# RECENT DEVELOPMENTS AND OUTLOOK IN U.S. METEOROLOGICAL SATELLITE ACTIVITIES.

DJJ Lecture
Inst. of Atmospheric Physics
Academia Sinica, PRC
5 November 1983

## I Introduction

A. Enjoy visiting you again and seeing the new developments here.
Especially pleased to see the McIdas interactive processor working, and the successful retrieval of soundings from TOVS. Congratulations (Zhou Fengxian, "Joe Feng Shiaban")

B. Today, I will ~~try to avoid covering~~ not talk about material you may have heard from earlier visitors; for example, ~~I will say very little about~~ the use of GOES and the results of the VAS experiment, which ~~since~~ I'm sure Prof. Suomi covered these subjects when he visited last year.

C. I will cover briefly the following topics today:

1. Improvements in ~~and status of NOAA~~ operational temperature soundings from NOAA/TOVS.
2. A new technique for estimating shelter temperatures from TOVS data.
3. Improved sea surface temperatures
4. Comparison ~~with~~ of operational wind estimates from GOES with RAWINS.
5. Some new satellite observations useful ~~important~~ for climate ~~studies and~~ research.

and

6. Outlook for operational meteorological satellites.

IAP - (11-5-83)

## II. Operational temperatures from TOVS.

A. Several improvements since FGGE in the retrieval processing and quality control:

1. A new method for correcting for clouds in partly cloudy areas.
2. A new method for cloudy retrievals ~~using~~ which must rely on the MSU only for the troposphere.
3. Improved objective quality control system.

B. Cloud correction (after Mc Millin + Dean).

- Slide (Fig. 9-2): Old (TARM-1) and new (TARM-2) methods compared.
  Average difference between satellite + radiosondes.
  Clear + partly cloudy (N*) retrievals.
  Data for 20 May - 2 June 1980, 30 to 60° N. lat. belt.
  Approx. 3000 soundings compared.
  1. Note significant reduction in bias in troposphere.
  Departure in upper stratosphere probably ~~primarily~~ due to radiation heating of R/S temperature element.
- Slide (Fig. 9-3): Same as above, but RMS difference.
  2. Significant improvement in surface to 500MB layer.
  3. Reduced No. of "Cloudy retrievals to about 17%
  [Point out problems in comparison with R/S. ± 6hrs., ± 250 km (2), sampling.]

SLIDE OFF

C. TOVS Cloudy retrievals (after N. Phillips) uses MSU + stratos. IR.
[More stringent use of R/S match-ups to determine regression coefficients -- island stations only; use of sea surface temp. as classification for regressions. ~~Category~~; MSU only works over ocean.)

- Vu-graph (Fig. 9-4): Comparison ~~with~~ between old method (NESS) and new (Phillips). Change-over in 1981.
  1. This comparison is for November 1980.
  2. Note especially the reduction in bias! VERY important for NWP

(* Slide + Vugraph numbers refer to SMA lectures.)

Fig. 9-2

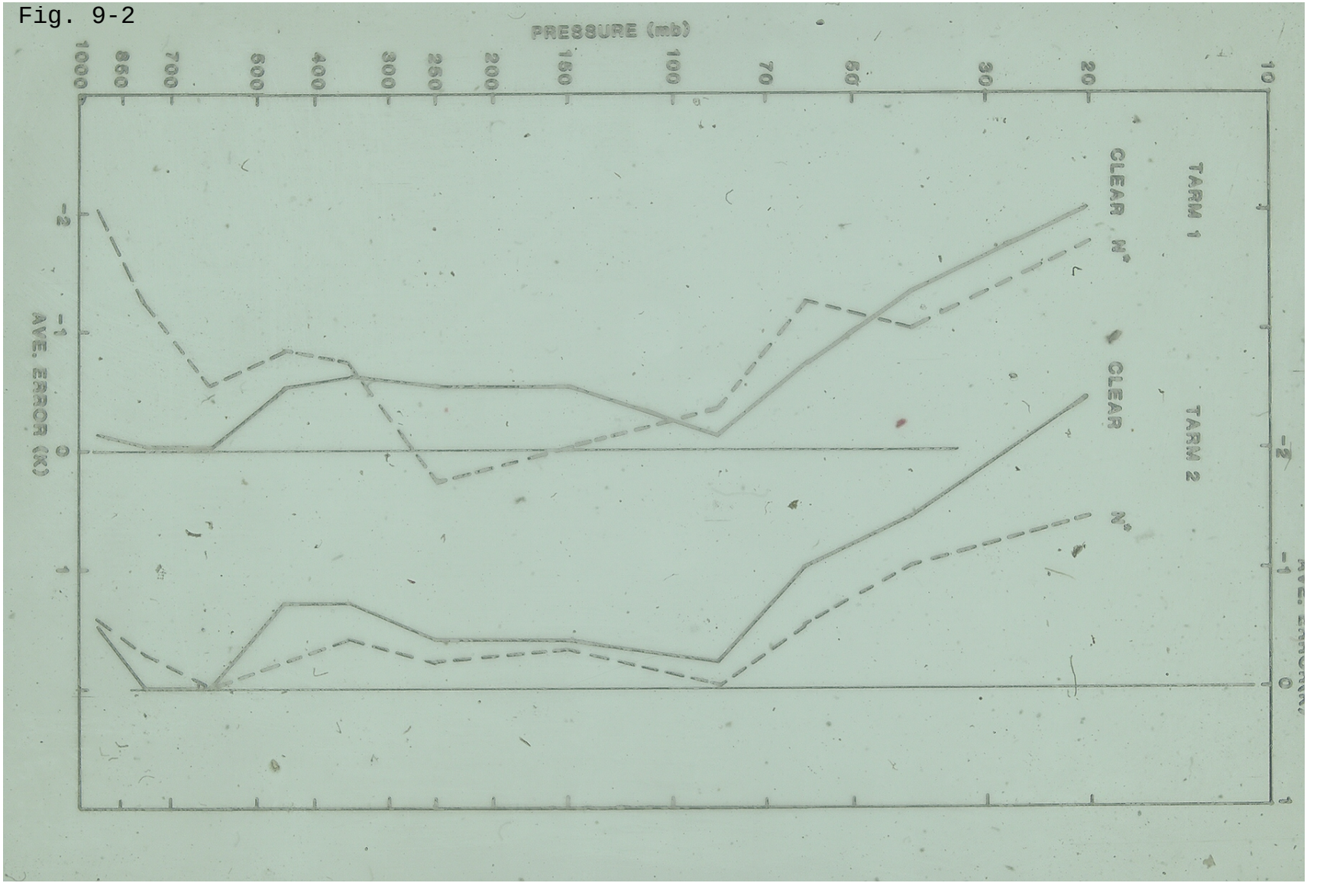
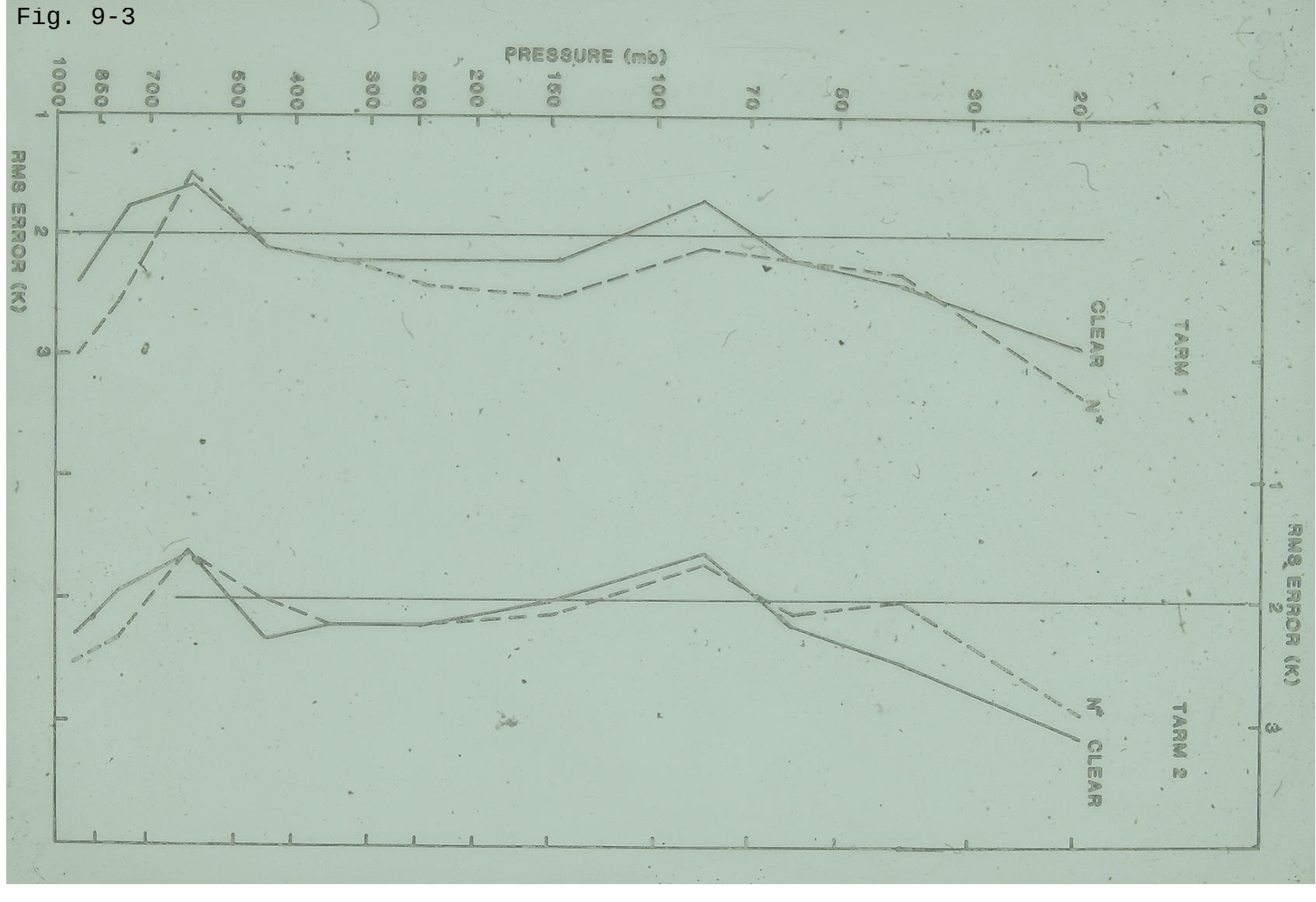

