Global Satellite Cloud Wind Data
(1967 – 2001)

- Coverage is rather good for American sector, 1973 – on.

- ATS-1 was launched Dec 1966. There is a chance to make more winds from the 10-inch pictures.

- These papers have 8 items and 29 pages

Roy Jenne
July 2001
Global Satellite Cloud Wind Data

7 June 2001

Roy Jenne

This bundle of papers has information about satellite cloud wind data. These wind data are typically calculated from 2 or 3 full disk images from Geosynchronous satellites that are separated in time by about 30 minutes. It takes 5 geosynchronous satellites to give good coverage around the whole equator. The first satellite (ATS-1) was launched by the US in Dec 1966. Cloud wind data coverage in the US sector (North and South America) became quite good in 1973, and even better since then. The world has usually had 4 or 5 of these satellites in operation starting in 1979, but the data coverage for the Indian Ocean has often been weak.

Summary: This bundle has about 8 items with 27 pages and 2 pages in the front.

1. Some Tasks That Should Be Done (RJ, July 2001, 1 p)

2. The Availability of Satellite Cloud Wind Data (RJ, 27 Apr 1999, 8 p)

   - The need to save the GOES data archive (RJ, 5 Apr 1999, 1 p)
   - The University of Wisconsin wants to make new cloud winds (RJ, 3 Mar 2000, 1 p)

4. Satellite Cloud Wind Data (RJ, 4 Jun 2001, 3 p)
   - This includes a map of forecast scores from reanalysis (1 p)


6. Climatology from Satellites (Barrett, 1974, book, 3 p here)

7. Cloud wind picture information
   *Handbook of Applied Meteorology, 1985* (2 p here)
   - This has a long data chapter that includes information about archived hard copy pictures in early years.
   - The real question is whether the USA could derive winds from hard copy ATS pictures during 1967 – 1972 (6 years) when our archives of digital data are very weak.

Can the USA derive winds for 1967 – 1972?

8. Symposium on Tropical Meteorology, June 1970 (7 p here)
   - This has a paper about calculating cloud winds from the ATS satellite data.
Some Tasks that Should Be Done

1. Be sure that the GOES data at University of Wisconsin are copied to new tapes (1978 – 2001)
   a. Move copies of primary GOES data to two other archives.

2. Europe (ESA) is calculating new winds for early years
   • Make these new winds available for the global dataset of satellite cloud wind data.

3. More cloud winds for 1967 – 72 would help reanalysis projects and climate research
   • Can more winds be calculated from old ATS pictures? At what cost?

4. Keep secure archives of all global cloud wind data in at least three places.

Roy Jenne
NCAR
July 2001
The Availability of Satellite Cloud Wind Data

Roy Jenne
27 Apr 1999


Table 1 shows the availability of cloud wind data on the real time tapes from NCEP during 1973 – 1998 (26 years). The counts are given for each 10-day period and for each 20 degrees of longitude centered on 0E, 20E, 40E, etc.

2. Geographic Information to Help View Table 1.

<table>
<thead>
<tr>
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<tbody>
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<td>73° W</td>
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<tr>
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<td>113–153° E</td>
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<tr>
<td>18° W–52° E</td>
</tr>
<tr>
<td>18° E</td>
</tr>
</tbody>
</table>

3. Comments About Data Coverage of Satwinds in Table 1, 1973 – 98

a. Data are available from the European sector (Meteosat) satellites during 1979, and then there is a data gap until Q3 of 1982. This is also a gap for African coverage. We hope that this gap can be filled in by the reprocessing of European Meteosat data (to be done during 1998 – 2001).

b. The data from the Japanese satellite, about 140°E, is almost continuous from Q4 1978 to the present. But typical data counts in a 20° band at 140°E were 150 reports per day during 1979 – 1984 increasing to 500 reports/day during 1988 – 1998 (Table 1).

   - Note below that the basic archive (from Japan) of Japanese GMS cloud winds was also used for reanalysis for mid-1978 – 1991.

c. The US GOES satellites mainly gave data for about 10 – 120°W during 1973 – Q1 1975; then the band of coverage became broader (about 10°W – 180°W during 1976 – 78, and later).

d. There is a little data for 40 – 180°E during 1973 – 74. These data have a different category in the format (called "cloud" instead of "ATS"), and they only give high-level winds (not low or mid-level). We are quite sure that these are "blow-off winds" estimated from still pictures.
(from polar orbiters) of the winds blowing off of the tops of cumulonimbus clouds. These are probably located at the level of the tropopause.

c. There is a gap of wind coverage over the Indian Ocean in Table 1 for FGGE (1979). The US had a satellite over the Indian Ocean during 1979. The cloud winds were prepared in delayed time, and they got into the FGGE dataset which was used for reanalysis. The primary data from this satellite for 1979 is at the University of Wisconsin.

4. The Data on the NCEP Observation Tapes

Consider a sample of data from the US GOES satellites in July 1973. There were low-level winds, high-level, and some at mid-levels. The data are on the tapes in a raob format structure. The data are given on the tapes at pressure levels. One low-level wind report has the same data given at each of two pressures; one high-level report has three levels as follows:

<table>
<thead>
<tr>
<th>Cloud Wind</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>At a low level</td>
<td>The same data is always at 2 levels (850, 700 mb)</td>
</tr>
<tr>
<td>Mid-level</td>
<td>Data at one level (500 mb)</td>
</tr>
<tr>
<td>High-level</td>
<td>Same data is always at 3 levels (300, 250, 200 mb)</td>
</tr>
</tbody>
</table>

This practice of assigning the same data to 2 or 3 levels was probably done so that the analysis programs would give sufficient weight to the data in the vertical structure of the atmosphere.

Data for Feb 1975 – on:
The coding of the cloud winds from NCEP changes on 1 Feb 1975. From that date on, they are given at a single level and they are put into the format structure for aircraft reports. It appears that the height of low-level winds is always at 988 meters. The height of upper cloud winds is more variable, but 10,626 meters (34,853 ft) seems to be a common number. During Feb 1995, there are still some cloud winds that follow the previous practice (of pressure levels).

