Chapter 13 Study Guide and Case Studies: Severe Weather – From Heat Waves to Great Storms

Key Concepts

- The temperature on Earth varies between -89 ºC (-129 ºF measured in Vostok, Antarctica) and 57 ºC (134 ºF Death Valley, U.S.).
- The temperature at the top of the troposphere is about -60ºC (-80 ºF)
- According to the WMO, a heat wave occurs when the maximum daily temperature exceeds the typical average maximum temperature by 5 ºC (9 ºF) for 5 or more consecutive days.
- Heat waves can form during stable atmospheric conditions with high surface air pressure.
- The heat index describes how air of a certain temperature feels when its relative humidity is taken into account. The heat index has a larger impact with increasing temperature or humidity.
- The urban heat island effect enhances heat waves. Paved ground traps heat, prevents cooling at night, the lack of trees reduces shade and prevents cooling by evaporation of water. The use of air conditioner for indoor cooling emits additional heat outside.
- The increased use of air conditioning during heat waves puts additional burden on the electric power grid.
- Heat waves can be hazardous to air traffic.
- Of all severe weather in the U.S. heat waves have claimed the most lives during the last 25 years.
- Cold waves or cold snaps can occur when Arctic air moves unusually far south.
- The wind chill factor describes how air of a certain temperature feels when current wind conditions are taken into account. The wind chill has a larger impact with decreasing temperature or increasing wind speed.
- In the U.S., a blizzard is a snow storm with blowing snow, low visibility, strong winds and that lasts at least 3 h.
- Clouds are named after their shape and the altitude at which they occur.
- Clouds form when water vapor condenses.
- Fog and clouds are physically identical but the former is near the surface.
- Air masses form over large flat areas with only light surface winds.
- Fronts form where air masses collide.
- Cold fronts are often associated with violent weather behind the front.
- Warm fronts are often associated with wide and extended rainfall leading the front.

- The passage of a front can be observed through changes in temperature, air moisture content, air pressure, clouds and precipitation patterns and shifts in wind direction.
- Wave cyclones can form along a stationary front in mid latitudes. A cold front then forms and catches up with a slower-moving warm front. Some wave cyclones can develop into large powerful storms.
- A Nor'Easter is a particularly strong winter storm on the North American east coast. Early Nor'Easters in late fall can be fed by late Atlantic hurricanes that move north.
- The Pineapple Express is a warm, soggy winter storm on the North American west coast. It is fed by moist, tropical moisture from the Pacific near Hawaii. The jet stream channels this moisture to form a so-called atmospheric river.

Key Terms

- heat waves
- relative humidity
- heat index
- urban heat island effect
- cold snaps
- wind chill factor
- blizzard
- cloud
- fog
- condensation
- rain
- sleet
- drizzle
- snow
- hail
- air masses
- fronts
- stationary front
- cold front
- warm front
- occluded front
- wave cyclone
- Nor'Easter
- Pineapple Express
- Atmospheric river

Questions for Review

1. What were the coldest and hottest temperature measured on Earth's surface?

2. Describe a heat wave.

3. When can heat waves form?

4. Describe how the heat index affects temperatures felt by humans.

5. What is the apparent temperature when the measured temperature is 105 ºF and the rel. humidity is 15%? What is it for 50% rel. humidity?

6. How does the urban heat island enhance a heat wave?

7. What happens to the electric power grid during a heat wave?

8. When can cold snaps form?

9. Describe how the wind chill factor affects temperatures felt by humans.

10. What is the apparent temperature when the measured temperature is 20 ºF and the wind speed is 5 mph? What is it for a wind speed of 30 mph?

