ITPP-5 - The use of AVHRR and TIGR in TOVS Data Processing

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Abstract

A fifth version of the International TOVS Processing Package (ITPP-5) is under development as discussed at the seventh meeting of the International TOVS Study Conference (ITSC-VII). The new version will include a number of significant improvements: (a) the use of AVHRR data for cloud clearing; (b) the use of the LMD "TIGR" statistical data set for the generation of first guess profiles and basis functions used in the "linear" simultaneous retrieval method; (c) the retrieval of cloud phase, infrared (11µm) cloud optical depth and cloud heights, microwave surface emissivity, and short wavelength channel solar surface reflectivity; (d) improved methods of error detection and channel filtering prior to the profile retrieval process; and (e) improved quality control of the end product.

This report details the modifications of ITPP implemented to date. Intercomparison of the results from ITPP-5 and ITPP-4 will be presented in a future paper to demonstrate the improvement in product quality achieved with these software refinements.

I. Introduction

The Advanced Very High Resolution Radiometer (AVHRR) is a companion to the TIROS Operational Vertical Sounder (TOVS) aboard all the NOAA satellites. Because of the AVHRR's high spatial resolution (1 km) compared to that of the TOVS (20 km for HIRS and 150 km for the MSU), the synergistic use of the two systems should improve sounding determinations under broken cloud conditions. Indeed, such improvements have been reported at past ITOVS conferences by Lloyd et al. (1985) and Hayden et al. (1985). The intent here is to refine techniques for using AVHRR in TOVS sounding retrieval and develop the software updates needed to include AVHRR in the International TOVS Processing Package (ITPP).

Over the past decade the Laboratory of Dynamic Meteorology (LMD) in France has developed another TOVS data processing system called 3-I (Chedin et al., 1985). The success of the 3-I retrieval approach can be attributed to the use of an excellent statistical sample of radiosondes carefully constructed by scientists at the LMD. This database of temperature, moisture, ozone, and calculated TOVS radiances is called the TIROS Initial Guess Radiance (TIGR), the latest version of which is described by Chedin et al. (1992). The ITPP requires the use of a temperature, water vapor, and ozone data set in order to specify a number of coefficients of regression relations used to generate first guest profiles, angle "correct" off-nadir radiance observations, and provide relations between surface skin temperature and "window" infrared radiance. Thus, in order to bring the ITPP and the 3I results into closer agreement, the TIGR data base is to be included in the ITPP5 system.

Finally, other elements of the ITPP are being upgraded. Included are (1) the installation of the improved Rapid Transmittance for TOVS (RTTOVS) developed by Eyre (1991); (2) the replacement of the use of basis functions with a TIGR-based statistical covariance matrix; (3) improvements in the formulations for the retrieval of cloud height, phase, and optical depth; (4) improvements in the retrieval of surface emissivity and solar reflectivity; and (5) improved procedures for error detection and radiance filtering prior to the profile retrieval, and improved quality control of the end product.

The updates, once implemented will result in a new version of the ITPP--ITPP-5. These tasks are not all completed at the time of this writing. In any event, this paper serves to describe the new algorithms to be used, including the logistics of including AVHRR within the TOVS data processing system. Results of tests of the new components of Version 5 are provided. A complete test of the ITPP-5 will be conducted by the end of 1993 and the results, in terms of comparisons with output obtained with similar modules of the ITPP-4, will be provided in a separate technical report to the International TOVS community.

