The Role Played By Azores High in Developing of Extratropical Cyclone Klaus

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Abstract: On 24 January 2009 southern France and northern Spain were affected by a severe windstorm associated with extratropical cyclone Klaus. This paper investigates the role played by Azores high in developing of extratropical cyclone Klaus. The 6-hour and daily NCEP/NCAR reanalysis data composites for meteorological elements (surface pressure, sea surface temperature , surface wind, surface relative humidity, and geopotential height and wind fields at 500 mb level) over the northern hemisphere for the period of 20-25 January 2009 were used in this study. In addition, satellite images for cyclone Klaus and its damage have been used. The results revealed that, the Azores high pressure system extended strongly and rapidly to the east direction towards the North Africa and it was accompanied with an eastward extension of a deep low pressure system over the northern Atlantic region. The combination of the two opposite pressure systems together over Atlantic Ocean creates a very strong pure westerly air current moving toward the eastward direction. This huge westerly winds set aside the air over the eastern Atlantic region and western European coasts and forced it to sweep and to circulate westward direction and develop cyclonic circulation system which originating in the west of Bay of Biscay, extratropical cyclone Klaus. The development theory and the life cycle of Klaus model are uncovered. Uncover of the life cycle model of cyclone Klaus conduct to a new theory of cyclones development which so called the cyclonic circulation theory. [Journal of American Science 2009;5(5):145-163]. (ISSN: 1545-1003).

Keywords: Azores high; cyclone Klaus; air mass; cyclonic circulation theory

1. Introduction

On the early morning of Friday January 23, a strong low pressure system, extratropical cyclone Klaus was developed over the northern Atlantic region with a minimum central pressure of 1000 mb. On Friday night, it moved eastward across the Bay of Biscay towards southern France bringing damaging winds to the southwest of France and to northern Spain. Klaus landfall strongly crossing southern France and northern Spain and entered the Bordeaux region of France early Saturday morning with a minimum central pressure of 966 mb and intense wind gusts on the order of 150 kph and higher. Surface wind speeds were recorded at 180 kph, and even at 200 kph on the first inland higher ground. These wind speeds correspond to those experienced in Hurricanes Category (III) according to the (Safir-Sampson) scale of hurricane intensity. The storm swept in from the Atlantic Ocean and continued to track east causing significant damage across northern Spain and waves as high as 21 meters off of the Basque coast. However, this storm wreaking havoc across the region. Klaus caused the death of 21 people and left a path of heavy destruction stretching from approximately Bordeaux to the Mediterranean coast and all along northern Spain. Besides expected substantial damages to property, life lines and electricity networks have also been hit hard. Similarly hard hit have also been forests in south-western France, with reported losses of up to 70% of stock in certain areas. An estimated 60 to 70 percent of the pine trees in Lands Forest, one of Europe's largest, had been uprooted. Storm Klaus caused widespread destruction: building damage, power outages, flooding and travel disruption, and the landscape of the Department of Les Lands was changed for perhaps the next hundred years. Recent assessments by catastrophe modeling firms estimate are ranging as high as €5 billion in respect of this storm. However, this storm was weakening in the afternoon of 24 January 2009.

There are several scientific literatures challenges the developing and life cycle of midlatitude cyclones and extratropical marine cyclones e.g. (Bjerknes (1919); Bjerknes and Solberg (1922); Bottger, et al., (1975); Hadlock and Kreitzberg (1988); Shapiro and Keyser (1990); Davies, et al., (1991); Wakimoto et al., (1992);

Neiman and Shapiro (1993); Neiman et al., (1993); Evans et al., (1994); Schultz et al., (1998) Nielsen and Sass (2003)). These literatures were refereed the development and life cycle of cyclones to the models of Norwegian frontal- cyclone model (Bjerknes 1921; Bjerknes and Solberg 1922) and Shapiro-Keyser life cycle model (Shapiro-Keyser 1990) for extratropical marine cyclones. Cyclonic development in midlatitudes was based on the concept of the polar front theory of atmospheric circulation (Bjerknes and Solberg 1922). In one hand, there are valuable researches challenge the field of hurricanes formation and hazards (e.g. Gray (2001); Zebrowski and Judith (2005); Asbury et al., (2006) and Hafez (2008)). In other hand, the effect of the geopotential height anomalies and blocking systems in the upper atmospheric levels upon the European climate studied by (Rex (1950a, 1950b, and 1951); Cohen et al., (2001); Hafez (2007 and 2008)…etc.). However, the present work aims to uncover the role played by Azores high in the developing of extratropical cyclone Klaus.

2. Data and Methodology

The 6-hour and daily NCEP/NCAR reanalysis data composites for meteorological elements (surface pressure, sea surface temperature, surface wind, surface relative humidity , and geopotential height at the 500 mb level) over the northern hemisphere for the period 20 to 25 January 2009 (Kalnay et al., 1996) were used in this study. In addition, satellite images for extratropical cyclone Klaus and its damage were used. Satellite images were obtained from Dundee Satellite Receiving Station and NOAA. In the present work, these datasets were analyzed using the anomalies methodology. The track of the center of the cyclone, labeled with passing dates, UTC times and minimum MSLP's analyzed by HIRLAM-AEMET numerical model, has been used. In addition to that the 6 hours time step air mass RGB composite satellite images through the developing stages in the life cycle of the cyclone Klaus has been analyzed.

3. Results

3.1 Analysis of synoptic situation of extratropical cyclone Klaus

The current study presents the synoptic regime analysis of the development and life cycle of extratropical cyclone Klaus that exited over middle of the North Atlantic Ocean, west of Bay of Biscay, on 23 - 24 January 2009. The available meteorological data sets as mentioned above in the section of data and methodology had been used in this analysis. Extratropical cyclone Klaus developed as a system with a clear surface pressure signal approximately started on day 23 about 0000 UTC, in the middle of the Atlantic, at position shown in Figure (1), with a minimum mean sea level pressure (MSLP) value of 1000 mb. Rapidly, reaching its explosive development rates as high as 34 mb in 24 hours, and registered maximum surface wind gusts of the order of 200 km/h. This cyclone moved eastward and its track was purely zonal and its speed was markedly high, reaching values above 100 km/h. A minimum surface pressure of about 964 mb at cyclone center took place on day 24 at about 0000 UTC. Figure (1) shows an approximate 6- hour track of the center of the cyclone, labeled with passing dates, UTC times and minimum [Source; High Resolution Limited Area Model, (HIRLAM-AEMET) Spain Agency of Meteorology]. However, the intensity of cyclone Klaus reached the intensity of hurricanes of category (3), according to Safir - Sampson hurricane scale (Zebrowski and Judith (2005)). However, Klaus formation may be is the start point that Atlantic hurricanes invade Western Europe.

Analysis of the wind field at the surface and at 500 mb level illustrates that the flow of air current is completely from west to east (purely zonal flow) over the northern Atlantic region through the period of 23-24 January. Analysis of the geopotential height at 500mb shows that the flow aloft over the northern Atlantic Ocean is completely westerly flow, and the Rossby wave was completely disappears on the synoptic charts over the northern Atlantic region through the period of 23-24 January 2009 see Figure (2). However, Rossby wave zonal phase propagation is always westward relative to the mean zonal flow, furthermore, the Rossby wave phase speed depends inversely on the square of the horizontal wavenumber. Therefore, Rossby waves are dispersive waves whose phase speeds increase rapidly with increasing wavelength, Holton (2004). Absents of Rossby wave stopped the westward motion of the air currents and this leads to increase of the phase speed of the air current to be completely the mean zonal wind flow. In addition to that, the analysis of the mean sea level pressure and geopotential height at 500mb illustrates that, the Azores high pressure system extended strongly and rapidly to the east direction towards the North Africa and it was accompanied with an eastward extension of a deep low pressure system over the northern Atlantic region through the period of 23-24 January 2009 as shown in Figure (2). The combination of the two opposite pressure systems together over Atlantic Ocean creates a very strong pure westerly air current moving toward the eastward direction. This huge westerly winds set aside the air over the eastern Atlantic region and western European coasts to forced to swept and to circulate westward direction and initiate the cyclonic circulation system which originating in the west of Bay of Biscay, extratropical cyclone Klaus, not only that but also to pushing Klaus itself to landfall strongly crossing southern France and northern Spain. Analysis of the 6-day mean anomaly of the geopotential height at 500 mb for the northern hemisphere for January 2009 revealed that there was an outstanding positive anomaly of more than +175 m over Eastern Atlantic region simultaneously with negative anomalies of less than -200 m over North Atlantic Ocean during the six days from 20 to 25 of January 2009 as clear from Figure (3a). In contradicting to that, the analysis of sea surface temperature over the northern Atlantic region shows no any significant variation of SST through that period, also, there were no positive or negative anomalies in SST temperature over this region through that period as shown in Figures (5 and 4a). Meanwhile, it is clear that, from surface relative humidity analysis that there are outstanding positive anomalies in relative humidity over the northern Atlantic Ocean through that period. See Figures (3b and 6). In addition to that, there are remarkable positive anomalies in the surface wind reached (+ 12 m/sec) at the surface, see Figure (4d).The advection of the different types of air mass over the northern Atlantic Ocean through the period 23-24 January 2009 can be noticed in the RGB satellite images (Figure 7). The composite satellite image is obtained by water vapors and infrared channel differences. The infrared channel is used in determining the temperature of satellite-observed surface. For this reason, the RGB is useful for observing the air mass type. Analysis of The 6 hours time step air mass RGB of the develop and life cycle of cyclone Klaus from 0000 UTC on 23 to 1800 UTC on 24 January 2009 shows clearly the development stages, whereas there is a two different air masses, air mass (1) and air mass (2), and fast moving nature of the cyclonic system, and the nearly zonal path that it followed, as it is illustrated in Figure (7).

