

UW-Madison.

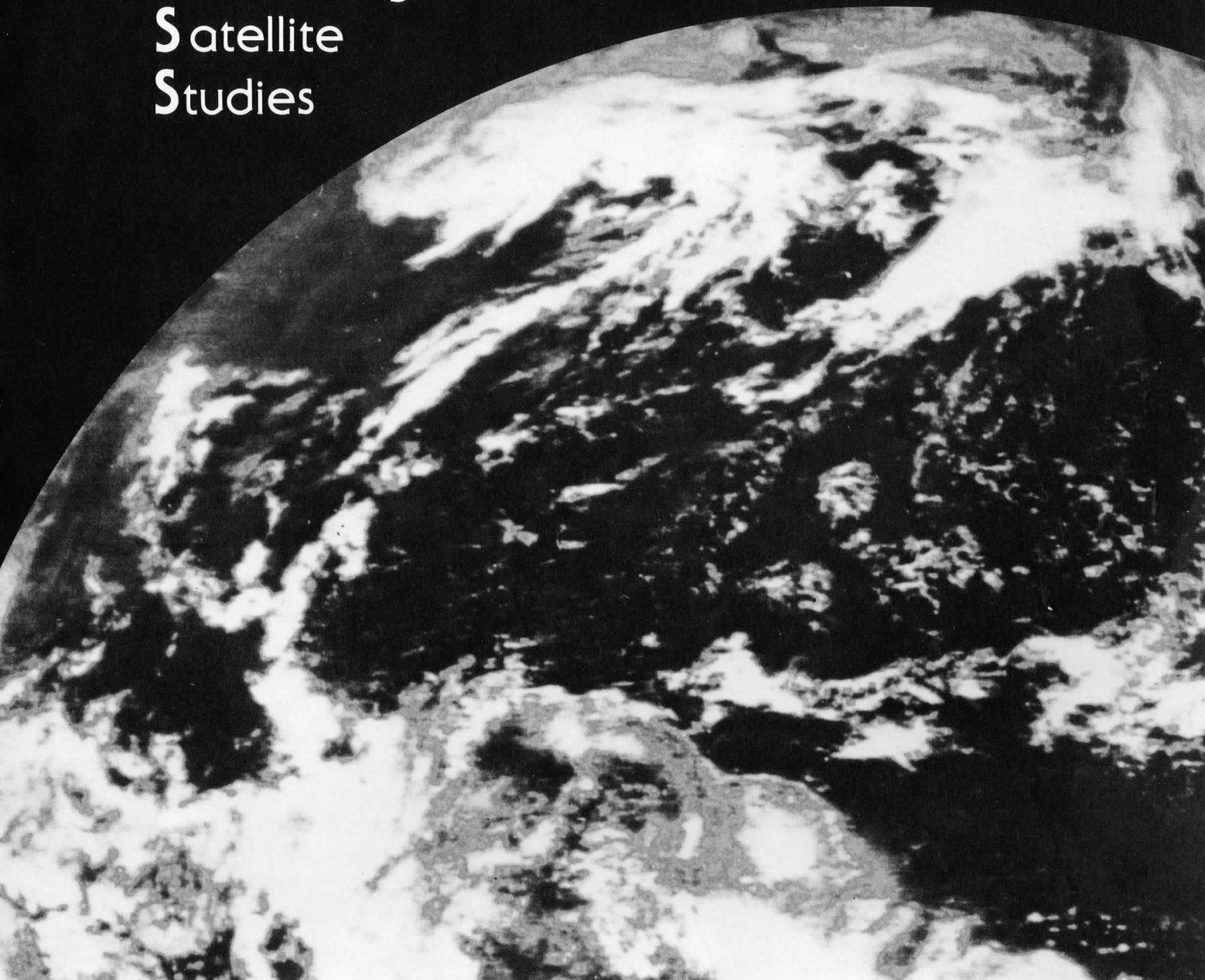
SSEC Publication No.88.00.A1. and Engineering Center

University of Wisconsin-Madison

FINAL REPORT: SATELLITE METEOROLOGY WITH TOVS  
THOMAS H. ACHTOR AND ANTHONY J. SCHREINER  
COOPERATIVE INSTITUTE FOR METEOROLOGICAL SATELLITE STUDIES  
UNIVERSITY OF WISCONSIN - MADISON

**A REPORT** from the

Cooperative  
Institute for  
Meteorological  
Satellite  
Studies



FINAL REPORT: SATELLITE METEOROLOGY WITH TOVS  
THOMAS H. ACHTOR AND ANTHONY J. SCHREINER  
COOPERATIVE INSTITUTE FOR METEOROLOGICAL SATELLITE STUDIES  
UNIVERSITY OF WISCONSIN - MADISON

The Schwerdtfeger Library  
University of Wisconsin-Madison  
1225 W Dayton Street  
Madison, WI 53706

NOVEMBER 1988  
SPACE SCIENCE AND ENGINEERING CENTER  
UNIVERSITY OF WISCONSIN  
MADISON, WI 53706  
608/264-5325

## TABLE OF CONTENTS

EXECUTIVE SUMMARY

PARTICIPANTS IN TRAINING SESSION

COURSE AGENDA

DAILY COURSE SUMMARY

LECTURE 1: OVERVIEW OF SATELLITE METEOROLOGY

LECTURE 2: OVERVIEW OF WEATHER SATELLITES

LECTURE 3: INTRODUCTION TO THE INTERNATIONAL TOVS PROCESSING PACKAGE

LECTURE 4: THE NATURE OF RADIATION

LECTURE 5: ATMOSPHERIC PROCESSES

LECTURE 6: RADIATIVE TRANSFER IN THE ATMOSPHERE

LECTURE 7: RADIATIVE TRANSFER EQUATION (RTE)

LECTURE 8: SOLUTIONS TO THE RTE

LECTURE 9: THE INFLUENCE OF CLOUDS

LECTURE 10: CLOUD CLEARING/CLOUD PARAMETERS

LECTURE 11: MICROWAVE RTE

LECTURE 12: THE INFLUENCE OF MOISTURE

LECTURE 13: RETRIEVAL OF MOISTURE PARAMETERS

LECTURE 14: TOVS INSTRUMENT CHARACTERISTICS

LECTURE 15: SEA SURFACE TEMPERATURE AND OTHER SATELLITE APPLICATIONS

LECTURE 16: ESTIMATION OF TROPICAL CYCLONE STRENGTH

LECTURE 17: TOVS RETRIEVAL ALGORITHM (ITPP)

LECTURE 18: DERIVED METEOROLOGICAL PARAMETERS

LECTURE 19: SIMULTANEOUS RETRIEVAL ALGORITHM

LECTURE 20: APPLICATIONS TO NUMERICAL METHODS

LECTURE 21: FUTURE SATELLITE SYSTEMS

USER'S GUIDE TO THE INTERNATIONAL TOVS PROCESSING PACKAGE

## EXECUTIVE SUMMARY

A two week training course in Satellite Meteorology, emphasizing the use of NOAA polar orbiting TOVS radiance measurements and the International TOVS Processing Package (ITPP) was held at the Space Research and Remote Sensing Center (SPARRSO) in Dhaka, Bangladesh on 12-24 November 1988. The Final Report contains;

- i) this executive summary of course proceedings and findings,
- ii) a course participant list,
- iii) a chronological outline of course activities,
- iv) a daily summary of course activities compiled from notes taken during the course,
- v) course lecture notes, and
- vi) The ITPP User's Guide (including the TOVS data processing procedure developed at SPARRSO).

The Satellite Meteorology with TOVS course included fifteen participants, from SPARRSO, the Bangladesh Meteorology Office, the Bangladesh Air Force and Dhaka University. Participants were presented material on the theoretical nature of the topic, development of meteorological products from the radiance measurements, applications of the data/products to research and operational weather analysis and forecasting problems, and the status of current and future satellite systems. Discussion sessions augmented the lecture materials with problems solving tasks. Laboratory sessions provided hands on training in the use of the International TOVS Processing Package, and use of the derived products in weather analysis and forecasting. Quizzes on lecture material, discussion section problem sets, and a laboratory case study provided means for evaluation of the course participants.

The accompanying instructor course summary, and the student evaluations completed on the last day of class, both conclude that the course provided a significant and important learning experience for the participants. For Bangladesh to develop useful products/techniques and benefit from satellite derived meteorological information, their scientists must develop an understanding of the basic theoretical principles of satellite meteorology. This course brought the beginnings of that understanding to most of the participants. It is of utmost importance for these Bangladesh scientists to continue working with satellite data, cooperating among agencies in Bangladesh, and interacting with the world scientific community to allow this knowledge to expand.

There were two severe problems during the course; i) the failure of the course textbooks to arrive in Bangladesh, and ii) the breakdown of the SPARRSO antenna system, which resulted in the inability to receive real-time HRPT (AVHRR and TOVS) data. The first problem resulted in a lack of reference material for participants during the course. We sincerely hope the texts will be mailed to participants as soon as possible in order to provide future reference.

The lack of real-time data was an even more severe problems. The course had originally been developed to use the ITPP daily to produce meteorological fields, from which a daily weather discussion was to be held. Since this did not occur, the course was forced to rely on one Bangladesh cyclone historical data set, and one North American case study prepared at the University of Wisconsin. These two cases did allow the basic understanding of ITPP operations and utilization of meteorological products to be taught. However, it is the instructors' conclusion that the course was not thorough enough in emphasizing correct ITPP procedures, quality control of the calculated meteorological state variable, and interpretation of results.

One final problem; the instructors have noticed that SPARRSO scientists are each responsible for several major agency activities, causing them to allocate their time among several diverse programs. The TOVS program in Bangladesh suffers from the fact that there is no individual scientist directing or conducting a well-conceived research (or operational) plan, although we observed several people capable of running the TOVS algorithm, and using the IIS with GEMPACK to display results. The field of atmospheric remote sensing is relatively new and constantly changing; a successful research/operational agency needs people who can work with the algorithms and understand the results, not merely someone to operate a "canned" routine. For this reason we highly recommend a future program where a high-level SPARRSO scientist or exceptional Phd candidate spend a period of time at CIMSS, working with the TOVS group, learning the intricacies of the field (ie. becoming an expert). Following an appropriate interlude, a CIMSS scientist could follow up with an extended visit to Bangladesh to help that scientist establish a quality research program at SPARRSO.

**PARTICIPANTS IN TRAINING SESSION  
SATELLITE METEOROLOGY WITH TOVS  
12-24 November, 1988**

**INSTRUCTORS:**

1. Thomas H. Achtor  
University of Wisconsin, Cooperative Institute for Meteorological  
Satellite Studies
2. Anthony J. Schreiner  
University of Wisconsin, Cooperative Institute for Meteorological  
Satellite Studies

**STUDENTS:**

**DHAKA UNIVERSITY, DHAKA, BANGLADESH**

1. Ayesha Akhtar Munim  
Associate Professor, Physics Department
2. Quamrun Nessa Begum  
Professor, Physics Department  
Head, Group on Atmospheric Physics

**BANGLADESH METEOROLOGY DEPARTMENT, DHAKA, BANGLADESH**

3. Santosh Chandra Matabbor  
Meteorologist
4. Md. Manzurul Hoque Khan

**SPARRO, DHAKA, BANGLADESH**

5. Dewan A. Quadir  
Principal Scientific Officer
6. Md. Shohrab Sikder  
Senior Scientific Officer
7. Md. Shafiqul Alam  
Scientific Officer
8. Suraiya Begum  
Scientific Officer
9. Siddiqua Perveen  
Scientific Officer
10. Mehrun Nessa  
Senior Scientific Officer
11. Md. Shafiuddin Sarker  
Scientific Officer
12. Md. Shah Alam  
Senior Scientific Officer

**BANGLADESH AIR FORCE**

13. M. Abul Hossain  
Flight Lieutenant
14. M. Belal Uddin  
Flight Lieutenant
15. M. Shafiullah  
Squadron Leader

## COURSE AGENDA

### METEOROLOGY WITH TOVS TRAINING COURSE

SPACE RESEARCH AND REMOTE SENSING ORGANIZATION (SPARSSO)  
DHAKA, BANGLADESH  
12-24 NOVEMBER 1988

INSTRUCTORS: THOMAS ACHTOR AND ANTHONY SCHREINER  
UNIVERSITY OF WISCONSIN / CIMSS

#### WEEK 1:

##### SATURDAY 12 NOVEMBER: DAY 1

08:00-09:00	REGISTRATION
09:00-09:30	OPENING CEREMONY
09:30-10:00	PRETEST
10:00-10:30	OVERVIEW OF SATELLITE METEOROLOGY
10:30-11:00	TEA BREAK
11:00-12:30	OVERVIEW OF WEATHER SATELLITES
12:30-12:50	TEA BREAK
12:50-14:00	INTRODUCTION TO THE INTERNATIONAL TOVS PROCESSING PACKAGE

##### SUNDAY 13 NOVEMBER: DAY 2

08:00-08:30	REVIEW OF PREVIOUS ACTIVITIES
08:30-09:00	QUIZ
09:00-10:30	NATURE OF RADIATION
10:30-11:00	TEA BREAK
11:00-12:30	ATMOSPHERIC PROCESSES
12:30-12:50	TEA BREAK
12:50-14:00	GUEST LECTURE: DR. D. QUADIR

FOR THE REMAINDER OF WEEK 1, THE SESSION FOLLOWING THE SECOND TEA BREAK WILL BE SPLIT INTO TWO GROUPS. ONE GROUP WILL RECEIVE HANDS ON TRAINING AT THE SPARSSO WORKSTATION, THE OTHER WILL BE IN A WORK ASSIGNMENT GROUP. THE WORKSTATION GROUP WILL LEARN ITPP PROGRAM OPTIONS, PROCESS TOVS DATA, MANUALLY EDIT THE RETRIEVALS, AND CREATE FINAL PRODUCTS FOR A GROUP WEATHER DISCUSSION. THE WORK ASSIGNMENT GROUP WILL WORK ON PROBLEM SETS FROM PREVIOUS LECTURES.

##### MONDAY 14 NOVEMBER: DAY 3

08:00-08:30	REVIEW OF PREVIOUS ACTIVITIES
08:30-09:00	QUIZ
09:00-10:30	RADIATIVE TRANSFER IN THE ATMOSPHERE
10:30-11:00	TEA BREAK
11:00-12:30	RADIATIVE TRANSFER EQUATION (RTE)
12:30-12:50	TEA BREAK
12:50-14:00	(A) AT WORKSTATION; (B) IN DISCUSSION

**TUESDAY 15 NOVEMBER: DAY 4**

08:00-08:30  
08:30-09:00  
09:00-10:30  
10:30-11:00  
11:00-12:30  
12:30-12:50  
12:50-14:00

REVIEW OF PREVIOUS ACTIVITIES  
QUIZ  
SOLUTIONS TO THE RTE  
TEA BREAK  
THE INFLUENCE OF CLOUDS  
TEA BREAK  
(B) AT WORKSTATION; (A) IN  
DISCUSSION

**WEDNESDAY 16 NOVEMBER: DAY 5**

08:00-08:30  
08:30-09:00  
09:00-10:30  
  
10:30-11:00  
11:00-12:30  
12:30-12:50  
12:50-14:00

REVIEW OF PREVIOUS ACTIVITIES  
QUIZ  
CLOUD CLEARING / CLOUD  
PARAMETERS  
TEA BREAK  
MICROWAVE RTE  
TEA BREAK  
(A) AT WORKSTATION; (B) IN  
DISCUSSION

**THURSDAY 17 NOVEMBER: DAY 6**

08:00-08:30  
08:30-09:00  
09:00-10:30  
10:30-11:00  
11:00-12:30  
  
12:30-12:50  
12:50-14:00

REVIEW OF PREVIOUS ACTIVITIES  
QUIZ  
THE INFLUENCE OF MOISTURE  
TEA BREAK  
RETRIEVAL OF MOISTURE  
PARAMETERS  
TEA BREAK  
(B) AT WORKSTATION; (A) IN  
DISCUSSION

**WEEK 2:**

**SATURDAY 19 NOVEMBER: DAY 7**

08:00-08:30  
08:30-09:00  
09:00-10:30  
  
10:30-11:00  
11:00-12:30  
12:30-12:50  
12:50-14:00

REVIEW OF PREVIOUS ACTIVITIES  
QUIZ  
TOVS INSTRUMENT  
CHARACTERISTICS  
TEA BREAK  
SEA SURFACE TEMPERATURE  
TEA BREAK  
(A) AT WORKSTATION; (B) IN  
DISCUSSION

**SUNDAY 20 NOVEMBER: DAY 8**

08:00-08:30  
08:30-09:00  
09:00-10:30  
  
10:30-11:00  
11:00-12:30  
12:30-12:50  
12:50-14:00

REVIEW OF PREVIOUS ACTIVITIES  
QUIZ  
ESTIMATION OF TROPICAL CYCLONE  
STRENGTH  
TEA BREAK  
RETRIEVAL ALGORITHM (ITPP)  
TEA BREAK  
(B) AT WORKSTATION; (A) IN  
DISCUSSION



FOR THE REMAINDER OF THE SECOND WEEK, THE SESSIONS FOLLOWING THE FIRST TEA BREAK WILL BE SPLIT INTO TWO GROUPS. ONE GROUP WILL BE RECEIVING HANDS-ON TRAINING AT THE WORKSTATION, WHILE THE OTHER GROUP WILL BE IN A WORK ASSIGNMENT GROUP. IN ADDITION TO THE LECTURE RELATED PROBLEM SETS AND THE REAL TIME TOVS PROCESSING, A CASE STUDY WILL BE INTRODUCED. EACH GROUP WILL EDIT THE TOVS DATA FOR QUALITY CONTROL AND EVALUATE THE WEATHER PHENOMENA DURING GROUP DISCUSSION.

**MONDAY 21 NOVEMBER: DAY 9**

08:00-08:30	REVIEW OF PREVIOUS ACTIVITIES
08:30-09:00	QUIZ
09:00-10:30	(A) AT WORKSTATION; (B) IN DISCUSSION
10:30-11:00	TEA BREAK
11:00-12:30	(B) AT WORKSTATION; (A) IN DISCUSSION
12:30-12:50	TEA BREAK
12:50-14:00	GUEST LECTURE: DR. A. M. CHOUDHURY

**TUESDAY 22 NOVEMBER: DAY 10**

08:00-08:30	REVIEW OF PREVIOUS ACTIVITIES
08:30-09:00	INTRODUCTION TO CASE STUDY
09:00-10:30	DERIVED METEOROLOGICAL PARAMETERS
10:30-11:00	TEA BREAK
11:00-12:30	GROUP LAB WORKING ON CASE STUDY
12:30-12:50	TEA BREAK
12:50-14:00	SIMULTANEOUS RETRIEVAL ALGORITHM

**WEDNESDAY 23 NOVEMBER: DAY 11**

08:00-08:30	REVIEW OF PREVIOUS ACTIVITIES
08:30-09:00	REVIEW OF QUIZ MATERIAL
09:00-10:30	DISCUSSION ON WEATHER AND SOCIETY
10:30-11:00	TEA BREAK
11:00-12:00	APPLICATIONS TO NUMERICAL METHODS
12:00-12:30	VIDEOTAPES: HIBBARD 4-D / SNOWSTORM
12:30-12:50	TEA BREAK
12:50-14:00	GUEST LECTURE: MR. S. KARMAKAR

**THURSDAY 24 NOVEMBER: DAY 12**

08:00-08:30	STUDENT EVALUATION OF COURSE
08:30-09:00	POST TEST
09:00-10:30	MOVIE: BANGLADESH CYCLONE PREPAREDNESS
10:30-11:00	TEA BREAK
11:00-12:00	FUTURE SATELLITE SYSTEMS
12:00-13:00	CLOSING CEREMONY

## DAILY COURSE SUMMARY

Day 1: Saturday, November 12

Course registration was held between 8 and 9 a.m. The instructors met the students and informally discussed their respective backgrounds. At 9 a.m., a formal welcome ceremony began. Dr. Ali, SPARRSO, welcomed the instructors and spoke of his desires for the course. Dr. Quadir, meteorologist and course participant, next spoke on the utility of TOVS data in the Bangladesh region. Tom Wagner, representing USAID, spoke briefly on this second phase of the ACEM program. Tom Achtor, University of Wisconsin course instructor, spoke on the need for the university, research and operational sectors of the scientific community to work together. Finally, Dr. Pramanik, Acting Chairman of SPARRSO, discussed the SPARRSO mission and several applications recently undertaken.

The officialdom departed and the instruction began. We found that the class participants included two (2) faculty members from the Dhaka University Physics Department, two (2) employees of the Bangladesh Meteorology Office, three (3) officers from the Air Force, and eight (8) employees of SPARRSO, a total of fifteen (15) (see participant list).

A pre-test was administered by Mr. Schreiner and Mr. Achtor to determine student abilities entering the course. The textbook that was to accompany the course was not handed out, since the shipment through the diplomatic pouch had not arrived. This was very unfortunate, since the textbook contained a great deal of supplementary information to the first week's lecture material.

The remainder of the day was taken up with lecture material; a course overview, followed by a historical discussion of weather satellites and their accompanying meteorological programs (see accompanying lecture notes for details). The final lecture of the day, on the International TOVS Processing Package, was started but not completed.

Examination of the pretest results indicated the class had a good knowledge of basic physics and meteorology. Most of the participants were professional meteorologists, which allowed a more rigorous presentation of course material. The pretest also indicated that the students had limited knowledge of the quantitative aspects of satellite meteorology.

Day 2: Sunday, November 13

A quiz was given on material from the lecture An Overview of Weather Satellites, delivered the previous day. This procedure was followed throughout the course; quizzes following the lecture topics of the previous day. The ITPP lecture was essentially started over to provide the complete concept. Slides were presented at the close of the lecture to display a case of TOVS data over North America depicting a strong mid-latitude cyclone. With the completion of these introductory

lectures, the course proceeded into a series of theoretical lectures to provide the necessary foundation for understanding the meteorological information gained from the satellite radiance measurements.

Lectures on the nature of radiation and atmospheric processes were presented during the morning sessions. The course is at the point where the textbook would be a valuable reference for the lectures. Unfortunately, after asking Tom Wagner to look into the matter, we heard no response.

The last presentation of Day 2 was a guest lecture by Dr. Dewan Quadir. He presented research results using TOVS data in the tropical regions of Bangladesh. Dr. Quadir stated that the TOVS data has been helpful in locating regions of lower pressure during Monsoon depressions and in determining atmospheric instability around Northwesters.

Day 3: Monday, November 14

Each day we learned more about the students and their backgrounds. This day began with the instructors answering any questions on the material previously covered. Three quizzes from the lectures of Day 2 were given. The quiz given on Day 2 was returned and discussed. From these first four quizzes, it was observed that most of the class has a good understanding of essential radiation physics. This will be beneficial as the theoretical work becomes more complex.

The lectures of Day 3 covered radiative transfer and the radiative transfer equation (see accompanying lecture notes). At this point, the mathematical and physical principles became more complex. The instructors monitored the level of understanding through questions, examples, review and discussion during tea breaks.

During the last period of the day the hands-on training using the SPARRSO VAX/IIS system began. The students were divided into two groups, A and B, with A in lab (computer training), and B in a discussion section. The lab course covered the ITPP processing steps, while the discussion section worked on problems derived from the lecture material. It was discovered in the lab that SPARRSO scientists were not applying quality control procedures to the TOVS data following retrieval generation. This is an essential operation, due to the radiation attenuation caused by clouds and water vapor. The course will cover in great detail causes of the radiative attenuation and procedures to correct for it. However, there must be a quality control procedure performed after generating retrievals, whether qualitative (interactively by a scientist) or quantitatively (a program in the ITPP). This must be impressed upon the SPARRSO scientists and the other participants.

It was also disclosed that the SPARRSO HRPT tracking antenna is not working. Since a great deal of the laboratory portion of the course was to be based on obtaining real-time data, running the ITPP, and quality controlling and displaying the results for weather discussion, we expressed concern over whether the antenna could be fixed.

Day 4: Tuesday, November 15

The day began with a short question and answer period. The three quizzes given the previous day were returned and discussed. Two quizzes were given on the previous day's material. It was decided by the instructors that due to significant sharing of answers, the individual numerical values of the quizzes are rather meaningless. Several people have poorer scores because they work independently, while some persons, who we perceive to have limited understanding, are doing very well since they sit next to persons who have better comprehension of the material. We feel the students who achieve the greatest understanding will be identified by other means. Therefore, results from the quizzes will be used only to determine when additional review might be beneficial. To this point the quiz results indicate that much of the class (about two-thirds) is still following the material. A high degree of understanding of the lecture material is necessary for RESEARCH work in this field. Understanding the theoretical basis of the data is not necessary for meteorological interpretation of the output of the ITPP. We feel it is important to try and keep as many students as possible following the theoretical material, since it is crucial for Bangladesh to develop a base of expert scientists from which future knowledge can expand.

The lectures this day pertained to solutions to the radiative transfer equation (see lecture notes). Several solution approaches were discussed and a lengthy example of one such method demonstrated the complexity of the calculations and the necessity of powerful computing facilities to process the data.

The last part of the day was again devoted to lab and discussion section. This material was identical to the previous day's, since the groups switched places.

Day 5: Wednesday, November 16

A quiz on solutions to the RTE was given at the beginning of class. The quizzes given the previous day were then returned and discussed. The first lecture this day was delivered on the influence of clouds, cloud clearing, and cloud parameters (1 extended lecture). The final lecture of the day covered the microwave version of the RTE. Following the second tea break, the class again divided into discussion (problem sets) and laboratory groups. The lab session demonstrated the retrieval algorithm, processing a raw TOVS data set to produce soundings using the ITPP. Near the end of the day the lab examined output of meteorological parameters.

We asked Hank Maurer, who arrived Tuesday, to look into the missing textbook problem. Tom Wagner had not responded to our inquiries of where the textbooks are. At this point it was becoming obvious that the textbooks would probably not arrive in time to be useful (if they arrive at all).

Day 6: Thursday, November 17

A quiz on the influence of clouds, cloud clearing and derived cloud parameters was given after the quizzes from the previous day were handed back. The microwave RTE lecture, began the day before, was completed and immediately followed by a lecture on the influence of moisture. The retrieval of moisture parameters, the final lecture of the week, covered the calculation of total precipitable water and outlined the procedures in defining the moisture profile used in the Smith Iterative Technique. This technique was compared to the technique used in Smith's Simultaneous Retrieval Method. In closing the instructor summarized the previous ten lectures, explaining the major points and subjects which were covered. This completed the theoretical portion of the course.

As usual, after the second tea break the class split into the lab and discussion groups. The discussion section performed a "selective atmospheric processes" problem. This was an extension of our atmospheric layer problem discussed in the atmospheric processes lecture. The lab group looked at quality control procedures for a case study of the May 1985 cyclone.

By this time it was apparent that the SPARRSO HRPT tracking antenna would not be repaired in time to permit real time data acquisition for use in class. It was decided to emphasize a case study brought from the United States during week 2. The case study consists of numerous maps of TOVS and radiosonde measurements at mandatory pressure levels for a mid latitude cyclone in October 1988. The case study would allow quality control procedures, analysis of meteorological fields and interpretation of results to be discussed. What was lacking is the hands on use of the ACEM system to ingrain a processing and display routine. This is not necessary for non-SPARRSO students, but would be very beneficial for SPARRSO scientists, since they currently lack a correct TOVS processing routine.

Day 7: Saturday, November 19

Quizzes from the cloud clearing, cloud parameters and influence of clouds lecture were handed back and discussed. The final quizzes for the theoretical portion of the lectures were handed out and cheerfully taken after the one day (weekend) break. A modification of the original lecture schedule was made to accommodate guest lecturers (see course summary schedule for details).

Lecture one of this day covered the TOVS instrument characteristics. A slide presentation displayed imagery of the HIRS, MSU and AVHRR bands on the NOAA satellites. This first presentation discussed the meteorological, as well as the radiative aspects of the imagery for each of the TOVS bands.

Following the first tea break, the next lecture discussed applications of the geostationary (VAS) and the polar orbiter (AVHRR) radiances toward deriving sea surface temperatures. Two other applications, derived imagery of atmospheric moisture and stability, and

inferring the intensity of tropical cyclones through the use of microwave radiances (TOVS/MSU) were also presented. The tropical cyclone application lecture was not completed, and was scheduled for continuation the next day.

Labs and discussions followed, as usual, after the second tea break. The discussion section began working on a problem involving calculation using the CO<sub>2</sub> absorption method. The Lab section was to continue discussion of editing TOVS retrievals, but the SPARRSO system went down completely in a power outage (no UPS). The lab group was then shifted to discussion.

**Day 8: Sunday, November 20**

Quizzes from microwave RTE, influence of moisture, and retrieval of moisture parameters lectures were returned and discussed to begin the day. The instructors were very happy with the results of all quizzes, especially the retrieval of moisture parameters quiz, as the results suggested the class continued to have a fairly high level of understanding. Immediately thereafter, a quiz on the TOVS instrument characteristics was taken.

The lecture series continued with the "Velden" technique of determining the intensity of the tropical cyclones using microwave (MSU) radiance information, plus a discussion of the May 1985 cyclone as viewed by the NOAA-10 satellite. Since SPARRSO has researched this case, a titillating discussion of the cyclone followed, concluding with a relaxing and fulfilling tea break.

The second presentation gave a detailed discussion of the simultaneous retrieval algorithm. The lecture examined the step-by-step process, describing how the observed radiances are transformed into atmospheric temperature and moisture profiles. In describing the events taking place in the simultaneous retrieval algorithm, questions arose on some important details. As time was running out, it was decided to deliver a short follow-up talk on the topic the following day.

Since the entire class spent yesterday working on a discussion problem of the CO<sub>2</sub> absorption technique (due to SPARRSO power-generation problems), the entire group participated in lab today. The lab section concentrated on the editing techniques for TOVS retrievals over an AVHRR satellite image.

**Day 9: Monday, November 21**

The final four days of the course remain, and both instructors continue to be somewhat civil to each other. The previous evening, a considerable effort was made to develop a written procedure for producing analyses over an AVHRR image as a final product to TOVS processing (the technique is detailed in the TOVS Processing Manual). This procedure was successfully accomplished and used in both lab sessions today, examining a TOVS pass from the May 1985 cyclone.

Discussion sections worked on the problem of deriving surface temperature using the split window technique. The purpose was two-fold; first, to obtain the surface temperature, accounting for the absorbed water vapor; and second, to derive the total precipitable water vapor. Everyone showed considerable vigor and a lively theoretical discussion ensued while deriving a solution to this problem for both discussion sections.

After the second tea break, a guest lecture was given by Dr. Choudhury. In this lecture, he discussed the usefulness of TOVS data in cyclone and monsoon depression analysis in the Bay of Bengal, and Northwesterers approaching Bangladesh from northern India.

Day 10: Tuesday, November 22

A quiz on determining cyclone intensity utilizing the "Velden" technique of applying TOVS microwave information, was given as a group assignment. Discussion of the technique and the answers to the quiz followed. This is the last quiz before the pre-test will again be given on the final day.

The first lecture began with a brief introduction, via slides, of a case study of a mid-latitude cyclone over North America. The remainder of the first lecture, entitled Derived Meteorological Products, explored the breadth of remote sensing research topics currently ongoing at the CIMSS in Madison, Wisconsin, USA. Examples included derived imagery, satellite derived motion vectors, and layered precipitable water studies. Student participation was so intense that everyone, including the Allam Brothers, had to be forced to take the first tea break.

The second lecture period began to examine the case study mentioned above. This was done in lieu of hands-on work at the ACEM system, since real-time data was not able to be obtained. It turned out that the case study was very useful to teach the concepts of retrieval coverage, data quality, quality control, and final product interpretation. Each student received a packet of maps containing TOVS derived temperatures, thicknesses, heights and moisture. They also received maps of co-located radiosonde information. The satellite derived information was analyzed and compared to the conventional radiosonde data. This study will be finished tomorrow, replacing the scheduled discussion and laboratory sections.

After the second tea break, including mouth-watering singalas, a rendition of the mathematical development of the simultaneous retrieval method was given. This was done to more closely examine the differences between this method and the Smith Iterative Method, discussed in an earlier lecture.

After class we visited the U.S. Embassy and had discussions with USAID personnel C. Hash and A. Hurdus. Among other things, we discussed the non-arrival of the textbooks. It is safe to assume they will not be distributed to the students during the course. We do hope they will be mailed to them when they arrive, so the students will have a good reference for future use.

Day 11: Wednesday, November 23

To begin the day, the quiz of the previous day was discussed. An intriguing essay question, which placed each student in a forecaster's role and asked him/her to evaluate various types of satellite derived products, was given to each student and later, created lively discussion. This period also included a discussion (oral quiz) of the material presented in the derived meteorological parameters lecture. The "quiz" was actually handed out and verbal answers were requested. Class participation was very good, with a dash of humor injected occasionally.

After the first tea break two videotapes were shown. The first was a demonstration of the four-dimensional capabilities of the UW McIDAS (Man-computer Interactive Data Access System) using model output analyses and forecasts. The second tape was home video of a snowstorm which occurred last year in Madison, Wisconsin.

The next lecture concentrated on applications of satellite derived information to numerical modelling, both analyses and forecasts. A major topic addressed techniques of incorporating various data types, with their particular spatial and temporal resolutions, into analysis packages. Also discussed was the procedure for introducing satellite data into a numerical model analyses, and from that, generating a set of forecast grids. Basic concepts of NWP models were detailed. Finally, advantages and disadvantages of using satellite data in numerical weather prediction (NWP) models were summarized. This was followed by the always enjoyable second tea (and singala) break.

Mr. Samanendra Karmakan of the Bangladesh Meteorology Office was a guest lecturer for the last period of the day. His topic was "Upper Air Observations in Weather Forecasting." Mr. Karmakan discussed radiosonde characteristics, quantities measured, products derived (Showalter Index, etc.). He then showed a myriad of equations of motion, then displayed a technique from Gray to calculate a parameter for cyclone development. Unfortunately, the radiosonde measurement must be near the cyclone center to predict the development. Our students immediately assailed Mr. Karmakan as to where or how often one might have a radiosonde observation in a cyclone to obtain such a value. Then they explained to him that TOVS provides coverage over much of the land and ocean, and Mr. Karmakan said yes, we need to do research on how to use this new instrument. Mr. Karmakan was also asked about Met. Office forecast procedures for severe weather development during Northwesters. Mr. Hossain (AF) also volunteered forecasting techniques used by the Air Force.

Day 12: Thursday November 24

The final day of class began with a student evaluation of the course. This was followed by another try at the Pre-test. Then, Mr. Karmakar (Met. office speaker of the previous day) presented himself and said, if we so desired, he would show a movie prepared by the Met. Office on hurricane forecasting, warnings and preparedness in Bangladesh. We felt it would be educational for us (the instructors) and



lead to quality discussion afterwards. The movie was very well done, with excellent footage of the May 1985 cyclone. It also gave us an understanding of conditions in the river delta by the Bay of Bengal, where total evacuation is impossible. Following a tea break, the last lecture of the course, on future satellite systems, was presented. This took until noon, when the closing ceremonies commenced. A student participant (Mr. Shafulliah) made several comments on his experiences in the course, and the instructors were also able to express their feelings (all which were rather positive).

In spite of several unfortunate situations (no textbooks, no real time HRPT for hands-on use), the course had gone quite well. The instructors were quite pleased with the education background of the students (quite high, allowing for a rather rigorous treatment of a difficult subject), the student enthusiasm towards the material, and the overall achievement of the majority of participants.

The student course reviews were mostly positive. It is important for the information that has been provided find some usefulness in the day to day activities of the course participants. This is certainly possible for SPARRSO, where the facilities exist, to examine TOVS satellite data. The other meteorological sectors in Bangladesh need to be included in remote sensing technology (especially the Met. Office). This can be accomplished by distribution of information and scientist exchange programs between SPARRSO and other scientific agencies and universities within Bangladesh and outside the country.

## LECTURE NOTES / HANDOUTS

### LECTURE 1: OVERVIEW OF SATELLITE METEOROLOGY

SATURDAY, 12 NOVEMBER: DAY 1

- I. Overview of weather satellites.
  - A. A discussion of some of the early pioneers and initial successes in satellite technology and application to meteorology.
  - B. An overview of the evolution of the polar orbiting platform series of satellites as related to temperature/moisture sensing of the atmosphere and other meteorological applications (fig. 1).
  - C. Discussion of the TIROS-N/NOAA series of polar orbiters.
  - D. A brief outline of the history of geostationary satellites for the United States and the international community.
- II. Introduction to International TOVS Processing Package (ITPP).
  - A. The history of the ITPP, including its initial impetus and evolution.
  - B. A discussion of how the ITPP works (fig. 2).
  - C. A brief overview of the different programs which are included in the processing package.
- III. The nature of radiation.
  - A. Definition of terms.
  - B. An explanation of the basic units which are used.
  - C. The electromagnetic spectrum (fig. 3).
  - D. Planck's law.
  - E. Related derivations of Planck's law.
- IV. Atmospheric processes.
  - A. Characteristics of irradiance (reflection, absorption, etc.).
  - B. Discuss the definition of "black body" and "gray body".
  - C. Conservation of energy.

- D. An example of absorption and emission within the Earth-Atmosphere system (fig. 4).
  - E. Composition of the atmosphere and its affect on the absorption and emission of "short" wave and "long" wave irradiance.
- V. Radiative transfer in the atmosphere.
- A. Discuss Beer's Law and the basis for computing the transfer of infrared radiation in the atmosphere.
  - B. The affects of atmospheric scattering in both the "short" wave and "long" wave are investigated.
  - C. A discussion of the mean global energy balance with respect to incoming and outgoing radiation (fig. 5).
  - D. Examination of the average radiation budget with respect to time.
  - E. The first satellite experiment to measure the net radiation.
- VI. The radiative transfer equation.
- A. Define the effects of transmittance of a monochromatic radiation within a thin slab of atmosphere.
  - B. Through an example demonstrate the effects of outgoing radiation passing through a multi-layered atmosphere (fig. 6).
  - C. Discuss the concept of weighting functions and their applications to atmospheric soundings.
- VII. Solutions to the radiative transfer equation.
- A. Brief historical background to the temperature profile inversion problem.
  - B. Some of the basic problems and assumptions made to alleviate them.
  - C. An outline of several different solution techniques used to derive the temperature profile from the measured radiances.
  - D. Working through a sample problem (fig. 7).
- VIII. The influence of clouds.
- A. What does a cloud look like in different channels of the HIRS (fig. 8)?

- B. What is the effect of clouds on the net radiation?
  - C. What is the effect of clouds on the atmospheric processes of infrared radiation?
- IX. Cloud clearing and cloud parameters.
- A. Discuss the basic methods of dealing with clouds.
  - B. For a given field-of-view mathematically define what the satellite is observing (fig. 9).
  - C. If the field-of-view is to be corrected for the contamination due to cloudiness what are the mechanisms to perform this?
  - D. In some instances the parameters of the cloud are desired (Cloud Slicing Technique).
- X. The microwave radiative transfer equation.
- A. What is the nature of microwave radiation in the atmosphere?
  - B. Discuss the development of the microwave radiative transfer equation.
  - C. What are some of the limitations and advantages of the microwave form of the RTE (fig. 10)?
- XI. The influence of moisture.
- A. The affect of moisture in both the infrared and microwave portions of the spectrum will be discussed (fig. 11).
  - B. Once the moisture has been identified, what is the procedure for compensating for the effects of water vapor ("split window" technique)? The discussion will be with respect to the infrared portion of the spectrum.
  - C. What are some of the advantages and limitations of the "split window" technique?
- XII. Retrieval of moisture parameters.
- A. From the calculation or correction in the "split window" method, an estimate of the total water vapor can be ascertained (fig. 12).
  - B. Outline the method used to derive a moisture profile with respect to layers rather than level measurements. Discuss the differences and difficulties between generating a temperature profile and a moisture profile.

- C. As a final summary of the temperature inversion problem a quick overview of the "simultaneous" retrieval method and how it differs with the "iterative" scheme which is discussed in an earlier lecture.

XIII. Sea surface temperature.

- A. A definition of the technique and the procedure used to generate sea surface temperatures is given.
- B. What are the advantages and disadvantages of the VAS technique versus than the AVHRR scheme?
- C. Deriving SST imagery from the VAS (fig. 13).
- D. Tropical cyclone analysis for MSU observations.

XIV. TOVS instrument characteristics.

- A. A description of the various instruments and sensors aboard the TIROS-N series of platforms.
- B. What are the orbit characteristics?
- C. An examination of the HIRS and MSU channels. (fig. 14).
- D. Some examples of the products available are shown.

XV. TOVS retrieval algorithm.

- A. An overview of the inputs required.
- B. A description of the major operations required to generate a TOVS temperature/moisture retrieval.
- C. For each of the special subroutines an explanation of what the algorithm is doing (fig. 15).
- D. For the retrieval calculation, a step by step description is offered.

XVI. Derived meteorological parameters.

- A. What are some of the products (besides temperature and dewpoint) which can be derived either directly or indirectly from the measured radiances defined by TOVS and VAS (fig. 16)?
- B. Also examples of products derived from remotely sensed satellite information which are not related to the temperature/moisture profile inversion scheme.
- C. Qualitative use of the imaged radiances.

XVII. Applications to numerical methods.

- A. A brief overview of satellite derived products and their inclusion in numerical weather prediction (NWP) models.
- B. What are the unique requirements needed to introduce satellite derived temperature/moisture profiles into NWP models?
- C. What are the characteristics of satellite data relative to numerical models (fig. 17)?
- D. Some examples showing assimilation of TOVS data into analysis and forecast models.

XVIII. Future satellite systems.

- A. Review of the current scenario.
- B. Future geostationary satellites.
- C. Future NOAA satellites (fig. 18).
- D. The Earth Observing System (EOS) program.
- E. Operational facility instruments.
- F. NASA research facility instruments.
- G. ESA research facility instruments.
- H. Japanese research facility instruments.

## LECTURE 2. OVERVIEW OF WEATHER SATELLITES

### References:

The Meteorological Satellite: Overview of 25 Years of Operation,  
W. L. Smith et al.

Meteorological Satellites - Past, Present and Future. Proceedings of  
session on Meteorological Satellites at AIAA 20th Aerospace Sciences  
Meeting, Orlando, FL, 1982.

### 1. EARLY ATTEMPTS TO VIEW THE EARTH/ATMOSPHERE ENVIRONMENT FROM SPACE

- 1919 Robert Goddard paper "A Method of Reaching Extreme Altitudes"
- 1929 rocket launch with barometer, thermometer and camera
- 1947 rocket launches yield first cloud pictures from high altitude
- 1957 Sputnik I, first artificial satellite
- 1960 TIROS I, first meteorological satellite
- 1966 ATS-1, first geostationary meteorological satellite

### 2. THE TIROS SATELLITE SYSTEM: OPERATIONAL PLATFORMS: 1960-PRESENT

- 31 satellites in TIROS/ESSA/ITOS/TIROS-N/NOAA series
- TIROS I to X: 1960 to 1965:
  - research and development satellites
  - TIROS-VIII (1965): first global real-time direct readout
- ESSA 1 to 9: 1966 to 1969:
  - first operational meteorological satellites
  - direct readout and on-board storage capability
- ITOS / NOAA 1 to 5: 1970 to 1976:
  - Very High Resolution Radiometer (1 km) visible and IR
  - first operational Vertical Temperature Sounding Instrument (VTPR)
- TIROS-N / NOAA 6 to 11: 1978 to present
  - AVHRR (Advanced Very High Resolution Radiometer)
  - HIRS (High-Resolution Infrared Sounder)
  - MSU (Microwave Sounding Unit)
  - SSU (Stratospheric Sounding Unit)
- NOAA-K,L,M: 1991 to
  - AVHRR
  - AMSU (Advanced Microwave Sounding Unit)
  - HIRS
  - AIRS (Advanced Infrared Sounder): 1995: Polar Platform

3. NIMBUS SATELLITE SYSTEM: R & D PLATFORMS: 1964 - PRESENT

- seven satellites in the experimental series
- carried more than 35 remote sensing instruments, including
  - ERTS (Earth Resources Technology Satellite)
    - prototype for Landsat
  - ERB (Earth Radiation Budget)
    - solar and earth radiation fluxes
  - SMMR (Scanning Multi-channel Microwave Radiometer)
    - sea/ice, ocean surface, snow cover, land parameters
  - TOMS (Total Ozone Mapping Sensor)
    - total column and vertical profiles of ozone
  - CZCS (Coastal Zone Color Scanner)
    - coastal dynamics, life forms

4. NIMBUS EXPERIMENTAL SOUNDING INSTRUMENTS

- SIRS (Satellite Infrared Spectrometer): Nimbus 3, 4
  - First vertical profiles of temperature from space
  - Grating Spectrometer; no scanning
  - Resolution: 230 km
  - 8 channels in 11 to 15  $\mu\text{m}$  band
- IRIS (Infrared Interferometer Spectrometer): Nimbus 3, 4
  - Michelson Interferometer; no scanning
  - Spectral range from 5 to 25  $\mu\text{m}$  (continuous)
  - Resolution: 155 km (Nimbus 3), 95 km (Nimbus 4)
- SCR (Selective Chopping Radiometer): Nimbus 4, 5
  - Selective absorption of gas; no scanning
  - Resolution: 75 km (Nimbus 4), 40 km (Nimbus 5)
  - 6 then 16 channels from 2 to 200  $\mu\text{m}$
- ITPR (Infrared Temperature Profile Radiometer): Nimbus 5
  - Fixed spectral filters; scanner
  - High spatial resolution temperature profiles: 30 km
  - 7 channels from 3.8 to 15  $\mu\text{m}$
- HIRS (High Resolution Infrared Spectrometer): Nimbus 6
  - Prototype for the current HIRS-2 on NOAA satellites
  - Mechanically scanned radiometer with spectral selection by interference filters
  - Resolution: 30 km
  - 17 channels from 0.7 to 15  $\mu\text{m}$



- NEMS (Microwave Spectrometer): Nimbus 5
    - First microwave measurements for temperature profiles
    - Dicke radiometer; no scanning
    - Resolution: 200 km
    - 5 channels from 20 to 60 GHz
  - SCAMS (Scanning Microwave Spectrometer): Nimbus 6
    - Mechanically scanned Dicke radiometer
    - Higher resolution than NEMS; 145 km
    - 5 channels from 20 to 60 GHz
5. TIROS-N / NOAA SERIES
- TIROS-N launch: October 1978
  - NOAA 10 launch: September 1986
  - NOAA 11 scheduled launch: November 1988
  - Three instruments for atmospheric sounding:
    - HIRS-2: High resolution Infrared Sounder
      - 19 channels from 3.7 to 15  $\mu\text{m}$  (plus visible)
      - resolution: 30 km
      - principal absorption bands:
        - 15  $\mu\text{m}$  - temperature sounding
        - 4  $\mu\text{m}$  - temperature sounding
        - 7  $\mu\text{m}$  - moisture sounding
    - MSU: Microwave Sounding Unit
      - 4 channels from 50 to 58 GHz: temperature sounding
    - SSU: Stratospheric Sounding Unit
      - 3 channels near 15  $\mu\text{m}$ : temperature sounding
6. GEOSTATIONARY SATELLITES
- ATS (Applications Technology Satellite): 1966-67
    - black and white photos on request
    - 4 km resolution
    - visible only
  - SMS (Synchronous Meteorological Satellites): 1974-75
    - Visible Infrared spin-scan radiometer (VISSR)
    - continuous coverage
    - 1 km visible, 4 km infrared resolution

- GOES (Geostationary Operational Environmental Satellites)
  - spin-scan radiometer
  - first launch: GOES-1: 1980
- VISSR
  - Resolution: visible 1 km, infrared 4 km
- VAS (Vertical Atmospheric Sounder): GOES-1:
  - first geostationary sounder
  - 12 channels from 3.7 to 15  $\mu\text{m}$
  - sounder resolution: 16 (and 8) km
- METEOSAT
  - spin-scan radiometer
  - visible, infrared and water vapor imagery
  - resolution: 5 km (2.5 vis)
- GMS
  - spin-scan radiometer
  - visible and infrared imagery
  - resolution: 5 km
- INSAT
  - 3 axis stabilized platform
  - visible and infrared imagery
  - resolution: 2.75 (vis) and 11 (IR) km

## 7. SATELLITE ORBITAL CHARACTERISTICS

### POLAR ORBITING METEOROLOGICAL SATELLITES: NOAA SERIES

- altitude: 870 km near polar orbit
- sun synchronous (equatorial crossing at same local solar time)
- period (1 orbit): 102 minutes
- 26 degree rotation of earth orbit per satellite orbit
- daily eastward procession: 1 degree

### GEOSTATIONARY ORBITING METEOROLOGICAL SATELLITES: GOES SERIES

- Altitude: 36,000 km in equatorial plane
- 24 hour rotational period
- Stationary over a fixed longitude
- View of full earth disk (140 deg. long. at equator)
- METEOSAT: 000 degrees
- GOES EAST: 075 degrees West longitude
- GOES WEST: 135 degrees West longitude
- GMS: 140 degrees East longitude
- INSAT: 074 degrees East longitude

### LECTURE 3. INTRODUCTION TO THE INTERNATIONAL TOVS PROCESSING PACKAGE

#### References:

Documentation of the TOVS Bangladesh Data Processing Software. J. Nelson, CIMSS Report, 1985.

