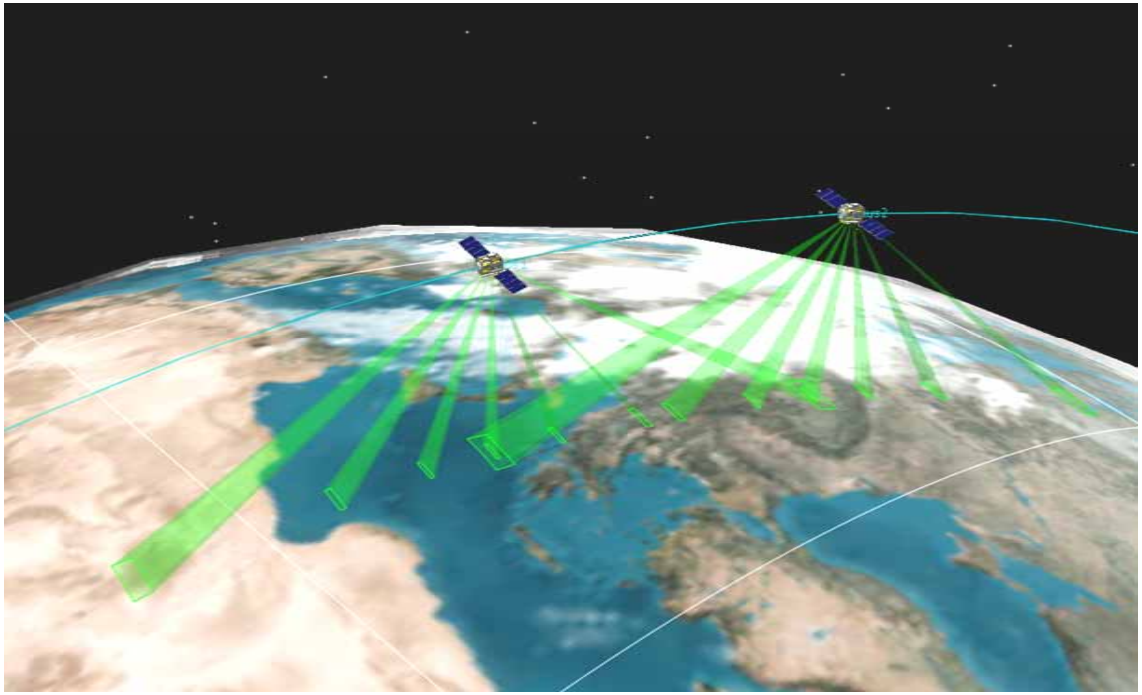
Formation Flying Orbital Geometry of the Dutch-Chinese FAST Micro-Satellite Mission



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Delft University of Technology

Outline

- Introduction
  - FAST (Formation for Atmospheric Science and Technology demonstration)
  - SPEX (Spectropolarimeter for Planetary EXploration)
- Problem description
- Analysis
  - Tool description
  - Simulation settings
  - Variables
- Results
  - Single satellite
  - Two satellites
- Conclusions

Introduction - FAST Mission

- Formation for Atmospheric Science and Technology demonstration
- 2 micro-satellites: FAST-D (Delft) and FAST-T (Tsinghua)
- Science payloads:
  - Spectropolarimeter (SPEX) on both spacecraft (S/C) for aerosol characterization
  - Laser altimeter (SILAT, Stereoscopic Imaging Laser Altimeter) on FAST-D and radar altimeter on FAST-T to determine seasonal variations in height profiles in the cryosphere
- Technology demonstrations:
  - Autonomous Formation flying (AFF) with distributed propulsion
  - Distributed, fault-tolerant, and out-of-core computing
  - Direct and routed (ground station and commercial satellite communication constellation) inter-satellite communication
  - Others
- Two formation 'modes':
  - Mode A (~1 year): 'close' FF for increased aerosol data return
  - Mode B (~1 year): separation of several hours between the two S/C ('train') to observe changes in aerosol characteristics within one day
- Launch: end 2011

Introduction - SPEX

- Spectropolarimeter for Planetary EXploration
- Designed to study Martian dust and clouds, but can also be implemented for Earth observation
- Under development by Dutch consortium (breadboard phase)
- Measures flux and polarization
- No mechanisms
- Miniaturized payload design (< 5 kg)
- Spatial resolution 18 km @ 600 km (1.7°)
- Spectral resolution 2 nm (400-800 nm)
- 9 viewing angles (±54°, ±36°, ±18°, nadir, 2 limb looking)

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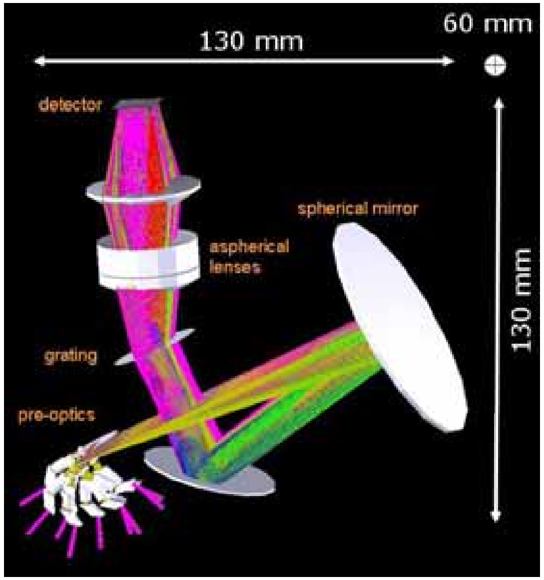
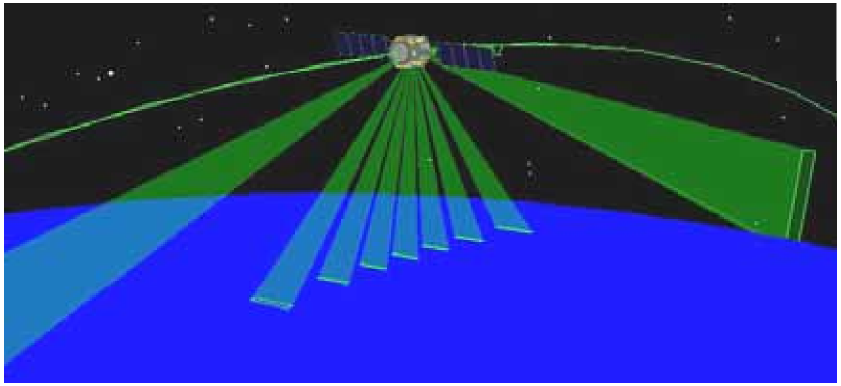
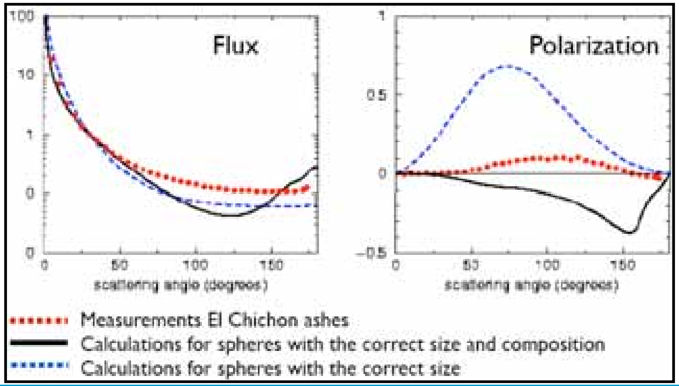
Introduction - SPEX







