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Carrier Phase Ambiguity Resolution for Ship Attitude Determination and Dynamic Draught

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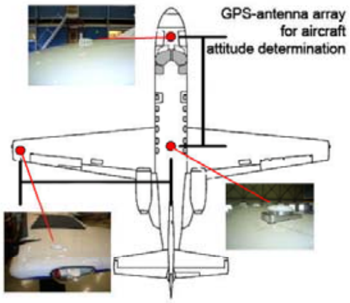
Challenge the future

Single baseline attitude determination: the Compass solution

Applications:

- ***Land***
- ***Sea***
- ***Air***
- ***Space***



Motivation of the work

- Single-frequency solutions are of interests for many different applications (e.g. low-power, low-cost)
- The ambiguity resolution process is particularly challenging
- A constrained (non-linear) method is given to tackle the GNSS-Compass problem
- We explore the performance of the Constrained LAMBDA method for maritime applications - ship attitude determination and dynamic draught -

Presentation outline

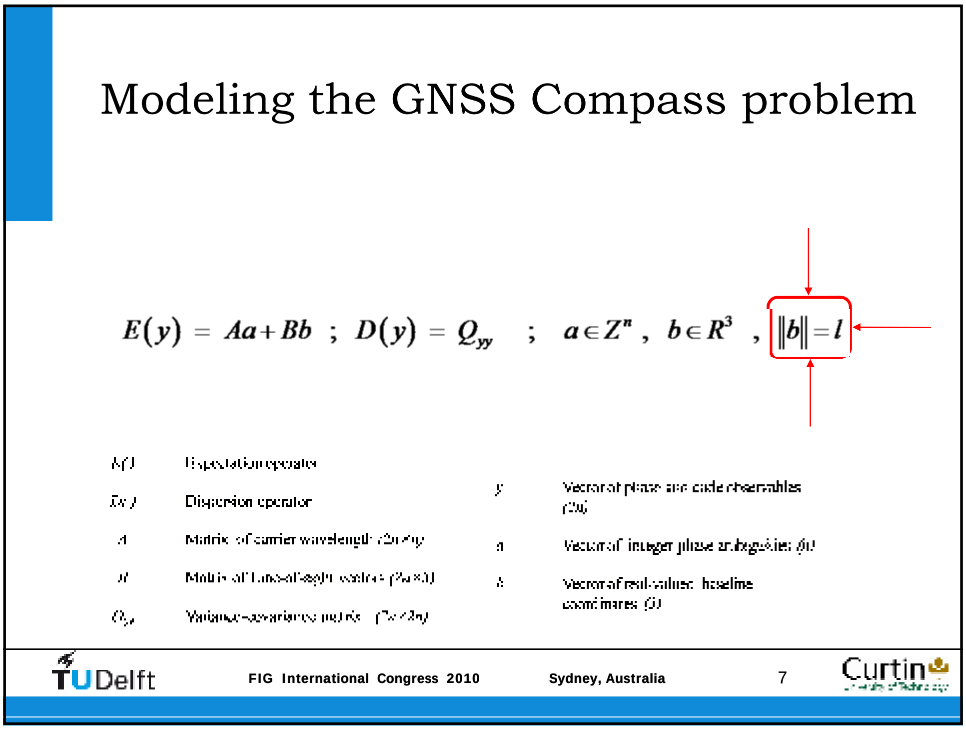
- The observation model: functional and stochastic model of the GNSS observables
- The LAMBDA method and its Constrained version
- Kinematic experimental results: navigation in the Hong Kong harbor
- Conclusions

Modeling the GNSS observations

- *2* antennae tracking the same *n+1* satellites
- Double Differences on short baselines
- Gauss-Markov model:

$$E(y) = Aa + Bb \;;\; D(y) = Q_{yy} \quad;\quad a \in Z^n \,,\; b \in R^3$$

$E(\cdot)$	Expectation operator		
$D(\cdot)$	Dispersion operator	y	Vector of phase and code observables (2n)
A	Matrix of carrier wavelength (2n×n)	a	Vector of integer phase ambiguities (n)
B	Matrix of Line-of-sight vectors (2n×3)	b	Vector of real-valued baseline coordinates (3)
Q_{yy}	Variance-covariance matrix (2n×2n)		



Modeling the GNSS Compass problem

$$E(y) = Aa + Bb \;;\; D(y) = Q_{yy} \;\;;\;\; a \in Z^n \;,\; b \in R^3 \;,\; \boxed{\|b\| = l}$$

