UPPER AIR WINDS FROM TRACKING THE MOTION OF CLOUDS.

I. Summary of the method

A. Use a sequence of cloud images, usually from two to five, acquired over a short time interval (usually within two hours).

1. Need for great stability from one image to the next in the sequence to assure registry with small error. Spin-stabilized satellite is best.

B. Clouds selected as wind tracers which move with the wind. Requires meteorological knowledge.

C. Movement of selected clouds is measured and the wind speed and direction calculated from these measurements, and satellite and image geometry. (Relative accuracy much more important than absolute accuracy of navigation here.)

D. Assign a pressure or height to the wind vector. This usually is the largest source of error.

II. Problems and limitations

A. Precision of registration of the sequence of images is very important to minimize geometric errors which can affect accuracy of wind estimates.

1. Spinning satellites have the stability necessary.

2. Care required in the telescope line-stepping mechanism: uniformity and reproducibility. (Not too difficult to achieve.)

- If 3-axis stabilized spacecraft is used,

very difficult to achieve the stability (over a period of 1 to 2 hours) which is required. A relative stability is needed from one image to another of about 1 km. on the earth's surface, with the sensor located nearly 36,000 km. away.

- Absolute location in earth coordinates is much less important. Only affects location of wind vector. Meteorologically significant only if off by 20 km or more.

B. Need to pick clouds that are believed to move with the wind is obviously very important.

1. Meteorological knowledge ~~very~~ important in this function, as well as use of most recent weather charts for guidance.

2. Must avoid orographic clouds, such as those affected by differential heating (land or sea breeze situations), mountain wave clouds, etc.
   - NESS does not use low-level clouds over land as tracers at all.
   - Most low-level clouds used are cumulus-congestus over oceans.
   - Most upper-level clouds used are some form of cirrus.
   - Very few clouds picked between these levels

3. Best results would be achieved using the smallest possible cloud elements and shortest time interval. E.g., cumulus-humilus during 10-20 min. interval.

- Dictates highest possible resolution visible images, which would require high sun angle. This limits the time period each day when winds can be obtained.

- Has been done for some specialized research programs but not in routine operations because of:
  - Time limitations using visible images.
  - Analysis and computation time when covering large areas of the earth.

C. Problem of height determination.

Several methods have been used or proposed:

1. Stereo viewing in the overlap area of the images from two adjacent satellites is the best method. Not used operationally because:
   - Limited region in which there is overlap.
   - The increased processing which is required.

   NESS and GSFC collect limited stereo data in support of special research programs.
2. Can visualize use of a laser "radar", but this would be very expensive!
3. Suomi proposes use of VAS channels for "temperature slicing" to estimate altitude of clouds, as viewed in each of the thermal channels.
   - Hasn't yet been demonstrated.
   - Problem of the broad weighting functions of the sounding channels; may not give sufficient vertical discrimination.
4. Estimating height from cloud radiation temperature measured in an infrared window channel.

- This is primary method used operationally today.
- NESS uses technique only for upper level clouds. Tests have shown that it is at least as accurate to assume a pressure height of ~850 mb. ~950 mb. for low-level wind tracers.
- Requires conversion of radiation temperature to sensible temperature; must estimate cloud emissivity. This is greatest source of error in upper level winds today. With large vertical wind sheers, height errors cause significant, and often large errors in wind vector at upper levels. (Most upper level cloud winds are around the 200 to 300 mb. level.)
- To convert sensible temperature to pressure, must use some knowledge of 3 dimensional distribution of atmospheric temperature.
  - NESS uses NMC analyses. (I believe ESA does also.)
  - JMA/MSC originally used climatology, which caused excessive errors in their high level winds. (I understand that they have now changed to the use of current analyses of temperature.)

D. Winds can be obtained only where there are suitable tracers.

1. Because of accuracy requirements, winds

limited to an area within a radius of 50 to 55 degrees of great circle arc around the satellite sub point. Geometric ~~are~~ errors become too large at more oblique angles of view.

2. At any given point, usually only one layer of clouds ~~are~~ is used. Thin cirrus thick enough to be used for upper-level winds usually sufficiently obscures underlying low-level clouds ~~enough~~ to "confuse" the computer processing of low-level winds.

3. Very few mid-level clouds used, because they are usually obscured by higher cloud layers; they don't exist by themselves. Altitude errors also are larger than for cirrus which tends to form beneath the tropopause.

III <u>NESS Operational Method</u>

A. <u>Low-level winds.</u>

1. Initial wind estimates generated automatically by computer.

(a) Four images, each 30 minutes apart, ingested into computer.

(b) Two best images selected by computerized quality control sequence.

(c.) Image fields are registered by prescribed set of landmarks.

(d) Cloud targets objectively selected at approximately 2.5° latitude + longitude intervals.

(e) Displacements calculated by cross-correlation technique between the two image fields.

(f) Output of wind vectors edited objectively by comparison with most recent 850 mb. analysis.

2. Results are displayed on an interactive processor for evaluation and final editing by a meteorologist.

3. Edited winds are formatted by computer for teletypewriter transmission using appropriate WMO code.
   - Note that all calculations, conversions, etc. are done by the computer. The human is called upon to exercise professional meteorological judgement.

