The altimeter and radiometer product suite for the Sentinel-6/Jason-CS mission

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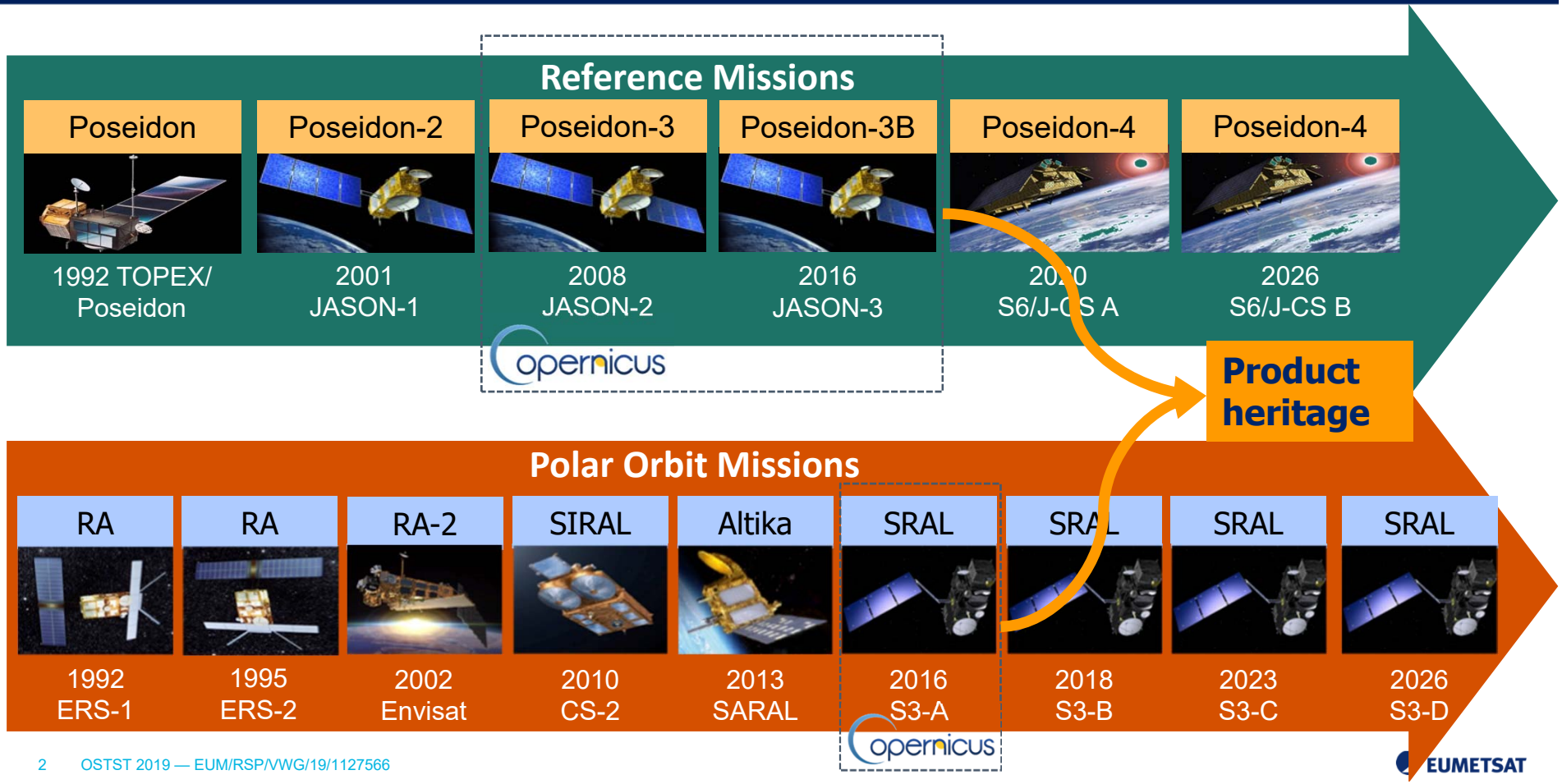
(EUMETSAT)

