Great Salt Lake–Effect Precipitation: Observed Frequency, Characteristics, and Associated Environmental Factors

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Goals of Study

- This climatology examines the environmental factors controlling the frequency, occurrence, and morphology of Great Salt Lake–effect (GSLE) precipitation events during the cool season (16 September–15 May).

- Data:
  - Weather Surveillance Radar-1988 Doppler (WSR-88D) imagery
  - radiosonde soundings
  - MesoWest surface observations from 1997/98 to 2009/10.

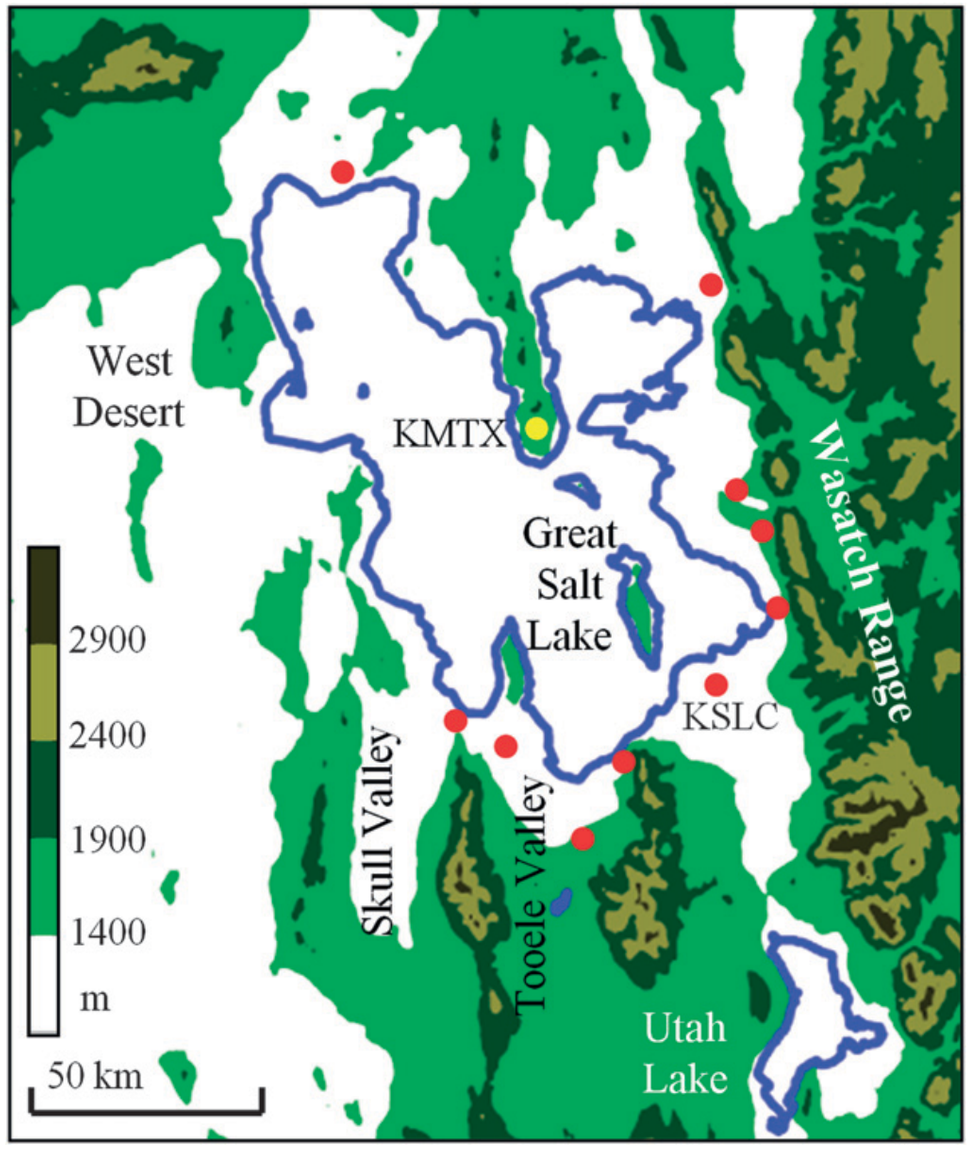


FIG. 1. Topography and landmarks of the study region; red dots mark the locations of mesonet stations used in the calculation of $\Delta T_{\text{LAKE–LAND}}$.

TABLE 1. Sounding and surface variables used in the analysis.

Variable	Levels
Temperature, geopotential height, RH, zonal and meridional wind components, wind speed, wind direction, fetch, potential temperature, equivalent potential temperature, lake–air temperature difference	Surface, 850–100 hPa in 10-hPa intervals
Mean RH, mean wind speed, lapse rate, vertical gradient in potential temperature, vector wind shear magnitude, speed shear, directional shear	All 50–550-hPa intervals between 850 and 300 hPa
Locomotive Springs RH	2 m
Lake–land temperature difference (mean of 11 sites surrounding the GSL)	2 m

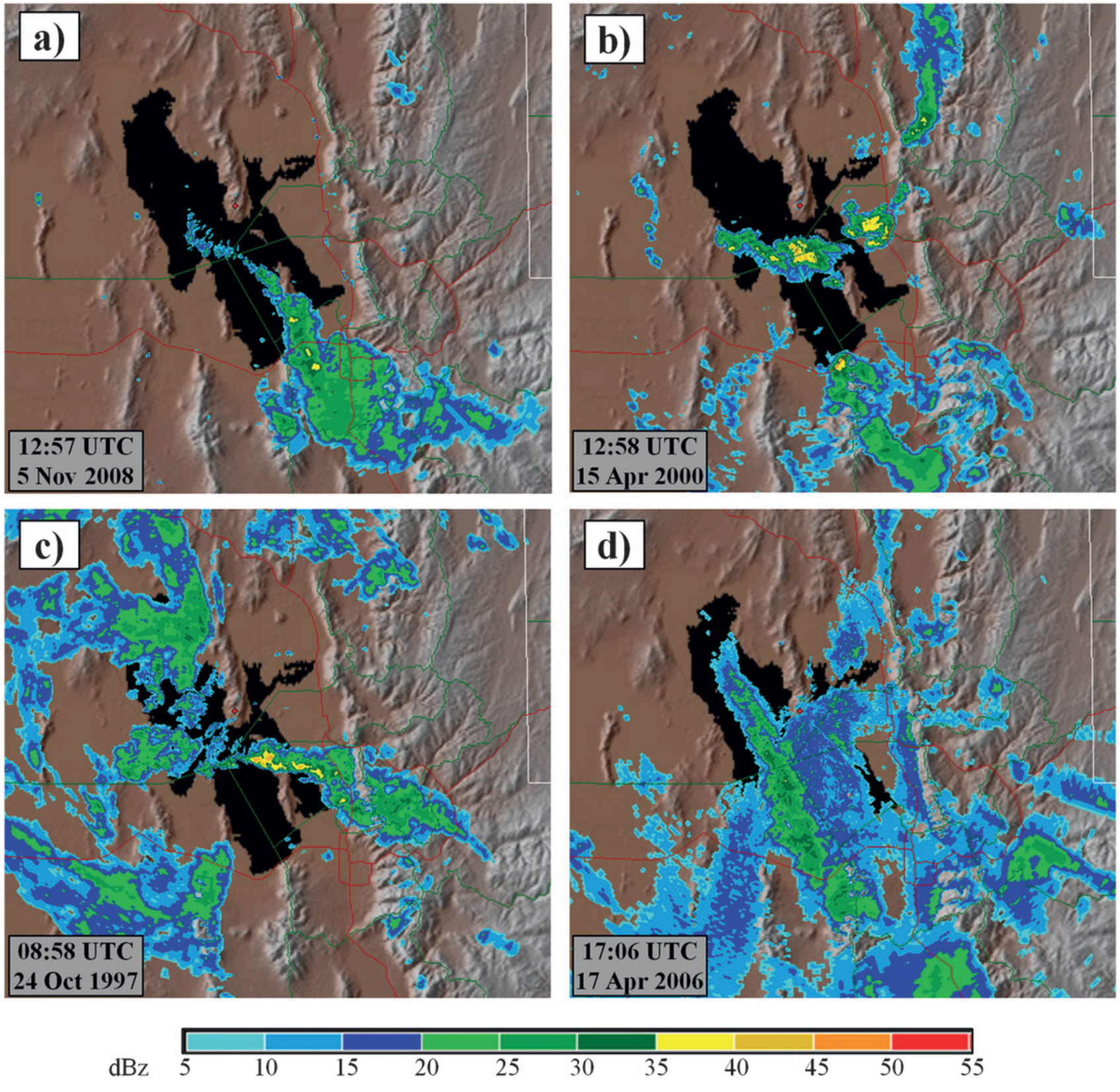
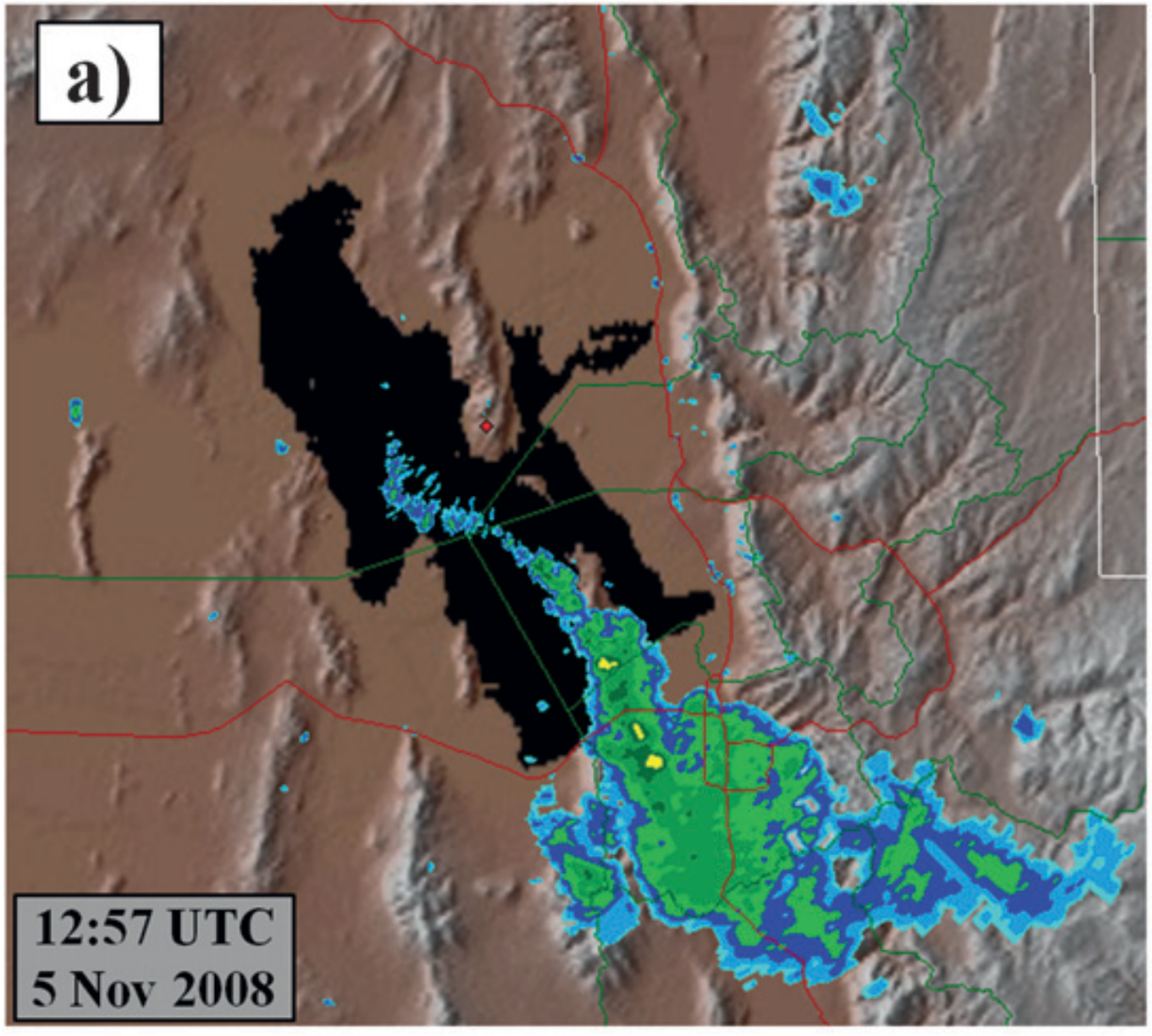
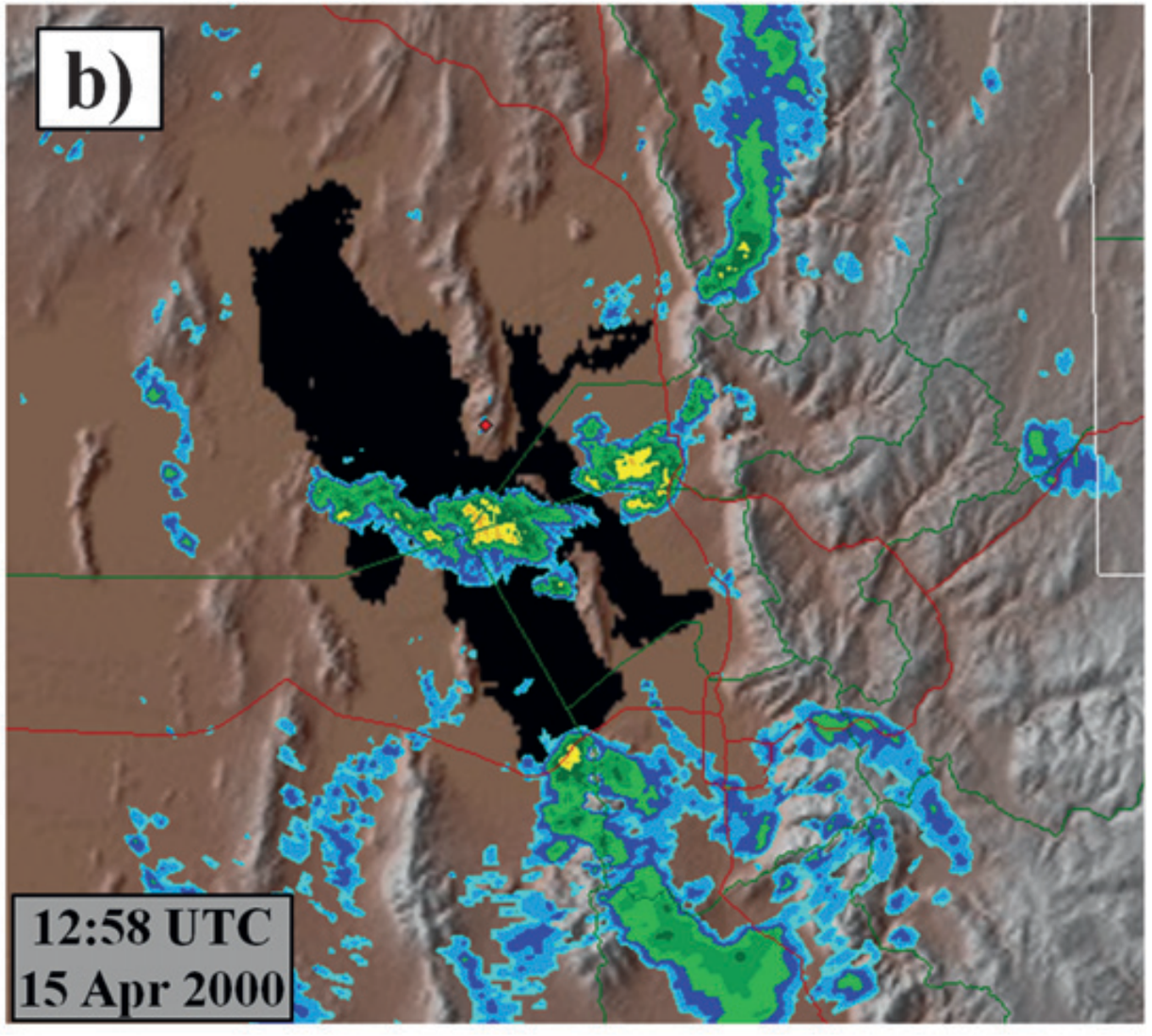


