

# **Assimilation of Long-Range Lightning Data over the Pacific**

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## **LONG-TERM GOALS**

A Pacific Lightning Detection Network (PacNet) has been constructed and expanded with support from ONR. PacNet currently consists of seven hybrid receivers. The sensors are sited in Kauai, Island of Hawaii, Unalaska, Kwajalein, Guam, Papua New Guinea, and Okinawa. In addition, a sensor will be installed in the Philippines in November 2008 (Fig. 1). The sensor in Kwajalein currently has communications issues that will be resolved in the near future. These sensors work together with the North-American Lightning Detection Network sensors located in the U.S. and Canada to form a network called PacNet/Long-Range Lightning Detection Network (PacNet/LLDN). Together the PacNet/LLDN sensors continuously monitor sferics over the Pacific Ocean and adjacent land areas. In addition, the project supports operational utilization of the data stream at NRL for (i) nowcasting convective activity, (ii) convective rainfall analyses over the Pacific, and (iii) to improve marine prediction of cyclogenesis and squall-line motion through sferics data assimilation in COAMPS and NOGAPS. Technology transfer to NRL will be accomplished in close collaboration with NRL scientists, with data processing and analysis support from University of Hawaii (UH) and Vaisala scientists.

## **OBJECTIVES**

The scientific and technical objectives of the Pacnet project are to collect long-range lightning data over the North Pacific Ocean, refine the relationships between lightning and storm hydrometeor characteristics and work toward implementation of operational assimilation of lightning derived products into COAMPS and NOGAPS. Various assimilation methods will be investigated, including 3D- and 4D-VAR, to find an optimal way to assimilate lightning data operationally into NOGAPS and COAMPS models. This work will be done in collaboration with NRL data assimilation team, including Allen Zhao, Keith Sashegyi, and Sue Chen.

In addition, lightning data from PacNet/LLDN together with data from TCS-08 operations will be used to investigate the morphology of lightning outbreaks in developing tropical cyclones over the Northwest Pacific Ocean (Fig. 2).

## **APPROACH**

Diabatic heating sources, especially latent heat release in deep convective clouds play an important role in storm development and dynamics. Lack of observations over the Pacific Ocean can lead to

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14. ABSTRACT <b>A Pacific Lightning Detection Network (PacNet) has been constructed and expanded with support from ONR. PacNet currently consists of seven hybrid receivers. The sensors are sited in Kauai, Island of Hawaii, Unalaska, Kwajalein, Guam, Papua New Guinea, and Okinawa. In addition, a sensor will be installed in the Philippines in November 2008 (Fig. 1). The sensor in Kwajalein currently has communications issues that will be resolved in the near future. These sensors work together with the North-American Lightning Detection Network sensors located in the U.S. and Canada to form a network called PacNet/Long-Range Lightning Detection Network (PacNet/LLDN). Together the PacNet/LLDN sensors continuously monitor sferics over the Pacific Ocean and adjacent land areas. In addition, the project supports operational utilization of the data stream at NRL for (i) nowcasting convective activity, (ii) convective rainfall analyses over the Pacific, and (iii) to improve marine prediction of cyclogenesis and squall-line motion through sferics data assimilation in COAMPS and NOGAPS. Technology transfer to NRL will be accomplished in close collaboration with NRL scientists, with data processing and analysis support from University of Hawaii (UH) and Vaisala scientists</b>					
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inadequate initialization of the numerical models and large errors in storm central pressure and rainfall forecasts. Specifying diabatic heating sources in the early hours of the forecast can improve the model's performance. Data from PacNet/LLDN are used to identify the areas and intensities of convective activity and latent heat release in storms over the Pacific Ocean.

Our hypothesis is that in cases of cyclogenesis in marine air masses, including subtropical cyclogenesis, the relationship between rainfall and lightning rates will be relatively robust because the aerosol and cloud microphysical environment is relatively uniform. Results of our comparison of the lightning rate measured by PacNet and rainfall and other hydrometeor characteristics obtained from TRMM's microwave imager and precipitation radar for a variety of storm systems over the central north Pacific indicate that the ratio of lightning to rainfall rate confirms a relatively stable relationship over the Pacific Ocean. This suggests that lightning data over the Pacific can be assimilated into numerical models as a proxy for latent heat and hydrometeor properties in deep convective clouds.

### ***Personnel and their tasks for the Project***

At UH, Professor Steven Businger, the PI, is working with Dr. Antti Pessi, Postdoctoral Fellow, on the data assimilation and lightning morphology studies in tropical cyclones.

Ken Cummins at the University of Arizona and staff at Vaisala (Nicholas W. S. Demetriades, Martin Murphy and others) will collaborate with UH to complete installation of new sensors and calibrate the network.

At the Naval Research Lab in Monterey, Allen Zhao, Keith Sashegyi, and Sue Chen will collaborate with Drs. Businger and Pessi on data assimilation studies. Dr. Joe Turk will investigate nowcasting applications of the lightning data stream over the Pacific.

### **WORK COMPLETED**

- 1.** The detection efficiency (DE) and location accuracy (LA) models for the long-range lightning detection network (LLDN) have been calibrated and validated. The result of this work is that the DE and LA models can be used in quantitative applications of long-range lightning data. A paper describing this work was accepted for publication in July 2008 in the *Journal of Atmospheric and Oceanic Technology* (Pessi et al. 2008).
- 2.** The DE and LA models were used to quantify the lightning rates over North Pacific Ocean storms. Satellite data from TRMM's precipitation radar and microwave imager were compared to the lightning rates from the PacNet/LLDN to establish relationships between lightning and hydrometeor characteristics over the North Pacific. This work was accepted for publication in October 2008 in the *Journal of Applied Meteorology and Climatology* (Pessi and Businger 2008a).
- 3.** The potential of lightning data assimilation into NWP models was investigated by using the results from (1) and (2) and by assimilating long-range lightning data over a poorly forecast extratropical cyclone over the eastern North Pacific Ocean. The results of this work were submitted to *Monthly Weather Review* in July 2008 (Pessi and Businger 2008b) and are currently in revision.

4. An operational image production and data feed was established to transfer long-range lightning data, satellite-lightning images, and lightning count graphs to the T-PARC/TCS-08 field catalog in near-real time.

5. Promising cases from TCS-08 operations period have been identified and these will be further investigated. For example, Typhoon Jangmi exhibited a rapid intensification period on 26-27 September, during which there were lightning outbreaks in the eyewall (Fig. 2).

6. A website has been constructed that describes the construction and calibration of PacNet/LLDN and results from data assimilation studies. The web site has both real-time and archived satellite-lightning images.

(See: <http://www.soest.hawaii.edu/MET/Faculty/businger/projects/pacnet/>)

## **7. New sensors installed in the Western Pacific:**

### **7.1. Status of sensor sites**

Vaisala began installation of long-range lightning sensor sites in the TPARC/TCS-08 region in June 2008. Table 1 shows the status of the first four sites. Guam was the first TPARC/TCS-08 sensor site installed with communications. This sensor became operational on 26 June 2008. Papua New Guinea was the second site installed with communications. It became operational on 8 August 2008. Okinawa was the third site installed. Unfortunately, this site is still not communicating to the Vaisala Network Control Center (NCC) in Tucson due to a lack of timely response from Vaisala's Japanese contractor. Vaisala's communications contractor plans to install sensor communications at the Okinawa site by 12 December 2008. Vaisala recently obtained a signed site agreement for a location in the Philippines. Sensor and communications installation is planned for 14 November 2008.

