NEW GENERATION GNSS SOLUTIONS:

Precise Positioning, Navigation & Applications

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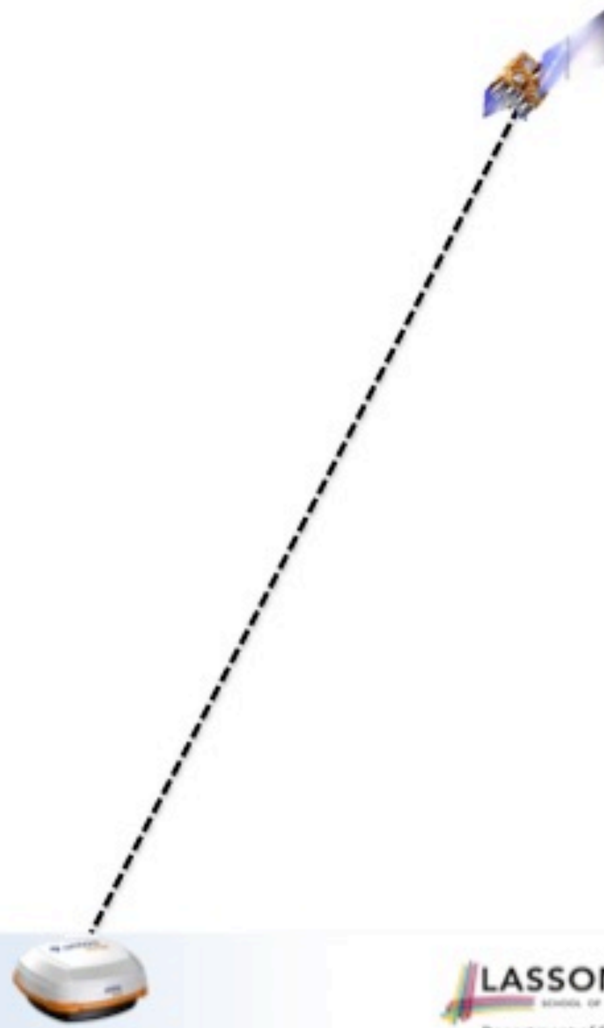
Webinar outline

- Challenges of single-receiver positioning
- Relative positioning
- Correction services technology
- Technology example: Atlas Correction Service
- Future trends

Challenges of single-receiver positioning

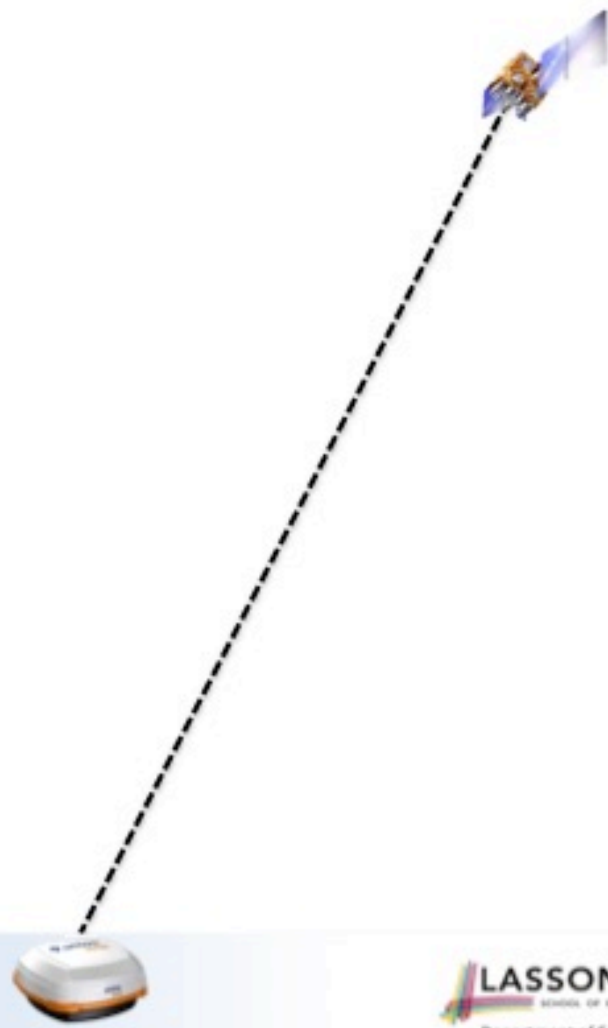
Idealized GNSS data processing model would assume perfect line-of-sight measurement of time/distance between satellite and receiver antennas.

However…

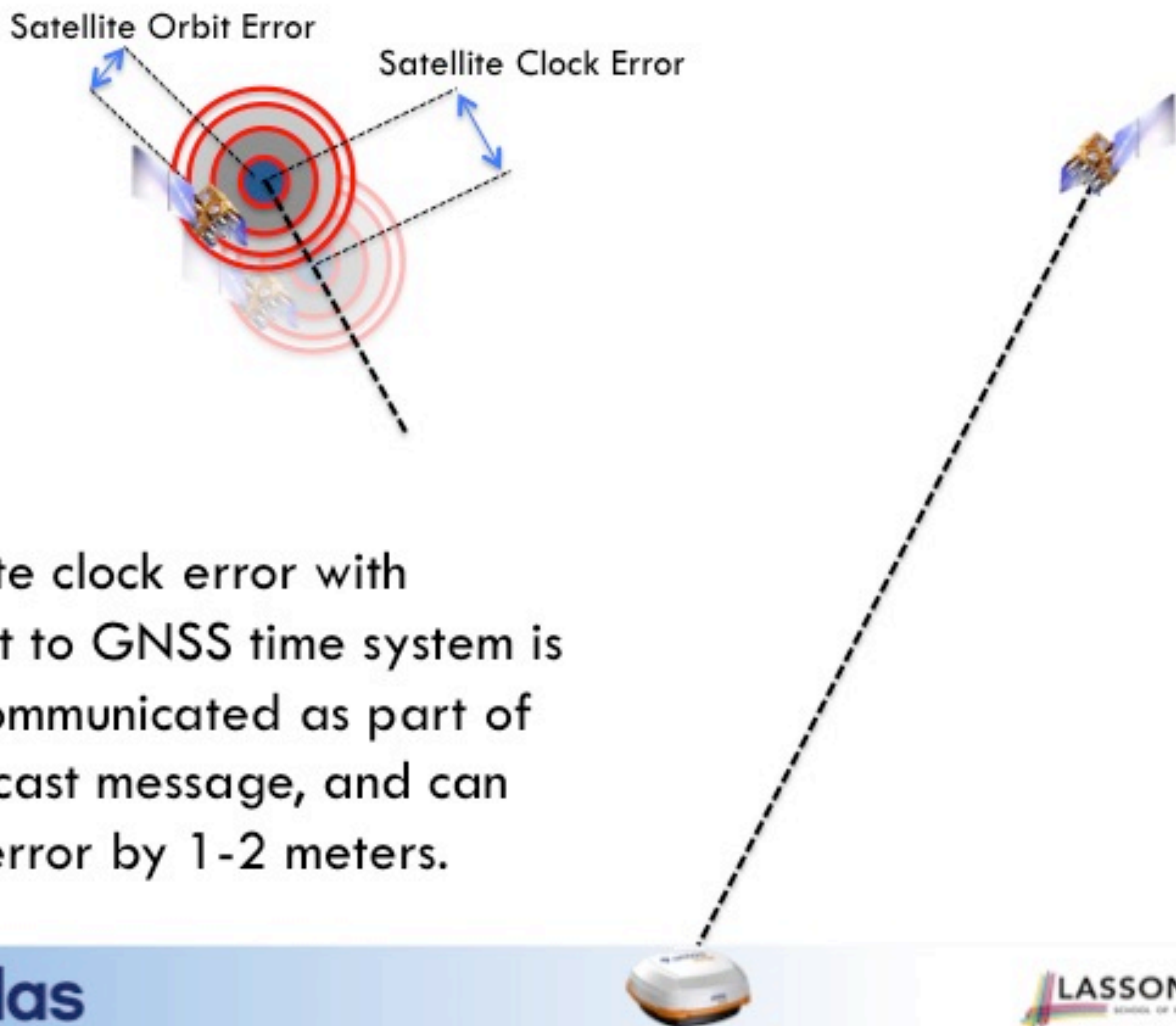


Challenges of single-receiver positioning

Satellite position, as broadcast in typical satellite signal messages, contain an error with respect to actual satellite coordinates of 1-2 meters.

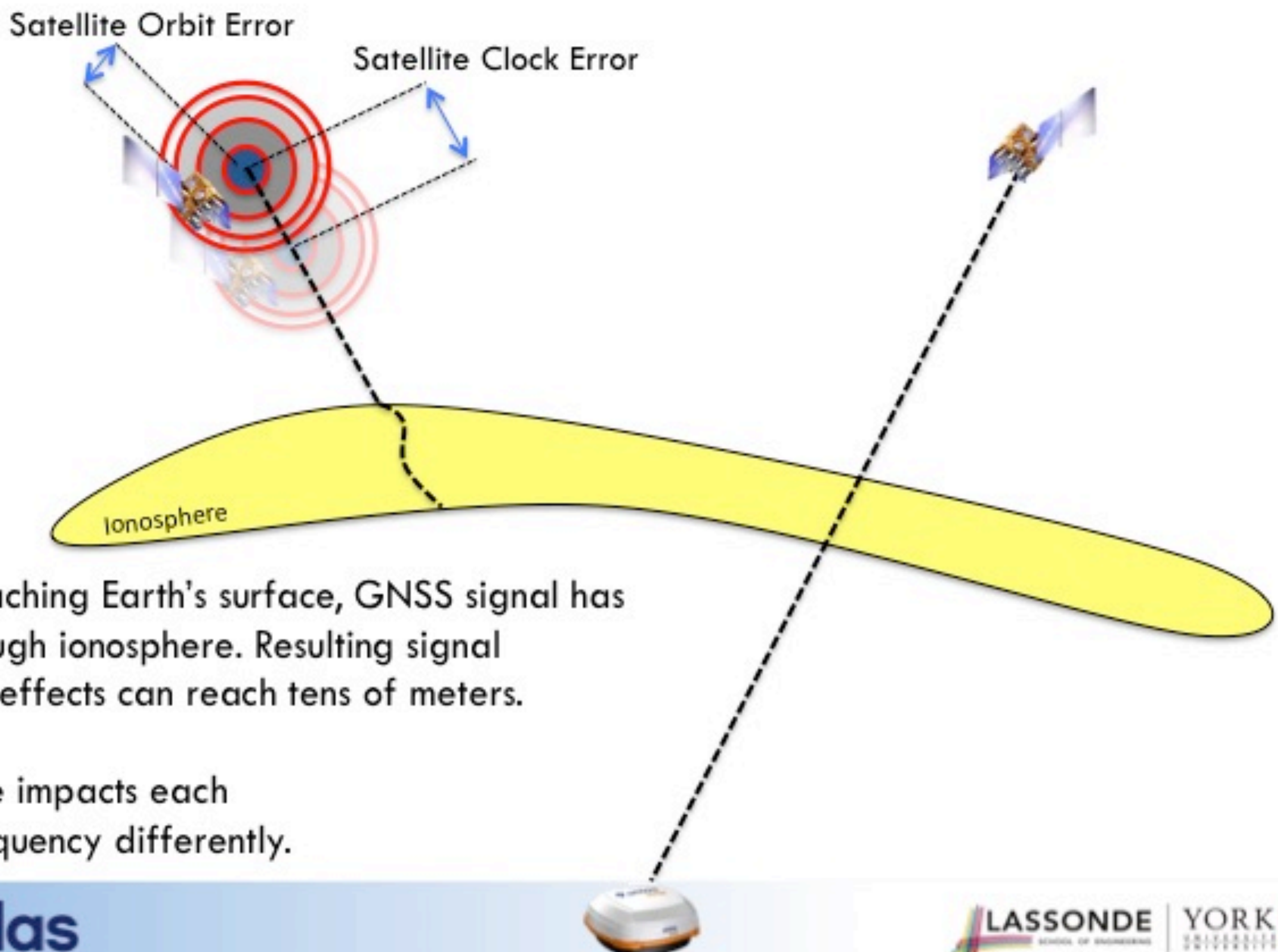


Challenges of single-receiver positioning



Satellite clock error with respect to GNSS time system is also communicated as part of broadcast message, and can be in error by 1-2 meters.