11. What is a blizzard?

12. How do clouds get their name?

13. What is fog?

14. Describe how a cold front forms and which type of weather is associated with it.

15. Describe how a warm front forms and which type of weather is associated with it.

16. How do wave cyclones form and evolve?

Case Studies

Case Study 1: The 1995 Chicago Heat Wave

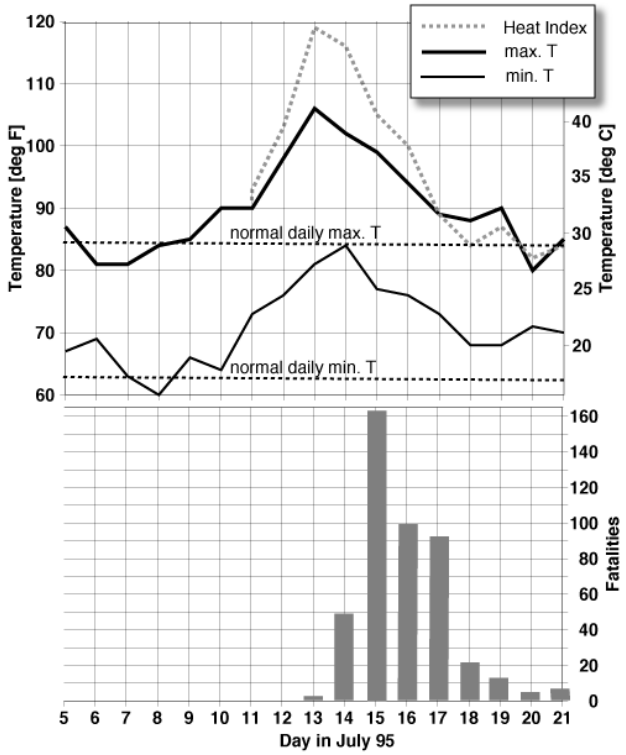

Figure 13.C1 Daily minimum and maximum temperatures in mid-July 1995. Prior to July 10, daily temperatures were normal. The heat wave started on July 11 when temperatures rose above normal. The heat wave had its climax on July 13-14 when both the daily minimum and maximum peaked. On July 13, the high humidity drove apparent temperatures to 120º F, a level considered dangerous in Table 13.3. On the same day, the daily minimum rose above 80º F, which is often considered a threshold for nighttime temperatures above which the human body has difficulties to recover from the daytime heat. Heat-related deaths started to rise significantly on July 14, during the climax of the heat wave, and peaked on July 15 (nearly 0.5 in of rain fell on that day). There is a lag between peak temperatures and the occurrence of heat-related fatalities. Data are from the National Climate Data Center (NCDC).[16]

In July 1995, a strong upper-level high-pressure system sat on top of a slow-moving hot, humid air mass on the surface. During the five-day period 12 – 16 July, heat records were broken at numerous weather stations in the central and northern Great Plains. In Chicago, the heat index rose to dangerous levels on July 12 and the daily minimum temperature (i.e. the nighttime temperatures) remained close or above 80º F, the threshold above which people start to have difficulties to recover from daytime heat. In his book "Heat Wave" (Eric Klinenberg describes very graphically, how this weather situation turned

catastrophic in Chicago. On 12 July, news media warned that a severe heat wave was on the way for the two following days. A day later, temperatures hit 106ºF, the heat index rose to 126ºF and temperatures in buildings rose to 120ºF even though the windows were open (Fig. 13.C1). Thousands of cars broke down in the street, roads buckled, train rails detached from their moorings and city workers hosed down bridges across the Chicago River to prevent them from locking. Soon, scattered power outages occurred, and air conditioning systems no longer worked. On July 14, 49,000 customers lost power for as long as two days. Young residents opened fire hydrants to shower themselves down. At one point, more than 3,000 hydrants spouted freely contributing to a doubling of overall water consumption. As a result, water pressure fell and some pumps left buildings without water for days. On July 14, a Friday, the heat index exceeded 100ºF for the third consecutive day.

City residents became ill because the human body can take only 48 h of uninterrupted exposure to such heat before breaking down. Sick people were transported to hospitals that quickly became overwhelmed. Some people had to wait two hours before an ambulance became free to take them to the hospital. More than 20 hospitals, most on the South and Southeast Sides of the city, went on bypass mode: closing the doors of emergency facilities and refusing to accept new admissions. Many heat victims were not discovered or taken to hospitals until it was too late. Victims were disproportionately the elderly and poor, who often did not have air conditioning. They also lived alone so no one was around to recognize that they needed help. Follow-up research also revealed that fatality rates were particularly high among older black males.

Some officials argued that the heat wave itself did not kill people, but that it hastened the demise of people who would have died anyway. They based their arguments on the fact that fatality rates very somewhat low after the heat wave. The Illinois Department of Health analyzed the mortality patterns following the heat wave and found that there was no compelling evidence for these conjectures. African-American politicians on the South Side called for the resignation of top city officials and the Commonwealth Edison, the primary utilities provider, became the target of the mayor and city council. In the end, the finger-pointing did not bring back the dead but revealed the signs of social breakdown when people die slowly and alone in their homes without the help from neighbors, friends and unassisted by the government. One should hope that this disaster helped Chicago, and other large cities, to prepare better for future such heat waves.

