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UNIVERSITY OF TECHNOLOGY

Centre for Marine Science and Technology

VALIDATION OF KEELCLEAR SOFTWARE IN TORRES STRAIT

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Prepared for:
Australian Reef Pilots

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SUMMARY

This report describes a set of field trials to validate the KeelClear software, developed by the Centre for Marine Science and Technology for Australian Reef Pilots, for UKC predictions in Torres Strait. The trials involved measuring dynamic sinkage of 11 ships, using real-time kinematic GPS surveying techniques.

Changes in dynamic draft through each transit were compared with predictions from KeelClear software. It was found that in most cases the measured dynamic draft was less than the KeelClear predictions, though there were some instances in which the dynamic draft exceeded the KeelClear predictions. These cases were primarily due to errors in raw and interpolated tidal streams, causing differences in speed-through-water for the same speed-over-ground.

When comparing measured calm water squat against KeelClear squat allowances at the same speed-through-water, measured bow and stern squat were generally slightly less than the KeelClear allowances.

Comparisons between traditional pilotage methods and KeelClear passage planning highlighted the need for a more consistent approach to UKC management than the traditional pilotage methods.

The trials have successfully validated the KeelClear squat model and general dynamic draft calculation. They have also demonstrated the importance of accurate tide and stream predictions for KeelClear passage planning, as well as the importance of real-time tide, stream and wave data for the real-time KeelClear program.

Further trials are recommended to validate the wave-induced motions allowance, once a wave buoy is installed.

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1 DESCRIPTION OF THE TRIALS

The trials were carried out from 31st Jan 2008 – 20th Feb 2008. The first trial was to measure the squat of the escort vessel Miralga. Subsequently 11 ships were tested transiting the Torres Strait.

1.1 Escort vessel squat test

On 31st Jan 2008, trials were conducted to measure the squat of the escort vessel "Miralga" as a function of speed. A base station was set up on the end of the Thursday Island wharf. This consisted of a Trimble SPS850 real-time kinematic GPS receiver, Trimble GPS controller, Zephyr geodetic antenna and GPS transmitter. The base station GPS antenna and transmitter are shown below:

A similar receiver, controller and antenna were set up on the stern of the Miralga, operating in "rover" mode. The base station transmitted real-time GPS corrections to the roving receiver at 1sec intervals, and both GPS receivers logged data at 1sec intervals. Data was logged internally on the receivers, and externally on the GPS controllers for backup.

Miralga was steered on opposing courses of 110º and 290º, for a distance of around 0.7nm in each direction. The current was running roughly parallel to the track, but varied in strength through the trial. The engine RPM was kept constant for each run up and back. A static reading was taken at each end for a vertical reference. The conditions tested were as follows:

Engine RPM	Speed-over-ground, course 110º	Speed-over-ground, course 290º	Speed-through-water at this RPM
1450	6.2kn	8.2kn	7.2kn
1800	7.8kn	10.0kn	8.9kn
2100	9.9kn	10.9kn	10.4kn
2400	10.5kn	11.5kn	11.0kn

By comparing the vertical elevation of the GPS antenna when under way, to its value when stationary, the squat of the Miralga's stern was obtained as a function of speed-through-water, as follows:

Speed-through-water	Miralga stern squat
7.2kn	0.08m
8.9kn	0.14m
10.4kn	0.33m
11.0kn	0.40m

1.2 Ship trials

Having calculated the squat of Miralga as a function of speed, the ship trials were commenced on 1st Feb 2008. The procedure for the ship trials was as follows, described for eastbound transits.

- Miralga meets the ship at the pilot boarding ground near Booby Island
- CMST technicians Dr Tim Gourlay and Mr Malcolm Perry board the ship at the pilot boarding ground near Booby Island
- GPS equipment is set up on the ship immediately and starts logging within 5-10 minutes
- Miralga travels in convoy with the ship, roughly 0.25nm ahead of the ship and slightly off to the starboard side
- Miralga acts as a vertical reference, as well as transmitting GPS corrections to the ship receivers
- Near the Herald Patches boarding ground, the ship's engines are stopped, put astern and then stopped again to bring the ship to a complete stop (less than 1kn speed-through-water)
- Miralga sits stationary alongside the stationary ship for a minimum of 2 minutes to get a static elevation reading
- GPS receivers are stopped, equipment dismantled and CMST technicians leave the ship on the Miralga

For westbound transits the procedure is the reverse of above, except that the static reading is still taken near Herald Patches boarding ground, i.e. at the start of the transit in this case.

An example trial with the Miralga and ANL Windarra is shown below. The moving base station GPS antenna can be seen on the stern of the Miralga.

1.3 GPS equipment used

For the ship trials, the real-time kinematic GPS equipment used was as follows:

Location	GPS equipment	Data recorded
Thursday Island Australian Reef Pilots' house	Trimble 5700 fixed base station	T01 files for post-processing
Miralga	Trimble SPS850 moving base station and GPS controller; GPS transmitter	T01 files for post-processing; real-time GPS data
Ship bow	Trimble SPS850 roving receiver and GPS controller	T01 files for post-processing ; real-time GPS data including Miralga corrections
Starboard bridge wing or bridge centreline	Trimble SPS850 roving receiver and GPS controller	T01 files for post-processing ; real-time GPS data including Miralga corrections
Port bridge wing	Trimble SPS850 roving receiver and GPS controller	T01 files for post-processing ; real-time GPS data including Miralga corrections

By using three real-time kinematic GPS receivers on the ship, and assuming the ship to be rigid, the position of any other point on the ship can also be found as a function of time.

An example of a GPS setup on the monkey island of the Iver Example is shown below. The escort vessel Miralga can also be seen off the starboard bow.

1.4 Other data recorded

As well as raw kinematic GPS data, the following were also recorded during the transit:

- Position of GPS receivers relative to ship centreline and midship plane
- Ship particulars
- Echo sounder data output (where available)
- Estimated wind and wave conditions
- Ship speed-through-water from ship log (where available), calibrated using speed-over-ground and measured current while passing Nardana Patches stream gauge
- Time of optimum static reading

1.5 List of ships tested

The ships tested are listed below, together with their relevant particulars at the time of the transit:

Ship	Type	L_{PP} (m)	Beam (m)	Draft fwd (m)	Draft aft (m)	Disp. (mt)	GM_T (m)
Stove Campbell	Bulk carrier	175.0	30.9	11.68	11.94	54,300	2.5
Prabhu Daya	Bulk carrier	185.0	32.3	12.14	12.14	62,400	3.2
ANL Windarra	Container ship	246.0	32.3	12.20	12.20	63,500	0.7
British Security	Product tanker	174.0	32.2	10.6	10.6	47,800	2.5
Athinea	Product tanker	238.0	43.0	11.38	11.38	95,400	8.2
Iver Example	Product tanker	174.0	32.2	10.7	10.9	48,900	1.9
Loyal Union	Bulk carrier	182.4	32.0	11.46	11.86	58,000	4.0
Triton Swift	Bulk carrier	182.0	32.3	11.70	12.04	60,600	4.2
Vanda Colossus	Bulk carrier	185.0	32.3	11.82	11.96	60,700	3.1
Cape Moreton	General cargo	150.0	24.9	8.30	9.60	26,800	4.6
Advance II	Product tanker	173.9	32.2	10.48	10.48	47,500	2.6

1.6 Environmental conditions

Since there was no wave buoy in Torres Strait at the time of the trials, and the Weipa wave buoy was damaged at the time, the only wave data available are visual estimates. Wind data was taken from the ship's anemometer or from visual estimates. The wind and wave conditions during the trials were approximately as follows:

Ship	Date	Route	Wind speed at Varzin	Wind direction	Sig. wave height at Varzin	Mean wave period	Wave direction
Stove Campbell	1 Feb	eastbound	12kn	N	0.5m	4s	NNW
Prabhu Daya	3 Feb	westbound	5kn	N	calm	-	-
ANL Windarra	5 Feb	eastbound	12kn	NNW	0.5m	4s	NNW
British Security	7 Feb	eastbound	20kn	NW	1.0m	5s	NW
Athinea	8 Feb	eastbound	25kn	NW	1.5m	5s	NW
Iver Example	12 Feb	eastbound	15kn	NW	1.0m	5s	NW
Loyal Union	13 Feb	westbound	15kn	NNW	1.0m	5s	NW
Triton Swift	15 Feb	westbound	8kn	NNW	1.0m	6s	W
Vanda Colossus	16 Feb	westbound	12kn	NNW	1.0m	4s	NW
Cape Moreton	17 Feb	westbound	20kn	NW	2.0m	6s	WNW
Advance II	20 Feb	eastbound	15kn	NNW	1.0m	4s	NW

2 PROCESSING THE RESULTS

2.1 Raw kinematic GPS elevation processing method

Two independent methods were used to measure elevation changes of the roving ship receivers, as follows:

Real-time processing

The Trimble SPS850 GPS receiver onboard Miralga transmitted real-time GPS corrections to the roving receivers at 1sec intervals. The real-time corrected rover elevations were logged on the GPS controllers. This method gave an accurate measurement of the roving GPS antennas' elevation relative to the Miralga moving base station, whenever the heave and pitch of Miralga were small and its elevation was near-constant.

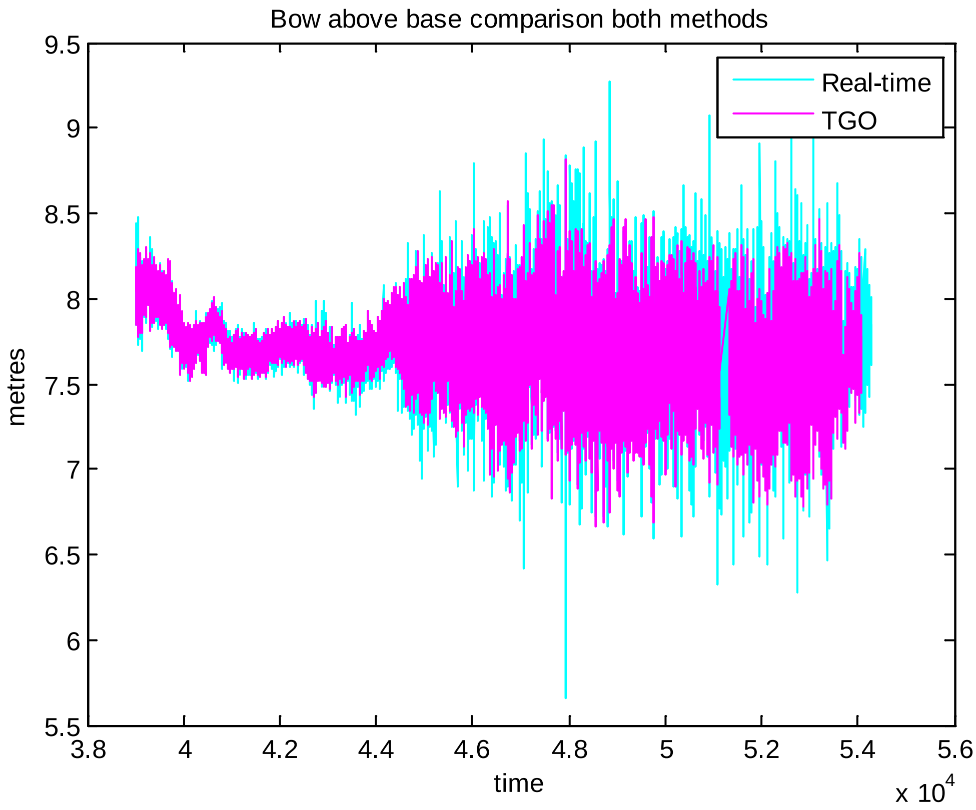
When Miralga was heaving and pitching significantly, a time-dependent error was introduced into the roving receiver elevations. However since all roving receivers were subject to the same error, differential measurements to give dynamic ship heel and trim were still accurate.

Post-processing using Trimble Geomatics Office (TGO)

As well as outputting corrected GPS elevations to the controllers, each GPS receiver logged raw GPS data internally. This was post-processed together with the fixed base station data from the Trimble 5700 receiver at the Thursday Island Australian Reef Pilots' house. By post-processing the ship roving receivers and the Miralga receiver in this way, the absolute elevations of all receivers (relative to mean sea level) were found.

Example comparison

The following graph shows an example comparison between the real-time and TGO post-processing methods, for the ship bow elevation relative to the Miralga moving base station on the ship "Vanda Colossus". We can see that in the calm water on the left of the graph, both methods give similar results. However in the rough water on the right of the graph, Miralga has significant heave and pitch which violates the steady base station assumption. In the rough water, the motion amplitudes are over-predicted when using the real-time corrections.



2.2 Dynamic elevation changes relative to the still water level

The primary purpose of these GPS measurements was to measure each ship's dynamic sinkage and dynamic draft. The dynamic sinkage of any point on a ship is the difference between its vertical position when under way, and the vertical position it would have when sitting stationary at its static draft.

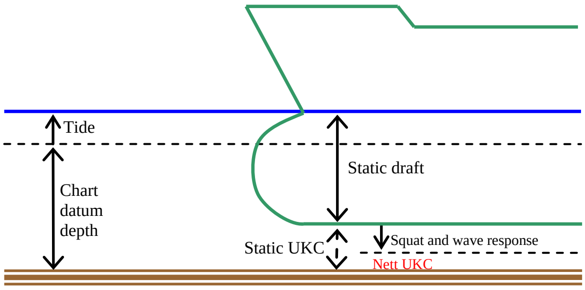
Dynamic sinkage is a combined effect of midship squat, dynamic trim and dynamic heel, as well as heave, pitch and roll due to wave motion.

In order to calculate dynamic sinkage, we need to have an accurate measure of each ship's vertical position when stationary. For this reason, a static reading was taken at the eastern end of each transit, where conditions are calmer than at the western end. Before this static reading, the ship was put astern to bring the speed-through-water down below 1 knot. Miralga came alongside the ship and sat in its lee so as to minimize its heave and pitch. The ship and Miralga then sat like this for a minimum of two minutes while GPS elevation readings were taken. This static reading gave the vertical elevation of each of the ship GPS receivers, relative to the Miralga GPS receiver.

When underway, the ship sinks down relative to the local still water level, as does the Miralga. By comparing the ship's GPS elevations when underway to those of the Miralga, subtracting the static readings, and allowing for the squat of the Miralga at a given speed through the water, the dynamic sinkage of the ship can be calculated relative to its static position.

Note that the method of using an escort vessel as a moving base station negates the need for accurate tidal height measurements in determining ship sinkage, since both vessels move up and down by the same amount due to the tide.

As shown below, the static draft at any point on the ship, added to the dynamic sinkage, gives the dynamic draft. When the dynamic draft is equal to or greater than the available water depth, the ship will touch bottom.



Note that the static draft, squat and wave response are all different at different points on the vessel, so these are calculated separately at all the outward extremities of the keel, approximated as follows:

Keel extremity	**Position**
Bow	Forward post on centreline
Stern	Aft post on centreline
Bulk carrier	
Port and Starboard forward shoulder	25% of L_{PP} aft of forward post, 1m inboard from maximum beam
Port and Starboard aft shoulder	70% of L_{PP} aft of forward post, 1m inboard from maximum beam
Container ship	
Port and Starboard bilge corner	Midships, 1m inboard from maximum beam

2.3 Processing details

In order to go from raw GPS elevations at each receiver, to dynamic ship sinkage measurements, the following steps were taken:

1. Raw GPS results from the roving and moving base receivers were analyzed to find the most suitable static reading, requiring the ship and Miralga to be stationary, and an adequate and preferably constant number of satellites for the full static reading.
2. All GPS elevation readings that were not of adequate survey quality (less than 30mm RMS error) were rejected.
3. Data from all receivers were cropped to only include time values that contained survey-quality data from all receivers. This produced a common time vector, and synchronous readings, for all receivers.
4. Raw elevation differences between the receivers were found, using either the real-time or post-processed method.

5. Miralga moving base elevations were subtracted off each of the ship receivers to give relative values.
6. Static readings were subtracted off to give dynamic elevation changes relative to the moving base station.
7. Miralga's speed-through-water at each point in the transit was calculated using measured speed-over-ground differences between the ship and Miralga. The ship's speed-through-water was either:
   - measured during the transit for ships with accurate logs. Ship logs were calibrated using the measured speed-over-ground and measured stream speed while passing Nardana stream gauge.
   - calculated using measured speed-over-ground and predicted tidal streams along the transit.
8. Miralga's dynamic sinkage at each point in the transit was calculated using its speed-through-water, and the results of the Miralga squat trial carried out on 31st Jan.
9. The dynamic sinkage of the ship relative to the Miralga was added to the dynamic sinkage of the Miralga relative to the still water level, to give the dynamic sinkage of the ship relative to the still water level.

In calm water, both the real-time and post-processed methods gave similar accuracy. In rough water, the most accurate method was to post-process the moving base and one ship receiver (chosen as the bow), and use the real-time results to determine dynamic heel and trim, hence giving the dynamic sinkage of any point on the ship. Although this was the method of choice, other variants were used when insufficient survey-quality data were available, as shown below:

Ship	**Method to calculate bow elevation relative to moving base**	**Method to calculate dynamic trim**	**Method to calculate dynamic heel**
Stove Campbell	Real-time	Real-time	Not measured*
Prabhu Daya	Real-time	Real-time	Not measured*
ANL Windarra	Real-time	Real-time	Real-time
British Security	Real-time static Post-processed moving	Real-time	Real-time
Athinea	Real-time static Post-processed moving	Real-time	Real-time
Iver Example	Post-processed	Real-time	Real-time
Loyal Union	Post-processed	Post-processed	Not measured*
Triton Swift	Post-processed	Real-time	Real-time
Vanda Colossus	Post-processed	Real-time	Real-time
Cape Moreton	Real-time	Real-time	Real-time
Advance II	Post-processed	Real-time	Real-time

* For the transits of Stove Campbell, Prabhu Daya and Loyal Union, the port receiver malfunctioned and its results were discarded. Since the other two receivers were on the ship centreline at the bow and bridge, squat and dynamic trim were still accurately obtained.

The methods used to estimate ship speed-through-water for each transit were as shown below:

Ship	Method to calculate ship speed-through-water, for Miralga squat estimates
Stove Campbell	Measured speed-over-ground and predicted tidal streams
Prabhu Daya	Measured speed-over-ground and predicted tidal streams
ANL Windarra	Constant engine revs (slow ahead) from Varzin W - Herald, speed-through-water approximately constant 10 knots
British Security	Constant engine revs (half ahead) from Varzin E – Herald, speed-through-water approximately 10.8 knots
Athinea	Measured speed-over-ground and predicted tidal streams, checked against Nardana stream meter
Iver Example	Measured speed-through-water from ship log, calibrated using measured ship speed-over-ground and measured tidal streams while passing Nardana stream meter
Loyal Union	Adverse current calculated from measured speed-over-ground and speed-through-water from ship's log, calibrated when passing Nardana stream meter. Calculated current then applied to ship speed-over-ground
Triton Swift	Measured speed-over-ground and predicted tidal streams, checked against Nardana stream meter
Vanda Colossus	Constant engine revs (half ahead) for whole transit, speed-through-water approximately 8.9 knots, calibrated when passing Nardana stream meter
Cape Moreton	Nardana stream meter out of service, but very little observed current; use measured speed-over-ground
Advance II	Measured speed-through-water from ship log, calibrated using measured ship speed-over-ground and measured tidal streams while passing Nardana stream meter

2.4 Results in rough water

For most of the transits, the sea was fairly rough to the west of Tucker Point, and fairly calm from Turtle Head to Pilot Knoll. Therefore for parts of some transits, Miralga was heaving and pitching too much to get accurate squat measurements, although dynamic trim and heel could still be accurately obtained.

In the case where Miralga was heaving and pitching significantly, but the ship's speed through the water remained approximately constant for the whole transit, an alternative method was used to determine dynamic sinkage. Post-processed data was used to find the ship's midship heave amplitude at each point in the rough sections of the transit. This was combined with the measured dynamic trim and heel at each point in rough water, and the measured midship squat in calm water (at the same speed) to determine overall dynamic sinkage.

In calm water, when Miralga was only heaving and pitching slightly, raw elevation differences between the ship's midships and the Miralga were averaged over a 60 second period to remove the effect of Miralga's short-period heave and pitch.

The table below shows the amplitude of Miralga's vertical motions for each transit, and the method used to calculate dynamic sinkage in rough water.

Ship	Maximum amplitude of Miralga motions where sinkage results given	Comments on rough-water dynamic sinkage
Stove Campbell	0.1 – 0.3m	No rough-water corrections required
Prabhu Daya	0.0 – 0.1m	No rough-water corrections required
ANL Windarra	0.3 – 0.5m	No rough-water corrections applied due to lack of accurate TGO data; results less accurate west of 142º08’
British Security	0.2 – 0.4m	No rough-water corrections applied due to changing STW; results less accurate west of 142º08’
Athinea	0.5 – 0.7m	No rough-water corrections applied due to changing STW; results less accurate west of 142º09’
Iver Example	0.2 – 0.5m	Midship squat estimate applied to rough-water results west of 142º10’
Loyal Union	0.2 – 0.3m	No rough-water corrections required
Triton Swift	0.2 – 0.3m	No rough-water corrections required
Vanda Colossus	0.4 – 0.6m	Midship squat estimate applied to rough-water results west of 142º14’
Cape Moreton	0.3 – 0.6m	No rough-water corrections applied due to changing STW; results less accurate west of 142º10’ and east of 142º18’
Advance II	0.3 – 0.5m	Midship squat estimate applied to rough-water results west of 142º10’ and east of 142º15’

2.5 Error considerations

The estimated RMS (root-mean-square) errors involved in calculating dynamic sinkage are as follows:

Measurement quantity	**Maximum RMS error**	**Comments**
Raw rover GPS elevations relative to mean sea level	30mm	All points with RMS error > 30mm rejected.
Raw moving base GPS elevations relative to mean sea level	30mm	All points with RMS error > 30mm rejected.
Error in static rover readings due to ship movement	5mm	Ship motion amplitudes typically < 30mm during static; estimate 5mm error in mean
Error in static moving base readings due to Miralga movement	30mm	Miralga motion amplitudes typically < 200mm during static; estimate 30mm error in mean
Error in calculating Miralga sinkage from trials on 31st Feb	20mm	Miralga motion amplitudes typically < 30mm during static and moving readings, giving around 5mm error in mean of each; also some drift due to rising tide; estimate 20mm total error
Error in interpolating to find Miralga sinkage during ship trials	30mm	RMS error in Miralga's speed-through-water around 0.2kn, giving RMS error in sinkage interpolation around 30mm
Error in averaging moving base readings while under way in *calm* water	15mm	Miralga motion amplitudes typically < 100mm in calm water; estimate 15mm error in mean
Error in averaging moving base readings while under way in *rough* water	100mm	Miralga motion amplitudes up to 500mm in rough water; estimate 100mm error in mean

Since the final dynamic sinkage results are obtained by adding or subtracting all of the above quantities, the overall RMS error is the square root of the sum of the squares, i.e. 65mm in calm water and up to 120mm in rough water. This is the expected standard deviation of measured dynamic sinkage, if a large number of trials were undertaken in the same conditions.

Assuming the errors follow a Gaussian (normal) distribution, the actual dynamic sinkage should lie within two standard deviations of the quoted values, with 95% confidence. Therefore all the results given in this report are the best estimate to the measured value, with a 95% confidence interval of $\pm 0.13\,\text{m}$ in calm water, and $\pm 0.24\,\text{m}$ in rough water.

2.6 Graphical results shown

The Appendix gives graphical results for each ship, as follows:

1. *Dynamic heel and trim*

This graph shows the *dynamic* heel and trim of the ship through the transit, measured relative to the static condition. Dynamic trim results are plotted in metres of sinkage difference between the bow and stern. For example, if the dynamic sinkage of the bow when under way was 0.70m and the dynamic sinkage of the stern was 0.30m, the dynamic bow-down trim would be 0.40m. Oscillations in the dynamic trim graphs are due to ship pitching.

Dynamic heel results are plotted in metres of sinkage difference between the port and starboard bilge corners. For example, if the dynamic sinkage of the starboard bilge corner at one point in the transit was 0.40m and the dynamic sinkage of the port bilge corner was 0.20m, the dynamic heel to starboard would be 0.20m. Oscillations in the dynamic heel graphs are due to ship rolling.

For some transits dynamic heel was not available, so only dynamic trim is shown for these, as described in Section 2.3.

2. *Ship and Miralga speed-over-ground*

Note that the ship keeps a much steadier speed-over-ground than the Miralga, since Miralga continually adjusts speed to hold her position relative to the ship. The differences in speed-over-ground between the ship and Miralga are used to estimate Miralga's speed-through-water at each point in the transit.

3. *Midship squat before Miralga averaging*

This graph shows the raw midship squat of the ship, before Miralga's motions are averaged out, and the oscillations in the graph show the smooth and rough sections of the transit.

4. *Calm water squat*

This graph shows the midship, bow and stern squat during the calm part of each transit, where results are most accurate. This graph is only shown for rough water transits.

5. *Dynamic sinkage*

This graph shows the dynamic sinkage (plotted as negative downwards) of each of the hull extremities relative to their static floating position, through the transit. Only parts of the transit with survey-quality results are shown, and note that rough water results are less accurate than calm water results, as described above.

6. *Dynamic draft*

This graph shows the dynamic draft of each hull extremity, which is the static draft plus the sinkage. The hull extremity with the largest dynamic draft is the point which comes closest to the seabed, and governs the nett underkeel clearance.

3 TABULATED RESULTS

3.1 Introduction

Each transit is broken into the same 8 transit sections used in the KeelClear program, divided at waypoints with the following longitudes:

Booby Island	141º49.7’E
Varzin West	141º51.8’E
Varzin East	141º58.1’E
Tucker Point	142º06.9’E
Turtle Head	142º11.6’E
Nardana	142º15.2’E
Pilot Knoll	142º17.0’E
OG Rock	142º20.2’E
Herald Patches	142º24.6’E

For each ship, a table of predicted and measured dynamic draft increase is shown. The measured dynamic draft in each case is taken from the graphical results in the Appendix. The measured dynamic draft increase is the dynamic draft minus the maximum static draft, rounded to the nearest 0.05m. This should ideally be close to, but less than, the KeelClear dynamic draft increase, which is the difference between the KeelClear static and dynamic underkeel clearance. Transit sections where the measured dynamic draft (best estimate) was greater than KeelClear predicted have been marked in yellow.

A screenshot of KeelClear v1.151 is also shown for the transit. Note that this is not a passage plan, as many of the transits were performed using traditional piloting methods rather than KeelClear software. The screenshot is reverse-engineered using measured values as inputs. Therefore some transits are assessed as “unsafe”, despite having been safely completed. This is due to several factors:

1. Traditional pilotage methods were used for many of the transits, rather than following a KeelClear passage plan.
2. KeelClear v1.151 uses a large “minimum UKC” of 1.0/1.2m, which can easily be breached for transits undertaken using traditional pilotage methods and then analyzed using KeelClear, given that the KeelClear squat and wave-induced motions allowances are designed to be conservative.
3. Where errors in predicted tidal streams cause the predicted speed-through-water to be larger than the actual, KeelClear gives unrealistically large squat allowances due to the unrealistically large speed-through-water.
4. The wave conditions input to KeelClear are only estimates, and may have been larger than the actual wave conditions in some cases, giving unrealistically large wave-induced motions allowances between Booby Island and Turtle Head.
5. KeelClear generally makes greater allowances for squat and wave-induced motions than traditional pilotage methods, and hence will increase safety for transits that follow a passage plan that is deemed safe.

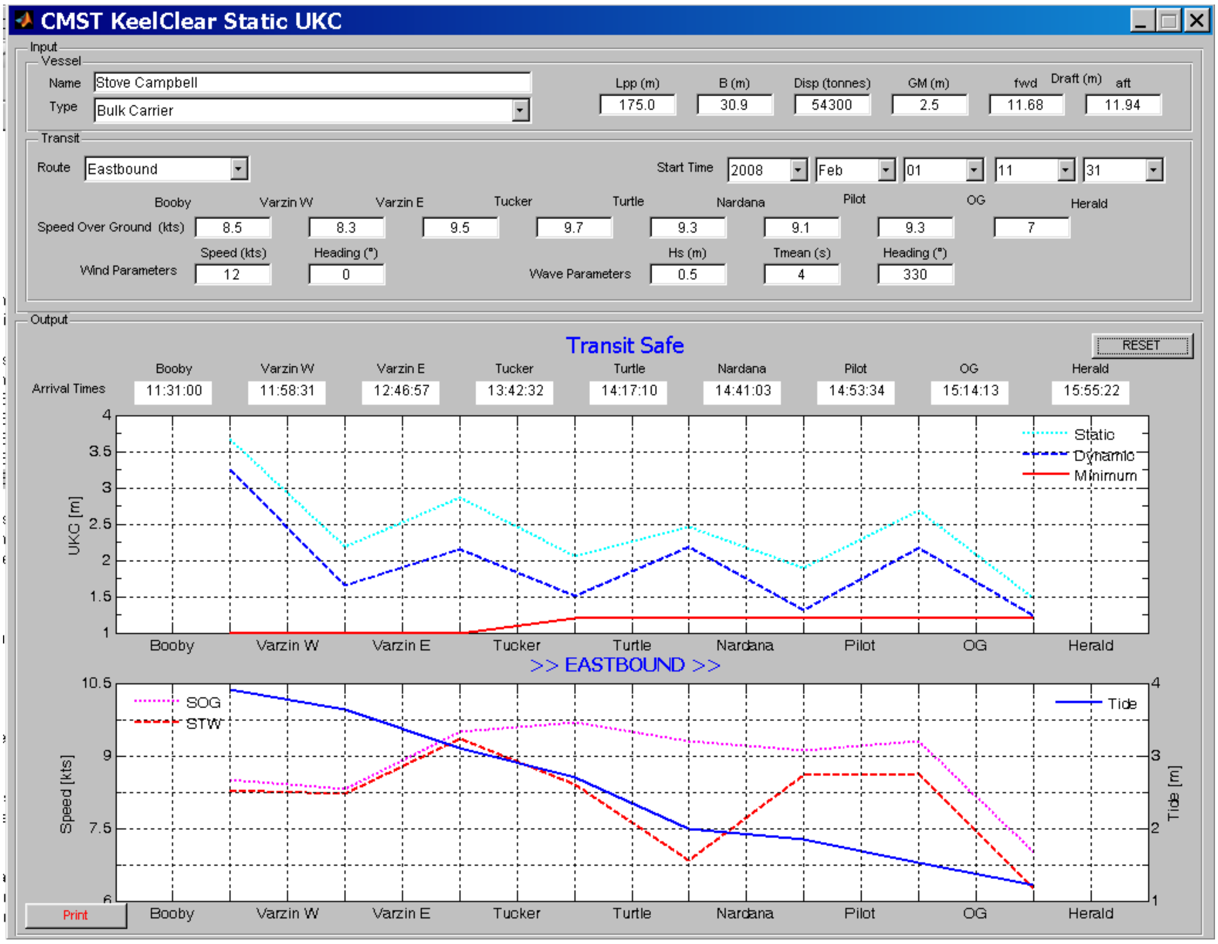
In future, KeelClear will be used as a passage planning tool, and only transits that are deemed “safe” will be allowed to proceed. The importance of meteorological effects on tidal streams that was observed in these trials also gives greater emphasis on the use of real-time KeelClear software, once real-time wave, tide and stream data are able to be input.

In order to best match the KeelClear predictions with the actual transit undertaken, the reverse-engineering of KeelClear was done using the same speed-over-ground and waypoint arrival times as were observed in the measured transits. The main difference between the screenshots and the actual transits performed is in speed-through-water. KeelClear uses predicted tidal streams and input speed-over-ground to estimate speed-through-water for each transit section. Errors in stream predictions occur due to meteorological effects on the tidal streams, and interpolation errors between the stream prediction locations. For some transits this results in unrealistically high predictions of the speed-through-water, and hence squat allowance, giving an "unsafe" assessment for the transit.

Note that the screenshots are taken from KeelClear v1.151, which uses the AMSA requirement of a "minimum UKC" of 1.0m along the whole channel, increased to 1.2m in the Prince of Wales Channel for drafts of 11.9m or larger. This is a more conservative program than KeelClear v1.1, which follows the PIANC recommendation of using a "safety margin" of 0.5m over sand and 1.0m over rock, and suitably conservative allowances for squat, heel and wave-induced motions.

The allowance for wave-induced motions at the western end of the transit is designed to minimize grounding probabilities over a 25-year period, since wave-induced motions follow a statistical distribution, and a longer time period will produce larger motions. Therefore the actual dynamic draft increase for individual transits should normally be significantly less than the allowance. In addition, input wave conditions are only estimates and do not reflect the exact wave conditions.

