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HotStuff V4

Improvements to the Live Export Heat Stress Risk Assessment Method

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Abstract

The 'HotStuff' software for the assessment of heat stress risk on livestock voyages west from Australia has been revised, updated and expanded. The primary changes are:

- the addition of ports in the Mediterannean, the Black Sea, West Africa and Russia
- route options via the Suez Canal or West Africa
- inclusion of port risk as a parallel assessment of the risk during the discharge phase (actually introduced at Version 3)
- inclusion of more voyage weather data and reanalysis of all voyage and port data
- removal of the hard-coded limit of 5 knots on the assumed effective crosswind while sailing
- updating the software programming environment

A preliminary review of the effectiveness of air exchange while sailing in still air has indicated that the technique should not be relied on for two-tier open decks. The resulting air exchange had previously been taken as equivalent to a 5 knot crosswind, and more recently a 7 knot crosswind. Preliminary results suggest that the front half of open decks could be ventilated by sailing forward and could still be allowed to be assessed assuming a crosswind of 5 knots. The front third could be assessed using an effective crosswind of 7 knots. For the rear half of two-tier open decks, the equivalent effective crosswind is close to zero. To manage heat stress risk, open decks should be ventilated and assessed as if they were closed. No modelling was done for single-tier decks.

The HotStuff method relies on accurate vessel data. There is also no treatment yet in HotStuff for reingestion of exhaust air into mechanical ventilation systems.

Executive summary

The HotStuff software implements an approach to the assessment of heat stress risk on live export voyages from Australia. It combines animal heat tolerance, weather statistics and vessel parameters to give a scientifically defendable estimate of the numerical risk of mortality in each line of livestock to be loaded. It is used as a risk management tool through the assessment of planned voyages so that unacceptable risk can be avoided well ahead of the loading.

This report documents a project to add to and update both the method and the software. The software is now at Version 4.0.

HotStuff Version 1.0 assessed only the sailing risk, and only for closed decks. That was the major area of risk in 2000. The process of development has been to add both user features and additional risk assessment capability where significant remnant risks existed.

Previously HotStuff looked only at discharge ports in the Arabian Gulf, the Gulf of Oman, and the Red Sea. The HotStuff database has been expanded to include particular discharge ports on the north and south coasts of the Mediterranean Sea, on the Black Sea, on the north west coast of Africa, and even up to near St Petersburg on the Baltic Sea. For each of these new destinations, the software allows a choice of sailing through the Suez Canal or around the west coast of Africa and uses the appropriate statistics in the risk assessment.

The risk while sailing is assessed using weather data from voluntary observing ships. The latest data from that source were obtained and all data were re-analysed carefully to produce statistics for the routes to each of the destination ports.

Version 4 of HotStuff also includes an assessment of the risk while docked in the discharge port. This assessment uses land-based weather data near each port. Because extreme wet bulb conditions are causally related to still conditions, the port risk assessment assumes zero crosswind. Both sailing and port risks must be acceptable for the voyage to proceed.

Open decks have until now been treated by relying on air exchange generated by sailing forward, equivalent to some 'effective crosswind'. Assessments of discharge phase risk assume still air in port. This study also included a preliminary assessment of the equivalence of the air exchange generated by crosswind and the air exchange generated by sailing forward. It is seen that sailing forward in still air is ineffective at generating air exchange for the rear half of two-tier open decks. The equivalent effective crosswind toward the rear of the animal housing is not 7 knots or 5 knots, but close to zero. While a similar effect might be expected for single-tier decks, no such modelling has been carried out.

There remain some practical areas which threaten the efficacy of the method:

- The pen air turnover (PAT) values have not been independently audited for all vessels. Any vessel which is using incorrectly high figures will be underestimating risk.

- All mechanically supplied air is treated as being fresh. For some vessel intakes and winds, re-ingestion of air discharged from the animal house will reduce the effective fresh air flow. No de-rating of ventilation capacity has yet been made to allow for this, such that risk may currently be underestimated.

- The current practice in two-tier open decks with low mechanical pen air turnover is still unsatisfactory from a risk view. In this context, 'low' PAT describes any deck which relies on crosswind to meet the heat stress risk criterion. That cut-off depends on the tier height and deck width, but would be in the range of 60 to 120 m/hr. The effective pen air turnover at the rear of wide two-tier decks could become extremely low in still conditions, even when sailing fast. Such decks should be ventilated and assessed as if they were closed at the sides.

The industry has at times noted that applying HotStuff can be time consuming and can also cause delay at loading. Suggestions are made on minimising the work and compliance costs associated with the risk assessment.

Contents

1 Background on HotStuff

HotStuff is the name of the software developed to automate calculations for the assessment of livestock heat stress risk on sea voyages out of Australia. It also calculates the maximum allowable stocking density within the given risk limits. The line of work that led to the development of HotStuff began in 2000 as a LiveCorp/MLA and Australian Government funded study into "Ventilation Efficacy on Livestock Export Vessels". Prior to that work, there was no scientific basis for the management of heat stress risk in livestock exports. In 2000, voyages had been taking place with a risk of heat stress that was unacceptably high. While the industry sought consensus on an appropriate approach to heat stress risk, the lack of a scientific method had made it difficult to criticise vessels, voyages or loadings which may have been too risky in some circumstances.

In 2000, the basic thermodynamics of livestock housing had been clearly documented. Among the outcomes was a new measure of ventilation rate; the Pen Air Turnover or PAT which is the ratio of the fresh air supply rate to the pen area. This measure differed from the previous volumetric air turnover measure in that the airflow was compared only to the pen area. It is the pen area, not the volume, which determines the animal mass housed, and hence the metabolic heat evolved.

During the 2002 northern summer, high mortality incidents in livestock export to the Middle East highlighted the systemic weaknesses in the standards and procedures that were being applied to animal welfare and heat stress risk management on such voyages. This accelerated the development of HotStuff to embody, and make available for use, the risk management knowledge which had been documented over the previous two years. Version 1.0 of HotStuff was released in final form in May 2003. In version 1.0, the closed deck risk assessment was substantially in its current form. The open deck issues were treated by giving guidance as to what the crosswind the captain needed to be certain of while sailing and before proceeding into port. While that approach on open decks was not really suitable for a regulatory role on risk, the introduction of a robust treatment of closed deck risks was a major step forward for the industry. Continued development, mainly on the software operation rather than the risk numbers, led to Version 2.0 in September 2003. Further interaction with users and with MLA led to Version 2.3 in February 2005. It is version 2.3 which has been in use up until the Version 4.0 release.

Version 3 was produced in April 2009 but not released in its developed form for use by the industry. It included a new approach to reducing the ship-sourced weather data to voyage weather statistics. That approach was further refined in producing Version 4. Version 3 also included an assessment of the risk when tied up in the discharge port, as a separate assessment to that of the risk when sailing. That important feature responded to several lower level incidents and near misses on vessels while in

port.

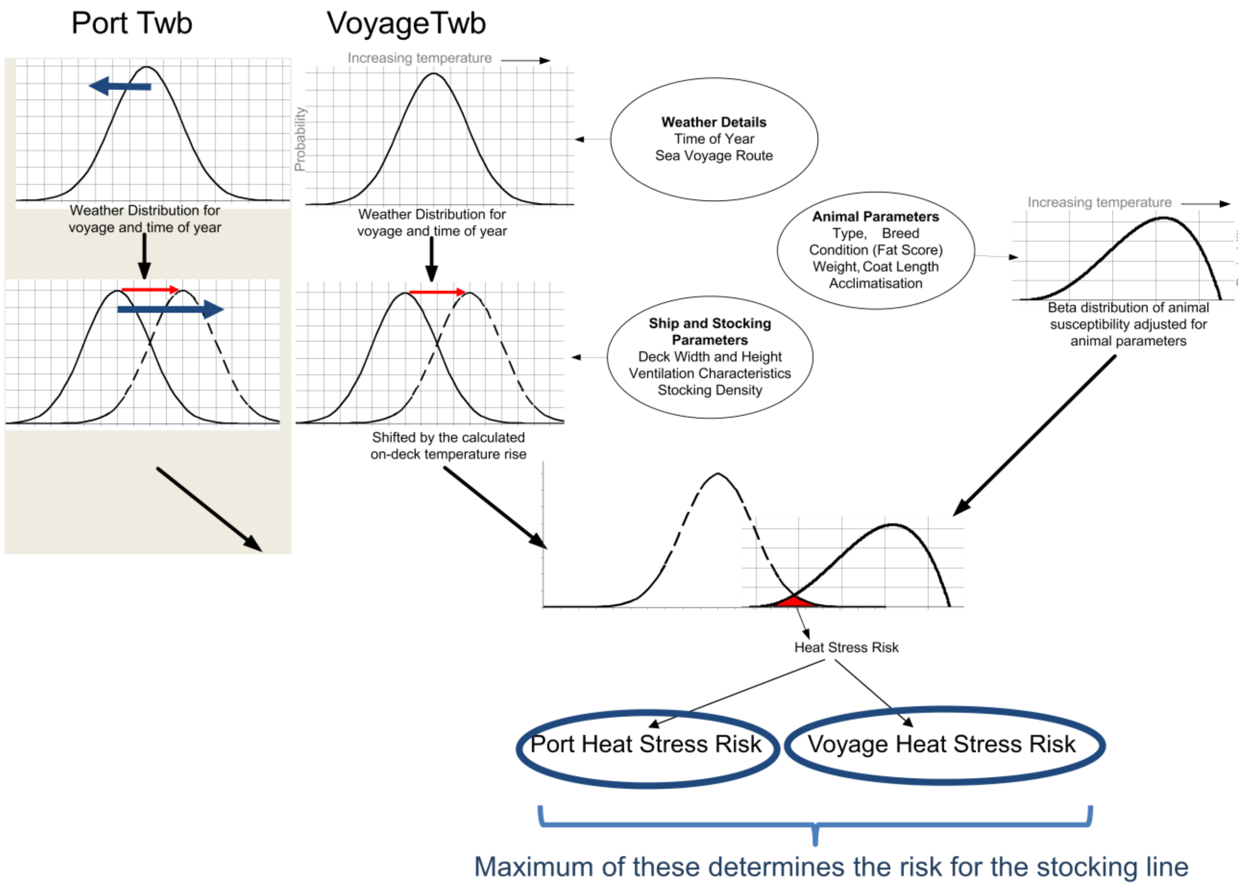

Figure 1 below describes the approach schematically. Version 3 did not include the recently added ports or routes and was superseded by Version 4.

Version 4.0 is the current development described in this report. It includes all previous HotStuff developments, plus those objectives noted in the following section. The voyage weather data has been re-analysed yet again for Version 4, with a close focus on the data and temperature distribution integrity. The method is summarised briefly as follows.

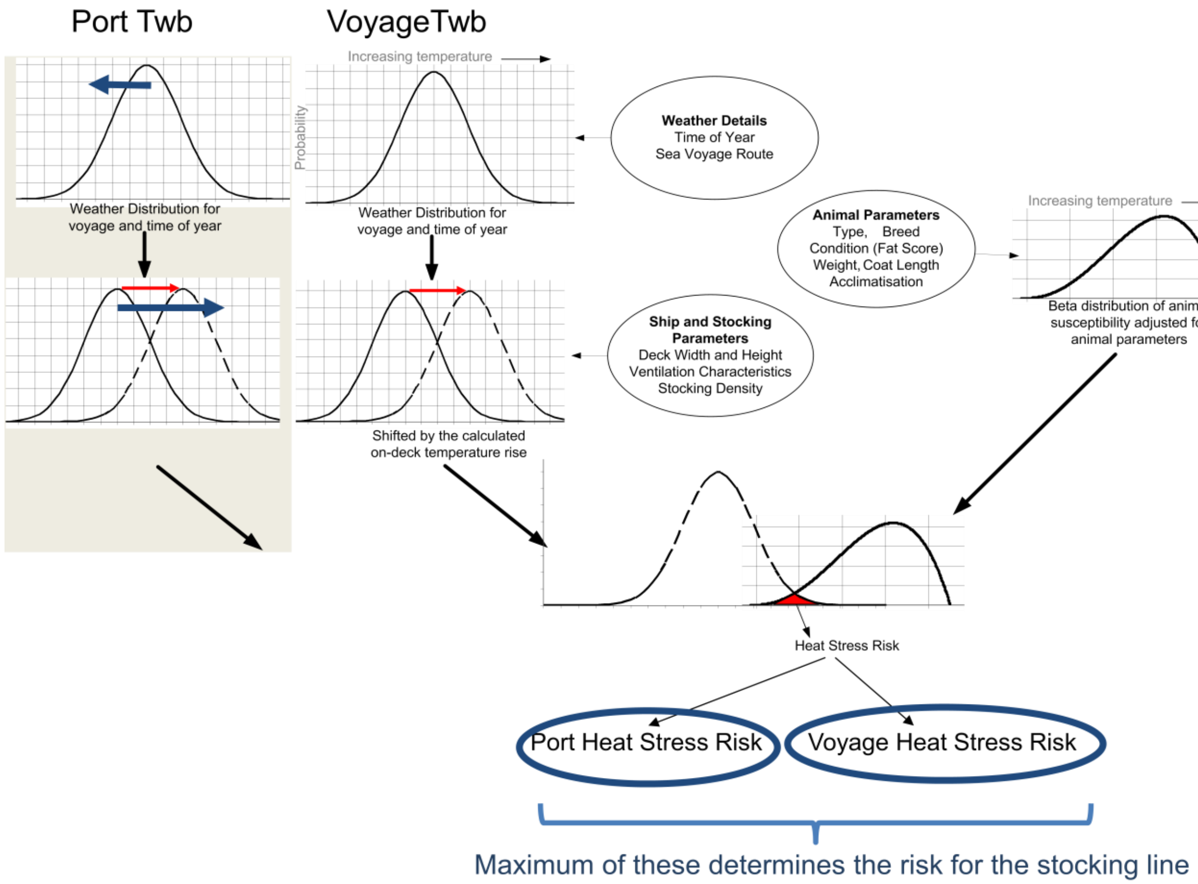

Figure 1. Flowchart of the heat stress assessment, with the shaded area being added since Version 2.3.

The probability of animal mortality is described statistically as a function of wet bulb temperature by a distribution which is a function of the animal's breed, condition, weight, coat and acclimatisation. The likelihood of reaching any given wet bulb temperature on a deck is also described by a probability distribution. First, the probability distribution of ambient wet bulb temperature has been assessed from weather observations for every voyage route for all twelve calendar months. Second, the ambient distribution is shifted hotter by an amount corresponding to the rise in wet bulb temperature on the deck. That rise is calculated from the heat output of the animals diluted by the fresh air flow rate. The result is probability distributions for the deck wet bulb temperature and the animal tolerance (mortality limit). The intersection between the hot end of the deck wet bulb probability distribution and the cool end of the animal mortality limit gives the risk level. This is done for each line of livestock, on each deck of the vessel, for the particular discharge date. The risk must be below the industry accepted level of 2% chance of a 5% mortality.

The above text describes the risk assessment while sailing. It uses the hottest wet bulb temperature distribution anywhere along the particular route. The shaded areas in Figure 1 indicate that since Version 2.3, the same process is repeated for the discharge phase risk (the "port risk") being the risk while the vessel is stationary alongside the wharf. Because the ventilation effects on open decks are very different when the vessel is stationary, a separate risk assessment was called for. In assessing port risk, only the port weather data are used and the crosswind for open decks is taken to be zero. The risk must be seen as acceptable in both sailing and port calculations. Version 4 calculates the port risk for all destination ports.

2 Project objectives

Reference is made to the W.LIV.0277 Project Agreement. The project objectives from that document are reproduced below, with elaboration in parentheses based on other parts of the document:

1. Include additional voyage routes and ports to the HotStuff model. (Principally around the Mediterranean and involving routes around Africa as described in Sections 3.1 and 3.2.)
2. Implement a revised data analysis for the sailing component of the voyage using the 250 nautical miles (or ~12hrs) of the particular voyage route that has the highest wet-bulb temperature probability distribution. (This included updating the voyage and port weather statistics using the latest data sources.)
3. Review and determine the minimum crosswind that can be generated on open decks of ships. (This is an initial, coarse computational fluid dynamics assessment to inform a judgement of how to direct further work on setting a reasonable upper limit.)
4. Participate in a review of the updated HotStuff 4.0 model and provide training to industry and government on the revised HotStuff model. (Industry interaction is ongoing.)

3 Method Enhancements

3.1 New ports

HotStuff 4 includes 19 destination ports not previously accommodated in the voyage risk assessment. There are now a total of 30 destination ports in the database. The ports now in HotStuff 4 are listed below.

Turkey, Mediterranean
- Izmir (Guzelyali)
- Antalya
- Mersin
- Tekirdag

Turkey, Black Sea
- Istanbul (Ataturk)
- Samsun
- Trabzon

Russia, Baltic
- Ust Luga (St Petersburg)

Russia, Black Sea
- Novorossiysk

Ukraine, Black Sea
- Odessa

Syria, Mediterranean
- Al Lathqiyah (Latakia)

Libya
- Tripoli (Tripoli Int Airport and Mitiga)
- Benghazi (Benina Airport)

Lebanon
- Beirut (Rafic Hariri Int Airport)

Egypt, Mediterranean
- Alexandria

Egypt, Red Sea
- Port Suez
- Adabiya (Ras Sedr)

Pakistan
Karachi

Morocco, Atlantic
Casablanca
Agadir (Inezgane)

Red Sea
Aqaba (Jordan)
Elat (Eilat) (Israel)
Jeddah (Saudi Arabia)

Persian Gulf
Dhahran
Kuwait City
Bahrain
Doha (International Airport)
Jebel Ali (and Dubai)

Gulf of Oman
Fujairah (UAE)
Muscat (Oman)

Section 3.4 summaries the wet bulb climatologies for all ports. The detail of that work is given in "Appendix 1. Port Wet Bulb Climatologies".

3.2 New routes

Earlier versions of HotStuff considered only destinations in the Arabian Gulf or the Red Sea. The new ports in West Africa, the Mediterranean, the Black Sea, and up to western Europe, required analysis of routes through areas of ocean not previously analysed. The routes are shown on a map in Figure 5 in Section 3.3.4.

3.2.1 West Africa

For analysis purposes, the routes around the west coast of Africa all start at the Cape of Good Hope, on the basis that there is no risk of heat stress across the Southern Ocean. While all the journeys via West Africa share the same routes initially, they start diverging to their different destinations off the coast of Morocco and fan out in the Mediterranean and in the Black Sea.

3.2.2 Suez Canal

The software now allows transit through the Suez Canal. Journeys that use the Suez Canal are assessed for port risk at Port Suez, in addition to their first destination port. This allows for the marshalling of vessels into convoys to transit the canal. Once through the canal, the paths fan out into the Mediterranean, to complete journeys to all the same ports that are accessed via West Africa. Many of the route segments after the canal are the same as those via West Africa, with the direction of travel being reversed.

For destinations past the Suez Canal, the choice of journey (via Suez or the Cape of Good Hope) is made in HotStuff by specifying a destination with the route appended, for example; Agadir-Cape or Agadir-Suez. With the destination so specified, the correct voyage weather statistics can be selected from the database.

3.3 Revised voyage weather analysis

While adding the new Ports and Journeys to the database, the statistics for both voyage weather and port weather were recompiled using expanded data sets and new analysis.

All versions of HotStuff have used data from the voluntary observing ships (VOS) scheme supervised by the World Meteorological Organisation. At each major revision, the latest VOS data have been added to the data set analysed. At this revision, data for 2008-2010 were included to augment the existing dataset from 2002-2007 which was used to derive the weather statistics in the HotStuff version 3 project. The current data set now covers the following range:

- UTC DateTime Range: 30 September 2002 to 29 December 2010
- Latitude Range: 89.9 deg to -80.5 deg
- Longitude Range: -180 deg to 180 deg

3.3.1 Cleaning of the VOS data

The VOS data, and the dataset itself, were examined for obvious errors and inconsistencies. There is a limit to the scrutiny that can be given to individual records in such a big dataset and so a number of rules were applied to initially 'clean' the dataset. Following good practice, the data were not deleted, but simply tagged in the database with a non-zero marker variable "MarkedAs" for later filtering and exclusion. The cleaning rules were applied to eliminate:

- Records where all three of Wet Bulb, Relative Humidity and Dew Point were missing.
- Duplicate data. (Ship Call Sign, Date, Time, Latitude and Longitude identical across two or more records.).
- Invalid or out of range UTC DateTime.
- Records where wet bulb temperature exceeded dry bulb temperature.
- Wet bulb temperatures below 10°C (possible but of no interest to this work).
- Wet bulb temperatures above 36°C.

With the records recovered by synthesis of the wet bulb temperature value, and those set aside by the cleaning rules, 405,877 distinct and valid temperature readings remained, covering the world's oceans.

The data locations (latitude and longitude) are plotted in Figure 2 below. The major sea routes are shown clearly by the density of recordings. Also apparent is that some ship locations are reported in the centre of continents. The number of such points gives some indication as to the general error rate in the dataset. They have not been excluded as they are relatively few in number and are unlikely to be included in the data subset for any journey. It would also be difficult to define the land mass areas in a way that facilitated automation of the exclusion.

Figure 2 shows the same dataset but viewed as the variation of wet bulb temperature with latitude.

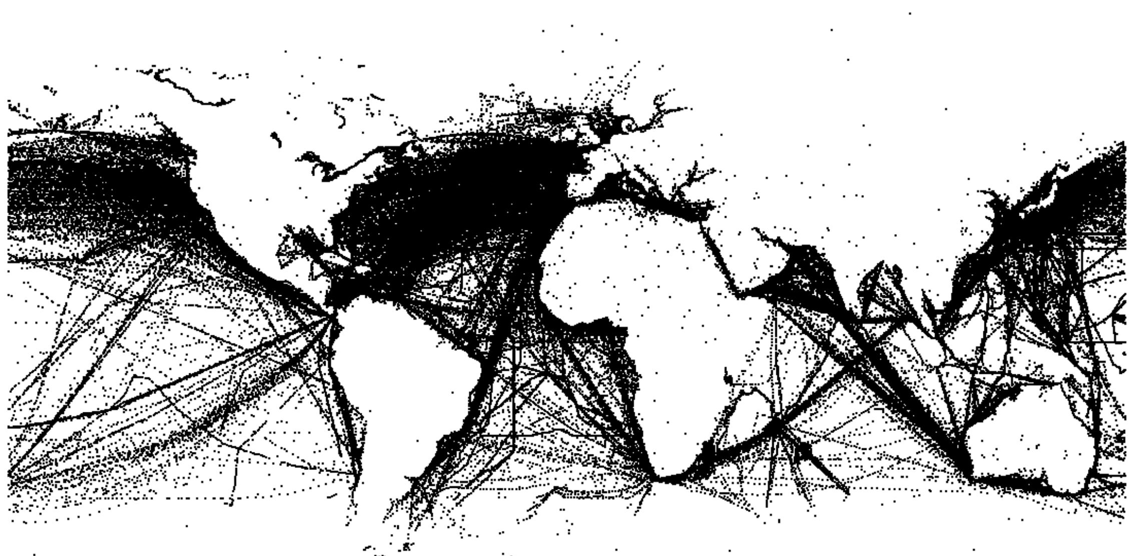

Figure 2. Area distribution of valid temperature data

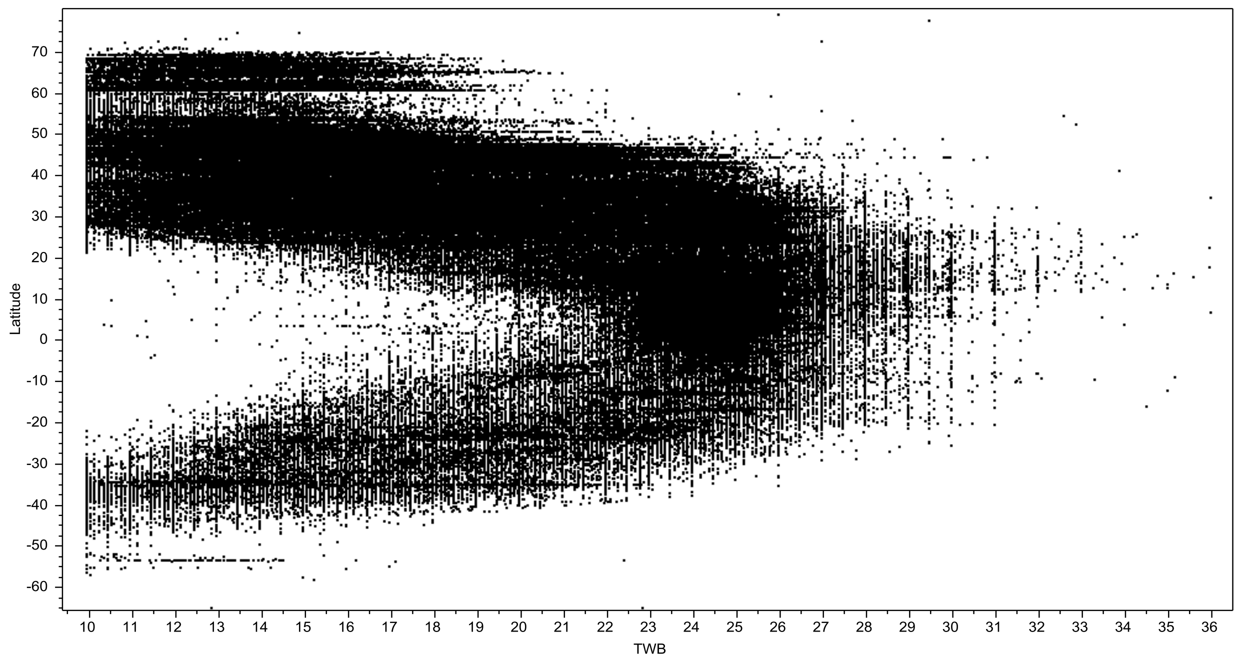

Figure 3. The overall wet bulb temperature distribution with latitude.

The banding in Figure 3 shows the propensity of observers to record the wet bulb temperature to the nearest half degree.

3.3.2 Wet bulb temperature synthesis

Many of the records had no value entered for the wet bulb temperature. The wet bulb temperature is central to the HotStuff method and without a wet bulb value the records cannot be used. For the observations where no direct wet bulb temperature was recorded, wet bulb temperatures were synthesised, where possible, from the available dew point and relative humidity measurements. Lookup tables were generated using standard psychrometric equations to allow wet bulb values to be added to the database. The form of the equations used is given in "Environmental Engineering in South African Mines", published by the Mine Ventilation Society of South Africa, 1982.

Table 1. Numbers of observations with each of the psychrometric parameters.

Reading	Number of points with reading	Number of points without reading
Wet Bulb	176,300	229,573
Relative Humidity	210,244	195,629
Dew Point Temperature	2,905	402,968

The calculated wet bulbs were added as new parameters in the database, to allow later distinction between the three 'sources' of wet bulb values. In the subsequent analysis, recorded wet bulbs were used wherever available, with wet bulb calculated from dew point used as the second option, and wet bulb from relative humidity used if the other two were not available.

3.3.3 Aggregation of VOS data

HotStuff uses weather data reduced by calendar month, and assigns the resulting wet bulb temperature distributions to the 15th day of each month. Even with the number of records collected, in many relevant areas of ocean, there are insufficient data to generate reliable statistics for periods much smaller than a month. Data for other dates are interpolated between the 15th days which fall either side of the date in question. This interpolation results in a variation of the wet bulb statistics which is piece-wise linear with time. At the 15th of each month, the gradient can change such that the effect of delaying a voyage from the 14th to the 15th of a month can be different to the effect of delaying from the 15th to the 16th. There are no 'jumps' or steps in the distribution; it is only the gradient of wet bulb temperature with time that changes. Figure 4 below shows that, for voyages to Kuwait, May and September are particularly hot compared to the trend from adjacent months. This means that, for example from Figure 4; after 15th September the assessed risk will fall quite rapidly with delay to the discharge date.

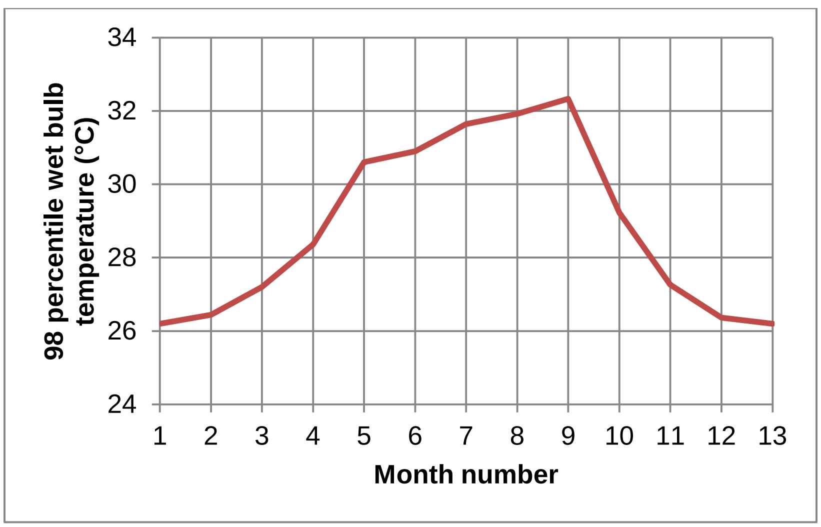

Figure 4. Variation of 98 percentile wet bulb temperature for voyage risk to Kuwait. Values for the 15th of each month are plotted against month number. January is repeated as month 13 to complete the loop.