### **7.2. Franklin Japan Corporation lightning sensor participation during TPARC/TCS-08**

Funding delays and unanticipated delays in sensor site installations meant that the West Pacific tropical cyclone genesis region would not have adequate lightning detection efficiency during the TPARC/TCS-08 field campaign. Therefore, Vaisala asked Franklin Japan Corporation (FJC) to share lightning data from their network of 15 sensors. These sensors have long-range lightning detection capabilities similar to the sensors currently installed in Vaisala's National Lightning Detection Network (NLDN). FJC graciously agreed to share their sensor data with Vaisala for the duration of the TPARC/TCS-08 field campaign. FJC sensor data started to participate in the TPARC/TCS-08 long-range lightning detection network on 22 August 2008.

FJC sensor data accomplished two goals. First, it immediately improved cloud-to-ground (CG) lightning detection efficiency within the West Pacific tropical cyclone genesis region during the TPARC/TCS-08 field campaign. Second, it provided Vaisala with a valuable dataset for calculating site error corrections at the Guam and Papua New Guinea sensor sites. Proper site error corrections are needed at each site to utilize the magnetic direction finding sensor measurements within Vaisala's lightning location algorithm. Without site error corrections, only time-of-arrival measurements can be used to locate lightning flashes.

*Table 1 Long range sensor site status for the first four TPARC/TCS-08 sensor sites.*

Sensor site	Sensor Installation Date	Communications Installation Date	Site error corrections completed
Guam	26 June 2008	26 June 2008	Yes
Papua New Guinea	8 August 2008	8 August 2008	Yes
Okinawa	14 August 2008	12 December 2008	No
Philippines	14 November 2008	14 November 2008	No

### 7.3. Projected Western North Pacific long-range lightning performance

Figures 3 and 4 show expected CG lightning flash detection efficiency (DE) over the North Pacific for night and day, respectively. CG lightning detection efficiencies generally range from 50 (20) to 80 (60) percent over the West Pacific tropical cyclone genesis region during the night (day).

The DE model used to create these projections has been improved since Vaisala sent the initial memorandum of understanding to the University of Hawaii and the Office of Naval Research in August 2007. DE model improvements were implemented as a result of validation studies performed by the University of Hawaii and Vaisala over the past year, as detailed in Pessi et al. (2008).

Figure 5 shows the expected CG lightning location accuracy over the North Pacific for both night and day. Typical CG median location accuracies are less than 8 km over the West Pacific tropical cyclone genesis region.

### 7.4. Vaisala commitment to data quality

Vaisala is committed to providing continuous high-quality lightning detection over the western Pacific tropical cyclone genesis region.

Vaisala plans to reprocess all lightning data in the TCS-08 domain for the entire time period of the field campaign, i.e. 1 August - 30 September 2008. All site error corrections will go through a sanity check before any reprocessing begins. Vaisala will QC the data and will supply sensor status for the time period of the field experiment.

Vaisala will provide the community with daily text files that contain all the lightning data we detected in the TCS-08 domain. Each lightning data record will have the following format: (1) date, (2) time (ms), (3) latitude, (4) longitude, (5) multiplicity, (6) chi square, and (7) length of the semi-major axis of the error ellipse. Reprocessing should be completed by 5 January 2009.

## RESULTS

A detailed comparison of the DE and LA model output with observations confirmed that these models simulate the performance of a long-range lightning detection network relatively well (Pessi et al. 2008). As a result the models can be used to quantify the lightning rates of PacNet/LLDN.

Three years of PacNet/LLDN observations were compared with TRMM's precipitation radar, microwave imager and lightning imaging sensor data to investigate the relationships between lightning, rainfall, and hydrometeor characteristics of the North Pacific storms. Lightning rates

showed a robust correlation between convective rainfall rates, radar reflectivity, storm height, latent heat, and cloud ice water content (Figs. 6 and 7) (Pessi and Businger 2008a).

Lightning data were assimilated into a mesoscale numerical model (MM5) to investigate the potential impact of assimilation of long-range lightning observations. Lightning data assimilation improved the storm central pressure forecasts significantly over the initially poorly forecast storm off the US West Coast (Fig. 8). Analysis of the dynamics of simulated rapid cyclogenesis in the storm shows that lightning and latent heating increased the temperature gradient across- and winds along the cold-front and this enhanced the low-level advection of high theta-e air over the storm center and thus dropping the surface pressure hydrostatically (Figs. 9 and 10). Evolution of this key dynamical process in the model is described in Pessi and Businger (2008b).

## **IMPACT/APPLICATIONS**

The expansion of PacNet/LLDN, the calibration of the network, and quantification of the relationship between observed lightning rates and latent heating profiles, together set the stage for assimilation of the long-range lightning data stream in an operational setting. Scientists at UH and Vaisala plan to work closely with those at NRL to identify the best strategy for this technology transfer.

The quality-controlled data set collected during the TCS-08 field campaign will be made available for investigations of the utility of these data in better understanding tropical cyclogenesis, the evolution of tropical squall lines and tropical to extratropical transition. Moreover, continuous long-range lightning data provided by PacNet/LLDN will be available for nowcasting applications.

## **RELATED PROJECTS**

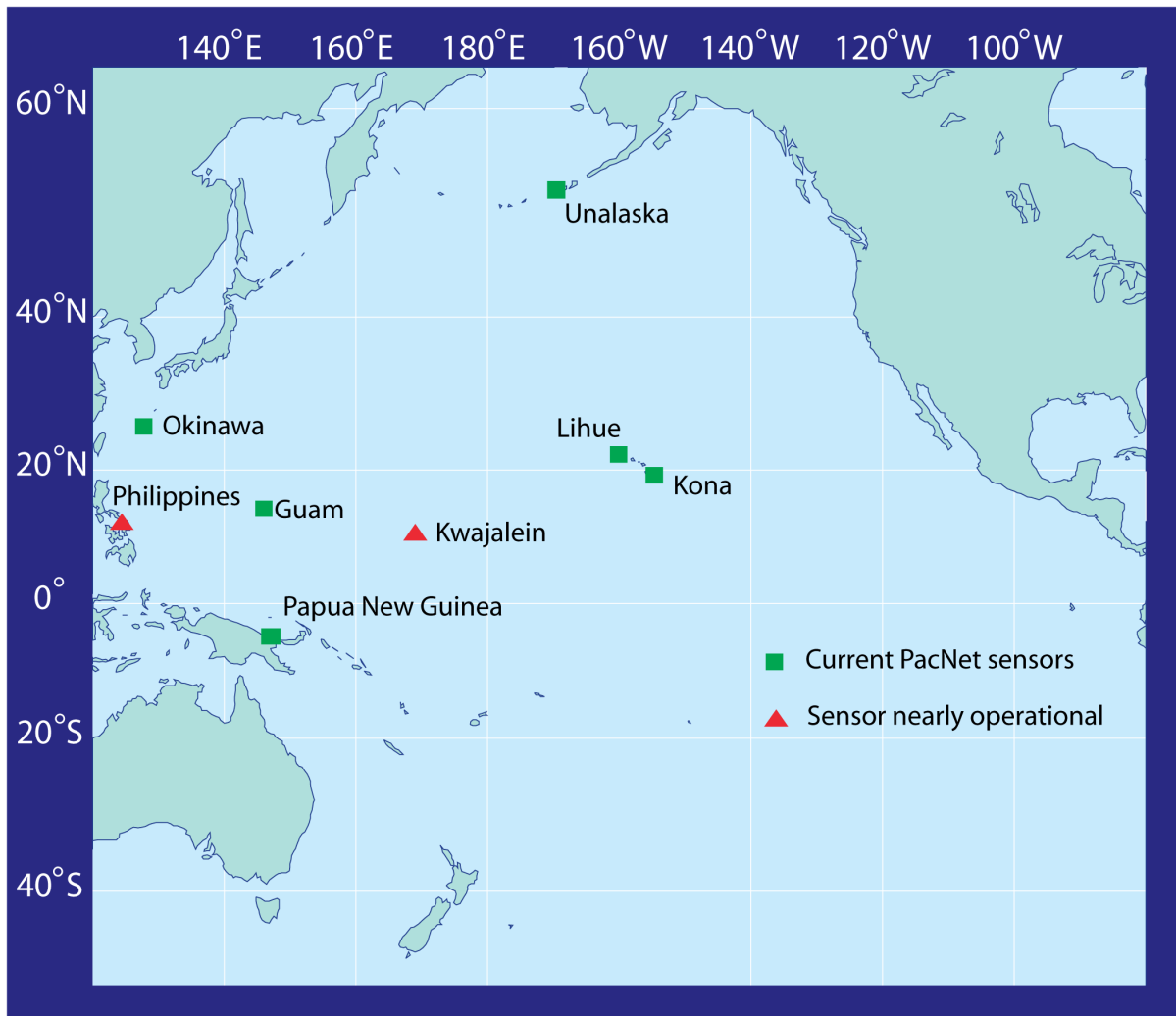
Vaisala has recently expanded their long-range lightning detection capabilities by installing several sensors in the Caribbean and Mexico. Figures 11 and 12 show expected CG lightning flash detection efficiency over the eastern North Pacific and western North Atlantic for night and day, respectively. The quality of the data stream from these sensors (and additional sensors that are still to be announced) provides additional incentive for adding lightning data assimilation to the NOGAPS model.

