Salvaliant Report

Corrected draft

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INTRODUCTION

1. The purpose of this report is, in broad summary, as follows:

    1.1. To explain the basic methodologies involved in wind and wave forecasting, and the nature and extent of the limitations thereof.

    1.2. To report on the weather, but in particular the wind conditions, which prevailed off the Western Cape between 21 and 25 June 2009.

WIND AND WAVE FORECASTING

Introduction

2. Wind and wave forecasting is similar to weather forecasting. It is a prediction of what the weather, wave or surface wind field will be like in an hour, tomorrow, or in a few days.

3. Wave forecasting is an active research field, and the best forecasts are made by the national weather services in USA and Europe. They do not, however, make tailor-made forecasts for specific clients. That market is dominated by

metocean service providers and consultants such as the American Meteorological Institute (*AMI*) and Terra Weather (*TW*).

4. Even the best national weather or metocean services cannot provide all of the information required for an accurate assessment of all risks associated with wave and wind conditions which may be encountered at sea. Some of the relevant wave and wind properties cannot be calculated or observed.

5. Although progress has been made in recent years in numerical wind and wave forecasting, and in providing tailor-made wave forecasts for end users, there are still many uncertainties, and important information is still not readily available to the end user in layman's terms.

6. The accurate forecasting of extreme weather, such as tornadoes, tropical cyclones, storm surges, and floods is, for example, still very challenging, and the subject of research worldwide.

Forecasting methodologies

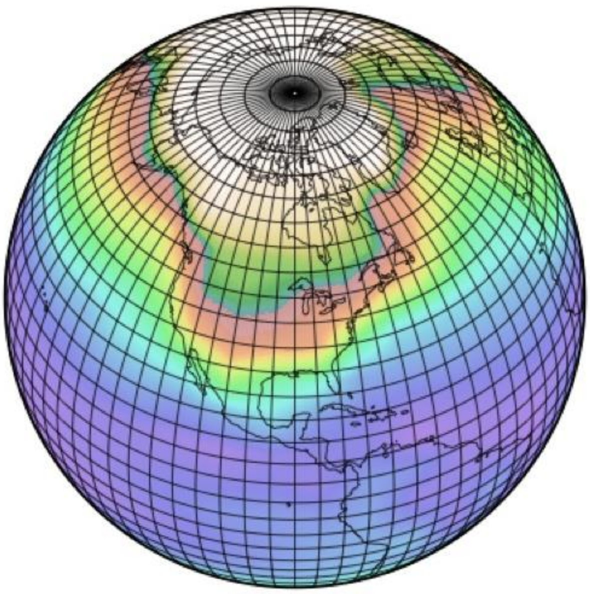
7. There are several different methods that can be used to create a forecast. The method a forecaster chooses depends upon the experience of the forecaster, the amount of information available to him or her, the level of difficulty that the forecast situation presents, and the degree of accuracy or confidence needed in the forecast.

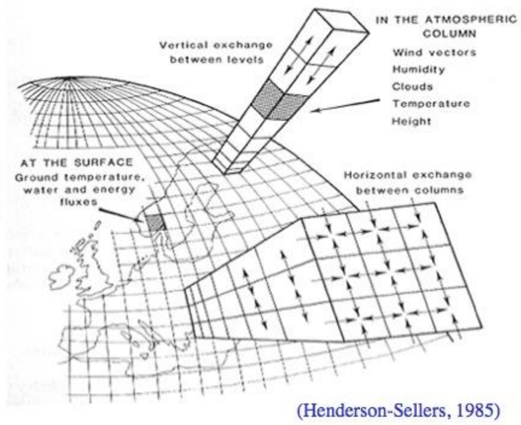
8. Numerical weather or wave prediction (***NWP***) uses the power of computers to produce a forecast. Complex computer programs, also known as forecast

models, run on supercomputers, provide predictions on many atmospheric variables such as temperature, pressure, wind, and rainfall.

9. The amount of computer time and power necessary to solve the equations limit the spatial and time resolution of the forecasting models.

10. Forecasted wind and wave properties are calculated for a discrete point location on a grid (for example 50 km by 50 km or 100km by 100km). The atmospheric models divide the atmosphere, oceans and land into a 3-dimensional grid system shown below. The equations are then calculated for each cell in the grid and at each time step (for instance every 3 hours).





(Henderson-Sellers, 1985)

11. Contrary to what one might expect, a higher resolution of the grid (for instance 50 km by 50 km as opposed to 100 km by 100 km) at sea will not necessarily result in the calculated wind or wave values being more accurate. Although a

chart for the estimated conditions would probably show a difference in the forecasted wind and wave conditions, the accuracy of the results is questionable due to limitations in the spatial and time resolution of the model, the equations used to simulate the weather and the waves, and the algorithm used to solve the equations (because the equations cannot be solved directly, one needs to use an algorithm to approximate those equations). This being the case, the difference in reporting in a position of say 1 to 2 degrees off the west coast of South Africa, would not make a big difference (particularly because of the paucity in observational data for that region, as dealt with further below).

12. Surface wind forecasts are meant to represent wind speeds at the standard height of 10 metres above sea level. Wind speed increases with height above the ground or sea surface and follows a logarithmic profile as a function of height above the sea surface. In reality, wind gusts can be 50% stronger than the average wind speed, with even stronger gusts near showers and cold fronts.

13. Wave forecasts depend upon accurate wind forecasts.

14. Weather forecasting involves the consideration and analysis of a combination of computer model simulations, observations from weather buoys or satellites, remote sensing, human intervention and local knowledge, wave and wind climatology, trends and patterns. By using these sources, reasonably accurate weather forecasts can be made up a few days in advance, although limitations exist in wind and wave forecasts, which may make them less accurate.

Comparing weather forecasts and the conditions actually experienced are key to improving forecasts, and the reason of the improvement in weather forecasting over the last 20 years.

15. The accuracy of a forecast (i.e. of the model output) depends upon the parameterisation of the particular model (i.e. the way physical phenomena are described by a set of mathematical equations), the extent and quality of the input data, and its assimilation into the model (for instance wind speed and direction as an input of wave forecasting, as explained below).

16. Forecasting is accordingly less accurate in regions where there are fewer or no observations, such as in the south Atlantic (where the long period swells that affected the region in which the Salvaliant lost her tow were generated).

17. Because forecasted wind and wave properties are calculated by computer, they will be different to the actual wind and wave properties which would be observed by a human being at the relevant time. The forecast properties usually represent a 3 hour average, centred on the time stamp (the time of the forecast), and are a lot smoother than reality.

18. As a result, one cannot expect to have an exact match between an observation at a certain time and position, and a weather forecast for that time and position. The timing of the forecasted event is not accurate enough to enable such a comparison. By way of analogy, it amounts to comparing the average speed of a car over a three hour journey to the instantaneous speed of that car at any time during the journey. One could not determine the accuracy of the average speed calculation by reference to the instantaneous

speed. If one was to undertake such a comparison between the forecasted parameters and those observed at a particular time, one would have to compare the forecast to an average of about three hours' worth of observations around the relevant time.

19. Furthermore, the longer the forecast period, the less accurate the forecast. A two day forecast is less accurate than a one day forecast. Two to three day rain forecasts are quite accurate in the Western Cape. The forecasting of extreme weather (such as the conditions experienced on 23 June 2009 of the west coast) is always problematic. Furthermore, because wave forecasts are reliant on wind forecasts, the former can only be less accurate that latter.

20. The AMI and TW wind and wave forecasts which were provided to the "Salvaliant" were the output of numerical wind and wave forecast models, sent as bulletins containing the relevant information. These bulletins contained information similar to that available on the internet on websites such as Windguru, Magic Seaweed or the US Navy's Fleet Numerical Meteorology and Oceanography Centre (FNMOC) website.

21. The added value of the forecasts provided to the "Salvaliant" lay in the format of the bulletins, and in the fact that they were tailor-made for the position in which the "Salvaliant" and her tow was estimated to be located from time to time.

22. These forecasts fall to be contrasted with those issued by the South African Weather Service (SAWS). It is understood that SAWS issues marine forecasts (24 hours) and advisories for two different zones:

22.1. The first is for Coastal Waters, which cover a range of up to 50 nautical miles offshore, for which Orange River to Cape Agulhas was the relevant zone.

22.2. The second is for the High Seas, and the relevant area is Cape West which covers the area 0° to 20° East and 30° to 40° south. This area is divided into two sub-areas on either side of 10° east. The area from 10° east to 20° east covers an area of approximately 500 nautical miles (between 10° to 20° east) by 600 nautical miles (between 30° to 40° south), an area of approximately 300,000 square nautical miles.

23. These SAWS forecasts are generic, both in the sense that they cover large areas, and a 24 hour period ie. as opposed to the much shorter intervals used in the metocean forecasts. The SAWS forecasts are, as a result, less precise in time and space.

24. Most wave models use the same forecast computer model, being Wavewatch III.

25. The wind input for the wave model is derived from an atmospheric model, run in house by the relevant metocean service provider, or from an atmospheric global climate model such as the Global Forecast System (***GFS***). The wave models accordingly depend on calculated surface wind speeds, representing wind speeds at a standard height of 10 metres above sea level, derived from numerical wind prediction models.

26. In general at a weather forecasting service a team of forecasters examine how the features predicted by the computer will interact to produce the day's

weather, also, where possible, using satellite remote sensing images and local observations. In the case of the “Salvaliant’s” forecast, the NWP output is sent out as a bulletin.

27. Computer models are programmed to solve mathematical equations (Navier Stokes equations) which describe the flow of air in the atmosphere, including the development and evolution of storms. The equations describe changes in wind, temperature, pressure, water vapour amount, cloud water amount, etc. at selected points in the atmosphere. For example, a modeller might start solving the equations at some time, T, calculating values at the selected points 10 seconds later. Using these new values, the solution can be computed at time T + 20 seconds. This process is often continued for hours as storms grow and decay within the modelled atmosphere.

28. The calculated surface wind speeds are then used for wave forecasting. The process of forecasting waves is accordingly a two-step process.

29. As wind speed increases with height above the ground or sea surface a logarithmic profile is used to derive wind speeds as a function as height above ground or sea level.

30. The equations used for the wave forecasts can be found in the manual for the Wavewatch III model. There are about 50 equations to be solved. The implicit assumption of these equations is that properties of the medium (water depth and current) as well as the wave field itself vary on time and space scales that are much larger than the variation scales of a single wave.

Errors and uncertainties in wind and wave forecasting.

31. The NWP method has limitations in that the equations used by the models to simulate the atmosphere are not precise. This leads to inaccuracies in the forecasts. The extent of the inaccuracies increases as a function of lead time. As set out above, the models depend on observations, and will be less accurate when their less observations available for the particular area in respect of which the forecast is being generated. As also already stated, there are no weather observations from the southern ocean which are assimilated by the numerical models used to produce the wind field. If the initial state is not completely known, the computer's prediction of how that initial state will evolve will not be entirely accurate. There are also not many observations to validate those models and improve them.

32. Predicting the significant wave height is the most important function of operational wave models. In spite of recent developments in wind and wave modelling, it is still a challenge to predict extreme wave heights accurately.

33. A model run a second time will give a different result than the first time. This is because the equations to be solved cannot not be solved directly but can only be approximated by complex algorithms.

34. In order to overcome inaccuracies in wave forecasting, some institutions provide probabilistic wave forecasts based on ensembles, which involve running a model several times. The probabilistic wave forecasts provide mean values, spread and probability at different thresholds of wind speed and wave height.

35. Surface currents are not yet taken into account operationally in the wave and weather models. This is particularly problem west and south of South Africa where the Agulhas Current and associated eddies or rings have the potential to deflect the direction of the swell by as much as 90° or to create island effects ie. such as where a swell wraps around an island and is deflected.

36. Adding ocean current in a wave forecast will also improve the wave forecasts, especially in the Agulhas current system and in the Gulf Stream, where the current is strong.

37. Neither TW nor AMI produce ocean ensemble ocean wave forecasts and do not integrate the effect of current.

THE WEATHER CONDITIONS WHICH PREVAILED OFF THE WEST COAST BETWEEN 21 AND 25 JUNE 2009

Introduction

38. A series of three low pressures and associated cold fronts passed over South Africa during the period 21 to 25 June 2009. There was no cut-off low experienced during this period, just the three cold fronts.

39. Low pressure systems and associated cold fronts in the southern hemisphere move from west to east and have the same pattern. In general, the wind is initially north-westerly and increases with time. The associated cold front moves in with gale to severe gale force winds, which become very gusty and it rains. As the cold front passes and the low pressure move eastwards, the

wind veers to the west and then to the south-west, south and sometimes even south-east.

40. The second storm on 23 June 2009 was the strongest, with westerly to south-westerly gale to strong gale force winds. For example, the maximum hourly average recorded wind speed at Cape Point was 45 knots (from the south-west) on 23 June[1].

41. Climatology, data from various coastal stations, and satellite derived surface wind speed estimates show that the winds were/are weaker to the north than to the south, with little change along the same latitude lane.

42. Climatology and satellite derived surface wind speed estimates also show that winds are weaker near the coast (Figure 2). This is due to the effect of the cold coastal upwelling that stabilizes the atmosphere in its first 50 meters, somehow partially isolating that surface layer from the storm. Winds are also generally weaker near the coast due to the orographic and friction effect. Such stabilisation of the atmosphere by a cold surface can be seen in the Cape Flats in winter when the cold surface air at night and early morning creates a stable layer at the surface that traps pollution at the surface. This stabilisation also explains why the speed of a strong southeaster is generally lower during the night and early morning above land in the Western Cape.

<u>Climatology</u>

[1] Which is far below the wind speeds associated with tropical cyclones, which range from 45 to 120 knots, depending on the particular classification prevailing in the relevant country.

43. South Africa has a subtropical climate, but the Western Cape coastline is affected by temperate weather systems, especially in winter, and the Western Cape climate has been characterised as Mediterranean.

44. The Western Cape is under the influence of the South Atlantic high pressure system, the Santa Helena anticyclone (Figure 1). This creates fair weather and low wind speeds in winter. Low pressure systems such as cold fronts and cut-off lows bringing high winds and rain to the Western Cape, especially from May to August, with on average one frontal system a week brushing the continent.

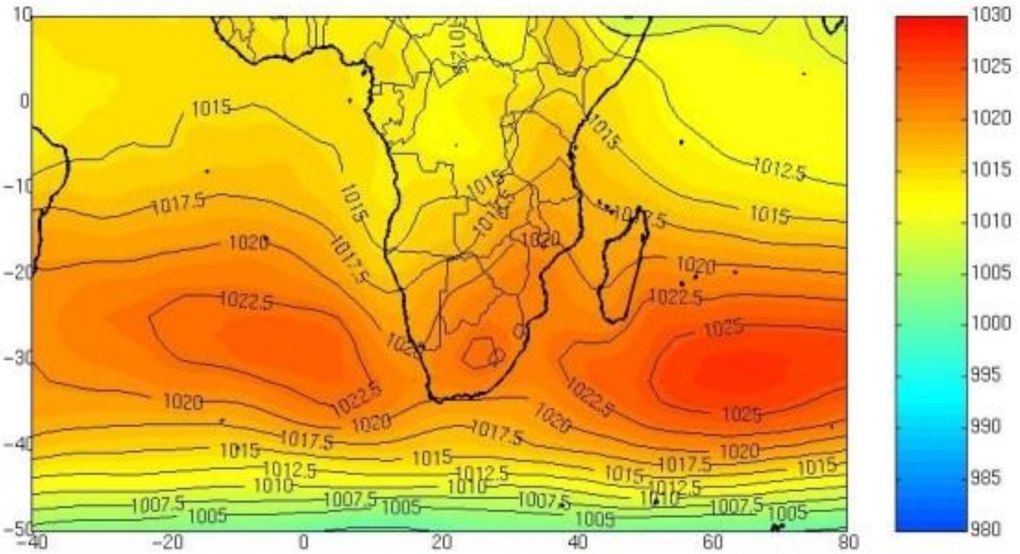


Figure 1: Sea level pressure winter climatology showing the dominant weather pattern around South Africa. To the west the Santa Helena anticyclone, to the east the Mascareigne anticyclone. To the south the belt of low pressure.