B. Upper-level winds.

Originally the "Man-Machine Interactive Processing System" or "MMIPS" was used. Functionally, the steps used with the MMIPS are the same as now, except that the film loops have been replaced by images in electronic form using an interactive processor. Following are the steps with MMIPS:

1. Movie loop of images used in a movie projector to project on a "digitizing board". The analyst selects suitable cloud targets for use by viewing the image sequence on the board. For those selected, a cursor is moved by the analyst to the beginning and end points; the coordinates of each pair of points are automatically entered into a computer for calculation.

[NOTE: Movie loop based on sequence of 5 GOES images (two hours) registered manually by landmarks. First and last frames are repeated 20 times; intervening images twice each.]

2. An images in the sequence in electronic form is viewed on the TV screen of MMIPS (an early form of interactive processor) to estimate cloud emissivity and display the computer calculated sensible temperature of the cloud top (based on the measured radiation temperature and estimated emissivity). This information is transferred to the main computer, along with the cloud displacements measured earlier.
3. Computer processes wind vectors from cloud displacement data and satellite-image geometry. (Digi-board also used to read landmark locations in each sequence.) The computer also computes the estimated heights by reference to the latest NMC global analysis of temperature at standard pressure levels, and the temperatures determined on the MMIPS. Objective quality control procedures are used to check the resulting upper level winds with the most recent 500 and 200 mb. analyses.
4. The computer converts the edited output to proper coded teletypewriter form for transmission.

C. Availability of winds

1. NESS calculates winds for the two GOES fields at observing times of 00, 12 and 18 GMT. Available within 3 hours of observation.
2. The winds are transmitted via the GTS of WMO

IV. Examples of wind fields produced from GOES

A. Operational winds, 12 January 1976

→ ✓ 1. Figure 10-1 (slide): low level winds
- A few winds over land – a mistake?
- Compare areas over Pacific without winds with next slide.

→ ✓ 2. Figure 10-2 (slide): upper level winds.
- Pacific coverage prevented tracking lower clouds.
- Notice upper level winds over land.

B. Operational winds, 13 April 1976.

→ ✓ 1. Figure 10-3 (slide): lower level winds
- no winds over land this time!

→ ✓ 2. Figure 10-4 (slide): few places where both levels obtained at same spot.

C. Research winds, 25 May 1980
No operational time constraints.

→ ✓ 1. Figure 10-5 (slide): low level winds.
- Still no winds over land.
- Greater density of winds than operational product.

→ ✓ 2. Figure 10-6 (slide): upper-level winds.
- Some cases where both low and upper level winds obtained at same location.

V. Comparison with rawin observations

Figure 10-7 (slide) A. GOES minus Rawins; winter 78/79 to winter 80/81
Vector difference in knots; note ordinate range = 0-20 kts.

→ ✓ B. Figure 10-8 (slide): GMS minus Rawins.
Ordinate range now 0 - 60 kts! [Problem of altitude determination.]

→ ✓ C. Figure 10-9 (slide): GOES minus Rawin; extended to winter 81/82
Ordinate now meters/sec.

