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Improving Precipitation Phase Determination through Air Mass Boundary Identification

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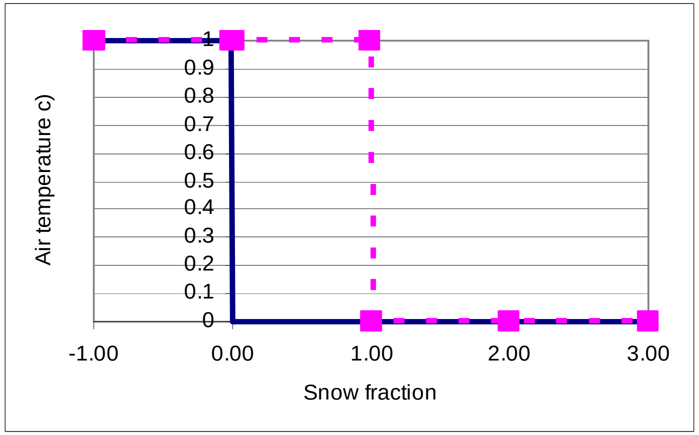
Introduction

- Correct determination of precipitation phases is important for estimates of snow storage in hydrological, regional and global climate models.
- Precipitation phase is especially critical for models simulating forest processes since canopy storage capacity is about one order of magnitude larger for snow than for rain.
- Hydrological models that apply the same surface-air temperature based precipitation phase identification scheme for all types of precipitation events neglect the fact that surface precipitation phase results from energy exchanges between air in the lower atmosphere and the falling precipitation.

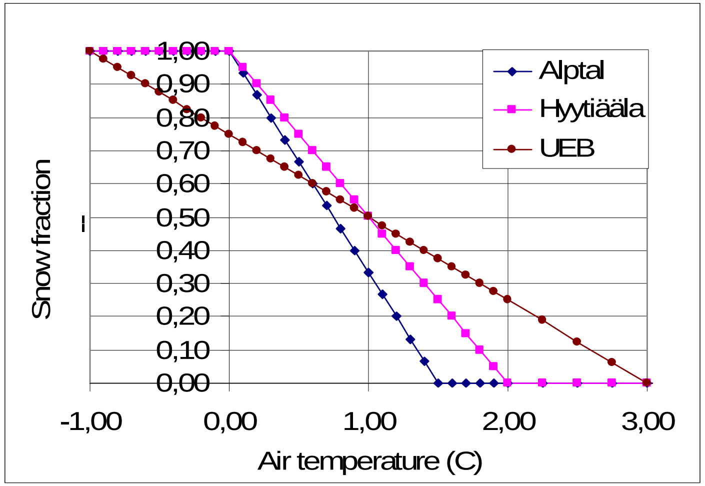
Linear snow/rain threshold schemes

a) one single surface air temperature threshold ($T_{R/S}$) separating rain from snow

