THE FEASIBILITY OF EXTRACTING LOWLEVEL WIND BY TRACING LOW LEVEL MOISTURE OBSERVED IN IR IMAGERY OVER CLOUD FREE OCEAN AREA IN THE TROPICS

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ABSTRACT

The feasibility of extracting low-level wind over the cloud free ocean is studied using the low level moisture observed in the infrared data on board a geostationary satellite. One can see a spatial pattern of brightness temperature (TBB) over the cloud-free ocean. When the atmosphere contains enough moisture, this TBB pattern represents rather the spatial distribution of water vapor than that of sea surface temperature. By tracing the TBB pattern in the sequence of IR images taken a short period apart by geostationary satellite, we can compute the TBB drift vector. In this study, we regard this vector as low-level wind, since water vapor generally drifts with wind and is concentrated in the lower atmosphere. Here, we assumed that the air mass deformation process is negligible and the advection of water vapor is dominant. Comparisons between the TBB drift vectors and low level cloud motion vectors show reasonable qualitative agreement. Further we discuss the use of the brightness temperature difference of split window (BTD) images for low level wind derivation, since the BTD is a good indicator for the total precipitable water in the atmosphere.

1. INTRODUCTION

Wind information from geostationary satellites has been an important input for numerical weather prediction. A sequence of visible or infrared geostationary satellite images has been used for the routine determination of cloud motion vectors at low and high levels of the atmosphere, respectively. These wind data are essential for current numerical weather prediction, although the cloud height assignment error limits the utility of these data. These cloud tracking techniques are not available in areas where there are no clouds to track.

Currently, techniques also employ a sequence of 6.7 pm or 7.2 pm water vapor radiance images for mid-level wind estimation, by tracking moisture emission patterns in cloud-free regions. This technique is effective for the derivation of mid-level wind, especially in the areas where no clouds exist (e.g., Eigenwilling and Fischer, 1982; Stewart et al., 1985). Height assignment remains a problem due to the broadness of the weighting function for the vapor channel.

Aoid (1979) studied the information content of satellite observations in the 10 |im wavelength region. He showed that the 10 |xm channel is a sensitive water vapor channel when observing the tropics. Aoki and Inoue (1982) illustrated the water vapor distribution over the western Pacific using the GeostationaryMeteorological Satellite (GMS) infrared channel data.

Inoue (1990) used the BTD of the Advanced Very High Resolution Radiometer (AVHRR) aboard NOAA-9 as an index of the water vapor content of the atmosphere. He showed good correlation between the derived water vapor and convective activity; the correlation was even higher than that with sea surface temperature over the western Pacific. This implies a strong link between the low level wind convergence and water vapor amount, since convective activity is known to be highly correlated with surface convergence.

In this paper, we study the feasibility of low-level wind derivation over cloud free regions by tracking the moisture pattern apparent in sequential images of the enhanced IR data. This paper is based on Inoue and Smith (1994) and is stressed here on the use of IR data. The idea of low level wind vector determination is basically the same as for water vapor motion using the 6.7 pm water vapor channels. At the presentation video animation of enhanced IR imagery is demonstrated. The video tape is produced from the CD ROM of GMS-4 Infrared Images over the TOGA-COARE Region by Tetsuo Nakazawa at MRI. One can see the rapid movement of the TBB spatial patterns over the cloud free ocean area in the animation.

2. RESULTS AND DISCUSSIONS

2.1 Enhanced IR Imagery

As shown in the enhanced IR imagery of GMS (Fig.l), the higher TBB region (>296K; three features are arrowed) moves with time very rapidly. We understand this movement is faster than the movement of ocean current. Figure 2 shows the information content in the infrared data of GMS (Aoki and Inoue, 1982). Information of water vapor (pl) indicates a larger value at the lower latitude than that of atmospheric temperature (p2) and sea surface temperature (p3). This means TBB over the cloud-free ocean area in the tropics contains a lot of information on water vapor. Therefore, we consider this TBB movement is caused by water vapor movement with low level wind since water vapor is generally concentrated at the lower atmosphere. If we compute this TBB movement, we can derive the low level wind. The feasibility of this idea is studied in the following sections.