3.2 Stove Campbell



Reverse-engineered KeelClear assessment for "Stove Campbell" transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	2.19	2.86	2.06	2.46	1.90	2.69	1.48
KeelClear minimum dynamic underkeel clearance (m)	1.65	2.16	1.52	2.19	1.31	2.16	1.24
KeelClear dynamic draft increase (m)	**0.54**	**0.70**	**0.54**	**0.27**	**0.59**	**0.53**	**0.24****
Measured dynamic draft (m)	12.20 ±0.13	12.40 ±0.13	12.35 ±0.13	12.20 ±0.13	12.25 ±0.13	12.20 ±0.13	12.20 ±0.13
Measured dynamic draft increase (m)	**0.25 ± 0.13**	**0.45 ± 0.13**	**0.40 ± 0.13**	**0.25 ± 0.13**	**0.30 ± 0.13**	**0.25 ± 0.13**	**0.25 ± 0.13**
Point of maximum dynamic draft	Aft post	Fwd post	Fwd post	Aft post	Aft post	Aft post	Aft post
Measured minimum nett UKC (m) from depth sounder (bow)	3.1	2.4	2.8	3.4	2.8	3.4	n/a*

Results summary for "Stove Campbell"

* soundings stopped to collate depth sounder data before disembarking

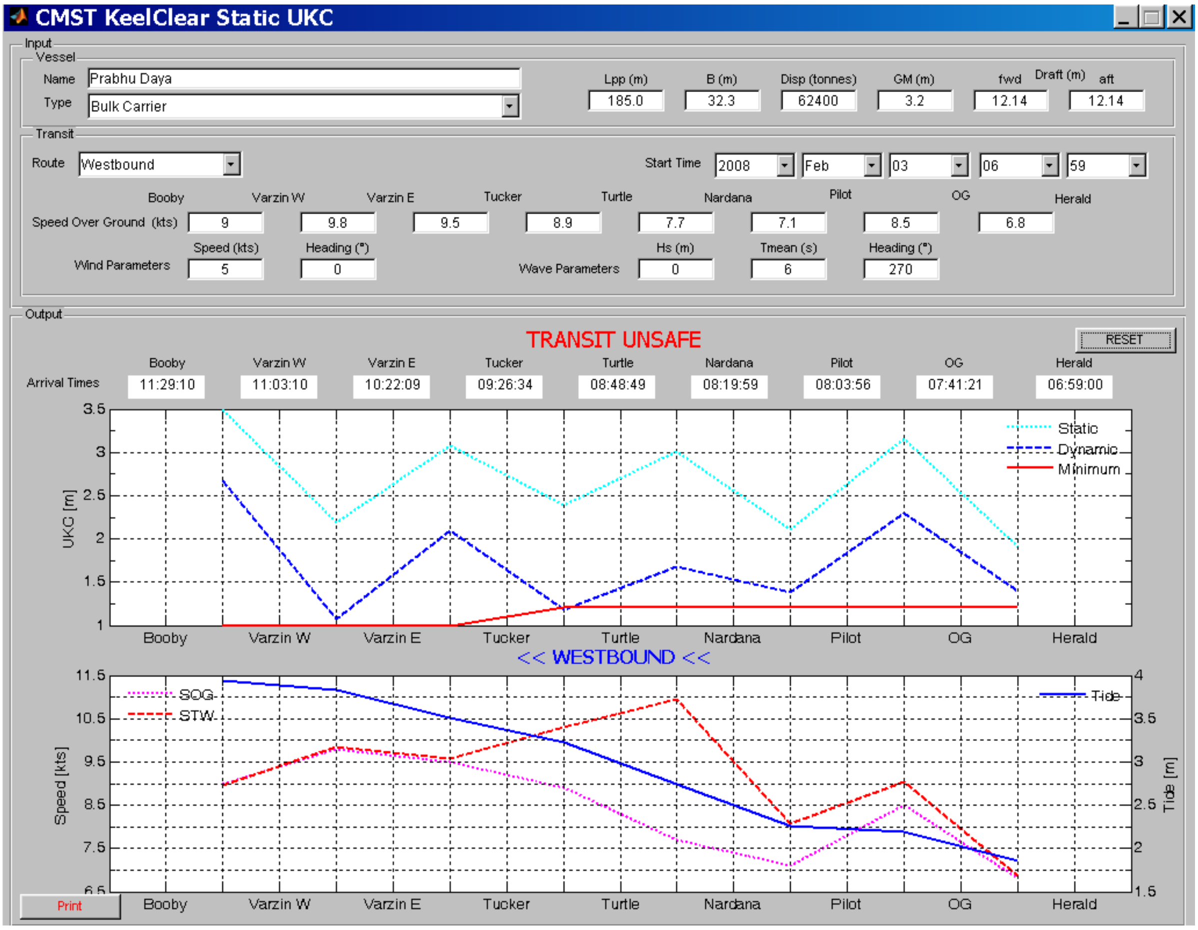
** ship decelerating to rest on this transit section

For the Stove Campbell transit, measured dynamic draft increases were all slightly less than the KeelClear allowances, excepting perhaps the OG – Herald section (within measurement error). On this transit section the ship was decelerating to rest, so the maximum speed was significantly greater than the speed used for the KeelClear screenshot, based on waypoint arrival times. Therefore the squat may have been greater than the KeelClear allowance.

On the other transit sections, the measured dynamic draft increase was less than the KeelClear allowance by up to (0.29 ± 0.13)metres.

The KeelClear dynamic underkeel clearance remained above the minimum for the whole transit.

3.3 Prabhu Daya



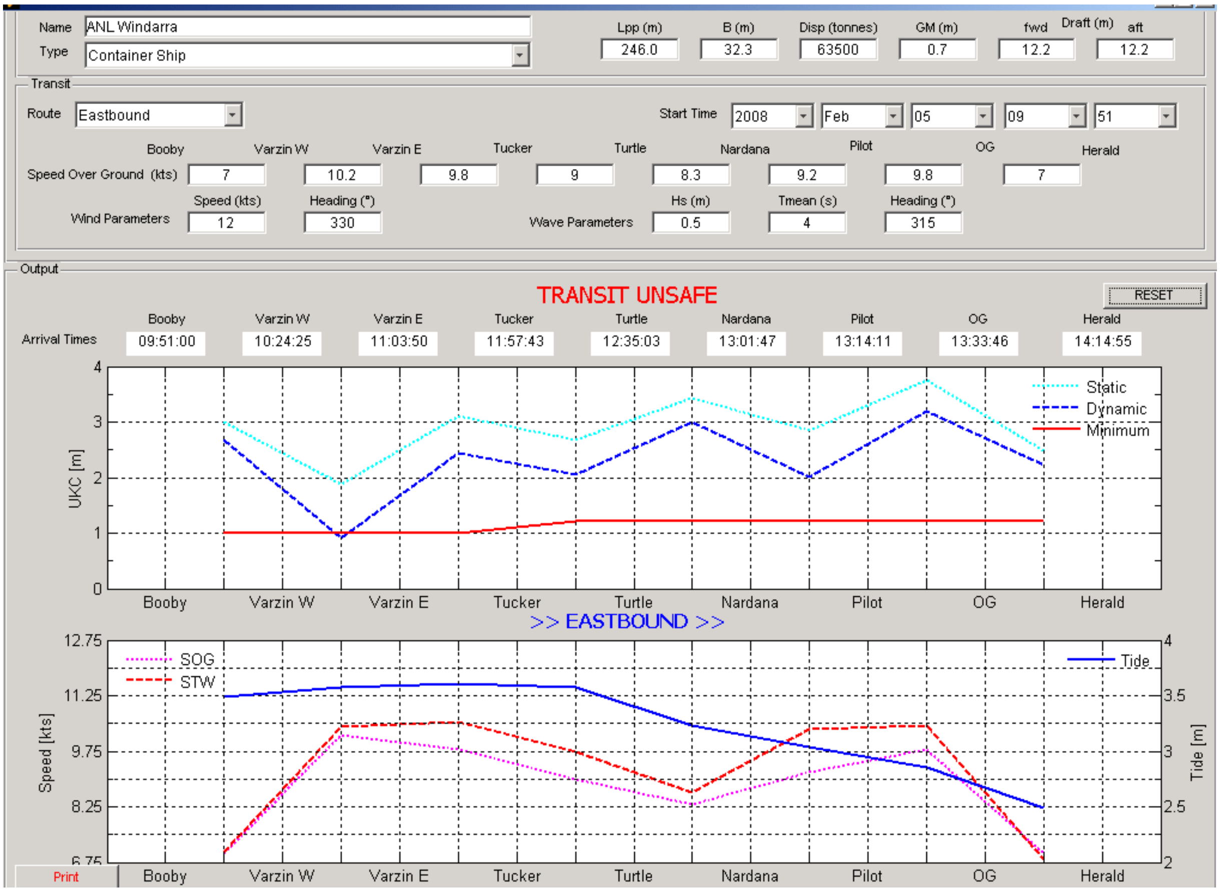
Reverse-engineered KeelClear assessment for "Prabhu Daya" transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	2.19	3.08	2.39	3.01	2.11	3.15	1.91
KeelClear minimum dynamic underkeel clearance (m)	1.08	2.10	1.19	1.68	1.39	2.29	1.39
KeelClear dynamic draft increase (m)	**1.11**	**0.98**	**1.12**	**1.33**	**0.73**	**0.86**	**0.52**
Measured dynamic draft (m)	12.95 ± 0.13	12.90 ± 0.13	12.95 ± 0.13	12.85 ± 0.13	12.80 ± 0.13	12.80 ± 0.13	12.50 ± 0.13
Measured dynamic draft increase (m)	**0.80 $\pm$ 0.13**	**0.75 $\pm$ 0.13**	**0.80 $\pm$ 0.13**	**0.70 $\pm$ 0.13**	**0.65 $\pm$ 0.13**	**0.65 $\pm$ 0.13**	**0.35 $\pm$ 0.13**
Point of maximum dynamic draft	Fwd post	Fwd post	Fwd post	Fwd post	Fwd post	Fwd post	Fwd post

Results summary for "Prabhu Daya"

For the Prabhu Daya transit, measured dynamic draft increases were less than the KeelClear allowances, with a minimum difference of (0.08 ± 0.13)metres, up to a maximum of (0.63 ± 0.13)metres. Eastward tidal streams were weaker than predicted on the Tucker – Turtle section, so the reverse-engineered KeelClear screenshot gives an unrealistically large dynamic draft increase on this section, leading to an "unsafe" assessment. This emphasises the need for real-time stream inputs to the KeelClear software.

3.4 ANL Windarra



Reverse-engineered KeelClear assessment for "ANL Windarra" transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	1.88	3.10	2.68	3.43	2.84	3.75	2.49
KeelClear minimum dynamic underkeel clearance (m)	0.89	2.43	2.04	2.97	1.98	3.16	2.20
KeelClear dynamic draft increase (m)	**0.99**	**0.67**	**0.63**	**0.46**	**0.86**	**0.59**	**0.29****
Measured dynamic draft (m)	12.80 ±0.24	12.75 ±0.24	12.75 ±0.24	12.80 ±0.13	12.70 ±0.13	12.65 ±0.13	12.60 ±0.13
Measured dynamic draft increase (m)	**0.60 ±0.24**	**0.55 ±0.24**	**0.55 ±0.24**	**0.60 ±0.13**	**0.50 ±0.13**	**0.45 ±0.13**	**0.40 ±0.13**
Point of maximum dynamic draft	Port corner	Aft post	Aft post	Port corner	Aft post	Port corner	Port corner
Measured minimum nett UKC (m) from depth sounder (bow.)	2.1	3.2	n/a*	3.6	n/a*	n/a*	n/a*

Results summary for "ANL Windarra"

* depth sounder data incomplete

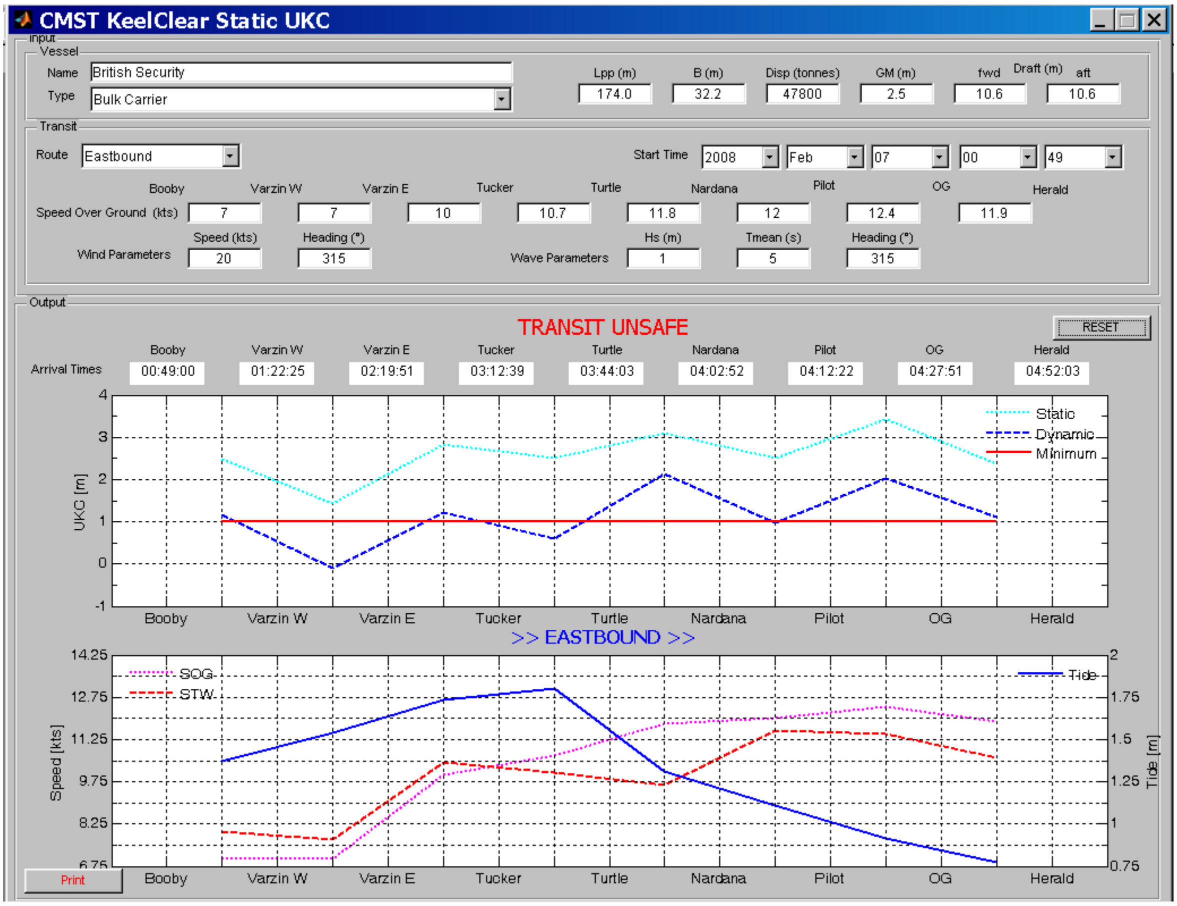
** ship decelerating to rest on this transit section

For the ANL Windarra transit, measured dynamic draft increases were generally less than the KeelClear allowances, by up to a maximum of (0.39 $\pm$0.24)metres. For the following transit sections, measured dynamic draft increases were greater than the KeelClear allowances:

- Turtle – Nardana: dynamic draft increase greater than KeelClear allowance by (0.14 $\pm$0.13)metres. Large dynamic draft increase here is principally due to turn-induced heel, however the turn is in deeper water so is not included in the KeelClear allowance.
- OG – Herald: ship was decelerating to rest, so the maximum speed was significantly greater than the speed used for the KeelClear screenshot, based on waypoint arrival times. Therefore the squat was greater than the KeelClear allowance.

Including estimated wave conditions caused the KeelClear dynamic underkeel clearance to be less than the minimum UKC on the Varzin W – Varzin E section, giving an “unsafe” assessment for the transit. This emphasizes the need for real-time wave inputs, both for modifying passage plans based on actual wave conditions, and for validating UKC software.

3.5 British Security



Reverse-engineered KeelClear assessment for “British Security” transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	1.44	2.83	2.50	3.11	2.51	3.41	2.38
KeelClear minimum dynamic underkeel clearance (m)	-0.10	1.22	0.61	2.14	0.97	2.03	1.10
KeelClear dynamic draft increase (m)	**1.54**	**1.61**	**1.89**	**0.96**	**1.54**	**1.39**	**1.27**
Measured dynamic draft (m)	10.90 ± 0.24	11.60 ± 0.24	11.50 ± 0.24	11.50 ± 0.13	11.65 ± 0.13	11.50 ± 0.13	11.50 ± 0.13
Measured dynamic draft increase (m)	**0.30 $\pm$ 0.24**	**1.00 $\pm$ 0.24**	**0.90 $\pm$ 0.24**	**0.90 $\pm$ 0.13**	**1.05 $\pm$ 0.13**	**0.90 $\pm$ 0.13**	**0.90 $\pm$ 0.13**
Point of maximum dynamic draft	Fwd post	Fwd post	Fwd post	Fwd post	Fwd post	Fwd post	Fwd post

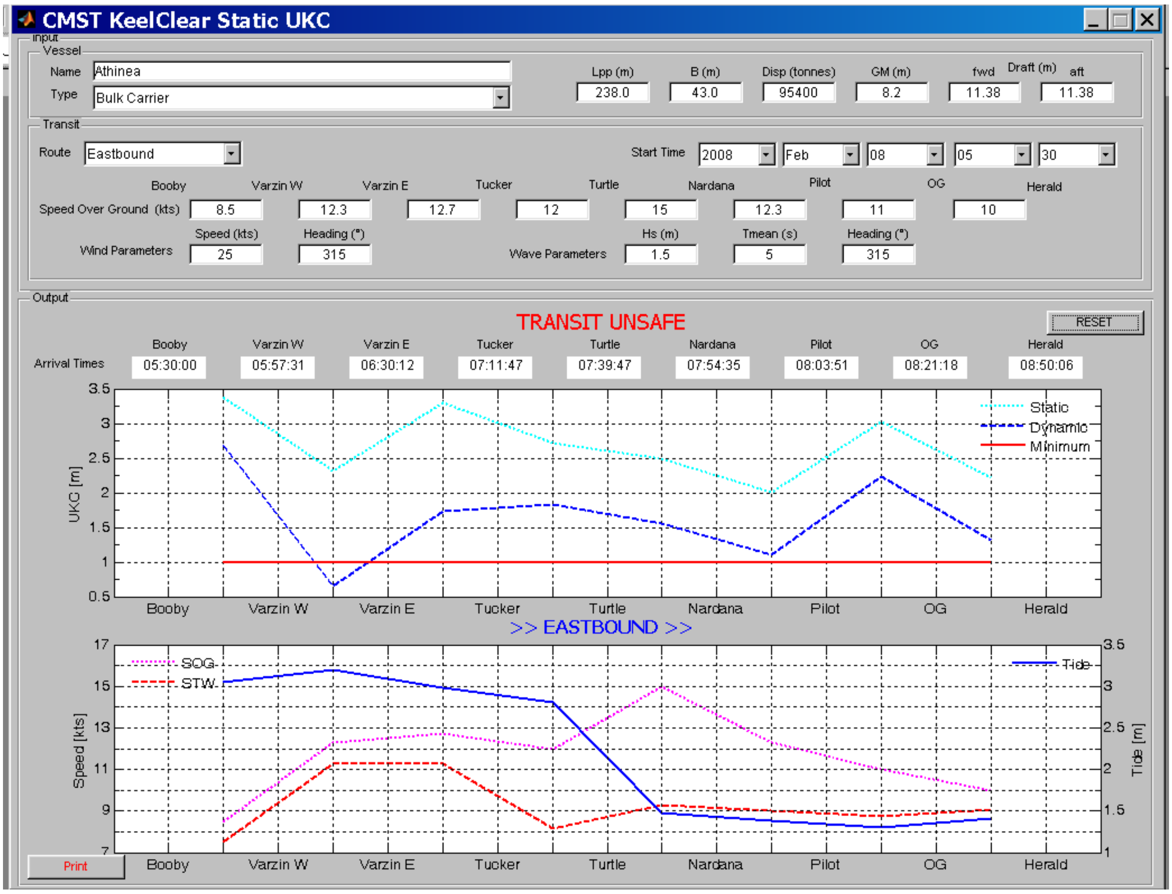
Results summary for "British Security"

For the British Security transit, measured dynamic draft increases were less than the KeelClear allowances, with a minimum difference of (0.06 ± 0.13)metres, up to a maximum of (1.24 ± 0.24)metres. The large differences at the western end, and resulting "unsafe" assessment of the transit, were due to the input of estimated wave conditions to the reverse-engineered KeelClear screenshot.

As described in Section 3.1, the wave-induced motion allowance works on a 25-year grounding probability, and the actual measured motions will usually (but not always) be significantly less than the allowance. The allowance is more conservative than traditional pilotage methods would allow, and use of the wave-induced motion allowance, combined with inputting real measured wave conditions, will increase transit safety. The wave-induced motion allowance has been designed in combination with a PIANC safety factor of 0.5m over sand and 1.0m over rock, however the present "minimum UKC" specified by AMSA is 1.0/1.2m. Therefore it is recommended that if this minimum UKC is to be made permanent, the KeelClear wave-induced motions allowance should be re-designed to complement the 1.0/1.2m "minimum UKC". This would result in a method that is equivalent to the PIANC method (and KeelClear v1.1), and less conservative than the KeelClear v1.151 method.

The large wave-induced motion allowance also emphasizes the need for real-time wave inputs, both for modifying passage plans based on actual wave conditions, and for validating UKC software.

3.6 Athinea



Reverse-engineered KeelClear assessment for "Athinea" transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	2.32	3.30	2.72	2.49	2.01	n/a**	n/a**
KeelClear minimum dynamic underkeel clearance (m)	0.78	0.87	0.91	0.63	0.17	n/a**	n/a**
KeelClear dynamic draft increase (m)	**1.53**	**1.43**	**0.81**	**0.86**	**0.84**	n/a**	n/a**
Measured dynamic draft (m)	12.60 ±0.24	12.70 ±0.24	12.40 ±0.24	12.00 ±0.13	11.85 ±0.13	n/a*	n/a*
Measured dynamic draft increase (m)	**1.20 ±0.24**	**1.30 ±0.24**	**1.00 ±0.24**	**0.60 ± 0.13**	**0.45 ± 0.13**	n/a*	n/a*
Point of maximum dynamic draft	Fwd post	Fwd post	Fwd post	Fwd post	Fwd post	n/a*	n/a*

Results summary for "Athinea"

* Post-processed GPS elevations not of survey quality east of 142º17'E, due to long baseline and insufficient satellites; also Miralga heaving too much for real-time squat measurements.

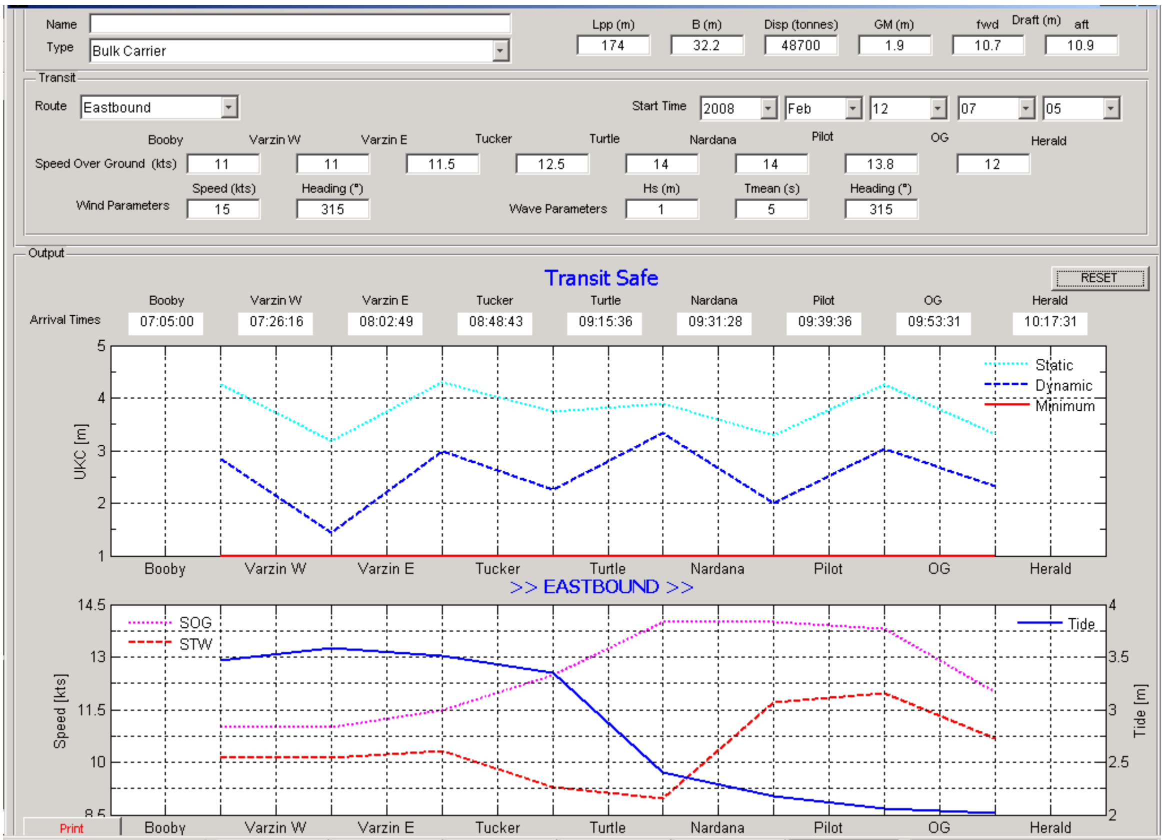
** KeelClear results not given since no measured data to compare to; disregard KeelClear screenshot from Pilot - Herald.

For the Athinea transit, measured dynamic draft increases were generally less than the KeelClear allowances, by up to a maximum of (0.39 ± 0.13)metres. Eastward tidal streams were weaker than predicted on the Tucker – Turtle section, so the reverse-engineered KeelClear screenshot has an unrealistically small speed-through-water on this section, and hence under-predicts the dynamic draft by (0.19 ± 0.24)metres, although this lies within the measurement error. The tidal stream discrepancy emphasises the need for real-time stream inputs to the KeelClear software.

Part of the problem with estimated tidal streams between Tucker and Nardana is the large spatial variation, tapering rapidly away from Hammond Rock to the west and east. Because of this large spatial variation, it may be appropriate in future to divide the transit into finer intervals near Hammond Rock.

The inclusion of estimated wave conditions causes the dynamic underkeel clearance to fall below the “minimum” from Varzin W to Varzin E, causing an “unsafe” assessment in a similar manner to the British Security transit.

3.7 Iver Example



Reverse-engineered KeelClear assessment for “Iver Example” transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	3.19	4.31	3.75	3.90	3.28	4.26	3.31
KeelClear minimum dynamic underkeel clearance (m)	1.42	2.99	2.27	3.33	2.01	3.03	2.32
KeelClear dynamic draft increase (m)	**1.77**	**1.31**	**1.48**	**0.57**	**1.27**	**1.23**	**0.99**
Measured dynamic draft (m)	11.60 ± 0.24	11.70 ± 0.24	11.65 ± 0.24	11.50 ± 0.13	11.60 ± 0.13	11.55 ± 0.24	11.55 ± 0.24
Measured dynamic draft increase (m)	$\mathbf{0.70 \pm 0.24}$	$\mathbf{0.80 \pm 0.24}$	$\mathbf{0.75 \pm 0.24}$	$\mathbf{0.60 \pm 0.13}$	$\mathbf{0.70 \pm 0.13}$	$\mathbf{0.65 \pm 0.24}$	$\mathbf{0.65 \pm 0.24}$
Point of maximum dynamic draft	Fwd post	Stbd fwd shoulder	Fwd post	Port fwd shoulder	Stbd fwd shoulder	Port fwd shoulder	Fwd post
Measured minimum nett UKC (m) from depth sounder (bridge)	3.2	3.5	4.0	3.5	3.0	3.4	n/a*

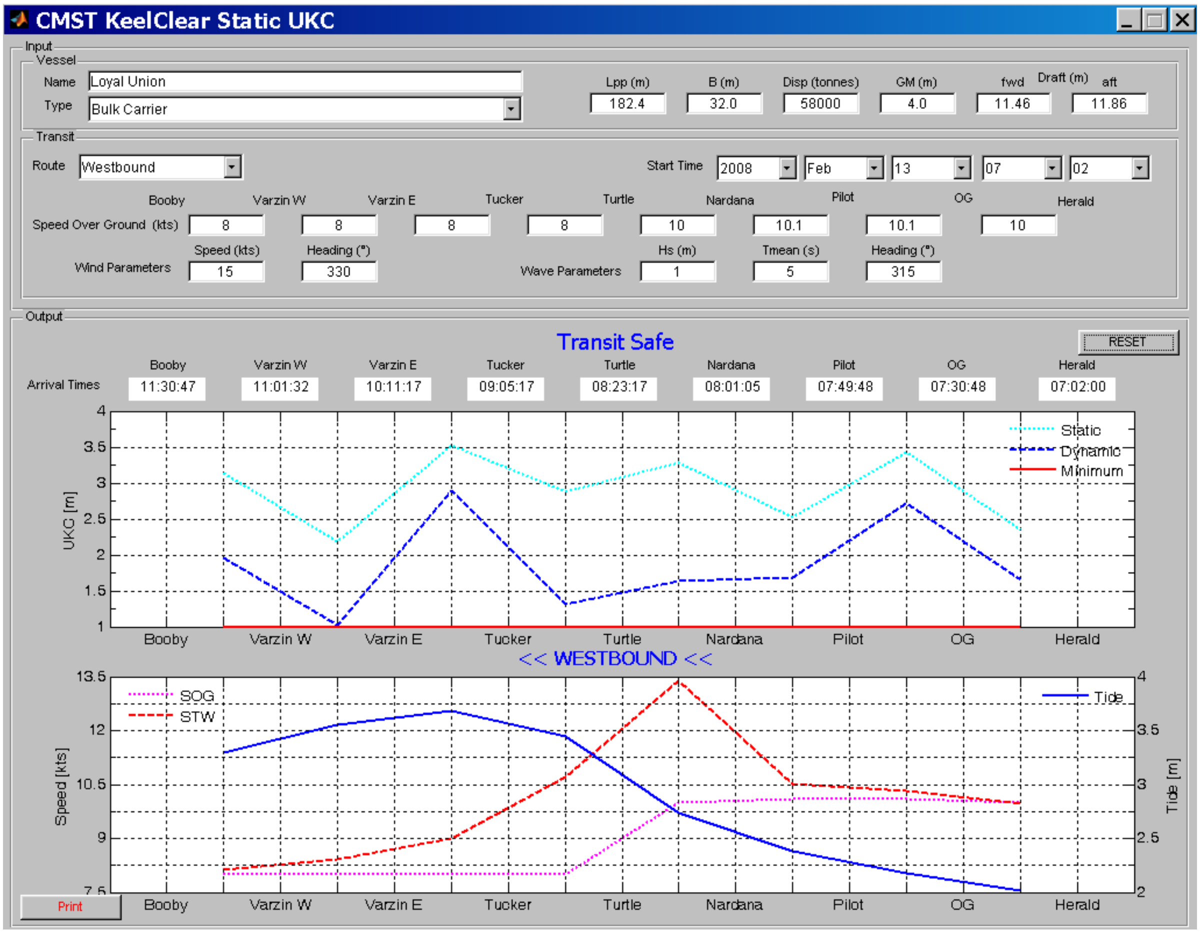
Results summary for "Iver Example"

* soundings stopped to collate depth sounder data before disembarking

For the Iver Example transit, measured dynamic draft increases were generally less than the KeelClear allowances, by up to a maximum of (1.07 ± 0.13)metres at the western end, since measured wave-induced motions will normally (but not always) be significantly less than the wave-induced motion allowance, as described in Section 3.1.

Eastward tidal streams were weaker than predicted on the Turtle – Nardana section, so the reverse-engineered KeelClear screenshot has an unrealistically small speed-through-water on this section. Hence KeelClear under-predicts the dynamic draft by (0.03 ± 0.24)metres, although this lies within measurement error. The tidal stream discrepancy emphasises the need for real-time stream inputs to the KeelClear software, and also suggests that finer transit section intervals may be appropriate near Hammond Rock (as discussed for the Athinea transit).