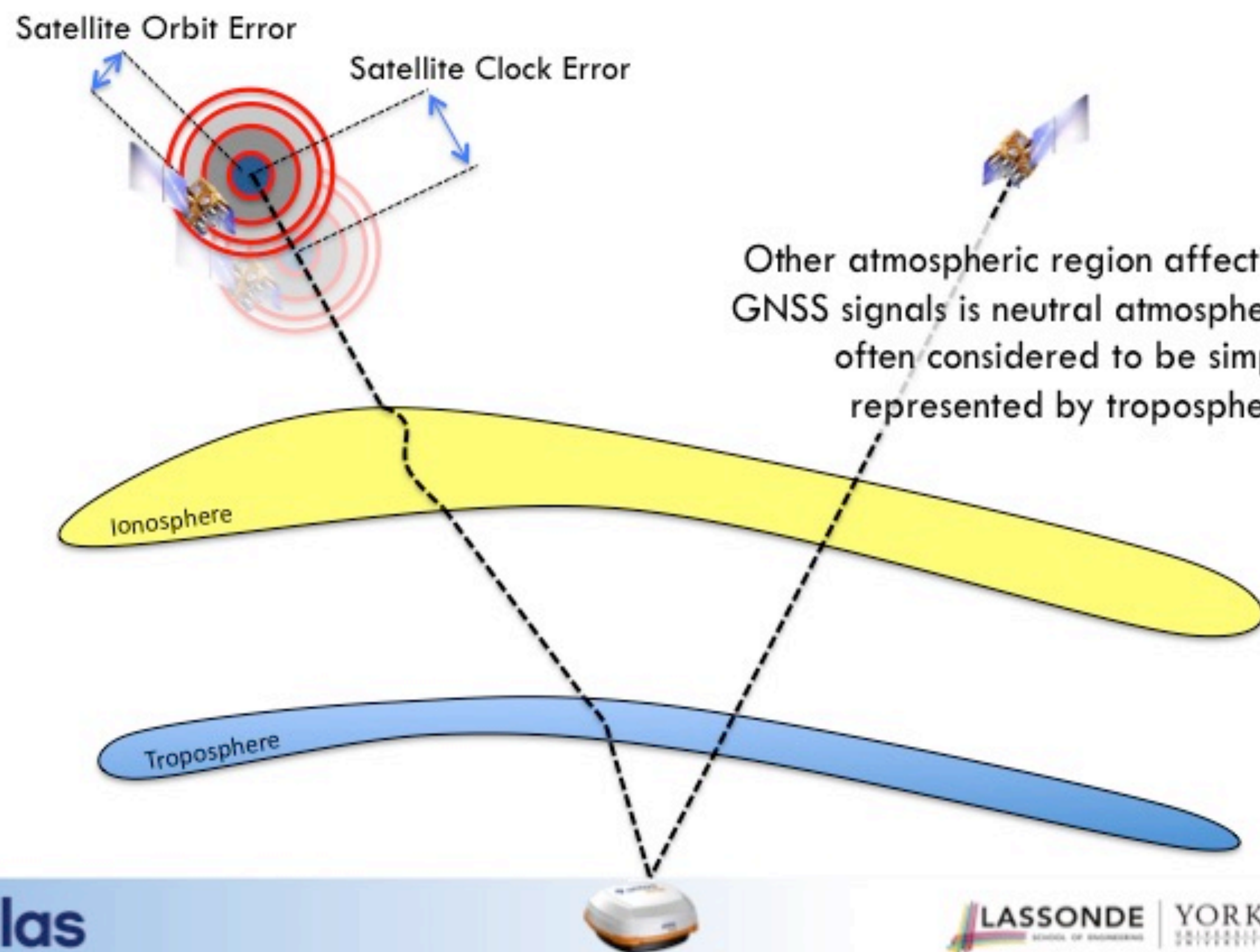
Challenges of single-receiver positioning



Before reaching Earth's surface, GNSS signal has to go through ionosphere. Resulting signal refraction effects can reach tens of meters.

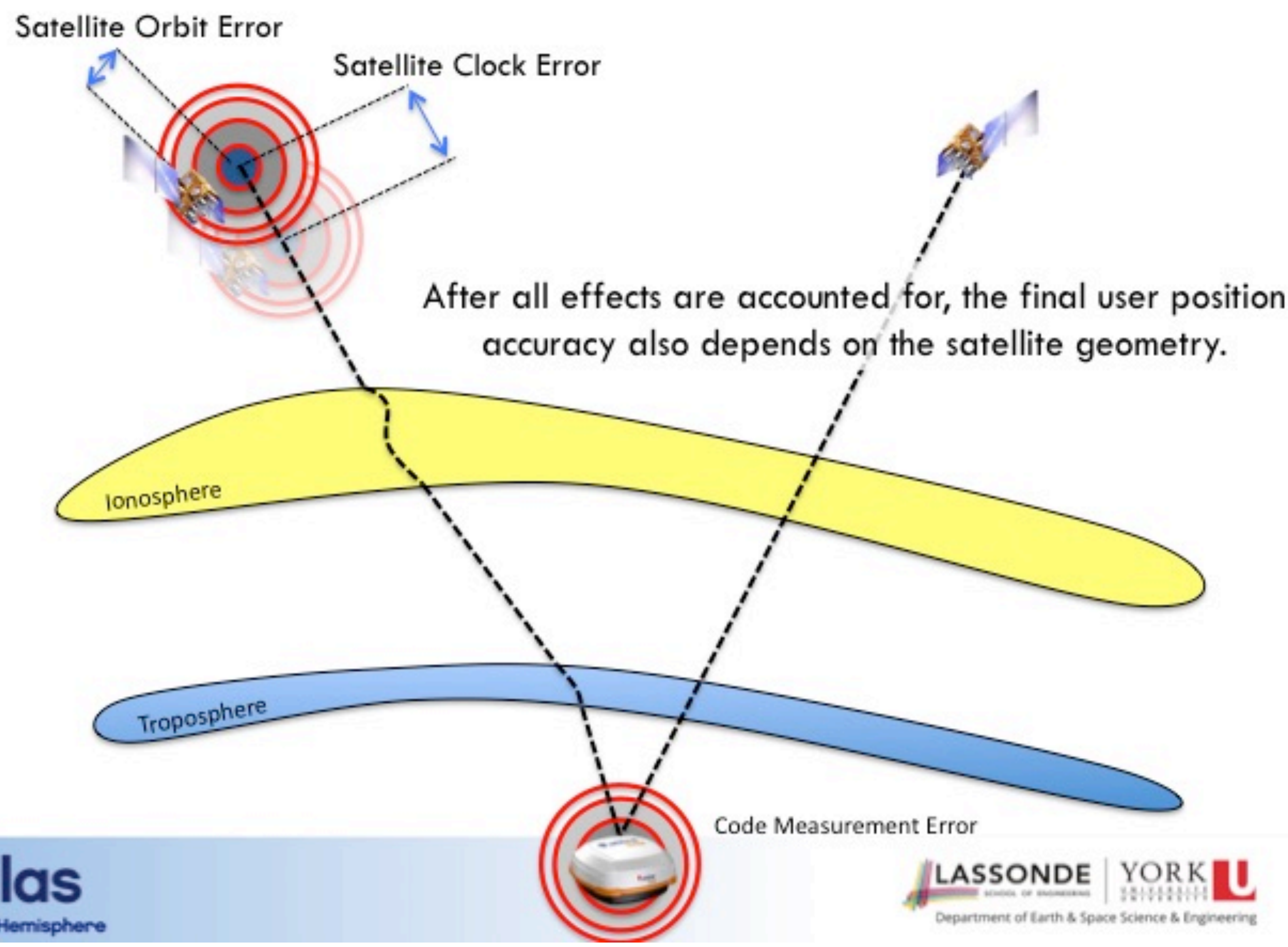
Ionosphere impacts each GNSS frequency differently.

Challenges of single-receiver positioning



Other atmospheric region affecting GNSS signals is neutral atmosphere, often considered to be simply represented by troposphere.

Challenges of single-receiver positioning

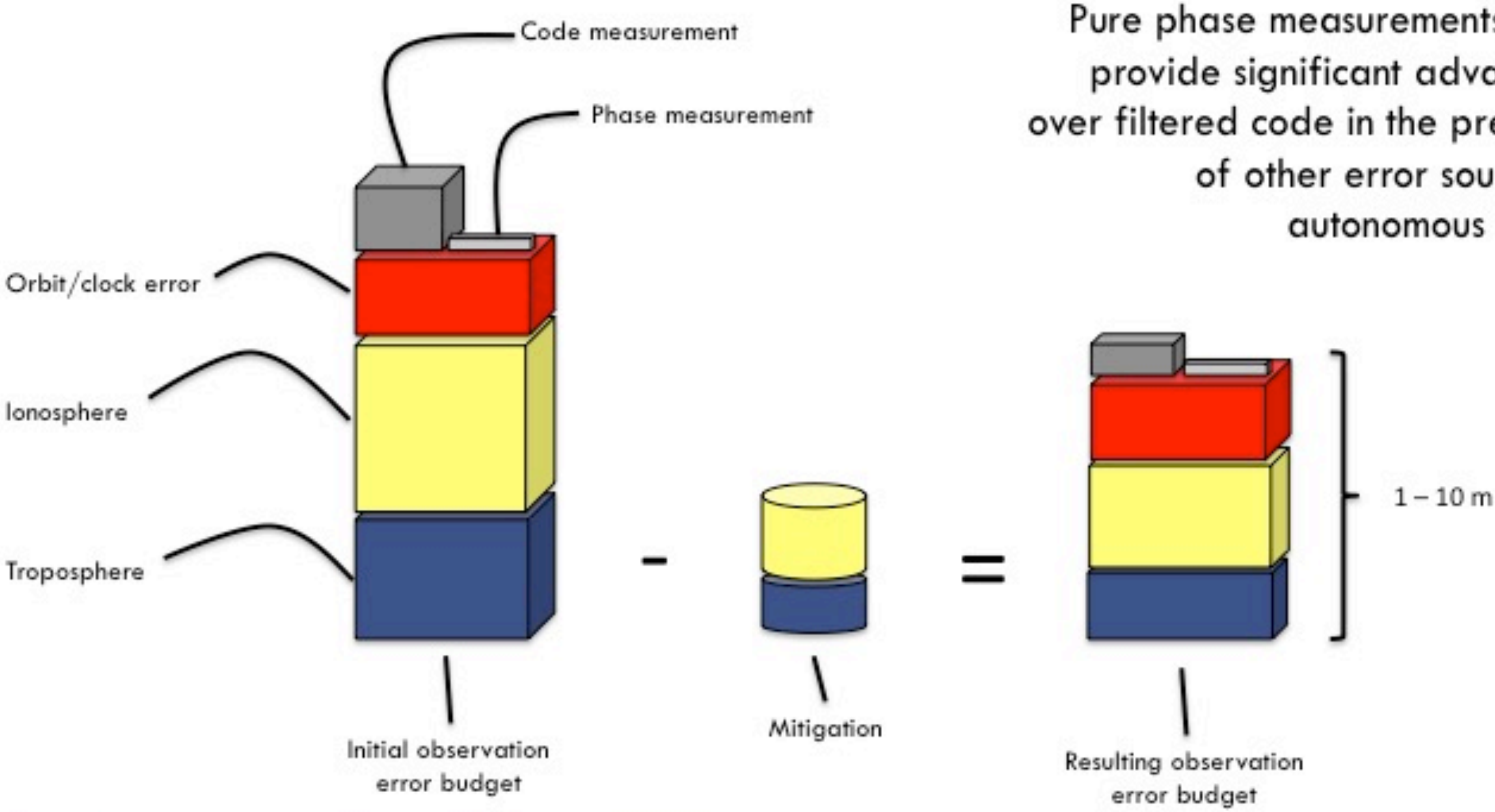


Challenges of single-receiver positioning

Effect	Magnitude	Mitigation	Post-mitigation impact
Satellite orbit/clock error*	1 - 2 m	None	1 - 2 m
Ionosphere	Up to tens of meters	Ionospheric model*	Up to several meters
Troposphere	2 - 20 m	Tropospheric model	0 - 2 m
Code measurement	1 - 3 m	Filtering	0.5 – 1.5 m
Phase measurement	0.5 – 10 cm	None	0.5 – 10 cm