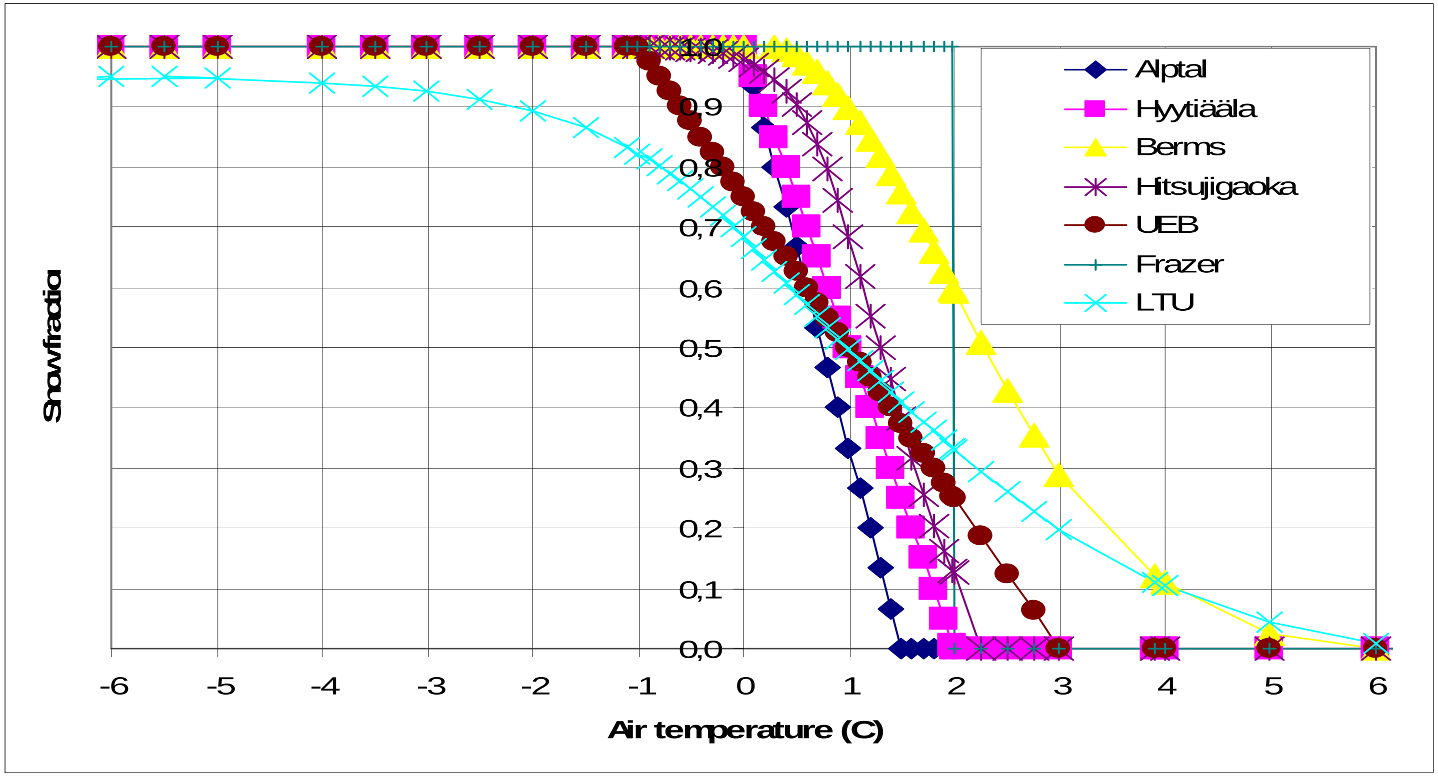


b) two surface air temperature thresholds,

- one for all snow (T_S)
- one for all rain (T_R)
- linear decrease in snow fraction in between



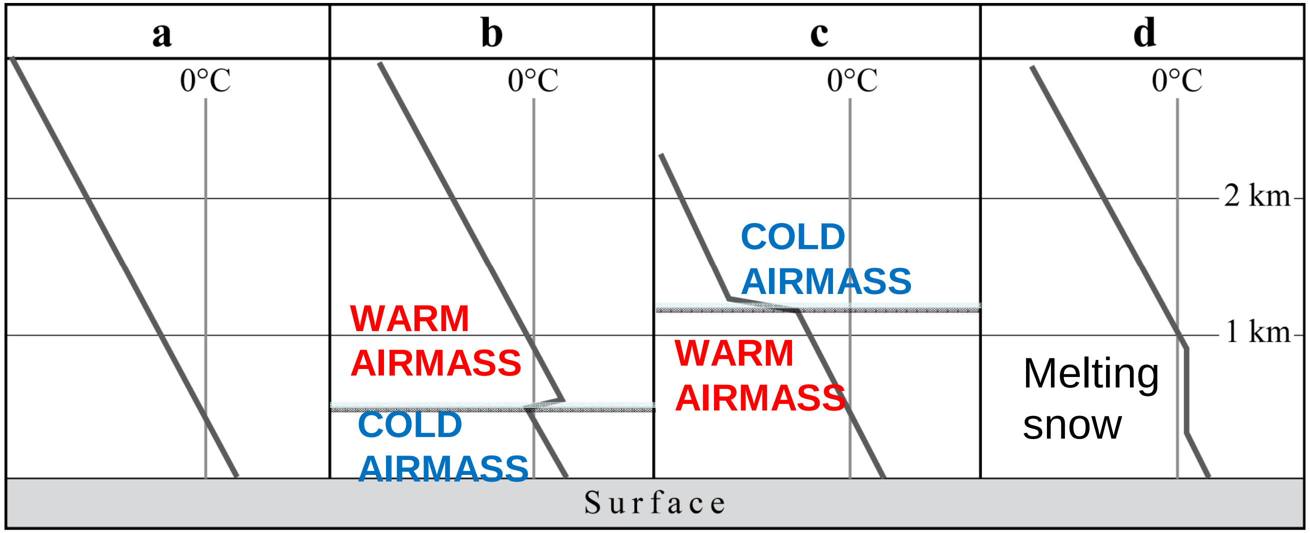
Large range in suggested relationships between snow fraction and surface air temperature



An Air Mass Boundary (AMB).....