TARM 1
TARM 2
CLEAR N°
CLEAR N°
PRESSURE (mb)
1000
850
700
500
400
300
250
200
150
100
70
50
30
20
10
AVE. ERROR (K)
-2
-1
0
1

Fig. 9-3


PRESSURE (mb)
1000
850
700
500
400
300
250
200
150
100
70
50
30
20
10
RMS ERROR (K)
1
2
3
TARM 1
CLEAR
N*
TARM 2
N*
CLEAR

Vu-Graph 9-4 Cloudy Soundings Considerably Improved in 1981

MISSING

D. Comparison of operational TOVS soundings with R/S, with these improvements.

- Vugraph (Fig. 9-5): Two different data sets used here. Appropriate to use the "clear" column on left, and the "partly cloudy" + "cloudy" columns on the right.
  1. Phillips' data used a more accurate comparison technique with R/S. by interpolation in time to that of TOVS, and interpolation of TOVS in space to location of R/S.
  2. Numbers in ( ) based on assuming an RMS error of 1°C. for the radiosondes.
  3. Results are much better than shown earlier. (Spatial + temporal variability of Temp)

III. Estimating shelter temperatures from TOVS operational data. (After Davis + Tanpley.)

A. Regression method.

1. Uses an "extrapolated temperature" using the two ~~upp~~ TOVS ~~temper~~ sounding temperatures nearest the earth's surface, the MSU channel 2 brightness temperature, and the "skin temperature" from window channel corrected for atmospheric absorption.
2. Regression coefficients determined in comparison with carefully selected + processed actual shelter temperatures. $[T_{SH})_{est} = a_0 + a_1 T_E + a_2 M_2 + a_3 T_{SK}]$

- Vugraph (Fig. 12-12) (bottom) $T_E = T_1 + (T_1 - T_2)\dfrac{\ln p_S - \ln p_1}{\ln p_1 - \ln p_2}$
  3. $\sigma$ varies from 1.68 to 2.61 °C. Compare with $\sigma$ of observed temps 1.43 to 1.94. (N. Hem. growing season is best.) $[\Delta T = T_{SK} - T_1]$

Vu-graph Off

Fig. 9-5

| PRESSURE | McMillin & Dean* CLEAR | McMillin & Dean* PARTLY CLOUDY | Phillips† PARTLY CLOUDY | Phillips† CLOUDY | Phillips† ALL |
|---|---|---|---|---|---|
| 1000-850 | 2.3°C. | 2.5°C. | 2.7 (2.5)°C. | 2.4 (2.2)°C. | 1.9 (1.6)°C. |
| 850-700 | 1.9 | 2.3 | 2.2 (2.0) | 2.3 (2.1) | 1.6 (1.2) |
| 700-500 | 1.7 | 1.7 | 1.6 (1.2) | 1.5 (1.1) | 2.0 (1.7) |
| 500-400 | 2.3 | 2.0 | 2.0 (1.7) | 2.2 (2.0) | |
| 400-300 | 2.2 | 2.2 | 2.2 (2.0) | 2.4 (2.2) | |
| 300-200 | 2.2 | 2.2 | 2.0 (1.7) | 1.9 (1.6) | |
| 200-100 | 2.0 | 2.1 | 1.5 (1.1) | 1.5 (1.1) | |
| 100-70 | 1.7 | 1.8 | | | |
| 70-50 | 2.2 | 2.1 | | | |
| 50-30 | 2.3 | 2.0 | | | |

* RMS OF DIFFERENCES BETWEEN SATELLITES AND RADIOSONDES. ~3000 PAIRS, 30-60°N., 20 MAY -2 JUNE 1980 BUT USING 1982 OPER. RETRIEVAL METHOD.

† √ OF ESTIMATED VALUES OF THE SQUARE OF SAT. ERROR PLUS SQUARE OF R/S ERROR. VALUES IN ( ) ASSUME RMS R/S ERROR OF 1.0°C. ONLY OCEAN RETRIEVALS, 30-60°N. 17-30 NOV. 1981 FOR 1000-100 MB. + ALL NOV. FOR 100-30 MB FOR ALL RETRIEVALS (CLR, PTLY CLDY, CLDY).

