Overview of Remote Sensing Activities in the Indian Ocean

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Acknowledgements

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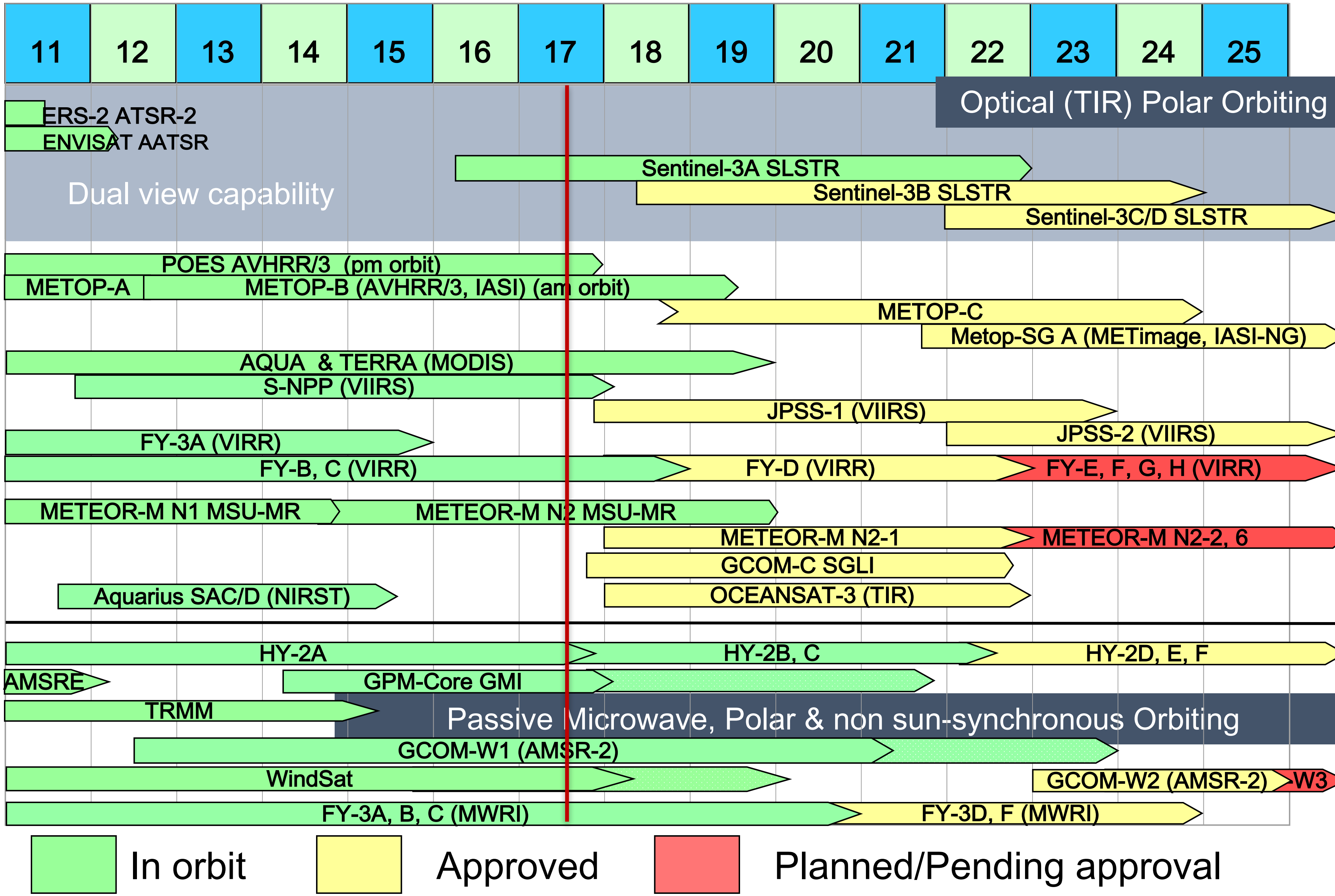
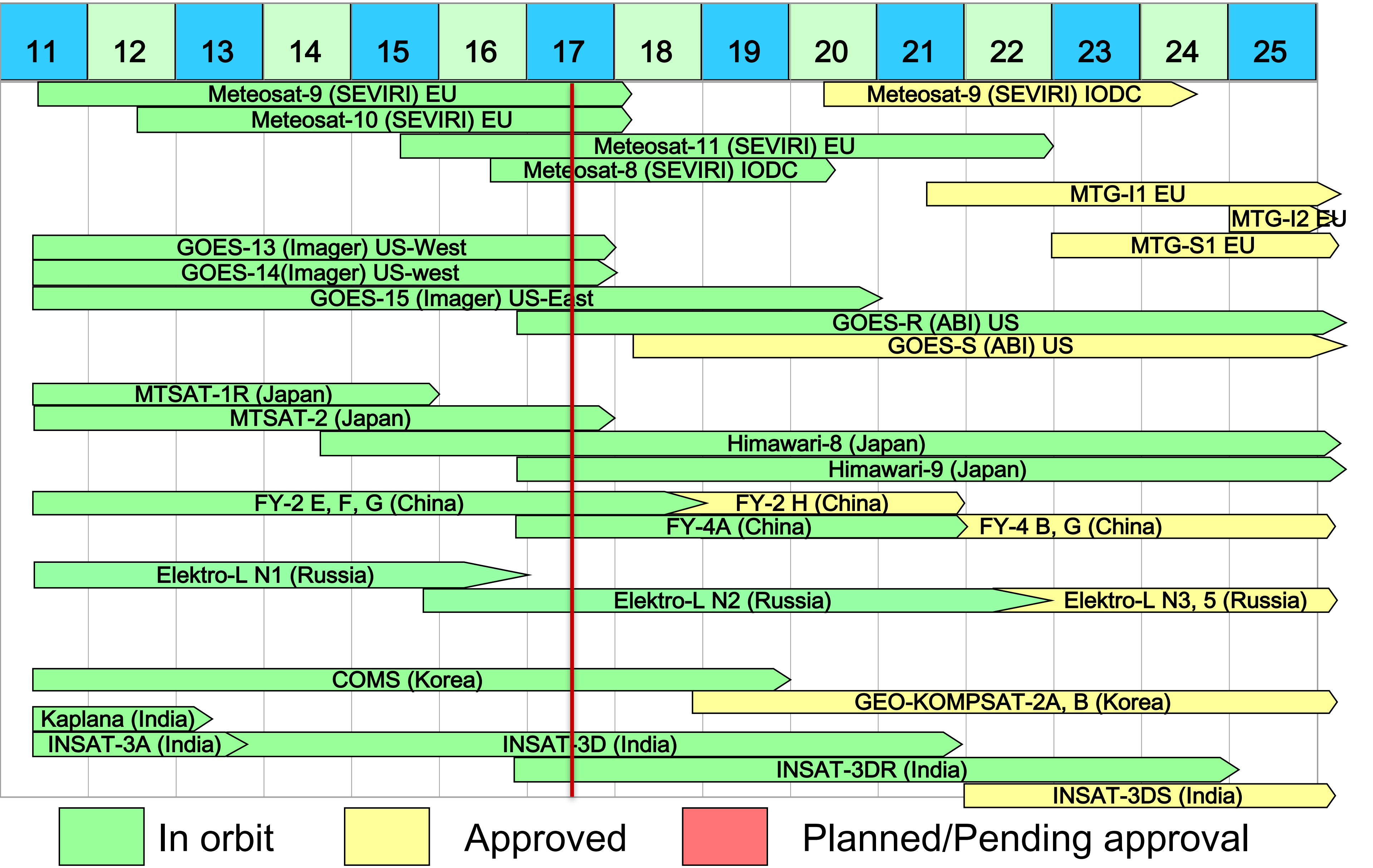
Main ocean parameters measured from space:

- ***Sea surface temperature*** *:* Onboard radiometers (passive micro-waves)
- ***Sea surface salinity*** : Radiometry/active micro-waves
- ***Ocean surface topography*** *(currents; tides, sea level) :* Satellite altimetry
- ***Surface winds*** : Active microwaves (radar altimetry/scatterometry)
- ***Wave height***: Altimetry; radar imagery
- ***Ocean mass***: Space gravimetry (GRACE)
- ***Ocean color*** (phytoplankton→ marine ecosystems): Multispectral imagery

