Physical and statistical approach for MSG cloud identification

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SEVIRI

The Spinning Enhanced Visible and Infrared Imager on board the First Meteosat Second Generation have been available since February 2003.
Its spatial resolution is 3 km at sub-satellite for all channels except 1km for the high resolution visible channel. The major improvement is its enhanced spectral characteristic that, combined with its higher temporal resolution (15 minutes) allows an accurate cloud cover analysis.

Spectral band	VIS 0.6	VIS 0.8	NIR 1.6	IR 3.9	WV 6.2	WV 7.3	IR 8.7	IR 9.7	IR 10.8	IR 12.0	IR 13.4	HRV
Central Wavelength (µm)	0.635	0.81	1.64	3.92	6.25	7.35	8.7	9.66	10.8	12	13.4	0.75

INTRODUCTION

Cloud detection is essential to estimate accurate atmospheric and geophysical parameters. A statistical and physical approach has been developed for MSG in order to improve cloud identification for very thin and very low cloud. The statistical algorithm is a pattern recognition technique that uses textural and spectral features, it was trained on the basis of MSG images collected for different seasons and different regions. The physical algorithm is based on dynamic threshold tests and it doesn't require any ancillary data. If the algorithms do not agree a decision has to be taken to decide the final FOV flag.

MODIS

The Moderate resolution Imaging Spectroradiometer on board AQUA and TERRA polar EOS satellites, provides global observations in VIS and IR region of the spectrum .

It measures radiances at 36 wavelength(from 0.4 to 14.5 µm) at 250m spatial resolution in two visible bands, 500m resolution in five visible bands and 1000m resolution in the infrared bands.

Physical approach

The algorithm is based on multispectral threshold technique applied to each pixel of the image.
The test depends on the solar illumination (day time, night time, sun glint) and on the viewing angles.
The thresholds have been determined on the basis of training database which gather pixels manually selected and labeled as cloud free.

Description of test sequences:	
over land, daytime • $T_{10.8}$< Tresh_$T_{10.8}$ • $R_{0.6}$ >Tresh_$R_{0.6}$ • $T_{10.8} - T_{12}$> Tresh_$T_{10.8}T_{12}$ • $T_{8.7} - T_{10.8}$> Tresh_$T_{8.7}T_{10.8}$ • $T_{10.8} - T_{3.9}$> Tresh_$T_{10.8}T_{3.9}$ and $T_{8.7} - T_{10.8}$>-4.5 -1.5(1/cos(asat)-1)	**over sea, daytime** • $T_{10.8}$< Tresh_$T_{10.8}$ • $R_{0.8}$ >Tresh_$R_{0.8}$ • $R_{1.6}$ >Tresh_$R_{1.6}$ • $T_{10.8} - T_{12}$> Tresh_$T_{10.8}T_{12}$ • $T_{8.7} - T_{10.8}$> Tresh_$T_{8.7}T_{10.8}$ • $T_{10.8} - T_{3.9}$> Tresh_$T_{10.8}T_{3.9}$
over land, night time • $T_{10.8}$< Tresh_$T_{10.8}$ • $T_{10.8} - T_{12}$> Tresh_$T_{10.8}T_{12}$ • $T_{8.7} - T_{10.8}$> Tresh_$T_{8.7}T_{10.8}$ • $T_{10.8} - T_{3.9}$> Tresh_$T_{10.8}T_{3.9}$ and $T_{8.7} - T_{10.8}$>-4.5 -1.5(1/cos(asat)-1) • $T_{3.9} - T_{10.8}$> Tresh_$T_{3.9}T_{10.8}$	**over sea, night time** • $T_{10.8}$< Tresh_$T_{10.8}$ • $T_{10.8} - T_{12}$> Tresh_$T_{10.8}T_{12}$ • $T_{8.7} - T_{10.8}$> Tresh_$T_{8.7}T_{10.8}$ • $T_{10.8} - T_{3.9}$> Tresh_$T_{10.8}T_{3.9}$ • $T_{12.0} - T_{3.9}$> Tresh_$T_{10.8}T_{3.9}$

