Lecture 1
14 September 1983
I.A.

Historical Overview of Meteorological Satellite Systems in the United States.

The launch by the Soviet Union of Sputnik I on October 4, 1957 dramatically demonstrated the practicality of placing an ~~artificial~~ satellite in orbit around the earth. It also served to shock the United States out of its technological complacency and started the "space race". Fortunately for meteorology, the concept of artificial earth satellites for weather observations had been considered by several people since the late 1940's.

A crude imaging system for observing clouds was being developed by Stroud and colleagues for flight on the ~~Vanguard~~ ill-fated Vanguard satellite series. Suomi also was developing his first earth radiation budget experiment for Vanguard. Neither ~~were launched~~ were successful on Vanguard. However Suomi's radiation experiment operated successfully on Explorer VII launched in 1959. A crude photocell on the spinning Explorer VI provided a crude cloud image -- so crude it was only a curiosity -- on April 15, 1959.

In late 1958, plans existed for a satellite to be equipped with television cameras. These plans were picked up and modified, beginning in April 1958, to become the first weather satellite -- TIROS I -- launched successfully on 1 April 1960, just two years later!

~~Rocket~~ pictures of clouds taken in the late 1940's from German V-2 rockets launched in New Mexico, USA, showed the potential of such observations from satellites in earth orbit, if and when feasible. The concept of such a satellite was put forth by Kellogg and Greenfield in 1951, based on these rocket photos. But it took the impetus of Sputnik I and the U.S. governments decision to place a high priority on the development of space technology to produce TIROS I.

It was a simple satellite and produced pictures that were crude by today's standards. Even though they were crude, they were good enough to see major storms and fronts, particularly over the oceans where inadequate weather observations were available. Indeed, within sixty hours of launch, cloud analyses -- or "nephanalyses" from the Greek word for cloud -- were being produced from the TIROS I pictures and distributed by facsimile transmissions to weather forecast offices.

Although intended to be an experimental research satellite, the crude results of TIROS I were good enough that planning was begun in ~~early~~ October 1960 for a ~~possible~~ operational satellite system. It came into being in 1966 with the launch of ESSA 1 and 2. However, the early TIROS series was continued through 1965 to provide some operational continuity and to test new space techniques.

Fig. 1-1

TIROS Polar-Orbiting Global Operational Meteorological Satellite System Evolution

