P5.23 IMPROVED DETECTION OF NOCTURNAL LOW CLOUDS BY MODIS

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1. INTRODUCTION

Low stratus and stratocumulus clouds pose a major weather hazard to aviation, navigation and ground transportation. Before the advent of multispectral imagers, weather satellites could only observe low clouds during the daytime when visible images were available. At nighttime, infrared images were often useless because low clouds blended into the thermal background at a similar temperature. With the coming of the five-channel AVHRR in the mid 1980's, and especially with the introduction of the GOES five-channel imager in the mid-1990's, the problem of low clouds at night was ostensibly solved by using what is commonly referred to as the "fog product" or the so-called "low cloud" product. The GOES low cloud products (Ellrod 1995; Lee et al. 1997) have since been used widely in forecasting applications. A similar capability is anticipated from the European Meteosat Second Generation (MSG), see Schmetz et al. (2002), and the Japanese Multi-functional Transport Satellite (MTSAT). The AVHRR products have been used primarily in research applications (Eyre 1984; d'Entremont 1986; d'Entremont and Thomason 1987; Olessen and Grassl 1985; Saunders and Kriebel 1988; Yamanouchi and Kawaguchi 1992).

The algorithms used to produce these products, up until this investigation, have been bi-spectral in nature, using the shortwave (3.7 µm for AVHRR and 3.9 µm for GOES) channel and the longwave infrared (10.8 to 11 µm) channel together to arrive at a product. The most common implementation is to perform a pixel-by-pixel brightness temperature difference (BTD; 11.0 - 3.7 µm) of the two channels, which forms the basis of a new image. The BTD image contains information about surface emissivity, cloud properties, aerosol properties, and dust loading. Low clouds and fog show up distinctly (high BTD) on the new image because of interchannel emissivity differences (i.e., clouds exhibit more properties of a blackbody at 11.0µm than at 3.7 µm.) Most land/sea features, with important exceptions described below, are associated with low background values (low BTD) on this image.

For stratus clouds and fog, the BTD at night depends on droplet size and ranges from about +0.5 to +6 K. The BTD can usually be used to distinguish stratiform cloud from the surface background. Clouds of relatively large droplet size yield BTDs in the neighborhood of +1 or +2 K. Unfortunately, for the purpose of cloud identification, large-droplet marine stratus can have BTDs nearly identical to the cloud-free ocean background. Under this circumstance the BTDs of the stratus and the sea surface will be similar, making it difficult to distinguish cloud from background on images. Near coastlines (under the influence of continental CCN) and over the continents, drop sizes tend to be smaller, associated with BTD values of around +2 to +5 K. The contrast created with the land surface is usually sufficient for cloud detection on BTD images. However, for low-cloud BTDs less than about +3 K, the cloud may not be detectable over low-emissivity deserts which have similar BTD values. Surface emissivity effects in the shortwave infrared range are discussed in Salisbury and D'Aria (1994).

In fact, it is these surface emissivity effects that complicate the use of the low cloud product over many parts of the world. Within the United States, the ambiguity is a relatively minor problem because low-emissivity deserts are limited to regions in the desert Southwest, where low clouds are relatively rare. In addition, loops of low-cloud images available from the GOES satellite reveal low clouds through their motion from one image to the next, alleviating the problem posed by deserts. The main difficulty arises in regions outside of the United States, especially in northern Africa and southwest Asia, where the requisite channels may not be available from the geostationary platform. Here

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there are large expanses of desert that can easily be mistaken for low clouds and fog on low cloud images produced by polar orbiting satellites. Over some of these desert regions low clouds are so rare that correct interpretation is not difficult. However, north of about 30° N stratus and fog are rather frequent, especially during the winter. In these regions correct interpretation is nearly impossible because the sandy deserts resemble low cloud, and vice versa.

Since images from low-earth-orbiting satellites are increasingly sought in this part of the world by Navy forecasters, and Internet communication is improving rapidly, the Naval Research Laboratory has begun providing these users with a suite of experimental MODIS value-added products, including low cloud products. Since November 2001 we have been providing NOAA-16 versions of this product, and since July 2002 we have been providing MODIS (Terra) equivalent versions using the same algorithms. Over water, the results have been excellent, but over land the ambiguity between low cloud and sandy deserts has created numerous interpretation difficulties.

