Radiation exposure estimation and information service using the Korean Radiation Exposure Assessment Model for aviation route dose (KREAM)

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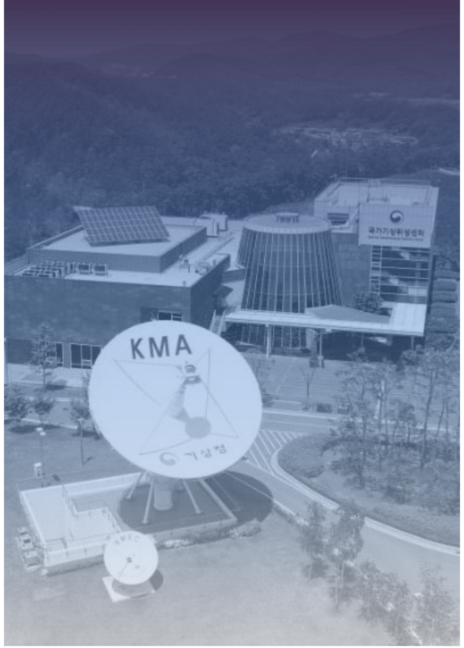

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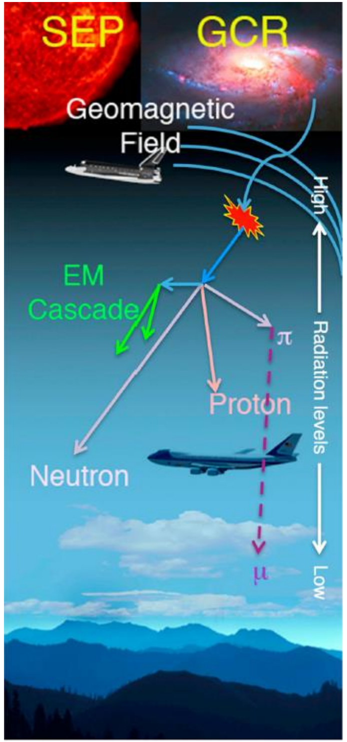
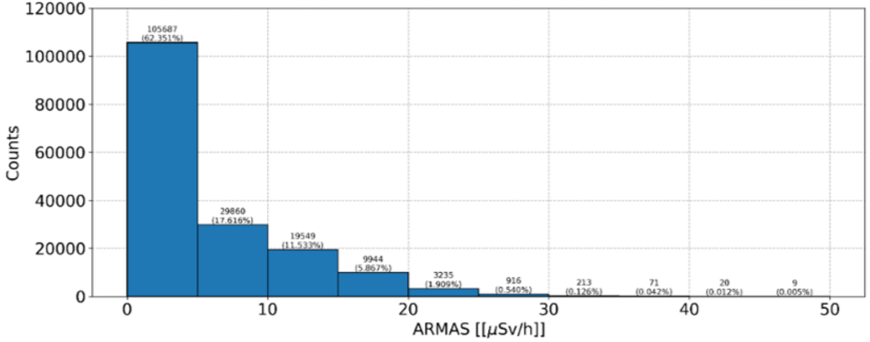


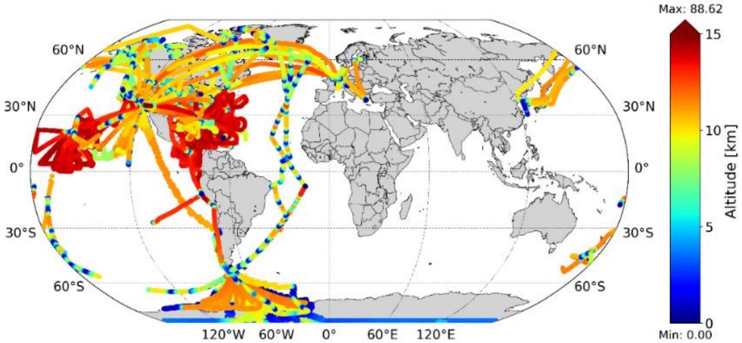
- KMA's KREAM is a model that calculates the radiation dose in the air up to an altitude of 80 km for a specific location.
- It is a physics-based model that considers both GCR and SEP and uses GEANT4 as a particle transport model and NRLMSIS00 as an atmospheric model.
- Input and output
  - Input: Sunspot number from NOAA
  - Output: Proton flux from GOES satellites
- Updated every hour (now cast)
- We provided the dose rate information using the KREAM on the KMA/NMSC website (https://nmsc.kma.go.kr).

