Homework 5 Solutions

1. A good air mass source region would have relatively uniform temperature and moisture characteristics over a very large area, typically on the order of a thousand miles or more. These would include oceans and the interior regions of continents, particularly where the terrain is relatively homogeneous. A good example of the latter is the vast, snow covered treeless plains Canada and Siberia. The major air mass types are: (a) Continental polar (cP): cold and dry, (b) Maritime polar (mP): cold and moist; (c) Continental tropical (cT): hot and dry; and (d) Maritime tropical (mT): hot and moist.

2. Lake effect snow occurs when cold, dry air blows over a large body of relatively warmer, unfrozen water, such as the Great Lakes in the United States. As the air passes over the lake, two things happen: the air warms due to convection and a large amount of evaporation occurs, making the air more humid. Both contribute to make the air more unstable. Downwind of the lake, the air may rise to form clouds and snow, especially if it is lifted along a terrain barrier. In general, for a city on the Great Lakes to experience heavy lake effect snow, the wind must be directly off the lake and at an orientation that allows air to travel over a large area of lake to gain lots of moisture. For this reason, cities that are located on the eastern sides of the Great Lakes, like Buffalo, tend to receive the most lake effect snow, as the predominant wind flow off the Great Lakes in winter is from a southwesterly to northwesterly direction. The particular wind directions for the cities to have the most lake effect snow are: (a) Chicago: north-northeast; (b) Cleveland: northwest to northeast; (c) Buffalo: west to southwest.

3. Clouds that form at a cold front are typically cumuliform (e.g. cumulonimbus). Precipitation occurs in a squall line, a heavy, narrow band of thunderstorms that moves quickly and is brief in duration at a given location. Along and ahead of the warm front, the clouds tend to be more stratiform (e.g. nimbostratus). Precipitation is lighter but much more widespread, tending toward the frozen forms of precipitation (freezing rain to sleet to snow) the further away from the warm front in the deeper layer of colder air. The differences are due to the vertical slope of the fronts and the differences in atmospheric stability. A cold front is very vertically steep and abrupt. Warm air rises very quickly in a very conditionally unstable atmosphere to form thunderstorms. The vertical slope of a warm front is much more gradual and the air tends to be more stable, resulting in less intense, but more widespread, precipitation.

4. Surface winds start out from the south-southwest with winds aloft slightly westerly. The clouds become darker and start to lower. At time 1555, a shelf cloud heralding a frontal squall line arrives, with gusty winds from the west, rain, and even some sleet. After the passage of the front, for example by about time 2030, the winds shift to the west and the sky begins to clear, with clouds transitioning to mostly fair weather cumulus. These clouds are for the most part not very vertically developed because the atmosphere is more stable following cold front passage, though there are a few isolated showers that occur. By the end of the day at sunset, skies are nearly clear.

5. A blizzard requires high winds (typically greater than 20-30 mph) and heavy to moderate snow, such that the blowing snows create near white out conditions. Though all locations near a surface low in the mid-latitudes of the northern hemisphere can have high winds, the coldest air, and location where snow occurs, is nearly always located to the north and west of the surface low. So relative to the location where the blizzard occurs the surface low would be located to the south and east. Because the wind around a mid-latitude cyclone in the northern hemisphere is counterclockwise, the surface wind would

probably be from the northeast during the height of the blizzard, with the snow gradually tapering off as the winds shift to the northwest over time. These types of lows generally form in the lee of the Rocky Mountains and move in a northeasterly direction through the Great Plains and upper Midwest.

6. Most likely answers, based on the idealized structure of a mature mid-latitude cyclone: (a) Occluded front; (b) Warm front; (c) Cold front; (d) Warm front.

7. A mid-latitude cyclone would typically be strongest at the start of the occluded stage/end of the mature stage. On a weather map, this would be depicted with a deep surface low pressure, with an occluded front extending to the south and east of the low center. The occluded front will eventually meet a cold and warm front. The cold front extends south from the occluded front and the warm front extends east of the occluded front. There are several examples in the book and lecture with weather maps that illustrate these ideas and including them and/or drawing is very helpful in answering the question. On the satellite image, a mid-latitude cyclone is clearly seen as a large comma-shaped cloud that, for the largest most developed storms, can cover a substantial portion of a continent. The surface low-pressure is located at the center of the comma cloud. At this stage, the upper level low would be located to the west of the surface low. This allows air to diverge in the upper-levels and rise above the surface, causing the surface low pressure to deepen and the storm to grow.