3.8 Loyal Union



Reverse-engineered KeelClear assessment for "Loyal Union" transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static UKC (m)	n/a**	n/a**	n/a**	n/a**	2.52	3.42	2.35
KeelClear minimum dynamic UKC (m)	n/a**	n/a**	n/a**	n/a**	1.68	2.72	1.65
KeelClear dynamic draft increase (m)	n/a**	n/a**	n/a**	n/a**	**0.84**	**0.70**	**0.70**
Measured dynamic draft (m)	n/a*	n/a*	n/a*	n/a*	12.40 ±0.13	12.40 ±0.13	12.40 ±0.13
Measured dynamic draft increase (m)	n/a*	n/a*	n/a*	n/a*	**0.55 ± 0.13**	**0.55 ± 0.13**	**0.55 ± 0.13**
Point of maximum dynamic draft	n/a*	n/a*	n/a*	n/a*	Fwd post	Fwd post	Fwd post
Measured minimum nett UKC (m) from depth sounder (pos. unkn.)	n/a**	n/a**	n/a**	n/a**	2.3	2.7	3.5

Results summary for "Loyal Union"

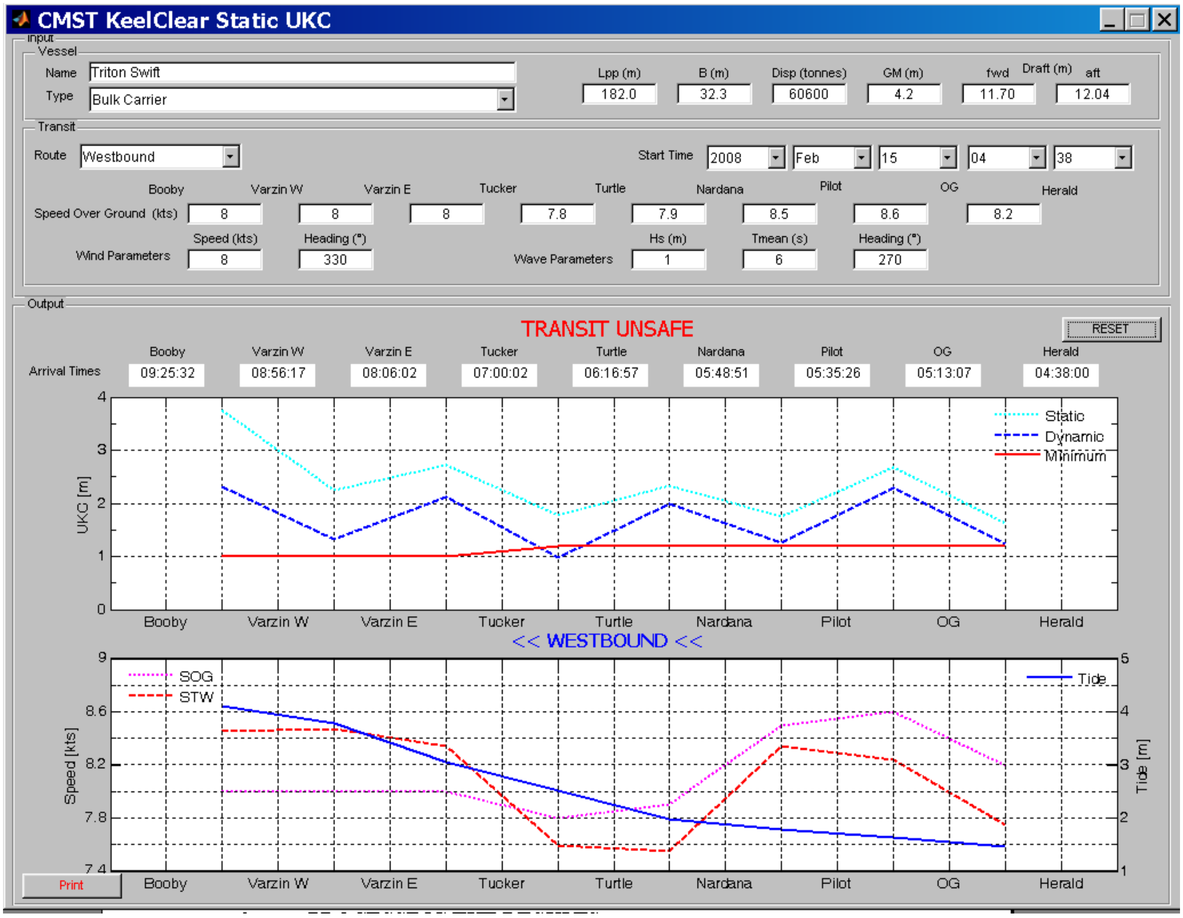
* Post-processed GPS elevations not of survey quality west of 142°16'E, due to long baseline and insufficient satellites; also real-time data incomplete.

** KeelClear and depth sounder results not given, since no measured data to compare to; disregard KeelClear screenshot from Booby - Nardana.

For the Loyal Union transit, post-processed GPS elevations were not of survey quality west of 142º16'E, due to the long baseline and insufficient satellites, and real-time data was incomplete, so only the part of the transit from Nardana to Herald was analyzed. Measured dynamic draft increases were all less than the KeelClear allowances, with a minimum difference of (0.15 ± 0.13)metres, up to a maximum of (0.19 ± 0.13)metres.

The KeelClear dynamic underkeel clearance remained above the minimum for the whole transit.

3.9 Triton Swift



Reverse-engineered KeelClear assessment for "Triton Swift" transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	n/a**	n/a**	1.78	2.33	1.75	2.69	1.62
KeelClear minimum dynamic underkeel clearance (m)	n/a**	n/a**	0.98	1.99	1.26	2.28	1.23
KeelClear dynamic draft increase (m)	n/a**	n/a**	**0.81**	**0.34**	**0.49**	**0.40**	**0.38**
Measured dynamic draft (m)	n/a*	n/a*	12.30 ± 0.13	12.25 ± 0.13	12.40 ± 0.13	12.35 ± 0.13	12.30 ± 0.13
Measured dynamic draft increase (m)	n/a*	n/a*	**0.25 $\pm$ 0.13**	**0.20 $\pm$ 0.13**	**0.35 $\pm$ 0.13**	**0.30 $\pm$ 0.13**	**0.25 $\pm$ 0.13**
Point of maximum dynamic draft	n/a*	n/a*	Port fwd shoulder	Port aft shoulder	Port fwd shoulder; stbd fwd shoulder	Port fwd shoulder	Port aft shoulder

Results summary for "Triton Swift"

* Post-processed GPS elevations not of survey quality west of 142º05'E, due to long baseline and insufficient satellites; also Miralga heaving too much for real-time squat measurements.

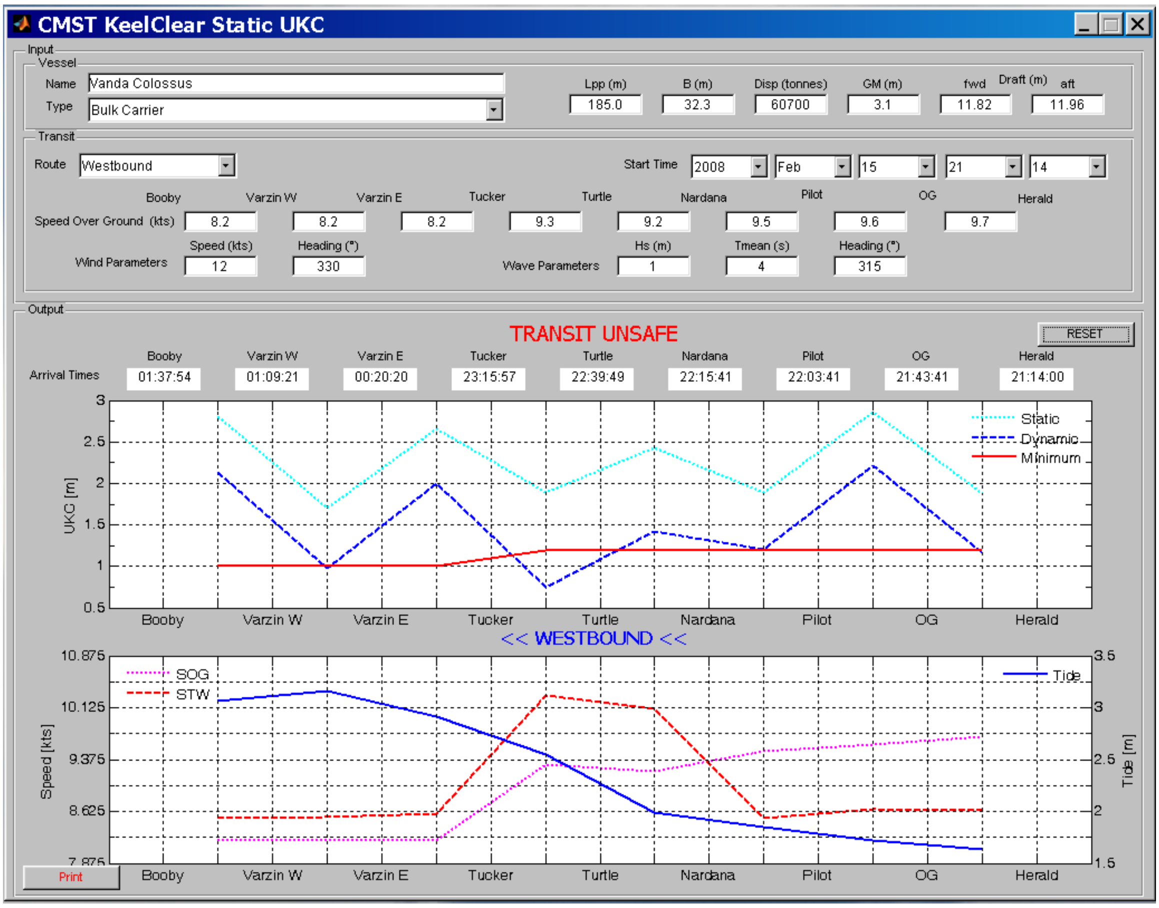
** KeelClear results not given, since no measured data to compare to; disregard KeelClear screenshot from Varzin W – Tucker.

For the Triton Swift transit, post-processed GPS elevations were not of survey quality west of 142º05'E, due to the long baseline and insufficient satellites. Miralga was heaving too much on this part of the transit to use the real-time method for calculating squat. Therefore no results are given from Varzin W – Tucker.

Measured dynamic draft increases were less than the KeelClear allowances, with a minimum difference of (0.10 ± 0.13)metres, up to a maximum of (0.56 ± 0.13)metres. The largest difference was on the Tucker – Turtle section, where estimated wave conditions were used to determine the KeelClear allowance, and the allowance is designed to be larger than is normally measured, as described in Sections 3.1 and 3.5.

The KeelClear dynamic underkeel clearance dropped below the minimum on the Tucker – Turtle section, mainly due to the reverse-engineering of the KeelClear screenshot using estimated wave conditions.

3.10 Vanda Colossus



Reverse-engineered KeelClear assessment for “Vanda Colossus” transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	1.70	2.65	1.89	2.43	1.89	2.86	1.87
KeelClear minimum dynamic underkeel clearance (m)	0.99	2.00	0.77	1.42	1.21	2.22	1.17
KeelClear dynamic draft increase (m)	**0.71**	**0.66**	**1.12**	**1.00**	**0.68**	**0.64**	**0.70**
Measured dynamic draft (m)	12.35 ±0.24	12.40 ±0.24	12.40 ±0.24	12.35 ±0.24	12.35 ±0.13	12.35 ±0.13	12.35 ±0.13
Measured dynamic draft increase (m)	**0.40 ±0.24**	**0.45 ±0.24**	**0.45 ±0.24**	**0.40 ±0.24**	**0.40 ± 0.13**	**0.40 ± 0.13**	**0.40 ± 0.13**
Point of maximum dynamic draft	Stbd fwd shoulder	Stbd fwd shoulder	Stbd fwd shoulder; fwd post	Port fwd shoulder	Stbd fwd shoulder	Stbd fwd shoulder; fwd post	Stbd fwd shoulder; fwd post
Measured min. nett UKC (m) from depth sounder (bridge)	2.1	3.1	2.2	n/a*	n/a*	n/a*	3.5

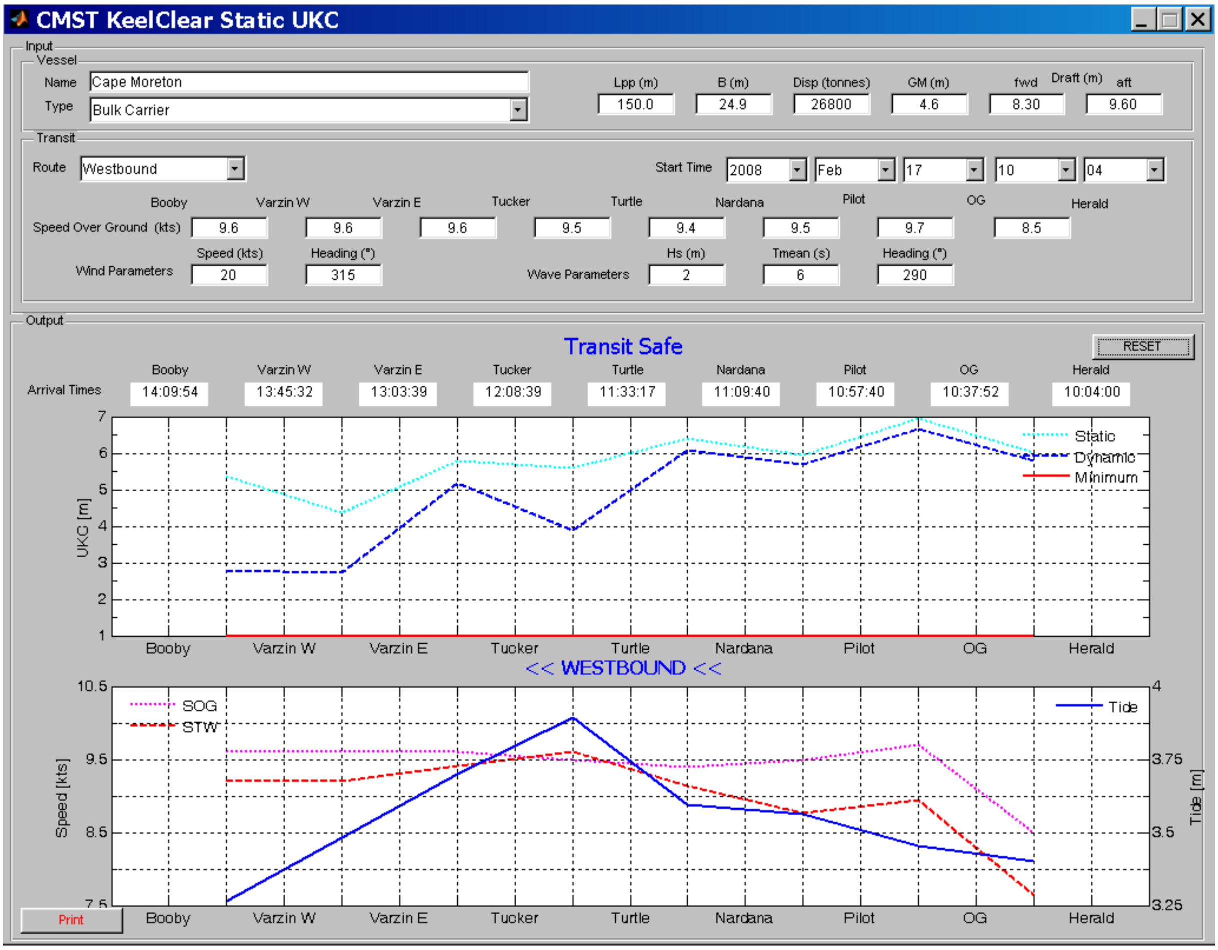
Results summary for “Vanda Colossus”

* depth sounder data incomplete

For the Vanda Colossus transit, measured dynamic draft increases were less than the KeelClear allowances, with a minimum difference of (0.21 $\pm$0.24)metres, up to a maximum of (0.67 $\pm$0.24)metres. The largest difference was on the Tucker – Turtle section, where estimated wave conditions were used to determine the KeelClear allowance, and the allowance is designed to be larger than is normally measured, as described in Section 3.1.

The KeelClear dynamic underkeel clearance dropped below the minimum on the Tucker – Turtle section, due to the large speed-through-water and hence squat allowance. This transit was undertaken using traditional piloting techniques, and the “unsafe” assessment of this transit according to KeelClear v1.151 shows that using KeelClear would have been a more conservative approach than traditional techniques in this instance. However, as mentioned in the case of British Security, the squat and wave-induced motions allowances are overly conservative if combined with a 1.0/1.2m “minimum UKC”.

3.11 Cape Moreton



Reverse-engineered KeelClear assessment for “Cape Moreton” transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	n/a**	n/a**	5.59	6.39	5.96	6.95	6.00
KeelClear minimum dynamic underkeel clearance (m)	n/a**	n/a**	4.05	6.09	5.68	6.68	5.79
KeelClear dynamic draft increase (m)	n/a**	n/a**	**1.53**	**0.30**	**0.28**	**0.28**	**0.21**
Measured dynamic draft (m)	n/a*	n/a*	9.90 ± 0.13	9.85 ± 0.13	9.85 ± 0.13	9.90 ± 0.13	9.90 ± 0.13
Measured dynamic draft increase (m)	n/a*	n/a*	**0.30 $\pm$ 0.13**	**0.25 $\pm$ 0.13**	**0.25 $\pm$ 0.13**	**0.30 $\pm$ 0.13**	**0.30 $\pm$ 0.13**
Point of maximum dynamic draft	n/a*	n/a*	Aft post	Aft post	Aft post	Aft post	Aft post

Results summary for "Cape Moreton"

* Post-processed GPS data incomplete; also Miralga heaving too much for real-time squat measurements west of 142º08'E.

** KeelClear results not given, since no measured data to compare to; disregard KeelClear screenshot from Varzin W - Tucker.

For the Cape Moreton transit, post-processed GPS elevations were incomplete, so the real-time method was used; however Miralga was heaving too much from Varzin W – Tucker to obtain accurate squat measurements. Therefore results are only given from Tucker – Herald.

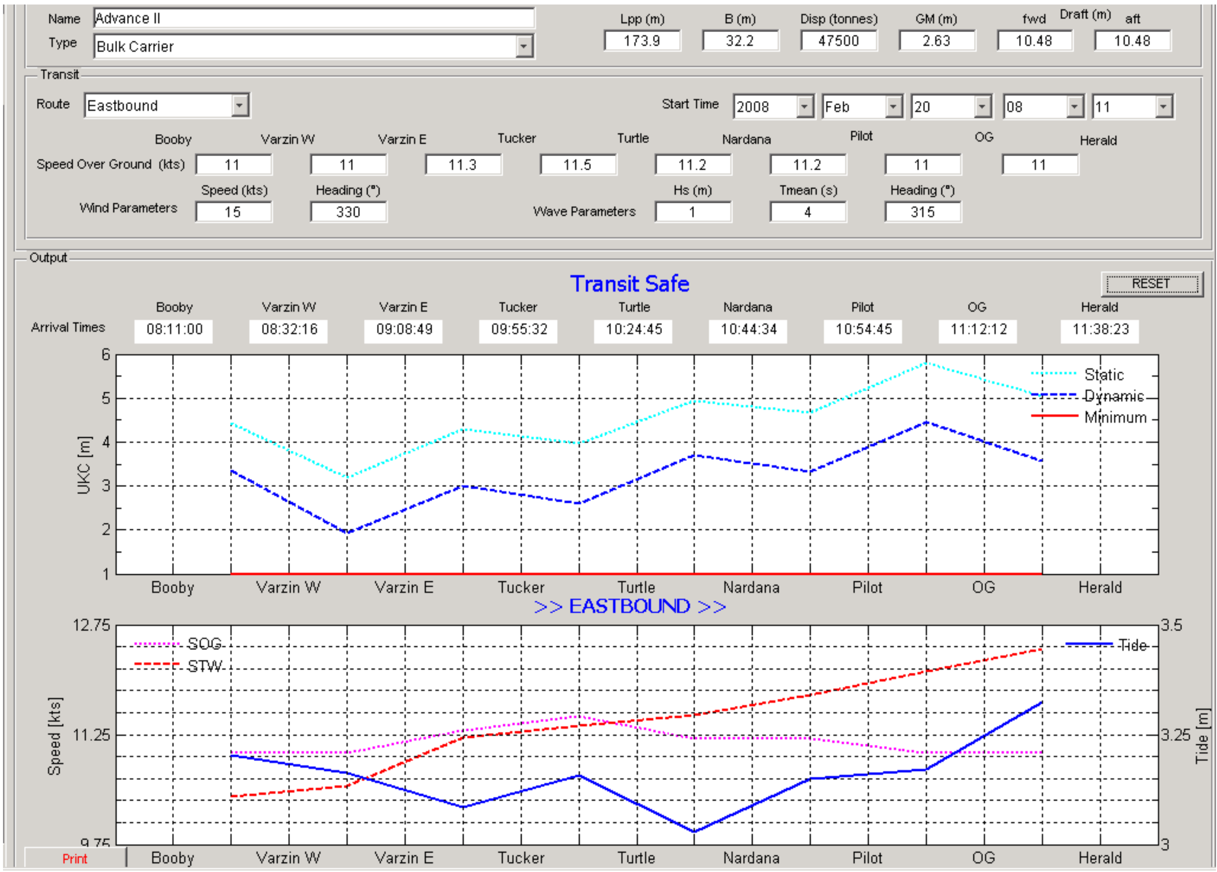
Measured dynamic draft increases were generally less than the KeelClear allowances, by up to a maximum of (1.23 ± 0.13)metres. The largest difference was on the Tucker – Turtle section, where estimated wave conditions were used to determine the KeelClear allowance, and the allowance is designed to be larger than is normally measured, as described in Section 3.1.

The westward current was weaker than predicted at the eastern end of the transit, giving an unrealistically small speed-through-water and hence squat allowance. Therefore the measured dynamic draft increase exceeded the KeelClear allowance by (0.02 ± 0.13)metres on the Pilot – OG section, although this lies within measurement error.

The tidal stream discrepancy emphasises the need for real-time stream inputs to the KeelClear software.

The KeelClear dynamic underkeel clearance remained above the minimum for the whole transit.

3.12 Advance II



Reverse-engineered KeelClear assessment for "Advance II" transit

	VarzinW VarzinE	VarzinE Tucker	Tucker Turtle	Turtle Nardana	Nardana Pilot	Pilot OG	OG Herald
KeelClear minimum static underkeel clearance (m)	3.18	4.30	3.97	4.95	4.67	5.79	5.04
KeelClear minimum dynamic underkeel clearance (m)	1.93	3.00	2.62	3.69	3.31	4.46	3.55
KeelClear dynamic draft increase (m)	**1.25**	**1.30**	**1.35**	**1.26**	**1.36**	**1.33**	**1.49**
Measured dynamic draft (m)	11.30 ±0.24	11.20 ±0.24	11.20 ±0.24	11.15 ±0.13	11.15 ±0.24	11.15 ±0.24	11.10 ±0.24
Measured dynamic draft increase (m)	**0.80 ±0.24**	**0.70 ±0.24**	**0.70 ±0.24**	**0.65 ± 0.13**	**0.65 ±0.24**	**0.65 ±0.24**	**0.60 ±0.24**
Point of maximum dynamic draft	Fwd post	Fwd post; stbd fwd shoulder	Fwd post; port fwd shoulder	Fwd post; stbd fwd shoulder	Fwd post; stbd fwd shoulder	Fwd post	Stbd fwd shoulder
Measured minimum nett UKC (m) from depth sounder (bridge)	3.4	4.4	3.9	5.1	4.5	5.3	6.2

Results summary for "Advance II"

For the Advance II transit, measured dynamic draft increases were less than the KeelClear allowances, with a minimum difference of (0.45 ± 0.24)metres, up to a maximum of (0.89 ± 0.24)metres. The westward current was weaker than expected at the eastern end of the transit, causing an unrealistically large speed-through-water according to the reverse-engineered KeelClear results, and hence an unrealistically large squat allowance.

The KeelClear dynamic underkeel clearance remained above the minimum for the whole transit.

3.13 Summary of comparisons between measured dynamic draft and KeelClear predictions

Almost all of the measured dynamic draft increases were less than the KeelClear allowances. This ensures that KeelClear provides a conservative UKC management tool, in that the actual clearance during a transit is at least as large as that predicted.

Cases where KeelClear was most conservative occurred where the estimated wave conditions were of large height and long period. For example, British Security had a measured dynamic draft increase that was (1.24 ± 0.24)metres less than the KeelClear allowance on the Varzin W – Varzin E section. This was the largest difference recorded between measured and predicted results. Note however that wave conditions were not measured for these transits, due to the lack of a wave buoy, so the input wave conditions are only visual estimates. Further trials should be performed once a wave buoy is installed, to better compare the wave-induced motions.

Note also that the allowance for wave-induced motions at the western end of the transit is designed to minimize grounding probabilities over a 25-year period, so the actual dynamic draft increase for individual transits should normally be significantly less than the allowance.

The other important factor governing discrepancies between the measured and KeelClear results was tidal stream prediction. Errors in tidal streams produce errors in the relationship between speed-through-water and speed-over-ground, and hence incorrect squat estimates. The main factors affecting tidal stream accuracy are:

1. Accuracy of modelled astronomical tidal streams at prediction locations
2. Spatial interpolation of tidal streams
3. Temporal interpolation of tidal streams
4. Meteorological effects

Factor 1 is handled by the BoM, who continue to improve their tidal stream models. Factor 2 has been improved by the BoM for 2008 by adding extra stream prediction locations for the Torres Strait. This could also be improved in the KeelClear software by breaking the transit into finer sections around Hammond Rock, although at the expense of graphical interface legibility. Factor 3 could be improved by the BoM by providing hourly stream predictions, rather than just slack water and maximum flow times. Factor 4 could be improved by CMST and/or BoM, by developing a neural net model for predicting meteorological effects on tidal streams into the near future. All effects could be mitigated by having access to more real-time stream data, to be fed into the real-time KeelClear software.

Apart from the OG – Herald section where the ship was completely stopped, in only a few cases was the measured dynamic draft increase greater than the KeelClear allowance. These included:

- ANL Windarra, Turtle – Nardana section. Here the dynamic draft increase was greater than KeelClear allowance by (0.14 ± 0.13)metres. The large dynamic draft increase here was principally due to turn-induced heel, however the turn is in deeper water so is not included in the KeelClear allowance.
- Athinea, Tucker – Turtle section. Here the dynamic draft increase was greater than KeelClear allowance by (0.19 ± 0.24)metres, which lies within the measurement error. The speed-through-water was under-predicted on this section due to inaccurate tidal stream predictions, leading to a KeelClear squat allowance that was too small.
- Iver Example, Turtle – Nardana section. Here the dynamic draft increase was greater than KeelClear allowance by (0.03 ± 0.24)metres, which lies within the measurement error. Again, speed-through-water was under-predicted on this section due to inaccurate tidal stream predictions, leading to a KeelClear squat allowance that was too small.

4 CALM WATER SQUAT RESULTS

A comparison was made between measured and predicted bow and stern squat along a straight section of the transit in calm water. This allowed a direct comparison of the squat on its own, between the measurements and the KeelClear allowances. The comparisons made in Section 3 along the entire transit include the combined effects of squat, heel due to turn and wave-induced motions.

The pure squat comparison was done along a calm section of each transit, where the speed-through-water and hence squat were at a maximum, to minimize the percentage error in the measured results. The environmental conditions for each squat comparison were as shown below.

	Longitude East	Speed-through-water (calculated as described in Section 2.3)	Water depth (based on chart datum depths and predicted tide heights)
Stove Campbell	142º02’	10.8kn	14.8m
Prabhu Daya	141º56’	10.0kn	14.3m
ANL Windarra	142º13.7’	10.0kn	15.6m
British Security	142º16.6’	10.8kn	13.1m
Athinea	142º10.5’	9.1kn	14.1m
Iver Example	142º16.2’	11.3kn	14.2m
Loyal Union	142º20.0’	11.6kn	15.3m
Triton Swift	142º16.5’	9.6kn	13.8m
Vanda Colossus	142º22.0’	8.9kn	13.9m
Cape Moreton	142º12.5’	9.5kn	16.0m
Advance II	142º10.3’	10.4kn	14.4m

Comparisons between measured and predicted bow and stern squat in calm water are shown below.

	Bow squat (metres)			Stern squat (metres)		
	Measured	KeelClear allowance	KeelClear allowance minus Measured	Measured	KeelClear allowance	KeelClear allowance minus Measured
Stove Campbell	0.70 ± 0.13	1.28	0.58 ± 0.13	0.35 ± 0.13	0.70	0.35 ± 0.13
Prabhu Daya	0.80 ± 0.13	1.15	0.35 ± 0.13	0.30 ± 0.13	0.63	0.33 ± 0.13
ANL Windarra	-0.08 ± 0.13	0.47	0.55 ± 0.13	0.45 ± 0.13	0.47	0.02 ± 0.13
British Security	1.05 ± 0.13	1.32	0.27 ± 0.13	0.40 ± 0.13	0.72	0.32 ± 0.13
Athinea	0.85 ± 0.13	0.88	0.03 ± 0.13	0.40 ± 0.13	0.48	0.08 ± 0.13
Iver Example	0.86 ± 0.13	1.36	0.50 ± 0.13	0.41 ± 0.13	0.75	0.34 ± 0.13
Loyal Union	0.95 ± 0.13	1.44	0.49 ± 0.13	0.0 ± 0.13	0.79	0.79 ± 0.13
Triton Swift	0.68 ± 0.13	1.10	0.42 ± 0.13	0.29 ± 0.13	0.60	0.31 ± 0.13
Vanda Colossus	0.55 ± 0.13	0.90	0.45 ± 0.13	0.29 ± 0.13	0.49	0.20 ± 0.13
Cape Moreton	0.29 ± 0.13	0.60	0.31 ± 0.13	0.19 ± 0.13	0.33	0.14 ± 0.13
Advance II	0.70 ± 0.13	1.08	0.38 ± 0.13	0.38 ± 0.13	0.59	0.21 ± 0.13

Measured bow squat was less than the KeelClear allowance by a minimum of (0.03 ± 0.13) metres, up to a maximum of (0.58 ± 0.13) metres, across all ships tested. Measured stern squat was less than the KeelClear allowance by a minimum of (0.02 ± 0.13) metres, up to a maximum of (0.79 ± 0.13) metres, across all ships tested. This pure squat comparison (without the effects of heel or wave-induced motions, and using the correct speed-through-water value) shows that the squat model used in KeelClear gives squat allowances that are slightly larger than the measured squat, ensuring a conservative UKC management tool.

5 CONCLUSIONS

The field trials conducted in Torres Strait through February 2008 have gained an accurate data set of measured squat, heel and wave-induced motions on 11 vessels transiting the Strait. Due to the length of the transit, this makes the field trials one of the largest, if not the largest, set of full-scale ship squat data yet obtained internationally. The trials were also performed in a very challenging environment, due to the rapidly varying tidal heights and streams. The complex tidal variations and length of the transit required a new GPS surveying method to be developed, involving moving and fixed base stations, which was a world first for ship squat trials.

The trials measured ship squat, trim, heel, heave, pitch and roll. Measured at 1 second intervals, this generated an enormous amount of data, which is presented in the graphical results in the Appendix. Because the data from an entire transit is presented on each graph, it is difficult to pick out some features, such as heel in turn, but it is straightforward to pick out the maximum dynamic draft increase, in order to determine dynamic underkeel clearance.

The measured dynamic draft increase was found in almost all cases to be less than the KeelClear allowance. Those cases where the measured dynamic draft increase was slightly larger than the KeelClear allowance were seen to be principally due to inaccurate tidal stream predictions, causing an inaccurate relationship between speed-over-ground and speed-through-water. This can be rectified with improved tidal stream modelling.

Pure squat comparisons were made between measured values and KeelClear allowances, in straight, calm water sections of the transit, so that the results were not contaminated by heel or wave-induced motions. It was found in all cases that the measured bow and stern squat were less than the KeelClear allowances. This confirms the squat model used in KeelClear as an accurate and conservative model for UKC management.

Since no wave buoy was in operation at the time of the trials, validation of wave-induced motion allowances was not able to be done, since the motions were measured but not the environmental conditions.

Actual dynamic underkeel clearance was measured using ship's depth sounders where available, and the results presented. However since exact tidal heights were not measured, and the depth sounders are of questionable accuracy, these results are of little use in the validation of KeelClear. Instead, the preferred validation method remains to independently verify the contributing factors of chart datum depths, tidal heights, squat, heel and wave-induced motions.

6 FUTURE IMPROVEMENTS

The following suggestions for future improvements of the KeelClear software are offered as a result of the field trials and analysis:

1. Installation of a wave buoy

These trials having been performed during the NW monsoon, significant wave-induced ship motions were measured, which suggests that wave-induced motions must be allowed for in Torres Strait. A pre-requisite for calculating wave-induced motion allowances is to have a wave buoy installed and measuring wave data in real-time, which can be transmitted to a server for use in the real-time KeelClear program.

2. Further trials to validate wave-induced motions

It is suggested that once a wave buoy is operational, further trials be performed to validate the wave-induced motions allowances in KeelClear. Once the wave buoy is operational, the real-time KeelClear program will be able to be used, and the trials would also serve to validate the complete process from KeelClear passage plan, to KeelClear real-time software, and its updates through the transit.

3. Installation of tidal stream gauges

The strong dependence of squat on speed-through-water, and the rapid tidal variations in Torres Strait, make tidal streams an important factor in real-time and predictive UKC software. Tidal stream residuals were seen to be significant during these transits, which warrants real-time input of tidal streams to the KeelClear software. Ideally this would not only be from Nardana, but from other locations through the transit, e.g. Varzin Passage, Harrison Rock and Alert Patches, the locations used by BoM for tidal stream predictions.

4. Better tidal stream modelling

Spatial and temporal interpolation of tidal streams is required for the KeelClear predictive and real-time software. It is recommended that:

- BoM are requested to provide hourly predictions of tidal streams (as is done for tidal heights), rather than just the maximum flow and slack water
- BoM are requested for any assistance they can provide with spatial interpolation of tidal streams between Varzin Passage, Harrison Rock, Nardana and Alert Patches
- CMST to consider breaking the transit into finer sections around Hammond Rock, to better capture the rapidly varying tidal streams
- CMST and/or BoM aim to develop a neural net model for predicting meteorological effects on tidal streams into the near future

5. Better tidal height modelling

Although tidal heights were not studied as part of these trials, similar recommendations would be made as for tidal streams, i.e.

- Measured tidal height data to be transmitted to a server for use in real-time KeelClear software
- BoM are requested for any assistance they can provide with spatial interpolation of tidal heights between Goods Island, Turtle Head, and Ince Point
- CMST to consider breaking the transit into finer sections around Hammond Rock, to better capture the rapidly varying tidal heights
- CMST and/or BoM aim to develop a neural net model for predicting meteorological effects on tidal heights into the near future

6. Better combination of wave-induced motions allowance and minimum UKC

The wave-induced motions allowance used in KeelClear v1.1 was designed to work in conjunction with the PIANC minimum nett UKC requirement of 0.5m over sand and 1.0m over rock. The minimum UKC specified by AMSA, and used for KeelClear v1.151, is 1.0m along the whole channel, increased to 1.2m in the Prince of Wales Channel for drafts of 11.9m or larger. It is suggested that if this minimum UKC is to be made permanent, the wave-induced motion allowance (which uses a statistical method to estimate the 25-year grounding probability as recommended by PIANC) is to be re-configured by CMST to work in conjunction with this new minimum UKC. This would result in a method that is equivalent to the PIANC method (and KeelClear v1.1), and less conservative than the KeelClear v1.151 method.