45. Figure 2 is a wind speed climatology. It will be noted that from Cape Point to Cape Columbine the wind speed climatology in June decreases by roughly 22%, from 17.5 knots to 13.6 knots on average. The wind is also weaker along the west coast due to the cold water of the Benguela Current, which, for

reasons explained above, creates a stable surface layer that partially isolates the surface from the storm, leading lower wind speeds. As also already referred to above, the wind decreases from south to north, with little variation in the latitude lanes (http://apdrc.soest.hawaii.edu/datadoc/qscat_mon_clima.php)

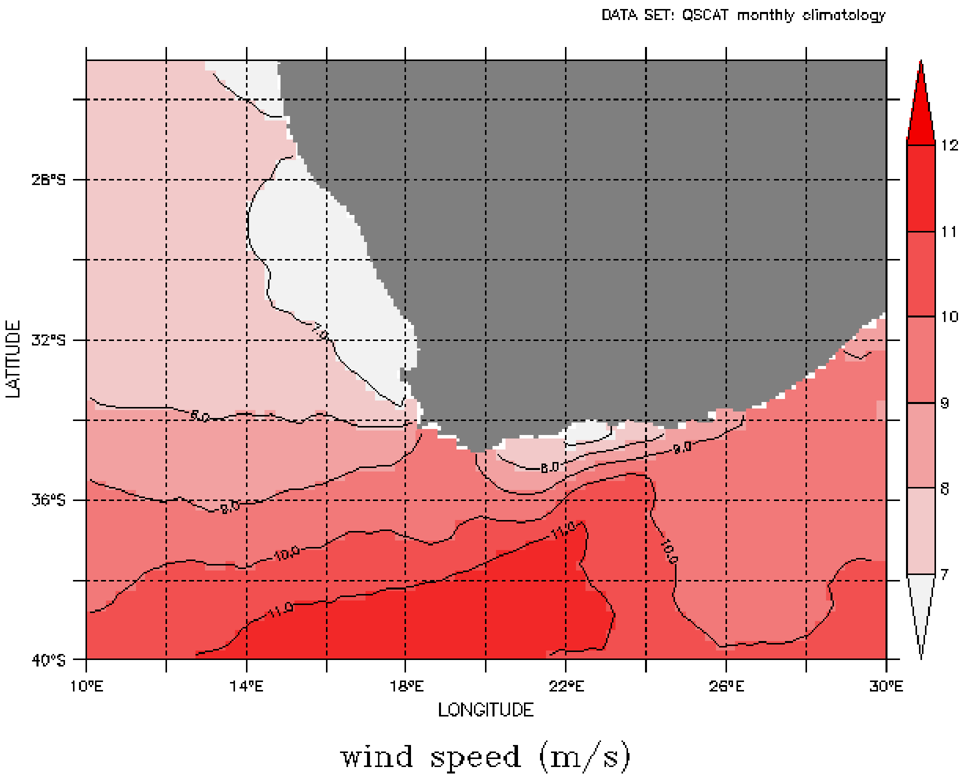
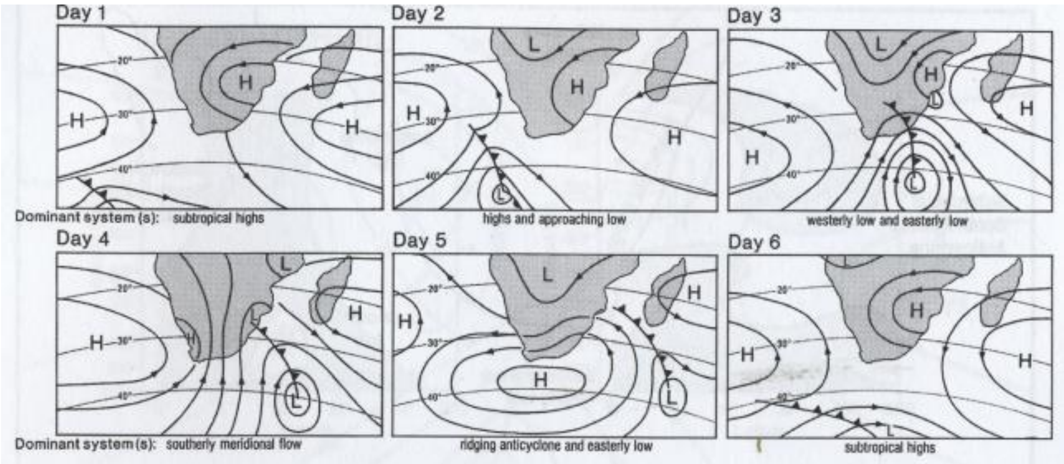


Figure 2: Wind speed climatology in m/s (for Knots multiply by 1.9) from Cape Point to Cape Columbine the wind climatology decrease roughly by 22 % from 17.5 Knots (9 m/s) to 13.6 Knots (7 m/s) on average. Wind is weaker to the north and also near the coast due to the cold coastal upwelling water that stabilise the atmosphere at the surface. There is little variation in the latitude lanes.

46. Figure 3 shows a typical weather pattern for South Africa. The country and surrounding ocean is under the influence of the subtropical high pressure systems on day 1, while a low pressure and attendant cold front move eastwards and cross the country on day 3, bringing strong winds from days 2 to 3 on the West Coast. The low pressures system and associated cold front (represented by a spiked line across the low pressure system) move from

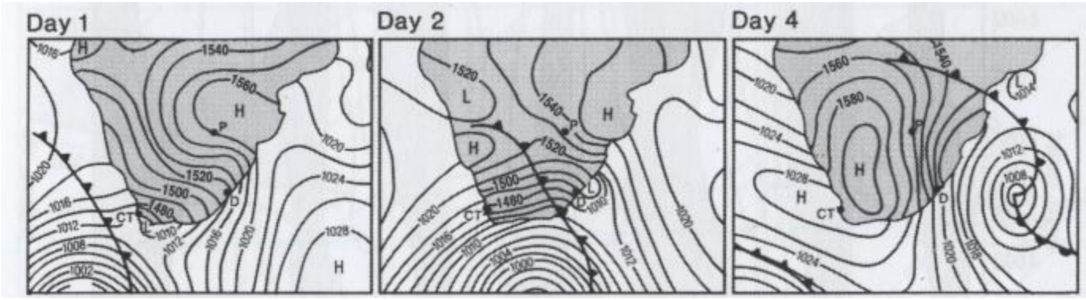
west to east while inside the system the wind is cyclonic (clockwise) and follows the isobars (circular lines of same pressure). The closer together the isobars, the stronger the winds. On days 4 to 6 the high pressure moves in, creating fair weather in winter but strong south-easterly winds in summer. Sometimes two or even three low pressures of different sizes can follow each other in winter. Periods of calm lasting two weeks are however not uncommon in winter.



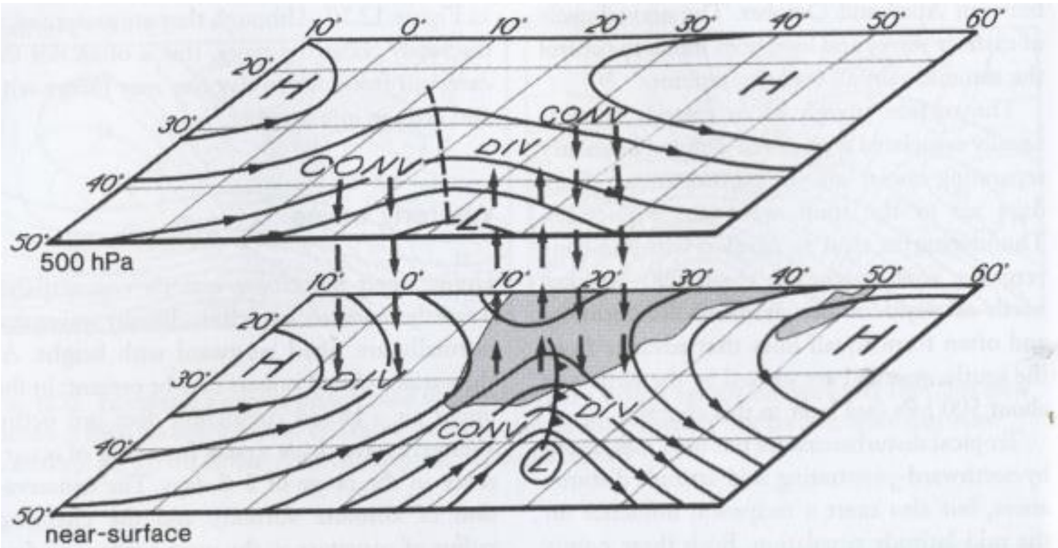
<u>Figure 3</u>: Typical weather pattern in South Africa. The spiked line is the cold front associated with the low pressure system to the south. The high pressures to the west and east of the continent are marked by an H, and wind is anticlockwise along lines of the same pressure (isobars). High pressures systems are almost stationary. The low pressure is marked by an L and moves from east to west while the winds move clockwise along quasi circular lines of the same pressure, also called isobars.

47. <u>Figure 4</u> shows a typical deep low pressure system passing across South Africa in winter, whilst <u>figure 5</u> shows the vertical structure of a low pressure system and associated cold front. On day 1 the wind is north-westerly and the cold front is just off the continent. Above the ocean, the wind is weaker to the north, where the isobars are wider. On day 2 the wind is south-westerly and the cold front is above the continent. Above the ocean, the wind is still weaker

to the north, where the isobars are wider. On day 4 it has passed the continent.



<u>Figure 4</u>: Typical low pressure system and cold front development in winter time.



<u>Figure 5</u>: Surface expression and mid-tropospheric expression of a low pressure system and cold front.

48. <u>Figure 7</u> shows the vertical structure of a cut-off low, another rain bearing system which is quite different in structure and effect from a low pressure system and attendant cold front, as discussed above. First, the waves are mostly from a south-easterly direction, and are in the 3 to 5 meter range, while for a cold front they move from a south-westerly direction and can reach up to 18 meters (largest wave recoded in South Africa) or more. Cut-off lows are

responsible also for most of the serious flooding in South Africa, and for the Western Cape's infamous "black southeaster" (basically persistent south-easterly wind, cloud and rain).

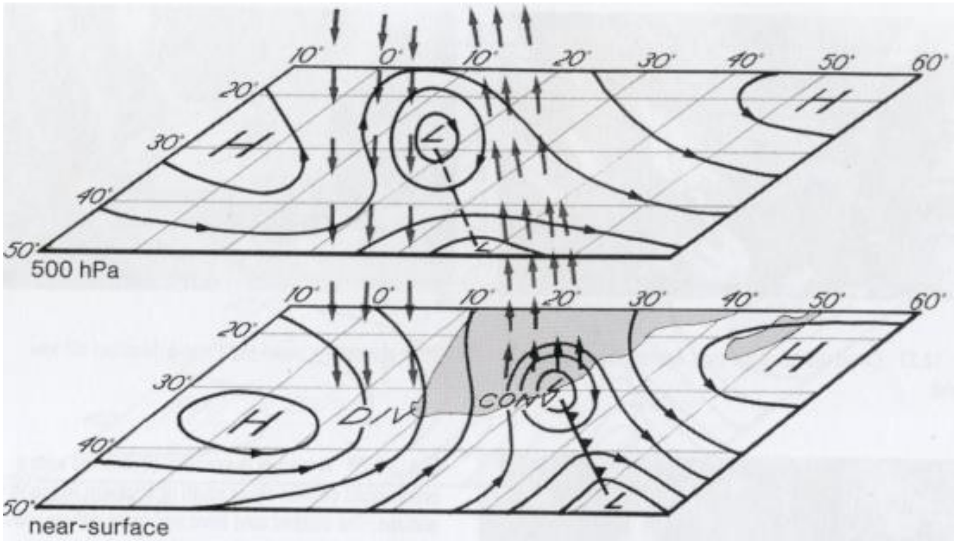


Figure 6: Surface expression and mid-tropospheric expression of a cut off low. The bottom panel is the near surface pressure while the top panel indicates high and low pressure in the middle of the troposphere, at a height of roughly 5000m.

49. The difference between a low pressure system and attendant cold front, and a cut-off low, is apparent from a comparison between Figures 7 and 8:

49.1. Figure 7 is a chart of the mid-tropospheric expression of the 23 June 2009 low pressure system. It reflects the height where the pressure is 500 millibar (500 mb is equivalent to 500HPa), using a scale of 1/10m (ie. 580 means 5800 meters). It is similar to the upper panel of Figure 6. A storm is about 10km high so the 500HPa is a good way to indicate the location of the storm in the middle of the troposphere. The low pressure is indicated by lower heights. Figure 7 and the following 500 mb charts are the product of the NCEP Atmospheric Global Model.

49.2. Figure 9 is a chart of a well-documented cut off low which occurred on 8 June 2011. It is clear from Figures 10, 12, 14, 16 and 18 that no cut off low was involved in the sequence of low pressure systems which affected the Western Cape between 21 and 25 June 2009.

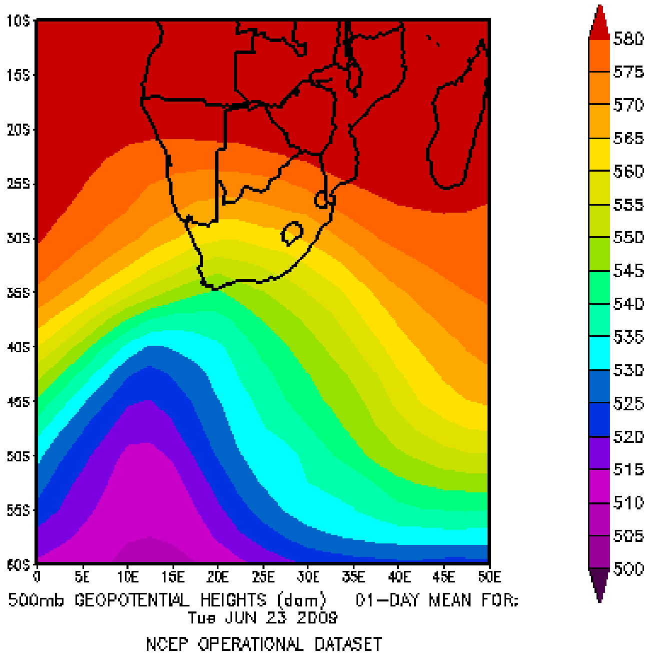


Figure 7: Mid tropospheric expression of the 23 June 2009 low pressure system and associated cold front. The units reflect the height of the 500 millibar pressure on a scale of 1/10m (iw. 580 means 5800 meters). The low pressure is clearly to the south of the continent and anchored in the sub-Antarctic, as indicated by the lower heights.

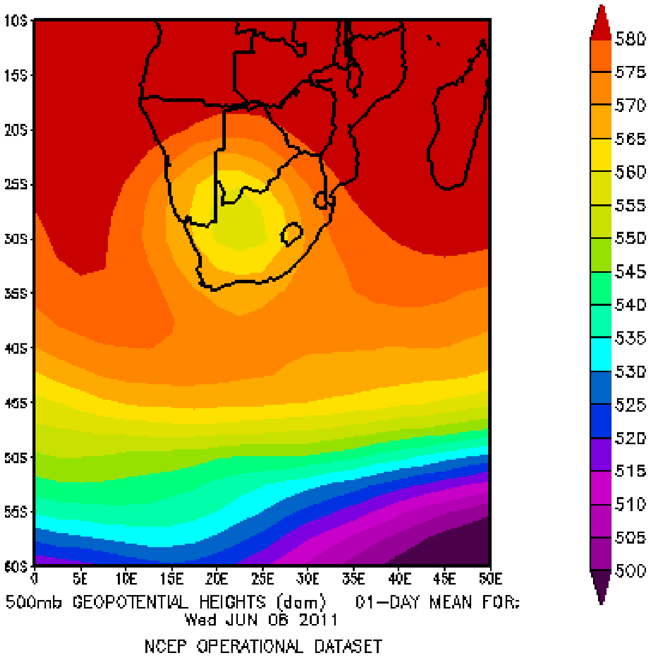


Figure 8: Mid tropospheric expression of a cut off low on 8 of June 2011 above South Africa, indicated by a circular pattern of low pressure at mid troposphere and clearly different from a cold front. The low pressure is clearly cut off from the low pressure systems to the far south hence the name "cut off low".

Weather conditions from the 21 of June to the 26 of June

50. At set out above, a series three low pressures and associated cold fronts passed over South Africa during the period 21 to 25 June 2009. This section of the report reflects and seeks to characterise the wind conditions which prevailed over the aforesaid period, and includes reference to synoptic charts prepared by the SAWS, 500 HPa heights charts, wind data from various coastal wind stations, and various satellite derived estimates of surface wind speeds and direction.

51. A synoptic chart provides a general description of the prevailing weather, and is not a forecast. A synoptic chart enables an assessment of the actual weather situation and particular weather pattern in the region of interest (i.e.

cold front or cut off low, as these weather patterns could have different effect). The synoptic charts (which are still manually drawn by SAWS personnel) are based on a combination of observation (visible on the charts as black dots with wind barbs), satellite derived observed estimations of rain, clouds, water vapour and wind, and weather forecast charts.

52. With regard to the coastal wind station data, it is important to note that due to the orographic effect (as explained above), the height of the anemometer (at the particular coastal wind stations), and the friction effect caused by buildings, vegetation, and the land in general, the wind speeds measured at the respective coastal wind stations cannot be directly compared to offshore conditions, where the winds would generally be stronger. The effect of the aforesaid variables will differ from coastal station to coastal station, and also in relation to wind direction (ie. a south-westerly wind may be impeded by a building but a northerly wind not). The coastal station wind data at least gives a good indication of the timing and intensity of events.

