Using Jason-CS or Sentinel-3 to validate KaRIN scales from 50 to 150 km

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Executive summary

- Baseline Cal/Val strategy : use SWOT nadir altimeter for λ ~ 150-1000 km
- Nadir altimeters should be flying concurrently with SWOT: Jason-CS, S3A, S3B…
- Altimeter tracks often in the KaRIN swath ⇨ independent SSH for CalVal
  - Advantage: no interpolation, no smoothing
  - Limit: altimeter noise, difference in measurement time

Objectives of this talk

- **Reminders : altimeter noise & natural variability ⇨ Spec for CalVal XOVERs**
- **Give an overview of cross-overs of interest for CalVal: where? when? length?**

Main conclusions

- Nadir altimeters can be used to validate KaRIN scales from 50 to 150 km
- Plenty of usable XOVER segments with time difference < 1h
- But only during specific periods (guaranteed for Sentinel-3, not with Jason-CS)
- CalVal capability can be extended to 1000 km (solar time of SWOT at launch)

REMINDER #1: ALTIMETER NOISE

Average limit of along-track altimetry

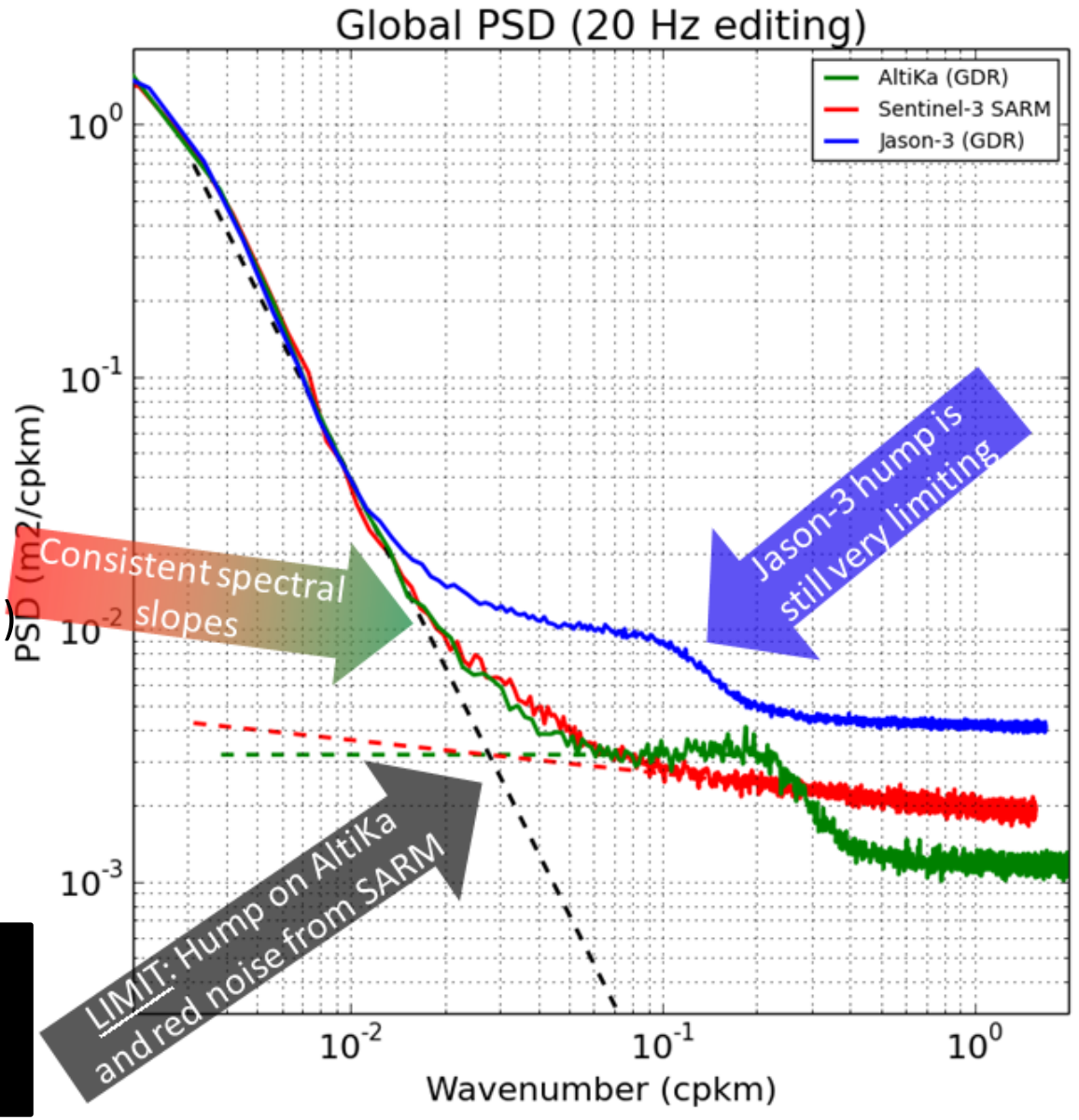
Current observability

- λ ~ 80 km with Jason-3
- λ ~ 30-50 km with Sentinel-3 & AltiKa
- Global average (all SWH dynamics)

In the future

- New SARM algorithms (e.g. LRRMC) might be able to lower the nadir noise
- Jason-CS is next-gen SARM (less noise)
- Sentinel-3C for continuity in 2024+
- Outlook for SWOT

In 2021, noise of altimeters is low enough to validate λ > 50 km



REMINDER #2: NATURAL VARIABILITY

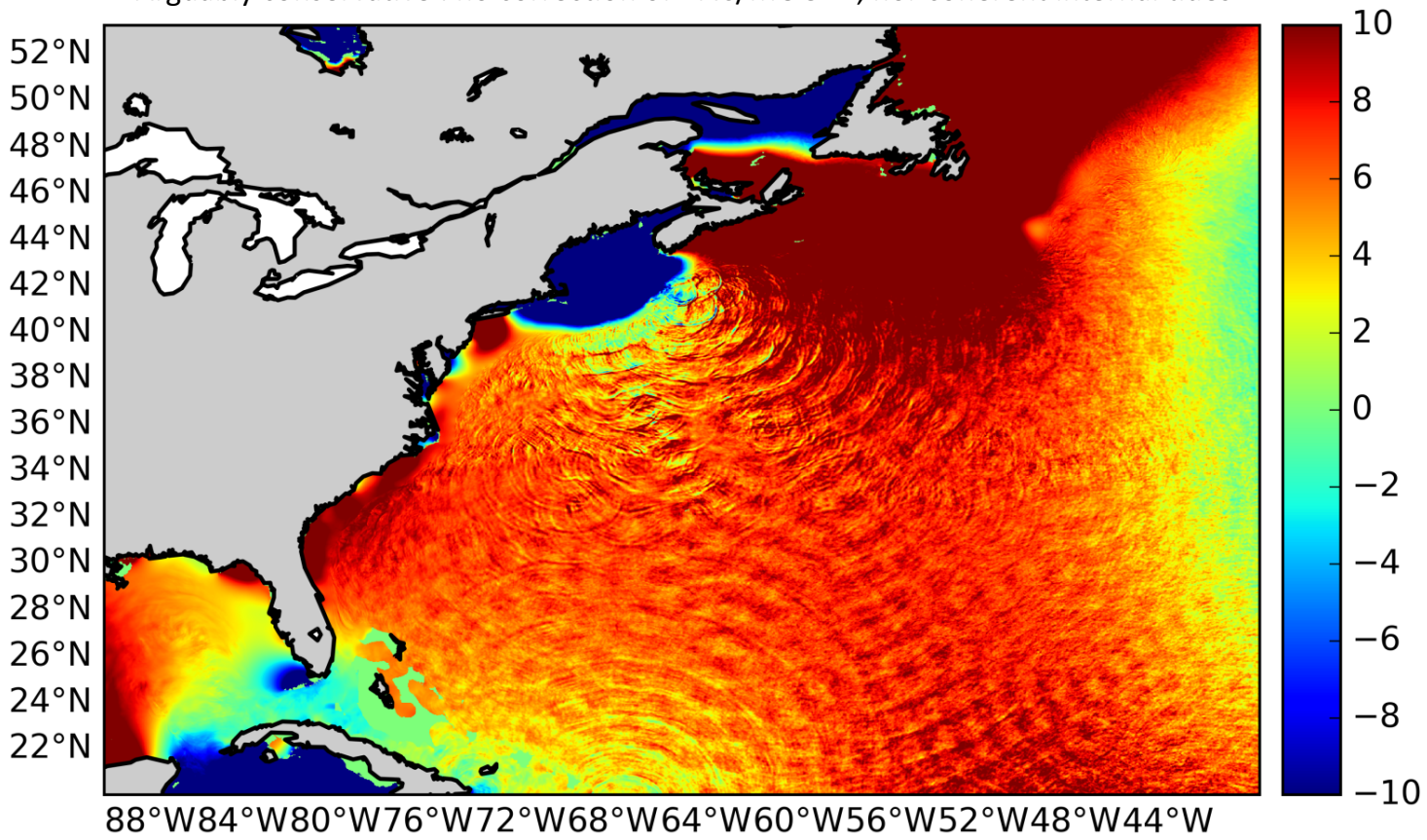
SSH variability in a few hours

- There is a lag δt between the measurement time of KaRIN and external altimeters
- But the SSH changes in a few hours (e.g. δSSH from internal tides/waves)
- At what point does δSSH from δt get close to the KaRIN requirement ?

Example : MITgcm in Gulf Stream region

1-hour SSH difference (cm)

Arguably conservative : no correction of DAC/MOG2D, nor coherent internal tides



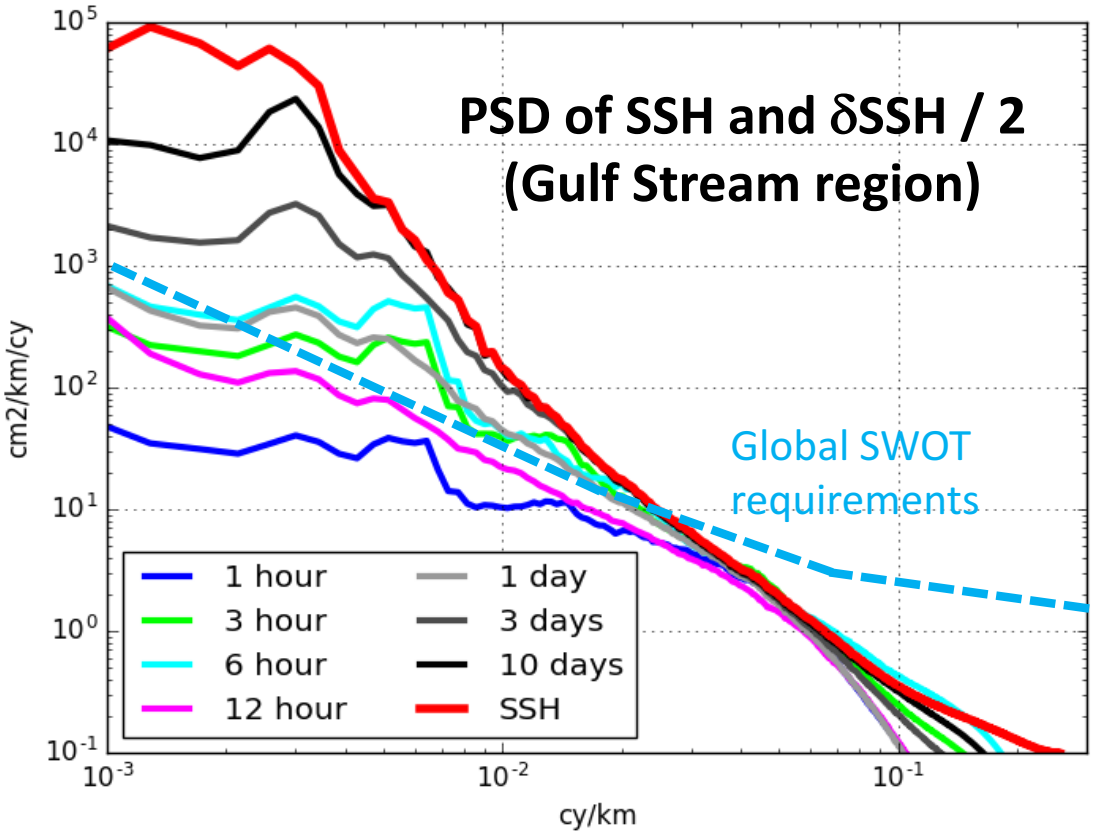
SSH variability (Gulf Stream region)

- Natural variability of δSSH versus KaRIN requirements
  - 1h δSSH is ok : below requirements for λ ~ 50 to 1000 km
  - 3h δSSH is the limit (natural variability ~ error budget)
  - 12h δSSH could also be tested (re-synch of tides, but not internal waves)

- Conclusion for SWOT Cal/Val

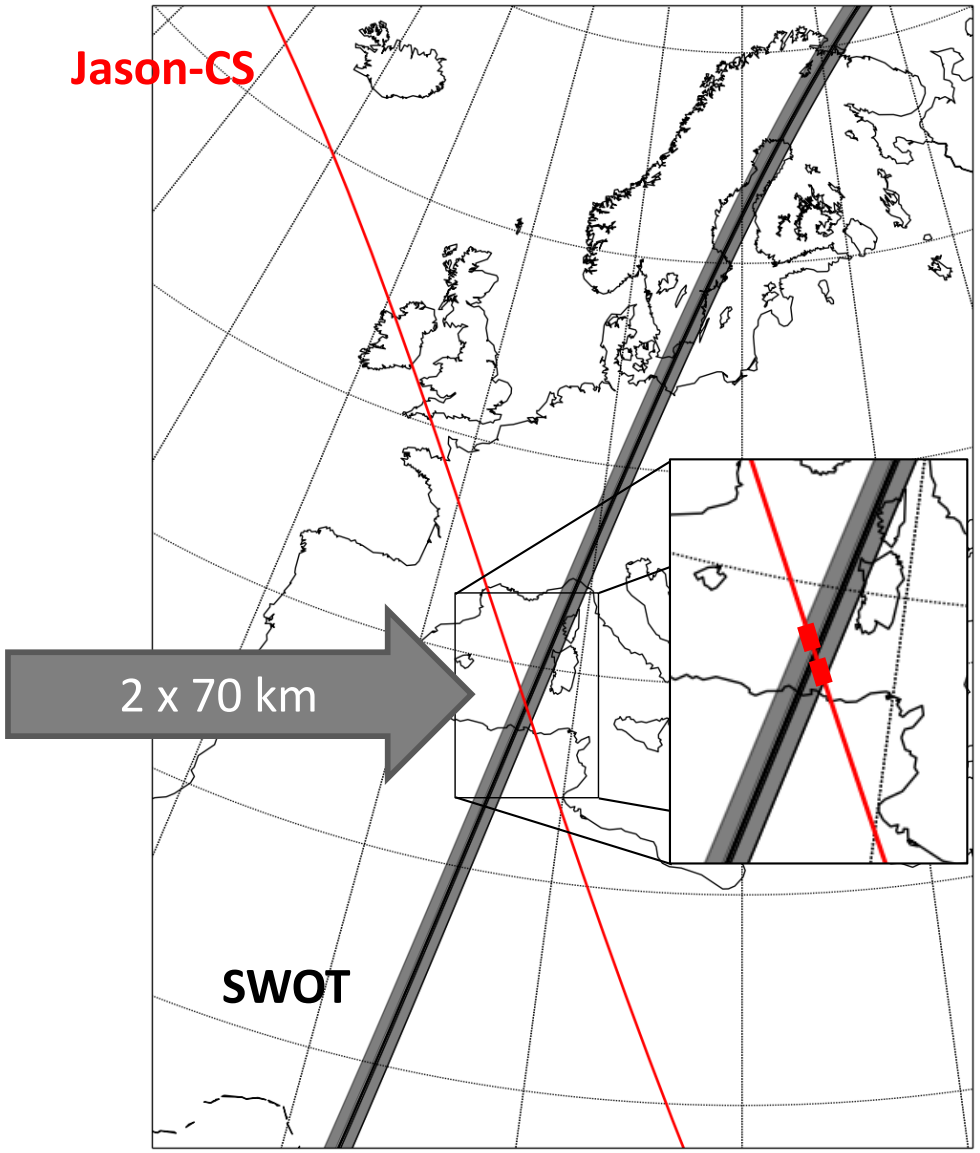
XOVER time difference must be 1h or less (probably conservative)