FIG. 2. Examples of GSLE precipitation context: (a) isolated areas of lake-effect precipitation, with no other precipitation falling in the surrounding valleys; (b) lake-effect precipitation concurrent with other primarily convective precipitation features; (c) lake-effect precipitation concurrent but not collocated with synoptic/transient stratiform precipitation; and (d) localized lake enhancement of transient precipitation.

isolated

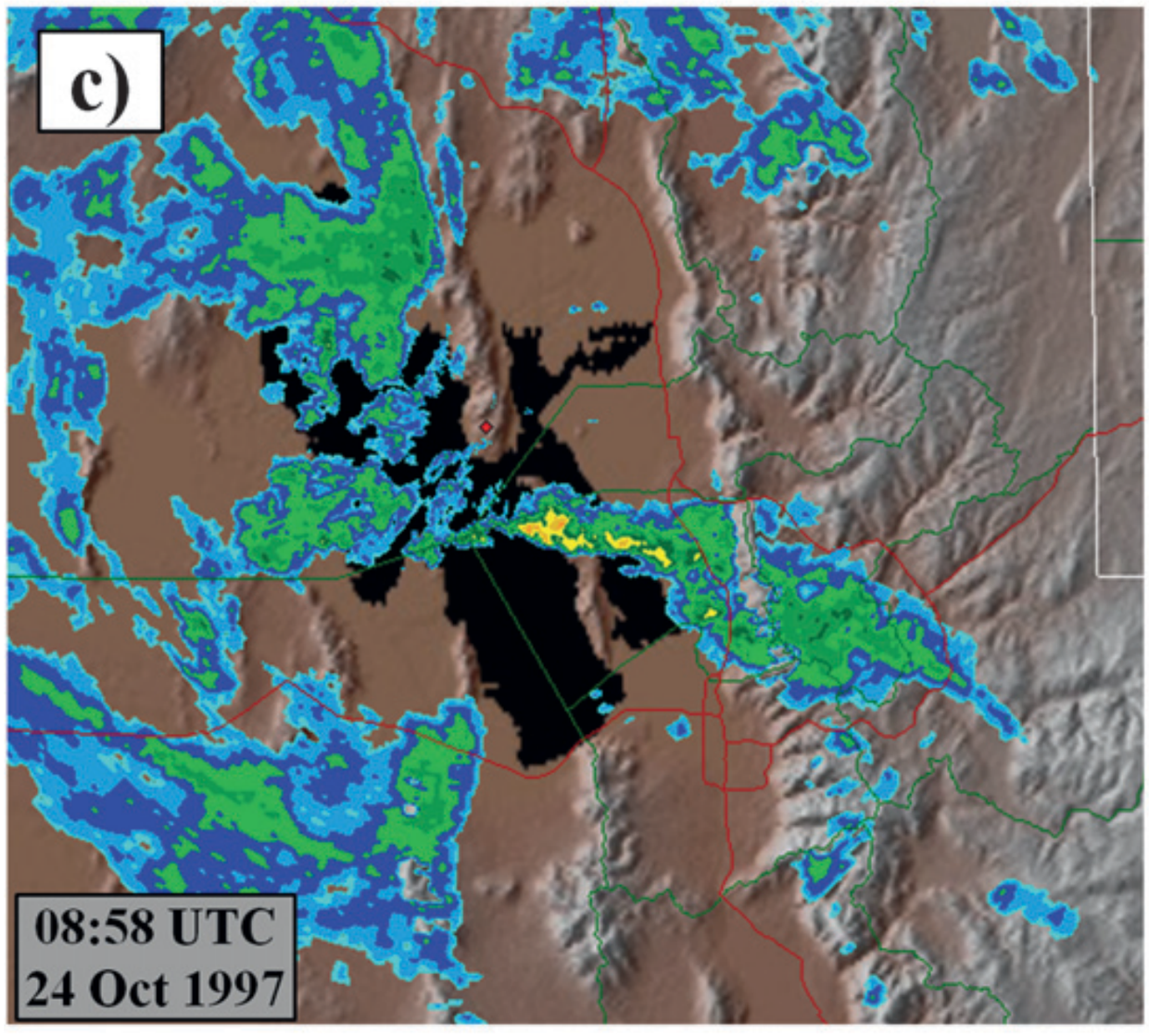
with other (convective) precip.

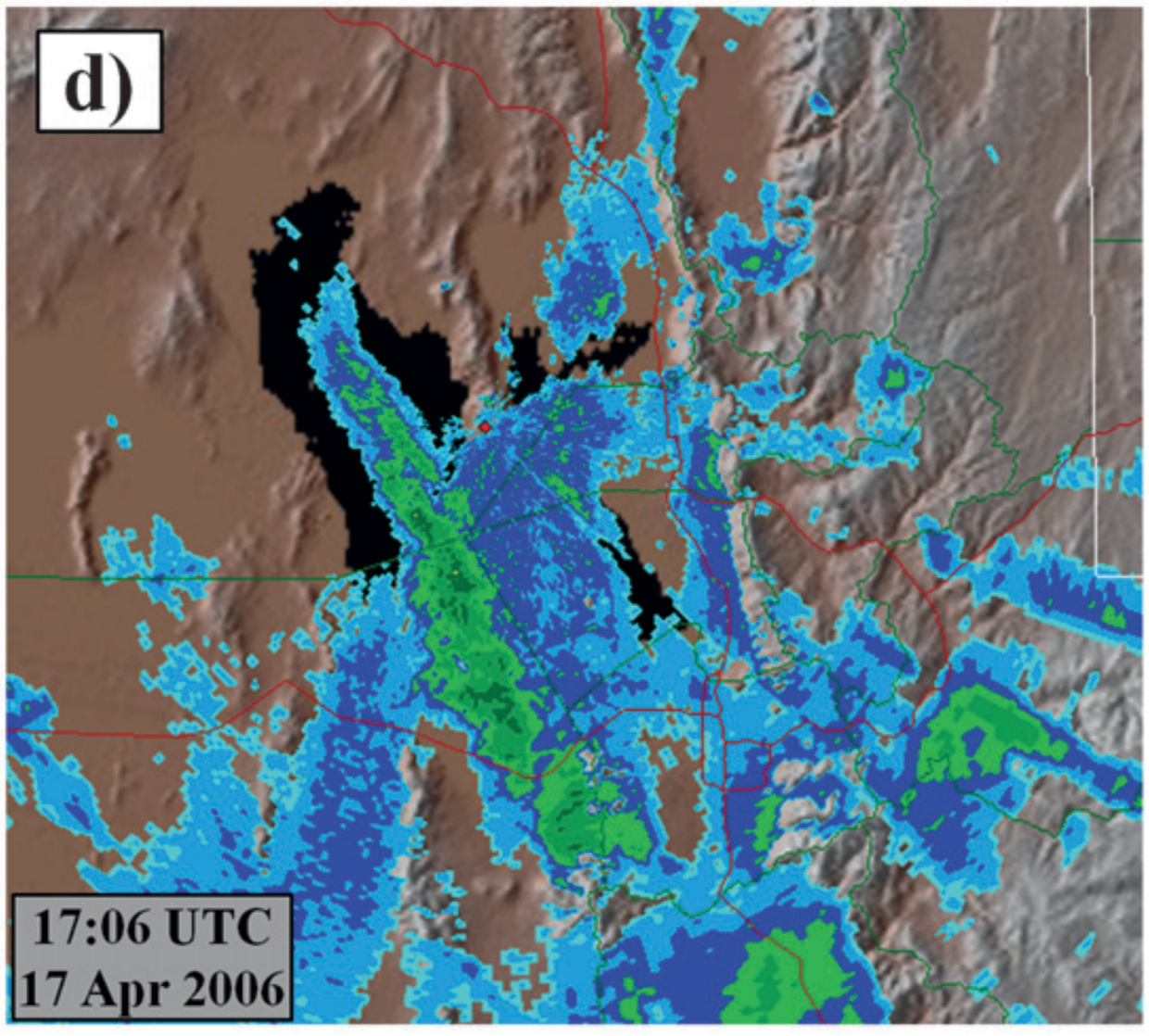




with other (stratiform) precip.

localized lake enhancement





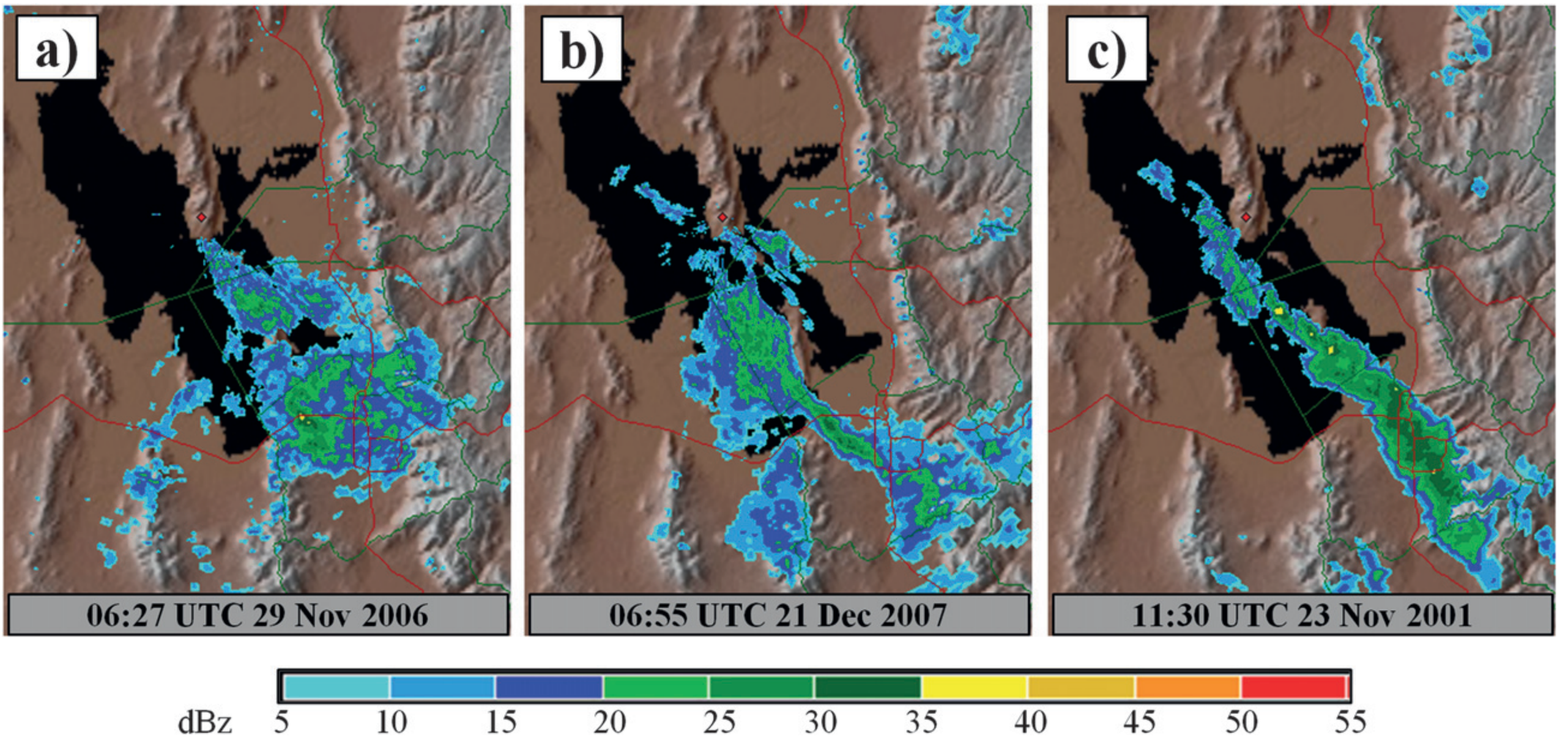


FIG. 3. Examples of GSLE morphology categories: (a) nonbanded, (b) mixed mode, and (c) banded.