2.2 Determination of Wind Vectors

In this study, we trace the horizontal pattern of the water vapor to estimate low level winds. In particular, cloud free ocean areas where surface temperature varies little with time and space, are treated. Small-scale details of TBB structures over cloud free areas are often conserved in consecutive sequence of one hour interval images and thus can be used for the determination of wind vectors. The McIDAS and the cloud tracking program developed at University of Wisconsin are used in this study (Soumi et al., 1983).

Because of the small size of the tracers and the general complexity of TBB structures over cloud-free areas, a single pixel method of tracking the TBB features was used. Navigation errors in current McIDAS is less than 12 visible pixels depending on time of a day (J.T. Young, personal communication). The relative navigation error between the two images is small since the time difference for the images is about one hour.

To detect the small-scale detail of the TBB pattern such as corners or peaks, the operator must be trained to look carefully at the two consecutive TBB images alternately in rapid repetition. The life time of the tracer depends on their dissipation by atmospheric turbulence and is a function of the size of the tracer and the eddy diffusivity of the atmosphere. For most cases the images in one hour or one-half hour interval are used, since the fuzzy character of TBB images makes it more difficult to

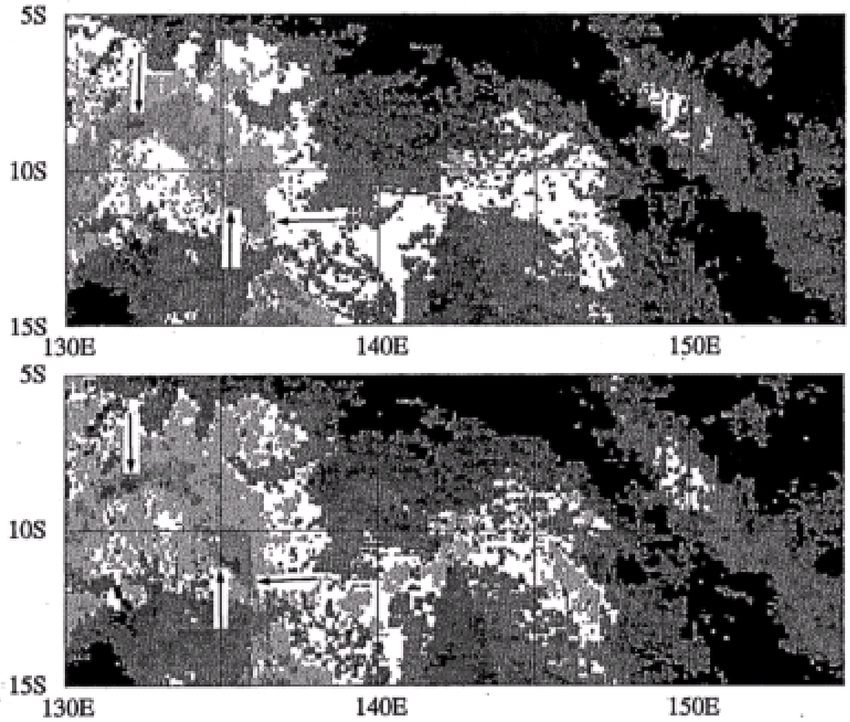


Figure 1. Enhanced GMS IR images taken at 19Z(top) and 20Z(bottom) Nov.15,1992.

