Satellite Observations, Operational Directions, and Opportunities

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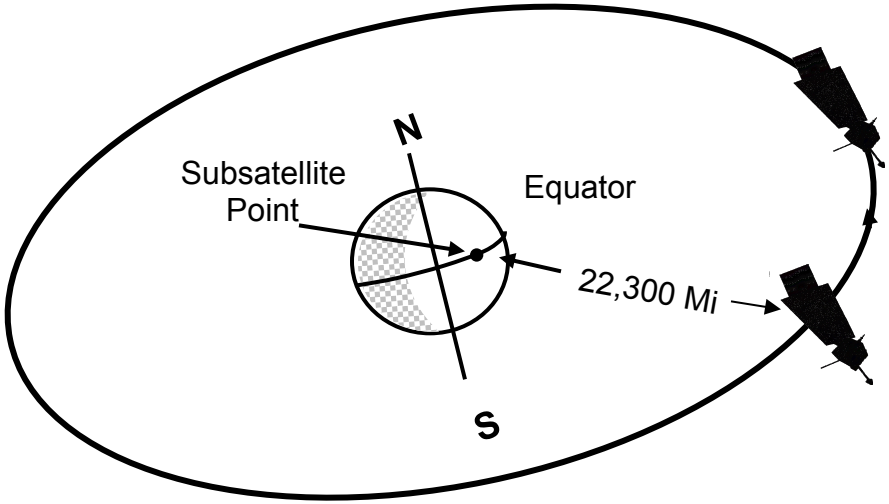
NOAA/NESDIS Office of Systems Development
Requirements, Planning, and Systems Integration

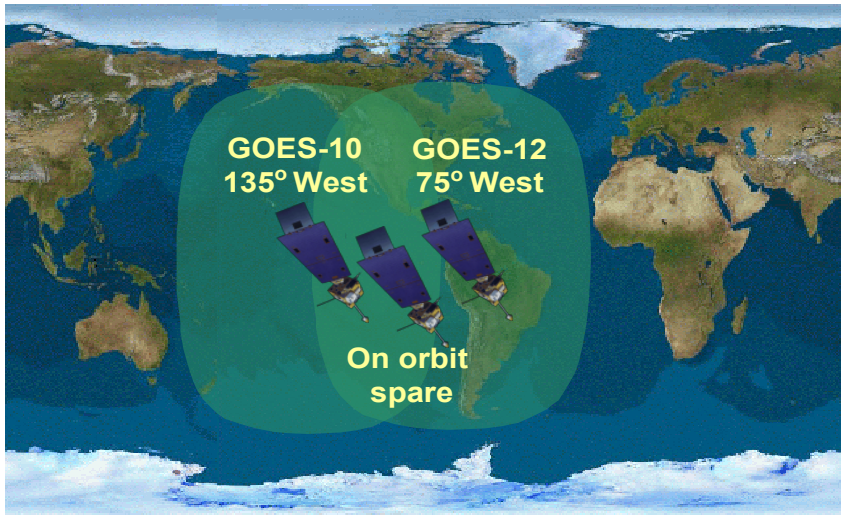
Overview

- GOES / GOES-R
- GOES-R Coastal Waters Capability
- POES / NPOESS
- Roadmaps
- Foreign Satellite Opportunities

GOES Mission

Two satellites and on-orbit spare

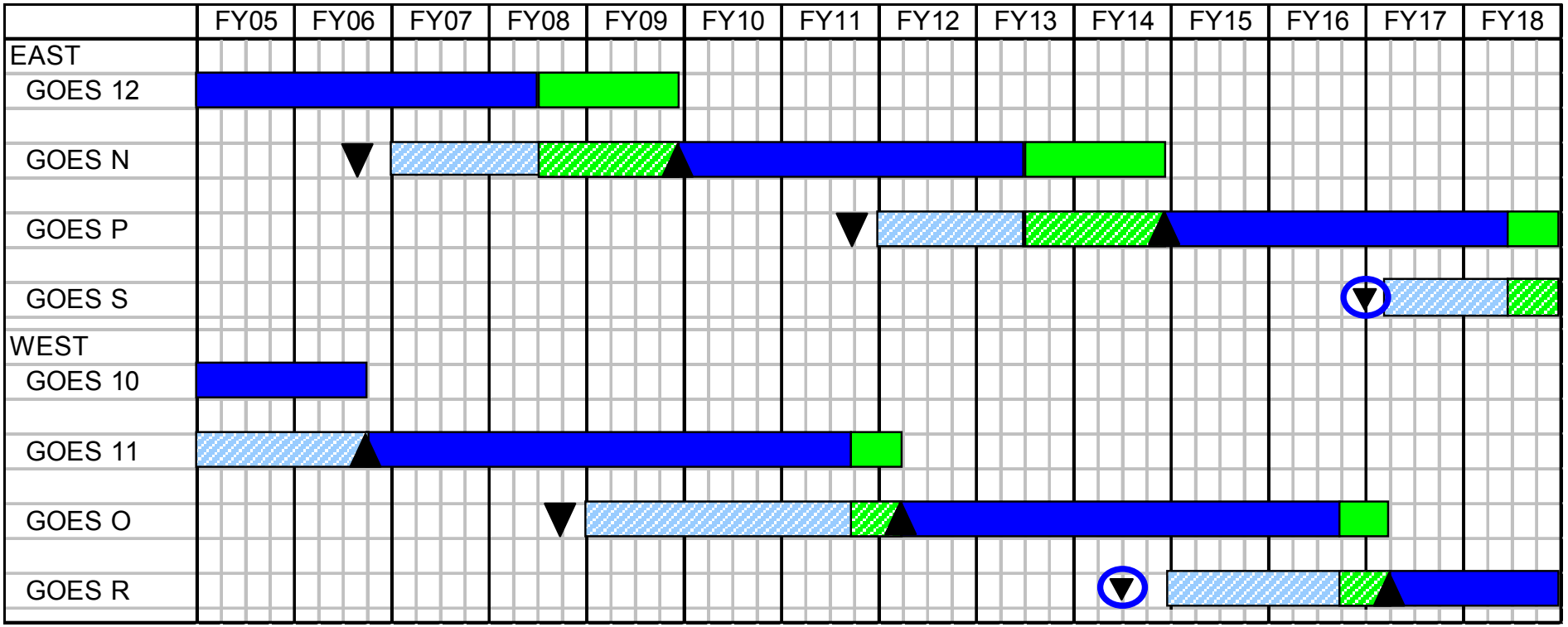




- GOES I-M (8-12)* series operational since 1994
- GOES-N launch planned for 2006, GOES O & P being built
- GOES-R series needed to replace the GOES-N series, expected launch need in 2014
- Part of US contribution to Global Earth Observation System of Systems (GEOSS)

* Note: satellites are labeled with letters on the ground and changed to numbers on-orbit

GOES
Launch and Operations



Planned Activation Date
Planned Launch Date
Launch Readiness (R-Series)
Projected On-Orbit Storage
Projected Operations
Updated Projections

GOES R Observational Requirements*

Allocated by Sensors

Absorbed Shortwave Radiation	Downward Solar Insolation	Rainfall Potential
Aerosol Detection	Dust/Aerosol	Rainfall Rate/QPE
Aerosol Particle Size	Energetic Heavy Ions	Reflected Solar Insolation
Aircraft Icing Threat	Enhanced "V"/Overshooting Top Detection	Sea & Lake Ice/ Displacement and Direction
Atmospheric Vertical Moisture Profile	Fire / Hot Spot Imagery	Sea & Lake Ice/Age
Atmospheric Vertical Temperature Profile	Flood/Standing Water	Sea & Lake Ice/Concentration
Capping Inversion Information	Geomagnetic Field	Sea & Lake Ice/Extent and Characterization
CH_4 Concentration	Hurricane Intensity	Sea & Lake Ice/Surface Temp
Clear Sky Masks	Ice Cover/ Landlocked	Sea Surface Temps
Cloud & Moisture Imagery	Imagery: All-Wx/Day-Nite	Snow Cover
Cloud Base Height	Land Surface (Skin) Temperature	Snow Depth
Cloud Ice Water Path	Leaf Area Index (LAI)	SO_2 Concentration
Cloud Imagery	Lightning Detection	Solar and Galactic Protons
Cloud Layers / Heights and Thickness	Low Cloud and Fog	Solar Flux: EUV
Cloud Liquid Water	Mag Electrons & Protons: Low Energy	Solar Flux: X-Ray
Cloud Optical Depth	Mag Electrons & Protons: Med & High Energy	Solar Imagery
Cloud Particle Size Distribution	Microburst Winds	Surface Albedo
Cloud Phase	Moisture Flux	Surface Emissivity
Cloud Top Height	Ocean Currents	Suspended Matter
Cloud Top Pressure	Ocean Color	Total Precipitable Water
Cloud Top Temperature	Ocean Optical Properties	Total Water Content
Cloud Type	Ocean Turbidity	Turbulence
CO Concentration	Oil Spill Location	Upward Longwave Radiation
CO_2 Concentration	Ozone Layers	Vegetation Fraction
Convection Initiation	Ozone Total	Vegetation Index
Derived Motion Winds	Pressure Profile	Visibility
Derived Stability Indices	Probability of Rainfall	Volcanic Ash
Downward Longwave Radiation	Radiances	

LEGEND

ABI	LM
HES	SEM
HES-CW	SXI

* Does not reflect individual geographic coverage requirements.

GOES R Rqmnts_Sensors v6-
HES CW

GOES-R Baseline Instruments

- Advanced Baseline Imager (ABI)
  - Monitors and tracks severe weather
  - Images clouds to support forecasts
  - Better resolution, faster coverage and more coverage simultaneously
- Hyperspectral Environmental Suite (HES)
  - Provides atmospheric moisture and temperature profiles to support forecasts and climate monitoring
  - Monitors coastal regions for ecosystem health, water quality, coastal erosion, harmful algal blooms
  - Better resolution, faster coverage, adds coastal water imagery
- Solar Imaging Suite (SIS) and Space Environmental In-Situ Suite (SEISS)
  - Images the sun and measures solar output to monitor solar storms (SIS)
    - Better Imager (UV over X-Ray)
  - Measures magnetic fields and charged particles (SEISS)
    - Better Heavy Ion detection, adds low energy electrons and protons
  - Enables early warnings for satellite and power grid operations, telecom services, astronauts, and airlines
- Geostationary Lightning Mapper (GLM)
  - Detects lightning strikes as an indicator of severe storms
  - Previous capability only existed on polar satellites

HES-CW Products and Applications

Products:

- Spectral water leaving radiances
- Chlorophyll
- Chlorophyll fluorescence
- Turbidity
- Spectral absorption and scattering

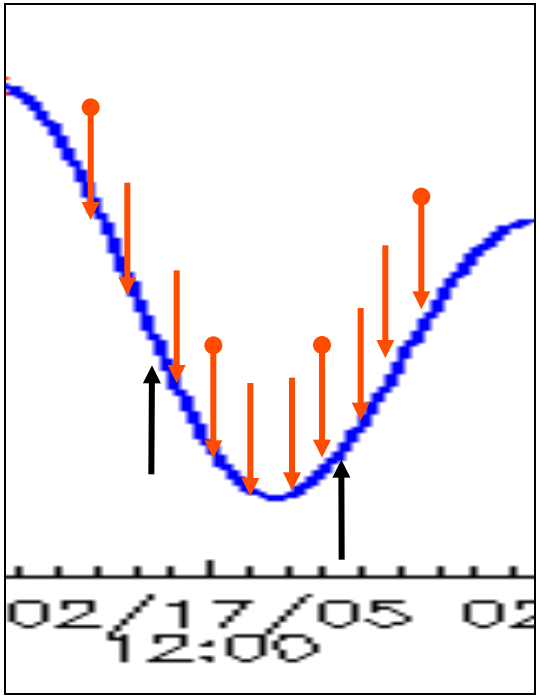
Applications:

- Water quality monitoring
- Coastal hazard assessment
- Navigation safety
- Human and ecosystem health awareness (Harmful Algal Blooms)
- Natural resource management in coastal and estuarine areas
- Climate variability prediction (e.g., role of the coastal ocean in the carbon cycle)
- Nowcast and Forecast models of the coastal ocean

Why HES-CW given VIIRS?

- Tides, diel winds (such as the land/sea breeze), river runoff, upwelling and storm winds drive coastal currents that can reach several knots. Furthermore, currents driven by diurnal and semi-diurnal tides reverse approximately every 6 hours.
- VIIRS daily sampling at the same time cannot resolve tides, diurnal winds, etc.
- HES-CW Can resolve tides from a geostationary platform and will provide the management and science community with a unique capability to observe the dynamic coastal ocean environment.
- HES-CW will provide higher spatial resolution (300 m vs. 1000 m)
- HES-CW will provide additional channels to measure solar stimulated fluorescence, suspended sediments, CDOM and improved atmospheric correction.

These improvements are critical for the analyses of coastal waters.

