# FORECASTING LIGHTNING OCCURRENCE BEYOND NOWCASTING

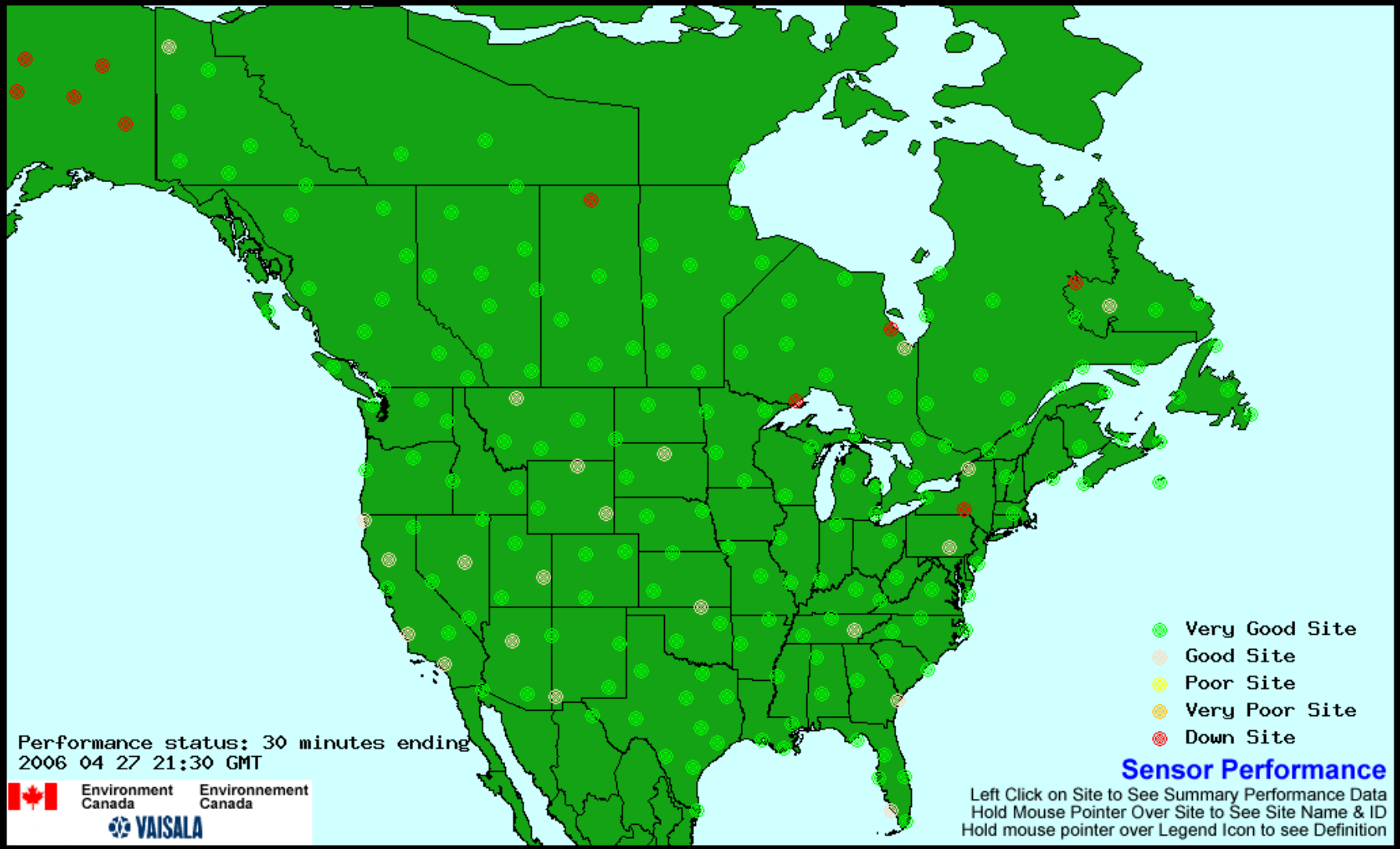
William R. Burrows

Environment Canada – Science and Technology Branch
Cloud Physics and Severe Weather Research Section
Downsview, ON
and
Hydrometeorology and Arctic Lab Group
Edmonton, AB

CMC/RPN people who's help is much appreciated:
Stéphane Bélair,
Michel Valin, Yves Chartier + service.rpn
Richard Verret, Gerard Croteau
Lewis Poulin, Vanh Souvanlasy

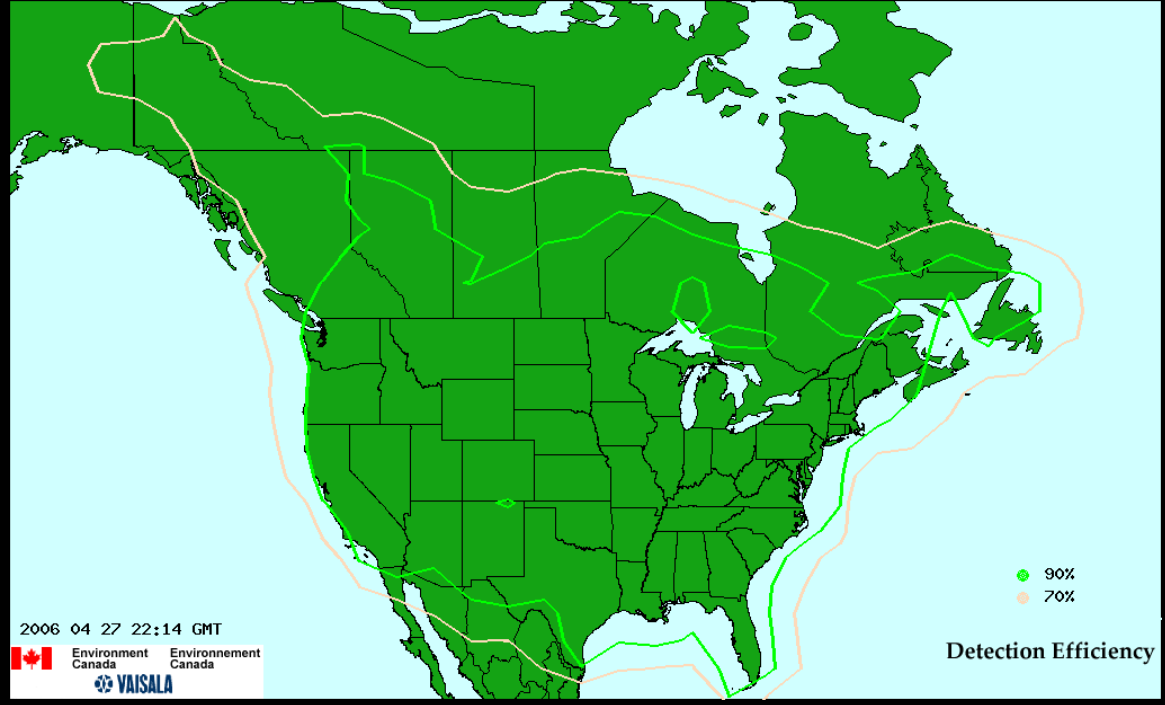
# INTRODUCTION

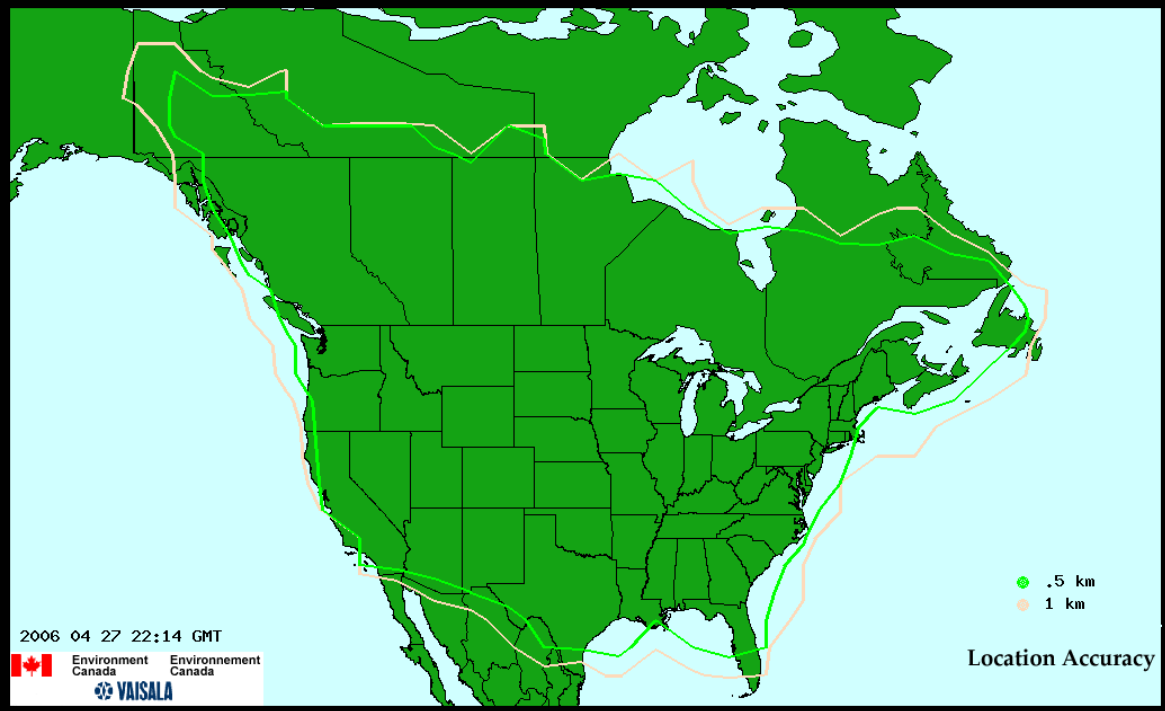
- Canada - vast area – convection occurs somewhere in all months
- 1-2 day lightning forecasts needed for public & forestry agencies, ~12 hours for aviation
- continuous space-time lightning detection since 1998 over southern Canada – large scale occurrence patterns in time and space are known
- lightning occurrence is episodic, large diurnal variation (Burrows et al., *Atmos.-Ocean*, 2002; Orville et al., *MWR*, 2002)
- lightning not directly forecast by the Canadian Meteorological Center's (CMC) operational NWP model (GEM - Côté et al., *MWR*, 1997 )
- an effective approach to forecast lightning beyond a few hours is statistical models using NWP output (Burrows et al., 2005)
- GEM $\Delta x$ =15 km … expect resolution accuracy to ~6-8$\Delta x$ … about 90-120 km




North American Lightning Detection Network

Green = 99-100% Up Time
Good Site = 83-98% Up Time
Poor Site = 50-82% Up Time
Very Poor Site = 17-49% Up Time
Down Site = 0-16% Up Time


90%
70%
2006 04 27 22:14 GMT
Environment Canada
Environnement Canada
VAISALA
Detection Efficiency


.5 km
1 km
2006 04 27 22:14 GMT
Environment Canada
Environnement Canada
VAISALA
Location Accuracy

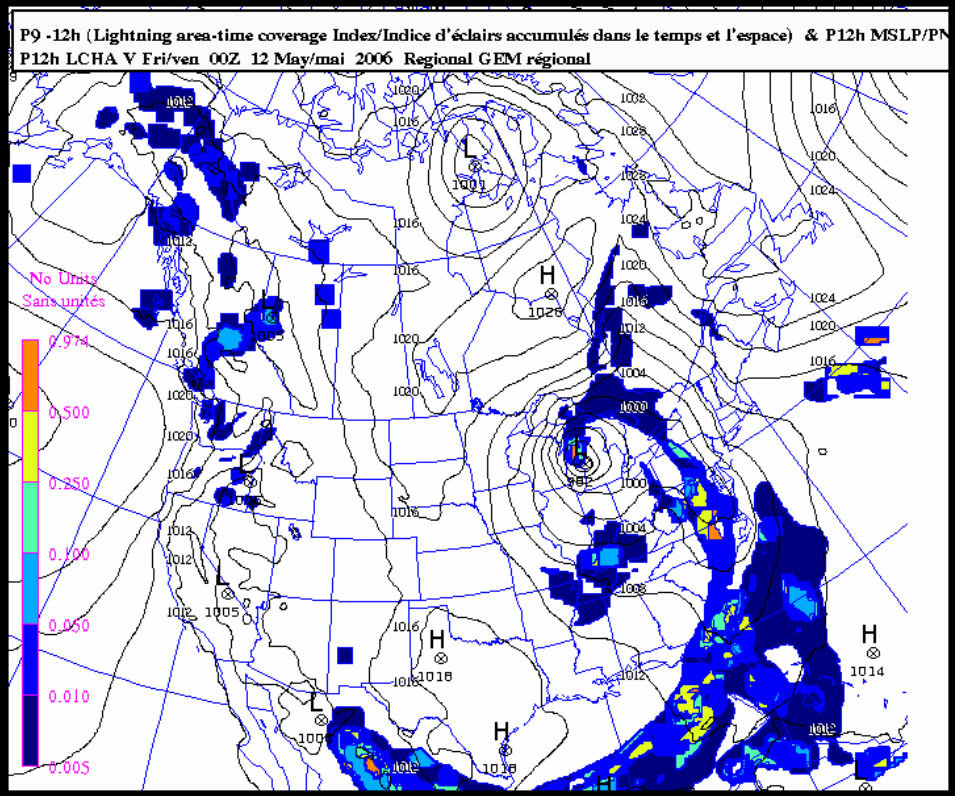
# An approach to statistical lightning forecasts

