*DOCUMENT 1.2.*

# SATELLITE DATA COLLECTION SYSTEMS HYDROLOGICAL APPLICATION

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## *SUMMARY*

*In the first section, after a rapid definition of data collection by satellite, the author reviews the principal systems created since 1971 and compares the two types, geosynchronous and low polar orbit.*
*The second portion of the document concerns the application of these systems to hydrology. Using programs in the United States as an example, the author presents the different kinds of needs and the measures taken ; he lists the principal technical elements necessary to compare, in these data collection sites, the possibilities offered by each of the two satellite systems.*
*Finally by looking at two large North American users, the author demonstrates research and applications already developed in Canada and the U.S.A. for use in hydrology of data collection by satellite.*


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## *RÉSUMÉ*

*Dans une première partie, après une rapide définition de la collecte de données par satellite, l'auteur passe en revue les systèmes réalisés depuis 1971, puis fait une comparaison entre les deux principaux, c'est-à-dire les systèmes géostationnaires et ceux à orbite basse.*
*La deuxième partie du document traite de l'application de ces systèmes à l'hydrologie. S'appuyant sur l'exemple des États-Unis, l'auteur introduit les différents types de besoins et les mesures effectuées ; il fournit les principaux éléments techniques nécessaires pour juger, sur des exemples de stations de mesures, des possibilités de l'un ou l'autre des deux systèmes.*
*Enfin, à partir des exemples de deux grands utilisateurs Nord Américains, l'auteur montre les recherches et les applications déjà réalisées dans ces pays pour l'utilisation en hydrologie des systèmes de collecte de données par satellite.*


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# 1. DATA COLLECTION DESCRIPTION

In a satellite data collection system, parameters such as temperature, pressure or other variables are sensed at the platform (in situ or direct sensing) and the data encoded, formatted and transmitted to processing facilities via a satellite communications link.

Satellite data collection can be described by several characteristics :

- the technique is used to monitor unattended sensory platforms via telecommunications,
- in situ data is collected data rather than remotely sensed data of the type obtained from radiometers or multispectral scanners,
- the systems employ large quantities (hundreds...) of low cost ($ 5,000) platforms,
- the platform message durations are short (32 to 1000 bits),
- position location can be accomplished by the measurement of Doppler effect or the measurement of range,
- the systems are compatible with both low and geostationary orbits ; thus possibly offering near real time or real time data as needed.

Many of the applications involve both the tracking of moving platforms (weather balloons, buoys, ice islands, wild animals) as well as the collection of data from fixed sites (moored buoys, water survey stations, volcano surveillance stations...).

In operation, data is relayed from the remote platforms to a satellite either randomly or upon interrogation command.
Data can be stored aboard the satellite for readout over a central receiving site or can be relayed directly to a control processing facility or to a local regional user terminal. Once data is received on the ground, information is formatted and disseminated to users. In the case of position location, the coordinates are computed and disseminated to the user along with the collected sensory information.

# 2. REVIEW OF EARLY AND PRESENT SYSTEMS

## 2.1. VARIOUS DATA COLLECTION SYSTEMS

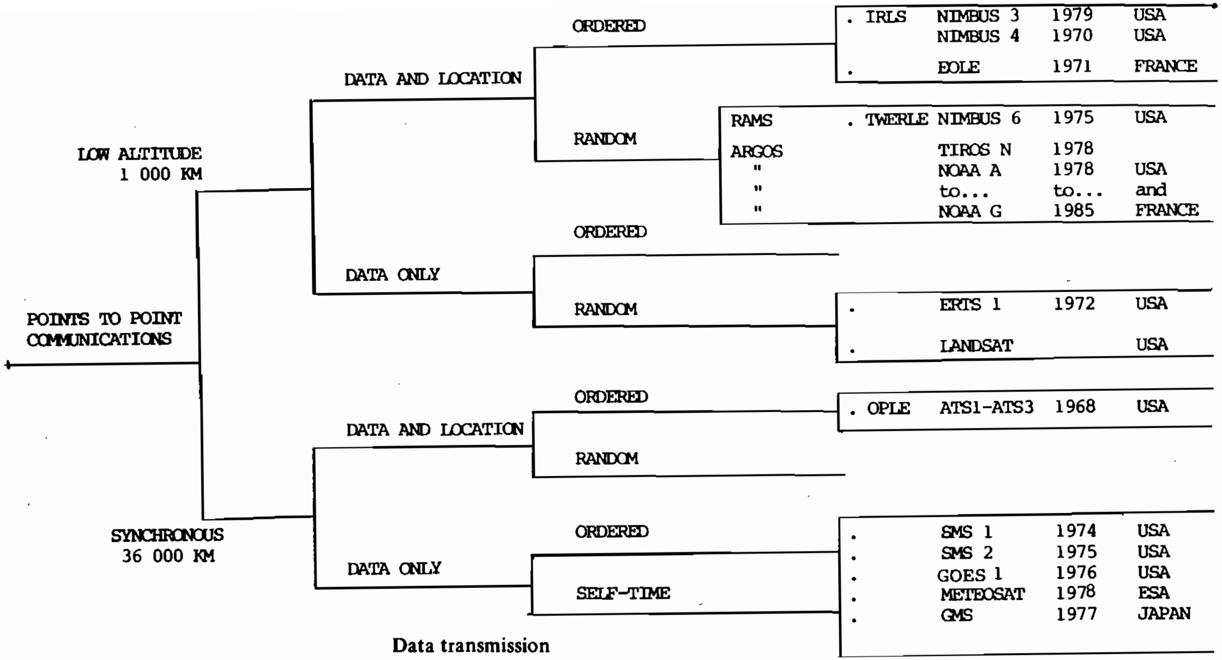
Several systems and techniques have been developed and tested, and others are planned for future launch. Figure 2.1. shows a decision tree for distinguishing various data collection systems.

## 2.2. INTERROGATION, RECORDING AND LOCATION SYSTEM (IRLS)

The major elements of the system (figure 2.2.) are :

- a central ground processing facility
- a satellite carrying receiving equipment
- the remote platforms

In operation unique addresses or codes identifying the platforms were programmed into the satellite from a ground acquisition facility at the beginning of each orbit.




**Systems**

| | |
|---|---|
| IRLS | Interrogation, Recording and Location System |
| RAMS | Random Access Measurement System |
| TWERLE | Tropical Wind Energy Conversion and Reference Experiment |
| NOAA | National Oceanic and Atmospheric Administration |
| ERTS | Earth Research Technology Satellite |
| ATS | Applications Technology Satellite |
| OPLE | Omega Position Location Equipment System |
| SMS | Synchronous meteorological Satellite |
| GOES | Geostationary Operational Environmental Satellite |
| GMS | Geostationary Meteorological Satellite System |

**Data transmission**

| | |
|---|---|
| ORDERED | upon receipt of a command transmitted via the satellite from a ground station |
| SELF-TIME | at pre-established intervals under control of an internal clock |
| RANDOM | at random times at a rate of once per 100 to 200 seconds |

Fig. 2.1. -- Various data collection systems

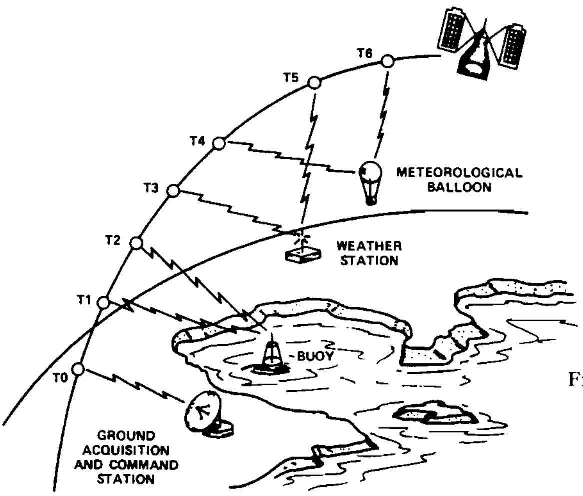



Fig. 2.2. – IRSL Concept
USA Nimbus 3 1969
Nimbus 4 1970
FRANCE Eole 1971-1974
(Ref. 5)

As orbital time elapsed the platforms were interrogated at predetermined times and the received data was stored aboard the satellite for retransmission to the ground facility at the end of each orbit. Position location was accomplished by a ranging technique with a minimum of two interrogations or range measurements required for each platform.

The IRLS was the first global satellite system that demonstrated the worldwide capabilities of satellite data collection. The IRLS and EOLE were ordered system that utilized *receivers on the platform* to initiate the platform transmission to the satellites. This resulted in substantial cost, size and power consumption requirements for these platforms..

## 2.3. RANDOM ACCESS DATA SYSTEM

The data collection system developped for the Landsat satellite series was the first random access system. In this system, platforms transmit their sensory information to the satellite randomly. The short duration transmission initiated by platform timers allows multiple platforms to be serviced (capacity for 2000 platforms simultaneously in the satellite field of view with a 95 % probability of data collection from each platform). The Landsat DCS uses an UHF uplink from platforms to the satellite while the data received by the satellite is retransmitted immediately on a S band downlink to the ground terminal.