For the i-th test the probability that the pixel is clear , $P_{i,clear}$, or cloudy, $P_{i,cloud}$, will be determinate.
If the i-th test is successful (the pixel is cloudy) the $P_{i,cloud}$ is determined on the basis of the distance between the real value and the threshold:

$$P_{i,cloud} = \frac{DiffTresh}{DiffTreshMax_{i,cloud}}$$

Otherwise, if the i-th test is not successful, it'll be

$$P_{i,clear} = \frac{DiffTresh}{DiffTreshMax_{i,clear}}$$

If $\sum_i P_{i,cloud} > 0$ then $P_{physical,cloud} = \max(P_{i,cloud})$,

if $\sum_i P_{i,cloud} = 0$ it'll be $P_{physical,clear} = \min(P_{i,clear})$

The *DiffTresh* is the difference between the threshold and the brightness temperature or the brightness temperatures difference. For each test, *DiffTresh* max values have been calculated on a sample of MSG imagery collected in different regions of the earth and at different times. *DiffTreshMax* has been defined as the mean of max values.

Statistical approach

The classification algorithm is based on a K-nn pattern recognition technique and it uses textural and spectral features estimated in boxes 3x3. Spectral and textural features characterizing each pixel are extracted for IR SEVIRI radiance data at 3.9µm (particularly useful in the detection of low level water clouds) 8.7 µm, 10.8 µm, 12 µm. The features are shown in the table:

Spectral features (describe the grey level range)	
Maxima	
Minima	
Ratio between maxima and minima	
Mean	
Textural features (describe aspects of the variability of a scene and are computed from th grey level differences between each individual pixel and its neighbors)	
Contrast $C(d,\vartheta) = \frac{1}{256}\sum_{d=0}^{255} P(d,\vartheta)\frac{d^2}{N}$	$P(d,\vartheta)$ is the grey level difference histogram, d is the difference between the grey levels separated in direction ϑ (0º,45º,90º, 135º) by the distance $\rho = 1$. $P(d,\vartheta)$ denotes the number of times difference d occurs between pairs of grey level at the specified distance and orientation in the box 3x3. N is the total number of pairs of points in the box separated by distance $\rho = 1$ in direction ϑ.
Entropy $ENT(d,\vartheta) = -\sum_{d=0}^{255}\left(\frac{P(d,\vartheta)}{N}\right)\log_e\left(\frac{P(d,\vartheta)}{N}\right)$	
Angular Second Moment $ASM(d,\vartheta) = \sum_{d=0}^{255}\left(\frac{P(d,\vartheta)}{N}\right)^2$	
Mean $M(d,\vartheta) = \frac{1}{256}\sum_{d=0}^{255} P(d,\vartheta)\frac{d}{N}$	
The area-averaged Robert Gradient is a measure of edge strength and it is maximum in regions of sharp brightness contrast. $\overline{RG} = \frac{1}{(M-\rho)(N-\rho)}\sum_{m=1}^{M-\rho}\sum_{n=1}^{N-\rho}\left\{\lvert I(m,n) - (I(m+\rho,n+\rho)\rvert + \lvert I(m+\rho,n) - I(m,n+\rho)\rvert\right\}$ $B(m,n)$ is the measured brightness at coordinate (m,n) in the MxN (3x3) box and ρ is the separation distance (in this case ρ=1)	

The large number of spectral and textural features can be reduced since not all of them are useful. The Fisher distance is the feature selection criterion: $D_{ijk} = \lvert v_{ij} - v_{ik}\rvert / (\sigma_{ij} + \sigma_{jk})$. This parameter measures the ability of the variable v_i to differentiate class C_k from class C_J.

Description of the classes
Clear over land
Clear over water
Low clouds
Cumulus
High stratiform clouds

K nearest neighbor classifier

The class likelihoods have been estimated as follows: $P(\vec{v},C) = \frac{K_i}{N_i V}$

where N_i is the number of samples in class C_i and K_i are the samples closest to the features vector $\vec{v}$, V is the volume in which those K_i reside. In order to define the distance between two points in the feature space and calculate the volume V, we have assumed that the feature space is a metric space and the function which expresses the distance between $\vec{v}_1$ and $\vec{v}_2$ is the *Euclidean distance* : $d(\vec{v}_1,\vec{v}_2) = (\sum_{i=1}^{d}(v_{1,i} - v_{2,i})^2)^{1/2}$

When the Euclidean distance measure is used, some features (the ones with the largest variance across the design set) tend do dominate this measure so it has been necessary to normalize the features.

