Rain-on-Snow
Snowmelt Modeling

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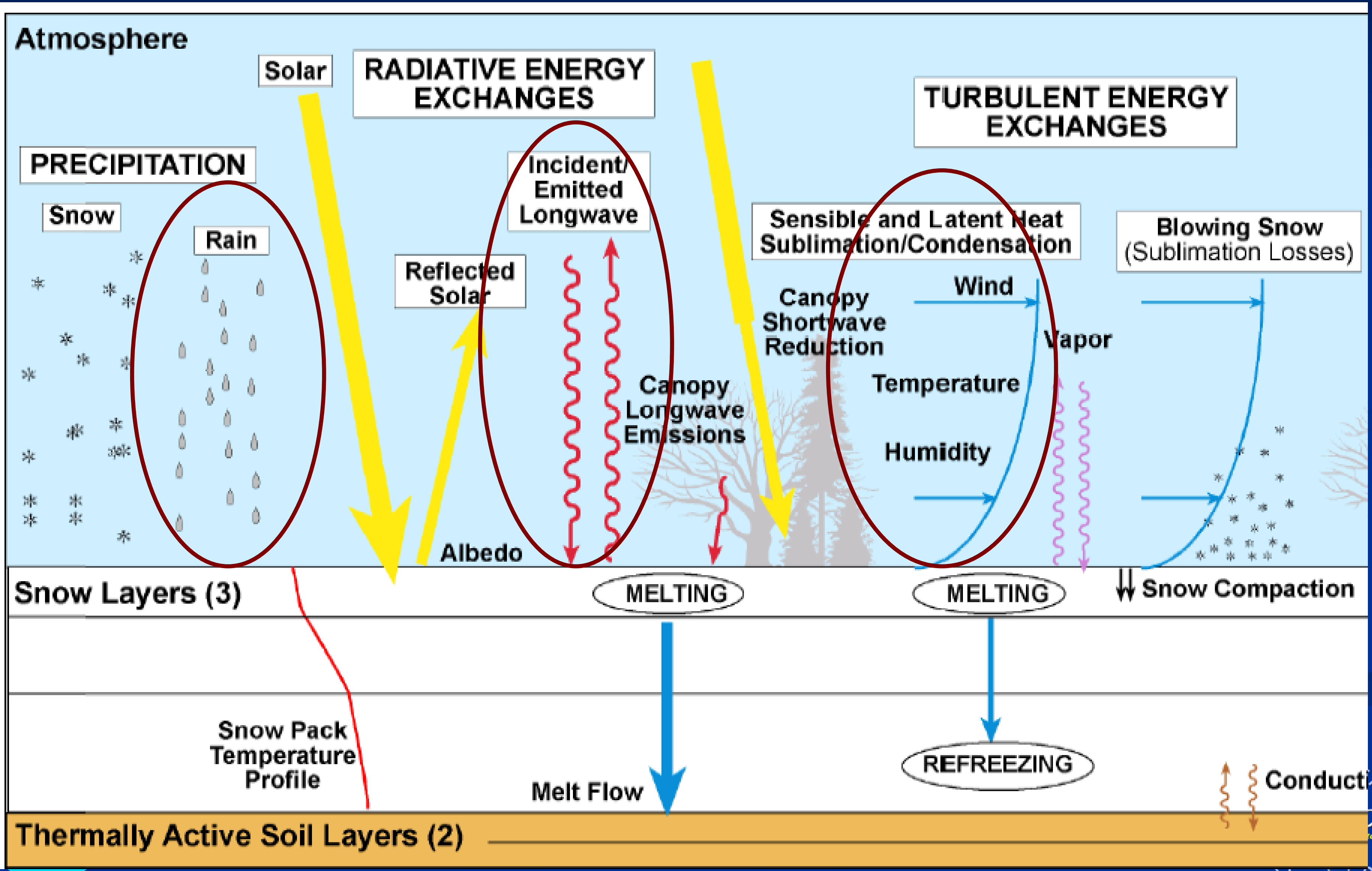
Snowmelt Due to Rain-on-Snow



Snowmelt Due to Rain-on-Snow

Simple Energy Balance

$$Mr = \frac{Cw * Px}{Lf} * (Tw - 273.16)$$

Mr = Melt Rate (mm)

