Predicting of lightning activity in Japan using mesoscale model output statistics

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1. Introduction

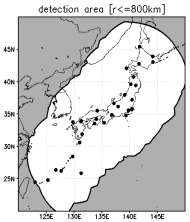
Today, lightning is a major cause of natural disasters to electric power facilities and transportation including aviation. In Japan, the number of the people killed in thunder is about ten per year. ¥200,000,000,000 /year (in Japan) losses, only economical loss, not include human damage. Especially, we use many digital technologies, these are extremely weak to lightning damages. (for example, computers, cell phones, etc…)

We need high accurate lightning forecast for preventing lightning disasters. Nowadays, we have powerful computer resource and also high resolution meso scale model. Japan Meteorological Agency (JMA) is now operating 5-km horizontal resolution meso-scale model (MSM) and 1-km resolution model is conducted for the research purpose.

Using these high resolution meso-scale models, we are trying to develop our lightning forecast. In this study, our operational and newly developed lightning forecasts using meso-scale models with1km and 5km horizontal resolution are introduced.

2. Lightning Data and Numerical Model Data

2.1. Lightning Location System in JMA (called "LIDEN")



Detection coverage of LIDEN and location of sensors (black dot).

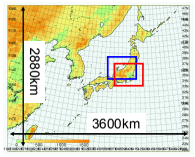
Observation:

Cloud-to-Ground lightning (CG) location data was observed by the Lightning Detection Network System (LIDEN) operated by JMA. LIDEN consists of 30 detecting stations, covering the whole land area of Japan and the surrounding sea, and measures CG strokes in the Time of Arrival method using the LF band (LIDEN also detects Cloud-to-Cloud lightning (CC) with the VHF band, but we don't use the CC data in this study). The average distance between stations is about 200 km.

In this study, the observed CG data was converted to 20-km horizontal grid with 3hour time interval. Using these gridded data, the lightning forecast skills were verified.

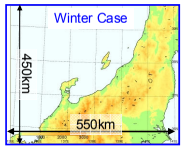
2.2. JMA Non-Hydrostatic Model (called "NHM")

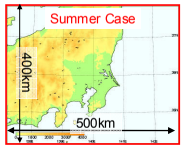
NHM-5km in operational (called "MSM")



JMA is now operating 5 km horizontal resolution model for operational forecast;
- 721x577x50 grid in x-y-z
- 8 times per day, 15 or 33 hour forecast
- Using Kain-Fritsch scheme for cumulus parameterization
- 1-moment 6-class with cloud-ice number cloud microphysics
- For more information, check Saito et al. (2007)

NHM-1km experiments





MRI/JMA is running 1 km horizontal resolution model for developing the numerical weather prediction.
- 550x450x50 grid in x-y-z for winter
- 500x400x50 grid in x-y-z for summer
- nested in NHM-5km
- 2 times per day, 9 hour forecast, later 6hours are used in winter case.
- 4 times per day, 17 hour forecast, later 12-hours are used in summer case.
- No cumulus parameterization
- 6-class with 2-moment in ice-phase cloud microphysics
- 2008 Dec. - 2009 Feb. for winter case
- 2008 Jun. – 2008 Aug. for summer case

3.Lightning Activity Indices

3.1. Traditional indices

Thermodynamic and kinematic indices for thunderstorm (traditional) prediction were calculated by NHM-1km and NHM-5km output.

SSI_{850}: Showalter Stability Index starting from 850 hPa to 500 hPa
K-index: $T_{850} - T_{500} + T_{d850} - (T_{700} - T_{d700})$
TT: Total - Totals, $2x(T_{850} - T_{500}) - (T_{850} - T_{d850})$
CAPE: Convective Availability Potential Energy
CIN: Convective Inhibition
LNB: Level of Neutral Buoyancy
LCL: Lifted Condensation Level

3.2. MSM-PoT (Probability of Thunderstorm) JMA operational lightning index using NHM-5km

MSM-PoT is developed by JMA for aviation safety. It has operated since May-2007 (slightly updated in Jul-2009).
Using "**Logistic Regression**":

$$\ln(P/(1-P)) = C_0 + C_1X_1 + C_2X_2 + \ldots + C_nX_n$$

P: Probability of Lightning
C: Regression Coefficients
X: Explanatory Variables

The best 5 explanatory variables in each grid from 16 candidates are independently selected for X, which consist of the following indices: (in importance order)

SSI, $SSI_{(925\text{-}700)}$, $CAPE_{925}$, LNB_{925}, Total-Totals, $\theta_{e(925\text{-}700)}$, K-index, $W_{ave(925,850,700,600,500)}$, CIN_{925}, Vor_{500}, θ_{e925}*UV, Qv_{925}, $Shear_{850\text{-}500}$, Qv_{925}*$CONV_{925}$, $CONV_{925}$, $Height_{10C}$,
(The latest version of PoT uses another variables after update 2009.)

X and C is decided in advance using the past few years data.

