Cloud Parameter Retrieval from MIPAS Spectra

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Clouds are a source of major uncertainty in climate models – it is thus important to accurately model clouds in order to determine their properties. In this work, three cloud parameters (cloud top height, cloud top temperature and cloud extinction coefficient) are used to model the radiance measured within the MIPAS field-of-view (FOV) as they represent the most obvious physical, thermodynamic and optical properties, respectively, of a cloud. Finally this model is implemented in an optimal estimations-type retrieval of cloud top height, cloud top temperature and cloud extinction coefficient from MIPAS spectra.

Forward Model: Radiance in MIPAS FOV

It is assumed that a cloud in the MIPAS FOV is horizontally homogeneous – that is, has a constant cloud top height (CTH) across the FOV and can be characterized by a single extinction coefficient (k_{ext}). It is also assumed that the temperature structure within the cloud can be determined by the wet adiabatic lapse rate estimated downwards from the cloud top temperature (CTT). The radiance is considered in the clearest microwindow of the MIPAS A band: 960 – 961 cm^{-1}. (Fig.1)

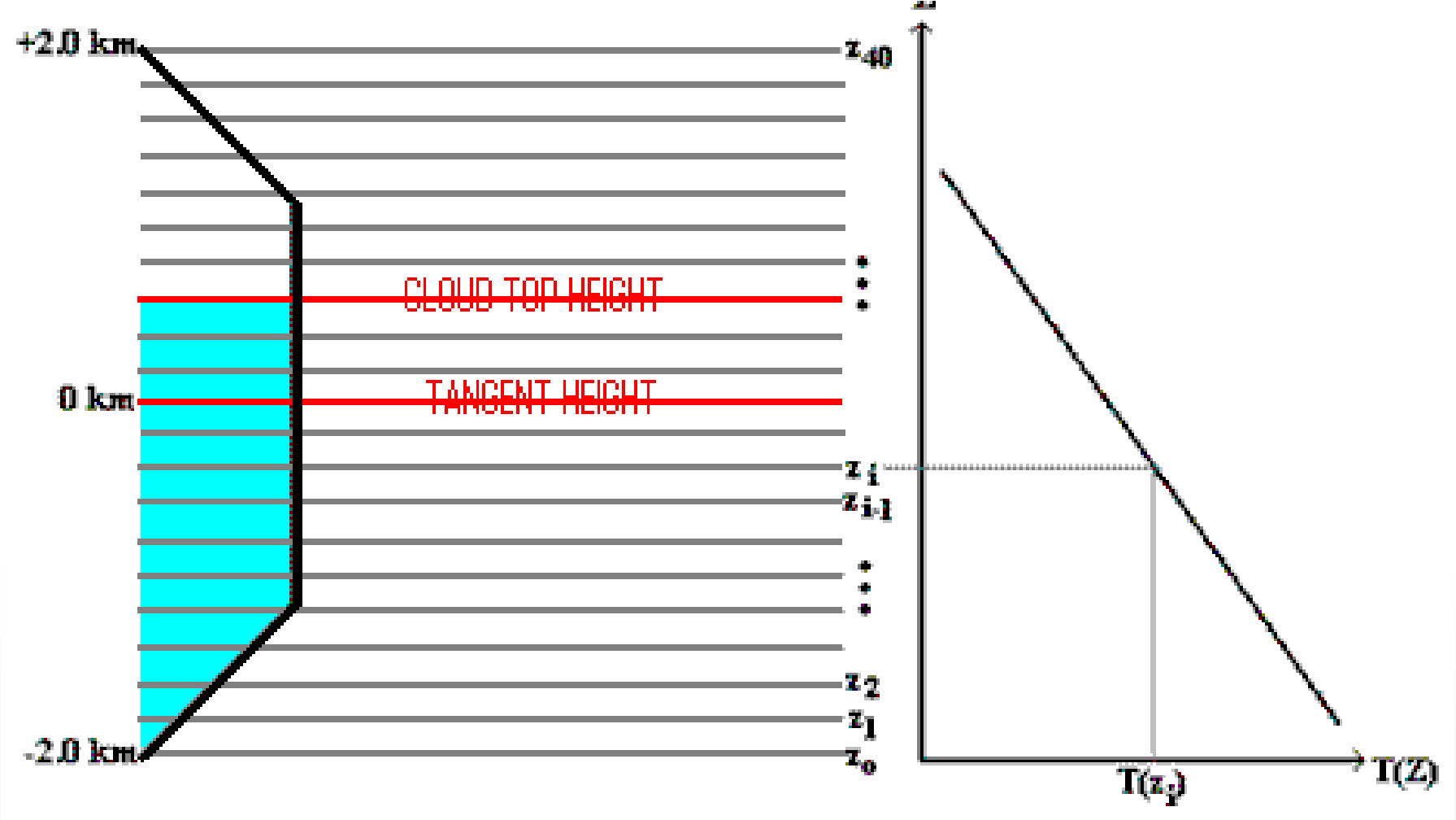


Fig. 1

The forward model of the radiance encountered in the MIPAS FOV can be expressed as:

$$R_{FOV}=\frac{\sum_{i=0(-d)}^{(z_{ct})}L_i\Phi_i}{\sum_{i=0(-d)}^{(d)}\Phi_i}$$

, where

$$L_i=k_{ext}\sum_{j=0(-x_{ct_i})}^{(x_{ct_i})}B(T_j)e^{-k_{ext}(x_j+x_{ct_i})}\Delta x_j$$

is the pencil beam radiance for temperature

$$T_j=T_{th_c}+\Gamma_{wet}\left(th_c-(th_{FOV}+z_i)+\frac{x_j^2}{2(R_e+th_c+z_i)}\right)$$

and pathlength

$$x_{ct_i}=\sqrt{(R_e+th_c+z_{ct})^2-(R_e+th_c+z_i)^2}$$

whereby R_e = Earth's radius, th_c = tangent height where cloud is first detected, th_{FOV} = tangent height of FOV modelled, T = temperature, z = relative position within the FOV, Φ = FOV convolution and Γ_{wet} = wet adiabatic lapse rate. (Fig.2)

