CLEAR-SKY MASK FOR THE AVHRR CLEAR SKY PROCESSOR FOR OCEANS

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1. Introduction

The AVHRR Clear Sky Processor for Oceans (ACSPO) is being developed at NESDIS to enhance production of clear-sky radiances over oceans (CSR), and sea surface temperatures (SST) and Aerosols derived from the CSRs. The key element of the ACSPO is its Clear-Sky Mask (CSM).

2. Objective of the ACSPO CSM

Maximize the amount of AVHRR pixels suitable for clear-sky products (including in the dynamic areas of the oceans), while keeping the residual cloud contamination at a predefined tolerance level.

3. ACSPO builds upon CLAVRx ([1])

- ACSPO focuses on clear-sky ocean (CLAVRx: land/ocean, cloud/clear).
- ACSPO CSM makes an emphasis on analysis of SST anomaly with respect to a reference field (Reynolds SST, T_R[4]), and on clear-sky radiative transfer model (RTM) [2,3] in conjunction with the Numerical Weather Prediction (NWP) forecast fields. CLAVRx makes use of the radiative properties of clouds, and to a lesser extent, on clear-sky RTM.
- ACSPO classification: 'Clear', 'Probably clear', 'Cloudy' (CLAVRx: 'Clear', 'Probably clear', 'Probably cloudy', 'Cloudy')
- Present ACSPO CSM: Optimized for CSR in the Earth emission bands and SST. Testing for CSR in Solar Reflectance Bands/Aerosols underway.

4. ACSPO CSM Tests

4.1. The SST Anomaly Test

A cold bias in SST, retrieved under clear-sky assumption, is one of the most obvious cloud signatures in AVHRR data. ACSPO calculates SST for each AVHRR pixel with different regression algorithms during the day and night:

Day: $T_S = a_o + a_1 T_4 + a_2 T_R (T_4 - T_5) + a_3 (T_4 - T_5)(\sec\theta - 1)$

Night: $T_S = a_o + a_1 T_4 + a_2 T_{3b} + a_3 T_5 + a_4 (T_{3b} - T_5)(\sec\theta - 1) + a_5 (\sec\theta - 1)$

Here, T_{3b}, T_4 and T_5 are brightness temperatures (BT) measured in AVHRR channels 3b, 4 and 5 respectively, and T_R is Reynolds 1° weekly (version 2) SST [4] interpolated to AVHRR pixels. The SST Anomaly test detects unrealistically cold T_S by comparison with T_R:

$\Delta T_S \equiv T_S - T_R > -\Delta(\text{Lat, Lon})$? (Yes – "Clear", No – "Cloudy")

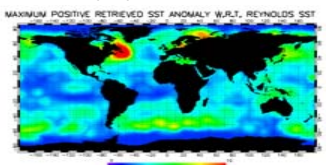

Fig.1. Δ(Lat, Lon) is defined as max (local positive ΔT_S) over 1 year (shown is NOAA-18 result for 2007, with some additional smoothing.) Distribution of ΔT_S is assumed symmetrical with respect to 0.

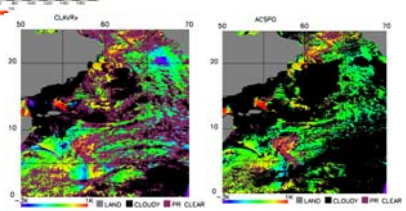

Fig.2. An example of rejecting cold ΔT_S with SST Anomaly test. N18 scene in the Arabian Sea on 26 Sep 2006: (left) CLAVRx; (right) ACSPO. ΔT_S is shown in clear pixels. (See also handling cold left tails in histograms in Section 5 by CLAVRx and ACSPO.)

4.2. The Radiance Test

The Radiance Test checks for consistency between each retrieval point: the measured and CRTM simulated BTs, in

$F < \varepsilon$? (Yes – "Clear", No – "Cloudy"), where

Night: $F = \{[(T_{3b} - T_{CS\,3b})^2 + (T_4 - T_{CS\,4})^2 + (T_5 - T_{CS\,5})^2]/3\}^{1/2}$

Day: $F = \{[(T_4 - T_{CS\,4})^2 + (T_5 - T_{CS\,4})^2]/2\}^{1/2}$,

T_{CS} CRTM simulated BTs with retrieved T_S and local NWP fields data,

ε is a predefined threshold.