Up to Version 2.3, the weather statistics were based on analysing the VOS data aggregated into regions or 'zones' that generally covered 10° of longitude and 5° of latitude. The areas were sized so as to give sufficient data points in each zone in each month that the statistical analysis was robust. Smaller zones were used in the Persian Gulf (4 zones) and the Red Sea (6 zones including the Gulf of Aden). The statistics for the journey were then taken as those of the hottest region that the route passed through. The use of large area aggregation of the VOS data would have tended to smear out any local hot spots.

For Version 3, the VOS data within a band around each route were 'collapsed' onto the route by being given a distance coordinate corresponding to the closest point on the route. This resulted in a distribution of relevant weather observations by journey distance only, rather than by latitude and longitude. The wet bulb temperature probability distribution was calculated as a function of journey distance by looking at a moving 250 nautical mile 'window' on the route data. The wet bulb distribution with the highest 98 percentile value was selected as controlling risk on that route for that month. The moving window on the data obviously gave the potential for the 98 percentile wet bulbs to be slightly higher than the result from the earlier fixed ocean areas and that is what happened.

As part of the work for HotStuff Version 4, another method was developed for VOS data reduction. The primary objective was to use database techniques to allow a high level of automation of the processing and calculation for each journey. The flexibility of data retrieval possible with a full relational database approach also facilitated the normally very manual task of examining closely both the data quality and the particular records which control the 98 percentile values.

3.3.4 Journeys, Routes, Segments and Waypoints

To process the cleaned VOS data into statistical information on weather expected for a particular voyage, a data structure was defined to describe the path of each voyage and to select and process the data relevant to that voyage path and date. The data structure can be described briefly as follows. The HotStuff 'Journeys' from a departure port to the first destination port are made up of a number of 'Routes' between Journey branching points. The Routes are not unique to one Journey but are strung together in various combinations to make all the Journeys required. The Routes may change direction and where they do, they are divided into 'Segments'. The Segments are great circle arcs between two points at which the route changes direction. Along each Segment, 'Waypoints' are defined, at approximately 50 nautical mile intervals. The Waypoints include the end points of the Segments. Figure 5 is a plot of all the Routes on a map covering the area of interest.

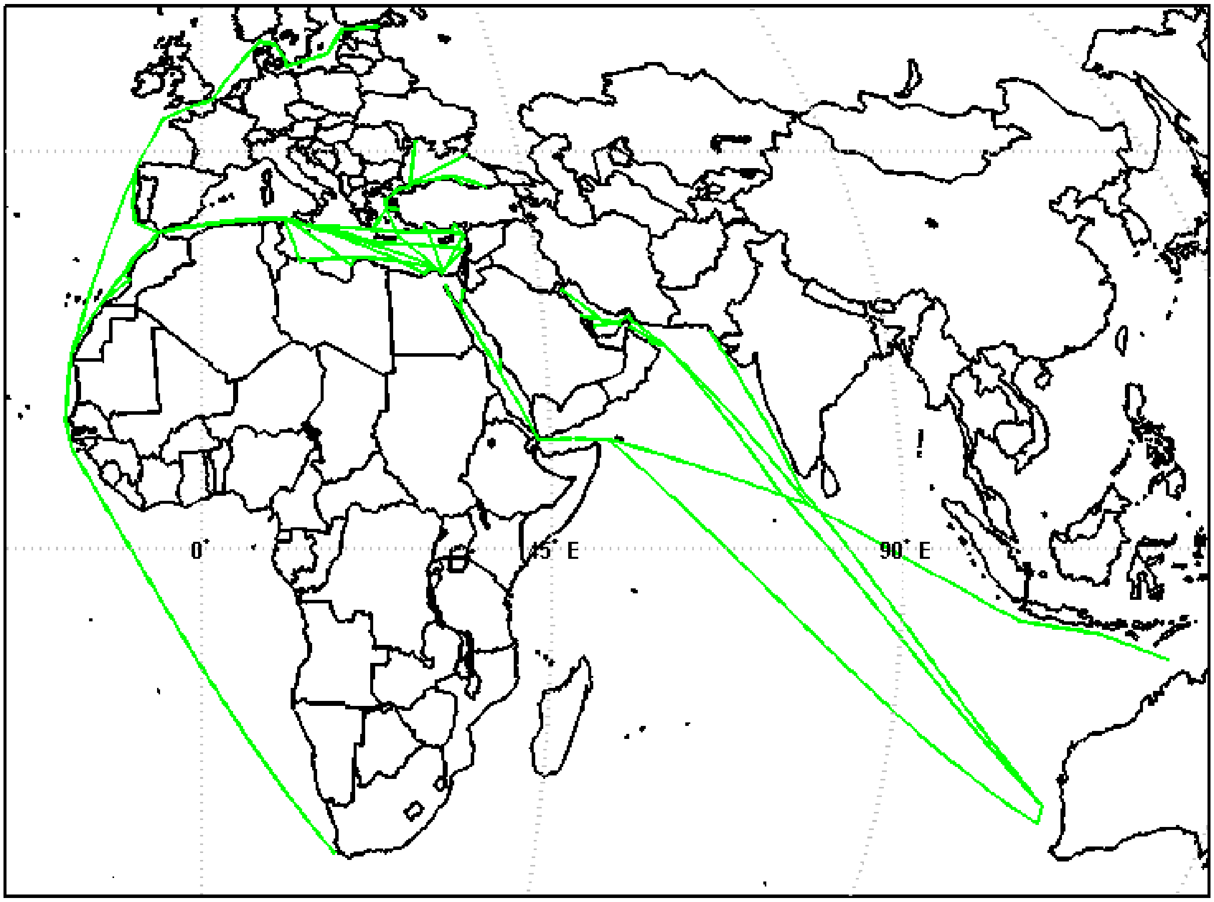

Figure 5. Routes used to form Journeys.

Whereas for Version 3, the data within a certain distance of the nominal route were collapsed onto the route, for Version 4, the data are associated with discrete Waypoints along the journey if they lie within a 150 nautical mile radius of the Waypoint. To give the moving average along the voyage, the weather records relevant to a particular Waypoint are taken as those around that Waypoint, or around the two Waypoints before and the two Waypoints after the Waypoint in question. The data associated with this string of five Waypoints, in any one calendar month, are used to give the weather statistics for the central Waypoint for the particular month. The wet bulb distribution is calculated at every waypoint on all the journeys, for each of the 12 calendar months. The data aggregation radius around each Waypoint was set to 150 nautical miles in order to aggregate sufficient data to give meaningful statistics. That is; data points up to 150 nm either side of the nominal route are included in the analysis.

Including the zone radii around the Waypoints on both ends of the group of 5, the 'window' measured along the route for Version 4 is 500 nautical miles long, twice as long as the 250 nm window that was nominated in the study objectives and used earlier for Version 3. At its maximum width, the window is only 200 nautical miles long, just under the 250 nautical miles envisaged at the start of the work. While the generally longer window will tend to 'average out' local peaks and give lower estimates of the peak 98 percentile, by including more data in each calculated distribution, the result is more robust statistically. As will be seen below, some distributions in some months have very few observation records, and so the longer window with more records is probably a better overall approach.

In this way, looking at the data around 5 Waypoints at a time, the Version 4 analysis is a discretised adaptation of the moving window used for Version 3. With the circles overlapping, the query included provision to make sure that each record was included only once. Figure 6 below shows diagrammatically the 'catchment area' for VOS records assigned to a Waypoint in the statistical reduction of weather data.

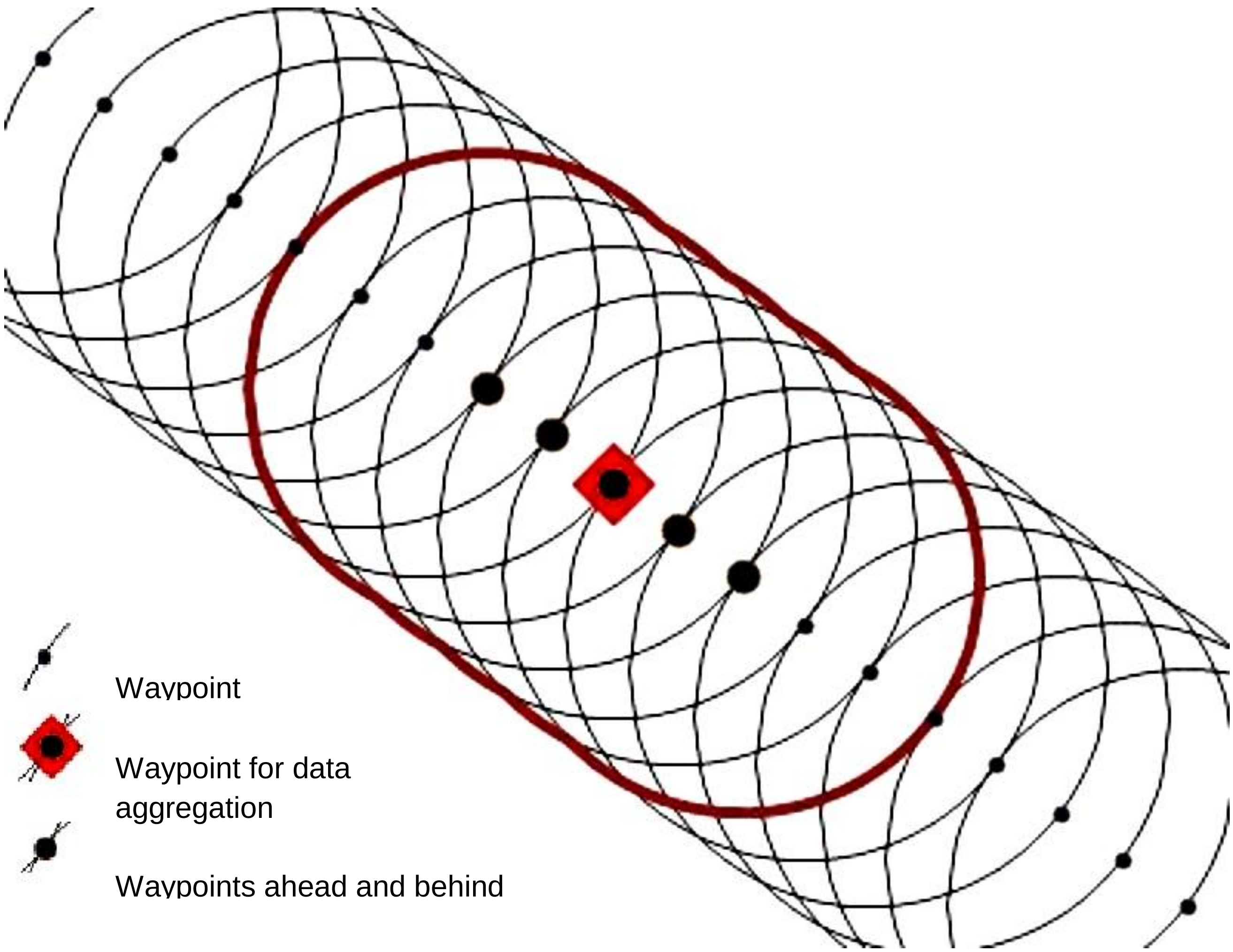

Figure 6. Aggregation of VOS data in a zone around a Waypoint and using two Waypoints ahead and two behind. The data zone is outlined in brown.

The scale of the database created to analyse the VOS data can be seen from the following numbers. HotStuff 4.0 now has:

- 74 distinct Journeys, made up from various combinations of
- 70 Routes, which are themselves combinations from the
- 106 Segments, which are divided into
- 1026 waypoints, the areas around which select data from the
- 405,877 unique valid records, which in turn were sorted from the
- 989,100 records in the data supplied.

Each Waypoint has percentile values from 1 to 99 for each of the 12 months, giving

- 1,218,888 wet bulb percentile values.

The dramatic expansion of the number of routes in HotStuff 4.0 increased the analysis task, however the database approach has allowed it to be done efficiently.

3.3.5 Review of the wet bulb distributions

With the database processing giving the wet bulb statistics as a function of Journey distance, there was still a need for a manual sensibility check on the outcome. For this purpose, wet bulb distributions for each Journey were plotted using 3D plotting software and rotated, stretched and zoomed, paying close attention to the highest 98 percentile figures which are the controlling parameter in the HotStuff risk assessments.

Visualisation of the T_{WB} distributions as shown in the example in Figure 7 assisted in verifying the shape and quality of the temperature distributions as a function of journey distance.

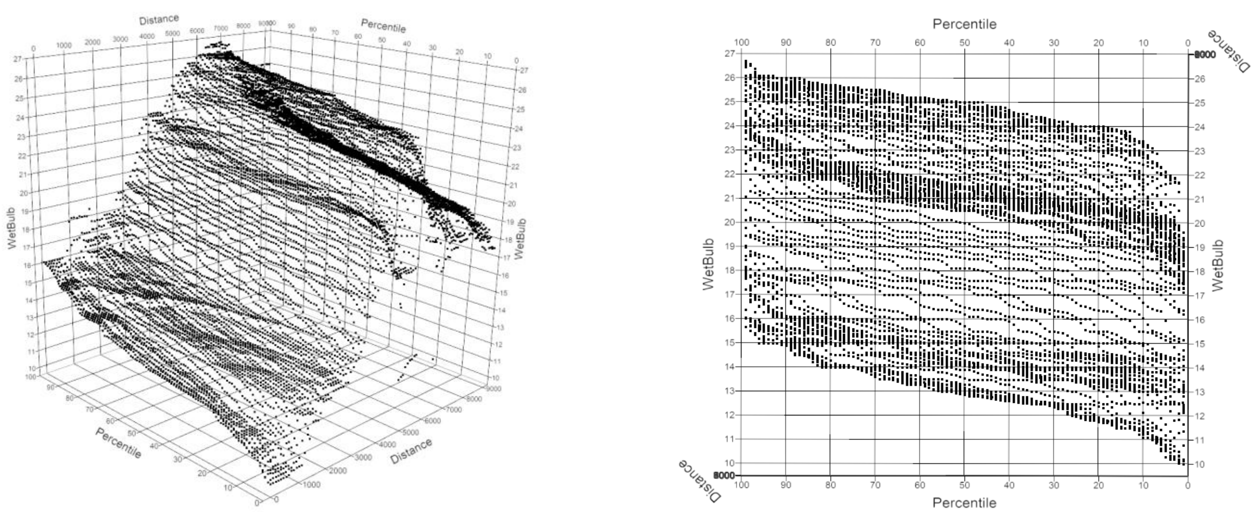

Figure 7. A typical distribution of T_{WB} (August) for the journey to Casablanca via West Africa. The right hand figure is looking along the distance axis so that the hottest distribution can be seen clearly.

Despite the averaging and inclusion of a 150 nautical mile net over temperature data samples in the vicinity of the journey way points, in some areas, there were not enough sample points to create a smooth distribution of T_{WB}. An example of this problem was found for voyages destined for Kuwait. Figure 8 shows the T_{WB} temperature distribution for the voyage to Kuwait from the South of Australia.

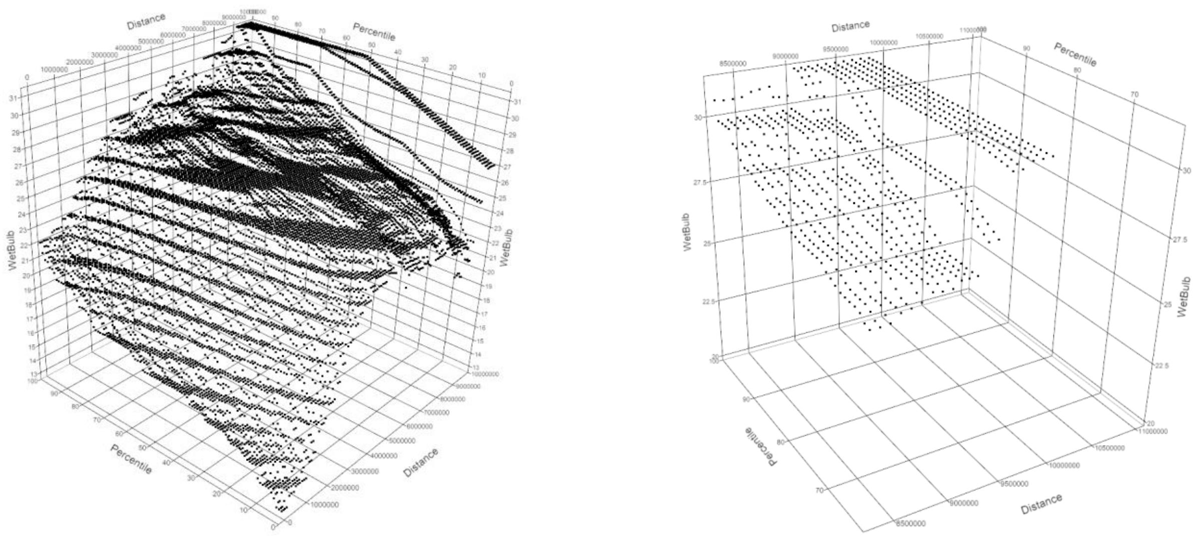

Figure 8. The plots show the effect of an inadequate number of sample data for the last few Waypoints in May for the voyage to Kuwait from the South of Australia. The left plot shows the whole Journey, while the right plot has had the distance scale adjusted to only show the distributions for the last few Waypoints.

The last 5 or 6 voyage waypoints have few temperature sample points, producing extended straight lines in the probability distribution. These distributions control the T_{WB} 98 percentile values that would be used to estimate voyage risk. With so few data points, the last few waypoints do not produce statistically valid probability distributions and with just a single very high wet bulb value, they give unreliably high estimates of the 98 percentile value. It was necessary to block out these waypoints from the analysis to avoid incorrectly increasing the T_{WB} 98 percentile distribution.

Table 2 below shows the Waypoints blocked out of the analysis for any affected Journeys where insufficient temperature samples were recorded.

Table 2. Waypoints deleted from Journey statistics following review of data quality

Voyage	Month	Number of Waypoints ignored
South to Kuwait	February	Last 6
South to Kuwait	May	Last 7
South to Kuwait	June	Last 9
South to Kuwait	July	Last 8
South to Kuwait	August	Last 8
South to Kuwait	September	Last 13
South to Kuwait	October	Last 7
South to Kuwait	November	Last 6
South to Kuwait	December	Last 7
North to Dharan	May, June, July, Aug, Sept, Nov, Dec	Last 4
North to Dharan	October	Points 5 to 17
Beirut	August	Last 2

3.3.6 Systematic correction of VOS data

After all detectable errors in the VOS data were addressed, there was still uncertainty as to the accuracy of wet bulb observations made by crew whose organisations have signed up as volunteer observers at sea. There are a number of sources of error which could shift the statistical results. In measuring wet bulb temperature, a measuring station in the sun, a wet bulb without adequate ventilation, a dry sock, or a salty sock, are all possible reasons why the wet bulb temperature might be recorded as being higher than the true value. As any of these could shift the indicated wet bulb by small amounts still within the possible range, it is not possible to eliminate such errors by inspection or by any obvious form of automated data processing.

Such errors have been addressed in HotStuff 4 by comparison of statistics from reliable land based data with statistics from adjacent VOS observations. The problem with such comparisons is that the continental weather patterns can obviously cause conditions on the land to be different to those over the adjacent sea. This problem was addressed by the selection of the three weather stations in

Table 3, which are all on tiny islands within or adjacent to popular shipping routes.

Table 3. Weather stations used to assess systematic error in the VOS wet bulb data.

Weather Station Location	Coordinates	Elevation	Location
Amihi	11.117N 72.733E	3 m	500 nautical miles NW of Colombo, Sri Lanka
Minicoy	8.300N 73.150E	2 m	410 nautical miles WNW of Colombo, Sri Lanka
Abu Musa	25.88N 55.02E	6 m	Arabian Gulf, 39.4 nautical miles NNW of Dubai.

Daily wet bulb temperature observations were provided for each of the weather stations. Some of the records go back to 1962, but also have large gaps. There are at least several years of data for each station. The data were aggregated by calendar month for each location and the 98th percentiles for these monthly data sets were calculated and compared to the corresponding monthly 98th percentiles of any valid VOS data readings within a 200 nautical mile radius of the weather station. The hottest months, May to October, were compared in detail.
Table 4 below shows the 98th percentile wet bulb temperatures (T_{WB}(98)) by month, for both the weather stations and the local VOS data.

Table 4. Weather station 98th percentile wet bulb data compared to local VOS data. The average difference for May to October inclusive is 0.8°C, with the VOS data being generally hotter.

	AbuMusa		Amihi		Minicoy		Average difference
Month	Station	VOS	Station	VOS	Station	VOS	
1	20.1	21.5	26.4	26.7	26.0	27.0	0.9
2	20.9	25.0	26.6	27.2	26.0	27.0	1.9
3	23.6	27.0	27.5	28.3	26.7	28.0	1.8
4	25.8	27.0	28.5	29.0	27.6	28.9	1.0
5	29.5	30.0	28.8	29.2	28.0	28.8	0.6
6	30.8	30.9	28.2	28.3	27.4	28.3	0.4
7	31.1	32.0	27.4	27.7	27.0	27.6	0.6
8	31.3	32.1	27.3	27.0	26.8	27.2	0.3
9	30.7	32.8	27.0	28.0	26.4	28.0	1.6
10	29.0	30.0	26.9	28.4	26.6	28.1	1.3
11	26.4	26.7	26.9	27.8	26.3	28.0	1.0
12	23.1	22.5	26.0	27.0	26.2	26.9	0.4

Average differences are shown per month, also with the average of just the hottest months (May – Oct) which control the T_{WB}(98). This difference showing the VOS data to be on average 0.8°C higher than the weather station data during the hottest months was used to offset the final $T_{WB}(98)$ dataset published to the HS4 software. A correction of 0.8°Cwas subtracted from all $T_{WB}(98)$ distribution values. The data by month were also plotted as the weather station 98th percentiles VS the VOS data 98th percentiles, as in Figure 9 below. With the advice from meteorologist Bruce Buckley that Minicoy was probably the most reliable weather station, the chosen offset of 0.8°C looks quite reasonable.

Previous efforts to compare VOS data with land-based data were made using Arabian Gulf land stations. With fewer VOS data nearby, a larger collection radius was required. The land stations were also continental rather than being on islands. The earlier offset arrived at was 1.0°C. Given the uncertainties with previous approaches, the new figure of 0.8°C can be seen as consistent with the earlier work.

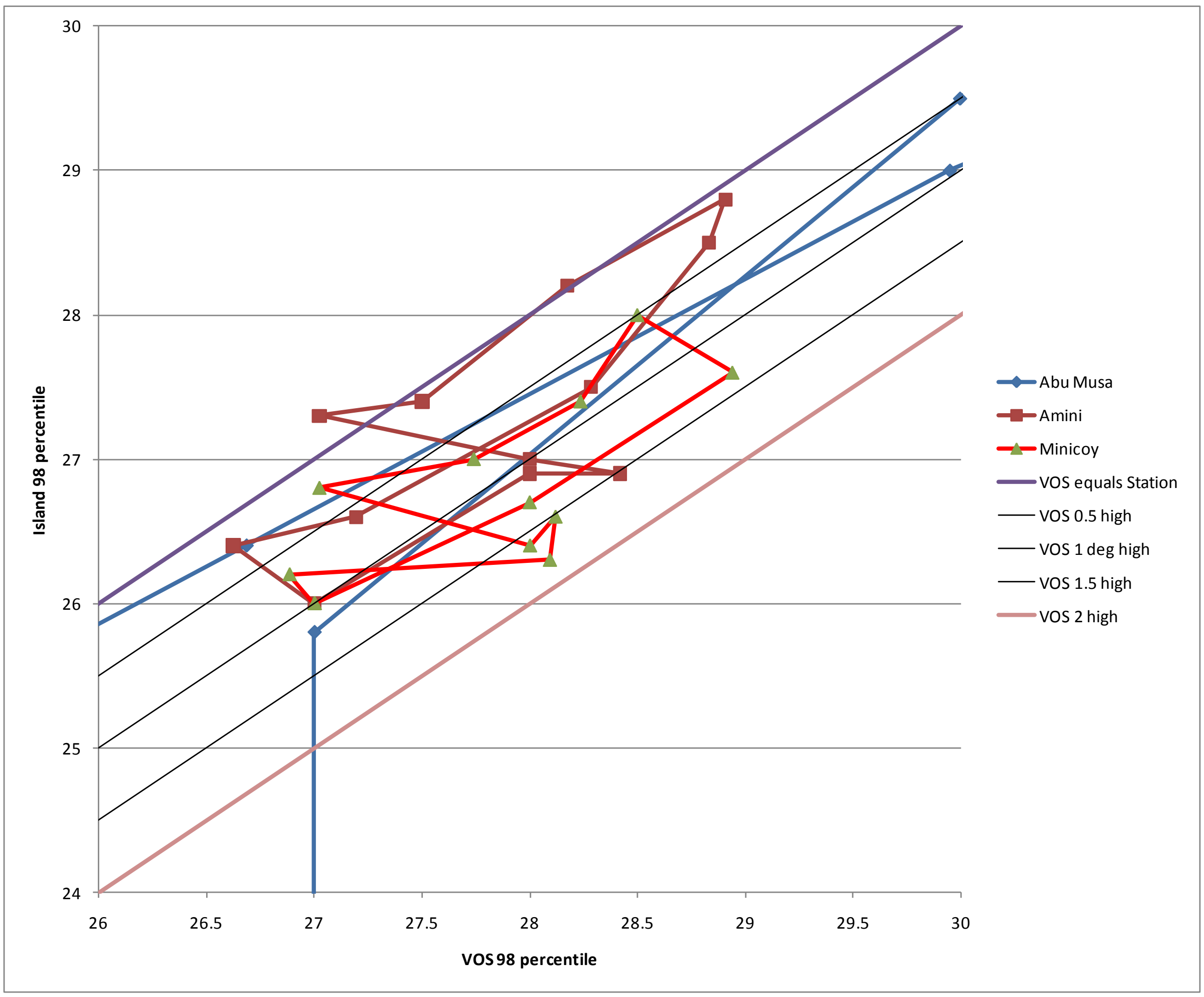

Figure 9. Correlation between VOS and weather station statistics.

3.3.7 Differences from previous versions

While the project to develop Version 3 of HotStuff included a revised weather analysis, Version 3 was not adopted. Consequently the interest here is in the differences between Version 4.0 and Version 2.3. The relevant parameter is the 98th percentile wet bulb temperature for each voyage. Table 5 below shows the data for voyages from southern Australia to Kuwait and Aqaba. Those destinations were chosen for initial examination as such voyages pass through all areas of the Gulf and the Red Sea respectively. The data are as they are in the HotStuff database. That is; they are corrected for the systematic VOS data deviations as noted above. Note that the voyage data shown will be different from the port data for the corresponding discharge ports, which are given in the following section.

Table 5. Comparison of voyage 98th percentile wet bulb temperatures for the extremities of the Arabian Gulf (Kuwait) and the Red Sea (Aqaba).

		Kuwait	
	Ver. 2.3	Ver. 4.0	CHANGE
January	27.8752	26.2	-1.6752
February	27.9726	26.44	-1.5326
March	28.1699	27.201	-0.9689
April	28.5699	28.3638	-0.2061
May	30.3914	30.6023	0.2109
June	31.8914	30.9	-0.9914
July	32.1806	31.64	-0.5406
August	32.8967	31.9211	-0.9756
September	31.6914	32.33	0.6386
October	29.6021	29.2275	-0.3746
November	28.0779	27.26	-0.8179
December	27.5672	26.36	-1.2072

		Aqaba	
	Ver. 2.3	Ver. 4.0	CHANGE
January	27.6699	27.9295	0.2596
February	27.8699	29.05	1.1801
March	28.3752	28.58	0.2048
April	28.5699	28.7496	0.1797
May	30.0752	30.1122	0.037
June	30.7699	31.344	0.5741
July	31.5833	30.788	-0.7953
August	31.4833	32.1277	0.6444
September	30.9752	30.924	-0.0512
October	29.8806	29.814	-0.0666
November	27.7726	29.36	1.5874
December	27.5672	27.2	-0.3672

Version 4 also rectifies a calculation error in the reingestion of open deck exhaust into decks above. The error was relatively minor as it related to a second order effect on PAT. The relevant calculation has not affected any voyage assessments as the port risk elements were not applied prior to Version 4.

3.4 Discharge port weather

Full descriptions of the wet bulb climatology datasets used are given in "Appendix 1. Port Wet Bulb Climatologies". The wet bulb summaries below are for all destination ports included in HotStuff 4, not just those added in Version 4.

Table 6. Summary of wet bulb climatology of destination ports.