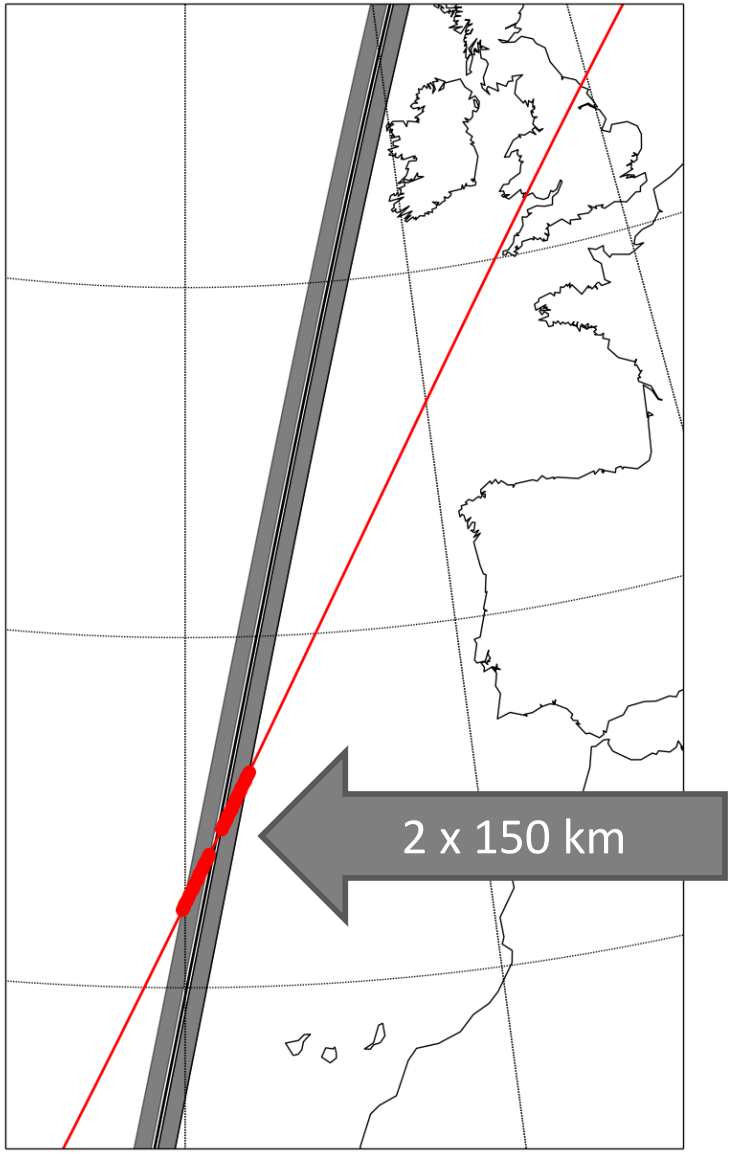
- Outlook: consolidate 1h threshold in other regions with different energy levels from mesoscale & internal waves/tides (e.g. what about 2h or 12h?)



GEOMETRY OF CROSS-OVER SEGMENTS

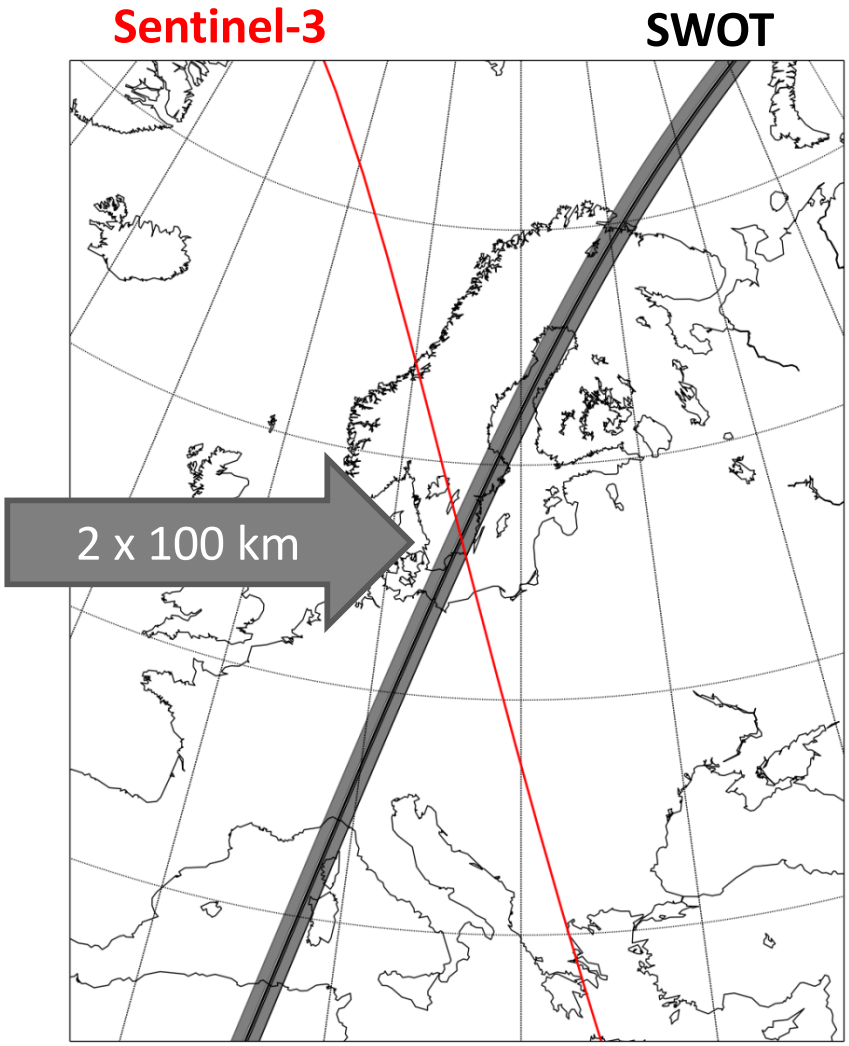
Geometry of Jason-CS overlap segments

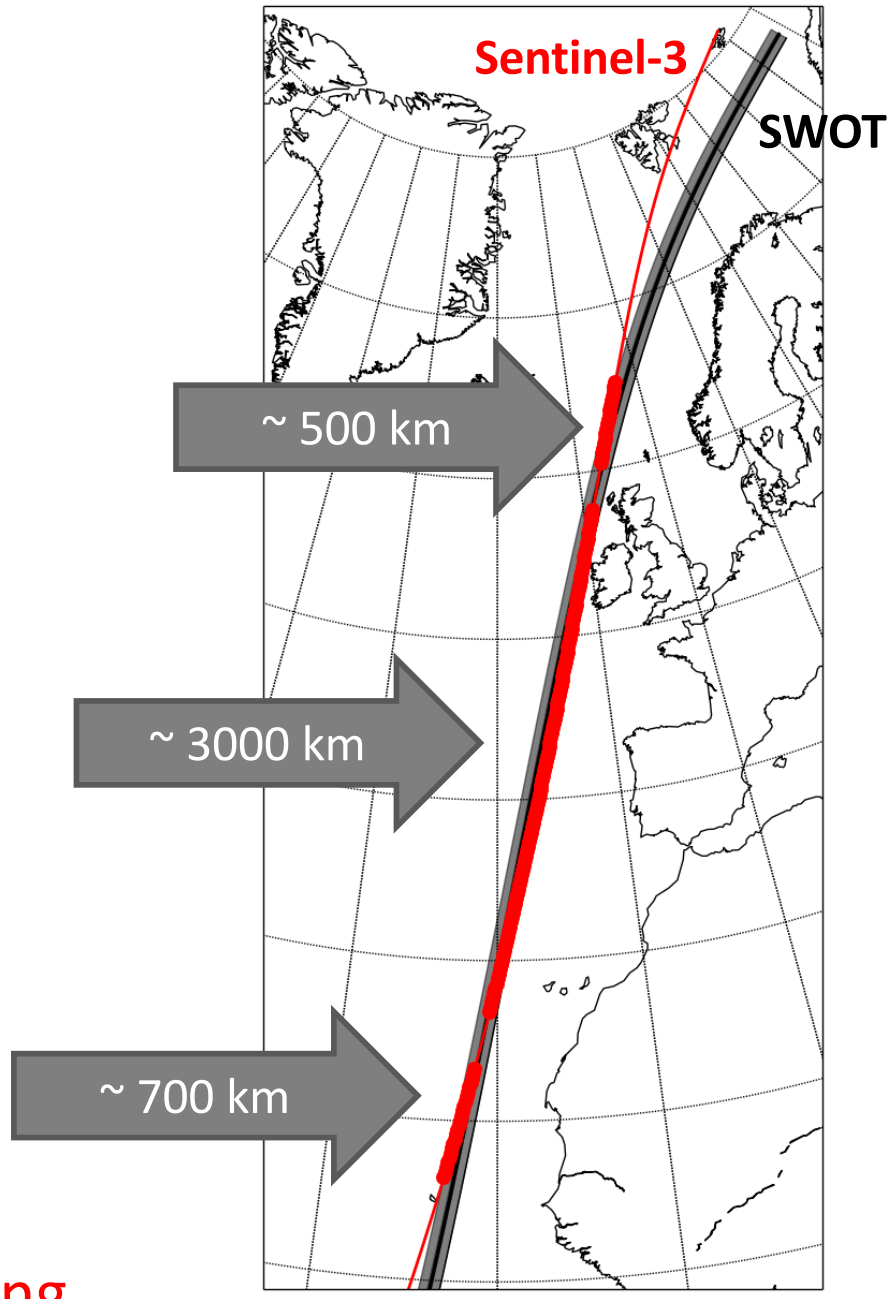




Ascending $_{SWOT}$ and Descending $_{JasonCS}$ or Ascending $_{JasonCS}$

Geometry of Sentinel-3 overlap segments



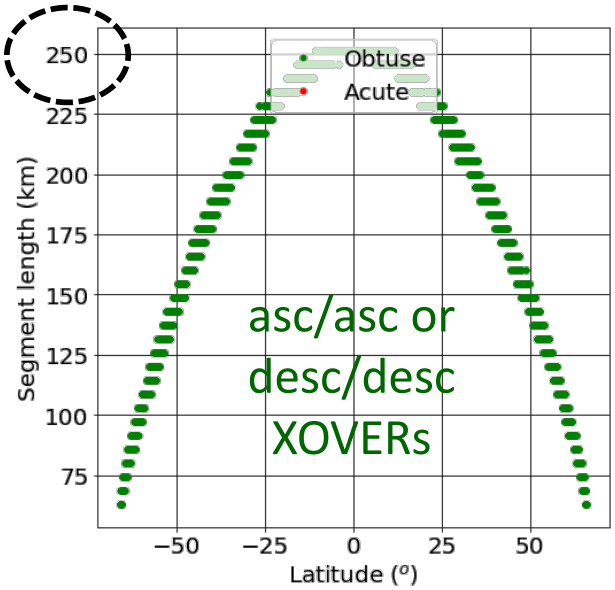


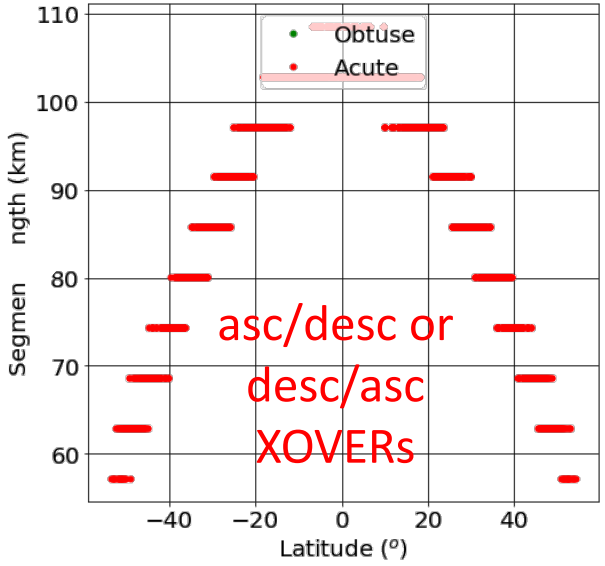
Ascending $_{SWOT}$ and Ascending $_{Sentinel-3}$