II. Radiative Transfer and TIGR Based Regressions

New computationally fast models have been developed for the determination of HIRS and MSU transmittances, using line-by-line transmittances and the regression algorithm (RTTOVS) developed by Eyre (1991). For the HIRS, line-by-line transmittances have been calculated with FASCD3P and the HITRAN91 spectroscopic database (both published by the U.S.Air Force Phillips Laboratory, Bedford, Massachusetts) at five zenith angles for the 1976 U.S. Standard Atmosphere, plus 31 additional atmospheres, chosen to represent a highly diverse set of temperature, moisture, and ozone conditions. The line-by-line output, which is at very high, variable spectral resolution, is reduced to 0.1 cm^{-1} resolution by simple averaging. The latter are convolved with the HIRS spectral response functions at 0.1 cm^{-1} resolution to obtain "channel transmittances." These in turn are transformed into optical thickness, which is then regressed against various combinations of temperature, water-vapor mixing ratio, ozone mixing ratio, and quantities derived from those basic atmospheric state variables. Transmittances are modeled separately for uniformly-mixed gases (referred to collectively as "dry"), water-vapor, and ozone. For the MSU, line-by-line transmittances are obtained with the models of Rosenkranz (1975) and Barrett and Chung (1962), for the same set of five zenith angles and 32 atmospheres. Transmittances for oxygen and water vapor are modeled separately; parameterization is identical to that for the HIRS "dry" and "wet" cases, respectively. This latest algorithm of Eyre (1991) represents an evolution of transmittance parameterization, from the original TOVS models of McMillin and Fleming (1976) and Fleming and McMillin (1977), through the microwave model of Eyre and Woolf (1988). The new regression model has been accepted by NESDIS for application to the sounding instruments on the next-generation operational meteorological satellites, both polar (NOAA/K HIRS, AMSU, and MHS) and geostationary (GOES/I SOUNDER and IMAGER). It has also been applied to several additional sensors. Among the infrared are AVHRR, VAS, METEOSAT, MAS, the MODIS Airborne Simulator, and aircraft (HIS) and ground-based (AERI) interferometer-sounders. The microwave include the SSM/I, SSM/T, and SSM/T2 instruments of the DMSP spacecraft, in addition to AMSU and MHS.

The full TIGR database consists of many thousands of atmospheric profiles. A reduced set, consisting of 1761 soundings representing a great diversity of meteorological conditions, was provided to CIMSS in conjunction with our AIRS development work. The new transmittance models discussed above were applied to this dataset to synthesize radiances and corresponding brightness temperatures for HIRS and MSU, in order to derive the many regression relations employed in the ITPP system. These include angle-adjustment ("limb-correction"), estimation of surface-skin temperature and longwave flux (which also entails simulation of the fluxes from the same atmospheres), and generation of first-guess profiles of temperature and moisture for the physical retrieval algorithm.

III. AVHRR Pre-Processing

AVHRR data is incorporated into the ITPP5 package via a pre-processor to the retrieval module. Collocation with TOVS data is accomplished for each HIRS FOV and also for the 8 pairs of HIRS FOV centered around it. AVHRR data corresponding to each individual HIRS FOV are classified as representing; a 1-deck scene, a 2-deck scene, or an unusable scene, by applying the spatial coherence technique of Coakley and Bretherton (1982). An evaluation of the linearity between the 3.7 and 11 μm AVHRR measurements within each of the 8 pairs of HIRS FOV is provided for use in subsequent clear radiance calculations within the retrieval algorithm.

Collocation with the TOVS data is accomplished by matching the 6.4 second HIRS scan with 39 0.6 second AVHRR lines (Hayden et al., 1985). Geometric considerations for matching the two (which scan in opposite directions) are those diagnosed by Aoki (1983). The accuracy of the collocation has been established by comparing the HIRS 11 μm values with the averaged, collocated AVHRR 11 μm data. An example of the scatter between the two for a square of 100 HIRS FOV is shown in figure 1.

In the spatial coherence technique, AVHRR data within a given HIRS FOV is separated into as many unique, nonoverlapping 3x3 boxes (each box corresponding to a HIRS FOV) as possible, and the mean and standard deviation of each is found. If the standard deviation is plotted against the mean, the resultant scatter diagram clearly shows the presence of any uniform regions within the FOV. A FOV which is entirely clear or cloudy will show a tight group of points of the same mean radiance value and low standard deviation. A FOV which contains some broken cloud of uniform nature will show two distinct areas of low standard deviation with different mean radiances, and a broad arch of higher standard deviation measurements connecting the two (figure 2). FOV which contain only one feature of uniform nature amidst a non-uniform cloud deck will show only one area of low standard deviation which tails off and ends in the higher standard deviation region of the plot.

(b) Amalgamation with TOVS

The ITPP5 retrieval algorithm acquires AVHRR pre-processing results for all HIRS FOV to aid in the process of cloud clearing and clear radiance calculation. The spatial coherence results are used primarily for the cloud clearing task and are averaged within the 3x3 retrieval box for the warm, overall and cold signals. The regression information between the 3.7 and 11 μm data is used to extrapolate to clear radiance values in instances where the relationship is mμ sufficiently linear and well defined.

