FY12 R3: Development of a Bayesian Cloud Mask for All GOES-R Applications

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GOAL

The aim of this project is to improve the quality of cloud detection for multiple GOES-R applications over both land and ocean by providing Bayesian clear sky probability estimates. Compared to the GOES-R baseline cloud mask the Bayesian technique exploits a systematic framework which uses as much prior information as possible and can automatically optimize the cloud detection to deal with the complexities and heterogeneities of over-land cloud detection for each individual pixel. As well as the improved skill that the prior information brings (e.g., Mackie *et al.,* 2010*),* the systematic aspect is important: where there are cloud detection failures, the path to improvement is clear since there is no need to devise *ad hoc* new tests. By having a systematic framework for both land and ocean, cloud masks modifications due to instrument performance changes (for example post-launch) can be rapidly included. A Bayesian cloud mask also delivers a probability of clear-sky (rather than a binary mask, or division into arbitrary levels of confidence in the clear or cloudy designation). This allows each user to choose the threshold of probability that defines valid pixels most appropriate for their application and can account for the sensitivity of their application to the amount of "undetected" cloud remaining for a particular choice of probability threshold. The preliminary results indicate that a Bayesian cloud mask will work better that the current GOES-R baseline cloud mask. Therefore, the approach undertaken from this project offers the possibility of an improved cloud mask which uses a common approach into which maintenance and improvement resources can be focused and also meets the needs of a variety of downstream users.

ACCOMPLISHMENTS:

The detection of cloud over land is significantly more difficult than cloud detection over ocean. Thus, the first year's work has been devoted to the issue of cloud detection over land. To ensure the best cloud mask a number of issues have been addressed. First, accurate land surface models coupled with a Radiative Transfer Model (RTM) are needed since a Bayesian approach depends on the accurate modeling of top of atmosphere radiances. Second, a framework to derive Probability Density Functions (PDFs) is needed to develop new PDFs which can be functions of multiple parameters/channels. The first year's work has progressed in each of these areas.

Choice of a Land Surface Reflectance Model

We have investigated a number of different land surface models and Figure 1 shows a comparison between two different Bidirectional Reflectance Distribution Functions (BRDFs), one from Mackie et al. (2010) and one from a new RTTOV11 module. These have been compared with observed BRDFs derived from SEVIRI observations using the equation

$$BRDF(t) = \frac{R(t)d^2(t)}{I\cos(\theta(t,x))}$$

where *R(t)* are the SEVIRI channel radiances at time t, *d(t)* is the Sun Earth distance at time t, *I* is the band solar irradiance and *θ(t,x)* is the solar zenith angle at time t and position x. Figure 1 shows the time dependent bias for the different BRDF models compared to observations of the 0.6, 0.8 and 1.6 μm channel BRDFs and shows that while the average daytime behavior is reasonable, discrepancies arise around dawn and dusk.

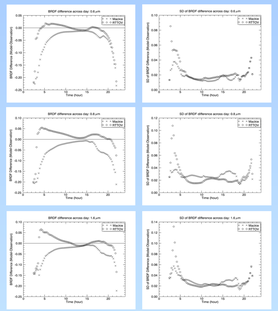

Figure 1. Bias and standard deviation for the 0.6, 0.8 and 1.6μm channels comparing the SEVIRI derived BRDFs with the Mackie and RTTOV models

In terms of spatial differences between the models and observations Figures 2 and 3 show comparisons between the observed, Mackie *et al.* and RTTOV BRDFs for an early morning time (06:12) and a noon (12:12) time. These figures indicate that the Mackie *et al.* BRDF does not represent the observations as well as the RTTOV one, particularly for the early morning time. The RTTOV model has therefore been selected and work is currently underway to incorporate it into the Generalized Bayesian Cloud Screening (currently used for the operational NOAA Geostationary Sea Surface Temperature projects).

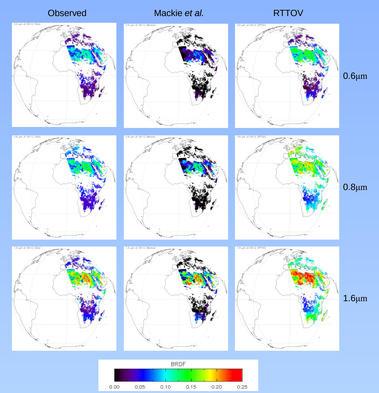

Figure 2. Maps of Observed, Mackie *et al.* and RTTOV derived BRDFs for an early morning time (06:12) on 01/08/09. The Mackie *et al.* BRDF underperforms relative to the RTTOV BRDF.

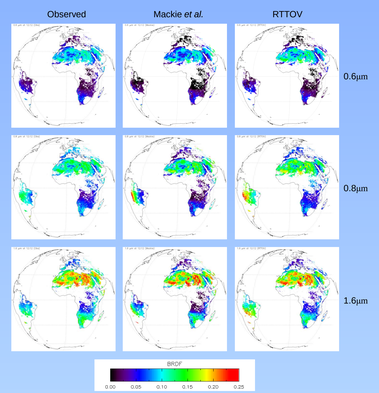

Figure 3. Maps of Observed, Mackie *et al.* and RTTOV derived BRDFs for a noon time (12:12) on 01/08/09.

