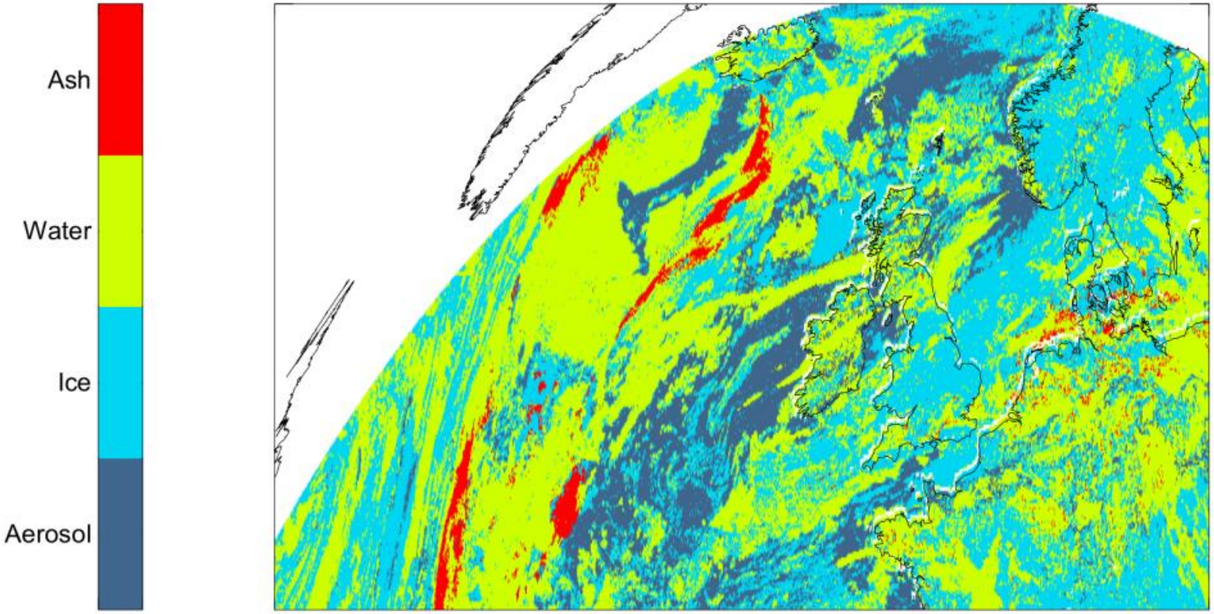


Probability for volcanic ash

Eyjafallajokull scene from 8 May 2010

- All SEVIRI channels fit
- Optical depth, effective radius, cloud top height and surface temperature retrieved
- Ice and liquid water cloud, ash and maritime aerosol used