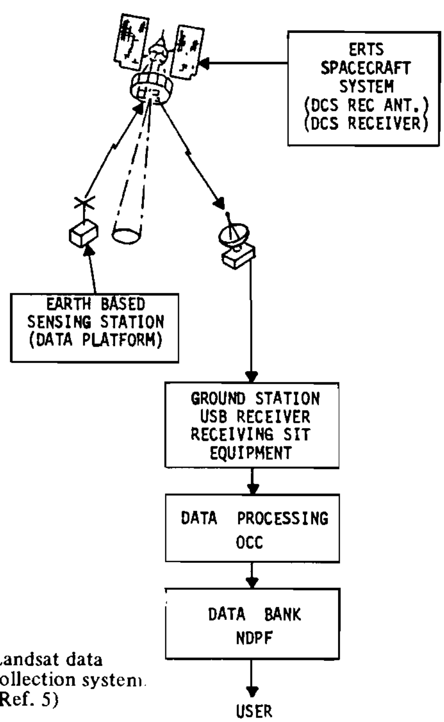



Fig. 2.3. – Landsat data collection system.
(Ref. 5)

## 2.4. RANDOM ACCESS DATA COLLECTION AND LOCATION SYSTEM

«RAMS» system using the multiple access technique was developped to support the Tropical Wind Energy conversion and Reference Level Experiment (Meteorological Experiment with approximately 400 balloons). RAMS carried by the Nimbus F satellite was launched in 1975 and is still in operation. RAMS permits global scale experiments to be performed utilizing low cost, simple data collection platform equipment.

The platforms transmit a one-second message to the satellite at random times at the rate of once per minute.
The satellite records a Doppler frequency measurement and a time tag and formats the received data. This information is stored aboard the satellite for readout over the Fairbanks, Alaska, ground station and transmission for processing.
The position location coordinates of each platform are computed and the data is transmitted to investigators.
Another application, as shown in fig. 2.4., used the OMEGA system to derive vertical profiles. The Carrier Balloon System (tested in 1975) involved large balloons carrying dropsondes commanded via SMS satellite.

As the sondes were released, they received and relayed the OMEGA signals to the large balloon for retransmission to a processing center via SMS satellite (geosynchronous).
The phase measurements derived from the sondes during descent were used to compute the vertical wind profile from 20 mb levels to the surface.
The position of large balloons were known using RAMS/Nimbus F low altitude satellite.

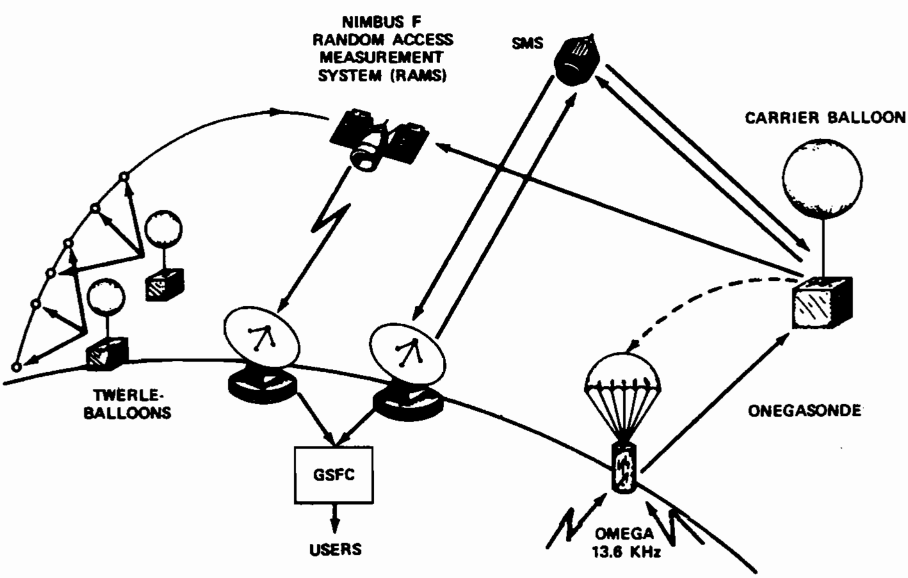



Fig. 2.4. – Nimbus F. RAMS System (Ref. 5)

## 2.5. ORDERED SYSTEM WITH SELF TIME CAPABILITY

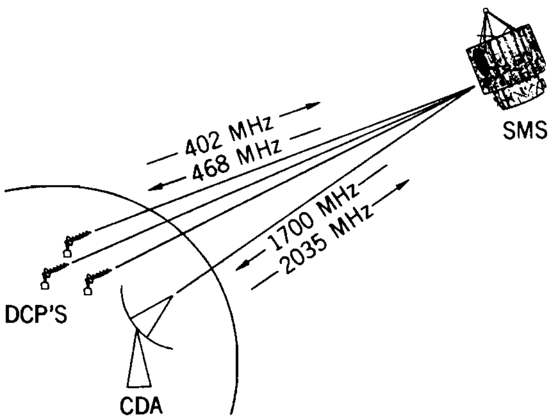



Fig. 2.5. SMS System (Ref. 5)

The SMS data collection system is principally an ordered system with the interrogations initiated by command.

**Interrogated DCPs** transmit their data upon receipt of a unique address command transmitted via the satellite from the ground station.

**Alarm DCPs** transmit an alarm signal when their sensors exceed a specified threshold value. Upon receipt of this alarm signal, the ground station will interrogate the platforms to obtain the actual data.

A self-timed capability allows transmissions at pre-established intervals under control of an internal clock (self-timed DCPs).

The system has a UHF platform to the satellite link and data is received at the ground through an S band downlink. The system is intended for non-moving applications and can handle 10,000 platforms.

## 2.6. COMMERCIAL SYNCHRONOUS SATELLITE DATA COLLECTION PROJECT

In 1977, Comsat General Corporation (USA) engaged in a joint development program with the US Geological Survey (USGS) and Telesat CANADA to collect environmental data via satellite.

This program represented the first use of present-day commercial satellite communications technology to improve the management of resources on earth.

Under a six-month evaluation program, Comsat erected 15 self-timed data collection platforms.

The DCPs automatically transmitted the data (mainly hydrological) in random bursts via Anik satellite operated by Telesat CANADA to control receiving and distribution points.

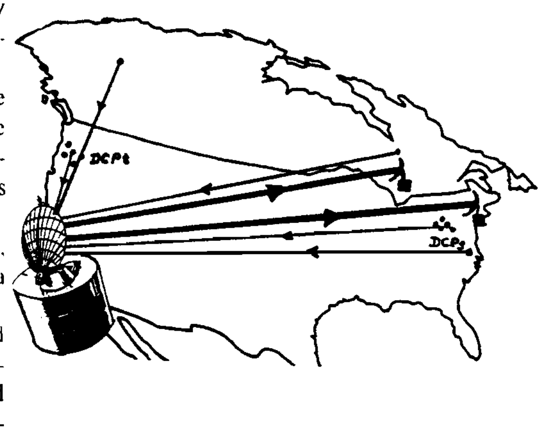



Fig. 2.6. – Comsat experiment (Ref. 11)

