Geostationary Satellite–based Convective Initiation Nowcasting: Overview of Current Capabilities and Operational Aspects

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Motivation & Goals of a Geostationary CI Algorithm

Detect Convective Initiation using geostationary satellites to provide increased lead times for ANY convective event

• Multi–spectral/Multi–platform
• Expandable as new geostationary sensors/platforms become available (GOES-R, MTG, FY-2+, Hyperspectral)
• Possess a high-quality object tracking procedure
• In-line validation methodology (challenging)
• Discerns non-obvious events in varying convective regimes
• Be able to effectively incorporate:
  o NWP model data
  o dual-polarimetric radar data (2013)
  o geostationary-based total lightning and lightning initiation (2015)
  o derived cloud properties
• Consider non-traditional approaches to use of spectral information (e.g., random forest, logistical regression)
Download latest satellite imagery...

Monitor Cumulus Cloud Development

Satellite Detection

Radar Detection

Forecast without satellite

Forecast with satellite

Make Cloud Mask

Produce MAMVs

Track “Cloud Objects” from ‘T1’ to ‘T2’ (Similar to “Cb-TRAM” Zinner et al. 2008)

Determine CI forecast for each tracked Cloud Object using 6 spectral/temporal differencing tests (aka: “Interest Fields”)

CI Definition: 1st ≥35 dBZ echo at ground, or at –10 ºC altitude
Object Tracking Methodology

Advec T1 objects to projected locations at T2
Object Tracking Methodology

T1 Advected

T2 Actual
Object Tracking Methodology

Look for overlap between Actual T2 objects and those projected from T1

Zinner et al. (2008)
**Current GOES Interest Fields in CI Nowcasting**

- **Cloud-top Glaciation**
  - 10.7-μm $T_B$ (one score) <0°C

- **Cloud Top Growth**
  - 10.7-μm $T_B$ time trend (two scores) $<-4°C (15\min)^{-1}$
  - $\Delta T_B (30\min)^{-1} < \Delta T_B (15\min)^{-1}$

- **Cloud height, relative to mid-troposphere**
  - Timing of 10.7-μm $T_B$ drop below 0°C (one score) Within prior 30 min

- **Cloud height**
  - 6.5 (or 6.7)–10.7-μm difference $-35°$ to $-10°C$ (one score)
  - 13.3–10.7-μm difference (one score) $-25°$ to $-5°C$
  - 12.0–10.7-μm difference $-3°$ to $0°C (GOES-II)$

- **Cloud-top height changes**
  - 6.5 (or 6.7)–10.7-μm time trend $>3° (15\min)^{-1}$ (one score)
  - 13.3–10.7-μm time trend (one score) $>3° (15\min)^{-1}$
  - 12.0–10.7-μm time trend $>2° (5\min)^{-1} (GOES-II)$

*Table from Mecikalski and Bedka (2006)*
A comprehensive series of tests are performed within the CIMSS developed post-processing algorithm, ultimately minimizing broken tracks for developing convection.
UAH CI AWIPS II Display
Courtesy NASA SPoRT

Tracked Cloud Objects
Forecasted CI events

<SPoRT> UAH Convective Initiation: Mon 17:16Z 31-Oct-11
* G-15 IMG – 0.65 um VIS Cloud and Surface Features Mon 17:15Z 31-Oct-11
CI Night time Event: 7 Sep 2011
Courtesy MLB-WFO
Validation, or a comparison to NEXRAD radar observed first-time 35 dBZ echo occurrences, was performed at 4 locations in the U.S. for ~10,000 CI events.

High false alarms are certainly a concern. Comes with the territory…

Subsequently, a testing database was developed that contains CI events (contingency table – $a, b, c, d$) over the United States, for all four seasons.

Includes a number of NWP variables appropriate in the pre-convective environment (e.g., CAPE, LFC, $Z_{\text{freeze}}$).

Developed to be expandable.