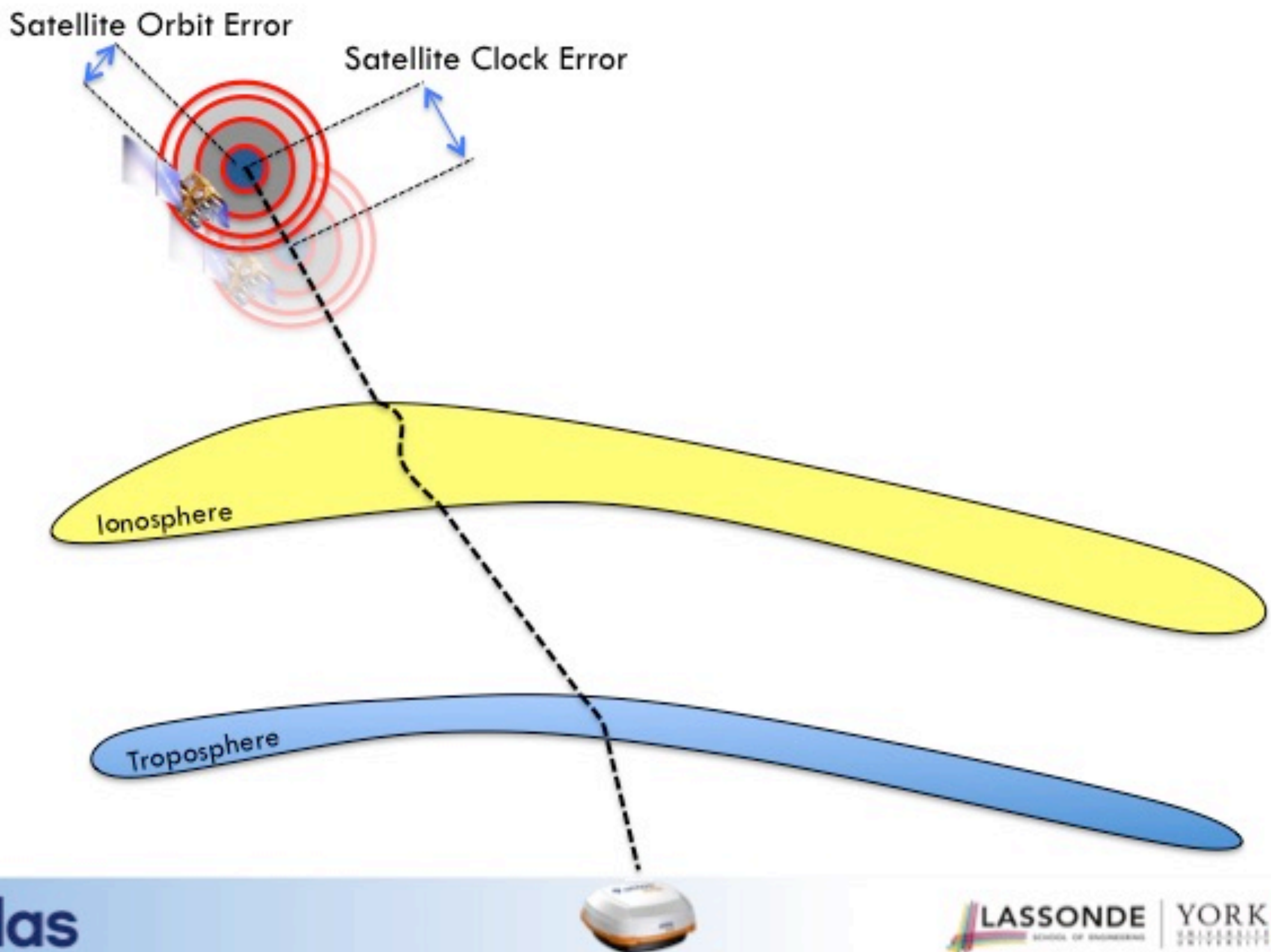
(*) As transmitted in GNSS broadcast messages

Challenges of single-receiver positioning

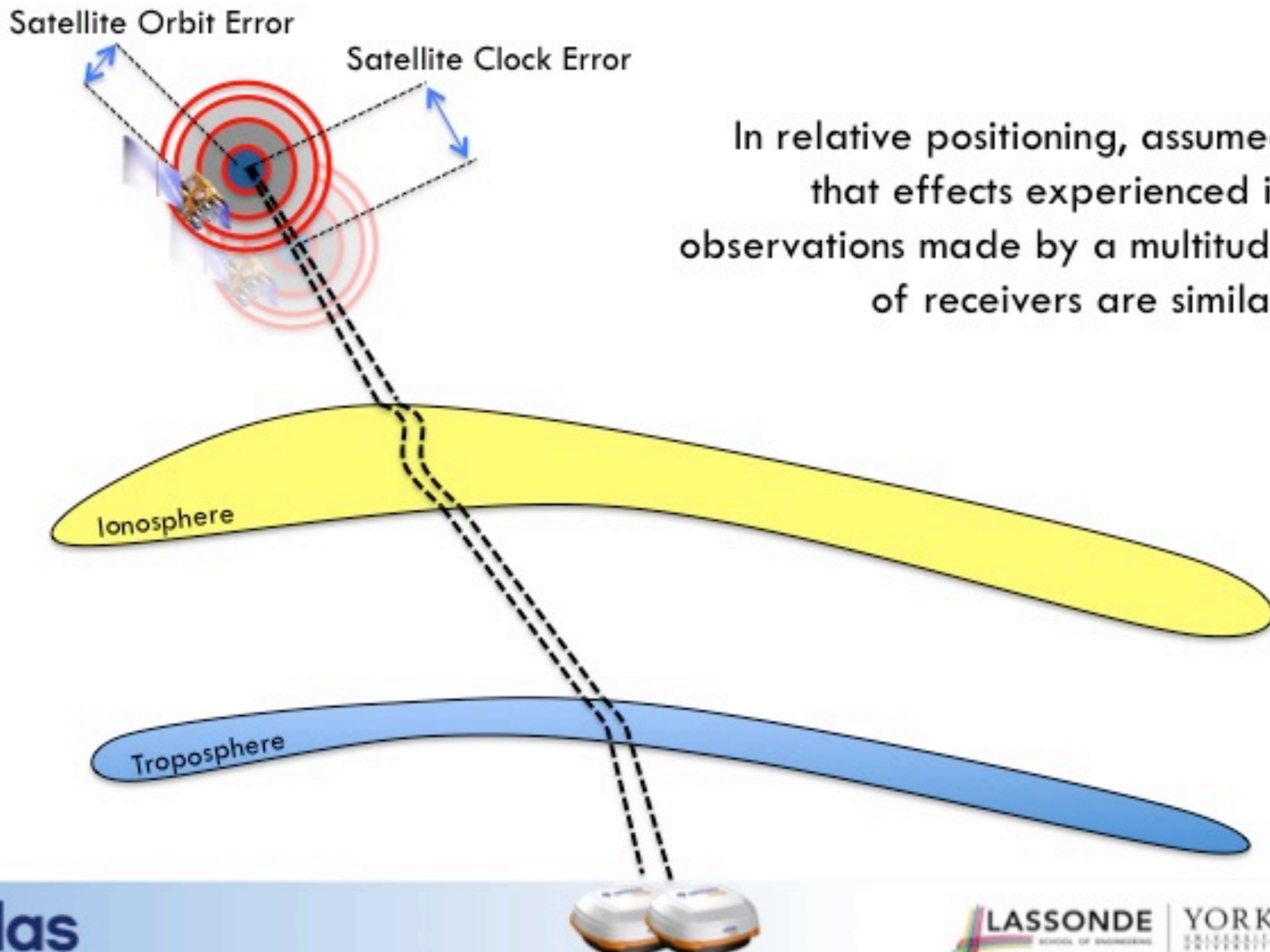


Pure phase measurements don't provide significant advantage over filtered code in the presence of other error sources in autonomous mode.

Relative positioning



Relative positioning



In relative positioning, assumed that effects experienced in observations made by a multitude of receivers are similar.

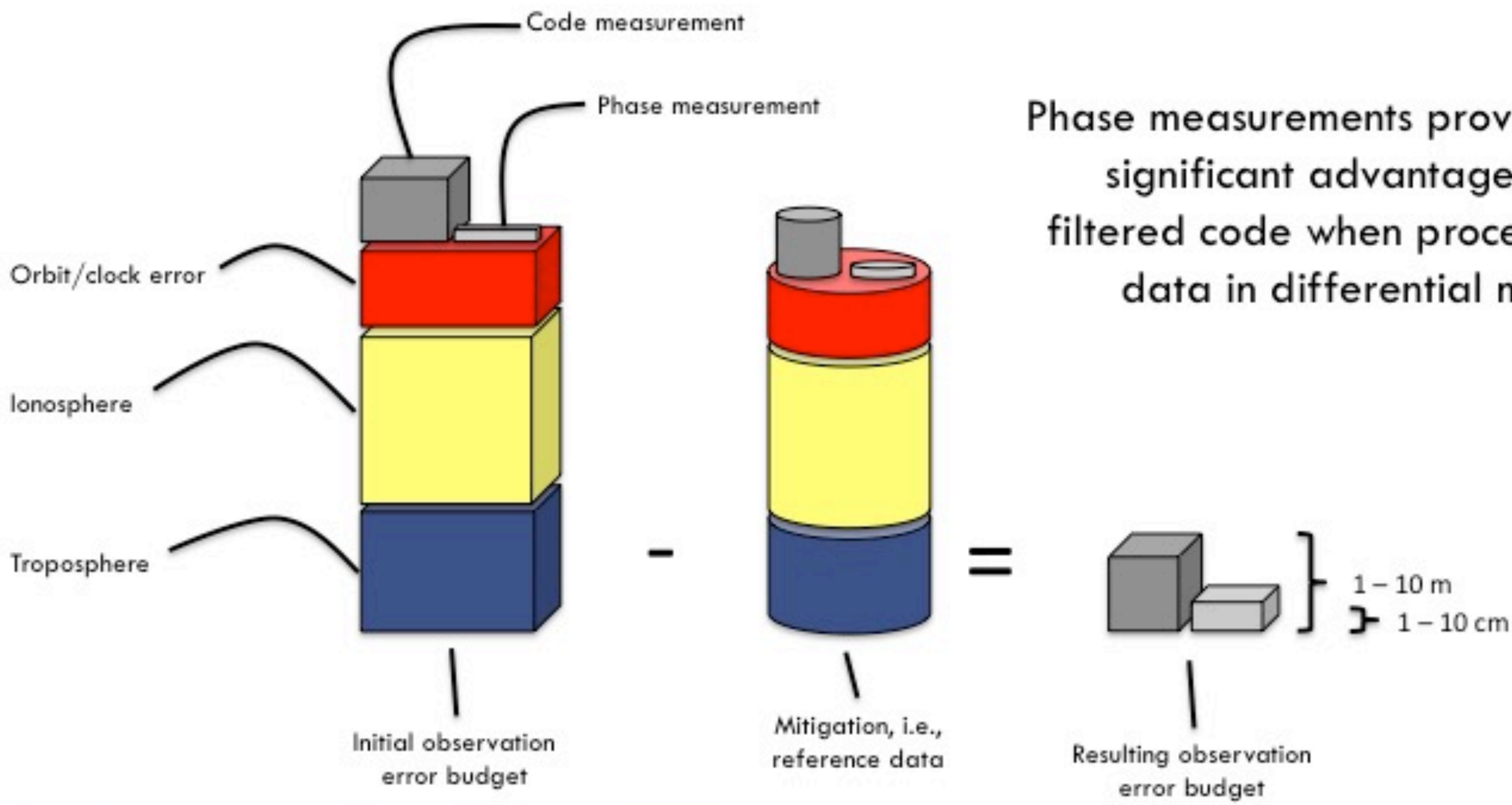
Relative positioning

Note that the effects are the same as in autonomous positioning

<table>
<tr><th>Effect</th><th>Magnitude</th><th rowspan="6">>>> Differencing >>></th><th>Post-difference impact</th></tr>
<tr><td>Satellite orbit/clock error*</td><td>1 - 2 m</td><td rowspan="3">Few mm to cm depending on distance</td></tr>
<tr><td>Ionosphere</td><td>Up to tens of meters</td></tr>
<tr><td>Troposphere</td><td>2 - 20 m</td></tr>
<tr><td>Code measurement</td><td>1 - 3 m</td><td>1.5 – 5 m</td></tr>
<tr><td>Phase measurement</td><td>0.5 – 10 cm</td><td>0.5 – 10 cm</td></tr>
</table>

