AVHRR AND TOVS IN LANNION:
CLOUD PROCESSING, VALIDATION OF R/T MODELS

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Abstract

The following text contains 3 parts:

Part 1: Cloud Clearing algorithm and cloud identification with AVHRR in Lannion

Part 2: HIRS 2 computed radiances in cloudy cases with AVHRR information using CATHIA data file

Part 3: Some results about the "errors" for computed radiances in a clear atmosphere.

In the near future, the first and second part should be joined to produce an automatic algorithm for "synthetic" cloudy HIRS 2 channels using AVHRR information.

Part One:
Cloud clearing algorithm and cloud identification with AVHRR in Lannion

1. DESCRIPTION OF THE CLOUD DETECTION ALGORITHM

This paragraph describes the algorithm operationally used in the Centre de Météorologie Spatiale in Lannion to detect the clouds with the AVHRR. The problems are pointed out, and the improvements are presented.

a) Description of the algorithm

This algorithm is a succession of threshold tests applied for every AVHRR pixel to various combinations of channels. An AVHRR pixel is said to be cloudy if one test is satisfied. The different tests are described in tables 1 and 2.

The thresholds are either constant values, or may depend on the geographical location of the pixel (like the threshold applied to the IR channel). As the algorithm has been designed to give a good description of the cloud cover in each HIRS field of view, each threshold is only computed once for every box of 34 by 39 AVHRR pixels centred around the HIRS measurements.

The threshold applied to (4) - (5), seuil45, is the one used by Saunders and Kriebel (1988). The threshold applied to the infrared channel 4 over the sea, seuil4, is given by a monthly atlas value of SST minus 3°K for water vapour absorption and minus 3°K for safety.

Table 1

<u>Description of the cloud detection tests</u>:

DAY WITHOUT SUNGLINT OVER LAND AND SEA

LAND	SEA
snow or ice detection test	((3)-(4))/cos(θs) < 20°C and (2)/cos(θs) > 17.5% and (4) < 273°K
(4) < seuil4	(4) < seuil4
INDEX < 0.1 and (4) < 292°K	INDEX > -0.117 and (4) < 292°K
SIGMA > 1.2°C	SIGMA > 0.2°C
((3)-(4))/cos(θs) > 25°C and (4) < 292°C	(4)-(5) > seuil45
(4)-(5) > seuil45	

θs is solar zenith angle.
INDEX = ((2)-(1))/((2)+(1))

DAY WITHOUT SUNGLINT OVER COAST

COAST	
snow or ice detection test	((3)-(4))/cos(θs) < 20°C and (2)/cos(θs) > 17.5% and (4) < 273°K
-0.117 < INDEX < 0.1 and (4) < 292°K	

if INDEX > 0.1 then LAND	if INDEX < -0.117 then SEA
(4) < seuil4	(4) < seuil4
SIGMA > 1.2°C	SIGMA > 0.2°C
((3) - (4))/cos(θs) > 25°C and (4) < 292°C	(4)-(5) > seuil45
(4)-(5) > seuil45	

Table 2

DAY WITH SUNGLINT:

SEA	COAST
SIGMA > 0.2°C	(4) < seuil4
(4) < seuil4	SIGMA > 1.2°C
(4)-(5) > seuil45	(4)-(5) > seuil45

NIGHT:

LAND	SEA	COAST
(3)-(5) > 1.5°C	(3)-(5) > 1.5°C	(3)-(5) > 1.5°C
(4)-(3) > 1.5°C	(4)-(3) > 1.5°C	(4)-(3) > 1.5°C
(4)-(5) > seuil45	SIGMA > 0.2°C	SIGMA > 1.2°C
(4) < seuil4	(4) < seuil4	(4) < seuil4
SIGMA > 1.2°C	(4)-(5) > seuil45	(4)-(5) > seuil45

DAWN TESTS:

LAND	SEA	COAST
(4) < seuil4	SIGMA > 0.2°C	(4) < seuil4
SIGMA > 1.2°C	(4) < seuil4	SIGMA > 1.2°C
(4)-(5) > seuil45	(4)-(5) > seuil45	(4)-(5) > seuil45

$$SIGMA = \left(|X_{i,j} - X_{i,j-1}| + |X_{i,j} - X_{i,j+1}| + |X_{i,j} - X_{i-1,j}| + |X_{i,j} - X_{i+1,j}| \right) / 4$$

where $X_{i,j}$ is the radiative temperature in channel 4 for the pixel i,j.

