AE3E09 Satellite Earth Observation Assignment 1: Virtual Satellite Constellation for Arctic Ice Changes

V.H.R.I. Doedée WB1317261, Prof: dr. M. Menenti

Abstract **- In this small study, a satellite constellation is proposed to study the polar sea ice change in the arctic region. First an introduction is made about the subject and the current status of the polar region is stated. Secondly, the parameters and characteristics of the problem are sketched and physical, measurable quantities are assigned to the parameters. Then, sensors are chosen for the variables which can be used in combination with a certain satellite design (LIDAR and GOES I-M Imager and Sounder), and this design is evaluated in terms of temporal resolution, accuracy, swath width etc, resulting in a satellite constellation made up of two satellites chasing each other closely in a sun-synchronous orbit with mean local solar time of 4.00 a.m. and 16.00 p.m. The resolution and swath width of the LIDAR are respectively 65,2 m and 56,93 km, those of GOES I-M Imaging system about 32,6 m and 66,76 km.**

I. Introduction

THIS time era is one of sustainability. For the first time in human history we have the means and possibilities to influence global atmospheric and climatic effects. One of the most prudent difficulties we face, apart from the CO_2 problem, is the polar ice change. There are many signs indicating that perhaps as soon as the year 2050, all polar ice will be melted during summer periods.

But why is the polar melt such an important issue? Clearly, there will be enormous economic boosts due to the creation of new shipping grounds, and the disappearance of land-ice on Greenland will create opportunities for agriculture and population. On the other side, the Arctic ice plays an important role in global climate preservation in a number of ways [eohandbook.com]:

1) A certain percentage of the solar radiation reaching the Earth's atmosphere and surface is reflected back out to space. The percentage of sunlight that is reflected depends on the albedo (reflectivity) of the surface. Ice and snow have a high albedo and hence reflect about 80% of incident sunlight. Once formed, ice tends to be maintained. However, if ice cover decreases, less solar radiation is reflected from the surface of the Earth and, as a result, the atmosphere absorbs more heat;
2) Each year, the Arctic and the Antarctic Oceans experience the formation and then melting of vast amounts of floating sea ice. At the North Pole, an area of ice the size of Europe melts away every summer and then freezes again the following winter. The thickness of this sea ice plays a central role in polar climate as it moderates ocean-atmosphere heat exchange by insulating the ocean from the cold polar atmosphere;
3) The distribution and duration of seasonal growth and melt of polar sea ice have a significant effect on the global ocean circulation pattern – known as thermohaline circulation. As the ice melts, causing an influx of fresh water into the surrounding ocean, the salinity and density of the water decrease. Conversely, as ice is formed, the salinity and density of the surface water increase. This causes the surface waters to sink, effectively driving deep ocean currents from the Polar Regions towards the equator. This outflow is balanced by a surface inflow of warmer, less dense water masses from low to high latitudes. The Gulf Stream, which carries warm surface water northwards from the Gulf of Mexico to the sub-polar latitudes east of Greenland, is extremely important in moderating the climate in Europe; the coastal waters of Europe are 4°C warmer than waters at the equivalent latitude in the North Pacific. However, the warm waters of the Gulf Stream cool and sink as they reach the Arctic. If this circulation pattern is disturbed in future by a dramatically reduced cover of seasonal Arctic sea ice, this may have a profound effect on the strength or direction of the Gulf Stream.
4) Continental ice has an impact on sea level. The ice sheets covering Antarctica and Greenland amount to about 28 million km3, which means that the sea level is about 65 m lower than it would be if all this ice melted. There are indications that changes are occurring at the margins of the ice sheets and it is these apparent changes that need to be quantified.

It is clearly imperative that a great understanding of the polar ice change (formation and melting) is needed. And due to the remoteness and bareness of this region, satellites are the most efficient way to observe the Arctic.

Major contributions to this field of study have been done by the ERS-1, ERS-2 and Envisat satellites, which have a 14-year record of Synthetic Aperture Radar (SAR) measurements. This instrument has been used to map the ice sheets with unprecedented detail and has demonstrated the impact of streaming ice flow for the regional ice sheet mass balance, as well as the critical importance of the rate of ice stream flow and ice shelf decay to the overall stability of the large ice sheets [eohandbook.com].

II. Current Status of Arctic Ice

Combined data from multiple sources indicate that, although the central parts of the large ice sheets appear stable and in balance, dramatic changes are taking place around their more dynamic margins, especially in Greenland, see fig, 1.