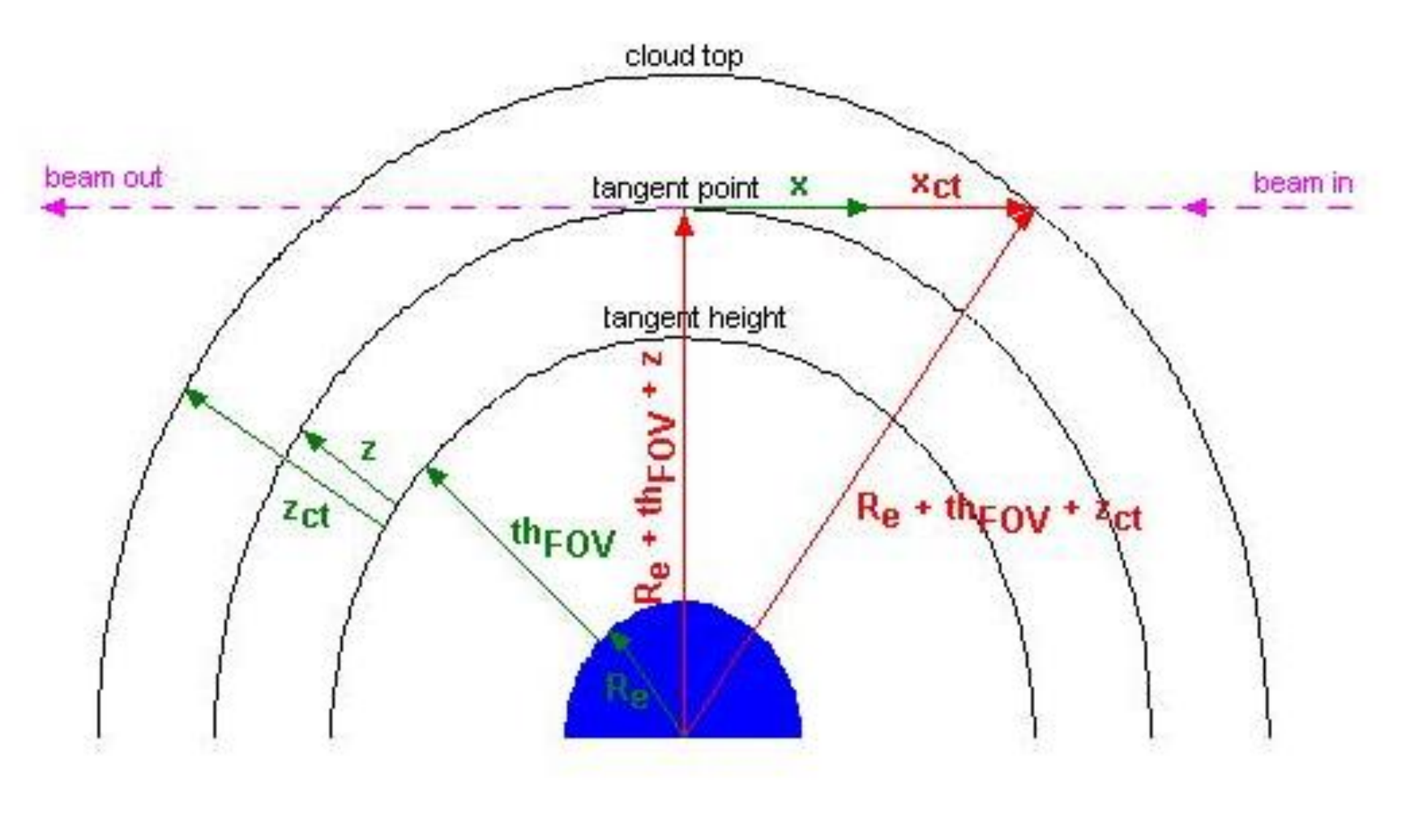


Fig. 2

Fig.3 shows the total radiance measured within two MIPAS FOVs (the FOV containing the cloud top and the FOV immediately below) calculated by this forward model for varying cloud top heights and extinction coefficients.

