Cross-over Calibration for hydrology:

- Why? How? Should you care?

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Introduction

A major component of the hydrology error budget is the systematic error (JPL error budget description, ref #D-79084)

- Cross-over calibration (XCAL) uses ocean coverage and inland interpolation to correct hydrology measurements

- Purpose of this talk: answer 3 questions about XCAL

1 - Why? (rationale of crossover algorithms)
2 - How? (algorithms in a nutshell)
3 - Should you care? (variability of residual errors)
Rationale for cross-over calibration
KaRIN’s systematic errors: example of roll

• To deliver good interferometric products, the relative position of antennas must be known within micro-meters (very hard)

• Antenna roll angle is not perfect? Linear cross-track error

• Baseline length is not perfect? Quadratic cross-track error

• Range timing bias in KaRIN? Time-varying offset error
Example of roll errors for inland products

- For the small targets of hydrology: bias in water height or river slope
- Can be very different with each cycle
- Basically a random error in time series

Roll angle (arcsec)

River Height Bias
Lake Height Bias
River Slope Bias

Roll signature on topography (cm)
Reducing systematic errors: example of roll

If the unknown parameter (e.g. roll angle, timing bias) is perfectly calibrated, its signature on water height is removed.

The challenge is to calibrate relevant parameters as accurately as possible:

- First level of correction w/ gyros, star-trackers and models…
- Residuals are still too high to meet the science requirements.

<table>
<thead>
<tr>
<th>Karlin Hydrology Error Component</th>
<th>Height Error [cm]</th>
<th>Slope Error [urad]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karlin Random</td>
<td>4.4</td>
<td>8.0</td>
<td>Height based on a 1 km² averaging area of water-only pixels; slope based on a 10 km downstream averaging of a 100 m river.</td>
</tr>
<tr>
<td>Karlin Systematic cross-track errors after cross-over correction</td>
<td>7.4</td>
<td>1.7</td>
<td>Residual after cross-over correction; these are the RMS cross-track slopes (and associated height) for the entire along-track land pass.</td>
</tr>
<tr>
<td>Karlin Systematic along-track height bias error</td>
<td>1.5</td>
<td>0.08</td>
<td>This is the RMS timing and dilation along-track height errors accumulated down to 0 Hz.</td>
</tr>
<tr>
<td>High Frequency errors (Unallocated margin, RSS)</td>
<td>1.15</td>
<td>0.5</td>
<td>RMS of systematic errors &gt; 0.5 Hz</td>
</tr>
<tr>
<td>Total (RSS) Error Requirement</td>
<td>8.9</td>
<td>8.2</td>
<td>Requirement</td>
</tr>
</tbody>
</table>

- Need a 2nd level of correction -> use of ocean-crossovers
Cross-over calibration in a nutshell
Example of roll XOVER calibration

- SWOT topography (LR on ocean) is skewed by uncalibrated residual roll
- When the opposite swath is visible (black diamond), roll is mitigated
- ~30,000 crossovers every 21 days
- Inland crossovers cannot be used (SNR and topography error, limited water coverage, layover)
- Roll correction must be interpolated between ocean crossovers
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• Combination of slow and rapid changes (K^{-2} law)
• Goal of calibration for hydrology is to mitigate the long wavelength error over inland segments
STEP1 - Inverse XOVER diamonds

• Roll is well observed in the open ocean
• No data for inland segments
STEP2 - Interpolate calibration

- Interpolated correction (black, thick) and residual (gray, thin)
- Slow signals are well captured everywhere
- Inland error is substantially reduced
- Uncorrected residuals due to rapid roll events occurring inland
Variability of residual systematic errors
• Hydrology requirement after calibration for topography is 7.4 cm RMS for roll and phase errors (from JPL D-79084)

▶ Requirement is largely met in canonical scenario

• Large margins to account for idealized assumptions
• Spatial variability: Asia is challenging and the main contributor
Seasonal variability from sea-ice coverage

Jan-Feb-Mar

- Strong seasonnal variability
- Sea-ice bridges very long inland arcs with no ocean crossover: very high errors
- Non-freezing Norwegian sea helps Europe

Jul-Aug-Sep

- Calibration performance is primarily limited by long arcs with frozen seas (main target if more margins are needed)
Slope performance (2-year simulation)

- Hydrology requirement after calibration for slope is 1.7 µrad RMS for roll and phase errors (from JPL D-79084)
- Requirement is met in canonical scenario
- Approximately 10% margins w.r.t error allocation variance
- Measured only with cross-track slope (worst case scenario)
- Same space/time variability as height once XCAL is applied
Conclusions and outlook
Conclusions and outlook

Hydrology requirements are met in canonical scenario
- 6.33 cm RMS (25% margins w.r.t to allocated error variance)
- 1.62 cm µrad (10% margins w.r.t to allocated error variance)
- Hydrology requirements also met in near real time (see backup)

Error variability might affect local studies of the science team
- High geographical variability (long inland arcs are challenging)
- High seasonal variability due to sea ice coverage

Way forward
- Add this variability in the hydrology science simulator
- Transition XCAL from prototype to operational software
- Explore optional algorithms (better products) as part of ST work
  - Use crossovers on big lakes, use static targets, use corner reflects (for long inland arcs)
  - Use other algorithms from Dibarboure et Ubelmann (2014)
  - Use better propagation schemes
REFERENCES
Delayed time versus NRT

- Global Hydrology requirement is met in NRT
- Approx 14% margins in NRT (w.r.t to error allocation variance)
- Performance still dominated by Northern arcs and frozen seas
- Good NRT performance due to 10-day sub-cycle of the science orbit
SWOT Measurement Review: ADT WG8 Operational Calibration

KaRIn LR/Ocean Processing Functional Flow

Multi-temporal calibration

- Compute multi-temporal match-ups
- Range empirical cross-calibration
- Roll/Phase crossover calibration

LR I2 SSH UnCal

Compute calibration correction for each pixel
Ponderation with Xover expected Ocean-leakage

1-day SLA variability (m²)

10-day SLA variability (m²)

- Important to weight XOVERs with Ocean slope variability at the crossover difference time
- Variability is generally high near the coasts (coastal Kelvin waves ans wind effects <10.5 days)
- In our canonical case, the GLORYS dataset provides a perfect parameter for calibration
- Before launch: necessary to build this input parameter from past and present altimetry
Arcsec to microradian on measured topography:
rollPSD1 = numpy.array(fid.variables['rollPSD'][:])*(1./3600*pi/180*1e6)**2  # arcsec**2 to urad**2
rollPSD2 = numpy.array(fid.variables['gyroPSD'][:])*(1./3600*pi/180*1e6)**2  # arcsec**2
PSroll1=(rollPSD1)*(1+const.sat_elev/const.Rearth)**2  # microrad**2
PSroll2=(rollPSD2)*(1+const.sat_elev/const.Rearth)**2  # microrad**2
PSroll=PSroll1+PSroll2  # microrad**2
Deg to microradian on measured topography:
PSphase=phasePSD*(pi/180*1e6)**2
*((1/(const.Fka*2*pi/const.C*const.B)*(1+const.sat_elev/const.Rearth)))**2 # microrad**2