# LEARNING TO LIVE WITH SNOW

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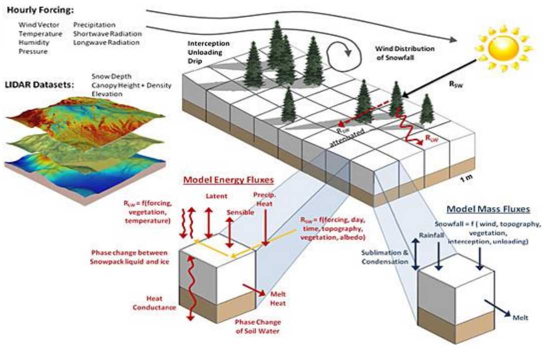
TÜRKİYE, AZERBAIJAN AND GEORGIA

# Outline

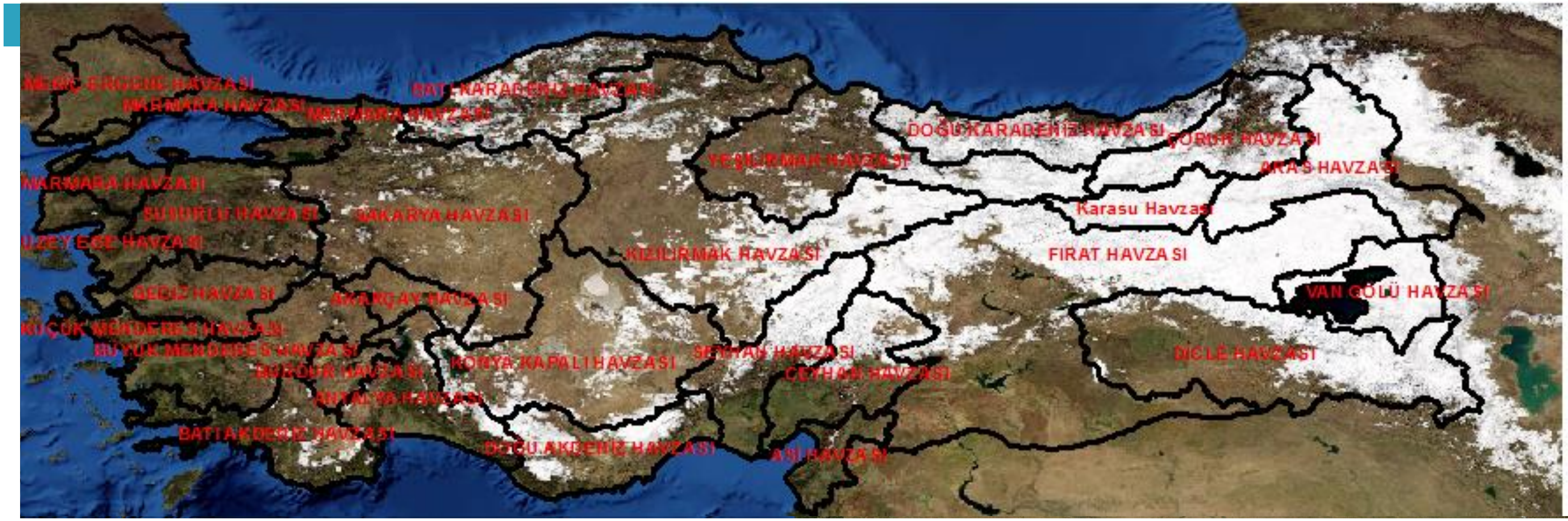



1. Snow potential of Turkey
2. Snowpack Components
3. Monitoring the properties of snowpack
   - ❖Automatic / Manual point measurements
   - ❖Snowpack modeling
4. Conclusions




# The Importance of Snow in Turkey

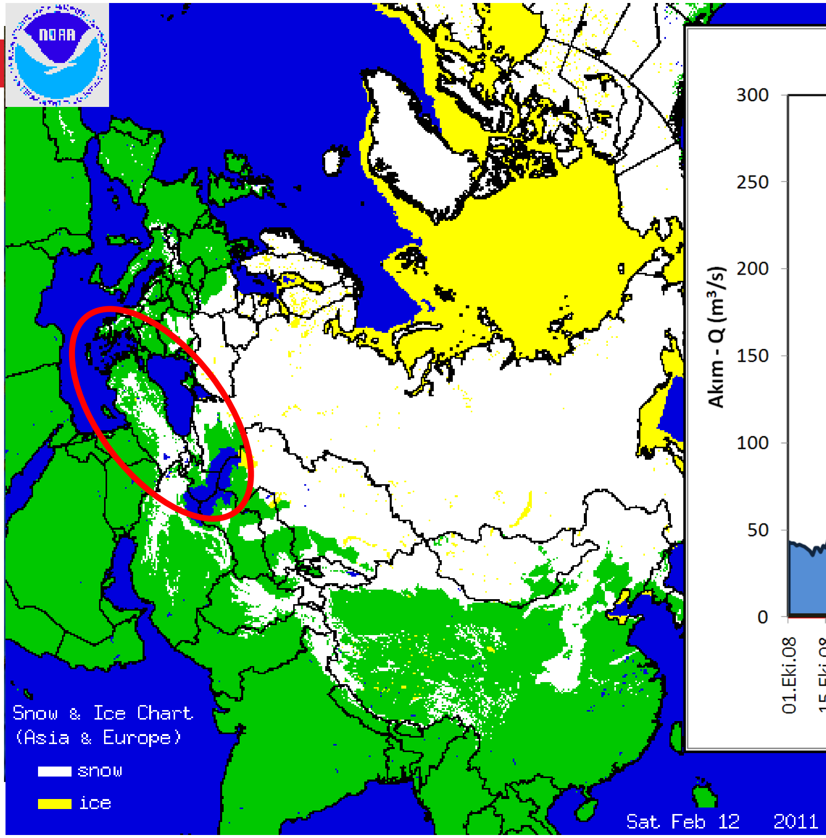


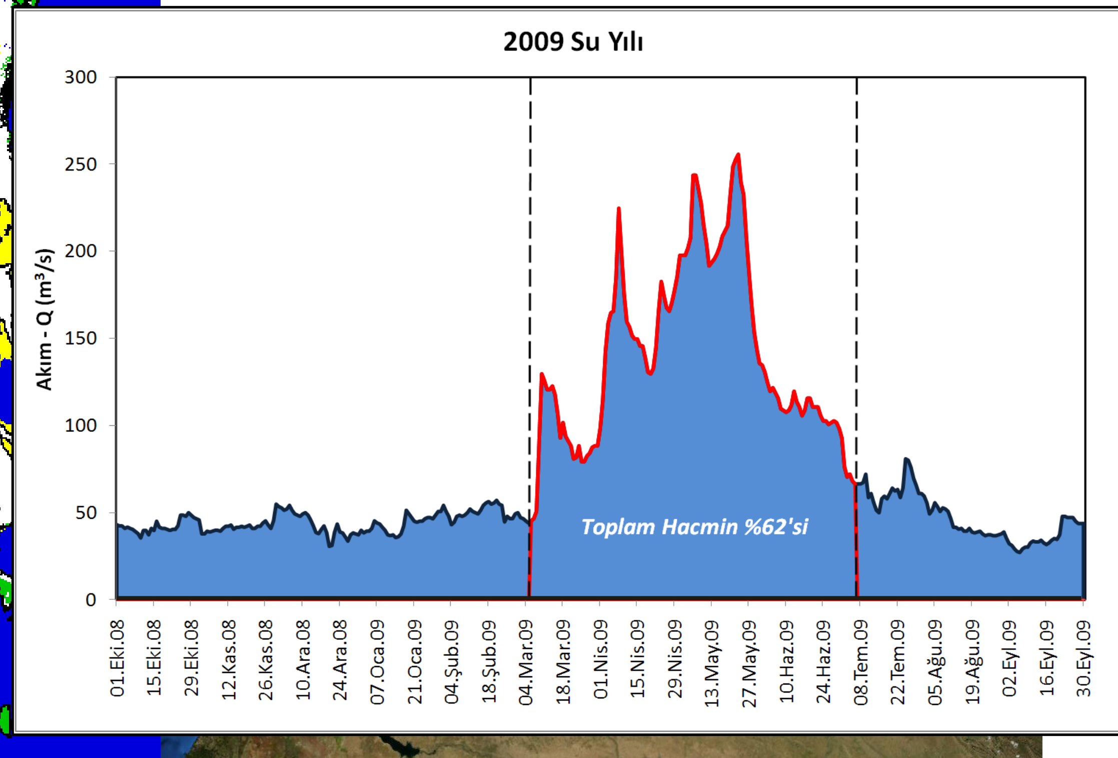



- Ave. elev. of Turkey > 1100 m, snow is frequent
- 4th highest country in Europe (Andorra, Georgia, Switzerland)
- Snow stays on ground in East and Central Anatolia → Dec. – May. (6 months)
- Most transboundary rivers are fed by snowmelt