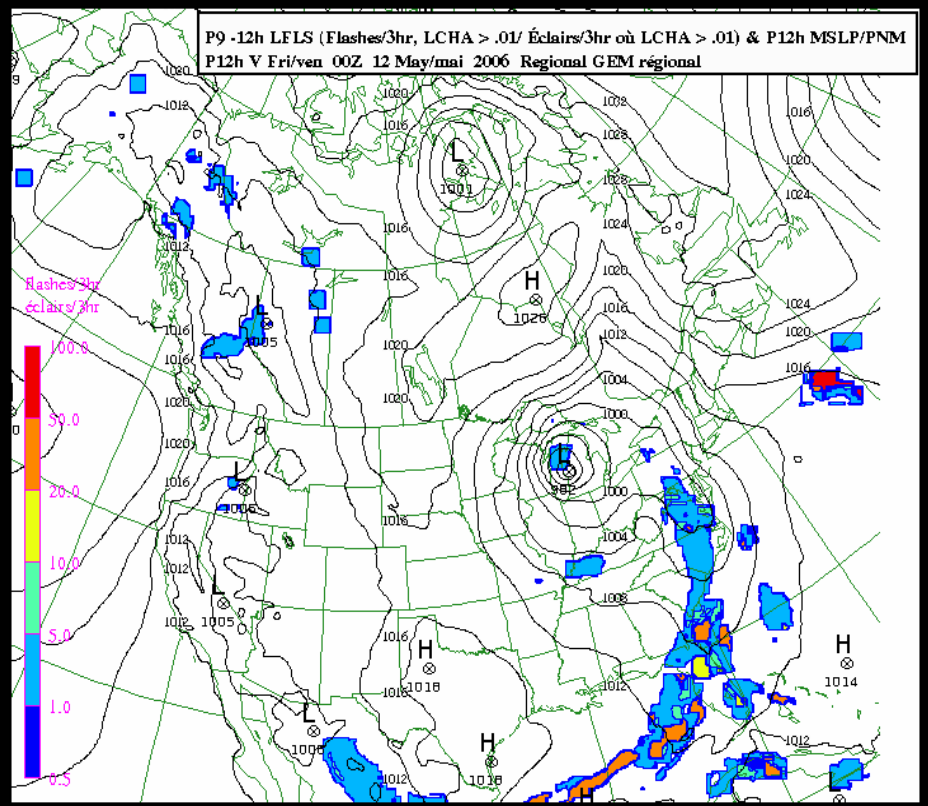
similar to “time-offset MOS” (Burrows, *MWR,* 1985)

- training data: match observed lightning with predictors derived from archived hourly 6-12 hr GEM prog data covering the 24 hr diurnal period …. 00Z run - covers 06-18 Z
  12Z run - covers 18-06 Z

- modeling: fit the predictand with a statistical algorithm

- forecasting: apply models in real time with predictors from latest NWP run for all 24-hr diurnal periods (0-24 hr, 24-48 hr, and longer)


P9 -12h (Lightning area-time coverage Index/Indice d'éclairs accumulés dans le temps et l'espace) & P12h MSLP/PN
P12h LCHA V Fri/ven 00Z 12 May/mai 2006 Regional GEM régional
No Units
Sans unités
0.974
0.500
0.250
0.100
0.050
0.010
0.005


P9 -12h LFLS (Flashes/3hr, LCHA > .01/ Éclairs/3hr où LCHA > .01) & P12h MSLP/PNM
P12h V Fri/ven 00Z 12 May/mai 2006 Regional GEM régional
Flashes/3hr
éclairs/3hr
100.0
50.0
20.0
10.0
5.0
1.0
0.5

# New Statistical Lightning Forecast Models

- forecast anywhere GEM does; continuous (no "box boundaries"); run year-round; 3-h intervals to 48 hr
- widespread forecaster use in CMAC west, PASPC, PYSPC
- 2 predictands: (1) LCHA time-area coverage index ("chances") of lightning
  (2) LFLS flash rate (nearest grid point count) (flashes / 3-h)
- predictors: two sources
  (1) major "environment" predictors found from current models
  (2) GEM convective parameterization (deep & shallow)
  - most predictors calculated hourly, some 3-hourly
  - set LFLS=0 & LCHA=0 where MSL pressure ≥ 1025 mb and Showalter index ≥ +5

- predictands & predictors calculated on
  moveable 9*9 grid-point box centered on each grid point (i±4, j±4)

- 8 models per predictand … 1 for each diurnal 3-h period (16 models total)

- training data: 1 day per month Mar.-Sep. (entire N. Am. window each day), thus … updates easier as GEM changes … could be “automated”

Images available about 0630Z and 1830Z on Ron Goodson's MSC internal website ("mrsid") :

http://ronlx.edm.ab.ec.gc.ca/

Archived Individual .png Images :

click on "Satellite and Maps Archive"

click on drop-down menu "Data Source" → Choose "LIGHTNING"

The "most recent" forecasts are animated:

http://ronlx.edm.ab.ec.gc.ca/lightning.html

links on CMAC - west & PASPC Ops web-pages ….

# Predictors

(1) Environment (mostly from summer severe weather programs):

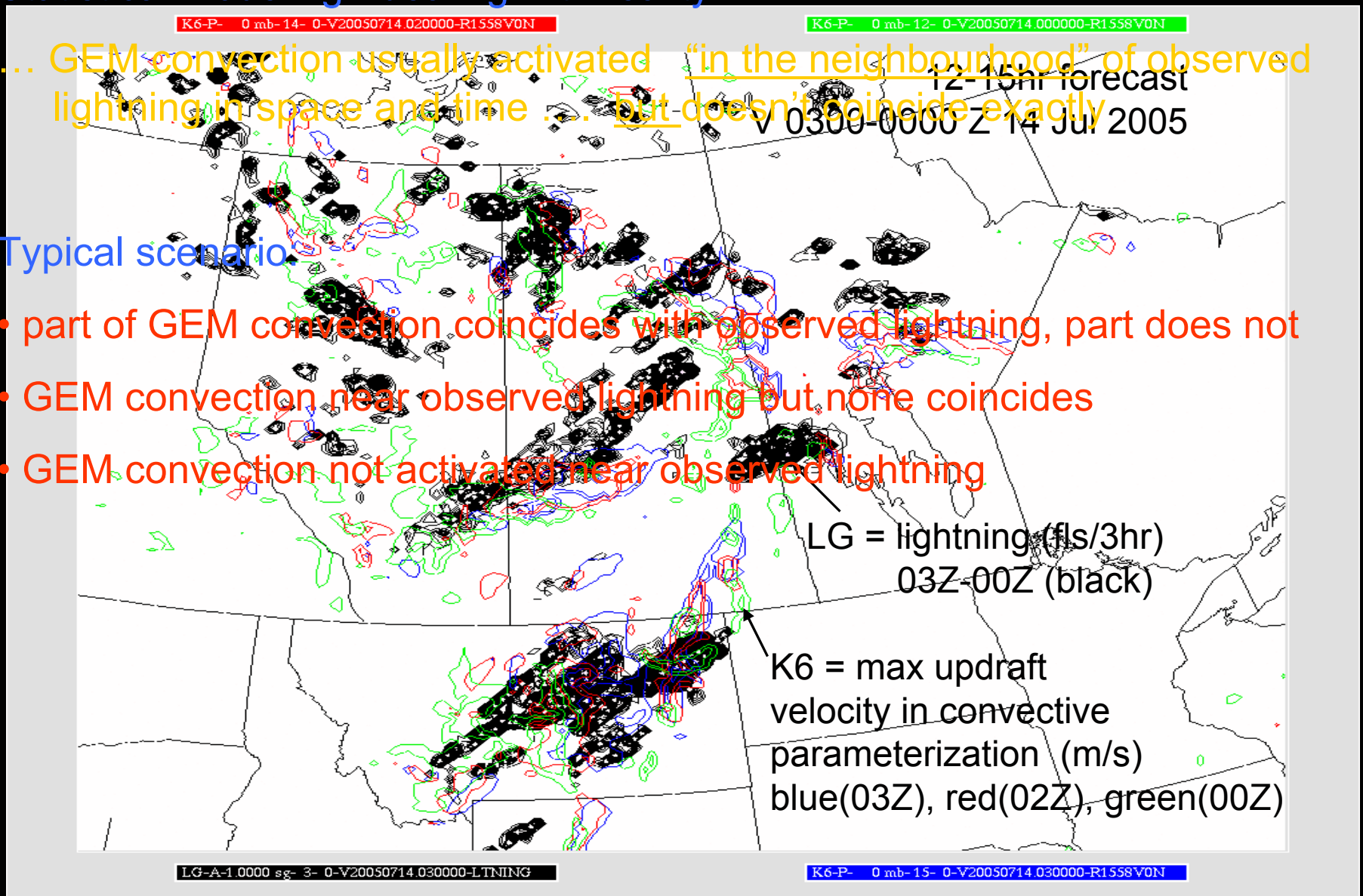
- hourly MSL pressure
- " max lifted parcel height (entrainment)
- " total precipitable water and PW above 700 hPa
- " wind shear (700 hPa – sfc): $(\Delta u^2 + \Delta v^2)^{1/2}$
- " Indices: Showalter index ; Lifted index (max in lowest 50 mb)
- " severe storm index (SSI)
- " SWEAT index
- " net CAPE: (CAPE – CIN)
- " 700 mb vertical motion
- " boundary layer helicity
- 3-h change of (500-1000) hPa thickness

(2) GEM Convective Parameterization:

- hourly vertical integrals of cloud liquid water and cloud ice
- " cloud location : base, top, depth
- " precipitation rates: deep & shallow convection
- " max updraft vertical velocity
- " max column $\dot{\theta}w$
- " K-F CAPE
- 3-hr accumulated implicit precipitation

## Statistical Modeling - dealing with reality …

… GEM convection usually activated "in the neighbourhood" of observed lightning in space and time … but doesn't coincide exactly




Typical scenario

- part of GEM convection coincides with observed lightning, part does not
- GEM convection near observed lightning but none coincides
- GEM convection not activated near observed lightning

what to do??? ….

One way: "spread out" (smooth) predictors and predictand …

# Lightning Predictands

box around a grid point at times ($t_{-3hr}$ to $t_{0hr}$) gives group of 324 point values to …calculate statistics from basic predictors to use as "derived" predictors

…calculate "derived" predictands

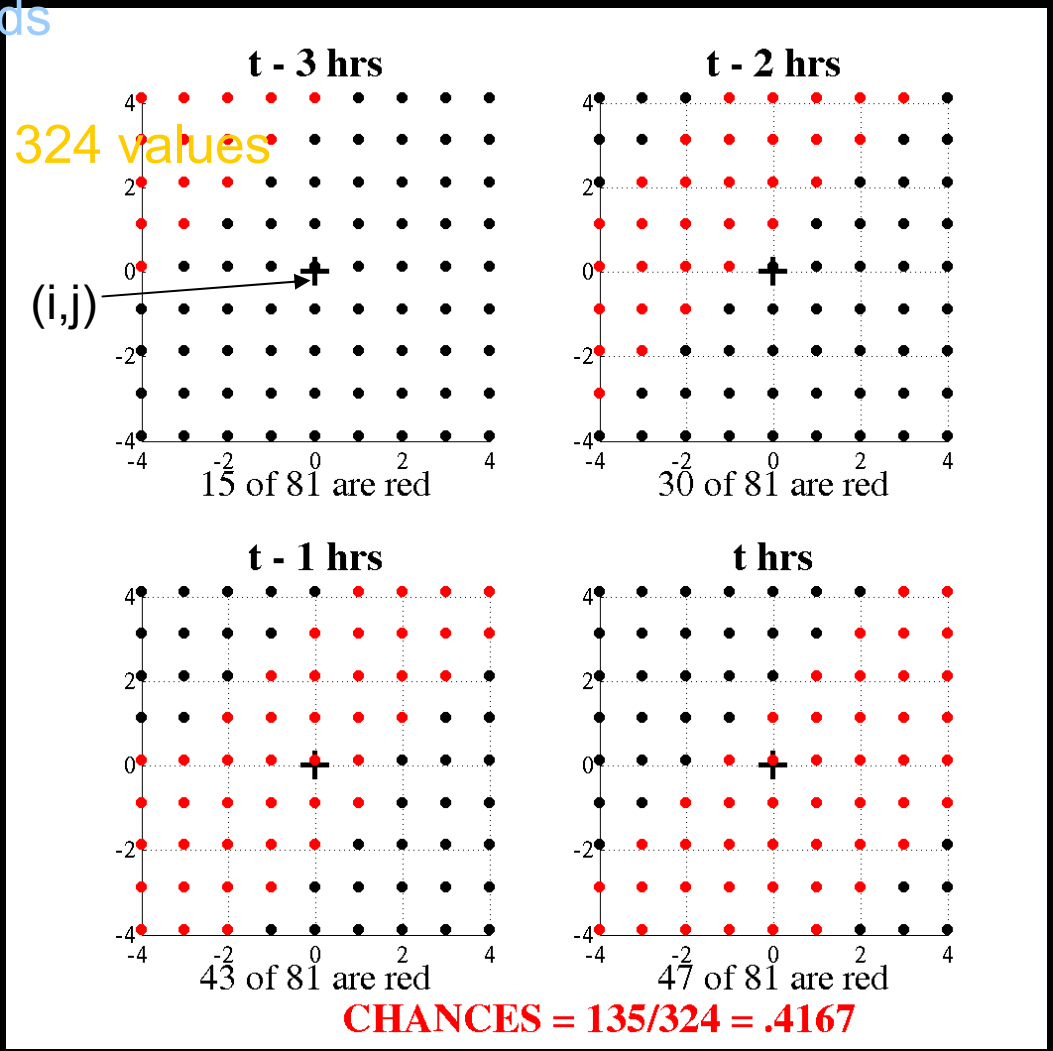
(1) LCHA ("time-area coverage") = fraction of 324 points where lightning occurred

Area of lightning moving by grid point (i,j)

