The impact of new signals on precise marine navigation - initial results from an experiment in Harwich harbour

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Alex Parkins[1], Alan Grant[2] and Paul Cross[1]

[1] Department of Civil, Environmental and Geomatic Engineering, University College London
[2] General Lighthouse Authorities of the United Kingdom and Ireland

International Maritime Organisation requirements for a future GNSS

IMO navigation requirements	Accuracy	Integrity			Continuity	Availability
		Alert limit	Time to alert	Integrity risk	over 3 hours	per 30 days
Ocean and coastal	10 m	25 m	10 s	10^{-5}	N/A	99.8%
Port approach	10 m	25 m	10 s	10^{-5}	99.97%	99.8%
Port navigation	1 m	2.5 m	10 s	10^{-5}	99.97%	99.8%
Automatic docking	0.1 m	0.25 m	10 s	10^{-5}	99.97%	99.8%

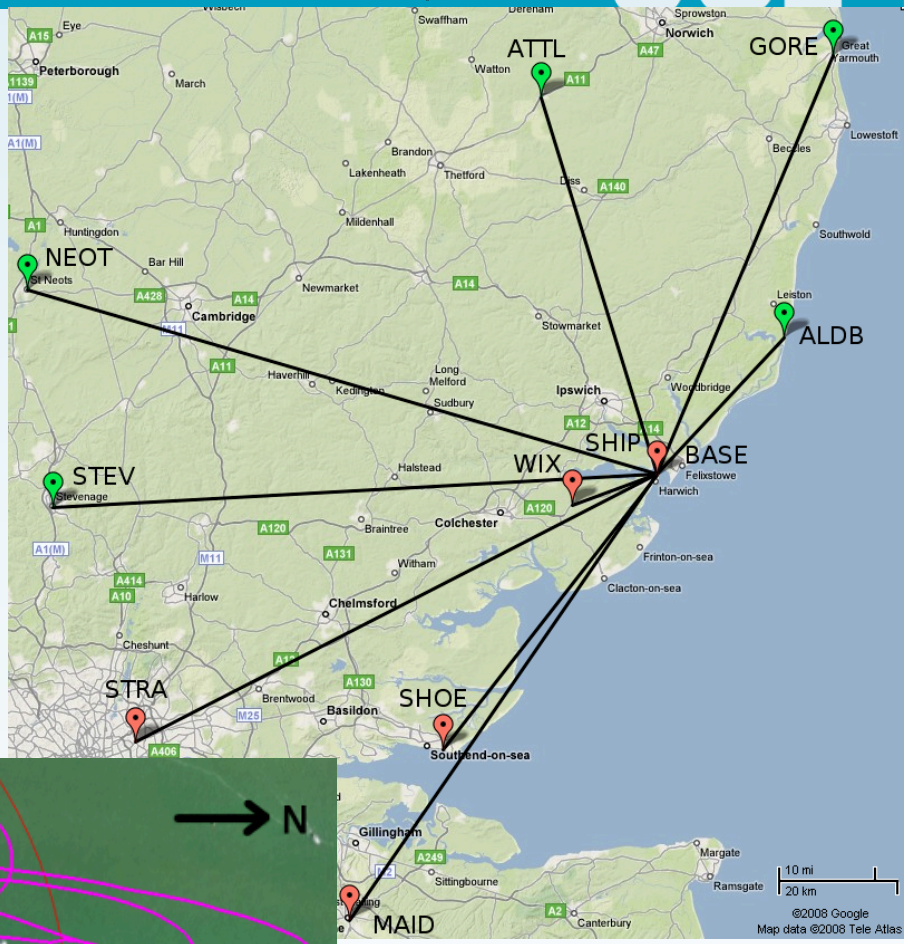
IMO Resolution A.915

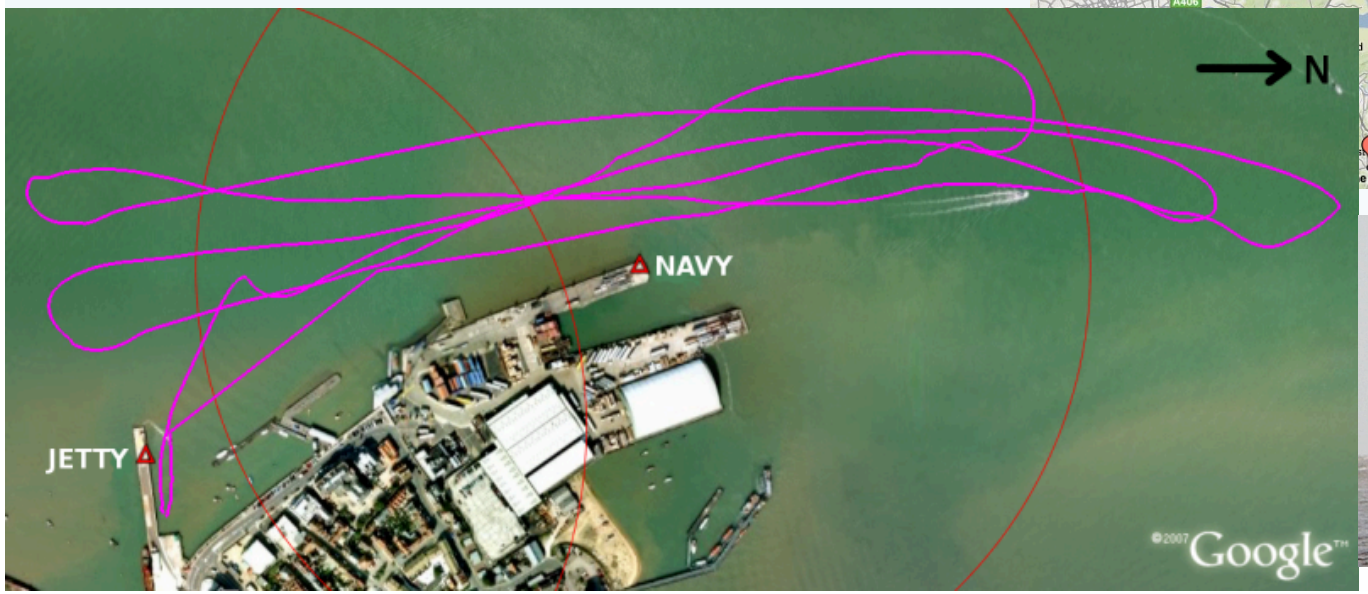
Research questions

- What techniques are capable of meeting these requirements?
- What infrastructure is required?
- What are the benefits of modernised GPS and Galileo?

Data collection (1)

- *THV Alert* simulating docking in Harwich harbour
- 1 hour 20 min of 1 Hz GPS data
- L2C signal recorded
- OS reference station data obtained
- Two total stations provide truth model

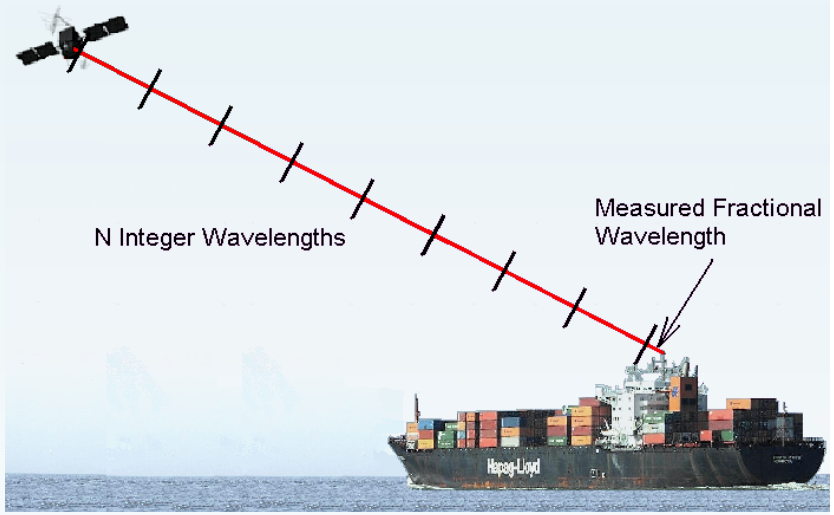




Data collection (2)

