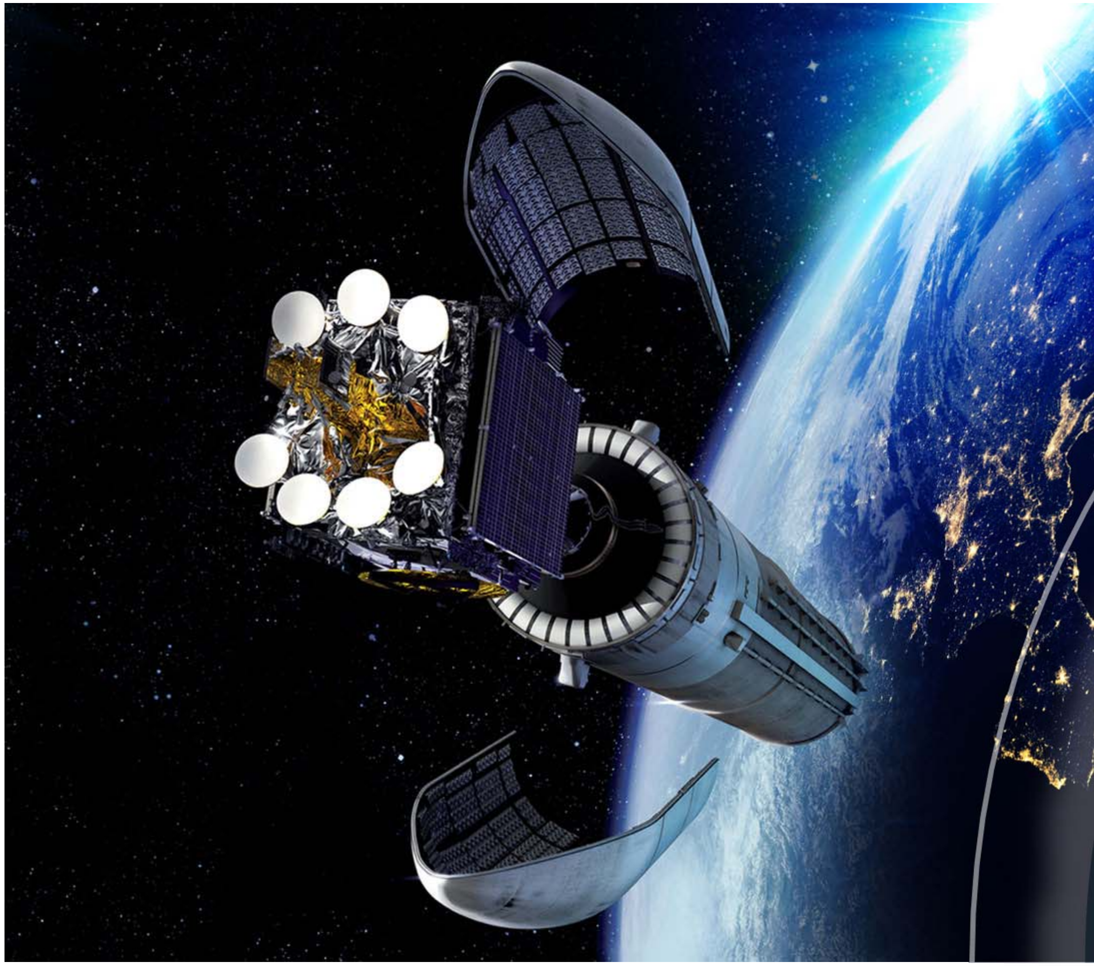

Short Latency GPS orbit solutions for LEO satellites

Ocean Surface Topography Science 2018

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ThalesAlenia Space
a Thales / Leonardo company

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Context and motivation

- Compute precise orbit with short latency (near real time)
  - Radio Occultation mission needs high precision and short latency
  - Could be extended to altimetry needs
- Dual-frequency / Single-frequency receivers
  - Dual-frequency receivers for altimetry missions, RO missions…
  - Possible extension to single-frequency TOPSTAR receiver (Merlin, Gokturk)
- Based on GPS only measurements
  - Perspective multiconstellation
  - Perspective hybrid GNSS / DORIS
- 2 approaches
  - Least Squares filter
  - Kalman filter
- Target precision
  - 5 cm 3D RMS

Precise Orbit Determination Process

- LEO precise orbit determination
  - GPS code + phase
  - Float ambiguities
- GNSS receiver
  - Dual frequency → ionofree combinaison
  - Single frequency → GRAPHIC combinaison
- Models

Theoretical Measurement Function
Propagation time
LEO and GPS clock biases
LEO and GPS 1st relativistic effects
Shapiro effect
Satellite geometry LEO & GPS (attitude)
Ambiguity
Wind up effect

Dynamical Model
Earth potential (120x120)
3rd body attraction (Sun and Moon)
Terrestrial, oceanic and polar tides
Direct solar radiation pressure
Relativity
Drag
Empirical forces (Hill)

Parameters
LEO position & velocity
Drag coefficient
DSRP coefficient
Hill coefficients
Receiver clock biais / epoch

Satellite Body
Sphere (SRP / Drag models)

Scenarios

- 2 different scenarios
  - MetOp-A
  - Jason-3
- Data set construction
  - IGS data sets
    - GPS orbits and clocks
    - antex files (PCO)
  - EOP
    - Bulletin B IERS
    - IGS ultra-rapid
  - Rinex observation files
  - Sun and Moon ephemeris (JPL DE-431)
  - Satellite description
  - Reference orbit for validation
    - SSALTO Jason3
    - EUMETSAT MetOpA orbits

