The GOES-R Geostationary Lightning Mapper (GLM) and Opportunities for Assimilation of the Data into NWP models

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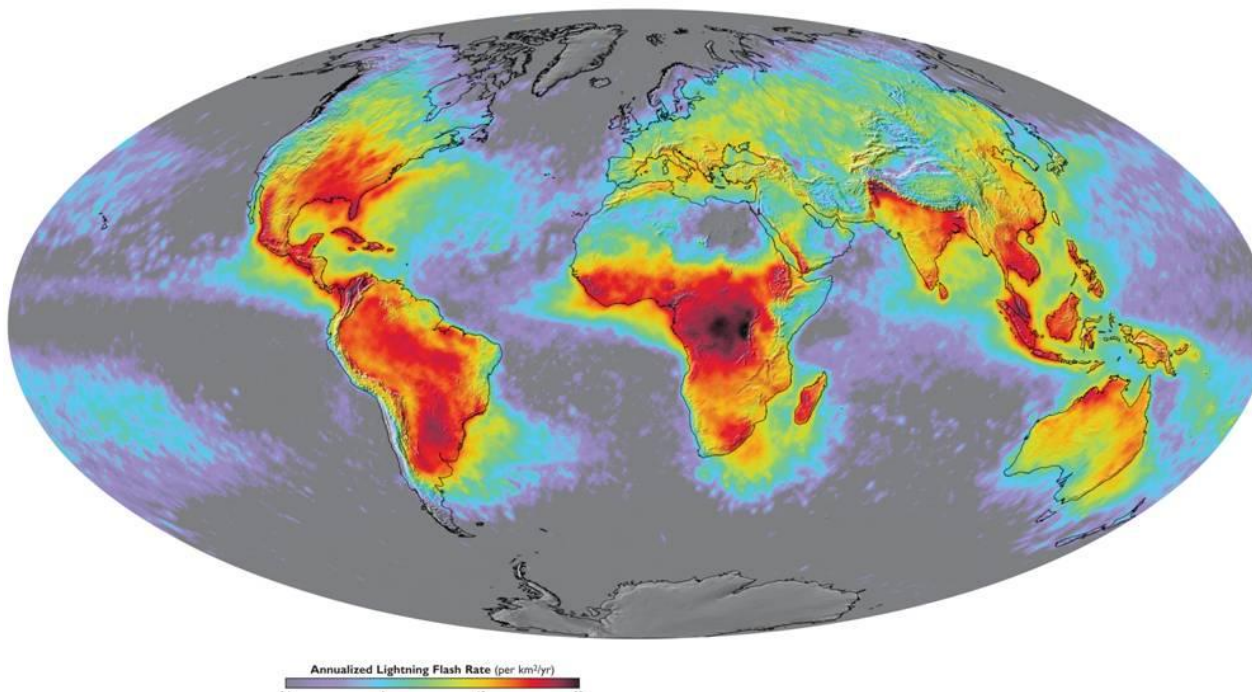
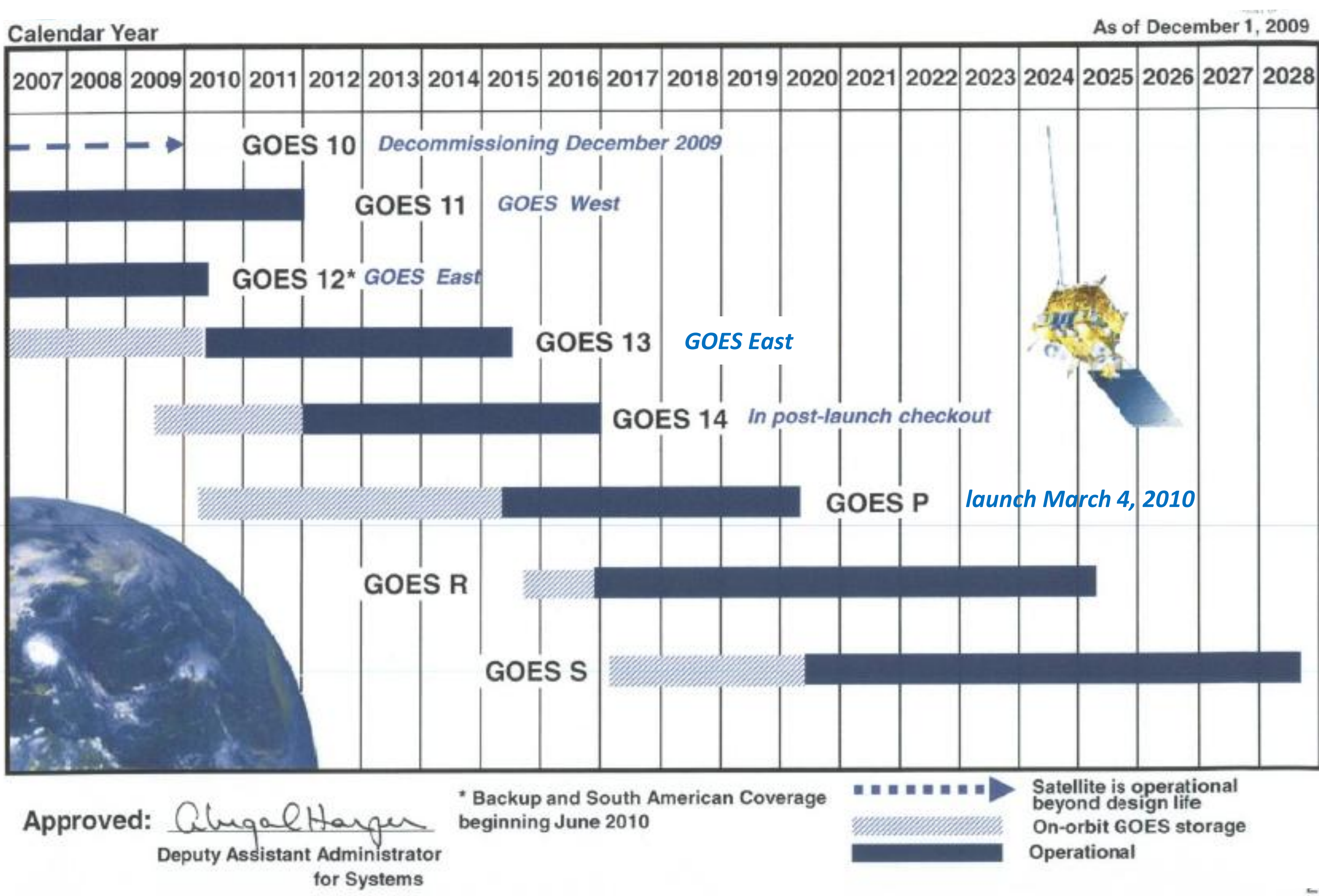
Outline of Presentation

1. GLM Instrument
2. Physical Basis- Electrification and Lightning
3. Lightning Data Assimilation and NWP Experiments
4. NOAA Hazardous Weather Testbed and Future Prospects
5. Summary

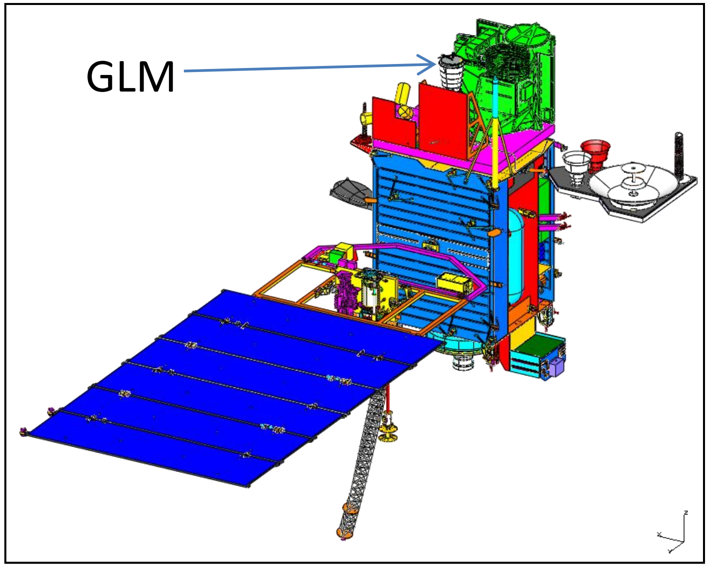
Global lightning from the NASA OTD (Orbcomm 1) and LIS (TRMM) instruments

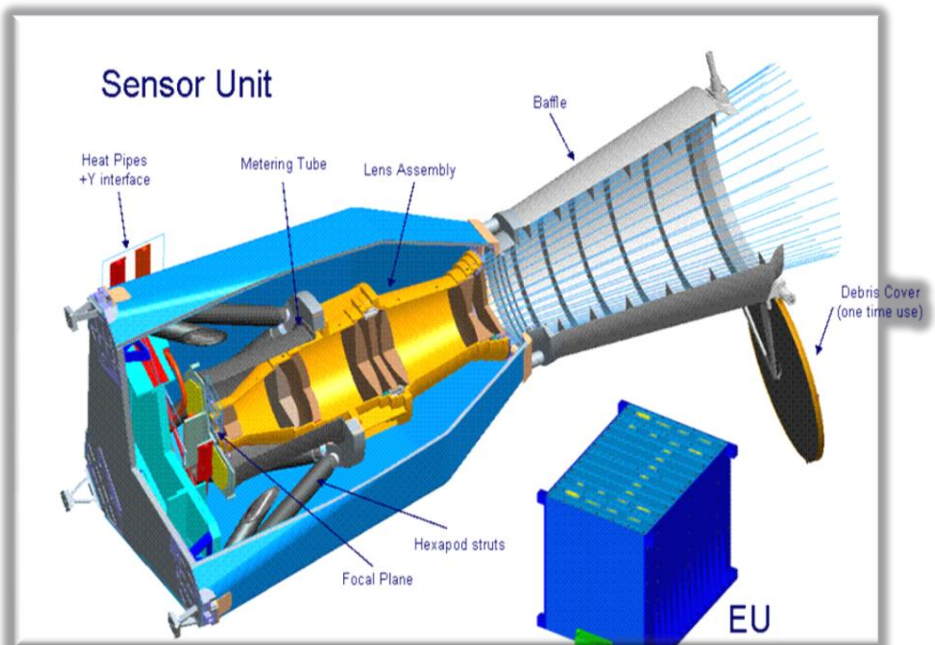


Launch Schedule



GOES-R Geostationary Lightning Mapper (GLM)





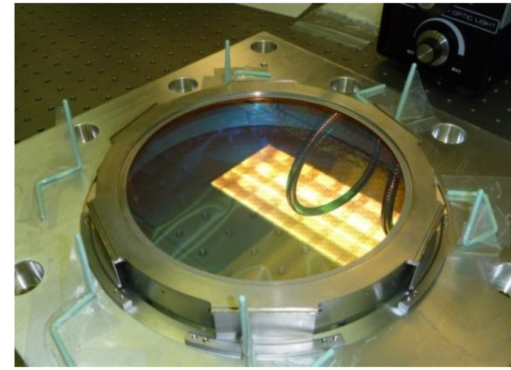
GLM Characteristics

- Staring CCD imager (1372x1300 pixels)
  - Single band 777.4 nm
  - 2 ms frame rate
  - 7.7 Mbps downlink data rate
  - Mass: 114 kg- SU (66 kg), EU (48 kg)
  - Avg. Operational Power: 290 W
  - Volume w/ baffle (cm^3): 81x66x150

- Near uniform spatial resolution/ coverage up to 52 deg lat
  - 8 km nadir to 14 km at edge
  - 70-90% flash detection
- L1 and L2+ products produced at Wallops for GOES-R Re-Broadcast (GRB)
- < 20 sec product total latency

GLM

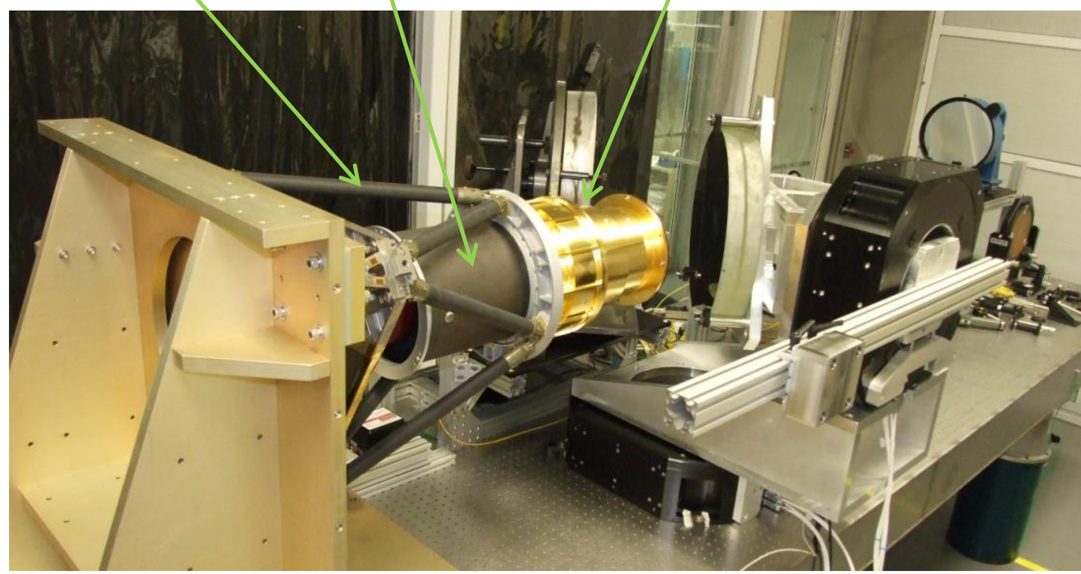
NB filter



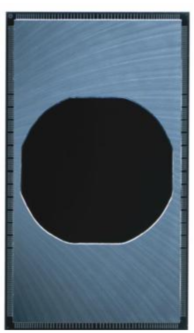
SU Mechanical Support Structure

Metering tube

Optical Assembly



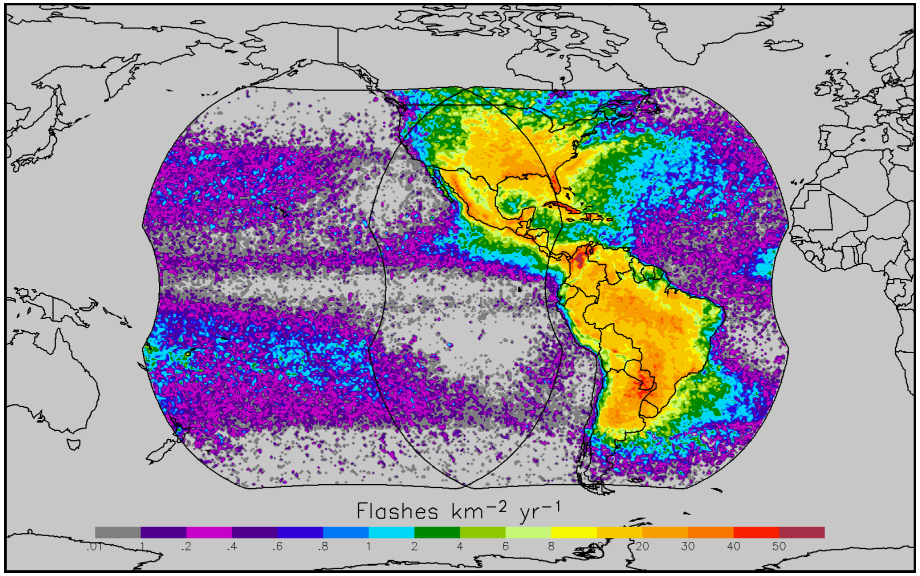
Alignment GSE with PTM Optical assembly, metering tube and SU support structure