Fig. 10-1 GOES Low Level Winds 1-12-76

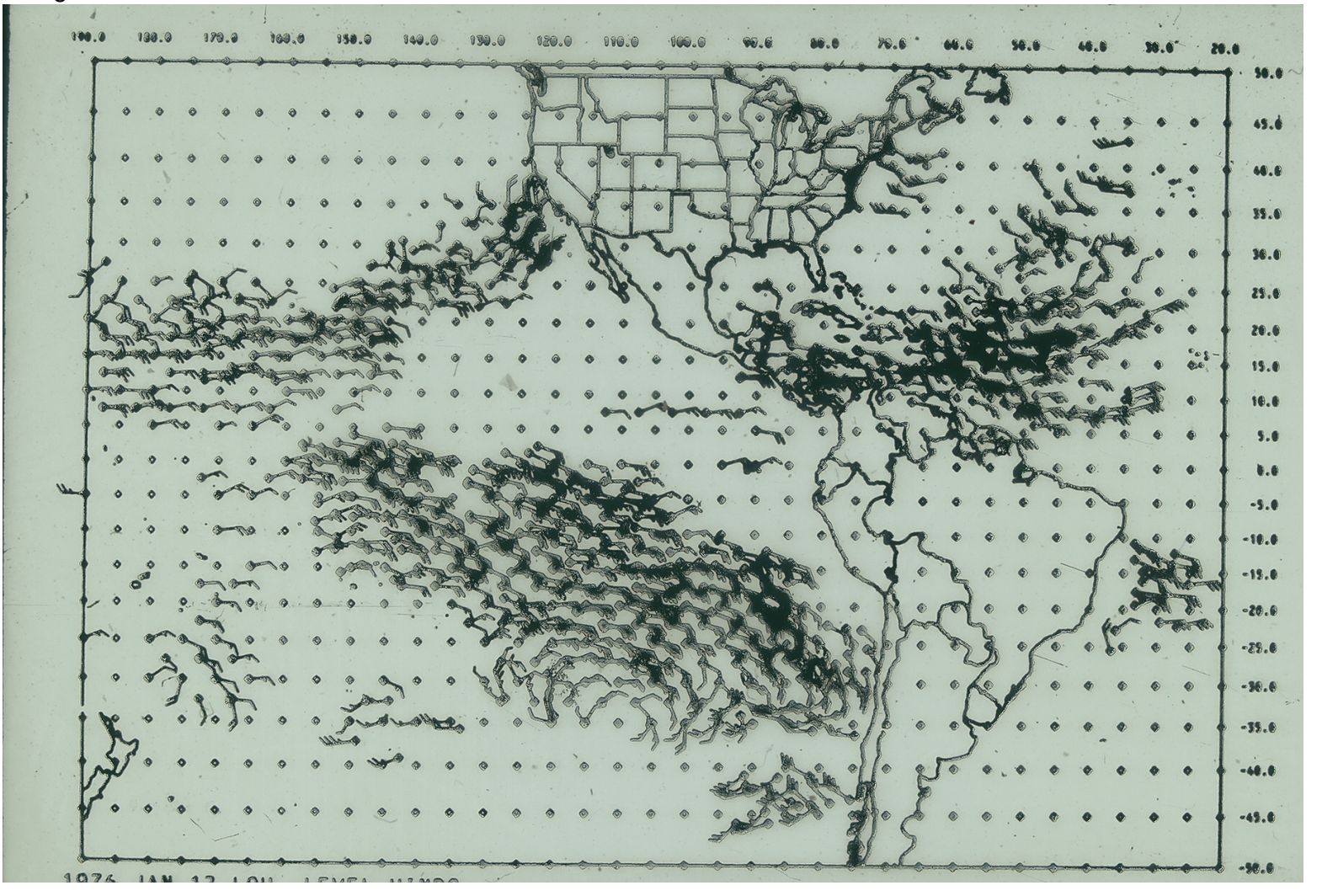


Fig. 10-2 GOES Upper Level Winds