GPS processing techniques

- Point positioning
  - Stand-alone code positioning
- Differential GPS (DGPS)
  - Local reference station used to reduce code error
- Single-epoch Real Time Kinematic (RTK)
  - Phase observations used as precise ranges
  - Robust against loss-of-lock and cycle slips
  - Reference station required

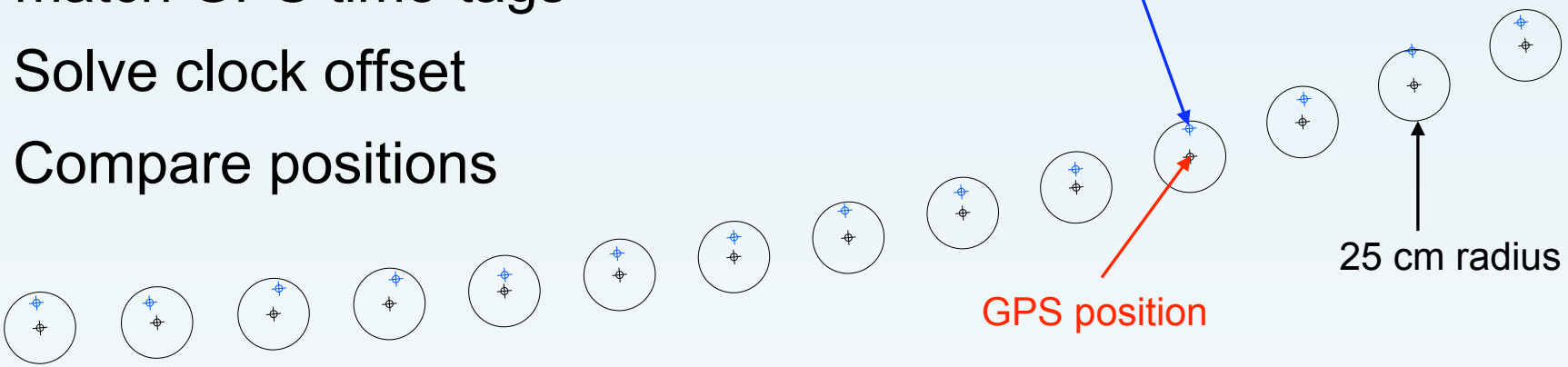


Variety of baseline lengths processed

- Determine infrastructure necessary to meet IMO requirements

Truth model (1)

