<u>Synoptic Meteorology I: Skew-*T*/Ln-*p* Diagram Applications</u>

Inversions

There are four different types of inversion layers, or inversions. The first is known as a *subsidence inversion*. A subsidence inversion typically separates a dry air mass above from a moist air mass below. When an air parcel sinks, no matter whether it is initially subsaturated or saturated, it warms at the dry adiabatic lapse rate (as no heat is exchanged between the air parcel and its surroundings upon descent; thus, its potential temperature does not change). It also becomes drier, but as there is no moisture exchange with its surroundings, the air parcel's water vapor mixing ratio does not change. Consequently, subsidence inversions are typically characterized by a well-mixed vertical layer, where "well-mixed" refers to nearly constant potential temperature and water-vapor mixing ratio over the layer.

Subsidence inversions are often found in the subtropics, particularly over water, in conjunction with the descending branch of the Hadley cell circulation. An example of a subsidence inversion is given in Fig. 1.

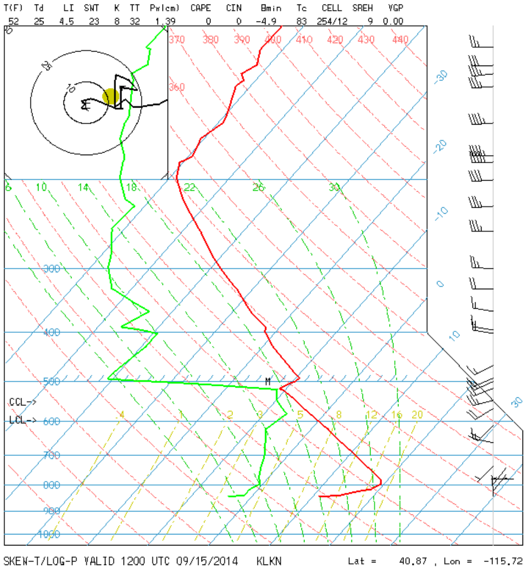

Figure 1. Skew-*T* diagram valid at 1200 UTC 15 September 2014 at Elko, NV (KLKN). In this diagram, a subsidence inversion is located just below 500 hPa. Note the distinct spreading apart of the temperature (thick solid red) and dew point temperature (thick solid green) traces at this altitude. Dry air, with $T_d << T$, is found above the inversion while moister air, with $\mathrm{T_d} \leq \mathrm{T}$, is found below the inversion. Image obtained from http://weather.ral.ucar.edu/upper/.

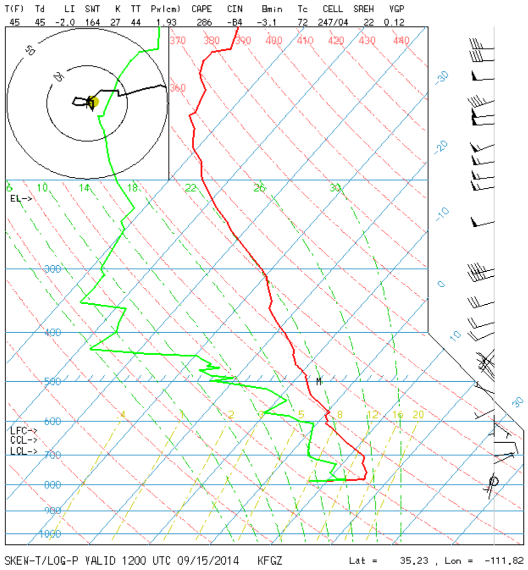

Figure 2. Skew-*T* diagram valid at 1200 UTC 15 September 2014 at Flagstaff, AZ (KFGZ). In this diagram, a radiation inversion is found right at the surface just above 800 hPa. Note how temperature rapidly increases with height through the radiation inversion, which is confined to a very shallow layer near the surface. Image obtained from http://weather.ral.ucar.edu/upper/.

The second type of inversion is known as a *radiation inversion*. At night, the Earth's surface loses heat to outer space by means of outgoing longwave radiation. When near-surface winds are calm, or nearly so; there is little to no cloud cover overhead; and particularly when the nights are long, a radiation inversion may form due to this heat loss. Radiation inversions are shallow, confined near the surface, and are typically found primarily in the observed temperature trace. An example of a radiation inversion is given in Fig. 2.