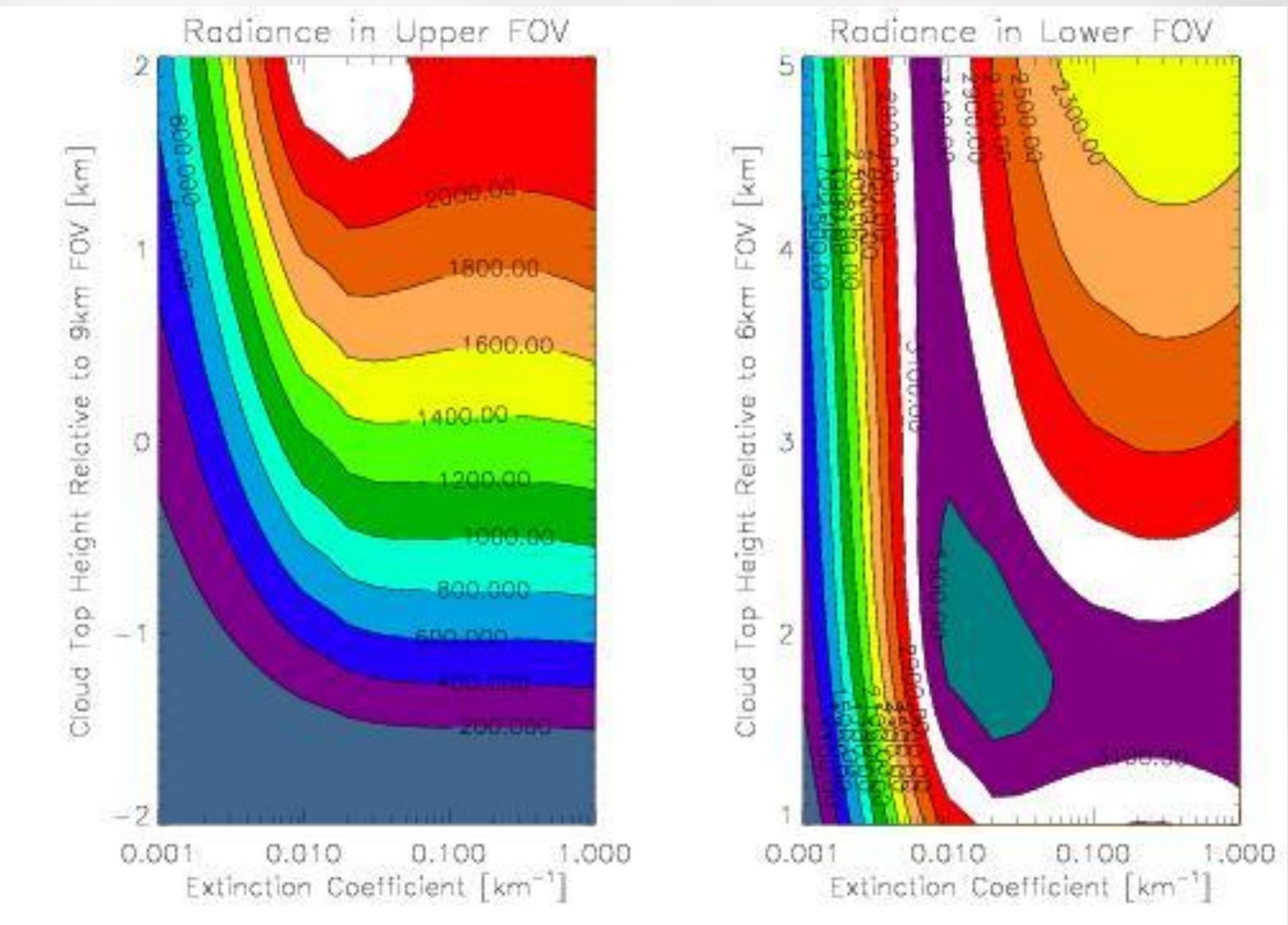


Fig. 3

Validation with RFM Simulations

Real MIPAS measurements (R_m) will include significant gaseous radiation contributions (R_g), while the Forward Model calculates only the radiation contribution by the cloud itself (R_c). It is thus necessary to deduce what portion of the measured signal is due to the cloud.

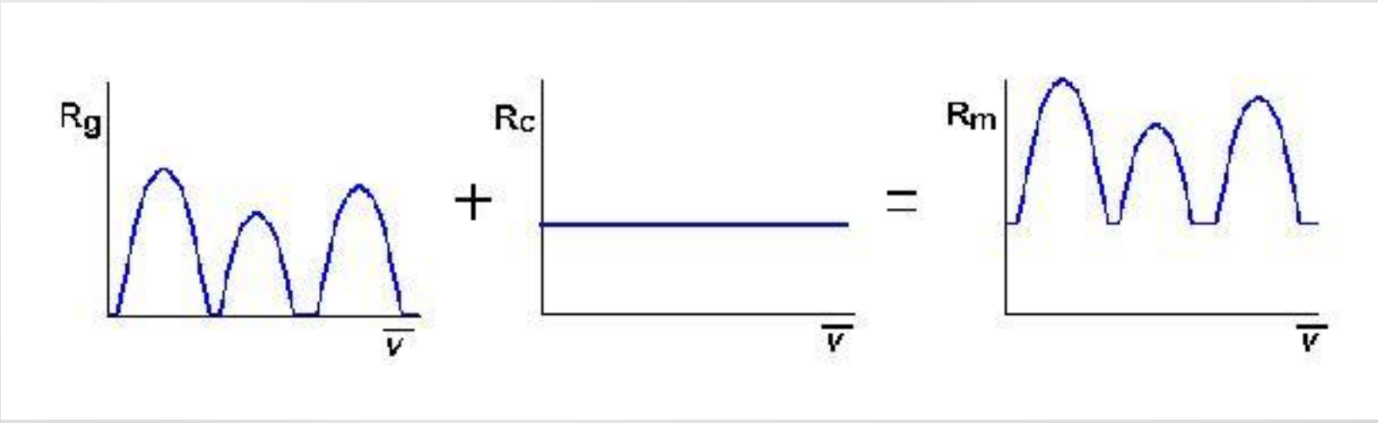


Fig. 7

Assuming that the cloud has a continuum signal and that the gaseous contribution has emission/absorption lines, take $R_m = x_1R_g + x_2R_c$, for constant coefficients x_i. Taking R_c = 1 nW / cm^2 sr cm^{-1} across the microwindow, a simple retrieval of $\mathbf{x} = (x_1, x_2)$ from $\mathbf{y} = \mathbf{K}\mathbf{x}$ for $\mathbf{y} = (R_m, R_m)$ and $\mathbf{K} = (R_g, R_c)$ gives x_2 equal to the radiance emitted by the cloud in the FOV. (Fig.7)

Comparing the Forward Model output with RFM simulations of cloud corrected for gaseous emission in the manner described above, it is clear (Fig.8) that the Forward Model does a good job at estimating the radiance measured by the MIPAS FOV.

