1. Parameters That Affect RSTs

Instructor Notes: This module is the fifth and last part of a lesson on Road Weather Impacts and Management Strategies. This presentation discusses how different environmental parameters impact road surface temperatures. This presentation should take approximately 15 minutes.

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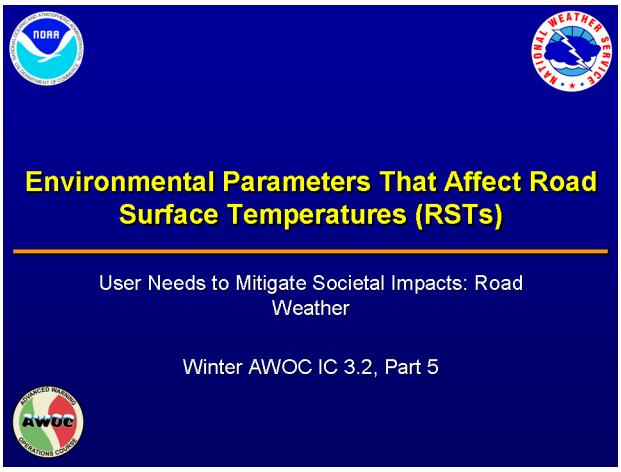

2. Learning Objective

Instructor Notes: There is one learning objective for this lesson: 1. Describe the parameters that impact road surface temperatures and when those parameters are most important.

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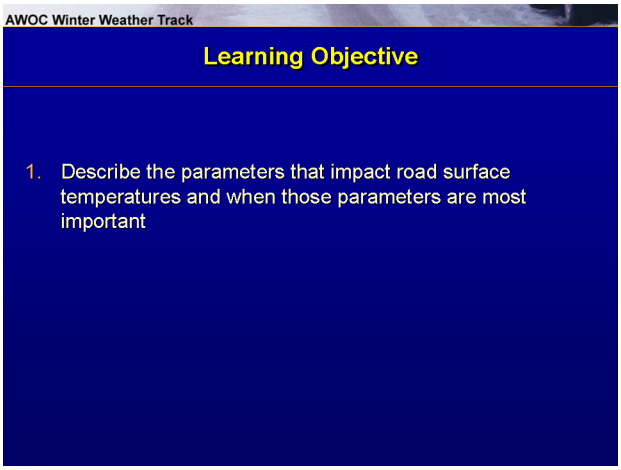

3. What Key Parameters Affect RSTs?

Instructor Notes: This presentation builds on the previous discussion on sub-advisory event significance by discussing the main physical processes that influence RSTs. [CLICK] These processes are related to boundary layer meteorology. [CLICK] This module, while not all inclusive, focuses on some of the key factors that determine RSTs and are governed by the different terms in the thermal energy balance equation for a road surface (National Research Council, 2003). These parameters include: - Absorption of insolation; - Heat flux from the atmosphere & surrounding soil; - Latent heat effects due to precipitation, run off and phase changes in water; and - Anthropogenic effects from traffic, treatment chemicals, and the urban heat island. [CLICK] Other topics not explicitly included in the thermal equilibrium equation, but still very relevant to RSTs and event significance, include: - Diurnal cycle, - Road classification & construction materials, and - Significant frost formation.

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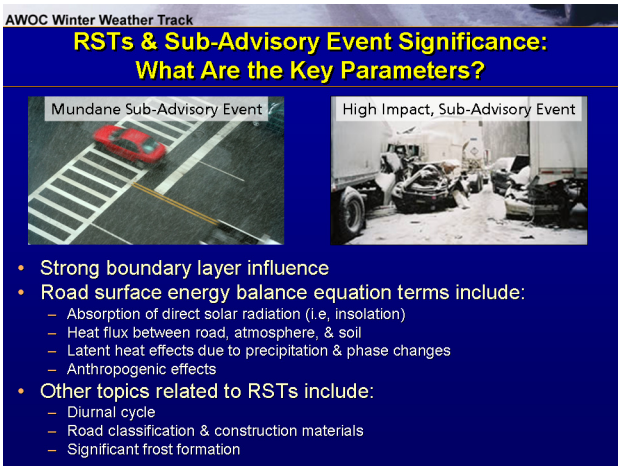