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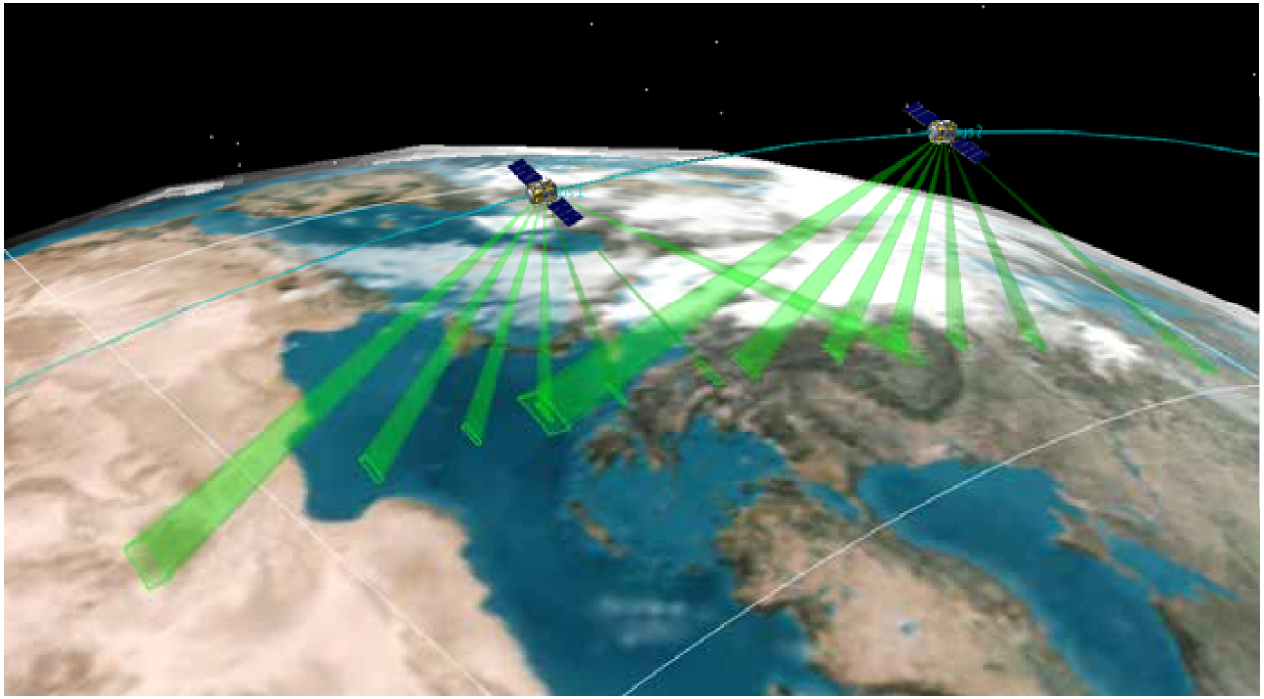
Problem description

- How to optimize SPEX data return using two spacecraft?
  - SPEX has limited swath width (max. 7˚) and therefore poor global coverage. How can this be improved using two spacecraft?
  - Due to Earth rotation, many geolocations, especially near the equator, will not be detected by all seven Earth-looking telescopes of SPEX. This results in incomplete datasets. How can this be circumvented using two SPEX instruments on different spacecraft?

Problem description

- Initial solution:
  - Leader-follower formation with overlapping fields of view. Result: Coverage of an area with all viewing angles in half the time



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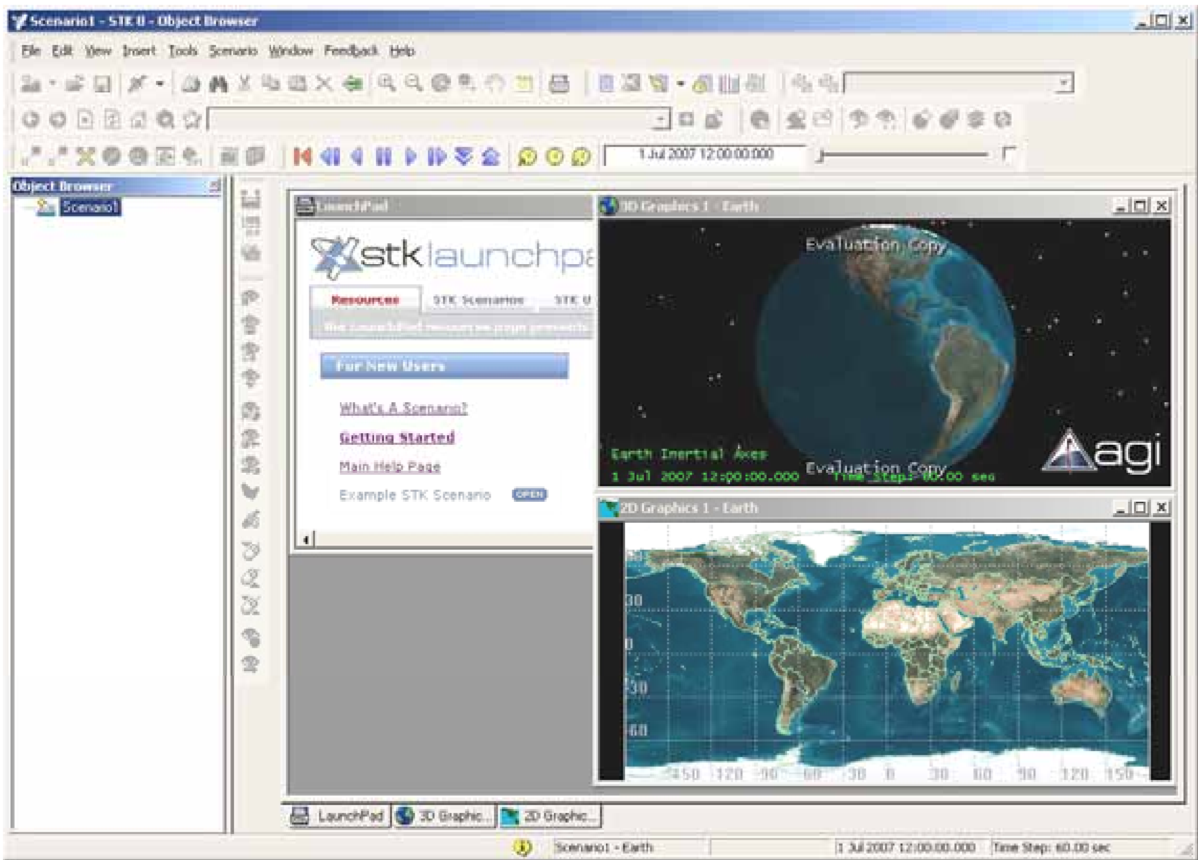
Analysis – Tool description

- AGI Satellite Tool Kit 8.1.1:



Analysis – Simulation settings

- Orbit simulation settings:
  - Propagator: J2Perturbation
  - Step size: 60 sec.
  - Epoch: January 1, 2012, 8:30
  - Date format: UTCG (Coordinated Universal Time Generator)
  - Coordinate system: J2000
- Orbit parameters:
  - Eccentricity (e): 0 [-]
  - Argument of perigee (ω): 0˚
  - Right Ascension of the Ascending Node (Ω): 60˚
  - True anomaly (v): 0˚
  - Sun Synchronous
  - 5 Altitudes:

	450 km	**550 km**	**650 km**	**750 km**	**850 km**
a [km]	6828.14	6928.14	7028.14	7128.14	7228.14
i [˚]	97.2188	97.5976	97.9908	98.3985	98.8212

Analysis – Simulation settings

- Symmetric problem ⇒ analyze only one hemisphere. Three 10˚x10˚ regions:

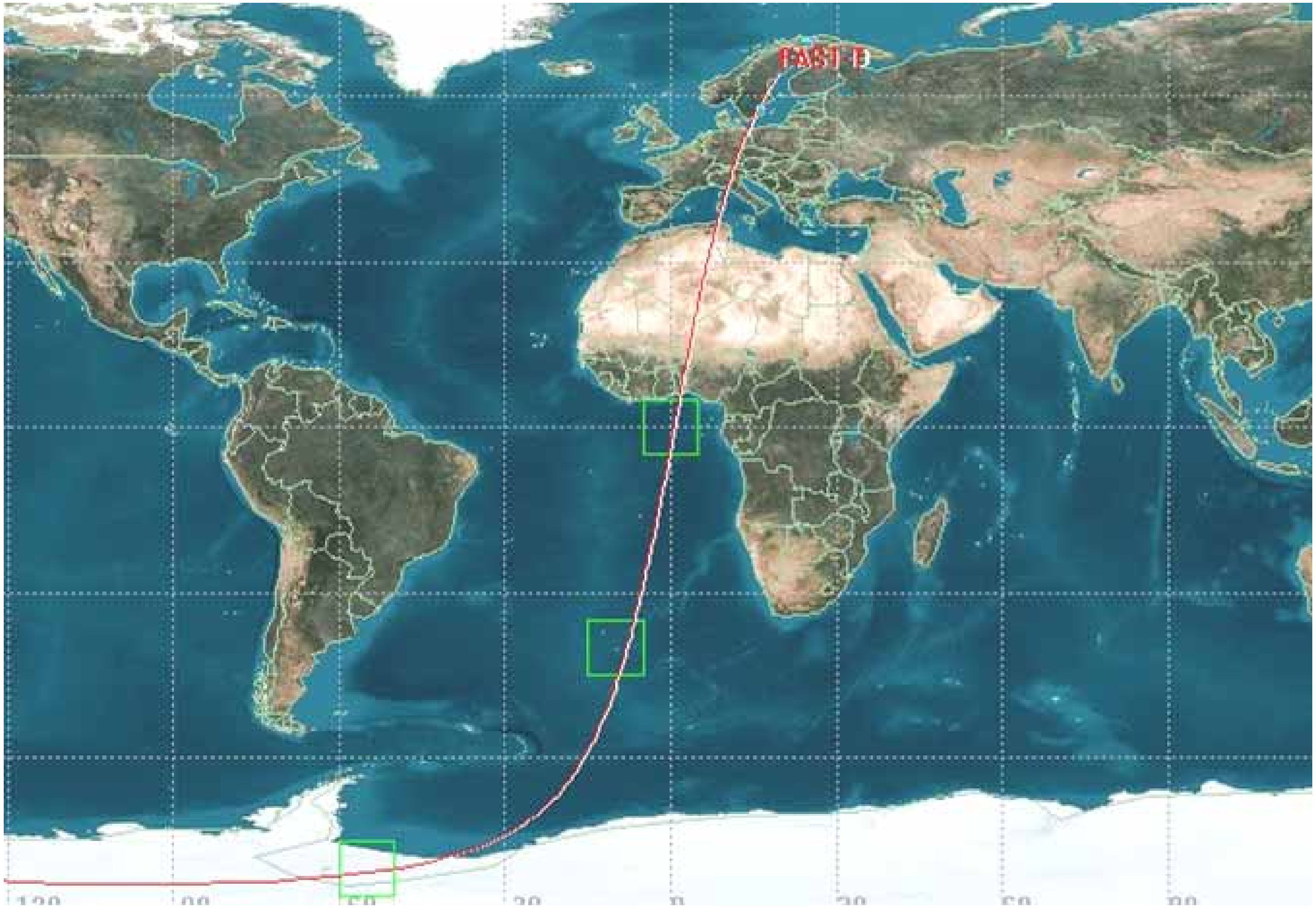
Region #	Central longitude [˚]	Central latitude [˚]
1	-80	-55
2	-40	-10
3	0	0

- Cover regions with points that can be detected by SPEX. Size of points has to be equal to SPEX spatial resolution (1.7˚x 1.7˚):

Altitude [km]	Point size [km^2]
450	179.56
550	265.69
650	372.49
750	497.29
850	636.42

- 3 viewing angles (+54˚, nadir, -54˚) instead of 7 to reduce computational load

Analysis – Simulation settings



Analysis – Variables

- Orbit altitude:
  - 450, 550, 650, 750, 850 km
- Attitude:
  - "Normal" (nadir pointing, x-axis aligned with satellite inertial velocity vector)[1]
  - "Yaw oscillation" (nadir pointing, yawing motion to compensate for Earth rotation)[2]
- Field of view (FOV) size (cross-track x along-track):
  - 5° x 1.7°
  - 6° x 1.7°
  - 7° x 1.7°
- Number of satellites:
  - 1 Satellite
  - 2 Satellites:
    - Leader-follower (Δv = 6.15°)
    - Stitching (Δv = 0.001°, one satellite rotated 7° off nadir in cross-track direction)
    - Pendulum ($\Delta\Omega$ = 0.5° – 0.95°)

[1] STK description: "nadir alignment with ECI velocity constraint"

[2] STK description: "nadir alignment with ECF velocity constraint"

