Freezing and Melting, Precipitation Type, and Numerical Weather Prediction

Quebec, January 1998

Sandy Lackmann, age 2.

Cary, NC, 25 January 2000

NWS/NCSU CSTAR Presentation, 2 November 2001

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Outline

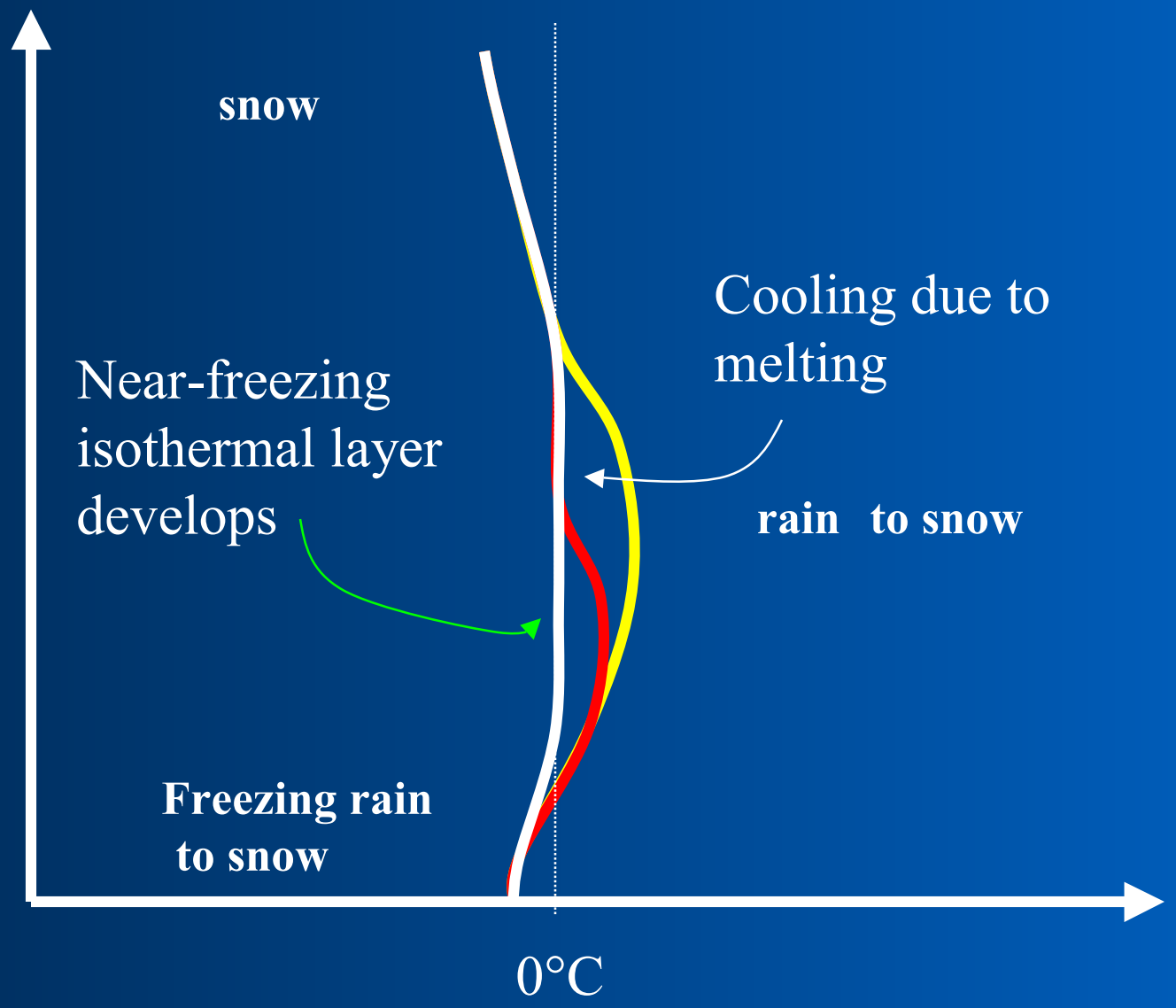
A. Melting Snow

- 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



Melting Snow Aloft: Is It Important?

A 100-mb deep above-freezing layer, subjected to 1.25 cm of liquid-equivalent snow melt, would experience:

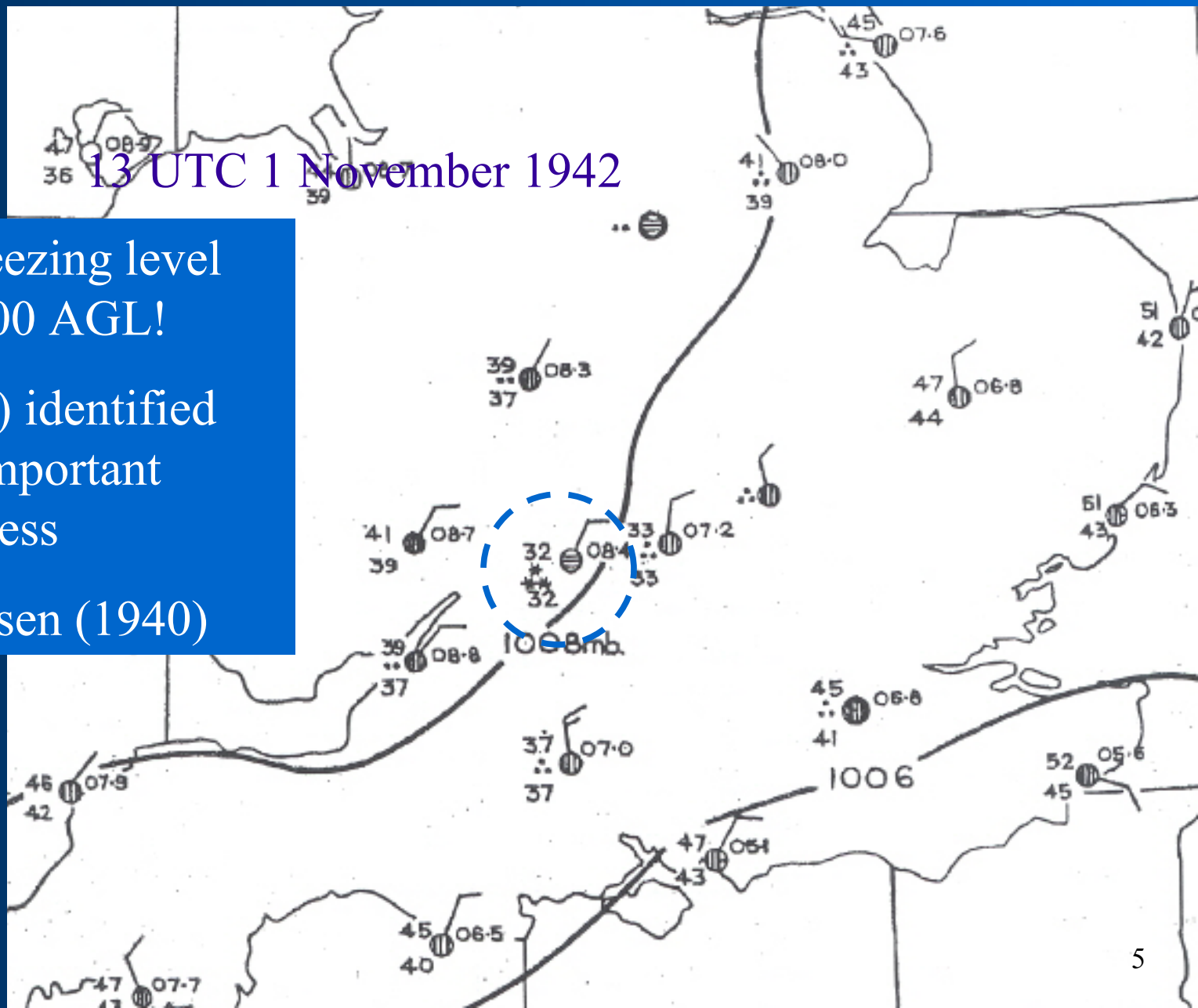
$$\Delta T_{melting} \approx -2.4°C$$

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 erradicate

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

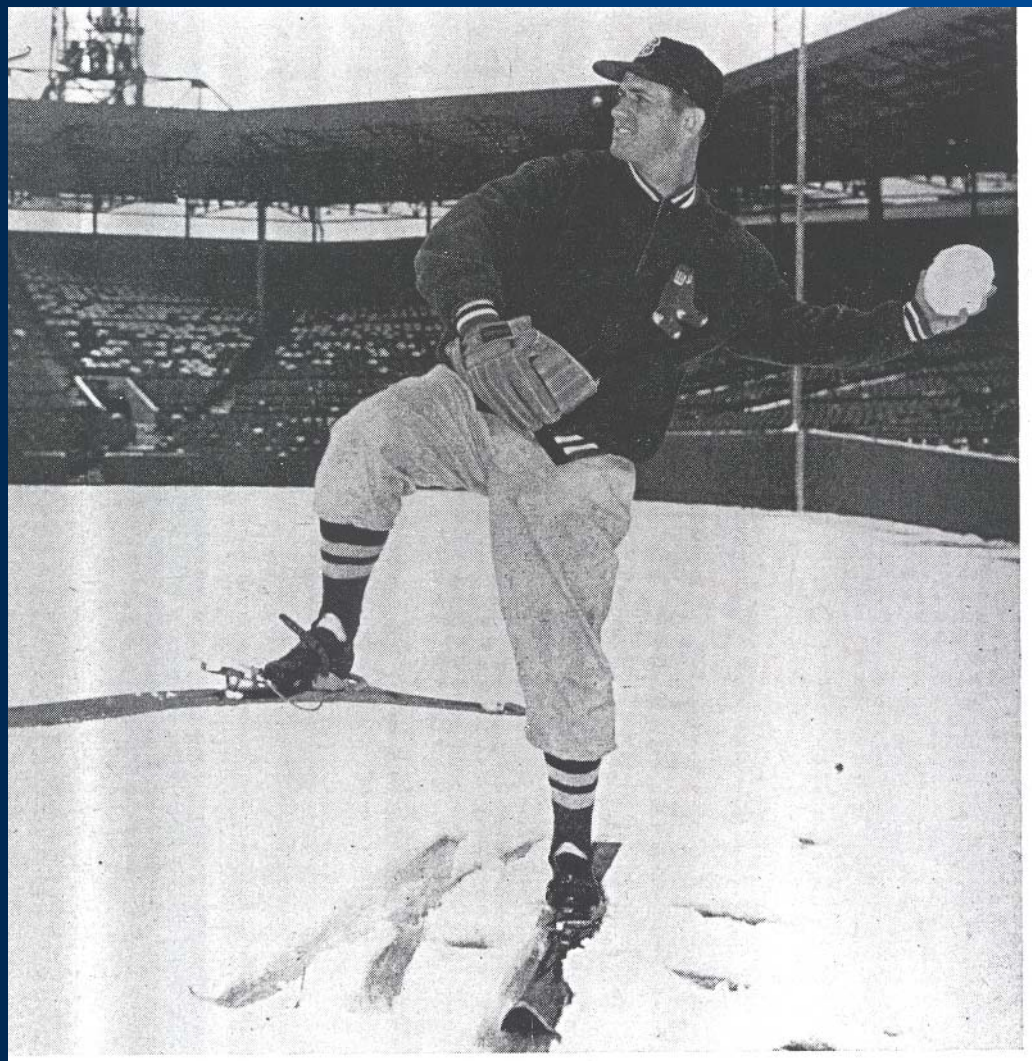


Wet-bulb freezing level 820 mb, 1,500 AGL!

Lumb (1960) identified melting as important cooling process

Cited Findeisen (1940)

Boston, MA April 1953



Mel Parnell of the Red Sox pitches snowballs instead of baseballs on the scheduled opening day at Boston.

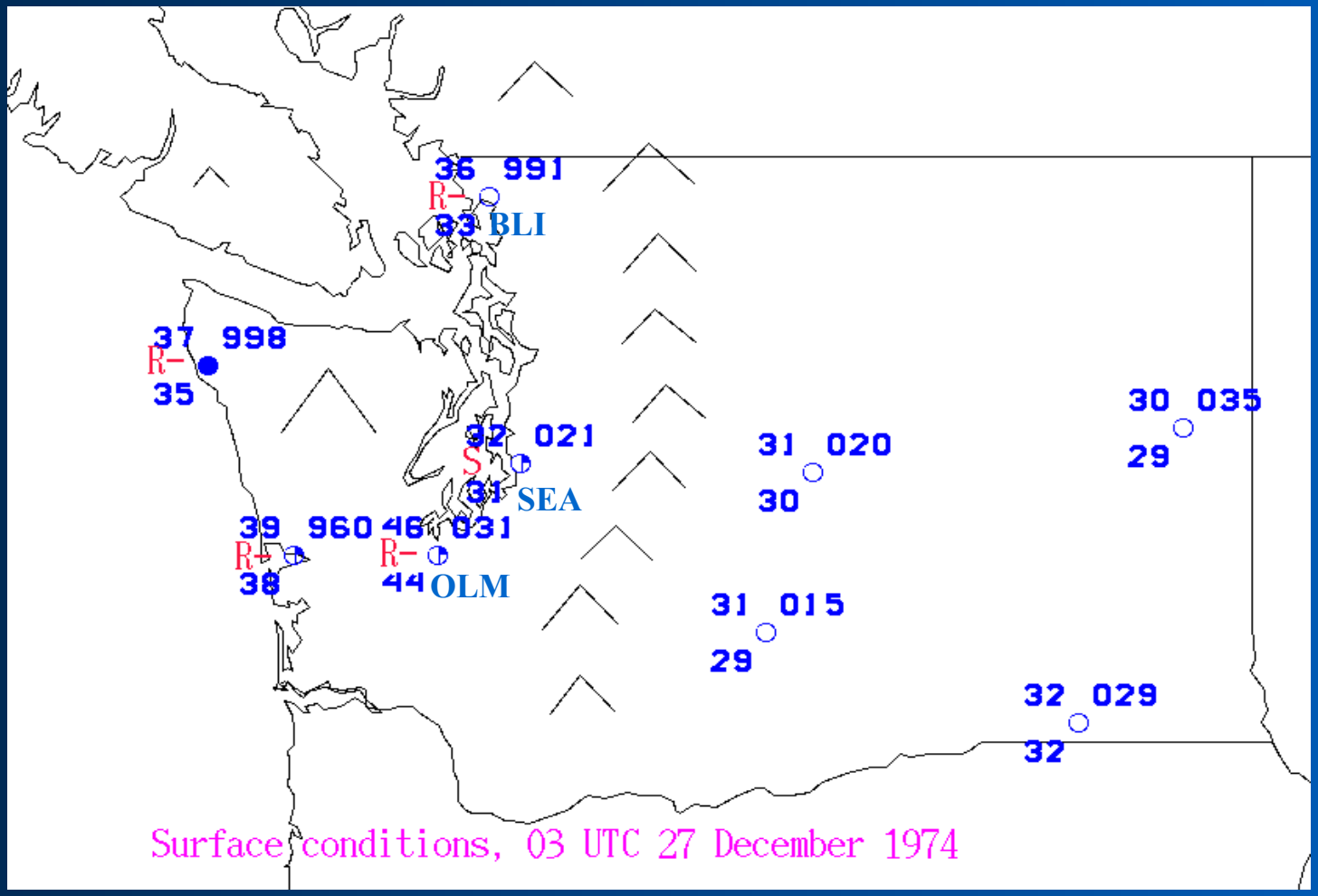
Why Did It Snow at Boston in April?

JAMES MCGUIRE AND SAMUEL PENN, *U. S. Weather Bureau, Boston*

Wexler et al. (1954): melting snow was critical

Cited Findeisen (1940)

Seattle, WA 26-27 December 1974



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!