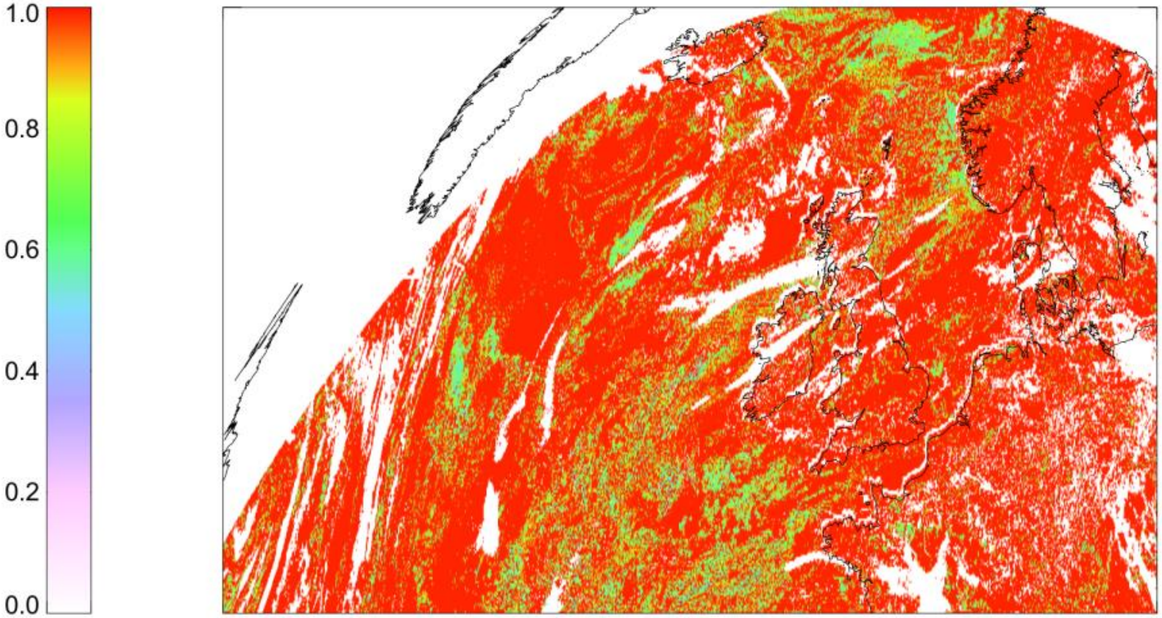
Type selection



Type with maximum probability

→ equivalent to minimum cost

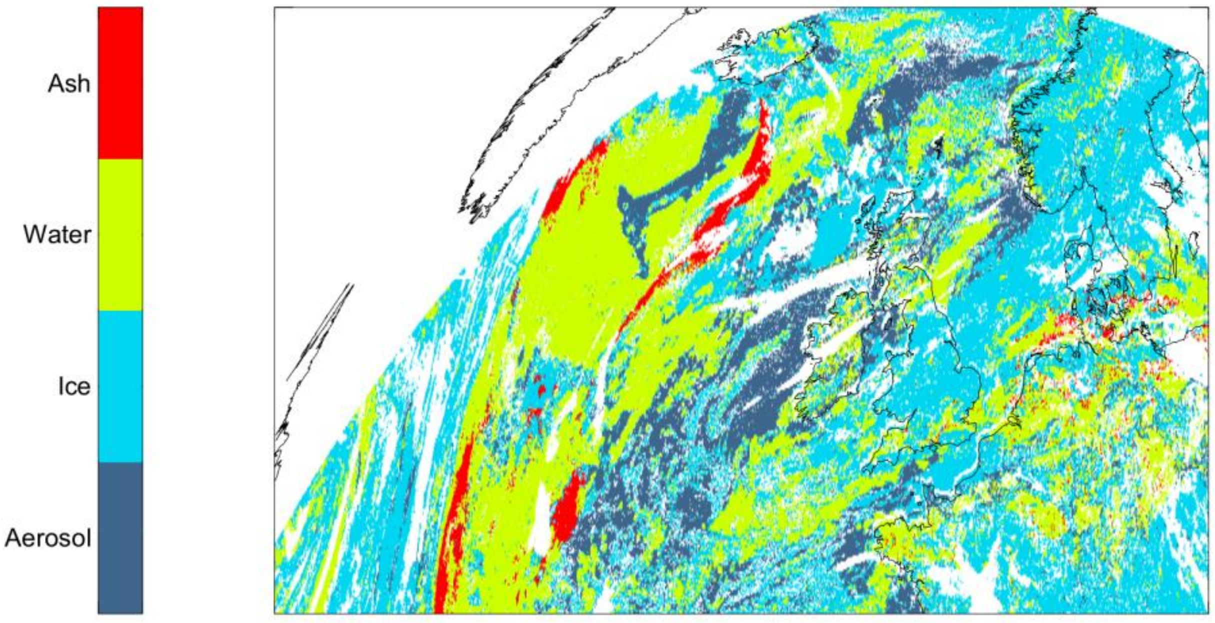
Type selection



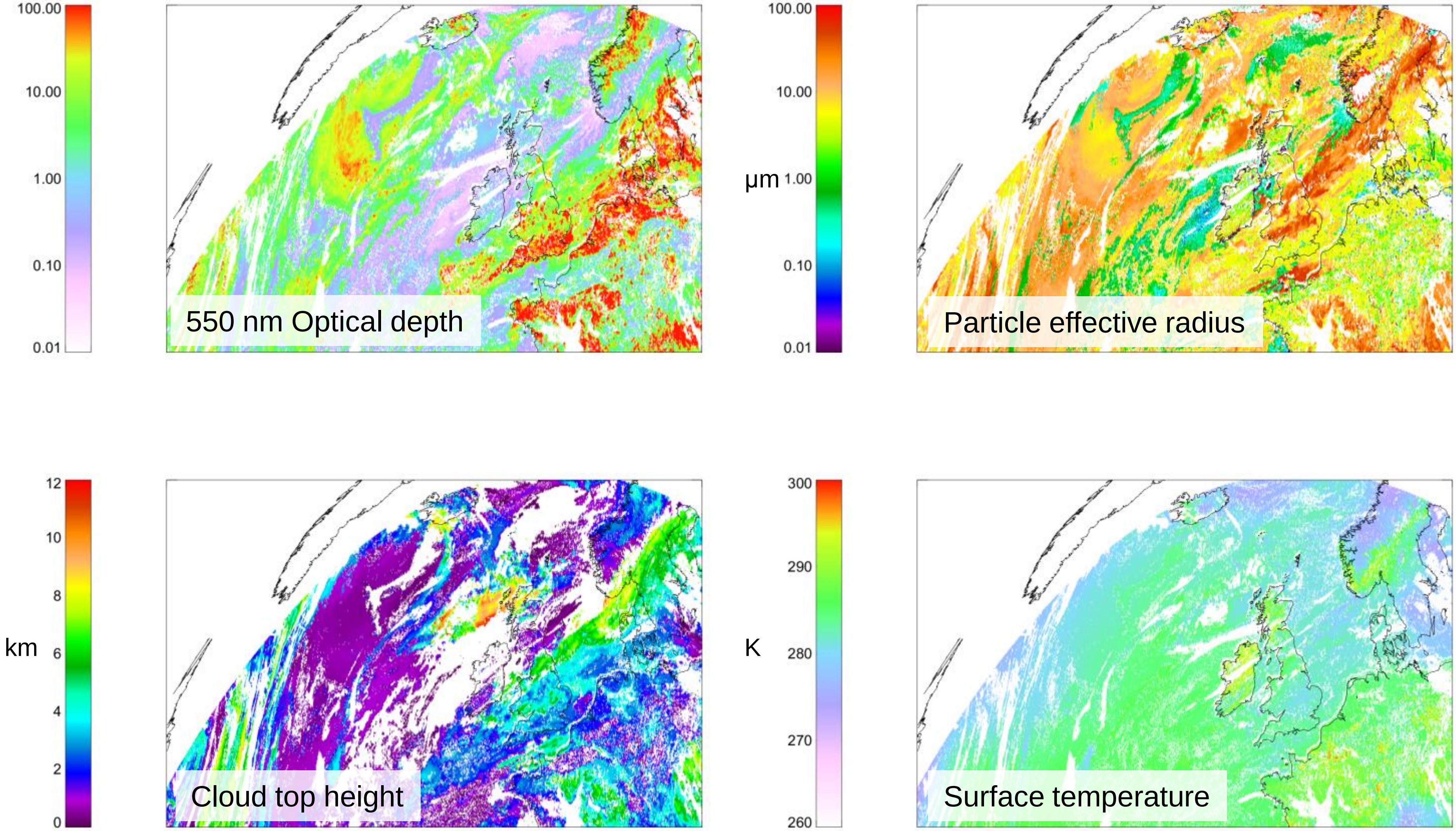
Probability of maximum type

→ where the forward model is not appropriate, the probability is low

Type selection



Type with a maximum probability, where confidence is at least 75%


100.00
10.00
1.00
0.10
0.01
550 nm Optical depth
μm
100.00
10.00
1.00
0.10
0.01
Particle effective radius
km
12
10
8
6
4
2
0
Cloud top height
K
300
290
280
270
260
Surface temperature

Conclusions

- Optimal estimation provides a framework for the estimation of both aerosol and cloud properties within the same retrieval
- Retrieval is attempted for every pixel – no “twilight zone” between definitely clear and definitely cloudy pixels
- $\chi 2$ statistic gives a quantitative measure of which assumed aerosol/cloud type best matches the observed radiances and how appropriate the forward model assumptions are

