NOTES AND CORRESPONDENCE

Jet Contrail Identification Using the AVHRR Infrared Split Window

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11 June 1988 and 27 December 1988

ABSTRACT

Advanced Very High Resolution Radiometer channels 4 (11 μm) and 5 (12 μm) are used together to produce images which greatly enhance contrails. Four steps are required: 1) select coregistered digital data sets from the two channels; 2) convert each raw grayshade to a calibrated brightness temperature; 3) subtract corresponding channel 5 temperatures from channel 4 temperatures, creating a field of temperature differences; and 4) display these differences as an image. On the image, the earth's surface and all but thin ice clouds are associated with small temperature differences (of about -1 to $+2$ K in the midlatitudes) and appear dark. Newly formed contrails and other thin ice clouds, which are associated with larger temperature differences (of about $+2$ to $+6$ K in the midlatitudes), appear bright and stand out well against a dark background.

1. Introduction

High resolution infrared (IR) satellite images often provide striking examples of contrails; corresponding visible images are usually less revealing (Scorer 1986; Carleton and Lamb 1986; Fett et al. 1977). Nevertheless, even on IR images thin or narrow contrails often lack strong signatures, hindering detection by an analyst. Also, natural cirrus clouds often mask contrails, making their detection more difficult.

The NOAA Advanced Very High Resolution Radiometer (AVHRR) has a spatial resolution at satellite subpoint of approximately 1 km and contains five spectral channels. IR channels 4 (11 μm) and 5 (12 μm), comprising a "split window," can be used together to produce images that reveal contrails more distinctly than images produced from either channel separately. First, the raw counts from two channels are calibrated, yielding a pair of brightness temperature values at each pixel location. The calibration is followed by a pixel-subtraction of 12-μm brightness temperatures from 11-μm brightness temperatures. The resulting field of brightness temperature differences (BTD) is then displayed as an image. Contrails, associated with large BTD values ($+2$ to $+6$ K in the midlatitudes), are easily seen on this image.

The technique exploits the different emissivities of semitransparent ice clouds at the two wavelengths. Brightness temperatures at 11 μm exceed those at 12 μm because proportionally more 11-μm radiation is transmitted through the cirrus from below. Inoue (1985) examined AVHRR digital images of cirrus which cover cumulonimbus. Cirrus covering active convection near the middle of cells had nearly identical brightness temperatures in the two channels (less than 0.5 K difference). Semitransparent cirrus near the periphery of the cloud systems, however, showed significantly higher brightness temperatures in channel 4 than in channel 5 (greater than 0.5 K difference).

Using AVHRR observations of cloudy and cloud-free areas, Inoue (1987) experimentally determined a simple relationship between the emissivities of channels 4 and 5 (Fig. 1). A channel 4 emissivity of 1.0 on Fig. 1 corresponds to thick cirrostratus or cirrus topping cumulonimbus. Emissivities between zero and 1.0, associated with brightness temperature differences in the two channels, represent semitransparent cirrus. An emissivity of zero corresponds to a cloud-free atmosphere. Figure 1 suggests that differences greater than about 1°–2°K can identify thin cirrus. Smaller differences correspond either to other cloud types or a cloud-free atmosphere.

The previous discussion implies that positive BTD values result only from the radiative properties of cirrus clouds. Over tropical oceans and land areas which are free of low clouds, this assumption is only partially valid. Over tropical oceans the differential water vapor attenuation in the two bands adds about 2 K to BTD values in addition to any contribution by cirrus (Inoue 1987). Over clear land, BTD values vary widely, apparently as a function of surface type and time of day. The author has observed daytime BTD values as high as +5°K over a daytime land surface. Negative values predominate at night (e.g., Saunders and Kriebel 1988).

