Near Real-time Cloud Classification, Mesoscale Winds, and Convective Initiation Fields from MSG Data

Wayne Feltz*, J. Mecikalski, and K. Bedka*
Cooperative Institute of Meteorological Satellite Studies (CIMSS)
University of Wisconsin, Madison, WI, USA*
University of Alabama, Huntsville, AL, USA#

4th COPS Workshop
Stuttgart, Germany

25 September 2006
OVERVIEW

• Heritage
• Proposed MSG Applications
• COPS as a Satellite Validation Resource
• Conclusion
HERITAGE

- UW-CIMSS Satellite-based Nowcasting and Aviation Applications (SNAAP)
- Primarily NASA funded through Advanced Satellite Aviation-weather Products (ASAP) initiative working with Federal Aviation Administration and National Center for Atmospheric Research USA
- 4th Year of Existence with UW-CIMSS Research Focus
  - Convection, Volcanic Ash, Turbulence
- Team continues to explore satellite-based aviation weather applications with emphasis on the 0-3 hour forecast problem
- Successfully proposed to apply GOES imager convective initiation algorithm on SEVIRI imager (August 2006) for future GOES-R Risk Reduction
Why satellite-based nowcasting/aviation applications?

- Aviation/nowcasting community demands high temporal and spatial resolution at specified levels in the atmosphere.
- Aviation weather hazard information is diagnostically driven and are only relevant on very short aviation time scales (0-3 hours for icing, convective initiation, turbulence, volcanic ash).
- Satellite data provides the primary information over data sparse oceanic, polar, and high terrain regions where commercial and general aviation aircraft operate.
- While above points single out aviation the same can points can be made for nowcasting problem in general.
Satellite-derived Convective Nowcasting and Aviation Applications
Satellite Convective Product Descriptions

• Uses GOES 1 km VIS and 4-8 km multispectral IR imagery every 15-30 mins

• Convectively-induced clouds are objectively identified at a 1 km resolution
  - “Fair-weather” cumulus, cumulus congestus, deep overshooting cumulus tops, and thick/thin anvil cirrus are identified
  - Cloud-top temperatures and multi-spectral band differences are analyzed to identify clouds in a pre-CI state

• Very high density “mesoscale” satellite winds are used to track cumulus over a 30-min period to identify persistent rapid growth

• Cumulus in a pre-CI state that exhibit rapid vertical growth are flagged as having good potential for future thunderstorm development
UAH/CIMSS Convective Cloud Mask Developed to Discriminate Between Cirrus Anvil (pink), Mature Cu (Pink, purple), mid-level Cu (light blue) and Cumulus (dark blue) Satellite CI Nowcasting Algorithm
Oceanic Cloud Classification

- Multi-spectral GOES-12 data can be used to classify the various cloud features present within a scene.
- Features highlighted here represent:
  1) small, immature cumulus
  2) mid-level cumulus
  3) deep convection
  4) thick cirrus anvil
  5) thin clouds
Product Description and Objectives

- High-density “mesoscale” satellite winds are obtained through adjustments in the feature tracking scheme, and relaxation of quality control and the NWP model “first-guess” constraints within the UW-CIMSS satellite wind algorithm.

- These adjustments allow recognition of highly detailed atmospheric flow patterns in near real-time.

- GOES-12 VIS, IR, and WV mesoscale winds are currently used to estimate thunderstorm growth rates in GOES imagery, but may also be applied to aviation flight planning and data assimilation applications.

- Little published information exists describing the agreement of satellite-derived winds with reliable ground-based and in situ wind observations.

- *We are challenged to understand the limitations of current generation satellite wind algorithms in preparation for future satellite instrumentation, as there will be an increasing demand for high density flow information derived from GOES-R ABI.*
Mesoscale vs Operational Satellite Derived Winds

**MESO Settings 15 Min Imagery**
- 33% Shown: 1074 AMVs

**OPER Settings 15 Min Imagery**
- All Shown: 300 AMVs

- 5 min resolution imagery will allow for better retrieval of mesoscale flows because the shape of cloud/WV features does not evolve much over short time scales

- 15 min resolution imagery includes movement components from both individual cloud elements and the broad scale cloud field, which are combined within a satellite wind
GOES-12 VIS, IR, and WV high-density “mesoscale” motion vectors (MESO AMVs) are currently used to estimate thunderstorm growth rates in GOES imagery.

To use these motion vectors toward aviation turbulence identification and flight planning, we must understand their accuracy relative to robust wind measurements.