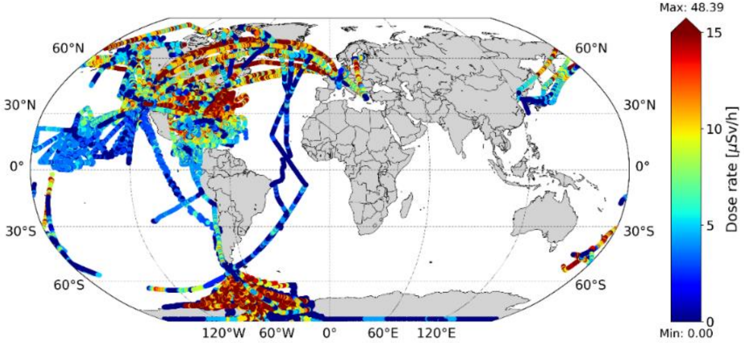
Model Inter-comparison

DATA

Data type	Name	Source of data	Period
Model	NAIRAS	SET	November 28, 2013 – March 31, 2022 (579 flights)
	CARI-7	FAA	
	KREAM	KMA	
Observation	ARMAS	SET	





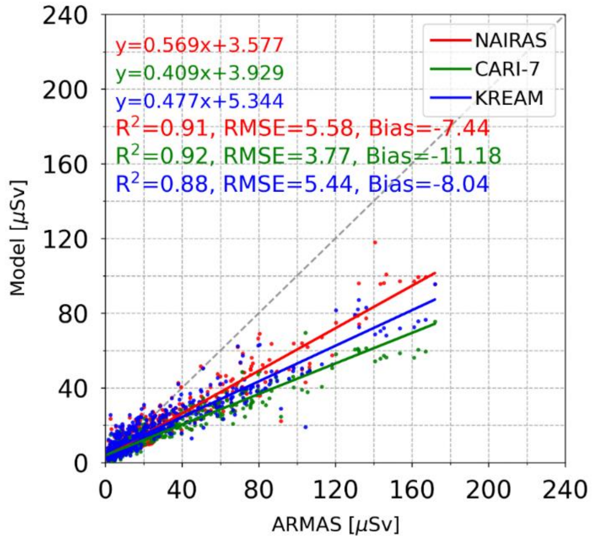


- A scientifically meaningful ARMAS flight rout is 579.
- The dose rate data covered from 0 to 50 μSv/hr, and the majority is between 0 and 5 μSv/hr (62% of all data)

- Most flights concentrate in the North America and the southern oceans of South America.
- The higher altitude or latitude, the higher dose rate distribution.

