P2.3

GOES/R DATA DISTRIBUTION VIA COMMERCIAL TERRESTRIAL AND C-BAND SATELLITE SYSTEMS

Richard H. Warren, Computer Sciences Corporation (CSC)
Shyam Bajpai, Ph.D., NOAA/NESDIS/OSD, SSMC1, Station 5218 *

1.0 INTRODUCTION

The data rate generated by the next generation of Geostationary Orbiting Environmental Satellites (GOES/R and subsequent satellites), planned for initial launch in the 2012 time frame, will be substantially higher than that of the current rate of 2.1 Mega bits per second (Mb/s). The current operational concept uses GOES as both a data collection and data broadcast platform but the existing satellite down link, satellite broadcast electronics and ground distribution systems will not be adequate to support this higher data rate (expected to be in the range of 50 to 100 Mb/s). Therefore, several studies are being conducted to explore flexible, reliable and cost-effective options to the current methodology that will allow users to continue to receive this data.

One series of studies (**Refs. 1** and **2**) was conducted to explore the technical and economic aspects of using commercial communication systems to distribute/rebroadcast GOES/R data. Current and projected future communications technologies provide considerable more options than were available 30 years ago when the original GOES distribution concept was developed. **Table 1** describes some of these technology changes.

	30 Years Ago	Present and Near Term	20 Years in Future
Satellite	• Limited coverage • Low data rates • Large receive antennas • Very expensive	• Ubiquitous coverage • Medium/high data rates • Smaller antennas • Moderate cost	• Very high data rates • $\leq$1Meter antennas • Low cost
Cable TV	• Limited availability • Analog only	• Better availability • Moving to digital	• Virtually universal availability • All digital
Cable TV modems	• No	• Some implementations in major areas	• Near universal
Internet	• R&D stage	• Most locations	• Virtually all locations
Wireless	• Limited • Analog	• Majority digital • Cellular • PCS • Some Wi-Fi	• Advanced digital • Cellular • PCS • Broadband • Advanced Wi-Fi
Higher order modulation methods (more bits per Hertz)	• No	• Some in use	• Major implementations
Data Compression	• Limited use	• Significant compression	• Major improvements
Broadband Wireline	• None	• xDSL	• Fiber-to-the-home
Optical Fiber	• R&D phase	• Long distance only	• Fiber-to-the-home

Table 1. Changes in Communications Technology

* *Corresponding author address:* Shyam N. Bajpai, Ph.D., 1335 East West Highway, Silver Spring, MD 20910, e-mail: shyam.bajpai@noaa.gov

The current GOES system consists of two operational satellites (GOES East and GOES West) positioned over the equator at the geosynchronous altitude of 35,786 km. At this altitude, the satellites rotate around the Earth at the same speed as the Earth rotates underneath them and therefore the satellites appear stationary to an Earth observer. GOES East, at 75^o longitude, and GOES West, at 135^o, have a commanding view of North and South America and portions of the Atlantic and Pacific Oceans (see **Figures 1** and **2)**. The GOES primary data-gathering onboard instruments are the Imager and the Sounder. The Imager is an imaging radiometer designed to sense radiant and solar reflected energy from the Earth. The Sounder is a radiometer that senses specific data parameters for atmospheric vertical temperature and moisture profiles, surface and cloud top temperatures, and ozone distribution.

In the current operational system, the raw Imager and Sounder data is down linked from each GOES to Wallops Island, Va., at a data rate of 2.6 Mb/s, where it is geo-located/calibrated and reformatted into 2.1 Mb/s GOES Variable Rate (GVAR) data. The GVAR data is then transmitted back to the GOES satellite where it is amplified, shifted in frequency and broadcast to Earth at L-band frequencies. It is available to any user with compatible L-band satellite receiving equipment.

It is expected that the future Imager and Sounder will produce higher resolution data with a data rate in the range of 50 to 100 Mb/s which the current onboard distribution systems will not be able to accommodate without major upgrades. As pointed out in the Lincoln Labs study (**Ref 3**), in addition to greater frequency spectrum, additional satellite DC and RF power, more complex modulation methods and/or a larger satellite antenna would be required to maintain this dual function role. Greater DC/RF power and/or a larger antenna have substantial weight and physical envelope implications for the GOES/R satellite. The additional spacecraft electrical power and the added spacecraft weight necessary to augment the existing onboard data distribution equipment to handle this increased data rate may make these changes uneconomical.