53. The first cold front approached the Cape on 21 June 2009 (Figures 9 and 10).

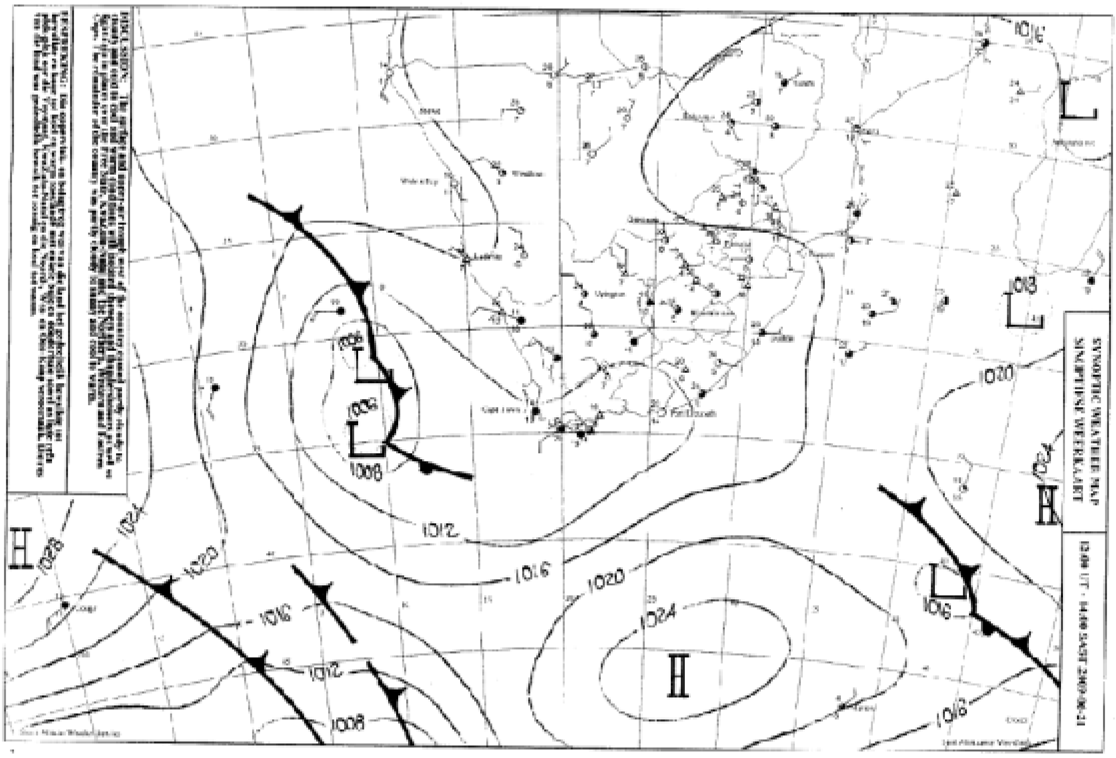


Figure 9: 21 June 2009: First low pressure system to the west of the country. The cold front is indicated by the spiked line.

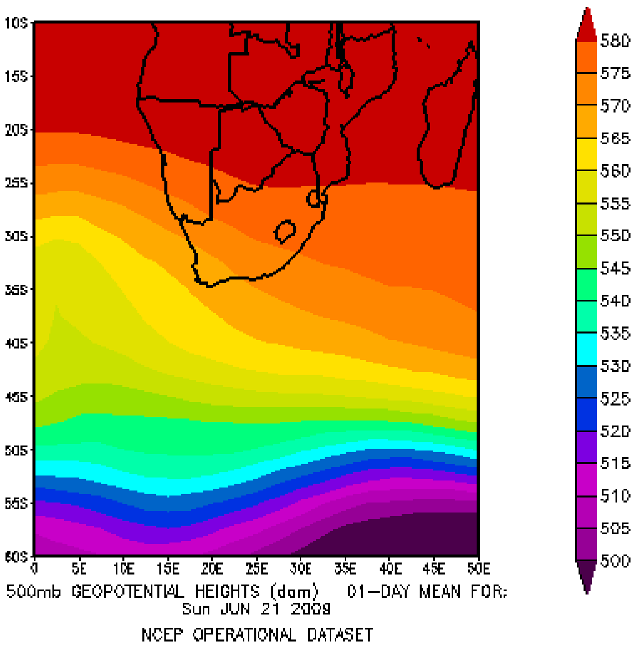


Figure 10: Mid tropospheric condition on 21 June 2009 associated with the first low pressure system. Unit is height of the 500 millibar in 10 of meter (580 means 5800 meters). It is the height where pressure is 500 millibar. This is clearly not a cut off low when compared with Figure 8. Low pressure is indicated by lower heights.

54. The low pressure associated with the cold front intensified, moved quickly eastwards on 21 and 22 June, and made landfall on 22 June at midday. By early afternoon on 22 June the frontal band had moved over the Western Cape coastline (Figures 11 and 12).

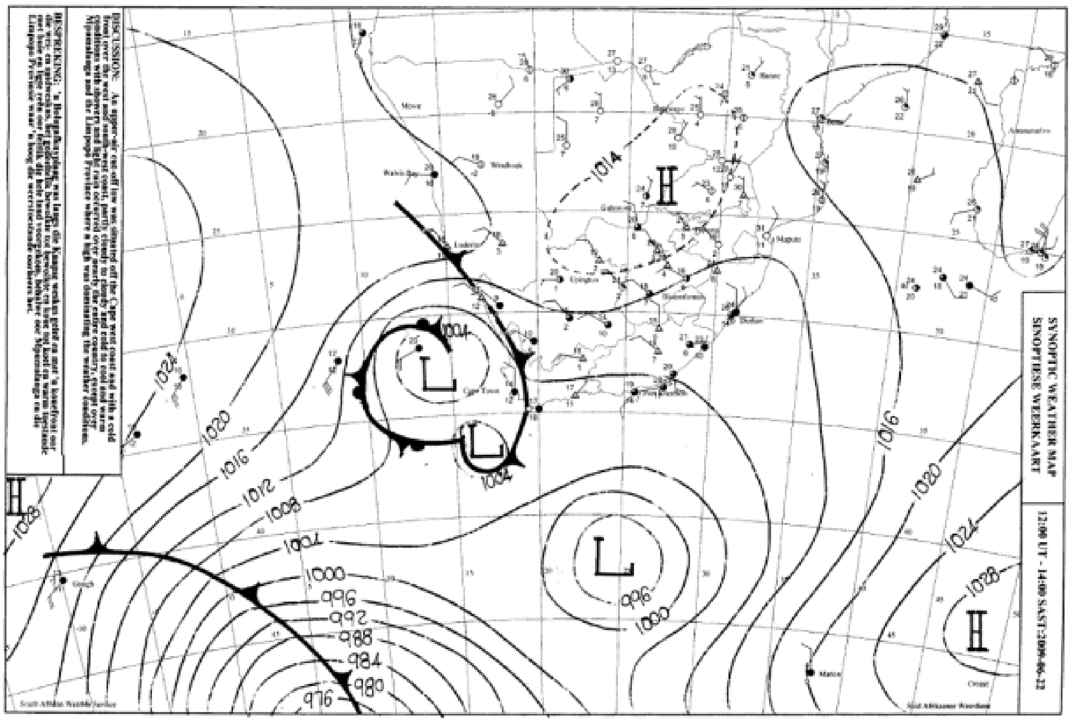


Figure 11: 22 June 2009 at 1400: The first low pressure system is affecting the West Coast. A deep low pressure system is present to the south-west of the domain.

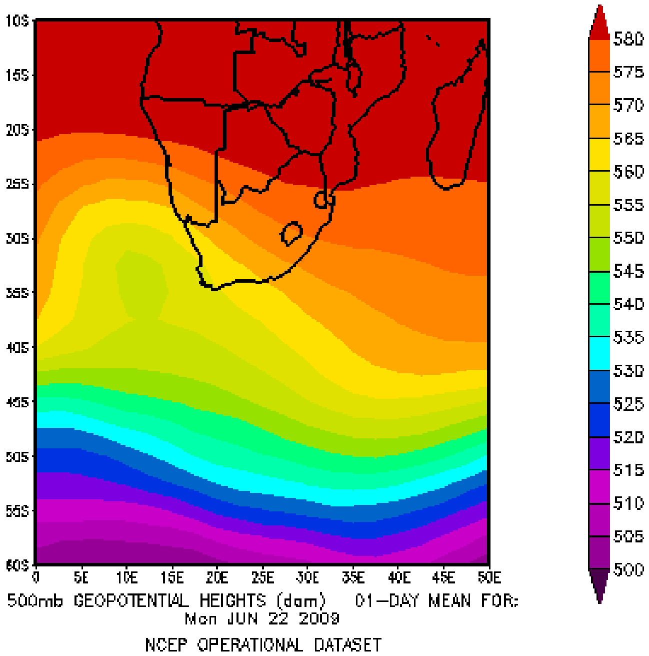


Figure 12: Mid tropospheric condition on 22 June 2009 associated with the low pressure system.

55. The wind dropped quickly during the night of 22 June as the first cold front had passed over the Western Cape coastline and moved eastwards. A second more intense and deeper cold front approached the Cape on 23 June, and made landfall during the afternoon (Figures 13 and 14). This front was unusual in its elongation, with a very long fetch creating strong south-westerly to southerly winds (and a very strong south-westerly swell).

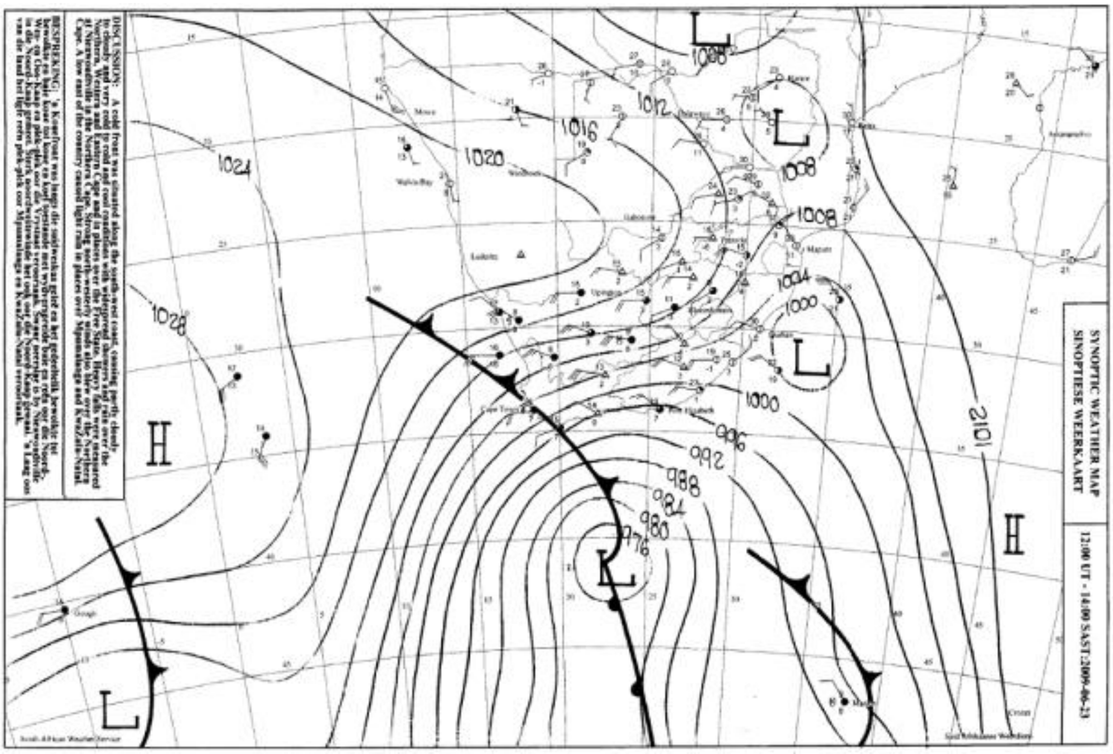


Figure 13: 23 June 2009 at 1400. The deep low pressure system is affecting the west coast. The isobars of the low pressure behind the cold front (spiked line) are tilted in such a fashion that one can expect gale force south-westerly winds and a large south-westerly swell just by looking at the chart.

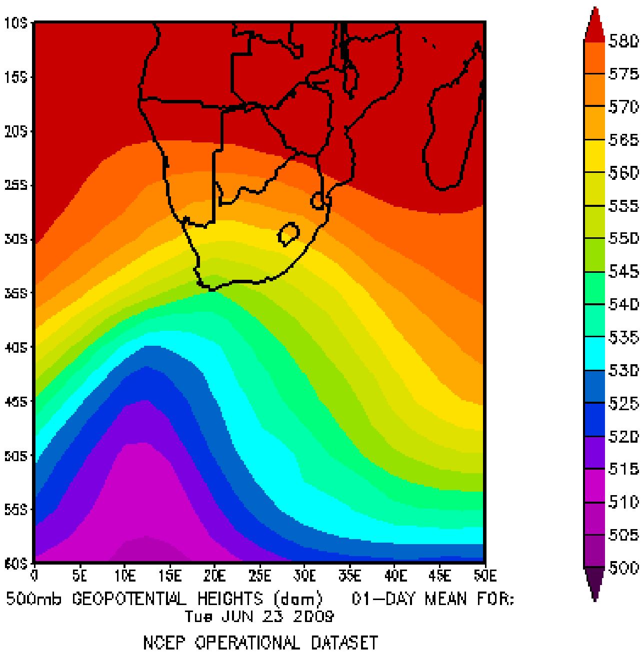


Figure 14: Mid tropospheric condition on 23 of June 2009.

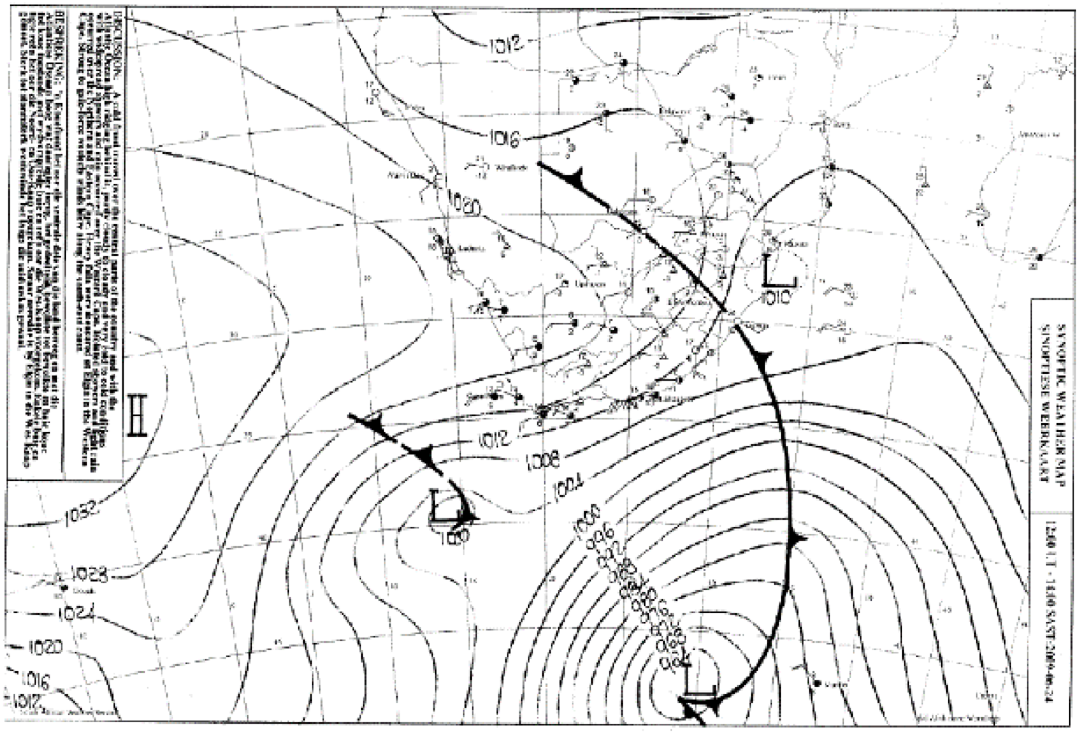


Figure 15: 24 June 2010 at 1400: the third low pressure system is west of the country.

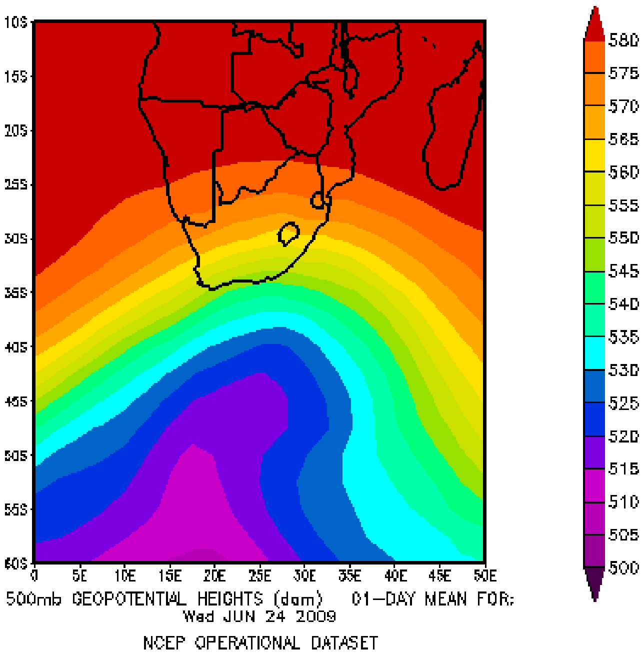


Figure 16: Mid tropospheric condition on 24 of June 2009.