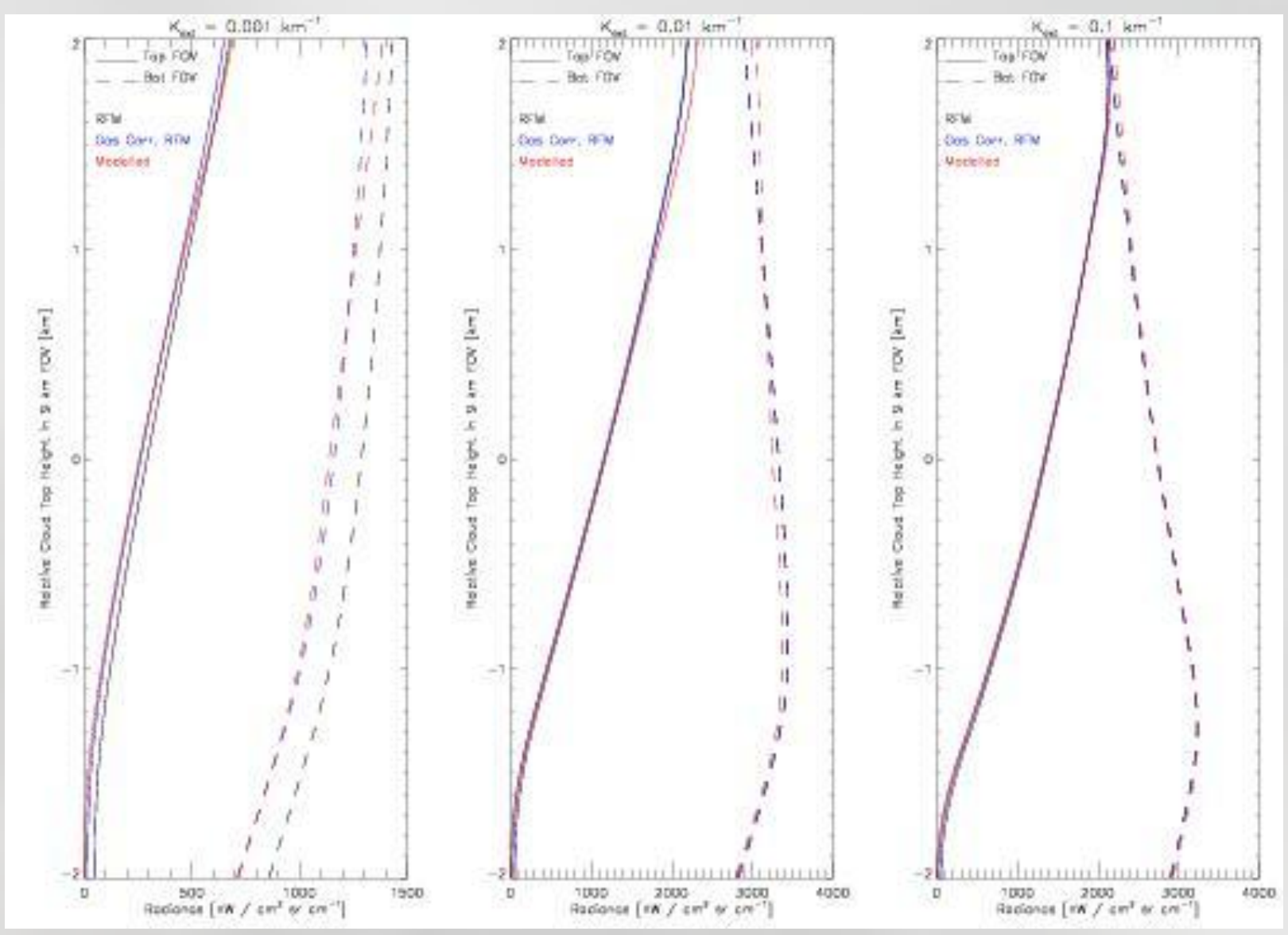


Fig. 8

Now, using the Forward Model and Retrieval described previously, Fig.9 shows that the retrieval is well able to return the simulated values of cloud top height, cloud top temperature and cloud extinction coefficient, certainly within retrieval error. This validation confirms that the forward model and retrieval work well and enable us, with confidence, to apply them to real MIPAS spectra known to contain cloud.

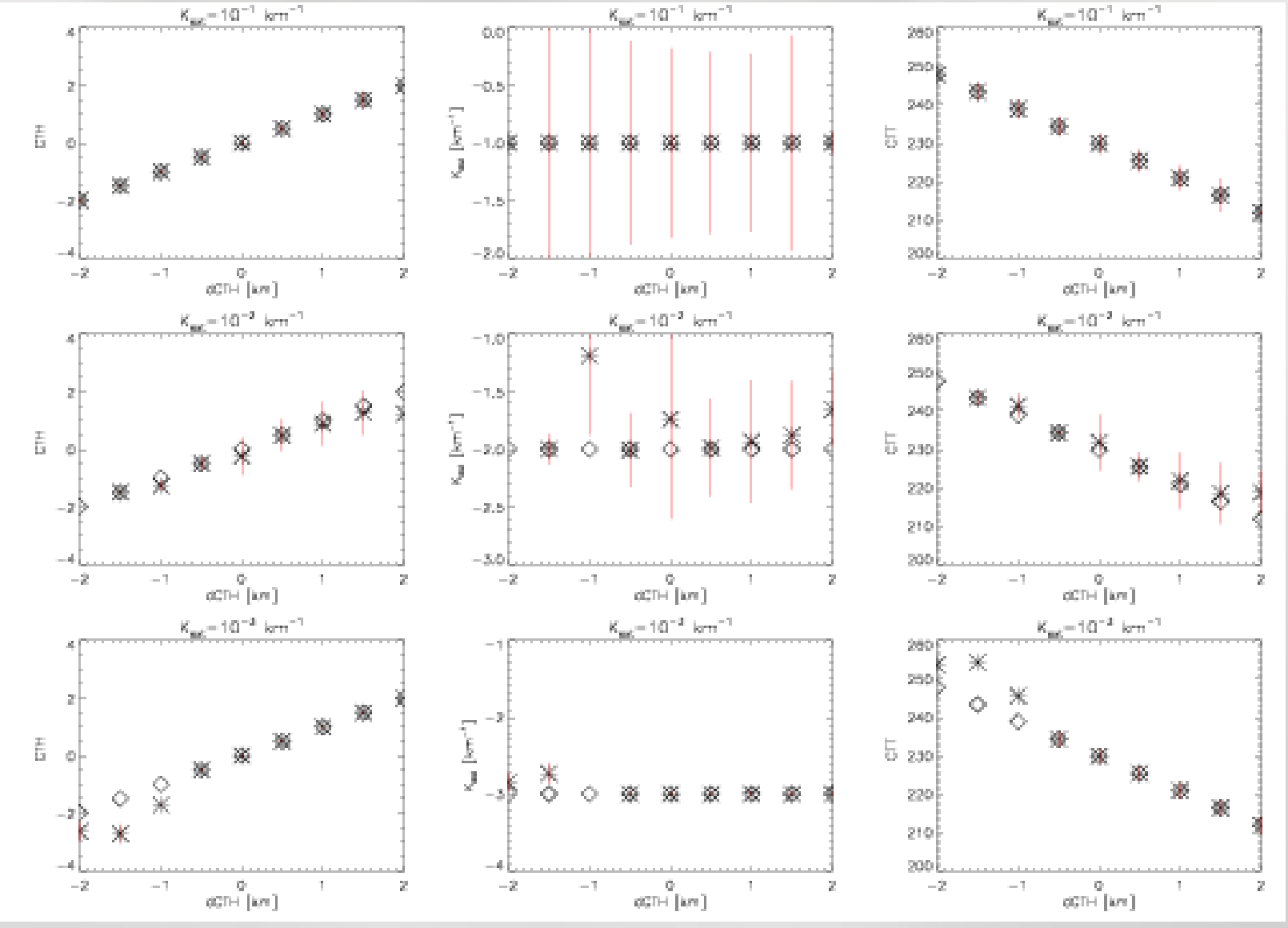


Fig. 9

Retrieval and *A Priori* Dependence

A sequential optimal estimation retrieval is required to contain enough information to accurately retrieve the three cloud parameters from two radiance measurements (L_c, radiance from FOV containing cloud top and L_b, radiance from FOV immediately below). Because there can be infinitely many clouds which can produce the two radiance measurements, information is added to the retrieval by way of the Colour Index (CI).