The **DAWN** is defined by the regions where the solar zenith angle Θs is between 80 and 90 degrees.

The **SUNGLINT** region is defined by geometrical conditions, ie:

* $|\Theta sol - \Theta sat| < 25°$ where Θ is the zenith angle.

* $140° < D\Phi < 220°$ where $D\Phi = -(\Phi sat - \Phi sol)$ if $(\Phi sat - \Phi sol) < 0°$
  $= 360° - (\Phi sat - \Phi sol)$ else.

Table 2

Over the land, the infrared threshold seuil4 corresponds to the warmer radiative temperature of channel 4 in the box of 34 by 39 AVHRR pixels minus 10°K. This threshold is not allowed to be colder than 263°K.

A test to detect the presence of snow or ice is applied during the day. If this test is satisfied, the pixel is said to be clear and covered by snow, and the following tests are not applied.

b) Problems

The main problems encountered by this algorithm are:

- cold grounds are wrongly classified as cloudy (mountains, ...);
- the night test applied to channel 4 is not adequate in coastal boxes: the clear ground (cold) may be assumed to be cloudy by mistake;
- low clouds are not detected in case of sunglint or at dawn;
- low clouds covered by thin cirrus are hardly detected by the night tests;
- the values of the thresholds applied to the vegetation index are not well tuned (some clouds are not detected over the sea and some clear arid land areas are said to be cloudy).

c) Future improvements

The future improvements will be:

- the use of the 2m air temperature given by the 00UTC SYNOP data to derive the threshold applied to the infrared channel 4 over land during the night;
- the use of an atlas of vegetation index over land in Europe.

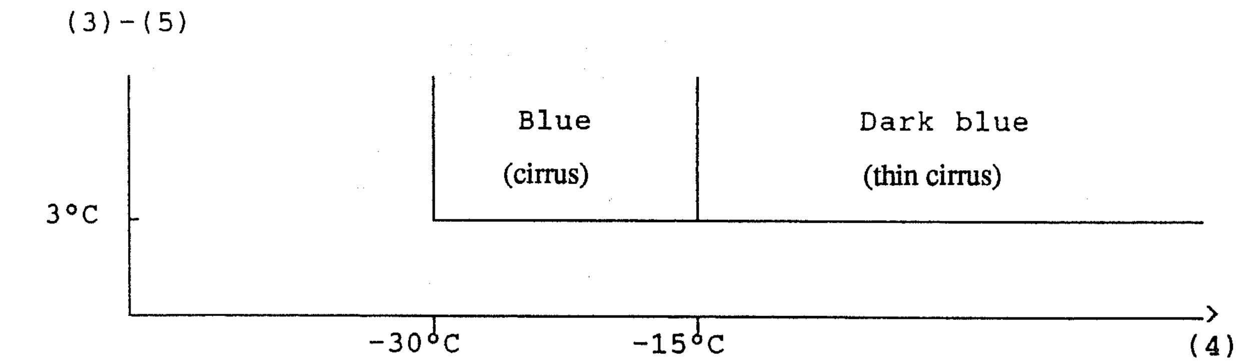
2. DESCRIPTION OF THE NIGHT CLOUD CLASSIFICATION ALGORITHM

The first aim of the night cloud classification was the detection of low clouds and the distinction between cirrus and high thick clouds, i.e. to do what can hardly be done with a single infrared channel. In the future, the result of this classification will also be a help to derive the temperature of the cloud tops and the cloudiness. The cloud classification algorithm is operational.