TURKEY

Izmir (Guzelyali)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	7.2	7.4	8.6	11.4	14.6	18.3	19.6	19.9	17.3	14.3	11.7	8.8
90th	10.8	11.1	12.1	14.1	17.7	20.2	21.3	21.9	19.7	17.0	15.1	12.3
98th	12.6	12.3	13.8	15.9	18.9	22.3	22.3	24.0	20.8	18.6	16.1	13.6
Maximum	13.6	14.1	15.1	17.2	20.2	23.7	23.6	25.0	22.4	19.1	17.5	14.9

Antalya

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	7.4	8.1	9.9	12.7	16.3	19.3	21.4	22.0	19.2	15.9	11.9	8.9
90th	10.9	11.4	12.7	15.0	18.6	21.5	23.8	24.2	21.6	18.4	15.0	12.4
98th	12.9	12.7	13.9	16.2	20.1	22.6	24.9	25.2	22.8	19.8	16.5	14.2
Maximum	15.7	14.1	15.7	17.3	22.0	24.0	26.3	26.4	24.5	21.8	19.5	16.1

Istanbul (Ataturk)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	4.2	4.4	5.6	9.3	13.6	17.4	19.4	19.7	16.9	13.7	10.2	6.6
90th	8.6	8.7	9.8	12.7	16.6	20.0	21.8	22.0	19.8	17.0	13.7	10.5
98th	10.1	10.0	11.5	14.3	17.9	21.2	23.5	23.8	21.0	18.6	15.4	12.1
Maximum	12.0	11.4	14.2	16.0	20.3	22.4	25.4	26.0	22.3	20.3	17.1	15.1

Mersin

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	9.1	9.5	12.9	15.5	18.7	22.9	25.5	26.5	22.9	18.1	14.7	10.8
90th	11.5	12.4	15.3	18.4	21.6	25.7	27.1	28.0	25.9	21.1	16.9	12.7
98th	12.3	13.6	16.5	20.8	22.2	26.6	27.7	28.9	26.6	22.5	17.7	13.8
Maximum	13.9	13.6	18.0	21.1	23.5	27.2	27.8	29.5	27.2	23.2	19.3	13.9

Tekirdag

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	3.8	4.4	6.1	10.1	14.2	18.0	19.9	20.1	17.4	14.0	10.2	6.1
90th	8.8	9.1	10.4	13.2	17.6	20.5	22.2	22.3	19.9	17.4	13.8	11.1
98th	10.8	11.0	12.0	14.5	19.2	22.1	23.4	24.4	21.1	19.2	15.7	13.1
Maximum	16.3	13.9	15.1	16.4	21.6	26.7	25.3	25.6	25.5	20.4	17.5	18.1

Samsun

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	4.5	4.9	6.0	9.2	13.4	17.3	19.5	19.8	17.1	14.1	10.3	6.7
90th	8.8	9.5	9.5	12.3	16.2	19.5	21.8	21.9	20.0	17.1	13.6	10.7
98th	10.6	11.6	11.6	14.5	17.7	21.4	23.0	24.1	21.6	18.6	15.3	12.1
Maximum	13.2	13.5	13.8	17.0	20.0	23.5	26.1	26.3	24.8	20.4	17.8	14.6

Trabzon

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	5.0	4.9	6.3	9.4	13.6	17.6	20.0	20.4	17.9	14.4	10.4	7.0
90th	8.8	9.3	10.0	12.7	16.4	19.9	22.3	22.7	20.3	17.5	13.6	10.8
98th	10.7	11.5	12.3	14.6	18.1	21.1	23.8	24.1	21.9	18.8	15.3	12.3
Maximum	14.7	14.2	17.4	20.4	19.3	23.1	25.4	26.3	24.0	21.1	17.8	15.0

RUSSIA

Ust Luga (Narva, ESTONIA)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	-4.5	-5.2	-2.1	2.4	7.1	11.9	15.3	14.2	10.2	5.3	0.2	-2.8
90th	0.9	0.9	2.0	7.0	11.7	15.8	18.7	17.3	13.7	9.5	5.5	2.4
98th	2.7	2.6	3.7	10.5	15.6	18.5	20.8	19.3	15.0	12.0	7.0	5.2
Maximum	5.1	4.7	6.5	12.6	19.4	20.7	22.3	22.3	17.1	13.3	8.9	8.7

Novorossiysk

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	1.8	1.9	5.5	9.2	12.9	17.0	19.0	18.6	15.8	12.0	5.6	3.4
90th	6.8	6.6	8.0	11.9	16.4	20.0	22.1	21.3	19.2	16.1	12.1	8.2
98th	7.9	7.9	9.6	13.6	17.9	21.2	23.5	22.9	20.7	17.9	13.9	10.0
Maximum	9.0	8.3	10.5	14.5	18.8	22.0	25.3	23.6	23.2	19.1	15.4	12.3

UKRAINE

Odessa

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	-1.6	-1.1	1.9	7.2	12.3	16.0	17.5	17.1	13.6	9.0	4.3	0.2
90th	3.4	3.7	6.2	10.4	15.9	18.9	20.3	19.9	17.2	14.3	10.3	5.9
98th	5.8	6.1	7.9	12.4	17.6	20.1	21.9	21.6	19.0	16.6	12.7	8.7
Maximum	8.7	7.8	11.0	15.0	20.3	22.0	23.3	25.1	20.5	20.3	14.5	11.0

SYRIA

Al Lathqiyah (Latakia)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	8.7	9.7	11.6	14.2	17.3	20.5	23.1	23.5	21.4	18.1	13.6	10.3
90th	11.2	12.2	14.1	16.2	19.4	22.5	24.4	24.9	23.3	20.6	16.5	13.5
98th	13.4	13.7	15.2	17.5	20.8	23.2	25.1	25.5	24.3	22.1	18.0	14.9
Maximum	16.2	15.5	17.1	19.3	22.9	24.4	26.1	27.2	25.8	23.9	20.1	16.3

LIBYA

Tripoli (Tripoli International Airport)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	9.2	9.7	11.5	13.7	16.8	19.5	21.0	21.6	20.7	17.9	13.5	10.2
90th	11.5	12.3	14.4	16.9	19.7	22.0	23.1	23.8	22.9	20.6	16.7	12.8
98th	13.0	14.3	16.4	19.1	21.5	24.3	24.3	25.2	24.5	22.0	18.4	14.1
Maximum	15.0	20.0	20.4	24.3	25.5	27.3	27.1	27.4	28.4	24.3	20.8	17.0

Tripoli (Mitiga)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	8.6	10.7	12.3	15.5	17.4	19.6	21.6	22.5	21.2	18.7	14.8	11.1
90th	11.9	13.7	15.2	16.5	19.0	21.5	23.4	24.4	22.8	21.4	17.5	14.2
98th	13.4	15.4	16.9	16.6	19.7	22.2	24.4	24.9	24.3	22.1	18.3	16.5
Maximum	13.5	16.0	17.2	16.7	19.9	22.5	24.5	25.0	24.8	23.1	18.3	16.8

Benghazi (Benina Airport)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.2	10.2	11.3	13.4	16.2	19.0	21.1	21.6	20.0	17.6	14.4	11.5
90th	12.0	12.4	13.9	16.5	18.8	21.1	22.9	23.4	22.2	19.8	16.6	13.5
98th	13.0	13.7	15.9	18.6	21.0	22.7	24.1	24.3	23.3	21.0	18.0	14.8
Maximum	14.8	16.3	19.6	23.0	24.3	27.2	26.1	28.1	24.6	23.4	20.4	17.0

LEBANON

Beirut (Rafic Hariri International Airport)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.5	10.9	12.2	14.6	17.6	20.6	22.8	23.2	21.5	19.0	15.1	12.1
90th	12.8	13.0	14.8	16.9	19.8	22.6	24.5	25.0	23.3	21.3	17.5	14.2
98th	14.1	14.3	16.3	18.3	20.8	23.6	25.4	25.8	24.4	22.6	18.7	15.4
Maximum	16.7	16.7	17.5	20.3	21.9	24.6	26.6	27.6	25.1	23.9	21.4	16.8

EGYPT

Alexandria

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.9	11.0	12.4	14.7	17.4	20.5	22.3	22.9	21.2	19.0	15.7	12.2
90th	13.0	13.1	14.9	16.9	19.4	22.1	23.7	24.2	22.9	21.4	18.3	14.6
98th	14.0	14.4	16.4	18.3	20.3	23.2	24.4	25.2	23.8	22.6	20.2	16.1
Maximum	15.4	16.4	18.5	21.4	22.1	24.5	25.1	26.3	25.4	24.0	21.8	18.4

Port Suez (Note: Limited length of record. Use in conjunction with Ras Sedr)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.4	11.0	12.7	14.7	16.3	19.8	21.0	22.0	20.7	18.5	15.4	11.0
90th	12.6	13.5	15.0	17.3	19.1	21.0	22.2	22.9	22.1	20.2	17.8	13.7
98th	13.3	15.1	16.4	18.3	19.6	21.4	22.9	23.8	22.7	21.4	18.5	16.9
Maximum	14.0	15.5	16.6	18.7	19.7	21.7	23.1	24.6	23.3	21.6	18.6	17.1

Sukhna (Ras Sedr)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.6	11.1	13.0	15.3	17.8	20.3	22.1	22.7	21.3	19.3	15.0	12.0
90th	12.7	13.6	15.8	17.3	19.5	21.6	23.3	24.1	22.9	21.4	18.0	14.0
98th	14.4	15.8	17.7	18.6	20.2	22.8	24.2	24.8	23.5	22.5	19.5	15.4
Maximum	19.2	18.0	21.2	20.0	21.1	23.5	25.1	25.3	24.1	24.2	20.8	17.2

Adabiya (Ras Sedr)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.6	11.1	13.0	15.3	17.8	20.3	22.1	22.7	21.3	19.3	15.0	12.0
90th	12.7	13.6	15.8	17.3	19.5	21.6	23.3	24.1	22.9	21.4	18.0	14.0
98th	14.4	15.8	17.7	18.6	20.2	22.8	24.2	24.8	23.5	22.5	19.5	15.4
Maximum	19.2	18.0	21.2	20.0	21.1	23.5	25.1	25.3	24.1	24.2	20.8	17.2

PAKISTAN

Karachi

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	12.8	15.2	19.3	22.9	25.7	26.7	26.3	25.3	24.5	22.3	17.6	14.1
90th	16.8	19.4	22.1	24.9	26.7	27.5	27.3	26.5	25.8	24.9	21.3	17.6
98th	18.9	21.0	23.2	25.6	27.4	28.5	27.9	27.3	26.6	25.6	23.0	20.2
Maximum	21.4	22.3	24.6	26.6	28.7	30.4	28.9	28.3	27.4	27.6	25.0	21.9

MOROCCO

Casablanca

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	11.0	12.1	13.3	14.1	16.1	18.4	20.2	20.8	20.0	17.5	14.1	12.2
90th	13.7	14.4	15.4	16.3	18.2	20.3	22.1	22.4	21.7	19.7	17.0	15.0
98th	15.2	15.9	16.7	17.5	19.2	21.4	22.9	23.3	22.7	20.8	18.6	16.5
Maximum	17.0	17.5	17.9	20.8	20.6	23.4	24.5	24.8	24.2	21.9	20.6	18.6

Agadir (Inezgane)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.9	12.4	13.8	14.6	15.9	17.6	18.9	19.1	18.8	17.0	14.3	11.8
90th	13.9	14.7	15.5	16.2	17.8	18.8	20.6	20.8	20.3	18.8	17.0	15.1
98th	15.5	16.2	16.7	17.4	19.1	19.7	21.8	22.1	21.3	20.0	18.5	16.5
Maximum	18.0	17.5	18.6	19.6	21.5	22.6	24.1	26.3	22.8	21.1	20.2	17.3

JORDAN

Aqaba Port

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	11.5	12.5	14.5	16.5	19.0	20.3	22.0	22.8	21.6	19.6	17.2	13.1
90th	13.3	15.4	18.1	18.5	20.6	22.9	23.6	24.5	22.8	21.5	19.6	16.0
98th	15.1	17.4	19.8	19.7	22.6	24.4	24.8	25.8	23.6	23.7	20.1	17.1
Maximum	17.6	17.8	21.4	20.1	24.1	25.8	25.5	26.0	24.0	24.6	23.7	19.5

Aqaba Airport

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.3	11.2	13.3	16.0	18.9	20.8	22.1	22.4	21.3	19.1	15.0	11.5
90th	12.8	14.0	16.7	18.9	21.6	23.2	25.1	25.6	24.2	21.6	17.8	14.0
98th	14.2	15.8	19.5	20.6	22.9	24.6	26.8	27.3	25.8	23.6	19.5	16.0
Maximum	17.5	20.3	24.3	23.8	24.9	26.7	28.1	29.7	28.3	25.8	21.2	20.0

SAUDI ARABIA

Jeddah (King Abdul Aziz International Airport)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	17.8	17.8	19.6	21.6	23.1	24.2	24.5	25.7	26.1	24.4	22.3	19.9
90th	21.3	21.8	22.2	23.7	25.1	26.0	26.7	28.1	27.7	26.2	24.1	22.7
98th	22.7	23.1	23.3	25.1	26.1	26.8	27.7	29.5	28.5	27.0	25.0	23.8
Maximum	23.9	23.9	24.6	26.6	27.6	28.4	29.0	31.0	29.3	28.0	26.1	24.8

Dhahran

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	12.3	13.4	15.4	18.5	21.1	22.0	23.2	24.2	23.6	21.9	18.1	14.2
90th	16.0	16.7	18.5	21.0	23.4	24.2	27.4	28.8	26.8	24.7	21.5	18.1
98th	17.8	18.1	19.9	22.1	25.2	26.1	29.2	30.1	28.5	25.9	22.9	19.8
Maximum	20.0	20.3	21.5	25.3	29.6	31.6	32.0	32.5	31.5	27.8	26.8	22.2

KUWAIT

Kuwait International Airport

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	9.5	10.7	13.2	16.9	20.0	22.0	23.0	22.6	20.9	18.5	14.4	10.6
90th	13.4	14.3	16.4	19.3	21.8	23.5	24.5	24.5	23.1	22.2	19.0	15.1
98th	16.0	16.1	18.1	20.3	22.8	24.6	26.1	28.0	26.4	24.2	21.1	17.6
Maximum	19.0	18.3	19.8	21.6	24.7	26.6	29.0	30.4	28.7	26.5	24.0	20.7

Kuwait City

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	10.2	12.2	14.1	17.9	20.8	22.4	23.1	23.6	22.2	19.8	15.3	12.7
90th	14.4	15.1	17.3	20.0	22.3	24.1	24.2	27.0	25.8	23.9	18.0	15.6
98th	16.2	16.3	18.5	20.9	23.8	25.3	27.9	29.4	28.1	24.8	21.7	18.4
Maximum	17.0	17.2	19.0	21.3	25.5	27.6	29.0	30.1	30.2	26.7	24.2	18.7

BAHRAIN

Bahrain International Airport

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	14.1	14.7	16.5	19.8	22.9	24.9	26.6	27.9	26.4	24.3	20.4	16.3
90th	17.1	17.6	19.3	21.9	25.0	26.7	29.1	29.9	28.4	26.1	23.0	19.6
98th	18.9	18.8	20.6	23.0	26.2	27.7	30.0	30.7	29.5	27.1	24.3	21.4
Maximum	20.8	20.4	22.9	24.9	28.4	29.7	31.2	31.5	30.8	28.5	26.1	23.1

QATAR

Doha International Airport

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	14.0	14.7	16.3	19.3	21.9	23.3	25.3	27.7	26.1	23.7	19.9	16.3
90th	17.4	18.2	19.4	21.7	23.9	26.2	29.0	29.9	28.4	25.9	22.8	19.9
98th	19.6	19.5	20.7	22.7	25.6	27.8	30.2	30.7	29.5	27.1	24.2	21.6
Maximum	20.9	20.5	22.1	23.6	27.1	29.8	31.2	31.1	30.2	28.6	25.4	23.6

UNITED ARAB EMIRATES

Dubai and Jebel Ali (Dubai International Airport)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	14.8	15.8	17.4	19.6	22.3	25.1	26.7	26.5	25.7	23.1	19.7	16.8
90th	17.6	18.5	19.8	21.4	24.4	27.4	28.7	28.5	27.8	25.7	22.1	19.4
98th	18.7	19.8	20.9	22.4	25.4	28.3	29.5	29.3	28.7	26.9	23.7	20.4
Maximum	20.1	21.5	21.7	23.8	27.4	29.2	30.4	30.4	29.5	28.3	25.0	22.7

Fujairah International Airport

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	15.8	17.6	18.8	21.1	23.3	27.2	28.9	28.6	27.2	23.7	20.4	17.8
90th	19.2	20.5	22.1	23.7	27.0	29.4	30.6	30.1	28.9	26.4	23.0	20.6
98th	20.7	21.8	23.9	25.3	28.2	30.7	31.4	30.7	30.6	27.6	24.1	22.0
Maximum	21.8	23.8	24.8	27.3	29.7	32.1	32.4	31.5	31.8	28.6	26.3	23.9

OMAN

Muscat (Old Seeb International Airport)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	17.3	17.7	19.9	22.0	23.7	26.0	27.4	26.7	25.3	23.2	20.6	18.6
90th	19.4	20.5	21.9	24.1	26.7	28.5	29.4	28.1	26.8	24.9	23.3	20.1
98th	20.7	22.2	23.1	25.1	27.7	29.6	30.4	28.8	27.3	25.5	24.2	21.2
Maximum	21.0	22.7	23.8	27.0	28.7	29.9	31.1	29.6	28.1	26.5	24.6	21.6

Muscat (New Seeb International Airport)

Percentile	January	February	March	April	May	June	July	August	September	October	November	December
50th	16.7	17.4	18.9	20.9	23.0	26.0	27.4	26.9	25.7	22.4	20.1	18.3
90th	19.1	20.2	22.0	23.4	26.4	28.4	28.9	28.2	27.2	25.3	22.3	20.7
98th	20.6	21.3	23.1	25.1	28.1	29.2	29.6	29.0	28.2	26.4	23.5	21.9
Maximum	22.1	22.4	24.6	25.7	29.8	30.5	31.1	30.4	29.3	27.5	24.6	22.8

3.5 Software changes

3.5.1 New method capability

The HotStuff software and underlying database has been modified to allow all the ports nominated above to be selected as destinations, and to include the route option (West Africa or Suez Canal) for the relevant ports. Version 4 calculates the risks for both the sailing and discharge phases. For open decks, the software calculates the required effective crosswind while sailing. Alternatively, when planning a voyage, an adjustable limit on effective crosswind can be set and the 'load to risk' functionality will maximise the loading within the risk limit, for that nominated effective crosswind. The previous adopted limit on crosswind while sailing was 5 knots. There is no hard coded limit in the software. The reasonable estimate of effective crosswind while sailing relates to the mixing of air through the deck caused by the forward motion of the vessel. With little prior data on that, it was suggested that the crosswind limit be raised to 7 knots. Section 4 includes recent analysis of the issue. Air exchange generated by forward motion of the vessel is generally effective for the forward third or so of a deck, but is ineffective for the stern third of open two tier decks.

The crosswind is taken as zero while in port.

3.5.2 Interface changes

A number of changes and improvements have been made to the user interface in HotStuff 4:

- The printed cargo list now includes the title of the voyage and is generated in Excel
- Mortality risk column has been removed from the printed cargo list
- The risk column heading has been changed to reflect the intent of achieving less than 2% risk
- Some interface changes were made for robustness.
    - Some controls were disabled to minimise error,
    - OK/Cancel buttons were added in places,
    - Some consistency checks were added to vessel and voyage imports.
- Date controls behaviour have been fixed for consistency
- Some display grid update issues have been fixed.

3.5.3 Platform Update

The software has been updated using current software environments. The latest version is written in Microsoft Visual Basic 2010, Visual Studio 2010 Version 10.0.30319.1 RTMRel

Crystal Reports has been removed as it had too many internal problems. It has been replaced with Microsoft Excel. In exporting to Excel, HotStuff 4 now supports both Excel 97-2003 (*.xls) and Excel 2007 (*.xlsx, *.xlsm).

4 Open deck air exchange

4.1 Introduction on open deck issues

The background in Section 1 noted that in the development of the risk assessment methods, the risk on open decks subject to the vagaries of the wind has been harder to quantify (and codify) than were the risks in closed decks. On first considerations, the addition of a randomly varying crosswind, on top of statistically described weather which varies seasonally, makes the problem very difficult. This is exacerbated by the lack of good records on the frequency of very low wind speeds. Fortunately for the simplicity of the approach, high wet bulb temperatures at sea are related to the low wind speeds. High winds cause waves which vertically mix the ocean upper layers, preventing the build-up of a warm stratified surface layer. High winds also vertically mix the air above the sea, such that the sensible and latent heat (surface evaporation) added to the air from the water is mixed away rapidly.

We are interested in the 98th percentile wet bulb temperatures in the air 5 to 20 metres above the sea. The very top end of the observed wet bulb temperatures only occur when the above two mixing effects are absent, that is; there is no, or very little, wind. Because of the very close physical coupling between the occurrences of the highest wet bulb temperatures and extremely low wind speeds, it is not necessary to treat wet bulb temperature and wind speed as independent stochastic variables. It is fair to assume that when the wet bulb temperature reaches 98th percentile values, the wind speed is very low. That assumption is inherent in the current HotStuff approach to open decks. To the extent that it may be possible to experience 98th percentile wet bulbs with a good breeze present, the method would be erring on the side of caution.

Since we must reasonably assume still air at the hottest times, we cannot rely on a crosswind in making risk assessments. This is true even while sailing. If the air is still, the vessel can generate an effective headwind by sailing forward, but cannot generate significant crosswind. Even without crosswind, the effective headwind was accepted as assisting deck air exchange in two ways; by the direct inflow onto each deck at the front of the vessel, and by turbulent mixing generated by the flow past the sides of the vessel. While the current work suggests the latter to be of minimal effect, these two effects have been relied on in the past to control heat stress in open decks.

This section describes Computational Fluid Dynamics (CFD) simulations performed as an initial investigation of the natural ventilation on live sheep transport ships under different head wind and cross wind conditions. The aim of this work is to estimate the required equivalent crosswind, necessary to produce adequate PAT, and specifically to look at the equivalence between forward sailing and a crosswind. The wider the vessel and the lower the deck height, the harder it is for natural ventilation to effect the necessary air exchange. Consequently, the vessels of primary interest at this stage are those which have very wide open decks and in which each deck level is a double-tier deck that consists of two tiers of sheep pens, each approximately 1.2 m in height. Walkways typically span the width and length of each double-tier deck at various locations between the sheep pens and these are the full height of the double-tiered deck (around 2.4 m). The section below describes modelling on generic 24 and 36 m wide decks, being near the narrow and wide limits of the current fleet decks.**Error! Reference source not found.**

4.2 Cross-wind modelling

Various CFD packages are available to analyse air flows such as those on a vessel deck. Previous work (project LIVE.116) used Fluent 6.1 which allowed detailed modelling of the heat generation and respiratory functions of the animals, to give some realism to flows and mixing at a local level in otherwise fairly still air. This study is predominantly concerned with the overall deck ventilation characteristics and how conditions vary throughout an entire open deck with prevailing winds, so that local detail is unimportant. To efficiently analyse the larger geometry and gain useful insights in the available time frame, Fire Dynamics Simulator (FDS) was chosen as the primary software package for these analyses. FDS is a product of the National Institute of Standards and Technology, a government research agency in the US. Results from the initial HotStuff work (Live.116 project) have been used to simplify the representation of the generation of heat and water vapour evolution from each animal.

Although FDS was originally written to simulate fires and the behaviour of the resulting plumes of smoke and gases around large structures and open volumes, it can also be used to great advantage in this type of application. Much of the efficiency of FDS is a result of its rectilinear mesh which requires all features and obstructions to be approximated as rectangular prismatic shapes that conform to the underlying mesh size. For the detail of animals on a deck, a considerable amount of pre-planning is required to ensure that the geometry is both realistic and adaptable enough to provide useful results efficiently.

After comparison of the typical vessel parameters, and using the typical sheep geometry from previous work (LIVE.116), the following approximations were made.

- The sheep pen deck heights were taken as 1.2 m.
- The deck length is constant at 115.2 m.
- Two different deck widths of nominally 36 m and 24 m can be accommodated within the model meshing.
- Sheep pens, ventilation risers and structural beams are positioned throughout the floor and intermediate decks in a similar fashion to the previous work.

Only one double-tier deck is analysed and it is assumed that the floor and ceiling are adiabatic and that there is no re-ingestion of heated air from lower decks. The underlying mesh size is 0.2 m × 0.2 m × 0.2 m, making a total of 870,912 and 1,285,632 cells for the 24 m and 36 m wide deck models respectively. The sheep are approximated as rectangular prisms 0.2 m wide, 0.4 m high and 0.6 m long, suspended above the deck at a height of 0.4m. Structural beams are modelled as being 0.2 m × 0.2 m in cross-section and the ventilation risers are 1.2 m × 2.4 m × 2.0 m. The complete models are comprised of unit pens, which are 18 m × 6 m × 2.4 m as shown in Figure 10. These unit pens are then copied and mirrored as required to create the 24 m and 36 m decks. Walkways and ramps are then added to finish off the models.
Table 7 summarises the major dimensions of the models and Figures Figure 11 to Figure 19 show the model geometry in greater detail.

Three general cases were analysed for each size deck and the models were run as fully transient solutions until a steady state was achieved. These were:

1. 20 knot head wind only (20 knots is typical of the fastest vessels)
2. 7 knot cross wind only (7 knots is the industry's current default limit on 'effective crosswind'.)
3. 5 knot cross wind only (5 knots was the previous default limit on 'effective crosswind'.)

The objective was to examine the equivalence between ventilation by sailing through still air, and ventilation only by a crosswind.

While a transient solution was appropriate for investigating the large eddy interactions, it resulted in long solution times. By their nature, areas of deck with low air exchange have a longer time constant associated with the transient behaviour. That is; they change more slowly. By initialising the deck temperature to that of the worst areas, the poorly ventilated areas could be set closer to their final condition, reducing solution times. The well ventilated areas always approach their steady state conditions rapidly and so a high initial temperature was not a problem for those areas. The crosswind simulations rapidly approached a steady state. The headwind models for 36 m wide decks were run twice; with two values of the deck-wide initial temperature T_0. One of the initial temperatures was set to ambient conditions, with the other being set to the high end of the final deck temperature range. If the initial conditions were either side of the final temperature, then results from the two runs could be seen as bracketing the answer that would be obtained with unlimited time, with the true answer lying in the gap between the two outcomes. In fact the higher of the two initial conditions was still not as hot as the rear of the deck became in the headwind cases. The final answer is then likely to creep up further in temperature if the computation were unconstrained by time.

Model computing times were typically around 20 hours for the crosswind studies to reach steady state in under 180 s of real time, whereas the headwind studies took 50 to 60 hours of computing and required up to 400 s of real time before steady state had been approximated.

Table 7. Generic 24 m and 36 m models.

Vessel Name	Overall Vessel Length (m)	Max Speed (Knots, m/s)	Approximate Sheep Pen Deck Length (m)	Sheep Pen Deck Width (m)	Sheep Pen Height (m)	Number of Double-Deck Levels
Generic 24 m	—	20	115.2	25.2	1.2	1
Generic 36 m	—	20	115.2	37.2	1.2	1

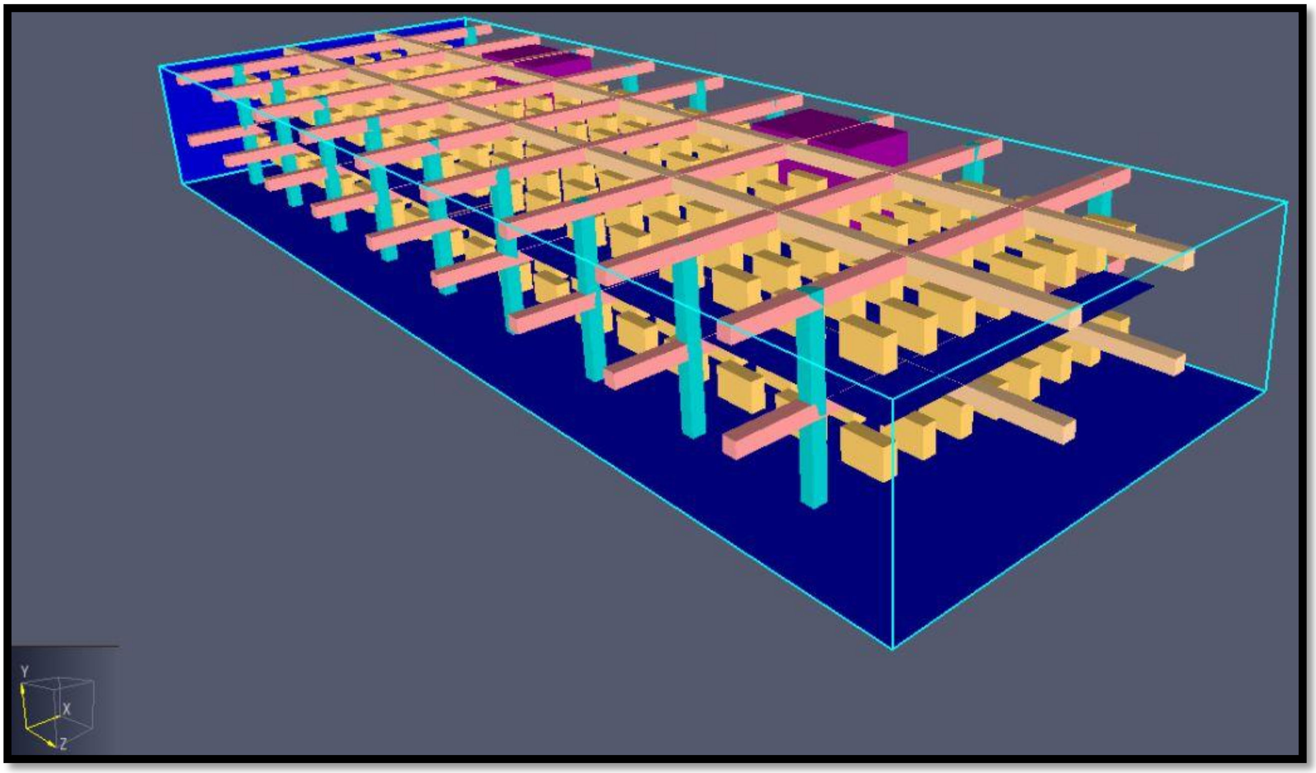

Figure 10. Unit pen (18 m x 6 m x 2.4 m) showing sheep (gold), ventilation risers (purple), vertical structural beams (light blue), cross beams (pink), lengthwise beams(light brown), lower and intermediate decks (dark blue).