What's next for ORAC

NOW

ORAC cloud
- Community algorithm
- Fully version controlled
- Single-view, Lambertian surface with thermal-IR
- All Fortran

ORAC aerosol
- Stand alone, no version control
- BRDF surface, multi-view, but no thermal-IR
- Fortran retrieval + IDL pre/post processing

ORAC SST
- Stand alone, no version control
- BRDF surface, multi-view, with thermal-IR
- Fortran retrieval + IDL pre/post processing

"ORAC IDL"
- Full IDL implementation
- More versatile
  - More instruments
  - Sounding channels
  - Online RTM
- Much slower

12 MONTHS

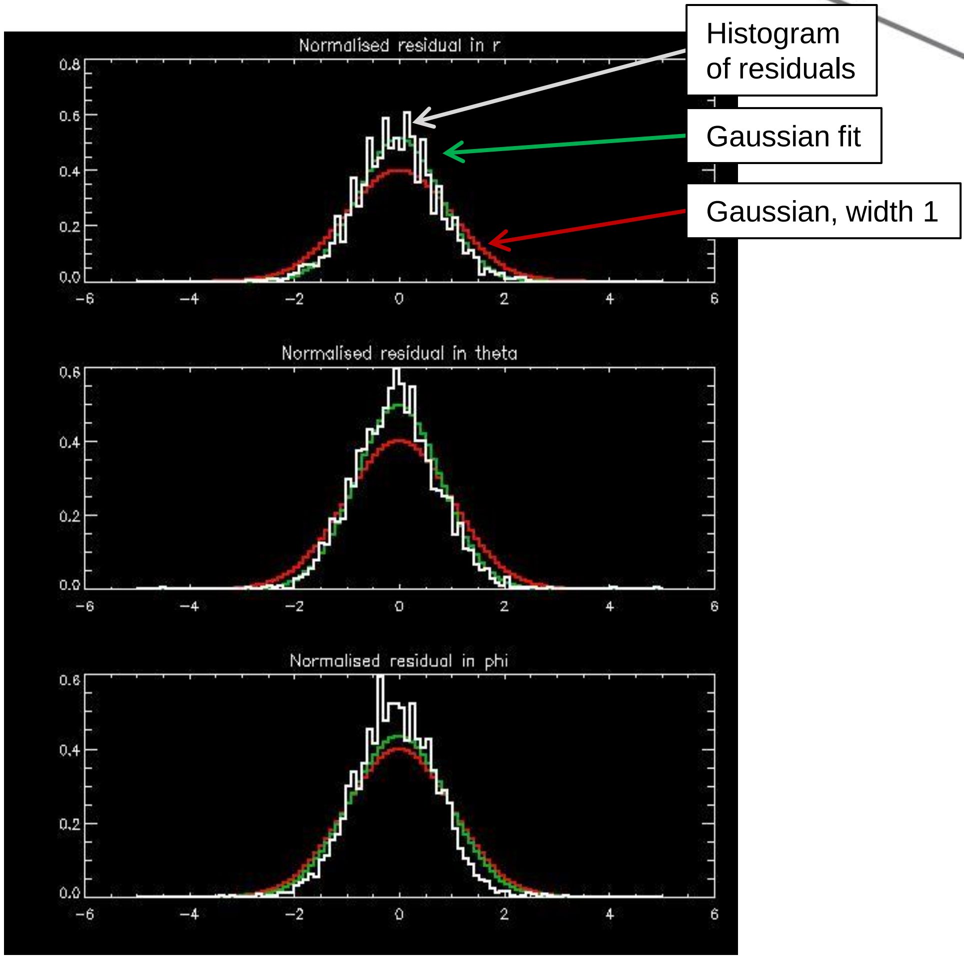
"Community ORAC"
- Community algorithm
- BRDF surface + multi-view
- Thermal IR
- Both aerosol/SST (IDL) and cloud (Fortran) pre/post processing

Specific improvements

"ORAC IDL"
- Full IDL implementation

A test case

- Simple numerical retrieval of three parameters from 3 measurements
  - Forward model is transform from Cartesian to polar coordinates
- Gaussian noise with standard deviation of 0.01 added to forward model