Currently ε is set to 1K. The work on more correct formulation of this test is underway. This test mainly cuts off pixels with negative ΔT_S's, producing warmer mean T_S with minor changes in higher moments of ΔT_S distribution. The elements of the radiative transfer equation are calculated with NWP data on 1° grid, and then interpolated in space to AVHRR pixels and used to simulate CSR from retrieved SST T_S in each AVHRR pixel.

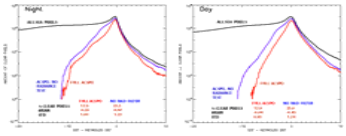

Fig. 3. Histograms of ΔT_S on 421 June 2007 day- and nighttime half-orbits over "clear" pixels, detected by ACSPO CSM with (violet) and without (black) the Radiance Test.

4.3. The CLAVRx cloud tests in ACSPO CSM

Four CLAVRx tests have been retained in the ACSPO CSM.

During daytime, 2 tests based on AVHRR reflectance channels are used:

- *Channel 3 Albedo Test (C3AT):*
  Channel 3a Albedo < T_{C3AT}? (Yes – "Clear", No – "Cloudy")
- *Reflectance Ratio Contrast Test (RRCT):*
  (Channel 1 Albedo)/(Channel 2 Albedo) < T_{RRCT} ? (Yes – "Clear", No – "Cloudy")

T_{C3AT} and T_{RRCT} are predefined thresholds.

ACSPO CSM uses the above tests in the same formulation as CLAVRx.

During nighttime, 2 tests based on thermal cloud emission properties are used for detection low warm stratus and cirrus (CLAVRx formulation):

- *Three Minus Five Test (TMFT):*
  $T_{3b} - T_5 < T_{TMFT}$? (Yes – "Clear", No – "Cloudy")
- *Ultra Low Stratus Test (ULST):*
  $T_{3b} - T_5 < T_{ULST}(T_4)$? (Yes – "Clear", No – "Cloudy"),

T_{TMFT} and T_{ULST} are predefined thresholds.

Additional analyses have shown that TMFT and ULST tests in original CLAVRx formulation cause massive misclassification of clear pixels as cloudy. In ACSPO, the TMFT and ULST are triggered with the measured BTs, only if they fail with the simulated BTs:

- *Three Minus Five Test (TMFT):*
  $T_{CS\,3b} - T_{CS\,5} > T_{TMFT}$ or $T_{3b} - T_5 < T_{TMFT}$? (Yes – 'Clear', No – 'Cloudy')
- *Ultra Low Stratus Test (ULST):*
  $T_{CS\,3b} - T_{CS\,5} > T_{ULST}(T_{CS\,4})$ or $T_{3b} - T_5 < T_{ULST}(T_4)$? (Yes – 'Clear', No – 'Cloudy')

ACSPO CSM uses C3AT, RRCT, TMFT and ULST with the same thresholds as in CLAVRx.

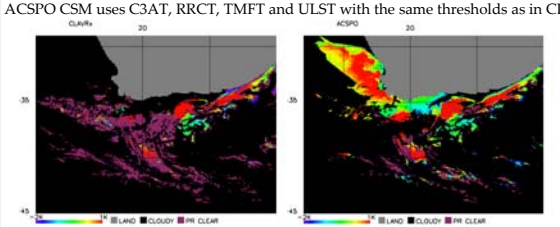

Fig. 4. ΔT_S in the S. Atlantic on 26 Sep 2006: (left) CLAVRx; (right) ACSPO.

4.4. The Uniformity Test (UT)

The ACSPO UT is used to detect areas with higher spatial inhomogeneity, likely associated with residual cloud. ACSPO UT differs from CLAVRx UT:

- It is applied to T_S (CLAVRx: to measured radiances);
- A median-based predictor is used (CLAVRx: spatial standard deviation).

CLAVRx UT: $\sqrt{\sum_{i=1}^{N} (x_i - mean(x))^2 / (N-1)} < T$?

ACSPO UT: $\sqrt{\sum_{i=1}^{N} (x_i - median(x))^2 / (N-1)} < T$?

(Yes – "Clear", No – "Probably Clear")

x_i are the elements of the tested field within 3x3 neighborhood of a given pixel, T is a predefined threshold, currently set to 0.3K. The median-based predictor is needed to reduce misclassification of pixels at sharp thermal fronts as 'Probably clear', which is typical for the STD predictor.