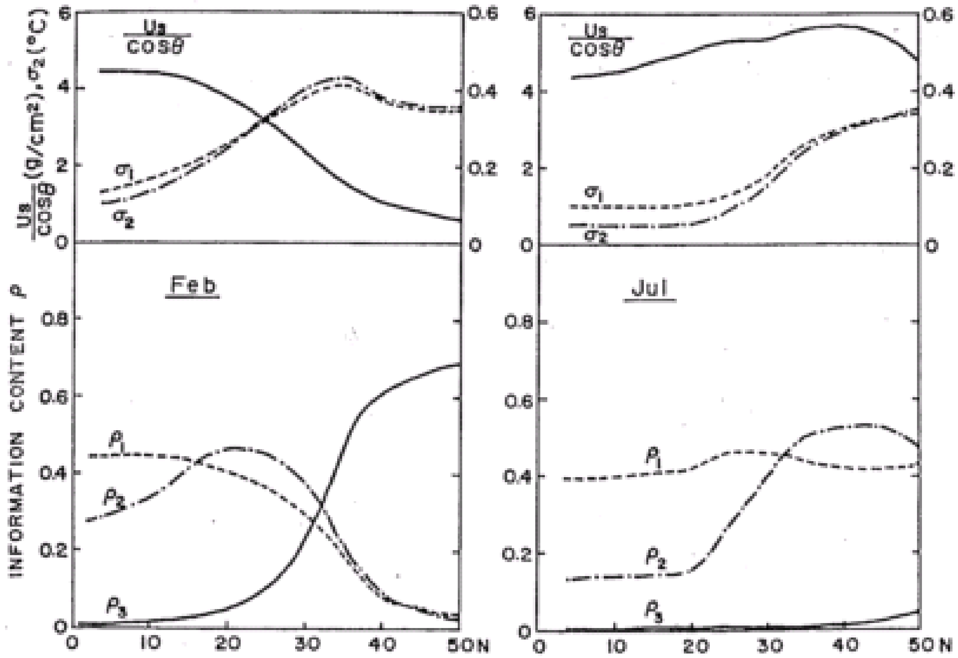


Figure 2. Information content of GMS IR channel. (after Aoki and Inoue,1982)

identify features after one hour. The assignment of height to the TBB wind vectors is not deterministic in this technique because the temperature of the water vapor overlaying a sea surface cannot be estimated from the IR data alone. To assign a specific height to the TBB wind, the level of the IR weighting function peak for the real atmosphere should be used, which requires a priori knowledge of the temperature and water vapor profile. For this study, the TBB winds were assigned a value between 700 hPa to the surface, since the radiation originated from lower than 700 hPa in the split window, as shown in the weighting function curve in Figure 3.

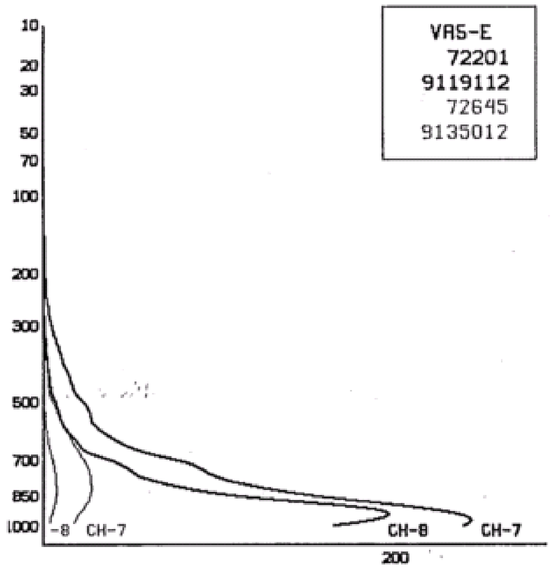


Figure 3. Weighting function of VAS channel-7 (12.5-12.8μm) and channel-8 (10.4-12.1μm) for moist (bold curve) and dry (thin curve) atmospheric conditions.

Inferring winds from the displacement of the TBB structures will be successful only when advective processes dominate in the lower troposphere within the one hour time interval. Therefore, good quality control is required in the application of this technique. Generally the condition of advection is satisfied, but sometimes complex changes of TBB structure appear in the sequence of IR image evidently due to local influences. Vertical motion and mixing processes may cause a spatial pattern modification in the TBB image. We believe that vertical motion is usually relatively small over cloud free area (e.g., Mosher, 1977). Henry and Thompson (1976) reported that modification which resulted in initial cloud formation required 2 - 3 hours in the most significant case when cold air surges over the warm ocean. These processes cannot explain all the dynamic changes visible in the enhanced IR images. Further investigations are required to more positively separate advective changes from those due to other dynamical processes.

2.3 Case Study 1

This case study is over the cloud free area south of Central America where the total cloud amount is very small on a climatological basis. Figure 4-a shows enhanced visible images taken by GOES-7 at 1501 UTC on 26 November 1991. Figs 4-b, c show a part of Fig. 4-a for infrared (channel 8) images at 1401 UTC and 1501 UTC on the day. Figure 4b, c indicate some spatial features (arrowed in the figure) of the brightness temperature which can be tracked to estimate the wind. This enhanced TBB pattern changes its shape varying rapidly with time as shown in Figs.4-b, c. This movement cannot correspond to an SST change. As Aoki (1979) showed, the 10pm wavelength acts as a water vapor channel in the case where the water vapor amount is high. In this case the rapid change of TBB pattern is likely induced by the low level moisture field deformation by the wind.