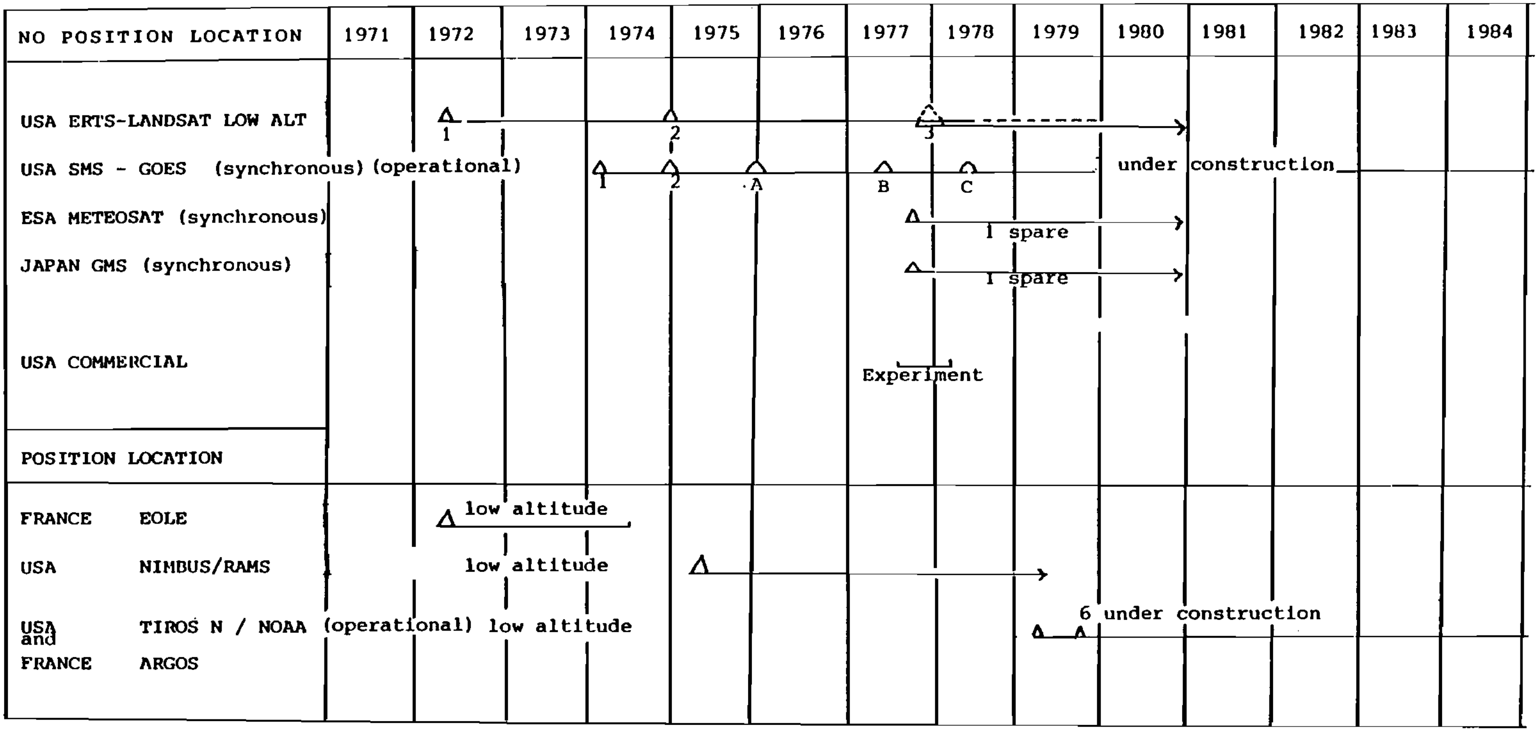



Table 2.7. – DATA COLLECTION MISSIONS

Two satellite data collection systems will be operational after 1978

- GOES System (still operational from 1976)
- TIROS N / ARGOS System

## 2.7. LAUNCH SCHEDULE OF DATA COLLECTION MISSIONS

In table 2.7. a launch schedule of early, present and up-coming data collection missions is shown. The systems are grouped on the basis of data collection only and data collection with position location.

Assuming a three-to-five-year lifetime for the synchronous missions and two years for the low altitude, two major operational programmes appeared after 1978.

- **GOES programme** with eight spacecraft which have been approved to data :
  - 5 launched successfully
  - 3 under construction
- **TIROS N / NOAA / ARGOS programme** with eight spacecraft which have been approved to date :
  - the first on launched in november 1978,
  - the second in Mai 1979,
  - 6 others under construction.

## 2.8. EARTH COVERAGE OF THE MAIN SYSTEMS

### 2.8.1. Data collection worldwide geosynchronous system

Three GOES satellites form a part of an international array of five geostationary spacecrafts , targeted for the first GARP global experiment, a project under the auspices of the World Meteorological Organisation (WMO) and the International Council of Scientific Unions (ICSU).

The other two satellites, added to the GOES satellites, provide near global coverage from approximately 70° N to 70° S.

- **Meteosat (European Space Agency)** centered over Greenwich Meridian (Eastern Atlantic) and launched in 1977.
- **GMS (Japan)** centered over 140° E (Western Pacific) and launched in 1977.

Figure 2.8.1. shows the coverage of the worldwide geosynchronous Meteorological Satellite System.

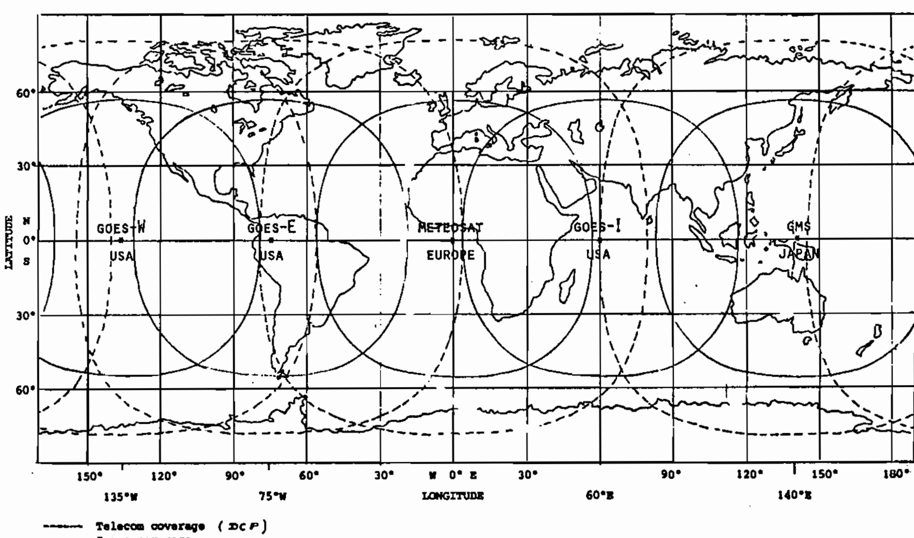



Fig. 2.8.1. – Coverage of the worldwide geosynchronous Meteorological Satellite System (Ref. 8)

### 2.8.2. NOAA/ARGOS low orbit operational system

The eight satellites will be launched successively in such a way as to keep two of them simultaneously on orbit.
The two satellites provide a worldwide converage for data collection and location.

## 2.9. CONCLUSION

Since May 1979, two major data collection satellite systems are available.

- **Geosynchronous system** (data collection ONLY)
  with four satellites simultaneously on orbit providing near global coverage.
  – 2 operational GOES [Fig. 2.9. (1)]
  – 2 other satellites :
  - METEOSAT
  - GMS [Fig. 2.9. (2)]
- **Low Polar Orbiting System** (data collection and location)
  with eight TIROS-N / NOAA / ARGOS satellites providing an operational system from the end of 1979 to 1986 at least [Fig.2.9. (3) and 2.9. (4)].

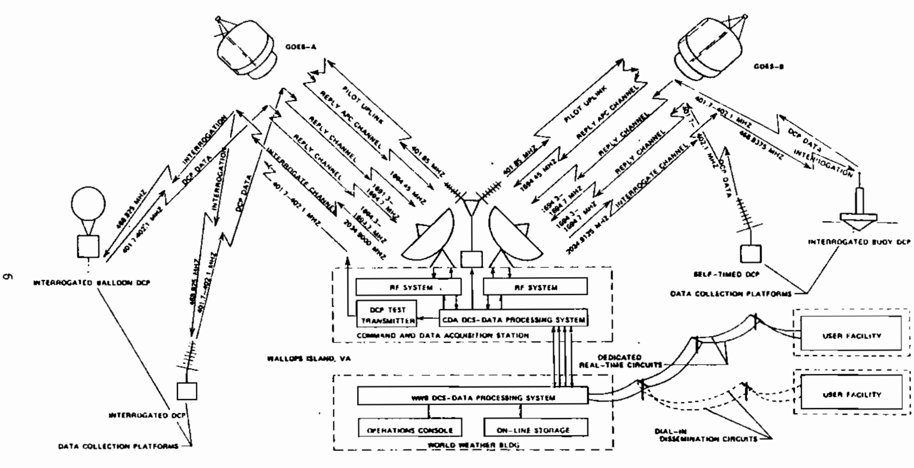



Fig. 2.9. (1) – GOES/DCS system description (Ref. 7)

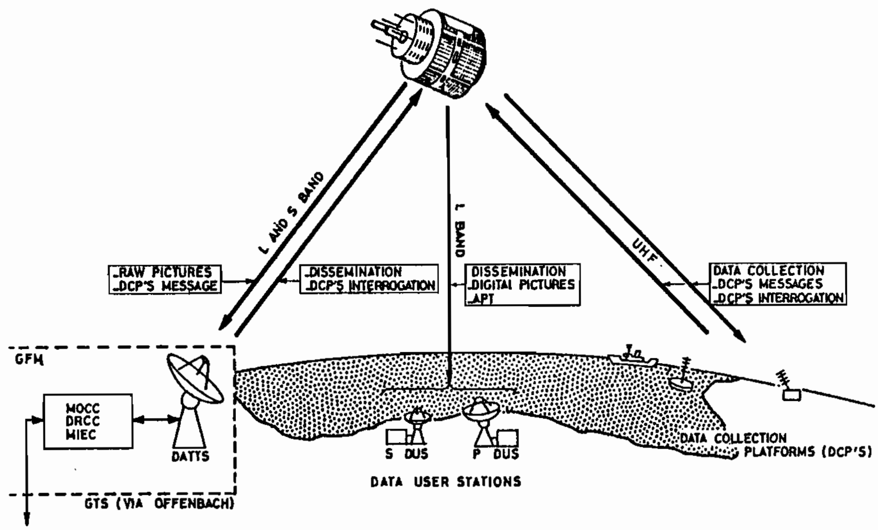



Fig. 2.9. (2) – METEOSAT System description (Ref. 8)