56. On the 24 in the afternoon a third cold front made landfall and caused winds to intensify in a north-westerly direction. Wind increased steadily along the coast and peaked up around midnight. Wind decreased during the night and veered from north-westerly to south-westerly. That storm did not last as long as the second cold front, having made landfall at around midday on the 24 and passed to the east by midday on the 25..

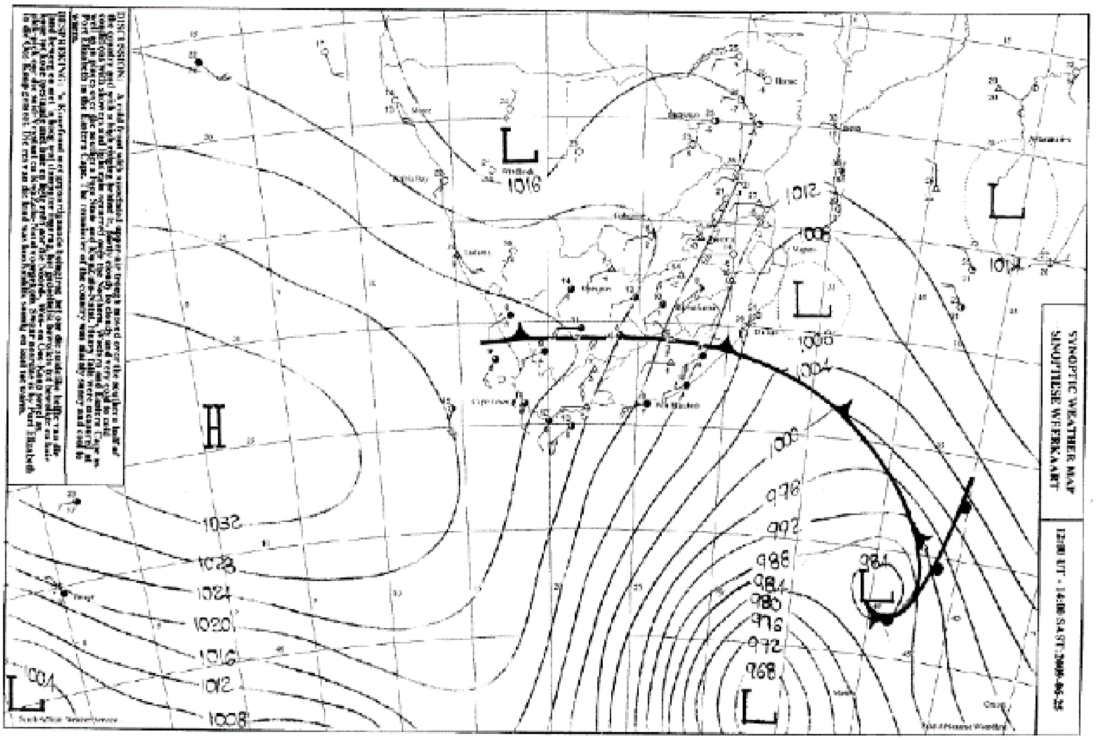
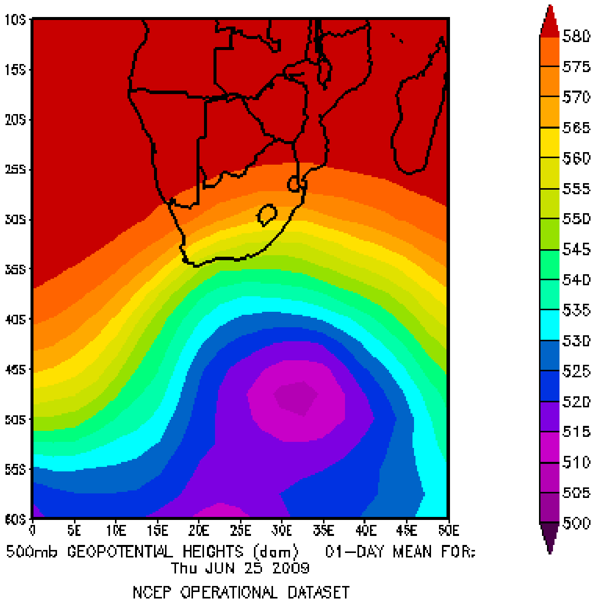


Figure 17: 25 June 2010 at 1400: a High pressure system is now west of the county.



<u>Figure 18</u>: Mid tropospheric condition on 25 June 2009.

<u>Coastal station wind data</u>

57. <u>Figures 19-24</u> show the hourly averaged wind speed and direction recorded at the coastal wind stations of Cape Point, Slangkop/Kommetjie, Cape Town harbour, Saldanha harbour and Cape Columbine.

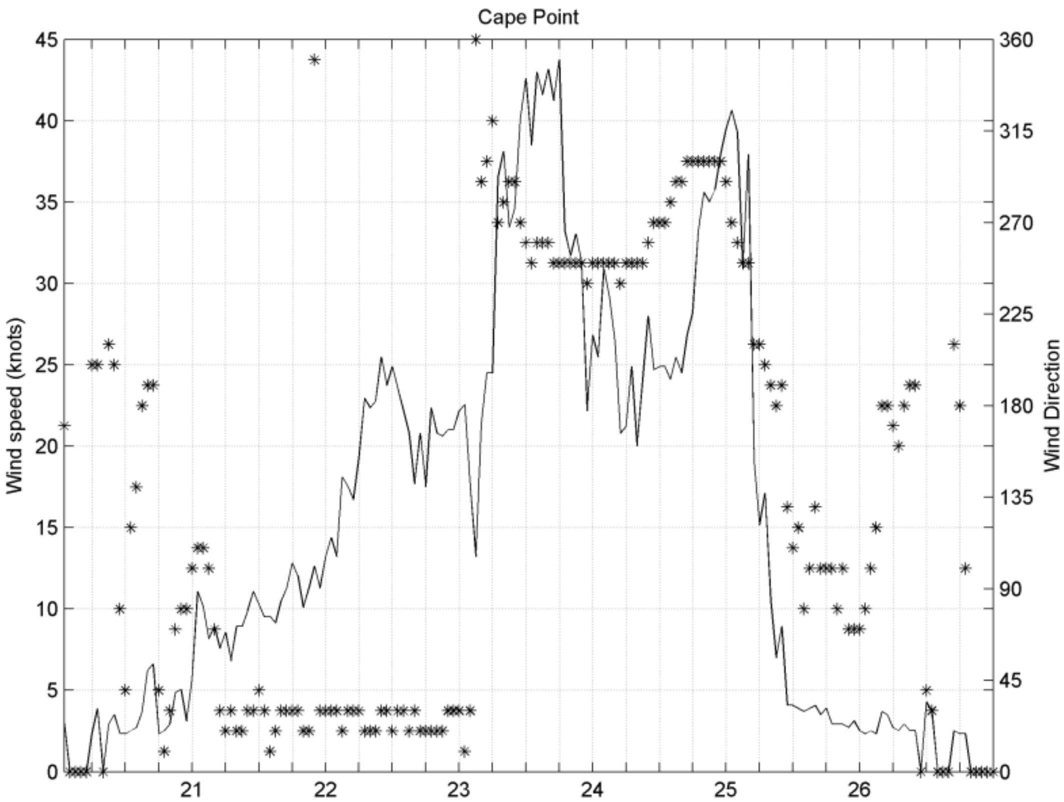


Figure 19: Hourly wind speeds (knots) and direction from 20 June 2009 (00h00 SAST) to 26 June 2009 (24h00 SAST) at **Cape Point** showing wind speeds and direction for the three low pressure systems. For the first low pressure system the maximum wind speed was 25 knots and northerly at 10h00 SAST on 22 June. For the second low pressure system the maximum wind speed was 44 knots at around 18h00 and west-south-westerly. For the third low pressure system the maximum wind speed was 40 knots and northerly on 25 June 2009 at 01h00 SAST (0 or 360 is northerly, 180 is southerly, 270 is westerly and 45 is easterly).

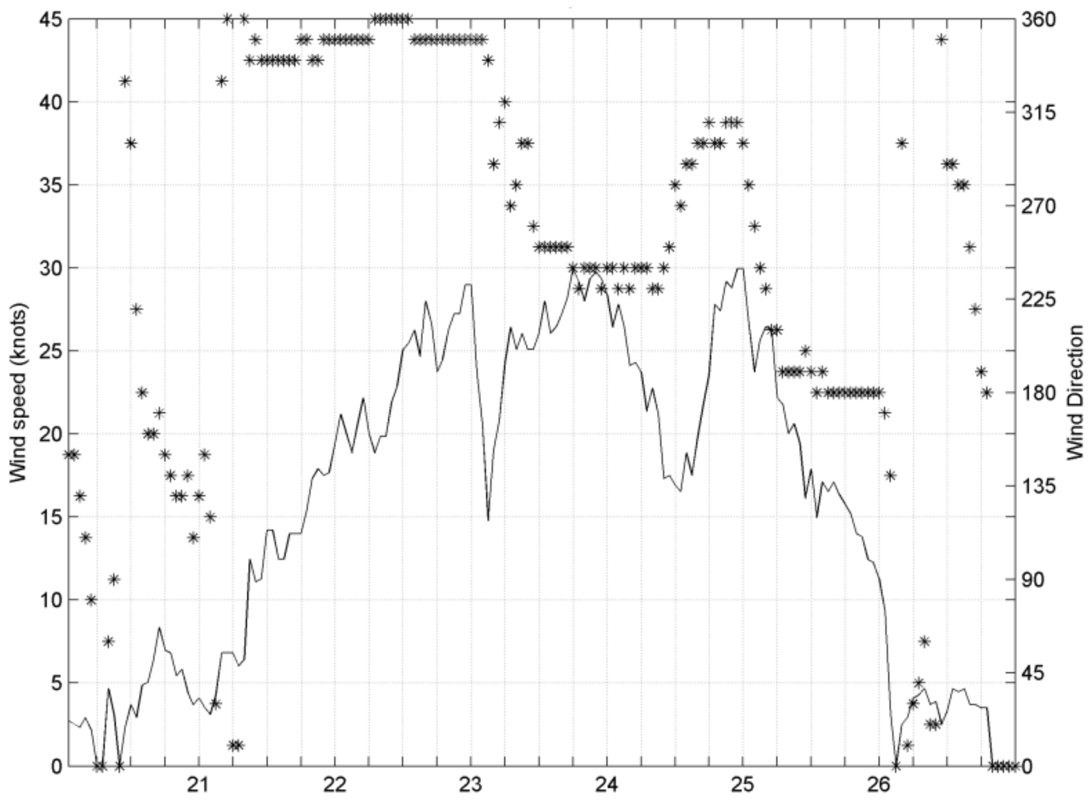
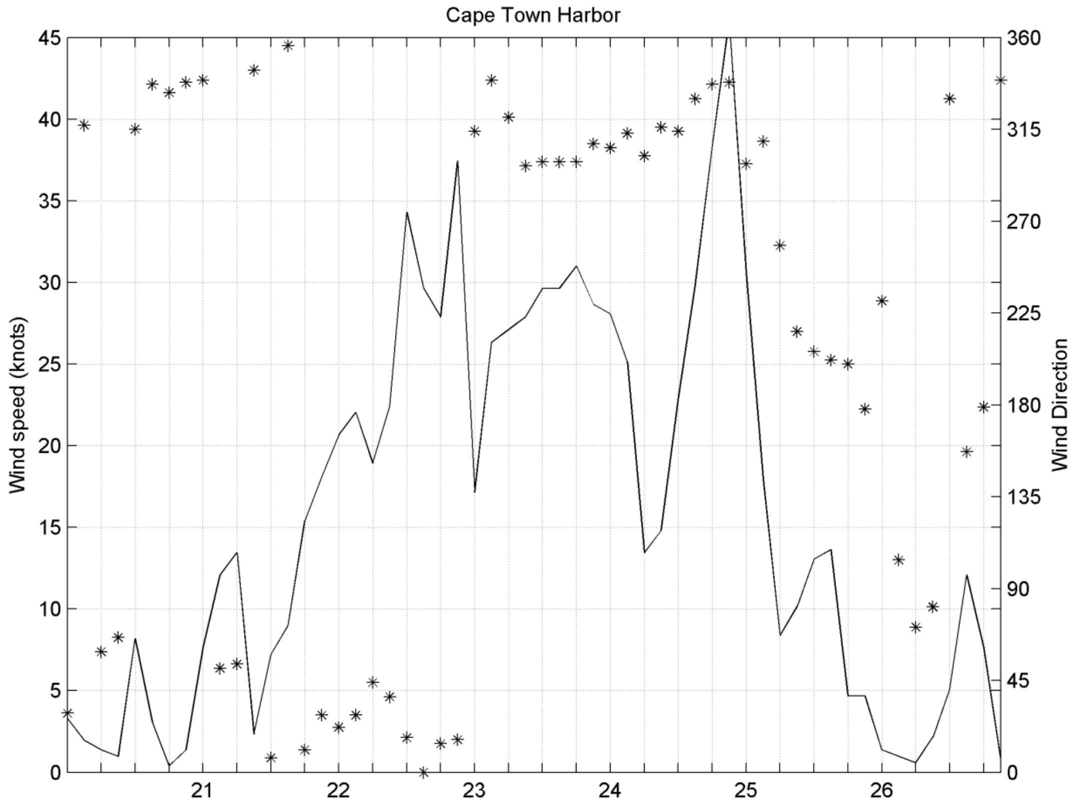


Figure 20: Hourly wind speeds (knots) and direction from 20 June 2009 (00H00 SAST) to 26 June 2009 (24h00 SAST) at **Slangkop (Kommetjie)** showing wind speeds and direction for the three low pressure systems. For the first low pressure system the maximum wind speed was 28 knots and northerly at 16h00 SAST on 22 June. For the second low pressure system the maximum wind speed was 30 knots at around 18h00 SAST and west-south-westerly. For the third low pressure system the maximum wind speed was 30 knots and north-westerly on 24 June at 22h00 SAST. (0 or 360 is northerly, 180 is southerly, 270 is westerly and 45 is easterly).



<u>Figure 21</u>: Hourly wind speeds (knots) and direction from 20 June 2009 (00h00 SAST) to 26 June 2009 (24h00 SAST) at **<u>Cape Town harbour</u>** showing wind speeds and direction for the three low pressure systems. For the first low pressure system the maximum wind speed was 36 knots and northerly at 19h00 SAST on 22 June. For the second low pressure system the maximum wind speed was 30.5 knots at around 18h00 SAST and north-westerly on 23 June. For the third low pressure system the maximum wind speed was 45 knots and north-westerly on 24 June at 21h00 SAST (0 or 360 is northerly, 180 is southerly, 270 is westerly and 45 is easterly).