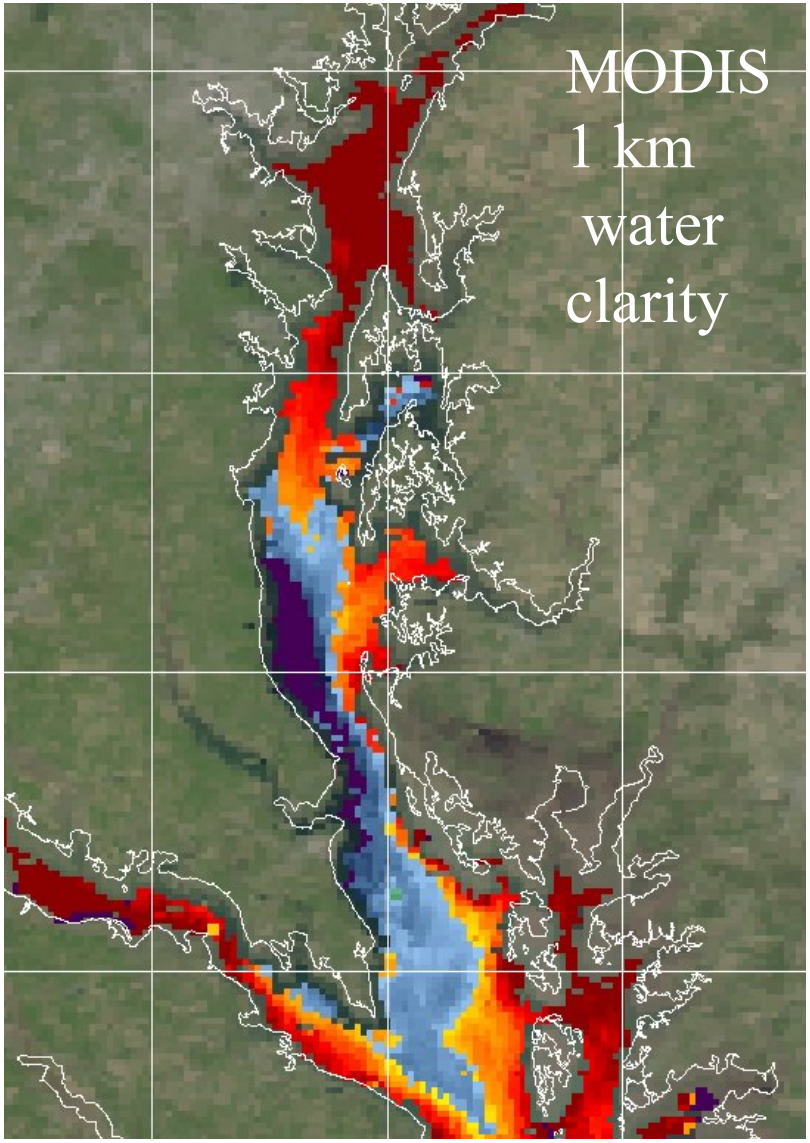


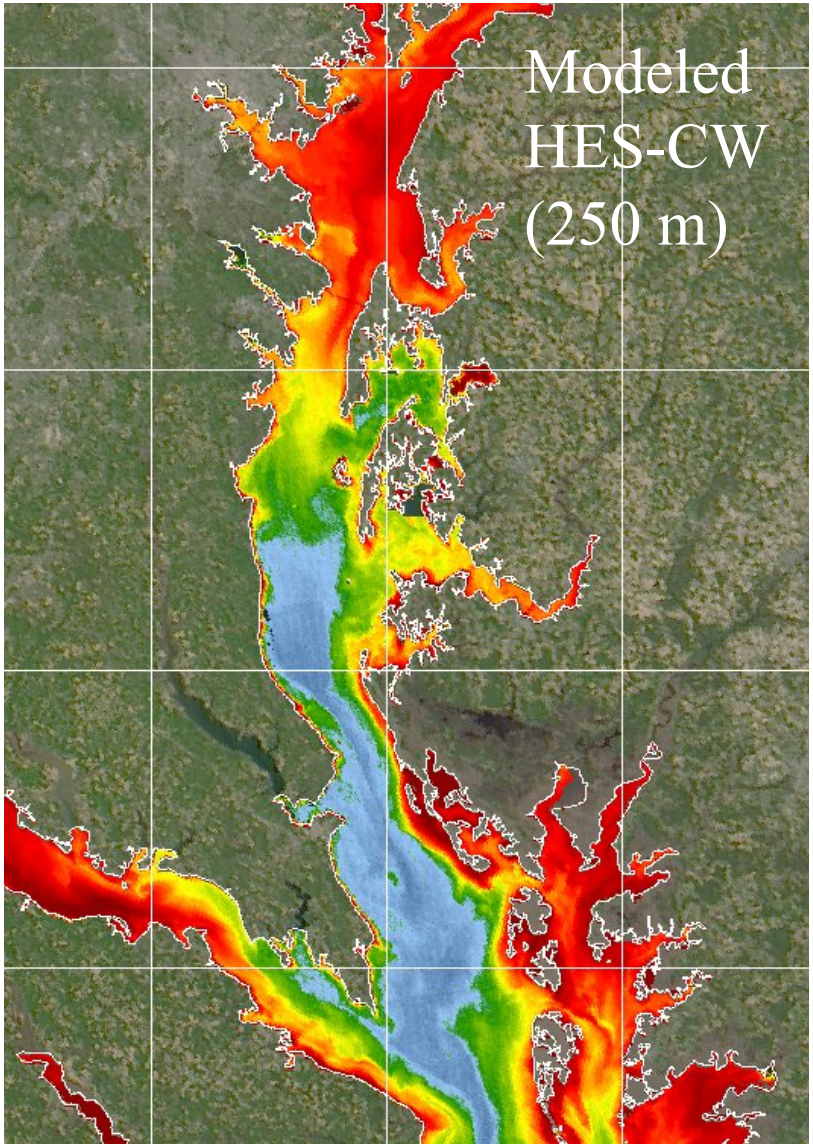
Example tidal cycle from Charleston, OR. Black arrows VIIRS sampling, red arrows HES-CW sampling.

Ocean Color Channel Comparisons

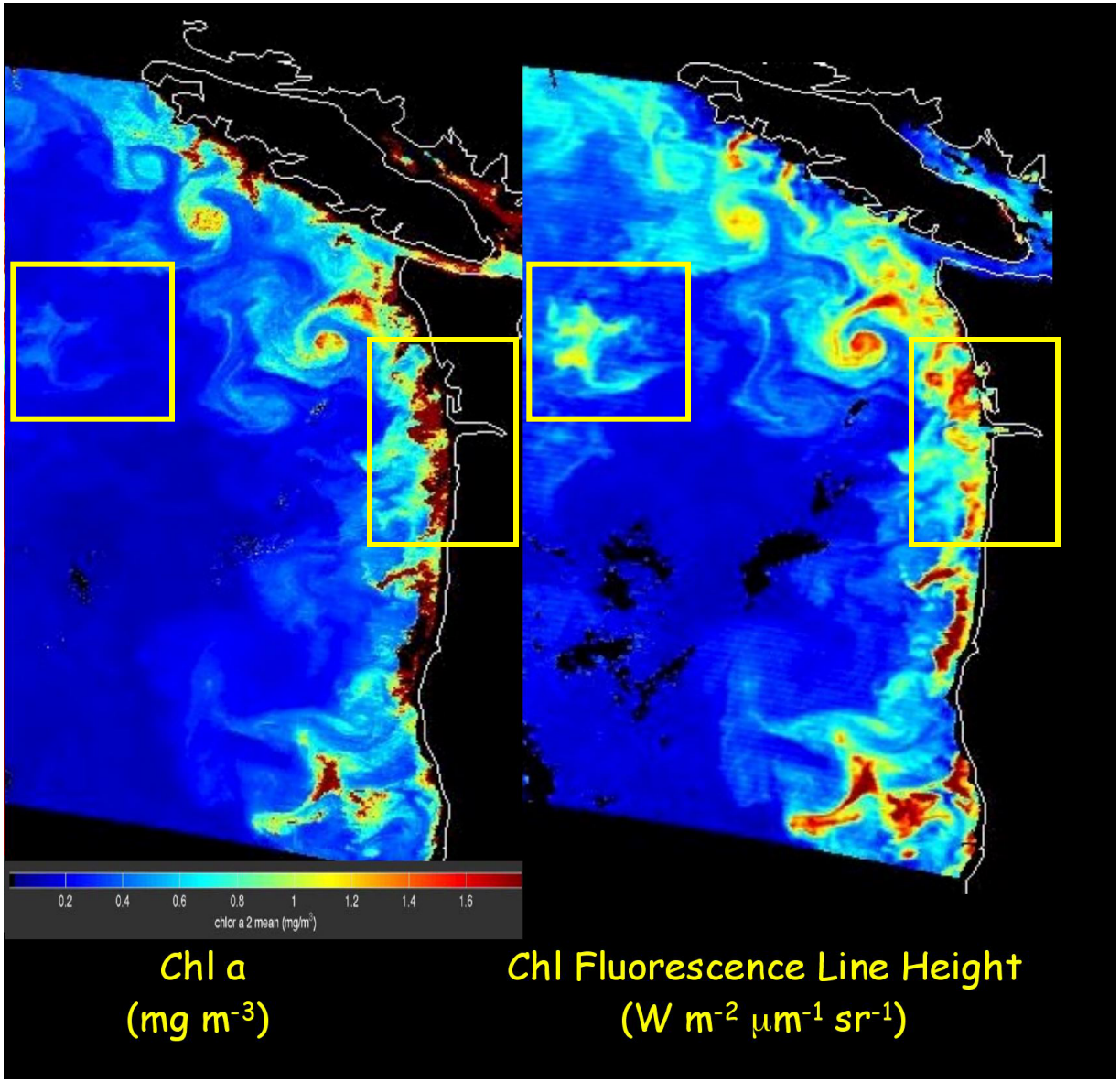
SeaWiFS		MODIS		VIIRS		MERIS		OCM	HES/CW	
http://www.orbimage.com		http://modis.gsfc.nasa.gov/about/specifications.php		http://www.ipo.noaa.gov/Technology/viirs_summary.html		http://esapub.esrin.esa.it	bw	http://www.ioccg.org/reports/ocm/ocm.html		bw
402-422	412	405-420	412	402-422	412	412.5	10	414	412	20
433-453	443	438-448	443	436-454	445	442.5	10	442	443	20
480-500	490	483-493	488	478-498	488	490	10	489	490	20
500-520	510					510	10	512	510	20
		526-536	531							
545-565	555	546-556	551	545-565	555	560	10	557	555	20
									580	20
						620	10		610	20
									645	10
660-680	670	662-672	667	662-682	672	665	10	670	667	10
		673-683	678			681.25	7.5		678	10
						708.75	10		710	10
		743-753	748	731-751	746	753.75	7.5		750	20
745-785	765					760.625	3.5	768		
						778.75	15			
845-885	865	862-877	869	846-885	865	865	20	867	865	20
						885	10			
						900	10			

HES-CW higher spatial resolution critical to monitor complex coastal waters





Chlorophyll and chlorophyll fluorescence of optically-complex coastal waters



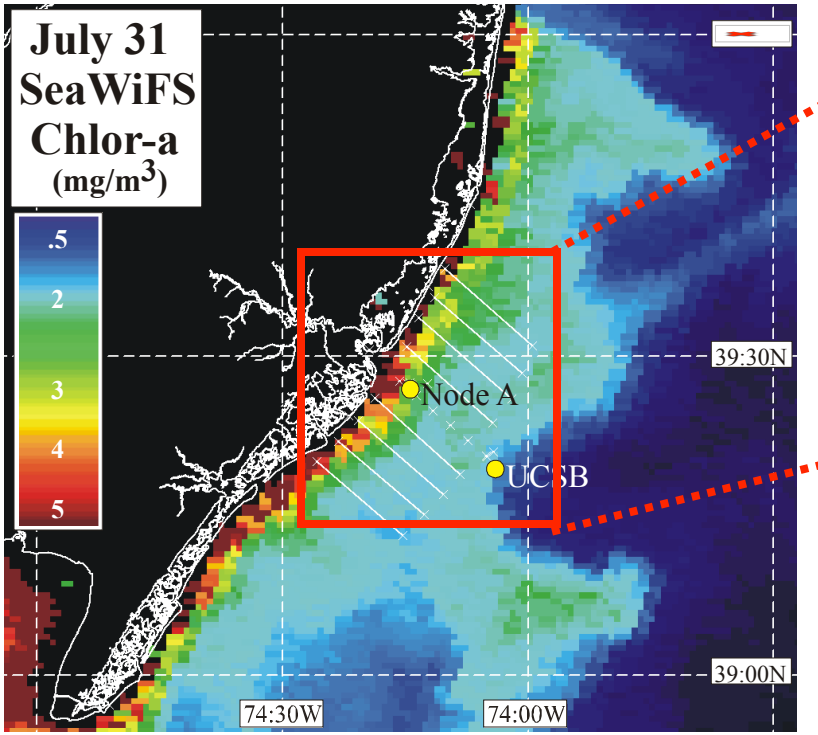
MODIS Terra scene from 3 October 2001.

