Cloud processing in IASI context

Lydie Lavanant

Météo-France, Centre de Météorologie Spatiale, BP 147, 22300 Lannion Cedex France

Summary

Developments are on-going at Météo-France/CMS for the processing of the future IASI interferometer sounder. A preliminary scheme in clear condition is already defined and is presented in full details in this issue (Monnier and al 2002).
This paper focuses on the processing of cloudy IASI spectra. In this study, the clouds are detected and characterized, in height and cover, by using the CO2-slicing method. Then IASI channels are selected using the Co2 cloud parameters and forecast as guess information and atmospheric temperature profiles are retrieved with a 1D-Var method in cloudy conditions.
Status on these developments and validation on a IASI Cloudy Data-Set provided by EUMETSAT for a global orbit are presented.

Cloud characterization

Calculation of the cloud-top pressure and the effective emissivity is done with the CO2-slicing method as described by Menzel and Stewart (1983) and Smith and Frey (1990).

$$\frac{(Rclr - Rmeas)_k}{(Rclr - Rmeas)_{ref}} - \frac{Ne_k (Rclr - Rcld)_k}{Ne_{ref} (Rclr - Rcld)_{ref}} = fpc$$

Rmeas: measured radiance
Rclr: clear radiance computed from a collocated forecast for the same fov
Rcld: black-body radiance at the cloud level n
k= channel in the CO2 band
ref= reference window channel = 899.75 cm-1

To summarize the method, the function fpc is computed for each pressure level of the RTIASI forward model and the cloud top pressure is the level which minimizes the function. This is done for several channels and the final cloud pressure is the weighted average:

$p_cld = \Sigma\ (p_cld(k)\ w^2(k)) / \Sigma w^2$

with $W = \delta f_{pc} / \delta \ln p$ the derivative of the cloud pressure function

Then, the effective emissivity is computed for the reference window channel by:

$$N\varepsilon = (Rclr - Rmeas)_{ref} / (Rclr - Rcld)_{ref} \qquad (2)$$

The method assumes that the cloud is a thin layer and the result is flagged bad if the emissivity is smaller than 0 or larger than 1.1

We tested the method on a data-set provided by EUMETSAT in the course of the ISSWG group. The test case corresponds to a simulated IASI global orbit from a NWP field of February 1996 with more than 13000 situations. The profiles are described on the 43 RTIASI forward model levels for the temperature, humidity and ozone parameters and on the 31 levels of the ECMWF model at that date for the Cloud Cover, Cloud Liquid Water Vapor content (CLWV) and Cloud Ice Water Vapor content (CIWV). In the data-set, each profile is collocated with a IASI cloudy spectrum at a 0.25 cm-1

resolution computed with the model of R. Rizzi (1998). Forecast profiles are simulated by adding a noise coherent with the forecast error covariance matrix to the profiles of the data-set.

We used the CO_2-slicing method at different frequency resolution in the IASI spectral band from 690 cm-1 to 810 cm-1. It appears that a 5cm-1 frequency step corresponding to 24 selected channels is a good compromise between the cloud pressure accuracy and the computer time. A larger step induces much more rejections when detecting low level clouds.

The CO2 cloud pressure accuracy directly depends on the correct description of the clear radiance Rclr in the fcp equation. In this simulation, we used the RTIASI (Matricardi, 1999) fast forward model to compute Rclr but we were unable to correctly simulate with RTIASI the radiances for the clear spectra of the data-set, mainly near the surface. Several degrees of departure exist, probably due to a bad account of the surface emissivity (unknown) or differences in the spectroscopy or modelisation betweeen the RTIASI and Rizzi models. As a consequence, we got cloud top pressure rms errors of more than 150hPa on all levels..

To solve the problem, we re-computed the cloudy IASI spectra for each profile of the dataset by using RTIASI in cloudy conditions. To do it, we adapted our RTIASI version, which in that version takes into account a one cloud black-body level, to get a more realistic vertical cloud absorption by using the cloudy routines developed by F Chevallier (2001) for ATOVS and already implemented in RTTOV7. These routines determine the effective emissivity of the cloud for the 31 levels of the model using the CLWV, CIWV and Cloud Cover information and compute a vertical absorption by the cloud which after integration inside the RTE equation allows a more realistic computation of cloudy radiances. A radiometric noise spectrum following the IASI instrument characteristics and a forward model noise of 0.2K are added to the synthetic cloudy spectrum.
Figure 1 is an example of cloudy spectrum for a semi-transparent cloud layer compared to its corresponding clear spectrum.