- **Separates two air masses with different characteristics e.g. one warm and one cold**

Vertical air temp. profiles in the lower troposphere for different near freezing precipitation events



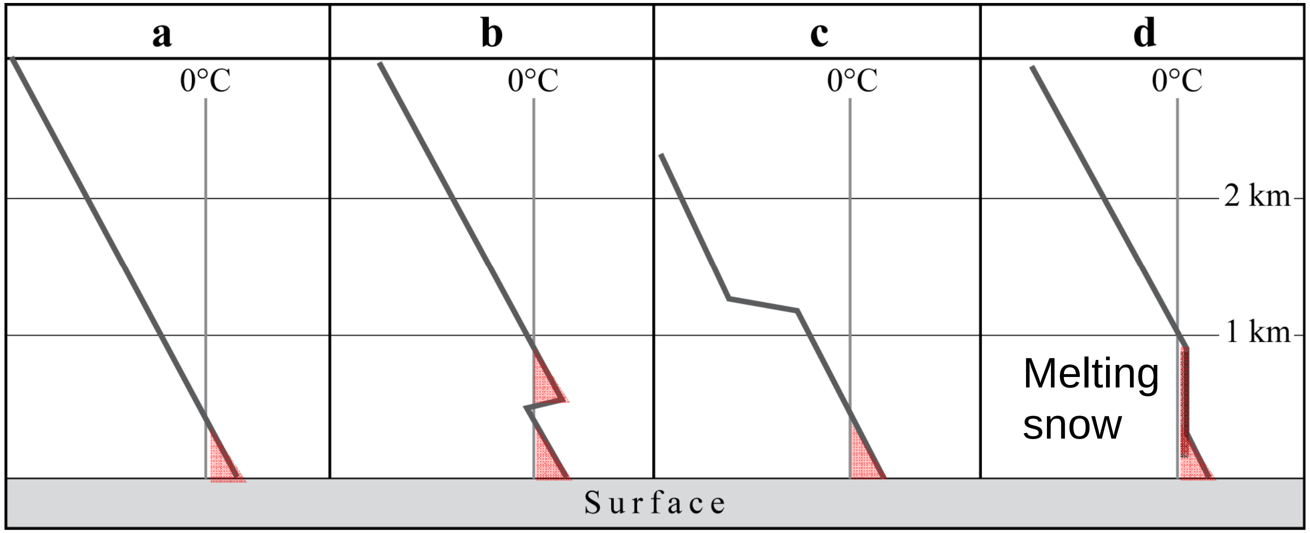
a) Steadily cooling air temp. with height, without AMB

b) AMB separating a cold (under) and a warm (above) air mass,

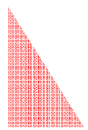
c) AMB separating a warm (below) and a cold (above) air mass,

d) Steadily cooling air temp. with height interrupted by an isothermal layer due to latent heat released when falling snow melts.

Vertical air temp. profiles in the lower troposphere for different near freezing precipitation events



AMB = air mass boundary



ABOVE FREEZING TEMPERATURE AIR PRECIPITATION MUST FALL THROUGH

a) Steadily cooling air temp. with height, without AMB

b) AMB separating a cold (under) and a warm (above) air mass,

c) AMB separating a warm (below) and a cold (above) air mass,

d) Steadily cooling air temp. with height interrupted by an isothermal layer due to latent heat released when falling snow melts.

Aim: To show that AMB identification can improve precipitation phase classification

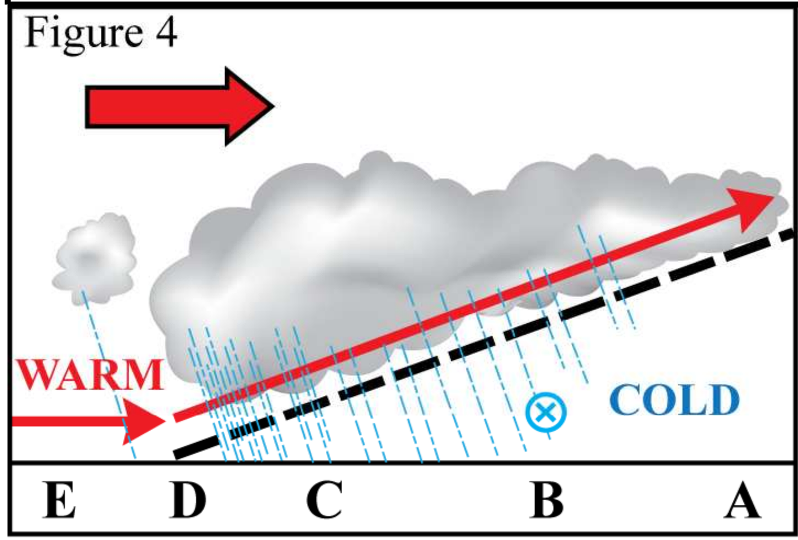
Objectives:

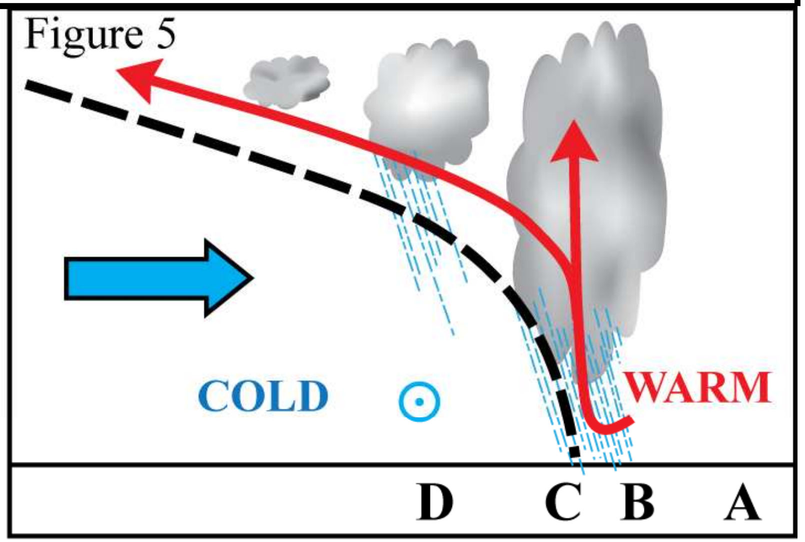
To use 20 years of manual precipitation observations from 8 weather stations in northern US

- **to separate different AMB using surface meteorological observations**
- **to identify AMB having different $T_{R/S}$, T_S, or T_R value/s**
- **to illustrate the improvement achieved by analyzing easily identifiable Cold-air-mass boundary (CAMB) events separated from non-CAMB events compared to when all events were analyzed together**
  - **the CAMB events were recognized by a rapid air temperature decrease**

Lower troposphere cross sections with stationary surface locations progressing in time from .....

... A to E in a warm AMB	... A to D in a cold AMB





Warm air advance

Cold air advance

Airmass boundary

Cold airsream blowing into the paper

Cold airstream blowing out of the paper

Warm air stream

COLD Cold airmass

WARM Warm airmass

Method

Surface AMB passage can be identified by...

- high wind speeds
- changes in wind direction
- changes in surface air temperature

Type of Front or Trough	Acronym	Change in Wind Direction	Wind Speed	Change in Temperature
Warm Front	**WF**	**Strong**	**-**	**Increase (weak)**
Ana-Cold Front	**ACF/CAMB**	**Strong**	**High**	**Decrease (strong)**
Kata-Cold Front (Upper)	-	-	Low	-
Kata-Cold Front (Lower)	**CAMB**	Strong	Low	**Decrease (weak)**
Occlusion Front	-	-	Low	-
Arctic/Barotropic Trough	**CAMB**	Weak	High	**Decrease (strong)**
Pre-Frontal Trough	**CAMB**	-	-	**Decrease (-)**

Bold font used for **identified** air mass types and the parameters used to identify them.

Location of used US Air Force Weather Stations

Note: **Temperatures reported in integers**

Precipitation classified as

snow for snow, groppel, and ice pellets,

freezing for freezing rain, & freezing drizzle,

rain for rain, and drizzle,

mixed for any combination of the above categories

AMB classification based on surface meteorological observations

Example : Identification of Cold air mass boundary (CAMB)

If the surface air temperature two hours before an observation (T_{t-2}) was at least 2°C warmer than during the observation (T_t) the event was classified as a CAMB

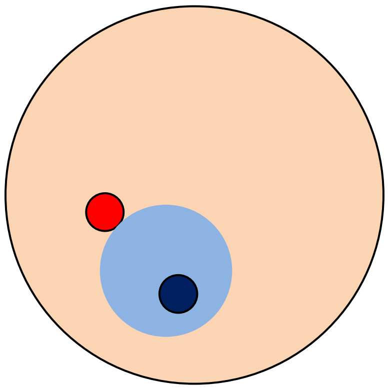
$$If\left[(T_{t-2} - T_t) \geq 2°C\right],$$