To begin the cloud clearing process, the clearest HIRS FOV is identified through analysis of the HIRS 11 μm brightness temperatures and a series of tests are performed using the AVHRR and HIRS information to decide if the scene is really clear. The "clear" tests are similar in nature to those employed in prior ITPP packages (which were restricted to the use of only HIRS window channel radiance data) with improvements afforded by the much higher spatial resolution AVHRR (Rochard et al., 1978 and Saunders and Kriebel, 1988). Information from guess profiles (obtained using a TIGR based regression with the MSU radiances) and independent regression estimates of surface-skin temperature from HIRS and AVHRR (using multi-spectral window channel regression equations) are also utilized in this process. Should any of the following conditions be met, the scene is classified as cloudy.

1. The average AVHRR 3.7 μm brightness temperature for the warm signal exceeds the average AVHRR 11 μm brightness temperature for the warm signal.
2. The skin temperature, as derived from AVHRR, is more than 10 degrees colder than the guess surface air temperature.
3. The average albedo for the warm signal in either of 2 AVHRR visible channels is greater than 0.25 (daytime).
4. The measured albedo in the HIRS visible channel is greater than 0.25 (daytime).
5. The average AVHRR 3.7 μm brightness temperature for the warm signal is more than 4 degrees warmer than the skin temperature, as derived by AVHRR (night).
6. The HIRS 3.7 μm brightness temperature is more than 4 degrees warmer than the skin temperature, as derived by HIRS (night).
7. Skin temperatures, as derived from AVHRR and HIRS, differ by more than 2 degrees.

If the scene (i.e., HIRS FOV) passes all of these tests, it is classified as clear.

Scenes which have been classified as cloudy must undergo further testing to ascertain the nature of the cloud conditions. In particular,

1. Cloud diagnostics are run using the CO_2-slicing algorithm (Smith and Platt, 1978; Menzel et al., 1983), which determines cloud height and amount by ratioing HIRS CO_2 channel data with HIRS 11 μm data. If the cloud amount resulting from CO2-slicing is zero the scene is re-classified as "possibly clear" for the purpose of sounding retrieval. The so-called "possibly clear" radiances are used for sounding retrieval only in the case where AVHRR determined clear or N* calculated clear radiances are not achievable within a particular 3x3 array of HIRS FOV's.
2. If the difference between HIRS and AVHRR derived skin temperatures is less than 4 degrees the scene is classified as overcast.
3. If the cloudy scene does not meet the first or second test, and the spatial coherence analysis yielded no warm or cold signals, the scene is classified as multi-level cloud and declared unuseable.

4. If none of the first three tests are passed, the scene is declared partly cloudy and clear column radiances are calculated.

Figure (3) shows visible and infrared 1 kilometer resolution images for a mixed cloud scene together with the type of cloud condition determined from the mix of AVHRR and HIRS data. The numbers 1, 2, 3, 4, 5 correspond to clear, partly cloudy single level, partly cloudy multilevel, single level overcast and multilevel overcast respectively.

(c) N* Determined Clear Radiances

If no clear HIRS fields of view are found within a 3 X 3 array and the center field of view (chosen as the clearest in the formation of the 3x3 array) is classified a single level partly cloudy, then an attempt is made to calculate clear radiances using the so-called N* algorithm (Smith, 1968 and Smith et.al., 1976). The N* equation

$$I_{\mathrm{clr}}(\nu) = \frac{I_1(\upsilon) - N^* I_2(\upsilon)}{1 - N^*}$$

where

$$N^* = \frac{N_1}{N_2} \approx \frac{I_1(w) - Iclr(w)}{I_2(w) - Iclr(w)}$$

is valid for the condition of a single level of broken or scattered cloud within the two HIRS fields of view. In the above relations, υ is any arbitrary channel, w is a "window" channel, either 3.7 µm or 11 µm, N is the fractional cloud cover, and subscripts 1 and 2 refer to two spatially adjacent HIRS FOV. The AVHRR data is used to validate the assumption of a single layer of cloud and to provide the "window" channel clear sky background radiances needed to determine N*. For this later purpose, the AVHRR clear sky 3.7 µm and 11 µm radiance values are used in a regression relation with HIRS 3.7 µm and 11 µm to account for minor spectral response differences between the two instruments.