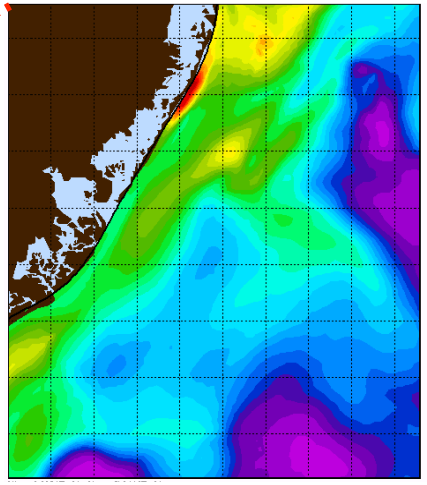
- **The ratio of Fluorescence Line Height (FLH) to chlorophyll is a good indicator of the health of the phytoplankton population.**
- **FLH separates chlorophyll from suspended sediments in the Columbia River Plume.**

Fluorescence line height not available from VIIRS.

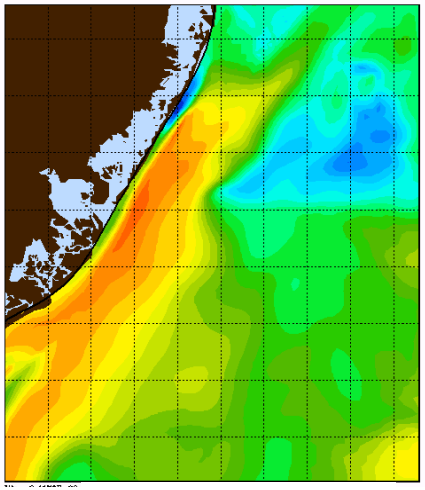
HES-Will support the higher temporal and spatial resolution required for coastal models

Satellite Measured





Large diatoms

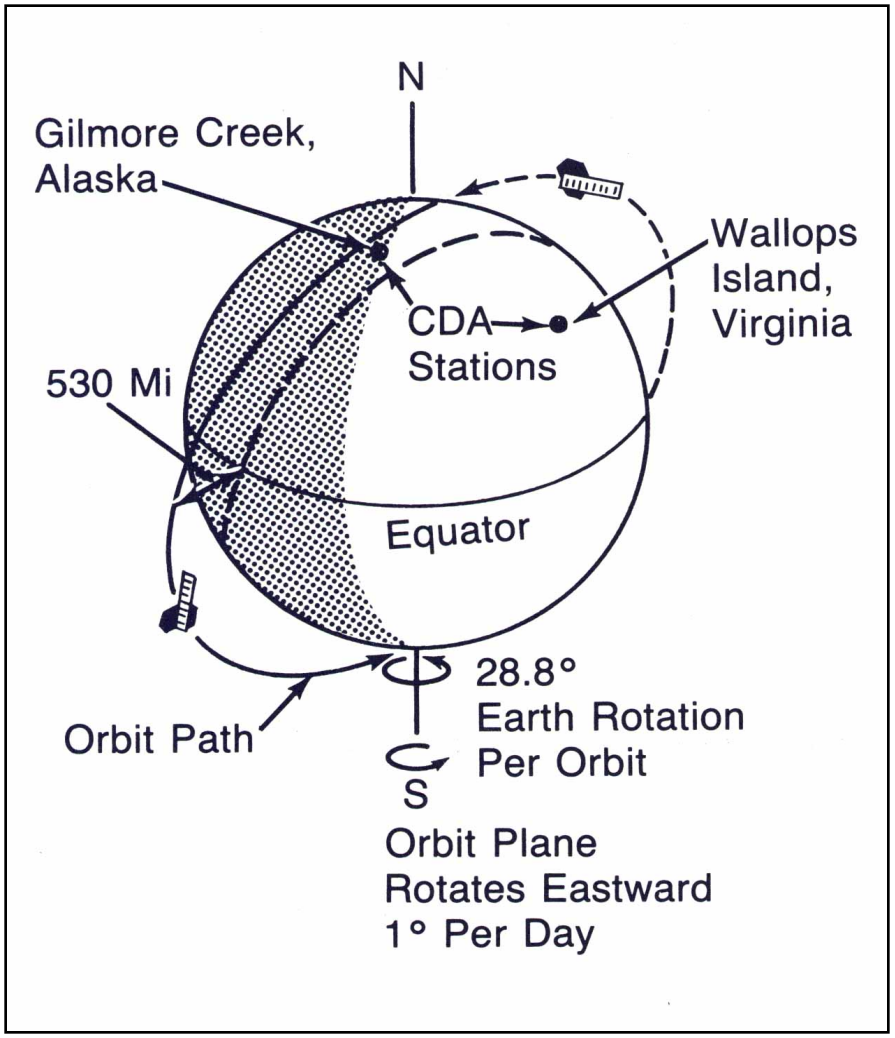


Small diatoms

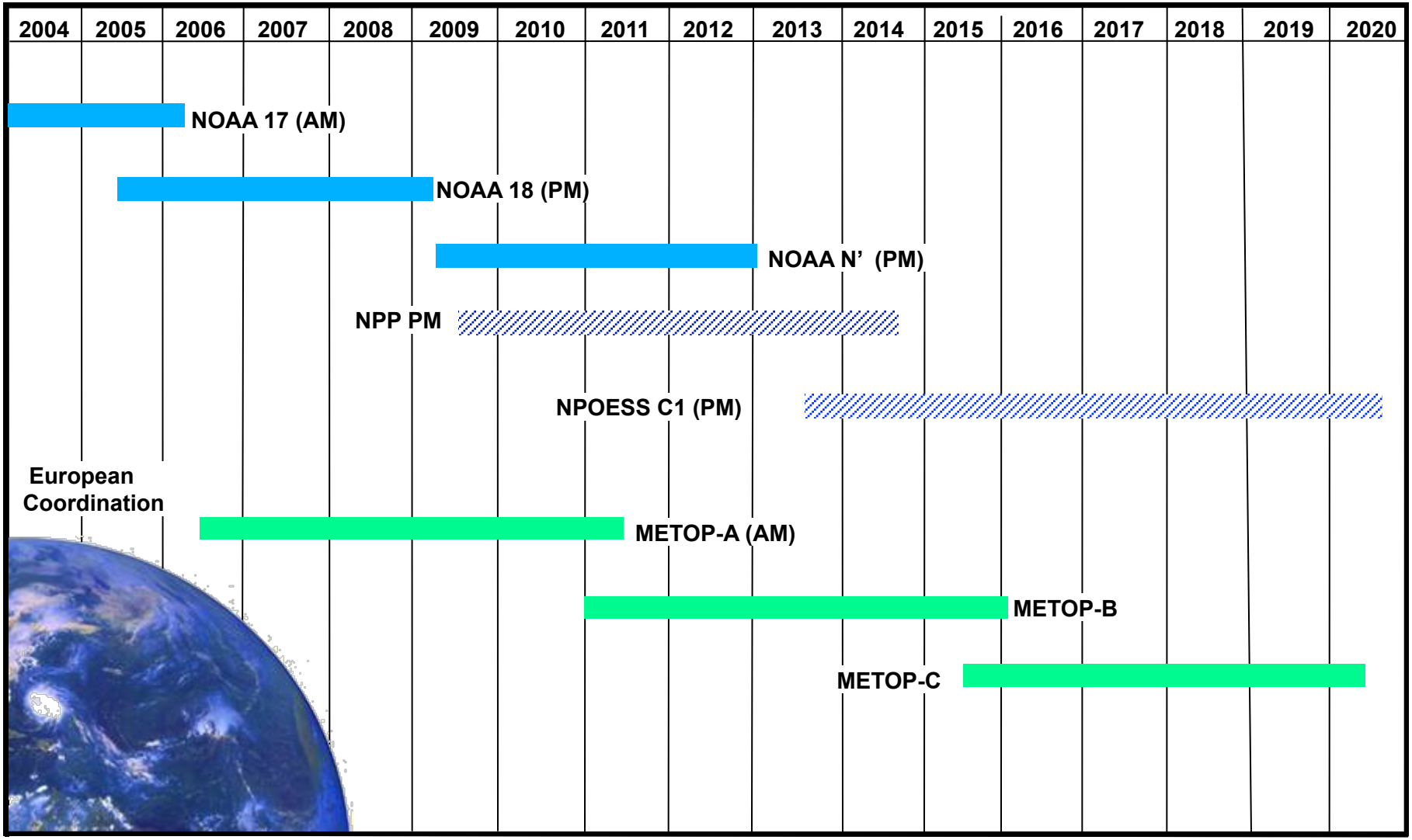
ECOSIM run for July 31, 2001 with ROMS Physical model 15 minute time step and 300 m spatial resolution
(Paul Bissett, Florida Environmental Research Institute)

Polar-orbiting Operational Environmental Satellites (POES)

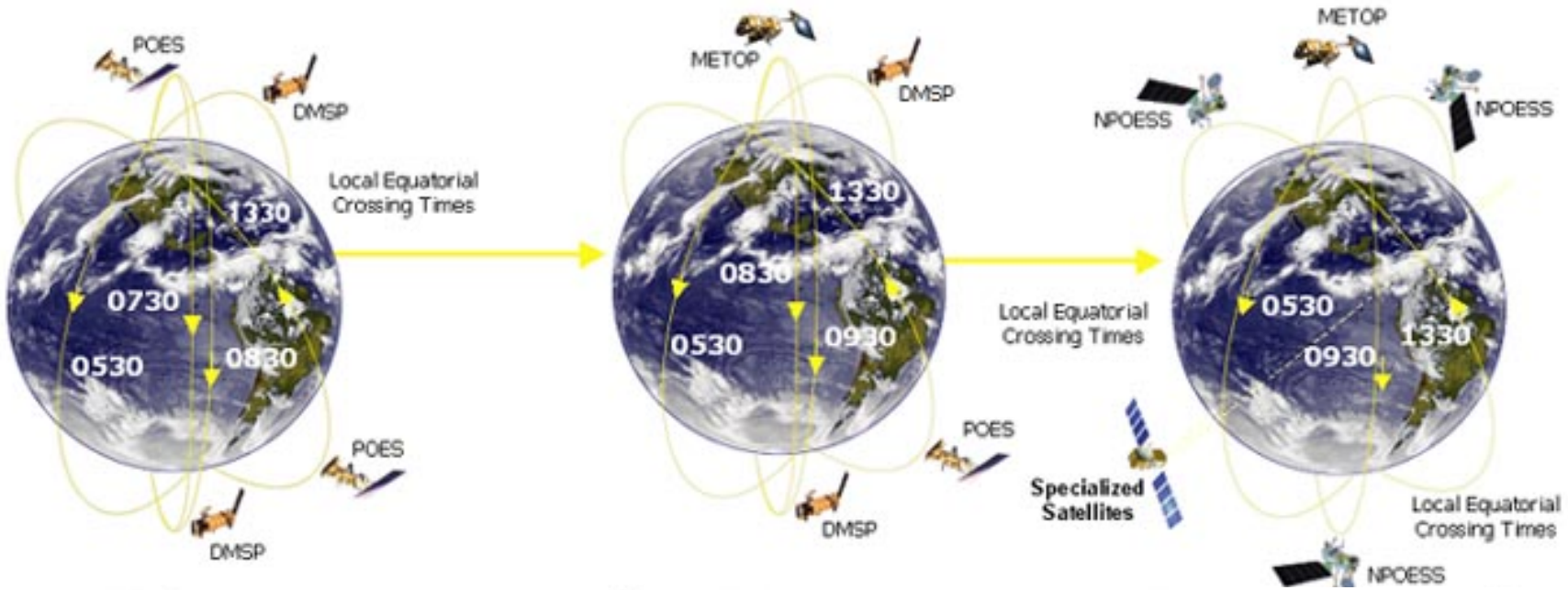
- High inclination (98.7°), sun-synchronous, 102-min orbit at 850 km altitude
- Global coverage every 12 hours
- Two satellites (AM & PM)
- Instruments
  - AVHRR (Advanced Very High-Resolution Radiometer)
  - HIRS (High-resolution Infra-Red Sounder)
  - AMSU (Advanced Microwave Sounding Unit) –A and –B
  - (SBUV/2) Solar Backscattered Ultra-Violet sensor



Polar
Launch and Operations



DMSP/POES Transition to NPOESS



Today

- 4-Orbit System
  - 2 US Military
  - 2 US Civilian

Tomorrow (2006)

- 4-Orbit System
  - 2 US Military
  - 1 US Civilian
  - 1 EUMETSAT/METOP

Future (2013-2025)

- 3-Orbit System
  - 3 US Converged
  - 1 EUMETSAT/METOP
  - Specialized Satellites