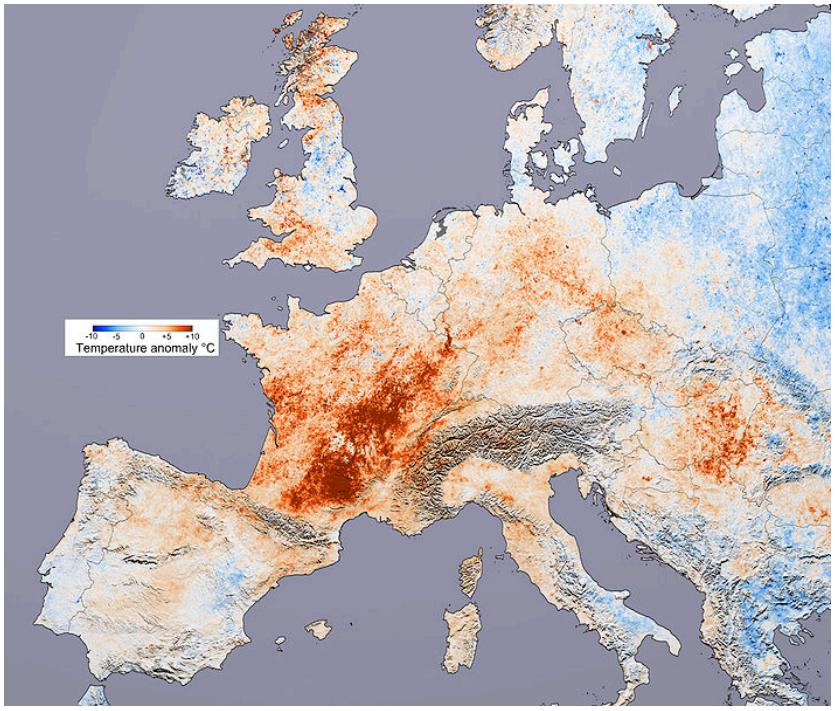

Figure 13.C2 Differences in daytime land surface temperatures collected in the two years by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. Covering the data range of 20 July – 20 August, temperatures were 10ºC (18ºF) hotter in 2003 than in 2001 along a wide swath across southern and eastern France. Temperatures were elevated also in many other European countries, even including parts of the U.K.. In London, trains were shut down over fears that tracks would buckle in the heat. In the Alps, rapid melting of snow and ice triggered the collapse of a rock face on the Matterhorn, Switzerland. (source: Wikipedia, originally NASA Earth Observatory[18])

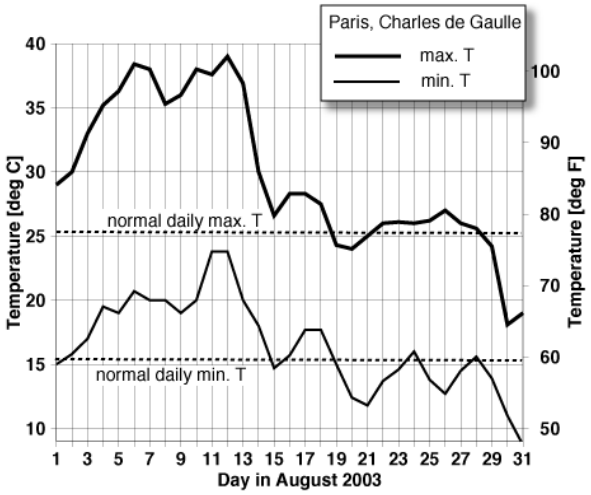

Figure 13.C3 Daily minimum and maximum temperatures at Paris, France Charles de Gaulle Airport in August 2003. During the first half of the month, daily highs and lows were above the averages for that month, indicating the temporal extend of the heat wave. Anomalies peaked around August 6th and again around August 12th. Daily highs were more than 10ºC (18ºF) above normal, and even nighttime temperatures were routinely above normal by 5ºC (9ºF) for the entire first half of the month. Data were obtained through freemeteo.com[20].