Lightning occurs at RED points

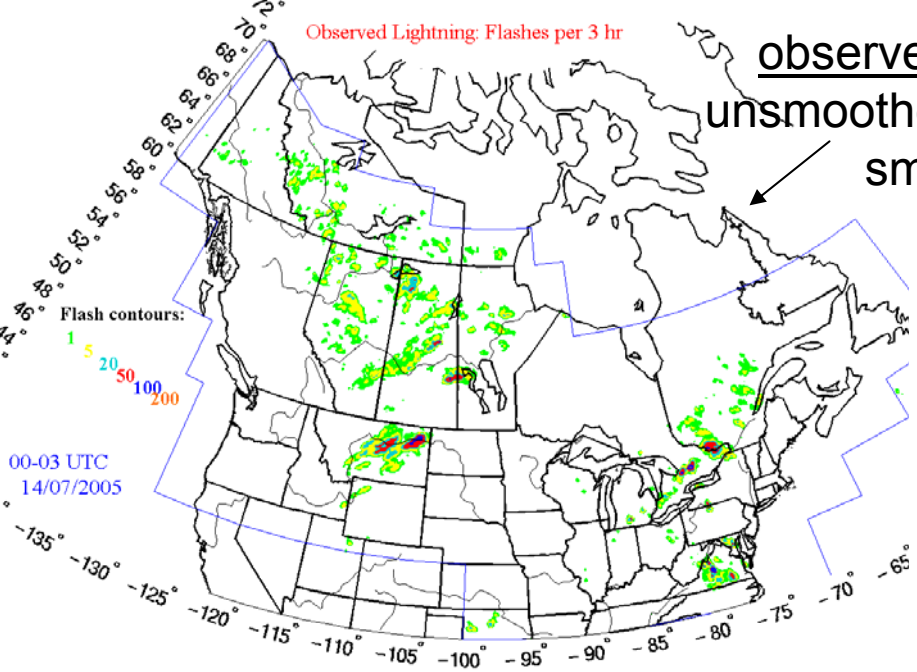
9*9 box at ($t_{-3hr}$ to $t_{0hr}$) gives 81*4 = 324 values

(2) LFLS ("Flash Rate") = average flash count where lightning occurred




- "areal-time coverage index" is like 3-hr "chance" or "risk" of lightning at point (i,j)

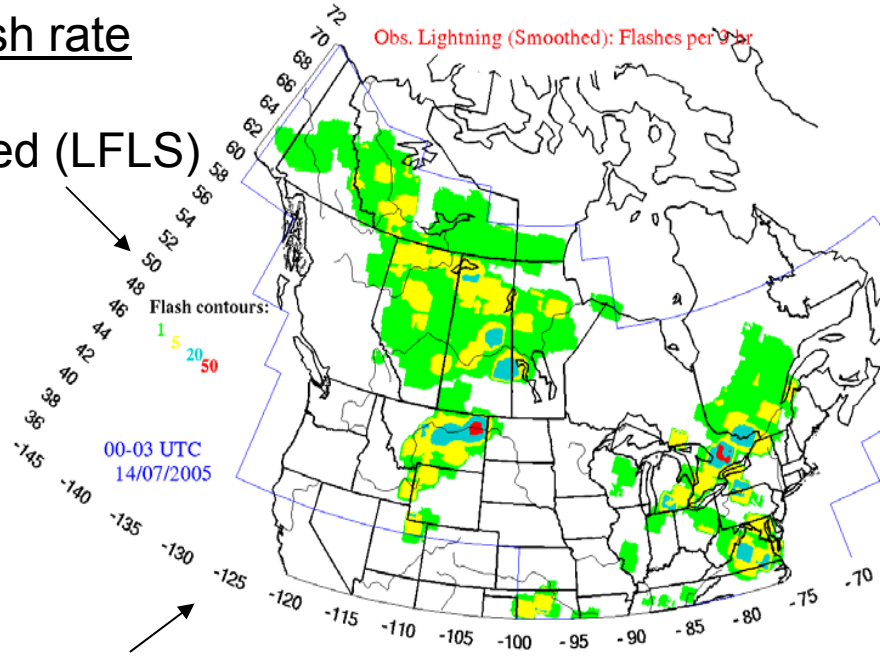
| LCHA | # Points (approx.) |
|---|---|
| .005 | 1-2 |
| .01 | 3-4 |
| .05 | 16 |
| .10 | 32 |




observed flash rate

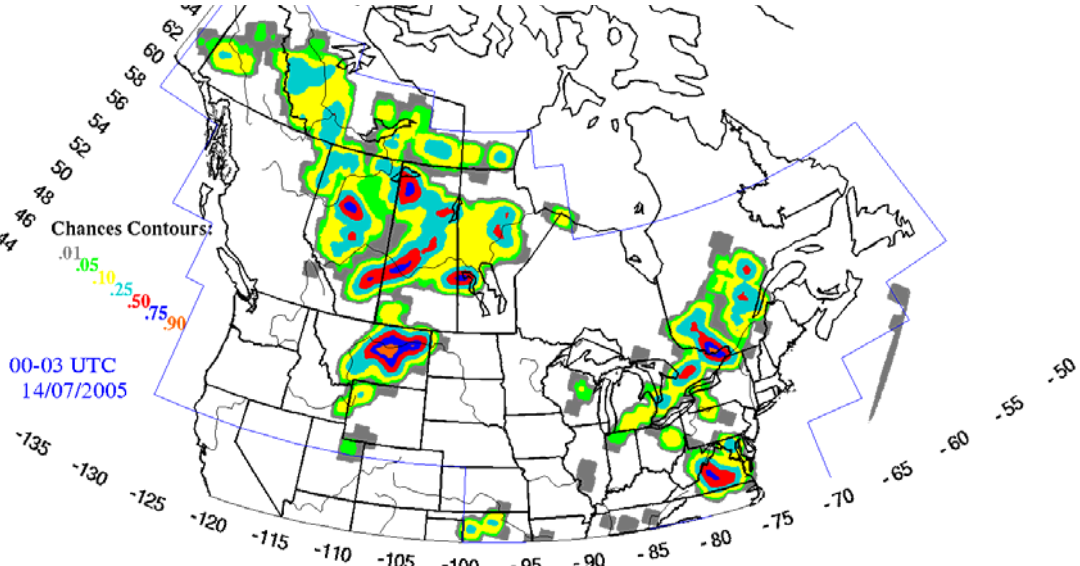
unsmoothed

smoothed (LFLS)




Predictands

observed “chances” (LCHA)




use threshold LCHA values to filter the LFLS forecast, i.e.

Keep LFLS forecast where LCHA > 0, .01, .05, .10, .25, etc.

“tune” LFLS forecast with LCHA threshold values for different regions, seasons, synoptic situations, diurnal times

# DERIVED PREDICTORS

thresholds chosen from histogram distribution or key values of basic predictors

predictors available hourly:

- fraction of 324 points where Showalter index < 0, < -2, <-5, <-10 °C
- " " " " " K-F updraft velocity > 0, 5,10,15,20,25,30,35 m/s
- " " " " " K-F cloud tops > 2, 4, 6, 8, 10, 12, 14 km
- mean updraft velocity for points with K-F updraft > 0 m/s

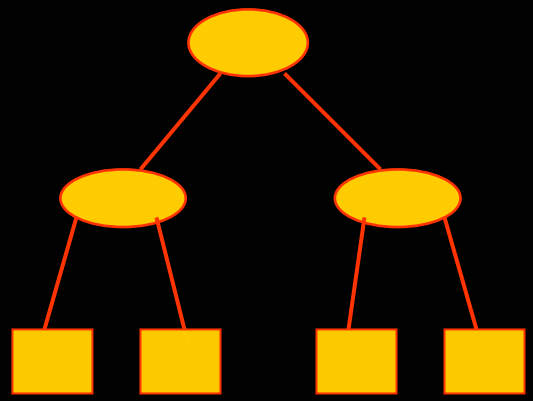
predictors available 3-hrly:

- fraction of 81 points with convective precip > 0
- mean/max convective precip. for points where it occurred
- max/min 3-hr thickness change (usually –tive for cold front, +tive for warm front)

DATA REDUCTION … reduces 165 predictors to 30-45

- keep predictors correlated > |.2| with predictand in training data overall and ≥95 percentile
- if some surviving predictors correlated > .9 with each other, keep the one correlated highest with the predictand

**Tree-Structured Regression (TSR):** available in R (rpart), CART, MATLAB (treefit)

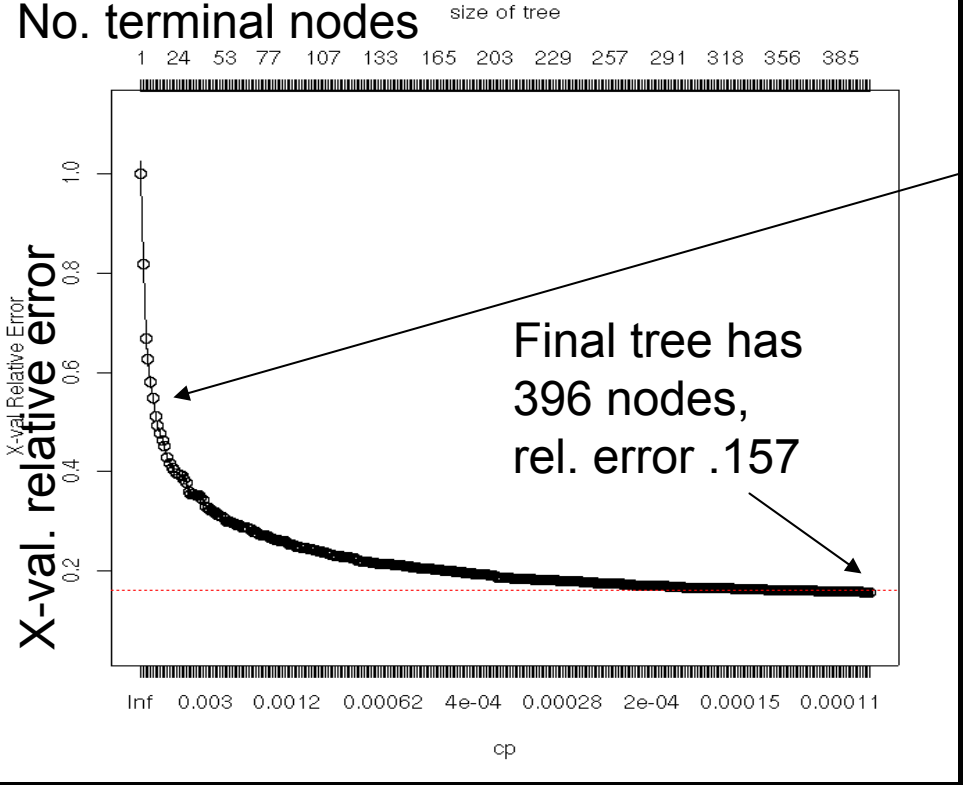


- at internal node, TSR finds threshold predictor value that splits it into two "child nodes" with max. reduction of variance …

  keep splitting until user-defined min. node population is reached or variance cannot be further reduced (terminal node)

  after each split, calculate tree error with independent *data or cross-validation … "best tree" is the one with minimum error*

- Nice Attributes: (1) predictor redundancy OK
  (2) fits distribution tails (if predictors available)
  (3) fit is ~continuous when many nodes




ry6 = fraction (of 324 points) where deep convection rain rate > $10^{-6}$ m/s

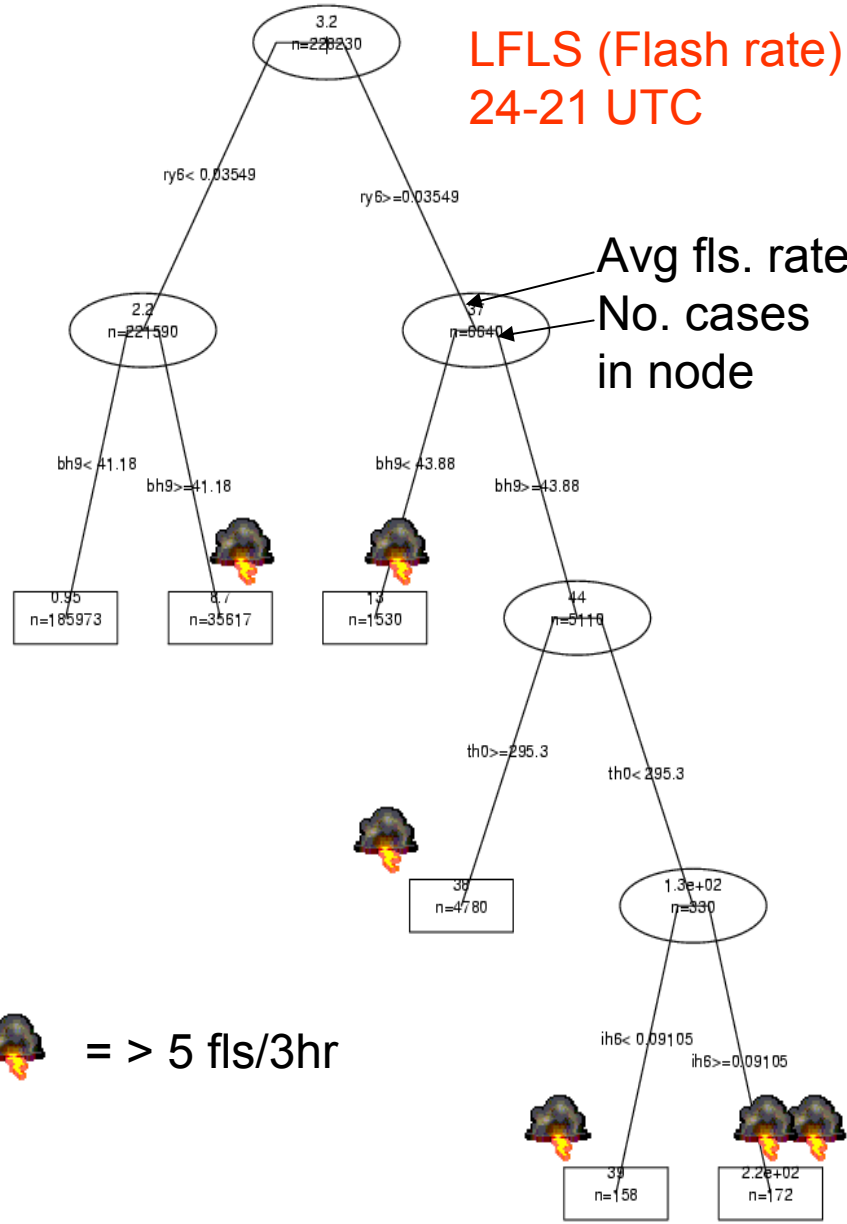
bh9 = mean environment lifted parcel max height (entrainment) (1000's ft)