## **REFERENCES/PUBLICATIONS**

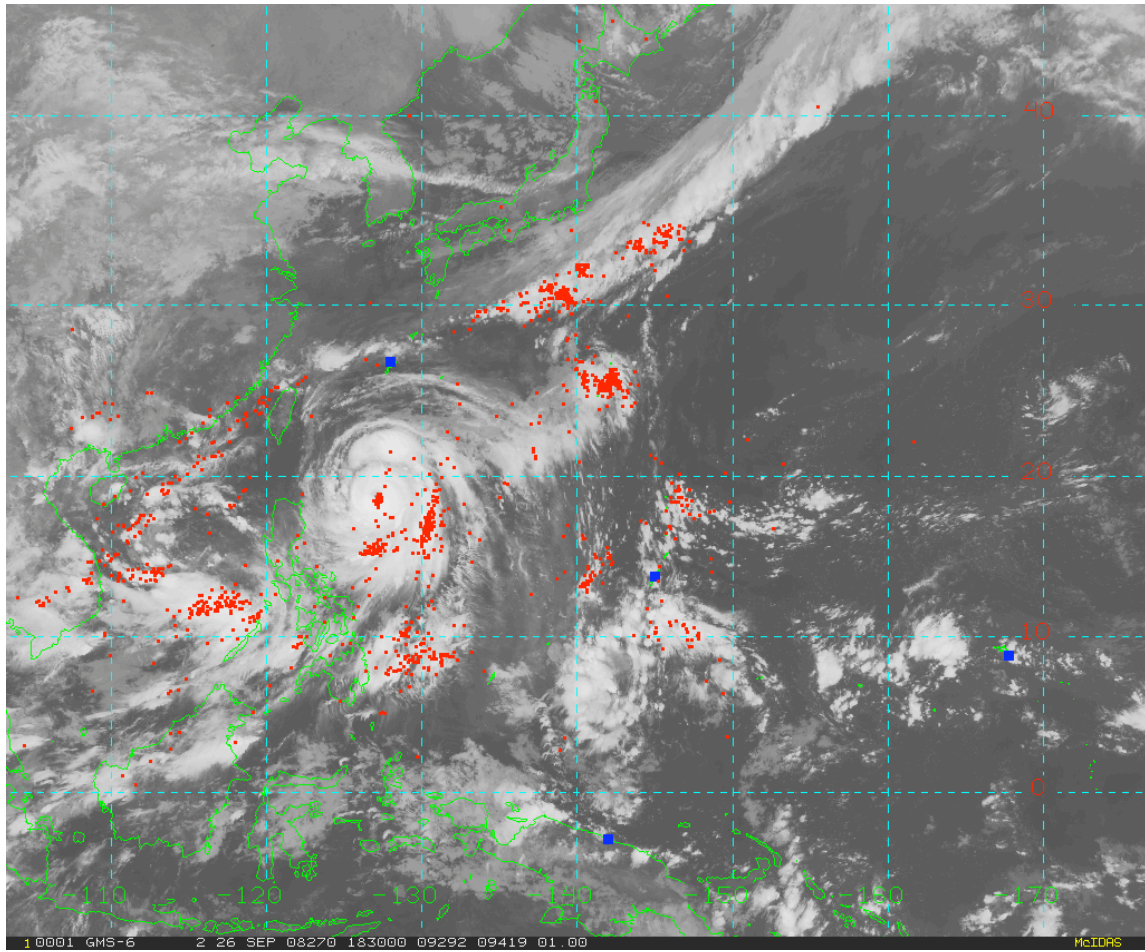
- Pessi, A., S. Businger, K. L. Cummins, N. W. S. Demetriades, M. Murphy, and B. Pifer, 2008: Development of a Long-Range Lightning Detection Network for the Pacific: Construction, Calibration, and Performance. *Journal of Atmospheric and Oceanic Technology*. [In press].
- Pessi, A., and S. Businger, 2008a: Relationships Between Lightning, Precipitation, and Hydrometeor Characteristics over the North Pacific Ocean. *Journal of Applied Meteorology and Climatology*. [In press].
- Pessi, A. and S. Businger, 2008b: The Impact of Lightning Data Assimilation on a Winter Storm Simulation over the North Pacific Ocean. *Monthly Weather Review*. [Submitted].
- Squires, K. and S. Businger, 2008: The Morphology of Eyewall Lightning Outbreaks in Two Category Five Hurricanes. *Monthly Weather Review*, **136**, 1706–1726.

## PRESENTATIONS

- Pessi, A., S. Businger, K. L. Cummins, N. Demetriades, and M. Murphy, 2008: The Promise of Long Range Lightning Networks in Storm Analysis and Forecasting. *88th Annual AMS Meeting*, New Orleans, January 2008.
- Pessi, A. and S. Businger, 2007: Long-Range Lightning Detection over the Pacific: Applications of the Data Stream for TCS-08. TCS-08 Status Meeting, Naval Postgraduate School, Monterey, CA, 11-12 September, 2007.