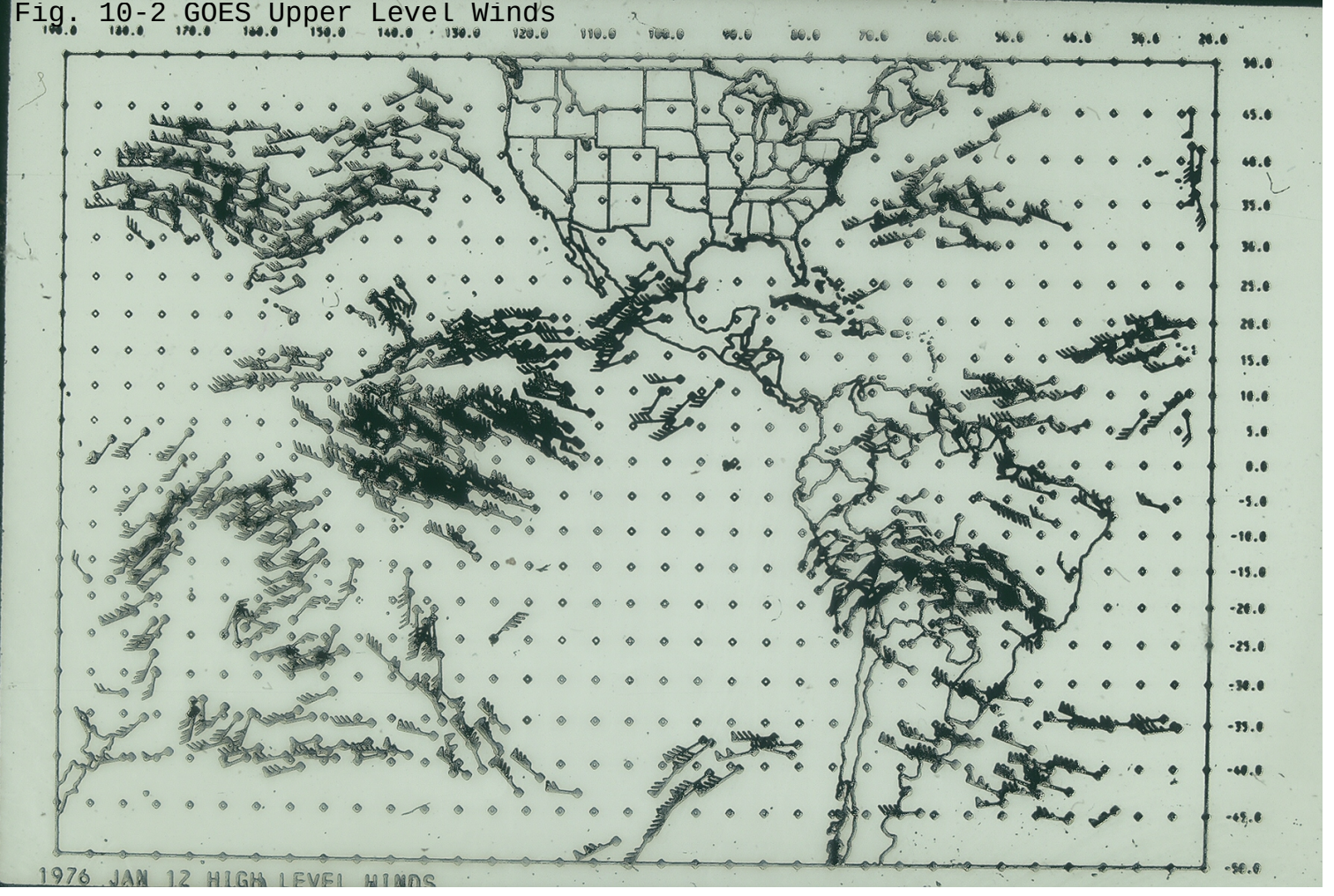


Fig. 10-3 Operational Winds - Lower Level Winds April 13, 1976