Figure 5a shows the vectors derived by tracking features in the infrared images (white) using the McIDAS. Wind vectors derived using BTD images (white) and cloud motion vectors from visible images (black) are also shown in Fig. 5b. The wind vectors determined from cloud and water vapor tracers using TBB and BTD images (see 2.5) show reasonable agreement with each other. Figure 6 shows the NMC stream line analysis at 1000 hPa. The analysis is consistent with the results of our wind estimation.

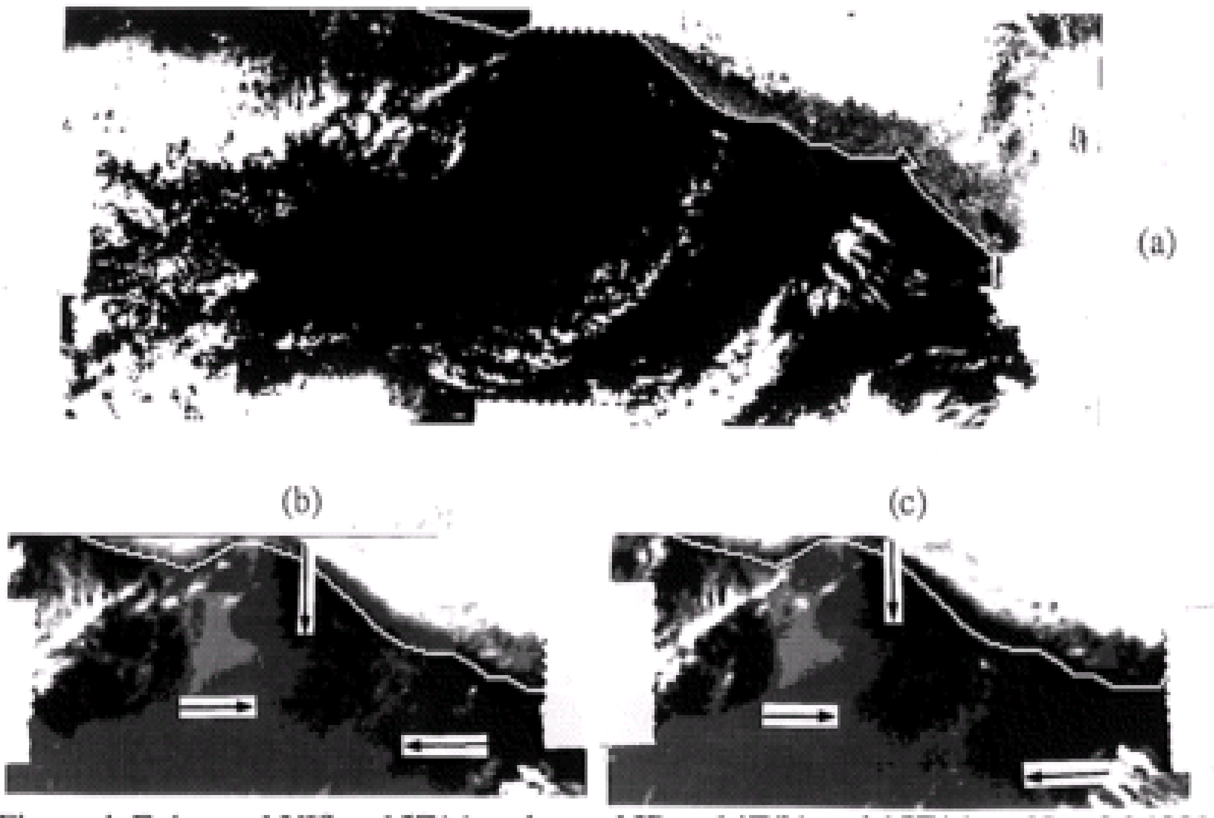


Figure 4. Enhanced VIS at 15Z(a), enhanced IR at 14Z(b) and 15Z(c) on Nov.26,1992.

