Geosynchronous Microwave (GEM) Sounder/Imager Observation System Simulation

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Abstract - **Precipitation sensitivity calculations suggest that a geosynchronous microwave (GEM) sounder/imager using millimeter- and submillimeter-wave channels at 50-57, 118, 183, 340, 380, and 424 GHz with a 2-3 meter diameter real aperture antenna will provide time-resolved radiance data valuable for tracking convective precipitation events using a numerical weather prediction (NWP) model. Presented are scattering-based Jacobian simulations of a landfalling hurricane that illustrate the capabilities of GEM for precipitation measurement and NWP-based radiance assimilation.**

I. Introduction

Passive microwave sounding and imaging from geosynchronous orbit was first studied in the mid-1970's, although initial proposals using microwave channels at ~183 GHz and lower frequencies required prohibitively large antennas. In 1992 [1] it was proposed that submillimeter-wavelength channels could be used for many of the sounding and cloud/precipitation imaging applications that previously were believed to require the use of longer wavelength channels. The capabilities of submillimeter-wave channels for precipitation imaging were further demonstrated in 1994 using airborne imagery of clouds at the 325 GHz water vapor line [2]. These studies suggested that by using key submillimeter-wavelength water vapor and oxygen bands the antenna costs for geosynchronous microwave precipitation imaging and temperature and moisture sounding could be significantly reduced while retaining good spatial resolution.

It was with this background that the Geosynchronous Microwave Sounder Working Group (GMSWG) was convened in 1996-1997 to develop a baseline model for a practical submillimeter-wave geosynchronous microwave (GEM) sounder and imager [3]. The GEM model uses absorption by oxygen at 50-57, 118, and 424 GHz, and by water vapor at 183, 340, and 380 GHz. A series of 15 submillimeter- and 29 millimeter-wavelength narrowband channels are implemented at these bands [4] to provide temperature and moisture profiling capability from the lower stratosphere down to the surface (Table 1). Owing to the wide frequency range spanned by the five GEM bands each of them is differently affected by liquid and ice water amount and hydrometeor size. The bands collectively provide additional information on cloud and precipitation type and amount.

The baseline GEM concept uses a 2-meter Cassegrain scanning antenna with a nominal surface accuracy of ~10 μm in a dual-stage scanning system. The dual-stage system consists of a slow momentum-compensated azimuth mechanism and fast scanning subreflector scanning system to provide both wide-area synoptic coverage and fast regional coverage with adaptive scan capabilities. The 2-m antenna will provide ~16 km horizontal subsatellite resolution at the highest GEM frequency. Oversampling is expected to be able to improve the spatial resolution by an additional ~25% for high signal events such as mesoscale convection. As a result GEM will be capable of either intensively observing specific areas near severe weather or obtaining synoptic information over an extended environment.

Engineering studies by NOAA/ETL and MIT Lincoln Laboratories suggest that the size, weight, and power consumption of GEM (estimated at ~1.5 x 2 x 2 m^3, 65 kg, and ~150 W, respectively) permit its incorporation onto a GOES R+ satellite bus without major modifications. Accordingly, GEM is being studied for potential operational use by both NOAA and the European community [5]. We illustrate here the precipitation sensitivity of GEM through an observation system simulation for a landfalling hurricane event (Hurricane Bonnie, August 1998).

II. GEM Radiative Transfer Simulation

The GEM simulation is based on 6-km resolution, 60-level microphysical cloud data obtained from MM5 model runs for Hurricane Bonnie using the Reisner five-phase microphysical cloud model. A forward radiative transfer model based on the discrete-ordinate (DO) method and incorporating both scattering effects and fast calculation of the Jacobian of the forward transfer process [6] was used to compute observed brightness temperature fields and their derivatives with respect to scattering and absorption coefficients and temperature. Brightness maps for the GEM 424±4 GHz channel at three-hour intervals are shown in Figure 1, and Jacobian cross-sections for a 33^o latitude slice across the hurricane core and rainbands are shown in Figure 2.