Type	GPS	Accuracy	EOP	Accuracy	Latency
Broadcast	Orbits	~ 100 cm			Real time
	Clocks	~ 5 ns RMS ~ 2.5 ns Sdev			
Ultra-rapid (predicted half)	Orbits	~ 5 cm	PM	~ 200 µas	Real time
	Clocks	~ 3 ns RMS ~ 1.5 ns Sdev	PM rate	~ 300 µas/day	
			LOD	~ 50 µs	
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	Clocks	~ 150 ps RMS ~ 50 ps Sdev	PM rate	~ 250 µas/day	
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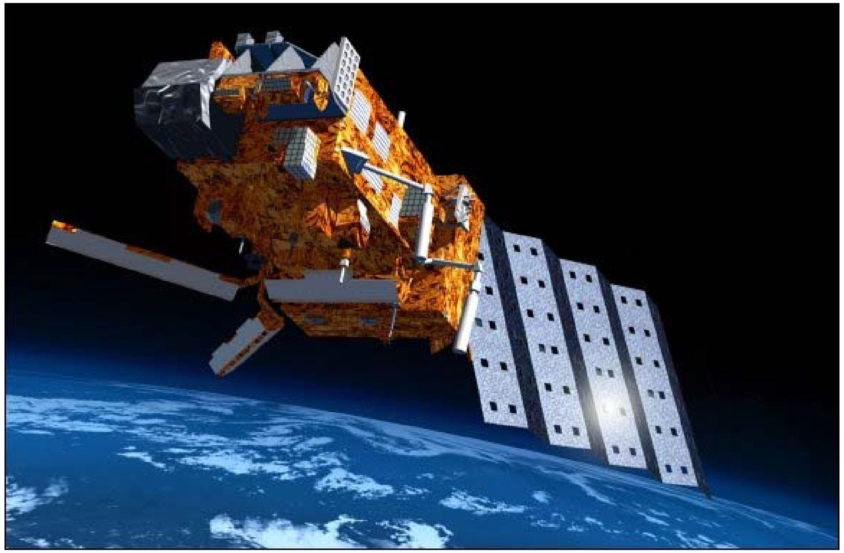
Rapid	Orbits	~ 2.5 cm	PM	~ 40 µas	17 – 41 h
	Clocks	~ 75 ps RMS ~ 25 ps Sdev	PM rate	~ 200 µas/day	
			LOD	~ 10 µs	
Final	Orbits	~ 2.5 cm	PM	~ 30 µas	11 – 17 days
	Clocks	~ 75 ps RMS ~ 20 ps Sdev	PM rate	~ 150 µas/day	
			LOD	~ 10 µs	

MetOp-A - Presentation

- Meteorological satellite
  - Inclination of 98.7°
  - Period of 101 minutes
  - Near circular orbit
  - Mean altitude of 817 km
- Mission
  - A more reliable weather forecast
  - Atmospheric and environemental surveys
- Satellite carateristics
  - 17.6 x 6.5 x 5.2 metres (deployed in orbit)
  - 4093 kg



MetOp-A - Data set

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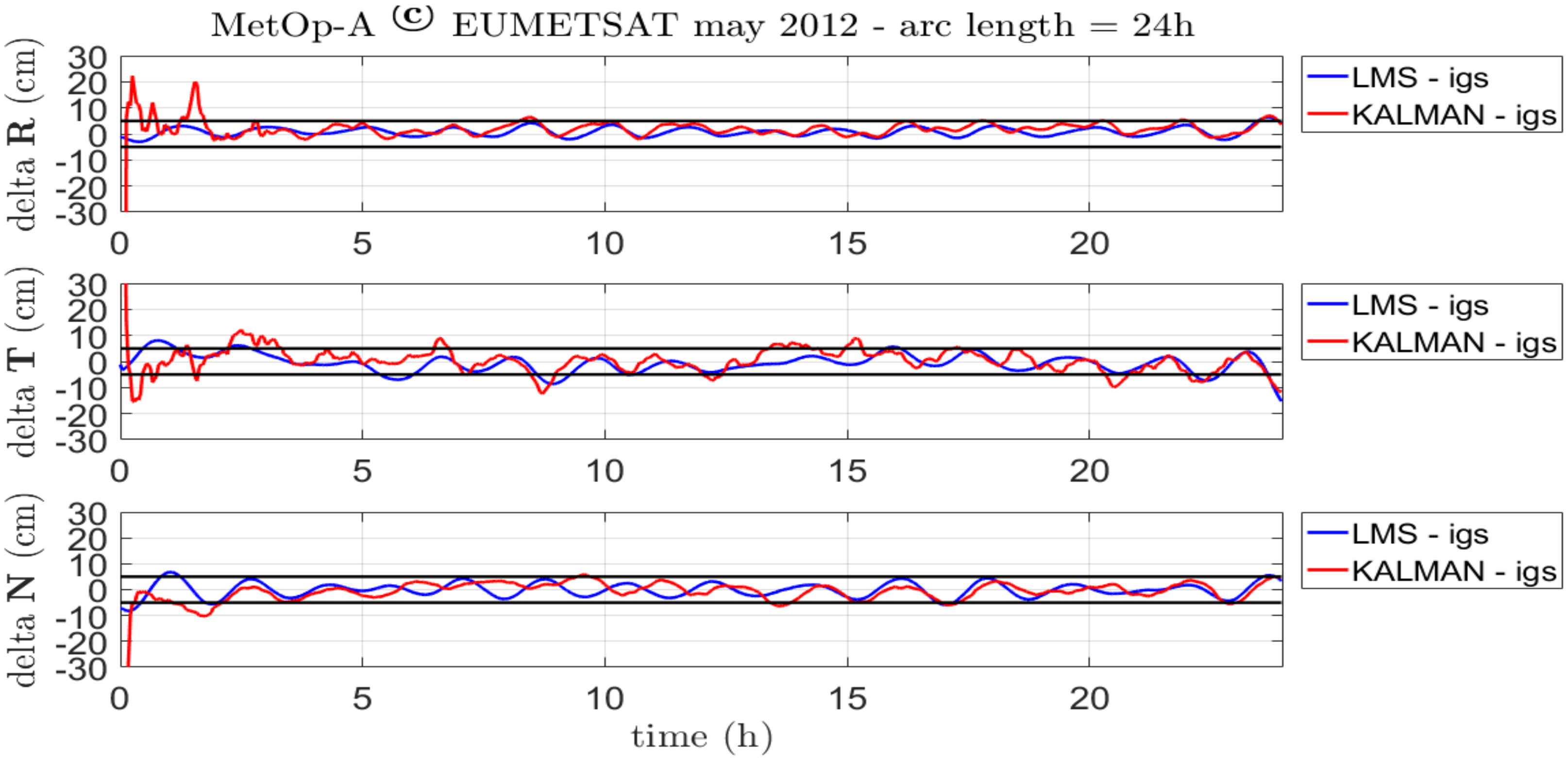
MetOp-A – Results with final IGS products