th0 = max $\Theta_w$ (deg K)

ih6 = fraction precipitable water > 40 mm

Flash Rate: 2400 – 2100 UTC

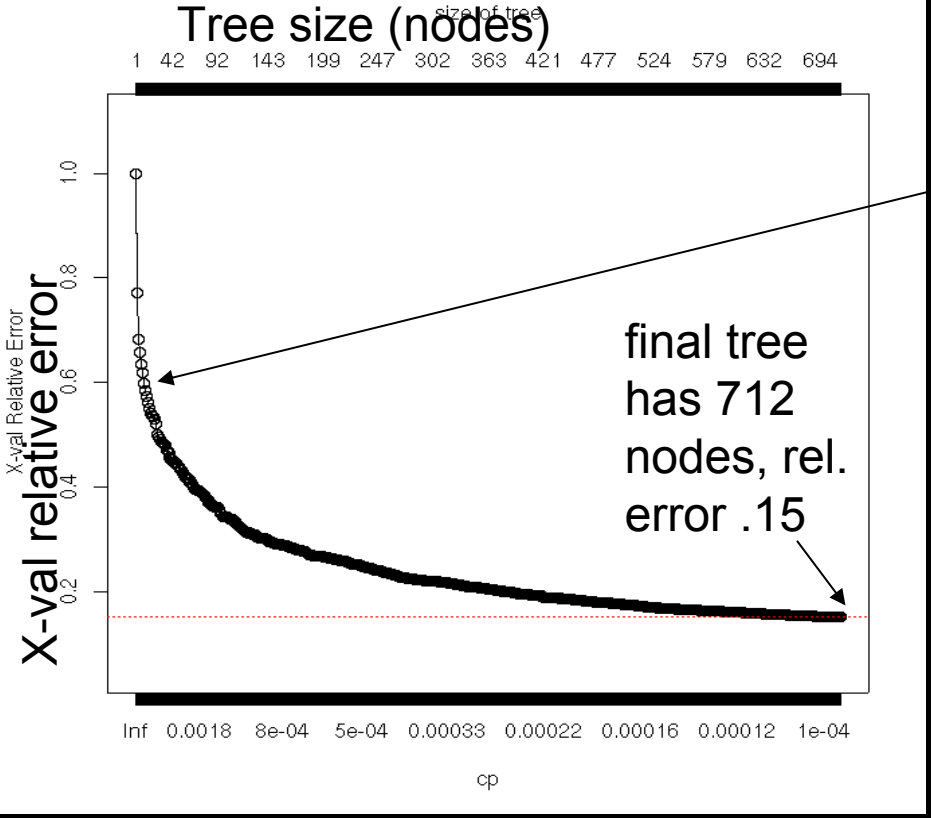
tree below has 6 terminal nodes, relative error .55



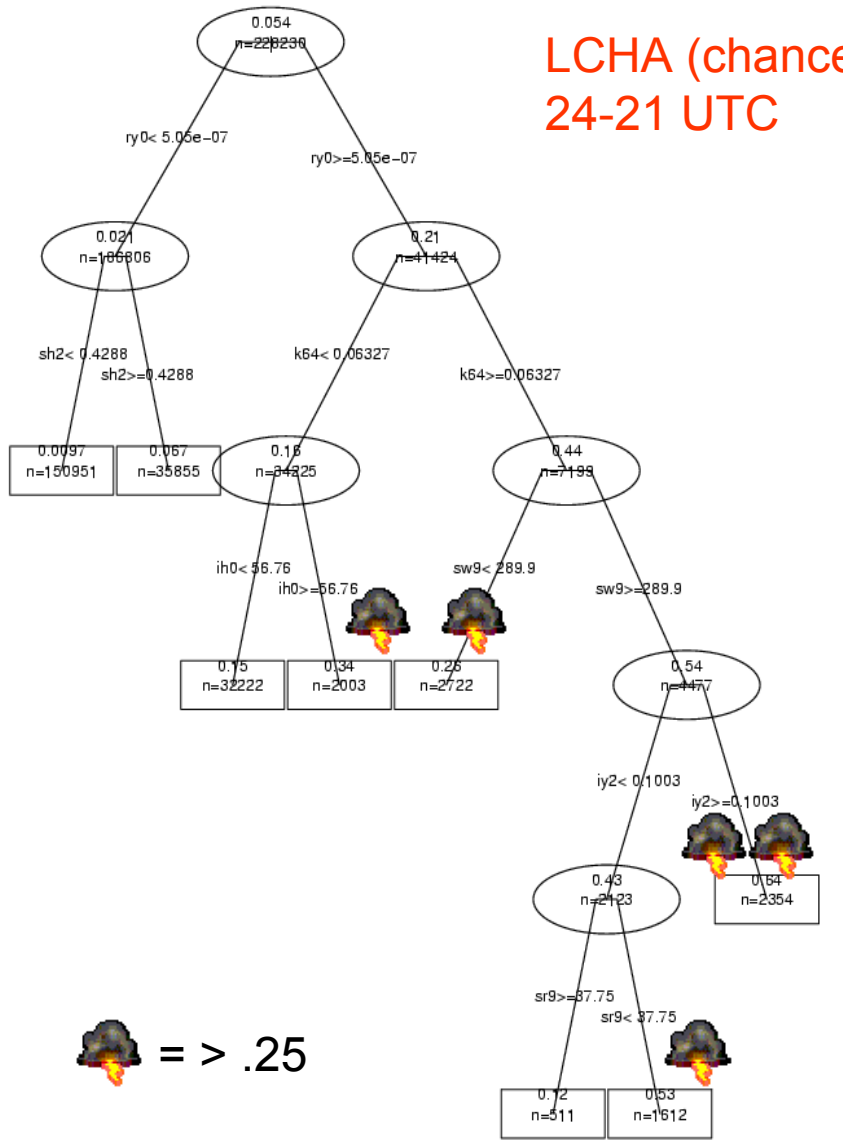

LFLS (Flash rate) 24-21 UTC

Avg fls. rate
No. cases in node

= > 5 fls/3hr




this tree has 8 terminal nodes, relative error 0.6




LCHA (chance
24-21 UTC

= > .25

ry0 = max deep convection rain rate (m/s)

sh2 = fraction of points Showalter index < 0

k64 = frac. where K-F updraft velocity > 20 m/s

ih0 = max precipitable water (PW) (kg/m$^2$)

sw9 = mean SWEAT index (deg K)

iy2 = fraction upper trop PW > 10 kg/m$^2$

sr9 = mean wind shear (700mb – sfc) (kt)

# HOW TO USE THE FORECASTS

LCHA and LFLS are the 2 primary forecasts – use them together to make a forecast better than either one

"best" forecast varies with season, synoptic situation, location, diurnal time

FL01, FL05, FL10, FL25 are the LFLS fcst filtered with the LCHA fcst –

FL01 = LFLS where LCHA >= .01 ( ltng at >3 of 324 data points)

FL05 = LFLS where LCHA >= .05 ( >16 of 324 data points)

FL10 = LFLS where LCHA >= .10 ( > 32 of 324 data points)

FL25 = LFLS where LCHA >= .25 ( > 81 of 324 data points)

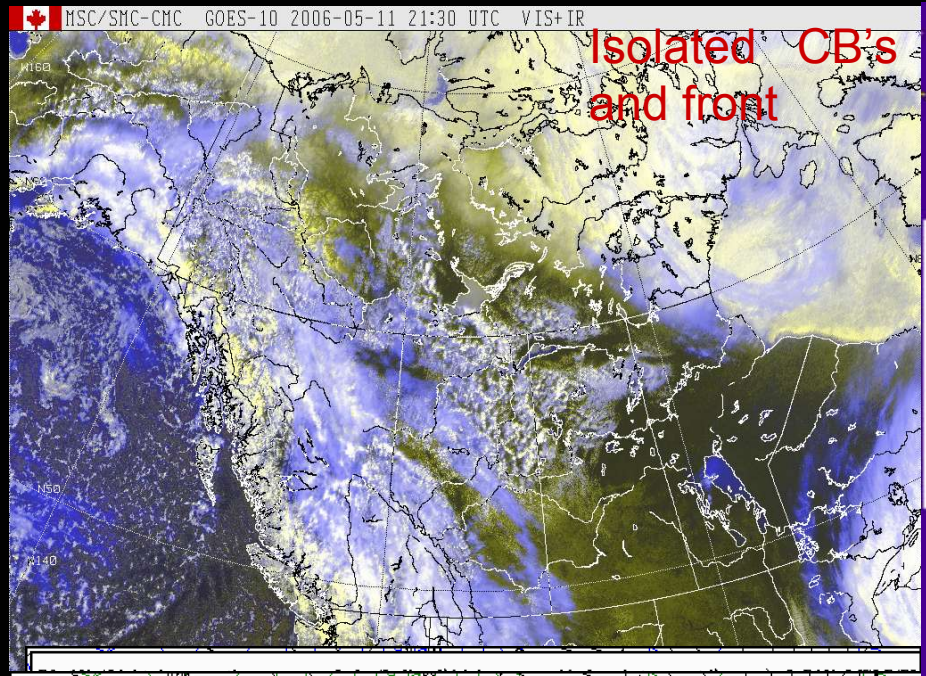
FL01 seems to work well for isolated, weak CB's not associated with fronts or associated with weak fronts

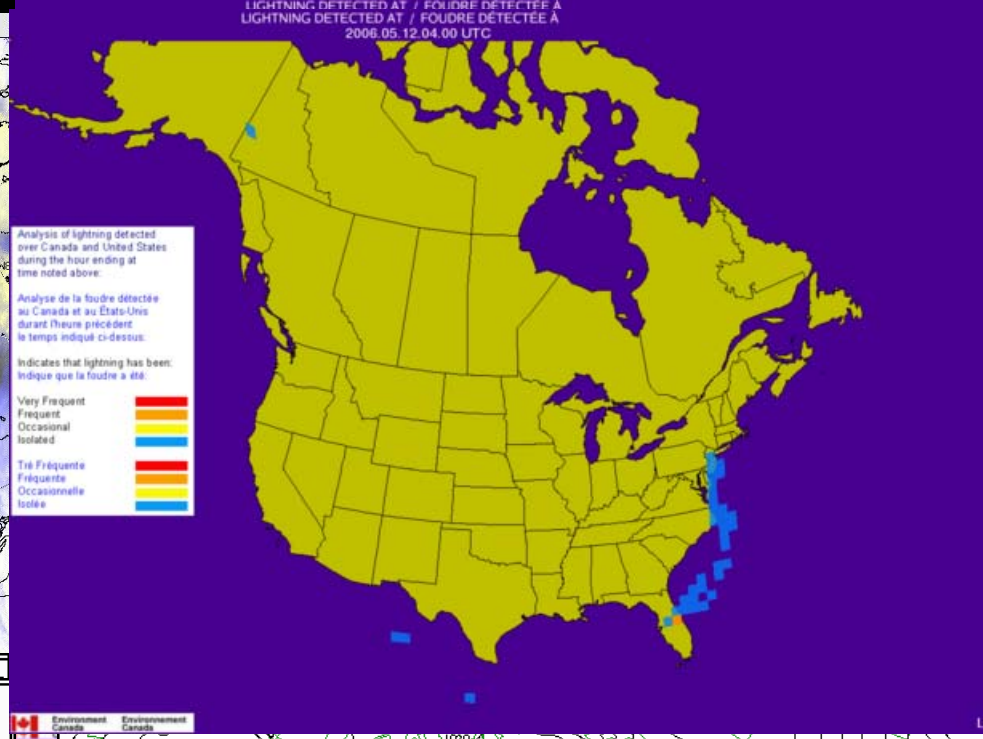
FL05 and FL10 seems to work well for CB's moving with large well defined fronts