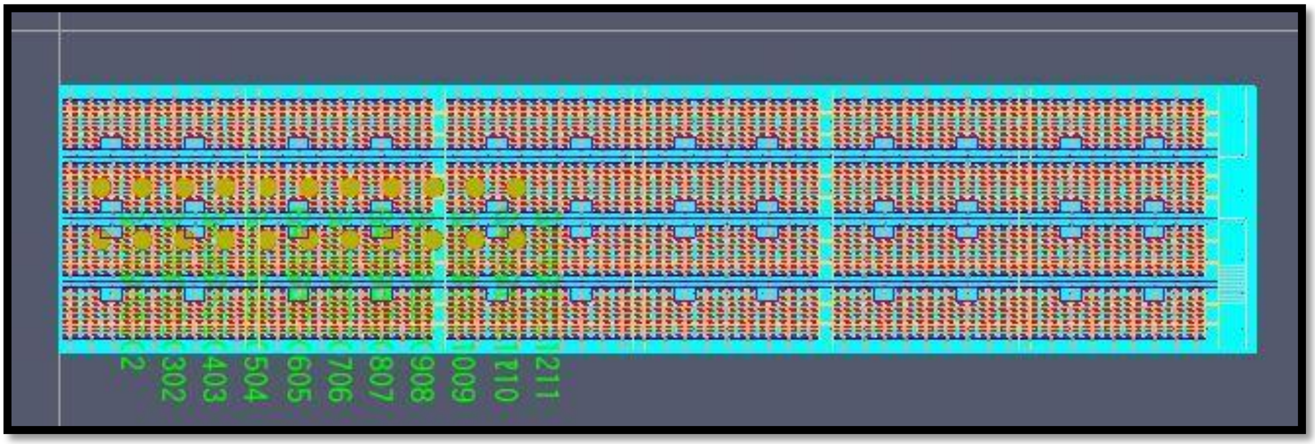

Figure 11. Plan view of complete model of 24 m deck consisting of 24 unit pens with virtual thermocouple locations shown as khaki coloured circular shapes in the central rear area of the deck (20 knot head wind case).

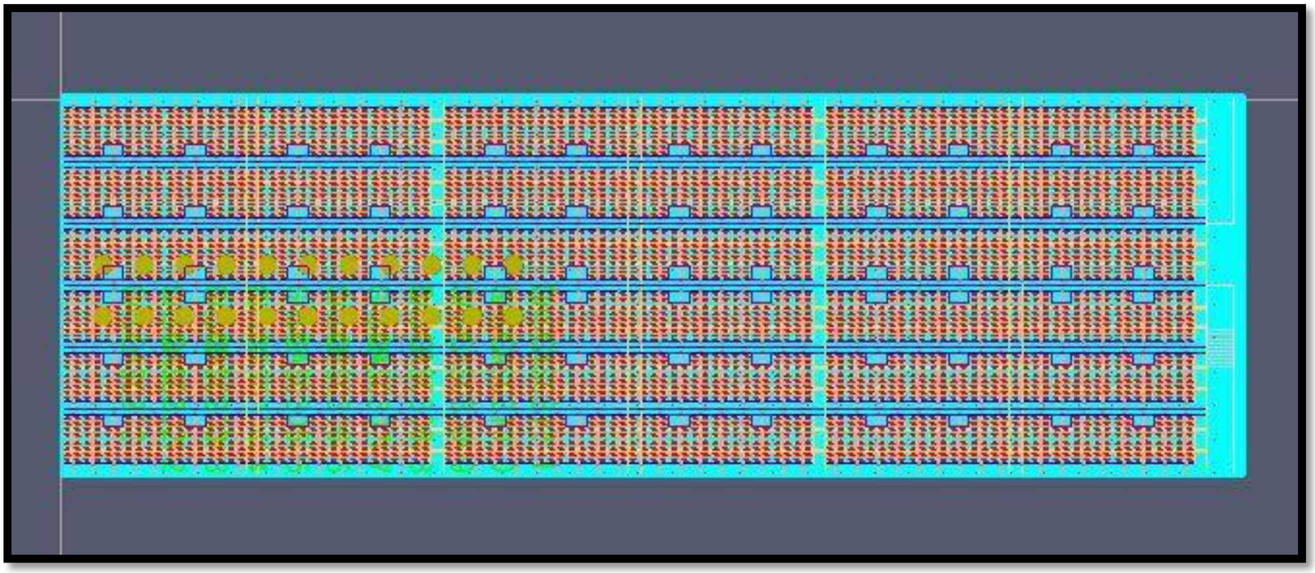

Figure 12. Plan view of complete model of 36 m deck consisting of 36 unit pens with virtual thermocouple locations shown as khaki coloured circular shapes in the central rear area of the deck (20 knot head wind case).

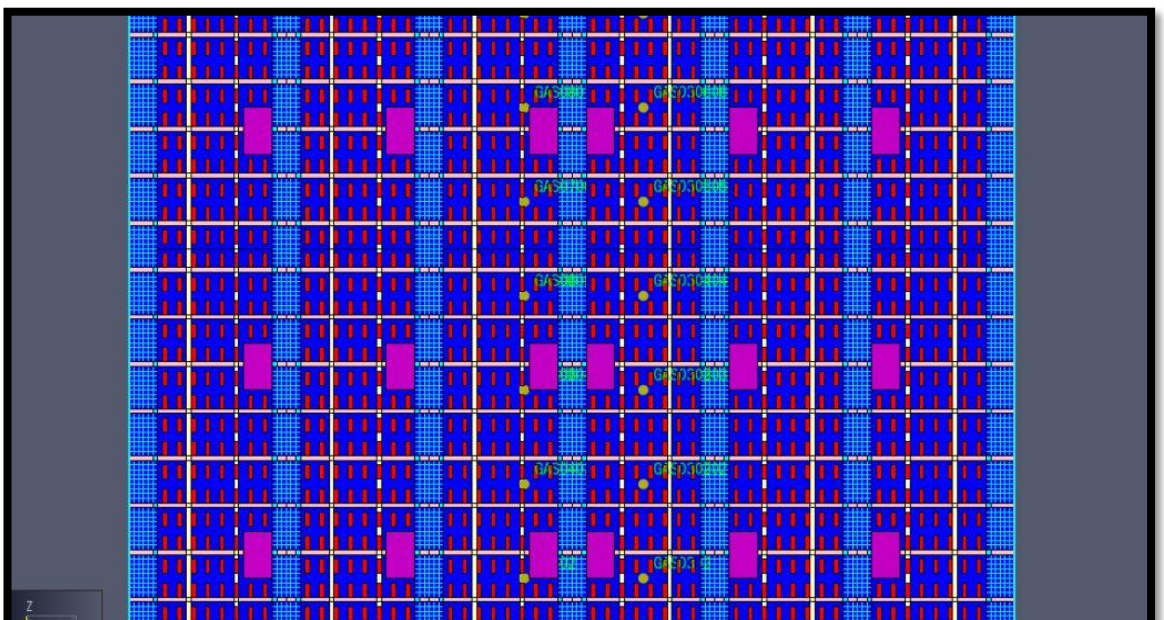

Figure 13. Close up plan view of 36 m deck rear section showing thermocouples and individual sheep. The underside of the sheep is shown in red to indicate heat generation (0.427 kW/m²) and water vapour evolution (0.3542 g/(m².s)) from this surface.

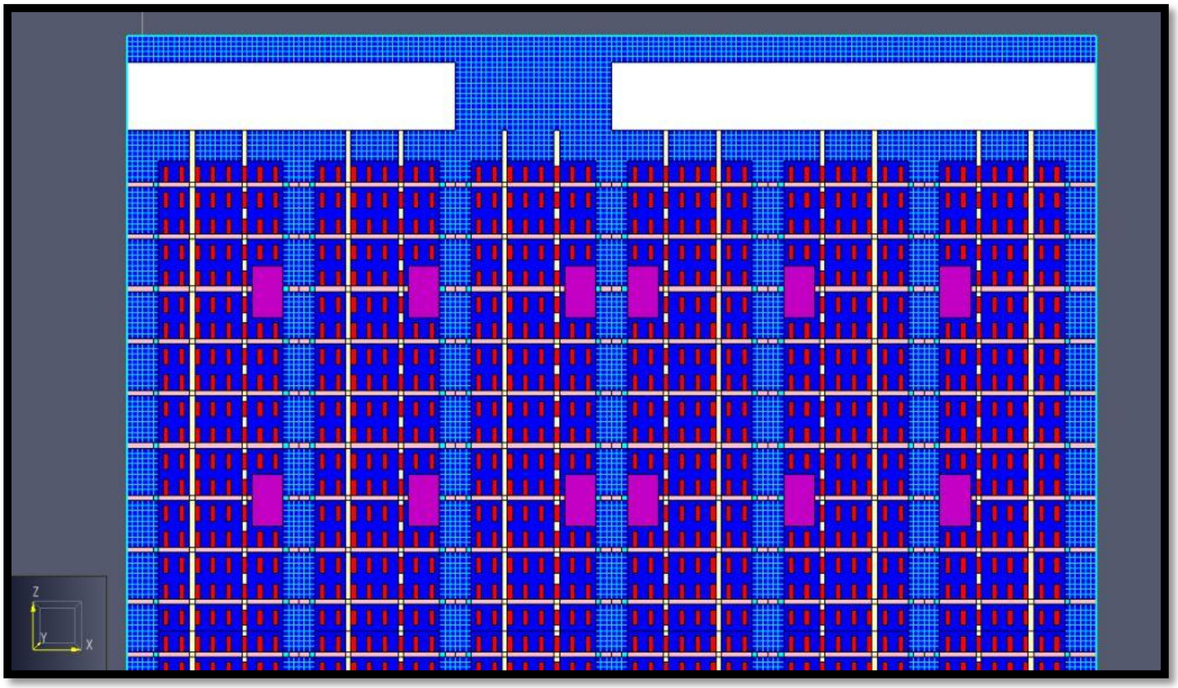

Figure 14. Close up plan view of 36 m deck front section showing ramps (white) and walkways.

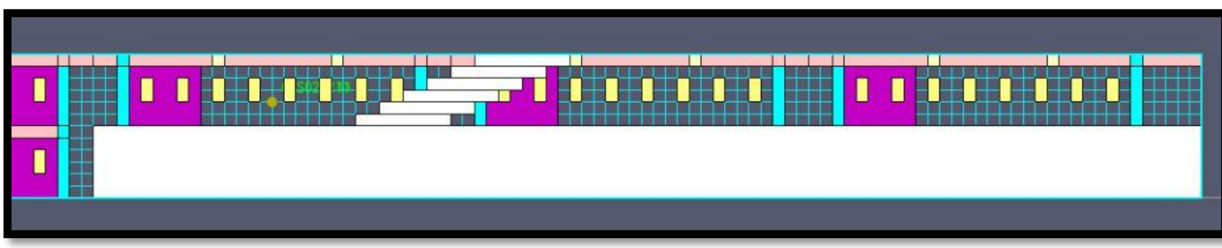

Figure 15. Close up front view of 36 m deck front section showing ramps (white) and walkways.

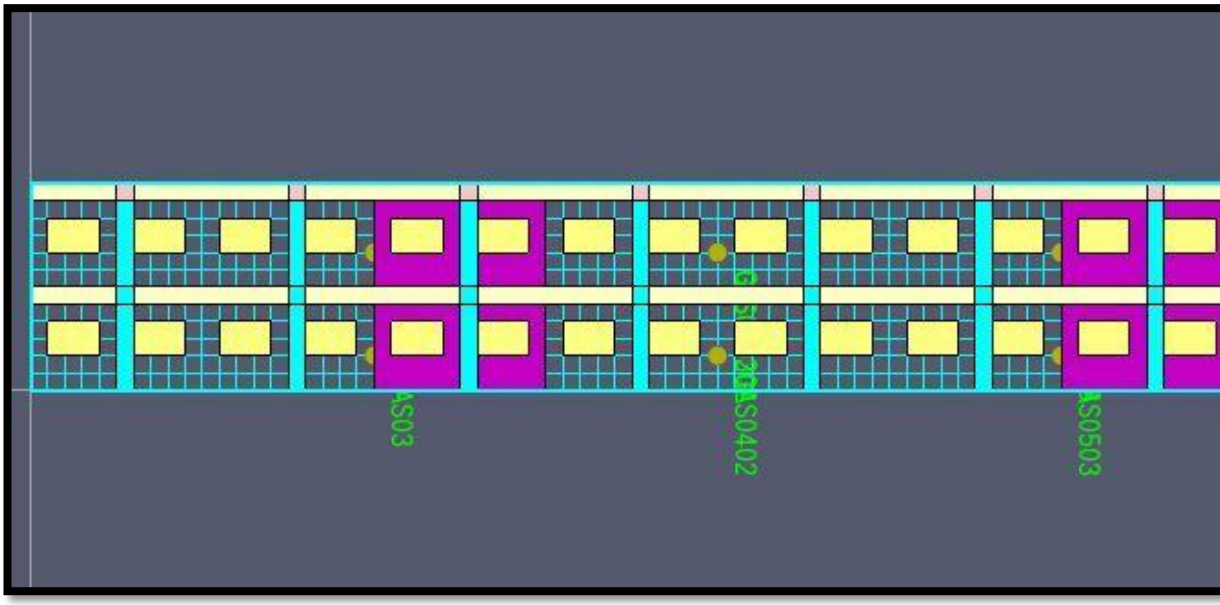

Figure 16. Side view of double deck showing sheep, ventilation risers, structural beams and thermocouple locations.

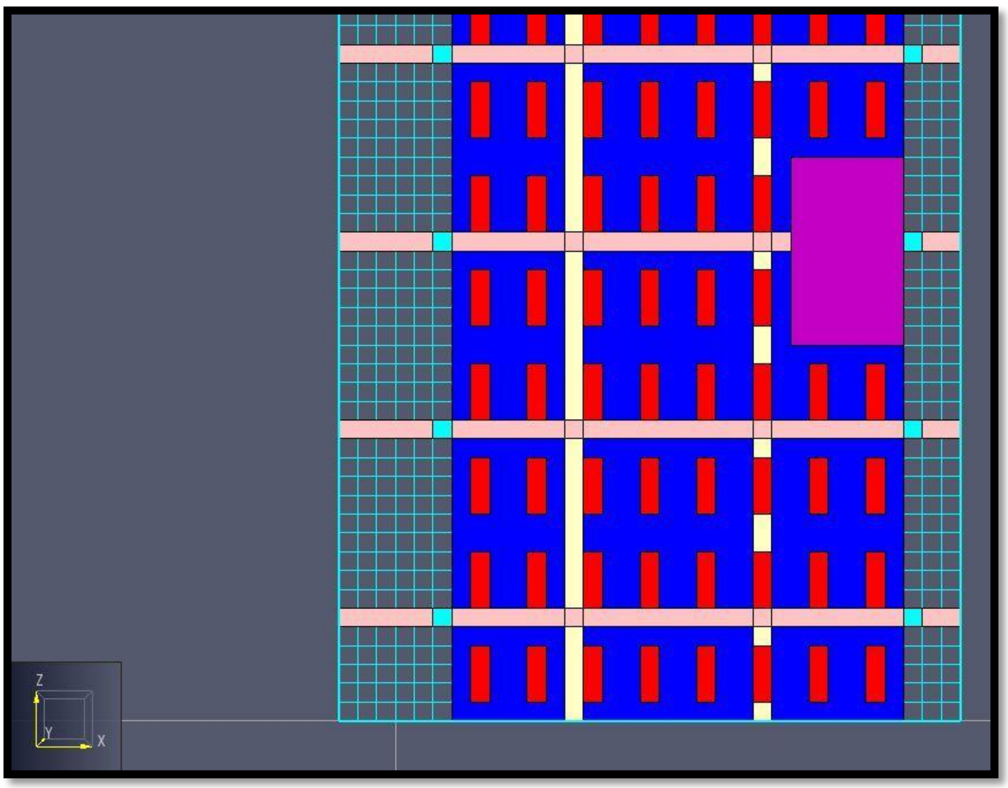

Figure 17. Plan view of unit pen showing 0.2m x 0.2m underlying grid size.

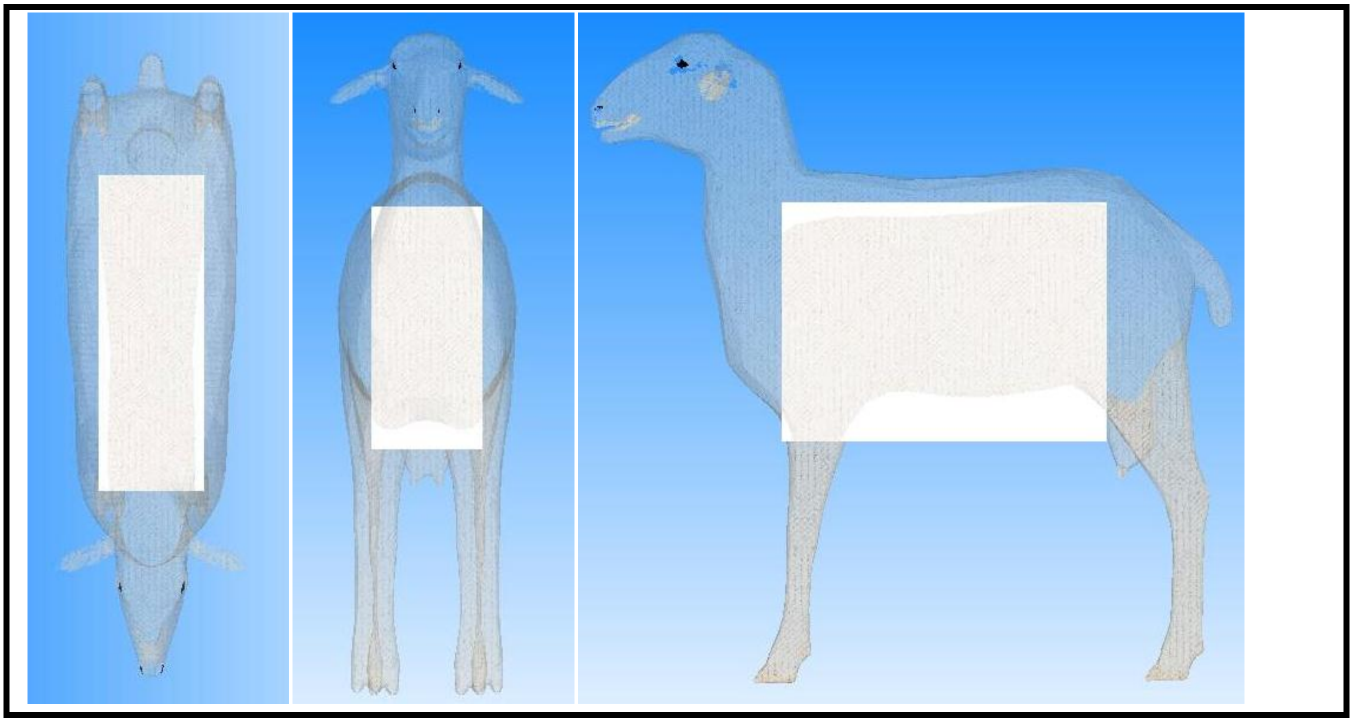

Figure 18. Indicative size and location of 0.2 m × 0.4 m × 0.6 m sheep model approximation.

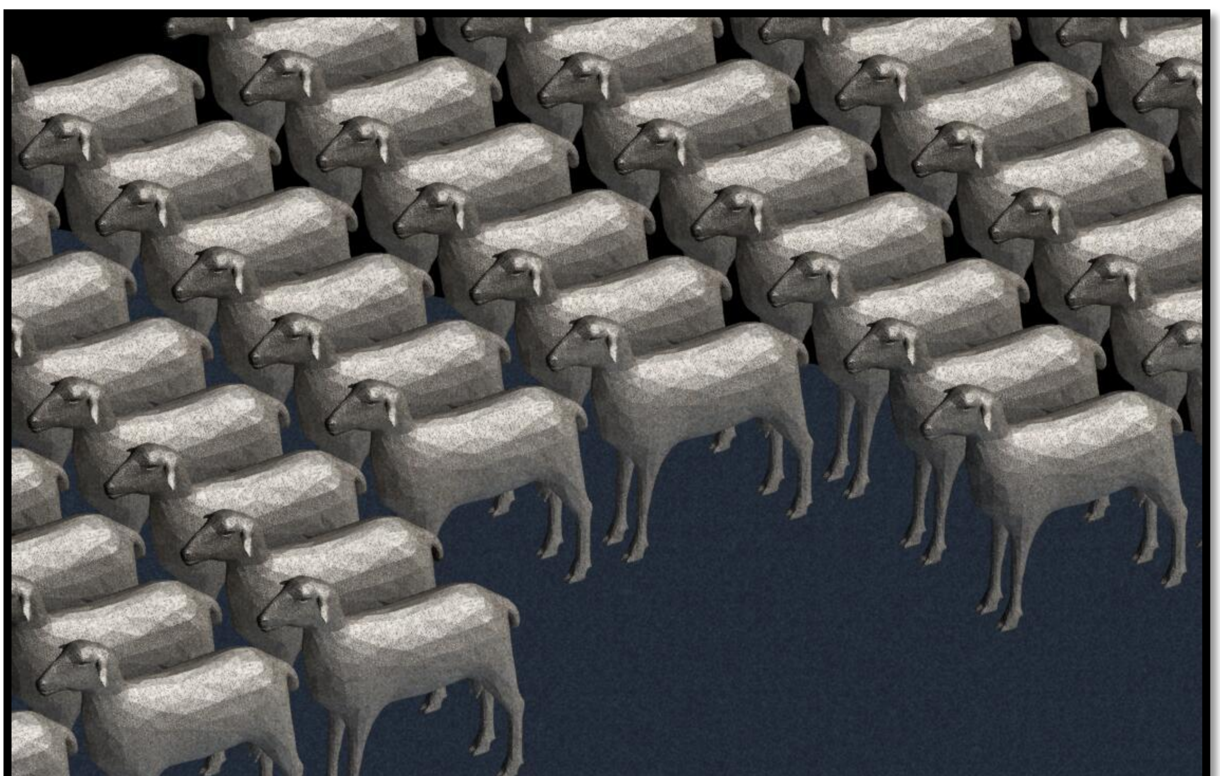

Figure 19. Indicative representation of sheep stocking density as modelled.

4.3 Results

Figure 20 to Figure 26 show dry bulb temperature contour plots at a height of 1.6 m above the bottom floor. This height corresponds to the underside of the sheep on the upper deck which was generally the hottest location on the deck. While the parameter of interest in heat stress is the wet bulb temperature, the wet bulb and dry bulb rise together and so the same conclusions can be drawn about ventilation by looking at either the dry bulb temperature or the wet bulb temperature. It is not necessary to post process the results to show wet bulb temperature. By plotting dry bulb temperature, we can understand the evolution of conditions on the deck. The coupled movement of wet and dry bulb temperatures in the simulations is confirmed by the observation from simulation outputs that the relative humidity dropped from ambient values by a maximum of approximately 3%. With the relative humidity lying in such a narrow band through the heating process, the wet bulb temperature will be correlated very closely with the dry bulb temperature.

Variations of the 20 knot head wind analyses were also investigated after review of the initial results. The analyses were also run with the sides of the deck closed by a 'curtain' for the front half of the deck, with the sides at the rear of the deck remaining open.

Finally, simulations were extended to include typical mechanical ventilation. A PAT of approximately 30 m/hr was included as supply from vents in three sides of each riser.

Note that the results from this work should not be compared directly to the more detailed work in Live.116 which was carried out to estimate the cross wind correlations. There are a number of simplifications made here which makes such comparison invalid. Notably:

- The 24 m cross wind correlation describes the effective PAT for “standard” 24 m decks which have a pen height of 1.3 m whereas these models have pen heights of 1.2 m.

- To simulate the cross wind velocity, a dynamic pressure difference was assumed either side of the deck. For the 3.6 m/s (7 knot) cross wind, the effective dynamic pressure assumed was 8 Pa on one side of the ship and -4 Pa on the other side. For the 2.57 m/s (5 knot) cross wind, the effective dynamic pressure assumed was 4 Pa on one side of the ship and -2 Pa on the other side. The real ship side pressures are of course non-uniform and no work was done to refine these estimates as it was unimportant for the question at hand. The boundary conditions may have generated a more favourable flow rate through the deck than would have existed in reality.

The plots compare headwind cases with cross wind cases or curtained cases. In plotting such data, the colour range is applied over an appropriate range of temperature. Where the temperature ranges are quite different between two plots being compared, the comparison is presented twice, with two different colour scales.

4.3.1 Cross wind compared to headwind

Figure 20 below compares a 5 knot crosswind with a 20 knot headwind on a 36 m wide deck. It is clear that about half of the deck in the headwind case is hotter than the worst spots under a 5 knot crosswind. It is noted that the transient simulation for the headwind case, starting at initial temperatures of 32°C and 38°C had not converged to a steady state even at 400 s of real time. There is no need to run from longer as both results show that the headwind case is significantly worse than the 5 knot crosswind case.

As the scaling of Figure 20 does not show detail above 34°C, it is repeated in Figure 21 with temperature scale ranging up to 40°C. With the 38°C initial condition, the rear of the deck is seen to be hotter than the initial condition, indicating that it may still be increasing in temperature. That is; the final answer, when converged, is likely to be hotter than either of the headwind cases shown.

As a 5 knot crosswind was clearly more effective than the headwind, there is perhaps little point in the 7 knot comparison. Nevertheless, this is given for a 36 m deck in Figure 22.

A similar comparison is given for a 5 knot crosswind and a 24 m deck in Figure 23.

These last two figures confirm the conclusion that the front of a deck sailing through still air will be well ventilated, and the rear of the deck will have very poor ventilation. All results suggest that it is inappropriate to use a single effective crosswind figure to assess risk over an entire open deck.