or Descending $_{Sentinel-3}$

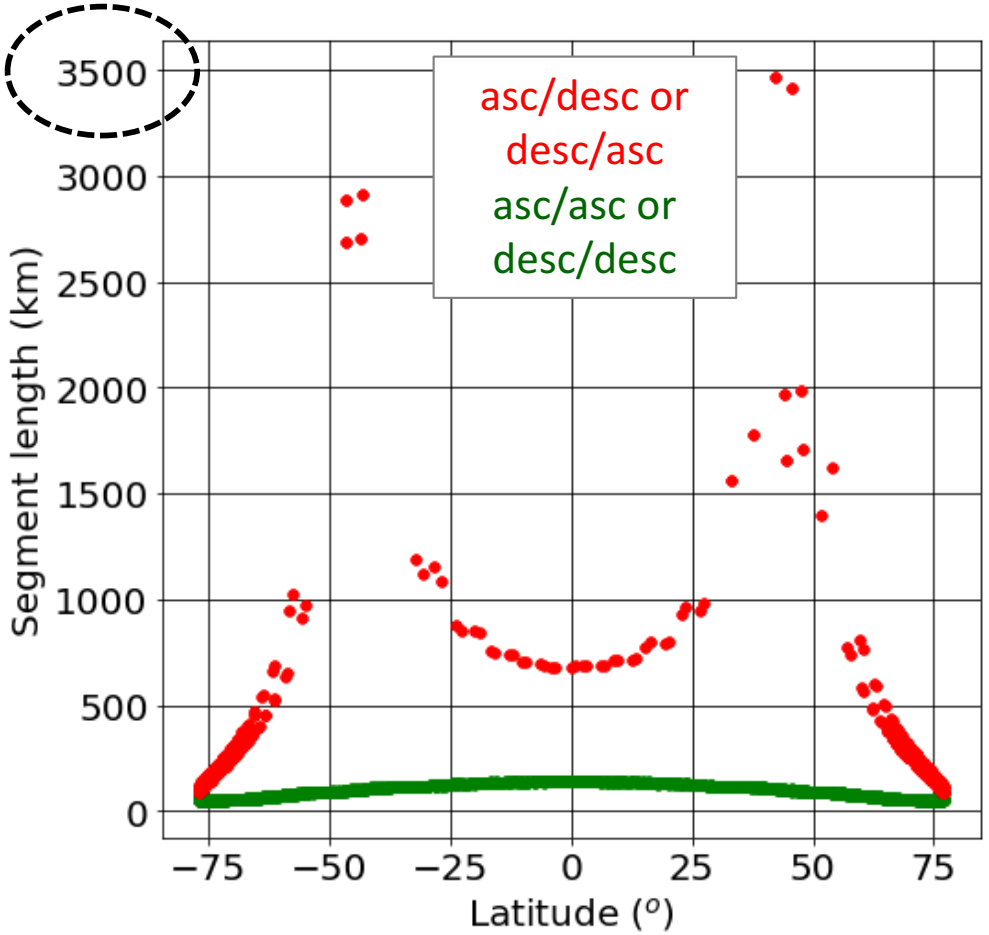
Length of XOVER in each KaRIN swath

Jason-CS





Sentinel-3A and 3B



Length x 2 if the 10km near-nadir gap of KaRIN is ignored

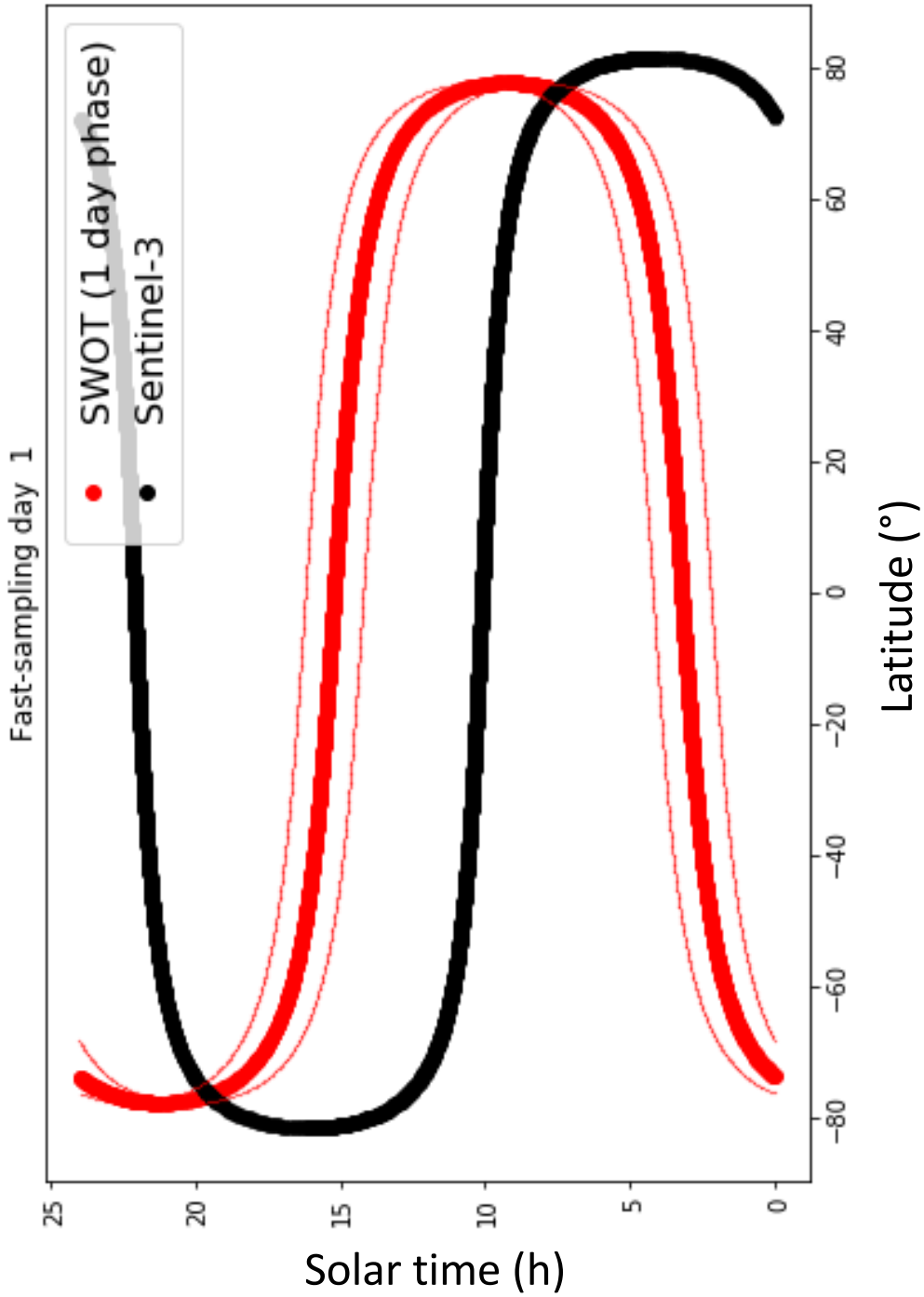
XOVERs can be long enough for λ up to 1000 km

CAN WE FIND 1-HOUR XOVERS?

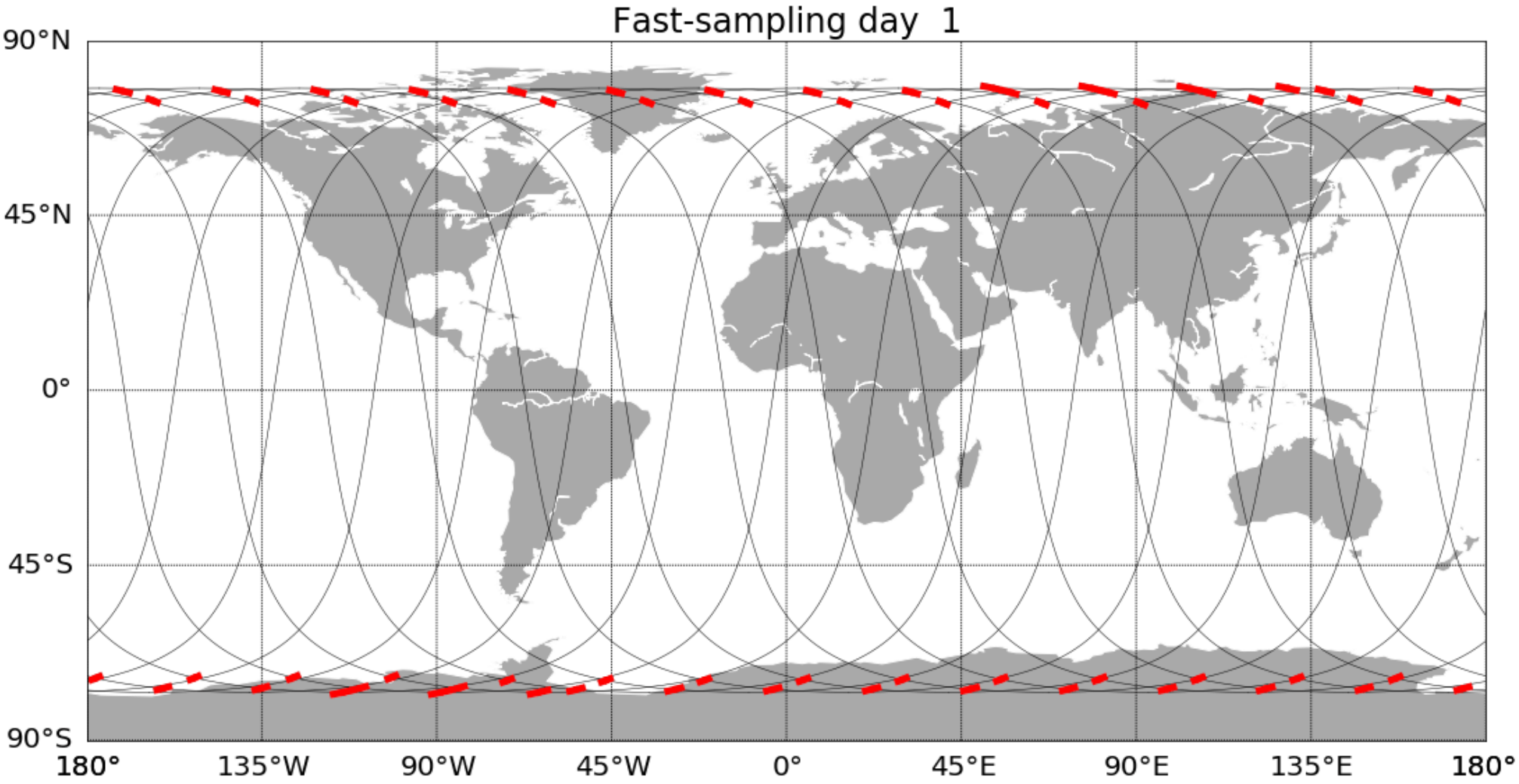
SENTINEL-3

The importance of solar time

- Sentinel-3A and 3B are sun-synchronous at 10h (black line)
- The solar time of SWOT cycles through 24h in approx. 150 days (thick red line)
- This effect controls when and where crossovers with $\delta t<1h$ can be found
- Animation below: 1h XOVERs can exist where black line is between thin red lines

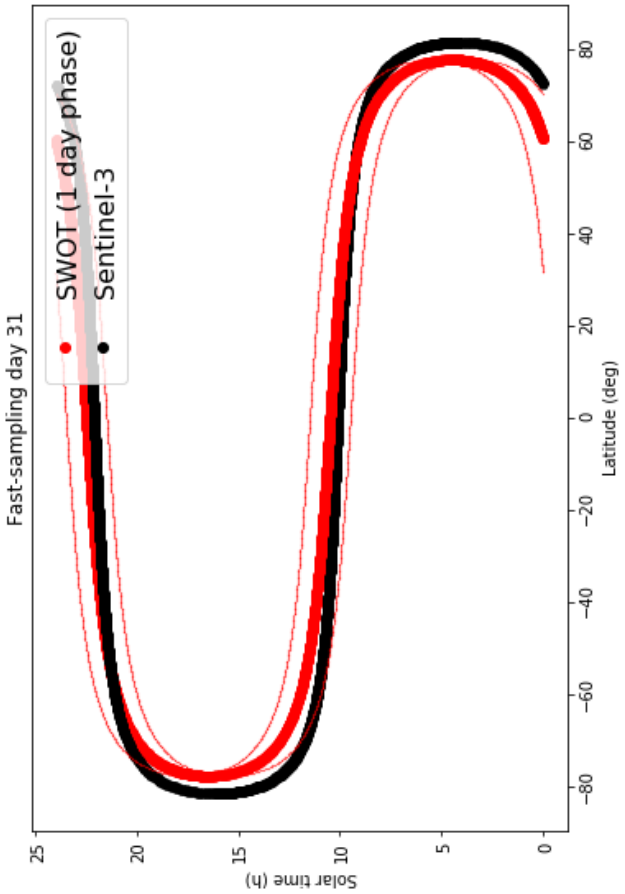


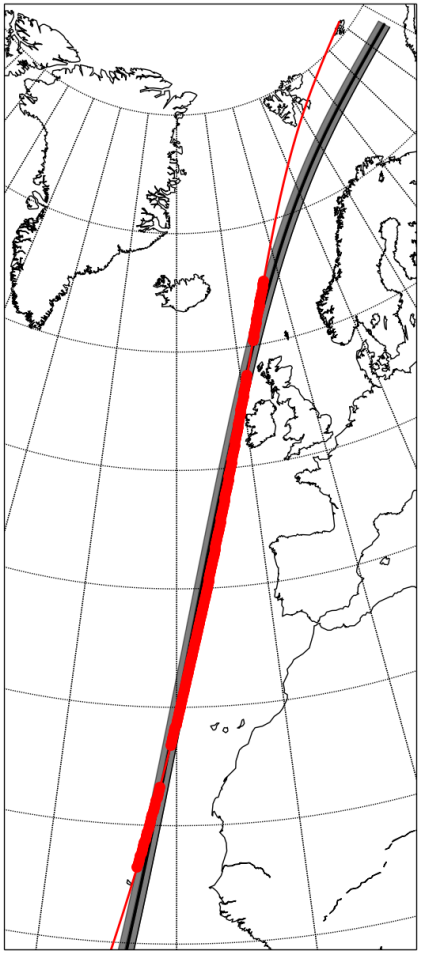
Animation: 150 days to cycle through all cases



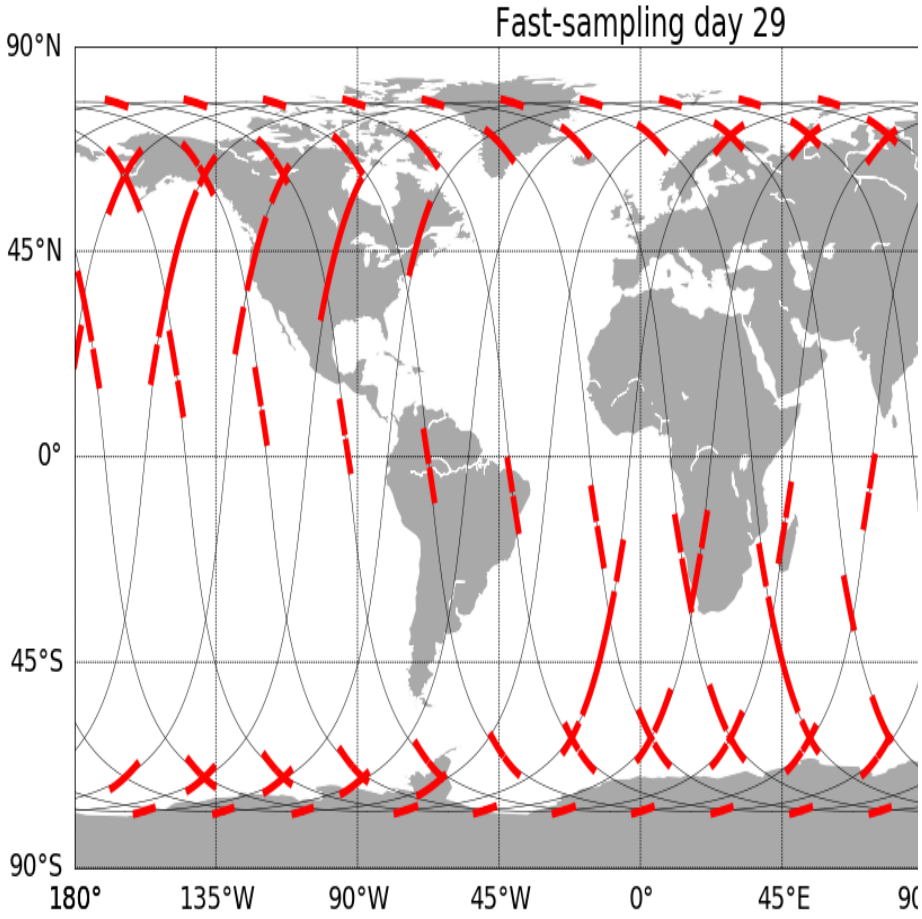
Case 1: good alignment of solar times

- Where a XOVER can exist, the time difference is always less than 1h
- Valid segments at all latitudes + some extremely long segments