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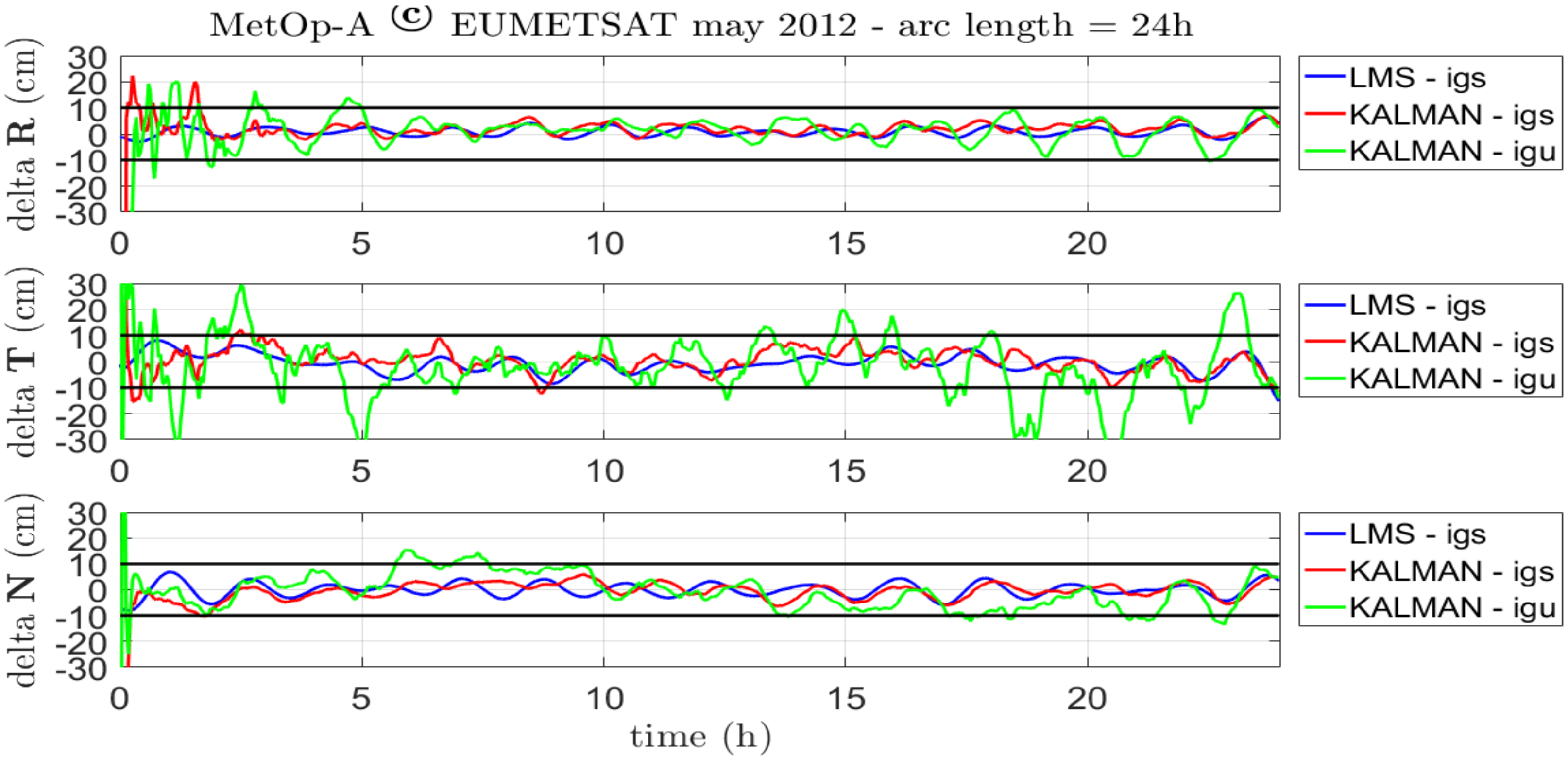
MetOp-A – Results with ultra-rapid IGS products