User Guide to the International TOVS Processing Package. T. H. Achtor, H. W. Woolf, A. J. Schreiner, CIMSS Report, 1988.

The International TOVS Processing Package. W. L. Smith, C. M. Hayden, A. J. Schreiner, H. M. Woolf. Presented at the Second International TOVS Study Conference. Igls, Austria, 1985. (Updated 1986).

#### ITPP:

A software package designed to process TOVS (TIROS Operational Vertical Sounder) radiance data to achieve vertical soundings of temperature and moisture.

#### BACKGROUND:

International Association of Meteorology and Atmospheric Physics (IAMAP) commissioned the International TOVS Working Group "to standardize a temperature and moisture retrieval algorithm, from the input of all members, such that the processed data of all members will be compatible."

- First ITSC meeting: August 1983, foundation of ITPP-1
- Fourth ITSC meeting: February 1988, Igls, Austria
- ITPP originally IBM version, later VAX version
- ITPP-4 presently under development
- ITPP for IBM PS/2 under development

#### ITPP GENERAL SUMMARY:

- The ITPP takes NOAA polar orbiter satellite raw radiance counts, formats, calibrates, navigates the data, and creates files necessary to run a physical simultaneous retrieval algorithm to produce vertical profiles of atmospheric temperature and moisture.

- Two data processing paths:

1. Direct readout (HRPT)
2. Tape input (1B format)

- Essential operations:

1. Software ingest
2. Preprocessing
3. Retrieval generation

#### DATA ACQUISITION

ITPP will operate on:

1. Raw TOVS TIP data embedded in the HRPT data stream
  - <PRETIP> separates TOVS from AVHRR in HRPT data stream
  - <PREING> decommutates (reformats) the data
  - <INGTOV> calibrates and earth locates data, and transforms raw radiance counts into brightness temperatures and writes result into a file named TOVSINGO.
  - <TOVPRE> transforms the data in TOVSINGO to file structures for image display and temperature and moisture retrieval.

Limb corrections can be applied to HIRS and MSU data

MSU radiances are interpolated to HIRS scan pattern

Output files are TOVORB\_ and TOVSND\_  
( \_ is a letter A-Z)

ITPP will operate on:

2. Archival TOVS data written to magnetic tape in Level 1B format
  - data has been through preliminary processing by a local receiving station or the NESDIS archive in the U.S.A.
  - tapes contain TOVS radiance counts, and calibration and navigation information
  - <INVTAP> prints out the tape inventory
  - <TOVTAP> does the tape to computer disk transfer
  - <TOVING> produces the calibrated, navigated, brightness file TOVSINGO (meeting point with direct readout process)

## RETRIEVAL PROCESSING

- <TOVPRE> takes file TOVSINGO and transforms the data into two files
  1. TOVORB\_ (where \_ is a letter A through Z)
    - formats each channel of the HIRS and MSU brightness temperatures for image display
  2. TOVSND\_ (where \_ is a letter A through Z)
    - formats all the brightness temperatures for a given geographical location to optimize retrieval processing

### 2 retrieval algorithms available in ITPP

1. <TOVRET> physical simultaneous retrieval of parameters
  - initial estimate of vertical profile
  - surface data recommended
  - determine size, spacing, areal coverage
  - determine type of retrieval
2. <TOVSTR> statistical retrieval
  - surface data recommended
  - determine size, spacing, areal coverage
  - determine type of retrieval

Output written to file TOVRET, which contains

- header information
- surface and atmospheric calculations (Tb, Tsk, T, Td, Z,)
- first guess information
- other pertinent information (stab, ozone, olr, cld, wind)

## POST PROCESSING

<FILRET> automated quality control module which eliminates soundings of questionable reliability

- uses objective analyses of
  - final vs. microwave only retrieval differences

- 1000 - 500 mb geopotential thickness field
- skin temperature vs surface temperature comparison

Manual editing operation using videographic computer displays of retrieval output and cursor

- scientist defines fields to examine
- locates questionable retrievals with cursor and flags them

<WINRET> calculates geostrophic winds

- geopotential fields constructed by objective analysis
- geostrophic approximation applied
- written to TOVRET file

## LECTURE 4. THE NATURE OF RADIATION

SUNDAY, 13 NOVEMBER: DAY 2

### References:

NOTES ON SATELLITE METEOROLOGY.

W. PAUL MENZEL, 1984.

ATMOSPHERIC SCIENCE: AN INTRODUCTORY SURVEY.

J. WALLACE AND P. HOBBS: ACADEMIC PRESS, 1977.

### RADIATION:

A PROCESS WHEREBY ENERGY IS TRANSFERRED ACROSS SPACE WITHOUT THE NECESSITY OF A MATERIAL MEDIUM (IN CONTRAST WITH CONDUCTION, CONVECTION, OR ADVECTION).

### RADIATIVE TRANSFER:

MECHANISM FOR EXCHANGING ENERGY BETWEEN BODIES OR MEDIUMS

### REMOTE SENSING:

THE OBSERVATION OF A TARGET BY A DEVICE SEPARATED FROM IT BY SOME DISTANCE.

### BASIC UNITS:

ALL FORMS OF ELECTROMAGNETIC RADIATION (EMR) TRAVEL IN A VACUUM AT THE SAME VELOCITY

$3 \times 10^8$  m/sec , denoted by letter 'c'

RADIATION FROM ONE "COLOR" (INFINITESIMAL REGION OF THE SPECTRUM) IS CALLED MONOCHROMATIC.

**FREQUENCY ( $f$ ):** NUMBER OF WAVES PAST A FIXED POINT IN A SECOND

**WAVELENGTH ( $\lambda$ ):** LENGTH OF A SINGLE WAVE, OR THE DISTANCE BETWEEN TWO SUCCESSIVE MAXIMA

THE SPEED OF EMR IS RELATED TO FREQUENCY AND WAVELENGTH BY:

$$c = f \lambda = 3 \times 10^8 \text{ m/sec}$$

or

$$f = c / \lambda \quad (\text{cycles / second})$$

**WAVENUMBER ( $\nu$ ):** NUMBER OF WAVES IN 1 CM

$$= 1/\lambda \quad (\text{CM}^{-1})$$

WAVELENGTH UNITS DEPEND ON THE SPECTRAL REGION CONSIDERED:

ANGSTROMS (A): VERY SHORT WAVELENGTHS  
 MICRONS ( $\mu\text{m}$ ): VISIBLE THROUGH INFRARED  
 CENTIMETERS (cm): MICROWAVE WAVELENGTHS

$$1 \text{ A} = 10^{-10} \text{ m} = 10^{-8} \text{ cm} = 10^{-4} \mu\text{m}$$

and

$$1 \mu\text{m} = 10^{-6} \text{ m} = 10^{-4} \text{ cm} = 10^4 \text{ A}$$

FREQUENCY UNITS ARE RELATED BY:

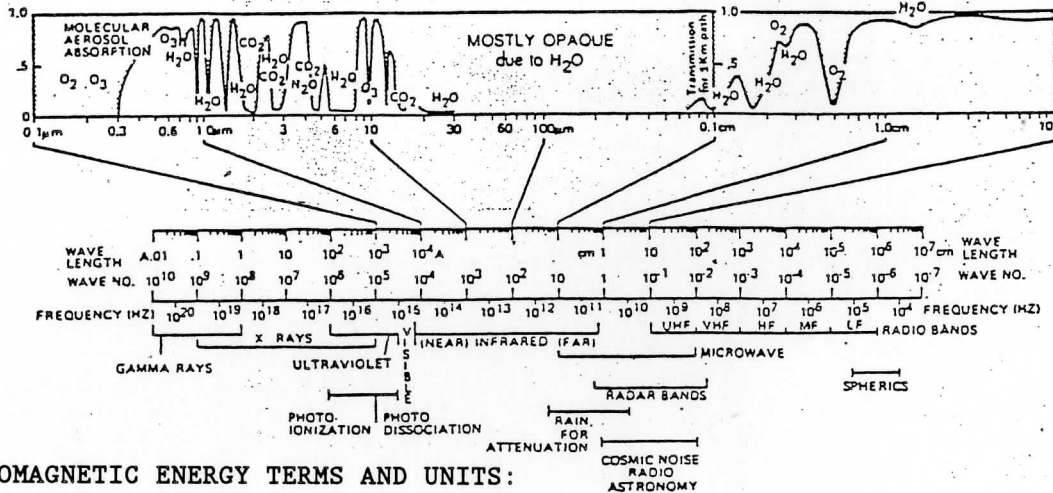
$$1 \text{ cm}^{-1} = 3 \times 10^{10} \text{ Hz} = 30 \text{ GHz}$$

and

$$1 \text{ GHz} = 10^9 \text{ Hz} = 1/30 \text{ cm}^{-1}$$

**ELECTROMAGNETIC SPECTRUM:**

THE TOTALITY OF ALL POSSIBLE WAVELENGTHS OF ELECTROMAGNETIC RADIATION (EMR)



**ELECTROMAGNETIC ENERGY TERMS AND UNITS:**

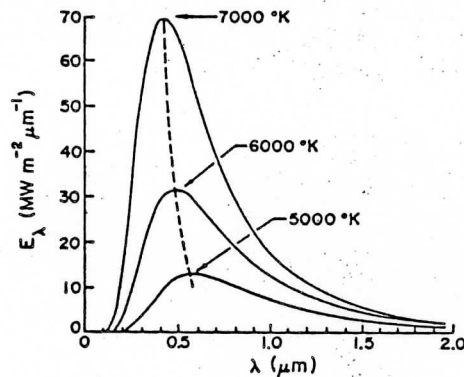
**RADIANT FLUX:** RATE OF ENERGY TRANSFER BY EMR  
 (WATTS = JOULES/SECOND)

**IRRADIANCE (E):** RADIANT FLUX PER UNIT AREA ( $\text{W}/\text{m}^2$ )

**MONOCHROMATIC IRRADIANCE ( $E_\lambda$ ):** RADIATION AT WAVELENGTHS WITHIN A PARTICULAR INFINITESIMAL WAVELENGTH INTERVAL OF THE SPECTRUM ( $\text{W} / \text{m}^2 / \mu\text{m}$ ), OR



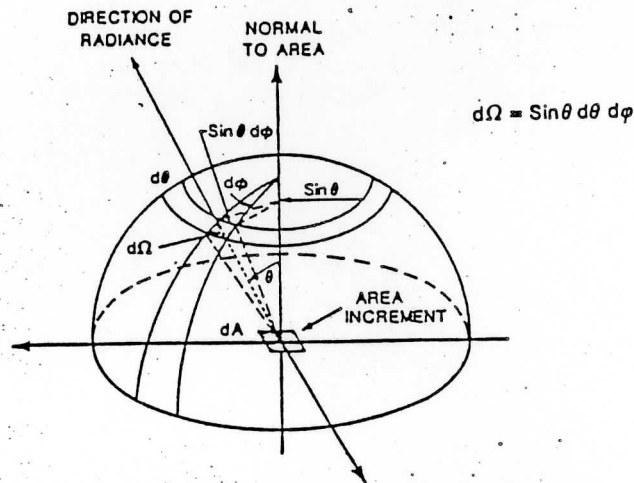
$$E = \int_0^{\infty} E_{\lambda} d\lambda$$



IRRADIANCE MAY CONSIST OF CONTRIBUTIONS FROM AN INFINITE NUMBER OF DIFFERENT DIRECTIONS. TO IDENTIFY THE IRRADIANCE COMING DIRECTIONS WITHIN A GIVEN SOLID ANGLE, WE DEFINE

ELECTROMAGNETIC ENERGY TERMS AND UNITS: (cont'd)

RADIANCE (L): IRRADIANCE PER UNIT SOLID ANGLE  
(W / m<sup>2</sup> / st)



ZENITH ANGLE ( $\theta$ ): ANGLE BETWEEN THE DIRECTION OF THE RADIATION AND NORMAL TO THE SURFACE IN QUESTION

DIFFUSE RADIATION: THAT EMANATING FROM A SOURCE THAT SUBTENDS A FINITE ARC OF SOLID ANGLE  $\partial\Omega$

PLANCK'S RADIATION LAW

BLACKBODY: A HYPOTHETICAL BODY COMPRISING A SUFFICIENT NUMBER OF MOLECULES ABSORBING AND EMITTING ELECTROMAGNETIC RADIATION IN ALL PARTS OF THE ELECTROMAGNETIC SPECTRUM SUCH THAT:

- 1) ALL INCIDENT RADIATION IS COMPLETELY ABSORBED, AND
- 2) IN ALL WAVELENGTH BANDS AND IN ALL DIRECTIONS THE MAXIMUM POSSIBLE EMISSION IS REALIZED.

IN OTHER WORDS, A BLACKBODY IS A PERFECT ABSORBER AND ISOTROPIC EMITTER OF ALL RADIATION

THE AMOUNT OF RADIATION EMITTED BY A BLACKBODY IS UNIQUELY DETERMINED BY ITS TEMPERATURE, AS DESCRIBED BY PLANCK'S LAW

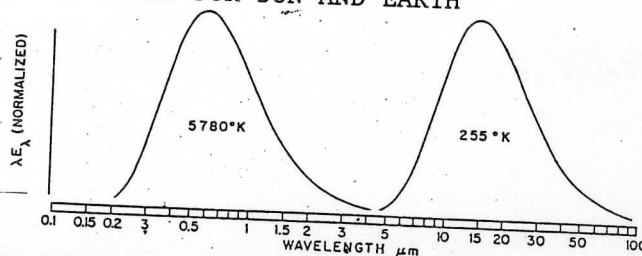
$$E_{\lambda, T} = \frac{C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)}$$

where

$$C_1 = 3.74 \times 10^{-16} \text{ Wm}^{-2} \text{ and}$$

$$C_2 = 1.44 \times 10^{-2} \text{ m K}$$

PLOTTING PLANCK FUNCTIONS FOR SUN AND EARTH



RELATED DERIVATIONS OF PLANCK'S RADIATION LAW

WEINS DISPLACEMENT LAW:

THE PEAK OF THE PLANCK FUNCTION CURVES SHIFTS TO SHORTER WAVELENGTHS WITH AN INCREASE IN TEMPERATURE.

BY DIFFERENTIATING THE PLANCK FUNCTION W.R.T. WAVELENGTH AND EQUATING THE RESULT TO ZERO, WE FIND THE WAVELENGTH OF MAXIMUM EMISSION, OR

$$\lambda_{max} = \frac{2879}{T}$$

WHICH STATES THAT THE WAVELENGTH OF MAXIMUM EMISSION VARIES INVERSELY WITH TEMPERATURE

AT VERY LONG WAVELENGTHS (E.G., MICROWAVE) THE PLANCK RADIANCE IS LINEAR WITH TEMPERATURE (RAYLEIGH-JEANS LAW)

IN THE NEAR INFRARED REGION AND TOWARDS SHORTER WAVELENGTHS THE PLANCK RADIANCE IS HIGHLY NON-LINEAR WITH TEMPERATURE (WIEN REGION). SUCH REGIONS ARE BETTER FOR VERTICAL TEMPERATURE SOUNDINGS.

STEFAN-BOLTZMAN LAW:

BY INTEGRATING THE PLANCK FUNCTION OVER ALL WAVELENGTHS IT CAN BE SHOWN THAT

$$E = \sigma T^4$$

WHICH SIMPLY STATES THAT BLACKBODY IRRADIANCE IS PROPORTIONAL TO TEMPERATURE RAISED TO THE FOURTH POWER

RADIANCE TEMPERATURE:

ULTIMATELY, WE ARE INTERESTED IN THE TEMPERATURE THAT CORRESPONDS TO A PARTICULAR PLANCK FUNCTION VALUE. BY INVERTING THE PLANCK FUNCTION AND SOLVING FOR TEMPERATURE

$$T = \frac{c_2 \nu}{\ln \left( \frac{c_1 \nu^3}{B \nu} + 1 \right)}$$

WHICH IS CALLED THE BRIGHTNESS TEMPERATURE, BUT MORE CORRECTLY IS THE RADIANCE TEMPERATURE OR EQUIVALENT BLACKBODY TEMPERATURE

## LECTURE 5. ATMOSPHERIC PROCESSES

### References:

Wallace, John M., and Peter V. Hobbs, 1977: Atmospheric Science: An Introductory Survey. Academic Press, New York, NY, 467 pp.

Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104 pp.

I. Characteristics of irradiance passing through a medium in thermodynamic equilibrium. (Consider an atmospheric slab, four processes modify the incident radiation,  $I_0$ , passing through the slab.)

- A. Reflection:  $r = I_r / I_0$  (reflectivity)
- B. Absorption:  $a = I_a / I_0$  (absorptivity)
- C. Transmission:  $t = I_t / I_0$  (transmissivity)
- D. Emission:  $e = I_e / B(T)$ ; compare to the perfect emitter, which is a Black Body emitter (emissivity)

II. Absorption and emission (Kirchoff's Law).

- A. Blackbody ( $e=1$ ) is a theoretical substance which emits the maximum amount of radiation for a given temperature..
- B. Gray body ( $e<1$ ) is a substance whose emissivity is independent of wavelength.
- C. Kirchoff's Law is defined for a body which is in thermodynamic equilibrium (the body is not heating up or cooling down), ( $a=e$ ) ; strong absorbers at a given wavelength are strong emitters at that wavelength.

III. Conservation of energy.

- A. For an absorbing medium, again in thermodynamic equilibrium, the total incident radiation ( $I$ ) is equal to sum of the amounts absorbed ( $aI$ ), reflected ( $rI$ ), and transmitted ( $tI$ ).

$$I = aI + rI + tI$$

or

$$1 = a + r + t$$

or

$$1 = e + r + t$$

- B. If the medium is assumed to be a black body, then

$$a = 1$$

and

$$r = t = 0,$$

which is another way of stating Kirchoff's Law.

- C. If the absorbing medium is in the "window region" of the radiation spectrum,

$$\begin{aligned}t &= 1 \\ &\text{and} \\ r &= a = 0\end{aligned}$$

- D. For each of the above examples the relationships are valid for irradiance emitted at a given wavelength.

IV. Selective absorption and emission.

- A. Earth's atmosphere absorbs in the infrared (outgoing earth) and transmits in the visible (incoming solar).
- B. Sample problem of a two-layer system. Assume the earth is a blackbody and is in thermodynamic equilibrium (temperature is constant). Let  $a_{IR} = 0.8$  and  $a_{VIS} = 0.2$ ;  $E$  is the solar irradiance absorbed by the earth-atmosphere system;  $Y_a$  is the irradiance emitted by the atmosphere (both up and down); and  $Y_s$  is the irradiance emitted from the earth's surface.

Then at the top of the atmosphere the balance equation is:

$$E - (1 - a_{IR}) Y_s - Y_a = 0$$

The radiation balance equation at the surface of the earth is:

$$(1 - a_{VIS}) E - Y_s + Y_a = 0$$

Solving for  $Y_s$  yields:

$$Y_s = \frac{(2 - a_{VIS})}{(2 - a_{IR})} E.$$

Using the Stefan-Boltzman Law and remembering from the previous problem that  $E = 241 \text{ W/m}^2$ ,  $T_s$  can be derived from  $Y_s$ .

$$T_s = 283^\circ \text{ K}$$

Whenever a gas, which is a weak absorber in the visible (short wavelengths) and a strong absorber in the infrared (long wavelengths), is a constituent of an atmosphere, it

contributes toward raising the surface temperature of the planet. This also leads to the concept of the "greenhouse", or more correctly, "atmospheric" effect.

C. Absorption (emission) line formation.

1. electronic excitation.
2. molecular or atomic vibration.
3. molecular or atomic rotation.

V. The earth-atmosphere system.

- A. Relative composition of the gases of the earth's atmosphere (table 1).
- B. The  $\text{CO}_2$  absorption band (uniformly mixed throughout the atmospheric column) (fig. 1).
- C. The  $\text{H}_2\text{O}$  absorption band (variable in space and time) (fig. 1).
- D. The  $\text{O}_3$  absorption band (fig. 1).
- E. The atmospheric window is the region between 800 to 1200  $\text{cm}^{-1}$  (12 to 8 micrometers) where the atmosphere is relatively transparent (with the exception of the ozone absorption band).
- F. The solar and infrared spectra are separated into two spectral ranges below and above 4 micrometers, and the overlap between them is relatively insignificant. This distinction makes it possible to treat the two types of radiative transfer and source functions separately and thereby simplify the complexity of the transfer problem.

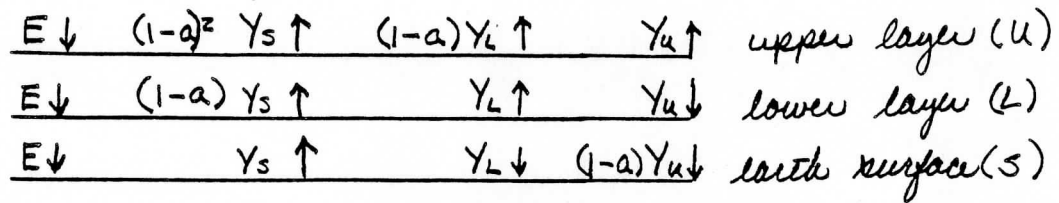
VI. Discussion problem.

Expanding on the selective absorption and emission problem of a two layer system discussed in lecture, let the atmosphere be represented by two layers and compute a vertical temperature profile for the three layer system (surface plus two atmospheric layers). Assume  $a_{\text{VIS}}=0$  and  $a_{\text{IR}}=.5$  (solar and long wave absorptivities, respectively).

Solution.

Let  $E$  be the solar irradiance absorbed by earth-atmosphere system;  $Y_S$  is the irradiance emitted by the earth's surface; and  $Y_U$  and  $Y_L$  are the irradiances emitted by the upper and lower atmospheric layers, respectively.

The following figure demonstrates the incoming and outgoing balances for each layer:



Keep in mind that the total absorptivities from one layer to another can be defined as probabilities, which means

$$a_{a-c} \neq a_{a-b} + a_{b-c}$$

but rather,

$$a_{a-c} = a_{a-b} \times a_{b-c}$$

The radiation equilibrium for each layer is defined as,

$$\textcircled{1} E = .25Y_S + .5Y_L + Y_U$$

$$\textcircled{2} E = .5Y_S + Y_L - Y_U$$

$$\textcircled{3} E = Y_S - Y_L - .5Y_U$$

Defining the variables "Y" in terms of E, there are three equations and three unknowns.

$$\textcircled{1} + \textcircled{2} \quad 2E = .75Y_S + 1.5Y_L \quad \textcircled{A}$$

$$\textcircled{2} - 2 \times \textcircled{3} \quad -E = -1.5Y_S + 3.0Y_L \quad \textcircled{B}$$

$$2 \times \textcircled{A} + \textcircled{B} \quad 3E = 6Y_L$$

$$\therefore Y_L = .5E$$

*Substitute  $Y_L$  in Eq. (A)*

$$2E = .75Y_S + 1.5(.5E)$$

$$1.25E = .75Y_S$$

$$\therefore Y_S = 1.7E$$

*Substitute  $Y_L$  and  $Y_S$  in Eq. (2)*

$$E = .5(1.7E) + (.5E) - Y_U$$

$$\therefore Y_U = .35E$$

Since  $E (= 241 \text{ W/m}^2)$  is defined from an earlier problem in lecture, and using the Stefan-Boltzman Law,

$$T_S = [1.7E/\sigma]^{1/4} = 292\text{K}$$

$$T_L = [.50E/.5\sigma]^{1/4} = 255\text{K}$$

$$T_U = [.35E/.5\sigma]^{1/4} = 234\text{K}$$

FIG.1:

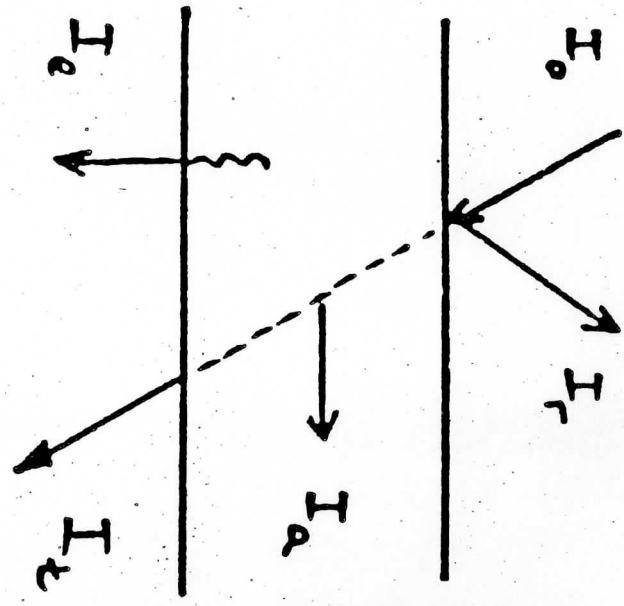
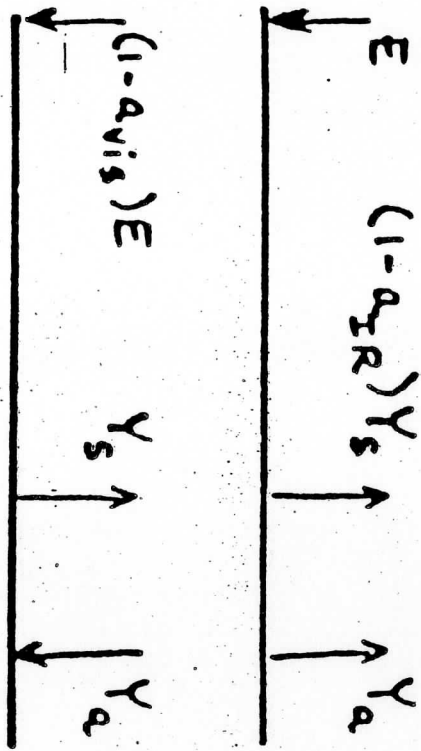
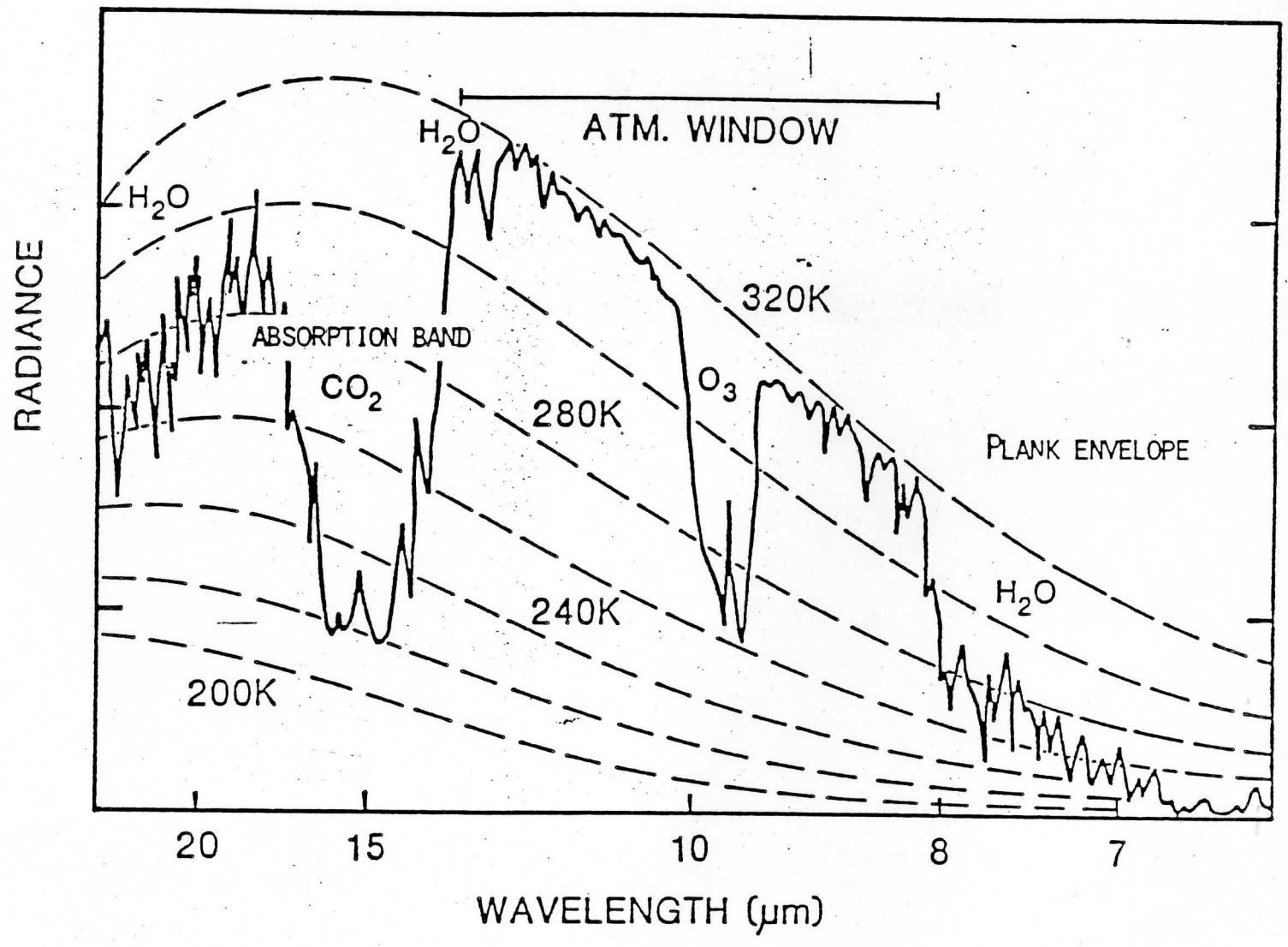




FIG. 2



### EARTH-ATMOSPHERE EMITTED IR RADIATION



- $\text{CO}_2$  UNIFORMLY  
MIXED IN ATMOSPHERE

- $\text{H}_2\text{O}$  VARIES WITH  
SPACE AND TIME

Table 1  
The Composition of the Atmosphere<sup>a</sup>

Permanent constituents		Variable constituents	
Constituent	% by volume	Constituent	% by volume
Nitrogen (N <sub>2</sub> )	78.084	Water vapor (H <sub>2</sub> O)	0-0.04
Oxygen (O <sub>2</sub> )	20.948	Ozone (O <sub>3</sub> )	0-12 × 10 <sup>-4</sup>
Argon (Ar)	0.934	Sulfur dioxide (SO <sub>2</sub> ) <sup>b</sup>	0.001 × 10 <sup>-4</sup>
Carbon dioxide (CO <sub>2</sub> )	0.033	Nitrogen-dioxide (NO <sub>2</sub> ) <sup>b</sup>	0.001 × 10 <sup>-4</sup>
Neon (Ne)	18.18 × 10 <sup>-4</sup>	Ammonia (NH <sub>3</sub> ) <sup>b</sup>	0.004 × 10 <sup>-4</sup>
Helium (He)	5.24 × 10 <sup>-4</sup>	Nitric oxide (NO) <sup>b</sup>	0.0005 × 10 <sup>-4</sup>
Krypton (Kr)	1.14 × 10 <sup>-4</sup>	Hydrogen sulfide (H <sub>2</sub> S) <sup>b</sup>	0.00005 × 10 <sup>-4</sup>
Xenon (Xe)	0.089 × 10 <sup>-4</sup>	Nitric acid vapor (HNO <sub>3</sub> )	Trace
Hydrogen (H <sub>2</sub> )	0.5 × 10 <sup>-4</sup>		
Methane (CH <sub>4</sub> )	1.5 × 10 <sup>-4</sup>		
Nitrous oxide (N <sub>2</sub> O) <sup>b</sup>	0.27 × 10 <sup>-4</sup>		
Carbon monoxide (CO) <sup>b</sup>	0.19 × 10 <sup>-4</sup>		

<sup>a</sup> After the U.S. Standard Atmosphere, 1976.

<sup>b</sup> Concentration near the earth's surface.

## LECTURE 6. RADIATIVE TRANSFER IN THE ATMOSPHERE

MONDAY, 14 NOVEMBER: DAY 3

### References:

Wallace, John M. and Peter V. Hobbs, 1977: Atmospheric Science an Introductory Survey. Academic Press, New York, NY, 467 pp.

Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104 pp.

### I. Beer's Law and Schwarzschild's equation.

#### A. Definitions.

1. Absorption coefficient is a measure of the fraction of the gas molecules per unit wavelength interval that are absorbing radiation at the wavelength in question.
2. Optical depth or optical thickness is a measure of the cumulative depletion that the beam of radiation has experienced as a result of its passage through the layer.

- B. Beer's law states that radiance decreases monotonically with increasing path length through the layer. Mathematically it is written,

$$I_{\lambda} = I_{\lambda} \exp(-K_{\lambda} u)$$

where,

$$u = \sec \phi \int_z^{\infty} \rho dz$$

The quantity  $u$  is called the path length.  $K_{\lambda} u$  is called the optical depth.

- C. Indirect calculation of the spectrum of solar radiation at the top of the atmosphere using ground-based measurements is an application of Beer's law.  $dL_{\lambda} = K(L_{\lambda} - B_{\lambda}) \rho \sec \phi dz$
- D. Schwarzschild's equation is the basis for computations of the transfer of infrared radiation.

### II. Atmospheric scattering is the process by which a particle in the path of an electromagnetic wave continuously abstracts energy from the incident wave and re-radiates that energy in all directions. The relative intensity of the scattering pattern depends strongly on the ratio of particle size or wavelength of the incident wave.

- A. Rayleigh scattering indicates that the intensity scattered by air molecules in a specific direction is inversely proportional to the fourth power of the wavelength

(generally to particles the size of air molecules). An example of Rayleigh scattering is why the sky is blue.

- B. Mie scattering is more complicated and varies rapidly with particle size (for example: smoke, smog, and dust). Since these particles tend to be non-uniform in size the rendered scattered light is neutral or whitish in color.
  - C. The scattering of visible radiation by cloud droplets, raindrops, and ice particles falls within the regime of geometric optics and produces a number of distinctive optical phenomena such as rainbows and halos.
  - D. Scattering of terrestrial radiation in the atmosphere is of secondary importance compared to absorption and emission of same.
- III. The mean global energy balance (fig. 1) can be discussed from two different perspectives.

A. A balance of incoming and outgoing radiation.

- 1. Incoming is defined as solar or short wave (sw) radiation; it is absorbed (by atmosphere, clouds, and surface), reflected (by clouds and surface), and back-scattered by air molecules.
- 2. Outgoing is made up of infrared or long wave (lw) radiation; it is emitted by surface, clouds, water vapor, and carbon dioxide, and absorbed by H<sub>2</sub>O and CO<sub>2</sub>.
- 3. Latent and sensible heat, originating from the underlying surface, arises from the evaporation/precipitation of water (latent heat of precipitation) and the conduction of sensible heat from the surface below.

B. An examination of the balance of radiation within the three different layers of the earth-atmosphere system (which layers are sources and sinks).

- 1. top of the atmosphere (total = 100units at top of the atmosphere):

$$\begin{aligned} \text{Incoming} + \text{Outgoing} &= \text{Net} \\ (100(\text{sw}))_{\text{in}} + \{-30(\text{sw})_{\text{ref}} + [-70(\text{lw})]\}_{\text{out}} &= 0 \end{aligned}$$

- 2. Atmosphere,

$$\begin{aligned} \text{Absorbed} + \text{Emitted} + \text{Flux} &= \text{Net} \\ 19(\text{sw}) + 15(\text{lw})_{\text{ab}} + \{-64(\text{lw})\}_{\text{em}} + \{30(\text{sl})\}_{\text{fl}} &= 0 \end{aligned}$$

3. Surface,  
Absorbed + Emitted + Flux = Net  
 $\{51(\text{sw})\}_{\text{ab}} + \{-21(\text{lw})\}_{\text{em}} + \{-30(\text{sl})\}_{\text{fl}} = 0$

IV. The first satellite experiment to measure the net radiation.

- A. Explorer VII, 1959.
- B. Two heat sensing detectors.
  1. White to reflect the shortwave sun's energy and thereby absorb only earth radiation.
  2. Black to absorb radiation at all wavelengths.
- C. Using Stefan-Boltzman and Kirchoff's laws, the following equations were derived:

$$F_o + F_s = [4\sigma a'_w (a_w^s - a_w^s)] (T_b^4 - T_w^4)$$

$$F_{\text{IR}} = [4\sigma (a_w^s - a'_w)] (a_w^s T_b^4 - a'_w T_w^4)$$

Where  $F_s$ ,  $F_{\text{IR}}$ , and  $F_o$  represent flux densities of the reflected short-wave, long-wave radiation, and direct solar.

V. The radiation budget.

The circulation of the earth's atmosphere and oceans can be envisioned to be powered by a heat engine. The shortwave radiation from the sun provides the fuel supply while the infrared radiation heat loss to space from the earth's surface and atmosphere is the exhaust. The engine is throttled, to a large extent, by storms and oceanic disturbances associated with the transformation of radiative heat to sensible and latent heat.

- A. Globally averaged monthly mean values of various radiation budget parameters (fig. 2) indicate that the net radiation integrated over an entire year must be near zero.
  1. Absorbed solar very nearly repeats cycle from one year to next.
  2. Longwave radiation and albedo appear to be 180 degrees out of phase.
    - a. Variation in outgoing longwave dominated by land masses which are more predominant in the northern hemisphere; thus in northern winter there is more snow and ice cover than for southern hemisphere winter which would increase albedo.

- b. Second consideration is that there tends to be more cloudiness in northern hemisphere winter than southern hemisphere winter which would increase albedo and decrease outgoing longwave radiation.
- B. Variation in time of net, incoming, and outgoing solar radiation (fig. 3).

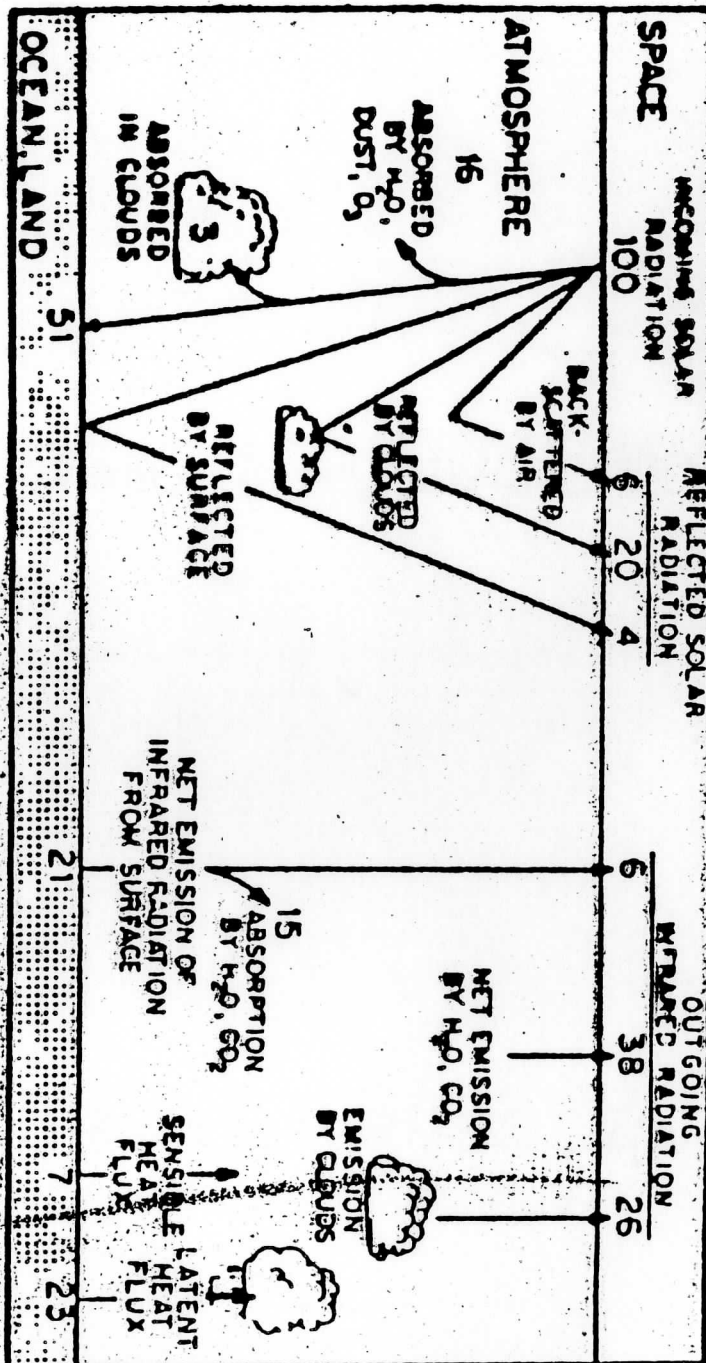
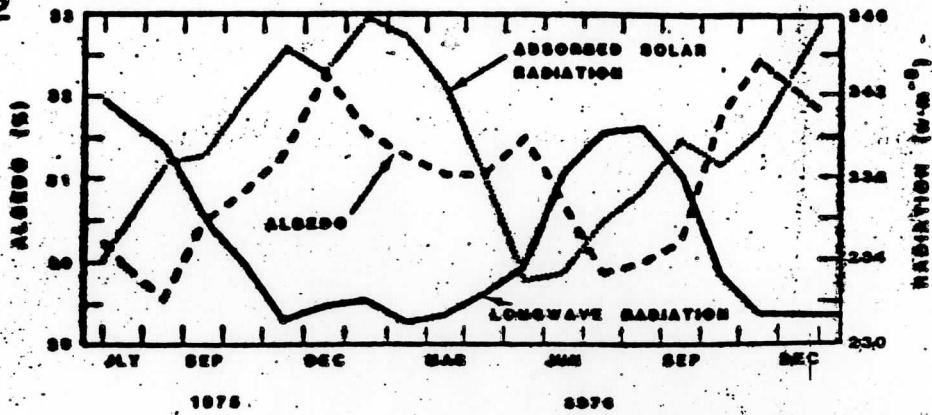




FIG. 2



Radiation Balance of the Earth as Measured by the ERS Instrument on NIMBUS-6

FIG. 3

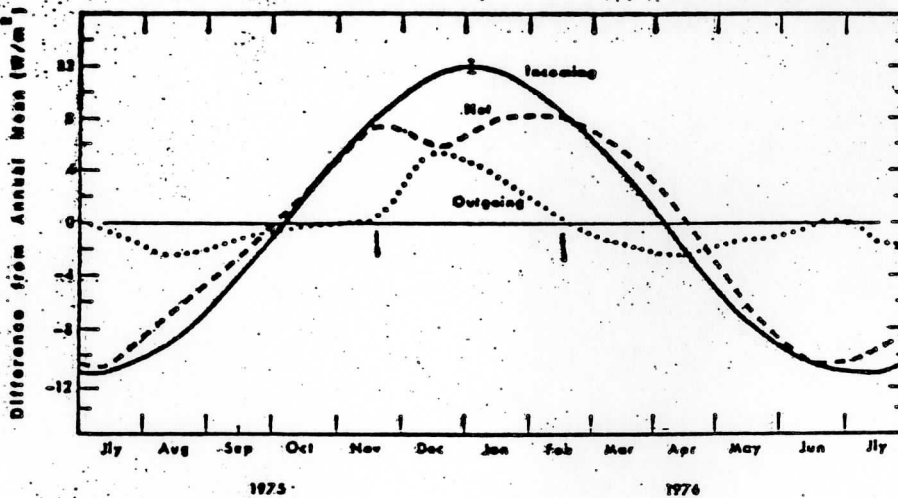


FIGURE 2 Globally averaged monthly mean values of radiation budget parameters;  
 3 variation in time of net, incoming, and outgoing Solar radiation.