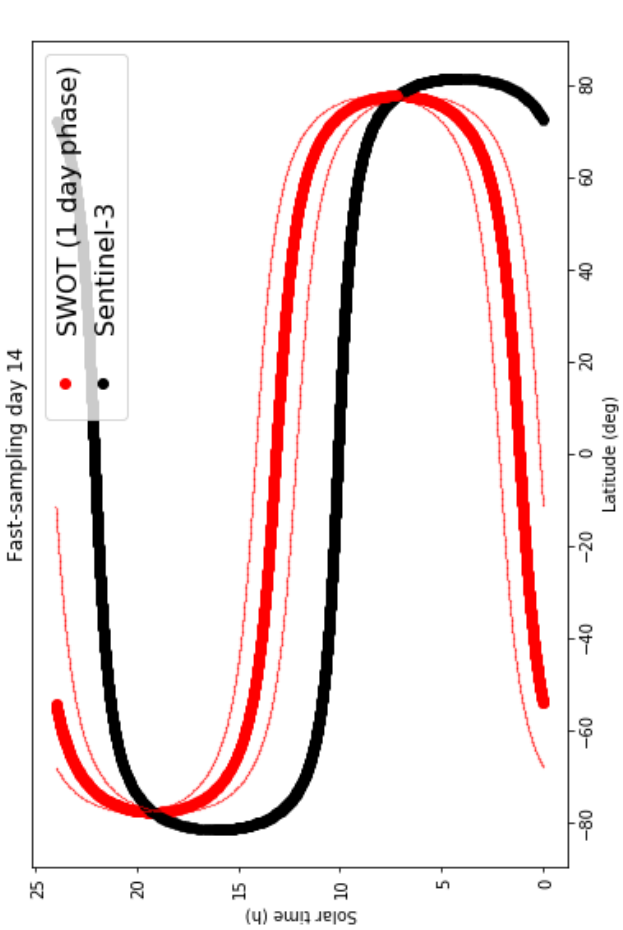
Longest XOVER found

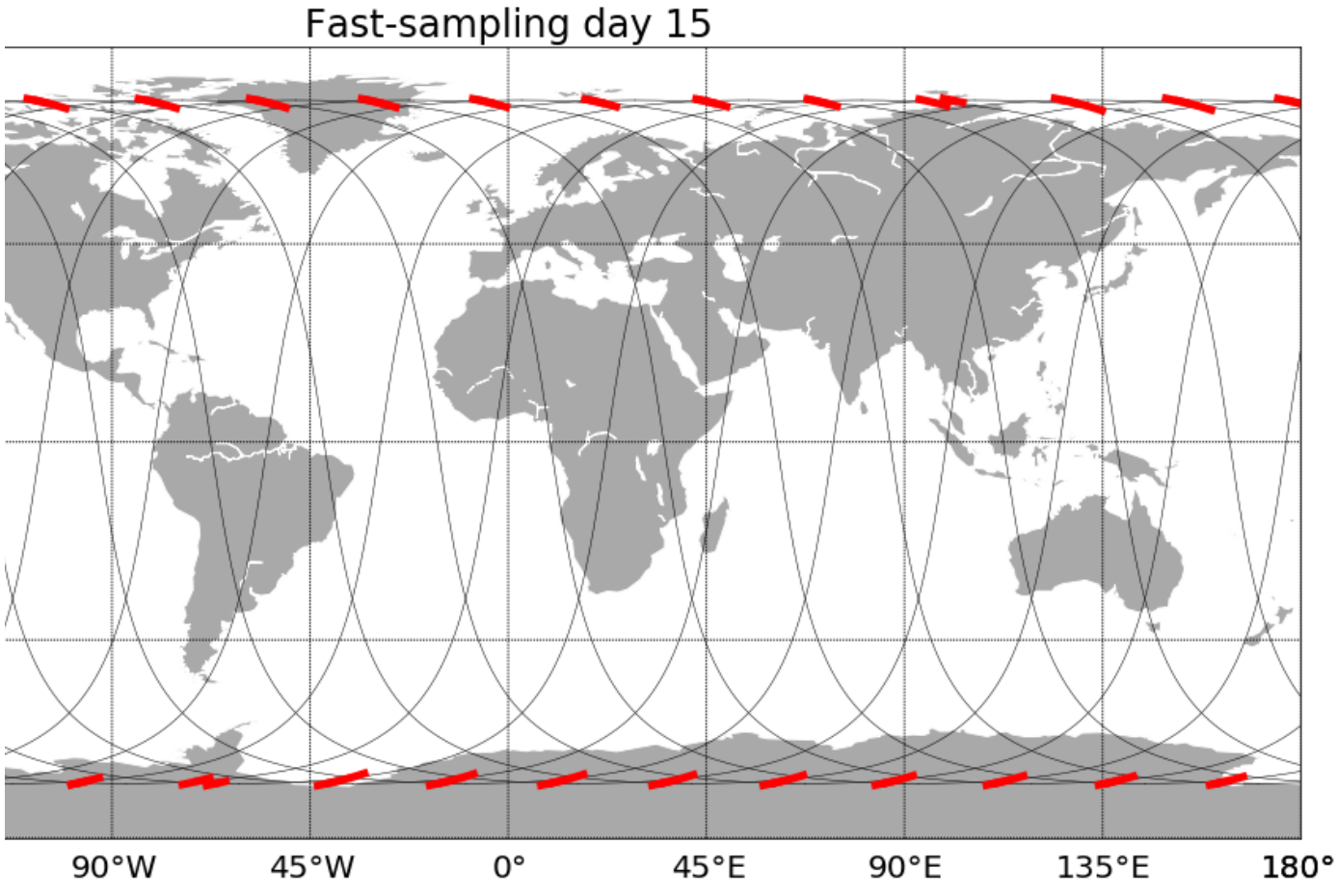


One random day's worth of S3A XOVERs when solar times are aligned
(S3B: same quantity, different regions)

Case 2: no alignment of solar times

- If S3 is in the KaRIN swath, the time difference is more than 1h ➔ useless for CalVal
- Except above 75° (black line is between the red lines) ➔ on ice / land (still useless)

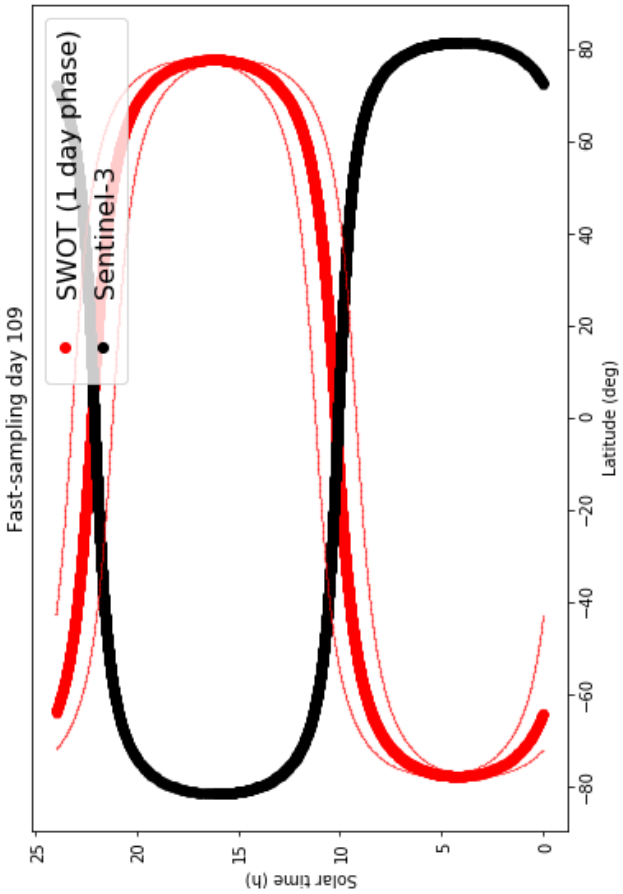




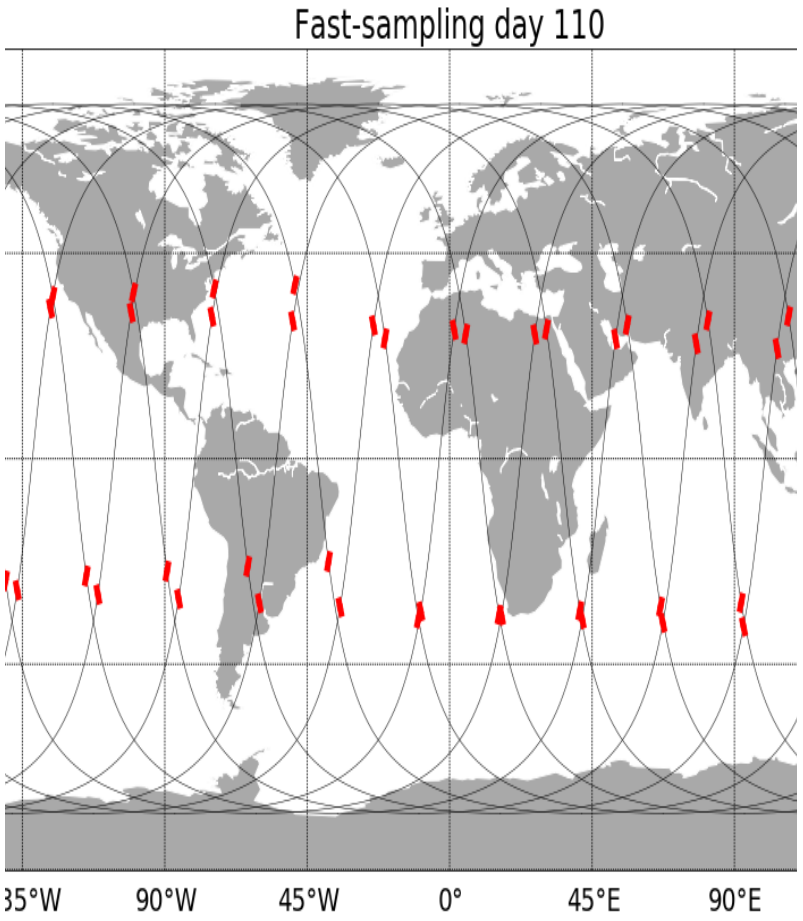
One day's worth of S3A XOVER when solar times are not aligned

Case 3: cross-alignment of solar times

- Solar times are aligned, but only for opposite directions ➔ short segments only
- Large scatter at low to mid-latitudes : changes rapidly every 4 days (S3 sub-cyle)