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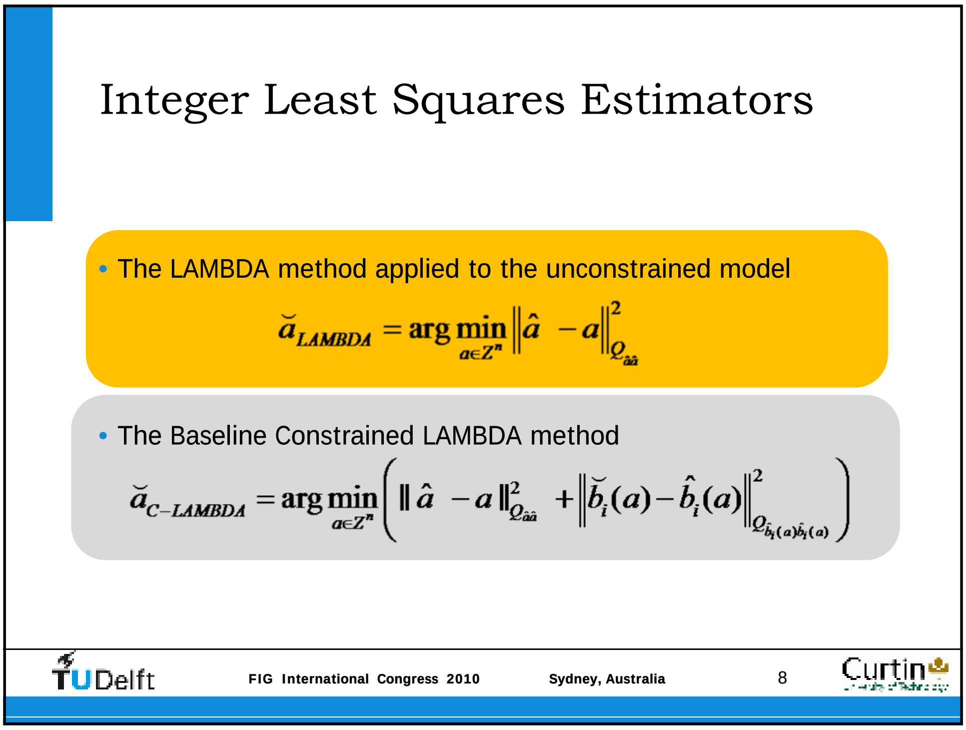

Integer Least Squares Estimators

- The LAMBDA method applied to the unconstrained model

$$\breve{a}_{LAMBDA} = \arg\min_{a \in Z^n} \left\| \hat{a} - a \right\|^2_{Q_{\hat{a}\hat{a}}}$$

- The Baseline Constrained LAMBDA method

$$\breve{a}_{C-LAMBDA} = \arg\min_{a \in Z^n} \left(\| \hat{a} - a \|^2_{Q_{\hat{a}\hat{a}}} + \left\| \breve{b}_i(a) - \hat{b}_i(a) \right\|^2_{Q_{\hat{b}_i(a)\hat{b}_i(a)}} \right)$$

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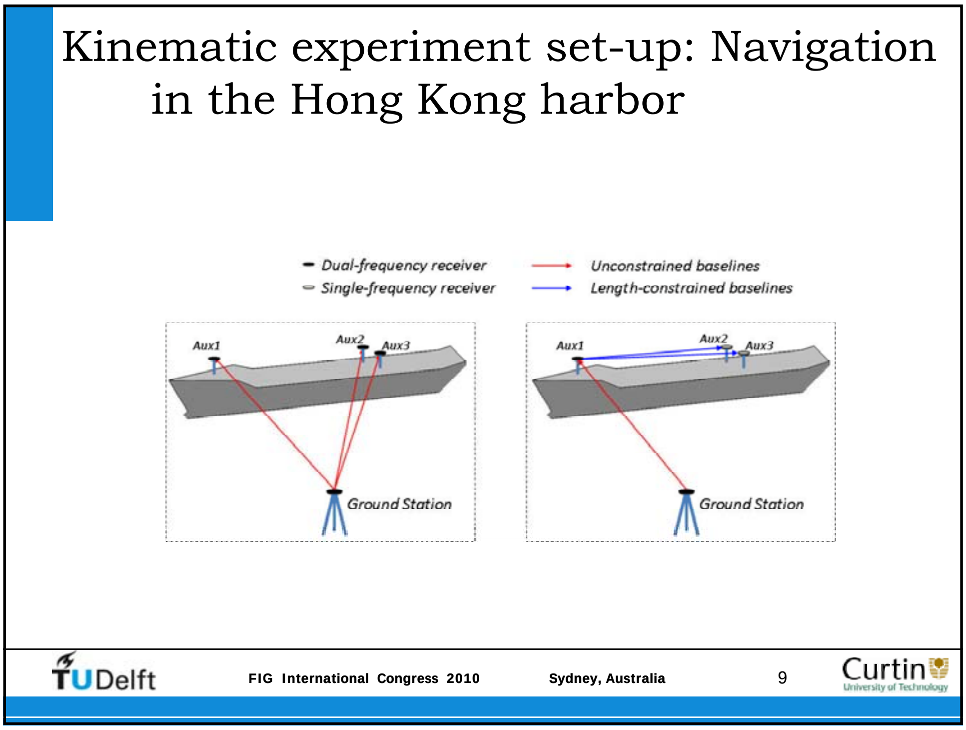