The validation of the single level cloud assumption is accomplished using AVHRR data in the following way:

(1) the results of the AVHRR preprocessor must indicate a single level of cloud (either type 2 or 3) for both fields of view being considered, and

(2) a regression relation between all the AVHRR 3.7 µm and 11 µm data within the two HIRS FOV must yield a standard error of less than that standard deviations expected as a result of the noise level of the observations (1.5 mw/m^2-strm-cm^{-1} in terms of the 11 µm radiance value). This test validates the N* relation since it can be shown that a linear relation between the radiances observed in two spectrally separated "window" channels (i.e., 3.7 and 11 µm) under

varying cloud amount conditions can only exist for the case of a single cloud temperature (i.e., altitude) condition.

Figure 4 shows examples of 3.7 µm vs 11 µm AVHRR radiance for two partly cloudy conditions, one corresponding to a FOV containing cloud of constant altitude, and another containing cloud of variable altitude.

IV. Summary

We are currently in the development of the fifth generation International TOVS Processing Package (ITPP5). Thus far, a module for incorporating AVHRR data, a new fast transmittance model, and the TIGR data base have all been successfully incorporated into the ITPP system. As of this writing, the simultaneous retrieval algorithm, modified to incorporate statistical basis functions based on the TIGR data set, is undergoing testing. Improvements in the generation of cloud parameters (phase, optical depth, and height), microwave surface emissivity, and solar reflectivity are in progress. Improved methods in error detection and channel filtering and quality control of the end product are to be accomplished prior to the release of the ITPP5. The entire effort is planned to be completed by Fall, 1993 with the ITPP5 software and documentation available to the scientific user community before the end of the year.

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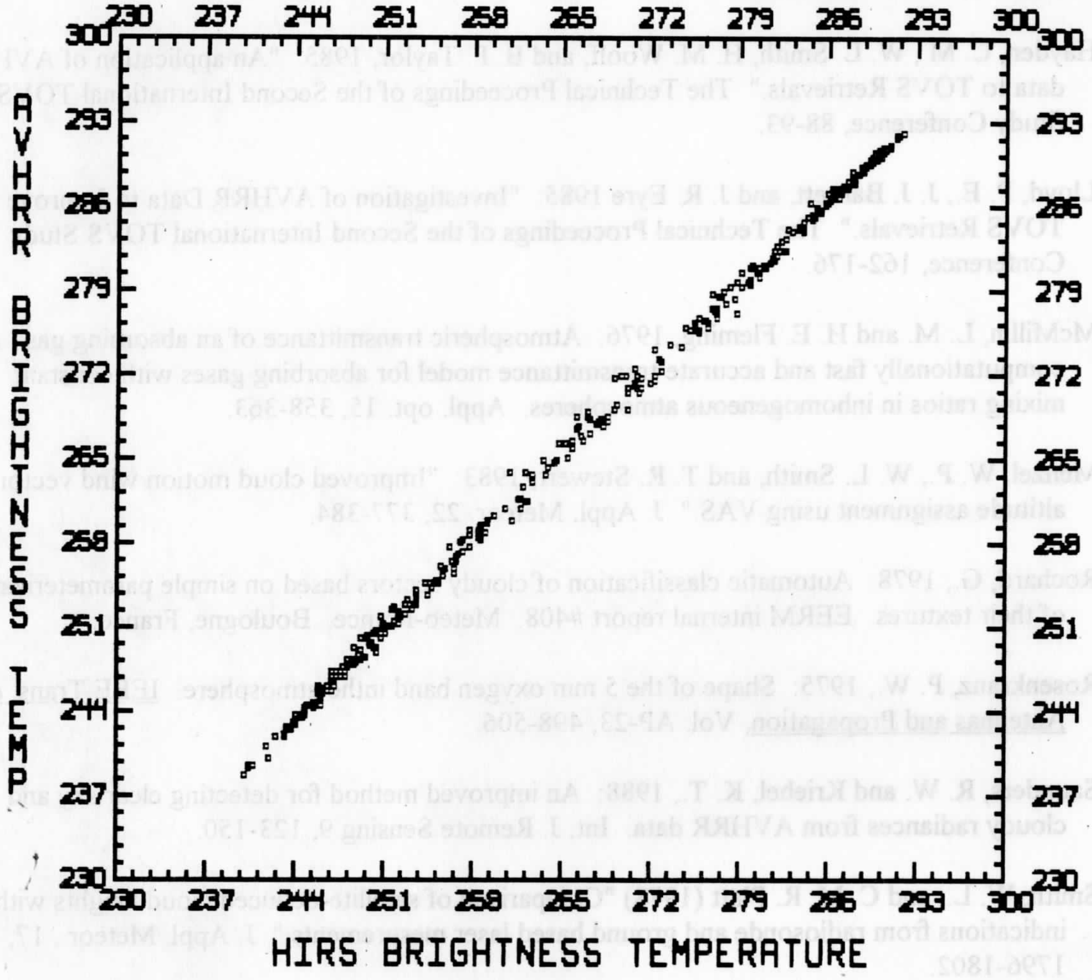

fig. 1: Scatter diagram comparing AVHRR measurements at 11 micrometers averaged over the collocated HIRS FOV with the HIRS 11 micrometer measurement for a square of 100 HIRS FOV. Values are brightness temperatures.