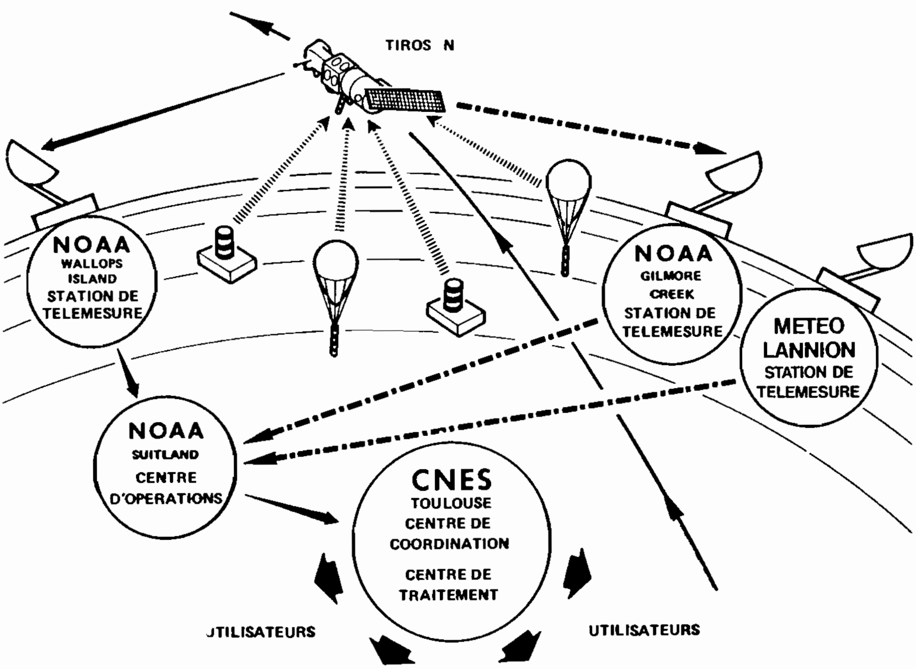



Fig. 2.9. (3) – Low Polar Orbiting System description (ARGOS System)

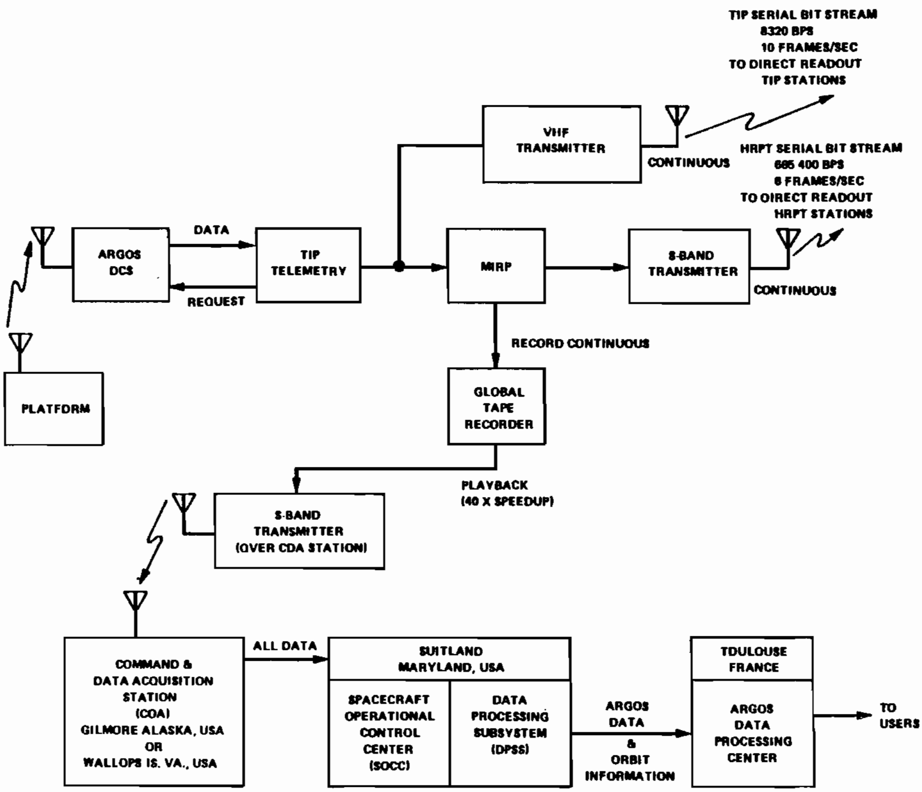



Fig. 2.9. (4) – ARGOS data handling

## 3. COMPARISON OF THE TWO MAJOR SYSTEMS

The two major systems :

- synchronous system
- low orbit system

are compared in their various parts :

- satellite system
- data collection platform (DCP)
- data processing
- data distribution
- charges

| *GEOSYNCHRONOUS SYSTEM* | *LOW ORBIT SYSTEM* |
|---|---|
| **3.1. SATELLITE SYSTEM** | |
| **Name and authority in charge** | |
| - GOES ............ NOAA (USA)<br>- METEOSAT.... ESA<br>- GMS................ IMA and NASDA | - TIROS N/ARGOS: NASA (USA), NOAA (USA), CNES (France), Service Argos Toulouse, France |
| **Satellite orbit** | |
| Geostationary, equatorial orbit<br>Altitude 36 000 km | Near polar<br>Altitude 830 km |
| **In orbit redundancy** | |
| **GOES System** : Operational with two space-craft on orbit<br>75° W longitude<br>135° W longitude<br>3 others satellites planned<br><br>**METEOSAT** : Pre-operationnal<br>One flight unit : 0° longitude<br>One spare<br>**GMS** : Pre-operationnal<br>One flight unit : 140° E longitude<br>One spare | Operational system (1978-1985)<br><br>Eight satellites programme<br>2 satellites simultaneously on orbit<br>(each one able to assume the data collection operation) |
| **Earth coverage** | |
| Near global 70° N to 70° S with the whole system. See figure 2.8.1. for individual satellite coverage | Each satellite provides a global coverage |
| **Capability** | |
| Data collection | Data collection and location |
| **DCP capacity** | |
| 10,000 DCP per satellite | 16,000 DCP for the system |
| **Data collection access type** | |
| Ordered<br>Self-timed | Random |
| **DCP reporting** | |
| On demand (interrogate)<br>Per 3-6 hours (self-timed) or less | When data collection platform is visible from one satellite (7 times a day at the equator to 28 times per day at the poles). |

| *GEOSYNCHRONOUS SYSTEM* | *LOW ORBIT SYSTEM* |
|---|---|
| **3.1. SATELLITE SYSTEM** (suite) | |
| **DCP radio frequency report channel** | |
| Bandwiths are divided in 3 kHz channels<br>- International DCPs<br>402 to 402,1 MHz<br>- Domestic DCPs<br>GOES : 401,7 to 402<br>METEOSAT : 402,1 to 402,2<br>GMS : 402,2 to 402,4 | 401.650 MHz<br>Unique frequency for all DCPs |
| **Interrogation channel** | |
| International DCPs<br>468, 875 MHz<br>Domestic DCPs<br>GOES : 468,825<br>: 468,837<br>METEOSAT : 468,925<br>GMS : 468,924 | No interrogation<br>Random access |
| **3.2. DATA COLLECTION PLATFORM** | |
| **DCP antenna type** | |
| Directional, 15° pointing accuracy<br>Gain 10 db - 13 db<br>Circular polarization | Omnidirectional<br>Linear or circular polarization |
| **DCP transmitter power** | |
| 5 watts with a directional antenna | 600 mW to 3 watts depending on antenna polarization and mission |
| **DCP report message** | |
| 1. Total duration<br>10 to 60 sec.<br>2. Bite rate<br>100 bits/sec.<br>3. Number of bits for sensor data<br>2000 to 5200 bits | 1. Total duration<br>0,3 to 0,9 sec.<br>2. Bite rate<br>400 bits/sec.<br>3. Number of bits for sensor data<br>Less than 256 bits i.e. 32 coded 8 bits analog sensors |
| **DCP power consumption** | |
| Higher than 600 mW<br>(depending on transmitting rate and duration) | About 100 mW for data collection<br>(including transmission periods) |

| *GEOSYNCHRONOUS SYSTEM* | *LOW ORBIT SYSTEM* |
|---|---|
| **3.2. DATA COLLECTION PLATFORM** (suite) | |
| **DCP sensor inputs** | |
| - parallel digital<br>- serial digital<br>- analog | - parallel digital<br>- serial digital<br>- analog |
| **3.3. DATA PROCESSING** | |
| **GOES system** | |
| The sensor outputs are converted to an ASCII coded serial message by the DCP for transmission to the satellite.<br>Once the message is received the data processing system :<br>- checks for the correctness of the platforms address<br>- examines for error conditions<br>- stores the message on disk in an area allocated to the User (or owner) platform. | The sensor outputs are converted into a binary coded serial message by the DCP for transmission to the satellite.<br>Once the message is received the data processing system :<br>- checks for the correctness of the platform address and errors conditions<br>- processes the data according to the User's need<br>Three types of processing are available in increasing order of complexity :<br>- coding of sensor data in decimal, octal hexadecimal, BCD<br>- conversion into physical parameters using the calibration curve of each sensor with possibility of inside-outside limits checking<br>- special processing (each one must be discussed separately)<br>The results of sensor data processing (and also location if needed) are broken down into «experimenters files» and stored. |
| **Time delay for disponibility of the results (at the processing center)** | |
| Near real time between measurement and distribution | Between 2h to 6h measurement to distribution delay |
| **Locations for the data processing centers and results dissemination outputs** | |
| GOES (SUITLAND) USA<br>METEOSAT (DARMSTAD) GERMANY<br>GMS JAPAN<br><br>Each center processes and disseminates the data of the DCPs in view of the corresponding satellite. | NOAA/ARGOS<br>Service Argos - Centre Spatial de Toulouse<br>18 av. Edouard Belin<br>31055 TOULOUSE CEDEX, FRANCE<br>Unique ARGOS center (Toulouse) processes and disseminates the data of all the DCPs in operation wherever on Earth. |