Back-thinned CCD

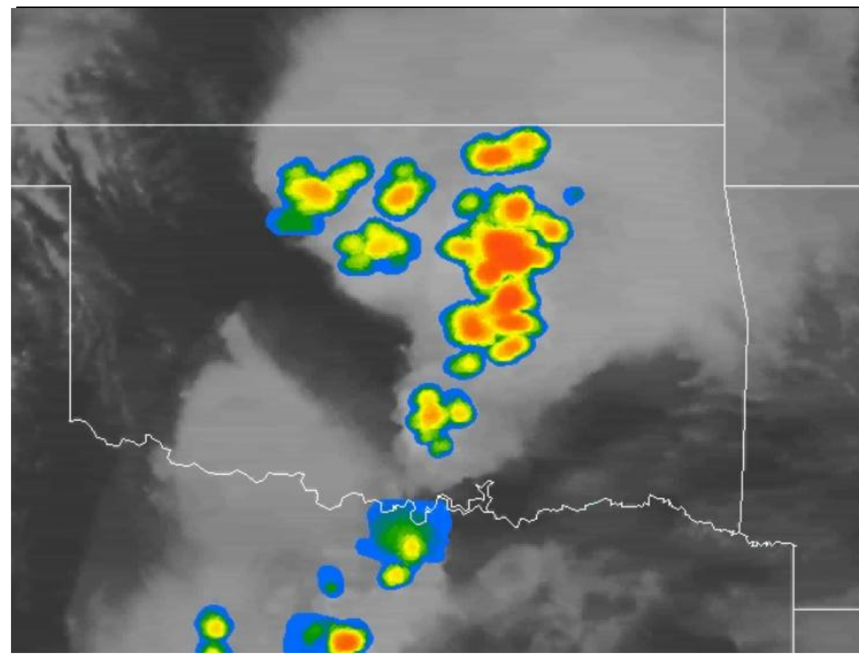
GOES-R Geostationary Lightning Mapper (GLM)

GLM Combined R/S Coverage



[May 3 1999 Oklahoma Tornado Outbreak](#)

(animation)



1-minute of observations from TRMM/LIS

Natural Hazards and Lightning

- Tornadoes
- Hailstorms
- Wind
- Thunderstorms
- Floods
- Hurricanes
- Volcanoes
- Forest Fires
- Air Quality/NOx

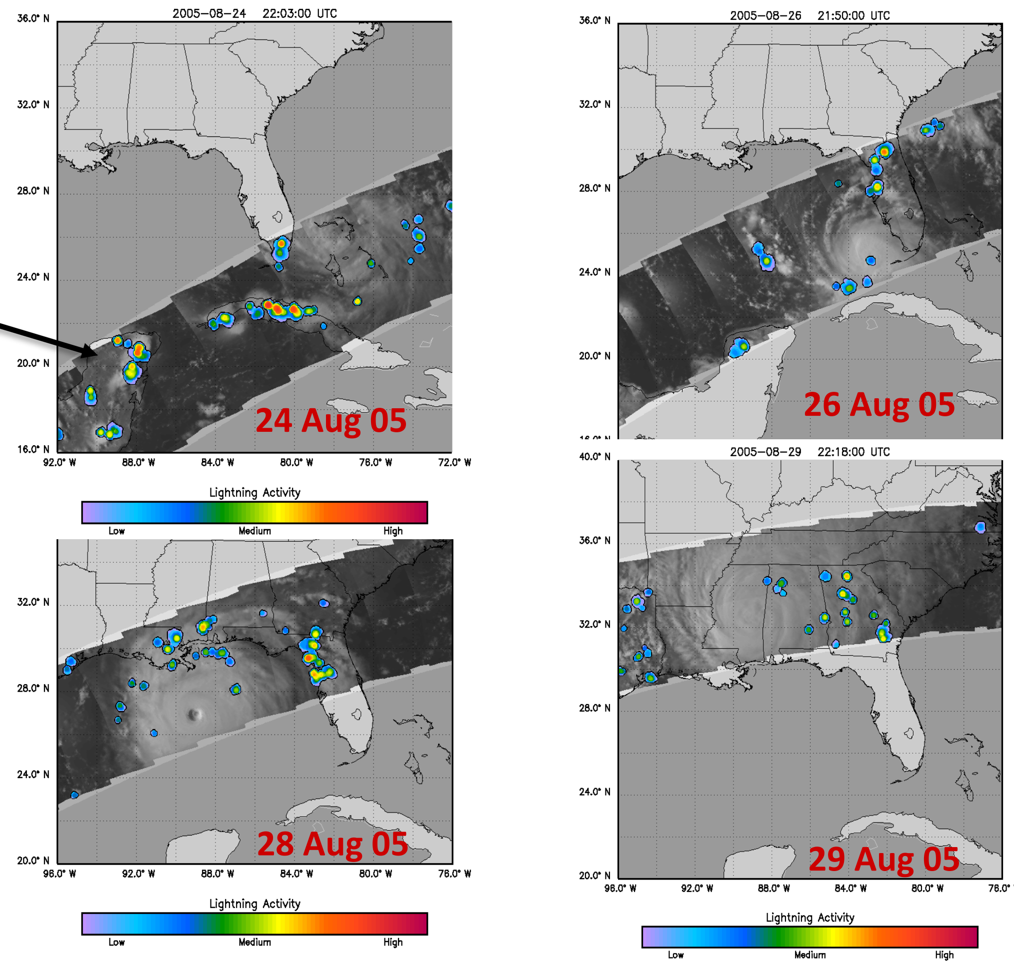
[Play lightning animation]

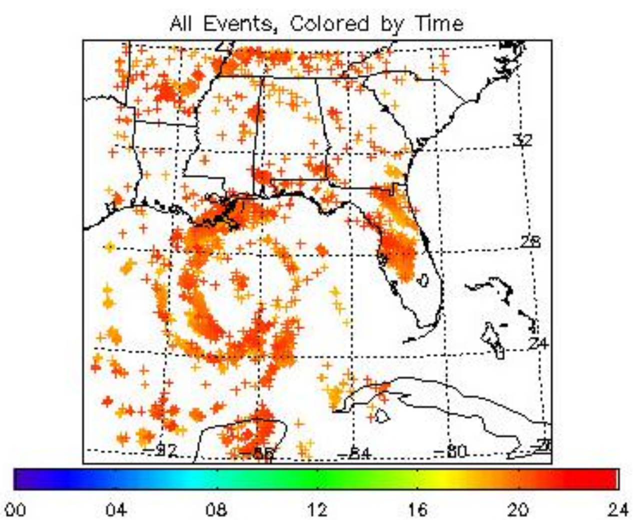
Hurricane Katrina Lightning

How does lightning activity vary as TC/Hurricane undergoes intensity change? Is there a useful predictor?

Lightning Imaging Sensor/TRMM

LIS Background Images
read out once per min
4 km ifov @ 777.4 nm
Orbit swath 600 km





Los Alamos Sferics Array, August 28, 2005, Shao et al., EOS Trans., 86

L1 Requirements for Lightning Detection

3 component products- L1 events, L2 groups and flashes)

Name	User & Priority	Product Geographic Coverage	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Product Refresh Rate /Coverage Time	VAGL	Measurement Precision	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Lightning Detection -Events -Groups -Flashes	GOES -R	Full Disk	Sfc to Cloud Top.	10 km	5 km	Real Time	70% minimum Flash Detection Efficiency (FDE)	Continuous	20 sec	5% (Std. Dev. of FDE)	Day and night	Quantitative out to at least 65 degrees LZA and qualitative beyond	Cloud cover conditions permitting obs. of lightning associated with threshold accuracy	Over lightning cases and mesoscale-sized surrounding regions

- LIRD Changes Aug 2009- product refinement, reduced latency (from 59 to 20 sec)

Event Processing (L1B)

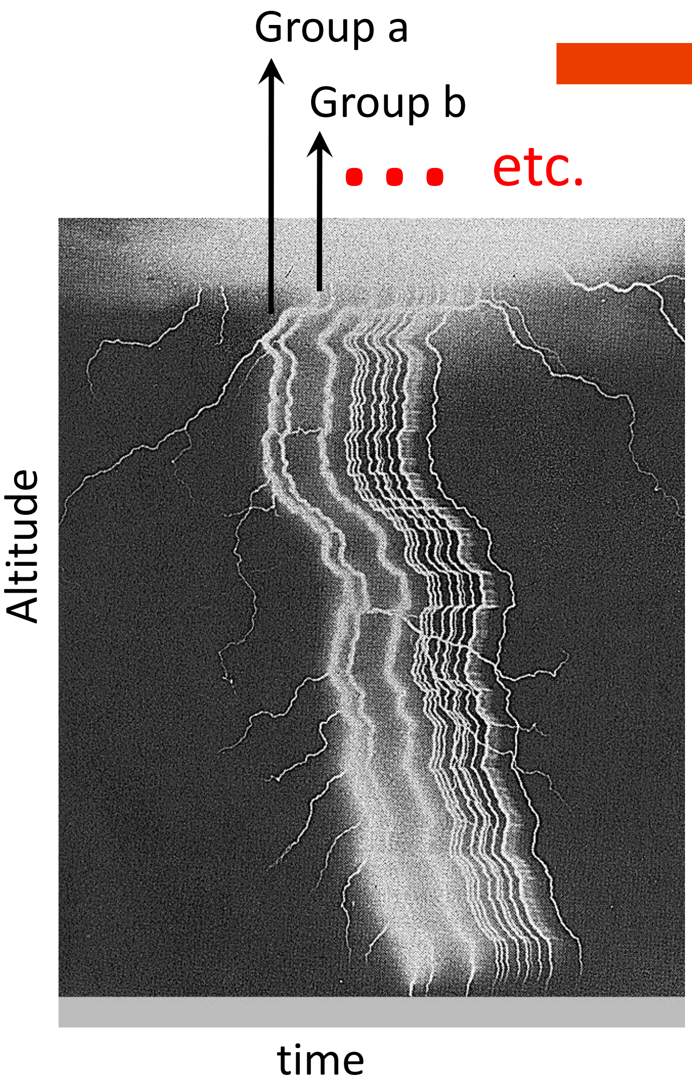
- An event is anything that exceeds the threshold
  - Noise, Proton hit, or lightning pulse
  - All events are transmitted to the ground along with housekeeping and subsampling of the background levels
  - Ground processing determines which events are lightning pulses by looking for strings of pulses, both spatially and temporally (coherency)
  - End-product is time-tagged, geolocated, measured, lightning (PORD Requirement)

Algorithm Overview (L2+)

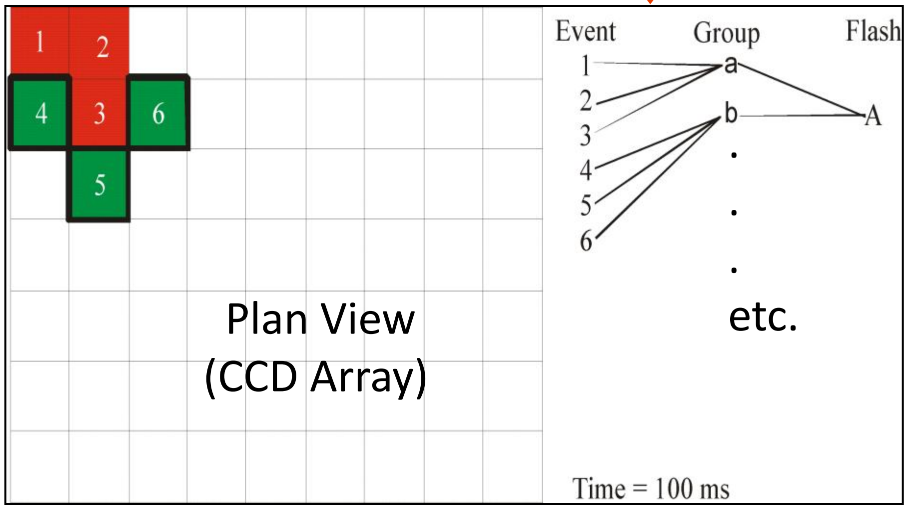
- The algorithm takes input Level 1B events (time, location, amplitude) and clusters them with other events that have similar temporal and spatial characteristics
- The GLM produces a series of events (time series) which are clustered by the GLM algorithm into L2 groups and flashes, similar to the basic lightning flash data of the National Lightning Detector Network (NLDN) system (i.e., not an imager)
- The data rate from the GLM is highly variable and can range from as little as 0 events per second (when hemispheric lightning rates are very low) to perhaps as many as 40,000 events per second for very, very brief periods during widespread severe storm episodes
- The GLM algorithm must be able to process this wide dynamic range of data rates while producing output groups and flashes in under 4 seconds (verified by speed tests)

A Time-Resolved Ground Flash

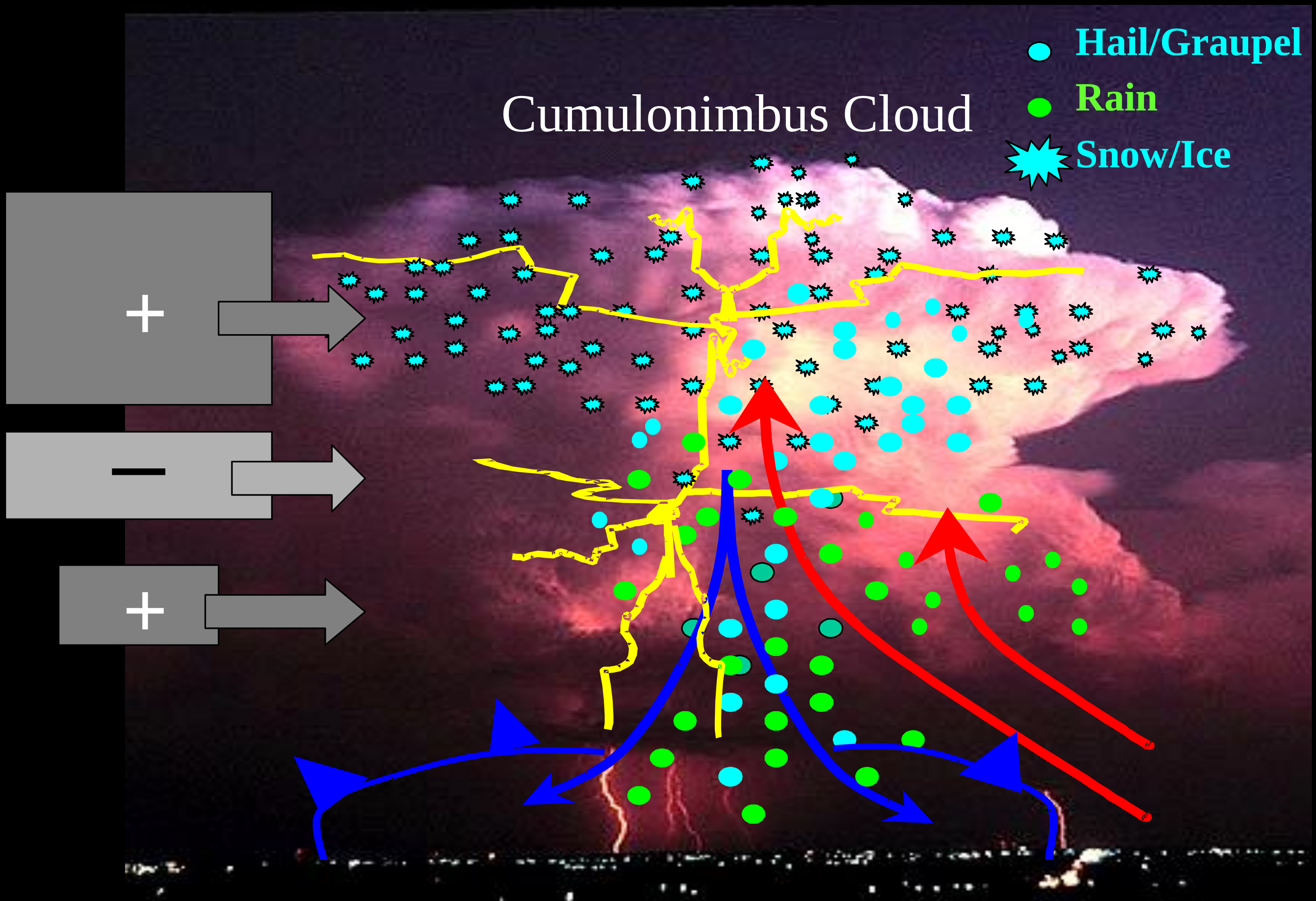
(Methodology based on 12 years successful on-orbit experience with TRMM LIS)



Groups Help Us Track the Strokes and other components of the lightning flash!