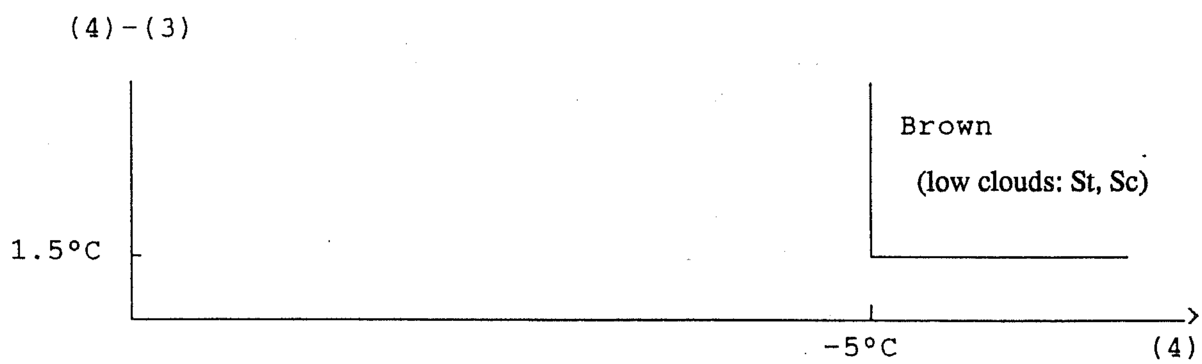
Table 3

Description of the cloud classification tests

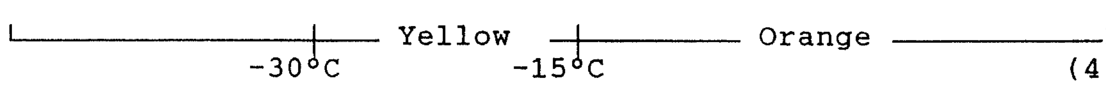
First step: semi transparent clouds detection



Second step: low clouds detection



Third step: medium clouds detection



Fourth step: high clouds and thick cirrus

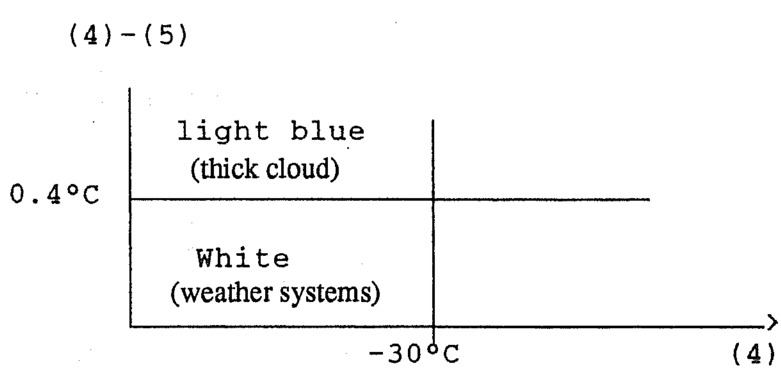
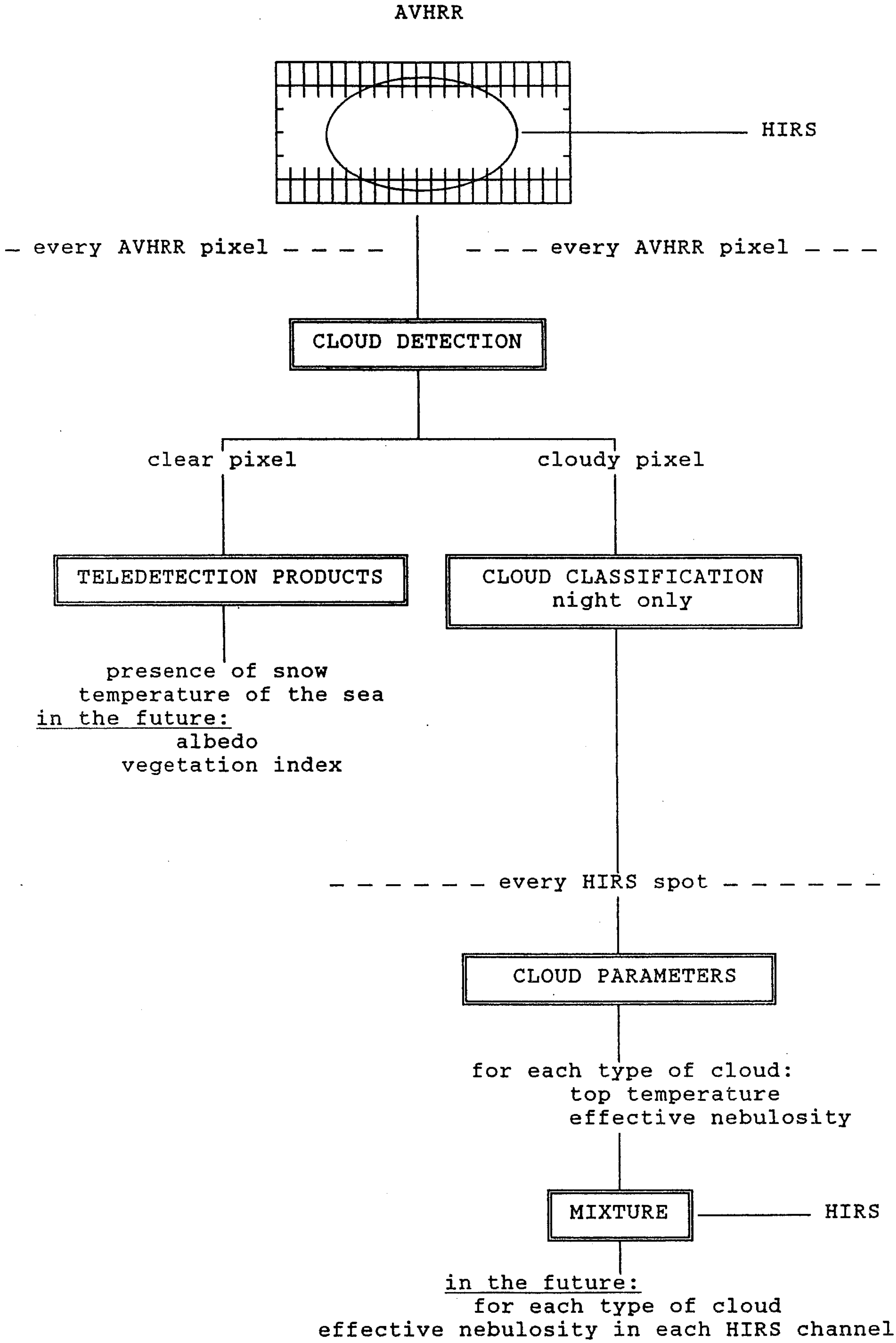