2. RESULTS

In order to address the desert/cloud ambiguity, our approach here has been to investigate other channels available from MODIS that have not been used previously in the construction of low cloud products. The domain of interest is the Arabian Sea, Gulf of Oman, and Persian Gulf. Four BTDs were constructed for examination. BTD I (Table I) represents the traditional method used to produce low cloud products. BTDs II – IV below are additional BTD's based partly on wavelengths around 4 μm. It is pointed out that BTD I is available from both MODIS and AVHRR, while BTDs II – IV are available from MODIS only.

TABLE I Brightness Temperature Differences. Channel indices refer to the MODIS.

Case	Channels	Wavelengths
BTD I	31 – 20	11 – 3.7 μm
BTD II	23 – 20	4.1 – 3.7 μm
BTD III	22 – 20	4.0 – 3.7 μm
BTD IV	23 – 22	4.1 – 4.0 μm

Unpublished investigations elsewhere using the GOES sounder have suggested that wavelengths around 4 μm have the capacity to distinguish between sandy deserts and low clouds. Thus, BTDs II – IV, newly available by virtue of MODIS aboard EOS Terra and Aqua platforms, were explored as the basis for improving upon the existing low cloud product.

a. AVHRR

To illustrate the problem of cloud/desert ambiguities, we present a case using NOAA AVHRR imagery. Fig. 1 (top) shows a NOAA-16 nighttime infrared image over the Gulf of Oman. There are large areas of low clouds within the scene, but they are difficult to pick out due to lack of thermal contrast with surface backgrounds. Over land in the northern portions of the scene, there are some whiter (colder) gray-shades, but these are mostly due to cold, cloud-free mountains.

Fig. 1 (bottom) shows a corresponding red/blue/green combination image based on the BTD I (Table I) image in the red gun and the longwave infrared image in both the blue and green guns. Over the water, the enhancement reveals major areas of low clouds in light red. However, there are land regions of low 3.7 μm emissivity that also appear in light red. Forecasters, particularly those new to a region, can easily be misled into believing that the latter areas are low clouds.

b. MODIS

The MODIS algorithm takes advantage of the multiple channels near 4 μm to lessen the component of "false positives" produced by low emissivity desert surfaces. Because of detector noise in these channels, the traditional 11.0 – 3.7μm difference is applied over the ocean (where no such ambiguities arise) and the new method is applied only to land surfaces where the benefits outweigh the cost of quality. Owing to spectral emissivity differences that exist between desert surfaces and clouds across the 3.7– 4.1μm range, BTD IV (Table 1) produces a relatively stronger signal for clouds, whereas BTD III produces a relatively stronger signal for land. This information represents a spectral orthogonality that can be combined into a single enhancement via a simple red/green/blue color composite as illustrated below.

MODIS nighttime products appear in Fig. 2 over the same region as Fig. 1. Fig. 2 (top) presents the 11.0µm image for this case study. Similar to the AVHRR example, it is very difficult to distinguish the low clouds from the clear-sky background. Fig. 2 (bottom) demonstrates a variation of the traditional 11.0 – 3.7µm product applied over both ocean *and* land (the scaled channel difference is loaded into the red and green color guns, and then combined with scaled 11.0µm data in the blue color gun to form the red/green/blue composite). Here, the intended effect is to enhance low clouds as various shades of yellow (the lightest shades corresponding to the higher (warmest) contributions from 11.0µm, and presumably the lowest clouds in a local region). Pointed out on this figure, however, are ambiguities that occur between desert surfaces and low clouds, similar to those observed in the AVHRR product (Fig. 1).

Fig. 3 incorporates BTD's III and IV (scaled BTD IV in both red and green guns, and scaled BTD III in blue gun) to remove a large portion of these problems. Though not eliminated altogether (a disproportionately lower amount of desert surfaces, owing to different soil composition, have been found to demonstrate BTD IV sensitivities as well, reducing the spectral orthogonality between clouds and land surface), we observe a substantial component of the ambiguity to be reduced. A minor problem with the land/sea database (used to determine which MODIS algorithm to apply) has resulted in the "sea algorithm" being applied to a small number of dry beds. This has resulted in false low clouds in these regions. Ongoing work will include an update to this land/sea database to eliminate this difficulty.