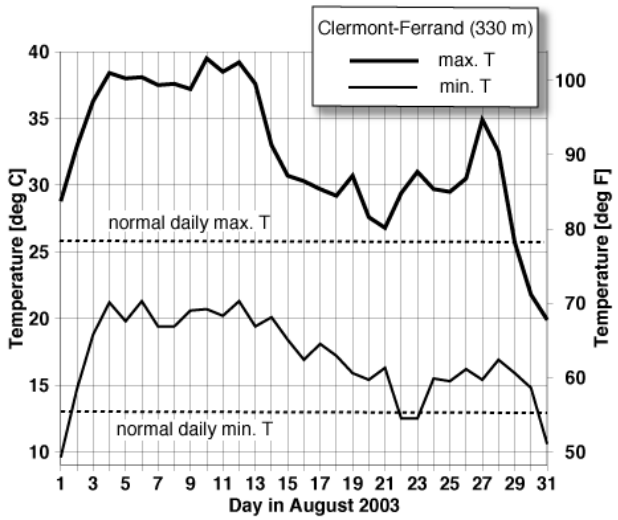

Figure 13.C4 Daily minimum and maximum temperatures in Clermont-Ferrand in the hilly Auvergne in August 2003. Clermont-Ferrand is located at 330 m above sea level. Daily highs and lows were above the averages for nearly the entire month. In the period August 4th – 13th, daytime temperatures were consistently near 38ºC (100.4ºF) and thereby 12ºC (21.6ºF) above normal. Nighttime temperatures were around 20ºC (68ºF) and thereby 7ºC (12.6ºF) above normal. Data were obtained through freemeteo.com[20].

Case Study 2: The 2003 European Heat Wave

Having the 1995 Chicago heat wave in mind, and the lessons to be learned from it, it is nearly unbelievable that a much larger disaster struck 8 years later in Europe.

Due to its proximity to the Atlantic Ocean, France usually experiences a mild marine west coast climate (Fig. 11.7). Average high temperatures in Paris are 25.2ºC (77.4ºF) in July, though the record high prior to 2000 was 40.4ºC (104.7ºF). The average low for this month is 15.5ºC (59.9ºF). The numbers for August are 0.1 and 0.2ºC lower (0.4 and 0.2ºF). Temperature highs are very similar in the hilly Auvergne region in central southern France, with daily average highs at 25.9ºC (78.6ºF) and 25.8ºC (78.4ºF) in July and August in Clermont-Ferrand, the capital of the Puy-de-Dôme department, but lows at only 13.4ºC and 13.2ºC (56.1ºF and 55.8ºF). Residential buildings in the countryside, and especially so in the Auvergne, are make of stone quarried in the area. The buildings usually do not take up much heat during the day, so they are cool at night and air conditioning is not needed. Typically, schools, many offices and businesses close for vacation from late July through August. People take vacation in the countryside or along the coast, thereby escaping the summer heat during work.

France and Europe had already experienced higher than normal temperatures in July, and devastating wildfires occurred in southern France, Spain, Portugal and also in Germany.

In Portugal, 40% of the forests were devastated by fires. But the heat brought in August was nothing the continent experienced in decades, perhaps even centuries (Figs. 13.C2, 13.C3, 13.C4). Central southern France was hardest hit in terms of above-normal temperatures but the sweltering heat spread throughout the continent. In the first half of August, temperatures routinely remained above normal by 10ºC (18ºF) or even more, with nighttime temperatures in Paris not dropping below 21ºC (69.8ºF) on August 11th and 12th. At London Heathrow airport, U.K., the thermometer climbed to 37.9ºC (100.2ºF) on August 10th. On that day, it was hotter in London than in Cairo, Egypt which measured only 34.4ºC (93.9ºF). Charles de Gaulle Airport in Paris measured 38ºC (100.4ºF). Drought conditions with only half the normal rainfall caused water level in rivers to fall to epic lows, and shipping transport ceased on the Elbe River in Germany and the Danube. The river Danube reached its lowest level ever, exposing sunken WWII ships. In many countries electrical power plants had to be shut down.