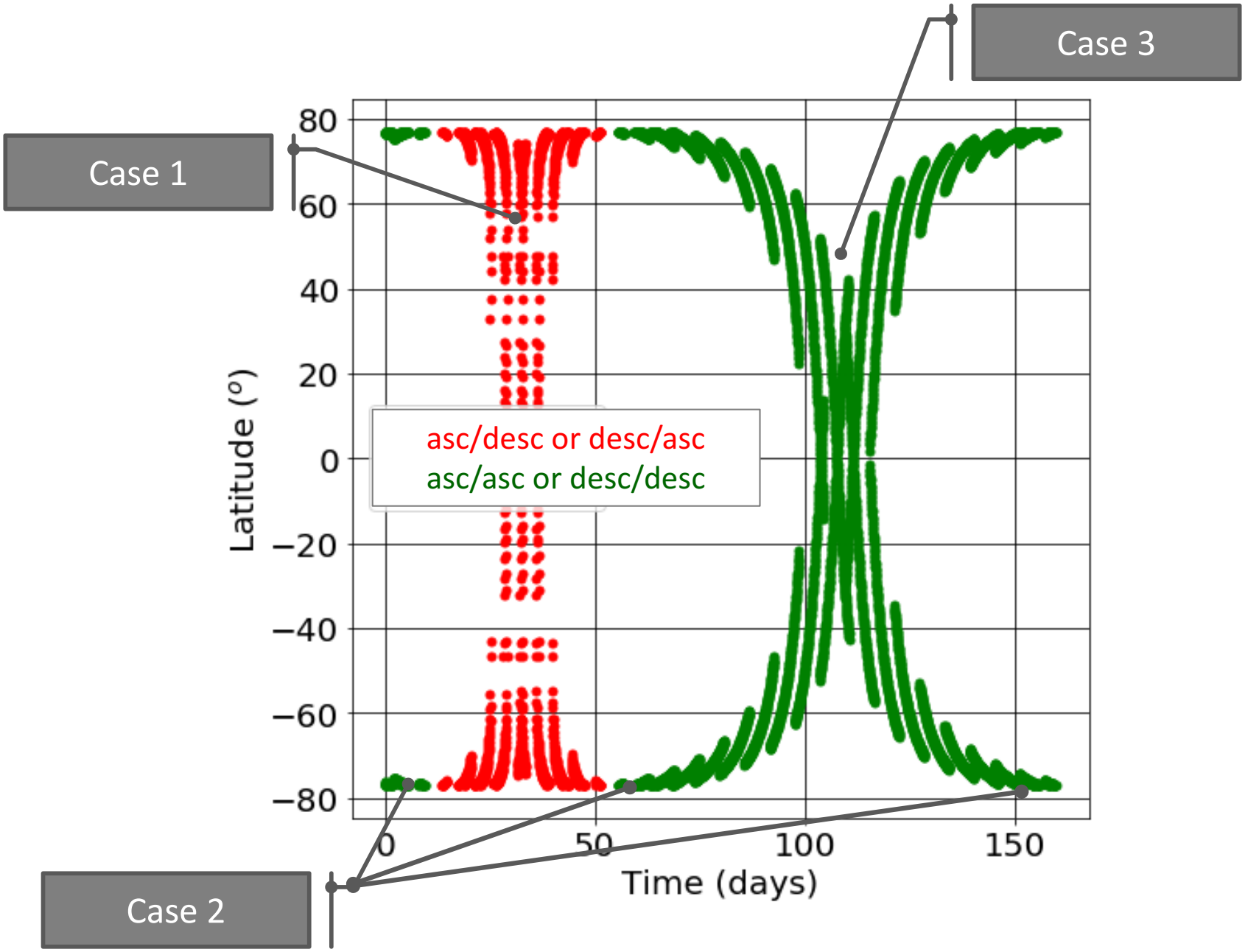


Typical XOVER of case 3

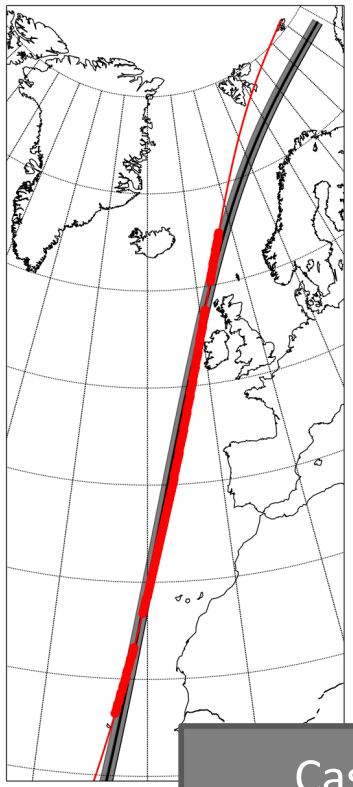


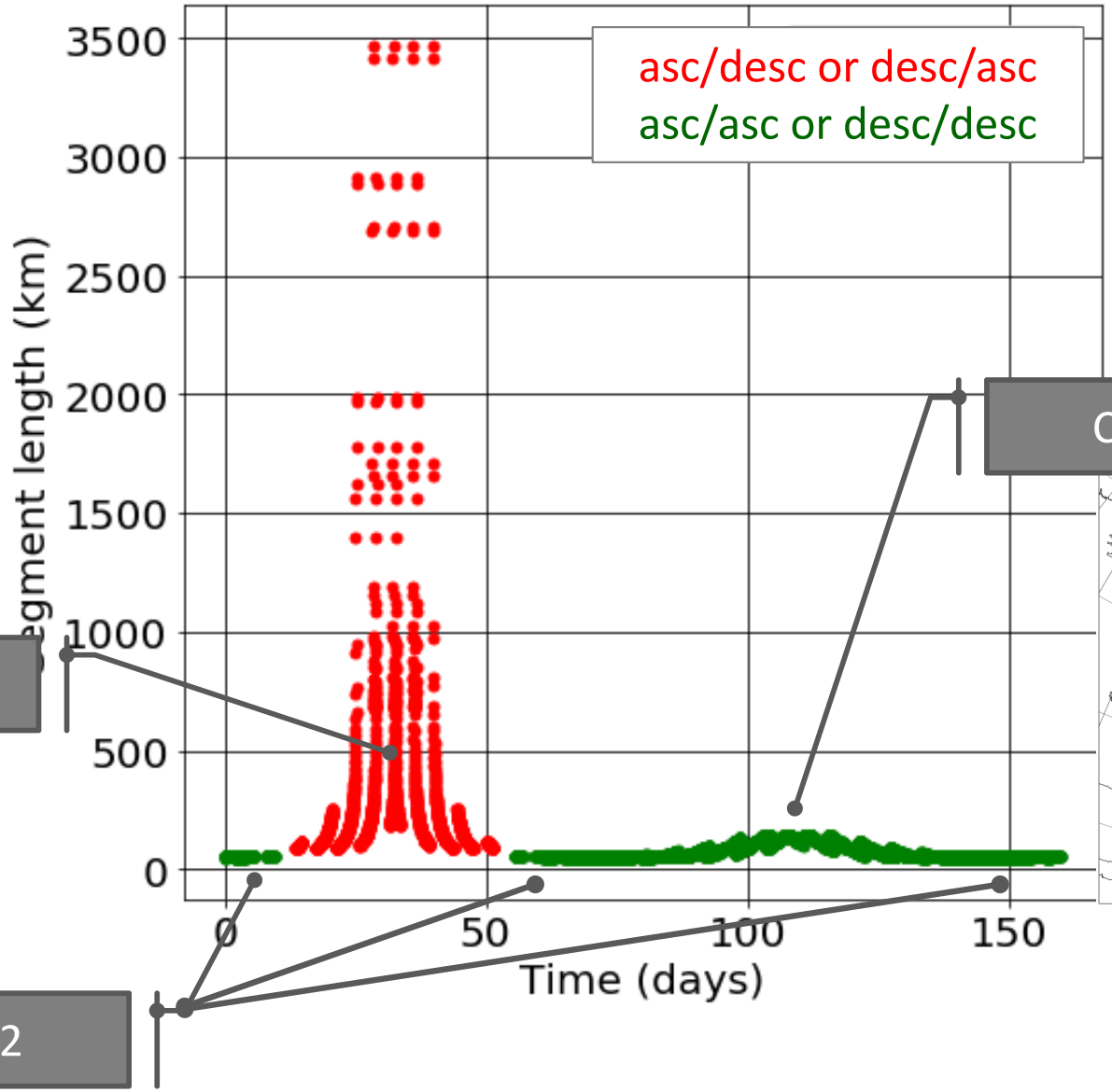
One day's worth of S3A XOVER when solar times are aligned in opposite direction (S3B: same quantity, different regions)

150 days to cycle through all cases: XOVER latitude



150 days to cycle through all cases: XOVER length



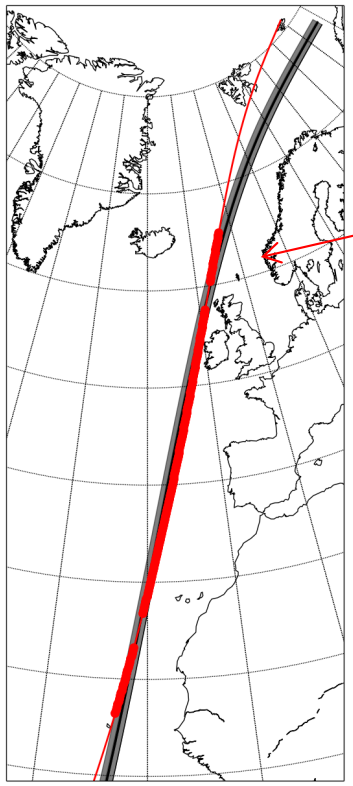


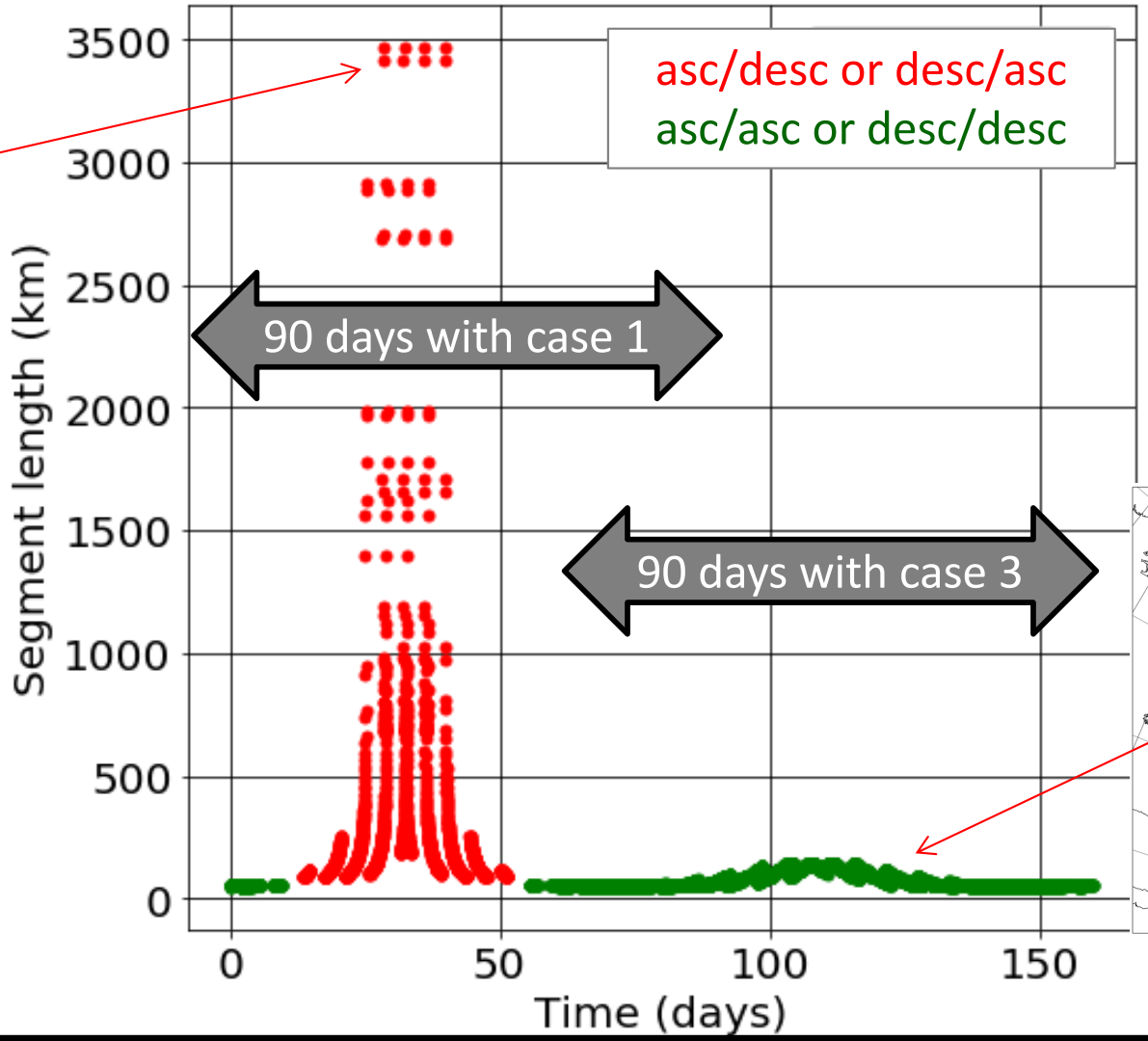
Case 1

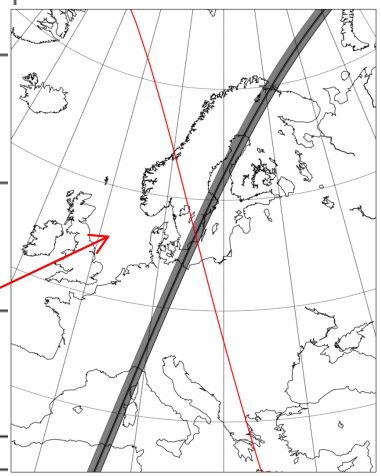
Case 2

Case 3

Length of XOVERs: when should be the sampling phase ?