Satellite altimetry instruments/missions



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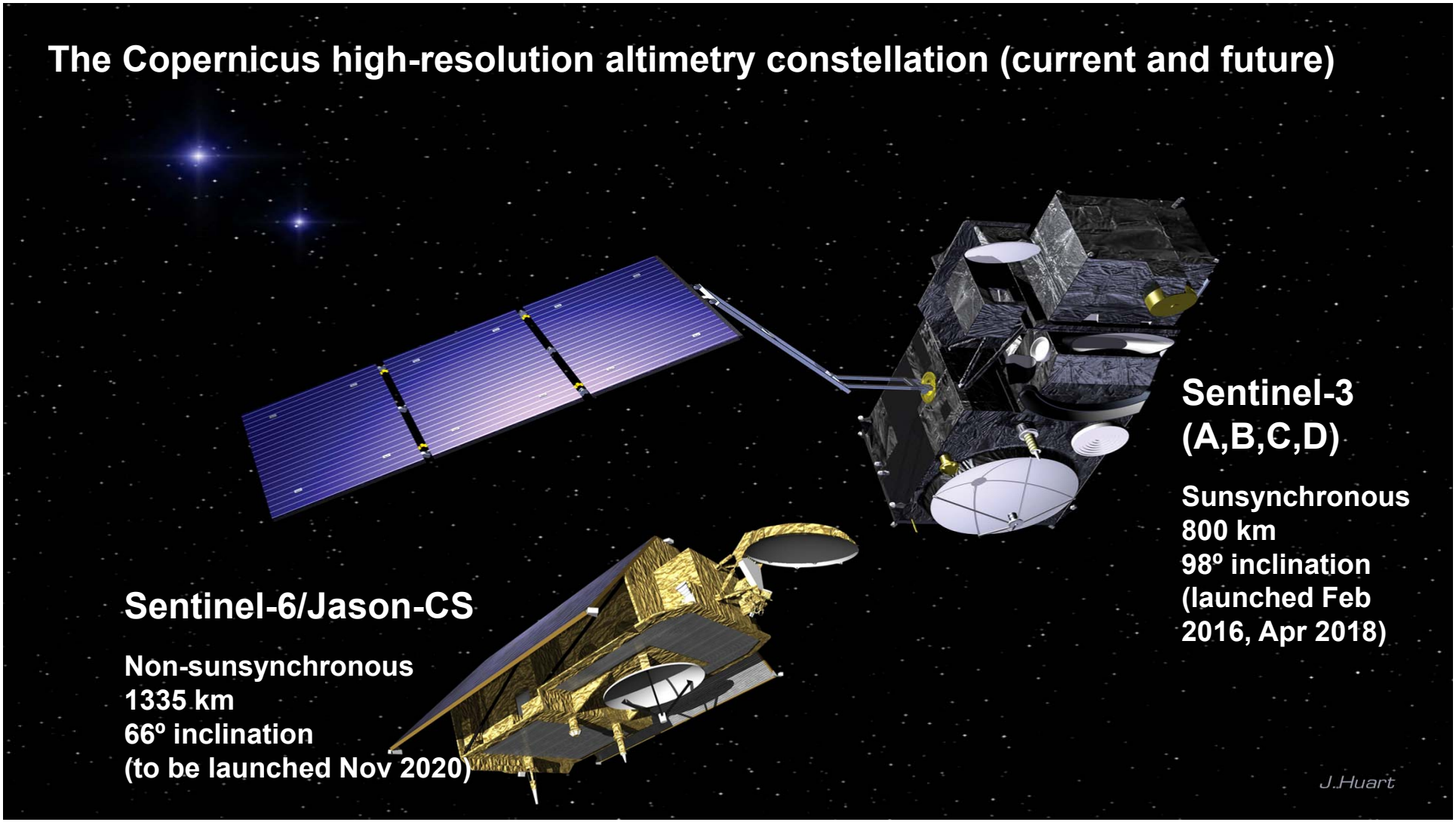
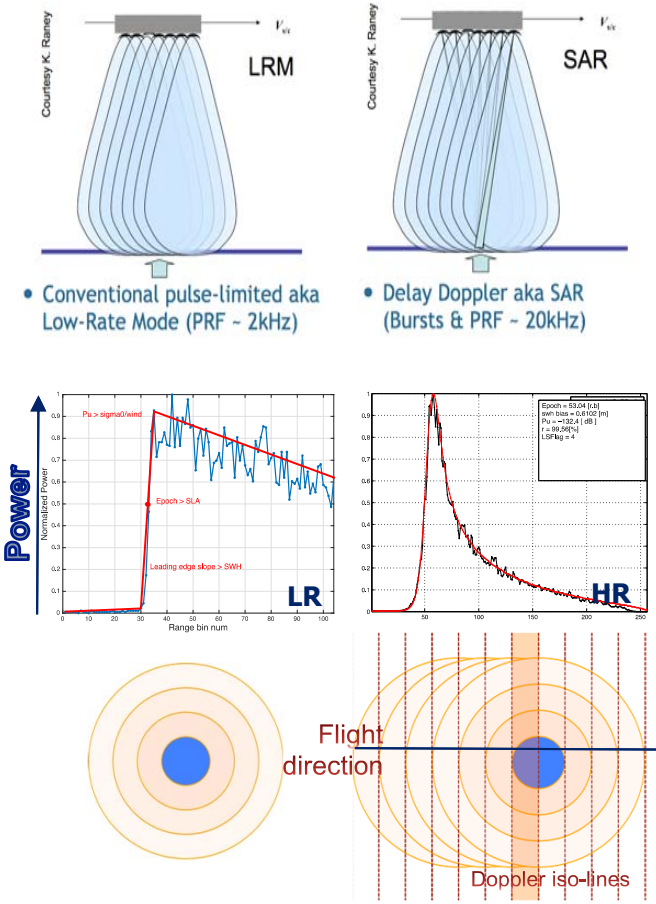

The Copernicus high-resolution altimetry constellation (current and future)
Sentinel-3
(A,B,C,D)
Sunsynchronous
800 km
98º inclination
(launched Feb
2016, Apr 2018)
Sentinel-6/Jason-CS
Non-sunsynchronous
1335 km
66º inclination
(to be launched Nov 2020)
J.Huart

Delay/Doppler or SAR Altimetry – quantum leap

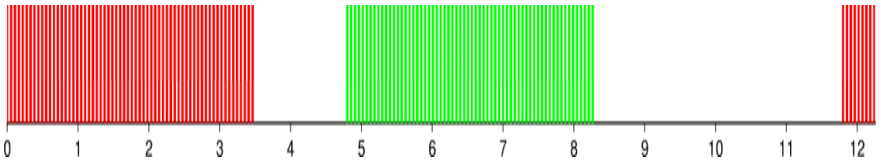


The **improvements** w.r.t. conventional ('LR' – Low Resolution) altimetry:

- More "**looks**" → higher SNR → more precise
- **Finer along-track spatial resolution**
  - ~ 300 meters along-track
- Less **contamination** close to land
  - Very well suited for coastal altimetry

Sentinel-3 and -6 in **HR altimetry over all ocean surfaces!**

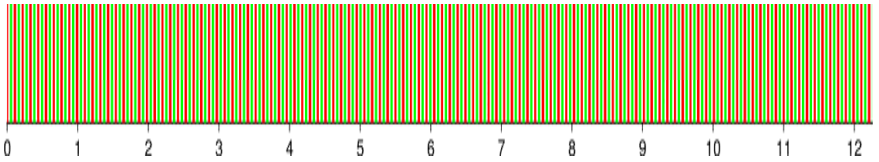
Closed-burst and open-burst SAR



CLOSED-BURST

SENTINEL-3 AND CRYOSAT-2

- In a **closed-burst** HR altimetry (S-3 and CS-2) **transmit** and **receive** are not interleaved and are not continuous.
  - N (= 64) echoes are tx @ a high PRF = 18 kHz → give a burst duration of ~3.5 ms.
  - But the burst-to-burst interval is ~11.8 ms.
- **70%** of the opportunity to make measurements **is not used**.
- This pulsing scheme does not allow for statistical equivalent Low Resolution measurement (pseudo-LRM).