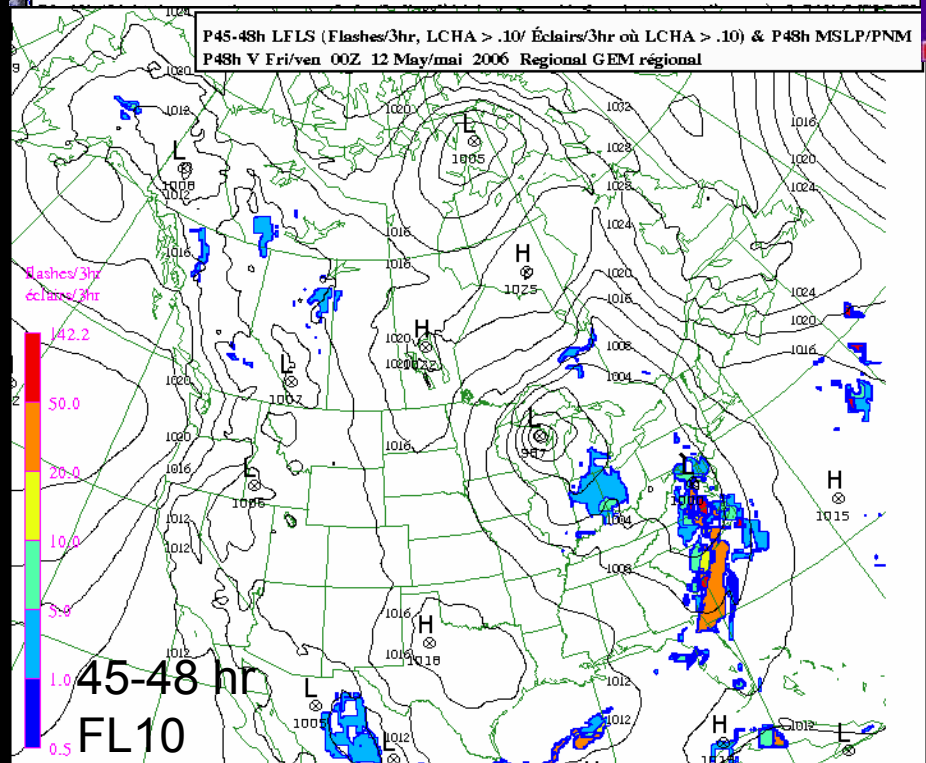
FL10 works well with most MCC's

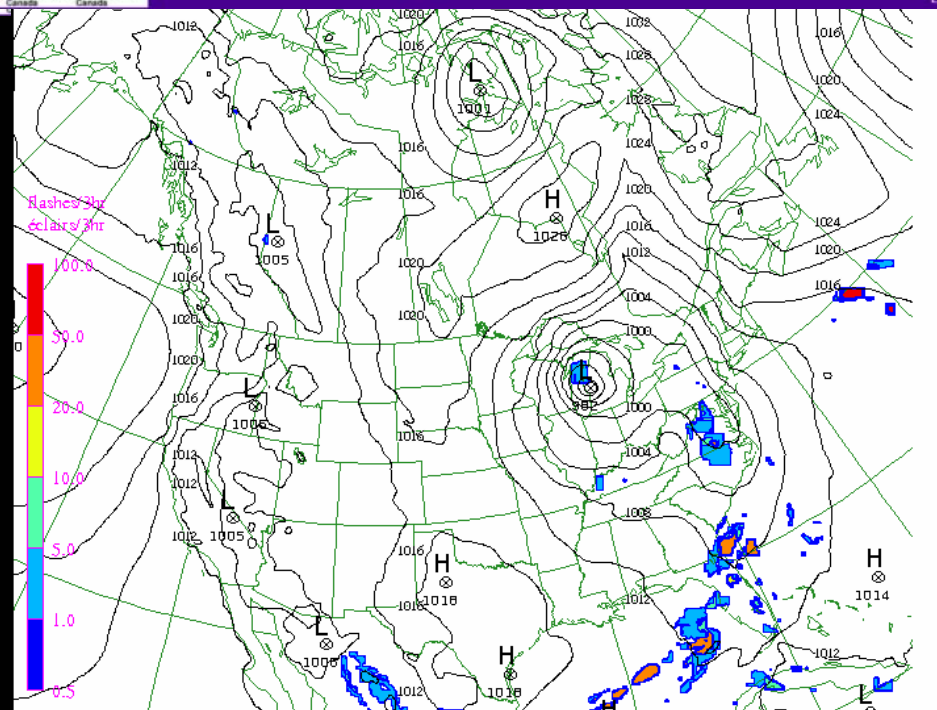
FL25 usually filters too much – but good for slow moving MCC's

DIURNAL: weak CB's 09-18Z … LCHA can catch areas FL01 filters out


MSC/SMC-CMC GOES-10 2006-05-11 21:30 UTC VIS+IR
Isolated CB's and front


LIGHTNING DETECTED AT / FOUDRE DÉTECTÉE À
2006.05.12.04.00 UTC
Analysis of lightning detected over Canada and United States during the hour ending at time noted above.
Analyse de la foudre détectée au Canada et au États-Unis durant l'heure précédent le temps indiqué ci-dessus.
Indicates that lightning has been: Indique que la foudre a été:
Very Frequent
Frequent
Occasional
Isolated
Très Fréquente
Fréquente
Occasionnelle
Isolée


P45-48h LFLS (Flashes/3hr, LCHA > .10/ Éclairs/3hr où LCHA > .10) & P48h MSLP/PNM
P48h V Fri/ven 00Z 12 May/mai 2006 Regional GEM régional
Flashes/3hr
éclairs/3hr
142.2
50.0
20.0
10.0
5.0
1.0
0.5
45-48 hr
FL10


Flashes/3hr
éclairs/3hr
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20.0
10.0
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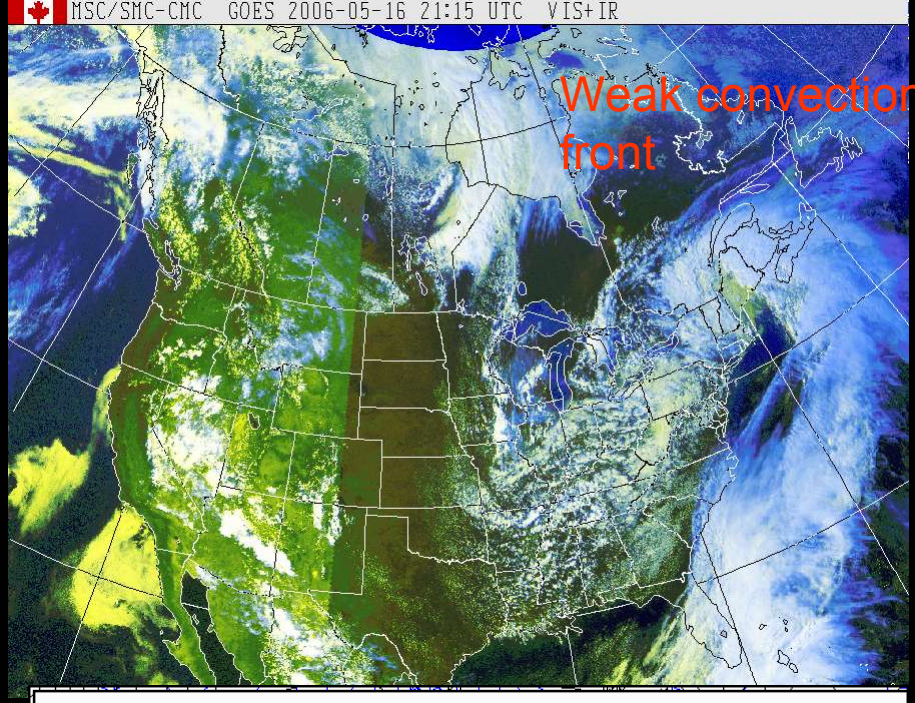
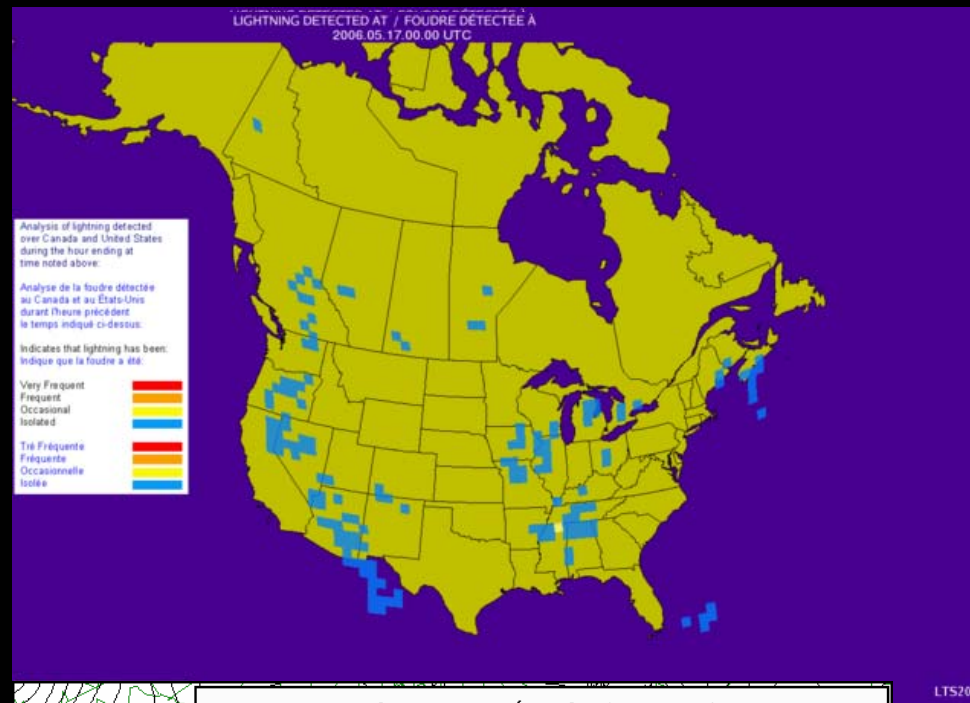
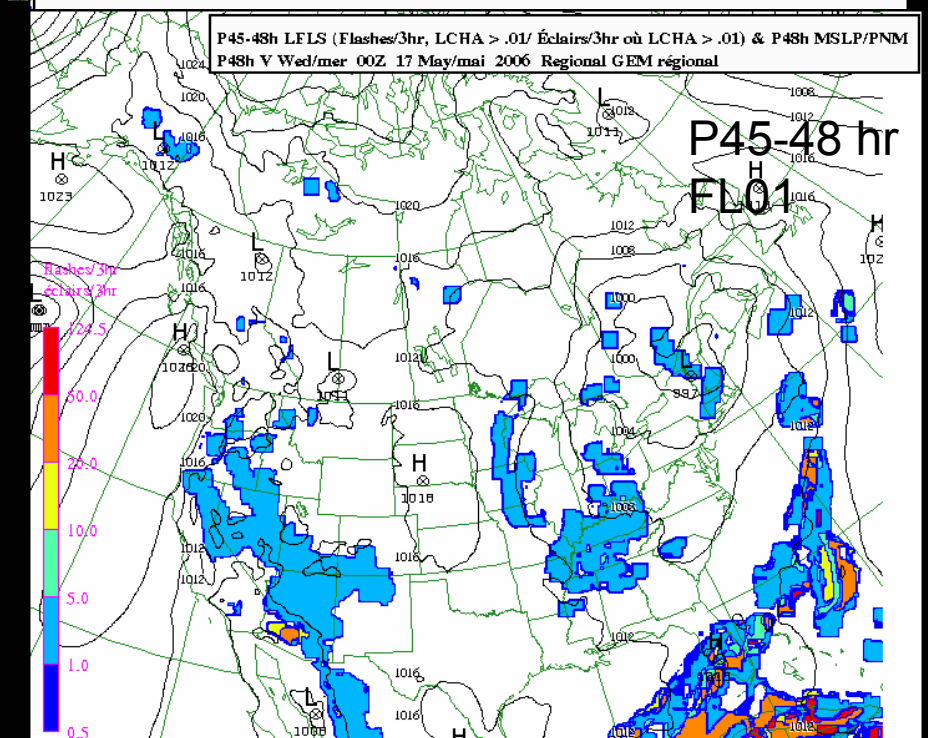
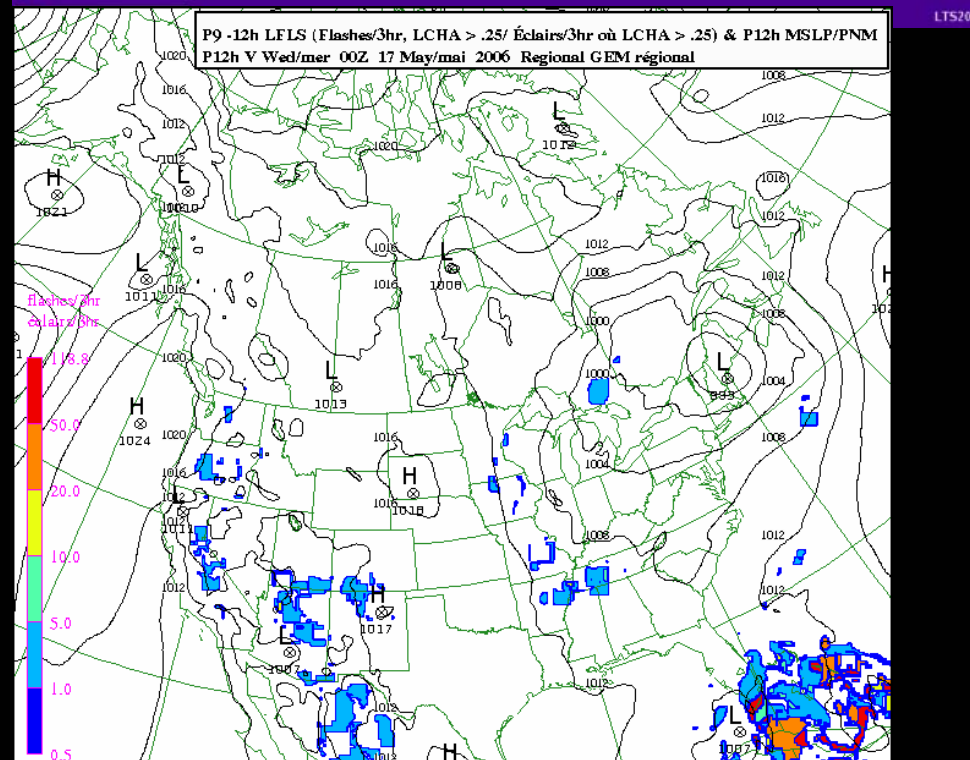
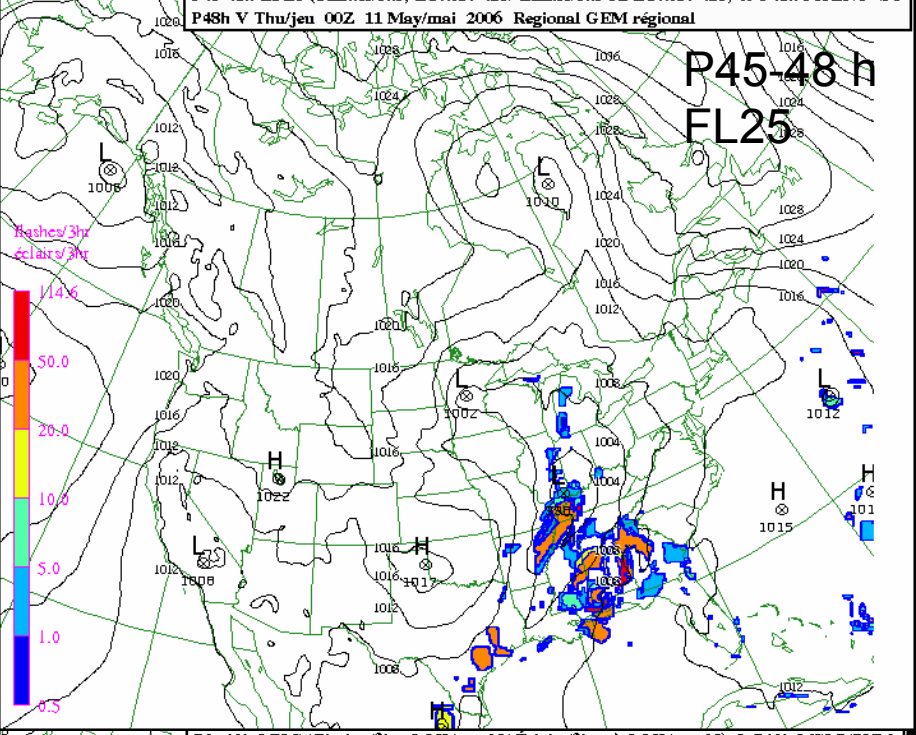
1.0
0.5