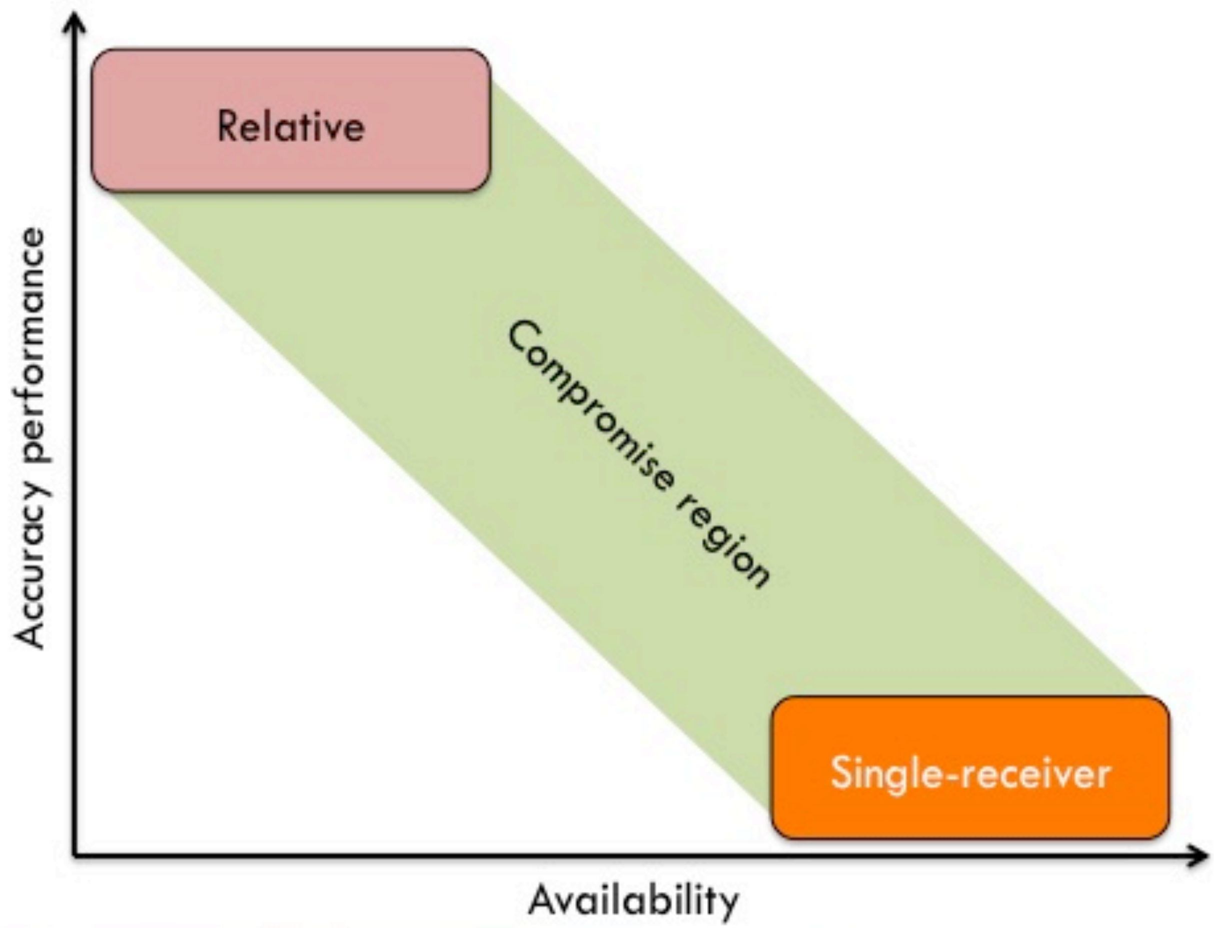
(*) As transmitted in GNSS broadcast messages

Relative positioning

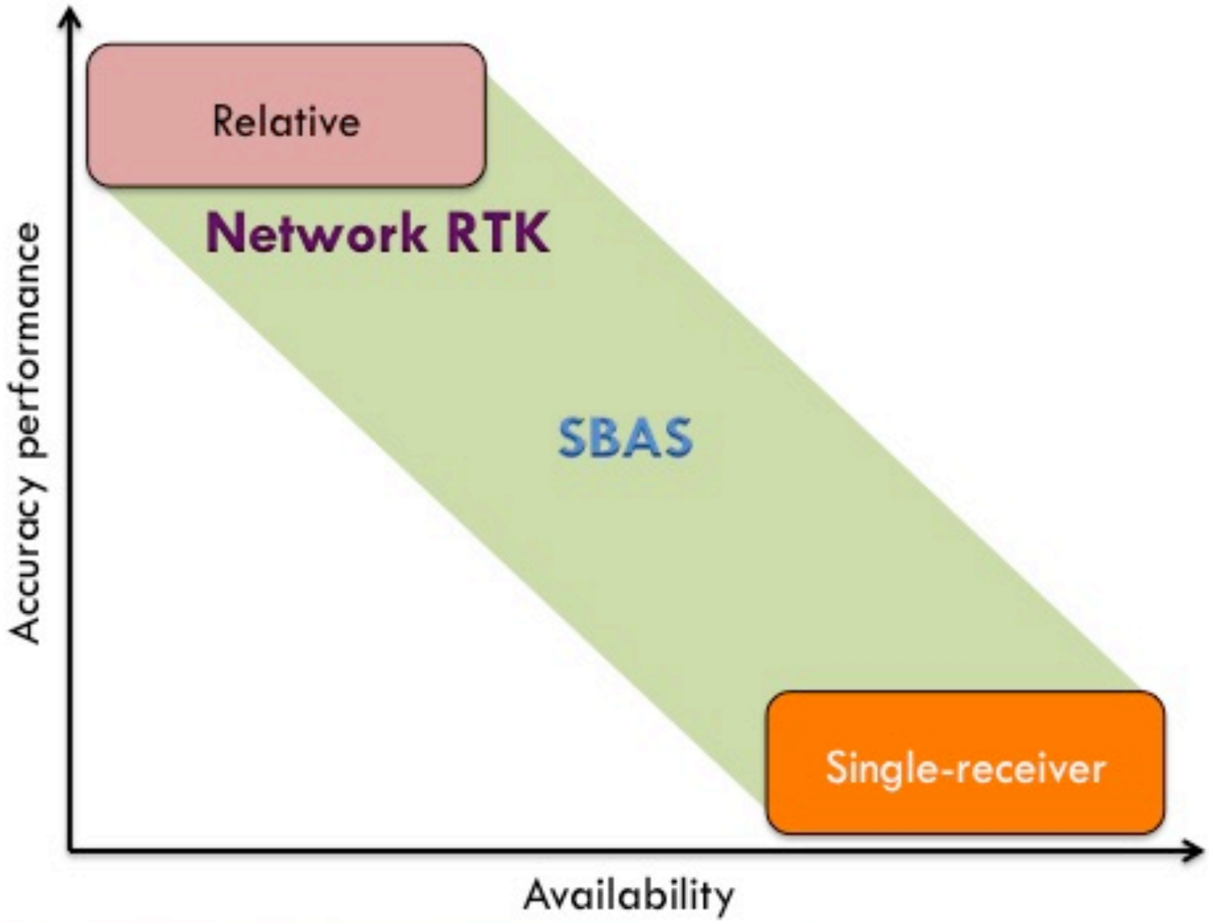


Phase measurements provide a significant advantage over filtered code when processing data in differential mode.