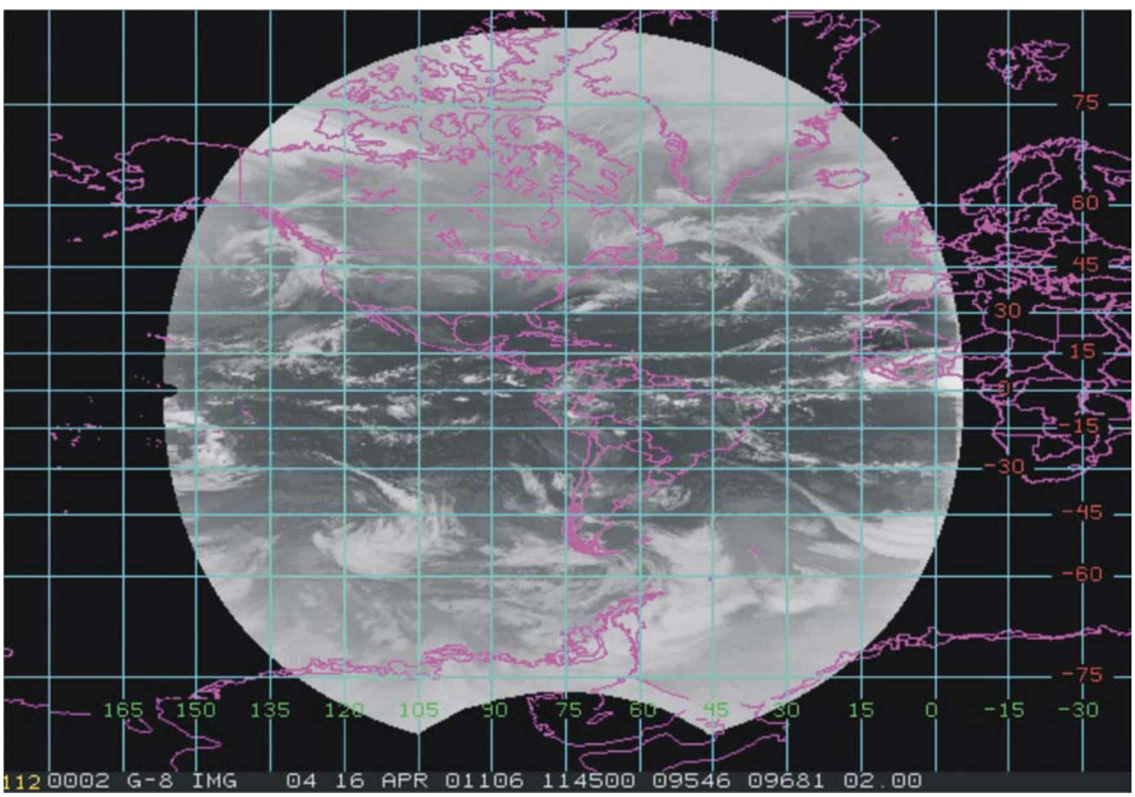


Figure 1. GOES East

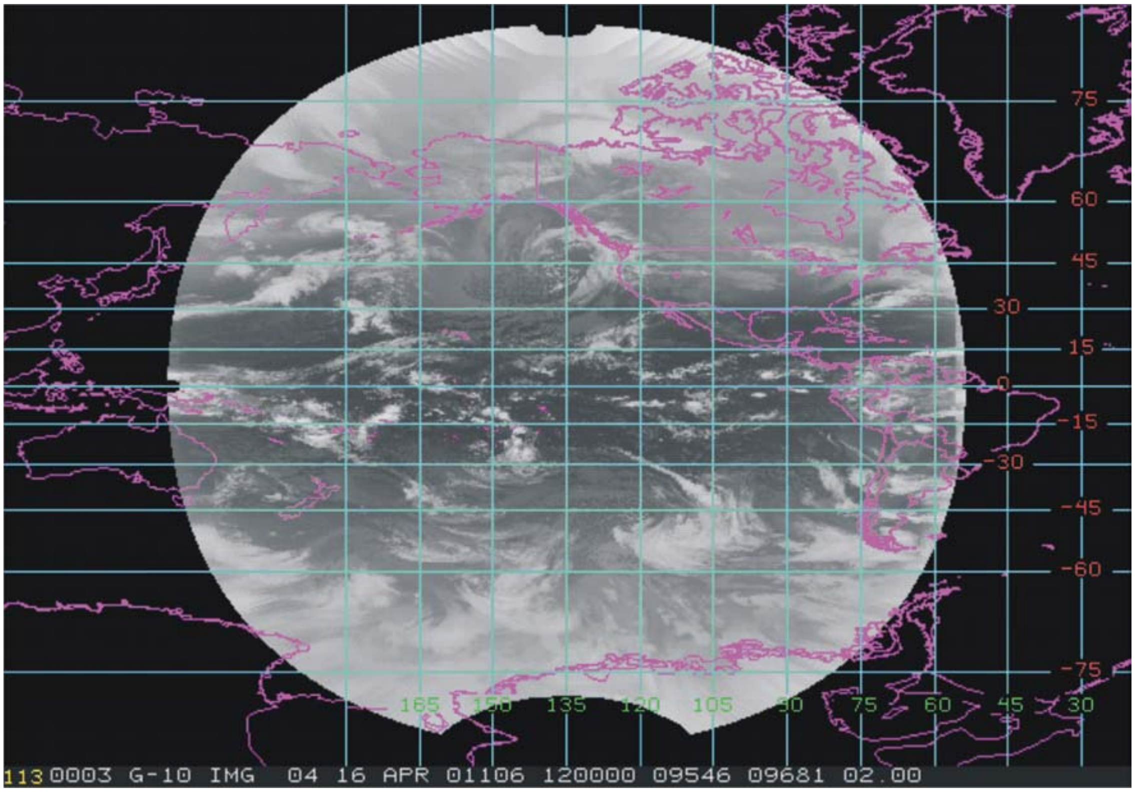


Figure 2. GOES West

For the past several years, NESDIS has been studying available options for data distribution for the GOES/R including commercial transmission services. The basic methods include:

1) Continuing to use the GOES as both a collection platform and a distribution platform via a new, higher-capacity onboard L-band transponder (**Figure 3**)
2) Using an onboard L-band transponder for distribution of some data and commercial C-band satellite system(s) for the remaining data
3) Using some combination of commercial C-band satellite(s) and terrestrial distribution system(s) (i.e., Internet, dial-up telephone, Digital Subscriber Link, etc.)
4) Using some combination of commercial C-band satellite system(s), terrestrial distribution system(s) and limited GOES onboard L-band broadcasting.