Kinematic experiment set-up: Navigation in the Hong Kong harbor

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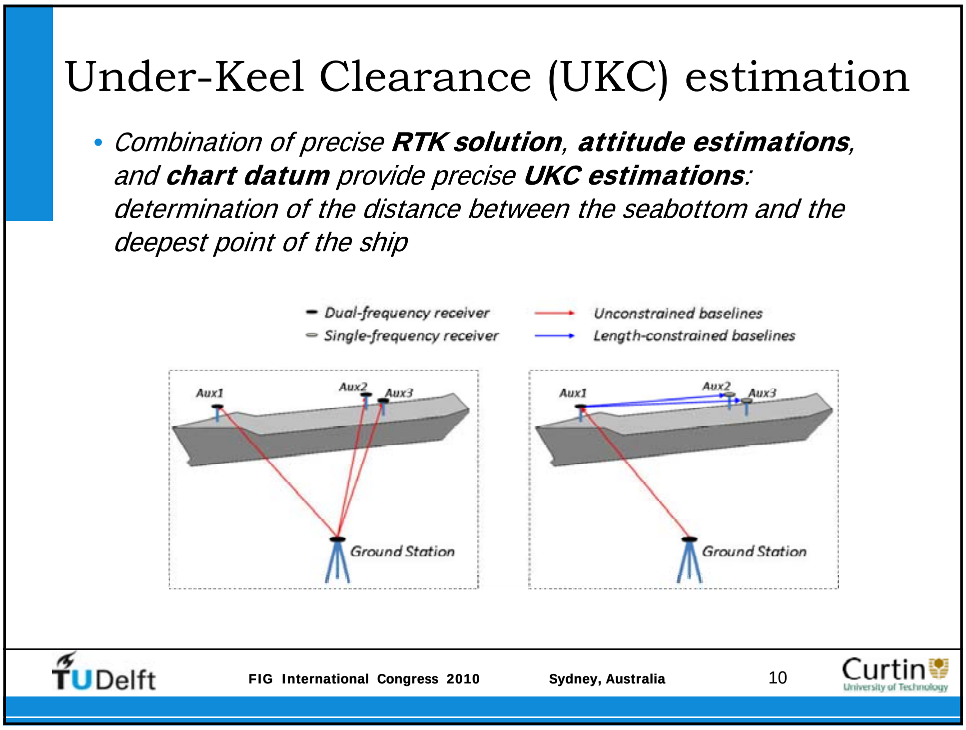

Under-Keel Clearance (UKC) estimation

- *Combination of precise **RTK solution**, **attitude estimations**, and **chart datum** provide precise **UKC estimations**: determination of the distance between the seabottom and the deepest point of the ship*