Table 13.C1 Fatalities from the 2003 European Heat Wave by Country[21]

Country	**# Fatalities**
France	14,800
Italy	4,000
Germany	3,500
Spain	2,000
Portugal	1,300
U.K.	900
Netherlands	500
total	27,000

Thousands of people lost their lives during this heat (Table 13.C1). The exact number of fatalities is still difficult to come by. Some sources mention number as high as 70,000. A number often circulated, 35,000, is based on 2004 estimates by the Red Cross. The Munich Re Insurance estimated 27,000 fatalities directly related to the heat. In Germany, the number initially reached into the 7,000 and it is currently not entirely clear how this number was cut in half at the end. At least in Germany, it was initially thought that heart attacks and circulatory failures were the main cause of death but more recent research suggests respiratory failure caused the elderly and sick to perish. As in Chicago, the elderly were affected most. Sadly, research of mortality data revealed that the ill elderly in nursing homes had a higher survival rate than the otherwise healthy elderly at home. Quite obviously, the healthy elderly often were home alone, perhaps living alone. But the problem also was that younger people were on vacation and/or not available to help in general. The fact that elderlies also may not be as embedded in the family structure as in other countries stirred quite some controversy and soul searching in France.

The heat wave was reportedly the hottest in continental Europe since 1540[19]. In their online summary on extreme weather event, the world meteorological organization (WMO) also cites evidence that humans contributed to the heat wave and that human influence doubles the likelihood for such devastating heat waves to reoccur. In France,

the elderly were more likely to die in winter than in summer, until about 50 years ago. Now the chances are higher to die during the summer.

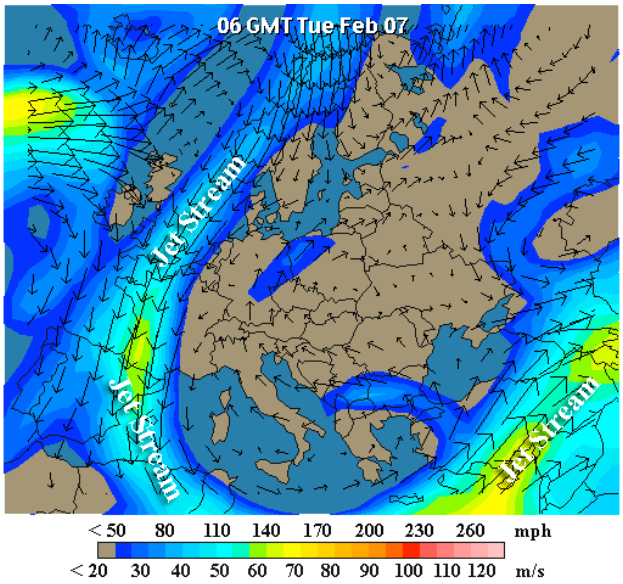

Figure 13.C5 In late January 2012, the jet stream over Europe took a major excursion from the north across France far into the Mediterranean Sea and around Italy and Greece. This allowed cold air from two high-pressure systems over Siberia to flow into eastern and central Europe. The highest high pressure was recorded at 1058 mbar in Haparanda, Sweden. (source: wunderground.com)

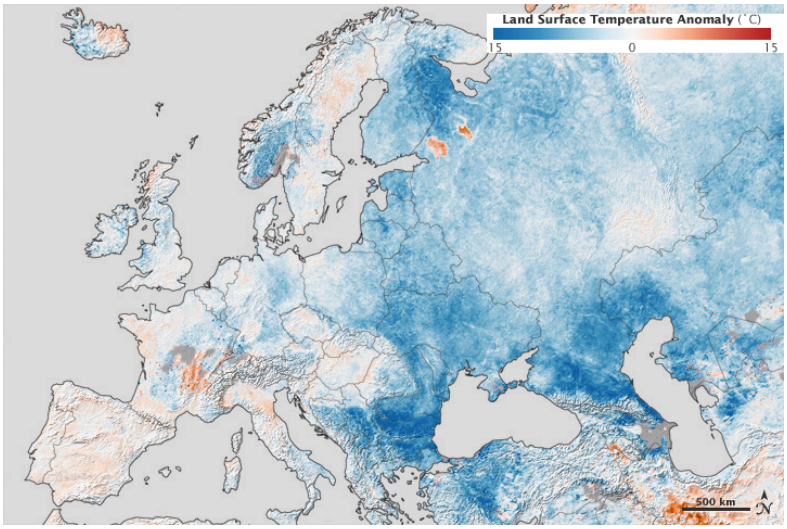

Figure 13.C6 Differences in daytime land surface temperatures collected between 25 Jan and 1 Feb 2012 compared to temperatures for the same dates from 2001 through 2011. The anomalies are based on observations by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. In southeastern and eastern Europe in particular, temperatures are anomalously low by as much as -15ºC (27ºF). The cold wave ended 18/19 Feb when thaw brought flooding to eastern Europe. (source: NASA Earth Observatory[22]; also found on Wikipedia)