Figure 9-5

Fig. 12-12

# RESULTS OF SHELTER TEMPERATURE DERIVATION

| OBSERVATIONS | N | | RESULTS BY USING Full Regression | $T_E$ only | $T_{SK}$ only |
|---|---|---|---|---|---|
| NOAA-6 APR-SEP | 1517 | $R^2$ | 0.97 | 0.91 | 0.81 |
| | | $\sigma_R$ | 1.76 | 2.39 | 3.28 |
| NOAA-6 OCT-MAR | 1099 | $R_2$ | 0.93 | 0.89 | 0.91 |
| | | $\sigma_R$ | 2.55 | 3.61 | 3.31 |
| NOAA-7 DAY (ALL) | 1273 | $R_2$ | 0.95 | 0.94 | 0.85 |
| | | $\sigma_R$ | 2.38 | 5.26 | 4.23 |
| NOAA-7 NIGHT (ALL) | 768 | $R_2$ | 0.94 | 0.90 | 0.93 |
| | | $\sigma_R$ | 2.46 | 4.70 | 3.24 |

$R^2$ = explained variance

$\sigma_R$ = standard deviation of residuals (approximates the error

N = Number of observations in the sample

$\sigma_{SH}$ = Average standard deviation of the ensembles of observed shelter temperatures corrected to the TOVS sounding locations.

| OBSERVATIONS | STATISTICAL RESULTS N | $R^2$ | $\sigma_R$ | $\sigma_{SH}$ | RANKING OF PREDICTORS * |
|---|---|---|---|---|---|
| NOAA-6 | | | | | |
| APR-SEP, ΔT POS. | 754 | 0.92 | 1.68 | 1.43 | $T_E$, $M_2$, ($T_{SK}$) |
| APR-SEP, ΔT NEG. | 763 | .93 | 1.76 | 1.56 | $T_E$, $T_{SK}$, $M_2$ |
| OCT-MAR, ΔT POS. | 168 | .94 | 2.61 | 1.73 | $M_2$, $T_E$, ($T_{SK}$) |
| OCT-MAR, ΔT NEG. | 931 | .93 | 2.42 | 1.85 | $T_{SK}$, $T_E$, ($M_2$) |
| NOAA-7 | | | | | |
| APR-SEPT, DAY | 693 | 0.90 | 2.08 | 1.51 | $T_E$, ($M_2$), ($T_{SK}$) |
| Oct.-MAR, DAY | 580 | .95 | 2.33 | 1.77 | $T_{SK}$, $T_E$, $M_2$ |
| NIGHT, ΔT > -4.3 | 392 | .94 | 2.54 | 1.71 | $M_2$, $T_E$, ($T_{SK}$) |
| NIGHT, ΔT ≤ -4.3 | 376 | .96 | 1.74 | 1.94 | $T_{SK}$, ($M_2$), ($T_E$) |

* IN ORDER OF SIGNIFICANCE; PREDICTORS IN ( ) ARE NOT SATISTICALLY SIGNIFICANT.

Figure 12-12

IV. Improved Sea Surface Temperatures

A. Use of the new five-channel AVHRR at night allows improved correction of window radiances for clouds and atmospheric absorption. The new algorithm was introduced operationally ~~in~~ on 10 November 1981.

- Slide (Fig. 13-4):
  1. Bottom shows the new results: Bias = +0.02; $\sigma$ = 0.58°C. Compared to oceanographic buoys and ships.
  2. Has subsequently degraded because of
     a. El Chichon volcano eruption.
     b. Degredation in 3.8 μm AVHRR channel.
        - Next 5 channel AVHRR to be launched in 1984.

B. A series of observations in time can be used to minimize effect of clouds on the infrared. Now use 24-hour sequence of 48 GOES IR observations to obtain SST for U.S. coastal waters, filtering out the clouds.

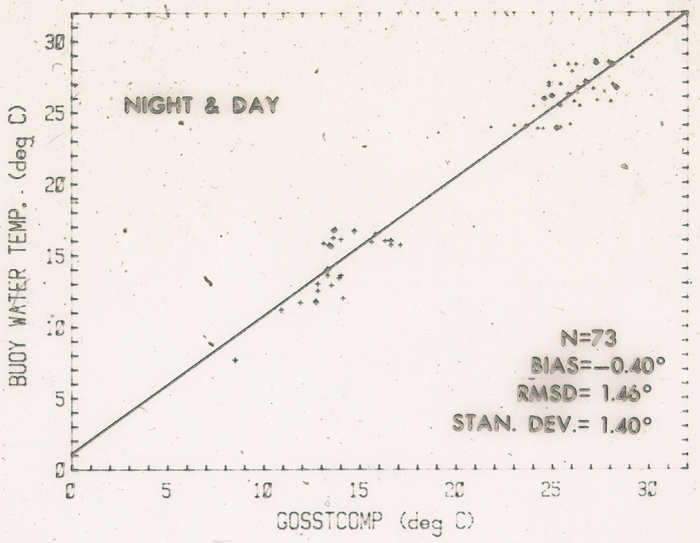
- Slide (Fig. 13-6):
  1. Example for the Gulf of Mexico - shows the "Loop current". Not as accurate as AVHRR, ~~Could~~ but is good for temperature gradients. Higher accuracy could be obtained by using the GOES VAS.

V. Operational upper air wind estimates from cloud displacements observed from GOES.

A. Basically two levels at about 850 mb. and 300-200 mb.

- Slide (Fig. 10-9):
  1. Comparison with rawins, seasonally from summer 1979 to winter 1981-82.
     - Some improvement in upper level (permanent?)
     - Problem of altitude estimates for upper level.
     - ESA has comparable results; Japan has improved.