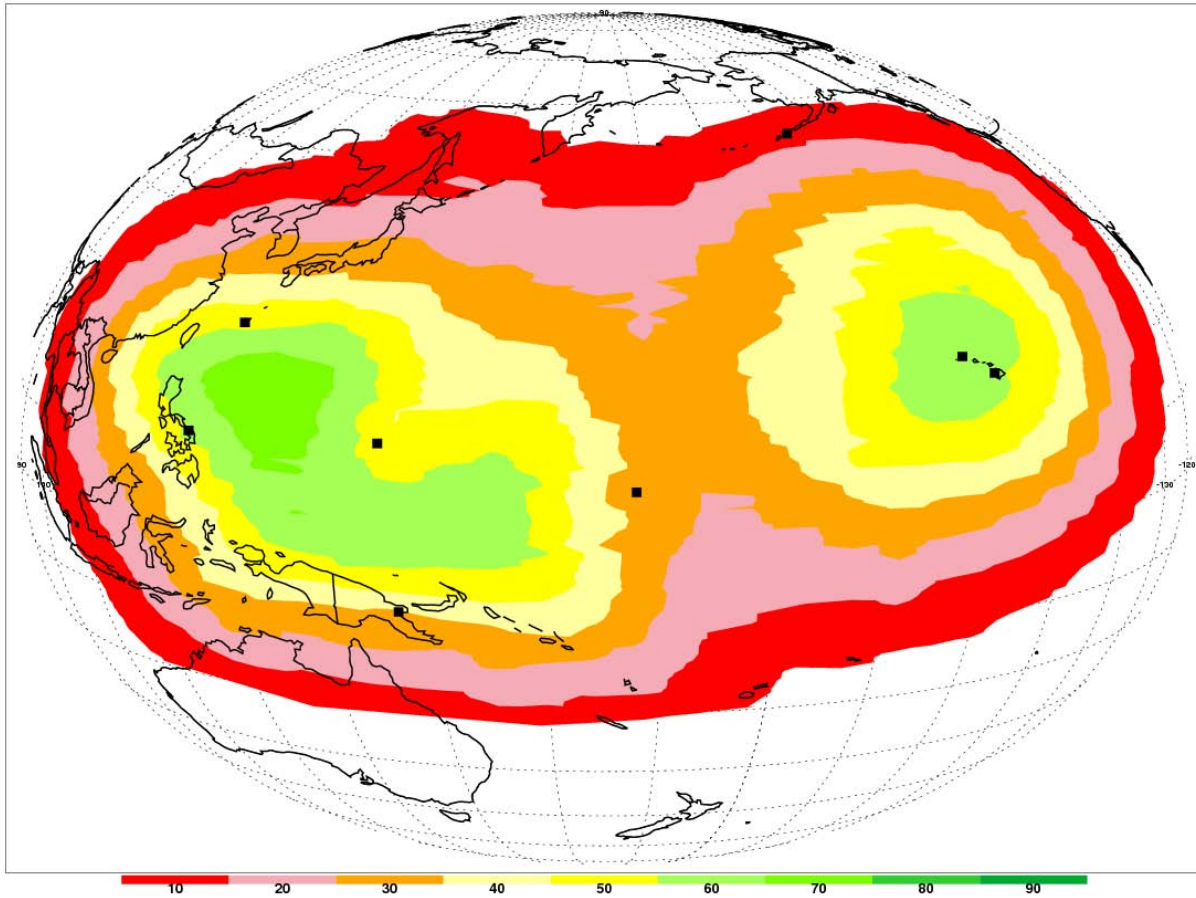


***Figure 1. PacNet's current lightning detector sites (green) and soon to be operational sites (red). Data from detectors located in the U.S. and Canada are used in the processing stream received at the Vaisala Thunderstorm Unit to complement the PacNet data.***

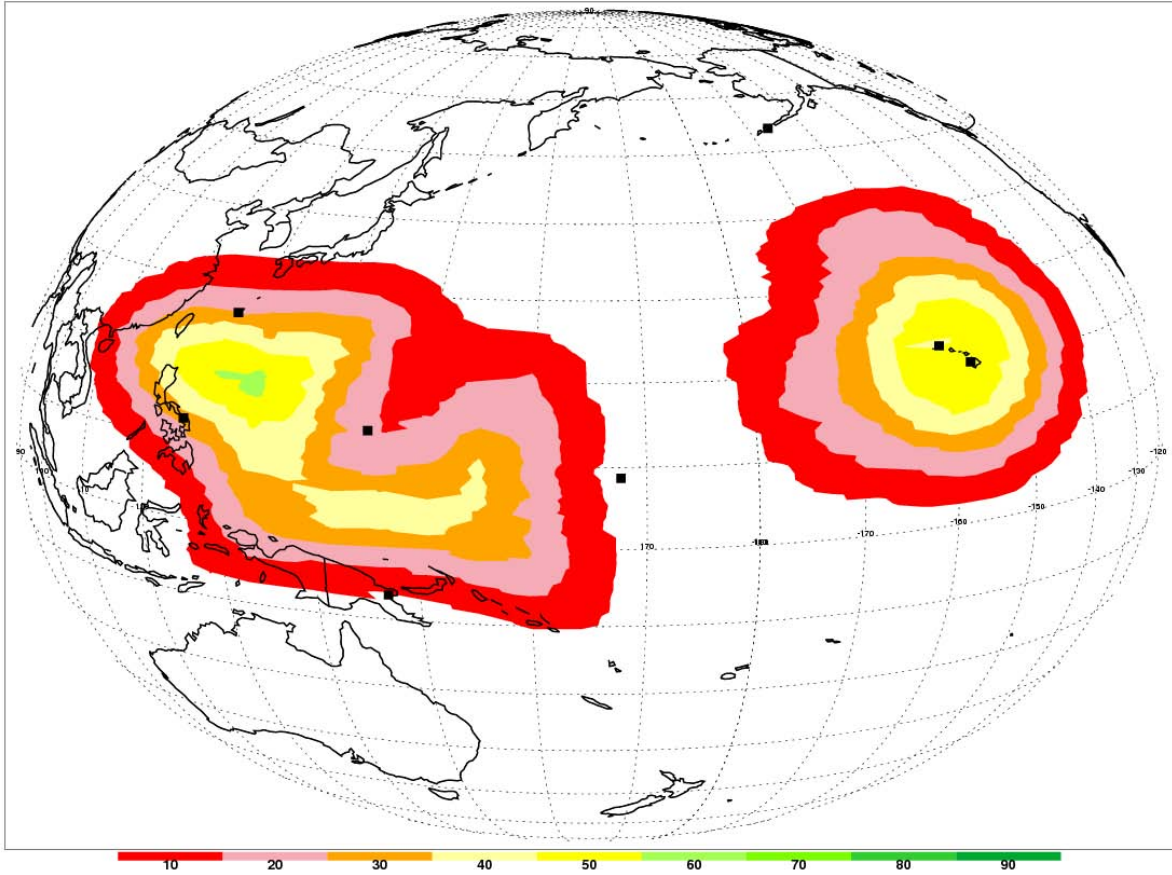


***Figure 2. GMS-6 infrared satellite image on 26 September 2008 1830 UTC overlaid with PacNet/LLDN lightning data detected between 18-19 UTC. Typhoon Jangmi had a rapid intensification period on 26-27 September, during which lightning outbreaks were observed in the eyewall.***