NPOESS EDR Requirements

Allocated by Sensors

★	Atm Vert Moist Profile
★	Atm Vert Temp Profile
★	Imagery
★	Sea Surface Temperature
★	Sea Surface Winds
★	Soil Moisture
	Aerosol Optical Thickness
	Aerosol Particle Size
	Aerosol Refractive Index
	Albedo (Surface)
	Auroral Boundary
	Auroral Energy Deposition
	Auroral Imagery
	Cloud Base Height
	Cloud Cover/Layers
	Cloud Effective Part Size
	Cloud Ice Water Path
	Cloud Liquid Water
	Cloud Optical Thickness
	Cloud Particle Size/Distrib
	Cloud Top Height
	Cloud Top Pressure
	Cloud Top Temperature
	Down LW Radiance (Sfc)
	Down SW Radiance (Sfc)
	Electric Fields
	Electron Density Profile
	Energetic Ions
	Geomagnetic Field
	Ice Surface Temperature
	In-situ Plasma Fluctuation
	In-situ Plasma Temp
	Ionospheric Scintillation
	Med Energy Chgd Parts
	Land Surface Temp
	Net Heat Flux
	Net Solar Radiation (TOA)
	Neutral Density Profile
	Ocean Color/Chlorophyll
	Ocean Wave Character
	Outgoing LW Rad (TOA)
	O^3 – Total Column Profile
	Precipitable Water
	Precipitation Type/Rate
	Pressure (Surface/Profile)
	Sea Ice Characterization
	Sea SFC Height/TOPO
	Snow Cover/Depth
	Solar Irradiance
	Supra-Therm-Aurora Prop
	Surface Type
	Surface Wind Stress
	Suspended Matter
	Total Water Content
	Vegetative Index

LEGEND

VIIRS	GPSOS
CMIS	ERBS
CrIS/ATMS	TSIS
OMPS	ALT
SES	APS

★ - KPPs

NPOESS Instrumentation

Sensor	Orbit (LTAN)		
	1330	1730	2130
VIIRS	X	X	X
CMIS	X	X	X
CrIS	X	X	Note 1
ATMS	X	X	Note 2
SESS	X		
OMPS	X		
ADCS	X	X	Note 3
SARSAT	X	X	X
ERBS	X		
SS*	X	X	X
ALT		X	
TSIS		X	
APS			X

* SS: Survivability Sensor

Note 1: METOP (2130) will fly the IASI sounder

Note 2: METOP (2130) will fly the AMSU-A and MHS

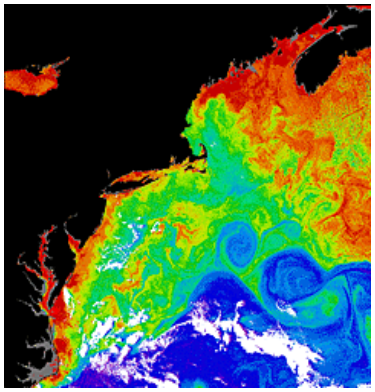
Note 3: METOP (2130) will also fly ADCS (Argos III)

VIIRS Key Characteristics

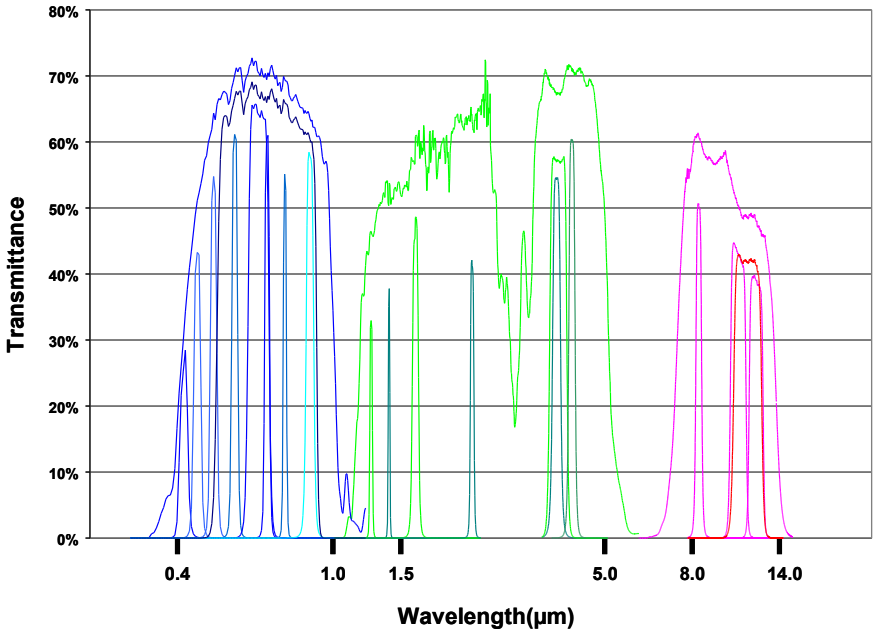
- Resolution
  - 5 Imaging Res Bands: 0.4 km @ nadir, 0.8 km @ EOS
  - 16 Moderate Res Bands: 0.8 km @ nadir, 1.6 km @ EOS
  - DNB at 0.74 km, constant across scan
- Sensitivity:
  - < 0.07 NEdT in M16 at 300 K
- Radiometric Accuracy:
  - < 2 % reflective, < 0.5 % emissive

- **Range: 0.4 to 12 microns**
- **Spectral bands: 22**
  - **Vis/NIR: 9**
  - **DNB: 1**
  - **SW/MW: 8**
  - **LW: 4**

Visible Imagery



Sea Surface Temperature



Other Polar Satellite Orbits

Non sun-synchronous

- Other polar orbits are needed when repeat coverage over same latitude band is more important than either global coverage or sun synchronous coverage
  - Examples:
    - TOPEX-POSEIDON RADAR Altimeter
      - 66^{o} inclination, for repeat coverage over the tropical and mid-latitude oceans
    - TRMM Microwave Imager and Precipitation RADAR
      - 35^{o} inclination for repeat coverage over the tropics
    - GEOSAT-Follow On RADAR Altimeter
      - 108^{o} inclination for repeat coverage over high latitude oceans

Continuity of Operational+ Satellite Programs
NOAA Satellite Launches* Scheduled to Maintain Continuity

2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

+ GOES 9 on standby 07/98, then backup to GMS-5 05/03 – 11/05, operated by Fairbanks at 155° East

GOES 10 *GOES West* To be moved to 60° W for S. America coverage

GOES 11 *GOES West on 4/06*

GOES 12 *GOES East on 4/03*

GOES N

GOES O

GOES P

GOES R***

GOES S***

NOAA 16 (PM)

NOAA 17 (AM)

NOAA N (PM)

NOAA N' (PM)

1st METOP (AM)

** European Coordination

2nd METOP

3rd METOP

NPP (PM)

NPOESS C1 (PM)

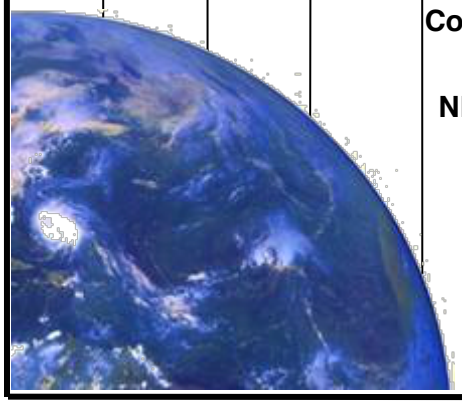
NPOESS C2 (mid AM)

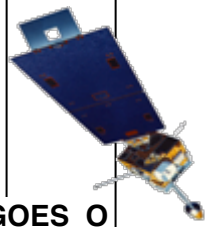
NPOESS C3 (AM)

NPOESS C4 (mid-AM)

NPOESS C5 (PM)

NPOESS C6 (AM)