Similar (more complex) relationships were used to try to identify other AMB

Acronym	Change in Wind Direction	Wind Speed	Change in Temperature
WF	**Strong**	**-**	**Increase (weak)**
ACF/CAMB	**Strong**	**High**	**Decrease (strong)**
-	-	Low	-
CAMB	Strong	Low	**Decrease (weak)**
-	-	Low	-
CAMB	Weak	High	**Decrease (strong)**
CAMB	-	-	**Decrease (-)**

Results: Identified AMB

Percentage of all precipitation events



GROUP	% OBS	SYMBOL
AP	100%	
CAMB	12%	
ACF	1%	
WF	1%	

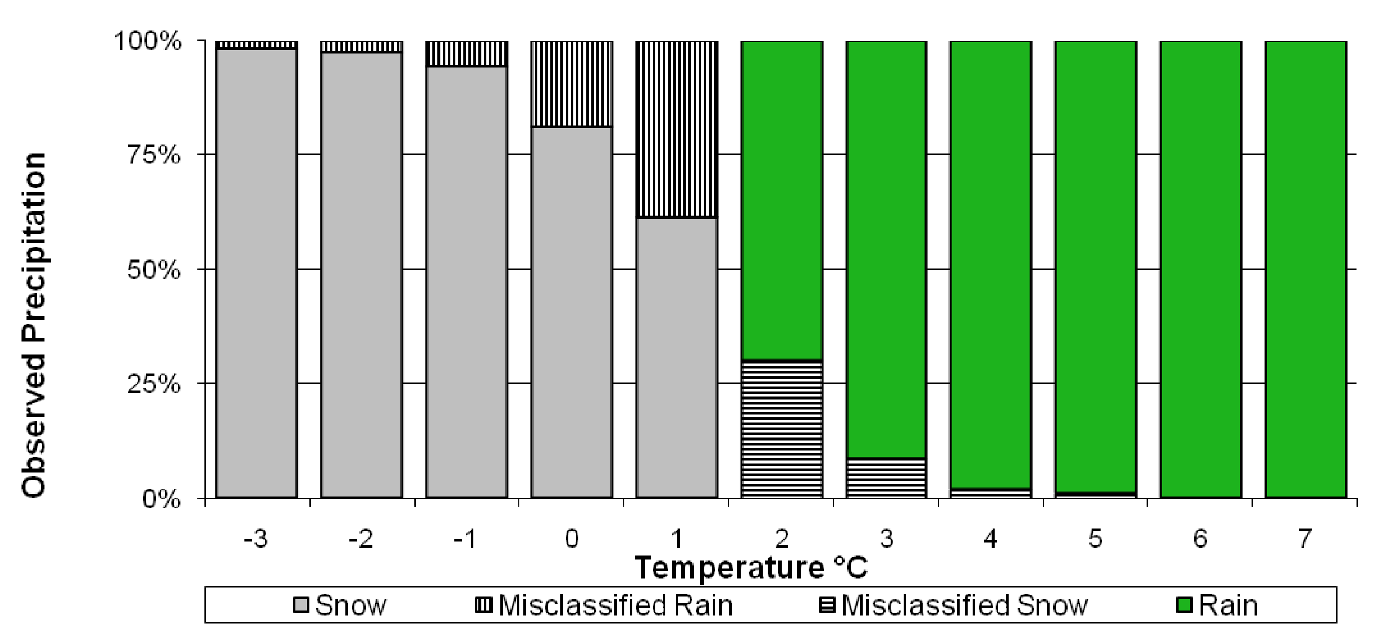
Comment: Less strict requirements on change rates would have produced larger percentages, e.g. for CAMB use of

- longer time periods
- smaller temperature changes

Air temperatures given in integers, so changes <1ºC in $T_{R/S}$, T_S and T_R could not be directly detected

Therefore, when changes in $T_{R/S}$ was analyzed, an indirect way was used to indicate if the $T_{R/S}$ was smaller or larger than the determined integer $T_{R/S}$- value by analyzing the amount of misclassified precipitation.