3.2. The role of Azores high in developing of extratropical cyclone Klaus

The results from the above mentioned synoptic study revealed that, the Azores high pressure system aloft becomes stronger than usual and was extended rapidly to NE direction towards the north Africa at 35° N and supply the north Atlantic region by westerly air current. This high pressure accompanied with an eastward extension of low pressure system over the northern east of Atlantic Ocean at higher latitudes 65° N through the period of 23-24 January 2009, that supply too the north Atlantic region by westerly air current; see Figures (2 and 3a). The combination of the two distinct pressure systems existed over the middle of Atlantic Ocean creates together a very strong purely westerly air current which moved toward the eastward direction causing of a wind storm. This huge completely westerly air current set aside the air over the eastern Atlantic region to forced to swept and to circulate westward direction and develop the cyclonic circulation system which originating in the west of the Bay of Biscay, extratropical cyclone Klaus, not only that but also to pushing Klaus itself to landfall strongly crossing southern France and northern Spain, reaching northern Italy and even the Adriatic Sea with intensity of hurricanes. It is clear from 500 mb level charts that the Rossby wave completely disappears over the northern Atlantic Ocean whereas, the not exist of Rossby wave add eastward wind to the phase air current speed through the two days 23 and 24 January 2009. In addition to that, analysis of the 6-day mean anomaly of the geopotential height at 500 mb for the northern hemisphere for January 2009 shows that there was an outstanding positive anomaly of more than +175 m over eastern Atlantic region near 30° N simultaneously with negative anomalies of less than -200 m over North Atlantic Ocean at higher latitudes near 65° N during the six days from 20 to 25 of January 2009, see Figures (2 and 3a). However, the strong of Azores high and its rapidly movement toward the north eastward direction creates a circulation between mild and humid air mass (1) in the northern Atlantic to the south and the other (mild to cold) and humid air mass (2) in the middle Atlantic region to the north. This circulation of the two different air masses (1and 2) formed the cyclonic circulation of extratropical cyclone Klaus. Figures (12 and 13) show constructs of the six phases of Klaus development of 6 hour intervals. Throughout six phases starting from phase (I) at 0000 UTC on 23 January 2009 ended by phase (VI) at 0600 UTC on 24 January 2009, the life cycle of cyclone Klaus has been occurred. Phase (I) is the initiation stage of Klaus, whereas, there were two different air masses (1 and 2) in the north Atlantic region, air mass (1) in the north meanwhile second air mass was in the south of it. See Figure (7a). Phase (II) is considered as the first circulation stage between the two air masses. At this stage, the air mass (2) jumped to the north and second air mass circulated to the west. See Figure (7b). Phase (III) represented second circulation stage; through it the air mass (2) moved to the westward direction and circulated toward air mass (1). Meanwhile the first air mass (I) was continued to circulate southward direction. See Figure (7c). Phase (IV) is the phase of developing of the cyclone, whereas, the two air masses touch each other and started to circulate together. See Figures (7d and 9a). Phase (V) is the cyclonic phase, through this stage the air mass (2) moved faster to the North West direction and going into the air mass (I). Simultaneously air mass (1) moved to the south east direction and all of them becomes a one moving system and create a cyclonic circulation. Figure (7e) shows the cyclonic circulation of the two air masses. The last phase is the other explosive phase at which the two air masses become circulated faster inside each with a cyclonic circulation. Through this stage, the eye of cyclone Klaus formed. See Figures (7f and 9b). However, the source of the developing of this cyclone was the huge westerly zonal air current aloft over the North Atlantic Ocean which mainly due to the strong and rapidly north east extension of the Azores high. See Figures (4c and 8).

Certainty, the life cycle model of cyclone Klaus is investigated thorough the present work. This Model is innovated as a result of the analysis of the air mass RGB satellite maps, wind field distribution and a satellite perspective of cyclone Klaus evaluation over the northern Atlantic region respectively, through the period of 0000 UTC on 23 to 1800 UTC on 24 January 2009; see Figures (7, 8, 9, 12 and 13). Whereas, the results revealed that the developing and life cycle model of Klaus, is a unique model which completely differ than both of Norwegian frontal- cyclone model (Bjerknes 1921; Bjerknes and Solberg 1922) and Shapiro-Keyser life cycle model (Shapiro-Keyser 1990) for extratropical marine cyclones. These two models for midlatitude cyclones development and life cycle had a principle concept of their development on the polar front theory of atmospheric circulation by (Bjerknes and Solberg 1922), see Figures (10 and 11) respectively. Meanwhile, Figures (12 and 13) illustrates the six phases of Klaus development theory from incipient phase, phase (I), to its explosive phase, Phase (VI) which called as; the cyclonic circulation theory. According to this theory, the cyclone developed as a result of the circulation between two different air masses (not from the conversions of the two different air masses in a front like the polar front theory by Bjerknes and Solberg (1922).

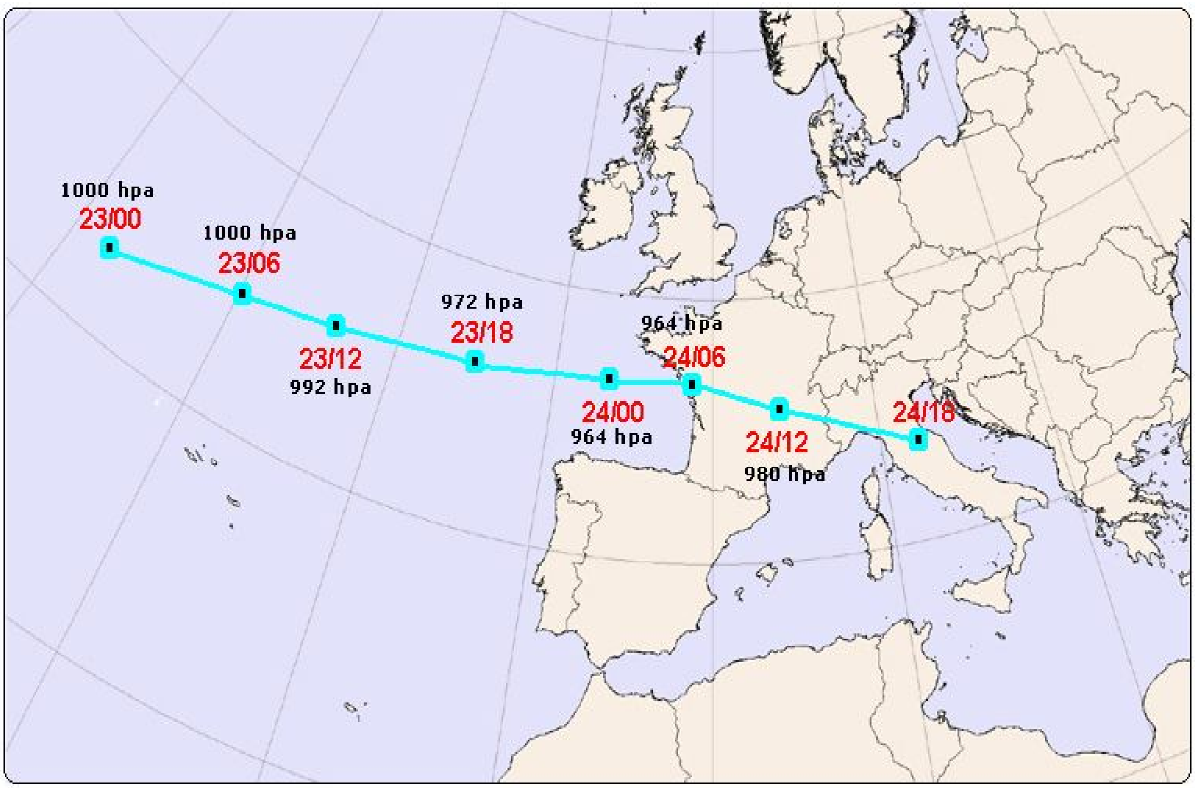


Figure 1: An approximate 6 hour track of the center of extratropical cyclone Klaus, labeled with passing dates, UTC times and minimum MSLP's analyzed by HIRLAM-AEMET numerical model. [Source; High Resolution Limited Area Model, (HIRLAM-AEMET) Spain Agency of Meteorology].