Figure 4 shows how two commercial C-band satellites could be used to distribute some or all of the GOES/R data.

Based on the experience gained with the current system and current user community, we defined a set of criteria by which to assess potential commercial satellite systems and services for appropriateness for our application. With initial operation of this system estimated to start in the year 2012, we included in our review existing systems and those that are expected to be operational in this time frame.

The key attributes include the following:

- Wide area of coverage – the present GOES communication coverage footprints are shown in Figures 1 and 2. Our studies emphasized CONUS coverage and address non-CONUS areas as a secondary requirement.
- A one-way communications system that broadcasts all data products in real-time.
- A single data channel for each satellite with a data rate of between 50-100 Mb/s.
- An average bit error rate probability of $1x10^{-7}$.
- Sufficient broadcast power to be effectively received via satellite antennas comparable in size to those presently being used to receive GVAR signals. This requirement places the diameter of the satellite dish at a value of between 2.4 and 4.5 meters. Non-antenna receiving site components (receivers, low-

P2.3

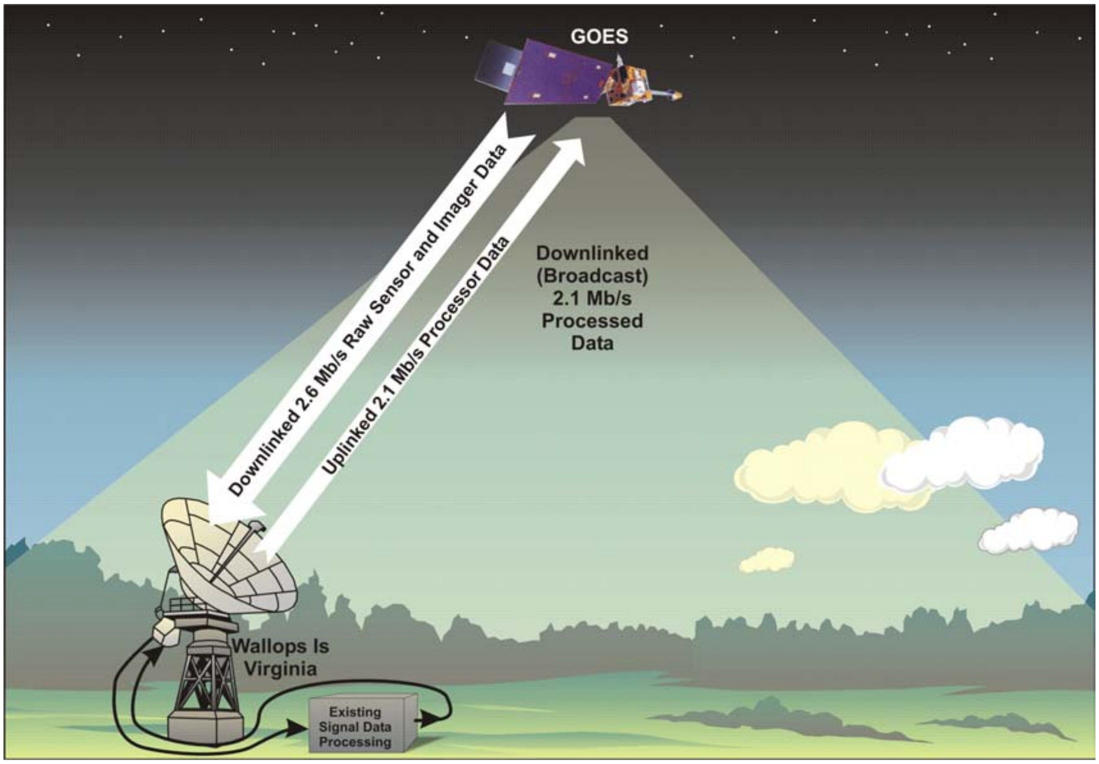


Figure 3. Existing GOES Data Distribution System

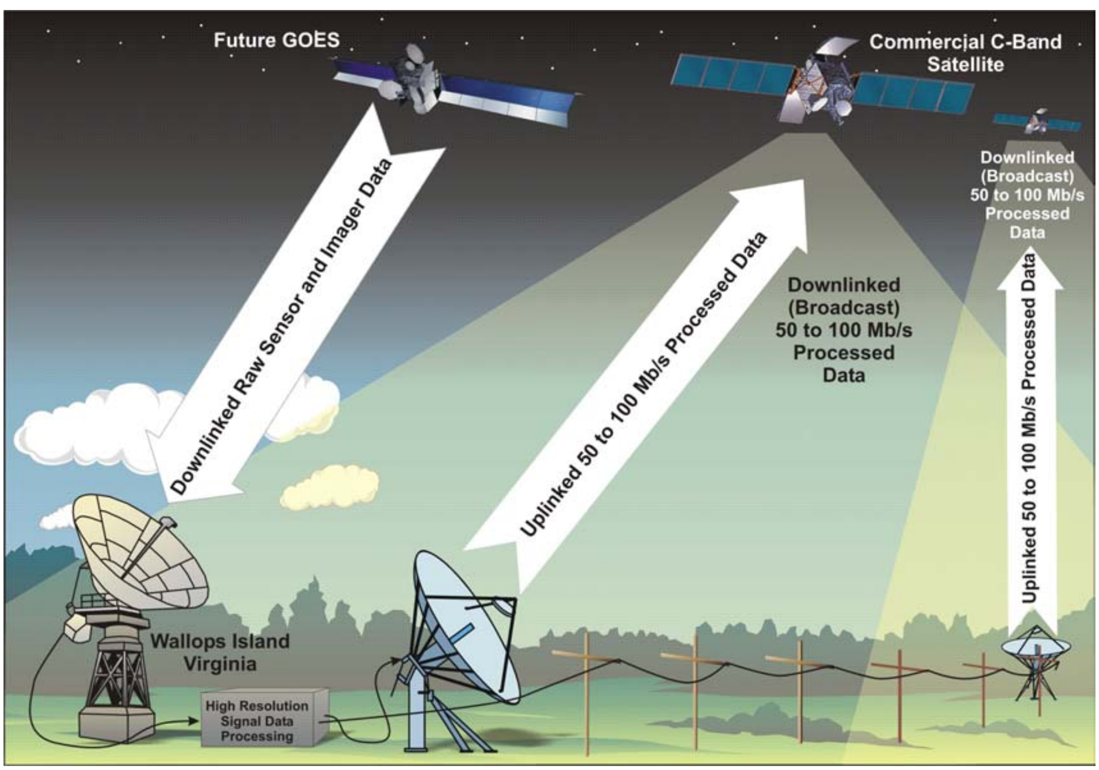


Figure 4. Using Commercial C-Band Satellites to Distribute High-Resolution GOES Data

noise amplifiers, etc.) are even now performing close to their theoretical limits.

- Therefore, it is expected that the diameter of the receiving antenna will continue to be the primary controllable factor in achieving satisfactory signal quality in the 2012 time frame.
- System data availability of at least 99 percent.
- The data available to the users within 1 minute of being processed by NOAA.

2.0 STUDY RESULTS

