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**Breakout 1a- Meteorology and Cloud Electrification**

Amanda Back- facilitator, Steve Goodman- rapporteur

## Inputs

- We need to go to higher resolution- sub-km scale, in particular to understand the optical output from lightning
- Need for realistic cloud (e.g., WRF) for realistic optical and RF propagation through the cloud
- Charge structure

## Outputs

- How do we validate is very much scale dependent. Each measurement provides a different perspective. Then, different combinations of measurements show still more aspects of the lightning discharge. Small scale, heavily instrumented locations in a variety of environments.

- Roadmap - Develop a multi-agency field campaign to observe cloud lifecycle beginning before electrification - perhaps Florida leveraging installed base of infrastructure at KSC augmented with deployable assets- fast scanning phased-array radar, instrumented airplanes, interferometer, LMA

## Top 3 Uncertainties

- Need for error bars with the measurement and model
- Model and observed updrafts disagree, as much as 200% in different regimes (Kristen R)
- Is an ensemble model approach better than a discrete approach to capture uncertainty?

# Breakout report

Breakout 1b: meteorology and cloud electrification

Tue 2 Apr 12:30 pm

Facilitator: Lang

Rapporteur: Bruning

# Meteorology and cloud electrification

- Inputs
  - Meteorological state of the atmosphere
    - From operational / global systems nested down
    - From specialized field campaign measurements
- Outputs
  - Electric fields distributed in 3D space, time-> feeds e.g. Dwyer model
  - Information on cloud structure associated with electrostatic conditions
- Top three uncertainties
  - **Electrification mechanisms** (reversal line for RGR-NI, including at low LWC, and other melting layer charging mechanisms) -> lab studies
  - **Cloud structure**: updraft speeds, cloud microphysical schemes
  - In scoping new work, **scale (time, space) of lightning we're intending to study** / employ: hemispheric scale? Whole storm lifecycle? Details of one flash?

- Got lots of qualitative ideas. What do we actually want to do in specifics if we write a roadmap?

**Breakout Session 2a – Streamers, leaders, and relativistic processes**
Lead/Rapporteur – Welliver, Notes – Tilles

Inputs
- Ambient (cloud) electric field; ambient chemistry (e.g., air, water)
- PIC codes (particle tracking) for high-energy (x-ray/γ-ray), photoionization (initiate branching)
- Fluid codes for large streamer/leader systems (electron density evolution, adaptive mesh)
- Stochastic TL-type codes (~fractal approach) – assume length scales, parametrize streamers

Outputs
- Current, optical emissions, RF spectra from streamer and leader models
- X-ray/Gamma-ray spectra, current, large-scale electric potential effects from RREA models

Gaps
- Ambient (cloud) electric field (everywhere, all the time)
- Conditions for initiation (hydrometeor and/or RREA field enhancements, air showers, etc.)
- Understand 1 (maybe 2) streamers well, but not big systems (branching, proximity, accelerations, etc.)
- Relationship between NBEs and gamma-ray production (new ALOFT observations)
- Streamer-to-leader interface (both at leader tip and gross behavior within lightning flash)
- Disagreement on cause of leader "stepping" (space leader vs. pause-and-step)
- No models "predict" typical leader behaviors (e.g., stepping, dart leaders); needs parametrization

Opportunities
- Hybrid fluid-particle models to understand branching behavior of large systems, photons, etc.
- Monte Carlo simulations of large-scale steamer/leader development (parametrized behavior)

# Breakout report

Breakout 2b: Streamers, leaders and relativistic processes

Tue, 12:30 pm

Facilitator: Sonja Behnke/Chris Hogg

Rapporteur: Chris Hogg/Sonja Behnke

# Lightning initiation

- Cosmic ray shower (XMS) vs runaway relativistic processes (JD)
  - Inputs
    - background electric field, resolution ~100s of meters, over storm scale
    - Cosmic ray showers (stochastic process, rate reasonably constrained)
  - Outputs
    - Initiation location, local field enhancement
- Runaway process well modeled, lacks observational basis for lightning initiate part
  - Modeling needs to address smaller spatial scales, use more realistic charge distributions
- Cosmic ray shower hypothesis founded in observations, need modeling to understand physics
  - With modeling work, gain understanding of relationship between shower energy and background electric field in order to make a parameterization

# Lightning initiation other

- Hydrometeor enhancement

# Breakout report

Breakout 3a: Gross discharge structure and extent in storms

Tue, 2:15 pm

Facilitator: Sonja Behnke/Chris Hogg

Rapporteur: Chris Hogg/Sonja Behnke

# Riousset fractal model (2007 JGR)

- Inputs
  - Background electric field
  - Initiation location/seed structure
- Outputs
  - Distribution of charge on channel
  - Time-resolved leader structure
  - Currents -- add
- Top three uncertainties
  - Channels don't decay – need to add to get dart leaders
  - Need to add return stroke/feedbacks
  - Three
- Improvements
  - How can detailed streamer/leader models improve on this model?
- Similarities to Ted's approach

# Breakout report

Breakout 3b: gross discharge structure and extent in storms

Tue, 2:10 pm

Facilitator: Tilles

Rapporteur: Bruning

# Gross discharge structure and extent in storms

- Inputs
  - 3D electrostatics (esp. electric field, then charge and potential?), and their rates of change in time
- Outputs
  - Flash path→ flash width and duration
  - Current flows along channel, which feeds back in its development
- Top three uncertainties
  - Observations of 3D electrostatic structure of storms, and how charging microphysics is coupled to to draft width, depth, turbulence
  - Which electrostatic variables govern (zeroth-order) the discharge extent?
  - What governs current flows along channels, and interdependency