For example, the following equation is used for a grid:
$\ln(P/(1-P)) = 0.40 + 1.1*SSI + 0.9cape - 0.3LNB + 0.05TT + 0.01\theta_e$

3.3. New Indices using NHM-5km and NHM-1km

High resolution model with detailed cloud microphysics can reproduce the realistic distribution of water substances, which are highly related to lightning. Graupel are especially related to lightning.

We developed newly lightning indices using meso-scale model (1km and 5km horizontal resolution) output, as follows:
- Maximum vertical velocity in a vertical grid.
- Maximum graupel mixing ration in a vertical grid.
- Vertical accumulated graupel amount in a column.
- Vertical accumulated graupel amount in a column above -10 C only.

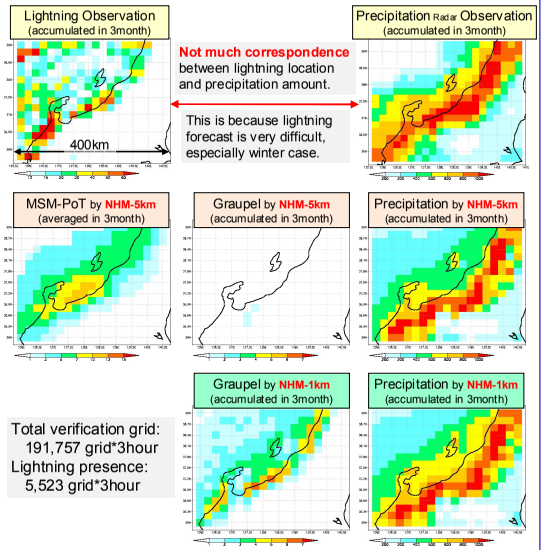
And more, 1-km resolution calculates the number concentration of graupel, snow, and cloud ice. It has already known that their collisions are important for producing electricity of thunderstorm (e.g Takahashi, 1984). We made newly indices based on the theory:
- Multiply graupel number concentration and (snow + cloud ice) number concentration in the cloud.
= "accumulation of [Qng * (Qnci + Qns)] from cloud base (or -10C level) to cloud top."

3.4. Verification

The whole indices are verified in 20-km each grid with 3-hour window through 3-monthes in 2 different seasons by lightning observations data set, which are observed by LIDEN. The boundary region of NHM-1km are excluded for the elimination of lateral boundary. The same verification grid are used for both the models.

4. Results in Winter : 2008.Dec-2009.Feb

Verification grid: **20km in space & 3hour in time** for all data



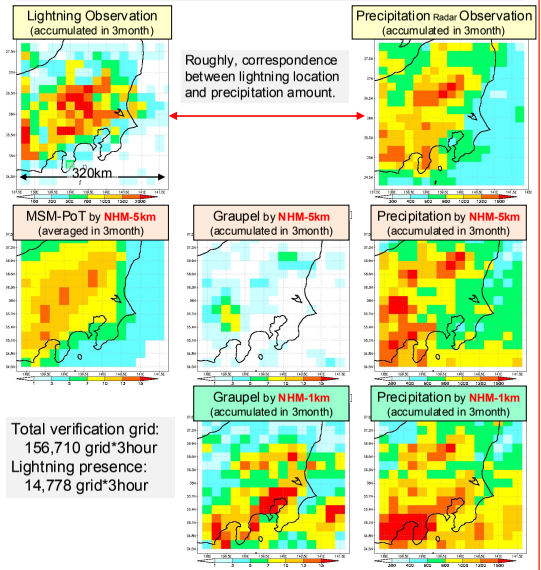
- While observed precipitation is widely distributed around coastal side, observed lightning is strongly concentrated on the coastline.
- Both the models are well reproduced precipitation amount. But precipitation is not signal for winter lightning in Japan area.
- Higher score area of MSM-PoT corresponds with lightning location.
- Graupel in NHM-5km is not produced much amount.
- Graupel in NHM-1km is produced a lot, and corresponds with lightning location very well.