3. CONCLUSIONS

The results of this study demonstrate how the nighttime low cloud product can suffer significant ambiguities between cloud and desert if only the 3.7 (or 3.9) µm and 11 µm channels are used in its formulation. Such problems are exacerbated over areas like the Middle East and Africa where deserts are common, and surface backgrounds are so variable. AVHRR examples showed that nighttime fog and low clouds could be detected over these regions, but that ambiguities are a problem. Using two additional MODIS channels, 3.96µm and 4.05 µm, many of the ambiguous desert areas can be filtered out, such the users could view low clouds without confusion. Even on the MODIS product, however, some ambiguities remain. At the conference we hope to offer a more refined product that will ready for operational use.

4. ACKNOWLEGEMENTS

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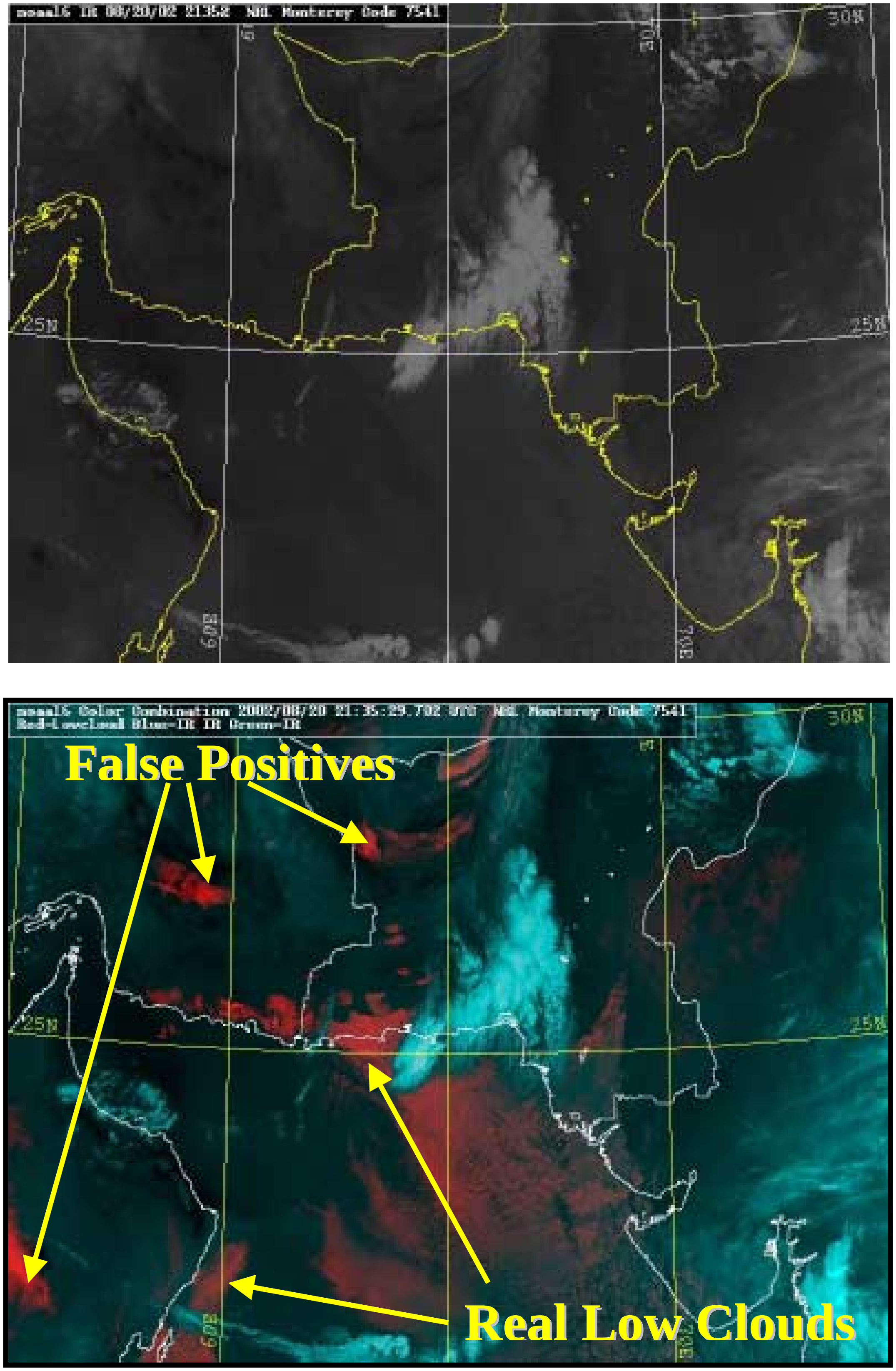