The cloud-wind data files for reanalysis:
The original NCEP data always has had a data type code for cloud winds, regardless of the data report format. In early years, the cloud winds were included in the NCEP file for “bogus” data. Bogus data meant data created by people to help the analyses. The NCEP cloud wind data files for reanalysis have all of the cloud wind data regardless of which original files they were in. The original formats have been preserved, but with a reanalysis header on each report.

5. Cloud Winds for US GOES, from the Permanent Archive Tape

This tape, for 1974 – on, gives cloud wind data for GOES satellites. The data has winds and sometimes temperature is included. There is just one level per report. A pressure is given for the height of the clouds; a height is not given. The pressures appear to be general numbers such as 900 mb, rather than precise numbers.

Figure 4 is a plot of the average number of Satwind reports each day from the NCEP tapes for 1962 – 1986.

7. The Basic Archive of GMS Winds from Japan (1978 – 91)

The complete Japanese archive of cloud winds from GMS satellites was sent to both NCEP and ECMWF; it was probably sent about 1993. It covers the years mid-1978 – 1991. This probably added some data to what was available on the real-time tapes from NCEP.


The original raw Meteosat-1 digital image data at full resolution, in three spectral channels, have been archived at half-hourly intervals in Europe. The data are a visible channel (2.5 Km), window IR (5 Km), and water vapor (5 Km). I hope that this data can be reprocessed to give good cloud winds.

9. A Project in Europe to Reprocess Meteosat Data

Attachment 1 is a sheet that describes the European progress in moving old Meteosat data to new tapes. Then they will calculate new cloud winds using modern methods.

10. The ATS-1 Satellite (Launched Dec 1966), Pictures for Jan 1967 – On

ATS-1 was launched in Dec 1966. There were half-hourly archives of data for Jan 1967 – Nov 1972 (see Jenne & McKee, 1985). I think that the digital data was lost, but there are 10-inch by 10-inch black and white images each half-hour for IR and Vis, for the full disk, and other sectors. I assume that these images still exist in 1999. Some film loops were also made. In 1985 we wrote that the negatives for ATS-1 and ATS-3 are from Jan 1, 1967 through Sep 2, 1974, and that similar data from SMS/GOES are available from June 27, 1974 to at least 1985. (See Handbook of Applied Meteorology, 1985, p 1237.)

11. Still To Do

- Compare counts of GOES winds on the NCEP tapes with counts on the delayed archive for 1974 – on.
- Include NCEP counts for the 1962 – 72 period.
### Satellite Cloud Wind Data

(10-day counts in 20-degree long. bands)

<table>
<thead>
<tr>
<th>OE</th>
<th>0E</th>
<th>2E</th>
<th>4E</th>
<th>6E</th>
<th>8E</th>
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Figure 6. Winds derived from cloud motion in satellite images. These counts are of data used in NCEP operations. Another text at NCAR has counts through 1998. Reanalysis also used the FGGE datasets (1979) and that includes coverage of cloud winds over the Indian Ocean. We hope to improve data coverage from Meteosat in the early 1980s, for the Europe – Africa sector.
Table 1, cont.

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</tbody>
</table>

This table was prepared by Gregg Walters at NCAR in Apr 1999.

Using UNIX script “baseball/bin/roystwndsql and FRONTAR program *baseball/bin/roystwsql

These cloud wind data are from the NCEP real-time data tape.
Figure 5. The number of aircraft and satwind observations used for the original operational analyses at NCEP are given. Since 1986 the number of aircraft reports has increased to 14,420 in 1998, not counting aircar data. Also the number of satwind reports increased to 18,368 per day in 1998.

Roy Jenne
April 1999
Satellite Cloud Drift Winds


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Wind data from NCEP GTS tapes

1974 GOES winds (NCDC)

1978 GMS archive winds 1991

NOTES:

1. ATS 1 From 7 Dec 1966 - 1974 (geosynchronous, Pacific)
2. ATS 3 From 5 Nov 1967 - 12 Dec 74, cloud camera
3. SMS-1 17 May 74-on (vis, IR radiometer)
4. The FGGE dataset (1979) has data from five satellites
The Need to Save the GOES Data Archive
(Prepare New Cloud Winds)

Roy Jenne
5 April 1999

There is a need to reprocess the GOES radiances and the Meteosat radiances to use modern methods to prepare better cloud drift winds. These derived winds are an important data input for the big reanalysis projects. Therefore we need projects in Europe and in the US to prepare new winds.

1. A project to make new Meteosat winds is in operation

First, Europe will reprocess Meteosat 2 data (1981 – 1988). This will be done between July 1999 and July 2000. In mid-2000, they may start a project to reprocess Meteosat-1 data (for 1977 – 1979). The reanalysis of 1979 – 1989 will not start until the new Meteosat winds are available. They now (Mar 1999) are copying Meteosat-2 data for 1981 – 1989 onto DLT tapes (volume 750 Gbytes/year). This is nearing completion. But there were media problems on 10% of the tapes that they have to take care of.

2. A project to make new GOES winds

ECMWF people have asked me several times whether the US could prepare new cloud winds from GOES data to use for reanalysis. In Feb 1999, I suggested that they write a letter on the subject that I could show to some of the right people in the US.

The US first needs to rescue the GOES archive from very old tapes at the University of Wisconsin. About 15-20% of these tapes are now so bad that only one read pass is possible. Two years ago, modest funding seemed to be in place to rescue the GOES archives. Now there again are no funds. Bob Fox (University of Wisconsin) thinks that the rest of the data rescue could be done for about $800K (need to check). It is a huge amount of data. The data for 1 Oct 1997 – on is already on new media. There are other reasons to rescue the GOES data and the cost is better than one might have guessed.

After the data is on good media, a project is needed to make new calculations of GOES cloud winds.