# The Importance of Snow in Turkey






- Snow stays on the ground for a long time in the Central and Eastern Anatolia Regions→ Nov. – Jun.
- It intensively feeds the rivers (transboundary) (2/3 ratio)

# Advantage? Disadvantage?



- Drinking water
- Agricultural irrigation
- Hydroelectric energy
- Winter tourism
- Fishing
- Art

- Warmup
- Transportation
- Communication
- Flood
- Avalanche
- Structure loads

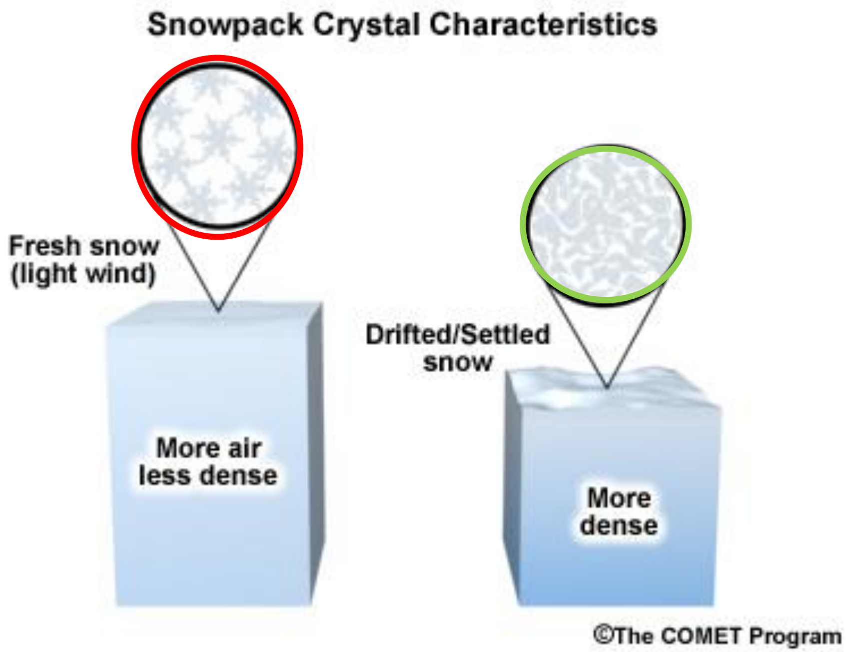
# Snowpack Components

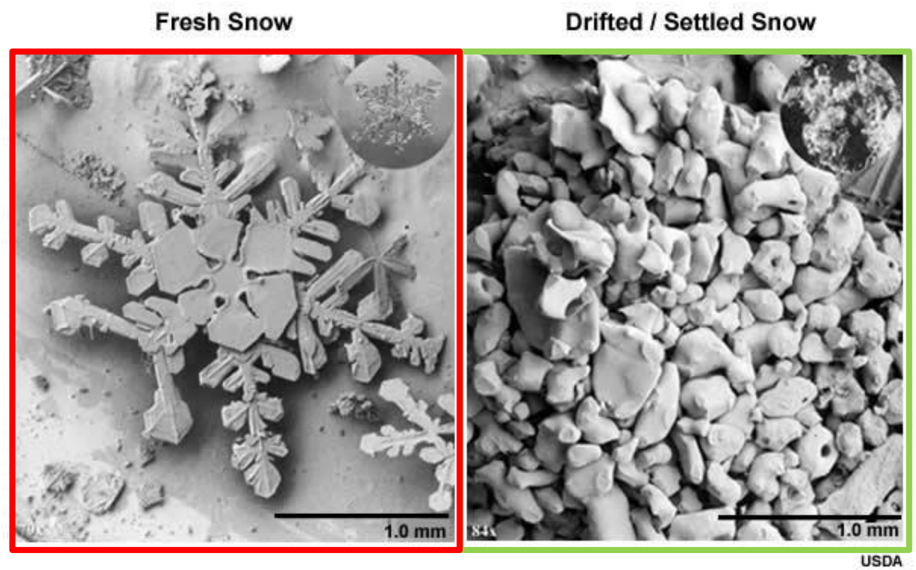


The snowpack, a mixture of three component ice, liquid water, and air, has a layered structure due to the intermittent snowfall events during the season.

# Snowpack Components





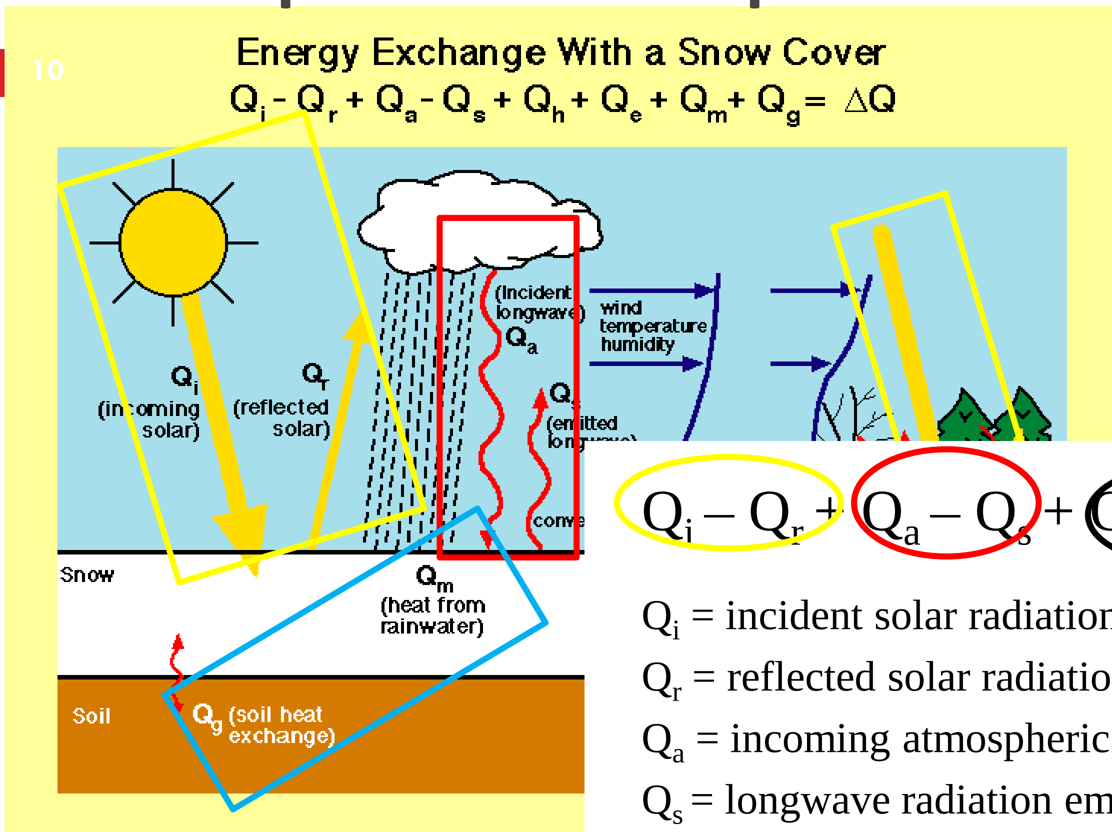



# Snowpack Components



- ❖ **Snow Depth (SD) → [mm or cm]**
- ❖ **Snow Density (ρ) → [ kg/m$^3$ ]**
- ❖ **Snow Water Equivalent (SWE) → [mm or cm]**
- ❖ **Snow Grain Size→ [mm]**
- ❖ **Snow Hardness (R)**
- ❖ **Temperature (T) → [C°]**
- ❖ **Liquid Water Content ($\theta_w$) → [%]**