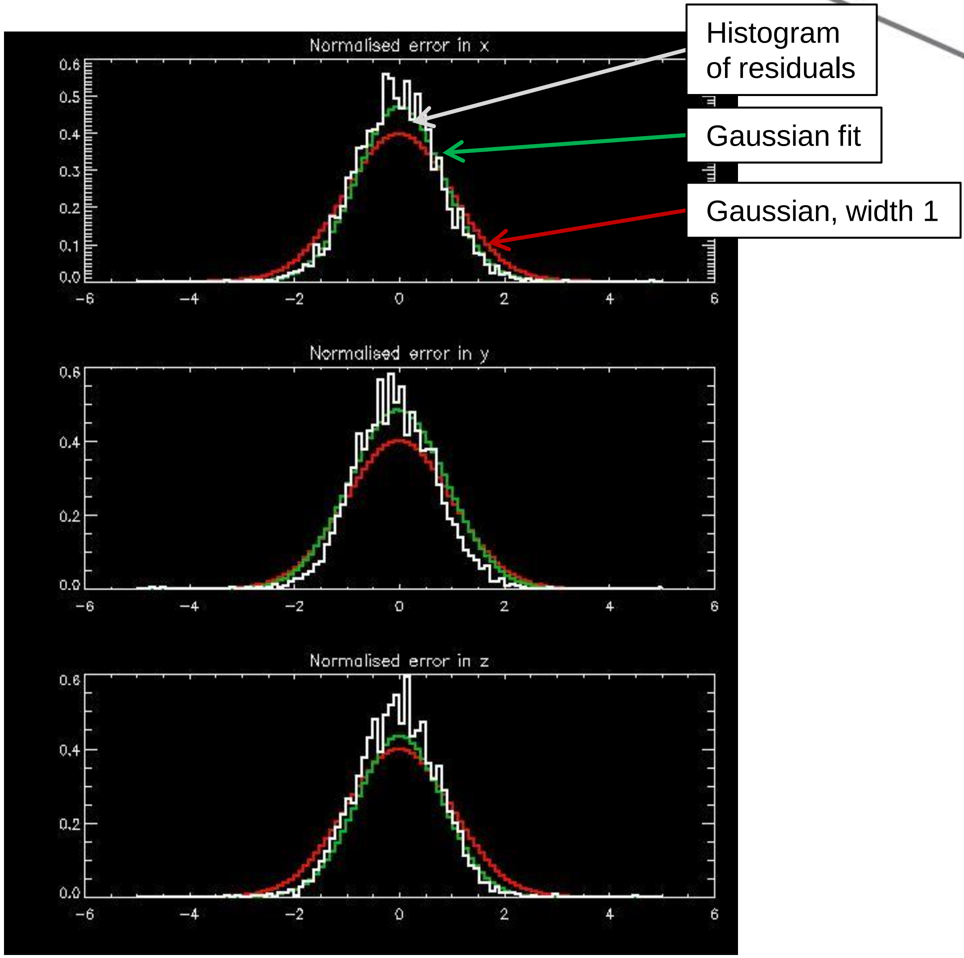


Distribution of measurement residuals, normalised by uncertainty

A test case

- Retrieved state and measurement both agree very well with theoretical distribution