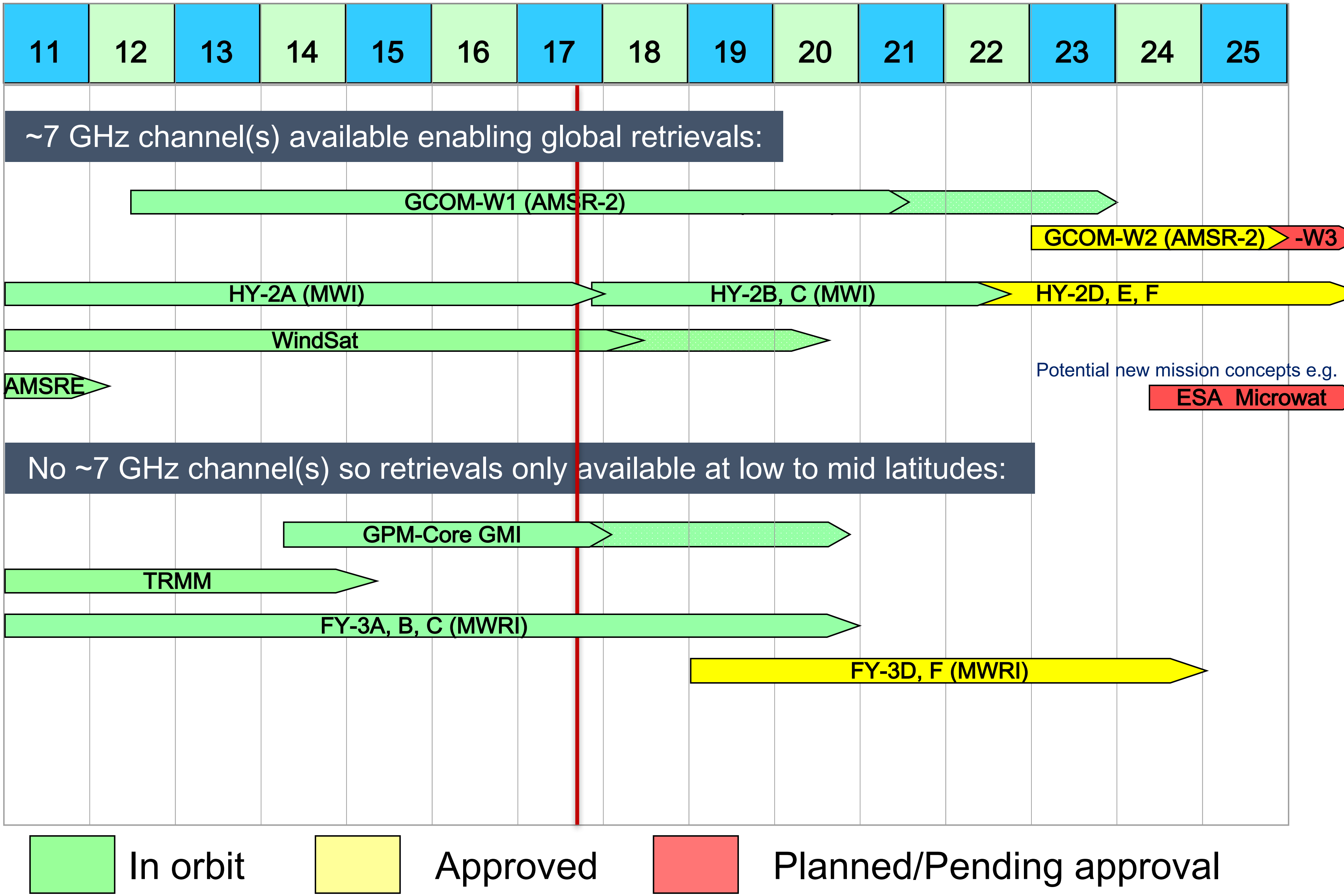
Sea Surface Temperature (Polar orbiting)



Sea Surface Temperature (Geostationary)

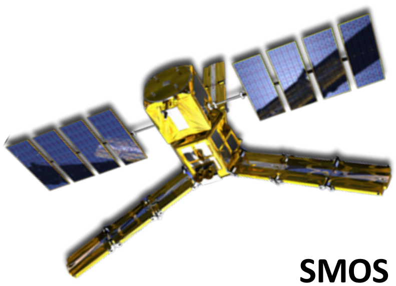


Passive Microwave Radiometers for SST



The three L-band (~1.4 GHz) satellite missions that have pioneered salinity measurements from space

Salinity from space using L-band radiometry



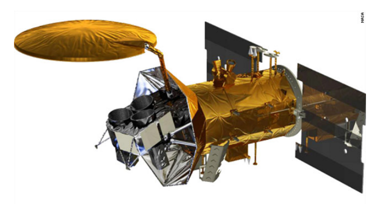
SMOS
Soil Moisture and Ocean Salinity

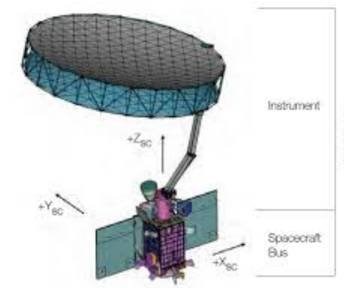
ESA Earth Observer (CNES PROTEUS platform)

The first Interferometer for earth observation!

Aquarius
Argentina-USA collaboration (CONAE/NASA)

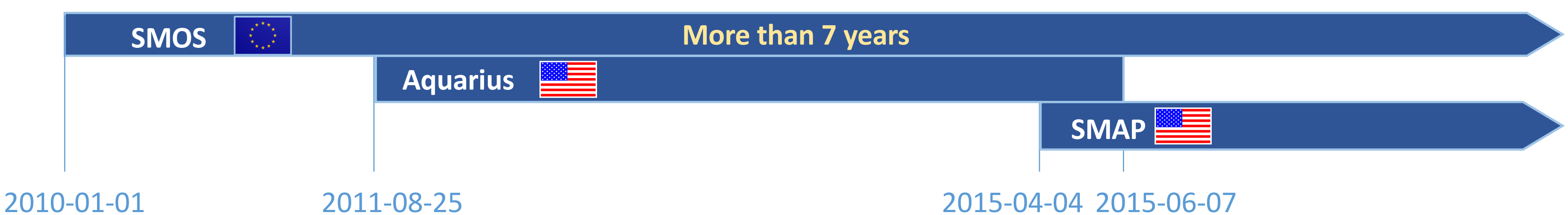
3 radiometers in the L-Band + 1 scatterometer