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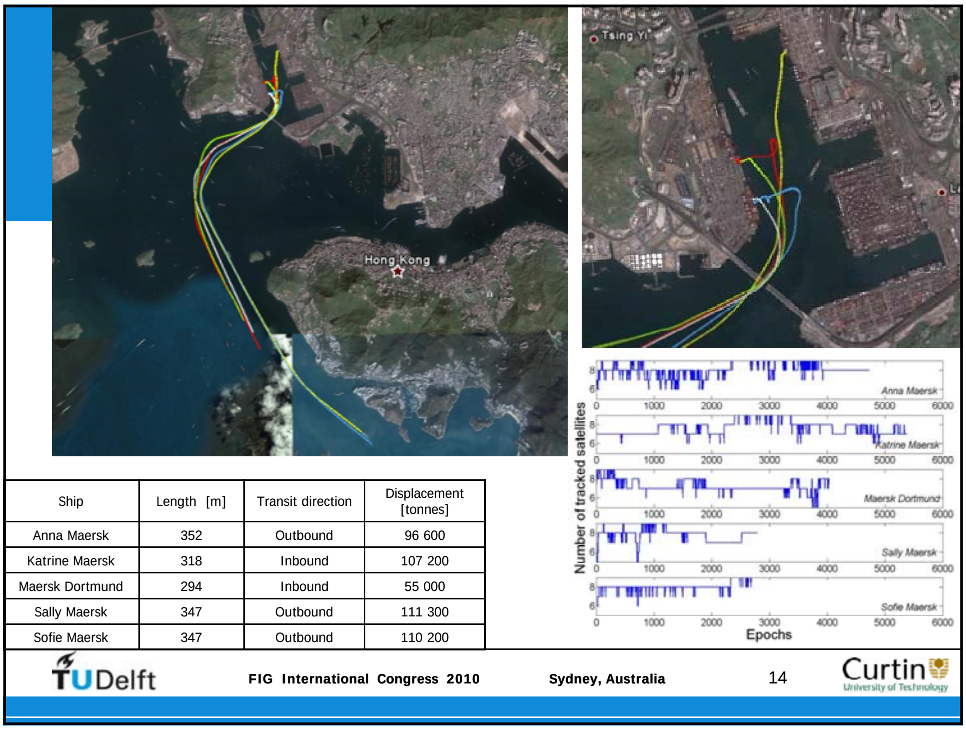

Ship	Length [m]	Transit direction	Displacement [tonnes]
Anna Maersk	352	Outbound	96 600
Katrine Maersk	318	Inbound	107 200
Maersk Dortmund	294	Inbound	55 000
Sally Maersk	347	Outbound	111 300
Sofie Maersk	347	Outbound	110 200

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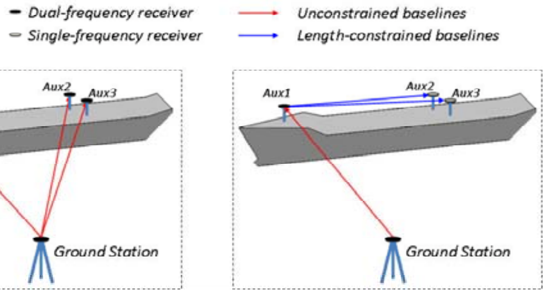
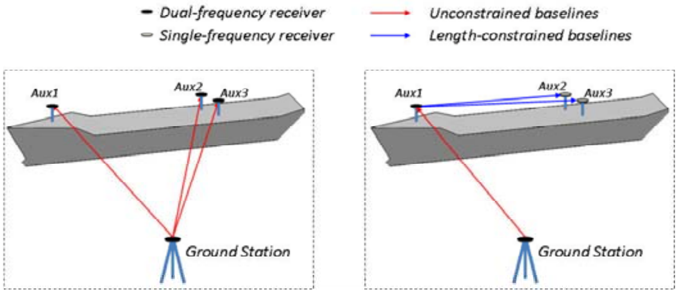
Kinematic experiment set-up: Navigation in the Hong Kong harbor



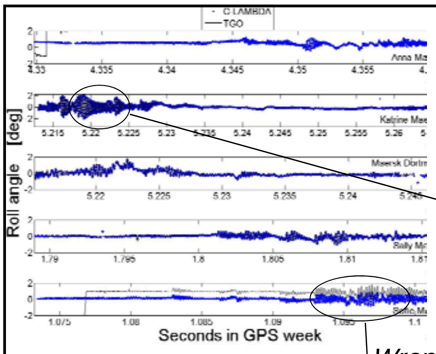
Single-frequency, single-epoch, unaided success rate