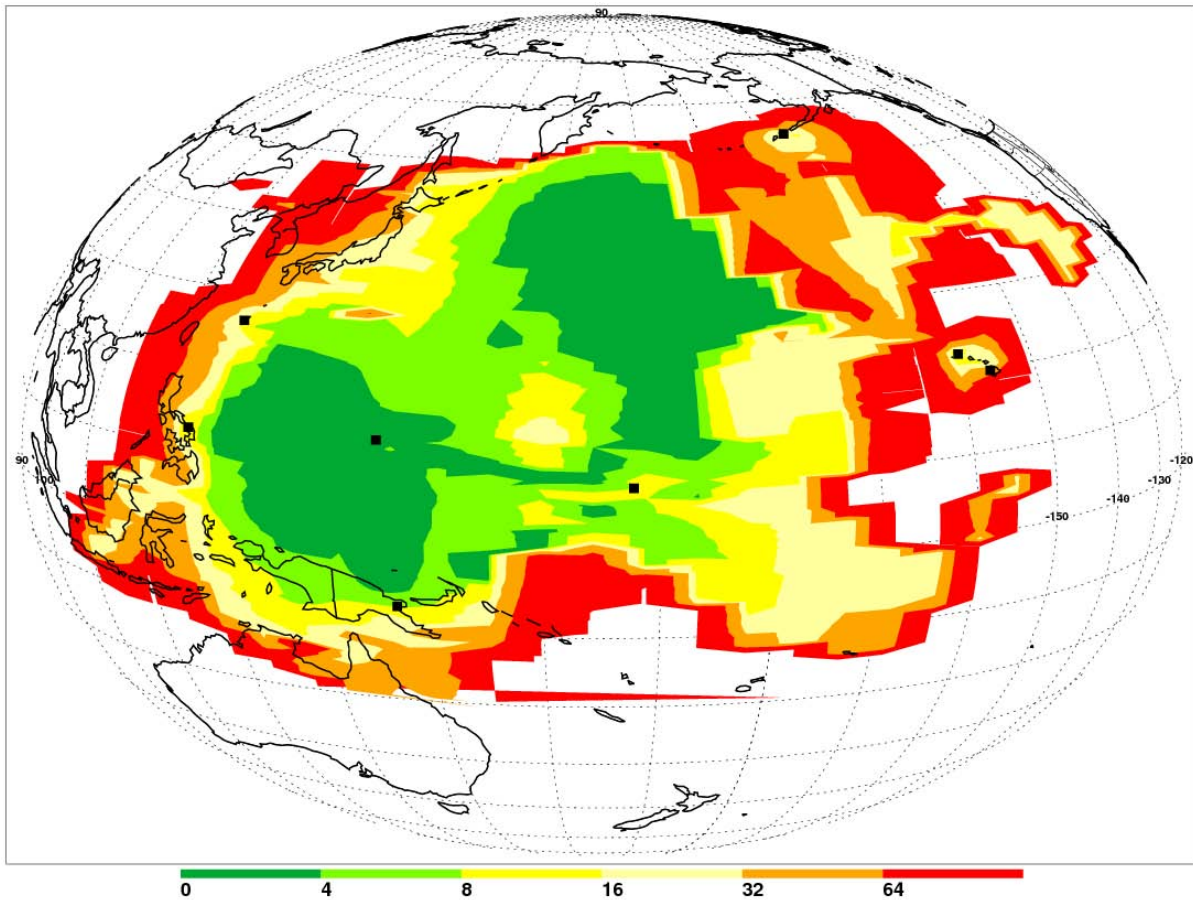




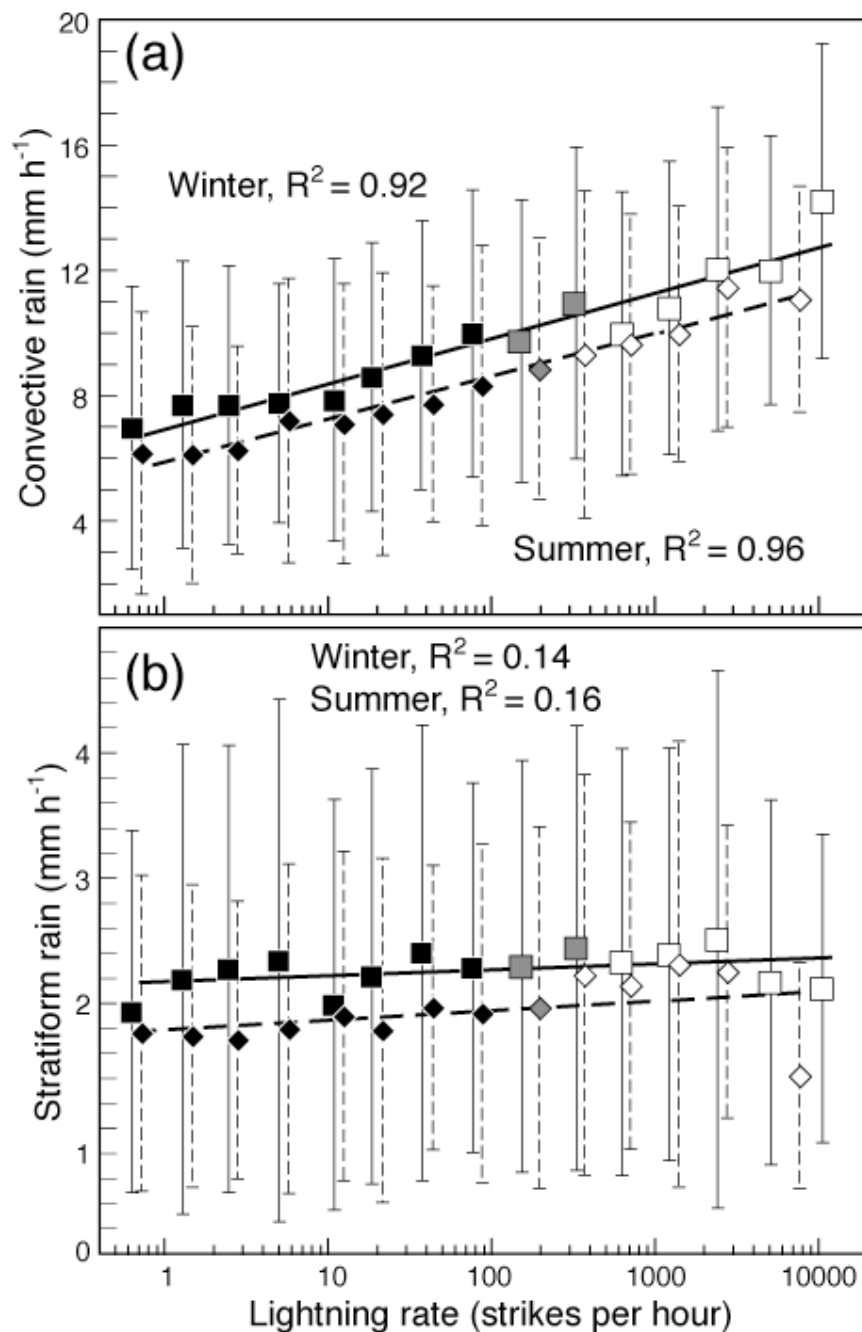
*Figure 3. Expected night time North Pacific CG lightning flash DE provided by Vaisala's long range lightning detection network by 12 December 2008. Shaded colors represent 10% increments of CG lightning flash DE, starting from >70% for the darker green shade to 10-20% for the red shade (see color scale at bottom of figure). NALDN sensors are not included in this projection.*