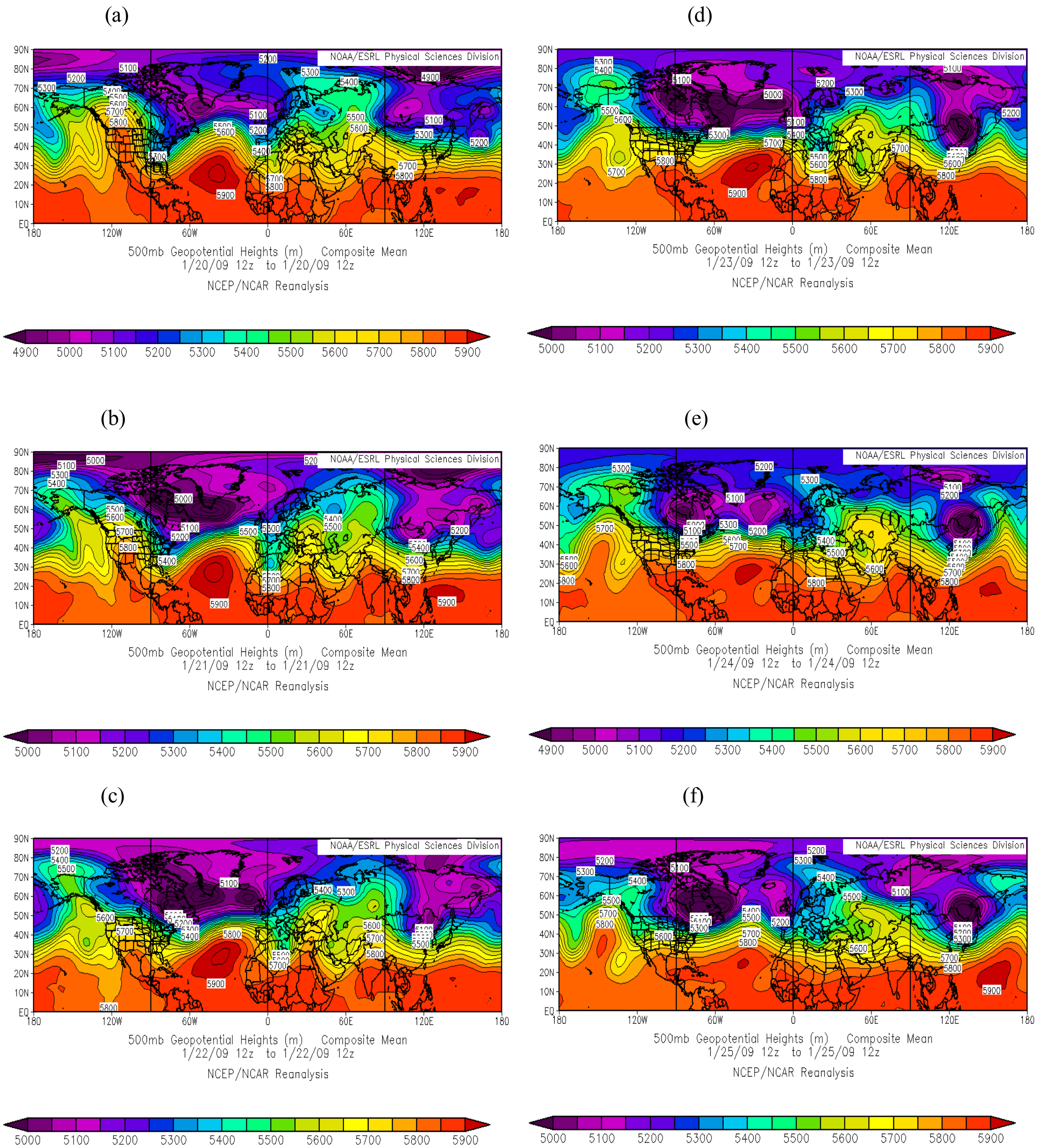
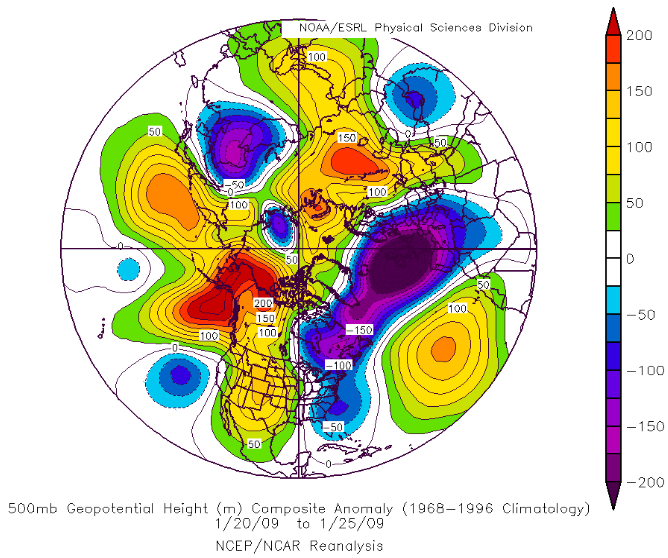


Figure 2: The daily mean of geopotential height (m) at level 500 mb for 1200 UTC over the northern hemisphere through the six days from 20 to 25 January 2009, (a, b, c, d, e, and f, respectively).

(a)



(b)

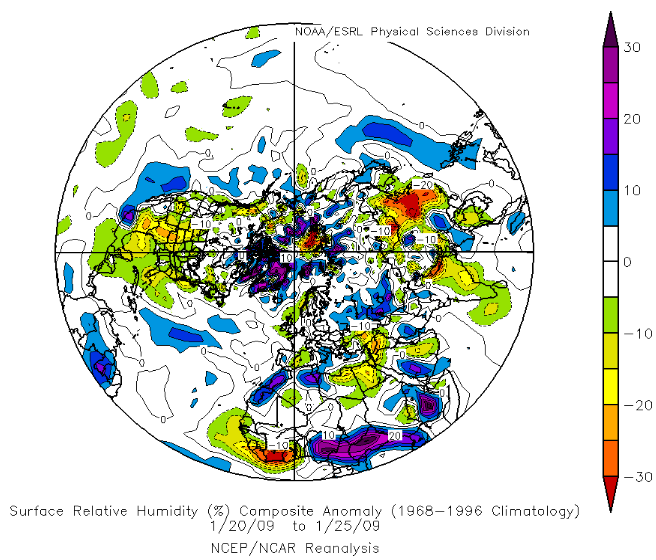


Figure 3: The six days mean composite anomaly over the northern hemisphere through the days from 20 to 25 January 2009. (a) for 500 mb geopotential height (m), and (b) for surface relative humidity.