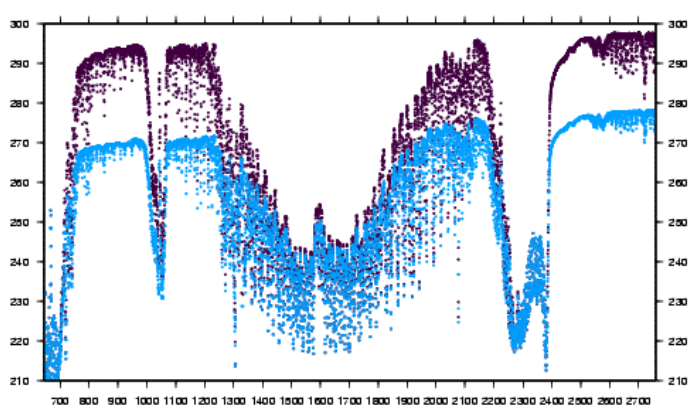
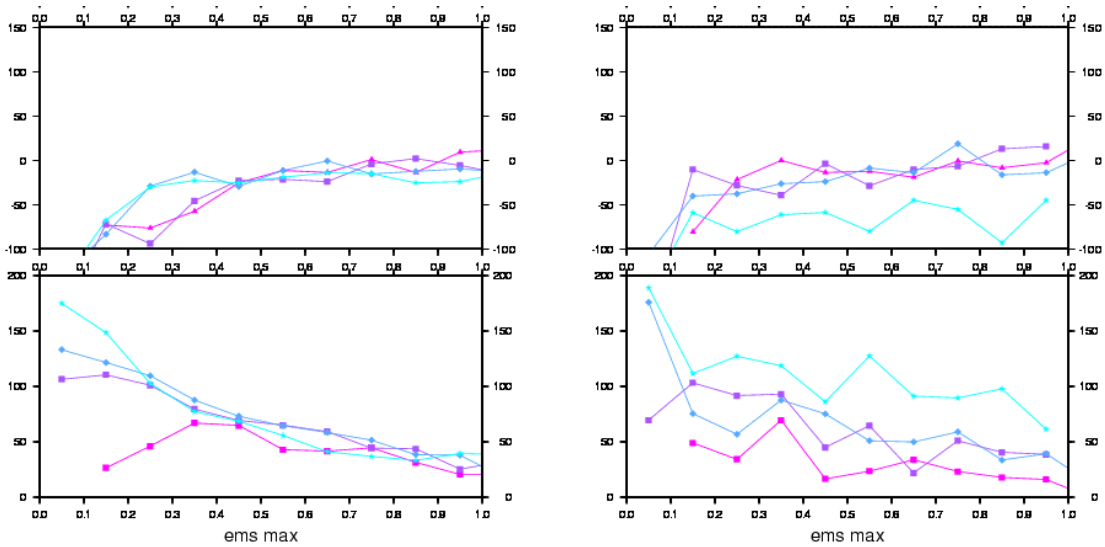