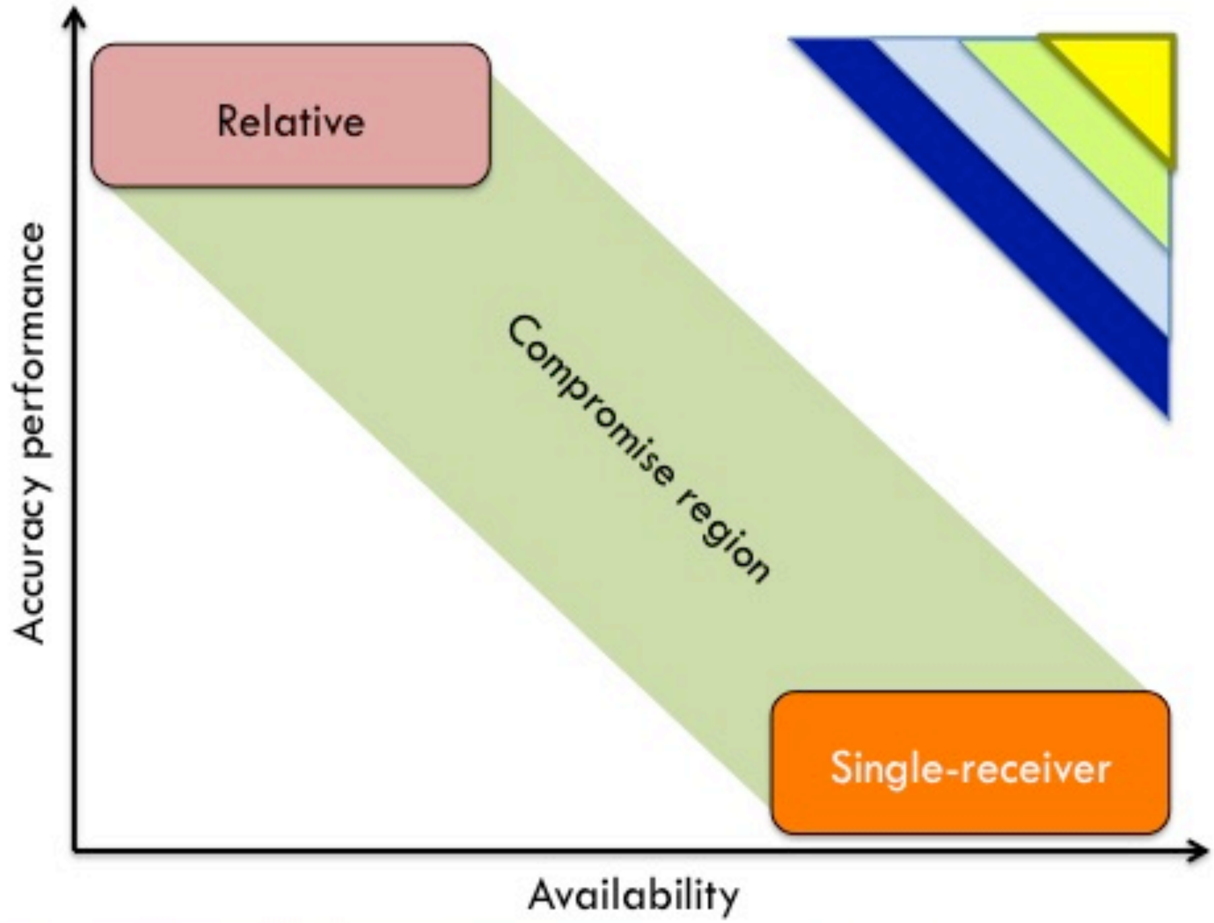
Relative vs. single-receiver



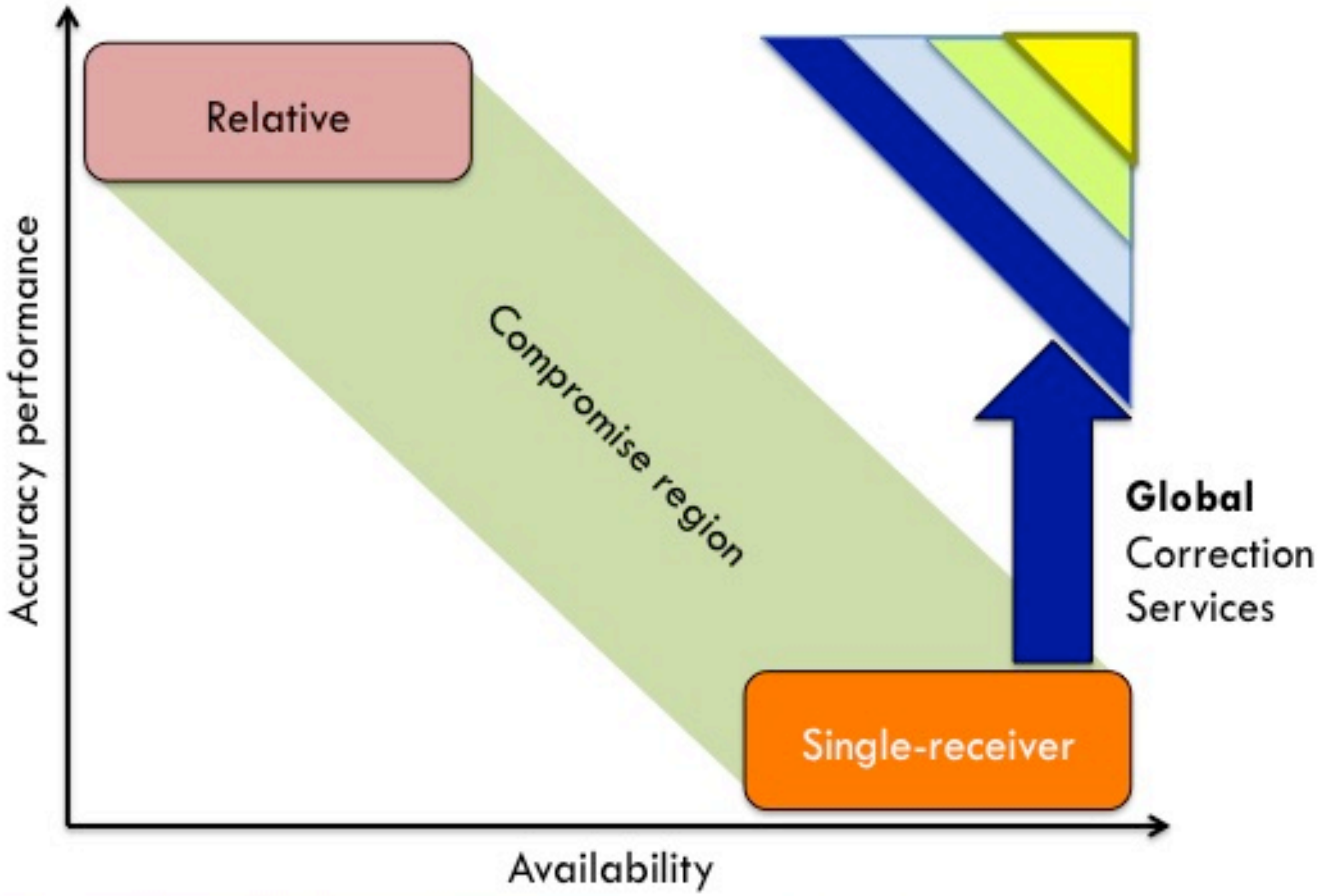
Relative vs. single-receiver



Relative vs. single-receiver



Relative vs. single-receiver



Global Correction Services

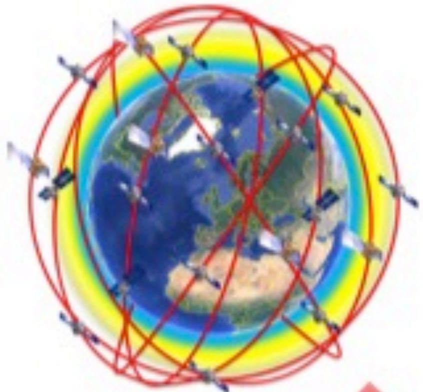
The infrastructure of global positioning systems consists of a global network of reference stations

The satellite data is transmitted to processing centers, where it is processed

The station network continuously tracks the satellites, collecting observation data

The estimation process converts observation data into satellite orbit and clock information

Global Correction Services



In addition to accurate orbits and clocks, other information such as atmospheric models can be generated

The end user receiver user the accurate satellite orbits and clocks to compute an accurate position solution.

The satellite "correction" data is then transmitted to end users over satellite or internet

The receiver implementation employs specialized algorithms that take advantage of carrier phase measurements, accurate satellite data, and comprehensive observation models.

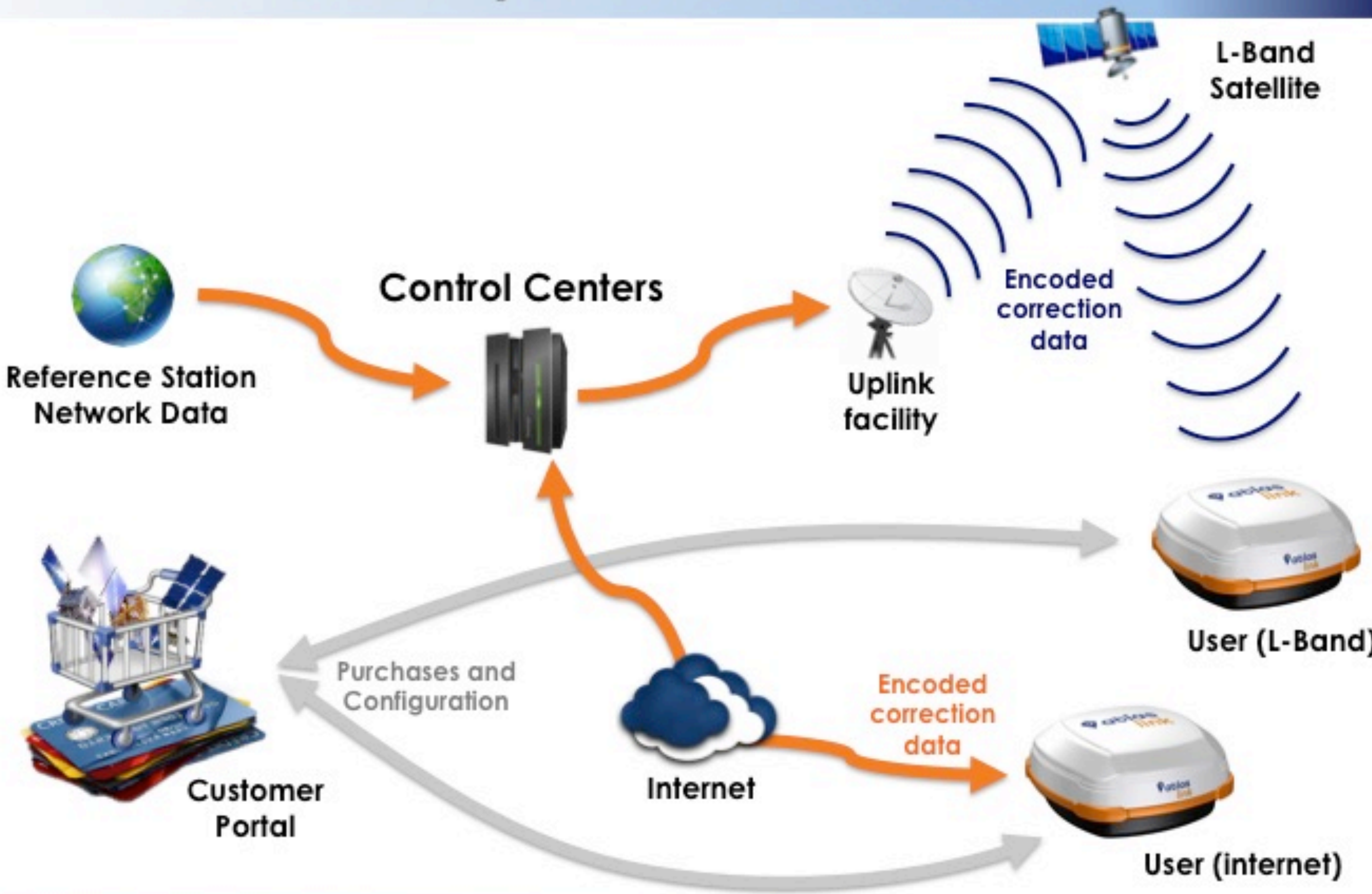
Global Correction Services

- Carrier-phase measurements contain an unknown component: the carrier-phase ambiguity
- Resolving multi-frequency ambiguities without accurate ionosphere information requires time. What does that mean?
- Global positioning systems experience a convergence phase before centimeter accuracies can be reached
- Convergence times are typically in the order of minutes