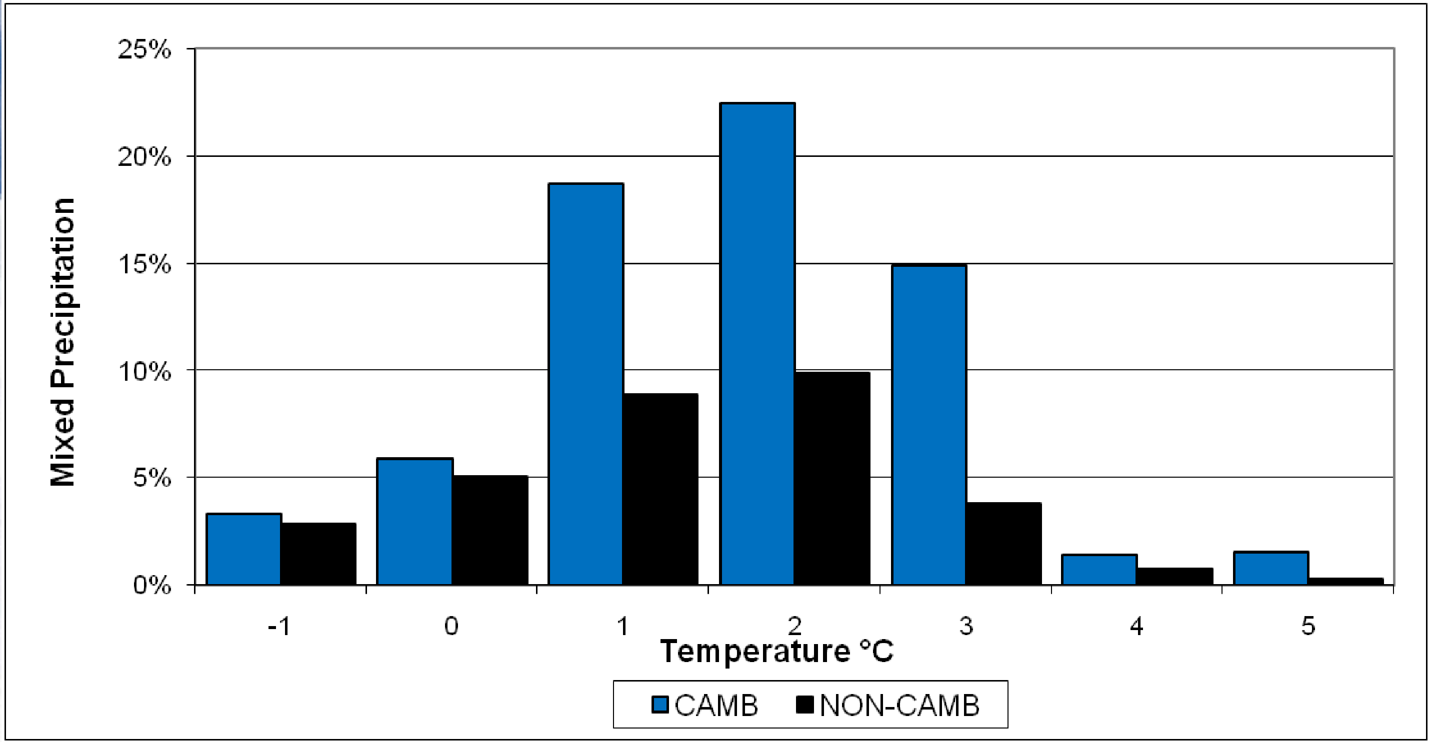
Correct and incorrect classified precipitation phase (%) for $T_{R/S}$ at 1°C.



Correct classified rain (■) Correct classified snow (□)