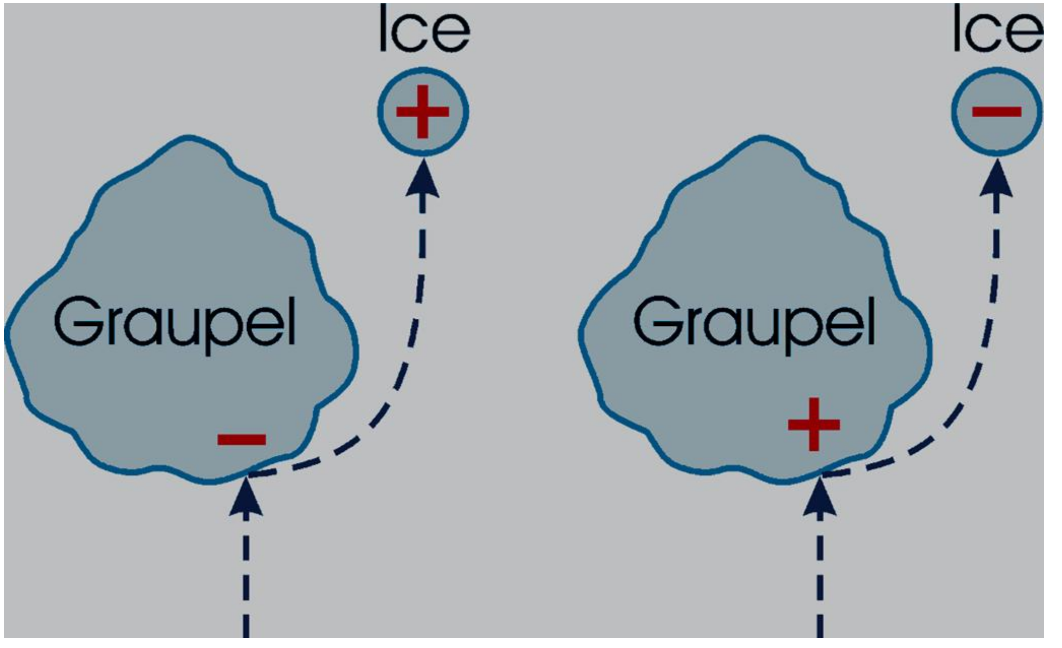
Thunderstorm Structure



+ = Positive Charge — = Negative Charge

Noninductive Mechanism

Need
• Riming graupel
• Liquid water
• Ice crystals

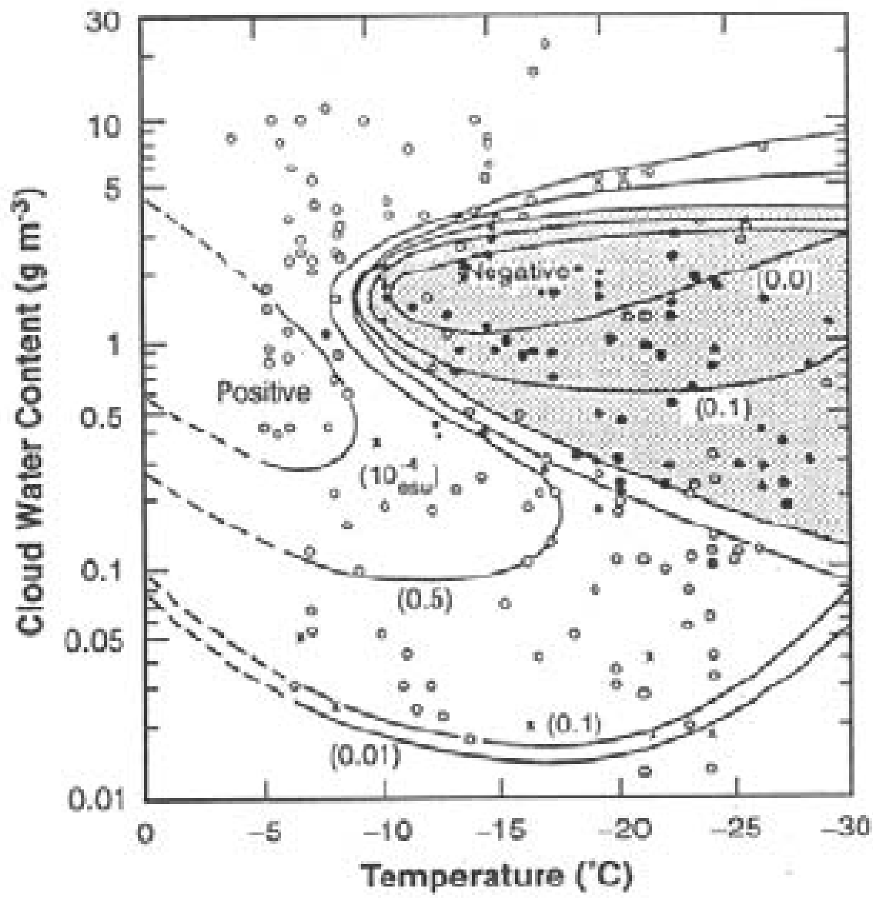


Reynolds, S.E., M. Brook, and M.F. Gourley, 1957: *J. Meteorology,14*, 14426-14437.

Takahashi, T., 1978: *J. Atmos. Sci., 35*, 1536-1548.

Jayaratne, E.R., C.P.R. Saunders, and J. Hallett, 1983: *Q. J. R. Meteorol. Soc., 109*, 609-630.

Laboratory Cloud Charging Results



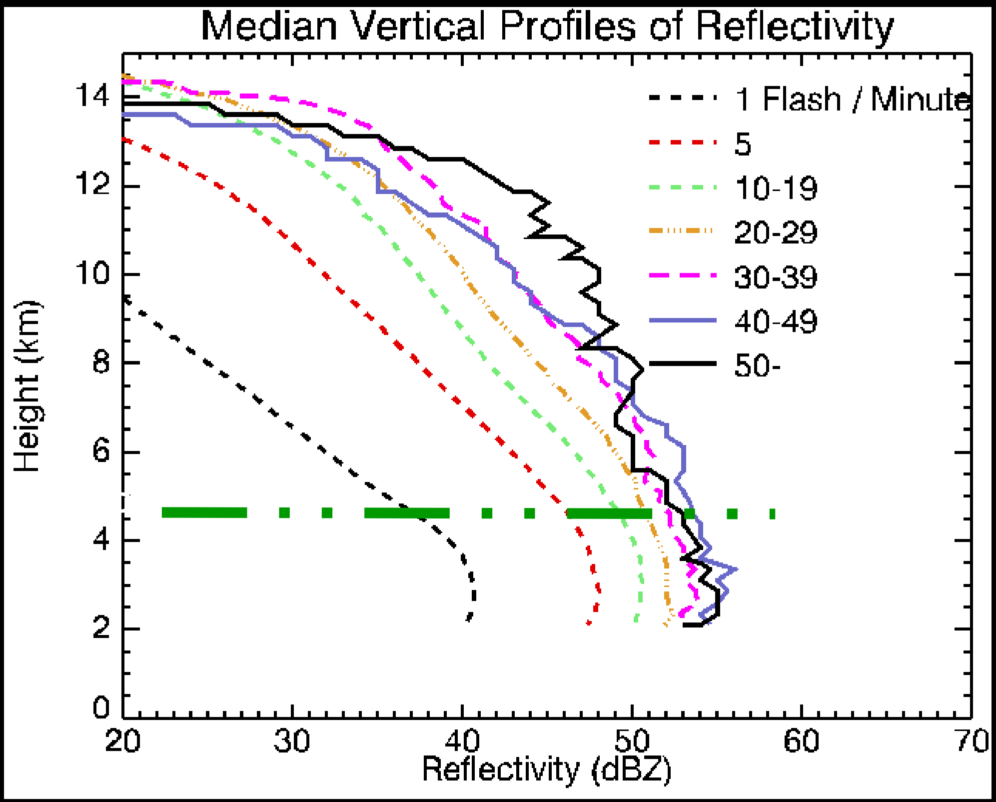
Large ice particles charge negatively

Laboratory charging results for temperature as a function of cloud water content (Takahashi et al., 1978)

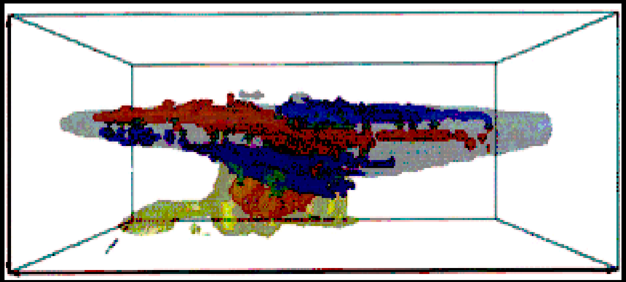
Physical Basis: Flash Rate Coupled to Mass in the Mixed Phase Region

TRMM PR and LIS

(Cecil et al., Mon. Wea. Rev. 2005)



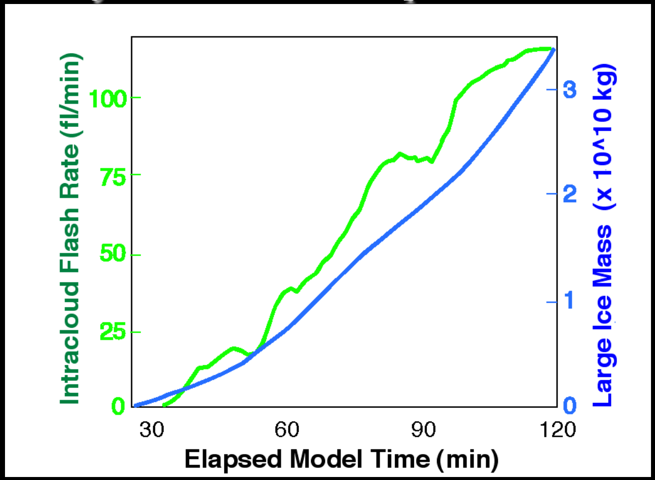
Process physics understood



Storm-scale model with explicit microphysics and electrification (Mansell)

Ice flux drives lightning

Physical basis for improved forecasts



IC flash rate controlled by graupel (ice mass) production (and vertical velocity)

Physical Basis:

Lightning Connection to Thunderstorm Updraft, Storm Growth and Decay

- Total Lightning —responds to updraft velocity and concentration, phase, type of hydrometeors, integrated flux of particles
- WX Radar — responds to concentration, size, phase, and type of hydrometeors-integrated over small volumes
- Microwave Radiometer — responds to concentration, size, phase, and type of hydrometeors — integrated over depth of storm (85 GHz ice scattering)
- VIS / IR — cloud top height/temperature, texture, optical depth

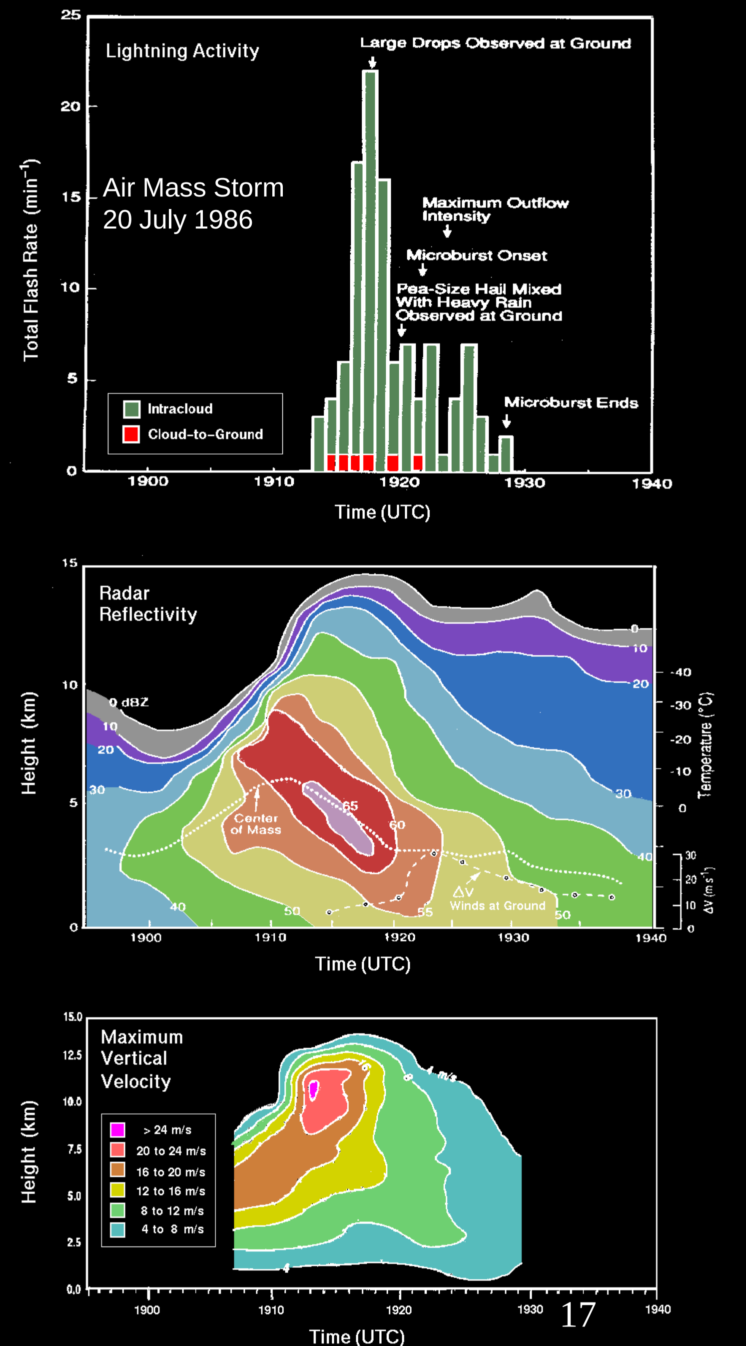
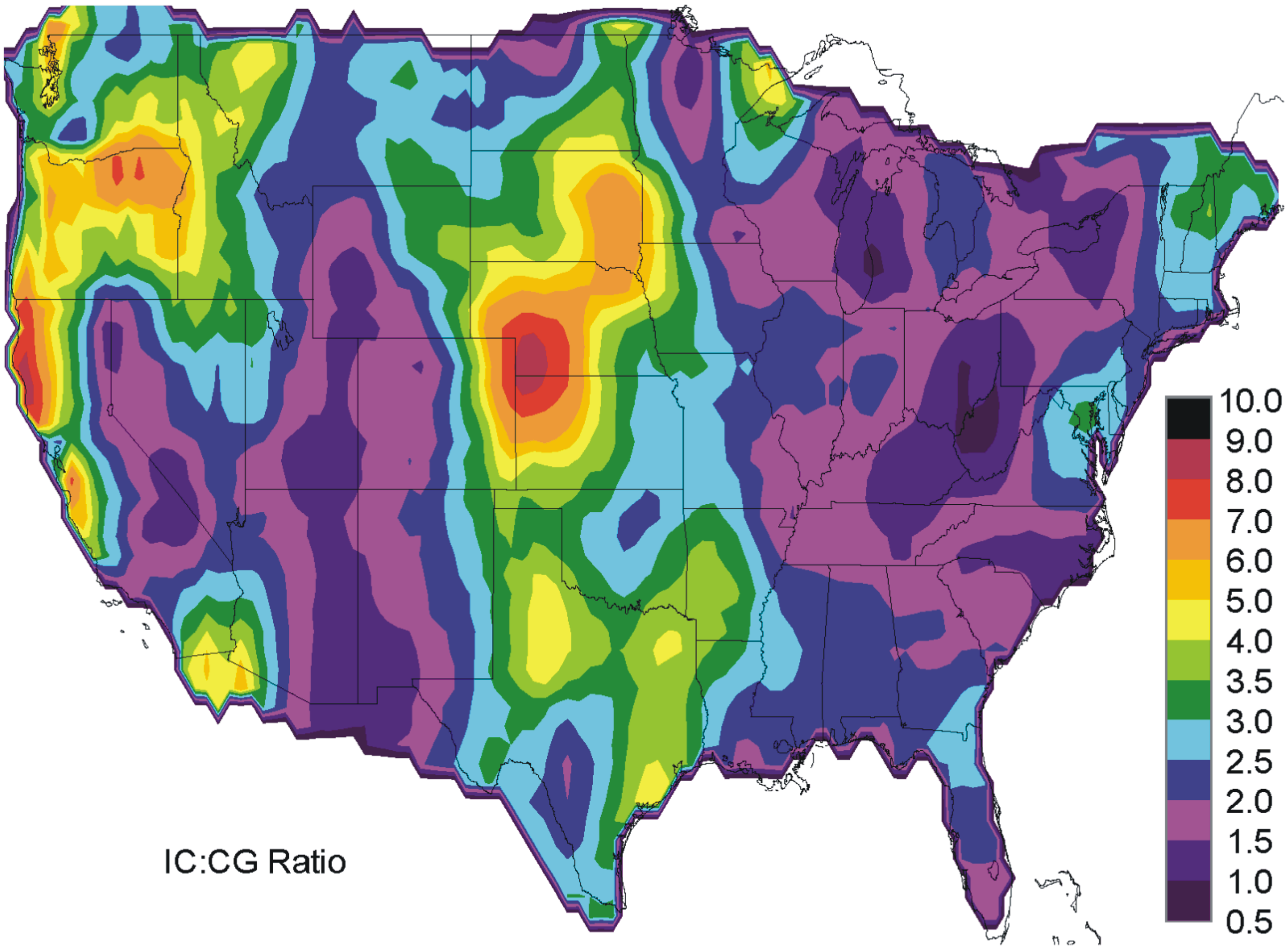