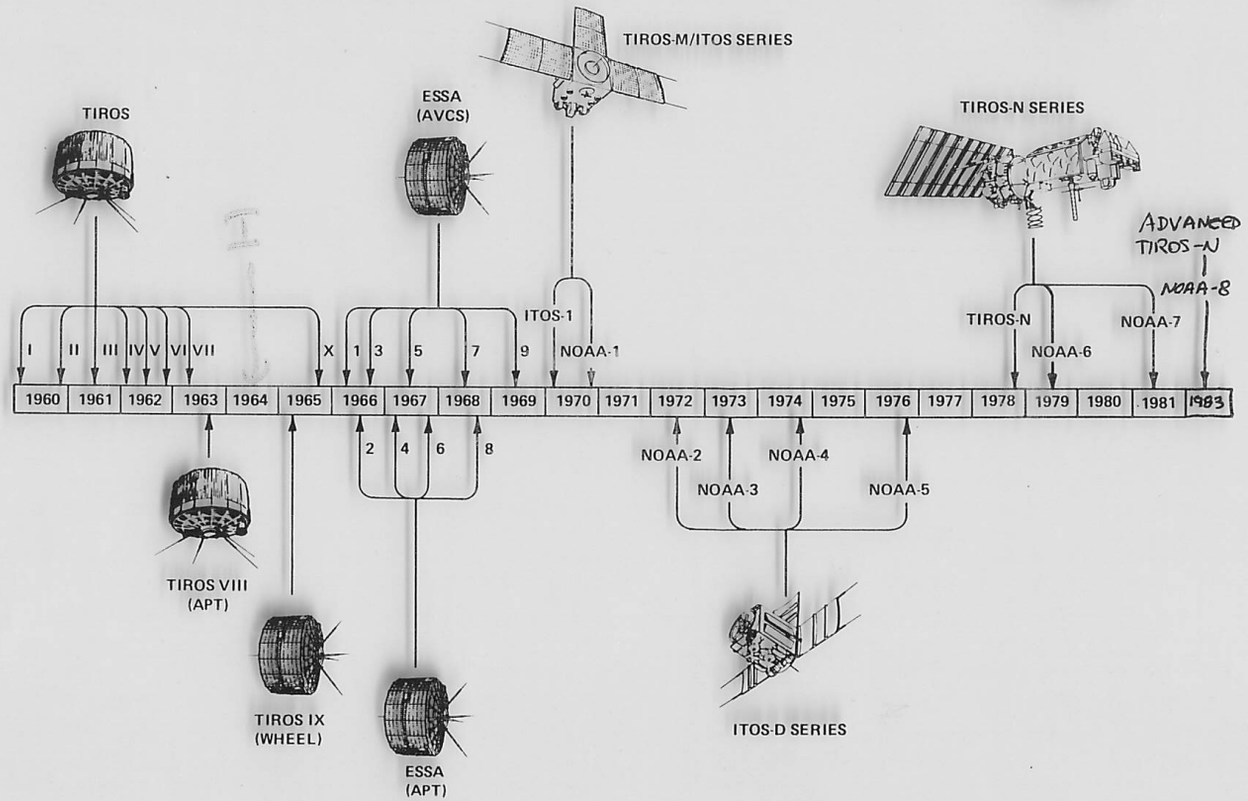


Fig 1-1: (Vu-graph of polar satellite schedule and evolution)

TIROS I design based on early technological constraints:

- RCA vidicon tube being developed was small (1.5 cm. dia), light weight and low power consumption. But resolution limited to 500 lines. Forces compromise between coverage and resolution.
- First tape recorders for space use could only store a small number of images. (14? per recorder, one recorder for each camera.)
- Launch vehicle (Thor-Able) of very limited performance dictated:
  - Small spacecraft, thus limited capability.
  - low altitude
  - limited inclination.
- No ~~active~~ active stabilization system developed at that time.
  - Spin stabilization - like gyroscope - chosen. (Explain satellite axis vs earth's axis.) | Spin rate limited by camera smearing
- Combined effect of orbit and stabilization on coverage.

~~Fig 1-1 (Vu-graph of polar satellite time history; keep on during discussion)~~

✓ Fig 1-2: (Slide, TIROS II cut-away drawing.)

TIROS spacecraft: ~~2 ft~~ (61 cm.) high x about 1m. dia. weight = 129 Kg.

- Two cameras w/optic axes ∥ spin axis. Explain resulting limited coverage.
  - Narrow + wide angle lenses used on TIROS I and II.
  - Beginning with TIROS-III, used wide angle lenses only.

    WHY? Coverage more important than resolution
    Problem of small field of view within large.
    Importance of redundancy for continuity.

Figure 1-2 : 5 cm. x 5 cm. slide

Cut-away drawing of TIROS II Spacecraft.

NOT AVAILABLE

- Point out other components in slide
  - IR package and magnetic orientation coil added to TIROS II. (Return to these later.)

* The mystery of the spin axis/optic axis "wandering.
- Sean Twomey (now prof., Univ. Arizona) diagnosis.
- Led to discovery of magnetic stabilization added to later spacecraft.
- Magnetic coil added to TIROS II to compensate for electrical current flowing in wiring of s/c.

Fig. 1-1 (vu-graph).

- Infrared scanning on early TIROS (e.g. TIROS II) using spacecraft motion to generate scan proved too difficult to reconstruct scan lines on earth surface.
- TIROS III — Adopted dual wide angle cameras (for reasons explained earlier).
  - Suomi's earth radiation balance sensors added. Hemispheric detectors on rim of s/c, white and black to give total solar and terrestrial radiation fluxes at the s/c.
- TIROS VIII — First use of Automatic Picture Transmission (APT),
- TIROS IX — First global daylight coverage resulting from
  - First launch into sun-synchronous orbit, and
  - Moving cameras so they view perpendicular to spin axis.
- ESSA series operational spacecraft.
  - Based on TIROS IX spacecraft plus APT and AVCS (2.5cm. dia vidicon) cameras developed in Nimbus R+D program to double the resolution.

[Briefly describe Nimbus program and role in developing sensors, many of which entered

the operational system -- such as APT, AVCS, ~~HR~~ VHRR, HIRS, are planned to do so -- such as SBUV, may do so -- such as CZCS, or established validity of new technique -- such as SIRS. Seven Nimbus S/C launched from 1966 to 1978; the last is still operating after almost 5 years in orbit. No more are planned.

Nimbus also one of the first 3-axis actively stabilized spacecraft to be used. (Momentum wheels + gas jets to "unload momentum".)

Plans to use Nimbus as operational spacecraft dropped because of its complexity and cost (at the time of decision in 1963).]

ESSA series considered operational stop-gap because it was too small to accommodate <u>new</u> or <u>improved</u> sensors, and lack of <u>nighttime</u> coverage because infrared sensors could not be used on spinning spacecraft effectively--

* needed a bigger box and three axis stabilization, plus more power.