Fig. 13-4 AVHRR 4 vs. 5 Channel Algorithms



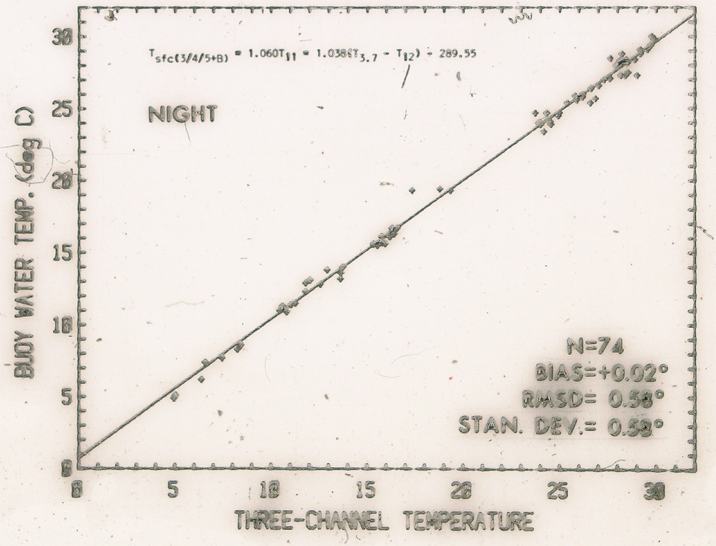
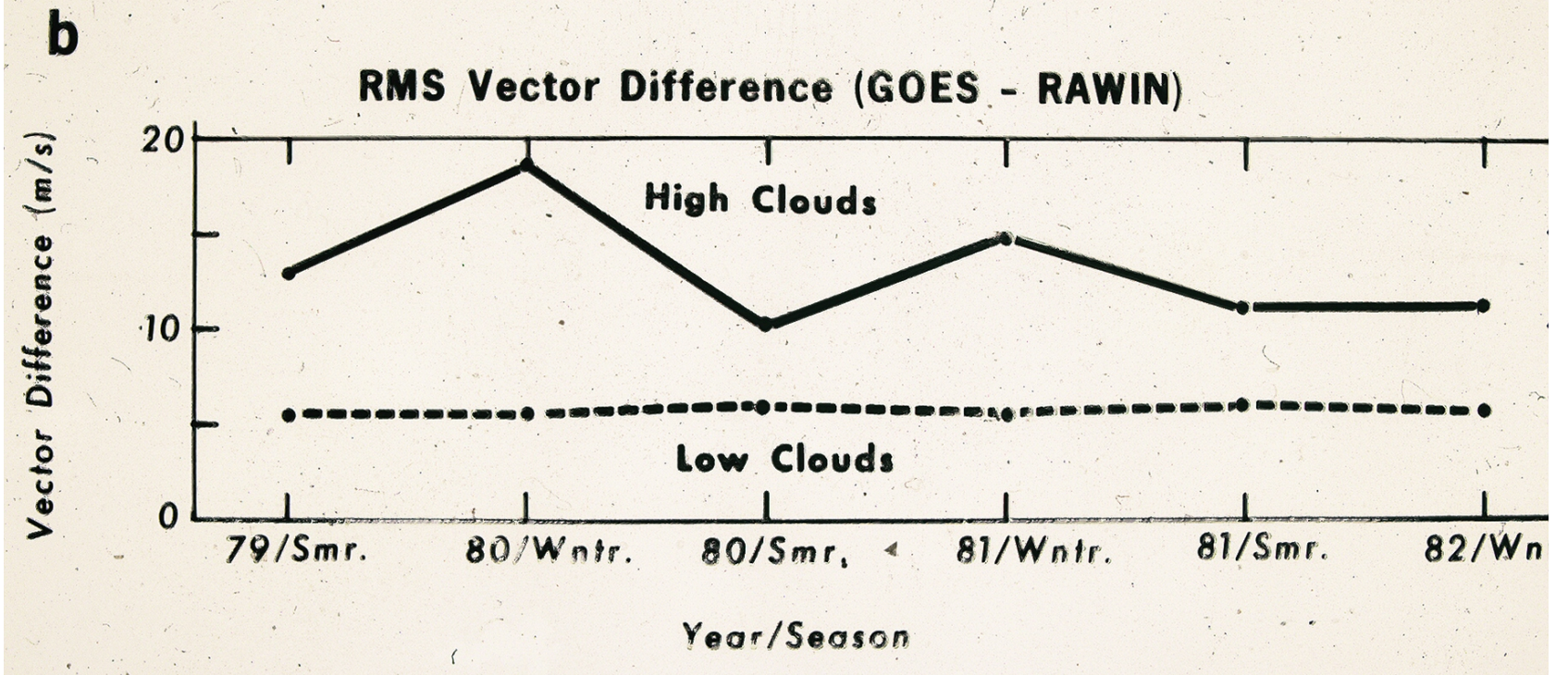



Fig. 13-6 Cloud Filtering Using 48 IR Images in 24 Hours - Gulf of Mexico

Fig. 10-9 GOES minus Rawins - 1979-1982



VI. New observations important for climate research.

A. Normalized vegetation index (NVI)

1. Global maps produced weekly on a subgrid of NMC NWP grid with a resolution of 15 (eq.) to 30 km (polar)
   - Uses visible + near-IR channels of AVHRR.

• Slide (Fig. 12-5):

2. NVI for Northern Hem. 23-29 Aug. 1982 (summer)
   - Point out sharp boundary in Africa.
   - Difference between Eastern + Western N. America
   - Himalayas.

• Slide (Fig. 12-6):

3. Contrast with winter NVI (21-27 March 1983).

B. Global snow coverage

1. Digital data base now exists from 1967, continuously up-dated.
   - Produce monthly and seasonal analyses and departures from mean. Available in map form and totals by continents, hemisphere, etc.

• Slide (Fig. 11-25):

2. Example shows ~~seasonal~~ interannual variation of seasonal (Dec.-Feb.) snow cover for the Eurasian continent, 1967-1982

C. Ocean surface winds

1. Measure with radio scatterometer. Actually responds to capillary waves produced by the wind, so is a better measure of surface wind stress.

2. Instrument was flown on SEASAT, 1978
   - Comparison with "ground truth" shows
     speed σ ~ 1.5 mps. } 2-25 mps. (limit of
     direction σ ~ 20° } ground truth.)

• Slide (Fig. 13-10):