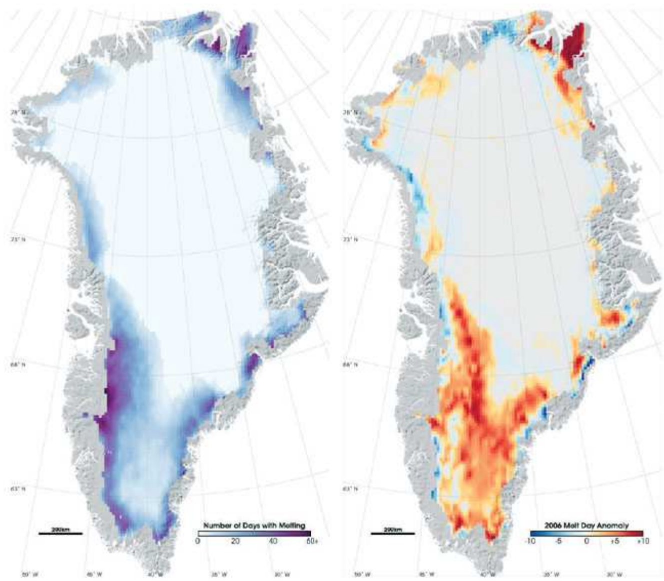

Figure 1. The left part of the figure shows the number of days when melting occurred in 2006, the bluer, the more days the ice melted. The right part shows how much the number of days is off from the 1988-2005 average; the red areas indicate the number of days above the average.

Another very important aspect of this problem is the decrease of the *perennial sea ice*. Perennial sea ice floats in the polar oceans and remains at the end of the summer, when the ice cover is at its minimum and seasonal sea ice has melted. In a study done by Krishna Ramanujan, 2003, it could be seen that temperatures in the Arctic are increasing at a rate of 1.2 degrees Celsius per decade.

Apart from the temperature raise significant physical shifts have recently been reported for polar environments and are attributed to pervasive alterations in the global climate. In the past 25 years, the hemispheric extent of annual sea ice in the Arctic has decreased by 3% per decade, with perennial sea ice decreasing at 9% per decade [Kristin L. Laidre, Mads Peter Heide-Jørgensen, 2004].

The perennial sea ice does not affect sea levels, but does have profound effect on global climate and biological shifts; shifts; changes in salinity, warmer air and water temperatures, shifts in thermohaline circulation, and reorganization of marine zooplankton communities all of which leave growing scientific consensus that the Arctic climate is undergoing considerable change [Kristin L. Laidre, Mads Peter Heide-Jørgensen, 2004]. In fig. 2, the perennial sea ice minimum (in September) and maximum (in March) can be seen for ’99-’00 and ’08-’09. It can be clearly seen that especially the perennial sea ice is decreasing, and is a reason for increasing concerns for many scientists.

But there are also signs indicating otherwise. Although due attention has been given to the hemispheric warming trends, recent work indicates that patterns of climate-induced change must be examined on regional scales. Studies in the Canadian high Arctic, Baffin Bay, and West Greenland report findings that are markedly different from the overall trends of sea ice reduction. Since 1970, the climate in West Greenland has cooled, reflected in both oceanographic and biological conditions. Contrary to a reduction of sea ice, Baffin Bay and Davis Strait display strong significant increasing tends in ice concentrations and extent, as high as 7.5% per decade between 1979 and 1996, with comparable increases detected back to 1953. Predictions for the future suggest similar trends, where climate models projecting sea ice trends over the next 50 years note Baffin Bay is one of the few areas with increased sea ice concentrations and sea ice thickness [Kristin L. Laidre, Mads Peter Heide-Jørgensen, 2004]. Due to these contradictions and our shortcomings in understanding all the different processes that play an important role in climate change and especially the Arctic ice sheets, more data needs to be gathered to create correct models and create more understanding for this subject.