MetOp-A - Results

LMS and Kalman performances

		Mean ± 2σ (mm)	RMS (mm)	3D RMS (mm)
LMS (final)	R	-8 ± 34	19	49
	T	-6 ± 70	36	
	N	-0.7 ± 56	28	
KALMAN (final) (after t0+5h)	R	20 ± 40	28	56
	T	-1.6 ± 80	40	
	N	-0.8 ± 54	27	
KALMAN (ultra-rapid) (after t0+5h)	R	-12 ± 84	43	141
	T	-30 ± 110	114	
	N	-7 ± 142	71	

Jason-3 - Presentation

- Altimeter satellite
  - Inclination of 66.05°
  - Period of 112 minutes
  - Near circular orbit
  - Mean altitude of 1354 km
- Mission
  - Global sea surface height
  - Earth's changing climate
- Satellite carateristics
  - 1 x 1 x 3.7 metres (depolyed in orbit)
  - 510 kg

Jason-3 - Data set

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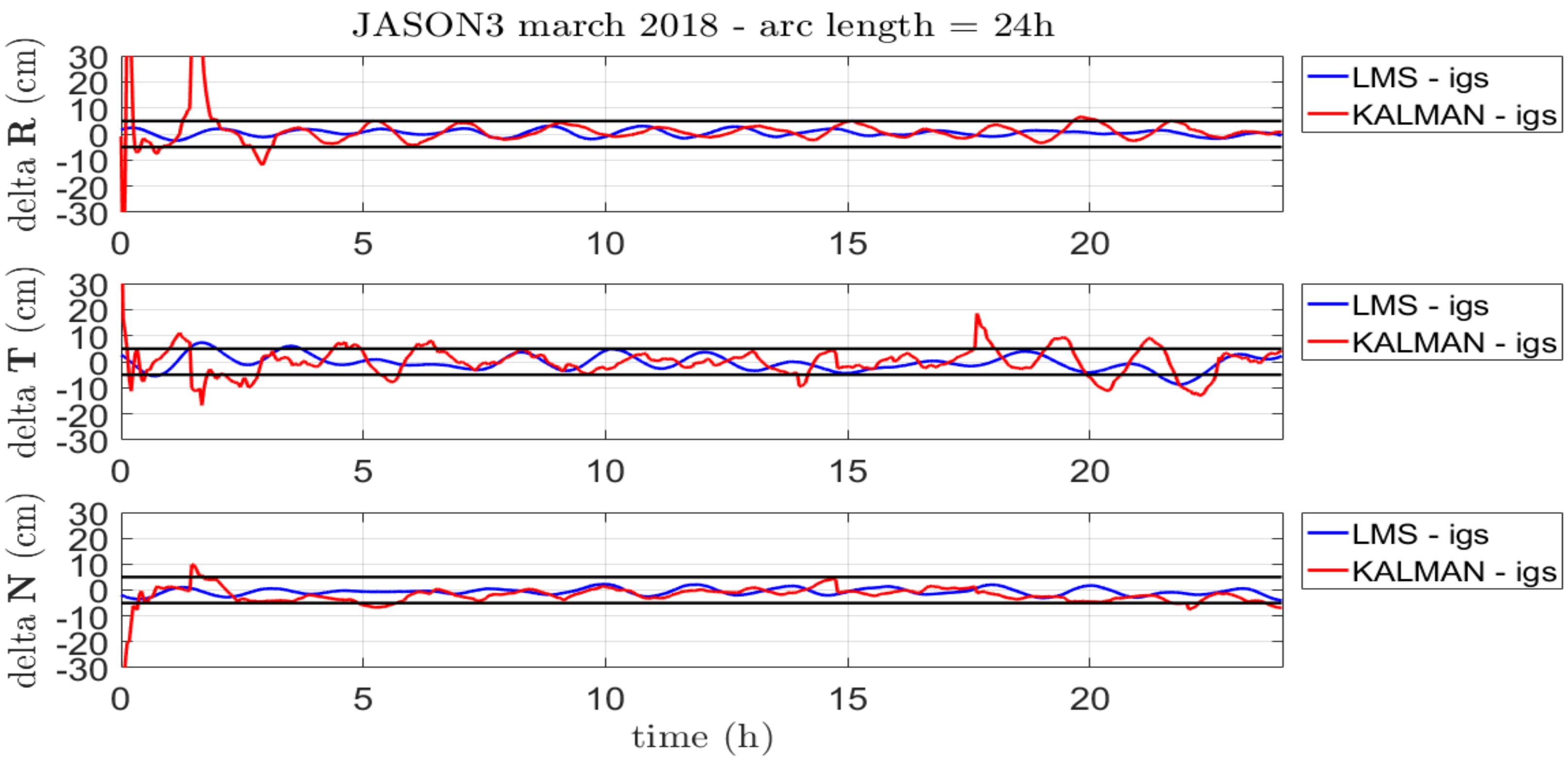