MESO and NOAA NESDIS operational (OPER) satellite motion estimates are compared here to 6-min NOAA Wind Profiler and rawinsonde data from the ARM SGP Central Facility.

From Apr. 12 to Nov. 31, 2005, there were 8588 MESO and 545 OPER AMV matches with QC’ed Profiler observations.

81% (95%) of MESO (OPER) AMVs had vector RMS difference values below 10 m/s.

One must evaluate whether greater flow detail (MESO method) or better relative accuracy (OPER method) will better suit his/her particular satellite wind application.
MESO and OPER AMVs are compared to a 381 level subset of radiosonde data to find the height where a given set of AMVs has the minimum vector RMS difference value (i.e. the “level of best fit”).

- If the min RMS falls below the horizontal line, the vectors were assigned a height that was too high, and vice-versa.

- Height assignments for VIS MESO vectors (IR window technique) and upper tropospheric IR MESO/OPER vectors was generally good.

- “Perfect” height assignment would have reduced RMS differences by 10 to 15%.

- Lower tropospheric IR vectors were assigned heights too low, yet more matches are needed to fully evaluate this.

- Remaining AMV “error” is likely produced by feature tracking problems within the AMV algorithm, atmospheric variability between sonde and AMV, or that satellite feature motion simply does not perfectly match the true flow.
**Infrared Interest Fields for CI Nowcasting**

<table>
<thead>
<tr>
<th>CI Interest Field</th>
<th>Critical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>![ ⭐️ ] 10.7 μm $T_B$ (1 score)</td>
<td>&lt; 0°C</td>
</tr>
<tr>
<td>![ ⭐️ ] 10.7 μm $T_B$ Time Trend (2 scores)</td>
<td>&lt; -4°C/15 mins [\frac{\Delta T_B}{30 \text{ mins}} &gt; \frac{\Delta T_B}{15 \text{ mins}}]</td>
</tr>
<tr>
<td>Timing of 10.7 μm $T_B$ drop below 0°C (1 score)</td>
<td>Within prior 30 mins</td>
</tr>
<tr>
<td>6.5 - 10.7 μm difference (1 score)</td>
<td>-35°C to -10°C</td>
</tr>
<tr>
<td>13.3 - 10.7 μm difference (1 score)</td>
<td>-25°C to -5°C</td>
</tr>
<tr>
<td>6.5 - 10.7 μm Time Trend (1 score)</td>
<td>&gt; 3°C/15 mins</td>
</tr>
<tr>
<td>13.3 - 10.7 μm Time Trend (1 score)</td>
<td>&gt; 3°C/15 mins</td>
</tr>
</tbody>
</table>

Roberts and Rutledge (WF, 2003) show the relationship between IR cloud top cooling and radar reflectivity change. When a cumulus cloud pixel IR $T_B$ rapidly drops to the 0 to -20 °C range, radar reflectivity increases and CI occurs.
Objective Cloud Classification

SATCAST Product Examples

Convective Initiation Nowcasting

Unidata NEXRAD Base Reflectivity Mosaic: 20060801 at 2045 UTC

GOES-12 Convective Initiation Nowcast: 20060801 at 2045 UTC

Region of Future Convective Development Highlighted By Satellite Before Observed By Radar

Unidata NEXRAD Base Reflectivity Mosaic: 20060801 at 2215 UTC

Operational RUC-20 CAPE: 20060801 at 2045 UTC

RUC-20 Convective Available Potential Energy (J/kg)
Geostationary Imager CI Nowcast Benefits

- All satellite inputs (winds, convective mask, and radiance tests all satellite derived)
- Takes advantage of temporal change of brightness temperature change, currently one of the few geostationary applications truly taking advantage of geostationary data temporally
- Provides ~45 minute lead-time for CI once cumulus clouds are present before 35 DBz radar reflectivity occurs (technical radar definition for convective initiation) of interest to many convective nowcasting efforts
Proposed GOES-R Risk Reduction Research (NOAA)

- Adapt current GOES imager software to MSG SEVIRI radiance inputs
- Optimize convective initiation, mesoscale AMV, cloud type classification
- Use the COPS ground-based instrument suite to validate products
- Provide optimal ABI convective initiation algorithm based on most advanced imager currently in operation
- Pave way for automated GOES-R ABI nowcast algorithm (~2012)
Channels Used in Convective Nowcasting
Objective Convective Cloud Classification from MSG SEVIRI

- SEVIRI has comparable spectral coverage to GOES-R ABI, which will allow us to evaluate the potential capability of ABI for monitoring and predicting the evolution and severity of convective storms.