OPEN-BURST

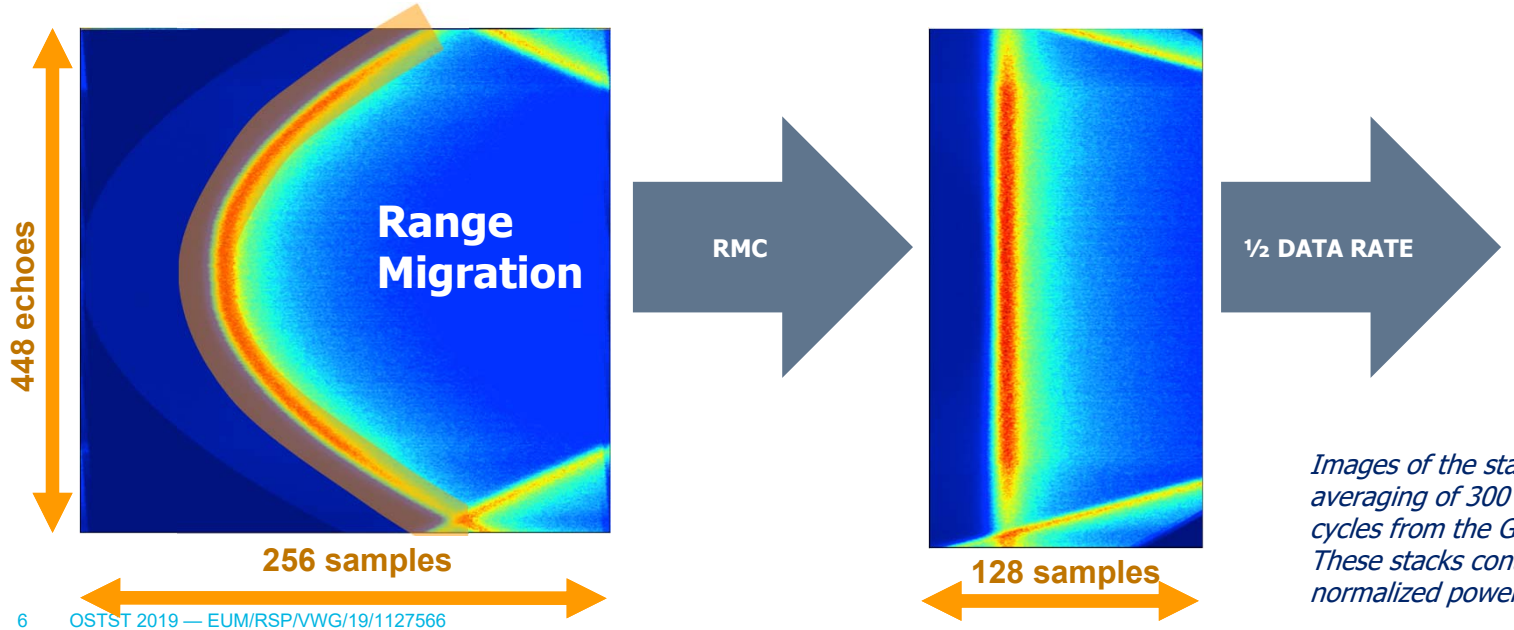
SENTINEL-6 / JASON-CS

- PRF ~ 9 kHz and continuously interleaved **transmit** and **receive**.
- All possible statistically independent measurements are made.
- HR and LR altimetry measurements can both be made from the same echoes, under the same conditions.
- LR from simple sequential averaging of all echoes yields optimal LR everywhere, both coastal and open ocean.
- Since all individual echoes will be downlinked, HR products can be generated on-ground.

Sentinel-6/Jason-CS HR operational modes

- Jason-CS will operate in “HR-RAW” over coastal areas. That means that the delay/Doppler map of 256 samples will be available for creating a HR multi-looked waveform.
- Note however the Doppler ambiguities.

- Jason-CS will operate in “HR-RMC” over open ocean. The number of samples is reduced to 128 in order to reduce on-board storage and downlink, while retraining most useful information.
- **The range migration correction is done on board and un-done on ground**



Images of the stacks are based on the averaging of 300 simulated Jason-CS radar cycles from the Ground Processing Prototype. These stacks contain I/Q values, but normalized power is shown here.