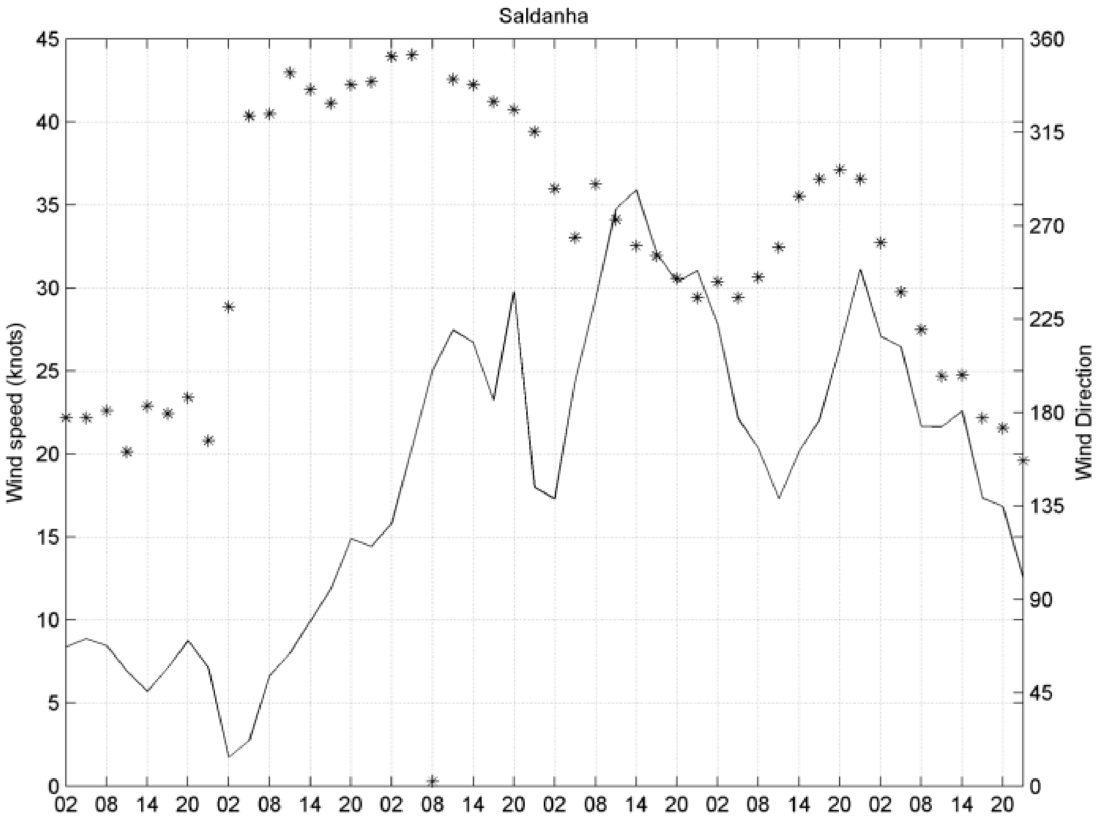
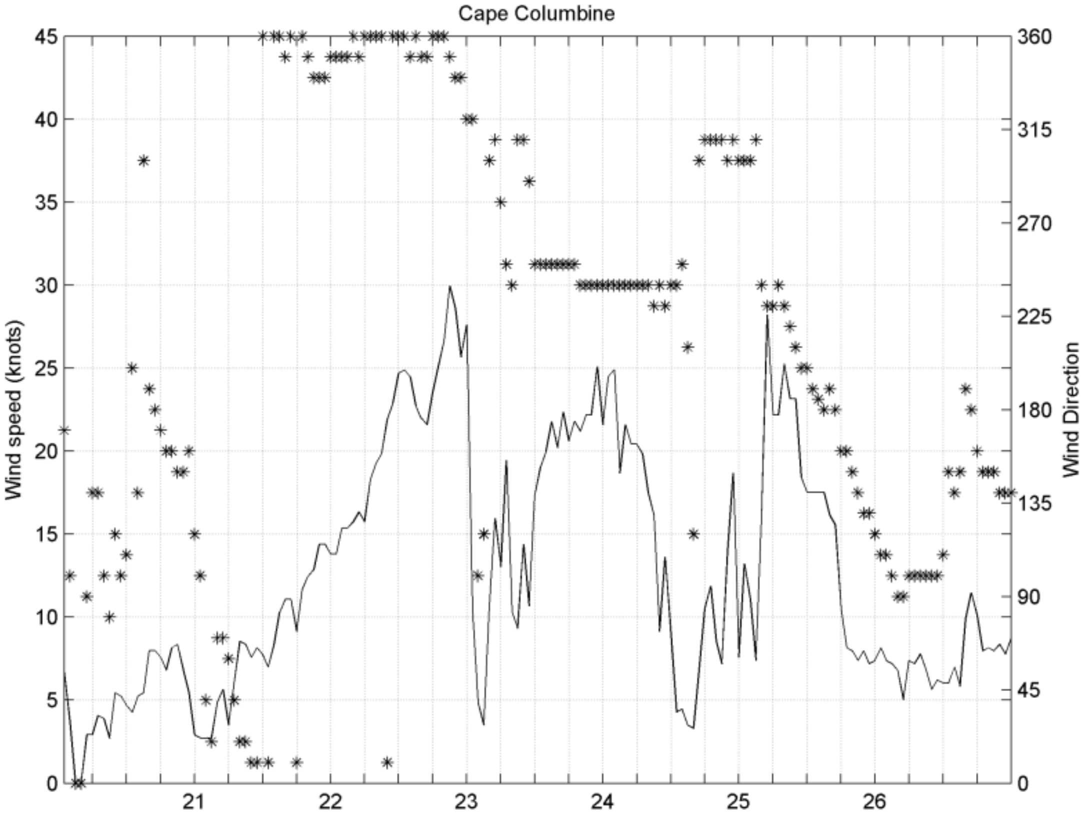


Figure 22: Hourly wind speed (knots) and direction from 20 of June 2009 (00h00 local time) to 26 June 2009 (24h00 SAST) at Saldanha harbour showing wind speeds and direction for the three low pressure systems. For the first low pressure system the maximum wind speed was 28 knots and north-westerly at 20h00 on 22 June. For the second low pressure system the maximum wind speed was 35 knots at around 14h00 SAST on 23 June and west-south-westerly. For the third low pressure system the maximum wind speed was 30 knots and north-westerly-westerly on 24 June at 23h00 SAST (0 or 360 is northerly, 180 is southerly, 270 is westerly and 45 is easterly).



<u>Figure 23</u>: Hourly wind speed (knots) and direction from 20 June 2009 (00h00 SAST) to 26 June 2009 (24h00 SAST) at Cape Columbine showing wind speeds and direction for the three low pressure systems. For the first low pressure system the maximum wind speed was 30 knots and northerly at 21h00 SAST on 22 June. For the second low pressure system the maximum wind speed was 25 knots at around 23h00 SAST and south-westerly. For the third low pressure system the maximum wind speed was 28 knots and northerly on 25 June at 01h00 SAST. (0 or 360 is northerly, 180 is southerly, 270 is westerly and 45 is easterly).

58. <u>For the first cold front the maximum hourly average wind speed on 22 June 2009</u>: at Cape Point was 25 knots (strong breeze, force 6) and northerly at 10h00; at Slangkop was 28 knots (near gale, force 7) and northerly at 16h00; at Cape Town harbour was 36 knots (gale, force 8) and northerly at 19h00; at Saldanha harbour was 28 knots (near gale, force 7) and north-westerly at 20h00; and at Cape Columbine was 30 knots (near gale, force 7) and northerly at 21h00.

59. For the second cold front the maximum hourly average wind speed on 23 June 2009: at Cape Point was 44 knots (strong gale, force 9) and west-south-westerly at 18h00; at Slangkop was 30 knots (near gale, force 7) and west-south-westerly at 18h00; at Cape Town Harbor was 30.5 knots (near gale, force 7) at 18h00; at Saldanha just over 35 knots (gale, force 8) and west-south-westerly at 14h00; and at Cape Columbine was 25 knots (strong breeze, force 6) and south-westerly at 23h00. As will be apparent, the winds during the second cold front were mainly gale force westerly to southerly. South-westerly winds blow onshore in False Bay. False Bay is somehow protected from north-westerly winds, but not from south-westerly to south-easterly winds.

60. The wind dropped quickly during the night and by midday on 24 June 2009 the wind speed ranged from 5 knots at Cape Columbine to 20 knots at Cape Point.

61. On 24 June 2009 in the afternoon the third cold front caused winds to intensify in a north-westerly direction with maximum winds recorded at the coastal weather stations during the night. That storm did not last as long, as can be seen from Figures 19 to 24 and from Figure 15.

62. For the third cold front the maximum hourly average wind speeds: at Cape Point was 40 knots (gale, force 8) and northerly on 25 of June 2009 at 01h00; at Slangkop was 30 knots (near gale, force 7) and north-westerly on 24 June at 22h00; at Cape Town Harbor was 45 knots (strong gale, force 9) and north-westerly on 24 June at 21h00; at Saldanha was 30 knots (near gale, force 7)

and north-westerly on 24 June at 23h00; at Cape Columbine was 28 knots (near gale, force 7) and northerly on 25 June at 01h00.

63. The wind dropped quickly during the night of 24 to 25 June and it veered to a southerly to south-easterly direction as the cold front moved to the east of the Western Cape and high pressure conditions set in.

64. In general the winds during the 3 cold fronts were mostly stronger to the south (Cape Point, Slangkop, Kommetjie, Cape Town) and weaker to the north (Saldanha and Cape Columbine). The highest costal station recorded wind speeds were 44 knots at Cape Point on 23 June during the second cold front and 45 knots at Cape Town harbour on 24 June at 21h00.[2]

<u>Satellite derived surface wind speed and direction estimates</u>

65. This section of the report deals with various satellite derived surface wind speed and direction estimates from the Jason satellite (obtained by Mr Marius Rossouw via from Fugro Oceanor), Windsat and QuikSCAT, as reflected in <u>figures 24 to 32</u> below.

66. Satellite derived wind speeds represent the surface wind speeds at a height of 10m. They are reliable within +/- 0.5 knots, but not reliable when it rains, or when the wind speeds are above 50 knots.

67. Mr Rossouw will explain who Fugro Oceanor is and what it does.

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[2] Those wind speed are by no mean comparable to those created by tropical cyclone whose wind speed ranges from 45 to 120 knots.

68. Windsat and QuikSCAT are two satellites dedicated to wind measurements. Other satellites can provide wind speeds (Jason, Aqua, Terra, and TRMM to name a few) but few can also provide the wind direction. The satellites estimate the wind speed with reference to the sea roughness. The greater the roughness the stronger the wind speed. The satellites transmit an electromagnetic wave down to the ocean surface which bounces back to the satellite, and that is modified by sea roughness.

69. The satellites are calibrated by comparing their backscatter signal to actual wind conditions as measured by an anemometer on a mooring buoy during a dedicated experiment.

70. As set out above, certain satellites are also able to estimate the wind direction. QuickSCAT and Windsat are such satellites, the former uses a scatterometer, and the latter a polarimetric radiometer, to estimate wind direction (the Jason satellite does not have this facility).

71. The QuickSCAT and Windsat charts were obtained from the National Oceanic and Atmospheric Administration (NOAA) in the USA, via their historical dissemination web site.

72. The black barbs on the charts indicate possible rain contamination leading to uncertainty in wind speed estimates. The general pattern of the respective storms is however well reproduced when compared with the SAWS synoptic charts.

73. Figure 24 is a google earth image reflecting 3 Jason satellite tracks, at 09h38 (SAST) on 22 June, 23h35 (SAST) on 23 June (which is apparently close to the time the Salvaliant's tow wire parted), and 23h18 (SAST) on 25 June 2009.

74. Figure 25 reflects the wind speed in knots as derived by the Jason Satellite during its fly-over at 09h30 on 22 June 2009. The Salvaliant was apparently between…..and……at that time, around the 34° latitude. As will be apparent, the Jason satellite estimated a prevailing wind speed of 30 knots (near gale, force 7) for that latitude.

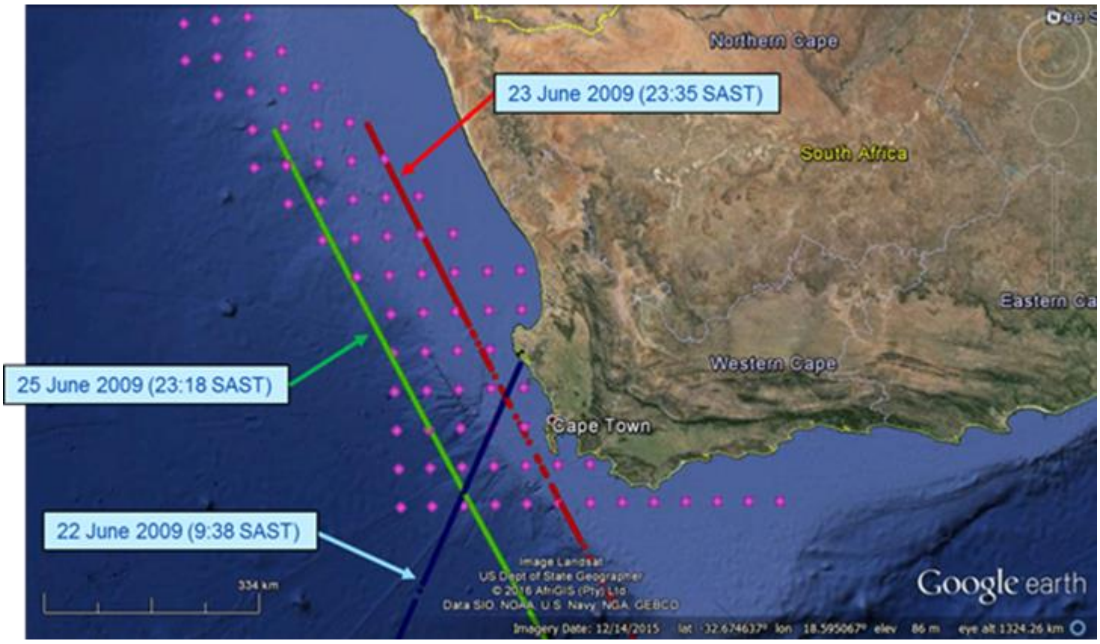


Figure 24: Google earth image provided by Mr Marius Rossouw reflecting the Jason satellite tracks on 22, 23 and 25 June 2009.

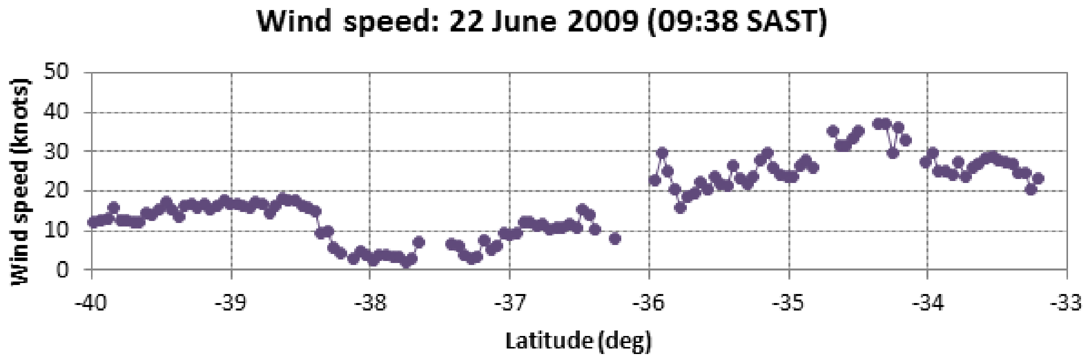
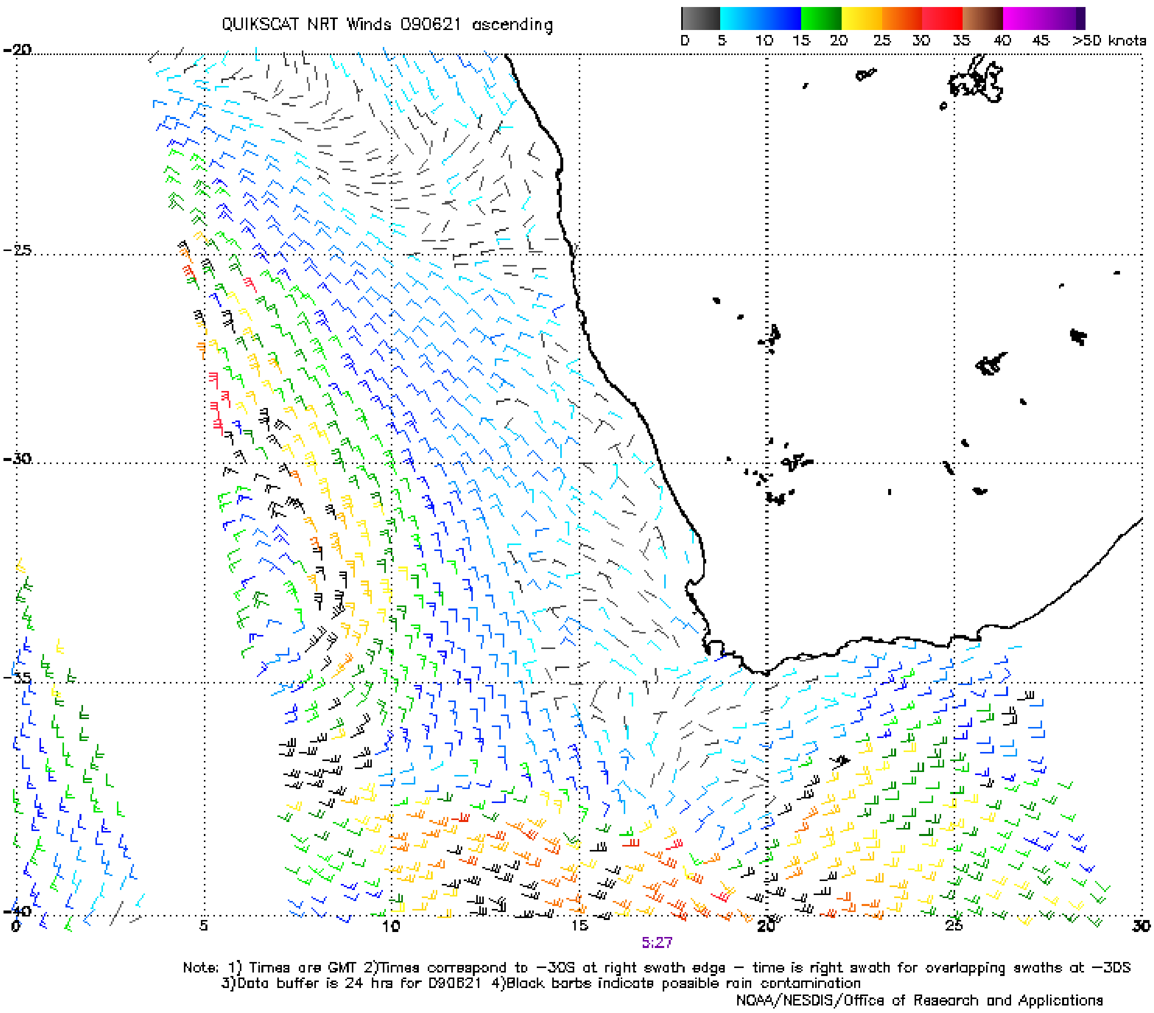
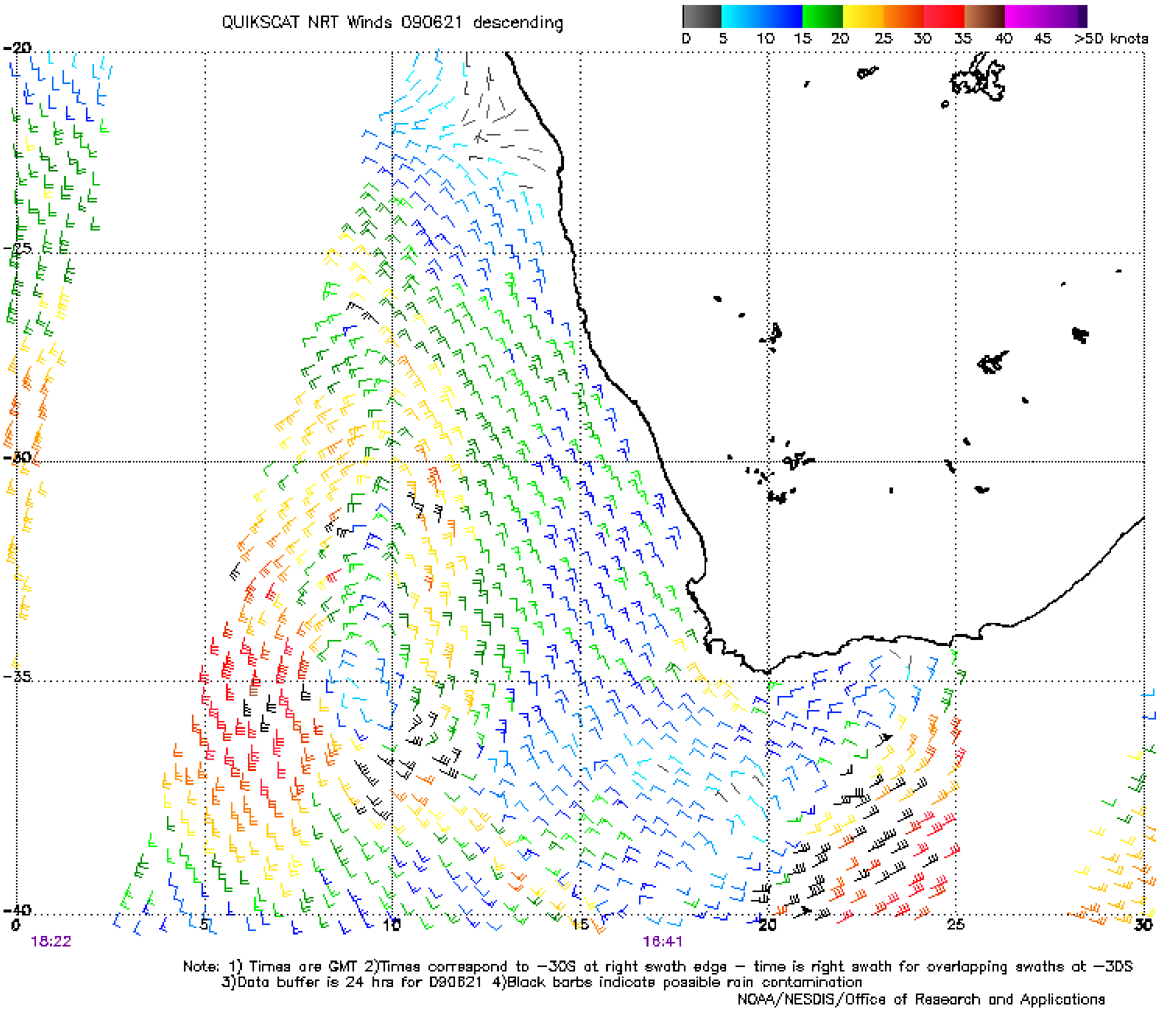