SEVIRI Convective Cloud Classifier over Central Africa
Test Water Phase Temporal Transitioning??
Cloud Phase Detection (Physical)
(Heidinger and Pavolonis technique)

RGB (0.65 μm, 1.6 μm, 11 μm (flipped))

New VIIRS Cloud Type

- Clear
- Fog
- Water
- Supercold Water/Mixed
- Opaque Icicle
- Cirrus
- Overlap
- Missing
Convective and Orographicly-induced Precipitation Study COPS

A field experiment within the German QPF Program PQP

**Goal:** Advance the quality of forecasts of orographically-induced convective precipitation by 4D observations and modeling of its life cycle

**Region:** Southwestern Germany, eastern France
**Duration:** 3 months
**Date:** Summer 2007
**Features:** Severe thunderstorm activity but low QPF skill

**Information:** www.uni-hohenheim.de/spp-iop/

COPS Natural convection laboratory
Suggested area (270 x 150 km²)
Supersites

S1
- AMF
  - WV DIAL
  - RR Lidar
  - WindTracer
  - MWL & WiLi
  - HATPRO
  - FZK Cloud Radar
  - UHOH X

S2
- CNRS Raman lidar
- CNRS Doppler lidar
- ASMUWARA
- Cloud radar

S3
- UNIBAS Raman lidar
- UK Doppler lidar
- UK Ozone an Aerosol Lidar
- MICCY · TARA

S4
- CNRS Raman lidar
- CNRS Doppler lidar
- ASMUWARA
- Cloud radar

Rhine valley
- RS Station (mobile)
- DOW

Between S1 and S3
- RS Station (mobile)
- DOW

Black-Forrest valley entrances
- 2 FZK Sodars
- UF Sodar

Tuttlingen

Hartheim

Lidars
- Cloud radars
- Precip. radars
- Radiometers

Sodars/RASS
- 2 FZK Sodars
- UF Sodar

FZK Cloud Radar
- UHOH X
COPS Coordination

- MSG cloud, wind, and convective initiation research and algorithm transitions are currently ongoing
- Product quicklooks will be implemented at UW-CIMSS with EUMETSAT coordination
- Products will be available for in field evaluation
- MSG nowcasting application location for COPS still to be determined (UW-CIMSS, EUMETSAT, COPS ...) using McIDAS or other software??
- MSG applications will be tested and working prior to COPS field experiment initiation so some maturity acquired before field use
- Time latency??
SUMMARY

- Proposed research focuses specifically on transitioning current GOES imager SATCAST algorithm for use with SEVIRI imager (more bands available) and then improving algorithm with additional channels.
- Cloud classification algorithm is already in test mode for SEVIRI, mesoscale winds, and CI in transition.
- The European COPS field experiment will be used as an DOE ARM-like validation resource to evaluate integrity of winds, cloud-type classification, and convective nowcast.
- We are collaborating with Volker Gaertner, Marianne Koenig, and Johannes Schmetz at EUMETSAT to allow use in post-COPS era.
References

UW-CIMSS Satellite-based Nowcasting and Aviation Applications (SNAAP) Team Highlights

- Successful testing of GOES CI algorithm by FAA Convective Research Team
- Strong collaboration with worldwide Volcanic Ash Advisory Centers with regard to automated satellite-based volcanic ash detection and cloud height estimate
- New collaborations with NCAR Turbulence experts and satellite-based pathway for integration into NCAR Graphical Turbulence Guidance product
- These external ASAP collaborations have lead to new research/funding opportunities (NASA CAN, NASA ROSES, NOAA)
- CIMSS NASA Aviation Safety and Security Program Award for outstanding contributions to aviation weather research and development towards ASAP and TAMDAR programs
- 7 peer-reviewed papers, 17 conference presentations, and two MS Degrees
Simulated 2 km ABI

Convectively Induced Turbulence from ABI

- High spatial resolution ABI imagery will allow us to observe the evolution of convectively-induced gravity waves, which can produce severe turbulence for aircraft.
Objective Convective Cloud Classification from MODIS

- Increased spatial resolution and spectral coverage from MODIS allows for better depiction of hazardous convection over both land and ocean

MODIS 3 Channel Composite Imagery

MODIS Convective Cloud Classifier

Identification of Overshooting Tops from MODIS

GOES-12 3 Channel Composite Imagery

GOES-12 Convective Cloud Classifier

Berendes et al. 2006