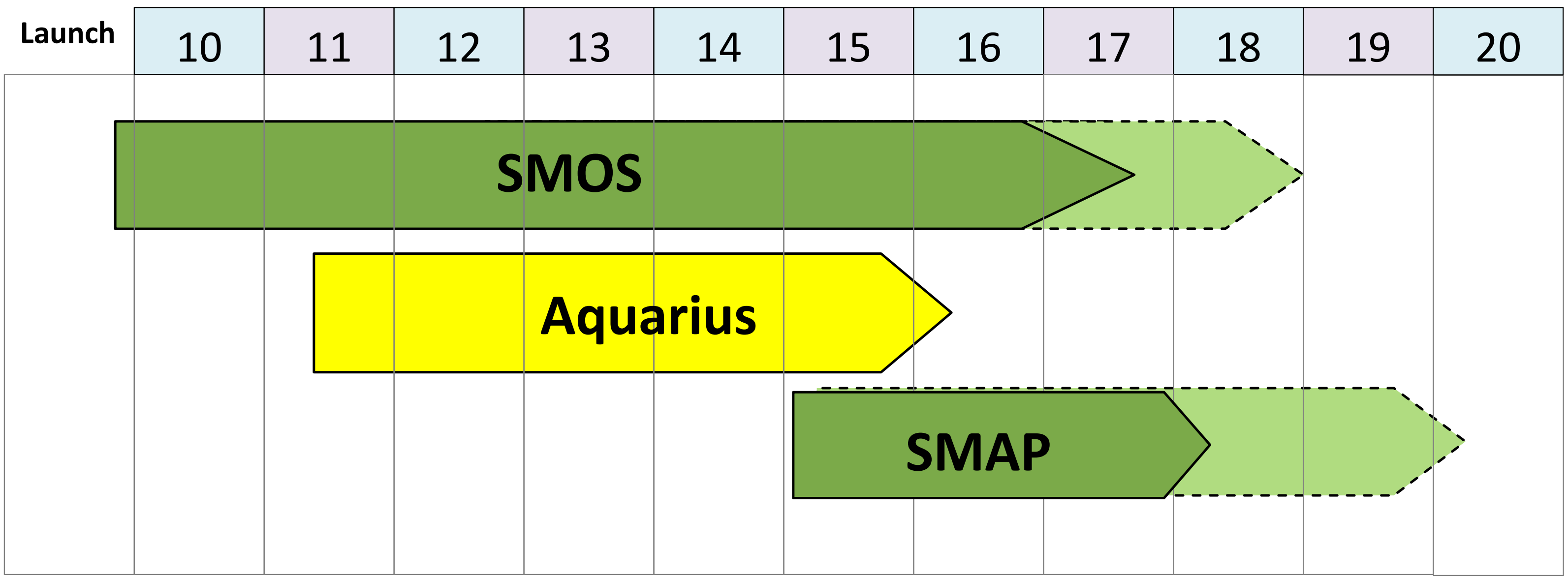


SMAP
Soil Moisture Active Passive
Built at JPL

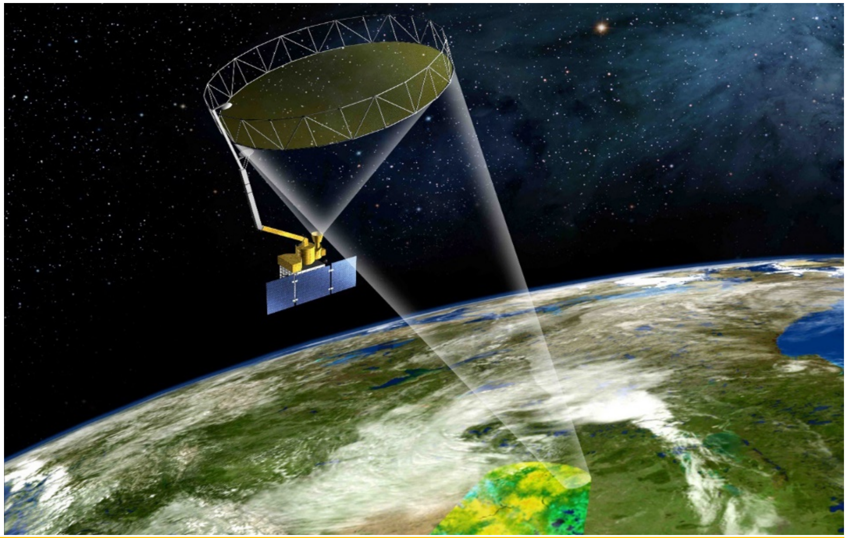
L- Band radiometer

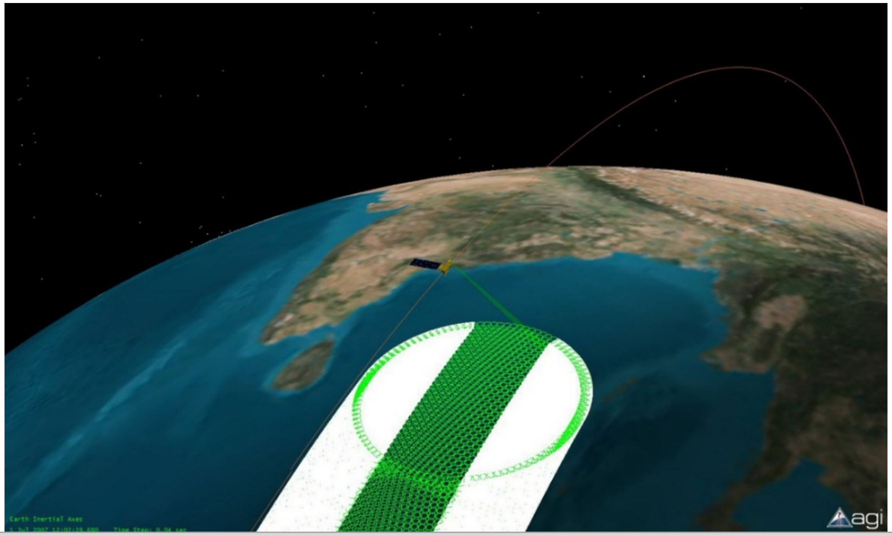


Continuity of satellite SSS missions not ensured beyond 2020; need community advocacy



SMAP
Soil Moisture Active Passive





- Polar Orbit @ altitude: 685 km.
- 8-day repeat.
- Local ascending/descending time: 6 PM/AM.
- Frequency 1.41 GHz.

- Full 360^{o} scan views the Earth.
- 1000 km wide swath.
- 3-dB (half power) footprint size: 40 km.
- Time for sampling 1 footprint: 17 msec.

Aquarius and SMAP have both about **the same instrument noise**.
The Aquarius data are pre-averaged during L1/L2 processing. The SMAP data do not.
Noise figures @ L2: **Aquarius ≈ 0.4 psu**. **SMAP ≈ 1.0 psu**.