Use of non–satellite datasets and other methods gets us closer to POD, FAR and CSI skills that provide more confidence to the nowcasts, while still identifying a large fraction of CI events.
Convective Regimes: False Alarm Reduction

- Statistical approach to adjusting interest field thresholds based on how cumulus clouds are growing regionally.
- Helps eliminate false alarms by increasing thresholds in environments with faster growing clouds (i.e., CI usually achieved in fastest growing clouds, while slower rising clouds in the same environment are no longer considered candidates for CI).
Current Version

- SATCAST:
  - 10.7 µm TB
  - 15- & 30-min 10.7 µm Trends
  - 6.7–10.7 µm TB difference & 15-min trend
  - 13.3–10.7 µm TB difference & 15-min trend
  - Convective Cloud Mask
  - MIT-LL Texture based cumulus field

- Environmental
  - Solar zenith angle
  - Amount of instability (CAPE)
  - Nearness to convective temperature
  - Elevated instability
Alternative Approaches – False Alarm Reduction

**Logistic Regression Method**
- Produced PODs of 63-73%
- False Alarms at 40-50%
- Results have no strong regional bias

**Probabilistic Method**
- Increased POD to ≥ 80%
- False Alarms reduced to 25-35%
- Results have no regional bias
Indicators being sampled for 2012

– SATCAST:
  • 10.7 µm TB
  • 15 min 10.7 µm Trends
  • 6.7–10.7 µm TB difference & 15-min trend
  • 13.3–10.7 µm TB difference & 15-min trend
  • Convective cloud mask at time 1 and time 2
  • Convective cloud mask change (i.e., cumulus to towering cumulus, cumulus staying cumulus, etc.)
  • Object size at t1 and t2
  • Change in object size for t1 and t2
  • Geographical locations (latitude/longitude)
  • Solar time

– Environmental (NWP)
  • Surface and most unstable convective available potential energy (CAPE)
  • Surface and most stable convective inhibition (CIN)
  • Surface and best lifted index (LI)
  • Lifted Condensation Level (LCL)
  • Level of Free Convection (LFC)
  • Convective Condensation Level (CCL)
  • Bulk Wind Shear and Low Level Wind Shear
  • Height of Freezing Level

12,000+ event CI database
• 143 CI events collected – convection was different across regions
• Active Collaborations with:
  o EUMETSAT’s Satellite Application Facility in support of Nowcasting & Very Short Range Forecasting (NWC SAF); also EUMETSAT’s Convective Working Group
  o Deutscher Wetterdienst (DWD)
  o Meteo Swiss
  o Japan Meteorological Agency
  o Republic Hydrometeorological Services of Serbia
New Research Directions
Cloud Properties: Detecting CI Beneath Cirrus Clouds

Mecikalski (2012) – Insights into detecting the “CI beneath cirrus” problem

Goal: Evaluate the parameters of visible optical depth (VOD), liquid water path (LWP), as related to cloud effective pressure, for cumulus growing beneath cirrus.

Result: When VOD is <15, infrared fields can be used similar to in clear sky conditions to nowcast CI.
• Ongoing work using derived cloud parameters (Mecikalski et al. 2011; Mecikalski 2012)

• Parameters rely heavily NWP data for their production, representing a continued commitment to “Data Fusion” techniques

• These datasets are similar to the convective cloud mask used heavily within SATCAST since 2005

• These fields contribute to both CI and Lightning Initiation detection

$r_e$ decreases at cold $T_B$ as particle settling in anvil

Increasing effective particle radius ($r_e$) → mixed phase region

$r_e$ decreases as cumulus deepen initially
The classification scheme of convective clouds into microphysical zones according to the shape of the temperature–effective radius relations

Note that in extremely continental clouds, the coalescence zone vanishes, mixed phase zone starts at $T<-15^\circ C$, and the glaciation can occur at the most extreme situation at the height of homogeneous freezing temperature of $-39^\circ C$. In contrast, maritime clouds start with large $r_e$ at their base, crossing the precipitation threshold of 14 $\mu m$ short distance above the base. The deep rainout zone is indicative of fully developed warm rain processes in the maritime clouds. The large droplets freeze at relatively high temperatures, resulting in a shallow mixed phase zone and a glaciation temperature reached near $-10^\circ C$. 