2. Case example

Washington State became overcast on 1 May 1985 as an upper trough approached from the west. All

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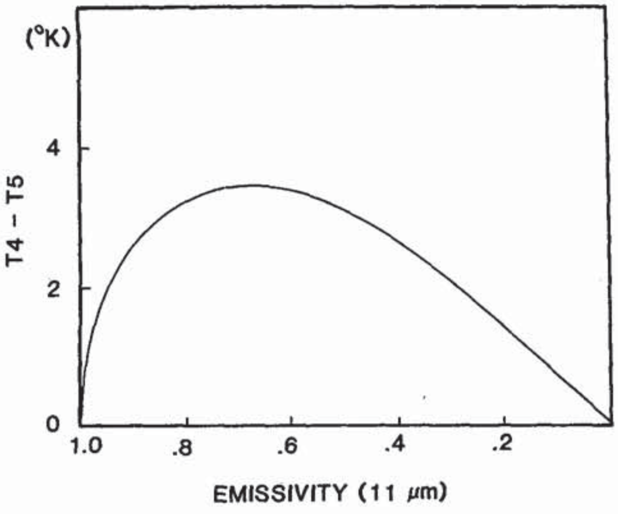

FIG. 1. Brightness temperature difference (T4-T5) of AVHRR channel 4 (11 μm) and channel 5 (12 μm) as a function of emissivity in channel 4. The curve plots the relationship: $E5 = 1 - (1 - E4)^{1.08}$, where $E4$ and $E5$ are the emissivities of channels 4 and 5. The curve applies to regions outside of the tropics for clouds near 210 K and a surface near 285 K. After Inoue (1987).

coastal stations reported scattered to broken low and middle clouds with cirrostratus above. Near the time of the NOAA-9 overpass (2223 UTC), a contrail formed in the moist air above the natural cloud. A visible image (not shown) revealed little trace of the contrail. On the 11 micron image the contrail is only barely detectable as a line from A to B (Fig. 2a). On the 12-μm image the contrail is slightly more discernible (Fig. 2b), but natural cirrus still masks its northern and southern ends. The BTD image (Fig. 2c) reveals the contrail unambiguously. Consisting of thin cirrus, the contrail is 2–5 K warmer in channel 4 than in channel 5 and appears in bright grayshades. The thicker, natural cirrus yields BTD values of only 1–2 K and appears in dark grayshades (Fig. 2c).

The technique was tested using a variety of datasets. In each case it greatly enhanced the signatures produced by contrails. Since the BTD values of contrails varied from scene to scene, it was not possible to establish a precise threshold for their detection. Nevertheless, contrails nearly always had higher BTD values than the background, causing them to stand out consistently. This example (Fig. 2c) distinguished contrails from dense cirrostratus clouds, but the technique also greatly enhanced contrails over a mostly cloud-free surface. In such cases the surface, associated with relatively small BTD values, appeared dark while contrails appeared bright.

3. Mature versus immature contrails

"Immature" contrails are defined here as either newly formed contrails, or contrails which grow little