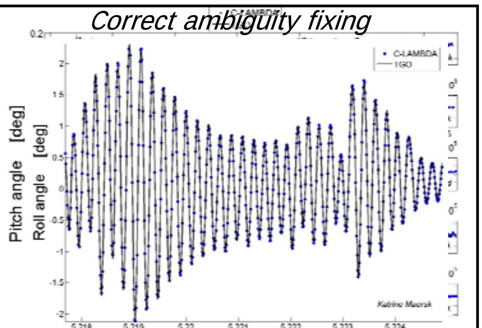
Ship	Receivers	*Baseline length [m]*	Single-frequency, single-epoch unaided (GPS-only) success rate	
			LAMBDA [%]	**C-LAMBDA [%]**
Anna Maersk *(outbound)*	Port-Bow	*253.65*	**14.5**	**55.3**
	Stbd-Bow	*249.48*	**35.2**	**78.9**
	Port-Stbd	*36.565*	**26.1**	**68.6**
Katrine Maersk *(inbound)*	Port-Bow	*213.91*	**16.4**	**76.4**
	Stbd-Bow	*213.86*	**16.8**	**75.7**
	Port-Stbd	*42.515*	**38.5**	**93.4**
Maersk Dortmund *(inbound)*	Port-Bow	*223.51*	**14.1**	**61.5**
	Stbd-Bow	*223.53*	**17.6**	**75.6**
	Port-Stbd	*30.27*	**12.1**	**69.8**
Sally Maersk *(outbound)*	Port-Bow	*242.23*	**19.9**	**80.5**
	Stbd-Bow	*242.22*	**16.9**	**71.6**
	Port-Stbd	*36.09*	**32.6**	**89.5**
Sofie Maersk *(outbound)*	Port-Bow	*242.21*	**27.6**	**77.4**
	Stbd-Bow	*242.17*	**29.9**	**77.2**
	Port-Stbd	*36.22*	**47.2**	**82.9**

Kinematic experiment set-up: Navigation in the Hong Kong harbor

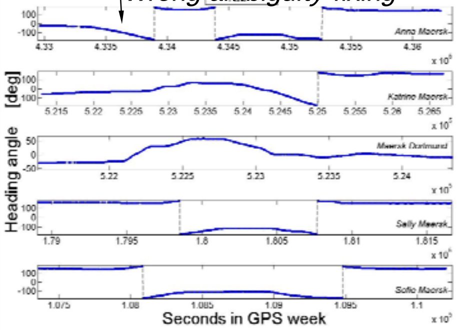


Correct ambiguity fixing

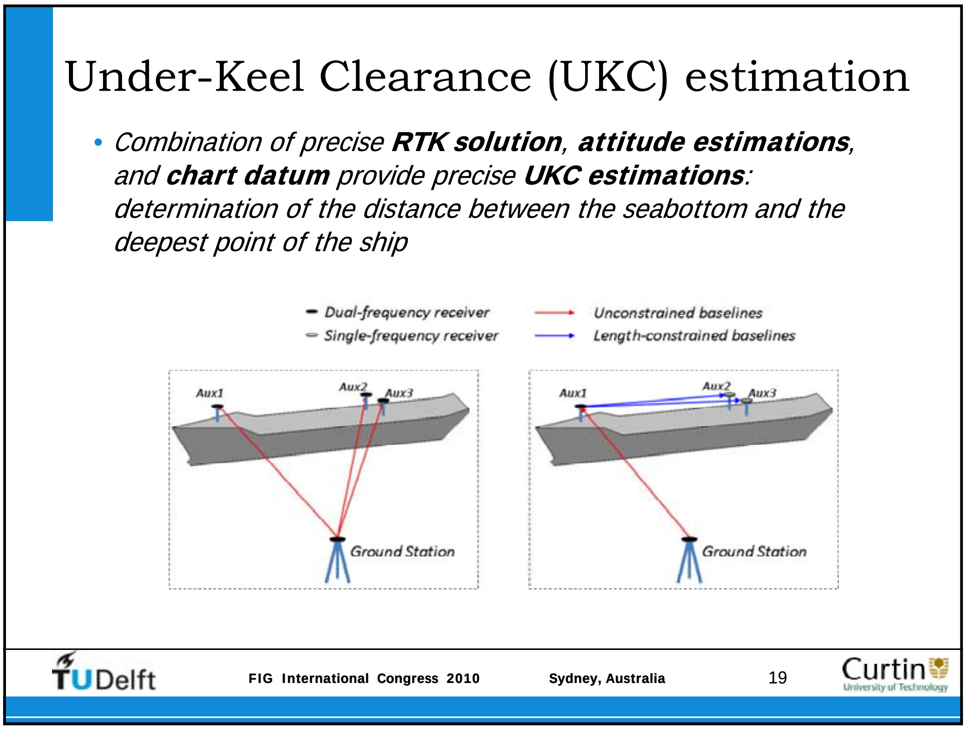




Wrong ambiguity fixing



Attitude solution



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Summary and Conclusions

- Introduction of the constraint → C-LAMBDA method
- High robustness and reliability already for single-epoch, single-frequency, unaided, unfiltered solutions
- Improved results using (only) 1 dual frequency receiver and 2 single frequency receivers
- Very high success rate, short Time-To-Fix
- Reliable and instantaneous estimations of ship's attitude and UKC

Thanks for your attention

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