Albany, NY 4 October 1987

Warm Snowstorms

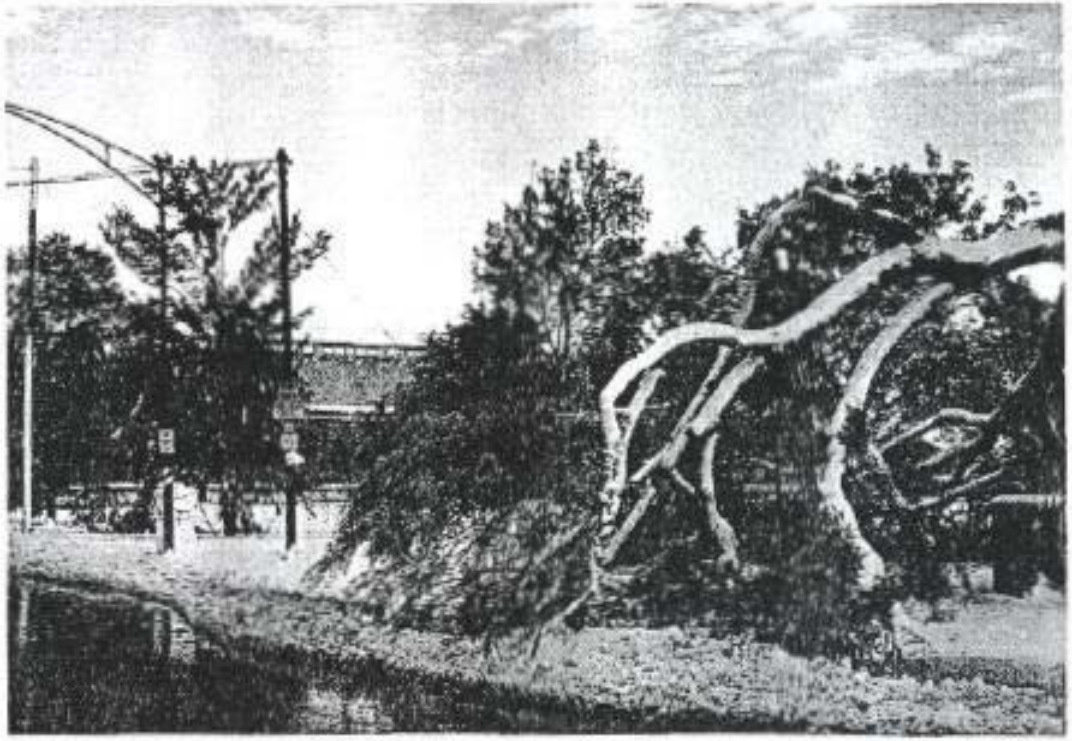
A Forecaster's Dilemma

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."

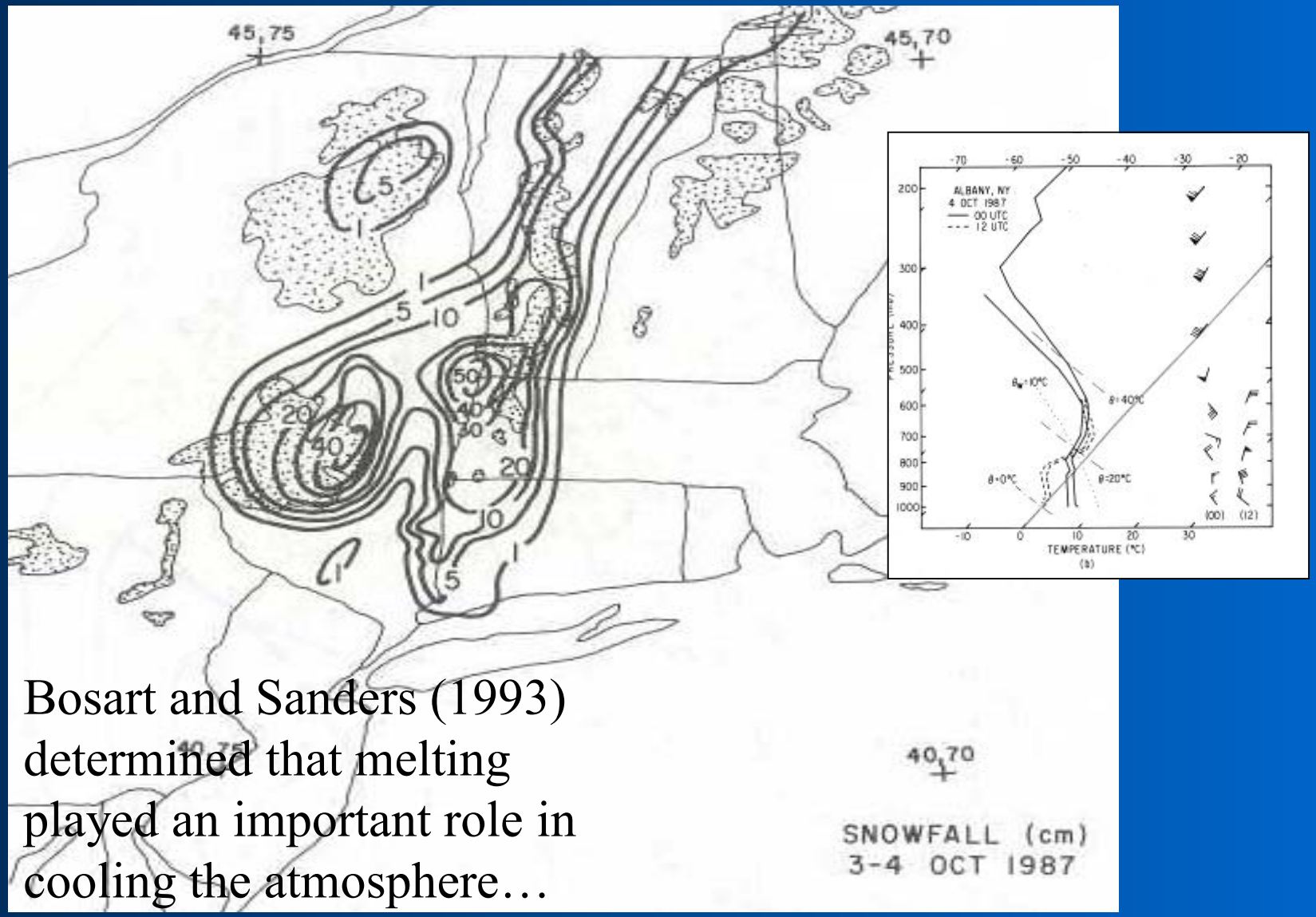
These strange storms often produce large, crippling snowfalls—despite the fact that temperatures on

STANLEY DAVID GEDZELMAN is a professor of meteorology at the City College of New York and a frequent contributor to *Weatherwise*. ELAINE LEWIS is the weathercaster for WTZA-TV in Kingston, New York.



DOWNED TREES AND POWER LINES in Albany, New York, on the afternoon of October 4, 1987.

Albany, NY 4 October 1987



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)

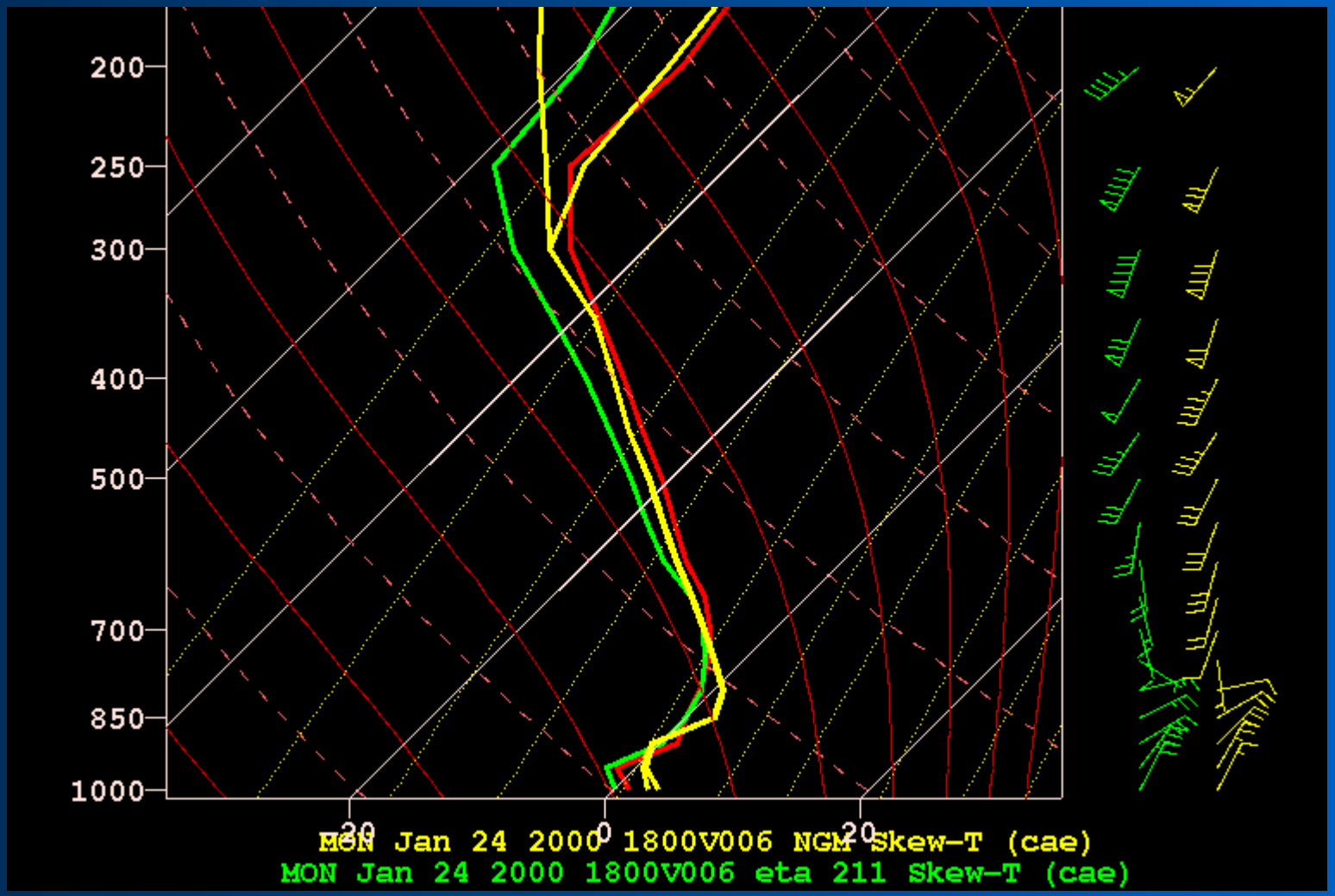
Nested Grid Model (NGM) is completely devoid of ice physics