7. Further analysis of the measured results

The measured results from these trials contain a wealth of information, not just on dynamic draft increase. The heel-in-turn through each turn in each transit will be studied in more detail over the coming months, providing an important dataset. In addition, hard over turns were performed in two of the transits, and analysis of the effects such drastic manoeuvring has on bow and stern squat will be the first such study that has been made worldwide.

Curtin

UNIVERSITY OF TECHNOLOGY

Centre for Marine Science and Technology

VALIDATION OF KEELCLEAR SOFTWARE IN TORRES STRAIT

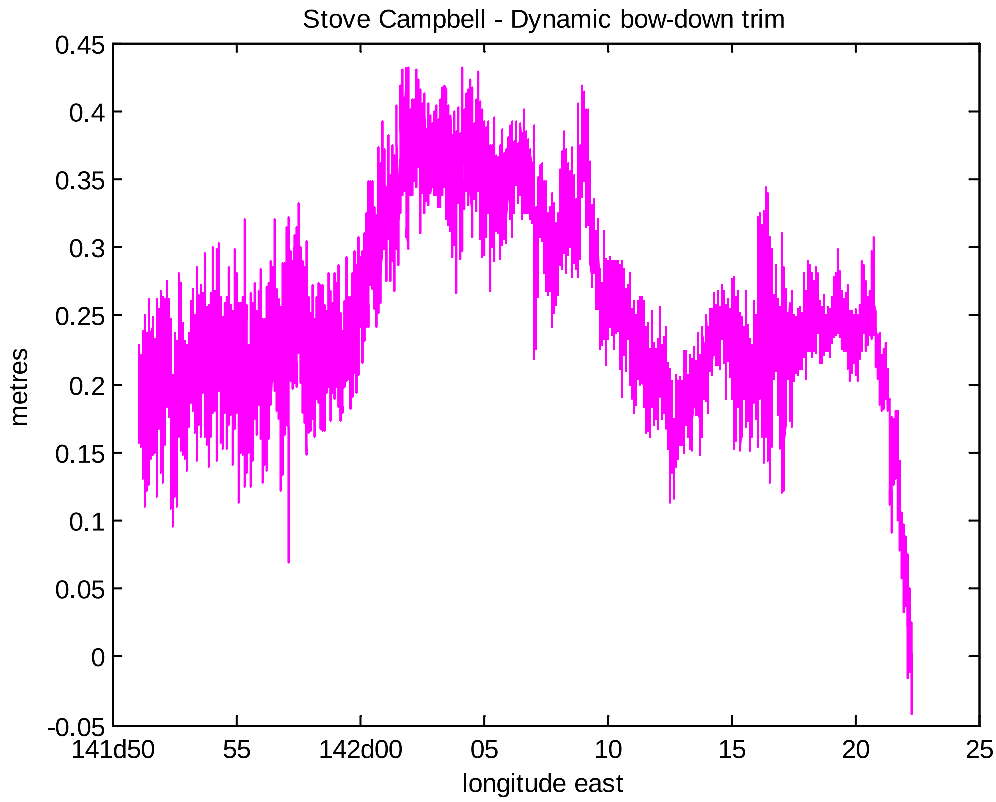
APPENDIX A – GRAPHICAL RESULTS

By:
Dr. Tim Gourlay

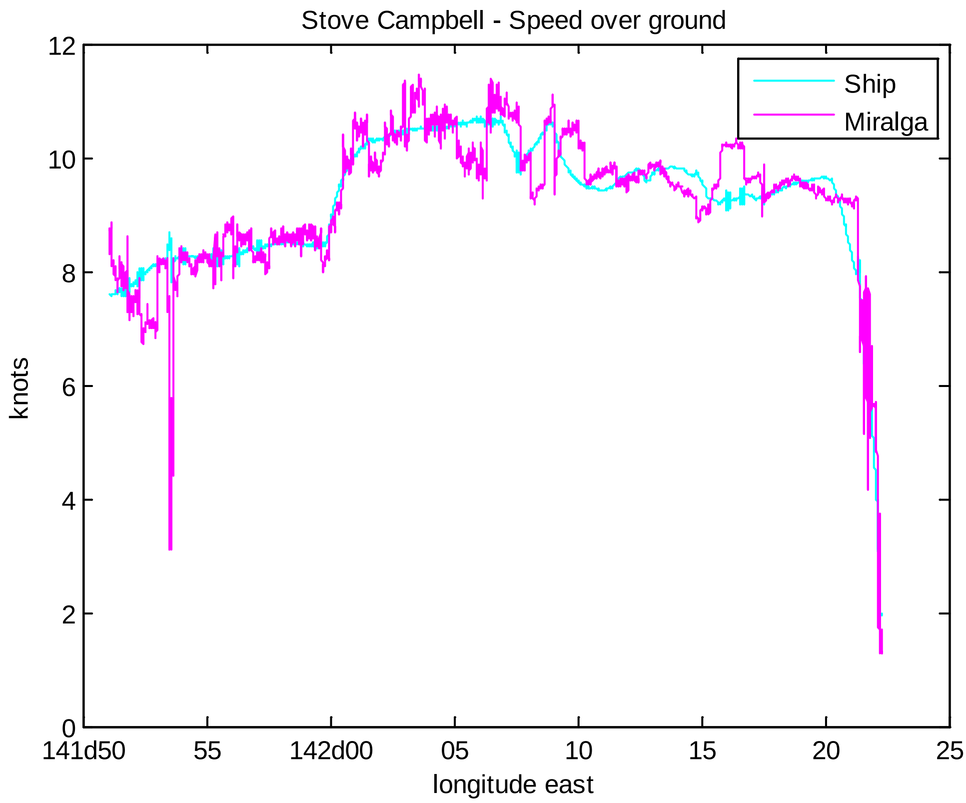
Prepared for:
Australian Reef Pilots

PROJECT CMST 739
REPORT CMST 2008-05

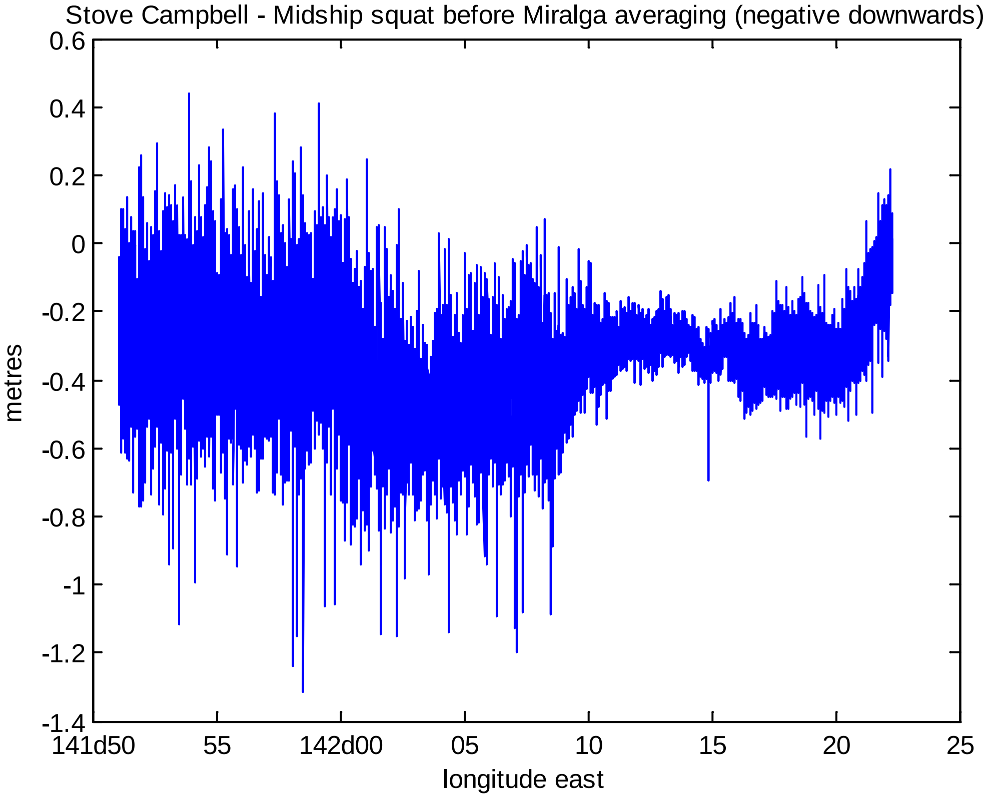
17th April 2008

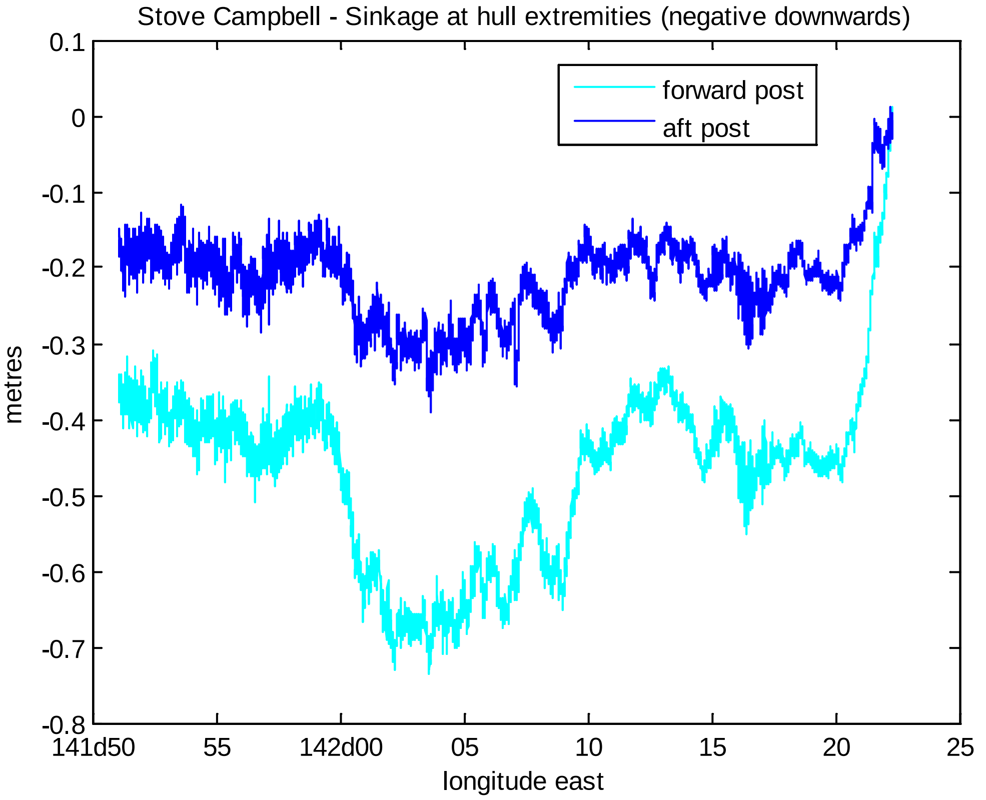


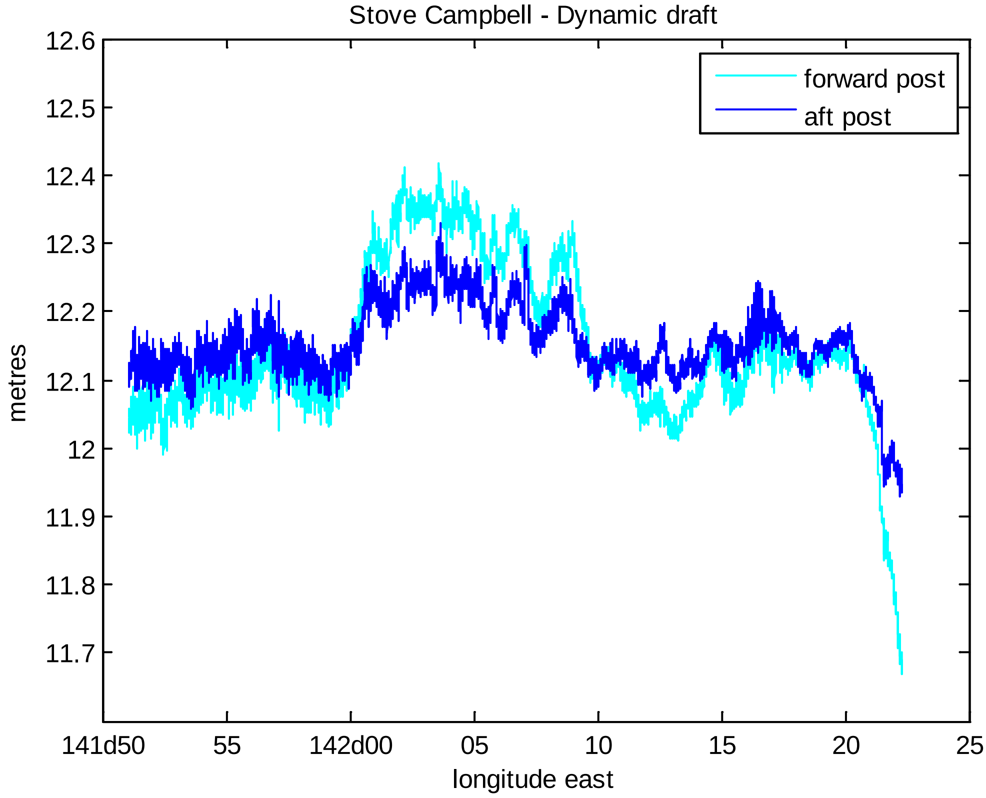
Stove Campbell - Dynamic bow-down trim
metres
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
141d50
55
142d00
05
10
15
20
25
longitude east



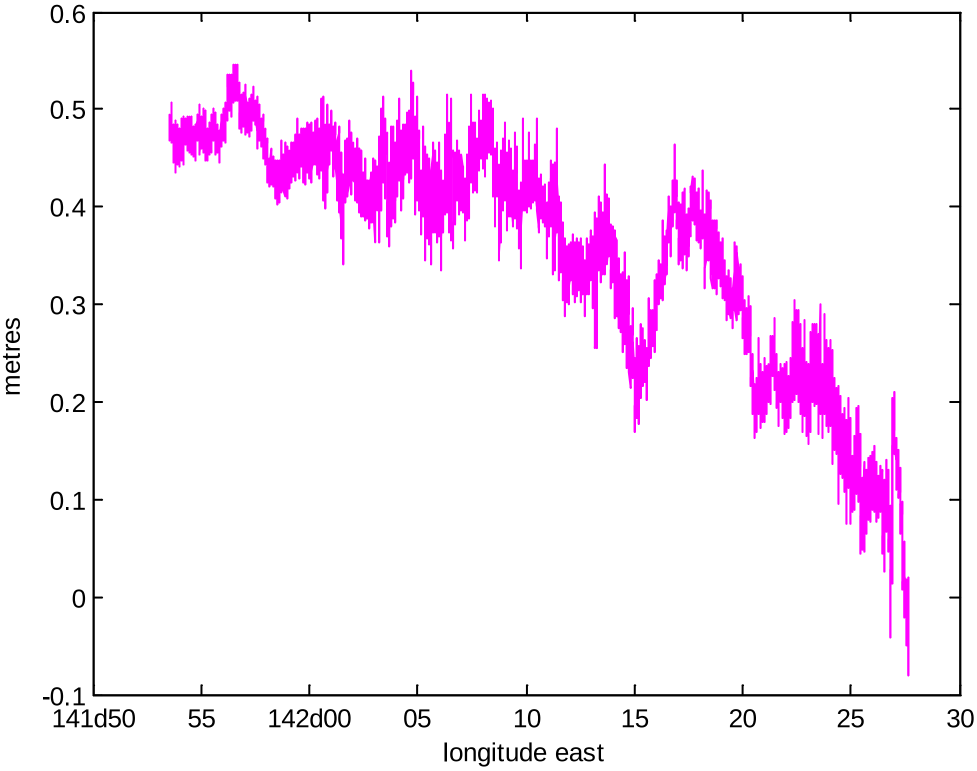
Stove Campbell - Speed over ground
knots
12
10
8
6
4
2
0
Ship
Miralga
141d50
55
142d00
05
10
15
20
25
longitude east


Stove Campbell - Midship squat before Miralga averaging (negative downwards)
metres
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
141d50
55
142d00
05
10
15
20
25
longitude east

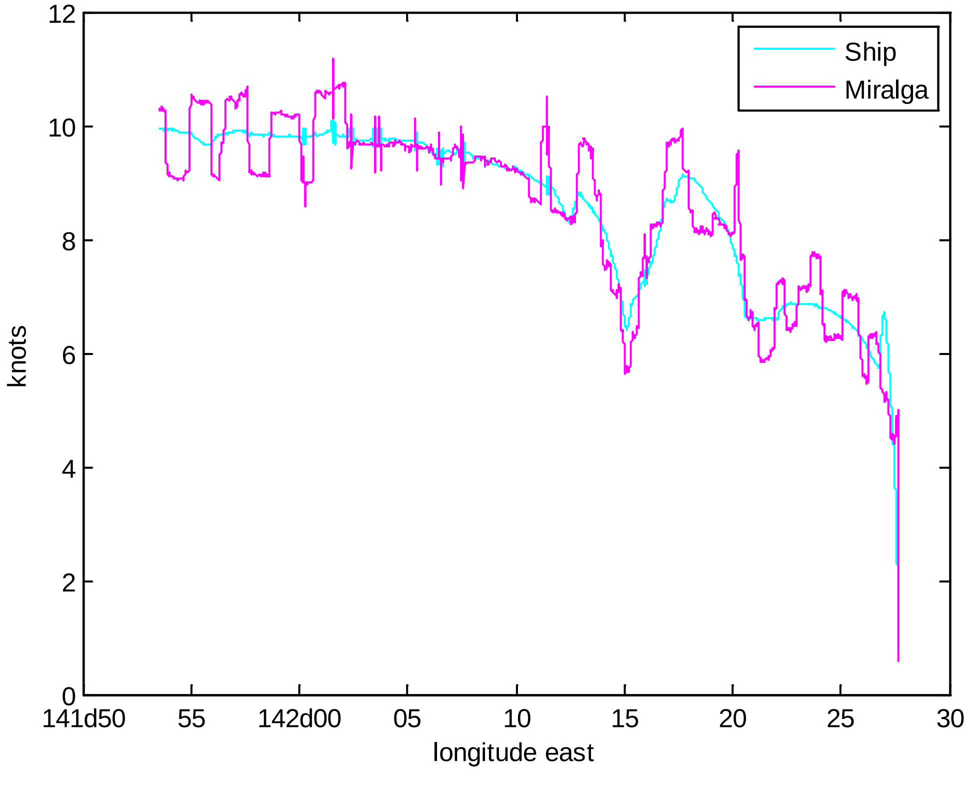

Stove Campbell - Sinkage at hull extremities (negative downwards)
forward post
aft post
metres
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
141d50
55
142d00
05
10
15
20
25
longitude east

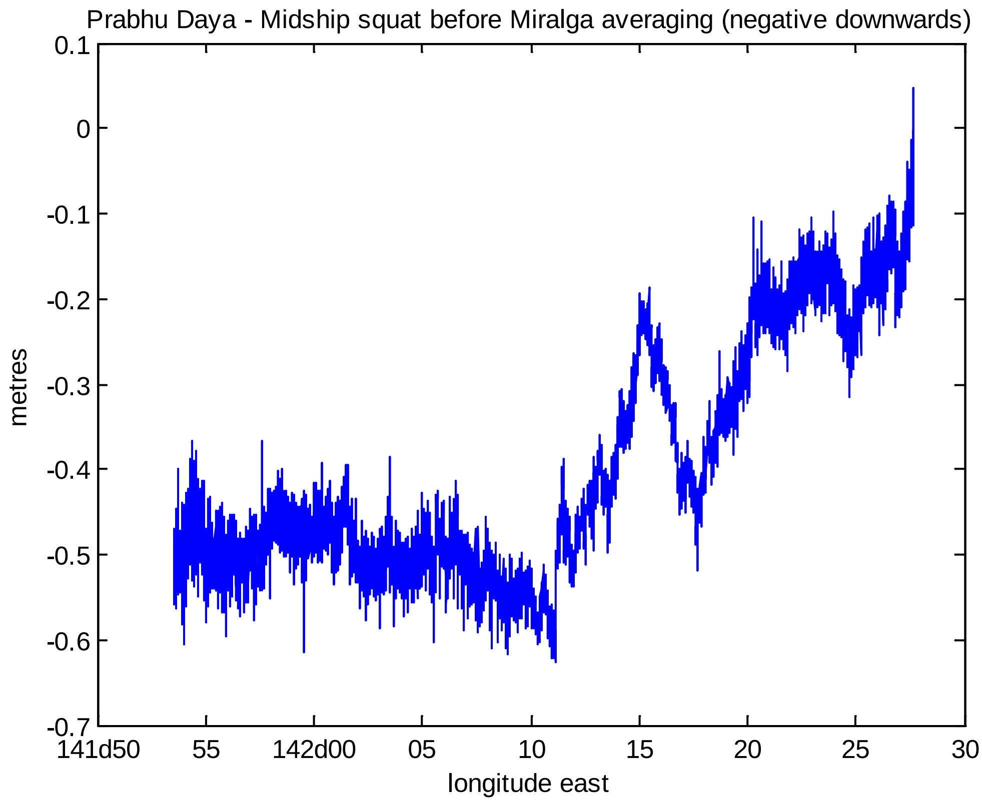

Stove Campbell - Dynamic draft
forward post
aft post
metres
12.6
12.5
12.4
12.3
12.2
12.1
12
11.9
11.8
11.7
141d50
55
142d00
05
10
15
20
25
longitude east

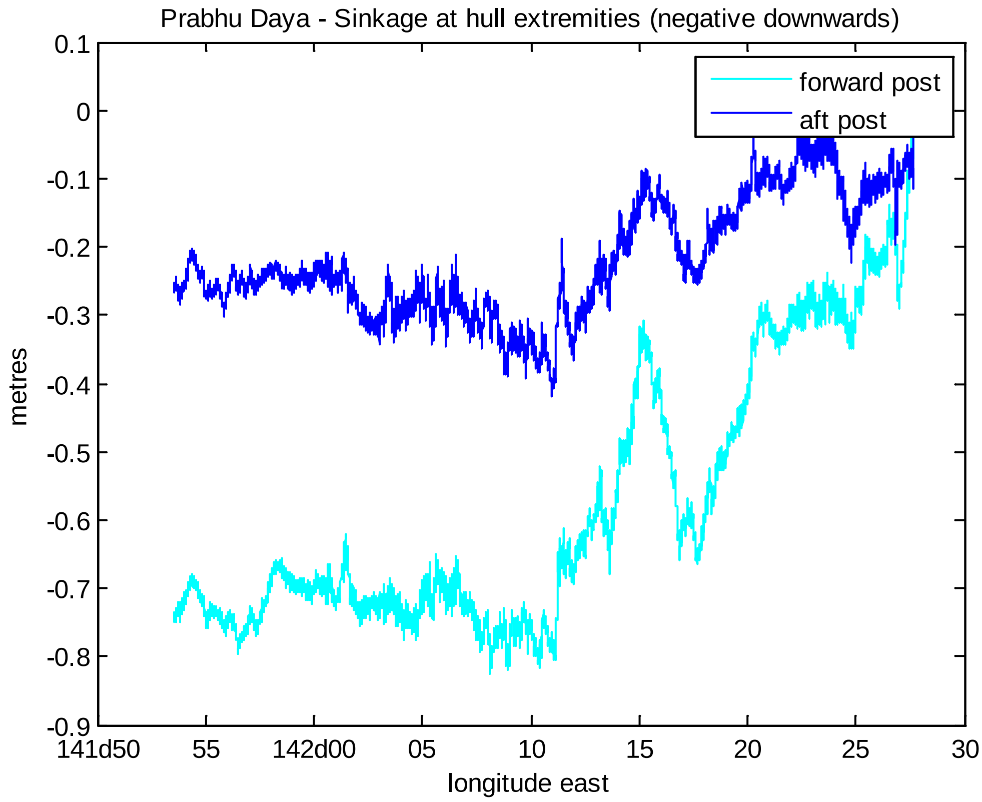
Prabhu Daya - Dynamic bow-down trim

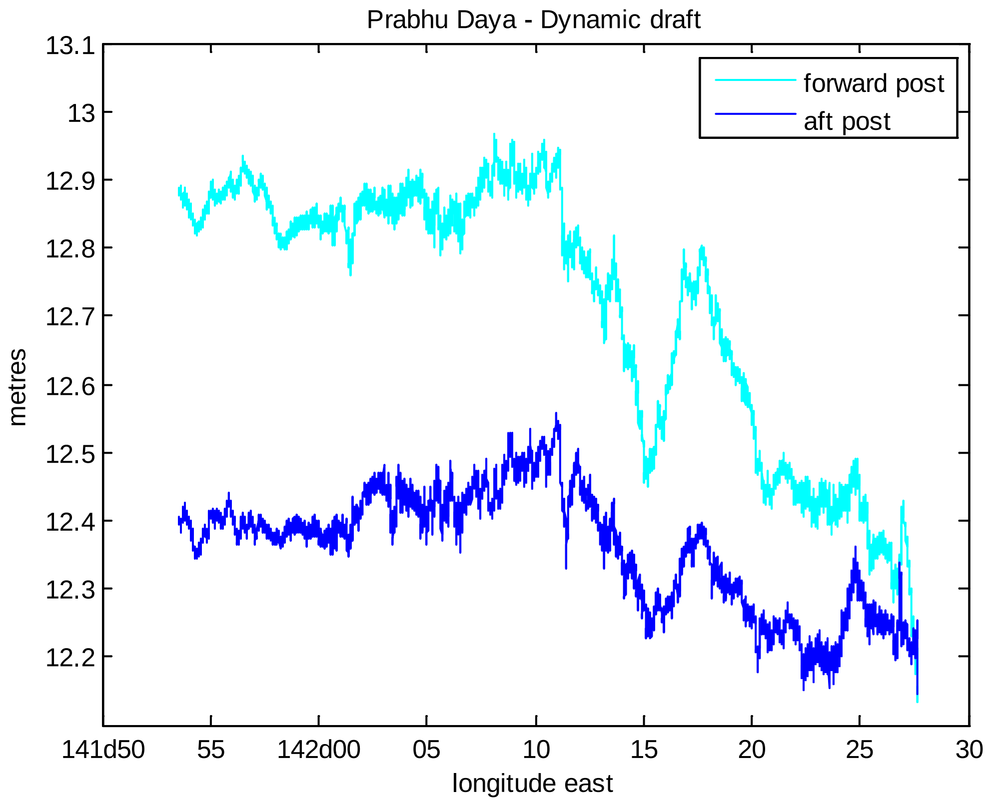


Prabhu Daya - Speed over ground

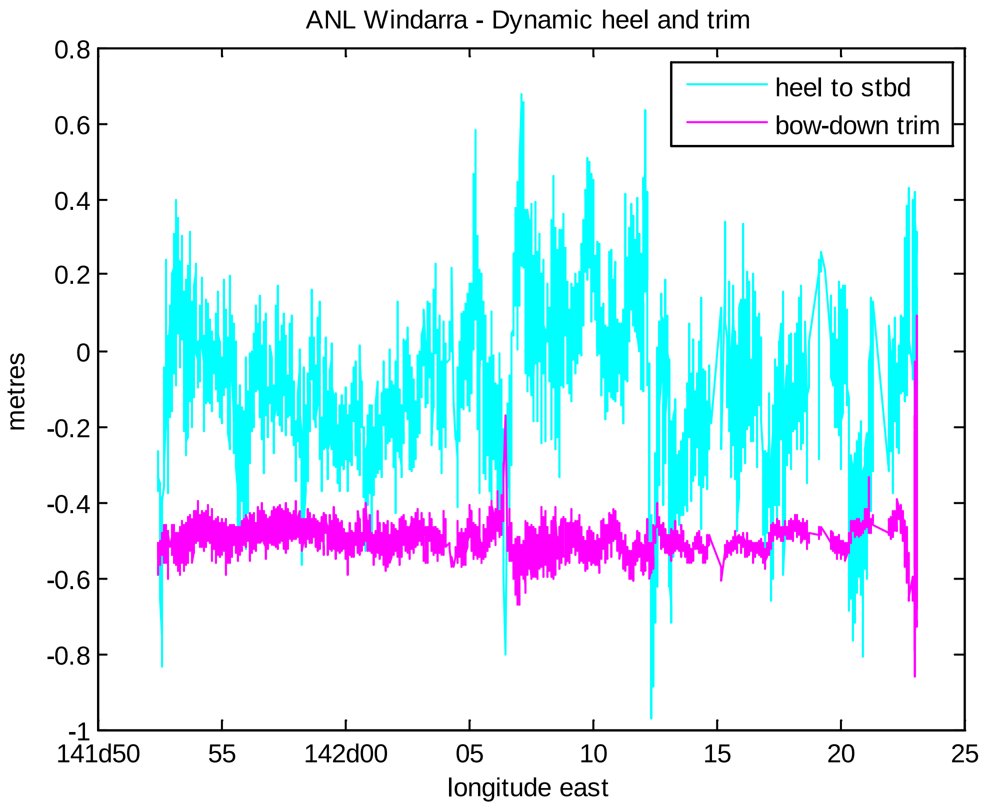


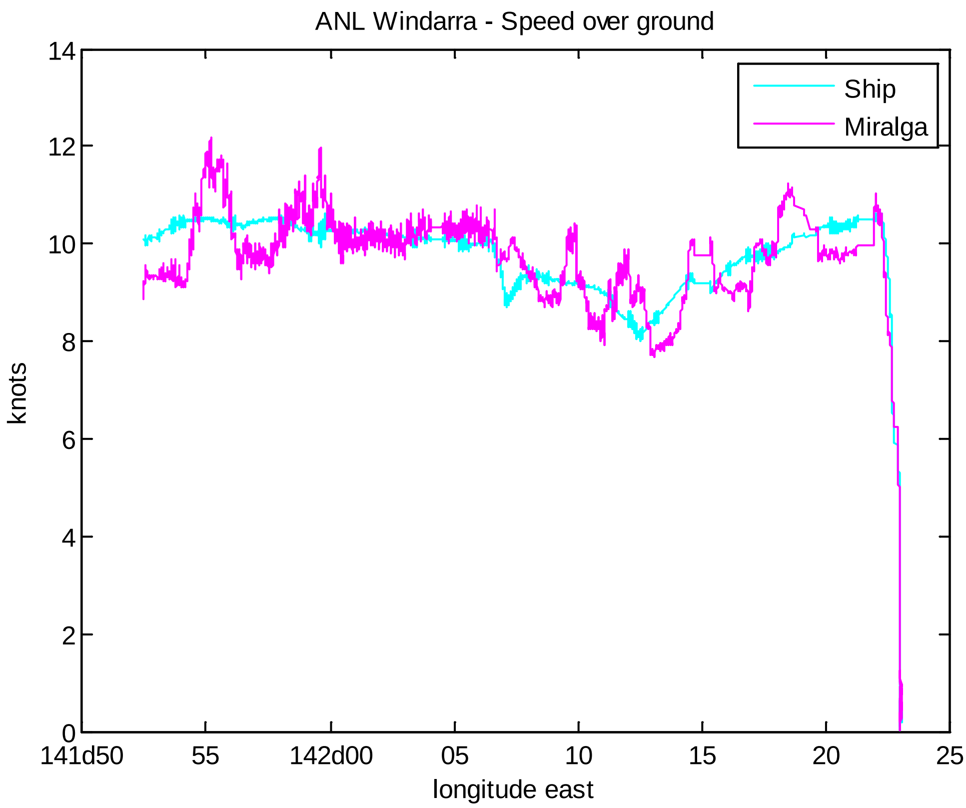

Prabhu Daya - Midship squat before Miralga averaging (negative downwards)
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
metres
141d50
55
142d00
05
10
15
20
25
30
longitude east

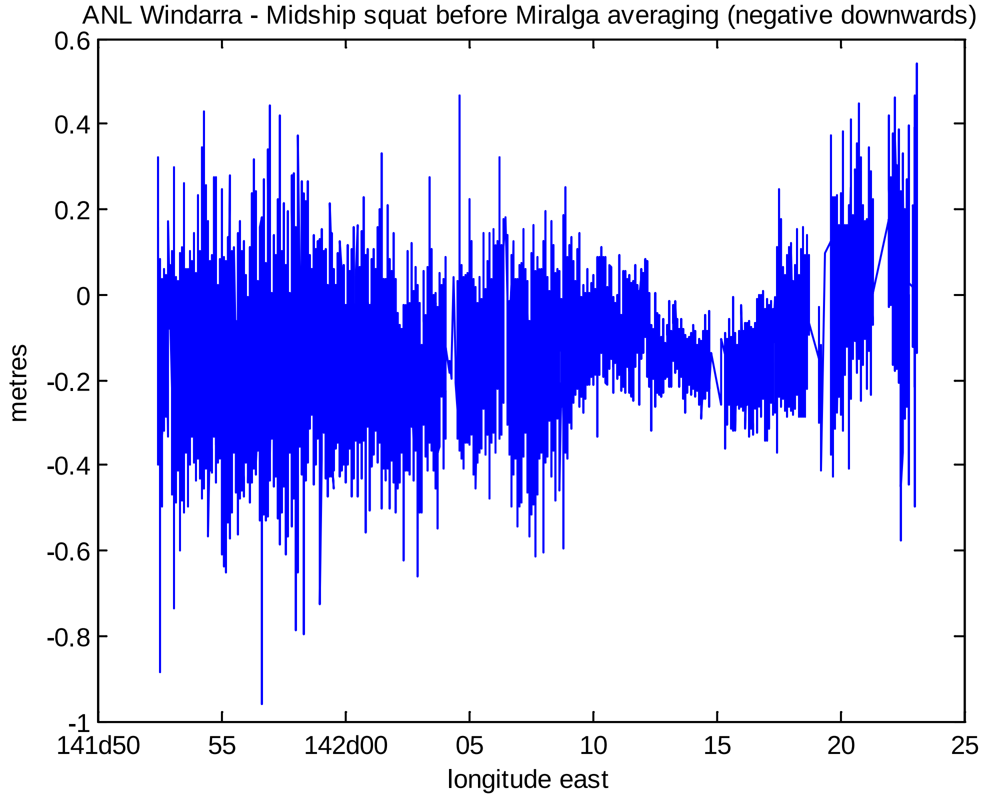

Prabhu Daya - Sinkage at hull extremities (negative downwards)
forward post
aft post
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
metres
141d50
55
142d00
05
10
15
20
25
30
longitude east