The third type of inversion is known as a *frontal inversion*. Recall that a) fronts are not lines but are transition zones between two distinct air masses and b) fronts slope upward over relatively cold air. Frontal inversions separate relatively cold, dry air masses below from relatively warm, moist air masses above. The vertical extent of a frontal inversion is limited to the vertical extent of the frontal zone. A schematic cross-section through a frontal zone and accompanying frontal inversion is given in Fig. 3.

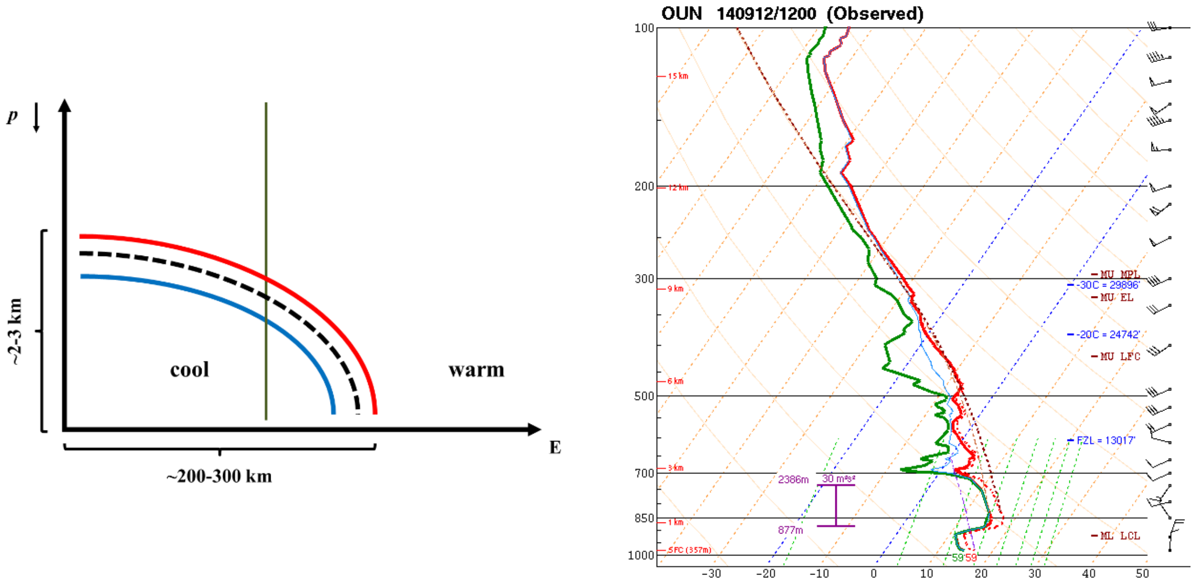

Figure 3. (left) Idealized schematic of a cold frontal zone that separates cool, dry air to the west from warm, moist air to the east. The cold front itself is denoted by the black dashed line while the vertical line denotes the location of the skew-*T*/ln-*p* diagram presented at right. (right) Skew-T diagram valid at 1200 UTC 12 September 2014 at Norman, OK (KOUN). In this diagram, a frontal inversion is centered at 900 hPa. Note how both temperature and dew point temperature rapidly increase with height through the frontal inversion, which separates cooler, drier air below the inversion from warmer, moister air above. Image from http://www.spc.noaa.gov/exper/soundings/.

Finally, the *tropopause*, or layer that separates the troposphere from the stratosphere, represents the fourth type of inversion. The tropopause can be identified from the observed temperature trace as the layer over which Γ is $< 2°\mathrm{C\ km}^{-1}$ for at least 2 km of depth. Oftentimes, $\Gamma < 0$ through the tropopause. An example tropopause on a skew-*T* diagram is given in Fig. 4.

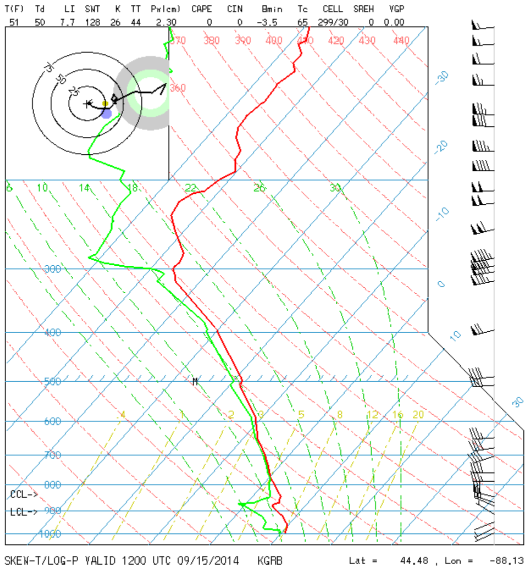

Figure 4. Skew-*T* diagram valid at 1200 UTC 15 September 2014 at Green Bay, WI (KGRB). In this diagram, the tropopause is found beginning just below 200 hPa. Note how both the temperature and dew point temperature lapse rates are small over a large vertical extent at and above this level. Image obtained from http://weather.ral.ucar.edu/upper/.