## LECTURE 7. RADIATIVE TRANSFER EQUATION (RTE)

### References:

Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104 pp.

Fritz, S., D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary, and J. C. Alishouse, 1972: Temperature Sounding from Satellites. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service, Washington, DC, NOAA Technical Report NESS 59, 49 pp.

I. Radiative transfer serves as a mechanism for exchanging energy between the atmosphere and the underlying surface and between different layers of the atmosphere.

II. Beer's law for a thin slab of atmosphere.

A. From Beer's Law the transmittance ( $\tau$ ) of a monochromatic beam of irradiance can be defined;

$$\tau = \frac{B_{out}}{B_{in}} = \exp(-Ku)$$

B. The "absorbing power" is defined as  $-K$ , which is large at wavelengths close to the center of absorption lines and small at wavelengths away from absorption lines.

C. The "path length" is defined as,

$$u \equiv \sec \phi \int_z^{\infty} \rho dz$$

which is dependent on the angle of the beam of monochromatic irradiance, the density of the layer, as well as the thickness.

III. Outgoing radiation at the top of the atmosphere for a multi-layer model of atmosphere.

A. The radiance leaving the earth-atmosphere system which can be sensed by a satellite borne radiometer is the sum of radiation emissions from the surface and each atmospheric level that are transmitted to the top of the atmosphere.

B. Assume the earth to be a blackbody emitter ( $e=1$ ), which is almost true in the infrared. The upwelling monochromatic irradiance in a cloudless atmosphere can be described as shown in figure 1.

C. Mathematically this can be shown as,

$$R_{SFC} = B(T_{SEC}) \tau(u_{SFC}) ; R_{LAYER} = \epsilon_L B(T(p_L)) \tau(u(p_L)).$$

where  $R_{sfc}$  is the upwelling irradiance contributed by the surface, and  $L_{layer}$  is the contribution for each of the layers in the simple layered model shown in figure 1.

- D. Using Kirchoff's law ( $e=a$ ;  $e=1-t$ ) for an infinitesimal layer at pressure  $p$ , and realizing that reflection by atmospheric molecules is negligible ( $r=0$ ) in the infrared because wavelength is much larger than molecular size, then:

$$\epsilon_L \tau(u(p_L)) = (1 - \exp(-K \Delta u)) \exp(-K u(p_L))$$

$$\epsilon_L \tau(u(p_L)) = -\Delta \tau(u(p_L))$$

- E. The upwelling monochromatic irradiance ( $R$ ) can be written in the form of a surface component and the sum of "1" layers making up the atmospheric component:

$$R = R_{sfc} + \sum_L R_L$$

Expanding this equation the summation form is,

$$R = B(T(p_{sfc})) \tau(u(p_{sfc})) - \sum B(T(p_L)) \Delta \tau(u(p_L))$$

- F. The integral form of the RTE for a given wavelength is then:

$$R_\lambda = B_\lambda(T(p_{sfc})) \tau_\lambda(u(p_{sfc})) - \int_0^{p_s} B_\lambda(T(p)) \frac{d\tau_\lambda(u(p))}{dp} dp$$

where the first term on the right-hand side is spectral radiance emitted by the surface and attenuated by the atmosphere and the second term is the spectral radiance emitted to space by the atmosphere. The term on the left-hand side is the upwelling irradiance measured by the instrument aboard the satellite.

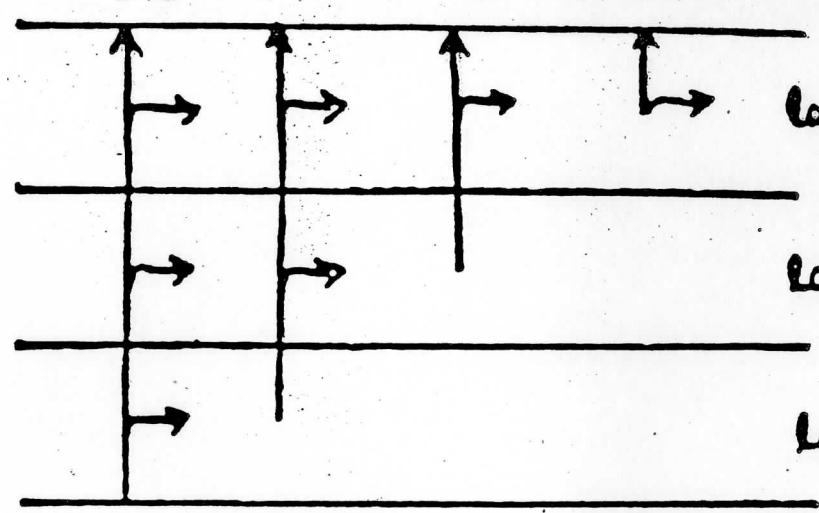
- G. The term  $d/dp$  for a unique wavelength is often called the weighting function, and when it is multiplied by the Planck function ( $B(T(p))$ ) yields the upwelling irradiance at altitude  $p$ . An example of several of the weighting functions for TOVS is shown in figure 2.
- H. The fundamental principle of atmospheric sounding is based on the solution of the radiative transfer equation. The observed radiance contains the temperature and gaseous profiles of the atmosphere, and the information content of the observed radiance from satellites must be related to the temperature field and absorbing gaseous concentration.

- IV. Characteristics unique to solution of temperature solution problem.
- A. Radiance arises from deep and overlapping layers (figure 3).
  - B. Because of large depth contributing to the outgoing radiance measurements, there is no unique relation between the spectrum of outgoing radiance and  $T(p)$  (figure 3).
  - C. The radiance observations are not independent.
  - D. Inverse solution has analytical difficulties; numerical approaches succeed. Since we are ultimately solving for temperature, which is under the integral operator, the solution leads to an ill-conditioned mathematical problem.

OUTGOING RADIATION AT TOP OF ATMOSPHERE,  
 CONSIDER A MULTILAYER MODEL OF ATMOSPHERE,

$$R_{sfc} + R_1 + R_2 + R_3 + \dots = R$$

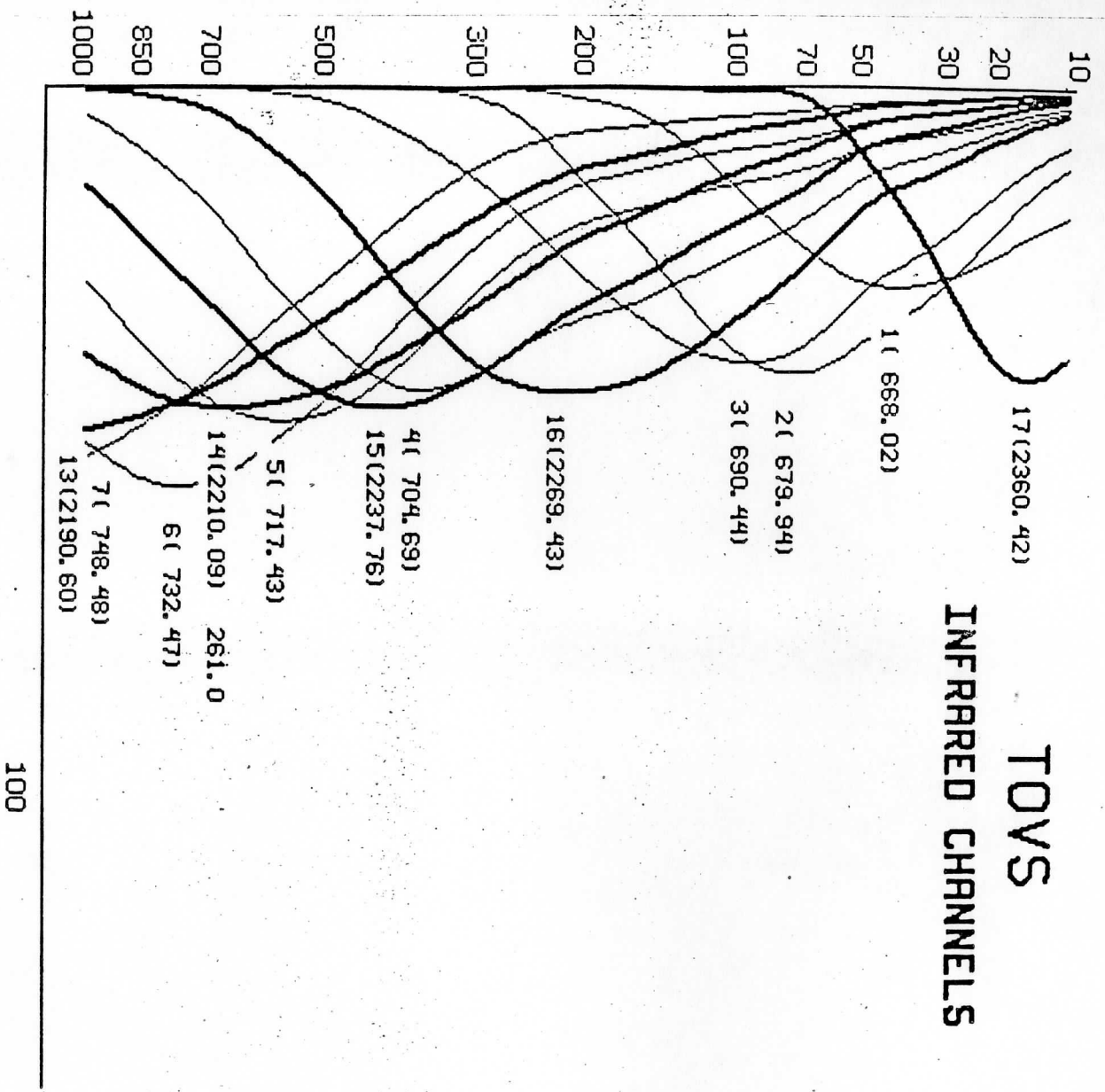
top  
  
  
  
  
  
sfc



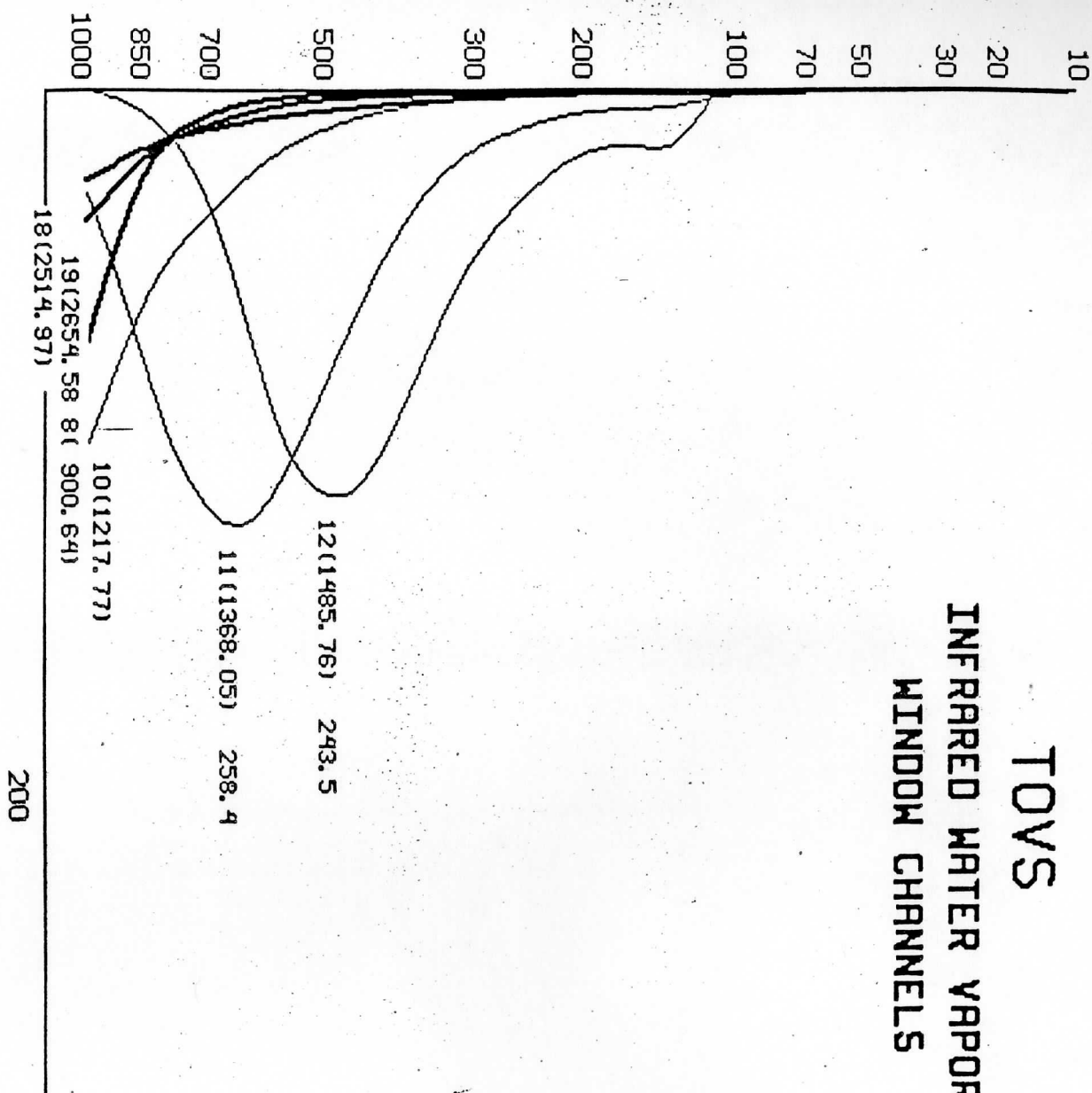
layer 3  
layer 2  
layer 1

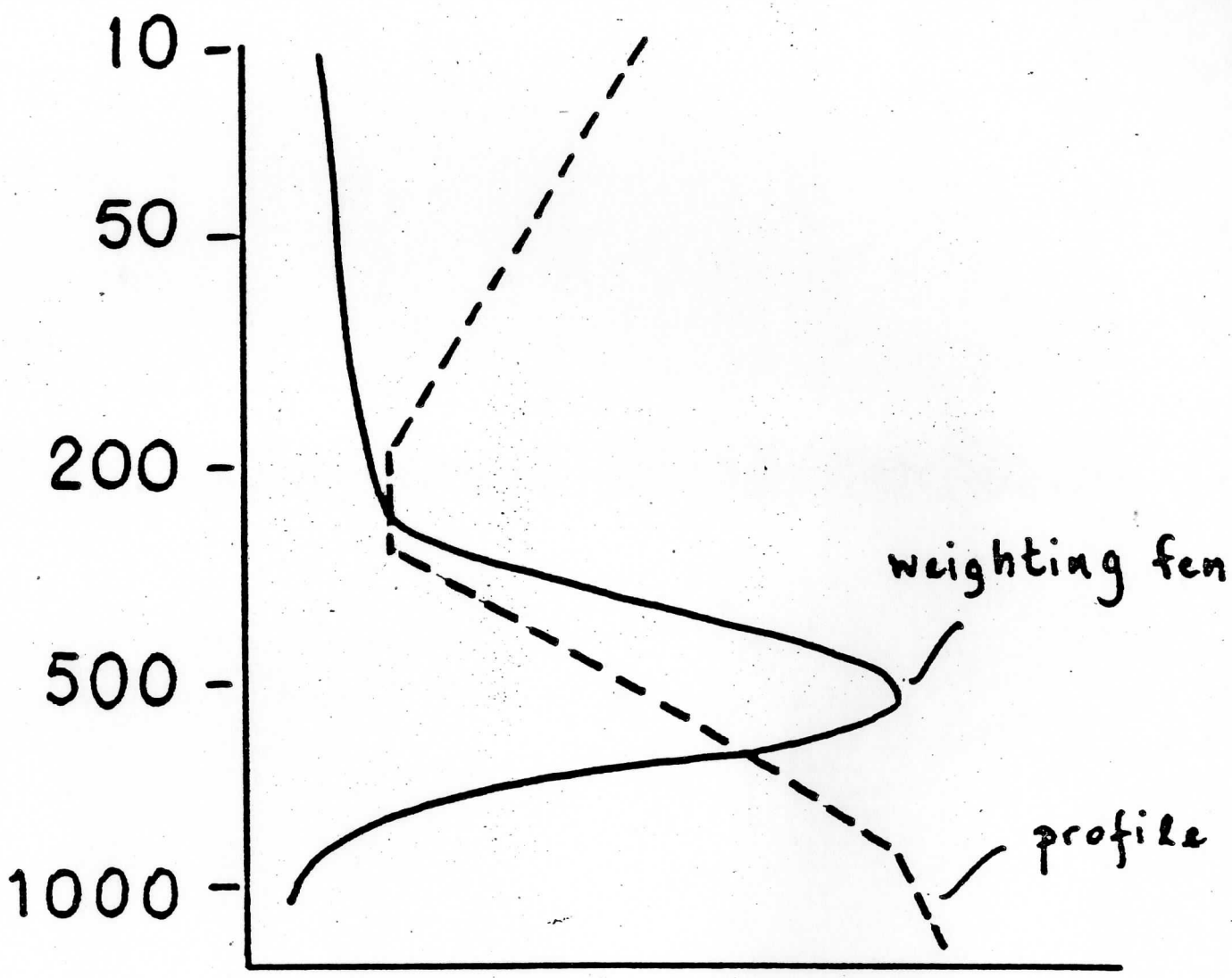
$\Delta u_3$   
 $\Delta u_2$   
 $\Delta u_1$

FIG. 2



# TOVS INFRARED WATER VAPOR AND WINDOW CHANNELS







LECTURE 8. SOLUTIONS TO THE RTE

TUESDAY, 15 NOVEMBER: DAY 4

References:

Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104 pp.

Fritz, S., D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary, and J. C. Alishouse, 1972: Temperature Sounding from Satellites. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service, Washington, DC, NOAA Technical Report NESS 59, 49 pp.

King, J. I. F., 1956: The radiative heat transfer of planet earth. In Scientific Use of Earth Satellites, University of Michigan Press, Ann Arbor, Michigan, 133-136.

Kaplan, L. D., 1959: Inference of atmospheric structure from remote radiation measurements. Journal of the Optical Society of America, 49, 1004.

Wark, D. Q., 1961: On indirect temperature soundings of the stratosphere from satellites. Journal of Geophysical Research, 66, 77.

- I. Background to the temperature profile inversion problem.
  - A. Early pioneers and sounders.
    1. King (1956) illustrated the feasibility of deriving the temperature profile from the satellite intensity scan measurement.
    2. Kaplan (1959) showed that vertical temperature soundings of the atmosphere could be inferred from satellite spectral radiance measurements in the 15 micrometer band of CO<sub>2</sub>.
    3. Wark (1961) proposed a satellite vertical sounding program to measure atmospheric temperature profiles.
    4. The first polar orbiting remote sensing platform was successfully launched in April 1969 (Nimbus 3) containing two sounding instruments: the SIRS (Satellite InfraRed Spectrometer) and the IRIS (InfraRed Interferometer Spectrometer).
  - B. Two basic assumptions or prerequisites about the atmosphere and instrument design.

1. The source of emission must be a relatively abundant gas of known and uniform distribution. Two gases which satisfy this condition are  $\text{CO}_2$  in the infrared region and  $\text{O}_2$  in the microwave region (figures 1 & 2).
  2. Choice of spectral bands are made such that a set of sounding wave numbers (or wavelengths) would cover a temperature profile in the troposphere and lower stratosphere (figure 3).
- C. No unique solutions for the detailed vertical profile of temperature.
1. The contribution to the earth-atmosphere outgoing radiances arise from relatively deep layers of the atmosphere.
  2. The contribution to the radiances observed within various spectral radiances overlap considerably thus giving rise to vertical dependency.
  3. In practice the measured radiance is measured only at a finite number of spectral ranges.
  4. The measurements of outgoing radiances contain errors.
- II. Transmittance determinations. The measured monochromatic irradiance is dependent upon the Planck function in addition to the atmospheric transmittance.
- A. Not limited to monochromatic irradiance, but rather, radiance measured over a spectral interval.
  - B. Computation of transmittances through an inhomogeneous atmosphere is rather involved and requires a significant computational effort.
  - C. Knowing a priori the mixing ratio and temperature profile the transmittances are pre-determined.
- III. Generally, two steps are taken to modify the Radiative Transfer Equation to make the problem more tractable.
- A. Start with a climatological or forecast profile,  $T_g(p)$ , as a first guess and reduce the problem to solving for the deviation,  $h$ , of the first guess subtracted from the satellite-derived temperature profile,  $T_s(p)$ .

$$T_g + h = T_s$$

- B. Since 85% of the energy on the 11 micrometer "window" comes from the boundary term, this measurement and the first approximation,  $T_g$ , can be used to determine a good first approximation of the surface temperature. Then the boundary

term for all the other spectral frequencies can be derived and thus simplify the RTE to an integral equation of the first kind.

IV. The following seven solution techniques are briefly described (if the student wishes to explore any one or all in detail please refer to the lecture manual and references included).

A. The direct linear inversion method (Fredholm Form of RTE).

1. Linearizes the RTE for a specified number of spectral bands.
2. The solution has been found to be unstable due to its approximation of the Planck function, and numerical round-off errors.

B. Iteration solution by Chahine Relaxation Method.

1. This method uses a mathematically proper nonlinear approach to solve the full radiative transfer equation.
2. Surface temperature and transmittance are assumed to be known.
3. Knowing the composition of  $\text{CO}_2$  and the level of the weighting function peaks, the temperature profile is recovered iteratively.

C. Smith's iteration solution.

1. Uses a nonlinear approach to solve the RTE.
2. Surface temperature and transmittances are assumed known.
3. The Planck function difference for the sensed atmospheric layer is independent of the pressure coordinate for each sounding wavelength.
4. No assumption imposed by the number of radiance observations available.

D. Solution by use of basis functions.

1. Requires linearization of the RTE in which the Planck radiance on temperature is linearized.
2. The temperature profile and the spectral bands are defined in terms of a specific number of basis functions where the number of basis functions for temperature are less than or equal to those for the spectral bands.

- E. Least squares regression.
  1. Assumes no knowledge of weighting functions or observation errors.
  2. Uses observed radiance and coincident radiosonde data to form statistical sample.
  
- F. Statistical regularization.
  1. Uses the physics of the RTE (not used in least squares regression).
  2. Weighting functions must be known to a high degree, and instrument must be calibrated in an absolute sense.
  
- G. Minimum information solution.
  1. Assumes the deviations from the actual temperature and the guess profile temperature are uncorrelated as are the deviations of the observed radiances from the calculated radiances.
  2. It also assumes the variances for each of the deviations are constant.
  3. The only unknown in this solution technique is the expected error of the guess profile, which can be estimated.
  
- V. A sample calculation of a temperature profile using the Smith's iteration solution.
  - A. Brief outline.
    1. Make an initial guess for  $T^{(n)}(p)$ ,  $n=0$ .
    2. Compute  $B_{\lambda}^{(n)}(T(p))$  and  $I_{\lambda}^{(n)}$ .
    3. Compute  $B_{\lambda}^{(n+1)}(T(p))$  and  $T_{\lambda}^{(n+1)}(p)$  for the desired levels.
    4. Make a new estimate of  $T^{(n+1)}(p)$  using the proper weights.
    5. Compare the computed radiance values  $I_{\lambda}^{(n)}$  with the measured data  $R_{\lambda}$ . If the residuals are not less than a preset small value, repeat steps 2 through 4 until convergence occurs.

B. Sample problem: Will expand upon the sample problem included in "Notes on Satellite Meteorology" through the second iteration.

VI. Problem Set for Discussion. Continue and finish the sample problem for iterative retrieval set up during the lecture.

Fig. 1

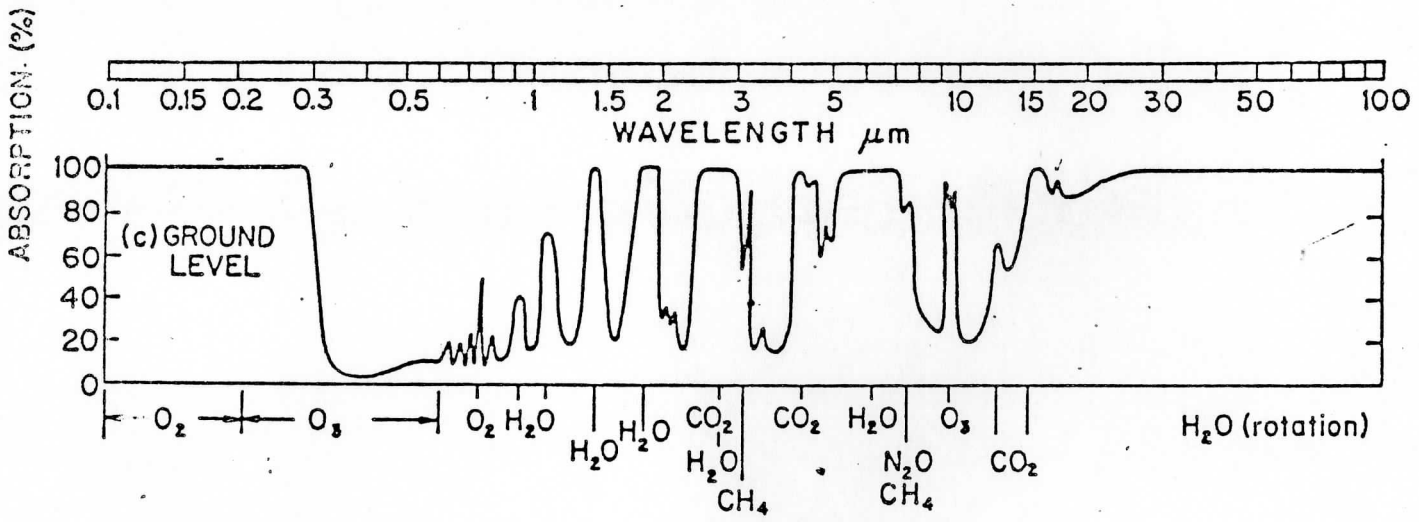


FIG. 2

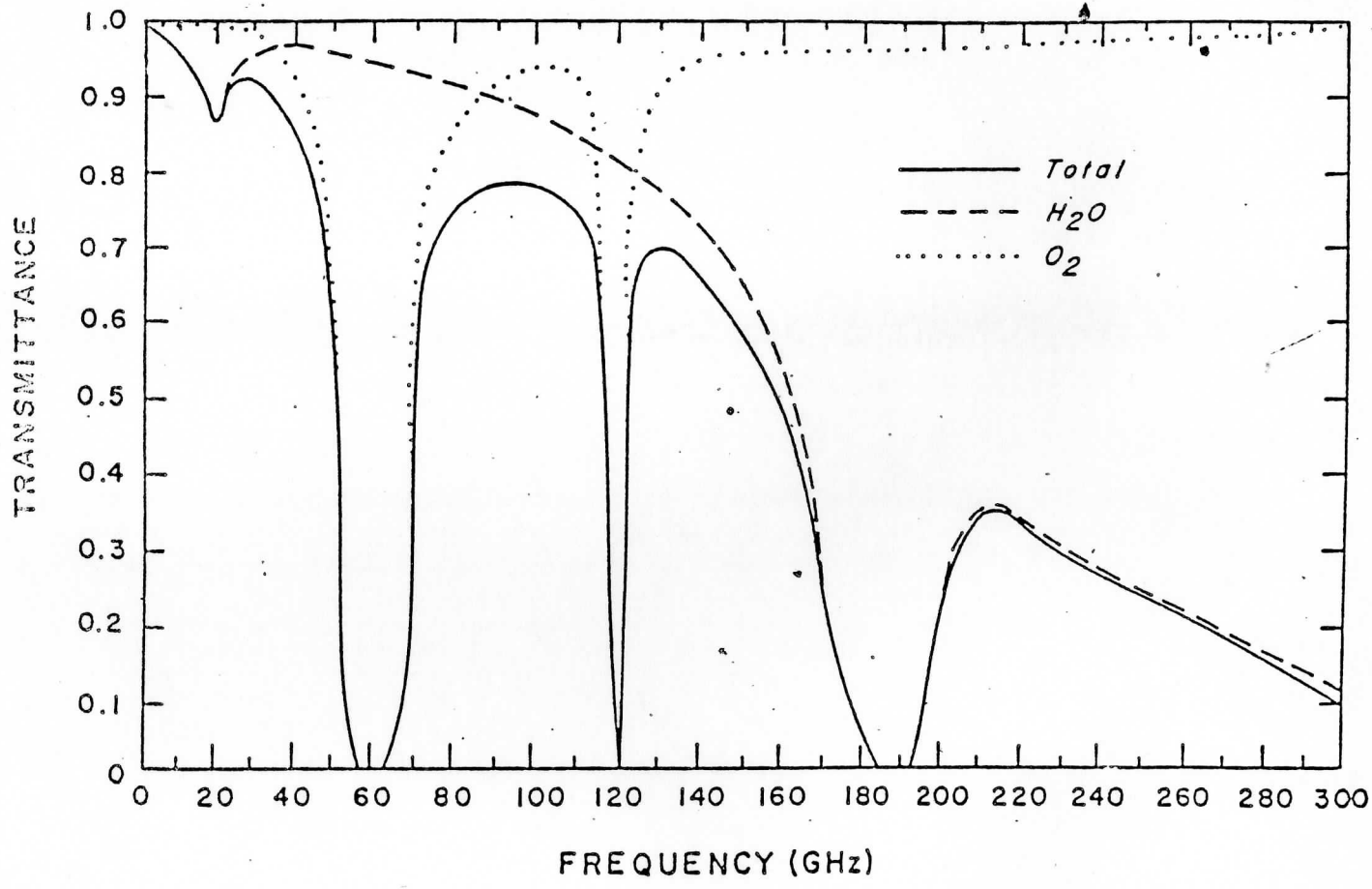
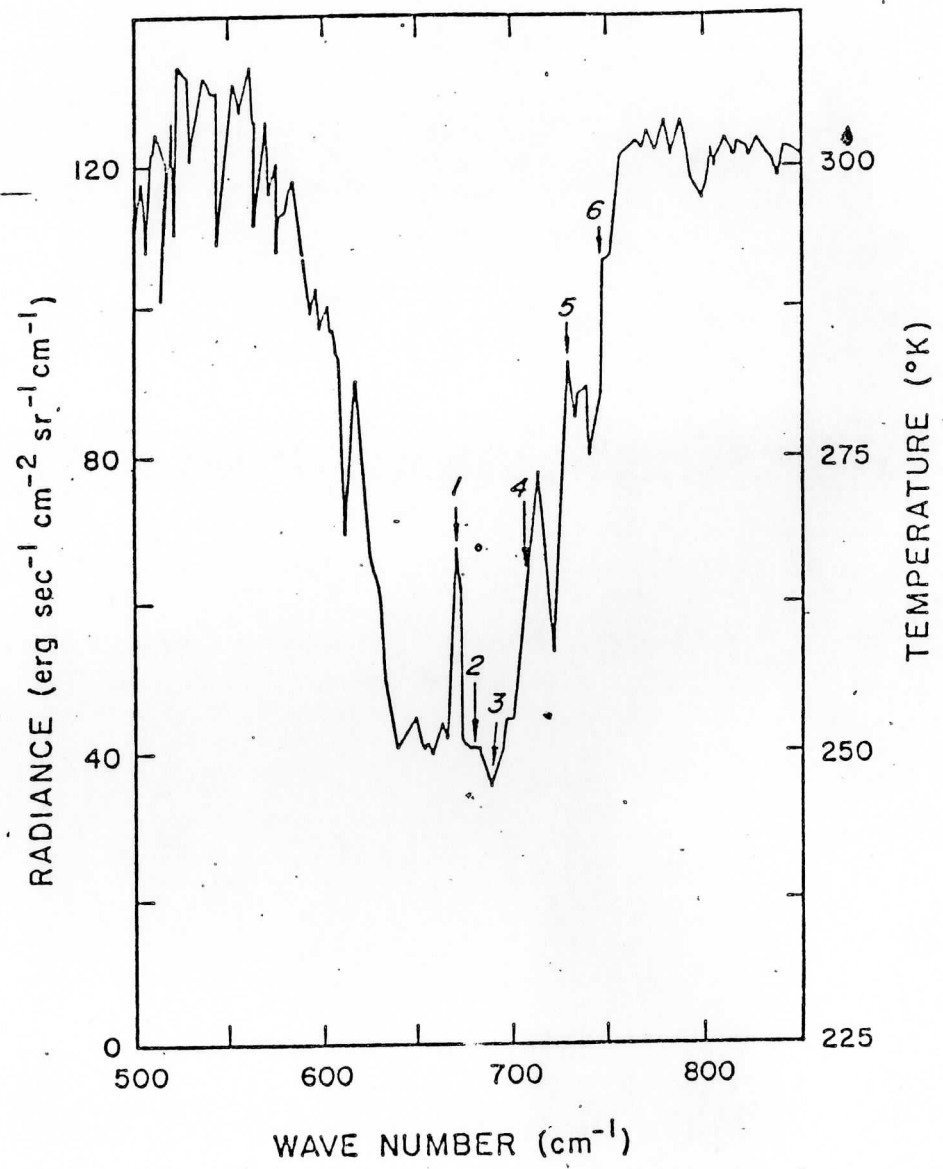


FIG. 3





## LECTURE 9. THE INFLUENCE OF CLOUDS

### References:

Smith, W. L., 1985: Satellites. Handbook of Applied Meteorology. Ed., D. D. Houghton. John Wiley & Sons, New York, NY, 380-472.

Hayden, C. M., W. P. Menzel, and A. J. Schreiner. 1984: The Clouds and VAS. AMS Conference on Satellite/Remote Sensing and Applications, Clearwater Beach, FL, June 25-29, 1984, 49-54.

Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104 pp.

- I. The characteristics of clouds relative to brightness temperature in the HIRS "window" channels and appearance in the visible image (figure 1 & 2).
  - A. Low level clouds (stratus- and cumulus-type); please refer to table 1.
    1. Tend to be highly reflective in the visible, especially the deep convective cumulus clouds.
    2. In the long wave "window" channel (11 micrometer), "fair weather" cumulus are relatively warm or slightly cooler than the radiating temperature of the surface; while cumulonimbus clouds are cold due to deep development into the high atmosphere.
  - B. Mid-level clouds difficult to distinguish with any degree of accuracy in the visible and long wave "window" channels. (Are better resolved using the "CO<sub>2</sub> slicing method", which will be discussed in the Cloud Clearing section.)
  - C. High level clouds (cirrus-type); again, please refer to table 1.
    1. In the visible cirrus-level clouds are nearly transparent.
    2. The 11 micrometer "window" channel signature for high-level clouds indicates very cold radiating temperatures due to their occurrence at high altitudes in the atmosphere.
- II. Net radiation and the effects of clouds (figure 3).
  - A. Solar radiation (short wave) is either transmitted through or reflected by clouds; a very small percentage is absorbed. The amount reflected or transmitted is dependent upon the thickness or type of cloud.

- B. Clouds in the atmosphere are highly opaque to terrestrial radiation (long wave) as in the short wave the opacity is proportional to the thickness as well as the height of the cloud.
- C. Clouds are generally transparent to microwave radiation.

NOTE: Because of available technology, infrared sounders were developed prior to the microwave sounding system. However, because of the cloud imposed limitations of infrared soundings, the evolution of the operational satellite has been towards an all-microwave sounding capability (for example the AMSU, Advanced Microwave Sounding Unit).

III. Effect of clouds on atmospheric processes of infrared radiation.

- A. Transmittance (or transmissivity) through clouds in addition to being dependent to angle of incident radiation, density of the medium, and thickness of the cloud; is also dependent on the droplet size and distribution within the cloud.
- B. Emittance (or emissivity) from clouds can be defined as

$$e = 1 - t,$$

in the same way emissivity was defined in clear air (but transmittance through cloud is not equal to transmittance through clear air).



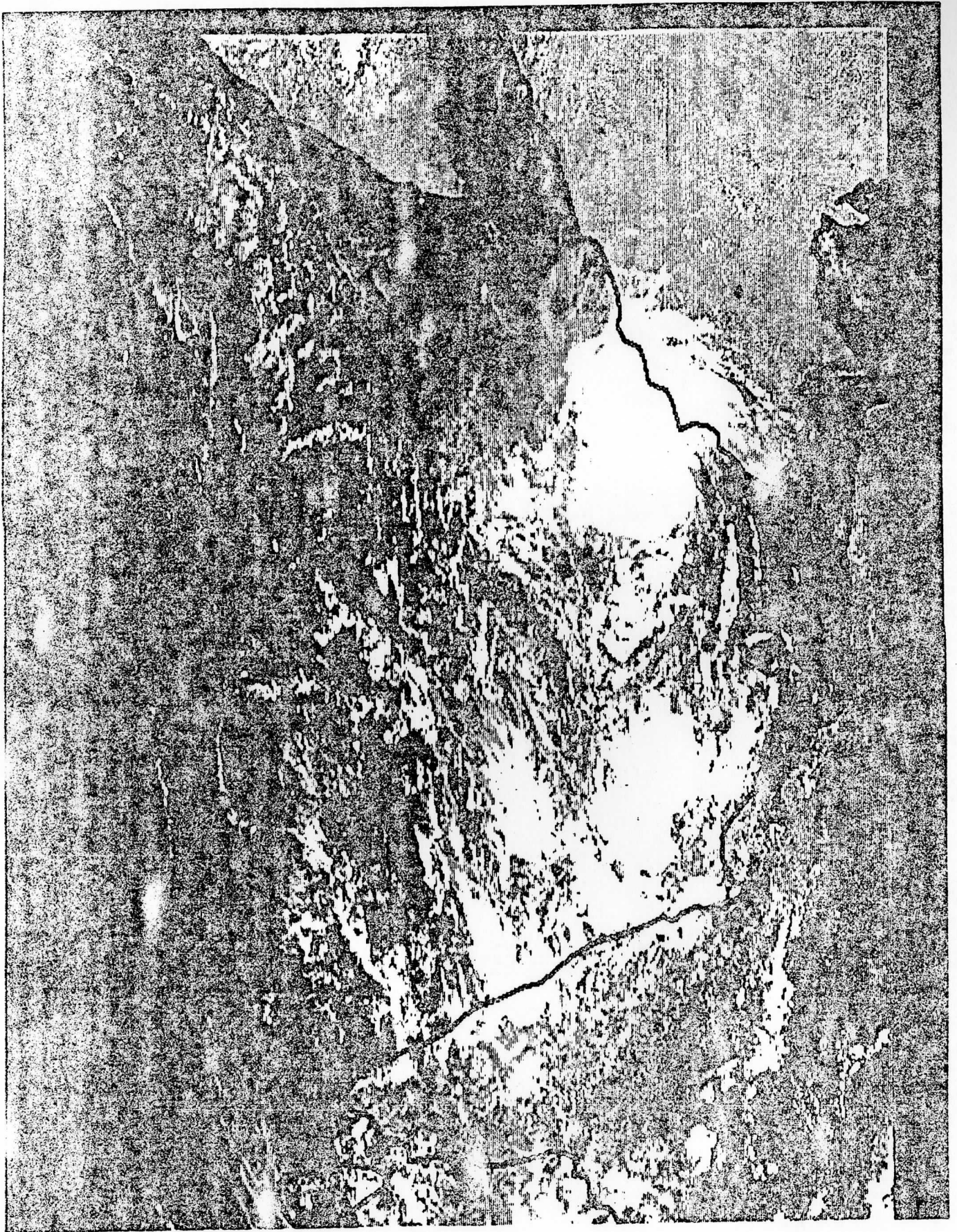
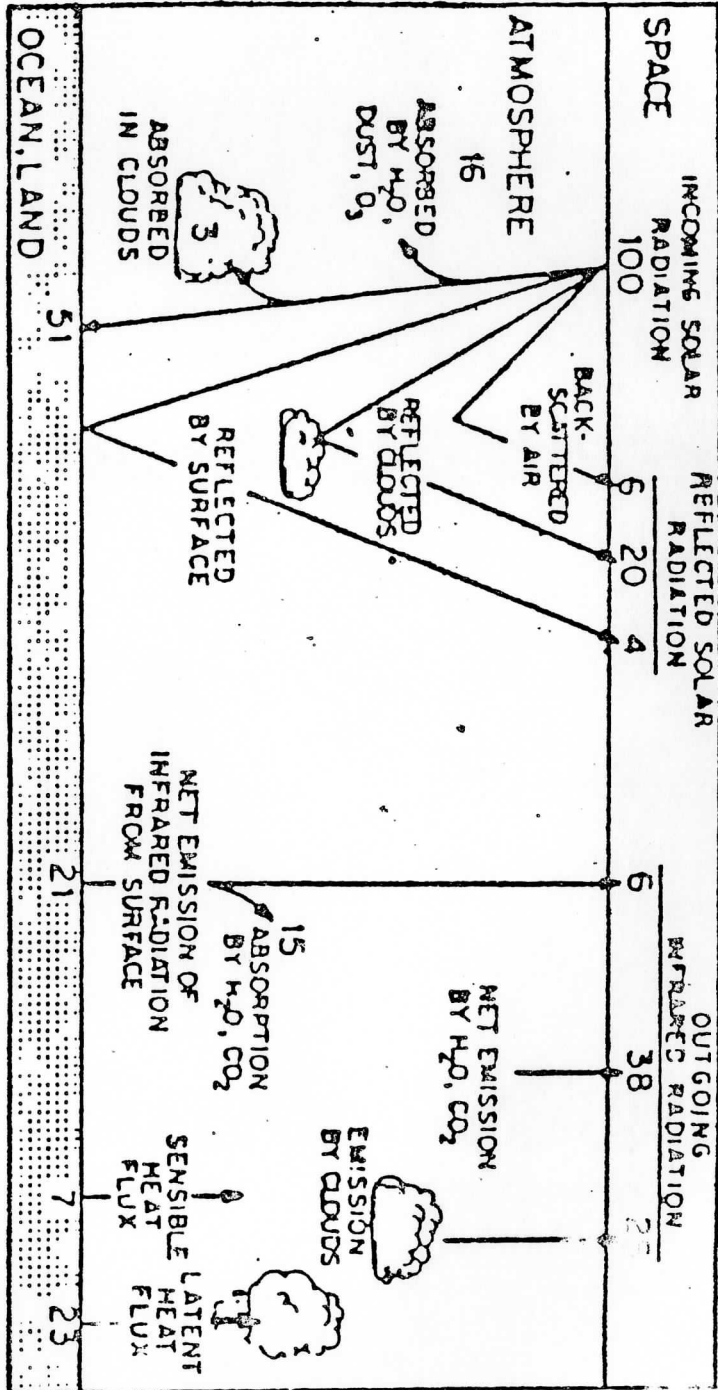
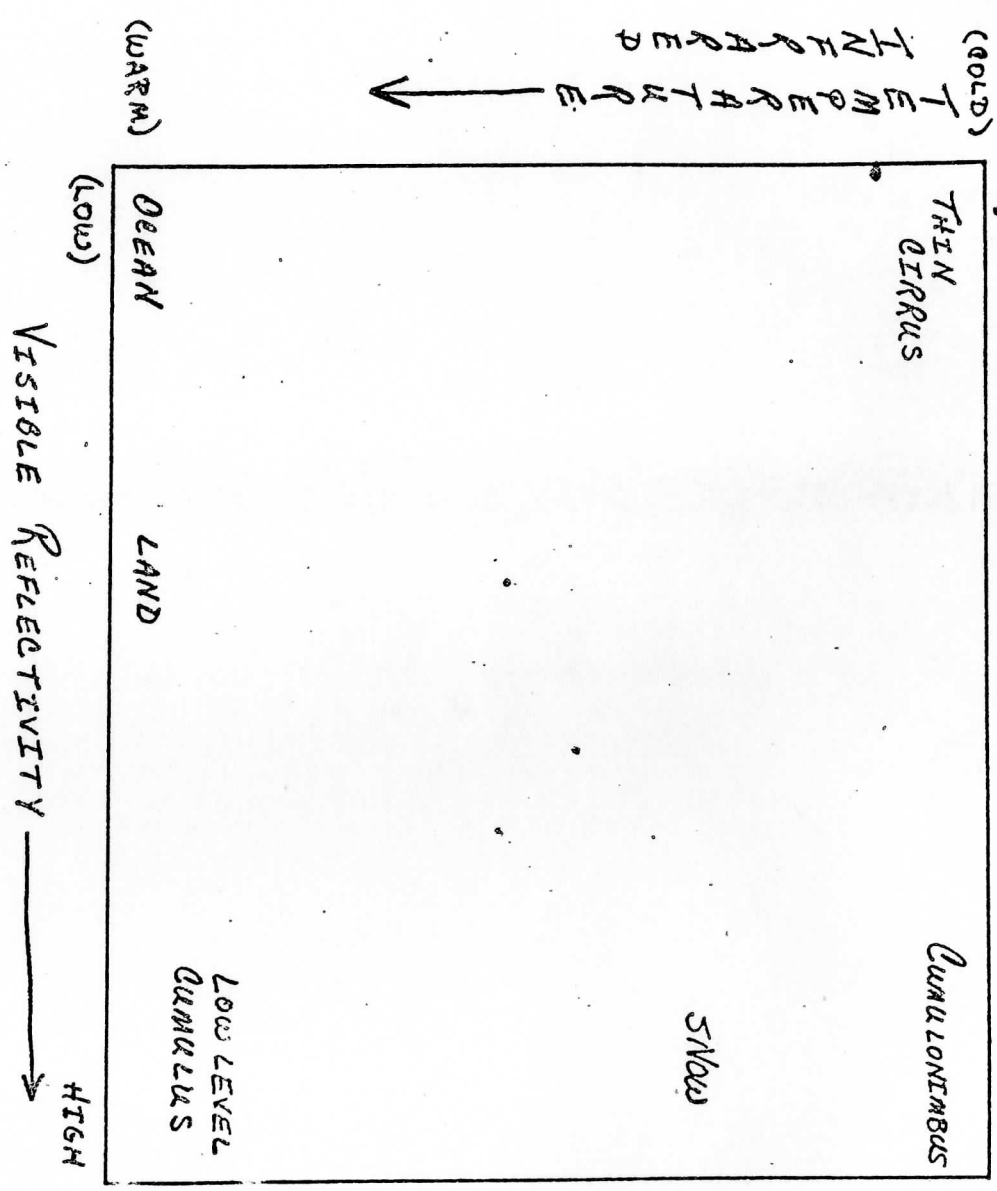


FIG. 3





## LECTURE 10. CLOUD CLEARING / CLOUD PARAMETERS

WEDNESDAY, 16 NOVEMBER: DAY 5

### Cloud Clearing

#### References:

Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104 pp.