\+ Non-Operational backup support to JMA due to GMS-5 failure

* Actual launch dates are determined by the failure of on-orbit assets

** Assumes METOP will provide the morning orbit and NOAA-N' will provide afternoon orbit instruments

*** GOES R-Series may be single or suite of satellites (distributed constellation)

Satellite is operational beyond design life

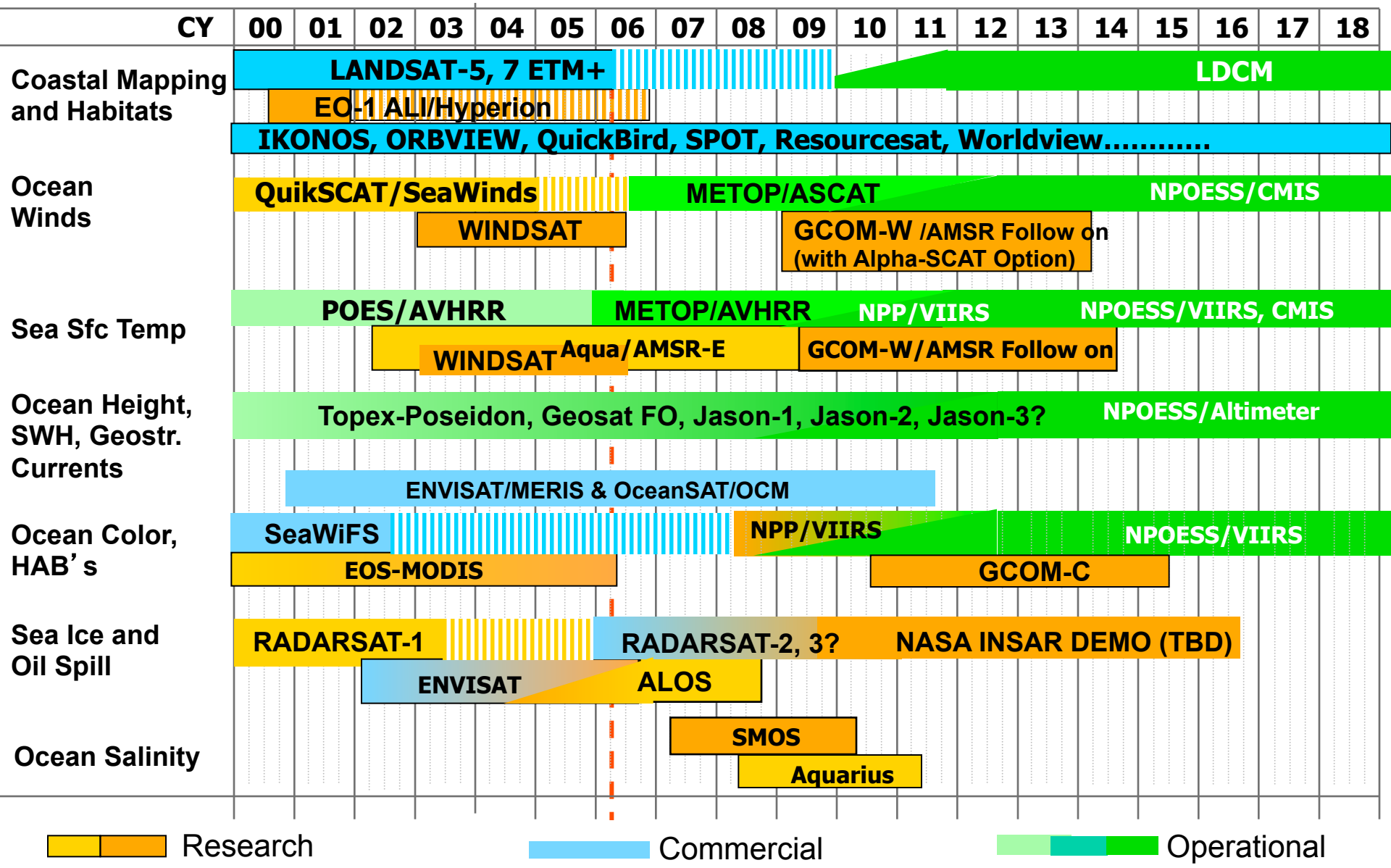
Satellite is providing backup support

On-orbit GOES storage

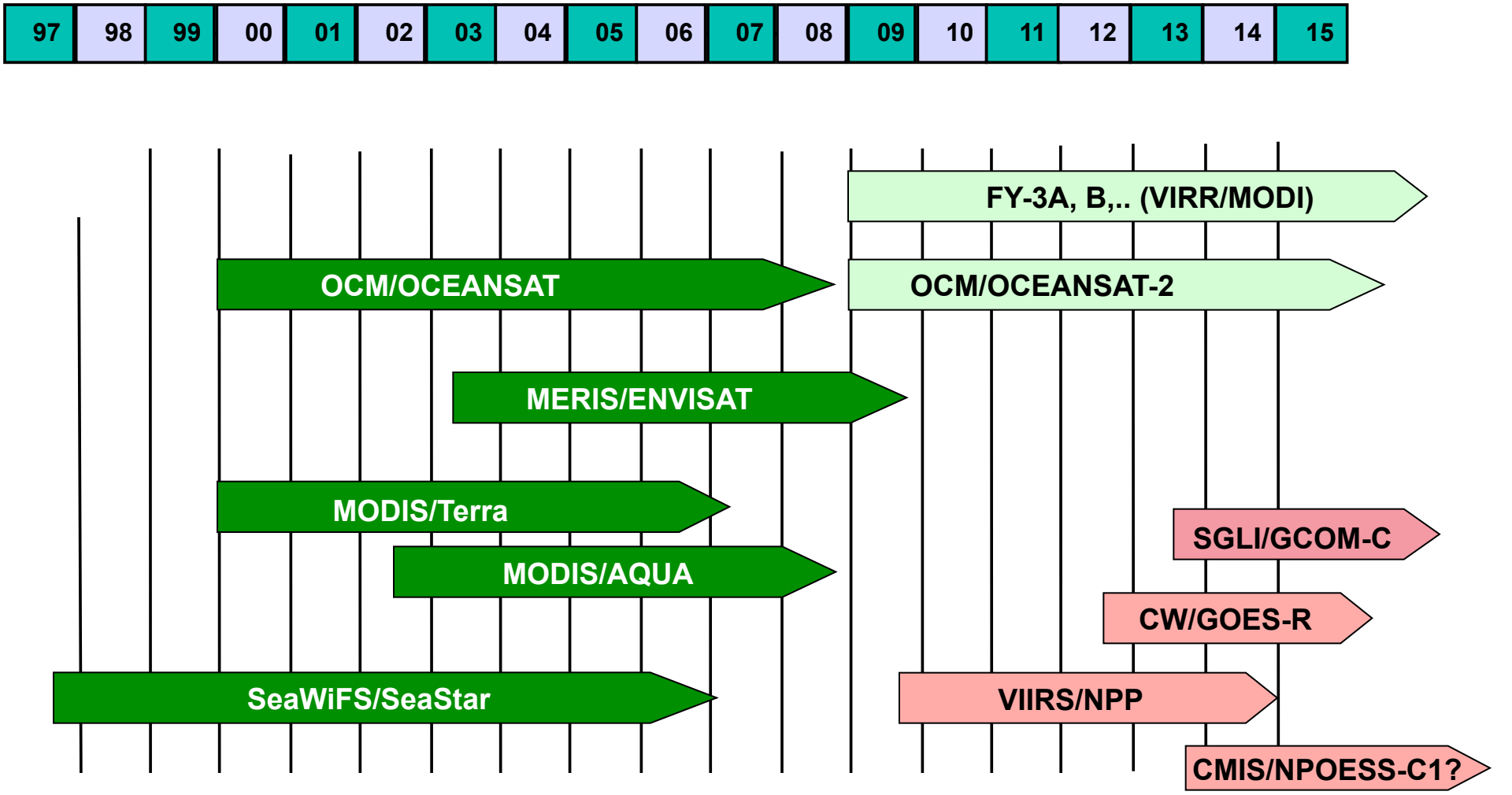
Extended operation

Roadmap to Address Operational Requirements (Polar-orbiting Satellites)

(coastal and ocean)



Ocean Color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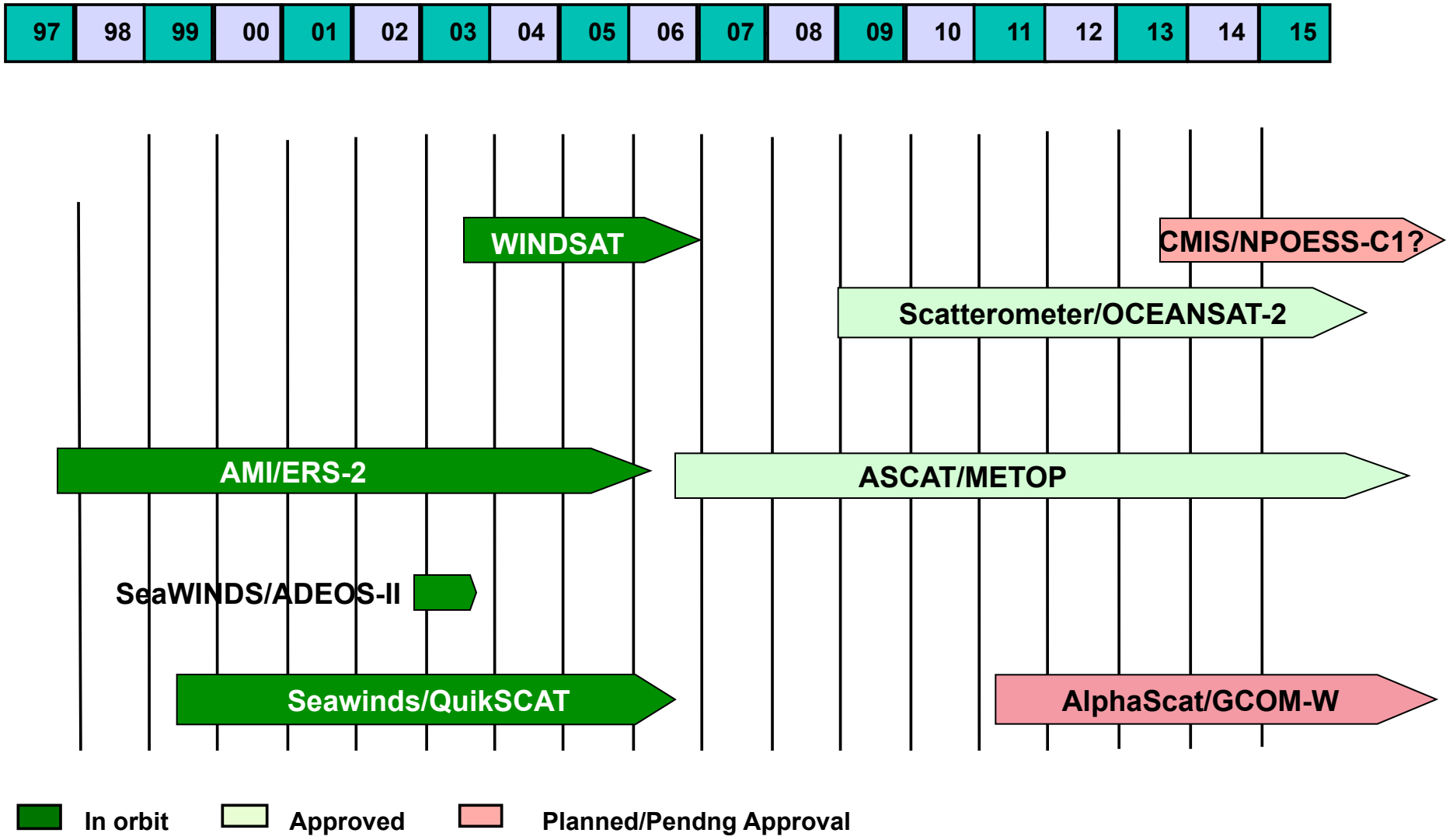
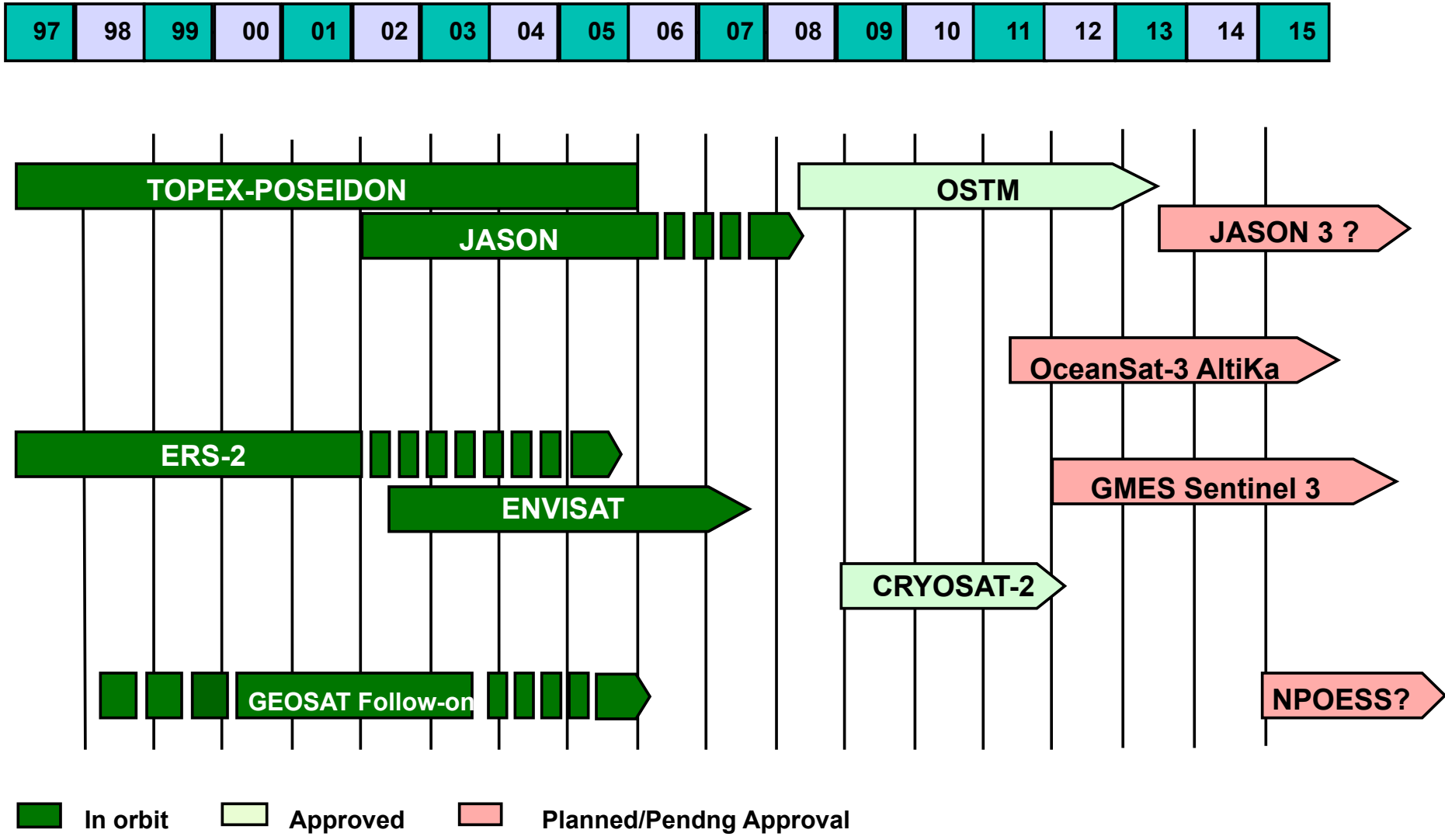
FY-3A, B,.. (VIRR/MODI)
OCM/OCEANSAT
OCM/OCEANSAT-2
MERIS/ENVISAT
MODIS/Terra
SGLI/GCOM-C
MODIS/AQUA
CW/GOES-R
SeaWiFS/SeaStar
VIIRS/NPP
CMIS/NPOESS-C1?
In orbit
Approved
Planned/Pendng Approval