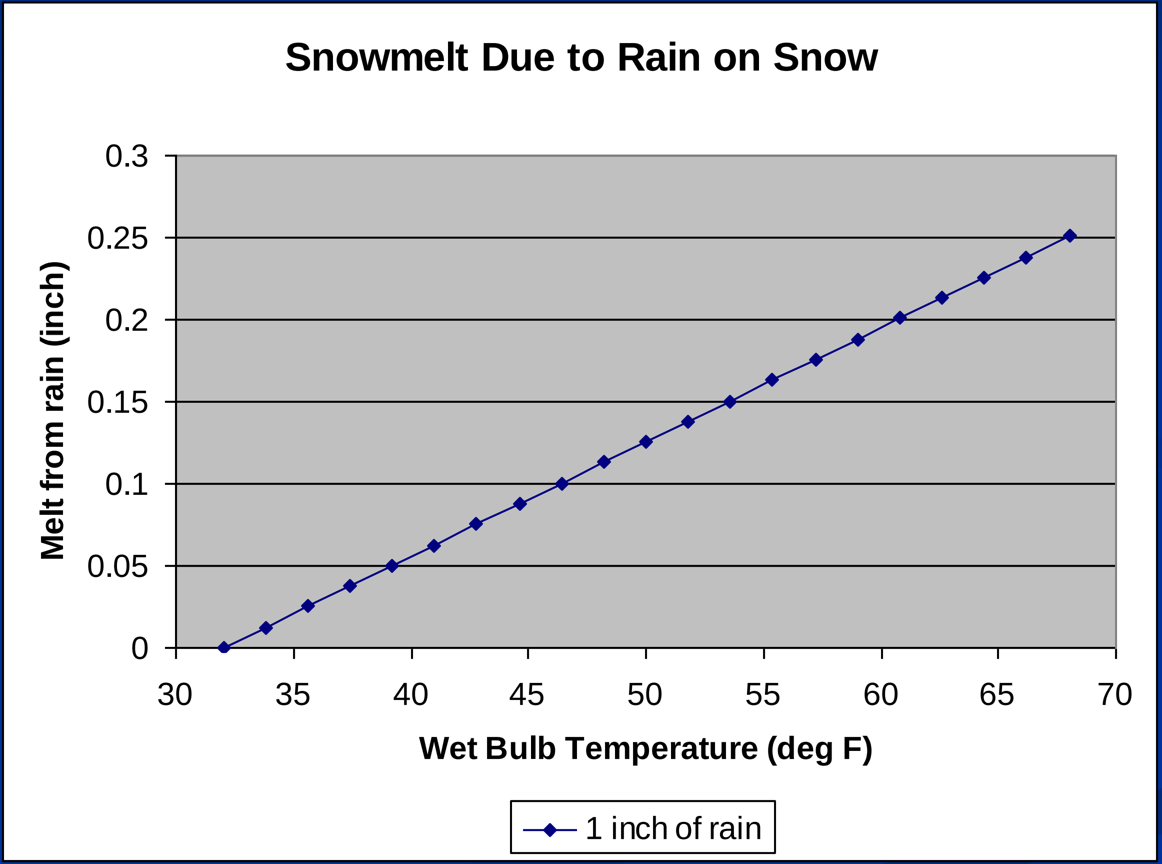
Cw = Specific heat of water

Px = Precipitation (mm)

Lf = Latent heat of fusion

Tw = Wet-bulb Temp. (K)

Tw	Melt (% of Px)
50 °F	12.5 %
68 °F	25.0 %



Rain-on-Snow

Snow-17 - Operational Equation

$$M = (0.0125 * Px * Ta)$$ { rainmelt}

$$+ 3.67 * 10^{-9} * \Delta t/6 * (Ta+273)^4 - 20.4$$ { longwave exchange}

$$+ 8.5 * UADJ * \Delta t/6 * [(0.9 * e_{sat} - 6.11) + 0.00057 * Pa * Ta$$

{turbulent transfer}

M = Melt (mm)

Ta = Air Temperature (°C)

Px = water equivalent of precipitation (mm)

UADJ = average wind function during rain-on-snow

e_{sat} = saturation vapor pressure at the air

Pa = mean sea level atmospheric pressure

Rain-on-Snow

Snow-17 - Operational Equation

$$M = (0.0125 * Px * Ta) \quad \{\text{rainmelt}\}$$

$$+ 6.12 * 10^{-10} * \Delta t\,[(Ta+273)^4 - 273^4] \quad \{\text{longwave exchange}\}$$

$$+ 8.5 * UADJ * \Delta t/6*[(0.9 * e_{sat} - 6.11) + 0.00057 * Pa * Ta$$

$$\{\text{turbulent transfer}\}$$

Assumptions:

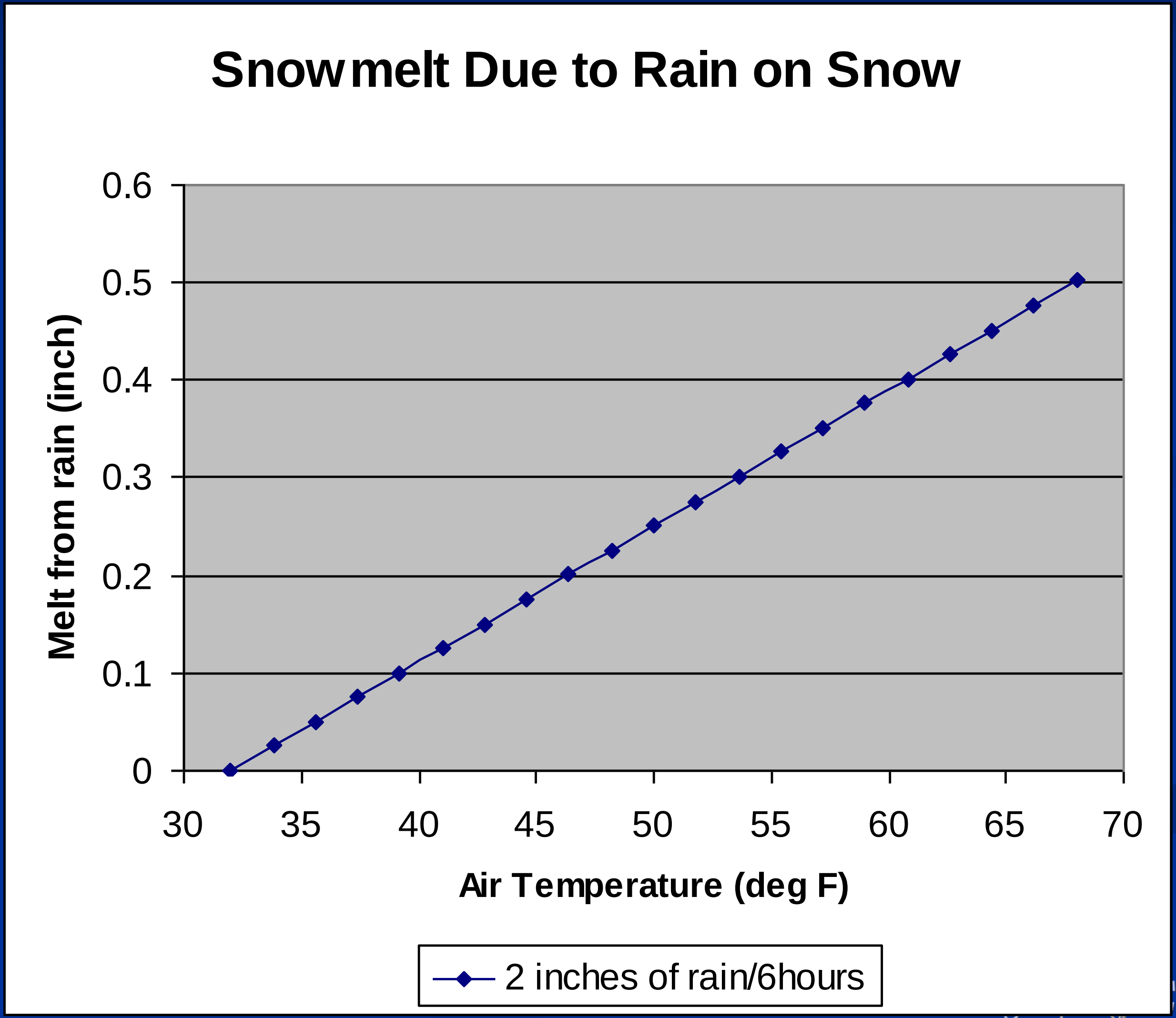
- no solar radiation
- relative humidity = 90%
- atmospheric radiation = black body at Ta
- wet bulb temperature (rainwater) = Ta
- UADJ is the **average** wind function during rain-on-snow events
- The snowmelt occurs at the **surface** of the snowpack

Rain-on-Snow

Snow-17 - Rainmelt

Assume a 6 hour event with constant Ta = 45 °F and 2 inches of rain

Ta	Melt (inches)
45 °F	0.18 (9%)