4. RSTs: We Need to Clarify the NWS Role

Instructor Notes: Before discussing how various parameters may impact RSTs, it's important to frame the context of this discussion. I've provided NWS headquarters guidance for support to DOTs on this slide to reiterate an important point: [CLICK] it's not the NWS role to provide detailed RST information to their local DOTs or the general public. [CLICK] However, RSTs play an important role in identifying the impacts of sub-advisory events. As a result, there's a benefit to NWS forecasters having a better understanding of the physical processes. This knowledge can then help forecasters better inform DOTs and the general public through their products and services of conditions during sub-advisory events that may not otherwise get their attention. If DOTs require more specialized information, please refer them to our partners in America's Weather Industry. [CLICK] As a result of NWS policy, the following discussion is qualitative, not quantitative, in nature.

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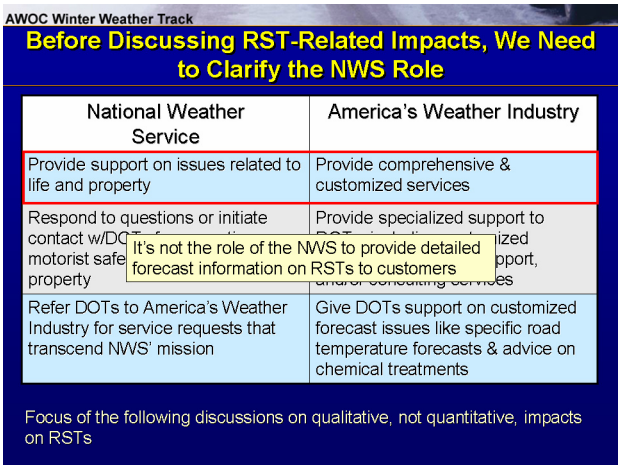

5. Angle of Direct Incoming Solar Radiation

Instructor Notes: Of all of the environmental parameter that impact RSTs, [CLICK] direct solar shortwave radiation, or insolation, is most significant during daytime hours. On a sunny day, the road surface warms due to the absorption of visible sunlight much faster than from changes in air temperature (i.e., the second most important term). Consequently, RSTs are often much higher than nearby air temperature observations during the day (NRC, 2003). [CLICK] The angle of direct incoming sunlight and cloud closer have the biggest impact on insolation received. Several variables impact the angle between the sun's position in the sky and the horizon at any given point in time. These variables include day of the year, time of day, and Latitude. Some CWAs may have local mesonetworks that measure incoming solar radiation directly. These observations aid in determining when (or if) RSTs may rise above freezing in certain areas. [CLICK] In the absence of these measurements, it's best to remember these qualitative relationships regarding insolation absorption: [CLICK] - Pavement generally receives more insolation on sunny days at the beginning and end of the winter season because of the higher solar angle and longer days; [CLICK] - More insolation is received near solar noon than near sunrise or sunset; [CLICK] – RSTs rise quickly when pavement is exposed to direct sunlight, even during the early morning hours when the sun angle is low; [CLICK] – Southern locations receive more insolation on sunny days because of the higher sun angle; and [CLICK] – Roads in mountainous terrain with exposure to the southern sky warm faster than roads where the southern sky is obscured.

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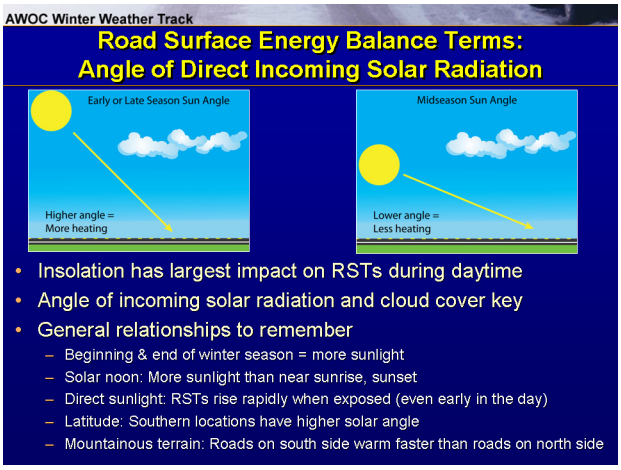