1. Interpolate total station positions to match GPS time-tags
2. Solve clock offset
3. Compare positions

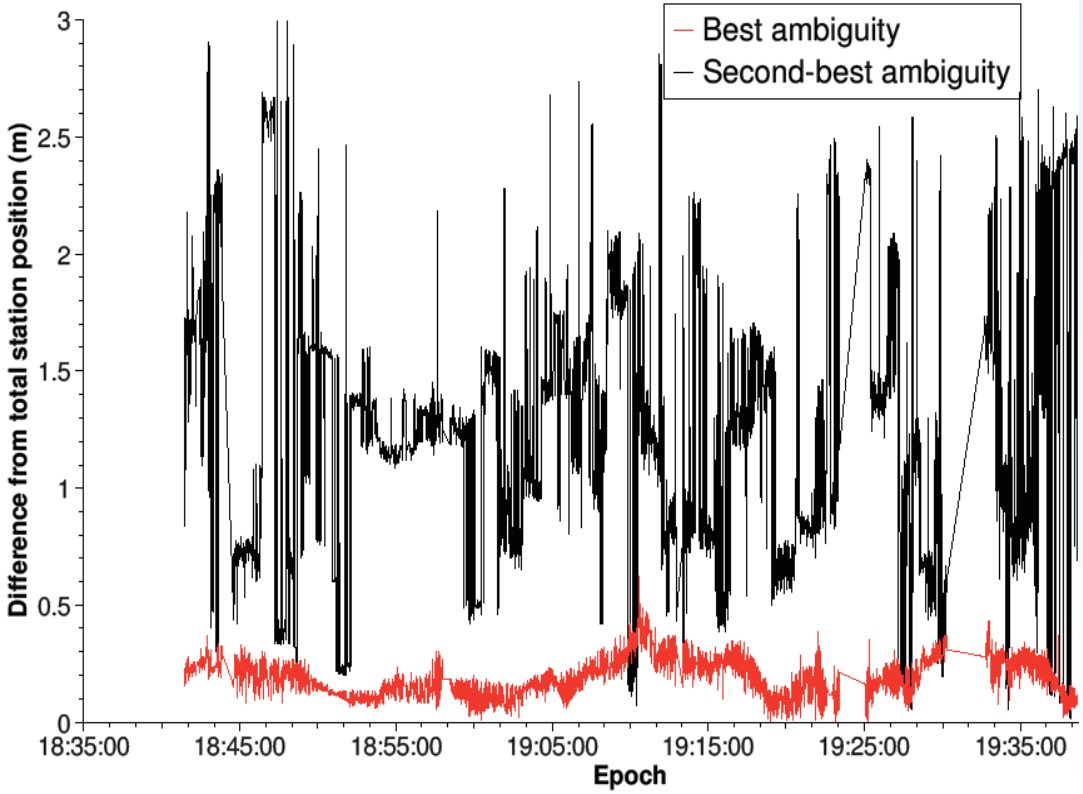


- Total station measurement update not synchronous with position output
  - Significant error source
- Total stations agree with each other to 0.5 m (95%)
  - But strictest IMO requirement is 0.1 m (95%)

Total stations not sufficiently accurate to provide truth model

Truth model (2)

- Short-baseline (1 km) RTK GPS is very accurate
  - But ambiguity resolution must be correct
- Total station measurements used to validate ambiguity resolution



- Best ambiguity set does not change
- Second-best set often changes

Use the short-baseline GPS as the truth model – ambiguities validated

Determining the requirements

Difficult to apply the IMO requirements directly

Definitions used:

- **Accuracy**
  - 95th percentile of the difference between the obtained positions and the truth
- **Integrity Risk**
  - Proportion of 10 s spans containing at least one integrity error and no valid positions
- **Availability**
  - Percentage of 10 s spans that contain at least one valid position
- **Continuity**
  - Percentage of the total experiment time covered by the longest span with no 10 s gaps

Were the requirements met?

	Point positioning	Differential GPS	Real Time Kinematic
Ocean and coastal	Yes	> 110 km baseline	Dual-freq. 1 km baseline
Port approach	Yes	> 110 km baseline	Dual-freq. 1 km baseline
Port navigation	Too low accuracy	> 110 km baseline	Dual-freq. 1 km baseline
Automatic docking	Too low accuracy	Too low accuracy	Dual-freq. 1 km baseline

Ambiguity resolution difficulties

- RTK limited by availability and continuity
  - Linked to ambiguity resolution success rate
- Difficult environment

Using single-epoch geometry-based technique:

- Phase observations cannot be checked for outliers before ambiguity resolution
- Outlier in a single phase observation can prevent successful ambiguity resolution