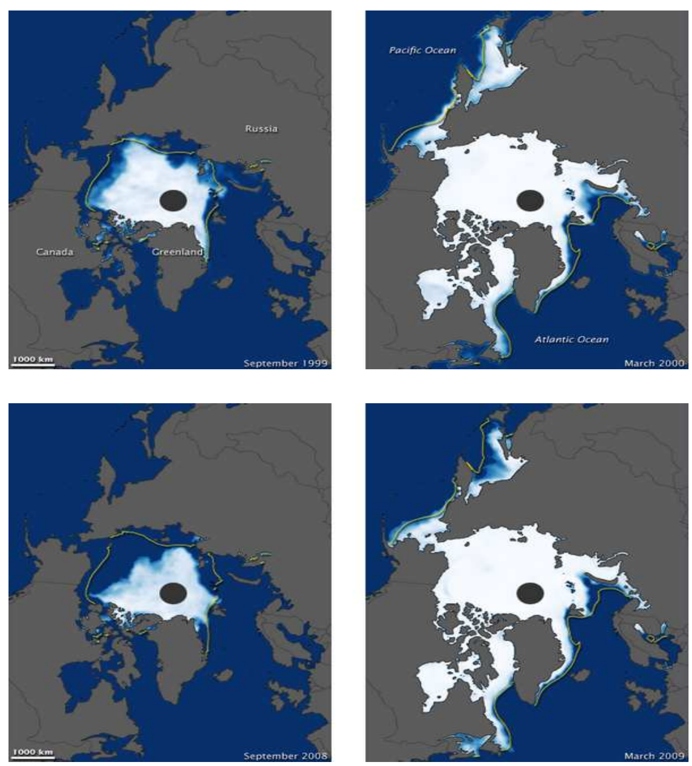

Figure 2. In the two figures above, the minimum and maximum sea ice extend during '99 and '00 respectively can be seen. Below, the minimum of '08 and

maximum of '09 is shown. It can clearly be seen that perennial sea ice is decreased most. The yellow line is the mean of 1979-2000. For a nice animatrion of the arctic sea ice, go to the website of Nasa's Earth observatory . Source: http://earthobservatory.nasa.gov/Features/WorldOfChange/sea_ice.php

III. Characteristics And Physical Parameters

The most important aspects of the ice change that need to be researched are:

1) Ice mass;
2) Temperature;
3) Precipitation;
4) Aerosol dispersion;
5) Reflection;
6) Surface Area.

Ice mass is impossible to remotely measure instantaneously. One first needs *a priori* information about, for instance, ice density. This in combination with ice height measurements can be combined to determine ice mass. The *a priori* information can be obtained by local measurements, or can be modeled with extremely complicated numerical models.

The temperature has to be measured for many different things; the sea water, the sea ice, the arctic ice, the atmosphere, the clouds, and also the temperature of the permafrost regions of Siberia, Canada, Greenland and Alaska can be very useful.

The precipitation is needed to figure out, in combination with atmosphere and sea levels, how much the accumulation of new Arctic ice is during winter periods and can also provide us information about the atmospheric composition of the Arctic region. This of course has a close relationship with the aerosol dispersion above the Arctic, which is partially responsible for the creation of precipitation.

Also, the reflection can be used in order to derive how much of the suns energy is absorbed by the Earth, and how much is radiated back out into space. This process is very important for the understanding of temperature rises in the Arctic but also global climate. The surface area can be calculated by looking at the reflectance data.

Of course, the Arctic being what it is, the observation of vegetation can be "left out of the equation".

IV. Relevant Platforms and Instruments

The requirements for this constellation are pretty demanding; we need at least 5-10 years of observations (preferably even more) in order to establish a relevant and scientifically based time series in order to evaluate changes in the climate or the polar caps. This can be established with multiple satellites launched a few years after each other in a lower orbit (meaning lower resolutions and specifications of the instruments needed), or a few (maybe even one), more expensive satellite(s) in a higher orbit (one has to bear in mind that there is a trade-off between sensor specifications and orbit).

Furthermore, we need to cover a large area with the observations; that is the Arctic, Greenland, Canada, Siberia, Alaska and even the northern Scandinavian parts of Europe. This has profound effects on spatial resolution; the larger the area needed to be covered, the smaller the spatial resolution is. However, the resolutions in spatial and resolution terms comply with this problem; we do not need an extremely high spatial resolution for this problem, probably a resolution of about 100-1000m is sufficient. Also, temporal resolution of about one hour can be established if we chose the satellites to be in a sun-synchronous near-polar orbit, which is the most obvious choice. This will also keep the amount of ground stations at a minimum.

There are many possibilities to remotely sense the required information of our problem. In the table below, the variables of our problem are listed and potential remote sensing systems are stated to obtain the desired information [John R. Jensen, 2007].

Table 1. An overview of the potential Remote Sensing Systems used in many applications., restricted on the subjects that are relevent to the melting of the Arctic ice [John R. Jensen, 2007].