# Snowpack Components




$$Q_i - Q_r + Q_a - Q_s + Q_h + Q_e + Q_m + Q_g = \Delta Q$$

$Q_i$ = incident solar radiation,

$Q_r$ = reflected solar radiation,

$Q_a$ = incoming atmospheric and terrestrial longwave radiation,

$Q_s$ = longwave radiation emitted by the snow cover,

$Q_h$ = sensible heat transfer,

$Q_e$ = latent heat transfer,

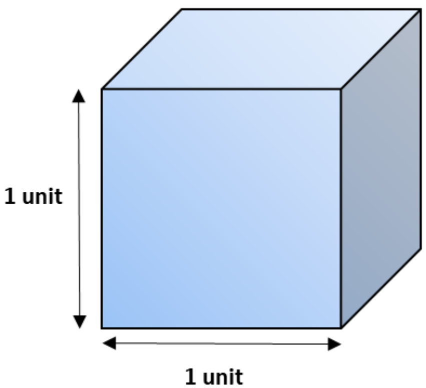
$Q_m$ = heat transfer due to mass changes,

$Q_g$ = heat transfer at the snow-soil interface,

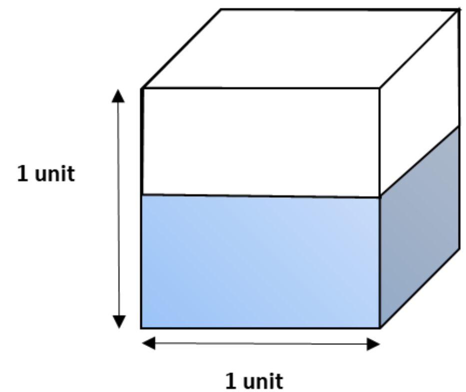
$\Delta Q$ = change in the heat storage of the snow cover