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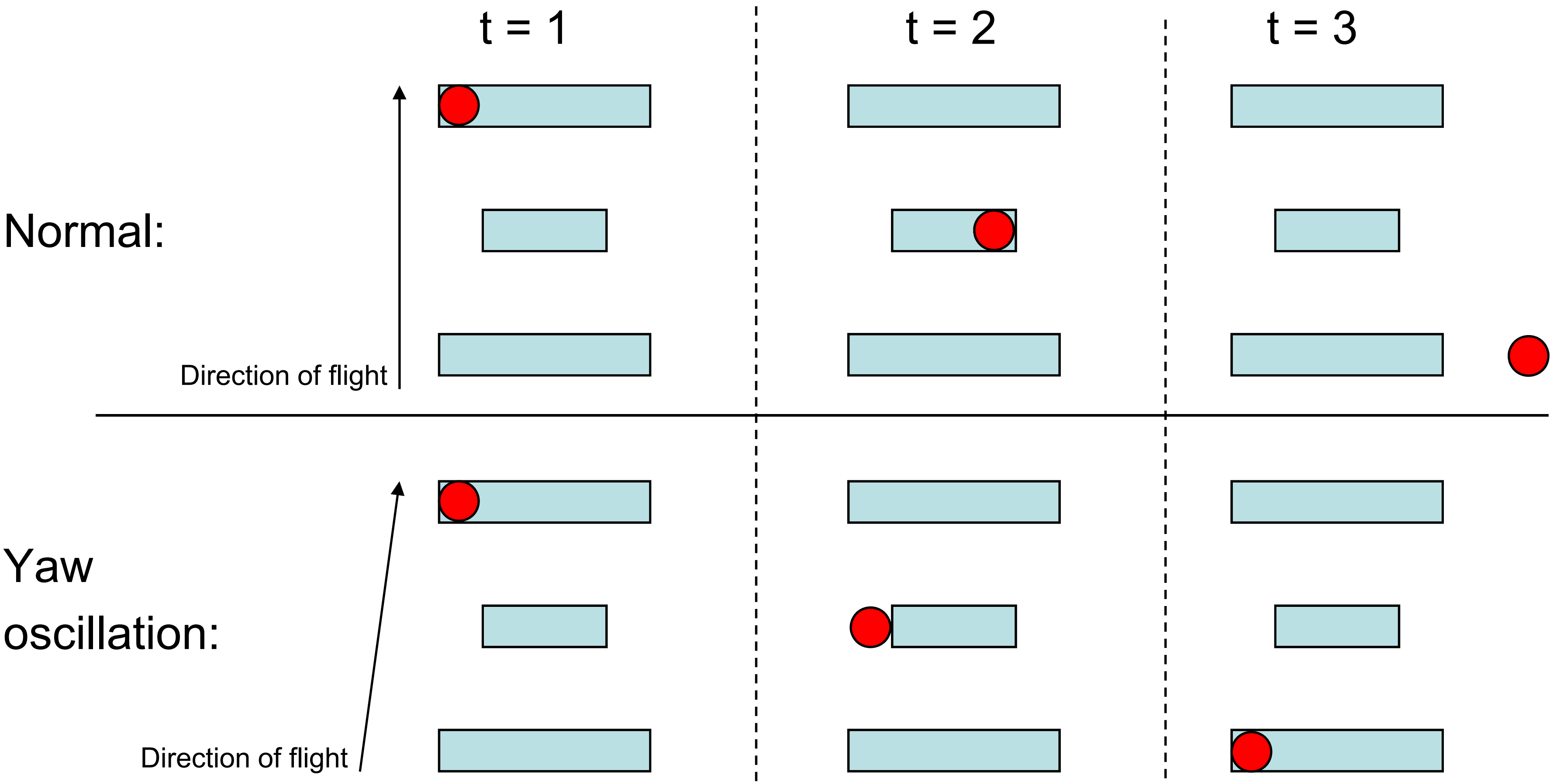
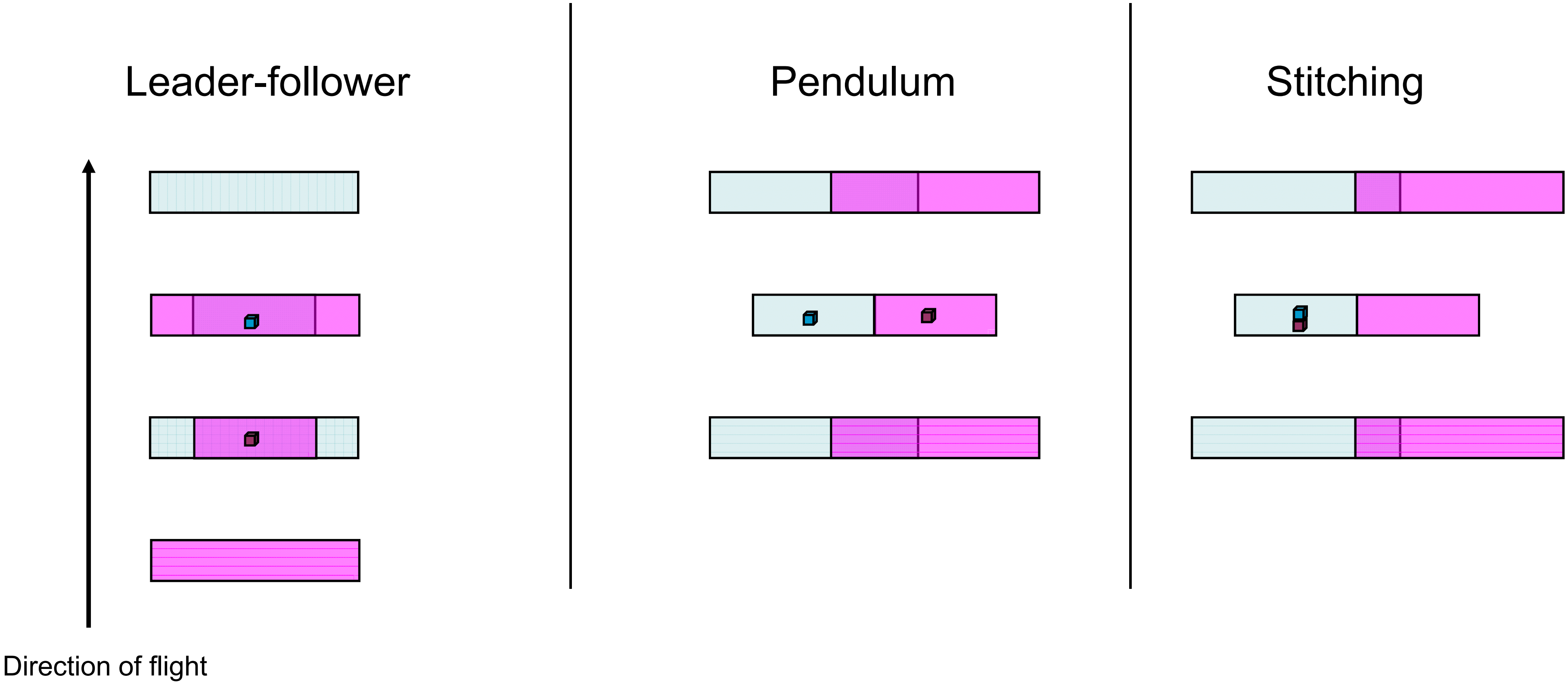
Analysis – Variables

- Attitude modes, difference near the equator:



Analysis – Variables

- Formation geometry options



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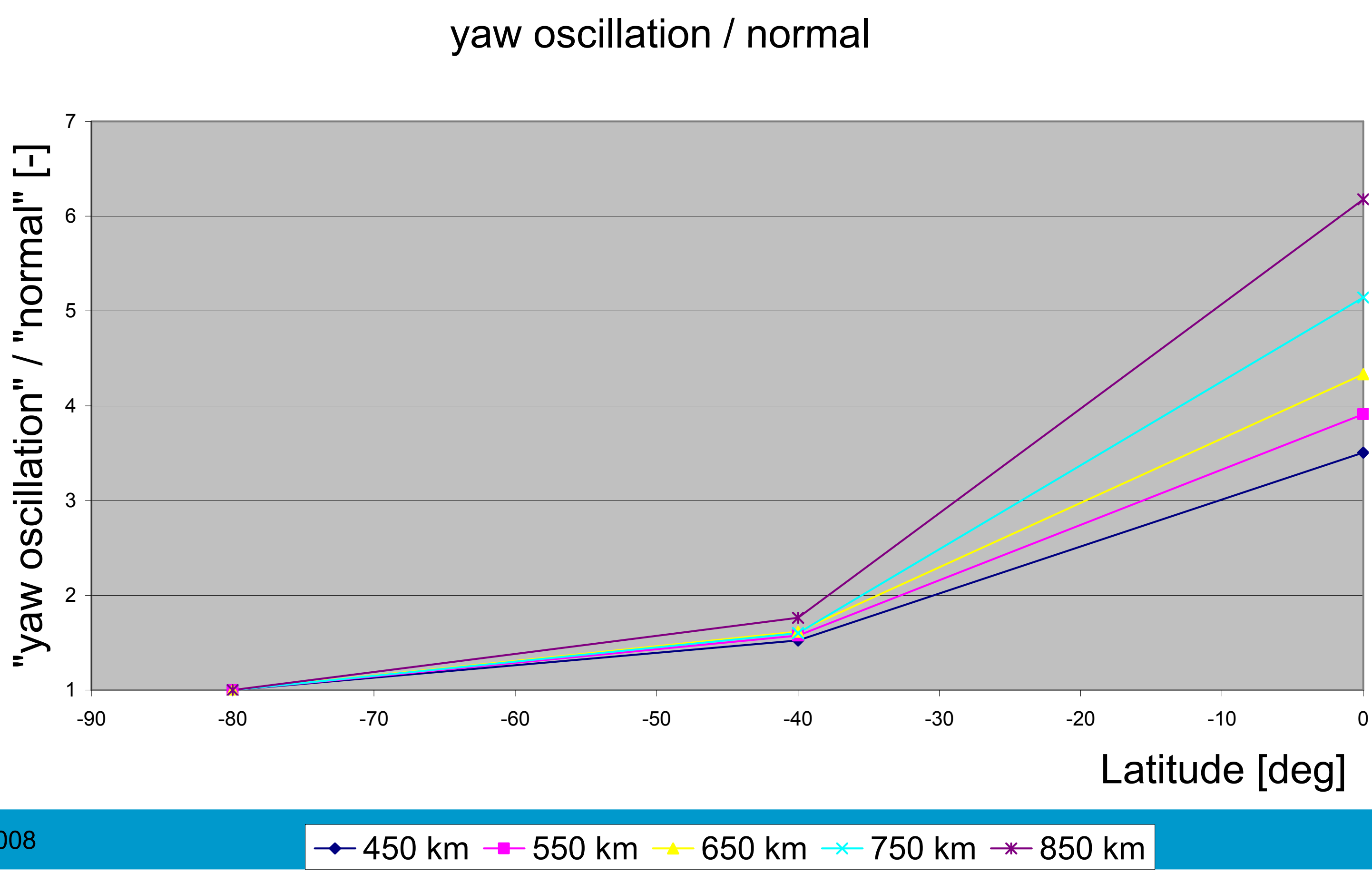
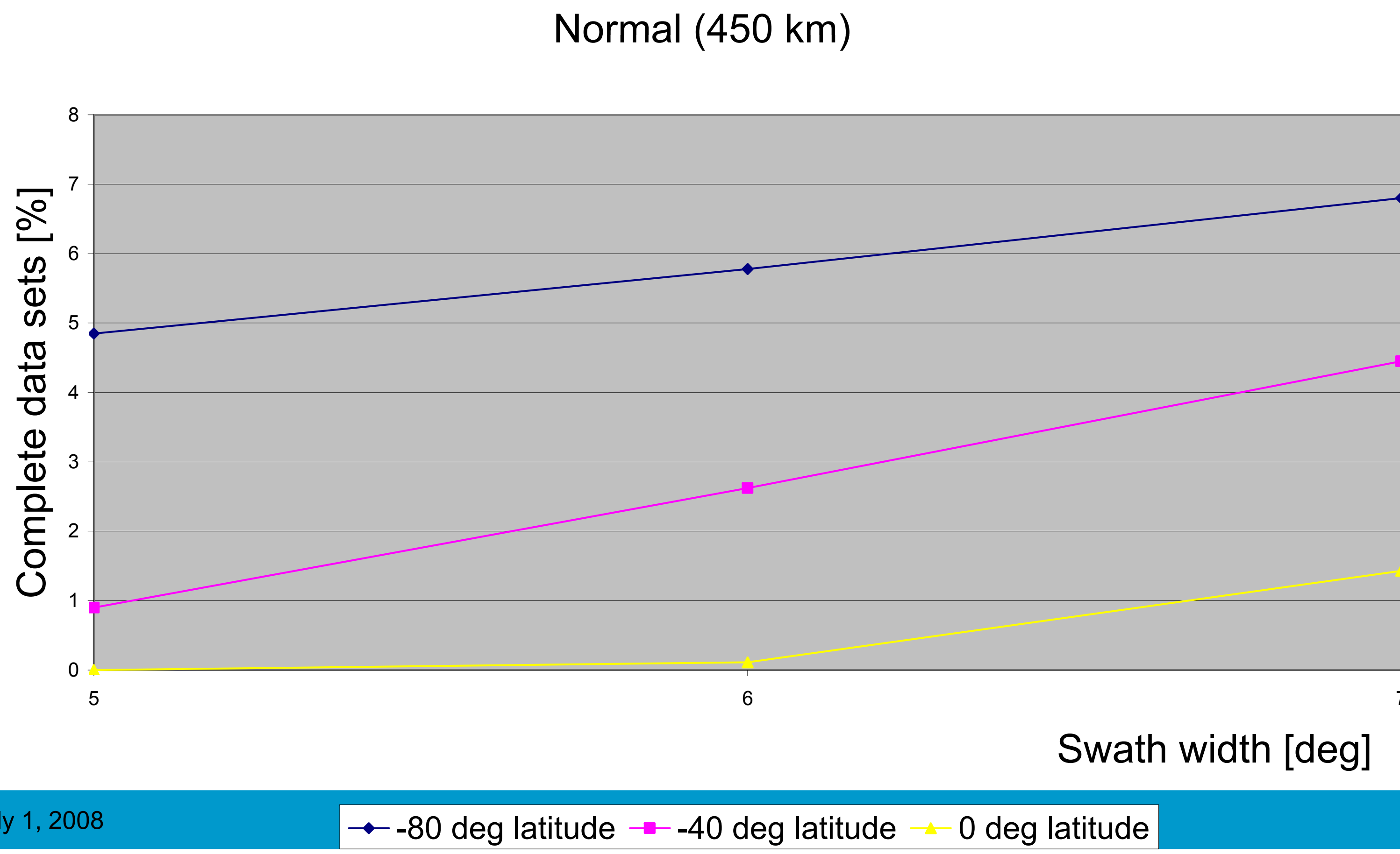
Results – Single satellite