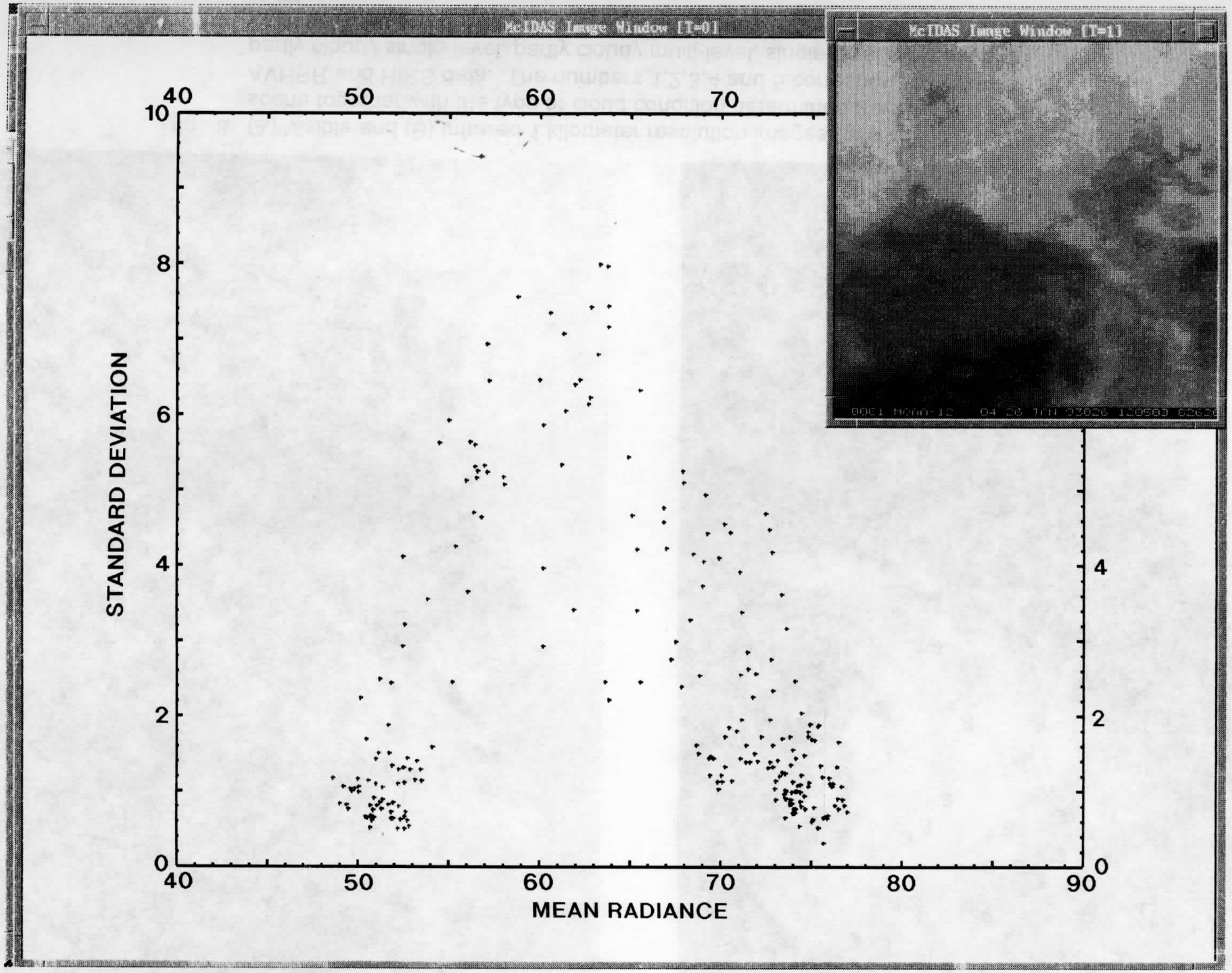

fig. 2: Coakley diagram showing means and standard deviations for 3x3 boxes of measured AVHRR 11 micron data within one HIRS FOV. The insert shows AVHRR 11 micron imagery roughly the size of a retrieval box centered on the HIRS FOV being examined.