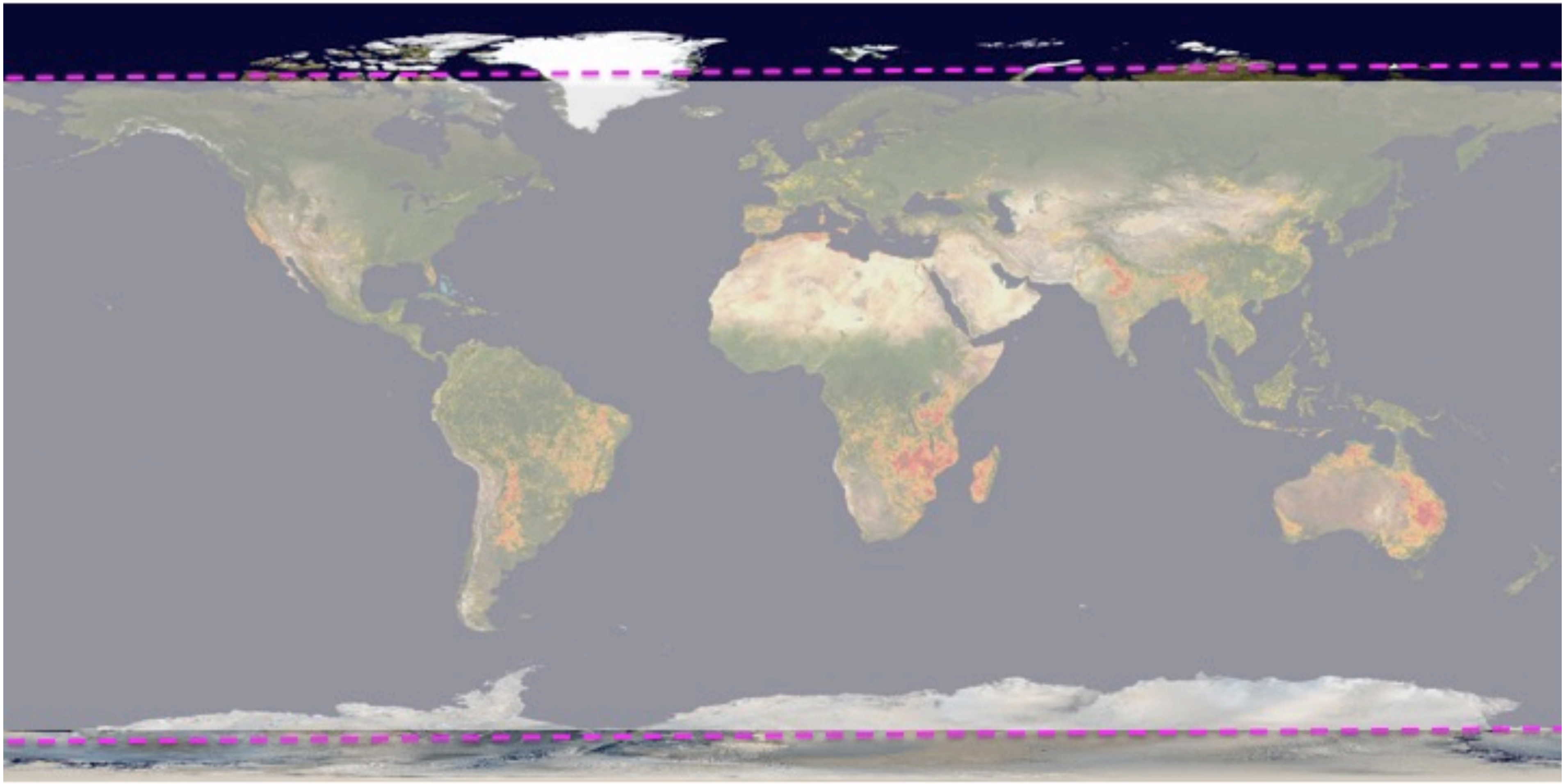
atlas

A practical correction service example

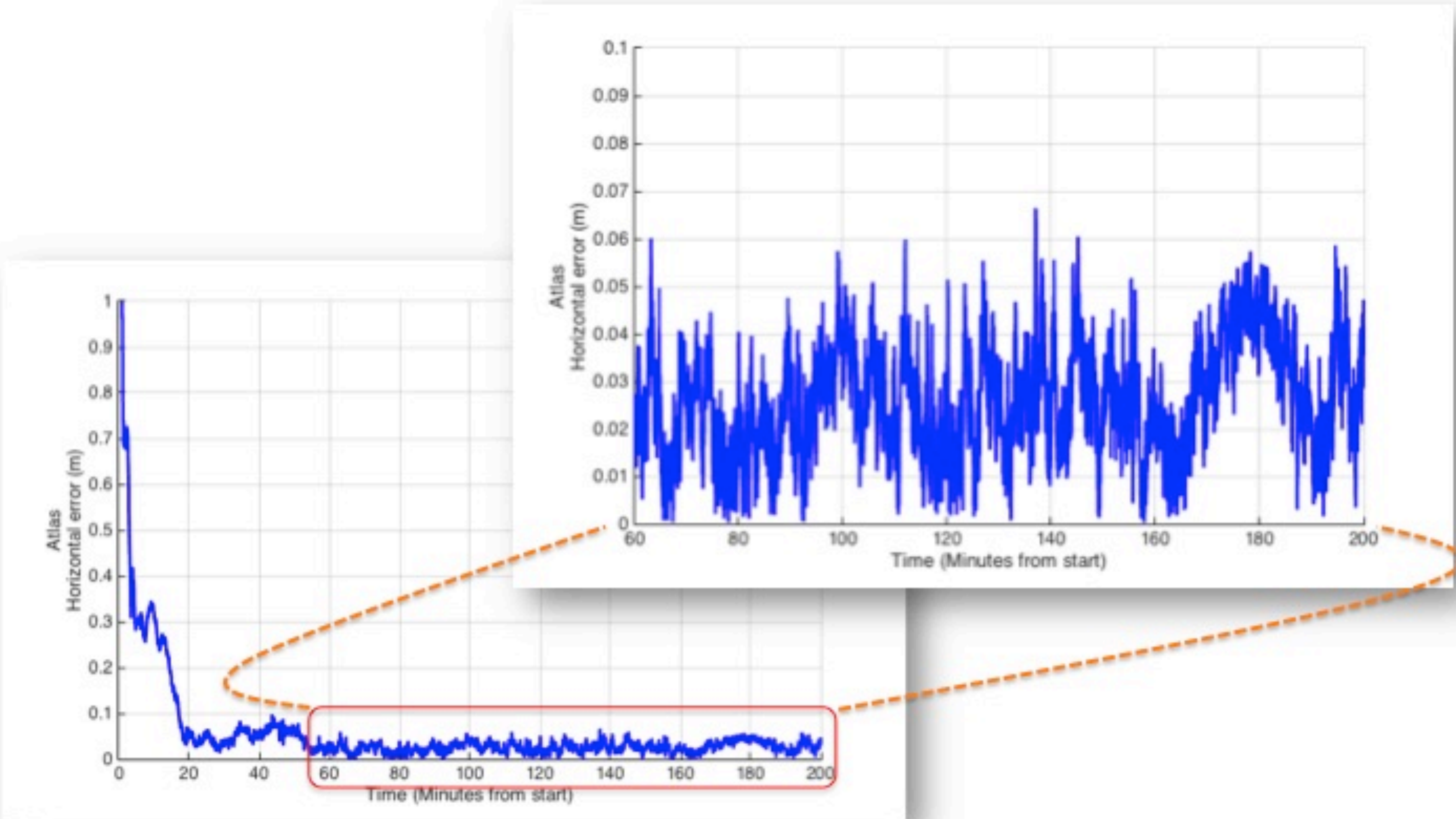
The Atlas system architecture



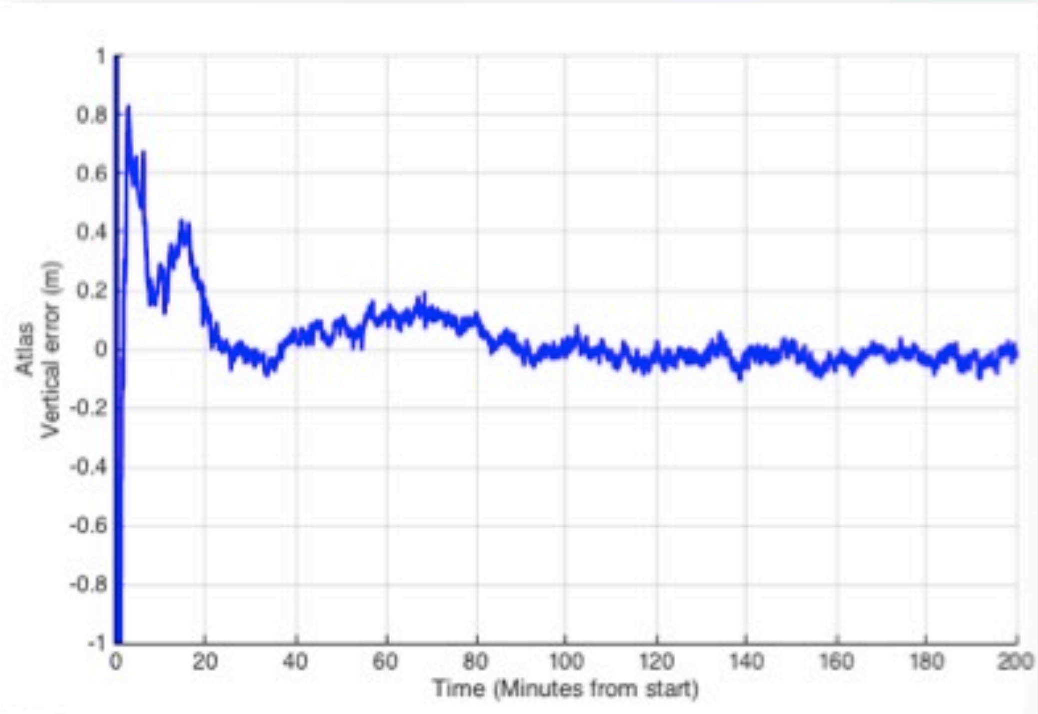
Satellite coverage