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

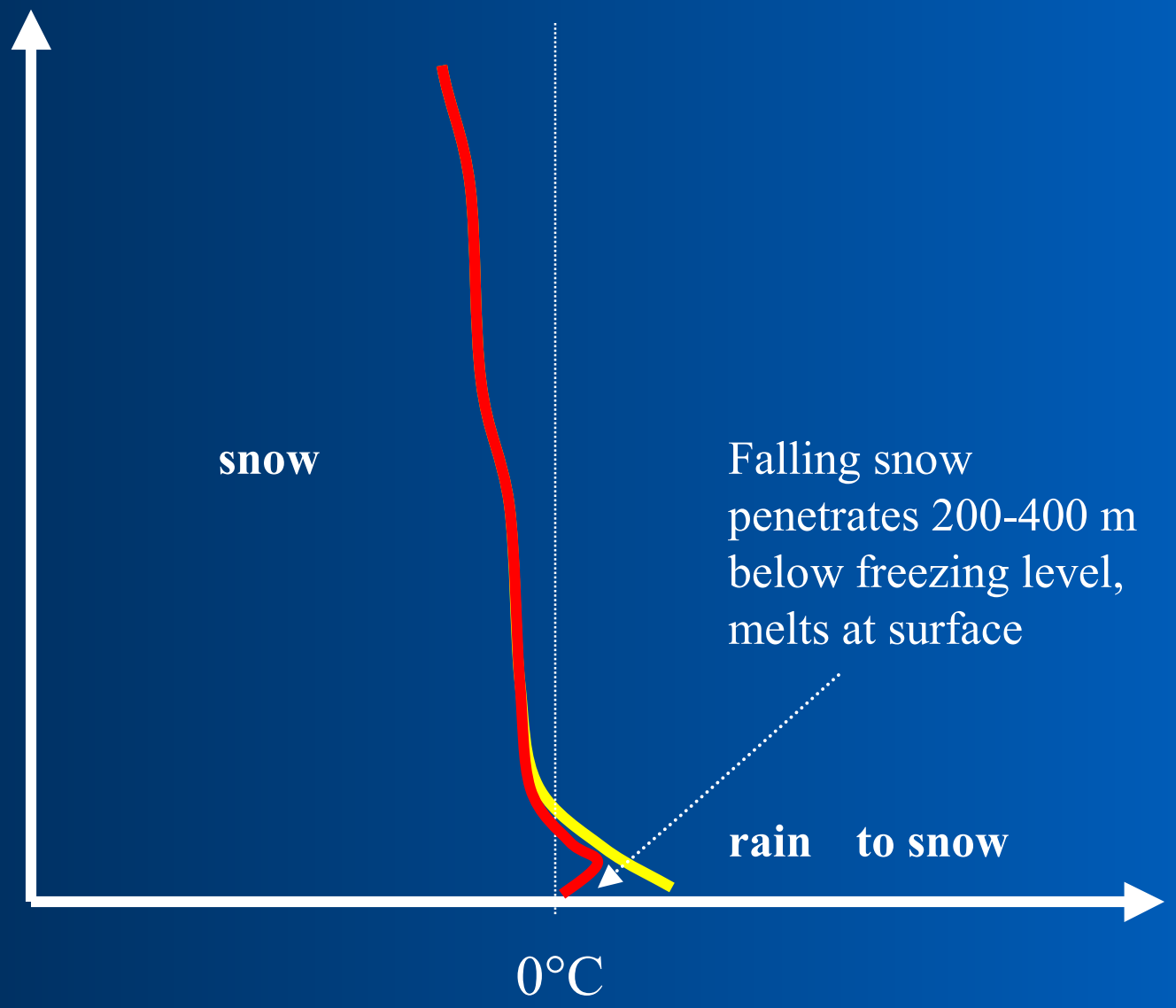
Based on this information, what is expected forecast bias in lower-tropospheric temperature (or 1000-850 thickness)?

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



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.

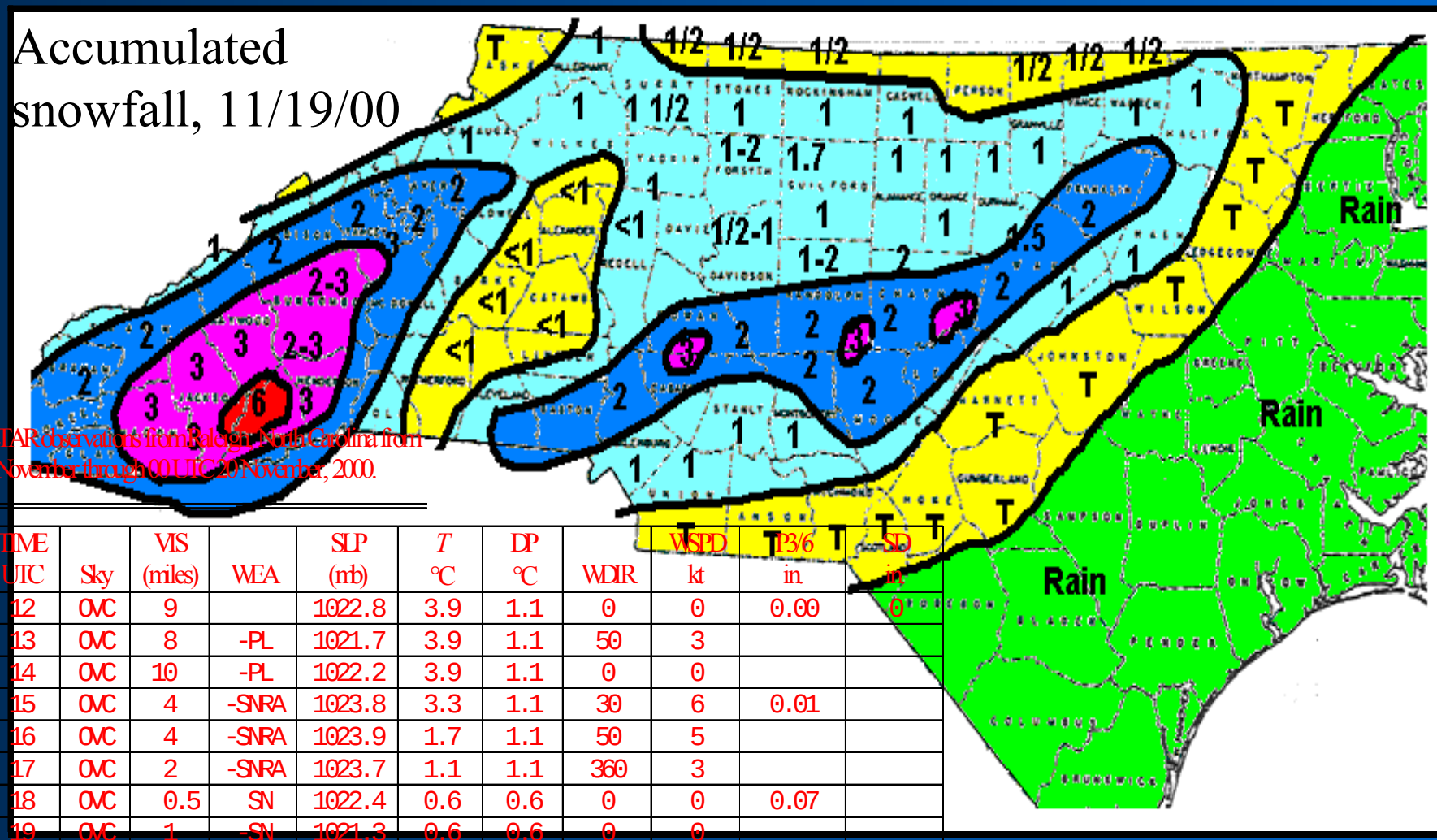
LSM assumption can be inconsistent with Eta grid scale precipitation scheme

