Outline

A. Melting Snow

• Melting aloft and the isothermal layer
• Examples
• Melting at the surface: the LSM
• How do numerical forecast models handle it?

B. Freezing Rain and Sleet

• Freezing aloft (sleet)
• Freezing rain thermodynamics
• Examples
• Model representations, biases, and limitations
Case 1: Melting Snow Aloft

- Near-freezing isothermal layer develops
- Cooling due to melting
- Freezing rain to snow
- Rain to snow
A 100-mb deep above-freezing layer, subjected to 1.25 cm of liquid-equivalent snow melt, would experience:

\[ \Delta T_{\text{melting}} \approx -2.4^\circ C \]

An above-freezing layer that is 150 mb deep with an average temperature of +1.8°C, would require 1.39 cm of liquid-equivalent precipitation (melting snow) to eradicate.

Of course, other processes can dominate!

An important paper on this topic: Kain, Goss, and Baldwin, 2000: *WAF* 15, 700-714.
Some Examples: Cotswolds, UK 1 Nov 1942

13 UTC 1 November 1942

Wet-bulb freezing level 820 mb, 1,500 AGL!

Lumb (1960) identified melting as important cooling process

Cited Findeisen (1940)
Why Did It Snow at Boston in April?

James McGuire and Samuel Penn, U. S. Weather Bureau, Boston
25 cm (9.8”) snow at SEA, with 65 mm (2.56”) liquid equivalent
0 snow at BLI, with only 11 mm (0.44”) liquid, none at OLM either
A formative event in my childhood, even though we didn’t miss school!
Warm Snowstorms
A Forecaster’s Dilemma

by Stanley David Gedzelman and Elaine Lewis

The heavy snowfall that surprised residents of eastern New York state and western New England on October 3–4, 1987, focused our attention on the fascinating phenomenon of “warm snowstorms.”

These strange storms often produce large, crippling snowfalls—despite the fact that temperatures on

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Bosart and Sanders (1993) determined that melting played an important role in cooling the atmosphere...
Which NCEP Models Account for Cooling Due to Melting?

Eta does include (but accuracy tied to QPF)

Nested Grid Model (NGM) is completely devoid of ice physics

Explains why NGM RH often greater than Eta at sub-freezing temps - NGM doesn't “know” about saturation with respect to ice!

Aviation/Medium-Range Forecast (AVN/MRF) models added ice physics on 15 May 2001
Example: 24 January 2000

- Model forecast soundings (6h) valid 1800 UTC 24 January 2000:
  - Eta develops isothermal layer, NGM does not
  - NGM has significantly warmer lower-tropospheric sounding
  - (NGM shows RH = 100% well above freezing level)
Hypothetical Example

Scenario: Eta-derived partial thickness values, forecast soundings foretell a borderline rain/snow situation

As event unfolds, radar & surface obs indicate precipitation much heavier than model QPF

Based on this information, what is expected forecast bias in lower-tropospheric temperature (or 1000-850 thickness)?

Warm

What evidence might radar imagery provide to monitor possible changeover to snow?

Constricting bright band (melting layer lowering)
Case 2: Melting Snow at the Surface

Falling snow penetrates 200-400 m below freezing level, melts at surface.
Case 2: Representation of Melting at the Surface

Eta land surface model (LSM) uses lowest AIR temperature to determine precipitation type. If < 0°C, snow assumed, if > 0°C, rain.

LSM assumption can be inconsistent with Eta grid scale precipitation scheme

Consider situation with $T_{\text{ground}} = 2^\circ\text{C}$, $T_{\text{2-meters}} = 2^\circ\text{C}$, heavy, wet snow falling

Will Eta land surface model account for latent heat absorption due to melting snow at ground?

NO… model assumes rain is falling because lowest air temperature above freezing: WARM BIAS
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Accumulated snowfall, 11/19/00
2-m Eta Temperature Forecast

Operational 30-h Eta 2-m temperature (dashed) and precipitation (solid) forecast, valid 18 UTC 19 Nov. 2000

Corrected 30-h temperature forecast, using 1st law to quantify sfc. cooling due to melting snow; shading < 1°C
Case 3: Freezing Aloft (Sleet)

- Snow
- Rain
- Freezing rain

Cooling due to melting
Warming due to freezing

Sleet to freezing rain

0°C
Freezing of Rain Aloft (Sleet Situation)

As of TODAY, NONE of the NCEP operational models account for the freezing of rain drops *aloft* (although RUC may).