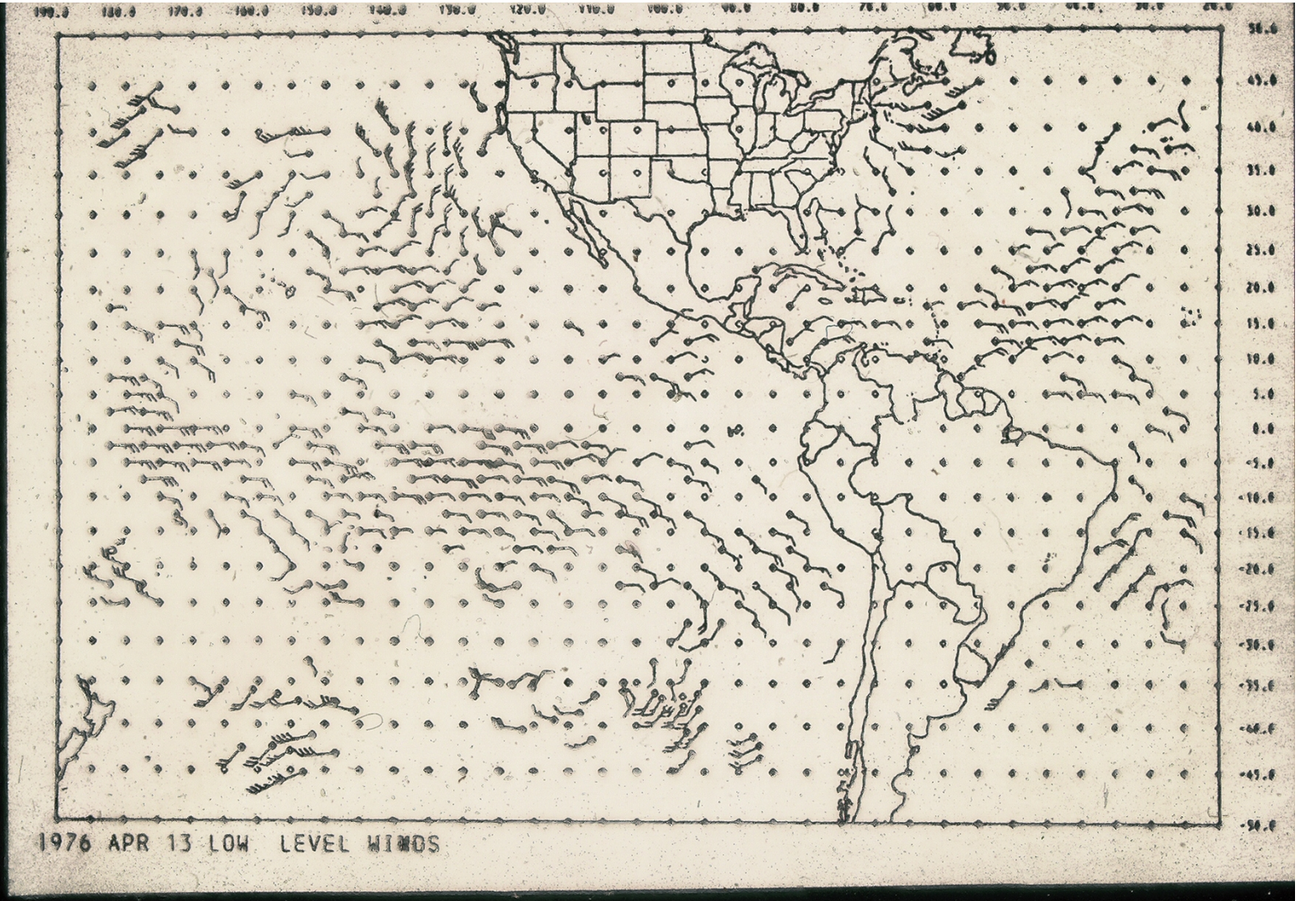


Fig. 10-4 Operational Upper Level Winds 4-13-76

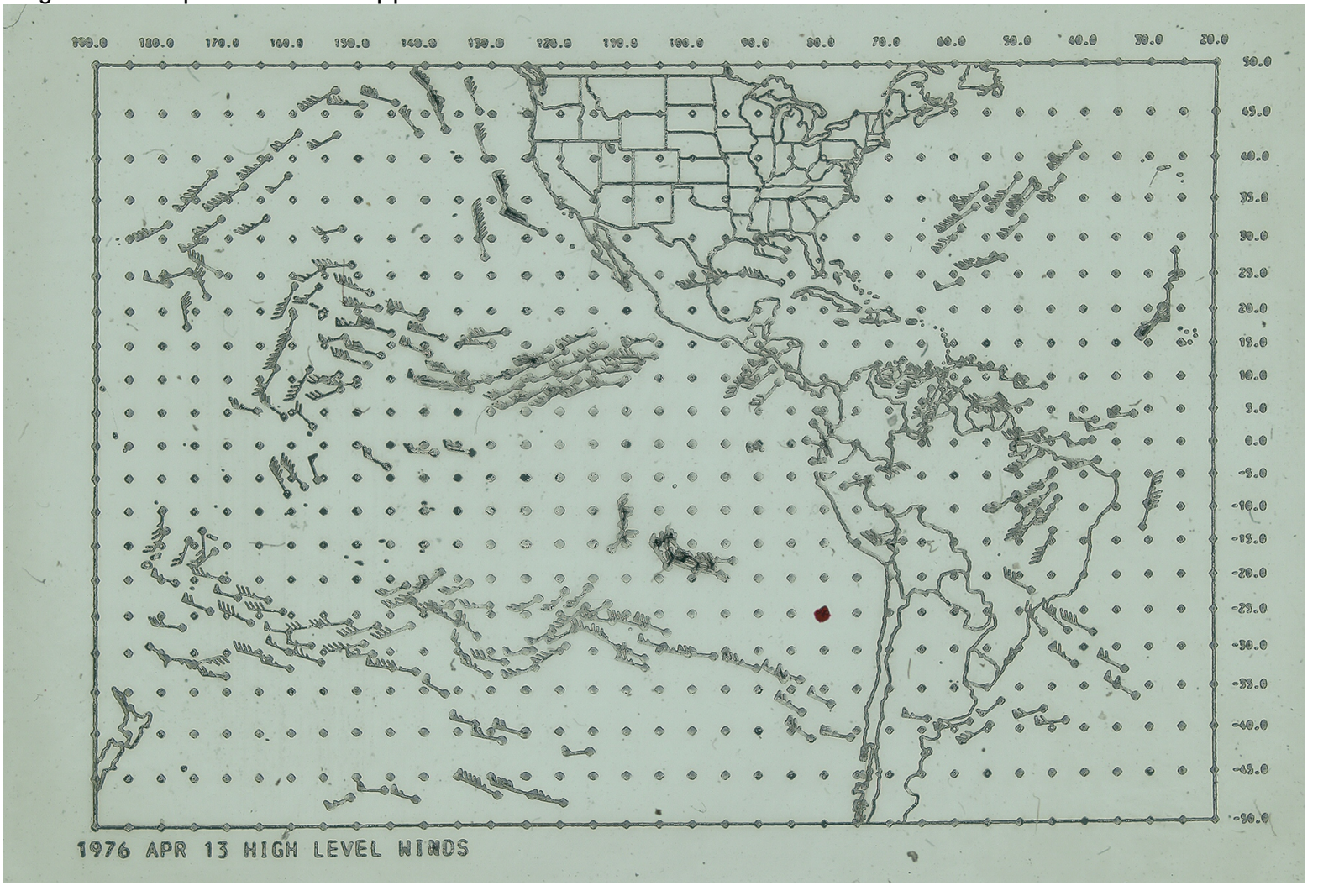