Fig. 1 Top) NOAA-16 Infrared image of the Gulf of Oman region. Due to lack of thermal contrast, it is difficult to distinguish low clouds from the background of a similar temperature; Bottom) Corresponding Multispectral composite: low clouds bright red; high clouds bright blue; false positives also red.

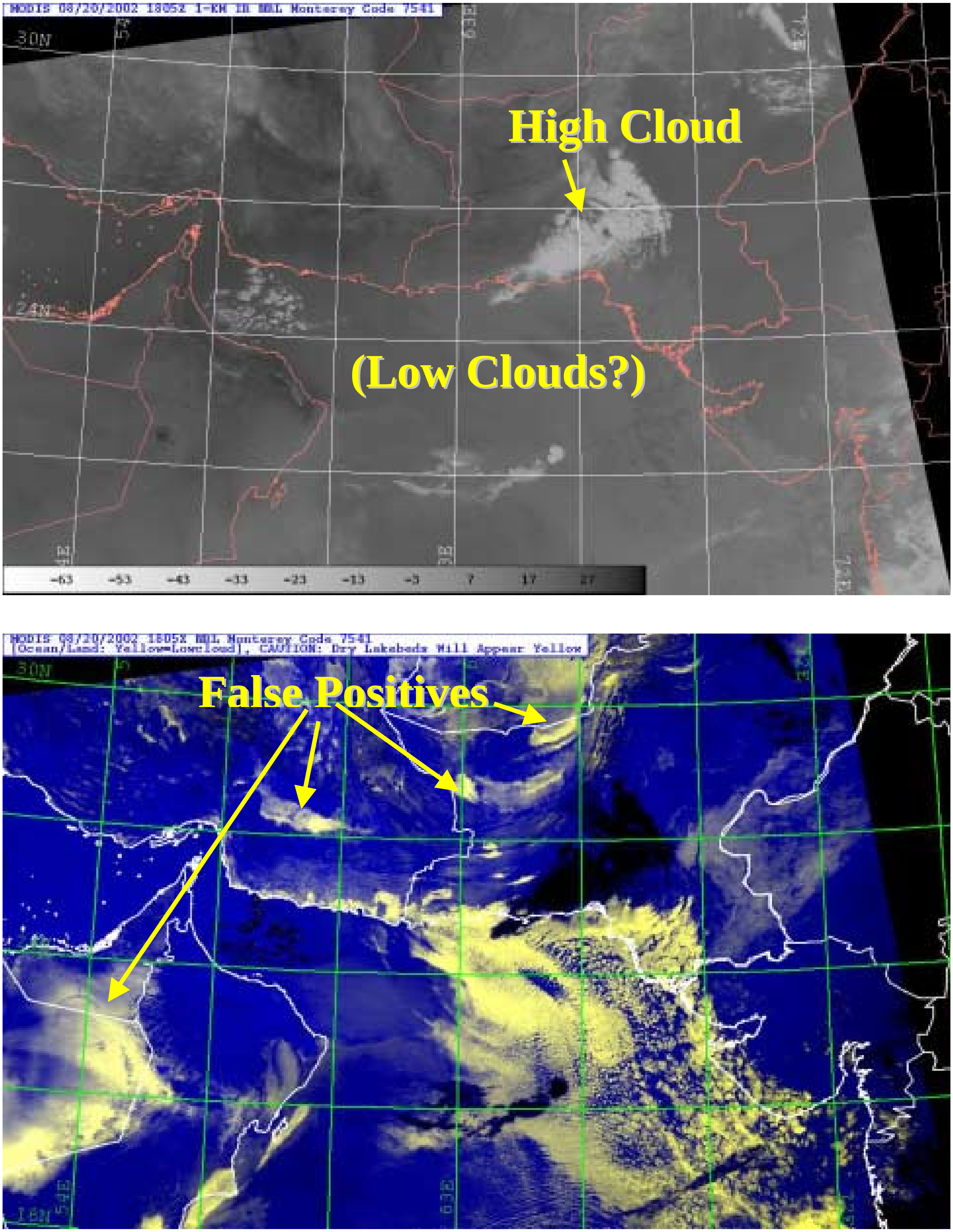

Fig. 2 Top) MODIS Infrared Image; Bottom) Corresponding Multispectral Composite where low clouds are yellow; the land/sea background is blue, and false positives are also yellow.