Fig. 12-5 Northern Hemisphere NVI, Aug. 23-29, 1982
Greenest

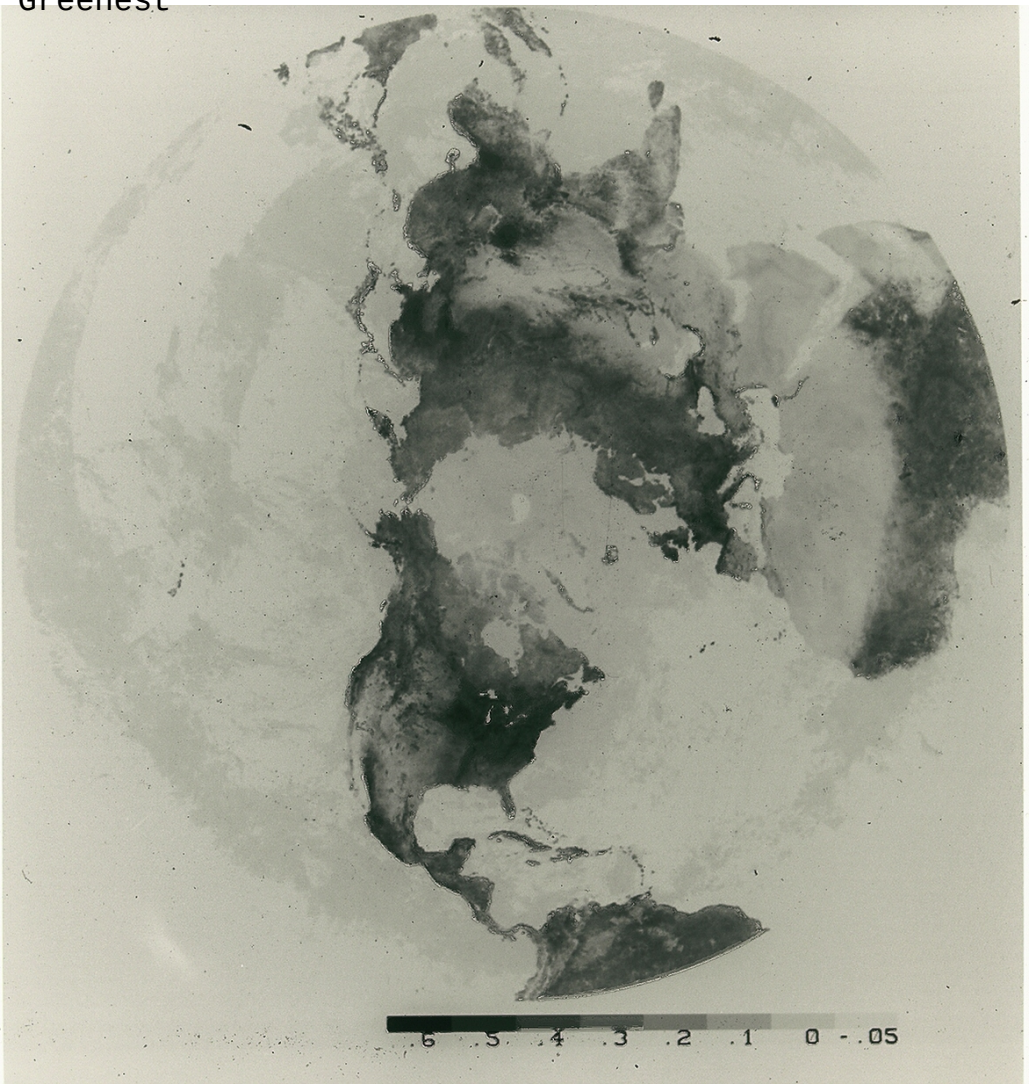


Fig. 12-6 Northern Hemisphere NVI, March 21-27, 1983
Greenest

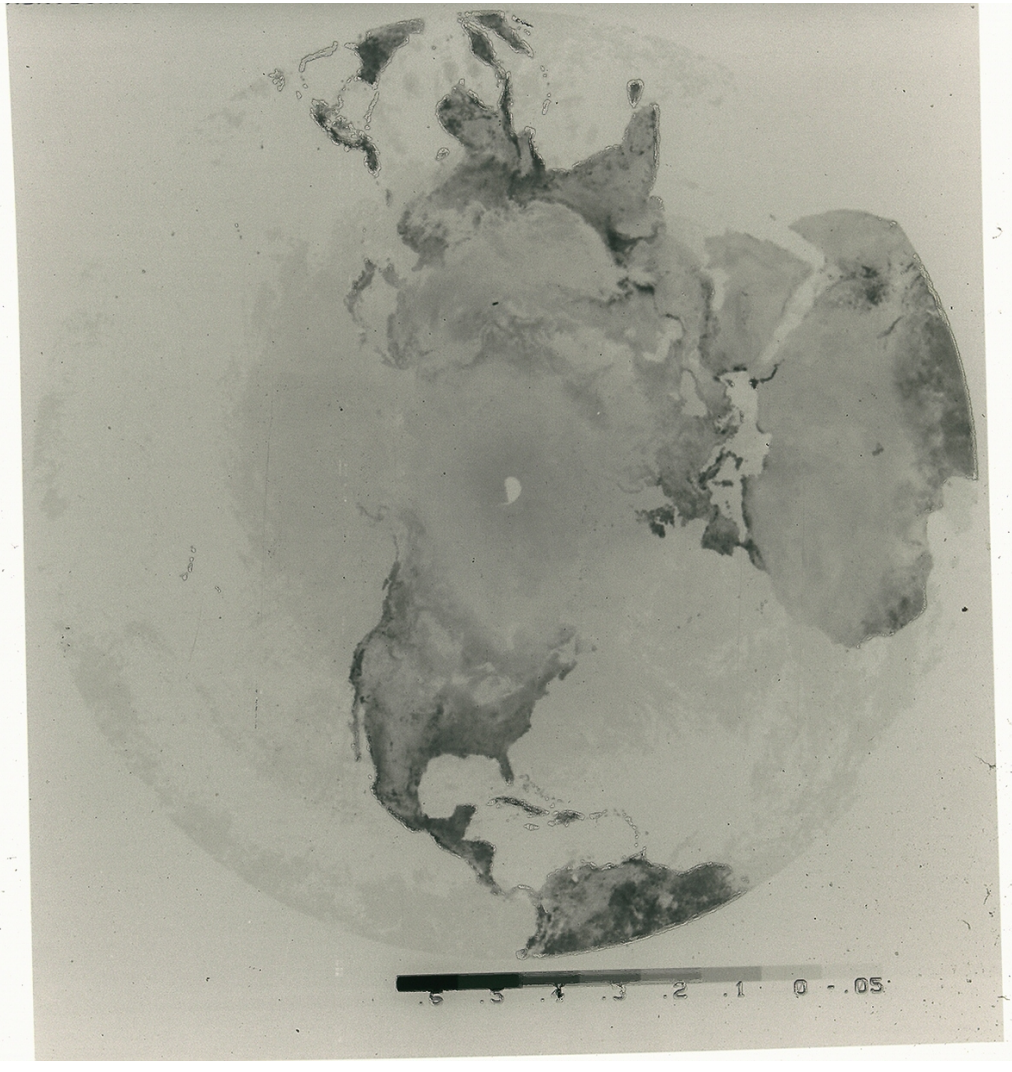


Fig. 11-25

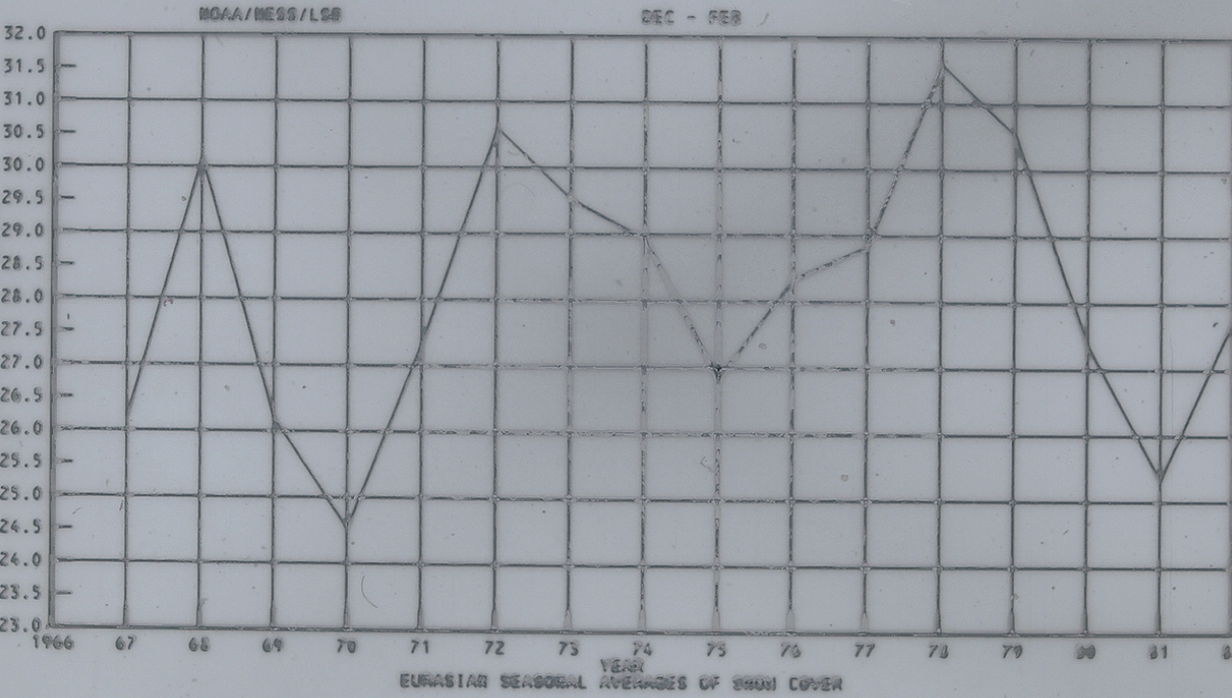
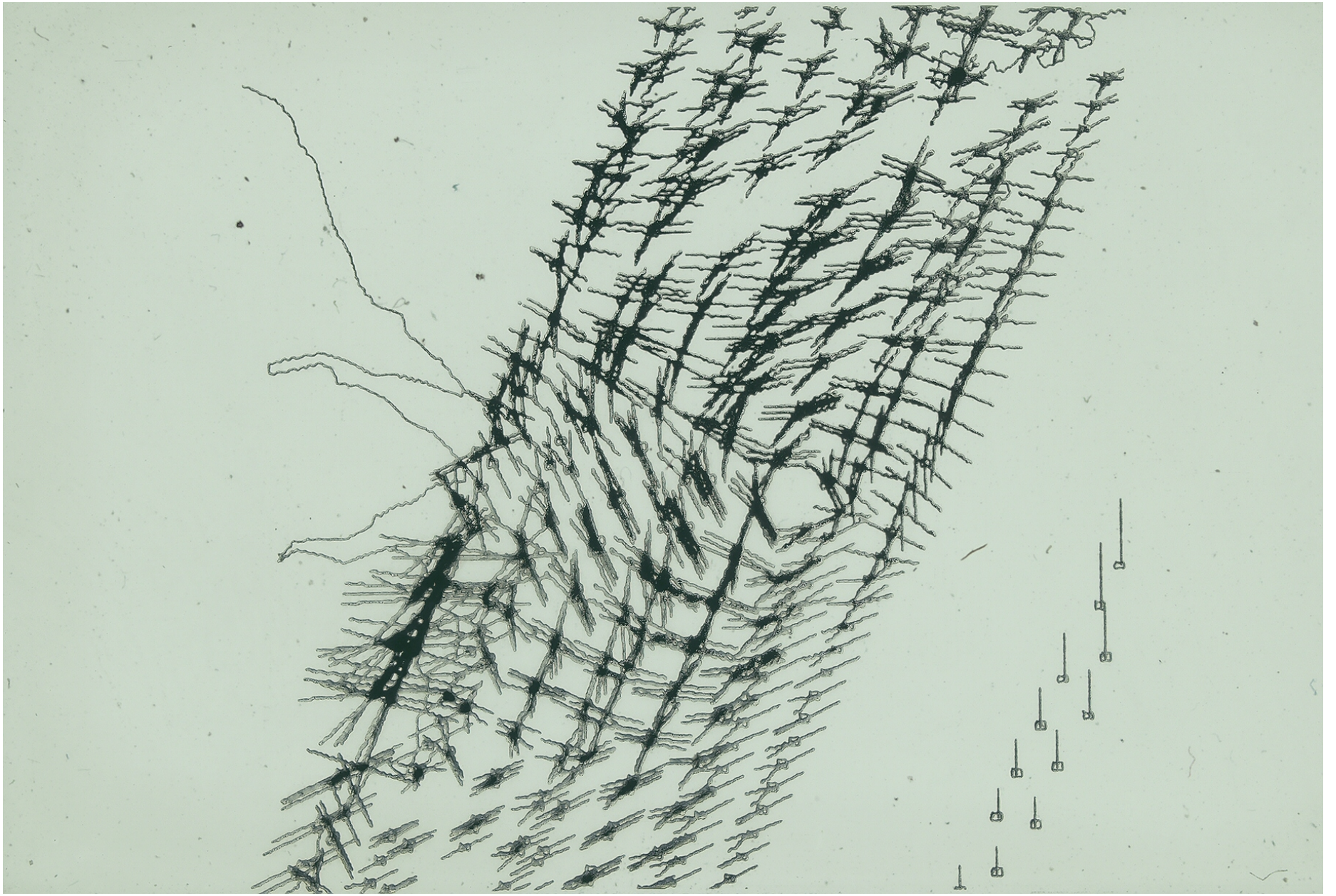

NOAA/NESS/LSB
DEC - FEB
32.0
31.5
31.0
30.5
30.0
29.5
29.0
28.5
28.0
27.5
27.0
26.5
26.0
25.5
25.0
24.5
24.0
23.5
23.0
1966
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
YEAR
EURASIAN SEASONAL AVERAGES OF SNOW COVER

Fig. 13-10 Typhoon Wendy, E. China Sea, July 30, 1978



• Slide (Fig 13-10)

3. Example of wind vectors over the China Sea 30 July 1978, showing Typhoon Wendy.
   - Direction ambiguity; up to 4 vectors at each point.
   - Length of line proportional to speed. Maximum = 35 mps.

D. Potential for ocean currents

1. Measure with precision altimeter; the example I will show is from SEASAT, where altimeter had a precision $\sigma = 8$ cm. (Absolute accuracy dependent on accuracy with which the orbit and the earth's mean geoid are known.)

• Slide (Fig. 13-12):

2. Example shows section of one orbit, altimeter profile.
   a. Effect of bottom topography: Puerto Rico trench - Continental rise.
   b. Effect of currents: Gulf stream; warm core eddy

3. Proposed TOPEX (+ ERS-1) for altimeter + spacecraft designed especially for ocean circulation measurement + scatterometer for surface winds.
   - World Ocean Circulation Experiment (WOCE), an experiment under the WCRP.

SLIDE OFF

VII. OUTLOOK FOR OPERATIONAL METSATS.

A. Polar orbiter, Advanced TIROS N.

• Vugraph (Fig. 3-6)

1. NOAA 8 is first of the Advanced TIROS N design, enlarged to carry more systems (SAR, SBUV, ERBE)
2. Point out sensors to be carried on each.
3. Question of use of NOAA D, last of original design. (NROSS?)