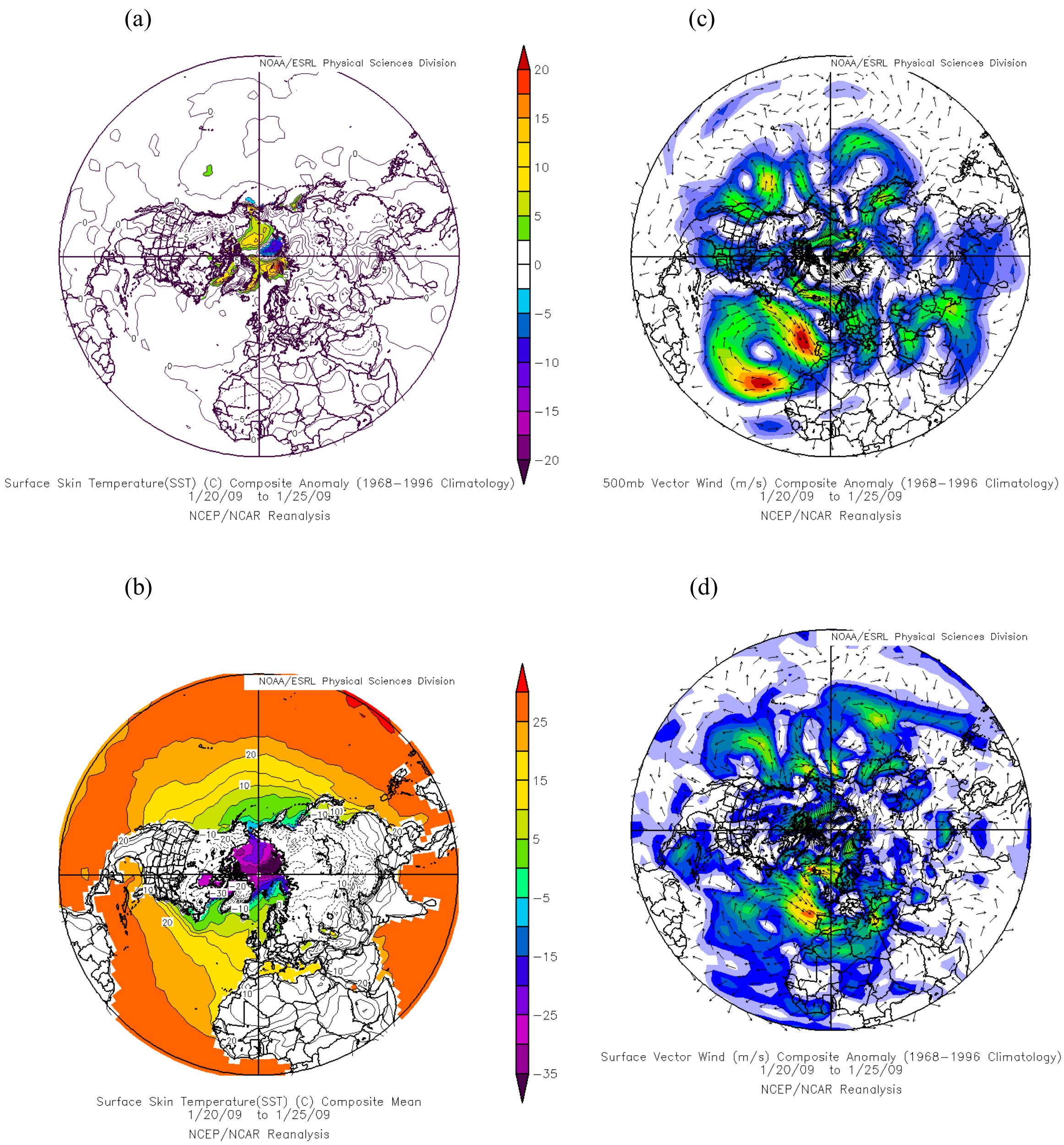


Figure 4: The six days mean composite over the northern hemisphere through the days from 20 to 25 January 2009. (a) for surface air temperature anomaly, (b) for surface air temperature, (c) for surface wind anomaly, and (d) for surface wind.

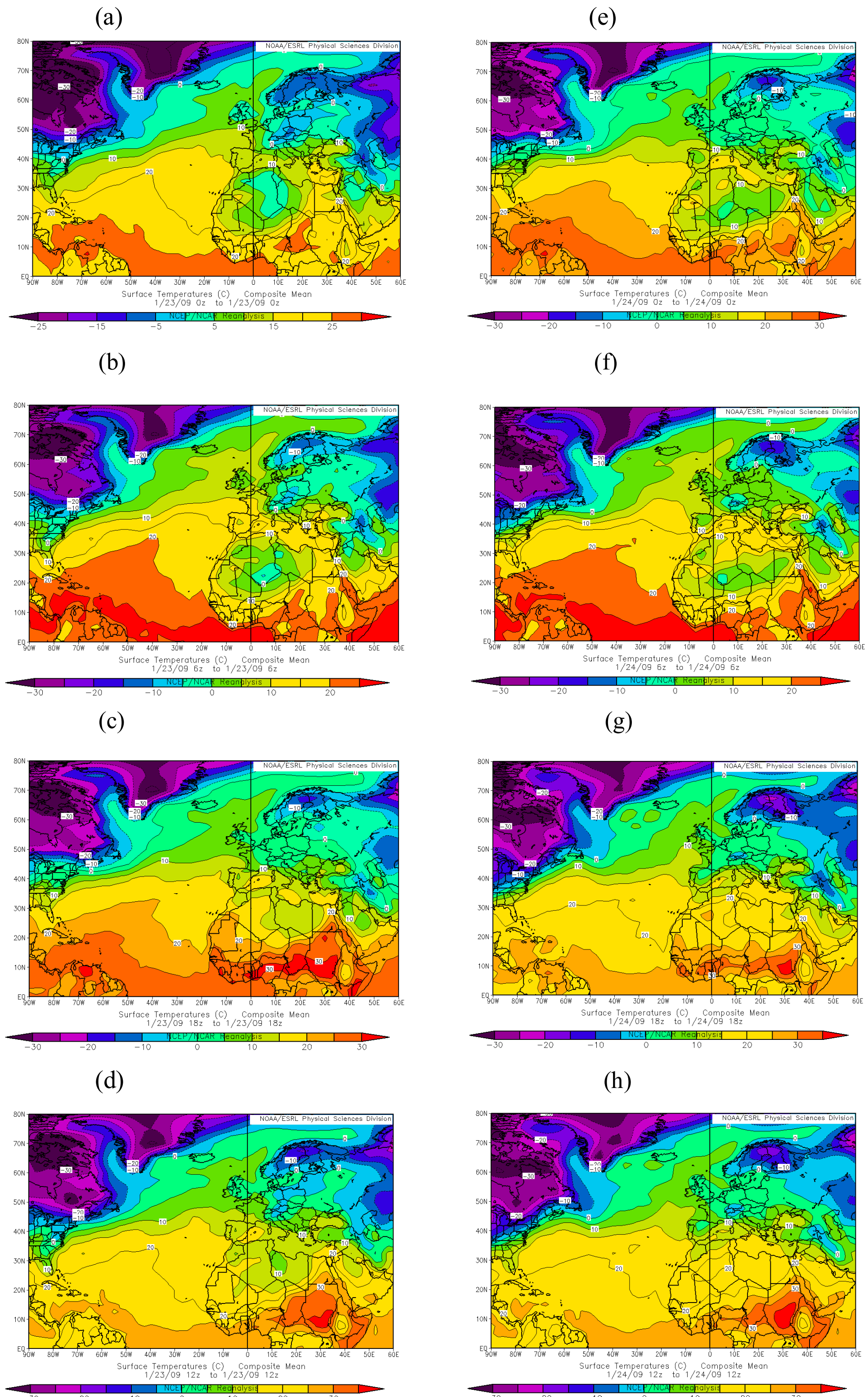


Figure 5: The 6 hour mean surface air temperature (°C) composite mean over the north Atlantic region through the period 23-24 January 2009.