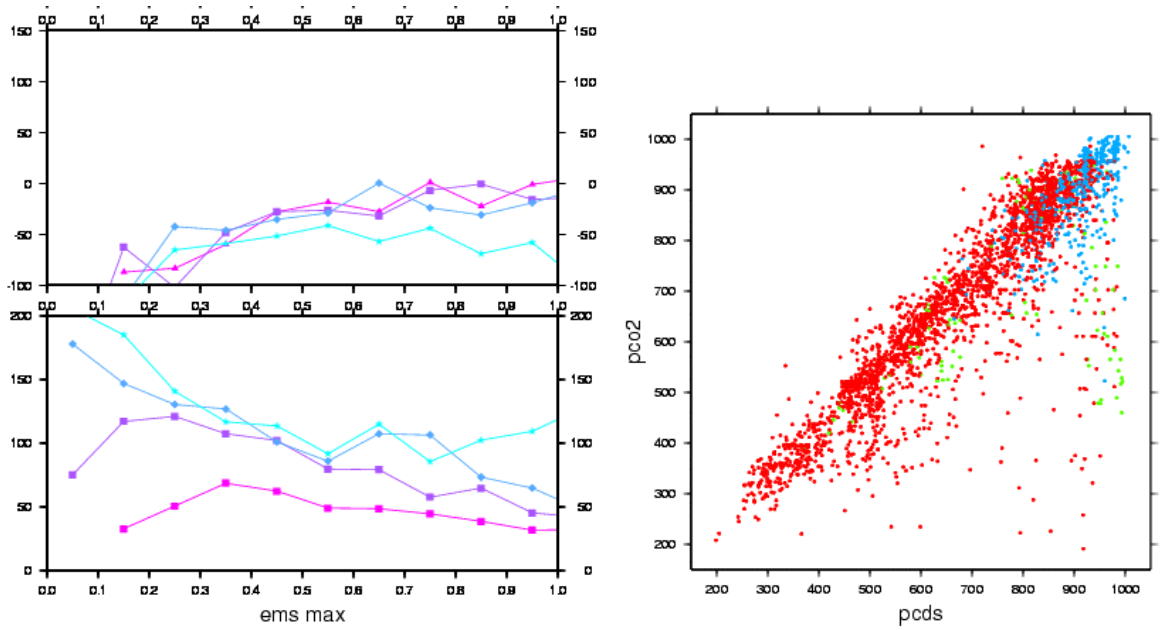
Figure 1: example of cloudy spectrum (in blue) compared to the corresponding clear one (in black) for a situation of the CDS data-set with a cloud top pressure at 309hPa.

The effective cloud emissivities associated to the profile with this updated RTIASI version are integrated starting at the top of the atmosphere to give a profile cloud top pressure when a value of 0.15 is reached. The arbitrary threshold value has been settled to minimize the bias in the cloud top pressure retrieval. A cloud top effective emissivity is then computed using the RTE in cloudy condition as described by equation 2. Having the cloudy spectra determination under control also allows to study the effect of the different sources of errors (radiometric and collocated profile errors) on the CO2 cloud products.

Figures 2a and b show the cloud top pressure accuracy for different cloud altitudes when considering separately situations with a one cloud layer from the others. In that case Rclr is computed with the noise-free collocated profile. As expected, the method works better for a single cloud level. The figures also indicate that the retrieved cloud pressure is more accurate for large differences between the simulated clear radiance Rclr and the observed radiance Rmeas, for high level clouds or cloud top effective emissivity larger than 0.3. For that reason, in the following steps of this study we only processed situations with one cloud layer.



Figures 2a (left), b(right): cloud top pressure accuracy in bias (upper figures) and standard deviations (lower figures) for situations with one cloud layer (in left) or several layers (in right). The results are for different cloud altitudes, respectively : pn > 800hPa , 650 < pn < 800 hPa , 500 < pn < 650 hPa and pn < 500 hPa.



Figures 3: the left figures has the same meaning as figure 1a but with a forecast as input to compute the clear radiances. Right figure: scatter plot of the cloud pressure.

As said, the accuracy of the retrieved cloud information highly depends on the correct simulation of Rclr. Figure 3 left shows the result when using a forecast to compute the clear radiance. The accuracy of the cloud top layer for high level clouds (in pink on the figure) is quite the same than on figure 2a. For low level clouds, the retrieval of the cloud pressure is highly degraded, in bias and standard deviation. The right figure shows the scatter plot of the cloud top pressure. We can see that most of the situations are well determined. Few of them are completely erroneous and largely increase the error statistics. A method should be added in future to detect and discard these situations before the inversion.

AVHRR cloud mask

As seen previously, the CO2-slicing method works much well for a single thin cloud layer, specially for high level clouds. The processing of the AVHRR pixels mapped inside the IASI fov is an efficient way to detect small amount of clouds because of its high spatial resolution and to determine the number of cloud layers and the complexity of the situation. The AVHRR processing provides accurate cloud top pressures for black-body layers (mainly at medium or low levels). The two methods are then complementary.

An operational AVHRR cloud mask package is implemented at CMS since several years and is now part of the AAPP package for ATOVS. It is based on a threshold technique applied every AVHRR pixel in the sounder fov. The thresholds are applied to various combinations of channels which depend on the geographical location of the pixel and on the solar illumination and viewing geometry. The thresholds are computed in-line from constant values from experience, from tabulated functions defined off-line through RTTOV simulations on a climatological data-set and from the TWVC computed through linear regressions with AMSU-A observations This routine has been updated to make the cloud detection inside the IASI fovs (Lavanant, 2001).