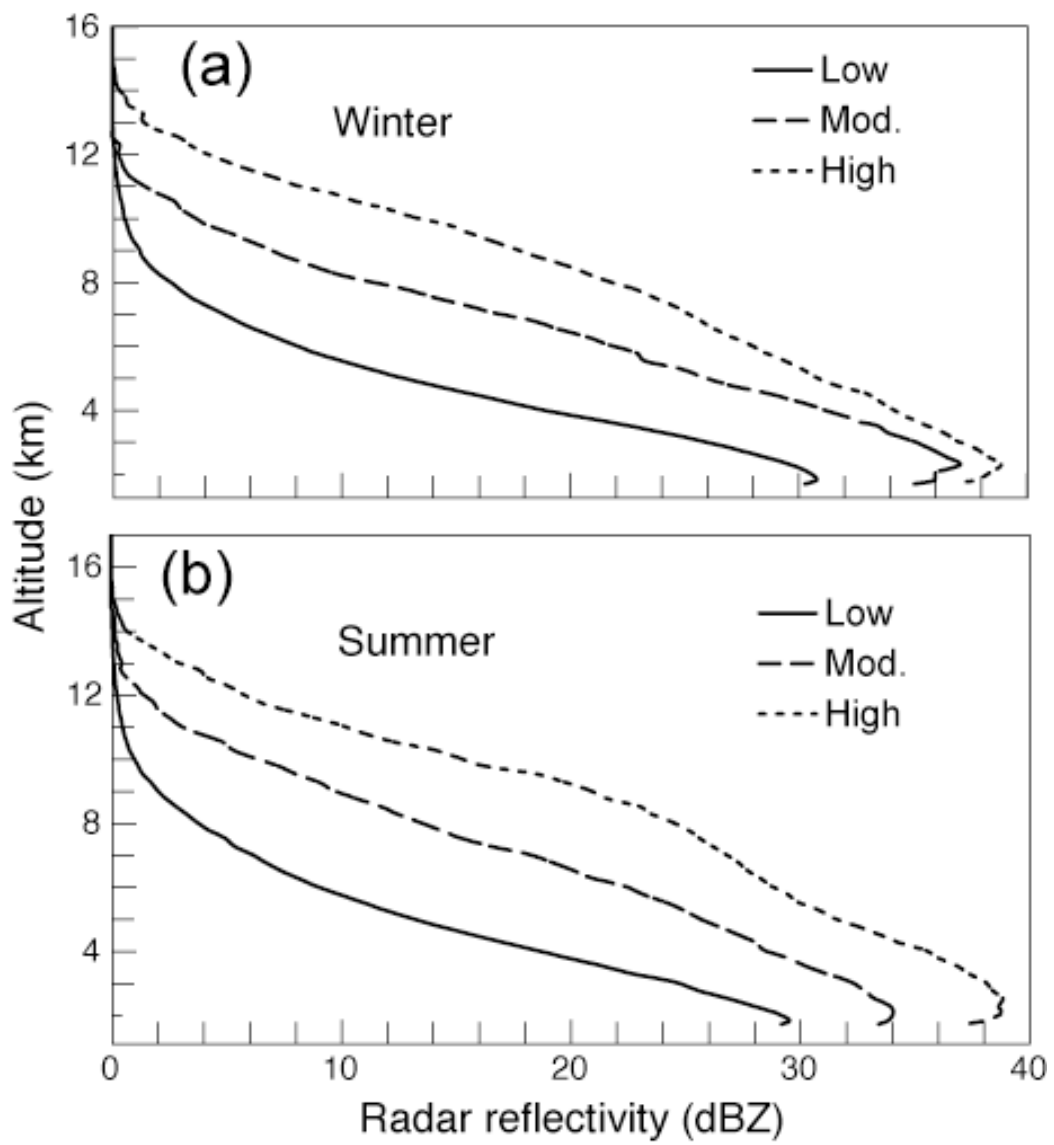
**Figure 4. Expected daytime North Pacific CG lightning flash DE provided by Vaisala's long-range lightning detection network by 12 December 2008. Shaded colors represent 10% increments of CG lightning flash DE, starting from >60% for the green shade to 10-20% for the red shade (see scale color scale at bottom of figure). NALDN sensors are not included in this projection.**



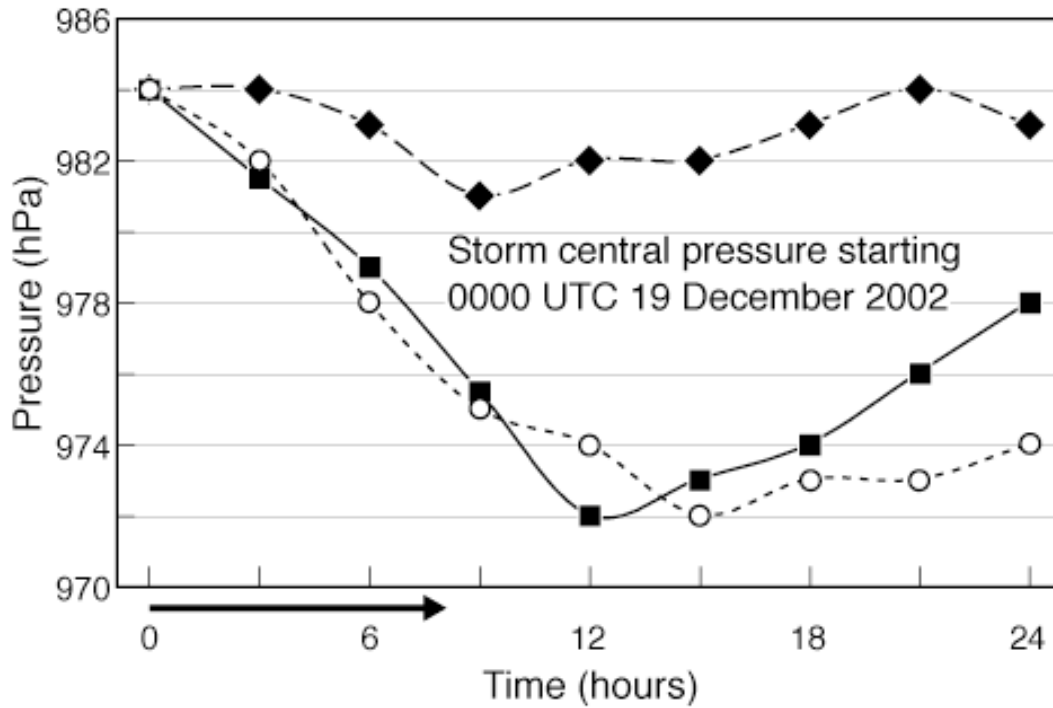
*Figure 5. Expected North Pacific CG lightning flash median location accuracy provided by Vaisala's long-range lightning detection network by 12 December 2008. Shaded colors represent median location accuracy, starting from 0 to 4 kilometers for the dark green shade to greater than 64 kilometers for the red shade (see color scale at bottom of figure).*



**Figure 6. Graphs showing (a) Convective rainfall vs. lightning rate and (b) stratiform rainfall vs. lightning rate. Squares and solid lines are for winter data, and diamonds and dashed lines for summer data. Filled symbols are PacNet data, open symbols are LIS data, and grey symbols are combined PacNet and LIS data. Abscissa shows the number of lightning flashes per hour normalized over 10,000 km<sup>2</sup>. The error bars are  $\pm 1$  standard deviation.**