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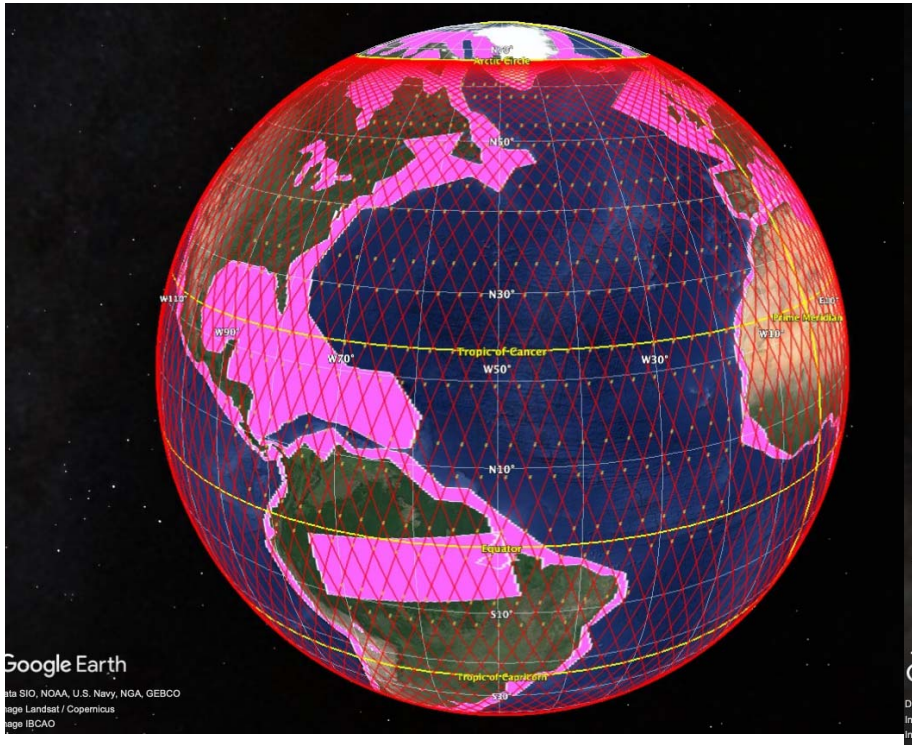
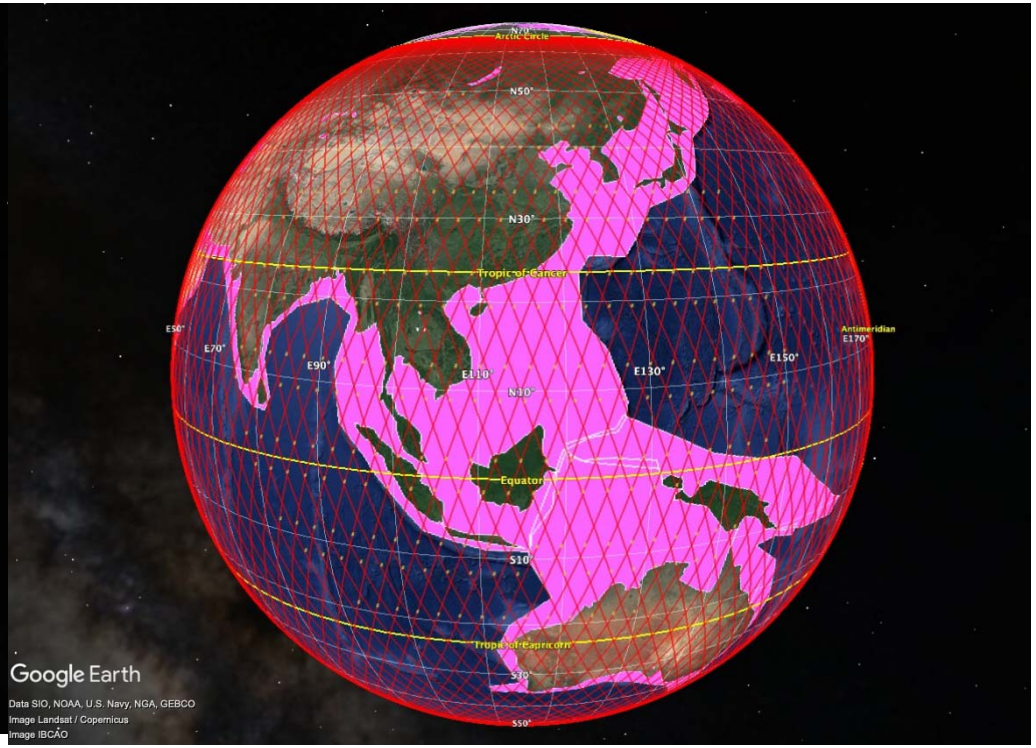
Mode Mask — Baseline operations

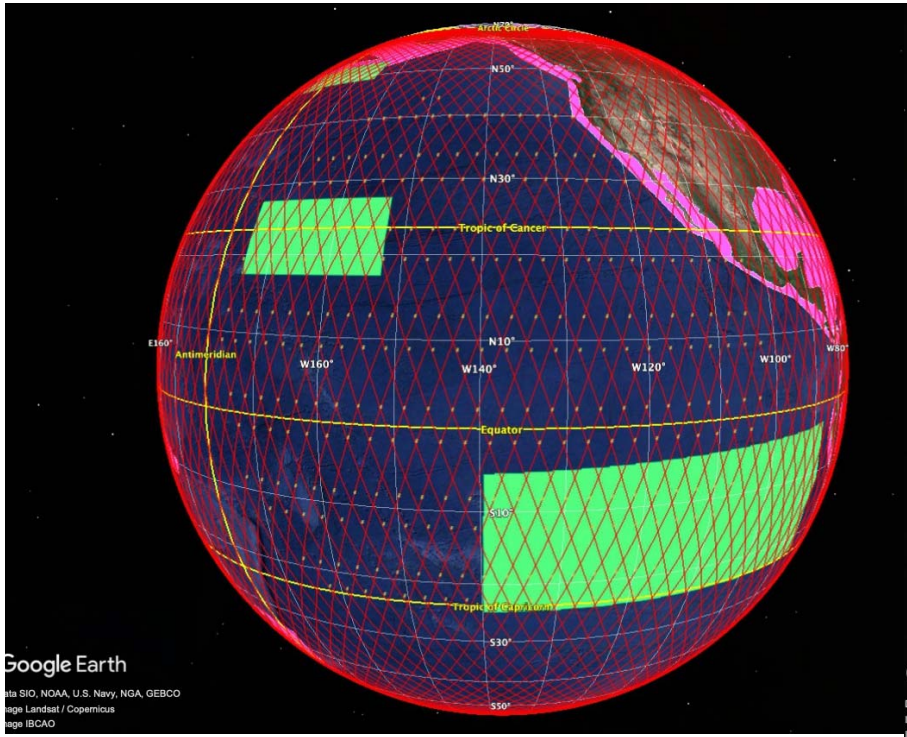
- LRM – everywhere
- Full SAR – coastal
- SAR RMC – open ocean