2.1 TERRESTRIAL TRANSPORT TECHNOLOGIES

A proposed terrestrial system framework for the GOES/R data distribution, shown in **Figure 5**, consists of GOES/R data/image processing and compression servers, a core network, an access network and a suitable interface to the users. The GOES/R servers or processing/compression interface provide the data/image information that users can request or access when needed. There may be one centrally located processing/ compression interface to the network or multiple servers/processing/compression interfaces distributed throughout the network. The core network provides interconnection of various network elements (servers, switches, etc.) in the overall terrestrial distribution network. The interconnection includes both signaling and transmission of the GOES/R data streams. The access network comprises the various access arrangements from the core network to the user interface equipment.

Choice of a processing/compression interface is critical in the usage and implementation of the terrestrial distribution network, directly affecting network resource provisioning and the cost of providing such service. The study examined the effects of data/image compression on the access network requirements and services performance.

It is estimated that in coming years, the majority of the users will be able to use the Internet to directly access the GOES/R data. This study analyzed the most promising technologies and their expected future growth. **Table 2** lists some of the terrestrial access technologies we considered. **Table 3** describes the expected data rates and physical constraints associated with the various implementations of the more popular access technologies, the Digital Subscriber Loop available from most local telephone companies. Finally, **Tables 4** and **5** detail the access technology cost structure and projected customer type versus expected access technology.