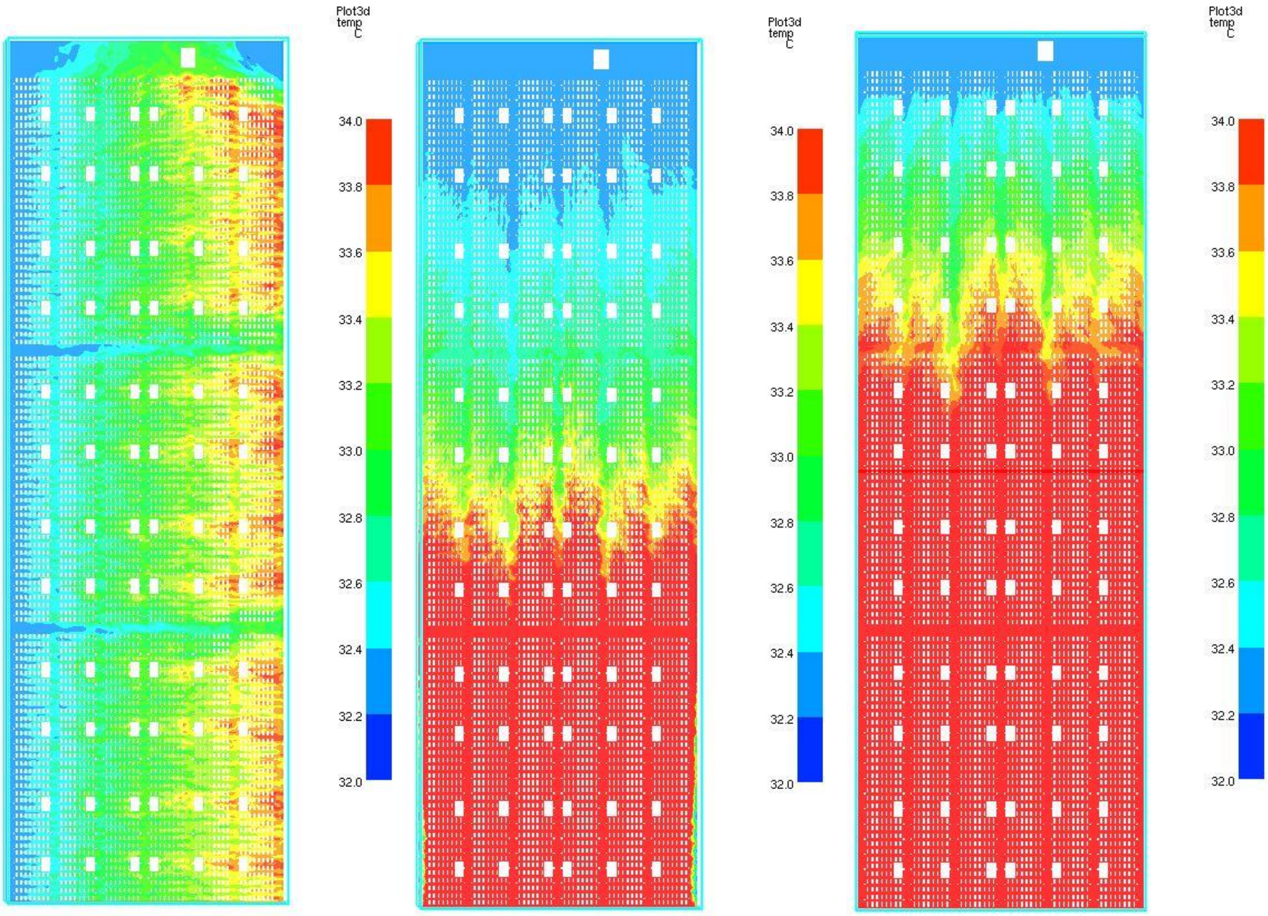

Figure 20. 36 m deck, 5 knot (2.57 m/s) crosswind (left) and 20 knot (10.28 m/s) headwind (right two images). The two headwind results started from different initial temperatures; 32°C in the centre, and 38°C on the right. Both ran for 400 s of real time. Temperature contours plotted at a height of 1.6 m from the lower deck floor, i.e., at the underbelly of the sheep on the upper deck.

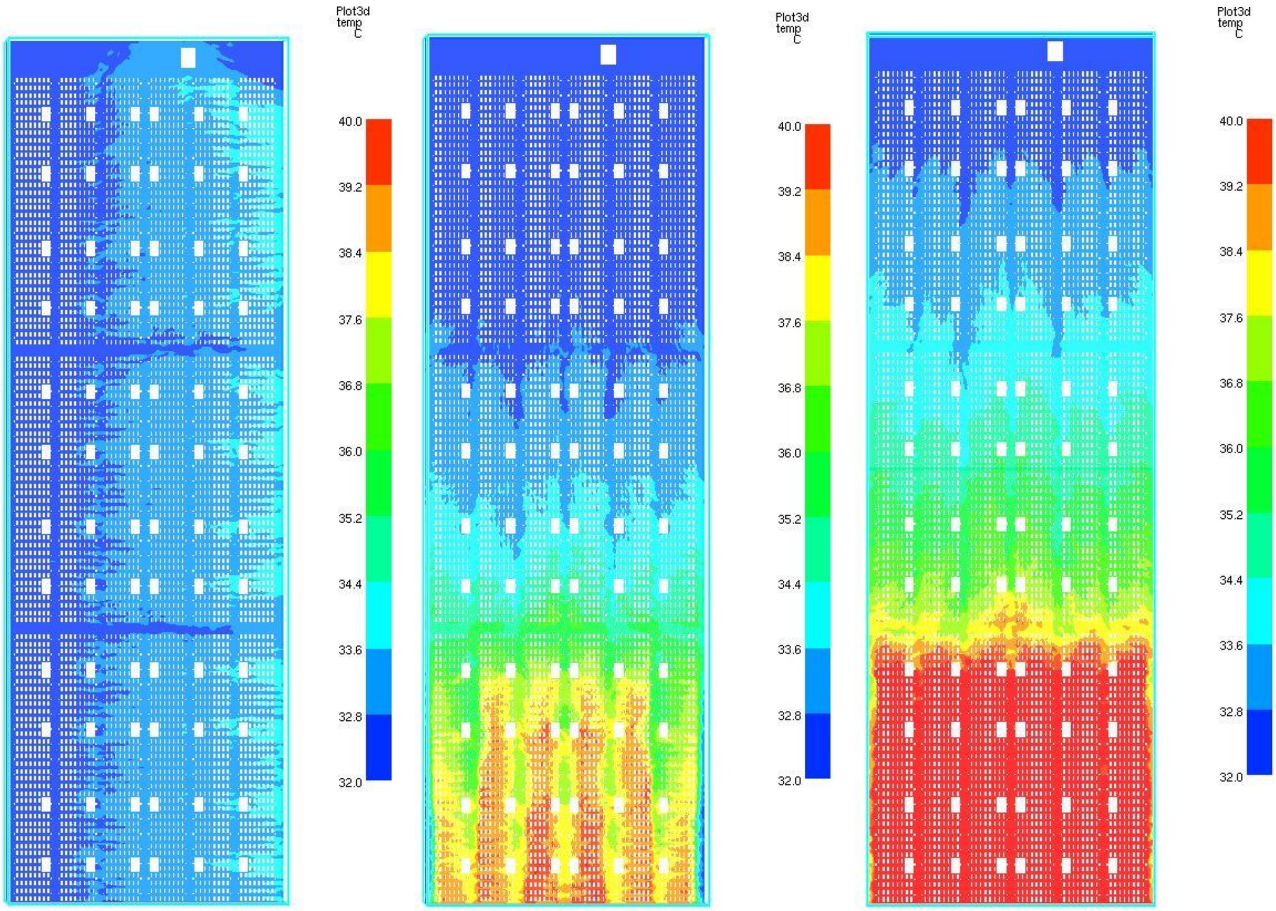

Figure 21. As for Figure 20, except with temperature scaled up to 40°C. 36 m deck, 5 knot (2.57 m/s) crosswind (left) and 20 knot (10.28 m/s) headwind (right two images). The two headwind results started from different initial temperatures; 32°C in the centre, and 38°C on the right. Both ran for 400 s of real time. Temperature contours plotted at a height of 1.6 m from the lower deck floor, i.e., at the underbelly of the sheep on the upper deck.

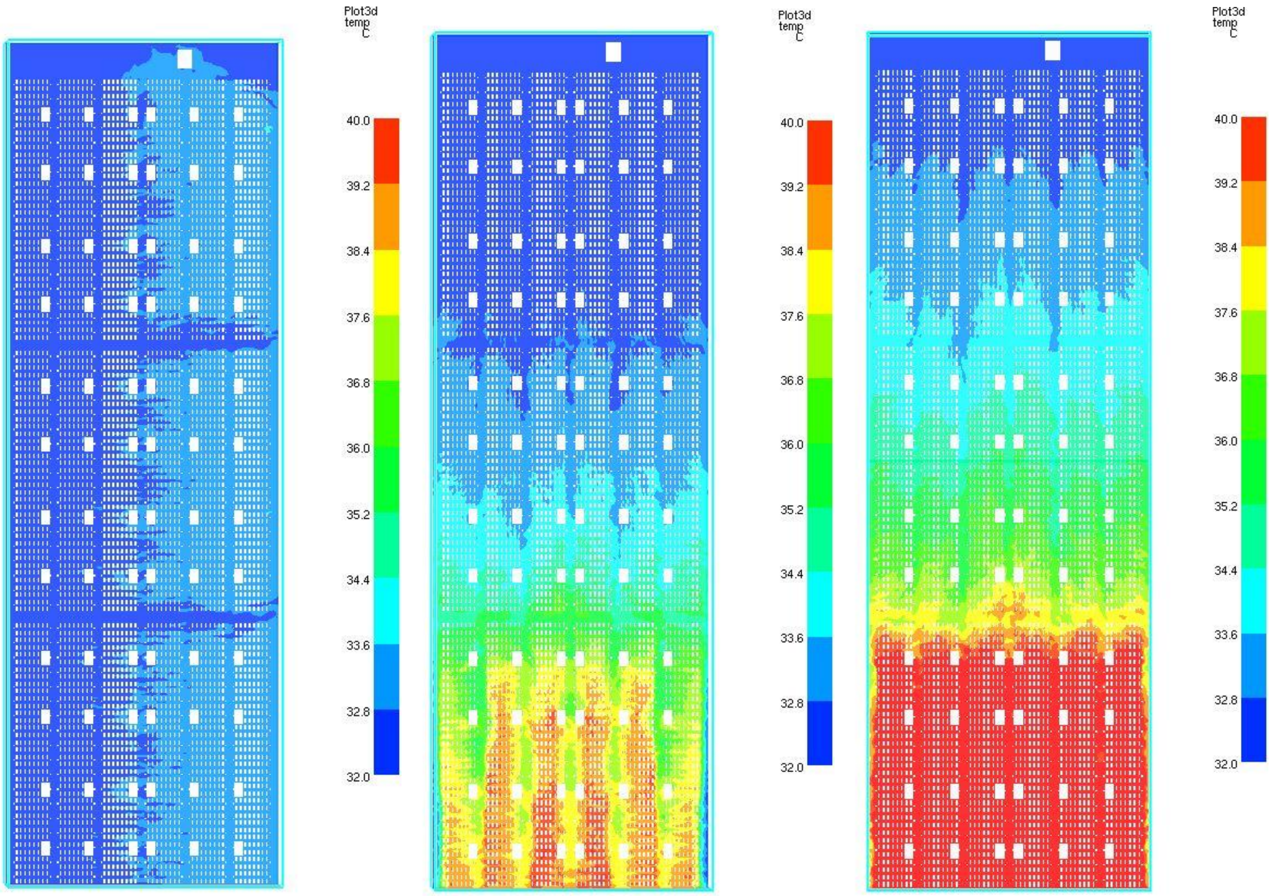

Figure 22. 7 knot comparison, with temperature scaled up to 40°C. 36 m deck, 7 knot (3.60 m/s) crosswind (left) and 20 knot (10.28 m/s) headwind (right two images). The two headwind results started from different initial temperatures; 32°C in the centre, and 38°C on the right. Both ran for 400 s of real time. Temperature contours plotted at a height of 1.6 m from the lower deck floor, i.e., at the underbelly of the sheep on the upper deck.

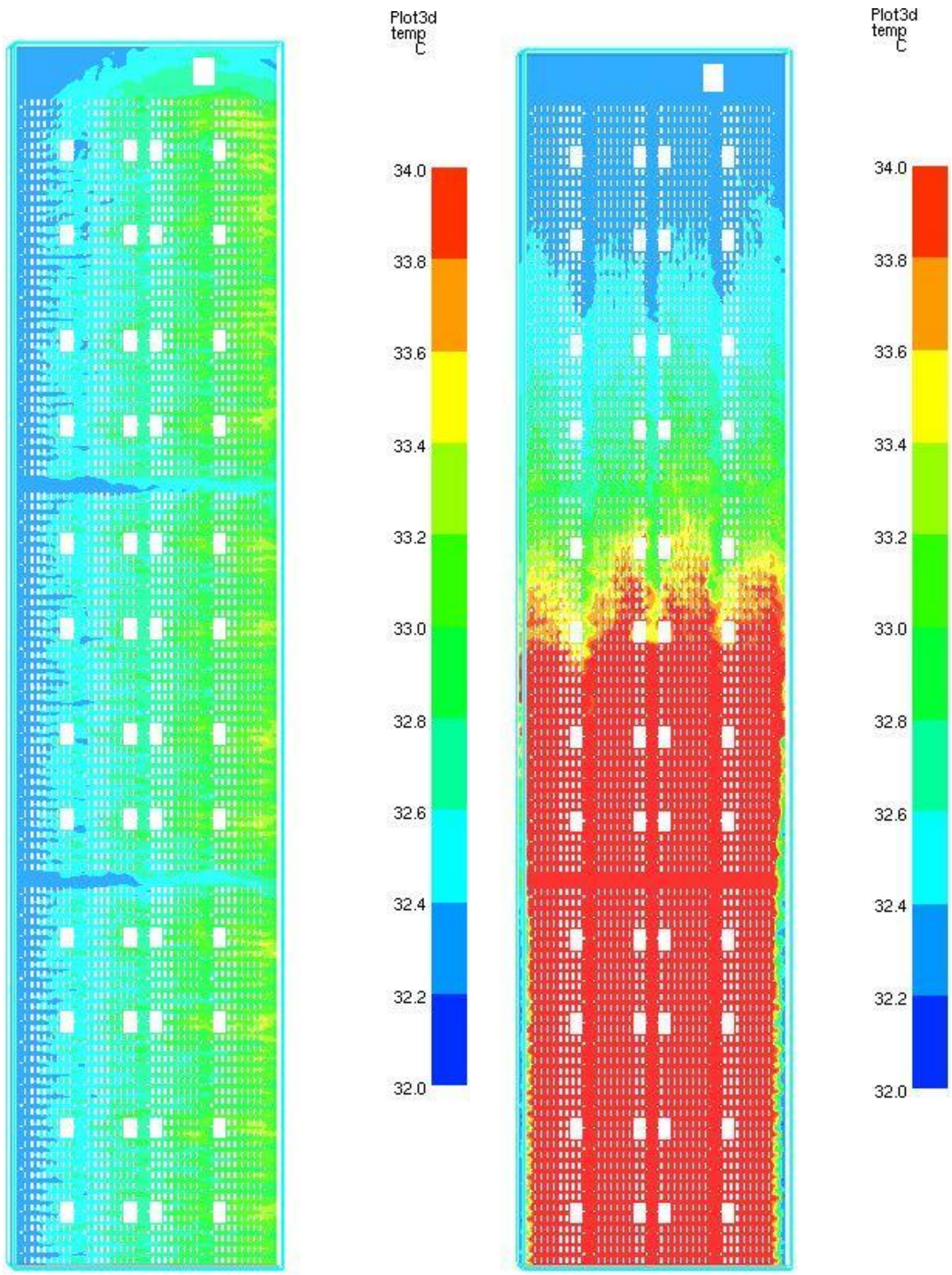

Figure 23. 24 m deck, 5 knot comparison, with temperature scaled up to 34°C. 24 m deck, 5 knot (2.57 m/s) crosswind (left) and 20 knot (10.28 m/s) headwind (right two images). The headwind result started from an initial temperature of 32°C and ran for 400 s of real time. Temperature contours plotted at a height of 1.6 m from the lower deck floor, i.e., at the underbelly of the sheep on the upper deck.

4.3.2 Partial side closure

It had been expected that when sailing through still air, turbulent buffeting along the sides of the vessel would generate significant air exchange extending across the deck. The results above do not show that effect. In fact, the simulations reveal that such inward diffusion of fresh air is made impossible by the very slow outward drift of air which has come down along the deck after entering at the front of the deck. The air escaping sideways reduces the longitudinal flow and so progressively slows the stern-ward progress of the remaining air. The result is that after a distance along the deck equivalent to a couple of deck widths, the air movement is in fact very slow, and so the effective PAT is very poor.

That the air spilt sideways slows the later air exchange suggests the idea of preventing that spillage. If all the air entering the front of the deck can be contained and channelled along the deck, more of the deck might be well ventilated when sailing in still air.

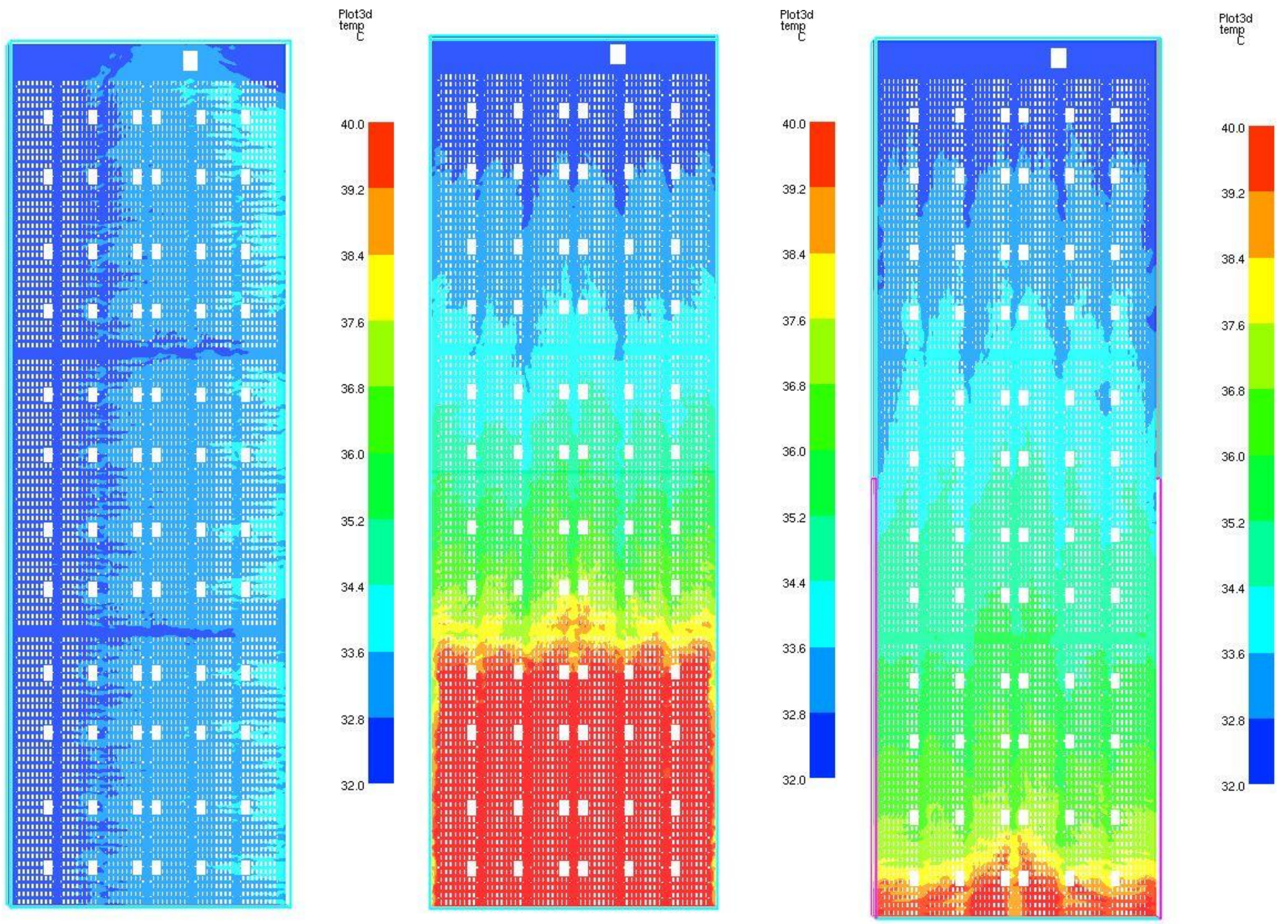

Figure 24. Effect of side curtains (right image). Temperature scaled up to 40°C. 36 m deck, 5 knot (2.57 m/s) crosswind (left) and 20 knot (10.28 m/s) headwind (right two images). The centre image has open sides, while the right image has 'curtains' sealing the sides for much of the length.

Such a simulation is included in Figure 24. While the temperatures are likely still to be unacceptable across large fractions of each deck, the result is clearly better than for open sides.

4.3.3 Mechanical ventilation

The wide, double-tier open decks in use typically have some mechanical ventilation installed, supplying air at a low rate. The results above include no mechanical ventilation. The simulations plotted in Figure 25 below explore the effect of adding ventilation to give a PAT of 30 m/hr. It is apparent that only the fine detail has changed. Ventilation at 30 m/hr shows essentially zero benefit.

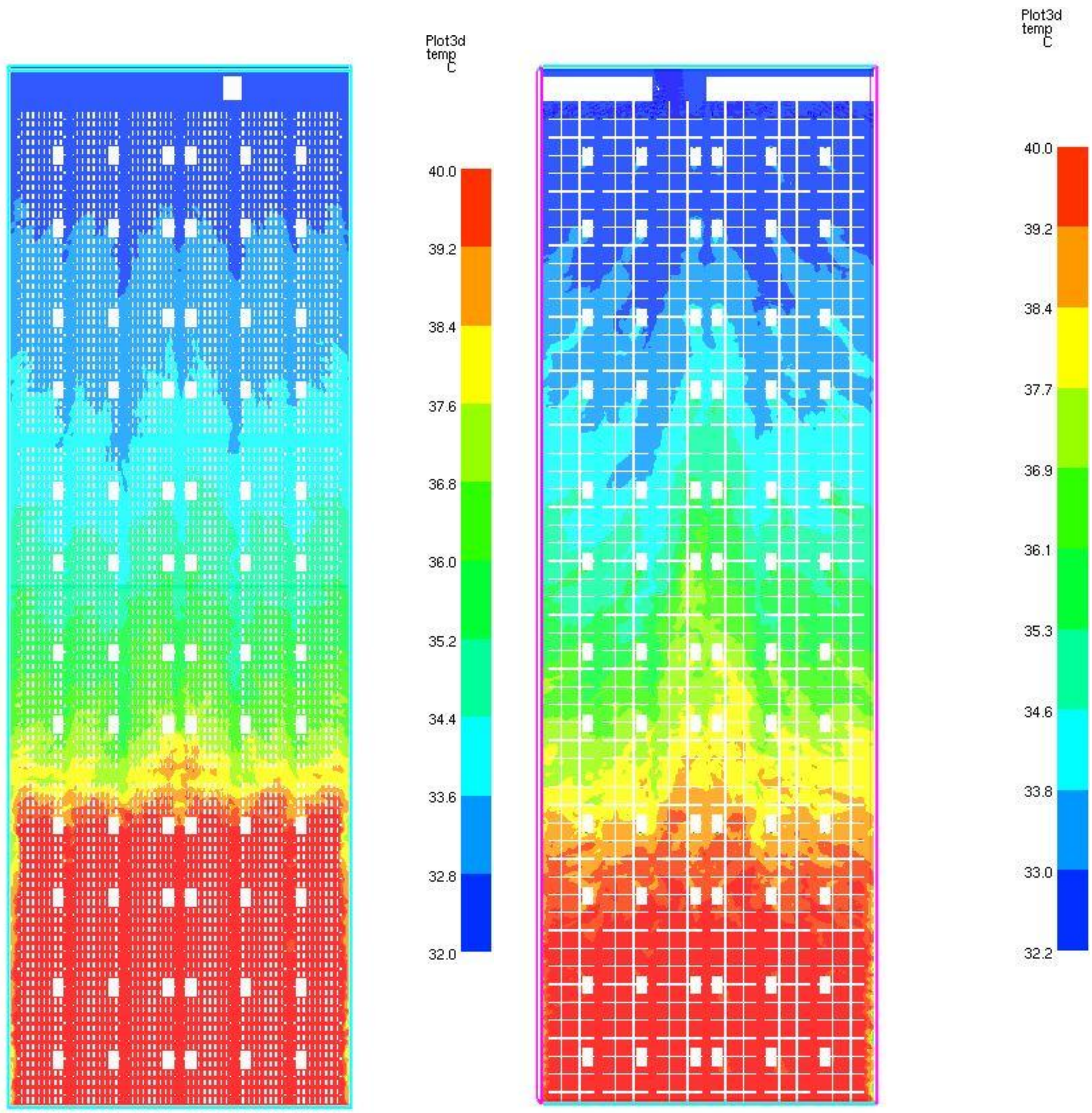

Figure 25. Effect of mechanical ventilation at a PAT of 30 m/hr (right image). The left image has no mechanical ventilation. Temperature scaled up to 40°C. 36 m deck, 20 knot (10.28 m/s) headwind.

4.3.4 Deck aspect ratio

The mechanism of sideways leakage of air entering at the front of the deck has been seen as causing low ventilation rates further back along the deck. This suggests that short wide decks may perform better when sailing in still air. Noting that 24 m decks are normally not as long as 36 m decks, the effect can be seen by plotting the two deck widths beside each other as in Figure 26. There does seem to be some influence in the effective air exchange persisting further along the wider deck. Of course, because narrower decks are also generally proportionately shorter, this cannot be taken as showing that wider decks are better.

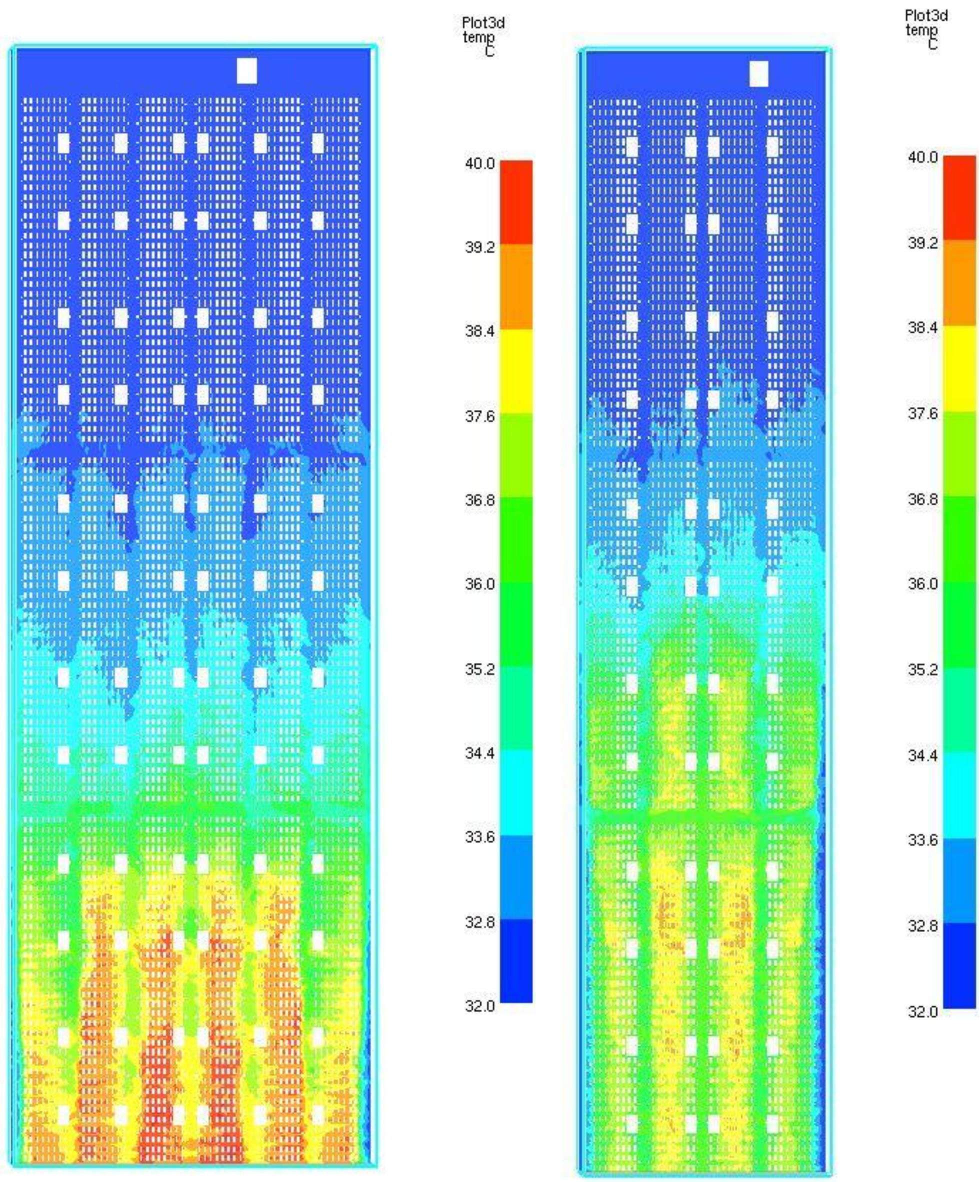

Figure 26. Effect of deck width. Temperature scaled up to 40°C. 20 knot (10.28 m/s) headwind. 36 m deck (left) and 24 m deck (right). T_0 = 32°C, run for 400 s.

4.4 DISCUSSION

Compared to the 20 knot headwind, both crosswinds examined (5 and 7 knots) give much better exchange of air for open two-tier decks, even for the 36 m wide decks. Prior to this modelling, it had been expected that the turbulent buffeting of the air flow along the sides of the open decks would generate significant mixing and air exchange for a long way into the deck. The plots show that this does not happen, and the modelling also gives part of the reason. The air which enters at the front of the deck slows as it moves along the deck and eventually moves slowly outward to discharge at the sides. This very slow outward flow flushes away any fresh air from turbulent mixing with the stale air from the interior of the deck. Whereas if the crossflow were neutral, successive eddies would diffuse fresh air in and stale air out, that mechanism is defeated by the slow flushing by air sourced from the centre of the vessel.