GSL Temperature

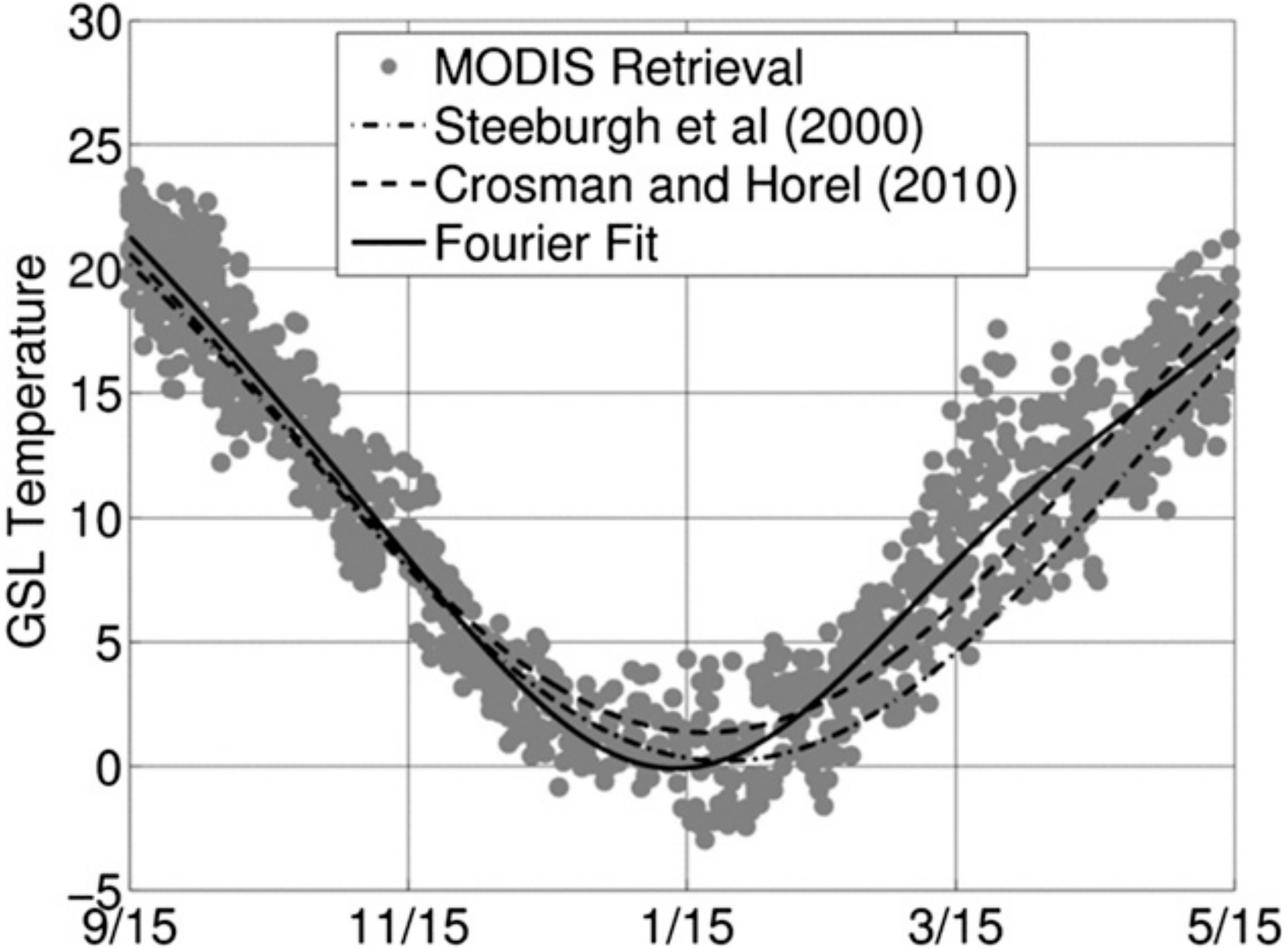


FIG. 4. MODIS GSL temperature vs three climatological curve fits.

Great Salt Lake Event Identification

- **GSLE events** were identified visually using lowest-tilt (0.5 deg) radar reflectivity images from the WSR–88D at Promontory Point, Utah (KMTX).

- **Time period:** the cool seasons (16 September–15 May) of 1997/98–2009/10.

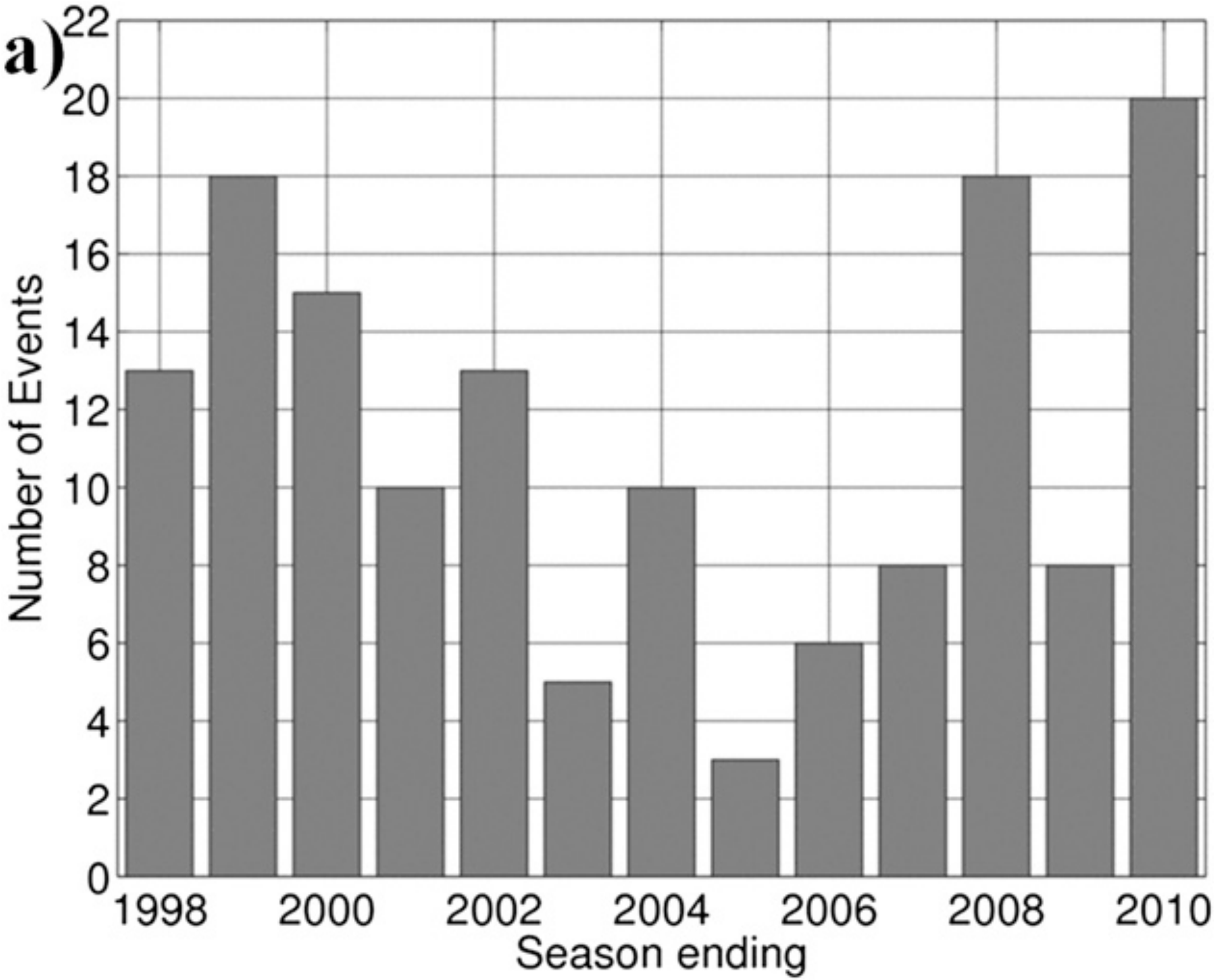
- **GSLE events:** periods $\geq$ 1 h where precipitation features were

  (a) coherent and quasi stationary with a distinct connection to the lake;

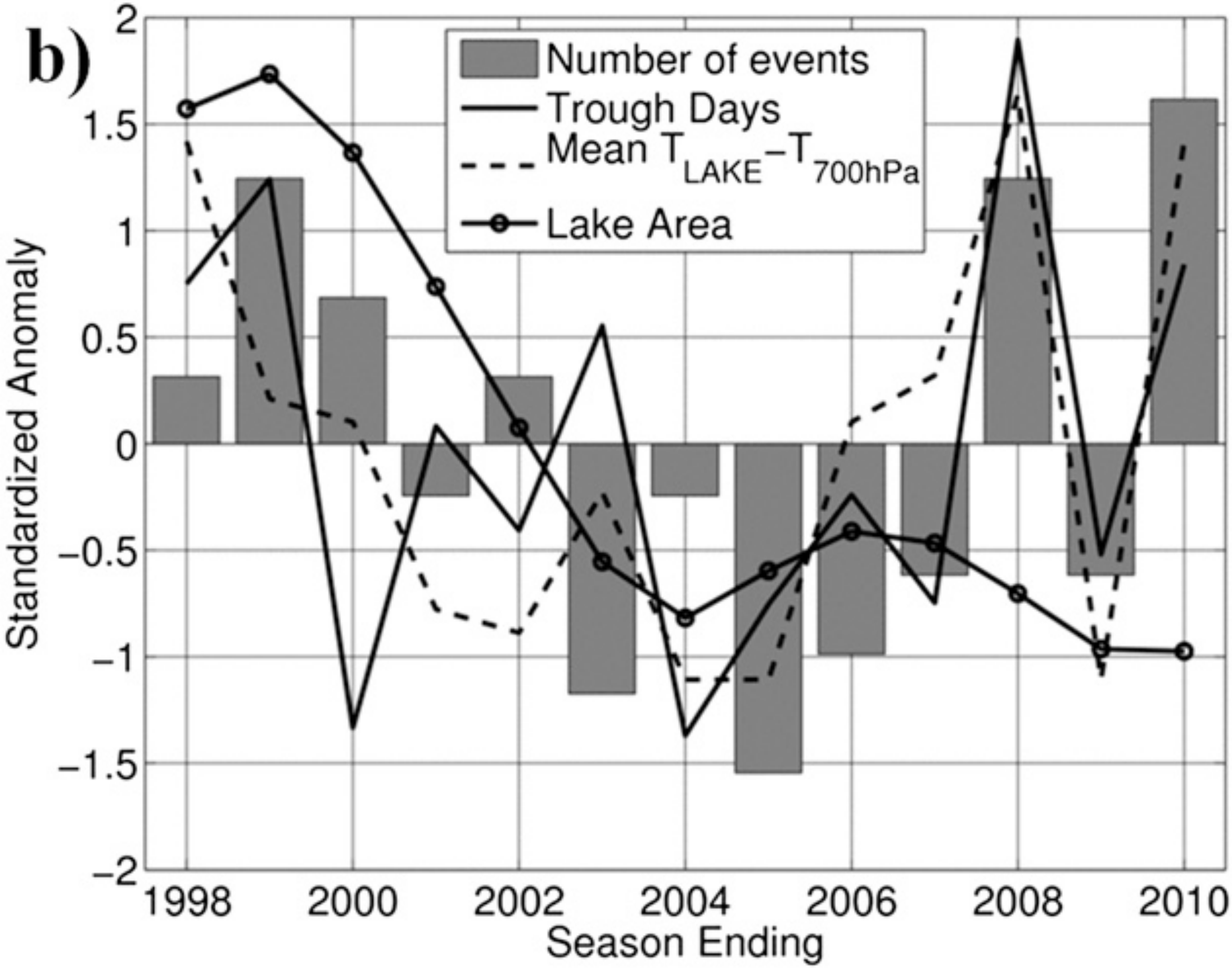
  (b) shallow and distinguishable from large, transitory “synoptic” features;

  c) exhibiting increasing depth and/or intensity in the downwind direction.