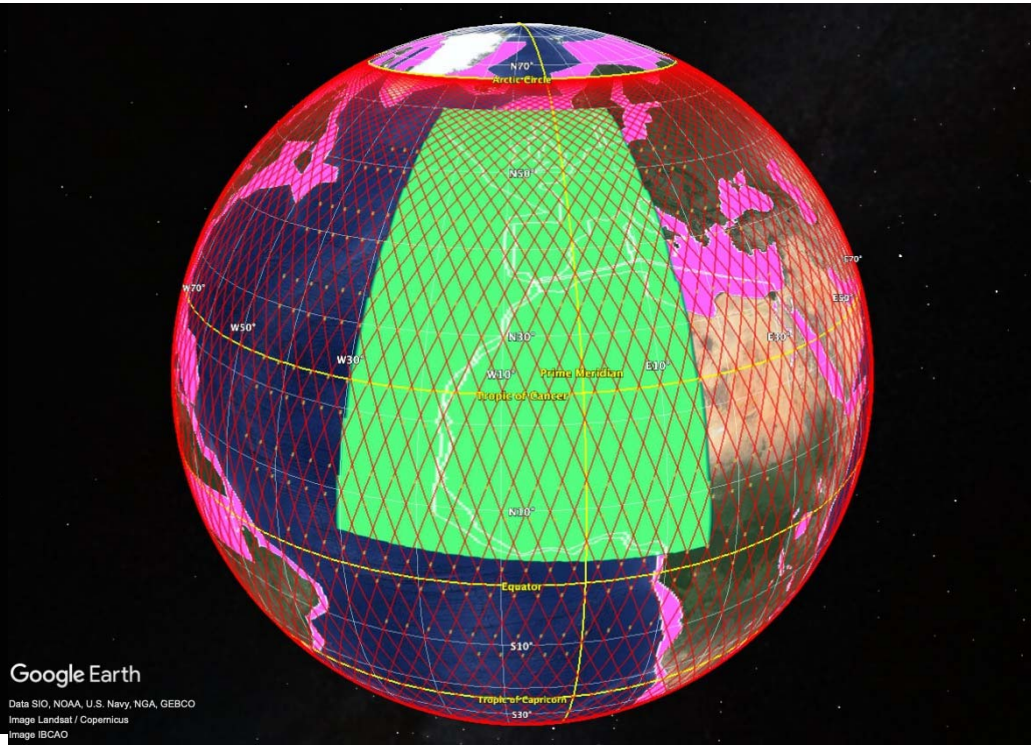




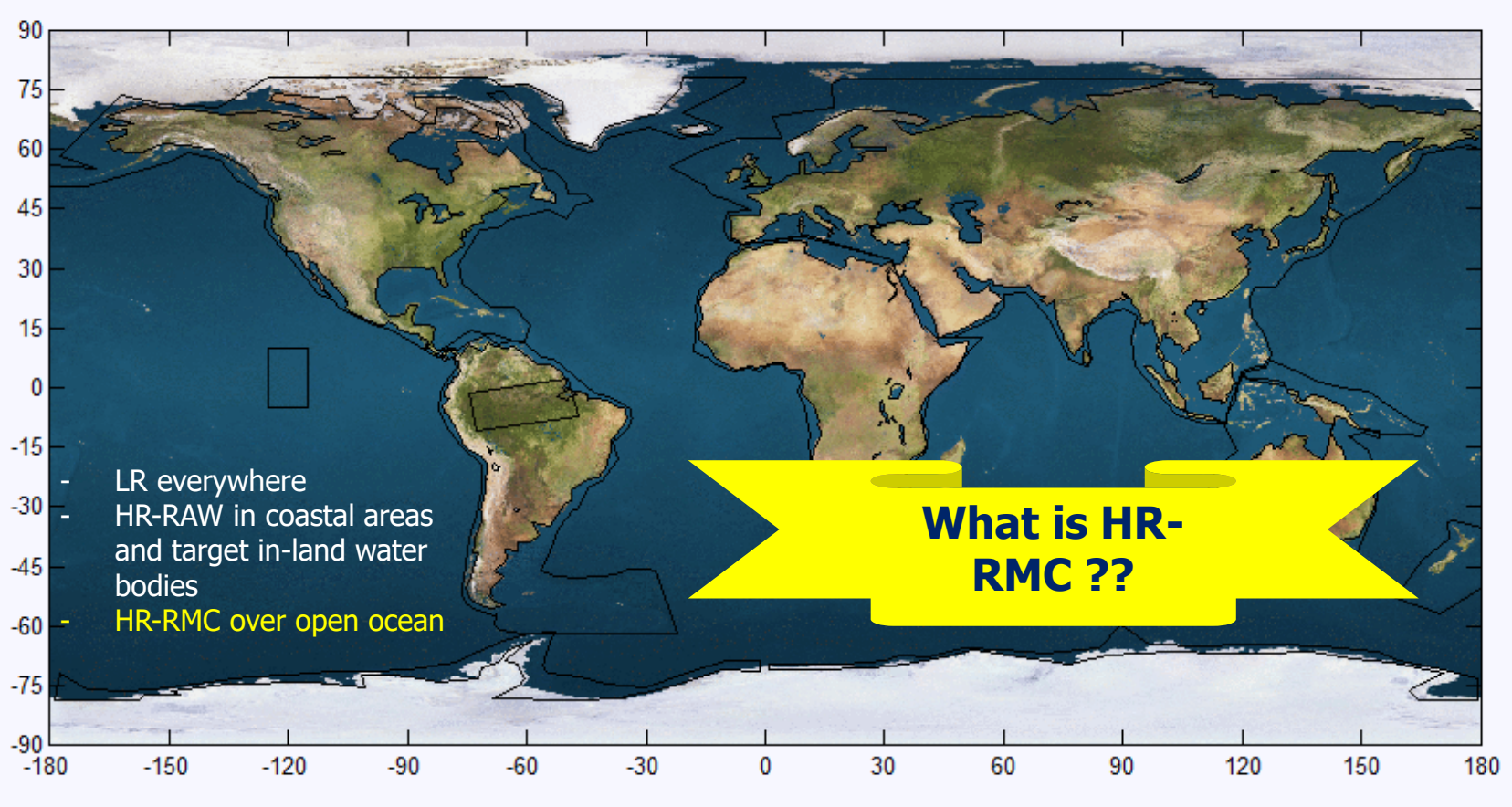
Varying Mode Mask — During commissioning

- As baseline, plus full SAR in …
- Pacific ocean boxes (Box 1)
- Continental/shelf Box 2