Figure from Gatlin and Goodman, JTECH, Jan. 2010- adapted from Goodman et al, 1988; Kingsmill and Wakimoto, 1991

Cloud Flash to Ground Flash Ratio

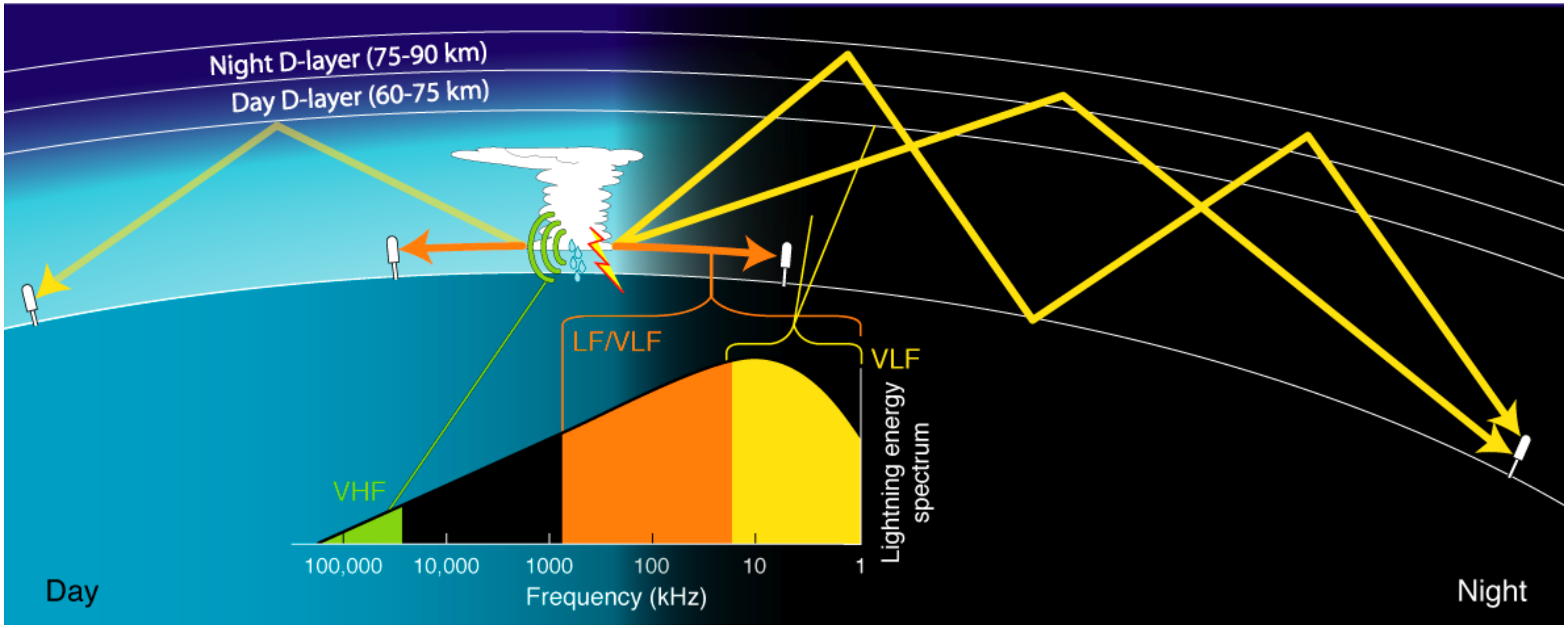


from Boccippio et al. (2001)

Lightning Data Assimilation into NWP Models

- Previous lightning data assimilation work:
  - Alexander et al., 1999; Chang et al. 2001 (latent heating)
  - Papadopoulos et al., 2005 (moisture profiles)
  - Mansell et al., 2006, 2007 (BL moisture and updraft speed; NLDN/LMA convective trigger switch for Kain-Fritsch)
  - Weygandt et al., 2006, 2008 (cloud and moisture fields-lightning-reflectivity relationship to create a latent heating-based temperature tendency field, applied to RUC /HRRR during a pre-forecast diabatic digital filter initialization)
  - Pessi and Businger, 2009 (Vaisala Pacnet long-range lightning data over the open ocean- tropical cyclones, oceanic storms)
- Workshop on Lightning Modeling and Data Assimilation (Mar. 15)
  - http://www.nssl.noaa.gov/research/forewarn/lt_workshop/

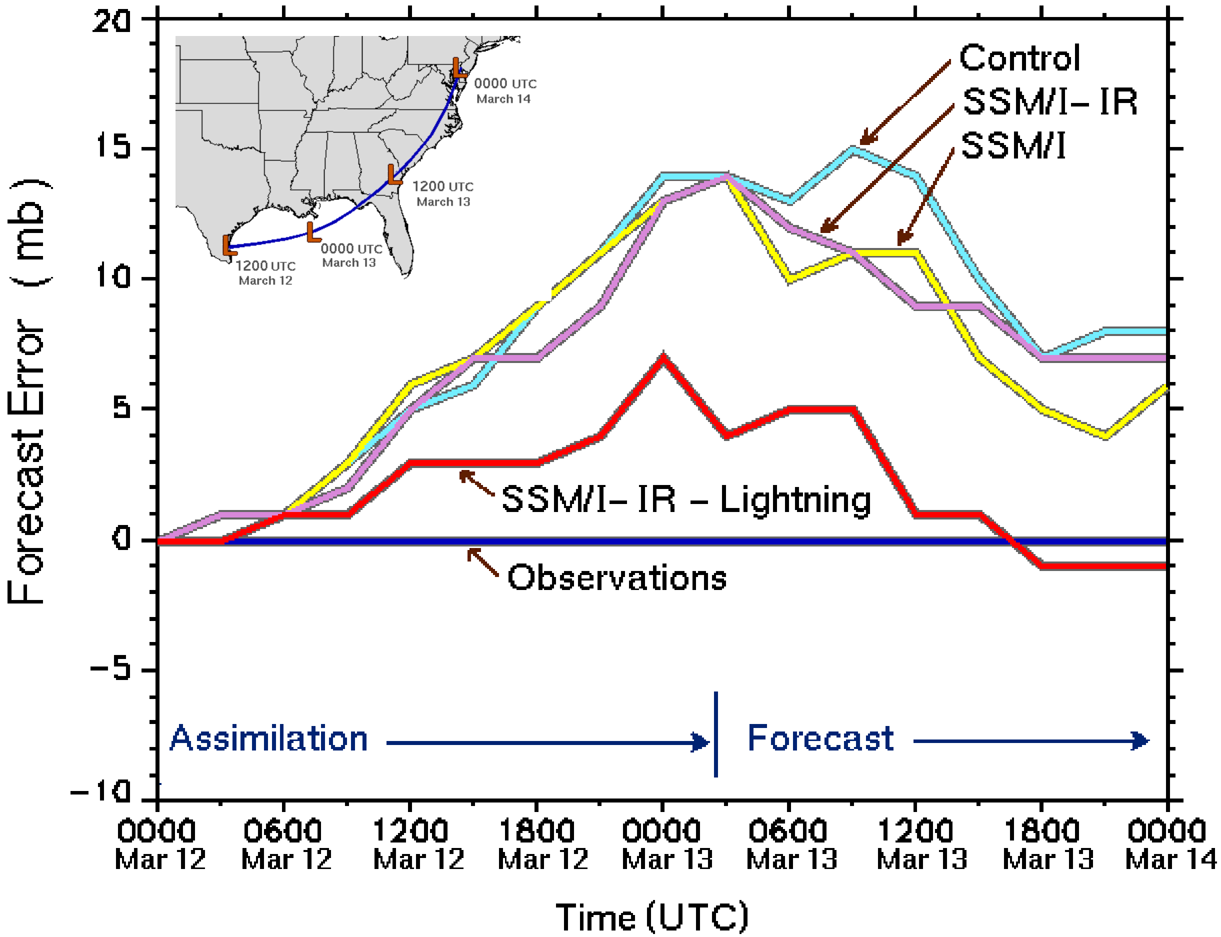
Background: VLF Signal Propagation



- Pulses of electromagnetic radiation produced by (**CG**) lightning flashes peak in the very low frequency (VLF) region of the spectrum (3-30 kHz). STARNet, UCONN Zeus, UK Met. ATDnet, WWLLN, PacNet, GLD360
- The Earth-ionosphere waveguide preferentially channels to great distances the pulses associated with current in the vertical channels in IC and CG flashes.
- This guided electromagnetic pulse is called a radio atmospheric, or sferic, and has a low attenuation in the VLF band and can propagate effectively in the earth-ionosphere waveguide for thousands of kilometers.
- Our ability to measure this impulse at great distances from the strike forms the basis for a long-range lightning geo-location network.
- VLF signals attenuate less during the night because the gradient in electron density with height increases (ionosphere is more sharply defined at night).
- VLF signals attenuate less over the ocean than over land because of the higher electrical conductivity of salt water.

Lightning Data Assimilation: Reduces Forecast Error

March 13, 1993 Superstorm (Alexander et al., 1999 MWR)



Lightning assimilated via latent heat transfer functional relationship

Lightning Data Assimilation

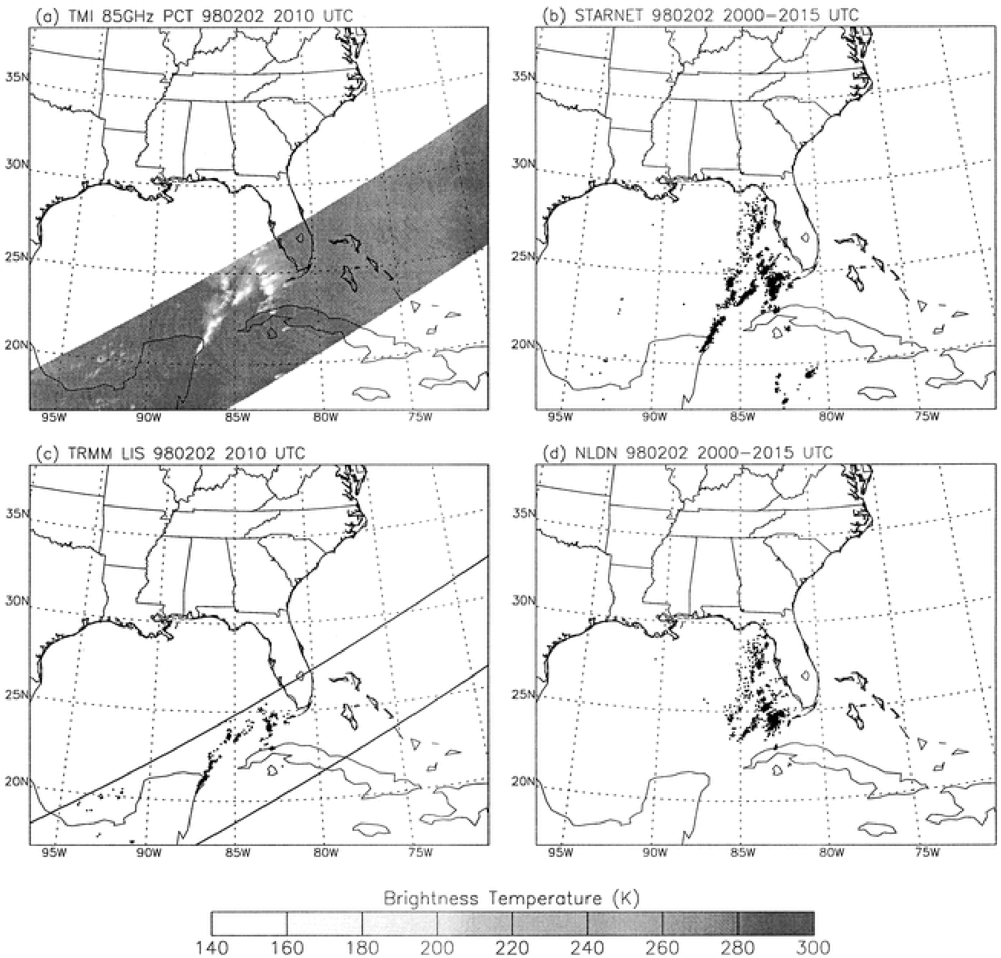
(Chang et al., Mon. Wea. Rev., August 2001)