Fig. 13-12 Seasat Altimeter Orbit Cross-Section, July 10, 1978

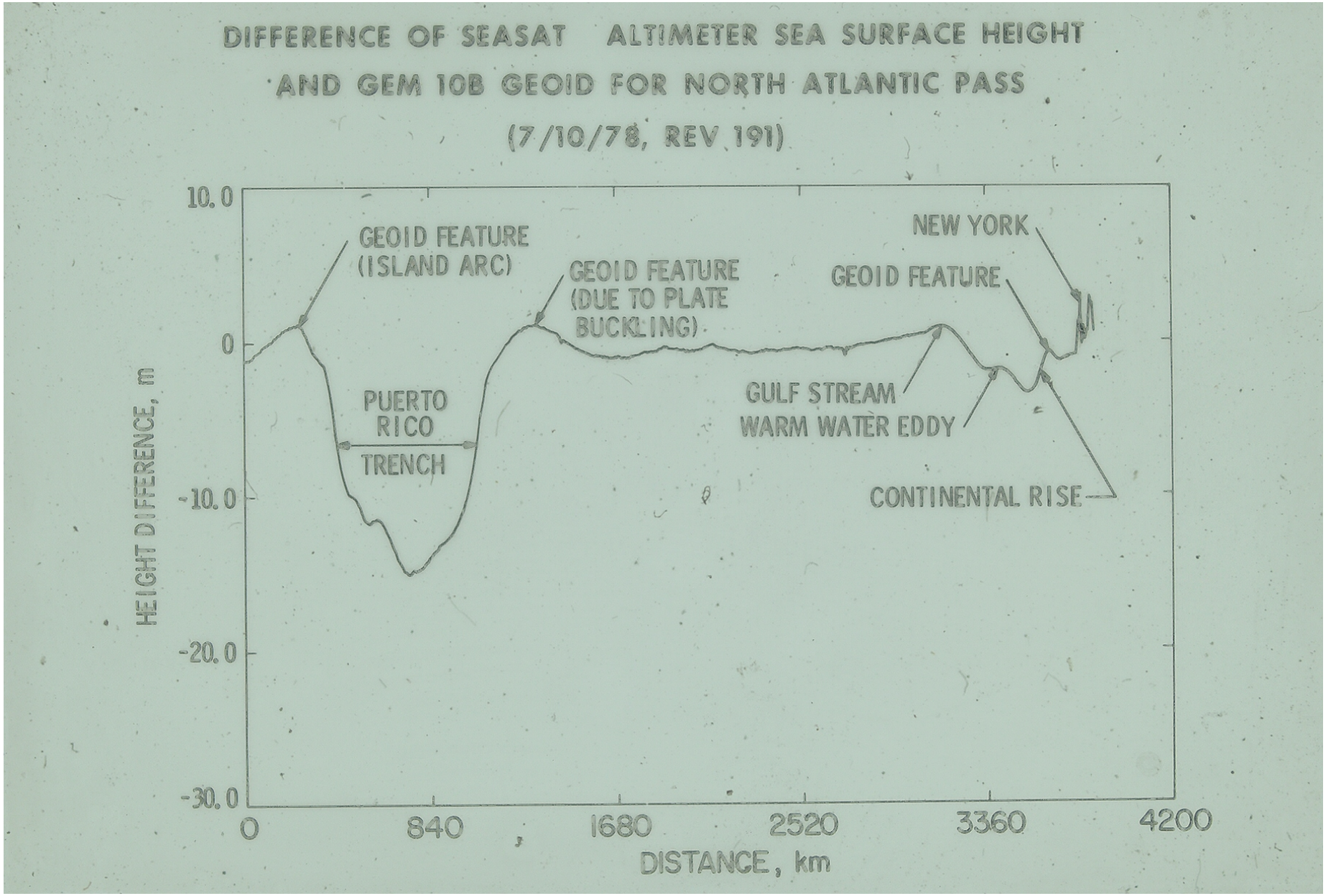


Fig. 3-6

# INSTRUMENTS ON NOAA S/C

| SPACE-CRAFT | LAUNCH DATE | TIME OF DAY | AVHRR CHAN. | HIRS | MSU | SSU | SEM | DCS | SAR | SBUV | ERBE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NOAA 6 | 6-79 | AM | 4 | x | x | x | x | x | | | |
| NOAA 7 | 6-81 | PM | 5 | x | x | x | x | x | | | |
| NOAA 8 | 3-83 | AM | 4 | x | x | x | x | x | x | | |
| NOAA F | 9-84* | PM | 5 | x | x | x | x | x | x | x | x |
| NOAA G | 3-85* | AM | 4 | x | x | x | (3) | x | x | (4) | x |
| NOAA H | 9-86* | PM | 5 | x | x | x | x | x | | x | |
| NOAA I | 3-87* | AM | 5 | x | x | (2) | (3) | x | x | | |
| NOAA J | 9-88* | PM | 5 | x | x | x | x | x | x | x | |
| ? NOAA D | (1) | | 4 | x | x | x | x | x | | | |

(1) NOAA D will be used if launch needed before NOAA F, or converted to an ocean satellite, or used later.
(2) One satellite will fly without an SSU.
(3) Two satellites will fly without an SEM.
(4) SBUV will fly only on afternoon satellites.
* Planning dates; will launch when needed.

Fig. 3-6

B. "NOAA - NEXT"

1. Continue to use Advanced TIROS-N S/C.
2. Replace the MSU and SSU with the AMSU (Advanced Microwave Sounding Unit); retain HIRS.
   a. Better coverage in cloudy areas over oceans.
   b. Improved vertical resolution.
   c. Nadir resolution: Temp ≐ 40 km; $H_2O$ ≐ 12 km.
   d. Useful humidity data.
3. Comparison of HIRS and AMSU weighting functions for temperature:

- Vu-graph (Fig. 9-6): HIRS } show individually + overlay.
- Vu-graph (Fig. 9-7): AMSU }
- Vu-graph (Fig. 9-8): AMSU $H_2O$ weighting functions.

C. Current GOES System.

1. All available spacecraft have been launched; GOES 6 (west) launched on 28 April 1983.
2. Two more GOES being built for delivery in 1986.
3. NOAA moving toward operational use of GOES VAS soundings; need additional ground equipment.

D. Other geostationary satellites:

1. Europe now committed to continuation of Meteosat system. Only minor changes to communications system.
2. Japan plans to continue GMS; I know of no changes planned.
3. Insat-B working well. India planning next procurement of spacecraft.