An estimate of the accuracy and limits of the cloud mask has been done on an interactive test file containing more than 7000 targets of 5x5 AVHRR pixels over 3 years. Of course, this validation does not take into account the accuracy of the AVHRR mapping into IASI because the targets are much more smaller than the IASI ellipse size. Table1 illustrates the efficiency of the cloud mask with the measurement conditions. As expected, the software is well detecting clouds (more than 98% of the cases) for all conditions. Concerning the clear targets, about 10% of them has been mis-classified as cloudy. This is due to the fact that the constant offsets applied to the IR and VIS thresholds are deliberately put small for detecting all clouds.

	Cloudy targets correctly detected	Cloud free targets correctly classified
Over sea : day	1774 (99.8%)	584 (87.8%)
Over sea : glint	269 (98.8%)	72 (89%)
Over sea : twilight	59 (98.3%)	12 (90%)
Over land :day	995 (99.5%)	638 (80.9%)
Over land :twilight	27 (100%)	11 (67.4%)

Table 1. Statistics on the cloud mask accuracy on the global AVHRR test file.

An indirect way for validating the AVHRR cloud mask information is to use them - number of cloud layers, cloud cover of each layer, cloud top temperature for the black-body cloud layers - for computing synthetic cloudy brightness temperatures and to compare them to the observations. Table 2

shows the statistics departures for a ten days period, Noaa16 and the HIRS 8 window channels, separately for clear and cloudy situations, over sea and land. In that case, only data with one black-body cloud layer is processed as this AVHRR package is unable to give an accurate cloud top temperature for semi-transparent clouds. The differences between sea and land statistics are mainly caused by the input surface temperature accuracy.

March 2001	Clear Land	Clear sea	Cloudy land (Cv >50%)	Cloudy sea (Cv > 50%)
N	937	103	136	55
Bias (K)	0.02	0.64	0.49	0.15
Std (K)	0.99	0.39	0.98	0.65

Table 2: Statistics of the departures between HIRS8 window channel observations and simulations. Cv stands for cloud cover.

Profile retrieval in cloudy conditions

Profile retrievals were done for only the situations with a one cloud layer below the 800 hPa level for which a large portion of the atmosphere is above the cloud. This corresponds to 1800 situations (15% of the global data-set compared to the fact that 30% of the situations were cloud-free).

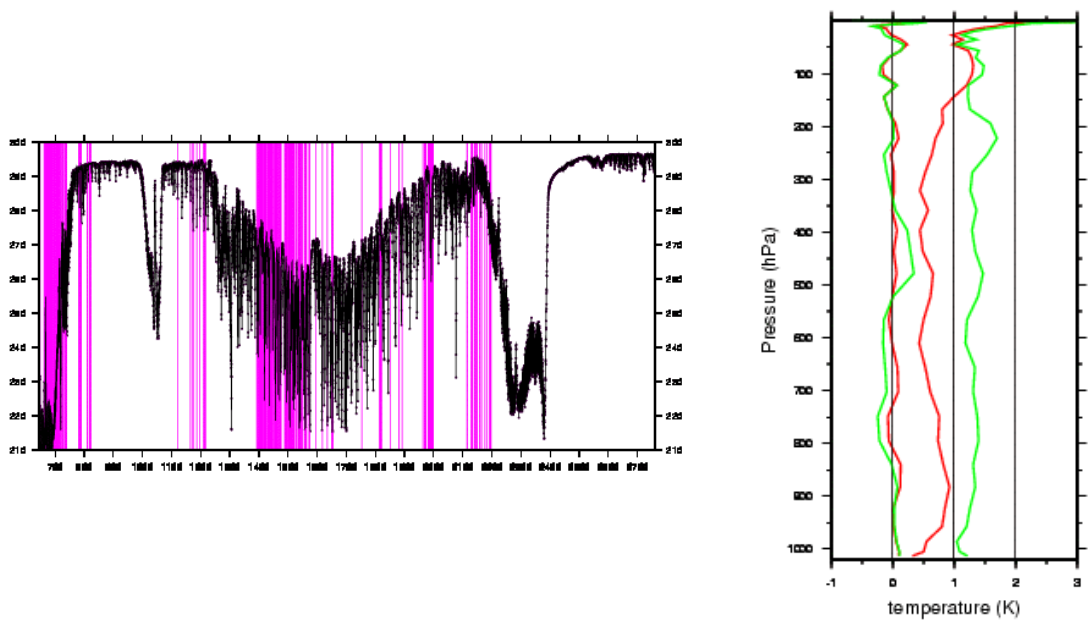


Figure 4: left: position of the selected 300 most informative channels in the IASI spectrum. Right: guess profile in green and retrieved profile for the clear situations of the data-set when using the 300 channels.