New CATDS SMOS SSS in very good agreement with SMAP data in river plumes

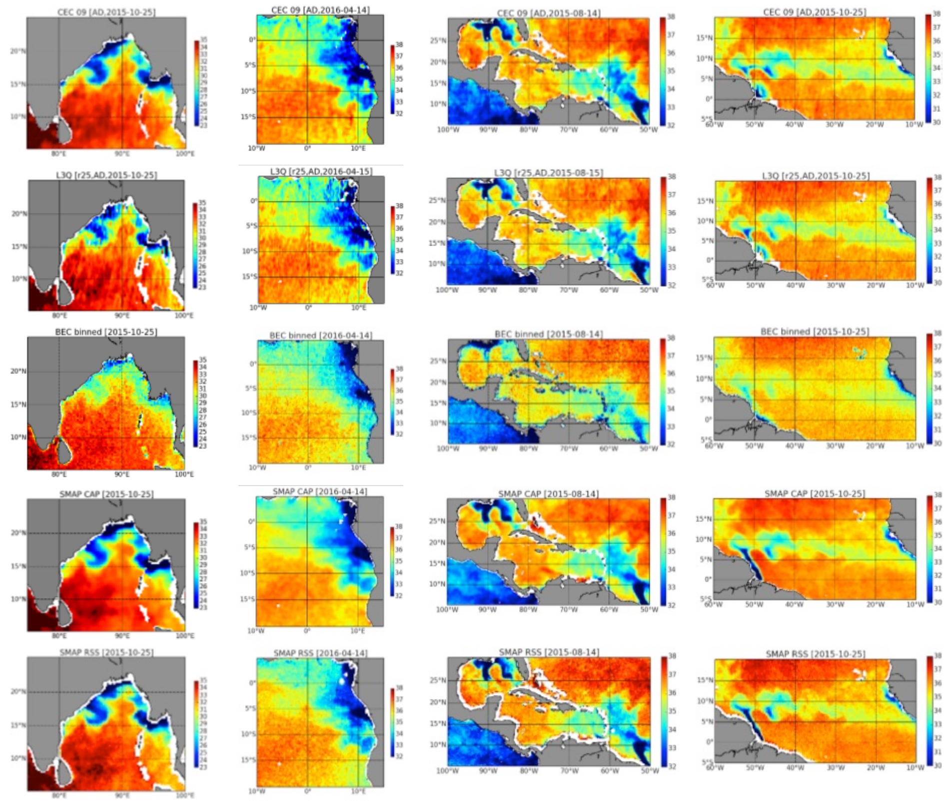
SMOS CATDS CEC LOCEAN Debias_v2

SMOS CATDS CPDC L3Q Binned - near-real time

SMOS BEC non bayesian binned

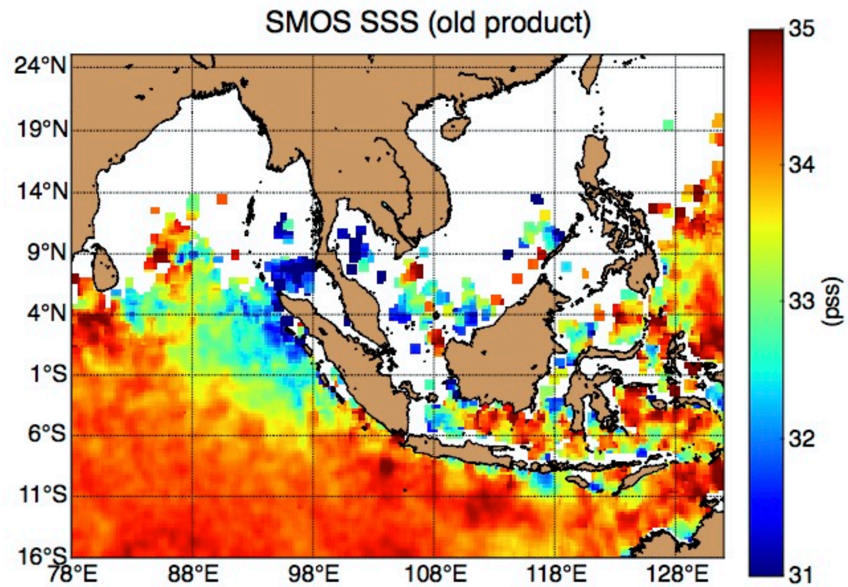
SMAP CAP/JPL

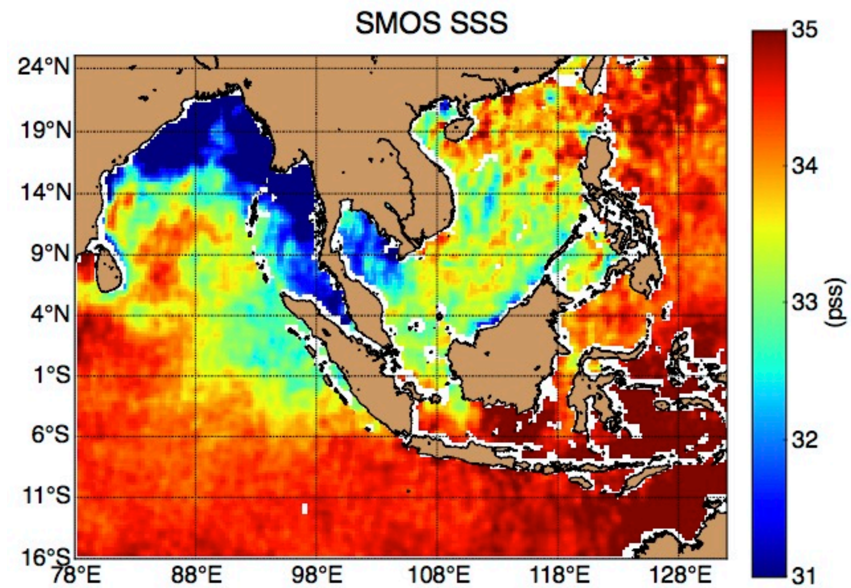
SMAP RemSS



Boutin et al., subm. RSE, 2017

Comparison of SSS, Nov. 2015 example: SMOS-old, SMOS-new, and SMAP





New SMOS SSS product in 2017 (CATDS, Boutin et al. 2017, RSE, submitted) brought significant improvements in marginal seas & coastal oceans.

New SMOS SSS very consistent with SMAP SSS in the Bay of Bengal.

Application example: Tuesday poster by Severine Fournier

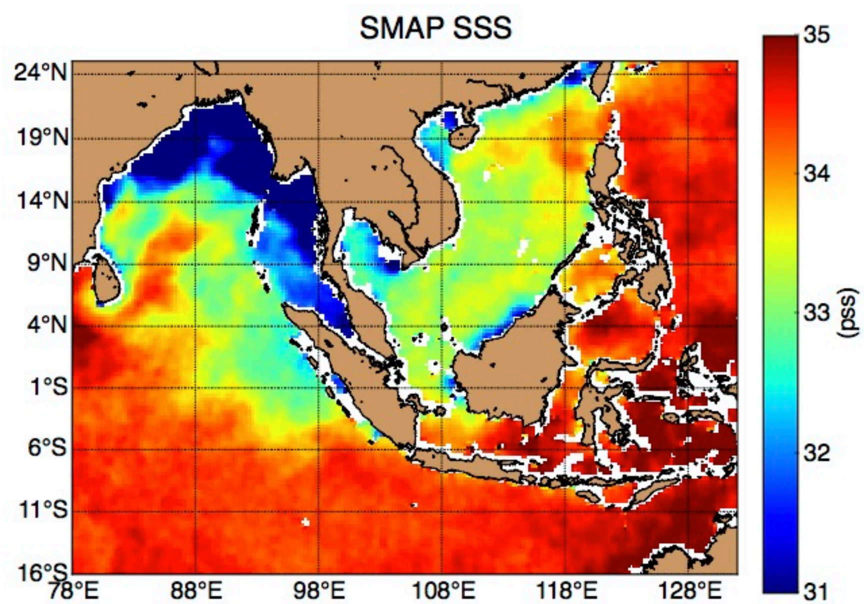
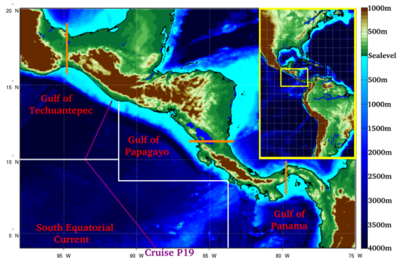


Image credit: Severine Fournier

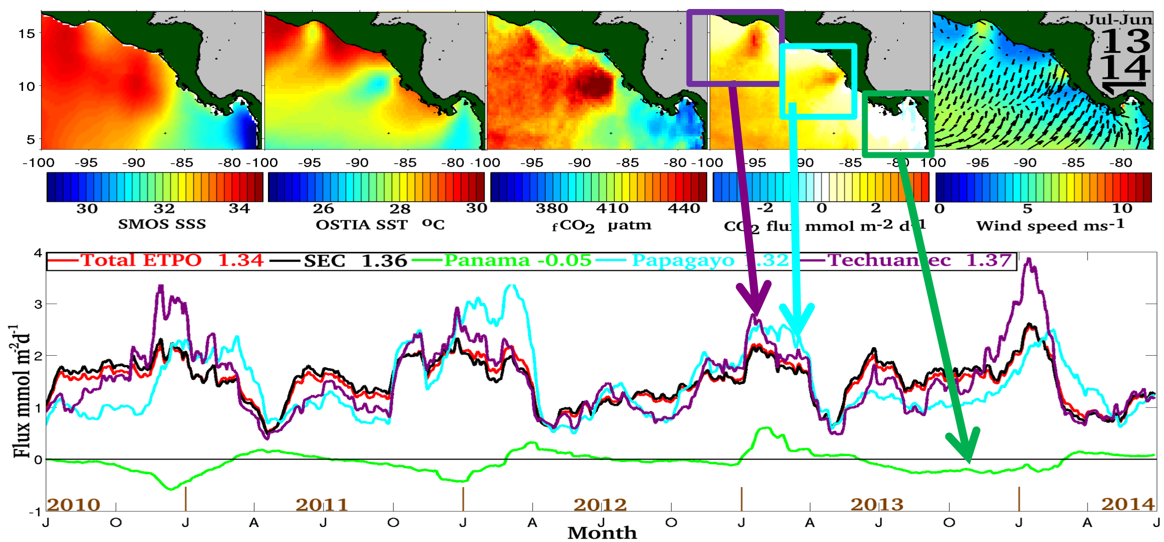
New insights of pCO_2 variability in the tropical eastern Pacific Ocean using SMOS Salinity

C W Brown, J Boutin, L Merlivat, LOCEAN Paris



A quantitative analysis of the opposite effects **of local upwellings and rainfall** on the variability of surface ocean CO_2 partial pressure and of the **air-sea CO_2 flux.**

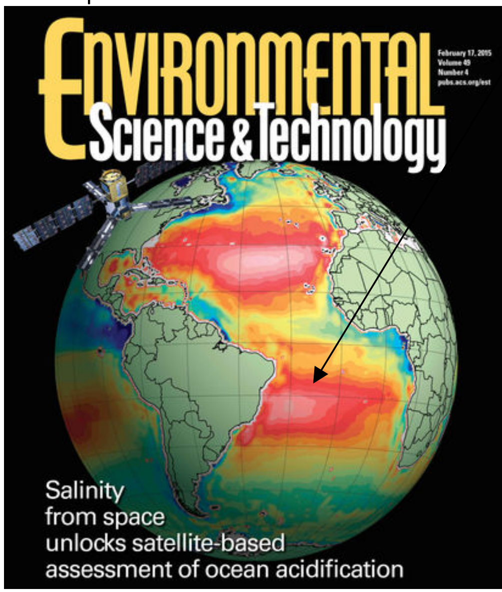
The synergistic use of SMOS SSS, together with satellite SST, precipitation and wind allows the first spatio-temporal mapping of pCO2 in certain dynamic regions and to distinguish atmospheric CO2 signatures from subsurface injection at the surface (here the coastal upwellings along the Pacific coasts of central America)



Brown et al. Biogeoscience, 2016

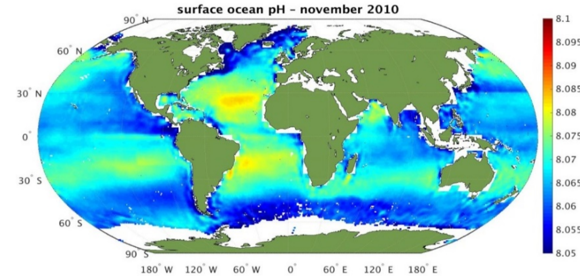
Biogeo-chimie à partir de la SSS SMOS data: cycle des carbonates

Spaceborne data estimation of alcalinity:



