

GROUND BASED SKY DOME PICTURES GENERATED BY INFRARED SPECTROMETRIC DATA.

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1. INTRODUCTION

Through several communications (Gillotay et al.; Besnard et al.), we showed the evolution of "Nephelo project", relative to the design of an infrared cloud cover imager, from the basic idea up to the comparison with other sky imaging techniques and cloud cover intensity measurement methods. Before approaching experimentally physical properties of clouds by the integration of "water vapour sensors" in Nephelo, it appeared necessary to determine with a relative accuracy shape, orientation and position of clouds on the sky dome. In order to approach phenomenon progressively we decided to go through a 2D modelling process.

2. MODEL DESIGN

2.1 Measurement grid

Measurement grid of Nephelo is calculated by means of a parallel plan model. The grid is defined as the intersection between the field of view of each sensor and a plan at a defined altitude. Figure 1 shows this grid at 3000 m high. The X-axis gives the footprint distance along the South-North axis and the Y-axis the footprint distance along the West-East axis.

2.2 Virtual cloud definition

The shape of the most current types of clouds except cirrus can be approximate by an ellipse. Since the beginning of this program experiments

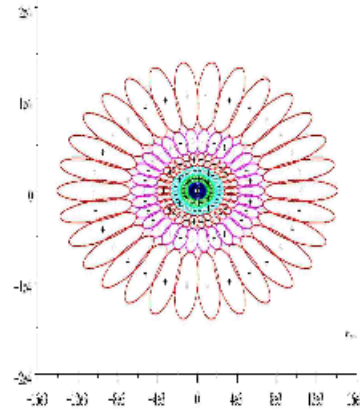


Figure 1: *Present grid of measurement of Nephelo.*

have demonstrated the fact that each Nephelo pyrometer measures the mean temperature of its integrated field of view on the sky dome, i.e. temperature of deep space and/or temperature of clouds. In the ellipse representing the virtual cloud, we considered that the emissivity is constant and equal to that of a black body. This virtual cloud can move at a constant speed along the main axis of the ellipse during the Nephelo turret scan.

2.3 Surface intersection between virtual cloud and measurement ellipse.

The surface intersection between virtual cloud and each captor ellipse is calculated following Monte Carlo method.

Figure 2 and 3 show that the criteria of quality of the random number generator in terms of distribution homogeneity and independence are perfectly respected.

The method generates random sets of x and y values scaled properly to the size of the "shooting box". We check for each point if it is included in the virtual cloud ellipse and also in

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one of the Nephelo ellipses. If points respect both criteria, they are used for calculation of the intersection surface. We run the Monte Carlo process (10^6 samples) when ellipses have an intersection determined by common x and y values.

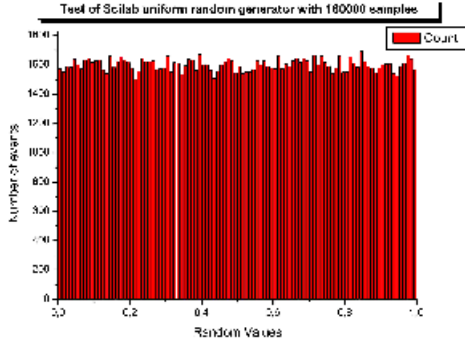


Figure 2: Homogeneity of the random generator.

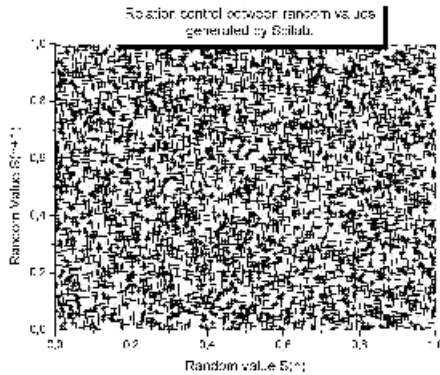


Figure 3: Independence of the random generator.

The temperature of each Nephelo ellipse is determined with the following equation:

$$T_{\text{nephelo}} = A \times T_{\text{virtual cloud}} + (1-A) \times T_{\text{background}} \quad (1)$$

Where A is the surface percentage of the Nephelo ellipse covered by the virtual cloud ellipse and $T_{\text{background}}$ defined as the minimal temperature value ranged by used pyrometers; in our simulation conditions $T_{\text{background}}$ is initially set to -57°C .

3 FIRST SIMULATIONS

For this first batch of simulation we placed at the origin of the referential an elliptic virtual cloud with its main axis along the x'ox axis. Parameters of this ellipse are as followed:

- a=3 km
- b=0.5 km
- CCW rotation angle= 0°

Main characteristics of the different trials performed and thermal footprints are summarized in table 1.