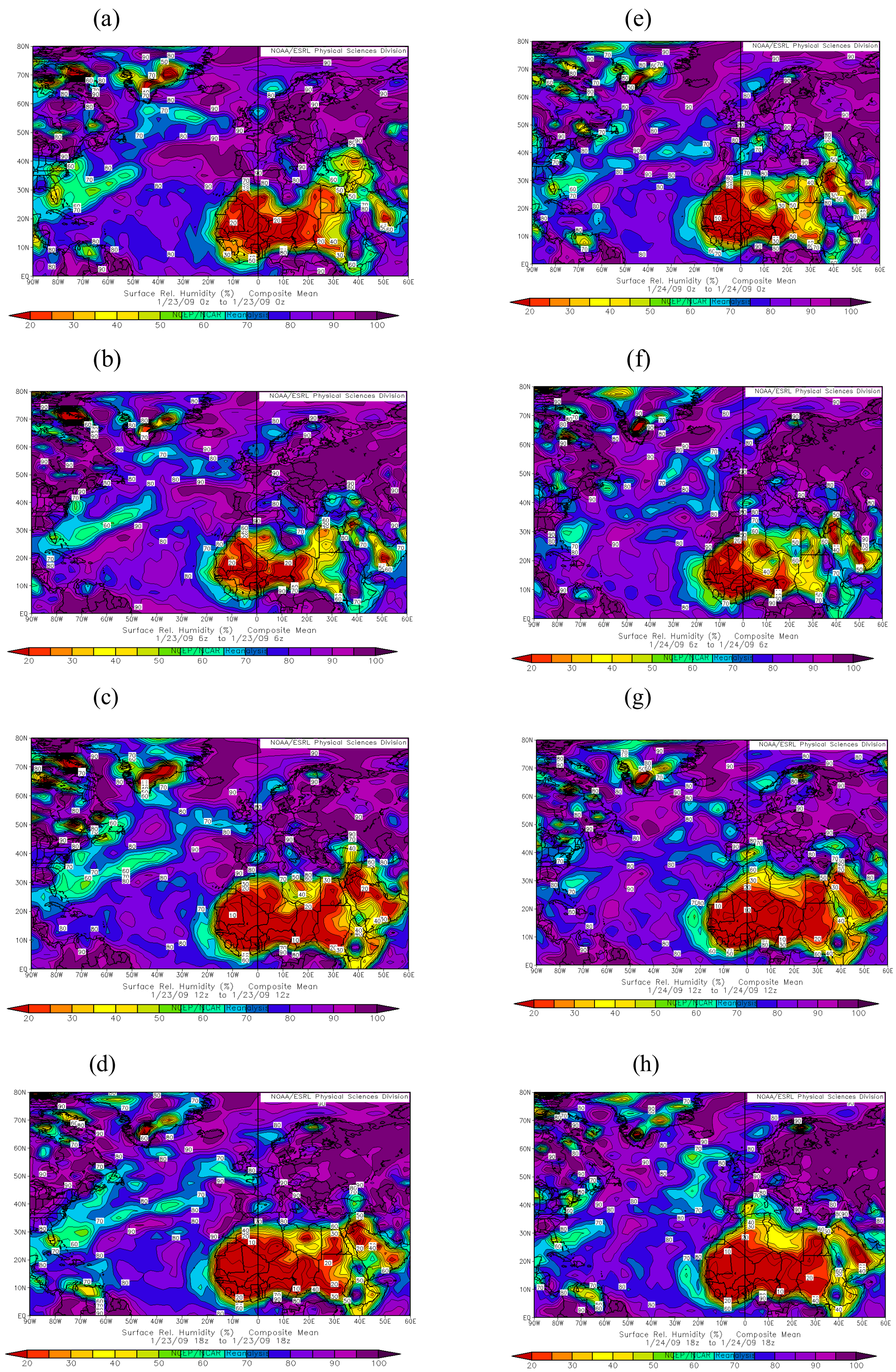


Figure 6: The 6 hour surface relative humidity (%) composite mean over the north Atlantic region through the period 23-24 January 2009.

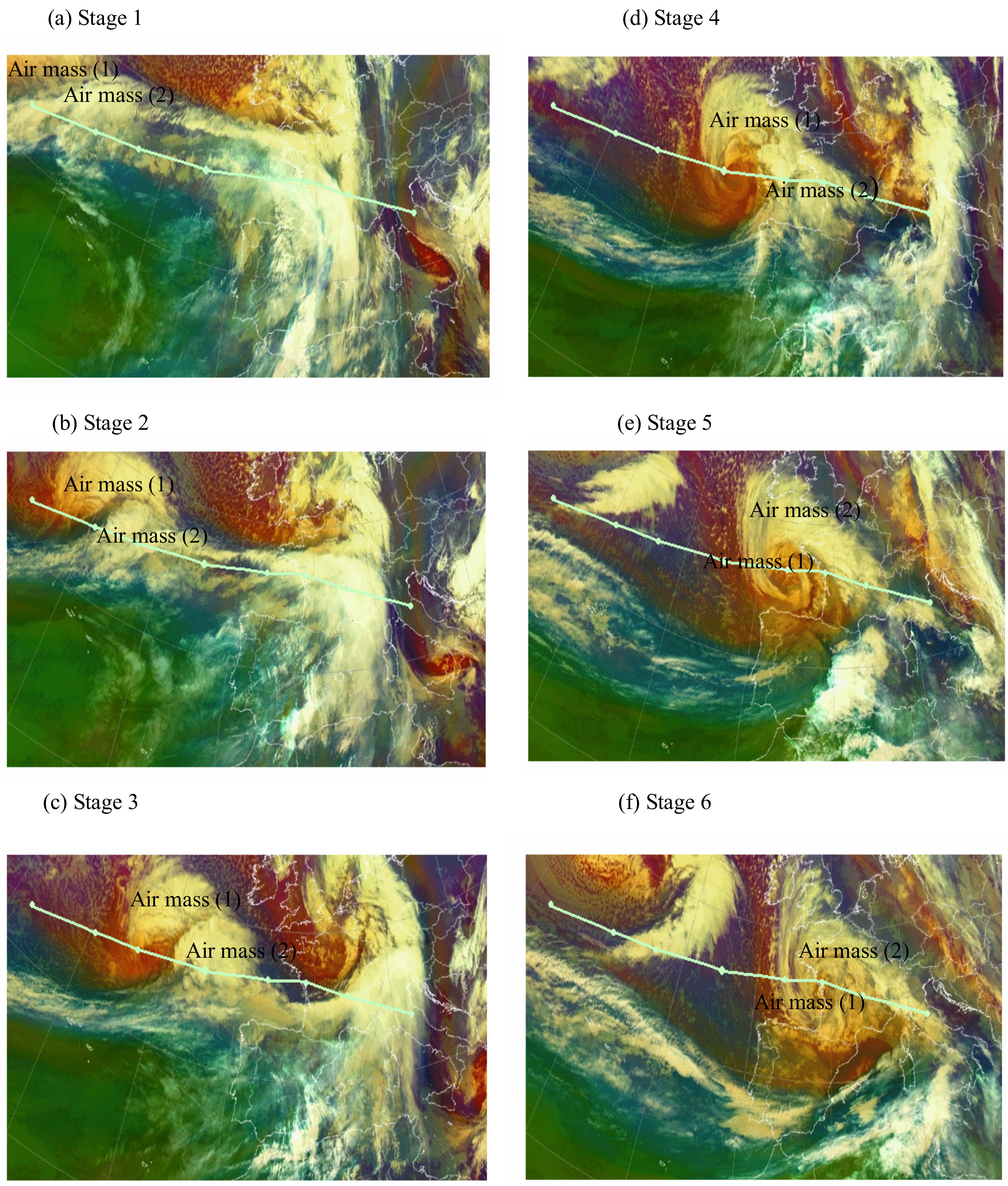


Figure 7: The 6 hours time step air mass RGB composites satellite images show clearly the developing stages in the life cycle, type of two air masses of the system, and the nearly zonal path of extratropical cyclone Klaus.