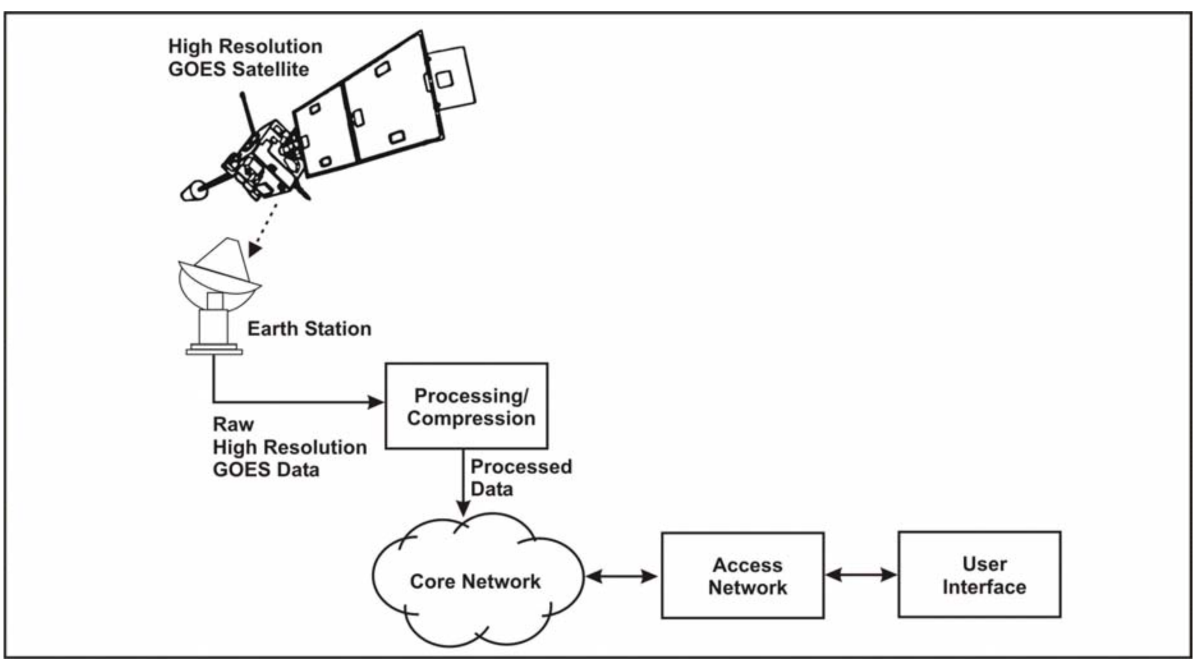


Figure 5. Terrestrial Distribution of NOAA Data and Image Information

P2.3

Technology	Backbone Network	Access Network	Medium	Customer Premise
xDSL	SONET/ATM/IP	DSL access	Twisted copper pairs	Telephone, PCs
FTTC	SONET/ATM/IP	Optical Network Unit	Fiber/Coax drop	Residential gateway device
All Optical Access	DWDM/SONET	Metro DWDM network	Multi wavelength fiber	Wavelength selecting devices, PCs
Cable TV	IP/ATM	Cable TV Modem	Coaxial cable, Hybrid Fiber/Coax	Set-top box, TV, cable modem, PC
Broadband Satellite	IP/ATM	Earth station	28-50 GHz frequencies	Satellite Antenna/ Receiver, PC, enterprise access device

Table 2. Access Technology Characteristics

Technology	Typical Speed	Maximum Distance *
DSL (Digital subscriber line)	160 Kb/s	18,000 feet
HDSL (High data-rate DSL)	1.544 Mb/s	12,000 feet
SDSL (Single-line DSL)	1.544 Mb/s	10,000 feet
ADSL (Asymmetric DSL)	1.5 to 6.144 Mb/s	12,000 to 18,000 feet
VDSL (Very high data-rate DSL)	13 to 52 Mb/s	1,000 to 4,500 feet
** Maximum distance between subscriber and telephone central office*		

Table 3. Characteristics of xDSL Systems

Technology	Typical Access Rate	Current Price ($/Month)
FTTC	MB/s (expected)	Trial
All Optical Access	Mb/s (expected)	Development
Dial-Up	64 Kb/s	15-45
Broadband Satellite	512 Kb/s	25-500
Cable TV Modem	Mb/s	35-45
xDSL	1.5 Mb/s to 6.144 Mb/s (ADSL)	60-100 (ADSL)

Table 4. Access Technology Cost

Customer	Suitable Access Technologies
National Weather Service/TV Station Manufacturer	All Optical Networks, Private Line/VPN (Virtual Private Networks)
FEMA (Fire, Rescue, Hospital), Military	Broadband Satellite
Universities, Schools, R&D, Government	VPN, All Optical Networks, xDSL
Commercial	VPN, All Optical Networks, xDSL
ISP	VPN, All Optical Networks, xDSL
Hobbyist (Amateurs)	Cable TV Modem, Dial-Up
General Public	Cable TV Modem, Dial-Up
International	Broadband Satellite, Cable TV Modem

Table 5. Access Distribution Technologies for GOES Data Users

2.2 SATELLITE TRANSPORT TECHNOLOGIES

Users without direct access to a high-speed Internet connection would find a satellite system a convenient alternative under certain conditions (physical space to mount a ~3.8 meter antenna and an unobstructed view toward the proposed satellite being two of the most important). C-band frequencies were chosen because they are relatively immune to signal attenuation compared to other available satellite frequency bands. **Tables 6** and **7** show the required increase in uplink transmit power and receive antenna diameter increase required to mitigate the effects of rain at rates of 15 mm/hour and 50 mm/hour.

One study (**Ref. 2**) reviewed many of the practical operational considerations of using commercial C-band satellites including specific satellites and their coverage patterns, system and service costs, antenna sizes and typical system performance parameters. One of this study's goals was to maintain receive antenna size at its current GOES L-band diameter of about 3.8 meters or perhaps even smaller. As discussed below, it may be technically possible to use receive antennas smaller than 3.8 meters to receive GOES/R signals at data rates of approximately 18 Mb/s. (At the time this study was performed, 18 Mb/s was believed to be the maximum data rate from GOES/R). Smaller antennas (2.4 meters, for

Frequency Band	Environment	Uplink (Transmit Power Multiplier Required)	Downlink (Receive Antenna Diameter Multiplier Required)
C-Band	Case A [1]	1.07X	1.01X
	Case B [2]	1.17X	1.01X
Ku-Band	Case A [1]	2.5X	1.4X
	Case B [2]	4.9X	1.88X
Ka-Band	Case A [1]	40.7X	2.54X
	Case B [2]	1,380X	6.17X
V-Band	Case A [1]	1,318X	16.2X
	Case B [2]	930,000X	219X
[1] Case A – Relatively high antenna elevation angle (40º) and vertically polarized signal. [2] Case B – Relatively shallow antenna elevation angle (20º) and horizontally polarized signal.			