Year to Year Variability

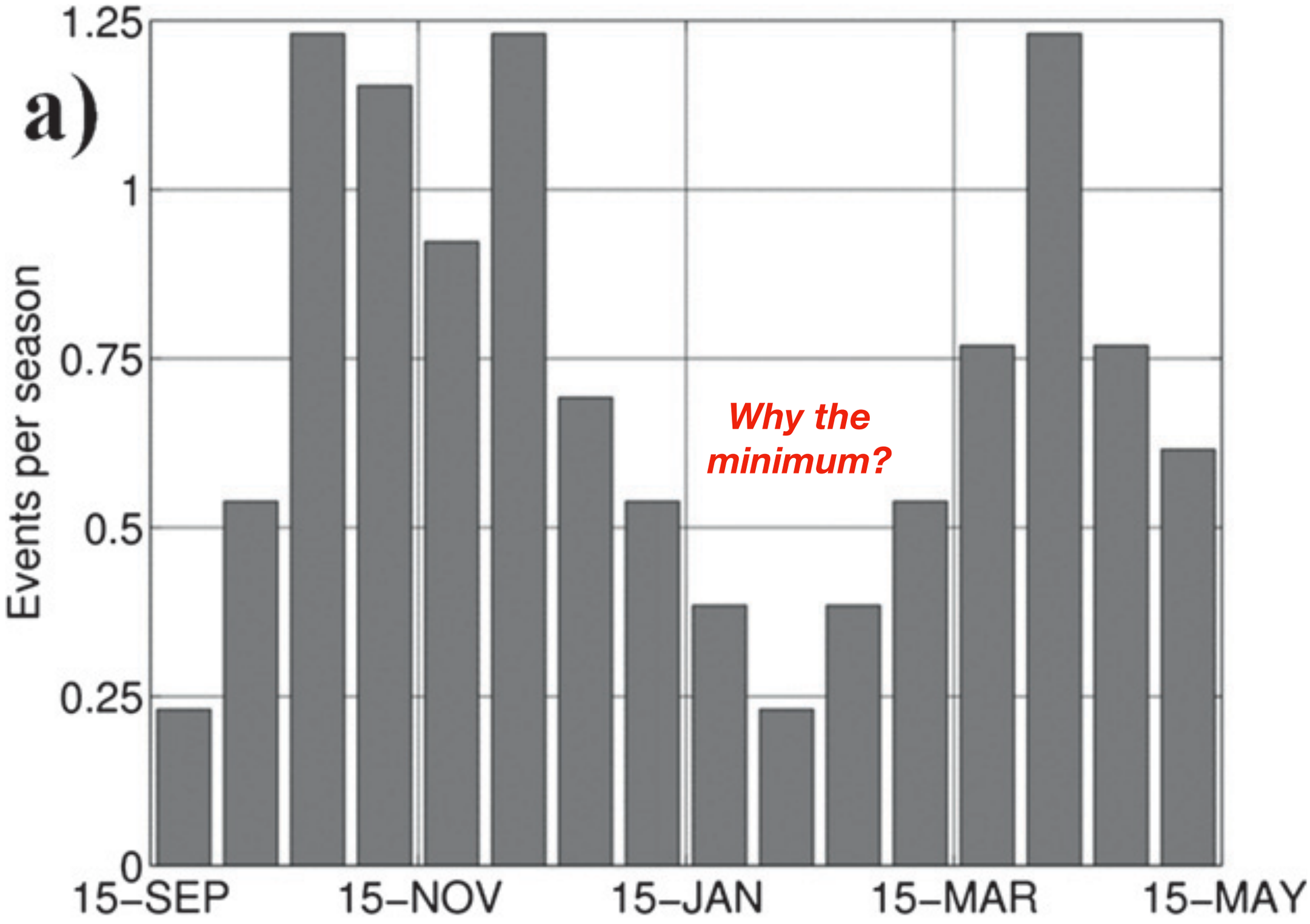


Year to Year Variability

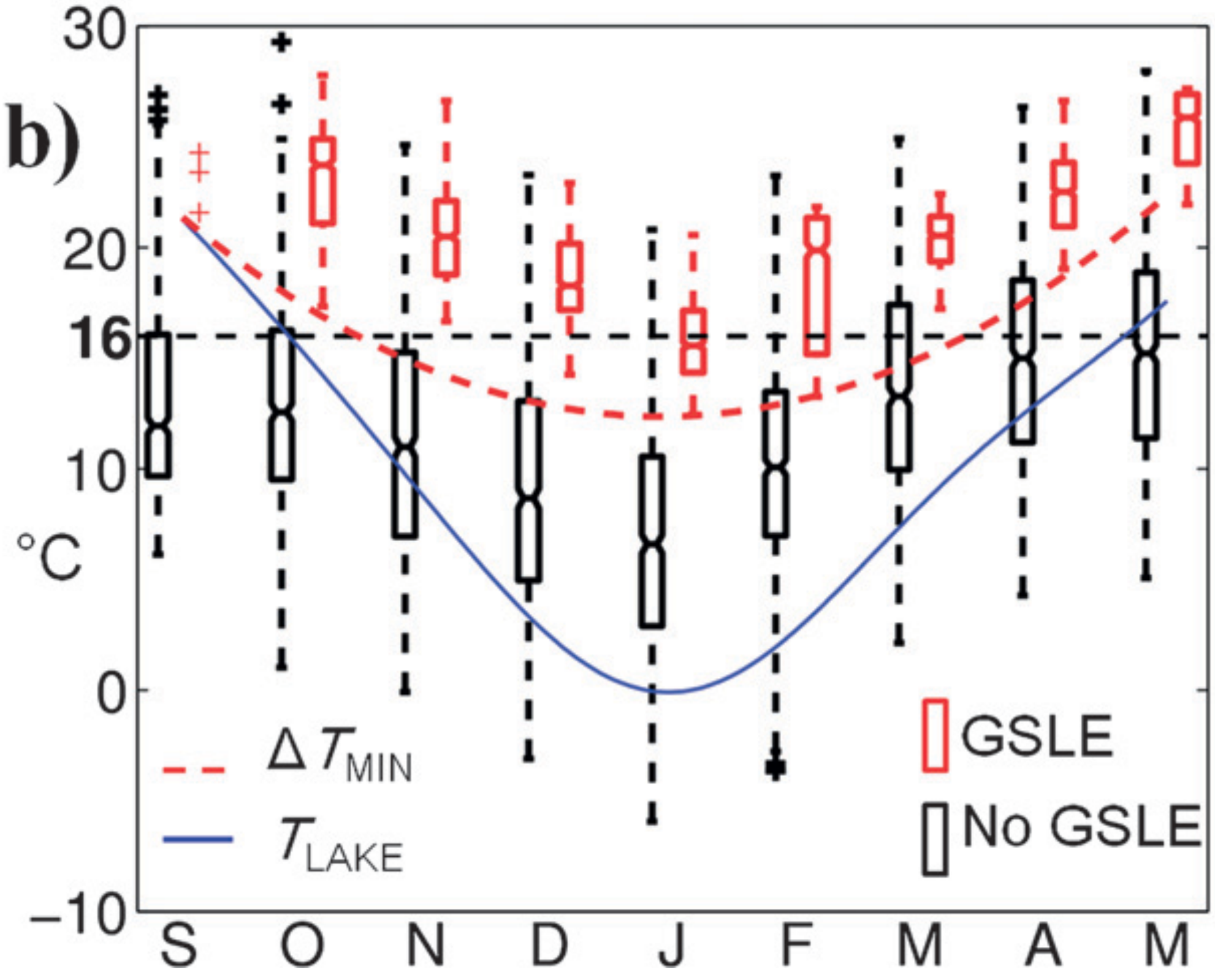


Seasonal Variability

(events per half month)



box & whisker: **lake-700 mb temperature difference, ΔT**



seasonally varying ΔT threshold for GSLE

operational forecast ΔT threshold for GSLE

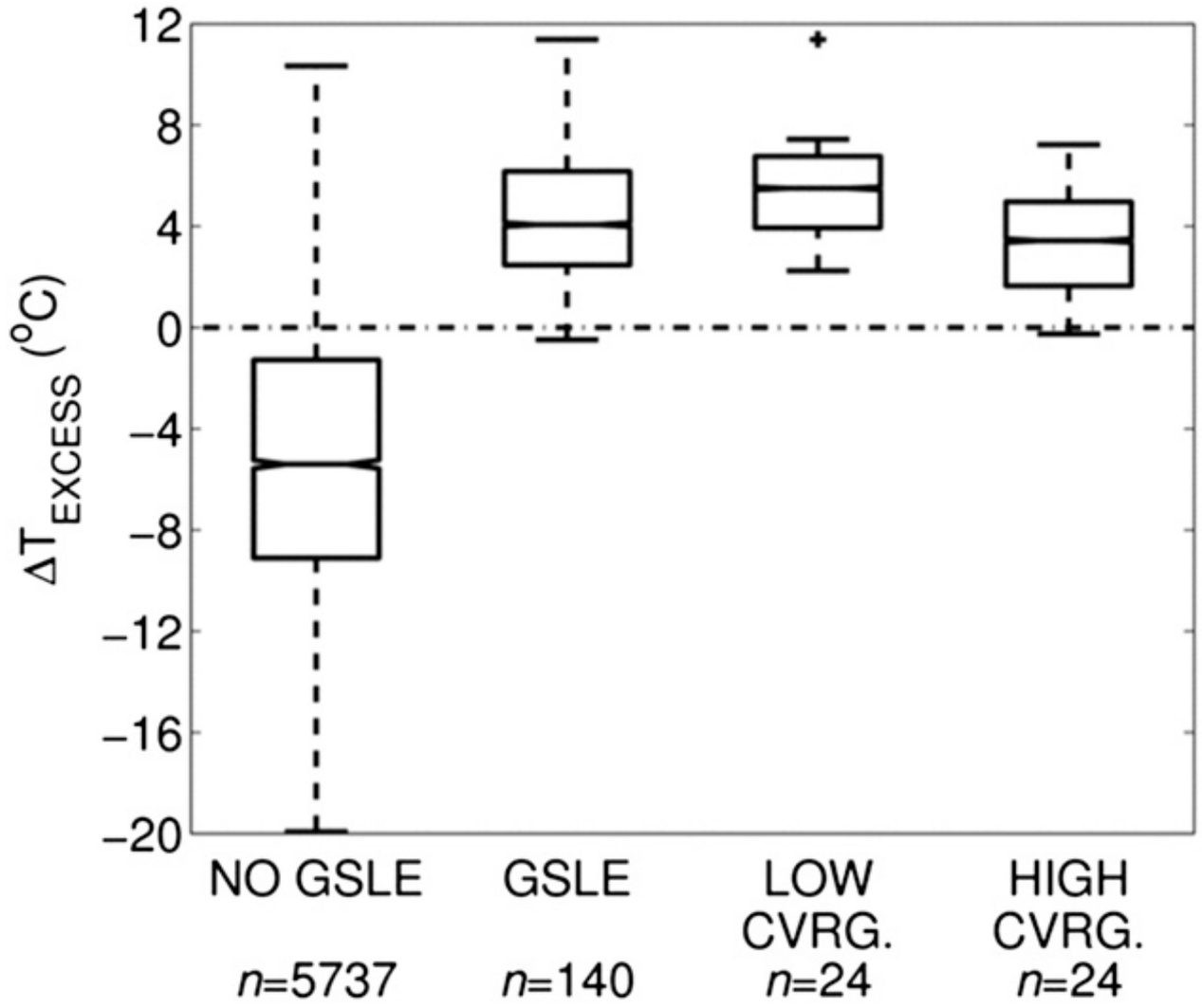


FIG. 9. Comparison of ΔT_{excess} for four categories of soundings: soundings with GSLE, without GSLE, with a pure lake effect and low coverage (<80 km^2 of 10-dBZ radar echoes, the lowest tertile), and with a pure lake effect and high coverage (>640 km^2 of 10-dBZ radar echoes, the highest tertile). Box top and bottom are the 25th and 75th percentiles, the median is denoted by a horizontal line in the box (medians of two distributions differ at the 90% level when the notches around their respective median lines do not overlap), whiskers extend to 1.5 times the interquartile range, and outliers beyond 1.5 times the interquartile range are denoted by plus signs (+).

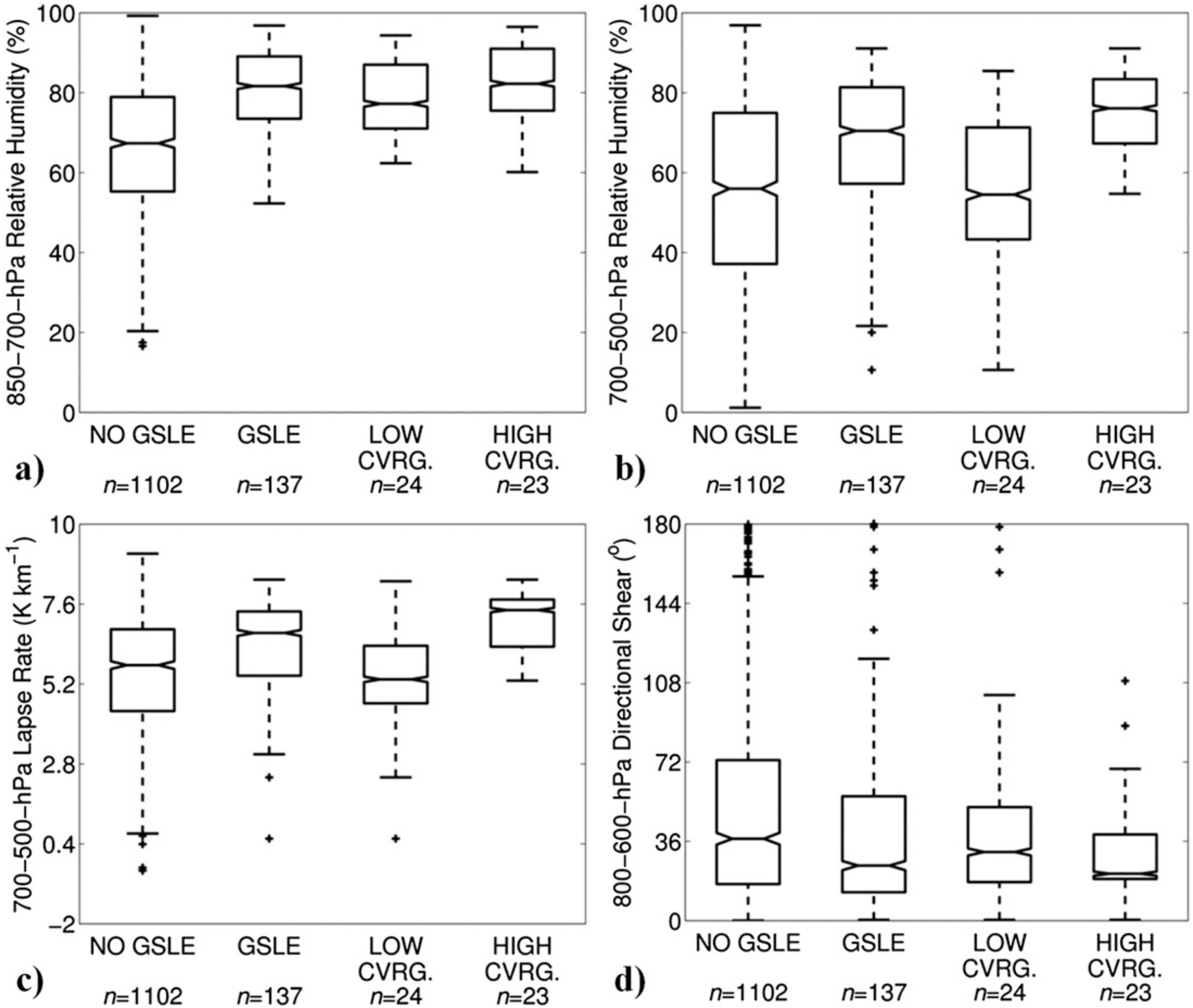
$$\Delta T_{\text{min}} = 0.000\,642\,5d^2 - 0.152d + 21.35(^{\circ}\text{C}),$$

where d is the number of days since 15 September.

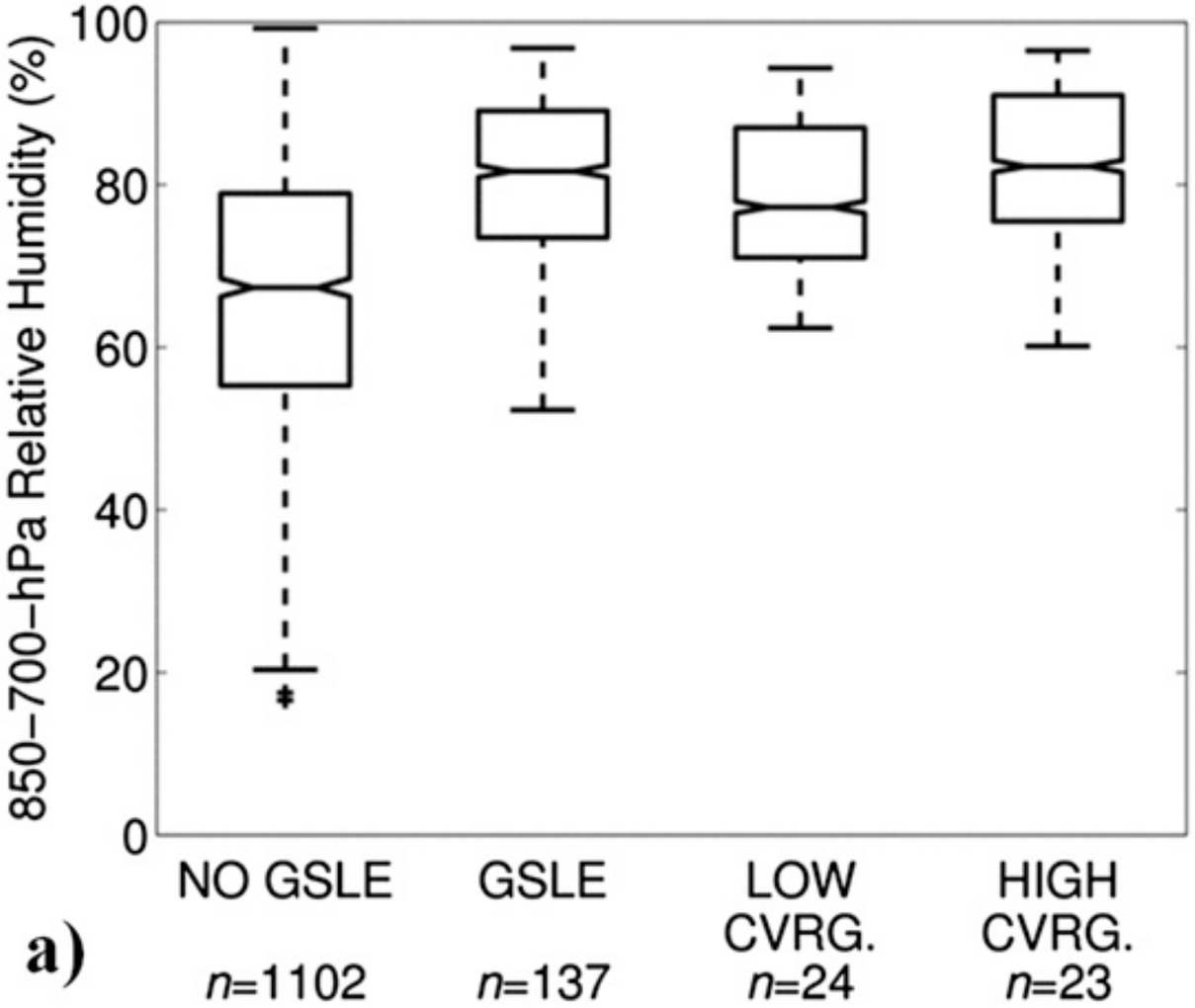
$$\Delta T_{\text{excess}} = \Delta T - \Delta T_{\text{min}}$$