# Snowpack Components

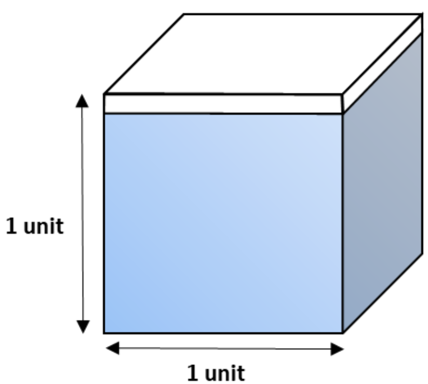




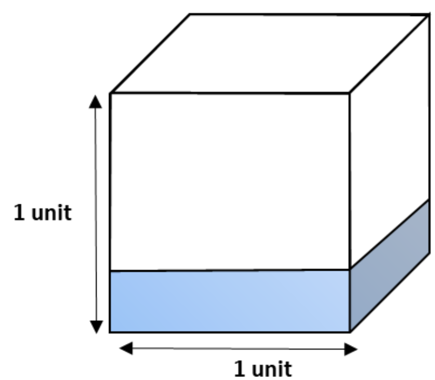

WATER
1000 $kg/m^3$




DENSE SNOW
350~450 $kg/m^3$



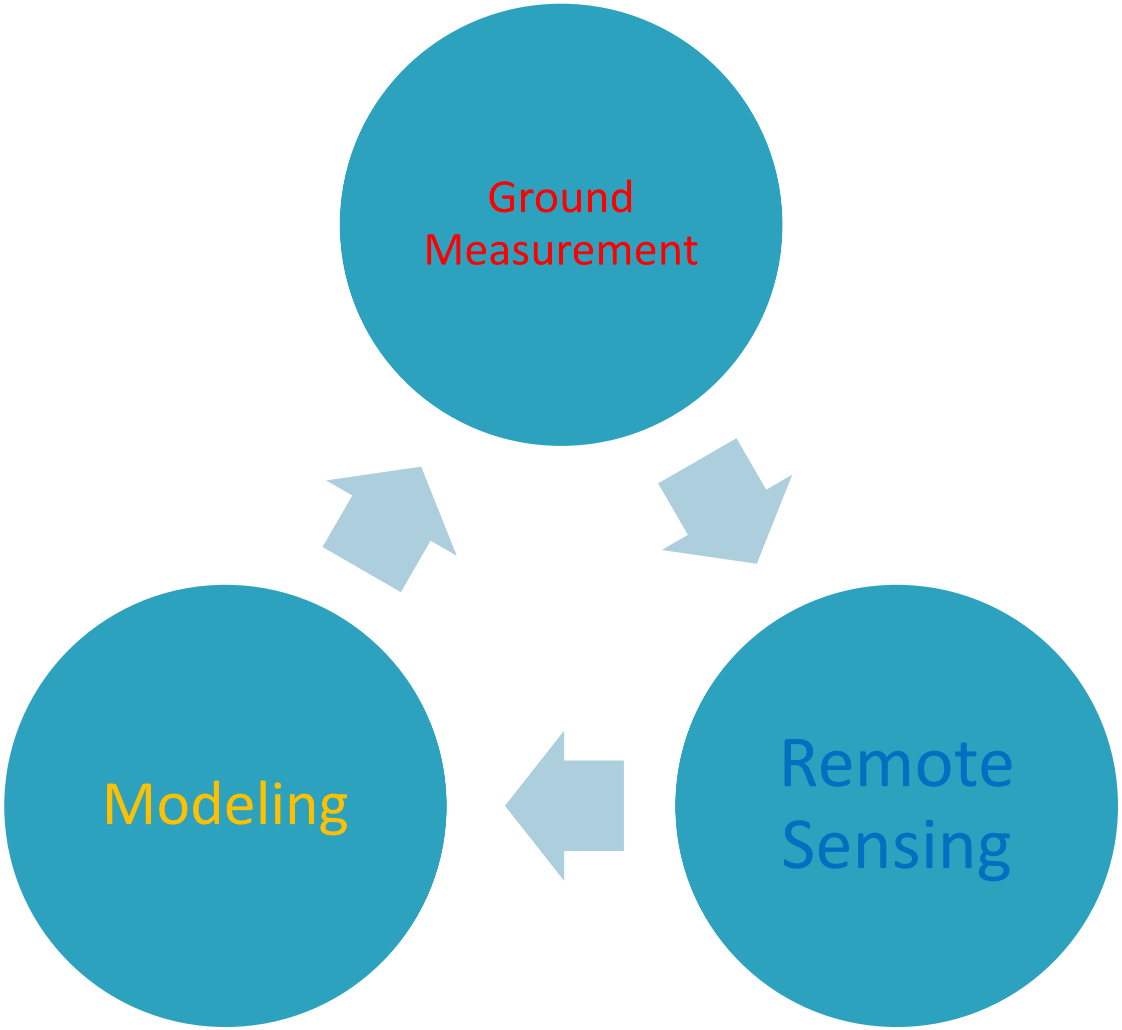

ICE
900~970 $kg/m^3$




FRESH SNOW
100~200 $kg/m^3$

# Snowpack Components

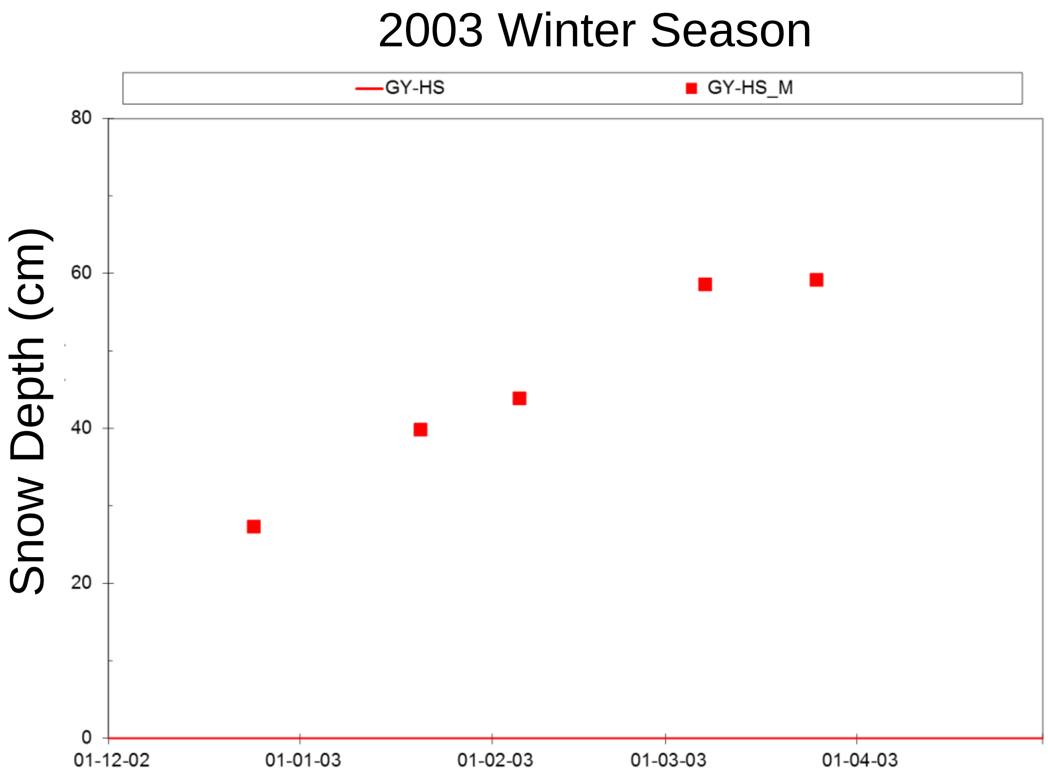




# Ground Measurements



## ❄ Manual Snow Observation Stations (KGI) (1960s)



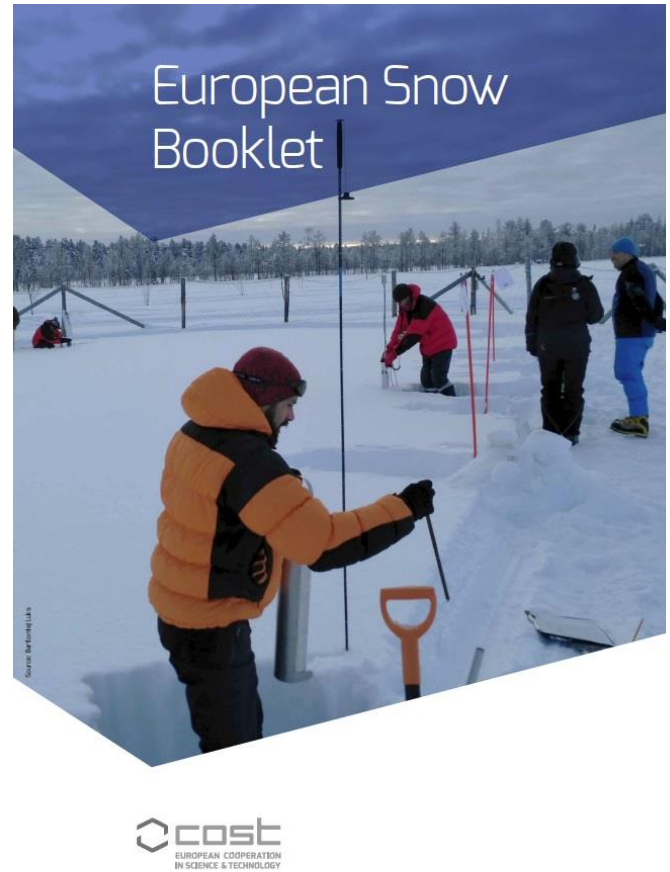


# Ground Measurements




COST Project Erzurum Meeting

March 2016