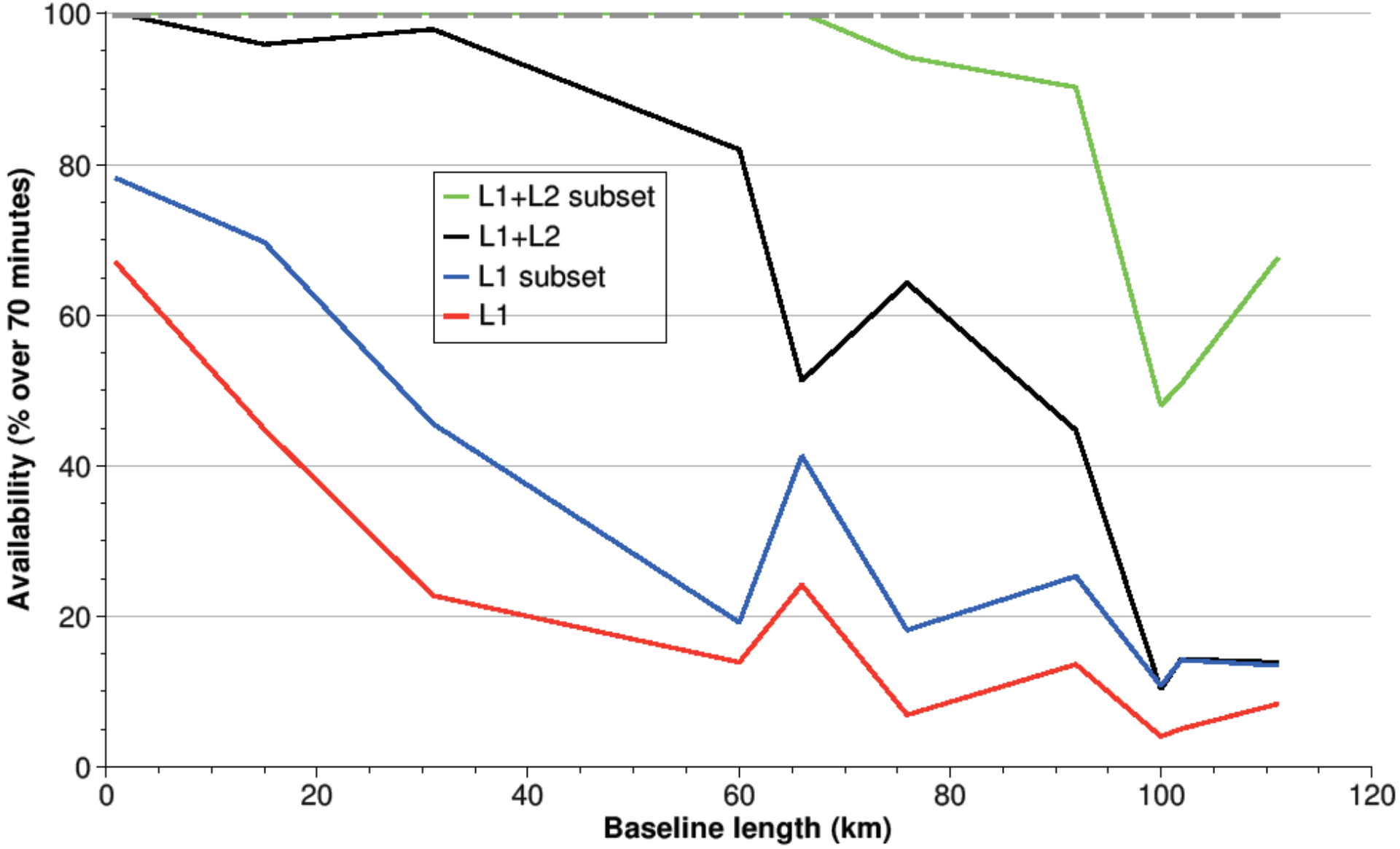
Subset ambiguity resolution algorithm

- Only apply if normal ambiguity resolution fails

1. Generate all ambiguity subsets
2. Order according to some criterion
3. Attempt to fix each in turn
   - Only accept if values are what we are expecting from previous epochs

- Computationally intensive

RTK availability



Summary

IMO navigation requirements	Accuracy	Integrity			Continuity	Availability
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- Point positioning for ocean and coastal, and port approach
- DGPS also meets port navigation requirements
- Dual-frequency RTK required for automatic docking
  - 1 km maximum baseline
- Subset ambiguity resolution extends this to 66 km

Further work

- Determine benefits of modernised GPS and Galileo

Acknowledgements

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