Cloud Layers

Cloud layers may be inferred from a skew-*T* diagram via consideration of the spacing between the temperature and dew point temperature curves. Clouds may be present if the dew point depression, defined as $T - T_d$, is ≤ 5°C. (Why do we not require the dew point depression to be approximately zero? Although a full discussion of the underlying physics is beyond the scope of this class, note that the temperature at which an air parcel becomes saturated depends on if the water substance is liquid or frozen. For liquid water, saturation does not occur until the dew point temperature equals the temperature; for frozen water, however, saturation can occur at a dew point temperature slightly less than the temperature. More discussion on this point is given in the next paragraph.) A small dew point depression is no guarantee for cloud cover, however! When $T_d \approx T$, such that the air is saturated (or nearly so), clouds are likely present.

Note that on a skew-*T* diagram, dew point temperature is plotted at all altitudes and temperatures. We do not change from dew point temperature to frost point temperature when the temperature is ≤ 0°C. Consequently, while the temperature and dew point temperature traces must overlap for there to be saturation when the temperature is above 0°C, the dew point temperature trace may be offset slightly to the left of the temperature trace for saturation to exist when the temperature is ≤ 0°C. We define the former situation as saturation with respect to liquid water and the latter situation as saturation with respect to ice.

A representative example of cloud layer identification is provided by Fig. 4. The temperature and dew point temperature traces overlap above 800 hPa and below 300 hPa, with minor offset at temperatures below 0°C. We can thus reasonably infer that clouds are present over a deep vertical layer bounded by 800 hPa and 300 hPa. Infrared satellite imagery from approximately the same time as the skew-*T* profile (Fig. 5) indicates the presence of clouds at Green Bay with relatively cold cloud tops between -40°C and -50°C, corresponding well to the observed 300 hPa temperature (-46°C). Note, however, that we are unable to infer cloud depth from this image.

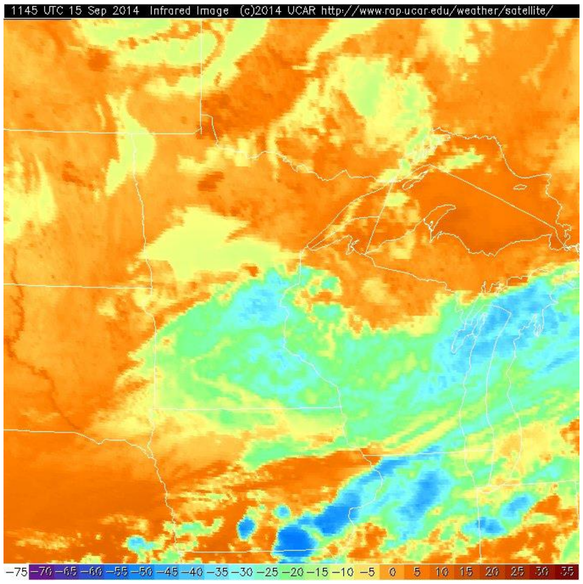

Figure 5. Infrared satellite image centered over Duluth, MN from the GOES-East geostationary satellite valid at 1145 UTC 15 September 2014. Shaded is cloud-top brightness temperature in °C per the color scale at the bottom of the image. Image obtained from http://weather.ral.ucar.edu/satellite/.

Fronts

The presence of a frontal inversion on a skew-*T*/ln-*p* diagram enables us to determine whether a front is present at a given location and, if so, at what altitude it may be found. Please refer to the discussion accompanying Fig. 3 for more information on this concept.

Horizontal Temperature Advection

Wind observations at multiple levels plotted along the side of a skew-*T* diagram can be used to infer layer-mean horizontal temperature advection following principles of the thermal wind. Please refer to our lecture on thermal wind balance and its accompanying examples for more information.