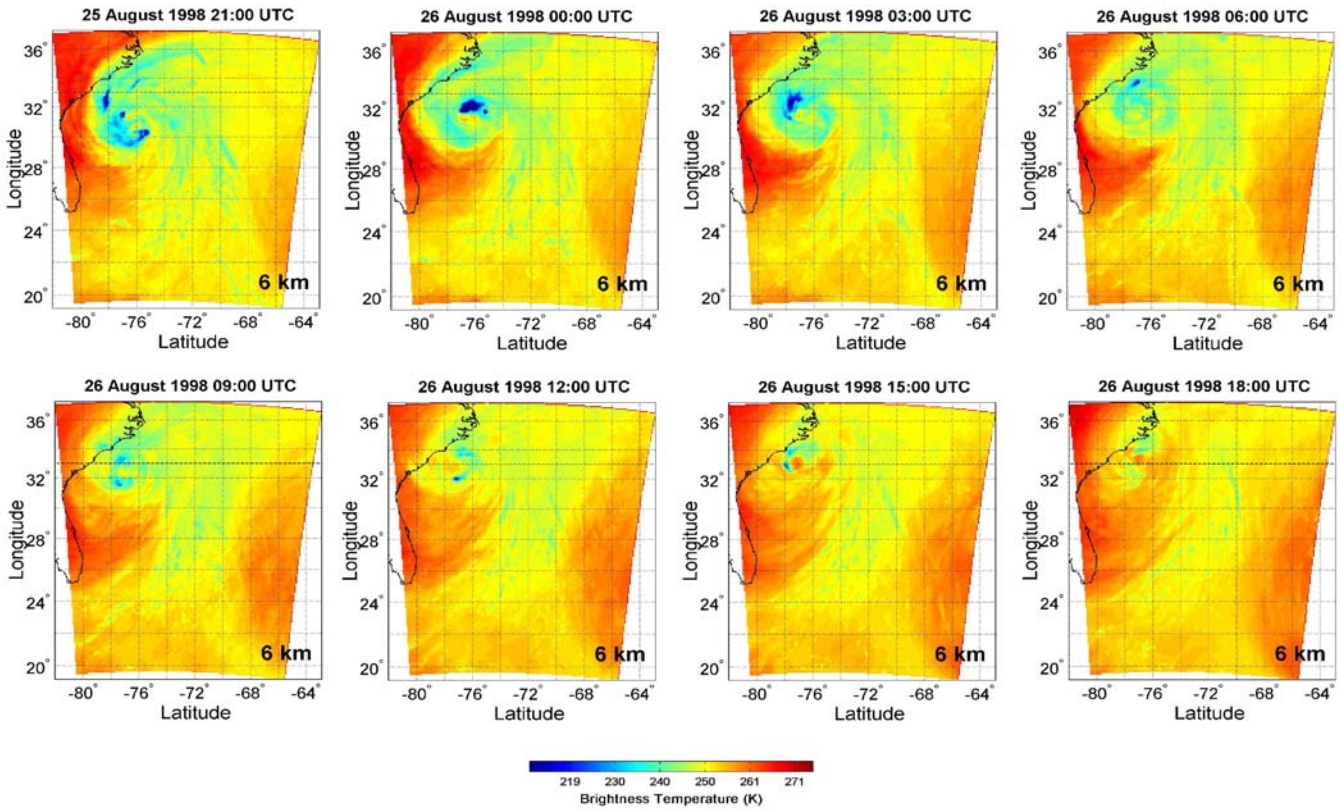

Figure 1. Simulated 424±4 GHz brightness imagery over Hurricane Bonnie at three hour intervals from August 25 2100 UTC to August 26 1800 UTC, 6-km grid resolution. The 424 GHz channel tracks cyclonic-flowing rainband structure beneath anti-cyclonic cloud tops.

Frequency Band (GHz)	Absorption Feature	Number of Channels	Receiver Noise Temperature (K)	ΔT_{RMS} (K)*	ΔT_{RMS} Required (K)	Footprint Size (km, nadir)
50-57 (AMSU-A)	Oxygen	11	750	0.04-0.1	0.1-0.6	139 (104)
118.750	Oxygen	11	1000	0.07-0.9	0.1-0.6	60 (45)
183.310	Water Vapor	7	1200	0.06-0.2	0.3-0.6	42 (31)
340 / 380.197	Window/Water Vapor	7	3500	0.3-3.4 *	0.3-0.5	19 (14)
424.763	Oxygen	8	4000	1.0-9.5 *	0.4-0.6	16 (12)

Table 1. GEM system parameters for a baseline 2-m diameter antenna and Nyquist sampling of a 1500 x 1500 km^2 region in 15 minutes. The effective integration time is 17 msec per sample. Asterisks indicate additional spatial averaging needed at some high altitudes to meet full sounding requirements. Footprint sizes in parentheses are effective resolutions for high signal events after deconvolution.