$\Delta T_{\text{excess}} > 0$ is required for GSLE

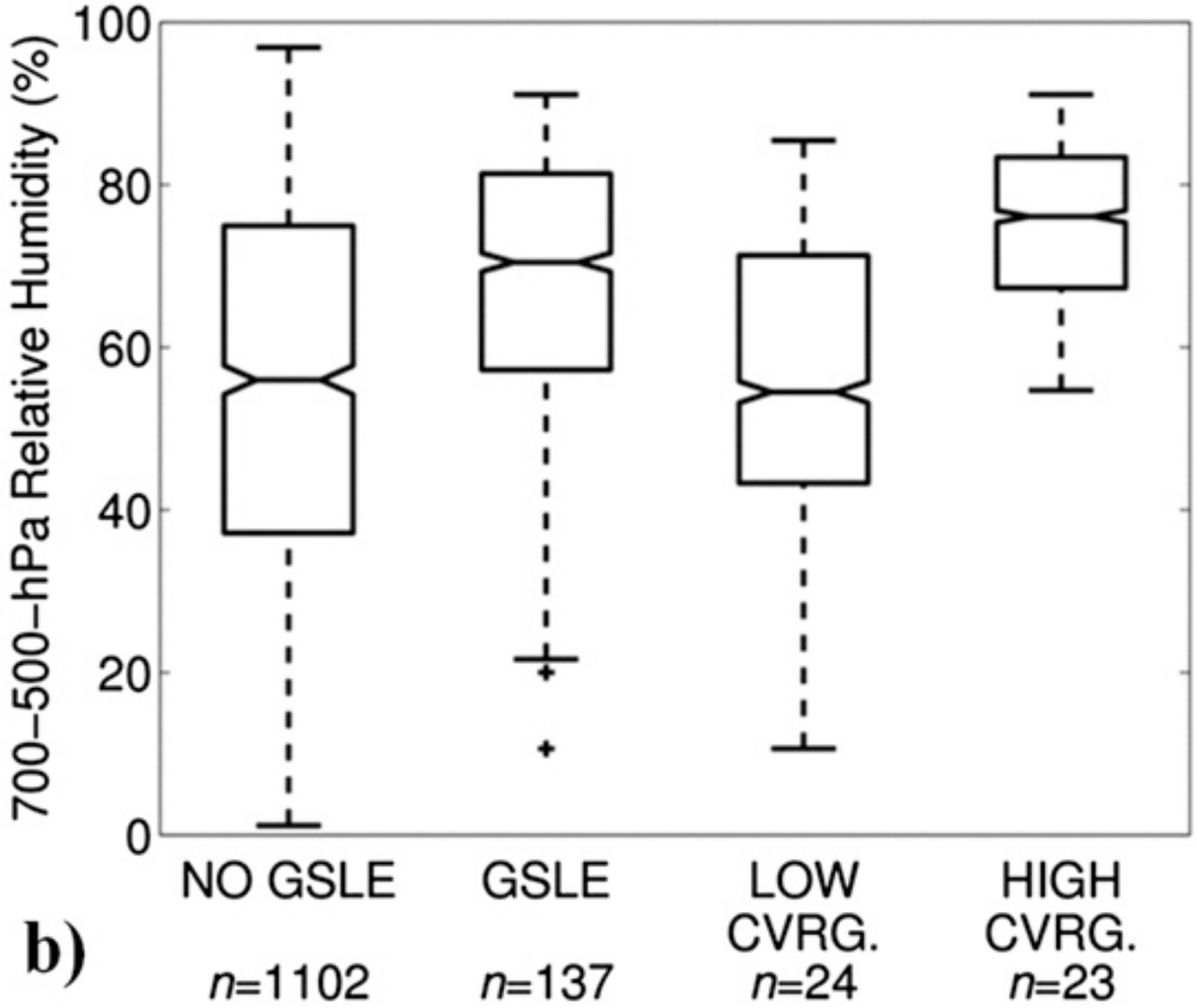
$\Delta T_{\text{excess}} > 0$



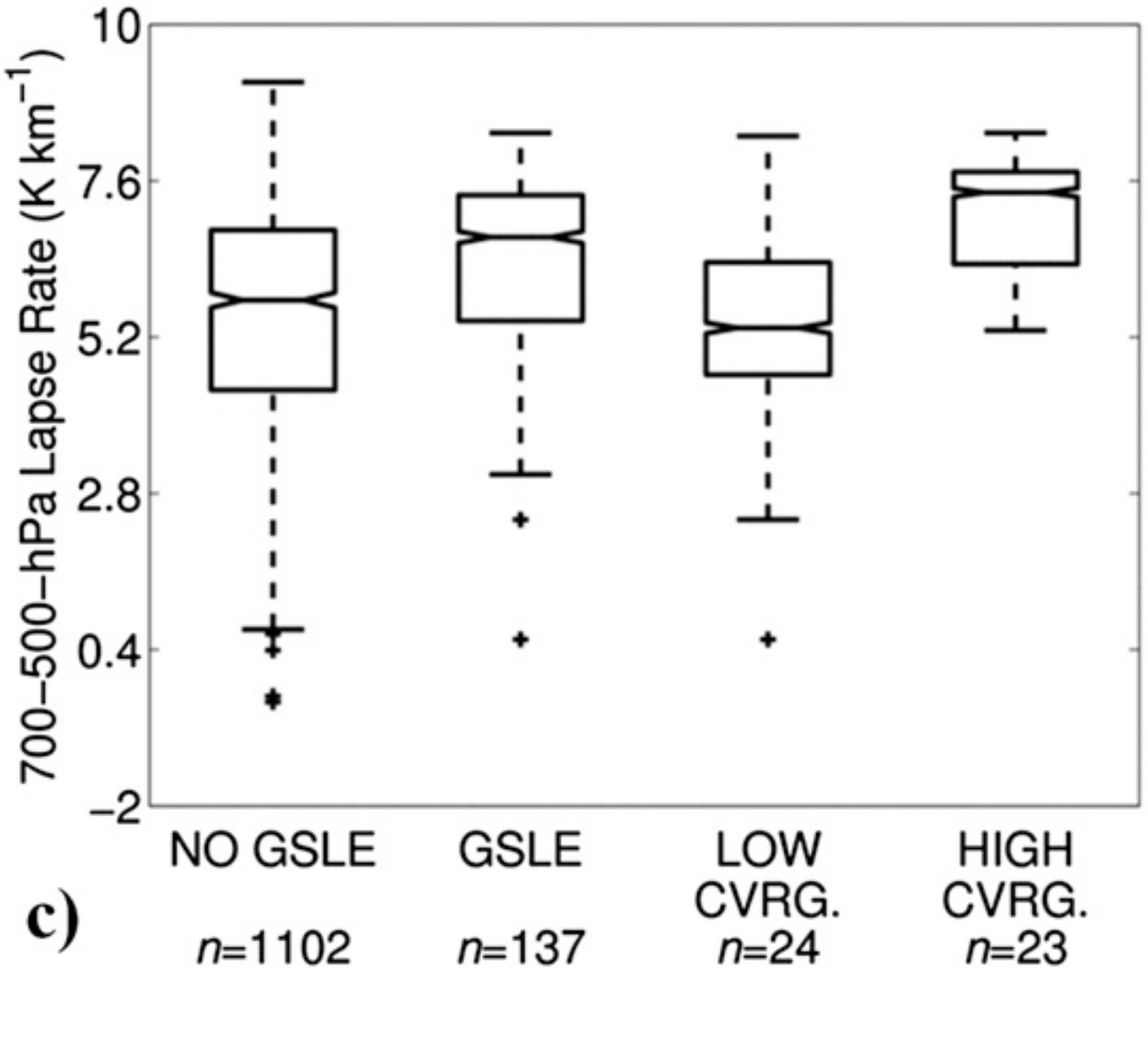
Which is the most predictive (sensitive, discriminating) parameter?

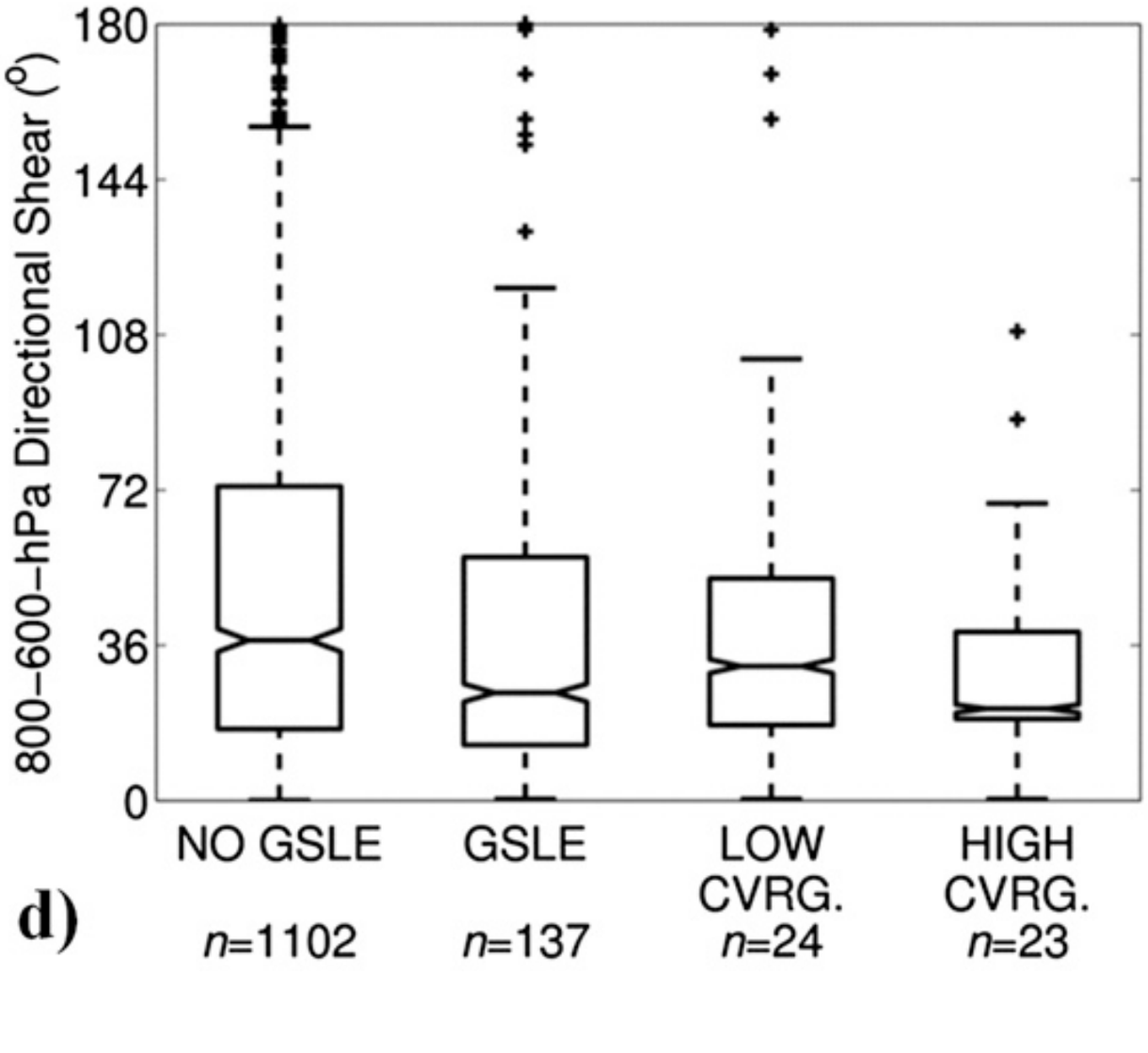

850–700–hPa Relative Humidity (%)
100
80
60
40
20
0
NO GSLE
n=1102
GSLE
n=137
LOW CVRG.
n=24
HIGH CVRG.
n=23

a)


700–500–hPa Relative Humidity (%)
100
80
60
40
20
0
NO GSLE
n=1102
GSLE
n=137
LOW CVRG.
n=24
HIGH CVRG.
n=23

b)


10
7.6
5.2
2.8
0.4
−2
700–500–hPa Lapse Rate (K km−1)
NO GSLE
GSLE
LOW CVRG.
HIGH CVRG.
c)
n=1102
n=137
n=24
n=23


180
144
108
72
36
0
800–600–hPa Directional Shear (°)
NO GSLE
GSLE
LOW CVRG.
HIGH CVRG.
d)
n=1102
n=137
n=24
n=23

Is there a favorable/more likely time for events to start and end? Why?