Fig. 10-5 Research Winds Upper Level - May 25, 1980

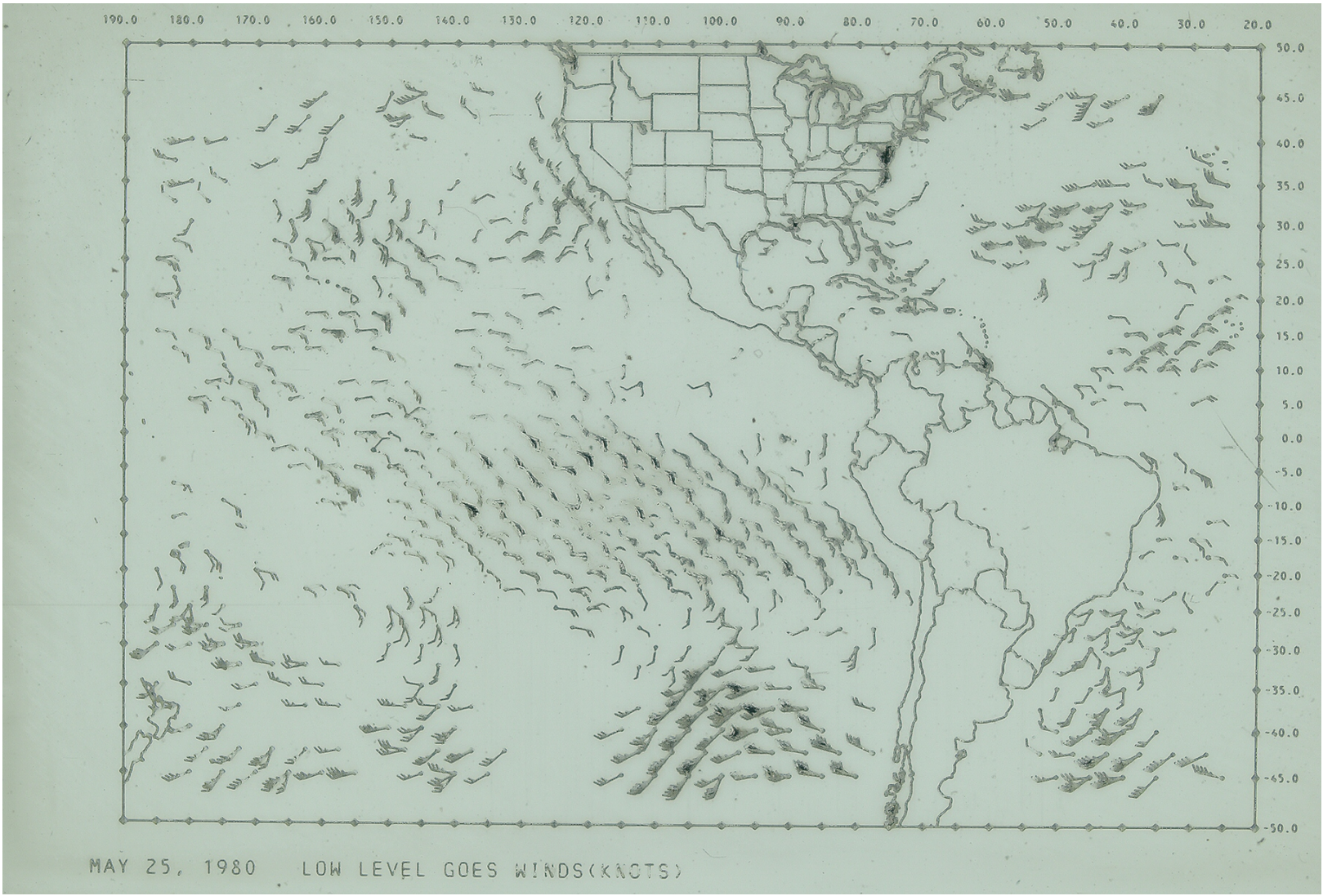


Fig. 10-6 Research