- Attitude: “normal” vs “yaw oscillation”



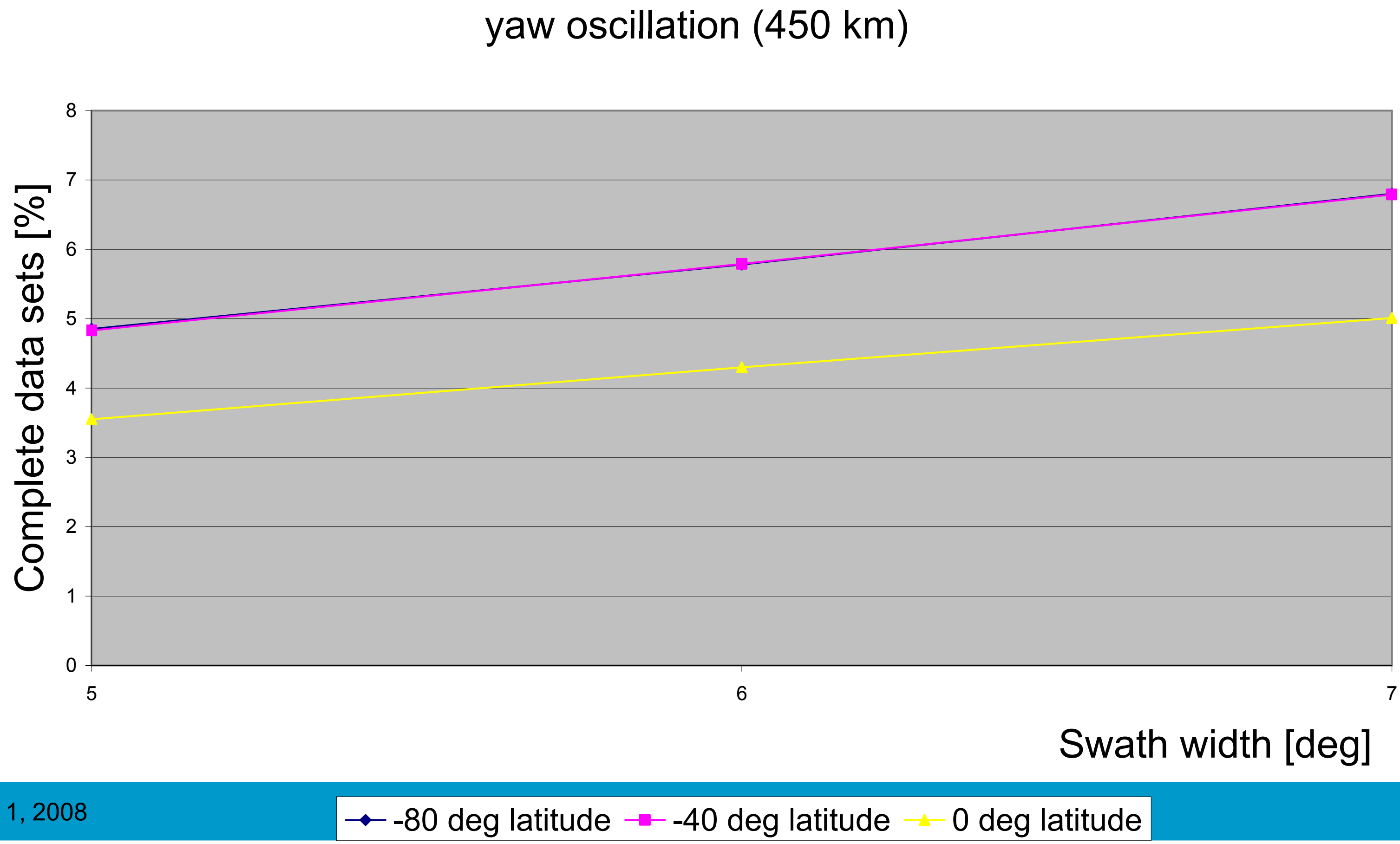
Results – Single satellite

- FOV size:



Results – Single satellite

- FOV size:



Results – Single satellite

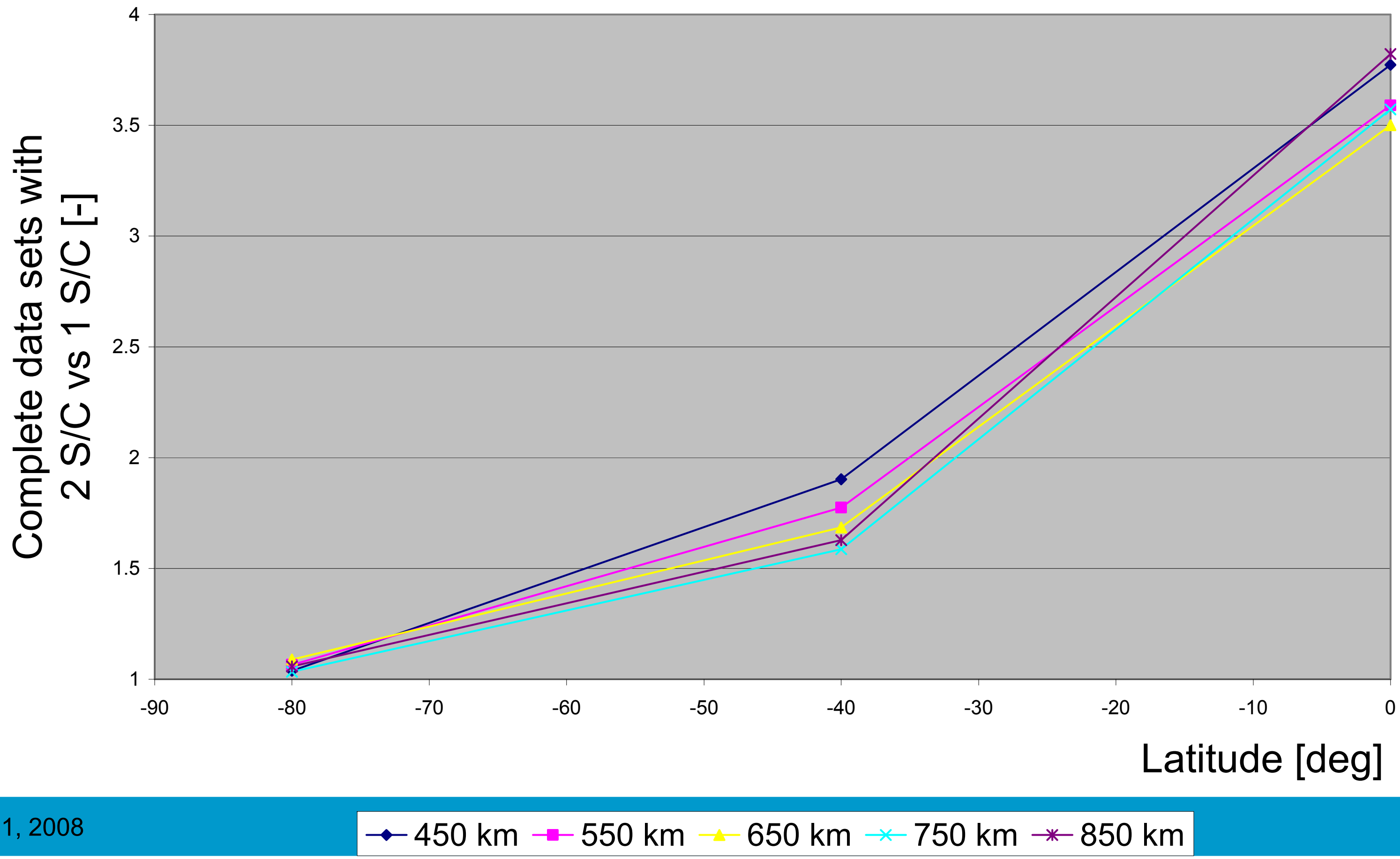
- “Yaw oscillation“ is superior to “normal” attitude mode, especially near the equator.
- In “normal” attitude mode, less than 7˚ swath width results in very little data obtained.
- In “yaw oscillation” mode, the difference in data obtained between 7˚ and 5˚ swath width is ~40%, as it should be (7/5-1=0.4)

Results – Two satellites

- Leader-follower vs. single satellite

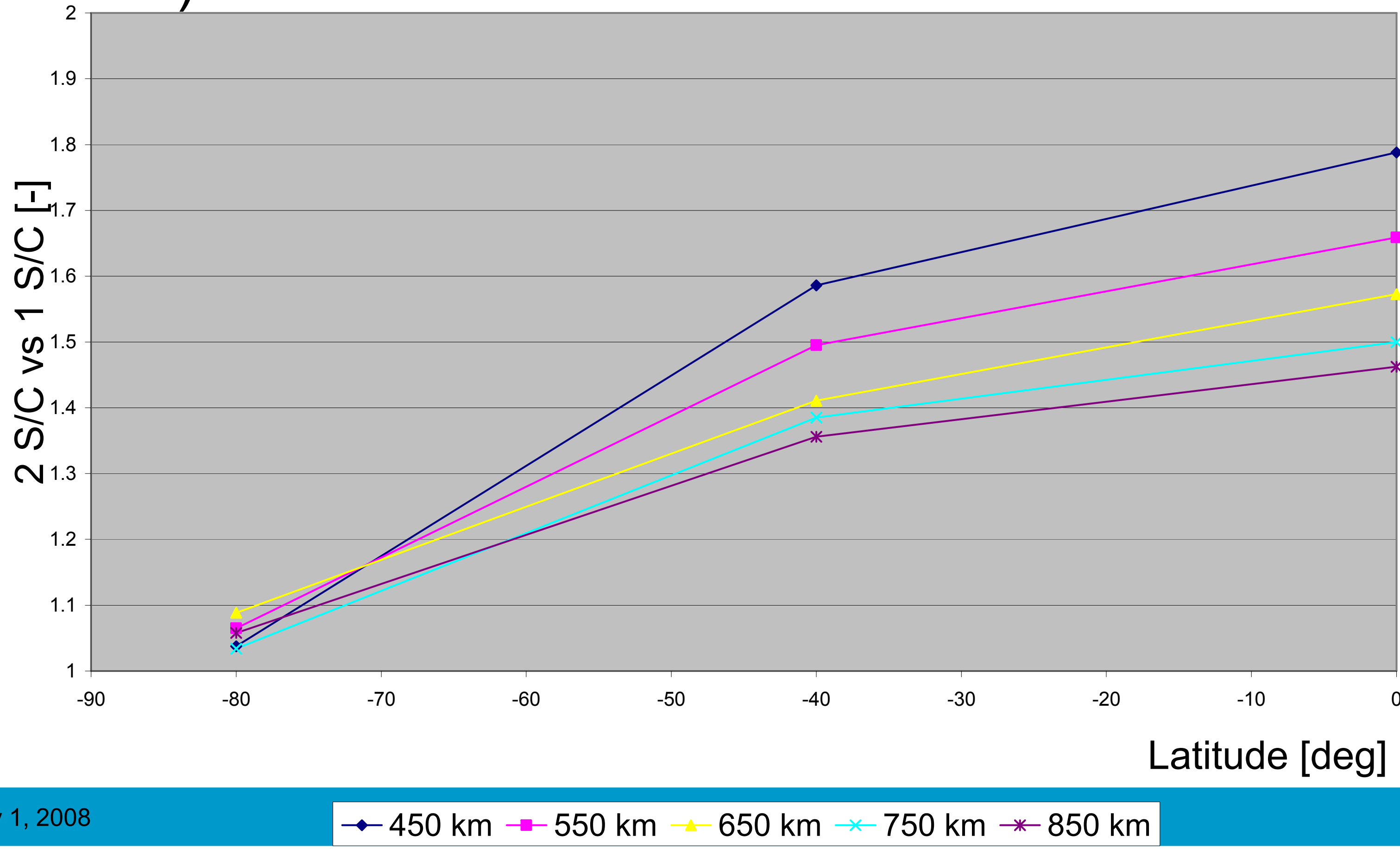
Results – Two satellites

- Leader-follower vs. single satellite ("normal" mode)