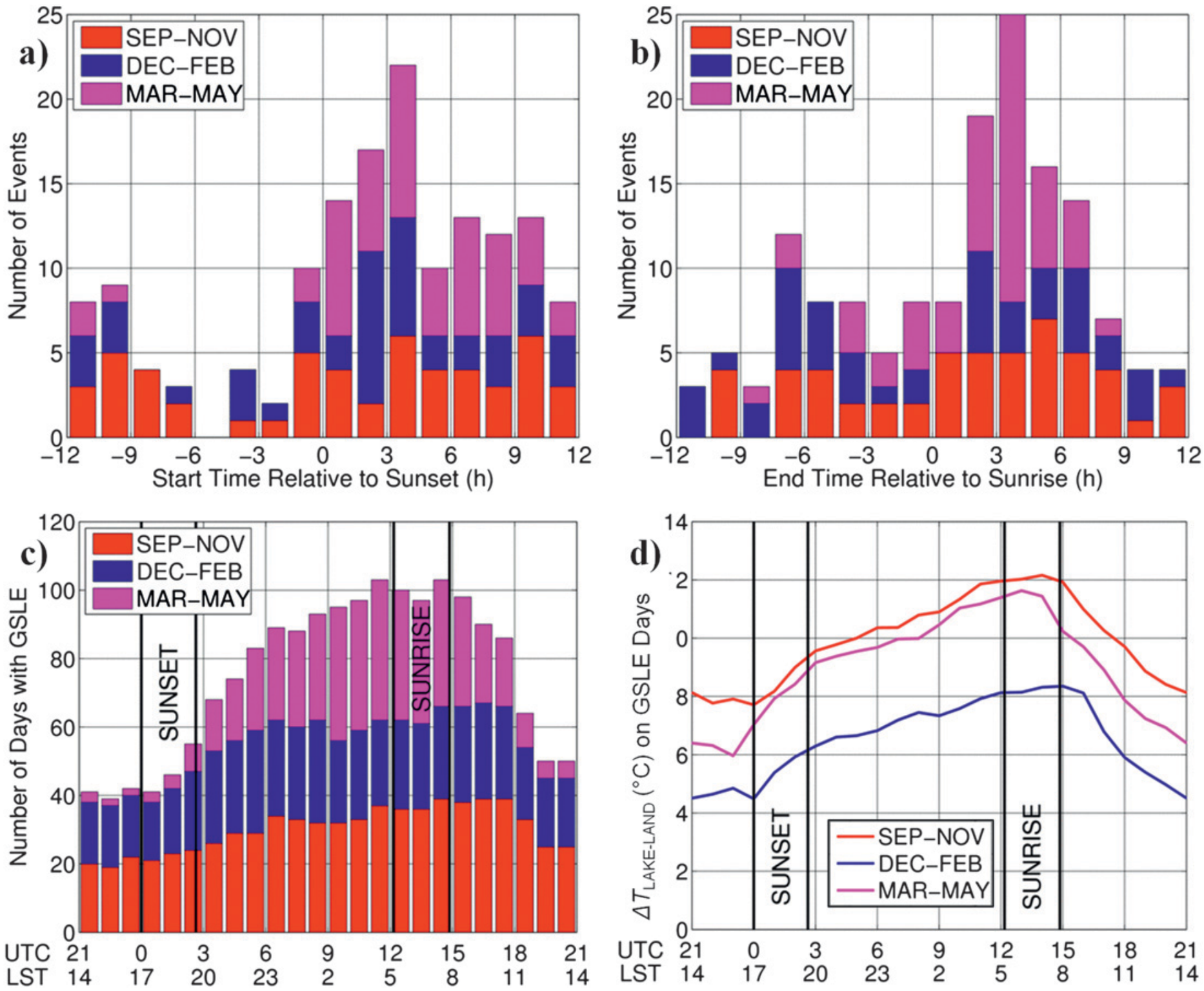
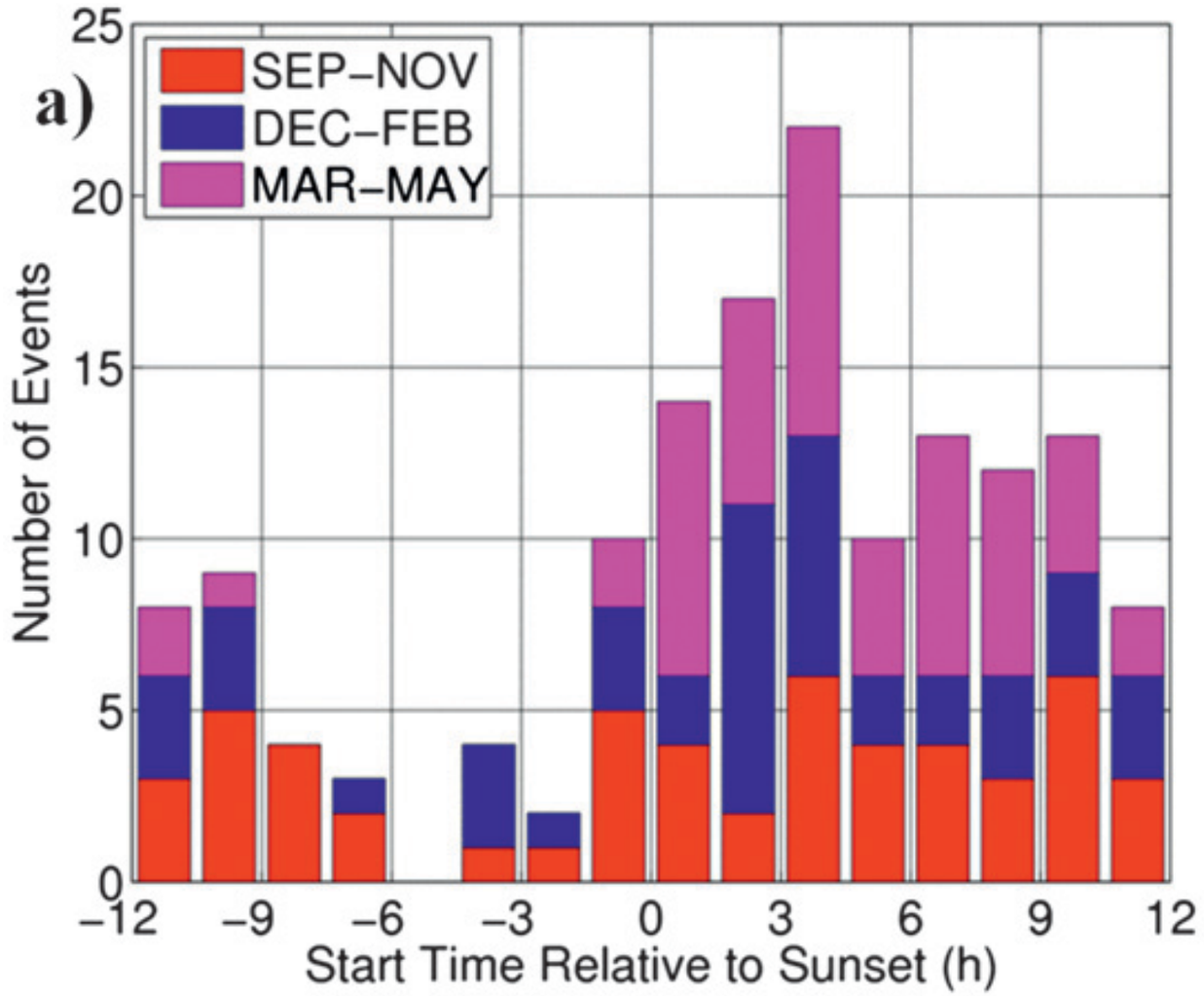
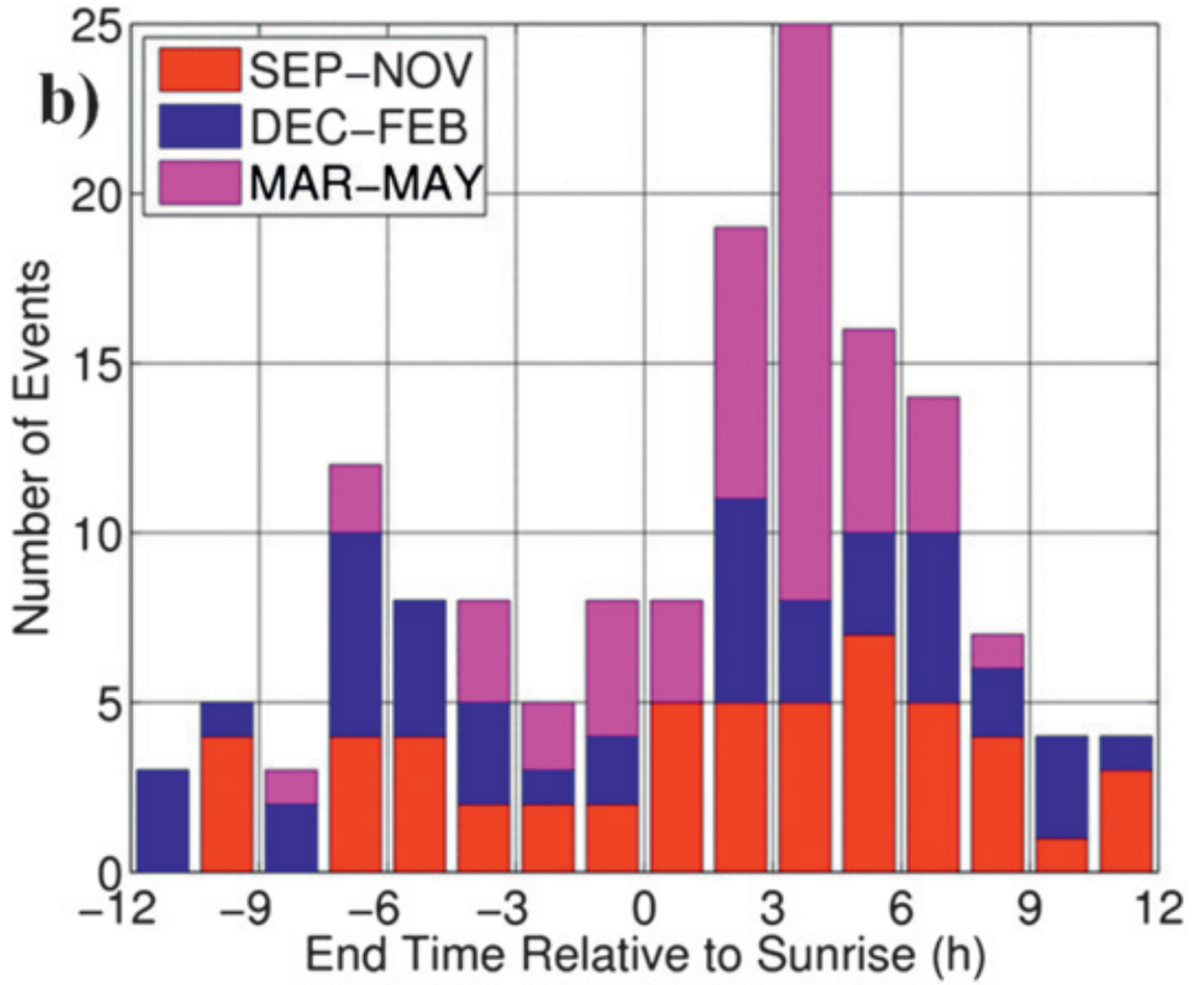
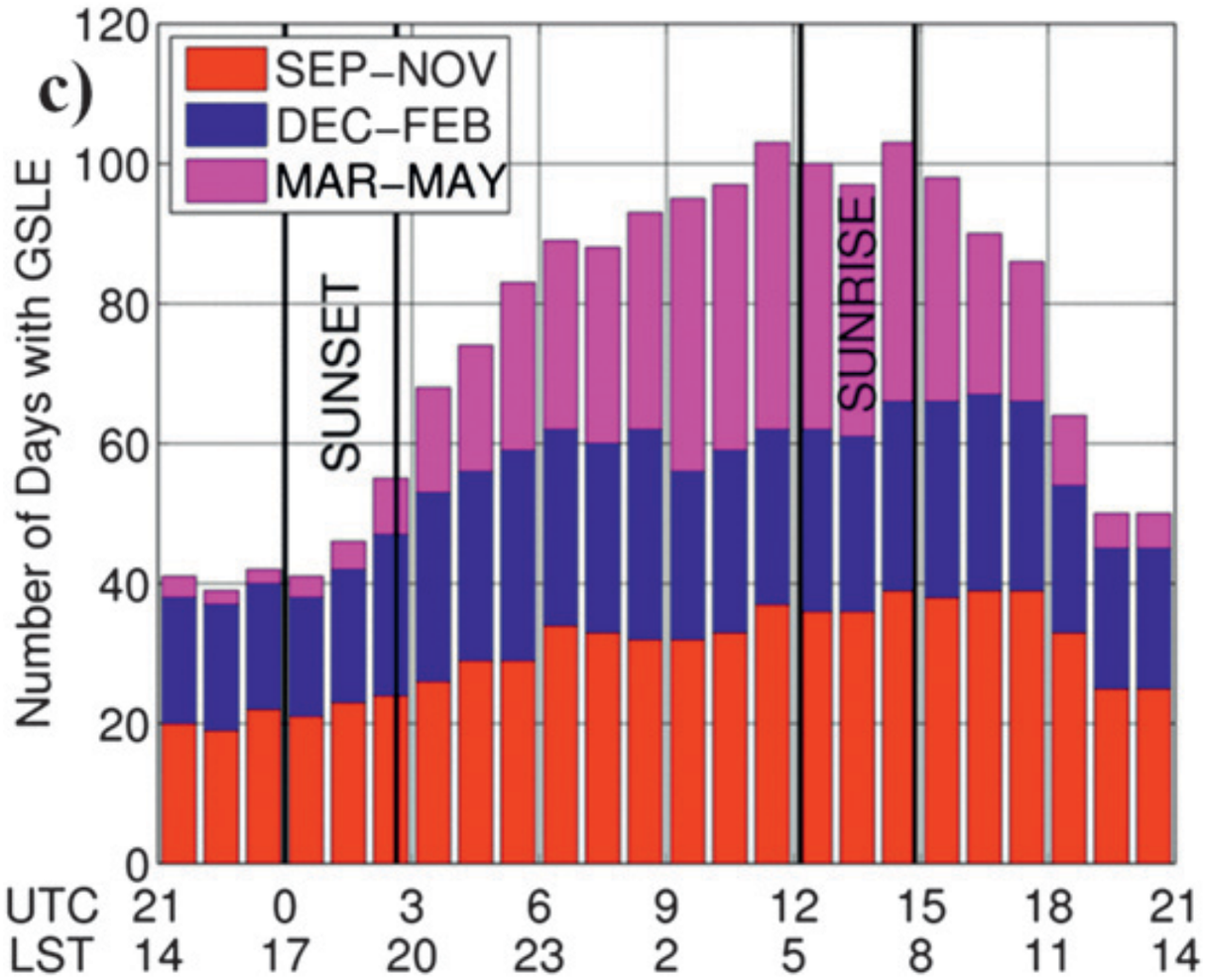


FIG. 12. Timing of GSLE events: (a) event start time relative to sunset (h); (b) event end time relative to sunrise (h); (c) number of days with GSLE at a given time of day (h, UTC and LST), where vertical bars indicate the ranges of sunrise and sunset times (16 September–15 May); and d) hourly median $\Delta T_{\mathrm{LAKE–LAND}}$ on days with GSLE.


a)
SEP–NOV
DEC–FEB
MAR–MAY
Number of Events
0
5
10
15
20
25
−12
−9
−6
−3
0
3
6
9
12
Start Time Relative to Sunset (h)


b)
SEP–NOV
DEC–FEB
MAR–MAY
Number of Events
0
5
10
15
20
25
−12
−9
−6
−3
0
3
6
9
12
End Time Relative to Sunrise (h)