Sentinel-6/Jason-CS data budget



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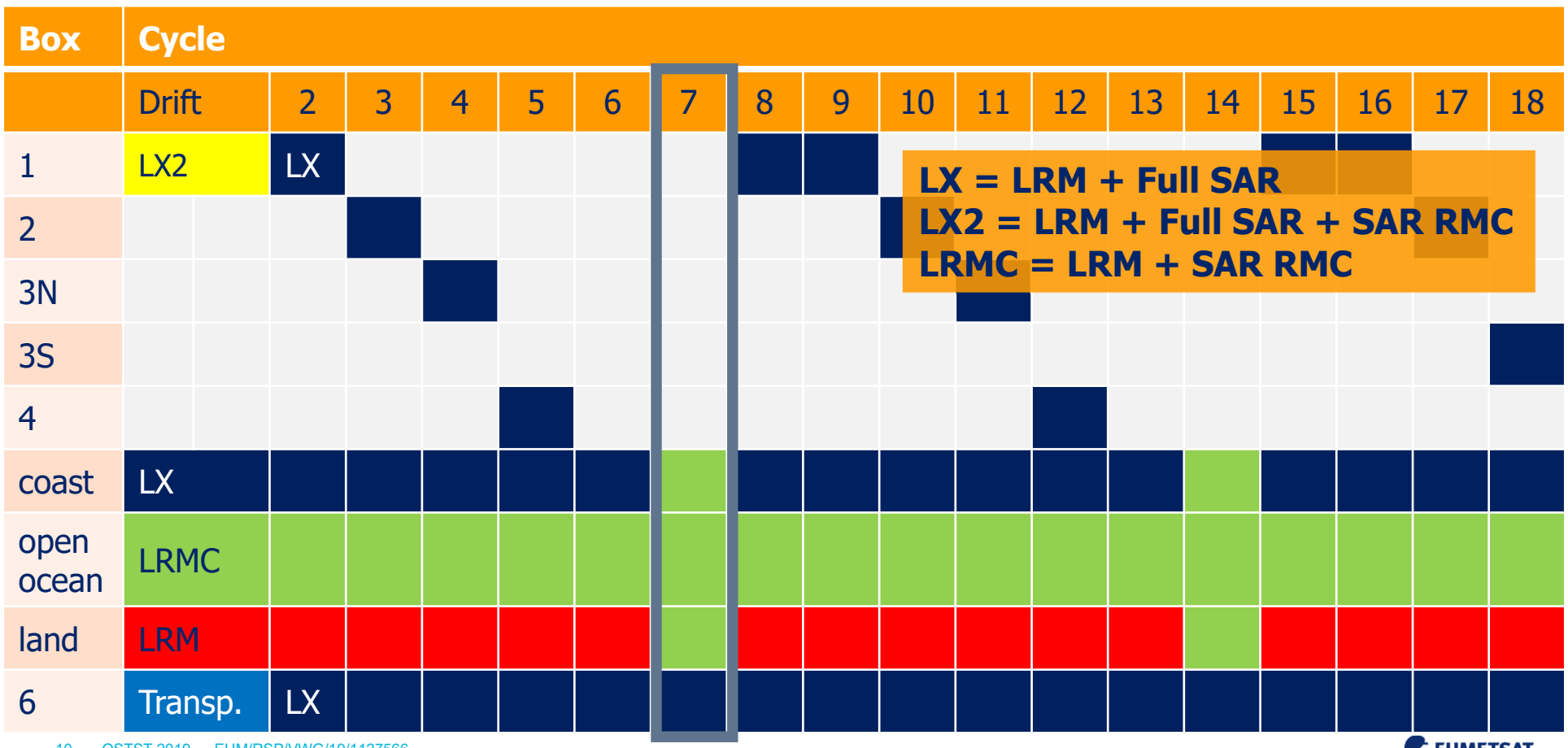
Example schedule



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Sentinel-6 user product overview

- **Level 1A**
  - Individual echoes; instrumental calibrations applied
  - From this the user can create L1B-S with software (provided by ESA)
- **Level 1B**
  - Calibrated waveforms, to be combined with L2 to form the equivalent of Jason's Sensor Geophysical Data Records (SGDR)
- **Level 2**
  - Equivalent to Geophysical Data Records (GDR)
  - Format more similar to Sentinel-3
  - Provided also in **reduced format** (with 1-Hz only) and in BUFR format (in NRT)
- **Level 2P**
  - As Level 2, with updated corrections and models (reduced)
  - Baseline HR only, LR under consideration
- **Level 3**
  - Harmonised with other missions (reduced)
  - Baseline HR only, LR under consideration

Near-Real time	Short Time Critical	Non Time Critical
• Mainly for **operational Met agencies** (wind and wave mainly) • Products split by **satellite dump/granules** (per ground station/10-minute chunks) • **NetCDF** and **BUFR**	• For **ocean modelling and assimilation** • Product split by pass (**pole to pole**) • **NetCDF**	• For **oceanographic and geophysical research and climate studies** • Products split by pass (**pole to pole**) • **NetCDF**
JASON-3		
• **3-hour latency** • **OGDR** • **1-Hz and 20-Hz** measurements (sea level, wind speed, wave height, etc.)	• **48-hour latency** • **IGDR** • **1-Hz and 20-Hz** measurements	• **60-day latency** • **GDR** • **1-Hz and 20-Hz measurements** • **SGDR** (including waveforms)
SENTINEL-6/JASON-CS		

• **3-hour latency**
• **Level 2:** Low- and high-resolution products
  • **Standard** (1-Hz and 20-Hz)
  • **Reduced** (1-Hz)
  • **BUFR** (1-Hz and 20-Hz)
• **Level 2P:** Harmonised L2 (1-Hz)
	• **36-hour latency**
	• **Level 1A:** Individual echoes (HR only)
	• **Level 1B:** LR and HR
	• **Level 2:** LR and HR
	  • **Standard** (1-Hz and 20-Hz)
	  • **Reduced** (1-Hz only)
	• **Level 2P:** Harmonised L2 (1-Hz)
	• **Level 3:** With orbit error correction, error information (1-Hz)
		• **60-day latency**
		• **Level 1A:** Individual echoes (HR only)
		• **Level 1B:** LR and HR
		• **Level 2:** LR and HR
		  • **Standard** (1-Hz and 20-Hz)
		  • **Reduced** (1-Hz only)
		• **Level 2P:** Harmonised L2 (1-Hz)
		• **Level 3:** With orbit error correction, error information (1-Hz)

"Annual" reprocessing of NTC products

- With any major product evolution
- To ensure consistency of data standard throughout the mission
- This is the new **"climate product"**

- **Level 2P and 3** products are produced with some delay with respect to the timeliness shown above.