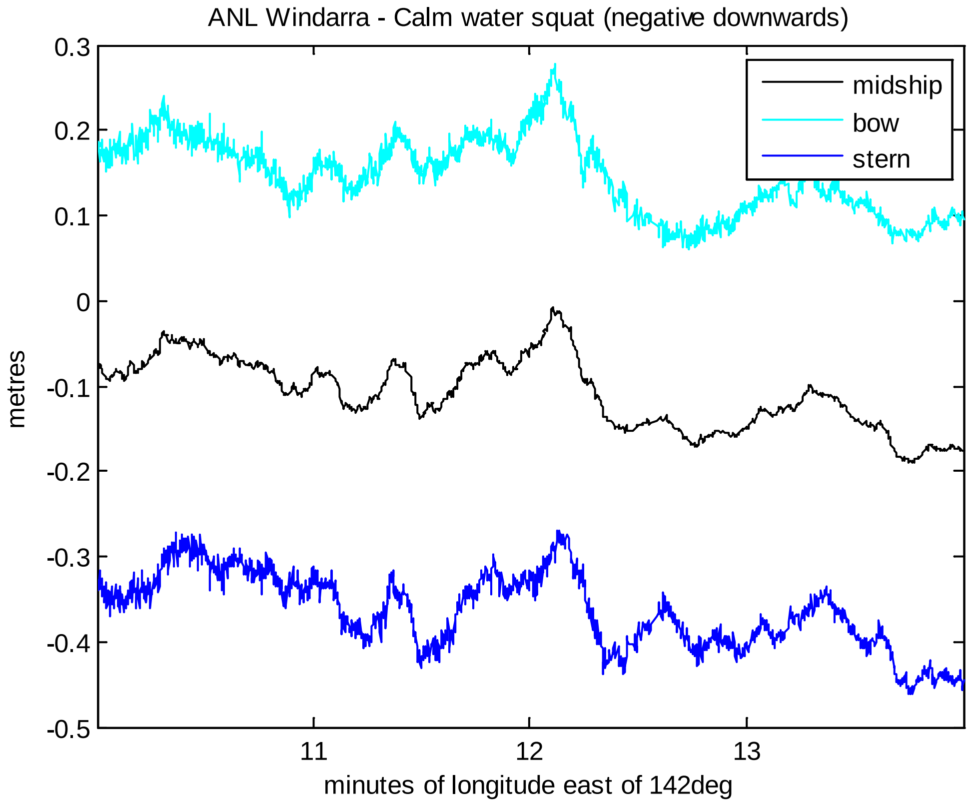


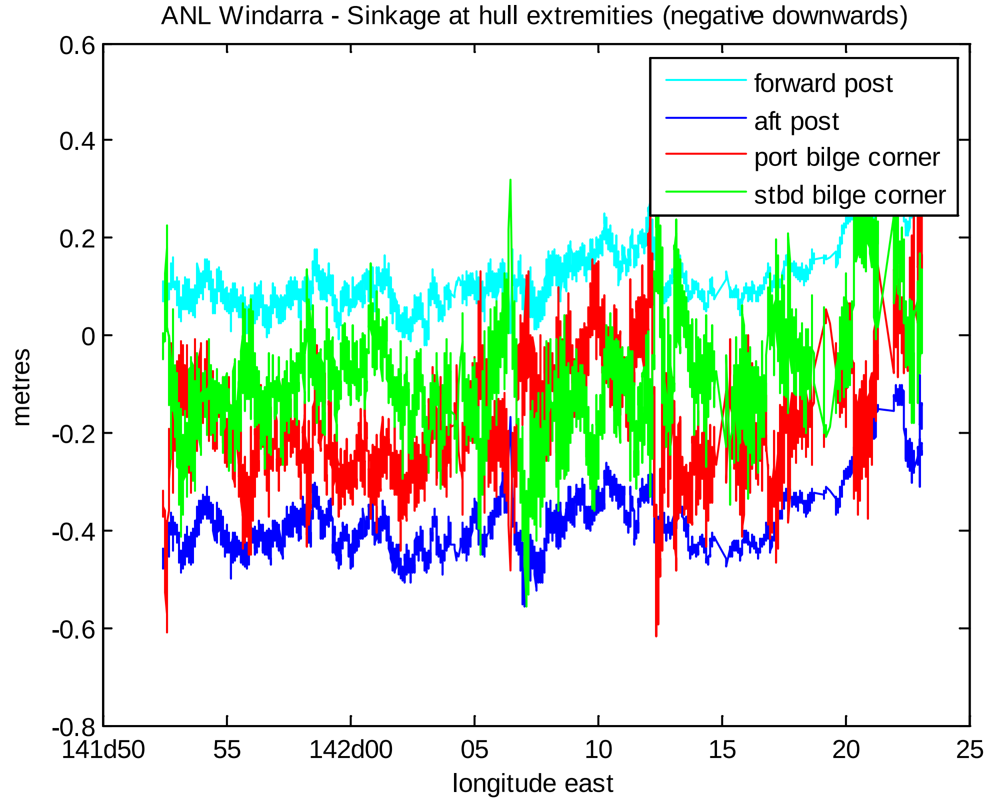
Prabhu Daya - Dynamic draft
forward post
aft post
metres
13.1
13
12.9
12.8
12.7
12.6
12.5
12.4
12.3
12.2
141d50
55
142d00
05
10
15
20
25
30
longitude east

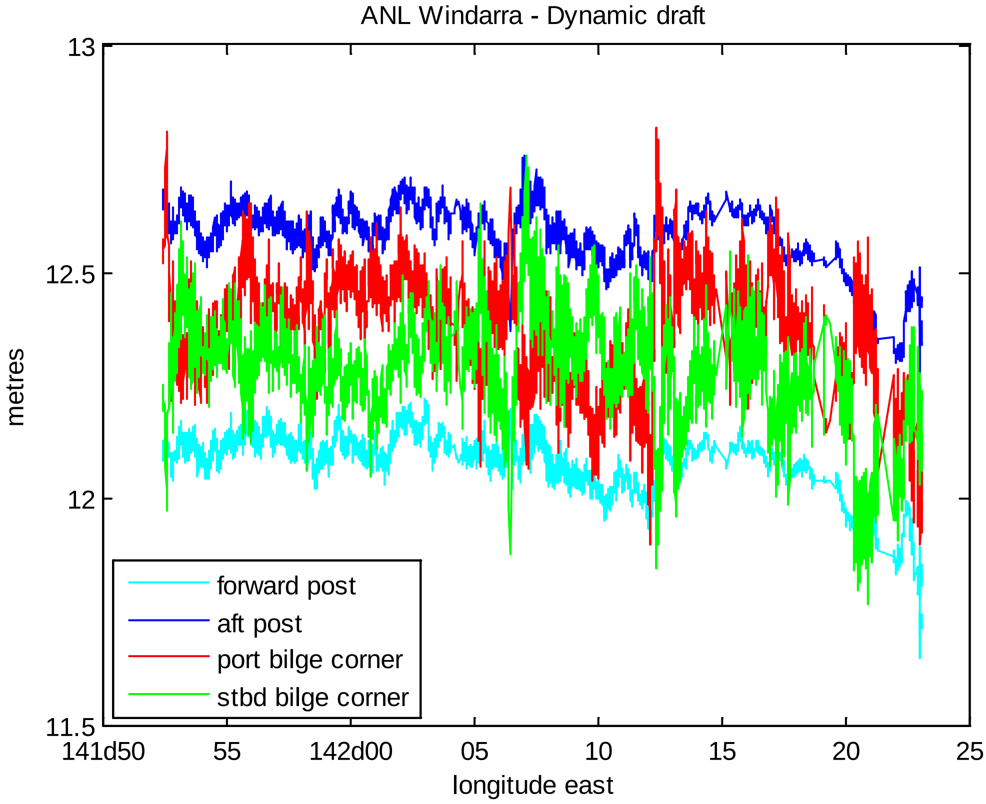

ANL Windarra - Dynamic heel and trim
heel to stbd
bow-down trim
metres
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
141d50
55
142d00
05
10
15
20
25
longitude east

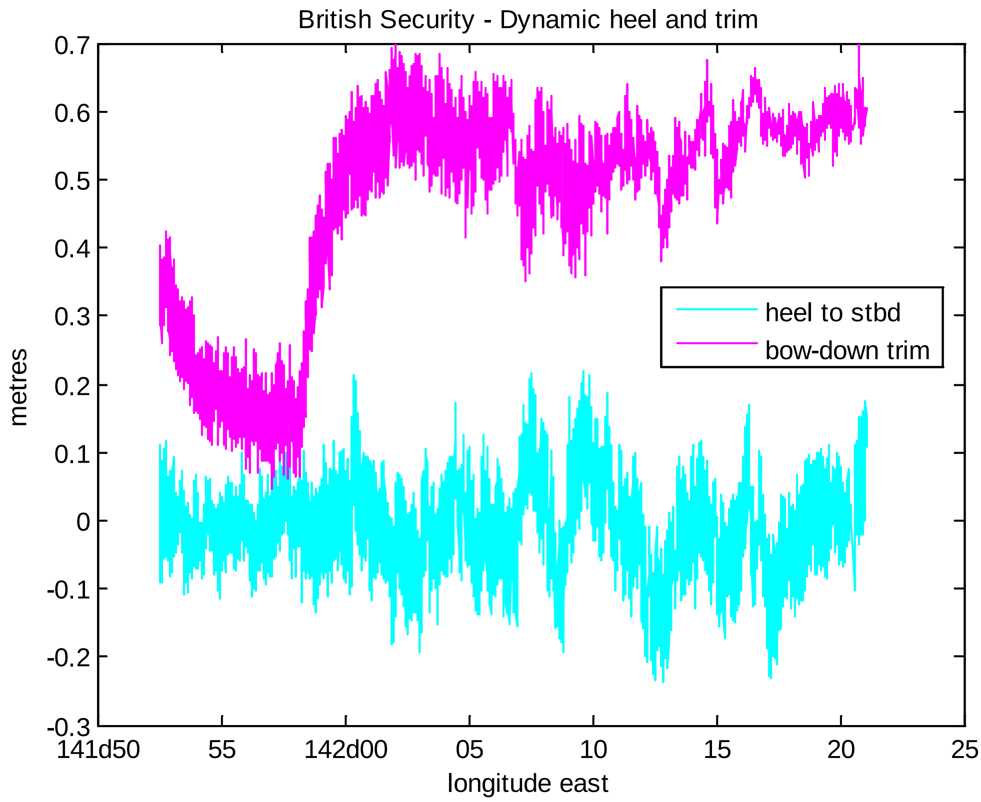

ANL Windarra - Speed over ground
Ship
Miralga
knots
14
12
10
8
6
4
2
0
141d50
55
142d00
05
10
15
20
25
longitude east

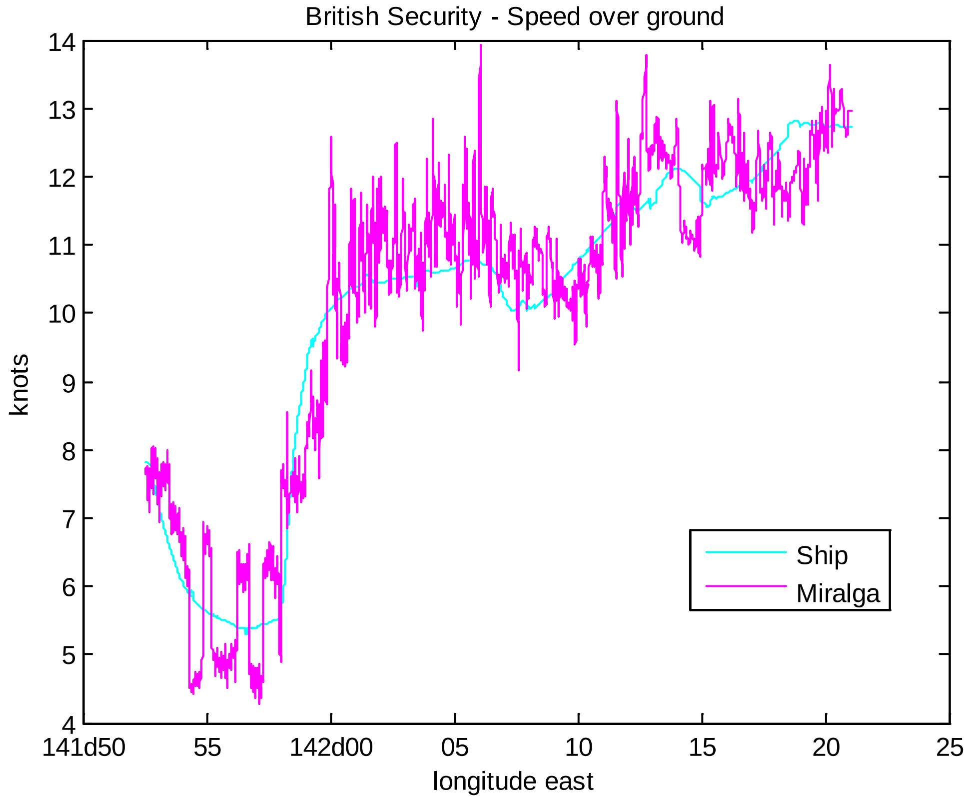

ANL Windarra - Midship squat before Miralga averaging (negative downwards)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
metres
141d50
55
142d00
05
10
15
20
25
longitude east

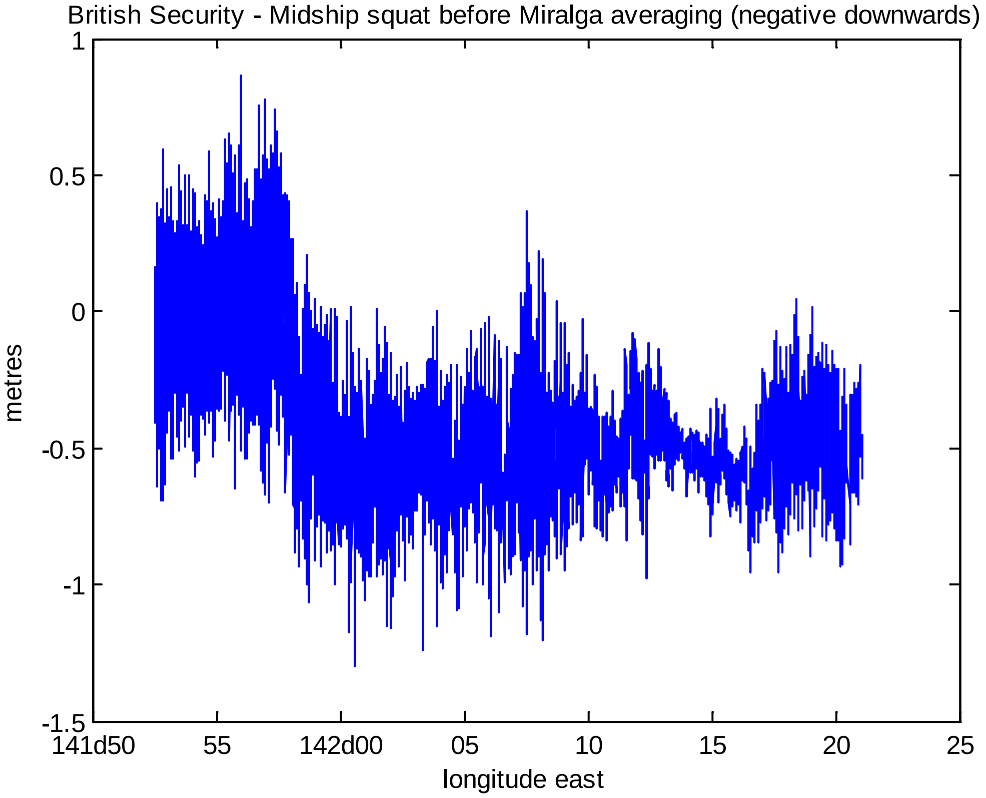

ANL Windarra - Calm water squat (negative downwards)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
metres
midship
bow
stern
11
12
13
minutes of longitude east of 142deg

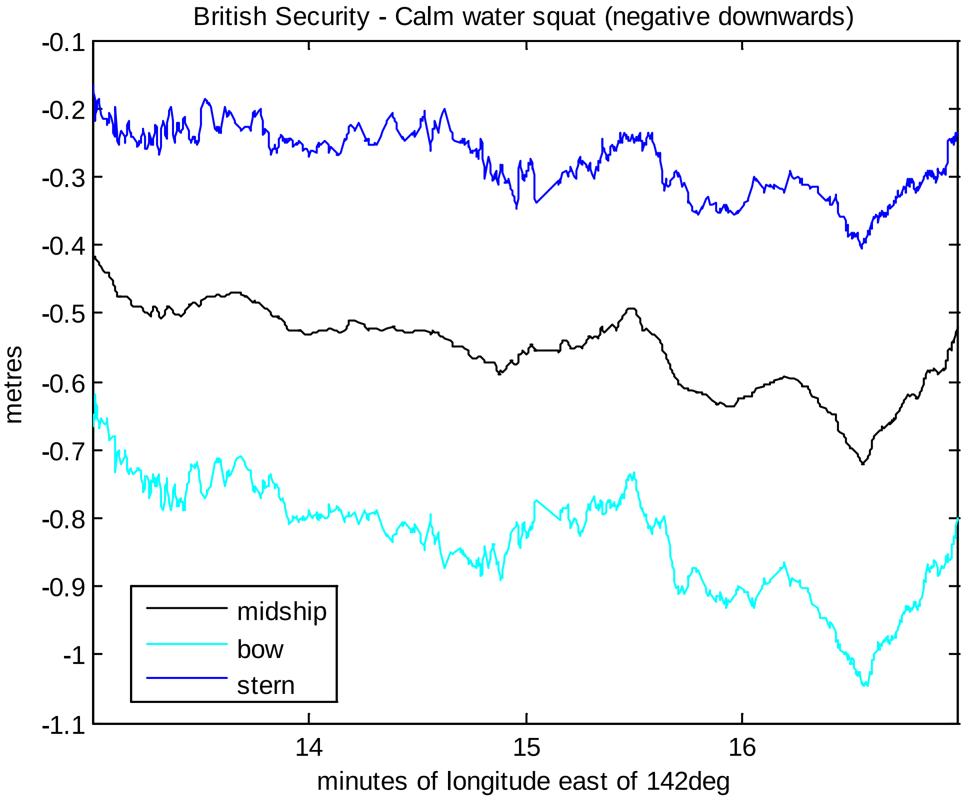

ANL Windarra - Sinkage at hull extremities (negative downwards)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
metres
141d50
55
142d00
05
10
15
20
25
longitude east
forward post
aft post
port bilge corner
stbd bilge corner

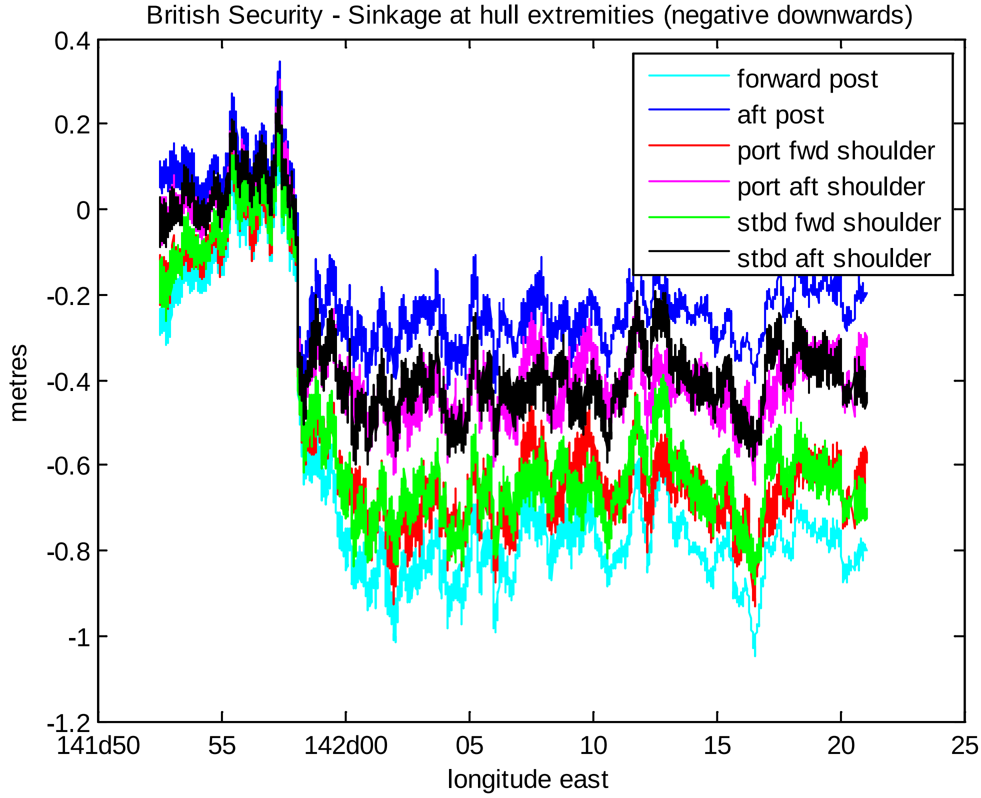

ANL Windarra - Dynamic draft
13
12.5
12
11.5
metres
141d50
55
142d00
05
10
15
20
25
longitude east
forward post
aft post
port bilge corner
stbd bilge corner

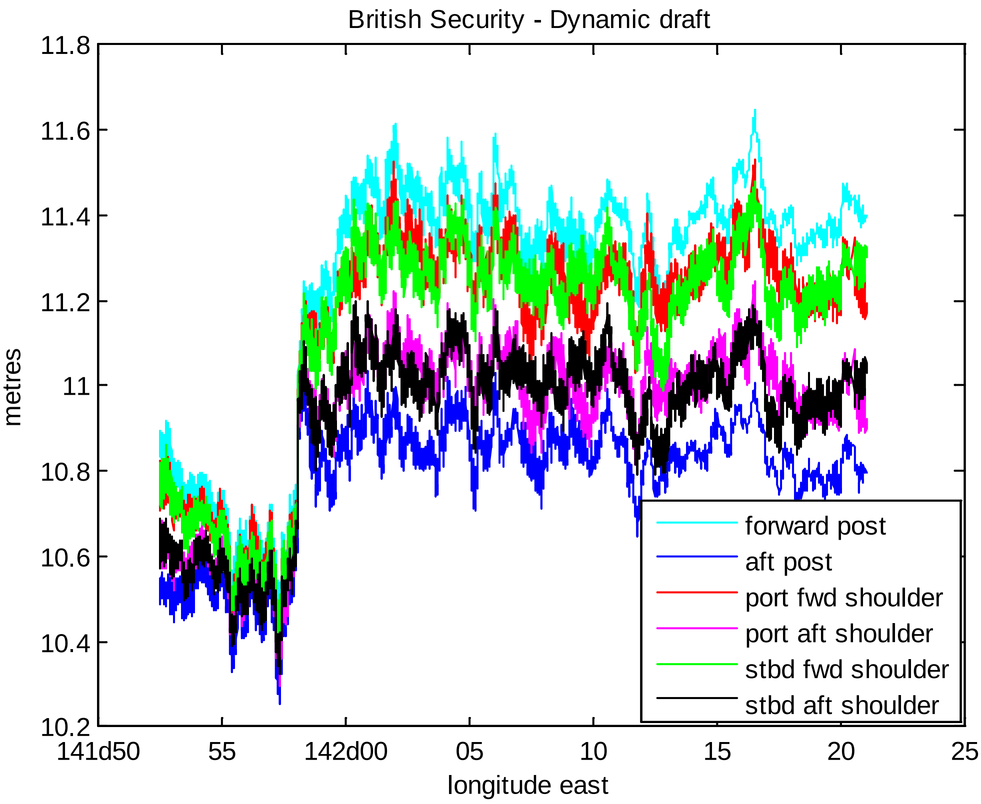

British Security - Dynamic heel and trim
metres
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
141d50
55
142d00
05
10
15
20
25
longitude east
heel to stbd
bow-down trim

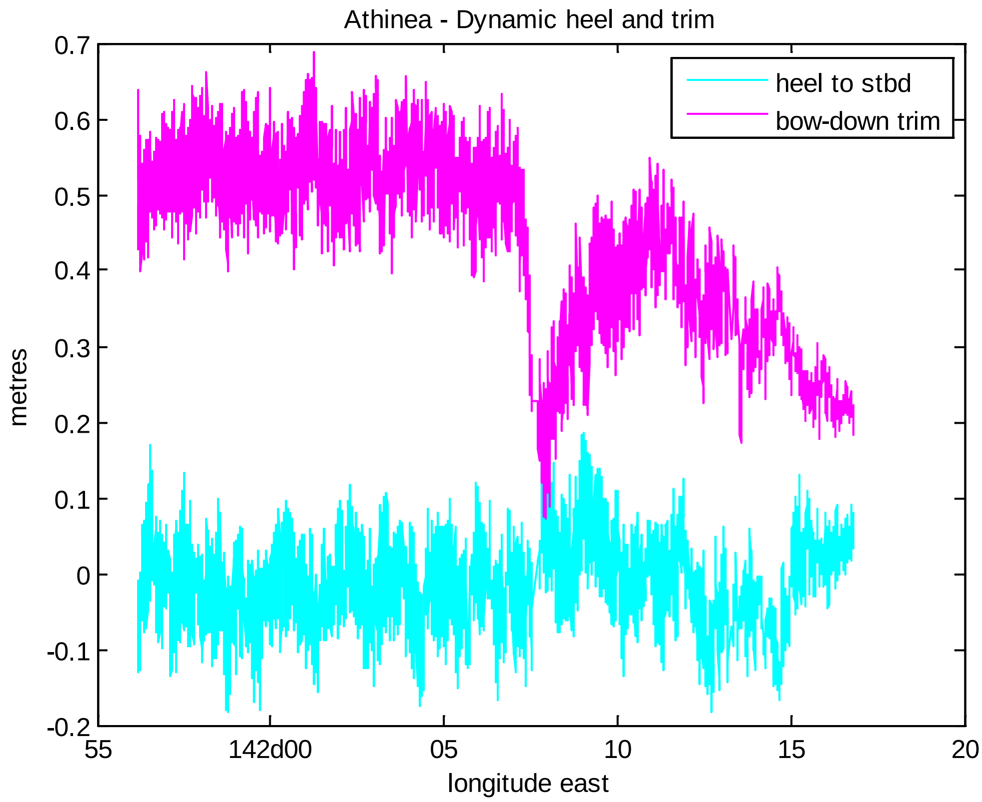

British Security - Speed over ground
knots
14
13
12
11
10
9
8
7
6
5
4
141d50
55
142d00
05
10
15
20
25
longitude east
Ship
Miralga

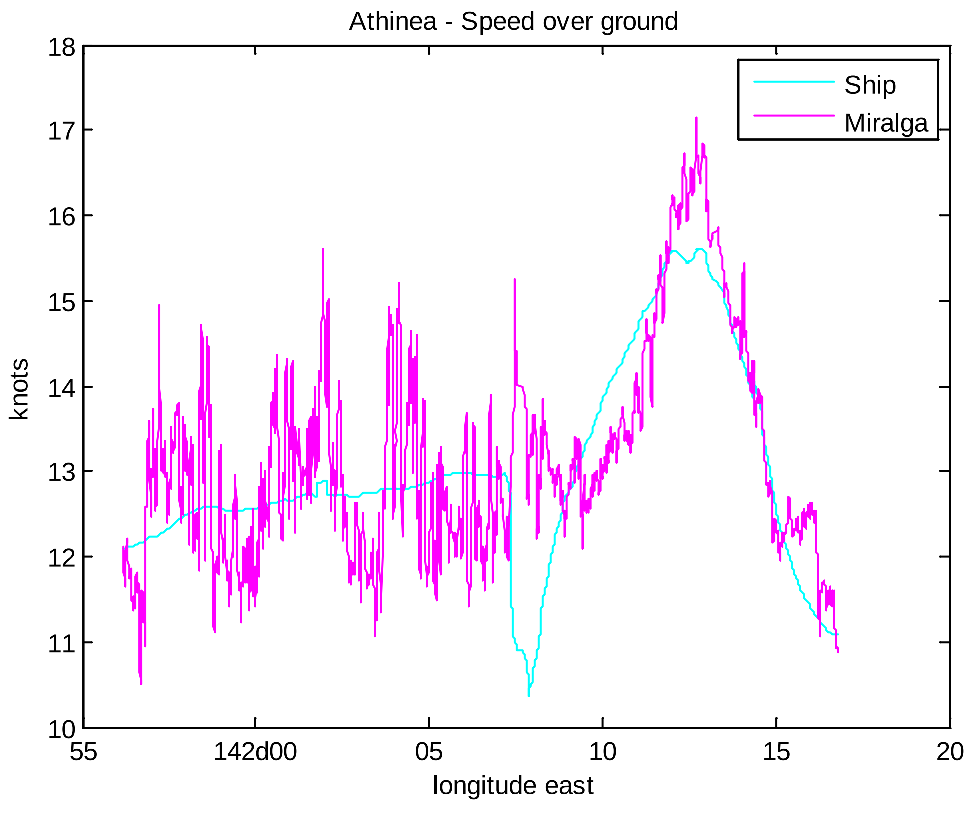

British Security - Midship squat before Miralga averaging (negative downwards)
metres
1
0.5
0
-0.5
-1
-1.5
141d50
55
142d00
05
10
15
20
25
longitude east

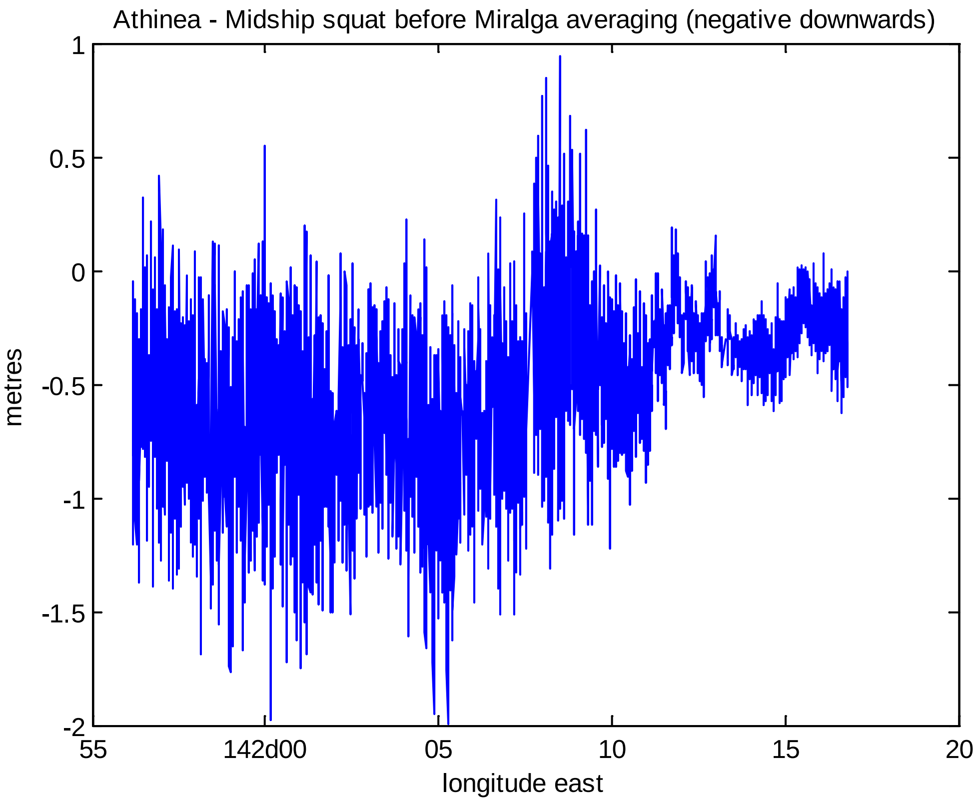

British Security - Calm water squat (negative downwards)
metres
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
midship
bow
stern
14
15
16
minutes of longitude east of 142deg