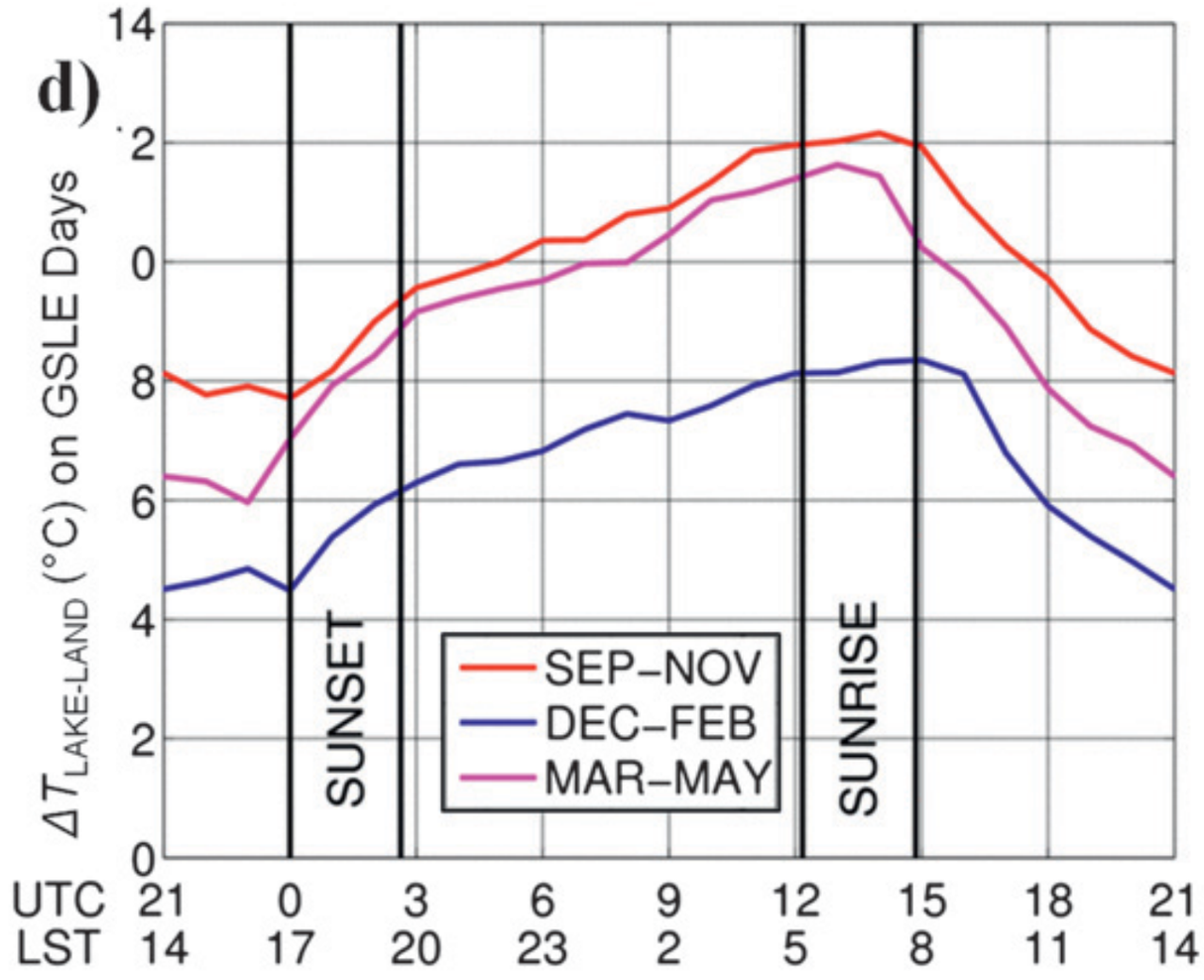


FIG. 12. Timing of GSLE events: (a) event start time relative to sunset (h); (b) event end time relative to sunrise (h); (c) number of days with GSLE at a given time of day (h, UTC and LST), where vertical bars indicate the ranges of sunrise and sunset times (16 September–15 May); and d) hourly median $\Delta T_{\mathrm{LAKE–LAND}}$ on days with GSLE.

00 UTC and 12 UTC profiles consistently differ

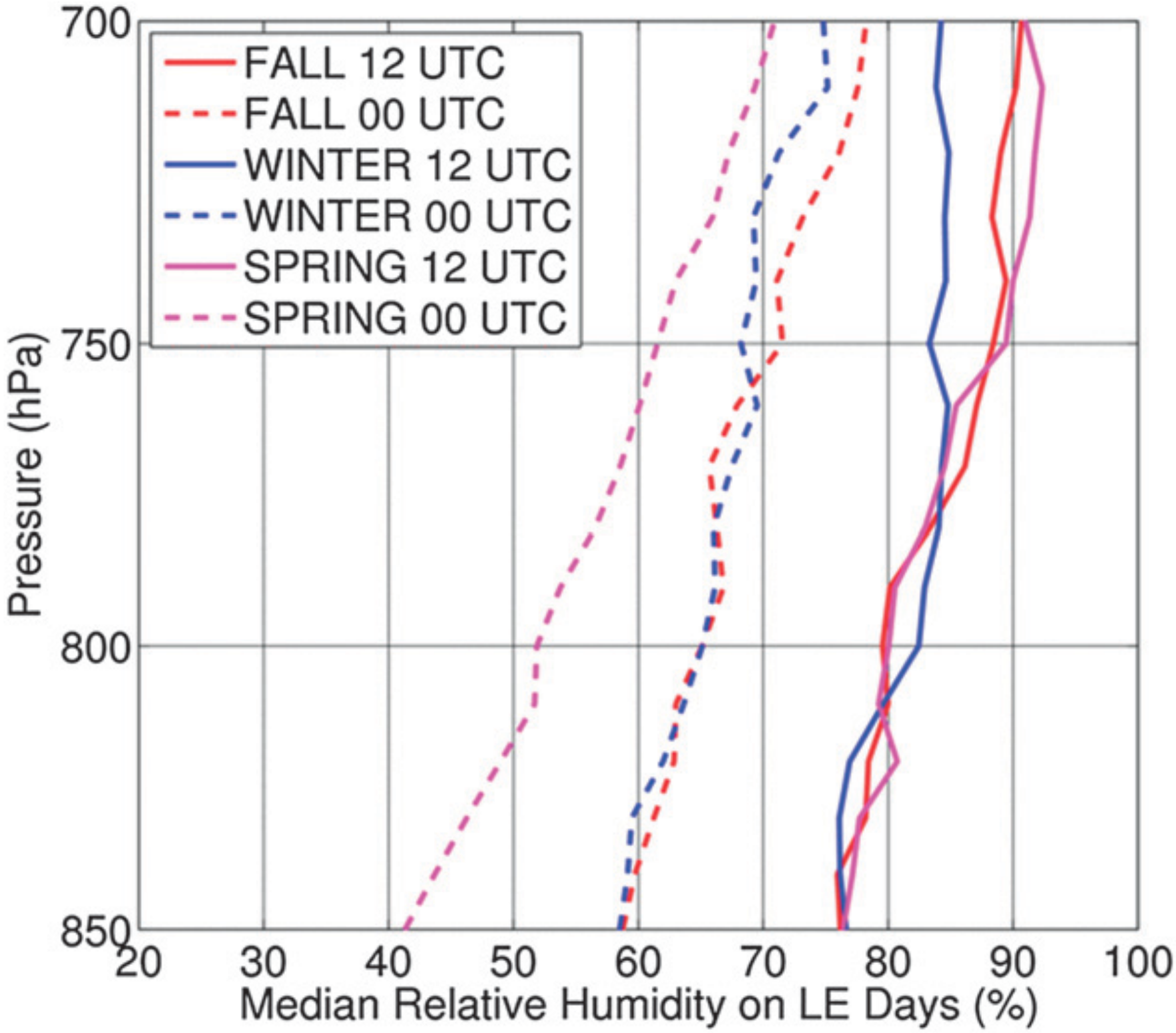
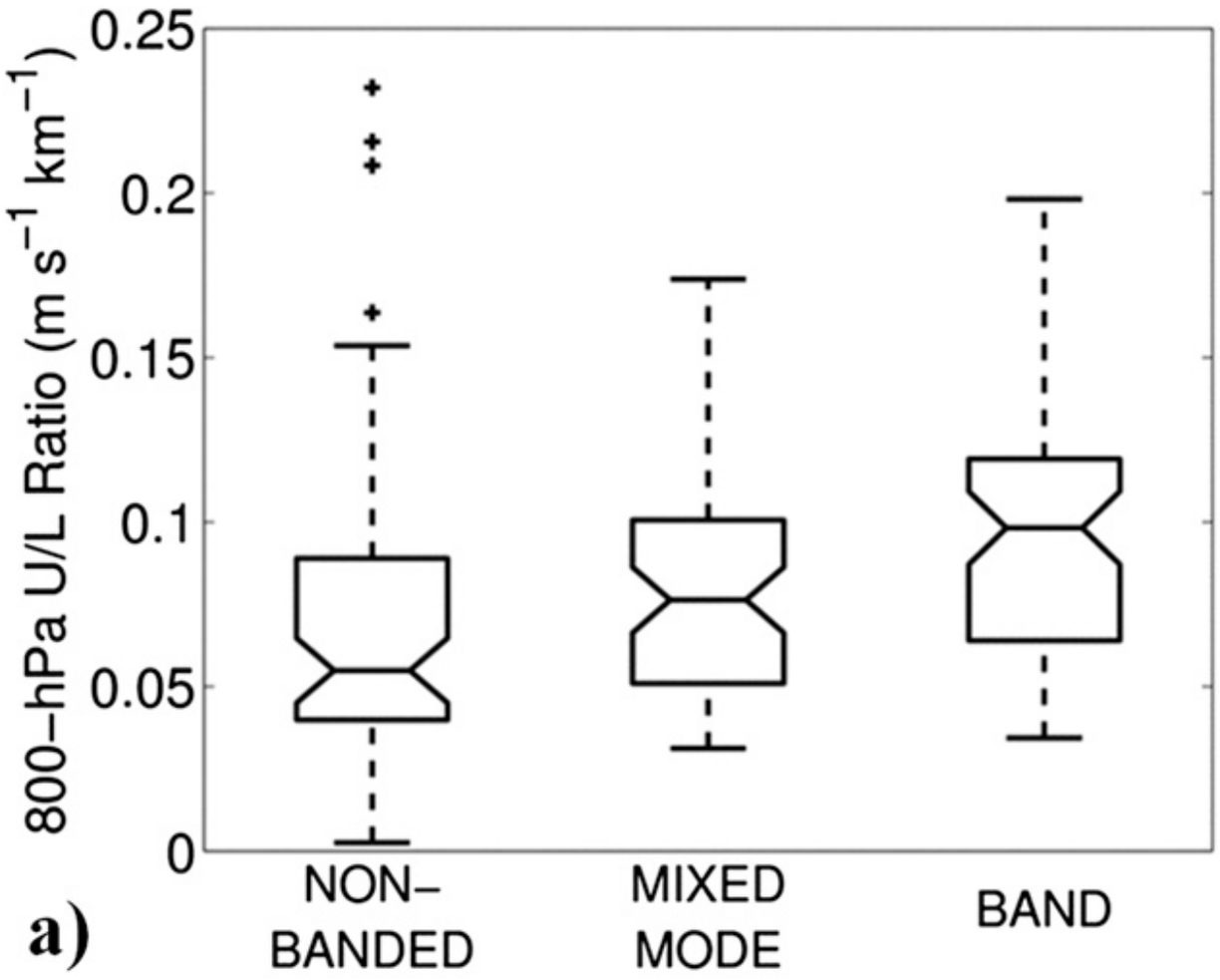
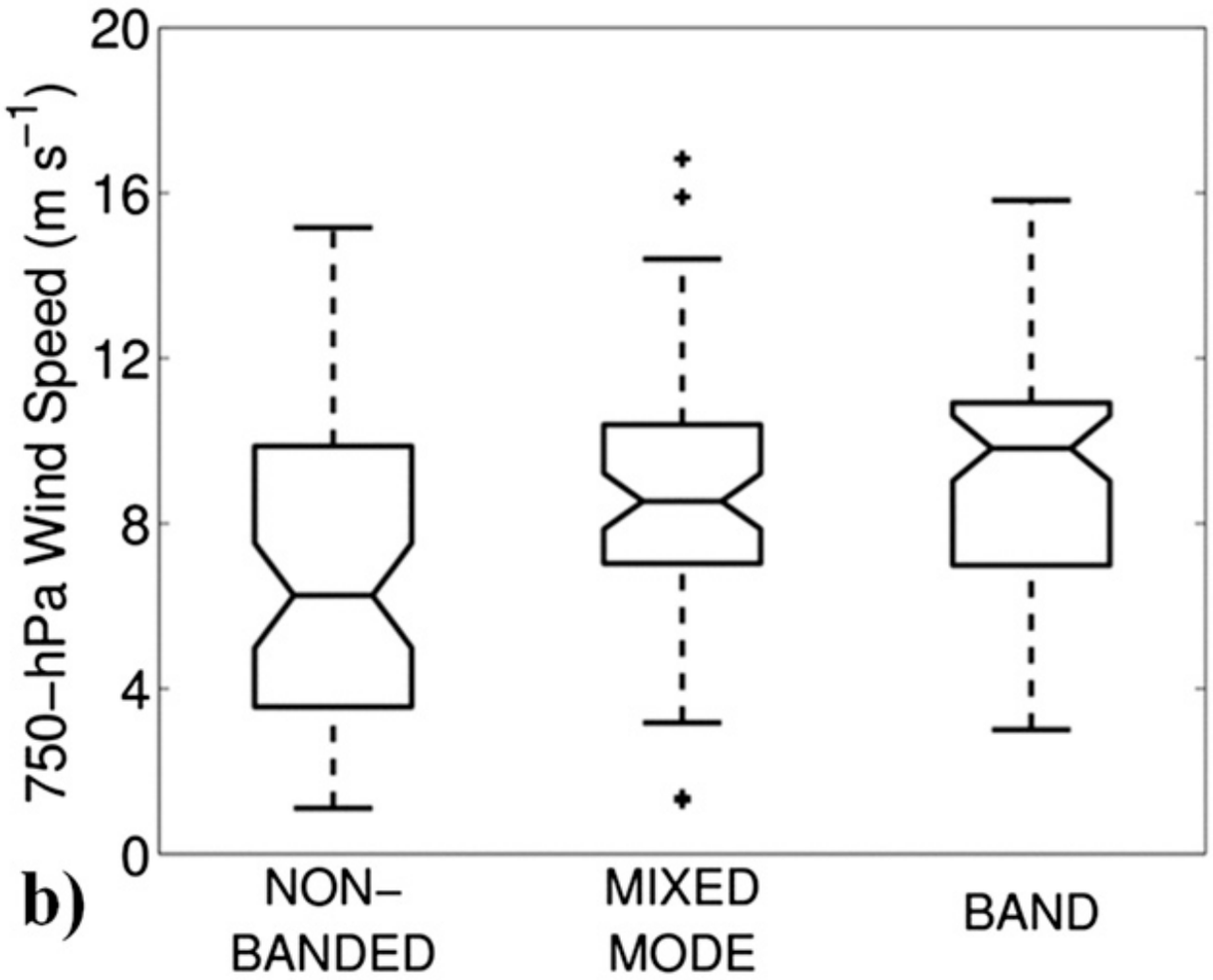


FIG. 13. Profiles of median RH (%) on days with GSLE.

How well can environmental parameters indicate GSLE mode?





The morphology differentiation factor U/L (wind speed divided by fetch) proposed by Laird et al. (2003b) in the Great Lakes shows some utility for GSLE.

Values of U/L were calculated using the 800-hPa wind speed, the level at which the relationship between U/L and GSLE mode was found to be strongest.

How well can 700-500 mb lapse rate diagnose GSLE coverage?