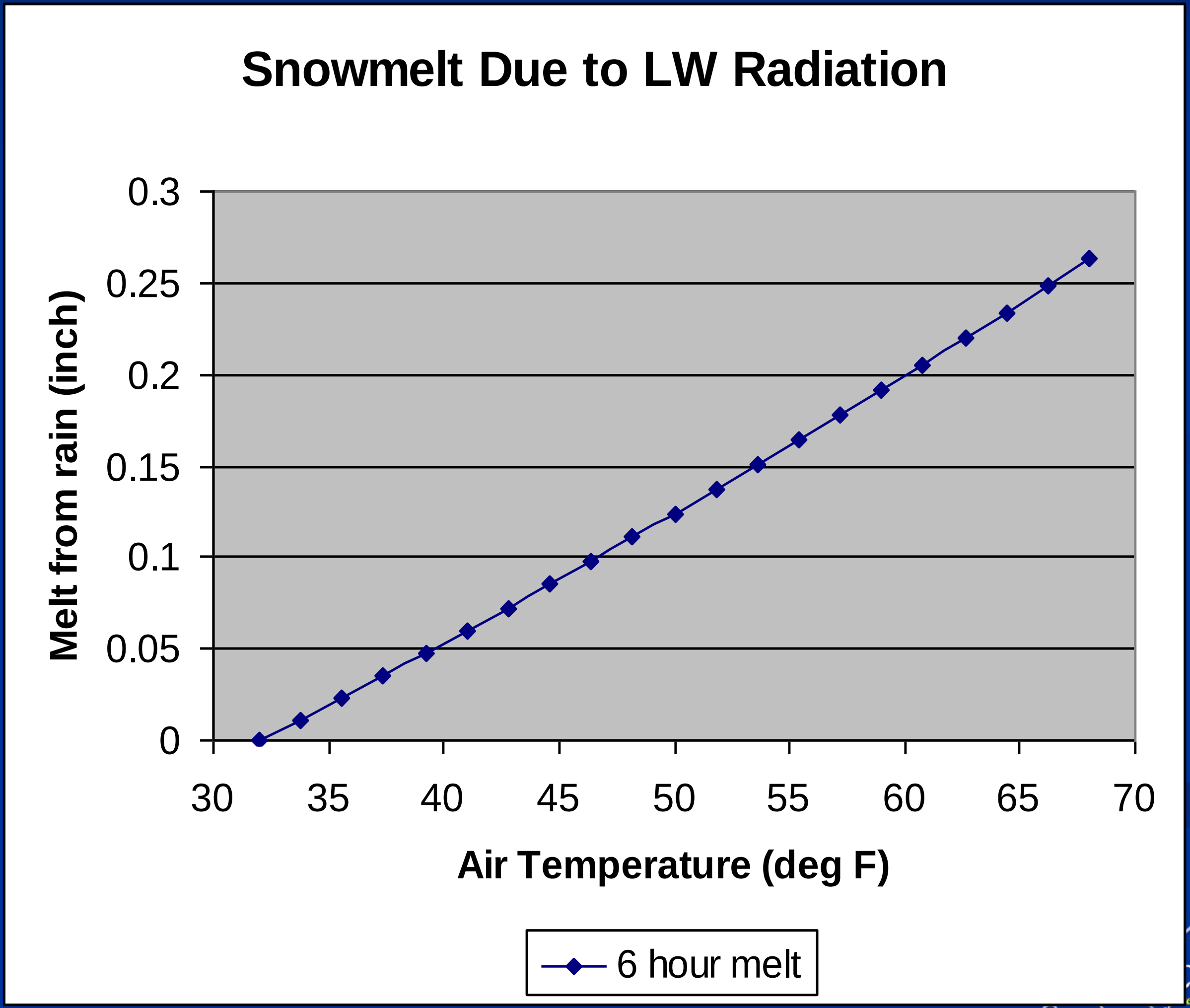
Rain-on-Snow

Snow-17 - Longwave Radiation

Assume a 6 hour event with constant Ta = 45 °F

Ta	Melt (inches)
45 °F	0.09 (4.5%)

Note: This melt is independent of rainfall amount



Rain-on-Snow

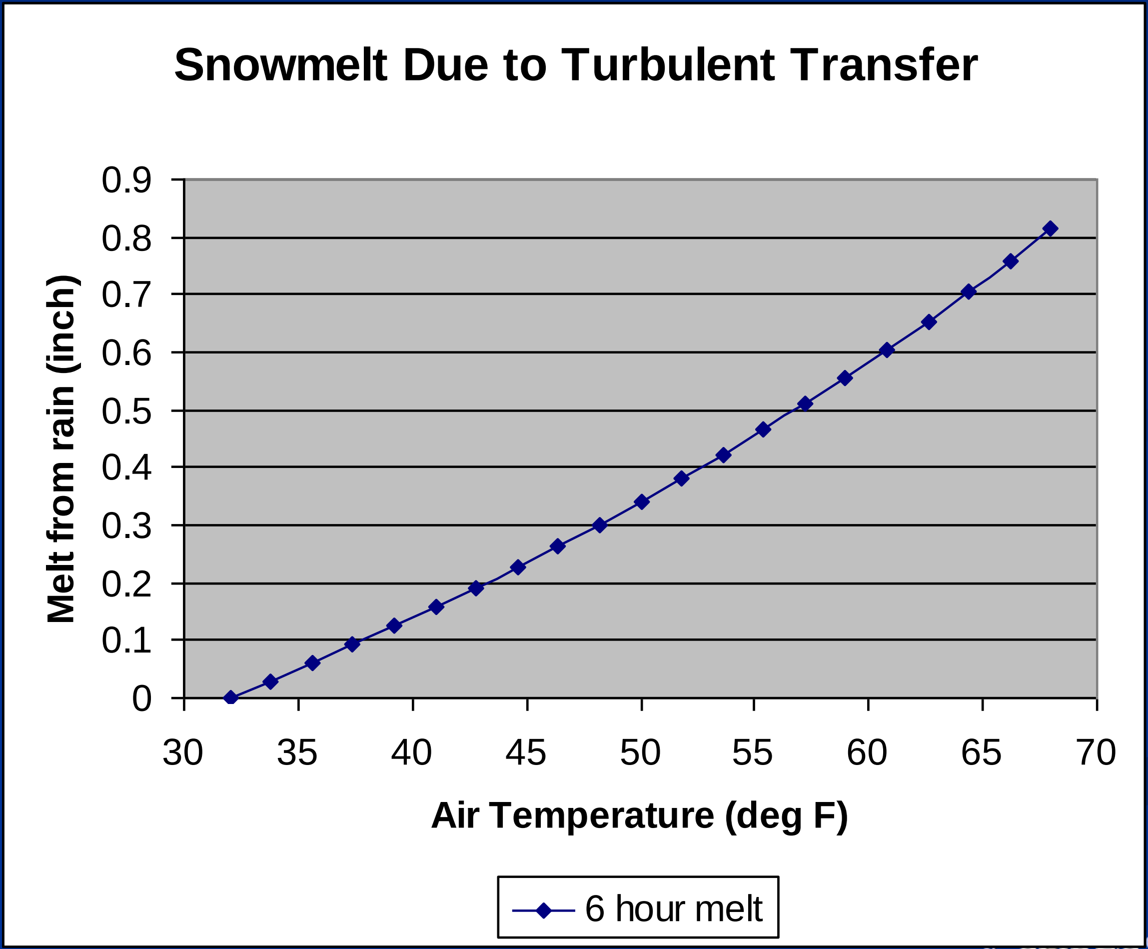
Snow-17 - Turbulent Transfer

Assume a 6 hour event with constant Ta = 45 °F

Ta	Melt (inches)
45 °F	0.23 (11.5%)

Note: This melt is independent of rainfall amount.