Table 6. Approximate Compensation Required to Mitigate Signal Attenuation at a Rain Rate of 15 mm/hour (0.6 inches/hour)

Frequency Band	Environment	Uplink (Transmit Power Multiplier Required)	Downlink (Receive Antenna Diameter Multiplier Required)
C-Band	Case A [1]	1.35X	1.02X
	Case B [2]	1.66X	1.05X
Ku-Band	Case A [1]	23.4X	3.35X
	Case B [2]	102X	7.16X
Ka-Band	Case A [1]	75,900X	20.9X
	Case B [2]	186,000,000X	162X
V-Band	Case A [1]	240,000,000X	2,750X
	Case B [2]	1.1×10^{14}X	624,000X
[1] Case A – Relatively high antenna elevation angle (40º) and vertically polarized signal. [2] Case B – Relatively shallow antenna elevation angle (20º) and horizontally polarized signal.			

Table 7. Approximate Compensation Required to Mitigate Signal Attenuation at a Rain Rate of 50 mm/hour (2 inches/hour)

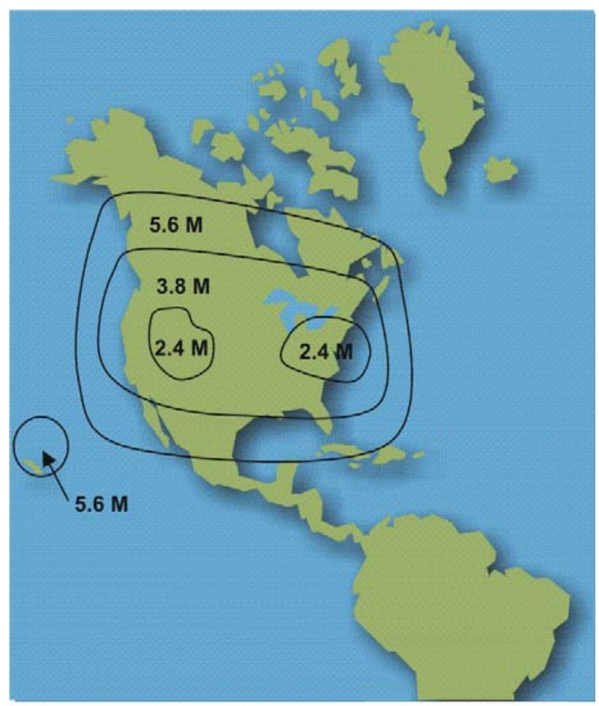
example) are preferable for a number of reasons. They are less expensive to purchase, easier to install, require a less robust foundation, and are less susceptible to damage from high wind, snow accretion, etc. Unfortunately because of the physics involved with antenna design, a smaller antenna reflector size automatically results in a wider antenna beamwidth.

Currently, geostationary satellites covering the United States are spaced 2 degrees apart from each other. Normally, a 2.4-meter antenna's beamwidth is wide enough to pick up signals (interference) from an adjacent satellite. This interference can be strong enough to render the desired signal unusable. In addition, terrestrial microwave signals and C-band satellite signals share the same radio frequencies. It is not unusual for smaller C-band satellite antennas to pick up these terrestrial signals particularly in RF-rich urban environments. These terrestrial signals can also interfere with the proper reception of satellite signals. Once the interfering terrestrial microwave signals have been identified and located, judicious placement of RF barriers, and/or repositioning of the satellite receive antenna can usually mitigate the terrestrial interference problem. Mitigation of the adjacent satellite interference problem is more difficult, usually requiring a large antenna or one with lower off-angle gain characteristics. We determined that, from the user's standpoint, the primary cost factor for a satellite data receiving system is the antenna. Satellite receivers and low noise amplifiers are already approaching their theoretic limit in terms of efficiency. Future improvements are expected to take place in processing speed, smaller size hardware, additional features, and improved user interfaces. Considering their current low price, substantial cost reductions are not expected in satellite electronics costs.

Therefore, because the receive antenna size and cost play such an important role in setting up a satellite receiving earth station, we have plotted antenna size as a function of user location. These plots take into account primarily satellite power and antenna characteristics, as well as the curvature of the Earth and other propagation phenomena. The required satellite power/bandwidth is the key cost driver in determining the overall cost of the distribution system operation.

The most important coverage area and the location of the primary GOES users is the continental United States. The available options for CONUS coverage are substantial. A number of domestic, and now some international, satellite operators are providing CONUS satellite coverage using geostationary satellites with C-band transponders. For illustrative purposes, we have chosen the AMC-4 satellite (formally named GE-4) located at 101 degrees W in the orbital arc. This location is generally regarded as one of the best geostationary orbital locations as it allows relative high receive antenna elevation angles. High elevation angles are preferred because they help reduce the effect of physical obstructions surrounding receive antenna locations and help minimize the reception of terrestrial interference.

Figure 6 shows a typical coverage pattern for North America using AMC-4. As discussed above, the use of a 2.4 meter receive antenna is somewhat problematic, but is theoretically possible depending on the strength of adjacent

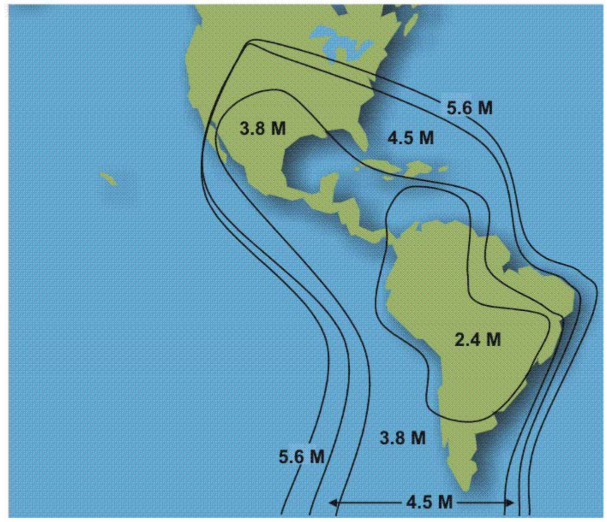


- Contours show estimated receive antenna size in meters
- Estimated monthly satellite charges (2005 estimated price) – $95K/month