Figure 25: 22 June 2009 09h38 SAST Jason satellite surface wind speed and direction estimate provided by Mr Rossouw.

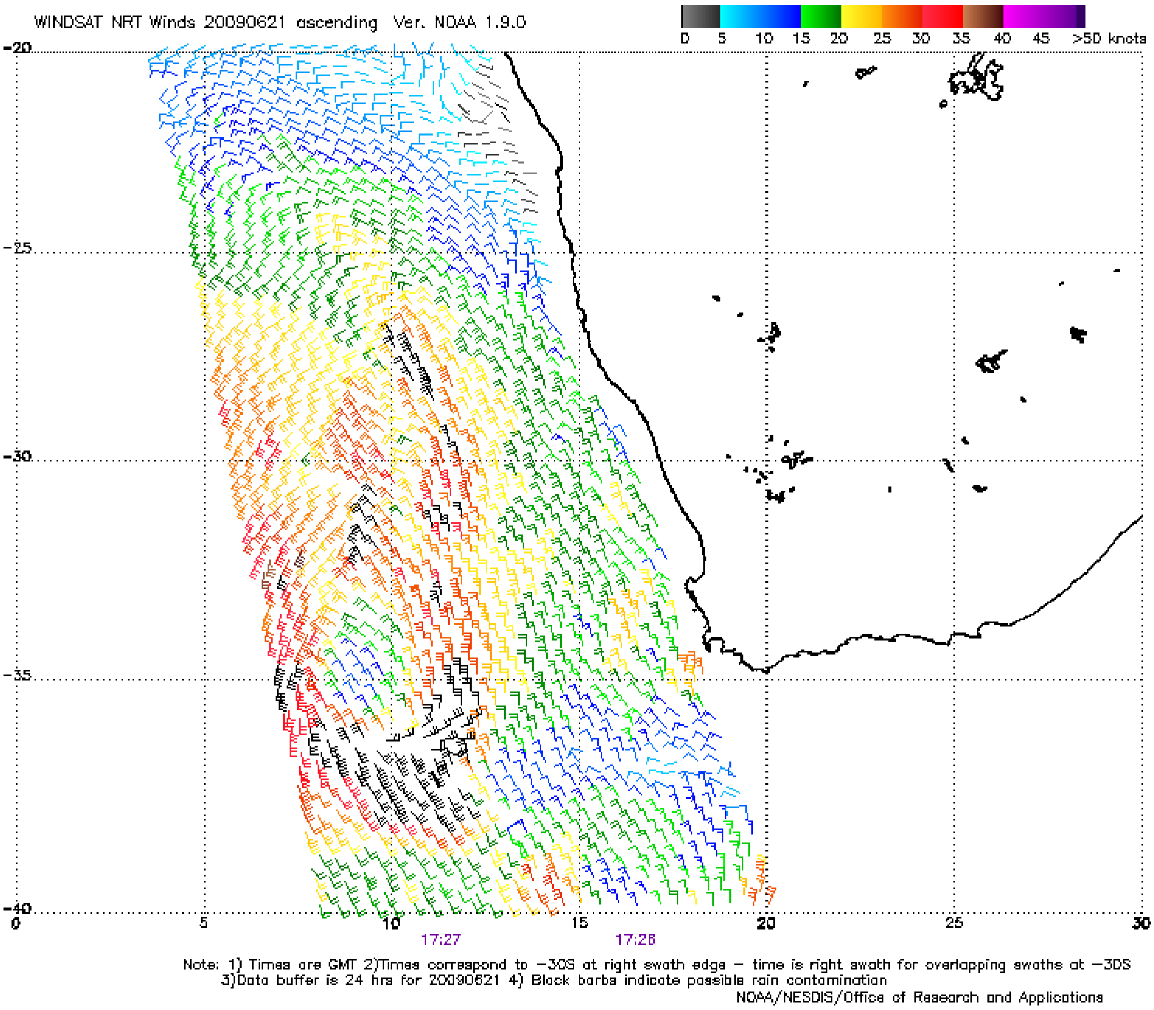
75. Figures 26, 27 and 28 are Windsat and Quikscat charts for 07.27 SAST, 18h41 SAST and 19.26 SAST respectively on 21 June 2009. The "Salvaliant" was South of Cape Agulhas on the 21 at midday and South-east of Cape Point at midnight.



<u>Figure 26:</u> 21 June 2009 0527 GMT (0725 SASAST) Quikscat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed south of Cape Agulhas, closest to the coast is about 5 knots and the direction primarily north-easterly

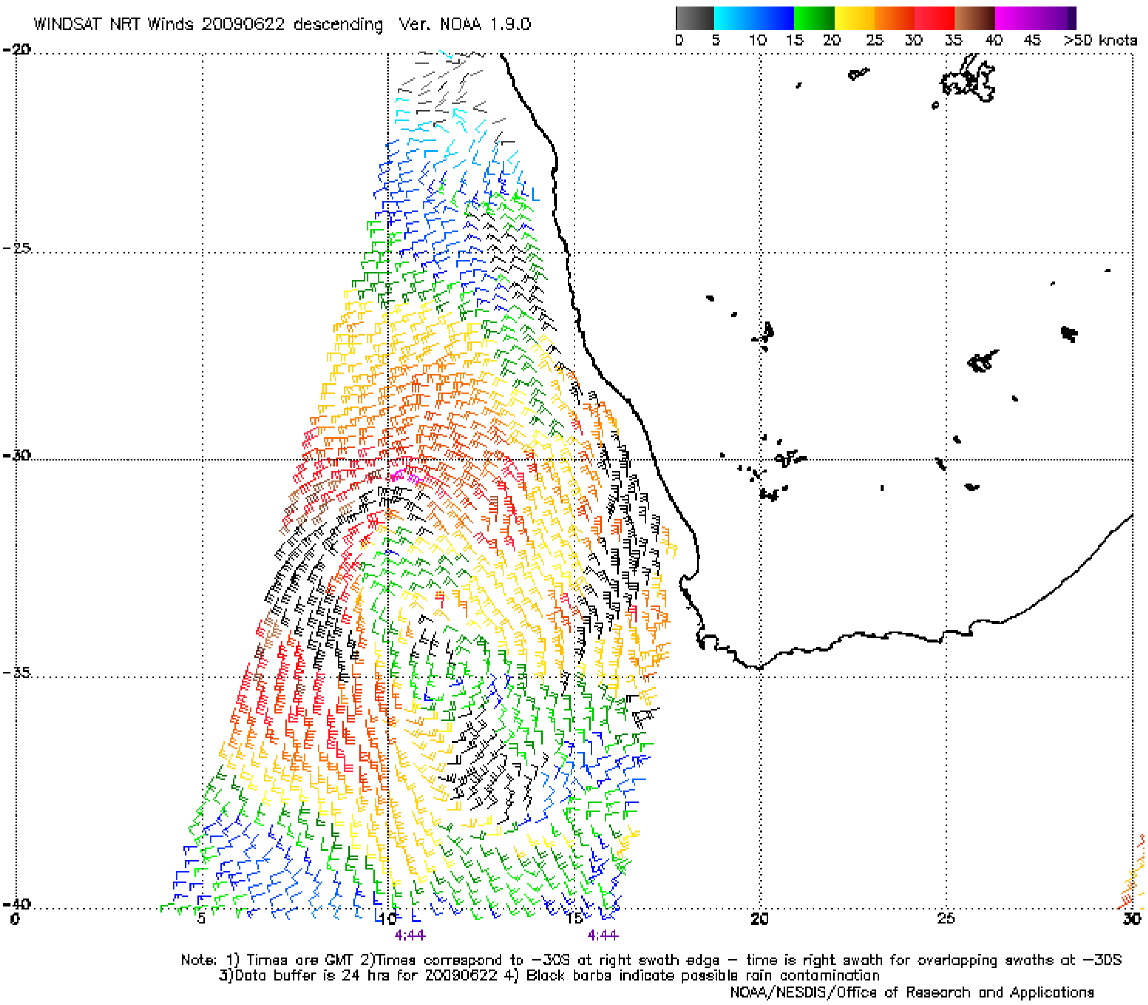


<u>Figure 27:</u> 21 June 2009 1641 GMT (1841 SASAST) Quikscat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed between Cape Agulhas and Cape Point, closest to the coast, is 20 to 25 Knots south of Cape Agulhas and the direction primarily north-westerly



<u>Figure 28</u>: 21 June 2009 17.26 GMT (19.26 GMT) Windsat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed between South of Cape Point, closest to the coast, is 25 Knots south of Cape Agulhas and the direction primarily northerly

76. <u>Figures 29, 30, 31 and 32</u> are Windsat charts for 06.44 SAST, 0701, 18.15 SAST and 19.09 SAST respectively on 22 June 2009. The "Salvaliant" was South-east of Cape Point at 0.0 on the 22, East of Llandudno on the 22 at midday and south of Dassen Island at midnight.



<u>Figure 29</u>: 22 June 2009 0444 GMT (0644 SAST) Windsat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed east of Cape Point, closest to the coast, is 25 Knots and the direction primarily south-westerly

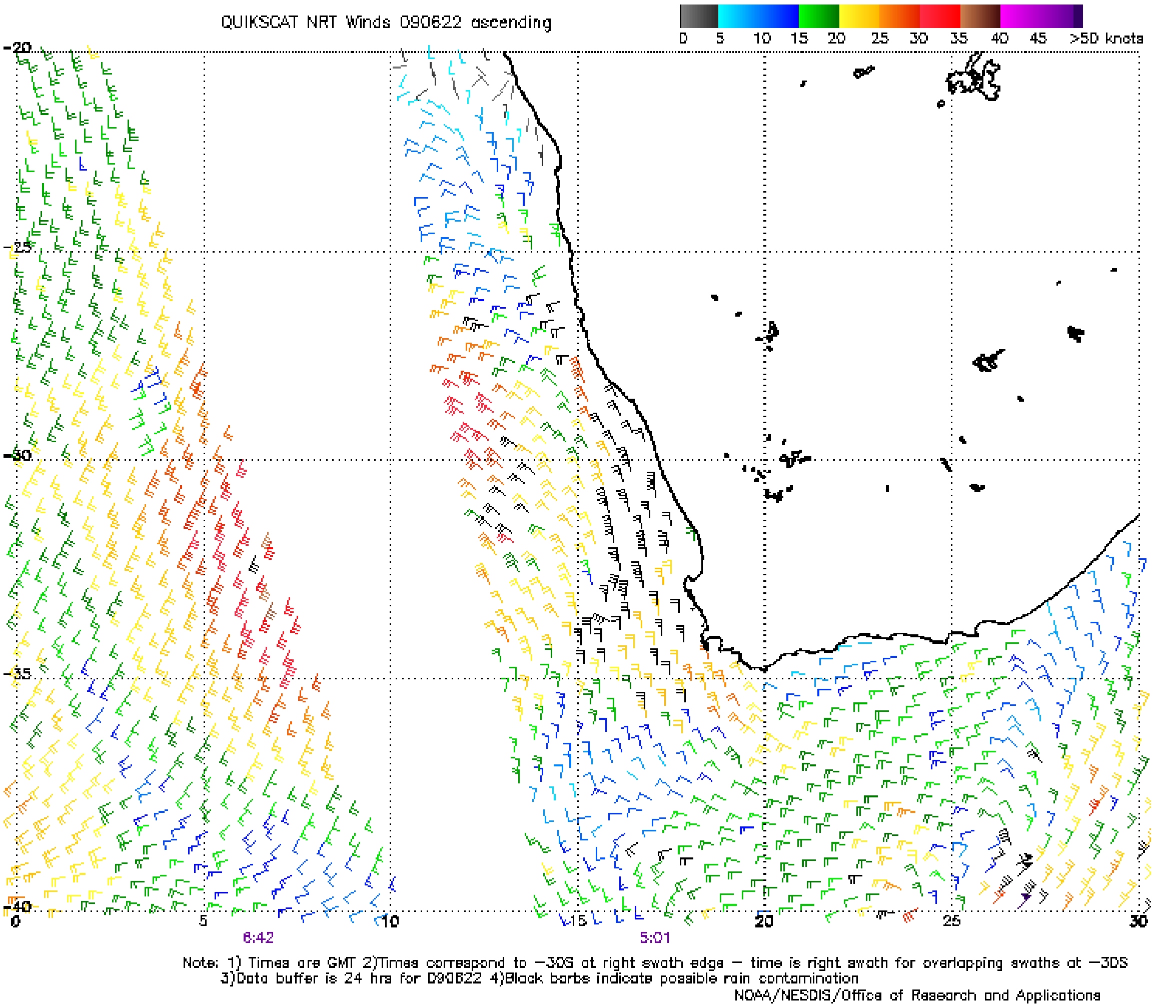


Figure 30: 22 June 2009 0501 GMT (07.01 SAST) Quikscat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed between Cape Point and Cape Town, closest to the coast, is 25 Knots and the direction primarily north-westerly.