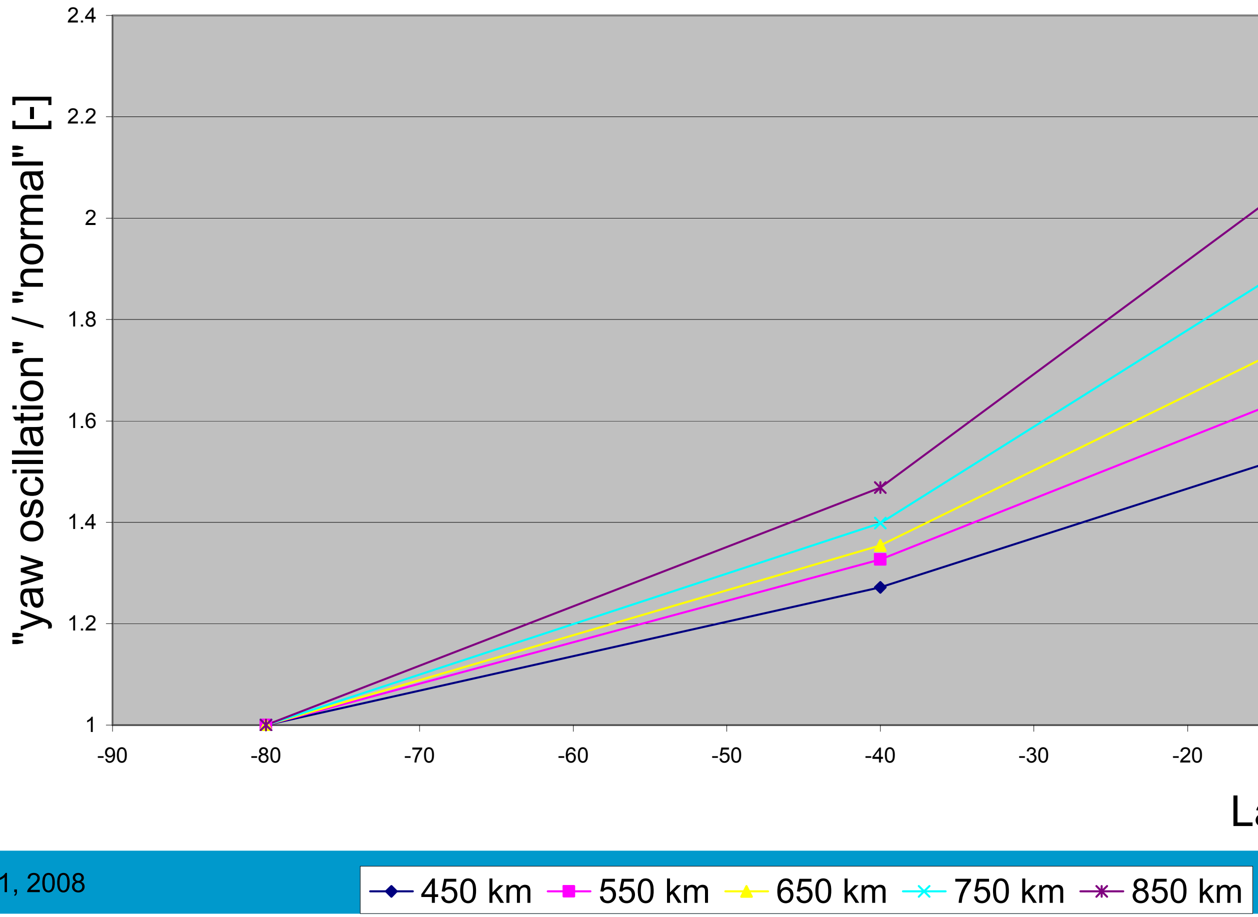
Results – Two satellites

- Leader-follower vs. single satellite (“yaw oscillation” mode)



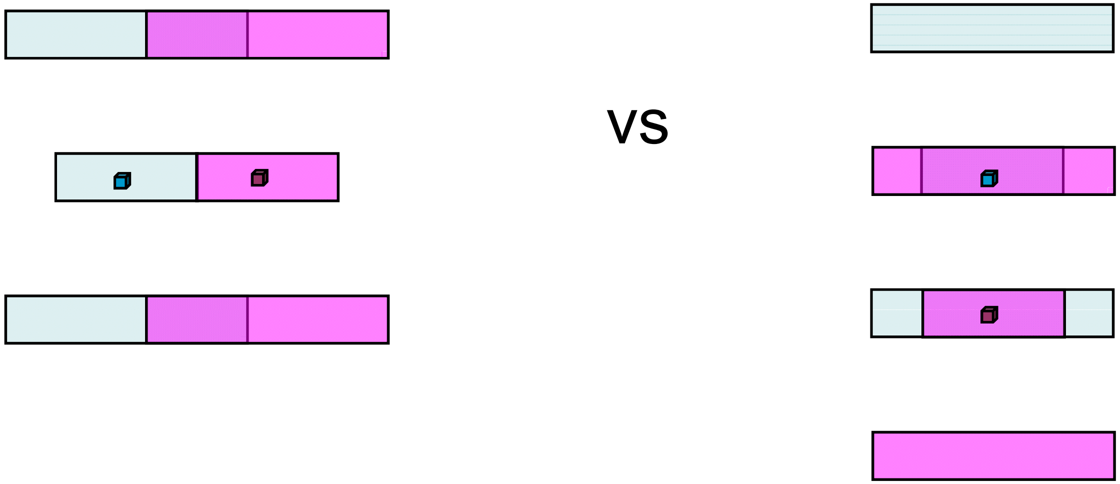
Results – Two satellites

- Leader-follower “yaw oscillation” vs. “normal”