(Bio)Physical Variables	Potential Remote Sensing Systems
Digital Elevation Model (DEM)	- GPS, Space Imaging IKONOS, LIDAR, SPOT, RADARSAT, QuickBird, OrbView-3, Shuttle Radar Topography Mission (STRM), Interferometric Synthetic Aperture Radar (IFSAR)
Snow and Sea Ice	
- Extent and characteristics	- Color and CIR aerial photography, AVHRR, GOES, Landsat (TM, ETM^+), SPOT, SeaWiFS, IKONOS, QuickBird, ASTER, MODIS, MERIS, ERS 1-2, RADARSAT
Surface Temperature (land, water, atmosphere)	- ASTER, AVHRR, GOES, Hyperion, MISR, MODIS, SeaWiFS, airborne thermal infrared
Atmosphere	
- Aerosols	- MISR, GOES, AVHRR, MODIS, CERES, MOPITT, MERIS
- Clouds	- GOES, AVHRR, MODIS, MISR, CERES, MOPITT, UARS, MERIS
- Precipitation	- Tropical Rainfall Measurements Mission (TRMM), GOES, AVHRR, SSM/1, MERIS
- Water vapor	- GOES, MODIS, MERIS
- Ozone	- MODIS
Water	
- Color - Surface hydrology - Suspended minerals - Chlorophyll	- Landsat (TM, ETM^+), SPOT, IKONOS, QuickBird, OrbView-3, ASTER, SeaWiFS, Modis, AVHHR, GOES, bathymetric LIDAR, MISR, CERES, Hyperion, TOPEX/POSEIDON, MERIS

As can be seen at first glance, many systems have multiple design purposes. For instance, IKONOS, GOES, SeaWiFS, MERIS and many others appear many times in the different potential systems. Others like MOPITT or TRMM are less common. Naturally, those instruments capable of multitasking have an advantage over those who are single purposely designed.

In order to design a constellation, resolution, spectral and temporal information about the instruments have to be known. In tables 2, 3 and 4 are an overview of several important remote sensing system operating specs, taken from [John R.

Jensen, 2007]. In appendix A, these data are shown in a figure for a more visual overview.

Table 2. The visible specifications of different systems, providing they have them. Some systems can be used multispectrally or panchromatic. Others like RADARSAT and ERS use totally different wavelengths.

System	Blue	Green	Red
Landsat 7 TM			
(ETM$^+$)	1	1	1
– Multispectral	0.52	-	0.9 µm
– Panchromatic			
Spot 4 HRV			
– Multispectral		1	1
– Panchromatic	0.51	-	0.73 µm
IKONOS			
– Multispectral	1	1	1
– Panchromatic	0.45	-	0.9 µm
QuickBird			
– Multispectral	1	1	1
– Panchromatic	0.45	-	0.9 µm
RADARSAT	HH Polarization C-band (5.3 GHz)		
SeaWiFS	3	2	1
MODIS	0.405 -	36 bands	- 15.385 µm
ASTER	0.52 -	3 bands	- 0.86 µm
MISR	0.44, 0.55, 0.67, 0.86 µm		
GOES I-M Imager	0.52	-	0.72 µm
GOES I-M Sounder	18 bands	0.70 –	14.71 µm
ERS-1 and 2	VV Polarization C-band (5.3 GHz)		

Table 3. The Near-infrared, Shortwave-infrared, Thermal-infrared and microwave properties of different systems.

System	NIR	SWIR	TIR	µWave
Landsat 7 TM (ETM$^+$)				
– Multispectral	1	2	1	
– Panchromatic				
Spot 4 HRV				
– Multispectral	1			
– Panchromatic				
IKONOS				
– Multispectral	1			
– Panchromatic				
QuickBird				
– Multispectral	1			
– Panchromatic				
RADARSAT				1
SeaWiFS	2			
MODIS				
ASTER	1.6 -	6 bands	- 2.43 µm	
	8.12 -	5 bands	- 11.6 µm	
MISR				
GOES I-M Imager			4	
ERS-1 and 2				1

Table 4. Spatial and Temporal resolution of our sensing systems. While spatial resolution can be relatively high, temporal resolution is preferably rather low in order to make detailed and up to date observations, especially during ice- melting or formation periods.

System	Spatial (m)	Temporal (days)
Landsat 7 TM (ETM$^+$)	30 and 60	16
– Multispectral	15	16
– Panchromatic		
Spot 4 HRV	20	Pointable
– Multispectral	10	Pointable
– Panchromatic		
IKONOS	4	Pointable
– Multispectral	1	
– Panchromatic		
QuickBird	2.44	Pointable
– Multispectral	0.61	
– Panchromatic		
RADARSAT	9-100	1-6 days
SeaWiFS	1130	1
MODIS	250, 500, 1000	1-2
ASTER	15	5
	30	16
	90	16
ERS-1 and 2	26-28	-
GOES I-M Series	700	0.5/hr

The swath width is dependent on the height of the orbit. The swath width can range to several tens of meters to several hundreds of kilometers. This in term is closely related to the revisiting time; if satellite design has a small footprint, a higher temporal resolution is preferred to cover the same target area, and thus a lower orbit has to be chosen etc. So there is, as stated before, an important trade-off between sensor, satellite and orbit characteristics; all these different aspects determine the constellation characteristics.