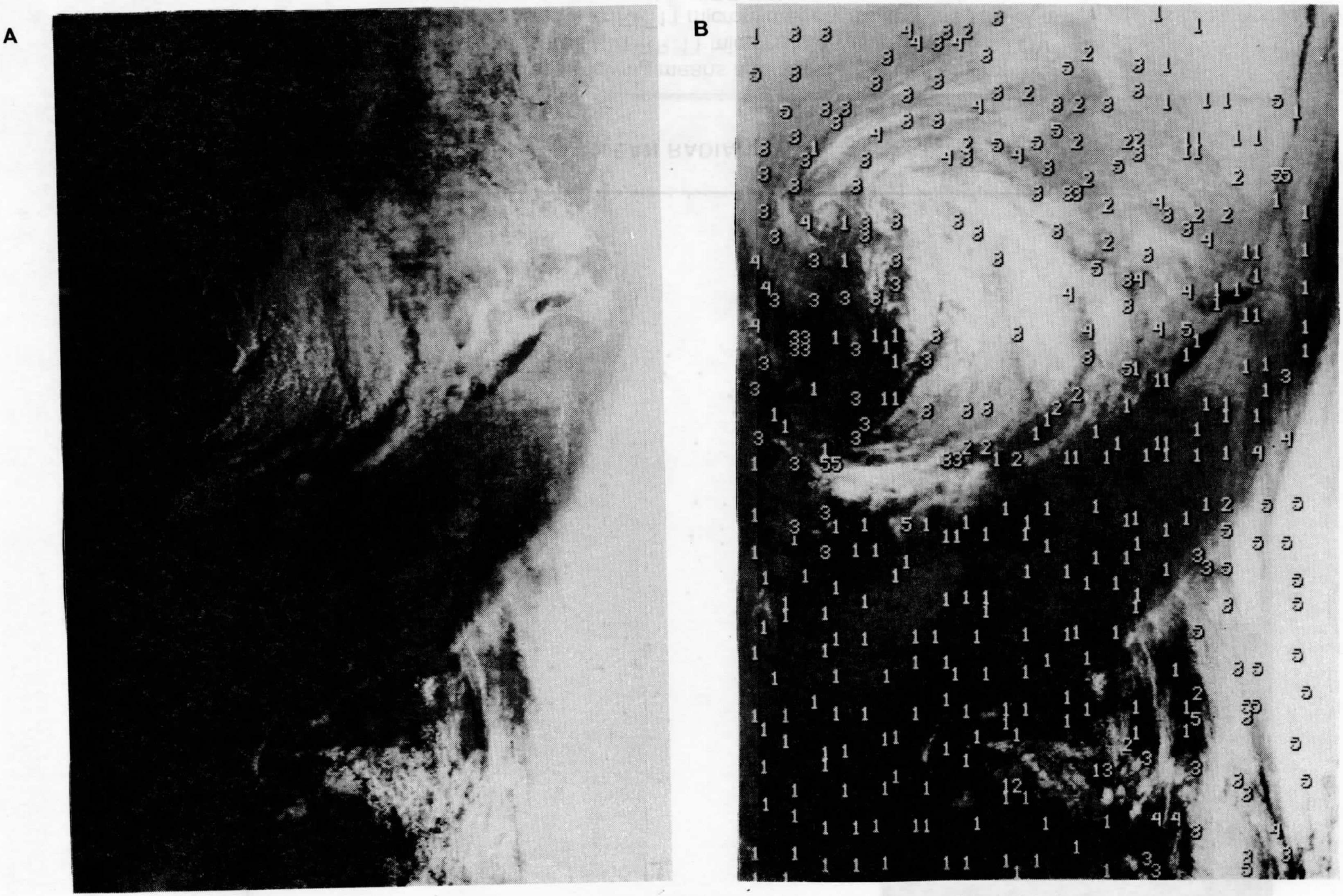

fig. 3: (A) Visible and (B) Infrared 1 kilometer resolution images for a mixed cloud scene together with the type of cloud condition determined from the mix of AVHRR and HIRS data. The numbers 1,2,3,4 and 5 correspond to clear, partly cloudy single-level, partly cloudy multi-level, single-level overcast and multi-level overcast, respectively. The terminator is present in the visible image.