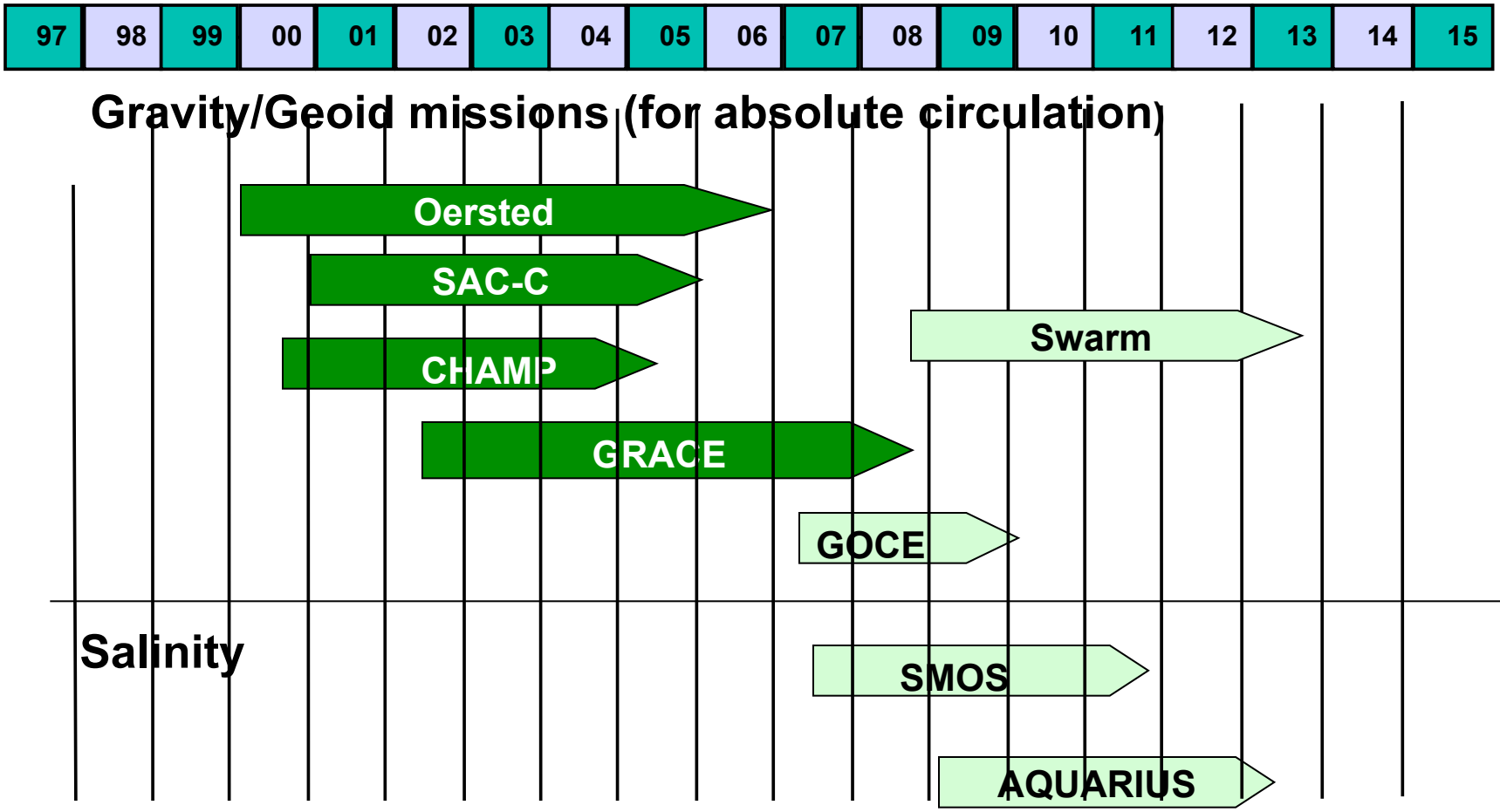
Surface Vector Winds



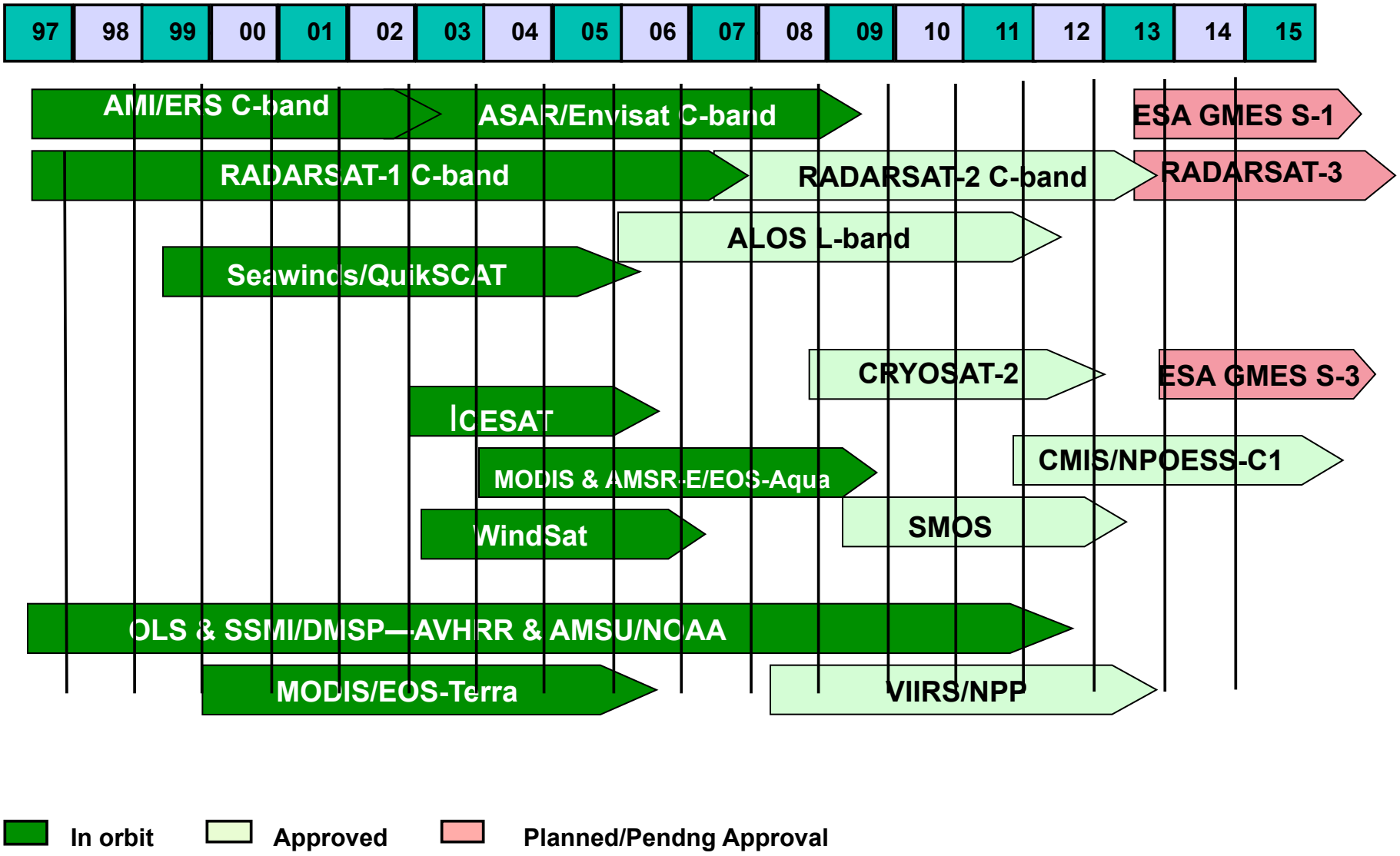
Sea Surface Height



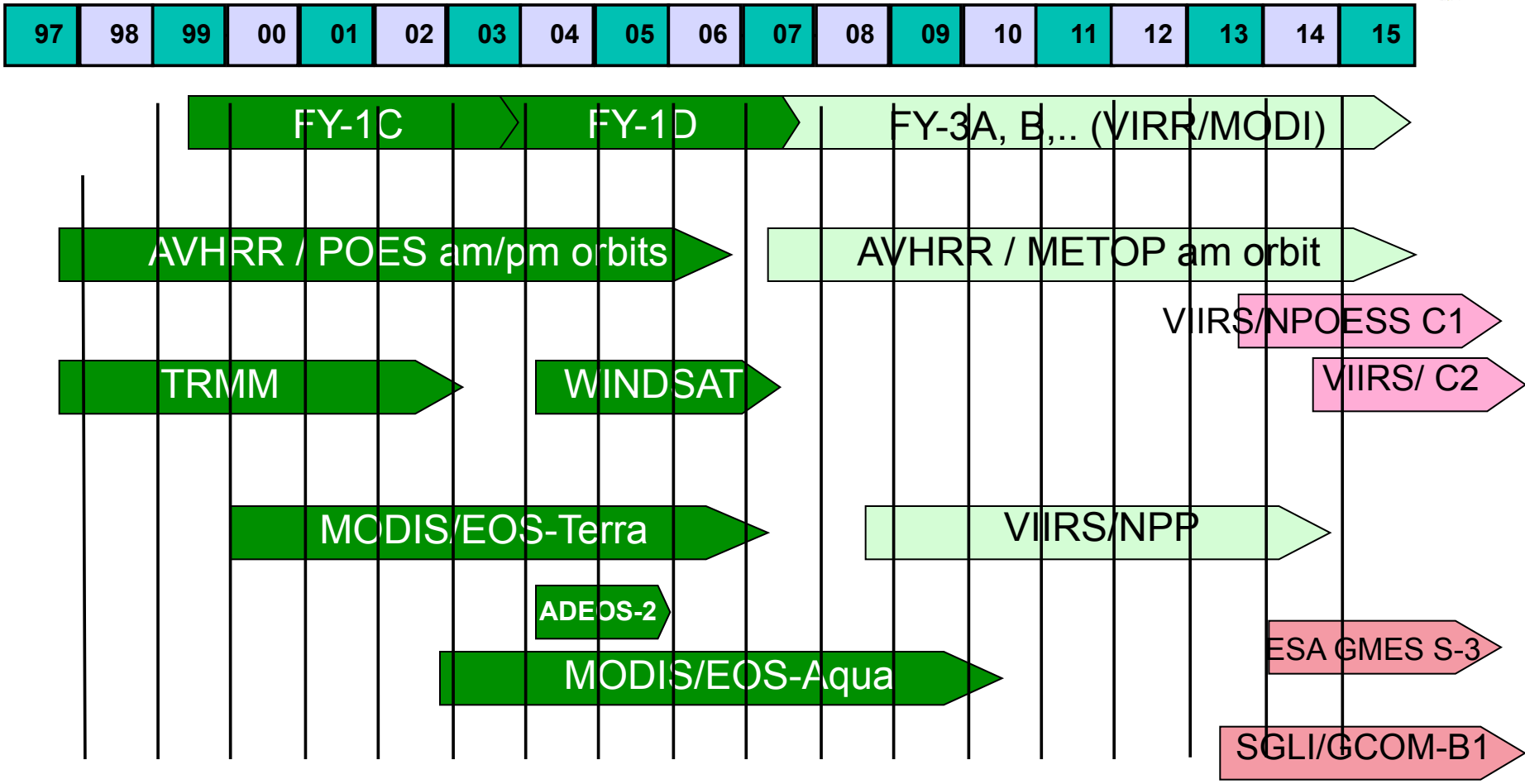
Geoid and Salinity Missions



Sea Ice (Concentration, Extent, Drift, Thickness)



Sea Surface Temperature



**Geostationary sats: GOES, MSG, MTSAT, FY-2 important but not shown

MSMR/IRS-P4

In orbit Approved Planned/Pendng Approval

Earth Gravity Missions

- International Decade of Geopotential Research, IUGG (IAGA & IAG), 1999

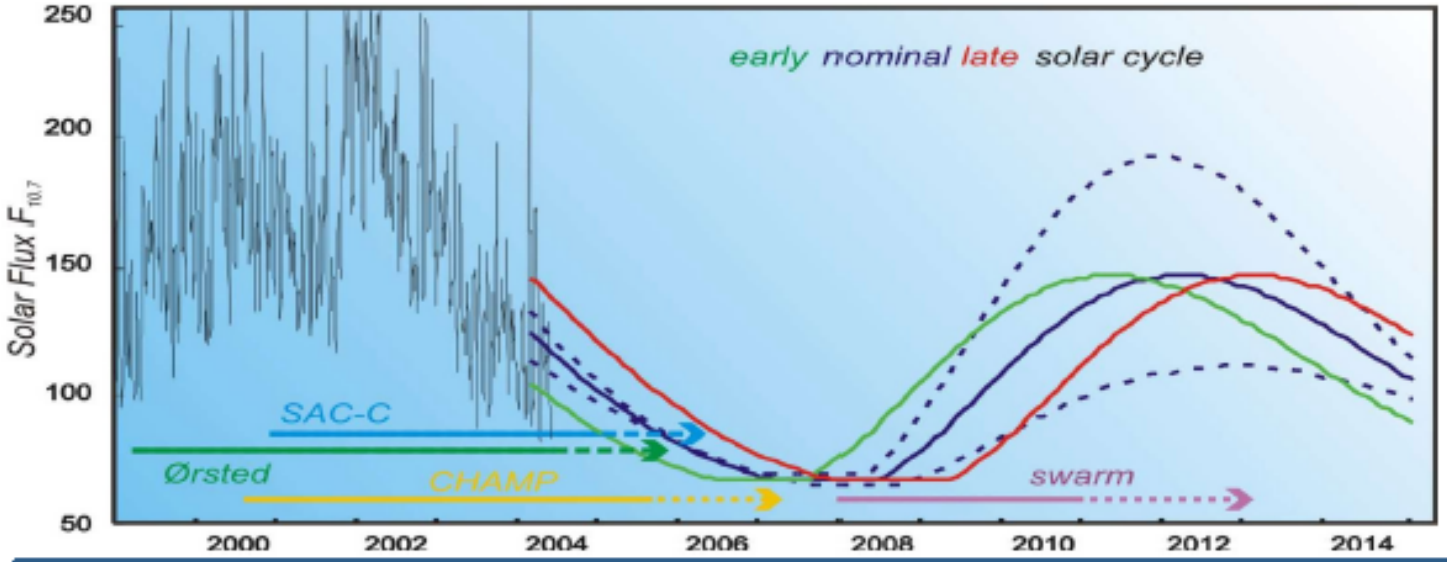
Mission (Country)	2000	2002	2004	2006	2008	2010	2012
Oersted (DK)							
CHAMP (GER)							
SAC-C (ARG/USA/DK)							
GRACE (USA/GER)							
GOCE (ESA)							
Swarm (ESA)							