Sentinel-6/Jason-CS Product Baseline

Product	Latency	Format	User Data Access		
			EUMETCast	GTS	Archive
ALT Low Resolution (LRM)	**NRT**	BUFR	L2	L2	L2
		NetCDF	L2, *L2P*	–	L2, *L2P*
	STC	NetCDF	*L2P*	–	L1b, L2, *L2P, L3*
	NTC	NetCDF	–	–	L1b, L2, *L2P, L3*
ALT High Resolution (SAR)	**NRT**	BUFR	L2	L2	L2
		NetCDF	L2, L2P	–	L2, L2P
	STC	NetCDF	L2P	–	L1a, L1b, L2, L2P, L3
	NTC	NetCDF	–	–	L1a, L1b, L2, L2P, L3
MWR	**NRT**	NetCDF	–	–	L2
	STC	NetCDF	–	–	L2
	NTC	NetCDF	–	–	L2

Note 1: ALT Level 2 NetCDF products: reduced (1-Hz only) and standard (1-Hz and 20-Hz)

Note 2: L2P and L3 products have slightly different latency *Note 3: L2P and L3 LR products under consideration*

Performance budgets for sea level (NRT/STC/NTC)

Requirement (cm)	Jason-3 O/I/GDR	Sentinel-3 NTC	Jason-CS Requirement	Jason-CS Goals
Range noise (LR)	1.8	1.7	**1.5**	1.0
Range noise (HR)		1.3	**0.8**	0.5
Ionosphere	1.0/0.5/0.5	0.5	**0.5**	0.3
Sea state bias	3.5/2.0/2.0	2.0	**2.0**	1.0
Dry troposphere	1.0/0.7/0.7	0.7	**0.8**/0.7/0.7	0.5
Wet troposphere	1.2	1.4	1.2/1.2/**1.0**	0.8
Orbit error	5.0/2.5/1.5	1.9	5.0/**2.0**/1.5	3.0/1.5/1.0
SSH error (LR)	**6.8/3.9/3.4**	**3.6**	**5.79/3.53/3.20**	**3.46/2.29/1.99**
SSH error (HR)		**3.5**	**5.65/3.29/2.94**	**3.35/2.12/1.80**
SWH	50/40/40 cm or 10%	20 cm or 4%	**15 cm + 5%**	10 cm + 5%
Wind speed (m/s)	1.6/1.5/1.5	2	**1.5**	1.0
Sigma naught (dB)	0.7	1	**0.3**	0.3

Product heritage

Jason-3

- Maintain similar variable names
- Same pole-to-pole pass numbering

Sentinel-3

- Level 1A and Level 1B products
  - L1A for HR; L1B as separate product
- HR data variables similar to S3
- SAFE packaging
  - Manifest (xml) and data files in directory per product (e.g. pass)
- Internal netCDF data compression
  - Reduced data volume without need for zipping/unzipping

Product novelties

New in Sentinel-6

- Separate HR and LR products
  - To be able deliver LR ahead of HR
  - Because of 100% (LR) versus ocean-only coverage (HR)
  - Quite different content
- No “enhanced” or SGDR product
  - L1B product linked to L2 (same number of 20-Hz records)
- SAFE packaging with “unique” internal filename, à la Jason
- NetCDF data grouping
  - For more convenient variable naming
  - Compartmentalise data
- Separate Level 2 MWR product
  - At original data rate (16 Hz)
  - Includes antenna temperatures and brightness temperatures

Grouping variables in GDR-F

Not grouped (as in Sentinel-3)

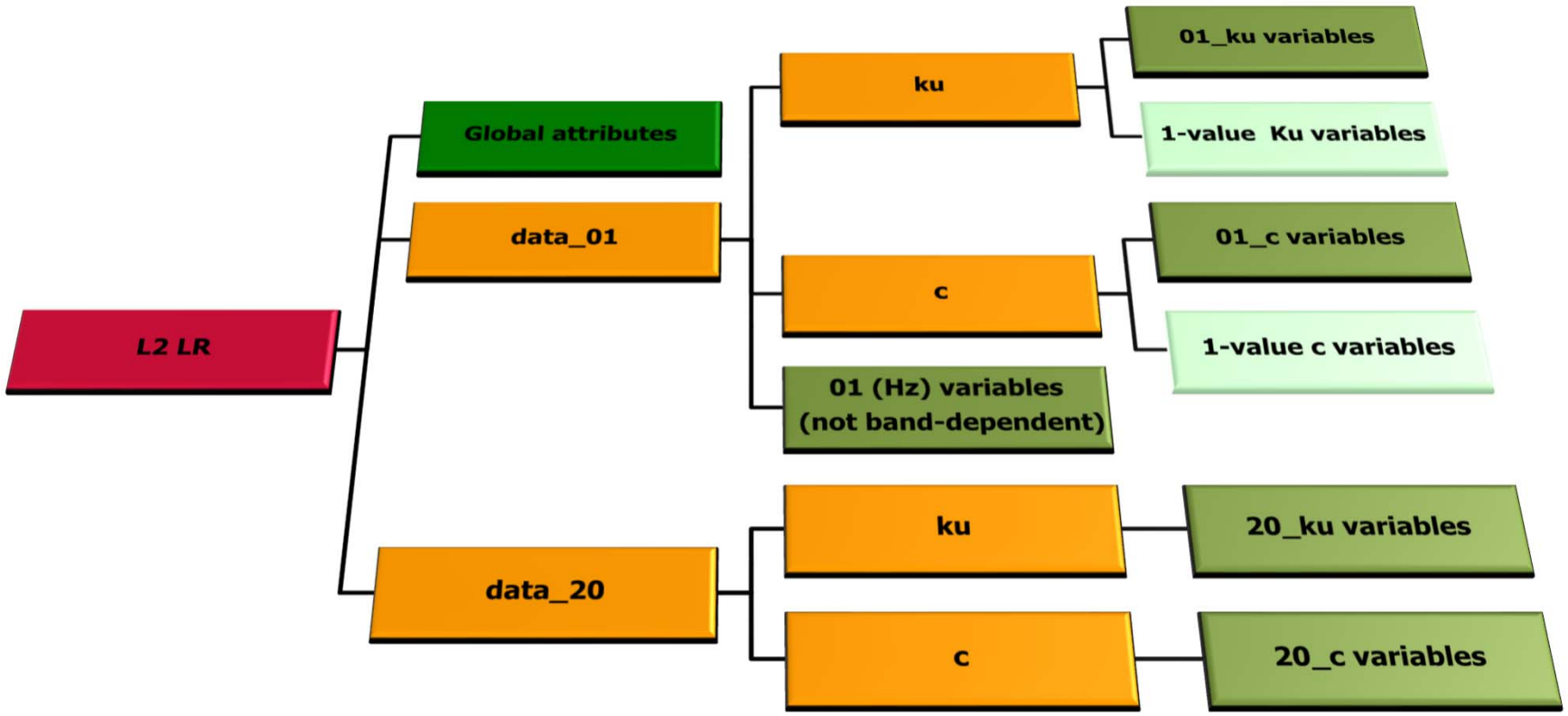
- Requires stringed variables like *time_20_ku, time_20_c*
- Creates confusing names like *sea_state_bias_c_20_ku*