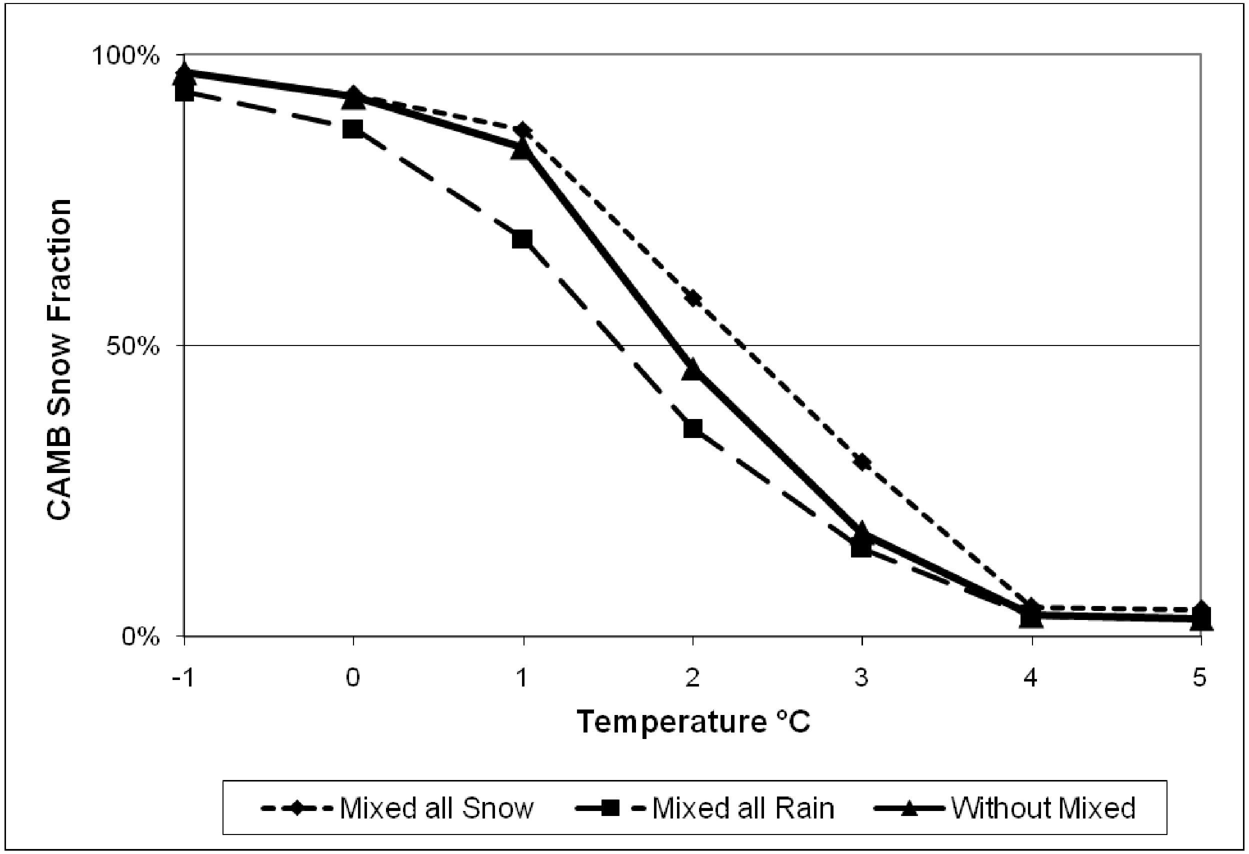
Misclassified rain (‖) Misclassified snow (═)

Observed mixed precipitation (%) for identified CAMB and non-CAMB.