**Breakout Session 4a – Discharge Chemistry**
Lead/Rapporteur – Lang, Notes – Welliver

Inputs
- Flash geometry and energetics, including channel length, currents, temperatures
- Corona and streamer-based phenomena, optical emission important

Outputs
- To start, can ignore chemical feedbacks on convection/lightning
- Use chemical/convection models to drive transport and follow-on chemical processes
- In near term, best to parameterize NOx/HOx production for inputs to global models

Gaps
- Per-flash NOx production still uncertain
- HOx production by streamer processes – prevalence of these processes in thunderstorms
- In situ measurements still sparse

Opportunities
- TEMPO + GLM analysis to help constrain NOx estimates
- Lab experiments with 337-nm and HOx production
- Solar-blind UV cameras on balloon soundings thru convection
- Aircraft campaign with EMI-resistant instruments

**Breakout 4b- Meteorological Uncertainty**

Amanda Back- facilitator, Steve Goodman- rapporteur

## Inputs

- Use HRRR, for example, to identify convection, then a hybrid solution nest within it that runs for a shorter period.
- Instead of a perfect model, pull in range of possibilities from multi-model ensembles.
- Need hydrometeor distribution- phase, type, size, etc, and temperature, 3-d winds
- Role for LES vs HRRR or Hi-res WRF?
- MPAS- flexible resolution in a single domain is attractive

## Outputs

- Radar validation
- WMO Joint Working Group on Forecast Verification Research tools
- Accumulated precipitation
- Some satellite, e.g., GPM and IMERG for precipitation; GOES for cloud tops

## Top 3 Uncertainties

- Mean Free Path- need sub-grid scale to track particle movements
- realistic storm updrafts.
- Hydrometeors as accurate as possible

**Breakout 6a- LTG Source Emissions, RF & Optical**

Marc Welliver- facilitator, Steve Goodman- rapporteur

## Inputs

- Optical, Local Thermodynamic Equilibrium (LTE) models produces the heating profile to determine the spectral emissions.
- Gas dynamics models with hydrodynamic expansion with optical power per unit length- first principles
- Laboratory measurements that could be scaled-up
- Meteorological initial and boundary conditions, forecast model interface to cloud that makes lightning

## Outputs

- Full model lightning spectrum
- Need two levels of detail from ELF to VHF to model streamers and branching.
- Optical- non LTE chemistry needed
- Lab measurements a good way to validate the models
- Ensembles attractive, attack the individual components
- Stochastic model of discharge structure

## Top 3 Uncertainties

- Not enough good validation data- need measurements at the source
- What data are available to validate point by point with RF or optical?
- Lightning statistics representing the average and variation.

# Breakout report

Breakout 6b: Lightning source emissions

Tue, 4:00 pm

Facilitator: Sonja Behnke/Chris Hogg

Rapporteur: Chris Hogg/Sonja Behnke

# Optical Emissions

- Want model that produces both spectral content and light curve
- Hot channel models
  - LANL model (Jeffrey)
    - Current waveform in, spectrum out
  - Caitano model
    - Current waveform in, temp and electron density in channel out (time series)
  - General agreement that detailed time profile of currents can produce good time series light curves, but more uncertainty surrounding spectral content
- Streamer models
  - Ningyu (2013 GRL?) light emissions from streamers (TGF models)
- Are there optical models of laboratory sparks?
- Uncertainties
  - Need to know plasma speciation – time resolved model of chemistry
  - Extend models to larger scales
  - streamer models need more work

# RF Emissions

- VLF emissions follow from currents
- VHF emissions poorly understood
- Ningyu has models of RF output from streamers
- Amitabh – new work shows evidence that VHF emissions mainly associated with inception of space stems
  - Potential for a parameterization?
- Lots of VHF from attachment process, unknown processes
- Additional ouput desires – polarization of VHF

# Breakout report

Breakout 7a: Lightning instrument emulation, forward modeling Tue, 4:00 pm

Facilitator: Eric Bruning

Rapporteur: Amanda Back

# Instrument emulation

- Inputs
  - 4D signal: source is a filament varying in space and time
  - 3D environment/cloud: hard to validate 3D structure of cloud with available observations, particularly cloud ice most impacting scattering
- Outputs
  - Simulated instrument output from many diverse instruments, possibly including some that don't exist yet
  - Example: more rigorous simulation of next-gen GLM before it's available
- Top three uncertainties
  - Hard to pin down forward model without quality model of source
  - How to validate cloud composition
  - Need obs:
    - Diverse lightning observing instruments colocated (starting a list)
    - Tens of sonde- or drone-type instruments that can penetrate storms

**Breakout Session 7b – Lightning Instrument Emulation and Forward Modeling**
Lead – Tilles, Rapporteur – Lang

Inputs
- RF/optical emission estimates
- Cloud and precipitation particle size distributions
- Ionospheric TEC maps for VHF transmission to space

Outputs
- Lightning signals detected by the instruments

Gaps
- Still don't understand full EM + infrasound spectrum of lightning emissions
- Cloud/precipitation particle size distributions poorly characterized
- Cloud scattering impedes detailed observations of fast processes via optical (e.g., K changes)

Opportunities
- Sandia/LANL may have access to infrasound measurements
- Explore 3D vs. 1D/parameterized optical scattering – grad student project
- VR-based visualization and analysis of lightning processes
- RF + 337-nm measurements of streamer processes, RF + optical in general
- What can we do beyond location + $I_{pk}$ & polarity for VLF?