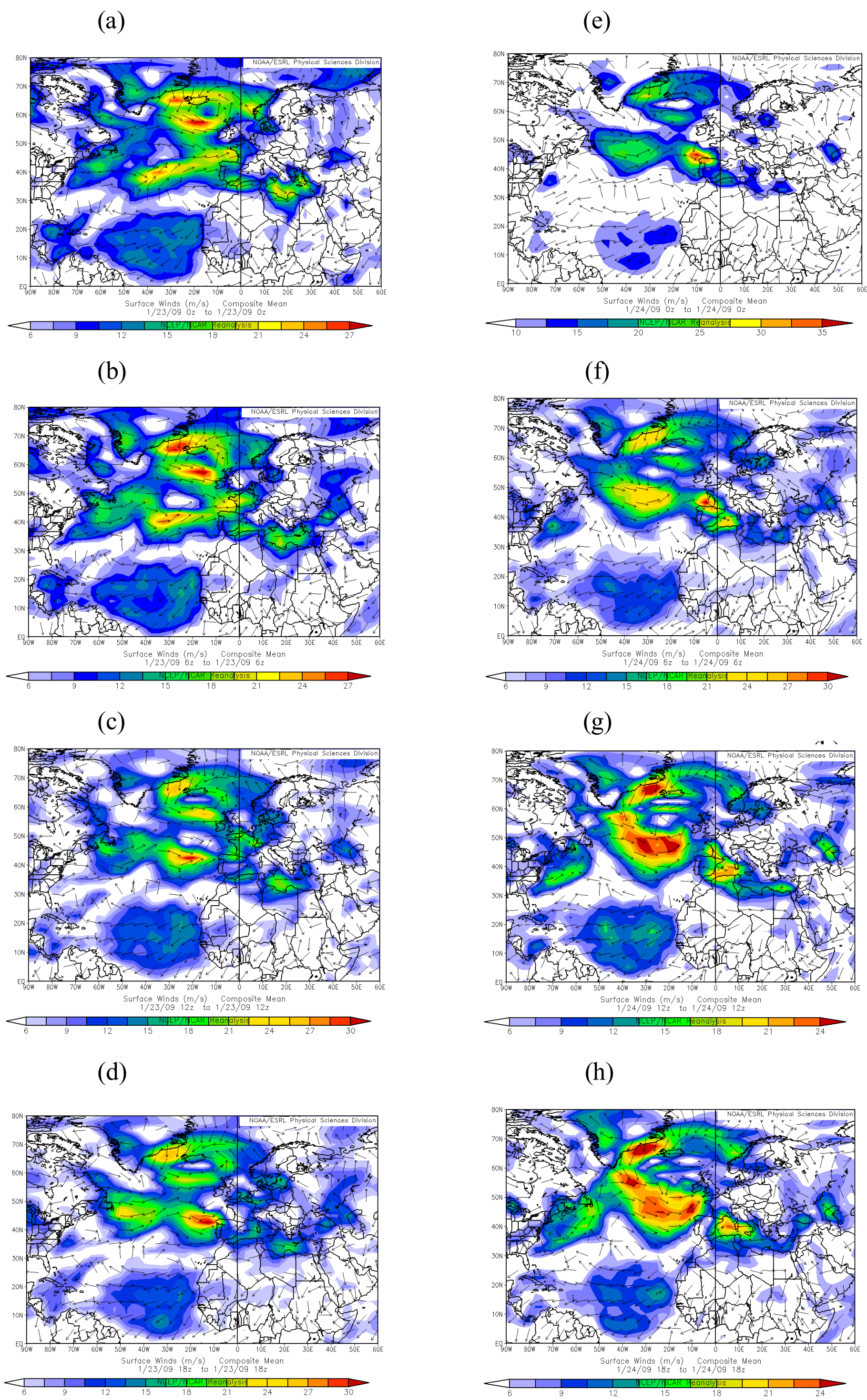
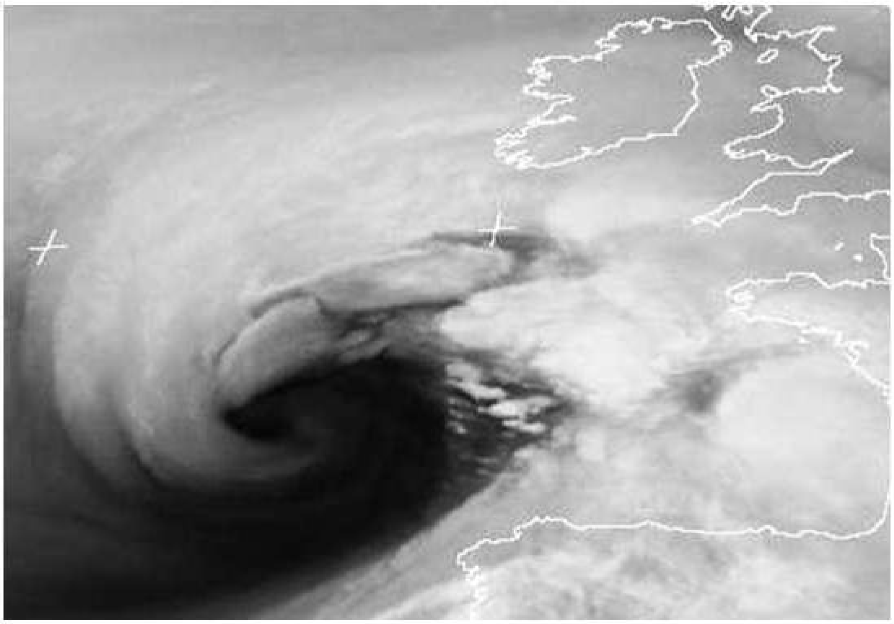


Figure 8: The 6 hour surface wind (m/s) composite mean over the north Atlantic region through the period 23-24 January 2009.

(a)



(b)

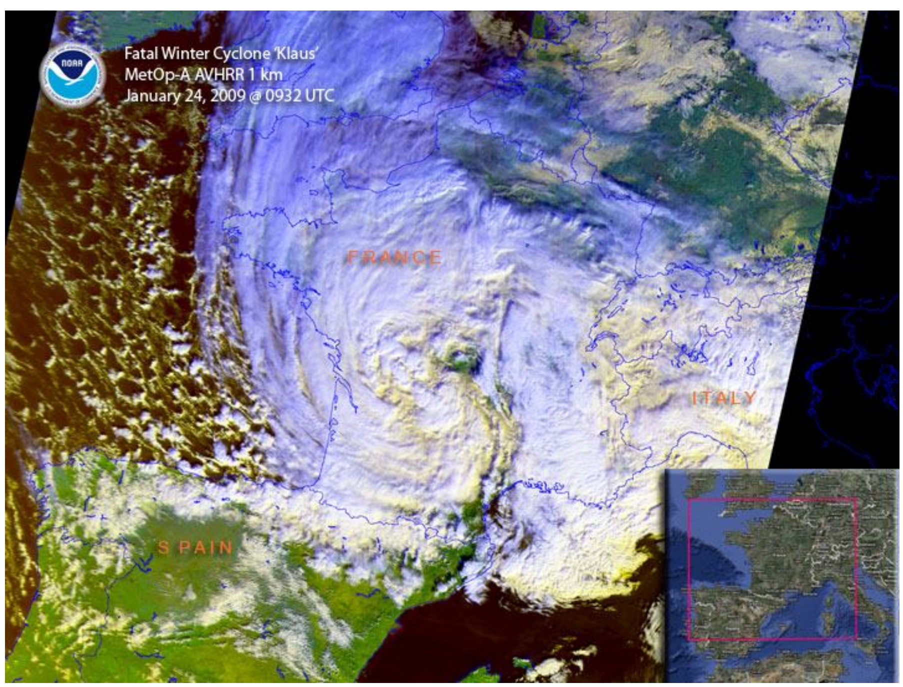


Figure 9: (a) Extratropical cyclone Klaus at 1800 UTC on 23 January 2009 as represented in satellite imagery (Source: Dundee Satellite Receiving Station and NOAA), and (b) Satellite image showing the location of Klaus over France and northern Spain at 0932 UTC 24 January 2009. (Source: MetOp-A AVHRR 1 Km, NOAA).

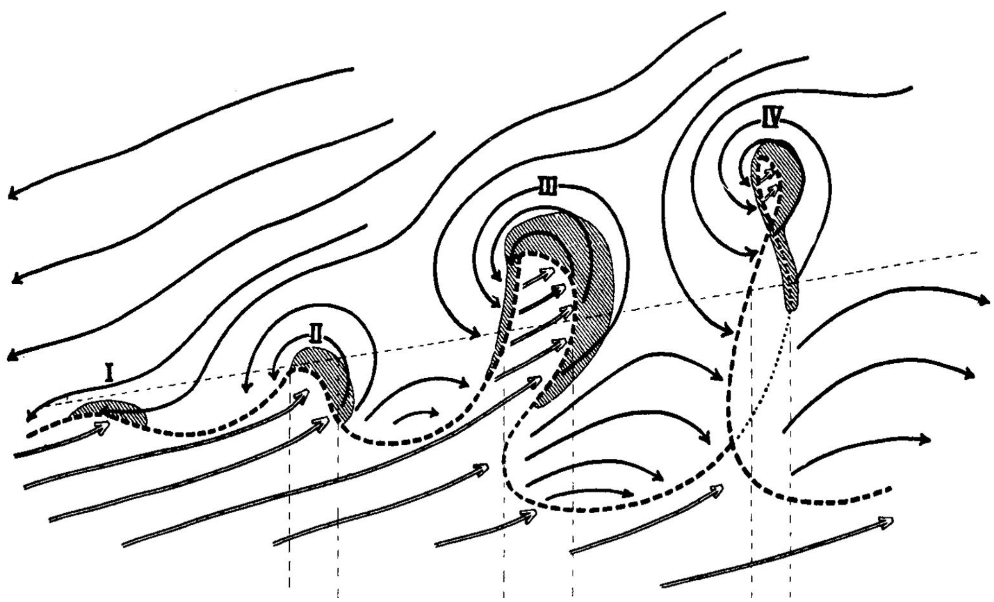


Figure 10: The Norwegian frontal-cyclone model (Bjerknes 1921; Bjerknes and Solberg 1922) describing the amplification of a frontal wave from initiation (I), through cyclogenses, (II, III), to frontal occlusion (IV). (Neiman and Shapiro, 1993)