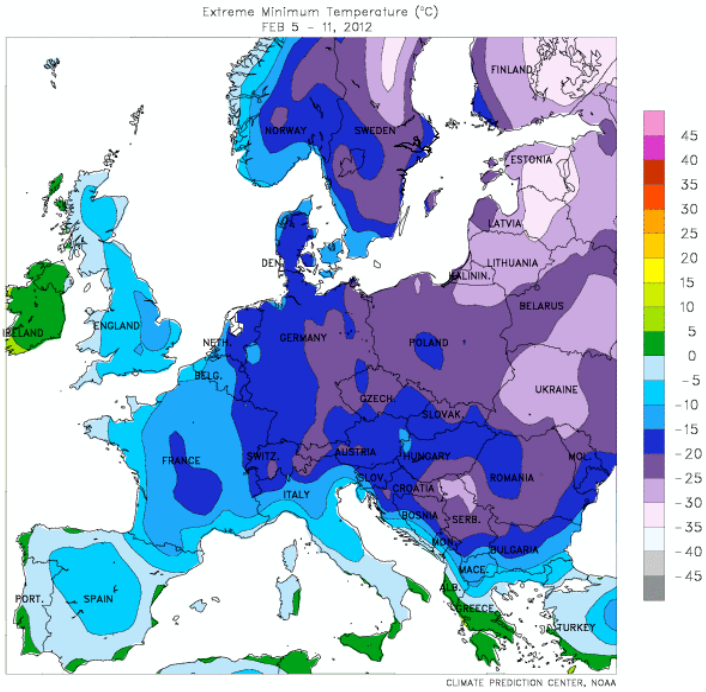

Figure 13.C7 Minimum temperatures (in ºC) in Europe, measured from 5 – 11 Feb 2012. The lowest temperature was measured on 6 Feb in Glattalp, Switzerland at -45ºC (-49ºF) (altitude: 1800 m/5900 ft). Winds gusted at 205 km/h (127 mph). (source: German Wikipedia; originally NOAA)

Table 13.C2 Fatalities from the 2012 European Cold Wave by Country (as of early Feb 2012)[22]

Country	# Fatalities	Comment
Russia	215	
Belarus	180	in domestic fires
Ukraine	151	mostly homeless
Poland	103*	from cold alone
Romania	80	
Italy	54	
Bulgaria	27	
Serbia	20	
France	4	
Croatia	3	
Greece	many	homeless
Netherlands	1	homeless
total	> 668	

*an additional 107 reportedly died from flames in house fires, plus 24 from CO poisoning

Case Study 3: The January/February 2012 European Cold Wave

In late January 2012, two high-pressure systems formed over Russia and Siberia and several low-pressure systems over the Atlantic Ocean and the Mediterranean Sea. At the same time, the jet stream formed an extreme excursion that allowed cold Arctic air from the Siberian high-pressure systems to flow far into lower latitudes in Europe. This set the stage of one of the most deadly cold waves in recent history. The hardest-hit areas, with temperature anomalies of -15ºC (27ºF) or larger were in southeastern and eastern Europe (Figs. 13.C5, 13.C6, 13.C7). But low temperature anomalies were recorded as far south as Libya which may have seen the heaviest snowfall since 6 Feb 1956. Rome experienced solid snow in the biggest snowstorm since 1986. Power outages affected 120,000 people. In the Balkan, heavy snowfall in blizzard conditions combined with unusually low temperatures, and many villages in the Balkan were cut off, involving 70,000 people in Serbia alone. Bosnia, Bulgaria and Serbia's capital, Belgrade measured the lowest temperatures since recording began 100 years ago: -15ºC (5ºF) in Belgrade and -30ºC (-22ºF) in Bulgaria. In Serbia, record-breaking electricity consumption prompted the government to mandate a shut-down of non-essential industries and lighting.