6. Clouds & Diurnal Cycle

Instructor Notes: Clouds can have a dramatic impact on RSTs because they can significantly reduce incoming solar radiation. [CLICK] Low-level, overcast skies, especially if there is precipitation, can reduce the insolation received down to 10-20% of the total for a clear day during the winter months (Oklahoma Mesonet, 2008; WI-MN Cooperative Extension, 2008). Two important points to remember: - Most U.S. locations receive as much or less insolation on a clear day in December than on a cloudy day in June and - RSTs trend more closely with nearby air temperatures on overcast winter days. [CLICK] Nocturnal overcast conditions have the opposite effect. Low-level nocturnal clouds restrict nighttime radiational cooling, resulting in warmer RSTs on overcast nights than on clear ones. [CLICK] Air temperatures are the most important factor in determining RSTs at night. So, if an arctic frontal passage occurs and low-level overcast conditions exist, the RSTs will likely drop significantly regardless of the cloud cover.

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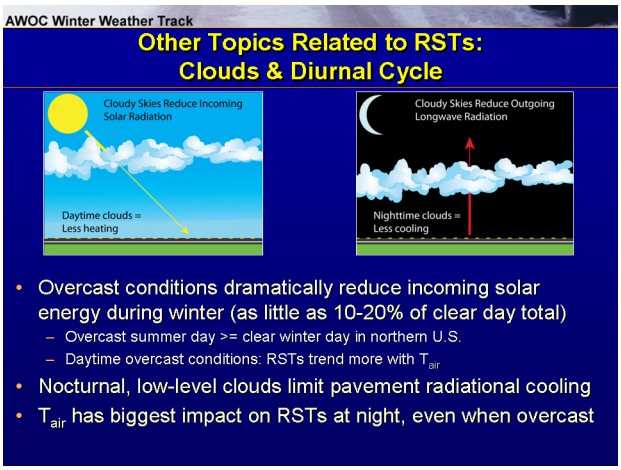

7. RSTs: Insolation & Diurnal Cycle Effects

Instructor Notes: Before we move on, let's show an example of RSTs (Moore and Miller, 2008) and how insolation, cloud cover, and diurnal cycle impact the data. This example is from a road weather information system (RWIS) site in the Billings, MT metro area. [CLICK] I have labeled the sunrise, solar noon, and sunset times on the chart to make the data easier to interpret. The data are for two autumn days: - Day 1 (Oct. 29th) is well above normal and - Day 2 (Oct. 30th) is well below normal. The skies were generally clear or had few clouds on these days except for the time window shaded in blue on the chart and labeled "Overcast". Here are a few important points relevant to our discussion: [CLICK] - First, notice that the road temperatures for both sensors warm up faster than the air temperature and are significantly warmer (~6-15 deg C) during the heat of the day. [CLICK] - On Day 2, the air temperatures remain below freezing during the day, but the RSTs warm above freezing for 3-7 hours (depending on the sensor) due to absorption of insolation. [CLICK] - Overnight on Day 1, the RSTs are generally cooler than the air temperatures under clear skies. [CLICK] Overnight on Day 2, the RSTs are generally warmer than the air temperatures under cloudy skies.