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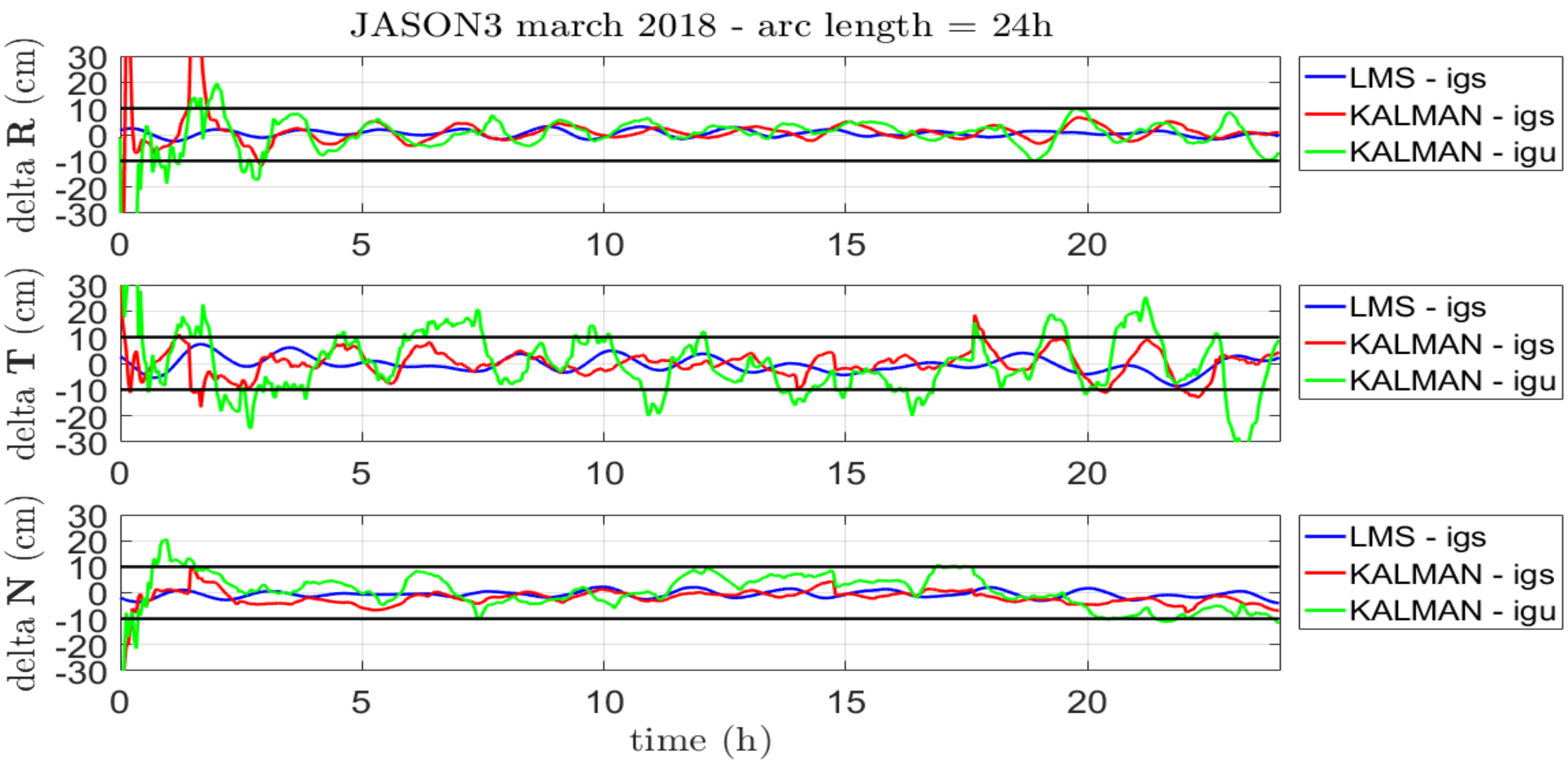

Jason-3 - Results

- LMS and Kalman performances

		Mean ± 2σ (mm)	RMS (mm)	3D RMS (mm)
LMS (final)	R	4 ± 24	13	36
	T	-4 ± 60	30	
	N	-6 ± 27	15	
KALMAN (final) (after t0+5h)	R	10 ± 46	25	59
	T	-0.7 ± 92	46	
	N	-18 ± 42	28	
KALMAN (ultra-rapid) (after t0+5h)	R	8 ± 76	39	128
	T	-6 ± 214	107	
	N	3 ± 118	59	

Single frequency receiver

- Motivation reminder
  - Single frequency receiver less costly
  - Industrial interest regarding TOPSTAR receiver developed by Thales

- What performances can we achieve using single-frequency receiver ?

- Single-frequency scenario
  - Adaptation of Jason-3 scenario
  - L1 code and phase measurements only
  - GRAPHIC formulation