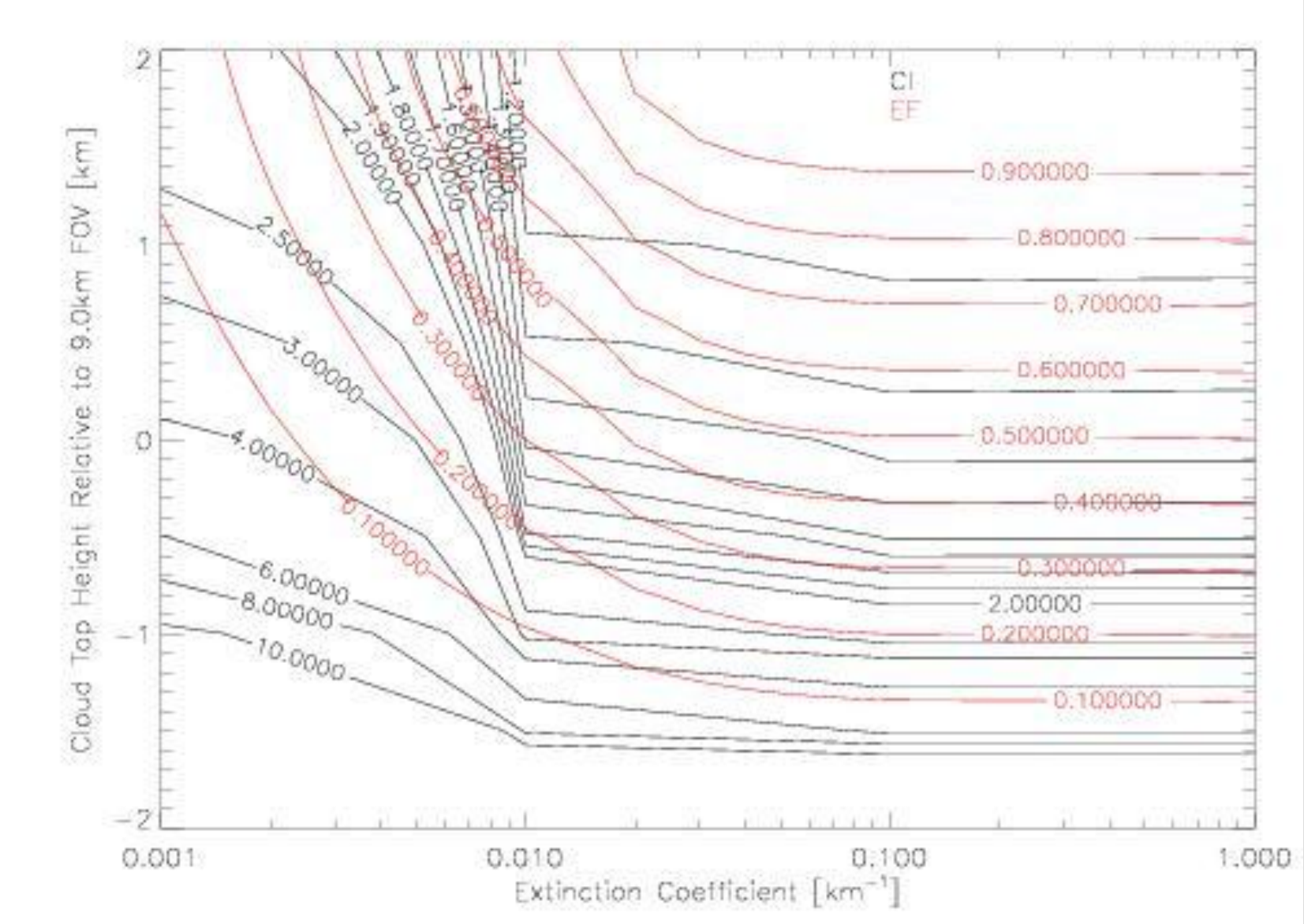


Fig. 4

CI is related to the cloud effective fraction (EF) of the FOV, where

$$EF=\frac{\int_{-d}^{z_{ct}}\left(1-e^{-k_{ext}x(z)}\right)\Phi(z)dz}{\int_{-d}^{d}\Phi(z)dz}$$

(Fig.4,5). This relation is not known, as the microwindows used in the CI method have not yet been optimized with respect to cloud amount. However, roughly

EF = 1.37 – 9.00logCI + 22.62(logCI)^2 – 23.90(logCI)^3 + 8.78(logCI)^4.