Grouped (as in Sentinel-6)

- All variables of same posting rate contained in groups with same dimension name (*time*)
- Variable names can be reused in groups: e.g. *altitude* in /**data_01** and /**data_20/ku**

<table>
<tr><th colspan="4">/ (root)</th></tr>
<tr><td colspan="4">Global attributes, common dimensions</td></tr>
<tr><th colspan="2">/data_01</th><th colspan="2">/data_20</th></tr>
<tr><td colspan="2">1-Hz time dimension, 1-Hz variables common to Ku- and C-band (time, location, tides, MSS)</td><td colspan="2">(Few, if any)</td></tr>
<tr><th>/data_01/ku</th><th>/data_01/c</th><th>/data_20/ku</th><th>/data_20/c</th></tr>
<tr><td>1-Hz Ku-band measurements and corrections</td><td>1-Hz C-band measurements and corrections</td><td>20-Hz Ku-band time, location, measurements and corrections</td><td>20-Hz C-band time, location, measurements and corrections</td></tr>
</table>

Example: NetCDF groups in Level 2 LR product



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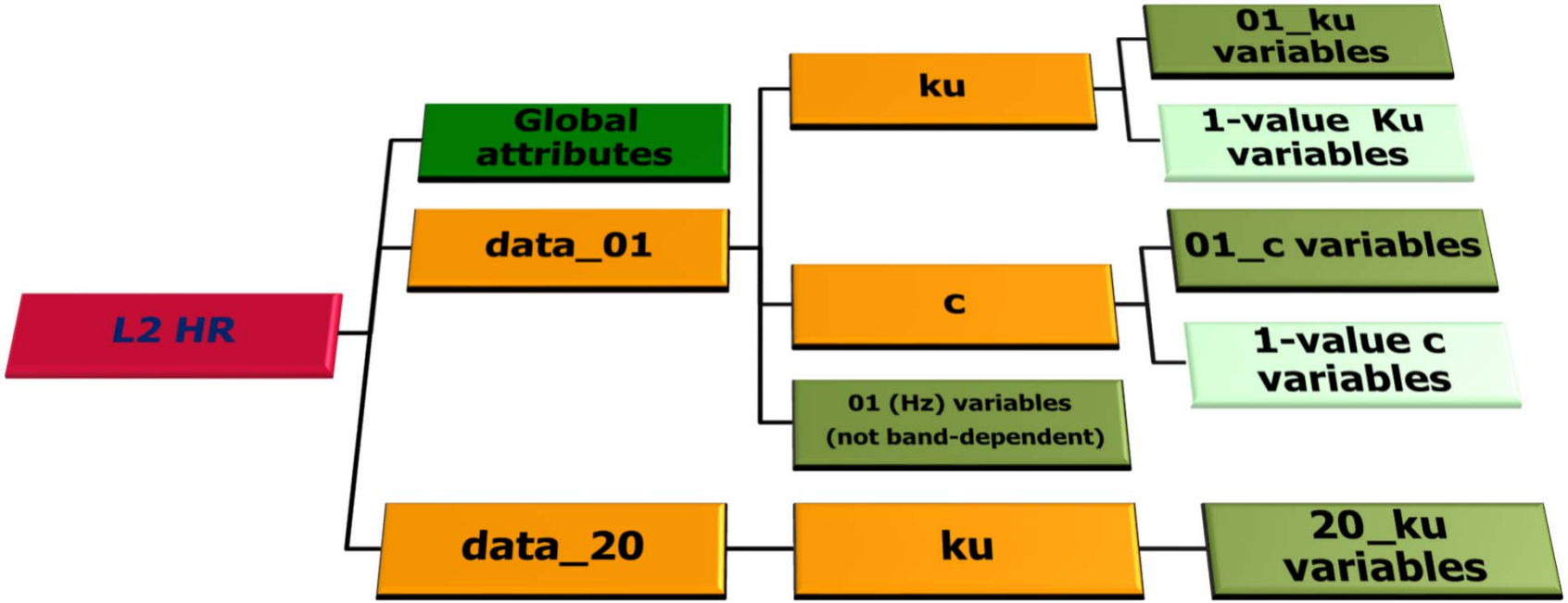
Example: NetCDF groups in Level 2 HR product



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Example of NetCDF variable grouping (Level 2)

Variable Name (dim)	Units	Scale factor	Format	LR		HR		*Contained in groups*
				data_01	data_20	data_01	data_20	
time (time)	s	-	double	x	ku, c	x	ku	1-Hz: **/data_01** 20-Hz: /**data_20/ku**, /**data_20/c**
time_tai (time)	s	-	double	x	ku, c	x	ku	
latitude (time)	degrees_north	1.e-6	int	x	ku, c	x	ku	
longitude (time)	degrees_east	1.e-6	int	x	ku, c	x	ku	
altitude (time)	m	1.e-4	int	x	ku, c	x	ku	
range_ocean (time)	m	1.e-4	int	ku, c	ku, c	ku	ku	1-Hz: /**data_01/ku**, /**data_01/c** 20-Hz: /**data_20/ku**, /**data_20/c**
range_ocean_numval (time)	1	-	byte	ku, c		ku		1-Hz only: **/data_01/ku, /data_10/c**
range_ocog (time)	m	1.e-4	int		ku, c		ku	20-Hz only: **/data_20/ku, /data_20/c**

Conclusions

- Sentinel-6 will introduce HR on the reference altimeter missions
  - "Interleaved mode" will allow LR/HR **simultaneously,** thus excellent to ensure continuity and opens the door to a lot more R&D
  - More data products and larger volumes than any previous mission → addressed with the RMC
  - New type of data products
  - 1-Hz range noise will be below 1 cm!
- Sentinel-6 will produce STC data faster than previous Jason missions
  - This will mainly benefit ocean modelers
- All Sentinel-6 data produced by EUMETSAT
  - Availability through EUMETCast and EUMETSAT Data Archive
  - BUFR provided in NRT (through GTS, mainly for Met Offices)

Questions, comments

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