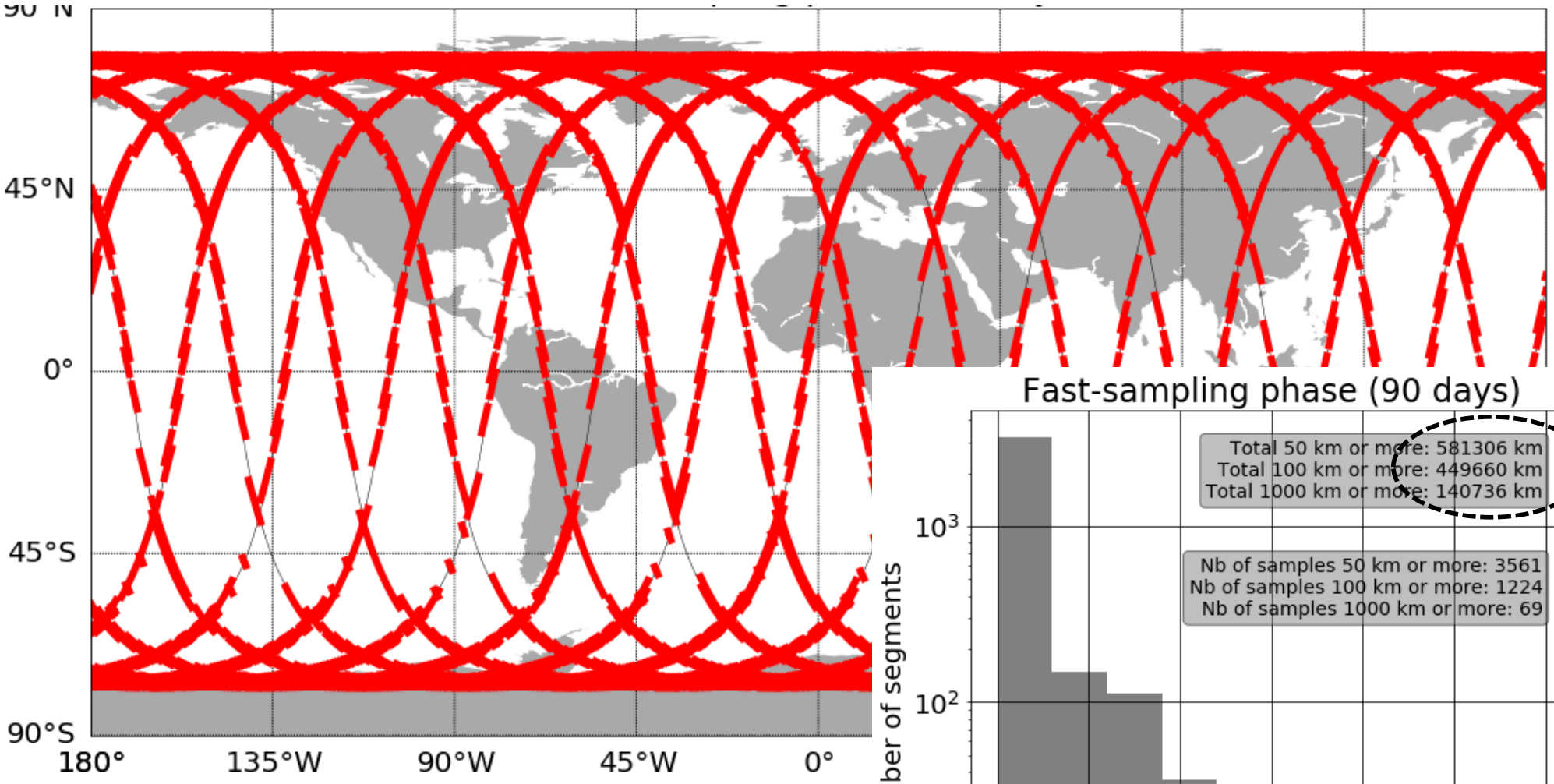






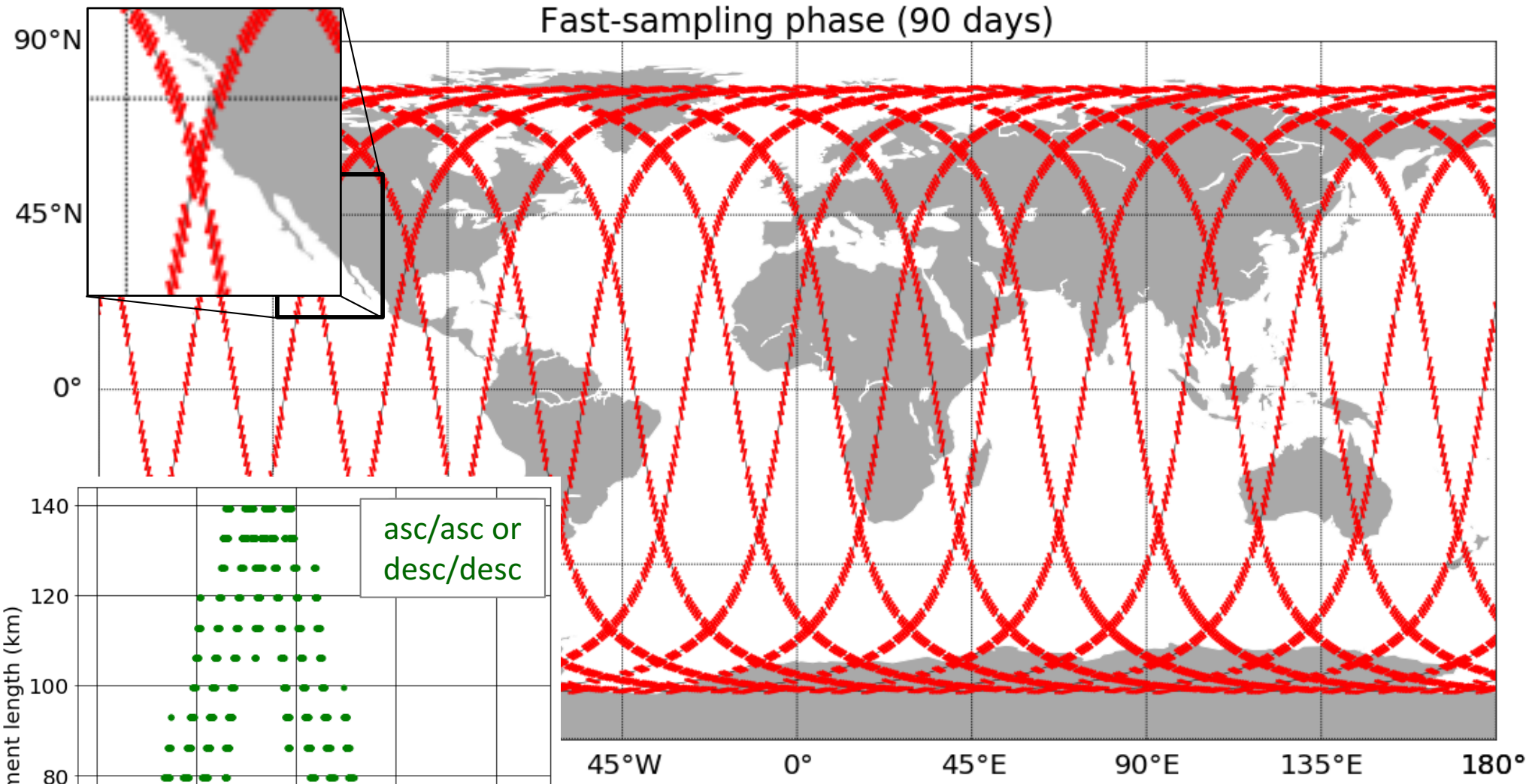
Sentinel-3 provides many 1h XOVERs during <u>any</u> 90-day period
Better if we align solar times (λ extended from 150 to 1000 km)

Best option: 90-day fast sampling w/ case 1



- Critical period of 25 days for 1h XOVERS
- 6.10^5 km worth of 1h XOVER segments
- 10^5 km of 1h segments longer than 1000 km
- All latitudes and basins are covered
- Enough PSD samples for χ^2

Good option: 90-day fast sampling w/ case 3



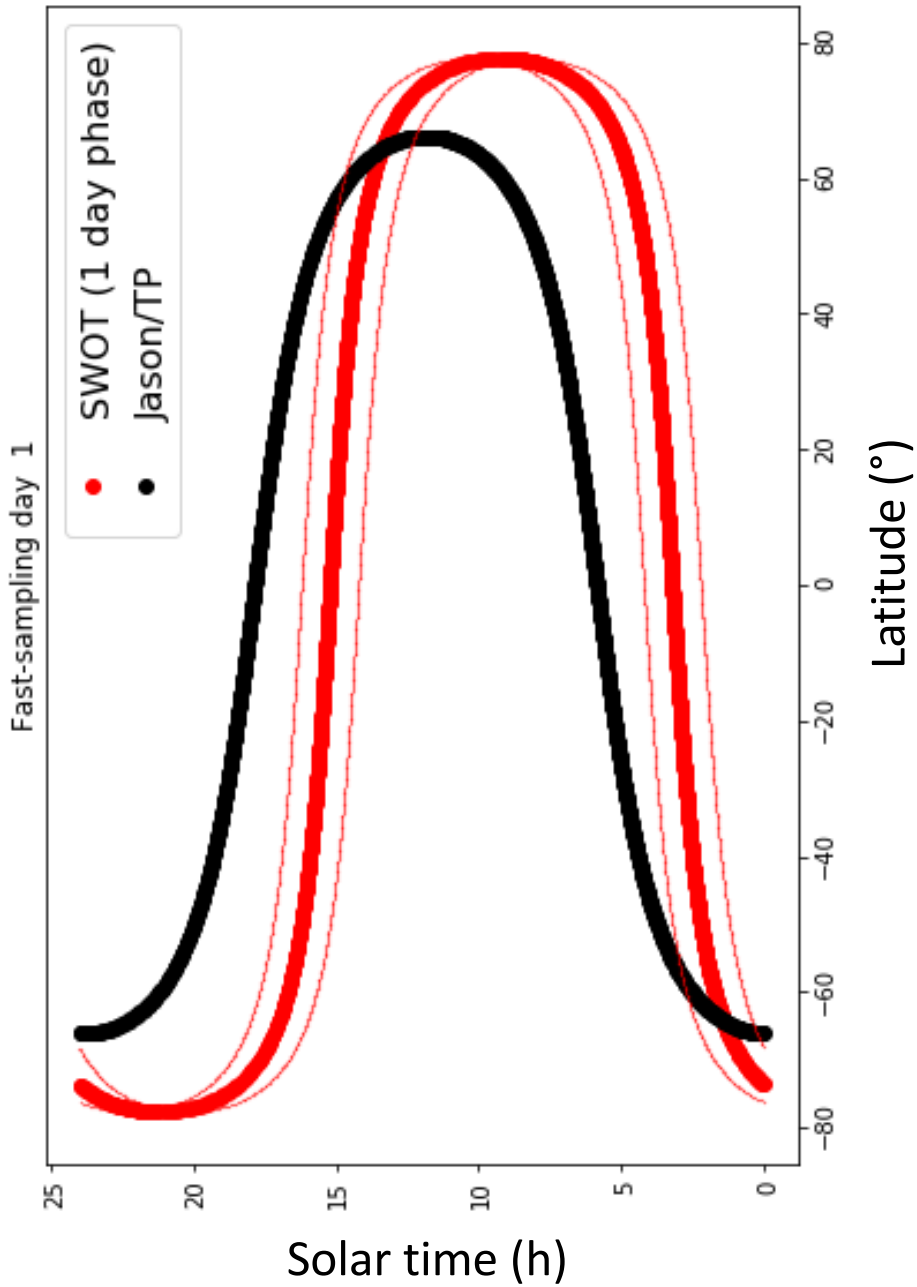
- Critical period of 50 days for 1h XOVERS
- o(10^5) km worth of XOVER, enough for χ^2
- All latitudes and basins are covered
- But segments < 140 km on each KaRIN swath

CAN WE FIND 1-HOUR XOVERS?

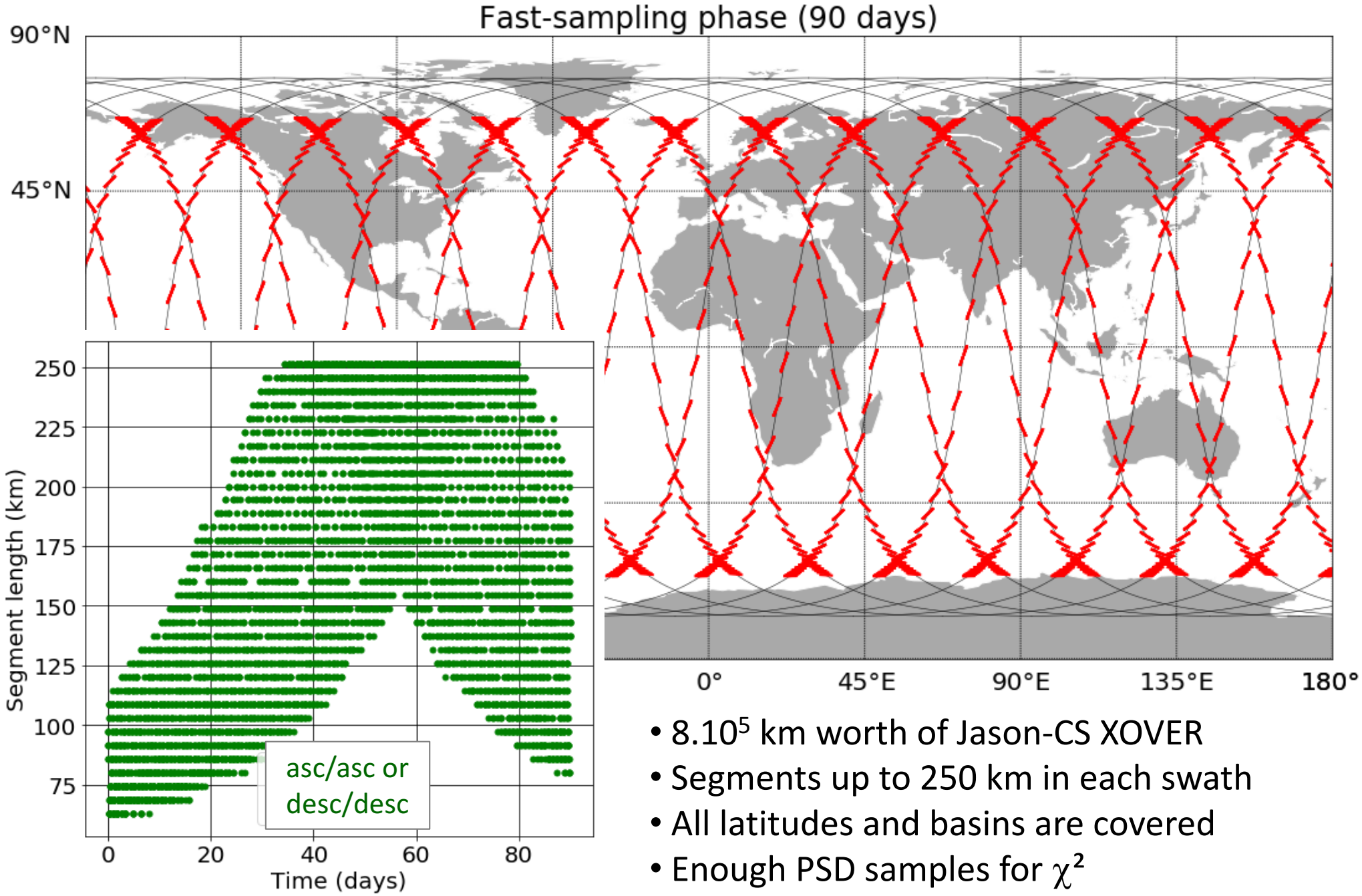
JASON-CS

The importance of solar time

- The solar time of SWOT cycle is approx. 150 days (thick red line)
- The solar time of Jason-CS drifts as well in 120 days (black line)
- ➡ Jason and SWOT align for ~85 days every 250 days
- After that: 6 months without 1h XOVERS except near 66°
- Hit or miss for low latitudes: controlled by solar time of SWOT at launch