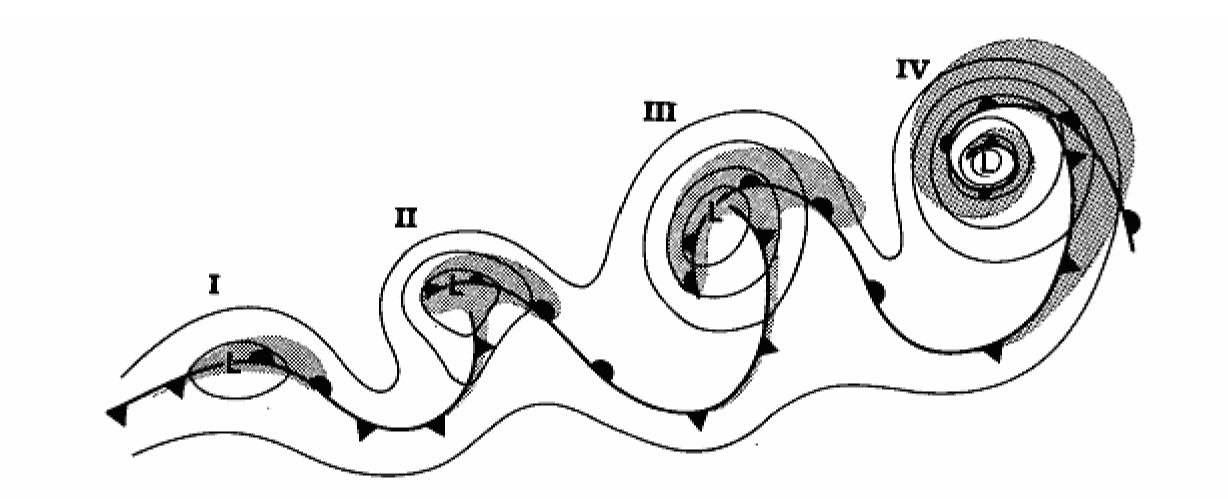
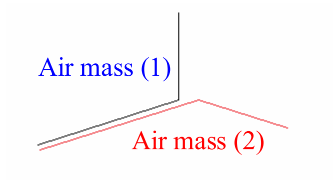


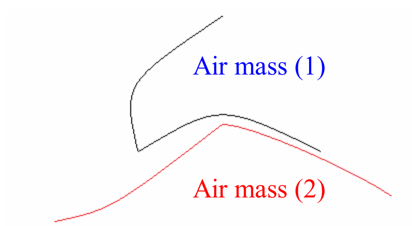
Figure 11: An alternative model of frontal-cyclone evaluation (Shapiro, and Keyser, 1990): incipient broad-baroclinic phase (I), frontal fracture (II), bent-back front and frontal T-bone (III), and warm-core frontal seclusion (IV). Sea level pressure, fronts and cloud signature. (Neiman and Shapiro, 1993).

PHASE (I): At 0000UTC 23 January 2009

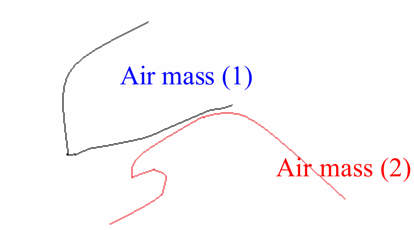


PHASE (II): At 0600UTC 23 January 2009

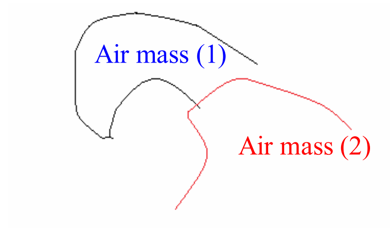
NORTH



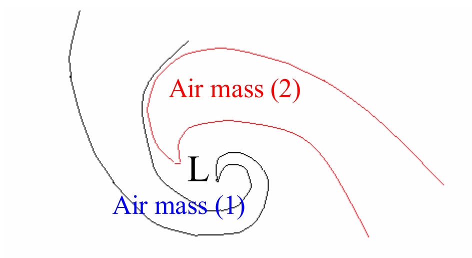
PHASE (III): At 1200UTC 23 January 2009



PHASE (IV): At 1800UTC 23 January 2009



PHASE (V): At 0000UTC 24 January 2009



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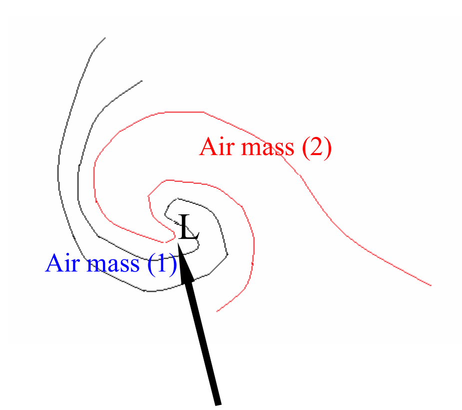
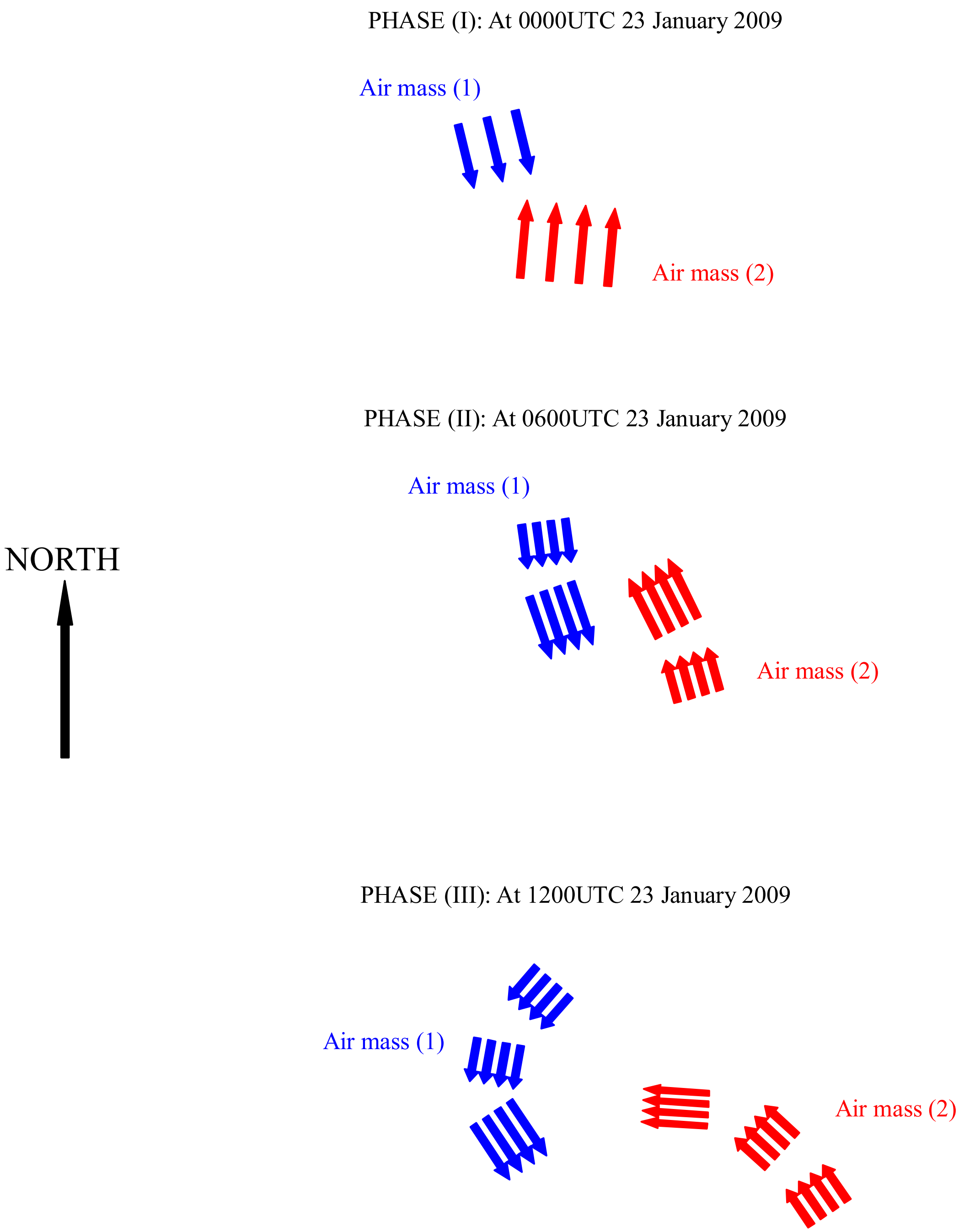
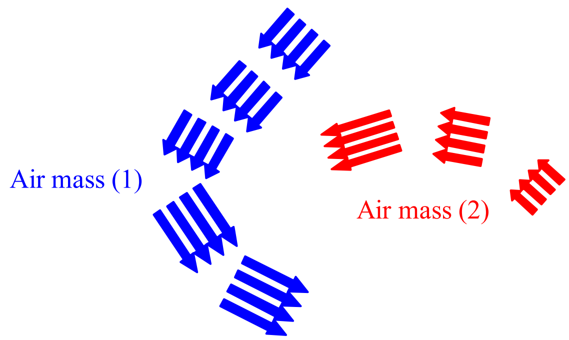