European Snow Booklet

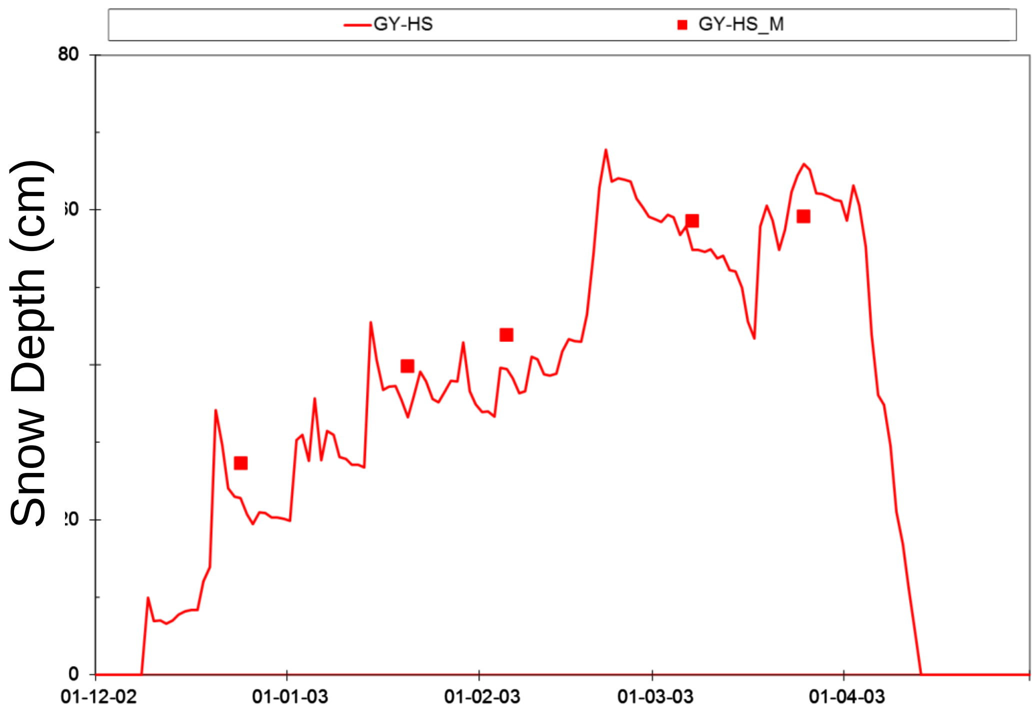
June 2019

# Ground Measurements

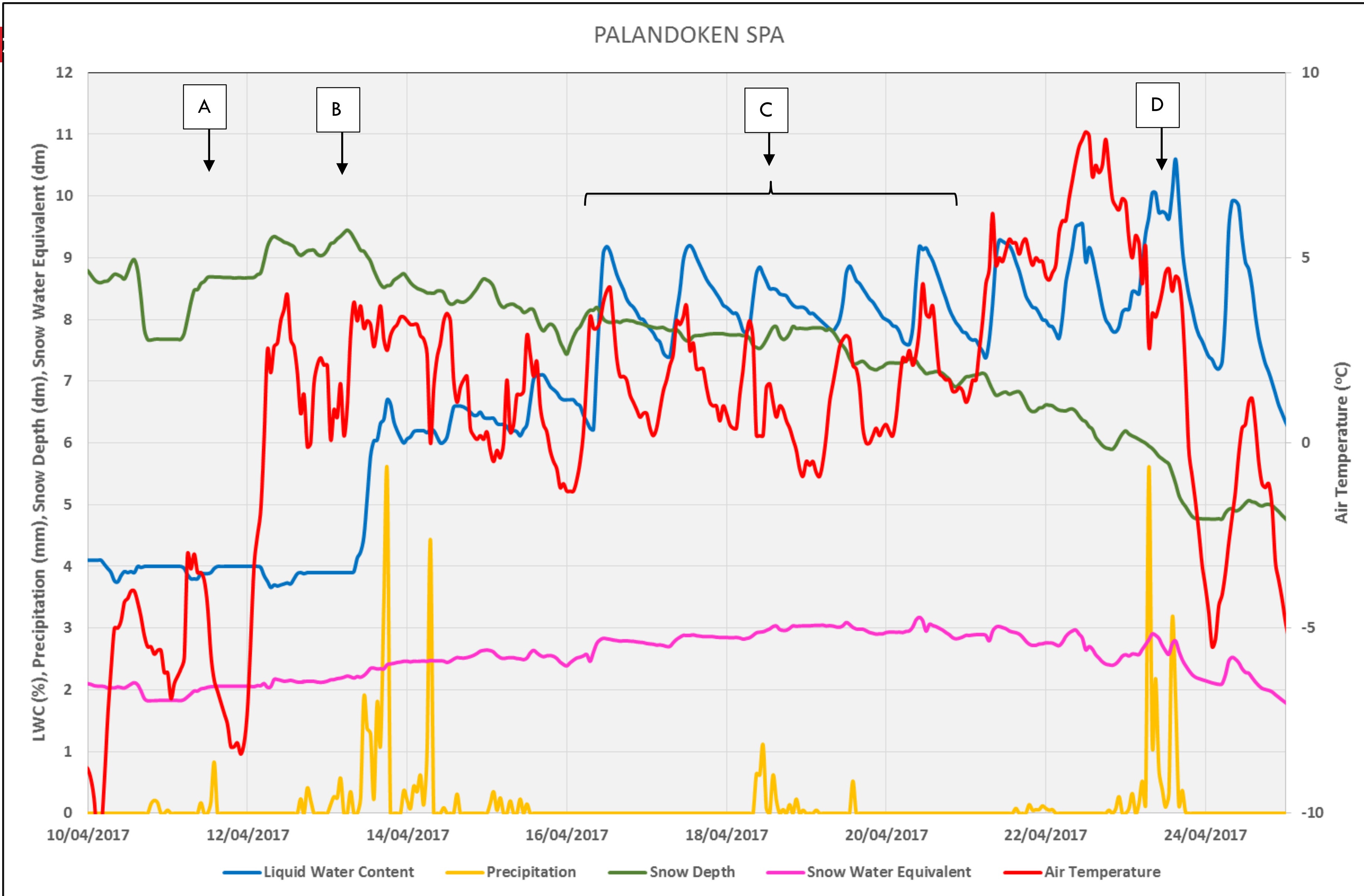


- Automated Snow Observation Stations (SNOTEL) (2000s)

2003 Winter Season



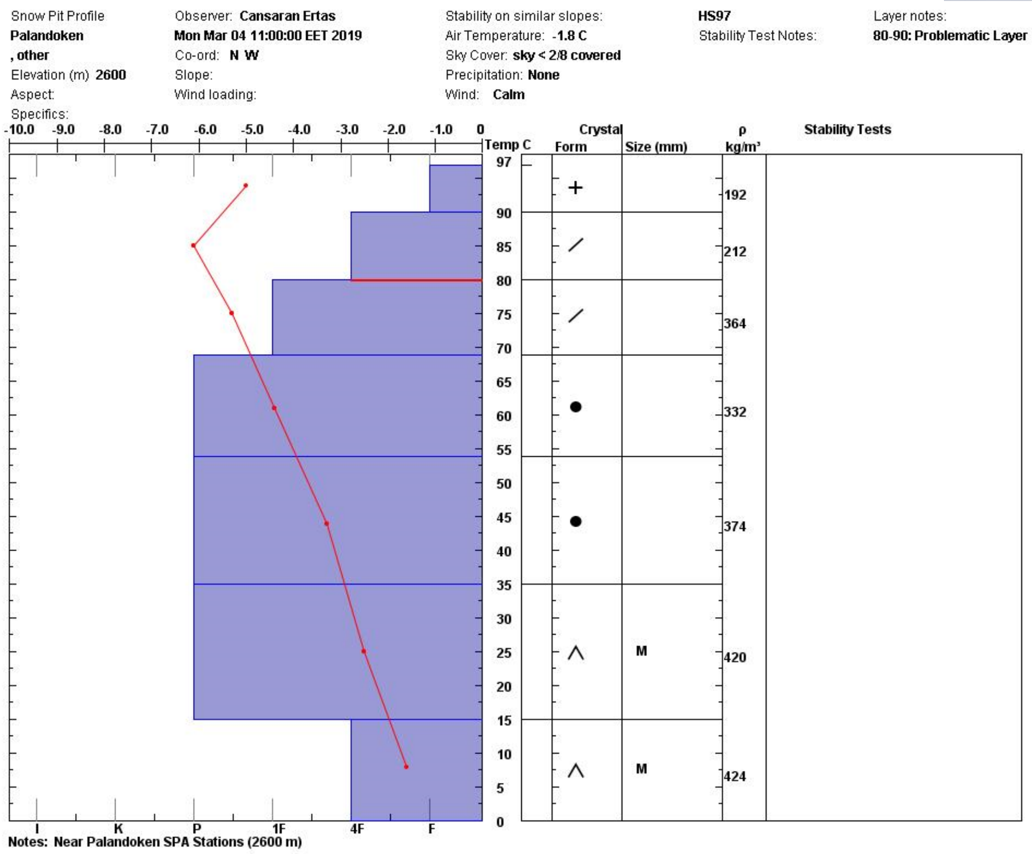

| Point A | Point B | Point C | Point D |
|---|---|---|---|
| • Air Temp. < 0 °C<br>• Constant LWC, SWE, SD | • Air Temp. > 0 °C<br>• Rain-on-snow<br>• Increase of LWC ~ 6-7% | • Diurnal cycle for LWC ~ 7-9%<br>• HS ↓ and SWE ↑ | • Max. LWC ~10%<br>• SWE ↓ and snowmelt |