Enter the ITOS (TIROS M) spacecraft — (1970)

Figure 1-3 (Vu graph) ITOS-D S/C

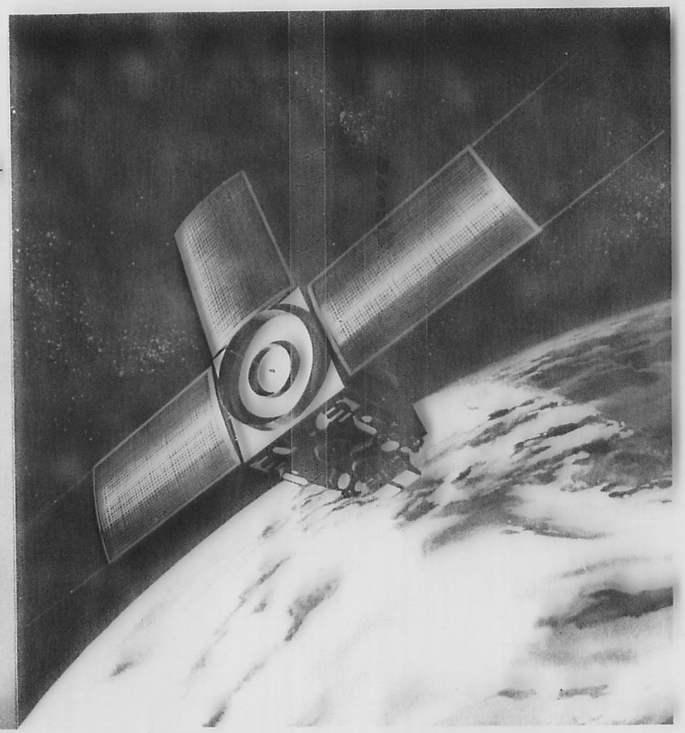
Key items: o Add momentum wheel to resemble spinning TIROS S/C (spin at higher RPM to compensate for lower mass.) Continue the use of magnetic torquing coil to orient the spin axis of momentum wheel. Add a servo-controlled (by earth sensors) to "despin" a box containing the sensors and electronics.

Fig. 1-3

RCA

ITOS

CUSTOMER	NASA/NOAA
MISSION	OPERATIONAL, METEOROLOGICAL
ORBIT	790 TO 820 nmi
DESIGN LIFE	1 YEAR
BOOSTER	DELTA 2310 (CONTRACTOR LAUNCH)
WEIGHT, S/C TOTAL	750 LB
PAYLOAD	225 LB
AVERAGE POWER, TOTAL	145 W
PAYLOAD	105 W
MAXIMUM ARRAY POWER	400 W
ATTITUDE CONTROL	MOMENTUM BIAS
LAUNCHES	8



Thus, the original problem of TIROS I and the "cartwheel" approach of ~~TIRO~~ TIROS IX have been married to produce a simple 3-axis stabilization system!

- Add three solar panels for more power.
- Flexible box with hinged sides for ease of assembly and repair.
- Evolution of Delta launch vehicle allowed
  - Higher orbit for better viewing angles. [Radiation hardening!]
  - Heavier s/c in sunsynchronous orbit. Could have full redundancy of both AVCS and APT in <u>one</u> spacecraft instead of two, with space for new sensors.

<u>Added</u> ~~Very High Resolution Radiometer (VHRR)~~ Scanning Radiometer (SR) to provide medium resolution, global operational coverage both day and night. (AVCS and APT continued temporarily for operational transition and to prove reliability of ~~VHRR~~ SR.)

Why scanning radiometers instead of TV?

- Precision of measurements of radiation intensity.
- Superior sensitivity and stability of reflective optics + detectors.
- Can measure throughout the visible and IR spectrum.

Figure 1-4 (Vu-Graph) - ITOS evolution.

Point out bottom of ITOS 1 - NOAA-1 s/c with 2 each AVCS, APT cameras and ~~VHRR's~~ SR's.

ITOS-D design (NOAA 2-5) dropped all TV cameras. APT signal derived from ~~VHRR~~ the SR. Could now add Very High Resolution Radiometers (VHRR) with

Fig 1-4

RCA

TIROS Satellite Evolution

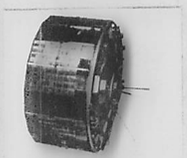
NOAA

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

TIROS R & D

2 FT, 283 LBS

TIROS IX (Wheel)