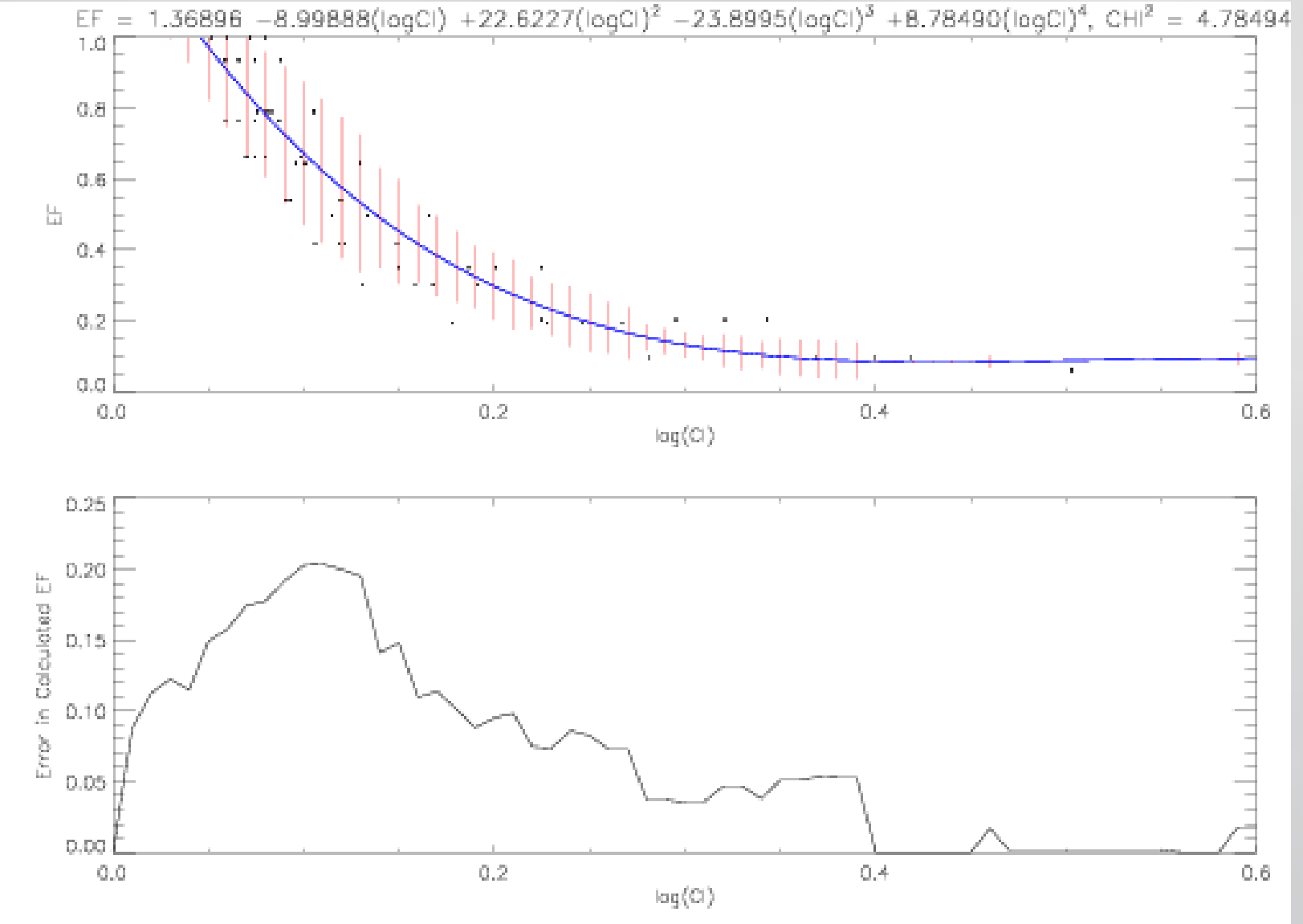
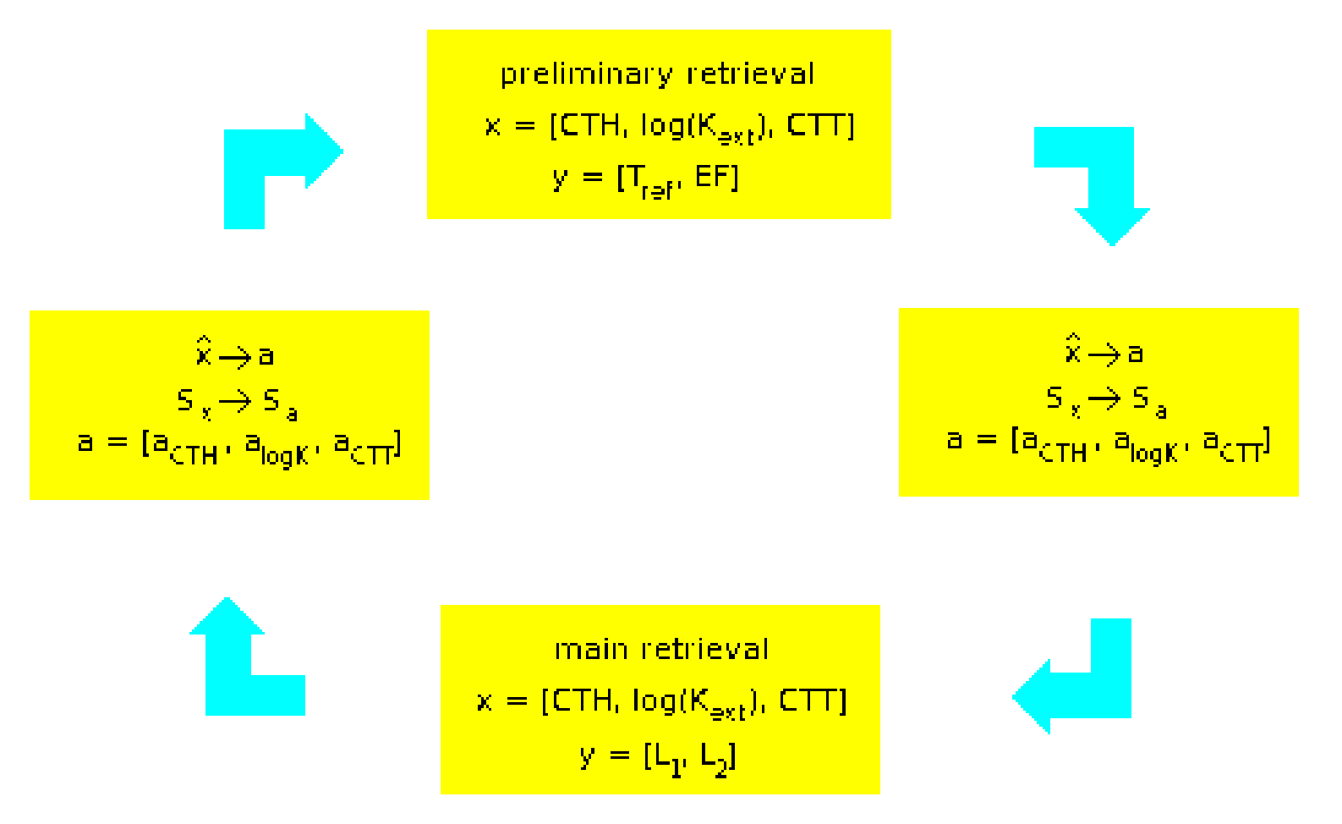


Fig. 5

Thus, a preliminary optimal estimation retrieval uses the ECMWF reference temperature at the tangent height of the FOV where cloud is first detected and EF as pseudo-measurements from which the three parameters are retrieved. These preliminary retrieved parameters then become the *a priori* and their error covariance matrix is used as the *a priori* covariance matrix in the real retrieval, which uses L_c and L_b as measurements in a Levenberg-Marquardt Optimal Estimation scheme. This sequential retrieval scheme places the *a priori* close to the correct cost-function minimum and ensures better accuracy in retrieval. (Fig.6)



preliminary retrieval
$x = [CTH, \log(K_{ext}), CTT]$
$y = [T_{ref}, EF]$

$\hat{x} \rightarrow a$
$S_x \rightarrow S_a$
$a = [a_{CTH}, a_{logK}, a_{CTT}]$

main retrieval
$x = [CTH, \log(K_{ext}), CTT]$
$y = [L_1, L_2]$

$\hat{x} \rightarrow a$
$S_x \rightarrow S_a$
$a = [a_{CTH}, a_{logK}, a_{CTT}]$

Fig. 6

Application to 2003 MIPAS Data

The sequential retrieval scheme has been run on a 2003 MIPAS level 1C spectra sampled one day out of every ten. The retrieved values of CTH, CTT and log(k_{ext}) have been averaged in 5º by 5º latitude-longitude bins for the full year-long period of study. The resulting maps of high cloud CTH, CTT and extinction (Fig.10-12) exhibit some reassuring behaviour, namely:

- "Hot spot" of high cloud over Indonesian toga core;
- Occurrence of high cloud over mountainous regions such as the Southern Andes and Rockies;
- Increased high cloud over Amazon Basin and the Congo;
- Increasing cloud top height towards the tropics;
- Retrieved CTT is nearly fully correlated with CTH;
- Retrieved log(k_{ext}) is more or less constant over the globe – probably a result of picking the highest cloud only in the MIPAS scan to analyze.