- Target expected
  - 10 cm 3D RMS

Single frequency receiver – Jason-3

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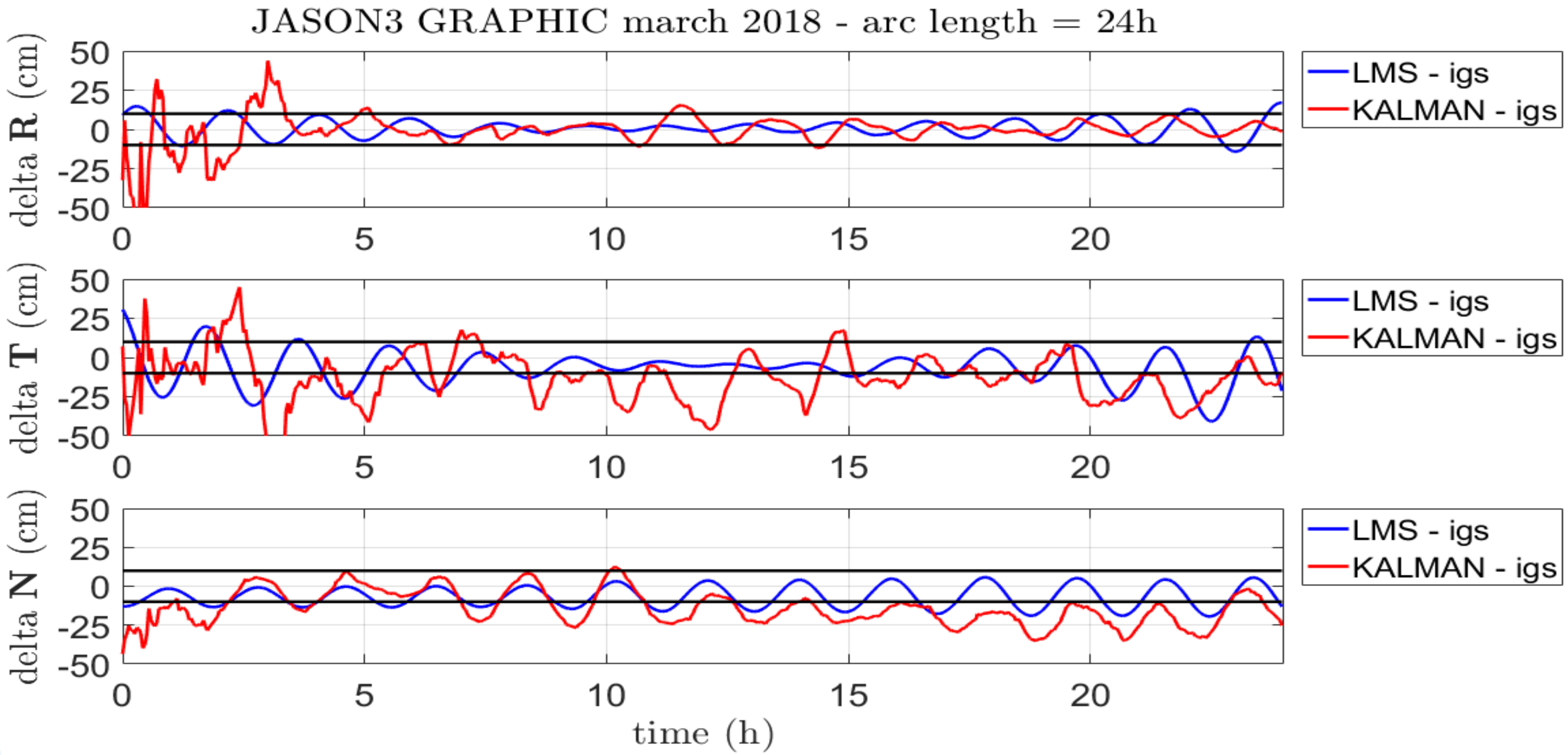

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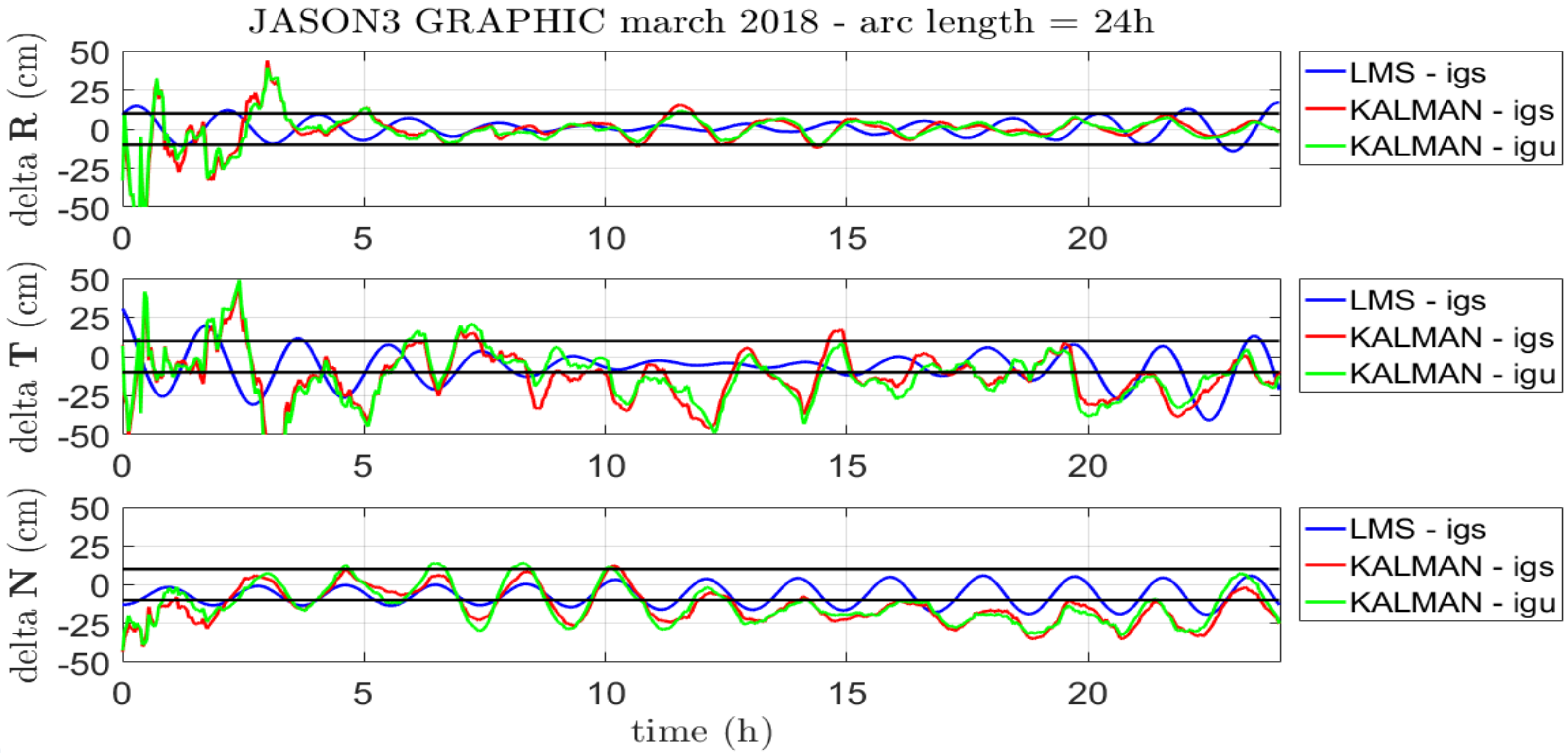