Zhao and Carr, 1997: Freezing neglected because grid-scale vertical motion too weak to advect falling rain above freezing level…. Irrelevant for rain *falling below* freezing level

Result: COLD bias in layer where freezing occurs

Biases may be “significant” (i.e., sufficient to alter precipitation type forecast based on model output)

**HOWEVER**: Eta precipitation scheme scheduled for upgrade on 27 November 2001; new scheme DOES account for freezing!!!!!
(B. Ferrier and B. Bua, personal communication, 1 Nov. 2001)
Case 4: Freezing at the Surface (FZRA)

Rain freezes at surface, latent heat release warms surface, lower atmosphere.

Freezing rain

0°C
January 30 2000

RDU maximum: 0°C (32 °F),
RDU precipitation: 28 mm (1.09”)
Only 3 mm (1/8”) ice in Wake Co.
Why not more???
Freezing Rain (cont.)

• Limiting Processes for Freezing Rain:
  1.) Downward IR from warm clouds (only if PBL clear)
  2.) Warm rain drops (sensible heat transfer)
  3.) Warm-air advection
  4.) Freezing!!! (Latent heat release can raise T to 0°C / 32°F)

Freezing rain is a self-limiting process (Stewart, 1985)

• Major [e.g, 12-25 mm (0.5” - 1”)] icing generally requires:
  • influx of colder or drier air, or
  • extremely cold and/or dry initial low-level air, or
  • another local cooling mechanism (e.g., upslope flow)
Freezing Rain: Heat Release at Surface

Eta LSM uses lowest AIR temp to determine precip type. If $< 0^\circ$C, snow assumed, if $> 0^\circ$C, rain.

Consider situation where $T_{\text{ground}} = -3^\circ$C, $T_{2\text{-meters}} = -2^\circ$C, and heavy, freezing rain is falling.

Will Eta land surface model know to release latent heat due to freezing of rain on ground?

NO, latent heat release unaccounted for because snow assumed: COLD BIAS
12 February 2001

Operational 30-h Eta 2-m temperature (dashed & shaded) and precip forecast, valid 18 UTC 12 Feb. 2001

Corrected temperature forecast, using 1st law to quantify sfc. warming due to freezing rain
Summary

For the case of heavy melting snow aloft:
   \textbf{Eta can represent, NGM cannot}
   Accurate representation tied to QPF

For the case of heavy melting snow at surface:
   \textbf{Usually warm bias (for all NCEP models)}

For the case of freezing rain or sleet:
   \textbf{Model cold bias in layer where freezing occurs}
Implications for the ModernForecaster:

1.) Forecasters have a comprehensive understanding of atmospheric processes

2.) To use NWP most effectively, forecasters must understand HOW MODELS represent these processes!

3.) This is a major challenge because
   - There are so many operational models now
     (RUC, NGM, AVN, MRF, NOGAPS, Eta, MM5, WRF, GEM, ECMWF, UKMET...)
   - Physics packages are frequently modified or upgraded in the models

4.) Forecasters must strive to anticipate model biases and use knowledge of model limitations to “stay a step ahead” of models
Acknowledgements

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Wyat Appel, Mike Brennan, Heather Reeves, Al Riordan, Mike Trexler, Scott Kennedy, and others at NCSU
Sources...


• Findeisen, W., 1940: The formation of the 0°C isothermal layer and fractocumulus under nimbostratus. *Meteor. Z.*, **57**, 49–54.


Sources... (cont.)


• ——, and co-authors, 1996: Changes to the operational “early” Eta analysis/forecast system at the National Centers for Environmental Prediction. *Wea. Forecasting*, 11, 391–413.


Past and upcoming model changes:
http://www.ncep.noaa.gov/NCO/PMB

Eta model change log:
http://www.emc.ncep.noaa.gov/mmb/research/eta.log.html

METED operational model matrix: [See also the meted NWP Section!]
http://meted.ucar.edu/nwp/pcu2/index.htm