Trial	Altitude (m)	Température ($^\circ\text{C}$)	Figure
1	10000	-43.1	
2	8000	-32.5	4
3	6000	-19	
4	4000	-4.5	
5	2000	8.3	5
6	1000	13	
7	500	14.7	

Table1

Temperature simulations are determined with MSISE-90 model for July 15th in Brussels ($50^\circ48'\text{N}-4^\circ21'\text{E}$).

Thermal footprints shown on figures 4 and 5 are obtained with a standard interpolation method. Irregularities are due to a leak of resolution.

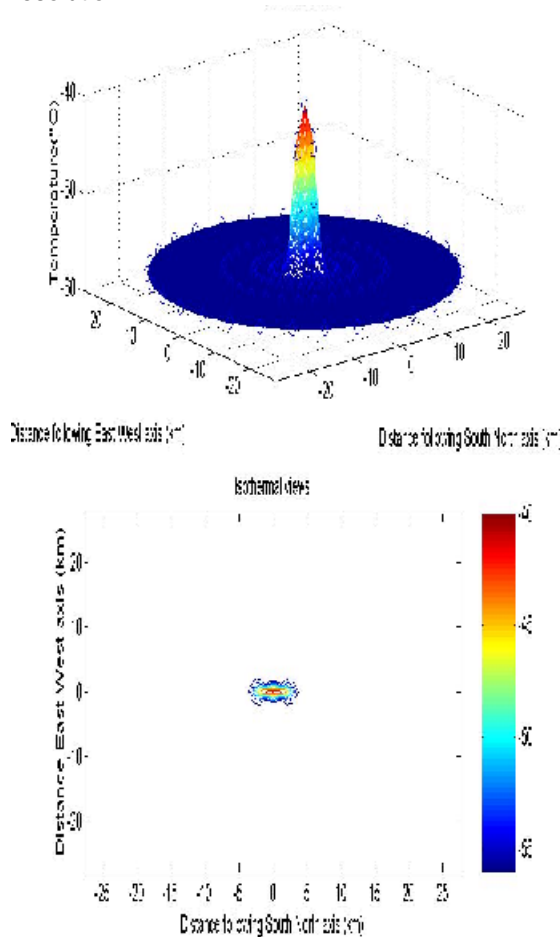


Figure 4: 3D view and footprint for trial #2.

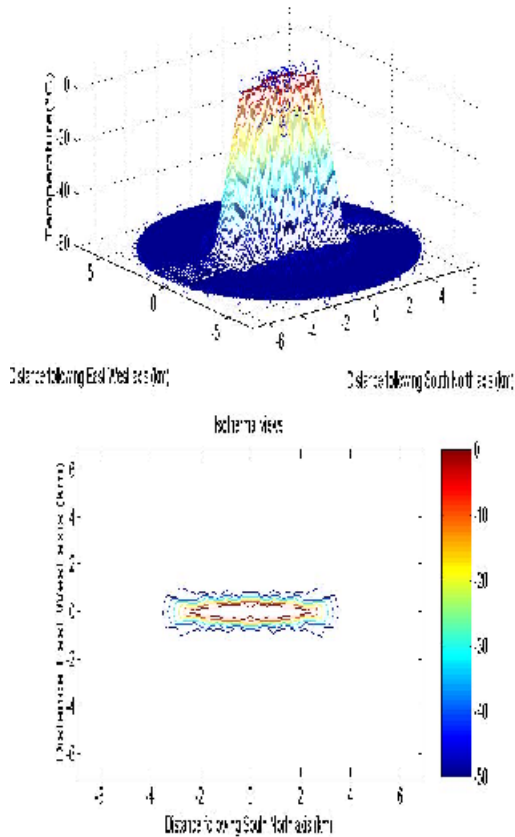


Figure 5: 3D view and footprint for trial # 5.

Considering the weakness of the resolution these thermal footprints should be considered carefully.

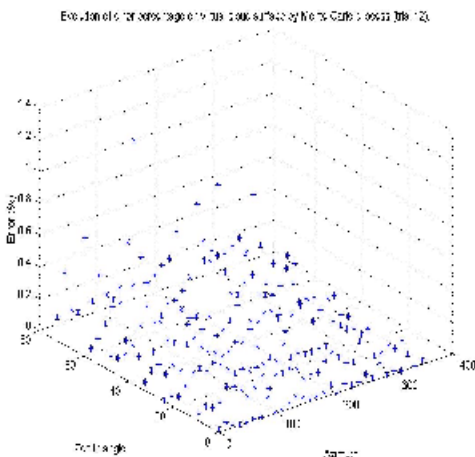


Figure 6: Relative error on cloud surface.