	Index	Threshold	Equitable threat score	Probability of Detection	False Alarm Rate	Heidke Skill Score	CSI: threat score
Traditional Index Using NHM-5km	SSI(mx)	8	0.05	0.78	0.27	0.09	0.08
	K-index(av)	16	0.05	0.85	0.28	0.10	0.08
	Total-Total(mx)	46	0.08	0.77	0.18	0.15	0.11
	CIN(av)	215 J/kg	0.04	0.80	0.31	0.08	0.07
	CAPE(mx)	60 J/kg	0.08	0.73	0.18	0.14	0.10
	LCL(av)	850 m	0.01	0.76	0.53	0.02	0.04
	LNB(mx)	710 hPa	0.14	0.69	0.10	0.24	0.16
Traditional Index Using NHM-1km	SSI(av)	8	0.05	0.66	0.22	0.10	0.08
	K-index(mx)	10	0.05	0.86	0.29	0.10	0.08
	Total-Total(mx)	44	0.07	0.80	0.20	0.14	0.10
	CIN(av)	140 J/kg	0.03	0.77	0.36	0.06	0.06
	CAPE(av)	90 J/kg	0.08	0.72	0.17	0.15	0.11
	LCL(mx)	810 m	0.01	0.77	0.50	0.03	0.04
	LNB(av)	690 hPa	0.14	0.73	0.10	0.24	0.16
Newly Index Using NHM-5km	MSM-PoT	6%	0.13	0.86	0.13	0.23	0.15
	Maximum W(av)	0.15 m/s	0.01	0.84	0.59	0.02	0.04
	Maximum Qg(mx)	0.001 g/kg	0.05	0.70	0.23	0.10	0.08
	Vertical Accumulated Qg(mx)	1.0 m*g/kg	0.06	0.63	0.18	0.12	0.09
	Vertical Accumulated Qg above -10C (mx)	1.0 m*g/kg	0.07	0.10	0.01	0.13	0.08
Newly Index Using NHM-1km	Maximum W(mx)	2.3 m/s	0.04	0.72	0.30	0.07	0.06
	Maximum Qg(mx)	0.07 g/kg	0.08	0.74	0.17	0.15	0.11
	Vertical Accumulated Qg(mx)	62 m*g/kg	0.07	0.76	0.19	0.14	0.10
	Vertical Accumulated Qg above -10C (mx)	0.1 m*g/kg	0.07	0.71	0.19	0.13	0.09
	accumulated NQg*(NQs+Nqci) (av)	$2.0x10^7$ m*num	0.09	0.79	0.17	0.16	0.11
	NQg*(NQs+Nqci) above -10C (av)	$1.0x10^8$ m*num	0.12	0.71	0.11	0.22	0.14

- Traditional indices show very low scores, except LNB.
- MSM-PoT shows good scores.
- Multiplication of "Qng*(Qns+qnci) above -10C" is also good score.

5. Results in Summer : 2008.Jun-Aug

Verification grid: **20km in space & 3hour in time** for all data



- In summertime, many lightning, which caused by thermodynamic instability, is observed over inland area. And also, precipitation is observed over inland area.
- The precipitation of both the models reproduce well over inland area, but failed southern side of Japan. (We don't know why.)
- MSM-PoT is well represented lightning potential in such situation.
- NHM-1km produces much graupel, but not consistent observed lighting.

	Index	Threshold	Equitable threat score	Probability of Detection	False Alarm Rate	Heidke Skill Score	CSI: threat score
Traditional Index Using NHM-5km	SSI(mx)	-13	0.14	0.66	0.20	0.25	0.21
	K-index(mx)	36	0.17	0.72	0.19	0.29	0.24
	Total-Total(av)	43	0.11	0.80	0.32	0.20	0.18
	CIN(av)	130 J/kg	0.04	0.90	0.60	0.08	0.12
	CAPE(mx)	420 J/kg	0.10	0.83	0.36	0.18	0.17
	LCL(mx)	500 m	0.00	0.79	0.76	0.01	0.09
	LNB(av)	440 hPa	0.10	0.82	0.36	0.17	0.17
Traditional Index Using NHM-1km	SSI(mx)	-13	0.12	0.72	0.26	0.22	0.19
	K-index(mx)	36	0.16	0.79	0.23	0.28	0.23
	Total-Total(mx)	45	0.11	0.78	0.30	0.21	0.19
	CIN(av)	385 J/kg	0.03	0.93	0.67	0.06	0.11
	CAPE(mx)	480 J/kg	0.09	0.83	0.38	0.17	0.17
	LCL(mx)	50 m	0.02	0.42	0.32	0.05	0.10
	LNB(av)	480 hPa	0.09	0.80	0.35	0.17	0.17
Newly Index Using NHM-5km	MSM-PoT	5%	0.14	0.81	0.26	0.25	0.21
	Maximum W(mx)	0.06 m/s	0.04	0.69	0.47	0.07	0.12
	Maximum Qg(mx)	0.001 g/kg	0.06	0.24	0.11	0.11	0.11
	Vertical Accumulated Qg(mx)	1.0 m*g/kg	0.06	0.22	0.10	0.11	0.11
	Vertical Accumulated Qg above -10C (mx)	1.0 m*g/kg	0.06	0.09	0.01	0.12	0.08
Newly Index Using NHM-1km	Maximum W(mx)	1.24 m/s	0.08	0.57	0.26	0.15	0.15
	Maximum Qg(av)	0.01 g/kg	0.13	0.35	0.09	0.23	0.18
	Vertical Accumulated Qg(av)	0.2 m*g/kg	0.12	0.42	0.13	0.22	0.18
	Vertical Accumulated Qg above -10C (mx)	2.0 m*g/kg	0.18	0.36	0.06	0.31	0.23
	accumulated NQg*(NQs+Nqci) (mx)	$2.0x10^8$ m*num	0.16	0.52	0.13	0.27	0.21
	NQg*(NQs+Nqci) above -10C (av)	$1.8x10^7$ m*num	0.18	0.44	0.09	0.31	0.23

- K-index shows is better than any other traditional scores.
- MSM-PoT is moderate scores.
- Water substances above -10 degree with NHM-1km is good index for the lightning prediction in both seasons.