V. Proposed Satellite Constellation

There are many constellations possible that can provide the information needed. Two things however are most prominent regarding this problem; elevation/composition and temperature. The first most important feature, elevation and composition, are taken together because they can be measured with a single instrument; LIDAR. However, LIDAR alone can only measure elevation, composition can be determined with the help of *in situ* data or special models.

The second parameter to be measured, temperature, can easily be found with the help of (thermal) infrared scanner, those such as the GOES I-M Imager and Sounder (more information, see appendix B). Normally, the GOES satellite (Geostationary Operational Environmental Satellite) is in a geostationary orbit. Its instruments however (the Imager and Sounder) are ideally suited for observing the atmosphere (temperature, clouds, precipitation etc.). These instruments are used, but on a lower orbit thus increasing spatial resolution. A constellation for observing the Arctic regions can then be as follows.

Two satellites (for convenience called DUOSAT-1 and 2); orbit at 500-650 km (depending on solar max or min, more on orbit later this section), DUOSAT-2 follows DUOSAT-1 as closely as possible, both equipped with GPS receivers in order to easily pinpoint their locations. DUOSAT-1 has a LIDAR sensor with two different wavelengths to compensate for the ionospheric interference (one eye-safe-near-infrared laser light at 1040 nm, and one 532 nm wavelength blue laser for water penetration capability), to measure elevation and ice/atmospheric composition. The laser footprint is approximately circular on the ground and varies of course with angle. The footprint can be calculated with:

$$F_p = \frac{h}{\cos^2(\theta_{inst})}\gamma \quad (1)$$

Where h is the height, θ_{inst} is the instantaneous scan angle and γ is the divergence of the laser beam. The across-track swath width is given by:

$$sw = 2h\tan\left(\frac{\theta}{2}\right) \quad (2)$$

Where h is again height and θ is the scan angle. Before we know these values, we need the height of the satellite, and thus the orbit first, which is treated later this section.

DUOSAT-2 has optical and thermal scanners (GOES I-M Imager and Sounder) for temperature measurements and actual footage of the surface. DUOSAT-2 is constantly measuring in off-nadir and nadir angles so as the satellites collect measurements of the object at the same time and still compensate for the non-linear emissivity effects at different angles. The maximum resolution achievable for an optical imager is given by:

$$d = \frac{D_f}{f}h = \theta_{IFOV}h \quad (3)$$

Where D_f is the aperture diameter, f is the focal length of the telescope, h is height of the satellite, and θ_{IFOV} is the instantaneous field of view. The swath width is determined when resolution size and amount of pixels are known. Before we can approximate the resolution, we need height, treated further in this section.

The advantage of two satellites is that risks are spread; should one satellite fail in-orbit or during launch, the other satellite may still proceed and gather important data.

The orbit of DUOSAT-1 and 2 is the same, only DUOSAT-2 is chasing the target, DUOSAT-1 as closely as possible. It is also reasonable to assume that DOUSAT will fly in a circular orbit, with eccentricity e zero. Ground stations near the Arctic (Svalbard, Greenland, Canada, Siberia etc.), are taken for granted. Also, because of the fact that it is an Earth observation mission, we want the lighting conditions to be more or less constant. This means we want to have a sun-synchronous orbit. With a sun-synchronous, circular orbit, the following equation applies [R. Noomen et al, 2007]:

$$a^{7/2} = -6.62034\cdot 10^{24}\cdot\cos(i) \quad (4)$$

Where a is the semi major axis ($m^{7/2}$), and i is the inclination (degrees). Candidate orbits that satisfy this equation are shown in table 5 below. It can be seen that an inclination of 96^0 is an absolute minimum.

Table 5. Possible inclinations and corresponding satellite semi-major axis a and height h for DUOSAT, satisfying (1). [R.Noomen et al, 2007]

***i* [^{0}]**	***a* [km]**	***h* [km]**
90	-	-
92	4735	-
94	5771	-
96	6478	100
98	7030	652
100	7489	1111
102	7885	1507
104	8234	1856
106	8546	2168
108	8830	2452
110	9090	2712

Due to the fact that we want a relatively low orbit in order to have a better resolution, a height of 652 km is chosen. With a sun-synchronous orbit, we know the orbital period is approximately one hour. The best mean solar time to pass the equatorial plane is at about 4:00 a.m. and 16:00 p.m. due to the thermal infrared measurements and the diurnal cycle [John R. Jensen, 2007]:

1) Short-wavelength reflected energy from the Sun can create annoying shadows in daytime thermal infrared imagery, but *only* during the daytime when certain materials might have different thermodynamic temperatures than their emmitive temperatures;
2) By 4:00 a.m., most of the materials in the terrain have relatively stable equilibrium temperatures in terms of thermal emmitance. This is called the diurnal cycle;
3) Convective wind currents usually settle down by the early morning, resulting in less wind smear or wind streaks on the imagery.