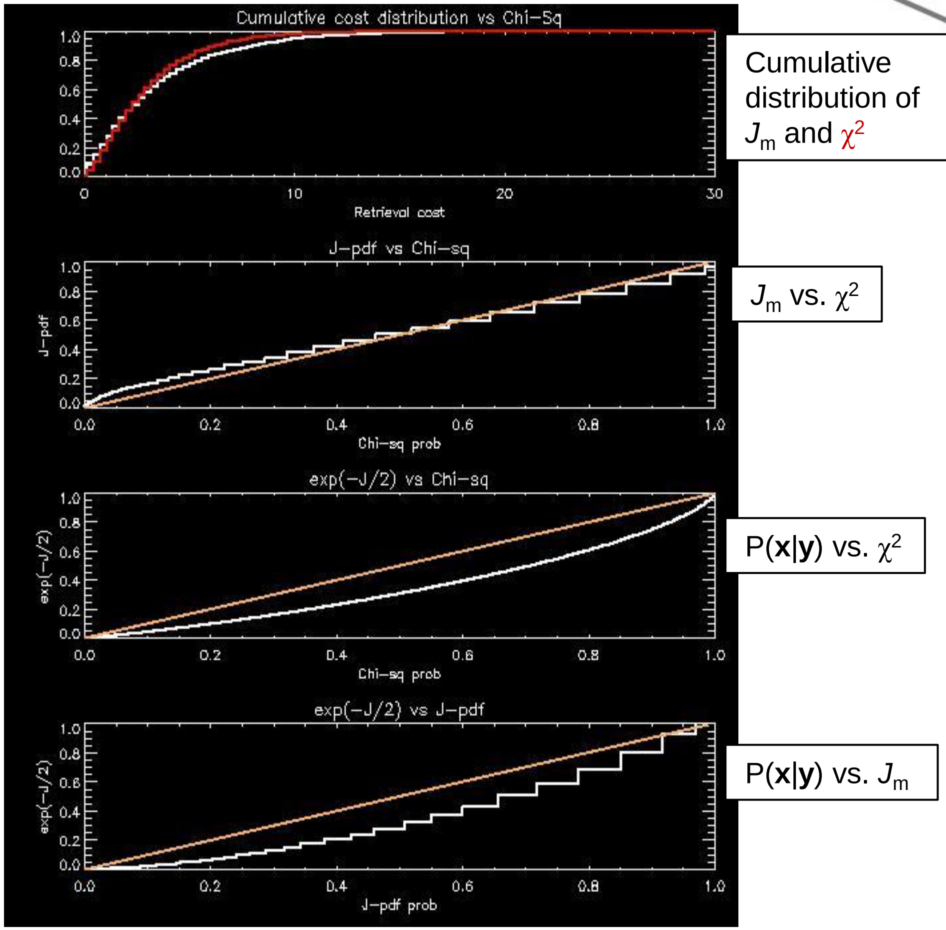
- Retrieval works!



Distribution of state vector residuals, normalised by retrieved uncertainty

A test case

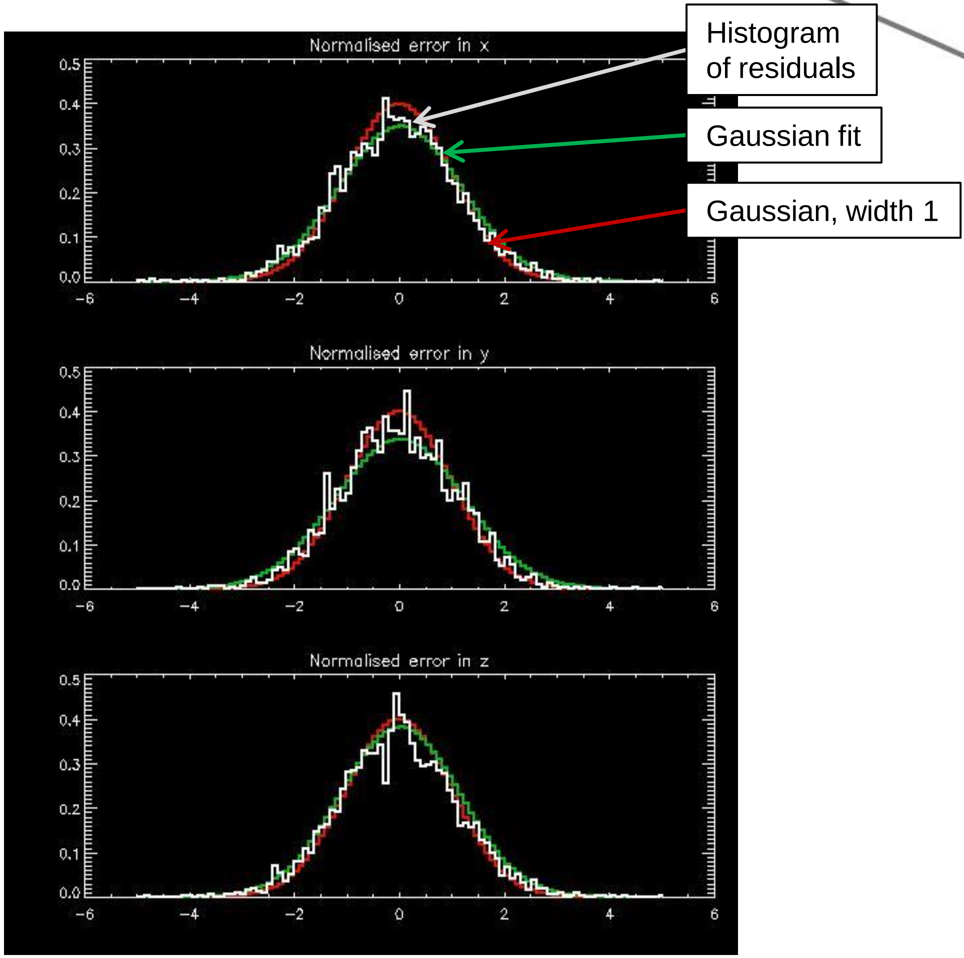
- Cumulative distribution of cost is very close to expected χ^2 distribution
- Note that the conditonal probability P(**x**|**y**) is pretty close to the χ^2 probabilty, but they are not the same