3. Production schedule for the next long reanalysis projects

The University of Wisconsin Wants to Make New Cloud Winds

Roy Jenne
3 Mar 2000

On 29 Feb 2000, I talked with Denise Laitsch from University of Wisconsin. They are very interested in helping reanalysis projects by calculating new cloud winds that remove the old problem of a slow speed bias. They have prepared an open proposal:

a. It would take about $200k to set up and test programs to make the calculations in an environment for fast production. This would take 2 or 3 months to accomplish.

b. To calculate winds 4x/day they would need about $50k per satellite year. They think that they could do about 10 satellite years in one calendar year.

c. ECMWF will start reanalysis production on these years about Jan 2001. The NCEP mesoscale reanalysis will start about 04/2001. The U of Wisc group could do a number of the most critical years before then, say 1980 – 85, if funding could start soon. Note that the later years of data will be needed somewhat later than early years.

d. With lesser funding amounts, they are still interested in carrying the project as far as they can.
Satellite Cloud Wind Data

Roy Jenne
4 Jun 2001

1. The following sections are from the 21-page text: Global Observations for Reanalysis, 1948 - on (Jenne, 17 Aug 1999). This text is on-line in PDF format at http://dss.ucar.edu/datasets/ds090.0/docs/papers/.

a. CLOUD WIND DATA FROM SATELLITES (1963 - ON, MOSTLY 1973 - ON)

Cloud winds: There are a few blow-off satellite winds starting in 1963. These were estimated by looking at the direction of the movement of clouds blowing off of the tall cumulus clouds. The more precise cloud drift winds start in 1967 for the region of the Americas. These are based on deriving cloud movement during the half-hour period between successive pictures from geosynchronous satellites. By the late 1970's, there were similar satellites operated by Europe and by Japan. These data are important sources of wind information over the oceans. The wind data is both for low cloud levels and high clouds.

The first geosynchronous satellite (ATS-1) was launched by the US in Dec 1966. A second satellite (ATS-3) was operational from Nov 1967- Dec 1974. ATS-1 was located about 151° West and ATS-3 was between 45° W and 95° W. But we do not have very many satwind observations to use during 1967 - 72.

The number of satwind reports available to use for reanalysis is about 82 reports per day in 1967, and 120 to 190 per day during 1968 - 72. For 1973 - 75, the counts increased markedly to 372, 482 and 1105 reports per day, respectively (Figure 5). The 5-day forecast scores in the Northern Hemisphere from reanalysis also increased to high levels in 1973 - 74 (Figure 11) and this added cloud wind data was probably one of the factors that helped.

The distribution of cloud wind data by year and by longitude is shown in Figure 6. The chart is based on cloud wind data used in operations at NCEP. It shows average data counts for each 20-degrees of longitude and for each 3-month period. During the FGGE year (Dec 78 – Nov 79), there was also a satellite over the Indian Ocean and data was processed in delayed time. It got into FGGE datasets and all of that data is being used in the reanalysis projects. There is a data gap during 1980 - 82 in the Europe – Africa sector (Figure 6). We hope that reprocessing efforts by Europe may fill that gap.

A project to prepare new Meteosat winds is in operation (written March 1999)

First, Europe will reprocess Meteosat 2 data (1981-1988). This will be done between July 1999 and July 2000. In mid-2000, they may start a project to reprocess Meteosat-1 data (for 1977 – 1979). The ERA-40 reanalysis of 1979 – 1989 will not start until the new Meteosat winds are available. They now (Mar 1999) are copying Meteosat-2 data for 1981 – 1989 onto DLT tapes (volume 750 Gbytes/year). This is nearing completion. But there were media problems on 10% of the tapes that they have to take care of.

The FGGE year: As noted above, there was good coverage of cloud winds for the FGGE year (Dec 1978 – Nov 1979), and these data are being used by the reanalysis projects. During FGGE, the US had two geosynchronous satellites viewing the Americas, Europe had one to view Europe and Africa, and Japan had one. Also, the US operated a satellite over the Indian Ocean during FGGE. A separate text about cloud winds and data coverage is available.

b. FORECAST SCORES RELATED TO AVAILABLE OBSERVATIONS

During the long reanalysis for 1948 – 98, NCEP ran one 8-day forecast each fifth day. NCEP has prepared plots of the annual 5-day forecast scores for each hemisphere, shown in Figure 11. It is difficult
to make an accurate 5-day forecast, but even these 5-day scores are quite good, especially in the Northern Hemisphere. We are pleased that the forecast scores from reanalysis are at modern levels for the Northern Hemisphere during 1973 – 98. The scores during this modern period (about 0.71 correlation) are much better than the NCEP operational scores used by the public in 1984 (about 0.55). The reanalysis scores for all of 1952 – 1998 are better than the operational scores in 1984. These high forecast scores for reanalysis give us confidence that the quality of the analyses should be high.

We think that the drop in forecast scores during 1971 – 72 in the Northern Hemisphere was caused by a drop in observations. We believe that the operational data ingest at NCEP was not maintained well during these last years of the old data ingest system. We plan to see if Navy (Monterrey) observations will help with the supply of data during 1971 – 72. NCEP started using a new data ingest system in Jan 1973. It lost the 06 and 18 GMT rawinsondes for two years, but this did not seem to hurt forecast scores much (Figure 11), if any. There may be a way to recover this data from another dataset from the USAF.

Update: NCAR added GTS data from the USAF for 1973 – 80 to help correct this period of low counts of raobs and pibals. This was done in year 2000.

The MIT dataset of raobs is for May 1958 – Apr 1963 (5 years). The forecast scores did not drop either before or after this period. Therefore most of the MIT observations were probably also carried in other component datasets. The Northern Hemisphere forecast scores dipped down in 1955. This may be explained by several months of missing data in the C-Cards dataset in 1955.

Satellite wind reports are based on the movement of clouds in successive satellite pictures. The number of cloud wind observations for reanalysis were about 120 to 190 per day during 1968 – 72. Then the counts increased markedly to 372/day in 1973, 482 in 1974 and 1105 in 1975. This increase in wind data coincides with better forecast scores for 1973 – 75 than for earlier years. I do not know why there were so few wind observations during 1967 – 72. The first geosynchronous satellite, ATS-1, was launched in Dec 1966, and ATS-3 was operational during Nov 1967 – Dec 1974.