Finally, we are able to classify the pixel as cloudy if $(P(\vec{v},C_{clear}) < P(\vec{v},C_{low\_cloud})) \vee (P(\vec{v},C_{clear}) < P(\vec{v},C_{cumulus})) \vee ((P(\vec{v},C_{clear}) < P(\vec{v},C_{High\_stratiform}))$

and $P_{knn,cloud} = \max(P(\vec{v},C_{low\_cloud}), P(\vec{v},C_{cumulus}), P(\vec{v},C_{high\_stratiform}))$

Otherwise, the pixel is clear if $(P(\vec{v},C_{clear}) > P(\vec{v},C_{low\_cloud})) \wedge (P(\vec{v},C_{clear}) > P(\vec{v},C_{cumulus})) \wedge (P(\vec{v},C_{clear}) > P(\vec{v},C_{High\_stratiform}))$

and $P_{knn,clear} = P(\vec{v},C_{clear})$.

Results

MSG cloud mask has been validated against MODIS cloud mask (Ackerman et al.,1998) and compared with SAFNWC cloud mask (Schroder et al.,2002). MODIS cloud mask is collocated within SEVIRI footprint. SEVIRI FOV is declared clear if a fixed percentage (70%, 90%,100%) of MODIS pixels within SEVIRI FOV has been determined to be clear. In result interpretation it should be observed that MODIS cloud mask not always detects cloudy pixels correctly. Moreover it sometimes classifies as uncertain pixels that CMESP detects correctly. The blue ring surrounds some pixels that SAF cloud mask detects wrongly.

Percentage of MODIS pixels determined to be clear within SEVIRI FOV	Total number of clear MODIS pixels used for validation	Total number of cloudy MODIS pixels used for validation
70 %	1546074	2225386
90%	1487811	2296947
100%	1416786	2386948

MODIS pixels have been collocated at SEVIRI spatial resolution

Percentage of MODIS pixels determined to be clear within SEVIRI FOV	FOVs detected exactly			
	Cloud Mask CMESP		Cloud Mask SAF	
	cloudy	clear	cloudy	clear
70%	90.4%	93.6%	88.3%	92.8%
90%	90.7%	95.2%	88.5%	94.1 %
100%	89.7 %	94.6%	87.5%	93.5 %

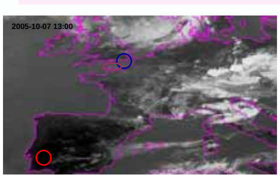
Comparison between SEVIRI and MODIS at SEVIRI resolution cloud mask

Ensemble of Statistical and Physical methods (CMESP)

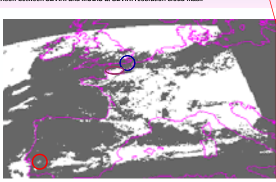
The physical and statistical approach run independently, then the individual decisions are matched; if the two methods do not agree, the final FOV flag will be clear if $P_{physical,clear} > P_{knn,cloud}$ or $P_{knn,clear} > P_{physical,cloud}$
If the difference between the probabilities is lower than 5%, a further test on the Robert Gradient ($\overline{RG}$) , has to be done:
If $\overline{RG} > \overline{RG}_{treshold}$ the pixel is cloudy.
$\overline{RG}_{treshold}$ is a dynamic threshold.

Summary

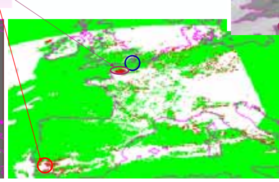
In this work, a physical and statistical approach has been developed for MSG and has been combined in order to improve cloud identification of very low and thin clouds. This approach does not need ancillary data which are not always available. The two approaches compensate each other. The statistical algorithm is very useful in low clouds and high stratiform clouds detection, while the physical one is essential in discriminating clouds from snow. Moreover, physical approach can be decisive in detecting clear pixels that sometimes are classified cloudy by the statistical method, because of their very high entropy or contrast, especially over not homogeneous land.



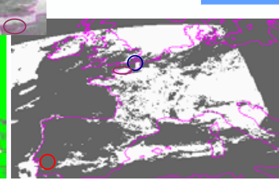
a) SEVIRI Channel 9, 10.8 µm



b) SEVIRI Cloud Mask CMESP cloudy clear



c) MOD IS Cloud Mask cloudy clear uncertain



d) SEVIRI Cloud Mask SAF cloudy clear

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