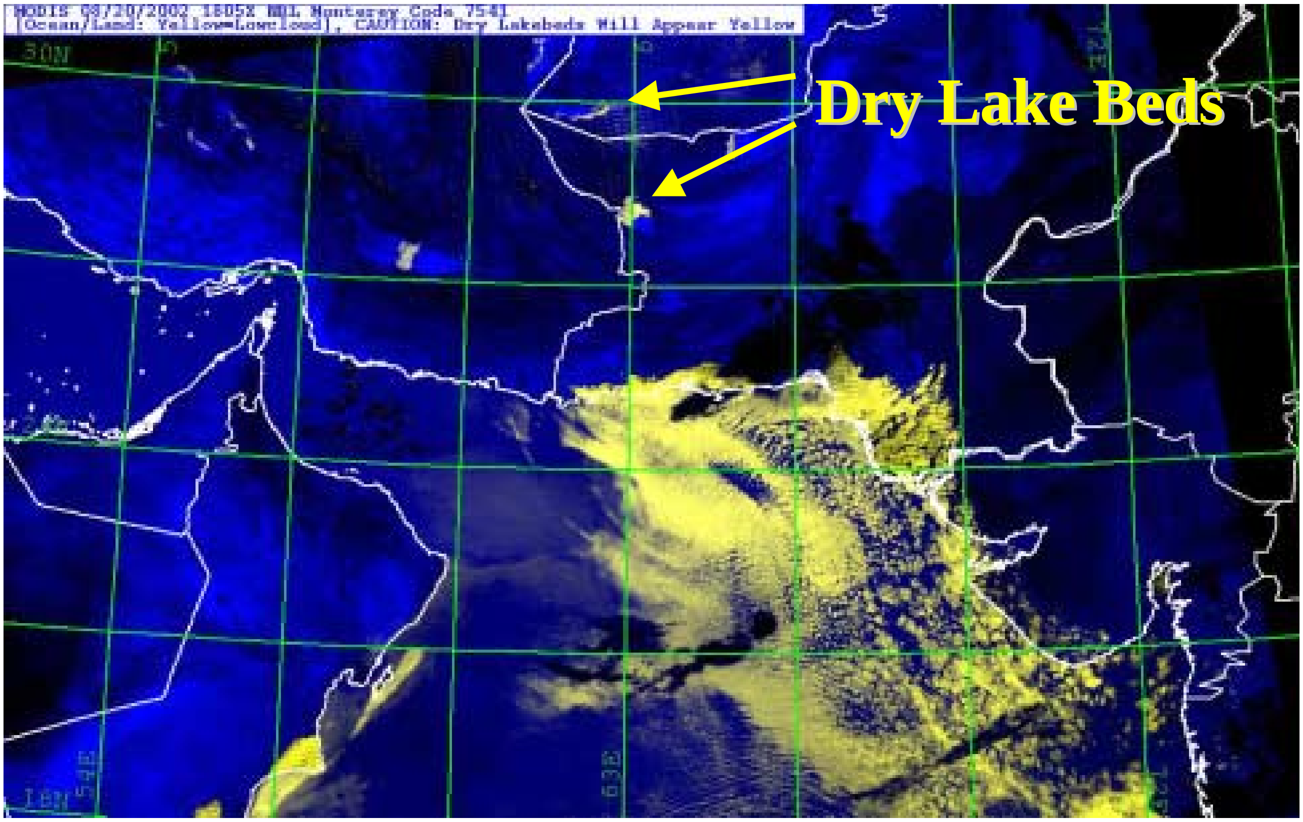

Fig. 3 Multispectral Composite where low clouds are yellow, and the land/sea background is blue. Most of the false positives from Fig. 2 (bottom) are removed. See text for explanation of dry lake beds.