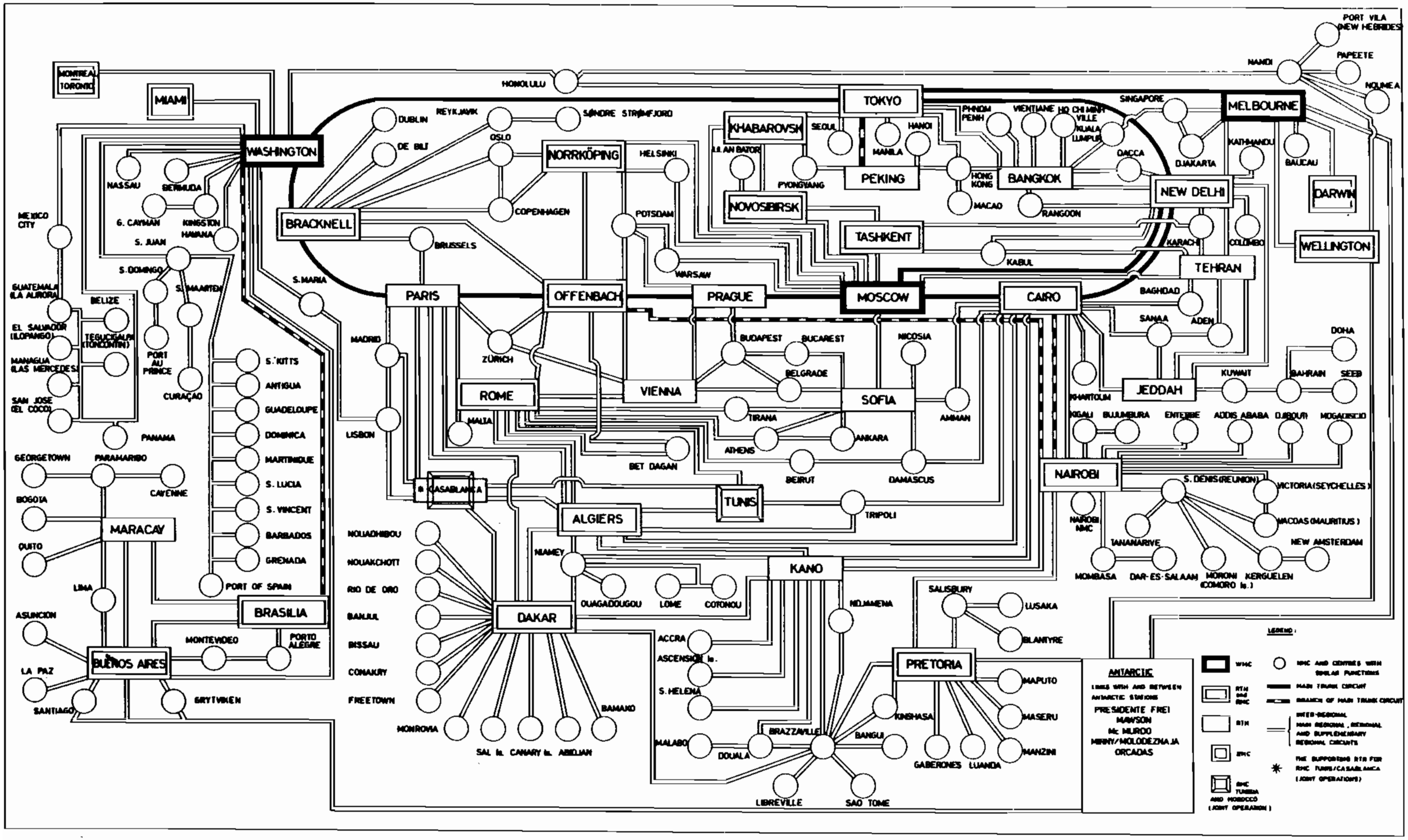



Fig. 3.4. – Global Telecommunications System of the World Weather Watch (WMO document).

| *GEOSYNCHRONOUS SYSTEM* | *LOW ORBIT SYSTEM* |
|---|---|
| **3.3. DATA PROCESSING** (suite) | |
| **Charges** | |
| **Data processing**<br>GOES : Free of charge<br><br><br><br><br><br><br>**Data dissemination**<br>At User's charge | **Data processing**<br>Data collection<br>- raw data (i.e. coding in decimal, octal hexadecimal, free of charge<br>- results in physical parameters : 1$ per platform per day<br>. Location : 20 $ per platform per day special contracts possible<br>**Data dissemination**<br>At User's charge |
| **3.4. DATA DISTRIBUTION** | |
| Once the data is stored, it can be accessed by a User «dialling in» to the system. Alternatively, data can be immediately routed directly to the User via one of the dedicated lines, or stored on magnetic tapes to be sent by mail. | Two cases must be considered :<br>. **Real time distribution using** :<br>- telephone (call from the USER and direct access to the computer)<br>- international or private telex<br>- computer to computer dedicated lines<br>- Global Telecommunications System of the World Weather Watch (automatic connection in Paris) with agreement of French Meteorological Office (see Fig. 3.4.).<br>. **Differed distribution by mail** :<br>It applies to listings magnetic tapes obtained through the weekly ending of Data Bank. |
| **3.5. CONCLUSION** | |
| **Major advantages of each system** | |
| - Operational for GOES System.<br>- Data available in real time (alarm possibility at any time).<br>- Data available on interrogation. The rate of reports can be variable on request.<br>- Self-timed DCP capability. Allows DCP to be used without command receiver, lower cost.<br>- 70° N to 70° S near global coverage using international DCP .<br>- Length of sensor data DCP message 2000 to 5000 bits. | - Operational and redundant.<br>- Global coverage.<br>- Simple data collection platform.<br>- Low cost (2000 $).<br>- Low weight.(1000 g for electronics).<br>- Low consumption : 100 mW in average for 8 sensors data collection platform. |

| *GEOSYNCHRONOUS SYSTEM* | *LOW ORBIT SYSTEM* |
|---|---|
| 3.5. **CONCLUSION** (suite) | |
| **Major parameters choice between the two systems** | |
| - Low latitudes (70° N to 70° S) DCP operation.<br>- Real time needs.<br>- Alarm need without delay .<br>- Large messages (2000 to 5000 bits) .<br>- Operational (GOES system) . | - Operational 1979-1987.<br>- High latitudes (data collection every 50 minutes in the polar areas and only 7 times per day at the Equator).<br>- Two to six hours measurements distribution delay acceptable.<br>- Measurement only when satellite in visibility acceptable.<br>- Global scale data collection program<br>- Location needed (moving DCO).<br>- Less than 256 bits message (32 x 8 bits analogic sensors).<br>- Lower cost of DCPs. |

# 4. HYDROLOGIC DATA COLLECTION

## 4.1. HYDROLOGIC DATA

The water data collection programs are designed to provide - generally national - water data bases to guide the development and conservation of a critical natural resource. Hydrological data collection can be divided in two groupings :

- that required for archiving for future use (historical data)
- that required for real time decision making (real time data)

**Historical water data** are used for design of dams, reservoirs, water supply sources, waste treatment facilities, flood prevention structures, irrigation projects, flood-plain management plans, navigation facilities. Or in other words historical hydrologic data are being collected and archived for : planning, designing, constructing, operating water resources systems and for forecasting of hydrologic conditions ranging from droughts to floods.

A small but growing part of the water data collection programs presently is structured to provide *real-time hydrologic data*.

Real time data are being collected for real time decision making and provided to computer models that attempt to predict river conditions and optimize the operation of water resource-systems.

These models involve flood control operations, flood warnings and forecasts, and river forecasts, and river forecasts for the management, of electric power generation, navigation, water supply, irrigation and water quality.

**Hydrologic data also are collected** to support interdisciplinary research, in such as :

- *Agriculture* (rain, snow, hail)
- *Biology* : monitoring of water systems : water flow and temperature for study of migration route of animals and nutrient budget, rates of water release from impoundments influence both warm and cold waterfisheries, competing uses of water for man and animals have to be evaluated (Ecosystem cost/use analysis)
- *Ecology* : monitoring water quality parameters : water pollution arising from the activities of man by industrial effluents
- *Meteorology* : precipitation, snow accumulations...