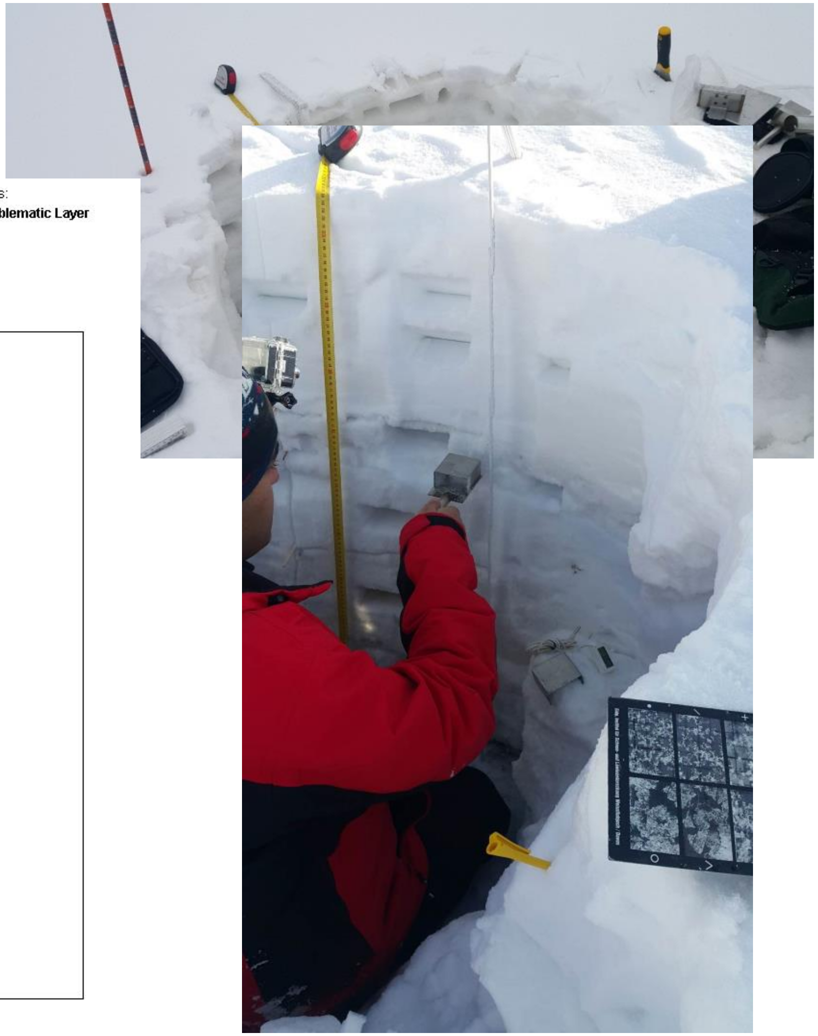


# Ground Measurements



- Snow Pit

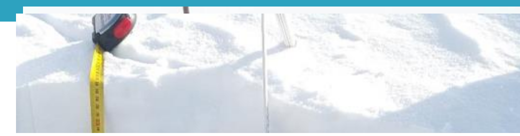


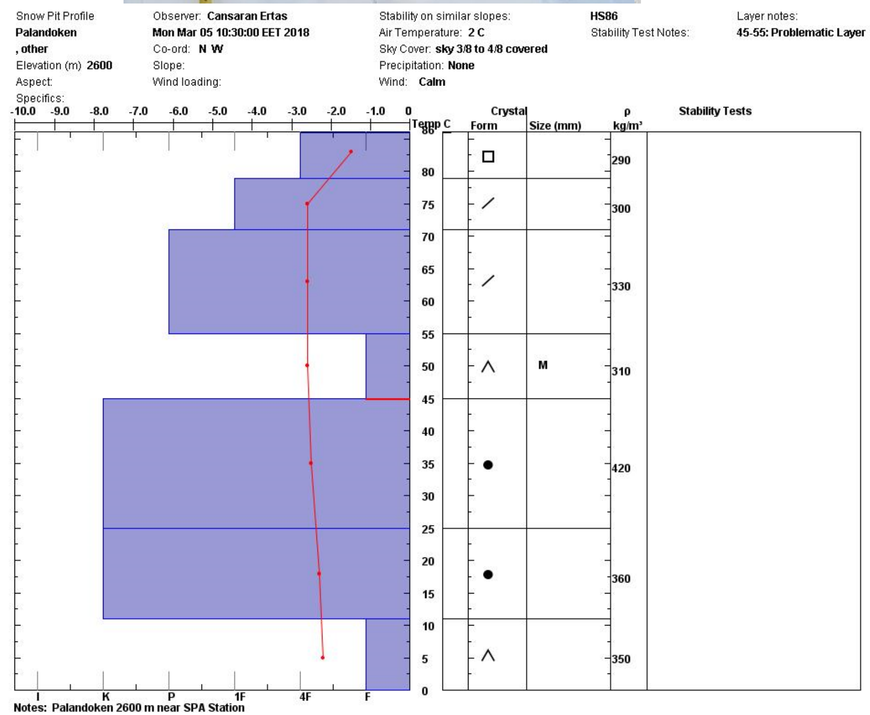



# Ground Measurements



## ❄ Snow Pit



# Ground Measurements



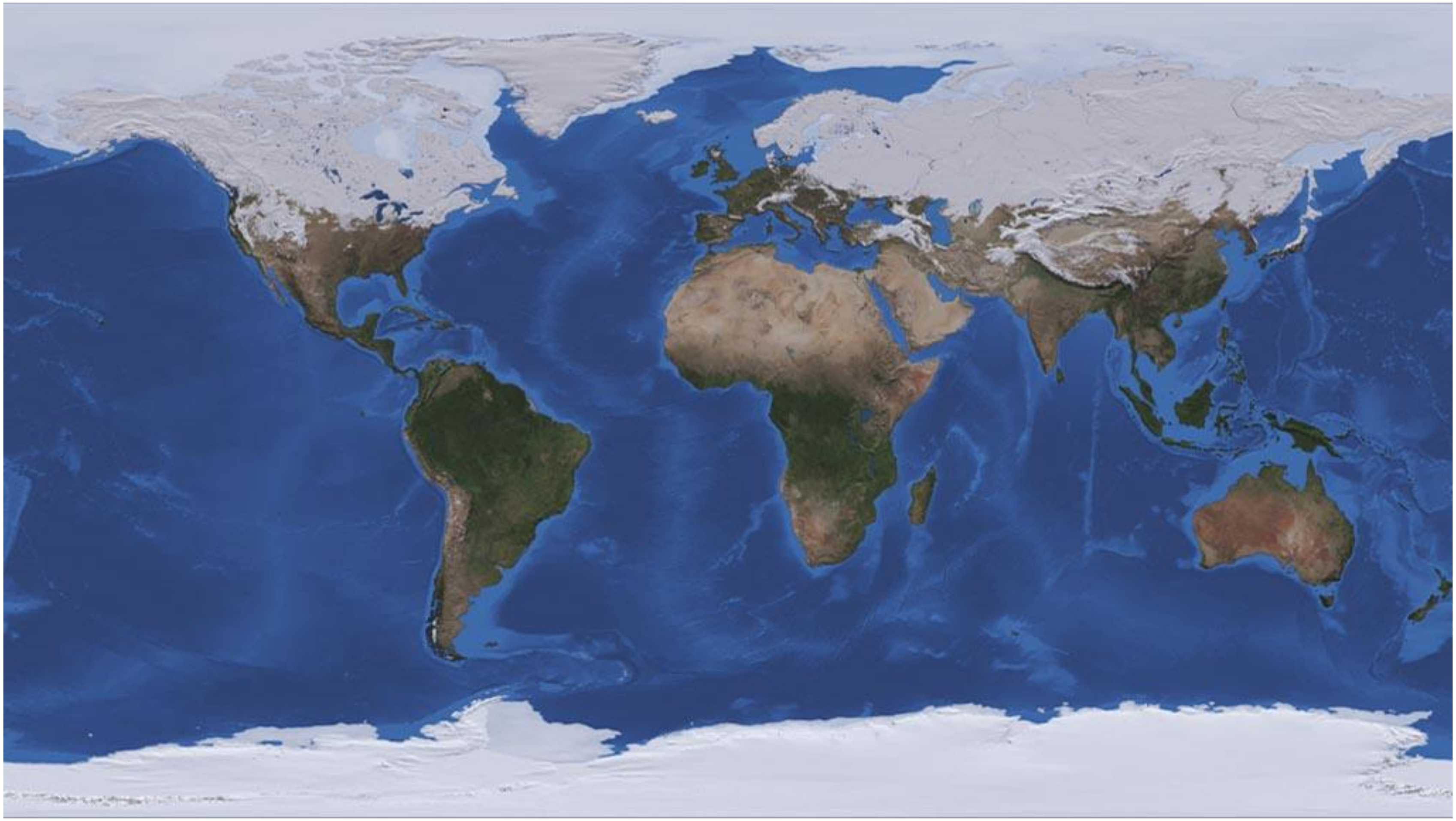
# Remote Sensing



- Snow is one of the brightest surfaces on Earth
- It is an important climate variable
  - Radiation (high albedo-energy balance)
  - Soil temperature / humidity (agriculture)
  - Water budget (hydrological cycle)
  - Climate change