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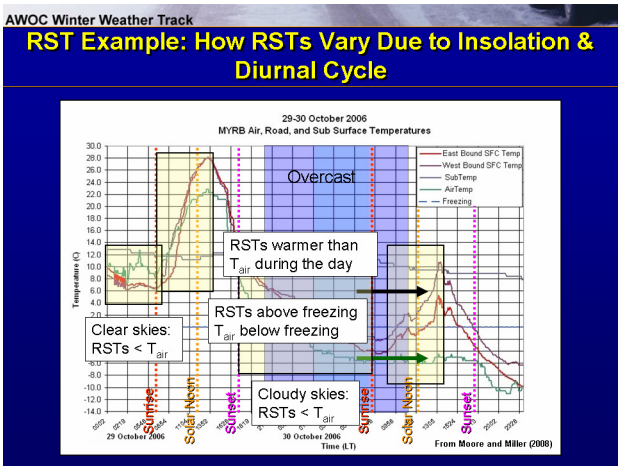

8. Heat Flux between the Air, Road, & Soil

Instructor Notes: The heat flux between the road, atmosphere, and surrounding soil can be very complex. For our purposes, however, NWS forecasters just need to understand how the heat flux works to equalize the temperatures of the road system. Remember that the magnitude of the heat flux depends on the temperature gradient. When there are significant temp differences in the system, the heat flux will work to bring the "road environment" into equilibrium. In other words, heat will transfer from the warmer parts of the system to the cooler parts of the system. [CLICK] Impacts to RSTs from heat flux are most important in two situations: [CLICK] – After a change in air mass causes rapid cooling of air temperature to below freezing and [CLICK] - When solar heating causes the road surface to warm above freezing during the day while air temperatures remain below freezing. These situations are important because the temperature gradients are maxi-

mized and the resulting heat flux impacts near-freezing RSTs. [CLICK] The impacts of heat flux are most evident near bridges and elevated roads. Soil temps change the slowest and are often a heat source or sink in the “road system”. The graphic shown illustrates this point very well as there is a substantial temperature gradient from the soil to the atmosphere. [CLICK] The RSTs for the surface based road sensor are warmer than those from a bridge-based sensor just a few hundred yards away. The difference in RSTs for this case varies between 2-4 deg C during overcast conditions with light snow, but becomes more dramatic the following morning as the sun breaks out.

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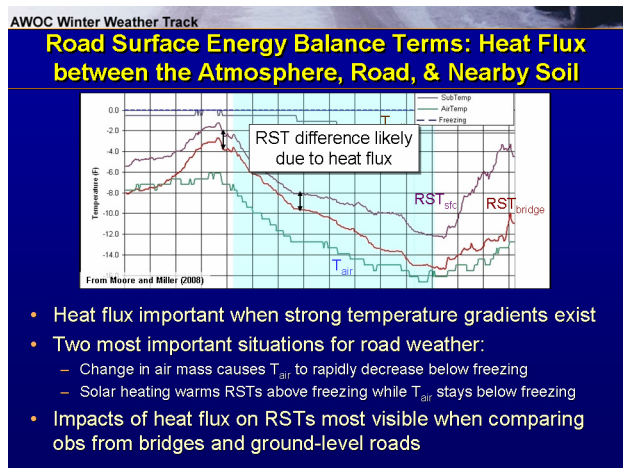

9. Precipitation & Latent Heat Impacts

Instructor Notes: Precipitation and latent heat can have an important impact on RSTs, but may be overlooked by forecasters. When precipitation falls on roads, the water, snow, and/or ice often resides on, or permeates into, the road surface. [CLICK] Whenever a solid or liquid phase of water is on or in the road surface, more energy is required to warm up the road surface because of water’s higher specific heat. So, wet roads warm slower than dry roads. However, the converse is also true (i.e., wet roads take longer to cool off than dry roads). [CLICK] Latent heat effects are most important during winter weather events when: - RSTs are relatively close to freezing, - Precipitation is occurring, and - RSTs are expected to cross the freezing point in either direction. Let’s show an example (Moore and Miller, 2008) to explain why. [CLICK] The data in the graph are the air temperature (green) and RSTs (red) for a location in Montana. [CLICK] The green bars above the line graph indicate when precipitation is occurring at the RWIS site. [CLICK] Around 2:30 am, freezing rain begins with both air and pavement temps below freezing. [CLICK] Within 30 minutes, the “freezing” of the rain has raised the RSTs to freezing while air temperatures remain nearly constant. [CLICK] Air temps then slowly rise until they pass freezing around 5:30 am. The air temps generally remain above freezing for the remainder of the event. [CLICK] However, the RSTs stay at 32 deg F until nearly 9:30 am. In this case, it took four hours after air temps rose above freezing for the ice on roads to melt. [CLICK] These four hours coincided with the morning rush hour period in this area and numerous accidents were reported. If a forecaster had issued a nowcast based on the air temperatures alone, they may have indicated that road condi-

tions would improve faster than they actually did.