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

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

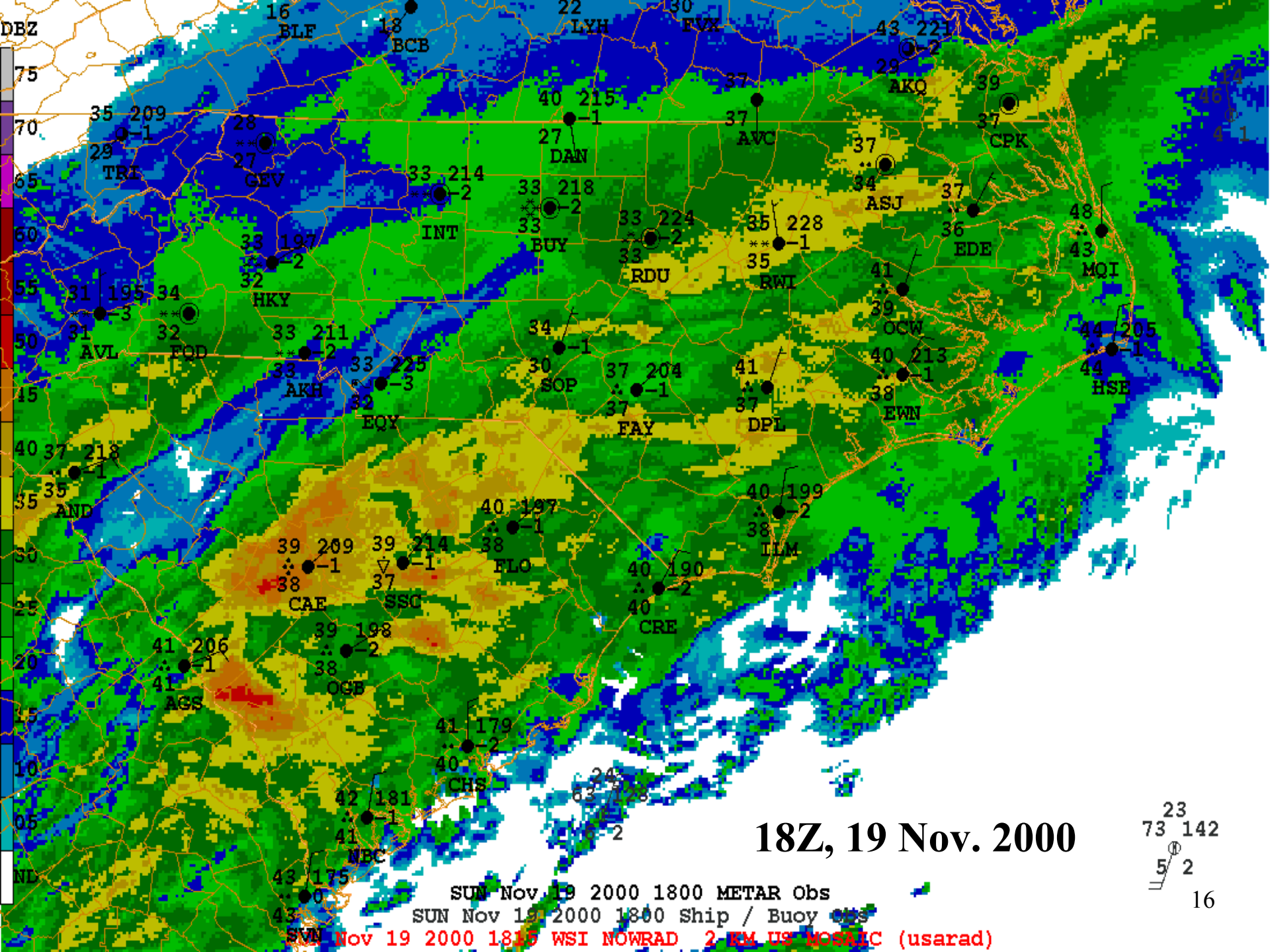
NO… model assumes rain is falling because lowest air temperature above freezing: WARM BIAS

Central NC, 19 November 2000

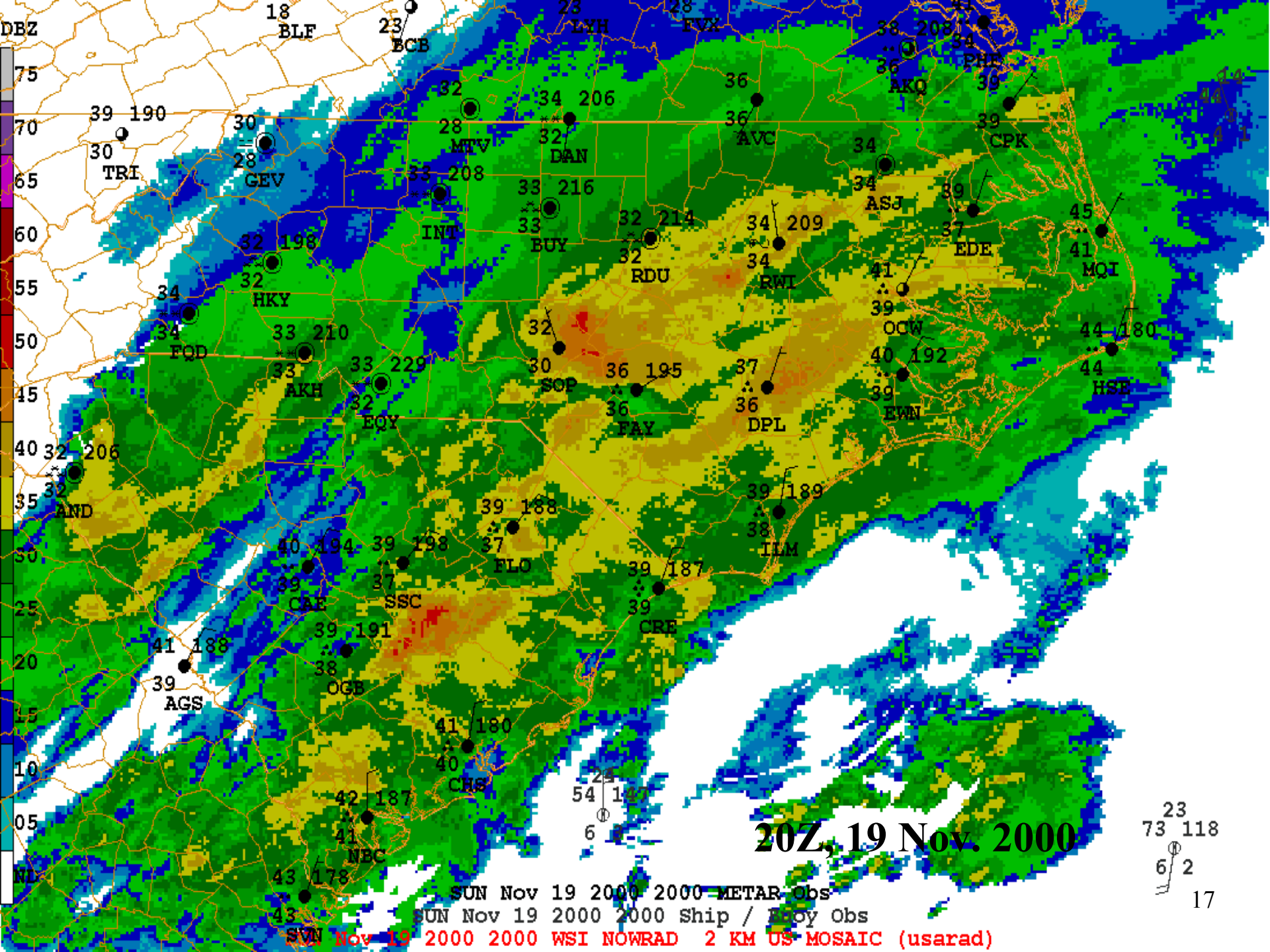


Hourly METAR observations from Raleigh, North Carolina from 12 UTC 19 November through 00 UTC 20 November, 2000.