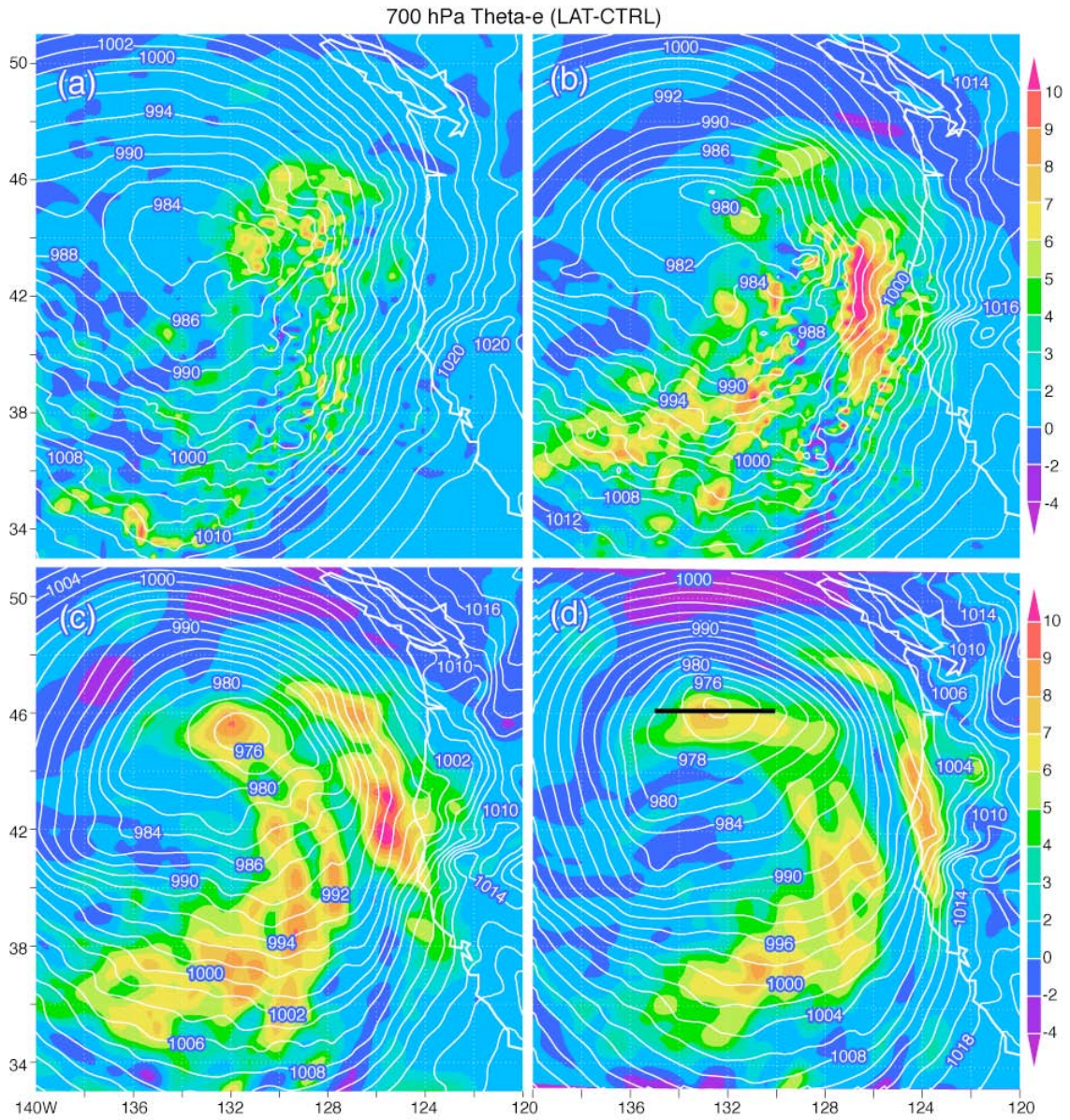


*Figure 7. Vertical profiles of PR reflectivity in (a) winter and (b) summer for three different lightning rate categories (low, moderate, and high lightning rate).*

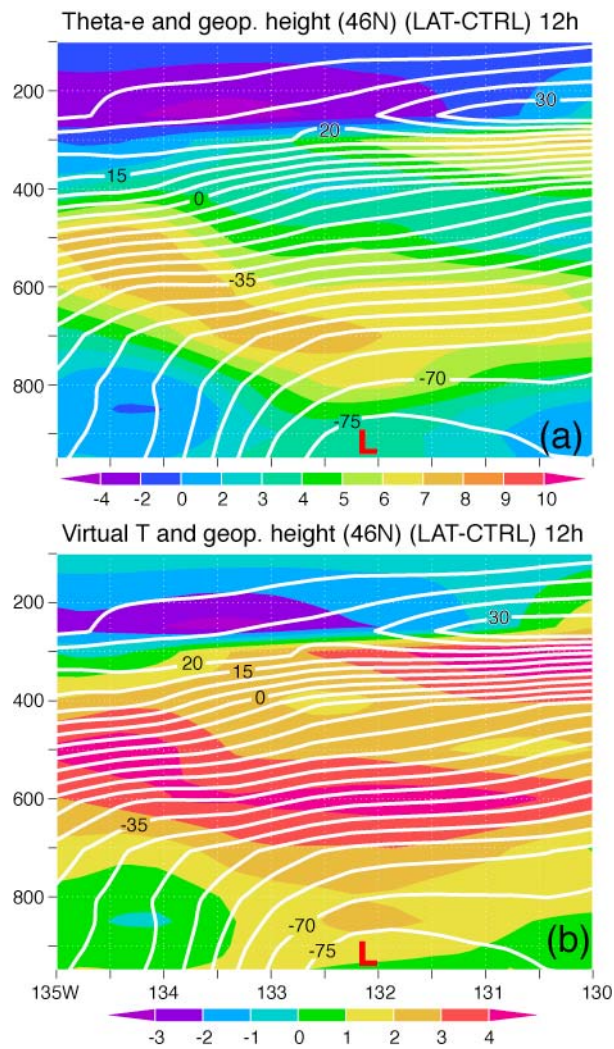


*Figure 8. Comparison of observed storm central pressure (solid) with that predicted by MM5 with (dotted) and without (dashed) lightning data. The model was initialized at 0000 UTC 19 December 2002 and run for 24 hours. The observed values are from the NWS North Pacific surface analyses at 0000, 0600, 1200, and 1800 UTC, and the values between them are linearly interpolated. The arrow shows the lightning data assimilation period.*