UADJ set to 0.09 (12 mph wind)



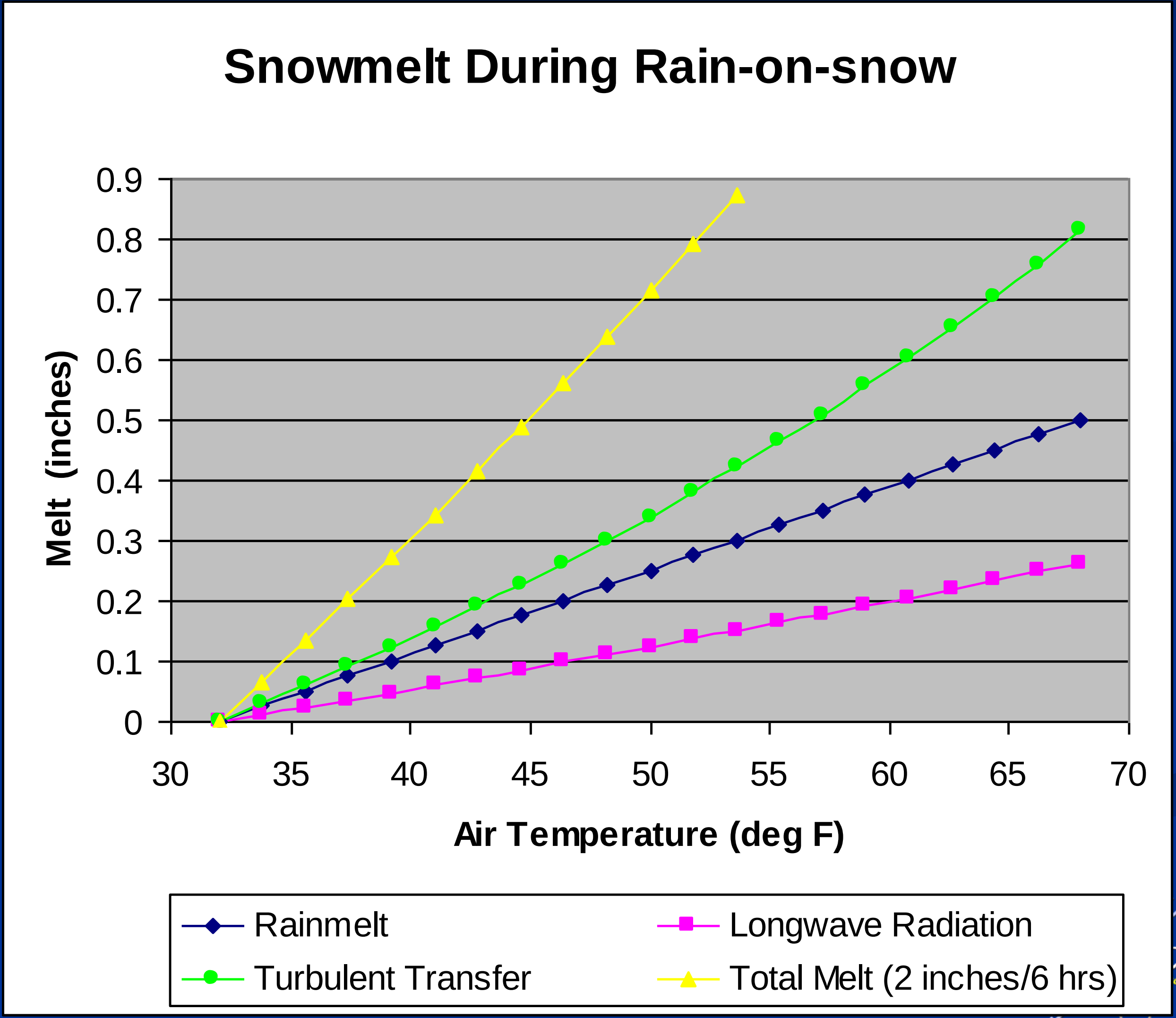
Rain-on-Snow

Snow-17 - Component Comparison

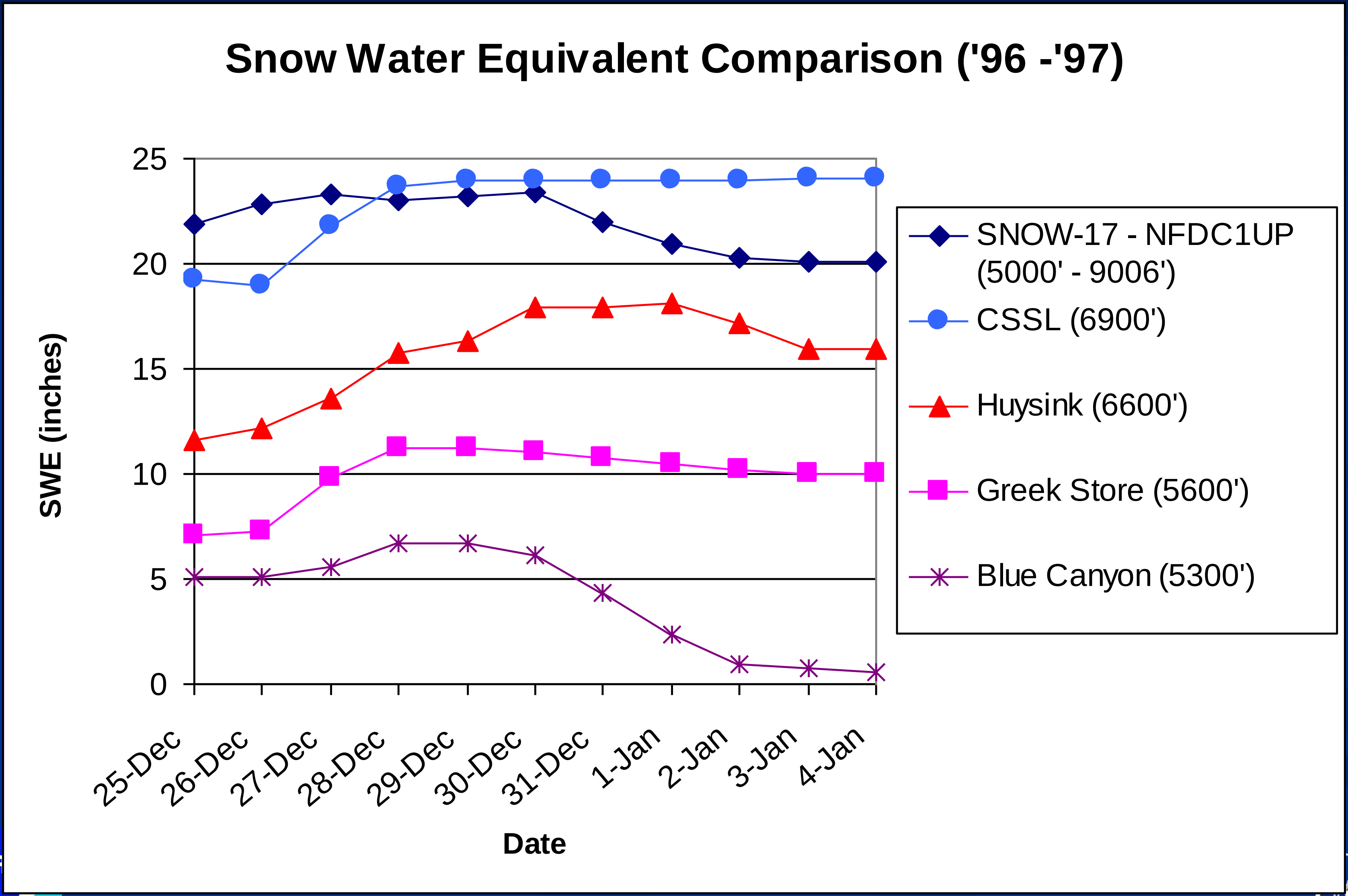
Assume 2 inches of rain during a 6 hour event with constant Ta

Ta	Total Melt (inches)
45 °F	0.50 (25%)
40 °F	0.30 (15%)
35 °F	0.11 (6%)

Note: 41 °F → 0.34 (17%)



Example – 1997 Event



Example – 1997 Event

Dec. 30, 1996 – Jan. 2, 1997

Blue Canyon (5300')
Average Temp (42.5 °F):