Table 4


AVHRR
HIRS
every AVHRR pixel
every AVHRR pixel
CLOUD DETECTION
clear pixel
cloudy pixel
TELEDETECTION PRODUCTS
presence of snow
temperature of the sea
in the future:
albedo
vegetation index
CLOUD CLASSIFICATION
night only
every HIRS spot
CLOUD PARAMETERS
for each type of cloud:
top temperature
effective nebulosity
MIXTURE
HIRS
in the future:
for each type of cloud
effective nebulosity in each HIRS channel

The algorithm is applied, after the cloud detection test, to every cloudy pixel only during the night. It consists in a succession of threshold tests described in tables 3 and 4. Seven classes are created. The classes can be divided in low clouds (brown-orange), medium (orange-yellow), semi-transparent (blue) and high thick clouds (white).

3. CLOUD PARAMETERS COMPUTATION

The aim of the AVHRR processing is to give a good description of the clouds within the infrared sounder HIRS field of view. The three important parameters are the cloud top temperature, the cloudiness, and the cloud type. The cloud top temperature and the cloudiness will be computed only once for each type of cloud in every HIRS field of view.

Presently, the cloud parameters are operationally computed only for the HIRS field of view containing a single homogeneous thick cloud layer. A method of adjustment of a curve on the bidimensional histogram 4/4-5 has been tested for cirrus cases (see Derrien et al., 1988), but has not yet been implemented in the operational scheme. In the future, the result of the classification will be used to allow the retrieval of top temperature and cloudiness of more than one cloud layer in a HIRS field of view.

References

Saunders, R.W. and K.T. Kriebel, 1988: An improved method for detecting clear sky and cloudy radiances from AVHRR data. Int.J.Remote Sensing, Vol 9, No. 1.

Derrien, M., L. Lavanant and H. Legleau, 1988: Retrieval of the top temperature of semi transparent clouds with AVHRR. IRS88 Conference LILLE. Deepack Publishing.

Part Two:
Computation of HIRS2 radiances in cloudy cases with AVHRR data using the CATHIA* file

1. INTRODUCTION

A HIRS2 cloud clearing scheme, using AVHRR data, is to be implemented at CMS Lannion. The first step is to use AVHRR brightness temperatures to estimate the cloud cover type, the cloud top temperature, its emissivity at AVHRR wavelengths and the fractional cloud cover in the HIRS2 field of view (FOV). The second step is to get these cloud parameters for each HIRS2 channel and especially to compute the cloud emissivities for each HIRS2 wavelength region. This should be possible by using the results of a statistical study on the CATHIA data set which is a compilation of collocated data (radiosonde profiles and TOVS/AVHRR measurements). A summary of the approach used in the CMS cloud clearing scheme is described here. Some parts are already implemented, like the CATHIA data set or parts of the first step. Some others have to be more carefully considered, like a third step (not described here) for synthetic cloud free radiances estimation with HIRS2 cloud parameters.