Fritz, S., D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary, and J. C. Alishouse, 1972: Temperature Sounding from Satellites. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service, Washington, DC, NOAA Technical Report NESS 59, 49 pp.

Smith, W. L., H. M. Woolf, and W. J. Jacob, 1970: A Regression Method for Obtaining Real-Time Temperature and Geopotential Height Profiles from Satellite Spectrometer Measurements and its Application to NIMBUS 3 "SIRS" Observations. Monthly Weather Review, 98, 582-603.

Hayden, C. M., W. P. Menzel, and A. J. Schreiner, 1984: The Clouds and VAS. AMS Conference on Satellite/Remote Sensing and Applications, Clearwater Beach, FL, June 25-29, 1984, 49-54.

- I. Definition. As seen in the previous days lecture the atmosphere is rarely, if ever, completely cloud-free. Because (as also was discussed previously) they modify the observed radiance seen by the satellite two options are available to compensate for their occurrence.
  - A. Identify and eliminate all fields-of-view in which they occur.
  - B. Identify and compensate or account for the effect of clouds on the observed radiances.
  - C. Two basic assumptions about the characteristics of clouds are made.
    1. The reflectivity of most clouds is near zero at intermediate wavelengths in the infrared (for example 15 micrometers).
    2. Clouds are composed of a single layer.
- II. The monochromatic radiance for a given field-of-view as seen by the satellite can be defined by the following mathematical expression (see figure 1):

$$R = NR^{cd} + (1-N)R^c.$$

Where  $R^{cd}$  is the average monochromatic radiance from the cloud covered portions of the field-of-view, and  $R^c$  is the average monochromatic radiance from the cloud-free portions of the field.  $N$  is the fraction of the field covered by clouds.  $R^{cd}$  can be further defined as,

$$R^{cd} = eB(T^{cd}) + (1-e)R^c.$$

In this case  $e$  is the monochromatic emittance of the cloud. The first term on the right is the Planck radiance of the cloud and the second term is the amount of "clear" Planck radiance transmitted through the cloud. If the above two equations were expanded to the complete radiative transfer equation for this non-reflecting single layer cloud, the resulting equation is non-linear and the cloud temperature, ( $T_{cd}$ ), and cloud amount, ( $N$ ), cannot be solved using the methods discussed in an earlier lecture. Therefore, techniques to correct for the cloud contamination have been devised which then simplify the solution for the temperature profile to one using only equivalent "clear" radiances. Three such techniques are discussed.

### III. Paired field-of-view technique.

- A. This technique assumes that adjacent fields-of-view (fov) are observing the same cloud (temperature and pressure of the cloud are equal), and the surface temperature are the same.
- B. The two equations for the monochromatic radiance for each fov is defined as,

$$\begin{aligned} R_1 &= N_1 R_1(\text{cld}) + (1-N_1)R_1(\text{c}), & (\text{for fov 1}) \\ R_2 &= N_2 R_2(\text{cld}) + (1-N_2)R_2(\text{c}), & (\text{for fov 2}) \end{aligned}$$

where "cld" and "c" represent cloudy and clear, respectively.

- C. Based on the assumptions made in II.A. form monochromatic radiance:

$$R(\text{cld}) = R_1(\text{cld}) = R_2(\text{cld})$$

and,

$$R(\text{c}) = R_1(\text{c}) = R_2(\text{c})$$

the quantity  $N^*$  can be determined,

$$\frac{N_1 [R_{(\text{cld})} - R(\text{c})]}{N_2 [R_{(\text{cld})} - R(\text{c})]} = \frac{R_1 - R(\text{c})}{R_2 - R(\text{c})} = \frac{N_1}{N_2} = N^*$$



then knowing  $N^*$  the above equation can be solved for the monochromatic clear radiance,  $R(c)$ , which is,

$$R(c) = \frac{R_1 - N^* R_2}{1 - N^*}$$

To get  $N^*$  use the "window" channel (knowing the surface temperature), then get the clear fov radiance for the remaining sounding channels. Effectively, the clear fields of view are being extrapolated from the cloud contaminated radiances (fig. 2).

- IV. Screen clouds with visible reflectance using a histogram technique in conjunction with the "window" channel.
  - A. Low reflectance (less than 15%) indicates cloud-free or cirrus.
  - B. High reflectance (greater than 45%) depicts thick cloud or snow.
- V. Use window channel brightness temperatures for shortwave (4.0 micrometers) and long wave (11 micrometers).
  - A. If the difference between the shortwave "window" and the long wave "window" is greater than 3K partial or thin cloud exists.
  - B. If the difference between the shortwave and longwave "window" is less than 3K opaque (thick cloud) or clear conditions exist.

#### Cloud Parameters

#### References:

- Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104 pp.
- Hayden, C. M., W. P. Menzel, and A. J. Schreiner, 1984: The Clouds and VAS. AMS Conference on Satellite/Remote Sensing and Applications, Clearwater Beach, FL, June 25-29, 1984, 49-54.
- Menzel, W. P., W. L. Smith, and H. M. Woolf, 1978: A Man Interactive Technique for Specifying Cloud Heights from Sounding Radiance Data. AMS Third Conference on Atmospheric Radiation, Davis, CA, June 28-30, 1978, 154-157.
- Menzel, W. P., W. L. Smith, and T. R. Stewart, 1983: Improved Cloud Motion Wind Vector and Altitude Assignment Using VAS. Journal of Climate and Applied Meteorology, 22, 377-384.

I. The "Cloud Absorption Technique". (Definition)

- A. This method combines infrared longwave-window channel (11 micrometers, channel 8) data with carbon dioxide absorption channels (14-15 micrometers, channels 5&7) data to specify a cloud height.
- B. There are two basic assumptions inherent in this method.
  - 1. The cloud has infinitesimal thickness; errors resulting from this assumption are typically one-fourth the cloud thickness or less.
  - 2. The cloud emittance is the same for the two spectral channels. The error due to this can be minimized by using spectrally close channels.

II. Cloud height.

- A. The equation used for determining the cloud height is:

$$R - R^C = Ne \int_{P_c}^{P_s} t(dB/dp) dp$$

where the above equation is for a single wavelength (monochromatic) of radiance. R is the measured radiance;  $R^C$  is the radiance observed in the absence of clouds (derived either from a temperature/moisture estimate or previously derived analysis of observed clear values). N is defined as the cloud amount; e is the emissivity; t is the transmittance functions; and finally B is the Planck radiance.

- B. A ratio of the above equation between two wavelengths for the same field-of-view becomes the mathematical expression. Since the same field of view is used, cloud amount is assumed to be the same; and based on the assumption in I.B.2. the emissivities are equal.
- C. Then varying the cloud pressure  $p_c$  in the integral limits until both sides are within some pre-determined "noise limit" the pressure of the cloud is obtained.

III. Effective cloud amount can be calculated by solving either equation for N once the pressure of the cloud has been established.

IV. Source of errors.

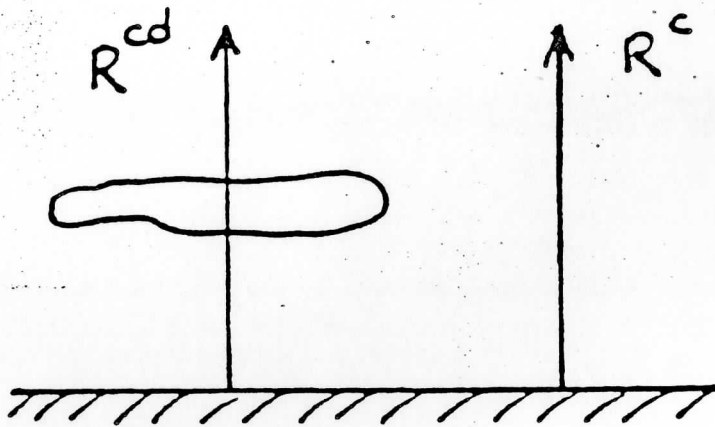
- A. Even though the same field-of-view is used for determining the pressure of the cloud the different channels are seeing different portions of the same cloud, if any.
- B. Estimating the clear column radiance.

1. By using a temperature/moisture estimate, the calculated radiance is only as accurate as the profile used in addition to the transmittance functions used to estimate the radiances for each channel.
  2. The error involved in using an analyzed grid of observed radiances is directly related to the accuracy of the cloud filtering.
- C. There is an inherent lack of vertical resolution in the radiance measurements.

V. Discussion problem.

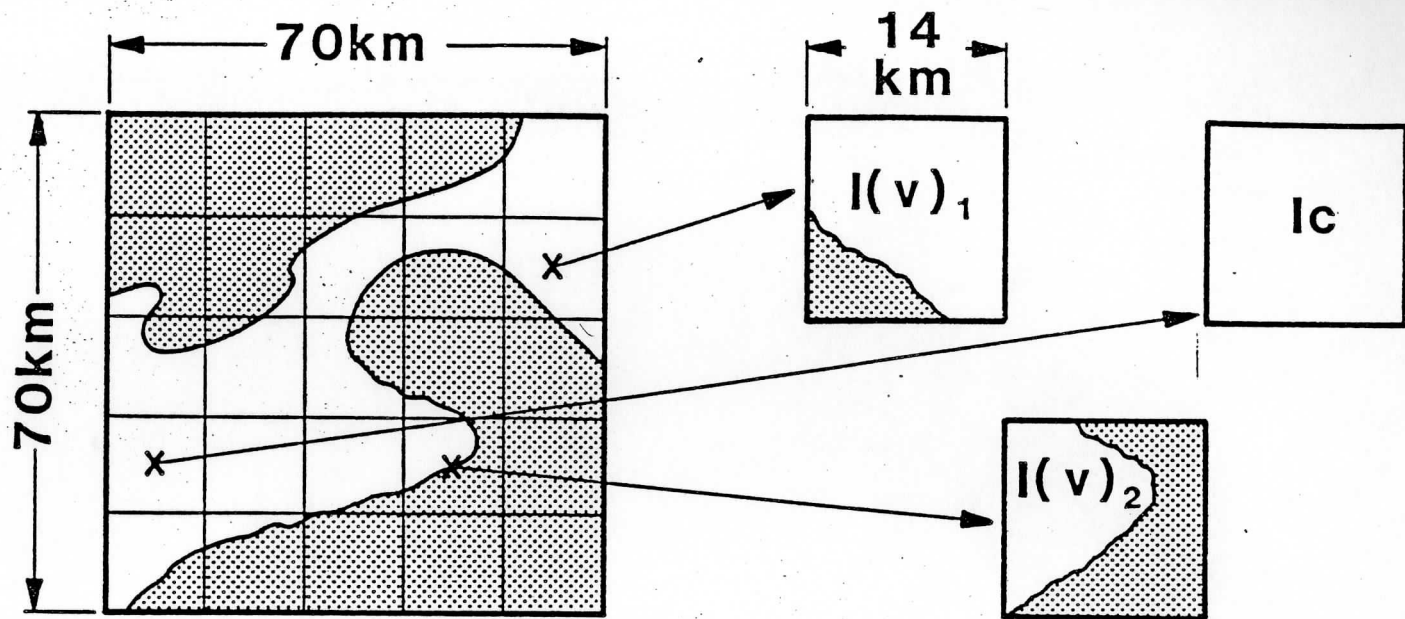
The radiances for a cloudy field of view are measured to be 98.1 and 86.3  $\text{mW/m}^2/\text{ster/cm}^{-1}$  in the 13.8 and 13.4 micrometer channels, respectively. The clear radiances inferred from a nearby clear field of view are 112.3 and 109.2, respectively. The 11.2 micrometer channel senses 48.3 and 86.8 for the same cloudy and clear fields of view. (a) Using the window channel technique, estimate the cloud top pressure in the cloudy field of view. (b) Using the  $\text{CO}_2$  absorption technique and the information in the table given below, estimate the cloud top pressure of the cloud in the cloudy field of view. Explain the difference with the window estimation. (c) Estimate the effective cloud amount using the cloud top pressure calculated above.

CLOUDS

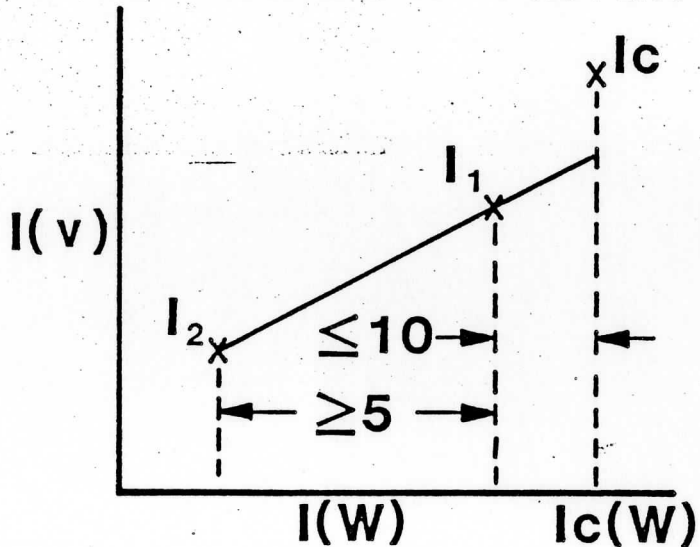


$N =$  FRACTIONAL CLOUD COVER

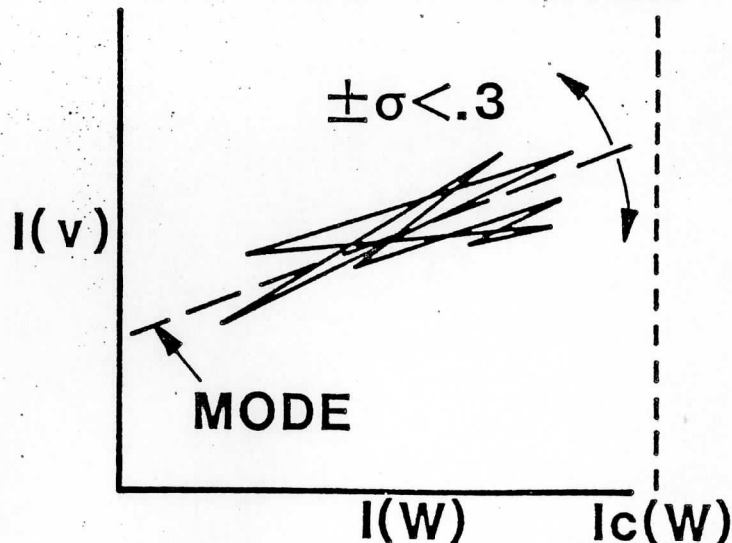
# VAS PARTLY CLOUDY RADIANCE CORRECTION



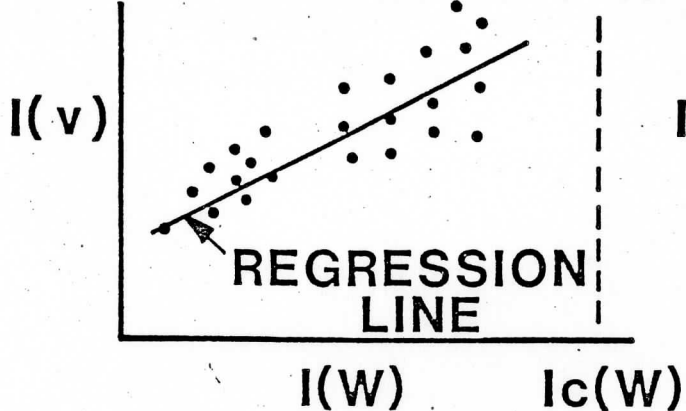
## PAIR WINDOW FILTER



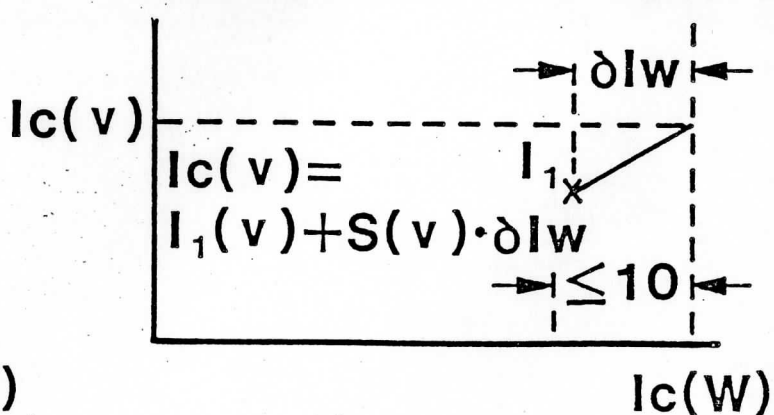
## PAIR SLOPE FILTER



## FINAL SLOPE (S(v))



## PAIR CLEAR ESTIMATE



## LECTURE 11. MICROWAVE RTE

### The Microwave Radiative Transfer Equation

#### References:

Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104pp.

Fritz S., D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary, and J. C. Alishouse, 1972: Temperature Sounding from Satellites. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service, Washington, DC, NOAA Technical Report NESS 59, 49pp.

Hidy, G. M., W. F. Hall, W. N. Hardy, W. W. Ho, A. C. Jones, A. W. Love, M. J. Van Melle, H. H. Wang, and A. E. Wheeler, 1972: Development of a Satellite Microwave Radiometer to Sense the Surface Temperature of the World Oceans. NASA, Washington, DC, 266pp.

- I. Nature of microwave radiation and atmospheric processes.
  - A. Emissivity in the microwave range of radiation is not unity.
    1. The emissivity is function of states of matter for water (ice vs. liquid vs. snow, fig.1).
    2. Surface emissivity is a function of soil type.
  - B. Scattering or reflection of microwave radiation result from water in either the solid or liquid phase. The magnitude of these effects is greatly dependent on the temperature, size of the particles, size distribution, and condensed water concentration (fig. 2).
- II. Review the infrared RTE (emissivity,  $e$ , is unity).
  - A. Surface term plus atmospheric term for clear conditions only.
  - B. Clouds influence the outgoing radiation in the infrared region.
    1. Eliminate them by "cloud clearing".
    2. By finding their height and amount modify the infrared RTE.
  - C. Because near the maximum radiance emission of the earth-atmosphere system, resolution is anywhere from 8km (VAS) to 30km (HIRS).

III. The microwave radiative transfer equation.

- A. Since  $e$  is not equal 1; then,

$$e + r = 1$$

where  $r$  is the reflectance term.

- B. As a result there are now three terms in the microwave form of the RTE.

1. Surface contribution term, similar to the infrared version of the RTE.
2. An atmospheric upwelling term, as found in the infrared RTE.
3. Term which represents the emission contribution from the entire atmosphere to the surface, reflected back to the atmosphere at the same frequency.

- C. Mathematically this is represented:

$$R_{\lambda} = \underbrace{\epsilon_{\lambda} B_{\lambda}(T_s)}_{(1)} \tau(p_s) + (1 - \epsilon_{\lambda}) \tau_{\lambda}(p_s) \int_{\phi}^{p_s} B_{\lambda}(T(p)) \quad (3)$$
$$\frac{d\tau'_{\lambda}(p)}{dp} dp + \int_{p_s}^{\phi} B_{\lambda}(T(p)) \frac{d\tau(p)}{dp} dp \quad (2)$$

Where the numbers in parentheses under each term correspond to the descriptions in III.B.1-3.

- D. In addition, the surface emissivity in the microwave region is a function of surface type, and it is a function of the amount of moisture in the surface (fig. 1).

IV. Limitations and advantages of the microwave form of the RTE.

- A. Limitations.

1. Coarse resolution.
2. Additional CPU time due corrections resulting from limb contamination.
3. Is affected by areas of heavy precipitation.

4. Due to variability of surface emissivity, additional calculations or pre-determined surface emissivity must be available.
5. Poor vertical resolution. Only four channels included in the MSU versus 20 channels in the HIRS.
6. Because of its insensitivity to moisture only temperature may be retrieved from the observed radiance information for the existing MSU aboard polar orbiters.

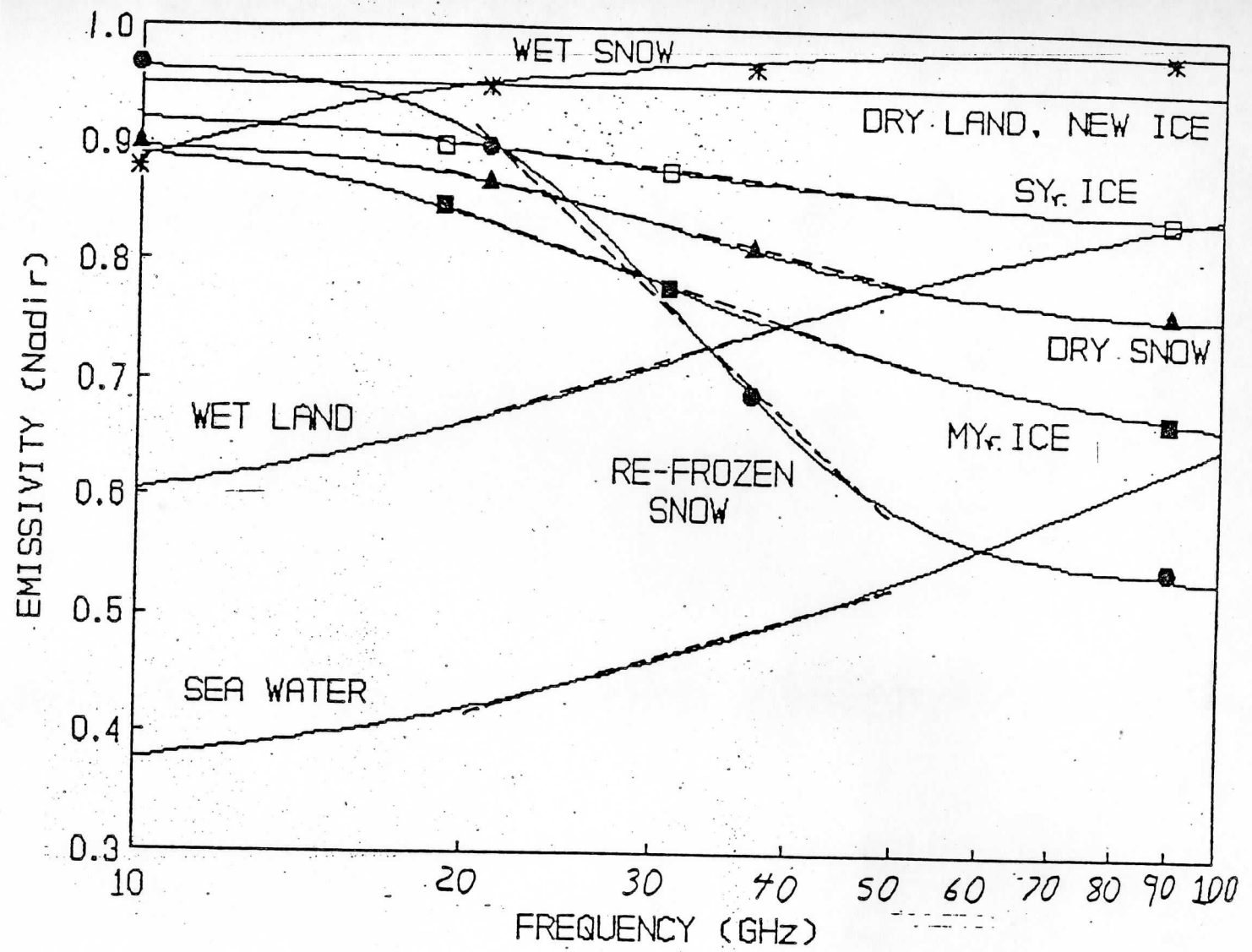
B. The one major advantage of the microwave radiance information is that it is less influenced by clouds and precipitation. Therefore it can be used to effectively infer atmospheric temperatures in all weather conditions. Although this is one advantage versus the numerous limitations described above, it bears repeating the considerable effort required to attempt to eliminate the affects resulting from cloud contamination in the infrared channels.

Therefore, the microwave, as will be seen later, plays an important role in the actual retrieval algorithm with respect to modifying the initial guess.



C. A second advantage is the ability to obtain weighting functions that peak in the stratosphere and higher.

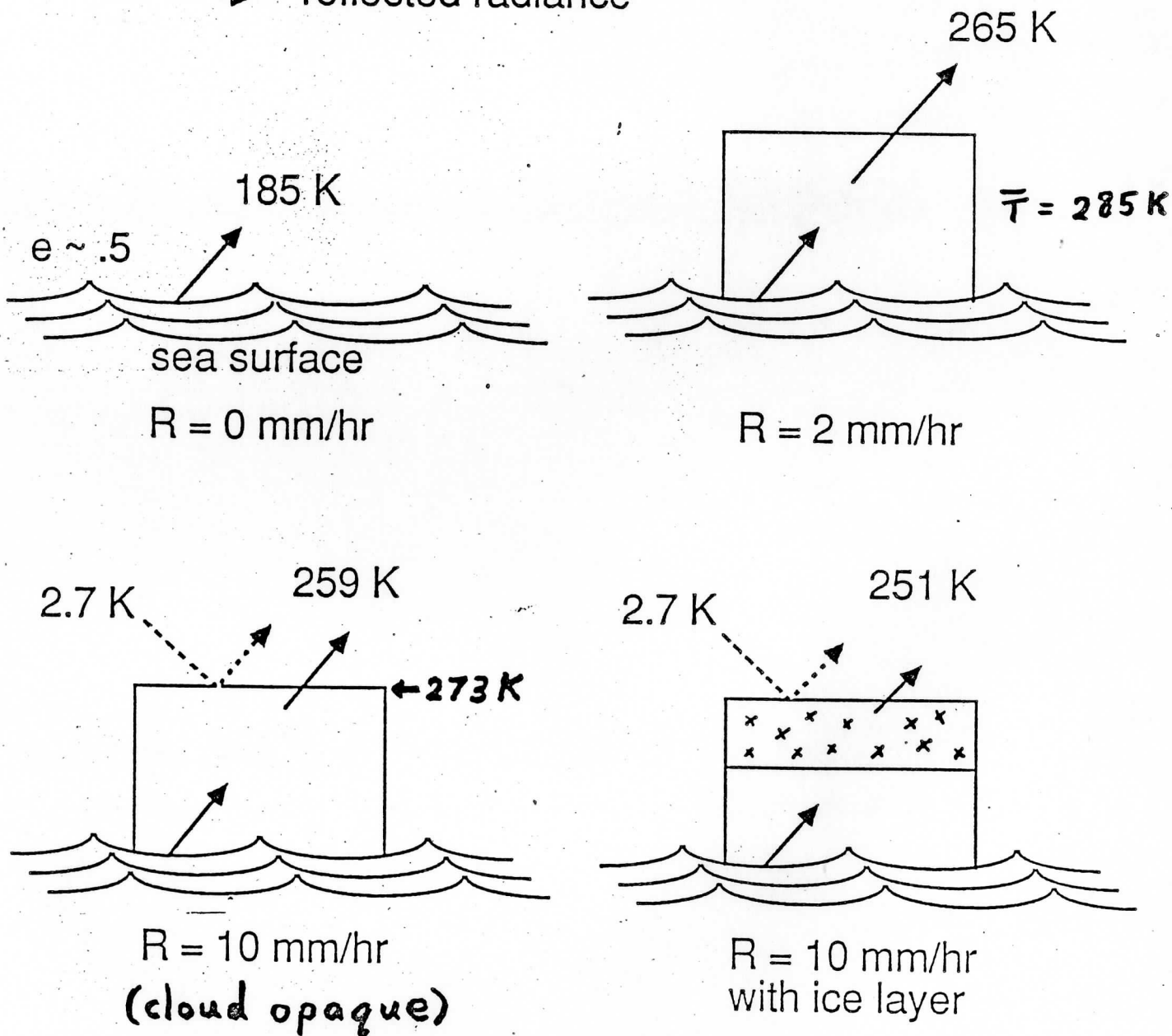


Fig. 1

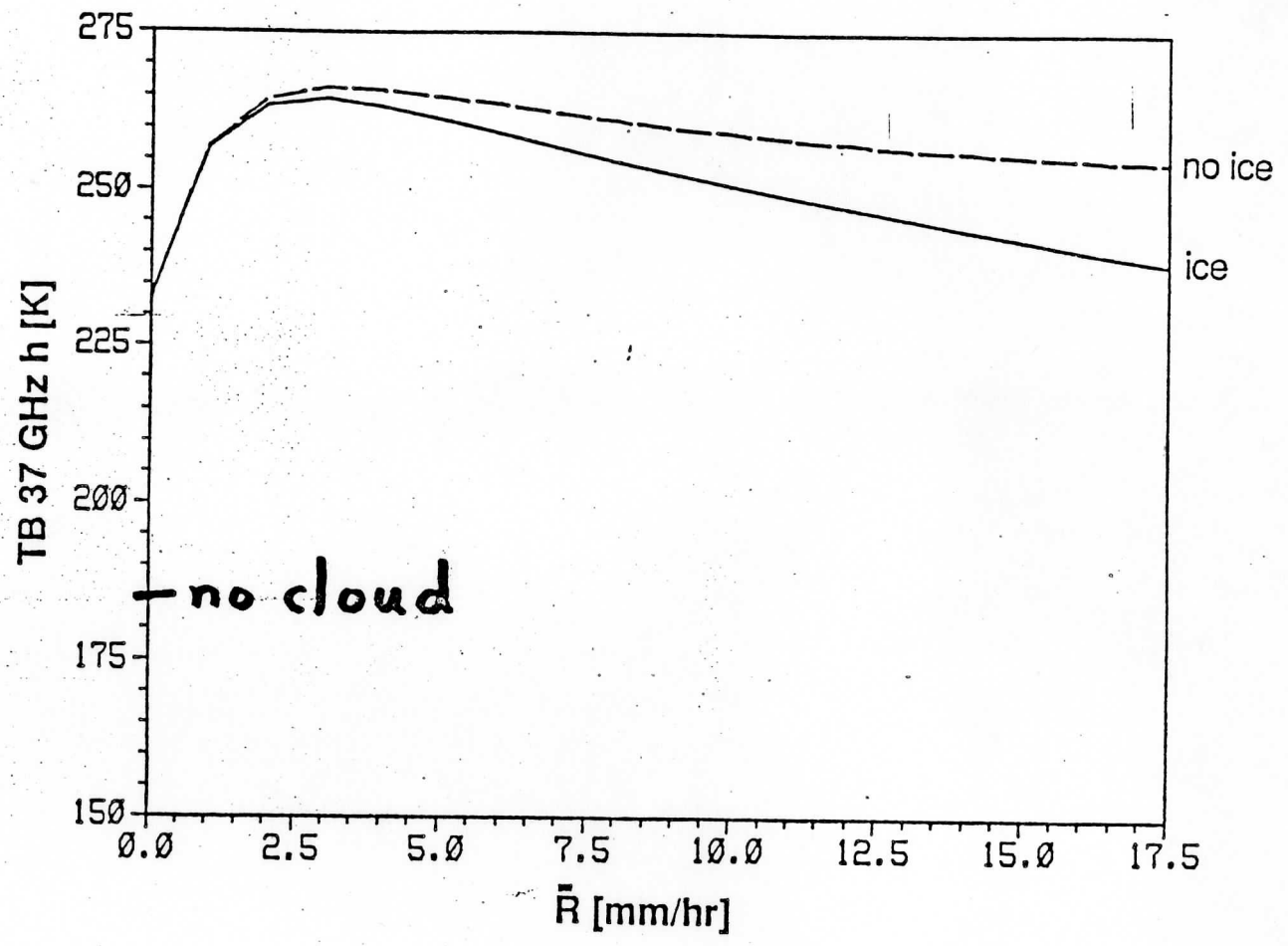


### Schematic for Microwave Radiative Transfer through Precipitating Clouds (37 GHz h)

 emitted radiance  
 reflected radiance



# Plane-parallel Liquid/Ice Cloud 37 GHz h



THURSDAY, 17 NOVEMBER: DAY 6

LECTURE 12. THE INFLUENCE OF MOISTURE

References:

Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104pp.

Fritz, S., D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary, and J. C. Alishouse, 1972: Temperature Sounding from Satellites. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service, Washington, DC, NOAA Technical Report NESS 59, 49pp.

Chesters, D., L. W. Uccellini, and W. D. Robinson, 1983: Low-Level Water Vapor Fields from the VISSR Atmospheric Sounder (VAS) "Split Window" Channels. Journal of Climate and Applied Meteorology, 22, 725-743.

Grody, Norman C., 1976: Remote Sensing of Atmospheric Water Content from Satellites Using Microwave Radiometry. IEEE Transactions on Antennas and Propagation, AP-24, 155-162.

Schaefer, G. and T. T. Wilheit, 1979: A Passive Microwave Technique for Profiling of Atmospheric Water Vapor. Radio Science, 14, 371-375.

I. The contamination due to moisture in the atmosphere is defined as the amount of upwelled radiation (either microwave or infrared) which is either absorbed or scattered. This absorption or scattering is a function of concentration and size distribution of water vapor. Once this affect has been defined (measured), it can be used to calculate the amount of moisture within the atmospheric column (this will be discussed in the next lecture).

II. Affect of moisture in the infrared.

A. The water vapor is best observed and evaluated by employing the use of the "window" channels in the infrared.

B. This correction can be expressed in terms a surface temperature,  $T_s$ , the observed clear "window" channel,  $T_b$ , such that:

$$\Delta T = T_s - T_b$$

where  $\Delta T$  is the water vapor correction.

C. The water vapor correction varies with wave length and air mass type.

1. The moisture correction ranges from a few tenths of a degree Kelvin in cold and dry atmospheres to as much

as 10 degrees Kelvin in warm and moist atmospheres in the 11 micrometer "window".

2. To observe the variability of the moisture correction with respect to wavelength, note that the Planck radiance varies with temperature with the 13th power in the 3.7 micrometer "window", and in the 11 micrometer region the Planck radiance varies with temperature to roughly the fourth power. The following sample problem best demonstrates this moisture variability.

$$B(T) \sim T^n$$

Where B is the monochromatic Planck radiance and n is the wavelength dependent nth power. Substituting and solving for the monochromatic brightness temperature,  $T_b$ , for both the shortwave (3.7 micrometer) and longwave (11 micrometer) "window" in the radiative transfer equation,

$$T_b \sim (t(p_s)T_s^n + (1-t(p_s))T_a^n)^{1/n}$$

In this case,  $t(p_s)$  is the atmospheric transmittance,  $T_s$  is the surface temperature, and  $T_a$  is atmospheric temperature. (An actual sample calculation will be performed by the student during discussion.) For the sake of completeness of the lecture the correction for molecular absorption in the 11 micrometer region is about twice as large as that for the 3.7 micrometer region due to the Planck radiance dependence discussed above.

III. Affects of moisture in the microwave are a function of two basic processes: emissivity and scattering. (These were briefly explained in the section on the microwave radiative transfer equation.)

A. Emissivity in the microwave range of radiation is not unity.

1. The emissivity is a function of the state of matter for water (ice vs liquid vs snow, fig.3).
2. Surface emissivity is a function of soil type.

B. Scattering or Reflection of microwave radiation.

1. The scattering is dependent on water in either the solid or liquid phase.
2. The magnitude of the scattering is also dependent on

the temperature, size of the particles, size distribution, and condensed water concentration (fig. 4).

NOTE: For a more extensive development and explanation of the affects of water vapor in the microwave range of radiation, the two references mentioned in the beginning of the outline provide more background. In addition, the NASA report noted in the microwave RTE outline is a very good reference.

IV. The Moisture correction technique also known as the "split window" technique.

- A. The definition of the "split window" correction is a means by which two neighboring channels in a relatively transparent or "window" region are used to correct for the influence of moisture in the atmosphere.
1. This correction is best evaluated by observing the area of interest in multiple infrared window channels.
  2. At least one channel is highly transparent in the atmosphere while the other is more sensitive to atmospheric water vapor the (so, surface radiance to space is partially absorbed).
- B. For a two channel system the resulting equation is,

$$T_s = T_{bW1} + K(T_{bW1} - T_{bW2}).$$

The constant, K, is a ratio of pre-determined atmospheric transmittances for the two "window" channels. The variable  $T_s$  is the surface temperature (or sometimes called the skin temperature) and  $T_{bW}$  are the two observed brightness temperatures for the "window" channels.

- C. This equation is derived from a specialized version of the radiative transfer equation.
1. Because the two channels are at adjacent wavelengths it is assumed the radiances are subject to nearly the same modifications by surface emittance, aerosols and clouds; and thusly the difference in brightness temperature is controlled by the differential molecular absorption.
  2. A simplified derivation of the "split window" technique starts with a simplified version of RTE (see full derivation in "Notes on Satellite Meteorology" by Menzel).

$$I_W = B_{SW}(1 - K_W u_S) + K_W u_S B_W$$

In this case  $I_W$  is the measured radiance for a window channel. The first term on the right represents the monochromatic Planck radiance of the window term at the surface, and the second term on the right hand side is the atmospheric contribution with  $B_W$  representing a mean atmospheric Planck radiance. The above equation can be linearized with respect to temperature, which results in,

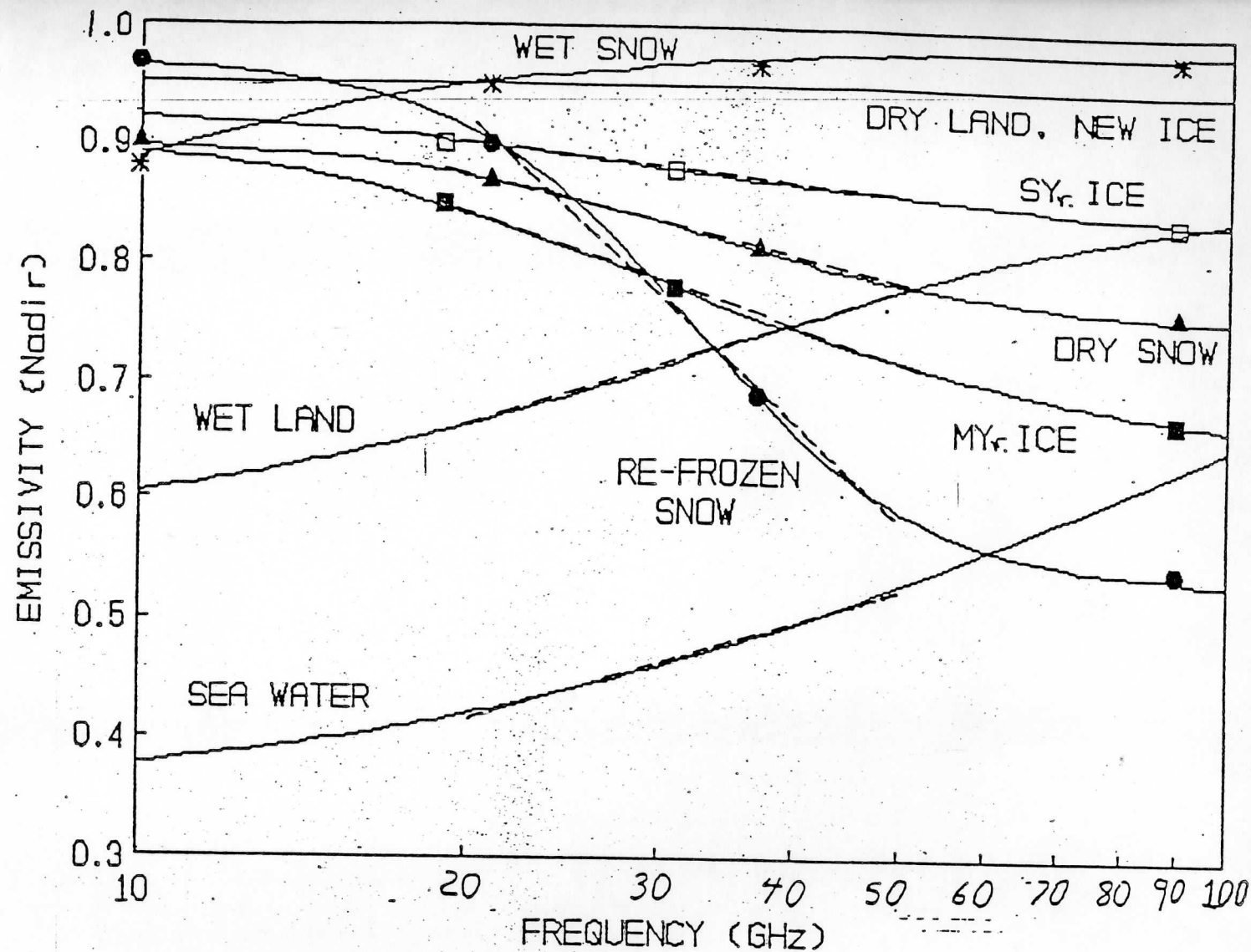
$$T_{bW} = T_S(1-K_W u_S) + K_W u_S T_W$$

Where  $T_b$  is an observed brightness temperature,  $T_S$  is the surface temperature,  $T_W$  is the mean atmospheric temperature corresponding to  $B_W$ . For two "window" channel wavelengths a ratio can be determined, and assuming the mean atmospheric temperatures for both channels are comparable ( $T_{W1} \sim T_{W2}$ ) the equation simplifies to,

$$\frac{T_S - T_{bW1}}{T_S - T_{bW2}} = \frac{K_{W1}}{K_{W2}}$$

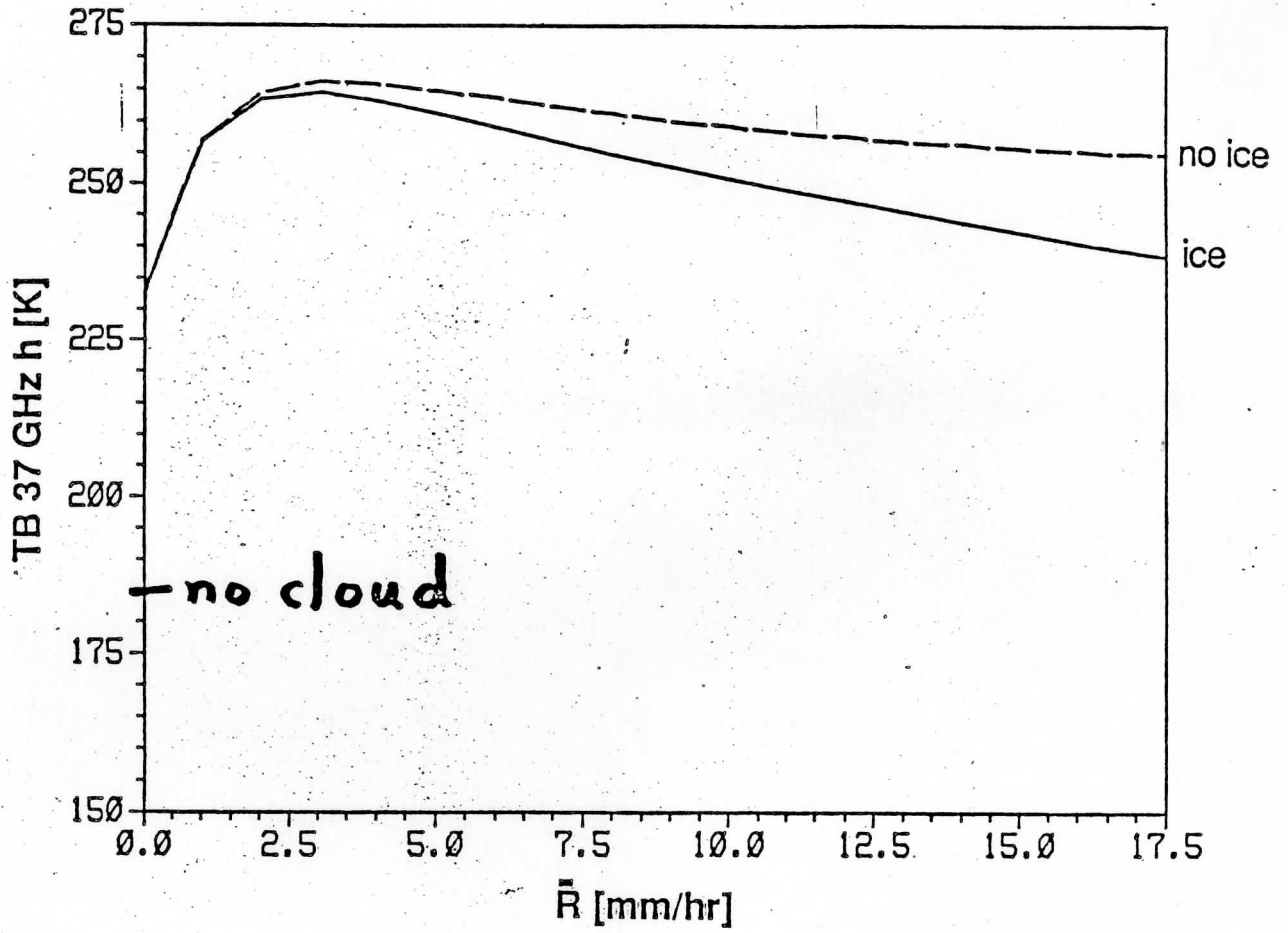
This can be simplified to the resulting "split window" equation listed above.

- V. Some advantages and limitations of the "Split Window" moisture correction technique.
- A. Because of its linear relationship it is a fast method for determining the surface temperature structure.
  - B. Accuracies to within 0.5-1.0K have been achieved in the last few years using this method.
  - C. It also is limited to the accuracy of the radiometer, field-of-view registration between the channels, and the criteria for cloud rejection.
  - D. The requirement of two HIRS channels at adjacent wavelengths is not satisfied in the NOAA series of sounders with the exception of the most recently launched NOAA-11; therefore, a true split window calculation was not available until now.