Rainfall = 19.8 inches

SWE loss = 5.3 inches

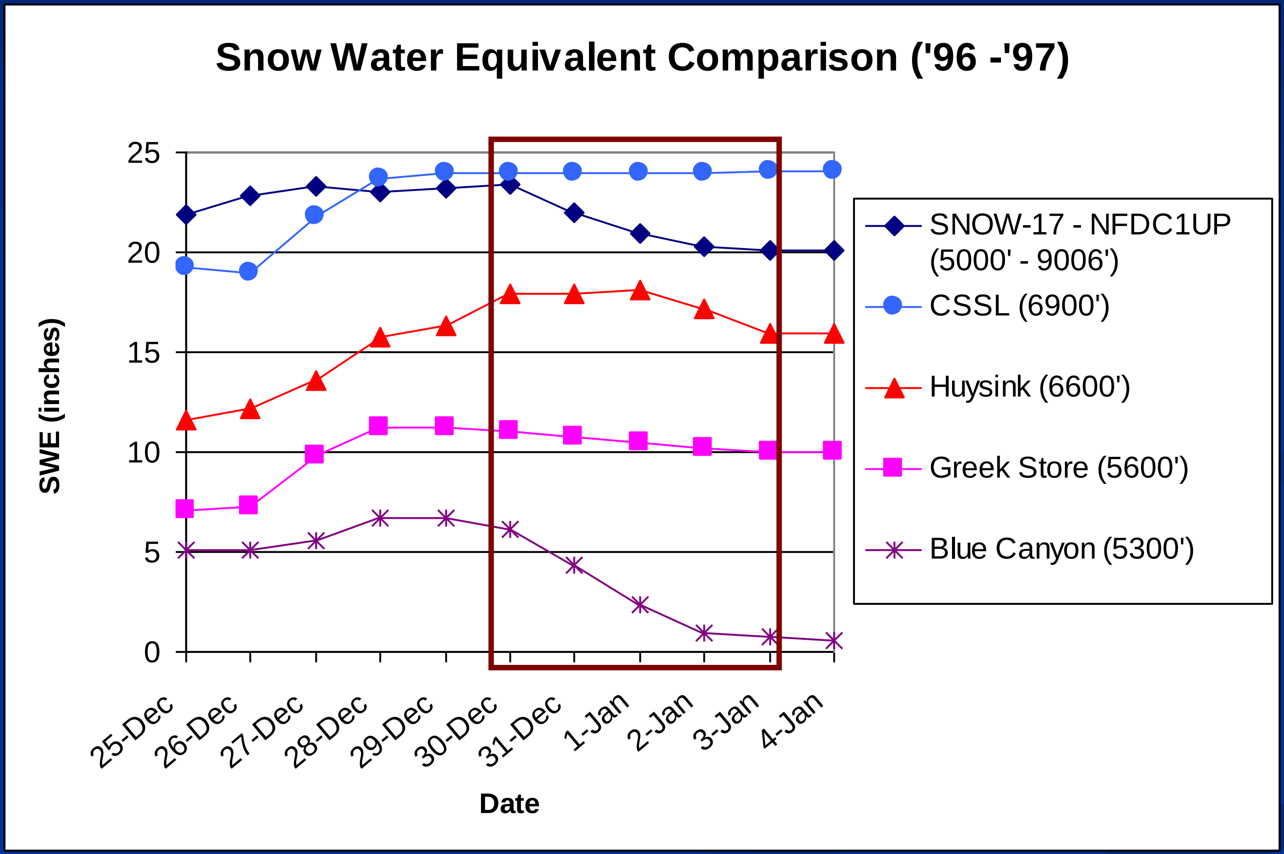
Ratio = 27 %

Greek Store (5600'):

Rainfall = 13.8 inches

SWE loss = 0.80 inches

Ratio = 6 %



Greek Store snowpack was deeper and less "ripe", more sheltered.

Rain-on-snow melt is highly dependent on pack conditions

Example – 1997 Event

Dec. 30, 1996 – Jan. 2, 1997

Huysink (6600')
Average Temp (42.5 °F)

Rainfall = 16.55 inches

SWE loss = 2.0 inches

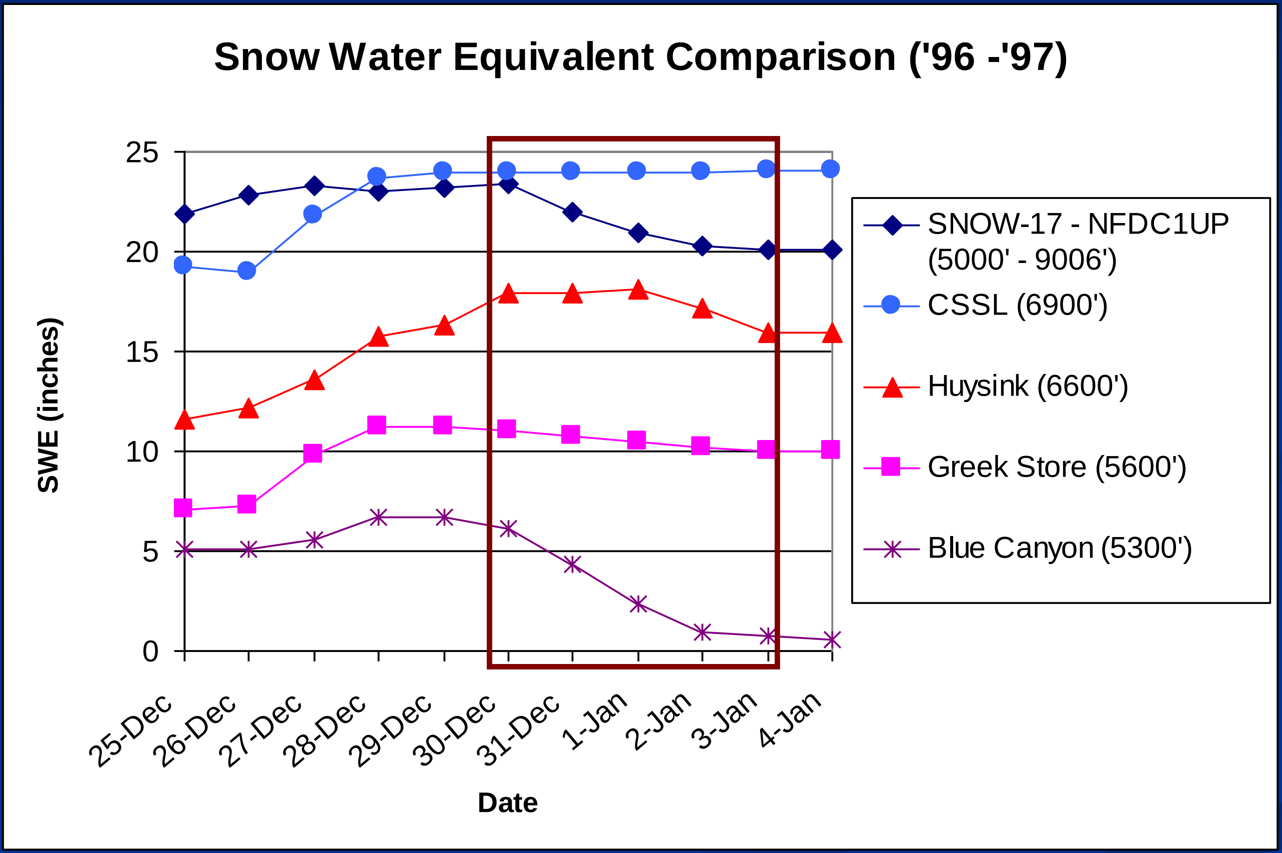
Ratio = 12 %

Central Sierra Snow Lab:
CSSL (6900'):

Rainfall = ??

