SELF ADAPTIVE ALGORITHMS FOR CHANGE DETECTION: OCA (THE ONE-CHANNEL CLOUD-DETECTION APPROACH) AN ADJUSTABLE METHOD FOR CLOUDY AND CLEAR RADIANCES DETECTION.

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1. INTRODUCTION

Many algorithms, have been up to now proposed, which are devoted to detect local abrupt changes, in the satellite multi-spectral radiance fields, possibly associated, from time to time, to different atmospheric or superficial phenomena (e.g. clouds, forest fires, volcanic eruptions, etc.). They usually are based on fixed-threshold tests on multi-spectral satellite radiances (or their combinations) which show their full weakness as soon as they are extended on different observational conditions or adapted to different satellite packages. Results particularly poor are achieved when such algorithms are applied at the global scale mainly because of the high-space-time variability of atmospheric and surface parameters whose knowledge is usually lacking or insufficient. A new approach (RAT- Robust AVHRR Techniques) to Earth surface and atmosphere monitoring by satellite has been recently proposed (Tramutoli 1998), which introduces the concept of local (i.e. punctual in the space-time domain) thresholds suitable for developing change-detection algorithms at the same time reliable and fully exportable (as based only on satellite data at hands). RAT approach has been already applied to several environmental emergencies with very encouraging results in the fields of fire detection (Lasaponara et al., 1998, Cuomo et al. 2001), monitoring of volcanic eruptions as well as stratospheric aerosols increase due to major eruptive events (Pergola et al. 1998, Tramutoli et al. 2000a, Pergola et al. 2001), hydrological (Tramutoli et al. 2001a) and seismic (Tramutoli et al. 2001b) risks.

OCA, the One-channel Cloud-detection Approach, discussed in this paper, is the application of the same approach to the problem of satellite cloudy radiances detection. It has been recently (Tramutoli et al. 2000b) proposed as a self-sufficient and self-consistent way for computing MSG-GERB cloud(y
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radiance)-masks and also to obtain clear-sky radiances whereas traditional cloud-clearing schemes usually fails.

In this paper OCA performances will be discussed by comparison with the, operationally well tested, cloud-detection scheme of the CMS-Lannion (Derrien et al., 1993). More than ten years of NOAA/AVHRR imagery have been processed, separately considering only two AVHRR channels (one in the visible and the other in the thermal infrared) mainly in order to assess OCA impact on radiometers (like GERB/MSG) with very low-spectral capabilities. Positive impacts expected also on multispectral VIS-IR sounders and particularly on those onboard geostationary satellites, will be also discussed with reference to present and future meteorological satellite missions.

2. OCA RATIONALE AND IMPLEMENTATION

Cloud detection is usually performed on a pixel-by-pixel base using a cascade of tests devoted to establish if satellite radiances, their linear combination or spatial variance, get values greater or lower than some pre-fixed threshold. Implicitly clouds are identified as an anomaly in the realisation of the clear-sky multi-spectral space-time process $R_i(r,t)$ (with $i=1..B$ being $B$ the number of spectral bands and band combinations) on the base of threshold tests like

$$R_i(r,t) > th_i \quad \text{or} \quad R_i(r,t) < th_i$$

where thresholds $th_i$ are specific for each band $i$ (or band combination) and, usually not, for the place $r$ (except for land/sea discrimination) and the time $t$ (except for day/night discrimination) of the observations. The low space-time dynamics of sea-surface properties makes cloud-detection over sea easier. Thin clouds, cirrus, clouds-edges, cold high reflective backgrounds (e.g. snow, ice) are the situations where cloud-detection techniques based on fixed generalised thresholds find their main difficulties. In all those cases, the OCA self-adaptive approach is expected to give major improvements by using local (i.e. in space and in time) thresholds, $th_i(r,t)$, automatically computed - for each spectral band (or band linear combinations) - and updated on the base only of satellite data at hands. In the following the results of OCA implementation on AVHRR imagery will be presented considering cloudy-radiance detection capabilities achievable by using only the visible (0.58-0.68µm) channel 1 and/or the TIR (10.5-11.3µm) channel 4.
2.1 OCA implementation

OCA scheme (see Tramutoli et al. 2000b for details) has been implemented on the base of NOAA/AVHRR imagery collected all over Europe from 1978 up to 1999.