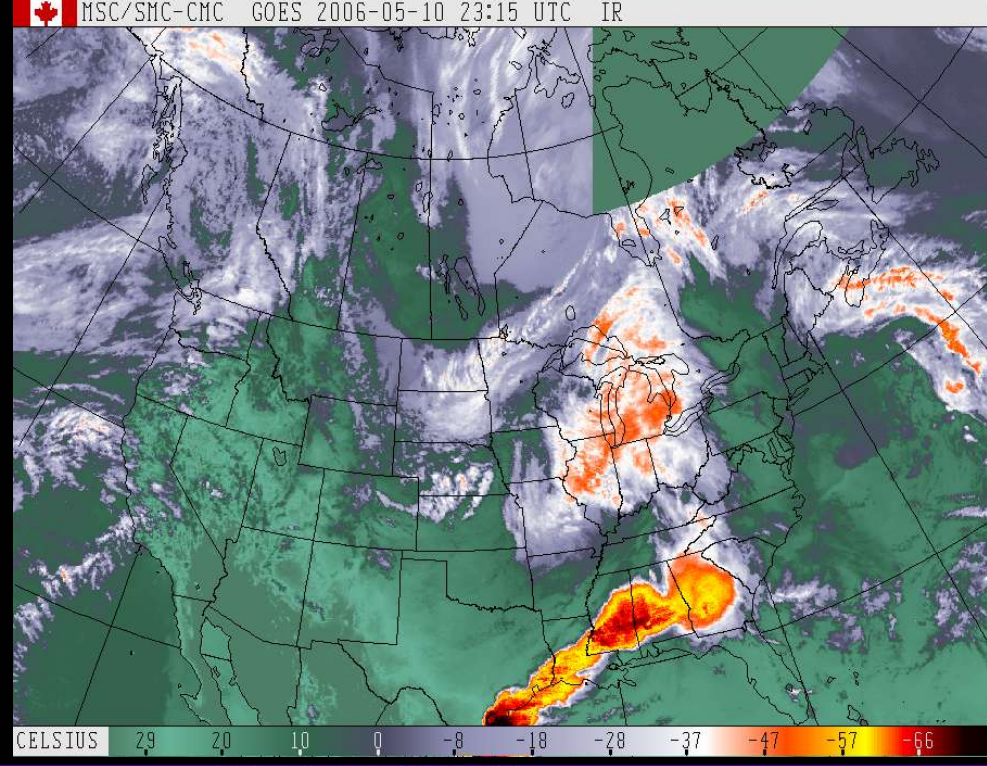

MSC/SMC-CMC GOES 2006-05-16 21:15 UTC VIS+IR
Weak convection, front

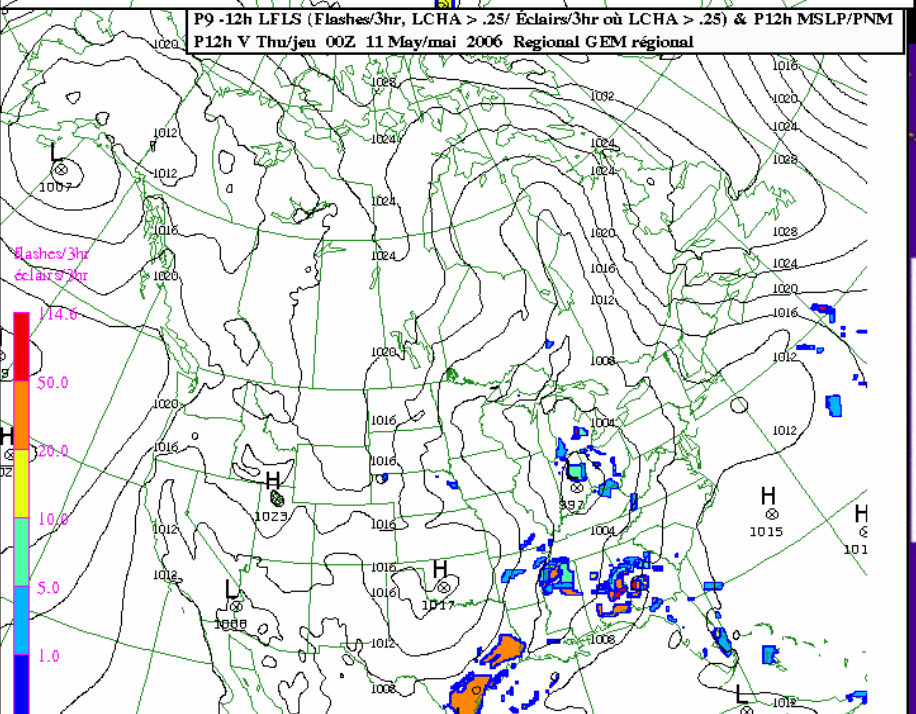

LIGHTNING DETECTED AT / FOUDRE DÉTECTÉE À
2006.05.17.00.00 UTC
Very Frequent
Frequent
Occasional
Isolated
Très Fréquente
Fréquente
Occasionnelle
Isolée

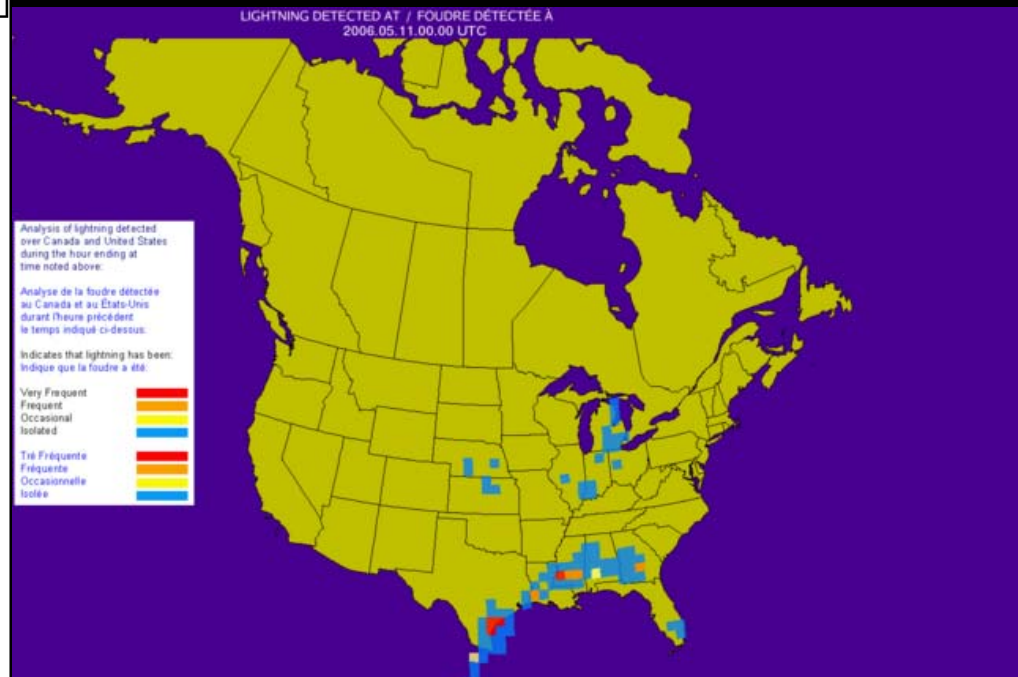

P45-48h LFLS (Flashes/3hr, LCHA > .01/ Éclairs/3hr où LCHA > .01) & P48h MSLP/PNM
P48h V Wed/mer 00Z 17 May/mai 2006 Regional GEM régional
P45-48 hr
FL01

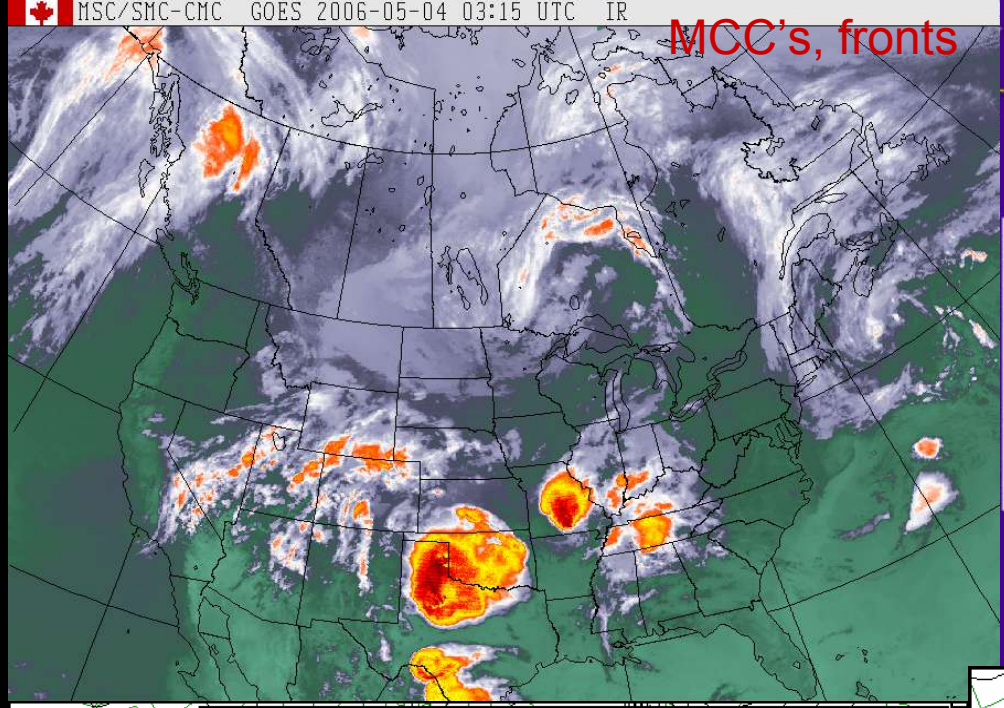

P9 -12h LFLS (Flashes/3hr, LCHA > .25/ Éclairs/3hr où LCHA > .25) & P12h MSLP/PNM
P12h V Wed/mer 00Z 17 May/mai 2006 Regional GEM régional

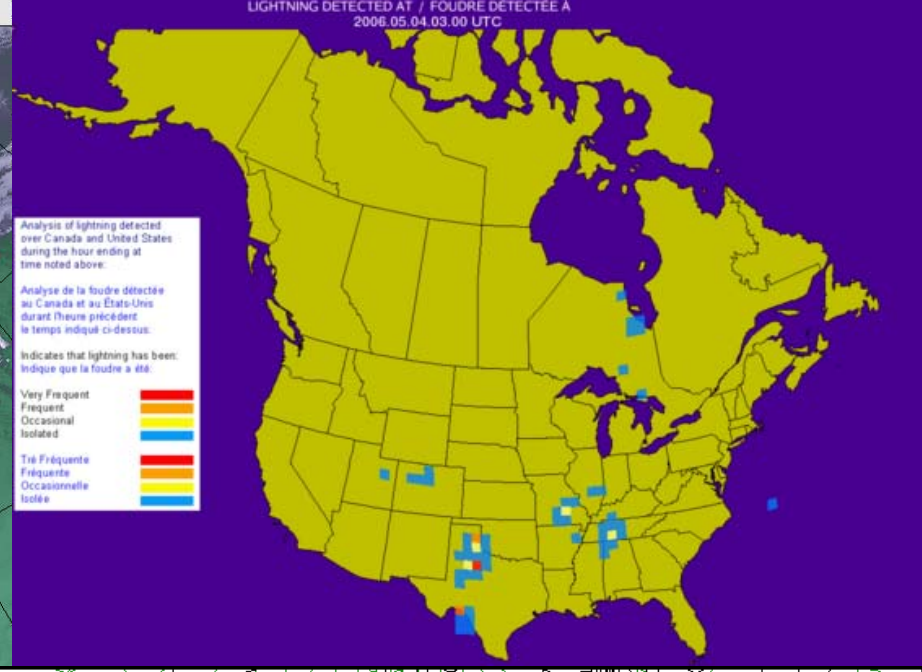

P48h V Thu/jeu 00Z 11 May/mai 2006 Regional GEM régional
P45-48 h
FL25
flashes/3hr
éclairs/3hr
14.6
50.0
20.0
10.0
5.0
1.0
0.5


MSC/SMC-CMC GOES 2006-05-10 23:15 UTC IR
CELSIUS 29 20 10 0 -8 -18 -28 -37 -47 -57 -66


P9 -12h LFLS (Flashes/3hr, LCHA > .25/ Éclairs/3hr où LCHA > .25) & P12h MSLP/PNM
P12h V Thu/jeu 00Z 11 May/mai 2006 Regional GEM régional
flashes/3hr
éclairs/3hr
14.6
50.0
20.0
10.0
5.0
1.0