SWE loss = 0.0 inches

Ratio = 0 %



At 6900' the rain passed through the deep CSSL snowpack with no melt.

Example – 1997 Event

Dec. 30, 1996 – Jan. 2, 1997

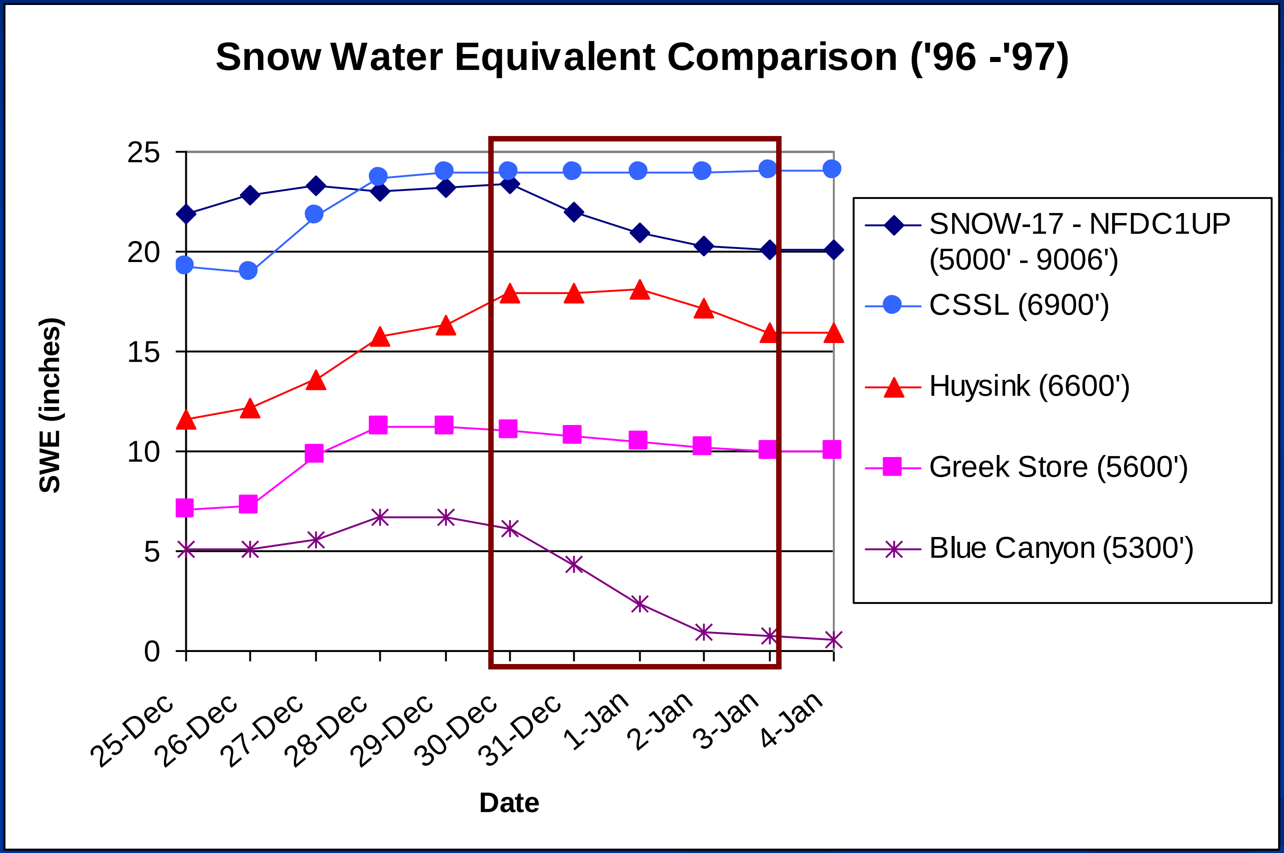
<u>SNOW – 17 (NFDC1UP):</u>

Average Temp (41 °F)

Rainfall = 18.0 inches

SWE loss = 3.28 inches

Ratio = 18 %



NFDC1UP is represents the basin average rain-on-snow snowmelt

Snowmelt Due to Rain-on-Snow

Summary

- Rain-on-Snow is a complex phenomena.
- Many variables need to be considered.
  (Temperature, humidity, wind speed, snowpack conditions, forests,…)
- The strongest component is usually turbulent transfer.
- All components together may reach 25% (or more) snowmelt-to-rain ratios in very warm events, especially at lower elevations.
- When snowpack is deep and still cold, little additional snowmelt occurs during rain-on-snow events.