# Remote Sensing





Snow Cover Northern Hemisphere ~ 50 milion $km^2$

# Remote Sensing



November 2018

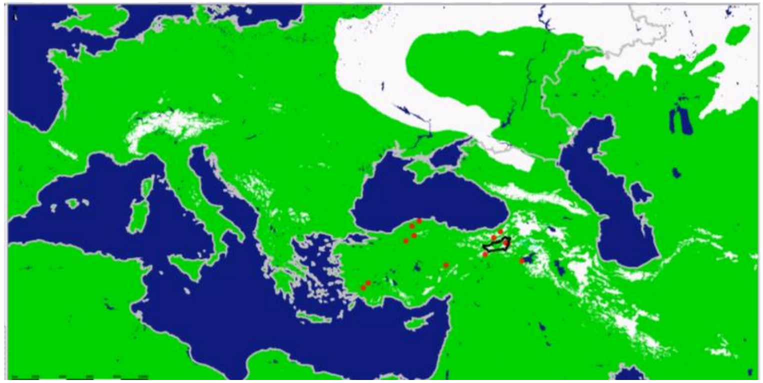
January 2019

March 2019

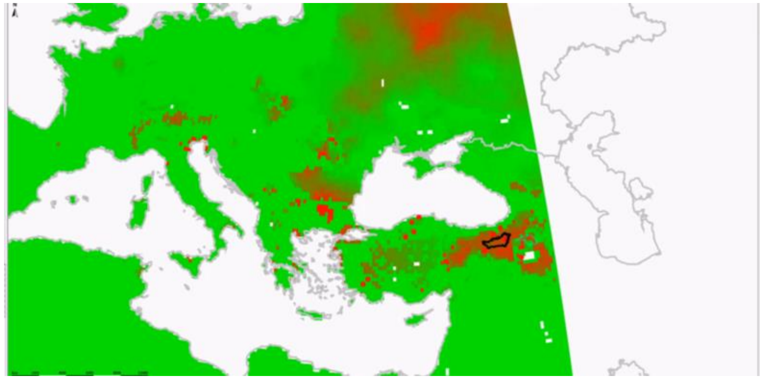
June 2019

# Remote Sensing





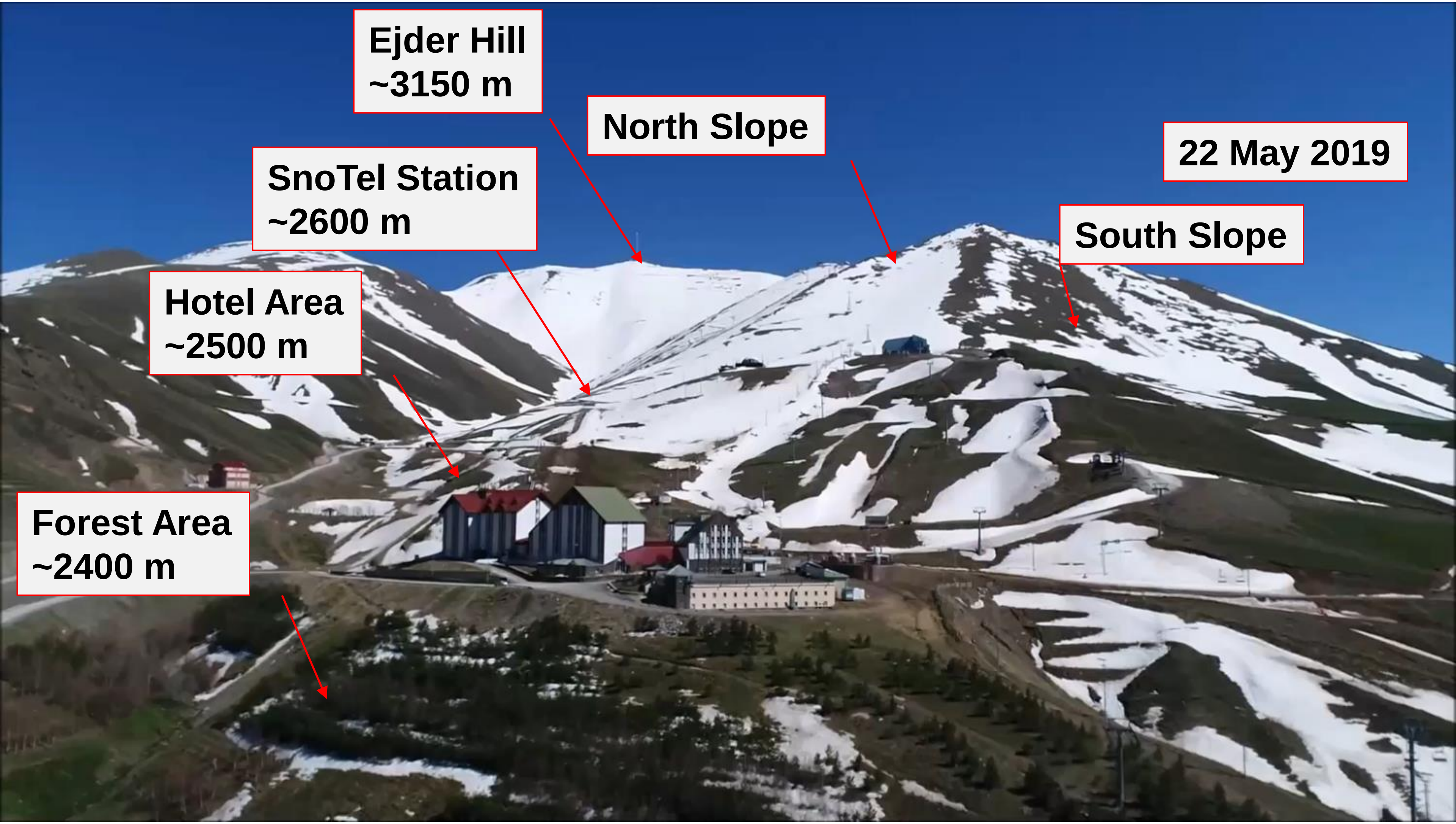
- IMS product
  - Snow cover
  - 4 km x 4 km spatial resolution