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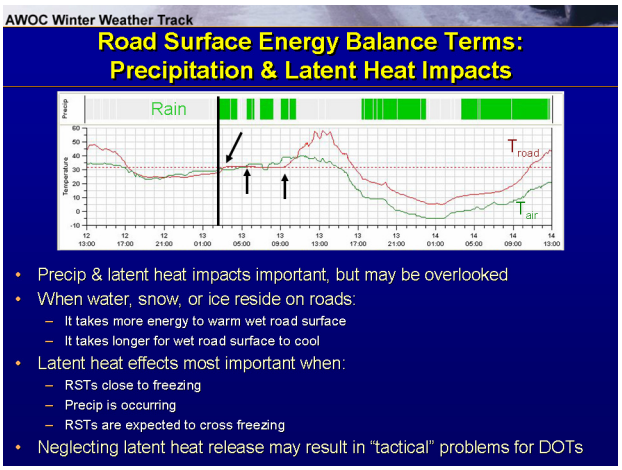

10. Anthropogenic Effects

Instructor Notes: While anthropogenic effects can impact RSTs, their impacts are often smaller and more localized than other thermal terms in the energy balance equation. Some examples of anthropogenic effects include: [CLICK] - Residual chemical treatments, regardless of the source (i.e., anti-icing or de-icing), lower the eutectic temperature of water. The moisture content of the precipitation and amount of chemical will determine the level of benefit. Some RWIS sites have sensors that measure the current freezing temperature of the road surface, which is an indication of significant chemical treatment present at that location. [CLICK] - Heat from vehicles in traffic can increase RSTs and help melt ice/snow. Moving traffic tends to melt only the snow and ice in the wheel wells, but stop-and-go traffic warms more of the road surface. In areas where there is significant congestion, RSTs may be as much as 7-10 deg F warmer than nearby roads where traffic is moving freely (Stern et al., 2006). [CLICK] - The urban heat island effect can result in higher RSTs in and downwind of downtown areas than may normally be expected (Basara, 2008).

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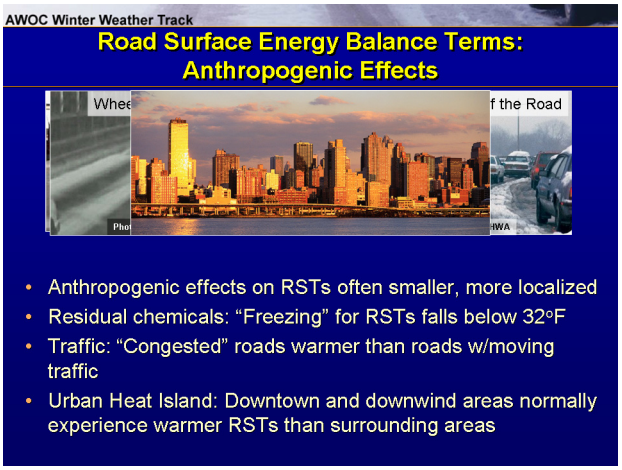

11. Differences in Road Classification

Instructor Notes: The biggest differences in RSTs are usually seen when comparing bridges and overpasses with nearby roads. [CLICK] Since there is little to no heat flux from the ground for bridges and overpasses, RSTs from these structures are more susceptible to changes in air temperature. The heat flux from bridges and overpasses is further enhanced during cold, windy conditions due to venting. [CLICK] This concept is well understood by most forecasters as icing on bridges and overpasses is often mentioned in NWS products. [CLICK] Another, less well understood factor is pavement thickness. [CLICK] In general, roads built to handle larger volumes of traffic (and hence, more weight) tend to be thicker than roads designed to carry less traffic. [CLICK] Thicker roads (e.g., interstates & other major arterials) store more heat than thinner roads (e.g., local, rural, & neighborhood streets) on sunny days (NRC, 2003). Since thicker roads store more heat, they can take longer to freeze up during winter precip. [CLICK] In some events, this reservoir of heat may be sufficient to prevent RSTs from falling below freezing on major roads while local roads experience icing. During other events, however, thicker roads may melt more snow and ice on roads that later re-freezes and results in more accidents.