Infrared cloud detection over land

Work has also progressed in developing and understanding a land based Bayesian cloud mask and the benefits of a Bayesian approach are already becoming apparent. Figure 4 shows a scene over Mongu, Zambia: for the 9th July 2003 showing thin cirrus (seen as a bluish haze in the image). The right hand side panels show two cloud masks, one based on optical data alone (normally thought to be more sensitive to clouds than the thermal infrared channels) together with a cloud mask based on the Bayesian clear-sky probability (in a thermal only configuration). The Bayesian correctly catches more of the thin cirrus when compared to the traditional cloud mask even though only the thermal infrared channels were used. Of course when optical data is combined with the thermal infrared using the new BRDF described above the cloud mask will be even more effective.

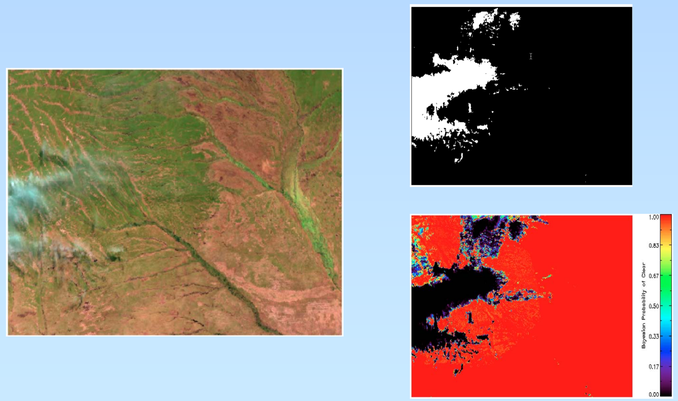

Figure 4. The left hand panel shows an image from Mongu, Zambia on 09/07/03 with some thin cirrus seen as a blue haze. The right hand panels show on the top a cloud mask derived from the optical data and on the bottom a cloud mask derived from thermal infrared imaging along using the Bayesian technique. The Bayesian cloud mask captures more of the thin cirrus and is expected to work even better when the optical data is also included.

ACCOMPLISHMENTS: END OF YEAR 2

In the second year work will continue to develop the algorithm for cloud detection over land. The initial work pioneered in Year 1 including the choice of a land surface BRDF as well as the initial setup of Probability Density Functions will be continued. In this year the PDFs for clear and cloudy pixels over land will be further developed via an iterative scheme with expert intervention to correct for any initial cloud detection errors. The final system will then be assessed using external datasets such as CALIPSO and the EUMETSAT SEVIRI cloud mask to characterize the performance using standard metrics (hit rate, true skill etc.) by region, time of day and for various clear sky probability thresholds. At the end of Year 2, the code will be transferred to NOAA for the final implementation.

ACCOMPLISHMENTS: 3RD YEAR FUNDING

In the third year we will extend the work done over land to the ocean. We note that while the ocean cloud mask is as important as the land cloud mask the problem is better understood with a much simpler surface (water) and a long operational heritage since a Bayesian cloud mask is currently used to generate NOAAs Geostationary Sea Surface Temperature products. The development of the ocean cloud mask is therefore simpler than over land and will take less time. As with the land cloud mask, we expect a significant improvement over the baseline GOES-R cloud mask. Figure 4 shows a preliminary cloud mask which uses the current GOES methodology and shows a clear improvement over the current GOES-R baseline cloud mask With the improvements developed for the land cloud mask (more complex PDFs, larger range of channels available from GOES-R for example) we expect a significant improvement over that shown in Figure 4.

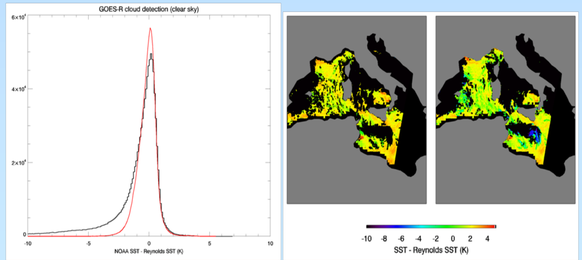

Figure 4 Left panel shows histograms of SEVIRI-retrieved SST minus Reynolds Daily-OI SST. The black line shows the distribution obtained using the current GOES-R cloud mask and shows a cold tail while the red line is the result of applying our Bayesian scheme threshold at 50% probability of clear-sky which returns a much more Gaussian distribution. The right hand side shows a comparison of part of the SEVIRI minus Daily-OI SST. The Bayesian mask has been applied to the left-hand image and shows little or no cloud contamination while the current GOES-R cloud mask had been applied on the right shows clear cloud contamination.

References

Mackie, A., Merchant, C.J., Embury, O. & P. Francis, "Generalized Bayesian cloud detection for satellite imagery Part 2: Technique and validation for daytime imagery", *International Journal of Remote Sensing*, **31**, 2595-2621, 2010

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