TMI
85 GHz Tb

STARnet
Sferics

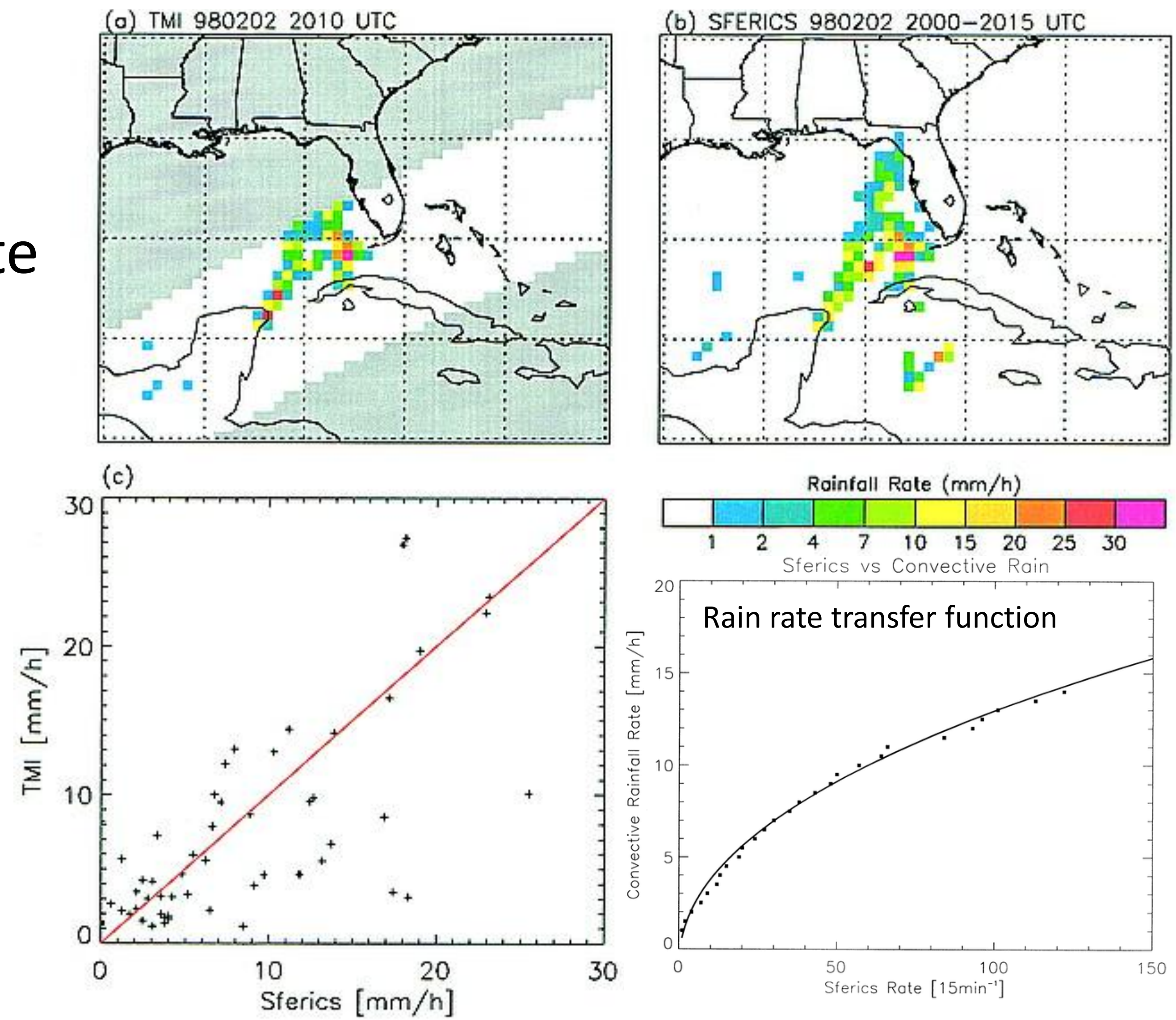
LIS
Total
Lightning

NLDN
CG Flashes



Establish a Lightning – Rain Rate Transfer Function

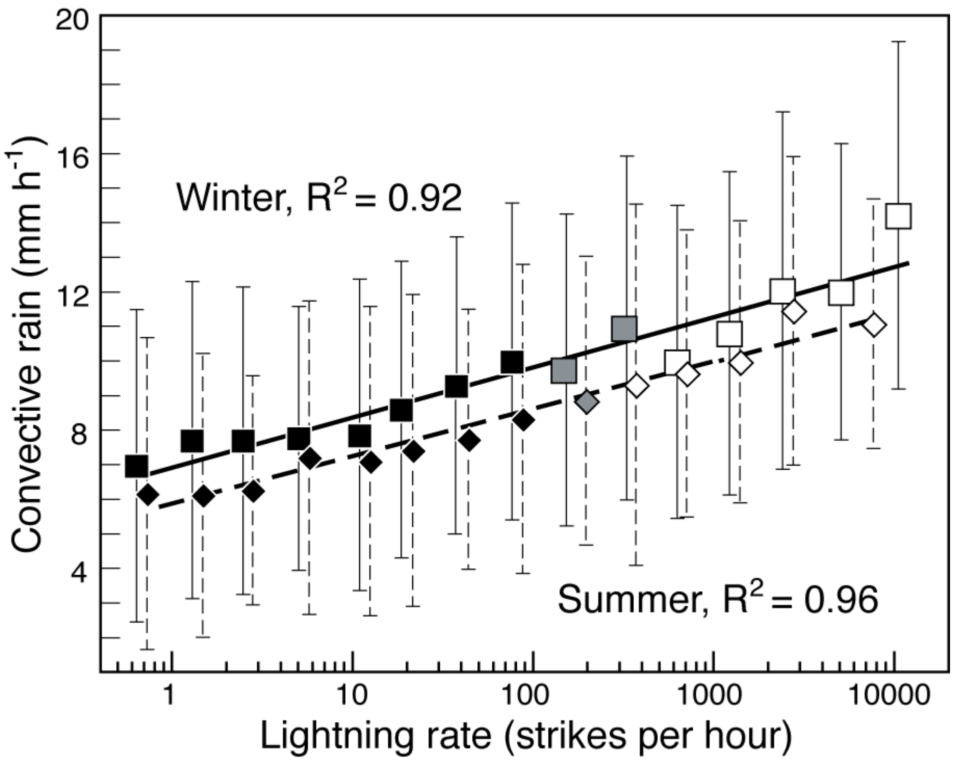
TMI
GPROF
Rain Rate



Sferics
Rain Rate

LTG-RR converted into parabolic Latent Heat profile centered at 500 mb

Lightning vs. Convective Rainfall



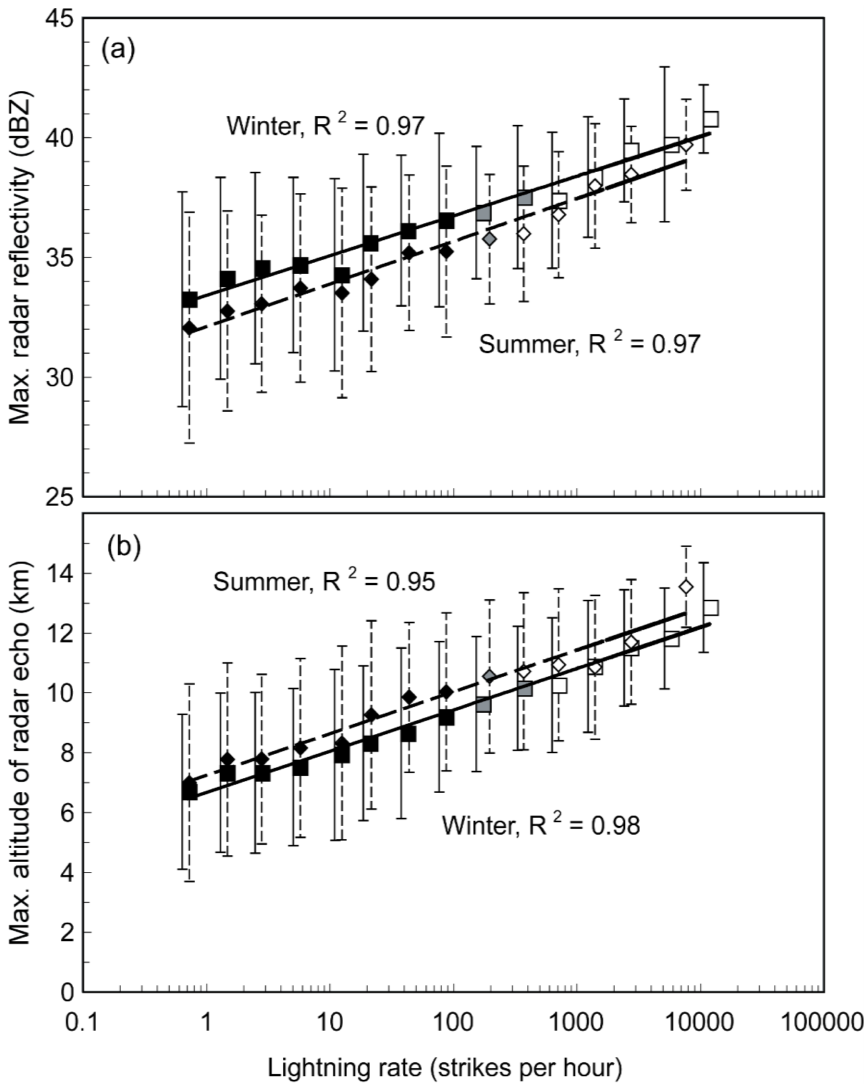
The log-normal relationship between lightning rate and rainfall intensity derived from TRMM and PacNet data is the key to use of lightning data in numerical weather prediction models (Pessi and Businger).

1. Pessi, A. T. et al., 2008: J. Atmos. and Ocean. Tech., 26, 145–166.
2. Pessi, A. T., and S. Businger, 2009: J. Appl. Meteor., 48, 833–848.
3. Squires, K. and S. Businger, 2008: Mon. Wea. Rev., 136, 1706–172.
4. Pessi, A. T., and S. Businger, 2009: Mon. Wea. Rev., 137, 3177-3195.

Lightning vs. Radar Reflectivity

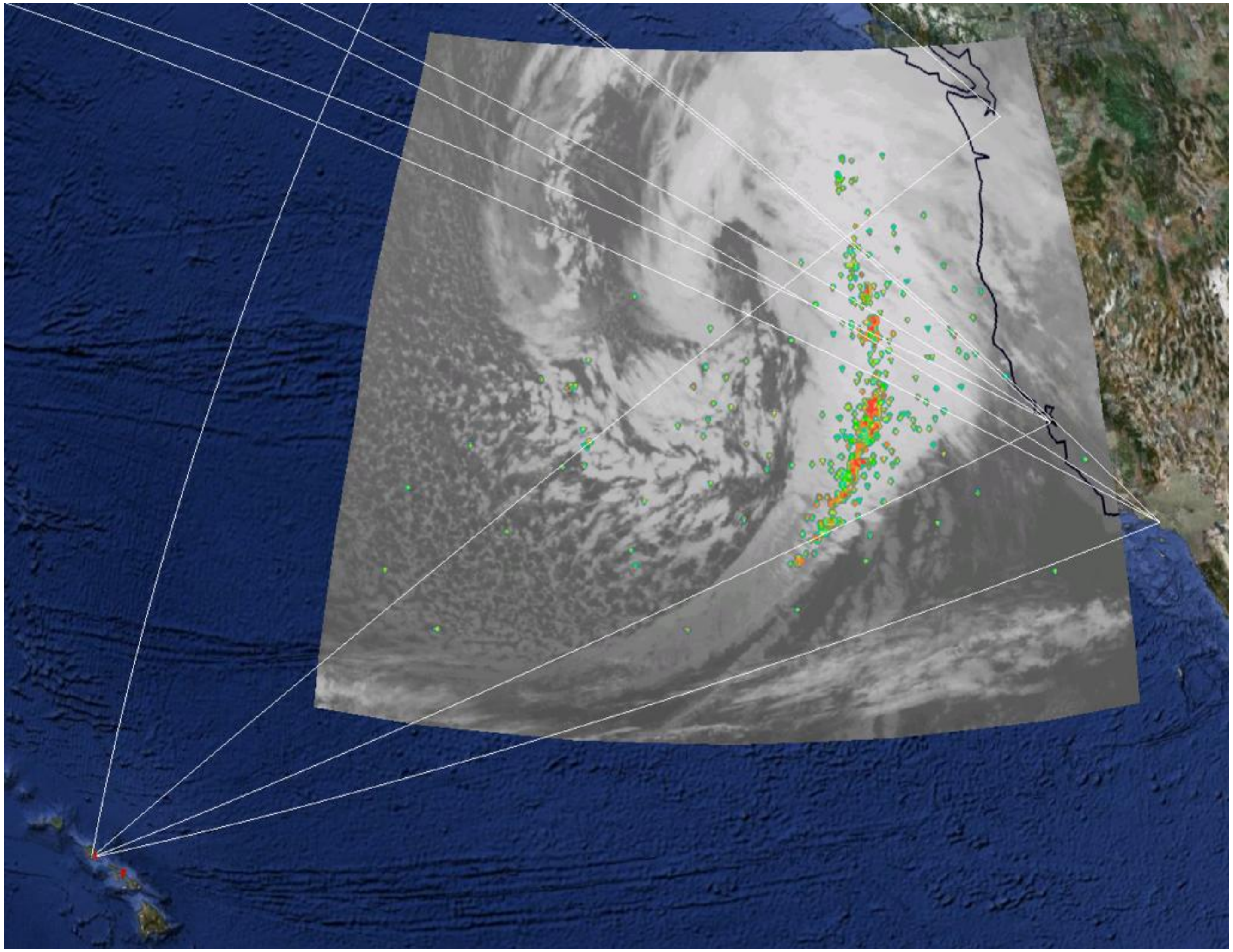
The relationship between lightning rate and weather radar products allows useful proxy products to be produced from the lightning data stream for many applications

(Pessi and Businger).