Winds Upper Level - May 25, 1980

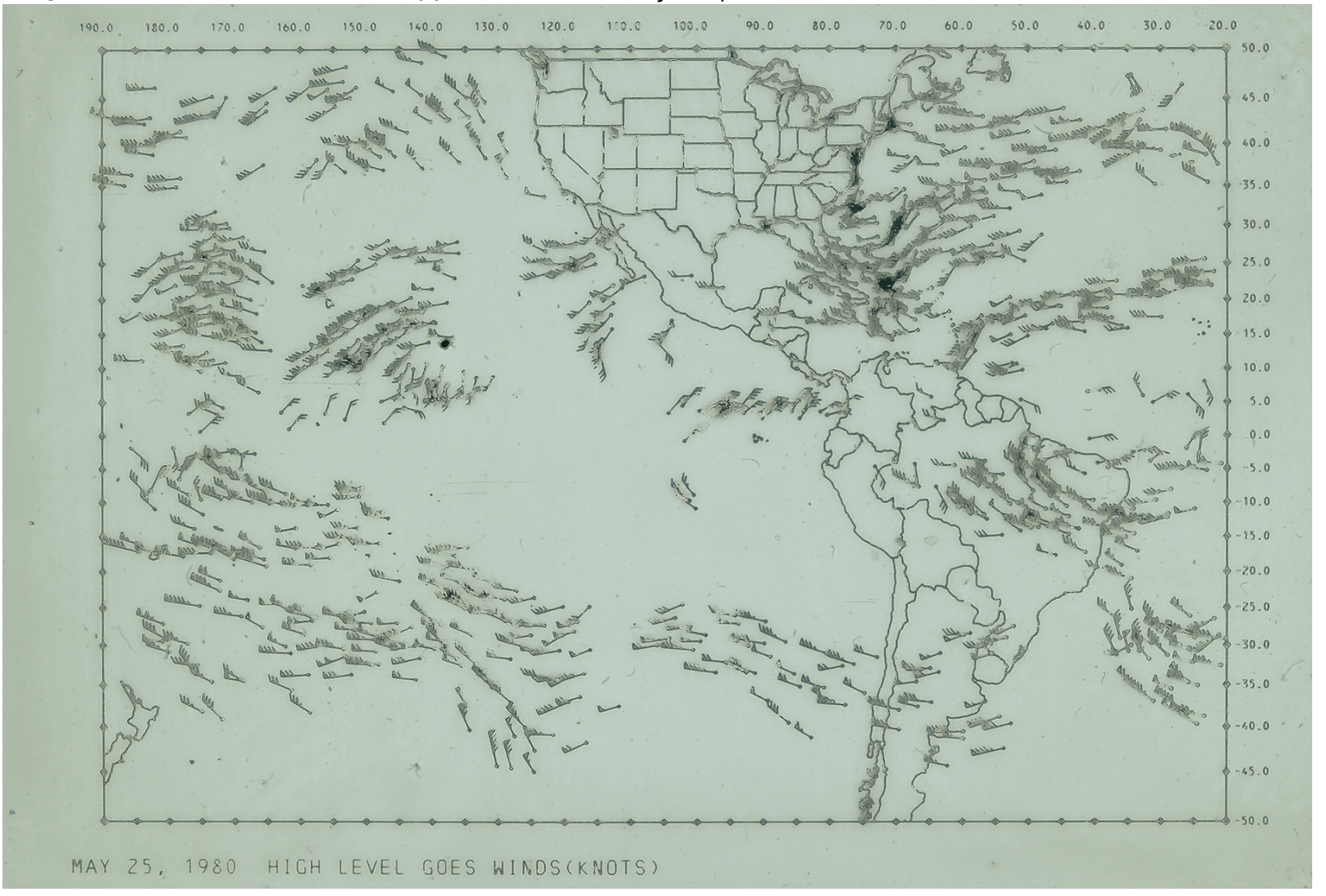
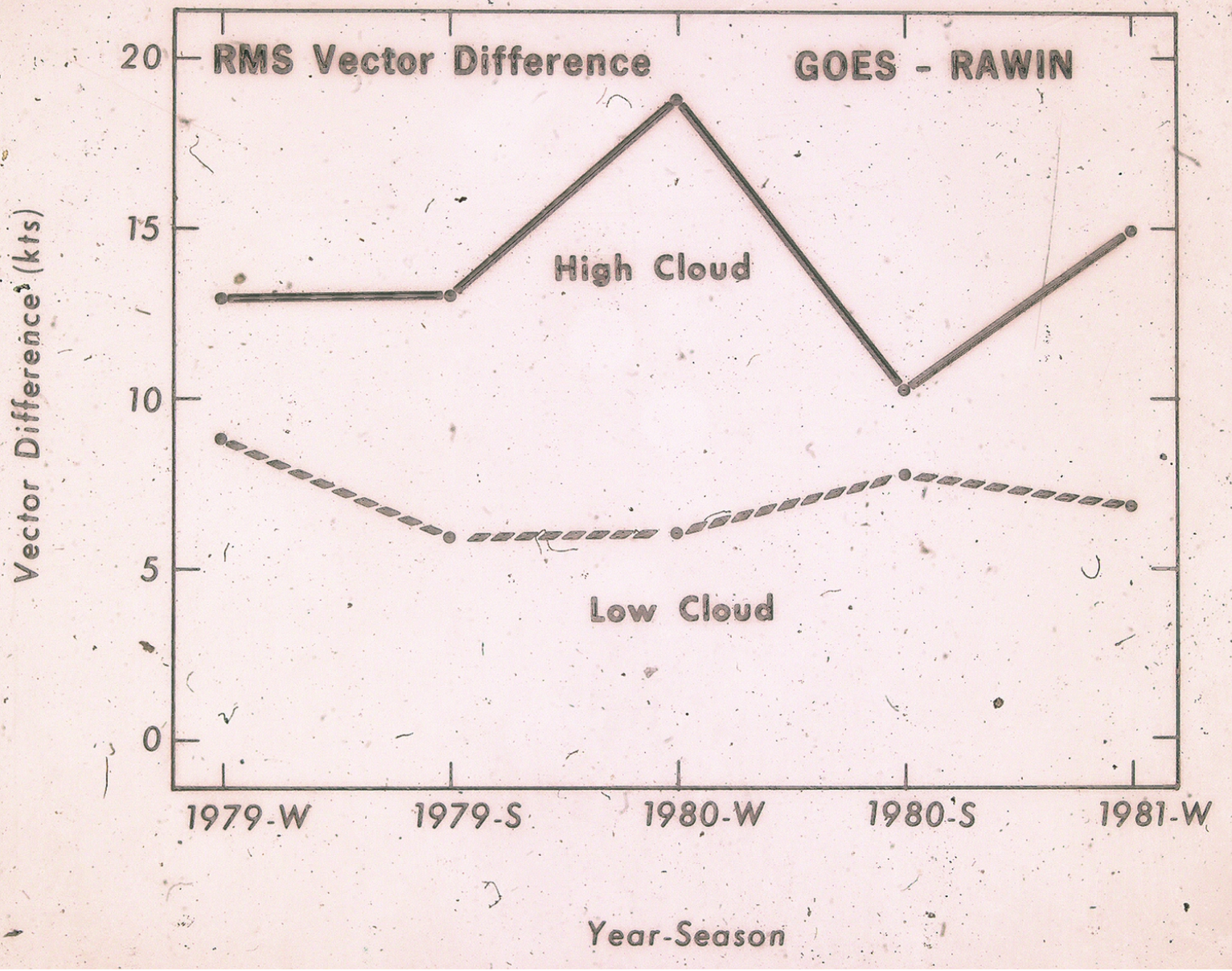