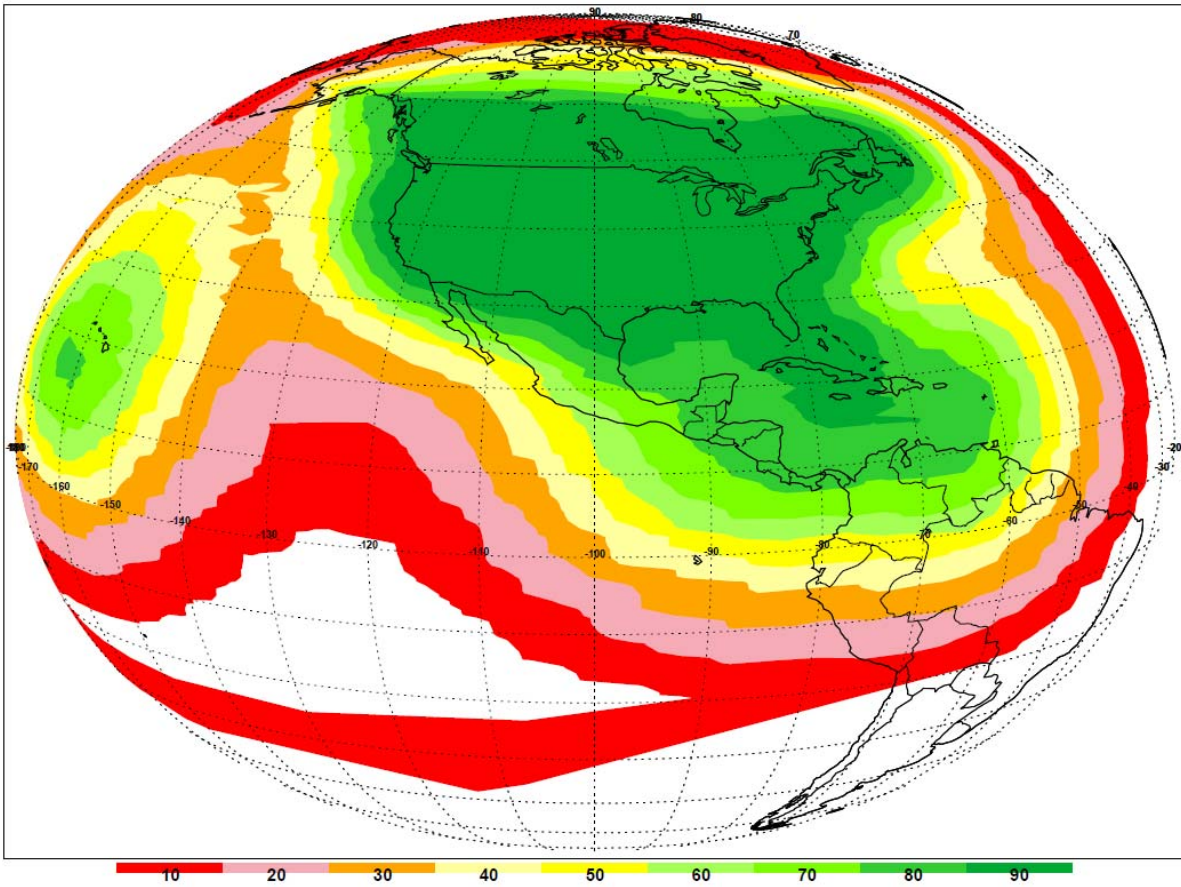


**Figure 9.** Difference in 700 hPa theta-e between the control and LHA runs at (a) 0300 UTC, (b) 0600 UTC, (c) 0900 UTC, and (d) 1200 UTC on 19 December 2002 (shaded, [K]). Sea-level pressure is shown from the lightning data assimilation run at given hour (contours, [hPa]).

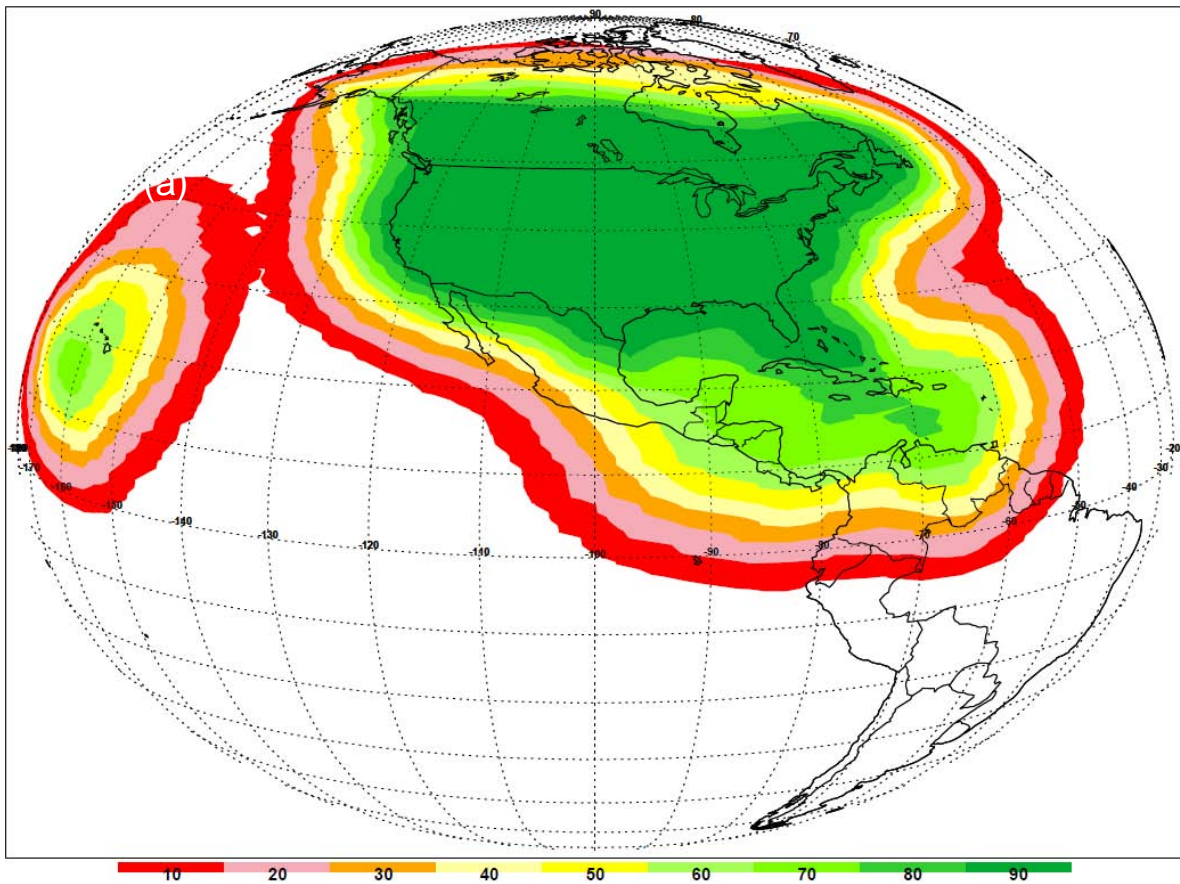


**Figure 10.** Cross-section across the storm along 46°N (horizontal line in Fig. 9d) valid at 1200 UTC on 19 December 2002. (a) Difference in  $\theta_e$  (K) and geopotential height (m) between the lightning data assimilation and control runs. (b) Difference in  $T_v$  (K) and geopotential height (m). The red “L” indicates the position of the surface low center.





**Figure 11** *Expected night time eastern North Pacific and western North Atlantic CG lightning flash DE currently provided by the North-American Lightning Detection Network and Vaisala's long range lightning detection network. Shaded colors represent 10% increments of CG lightning flash DE, starting from >90% for the darkest green shade to 10-20% for the red shade (see color scale at bottom of figure). Greater than 90% CG lightning flash DE over North America is provided by the North American Lightning Detection Network.*



**Figure 12** *Expected day time eastern North Pacific and western North Atlantic CG lightning flash DE currently provided by the North-American Lightning Detection Network and Vaisala's long range lightning detection network. Shaded colors represent 10% increments of CG lightning flash DE, starting from >90% for the darkest green shade to 10-20% for the red shade (see color scale at bottom of figure). Greater than 90% CG lightning flash DE over North America is provided by the North American Lightning Detection Network.*