### Plane-parallel Liquid/Ice Cloud 37 GHz h



# TOVS INFRARED WATER VAPOR AND WINDOW CHANNELS

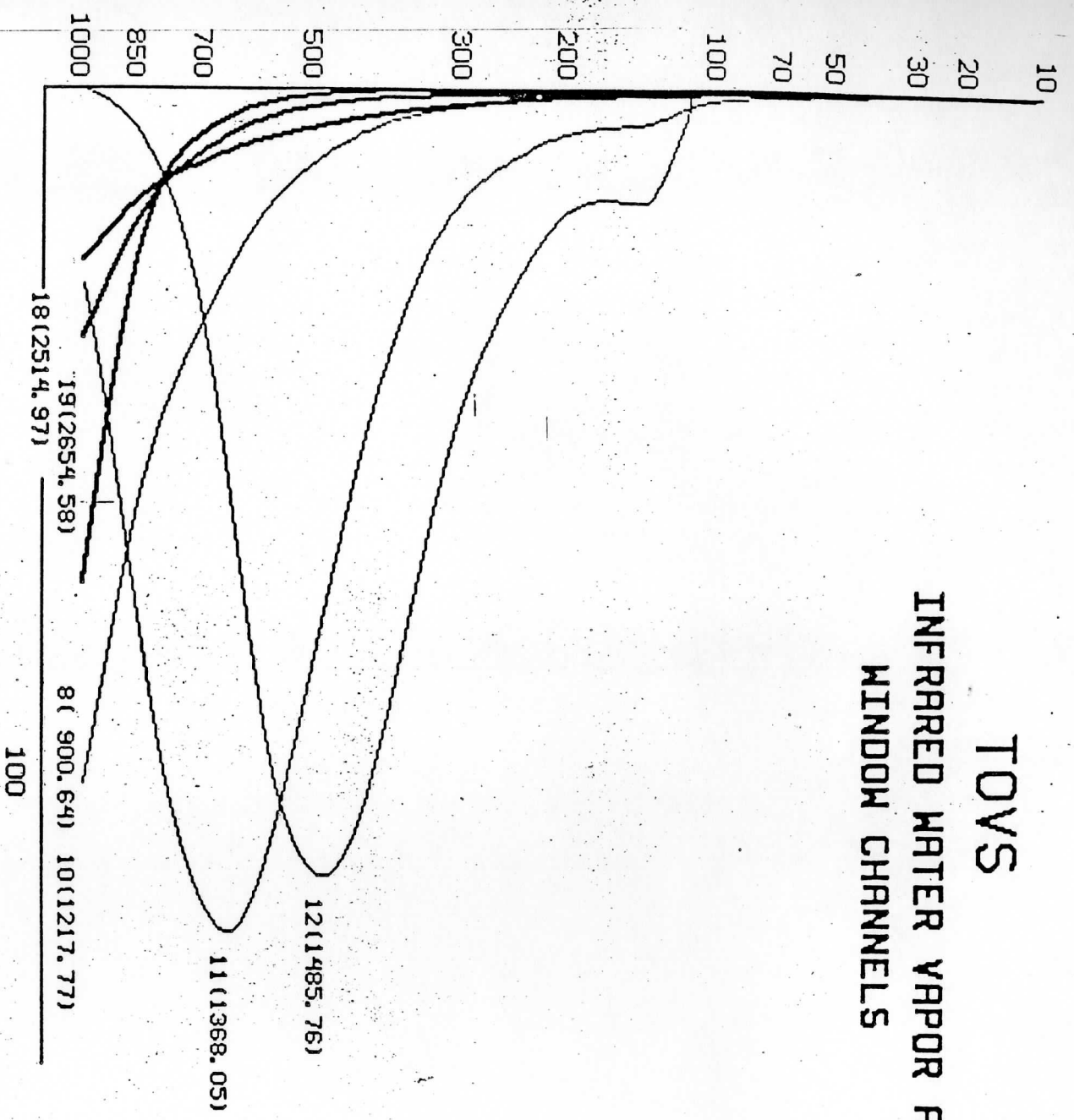
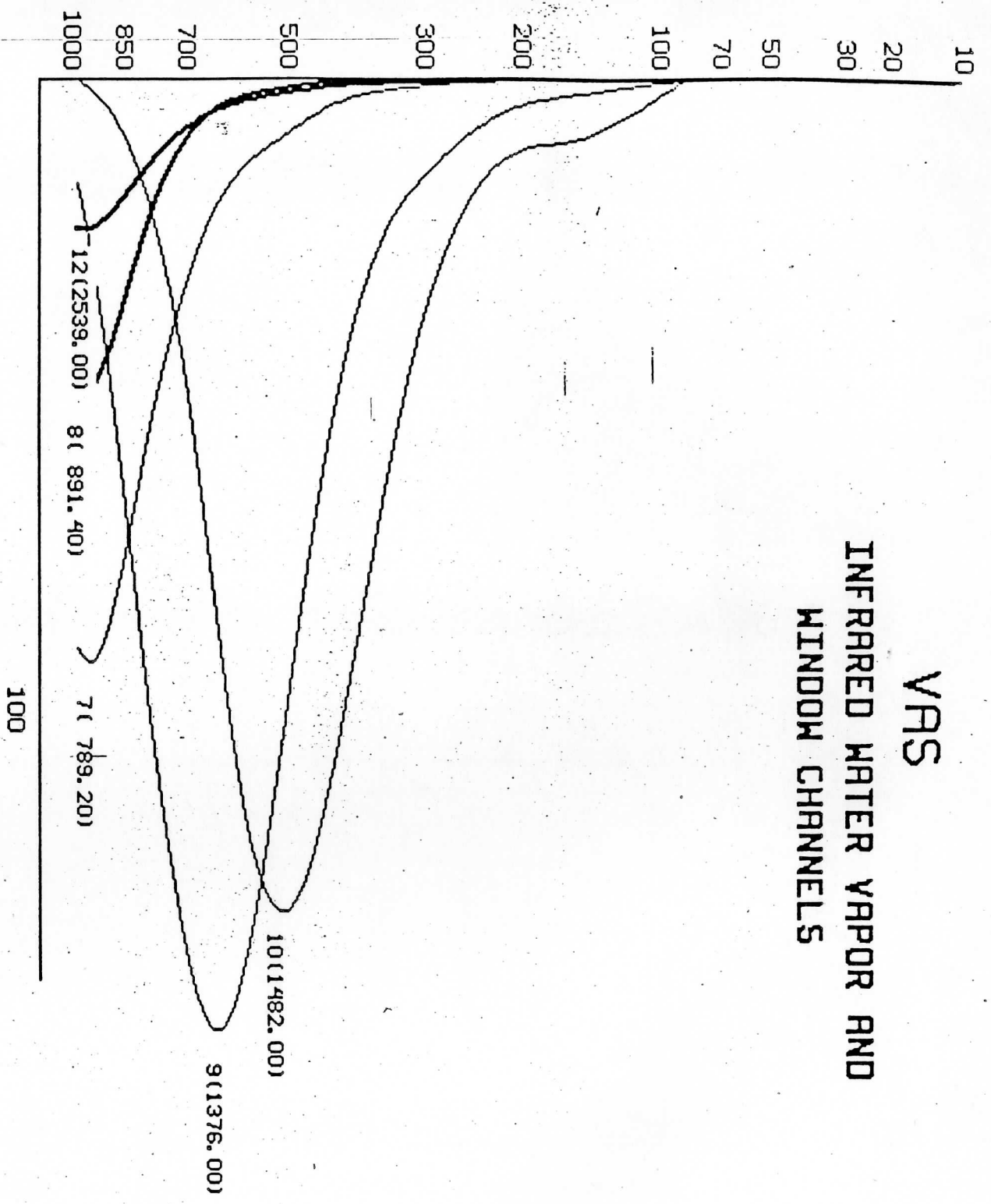


FIG. 6

# VRS INFRARED WATER VAPOR AND WINDOH CHANNELS



## LECTURE 13. RETRIEVAL OF MOISTURE PARAMETERS

### References:

- Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104pp.
- Hayden, C. M., W. L. Smith, and H. M. Woolf, 1981: Determination of Moisture from NOAA Polar Orbiting Satellite Sounding Radiances. Journal of Applied Meteorology, 20, 450-466.
- Smith, William L., 1983: The Retrieval of Atmospheric Profiles from VAS Geostationary Radiance Observations. Journal of Atmospheric Sciences, 40, 2025-2035.
- Chesters, D., L. W. Uccellini, and W. D. Robinson, 1983: Low-Level Water Vapor Fields from the VISSR Atmospheric Sounder (VAS) "Split Window" Channels. Journal of Climate and Applied Meteorology, 22, 725-743.
- Smith, W. L., H. M. Woolf, C. M. Hayden, and A. J. Schreiner, 1985: The Simultaneous Retrieval Export Package. The Technical Proceedings of the Second International TOVS Study Conference, Igls, Austria, Feb 18-22, 1985, 224-253.

### I. Total water vapor estimation.

- A. The total precipitable water is defined as the total atmospheric water vapor contained in a vertical column of cross-sectional area extending from the earth's surface to the top of the atmosphere, which is generally correlated to precipitation amounts in rain and thunderstorms.
- B. An initial approximation is derived by performing a small manipulation of the "split window" correction. The residual absorption,  $u$ , is a measure of the precipitable water.

$$u_S = (T_{bW} - T_S) / [K_W(T_W - T_S)]$$

Where  $u_S$  is proportional to the precipitable water vapor in the atmospheric column. The accuracy of the determination depends upon the contrast between the surface temperature,  $T_S$ , and the effective temperature of the atmosphere,  $T_W$ . For example in an isothermal atmosphere the solution is unresolved.

- C. A more general solution which is resolvable in an isothermal atmosphere as well employs the ratio method also utilized in the "split window" correction. The resulting equation is,

$$u_S = (T_{bW2} - T_{bW1}) / (B_1 T_{bW1} - B_2 T_{bW2}).$$

The coefficients  $B_1$  and  $B_2$  are pre-determined values based on prescribed temperature and water vapor profiles coincident with in-situ observations of  $u_g$ . (A more detailed development of the above solution is located in the Menzel text, "Notes on Satellite Meteorology".)

II. Determination of moisture profiles from observed radiances is more complicated than retrieving temperature profiles.

- A. The radiation received at the satellite is a function of the transmittance properties of the atmosphere at that frequency. For this reason measurements of frequencies used to derive temperature information are chosen such that the absorbing constituent may be considered relatively constant and the signal received at the satellite is a function of only the atmospheric temperature profile. In the case of moisture, frequencies must be chosen such that the signal is dependent on both the atmospheric temperature and the concentration of water vapor.
- B. In the case of temperature derivation the profile is almost independent of moisture, but conversely the moisture determination is highly dependent on the vertical temperature structure. (For example, the sensitivity of atmospheric moisture to temperature lapse rate in the precipitable water determination shown above.)
- C. In temperature profiling frequencies can be chosen to ensure uniform sampling through the depth of the atmosphere, this cannot be done in the case of water vapor sounding because the transmittance properties vary with the concentration.
- D. It is difficult to "see through" a layer of moisture to determine what lies below. Thus, although moisture can certainly be sensed, it is difficult to determine its vertical profile. (Show a slide of VAS moisture channel(s) to demonstrate this, fig.1.)
- E. Since it is difficult to produce the type of detailed moisture profile available with a radiosonde observation, the emphasis recently has been to redirect attention toward layer-average estimates.

III. The information content of the TOVS in the water vapor absorption bands.

- A. The TOVS instrumentation includes three channels directed to the retrieval of water vapor estimates. (Show slide of weighting functions, fig. 2.)
  - 1. The 8.3 micrometer band which peaks nominally between 900mb and the surface for a standard atmosphere.

2. The 7.3 micrometer band which peaks around 700mb for a standard atmosphere.
  3. Finally, the 6.7 micrometer band with its peak level of energy contribution located around 500mb.
- B. The weighting functions for these three channels are sensitive to the amount and distribution of water vapor in the atmosphere (see fig. 2).
1. Accompanying a rise of water vapor is a weighting function which peaks higher in the atmosphere and a decrease in the radiance which arises from a lower ambient temperature in the higher atmospheric layer.
  2. Note that the 8.3 micrometer channel registers a difference of only 2-3 degrees Kelvin despite dramatic changes in the low-level moisture.
- C. The aim of the algorithm development has been to overcome the inherent insensitivity of the measurement and to maximize the information content apparent in the simulated temperature profile weighting functions.

IV. A brief outline of the retrieval technique used for generating layered moisture profiles is described.

- A. An initial temperature profile is estimated using the three upper level microwave channels from the MSU plus the surface observations.
- B. A first estimate of the moisture is generated from the surface mixing ratio

$$w = w_0 (p/p_0)^3,$$

which is a simple power law relationship.

- C. A first estimate of the transmittance functions for 40 levels using the "initialized" temperature/moisture profile is created.
  1. The estimated transmittances are used to calculate a simulated atmospheric radiance for the 8.3 micrometer channel.
  2. If the simulated and observed values are not within a certain criteria, the moisture profile is altered by using an iterative scheme similar to the one outlined in the "temperature inversion" lecture and the transmittances are recalculated.
  3. In the majority of cases it is unnecessary for a second estimate of the retrieval because of a

discrepancy between observed and calculated values of brightness temperature at 8.3 micrometers.

- D. Given the "final" transmittance functions then the temperature profile is again updated using the HIRS "longwave" and "shortwave" channels.
- E. This "updated" temperature/moisture profile is then used to determine the calculated brightness temperatures for all HIRS channels for comparison to the observed.

#### IV. Discussion problem.

A radiometer observes clear column brightness temperatures of 291.2 and 280.8 degrees Kelvin at 11.2 and 12.7 micrometers, respectively. (a) Assuming weak absorption with water vapor absorption coefficients of .21 and .47  $\text{cm}^2/\text{g}$  for 11.2 and 12.7 micrometers, respectively, what is the surface temperature? (b) If the mean atmospheric temperature is 250.0 degrees Kelvin for the 12.7 micrometer band, what is the estimated total precipitable water vapor?

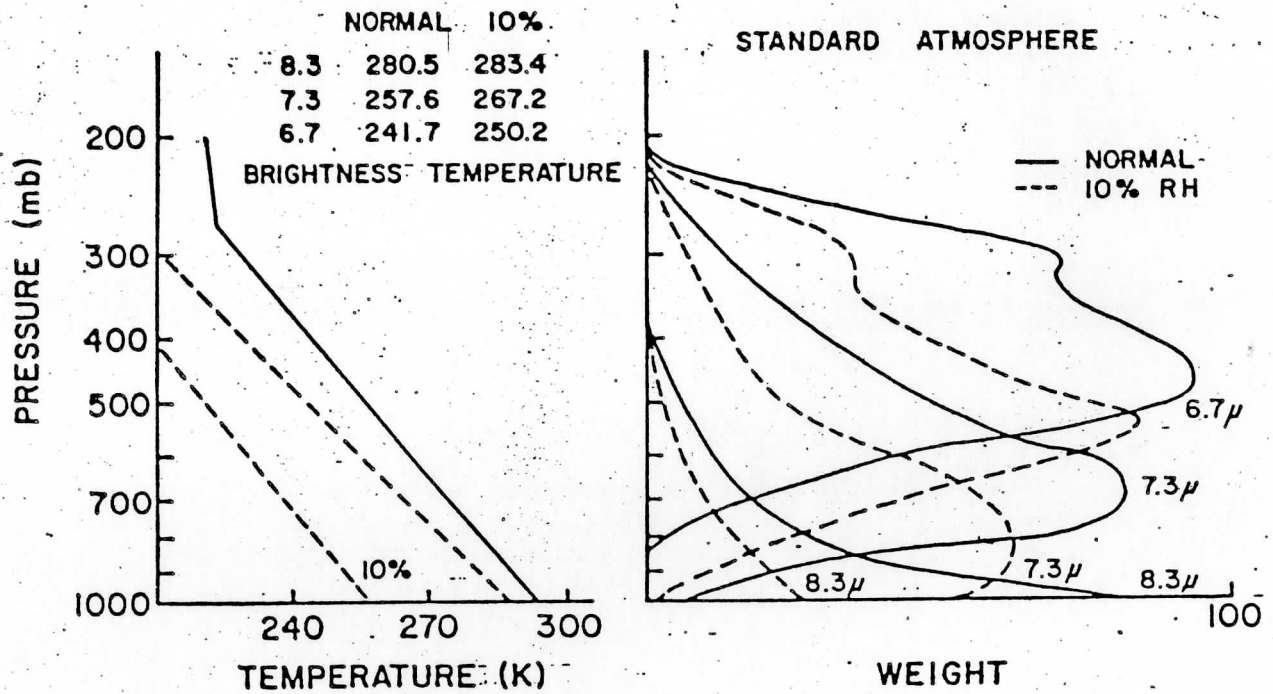


FIG. 3. Left: midlatitude standard atmosphere temperature and dew-point profile (10% relative humidity profile also shown). Right: brightness temperature weighting functions for TOVS 6.7  $\mu\text{m}$  water vapor band for profiles shown left.



LECTURE 14. TOVS INSTRUMENT CHARACTERISTICS

SATURDAY, 19 NOVEMBER: DAY 7

References:

THE TIROS-N/NOAA OPERATIONAL SATELLITE SYSTEM: W. JOHN HUSSEY. U.S. DEPARTMENT OF COMMERCE, NOAA, 1979.

ADVANCED TIROS-N (ATN) NOAA-H: NOAA/NASA, 1988.

THE TIROS-N OPERATIONAL VERTICAL SOUNDER: W. L. SMITH, H. M. WOOLF AND C. M. HAYDEN. BAMS 60, 10, 1177-1187.

MISSION OBJECTIVES OF NOAA SERIES SATELLITES:

1. MONITOR THE ATMOSPHERE ON A CONTINUOUS, GLOBAL BASIS WITH DIRECT READOUT TO LOCAL GROUND STATIONS
2. SOUND THE ATMOSPHERE ON A CONTINUOUS, GLOBAL BASIS TO PROVIDE QUANTITATIVE DATA FOR NUMERICAL WEATHER PREDICTION
3. APPLYING ENVIRONMENTAL SATELLITE DATA TO IMPROVE ENVIRONMENTAL MONITORING AND SERVICES.

TIROS-N SERIES INSTRUMENTATION:

TOVS (TIROS OPERATIONAL VERTICAL SOUNDER)

- HIRS/2 (HIGH RESOLUTION INFRARED RADIATION SOUNDER)
- MSU (MICROWAVE SOUNDING UNIT)
- SSU (STRATOSPHERIC SOUNDING UNIT)

AVHRR (ADVANCED VERY HIGH RESOLUTION RADIOMETER)

SAR (SEARCH AND RESCUE)

DCS (DATA COLLECTION SYSTEM)

SBUV/2 (SOLAR BACKSCATTER ULTRAVIOLET SPECTRAL RADIOMETER)

ORBIT:

3-AXIS STABILIZED SPACECRAFT

870 KM CIRCULAR, NEAR-POLAR ORBIT

ORBITAL PERIOD = 102.12 MINUTES, SUN SYNCHRONOUS

**HIRS INSTRUMENT CHANNELS:**

CHANNELS 1-7: 15 $\mu$ m BAND

CHANNEL 8: WINDOW (IR)

CHANNEL 9: OZONE

CHANNEL 10-12: WATER VAPOR

CHANNEL 13-17: 4.5 $\mu$ m BAND

CHANNEL 18-19: WINDOW (SW IR)

CHANNEL 20: WINDOW (VISIBLE)

**MEASUREMENTS:**

SURFACE TEMPERATURE

TEMPERATURE SOUNDING

WATER VAPOR SOUNDING

CLOUD DETECTION

TOTAL OZONE CONCENTRATION

SURFACE EMISSIVITY / CLOUD ATTENUATION

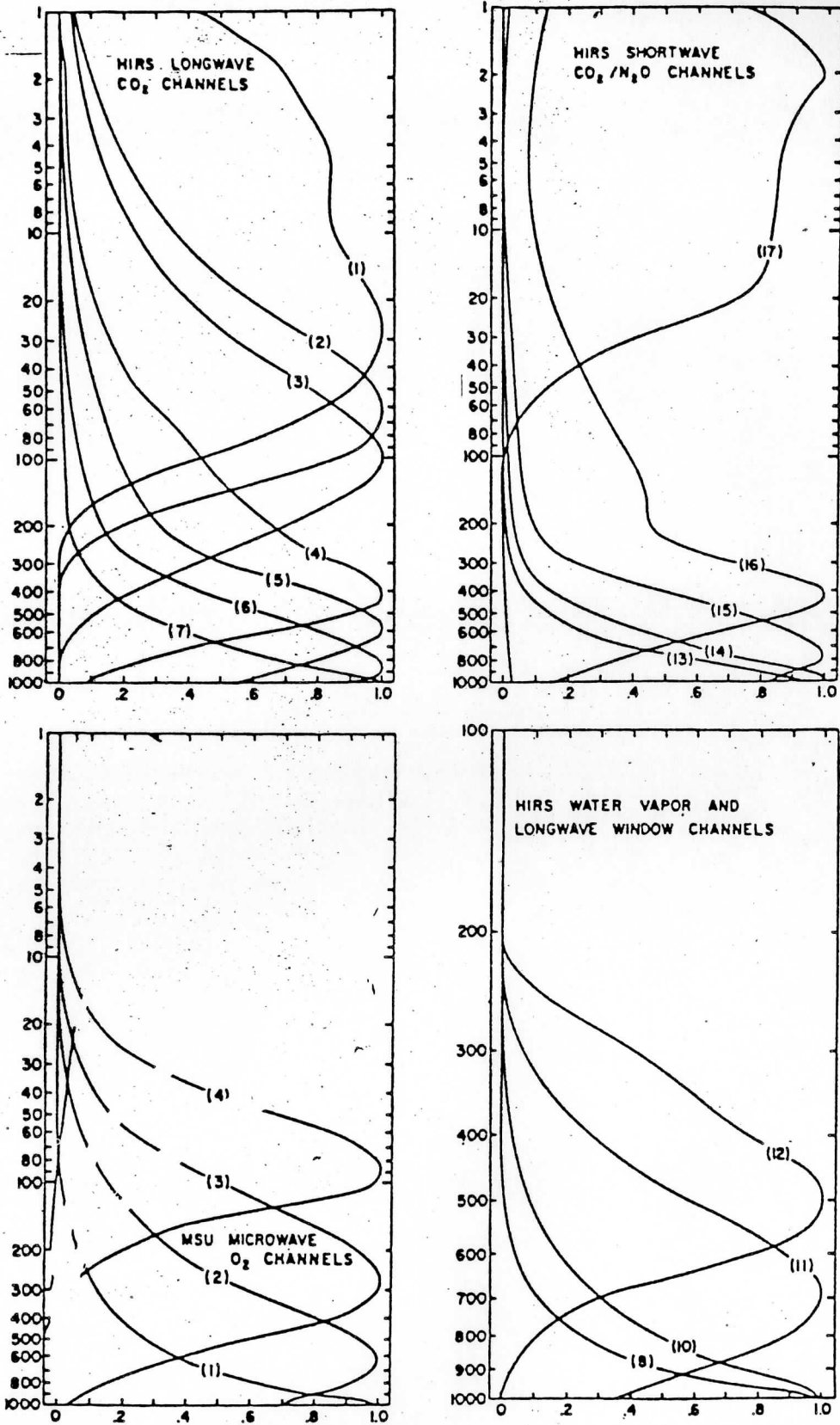


FIG. 1. TOVS weighting functions (normalized).

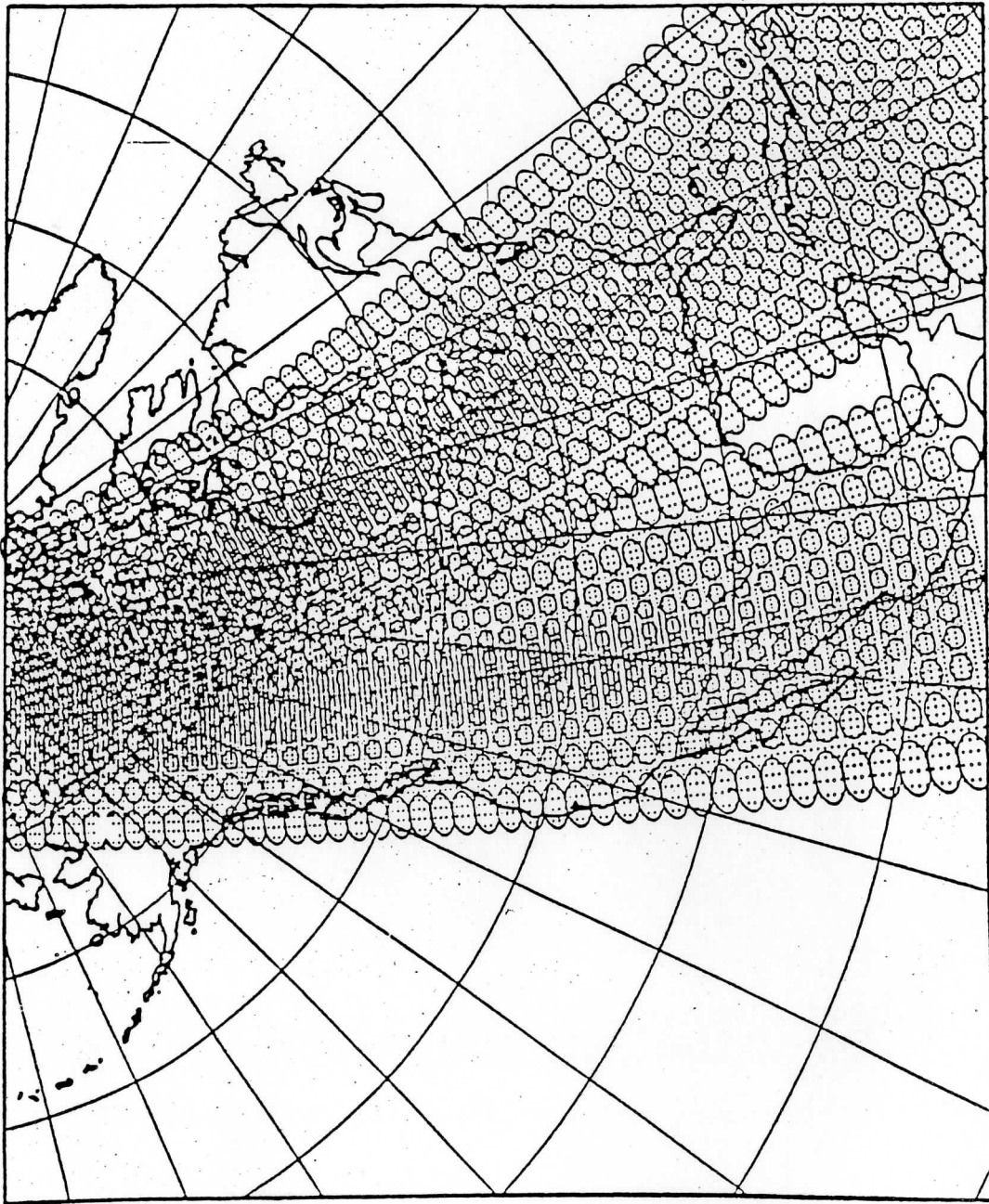


FIG. 2. HIRS and MSU scan patterns for two consecutive orbits.

TABLE 1. Characteristics of TOV sounding channels.

HIRS Channel number	Channel central wavenumber	Central wavelength ( $\mu\text{m}$ )	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	668	15.00	CO <sub>2</sub>	30 mb	<i>Temperature sounding.</i> The 15- $\mu\text{m}$ band channels provide better sensitivity to the temperature of relatively cold regions of the atmosphere than can be achieved with the 4.3- $\mu\text{m}$ band channels. Radiances in Channels 5, 6, and 7 are also used to calculate the heights and amounts of cloud within the HIRS field of view.
2	679	14.70	CO <sub>2</sub>	60 mb	
3	691	14.50	CO <sub>2</sub>	100 mb	
4	704	14.20	CO <sub>2</sub>	400 mb	
5	716	14.00	CO <sub>2</sub>	600 mb	
6	732	13.70	CO <sub>2</sub> /H <sub>2</sub> O	800 mb	
7	748	13.40	CO <sub>2</sub> /H <sub>2</sub> O	900 mb	
8	898	11.10	Window	Surface	<i>Surface temperature</i> and cloud detection.
9	1 028	9.70	O <sub>3</sub>	25 mb	<i>Total ozone</i> concentration.
10	1 217	8.30	H <sub>2</sub> O	900 mb	<i>Water vapor sounding.</i> Provides water vapor corrections for CO <sub>2</sub> and window channels. The 6.7- $\mu\text{m}$ channel is also used to detect thin cirrus cloud.
11	1 364	7.30	H <sub>2</sub> O	700 mb	
12	1 484	6.70	H <sub>2</sub> O	500 mb	
13	2 190	4.57	N <sub>2</sub> O	1 000 mb	<i>Temperature sounding.</i> The 4.3- $\mu\text{m}$ band channels provide better sensitivity to the temperature of relatively warm regions of the atmosphere than can be achieved with the 15- $\mu\text{m}$ band channels. Also, the short-wavelength radiances are less sensitive to clouds than those for the 15- $\mu\text{m}$ region.
14	2 213	4.52	N <sub>2</sub> O	950 mb	
15	2 240	4.46	CO <sub>2</sub> /N <sub>2</sub> O	700 mb	
16	2 276	4.40	CO <sub>2</sub> /N <sub>2</sub> O	400 mb	
17	2 361	4.24	CO <sub>2</sub>	5 mb	
18	2 512	4.00	Window	Surface	<i>Surface temperature.</i> Much less sensitive to clouds and H <sub>2</sub> O than the 11- $\mu\text{m}$ window. Used with 11- $\mu\text{m}$ channel to detect cloud contamination and derive surface temperature under partly cloudy sky conditions. Simultaneous 3.7- and 4.0- $\mu\text{m}$ data enable reflected solar contribution to be eliminated from observations.
19	2 671	3.70	Window	Surface	
20	14 367	0.70	Window	Cloud	<i>Cloud detection.</i> Used during the day with 4.0- and 11- $\mu\text{m}$ window channels to define clear fields of view.

MSU	Frequency (GHz)	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	50.31	Window	Surface	<i>Surface emissivity</i> and cloud attenuation determination.
2	53.73	O <sub>2</sub>	700 mb	<i>Temperature sounding.</i> The microwave channels probe through clouds and can be used to alleviate the influence of clouds on the 4.3- and 15- $\mu\text{m}$ sounding channels.
3	54.96	O <sub>2</sub>	300 mb	
4	57.95	O <sub>2</sub>	90 mb	

SSU	Wavelength ( $\mu\text{m}$ )	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	15.0	CO <sub>2</sub>	15.0 mb	<i>Temperature sounding.</i> Using CO <sub>2</sub> gas cells and pressure modulation, the SSU observes thermal emissions from the stratosphere.
2	15.0	CO <sub>2</sub>	4.0 mb	
3	15.0	CO <sub>2</sub>	1.5 mb	

LECTURE 15. SEA SURFACE TEMPERATURE AND OTHER SATELLITE APPLICATIONS

References:

AN INTERACTIVE METHOD FOR PROCESSING AND DISPLAY OF SEA-SURFACE TEMPERATURE FIELDS USING VAS MULTISPECTRAL DATA. J. BATES, W. SMITH, G. WADE AND H. WOOLF, BAMS, 68, 6, 602-606.

COMBINED ATMOSPHERIC SOUNDING/CLOUD IMAGERY-A NEW FORECASTING TOOL. W. SMITH, G. WADE, H. WOOLF, BAMS, 66, 2, 138-141.

SEA SURFACE TEMPERATURE:

A REGRESSION TECHNIQUE SIMILAR TO AVHRR, UTILIZING MEASUREMENTS IN THE 3.9  $\mu\text{m}$ , 11.2  $\mu\text{m}$ , and 12.6  $\mu\text{m}$  SPECTRAL REGIONS

- COMPOSITE TECHNIQUES OVER HOURS, DAYS, ETC.
- INTERACTIVE CLOUD SCREENING TECHNIQUES
- HOURLY GENERATION CAPABILITY ALLOWS CLOUDS TO "MOVE OUT OF THE WAY" FOR MORE COMPLETE COVERAGE
- EFFECTIVE RESOLUTION OF 8 KM

PROCEDURE:

1) SCREENING FOR CLOUDINESS

- VISIBLE ALBEDO THRESHOLD DURING DAYLIGHT
- MAX / MIN THRESHOLDS ON IR Tb
- MAX / MIN THRESHOLDS ON IR Tb DIFFERENCES
- SPATIAL COHERENCE TESTS OF THE RADIANCE FIELDS

2) USES REGRESSION MODEL RELATING VAS WINDOW CHANNEL RADIANCES TO COINCIDENT NOAA MOORED-BUOY OBSERVATIONS

TABLE 1

ACHIEVEMENT OF THE TECHNIQUE:

- 1) 8 km VAS-SST RETRIEVALS FOR EACH IR FOV

- 2) PUTS RETRIEVALS BACK INTO IMAGE FORMAT
- 3) FORMS A SST COMPOSITE IMAGE USING THE LATEST SST INFORMATION FOR EACH FOV

ADVANTAGES:

- 1) GEOSTATIONARY ORBIT MINIMIZES ZENITH ANGLE CHANGES
- 2) CONTINUOUS VIEWING TO MINIMIZE CLOUD EFFECTS

DISADVANTAGES:

- 1) LARGER FOV (8-16 km) vs. AVHRR (1-4 km)
- 2) LIMITED AREA COVERAGE

COMBINED SOUNDING PRODUCTS/IMAGERY

USES INFRARED RETRIEVALS IN CLEAR OR LOW CLOUD AREAS AND CLOUD IMAGERY IN OTHER CLOUDY AREAS

RETRIEVAL PRODUCTS CURRENTLY USED:

- 1) STABILITY (TOTAL TOTALS)
- 2) TOTAL PRECIPITABLE WATER VAPOR

REQUIREMENTS (OR DESIRED QUALITIES):

- 1) PRESERVE FULL RESOLUTION OF THE DATA
- 2) DISPLAY REAL DATA ONLY (NOT FROM OBJ ANAL)
- 3) PROVIDE REAL TIME IMAGE OF DERIVED QUANTITY

A TIME SEQUENCE OF THESE IMAGES ALLOWS THE FORECASTER TO MONITOR THE EVOLUTION OF THESE FIELDS WITH TIME BETWEEN CONVENTIONAL RADIOSONDE OBSERVATION TIMES

AT THE SAME TIME THE FORECASTER CAN MONITOR THE EVOLUTION OF CLOUDINESS ASSOCIATED WITH THE WATER VAPOR AND STABILITY

LECTURE 16. ESTIMATION OF TROPICAL CYCLONE STRENGTH

SUNDAY, 20 NOVEMBER: DAY 8

MONITORING TROPICAL CYCLONE EVOLUTION WITH NOAA SATELLITE MICROWAVE OBSERVATIONS. C. VELDEN AND W. SMITH, JCAM, 22, 5, 714-724.

OBSERVATIONAL ANALYSES OF NORTH ATLANTIC TROPICAL CYCLONES FROM NOAA POLAR-ORBITING SATELLITE MICROWAVE DATA. C. VELDEN (TO BE PUBLISHED IN FEB 1989, J. OF APPLIED MET.)

USES TOVS MSU SOUNDINGS, WITH EMPHASIS ON CH. 3

DEVELOPS A RELATIONSHIP BETWEEN:

- 1) THE HORIZONTAL TEMPERATURE GRADIENT OF THE UPPER LEVEL WARM CORE
- 2) THE SURFACE INTENSITY AS MEASURED BY RECONNAISSANCE REPORTS

WARM CORE THE RESULT OF:

- 1) LATENT HEAT RELEASE IN DEEP CONVECTION
- 2) SUBSIDENCE IN THE EYE REGION.

BOTH ARE MEASURES OF THE STORM INTENSITY

OVER 300 CASES OF MSU OBSERVATIONS DURING 18 NORTH ATLANTIC TROPICAL CYCLONES (1979-1985)

REGRESSION RELATIONSHIP ALSO ACCOUNTS FOR:

- 1) STORM LATITUDE
- 2) EYE SIZE
- 3) INTENSITY TENDENCY

**SOME OBSERVATIONS**

- 1) HORIZONTAL RESOLUTION OF MSU VARIES FROM 110 KM AT NADIR TO 250 KM AT LIMBS
  - WARM CORE COULD BE "SEEN" BY MORE THAN 1 FOV, AND THUS WEAKENED
  - PASSES THAT ARE NOT CENTERED ARE NOT USED
- 2) WEAK STORMS OR DIVIDED SIGNAL AND INSTRUMENT NOISE MAY ALL LEAD TO POOR DEPICTION OF WARM CORE
- 3) STRONG CYCLONES AND THOSE WITH LARGE EYES HAVE A GREATER SIGNAL



- 4) PRECIPITATION ATTENUATION EFFECTS IN MSU-3 ARE MINIMAL. THEY CAN BE LARGE IN MSU-2
- 5) MICROWAVE SIGNATURE SEEMS TO BE RELATED TO STORM STAGE AND/OR SURFACE PRESSURE INTENSITY. A TIME LAG TO THE UPPER TROPOSPHERE RESPONSE SEEMS TO BE PRESENT
- 6) STORMS WHICH ARE RECURVING AND INTERACTING WITH MID LATITUDE BAROCLINIC REGIONS NECESSITATE TECHNIQUE ADJUSTMENT

#### ESTIMATION OF SURFACE INTENSITY AND MAXIMUM SURFACE WINDS

##### TECHNIQUE:

- 1) MSU CHANNELS 1 AND 2 MUST BE INTERACTIVELY EDITED FOR PRECIPITATION ATTENUATION
- 2) MICROWAVE 4-CHANNEL SOUNDINGS ARE INTERACTIVELY PRODUCED USING THE PHYSICAL RETRIEVAL METHOD (ITPP)
  - A CORE SOUNDING AND 10 ENVIRONMENTAL SOUNDINGS AT 6 TO 10 DEGREES FROM THE CENTER ARE PRODUCED
- 3) 250 MB TEMPERATURES ARE THEN AVERAGED FOR THE ENVIRONMENTAL SOUNDINGS
- 4) THE ENVIRONMENT MINUS CORE 250 MB TEMPERATURE IS THEN RELATED TO A SURFACE INTENSITY PARAMETER (\*\*)

(\*\*) SUBTRACT RECONNAISSANCE MEASURED STORM CENTRAL PRESSURE FROM THE AVERAGE ENVIRONMENTAL SURFACE PRESSURE (DETERMINED BY AVERAGING SURFACE OR SHIP REPORTS SURROUNDING THE STORM AT A 6 TO 10 DEGREE RADIUS FROM THE STORM CENTER)

(I.E., RELATING UPPER TROPOSPHERIC TEMPERATURE GRADIENT WITH A SURFACE PRESSURE GRADIENT)

#### RESULTS

FROM 103 CASES...THE LINEAR REGRESSION RELATIONSHIP FOR SURFACE INTENSITY IS

$$dP_{sfc} = 17.5 * dT_{250} - 2$$

standard deviation = 8 mb  
correlation coefficient = .91

FROM 103 CASES...THE LINEAR REGRESSION RELATIONSHIP FOR MAXIMUM SURFACE WINDS IS

$$V_{max} = 28 * dT_{250} + 18$$

standard deviation = 13 kts  
correlation coefficient = .89

(THESE EQUATIONS ARE CONSIDERED ACCURATE FOR NORTH ATLANTIC HURRICANES ONLY !!)