	TIME UTC	Sky	VIS (miles)	WEA	SLP (mb)	*T* °C	DP °C	WDIR	WSPD kt	P3/6 in.	SD in.
KRDU	12	OVC	9		1022.8	3.9	1.1	0	0	0.00	0
KRDU	13	OVC	8	-PL	1021.7	3.9	1.1	50	3		
KRDU	14	OVC	10	-PL	1022.2	3.9	1.1	0	0		
KRDU	15	OVC	4	-SNRA	1023.8	3.3	1.1	30	6	0.01	
KRDU	16	OVC	4	-SNRA	1023.9	1.7	1.1	50	5		
KRDU	17	OVC	2	-SNRA	1023.7	1.1	1.1	360	3		
KRDU	18	OVC	0.5	SN	1022.4	0.6	0.6	0	0	0.07	
KRDU	19	OVC	1	-SN	1021.3	0.6	0.6	0	0		
KRDU	20	OVC	0.5	SN	1021.4	0.0	0.0	0	0		
KRDU	21	OVC	0.75	-SN	1021.2	0.0	0.0	0	0	0.23	
KRDU	22	OVC	0.75	-SN	1020.5	0.0	0.0	0	0		
KRDU	23	OVC	1.5	-SN	1020.6	0.0	0.0	0	0		
KRDU	00	OVC	5	BR	1020.2	0.0	0.0	0	0	0.50	2



18Z, 19 Nov. 2000


DBZ
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DAN
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CPK
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ASJ
EDE
HKY
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EQY
SOP
FAY
DPL
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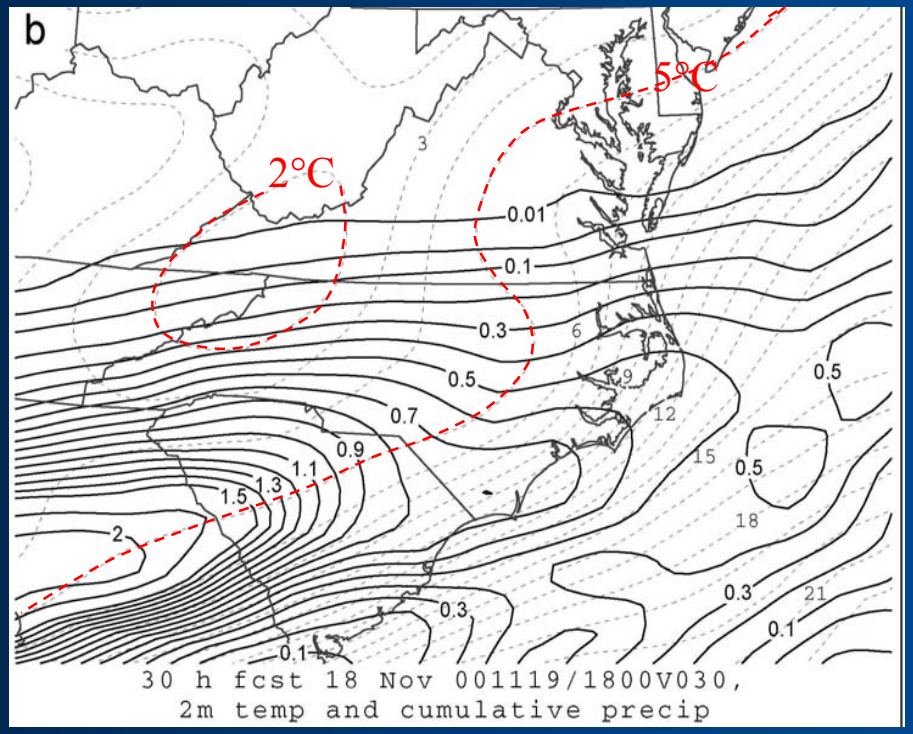
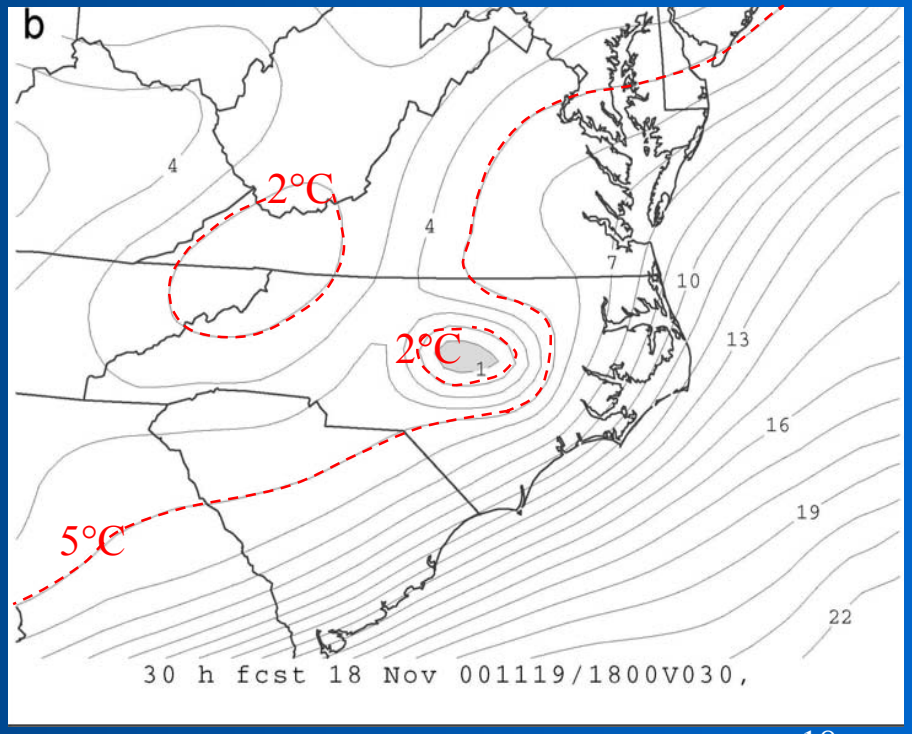
SUN Nov 19 2000 2000 Ship / Buoy Obs
Nov 19 2000 2000 WSI NOWRAD 2 KM US MOSAIC (usarad)
20Z, 19 Nov. 2000