The air flow at the front of sailing open decks is fast, and conditions there are quite fresh, however further back along the vessel, velocities slow and residence times increase. Inclusion of side curtains to give an effective channelling of air along the deck results in better air exchange generally, and an area of very poor PAT that is confined to a smaller region at the rear of the deck.

The sides of the curtain would need to be tied tightly against the decks to ensure it provides the most effective channelling of the air flow. When an appreciable crosswind is present however, it would be more beneficial to raise the curtain and make use of the crosswind. Such a device, while beneficial, may be seen as impractical to deploy. Other approaches with movable openings along the side may have similar drawbacks in complexity and also add topside mass. The best answer is of course the one that has been known since 2000; to provide ventilation for the open decks as if they were closed. There are then no additional issues created by still air, whether sailing or in port.

With regards to the 20 knot headwind used in these studies, it is noted that the maximum speed of the vessels to which this is most relevant is 17.2 knots.

The conclusions from this CFD study are:

- The conditions on two-tier open decks sailing through still air will be very uneven, with excellent air exchange at the front, and very poor air exchange at the back.
- For a deck with an obstruction (such as a bridge structure) at the rear, perhaps a half of the deck at the rear may have very poor air exchange. Note that this study has not considered bluff walls in front of the animal housing. That case would give extremely poor results in still air.
- For the rear half or so of two-tier open decks, forward movement and turbulent mixing down the sides of the vessel are not sufficient to generate air exchange equivalent to either a 5 or 7 knot cross wind.
- The very uneven nature of air exchange due solely to forward vessel movement makes comparisons to a single equivalent crosswind misleading. It would be preferable to categorise the areas of the deck which may become unsafe in such conditions.
- The risk of low still-air ventilation rates at the rear of large open decks is such that an individual assessment should be made of all vessel decks which cannot rely on fans alone to achieve a PAT appropriate for their livestock and destination. This can obviously be avoided

by provision of appropriate levels of mechanical ventilation such that risk assessment need not rely on the decks being open.

5 Limitations of the HotStuff method

While the method has been very successful in eliminating the riskiest voyages, it should always be remembered that: (a) zero risk is almost always an unrealistic target, and; (b) all methods dealing with stochastic systems and limited data will have approximations and assumptions. The purpose of this section is to document the known issues around both the model and its implementation.

5.1 Vessel PAT values

For many vessels, there has been no independent check on the claimed PAT values. For wide two-tier open deck vessels, mechanically supplied air at PAT values below 60 to 120 m/hr (depending on deck dimensions) are likely irrelevant, as they require significant crosswind to give a high enough effective PAT. A high crosswind will then dominate the air exchange. For all other cases (mechanical PAT above 60 to 120 m/hr), the risk is critically dependent on the mechanical PAT. If the value of PAT in the HotStuff database is overstated, the risk will be underestimated. The consequence of that is that voyages with unacceptable risk might still be approved and proceed. It is unlikely that many decks have a significantly understated airflow in the database.

Some of the parameters in the HotStuff model have been difficult to estimate accurately. Much effort has been spent over the last decade on the processing of weather statistics and on the tolerance of animals to hot conditions. In contrast, very little effort has been spent on assessing the true PAT of individual decks on the vessels. The PAT values adopted are those supplied by the ship owners. Some of the data are based on fan nameplate figures; some are known to be the result of careful measurements, while the origin of other data is untraced. There is a clear need for defendable, accurate PAT data for the entire fleet.

5.2 Reingestion of discharged air

The assessment of risk is based on PAT values assuming that the air supplied is 100% fresh air. Where air that has been heated by the animals is discharged from the animal space and then reingested by the ventilation system, that assumption breaks down. If the discharge plume from the side of a vessel has been diluted 1 part to 9 parts by fresh air before reaching a supply fan intake, the PAT relevant to that supply fan should really be taken as only 90% of the value calculated on flow measurement alone.

In slight crosswinds, reingestion will be an issue for intakes beside animal housing. In still air while in port, intakes above the top cover deck are also likely to be ingesting a significant fraction of discharged air. The only way to be certain of avoiding that case is not to let much air discharge from the vessel sides, but to take it all upwards in exhaust risers and discharge it above the intake level. Closed decks generally have some exhaust capacity to assist this, however open decks do not, and the air from the open deck sides is free to rise thermally, flow over the top of the vessel, and into the supply fans.

Reingestion from above the top cover deck is unlikely to be an issue while sailing. The air flow over the vessel at between 16 and 22 knots will sweep the discharged air back along the sides, keeping it away from the intakes and diluting it. Intakes at the side of the animal housing may see reingestion while sailing and that should be acknowledged in the PAT figures.

5.3 Open decks and crosswind

The work in Section 4 is the first to look at the air exchange from sailing forward in still air. It is clear that sailing forward is very poor at ventilating the back half of two-tier sheep decks. Just how poor the result was for the back half of the deck came as a surprise to the authors. It must be regarded as inappropriate to place reliance on crosswind when assessing the risk of different loadings on the back half of such decks. To manage risk, such decks should be provided with effective mechanical ventilation, with the risk assessment being applied without any crosswind.

Earlier work (Live.116) concluded that mechanical ventilation at rates below the threshold levels of air exchange provided by thermal convection was ineffective and made essentially no contribution to improving deck conditions. The CFD study for the present work is consistent with that finding, demonstrating that mechanical PAT values as low as 30 m/hr are not effective at all. They make essentially no improvement to the conditions that would be expected with zero mechanical ventilation.

6 Implementation

A number of issues have been raised on the use and implementation of HotStuff. The primary concerns are around time to use the software and repetition of the activity. Some exporters find that it takes a long time to enter vessel stocking data into HotStuff. Perhaps more of an issue is the time taken to modify and re-enter data when the lines purchased change, the discharge ports vary, or the shipping date slips. Besides the unhelpful note that doing the risk calculations by hand would take a lot longer, there are some suggestions that may help. The suggestions arise from seeing the context of the method; it is about managing risk and the focus must stay on that objective while using the software.

6.1 Using the risk margin

During cooler northern hemisphere weather, the majority of vessels and loadings will be well within the nominated risk limits. In most such voyages, it will be unnecessary to enter exact stockings into HotStuff. The HotStuff loadings may contain more animals, of greater weight, poorer acclimatisation, etc. and still not exceed the risk limits. At the time of sailing, if there are fewer animals than in the risk assessment, the risk is obviously reduced. Similarly, if the animals are lighter or more acclimatised than assessed, the actual risk will be lower than calculated. In those cases, there is no risk assessment need to amend the HotStuff datagrid, it will be evident to the authorities both that the assessed risk is acceptable and that the risk as loaded is lower than the assessed risk. That is; time can be saved by making use of the risk margin and entering stocking that is slightly riskier than actual.

Of course, if the assessed risk is close to the limit, then amending the HotStuff entries as the stock change may be necessary. This is no different from any other business activity in that risks that become significant should be monitored and assessed closely.

6.2 Using the weather trend with date

A similar approach applies to discharge date. As the discharge date moves towards cooler times, the risk will reduce. Taking Kuwait as an example destination; as the discharge date moves away from 15th January and towards 15th September, the assessed risk will increase. If a voyage is planned for say 10th April but could be a few days later, it may be reasonable to point HotStuff to a 15th April discharge. If the risk is acceptable for 15th April, it will be acceptable for dates just before that, so the planned voyage could slip by up to 5 days without having to rework the HotStuff data.

After the 15th September, any slippage just moves the risk away from the limit. If a voyage which is acceptable when assessed for 21st September slips to 24th September, there would be a reduction in assessed risk and so HotStuff need not be revisited.

It is noted that date changing is in fact relatively straightforward and need not be time consuming. The comments above also apply to the whole regulatory process around the voyage risk assessment. There need not be a review at any level if the actual discharge date has moved from the HotStuff assessed date in a direction that clearly reduces risk.

7 Conclusions

7.1 HotStuff 4.0 Software

Version 4.0 of the HotStuff software is released for use. Relative to Version 2.3, it improves the risk assessment in a number of ways and extends the method to more routes and ports. Version 4.0 should be applied in place of Version 2.3.

7.2 Open two-tier decks

The risk of sailing poorly ventilated open two-tier decks in still air has been known about for a long time but not previously understood as well as it is now. While the work here is more in the nature of a scoping study, some conclusions are clear. The front half of open decks can be ventilated by sailing forward and could still be allowed to be assessed assuming a crosswind of 5 knots. The front third could be assessed using an effective crosswind of 7 knots. The rear half of open decks cannot be adequately ventilated just by sailing when the air is very still. No crosswind concession is appropriate for the rear half of open decks.

7.3 Open single-tier decks

While no modelling has been done for headwinds applied to single-tier decks, it would be expected that the same behaviour would be seen, but perhaps less severe.

7.4 Vessel parameters

The HotStuff method relies on mathematically calculating risk from realistic input numbers. The accuracy of the inputs is important.

7.5 Reingestion

Reingestion of exhausted air will reduce the effective PAT in the receiving deck space. Reingestion from the sides of open decks in still air is treated in HotStuff. It does not yet treat reingestion into fan intakes for mechanically supplied ventilation.

8 Appendices

8.1 Appendix 1. Port Wet Bulb Climatologies

This appendix describes the wet bulb temperature datasets obtained for this project, summarises the key wet bulb climatologies for the designated destination ports and outlines the limitations of the datasets.

The wet bulb temperature datasets obtained for this study are from the meteorological observing networks operated by the National Weather Services of the countries in which the ports are located. Datasets are those available as at December 2010 and include all available dates. Wet bulb temperature data was rarely available from the ports themselves and so the data from the nearest representative land-based weather station was used, with the data from international and major domestic airports used as much as possible. The requirements of ICAO for the weather stations at international and significant domestic airports to undergo regular maintenance, and for the instruments to be subject to routine calibration, mean that data from those stations are expected to be high quality.

The wet bulb temperature climatology for each of the locations in the following sections are summarised in Section 1.1.

8.2 TURKEY

8.2.1 Izmir

The closest suitable weather station to the Port of Izmir is Guzelyali (Station number 172200, 38.433°N, 27.147°E), located approximately 2 km away to the southeast, as illustrated in Figure 27

Figure 27. Wet bulb temperature data were obtained for this location for the period from 15 January 1950 through to 1 December 2010. The flat terrain and very close proximity of this weather station to the port should make the wet bulb temperature climatology very representative of that experienced in the port.

Figure 27. Google Earth image showing the location of the Port of Izmir and the nearby weather station of Guzelayi.

8.2.2 Antalya

The closest suitable weather station to the Port of Antalya is Antalya weather station (Station number 173000, 36.867°N, 30.733°E), located approximately 12 km away to the east north east at an elevation of 54 metres, as illustrated in Figure 28. Wet bulb temperature data were obtained for this location for the period from 1 January 1951 through to 1 December 2010. The weather station is on undulating hills in close proximity to the ocean directly across the bay from the port and this should make the wet bulb temperature climatology quite representative of that experienced in the port.

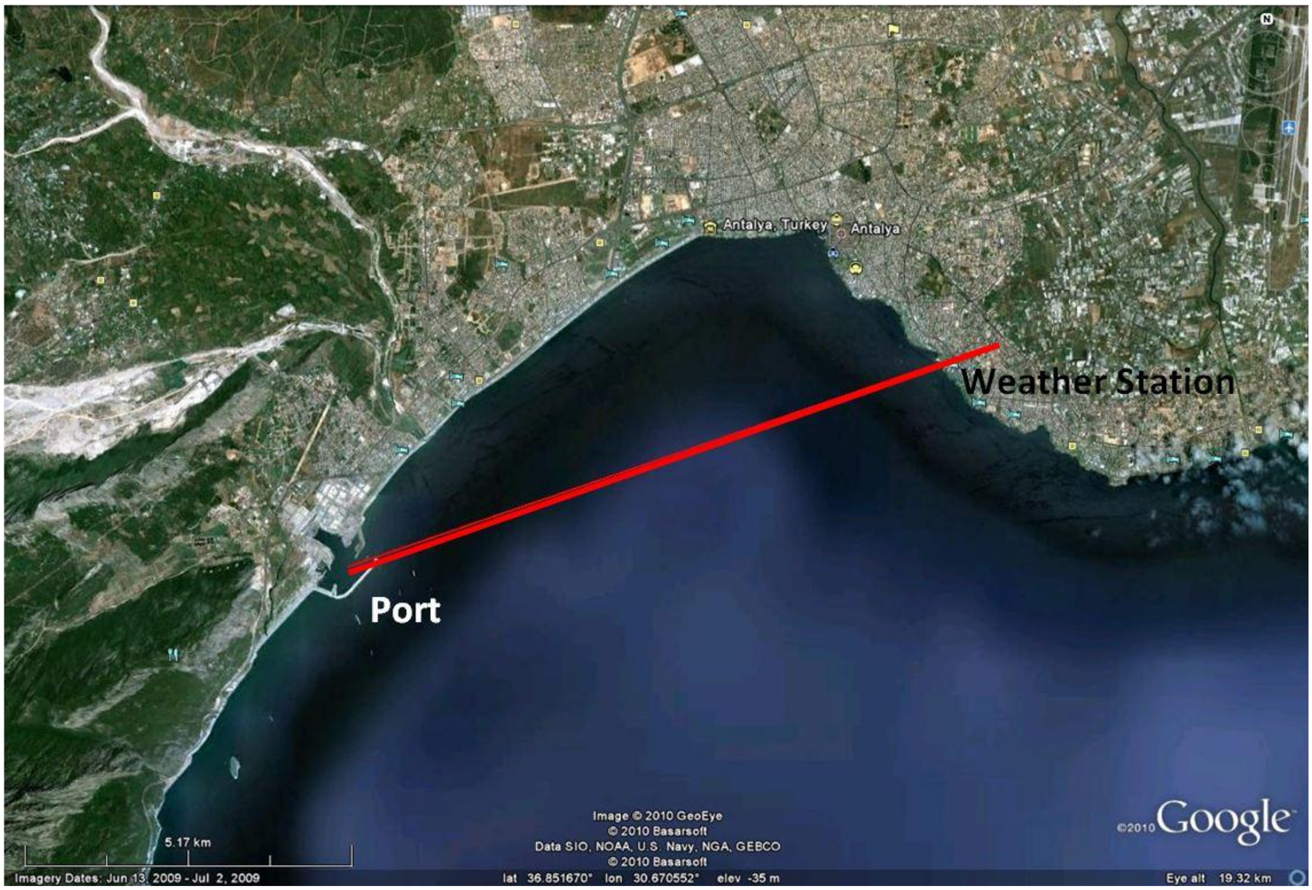

Figure 28. Google Earth image showing the location of the Port of Antalya and the weather station of Antalya.

8.2.3 Istanbul

The closest suitable weather station to the Port of Istanbul is the Istanbul (Ataturk) International Airport weather station (Station number 170600, 40.967°N, 28.817°E), located approximately 16 km away to the west at an elevation of 37 metres, as illustrated in Figure 29. Wet bulb temperature data were obtained for this location for the period from 13 June 1945 through to 1 December 2010. The weather station is on level ground in close proximity to the ocean directly across the water from the port. This should make the wet bulb temperature climatology quite representative of that experienced in the port.

Figure 29. Google Earth image showing the location of the Port of Istanbul and the weather station at Istanbul (Ataturk) International Airport.

8.2.4 Mersin

The closest suitable weather station to the Port of Mersin is the Mersin weather station (Station number 173400, 36.800°N, 34.633°E), located either within or adjacent to the port at an elevation of 3 metres, as illustrated in Figure 30. Wet bulb temperature data are somewhat limited for this location, with a short period of record from 1974 and a few days in 2003. However the record is reasonably continuous from 20 April 2007 through to 1 December 2010. The weather station is close to sea level, very close to or within the port. Noting its limited length of record, the climatology does provide a relative indication of the probability of heat stress at this location, although a slightly more conservative approach could be adopted for this location due to the fact that only 4 years of data are available for the summer months.

Figure 30. Google Earth image showing the location of the Port of Mersin. The Mersin weather station appears to be within or adjacent to the port and is shown by the red dot.

8.2.5 Tekirdag

The closest suitable weather station to the Port of Tekirdag is the Tekirdag weather station (Station number 170560, 40.983°N, 27.550°E), located approximately 2.5 km away to the east at an elevation of 3 metres, as illustrated in Figure 31. Wet bulb temperature data were obtained for this location for the period from 17 January 1963 through to 1 December 2010. The weather station is on level ground close to sea level in very close proximity to the ocean and relatively close to the port. This should make the wet bulb temperature climatology very representative of that experienced in the port.

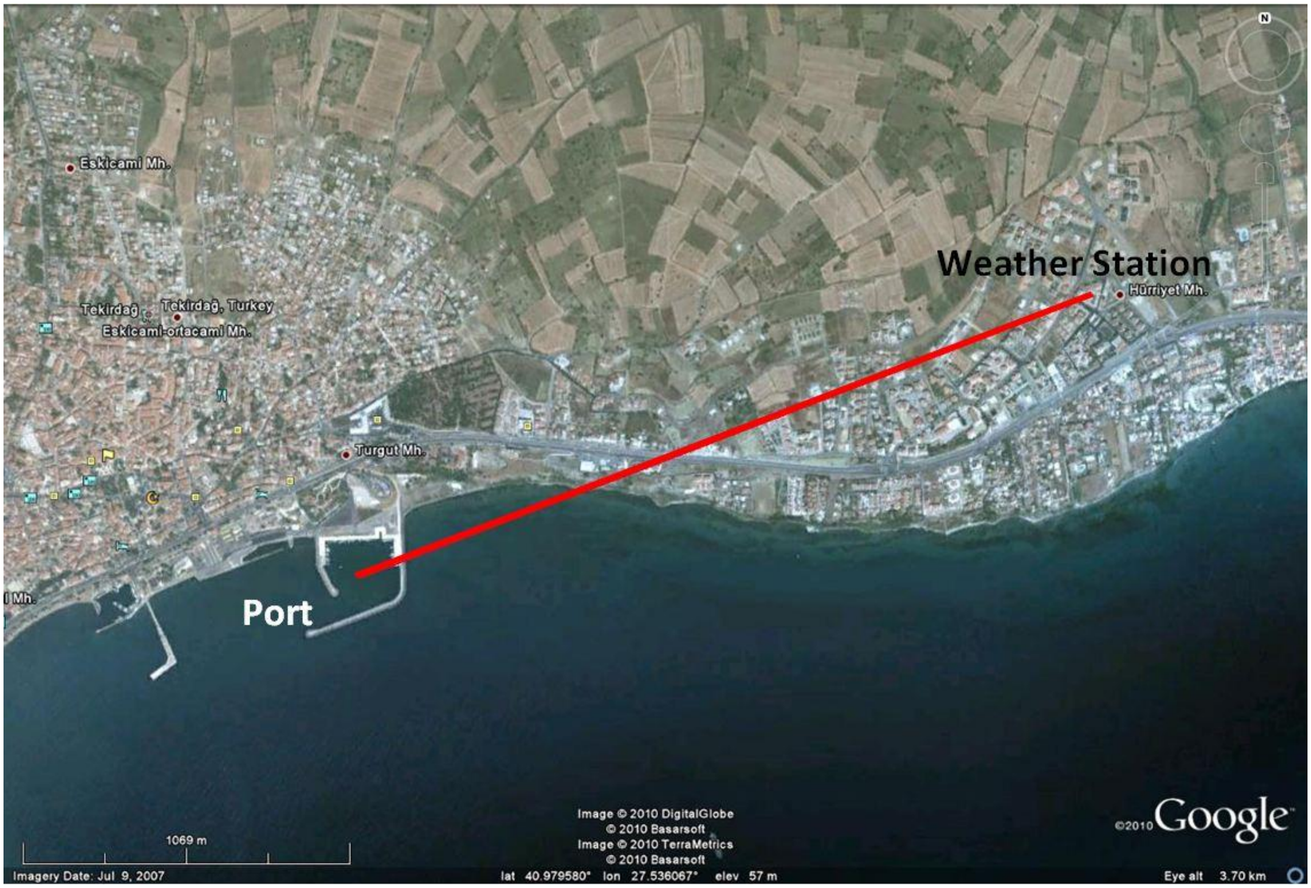

Figure 31. Google Earth image showing the location of the Port of Tekirdag and the weather station at Tekirdag.

8.2.6 Samsun

The closest suitable weather station to the Port of Samsun is the Samsun Airport weather station (Station number 170300, 41.283°N, 36.300°E), located approximately 3.5 km away to the west south west at an elevation of 4 metres, as illustrated in Figure 32. Wet bulb temperature data were obtained for this location for the period from 8 May 1951 through to 1 December 2010. The weather station is on level ground close to sea level, directly inland for the port, with no significant topography in between. It is relatively close to the port. This should make the wet bulb temperature climatology quite representative of that experienced in the port.

Figure 32. Google Earth image showing the location of the Port of Samsun. The Samsun Airport weather station can be see a short distance inland from the port.

8.2.7 Trabzon

The closest suitable weather station to the Port of Trabzon is the Trabzon weather station (Station number 170380, 41.000°N, 39.717°E), located approximately 2 km away to the west south west at an elevation of 34 metres, as illustrated in Figure 33. Wet bulb temperature data were obtained for this location for the period from 10 May 1951 through to 1 December 2010. The weather station is on low undulating hills only 2 km away from the port and slightly inland, with no significant topography in between. This should make the wet bulb temperature climatology quite representative of that experienced in the port.

Figure 33. Google Earth image showing the location of the Port of Trabzon. The Trabzon weather station can be seen a short distance west south west from the port.

8.3 RUSSIA

8.3.1 Ust Luga (Narva, ESTONIA)

The closest suitable weather station to the Russian Port of Ust Luga is just across the border at the Estonian weather station at Narva (Station number 260580, 59.467°N, 28.050°E), located approximately 33 km away to the south west at an elevation of 30 metres, as illustrated in Figure 34. Wet bulb temperature data were obtained for this location for the period from 2 January 1959 through to 1 December 2010. The weather station is on low undulating hills 33 km away from the port to the southwest. Although further away from the port than would be ideal, the Narva weather station is very close to the ocean, with no topographical features present that are likely to affect the wet bulb climatology. This should make the wet bulb temperature climatology suitably representative of that experienced in the port.

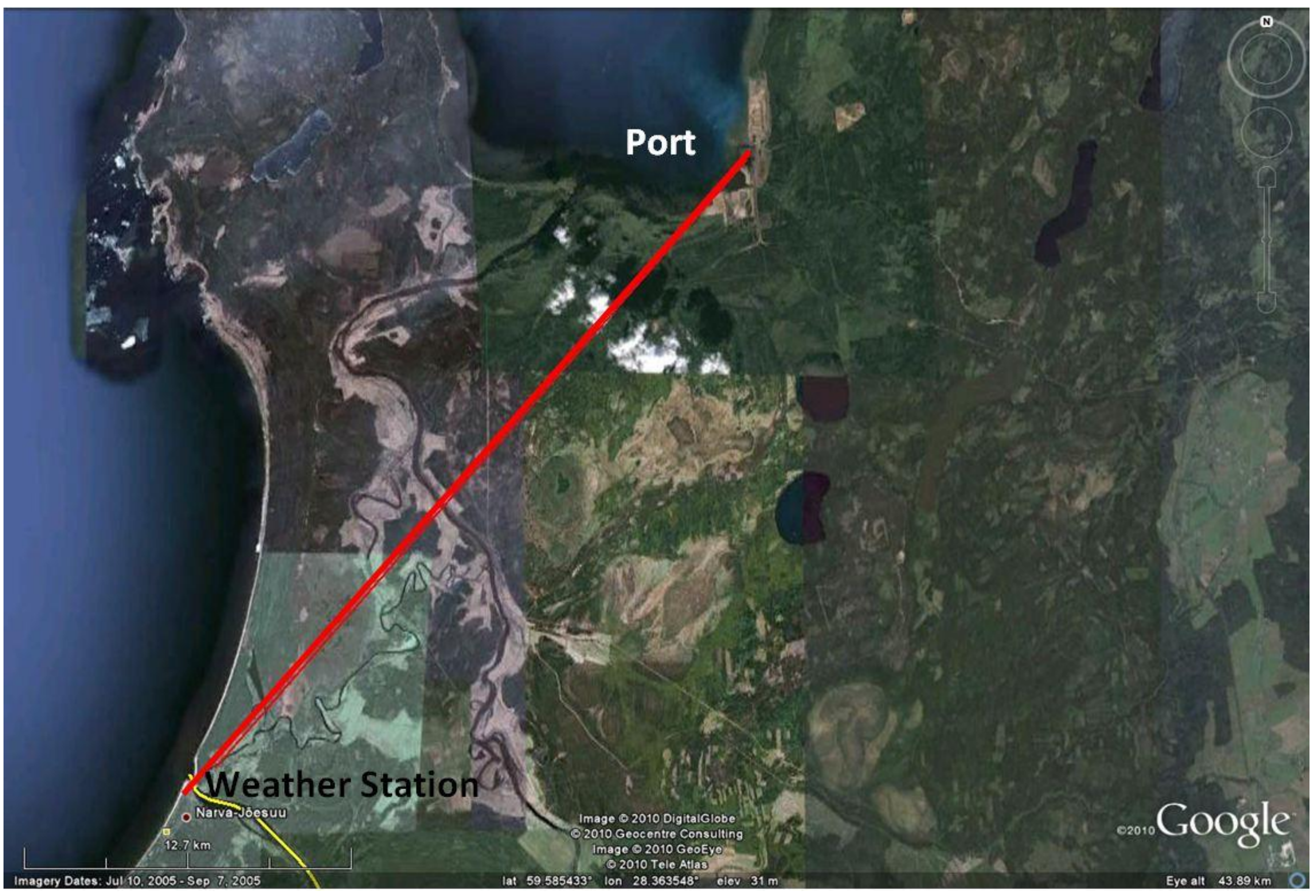

Figure 34. Google Earth image showing the location of the Port of Ust Luga. The Estonian weather station of Narva can be seen to be facing the same ocean but to the southwest across the border from Ust Luga port.

8.3.2 Novorossiysk

The closest suitable weather station to the Russian Port of Novorossiysk is the Novorossiysk weather station (Station number 370060, 44.7°N, 37.8°E). The location of this weather station, now closed, is not precisely known but its elevation of only 3 m indicates it was close to the water in this region which has steep mountains on all sides, as can be seen in Figure 35. Wet bulb temperature data were obtained for this location for the period from 2 December 1987 through to 31 December 1994, approximately 7 years. The likely location close to the sea makes its limited wet bulb temperature record suitably representative of that experienced in the port. This location does not appear to be a high risk location for heat stress, making the limited period of record satisfactory in this instance.

Figure 35. Google Earth image showing the location of the Port of Novorossiysk. The weather station of Novorossiysk is not precisely known, being closed many years ago, but it can be seen that the region is mountainous and the weather station's elevation of 3 m puts it in a similar environment to that of the port.

8.4 UKRAINE

8.4.1 Odessa

The closest suitable weather station to the Port of Odessa is the coastal Odessa weather station (Station number 338370, 46.433°N, 30.767°E), located approximately 6 km away to the south at an elevation of 42 metres, as illustrated in Figure 36. Wet bulb temperature data were obtained for this location for the period from 31 December 1936 through to 1 December 2010, a very long and reliable period of record. The weather station is very close to the coast on the first hill only 6 km away to the south of the port. This should make the wet bulb temperature climatology very representative of that experienced in the port.