The world’s satellite sounders started in April 1969 but they were first used in the NCEP/NCAR reanalysis in March 1975. The Northern Hemisphere forecast scores are almost equally good for 1973 – 98. Therefore, it is likely that VTPR soundings only helped the Northern Hemisphere over portions of the Pacific Ocean. Parallel reanalysis tests were made for Jan – Feb 1979 using VTPR, TOVS, and nosat cases. The differences between TOVS and VTPR analyses were small, but nosat was quite different over remote ocean areas. Sounders help the placement of daily circulation patterns, especially in the west wind belt of the Southern Hemisphere.

The forecast scores for the Southern Hemisphere became relatively good during about 1985 – on, but significantly worse than the Northern Hemisphere. When TOVS radiances are directly used (not the soundings) for the next reanalyses, we hope that the Southern Hemisphere scores will look better for the whole 1979 – 99 TOVS period and perhaps for the whole period starting fall 1972 when the VTPR sounders started.

Australia prepared bogus point data of sea level pressure taken from their maps of analyzed pressure. These were used at the wrong location (180 degrees of longitude off) during Jan 1980 – Mar 1993 in the long reanalysis. The first guess checks threw out half of the data, but some bad data was used, and the analysis did not have the benefit of using the data in the right location. This probably hurt the Southern Hemisphere forecast scores during this period. However, the year 1979 had the benefit of all the FGGE data and the SLP bogus was properly used, yet it does not have high forecast scores.
Figure 11. NCEP five-day forecast scores for reanalysis are given in heavy lines for each hemisphere. We think that the drop in 1971 – 72 (N. Hemisphere) was caused by a drop in observations. The forecast scores for reanalysis, for 1952 – 1998 in the N. Hemisphere are better than the operational scores in 1984. This chart is from Kistler and Kalnay in May 1999. An earlier 1997 version had a mechanical problem.
12. Experiments

<table>
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<th>Location</th>
<th>Data Years</th>
<th>Sent</th>
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</tr>
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<td></td>
<td>Not used</td>
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<tr>
<td>Gateway Raobs</td>
<td>Jun – Sep 1974</td>
<td>Jul 27, 98</td>
<td>Same</td>
</tr>
</tbody>
</table>

Note: Several types of Gateway data were all used.

13. Satellite Cloud Winds

- On tapes originally from NCEP (from satellites: US, Japan, Europe)
  - The dataset for 1973 and later (NCEP used this)
  - The 1962 – 72 set (Sent 1968 – 72 to NCEP on March 20, 1996 [final version])
  - The ATS-1 satellite was launched Dec 1966
- GOES wind data on tapes from NOAA SDS (Jan 1974 – on). This “permanent” US satellite archive started in 1974. This should duplicate US data on the NCEP tapes. NCAR has this archive for 1974 – 84 (received in 1984).
  - Data for 1974 – 78 was ready for reanalysis on 20 Feb 1996.
- Note: There are gaps on these tapes for Nov 74, Aug 75, and May 80 – Sep 81 (17 months). The NCEP tapes probably do not have a data gap.
- Basic archive on GMS winds (1978 – 91)
  - NMC got this directly from Japan
- Cloud winds for FGGE. From five satellites (1979).
  - These are in the FGGE dataset, which has been used for reanalysis.
- 1998 update:
  - Europe is calculating new winds from old Meteosat data
  - NCAR will send a copy of the GOES permanent archive for 1974 – 84 to ECMWF and NCEP.
  - The cloud winds on the NCEP tapes are being used for reanalysis.

14. Snow Cover Data

a. NCEP used weekly snow cover grids from another source for 1973 – on. I think these were also based on the weekly snow cover maps. NCEP had a snow cover problem for 1974 – 94. They kept using 1973 for each of the years. They caught the problem so 1995 – on is okay. And years 1976 – 79 were rerun.

b. DS315: Weekly snow and ice cover grids (from NMC/ Navy maps, ice center), Dewey and Heim, 1966 – 1983. NCAR sent this tape to NCEP so that they used this weekly snow grid data from Jan 1966 – 1972 (a polar stereo grid).

c. For 1948 – 65, NCEP used climatological areas for snow and no-snow, and gave freedom to the model in between. They did not have any snow analyses to use for these years.

Note: I made a text about sources of observations with daily snow observations, or present weather snow. Also, ISCCP is using a dataset from the USAF (I think) to help determine the surface albedo.

15. Tropical Storm Data (Location, Intensity)

We obtained a dataset of world wide tropical storm data about 1993. It appears that we will be able to obtain an update about April 1999. Charles Neumann worked in the Hurricane Center in Miami for many years. He has been retired for several years, but he is still updating these tropical storm files and removing some old problems in the data.
Satellite infra-red sensor systems

Climatologically, the most useful radiometers measuring radiation intensities in selected, narrow bands of the electromagnetic spectrum have been infra-red radiometers of the medium resolution infra-red (M.R.I.R.) and high resolution infra-red (H.R.I.R.) types. The functions of these two radiometer families may be differentiated as follows:

1 The M.R.I.R. systems were designed chiefly to provide broad resolution data for general radiation balance studies. The best linear resolution for Tiros M.R.I.R. radiometers was approximately 64 km. Characteristically, whether flown on Tiros, Nimbus or Cosmos satellites the M.R.I.R. have been multispectral sensors, capable of investigating simultaneously in several wavebands. Lesser (low resolution) radiometers for even more general radiation balance studies have been flown in various weather satellites, but their data have figured little in published work in climatology.
Fig. 5.16 Cloud motion vectors for A.T.S.-I, 7 November 1969, using photographs taken at 2130 and 2154 G.M.T. Each vector is represented by a five-digit number. The first two digits give the direction from which the cloud moved in tens of degrees, and the last three the speed in knots. (From Leese & Novak 1971)

Page 142 in "Climatology from Satellites"

23 An Essa 3 photograph of the Arabian Sea, 9 November 1966, portrayning a mature hurricane complete with eye, and a second tropical vortex over Ceylon. (See p. 274) (E.S.S.A. photograph)
24 One of the most damaging hurricanes in history, the 'Bangladesh Cyclone' of November 1970, photographed over the Bay of Bengal by Itos-1 on 11 November 1970. (See p. 268) (N.O.A.A. photograph)
42.1 INTRODUCTION

In this chapter the history and status of world surface and upper-air observing networks are surveyed to give an indication of what data are potentially available in digital or manuscript form. The history for the United States and Canada is given in much more detail than that for the rest of the world. The World Meteorological Organization publication, *Catalogue of Meteorological Data for Research*, contains information about data from specific countries; from it one can infer some history of the observing networks. In the United States and in many other countries, there are numerous observations of elements such as rainfall, temperature, and radiation that are not taken by the national meteorological services. In the United States the National Weather Service operates a few hundred observing stations and manages about 11,000 cooperative stations that measure at least precipitation. The National Climatic
* See below: There are 10 x 10 inch pictures from ATS during Jan 1, 1967 thru Sep 2, 1974.