## 4.2. MAJOR HYDROLOGIC DATA COLLECTION SITES EXISTING IN USA (1975)

| Agency | Water stage | Water quality | Ground water | Total |
|---|---|---|---|---|
| National Oceanic and Atmospheric Administration (NOAA) | 1,000 | | | 1,000 |
| US Geological Survey (USGS) | 18,000 | 6,000 | 18,000 | 42,000 |
| Environmental Protection Agency (EPA) | | 600 | | 600 |
| Corps of Engineers (COE) | 2,000 | 2,000 | | 4,000 |
| BUREC | 200 | 300 | 5,000 | 5,500 |
| STATE | 1,500 | 1,000 | | 2,500 |
| Total. . . . . . . . . . . . . . . . . . . | ≃23,000 | ≃10,000 | ≃23,000 | ≃57,000 |

Table 4.2. summarizes the major hydrologic data collection sites existing in the US in the year 1975 by major agency and type of measurement. This table shows the dominant role of USGS hydrologic network which is the largest operated by a single agency.

Not all of the 57,000 sites are potential candidates for telemetry or satellite relay (at some sites, the current state of the art of sensors, and/or budgetary constraints mandate that the data be collected physically. At other sites the data load is so small or is required so unfrequently as to negate investment for telemetry or satellite relay).
For example, for two major users (USGS and EPA respectively) :

- Total of existing sites : . . . . . . . . . . . . . . . . . . . . . . . . . . . . 42,000 4,000
- Total of potentially amenable to data telemetry (or satellite relay): 24,000
- Total addressable market (sites already equipped with data storage capability*) : . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .11,000 4,000

* the addition of telemetry for sites, already equipped with data storage capability represents a relatively manageable expense.

| TYPE | USA - CANADA 1975 Total number of sites to be needed | MEASUREMENT | | SENSOR | | REMARKS |
|---|---|---|---|---|---|---|
| | | Sampling rate | Frequency of transmission | LIFE | REPAIR INTERVAL | |
| Precipitation | 20,000 / 5,000 | 15 minutes | 3 hourly 5%-10% on demand | 10 years | 1 month | |
| Water level | 6,000 / 1,200 | 15 minutes | 3 hours | <10 years | 6 months | 5% - 10% required on demand |
| | 3,000 / 400 | 30 minutes | 3 hours | " | " | |
| | 3,000 / 400 | 1 hour | 3 hours | " | " | |
| Ground water Depth to water table | 10,000 / < 100 | 1 hour | Daily | 10 years | 6 months | |
| Snow depth | 300 / <10 | Daily | Daily | 10 years | 1 year | |
| Snow moisture equivalent | 2,000 / 200↗ | Daily | Daily | 5 years | 1 year | |
| Evaporation | 1,000 / 10 | Daily | Daily | 5 years | Weekly | |
| Water temperature | 900 / 100 | 1 hour | 3 hours | 1 year | 1 week | |
| Wind direction | 500 / 300 | 5 minutes | 1 hour | 5 years | 6 months | |
| Wind velocity | 500 / 300 | 5 minutes | 1 hour | 5 years | 6 months | |
| Soil moisture | 500 / < 10 | 12 hours | 12 hours | 5 years | 1 month | |
| Specific conductance | 400 / 75 | 1 hour | 3 hours | 1 year | 1 month | |
| Ice thickness | 300 / < 10 | Daily | Daily | 5 years | 1 year | |
| Air temperature | 300 / 300 | 1 hour | 1 hour | 10 years | 1 year | |
| Dew point-frost point | 300 / 300 | 1 hour | 1 hour | 10 years | 6 months | |
| Dissolved oxygen | 200↗ / 50 | 1 hour | 3 hours | 6 months | 1 week | |
| PH | 150↗ / 50 | 1 hour | 3 hours | 1 year | 1 week | |
| Water velocity | 100 / <10 | 6 minutes | 3 hours | 5 years | 1 month | USA only |
| Incoming solar radiation | 50 / <10 | Daily | Daily | 1 year | 1 month | |
| Net radiation | 25 / 10 | Daily | Daily | 6 months | 1 month | |
| River discharge | 10 / 5 | 3 minutes | 3 hours | 5 years | 6 months | |
| Ice presence | 5 | Daily | Daily | 1 year | 1 year | |

Table 4.3. – Types of hydrological parameters and estimate of the total number of stations of each type to be needed in North America in 1975.

## 4.3. TYPES OF HYDROLOGIC PARAMETERS AND ESTIMATE OF THE TOTAL NUMBER OF STATIONS OF EACH TYPE TO BE NEEDED IN NORTH AMERICA IN 1975

The hydrologic parameters listed in table 4.3. are essential to measure the phenomena described in paragraph 4.1. The numerator under the heading «Total number of sites» is the estimate of the total number of stations of that parameter type, to be needed in North America in 1975. The denominator is the estimate of the number of stations of that parameter type where real time data is required.

The table 4.3. gives also :

- **For measurement** :
  - The sampling rate : number of measurements taken from a single sensor per unit time.
  - Frequency of transmission : number of measurement (or collection) transmissions per unit time (when real time is not needed this frequency is not critical and can be once a day or less often).
- **For sensor** (developped in 1975)
  - Life : period of operation of the sensor with repair or attention (cleaning...)
  - Repair interval : period of time without repair or attention.

## 4.4. DATA COLLECTION HYDROLOGIC STATIONS

### 4.4.1. Definition of the number of bits per sample or measurement

The number of binary digits which express the number of possible levels of the measure range.

***Example*** :

- *range* : 0-100 deg.C
- *resolution* : 0.1 deg. C
- *number of levels* : (range)/(resolution) = 1,000
- *express number of levels in binary bits* : Since 512 can be represented by 9 binary bits ($2^9$) and 1024 can be represented by 10 bits ($2^{10}$) ; bits per sample : 10.

### 4.4.2. Data collection hydrologic stations. Number of bits per sample

Many of the preceeding types of parameters can be colocated at a common observation point or data collection hydrologic stations. For example, a water level station with two sensors :

- water level sensor
- precipitation sensor

The number of bits per sample is calculated in detail (according to the characteristics of the sensors).

- **Water level station**
  - *Water level sensor*
    - Range : 0 to 99 feet
    - Resolution : 0.01 foot
    - Number of levels : 99/0.01 $\simeq$ 10,000
    - Bits per sample : since $2^{13}$ = 8,192 levels and $2^{14}$ = 16,284 levels, 14 bits per sample are necessary
  - *Precipitation sensor*
    - Range : 0 to 99 inches/hr
    - Resolution : 0.1 inches/hr
    - Number of levels : 99/0.1 = 1,000
    - Bits per sample : 10
  - *Total number of bits per sample*

  Each sample including water level and precipitation measurements : 24 bits.

The same evaluation has been done for other types of stations such as :

| | Number of bits per sample (see definition) |
|---|---|
| **Snow station** | |
| - Snow moisture equivalent | 10 |
| - Snow deph | 12 |
| | 22 |
| **Atmospheric station** | |
| - Air temperature | 12 |
| - DEW/FROST point | 11 |
| - Wind direction | 9 |
| - Wind velocity | 8 |
| - Incoming solar radiation | 7 |
| - Net radiation | 7 |
| | 54 |
| **Water quality station** | |
| - Water temperature | 10 |
| - Specific conductance | 6 |
| - Dissolved oxygen | 6 |
| - pH | 7 |
| - Water level | 14 |
| | 43 |
| **Water level station** | |
| - Water level | 14 |
| - Precipitation | 10 |
| | 24 |
| **Ice presence** | |
| - Ice presence | 1 |
| - Ice thickness | 8 |
| | 9 |

These numbers of bits must be compared to the characteristics of satellite DCP.

***Report message***

Number of bits for sensor data (per message) (see 3.2.)

- 2000 to 5200 bits for synchronous system
- 256 bits for ARGOS System.

There is no data limitation problem with the two systems if each message sent by the DCP is really received by the satellite. That is always the case for geosynchronous systems : the satellite remains in view of the DCP.

For low altitude systems using drifting satellites, a satellite is not generally in view of the DCP when the measurements are made so that DCP must have storage capability.

### 4.4.3. Limitations of low orbit system. Characteristics of TIROS N-ARGOS system

***(a) Collection transmission frequency***

The visibility performance of the TIROS/ARGOS System is depending on the hydrologic site latitude.

The number of passes per day is summarized in table 4.4.3. (the average duration of a pass is ten minutes)

At the Equator transmitted data is collected 7 times per day

At the poles transmitted data is collected 28 times a day or every 50 minutes.

Table 4.4.3.

| Latitude | Number of passes per 24 h |
|---|---|
| ± 0° | 7 |
| ± 15° | 8 |
| ± 30° | 9 |
| ± 45° | 11 |
| ± 55° | 16 |
| ± 65° | 22 |
| ± 75° | 28 |
| ± 90° | 28 |

The collection transmission frequencies per 24 hours (according to the latitude) are roughly, the numbers of passes.