Single frequency receiver – Jason-3

LMS and Kalman performances

		Mean ± 2σ (mm)	RMS (mm)	3D RMS (mm)
LMS (final)	R	8 ± 116	58	172
	T	-66 ± 225	131	
	N	-67 ± 136	95	
KALMAN (final) (after t0+5h)	R	2 ± 102	51	265
	T	-129 ± 268	186	
	N	-148 ± 212	182	
KALMAN (ultra-rapid) (after t0+5h)	R	-1 ± 92	46	264
	T	-126± 268	184	
	N	-142 ± 233	184	

Conclusion & perspectives

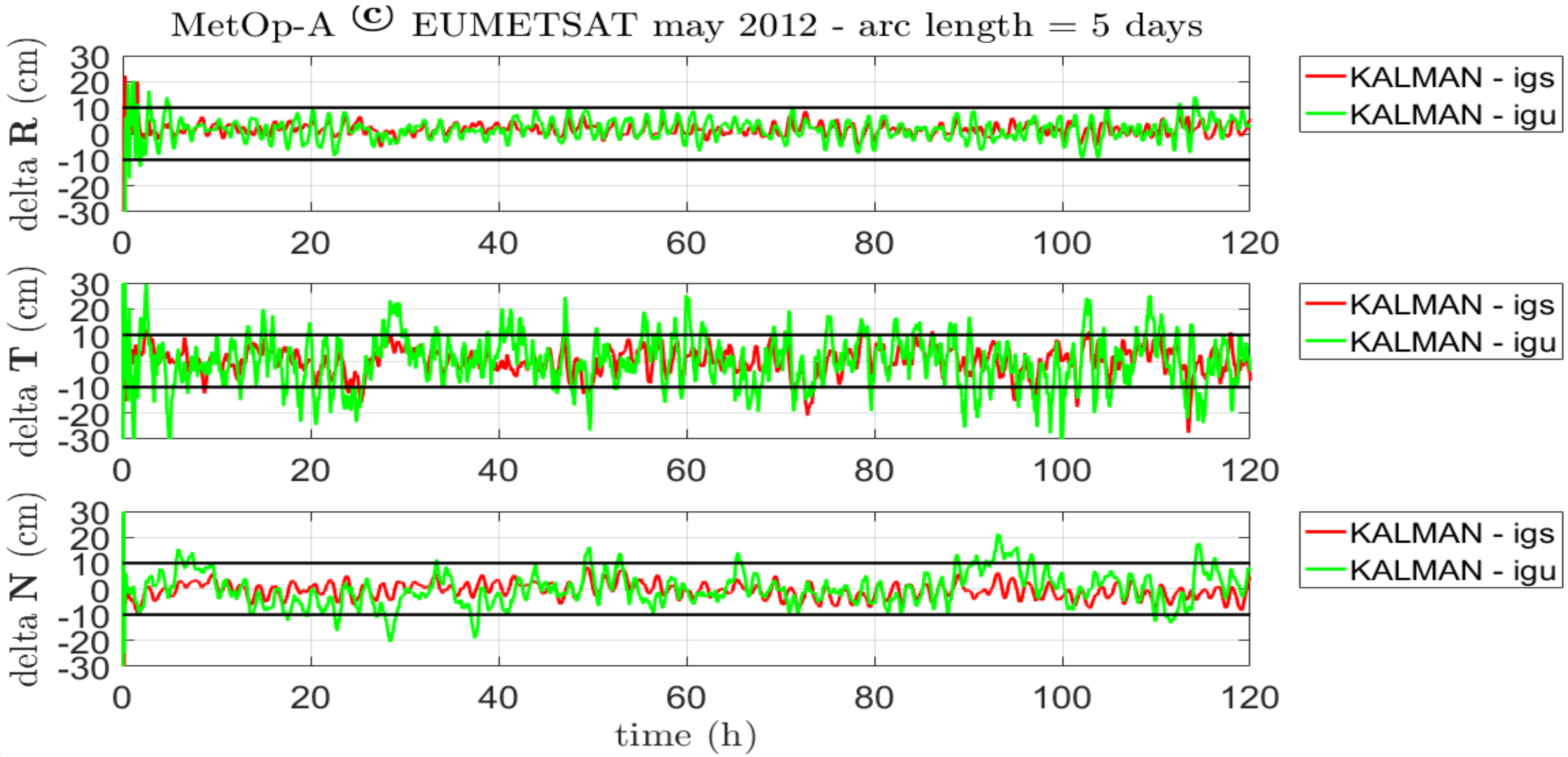
- Performances on the radial direction (RMS)