Figure 6. AMC-4 18 Mbp/s North America (shared transponder)

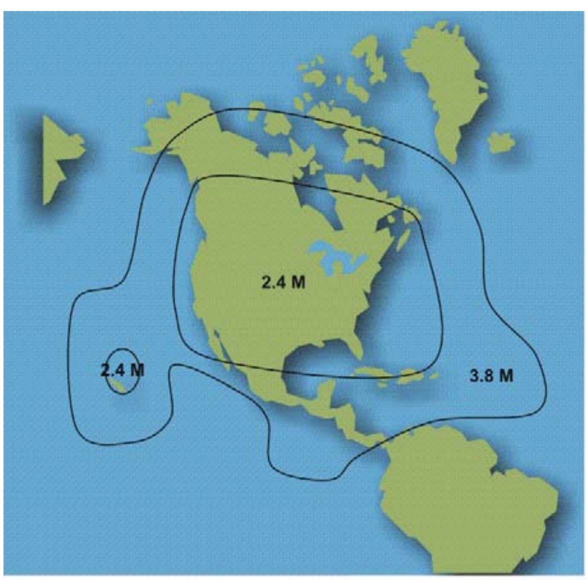
satellite interference. If adjacent satellites and the leased satellite were all owned/operated by the same entity, it would be easier to minimize interference by coordinating transponder carrier frequencies on adjacent satellites. Terrestrial interference must still be addressed on a local case-by-case basis. The possibility of prearranged adjacent satellite frequency pattern coordination would make the footprint shown in **Figure 7** more desirable. The theoretical possibility of using a 2.4 meter receive antenna virtually everywhere in CONUS, a 3.8 meter in Central America and the Caribbean with 2.4 meter access in Hawaii may justify the expected increases in monthly costs from the Figure 6 estimate of $95K/month to the Figure 7 estimate of $200K/month. The cost estimates were the satellite operator’s best estimate (in 1998) as to the 2005 expected cost for sufficient satellite bandwidth and power to provide the contours shown.

Satellite transponder monthly lease costs are determined by the amount of satellite power/bandwidth required. The critical satellite power/bandwidth determining factors are the broadcast transmission data rate and the receive antenna size. **Figures 8**, **9**, and **10** show selected data rates, receive antenna sizes and estimated monthly costs for relatively narrow geographical coverage areas. Figures 9 and 10 show wider Intelsat coverage areas more in line with current GOES coverage patterns.



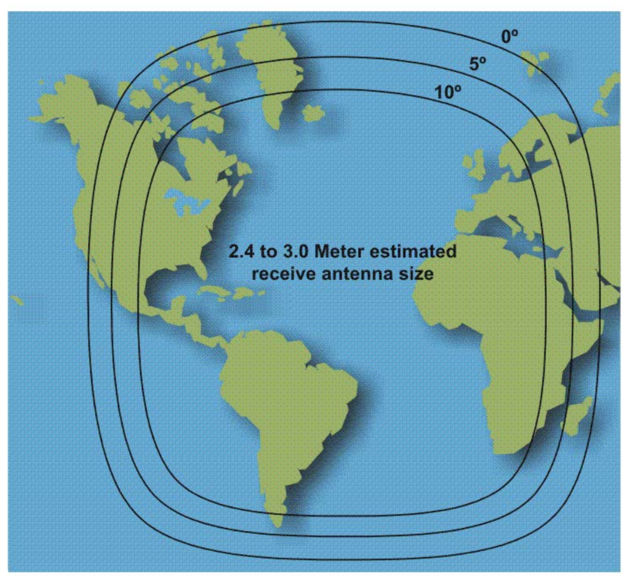
- Contours show estimated receive antenna size in meters
- Estimated monthly satellite charges (2001 prices with 10-year lease)
  - 18 Mb/s $94K/month
  - 9 Mb/s $47K/month
  - 5 Mb/s $26.2K/month
  - 2.1 Mb/s $11.2K/month

Figure 8. PanAmSat IR South America and Central America (shared transponder)



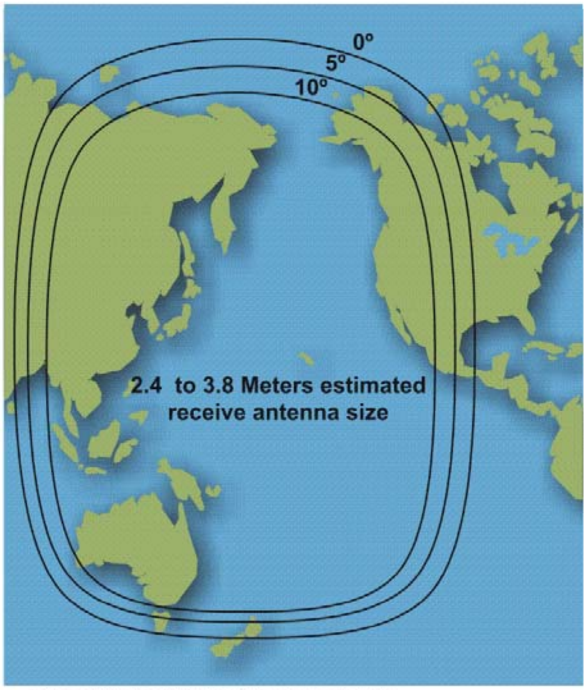
- Contours show estimated receive antenna size in meters
- Estimated monthly satellite charges (2005 estimated price)
  - $200K/month