A unique mean channels selection for the global orbit was done in clear condition, by using the Rogers DFS method (Rodgers, 1996) with in input the forecast error covariance matrix and temperature and humidity profiles for 5 different air masses and 3 surface emissivity spectra. A detailed description of the method is given in (Rabier, 2001 and Monnier, 2002). The 300 most informative channels have been selected and shown on figure 4. No attempt of variable channels selections function of the cloud height has been done in this study, because of the computer time consuming. On a 450MHz work station, a channels selection takes about one hour and half.

Nevertheless, this should be improved in future studies, because a large number of selected channels are viewing the surface (about 30%) and are less efficient in cloudy conditions.

The 1D-Var method has been used in two different ways for retrieving the temperature profiles of the cloudy situations.
First, using the CO2 cloud top pressure and a threshold on the difference between the simulated clear radiances from forecast and the observations, only channels un-contaminated by the clouds have been selected and the 1D-Var is done in clear conditions. About 60% of the 300 channels were used, of course depending of the profile air-mass and cloud level. Figure 5 shows the number of selected channels as function of the cloud top pressure for the 1800 profiles.

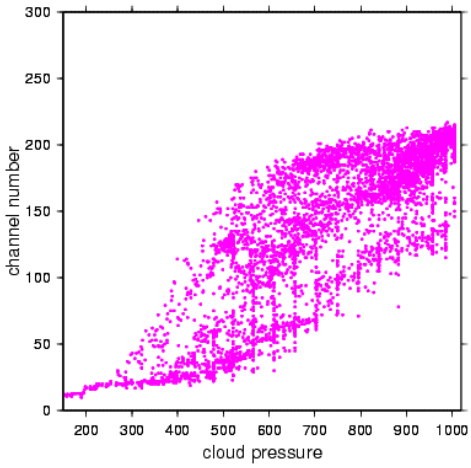
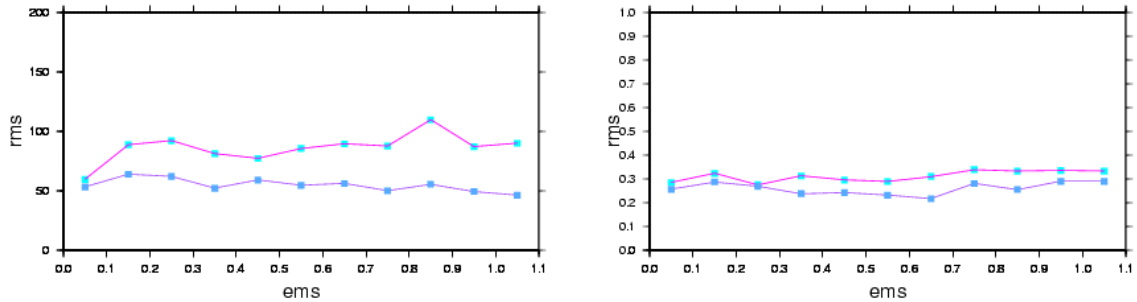


Figure 5: selected channels above the cloud in the 300 clear-sky series as function of the cloud top pressure

Second, un-contaminated channels plus some additional ones viewing the cloud are used. These extra channels are selected when the departures between the observations and the synthetic cloudy radiances computed with the forecast and the CO2 cloud guess information, are smaller than a threshold (put to 0.3K). Generally more than 80% of channels were used. In that case, 1D-Var is used in cloudy condition with the cloud information (logarithm of the cloud top pressure and cloud top effective emissivity) as control variable. The background is the forecast plus the cloud information estimated with the CO2-slicing method. The error covariance matrix for the cloud is diagonal with log(100) for the pressure and 0.2 for the emissivity, following the statistics of figure 3a. A similar study was done by Li (2000) for the GOES sounder.