**VARIANCE:**

- 1) RADIOMETRIC NOISE
- 2) LOCALIZED WARMING NOT RESOLVED BY THE INSTRUMENT
- 3) VERTICAL VARIATION OF MAX WARMING IN INDIVIDUAL STORMS
- 4) SCAN ANGLE CORRECTIONS
- 5) MAX WARM ANOMALY NOT CENTERED IN MSU SCAN SPOT (FOV)
- 6) PRECIPITATION
- 7) VARIATION IN STORM (EYE) SIZE
- 8) VARIATION IN STORM INTENSITY TENDENCY
- 9) VARIATIONS IN UPPER TROPOSPHERIC THERMAL ENVIRONMENT, ESPECIALLY IN HIGHER LATITUDES

**FUTURE WORK:**

- 1) SSM/I ON DMSP
- 2) AMSU (50 KM RES.) ON NOAA SATELLITES OF THE 1990's

LECTURE 17. TOVS RETRIEVAL ALGORITHM (ITPP)

DATA:

- 1) TOVS RADIANCES IN ITPP "TOVSND" FILE
- 2) INITIAL ATMOSPHERIC CONDITIONS (GUESS)
- 3) SURFACE CONDITIONS (OPTIONAL)

KEYINS:

```
$RUN TOVRET
ENTER LETTER OF FILE TO PROCESS = A
ENTER SFC-DATA FLAG (1=YES, 0=NO) = 0
ENTER GUESS TYPE (0=REGRESSION, 1=CLIMATOLOGY) = 0
ENTER START-LINE (DEFAULT=2) = 2
ENTER START-ELEM (DEFAULT=2) = 2
  TO MAKE SINGLE SOUNDING, LET NUM-LINES AND NUM-ELEMS=1
ENTER NUMBER OF LINES (DEFAULT=98) = 98
ENTER NUMBER OF ELEMS (DEFAULT=54) = 54
ENTER LINE-INCREMENT (DEFAULT=3) = 3
ENTER ELEM-INCREMENT (DEFAULT=3) = 3
ENTER TOPOGRAPHY FLAG (0=HI-RES, 1=LO-RES) = 0
  MWHS=RTVL USING MSU + HIRS (STRATOSPHERIC) CHANNELS
  IF=0, OUTPUT ONLY FULL-HIRS SOUNDINGS
  IF=1, OUTPUT MWHS SOUNDING IF FULL-HIRS FAILS
  IF=2, OUTPUT ONLY MWHS SOUNDINGS
ENTER VALUE FOR MWHS = 1
ENTER DIAGNOSTIC PRINT FLAG (0=NO, 1=YES) = 0
ENTER RETRIEVAL-FILE INIT FLAG (0=NO,1=YES) = 1
```

FLOW CHART OF TOVRET OPERATIONS:

CHECK LIMB CORRECTION FLAG

CALL PICKCL (\*\*) (FOR ALL FOVS)

DETERMINE SCAN ANGLE AND LOCAL ZENITH ANGLE

DETERMINE TIME

TOPOGRAPHY (LAND/SEA)

GET GUESS AND DO OPERATIONS

SKIN TEMPERATURE (PRELIMINARY)

CLOUD PARAMETERS (PRELIMINARY / CO<sub>2</sub> SLICE)

CALL HTMWR(\*) - RETRIEVAL CALCULATION (MSU + HIRS STRATO)

SKIN TEMPERATURE (FINAL)

CLOUD PARAMETERS (FINAL)

H<sub>2</sub>O<sub>v</sub> MIXING RATIO ADJUSTMENT FOR CLOUDS

CALL HTMWR(\*) - RETRIEVAL CALCULATION (ALL USEABLE CHANNELS)

OZONE RETRIEVAL

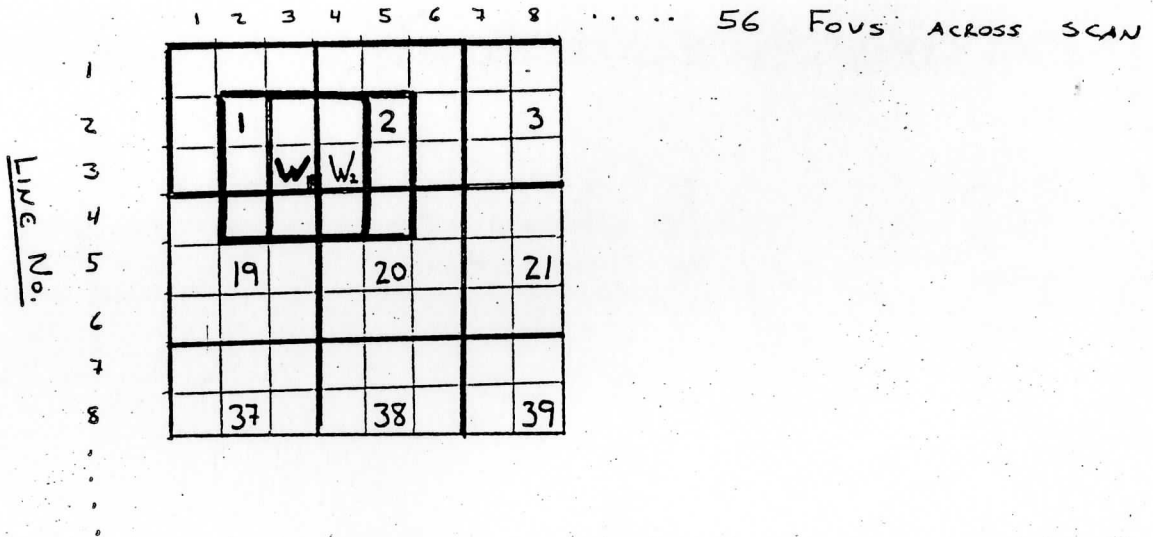
DERIVED PARAMETER CALCULATION

WRITE OUTPUT FILE

END

PICKCL

DETERMINES HIRS FOV SELECTION AND SPACING



1. From keyin input determine 3 x 3 FOV spacing box
2. Compare all Tb Ch.8 for 9 FOV box; find warmest
3. This becomes the center of the retrieval box

4. Determine which other FOVs are within 3 degrees  
apply weighting factor to average all channels of  
those selected to reduce noise
5. Result is 1 set of averaged radiance set for the large  
retrieval box (comprised of 9 HIRS FOVS)

#### SKIN TEMPERATURE (PART 1)

USED ONLY FOR CLIMATOLOGY 1ST GUESS AND/OR NO SURFACE INFORMATION

1. Do limb correction (if not done)
2. Uses weighted average retrieval box
3. Compare Tb Ch.8 against Tb Ch.10
4. Compare largest of these values with Tb MW Ch.1
5. Highest Tb = Tsk (skin temperature)
6. If using Climatology Tsk is completed for now
7. Otherwise, from regression model compare Tsk with the temperature of  
the lowest level (Tgs)
  - if Tgs > Tsk; use Tgs
  - if Tsk > Tgs; average them
  - result is Tsta (station temperature)
8. Check Tsta and guess for super adiabatic lapse; correct
9. Update mixing ratio for surface and atmosphere  
(if no surface data - use guess)
10. Update guess to include Tsta and new mixing ratio

#### SKIN TEMPERATURE (PART 2)

DIRTY WINDOW CORRECTION FOR WATER VAPOR

1. Apply correction to Tb Ch.18 for reflected solar (Ch.21)
2. Compare to Tb Ch.8; use maximum

SPLIT WINDOW TECHNIQUE FOR DETERMINING SKIN TEMP (Tsk)

DAY - 2 CHANNEL:  $Tsk = a*Ch.8 + b*Ch.10$

NIGHT - 3 CH:  $Tsk = a*Ch.8 + b*Ch.10 + c*Ch.18$

## CLOUD PARAMETERS

ITPP uses Ch.5 and Ch.7 for CO<sub>2</sub> slicing technique

(recent study - it is better to use Ch.7 and Ch.8)

Result is:

- 1) Cloud Amount
- 2) Cloud Height

## RETRIEVAL (HTMWR)

INPUT: HIRS, MSU RADIANCES  
SURFACE INFORMATION (T, WV)  
TOPOGRAPHY / ELEVATION  
SATELLITE ID

RETRIEVAL STEP 1 (MSU + HIRS Ch.1-3):

RETRIEVAL STEP 2 (MSU + ALL SELECTED HIRS)

1. Obtain input (see above)
2. Calculate transmittances of HIRS/MSU  
(Based on guess profile  $f(T, wv, \text{scan angle})$ )
3. Calculate emissivity ( ) using MSU Ch.1
4. Calculate basis functions  
(linear combination of coefficients and basis functions  
represent profiles-smooths data over 40 vertical points)
5. Clear check (\*)
6. Surface Tsk adjustment
7. Calculate all HIRS/MSU Tb from guess profiles and surface
8. Construct matrices for retrievals

-----  
These steps done only in retrieval step 2:

- 8a. Short wave / Long wave absorption band check (\*)
- 8b. Cirrus check (\*)

- 
9. Construct surface temperature/moisture vector
  10. Conduct Tb (observed) vs. Tb (calculated) error scaling  
for all channels to reduce expected noise

11. Do least squares solution to generate retrieval coefficients for basis functions
12. Update temperature and mixing ratio profiles from #11
12. Update Tsk and surface water vapor adjustment from #11
13. Calculate  $T_b$  (obs) -  $T_b$  (calc)
14. Return to TOVRET

**CLEAR CHECK**

SPLIT WINDOW TECHNIQUE: Tsw

OBSERVED (a priori) or CALCULATED: Tsta

1. Compare Tsw with Tsta:

If less than 5 deg. difference = CLEAR

If 5 to 9 deg. difference = another check

(If T<sub>sw</sub> greater than Ch.18 by 4 deg. = CLOUDY

(If T<sub>sw</sub> greater than Ch.19 by 8 deg. = CLOUDY)

If more than 10 deg. difference = CLOUDY

CLEAR: use T<sub>sw</sub> (split window)

CLOUDY: use Tsta (other)

**SHORT WAVE / LONG WAVE ABSORPTION BAND CHECK**

ITPP USES HIRS Ch.5 and Ch.7

1. Compare  $T_b$  (obs) -  $T_b$  (calc) =  $dT_b$  (delta  $T_b$ )

If  $dT_b5 + dT_b7 \Rightarrow 0.5$  deg. use SW and LW channels  
(there is little cloud effect)

If  $dT_b5 + dT_b7 \leq 0.5$  deg. AND

- If  $dT_b14 > dT_b5$  then suppress Ch.5-7  
(15 $\mu$ m wv contamination)

- If  $Abs(dT_b6) < Abs(dT_b14)$  then suppress Ch.13-15  
(which is worse, SW or LW)

**CIRRUS CHECK**

Uses HIRS Ch. 4, 5, 6, 7 and 10

Compare for all these channels:

If  $T_b(\text{obs}) - T_b(\text{calc}) < -1.0$  deg. then do NOT use that channel

If 3 of these channels fail - do not use HIRS for retrieval



## LECTURE 18. DERIVED METEOROLOGICAL PARAMETERS

TUESDAY, 22 NOVEMBER: DAY 10

### References:

- Menzel, W. Paul, 1984: Notes on Satellite Meteorology. Western Australian Institute of Technology, Perth, Australia, 104pp.
- Fritz, S., D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary, and J. C. Alishouse, 1972: Temperature Sounding from Satellites. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Service, Washington, DC, NOAA Technical Report NESS 59, 49pp.
- Smith, W. L., H. M. Woolf, C. M. Hayden, and A. J. Schreiner, 1985: The Simultaneous Retrieval Export Package. The Technical Proceedings of the Second International TOVS Study Conference, Igls, Austria, Feb. 18-22, 1985, 224-253.
- Ma, X. L., W. L. Smith, and H. M. Woolf, 1984: Total Ozone from NOAA Satellites - A Physical Model for Obtaining Observations with High Spatial Resolution. Journal of Climate and Applied Meteorology, 23, 1309-1314.
- Velden, C. S. and W. L. Smith, 1983: Monitoring Tropical Cyclone Evolution with NOAA Satellite Microwave Observations. Journal of Climate and Applied Meteorology, 22, 714-724.
- Menzel, W. P., W. L. Smith, and T. R. Stewart, 1983: Improved Cloud Motion Vector and Altitude Assignment Using VAS. Journal of Climate and Applied Meteorology, 22, 377-384.
- Schreiner, A. J. and C. M. Hayden, 1988: An Evaluation of VAS Satellite Moisture Retrievals and Moisture Bogus Data in the Gulf of Mexico. University of Wisconsin, Cooperative Institute for Meteorological Satellite Studies, 24pp.
- Smith, W. L. and F. X. Zhou, 1982: Rapid Extraction of Layer Relative Humidity, Geopotential Thickness, and Atmospheric Stability from Satellite Sounding Radiometer Data. Applied Optics, 21, 924-928.
- Wylie, D. P. and W. P. Menzel, 1988: Cloud Cover Statistics using VAS. SPIE Conference on Nonlinear Optical Beam Manipulation, Beam Combining, and Atmospheric Propagation, Bellingham, WA, 874, 253-259.
- Smith, W. L., G. S. Wade, and H. M. Woolf, 1985: Combined Atmospheric Sounding/Cloud Imagery-A New Forecasting Tool. Bulletin of the American Meteorological Society, 66, 138-141.
- Bates, J. J., W. L. Smith, G. S. Wade, and H. M. Woolf, 1987: An Interactive Method for Processing and Display of Sea-Surface Temperature

Fields using VAS Multispectral Data. Bulletin of the American Meteorological Society, 68, 602-606.

Togstad, W. E., W. L. Smith, and G. S. Wade, 1980: The April 1980 Heat Wave as Depicted by TIROS-N. Bulletin of the American Meteorological Society, 61, 1406-1407.

Velden, C. V., W. L. Smith, and M. Mayfield, 1984: Applications of VAS and TOVS to Tropical Cyclones. Bulletin of the American Meteorological Society, 65, 1059-1067.

Stewart, T. R., C. M. Hayden, and W. L. Smith, 1985: A Note on Water-Vapor Wind Tracking Using VAS Data on McIDAS. Bulletin of the American Meteorological Society, 66, 1111-1115.

Martin, D. W. and M. R. Howland, 1986: Grid History: A Geostationary Satellite Technique for Estimating Daily Rainfall in the Tropics. Journal of Climate and Applied Meteorology, 25, 184-195.

- I. Meteorological parameters which are a direct result of the solution of the radiative transfer equation (RTE).
  - A. Temperature. (Menzel, 1984; Fritz et al., 1970; and Smith et al., 1985).
    - 1. Sea surface temperature (fig. 1, both VAS & TOVS).
    - 2. Atmospheric temperature profiles (fig. 2 & 3, analyses and profiles).
  - B. Moisture. (Menzel, 1984; Fritz et al., 1970; and Smith et al., 1985).
    - 1. Total precipitable water (fig. 4).
    - 2. Dew point as a function of pressure (fig. 5).
  - C. Ozone from TOVS only (fig. 6). (Ma et al., 1984).
  - D. Cloud height, amount, and temperature, from which cloud climatology studies are being performed (fig. 7). (Menzel, et al., 1983; Wylie and Menzel, 1988).
- II. From the primary parameters other important meteorological variables are derived.
  - A. Geopotential height and thickness (fig. 8 & 9). (Menzel, 1984).
  - B. Thermal Winds (fig. 10). (Menzel, 1984).
    - 1. Geostrophic.
    - 2. Gradient.

- C. From surface and satellite-derived dew points, layered precipitable water is determined (fig. 11 & 12). (Schreiner and Hayden, 1988).
    - 1. As a function of pressure.
    - 2. As a function of sigma coordinates.
  - D. Variables which are used as aids in forecasting the occurrence of severe thunderstorms; can be updated hourly when using VAS (fig. 13). (Smith and Zhou, 1982).
    - 1. Total-totals (definition).
    - 2. Lifted index (definition).
    - 3. Keller index (definition).
- III. From the observed radiances, images of satellite-derived products are produced.
- A. Total precipitable water vapor (fig. 14). (Smith et al., 1985).
  - B. Total Totals (stability) index (fig. 15). (Smith et al., 1985).
  - C. Sea surface temperature (fig. 16). (Smith et al., 1987).
  - D. Rain intensity is derived from the use of geostationary satellite visible and infrared data (fig. 17). (Martin and Howland, 1986).
- IV. Through the use of a loop of three or more geostationary satellite images, motion vector products are determined. These winds are now being generated both interactively and in automated fashion.
- A. Infrared cloud motion vector winds (fig 18). (Stewart et al., 1985).
  - B. Water vapor motion vector "winds" (fig. 19). (Stewart et al., 1985).
  - C. Derived imagery motion vectors. Currently in the development stage, this scheme will be used to track "signatures" of any type of tracer (for example, precipitable water) for the purpose of studying the motion characteristics of a particular tracer of interest (which in this case is moisture divergence) (fig. 20).
  - D. Deep layer mean. This satellite-derived product combines the information gleaned from the infrared cloud motion winds, the water vapor motion vectors, and the gradient winds elicited from the satellite temperature/moisture profiles. All three of these remotely sensed data sources in addition to any radiosonde data, if available, are combined to produce a three dimensional wind analysis, which

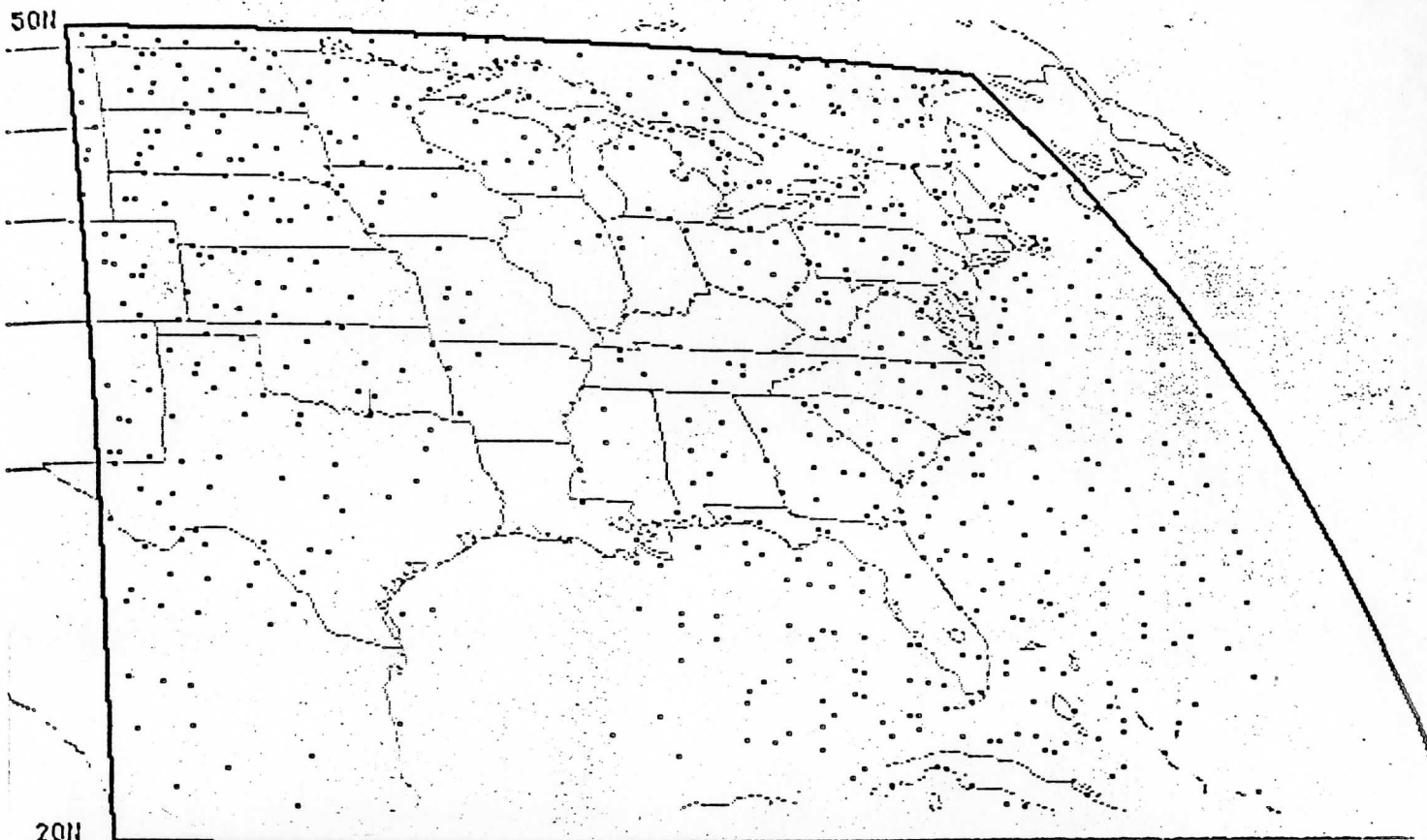
is used in forecasting the tracks of tropical cyclones and hurricanes (fig. 21) (Velden et al., 1984).

V. Operational products available from microwave sounders.

- A. It is possible to monitor the intensity of tropical cyclones as categorized by its surface central pressure and maximum sustained wind speed at the eye wall with satellite microwave observations (fig.22) (Velden and Smith, 1983).
- B. Definition of thermal patterns, especially by using the image defined by a limb-corrected channel 2 from the MSU (fig. 23) (Togstad et al., 1980).

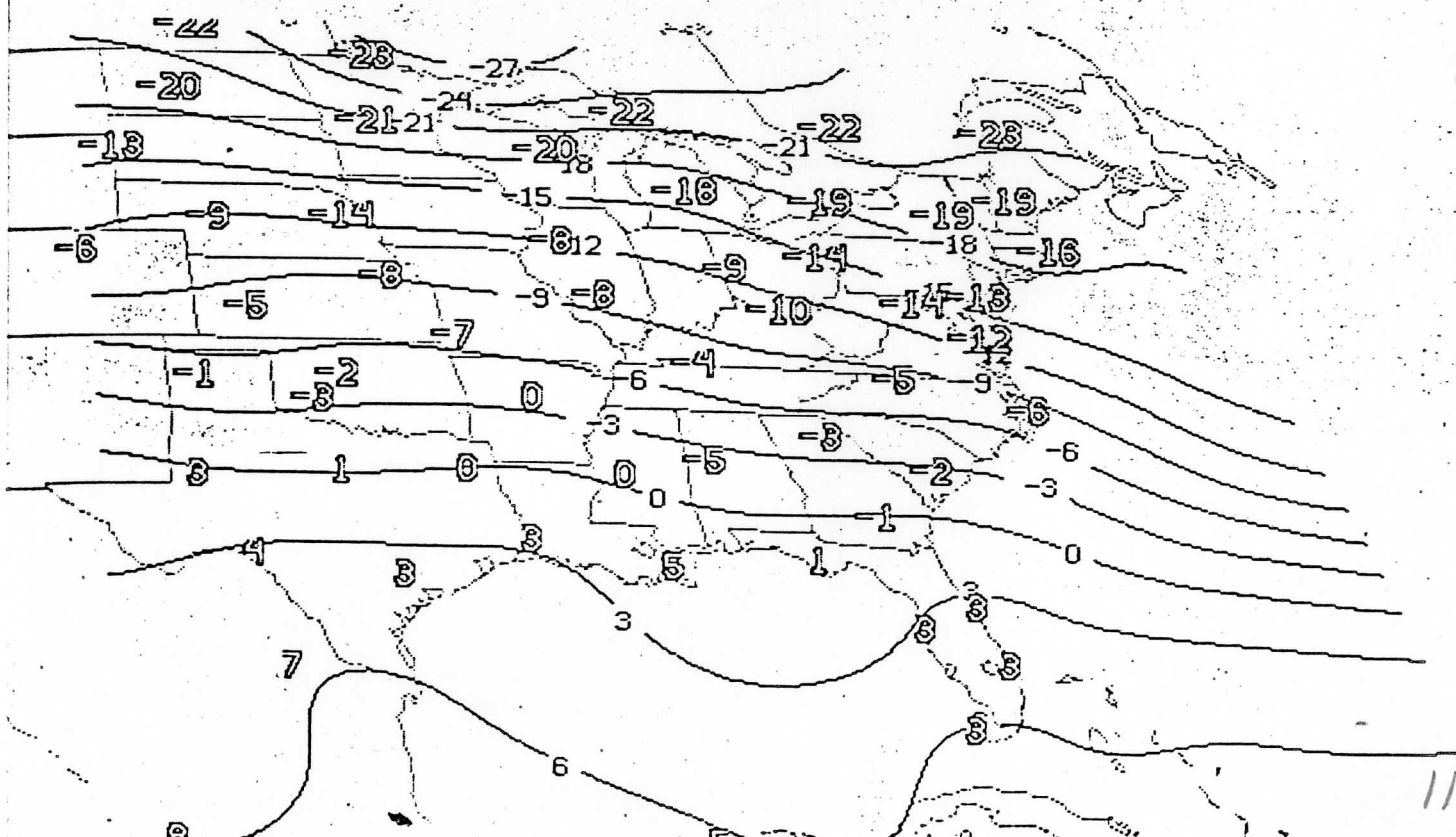
14 FEBRUARY 1986 1200GMT  
DATA COVERAGE

TOVS



14 FEBRUARY 1986 1200GMT  
700MB T (C)

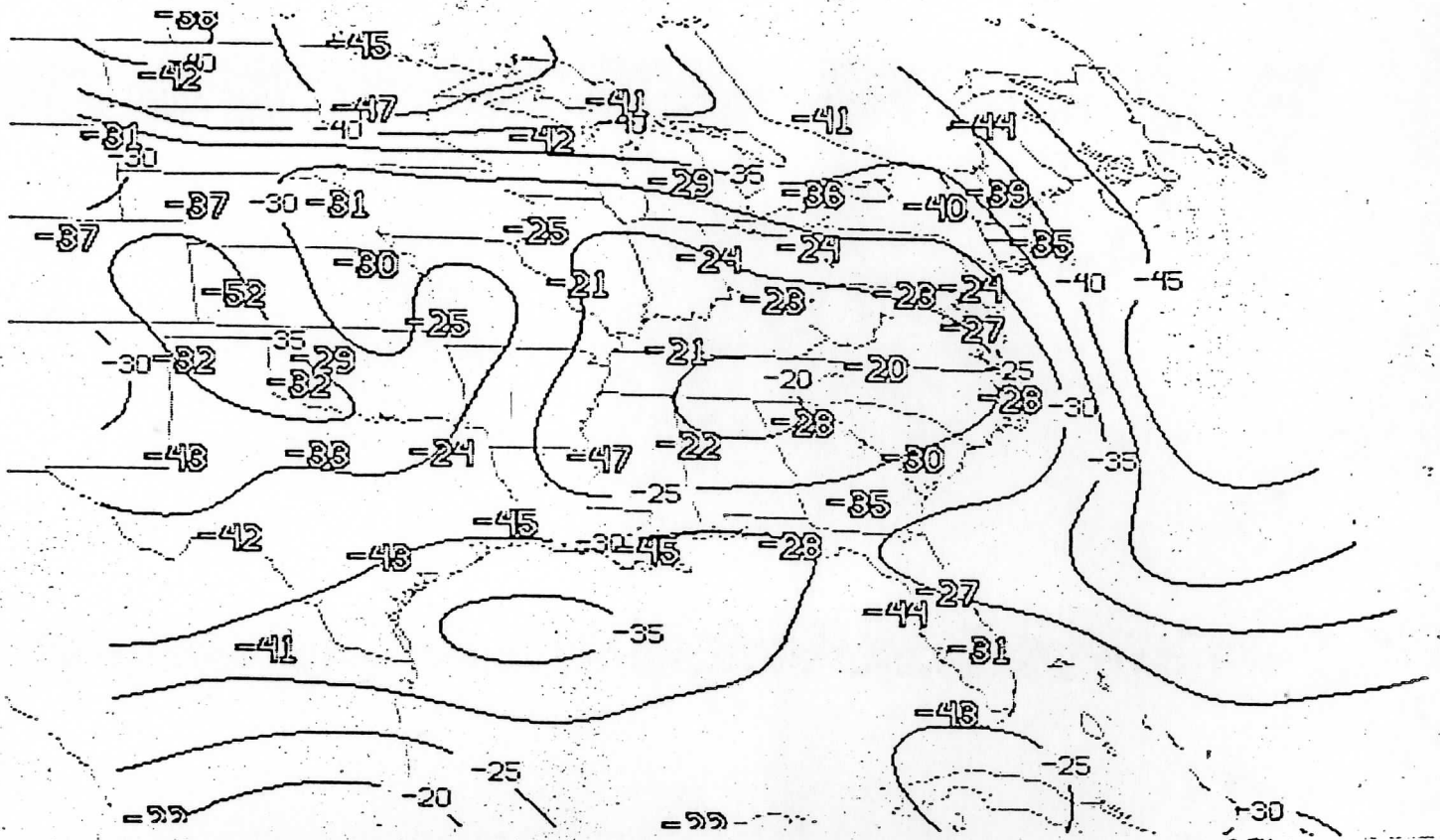
TOVS ANAL  
RAOB PLOTTED



6. 5

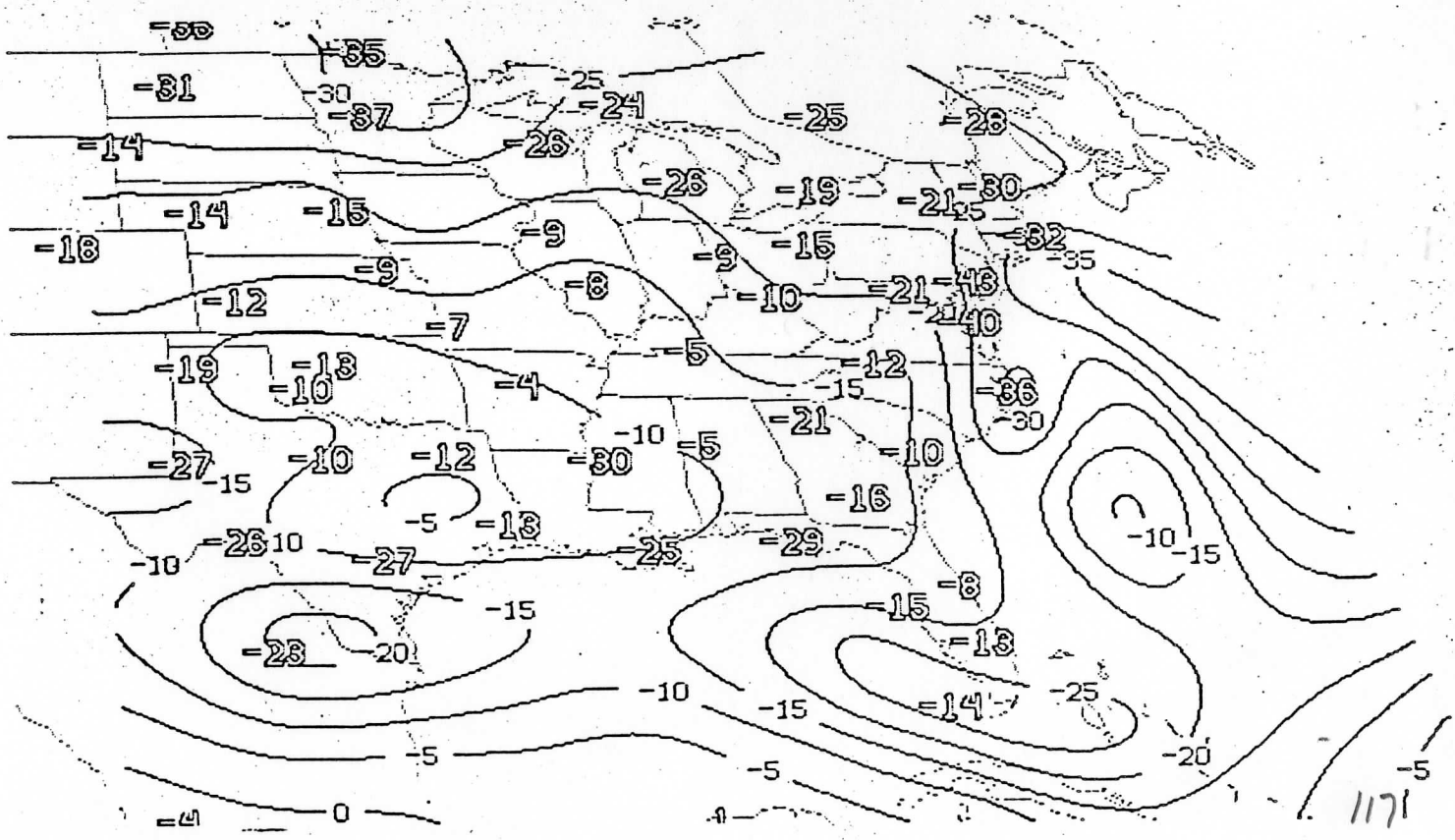
14 FEBRUARY 1986 1200GMT  
500MB TD(C)

TOVS ANAL  
RAOB PLOTTED



14 FEBRUARY 1986 1200GMT  
700MB TD(C)

TOVS ANAL  
RAOB PLOTTED



1171

JOURNAL OF CLIMATE AND APPLIED METEOROLOGY

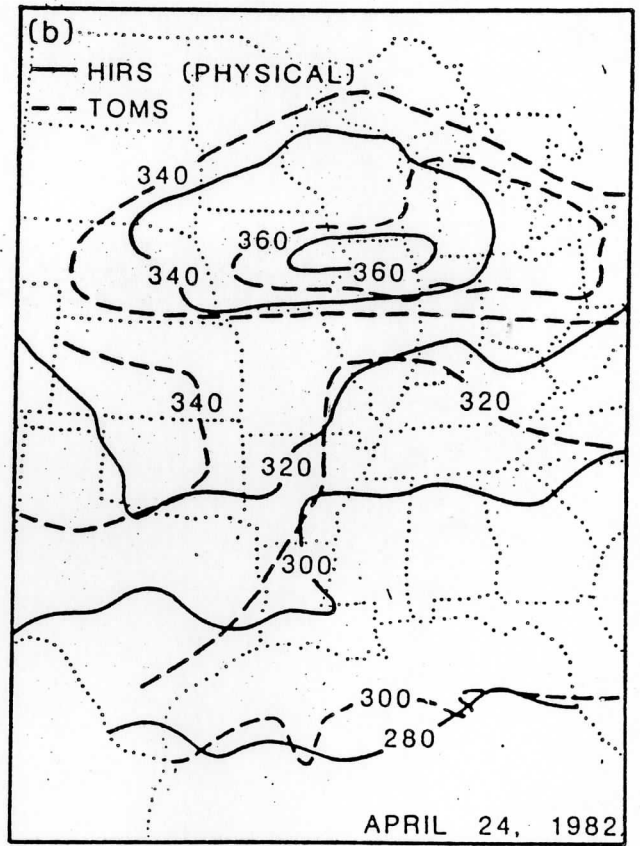
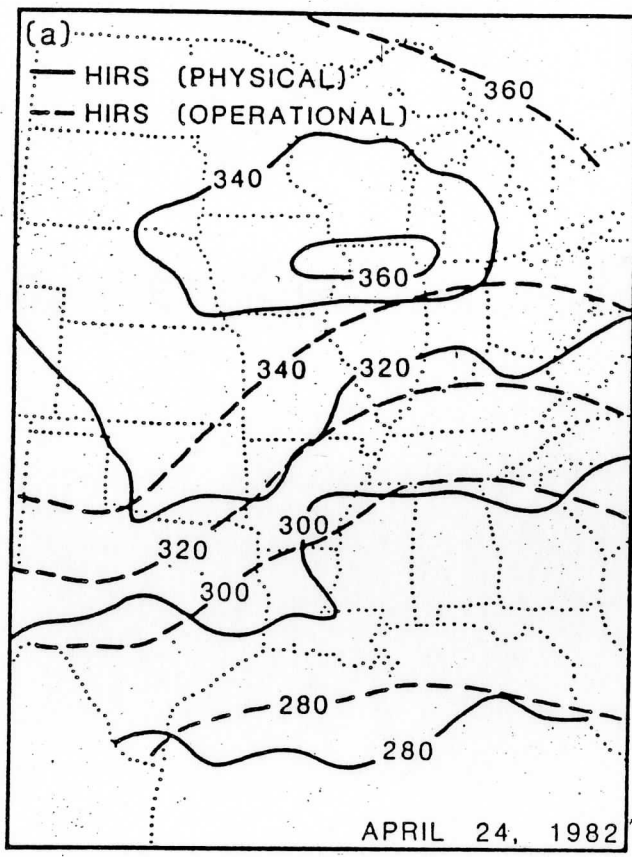
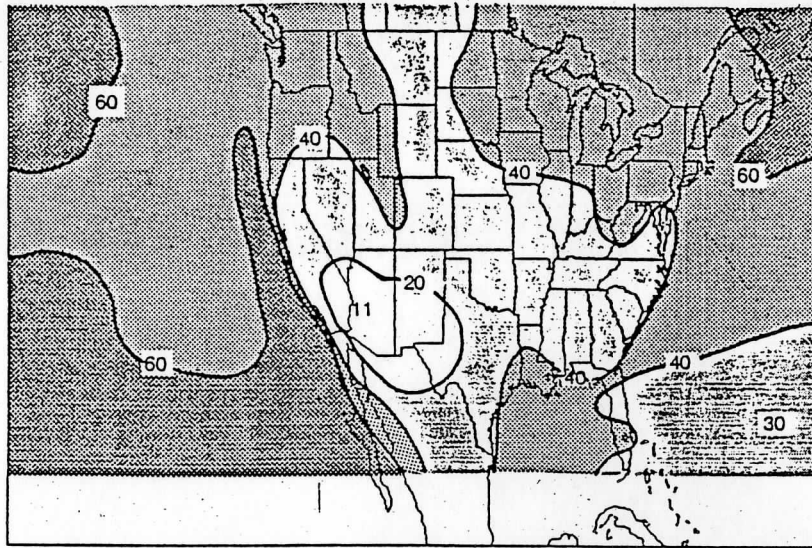
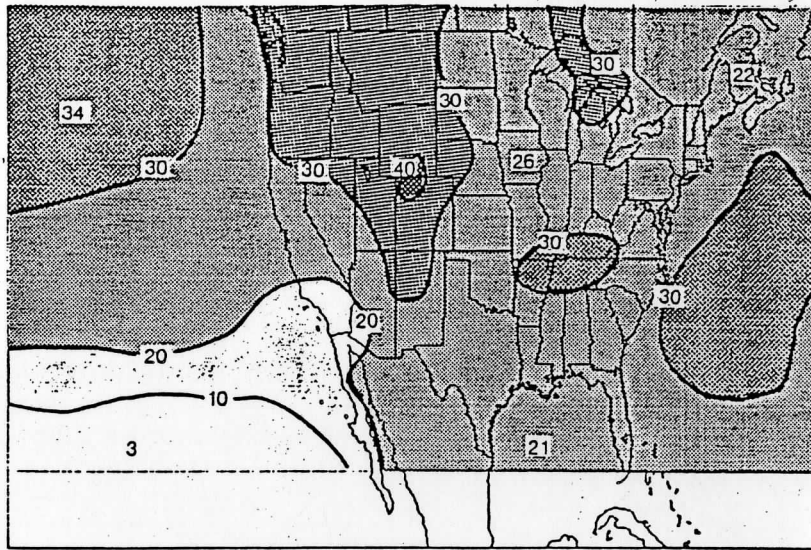


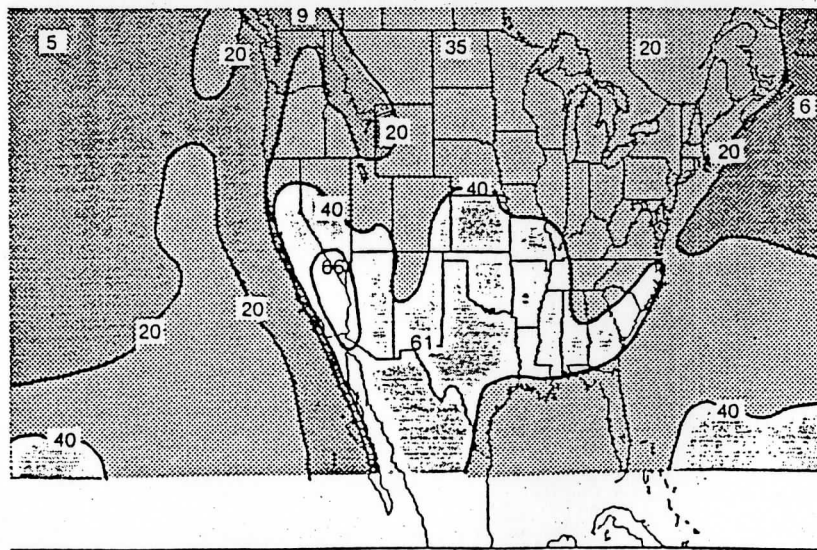
FIG. 1. Analyses of total ozone for 24 April 1982 retrieved from HIRS radiances using the physical algorithm with (a) operational pure regression retrievals and (b) ozone retrievals from TOMS measurements of the absorption of backscattered ultraviolet radiation.



Probability of Opaque Cloud Cover (%)



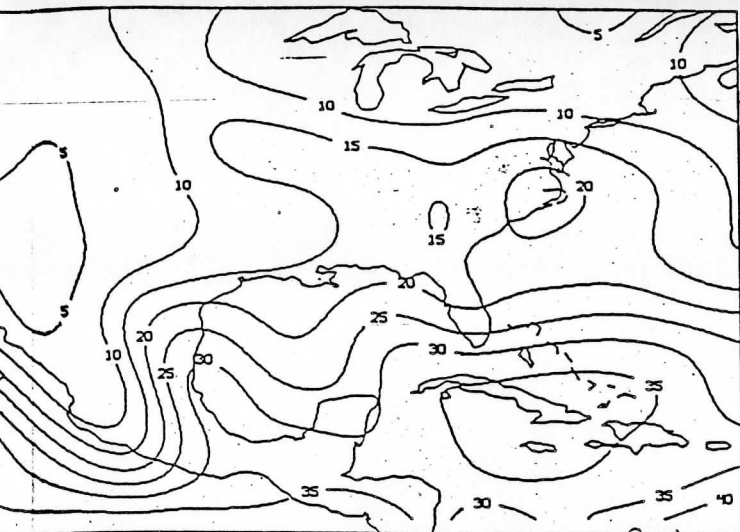
Probability of Cirrus Clouds (%)



Probability of Clear Sky (%)

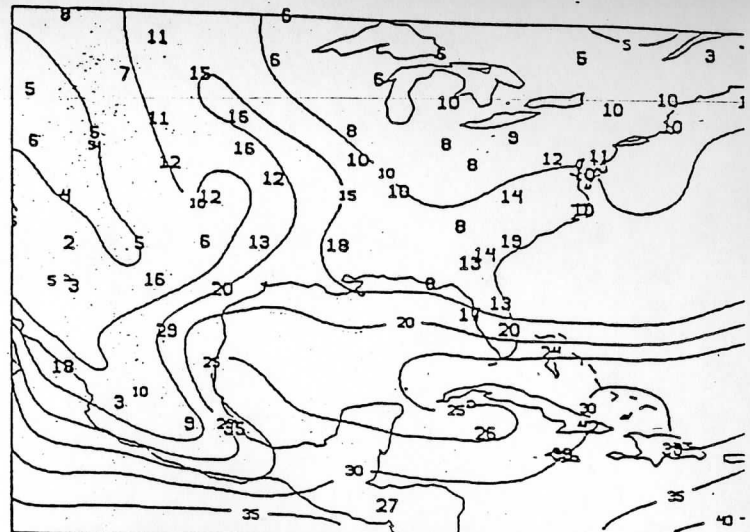
The geographical distributions of (A) cloudy, (B) cirrus, and (C) clear sky conditions from October 1985 through October 1987.





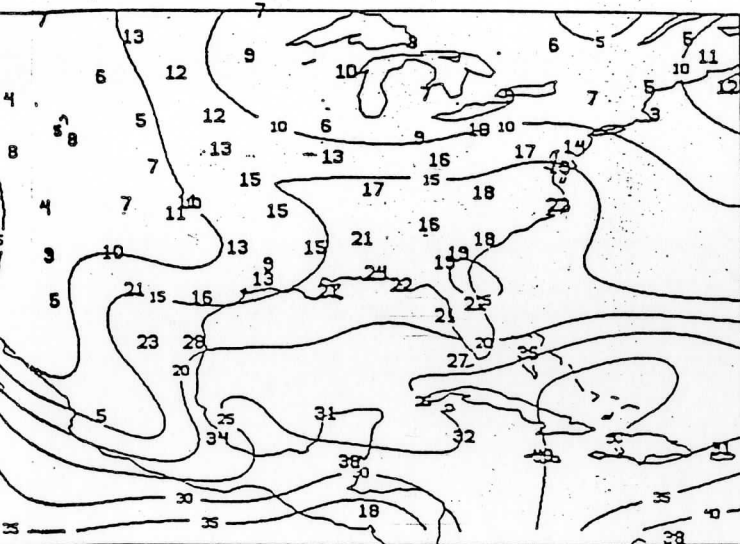
LAYERED PRECIPITABLE WATER (MILLIMETERS)  
SURFACE TO 0.70 SIGMA

4 MAY 1988 1200UTC  
VAS ANALYSIS



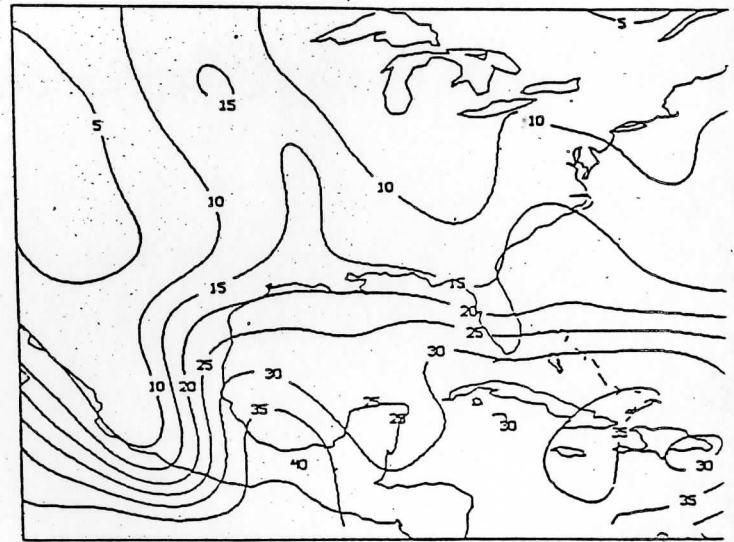
LAYERED PRECIPITABLE WATER (MILLIMETERS)  
SURFACE TO 0.70 SIGMA

3 MAY 1988 1200UTC  
12HR RAFS FCST (VALID 1200UTC)  
RAOB VALUES (PLOTTED)



LAYERED PRECIPITABLE WATER (MILLIMETERS)  
SURFACE TO 0.70 SIGMA

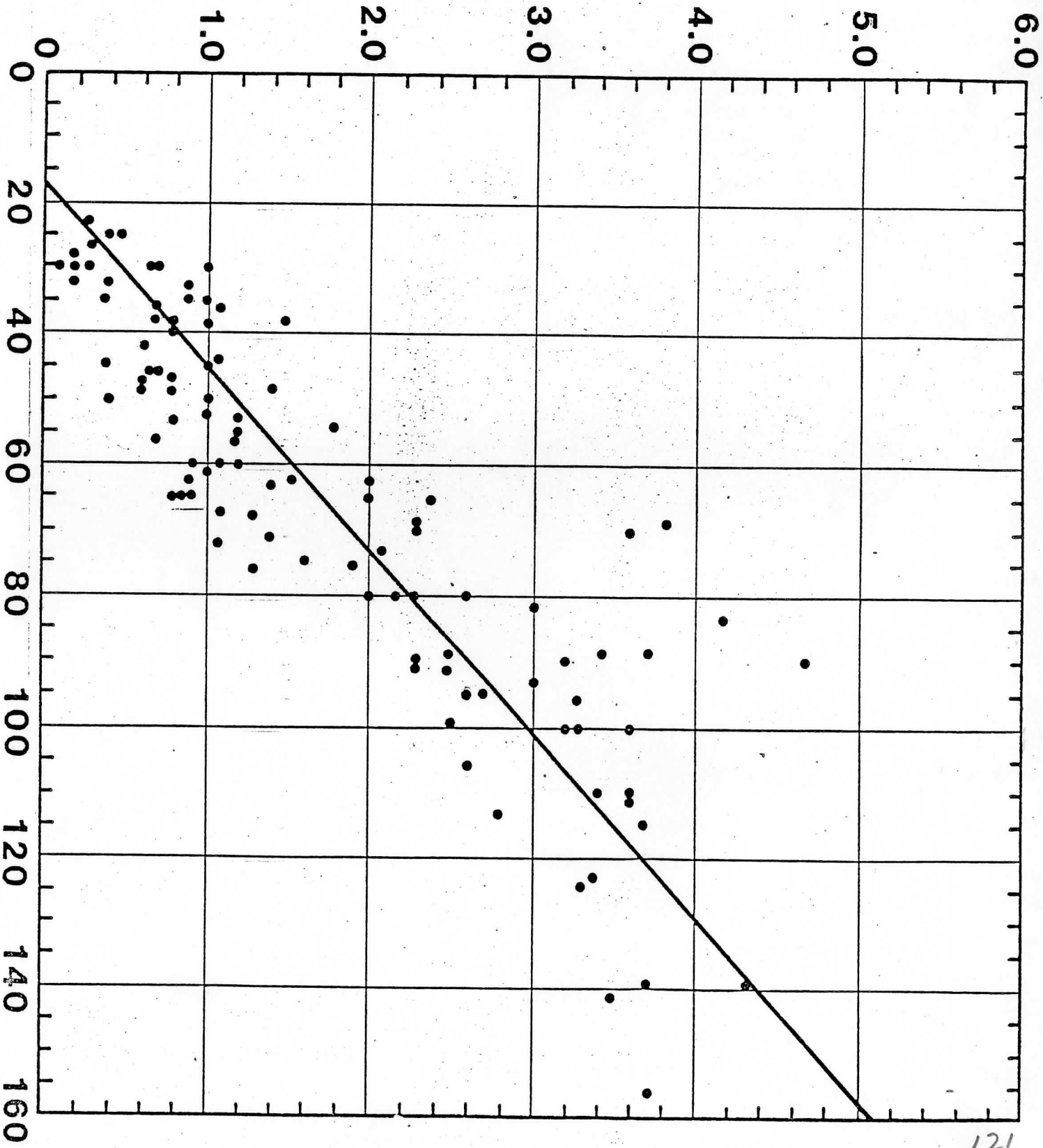
4 MAY 1988 1200UTC  
12HR RAFS FCST (VALID 1200UTC)  
RAOB VALUES (PLOTTED)



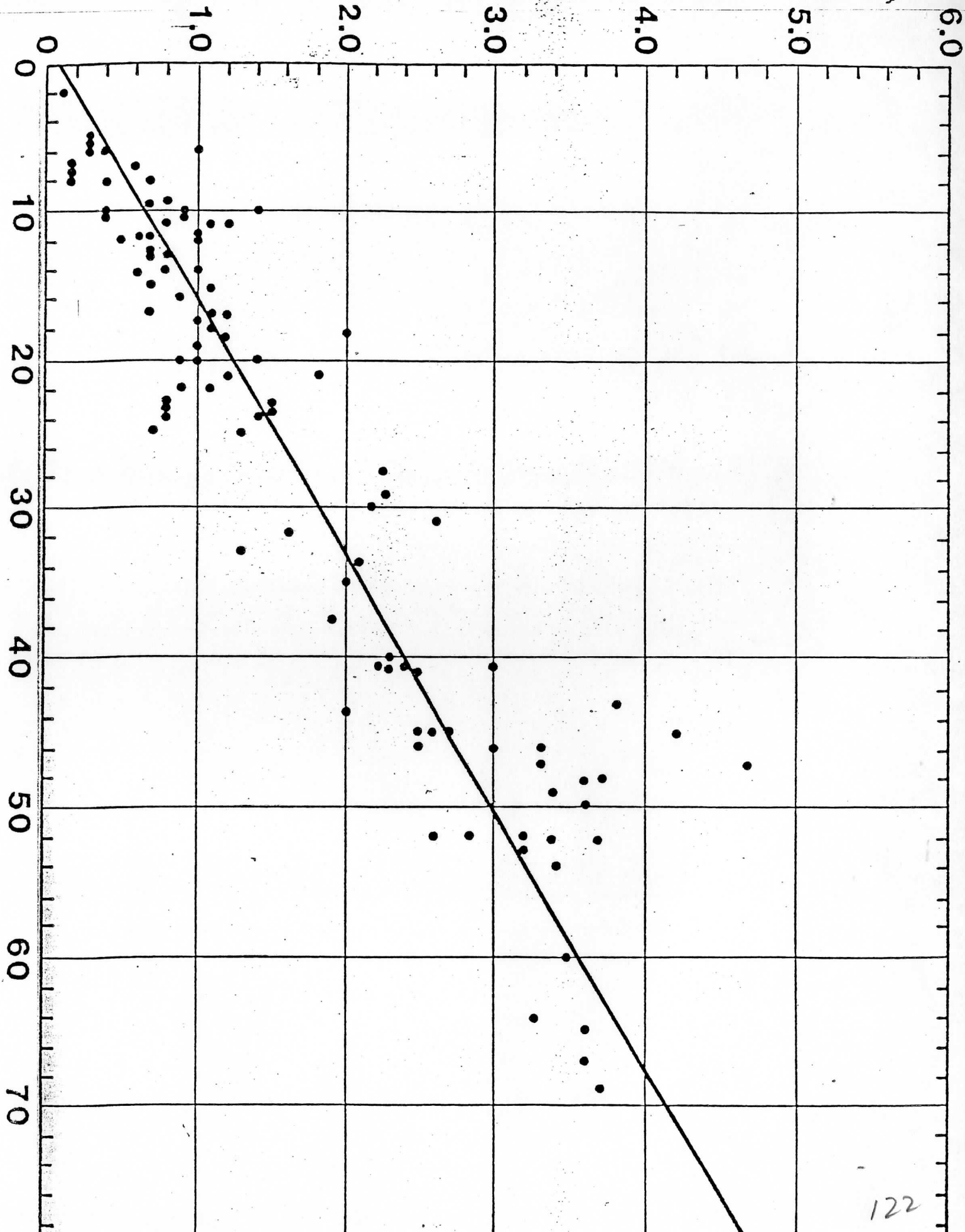
LAYERED PRECIPITABLE WATER (MILLIMETERS)  
SURFACE TO 0.70 SIGMA

3 MAY 1988 1200UTC  
VAS ANALYSIS

MSU  $\Delta T_{250} (^{\circ}\text{C})$



MSU  $\Delta T_{250}$  ( $^{\circ}\text{C}$ )



## LECTURE 19. SIMULTANEOUS RETRIEVAL ALGORITHM

- I. This retrieval algorithm permits the simultaneous retrieval of surface-skin temperature, and the temperature and moisture profiles. Briefly, the basic outline is defined as follows.
  - A. The radiative transfer equation is integrated by parts and treated in perturbation form. The perturbation is defined with respect to some estimate or mean condition.
  - B. Then the perturbations of temperature and water vapor are expressed as a linear expansion of basis functions, where for application to the TOVS the channel weighting functions are used.
  - C. Ancillary observations become extra equations and add further to the stability of the matrix solution.
  - D. A least squares solution is employed.
- II. Advantages of the "simultaneous" method over the iterative method.
  - A. The main advantage of the "simultaneous" method is that it enables the temperature and water vapor profiles and the surface skin temperature to be determined simultaneously using all the radiance information available.
  - B. Since only a single matrix inversion is required for the specification of all parameters, the solution is more computationally efficient than the iterative technique.
  - C. Ancillary observations of temperature and/or moisture from surface sensors or aircraft, for example, can be readily incorporated in the solution.
- III. Both methods discussed in this course are physical in nature, in that they are based upon physical relationships between measured radiance and the vertical temperature/moisture profile.