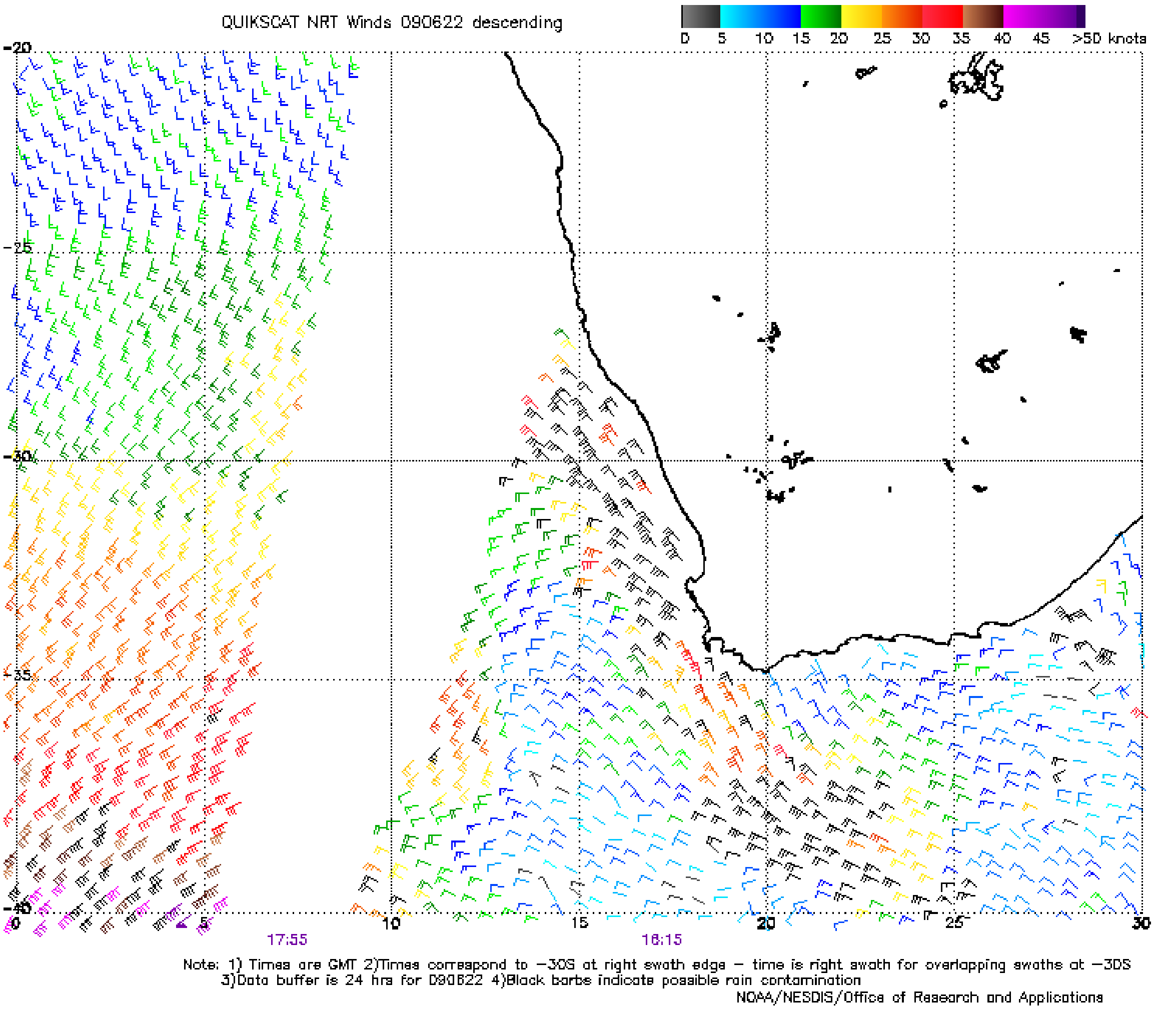


Figure 31: 22 June 2009 1615 GMT (18.15 SAST) Quikscat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed near Cape Town and Cape Columbine, is 35 Knots and the direction primarily north-westerly.

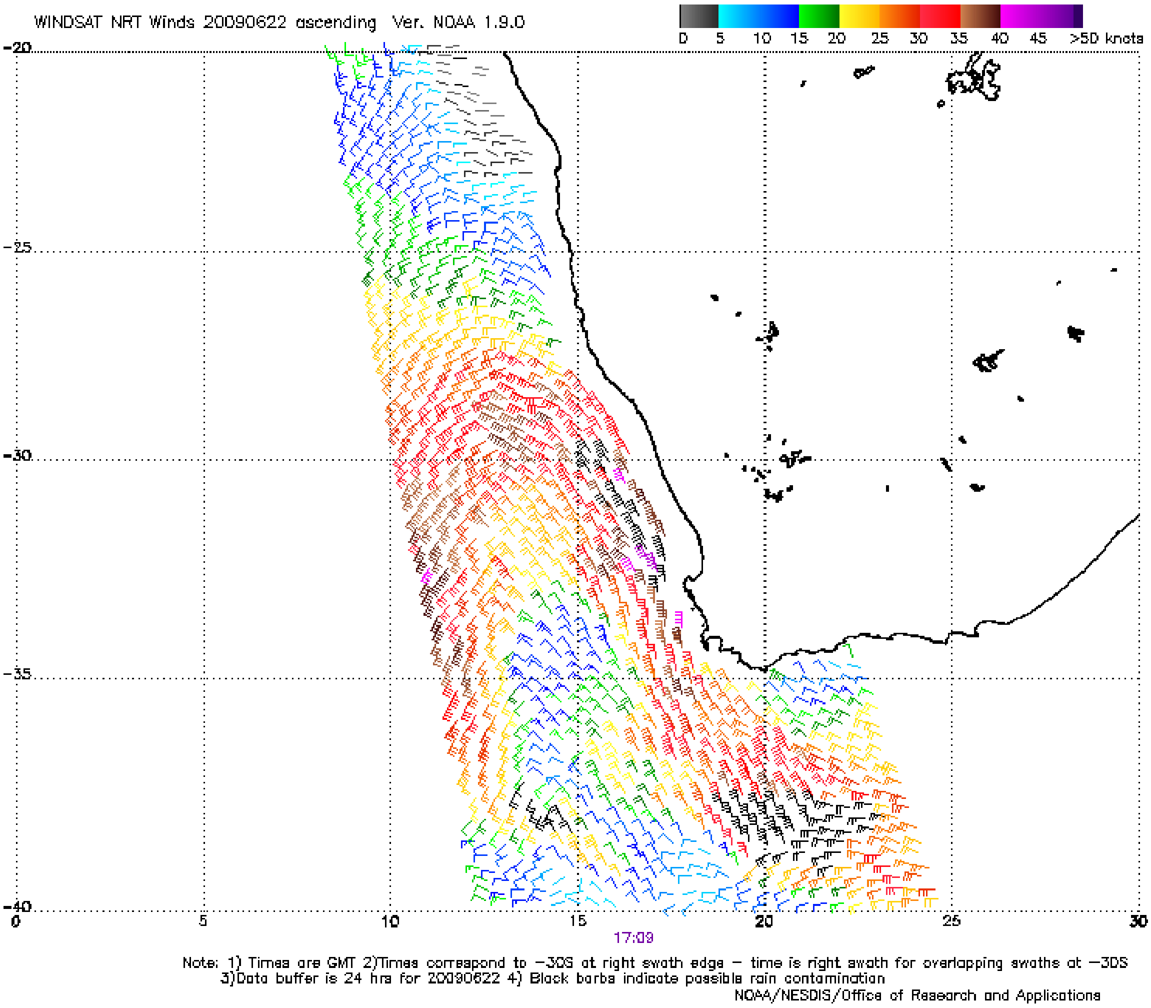


Figure 32: 22 June 2009 1709 GMT (19.09 SAST) Windsat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed between Cape Town and Cape Columbine, is 40 to 45 Knots and the direction primarily north-westerly

77. Figures 33 and 34 are Windsat charts for 06h26 SAST and 18h51 SAST respectively on 23 June 2009. The "Salvaliant" was between Dassen Island and Saldanha on the morning of 23 June and abeam Saldanha in the evening.

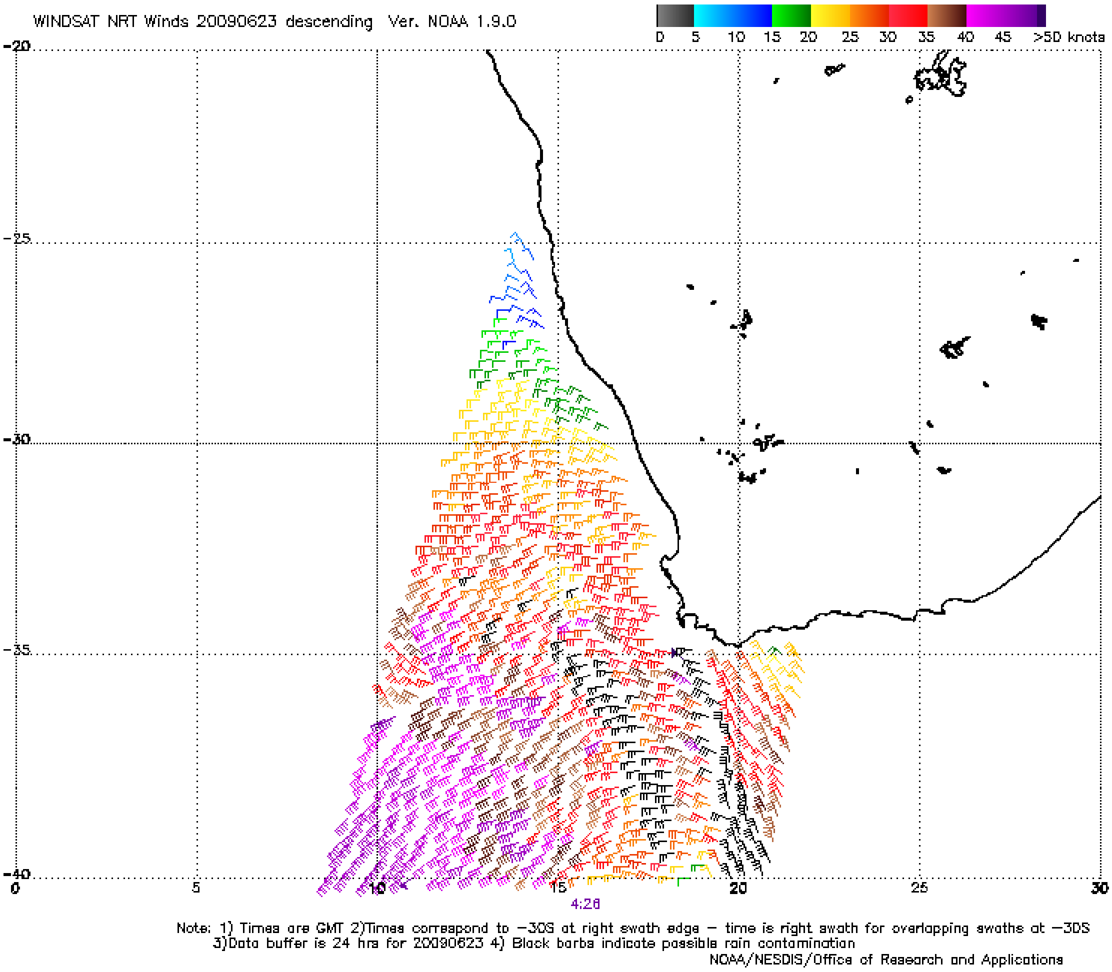
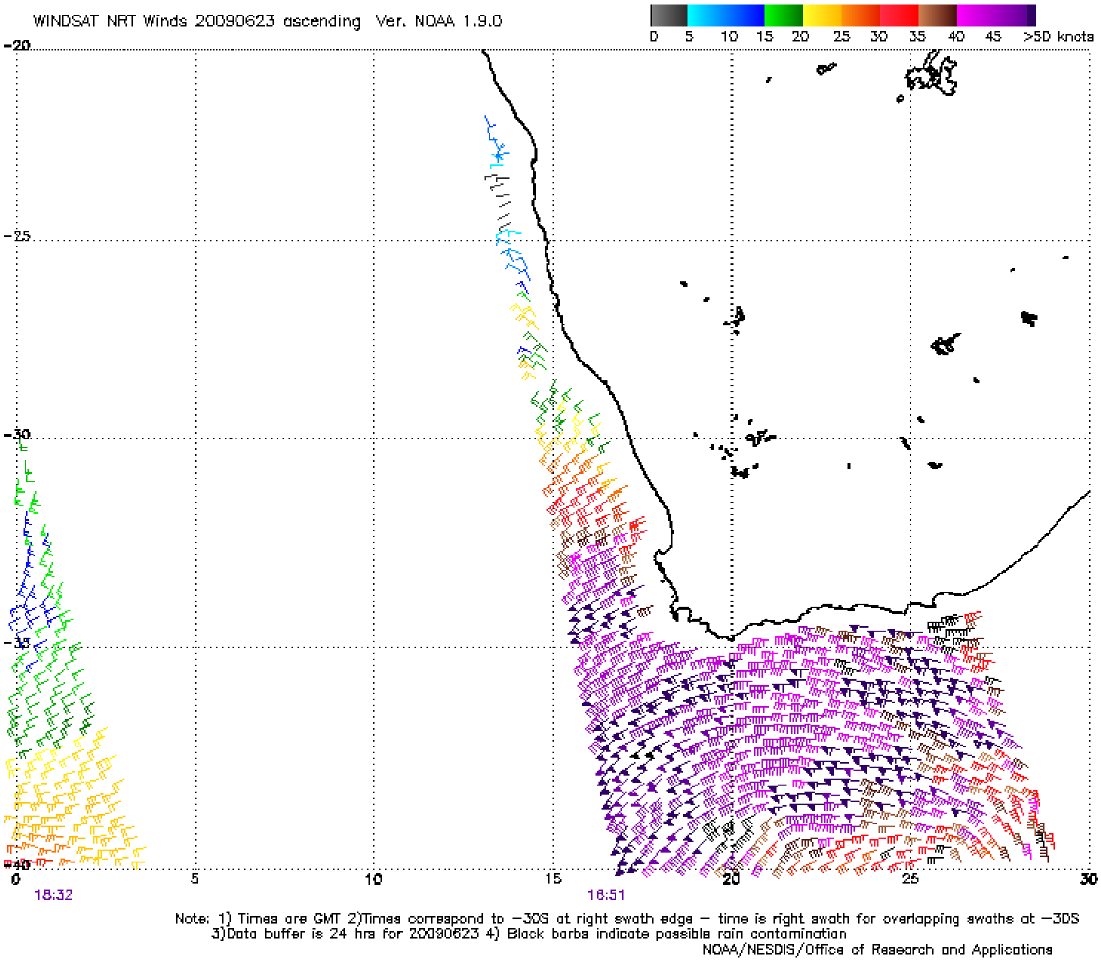


Figure 33: 23 June 2009 04h26 GMT (06h26 SAST) Windsat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed between Cape Town and Saldanha, closest to the coast (ie. in the grid which includes Cape Town) is about 30 to 35 knots and the direction primarily westerly. The wind is strongest to the west and south west of the continent, where the speeds reach about 40-45 knots, from the west or south-west. The winds are weaker to the north.



<u>Figure 34</u>: 23 June 2009 16h51 GMT (18h51 SAST) Windsat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed between Cape Town and Saldanha, closest to the coast (ie. in the grid which includes Cape Town), is about 35 to 45 knots, from the west-south-west. The wind is 40-45 knots to the south and south-west of the continent, from the south-west. The winds drop very quickly to the north of Cape Columbine.

78. <u>Figure 35</u> reflects the wind speed in knots as derived by the Jason Satellite during its track at 23h35 on 23 June 2009. The "Salvaliant" was in the vicinity of Saldanha at the time, around the 33° latitude, as reflected by the blue line on the graph. As will be apparent, the Jason satellite estimated a prevailing wind speed of 35 knots (gale, force 8) for that latitude.

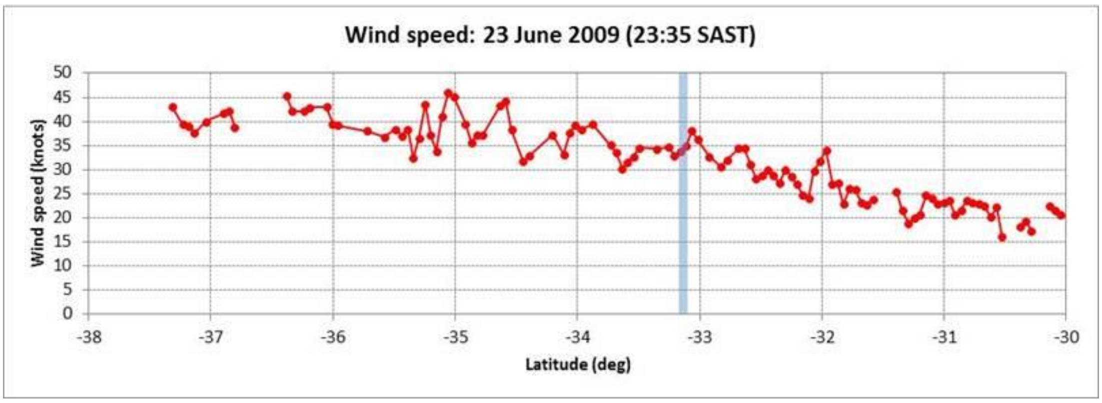


Figure 35: 23 June 2009 23H35 SAST Fugro Oceanor surface wind speed and direction estimate provided by Mr Rossouw.