Courtesy D. Rosenfeld
Cloud drop
Rain drop
Ice crystal
Ice precipitation

Maritime, Moderate Updraft

Updraft

D. Rosenfeld
Cloud drop
Rain drop
Ice crystal
Ice precipitation

Maritime, Strong Updraft

Updraft

D. Rosenfeld
Cloud drop
Rain drop
Ice crystal
Ice precipitation

Severe

Updraft

D. Rosenfeld
Cloud drop
Rain drop
Ice crystal
Ice precipitation

Updraft

D. Rosenfeld
Updraft

Continental Severe

- Cloud drop
- Rain drop
- Ice crystal
- Ice precipitation

D. Rosenfeld
Lightning indicator values > 4 denote lightning strikes

7/3/11 New Orleans – Threshold Adjustment (25 min lead time)

Removal of false alarms

Changes:
LI1: -18 °C > 10.7 µm > 0 °C AND 3.9–10.7 µm > 17 °C
LI1: 10.7 µm < -5 °C AND 3.9–10.7 µm > 17 °C

LI3: 3.9 µm < 0.11 AND 3.9 µm reflectivity 15 min trend is < -0.02
LI3: 3.9 µm < 0.08 AND 3.9 µm reflectivity 15 min trend is < -0.02

Improvement in hits vs. false alarms:
60% hits, 40% FA
67% hits, 33% FA
WRF Lightning Threat Forecasts

Ground truth
LTG flash extent density (dBZ)
30 March 2002, 0400 UTC

WRF forecast: LTG Threat 1 (dBZ)
30 March 2002, 0400 UTC

WRF forecast: LTG Threat 2 (VII)
30 March 2002, 0400 UTC

Blended LTG Threat 3 (dBZ)
30 March 2002, 0400 UTC

McCaul et al. (2009)
• Created an algorithms that links 0-1 hour lightning initiation to forecast of a short-term lightning threat (density), or potential amounts per storm.
• Explore distance-weighted method to account for expected differences in lightning/storm initiation location and WRF-based lightning threat forecasted storms.
• Validate using LMA for truth flash density.
• Refine GOES lightning initiation method.
• Preparing for GLM
Questions: How to recover the cloudy–only signal from the IR scene, especially when it is obvious the IR pixel is artificially cooler than a clear–sky value would be?

Sharpening can only really work on IR pixel that have <9 clear HRV (CCM-determined) pixels.

The goal is to draw out the IR signal from non–cloudy IR pixels, and then: (1) normalize IR channel values, and (2) compute the normalized IR “interest fields” that are valuable for determining whether a cumulus cloud is growing toward CI or LI.
MSG IR & Dual–Polarimetric Radar Relationships

Expand GOES–NEXRAD work to include dual–polarimetric radar variables, Meteosat Second Generation (MSG) SEVIRI interest fields and derived cloud–top parameters, for lightning and non–lightning storms,

…in preparation for GOES-R.

Matthee et al. (2012a,b)
New Research Avenues

• Routine Use of Various Observation types for CI Nowcasting
  – Radar for in-line, real-time validation
  – Retrieved cloud properties
  – Formation of a robust nighttime cumulus cloud typing algorithm (not just low clouds)

• Use of Satellite–derived Cloud Patterns in CI Nowcasting
  – Purdom (1982) In, Nowcasting (K. A. Browning)
  – Involves pattern recognition/data mining

• Link CI with “Storm Intensity” and Geostationary Lightning Imaging
  – Lightning timing and amounts (flash density) can be nowcasting (next slides)
  – Couple Geostationary data to Passive Microwave

• Determine the Limits of CI Nowcasting Accuracy…
  – Motivate new sensor design
  – Leverage EUMETSAT collaboration and lessons learned for GOES-R

• Exploit use of Hyperspectral Data
  – Quantification of environmental (convective regimes)
  – Couple nowcasting with near–casting

• Organized plans for using “customer” feedback:
  – Work to obtain forecaster feedback, and incorporate improvements/suggestions
  – Work within NOAA/ESSL Testbed framework

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