WEDNESDAY, 23 NOVEMBER: DAY 11

LECTURE 20. APPLICATIONS TO NUMERICAL METHODS

References:

A MESOSCALE DATA ASSIMILATION SYSTEM FOR REAL-TIME USE IN THE McIDAS ENVIRONMENT, G. MILLS, G. CALLAN AND B. GOODMAN. CIMSS REPORT, 1985.

ANALYSIS AND FORECAST EXPERIMENTS INCORPORATING SATELLITE SOUNDINGS AND CLOUD AND WATER VAPOR DRIFT WIND INFORMATION, B. GOODMAN, G. DIAK AND G. MILLS. SECOND CONF. ON SATELLITE METEOROLOGY, WILLIAMSBURG, VA, 1986.

METHODS OF INCORPORATING SATELLITE DATA INTO MESOSCALE NUMERICAL MODELS, G. DIAK AND G. MILLS. SYMPOSIUM ON MESOSCALE ANALYSIS AND FORECASTING, VANCOUVER, CANADA, 1987.

SATELLITE MEASUREMENTS HAVE BEEN USED ROUTINELY IN GLOBAL SCALE MODELS FOR OVER A DECADE.

- GLOBAL TOVS RETRIEVALS ARE THE MAJOR ATMOSPHERIC INPUT TO NMC AND ECMWF NUMERICAL MODELS OVER OCEAN REGIONS

MESOSCALE MODELLING HAS MORE RECENTLY BEGAN TO USE SATELLITE INFORMATION

- MAJORITY OF APPLICATIONS USE SOUNDINGS AND WINDS
- DERIVED PARAMETERS ALSO UNDER STUDY
  - SST
  - LAND/SURFACE ENERGY BALANCE PARAMETERS
  - RAINFALL RATES

DATA ANALYSIS AND INTERPRETATION

OBSERVATIONAL DATA MUST BE LINKED TO MODEL THROUGH SPATIAL AND TEMPORAL INTERPOLATION TO MODEL GRID

ESSENTIAL COMPONENTS OF SYSTEM:

1. MODEL FORECAST TO NEXT DATA INSERTION TIME
2. CORRECTION OF FORECAST FIELDS TO FIT OBSERVATIONAL DATA (ANALYSIS PHASE)
3. INITIALIZATION PROCESS TO BALANCE THE CORRECTED FIELDS PRIOR TO THE NEXT FORECAST PHASE

THE DESIRABLE PRINCIPLES OF SUCH A SCHEME:

1. ANALYSIS MUST FIT OBSERVATIONS TO WITHIN THEIR ESTIMATED OBSERVATIONAL ERRORS

2. ANALYZED FIELDS MUST BE INTERNALLY CONSISTENT, MATCHING THE STRUCTURE, SCALE AND BALANCE OF THE ATMOSPHERE
3. ANALYSIS MUST BE NEAR THE FORECAST BASED ON EARLIER OBSERVATIONS, UNLESS CURRENT OBSERVATIONS INDICATE OTHERWISE

MANY DIFFERENT APPROACHES EXIST DEALING WITH THE ASSIMILATION INTERVALS AND INITIALIZATION PROCEDURES

EX: 6 HOUR UPDATE CYCLE WITH A +/- 3 HOUR DATA EXCEPTANCE WINDOW, FOLLOWED BY A NON-LINEAR NORMAL MODE INITIALIZATION AFTER ANALYSIS

EX: 2 HOUR UPDATE CYCLE; CONTINUOUS DATA INSERTION (GFDL)

EX: "NUDGING" TECHNIQUE TO STEER MODEL TO DATA DURING THE SIX HOURS TO ANALYSIS TIME (UKMO)

#### SUMMARY OF ANALYSIS OF CHARACTERISTICS

A SYSTEMATIC FRAMEWORK FOR BLENDING OBSERVATIONS OF DIFFERING ERROR CHARACTERISTICS WITH OTHER INFORMATION, SUCH AS RECENT MODEL PREDICTION

- MORE ACCURATE DATA RECEIVE MORE WEIGHT IN THE ANALYSIS
- DATA DISTRIBUTION IS ACCOUNTED FOR BY ASSIGNING LESS WEIGHT TO OBSERVATIONS CLUSTERED TOGETHER
- OBSERVATIONS CHARACTERIZED BY SYSTEMATIC ERRORS RECEIVE LESS WEIGHT THAN DO THOSE WITH RANDOM ERRORS

METHOD IS SPATIALLY COHERENT, GIVEN A REASONABLE DATA DISTRIBUTION

INCORPORATES TEMPORAL CONTINUITY THROUGH USE OF A RECENT PREDICTION FROM THE PRECEDING ANALYSIS AS A FIRST GUESS

DYNAMIC CONSTRAINTS ARE INCORPORATED INTO THE MODELLED GUESS ERROR COVARIANCE FUNCTION

SCALE RESPONSE OF THE ANALYSIS IS GOVERNED BY THE SHAPE OF THIS FUNCTION

#### CHARACTERISTICS OF SATELLITE DATA

ON GLOBAL/SYNOPTIC SCALES TOVS DATA MAY BE TREATED IN A MANNER SIMILAR TO OTHER PROFILES (RAOBS, ETC)

IN THE MESOSCALE THE USE OF DISSIMILAR DATA TYPES CAN LEAD TO A DEGRADATION OF QUALITY WHEN ALL DATA TYPES ARE TREATED IN A TRADITIONAL MANNER

THE MOST DETRIMENTAL FEATURE OF SATELLITE SOUNDINGS ARE THEIR BIASES. THEY ARISE FROM A NUMBER OF SOURCES:

1. VERTICAL RESOLUTION LIMITED TO 5 OR SO LEVELS

2. ERRORS IN THE RETRIEVAL RESULTING FROM INACCURATE REPRESENTATION OF TRANSMISSIVITY AND EMISSIVITY
3. ON BOARD INSTRUMENTATION-INDUCED ERRORS

MAJOR ATTRACTION OF SATELLITE DATA IN THE MESOSCALE, EVEN WITH THE BIAS PROBLEM, IS THE DEPICTION OF HORIZONTAL GRADIENTS

SEVERAL GROUPS HAVE HAD SUCCESS MERGING HORIZONTAL GRADIENTS FROM SATELLITE MEASUREMENTS WITH MODEL PROGNOSIS FIELDS

IF ONE USES GEOSTATIONARY SATELLITE SOUNDING DATA WITH HIGH TEMPORAL RESOLUTION, BY ANCHORING THE SATELLITE GRADIENT INFORMATION TO AN ANALYSIS, THE 1ST ORDER BIASES CAN BE ELIMINATED (I.E., LOOK AT THE TIME CHANGE OF THE GRADIENT INFORMATION)

ALSO, THE INFRARED SOUNDER GENERATES RETRIEVALS IN CLOUD FREE REGIONS, WHILE CLOUD MOTION VECTORS (WINDS) CAN BE CONSTRUCTED IN CLOUDY REGIONS (1 LEVEL) TO PROVIDE SOME INFORMATION OVER THE ENTIRE VIEWING AREA

#### ASSIMILATION OF TOVS DATA INTO ANALYSIS AND FORECAST MODELS

CURRENTLY, POSITIVE IMPACT USING TOVS RETRIEVALS IN NWP MODELS DEPENDS LARGELY ON:

- 1) GEOGRAPHY OF THE MODEL DOMAIN
- 2) AVAILABILITY/DENSITY OF RADIOSONDE DATA (AND SURFACE)
- 3) SCALE OF MODEL DOMAIN

TOVS RMS TEMPERATURE ERRORS ARE TYPICALLY QUOTED AT ABOUT 2 DEGREES, WHICH IS ABOUT THE SAME LEVEL OF ERROR DISPLAYED BY A GOOD MESOSCALE MODEL IN AN AREA OF DENSE CONVENTIONAL OBSERVATIONS (TABLE 1)

TOVS ERROR LIMITS ARE MOSTLY A FUNCTION OF LIMITED VERTICAL RESOLUTION

EYRE ET AL. HAVE DONE ANALYSIS OF INFORMATION CONTENT OF DATA IN RELATION TO THE QUALITY OF FORECAST FIELD (FIG. 1)

- IMPROVEMENTS BY TOVS AVERAGES TENTHS OF A DEGREE
- THIS IS FOR "BEST" MESOSCALE MODELS. LESS SOPHISTICATED MODELS, A SYNOPTIC OR GLOBAL SCALE DOMAIN AND/OR A LACK OF A DENSE RADIOSONDE NETWORK ALL WILL CAUSE TOVS DATA TO BE MUCH MORE IMPORTANT TO THE ANALYSIS FIELD.
- HORIZONTAL GRADIENT AND/OR VERTICAL THICKNESS INFORMATION IS THE BEST WAY TO REPRESENT THE TOVS INFORMATION

SUMMARY:

SATELLITE SENSORS ARE THE ONLY ROUTINELY AVAILABLE SOURCE OF INFORMATION OVER LARGE AREAS.

FUTURE INSTRUMENT DEVELOPMENT PROMISES TO ALLEVIATE

- THE HORIZONTAL LIMITATIONS OF INFRARED SOUNDERS (I.E., GEOSTATIONARY MICROWAVE)
- THE CURRENT VERTICAL LIMITATION (INTERFEROMETER)

IT IS ALSO CLEAR THAT SATELLITE SYSTEMS, WHATEVER THEIR SHORTCOMINGS, HAVE CONTRIBUTED TREMENDOUSLY TO OUR UNDERSTANDING OF THE ATMOSPHERE AND HAVE PROVIDED MUCH OF THE IMPETUS FOR THE SUBSTANTIAL PROGRESS OF DATA ASSIMILATION IN RECENT YEARS



## DATA AVAILABLE

Table 1. Data Types for Mesoscale Analyses

---

Temperature & Moisture	
Soundings	Operationally or
- VAS	quasi-operationally
- TOVS	available from
Cloud Drift & Water	satellites.
Vapor Winds	

---

Sea Surface Temperatures	
Surface Energy Balance	
Cloudiness - Cloud Amount,	
Height,	
- Bogus Moisture	Satellite
- Diagnosed	Products
Rainfall/	available in
Diabatic	research mode
Heating Rates	or planned.
Processed Imagery	
Seasat Winds	
Windsat	
Interferometer Sounder	
Geostationary Microwave	

---

Surface Data	Basically
Radiosonde Data	ground-based,
ASDAR	available now
Profilers	or in the
Doppler Radar	future.
Over Horizon Radar	

# ASSIMILATION ASPECTS OF TEMPERATURE AND MOISTURE RETRIEVALS

Table 2. Characteristics of Satellite Data

TOVS	VAS	CDVWV
<u>Advantages:</u>		
moderate/high horizontal resolution	high horizontal resolution	high horizontal resolution where tracers exist
regular coverage at set times depending on orbits	user-selected frequent coverage in clear areas	frequent coverage if rapid-scan mode used
spatially correlated errors--good gradient information	spatially correlated errors--good gradient information	
<u>Disadvantages:</u>		
low vertical resolution	low vertical resolution	level assignment uncertainties
different error characteristics for clear, partly and cloudy retrievals	gaps in coverage in cloudy areas	single level only
spatially correlated errors (biases)	spatially correlated errors (biases)	

LECTURE 21. FUTURE SATELLITE SYSTEMS

THURSDAY, 24 NOVEMBER: DAY 12

REVIEW OF CURRENT SCENARIO

1. POLAR ORBITING

- NOAA 10 & 11: AVHRR IMAGER  
TOVS SOUNDER (IR & MSU)
- DMSP: OLS IMAGER  
SSM/T (MW)  
SSM/I (MW)

2. GEOSTATIONARY

- GOES 6 & 7: VISSR IMAGERY (VIS, IR, MSI)  
VAS SOUNDER (IR)
- METEOSAT: VIS, IR, WV
- GMS: VIS, IR
- INSAT: VIS, IR

FUTURE GEOSTATIONARY SATELLITES: GOES I-M

- INDEPENDENT/CONCURRENT IMAGER AND SOUNDER
- IMPROVED CALIBRATION AND RESOLUTION
- SOUNDER: SIMILAR TO HIRS (POLAR ORBITER)  
SIMULTANEOUS SOUNDING OF 19 CH.
  - VISIBLE 1 CHANNEL 8 km 0.7  $\mu\text{m}$
  - SHORTWAVE 6 CHANNELS 8 km 3.7-4.6  $\mu\text{m}$
  - MIDWAVE 5 CHANNELS 8 km 6.7-11.0  $\mu\text{m}$
  - LONGWAVE 7 CHANNELS 8 km 12.0-14.7  $\mu\text{m}$
- IMAGER: SIMILAR TO AVHRR (POLAR ORBITER)  
SIMULTANEOUS IMAGING OF 5 CHANNELS
  - VISIBLE 0.7  $\mu\text{m}$  1 km
  - SHORTWAVE 3.9  $\mu\text{m}$  4 km
  - MOISTURE 6.8  $\mu\text{m}$  8 km

- LONGWAVE 10.7  $\mu\text{m}$  4 km
- LONGWAVE 12.0  $\mu\text{m}$  4 km

**GOES I-M DIFFERENCES FROM GOES VISSR/VAS**

- SPACECRAFT STABILIZED, NOT SPIN SCAN
- SEPARATE/CONCURRENT IMAGER AND SOUNDER
- 4 km RESOLUTION IN IR MSI IMAGES
- BASED ON AVHRR AND HIRS SUCCESSES

**FUTURE NOAA SATELLITES: NOAA**

- NOAA I, J, D WITH PRESENT CONFIGURATION
- NOAA K (1992): BEGINNING OF AVHRR/HIRS/AMSU CONFIGURATION

**ADVANCED MICROWAVE SOUNDING UNIT (AMSU)**

- 15 CHANNEL RADIOMETER FOR ALL WEATHER SOUNDING
- 50 km HORIZONTAL RESOLUTION
- SURFACE (WINDOW) CHANNEL FOR EMISSIVITY
- 5 CHANNELS IN 52-55 GHz REGION FOR TEMPERATURE SOUNDINGS
- 6 STRATOSPHERIC CHANNELS NEAR 57 GHz FOR TEMPERATURE PROFILE STABILITY
- 3 CHANNELS (23, 31, AND 89 GHz) FOR MOISTURE
  - COLUMN WATER VAPOR MASS
  - CLOUD LIQUID WATER
  - RAIN DISTRIBUTION AND INTENSITY
  - SNOW COVER AND DEPTH

**EARTH OBSERVING SYSTEM (EOS) PROGRAM**

**EOS MISSION:**

TO ADVANCE THE SCIENTIFIC UNDERSTANDING OF THE ENTIRE EARTH SYSTEM ON THE GLOBAL SCALE THROUGH DEVELOPING A DEEPER UNDERSTANDING OF THE COMPONENTS OF THAT SYSTEM AND THE INTERACTIONS AMONG THEM, AND HOW THE EARTH SYSTEM IS CHANGING.

EOS MISSION OBJECTIVES:

- TO CREATE AN INTEGRATED SCIENTIFIC OBSERVING SYSTEM WHICH WILL ENABLE MULTIDISCIPLINARY STUDY OF THE EARTH'S PROCESSES
- TO DEVELOP A COMPREHENSIVE DATA AND INFORMATION SYSTEM TO SERVE THE NEEDS OF SCIENTISTS
- TO ACQUIRE AND ASSEMBLE A GLOBAL DATA BASE EMPHASIZING REMOTE SENSING MEASUREMENTS TO ENABLE DEFINITIVE STUDIES OF ASPECTS OF EARTH SYSTEM SCIENCE.

EARTH OBSERVING SYSTEM (EOS) PROGRAM (CONT'D)

POLAR PLATFORM CONFIGURATION

- 1990 - 1995: INSTRUMENT DEVELOPMENT
- 1995: DEPLOYMENT BEGINS

NASA PLATFORM

- 824 km, SUN-SYNCHRONOUS, 1:30 PM EQUATOR CROSS (ASC)

ESA PLATFORM

- 824 km, SUN-SYNCHRONOUS, 10:00 AM EQUATOR CROSS (DES)

JAPANESE AND 2ND NASA PLATFORM ALSO PLANNED MANNED SPACE STATION

- 335-460 km ORBIT ALTITUDE, 28.5° INCLINATION

OPERATIONAL FACILITY INSTRUMENTS

AMSU: ADVANCED MICROWAVE SOUNDING UNIT

AMSU-A: 15 CHANNELS FOR TEMPERATURE SOUNDING

AMSU-B: 5 CHANNELS FOR MOISTURE MEASUREMENTS

SWATH 1800 km, RESOLUTION 50 km (T), 5 km (WV)

AMRIR: ADVANCED MEDIUM RESOLUTION IMAGING  
RADIOMETER

FOLLOW-ON TO CURRENT AVHRR/HIRS INSTRUMENTS

11 CHANNEL VIS/IR, SWATH OF 2900 km

GOMR: GLOBAL OZONE MONITORING RADIOMETER (AFTERNOON)

UV RADIOMETER FOR TOTAL OZONE

LIMB SCAN IR RADIOMETER FOR VERTICAL DISTRIBUTION

SEM: SPACE ENVIRONMENTAL MONITOR

IS SITU MEASUREMENTS OF PLASMA, PARTICLES, PARAMETERS

OPERATIONAL FACILITY INSTRUMENTS (CONT'D)

ERBI: EARTH RADIATION BUDGET INSTRUMENT (SCANNER AND NON-SCANNER)

MEASUREMENT OF THE EARTH'S RADIATION BUDGET

0.2-50.0  $\mu\text{m}$  USING SELECTED FILTERS

SCATT-1: SCATTEROMETER (AFTERNOON)

MICROWAVE SYSTEM FOR WIND VELOCITY OVER OCEAN

2 PARALLEL SWATHS 120-700 km WIDE

ALT-1: ALTIMETER (AFTERNOON)

RADAR ALTIMETER FOR OCEAN AND ICE TOPOGRAPHY

NASA RESEARCH FACILITY INSTRUMENTS

MODIS: MODERATE-RESOLUTION IMAGING SPECTROMETER

T- SCANNER, 1800 km SWATH, 1 km RESOLUTION

- 64 BANDS IN REGION FROM 0.4-1.04  $\mu\text{m}$

N- SCANNER, BUT NO OFF NADIR VIEWING

RESOLUTION TO 250 m

40 BANDS, SPECTRAL COVERAGE 0.47-14.2  $\mu\text{m}$

HIRIS: HIGH-RESOLUTION IMAGING SPECTROMETER

PROGRAMMABLE, LOCALIZED MEASUREMENTS

30 km SWATH, RESOLUTION TO 30 m

200 SPECTRAL BANDS, 0.4-2.5  $\mu\text{m}$

SAR: SYNTHETIC APERTURE RADAR

IMAGING RADAR FOR ALL WEATHER SURFACE PROCESSES FOR LAND,  
VEGETATION, ICE AND OCEANS

GLRS: GEODYNAMICS LASER RANGING SYSTEM

FOR STUDY OF CRUSTAL MOVEMENTS IN TECTONICALLY ACTIVE REGIONS

LAWS: LASER ATMOSPHERIC WIND SOUNDER

DOPPLER LIDAR FOR DIRECT TROPOSPHERIC WIND MEASUREMENTS

TROPOSPHERIC WIND PROFILES AT 100 km GRIDPOINT SPACING

AIRS: ATMOSPHERIC INFRARED SOUNDER

HIGH HORIZONTAL AND VERTICAL RESOLUTION  
(15 km & 1 km) ATMOSPHERIC SOUNDINGS

3-5  $\mu\text{m}$  AND 8-17  $\mu\text{m}$  SPECTRAL BANDS

ESA RESEARCH FACILITY INSTRUMENTS

MERIS: MODERATE-RESOLUTION IMAGING SPECTROMETER

FOR GLOBAL OCEAN COLOR MONITORING

9 BAND SELECTION FROM 60 AVAILABLE

0.4-1.04  $\mu\text{m}$ , 500 m RESOLUTION

HRIS: HIGH-RESOLUTION IMAGING SPECTROMETER

FOR LAND AND COASTAL APPLICATIONS

10 BANDS SELECTABLE FROM 100

0.4-2.5  $\mu\text{m}$ , 20 m RESOLUTION

ATLID: ATMOSPHERIC LIDAR

CLOUD HEIGHTS, AEROSOL DISTRIBUTION DISCONTINUITIES

RESOLUTION TO 10 km (HOR) / 100 m (VERT)

SCATT-2: SCATTEROMETER

MEASUREMENT OF SURFACE WINDS OVER OCEAN

SWATH WIDTH TO 700 km

ACCURACY 2 m/s TO 10%

ALT-2: ALTIMETER

DUAL FREQUENCY RADAR ALTIMETER

OCEAN AND ICE SHEET TOPOGRAPHY

SAR-C: SYNTHETIC APERTURE RADAR - C BAND

LAND, OCEAN AND ICE STUDIES

SWATH TO 800 km @ 200 m

JAPANESE RESEARCH FACILITY INSTRUMENTS

ITIR: INTERMEDIATE THERMAL INFRARED RADIOMETER

LAND SURFACE MONITORING OF NONRENEWABLE RESOURCES

SPECTRAL RANGE 0.85-11.7  $\mu\text{m}$ , RESOLUTION 15-60 m

AMSR: ADVANCED MICROWAVE SCANNING RADIOMETER

WATER VAPOR, SST AND SEA SURFACE WIND OBSERVATION

SPECTRAL RANGE 6.6-31.5 GHz, RESOLUTION 9-50 km

SWATH WIDTH OF 1200 km



USER'S GUIDE TO THE INTERNATIONAL TOVS PROCESSING PACKAGE  
(VAX VERSION)

BY THOMAS ACHTOR, HAROLD WOOLF, ANTHONY SCHREINER

COOPERATIVE INSTITUTE FOR METEOROLOGICAL SATELLITE STUDIES  
UNIVERSITY OF WISCONSIN - MADISON  
SEPTEMBER 1988

- I. INTRODUCTION
- II. DATA ACQUISITION
  - A. Introduction
  - B. Real Time Acquisition
  - C. Acquisition of TOVS through level 1B data tape
- III. RETRIEVAL PROCESSING
  - A. Preprocessor
  - B. Retrieval Processing

## TOVS DATA PROCESSING PROCEDURE

NOVEMBER 1988

This document presents a procedure to be followed for processing the NOAA polar orbiter TOVS data. There are several important steps that should be followed to obtain the highest quality data sets, including a thorough quality control procedure. This document should be used in conjunction with the User's Guide to the International TOVS Processing Package.

### Procedure to Obtain TOVS Research/Operational Data Sets:

- 1) Ingest TOVS radiance data into host computer via direct ingest or 1-B magnetic tape
- 2) Run the ITPP, including
  - a) PRETIP
  - b) PREING
  - c) INGTOV
  - d) TOVPRE
  - e) TOVRET
- 3) Display an AVHRR or TOVS image for use in quality control
- 4) Display TOVS retrieval products over the AVHRR (or TOVS) image for several atmospheric levels or layers (eg: 850, 700, 500, 300, 200 mb) and use editing program to delete soundings of questionable or poor quality.
  - a) Temperature difference between guess and retrieval
  - b) Absolute temperature
  - c) Total Precipitable Water Vapor
  - d1) geopotential thickness (if no surface data is used)
  - d2) geopotential height (if surface data is used)(note: an automated editing program <FILRET> is contained in the ITPP. However, experience has shown that a knowledgeable meteorologist provides better quality control than automated techniques.)
- 5) Compress the TOVRET file after editing, using <COMRET>
- 6) Remap the AVHRR image to Mercator coordinates
- 7) Using GEMPACK, link the TOVSND file to GEMPACK
- 8) Allocate the IIS image processor to GEMPACK
- 9) Enter GEMPACK
- 10) Fit the data grid size to the image gridsize (i.e. insure proper navigation of both data).
  - a) estimate the latitude/longitude bounds from the image
  - b) in GEMPACK you must adjust the scale/aspect ratio to match data
- 11) Use GEMPACK to display final TOVS retrieval products over the AVHRR image.

USER'S GUIDE TO THE INTERNATIONAL TOVS PROCESSING PACKAGE  
(VAX VERSION)

BY THOMAS ACHTOR, HAROLD WOOLF, ANTHONY SCHREINER

COOPERATIVE INSTITUTE FOR METEOROLOGICAL SATELLITE STUDIES  
UNIVERSITY OF WISCONSIN - MADISON  
SEPTEMBER 1988

## I. INTRODUCTION

This User's Guide is designed for scientists wanting to utilize the International TOVS Processing Package (ITPP). The guide instructs ITPP users of the keyins necessary to run the Package, from software ingest of TOVS radiance data to retrieval product analysis. The content of the Guide is designed to follow the sequence of procedures necessary to complete an entire cycle of the ITPP.

The software modules contained in the ITPP are invoked interactively with the keyin format:

```
$RUN PROGRAMNAME
```

Most programs will then provide a series of prompts, which require the user to enter a value or use the default value. In the examples included below, examples of user input follow an = sign. In section II the steps to process direct readout (HRPT) data are discussed. Appendix A describes the preprocessing steps for archived 1B data. Section III then discusses the temperature and moisture retrieval route that follows after either of these preprocessing routes. Finally, Appendix B contains a technical documentation of the ITPP.

## II. DATA ACQUISITION

### A. Introduction

The ITPP is structured to accept TOVS data in two formats; 1) raw TOVS TIP data embedded within the HRPT data stream, from a direct readout facility, and 2) level 1B archived data from magnetic tape. While the initial steps to prepare the TOVS data for retrieval processing require different software modules, the process is the same once the data has been calibrated, navigated and formatted.

### B. Real Time Acquisition

The first requirement in direct readout operations is to make sure the orbital elements are updated (on a weekly basis for TOVS). The orbital elements are contained in a TBUS message, available on the GTS circuit and other means. The TBUS orbital elements are predictive in nature,

valid for the next few days in the future. The software program to enter orbital element information to the ITPP is <PUTELE>. The orbital elements may be entered directly by keyin or from an ASCII file containing the elements.

```
$RUN PUTELE
ENTER NOAA-NUMBER (5=TIROS) = 10
ENTER 1 TO INIT. FILE AND STORE DATA, 0 TO ADD ONLY = 0
ENTER 1 IF READING FROM ASCII FILE, 0 IF USING KBD = 0
YEAR, MONTH, DAY = 87 11 04
HOURS, MINUTES, SECONDS = 12 15 29.3
SEMI-MAJOR AXIS = 7192.4
ECCENTRICITY = 00015
INCLINATION = 99.
LONGITUDE OF ASCENDING NODE = 125.62
ARGUMENT OF PERIGEE = 302.74
MEAN ANOMALY = 57.3
ADDED RECORD = 61 87 11 4 12 15 29.30
ORBITAL-ELEMENT FILE HAS BEEN UPDATED FOR SATELLITE = 10
FORTRAN STOP
```

With the proper orbital elements, the accurate acquisition of NOAA HRPT satellite data can begin. First, one must know the space and time windows for the nearest satellite overpass. A printout of the satellite overpass data can be obtained using the program <ORBITS>.

```
$RUN ORBITS
ENTER NOAA-NUMBER (5=TIROS) = 10
ENTER DATE...YDXXX OR YYMMDD = 871104
ENTER START TIME ... HHMM = 1200
ENTER STOP TIME ... HHMM = 1400
ENTER LOWER-BOUNDARY LATITUDE, DEGREES, +N, -S ... = 20
ENTER UPPER-BOUNDARY LATITUDE, DEGREES, +N, -S ... = 60
ENTER LEFT-BOUNDARY LONGITUDE, DEGREES, +E, -W ... = -100
ENTER RITE-BOUNDARY LONGITUDE, DEGREES, +E, -W ... = -40
ENTER 0 FOR CRT OUTPUT, 1 FOR PRINTER = 0
```

The output includes the time (1 minute intervals) when a given pass crosses a latitude / longitude boundary within the designated window (see below).

ORBITAL TRACK(S) FOR NOAA-10 ON DAY 871104 FROM 1200 TO 1400 GMT,  
BETWEEN LATITUDES 20 AND 60, LONGITUDES -100 AND -40  
...USING ORBITAL ELEMENTS FOR DAY 299.

TIME	LATITUDE	LONGITUDE
1309	58.76	-68.49
1310	55.34	-70.57
1311	51.89	-72.36
1320	20.58	-82.50

ORBITS ENDED

The user then defines the temporal range (start / stop times) of their data request and informs the receiving station personnel. This process is station dependent, given the wide variety of computer and display types used to process the ITPP. Therefore, for the purposes of this user guide, it is assumed the data is then ingested into the resident computer system.

Once the raw radiance data is resident in the computer system, the ITPP processing begins with the software ingest. Certain installations utilize the module <PRETIP> to extract TOVS TIP data from the HRPT data stream.

\$RUN PRETIP

There are no input prompts to <PRETIP>. The process is very I/O intensive and can take 10-15 minutes to execute. Output indicates the number of records processed (see below).

```
DATA TYPE 3 (anything other than a 3 is an error message)
WROTE RECORD 1
WROTE RECORD 11

WROTE RECORD 1701
ALL DONE, NRET = 1710
FORTRAN STOP
```

Processing the TOVS TIP data requires a number of tasks; decommutation of raw data, navigation and earth location, and in-flight calibration. The modules <PREING> and <INGTOV> accomplish these tasks.

<PREING> decommutates (reformats) the data, writing the result to output file TOVSTIPO.

```
$RUN PREING
ENTER YEAR AND MSU DIAGNOSTIC-PRINT FLAG (0=OFF, 1=ON) = 87 0
ENTER NO. OF RECORDS TO SKIP = 0
```

There is a steady stream of output across the CRT, indicating major frame locations, spacecraft time elements, etc. At the end of execution, output should read something like:

```
REACHED END OF HIRS DISK AREA
NO. OF HIRS LINES = 100, NO. OF MSU LINES = 24.
TIME COVERAGE (S/C DAY) + MSEC (300.) 45740232. TO (300.) 46380532.
NO. MINOR FRAMES INPUT = 6674 NO. MINOR FRAMES W/ERR = 0
INPUT PARAMETERS FOR INGEST (SAT-ID, YR, MO, DY)=10 87 10 27
FORTRAN STOP
```

The example shows the number of HIRS and MSU lines for about 10 minutes of data.

<INGTOV>, using file TOVSTIPO, calibrates and earth locates the data, transforming the raw radiance measurements into brightness temperatures and writing them to a system disk file named TOVSINGO. A "switch" can either process HIRS data or, if the user desires only microwave information, not process the HIRS.

```
$RUN INGTOV
ENTER DO-HIRS SWITCH (0=YES, 1=NO) = 0
ENTER HIRS DEBUG FLAG (0=OFF, 1=YES) = 0
ENTER MSU DEBUG FLAG (0=OFF, 1=YES) = 0
```

The CRT output from <INGTOV> shows the orbital parameters used, the MSU ingest, the HIRS ingest, the calibration and navigation of the data, and the filling of the TOVSINGO.

The file TOVSINGO has exactly the same structure whether the TOVS TIP data has come from real time direct ingest or from level 1B magnetic tape. To provide continuity for real-time TOVS processing this Guide will continue on that path. Users of archive 1B data should refer to Appendix A for the software operations to reach this same stage in processing.

### III. RETRIEVAL PROCESSING

Regardless of the data source, direct readout HRPT or archive 1B, ITPP software will reach the same point in processing by writing the file TOVSINGO. For this point the processing steps are identical, regardless of raw data input.

#### A. Preprocessor

The software module <TOVPRE> transforms the calibrated, earth located HIRS and MSU brightness temperatures in file TOVSINGO to file structures for image display and retrieval. Additionally, HIRS and/or MSU limb

corrections can be applied at this stage. Finally, the MSU radiances are interpolated to the HIRS scan pattern.

Data from TOVSINGO is formatted into file TOVORB(A..Z) for image display and TOVSND(A..Z) for retrievals. TOVORB\_ has all the brightness temperatures for a given channel contiguous on disk, to optimize imaging, while TOVSND\_ has all the brightness temperatures for a given geographical location contiguous on disk, to optimize retrieval processing. These two data structures have 26 available files each; that is, one can have 26 pairs of distinct TOVORB and TOVSND files on the system simultaneously (TOVORBA, TOVSNDA; TOVORBB and TOVSNDB, etc).

```
$RUN TOVPRE
ENTER LETTER OF FILE FOR OUTPUT = A
ENTER HIRS LIMB CORRECTION FLAG (1=ON, 0=OFF) = 0
ENTER MSU LIMB CORRECTION FLAG (1=ON, 0=OFF) = 0
```

The limb correction flag should be turned off for the physical retrieval technique <TOVRET> and turned on for the statistical technique <TOVSTR>. Output from <TOVPRE> indicates processing steps completed.

At this point all steps necessary to prepare the TOVS radiance data for retrieval processing or image display have been completed. To list out the contents of the TOVORB\_ and TOVSND\_ files (where \_ indicates file suffix letter A through Z), use the program <TOVDIR>.

```
$RUN TOVDIR
```

The program output is a listing of the file contents with necessary additional information, including date, start time, end time, number of lines, satellite number, ascending or descending mode, HIRS or MSU limb correction, file status and number of retrievals in TOVRET\_.

The brightness temperature for a given HIRS or MSU channel, or the latitudes/longitudes of the fields of view may be printed using the program <TOVMAP>. The output is a printed map of brightness temperatures (or lat/long) for a specified channel over the range of the pass.

```
$RUN TOVMAP
ENTER FILE LETTER = A
ENTER UP TO 7 PARAMETER NOS. IN I3 FORMAT
... IF <7, END STRING WITH -1
= 1 2 11 -1
ENTER STARTING ROW-NUMBER, 0 TO TERMINATE
= 1
ENTER STARTING ROW-NUMBER, 0 TO TERMINATE
= 21
ENTER STARTING ROW-NUMBER, 0 TO TERMINATE
= 0
```

The HIRS or MSU channel parameter numbers are shown in Table 1. Select up to seven channels for display at one time. The program will draw a map of 20 HIRS lines, but prompts you for additional line number input to create a map of greater size. Thus, responding to the prompt for the STARTING ROW NUMBER with the keyins in 1, 21, 41, 61, 81, 0 will create a map of the entire pass. The above input will print out the first 40 lines of brightness temperatures for HIRS channels 1, 2 and 11.

TABLE 1: TOVMAP Parameter List

Param.#	Quantity	Wavelength	Peak
1	Latitude of HIRS FOV (N+,S-)		
2	Longitude of HIRS FOV (E+,W-)		
3	Solar Zenith Angle (9000 IF NIGHT)		
4	HIRS Ch. 1	15.00um	30 mb
5	HIRS Ch. 2	14.70um	60 mb
6	HIRS Ch. 3	14.50um	100 mb
7	HIRS Ch. 4	14.20um	400 mb
8	HIRS Ch. 5	14.00um	600 mb
9	HIRS Ch. 6	13.70um	800 mb
10	HIRS Ch. 7	13.40um	900 mb
11	HIRS Ch. 8	11.10um	Sfc
12	HIRS Ch. 9	9.70um	25 mb
13	HIRS Ch.10	8.30um	900 mb
14	HIRS Ch.11	7.30um	700 mb
15	HIRS Ch.12	6.70um	500 mb
16	HIRS Ch.13	4.57um	1000 mb
17	HIRS Ch.14	4.52um	950 mb
18	HIRS Ch.15	4.46um	700 mb
19	HIRS Ch.16	4.40um	400 mb
20	HIRS Ch.17	4.24um	5 mb
21	HIRS Ch.18	4.00um	Sfc
22	HIRS Ch.19	3.70um	Sfc
23 #	MSU Ch. 1A		
24	MSU Ch. 1	50.31GHz	Sfc
25	MSU Ch. 2	53.73GHz	700 mb
26	MSU Ch. 3	54.96GHz	300 mb
27	MSU Ch. 4	57.95GHz	90 mb
28	TOTAL OUTGOING LONGWAVE FLUX (Watt/sq.meter,*100)		
29	HIRS Ch.20	0.70um	Vis
30 ##	BRIGHTNESS TEMPERATURE, HIRS Ch. 18A		

NOTE: ALL TEMPERATURES ARE IN DEGREES \* 100

# MSU Ch. 1A: If MSU data are limb-corrected, this is Ch. 1 with surface effects retained; if not limb-corrected, this space is indexing information and is not mapable.

## For daytime pass, this is Ch. 18 (4 um window) with a first-order approximate correction for reflected sunlight.



## B. Retrieval Algorithms

To summarize ITPP processing to this point; following the hardware and software ingest of the data, calibration and earth location, file formatting and preprocessing, the calculation of vertical temperature and moisture profiles can be accomplished. Additionally, geopotential height, stability parameters and total ozone computations are determined and written to the output file. Two retrieval algorithms are included in the ITPP, a physical retrieval technique, <TOVRET>, and a statistical method, <TOVSTR>.

<TOVRET> is the most recent improvement in the physical retrieval technique (Smith, Hayden, Schreiner and Woolf, 1986). It obtains solutions for temperature and water vapor in a single step from combined infrared and microwave radiances. Although the most accurate retrieval technique in the ITPP, it is also the most demanding of computer resources. There are many options within <TOVRET> which will be discussed below.

To briefly summarize the <TOVRET> retrieval technique; an initial estimate of the vertical structure is made, using climatology, regression coefficients obtained from a prior source, or numerical model output. Surface data may also be used to "anchor" the profiles to known surface conditions. From this point the guess profile or initial estimate is adjusted, using the MSU data and the stratospheric HIRS channels. This is referred to as the "improved guess". Finally, the full HIRS radiances are applied to this guess to provide a final vertical retrieval.

```
$RUN TOVRET
ENTER LETTER OF FILE TO PROCESS = A
ENTER SFC-DATA FLAG (1=YES, 0=NO) = 0
ENTER GUESS TYPE (0=REGRESSION, 1=CLIMATOLOGY) = 0
ENTER START-LINE (DEFAULT=2) = 2
ENTER START-ELEM (DEFAULT=2) = 2
  TO MAKE SINGLE SOUNDING, LET NUM-LINES AND NUM-ELEMS=1
ENTER NUMBER OF LINES (DEFAULT=98) = 98
ENTER NUMBER OF ELEMS (DEFAULT=54) = 54
ENTER LINE-INCREMENT (DEFAULT=3) = 3
ENTER ELEM-INCREMENT (DEFAULT=3) = 3
ENTER TOPOGRAPHY FLAG (0=HI-RES, 1=LO-RES) = 0
  MWHS=RTVL USING MSU + HIRS (STRATOSPHERIC) CHANNELS
  IF=0, OUTPUT ONLY FULL-HIRS SOUNDINGS
  IF=1, OUTPUT MWHS SOUNDING IF FULL-HIRS FAILS
  IF=2, OUTPUT ONLY MWHS SOUNDINGS
ENTER VALUE FOR MWHS = 1
ENTER DIAGNOSTIC PRINT FLAG (0=NO, 1=YES) = 0
ENTER RETRIEVAL-FILE INIT FLAG (0=NO,1=YES) = 1
```

The starting line and element are 1 FOV in from the edge in this example and cover the full 100 lines of the pass (refer to number of lines and elements). The line and element increment refers to the number of FOVS

to be included in 1 sounding; 3 provides approximately a 75 km retrieval linear boundary; a 5 x 5 would be around 125 km. High resolution topography is now included globally for the ITPP. The retrieval types in the physical technique are clear (full HIRS), and cloudy (MSU, and HIRS channels peaking above cloud top). Diagnostics are used for debugging or getting detailed information on a very few soundings. Finally, initializing the retrieval file will destroy any retrievals previously made in the file; not to initialize if you wish to add retrieval to the existing file.

The output from <TOVRET> will indicate when a line of retrieval processing is completed, and how many soundings have been made.

```
FINISHED A LINE, NUMBER OF SOUNDINGS=19
FINISHED A LINE, NUMBER OF SOUNDINGS=38
.
FINISHED A LINE, NUMBER OF SOUNDINGS=627
ALL DONE
FORTRAN STOP
```

A discussion of the post processing follows an explanation of the statistical technique <TOVSTR>. The statistical retrieval algorithm <TOVSTR> does a simple regression of TOVS brightness temperatures against a set of coefficients determined from latitudinally segregated radiosonde data. The keyins for <TOVSTR> are similar to <TOVRET>.

```
$RUN TOVSTR
ENTER LETTER OF FILE TO PROCESS = A
ENTER CLEAR FORCE FLAG (1=YES, 0=NO) = 0
MWHS=MICROWAVE + HIRS (STRATOSPHERIC) CHANNELS
  ONLY MEANS DO NOT ATTEMPT FULL HIRS RETRIEVAL
  KEEP MEANS OUTPUT MWHS IF FULL HIRS RETRIEVAL FAILS
ENTER MWHS-ONLY FLAG (1=YES, 0=NO) = 0
ENTER MWHS-KEEP FLAG (1=YES, 0=NO) = 1
ENTER SFC-DATA FLAG (1=YES, 0=NO) = 0
ENTER START-LINE (DEFAULT=2) = 2
ENTER START-ELEM (DEFAULT=2) = 2
  TO MAKE SINGLE SOUNDING, LET NUM-LINES AND NUM-ELEMS=1
ENTER NUMBER OF LINES (DEFAULT=98) = 98
ENTER NUMBER OF ELEMS (DEFAULT=54) = 54
ENTER LINE-INCREMENT (DEFAULT=3) = 3
ENTER ELEM-INCREMENT (DEFAULT=3) = 3
ENTER RETRIEVAL-FILE INIT FLAG (0=NO,1=YES) = 1
```

The output from <TOVSTR> will look the same as that for <TOVRET>.

The TOVRET file structure contains 112 Integer \* 4 words, which include header information, retrieval location, time, temperatures, dewpoints, observed brightness temperatures, skin temperature, first guess information, cloud properties, and other derived quantities. The exact

location and type of information can be found in the Documentation of TOVS Processing Software (DADOCVAX), page 11, which is included as Appendix B to this Guide.

### C. Post Processing

An automated quality control algorithm is included in the ITPP. The program, <FILRET>, eliminates soundings of questionable reliability by objective analysis of (1) differences between infrared and microwave retrievals at the same location, (2) the variability in the 1000-500 mb thickness field, and (3) longwave-window comparison to surface temperature.

```
$RUN FILRET
ENTER FILE NUMBER = 1
ENTER SEARCH RADIUS (0 FOR DEFAULT=3) = 0
ENTER MAXIMUM SAMPLE (0 FOR DEFAULT=10) = 0
ENTER MINIMUM SAMPLE (0 FOR DEFAULT=5) = 0
ENTER NO. OF FILTER PARAMETERS (0 FOR DEFAULT=6) = 0
ENTER 1 TO AVOID FLAGGING ISOLATED SOUNDINGS = 1

NO. OF PROFILES FAILED/FILTERED = 53/334
FORTRAN STOP
```

In this example the defaults were used and 53 of 334 (16%) retrievals were flagged as failing the quality control tests.