Precipitation Type

Information plotted on a skew-*T* diagram can be used to estimate the precipitation type that is present or forecast to occur. To illustrate this, let us consider two thought exercises:

- **Saturated**. Here, we assume that the troposphere is saturated between the surface and the level at which precipitation originates. Examples of each situation are given in Figs. 6-7.
    - **Snow**: Snow is the most likely precipitation type if the temperature is below 0°C throughout the entire layer between where snow formed and the surface.
        - **Exception**: An exception to this rule occurs if the level or layer from which precipitation falls is characterized by temperatures no colder than -10°C. Snowflake growth is most efficient when the air temperature is -10°C to -20°C. At temperatures between 0°C and -10°C, supercooled water and small ice pellets dominate. Thus, even if the temperature is < 0°C between the precipitation formation layer and the surface, sleet, graupel, or freezing rain/drizzle are more likely than snow in this scenario.
    - **Rain**: Rain is the most likely precipitation type when there is a sufficiently deep (≥ 1 km) and/or sufficiently warm (≥ 3°C) layer ending at the surface over which the temperature is above 0°C.
    - **Sleet/Graupel**: Sleet or graupel is the most likely precipitation type if precipitation that begins as snow falls through a layer in the lower troposphere over which the temperature is > 0°C and subsequently falls through a deep (~1 km) layer ending at the surface in which the temperature is below 0°C.
    - **Freezing rain**: Freezing rain is the most likely precipitation type if precipitation that begins as snow falls through a layer in the lower troposphere over which the temperature is > 0°C and subsequently falls through a shallow (~100-500 m) layer ending at the surface in which the temperature is below 0°C.
- **Subsaturated**. Here, we assume that the troposphere is subsaturated over one or more layers between the surface and the level at which precipitation originates.
    - To assess precipitation type, we must first consider that some of the precipitation that falls into the sub-saturated layer will evaporate (liquid to vapor) or sublimate (solid to vapor) before reaching the ground. Both phase changes require heat input into the water substance and thus *cool* the surrounding air. The increased water vapor content results in a higher dew point temperature and, eventually, saturation may be reached – but with a colder temperature than initially observed.

- When this is the case, one must first identify the temperature to which the air will be cooled by evaporation and/or sublimation (the *wet-bulb temperature*), after which the saturated rules above may be used to identify precipitation type.

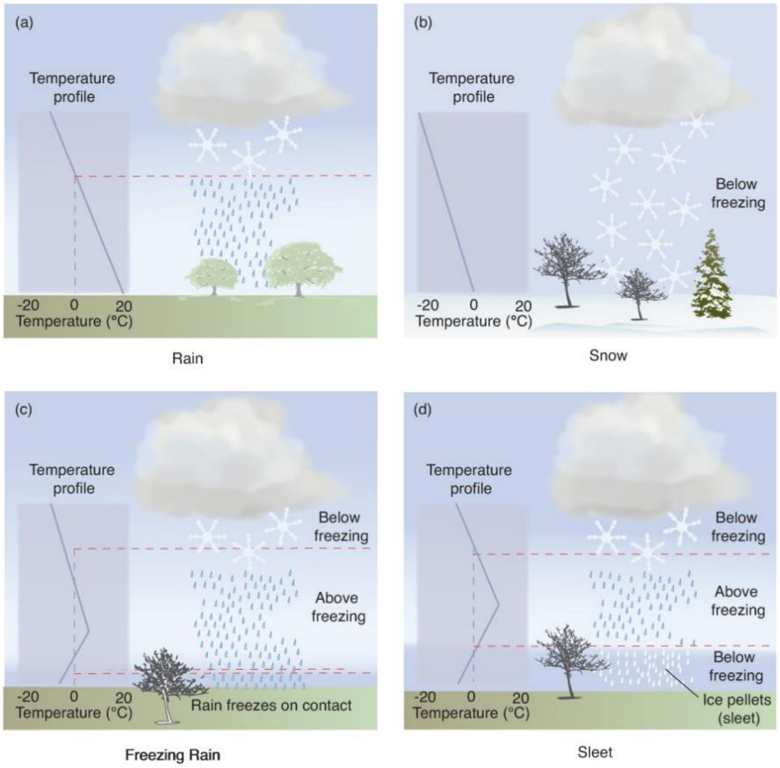

Figure 6. Idealized temperature profiles, assuming a saturated troposphere between surface and the level from which precipitation originates, leading to (a) rain, (b) snow, (c) freezing rain, and (d) sleet or graupel. Figure reproduced from *Meteorology: Understanding the Atmosphere* (4th Ed.) by S. Ackerman and J. Knox, their Fig. 4-36.