LIGHTNING DETECTED AT / FOUDRE DÉTECTÉE À
2006.05.11.00.00 UTC
Analysis of lightning detected over Canada and United States during the hour ending at time noted above.
Analyse de la foudre détectée au Canada et au États-Unis durant l'heure précédent le temps indiqué ci-dessus.
Indicates that lightning has been:
Indique que la foudre a été:
Very Frequent
Frequent
Occasional
Isolated
Très Fréquente
Fréquente
Occasionnelle
Isolée


MSC/SMC-CMC GOES 2006-05-04 03:15 UTC IR
MCC's, fronts


LIGHTNING DETECTED AT / FOUDRE DÉTECTÉE À
2006.05.04.03.00 UTC
Analysis of lightning detected over Canada and United States during the hour ending at time noted above:
Analyse de la foudre détectée au Canada et au États-Unis durant l'heure précédent le temps indiqué ci-dessus:
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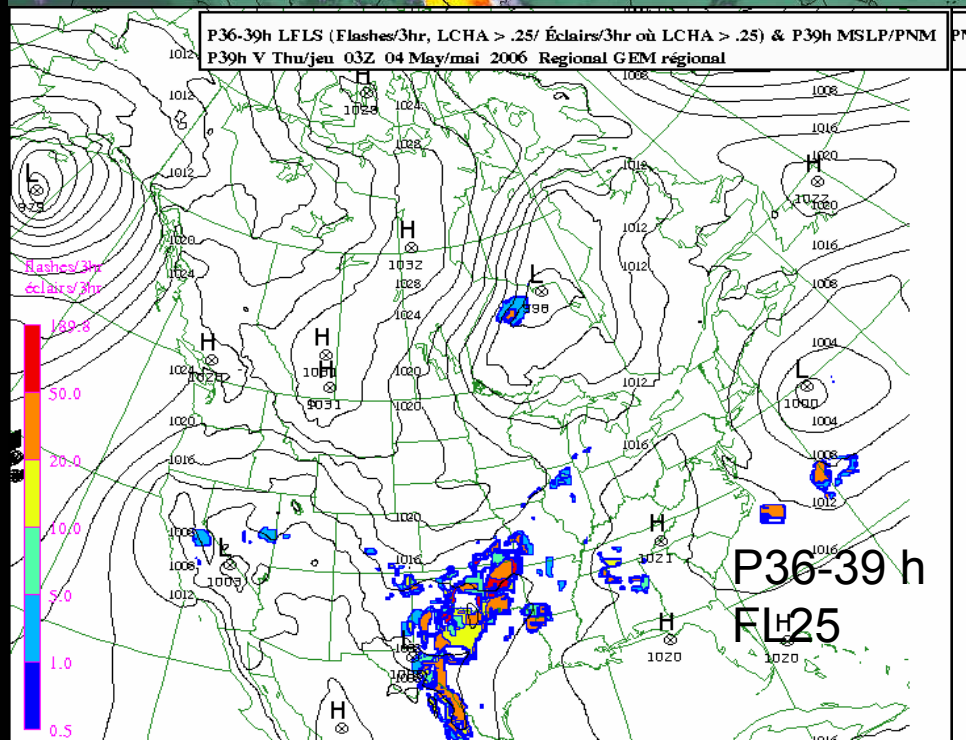
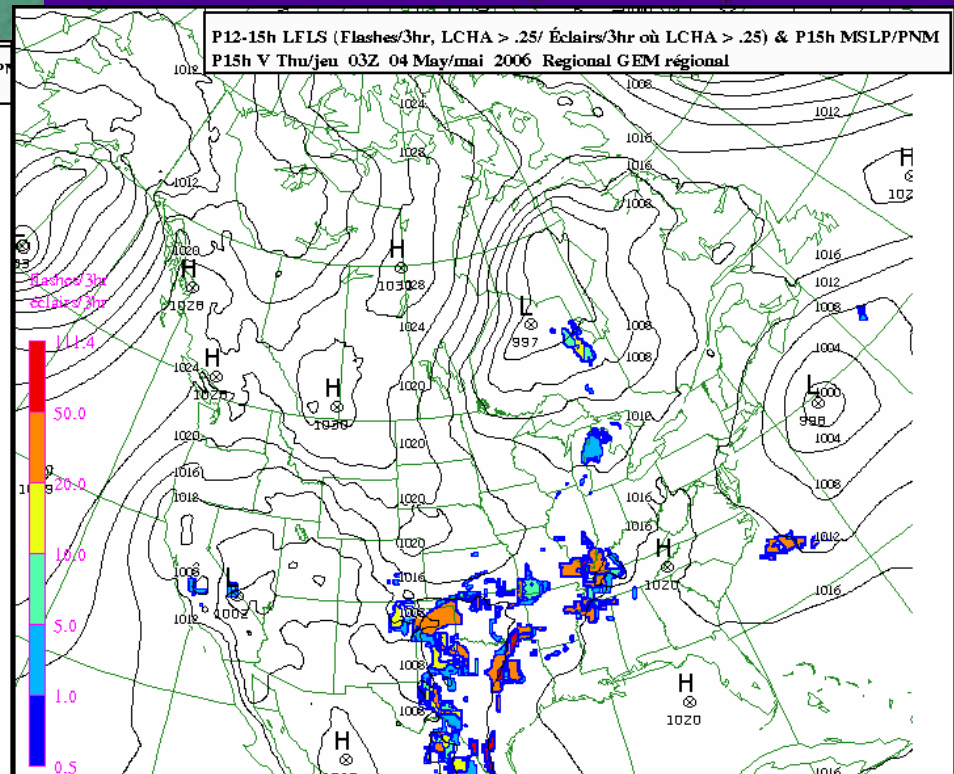
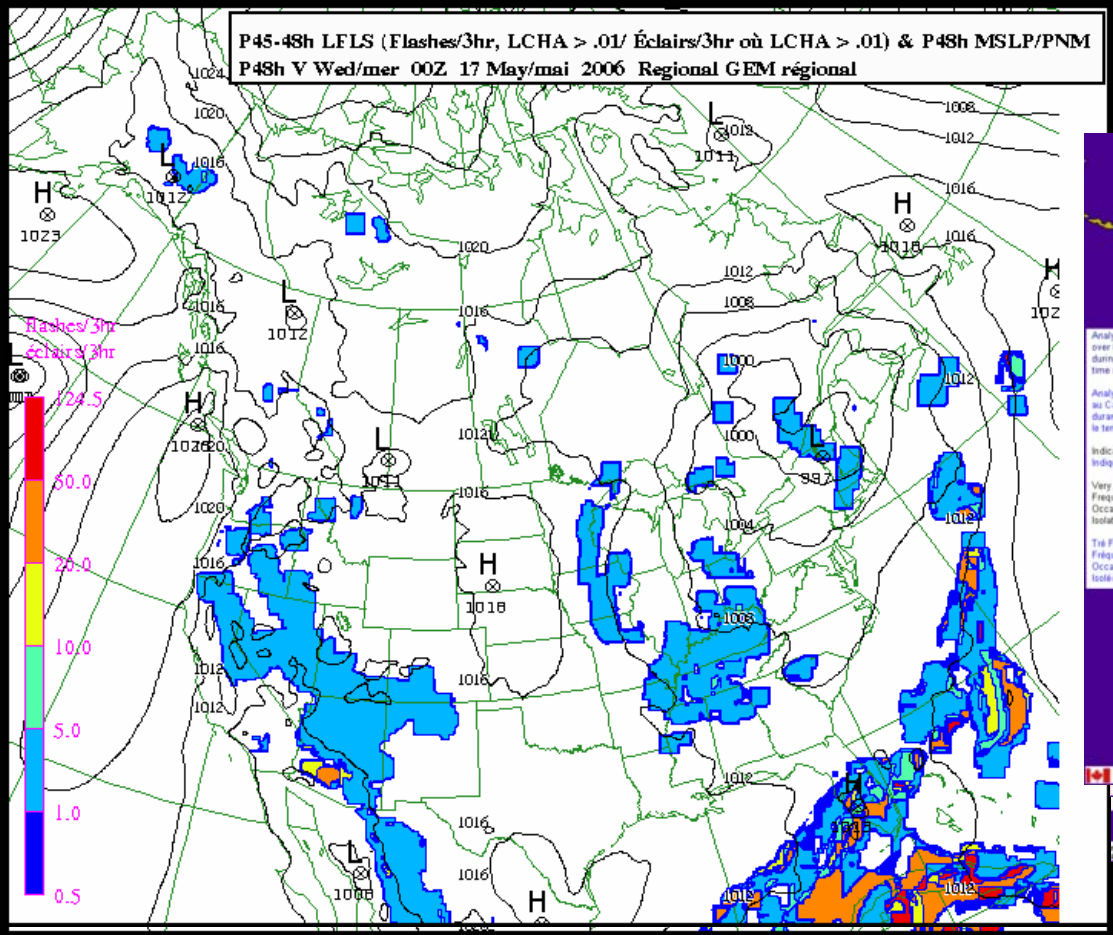
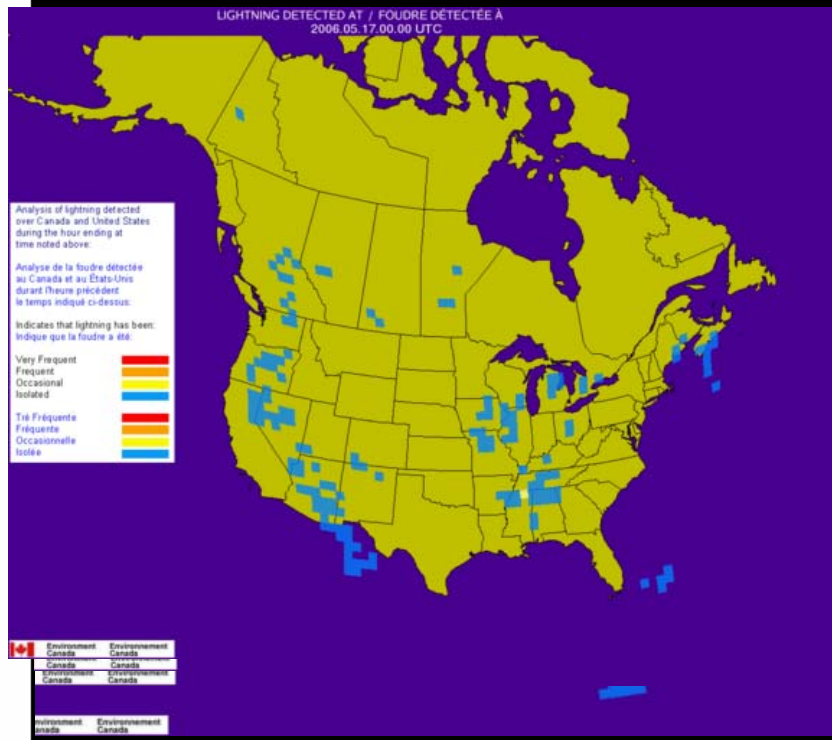
Isolée


P36-39h LFLS (Flashes/3hr, LCHA > .25/ Éclairs/3hr où LCHA > .25) & P39h MSLP/PNM
P39h V Thu/jeu 03Z 04 May/mai 2006 Regional GEM régional
Flashes/3hr
éclairs/3hr
100.0
50.0
20.0
10.0
5.0
1.0
0.5
P36-39 h
FL25

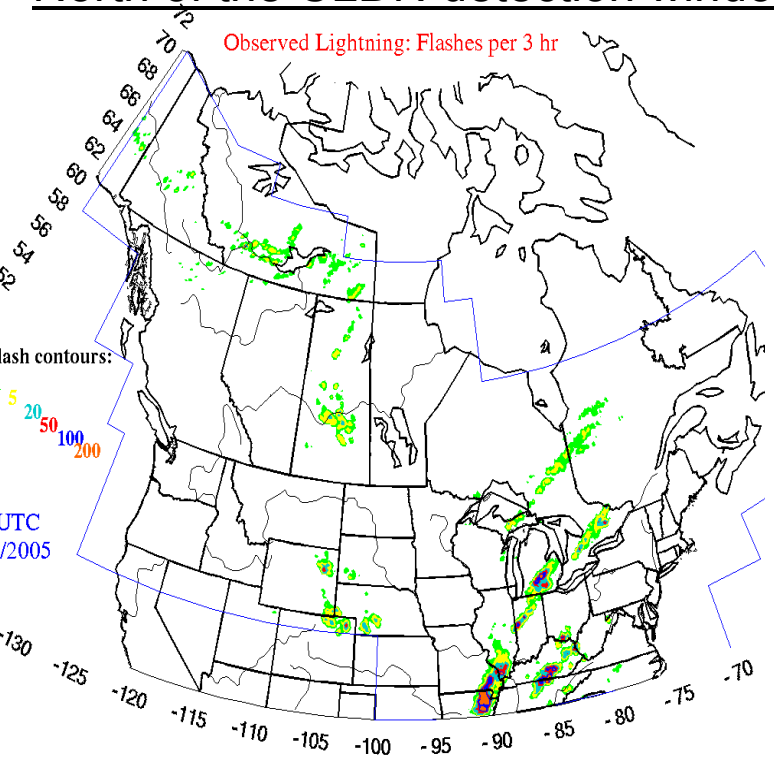

P12-15h LFLS (Flashes/3hr, LCHA > .25/ Éclairs/3hr où LCHA > .25) & P15h MSLP/PNM
P15h V Thu/jeu 03Z 04 May/mai 2006 Regional GEM régional
Flashes/3hr
éclairs/3hr
100.0
50.0
20.0
10.0
5.0
1.0
0.5