Model Inter-comparison

Statistical results



- R^2

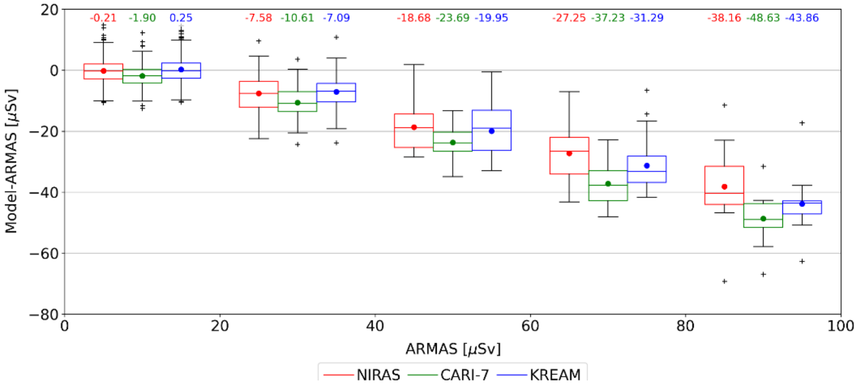
KREAM < NAIRAS < **CARI-7**

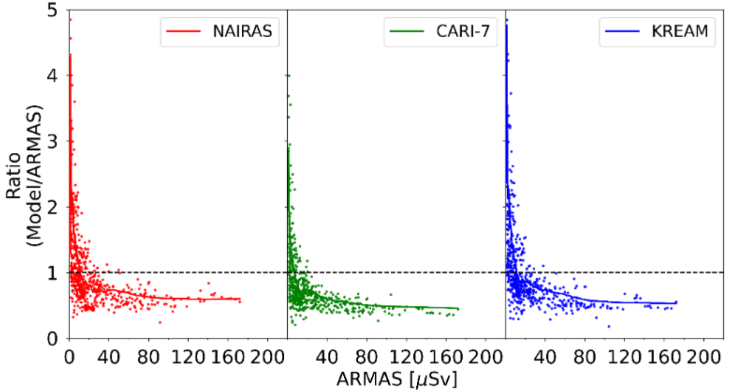
- RMSE

CARI-7 < KREAM < NAIRAS

- Bias

NAIRAS < KREAM < CARI-7

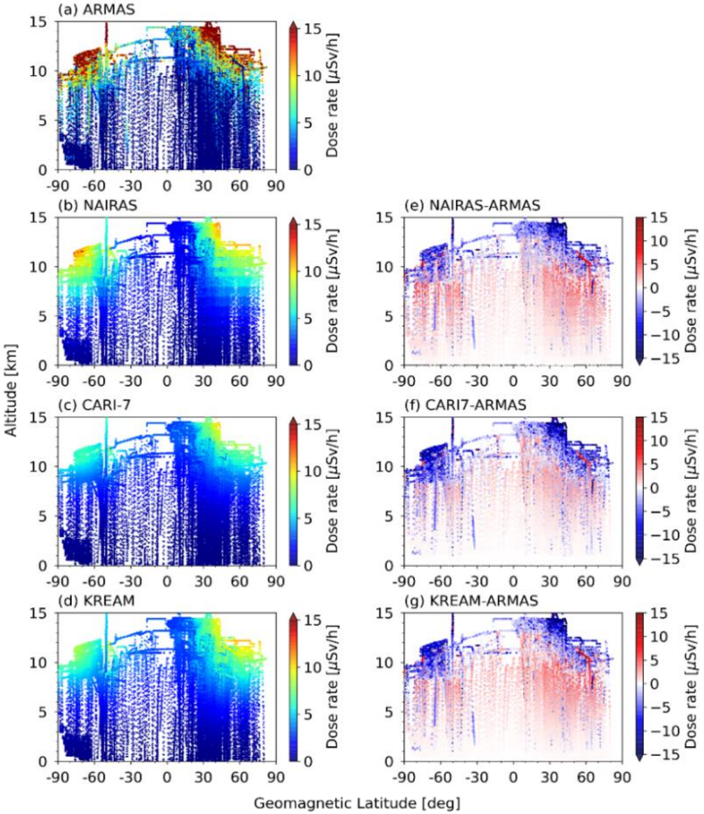




- All models underestimate the does rate.
- The differences are close to zero when ARMAS is 0-20 μSv.
- The higher the total dose rate of ARMAS, the bigger the model errors are estimated.

Model Inter-comparison

The spatial distribution of radiation dose rates



- Dose rate shows a symmetric distribution around the geomagnetic equator and are increased with altitude and geomagnetic latitudes in common.
- The differences between the model and measured effective dose are minus, especially at geomagnetic mid-latitudes where data are concentrated.

KREAM Dose Rates for the Episodic SPE

Rank	Dates	Flux_p	10km	11km	12km
1	1991-03-24	43000	94	125	158
2	1989-10-20	40000	98	128	162
3	2001-11-06	31700	80	106	133
4	2003-10-29	29500	78	102	128
5	2000-07-15	24000	72	93	116
6	2001-11-24	18900	56	73	92
7	2000-11-09	14800	53	69	87
8	2001-09-25	12900	55	71	87
9	1994-02-21	10000	51	66	82
10	1989-08-13	9200	52	66	81
11	1989-12-01	7300	42	54	67
12	2012-03-08	6530	43	55	68
13	2012-01-24	6310	43	56	69
14	2005-01-17	5040	37	48	59
15	1992-05-09	4600	36	46	56
16	1989-09-30	4500	36	46	56
17	1989-03-13	3500	30	39	47
18	2005-05-15	3140	29	37	45
19	1991-06-11	3000	29	37	45
20	1982-07-13	2900	29	32	44
21	1992-10-31	2700	26	33	40
22	2002-04-21	2520	25	32	39
23	1984-04-26	2500	25	32	39
24	2001-10-02	2360	26	32	39

⋮

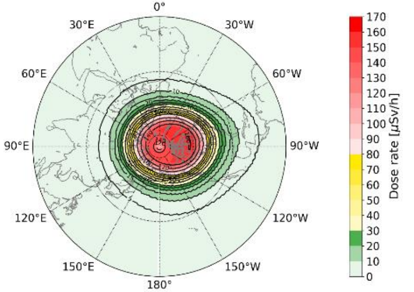
ICAO threshholds for space weather advisories

Impact	Units	Advisory Level: Moderate	Severe
Global Navigation Satellite System (GNSS)			
Amplitude Scintillation (S4)	dimensionless	0.5	0.8
Phase Scintillation (Sigma-Phi)	radians	0.4	0.7
Vertical Total Electron Content	TEC Units	125	175
Radiation			
Effective Dose *	mSv/h	0.030	0.080
HF			
Auroral Absorption (Kp)	Kp index	8	9
Polar Cap Absorption	dB (30MHz Riometer data)	2	5
Solar X-rays, 0.1–0.8 nm	W/m^{-2}	1×10^{-4}	1×10^{-3}
Post-Storm Depression (MUF) **	%	30	50