At the poles, the collection period is 50 minutes (in average). At the Equator, the time between each of the 7 passes is not constant (variation from 100 minutes to 300 minutes).

| Low orbit satellites cannot be used for real time monitoring |
|---|

***(b) Number of samples per collection interval***

*Definition* : total number of measurements of the parameters taken during the collection interval (or period).

(Number of bits per sample) x (Number of samples per collection interval*) = Number of of bits to be transmitted.

*The ARGOS message capacity for sensor data is 256 bits*

*Example : Data from «water quality station»*

One can see 4.4.2. that 43 bits per measurement are necessary, 256/43 ≃ 5 successive measurements can be stored without exceeding the ARGOS message.

The needed sampling rate for water quality parameters (see table 4.3.) is 1 hour.

The maximum collection interval can be 5 hours (without exceeding the 256 bits Argos message capacity).

* assuming that DCP has a storage capability.

Argos low orbit satellite system meets the data requirements (for the «water quality station») *at any latitude* for the number of bits to be collected and transmitted (maximum time interval between two passes 5 hours).
Argos low orbit satellite system does not meet the data frequency transmission requirements of 3 hours (see table 4.3.).
This example shows the capability of this system in terms of data collection (in the worst case i.e. at the Equator). It shows also the limitations of this system in terms of measurement-to-collection delays.

## 4.5. NORTH AMERICA USERS OF DATA COLLECTION IN HYDROLOGY

### 4.5.1. U.S. Geological Survey

The US Geological Survey operates a network of hydrologic sensors that automatically record the data on sites. These data routinely :

- are manually retrieved at intervals of 4-6 weeks,
- are manually prepocessed,
- entered into the geological survey's national telecomputing network.
  (computer center in Reston, Virginia with two 370/155 computers and a network of over 180 remote computer terminals accross the USA).

This network is used to perform most of the Survey's basic hydrologic data processing and hydrologic analysis with the Survey's WATSTORE System (water data storage and retrieval system). WATSTORE is a collection of computer programs and files that are used by the Survey to process virtually all the water-resources data that the Survey collects.

One of the tasks being undertaken is the experimental use of the WATSTORE system for processing and filing the satellite data relayed from three different satellite data collection systems (see figure 4.5.1.).

- All DCS data relayed through the Landsat system are routinely sent in real time to the Landsat Operation Control Center in the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center in Greenbelt, Maryland. Under a NASA-US Geological Survey agreement, these data also are sent in real time via a dedicated line to Reston where they are recorded on a 9-track magnetic tape recorder. Periodically these data are transferred to an on line disk file in the Reston computer center, where programs are available to retrieve, process and disseminate the data over the remote terminal network.
- All DCS data relayed through the SMS/GOES system are routinely received by a National Oceanic and Atmospheric Administration/National Environmental Satellite Service (NOAA/NESS) tracking station at Wallops Island, Virginia, and sent in real time to the NOAA World Weather Building in Suitland Maryland. These data are filed in a NOAA/NESS mini-computer. Under a NESS-Geological Survey agreement, this mini-computer, one or more times a day, will sign on to the Reston computer and will enter a computer job containing all of the Survey's DGS data that have been accumulated since the last time of data entry. These data then are processed and placed in an on-line file in the computer for retrieval.
- The DCS data to be relayed through the commercial COMSAT General system will be accumulated at the COMSAT General earth station in Southbury, Connectitut. The DCS data will be periodically and automatically transferred from a Comsat General Computer to the Reston computer where they will be filed on an on-line

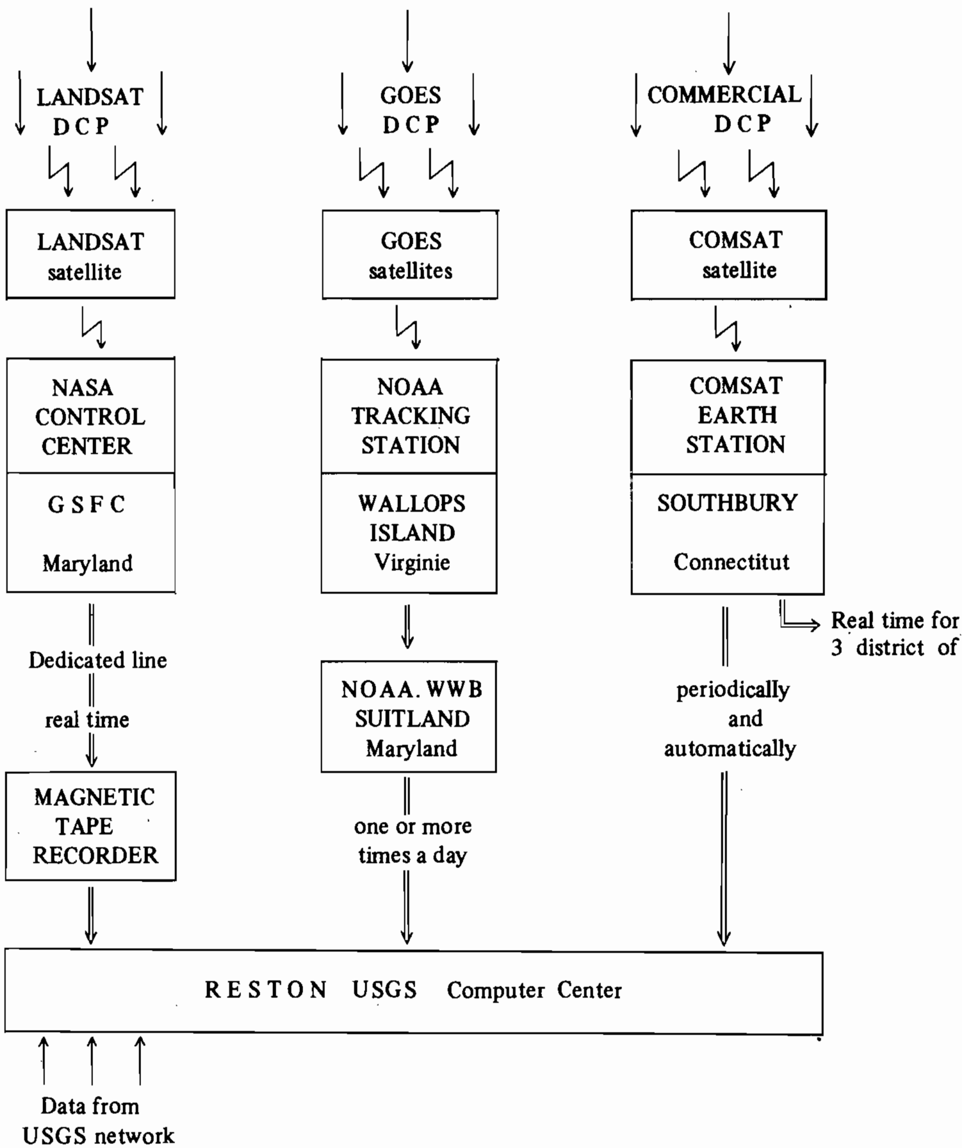



Fig. 4.5.1. – Testing of the satellite Data Collection Systems by USGS

disk file. In addition to the data being made available to the Reston computer, it also will be possible for the two US Geological Survey district offices in Harrisburg, Pensylvania, and Fortland, Oregon, to use their Reston computer - compatible terminals to occasionnally connect to the COMSAT computer to directly retrieve unprocessed real-time data.

The automatic collection of data in real time offers two benefits :

- the first is that the real time processed data can be used to monitor the performance of the instrument network (stations are visited only when instruments fail or conditions warrant the collection of supplementary data - when water quality or discharge is outside the normal range).
- the second is that a real time data service can be offered to the water resources management community (growing pressure of municipal, industrial use and environmental protection).

The increasing cost of manpower, the decreasing cost of electronics, and cost effectiveness of satellite telemetry probably will result in an eventual automation of the collection of hydrologic data.

*Note 1* : USGS made in 1975 an experimental integration of the LANDSAT data collection system with the geological survey's network. The objective of this experiment was to simulate an operational system for collecting, relaying, processing and dissemination hydrologic data. About 90 DCP in 24 USGS districts, were used for the experiment.

*Note 2* : The water resources division of the USGS in installing (1977) over 120 self-timed DCPs to operate with GOES for the collection of hydrologic data.