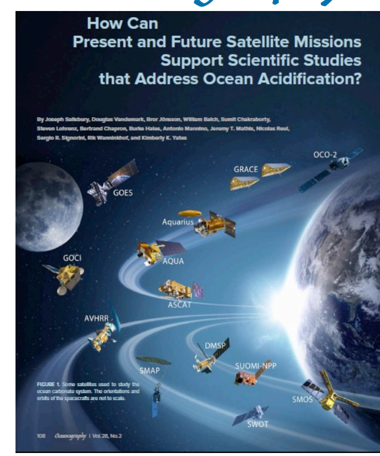
Land et al., *Environmental Science & Technology,* 2015

- First Estimation of **Total Alcalinity A_T** of surface water from spaceborne measurements of SSS & SST:
- **A_T** =Funct(SSS,SST) (lee et al 2006)
  SSS,SST = SMOS CATDS, GHRSST
- **A_T** little impacted by biological processes
- **A_T** strongly correlated with SSS
- First-ever estimates of EO-based **global surface ocean pH using SMOS SSS, satellite SST & ocean color**
- **Help defining future mission concepts to monitor ocean acidification**



First-ever estimates of EO-based global surface ocean pH. (credits: ESA/R. Sabia)

THE OFFICIAL MAGAZINE OF THE OCEANOGRAPHY SOCIETY
Oceanography



Salisbury et al., *Oceanography*, 2015

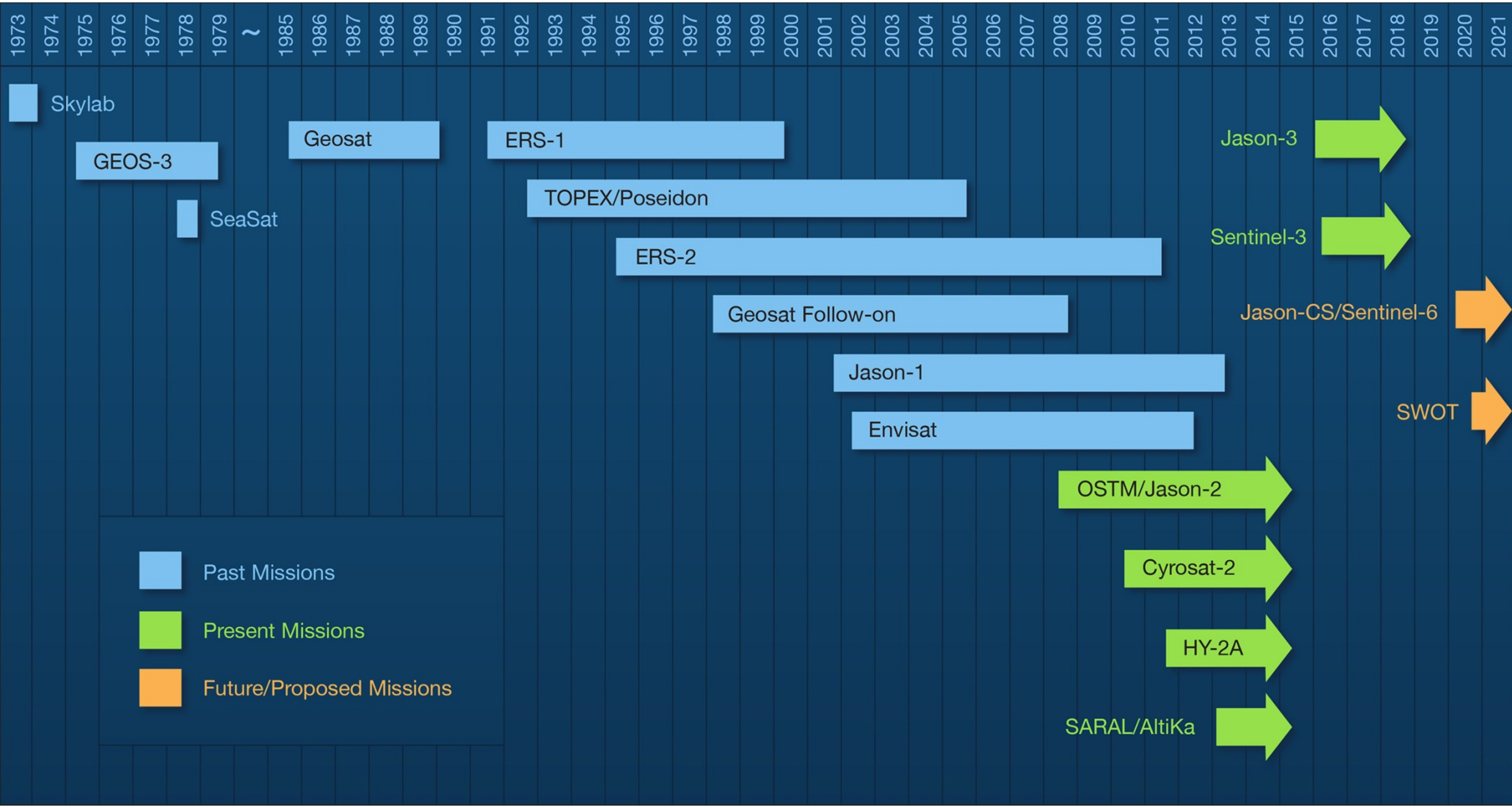
50-100 km/weekly to monthly

Accuracy of ±0.2 pss SSS⇔ ±10-15 µmol^{-1} **A_T**

SMOS data allows a global monitoring of **A_T**

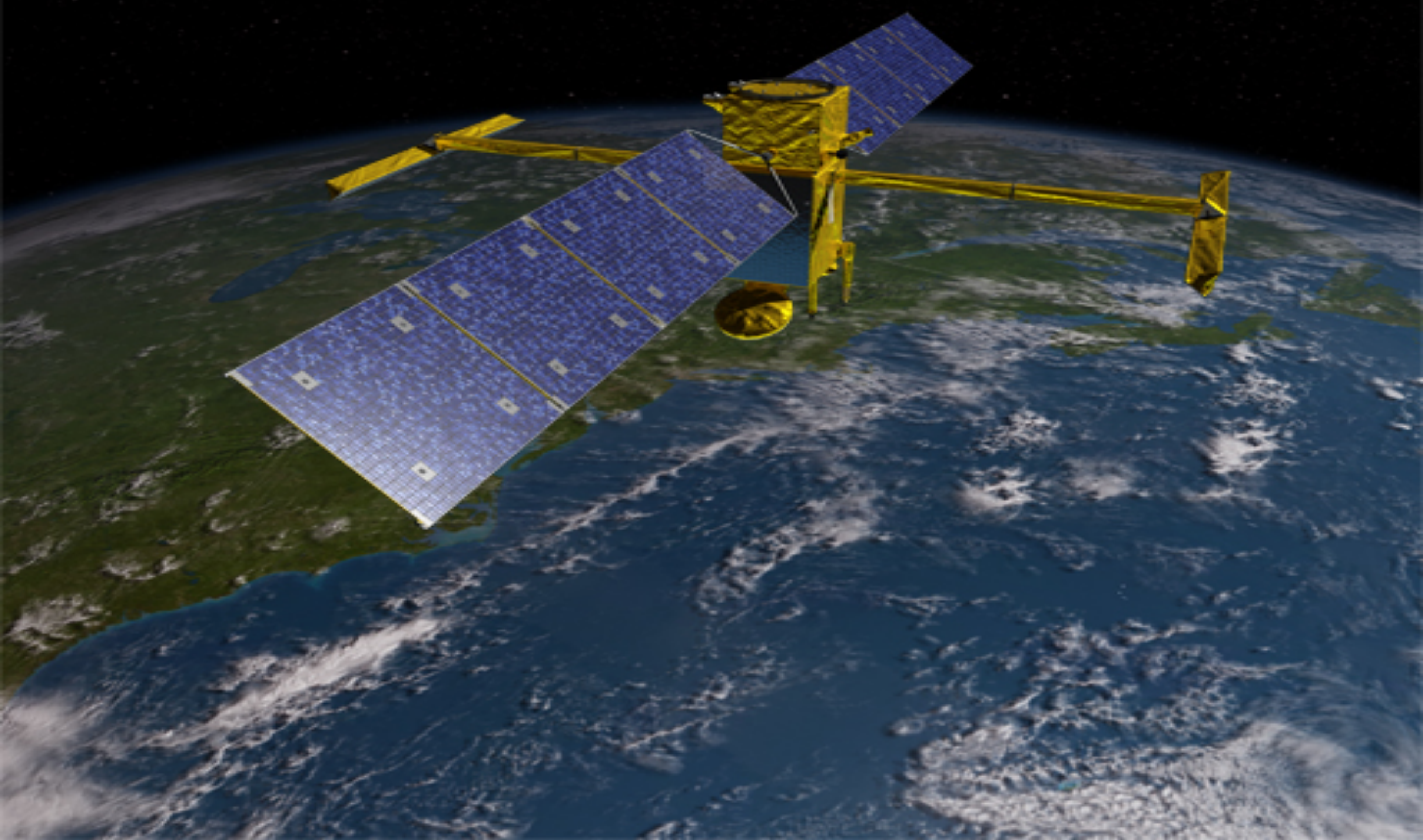
Particularly in intense mixing zones (river plumes, current fronts)