A. **Building homogeneous historical data-sets.** Following RAT prescriptions (see Tramutoli 1998 for details) separate historical data sets have been built in order to guarantee the best possible homogeneity of observational conditions in terms of time of the day (four different data sets for NOAA images obtained around the four synoptic hours 00, 06, 12 and 18) and month of the year (further 12 data-set subdivisions). After calibration all images were accurately navigated by SANA (Sub-pixel Automatic Navigation for AVHRR, Pergola and Tramutoli, 2000) and co-registered on the same geographic projection. Each of those 48 (4x12) calibrated and co-registered imagery data sets can be then considered as a space-time process described by the signal $R_i(x,y,t)=R_i(r,t)$ measured in the spectral band $i$ at the time $t \in T$ from a ground pixel centered at $r=(x,y)$, being $T$ the collection of $N$ temporal sites ($T\equiv\{t_1,t_2,\ldots,t_N\}$) corresponding to the chosen data-set (i.e. the time slot identified by the month of the year and the time of the day). At each fixed time $t'$, $R_i(r,t')$ represents a realization of a purely spatial process. At each fixed location $r'$, $R_i(r',t)$ represents a realization of a time-series process.

B. **Computing reference fields.** The time-means, $\mu_{VIS}(r,T)$ and $\mu_{TIR}(r,T)$, and variance, $\sigma^2_{VIS}(r,T)$ and $\sigma^2_{TIR}(r,T)$, have been computed on AVHRR channel 1 (VIS) and channel 4 (TIR) for each data-set (time-slot T) after the application of the $k\sigma$-clipping procedure described in Tramutoli (1998) and devoted to exclude spurious minima or maxima (associated for instance to clouds or cloud-shadows) from the time-series. The scenes $\mu_{VIS}(r,T)$ and $\mu_{TIR}(r,T)$ have been used then as reference fields for VIS and TIR clear-sky radiances. Similarly $\sigma^2_{VIS}(r,T)$ and $\sigma^2_{TIR}(r,T)$ will represent the reference fields for the normal variability of the signal in absence of clouds. Should be noted that $\mu(r,T)$ and $\sigma^2(r,T)$ are locally defined, i.e. specific for each location $r$ and time-slot $T$.

C. **Detecting signal anomalies:** for each pixel of the image at hands ($t=t'$) the ALICE (Absolutely Llocal Index of Change of the Environment) index was computed in order to detect $illocal$ anomalies in the field of AVHRR visible reflectances $VIS(r,t')$ or TIR radiances $TIR(r,t')$ comparing them with their $illocal$ normal (i.e. clouds-free) behaviors $\mu(r,T)$ and variability $\sigma(r,T)$ in the time slot $T$:

$$\otimes_{VIS}(r,t',T) = \frac{[VIS(r,t') - \mu_{VIS}(r,T)]}{\sigma_{VIS}(r,T)}$$
\[ \bigotimes_{TIR} (r, t', T) = \frac{[TIR(r, t') - \mu_{TIR}(r, T)]}{\sigma_{TIR}(r, T)} \]

3. OCA PERFORMANCES EVALUATION

In the following OCA performances will be discussed with reference to the time slot T including AVHRR imagery collected during the month of June around midday (11:00-14:00 GMT). In order to appreciate finest details only a small portion of the European area (including Southern Italy) will be depicted and used for the discussion. Figures 1 and 2 show the reference fields \( \mu_{VIS}(r, T) \), \( \mu_{TIR}(r, T) \), \( \sigma_{VIS}(r, T) \) and \( \sigma_{TIR}(r, T) \) computed for the selected area and time slot T on the base of AVHRR imagery collected over Europe from 1978 up to 1999 (all NOAA passes starting from 1994). Figures 3 and 4 show, in the case of one AVHRR pass (June 25th, 1995 around midday) the result of the application of the OCA approach separately on VIS and TIR radiances, using different cuts K defined by

\[ \bigotimes_{VIS} (r, t', T) = \frac{[VIS(r, t') - \mu_{VIS}(r, T)]}{\sigma_{VIS}(r, T)} > K \]
\[ \bigotimes_{TIR} (r, t', T) = \frac{[TIR(r, t') - \mu_{TIR}(r, T)]}{\sigma_{TIR}(r, T)} < -K \]

At different values of K, correspond different cuts on VIS reflectances and TIR radiances which permits to tune OCA products on the base of specific application requirements. Low values of K correspond to a drastic cut on cloudy radiances (assumed to be associated to higher VIS and lower TIR values) to be applied as far as clear-sky radiances are requested. Higher values of K will give instead a more reliable identification of really cloudy locations. Figure 3 and 4 permit to appreciate OCA tunability also by comparison with the corresponding cloud-mask (operational at that date) from CMS.
Figure 1: Reference fields $\mu_{VIS}(r, T)$ (left) and $\sigma_{VIS}(r, T)$ (right) computed for the time slot $T$ (June, midday) on the base of AVHRR imagery collected over Europe from 1978 up to 1999. Brighter tones correspond to higher VIS reflectance values.