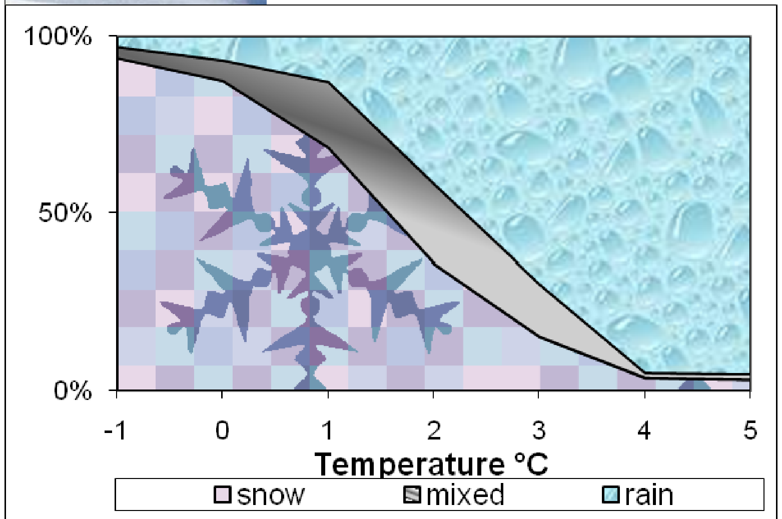


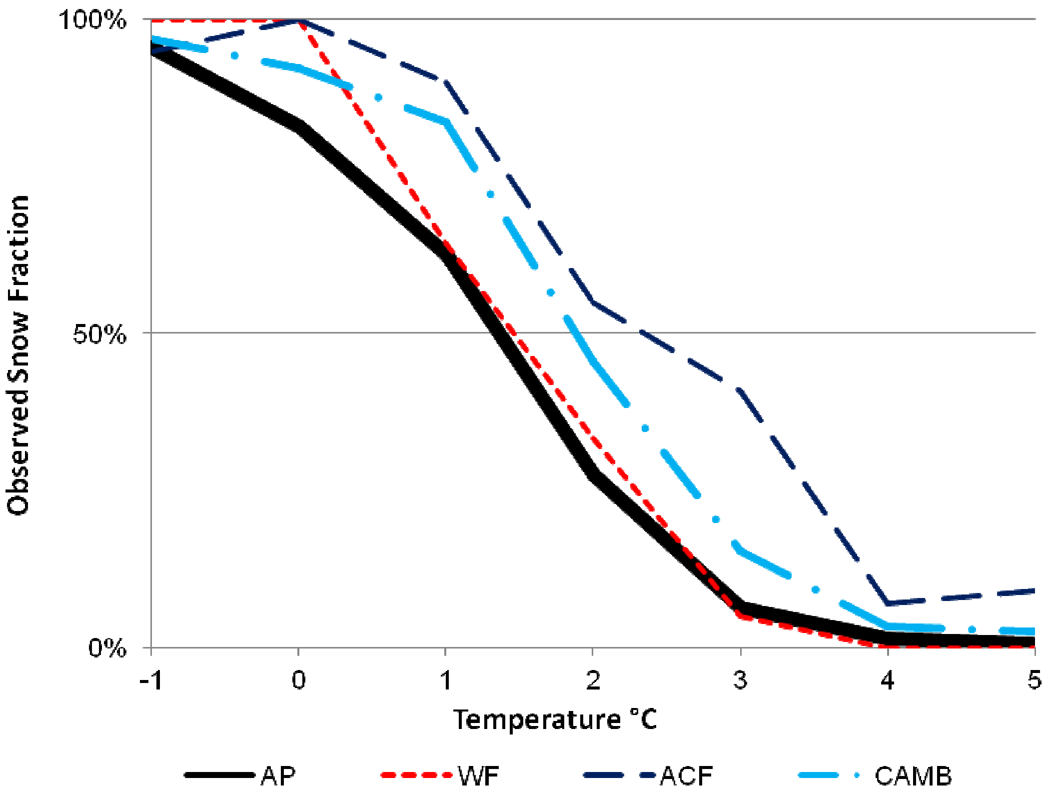
Applied Geology

Differences in rain vs snow plot depending on how mixed precipitation is treated



Large divergence in snow fraction SF between AMB





AP = all precipitation events
WF = warm fronts
ACF = Ana-cold fronts
CAMB = Cold air mass boundaries

Applied Geology

Results

- When a 2-hour requirement was used to separate CAMB and non-CAMB events the …
  - T_S and T_R values (0°C; 4°C) for CAMB events were 1°C warmer than for non-CAMB (-1°C; 3°C).
  - (but the changes in T_{RS}-values were < 1°C)
- When CAMB and non-CAMB were analyzed separately, the number of misclassified precipitation events was reduced by 23%.

Discussion

- With air temperatures given in 0.1ºC differences in $T_{R/S}$ would probably have been possible to identify.
- Since CAMB often produces more precipitation than other types of precipitation events, it is likely that the improvement in misclassified precipitation would have been even larger if the study hade been made on precipitation mass instead of on number of events.
- Other AMB might be identifiable at a finer temperature scale and it would be interesting to check if other temperature changes (2ºC) and time steps (t two h) would have produced larger or smaller improvements.
-

Applied Geology

Complications with a 24 hour time step...

- Daily surface temperature variations due to diurnal variations in cloudiness
  - If clouds move in just after sunset after a warm day, heat is trapped in the atmosphere overnight (may be mistaken for a warm front)
  - If clouds move in after cold night, chill is trapped in the atmosphere (may be mistaken as a cold front).
- So it will be more complex to avoid misinterpretation at the 24 hr scale.

Difficulties with trying to develop a 24 hour time step

Need to overcome cooling and warming due to varying cloud and fog conditions that are not associated with fronts (these should not produce much precip).

However, 24 hr Temperature changes due to the time of day clouds move over a location will effect this kind of analysis. If clouds move in just after sunset, then more heat is trapped in the atmosphere overnight (this may be mistaken for a warm front), and vice versa with daytime temperatures being lower if clouds move in after a full night of cooling (may be mistaken as a cold front). So it will be more complex to avoid misinterpretation at the 24 hr scale, not impossible, but it may be impracticle

Conclusions

- A promising method to reduce the amount of misclassified precipitation in hydrological models by separating observations into AMB categories is presented.
- All information used for this analysis is already available, no new information has to be gathered
- This separation can be done using easily identifiable surface AMB characteristics such as surface air temperature, wind speed and wind direction.
- CAMB observations were identified by $If\left[(T_{t-2} - T_t) \geq 2°C\right]$, and were found to be 12% of all precipitation.
- Analyzing CAMB separately from non-CAMB obs. reduced the misclassified precipitation observations from 7% to 5.4% (23%)