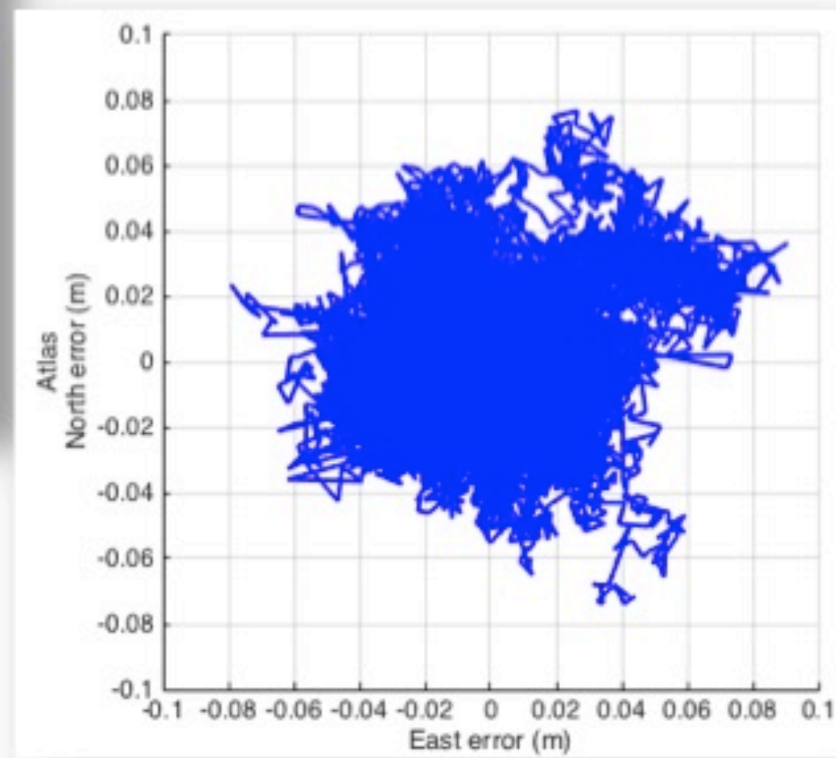


Atlas positioning performance

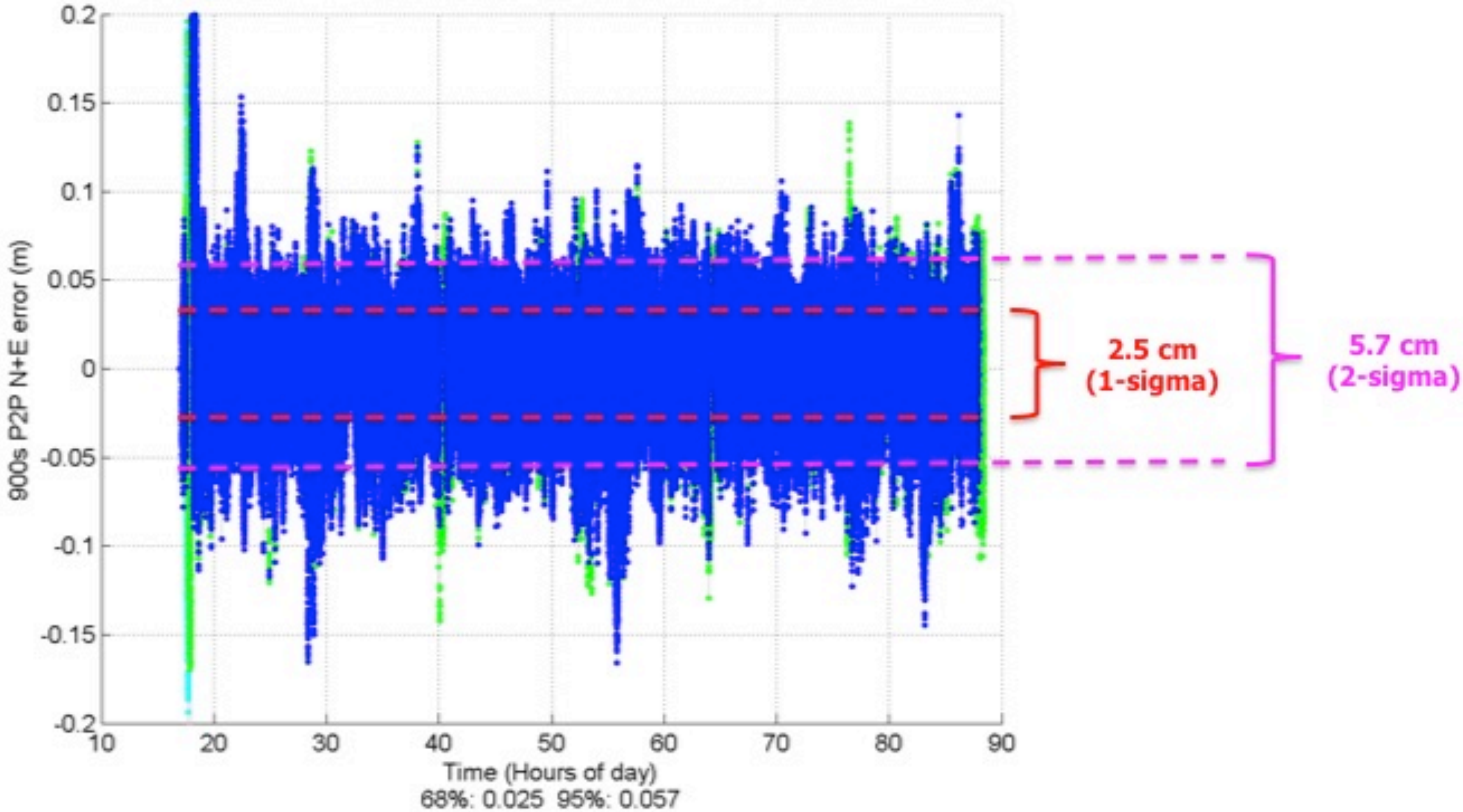


Atlas positioning performance

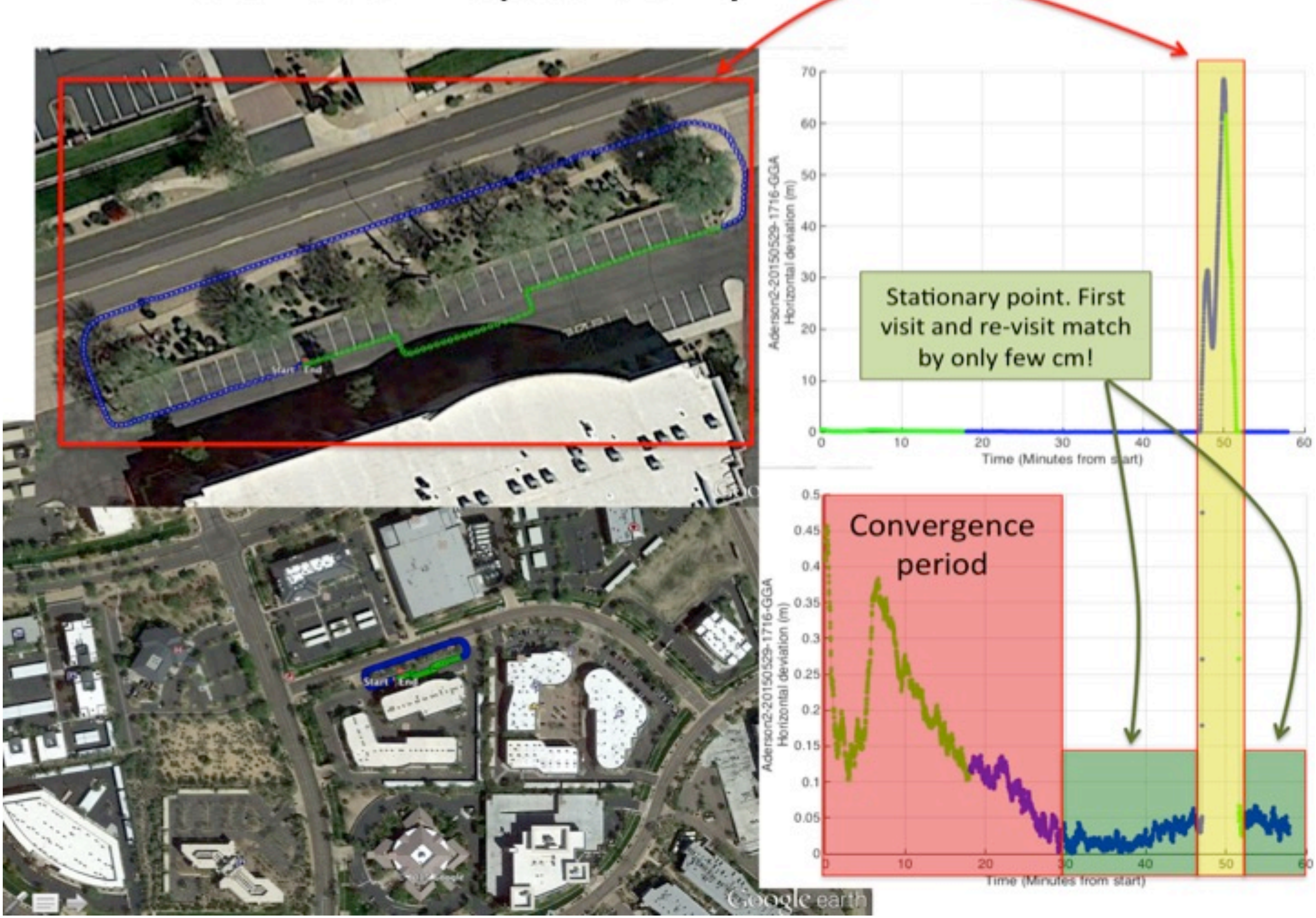




Atlas positioning performance (pass-to-pass)