A test case

Assumed uncertainty 50% too small….

- Retrieval still works
- Even retrieved uncertainty is acceptable…

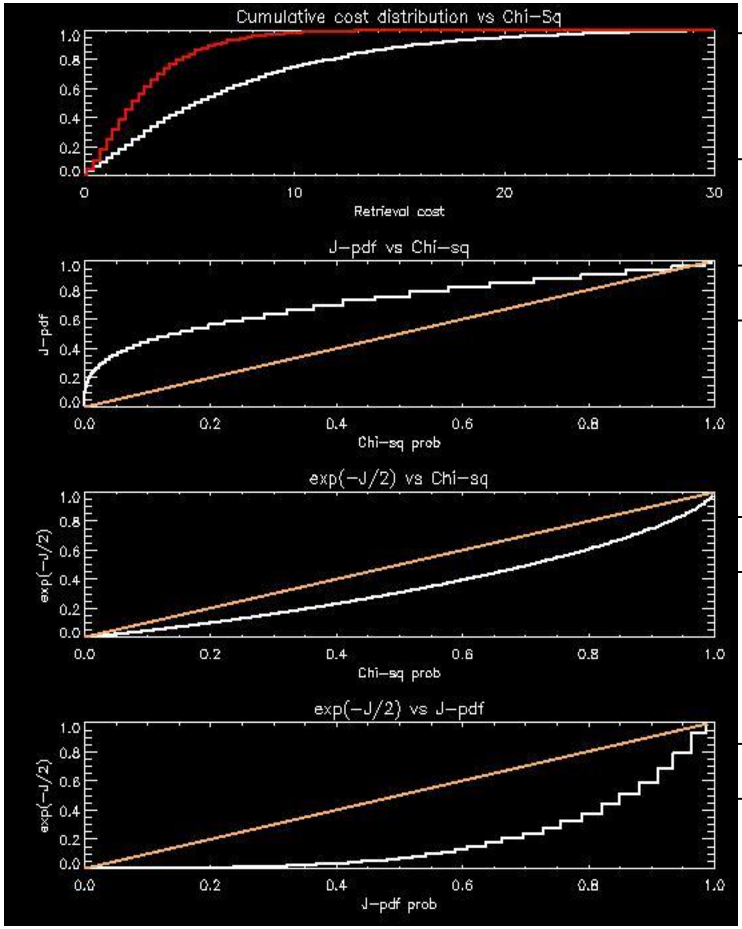


Distribution of state vector residuals, normalised by retrieved uncertainty

A test case

Assumed uncertainty 50% too small….

- χ^2 comparison breaks down
  - Too many high-cost retrievals
- However, the results are still qualitatively useful
  - Better states still provide higher χ^2 probabilities



Cumulative distribution of J_m and χ^2

J_m vs. χ^2

P(**x**|**y**) vs. χ^2

P(**x**|**y**) vs. J_m