CHARTS DERIVED FROM SATELLITE DATA

Maps of snow cover, lake and sea ice, and ocean current temperature also are prepared from satellite data. Most of these are described in the Section 42.9 on maps and charts.

Satellite Pictures and Movie Products

GOES/SMS DATA PRODUCTS

The SDSD maintains an archive of all data received from the two operational geostationary satellites under NOAA control (GOES-EAST at 75° west longitude and GOES-WEST at 135° west). Tables 42.7 and 42.8 show the dates of data from various U.S. satellites in this series. The data include copies of each half-hourly transmission (full disc, visible and infrared imagery, and various high resolution visible and infrared sectors) archived on 25 x 25 cm (10 x 10 inch) black-and-white negatives. GOES-EAST data are acquired on the hour and half hour (i.e., 1200Z and 1230Z), and GOES-WEST data on the quarter hour (i.e., 1215Z and 1245Z). The VISSR sensor scans the full earth disk in 18.2

Data

1237

TABLE 42.7  U.S. Geostationary Satellites Whose Data Are Archived at Satellite Data Services Division

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Launched</th>
<th>Period</th>
<th>Perige (km)</th>
<th>Apogee (km)</th>
<th>Inclination (degrees)</th>
<th>Dates of Data on Archive at SDSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATS-1</td>
<td>12/6/66</td>
<td>24 hr</td>
<td>41,257</td>
<td>42,447</td>
<td>0.2</td>
<td>1/1/67-10/16/72</td>
</tr>
<tr>
<td>ATS-III</td>
<td>11/5/67</td>
<td>24 hr</td>
<td>41,166</td>
<td>41,222</td>
<td>0.4</td>
<td>3/2/68-9/2/74</td>
</tr>
<tr>
<td>SMS-1</td>
<td>5/17/74</td>
<td>24 hr</td>
<td>35,605</td>
<td>35,975</td>
<td>0.6</td>
<td>6/27/74-1/7/76</td>
</tr>
<tr>
<td>SMS-2</td>
<td>2/6/75</td>
<td>24 hr</td>
<td>35,482</td>
<td>36,103</td>
<td>0.4</td>
<td>3/10/75-8/4/81</td>
</tr>
<tr>
<td>GOES-1</td>
<td>10/6/75</td>
<td>24 hr</td>
<td>35,728</td>
<td>36,847</td>
<td>0.8</td>
<td>1/8/76-3/15/80</td>
</tr>
<tr>
<td>GOES-2</td>
<td>6/16/77</td>
<td>24 hr</td>
<td>35,600</td>
<td>36,200</td>
<td>0.5</td>
<td>8/15/77-9/15/80</td>
</tr>
<tr>
<td>GOES-3</td>
<td>6/15/78</td>
<td>24 hr</td>
<td>35,600</td>
<td>36,200</td>
<td>0.5</td>
<td>7/13/78-3/5/81</td>
</tr>
<tr>
<td>GOES-4</td>
<td>9/9/80</td>
<td>24 hr</td>
<td>35,782</td>
<td>36,200</td>
<td>0.2</td>
<td>3/5/81-Present</td>
</tr>
<tr>
<td>GOES-5</td>
<td>5/15/81</td>
<td>24 hr</td>
<td>35,600</td>
<td>35,600</td>
<td>0.2</td>
<td>7/9/81-Present</td>
</tr>
<tr>
<td>GOES-6</td>
<td>4/28/83</td>
<td>24 hr</td>
<td>35,786 Avg.</td>
<td>---</td>
<td>0.14</td>
<td>6/1/83-Present</td>
</tr>
</tbody>
</table>

minutes, viewing in the visible spectrum (0.55-0.75 μm) and in the infrared window region (10.5-12.6 μm). In the infrared, the spacecraft scans one line on each "spin," creating a full disc picture containing 1750 lines with a nominal resolution of approximately 8 km at nadir. In the Visible, 8 parallel lines are scanned with each spin, creating a full disc picture containing 14,000 lines, with a resolution of approximately 1 km at nadir. Visible channel scan lines are combined in groups of 2, 4, or 8 lines to provide 2, 4, or 8 km resolution images, respectively. Full disc photographic displays are prepared every half hour from each satellite. Smaller "sectors" are also routinely produced every hour or half hour. Partial disc pictures at more frequent intervals (15, 10, 5, or 3 minutes) may be scheduled to meet special requirements (i.e., severe storms).

The routine full disc, sectors, and "rapid scan" data are archived as 10 x 10 inch negatives, and can be reproduced as either prints, positive transparencies, or duplicate negatives in sizes ranging from 10 x 10 to 30 x 30 inches. A portion of each image may also be enlarged to any size specified. Film loops or movies (16 mm) can be constructed on request for any specific period by registering the land masses and "animating" the imagery. Standard 10 x 10 inch negatives are available from ATS I and ATS III from January 1, 1967, through September 2, 1974. Similar data from the SMS/GOES series are available from June 27, 1974, to the present. Table 42.7 lists pertinent orbit data and dates of data on archive at SDSD for all of these satellites. Table 42.8 lists the location and status of these satellites.

Standard sectors include: the WB-I from GOES EAST (United States, Central America, and Caribbean) 1 nautical mile visible image; and the DB-5 (NEUS) infrared sector. The 14 disc images are from the rapid scan data acquisition periods, and normally cover from the North Pole to about 30° north. See Table 42.9 for daily acquisition rates.