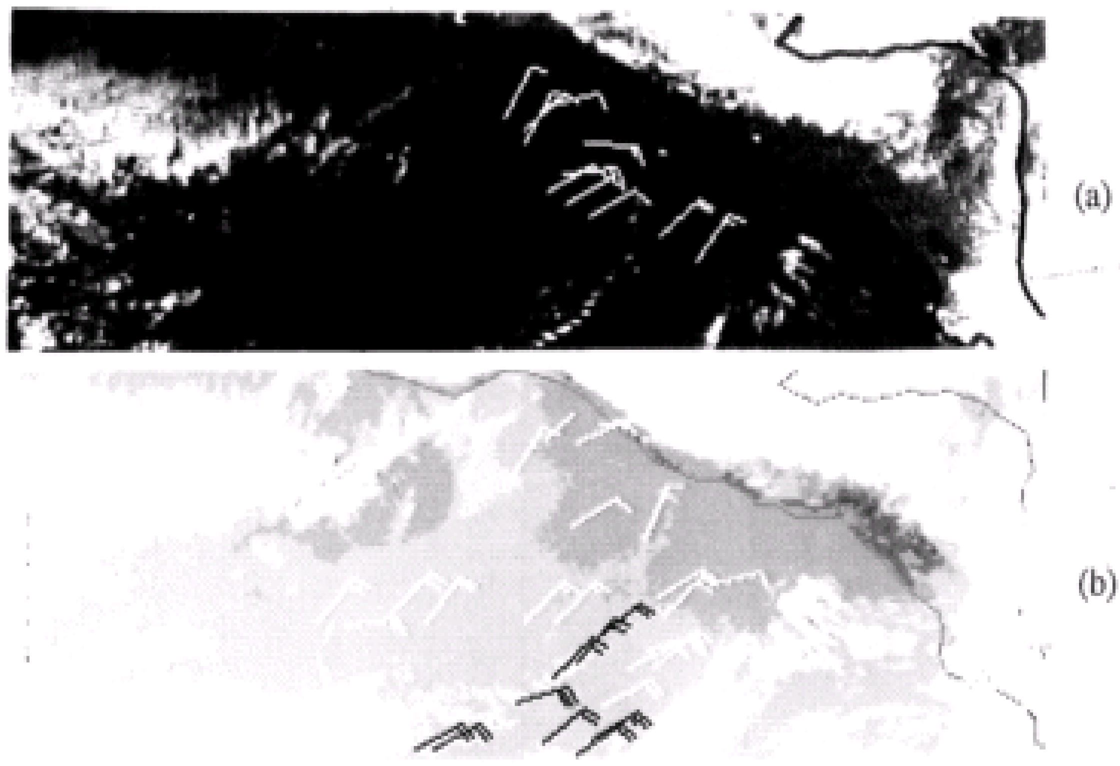


Figure 5. Wind vectors from IR in (a), BTD (white) and Cloud (black) on Nov.26,1992.

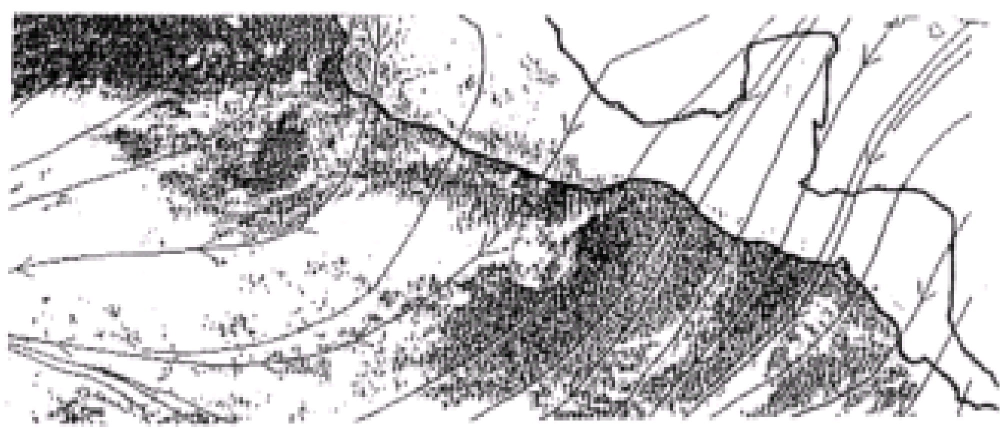


Figure 6. NMC stream line analysis at the level of 1000hPa at 12Z on Nov.26,1992.