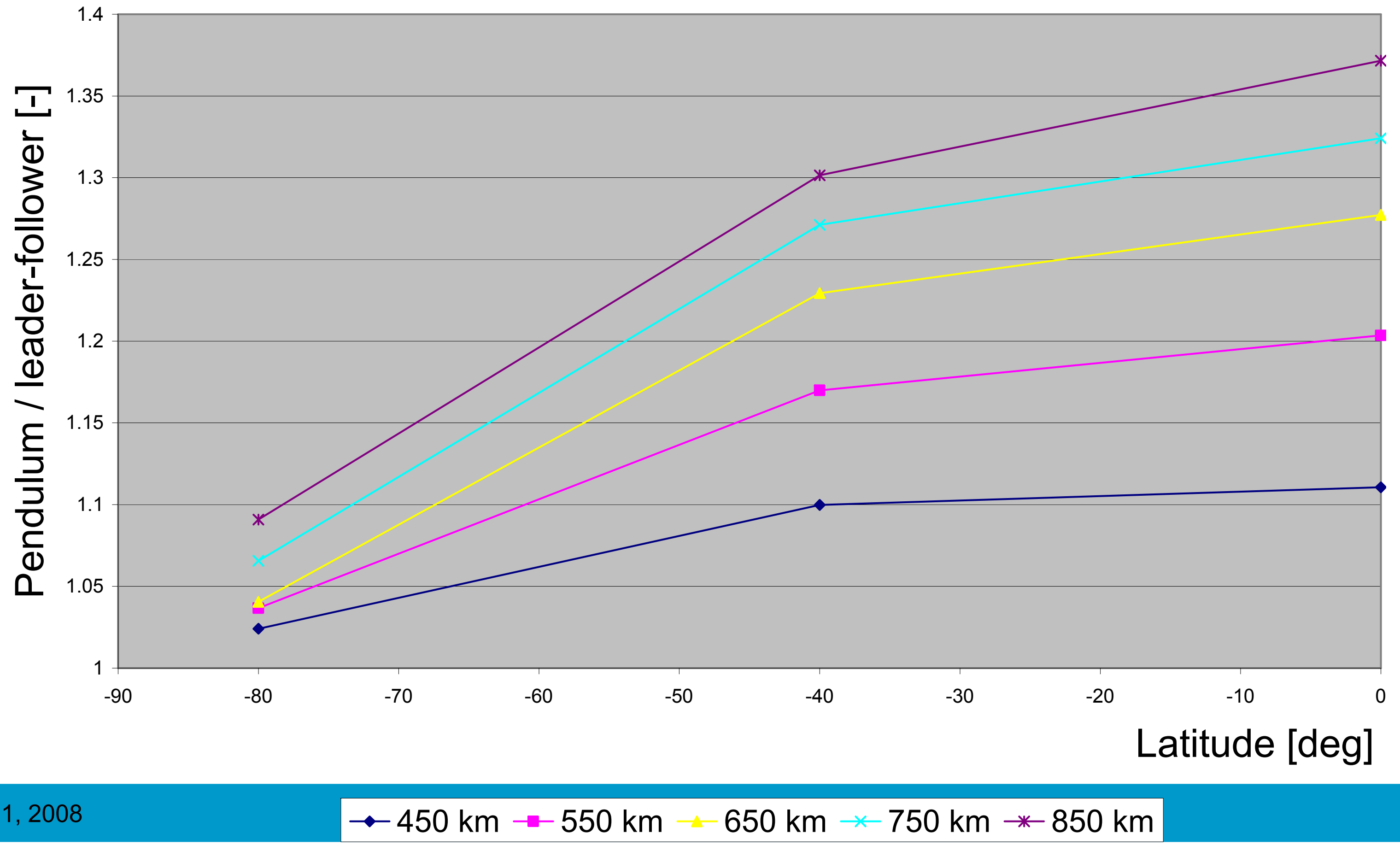
Results – Two satellites

- Pendulum vs. leader-follower



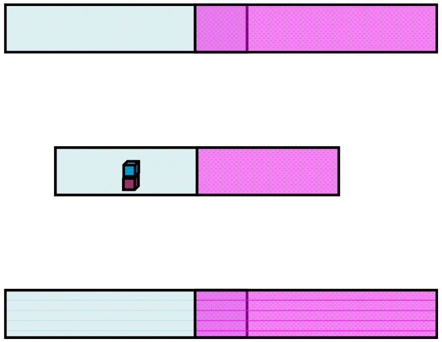
Results – Two satellites

- Pendulum vs. leader-follower (“yaw oscillation” mode)

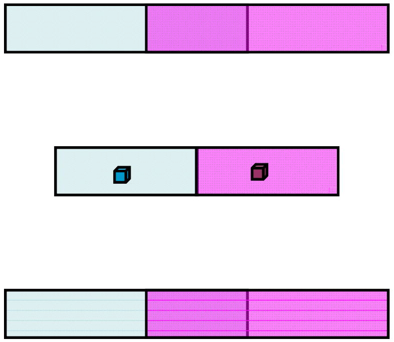


Results – Two satellites

- Stitching vs. pendulum

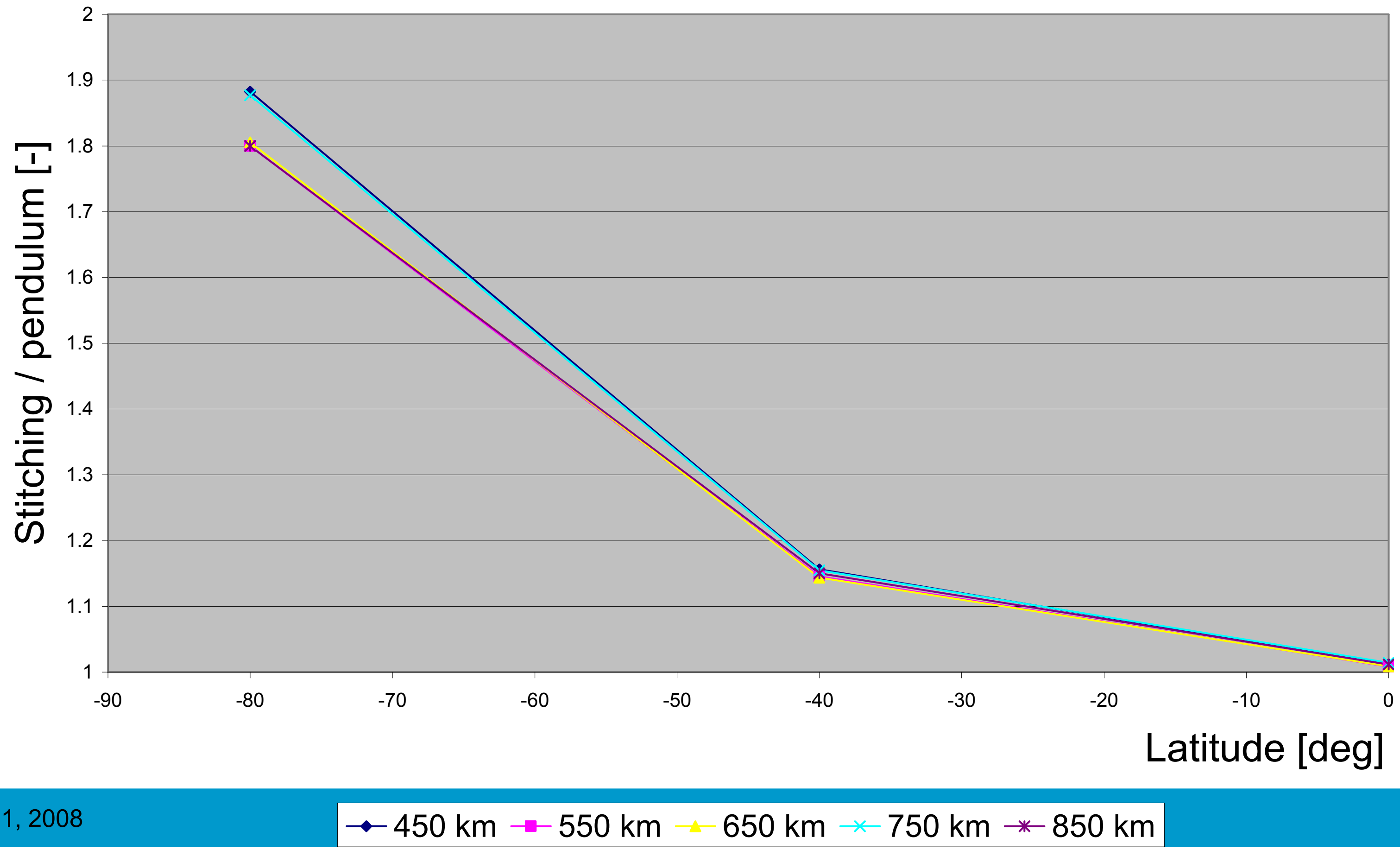


vs



Results – Two satellites

- Stitching vs. pendulum ("yaw oscillation" mode)



Results – Two satellites

•Increase in data return (850 km altitude, 7˚ swath width). Percentage of points for which a complete data set has been obtained in the region of interest:

	-80˚ latitude	-40˚ latitude	0˚ latitude
1 S/C “normal”	15.2	6.9	1.6
Leader-follower “normal”	16.1	11.3	5.9
1 S/C “yaw oscillation”	15.2	12.2	9.6
Leader-follower “yaw oscillation”	16.1	16.5	14.0
Pendulum “yaw oscillation”	17.5	21.5	19.2
Stitching “yaw oscillation”	31.6	24.8	19.5

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Conclusions

- Data return:
  - The SPEX swath width should be as large as possible (7°)
  - Yaw oscillation combined with stitching mode results in the highest number of complete data sets obtained
  - A higher altitude always results in more complete data sets obtained (at the cost of spatial resolution)
- Discussion points:
  - Initial analysis indicates that the laser altimeter can cope with a small roll angle and a small yaw oscillation. For the radar altimeter, this still needs to be assessed
  - Yaw oscillation will have a negative effect on power generation
  - Trade-off between spatial resolution and global coverage

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