2 FT, 320 LBS

TOS

ESSA-AVCS

2 FT, 340 LBS

ESSA-APT

2 FT, 300 LBS

ITOS

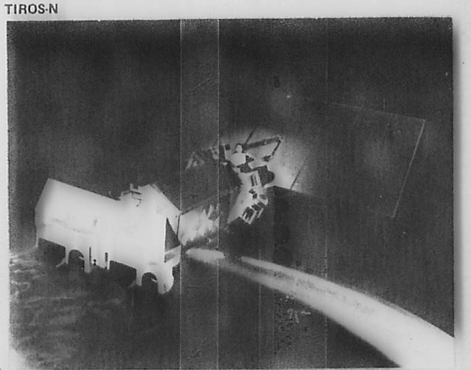
ITOS-1

4 FT, 690 LBS

NOAA-2

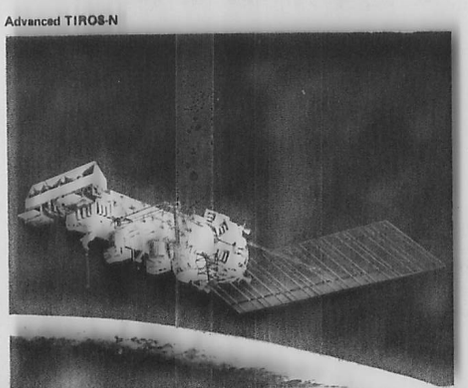
4 FT, 750 LBS

TIROS-N



12 FT, 3,127 LBS

Advanced TIROS-N



14 FT, 3,800 LBS

High Resolution Picture Transmission (HRPT). Also first operational sounder: the Infra-red Temperature Profile Radiometer (ITPR).

The ITOS ~~series~~ s/c served the operational system faithfully from 1970 to 1978-79 when the TIROS-N series was introduced.

Main driver for TIROS N was to improve the temperature soundings and sea surface temperatures needed for numerical weather prediction, including the Global Weather Experiment and the WWW.

These dictated a larger s/c and more solar power. To save the cost of developing a new s/c, an existing design for a military weather satellite was adopted but with entirely new sensors. The use of this s/c forced two compromises: It was designed for use at an altitude below about 900 km, thus it was not radiation-hardened for use at the higher altitude of the ITOS series. It was not large enough to carry fully redundant sensors and subsystems for reliable, continuous operation.

Therefore, the existing design necessitated:

1. Two s/c in orbit for reliability (and coverage, because of lower altitude).
2. Some sacrifice in viewing angle in the tropics at point of contiguity of coverage between adjacent orbits

A bonus of the two-s/c system is more frequent coverage when both s/c are operational.

Figure 1-4 (Vu-Graph): Comparison of ITOS - TIROS N - Adv. TIROS N. Advanced TIROS-N has a "stretched body" to accomodate more systems than TIROS N and providing "growth capability" for experimental or new sensors.

	TIROS-N	Advanced TIROS-N
Operational	AVHRR (Advanced Very High Resolution Radiometer)	AVHRR
	TOVS (~~HRR~~ HIRS, MSU, SSU)	TOVS {TIROS Operational Vertical Sounder}
	ARGOS {Data Collection & Location System}	ARGOS
	SEM (Solar Environment Monitor)	SEM
		SBUV
Experimental		Search + Rescue (SAR)
		ERBE {Earth Radiation Budget Experiment}

The need for more frequent observations, especially of severe storms, led to the desire for a geostationary satellite for meteorology.

- Uniqueness of geostationary orbit, 36,000 km high.
- Problem of detector ~~stab~~ sensitivity + spacecraft stabilization in the mid-1960's.
- Suomi's idea and Newell's (NASA's) gamble. The "pin-hole" spin-scan camera, "retrofitted" on ATS-1. Single visible channel, launched ~ 1966, provided the remarkable sequences of images which permitted the continuous tracking of serious storms such as typhoons.

  Use of VHF transmitter on ATS-1 also demonstrated WEFAX system of broadcasting pictures and

weather charts to low cost receiving stations adapted from those suitable for APT reception.

- A three-channel version of the camera, for color images, was also flown on ATS-3 in 1967. While the color failed after a short time, the black and white images from ATS-1 and 3 were used for several years until operational system introduced in 1974.
- Discovery by Suomi: Stability of the spacecraft (spin-stabilized) + camera scanning system (s/c spin plus stepped mirror) permitted "moving pictures" of clouds with sufficient precision to obtain useful estimates of upper air winds.
- Dramatic results for storms led to prompt government approval to introduce operational, two-s/c system.
  - Spin stabilization still used.
  - New spin-scan camera: The Visible-Infrared-Spin Scan Radiometer (VISSR).
    - Added thermal infrared channel for 24hr. viewing
    - Increased visible resolution to 1 km.
  - Added Data Collection System (DCS). (Puerner)
  - Implemented in 1974 with launch of Synchronous Meteorological Satellite (SMS)-1. Followed by SMS2 and GOES (Geostationary Operational Environmental Satellite)-1 through 6. Two more are being built.

This brief historical summary shows the importance of unexpected events and discovery, coupled with the ingenuity of individuals in the government, universities and industry in shaping the ~~evolu~~ evolution of the operational meteorological satellite system of the United States.

In the next two lectures, I will ~~look~~ cover in more detail the polar and geostationary satellites respectively. In the fifth lecture, I will present my (prejudiced) views of the outlook for future developments of the operational systems.