With height known, we can calculate footprint and across track swath with for LIDAR and resolution for the optical imager. For θ_{inst} we take 1 mrad, for γ we take 0.1 mrad, and for the scan angle 5^0 is taken. The diameter of the aperture is 0.1 mm and the focal length is taken to be 2 m, resulting in a θ_{IFOV} of $5*10^{-5}$. A sensor with 2048*2048 pixels is taken just for reference. The swath width is easily calculated; it's the number of pixels times resolution size. This results in the following numbers:

$$F_p = \frac{652000}{\cos^2(1 \cdot 10^{-3})} 0,1 \cdot 10^{-3} = 65,2\ m$$

$$sw_{LIDAR} = 2 \cdot 652000 \tan\left(\frac{5/180\,\pi}{2}\right) = 56,93\ km$$

$$d = 5 \cdot 10^{-5} \cdot 652000 = 32,6\ m$$

$$sw_{GOES} = 2048 \cdot 32,6 = 66,76\ km$$

All these specifications result in the satellite constellation below. Also, in figure 3 a small visual representation of the constellation is given for interpretation.

Table 6. The final results of a possible satellite constellation design.

	System	Resolution*	Swath Width	Orbit
DUOSAT-1	LIDAR	F_p = 65,2 m	56,93 km	Sun-Synchronous
	1040 nm			Mean solar time
	532 nm			4.00a.m. – 16.00p.m.
DUOSAT-2	GOES			Sun-Synchronous
	VIS	± 32,6 m	66,76 km	Mean solar time
	NIR	± 32,6 m	66,76 km	4.00a.m. – 16.00p.m.
	TIR	± 32,6 m	66,76 km	

*Resolution of an optical sensor is dependent on wavelength.

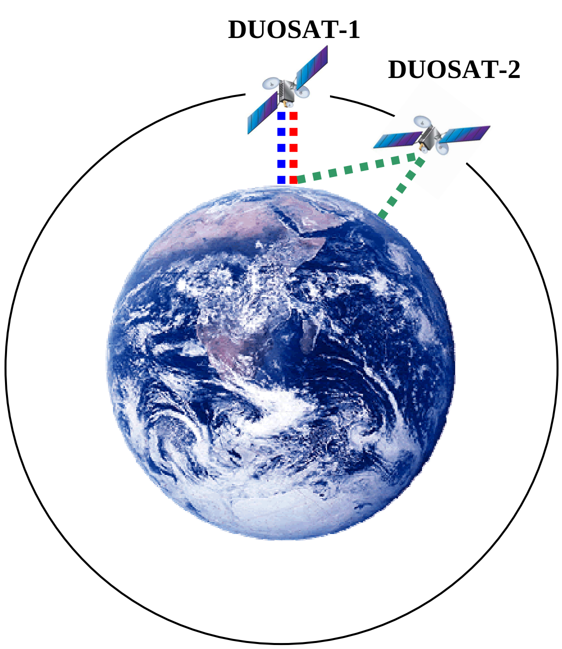

Figure 3. A representation of our constellation where DUOSAT-2 is in pursuit of DUOSAT-1. Height is 652 km.

Appendix A; Figure Of Spatial Resolution Of Different Systems Plotted Against Temporal Resolution