Altimetry Missions (1973-2017)



SWOT MISSION

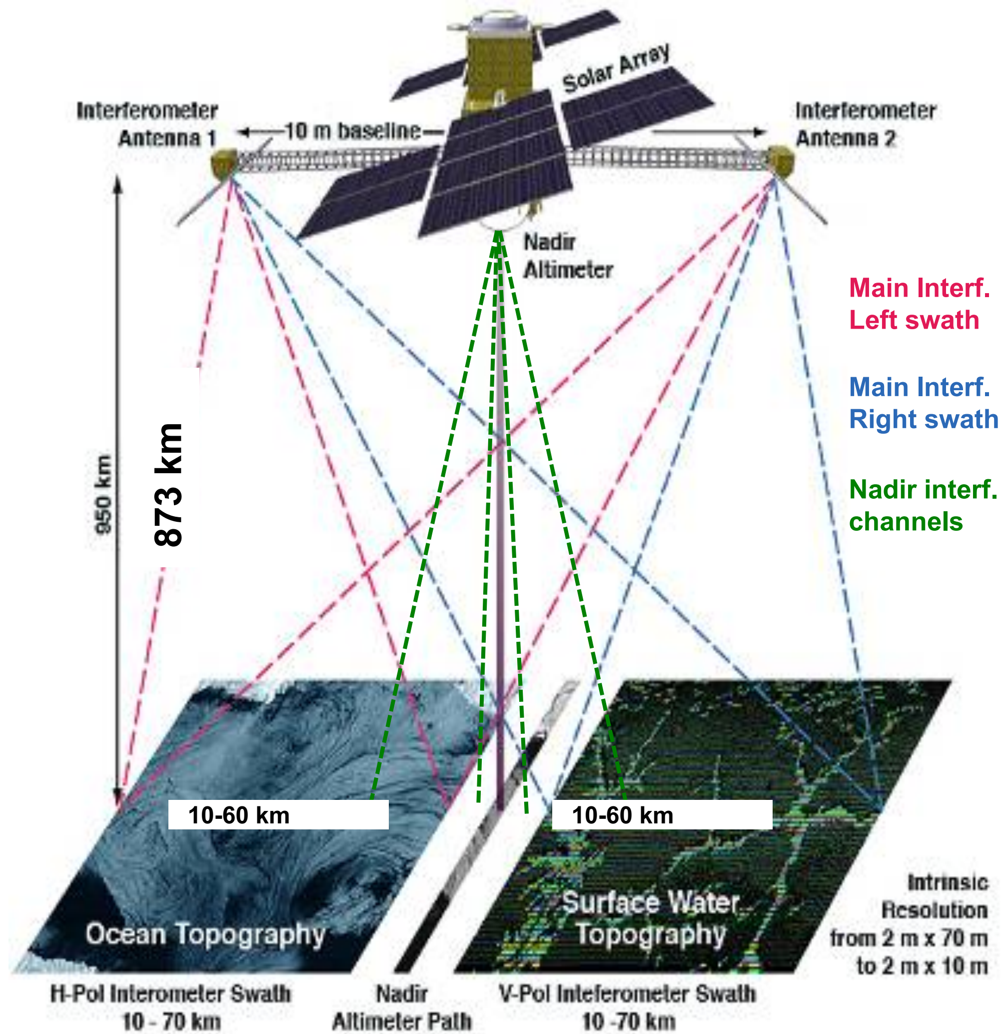
Launch Date: April, 2021



SWOT Mission description

Mission Architecture

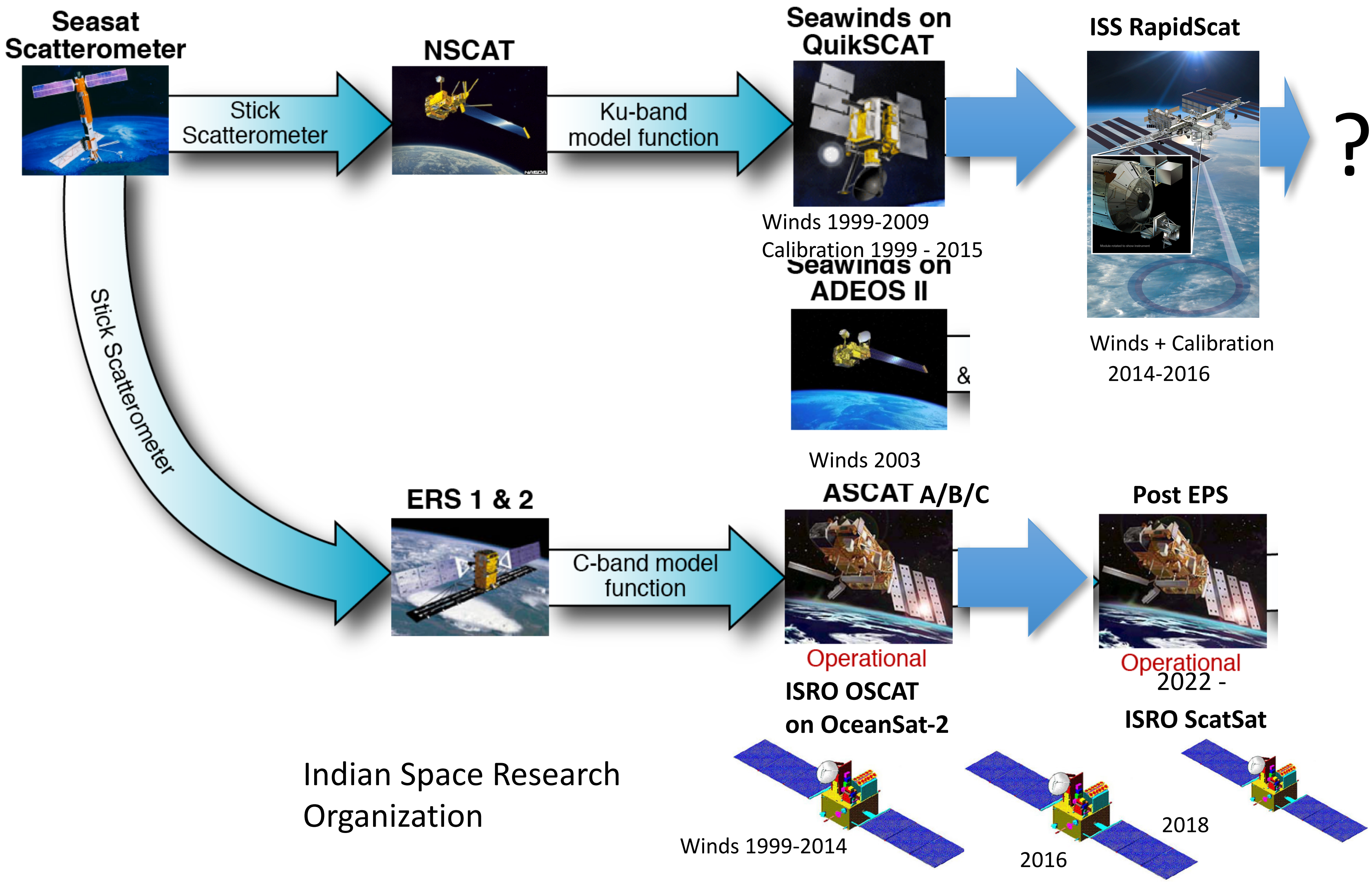
- Ka-band SAR interferometric (KaRIn) system with 2 swaths, 50-60 km each
- Produces heights and co-registered all-weather imagery
- Intrinsic resolution 2 m x 10-70 m grid
- Use conventional Jason-class altimeter for nadir coverage, radiometer for wet-tropospheric delay, and GPS/Doris/LRA for POD.