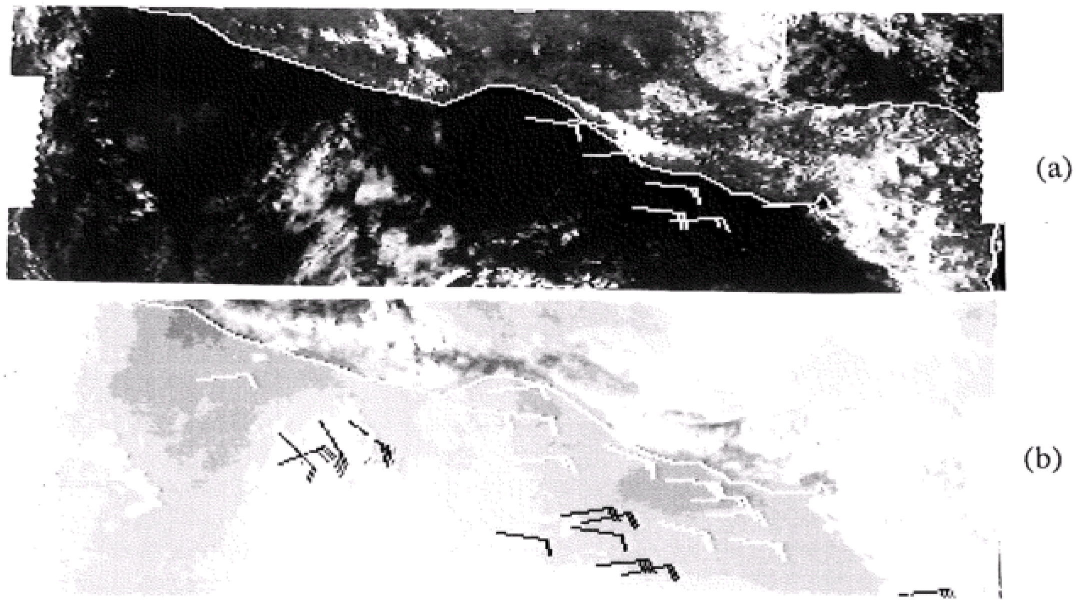


Figure 7 a, b. Enhanced visible (a) and infrared (b) image at 2101 UTC on 15 November 1991,with vectors from IR in (a), BTD (white) and Cloud (black) in (b).

2.4 Case Study 2

Figures 7a and 7b show enhanced visible and infrared images at 2101 UTC on 15 November 1991. In Fig. 7b, we can also identify some features of the TBB pattern over cloud free area. This TBB pattern also changes its shape rapidly with time as was seen in case study 1. The derived wind vectors are shown in Fig. 7a, and BTD wind vectors (white) and cloud motion vector from visible image (black) are also shown in the Fig. 7b. These wind vectors are consistent with each other.