In Germany, freezing on Elbe-Havel and the Main-Danube canals led to a shutdown of shipping. In Romania, the Danube froze over completely. In Hamburg, Germany, the Alster River froze over to allow ice-skating for the first time in 15 years. People also ice-skated on the frozen canals in Amsterdam, Netherlands. Parts of Lake Constance were frozen for the first time since 1963, as were parts of Lake Zurich, Switzerland. In the east, Georgia experienced its coldest winter in nearly 50 years, with important water bodies freezing over. Some areas experienced extremely strong winds. In the Balkan, they contributed to the blizzard conditions. In Krk, Croatia, winds gusted at 205km/h (127 mph). In Portbou in Catalonia, Spain, winds clocked at 175 km/h (109 mph) as temperatures dropped to -23ºC (-9ºF). In the Alps, high winds around Lake Geneva caused freezing spray to cover everything from trees to cars (Fig. 12.16b).

The cold waves killed more than 650 people (Table 13.C2). As reported in the news, the hardest-hit countries, recording the highest number of fatalities, were Russia, Belarus and Ukraine where temperatures dropped as low as -35ºC (-31ºF). 215 people lost their lives in Russia and 151 in Ukraine. In Ukraine, many of the dead were homeless people and health officials blamed alcohol as a contributing factor in many deaths. In central Europe, the hardest hit country was Poland, with 103 fatalities from the cold alone. However, fire and rescue services reported 360 domestic fires during one night (11 – 12 Feb) in which 107 people died in flames. An additional 24 people died from carbon monoxide poisoning. Taken together, with 234 fatalities Poland, was the hardest hit country in all of Europe.

Case Study 4: The 1991 Halloween 'Perfect Storm' Nor'Easter

The 1991 'Perfect Storm' was a Nor'Easter that was strengthened by a hurricane. The initial low pressure of the storm formed off the Canadian coast on 28 October. Forced southward by a high pressure farther north it strengthened while moving south and strengthening (Fig. 13.C8). The storm encountered and was subsequently fueled by category-2 Hurricane Grace that had developed earlier and unusually far north in the western north Atlantic. On 1 November the 'Perfect Storm' developed hurricane-force winds with peak sustained winds of 120 km/h (75 mph) and a central low pressure of 972 mbar (30 Oct). It became a category 1 hurricane that approached the U.S. east coast before turning north and moving out into the open ocean before it made landfall in Nova Scotia.

Damage from the storm totaled over $200 million and 13 people lost their lives. The storm generated strong waves in the open ocean, where a Canadian buoy reported significant wave heights of 30.7 m (average high waves), the highest ever records in the area, and two U.S. NOAA buoys 100-150 km farther south measured 12 and 9 m. Approaching the beaches, surges of up to 10 m in height cause severe erosion from Canada to Florida and to Puerto Rico. In Massachussetts, where damage was heaviest, 100 homes were destroyed.

The fishing vessel Andrea Gail sank in the storm, and its crew of six perished. The loss of the vessel inspired a book and a movie.

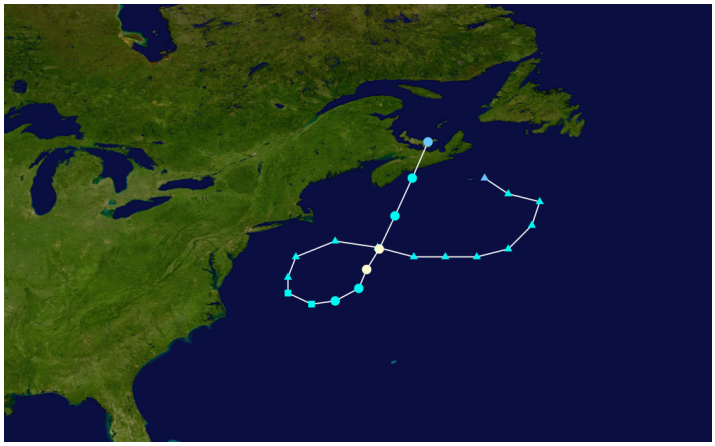

Figure 13.C8 The unusual track of the 1991 'Perfect Storm'. It formed on 28 October in the north as a Nor'Easter and tracked east, then south. Fueled by moisture from late Hurricane Grace, it strengthened on its southwesterly track. It then moved into an unusual counter-clockwise loop. Warm waters of the Gulf Stream allowed the storm to strengthen to a hurricane (with a warm core, thereby making it a tropical cyclone). It quickly moved north, making landfall in Nova Scotia on 2 November. Colors mark the strength of the storm: depression (darker blue) tropical storm (light blue) category 1 hurricane (yellow). Triangles mark periods as extratropical cyclone, circles mark a tropical cyclone. (source: Wikipedia; originally NOAA)