The simulations show that the most-transparent 424 GHz GEM channel imagery (Figure 1) provides excellent tracking of cyclonic-flowing rainband structure beneath the anti-cyclonic cloud top flow. This significantly increased degree of cloud top penetration relative to infrared channels is facilitated by a approximately hundred-fold increase in wavelength. Brightness temperatures range from as cold as ~210 K up to ~275 K, with rainband perturbations being statistically monotonic and negative with surface precipitation rate. Brightness temperature perturbations over rainbands are the result of both scattering of cold space by upper-cloud ice and absorption by both liquid and frozen hydrometeors. The highest resolution GEM imagery (~12 km after deconvolution for a 2-m antenna) will be similar to that shown in Figure 1 (~6 km resolution).

Figure 2 shows Jacobian cross sections for the scattering coefficient, absorption coefficient, and temperature for each frame in Figure 1 in groups of vertically-stacked triplets. Sensitivities to scattering are negative and extend down to ~6 km below the cloud tops. Sensitivities to absorption are either negative at low albedos and in clear air or positive if the scattering albedo is large. This bimodal response illustrates the need for scattering-based Jacobian calculations for all-weather microwave radiance assimilation. The Jacobians profiles revert to their expected clear-air forms outside of the hurricane and illustrate the sounding capabilities of the 424 GHz band. Use of such GEM imagery at update intervals as short as 15 minutes is expected to facilitate the "lock-in" of an NWP onto the hydrometeor state.