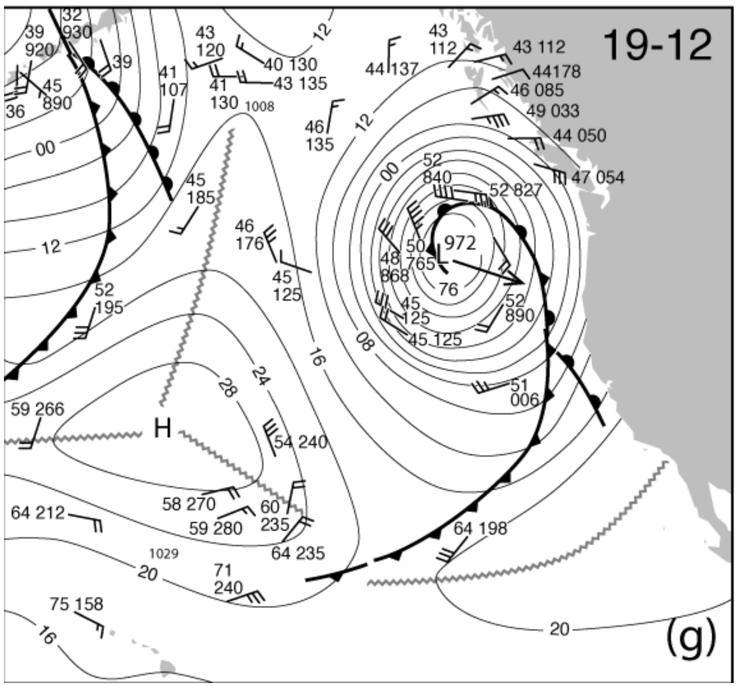
Radar Reflectivity Product

Businger, [North Pacific Storm animation]()

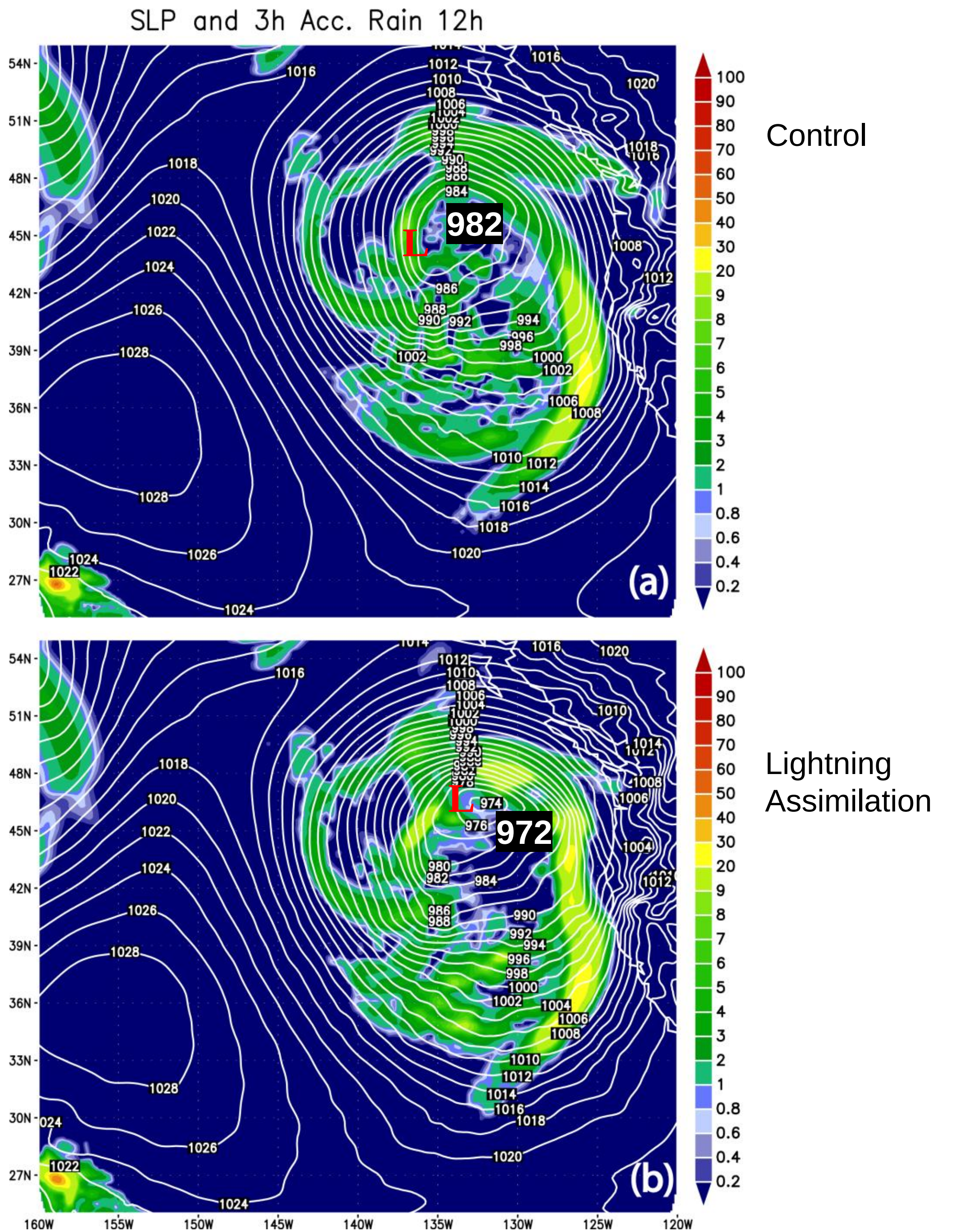


Lightning-derived reflectivity with airline flight tracks overlaid on IR satellite image (Pessi and Businger).

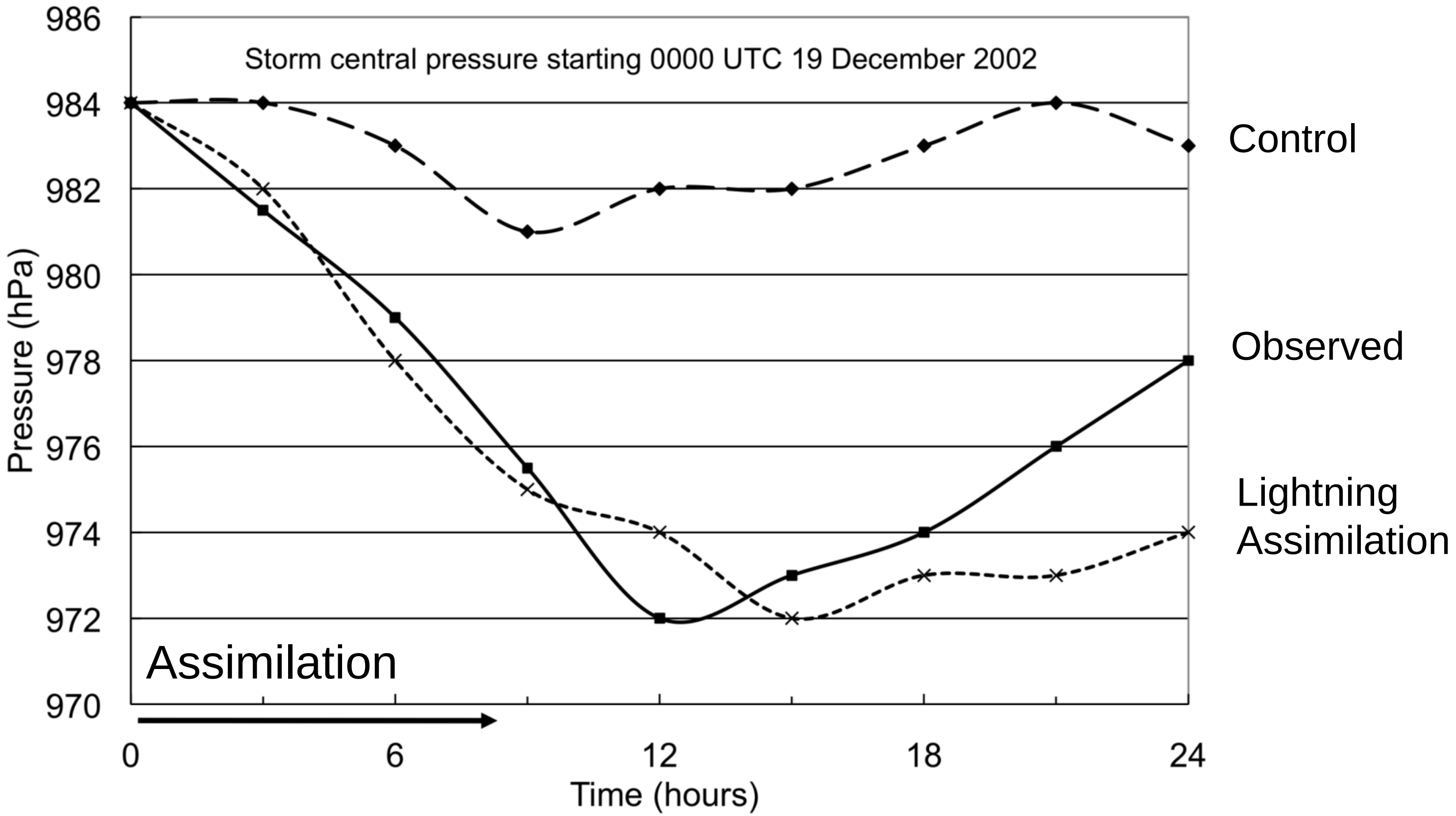
12-Hour Forecast of Sea-Level Pressure and 3-h Rainfall



Surface analysis
Valid 1200 UTC
19 December 2002



Central Pressure



Advection of High Theta-e Air into the Storm Center

<u>Upper figure:</u>

(a) CTRL, (b) LDA

Wind speed at 400 hPa (m/s, shaded)

Temperature at 400 hPa (K, contours)

Latent heating, as informed by the high lightning rates, increased temperature and ∇T across the front. This resulted in increased along-front winds, consistent with thermal wind balance.

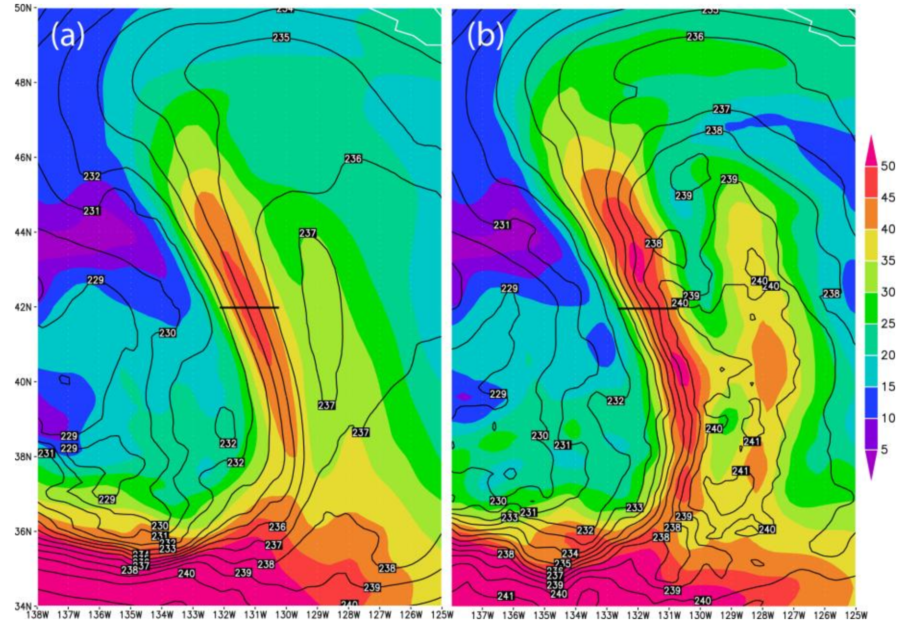
<u>Lower figure:</u>

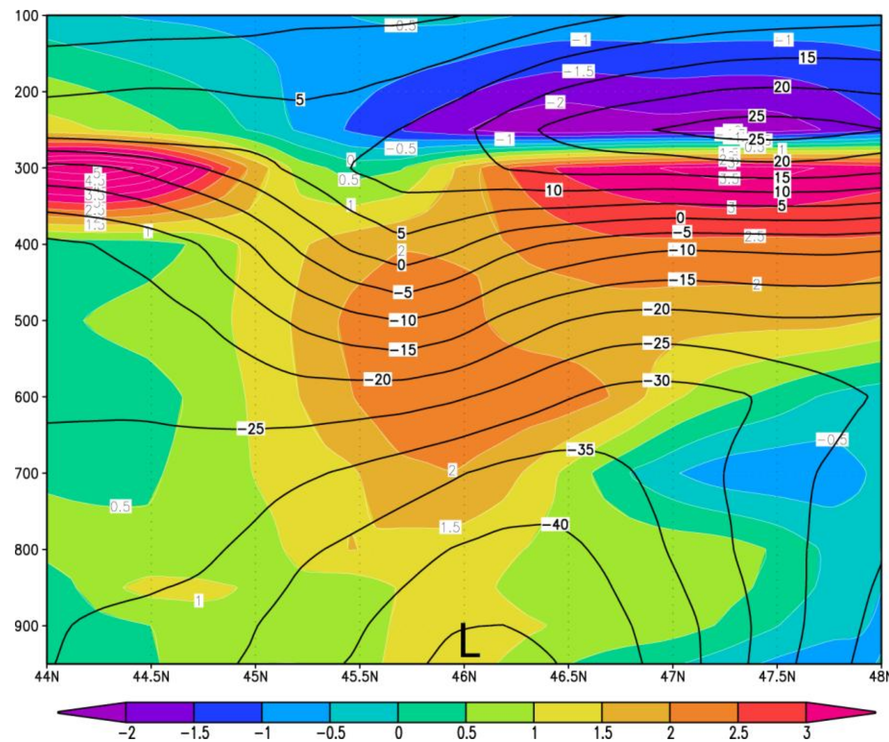
Difference between LDA and CTRL in:

Virtual temperature (K, shaded)

Geopotential height (m, contours)

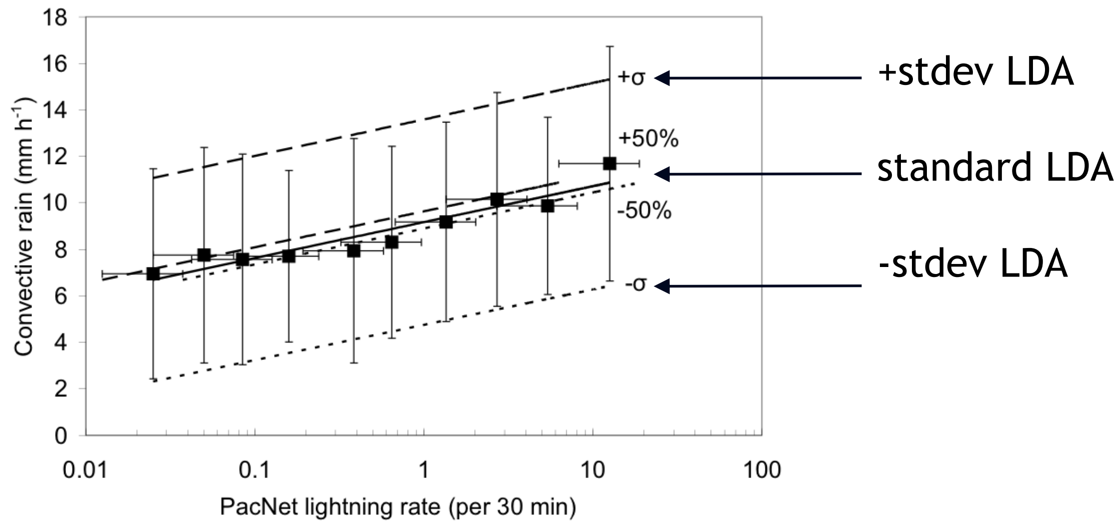
Enhanced advection of warm air over the storm center dropped the surface pressure hydrostatically.

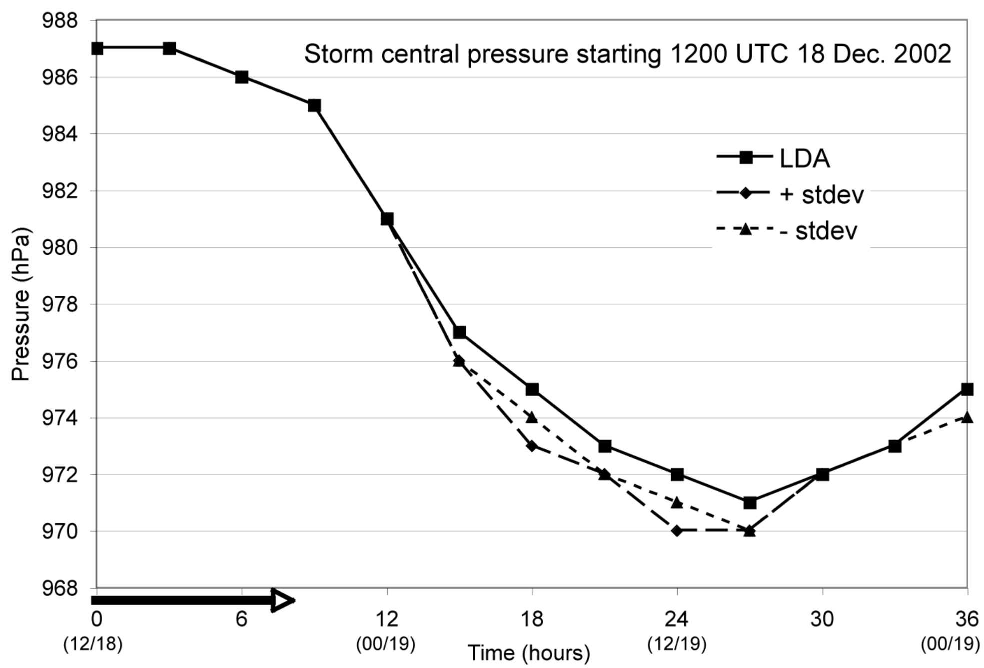




Sensitivity Studies

How do the errors in lightning rates and/or DE model, and lightning-rainfall relationship affect the model results?