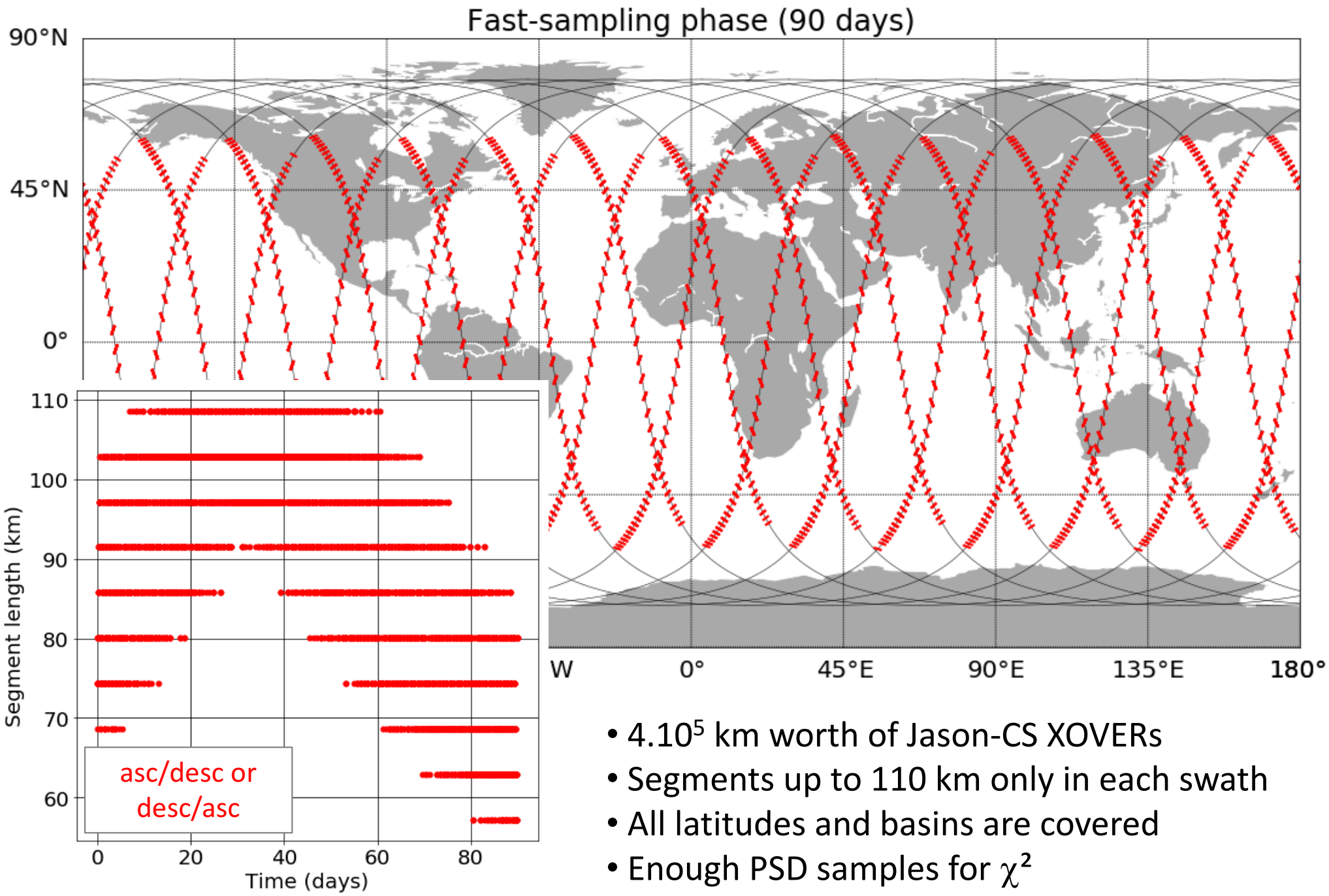


GOOD: alignment asc/asc



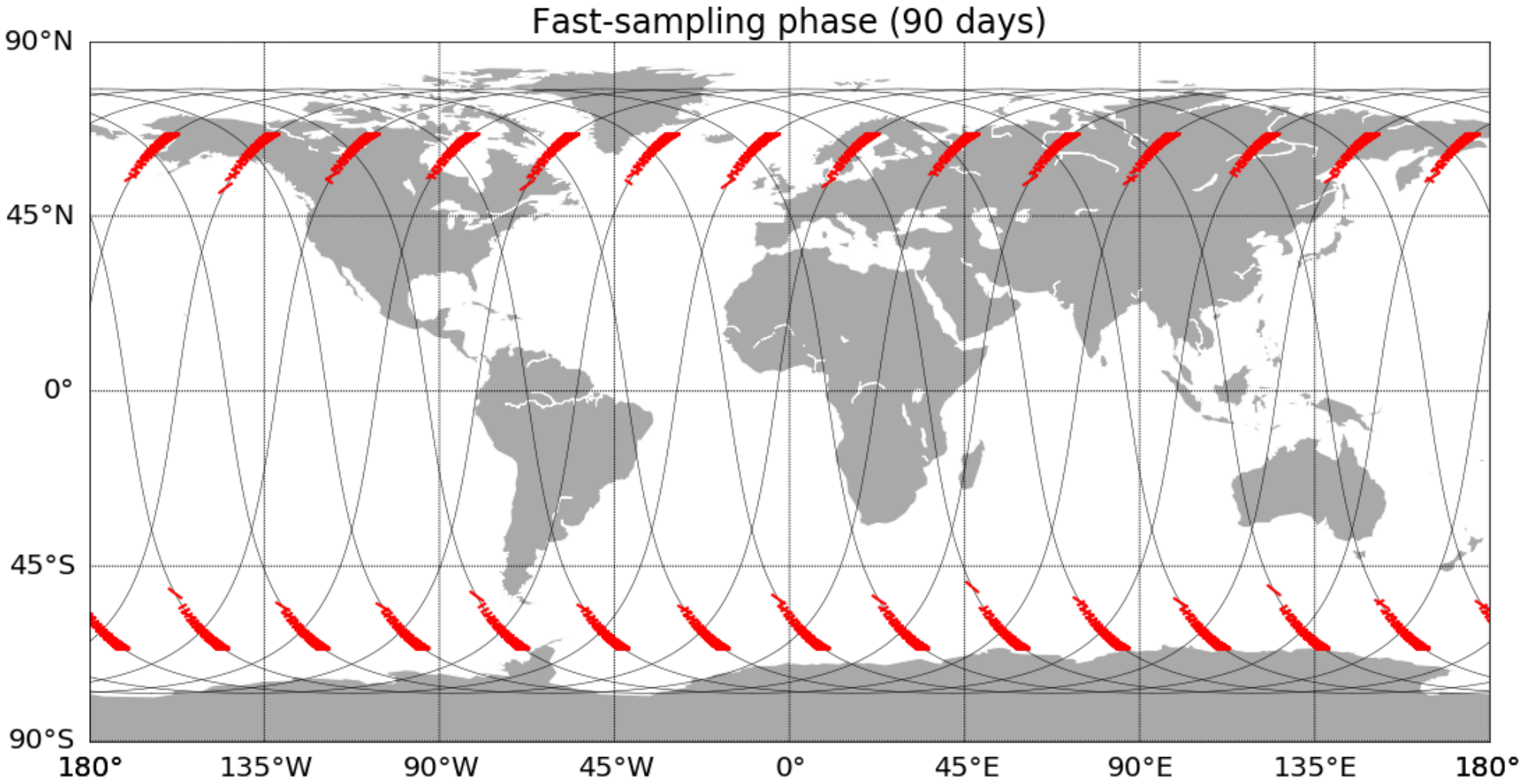
- 8.10^5 km worth of Jason-CS XOVER
- Segments up to 250 km in each swath
- All latitudes and basins are covered
- Enough PSD samples for χ^2

MEDIUM: alignment asc/desc



- 4.10^5 km worth of Jason-CS XOVERs
- Segments up to 110 km only in each swath
- All latitudes and basins are covered
- Enough PSD samples for χ^2

BAD: no alignment for 90 days



- 1h XOVERs exist only at latitudes above 55°
- Typical XOVER segment is 40 to 60 km long (one on each KaRIN swath)
- Very few XOVERs longer than 70 km

If Jason-CS is used for CalVal, it is mandatory to control SWOT's solar time at launch

Summary: Jason-CS and Sentinel-3

- Sentinel-3
  - S3A+S3B: two satellites (twice as many XOVER segments)
  - Many XOVERs at all latitudes during any 90-day period
  - Huge improvement if SWOT'solar times aligned with 10am/pm
  - Can be used to validate KaRIN up to 1000 km
- Jason-CS
  - Many XOVERs at all latitudes only during specific periods
  - 90-day fast sampling does <u>not</u> guarantee 1h XOVERs below 55°
  - Solar times <u>must</u> be aligned (hit or miss for low/mid latitudes)
  - Cannot validate λ ~ 250 to 1000 km (XOVERs are too short)

Sentinel-3 is a better Cal/Val asset for 50 to 1000 km

CONCLUSIONS

Conclusions and Outlook

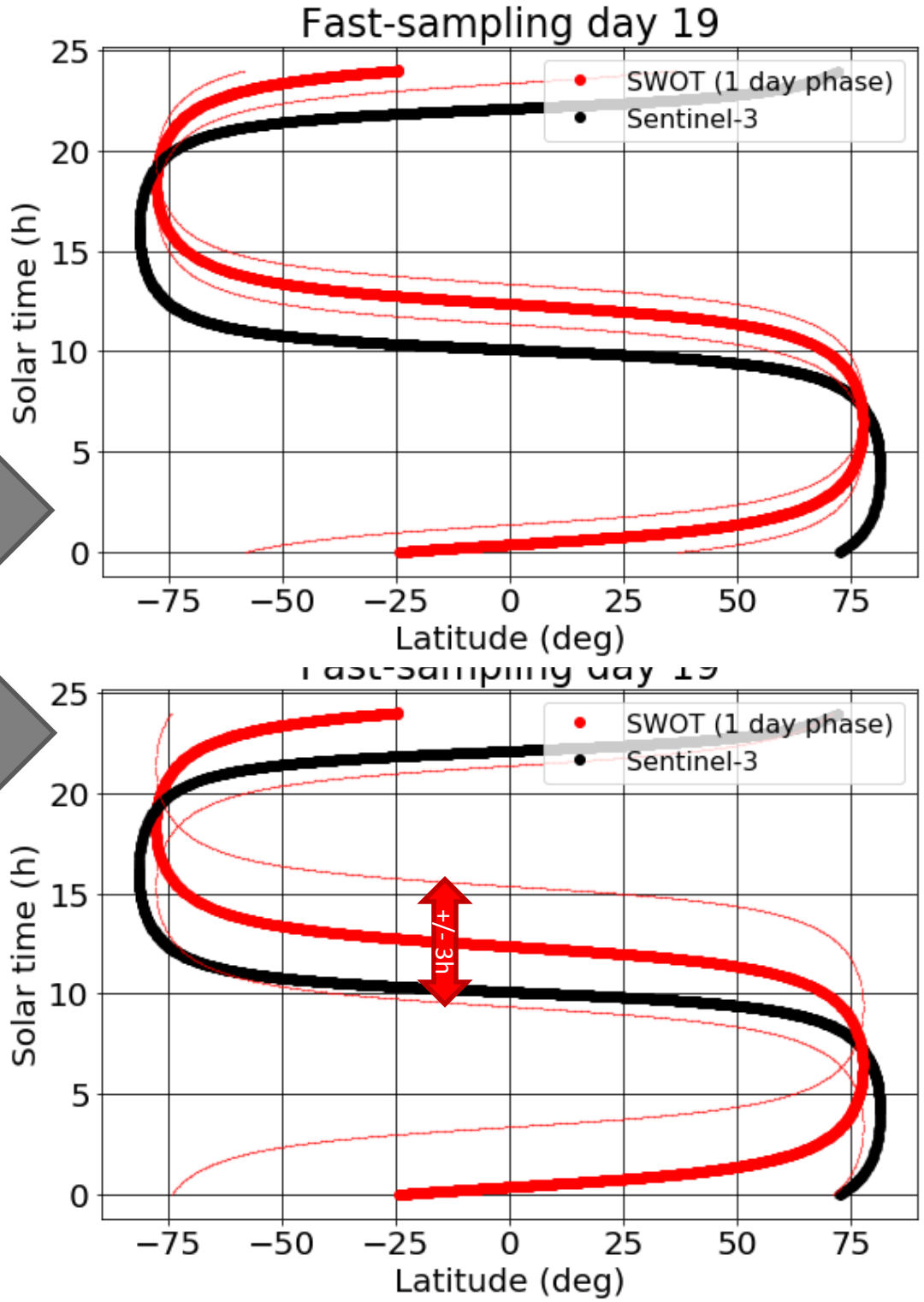
- Altimeter noise is a limiting factor (λ > 50 km for Sentinel-3 and Jason-CS)
- Natural variability may strongly limit XOVER usage (1h is safe in Gulf Stream region)
- Availability of XOVERs with time difference less than 1 hour
  - Many samples over 90 days : o(10^5) to o(10^6) km total, all basins, and all latitudes
  - Sentinel 3A + 3B can segments up to 3000 km (250 km for Jason-CS)
- But only when satellite solar times are aligned
  - Sentinel 3A + 3B: happens twice every 150 days (25 days each) ➔ reliable on 90 days
  - Jason-CS: happens twice every 500 days (85-day each) ➔ hit or miss
- **Conclusions**
  - **Enough samples to validate the error budget for λ ~ 50 to 150 km (1000 km with S3)**
  - **In-situ Cal/Val might focus on 2D validation and λ < 50 km**
  - **Aligning SWOT's solar time at launch is desirable for S3 (and mandatory for Jason-CS)**
- Outlook
  - Test different regions and models to infer if XOVERs with 3h or more can be used (more samples + global ocean = more robust Cal/Val)

BACKUP SLIDES

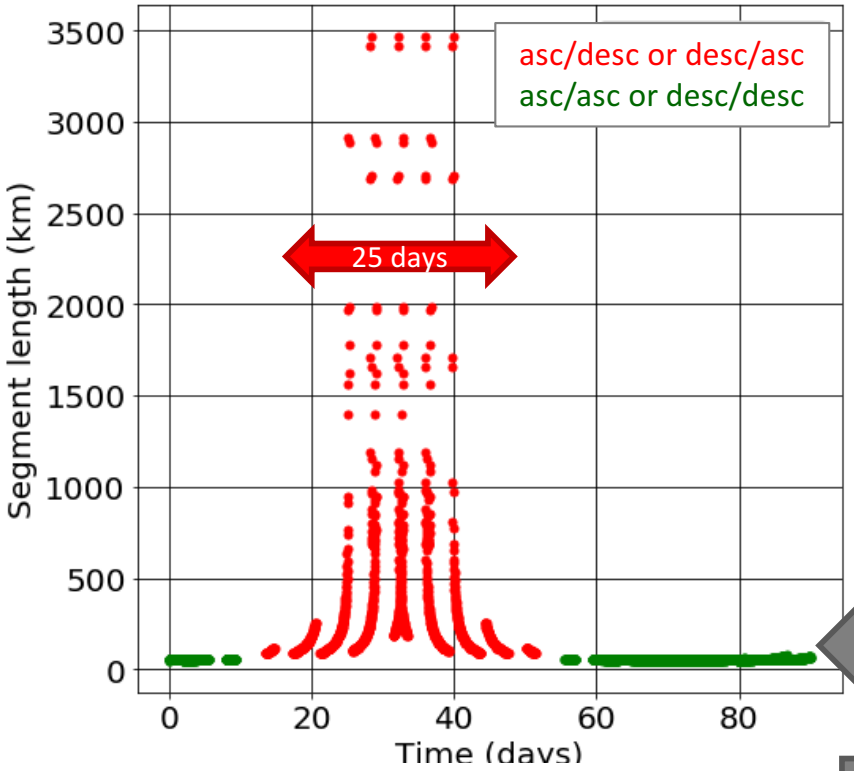
What if a 3h time difference is acceptable in certain regions ?

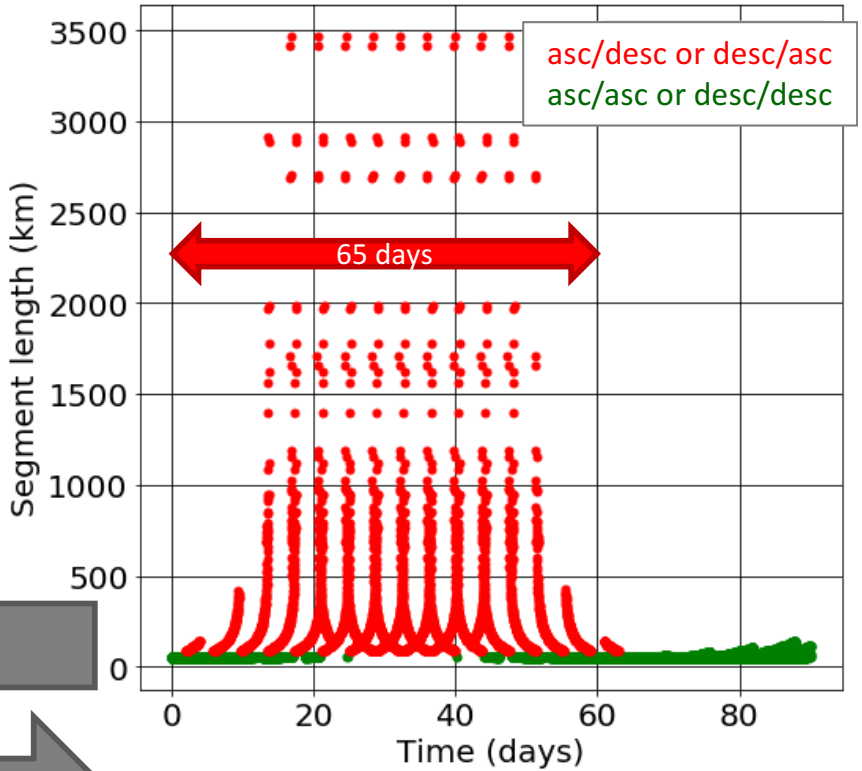
1h limit

3h limit



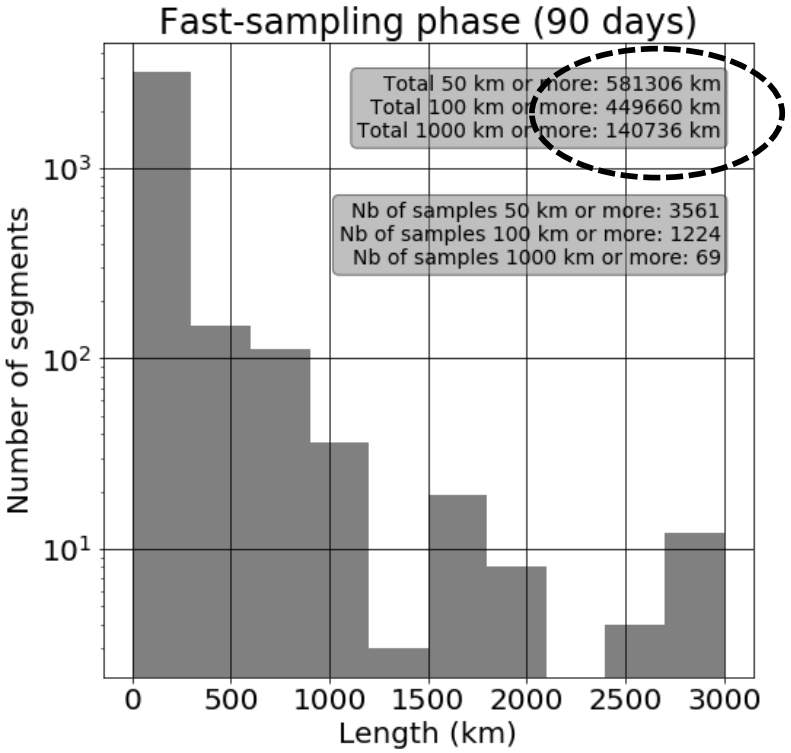
- The critical period where solar times are aligned widens
- Three times more XOVERs
- Three times more very long XOVERs
- Still very import to align solar times