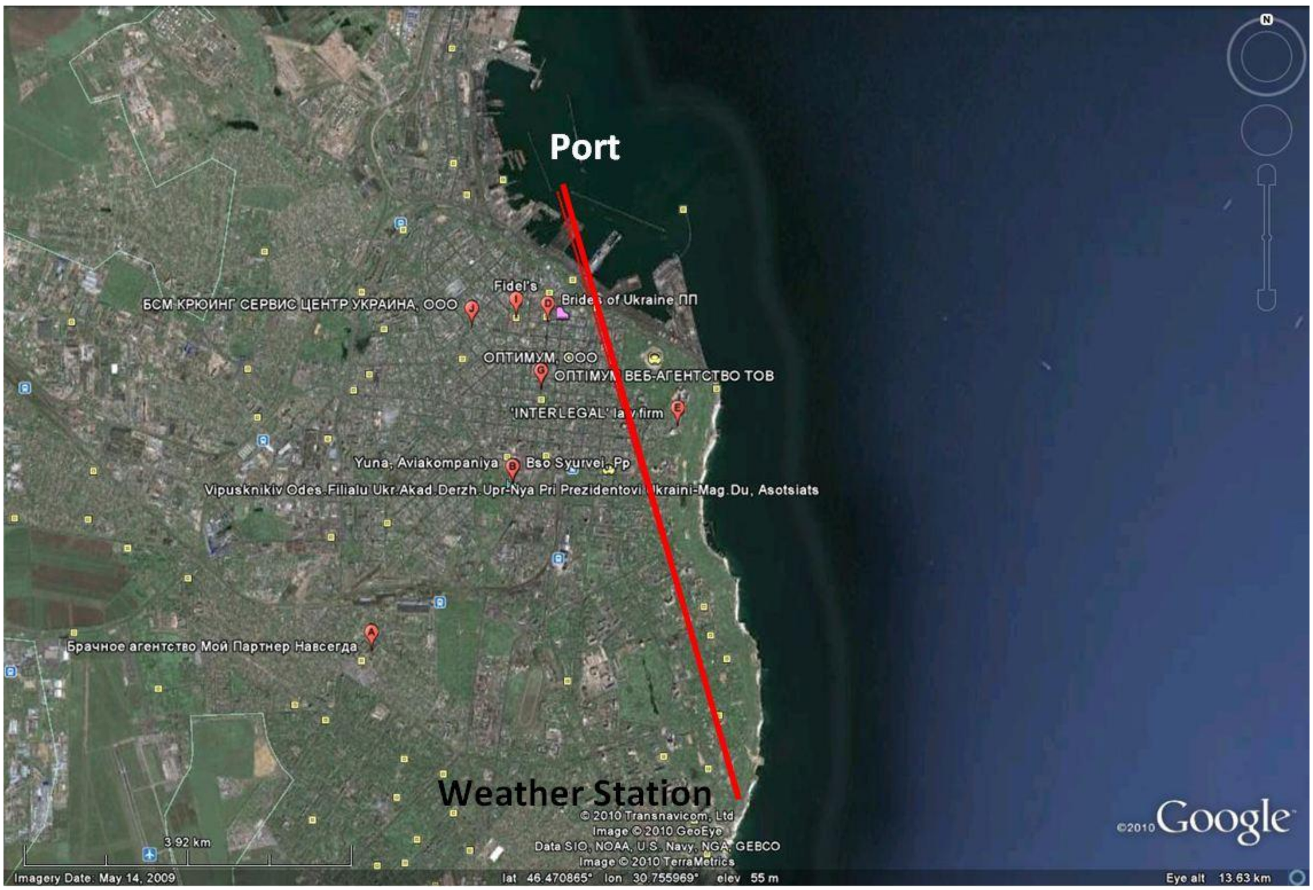

Figure 36. Google Earth image showing the location of the Port of Odessa. The coastal Odessa weather station can be seen a short distance south of the port.

8.5 SYRIA

8.5.1 Al Lathqiyah (Latakia)

The closest suitable weather station to the Port of Al Lathqiyah (Latakia) is the Latakia weather station (Station number 400220, 35.533°N, 35.767°E), located at an elevation of 7 metres within the port, as illustrated in Figure 37. Wet bulb temperature data were obtained for this location for the period from 10 November 1960 through to 1 December 2010, a long and reliable period of record. The weather station is within the grounds of the port. This should make the wet bulb temperature climatology very representative of that experienced by ships within the port.

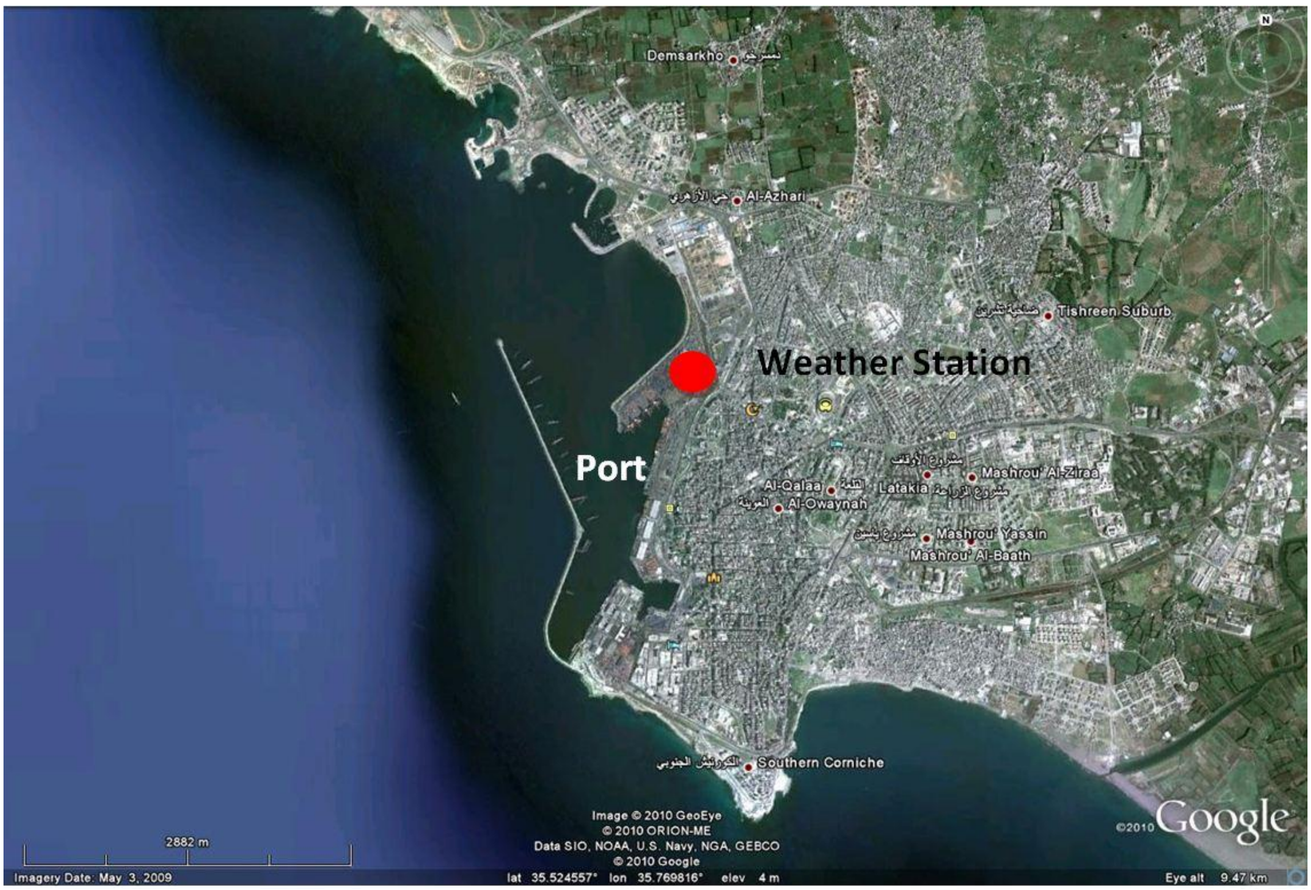

Figure 37. Google Earth image showing the location of the Port of Latakia with the location of the weather station indicated by the red dot.

8.6 LIBYA

8.6.1 Tripoli

For the Port of Tripoli there are two choices of weather station. The first is the Tripoli International Airport weather station (Station number 6210100, 32.700°N, 13.083°E), located at an elevation of 63 metres, 26 kilometres south of, and inland from, the port, as illustrated in Figure 38. This is further away from, and inland from, the port than is desirable. Wet bulb temperature data were obtained for this location for the period from 1 July 1943 through to 1 December 2010, a very long and reliable period of record. The terrain is quite flat in this region and the wet bulb temperatures in general could be expected to be fairly uniform across the region, although it is further inland than would be desirable.

The second choice is the Mitiga weather station at the Umm Aitiquah Airport (Station number 620525, 32.900°N, 13.267°E), located at an elevation of 11 metres only 6 kilometres to the east of the port and only 1.4 km inland. The length of record for this weather station is fairly short, from 17 May 2005 through to 1 December 2010. This is short but would be representative of the general wet bulb temperature climatology experienced by ships within the port, although its short length of record means it has not been as exposed to the extremes of wet bulb temperatures in every month. The best approach for Tripoli would be to use the highest reported wet bulb temperature from either weather station for each month.

Figure 38. Google Earth image showing the location of the Port of Tripoli with the location of the Mitiga weather station indicated by the red dot and the red line showing the distance to the Tripoli International Airport.

8.6.2 Benghazi (Benina)

The closest suitable weather station to the Port of Benghazi is the Benina (Benghazi) Airport weather station (Station number 620530, 32.100°N, 20.267°E), located at an elevation of 132 metres at a distance of 20 km to the east of the port, as illustrated in Figure 39. Wet bulb temperature data were obtained for this location for the period from 1 November 1943 through to 1 December 2010, a very long and reliable period of record. The weather station is 16 km inland and more elevated than the port, but the land is gently sloping and fairly level. Therefore the wet bulb temperature climatology for the airport should be generally representative of that experienced in the port.

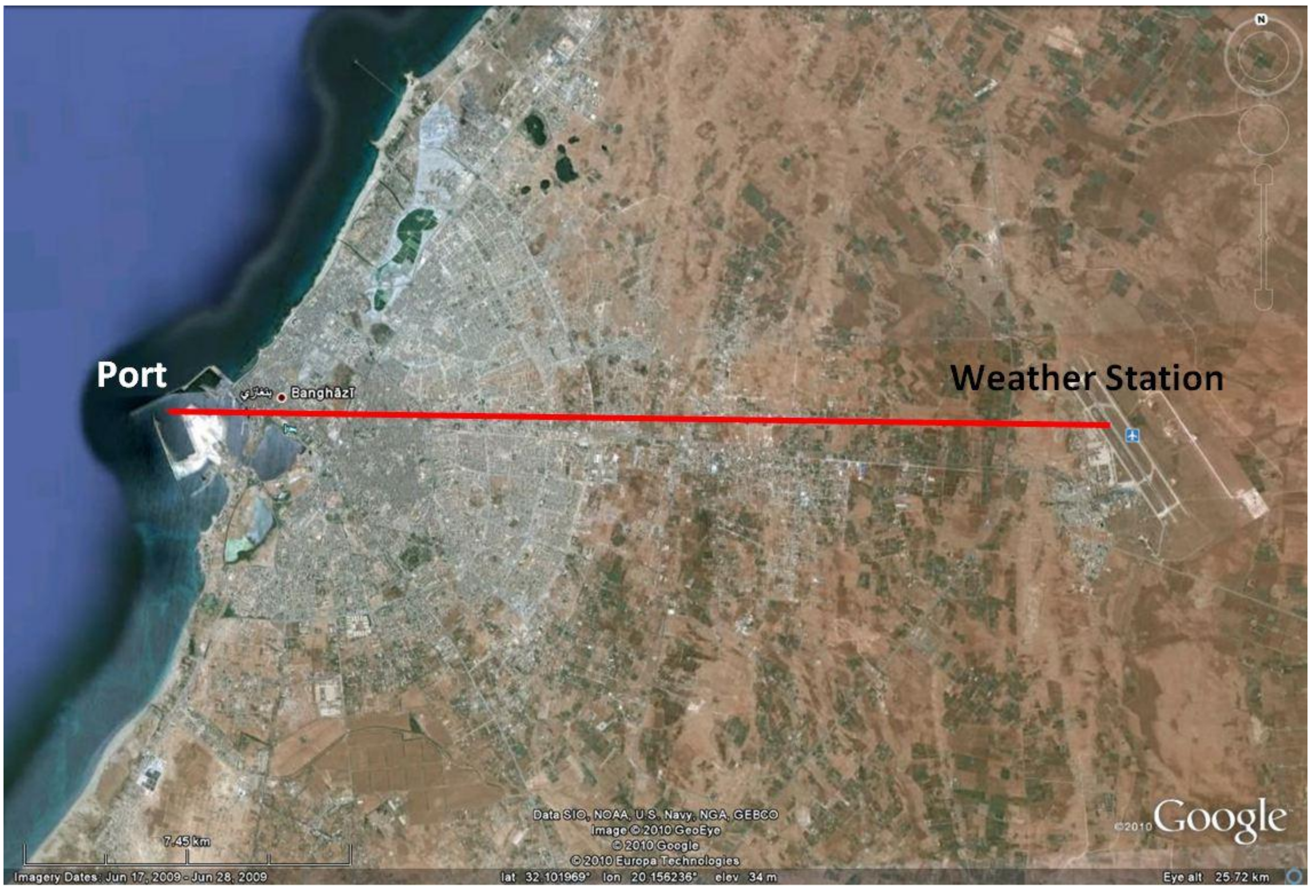

Figure 39. Google Earth image showing the location of the Port of Benghazi with the Benina (Benghazi) Airport located 20km to the east of the port.

8.7 LEBANON

8.7.1 Beirut (Rafic Hariri International Airport)

The closest suitable weather station to the Port of Beirut is the Rafic Hariri (Beirut) International Airport weather station (Station number 640100, 33.821°N, 35.488°E), located at an elevation of 19 metres at a distance of 9 km to the south of the port, as illustrated in Figure 40. Wet bulb temperature data were obtained for this location for the period from 1 December 1957 through to 1 December 2010, a very long and reliable period of record. The weather station is 9 km south of the Beirut Port and right on the coast. The wet bulb temperature climatology for the airport should be very representative of that experienced in the port.

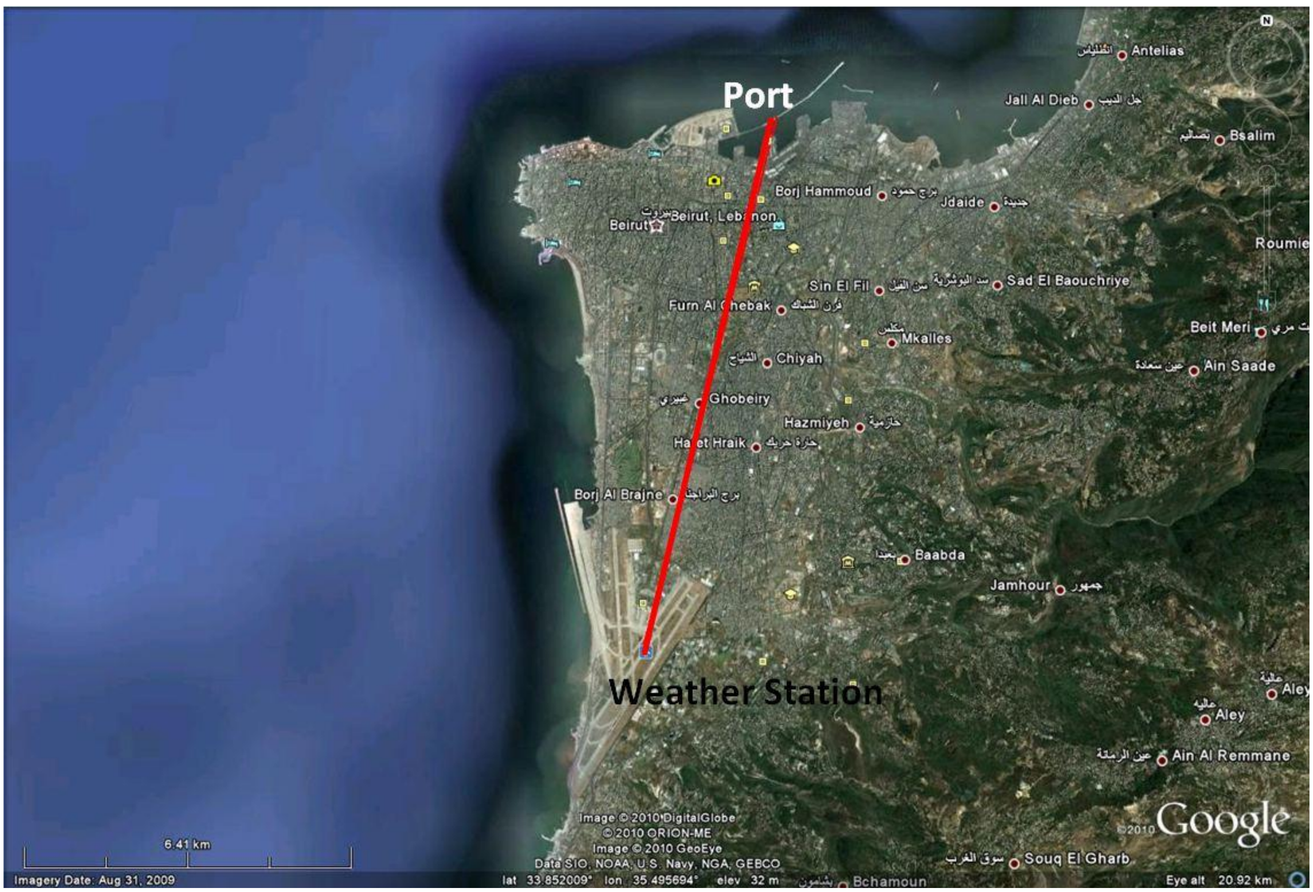

Figure 40. Google Earth image showing the location of the Port of Beirut with the Rafic Hariri (Beirut) International Airport located 9 km to the south of the port.

8.8 EGYPT

8.8.1 Alexandria

The closest suitable weather station to the Port of Alexandria is the Alexandria Airport weather station (Station number 623180, 31.167°N, 29.933°E), located at an elevation of 7 metres at a distance of 6 km to the east of the port, as illustrated in Figure 41. Wet bulb temperature data were obtained for this location for the period from 1 December 1957 through to 1 December 2010, a very long and reliable period of record. The weather station is on flat land close to the sea and the wet bulb temperature climatology for the airport should be very representative of that experienced in the port.

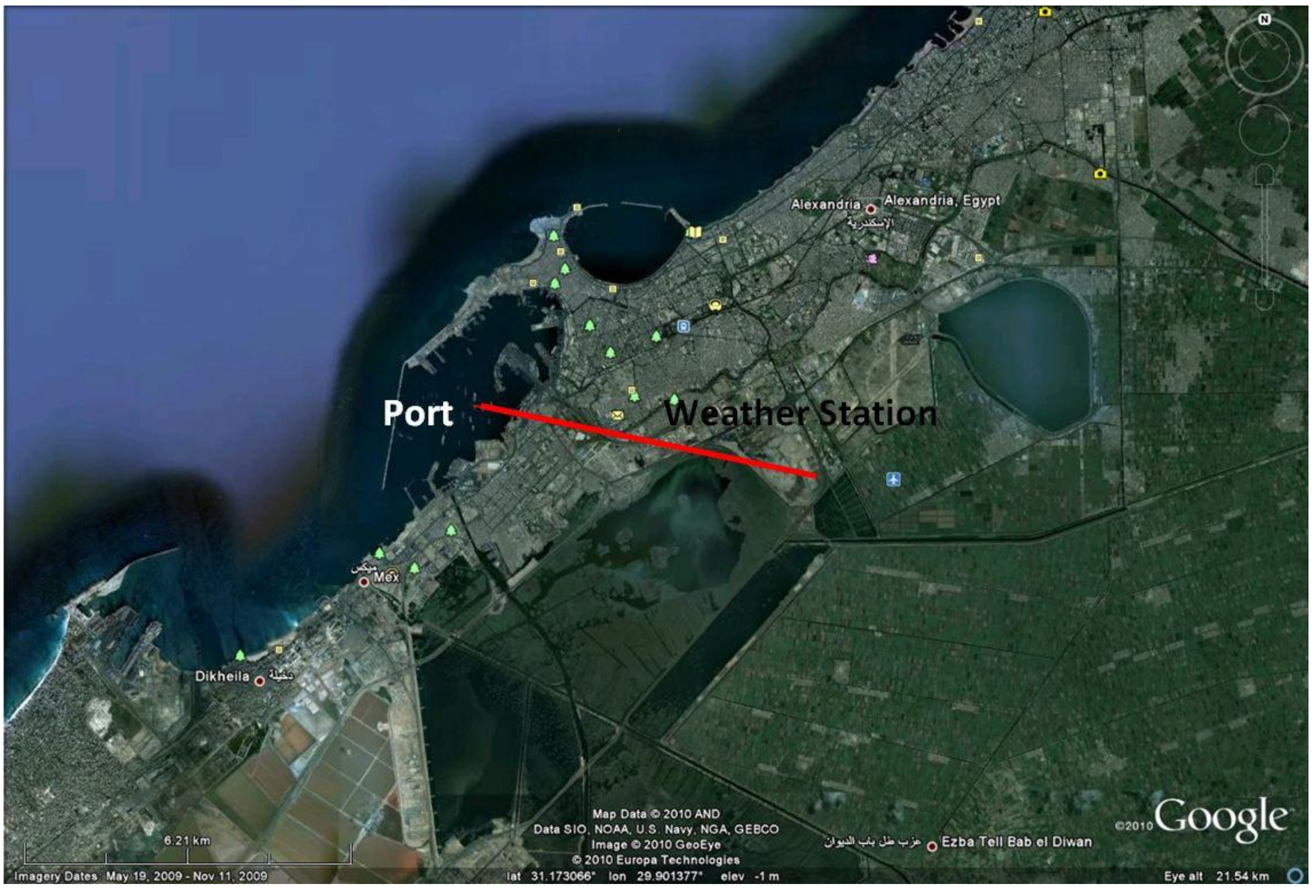

Figure 41. Google Earth image showing the location of the Port of Alexandria with the Alexandria Airport located 6 km to the east of the port.

8.8.2 Port Suez

The closest suitable weather station to Port Suez is the Port Suez weather station (Station number 624500, 29.933°N, 32.549°E), located at an elevation of 3 metres within the grounds of the port, as illustrated in Figure 42. Wet bulb temperature data were obtained for this location only for the limited period from 2 October 1964 through to 20 September 1966. The Port Suez Authority have been contacted to see if there are longer climatological records available but at the time of writing of this report no response had been received. Although the wet bulb climatology is within the port and hence is very representative of that experienced in the port, its limited length of record means this data should be used in conjunction with the data from Ras Sedr, further south along the coast, which has a longer period of record.

Figure 42. Google Earth image showing the location of Port Suez with the weather station located within the port, shown by the red dot.

8.8.3 Sukhna

The closest suitable weather station to the Port of Sukhna is the Ras Sedr weather station (Station number 624550, 29.583°N, 32.717°E), located at an elevation of 17 metres almost due east of the port close to the eastern shore of the Red Sea, a distance of 35 km, as illustrated in Figure 43. Wet bulb temperature data were obtained for this location for the period from 1 September 1999 through to 1 December 2010. The Egyptian Meteorological Authority have been contacted to see if there are climatological records available for the Sukhna area but at the time of writing of this report no response had been received. Fortunately the Ras Sedr data is very close to the Red Sea coastline and it is felt that the wet bulb climatology is still very representative of that experienced in the port. The 11 year length of record is shorter than is ideal but fortunately the weather is relatively constant from year to year at this location.

Figure 43. Google Earth image showing the location of the Port of Sukhna with the Ras Sedr weather station located on the eastern side of the Red Sea 35 km to the east of the port.

8.8.4 Adabiya

The closest suitable weather station to the Port of Abadiya is the Port Suez weather station (Station number 624500, 29.933°N, 32.549°E), located at an elevation of 3 metres 10 km to the northeast of Abadiya, as illustrated in Figure 44. Wet bulb temperature data were obtained for this location only for the limited period from 2 October 1964 through to 20 September 1966. The Port Suez Authority have been contacted to see if there are longer climatological records available for Port Suez and the Egyptian Meteorological Authority have been contacted to see if there is any historical weather information for Abadiya or any nearby locations. At the time of writing of this report no response had been received. Given the limited length of the records for Port Suez, the wet bulb climatology should be based upon the highest value recorded each month from either Port Suez or Ras Sedr, which has a longer period of record.

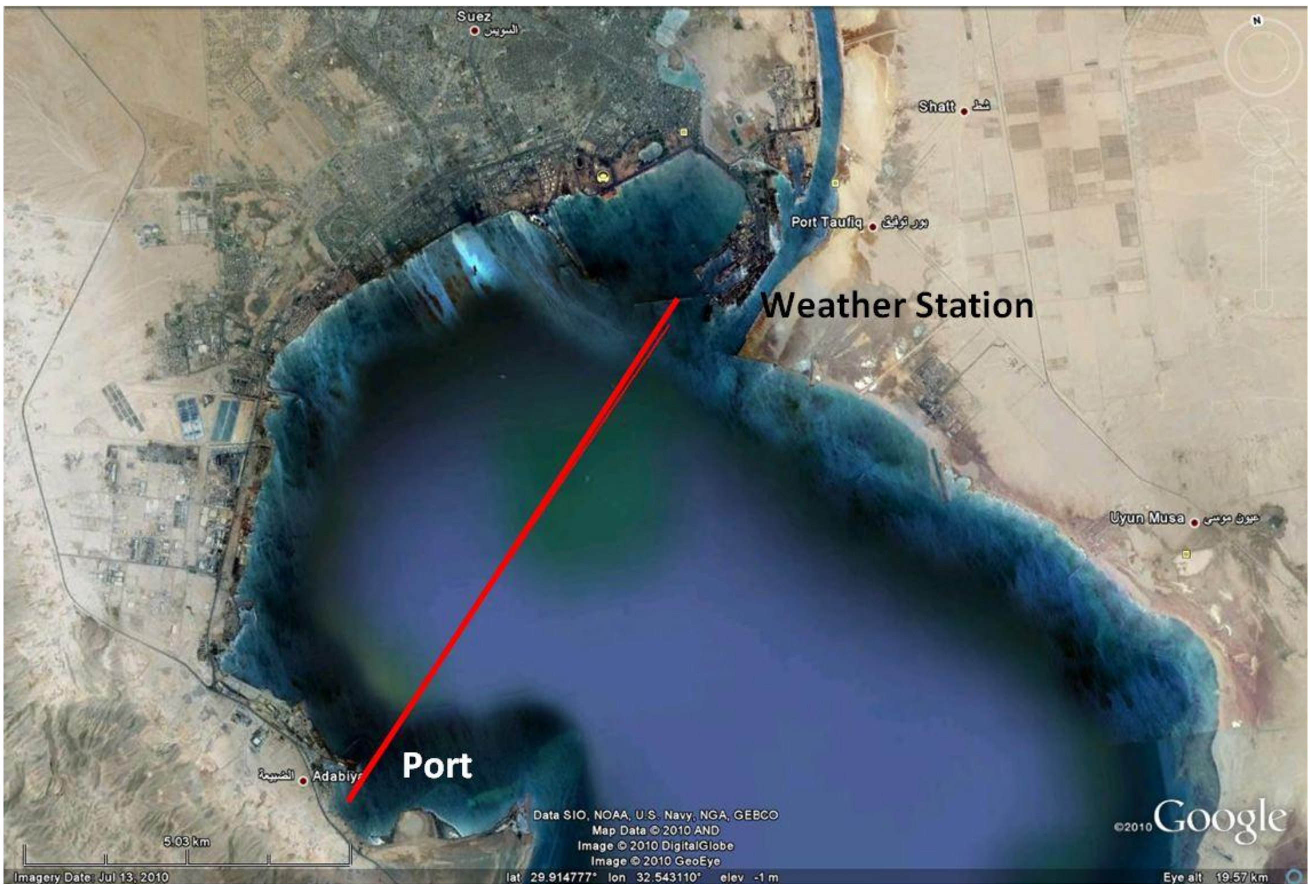

Figure 44. Google Earth image showing the location of the Port of Abadiya with the weather station of Port Suez located 10 km to the northeast by the red line.

8.9 PAKISTAN

8.9.1 Karachi

The closest suitable weather station to the Port of Karachi is the Karachi International Airport weather station (Station number 417800, 24.900°N, 67.133°E), located at an elevation of 22 metres at a distance of 17 km to the east north east of the port, as illustrated in Figure 45. Wet bulb temperature data were obtained for this location for the period from 6 May 1942 through to 1 December 2010, a very long and reliable period of record. The weather station is on flat land inland from the port and the wet bulb temperature climatology for the airport should be quite representative of that experienced in the port, noting there are extensive waterways to the south and southwest of the airport.

Figure 45. Google Earth image showing the location of the Port of Karachi with the Karachi International Airport weather station located 17 km to the east north east of the port.

8.10 MOROCCO

8.10.1 Casablanca

The closest suitable weather station to the Port of Casablanca is the Casablanca International Airport weather station (Station number 601550, 33.567°N, 7.667°W), located at an elevation of 57 metres at a distance of 6 km to the south west of the port, as illustrated in Figure 46. Wet bulb temperature data were obtained for this location for the period from 4 January 1957 through to 30 November 2010, a very long and reliable period of record. The weather station is on flat, slowly rising land only 3.4 km inland from the Atlantic Ocean and the wet bulb temperature climatology for the airport should be very representative of that experienced in the port.