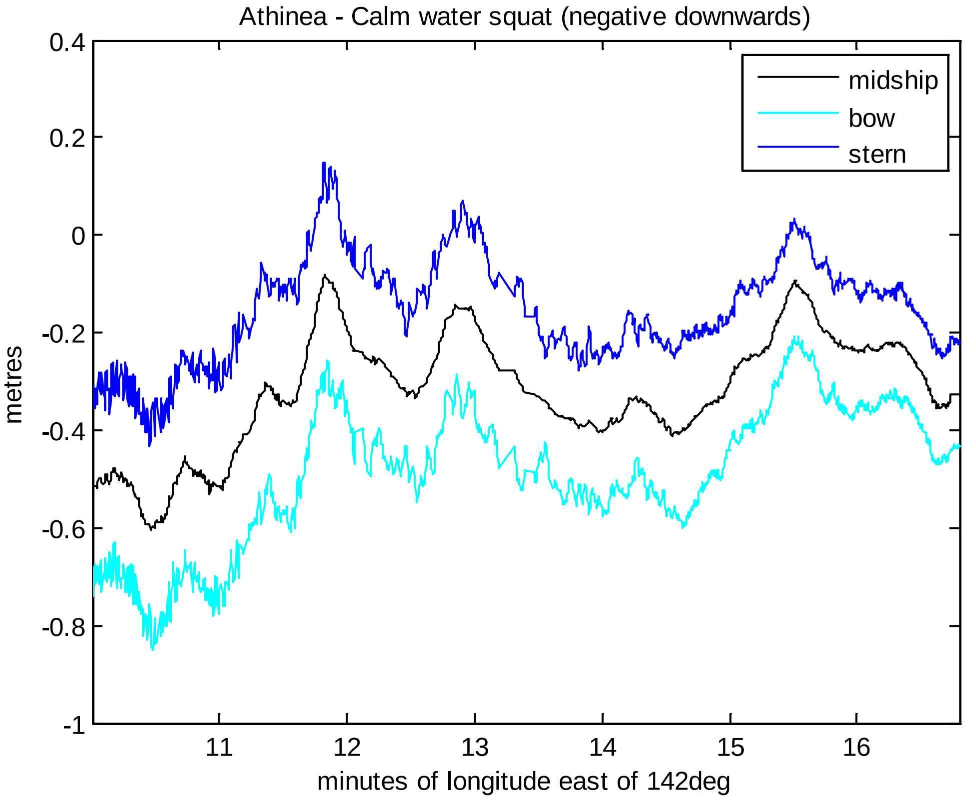

British Security - Sinkage at hull extremities (negative downwards)
metres
longitude east
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
141d50
55
142d00
05
10
15
20
25
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder

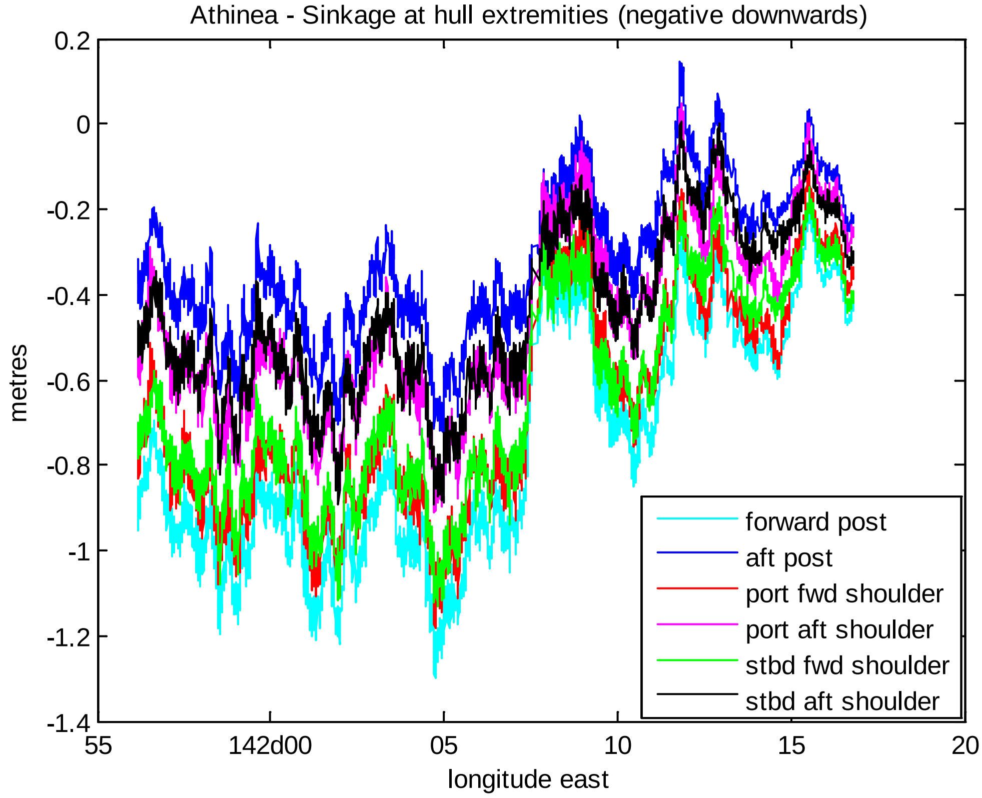

British Security - Dynamic draft
metres
longitude east
11.8
11.6
11.4
11.2
11
10.8
10.6
10.4
10.2
141d50
55
142d00
05
10
15
20
25
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder

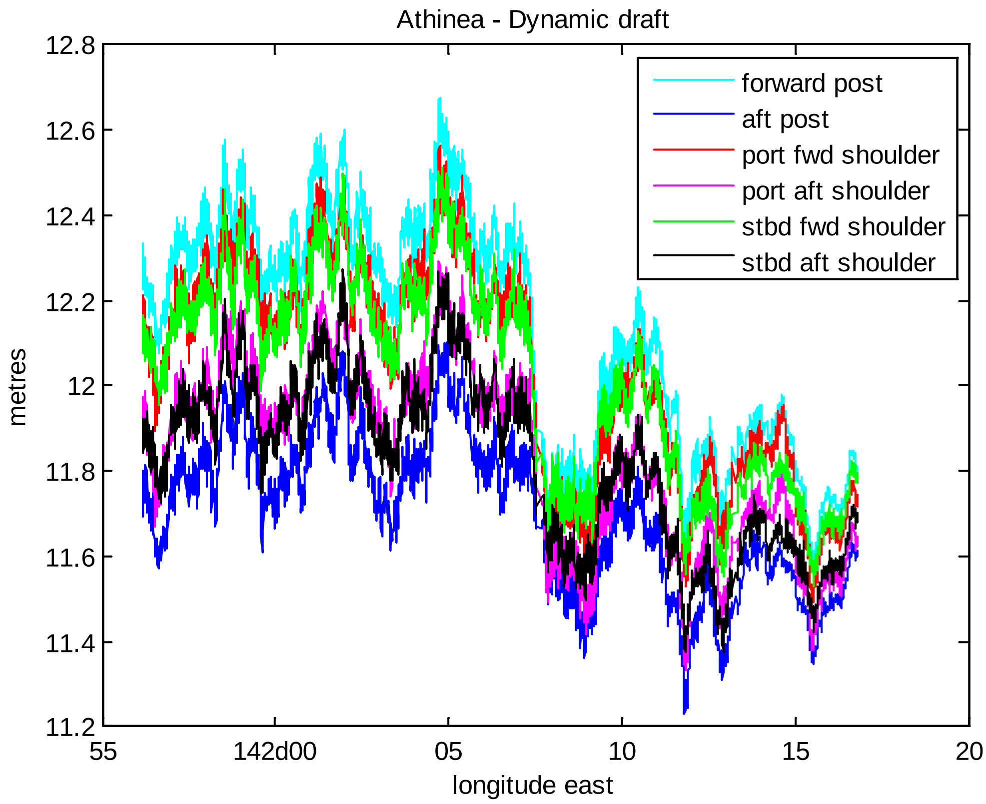

Athinea - Dynamic heel and trim
metres
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
55
142d00
05
10
15
20
longitude east
heel to stbd
bow-down trim

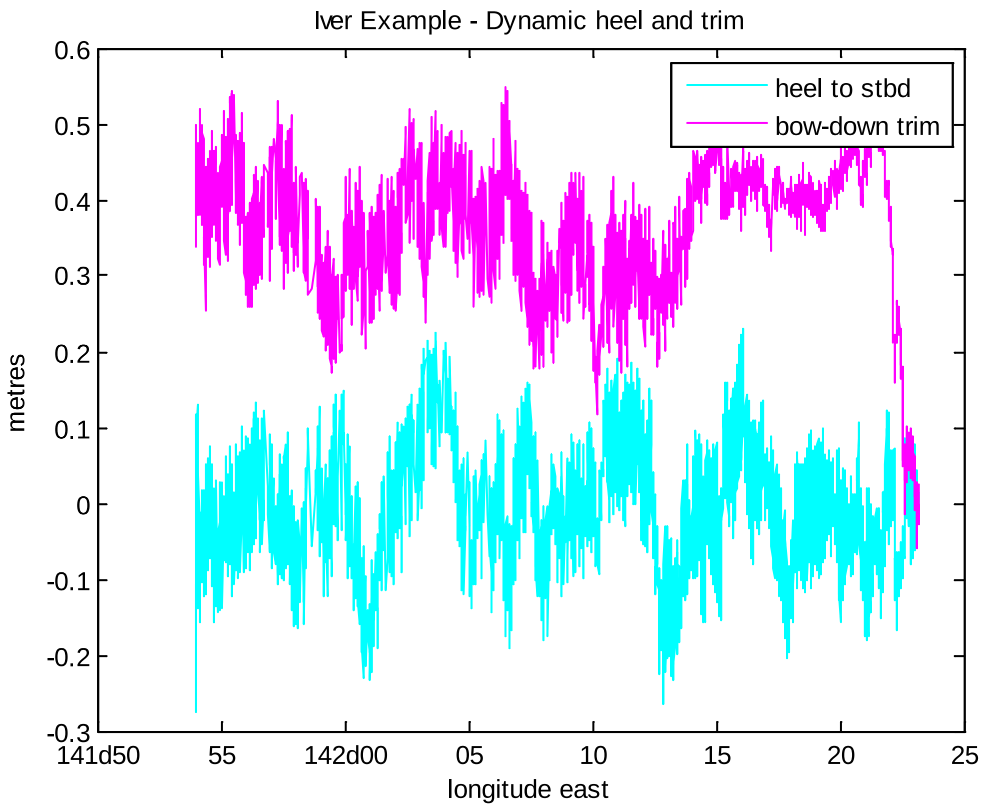

Athinea - Speed over ground
knots
18
17
16
15
14
13
12
11
10
55
142d00
05
10
15
20
longitude east
Ship
Miralga

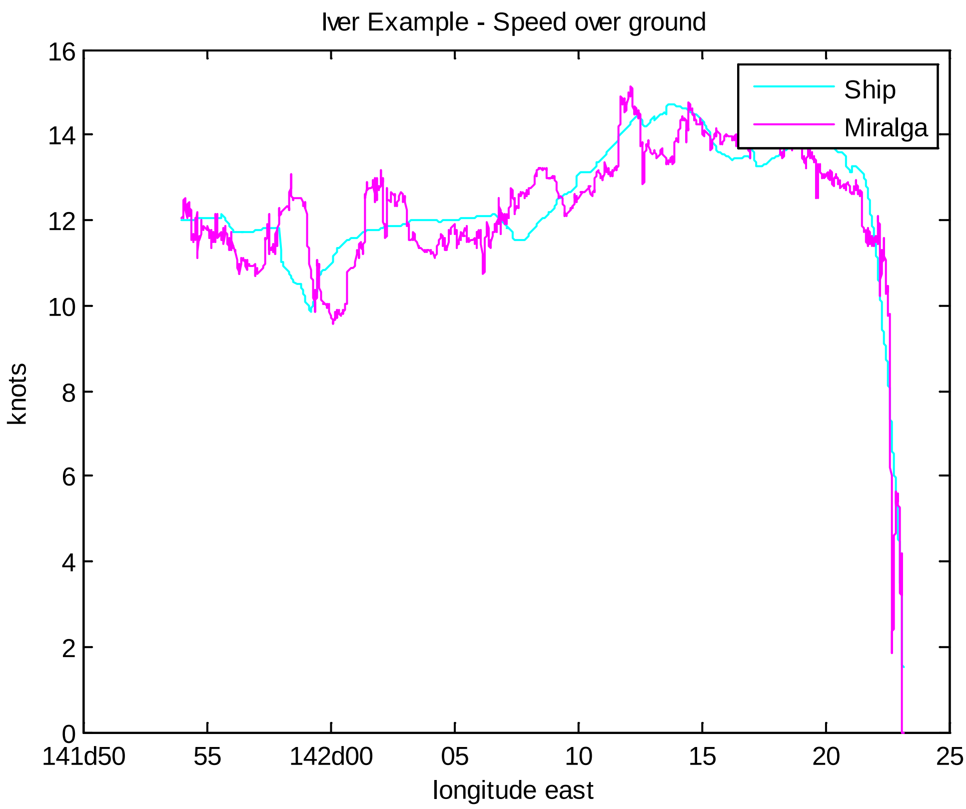

Athinea - Midship squat before Miralga averaging (negative downwards)
1
0.5
0
-0.5
-1
-1.5
-2
metres
55
142d00
05
10
15
20
longitude east

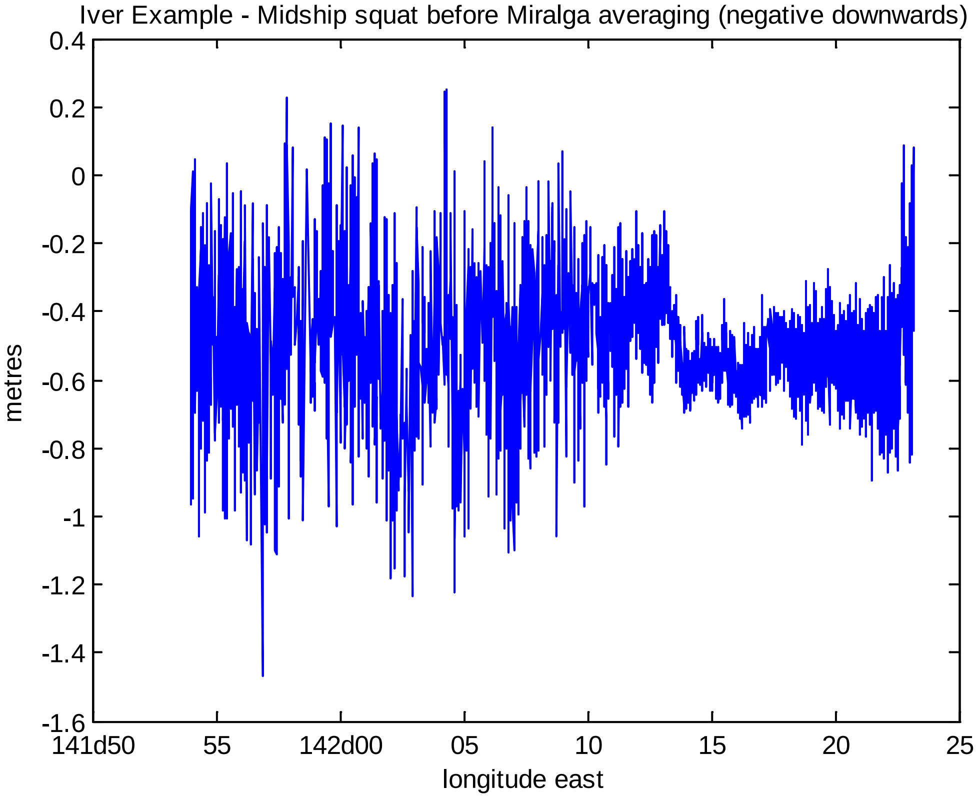

Athinea - Calm water squat (negative downwards)
midship
bow
stern
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
metres
11
12
13
14
15
16
minutes of longitude east of 142deg


Athinea - Sinkage at hull extremities (negative downwards)
metres
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
55
142d00
05
10
15
20
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder

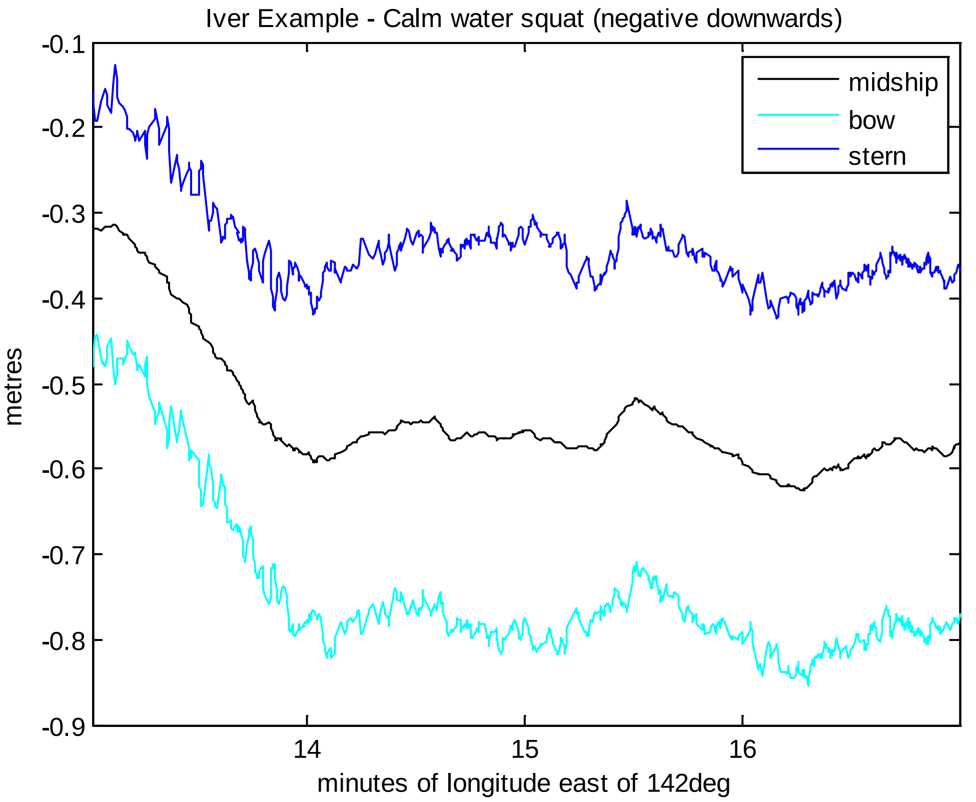

Athinea - Dynamic draft
metres
12.8
12.6
12.4
12.2
12
11.8
11.6
11.4
11.2
55
142d00
05
10
15
20
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder


Iver Example - Dynamic heel and trim
heel to stbd
bow-down trim
metres
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
141d50
55
142d00
05
10
15
20
25
longitude east

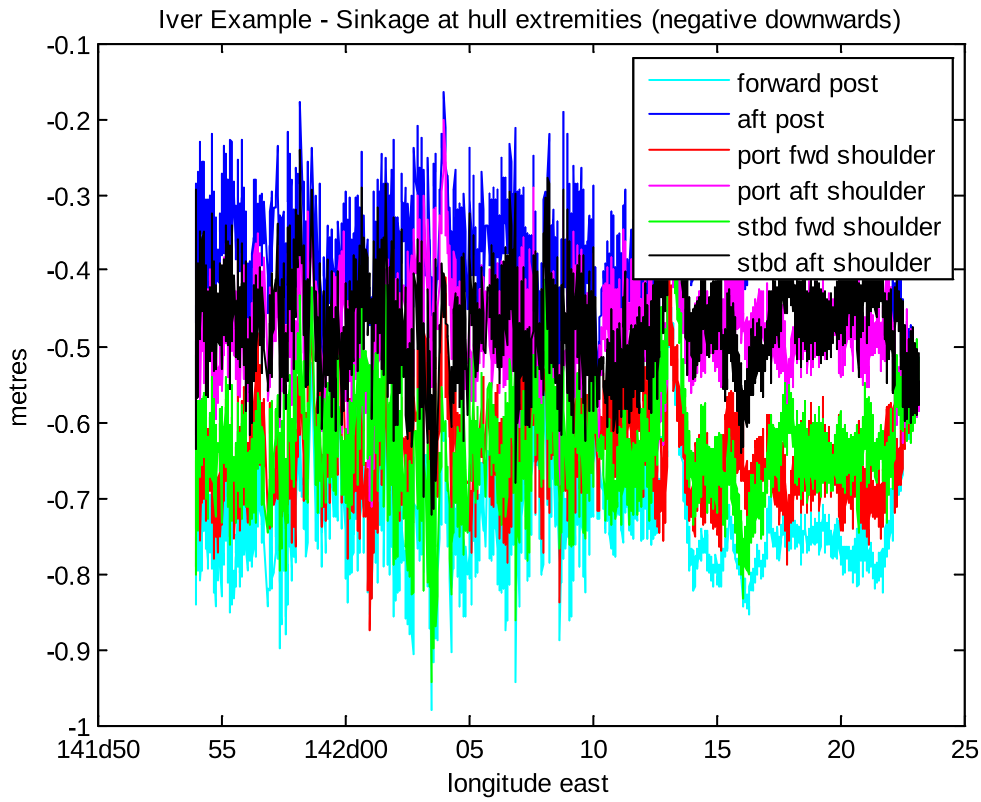

Iver Example - Speed over ground
Ship
Miralga
knots
16
14
12
10
8
6
4
2
0
141d50
55
142d00
05
10
15
20
25
longitude east

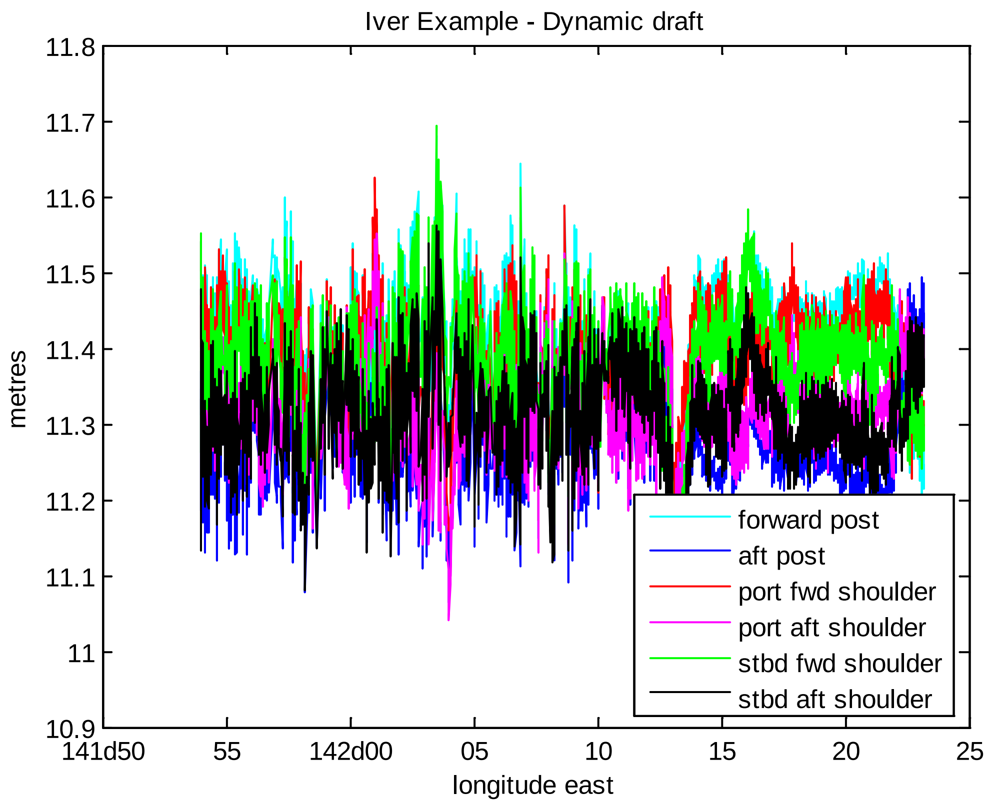


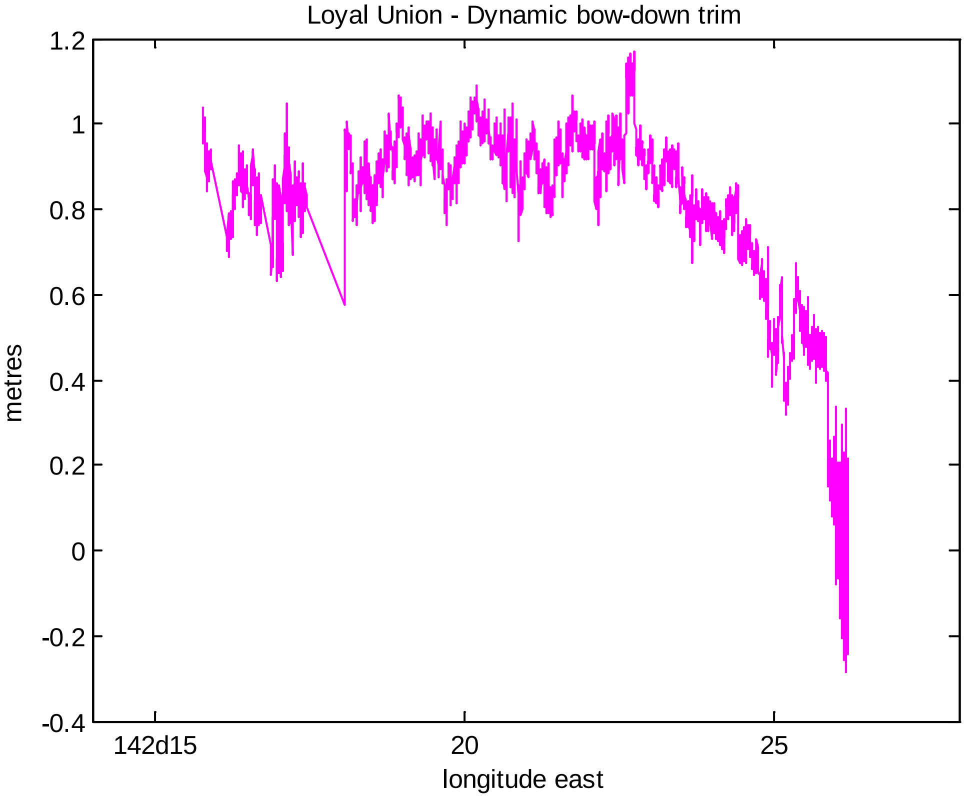
Iver Example - Midship squat before Miralga averaging (negative downwards)
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
metres
141d50
55
142d00
05
10
15
20
25
longitude east

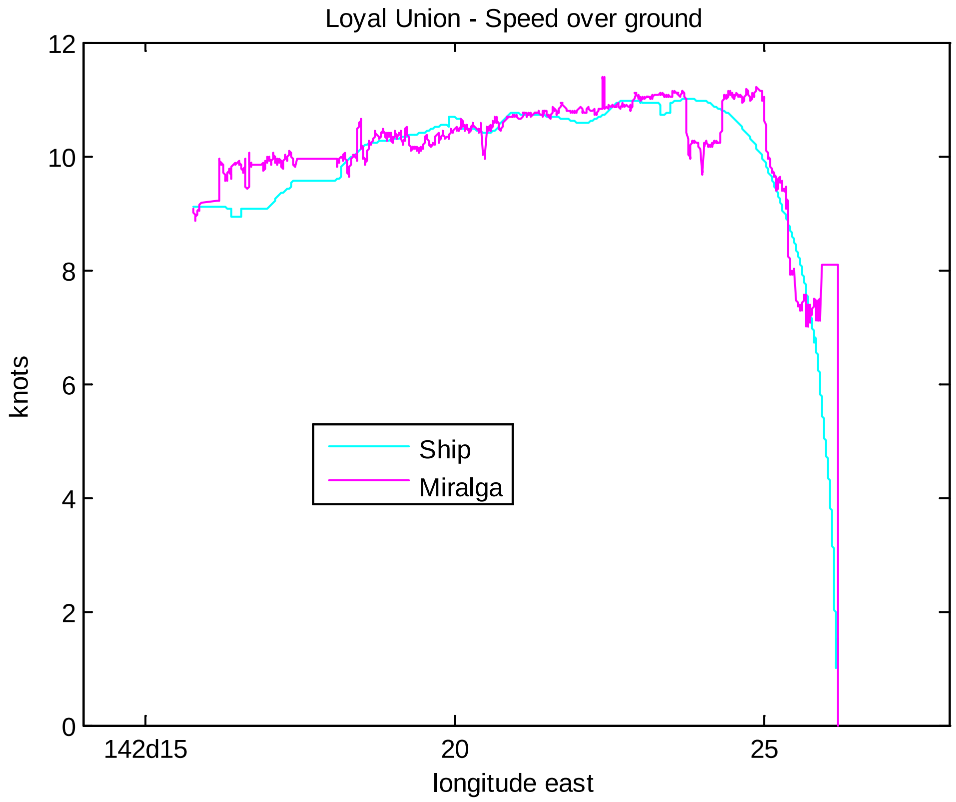


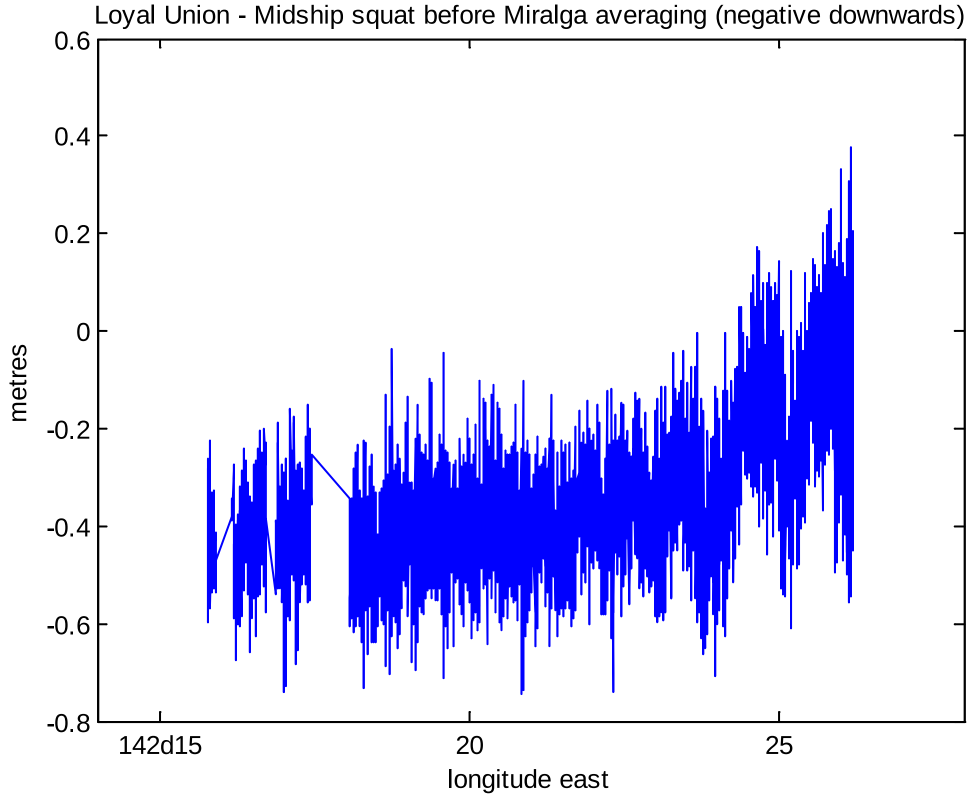
Iver Example - Calm water squat (negative downwards)
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
metres
midship
bow
stern
14
15
16
minutes of longitude east of 142deg

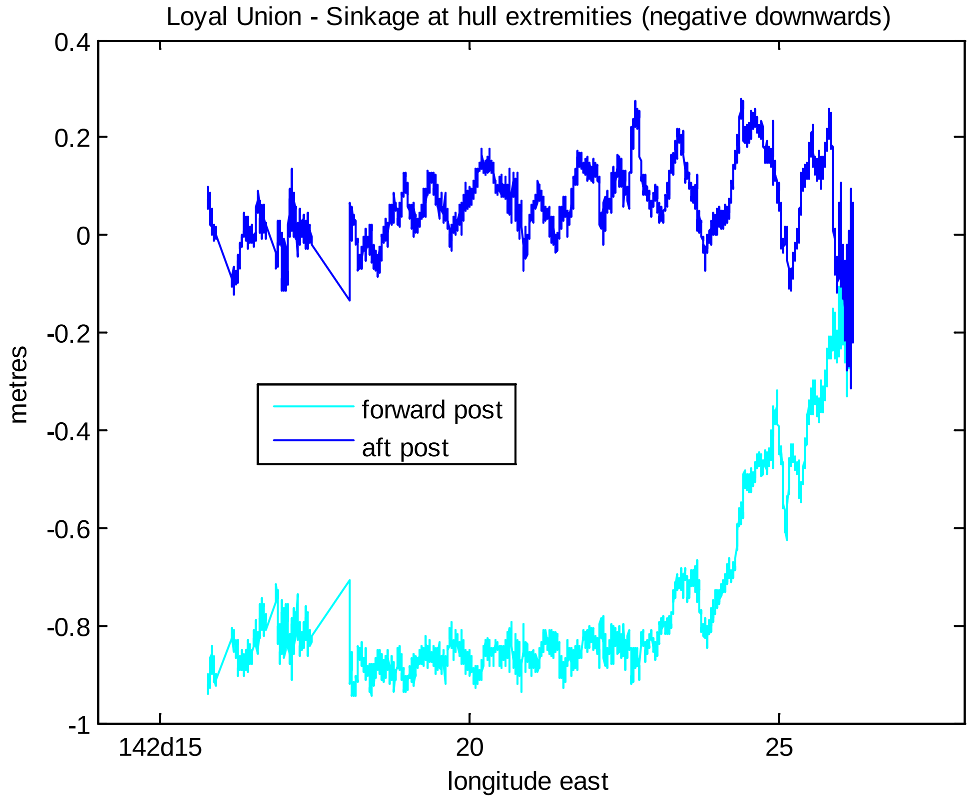

Iver Example - Sinkage at hull extremities (negative downwards)
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
metres
141d50
55
142d00
05
10
15
20
25
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder

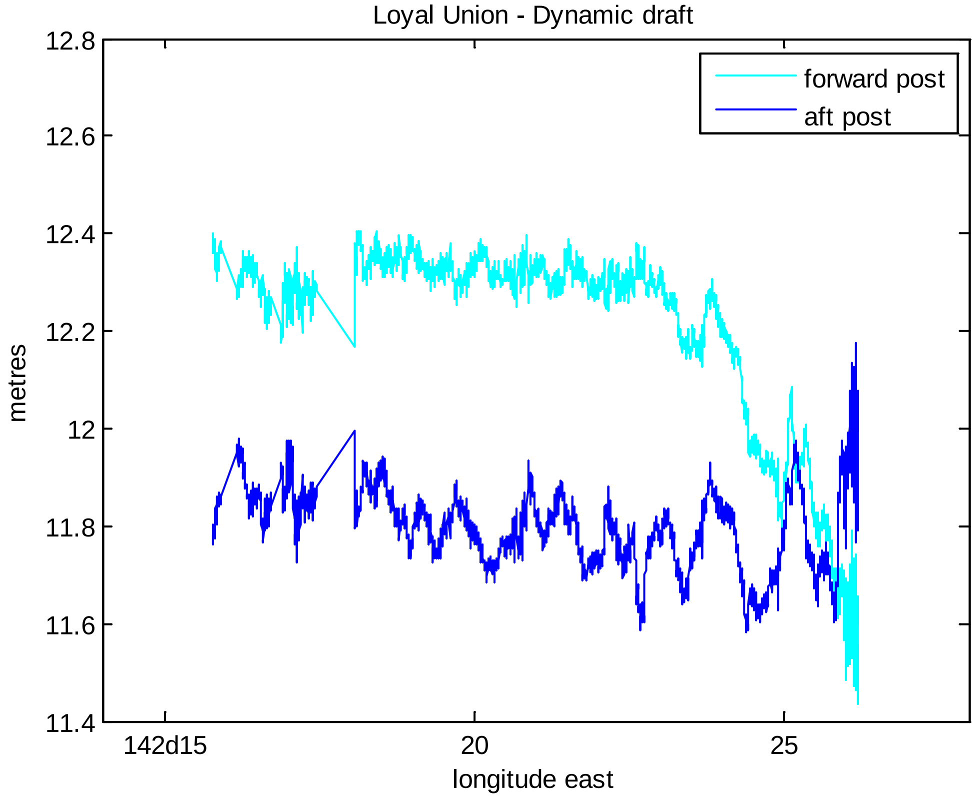

Iver Example - Dynamic draft
11.8
11.7
11.6
11.5
11.4
11.3
11.2
11.1
11
10.9
metres
141d50
55
142d00
05
10
15
20
25
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder


Loyal Union - Dynamic bow-down trim
metres
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
142d15
20
25
longitude east

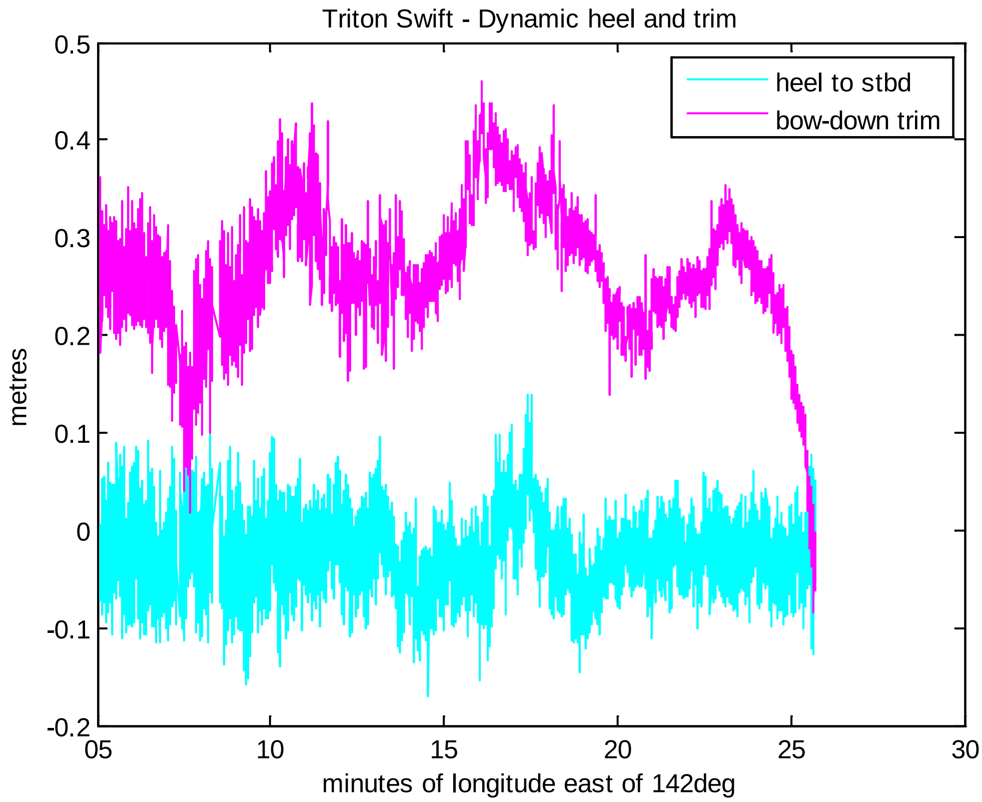

Loyal Union - Speed over ground
knots
12
10
8
6
4
2
0
Ship
Miralga
142d15
20
25
longitude east

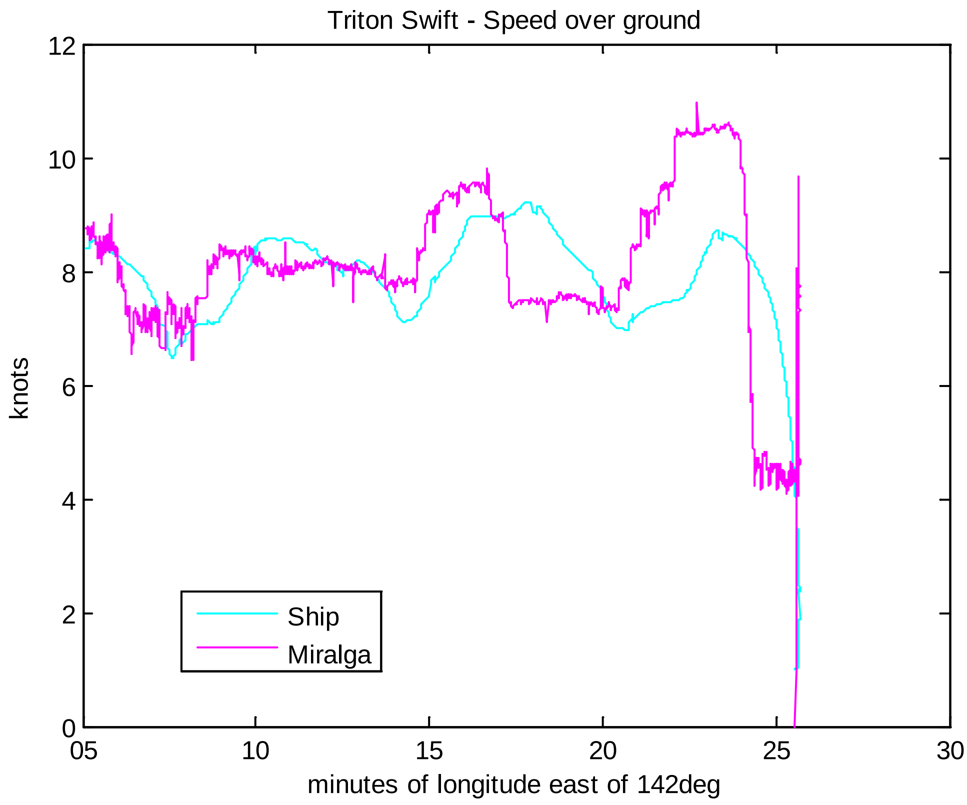

Loyal Union - Midship squat before Miralga averaging (negative downwards)
metres
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
142d15
20
25
longitude east

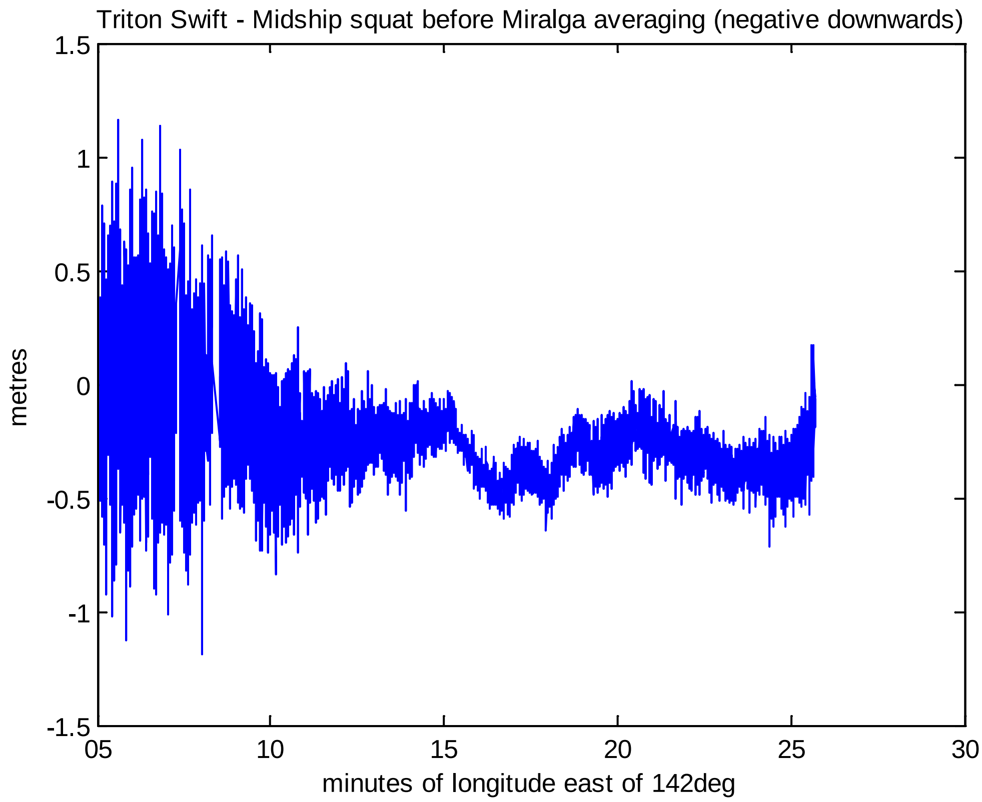

Loyal Union - Sinkage at hull extremities (negative downwards)
metres
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
forward post
aft post
142d15
20
25
longitude east

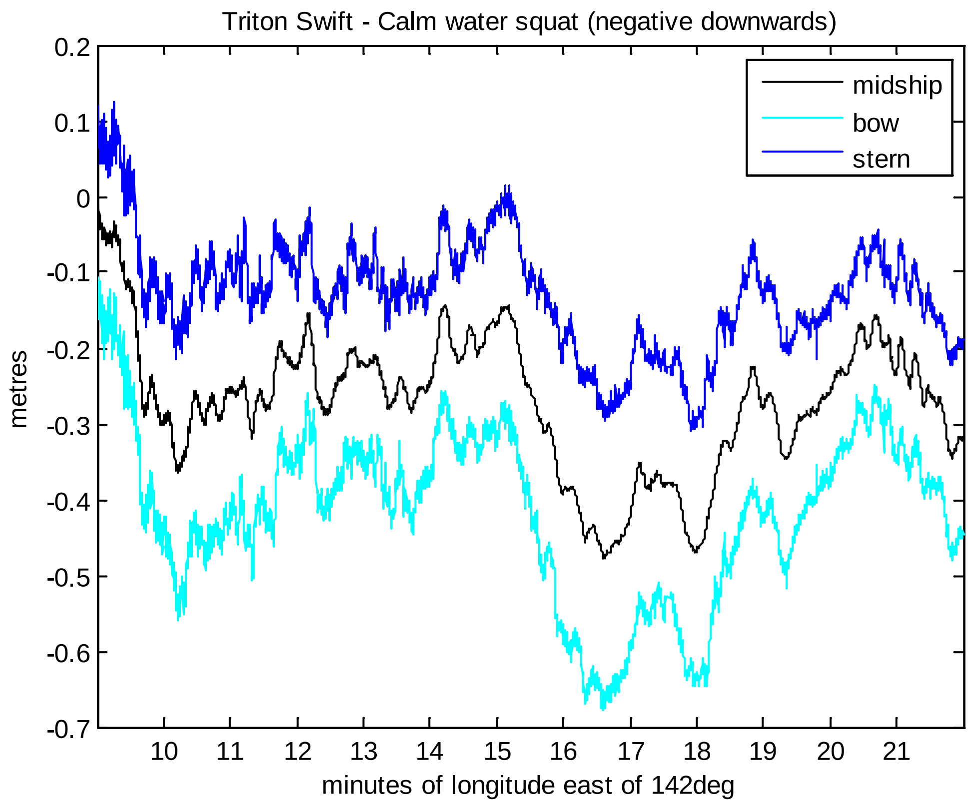


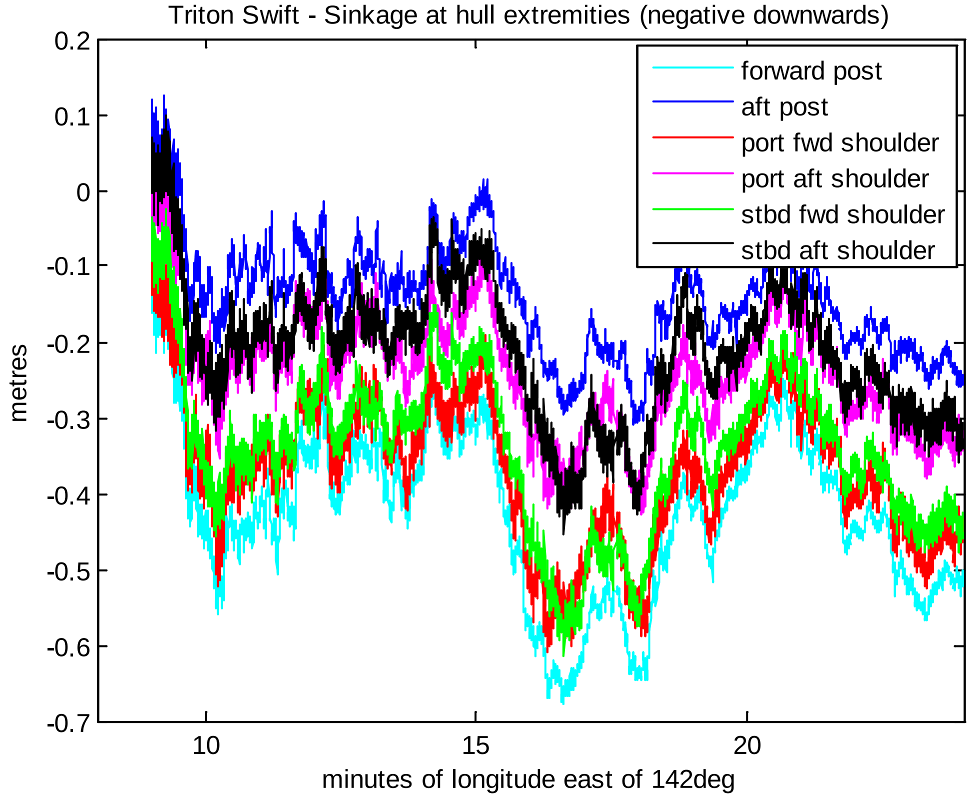
Loyal Union - Dynamic draft
forward post
aft post
metres
12.8
12.6
12.4
12.2
12
11.8
11.6
11.4
142d15
20
25
longitude east

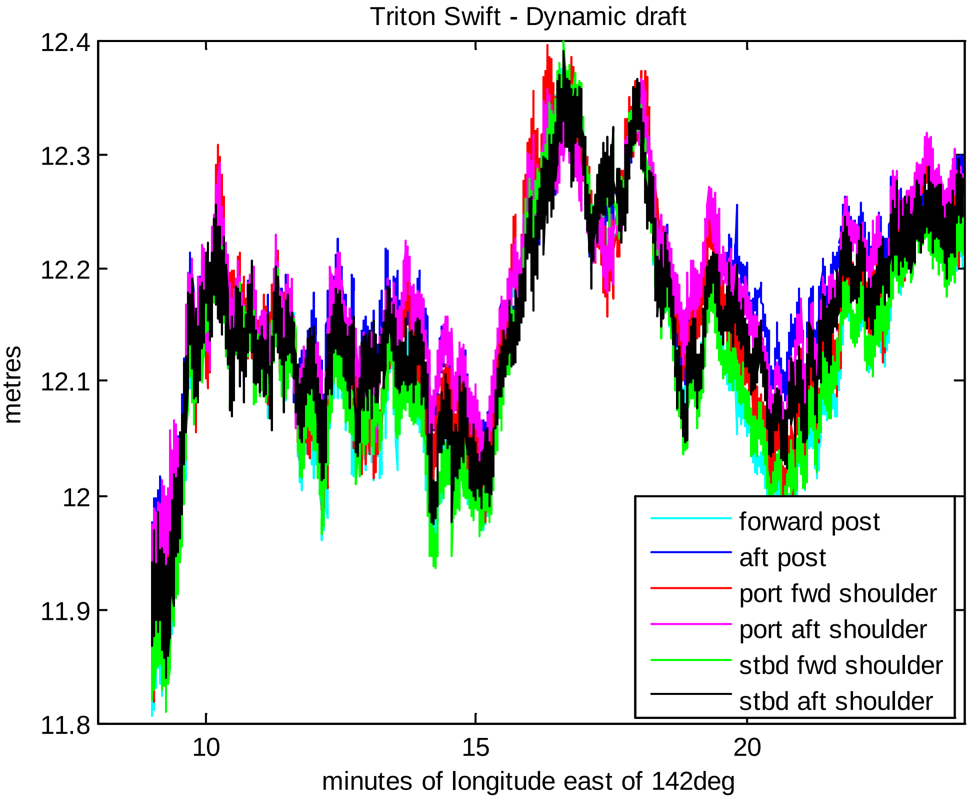

Triton Swift - Dynamic heel and trim
heel to stbd
bow-down trim
metres
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
05
10
15
20
25
30
minutes of longitude east of 142deg

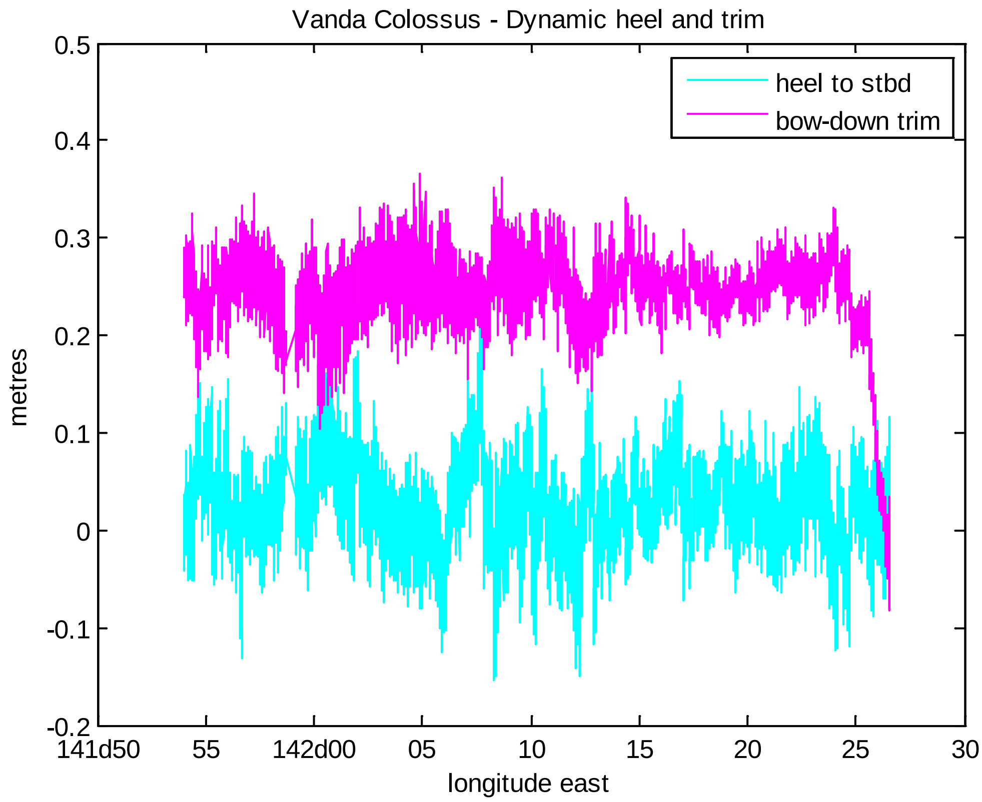

Triton Swift - Speed over ground
Ship
Miralga
knots
12
10
8
6
4
2
0
05
10
15
20
25
30
minutes of longitude east of 142deg

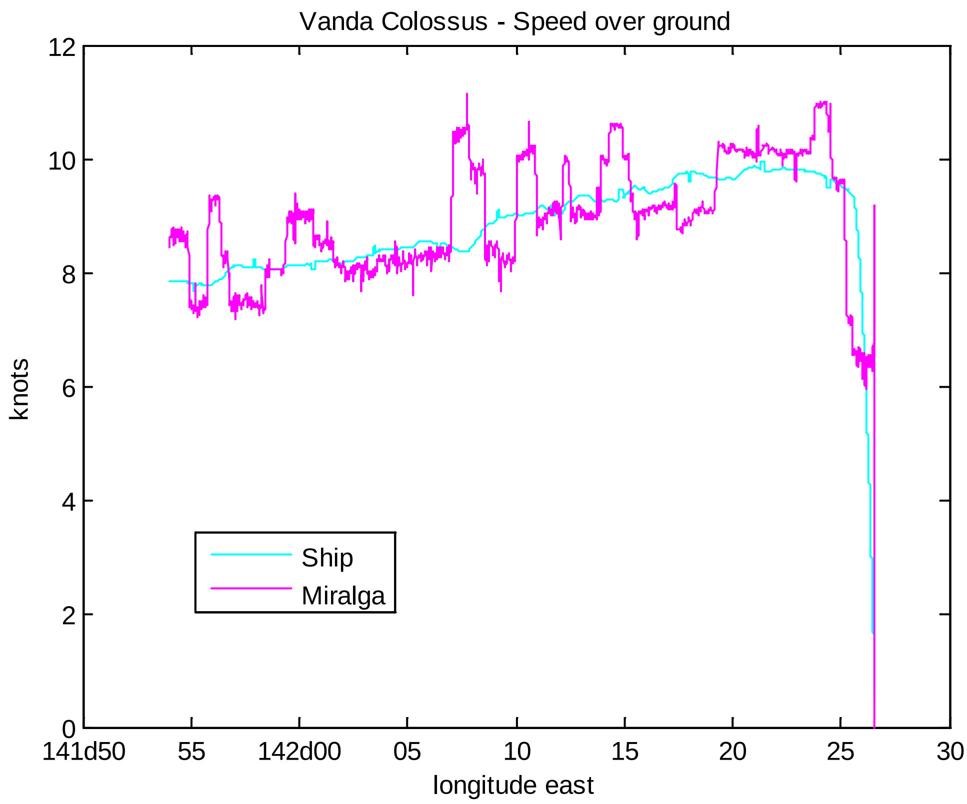

Triton Swift - Midship squat before Miralga averaging (negative downwards)
metres
1.5
1
0.5
0
-0.5
-1
-1.5
05
10
15
20
25
30
minutes of longitude east of 142deg

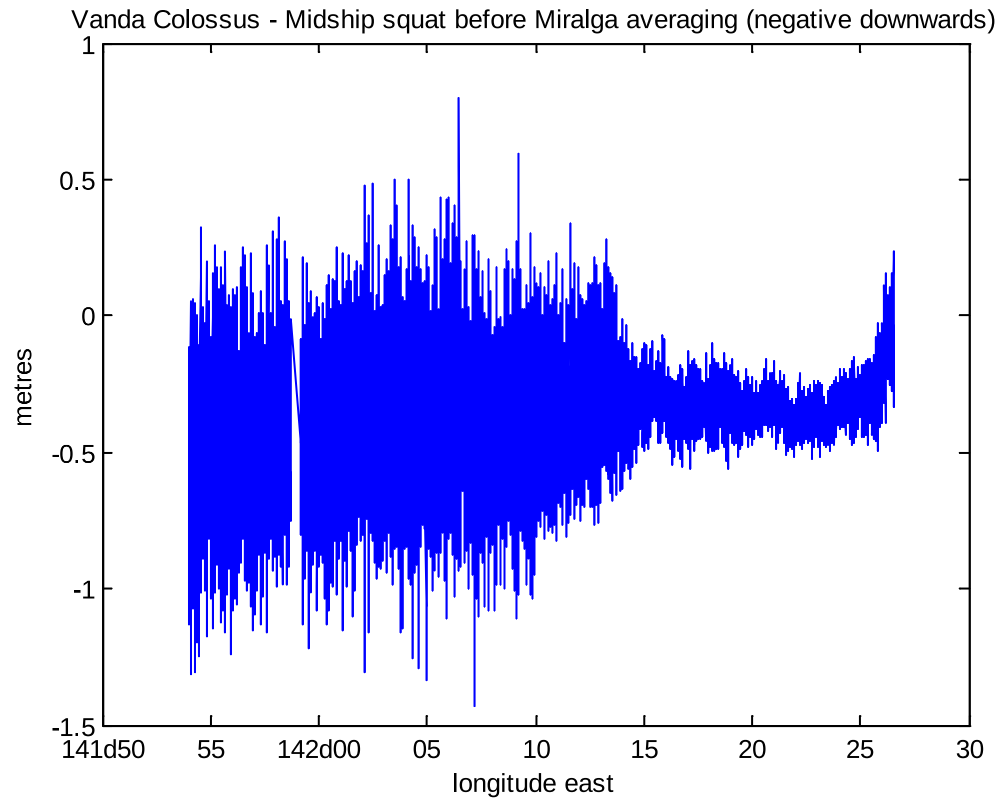

Triton Swift - Calm water squat (negative downwards)
metres
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
10
11
12
13
14
15
16
17
18
19
20
21
minutes of longitude east of 142deg
midship
bow
stern

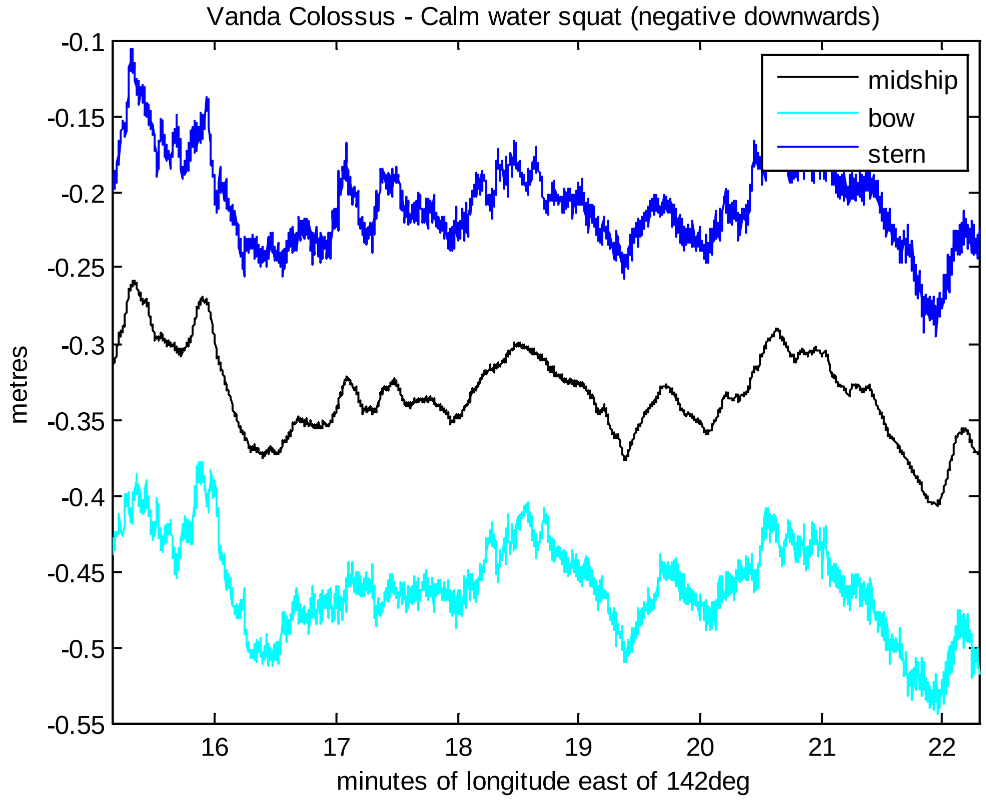

Triton Swift - Sinkage at hull extremities (negative downwards)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
metres
10
15
20
minutes of longitude east of 142deg
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder

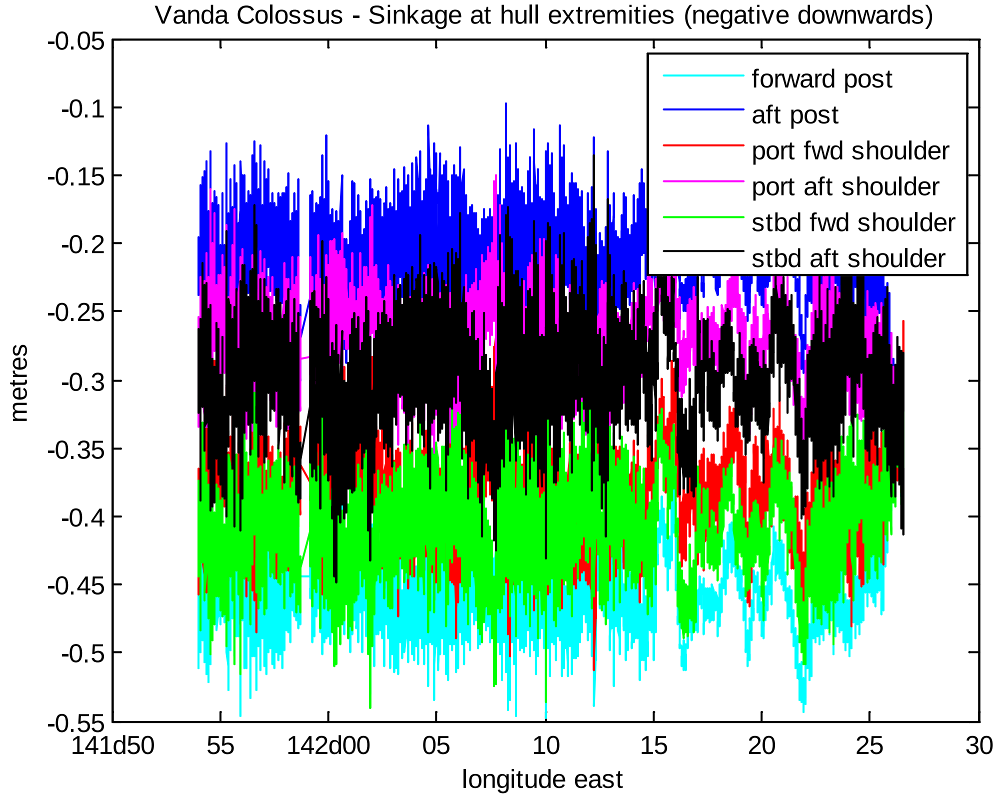

Triton Swift - Dynamic draft
12.4
12.3
12.2
12.1
12
11.9
11.8
metres
10
15
20
minutes of longitude east of 142deg
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder


Vanda Colossus - Dynamic heel and trim
heel to stbd
bow-down trim
metres
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
141d50
55
142d00
05
10
15
20
25
30
longitude east

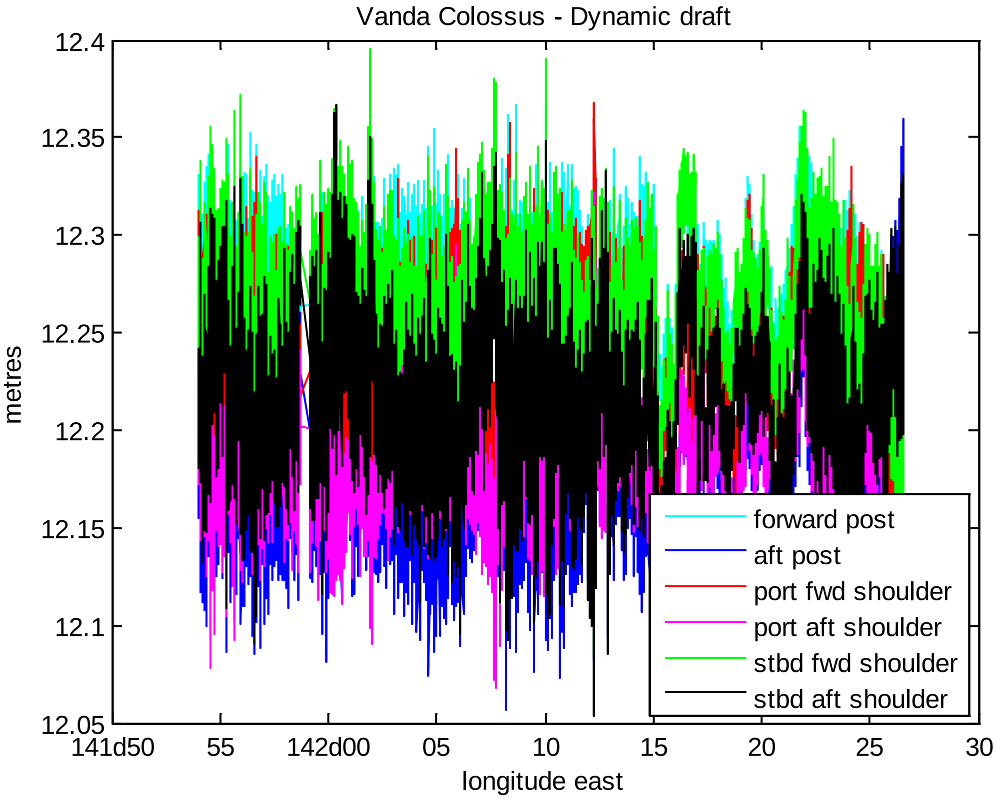

Vanda Colossus - Speed over ground
knots
12
10
8
6
4
2
0
Ship
Miralga
141d50
55
142d00
05
10
15
20
25
30
longitude east