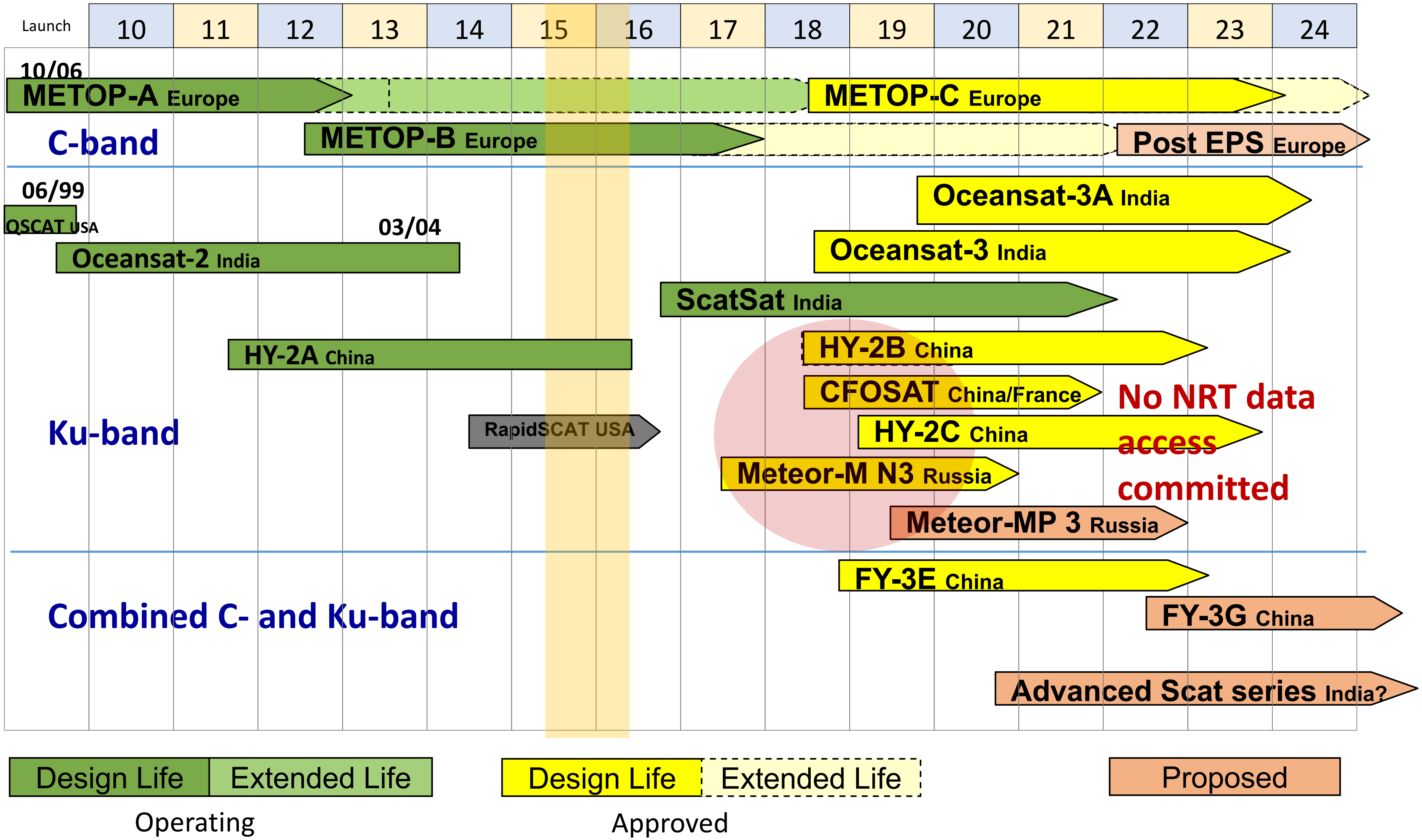
- Partnered mission NASA, CNES & CSA
- Mission life of 3 years
- 873 km Orbit, 78º Inclination, 22 day repeat
- Launch: 2020

Courtesy: R. Morrow

Scatterometer Constellation Evolution

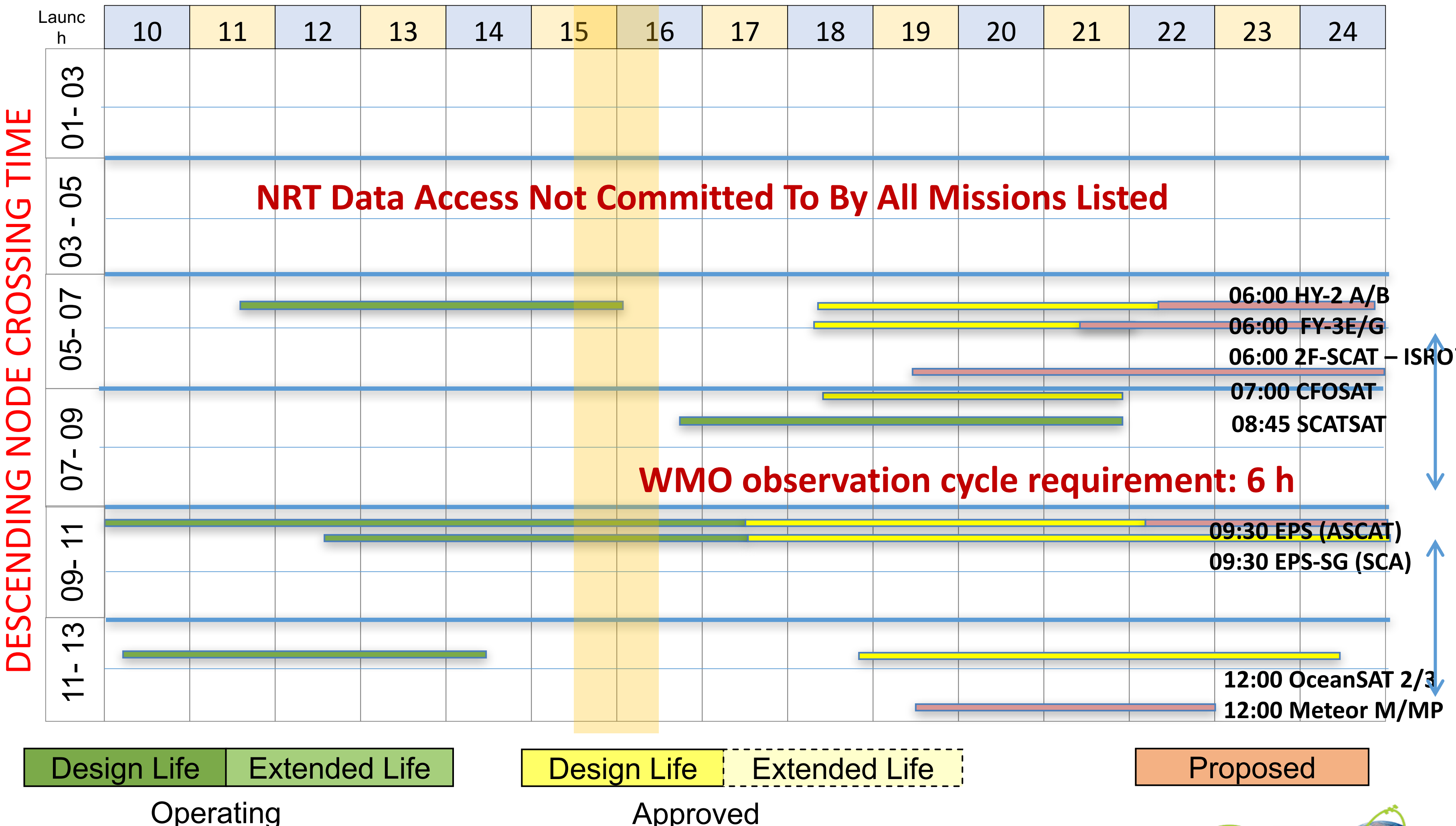


CEOS Ocean Vector Surface Winds Virtual Constellation (OSVW-VC) Current status and outlook – NRT data access



Source: WMO OSCAR database and direct interactions with agencies

Ocean Vector Surface Winds Constellation
Local time coverage assessment (ground track) - NRT data access