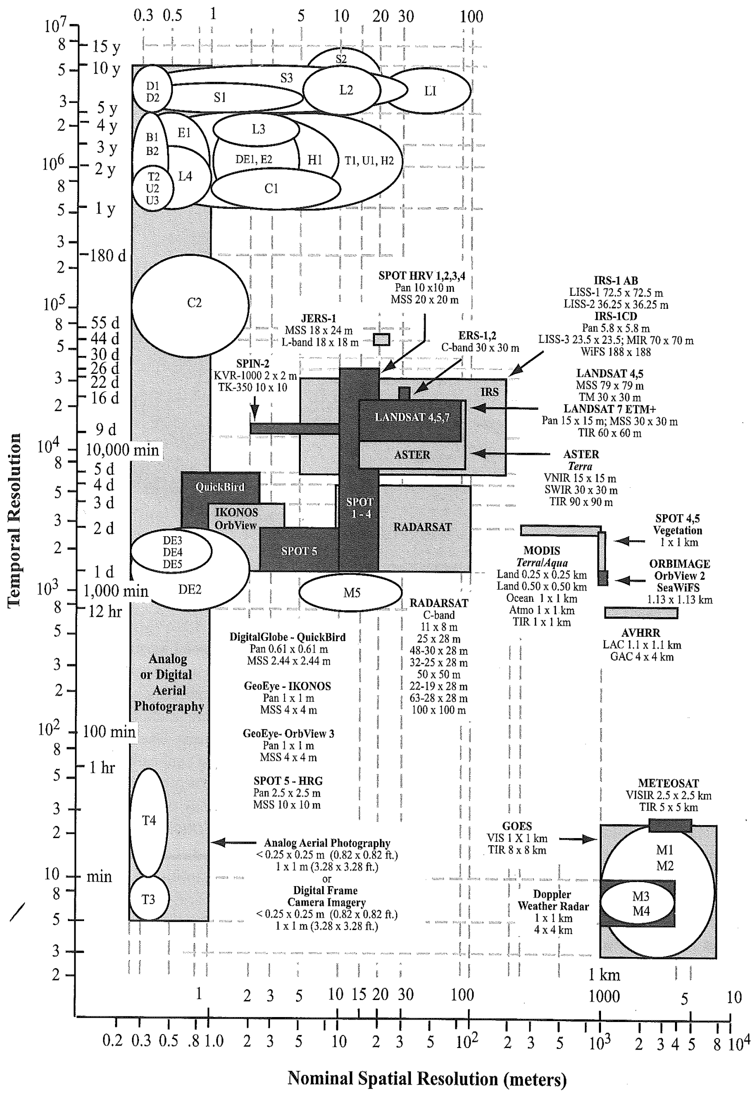

Figure 4. In this image, the data from table 2, 3 and 4 is plotted; the temporal resolution versus the nominal spatial resolution. In essence, it depicts a bit the different applications possible for the chosen temporal/spatial resolution. Source: [John R. Jensen 2007]

VII. Appendix B; GOES I-M Imager and Sounder Information

The following information is taken from the website of NOAA Satellite and Information Service.

A. *GOES I-M Imager*

The GOES I-M Imager is a five channel (one visible, four infrared) imaging radiometer designed to sense radiant and solar reflected energy from sampled areas of the earth. By means of a servo driven, two-axis gimbaled mirror scanning system in conjunction with a Cassegrain telescope, the Imager's multispectral channels can simultaneously sweep an 8-kilometer (5 statute mile) north-to-south swath along an east-to-west/west-to-east path, at a rate of 20 degrees (optical) east-west per second. This translates into being able to scan a 3000 by 3000 km (1864 by 1864 miles) "box" centered over the United States in just 41 seconds. The actual scanning sequence takes places by sweeping in an East-West direction, stepping in the North-South direction, than sweeping back in a West-East direction, stepping North-South, sweeping East-West, and so on.

The Imager consists of electronics, power supply, and sensor modules. The sensor module containing the telescope, scan assembly, and detectors, is mounted on a baseplate outside the main structure of the spacecraft, together with shields and louvers for thermal control. The electronics module provides redundant circuitry and performs command, control, and signal processing functions; it also serves as a structure for mounting and interconnecting the electronic boards for proper heat dissipation. The power supply module contains the converters, fuses, and power control for interfacing with the spacecraft electrical power subsystem. The electronics and power supply modules are mounted inside the spacecraft on the internal equipment panel.

Imager Instrument Characteristics (GOES I-M)					
Channel number:	1 (Visible)	2 (Shortwave)	3 (Moisture)	4 (IR 1)	5 (IR 2)
Wavelength range (um)	0.55 - 0.75	3.80 - 4.00	6.50 - 7.00	10.20 - 11.20	11.50 - 12.50
Instantaneous Geographic Field of View (IGFOV) at nadir	1 km	4 km	8 km	4 km	4 km
Radiometric calibration	Space and 290 K infrared internal backbody				
Calibration frequency	Space: 2.2 sec (full disc), 9.2 or 36.6 sec (sector/area) Infrared: 30 minutes typical				
System absolute accuracy	IR channels: less than or equal to 1 K Visible channel: 5% of maximum scene irradiance				
Imaging rate	Full earth disc, less than or equal to 26 minutes				

Figure 5. Information on the GOES I-M Imager. Source: http://noaasis.noaa.gov/NOAASIS/ml/imager.html

B. *GOES I-M Sounder*

The GOES I-M Sounder is a 19-channel radiometer that senses specific data parameters for atmospheric temperature and moisture profiles, surface and cloud top temperature, and ozone distribution. The atmospheric profiles that are produced are very similar to what has been achieved for decades using balloon-borne radiosondes. But the satellite Sounder system is able to achieve a greater number of profiles, and many more locations than is possible with a ground-based, balloon system.