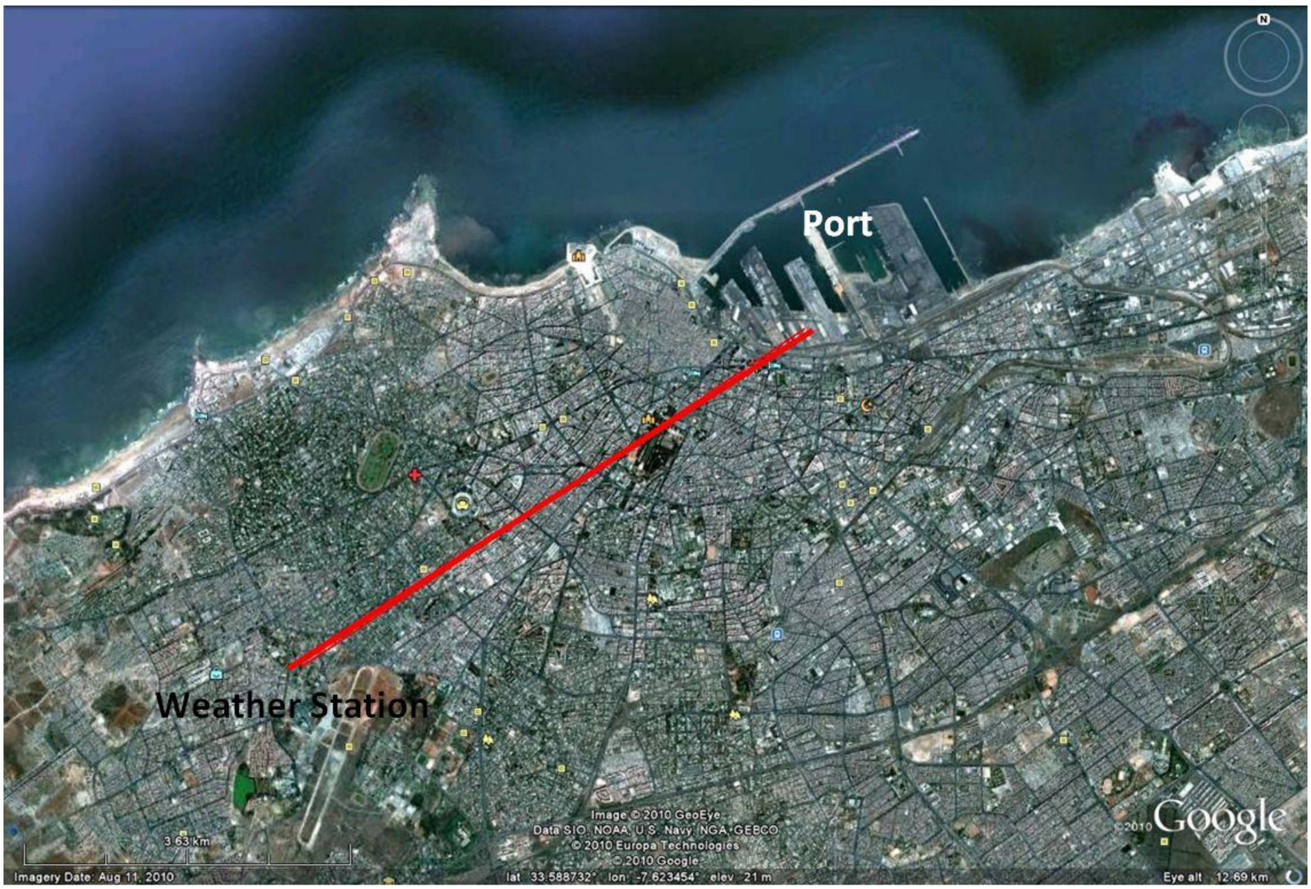

Figure 46. Google Earth image showing the location of the Port of Casablanca with the Casablanca International Airport weather station located 6 km to the south west of the port.

8.10.2 Agadir

The closest suitable weather station to the Port of Agadir is the Inezgane (Agadir) International Airport weather station (Station number 602500, 30.383°N, 9.567°W), located at an elevation of 23 metres at a distance of 7 km to the south east of the port, as illustrated in Figure 47. Wet bulb temperature data were obtained for this location for the period from 15 June 1945 through to 26 December 1991 with a few days from 2005 and 2006, which is still a relatively long period of record. The weather station is on flat, slowly rising land only 3 km inland from the Atlantic Ocean and the wet bulb temperature climatology for the airport should be very representative of that experienced in the port.

Figure 47. Google Earth image showing the location of the Port of Agadir with the Inezgane (Agadir) International Airport weather station located 7 km to the south east of the port.

8.11 JORDAN

8.11.1 Aqaba

The closest suitable weather station to the Port of Aqaba is the Aqaba Port weather station (Station number 403410, 29.483°N, 34.983°E), located at an elevation of 3 metres at a distance of 2 km to the north of the port, as illustrated in Figure 48. Wet bulb temperature data were obtained for this location for the period from 20 August 1965 through to 2 March 1978, a moderate length weather record for a location only 2 km from the location of the port. The weather station is adjacent to the Red Sea and the wet bulb temperature climatology for the airport should be very representative of that experienced in the port. A longer period of more up to date record is available from the Aqaba Airport (Station number 403400, 29.550°N, 35.000°E), located at an elevation of 51 metres at a distance of 15 km to the north of the port, as illustrated in Figure 49. Wet bulb temperature data were obtained for this location for the period from 2 June 1963 through to 31 December 2010, a very long and reliable length of weather record. Given its long history and regular calibration, the airport wet bulb climatology is preferred even though it is further from the port.

Figure 48. Google Earth image showing the location of the Port of Aqaba with the Aqaba weather station located 2 km to the north of the port, shown by the red dot.

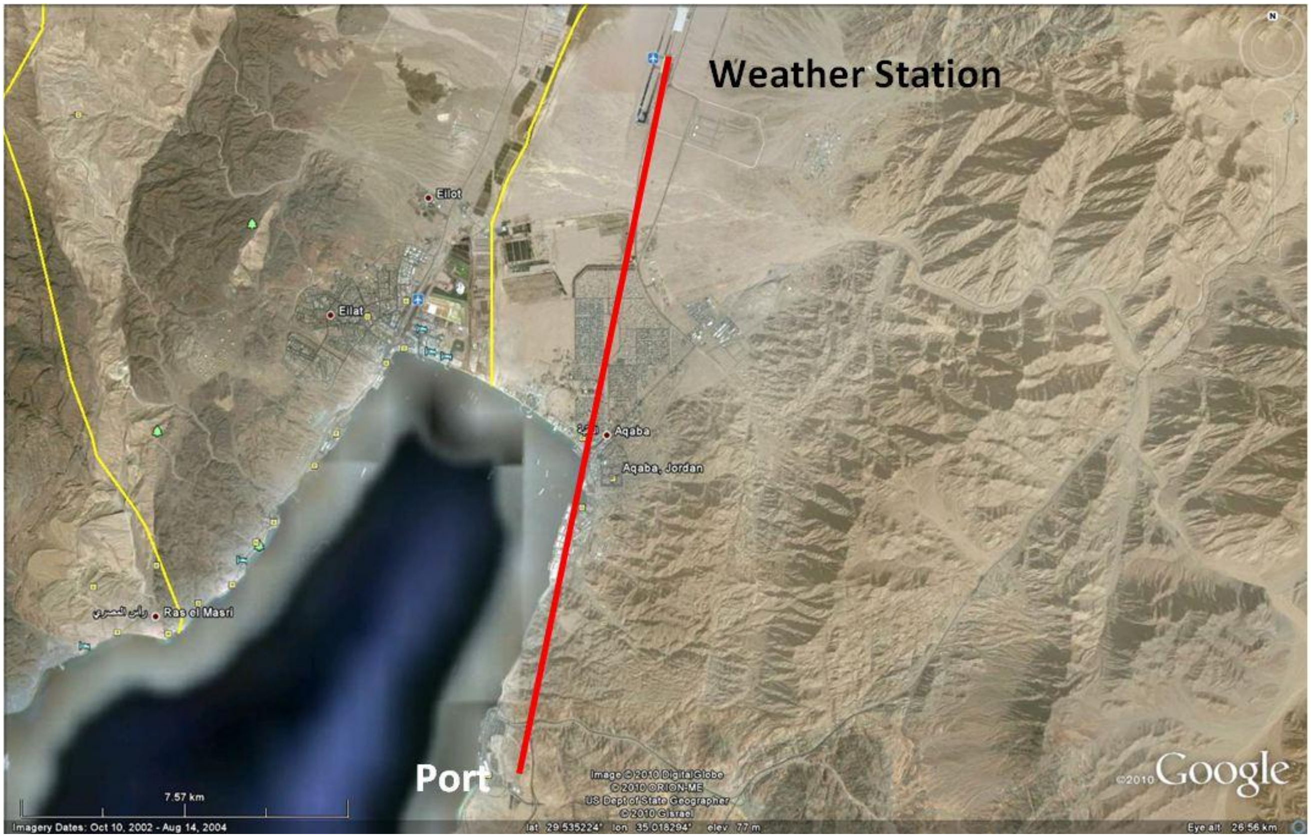

Figure 49. Google Earth image showing the location of the Port of Aqaba with the Aqaba Airport weather station located 15 km to the north of the port, shown at the top of the red line.

8.12 SAUDI ARABIA

8.12.1 Jeddah

The closest suitable weather station to the Port of Jeddah is the King Abdul Aziz (Jeddah) International Airport weather station (Station number 410240, 21.700°N, 39.183°E), located at an elevation of 17 metres at a distance of 26 km to the north of the port and 9 km inland from the Red Sea over a flat coastal plain, as illustrated in Figure 50. Wet bulb temperature data were obtained for this location for the period from 1 January 1983 through to 1 December 2010, a long and reliable period of record. The wet bulb temperature climatology for the airport should be quite representative of that experienced in the port.

Figure 50. Google Earth image showing the location of the Port of Jeddah with the King Abdul Aziz (Jeddah) International Airport weather station located 26 km to the north of the port.

8.12.2 Dhahran

The closest suitable weather station to the Port of Dhahran (Ad Dammam) is the Dhahran Airport weather station (Station number 404160, 26.267°N, 50.167°E), located at an elevation of 17 metres at a distance of 23 km to the south of the port and 5 km inland from the Arabian Sea over a flat coastal plain, as illustrated in Figure 51. Wet bulb temperature data were obtained for this location for the period from 14 February 1946 through to 1 December 2010, a very long and reliable period of record. The wet bulb temperature climatology for the airport should be very representative of that experienced in the port.

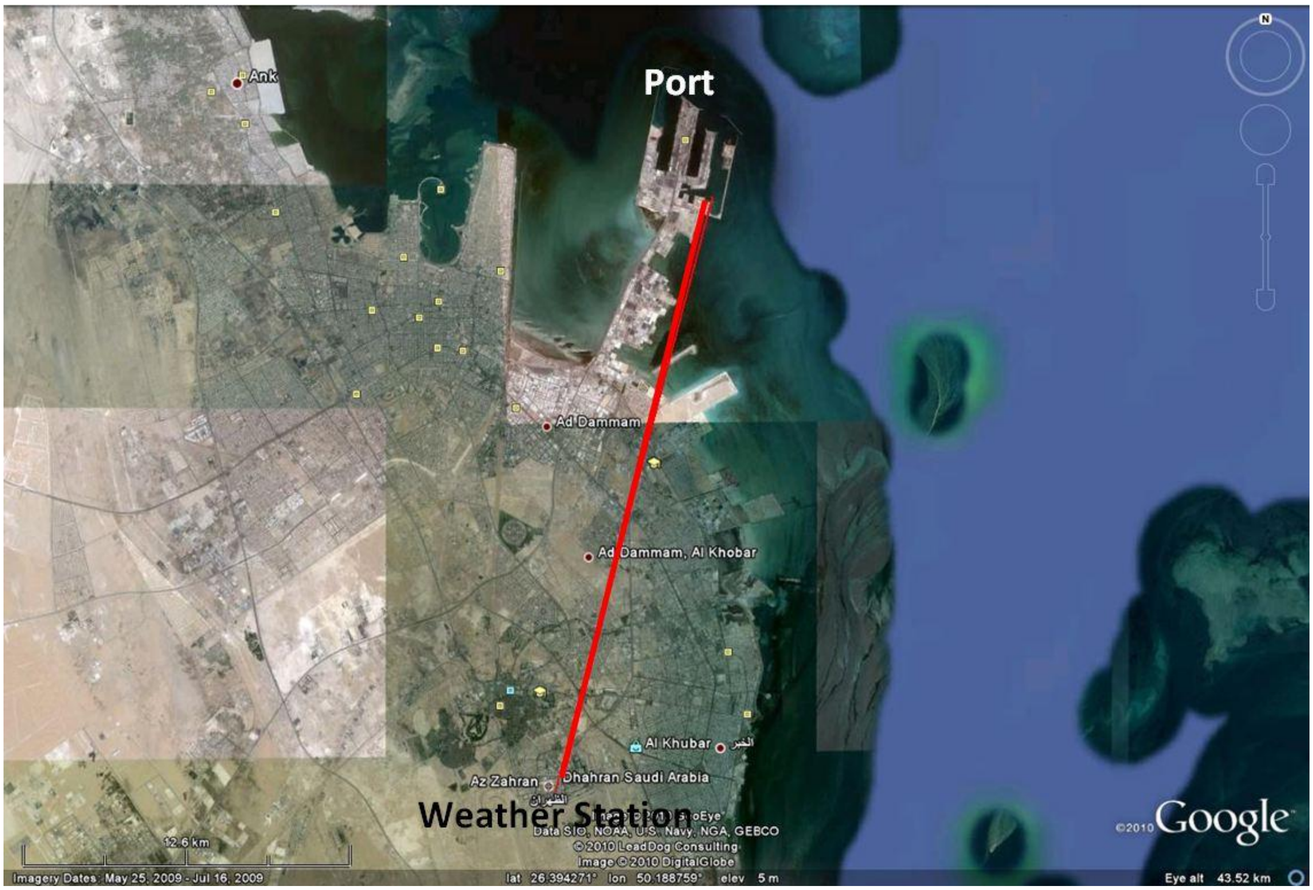

Figure 51. Google Earth image showing the location of the Port of Dhahran (Ad Dammam) with the Dhahran Airport weather station located 23 km to the south of the port.

8.13 KUWAIT

8.13.1 Kuwait

There are two possible weather stations to represent the Port of Kuwait. The first is the Kuwait International Airport weather station (Station number 405820, 29.222°N, 47.966°E), located at an elevation of 48 metres at a distance of 15 km to the south of the port and 12.6 km inland from the Arabian Sea over a flat coastal plain, as illustrated in Figure 52. Wet bulb temperature data were obtained for this location for the period from 25 January 1963 through to 1 December 2010, a very long and reliable period of record.

The second weather station available is the Kuwait City weather station (Station number 405810, 29.378°N, 47.996°E), located at an elevation of 7 metres at a distance of 7 km to the east north east of the port and adjacent to the Arabian Gulf. Wet bulb temperature data were obtained for this location for the period from 28 January 2007 through to 1 December 2010, a relatively short period of record. The best wet bulb temperature climatology for the port should be the Kuwait City climatology, unless there are higher values from the airport location as it is in a more representative location.

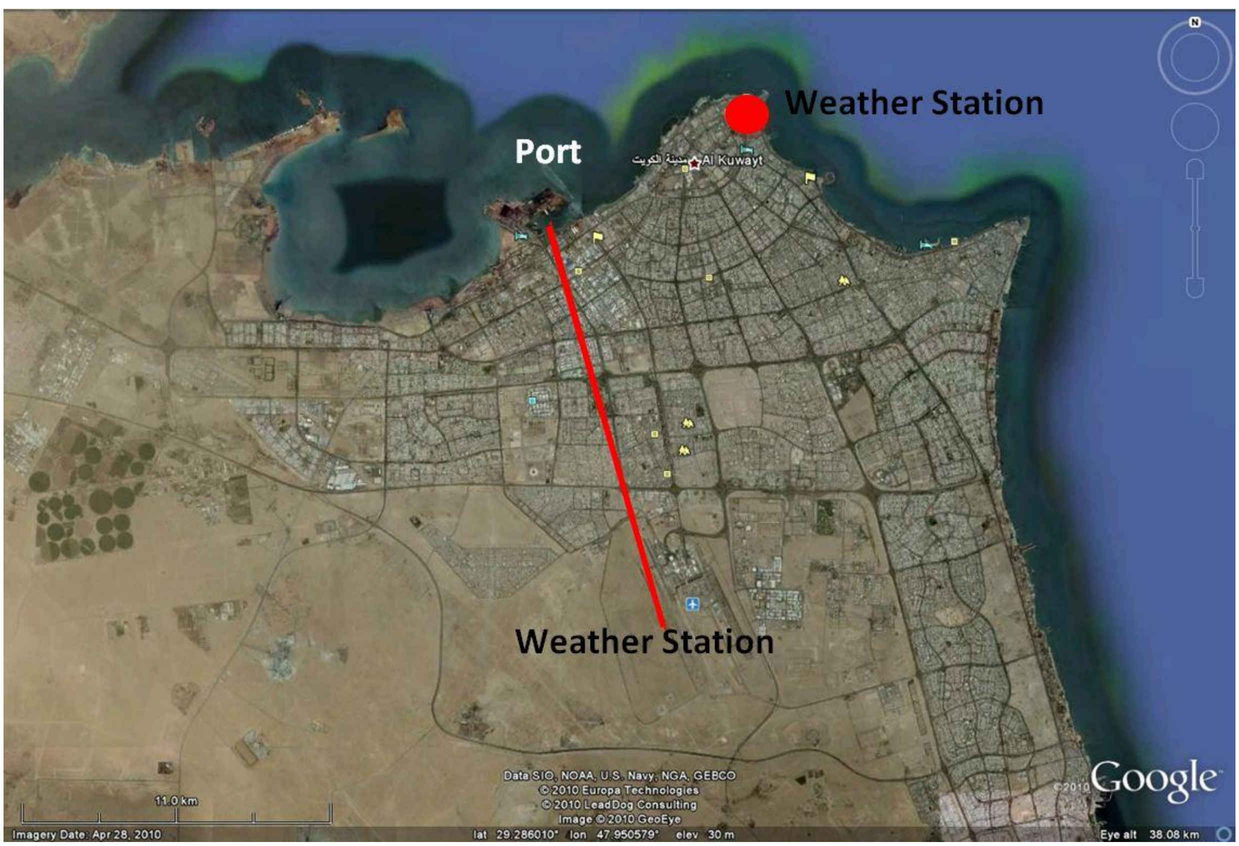

Figure 52. Google Earth image showing the location of the Port of Kuwait with the Kuwait International Airport weather station located 15 km to the south of the port and the Kuwait City weather station 7 km to the east north east.

8.14 BAHRAIN

8.14.1 Manama

The closest suitable weather station to represent the Port of Manama is the Bahrain International Airport weather station (Station number 411500, 26.267°N, 50.650°E), located at an elevation of 2 metres at a distance of 7 km to the north northwest of the port and adjacent to the Arabian Sea, as illustrated in Figure 53. Wet bulb temperature data were obtained for this location for the period from 19 March 1944 through to 1 December 2010, a very long and reliable period of record. The wet bulb temperature climatology for the airport should be a very representative climatology for the port.

Figure 53. Google Earth image showing the location of the Port of Manama with the Bahrain International Airport weather station located 7 km to the north northwest of the port.

8.15 QATAR

8.15.1 Doha

The closest suitable weather station to represent the Port of Doha is the Doha International Airport weather station (Station number 411700, 25.250°N, 51.567°E), located at an elevation of 10 metres at a distance of 4.5 km to the south of the port and adjacent to the Arabian Sea, as illustrated in Figure 54. Wet bulb temperature data were obtained for this location for the period from 1 January 1983 through to 1 December 2010, a long and reliable period of record. The wet bulb temperature climatology for the airport should be a very representative climatology for the port.

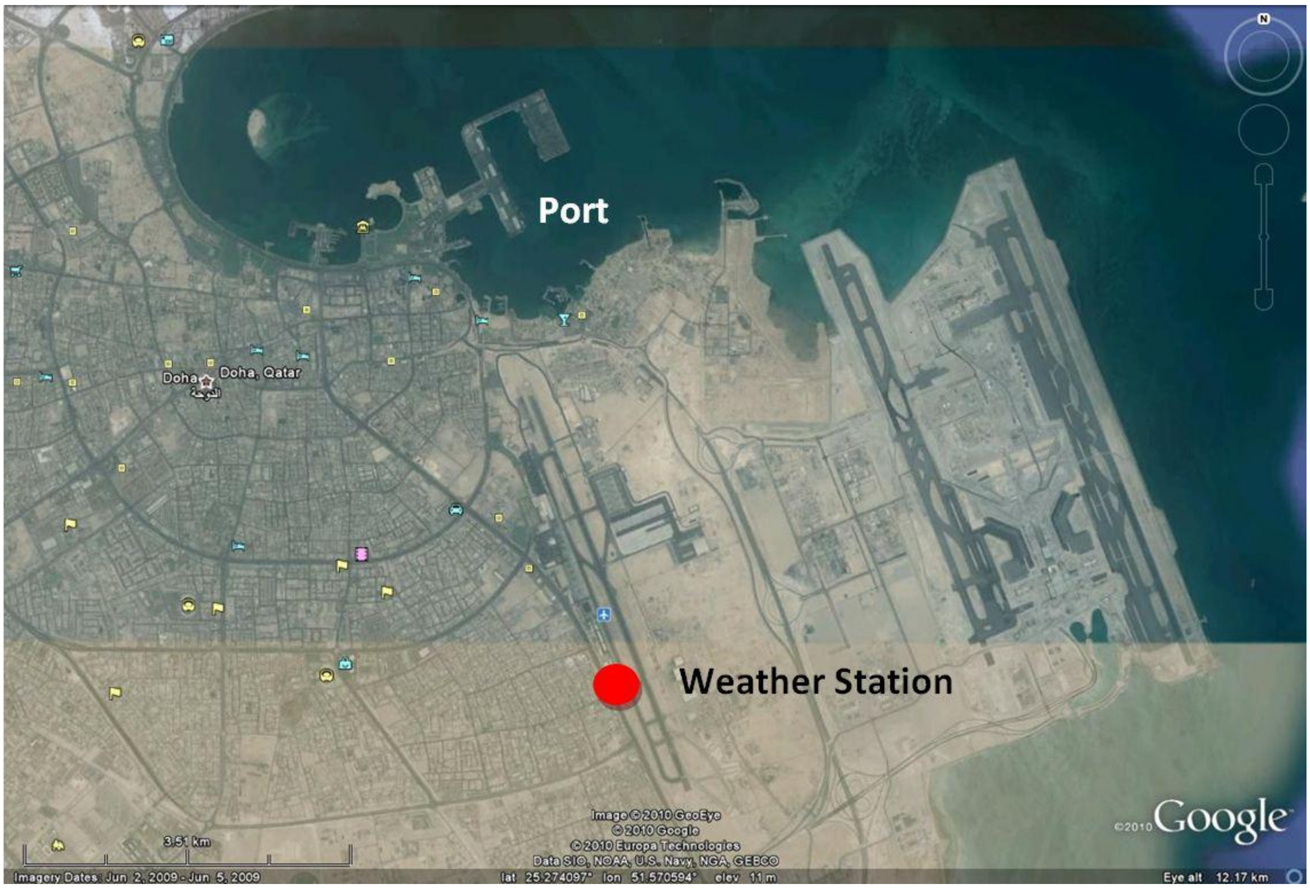

Figure 54. Google Earth image showing the location of the Port of Doha with the Doha International Airport weather station located 4.5 km to the south of the port.

8.16 UNITED ARAB EMIRATES

8.16.1 Dubai and Jebel Ali

The closest suitable weather station to represent the Ports of Jebel Ali and Dubai is the Dubai International Airport weather station (Station number 411940, 25.250°N, 55.333°E), located at an elevation of 10 metres at a distance of 40.5 km to the northeast of the Port of Jebel Ali and 7 km inland from the Port of Dubai, as illustrated in Figure 55. Wet bulb temperature data were obtained for this location for the period from 1 January 1983 through to 1 December 2010, a long and reliable period of record. The wet bulb temperature climatology for the airport should be a quite representative climatology for the two ports.

Figure 55. Google Earth image showing the location of the Ports of Doha (top) and Jebel Ali (lower left) with the Dubai International Airport weather station located 7 km inland from the Port of Dubai shown by the red dot.

8.16.2 Fujairah

The closest suitable weather station to represent the Port of Fujairah is the Fujairah International Airport weather station (Station number 411980, 25.100°N, 56.333°E), located at an elevation of 46 metres at a distance of 8.5 km to the south southwest of the port, as illustrated in Figure 56. Wet bulb temperature data were obtained for this location for the period from 17 September 1991 through to 1 December 2010, a long and reliable period of record. The wet bulb temperature climatology for the airport should be a quite representative climatology for the port.

Figure 56. Google Earth image showing the location of the Port of Fujairah with the Fujairah International Airport weather station located 8.5 km to the south southwest of the port.

8.17 OMAN

8.17.1 Muscat

The Port of Muscat is located in a marked inlet surrounded by relatively high terrain. There is no weather station in the immediate vicinity of the port. The best available is from the old and new Seeb International Airport weather stations (Station numbers 404620 and 412560, both at 23.583°N, 58.283°E), located at an elevation of 14 metres at a distance of 31.5 km to the west of the port, as illustrated in Figure 57. Wet bulb temperature data were obtained for the old Seeb Airport for the period from 2 May 1974 through to 1 December 1982, a relatively short and incomplete period of record. Wet bulb temperature data were also obtained from the new Seeb International Airport from 1 January 1983 to 22 December 2010, a long and continuous period of record.

The wet bulb temperature climatology for the airport, particularly the new airport which has more current data, should be a generally representative climatology for the port but this is one location where it is quite possible that the wet bulb temperature distributions within the port may be a little higher than for the airport.

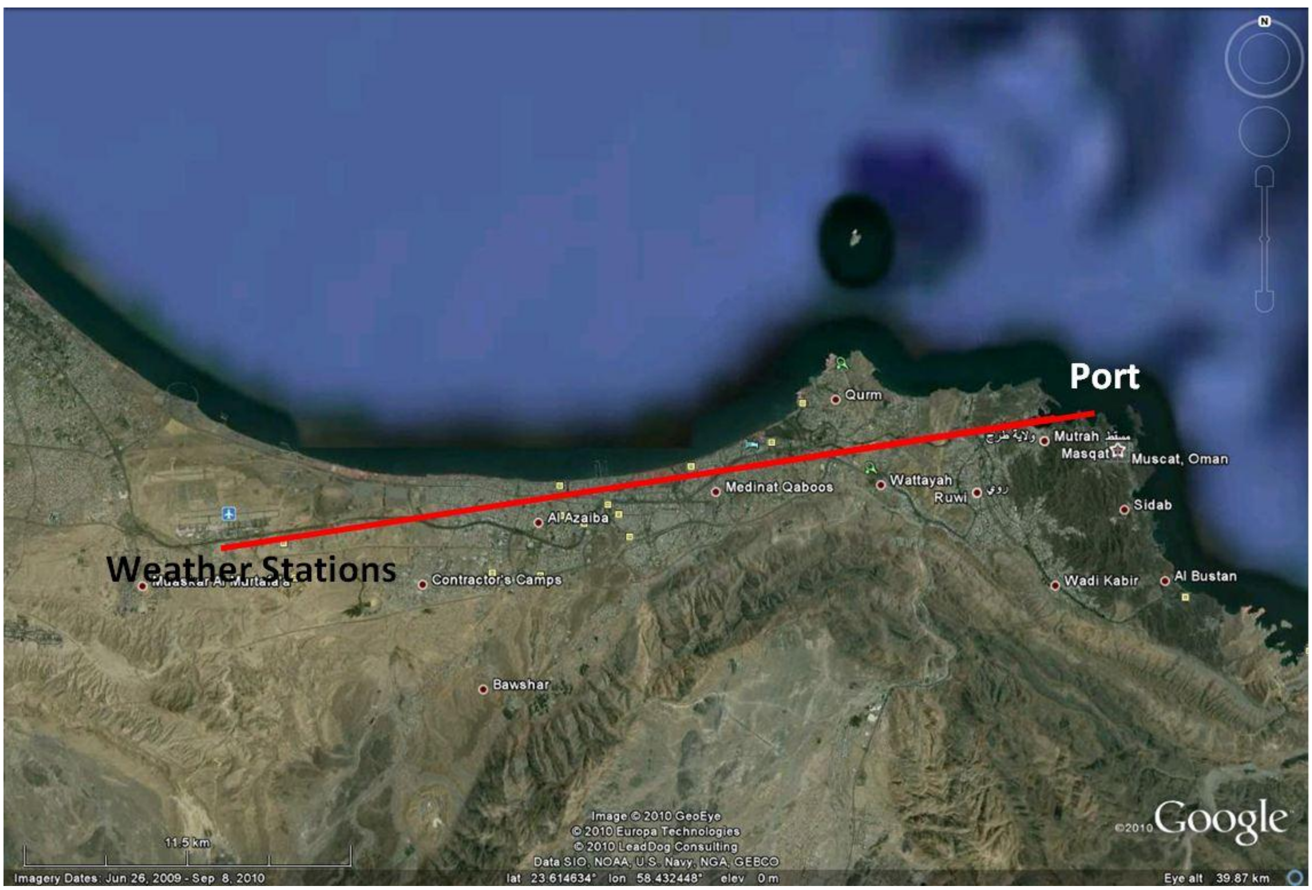

Figure 57. Google Earth image showing the location of the Port of Muscat with the Seeb International Airport weather station located 31.5 km to the west of the port.