An alternative method is to manually edit the retrievals, looking at thicknesses or level temperature fields, total column precipitable water vapor, and, perhaps, geopotential height (if surface data are used in the retrieval generation process). At this point an experienced meteorologist can outperform an automated quality control algorithm.

Once the retrieval file has been edited it must be compressed. The program <COMRET> compresses the TOVRET file by deleting soundings that have been flagged by <FILRET> and moving the remaining soundings to replace the "empty" records.

```
$RUN COMRET
```

Following the quality control and file compression procedures, geostrophic winds can be calculated using the program <WINRET>. The algorithm does a least squares objective analysis of the geopotential fields for the calculation.

```
$RUN WINRET  
ENTER FILE NUMBER = 1
```

```
WINDS WERE OBTAINED FOR 293 OF 339 SOUNDINGS  
FORTRAN STOP
```

Finally, any record in the TOVSND file can be plotted to a printer using the program <TOVPLTEM>. The program is set up for printer output of level temperatures, but can be modified to print any record.

```
$RUN TOVPLTEM  
ENTER UP TO SIX PRESSURE LEVELS IN I5 FORMAT = 850 700 500 300  
ENTER FILE LETTER = A  
ENTER LAT, LON (DEG * 10) AT NW CORNER OF 15 X 15 DEG REGION  
...USE 999 999 TO TERMINATE  
= 525 -850  
= 999 999  
FORTRAN STOP
```

Various installations have added additional software for display of retrieval products.

## APPENDIX A:

### Acquisition of TOVS through level 1B data tape

Level 1B TOVS data have already been through preliminary processing by a local receiving station or NESDIS operations. The tapes contain the TOVS radiance measurements, and calibration and earth location information. To inventory the contents of a 1B tape, the software module <INVTAP> has been supplied. The output is a printout of data type, times and locations for each file.

```
$RUN INVTAP  
ENTER NUMBER OF FILES=2
```

To produce the system disk file TOVSINGO, discussed above, two software modules are invoked; <TOVTAP>, which does tape to disk transfer, and <TOVING>, which produces the calibrated, earth-located brightness temperature file TOVSINGO.

```
$RUN TOVTAP  
ENTER FILE NUMBER FOR HIRS = 1  
ENTER FILE NUMBER FOR MSU = 2  
ENTER STARTING TIME = 1242  
ENTER ENDING TIME = 1252
```

```
$RUN TOVING  
ENTER NOAA-NUMBER (5=TIROS-N) = 10
```

The user has now reached the same point discussed in section II. B., the creation of file TOVSINGO. From this point on the retrieval processing is identical for direct readout and 1B data. Proceed to section III. Retrieval Processing to continue.

APPENDIX B

DOCUMENTATION OF THE ITPP / VAX VERSION

1 (HMW) DOCUMENTATION FOR INT'L-TOVS-PROCESSING SOFTWARE/DATA PACKAGE, VAX

2 \*\*\*\*\*

3 \*\*\* THIS IS THE FIRST FILE IN PART 2 OF THE TAPE \*\*\*

4 VERSION 3.2, DECEMBER 1987

5 LATEST CHANGE: 16 SEPTEMBER 1988

6 \*\*\*\*\*

7  
8 THIS DOCUMENT DESCRIBES, IN BRIEF OUTLINE FORM, PROCEDURES FOR ESTAB-  
9 LISHING A LOCAL/REGIONAL SYSTEM FOR PROCESSING TOVS (HIRS+MSU) SOUNDING  
10 DATA FROM THE TIROS-N/NOAA SERIES OF POLAR-ORBITING SPACECRAFT, USING  
11 THE SOFTWARE IN PART 1 OF THIS TAPE, AND THE SUPPORTING DATA CONTAINED  
12 IN SUBSEQUENT FILES ON THIS TAPE (PARTS 2 AND 3).

13 THE ALGORITHMS AND DATA-PROCESSING TECHNIQUES WERE ORIGINALLY  
14 DEVELOPED FOR 'MCIDAS' (MAN-COMPUTER INTERACTIVE DATA ACCESS SYSTEM) AT  
15 THE SPACE SCIENCE AND ENGINEERING CENTER OF THE UNIVERSITY OF WISCONSIN  
16 IN MADISON (UW/SSEC). INITIALLY BASED ON THE HARRIS 'SLASH-6' MINI-  
17 COMPUTER, MCIDAS IS CURRENTLY IMPLEMENTED ON THE IBM 4381 AT THE SSEC.  
18 THE ORIGINAL 'EXPORT' SOFTWARE WAS CONFIGURED FOR AN IBM-OS SYSTEM TO  
19 PROVIDE THE MOST REASONABLE PORTABILITY, GIVEN THE RESOURCES AVAILABLE  
20 TO THOSE RESPONSIBLE FOR ITS MAINTENANCE. THE PACKAGE CONTAINED IN THIS  
21 TAPE HAS BEEN MODIFIED TO EXPEDITE ITS IMPLEMENTATION ON A VAX SYSTEM.

22  
23 \*\*\*\*\*

24 QUESTIONS AND/OR COMMENTS CONCERNING THE SYSTEM AND ITS IMPLEMENTA-  
25 TION, ESPECIALLY IN REGARD TO POSSIBLE ERRORS, SHOULD BE ADDRESSED TO

26 MR. HAROLD M. WOOLF

27 UW/SSEC/CIMSS

28 1225 WEST DAYTON STREET, SECOND FLOOR

29 MADISON, WISCONSIN 53706

30 TELEPHONE ... (608) 264-5325

31 TWX/TELEX ... 256-452-UOFWISC MDS

32  
33 CONTENTS OF THE REMAINING FILES IN THIS PORTION OF THE TAPE

34 \*\*\*\*\*

35 FILE 2. LOW-RESOLUTION (60 NAUT.MI.) GLOBAL TOPOGRAPHY

36 FILE 3. HIGH-RESOLUTION (10 NAUT.MI.) TOPOGRAPHY BIT MAP, NOR.HEM.

37 FILE 4. HIGH-RESOLUTION (10 NAUT.MI.) TOPOGRAPHY HEIGHTS, NOR.HEM.

38 FILE 5. HIGH-RESOLUTION (10 NAUT.MI.) TOPOGRAPHY BIT MAP, SOU.HEM.

39 FILE 6. HIGH-RESOLUTION (10 NAUT.MI.) TOPOGRAPHY HEIGHTS, SOU.HEM.

40 \*\*\*\*\*

41 NOTES ON FORTRAN SOURCE (PART 1)

42 \*\*\*\*\*

43 EACH ROUTINE IS NOW IN A SEPARATE FILE ON THE TAPE. THIS IS A MAJOR  
44 DEPARTURE FROM PREVIOUS RELEASES, IN WHICH ALL MAIN PROGRAMS WERE IN ONE  
45 FILE, ALL SUBROUTINES IN ONE FILE, AND ALL FUNCTIONS IN ANOTHER. THE NEW  
46 STRUCTURE SHOULD SIMPLIFY INSTALLATION AND/OR UPDATING OF ROUTINES.

47 OBSERVE THAT IN MOST ROUTINES IN WHICH A FILE IS OPENED, THE 'OPEN'  
48 STATEMENT IS NOT EMPLOYED DIRECTLY; RATHER, A CALL IS MADE TO SUBROUTINE  
49 'OPEND'. THIS ARTIFICE HAS BEEN EMPLOYED AS PART OF A MAJOR RESTRUCT-  
50 URING OF THE ITPP SOFTWARE AT CIMSS, IN WHICH THE ORIGINAL IBM VERSION  
51 HAS BEEN UPGRADED TO FORTRAN-77 IN ORDER TO ACHIEVE MORE COMPATIBILITY  
52 WITH THE 'DOMESTIC' TOVS SOFTWARE AND THE VAX ITPP, BOTH OF WHICH WERE

53 ALREADY IN FORTRAN-77. WHILE THERE ARE STILL SOME DIFFERENCES AT THE  
54 MAIN-PROGRAM LEVEL, IT HAS BEEN POSSIBLE, THROUGH THIS CHANGE, TO  
55 ESTABLISH A SINGLE VERSION FOR MANY ROUTINES. THE USER MAY REPLACE  
56 THESE CALLS WITH EXPLICIT 'OPEN' STATEMENTS IF DESIRED.

57 THE FIRST CARD OF EACH MAIN PROGRAM HAS THE FORM

58 PROGRAM XXXXXX

59 EACH MAIN PROGRAM AND SUBPROGRAM CONTAINS A COMMENT CARD OF THE FORM  
60 C \*\*\*\* VERSION OF DD.MM.YY (DAY.MONTH.YEAR)

61 USERS FOR WHOM THIS IS NOT THE FIRST PACKAGE SUPPLIED WILL FIND THE  
62 'VERSION-DATES' AN INDISPENSABLE MEANS OF DETERMINING WHICH ROUTINES  
63 HAVE BEEN CHANGED SINCE THEIR INITIAL IMPLEMENTATION. ALTHOUGH IN THE  
64 PAST UPDATES TO THE PACKAGE HAVE BEEN PROVIDED IN THE FORM OF SELECTED  
65 SOFTWARE AND COEFFICIENTS, THE MOST RECENT CHANGES ARE TOO EXTENSIVE,  
66 AND THE NUMBER OF USERS WORLD-WIDE TOO GREAT, TO PERMIT SUCH 'LIMITED-  
67 EDITION' UPDATING. HENCEFORTH, UPDATES - TO SOFTWARE, COEFFICIENTS, OR  
68 BOTH - ARE IN THE FORM OF A NEW TOTAL-PACKAGE TAPE. IT IS LEFT TO  
69 INDIVIDUAL USERS TO DETERMINE WHICH 'NEW ITEMS' ARE RELEVANT.

70 \*\*\*\*\*

71 NOTES ON SUPPORTING-DATA FILES

72 \*\*\*\*\*

73 A NEW HIGH-RESOLUTION (10 NAUT.MI.) TOPOGRAPHY SCHEME HAS BEEN IM-  
74 PLEMENTED THAT REQUIRES ONLY ONE-FOURTH THE DISK SPACE OF THE ORIGINAL.  
75 THE STANDARD PACKAGE CONTAINS COMPLETE DATASETS FOR BOTH NORTHERN AND  
76 SOUTHERN HEMISPHERES (SEE NOTE BELOW REGARDING INSTALLATION).

77 COEFFICIENT/PARAMETER FILES FOR THE ITPP (PART 3) WILL BE FOUND  
78 FOLLOWING THE TOPOGRAPHY FILES.

79  
80 FOR EACH SATELLITE IN THE SERIES. THERE IS A SET OF NINE FILES AS  
81 DEFINED BELOW. THE CURRENT TAPE IS VALID FOR TIROS-N THROUGH NOAA-10  
82 (SIX SPACECRAFT), AND THUS CONTAINS 54 COEFFICIENT FILES IN ADDITION TO  
83 THE BASIC FILES NOTED ABOVE. A DOUBLE E-O-F TERMINATES THE TAPE. NOTE  
84 THAT THE FOLLOWING FILE NUMBERS ARE RELATIVE WITHIN EACH GROUP.

85  
86 FILE 1. ORBITAL ELEMENTS

87 FILE 2. INGEST PARAMETERS

88 FILE 3. COEFFICIENTS FOR HIRS RADIATIVE-TRANSFER COMPUTATIONS

89 FILE 4. COEFFICIENTS FOR MSU (NADIR) RADIATIVE-TRANSFER COMP

90 FILE 5. COEFFICIENTS FOR MSU (SLANT) RADIATIVE-TRANSFER COMP

91 FILE 6. COEFFICIENTS FOR HIRS LIMB-CORRECTION

92 FILE 7. COEFFICIENTS FOR MSU LIMB-CORRECTION

93 FILE 8. SYNTHETIC COEFFICIENTS FOR PHYSICAL RETRIEVAL

94 FILE 9. SYNTHETIC COEFFICIENTS FOR STATISTICAL RETRIEVAL

95  
96 THE COEFFICIENTS IN FILES 2 THROUGH 9 ARE DETERMINED INITIALLY FOR  
97 EACH SATELLITE, AND CAN BE CONSIDERED FIXED FOR ITS OPERATIONAL LIFETIME  
98 UNLESS MAJOR CHANGES OCCUR IN THE PERFORMANCE OF ONE OR MORE SPECTRAL  
99 CHANNELS.\* ORBITAL ELEMENTS IN FILE 1 (UPDATED WEEKLY) ARE NEEDED FOR  
100 NAVIGATION (EARTH-LOCATION) OF REAL-TIME DATA OBTAINED VIA DIRECT READ-  
101 OUT OF THE SPACECRAFT (VHF OR HRPT). THE ELEMENTS INCLUDED ON THIS TAPE  
102 ARE PROVIDED TO ASSIST IN INITIAL IMPLEMENTATION OF THE SYSTEM; USERS  
103 MUST MAKE THEIR OWN ARRANGEMENTS FOR CONTINUED ACQUISITION OF THAT  
104 INFORMATION FOR REAL-TIME APPLICATIONS.



105  
 106 \*OCCASIONALLY, SOME OF THE MSU CALIBRATION QUALITY-CONTROL LIMITS IN  
 107 FILE 2 MAY NEED TO BE ADJUSTED TO AVOID DISCARDING GOOD DATA AS A  
 108 RESULT OF CHANGES IN GAIN OR OTHER INSTRUMENT CHARACTERISTICS.  
 109 PROGRAMS \*XMSUIP\* AND \*UMSUIP\* ARE PROVIDED TO PERMIT EXAMINATION  
 110 AND MODIFICATION, RESPECTIVELY, OF THOSE PARAMETERS.

111 \*\*\*\*\*

112 CONSTRUCTING THE TOVS DATA-PROCESSING SYSTEM

113 \*\*\*\*\*

114 THE SYSTEM MAKES EXTENSIVE USE OF UNFORMATTED, DIRECT-ACCESS DISK  
 115 FILES FOR EFFICIENCY IN I/O OPERATIONS. TO ASSIST IN ESTABLISHING THE  
 116 PERMANENT DATA FILES (ORBITAL ELEMENTS, COEFFICIENTS, AND TOPOGRAPHY),  
 117 SOFTWARE HAS BEEN PROVIDED TO READ THE DATA FROM ASCII FILES EXTRACTED  
 118 FROM THE TAPE, AND WRITE TO BINARY DISK FILES.

PROGRAM	TAPE	FILE	ASCII FILE(S)	BINARY FILE(S)
*****	*****	*****	*****	*****
TOPOGF		2+	TOPOLRES.ASC	TOPOLRES.DAT
TOPOGH**		3+	BMAPTOPN.ASC	BMAPTOPN.DAT
		4+	HRESTOPN.ASC	HRESTOPN.DAT
		5+	BMAPTOPS.ASC	BMAPTOPS.DAT
		6+	HRESTOPS.ASC	HRESTOPS.DAT
PUTELE		1*	ORBELNXX.ASC	ORBELNXX.DAT (XX=05,06,....)
INGPAR		2	INGEPAXX.ASC	INGEPAXX.DAT
HIRTCF		3	HIRTCOXX.ASC	HIRTCOXX.DAT
MSUTCF		4	MSUTCXXX.ASC	MSUTCXXX.DAT
MSZTCF		5	MSZTCOXX.ASC	MSZTCOXX.DAT
HIRLCF		6	HIRLCOXX.ASC	HIRLCOXX.DAT
MSULCF		7	MSULCOXX.ASC	MSULCOXX.DAT
RTVCFS		8	RTVSCOXX.ASC	RTVSCOXX.DAT
RTVCFL		9	RTVLCOXX.ASC	RTVLCOXX.DAT

137  
 138 NOTES:

139 \* IN THE BASIC GROUP (FIRST SIX FILES IN PART 2 OF THE TAPE)  
 140 \*\* IF GLOBAL TOPOGRAPHY IS NOT REQUIRED, THE USER SHOULD ESTABLISH ONLY  
 141 THE HEMISPHERE HE NEEDS, AND IN SUBROUTINE \*NTOPO\* OF PROGRAM \*TOVRET\*  
 142 REPLACE THE CALL TO SUBROUTINE \*HRTPO\* WITH A DIRECT CALL TO \*HRTOPN\*  
 143 (NORTHERN HEMISPHERE) OR \*HRTOPS\* (SOUTHERN HEMISPHERE).  
 144 \* WITHIN A SATELLITE-SPECIFIC GROUP

145  
 146 NEARLY ALL OF THE SOFTWARE PROVIDED IN PART 1 IS FOR PROCESSING HIRS  
 147 AND MSU DATA TO OBTAIN PROFILES OF ATMOSPHERIC TEMPERATURE, HUMIDITY,  
 148 GEOPOTENTIAL HEIGHT, AND GEOSTROPHIC WIND, AND FOR DISPLAYING AND  
 149 MANIPULATING THOSE PROFILES IN VARIOUS WAYS. ESSENTIAL OPERATIONS ARE  
 150 \*INGST\*, \*PREPROCESSING\*, AND \*RETRIEVAL\*. THE TERM \*RTC\* STANDS FOR  
 151 RADIATIVE-TRANSFER COEFFICIENTS, AND \*LCC\* STANDS FOR LIMB-CORRECTION  
 152 COEFFICIENTS. WHERE INPUT PARAMETERS ARE REQUIRED, PROGRAMS PROMPT  
 153 FOR KEYBOARD INPUT IN THE INTERACTIVE MODE OF EXECUTION. IF BATCH  
 154 OPERATION IS DESIRED, THE USER MUST MAKE THE NECESSARY CHANGES.

155 TWO PROGRAMS, RAOHIR AND RAOMSU (LAST TWO FORTRAN-SOURCE FILES),  
 156 ARE SUPPLIED TO DEMONSTRATE THE PROCEDURES FOR CALCULATING, FROM RADIO-

157 SONDE TEMPERATURE AND HUMIDITY PROFILES, HIRS RADIANCES AND BRIGHTNESS  
 158 (EQUIVALENT-BLACKBODY) TEMPERATURES, AND MSU ANTENNA OR BRIGHTNESS TEMP-  
 159 ERATURES, RESPECTIVELY.

160  
 161 INGEST

162 \*\*\*\*\*

163 FUNCTION: PRODUCE CALIBRATED, EARTH-LOCATED HIRS AND MSU RADIO-  
 164 METRIC MEASUREMENTS FROM TOVS 'TIP' DATA. TWO VERSIONS ARE PROVIDED;  
 165 THE ESSENTIAL DIFFERENCE IS IN THE TYPE OF INPUT DATA THEY ARE DESIGNED  
 166 TO HANDLE - EITHER ARCHIVAL ('LEVEL 1-B') OR DIRECT-READOUT (REALTIME).

PROGRAM	INPUT(S)	OUTPUT(S)	( ) = LUN
*****	*****	*****	
ORBITS	*ORB-ELEM(11) PROMPTS	PRINTOUT OF SUBSATELLITE TRACKS FOR SPACECRAFT, SPACE AND TIME WINDOWS OBTAINED FROM PROMPTS	

174 \* UPDATED BY PROGRAM 'PUTELE' WITH DATA OBTAINED FROM DIRECT READOUT  
 175 USER SERVICES.

176  
 177 LEVEL 1-B: DATA THAT HAS BEEN THROUGH PRELIMINARY PROCESSING BY  
 178 NESDIS OPERATIONS' TOVS GROUND SYSTEM, AND IS PROVIDED ON STANDARD COM-  
 179 PUTER TAPE TO USERS, UPON REQUEST, BY THE SATELLITE DATA SERVICES BRANCH  
 180 OF NESDIS. SUCH TAPE CONTAINS, IN ADDITION TO VALUES (IN DIGITAL COUNTS)  
 181 REPRESENTING RADIOMETRIC MEASUREMENTS, EARTH-LOCATION INFORMATION AND  
 182 CALIBRATION PARAMETERS REQUIRED TO TRANSFORM THE RAW DATA VALUES INTO  
 183 RADIANCE OR BRIGHTNESS TEMPERATURE. THREE PROGRAMS ARE SUPPLIED FOR  
 184 THIS TYPE OF OPERATION:

PROGRAM	INPUT(S)	OUTPUT(S)	( ) = LUN
*****	*****	*****	
INVTAP	1-B TAPE(10) *PROMPTS	PRINTOUT OF DATA TYPE, TIMES, AND LOCATIONS FOR EACH FILE	
TOVTAP	1-B TAPE(10) **PROMPTS	SELECTED HIRS(11) AND MSU(12) DATA ON DISK; PRINTOUT OF RELEVANT INFORMATION	
TOVING	HIRS DISK(11) MSU DISK(12) HIRS RTC(13) ***PROMPTS	CALIBRATED, LOCATED DATA ON DISK(20); PRINTOUT	

192  
 193  
 194  
 195  
 196  
 197  
 198  
 199 NOTES:

200 \* NUMBER OF FILES TO READ; PROGRAM TERMINATES ON DOUBLE EOF IF ENCOUN-  
 201 T-ERED BEFORE COUNT IS SATISFIED.

202 \*\* PHYSICAL FILE NUMBERS OF HIRS AND MSU DATA, PLUS BEGINNING AND END-  
 203 ING TIMES.

204 \*\*\* SATELLITE NUMBER (USE 5 FOR TIROS-N) -- REQUIRED BECAUSE  
 205 INFORMATION IN TAPE HEADER RECORDS IS CONFUSING, I.E.  
 206 TIROS-N IS 1; NOAA-6 IS 2; 7 IS 4; 8 IS 6; 9 IS 7; 10 IS 8.

207  
 208 DIRECT-READOUT: DATA OBTAINED ON-SITE BY DIRECT DOWNLINK FROM THE

209 SPACECRAFT. THE SSEC SYSTEM USES DATA FROM THE VHF (137MHZ) BEACON.  
 210 SUCH DATA CAN ALSO BE ACQUIRED BY EXTRACTING 'TIP' FROM AN HRPT DATA-  
 211 STREAM; A MODEL OF THE NECESSARY SOFTWARE IS PROVIDED AS A GUIDE TO THE  
 212 USER. PROCESSING OF DIRECT-READOUT DATA IS MUCH MORE COMPLEX THAN THAT  
 213 OF LEVEL 1-8, SINCE THE USER MUST DO EVERYTHING - DECOMMUTATION OF RAW  
 214 DATA, NAVIGATION OR EARTH-LOCATION, AND IN-FLIGHT CALIBRATION. THREE  
 215 PROGRAMS ARE SUPPLIED:

PROGRAM	INPUT(S)	OUTPUT(S)
*****	*****	*****
PRETIP	HRPT FILE	DISK FILE(9) CONTAINING TIP DATA

221 NOTE: THE SUBROUTINES 'CMHOPN', 'CMHSET', AND 'CMHGET', REFERENCED IN  
 222 THIS PROGRAM, ARE NOT INCLUDED. THE PROGRAM IS SUPPLIED TO INDICATE  
 223 THE PROCESSING REQUIRED TO EXTRACT TIP DATA FROM THE HRPT STREAM;  
 224 SOFTWARE TO PERFORM THAT FUNCTION IS HIGHLY INSTALLATION-DEPENDENT  
 225 AND MUST BE PROVIDED BY THE USER.

PREING	DISK FILE(9) *PROMPTS	DISK FILE(10) CONTAINING DECOMMUTATED HIRS AND MSU DATA PRINTOUT
--------	--------------------------	--

INGTOV	DECOM DATA(10) **ORB-ELEM(11) HIRS RTC(13) ING-PARAM(15)	CALIBRATED, LOCATED DATA ON DISK(20) PRINTOUT
--------	---	--

235 NOTES:

236 \* YEAR; FLAG FOR DETAILED (DIAGNOSTIC) MSU PRINTOUT.

237 \*\* UPDATED BY PROGRAM 'PUTELE' WITH DATA OBTAINED FROM DIRECT READOUT  
 238 USER SERVICES.

240 THE DATA IN FILE 20 WILL HAVE THE SAME FORMAT, REGARDLESS OF THE  
 241 SOURCE AND TYPE OF INGEST. THIS FILE SERVES AS INPUT TO THE NEXT STEP.

243 PREPROCESSOR

244 \*\*\*\*\*

245 FUNCTION: TRANSFORM CALIBRATED, EARTH-LOCATED HIRS AND MSU MEASURE-  
 246 MENTS PRODUCED BY INGEST, INTO DATASETS FOR DISPLAY AND RETRIEVAL.  
 247 THE IMAGER (TOVORB), SOUNDER (TOVSND), AND RETRIEVAL (TOVRET) FILE  
 248 NAMES HAVE BEEN STRUCTURED TO PERMIT UP TO 26 ON-LINE DATASETS, BY  
 249 INCORPORATING A LETTER FROM 'A' TO 'Z' INTO A ROOT. TOVPRE AND SUBSE-  
 250 QUENT PROGRAMS PROMPT FOR A 'FILE LETTER' TO POINT TO A SPECIFIC SET.

PROGRAM	INPUT(S)	OUTPUT(S)
*****	*****	*****
TOVPRE	INGEST OUTPUT(20) HIRS RTC(13) HIRS LCC(15) MSU LCC(16) LO-RES TOPOG(17) PROMPTS FOR FILE, LIMB-CURRN OPTION	IMAGER FILE(22) SOUNDER FILE(23) PRINTOUT

261  
 262 TOVMAP IMAGER FILE(22) PRINTOUT OF DATA IN (LINE,ELEMENT)  
 263 PROMPTS FOR FILE, COORDINATES  
 264 PARAM(S), START-LINE  
 265  
 266 BRITEM SOUNDER FILE(23) DISPLAY OF ALL TBB'S AT ONE POINT  
 267 PROMPTS FOR FILE,  
 268 LOCATION  
 269

## NOTE:

270  
 271  
 272 THE PREPROCESSOR PERFORMS THE FOLLOWING FUNCTIONS:

273 IF THE MSU \*LIMB-CORRECTION\* FLAG IS ON, MSU DATA ARE CORRECTED FOR  
 274 ANTENNA PATTERN (TRANSFORM ANTENNA TEMP. TO BRIGHTNESS TEMP.);  
 275 LIMB EFFECTS (NORMALIZE TO THETA = 0);  
 276 SURFACE REFLECTIVITY (NORMALIZE TO SFC.EMIS. = 1);  
 277 LIQUID WATER (PRECIPITATING CLOUD) ATTENUATION.

278 IF THE HIRS \*LIMB-CORRECTION\* FLAG IS ON, HIRS DATA ARE CORRECTED FOR  
 279 LIMB EFFECTS, AND WATER VAPOR ATTENUATION IN THE WINDOW CHANNELS.  
 280 IN ADDITION, HIRS CHANNELS 17 AND 18 ARE CORRECTED, IN DAYLIGHT, FOR  
 281 FLUORESCENCE AND REFLECTED SUNLIGHT, RESPECTIVELY, REGARDLESS OF  
 282 THE STATE OF THE LIMB-CORRECTION FLAG.

283 MSU AND HIRS ARE COLOCATED BY INTERPOLATING THE MSU OBSERVATIONS TO  
 284 THE HIRS SCAN PATTERN.

285 OUTPUT FILE 22 HAS ALL DATA FOR ONE PARAMETER CONTIGUOUS ON DISK,  
 286 AND THUS IS OPTIMIZED FOR IMAGING;

287 OUTPUT FILE 23 HAS ALL DATA FOR ONE SCAN SPOT CONTIGUOUS ON DISK,  
 288 AND THUS IS OPTIMIZED FOR SOUNDING.

289  
 290 PROGRAMS \*MSUPRO\* AND \*MSUPLT\* PERFORM FUNCTIONS SIMILAR TO THOSE OF  
 291 TOVPRE AND TOVMAP, BUT FOR MSU ONLY, WHICH WAS THE DATA AVAILABLE  
 292 FOR MAJOR PORTIONS OF THE LIFETIMES OF NOAA-6 AND NOAA-8.  
 293

## RETRIEVAL

294 \*\*\*\*\*

295  
 296 FUNCTION: DETERMINE, FROM PREPROCESSED HIRS AND MSU DATA, VERTICAL  
 297 PROFILES OF ATMOSPHERIC TEMPERATURE, HUMIDITY, AND GEOPOTENTIAL HEIGHT,  
 298 AS WELL AS TOTAL-OZONE AND STABILITY PARAMETERS, AT HIGH SPATIAL RESOLU-  
 299 TION. SEE NOTE ON \*SURFACE DATA\* AT THE END OF THIS DOCUMENT. THERE  
 300 ARE TWO VERY DIFFERENT RETRIEVAL PROGRAMS INCLUDED IN THIS PACKAGE:  
 301 STATISTICAL (TOVSTR) AND PHYSICAL (TOVRET).  
 302

PROGRAM	INPUT(S)	OUTPUT(S)
*****	*****	*****
TOVSTR	LO-RES TOPOG(17) IMAGER FILE(22) SOUNDER FILE(23) *RTVL LOEF(25) PROMPTS FOR FILE, PARAMETERS	RETRIEVAL FILE(24) PRINTOUT

303  
 304  
 305  
 306  
 307  
 308  
 309  
 310  
 311 TOVSTR IS A FAST STATISTICAL RETRIEVAL, USING THE N# PROCEDURE TO  
 312 OBTAIN CLEAR-COLUMN RADIANCES. IT IS MUCH LESS DEMANDING OF COMPUTER

313 RESOURCES THAN THE PHYSICAL RETRIEVAL PROGRAM, TOVRET. DATA PROVIDED  
 314 TO THIS PROGRAM MUST HAVE BEEN LIMB-CORRECTED IN TOVPRE.

315 NOTE:

316 \* COEFFICIENTS STAGED TO DISK BY \*RTVCFL\*

317	PROGRAM	INPUT(S)	OUTPUT(S)
318	*****	*****	*****
319	TOVRET	HIRS RTC(13)	RETRIEVAL FILE(24)
320		*MSU RTC(14)	PRINTOUT
321		+HIRS LCC(15)	
322		*MSU LCC(16)	
323		LO-RES TOPOG(17)	
324		*MSU RTC(18)	
325		HI-RES TOPOG(27,37)	
326		IMAGER FILE(22)	
327		SOUNDER FILE(23)	
328		**RTVL COEF(25)	
329		***PROMPTS FOR FILE,	
330		PARAMETERS	

333 THIS PROGRAM CAN OPERATE ON HIRS AND MSU DATA THAT HAVE BEEN LIMB-  
 334 CORRECTED OR NOT ... THE LATTER SEEMS TO GIVE BETTER RESULTS.

335 NOTES:

336 \* THE RTC IN FILE 14 ARE FOR LIMB-CORRECTED MSU DATA; THOSE IN FILE  
 337 18, FOR NON-LIMB-CORRECTED DATA.

338 \* NEEDED FOR REGRESSION ESTIMATION OF FIRST-GUESS TEMPERATURE AND  
 339 OZONE PROFILES.

340 \*\* COEFFICIENTS STAGED TO DISK BY \*RTVCF\*

341 \*\*\* SPECIFY VARIOUS OPTIONS TO CONTROL EXECUTION OF PROGRAM - SEE  
 342 SOURCE CODE FOR PARAMETERS AND THEIR MEANINGS.

343 \*\*\*\*\*

344 TOVRET IS OUR MOST UP-TO-DATE MODEL; IT OBTAINS SOLUTIONS FOR  
 345 TEMPERATURE AND WATER VAPOR IN A SINGLE STEP FROM COMBINED INFRARED  
 346 AND MICROWAVE MEASUREMENTS.

348 PROGRAM \*MSURET\* PERFORMS A PHYSICAL (ITERATIVE) RETRIEVAL ON MSU-  
 349 ONLY DATA PROCESSED BY MSUPRO.

351 FILTERING

352 \*\*\*\*\*

353 FUNCTION: ELIMINATE SOUNDINGS OF QUESTIONABLE RELIABILITY BY OBJECT-  
 354 IVE ANALYSIS OF DIFFERENCES BETWEEN INFRARED AND MICROWAVE RETRIEVALS  
 355 FOR THE SAME LOCATION, AND OF VARIABILITY IN 1000-500MB THICKNESS AND  
 356 LONGWAVE-WINDOW VS. SURFACE TEMPERATURE.

357	PROGRAM	INPUT(S)	OUTPUT(S)
358	*****	*****	*****
359	FILRET	RTVL FILE(24)	RTVL FILE(24), WITH *FAILED*
360		*PROMPTS	SOUNDINGS FLAGGED
361			PRINTOUT

364 NOTE:

\* TO CONTROL FILTERING PARAMETERS ... SEE SOURCE CODE FOR DETAILS

ENHANCEMENT

\*\*\*\*\*

FUNCTION: ADD MICROWAVE-ONLY SOUNDINGS IN AREAS WHERE INFRARED RETRIEVALS WERE NOT MADE, OWING TO HEAVY CLOUDINESS, OR WERE FLAGGED \*FAILED\* BY THE FILTER PROGRAM. THIS PROGRAM WAS ORIGINALLY DEVELOPED WHEN ONLY STATISTICAL RETRIEVALS COULD BE MADE (BY TOVSTR); IF THE PHYSICAL RETRIEVAL TOVRET IS USED, ENHANCEMENT SHOULD NOT BE NEEDED.

PROGRAM	INPUT(S)	OUTPUT(S)
*****	*****	*****
ENHRET	LO-RES TOPOG(17) SOUNDER FILE(23) RTVL FILE(24) *RTVL COEF(25) PROMPT FOR FILE	RTVL FILE(24)

NOTE:

\* SAME COEFFICIENTS AS USED WITH TOVSTR

GEOSTROPHIC WINDS

\*\*\*\*\*

FUNCTION: DETERMINE GEOSTROPHIC WINDS FOR \*GOOD\* SOUNDINGS IN RETRIEVAL FILE, BY LEAST-SQUARES OBJECTIVE ANALYSIS OF HEIGHT FIELDS.

PROGRAM	INPUT(S)	OUTPUT(S)
*****	*****	*****
WINRET	RTVL FILE(24) *PROMPTS	RTVL FILE(24)

NOTE:

\* TO CONTROL QUANTITY OF PRINTOUT

REDUNDANCY ELIMINATION

\*\*\*\*\*

FUNCTION: ELIMINATE REDUNDANT INFRARED RETRIEVALS, BASED ON VARIABILITY IN SELECTED HIRS CHANNELS.

PROGRAM	INPUT(S)	OUTPUT(S)
*****	*****	*****
REDRET	RTVL FILE(24) *PROMPTS	RTVL FILE(24)

NOTE:

\* FOR FILE AND TO SPECIFY OTHER THAN DEFAULT CONTROL PARAMETERS

RETRIEVAL PLOTTERS

\*\*\*\*\*

FUNCTION: TO PLOT VARIOUS QUANTITIES FROM THE RETRIEVAL FILE. INPUT CONSISTS OF THE RETRIEVAL FILE(24) AND PROMPTS TO CONTROL THE LOCATION AND PARAMETERS PLOTTED ... SEE SOURCE CODE FOR DETAILS.

```

417 PROGRAM PRODUCT
418 *****
419 TOVPLF IR-MW SOUNDING DIFFERENCES, WITH CHARACTERS APPENDED
420 TO DENOTE RESULTS OF FILRET AND REDRET
421 TOVPLT IR-RETRIEVAL TEMPERATURES
422

```

```

423 TOVPLF SHOULD BE RUN BEFORE THE NEXT PROGRAM TO BE DESCRIBED
424 (COMRET); TOVPLT SHOULD BE RUN AFTER FILE-COMPRESSION. THE LATTER
425 PROGRAM MAY BE REPLICATED AND/OR MODIFIED TO PLOT OTHER QUANTITIES
426 FROM THE RETRIEVAL OUTPUT.
427

```

#### 428 FILE COMPRESSION

```
429 *****
```

```

430 FUNCTION: COMPRESS THE RETRIEVAL FILE BY DELETING SOUNDINGS THAT
431 HAVE BEEN FLAGGED BY FILRET AND/OR REDRET, AND MOVING THE REMAINING
432 SOUNDINGS TO REPLACE THE 'EMPTY' RECORDS.
433

```

```

434 PROGRAM INPUT(S) OUTPUT(S)
435 *****
436 COMRET RTVL FILE(24) RTVL FILE(24)
437

```

```
438 *****
```

```
439 NOTE ON 'SURFACE DATA'
```

```

440
441 PROGRAMS ENHRET, TOVRET, AND TOVSTR INVOKE SUBROUTINE GETSFX, WHICH
442 IS OBVIOUSLY, FROM INSPECTION OF THE SOURCE CODE, A DUMMY ROUTINE.
443 THE USER SHOULD PROVIDE AN INTERFACE TO ACTUAL GRIDDED SURFACE DATA
444 (1000MB HEIGHT, TEMPERATURE, AND DEWPOINT) IF SUCH INFORMATION IS
445 AVAILABLE.
446

```

```

447 *****
448 STRUCTURE OF THE 'TOVORB' AND 'TOVSND' FILES
449

```

```
450 *** TOVORB
```

```
451 ACCESS ROUTINE: TSNIO
```

```
452 RECORD LENGTH = 112 INTEGER=4 WORDS
```

```
453 CONTENTS OF FIRST RECORD ('DOCUMENTATION' OR 'HEADER'):
```

```

454
455 IBUF( 1) = YYDDO AT START OF PASS
456 IBUF( 2) = HHMMSS AT START OF PASS
457 IBUF( 3) = HHMMSS AT END OF PASS
458 IBUF( 4) = NUMBER OF HIRS LINES IN PASS
459 IBUF( 5) = SATELLITE IDENTIFICATION (1=ODD, 2=EVEN)
460 IBUF( 6) = STATUS (TO IDENTIFY USER, ETC.)
461 IBUF( 7) = DIRECTION (1=ASCENDING, 2=DESCENDING)
462 IBUF(50) = START TIME OF PASS IN MILLISECONDS
463 IBUF(51) = HIRS LIMB-CORRECTION FLAG
464 IBUF(52) = MSU LIMB-CORRECTION FLAG
465 IBUF(53:112) = NOT USED
466

```

```
467 ORGANIZATION OF DATA IN SUBSEQUENT RECORDS:
```

```
468
```

469 THERE ARE 30 PARAMETERS, EACH OF WHICH IS ALLOTTED 50 RECORDS ON  
 470 DISK, PROVIDING FOR 100 HIRS SCAN LINES (STORED TWO LINES PER RECORD).  
 471 IF THE 'IMAGE' OR ORBITAL PASS CONTAINS LESS THAN 100 LINES, THE UNUSED  
 472 PORTION OF EACH 'LOGICAL (PARAMETER) FILE' IS FILLED WITH 999999 TO  
 473 SERVE AS A 'MISSING' INDICATOR TO SOFTWARE THAT ACCESSES THE FILE.  
 474

475 THE PARAMETERS ARE AS FOLLOWS:

476  
 477 1 LATITUDE (DEG X 100,+N,-S)  
 478 2 LONGITUDE (DEG X 100,+E,-W)  
 479 3 SOLAR ZENITH ANGLE (DEG X 100; 9000 IF NIGHT)  
 480 4 BRIGHTNESS TEMPERATURE (DEG X 100), HIRS CHANNEL 1  
 481 5 BRIGHTNESS TEMPERATURE (DEG X 100), HIRS CHANNEL 2  
 482 . . . .  
 483 22 BRIGHTNESS TEMPERATURE (DEG X 100), HIRS CHANNEL 19  
 484 23 BRIGHTNESS TEMPERATURE (DEG X 100), MSU CHANNEL 1A  
 485 24 BRIGHTNESS TEMPERATURE (DEG X 100), MSU CHANNEL 1  
 486 25 BRIGHTNESS TEMPERATURE (DEG X 100), MSU CHANNEL 2  
 487 26 BRIGHTNESS TEMPERATURE (DEG X 100), MSU CHANNEL 3  
 488 27 BRIGHTNESS TEMPERATURE (DEG X 100), MSU CHANNEL 4  
 489 28 TOTAL OUTGOING LONGWAVE FLUX (WATT/SQ-METER, X 100)  
 490 29 BIDIRECTIONAL REFLECTANCE DERIVED FROM HIRS CHANNEL 20(VIS)  
 491 30 BRIGHTNESS TEMPERATURE (DEG X 100), HIRS CHANNEL 18A  
 492

493 EXPLANATION OF EXTRA BRIGHTNESS TEMPERATURES:

494  
 495 ITEM 23 . . . IF MSU DATA ARE LIMB-CORRECTED, THIS IS CHANNEL 1 WITH  
 496 SURFACE EFFECTS RETAINED; IF NOT LIMB-CORRECTED, THIS IS  
 497 INDEXING INFORMATION AND NOT MAPPABLE.

498 ITEM 30 . . . IF DAYTIME, THIS IS CHANNEL 18 (4 MICRON WINDOW) WITH  
 499 A FIRST-ORDER APPROXIMATE CORRECTION FOR REFLECTED SUNLIGHT.  
 500

501 THE ACCESS ROUTINE 'TSNDIO' DOES THE INTERNAL CALCULATIONS TO LOCATE  
 502 THE DATA ON DISK, GIVEN PARAMETER NUMBER, INITIAL LINE, INITIAL ELEMENT,  
 503 NUMBER OF LINES, AND NUMBER OF ELEMENTS.  
 504

505 \*\*\* TOVSND

506 ACCESS ROUTINE: SNDIO

507 RECORD LENGTH = 112 INTEGER\*4 WORDS

508 FIRST RECORD IS 'HEADER', AND IS IDENTICAL TO THAT FOR 'TOVORB'  
 509

510 ORGANIZATION OF DATA IN SUBSEQUENT RECORDS:

511  
 512 PARAMETERS 1 THROUGH 29 (SEE 'TOVORB' DESCRIPTION FOR CONTENTS)  
 513 ARE STORED AS A VECTOR WITH COORDINATES OF LINE AND ELEMENT (OR SPOT).  
 514 THUS EACH 112-WORD RECORD CONTAINS DATA FOR FOUR HIRS FIELDS-OF-VIEW.  
 515 THE ACCESS ROUTINE 'SNDIO' DOES THE INTERNAL CALCULATIONS TO LOCATE  
 516 THE DATA ON DISK, GIVEN LINE AND ELEMENT.  
 517

518 \*\*\*\*\*  
 519 STRUCTURE OF THE 'TOVRET' FILE  
 520



```

521     ACCESS ROUTINE: RETIO
522     RECORD LENGTH = 112 INTEGER*4 WORDS
523     CONTENTS OF FIRST RECORD ('DOCUMENTATION' OR 'HEADER'):
524     IBUF( 1) = YYDDO AT START OF PASS
525     IBUF( 2) = HHMMSS AT START OF PASS
526     IBUF( 3) = HHMMSS AT END OF PASS
527     IBUF( 4) = NUMBER OF HIRS LINES IN PASS
528     IBUF( 5) = SATELLITE IDENTIFICATION (1=ODD, 2=EVEN)
529     IBUF( 6) = STATUS (TO IDENTIFY USER, ETC.)
530     IBUF( 7) = DIRECTION (1=ASCENDING, 2=DESCENDING)
531     IBUF(8:49) NOT MEANINGFUL
532     IBUF(50) = START TIME OF PASS IN MILLISECONDS
533     IBUF(51) = HIRS LIMB-CORRECTION FLAG (0=ON, 1=OFF)
534     IBUF(52) = MSU LIMB-CORRECTION FLAG (0=ON, 1=OFF)
535     IBUF(53:109) NOT MEANINGFUL
536     IBUF(110) = LINE-COORDINATE OF LAST SOUNDING MADE
537     IBUF(111) = ELEM-COORDINATE OF LAST SOUNDING MADE
538     IBUF(112) = NUMBER OF SOUNDINGS MADE
539     CONTENTS OF INDIVIDUAL SOUNDING RECORDS
540     ALL PRESSURES ARE IN UNITS OF MILLIPARS.
541     ALL TEMPERATURES ARE IN UNITS OF DEGREES KELVIN X 100.
542     A VALUE OF 999999 DENOTES 'MISSING' OR 'FILL'.
543     IBUF( 1) = LATITUDE (DEG X 100,+N,-S)
544     IBUF( 2) = LONGITUDE (DEG X 100,+E,-W)
545     IBUF( 3) = TIME (HHMM)
546     IBUF( 4) = SURFACE ELEVATION (METERS ABOVE MSL)
547     IBUF(5:19) = GEOPOTENTIAL HEIGHT (METERS)
548     IBUF(20) = AIR TEMPERATURE AT GROUND LEVEL (OR 1000 MB)
549     IBUF(21:34) = AIR TEMPERATURE AT 850, 700, ..., 10 MB
550     IBUF(35) = DEW-POINT TEMPERATURE AT GROUND LEVEL (OR 1000 MB)
551     IBUF(36:40) = DEW-POINT TEMPERATURE AT 850, 700, ..., 300 MB
552     IBUF(41:59) = HIRS BRIGHTNESS TEMPERATURES, CHANNELS 1 - 19
553     IBUF(60:63) = MSU BRIGHTNESS TEMPERATURES, CHANNELS 1 - 4
554     IBUF(64) = SURFACE SKIN TEMPERATURE
555     IBUF(65) = IMAGE-LINE COORDINATE AT CENTER OF RETRIEVAL BOX
556     IBUF(66) = IMAGE-ELEMENT COORDINATE AT CENTER OF BOX
557     IBUF(67) = PRESSURE AT GROUND LEVEL
558     IBUF(68:77) = FIRST-GUESS TEMPERATURE AT 1000, 850, ..., 100 MB
559     IBUF(78:82) = FIRST-GUESS DEW-POINT AT 850, 700, ..., 300 MB
560     IBUF(83:90) = FILL
561     IBUF(91) = TOTAL-TOTALS STABILITY INDEX (DEG X 100)
562     IBUF(92:95) = FILL
563     IBUF(96) = TOTAL OZONE (DORSON UNITS X 100)
564     IBUF(97) = TOTAL PRECIPITABLE WATER VAPOR (MM X 100)
565     IBUF(98) = TOTAL OUTGOING LONGWAVE FLUX (WATT/SQ-METER, X 100)
566     IBUF(99) = CLOUD PRESSURE
567     IBUF(100) = CLOUD TEMPERATURE
568     IBUF(101) = FILL
569     IBUF(102) = RTVL TYPE (CLEAR=10, PARTLY-CLOUDY=20, MW+HS=30)
570     IBUF(103) = SOLAR ZENITH ANGLE (DEG X 100; 9000 IF NIGHT)
571     IBUF(104:112) = WINDS (DDFFF: DEG, METERS/SEC)
572     *****

```