Model insensitive to assimilated rainfall rates and very insensitive to errors in lightning rates.

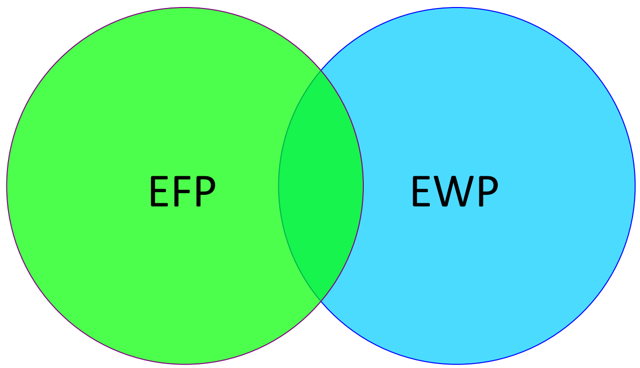
NOAA Hazardous Weather Testbed

Collaboration with GOES-R Proving Ground

Spring Program 2010
May 17-June 18

EWP 2010- 16 forecasters
EFP 2010 - 12 forecasters

Experimental
Forecast
Program

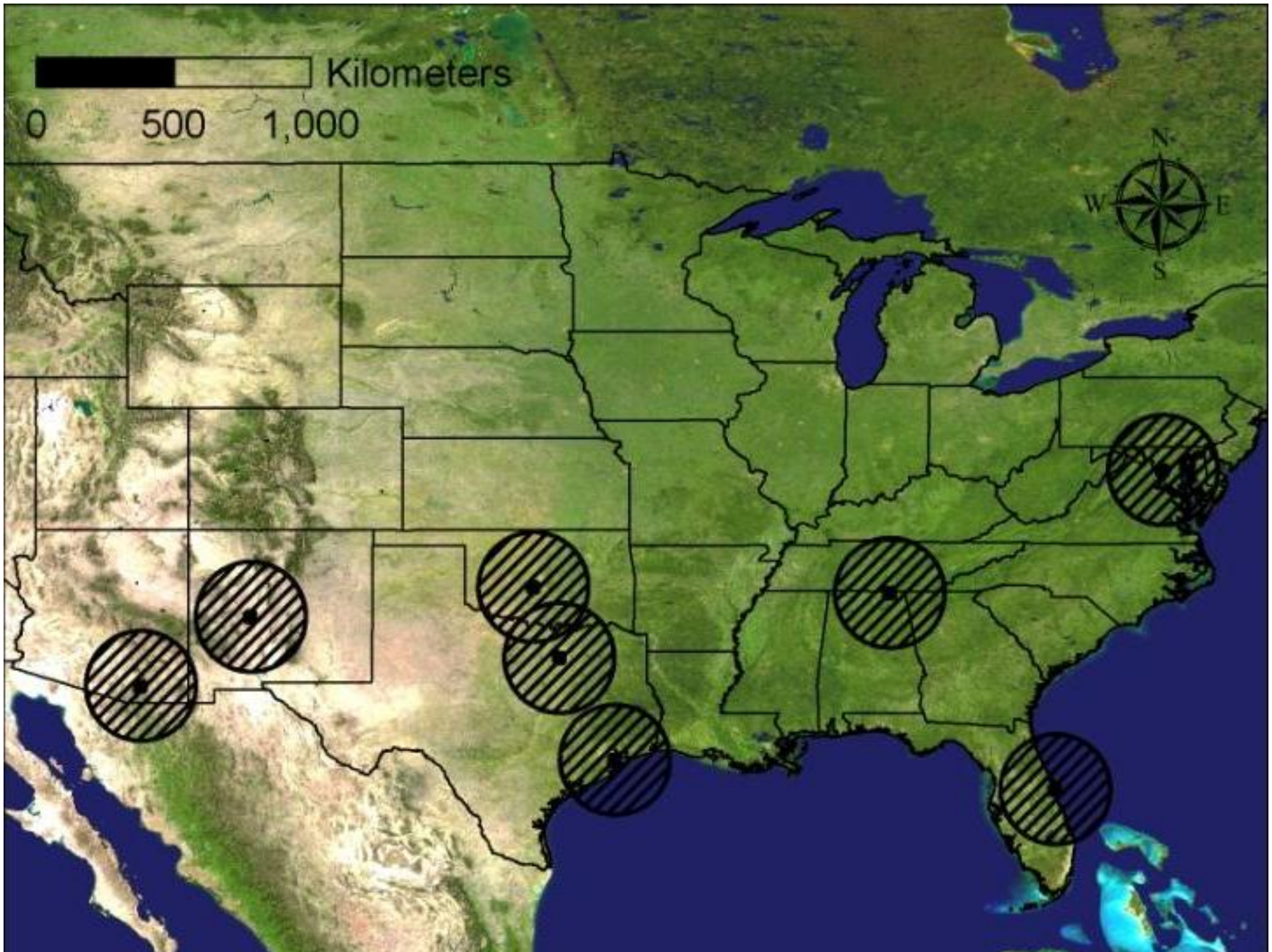


Experimental
Warning
Program

*Prediction of hazardous weather events from **a few hours to a week in advance***

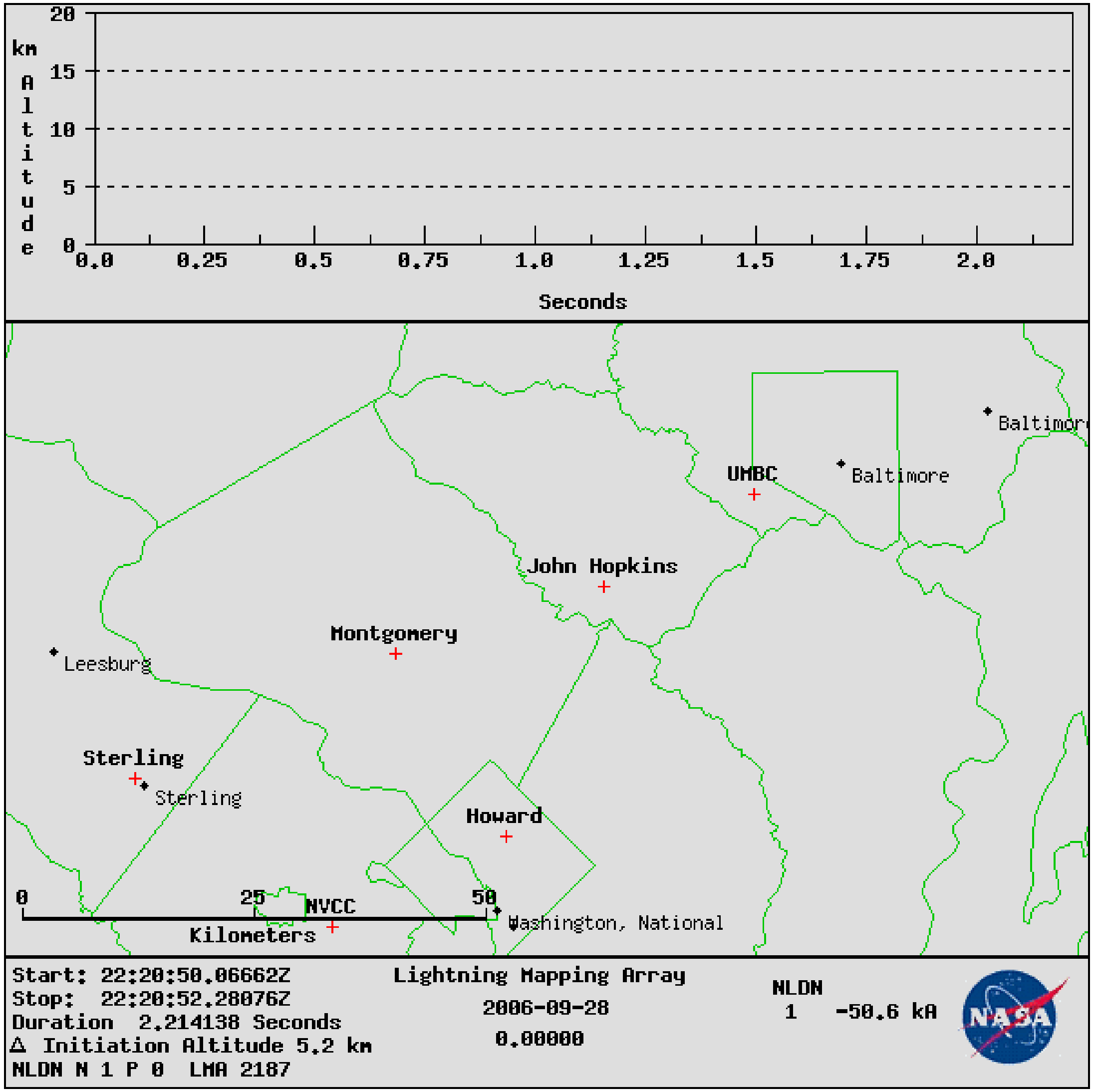
*Detection and prediction of hazardous weather events **up to several hours in advance***

Regional Operational and Research VHF Total Lightning Networks in USA



DCLMA Area Lightning Discharge

- 2.2 sec hybrid flash
- 50 km horiz extent
- Initiation at 5.2 km
- VHF Sources 2187
- CG strike at 2 s

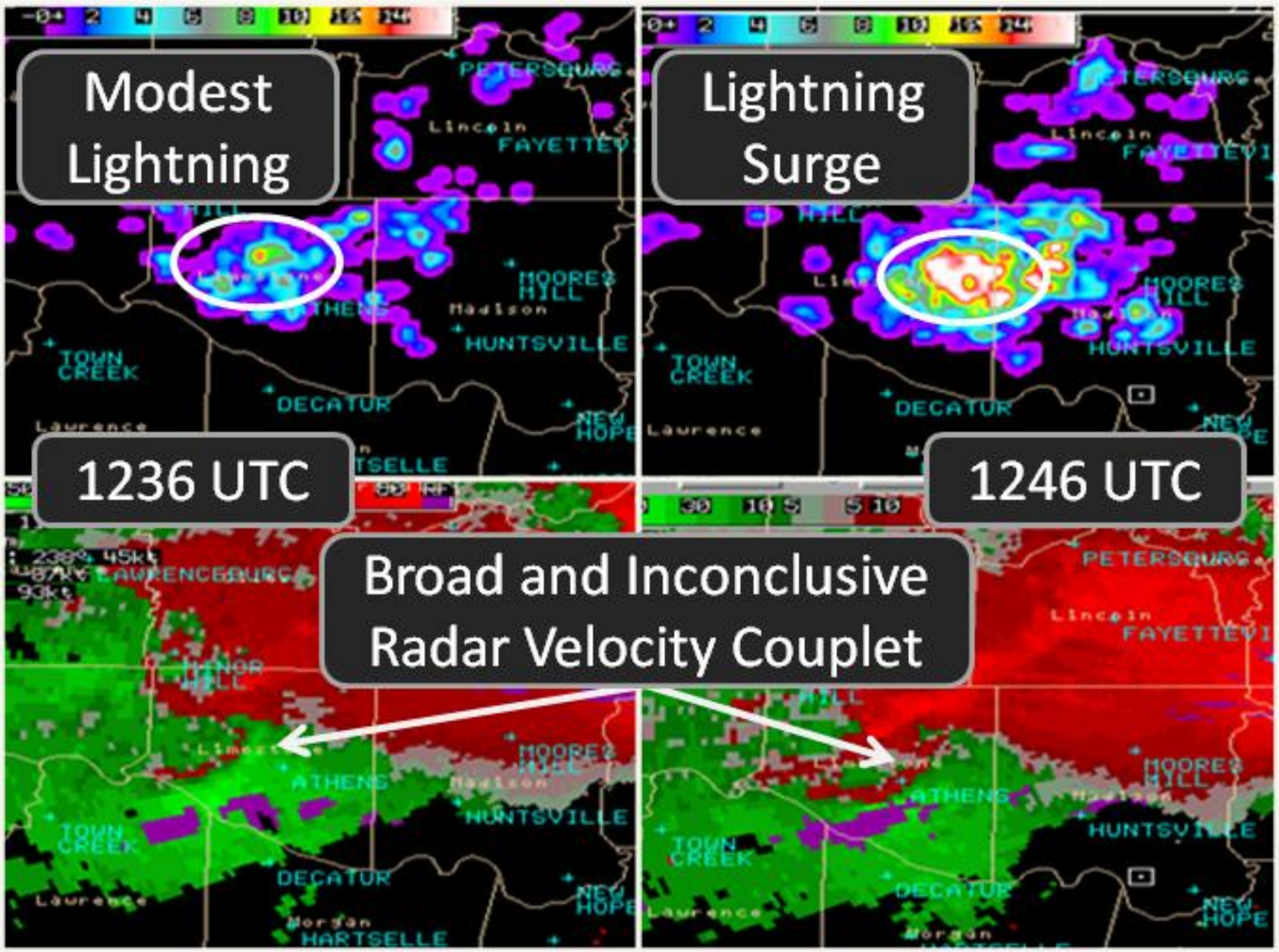


GLM will map initiation and propagation of each flash, detect in-cloud and CG lightning, but unable to distinguish between them based on the optical properties alone

http://branch.nsstc.nasa.gov/PUBLIC/DCLMA

Animated gif

Lightning Trends Depict Storm Intensification



Total lightning (Upper) from the North Alabama LMA coincident with NEXRAD radar-derived storm relative velocity (Lower) at 1236 (Left) and 1246 (Right) UTC on 6 May 2003. The lightning surge of over 200% occurs 14 minutes prior to a confirmed tornado touchdown. Image courtesy of Geoffrey Stano and SPoRT.

WRF Lightning Threat Forecasts
Background

- High-resolution explicit convection WRF forecasts can capture the character and general timing and placement of convective outbreaks well;
- Traditional parameters used to forecast thunder, such as CAPE fields, often overestimate LTG threat area; CAPE thus must be considered valid only as an integral of threat over some ill-defined time;
- No forward model for LTG available for DA now; thus search for model proxy fields for LTG is appropriate;
- Research results with global TRMM data agrees with models (e.g., Mansell) that LTG flash rates depend on updraft, precip. ice amounts.

WRF Lightning Threat Forecasts

Objectives

(McCaul, E. W., Jr., S. J. Goodman, K. LaCasse and D. Cecil, 2009: Forecasting lightning threat using cloud-resolving model simulations. Wea. Forecasting, 24, 709-729).