2-m Eta Temperature Forecast

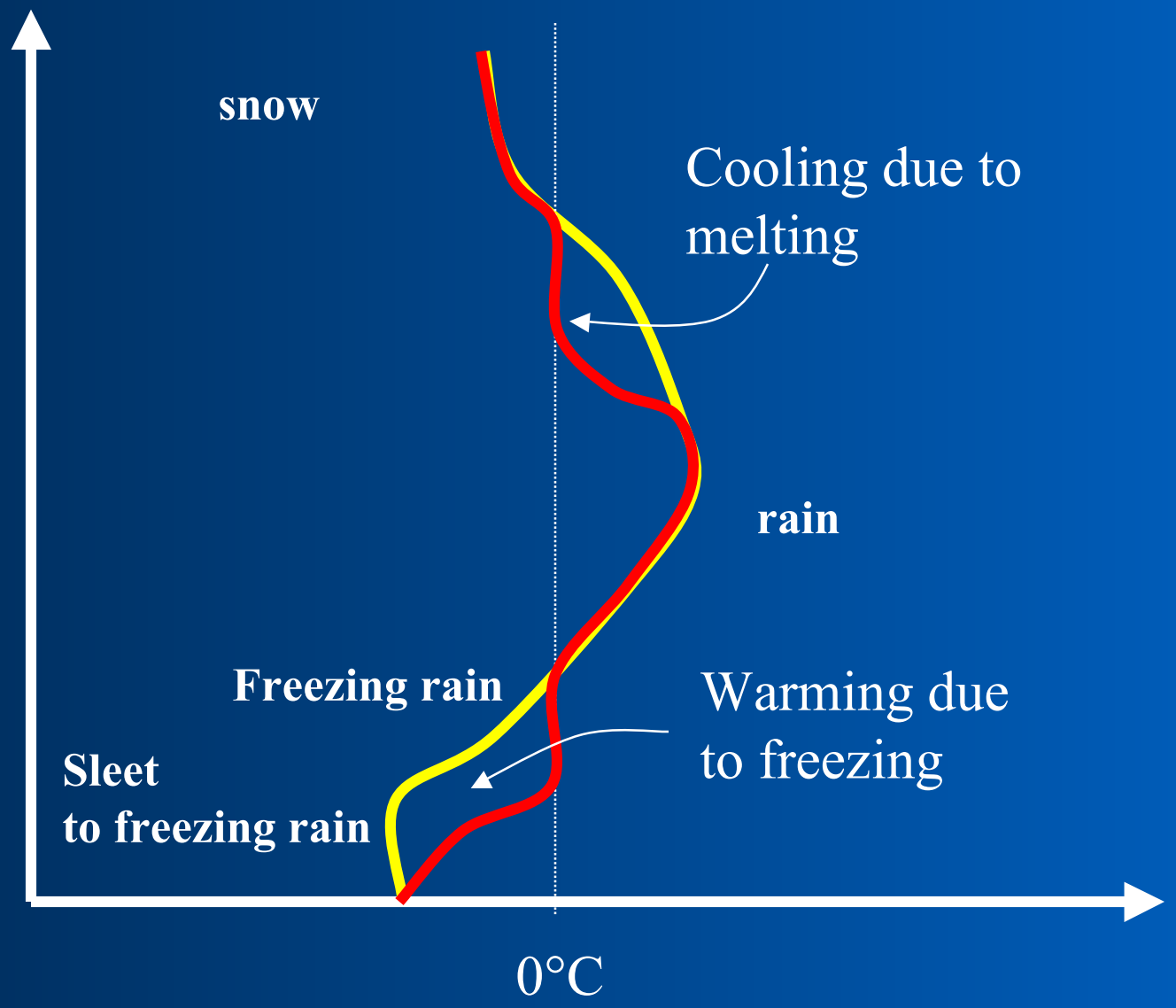
Operational 30-h Eta 2-m temperature (dashed) and precipitation (solid) forecast, valid 18 UTC 19 Nov. 2000



Corrected 30-h temperature forecast, using 1st law to quantify sfc. cooling due to melting snow; shading < 1°C



Case 3: Freezing Aloft (Sleet)



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).

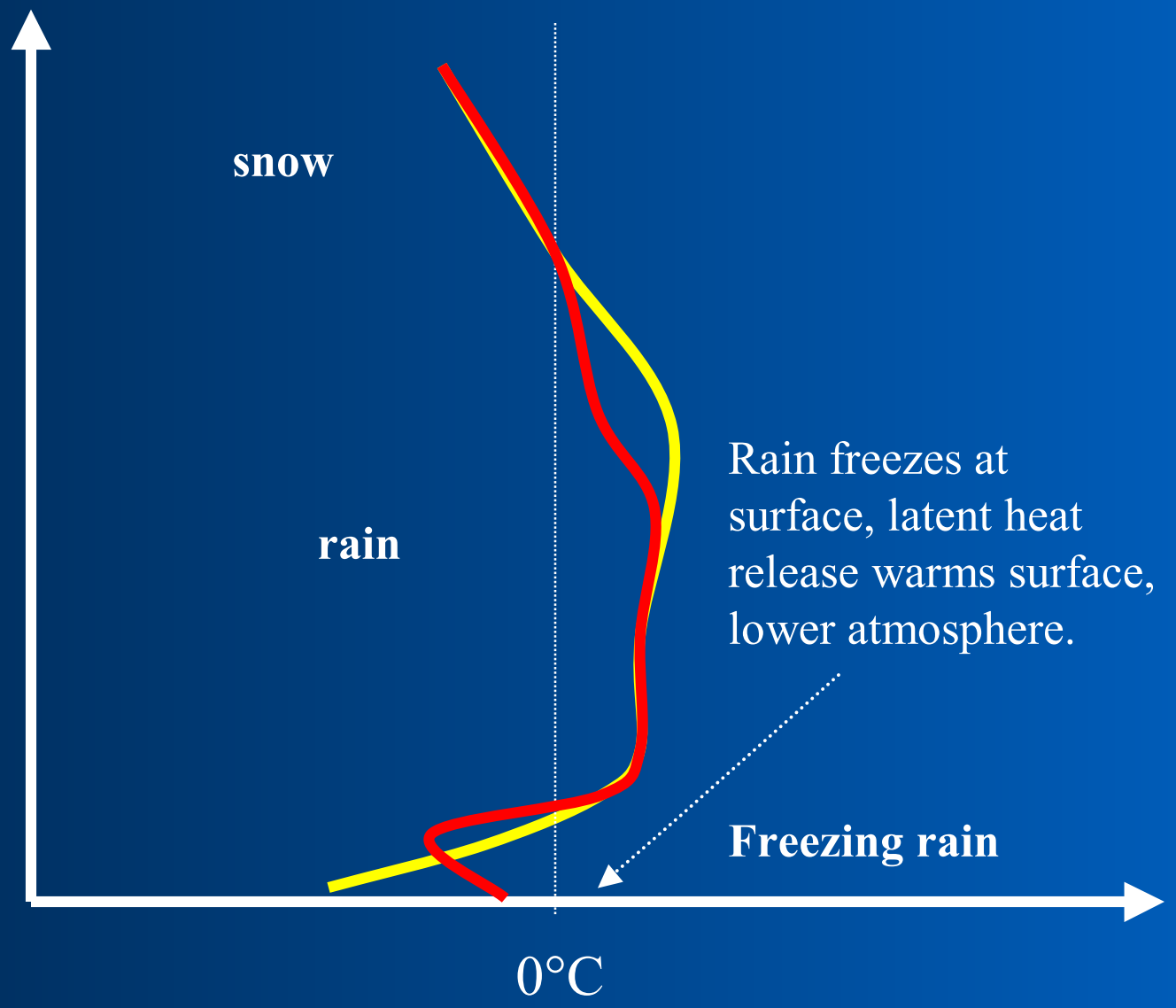
Zhao and Carr, 1997: Freezing neglected because grid-scale vertical motion too weak to advect falling rain above freezing level…. Irrelevant for rain *falling below* freezing level

Result: COLD bias in layer where freezing occurs

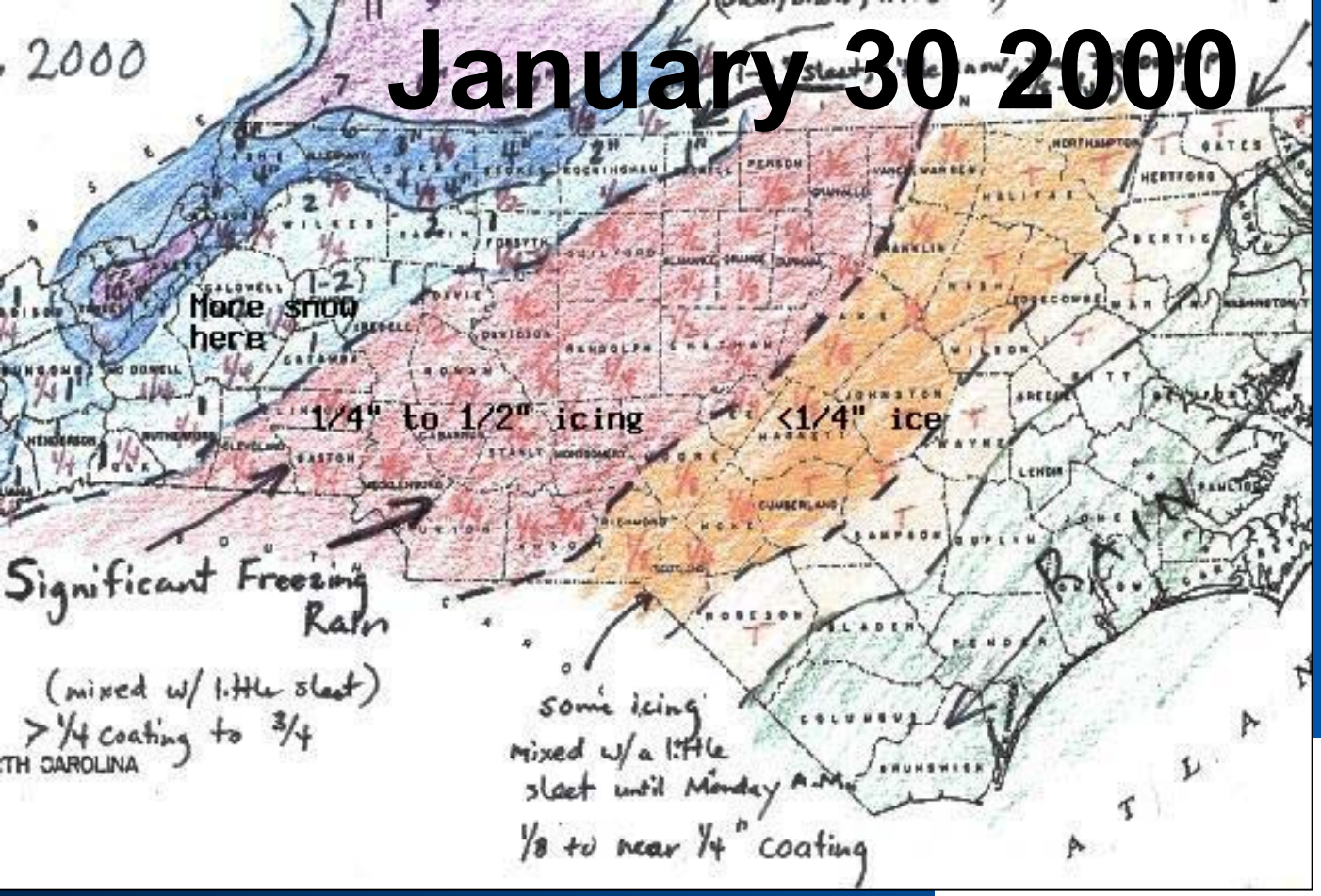
Biases may be "significant" (i.e., sufficient to alter precipitation type forecast based on model output)