GOES-EAST and GOES-WEST full disc imagery are also available on 35 mm microfilm. Each reel of microfilm contains approximately 15 days of full disc visible and infrared data, every 1 hour, from one of the two satellites. GOES-EAST microfilm currently cover the period from September 1, 1974, through July 15, 1979, and GOES-WEST from March 11, 1975, through July 31, 1980 (on July 1982).

POLAR ORBITER FLM PRODUCTS: ITOS (IMPROVED TIROS) AND NOAA SATELLITE SERIES (1970 TO PRESENT)
SYMPOSIUM ON TROPICAL METEOROLOGY

JUNE 2-11, 1970

University of Hawaii
Honolulu, Hawaii

EXTENDED ABSTRACTS

The paper about cloud winds from ATS is included here.

ATS winds 1970

AMERICAN METEOROLOGICAL SOCIETY
WORLD METEOROLOGICAL ORGANIZATION
Cloud winds
from ATS

WIND ESTIMATION FROM GEOSTATIONARY SATELLITE PICTURES

L. F. Hubert and L. F. Whitney, Jr.
National Environmental Satellite Center, ESSA
Washington, D.C.

June 1970

INTRODUCTION

Meteorologists have a new type of upper air data, thanks to picture sequences being obtained from the geostationary satellites. Because several pictures are taken during the lifetime of individual trackable cloud features, their motions can be measured. Certain clouds are carried along mostly by their ambient wind, consequently measurements of those cloud motions are wind estimates. For convenience, we call these estimates "ATS winds."

Our primary purpose is to assess the accuracy of these measurements as wind estimates for specific levels. Our secondary purpose is to describe the techniques used in cloud target selection. Because this subjective selection critically affects accuracy statistics, both matters must be considered.

The accuracy statistics summarize deviations between rawin observations and nearby wind estimates made from ATS pictures. Insofar as possible we identify the various reasons for these deviations. Approximately two-thirds of the total ATS wind error at specific levels is due to uncertainty of cloud height. Poor wind estimates result, for example, from tracking a cloud at one level and mistakenly assigning the estimate to a different level.

In addition to yielding an estimate of cloud height, the selection technique must also discriminate between advective and non-advective cloud motion: only "passive tracers" should be tracked. Clouds formed at the crests of gravity waves, for instance, do not move with the ambient wind and are to be avoided for this purpose.

PROCEDURE

ATS winds are derived through a series of steps, each of which influences the data quality. The problems that introduce error are identified in this section and discussed later. Quite apart from the errors themselves, the procedure itself, that is used to measure error, affects the reported error.

Procedure for Deriving ATS Winds

In principle, the satellite camera is stationary relative to the earth so that fixed earth features are photographed identically on all pictures—only clouds change location on the image. Time lapse movies are produced to animate this cloud motion; the motions, in turn, are measured on a projected display. The steps and associated problems for wind derivation are:

1. Re-photographing with a movie camera the individual images that were taken from the satellite at intervals up to 30 minutes.*
   *Problem: Picture-to-picture registration is the chief problem here together with the requirement to choose the proper total time interval.

2. Projecting the sequence repetitively onto a worksheet. By splicing the film strip into an endless loop, a few feet of film can provide any desired number of repetitions.

3. Selecting cloud targets, marking their initial and final positions on the worksheet, and classifying target cloud type.
   *Problems: Choice of passive tracers and the deduction of cloud type.
   *Marking the initial and final positions of individual targets is sometimes difficult because of cloud development.

4. Measuring, scaling, and recording the cloud displacement vectors.
   *Problem: In addition to the problem of accurate measurements of short line segments on the worksheet, great care is required for photogrammetric computations. Foreshortening and scale varies in a non-linear manner because the earth's spherical surface is displayed on a flat worksheet. Perspective distortion affects both direction and magnitude of the vectors.

Procedure for Estimating Accuracy

It is important for the reader to appreciate the interrelation of our method of obtaining ATS winds and our method of measuring their accuracy. Another evaluation method, equally valid, might yield somewhat different "accuracy" statistics.

*At Stanford Research Institute (1) a closed circuit television system has been developed to replace the movie camera and projector. The basic procedure is unchanged however, and some of the ATS winds included in our statistics were obtained on that equipment.
Statistics presented in the next section measure two aspects of accuracy. First we measure the degree of success achieved in judging cloud genera. This result, in turn, indicates that low cloud targets, on the average, are best assigned to 3,000 ft and targets judged to be cirrus are best assigned to 30,000 ft. Second, we summarize deviations between ATS winds and nearby rawin observations at those levels. Those deviations are presented as errors of the ATS winds.

The meteorological situation is a critical variable and the "accuracy" depends, in some situations, on the analyst's skill in deducing it. For example, where the vertical wind shear is small, misclassification of cloud target has only small influence and the analyst might measure the displacement of many targets even though he was uncertain whether they were cirrus or middle clouds. Where the vertical shear is large, on the other hand, the skilled analyst would not accept poorly identified targets.

Now our two representative levels, 3,000 ft and 30,000 ft, are the product of several different analysts who made the numerous measurement that comprise our sample. If the whole set were derived a second time by the same analysts, their greater experience and skill might produce different accuracy statistics.

ACCURACY OF ATS WINDS

The statistics presented in this section have been devised to answer two questions:

1. At what elevation is the field of flow represented by low cloud trajectories; and what elevation best fits the upper cloud trajectories?

2. Once those "best levels" have been found, how accurate are the ATS winds as estimates for those specific levels?

Two frequency distributions were constructed to answer the first question. The cloud levels (defined as the "level of best fit", explained below) were tabulated by 2,000 ft class intervals and plotted for figures 1 and 2. For low clouds, figure 1, the distribution mode falls in the lowest class interval. Upper cloud target heights have two modes, revealing that despite the analyst's effort to track cirrus, many middle cloud targets were followed.

Taken at face value, these histograms suggest that ATS winds from low cloud targets be assigned to the lowest 2,000 ft and the ATS winds from upper cloud targets be assigned to 30 to 32,000 ft. But that could be incorrect.