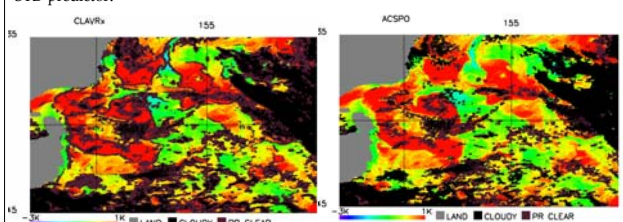

Fig. 6. ΔT_S off the E. Australia on 26 Sep 2006: (left) CLAVRx; (right) ACSPO. Note reduced proportion of 'probably clear' pixels in ACSPO CSM.

4.5 Clear pixel rejection rate by different ACSPO tests

'Clear'/'Cloudy' Tests	Day	Night
Radiance Test	71.37	65.74
SST Anomaly Test	2.74	10.10
C3AT	1.81	-
RRCT	0.14	-
ULST	-	0.22
TMFT	-	0.11
'Clear'/'Probably Clear' Test		
Uniformity test	11.90	10.77
Total	87.96	86.94

Shown is % of total ocean pixels rejected by a given test after the previous test is applied. Statistics are based on 30 NOAA 18 orbits for June 1-2 2007. The 'Clear'/'Cloudy' tests are listed in order of decreasing clear pixel rejection rate. The Uniformity test is applied after the 'Clear'/'Cloudy' tests and it further classifies the 'Clear' pixels into 'Clear'/'Probably Clear' categories.

5. Global Statistics of SST Anomalies

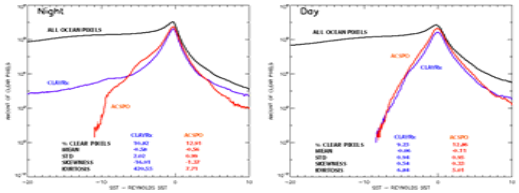

Fig. 7. Histograms of ΔT_S by CLAVRx and ACSPO, accumulated over 421 NOAA-18 day- and nighttime half-orbits in June 2007. In the daytime, the ACSPO CSM provides more clear pixels, with warmer mean ΔT_S and approximately the same higher-order moments of the Gaussian distribution. In the nighttime, ACSPO CSM provides significantly more clear pixels, warmer mean ΔT_S, and significantly better STD, skewness and kurtosis.

6. Conclusions

The general concept of the ACSPO Clear-Sky Mask is as follows:

- Emphasis on clear-sky applications and directly addressing of cloud effects on the retrieved parameters (rather than relying on indirect cloud tests).
- Use of the most reliable and accurate a priori information (Reynolds OISST and NWP fields) in conjunction with clear-sky RTM.
- Presumption of clear-sky conditions: If the empirical test shows 'cloudy' on simulated Clear-Sky BTs, then this test is not applied with measured BTs and the pixel is considered 'Clear'.
- As a result, the ACSPO CSM provides more clear pixels than CLAVRx with similar or improved statistics of SST anomalies and crispier instantaneous SST fields (especially over dynamic areas of the oceans).

7. Future work

- Further development, optimization and peer-review of ACSPO CSM (sensitivity analyses to retrieved and apriori SSTs, day/night continuity, ..)
- Flexible design/Portability of ACSPO CSM with other platforms/sensors:
  - MSG/SEVIRI to get ready for GOES-R/ABI
  - MODIS to get ready for NPOESS/VIIRS
- Extend the ACSPO CSM with clear-sky radiances in the solar reflectance bands and Aerosol retrievals.

8. References

1. Heidinger A., 2004: Clouds from AVHRR extended (CLAVRx) Cloud Mask algorithm theoretical basis document. NOAA/NESDIS/STAR.
2. Han Y., et al, 2005: User's Guide to the JCSDA Community Radiative Transfer Model (Beta Version) NOAA/NASA JCSDA.
3. Liang, X, et al, 2008: Validation of the CRTM against ACSPO radiances for improved cloud detection and physical SST retrievals. 5th GOES Users' Conference, New Orleans, USA, January 23-24 2008.
4. Reynolds, R. , et al, 2002: An Improved in situ and satellite SST analysis for climate, *J. Clim.*, 7, 929-948.

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