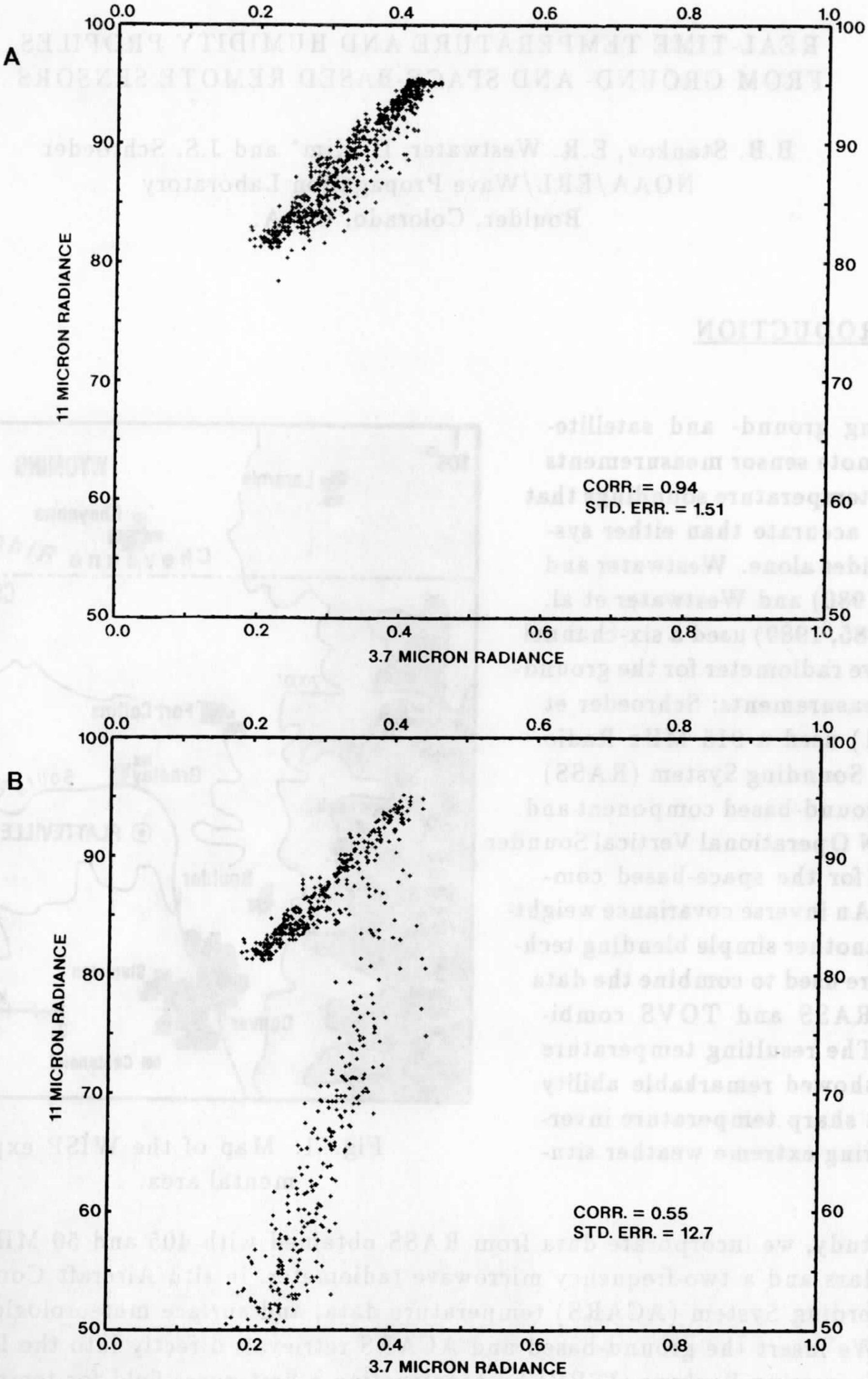

fig. 4: Scatter diagrams comparing 3.7 and 11 micrometer AVHRR radiance within pairs of collocated HIRS FOV; (a) cloud altitude constant and (b) cloud altitude variable.

TECHNICAL PROCEEDINGS OF
THE SEVENTH INTERNATIONAL TOVS STUDY CONFERENCE

Igls, Austria

10-16 February 1993

Edited by

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July 1993