If ATS winds are to be assigned to the level where the average vector error is minimized that is not necessarily the modal "level of best fit." For this particular sample of low cloud targets, the error-minimizing level appears to fall in the next higher interval—2,000 to 4,000 ft. But exhaustive study of this point does not promise to be very rewarding because the error-minimizing level probably changes with changing synoptic situation. Moreover for our sample, the average error is about the same at other low levels. This is illustrated by the very close resemblance of the error curves for 3,000 ft and 5,000 ft on figure 3.

The principal mode and the median "levels of best fit" for upper cloud targets are quite near 30,000 ft. For the reasons discussed in connection with low level targets and because this is near the standard analysis level of 300 mb, we assign our upper level ATS winds to 30,000 ft for accuracy evaluation.

The Level of Best Fit (LBF)

Soundings of temperature and humidity are inadequate to specify the elevation of cloud targets. At upper levels, humidity is unreliable and frequently unreported. The elevation of upper clouds often is determined by subtle lapse-rate changes that are not shown by the encoded data. While these problems are less severe at cumulus levels, nevertheless target cloud heights are poorly indicated. Some reasons are:

- the mesoscale humidity pattern is irregular.
- selected target clouds may be isolated patches not at the same level as the larger scale humidity layer.
- time lag of the humidity element can indicate a higher cloud top than actually exists.

Consequently, for our purposes, target cloud height is determined from the wind soundings on basis of the following assumption. It is assumed that the minimum vector deviation between the target cloud and the balloon trajectories occurs at the cloud level. This is called the "level of best fit" (LBF). While the assumption is not valid in every case, in all likelihood it is satisfactory for the purpose of studying height distribution of target clouds.

To find the level of best fit for ATS winds, each wind vector has been plotted on the hodograph of a nearby upper air observation. The hodograph (interpolated) level which is nearest the end of the ATS wind vector is taken as the LBH. Notice that by this procedure it is possible for a low cloud LBH to occur at cirrus levels and vice versa. Hence measurement errors introduced anywhere in the data reduction system, makes the target selection appear to be less skillful than, in fact, it was.

Vector Errors at 3,000 ft and 30,000 ft

The question of accuracy, posed at the beginning of this section, is answered by computing vector deviations (errors) of the ATS winds from either of two observed winds. The ATS winds judged to be from...
low cloud trajectories are compared with the 3,000 ft observed wind; the target trajectories judged to be
cirrus are compared with 30,000 ft winds. For this error assessment we examine vectors rather than speed
more or one or other of its components.
Percent cumulative frequencies of errors for low and for upper clouds are shown in figures 3 and 4.
Figure 3 shows that half of the targets judged to be low clouds deviated from the observed 3,000 ft wind
no more than 6 kts while figure 4 shows that half of the adjusted cirrus targets deviated no more than
17 kts from the observed 30,000 ft winds.

Direction Errors at 3,000 ft and 30,000 ft

Despite significant vector errors of ATS winds, their general pattern corresponds to the real flow
pattern. Streamline analyses of ATS winds delineate cyclones and anticyclones, troughs and ridges, and
s sometimes more subtle flow configuration. This characteristic is depicted by cumulative frequencies of
direction error in figure 5. More than 70% of the directions are within ±10 degrees of the observed
wind at the two respective levels.

SOURCES OF ATS WIND ERROR

Various errors inherent in this system combine to produce the total error discussed in the foregoing
section. While data available at this time is inadequate to measure their individual contribution, the
significant sources can be identified and ranked relative to each other. In decreasing order of signif-
ance, the error sources are:
1. Uncertainty of target clouds height.
2. Non-adveptive cloud motion.
3. Measurement errors. Those due to imprecise picture registration, poor resolution, etc.
4. Non-representative radars. While this does not affect the ATS wind, it does contribute to the
discrepancy statistics.

Uncertainty of Cloud Height and Non-Adveptive Motion

Cloud height uncertainty exists because picture interpretation yields no direct cloud height information.
Therefore it is necessary to judge cloud genus and, based on that judgment, assign the wind estimate to
two statistical "best levels." Error is introduced because some of the cloud targets are at levels other
than the "best levels" and their motion does not correspond to the flow at the assigned elevation.

By non-adveptive motion we mean that part of target motion that is different from the horizontal air
flow. Some of the responsible mechanisms are:
- gravity waves,
- vertical cloud growth and distortion by vertical wind shear,
- cloud formation on one edge and/or evaporation on the other.

The ATS analyst strives to eliminate all targets from his consideration where it appears these mechanisms
seriously affect motion.

The vertical motions induced by gravity waves generate cloud lines along the wave crest if humidity is
sufficient. Absence of detailed data has made it impossible to document the presence of gravity waves
but a surprising number of patterns changes and changes are most plausibly accounted for by that
mechanism. As expected from theory, the orientation of wave crests and their direction of motion bear no
fixed relation to the ambient wind.

Low level clouds being stretched horizontally as they penetrate vertical shear layers can be seen on
every ATS sequence. Only when the analyst can take this into account by calculating displacement of the
up-shear edge are the targets used.

Dissipation on one boundary of a cloud cluster and formation on the opposite side is virtually
impossible to detect on ATS pictures, but it must occur with some of the target clouds. Observations and
theory show that, depending on the circumstances, convection can propagate either up-shear and downshear.
In general the speed that a cloud cluster moves by this mechanism is small relative to the average wind
speed and its contribution to the total error probably can be neglected.

But the influence of evaporation of cirrus sometimes cannot be neglected. Near active convection, high
level subsidence often evaporates cirrus plumes moving away from their source. The leading edge of such
cloud then advances more slowly than the air flow. Such targets must be avoided.

Selecting and Classifying "Passive Tracers"

The display of motion in time lapse sequences provides a powerful means of adding meteorological
deduction to picture interpretation. Time lapse sequence enables one to examine pattern behavior—a
significant advantage over instantaneous views at the beginning and end of a time period. Not only are
cloud brightness, texture, and pattern observed but so are time changes and the motions of several cloud
layers.