Fig. 10-7 GOES minus Rawins 1979-1981



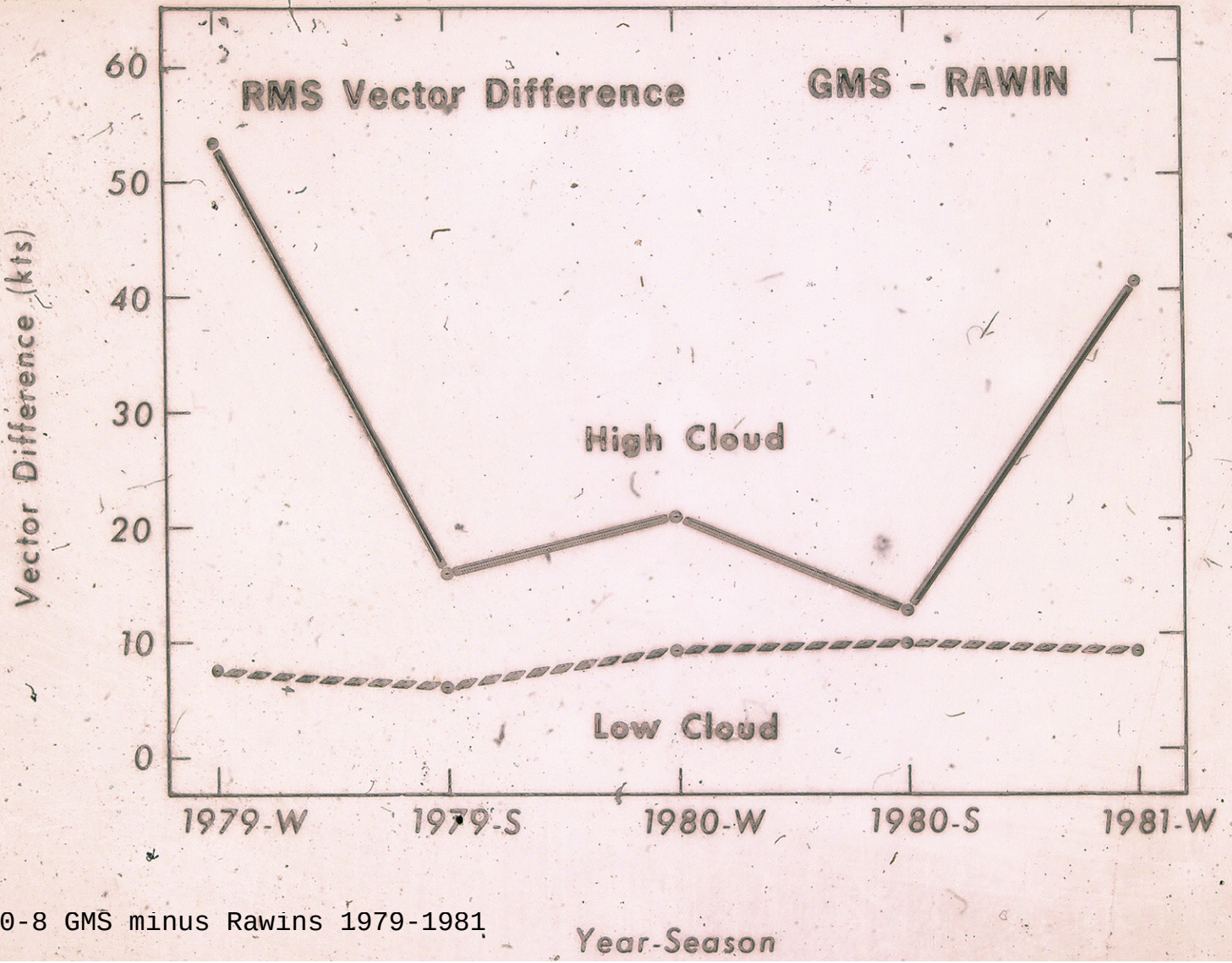
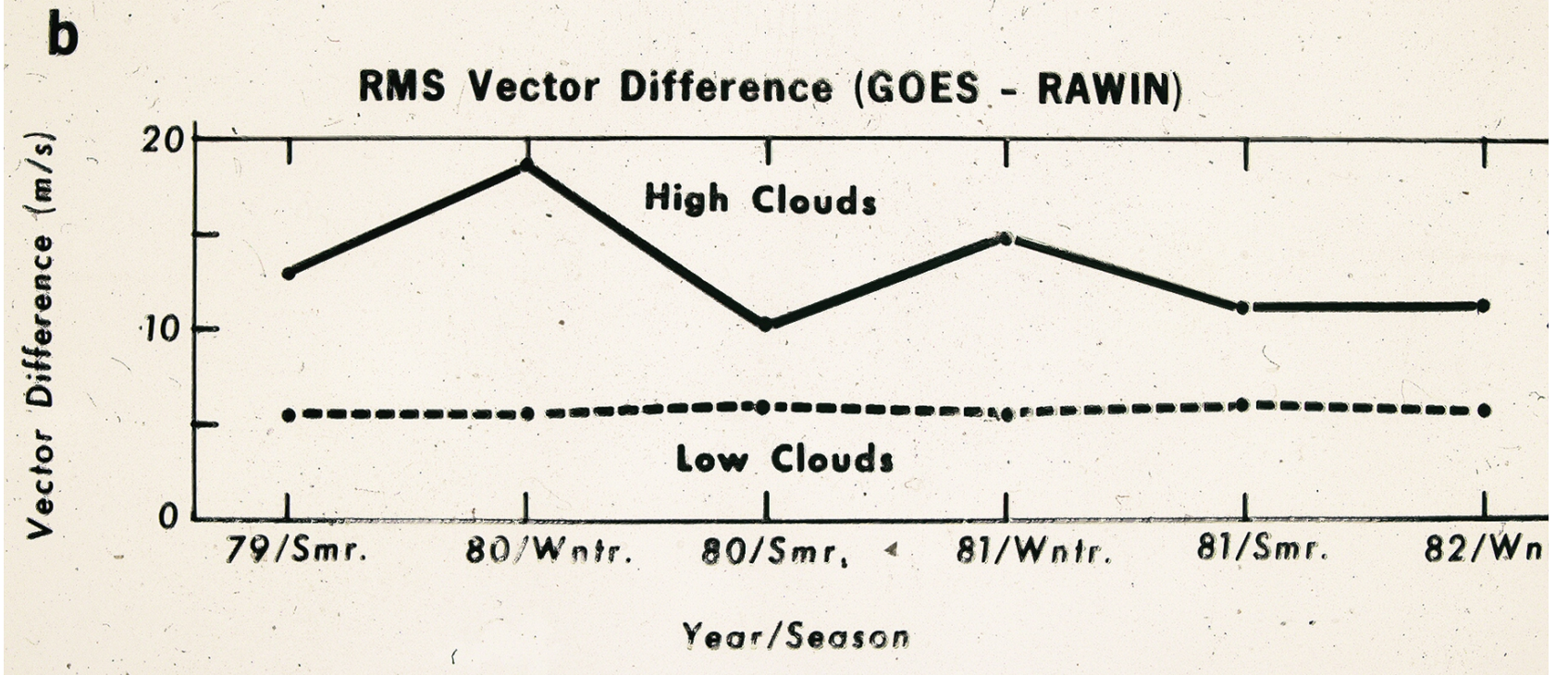


Fig. 10-8 GMS minus Rawins 1979-1981

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



D. No curves for Meteosat, but I understand that they are comparable to GOES.

VI. Uses

A. Primary use is input to numerical weather prediction models.

B. Use in briefing/preparing trans-ocean jet aircraft

C. Potential in mesoscale analysis, especially in conjunction with geostationary satellites not explored.