Figure 7. AMC-4 18 Mbp/s North America and Central America (total transponder)



- 18 Mb/s single carrier saturated operation
- Estimated monthly satellite charges (2001 prices)
  - $275K/month

Figure 9. Intelsat IX Series (total transponder)



- Typical Series VIII performance shown
- 18 Mb/s single carrier saturated operation
- Estimated monthly satellite charges (2001 prices)
  – $275K/month

Figure 10. Intelsat VIII Series (total transponder)

3.0 BENEFITS OF COMMERCIAL SERVICE

GOES/R is scheduled to be initially operational circa 2012 and this series of satellites is expected to continue in operation for at least another 10 years.

As we have witnessed particularly over the past decade, communications technology is changing rapidly. Commercial data distribution systems/services can provide greater data distribution flexibility than the current methodology. Commercial terrestrial/satellite systems and services can be replaced as needed, expanded to accommodate different data rate(s) or can be discontinued if another technology becomes available that is more efficient, reliable and/or cost effective. In addition, this approach may also reduce the satellite weight, electrical power communication system complexity/risk, etc., resulting in potentially substantial satellite acquisition cost savings.

NOAA has been using commercial satellite data distribution services for more than 30 years, for example:

- Polar Orbiting Environmental Satellite System – NESDIS
- Advanced Weather Interactive Processing System – NWS
- Weather Wire – NWS
- World Area Forecast System – NWS

Many other Government agencies such as the Department of Defense and the Federal Aviation Administration are also taking an advantage of available commercial services because of their inherent flexibility, their ability to incorporate the latest improvements in communications technology and the promise of substantial cost savings.

4.0 CONCLUSIONS

Our comparison of satellite and terrestrial technologies revealed that satellite distribution systems are expected to be more advantageous in terms of reliability and immediacy of data transmission to several types of users, in particular to large data-volume users such as the National Weather Service (NWS) and rural users without direct high-speed terrestrial Internet access. In contrast, urban users with ready access to high-speed “last mile” terrestrial transmission services can access the data with a speed limited only by cost and Internet performance.

Terrestrial communications are in a constant state of change. Each advance in speed, capacity, or throughput by one vendor seems to be matched or exceeded by another in increasingly shorter periods of time. The current “best effort” performance of the Internet is expected to improve significantly in the next few years and therefore we expect it to be the dominant terrestrial method to access GOES/R data where high-speed “last mile access” is available.

Because of the long lead times required for implementation and their 10-15 year lifetime, commercial satellites recently commissioned or in the planning stages are expected to be in service in the time frame of interest. The electrical and mechanical characteristics are known and their capacity/performance can be readily assessed. Based on our analysis of the expected cost, bandwidth and operation during inclement weather, we have found that a geosynchronous C-band satellite broadcast is the best solution for satellite data distribution. The current GOES L-band broadcast coverage footprints can be mostly achieved by a combination of more than one C-band satellite and, as an added bonus, data rates can be separately set for each major geographical area.

From the user's perspective, the satellite receive antenna size is the major installation hindrance and cost variable. A receive antenna size of 3.8 meters and even smaller, is feasible under certain, albeit ideal, circumstances. From the system operator's perspective, current and out-year monthly broadcast transmission costs are fully quantifiable (10-year and longer lease periods are available) and are expected to remain relatively stable.

Future advances in both Internet performance and high-speed geographic coverage may minimize these current advantages of satellite transmission. With a terrestrial system favoring the urban users and a satellite system favoring the critical and rural users, we have found that the optimum configuration may be a hybrid satellite/terrestrial distribution system. This configuration provides satellite and Internet distribution to users such as the NWS, and Internet-only capability for less demanding and/or cost constrained users. A commercial satellite/terrestrial hybrid will give NOAA an array of long-term flexibility and economic options to tailor the distribution of data to future user needs with an inherent, robust backup capability.

Acknowledgements:

Authors would like to thank Mr. Jamie Hawkins, Deputy Assistant Administrator, NOAA/Ocean Service, Mr. Michael Crison, Director, NOAA/NESDIS Requirements Planning and Systems Integration, Dr. Gerald Dittberner, Chief Advanced Planning, NOAA/NESDIS/OSD/RPSI, and Mr. William Hill, CSC Federal Sector Manager of Advanced Meteorological Programs for their encouragement and support.

References:

1) GTE Information Systems LLC, October 1999: *Future GOES High Resolution Data Distribution Satellite and Terrestrial Technology Assessment for the Years 2005-2008.*

2) DynCorp Information Systems LLC, May 2001: *Operational Considerations for Distribution of Future High Resolution Data via Commercial Satellite Systems.*

3) Taylor, J.O., 12/9/98: *Future GOES L-Band Data Capacity*, MIT Lincoln Labs.