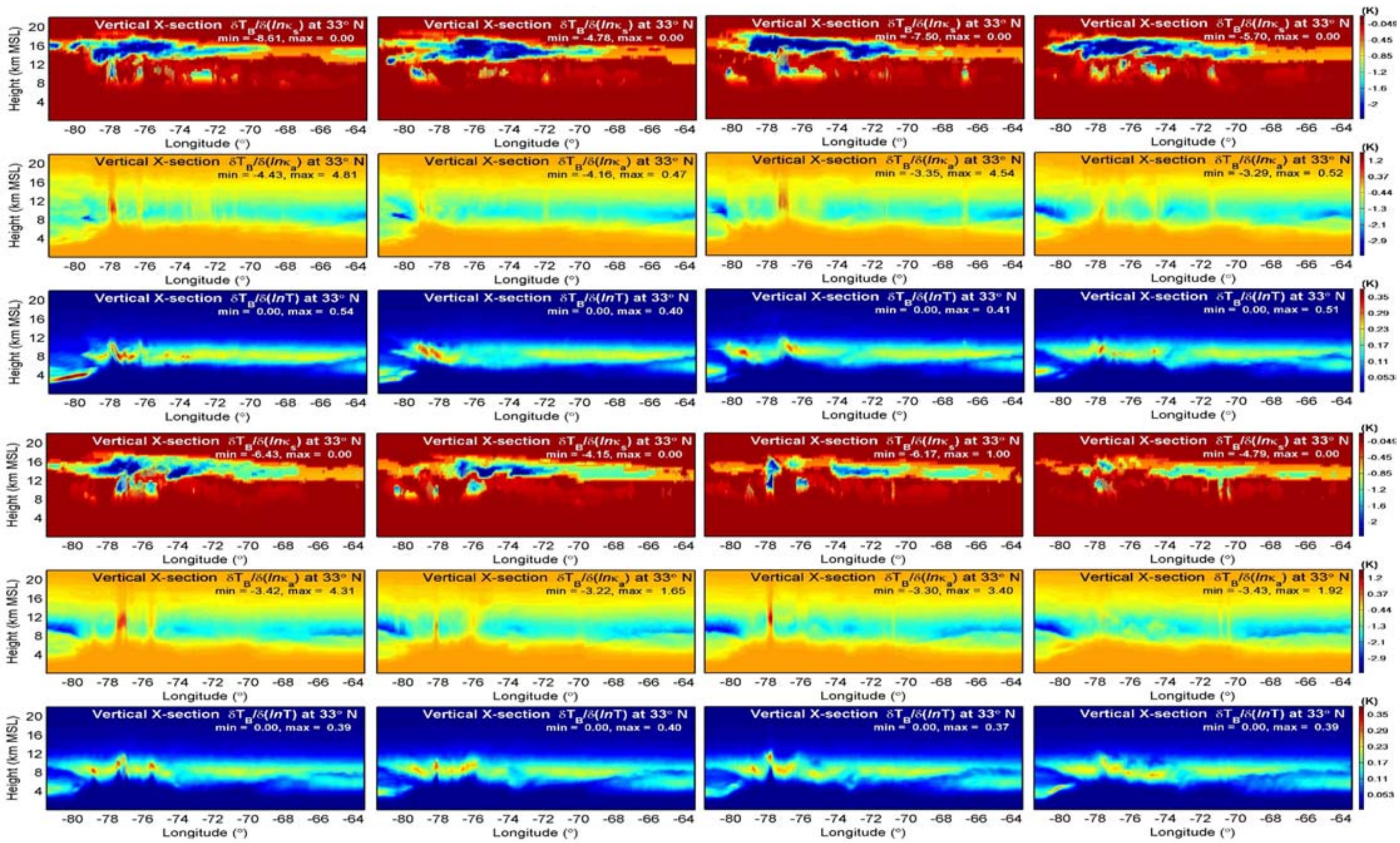

Figure 2. Vertical Jacobian cross-sections at 424±4 GHz through each of the eight frames of Hurricane Bonnie shown in Figure 1. Sensitivities of the upwelling brightness with respect to scattering coefficient (top), absorption coefficient (middle), and temperature (bottom) are shown in groups of three vertically-stacked maps. Each time frame shown in Figure 1 is associated with one such triplet of maps.

III. POTENTIAL APPLICATIONS OF GEM

GEM will fill key data gaps in current synoptic observation systems over opaque clouds and offshore regions and permit time-resolved observations of precipitation over nearly an entire hemisphere. The capabilities are complementary to current and future ground-based and satellite weather systems, including POES HIRS, AVHRR, CrIS, AMSU-A/B, GOES ABI and GIFTS, and NEXRAD. Used in conjunction with low earth orbit (LEO) satellites GEM can provide a temporal interpolation capability, particularly when used to lock NWP models via radiance assimilation.

Because of the rapid evolution of convective precipitation events, particularly for economically costly severe storms, monitoring precipitation and latent heating is challenging Existing LEO satellites do provide an adequate sampling frequency to capture the considerable spatial and temporal variability of precipitation events, especially over the full cycle of a convective storm. Using GEM it will be possible to more accurately observe the diurnal and life-cycle behavior of precipitation, latent heating, and atmospheric water budgets for both weather and climate applications than using LEO microwave or infrared systems alone.

REFERENCES

[1] Gasiewski, A.J. "Numerical Sensitivity Analysis of Passive EHF and SMMW Channels to Tropospheric Water Vapor, Clouds, and Precipitation", *IEEE Trans. Geoscience Remote Sensing,* vol. 30, no. 5, pp. 859-870, September 1992.

[2] Gasiewski, A.J., Jackson, D.M., Wang, J.R., Racette, P.E., and Zacharias, D.S., "Airborne Imaging of Tropospheric Emission at Millimeter and Submillimeter Wavelengths," *Proceedings of the 1994 International Geoscience and Remote Sensing Symposium,* vol. 2, pp. 663-665, 1994.

[3] Staelin, D.H., J.P. Kerekes, and F.J. Solman III, "Geosynchronous Microwave Sounder Working Group (GMSWG) Final Report", NOAA GOES Program Office NESDIS Office of Systems Development working group report, MIT Lincoln Laboratory, Lexington, MA, August 1997.

[4] Klein, M., and A.J. Gasiewski, "The Sensitivity of Millimeter and Sub-millimeter Frequencies to Atmospheric Temperature and Water Vapor Variations," *J. Geophys. Res.(Atmospheres),* vol. 13, pp. 17481-17511, July 16, 2000.

[5] Bizzarri, B., A.J. Gasiewski, and D.H. Staelin, "Initiatives for Mw/Sub-Mm Sounding from Geostationary Orbit," *Proceedings of the 2002 International Geoscience and Remote Sensing Symposium*, Toronto, Canada, June 24-28, 2002.

[6] Voronovich, A., A.J. Gasiewski, and R.J. Hill, "A Fast Multistream Scattering-Based Jacobian for Microwave Radiance Assimilation", to be submitted to *IEEE Trans. Geosci. Remote Sensing*, in preparation, April 2003.