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*CATHIA: Calcul Automatique des Températures et Humidités Incluant le AVHRR

2. AVHRR CLOUD PARAMETERS

The analysis of the cloud cover with the AVHRR data is done in boxes of 34*39 pixels around the centres of the HIRS2 FOV.

A discrimination between the ground, the sea and the clouds is done with a threshold technique applied every AVHRR pixel, like the one described by Saunders (1988). For an operational use of the scheme, the threshold values are now updated to take into account seasonal and zonal effects. The results of this step are, for a partially cloud covered HIRS FOV, the surface brightness temperature Ts and the channel(4)-channel(5) brightness temperature difference DTS, in clear-sky conditions, which is a function of the atmospheric absorption.

For a black-body cloud layer, the cloud top temperature is directly estimated from the coldest brightness temperature in the ellipse. For a semi-transparent cloud layer, the bidimensional histogram (channel(4) against channel(4)-channel(5)) is processed to obtain the cloud top brightness temperature. For this, we assume that the emissivity E of the clouds may be expressed as an exponential function of cloud thickness:

$$E=1-\exp(-\beta z) \qquad (1)$$

where β is the extinction coefficient and z the cloud thickness.

The cloudy equation for channel i (i=4 or 5) is:

$$I=(1-N*Ei)*Isi+N*Ei*Ici \qquad (2)$$

where I is the measured radiance, Is the clear-sky radiance, Ic the upwelling blackbody radiance and N the cloud amount in the pixel.

From these equations and assuming N=1 for a semi-transparent cloud layer, the brightness temperature difference T4-T5 is related to the surface brightness temperature channel(4) Ts and the cloud top brightness temperature Tc by the equation:

$$T4-T5 = (1 - A - (1 - A)^{b}) * (Ts-Tc) + DTS * (1 - A)^{b} \qquad (3)$$

with A = (T4-Ts)/(Tc-Ts) and b = β_5/β_4 the ratio of extinction coefficients for channels 5 and 4.

The values of the two unknown parameters, Tc and b, are determined by a least-square fit of the curve on the bidimensional histogram (T4/(T4-T5)).

With the averaged AVHRR measured radiance in the HIRS2 FOV, the blackbody cloud and surface radiances, it is quite easy to compute the effective emissivity N*E of the cloud by using equation (2).

With two cloud layers, we directly determine the top brightness temperature of the lower cloud when this one is thick enough and we get the temperature of the highest cloud by fitting the curve (3) on the modified bidimensional histogram (the pixels corresponding to the low cloud having been suppressed).

3. HIRS2 CLOUD PARAMETERS

In a HIRS2 cloud clearing scheme, it is necessary to obtain the cloud parameters for all HIRS2 channels; ie, the same parameters as those determined in HIRS2 FOV from AVHRR pixel processing except that the cloud emissivity which is a function of wavenumber, have to be computed now for all HIRS2 channels.

We assume that a simple relation, probably a function of the cloud type, may exist between emissivities for different wavelength regions and that it can be derived only once with a statistical method. If this is true it will be possible, to use this relation in an operational scheme and to compute HIRS2 cloud emissivities from AVHRR emissivities determined in the previous step.

The CATHIA data set is a compilation of collocated data (radiosonde profiles, TOVS/AVHRR measurements) and will be used to get the relation between the emissivities.

By applying the AVHRR processing, as previously described, to each satellite observation, the cloud type, the surface temperature Ts, the cloud top temperature Tc and the effective emissivities N*E(AVHRR) are determined.

The 4A radiative transfer model (Scott and Chedin, 1981) has been applied to each radiosonde profile and incidence angle corresponding to collocated TOVS measurements. It gives, for all HIRS2, MSU and AVHRR channels, the atmospheric transmittances from the satellite to each of the 40 pressure levels of the model.