We studied also carefully the accuracy of the Monte Carlo integration for Nephelo and virtual cloud ellipses which are extremely weak even for

configuration where the “shooting box has significant dimensions. Figure 6 and 7 show respectively accuracy for Nephelo ellipse and virtual cloud ellipse as a function of zenith angle and azimuth. These figures show that more the zenith angle and the distance between the virtual cloud and the measurement ellipse are important more the error percentage is important. This phenomenon is due to the size of the Monte Carlo “shooting box”.

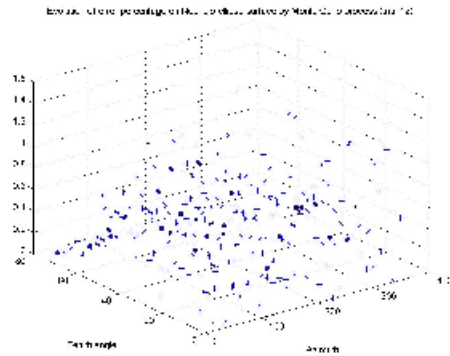


Figure 7: Relative error on Nephelo ellipse surface.

4. SECOND ORDER MOMENT METHOD FOR SHAPE CONSTRUCTION

4-1 METHOD DESCRIPTION

This method based on inertia moment (m_{nk}) calculation could be described as follow:

$$m_{nk} = 1/N \sum P(x_i - x_g)^n (y_i - y_g)^k \quad (2)$$

Where :- N is a normalization factor

- P is a weighting factor.

- The sum is performed on the 181 points of the Nephelo “picture”.

Summations above and below are performed on the 181 points of measurements provided by Nephelo.

After several trials, we defined N and P as follow:

$$N = \sum S_i B(T_i) \quad (3)$$

To take into account the overlap between the ellipses of measurement, as shown on figure 1, which is not a constant for the different crowns of measurement, we redefined for each crown ‘measurement surfaces’ S_i as elementary elements of a radar diagram.

B(Ti) is a Boolean function with a conditional temperature. If the measurement ellipse of Nephelo receives no signal from the virtual cloud B(Ti) is equal to zero and in the opposite case equal to 1. We performed each computation considering two conditions:

$$T > -57^{\circ}\text{C} \text{ (background temperature)} \quad (4)$$

$$T = T_{\text{simulation}} \quad (5)$$

$$P = S_i B(T_i) \quad (6)$$

Considering these formulas, we compute the following values: $m_{20}/m_{02}/m_{11}$ by means of equations (7) to (9)

$$a = [m_{02} + m_{20} + [(m_{20} - m_{02})^2 + 4m_{11}^2]^{1/2}]^{1/2} \quad (7)$$

$$b = [m_{02} + m_{20} - [(m_{20} - m_{02})^2 + 4m_{11}^2]^{1/2}]^{1/2} \quad (8)$$

$$\theta = 1/2 [\text{atan2}(2m_{11}/(m_{20} - m_{02}))] \quad (9)$$

where 'a' is the inertia moment along the main axis of the shape, 'b' the inertia moment perpendicular to a and 'theta' the CCW angle between 'a' and the horizontal axis.

4.2 SHAPE CONSTRUCTION vs. ALTITUDE

4.2.1 Simulations performed

We applied the method described in the previous paragraph to trials 1 to 7. Figures 8 and 9 show respectively results of trials 2 and 5. On these figures black stars show measurement points at a temperature greater than the background temperature (-57°C) and lower than the simulation temperature and blue stars measurement points at the simulation temperature. Inside ellipse is built with the second order moment method with the points represented by blue stars and outside one using black and blue points.

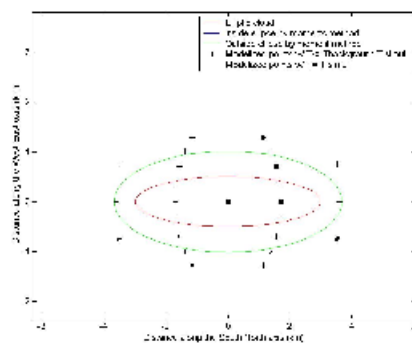


Figure 8: Results for trial # 2.

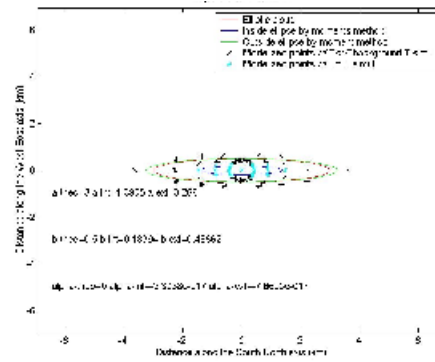


Figure 9: Results for trial # 5.