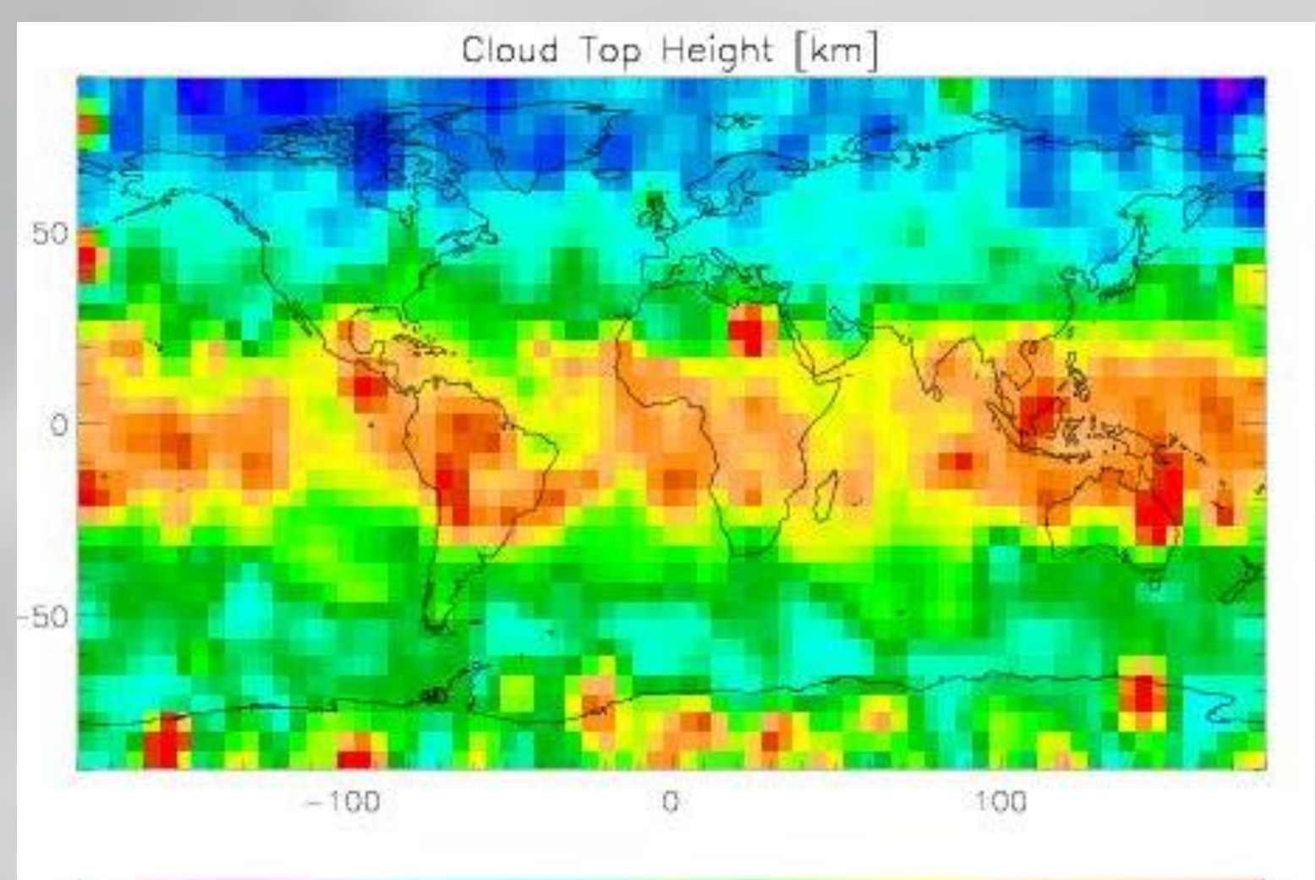


Fig. 10

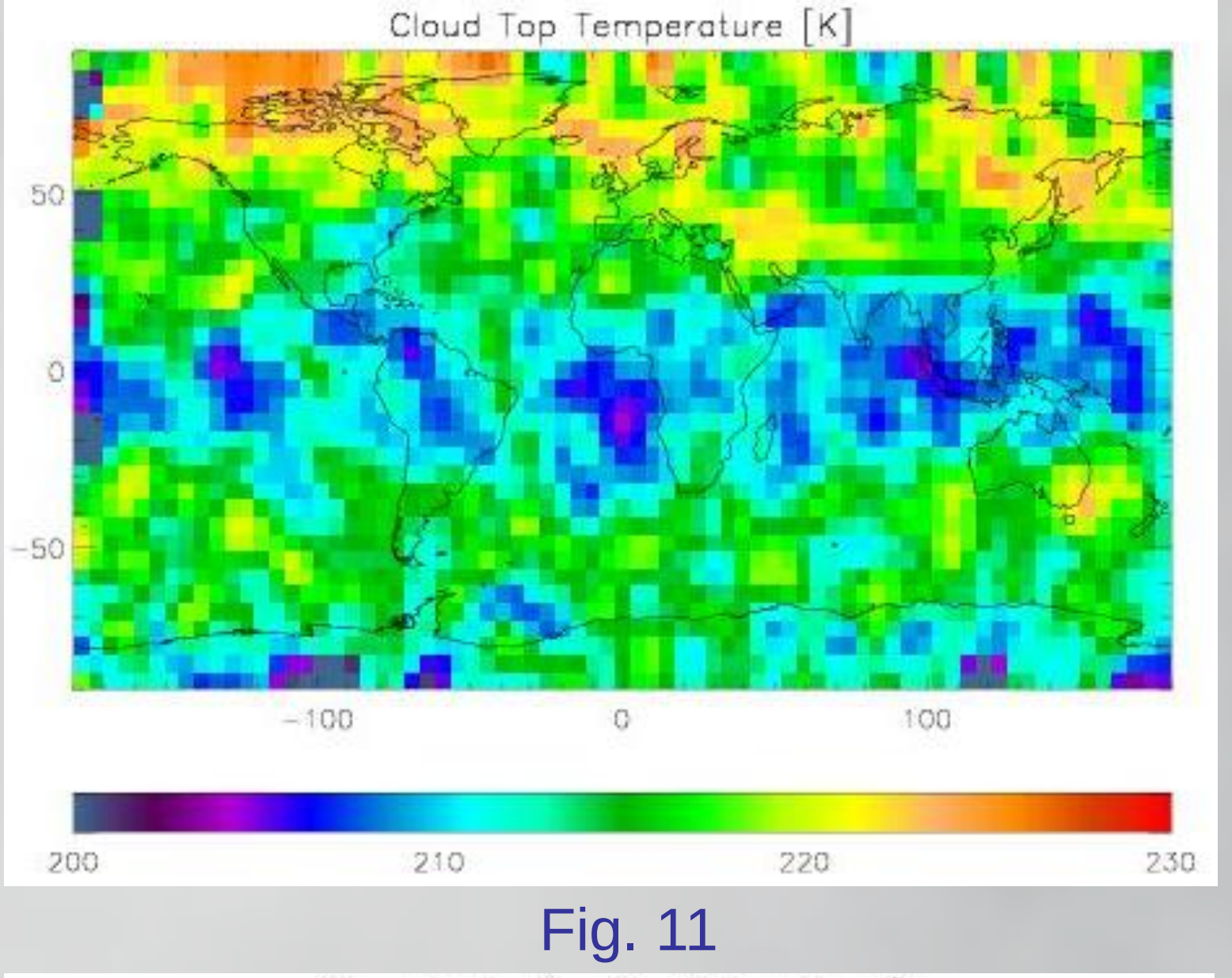


Fig. 11

This preliminary study confirms that cloud top height, cloud top temperature and cloud extinction coefficient can be successfully retrieved by modelling clouds quite simply and using a sequential optimal estimations-type retrieval whereby an estimate for cloud effective fraction initiates the