Figure 12: The six development phases and the life cycle model of extratropical cyclone Klaus (the development building upon the air masses). [The cyclonic circulation theory]


PHASE (I): At 0000UTC 23 January 2009
Air mass (1)
Air mass (2)
PHASE (II): At 0600UTC 23 January 2009
Air mass (1)
NORTH
Air mass (2)
PHASE (III): At 1200UTC 23 January 2009
Air mass (1)
Air mass (2)

PHASE (IV): At 1800UTC 23 January 2009



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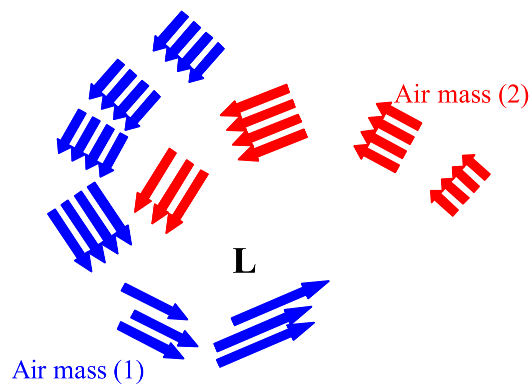

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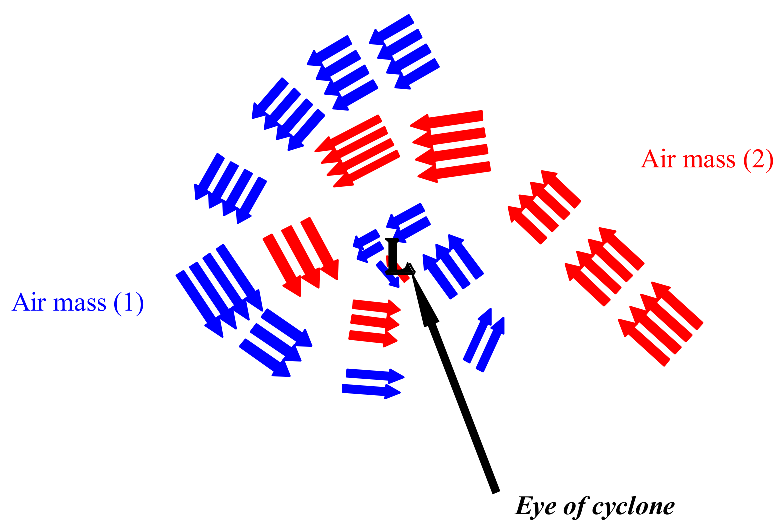

Figure 13: The six development phases and the life cycle model of extratropical cyclone Klaus (the development building upon the circulation of wind field (arrows)). [The cyclonic circulation theory]

4. Conclusions

On 23-24 January 2009, southern France and northwestern Spain were subjected to hurricane-force winds over the weekend, leaving a trail of destruction and disruption. The strong winds, combined with heavy rain, were the result of a deep low pressure system of extratropical cyclone Klaus. At least 23 people were killed during the passage of this storm which caused damage from the Dordogne area to the Pyrenees. Klaus moved across the Bay of Biscay on 23 January and into the Bordeaux region of France on 24 January, bringing powerful winds and torrential rain to southern France and northwestern Spain. Wind gusts of around 160 kmph were recorded in various locations across the region (with gusts reaching 184 kmph in the eastern Pyrenees near Perpignan). Klaus continued to track eastwards across southern France before moving into the Mediterranean Sea. Hundreds of thousands of trees had been flattened by the storm in the Gironde and Landes departments. The Landes forest is reported to have sustained severe damage while the Gironde region in southwestern France has also seen vast forest areas flattened by the storm. The synoptic analysis of the situation over the Atlantic Ocean and the northern hemisphere using of the available meteorological data and using of anomalies methodology was done. The role played of Azores high on the formation of Klaus had been studied. Through the present work there are remarkable results had been achieved.

1. The results revealed that the strong and north eastward movement of the Azores high through the period 23-24 January 2009 causing of a huge westerly air current over the middle of the northern Atlantic region. This huge completely westerly air current set aside the air over the eastern Atlantic region to forced to swept and to circulate westward direction and made the cyclonic circulation that develop extratropical cyclone Klaus.

2. The 6-day mean anomaly analysis of the geopotential height at 500 mb for the northern hemisphere for January 2009 shows that there was an outstanding positive anomaly of more than +175 m over eastern Atlantic region near 30° N simultaneously with negative anomalies of less than -200 m over North Atlantic Ocean at higher latitudes near 65° N during the six days from 20 to 25 of January 2009.

3. Anyalysis of the 6 hour geoptential height and wind fields for 500 mb level appears that the Rossby wave was completely absents over the north Atlantic region through the period of 23-24 January 2009, whereas this absence of Rossby wave push the westerly phase speed, over the north Atlantic region, eastward toward western Europe by the eliminates of westward wind speed of Rossby wave, which also leads to the strong wind storm.

4. The analysis of the 6 hours time step air mass RGB satellite images, wind field distribution, and a satellite perspective of cyclone Klaus evaluation over the northern Atlantic region through the period of 0000 UTC on 23 to 1800 UTC on 24 January 2009 leads to uncover the development six phases of extratropical cyclone Klaus and to construct its life cycle model.

5. The life cycle model of Klaus is a unique model which completely differs than both of Norwegian frontal- cyclone model (Bjerknes 1921; Bjerknes and Solberg 1922) and Shapiro-Keyser life cycle model (Shapiro-Keyser 1990) for extratropical marine cyclones.

6. Knowing of the life cycle model of Klaus is conduct to innovate a new theory of cyclonic formation is so called; the cyclonic circulation theory.

7. According to the cyclonic circulation theory, the cyclone is develop as a result of the circulation between two different air masses, through a six phases from incipient phase , phase (I), to its explosive phase, phase (IV). See Figures (12 and 13). However, there is no a front between the two air masses or a warm sector existed here.

Finally, one can conclude that the Azores high pressure system played a great role in the developing of the extratropical cyclone Klaus on 23-24 January 2009 over the middle of the northern Atlantic Ocean, west of the Bay of Biscay, by supporting the north Atlantic with a strong westerly air current and swept the air over the eastern north Atlantic Ocean and western Europe to move toward the westward direction and creates the cyclonic circulation over the east of the northern Atlantic region. After a one hundred years since the polar front theory made by Bjerknes, (1919, 1921 and 1922), there is another theory of midlatitude cyclonic formation, the cyclonic circulation theory. The analysis of the development stages of extratropical cyclone Klaus is considered as the practical application which leads to this theory.

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