Absolute magnetics with precise attitude determination

Gravity static and time variable

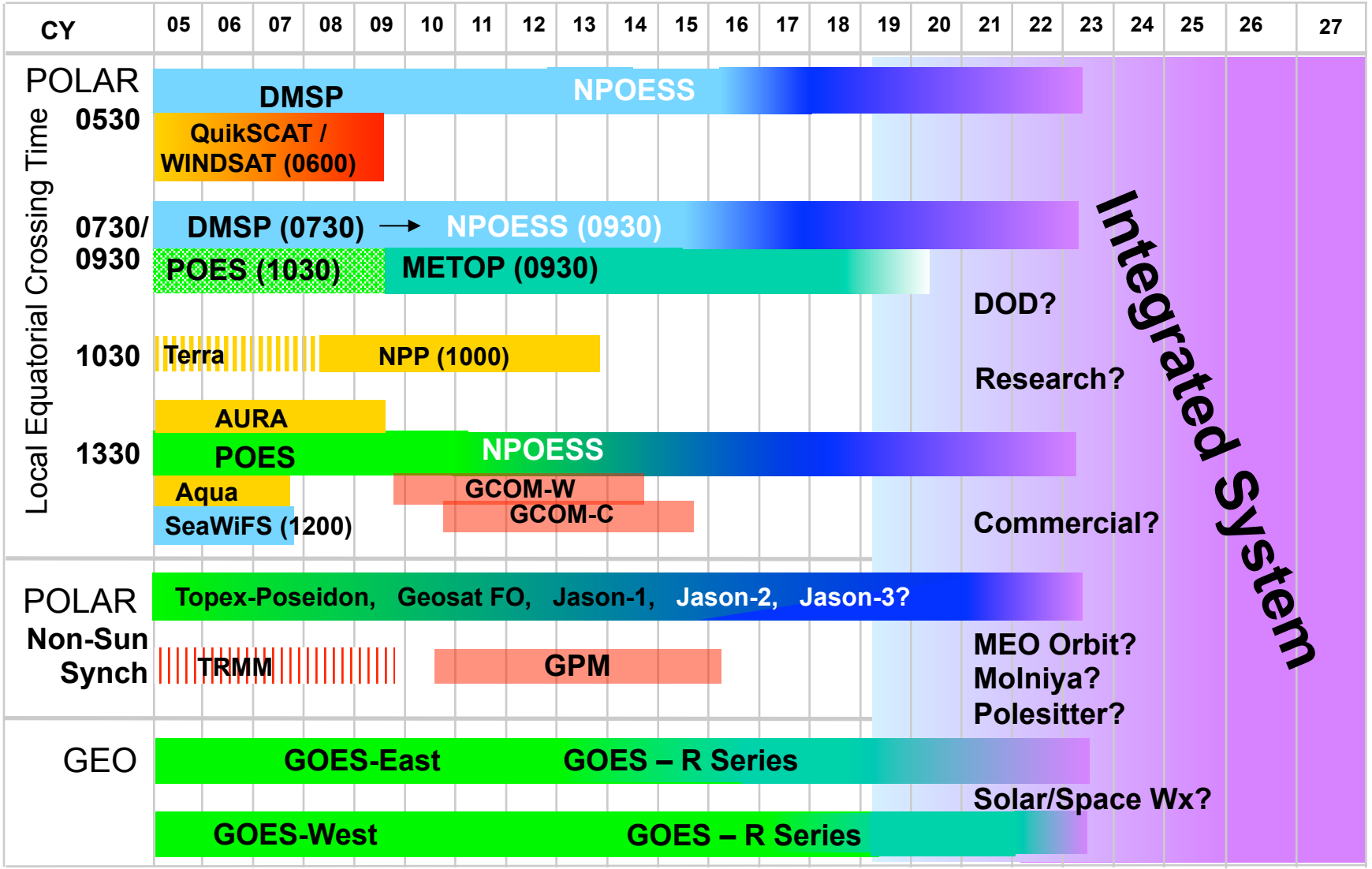
Combination of absolute magnetics and gravity

- Continuation of current missions greatly improves the estimation of the secular variation of the core field (full solar cycle)
- Analysis of existing data will benefit from Swarm models and tools



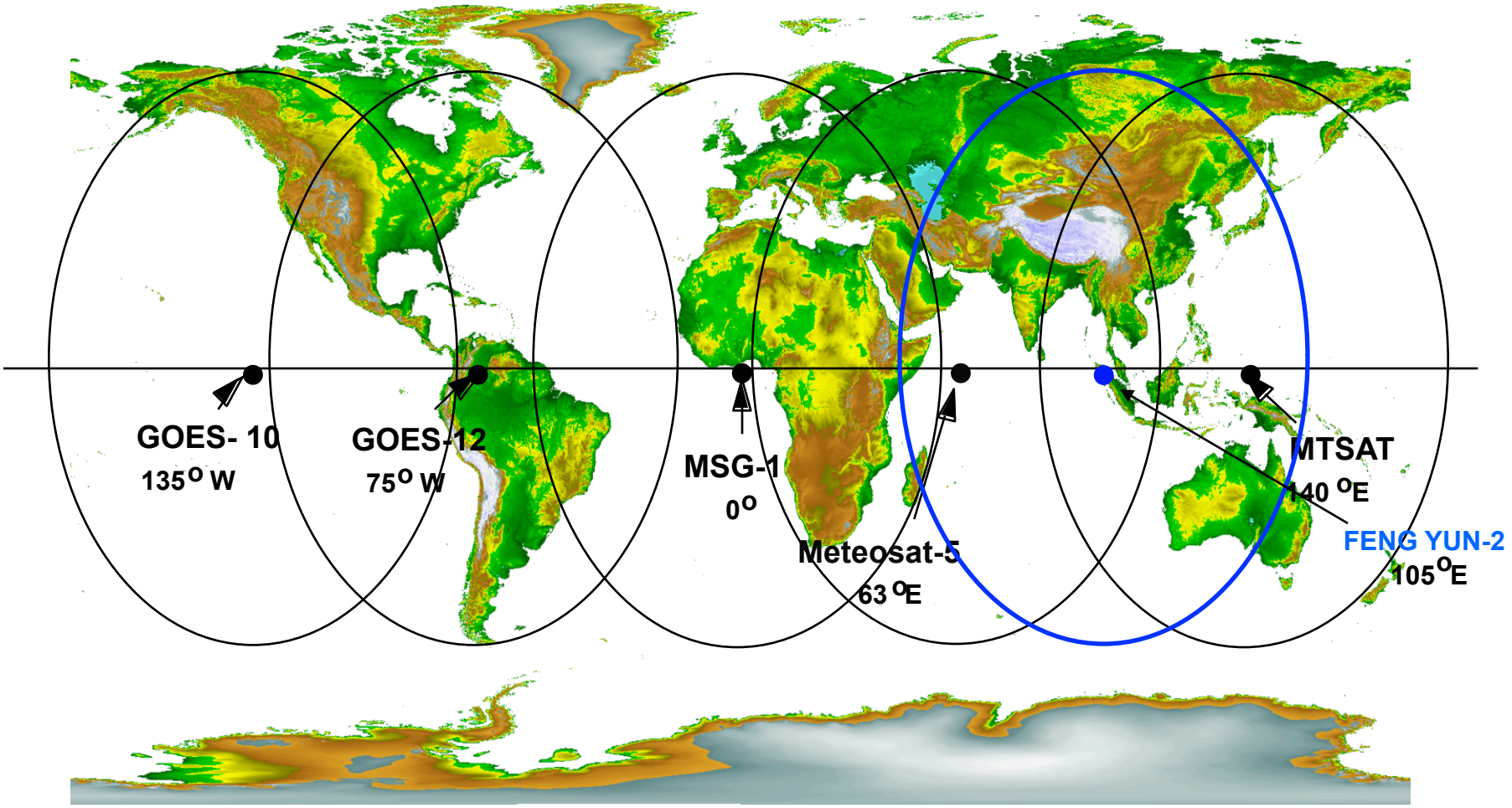
Long-Range Integrated Satellite Transition

(U.S. Only)

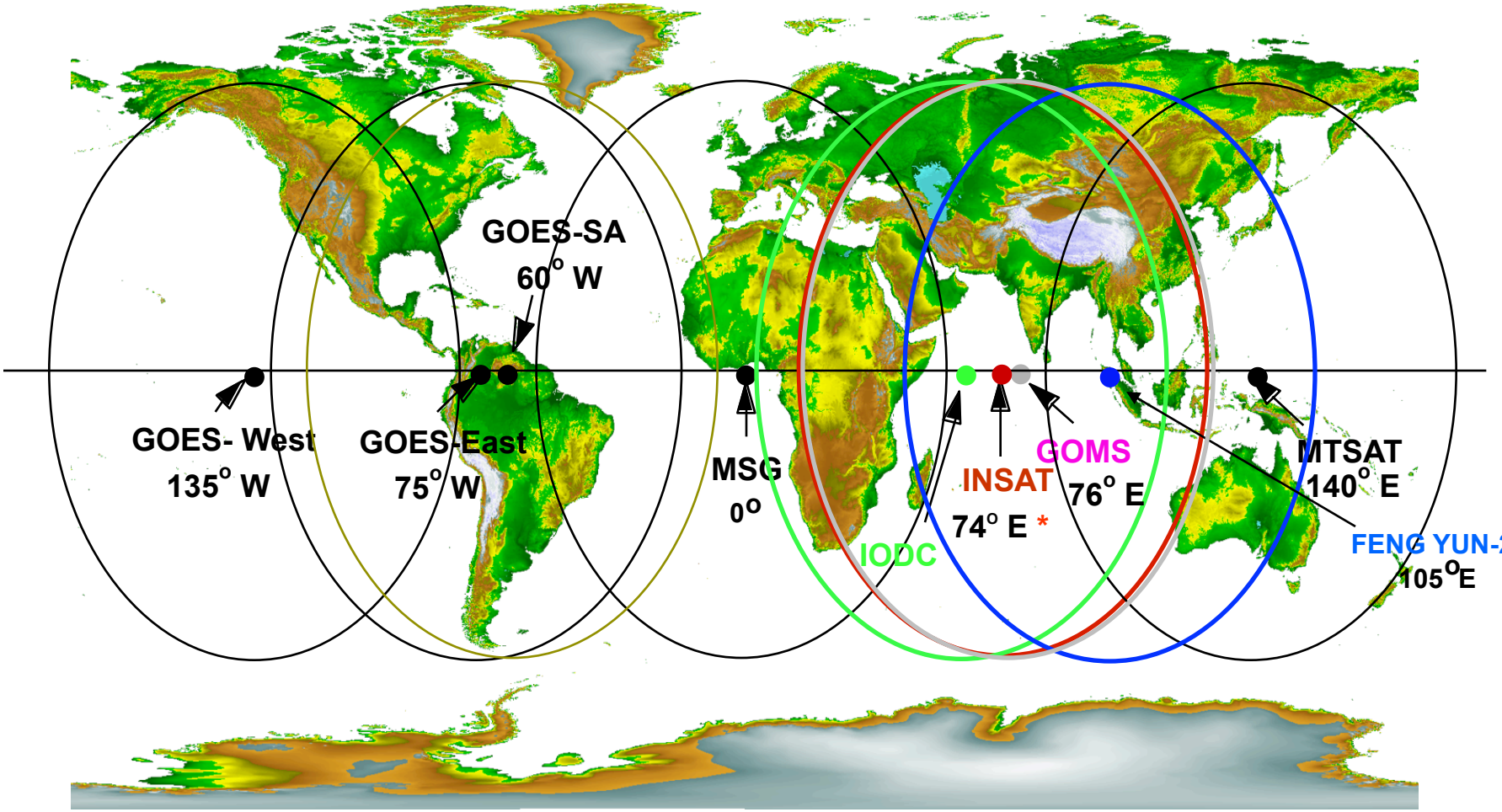


GLOBAL OPERATIONAL GEOSTATIONARY SATELLITE COVERAGE

(as of Apr 2006)



GLOBAL
GEOSTATIONARY SATELLITE COVERAGE
(Planned)



* As of February 2006, INSAT latency (> 1 hr), refresh (3-hours), and navigation errors (> 10-km) make the data unusable for NOAA operational applications

Summary of Non-NOAA Satellite Opportunities

Earth Observation

ADEOS, ALOS, GOSAT, GCOM W, GCOM C	JAXA
INSAT, OCEANSAT, RESOURCESAT, CARTOSAT	India
COSMIC (GPS Soundings)	Taiwan
Communications, Oceans, & Meteorological Satellites	Korea
ENVISAT, CRYOSAT, GOCE, SMOS, ADM, SWARM, EarthCARE	ESA
FY-1, 2, 3, 4 -- Polar (1,3) and Geo (2,4)	China
RADARSAT 1, 2 & 3	Canada
LANDSAT	USGS
IKONOS, QUICKBIRD, ORBVIEW, WorldView, SPOT, DMC, LANDSAT, TerraSAR, ROCSAT, KOMPSAT, RAPIDEYE, …	Commercial
CBERS	Brazil/China

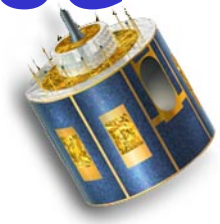
From MOP to MTG

1977 — 2002 — 2015

MOP

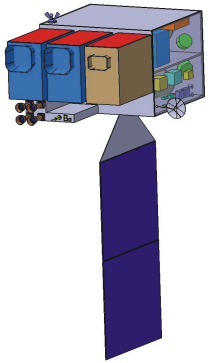
1 observation mission:
-MVIRI: 3 channels
-**Spinning** satellite
800 kg

MSG



2 observation missions:
- SEVIRI: 12 channels
- GERB
- **Spinning** satellite
2,2 t