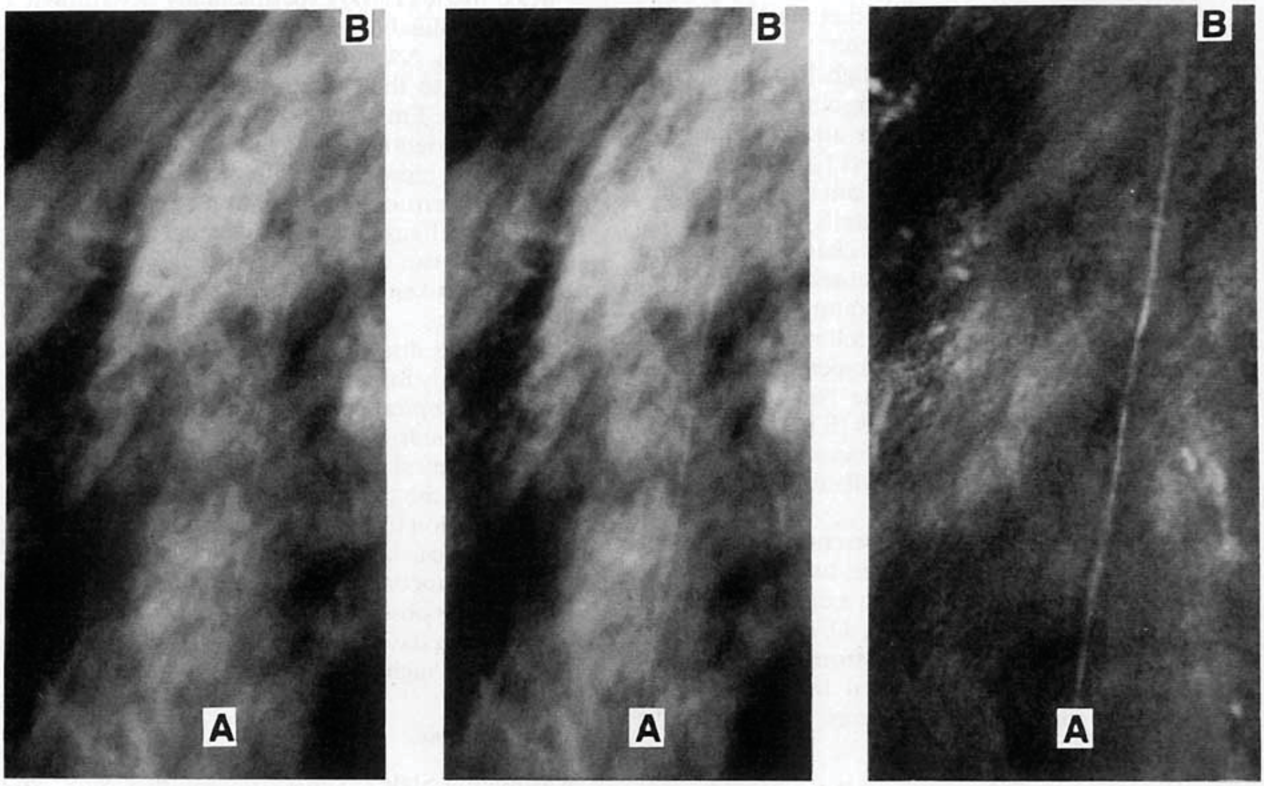

FIG. 2. AVHRR images over Washington State, 2223 UTC, 1 May 1985: (a) channel 4 (11 μm); (b) channel 5 (12 μm); (c) brightness temperature difference (channel 4–channel 5). Contrail lies from point A to point B in all three images.

after initial formation. The semitransparent qualities of immature contrails make their identification nearly impossible on IR satellite images. Since they produce high BTD values, however, immature contrails can easily be observed on BTD images. "Mature" contrails are defined here as contrails which grow naturally after formation; they differ from natural cirrus mainly in their elongated shapes. Mature contrails are less transparent and produce somewhat lower BTD values than immature contrails. While mature contrails often appear on IR images, BTD images often provide better tools for their observation.

Immature contrails are generally narrower than mature contrails and are probably geometrically thinner as well. Modeling results of ice clouds in an otherwise dry atmosphere suggest that the highest BTD values (greater than about 1 K) should result from clouds with geometric thickness of 500–1000 m (Yamanouchi et al. 1987). This range may approximate the thickness of natural, semitransparent cirrus, but probably overstates the geometric thickness of many contrails. A newly formed contrail is probably geometrically thin and optically thick in comparison to most naturally occurring cirrus clouds. The relatively high optical thickness should result as a jet aircraft injects a small volume of air with a large initial supply of water vapor, creating a dense ice cloud.

4. Applications

This technique will serve climate researchers investigating the interaction of contrails with natural clouds. It should help answer recent questions about whether contrails add significantly to high-level cloudiness (Carleton and Lamb 1986; Detwiler 1986). If applied in real time, the enhancement described here should also greatly improve the ability to track high-altitude aircraft using satellite images (Fett et al. 1977).

Acknowledgments. The author recognizes the invaluable contributions of Mr. James Clark, Dr. Paul Tag, Dr. James Boyle and Ms. Rosemary Lande, all from our facility. An anonymous reviewer contributed many valuable suggestions.

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