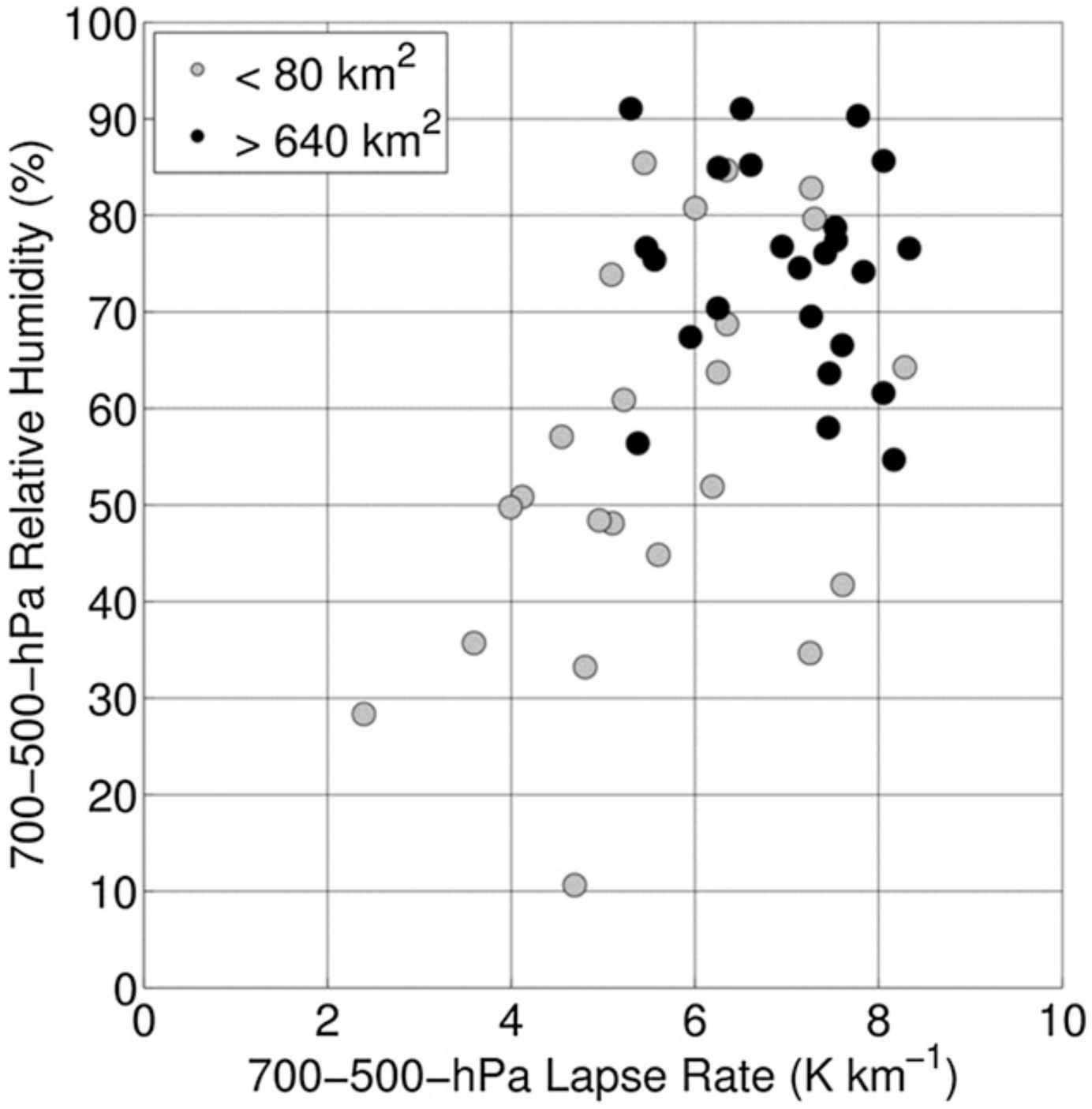


FIG. 17. GSLE coverage (area extent of radar echoes ≥10 dBZ; km^2) vs 700–500-hPa lapse rate and RH.

Utility of various forecast parameters for GSLE

TABLE 3. Utility of various forecast parameters, where $N_{soundings}$ is the total number of soundings that meet the given criteria, N_{GSLE} is the number of soundings that meet the criteria and are associated with GSLE, FO is the frequency of occurrence of GSLE, FAR is the false alarm rate, and POD is the probability of detection.

Condition	$N_{soundings}$	N_{GSLE}	FO (%)	FAR (%)	POD (%)
$\Delta T \geq 16°C$	1432	275	19	81	91
$\Delta T \geq 22°C$	365	120	33	67	47
$\Delta T \geq 25°C$	38	19	50	50	12
$\Delta T \geq 16°C$ and shear $< 60°$	936	194	21	79	72
$\Delta T \geq 16°C$, shear $< 60°$, and no stable layers	619	145	23	77	55
$\Delta T_{excess} \geq 0$	1134	264	23	77	96
$\Delta T_{excess} \geq 2$	673	203	30	70	79
$\Delta T_{excess} \geq 0$ and $RH_{850–700} > 55\%$	884	236	27	73	94
$\Delta T_{excess} \geq 2$ and $RH_{850–700} > 55\%$	529	189	36	64	79

$$FO = N_{GSLE}/N_{soundings}$$

$$FAR = 1 - FO$$

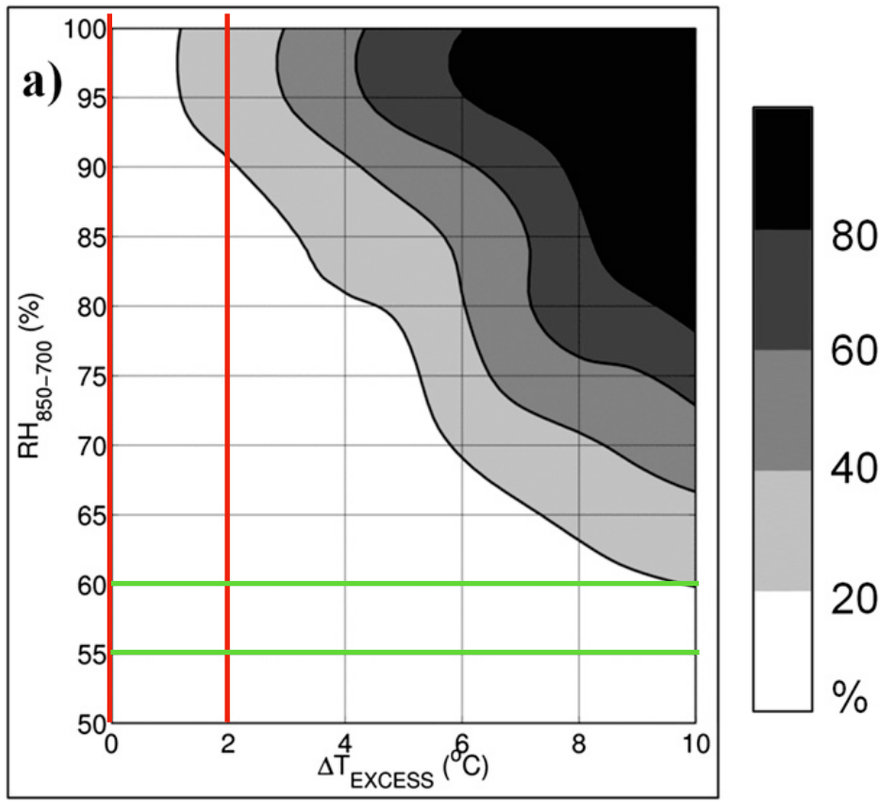
$$POD = \frac{TP}{TP + FN}$$

True Positive $TP = N_{GSLE}$

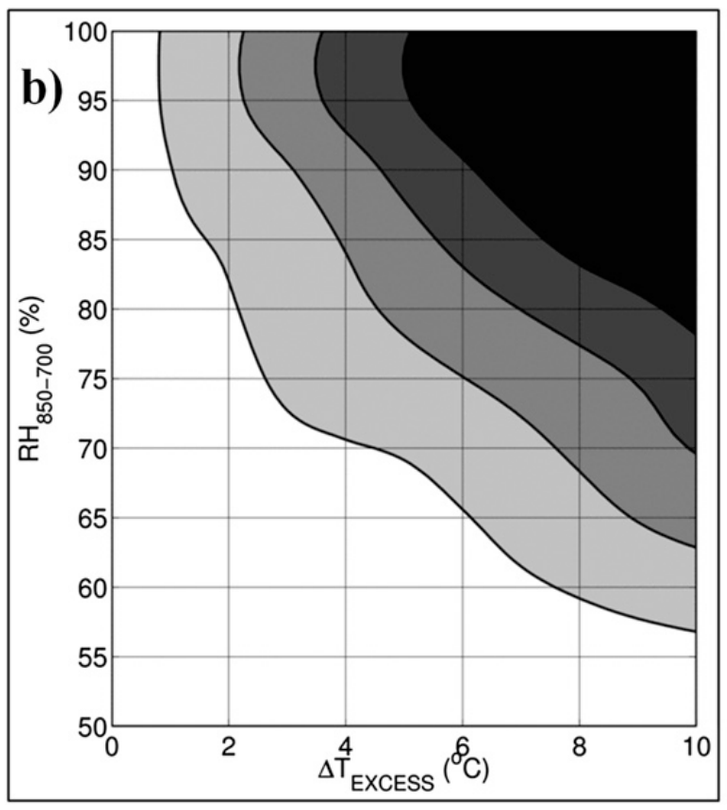
False Negative FN = GSLEs that occurred but were not predicted

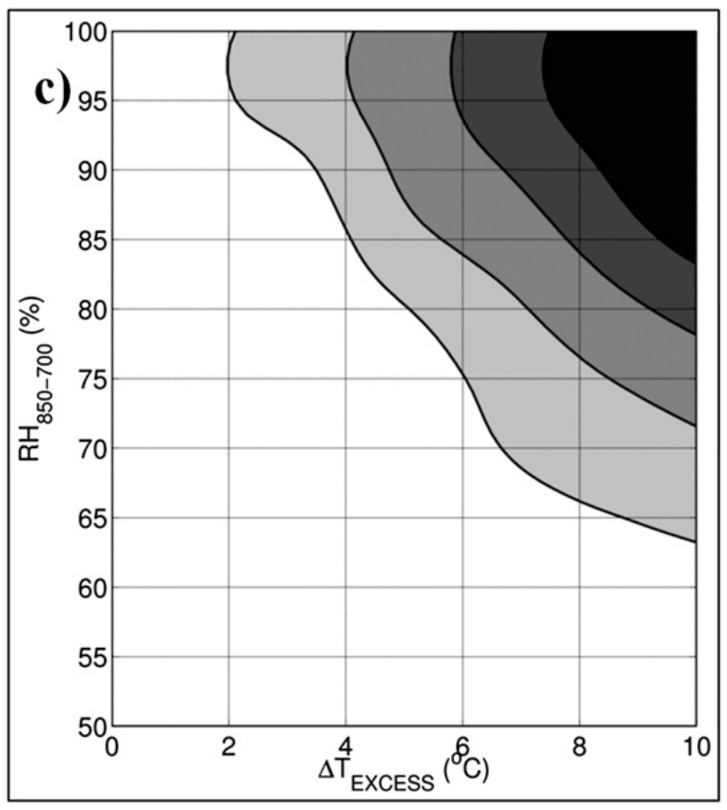
Probabilistic Forecasting

all 700-mb wind directions



700-mb wind direction 290-360 deg





700-mb wind direction 1-289 deg

FIG. 15. (a) Fraction of soundings with GSLE (%, shaded according to scale at right) as a function of ΔT_{excess} (°C) and $RH_{850–700}$ (%). (b) As in (a), but for 700-hPa wind directions 290°–360°. (c) As in (a), but for 700-hPa wind directions 1°–289°.

NWP RH Forecast Skill

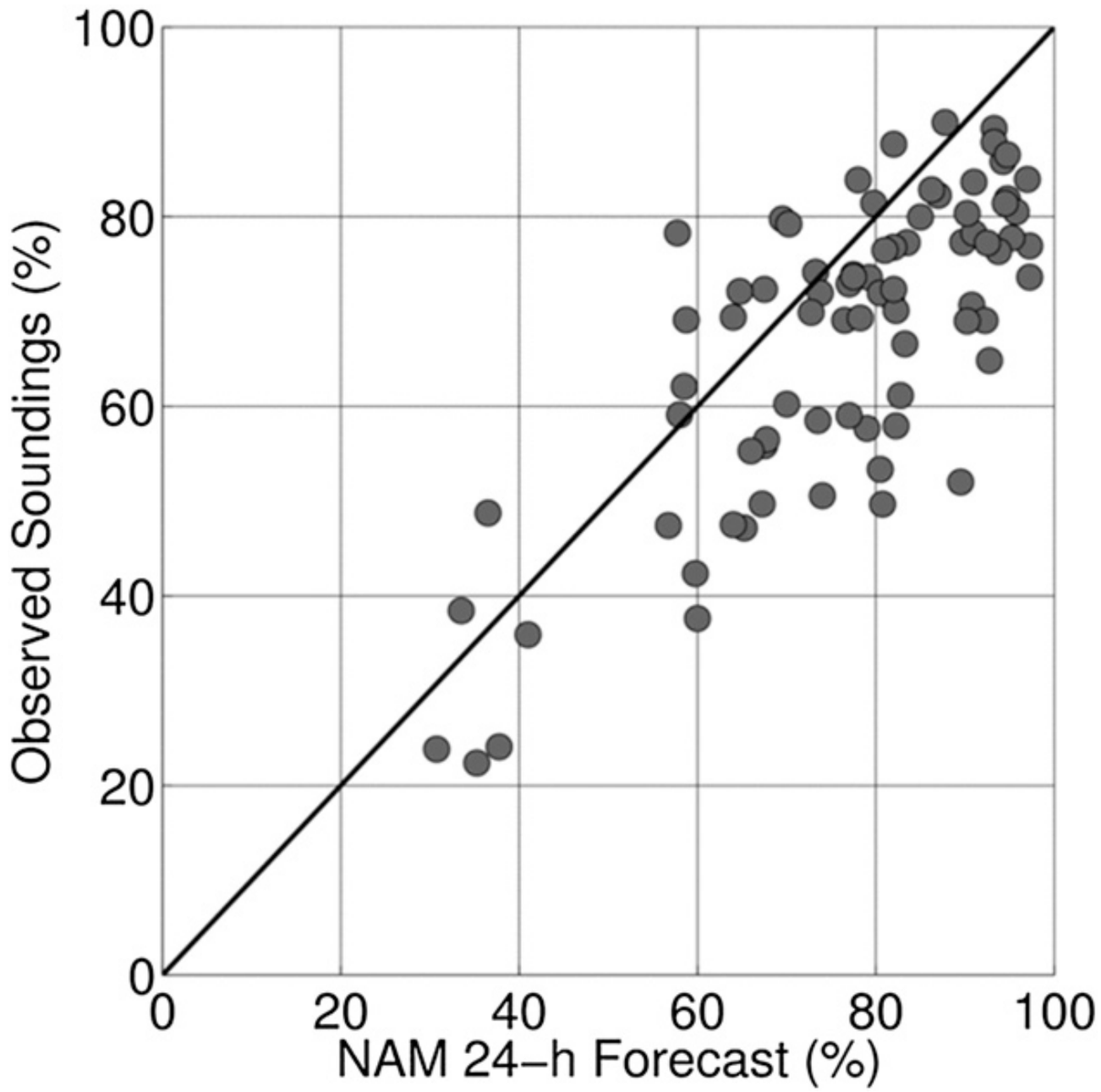


FIG. 16. Observed 850–700-hPa RH (%) from KSLC soundings vs 24-h NAM forecasts, from the 2008/09 and 2009/10 cool seasons. Diagonal line indicates a perfect forecast.