# A Diurnal Cycle of FL01 Forecasts



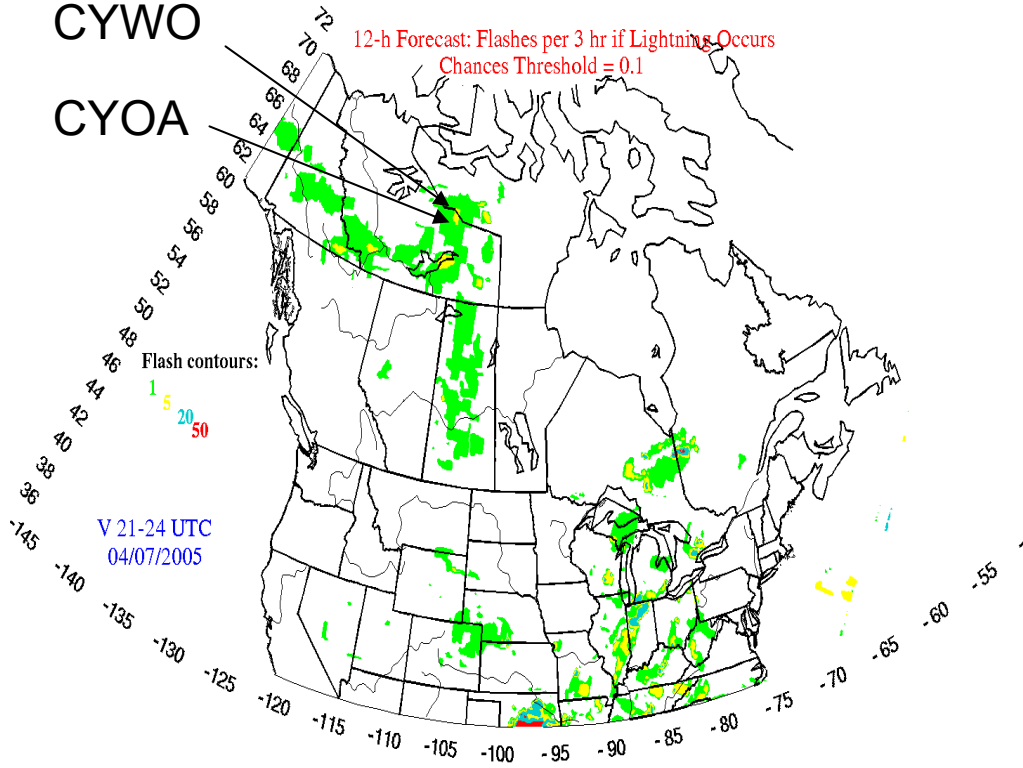
# North of the CLDN detection window




OBS

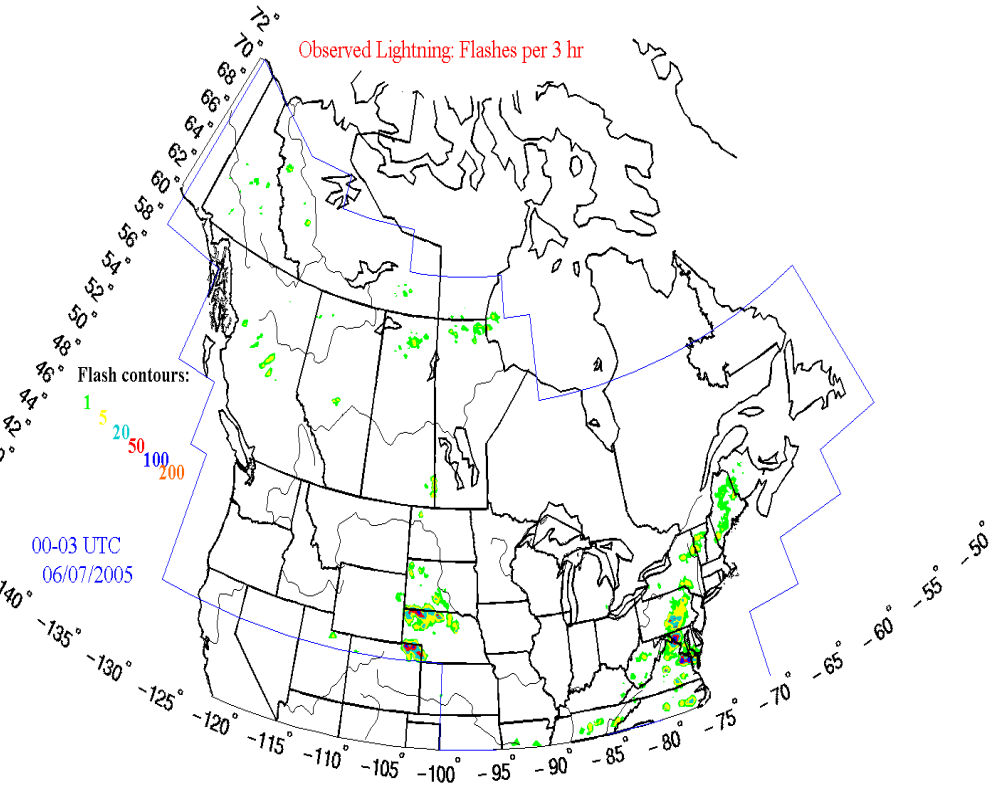
CYWO

CYOA

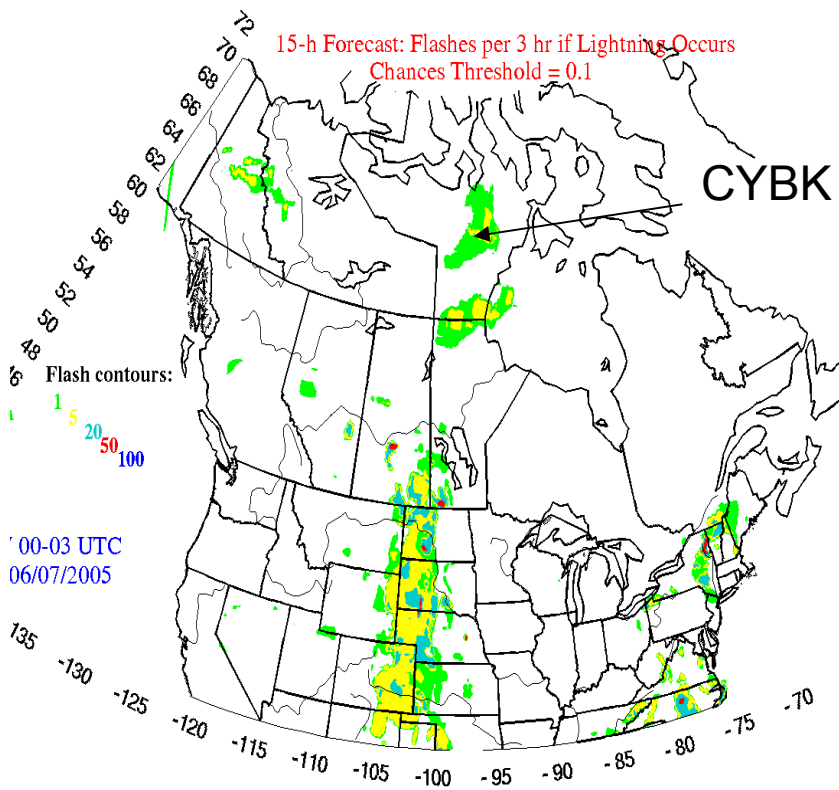



P12h FL10
V 21-24 04 Jul 2005

CYWO (Lupin)
CYWO 042200Z 22017G23KT 15SM TS BKN040CB BKN090 BKN200 21.1/9.2
RMK CB5AC1CI1 LTGCG N SH DSNT ALQDS SLP988 SKY89=
CYOA (Ekati)
CYOA 042200Z 22020G30KT 15SM FEW040 FEW050CB SCT080 BKN230 20.2/9.9
RMK CU1CB2AC1CI1 CB 4N SLP007 SKY58=

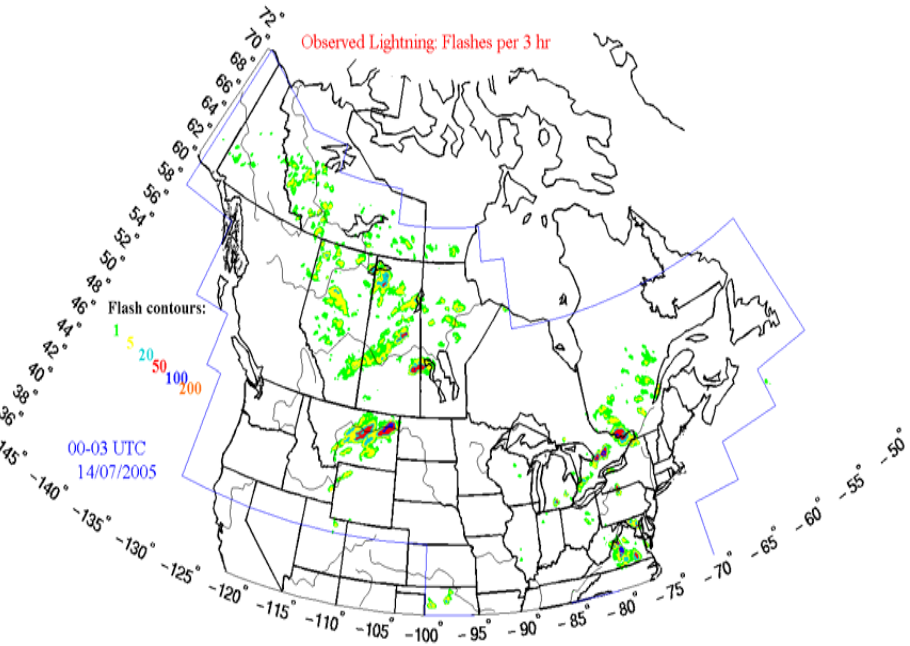


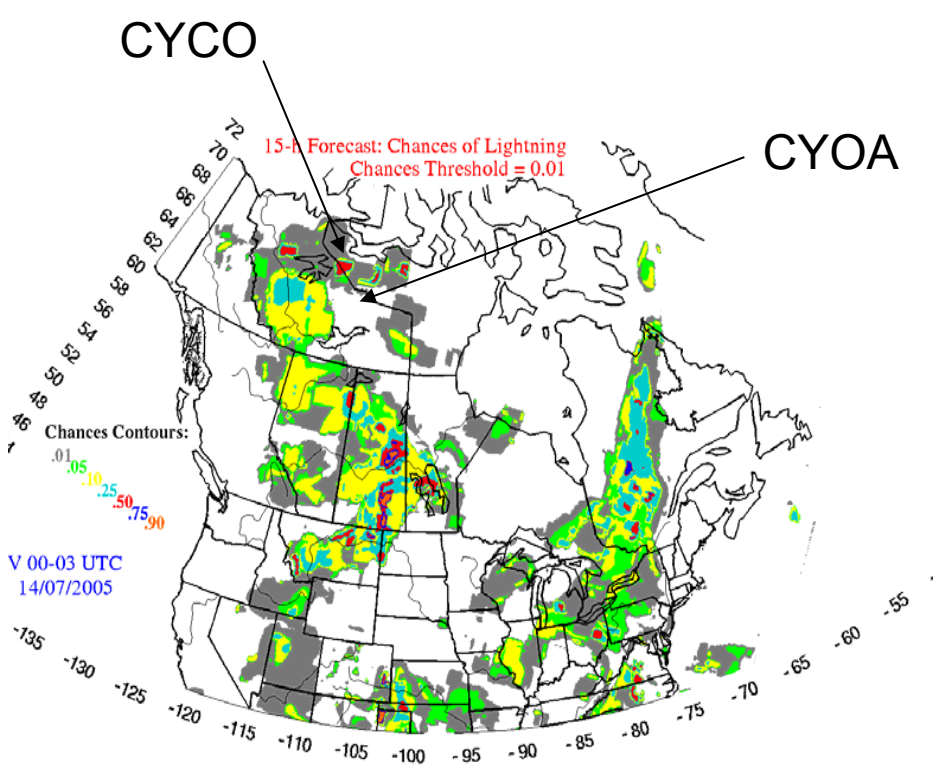

OBS




P15h FL10
V 00-03Z, 06 Jul 2005

CYBK (Baker Lake)
CYBK 060300Z CCA 36012KT 20SM FEW025CB FEW070 FEW220 16.9/10.3
RMK CB1AC1CI1 CB TR AC TR CB - NE DIST SLP996 53006 SKY13=




P15h LCHA > .01
V 00-03Z, 14 Jul 2005

CYCO (Kugluktuk)
CYCO 140033Z 36003KT 15SM -TSRA CF1CB6AC1CI0 LTGCG SKY9X=
CYCO 140100Z 10012KT 15SM -TSRA SF1CB5AC2CI0 LTGCG
CYCO 140300Z 15003KT 15SM -TSRA 11.3/10.2 SF1CB3AC4 LTGCG SKYXX=

CYOA (Ekati)
CYOA 132200Z 26011KT 15SM VCSH SCT050CB BKN230 25.4/12.0 RMK CB3CI1
CYOA 132300Z 16007KT 15SM VCSH SCT050CB BKN230 25.8/12.2 RMK CB4CI0

# Conclusions and Remarks

- new model forecasts running in real time to 48 hrs ….
  - combine “time-area index (LCHA) ” and “flash rate (LFLS)” forecasts … LFLS forecast can be filtered by thresholds of LCHA …
  - different thresholds work better for some synoptic situations …
  - FL01 and FL05 seem to be the most versatile
- forecaster acceptance has been very good CMAC west, PASPC, PYSPC
- large window covers USA … Vaisala getting forecasts – very interested
- good indication of target areas for convective assessment
- useful for area forecasts
- only 7 day’s training data … easier to update and maintain
- run year round

- not sure if 9*9 box is the right size  - easy to do other sizes

- other image overlays may be added in time in Edmonton :
  e.g. thickness, precipitable water, θw and others

- forecasters will suggest other changes as we go along