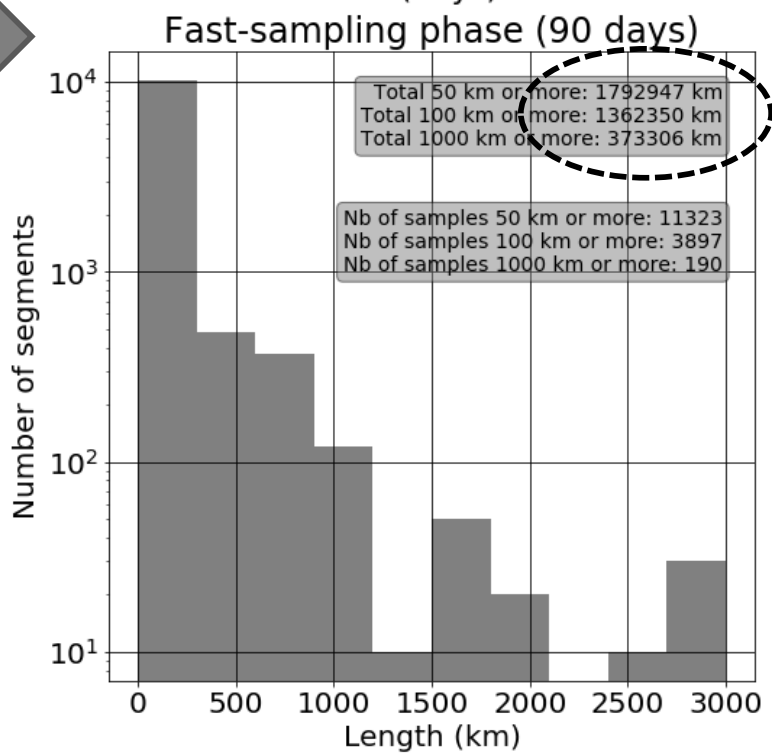




1h limit

3h limit

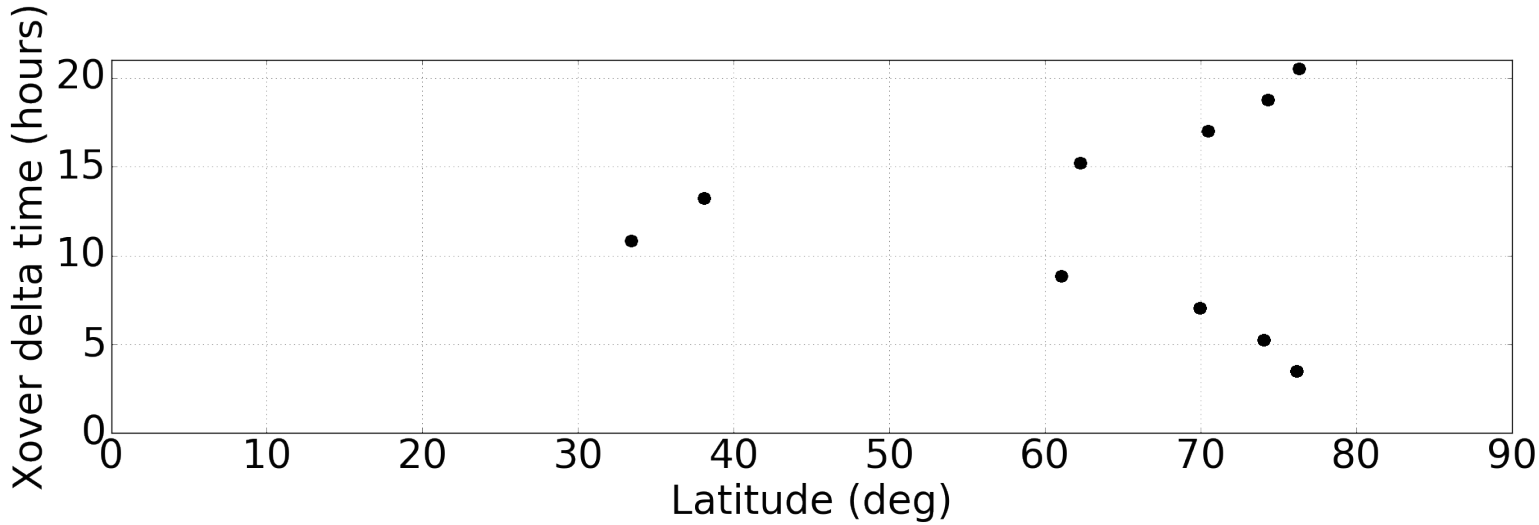




SWOT x SWOT : No XOVER with short dT

- No XOVER with 1-hour or 2-hour differences below 75°
- The nadir altimeter of SWOT cannot be used for a mono-mission XOVER validation (more than 6h ⇨ too much natural variability)
- SWOT's altimeter is LRM (noise is a limit below 70-80 km)

⇨ The nadir altimeter of SWOT is primarily useful for the along-track validation (scales > 150 km)



Reality VS. specs (defined for SWH=2m)

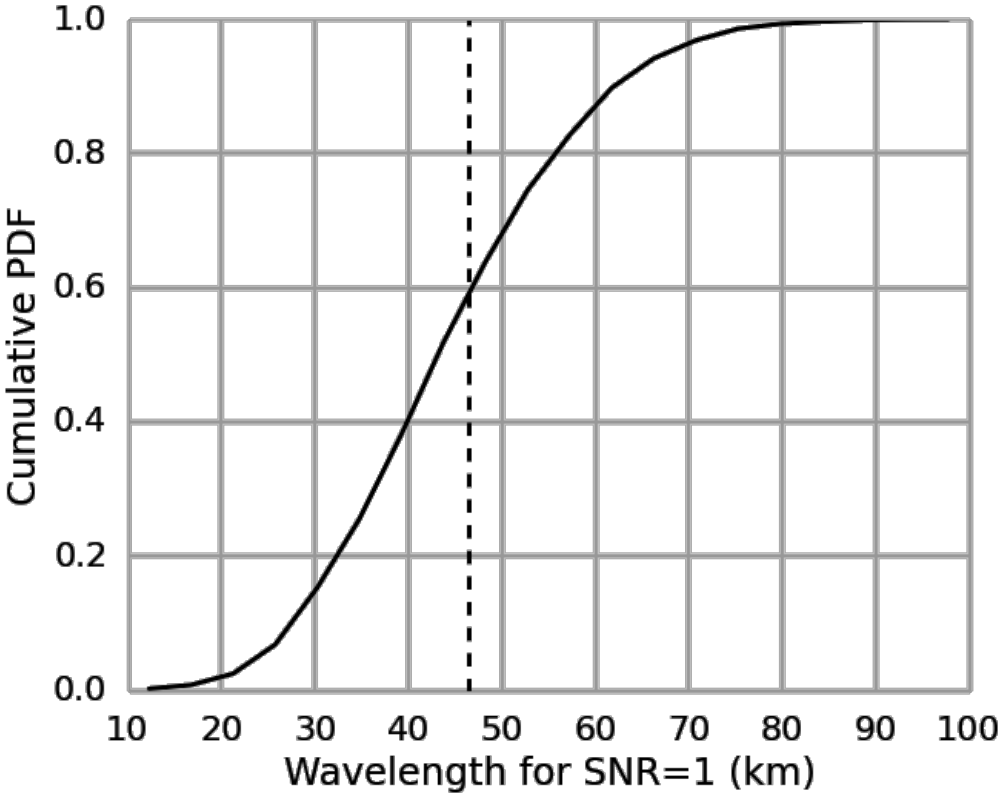
- The KaRIN noise and S3 noise are modulated by SWH
- SSH and SWH have regional and seasonal variability
- Climatology used to gauge actual observability

(as a PDF of wavelength when SNR=1)

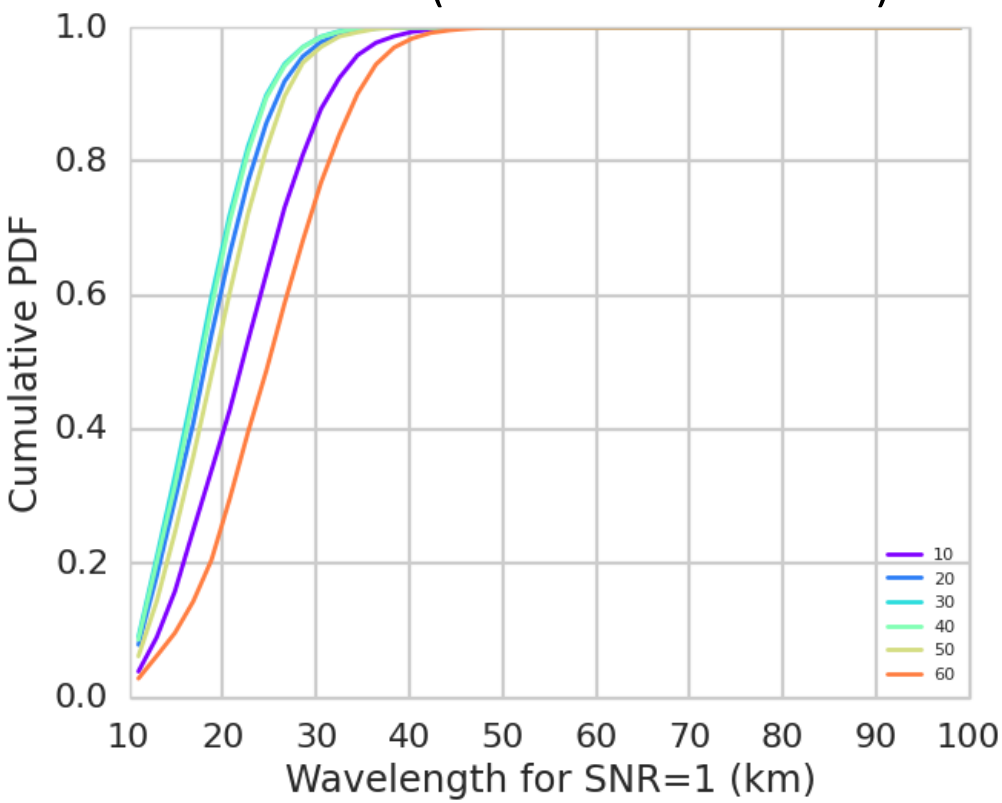
- The median (50% of the oceans) observability wavelength is
  - 20 km for SWOT (SRD requirement is for SWH = 2m)
  - 45 km for Sentinel-3

λ > 50 km is met over 70% of the global ocean, even including SWH > 2m

Sentinel-3 SARM

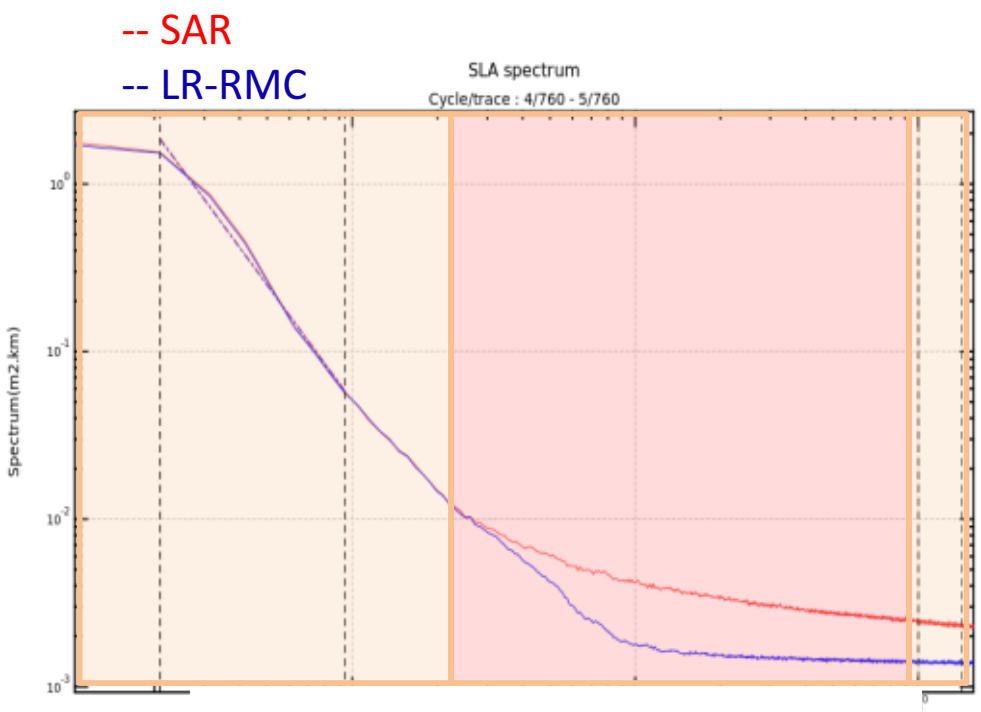


KaRIN (15-60 km cross-track)



Global PDF of the observability limit (SNR=1 as per SWOT SRD definition)

LR-RMC processing: performance assessment



Global analysis (1 cycle of S3A)

- Large reduction of noise for HF content
- Same behavior as classical SARM processors for large scales
- SARM exibits a red noise for scales lower than 50km, linked with swell conditions
- Possible low-pass filtering residual near 20km, but the LR-RMC spectra looks much cleaner than SARM

Courtesy of Boy et al.