Such pattern behavior permits the analyst to deduce a great deal about the synoptic situation and the
vertical structure of the flow pattern. Once the synoptic structure is known, cloud genus (or height)
can be deduced by judging how pattern behavior fits the appropriate synoptic model. Those motions that
do not conform to the synoptic situation and those motions that appear to show the same cloud layer
moving in two directions, are suspect. Thus, a view of pattern behavior plays two crucial roles; it aids
in deducing cloud genus and it reveals non-adveptive processes.
Measurement Errors

The largest measurement errors result from imprecise registration. Picture-to-picture registration can be achieved by matching earth features but precision is limited by the resolving capability of the system and by distortion. Even when landmarks are matched, distortion that is different from picture to picture, puts portions of the image out of register.

On the basis of registering and analyzing many hundreds of ATS pictures, Professor Fujita, University of Chicago, estimated good quality ATS-3 pictures can be registered within 10 km at the subpoint (private communication). Where the image centers of the first and last pictures are misregistered 10 km, displacement vectors in the central part of the pictures will contain a 10-km error. The error increases toward the horizon because of scale variation.

Effect of Scale Variability

ATS image scale decreases toward the horizon but the amount of error increase depends on the orientation of the cloud vector as well as on its distance from the satellite subpoint. How the error depends on orientation of the displacement vector can be understood by examining separately, two components of the scale change.

A horizontal line segment of given length and distance from the subpoint will be pictured as different lengths (scales) depending on whether it is oriented along a radius of the image disc or perpendicular to that radial. Segments along the radials are foreshortened because the earth's curvature presents the segment to the camera partly end-on. The same segment lying perpendicular to the radial will not be foreshortened--its only scale changes will be due to its (slightly) greater distance from the satellite.

Figure 6 illustrates the scale changes in component form: the radial component change is due to foreshortening combined with increasing distance to the satellite while the tangential component changes only because of increasing distance.

Wind Velocity Errors

For a given displacement error, the velocity error is inversely proportional to the time interval from first to the last picture. The curves in figure 7 show the velocity errors for three time intervals based on a registration error of 10 km at the satellite subpoint. The error increases with distance from the subsatellite point due to the scale change illustrated in Figure 6. The two upper curves and the lower curve correspond to an "average" vector orientation of 45° from the radial direction. In addition a "maximum error" curve is shown corresponding to a displacement along the radial direction.

Non-Representative Rawins

Some of the discrepancies between ATS winds and rawins are due to errors in the rawinsonde data, not in the ATS measurements. Other discrepancies are due to the change of wind from time of the balloon observation to time of the ATS picture sequence. Most of the ATS winds were derived from periods within three hours of the upper air observation time, but for some cases it was necessary to interpolate an 1800 sounding from the adjacent 0000 GMT and 1200 GMT observations. This was done only when the 12-hour change was small.

We cannot estimate the net contribution of rawin error to our total error statistics. Klein (2) shows that the root-mean-square error of rawin measurements vary from 5 kt to 17 kt, depending on wind speed. The average speed of our ATS winds suggests that the applicable rawin error is at the lower end of this range.

CONCLUSIONS

Generally two levels of cloud motion are easily distinguished--one at cumulus levels and one at cirrus levels. By comparing motions of clouds thought to be cumulus with 3,000 ft observed wind we derive a mean error of 8 kts. By comparing motions of clouds thought to be cirrus with 30,000 ft winds, we derive a mean error of 17 kts. Height ambiguity of target clouds is the principal source of ATS wind errors.

Despite the magnitude of vector error, ATS winds are valuable for analysis because their direction conforms well to the actual wind direction. More than 70% of the ATS winds are within 10° of the observed wind direction.

REFERENCES


ZIPSER: The latest estimates made by various GARP planning groups for accuracy requirements for tropical wind measurements are the order of 2-3 meters per second at 4 tropospheric levels. In view of the fact that some of your most significant discrepancies result from sources that may not be easily correctable, such as the propagation problem where cloud velocity and air velocity are not the same, what is your prediction of the potential of the cloud motion technique for meeting GARP requirements?

HUBERT: Propagation appears not to be a significant error source—largest error shown in my statistics is due to uncertainty of target cloud height. This error will be reduced when infrared data are available. We are able to make wind estimates at low levels almost within this 2-3 mps requirement. I would estimate that the cirrus-level estimates may not attain this accuracy, although we can expect significant improvement over the accuracy of this sample.

ITAGAKI: Is it possible to measure cloud height especially of large convective clouds close to subpoint picture?

HUBERT: ATS resolution is not fine enough to see shadow. Thus it is not possible to measure shadow length.

RODENHUIS: Would the calculation of wind shear (horizontal or vertical) be more representative or accurate than the calculation of the vector wind itself? It seems to me that it would be possible to eliminate some of the systematic errors.

HUBERT: At present vertical shear calculation would be subject to great error because height increment between two cloud levels, i.e., \( \frac{\Delta v}{\Delta z} \) may have great uncertainty.

GRAY: I feel there are some basic problems here because you can't separate broad-scale and cumulus scale motions. In regions where the tropospheric shears are small the results should be good. When shears are larger extra problems result. The directions appear extremely good.

HUBERT: I agree—there is a larger problem of measuring shear where shear is large. The experienced analyst, in fact, will avoid selecting targets where shear is large because he knows his results are uncertain.

SEREBRENY: It's a question of what one means by accuracy—accuracy according to what standards—surely not according to comparison with radiosonde winds. The accuracy is currently a matter of accuracy of location (within the 10 km's mentioned by Mr. Hubert) not of obtaining accuracy of wind speed.

HUBERT: Rawins are indeed non-representative sometimes. Simply because ATS winds and Rawins disagree is no reason to believe all "error" is due to ATS inaccuracy.

REDIENT: Even though accuracy is not up to conventional concepts, the data is useful because of the large distances and the present lack of data. Particularly it locates shapes and high speed wind zones.

HUBERT: Thank you for repeating this point that I should have emphasized more. That was the point of my slide that showed that ATS wind directions compared well with Rawins.

WILLIAMS: How, on a real-time basis for forecasting purposes, can target clouds be chosen to insure that these clouds will be visible in the next ATS photograph? To give accurate present wind data, it seems that current ATS pictures are needed.

HUBERT: The targets are selected by viewing an ATS-sequence that covers, e.g., 2 hours. Only those targets that endure for the entire sequence are measured.