retrieval close to the correct cost minimum. This retrieval method has been successfully applied to a year's worth of MIPAS level 1C data to produce global maps of cloud top height, cloud top temperature and cloud extinction coefficient which compare well with existing cloud climatologies.

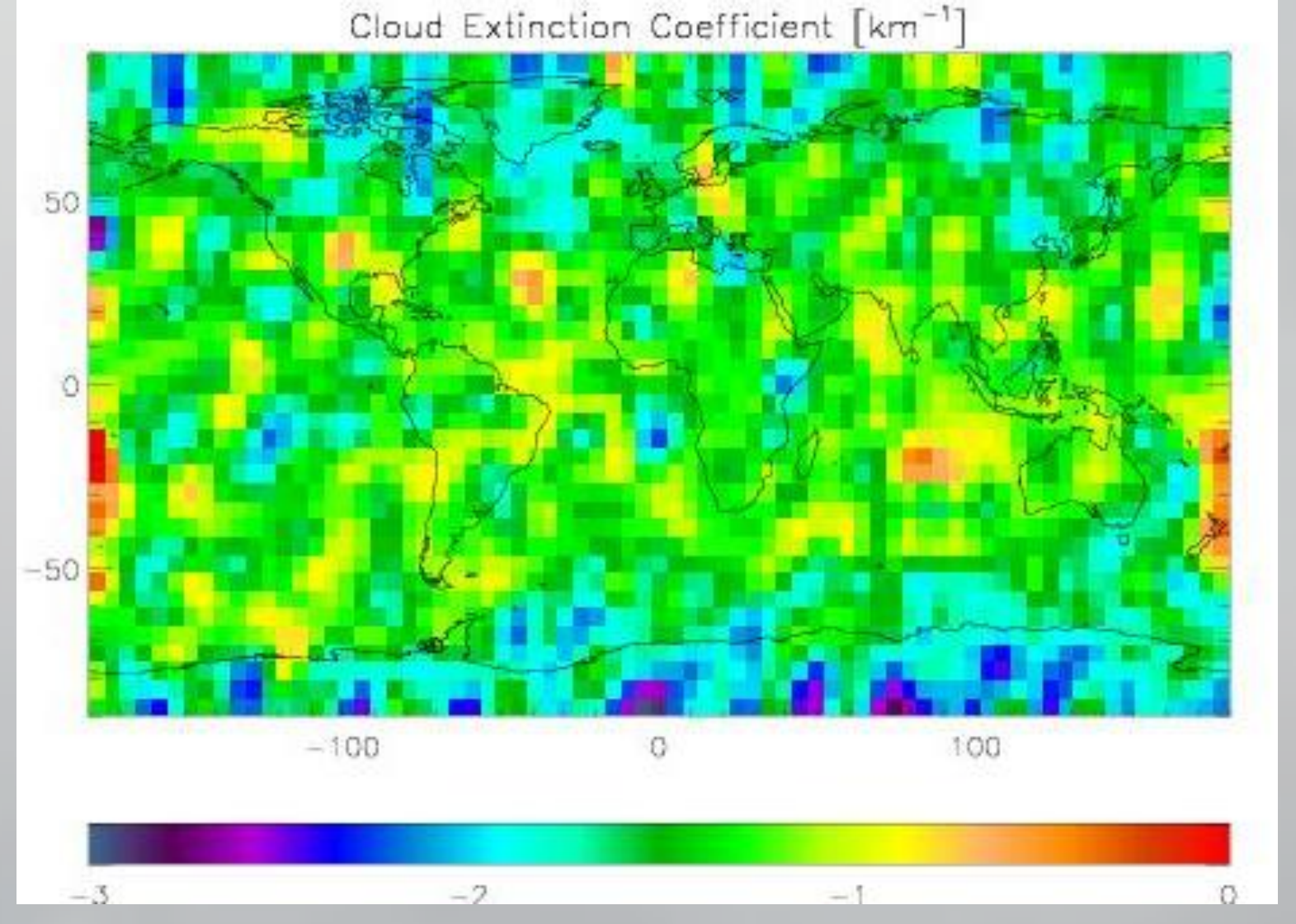


Fig. 12

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