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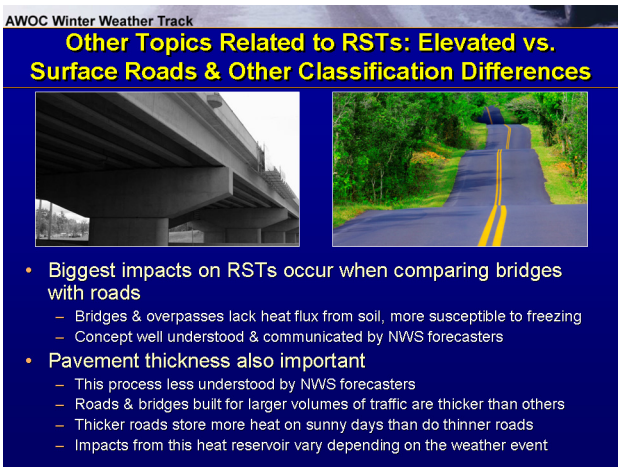

12. Construction Materials

Instructor Notes: Asphalt and concrete are common road building materials throughout the U.S. While these materials have some similar traits (e.g., heat capacity/emissivity), they also have some different traits (e.g., albedo) that may cause significant variations in RSTs. [CLICK] Asphalt generally has a lower albedo than cement, especially when it is new. [CLICK] As a result, asphalt roads warm up faster when exposed to direct insolation. [CLICK] Asphalt and cement have similar heat capacity coefficients with cement's being slightly lower. [CLICK] In the absence of strong solar heating, a cement road radiates its heat away slightly faster than asphalt at similar temperatures. However, this difference is rarely significant. [CLICK] Asphalt is generally more porous than cement. Because asphalt is more porous, it can hold more water. [CLICK] Conversely, liquid pre-

cipitation that falls on cement roads is more likely to run off or puddle on the road surface. [CLICK] Asphalt roads, because they hold more water, often take longer to dry and require more chemical treatment than cement roads.

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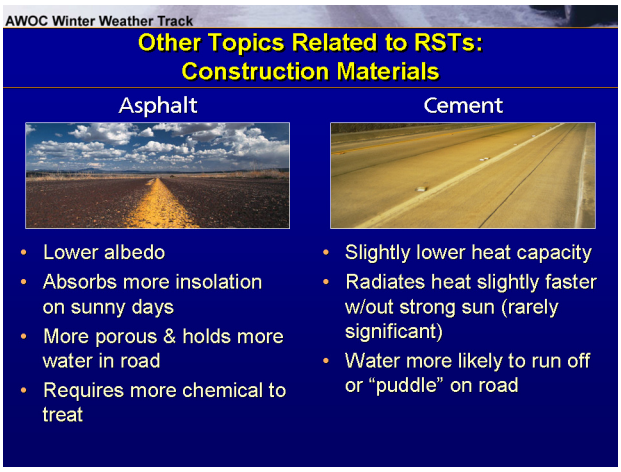

13. Significant Frost Formation

Instructor Notes: The last issue we'll discussrelated to RSTs is the formation of significant frost on roadways. While a little frost usually doesn't cause travel problems, heavy ice deposition on roads can increase the accident rate. [CLICK] The two most important parameters to identify when frost formation on roads is possible are (Takle, 1990): - RSTs below freezing and - Dewpoint air temperatures greater than the RSTs. [CLICK] If these conditions exist for an extended period of time, than the frost build up on pavement may become slick and hazardous. [CLICK] Often, these same conditions will result in the formation of ground fog. If you're forecasting dense fog with near or below freezing air temperatures, monitor RWIS data in these areas to determine if RSTs may drop below freezing. For instance, RWIS sites in Iowa have been used to generate frost forecasts for nearby bridges. During the study's evaluation period, these RWIS/frost model forecasts had better skill than more traditional NWP and private sector forecasts for the same area (Pisano et al, 2003).