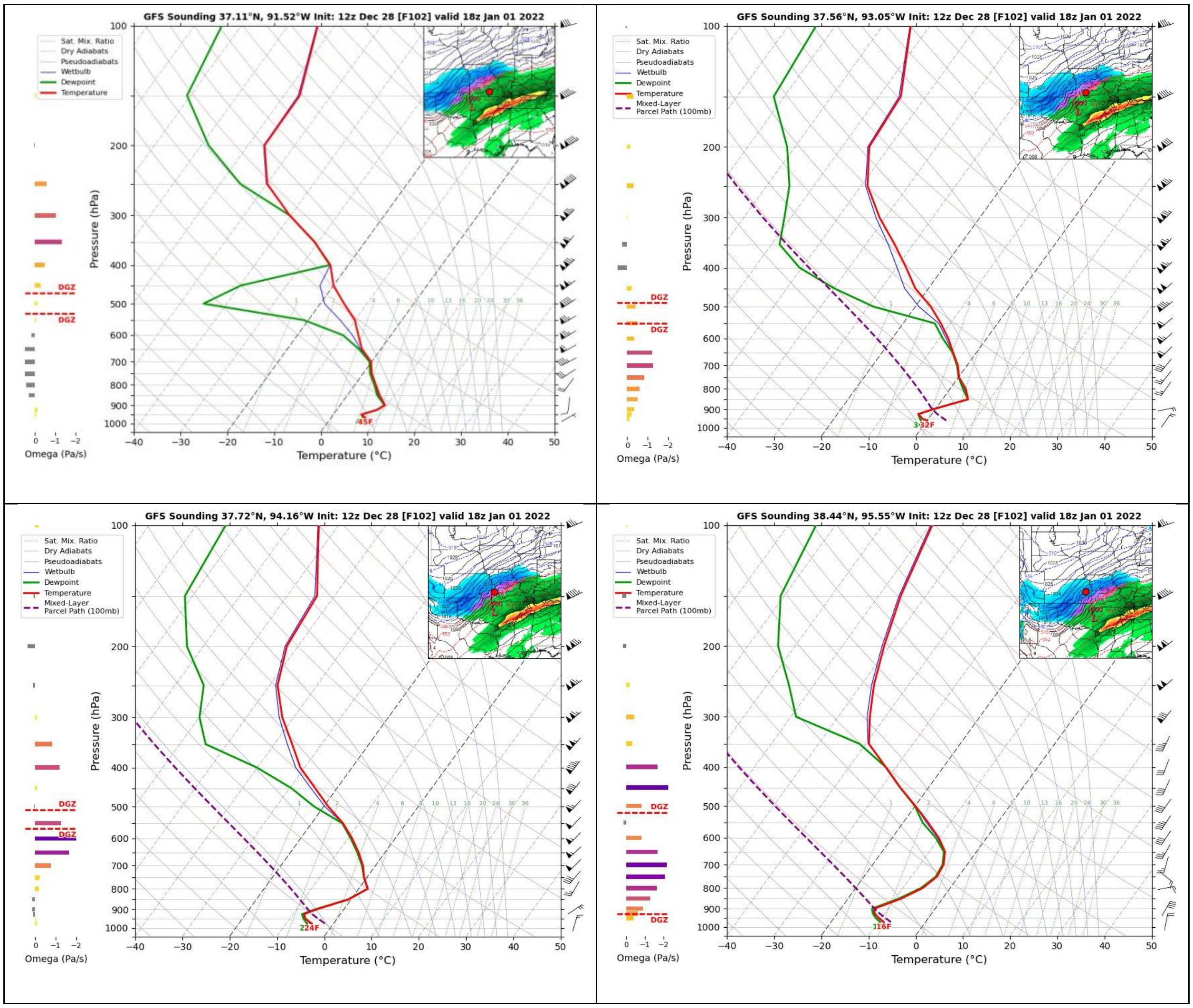

Figure 7. Global Forecast System-derived forecast skew-*T*, ln-*p* diagrams valid at 1800 UTC 1 January 2022 associated with (upper left) rain, (upper right) freezing rain [note the shallow layer of near-surface subfreezing air below a thick layer of above-freezing air], (lower left) sleet [note the thick layer of near-surface subfreezing air below a thin layer of above-freezing air], and (lower right) snow. Locations for each diagram are indicated by the red dot in each panel's inset. Figures obtained from https://www.tropicaltidbits.com/analysis/models/.