For each HIRS2 channel, the clear-sky radiance Is is computed by using the surface temperature Ts and the whole atmospheric transmittance from the satellite to the surface. The upward blackbody radiance Ic is obtained from the cloud top temperature Tc and the atmospheric transmittance from the satellite to the pressure corresponding to Tc (given by the radiosonde profile). So, with the measured upward radiance I, the effective emissivity N*E(HIRS2) is calculated from equation (2). That will give the relation emissivities for different wavelength regions.

Table 5 statistics on radiosonde profiles (in number of profiles)

SEA	77
LAND	36
COAST	38
DAY	87
NIGHT	64
WINTER	8
SPRING	73
SUMMER	33
FALL	37
TROPICAL	1
MID-LATIT.	142
POLAR	8

Table 6 statistics on cloud types

CLEAR	20%
SINGLE LAYER	60%
TWO LAYERS	15%
MORE	5%
Sc	25%
Cu	25%
St	8%
Ci	23%
Cn	8%
Ac	8%
fog	17 ellipses

	4A Clear Case			EMS HX = EMS A4 Cloudy Case (AVHRR4)			MODEL → EMS HX Cloudy Case (AVHRR4,5)		
	N	MOY	SIG	N	MOY	SIG	N	MOY	SIG
CHANNEL H7:	116	.83	.58						
Low Clouds				82	.36	.76	82	-.34	.48
High Clouds				31	1.31	1.59	31	.09	1.26
CHANNEL H8:	116	.2	.6						
Low Clouds				82	.1	.21	82	-.07	.21
High Clouds				31	.32	.76	31	-.13	.52
CHANNEL H13:	116	.16	.45						
Low Clouds				82	-.04	0.46			
High Clouds				31	-.1	1.56	31	.33	1.10

Table 7
Statistics comparing observed HIRS brightness temperatures
with brightness temperatures computed as through 4A

4. THE CATHIA DATA SET

A data set of 1333 situations has been created containing:

- satellite AVHRR/TOVS data (1333 ellipses) from 143 orbits;
- 151 collocated radiosonde profiles and their respective AVHRR/TOVS synthetic cloud-free radiances.

The data for each profile consist of pressure, air temperature and dew-point temperature. They have been selected from different campaigns, some of them specifically made for the CATHIA data set which means: a perfect time collocation of the satellite-radiosonde measurements and the largest cloud type diversity as possible. For marine radiosonde observations, a sea surface temperature, measured at the station or in the vicinity, has been assigned to the profile. Over land, the considered surface temperature is that of the lowest-level pressure measurement.

The satellite data for each situation consist of TOVS measurements, HIRS2, MSU (corrected by ITPP) and SSU interpolated in the ellipse, and AVHRR measurements collocated in the ellipse (34*39 box centred on the ellipse with the data around set to 0). For a given radiosonde observation, the nearest NOAA orbit, in space and time, is considered. Several HIRS2 ellipses have been selected around the radiosonde station (often in a square 3*3 around the station) in order to have the largest diversity in cloud types, cloud amount and number of cloud layers. For that, we assume that the atmospheric profile was the same over a few tenths of kilometers around the station.

Tables 5 and 6 give some statistics, for, respectively, the radiosonde profiles and the selected cloud types. More details, and also the satellite pictures for all the situations, can be found in the CATHIA data set report.

The 4A radiative transfer model is applied to synthetic computations of atmospheric transmittance over 40 pressure levels (from 0.05 mb to 1013 mb) and radiances. In most of the cases, the balloon-borne instruments transmitted data up to pressures of about 100-50 mb. Therefore, the profiles have been extended to a 0.05 mb pressure by using the TIGR data set see Chedin and Scott (1983) with a nearest neighbouring technique. Surface emissivities used in 4A computation method and details in the processing are given in the CATHIA data set report.

5. PRELIMINARY RESULTS

The results summarized in table 7 have been obtained using AVHRR information in the HIRS2 field of view and using the previous method.

5.1 Clear case - (left part of table 7)

A fast line-by-line method for atmospheric absorption (Scott and Chedin, 1981), has been used for N=116 clear ellipses among the 1333 of CATHIA. The table gives the bias (MOY) and the standard deviation (SIG) between observed HIRS 2 radiative temperatures (in Kelvin) and computed values from radiosondes (using 4A algorithm) for channels 7,8 and 13.