8. After mid-latitude cyclones become occluded, the upper-level low becomes situated directly over the surface low, or the system becomes "vertically stacked." As this happens, air ceases to diverge in the upper-levels above the surface low, causing the upward vertical motion to weaken. Without upward motion to continue to deepen the surface low, the surface pressure will eventually rise and the storm will die out.

9. Given favorable upper-level dynamics, these storms may become quickly much stronger if they move over relatively warm, open water. The increase in atmospheric moisture causes more latent heat release in clouds, providing the storm an extra source of energy. When these storm form just off the Atlantic Coast of the United States they are called Nor'easters, reflecting the direction from which the strongest onshore winds blow. Locations to the north and west of the surface low of a Nor'easter typically experience heavy snow. In the classic example of the 1993 East Coast Superstorm discussed in the text, most interior areas of the mid-Atlantic states and Northeast experienced more than two feet of snow with blizzard conditions. These storms feed off the warm waters of the Gulf Stream as they move to the northeast, paralleling the east coast of the United States.

10. The "piece of energy" actually refers to a shortwave upper-level disturbance, or relatively small area of spin in the atmosphere. The upper-level disturbance may help to strengthen an upper-level trough by making the trough deeper and/or increasing upper-level the pressure gradient. Either would increase the amount of upper-level divergence and upward motion ahead of the upper-level trough, which would deepen the surface low and create a more intense mid-latitude cyclone.

11. A numerical weather model divides the model simulation domain into a large number of grid boxes. Some initialization scheme is used to interpolate meteorological observations, for example surface data and upper-air data collected from weather balloons, to each of the grid boxes. To generate a forecast, the numerical model integrates a series of dynamical equations forward in time that describe atmospheric motion from the initial observed state. Physical processes, such as precipitation, clouds, radiation, and

turbulence, that cannot be explicitly represented in these dynamical equations on the grid are accounted for in separate sub-models, or parameterizations. Parameterizations attempt to represent such sub-grid scale processes in some sort of reasonable way. Because this process involves thousands of complex calculations, it can only practically be done with a computer. Weather forecasting was actually one of the very first applications of computers when they were invented in the 1940s and 1950s. Most modern day numerical weather forecasts, for examples, are generated on very fast and powerful supercomputers. A computer model forecast will always be unreliable to make a deterministic forecast (forecast for a particular time and place) after about a week or two because of the principle of chaos in a non-linear system: small errors in the specification of the initial state will lead to more and more divergent model solution further out in time. As there will always be some uncertainty in the specification of the initial state because of uncertainties in observed data or how they are interpolated to the model grid, the problem is unavoidable—no matter how sophisticated the numerical model is.

12. **There are two ways to answer this question**. Sample acceptable answers are given for both. **DISAGREE**: The statement demonstrates a logical misunderstanding between a weather forecast and a climate forecast. Weather forecasts are designed to forecast conditions at a particular time and place. Climate forecasts are designed to forecast the likelihood of deviation from the average state of the climate. Climate forecasts are thus not designed to forecast a specific storm event months or years from now—and this is impossible because of chaos in non-linear system. Climate forecasts, however, have value if the climate is sensitive to forcing factors on a long-timescale and we have a good scientific understanding of why this is the case, from statistical analyses of historically observed data and/or use of a physical model. This likely true, for example, with ocean temperatures associated with El Niño or the increase in greenhouse gases. **AGREE**: The TV meteorologist mostly bases their forecast on a computer model. Some major weaknesses of these models are: (a) They attempt to account for many complex non-linear interactions, not all of which can possibly be accounted for; (b) Fundamental physical processes are not explicitly represented in model parameterizations, rather these take many varied engineering-based approaches to estimate them—sometimes very crudely and poorly; (c) And, most importantly, there is still a great deal about the climate system we do not understand. For example, though we have some physical understanding of what causes an El Niño, we don't have a physical understanding of other natural modes of variability that affect climate, like the Arctic Oscillation or the Pacific Decadal Oscillation—none of which are represented in a global climate model well!