79. Figure 36 is a Windsat chart for 05h59 SAST on 24 June 2009, and figures 37-38 QuickSCAT charts for 07h50 SAST and 19h03 SAST on 24 June 2009, and 07h24 SAST on 25 June 2009.

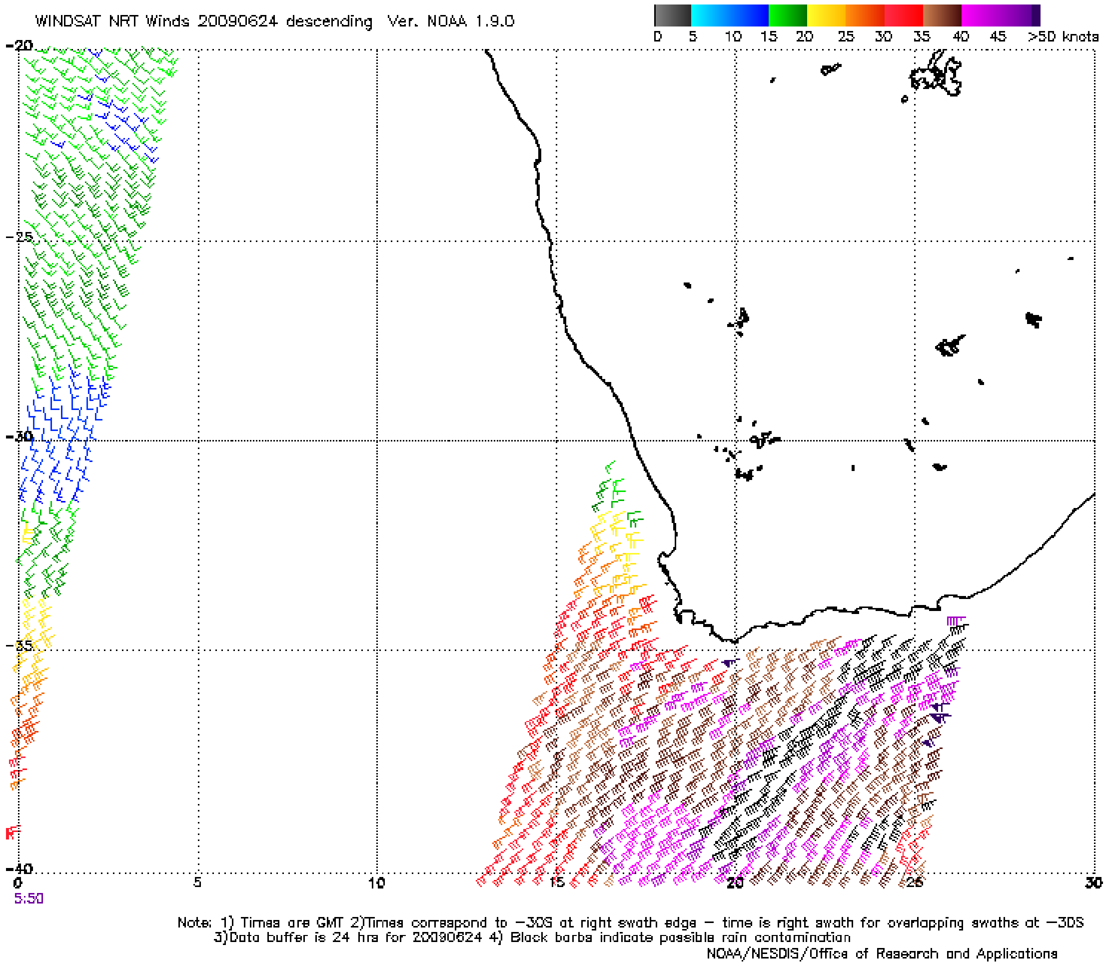


Figure 36: 24 June 2009 03h59 GMT (05h59 SAST) Windsat surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed between Cape Town and Saldanha, closest to the coast (ie. in the grid which includes Cape Town) is about 20 to 35 knots, from the south-west. The wind is as strong to the west, and stronger to the south, where the direction south-westerly. The wind drops very quickly to the north of Cape Columbine (15 to 15 knots).

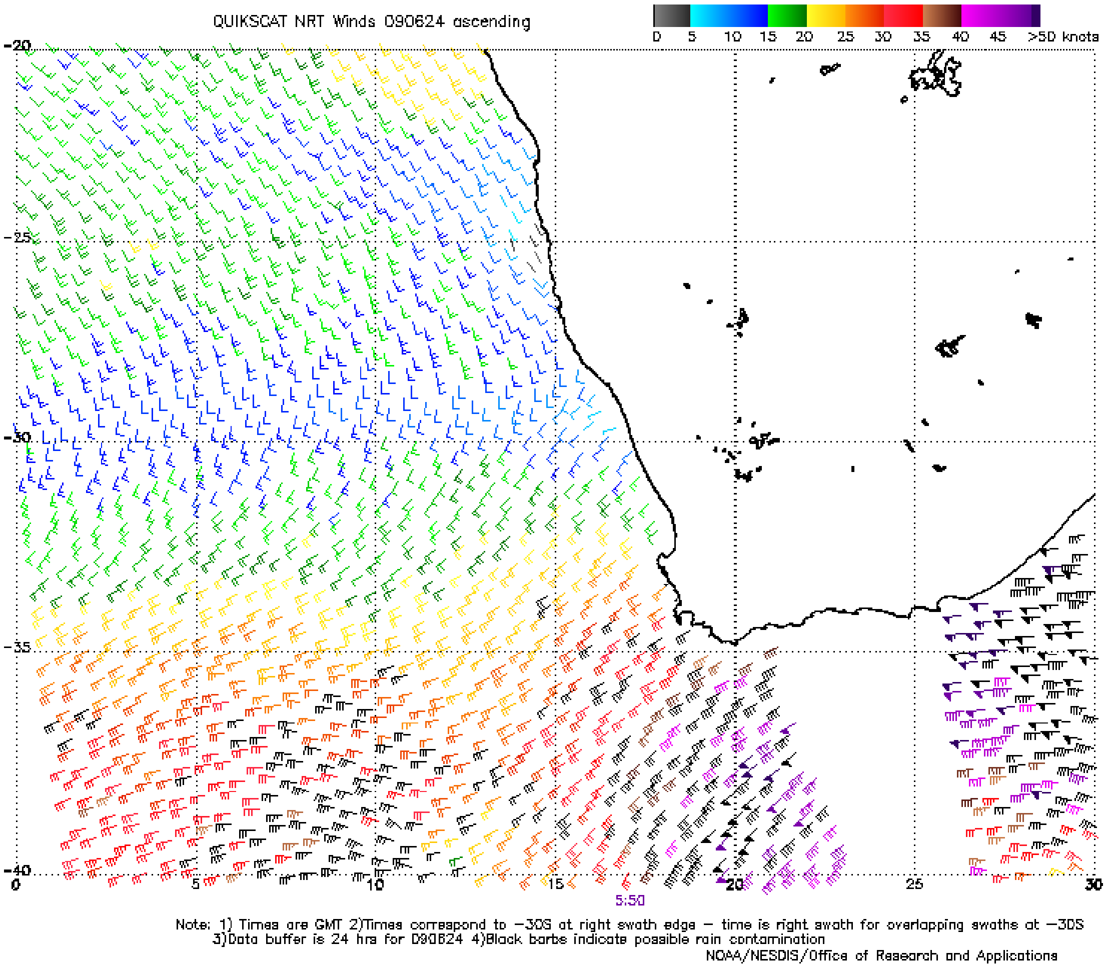


Figure 37: 24 June 2009 05h50 GMT (07h50 SAST) QuikSCAT surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed from Cape Town to Saldanha, closest to the coast (ie. in the grid which includes Cape Town) is about 25 to 30 knots, from the south-west. The wind is as strong to the west and stronger in the south, where it reaches 40-45 knots from the south-west. The wind drops very quickly to the north of Cape Town.

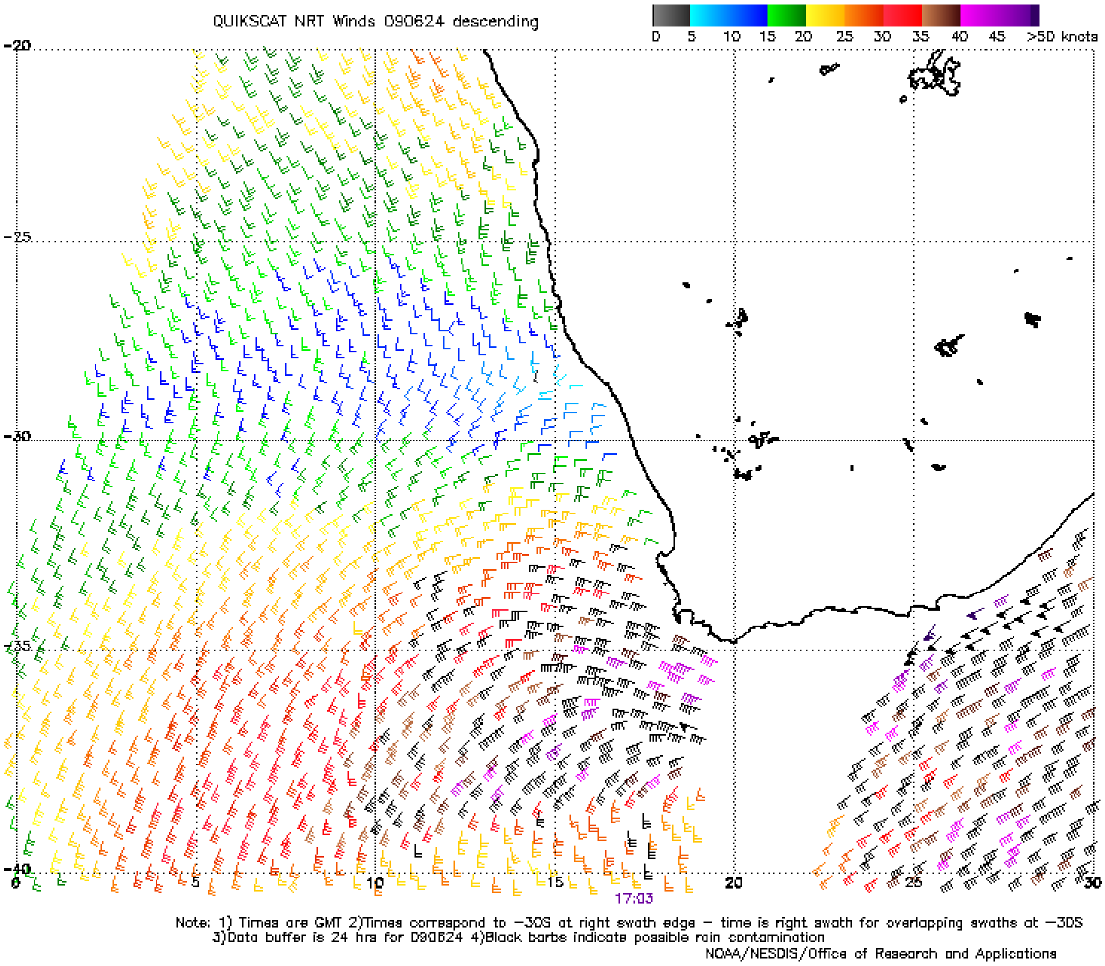


Figure 38: 24 June 2009 17h03 GMT (19h03 SAST) QuikSCAT surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed from between Cape Town and Saldanha, closet to the coast (ie. in the grid which includes Cape Town) is about 30 to 35 knots, from the west-north-west. The wind is stronger to the south, where is reached 40-45knots from the west-north-west, and drops very quickly to the north of Cape Columbine.

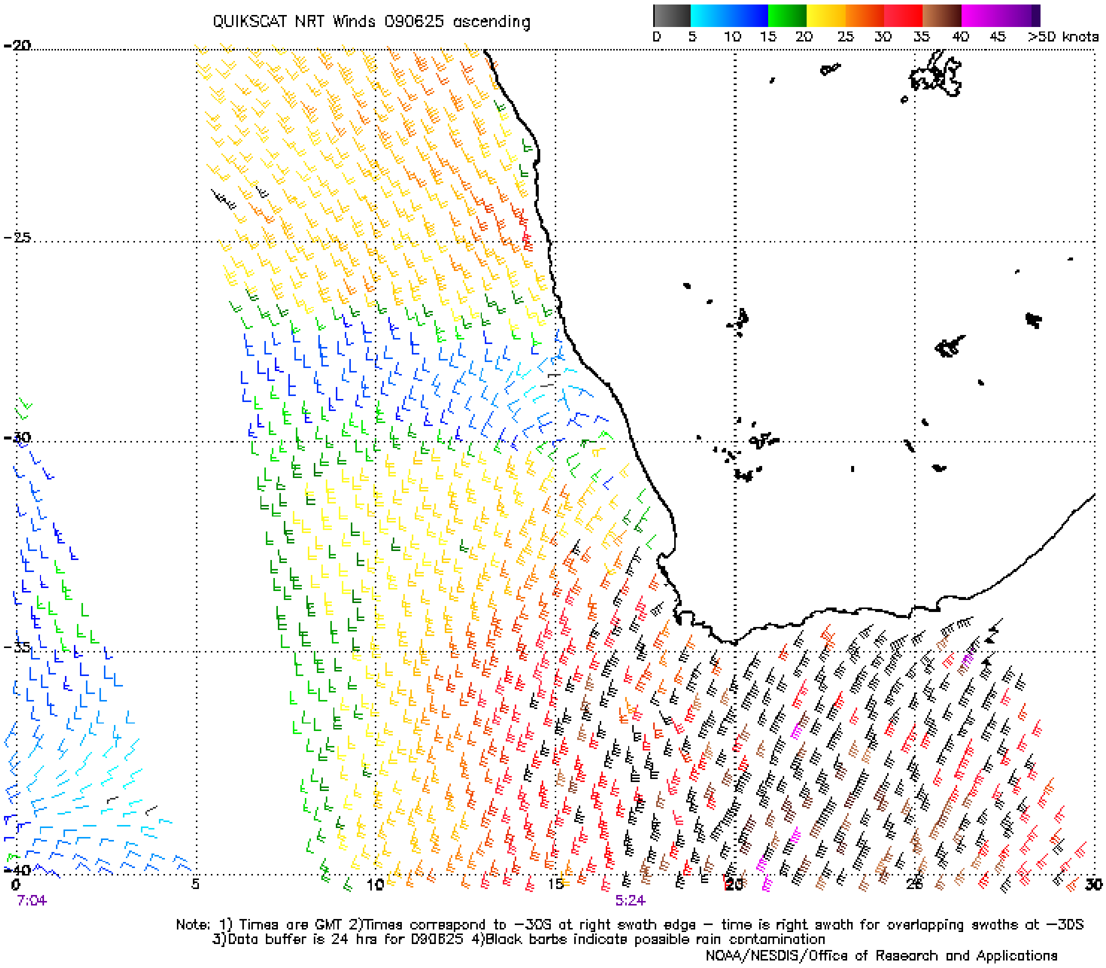


Figure 39: 25 June 2009 05h24 GMT (07h24 SAST) QuikSCAT surface wind speed and direction estimates. The black barbs indicate possible rain contamination. The wind speed between Cape Town and Saldanha, closest to the coast (ie. in the grid which includes Cape Town) is about 30 to 35 knots, from the south-south-west. The winds drop very quickly to the north of Cape Columbine, and decrease from 35 knots to 15 knots within 150 km of Cape Town, just north of Cape Columbine

80. The satellite derived wind estimates clearly show the spatial extent and the intensity of the storms, with the winds stronger to the south of Cape Point, weaker to the north of Cape Town, and as strong to the west of the continent. The satellite estimates show that the wind can decrease rapidly north of Cape Columbine. A decrease of 20 knots from Cape Town to just north of Cape Columbine is not uncommon in the charts presented above and many others not shown here.

81. The wind measured at Cape Point, the synoptic charts on the 23 and the satellite estimate in the 23 give a good indication of what the wind speed and direction would have been on the 23 of June in False Bay: Gale Force Westerly to South Westerly, the latter being onshore for False Bay. First the elongated isobar of the synoptic charts on the 23 indicate the South Westerly direction, secondly the gale force westerly South-westerly measured at Cape Point on the 23 indicated the potential strength of the wind in False Bay. We note that the maximum wind speed is reached for a westerly-south-westerly direction at cape Point on the 23 which is quite unusual for a cold front as the strongest winds associated with cold front are usually north-westerly. This is due to the elongated shape of that storm. Furthermore the wind speed during the 23 estimated from the satellite are stronger at the latitude of Cape Point reinforce the idea that Gale Force wind westerly to South-westerly prevailed during the 23 of June.