Vanda Colossus - Midship squat before Miralga averaging (negative downwards)
1
0.5
0
-0.5
-1
-1.5
metres
141d50
55
142d00
05
10
15
20
25
30
longitude east

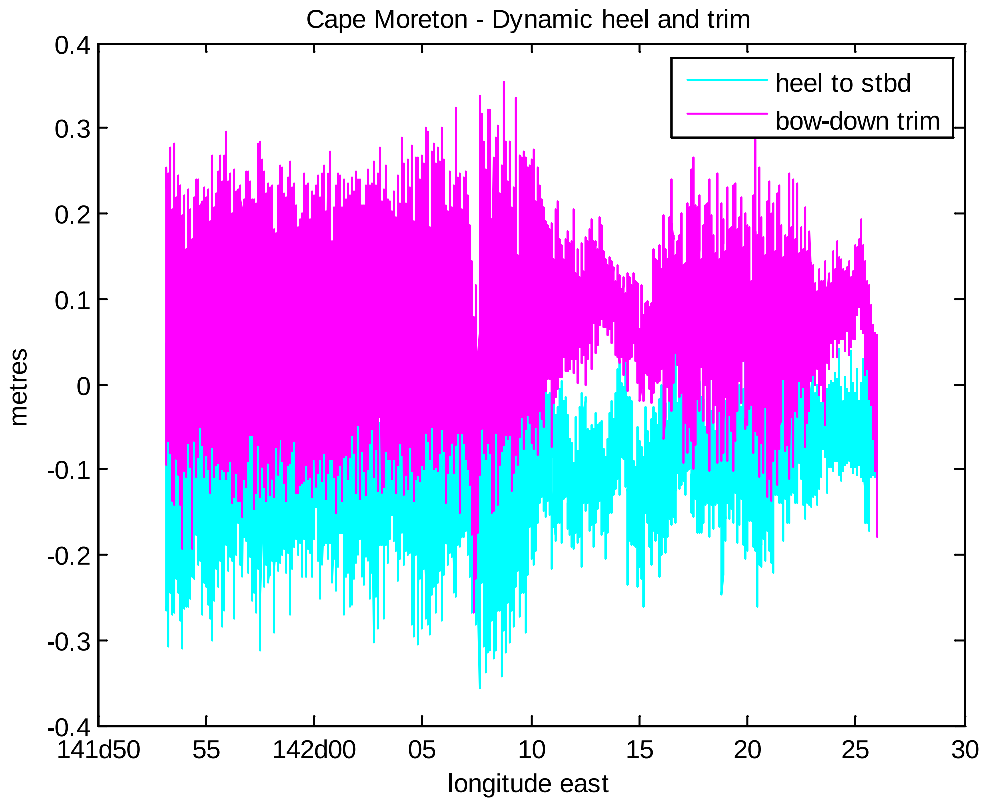

Vanda Colossus - Calm water squat (negative downwards)
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
-0.5
-0.55
metres
16
17
18
19
20
21
22
minutes of longitude east of 142deg
midship
bow
stern



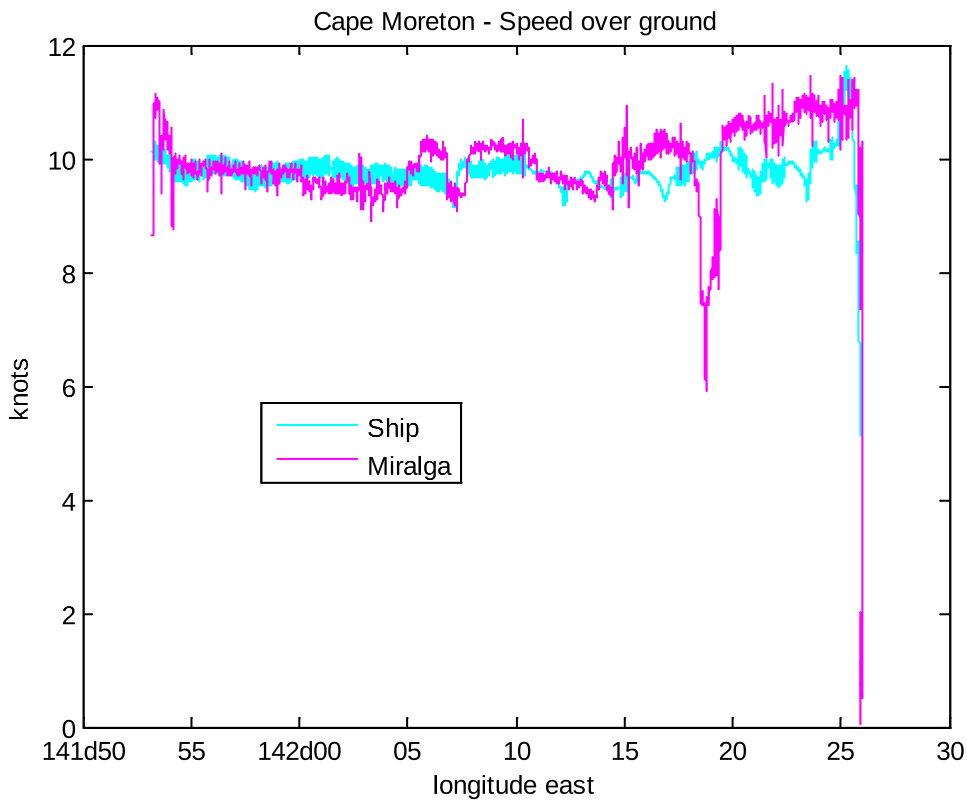
Vanda Colossus - Sinkage at hull extremities (negative downwards)
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
-0.5
-0.55
metres
141d50
55
142d00
05
10
15
20
25
30
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder



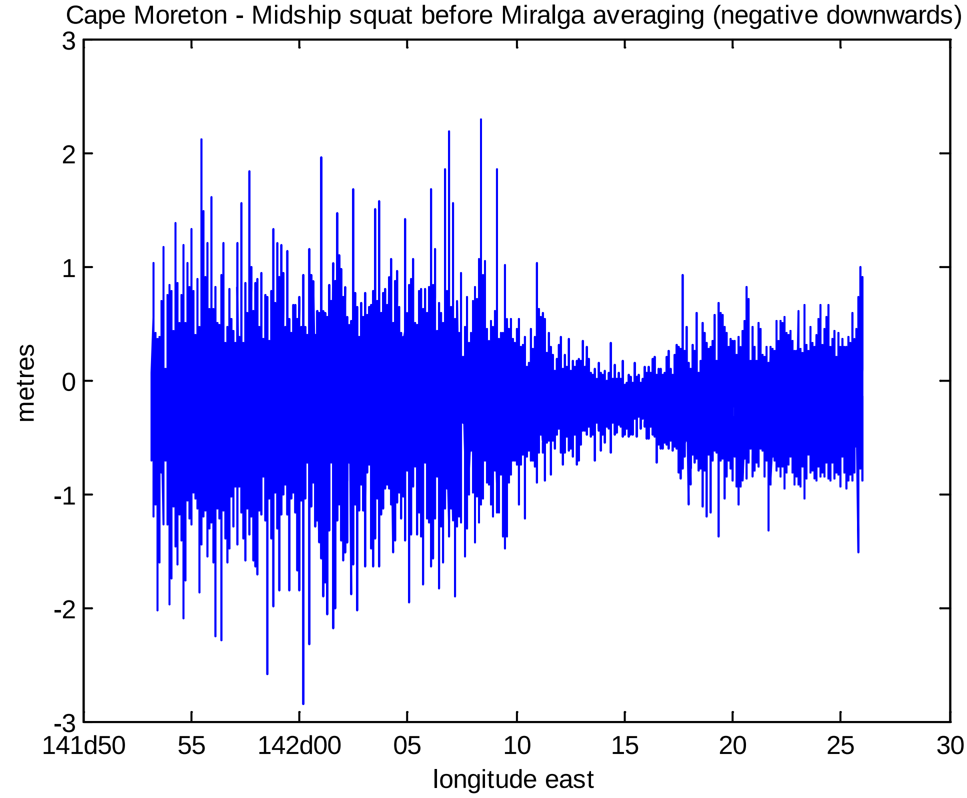
Vanda Colossus - Dynamic draft
12.4
12.35
12.3
12.25
12.2
12.15
12.1
12.05
metres
141d50
55
142d00
05
10
15
20
25
30
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder



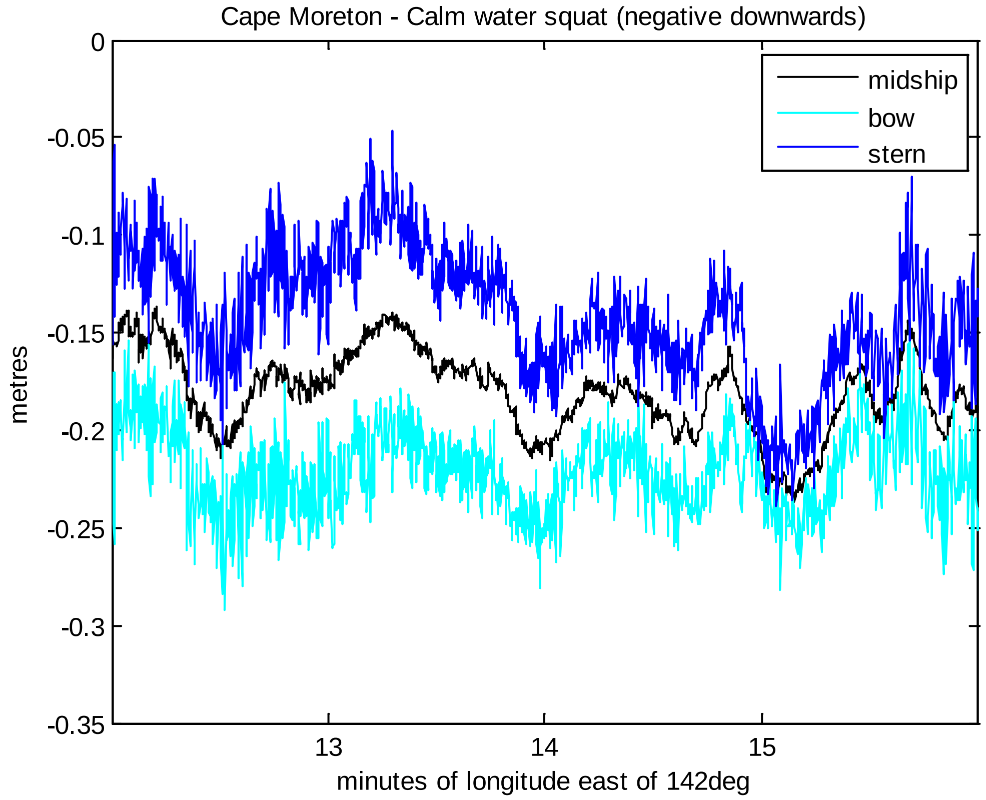
Cape Moreton - Dynamic heel and trim
heel to stbd
bow-down trim
metres
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
141d50
55
142d00
05
10
15
20
25
30
longitude east



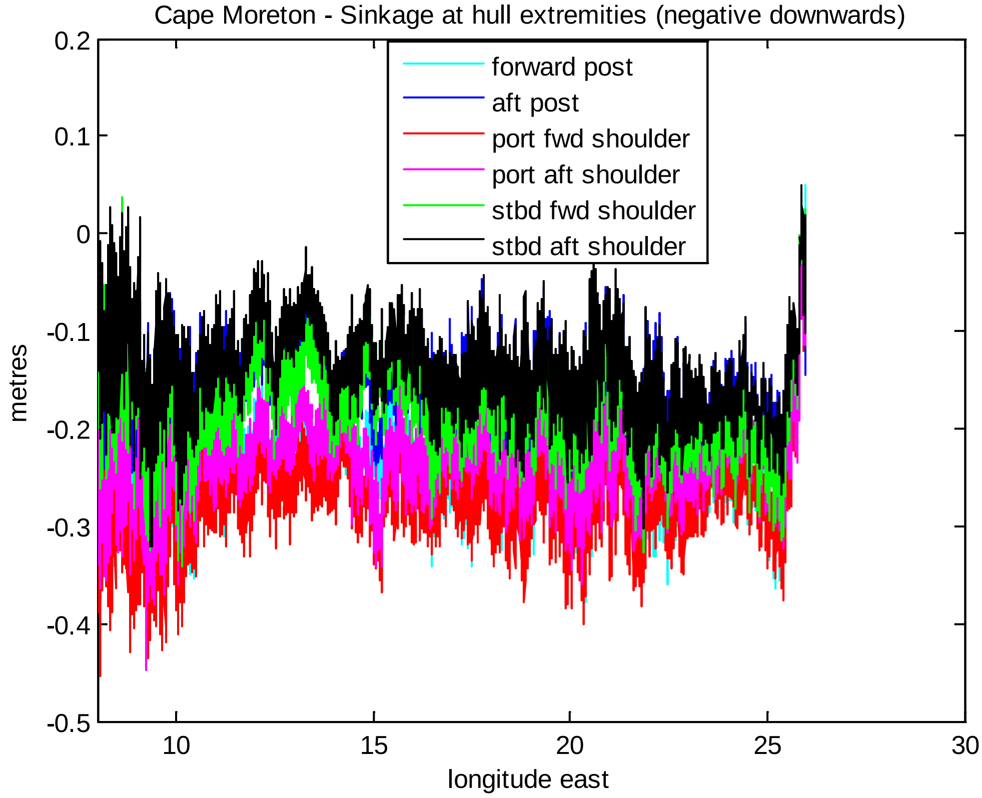
Cape Moreton - Speed over ground
Ship
Miralga
knots
12
10
8
6
4
2
0
141d50
55
142d00
05
10
15
20
25
30
longitude east

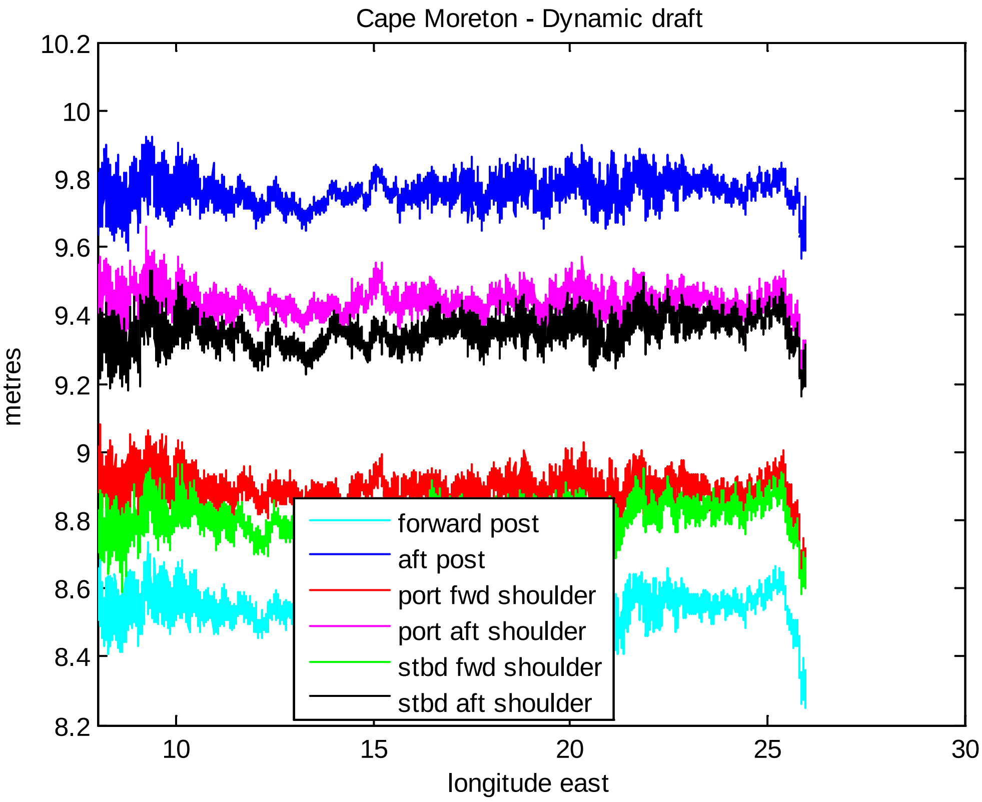


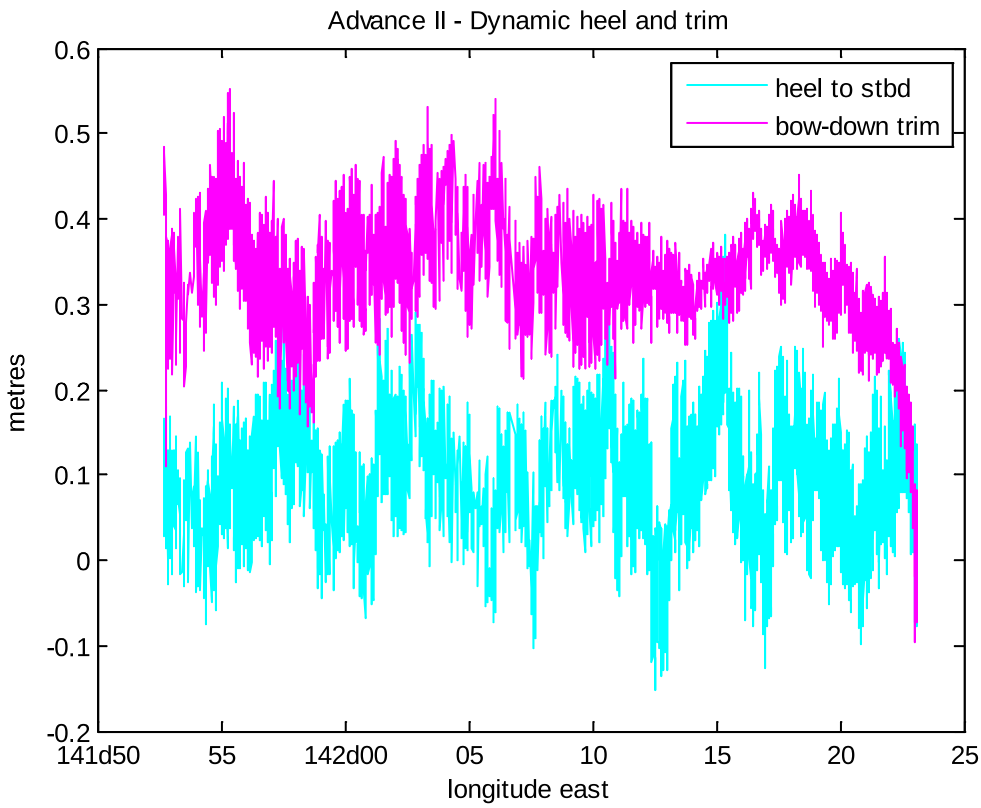
Cape Moreton - Midship squat before Miralga averaging (negative downwards)
3
2
1
0
-1
-2
-3
metres
141d50
55
142d00
05
10
15
20
25
30
longitude east

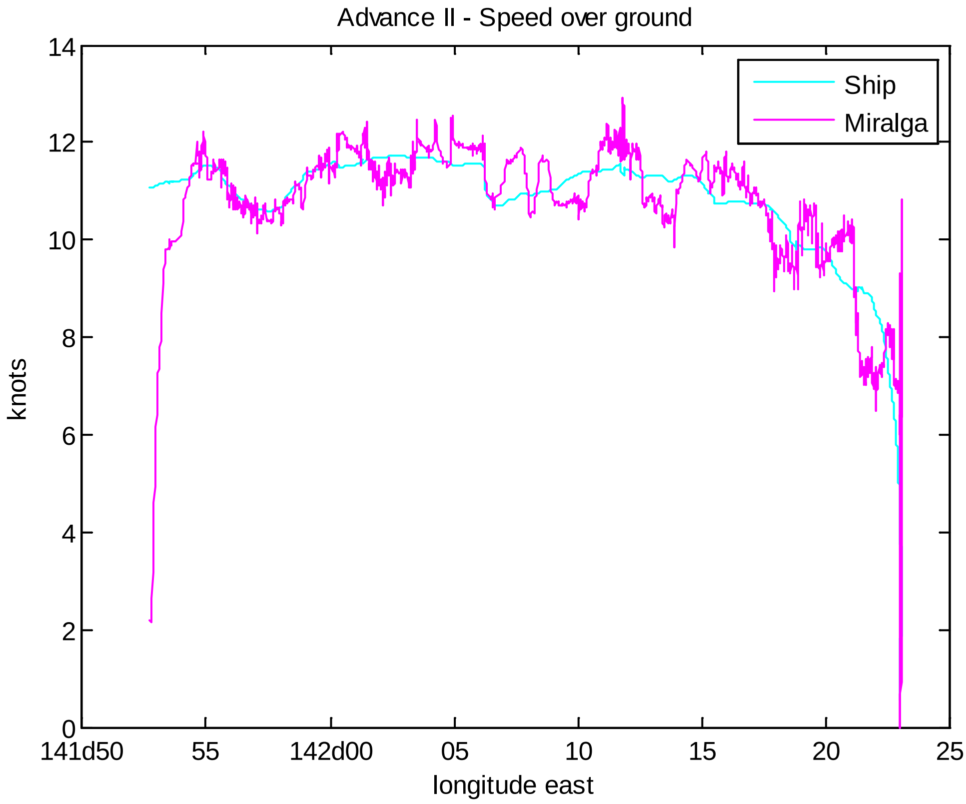


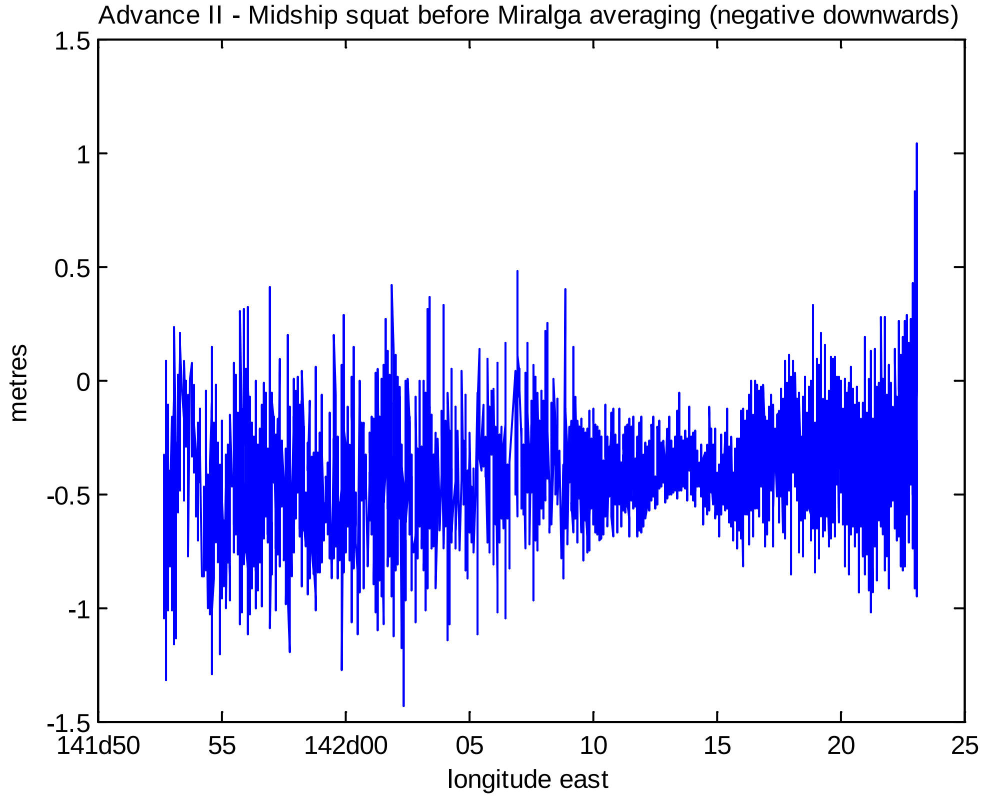
Cape Moreton - Calm water squat (negative downwards)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
metres
midship
bow
stern
13
14
15
minutes of longitude east of 142deg


Cape Moreton - Sinkage at hull extremities (negative downwards)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
metres
10
15
20
25
30
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder

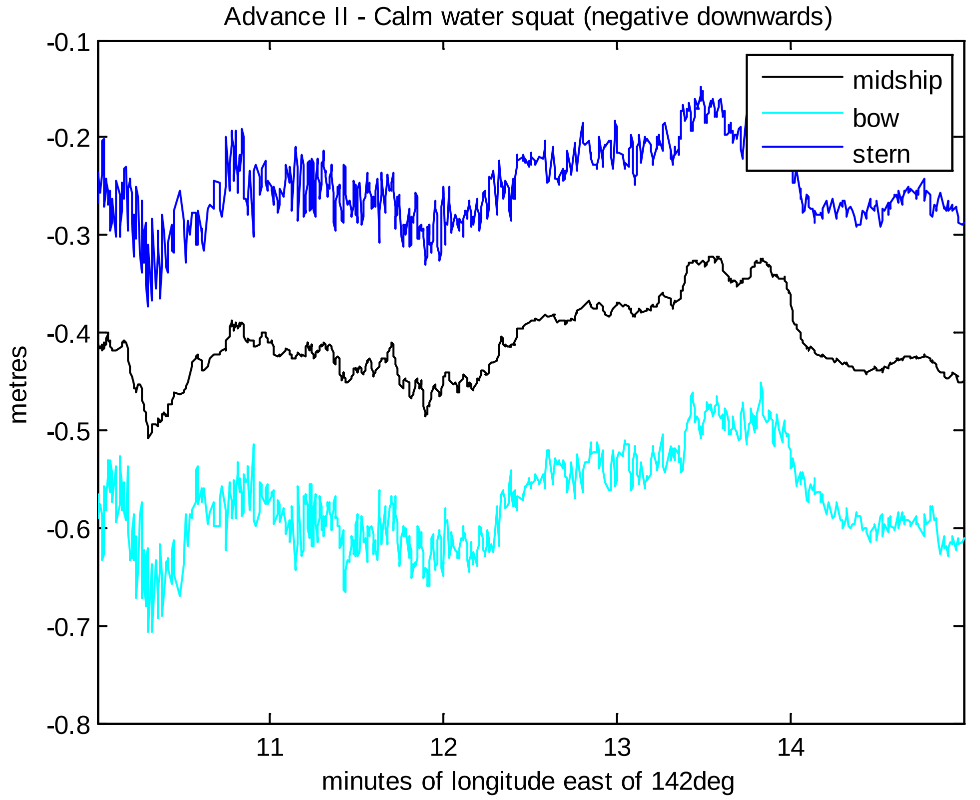

Cape Moreton - Dynamic draft
10.2
10
9.8
9.6
9.4
9.2
9
8.8
8.6
8.4
8.2
metres
10
15
20
25
30
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder


Advance II - Dynamic heel and trim
heel to stbd
bow-down trim
metres
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
141d50
55
142d00
05
10
15
20
25
longitude east

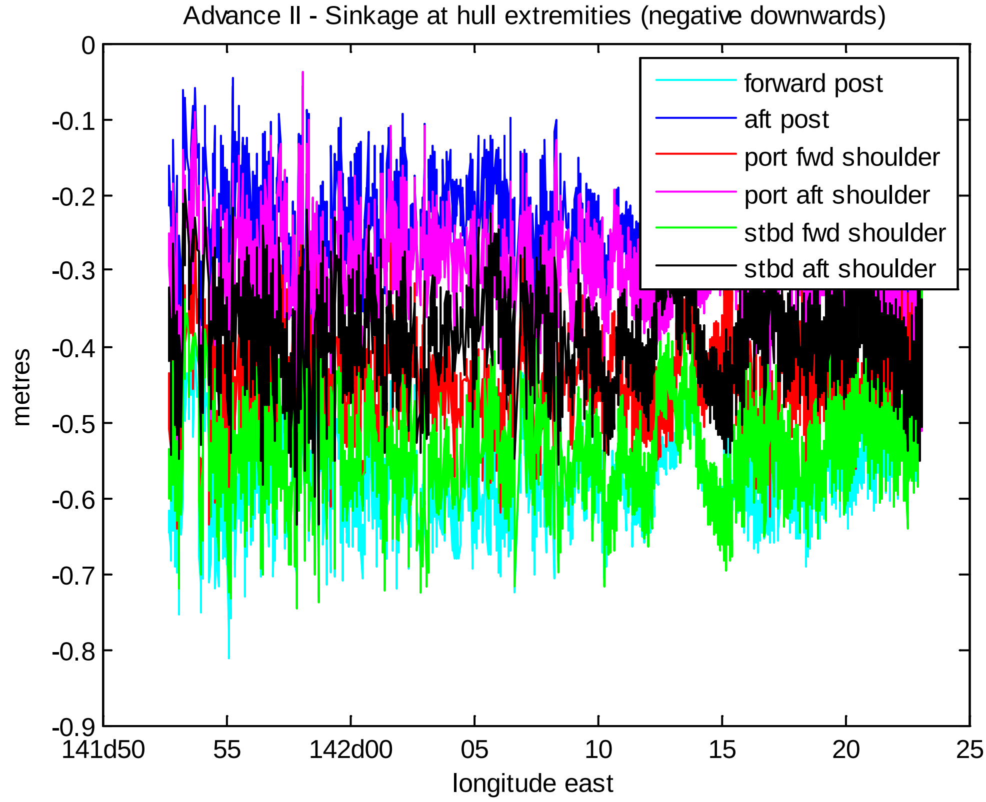

Advance II - Speed over ground
Ship
Miralga
knots
14
12
10
8
6
4
2
0
141d50
55
142d00
05
10
15
20
25
longitude east

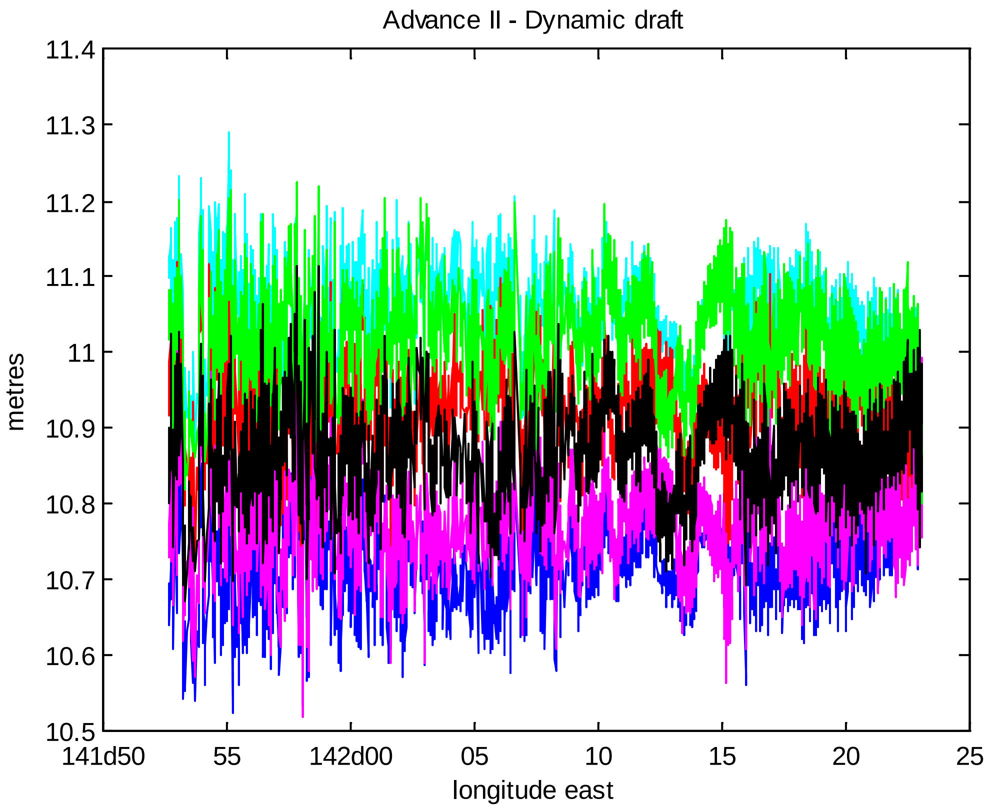


Advance II - Midship squat before Miralga averaging (negative downwards)
1.5
1
0.5
0
-0.5
-1
-1.5
metres
141d50
55
142d00
05
10
15
20
25
longitude east



Advance II - Calm water squat (negative downwards)
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
metres
midship
bow
stern
11
12
13
14
minutes of longitude east of 142deg


Advance II - Sinkage at hull extremities (negative downwards)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
metres
141d50
55
142d00
05
10
15
20
25
longitude east
forward post
aft post
port fwd shoulder
port aft shoulder
stbd fwd shoulder
stbd aft shoulder


Advance II - Dynamic draft
11.4
11.3
11.2
11.1
11
10.9
10.8
10.7
10.6
10.5
metres
141d50
55
142d00
05
10
15
20
25
longitude east