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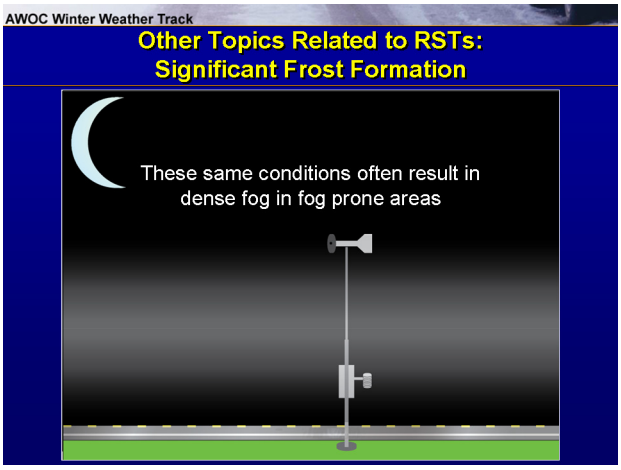

14. Summary

Instructor Notes: In summary, this module discussed the physical processes that are most likely to impact RSTs based on the thermal energy balance equation for a road surface and other related factors. [CLICK] The most important points to remember from these discussions are: [CLICK] - On sunny days during winter months, the absorption of sunlight on clear days has the most significant impact on RSTs; [CLICK] - Air temperature has the biggest impact on RSTs at night and during overcast conditions; [CLICK] - Heat flux impacts RSTs significantly where large temperature gradients exist between the road, atmosphere, and surrounding soil; [CLICK] - Latent heat requirements of water can result in phase changes taking longer than expected unless you monitor RWIS RST data, and [CLICK] - Anthropogenic effects can be significant on certain road segments, but are often localized. [CLICK] This module also discussed processes that impact, or are impacted by RSTs. The important points from these discussions include: [CLICK] – Roads built to carry higher volumes of traffic are thicker and store more heat on sunny days than do roads built for lower volumes; [CLICK] – On sunny days, asphalt pavement heats up faster than cement; [CLICK] – Due to its more porous nature, asphalt pavement usually requires more treatment chemical than cement at the same RST; [CLICK] – Lastly, during cold season dense fog events where surface temperatures may fall below freezing, don't forget to monitor RSTs & other data for frost formation conditions. [CLICK] If you are interested in learning about planetary boundary layer processes, use the link shown to learn more about COMET's instructor led course on the subject or login to the NWS Learning Center and do an exact phrase search for "boundary layer". [CLICK] You have completed the content for Winter AWOC IC 3.2. To receive credit in the NWS Learning Center, you need to take the quiz and fill out the survey evaluation in the LMS. I recommend that you complete both of these steps as soon as possible and prior to starting the next lesson in this course.

Student Notes:

AWOC Winter Weather Track

Summary of "Environmental Parameters That Impact RSTs" Module

- Physical processes most likely to impact RSTs:
  - **Clear days:** Absorption of sunlight most significant
  - **Cloudy days & nighttime:** T_{air} is most significant
  - **Heat flux:** Important when large temperature gradients exist
  - **Latent heat effects:** Can delay melting/freezing more than anticipated
  - **Anthropogenic effects:** Can be significant, but often localized
- Other important factors to remember include:
  - Higher volume roads are thicker & store more heat than lower volume roads
  - Asphalt heats up faster on sunny days than cement
  - Asphalt also requires more treatment chemical to be effective
  - Don't forget about road frost formation during winter-time dense fog events!
- For more info on BL Training:
  - COMET ILT Course: http://courses.comet.ucar.edu/course/view.php?id=13
  - NWS Learning Center
- Complete the quiz and survey in the LMS for this lesson