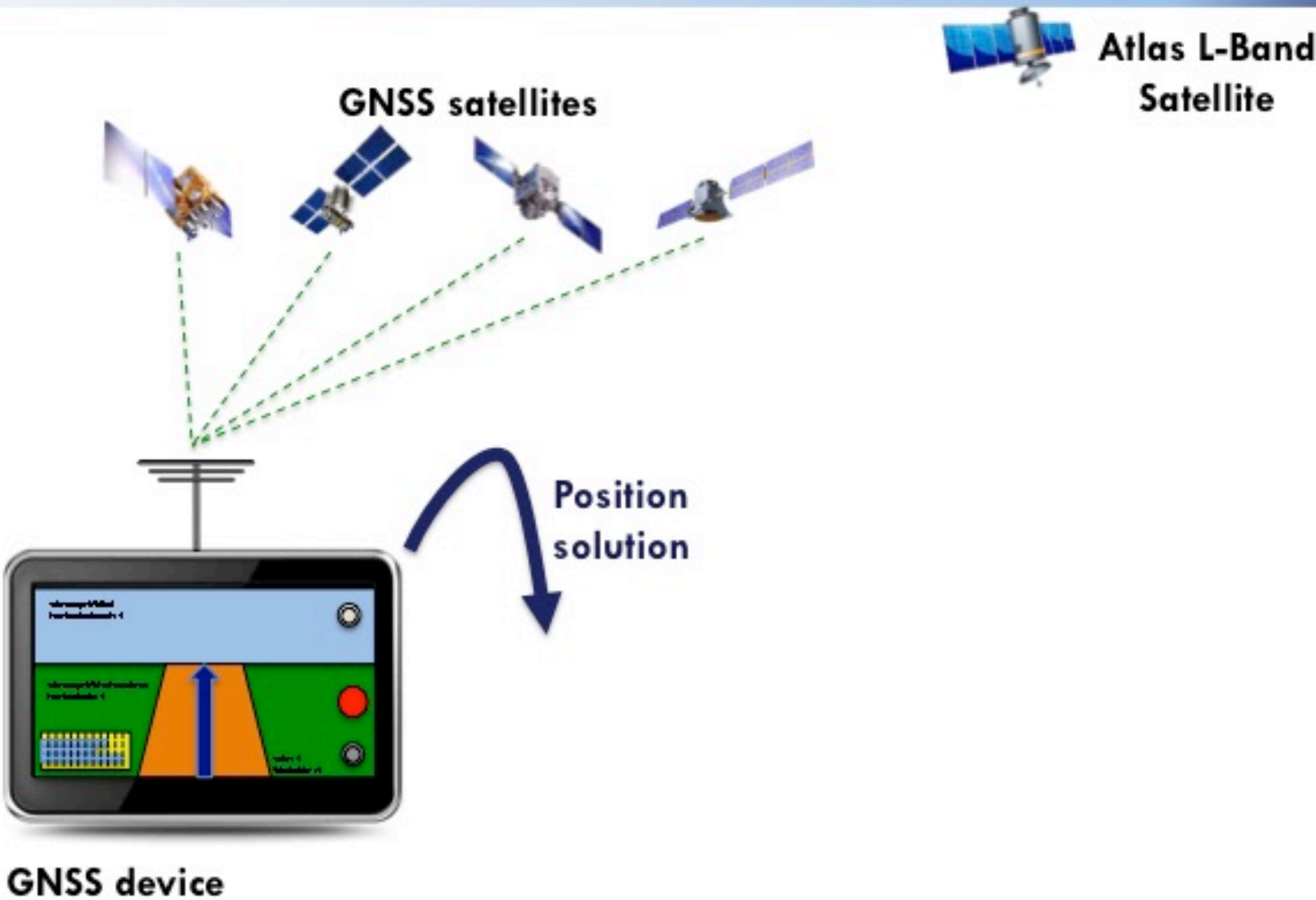


Field Tests - Repeatability

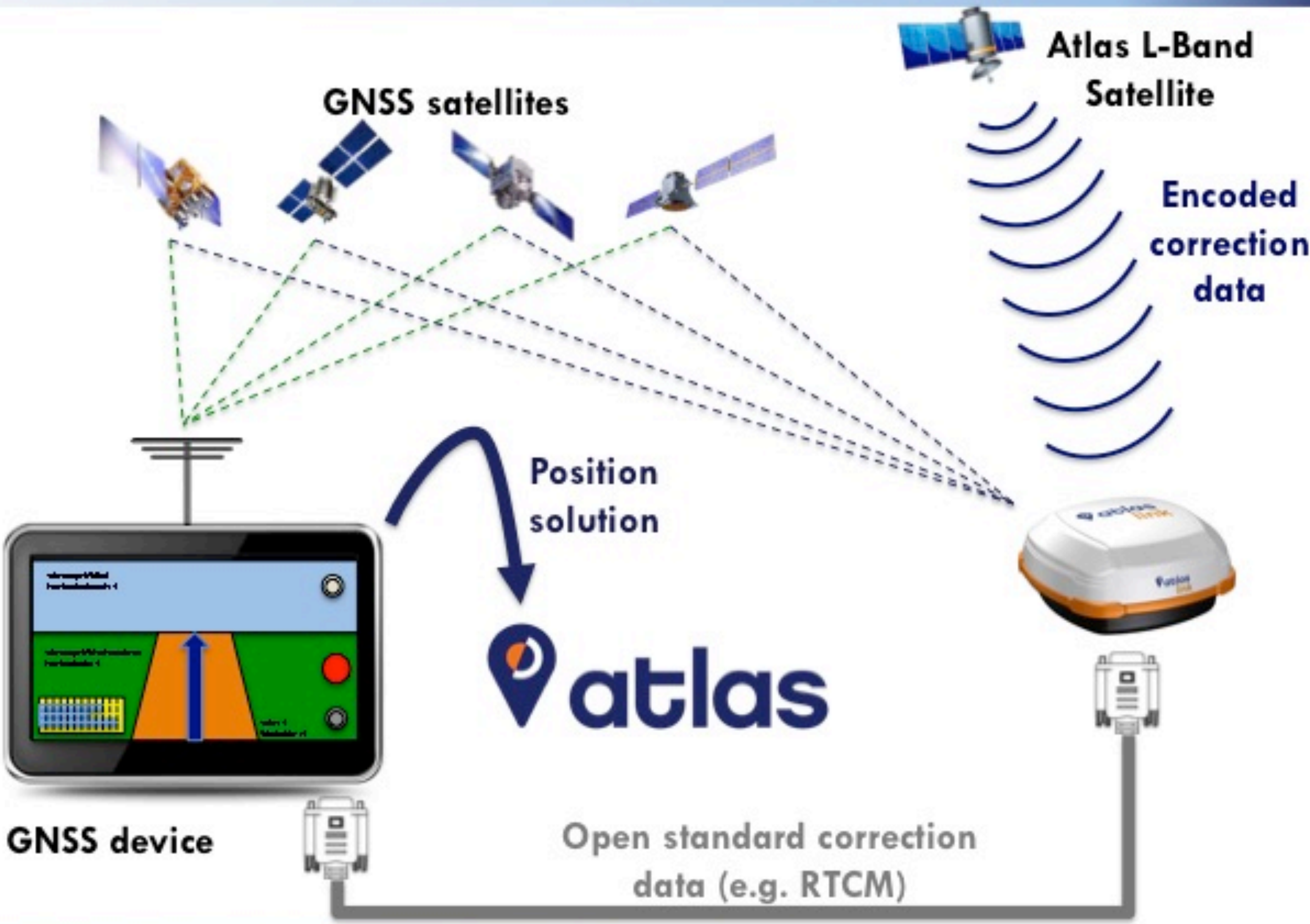


AtlasLink™ smart antenna

SmartLink™

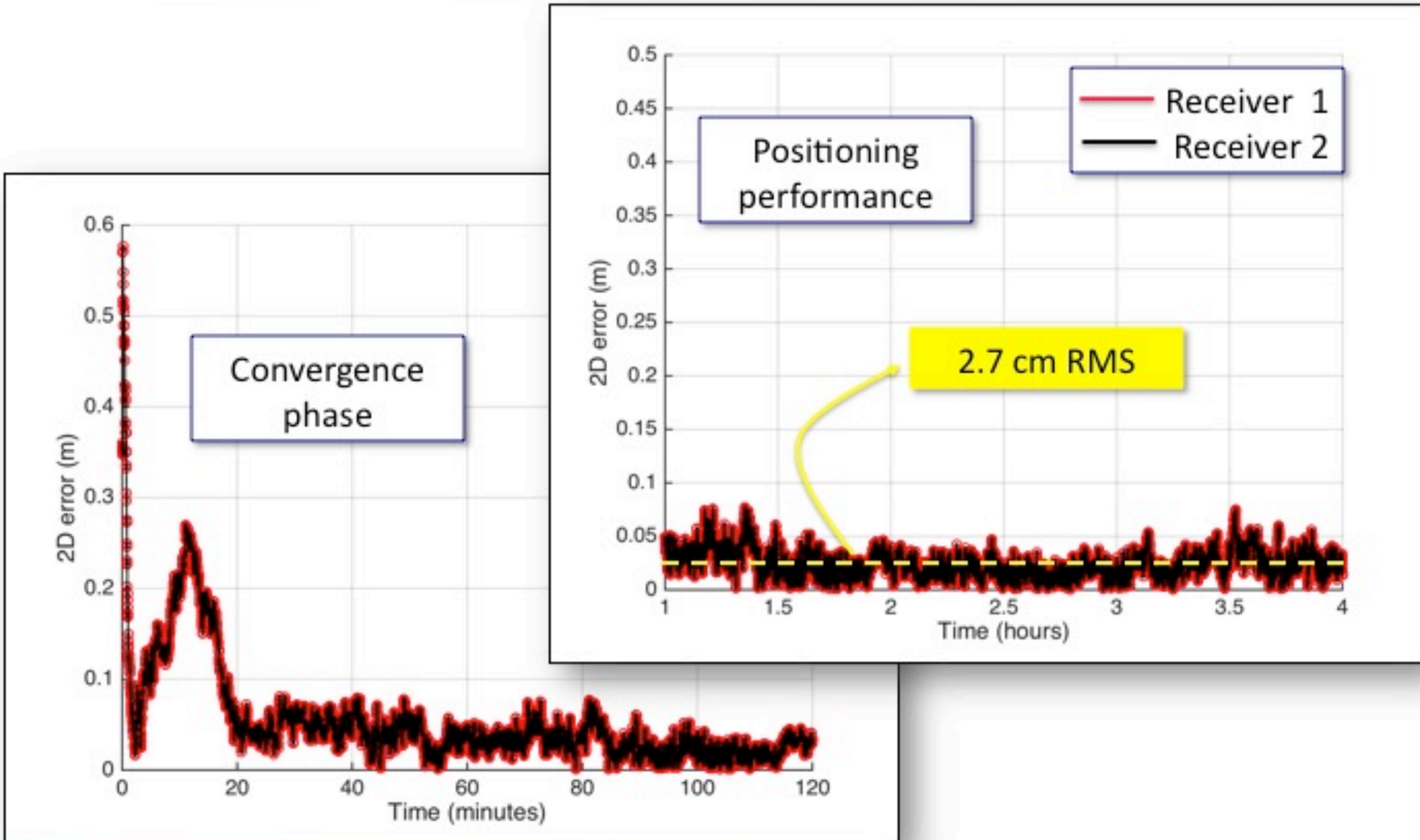

Atlas L-Band
Satellite
GNSS satellites
Position
solution
GNSS device

SmartLink™

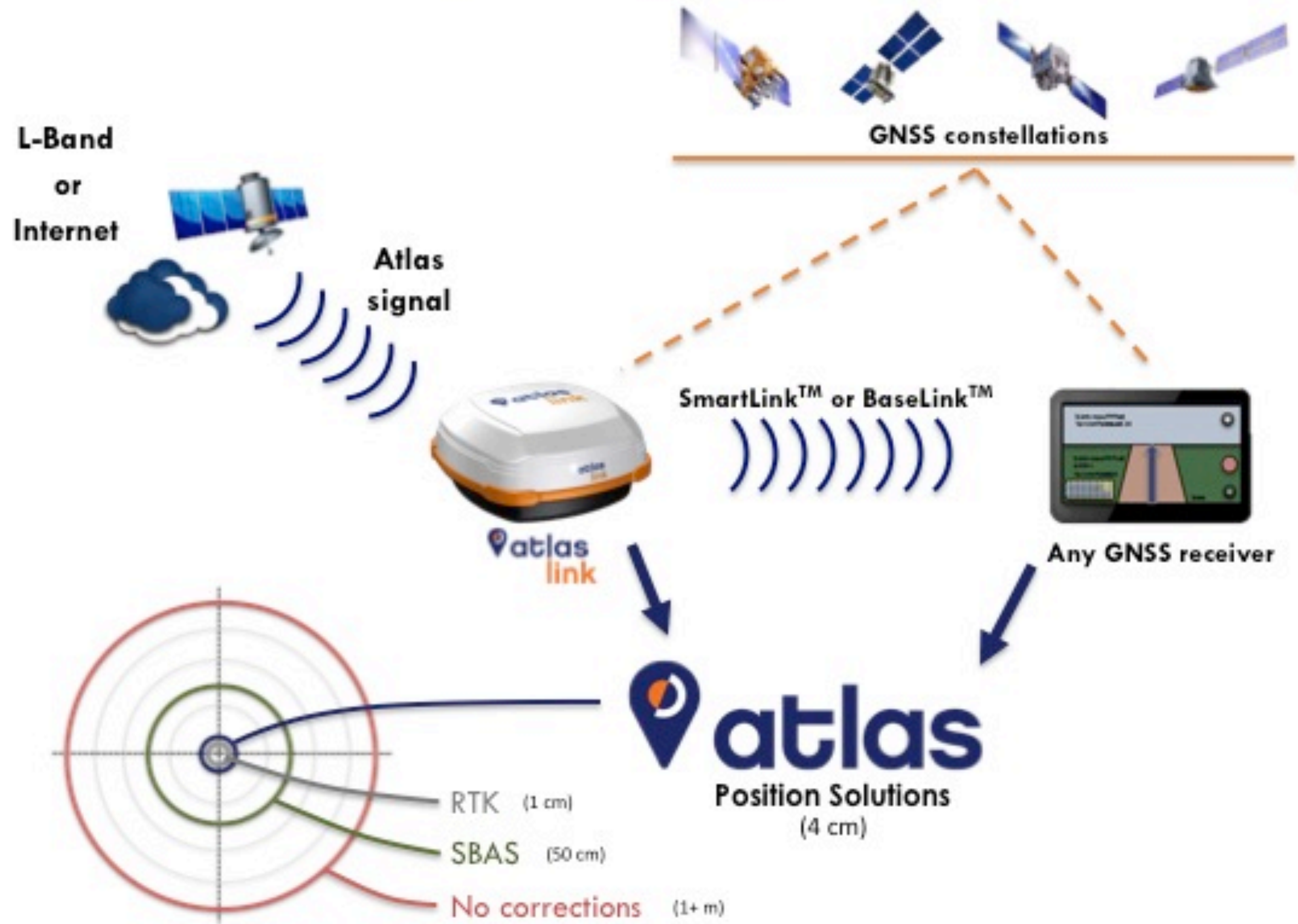

GNSS satellites
Atlas L-Band
Satellite
Encoded
correction
data
Position
solution
atlas
GNSS device
Open standard correction
data (e.g. RTCM)

SmartLink^{TM}

SmartLink™


Convergence phase
2D error (m)
Time (minutes)
Positioning performance
Receiver 1
Receiver 2
2.7 cm RMS
2D error (m)
Time (hours)

Atlas system summary



Future trends: Accuracy

Can remaining errors be reduced to reach best relative positioning accuracies?

- Improvement potential from detailed error analysis:
  - Ionospheric estimation
  - Tropospheric estimation
  - Pseudorange and phase multipath and noise
  - Satellite orbits, clocks and equipment delays (post-processed and real-time)

Future trends: Accuracy

- Ionospheric estimation:
  - Improvements, especially with new multi-frequency combinations
  - Improved models for single-frequency processing
- Tropospheric estimation:
  - Small improvements possible
- Pseudorange and phase multipath and noise:
  - Initial small improvements made
  - Room for more improvements
- Satellite orbits, clocks, and equipment delays (post-processed and real-time):
  - Small improvements possible
  - Real-time product accuracy approaching post-processed
  - Greater access to satellite bias corrections via real-time streams

Future trends: Convergence

Can initial convergence period be reduce to allow performance comparable to (network) RTK?

- Improvement potential:
  - Multi-frequency and multi-constellation measurements
  - Consistency, quality and integrity of solution performance
  - Mitigating pseudorange and phase noise and multipath
  - Use of other data to aid initialization
  - Robust re-convergence
  - Robust ambiguity resolution and validation

Future trends: Convergence

- Multi-frequency and multi-constellation measurements:
  - Significant reductions
- Consistency, quality and integrity of solution performance:
  - More research being done
- Mitigating pseudorange and phase noise and multipath:
  - Early research results show some improvements
- Use of other data to aid initialization:
  - (Network) RTK; inertial
- Robust re-convergence:
  - Has been developed
- Robust ambiguity resolution and validation:
  - Good resolution results; research continuing

Future trends: Consumer market

Will global services be used with next-generation low-cost, multi-GNSS, multi-frequency chips and antennas for much wider usage?

- Improvement potential:
    - Mitigating pseudorange and carrier-phase noise, multipath, and phase cycle slips
    - Assisted GNSS
    - GNSS + IMU + other sensors

Future trends: Consumer market

- Mitigating pseudorange and carrier-phase noise, multipath and phase cycle slips:
  - Will be very challenging
  - Greatest limitation to implementation
- Assisted GNSS:
  - Already used in mobile phones for C/A-code processing
  - Maybe adaptable to global services tech
  - Can only help make implementation possible
  - MEMS-based IMUs, magnetometers, etc.
- GNSS + IMU + other sensors:
  - Very active research
  - More robust positioning

Future trends: Summary

- With more signals, global services performance is getting more RTK-like
- But as or more importantly:
  - Globally available, general corrections from various sources are now being generated for few-cm single user receiver positioning and navigation
  - Precision solutions are expected from lower-cost, multi-sensor systems

QUESTIONS?

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