Figure 2: As Figure 1 for reference fields $\mu_{TIR}(r, T)$ (left) and $\sigma_{TIR}(r, T)$ (right). Brighter tones correspond to higher TIR radiances values.

Table 1 describes the results of the comparison of several OCA products with coincident cloud-masks obtained at CMS. Results are reported for a single channel (VIS and TIR separately) as well as for a double channel approach (pixels are flagged cloudy even if only one of the VIS or TIR tests are satisfied) using different cut levels $K$. 
Figure 3: OCA tunability. From top-left clockwise: 25 June 1995 - AVHRR VIS Channel 1; CMS operational cloud mask (blue=cloudy); OCA tests (see text) at K=1, 2, 3 and 4 (green=cloudy).

Figure 4: As Figure 3 for AVHRR TIR Channel 4.
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<table>
<thead>
<tr>
<th>VISIBLE TEST AVHRR CH1 <strong>local</strong> thresholds</th>
<th>COINCIDENCES (%) OVER THE TOTAL OF CMS CLOUDY PIXELS (OCA AND CMS)/CMS</th>
<th>OCA EXCESS (%) OVER THE TOTAL OF CMS CLOUDY PIXELS (OCA ONLY)/CMS</th>
<th>COINCIDENCES (%) OVER THE TOTAL OF OCA CLOUDY PIXELS (OCA AND CMS)/OCA</th>
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<tr>
<td>K=1</td>
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<td>17</td>
<td>83</td>
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<td>K=2</td>
<td>77</td>
<td>8</td>
<td>90</td>
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<tr>
<td>K=3</td>
<td>71</td>
<td>4</td>
<td>94</td>
</tr>
<tr>
<td>K=4</td>
<td>65</td>
<td>3</td>
<td>96</td>
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<th>THERMAL IR TEST AVHRR CH4: <strong>local</strong> thresholds at</th>
<th>COINCIDENCES (%) OVER THE TOTAL OF CMS CLOUDY PIXELS (OCA AND CMS)/CMS</th>
<th>OCA EXCESS (%) OVER THE TOTAL OF CMS CLOUDY PIXELS (OCA ONLY)/CMS</th>
<th>COINCIDENCES (%) OVER THE TOTAL OF OCA CLOUDY PIXELS (OCA AND CMS)/OCA</th>
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<td>K=2</td>
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<td>2</td>
<td>92</td>
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<td>K=3</td>
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<td>K=4</td>
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<td>95</td>
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<th>VIS OR TIR TEST AVHRR CH1 - CH4 <strong>both local</strong> thresholds at</th>
<th>COINCIDENCES (%) OVER THE TOTAL OF CMS CLOUDY PIXELS (OCA AND CMS)/CMS</th>
<th>OCA EXCESS (%) OVER THE TOTAL OF CMS CLOUDY PIXELS (OCA ONLY)/CMS</th>
<th>COINCIDENCES (%) OVER THE TOTAL OF OCA CLOUDY PIXELS (OCA AND CMS)/OCA</th>
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<tr>
<td>K=1</td>
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<tr>
<td>K=4</td>
<td>65</td>
<td>3</td>
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**Table 1:** OCA vs operational products (CMS 1995)

Compared with the multi-spectral CMS product it is possible to note as, even using an unique spectral band (VIS), the use of **local** thresholds, permits to obtain high detection capability (more than 80% of coincidence using AVHRR VIS channel only) together with a simple tunability. Should be noted also as, for the considered time-slot, the VIS test is more efficient in detecting most of clouds, but we will see that TIR test permits a more refined cloud discrimination in the more difficult cases. Figure 5 shows where the combined VIS +TIR OCA tests (at the more drastic level K=1) give the same results of CMS (coincidences=red) where they detect less (blue) or more (green) cloudy pixels. The analysis on discrepancies is particularly interesting as it permits to emphasize the main limits of traditional (fixed threshold) approaches and, at the same time, OCA potential.
**Figure 5**: OCA vs operational products (CMS 1995): OCA VIS & TIR tests at K=1 for AVHRR pass on 25 June 1995. Pixels detected as cloudy are coloured in: green (OCA only), blue (CMS only), red (both).