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)

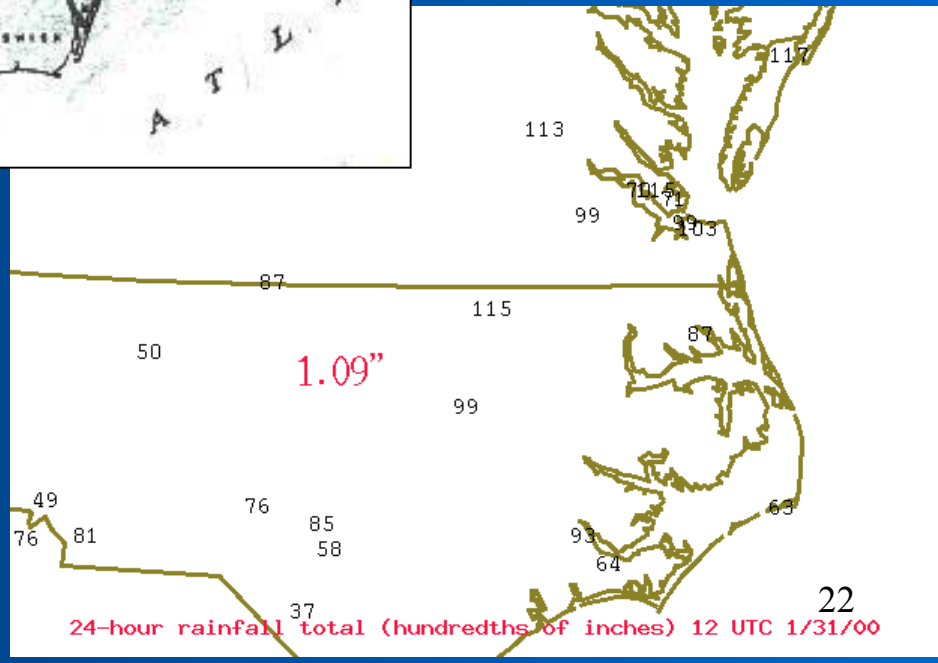


January 30 2000



Case summary by
Phil Badgett, NWSFO
RAH

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°C, snow assumed, if > 0°C, rain.

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

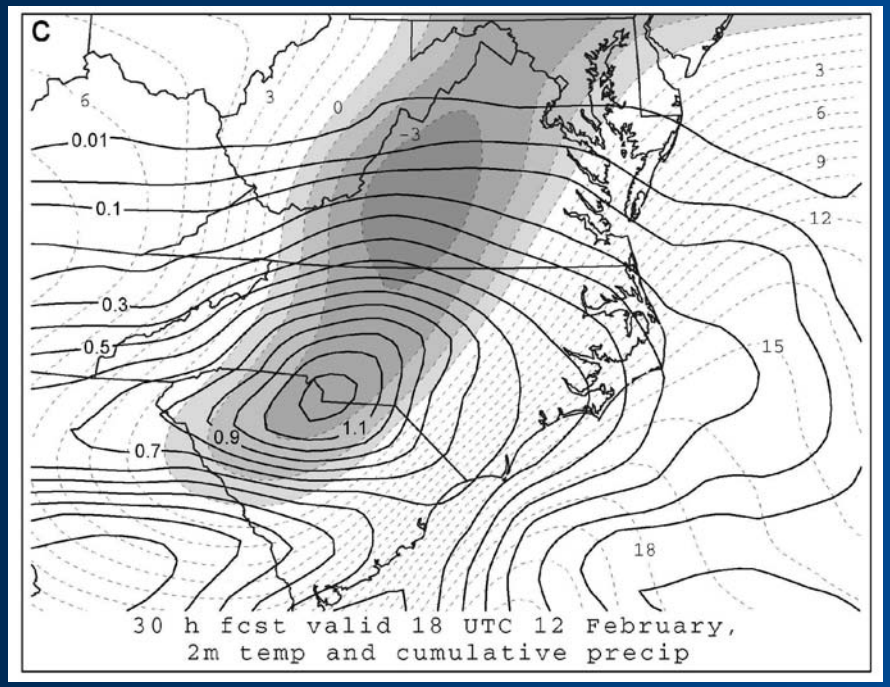
Will Eta land surface model know to release latent heat due to freezing of rain on ground?

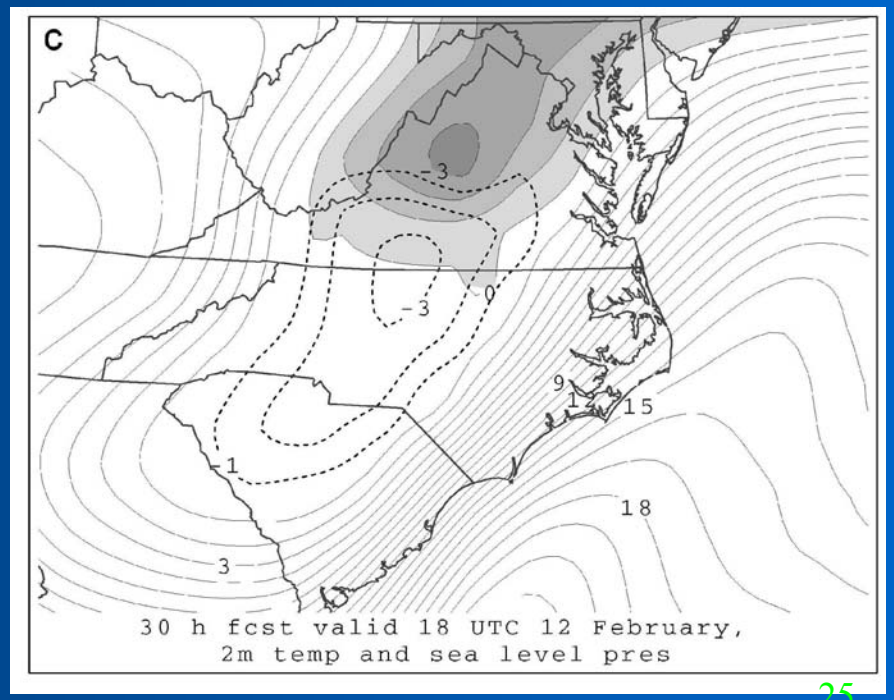
NO, latent heat release unaccounted for because snow assumed: COLD BIAS

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:

Eta can represent, NGM cannot

Accurate representation tied to QPF

For the case of heavy melting snow at surface:

Usually warm bias (for all NCEP models)

For the case of freezing rain or sleet:

Model cold bias in layer where freezing occurs

Implications for the Modern Forecaster:

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

NOAA CSTAR program

NWSFO RAH, GSP (Kermit Keeter, Larry Lee, Rod Gonski, Gail Hartfield, Jonathan Blaes, and others)

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Greg Fishel (WRAL-TV)

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

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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