The Sounder has 4 sets of detectors (visible, long wave IR, medium wave IR, short wave IR). The incoming radiation passes through a set of filters before reaching the detectors. The filters are mounted on a rotating (28.2 cm) wheel containing 18 filter windows, divided into 3 concentric rings, one for each IR detector group. The outer ring contains 7 long wave filters, the middle ring 6 short wave filters, and the inner ring 5 medium wave channels. The visible wave lengths do not pass through a filter. Approximately one-fourth of the wheel has no filters. While this "dead zone" is rotating in front of the detectors, the scanning mirror is stepped to the next location then stopped while the channels are sampled. The mirror scanning sequence takes places by sweeping in an East-West direction, stepping in the North-South direction, than sweeping back in a West-East direction, stepping North-South, sweeping East-West, and so on, similar to the Imager.

The Sounder consists of electronics, power supply, and sensor modules. The sensor module containing the telescope, scan assembly, and detectors, is mounted on a baseplate outside the main structure of the spacecraft, together with shields and louvers for thermal control. The electronics and power supply modules are mounted inside the spacecraft on the internal equipment panel.

Sounder Instrument Characteristics (GOES I-M)		
Channel Numbers	Wavelength (um)	Maximum Temperature Range (K)
Long wave IR		
1	14.71	space - 280
2	14.37	space - 280
3	14.06	space - 290
4	13.64	space - 310
5	13.37	space - 320
6	12.66	space - 330
7	12.02	space - 340
Medium wave IR		
8	11.03	space - 345
9	9.71	space - 330
10	7.43	space - 310
11	7.02	space - 295
12	6.51	space - 290
Short wave IR		
13	4.57	space - 320
14	4.52	space - 310
15	4.45	space - 295
16	4.13	space - 340
17	3.98	space - 345
18	3.74	space - 345
Visible 19	0.70	Not Applicable
Nominal Circular Field of View (IGFOV)	242 urad for all channels	
Radiometric calibration	Space and 300 K infrared internal backbody	
Calibration frequency	Space: 2 minutes typical Infrared: 30 minutes typical	
System absolute accuracy	IR channels: less than or equal to 1 K Visible channel: 5% of maximum scene irradiance	
Sounding rate	3000 by 3000 km, less than or equal to 42 minutes	

Figure 6. Information on the GOES I-M Sounder. Source: http://noaasis.noaa.gov/NOAASIS/ml/sounder.html

References

[1] www.eohandbook.com, "*CEOS EO Handbook – Case Studies Satellite Observations in support of Climate Challenges*", November 2009

[2] http://www.nasa.gov/centers/goddard/news/topstory/2003/1023esuice.html, "*Recent Warming of Arctic may affect worldwide Climate*", October 23, 2003 - (date of web publication)

[3] Andrew C. Revkin, "*No Escape: Thaw Gains Momentum*", New York Times, Published: October 25, 2005, http://www.nytimes.com/2005/10/25/science/earth/25arctic.html?pagewanted=1

[4] Andrew C. Revkin, "*Arctic Melt Unnerves the Experts*", New York Times, Published: October 2, 2007, http://www.nytimes.com/2007/10/02/science/earth/02arct.html?_r=1

[5] Kristin L. Laidre, Mads Peter Heide-Jørgensen, "*Arctic sea ice trends and narwhal vulnerability*", 2004, Published by Elsevier, Biological Conservation 121 (2005) 509–517

[6] Krishna Ramanujan, "*The Arctic Perennial Sea Ice Could Be Gone by End of the Century*", 10-23-2003 NASA Goddard Space Flight Center, http://www.nasa.gov/vision/earth/environment/Perrenial_Sea_Ice.html

[7] John R. Jensen, University of South Carolina, "*Remote Sensing of the Environment*", 2007 Prentice Hall Series.

[8] R. Noomen, Q.P. Chu, A. Kamp, "*Space Engineering and Technology III*", Faculty of Aerospace Engineering 2007, TU Delft.

[9] NOAA, National Oceanic and Atmospheric Administration, GOES Imager Instrument, GOES Sounder Instrument, http://noaasis.noaa.gov/NOAASIS/ml/imager.html, http://noaasis.noaa.gov/NOAASIS/ml/sounder.html,