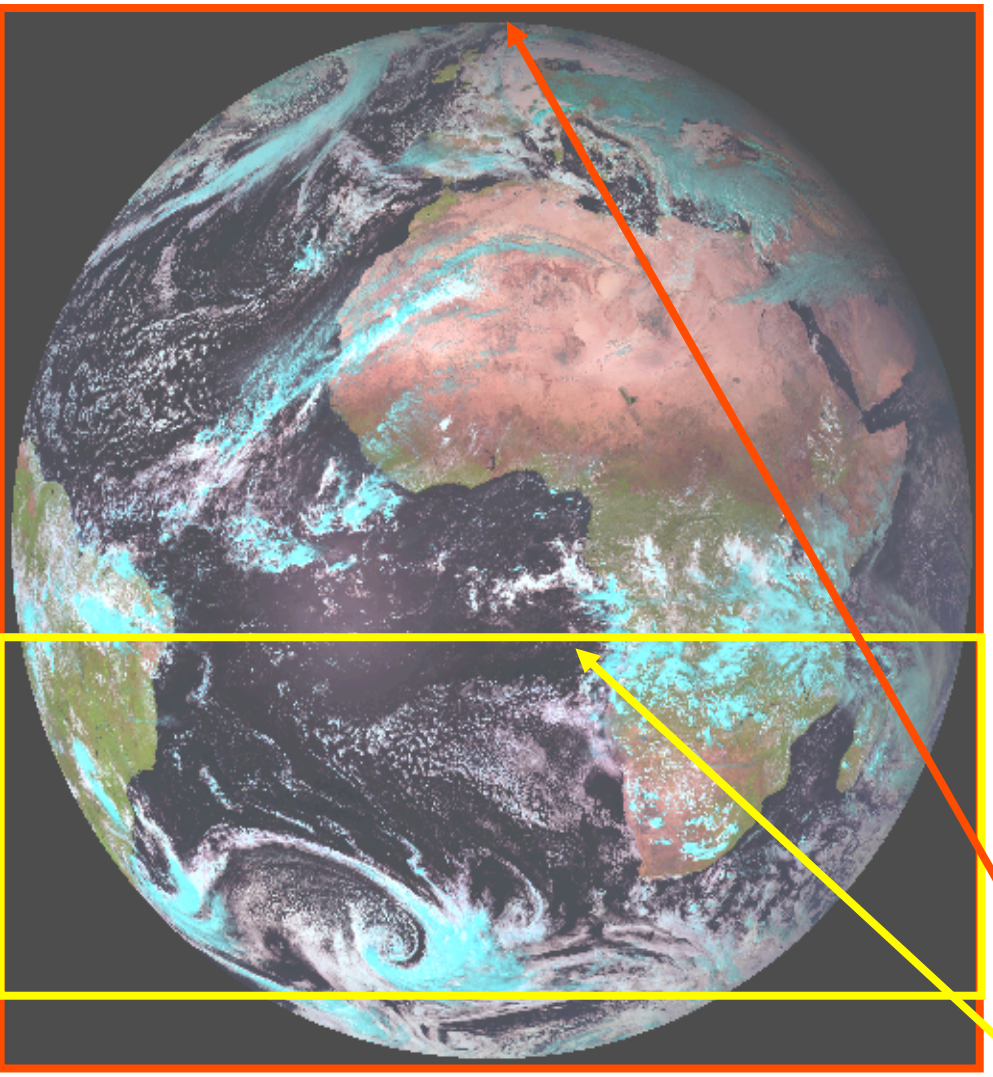
MTG



5 observation missions:
- HRFI: 5 channels
- FDHSI: 22 channels
- Lightning Imager
- Infra-Red Sounder
-**3-axis stabilised** satellite(s)
5,1 t

UVS
coordinated with GMES Sentinel 4

MTG Flexible Combined (FC) Imager



The Flexible Combined Imagery Mission shall

- fully cover FDHSI user/service needs
- support HRFI user/service needs as possible

Challenges compared to MSG:

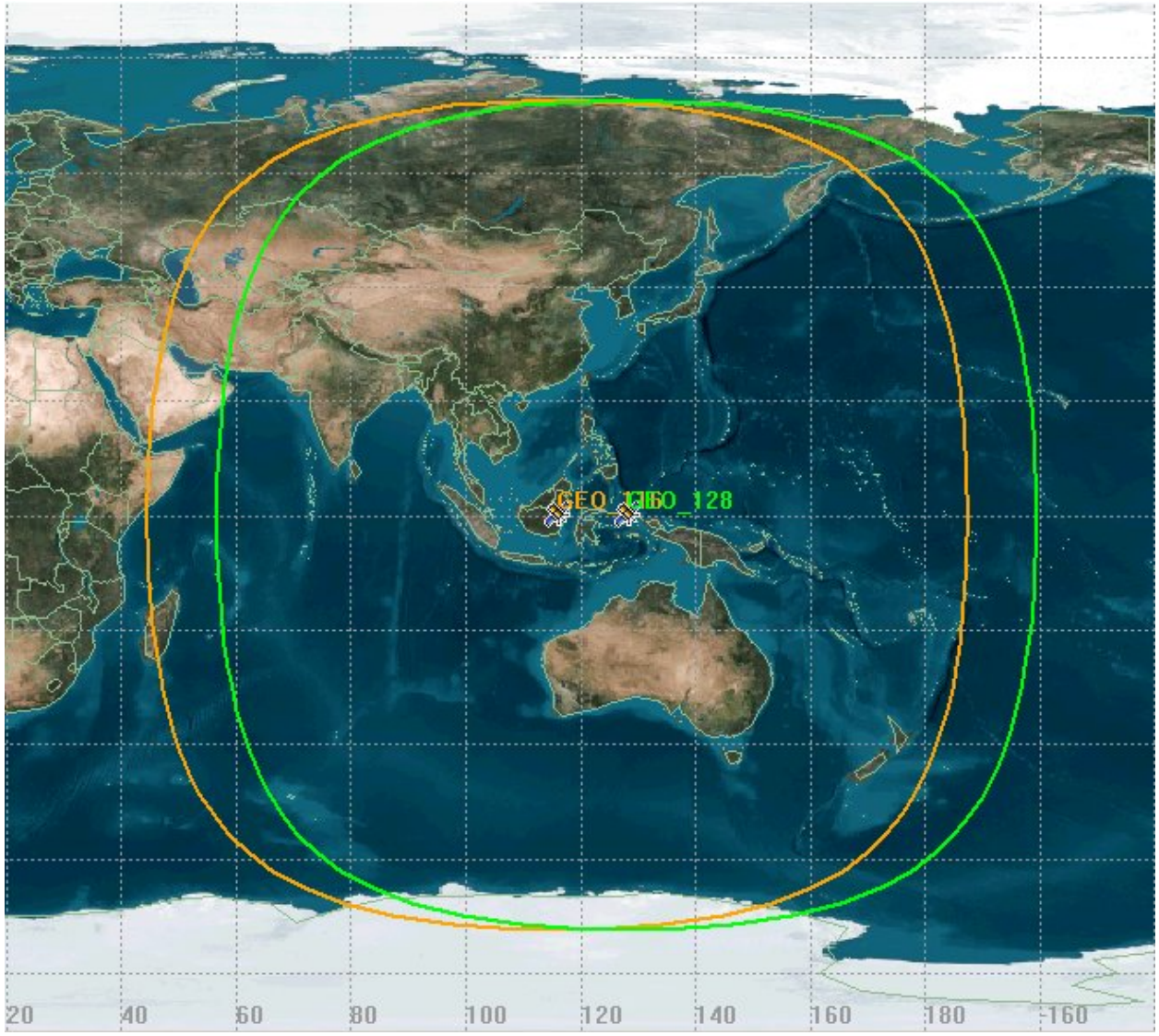
- improved Spatial Resolution (0.5 km - 2 km)
- faster basic repeat cycle (brc = 10 min)
- better spectral coverage (more channels)
- improved spectral accuracy
- improved radiometric accuracy

	Coverage	Repeat cycle
Full Disk Coverage	18°x18°	10 min
Local Area Cov.	1/4 FD	10/4 min

Imagery Requirements

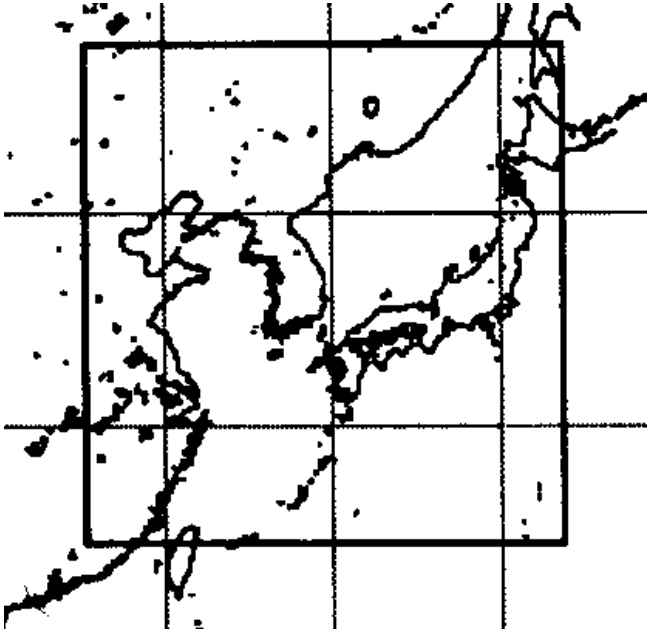
	Meteosat 1st Generation			Meteosat 2nd Generartion			Meteosat 3rd Generation		
'Core' channels	Central wavelength (µm)	Width (FWHM) (µm)	Spatial Sampling (km)	Central wavelength (µm)	Width (FWHM) (µm)	Spatial Sampling (km)	Central wavelength (µm)	Width (FWHM) (µm)	Spatial Sampling* (km)
FC-VIS 0.4							0.444	0.06	1.0
FC-VIS 0.5							0.510	0.05	1.0
FC-VIS 0.6	0.7	0.35	2.5	0.635	0.08	3.0	0.645	0.08	0.5
FC-VIS 0.8				0.81	0.07	3.0	0.86	0.07	1.0
FC-NIR 0.9							0.96	0.06	1.0
FC-NIR 1.3							1.375	0.03	1.0
FC-NIR 1.6				1.64	0.14	3.0	1.61	0.06	1.0
FC-NIR 2.1							2.26	0.05	0.5
FC-IR 3.8 *				3.9	0.44	3.0	3.8	0.40	1.0
FC-IR 6.7	6.1	1.3	5.0	6.3	1.0	3.0	6.3	1.00	2.0
FC-IR 7.3				7.35	0.5	3.0	7.35	0.50	2.0
FC-IR 8.5 *				8.7	0.4	3.0	8.7	0.40	2.0
FC-IR 9.7				9.66	0.3	3.0	9.66	0.30	2.0
FC-IR 10.8	11.5	1.9	5.0	10.8	1.0	3.0	10.5	0.7	1.0
FC-IR 12.0				12.0	1.0	3.0	12.3	0.5	2.0
FC-IR 13.3				13.4	1.0	3.0	13.3	0.60	2.0
Repeat Cycle :	30 min			15 min			10 min		

COMS Coverage (116 or 128° E)



GOCI Requirement

Item	Requirements					
Spatial Resolution	500m X 500m (+/- 10%)					
Coverage	2,500km X 2,500km					
No. of Band	8 Visible bands					
Band Center Band Width Nominal Radiance Max Radiance NEdL SNR	Band Center [nm]	Band Width [nm]	Nom. Rad [Wm^{-2} $um^{-1}sr^{-1}$]	Max. Rad. [Wm^{-2} $um^{1}sr^{-1}$]	NEdL	SNR
	412	20	100	150.0	0.100	1,000
	443	20	92.5	145.8	0.085	1,090
	490	20	72.2	115.5	0.067	1,170
	555	20	55.3	85.2	0.056	1,070
	660	20	32.0	58.3	0.032	1,010
	680	10	27.1	46.2	0.031	870
	745	20	17.7	33.0	0.020	860
	865	40	12.0	23.4	0.016	750
MTF	≥ 0.3 at Nyquist frequency					
Dynamic Range	≥ 11bit					
Sensor Calibration	- Calibration type : Solar Calibration - Accuracy of Radiometric Calibration : ≤ 3%					
Number of observation	· 10:00 ~ 17:00 : 8 times, · 22:00, 02:00 : 2 times					



Oceansat-2 Ocean Colour Monitor

	1999	2007	2011 – 12 ?
Sensor	OCM - 1	OCM - 2	OCM – 3 Planning
Resolution (km)	0.360	0.360	0.360
Swath(km)	1420	1420	1420
Repeativity(days)	2	2	2
Equatorial crossing (hrs)	12:00	12:00	12:00
Spectral bands (nm)	412±10 443±10 490±10 510±10 555±10 670±10 765±20 865±20	412±10 443±10 490±10 510±10 555±10 620±10 745±20 865±20	412±10 443±10 490±10 510±10 555±10 620±10 660 681 710 740 865 1040
Radiometric quantisation	12	12	---
SNR	~350	500	---