1. Create WRF forecasts of **Total Lightning** threat (1-24 h), based on two proxy fields from explicitly simulated convection:
   - graupel flux near -15 C (captures LTG time variability)
   - vertically integrated ice (captures anvil LTG area)

2. Calibrate each threat to yield accurate quantitative peak flash rate densities based on VHF Lightning Mapping Array (LMA) total LTG

3. Evaluate threats for areal coverage, time variability

4. Blend threats to optimize results for amplitude, area

5. Examine sensitivity to model mesh, microphysics

WRF Lightning Threat Forecasts Methodology

1. Use high-resolution 2-km WRF simulations to prognose convection for a diverse series of selected case studies

2. Evaluate graupel fluxes in the mixed-phase charging zone at -15C level; vertically integrated ice (VII=cloud ice+snow+graupel); dBZ also considered, but set aside because of nonlinearities

3. Calibrate WRF LTG proxies using peak total LTG flash rate densities from North Alabama LMA (NALMA) vs. strongest simulated storms; relationships ~linear; regression line passes through origin

4. Truncate low threat values to make threat areal coverage match NALMA flash extent density obs

5. Blend proxies to achieve optimal performance

6. Experiments to study CAPS 4-km ensembles to evaluate sensitivities

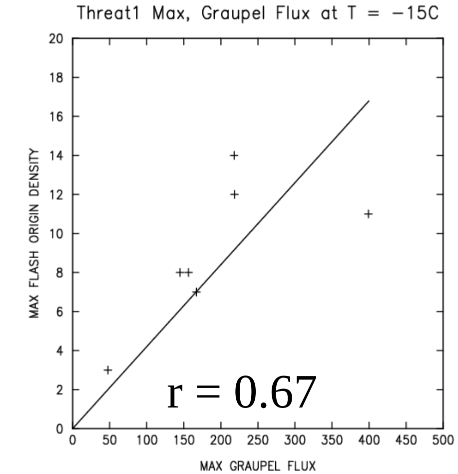
WRF Lightning Threat Forecasts Methodology

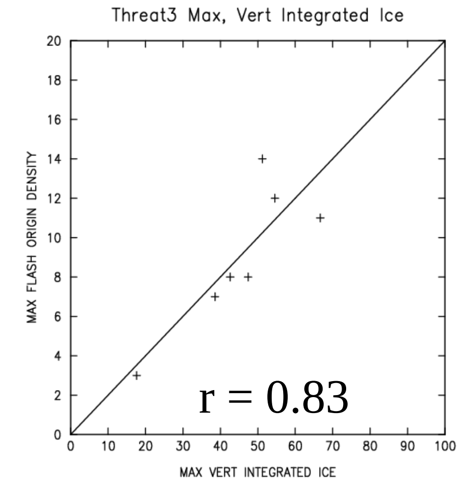
1. Regression results for threat 1 “F_1” (based on graupel flux, FLX = **$w*q_g$** at T=-15 C):

   F_1 = 0.042*FLX (require F_1 > 0.01 fl/km^2/5 min)

2. Regression results for threat 2 “F_2” (based on Vertically Integrated Ice, VII, cloud ice + snow + graupel from WRF WSM-6):

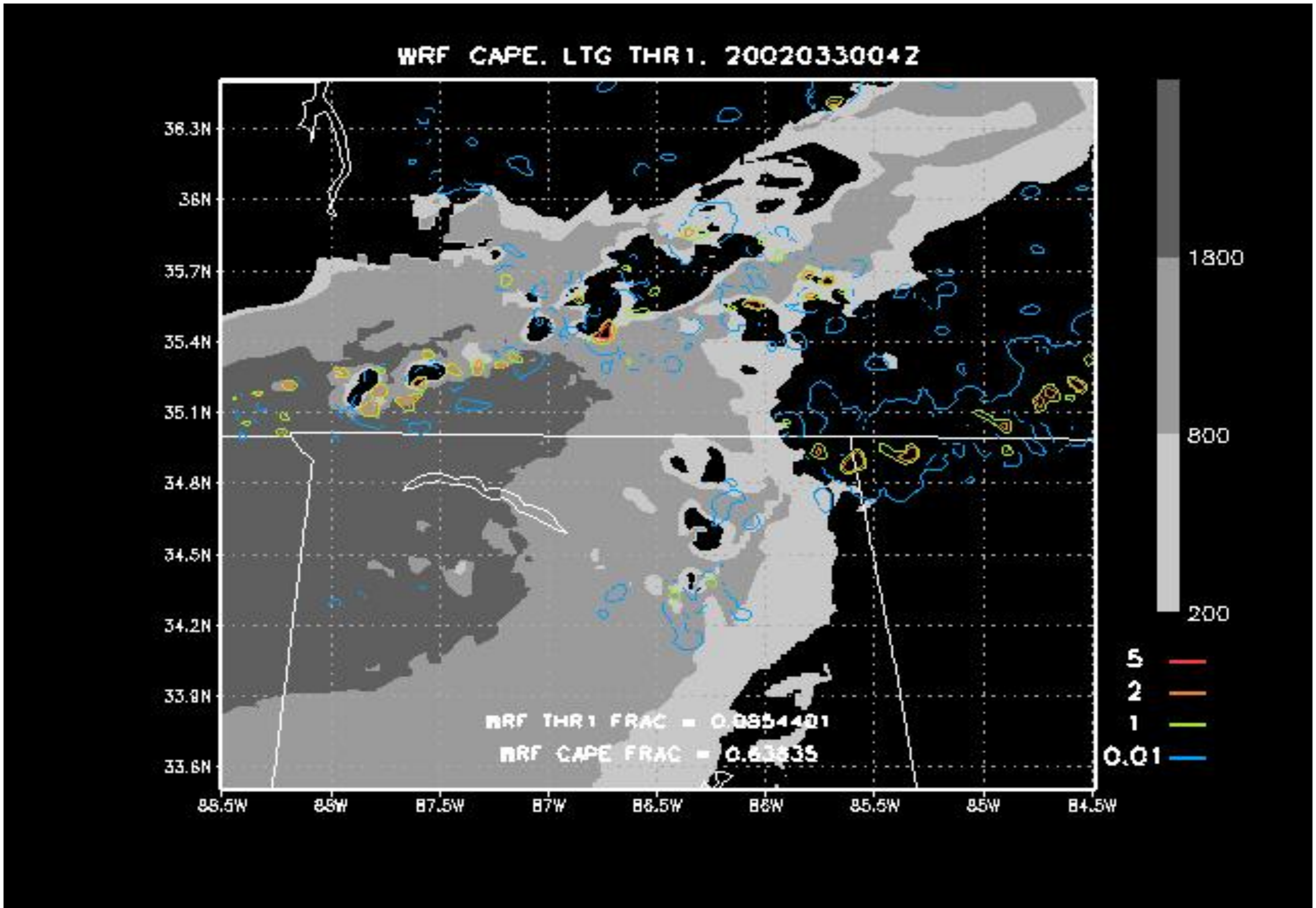
   F_2 = 0.2*VII (require F_2 > 0.4 fl/km2/5 min)





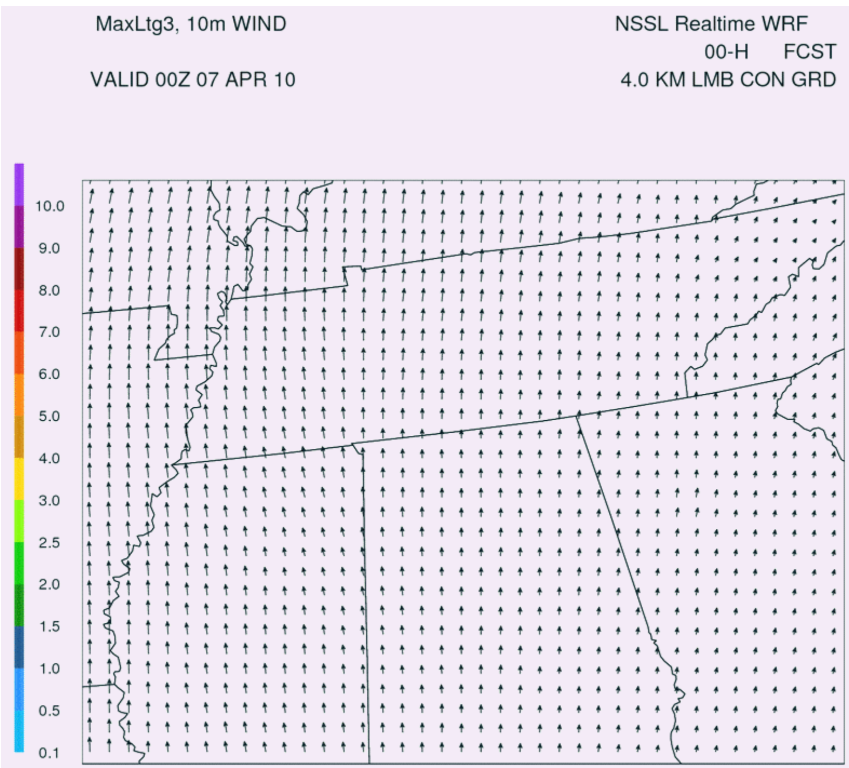
Comparison of Areal Coverage: CAPE vs Threat 1 Graupel Flux

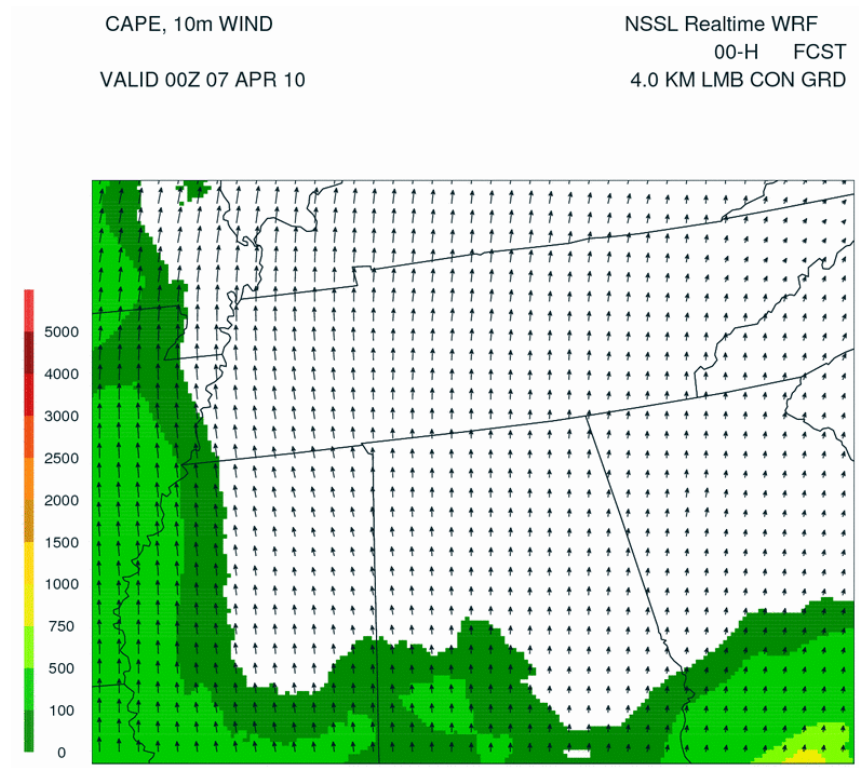
CAPE overpredicts lightning threat area



HWT Blog

http://goesrhwt.blogspot.com/





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EWP ready to go... 5/19/2010

Some notes from the briefing...

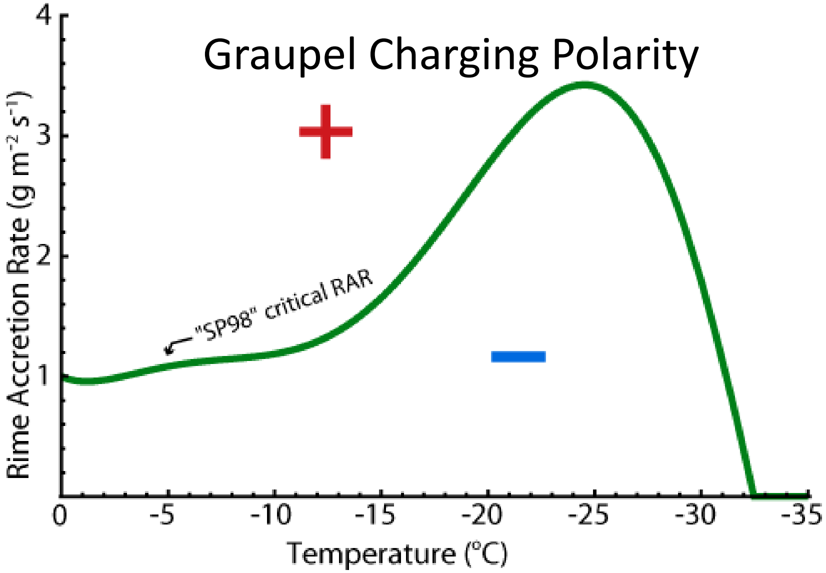
The NSSL-WRF lightning threat forecast was shown to the forecasters for this evening and it helped us identify which storms may have stronger updrafts because of their increased lightning output, which we couldn't necessarily determine from the synthetic satellite or radar output.

Thursday, May 20, 2010

- At 1:30 PM, the North Alabama Lightning Mapping Array (NALMA) showed lightning activity along the northern Mississippi-Alabama border. The 00Z 20 May NSSL-WRF run in support of the NSSL/SPC EFP shows continued evolution of this convection toward central Alabama by 00-02Z this evening.
- The lightning threat field in the NSSL-WRF using the McCaul blended vertically integrated ice / graupel flux method shows lightning activity extending north-south through Alabama at 1Z. The predicted flash rates are somewhat less over the far northern part of the domain.

RESEARCH NEEDED TO ASSIMILATE LIGHTNING FLASH RATES DIRECTLY IN ENSEMBLES

(MacGorman, Mansell, Ziegler et al., NSSL/CIMMS)



(SP98 = Saunders, C.P.R., & S.L. Peck, 1998: *J. Geophys. Res.*, **103**, 13949).

- **Determine grid resolution (<4 km) at which storm updraft similitude adequate**
- **Improve model microphysics (particularly ice)**
- **Add simplified electrification parameterization to forecast model**
- **Develop simple flash parameterization, such as:**
  - **determine threshold of charge for first flash at grid point**
  - **estimate subsequent flash rates from charging rates**
- **Determine how to map GLM data to model grid in space and time**
- **Assimilate GLM flash rates**
  - **assimilate where there is existing model convection**
  - **determine how to initiate missing convection**

Summary

- GLM instrument development on schedule
  - EDU risk reduction completion summer 2010
  - FM 1 optical component long lead items in procurement
  - Full CDR Fall 2010
- Ver. 1 of ATBD, Val Plan, Proxy Data, L2 Prototype S/W
  - Product demonstrations at NOAA Testbeds
    - Hazardous Weather Testbed (2010 Spring Program with VORTEX-II IOP, Summer Program)
    - Joint Hurricane Testbed (NASA GRIP, NSF PREDICT)
    - Aviation Weather Testbed (NextGen)
    - Continue Regional WFO demonstrations (Norman, Huntsville, Sterling, Melbourne, …)
- New Risk Reduction/Advanced Product Initiatives
  - Data Assimilation: JCSDA FFO 2010 funding two new GLM investigations
  - High Impact Weather Working Group- GOES-R DA focus on short-range NWP
  - Combined sensors/platforms (e.g., ABI/GLM ; ABI/GLM/GPM)
  - GLM proxy data 12-mo. campaign in Sao Paulo in partnership with InPE and CHUVA GPM pre-launch ground validation program
  - NSF Deep Convective Cloud and Chemistry (DC3) Experiment 2012