5.2 Cloudy case - use of AVHRR4 (middle part of table 7)

The effective nebulosity (N_ε) has been computed for 82 ellipses of "low" clouds and 31 ellipses of high clouds among the 1333 of CATHIA according to the previous method. The statistics table shows the bias and standard deviation between observed HIRS 2 radiative temperatures (cloudy ellipses) and computed values using the N_ε obtained for AVHRR Channel 4.

5.3 Cloudy case - use of AVHRR4 and 5 (right part of table 7)

The effective nebulosity for HIRS 2 Channels 7,8 and 13 has been computed using a linear regression with Channels AVHRR 4 and 5.

All these results are encouraging but must be extended to all HIRS 2 Channels and using an automatic selection of usable cloudy ellipses. As expected the errors are smaller in the clear case than in the cloudy cases. Note also the improvement brought by using two AVHRR channels rather than one to work out the N_ε.

6. SUMMARY

The CATHIA data set of coincident satellite data-radiosonde profile has been created in order to get the relation between cloud emissivities in different wavelength regions. This relation is probably dependent on the cloud type, but we expect that it will be stable for each cloud type in order to use it in an operational scheme.

A lot of work has still to be done. The AVHRR processing scheme, which has only been tested during night and over sea, gave a good improvement of the cloud top temperature achievement, especially for high level layers. The processing of the CATHIA data set is only at its beginning, but the first results seem to be encouraging.

References

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Chedin, A. and N.A. Scott, 1983: 'Improved initialization inversion procedure (3I). First International TOVS Study Conference.

Part Three:
Some results about the "errors" for computed radiances in a clear atmosphere

1. PREPROCESSING OF AVHRR AND TOVS

In this area the following tasks are carried out in CMS/LANNION on a regular basis:

- For each new TIROS-N satellite, we compare CMS/LANNION preprocessing results and a corresponding preprocessed orbit from NOAA/NESDIS (CCT tape, GAC, HIRSX, MSUX, SSUX).

- For AVHRR, we operationally compare SST "in situ" measurements and satellite derived SST obtained by a linear combination of AVHRR channels 4 and 5 (now:

  $$T_s = 3.\, T_{C4} - 2.\, T_{C5} + 0.5$$

  T_{C4}, T_{C5} radiative temperatures of channels 4 and 5 °C for NOAA 10 and 11). The bias is less than 0.3°C.

- We also compare HIRS2 channels 20, 8 and 19 with AVHRR channels 1 and 2, 4 and 5, and 3 according to our matching of AVHRR and HIRS2 (see Rochard, 1986 and Rochard, 1988).

- For MSU we apply the ITPP3 algorithm to correct MSU from both emissivity of the surface, liquid water, limb effect and antenna pattern effect.

- SSU has only been used for experimental research with Laboratoire de Météorologie Dynamique.

2. COMPARISON BETWEEN DIFFERENT RADIATIVE TRANSFER CODE (ITPP3 AND 4A)

- An internal report (Lavanant and Rochard, 1988) describes ITPP3 and 4A results on CATHIA. The conclusion is very similar to the ones given in Chedin (1988): the difference between the two radiative transfer models is not significant for operational use of HIRS2 and MSU.

- In Lannion we use operationally the EVA algorithm (Etalonnage Vérifié Automatiquement) with about 20 daily radiosonde observations in the Lannion area of TIROS N visibility plus AVHRR and TOVS at the same place (but not exactly the same time).

Every day we compare ITPP3 and 3R (Same results as 4A but much faster, see Flobert et al. (1986). The results are similar to the CATHIA results. The main problem is for high atmospheric level channels and the radiosonde extrapolation.

3. CONCLUSIONS

Several tests have been carried out in CMS/LANNION in order to compare the performance of various direct radiative transfer codes for HIRS computations. The codes which have been tested are 4A, ITPP3 and 3R. So far, the results do not show any significant differences regarding the errors of computed radiances. The main basic problem which is left concerns the computation of channels peaking at high levels in the stratosphere, where no radiosonde information is available.

References

Chedin, A., 1988: ITRA report, IRS commission, campaign and workshop. Edited by A. Chedin, May 1988.

Flobert, J-F., N.A. Scott and A. Chedin, 1986: Fast model for TOVS radiance computation. Proceedings of the 6th conference on Atmospheric Radiation (AMS), Williamsburg, 1986.

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