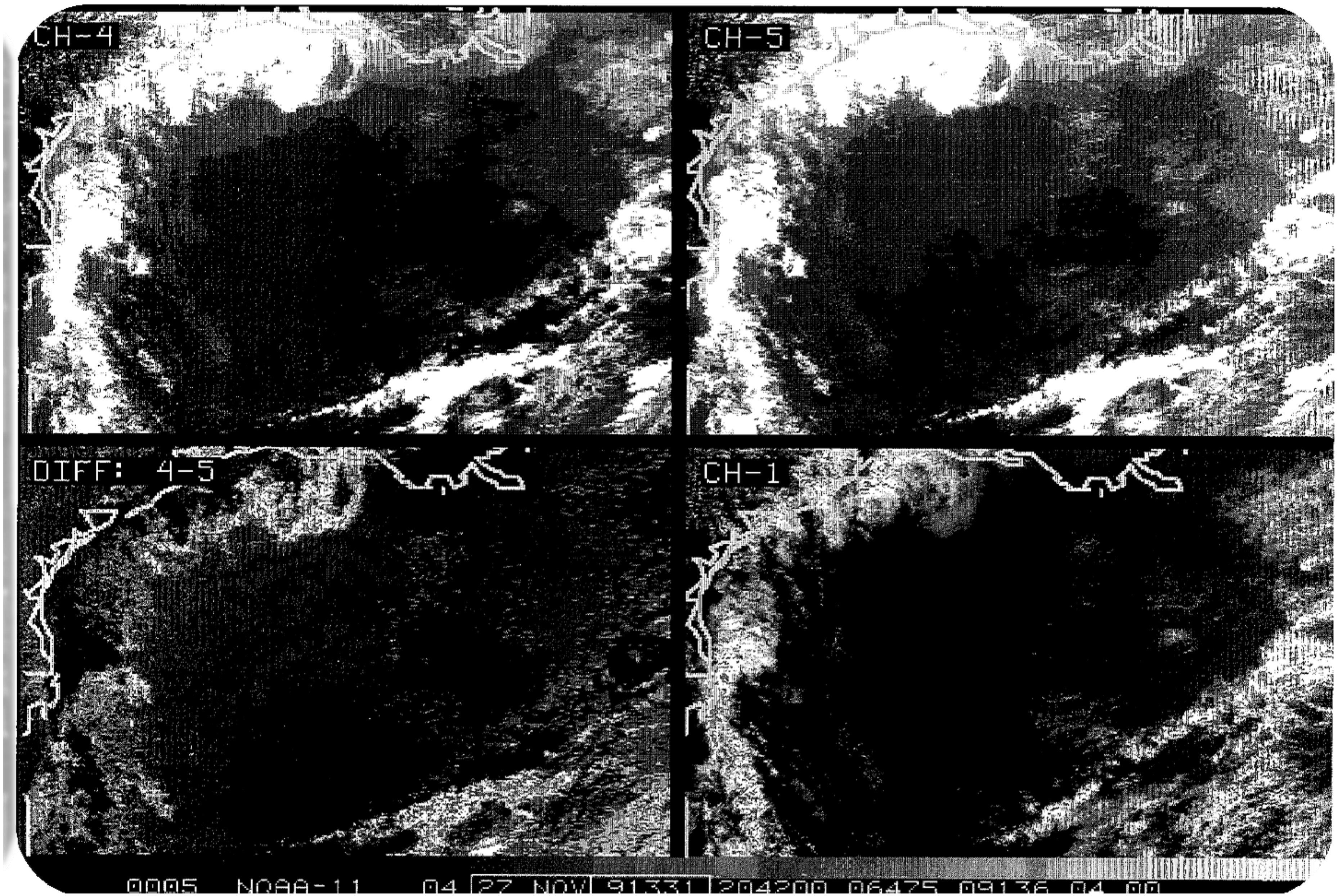
The above two studies and Fig. 1 are cases of relatively large cloud-free areas over the ocean. In general, there are a number of small scale clouds over the ocean and a sufficient number of cloud drift wind vectors can be estimated if we do not care about retrieval time as is done in a research. However, we can demonstrate the importance of our technique over regions where no appropriate cloud tracers exist or where the number of cloud wind vectors are relatively small. The low-level water vapor sensing technique proved to be useful. We want to point out that more attention should be paid to the higher TBB region where no appropriate cloud seems to exist.

Height assignment is very important in satellite wind estimation. At this stage we note that our estimated wind fields are similar to the lower level wind field. It is possible to assign the height of the wind vectors from the weighting function computed from the daily numerical forecast data. Further study is required in the height assignment of our technique.

2.5 BTD Images by NOAA Polar Orbitor

Figure 8 shows enhanced images of AVHRR on board NOAA polar orbiting satellite over the Gulf of Mexico on 27 November, 1991. One can see wide cloud free area over the region in the channel 1 (CH-1) image. The images of channel 4 and 5 (CH-4 and CH-5) show different TBB patterns over the cloud free area due to the differential absorption characteristics by water vapor. The BTD image (DIFF: 4-5) shows wave-like patterns over the cloud free area.

Inoue (1990) demonstrated that the BTD is quasi-linearly correlated with the total precipitable water. Therefore, we understand this wave like pattern represents spatial distribution of the water vapor which is generally concentrated in the lower atmosphere. In the BTD images we can see finer spatial distribution of water vapor over the cloud free ocean. Inoue and Smith (1994) studied the feasibility of the retrieval of low level wind by tracing the pattern which appeared in the BTD images taken by VAS on board GOES-7. The noisy characteristics of channel 7 of VAS caused the fuzziness in BTD images. GMS-5 and the future GOES-I/M series of geostationary satellites will have the split.


CH-4
CH-5
DIFF: 4-5
CH-1
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