Figures 6: Cloud information improvement after 1D-Var. In pink: before, in purple, after 1D-Var

Figures 6 show the improvement of the cloud top pressure after the 1D-Var retrieval. Just for the visualization, situations with a departure larger that 300 hPa between the CO2 retrieved cloud top pressure and the 'true' one have been discarded as completely erroneous. That corresponds to 25 situations (over the 1800) and smoothes the results (see figure 3a for comparison).

Figure 7 shows the statistics in bias and standard deviation of the retrieved temperature profiles for the 1800 sub data-set, for the two 1D-Var running conditions. The background is in green, the retrieved profile above the cloud with un-contaminated channels in black and the retrieved profile with the cloud information as control variables inside 1D-Var in red. It is not surprising the background is not improved near the surface, inside or below the cloud. But, even if the CO2 cloud guess is not very accurate (about 100hPa) for the processed low clouds, this information is useful and slightly improves the temperature profile compared to a retrieval with un-contaminated channels near the cloud. That is because more information just above the cloud is then used due to the relatively large shape of the weighting functions.

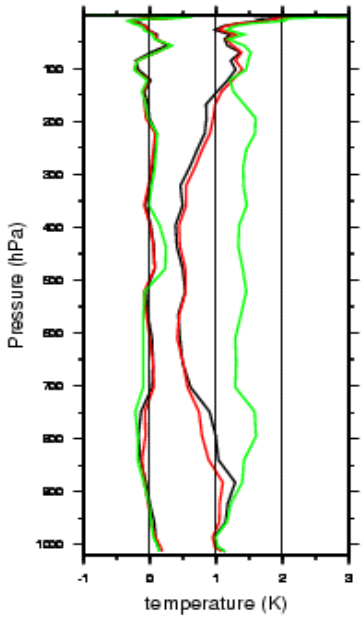


Figure 7: Cloudy temperature profiles statistics in bias and standard deviation with the forecast in green, the retrieved profiles with 1D-Var in clear conditions (cloud-free channels) in black and 1D-Var with cloud as control variables in red.

Conclusion

Cloudy routines, determining the vertical cloud IR absorption from the vertical cloud information of the ECMWF NWP profiles, have been implemented inside RTIASI. The updated forward model has been used to create cloudy and noisy IASI spectra for a simulated global orbit originally created by R. Rizzi. The CO2-slicing method has been tested on this data-set to retrieve the cloud characteristics with a profile forecast to compute the clear radiance and a set of 24 channels inside the CO2 band. This method is efficient for high-level clouds and is even useful for low-level single layers for the initialization of the 1D-Var method with the cloud information as control variable: the retrieved profile is slightly better of a few tenths of degrees compared to a clear 1D-Var with cloud-free channels. The AVHRR description inside the IASI fov is also useful to detect small amount of clouds and gives accurate cloud top temperature for blackbody low clouds and in that sense is complementary to the CO2 method.

References

Smith, R. Frey, 1990. On cloud altitude determinations from High Resolution Interferometer Sounder (HIS) observations. *J. Appl. Meteor.*, **29**, 658-662.

Menzel, W. Smith, T. Stewart. 1983.Improved cloud motion wind vector and altitude assignment using VAS. *J. Appl. Meteor.*, **22**,377-384.

Rizzi and al. 1998. Simulation of IASI radiances in presence of clouds. Contract number EUM/CO/96/390/DD.

Chevallier and al. 2001. Model clouds over oceans as seen from space: comparison with HIRS/2 and MSU radiances. *J. of Climate*, **14**, 4216-4229

Rodgers. 1996. Information content and optimisation of high spectral resolution measurements. *Optical Spectr. Tech. and Instr. for Atmos. and Space Research*, **2830**, 136-147

Rabier and al 2001. Channel selection methods for Infrared atmospheric sounding interferometer radiances. *Q. J. R. Meteorol. Soc*, **128**.

Monnier and al. 2002. Temperature, humidity and surface emissivity retrieval experiments with IASI simulated data. This issue.

Lavanant L. 2001. Retrieval of cloud and surface parameters with AVHRR for IASI processing. Validation part. MASSIF2 EUMETSAT contract.

Matricardi, M. and R. Saunders, 1999: "A fast radiative transfer model for Infrared Atmospheric Sounding Interferometer radiances." J. Appl. Opt., 38, 5679-5691.

Li, P. Menzel, A. Schreiner. 2000. Variational retrieval of cloud parameters from GOES sounder longwave cloudy radiance measurements. *J. Appl. Meteor.* , **40**.