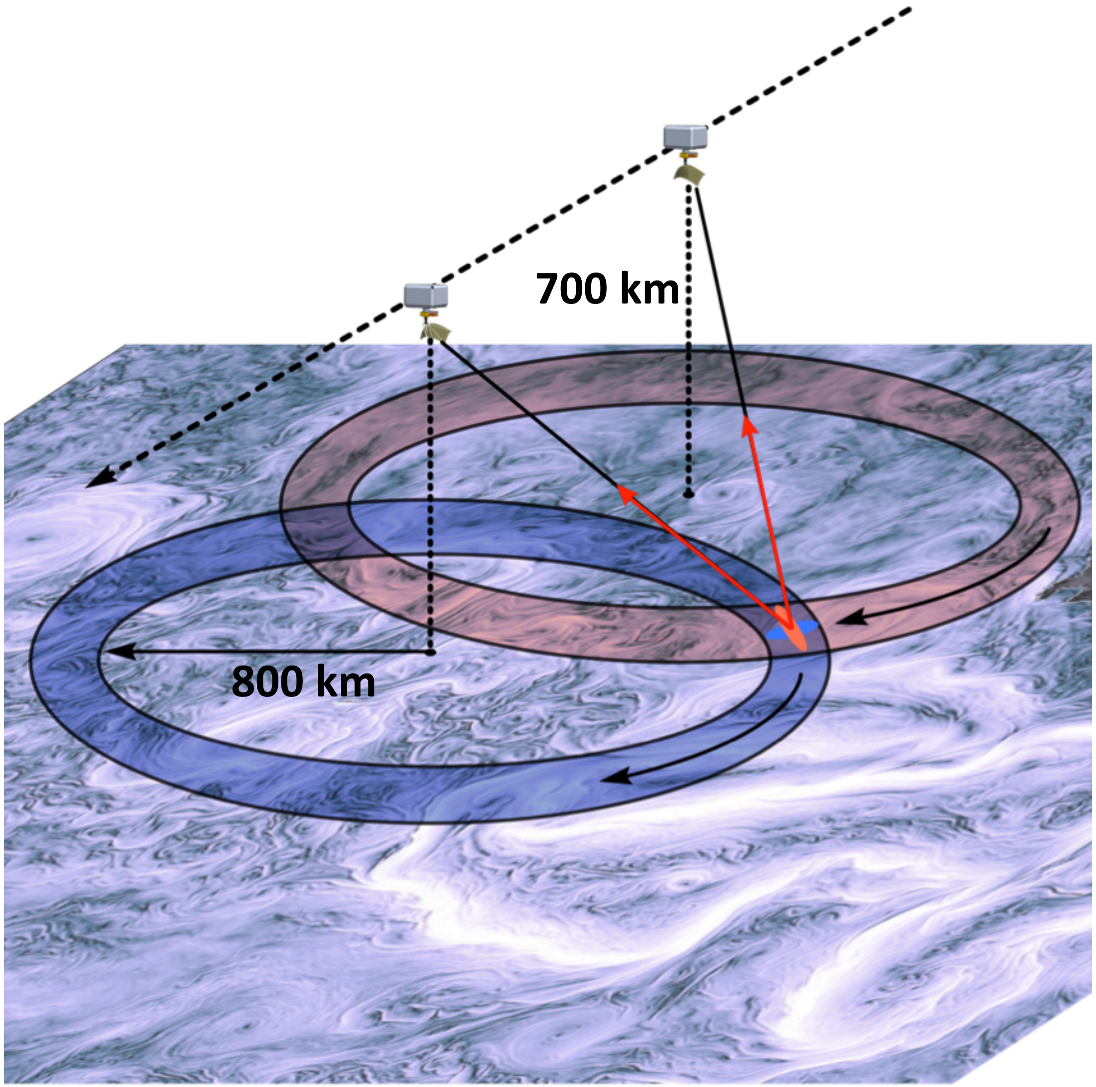
Source: WMO OSCAR database and direct interactions with agencies

Committee on Earth Observation Satellites

New Concept: Simultaneous Wind and Surface Currents

- Surface currents are poorest observed ocean surface variable
- Surface currents play important roles in coupling the atmosphere and the ocean, and are different from geostrophic currents in critical ways
- Key outstanding questions
  - How do currents modify air/sea coupling (in a two-way coupled sense)?
  - How are winds and surface currents coupled?
  - How great is the equatorial upwelling, and what is the wind-induced variability?
  - How do winds and currents move fresh water Arctic and Nordic Seas?
- Applications:
  - Debris transport, nutrient transport and primary productivity, iceberg transport and primary productivity, ice motion, seasonal to interseasonal forecasting, ocean forecasting and more

Doppler Scatteometer Measurement Concept



- Ka-band rotating pencil beam Doppler scatterometer
- Ku-band rotating beam scatterometer
- Winds measured from Ka/Ku σ_0 measurements at multiple azimuth angles
  - Heritage: QuikSCAT, RapidScat, OSCAT
- Surface currents from Doppler measurements at multiple azimuth angles
  - Heritage: SAR Doppler, Along-track interferometry, field tested
- Temporal coverage achieved by 1600 km swath

Current Ocean-Color Sensors

SENSOR / DATA LINK	AGENCY	SATELLITE	LAUNCH DATE	SWATH (KM)	SPATIAL RESOLUTION (M)	BANDS	SPECTRAL COVERAGE (NM)	SPECTRAL RESPONSE FUNCTION	ORBIT
COCTS CZI	SOA (China)	HY-1B	11 April 2007	3000 500	1100 250	10 4	402 - 885 433 - 695		Polar
GOCI	KARI/KIOST (South Korea)	COMS	26 June 2010	2500	500	8	400 - 865		Geostationary
MODIS-Aqua	NASA (USA)	Aqua (EOS-PM1)	4 May 2002	2330	250/500/1000	36	405-14,385	SRF-link	Polar
MODIS-Terra	NASA (USA)	Terra (EOS-AM1)	18 Dec 1999	2330	250/500/1000	36	405-14,385	SRF-link	Polar
OCM-2	ISRO (India)	Oceansat-2 (India)	23 Sept 2009	1420	360/4000	8	400 - 900		Polar
OLCI	ESA/ EUMETSAT	Sentinel 3A	16 Feb 2016	1270	300/1200	21	400 - 1020	SRF-link	Polar
VIIRS	NOAA (USA)	Suomi NPP	28 Oct 2011	3000	375 / 750	22	402 - 11,800	SRF-link	Polar

Scheduled Ocean-Color Sensors

SATELLITE	AGENCY	SENSOR / DATA LINK	LAUNCH DATE	SWATH (KM)	SPATIAL RESOLUTION (M)	# OF BANDS	SPECTRAL COVERAGE (NM)	ORBIT
HY-1C/D (China)	CNSA (China)	COCTS CZI	2018	3000 950	1100 250	10 4	402 - 12,500 433 -885	Polar
GCOM-C	JAXA (Japan)	SGLI	Dec 2017	1150 - 1400	250/1000	19	375 - 12,500	Polar
HY-1E/F (China)	CNSA (China)	CZI	2021	2900 1000	1100 250	10 4	402 - 12,500 433 - 885	Polar
EnMAP	DLR (Germany)	HSI	2017	30	30	242	420 - 2450	Polar
OCEANSAT-3	ISRO (India)	OCM-3	2018-2019	1400	360 / 1	13	400 - 1,010	Polar
Sentinel-3B	ESA/ EUMETSAT	OLCI	Nov 2017	1265	260	21	390 - 1040	Polar
JPSS-1	NOAA /NASA (USA)	VIIRS	2017	3000	370 / 740	22	402 - 11,800	Polar
SABIA-MAR	CONAE	Multi-spectral Optical Camera	Sept 2021	200/2200	200/1100	16	380 - 11,800	Polar
GeoKompsat 2B	KARI/KIOST (South Korea)	GOCI-II	March 2019	1200 x 1500 TBD	250/1000	13	412 - 1240 TBD	Geostationary
PACE	NASA	OCI	2022/2023	2000	1000	hyperspectral (5 nm from 350 to 890 nm + 6 in NIR-SWIR)	350-2250 nm	Polar
GISAT-1	ISRO (India)	HYSI-VNIR	*(planned)	250	320	60	400-870	Geostationary (35.786 km) at 93.5°E
ACE	NASA	OES	>2020	TBD	1000	26	350-2135	Polar
GEO-CAPE	NASA	Coastal Ocean Color Imaging Spec (Name TBD)	>2022	TBD	250 - 375	155 TBD	340-2160	Geostationary
HyspIRI	NASA	VSWIR instrument	>2022	145	60	10 nm contiguous bands	380 - 2500	LEO, Sun Sync.

Summary

- SST: The biggest issue right now will be a lack of future microwave missions.
  - AVHRR -19 (NOAA 19) could very well be the last US polar orbiter. The Pathfinder SST data set which is the longest satellite derived climate data record has been discontinued.
- SSH: Jason-3 is the only altimeter from NASA onboard.
  - SWOT is scheduled for 2021.
- Salinity: Aquarius version 5 will come out late 2017. SMAP salinity.
  - No future salinity mission or follow-on to Aquarius
- Winds: Lack of Scattermeters.
  - No future Scatterometer missions planed by NASA
  - IOVWST supports the Doppler Scatterometer mission concept.
- Ocean color: Many ocean color sensors are launched and also scheduled for launch by many countries
  - PACE is scheduled to launch in 2022/23