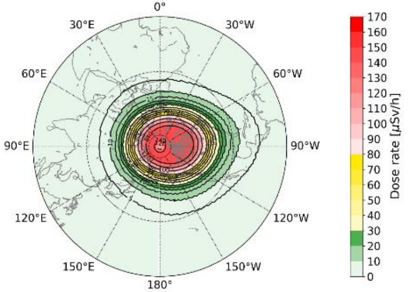
The rank of SEP events according to the ICAO threshhold for radiation effective dose

	10km	11km	12km
Severe	1~3	1~5	1~10
Moderate	4~17	6~36	11~51
Low	18~	37~	52~

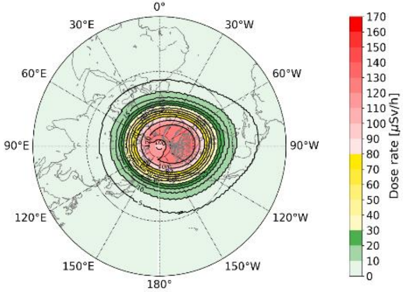
1989/10/20 1600Z 162 uSv/h (40,000 pfu)



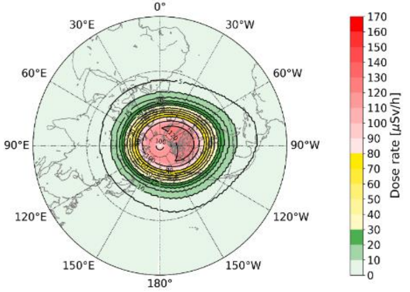
1991/03/24 0350Z 158 uSv/h (43,000 pfu)



2001/11/06 0215Z 133 uSv/h (31,700 pfu)



2003/10/29 0615Z 128 uSv/h (29,500 pfu)



Summary & Discussion

This study can be summarized as follows.

- R^2 among ARMAS and models is ordered by CARI-7 (0.92) > NAIRAS (0.91) > KREAM (0.88). RMSE of effective dose in µSv is ordered by CARI-7 (3.77) < KREAM (5.44) < NAIRAS (5.88). Bias of effective dose in µSv is ordered by NAIRAS (-7.44) < KREAM (-8.04) < CARI-7 (-11.18). The model underestimation errors especially are at high altitude (about <10km) and high geomagnetic latitude (about <40°) for all models.
- Dose rate estimation for 267 episodic solar proton events (SPE) since 1976 was carried out. At October 20, 1989, when the 10 MeV proton flux was 40,000 pfu, the largest dose rate at 12km altitude was appeared as 161 µSv/hr. It is severe levels according to the ICAO threshold for radiation (>80 µSv/hr). . Also top 10 events at 12km are included to the severe level.

The result of this study implies that the underestimated radiation gives aircrew and passengers a reduced risk perception for ionizing radiation. The model errors should be checked and improved in cases with high dose rates. And we can roughly estimate the dose rate according to the proton flux.

Thank you

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KREAM data resolution

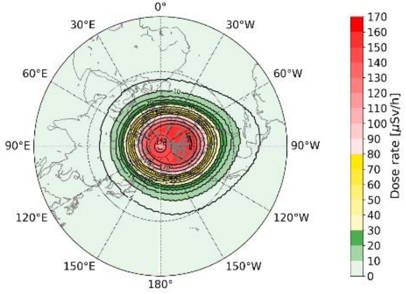
- **Lat. and Lon.**: 1° x 1°
- **Alt.**: total 148 layers
  0~5km: 51 layers at 100m interval
  5~15km: 50 layers at 200m interval
  15~50km:: 35 layers at 1km interval
  50~80km: 12 layers at 2.5km interval

Comparison with top 2 of SEPs

The greatest SPE was on March 24, 1991, and the highest dose rate was on October 20, 1989. Both events correspond to the SC22 period.

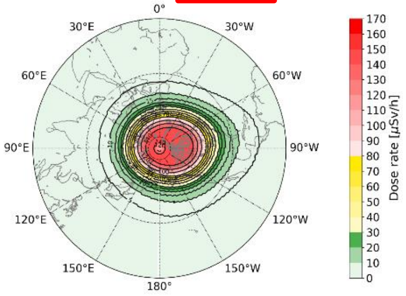
Rank 2

1989/10/20 1600Z 162 uSv/h (40,000 pfu)



Rank 1

1991/03/24 0350Z 158 uSv/h (43,000 pfu)



- The reason that the estimated dose rate of rank2 is higher than rank1 is due to the seasonal trend of the model.
- The seasonal trend may originate from the combination of various sources, including terrestrial and ex-terrestrial factors, such as the temperature, the change in the heliolatitude of the Earth, and the solar cycle.