4-2-2 Results

- In the conditions of the simulations, where the dimension of the virtual cloud located at the zenith are relatively small ($a=3 \text{ km } b=0.5 \text{ km}$), the temperature of the shape disappears totally of the footprint above 4500 m. This altitude limit will be smaller for clouds located in area with important values of zenith angle. We can say, in terms of field of applicability of this model that the altitude is strongly dependant on the size of the virtual cloud. Nevertheless, low altitude real clouds, and most of the mid-altitude clouds up to 4500-5000 m) could be simulated by his method, e.g. small Cumulus with ceiling high in the range of 2000 to 3000 m.

- As we can expect, globally inside ellipse underestimates the size of the shape and outside ellipse overestimates it. Due to the lack of resolution of the Nephelo "picture" an iteration temperature between -57°C and temperature simulation does not provide any consistent optimisation in the shape description. Regular interpolation methods (linear or spline) could be used but controlled carefully by the establishment of cut away curves T versus distance.

- The second order moment method drove to accurate results concerning the angle of the main extension however about the description of the virtual cloud shape we looked for to obtain optimized results.

- Finally, notice that altitudes used in these simulations are generated by the MSISE-90 model that considers troposphere as an adiabatic media. Corrections could be introduced to simulate real cases

4.3 SHAPE DESCRIPTION OPTIMIZATION

This method is based on an individual treatment of measurement ellipses partially overlapped by the virtual cloud (see black stars on figures 8 and 9) as they are at the limit of the shape.

For each ellipse, we analysed the first neighbourhood looking for where a measurement ellipse fully overlapped is located: above, below, left or right along the same diameter. To ease the understanding of the method an example based on a matrix of squares is presented on figure 10.

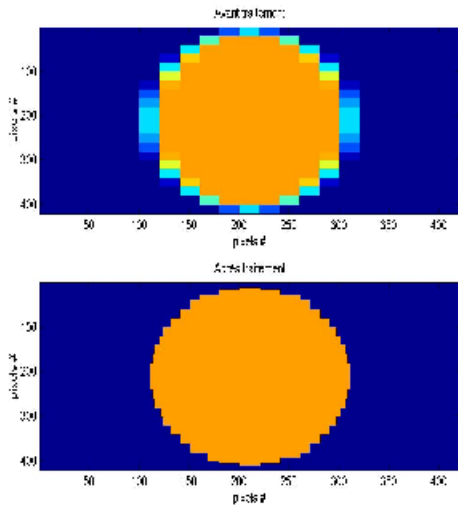


Figure 10: Edge optimisation, before and after treatment by the neighbourhood method.

Figure 10 show irregularities in the description of the shape that can be cleared by a single 'spline' process. However we should keep in mind that the interface cloud/no cloud is not strict for most of cloud types except for 'congestus cumulus'.

4.4 TRUE CLOUDS TREATMENT

Previous paragraphs showed the different steps of the method design. For treatment of true situation it is necessary to proceed as follow:

- Determination of an average minimum temperature that will be considered as background temperature. This step is due to the fact that "pure blue sky" is quite never observed in regular observation area. Cirrus and/or aerosols that are emitting in the thermal infrared wavelengths could generate this situation.
- Determination of the cloud cells number in the field of view of the instrument by means of a neighbourhood process.
- Determination of cloud base temperature (ceiling).
- Picture re-construction with the methods described above

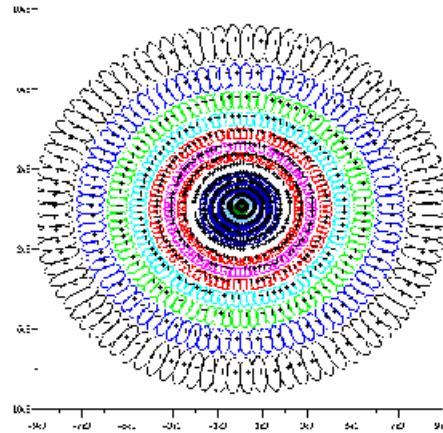


Figure 11: Future grid of measurement of a Nephelo with 13 captors.

We will present pictures generated with the actual turret (7 pyrometers with a 12° interval and a stepping of 12°). We are actually optimising the turret with a greater number of sensors providing an individual filed of view of 4° instead of 12° presently as shown on figure 11.

5. CONCLUSION

The 2-D simulations presented above permitted to optimise the geometry of the Nephelo grid of measurements and to move from a 7 captors to a 13 captors configuration.

The virtual clouds simulations show that it was possible to detect, with a good accuracy, relatively small clouds (3 km x 0.5 km) at altitude up to 4.5 km. The neighbourhood method allows also reconstructing the image of the virtual cloud despite the low resolution of the 7-captor Nephelo.

This last aspect is of major interest for the treatment of the real clouds, by convoluting elementary ellipses, and the analysis of their water contents, with specific captors, planned for the future development of the instrument.

6. ACKNOWLEDGMENTS

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