**Figure 6**: Top: detail of the white box (rotated) of Figure 5. Bottom: values of significant variables across the red line. Green bars indicate pixels detected as cloudy by OCA tests on VIS (left) and TIR (right) radiances using a K=1 threshold. Blue bars refer to CMS cloud mask.
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Figure 6 gives a clear example of a successful OCA cloud-detection even in presence of a quasi-transparent (less than 4% of visible reflectance, TIR brightness temperature higher then 287 K) cloud. By the other side, still in Figure 6 (bottom), should be noted as the local threshold approach permit to avoid (as instead happens in the case of the CMS approach) to take Ventotene (and the neighboring Santo Stefano) island for a cloud. The reason is quite evident looking to the behavior of the used OCA threshold (in the visible) across the red line in Figure 6 (left) that includes land and sea pixels. OCA thresholds, indeed, take different values for land and sea locations (so an higher VIS value in correspondence of islands and land-sea interfaces) which are completely determined on the base only of historical satellite records (Figure 7).

![Figure 7: Detail of the white box of Figure 5. Top from left to right: 25 June 1995 (midday) AVHRR ch 1 VIS reflectance, reference fields $\mu V I S(r,T)$ and $\sigma V I S(r,T)$ (right) computed for the time slot $T$ (June, midday) on the base of AVHRR imagery collected over Europe from 1978 up to 1999. Brighter tones correspond to higher VIS reflectance values. Bottom the same for AVHRR ch 4 TIR. Brighter tones correspond to higher TIR radiances values.]

4. EXPECTED IMPROVEMENTS MOVING FROM POLAR TO GEO-STATIONARY SATELLITES.

Should be noted as the OCA sensitivity in detecting local signal "anomalies", possibly related to clouds, strongly relies (see Section 2.1.B before) on the local value of the reference field $\sigma r(T)$ which
represents the normal (i.e. in absence of clouds) variability of the measured signal as observed in the past. The local value of $\sigma(r, T)$ depends on the normal variability of the measured signal due to variable observational (mainly time $t$ time of the day and day of the month, satellite view angle and, during daytime, solar-satellite relative positions) and physical conditions of Earth surface (mainly temperature and spectral emissivity) and atmosphere (mainly spectral transmittance).

Should be noted that differences in the local view angles (with consequent reduction of both, spatial resolution and intensity of measured radiances in off-nadir views), introduce spurious space-time variations of the measured signal due simply to the change in observational conditions (e.g. related to the image-to-image change of the size of the ground resolution cell consequent to the change of the satellite angle of view).

Several aspects can be then considered which strongly suggest that OCA results achieved on NOAA-AVHRR data can be extended and improved by exploiting instrumental packages at higher time-resolution on board of geo-stationary satellites:

a) the improved quality of the image to image superimposition together with the saving of the same angle of view for each portion of the scene (offered by the geo-stationary attitude) will increase the sensitivity of the proposed method (reducing the local value of $\sigma(r, T)$) which strongly relies on the multi-temporal analysis of satellite radiance on a pixel-by-pixel base.

b) the improved time-resolution will reduce both the natural (lower image-to-image variability of the local signal) and observational (greater homogeneity of time-series elements on reduced time-slots) noise again reducing $\sigma(r, T)$ and consequently increasing the sensitivity of OCA toward relatively lower signal variations.

c) short time gradients $\Delta R(r, t) = R(r, t) - R(r, t_{0})$ used instead of corresponding instantaneous variables, will permit the definition of ALICE indexes like

$$\Theta_{\Delta R}(r, t', T) = \frac{[\Delta R(r, t') - \Delta R_{REF}(r, t < t', t \in T)]}{\sigma_{\Delta R}(r, t < t', t \in T)}$$

again with reduced natural/observational noise $\sigma_{\Delta R}(r, t', T)$ and increased sensitivity in detecting signal variation even in presence of a larger Field of View (FOV).

5. FINAL REMARKS

Preliminary results achieved using the self-adaptive One-channel Cloud-detection Approach (OCA) suggest a more effective (and tunable) way to define thresholds (locally variable instead of fixed) to be used in current (or new) cloud-detection schemes for multi-spectral sounders. On the other hand OCA
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might represent an unique possibility to obtain similar products also for sounders (e.g. MSG/GERB), with
very low spectral and spatial resolution. In those cases OCA might permit a self-consistent definition and
detection of clear sky radiances without burden of using ancillary (e.g. co-located MSG/SEVIRI) cloud-
masks often requiring huge additional computing time.

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