	Dual-frequency	Single-frequency
LMS (final)	13 mm	58 mm
Kalman (final)	25 mm	51 mm
Kalman (ultra-rapid)	39 mm	46 mm

- Kalman filter can achieve high precision (close to LMS performances)
- On-going/potential improvements axes
  - Box wing model
  - Model noise tuning for Kalman
  - Integer ambiguity resolution
  - Antenna Phase Center Variations

Thank you for your attention

MetOp-A – Results over a period of 5 days

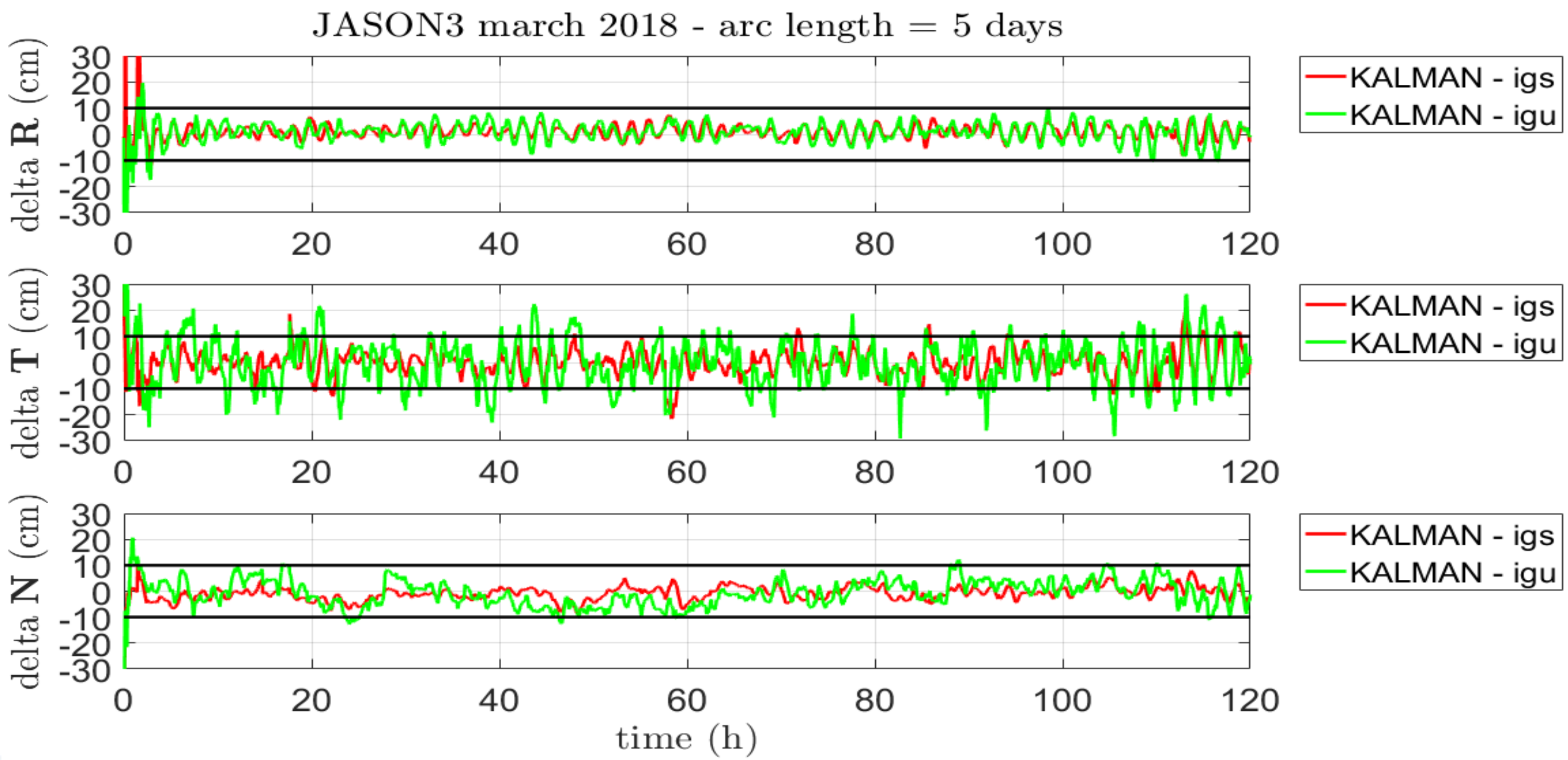


MetOp-A – Results over a period of 5 days

- Kalman performances over a period of 5 days

		Mean ± 2σ (mm)	RMS (mm)	3D RMS (mm)
KALMAN (final) (after t0+5h)	R	16 ± 45	28	68
	T	-2 ± 108	54	
	N	-8 ± 60	31	
KALMAN (ultra-rapid) (after t0+5h)	R	16 ± 76	41	126
	T	-2 ± 193	96	
	N	-11 ± 138	70	

Jason-3 – Results over a period of 5 days



Jason-3 – Results over a period of 5 days

Kalman performances over a period of 5 days

		Mean ± 2σ (mm)	RMS (mm)	3D RMS (mm)
KALMAN (final) (after t0+5h)	R	10 ± 48	26	62
	T	-2 ± 100	50	
	N	-8 ± 50	26	
KALMAN (ultra-rapid) (after t0+5h)	R	9 ± 67	35	105
	T	-4 ± 171	85	
	N	-7 ± 100	50	