- SSMI/S product
  - Snow Water Equivalent
  - 25 km x 25 km spatial resolution

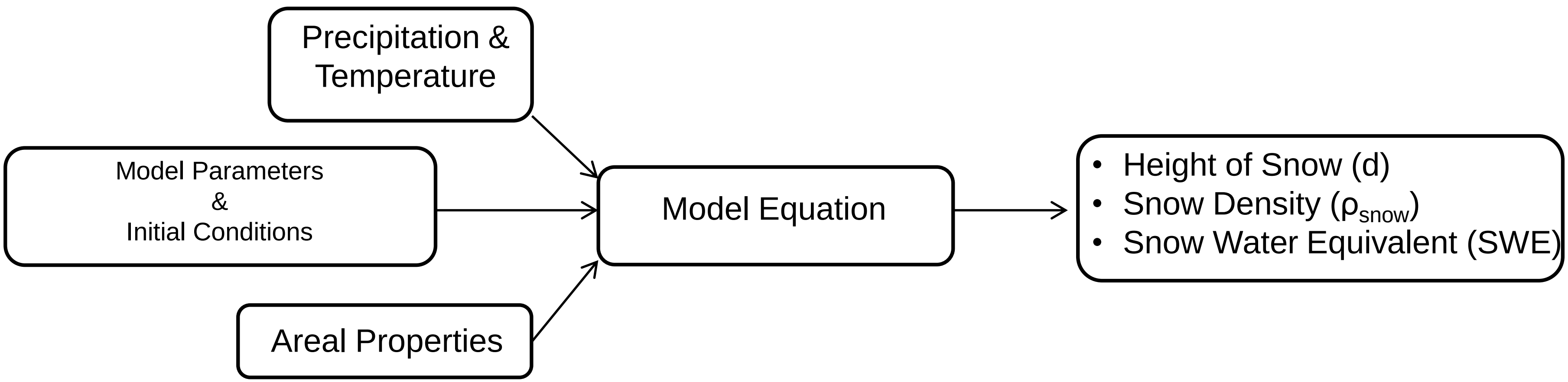
# Remote Sensing





# Snowpack Modeling

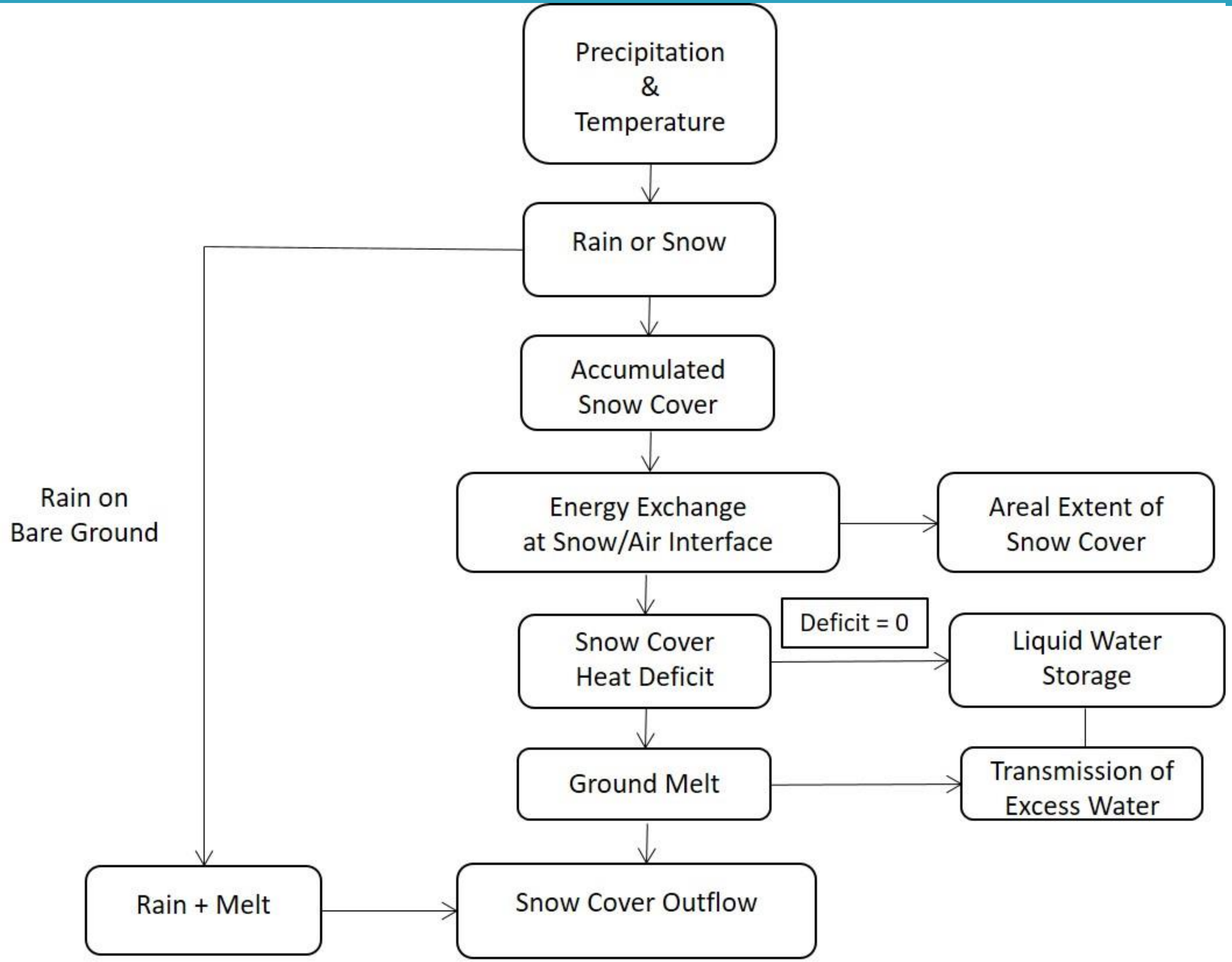





1. Form of precipitation,
2. Accumulation of the snow cover,
3. Energy exchange at the snow-air interface,
4. Internal state of the snow cover,
5. Transmission of water through the snow cover, and
6. Heat transfer at the soil-snow interface.

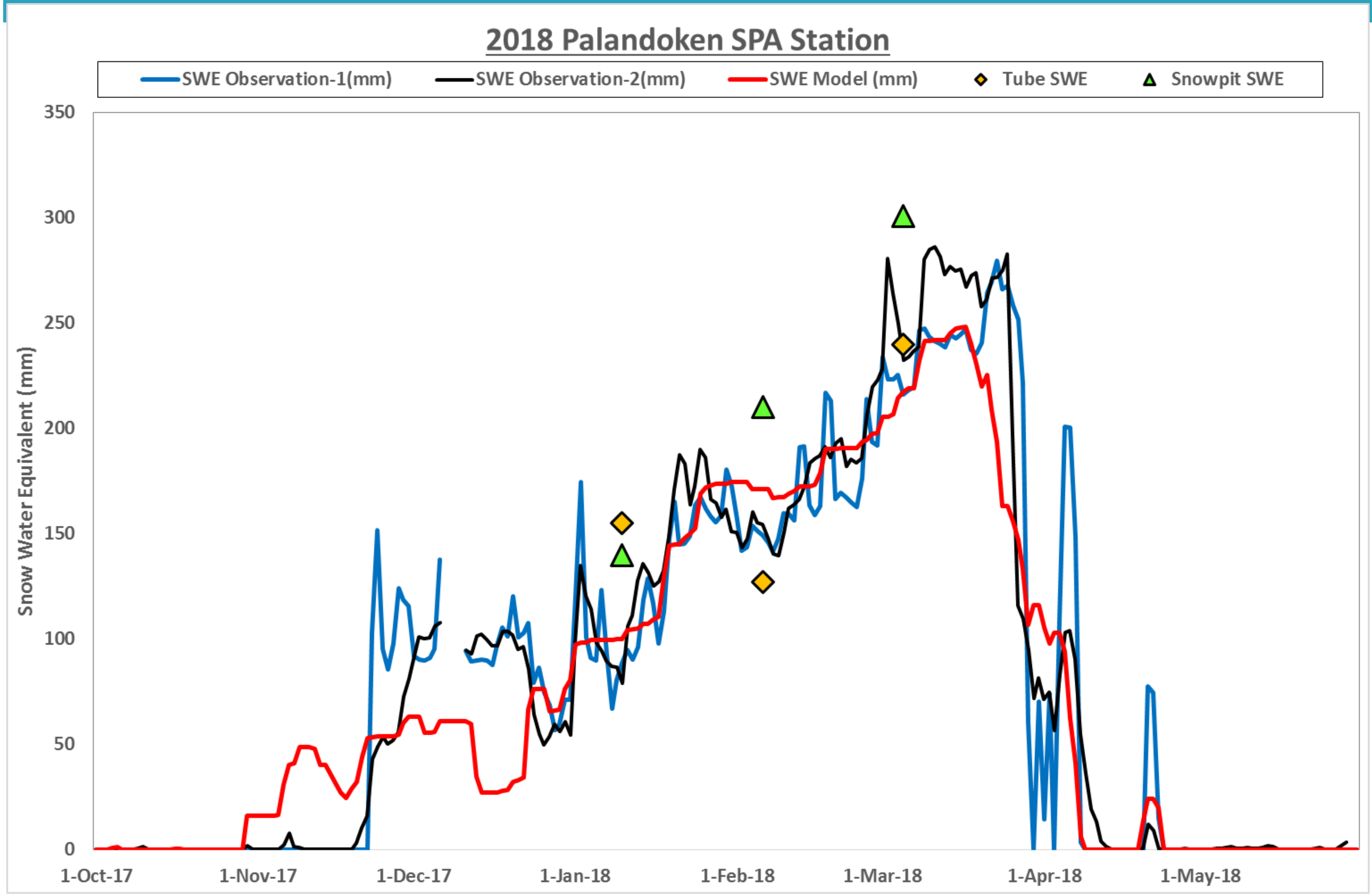
# Snowpack Modeling





# Snowpack Modeling





# Conclusions



- SnoTel stations can provide important snow component data in real-time during a snow season
- Snow data can be utilized in snow and/or hydrologic models
- Manual ground measurements (tube, pit) and snowpack model can assist automatic snow data

# Conclusions



- Continuous measuring and modeling snowpack dynamics in a mountainous basin important impact on a number of key processes in snowmelt and runoff modeling.
- The model results provide an acceptable match with the ground observations, so it can be used as tool in order to fill missing data.

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Thank you for your attention..