Fig. 9-6

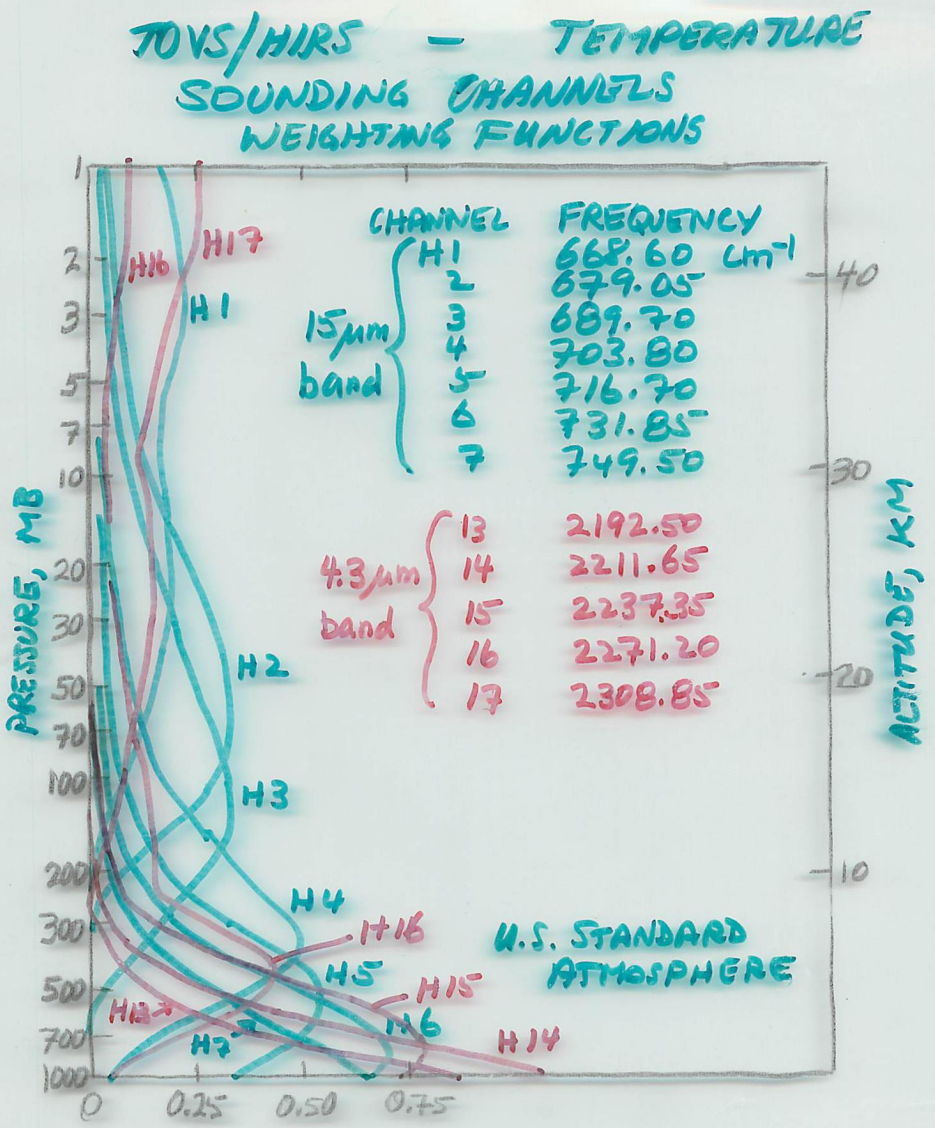



Figure 9-6

Vu-Graphs 9-7 and 9-8 Overlays

MISSING

E. "GOES-NEXT"

1. Specifications have been given to NASA; first delivery about 1989.
2. Considerable improvement over current GOES proposed; dependent on cost proposals. Summary of specs:

- Vu-graph (Fig. 5-1):

3. - Note accuracy & speed of image location.
   - Simultaneous sounding and imaging.

- Vu-graph (Fig. 5-2):

4: Imager very similar to AVHRR, except IR resolution (but that improved by factor of 2 over GOES VAS/VISSR). High precision.

- Vu-graph (Fig. 5-3):

5. Sounder much better than VAS:
   - More channels giving better vertical resolution.
   - Faster for more frequent soundings (and full time)
   - Twice the ~~spatial~~ horizontal resolution

Fig. 5-1

# GOES-NEXT REQUIREMENTS

## SPACECRAFT

- FLEXIBLE DESIGN - ABLE TO FLY A FUTURE SENSOR SYSTEM
- USE CURRENT GOES FREQUENCIES, IF POSSIBLE.
- MAINTAIN ORBIT INCLINATION WITHIN 0.1° OF EQUATOR DURING SATELLITE LIFE.
- MEANS TO DETERMINE ORBIT AND ATTITUDE TO LOCATE IMAGES WITHIN 2 KM WITHIN 3 MINUTES OF INITIATION OF IMAGE ACQUISITION.
- SYSTEM MUST BE HIGHLY RELIABLE, SECURE, FLEXIBLE, NOT SUBJECT TO DISTURBANCES THAT RESULT IN LOSS OF DATA, AND PROVIDE AN ECONOMICAL AND STABLE PLATFORM WITH RELIABLE SERVICE AT LEAST COST ON A PER YEAR BASIS.
- LAUNCH WILL BE BY SPACE TRANSPORTATION SYSTEM ("SHUTTLE").

## DATA COLLECTION SYSTEM — No Change

WEFAX (LR-FAX): — No change in frequency or format, but provide dedicated, full time service.

(*) SIMULTANEOUS SOUNDINGS AND IMAGING

Figure 5-1

# GOES-NEXT (CONTINUED) -2-

## IMAGING SENSOR - 5 CHANNELS

| CHANNEL | SPECTRAL INTERVAL | RESOLUTION | NEΔT | DIGITAL PRECISION |
|---|---|---|---|---|
| 1 | 0.55-0.75 μm | 1 KM | * | 6 BIT |
| 2 | 3.80-4.00 | 4 KM | 1.4° @ 300K | 10 |
| * 3 | 6.50-7.00 | 8 | 1.0 @ 230K | 10 |
| 4 | 10.20-11.20 | 4 | {0.35 @ 300K, 1.4 @ 200K} | 10 |
| 5 | 11.50-12.50 | 4 | 0.35 @ 300K | 10 |

* 1 to 1.5 SIGNAL TO NOISE AT ALBEDO OF 0.5%

- TIMELINESS:
  - FULL 5-CHANNEL IMAGE WITHIN 60° GREAT CIRCLE ARC OF SUB POINT IN 20 MINUTES OR LESS.
  - LIMITED AREAS IMAGED QUICKER IN PROPORTION TO REDUCTION IN AREA COVERED. (E.g. 50°N TO 25°N IN 4-5 MINUTES)
  - * DATA TO LOCATE EACH IMAGE AVAILABLE TO THE END PRODUCT USER WITHIN 3 MINUTES OF INITIATION OF IMAGE ACQUISITION.
- EARTH LOCATION ACCURACIES:
  - COREGISTER CENTERS OF TWO SUCCESSIVE IMAGES: ±2 KM (GOAL = ±1 KM)
  - LOCATE IMAGE ON EARTH GRID TO: ±2 KM (OPTION ±4 KM IF SIGNIFICANTLY CHEAPER)
  - ALIGNMENT OF ALL IR CHANNELS MUST BE WITHIN ONE TENTH OF THE FIELD-OF-VIEW OF EACH (11 microradians).

Figure 5-2

Fig. 5-3

# GOES-NEXT - (CONTINUED) -3-

## SOUNDING SENSOR - MINIMUM OF 14 CHANNELS

| CHANNEL | WAVE-LENGTH | WAVE-NUMBER | BAND-WIDTH | NOISE EQUIVALENT NOISE INCREMENT (NE ΔN) |
|---|---|---|---|---|
| 1 | 14.73 μm | 679 $cm^{-1}$ | 10 $cm^{-1}$ | .87 * |
| 2 | 14.47 | 691 | 12 | .67 |
| 3 | 14.29 | 700 | 10 | .72 |
| 4 | 14.08 | 710 | 10 | .70 |
| 5 | 13.61 | 735 | 13 | .56 |
| 6 | 13.37 | 748 | 16 | .44 |
| 7 | 12.71 | 787 | 20 | .38 |
| 8 | 11.21 | 892 | 50 | .16 |
| 9 | 7.33 | 1365 | 50 | .18 |
| 10 | 6.82 | 1467 | 140 | .074 |
| 11 | 4.519 | 2213 | 35 | .0086 |
| 12 | 3.968 | 2520 | 100 | .0033 |
| 13 | 3.744 | 2671 | 100 | .0036 |
| 14 | 0.696 | 14,367 | 1000 | 0.1% ALBEDO |

* $mW/(m^2\,sr\,cm^{-1})$

- SOUNDING ACCURACY: AT LEAST EQUAL TO CURRENT NOAA TOVS SOUNDINGS.
- * RESOLUTION: FOV OF EACH CHANNEL = 8 X 8 KM AT NADIR (192 μ radians)
  SOUNDINGS PROCESSED FOR 60 X 60 KM AREA
- COVERAGE: UP TO 60° GREAT CIRCLE ARC FROM NADIR.
- * TIMELINESS: ANY 3000 X 3000 KM AREA WITHIN 40 MINUTES.
  - SMALLER AREAS, PROPORTIONATELY QUICKER.
- CHANNEL REGISTRATION: EACH CHANNEL MUST BE, WITHIN ± 2 PERCENT OF ITS FIELD OF VIEW, COINCIDENT WITH FOV OF CHANNEL 8.

Figure 5-3