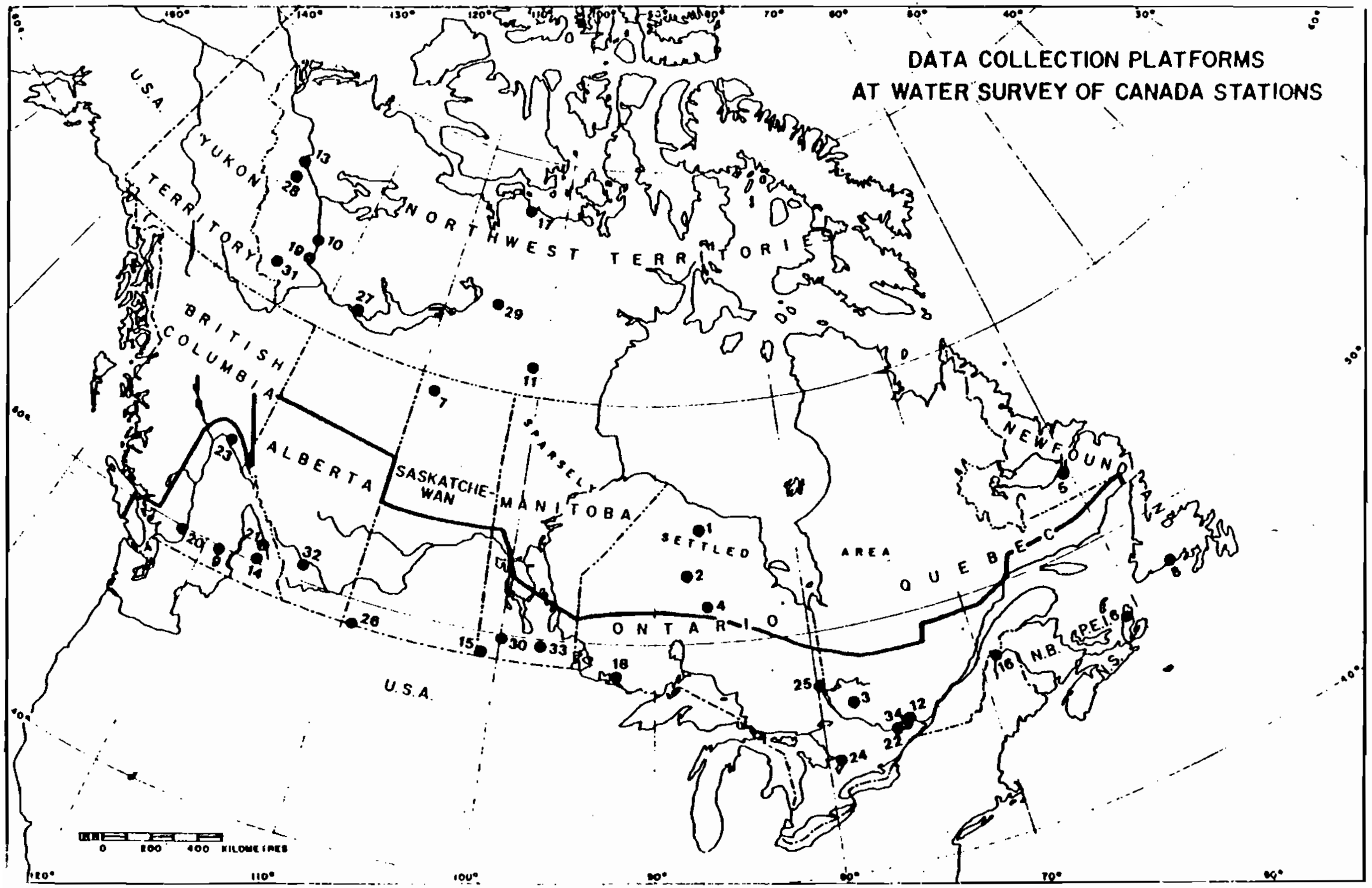
### 4.5.2. **Canadian User** (Applied Hydrology Division, Department of the Environment, Principal Investigator : R. HALLIDAY)

The role of Water Survey of Canada (similar to USGS in USA) is that of monitoring river flows and lake levels at about 2400 gauging stations under agreement with the Provincial governments and making the data available to users. The water survey operates about 100 water telemetry systems using telephones lines. For the vast majority of the gauging stations, however, it is prohibitively expensive to install either telephone or radio telemetry systems.

In response to a demand for near real time data from additional sites, it was decided to implement a network of about 30 sites on a quasi operational basis using LANDSAT 1. Some typical examples of data uses are as follows :

- 6 DCPs were used in the Mackensie River basin to provide data for the preparation of daily water level forecasts during the short navigation season.
- 3 DCPs were installed in the Ottawa river basin and one on the Saint John River to provide data for input into streamflow synthesis and reservoir regulation models of the watersheds.
- 1 DCP was installed on the Severn River. This gauging station on the Trent-Severn Waterway is below the confluence of several small streams, all of which are regulated. The river is also regulated downstream from the DCP site. Water level and water velocity data are used to compute river discharge. Water temperature data are also transmitted to assist in winter flow computations.

The location of the sites are illustrated in figure 4.5.2.


DATA COLLECTION PLATFORMS
AT WATER SURVEY OF CANADA STATIONS
U.S.A.
YUKON TERRITORY
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
NEWFOUNDLAND
N.B.
P.E.I.
N.S.
SETTLED AREA
SPARSELY
U.S.A.
0 200 400 KILOMETRES

ig. 4.5.2. (Ref. 16).

The sensors used with the DCP are summarised as follows :

| Paremeter | Sensor |
|---|---|
| Water level | Float pressure |
| Water velocity | Electromagnetic acoustic |
| Ice condition | Electro-mechanical |
| Precipitation | Weighing type |
| Air temperature | Platinium resistance bulb |
| | Thermister |
| Water temperature | Thermister |
| Snow water content | Snow pillow |

*Data handling and processing*

All messages relayed by LANDSAT are received in Alaska, California and Maryland, then sent over Nascom lines to the GSFC Maryland.
The Canadian messages are sent by teletype to the Canada Centre for Remote Sensing in Ottawa, usually within 15 to 20 minutes after each LANDSAT pass. A software data retrieval system sorts the user data platforms, reformats the data into engineering units and stores individual user files on disk. A user may then access the file usually daily, using a teletype or telex remote terminal.
Data are also sent by punch cards and uncalibrated computer listings which arrive about two weeks after transmittal by the DCP. The data received on a near real-time basis are usually discarded a short time after use, but the data received in card form are retained for archival purposes and to develop statistics on DCP performances.

*Significant results*

The LANDSAT program has demonstrated that the polar orbiting satellites can be used to relay hydrologic data from any part of Canada to a user without difficulty and at low cost. These data can be used for many operational purposes such as :

- hydroloelectric power plant operation
- water supply for municipalities, industries and irrigation
- navigation
- flood forecasting
- operation of flood control structures and systems
- recreation

*Benefits*

There are several ways in which real time data acquisition can aid hydrometric field operations : these are :

- **planning of field trips** : If the real time data indicates that all sensors at a site are operating normally and if flow conditions are such that a discharge measurement is not required, then a visit to the station can be omitted.
- **planning of sensor maintenance** : If real time data indicate a sensor malfunction it is usually possible to diagnose the problem by examining the incoming data. A decision can be made whether immediate repairs are warranted, or whether maintenance should be included on the next scheduled trip into an area. In either case the repair is completed in one trip where otherwise two may be needed (one to discover the problem, the second to do the repairs).

- **Filling in missing record** : when field recorders have stopped but sensors continue to function, the real time data can be used to fill in data that would otherwise be missing.
- **Primary collection of data** : If the cost of acquiring real time data and the reliability of the system proved better than using in situ recorders, then satellite telemetry could be used as a primary means of data collection.

The current capital cost of satellite telemetry of water level data in Canada is about $5,000 for a DCP plus $1,000 for a water level encoder.
Operating costs of a DCP are small and about $100 a year (repairs). These costs does not include processing and dissemination charges.

*Future*

The deployment of DCPs in Canada proceeded at a relatively slow pace. The principal reason has been the lack of an operational satellite system. The service provided by LANDSAT is excellent but the system is experimental and therefore cannot be used as the basis for any long term project.
The operational GOES system often cannot be used in mountainous or high latitude areas because of antenna aiming problems. It now seems likely that the Water Survey of Canada will select GOES self-timed DCPs at all sites where it is technically feasible and will use the TIROS N-NOAA-ARGOS system where GOES is not feasible (this assumes of course, that the ARGOS System meets published specifications). A contract for development of an ARGOS-GOES DCP has recently been awarded to a Canadian company.

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Ref. 11 – New ventures in satellite communications, Comsat General Corp., 950 L'Enfant Plaza S.W., Washington, DC 20024, USA.

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Ref. 14 – *DCS platforms were used to provide operational data to control water flow during flood stages of Salt River in March 1973. DCS System proved more reliable and useful than microwave system now in use.*
State Department of Water Resources USGS ; Watershed Division, Salt River Project ; William WARSKOW, Lead Watershed Specialist, Watershed Div. Salt River Project, Po Box 1950, Phoenix, Arizona 85001, (602) 273-5680 ; Herb SCHUMAN, USGS, Phoenix, Arizona, 8 (602) 262-318 b ; USA.

Ref. 15 – *A DCP network (20 platforms) and ERTS imagery are being used to monitor and make environmental assessments and manage the water resources of 3500 sq. kilometers in the Everglades. Proved particularly useful during the 1973-74 winter spring draught where damage was minimized by planning based upon accurate knowledge of the water stored in the various lakes, canals and conservation areas. Soil moisture sensors on the DCP's are also being used to warm of potential fire hazards.*
Florida Fish & Wildlife Office USGS, Corps of Engineers US Forest Service.
David COX (305) 724-1571, Edward VOSATKA, Florida Game and Fresh Water Fish Commission, 7630 Coral Drive, West Melbourne, Florida 32901, USA.

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