The Development of LEO-NEqO Trapped Particles Forecasting System

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Problem Statement

- Lack of low energy trapped particles models on LEO-NEqO orbit.
- The limitation of widely use NASA's AP-8 and AE-8
  - Only identify fluxes under two conditions -> a solar maximum and minimum (Zheng et al. 2003).
  - Static models based on data from 38 satellites in the early 1960s to mid-1970s ->remove the influence of solar events and worst case analysis.
  - Run with the same internal geomagnetic field models -> the secular changes influencing the SAA location is not accounted (Lauenstein et al. 2005).
  - The AP-9 and AE-9 (Ginet et al. 2013) -> improving the AP-8 and AE-8 -> have limitation specially for LEO and inner belt particles (Ginet et al. 2013).

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Problem Statement

- Some gaps in established system:
  - the Space Environment Information System (SPENVIS) (Heynderickx et al. 2004) -> depend on AP-8 and AE-8 models to predict the trapped particles fluxes.
  - The SPACECAST (Horne et al. 2013) -> the latest and state of the art energetic particles forecasting system -> designed for outer radiation belt and focused on high energetic particles.
  - The Systems Tool Kit (STK) with its add-on module Space Environment and Effect Tools (SEET) -> uses AP-8 and AE-8 models for analyzing the distribution of trapped particles at LEO orbit.

Objectives

- To develop a model that could perform a daily forecast of trapped particles fluxes at LEO-NEqO orbit.
- To estimate the distribution of forecasted trapped particles fluxes over the modeled area.
- To integrate the forecasting and estimating model in a system and displayed the result on a web based (named UKMtrapcast system).

Scope of Research

- The region of forecasting is limited to -15° to +15° of latitude, and from -180° to +180° of longitude.
- The National Oceanic and Atmospheric Administration (NOAA) - Polar Orbiting Environmental Satellites (POES) data was utilized in this work due to its open access with the 0° direction observation data.
- Limit to L < 4 (Rodger et al. 2010; Asikainen & Mursula 2011) to avoid contamination issue.
- Use all electron energy channel except mep0p6.
- Draw the forecasted maps of trapped particles fluxes distribution in a geographic coordinate and works on a daily basis.

Methodology

NOAA DATA
(NOAA 15, 18, 19,
METOP02)

SORTING
CLEANING
COMBINING
LOG TRANSFORMING
GRIDDING
(MATLAB)

HBST
FORECASTING
(spTimer R package)

KRIGING
ESTIMATION
(field R package)

UKMtrapcast
System
(Matlab-R)

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HBST-Gaussian Process (GP) model

$$\mathrm{Z}(\mathrm{s_i}, \mathrm{T}+1) = \mathrm{E}(\mathrm{s_i}, \mathrm{T}+1) + \epsilon(\mathrm{s_i}, \mathrm{T}+1)$$

$$\mathrm{E}(\mathrm{s_i}, \mathrm{T}+1) = \mathrm{x}'(\mathrm{s_i}, \mathrm{T}+1)\beta + \eta(\mathrm{s_i}, \mathrm{T}+1)$$

Kriging Interpolation technique

$$\hat{Y}(s_0) = \boldsymbol{X}(s_0)'\widehat{\boldsymbol{\beta}} + C'\boldsymbol{\Sigma}^{-1}\left(\boldsymbol{Y}(s) - \boldsymbol{X}(s)\widehat{\boldsymbol{\beta}}\right)$$

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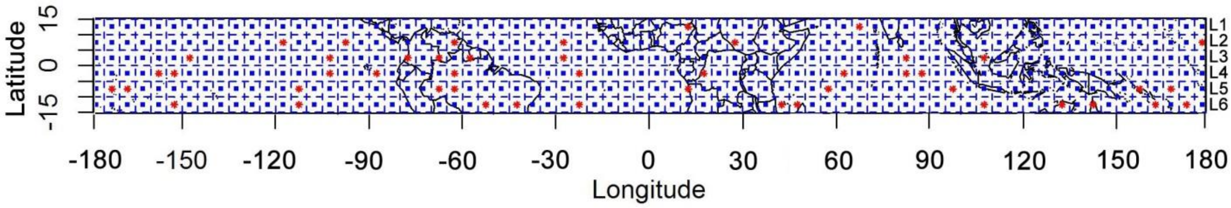
Gridding Process



- Blue Squared Point is the fitting point for HSBT model
- Red Dot Stared Point is the validation point (not included for the HBST process)

Flow Chart of UKMtrapcast System

Start

Initial data module: Take seven previous days

Initial result module: Process the data to generate forecasted maps of trapped particles

Go to Daily update panel
- Activate Auto FTP module
- Activate Auto Backup module
- Activate Auto Store module
- Activate Auto Processing module
- Activate Auto Forecasting module

Activate UKM Backup module

Store maps in UKMtrapcast web server

Check maps availability with Particles panel

Display results in UKMtrapcast web

Finish

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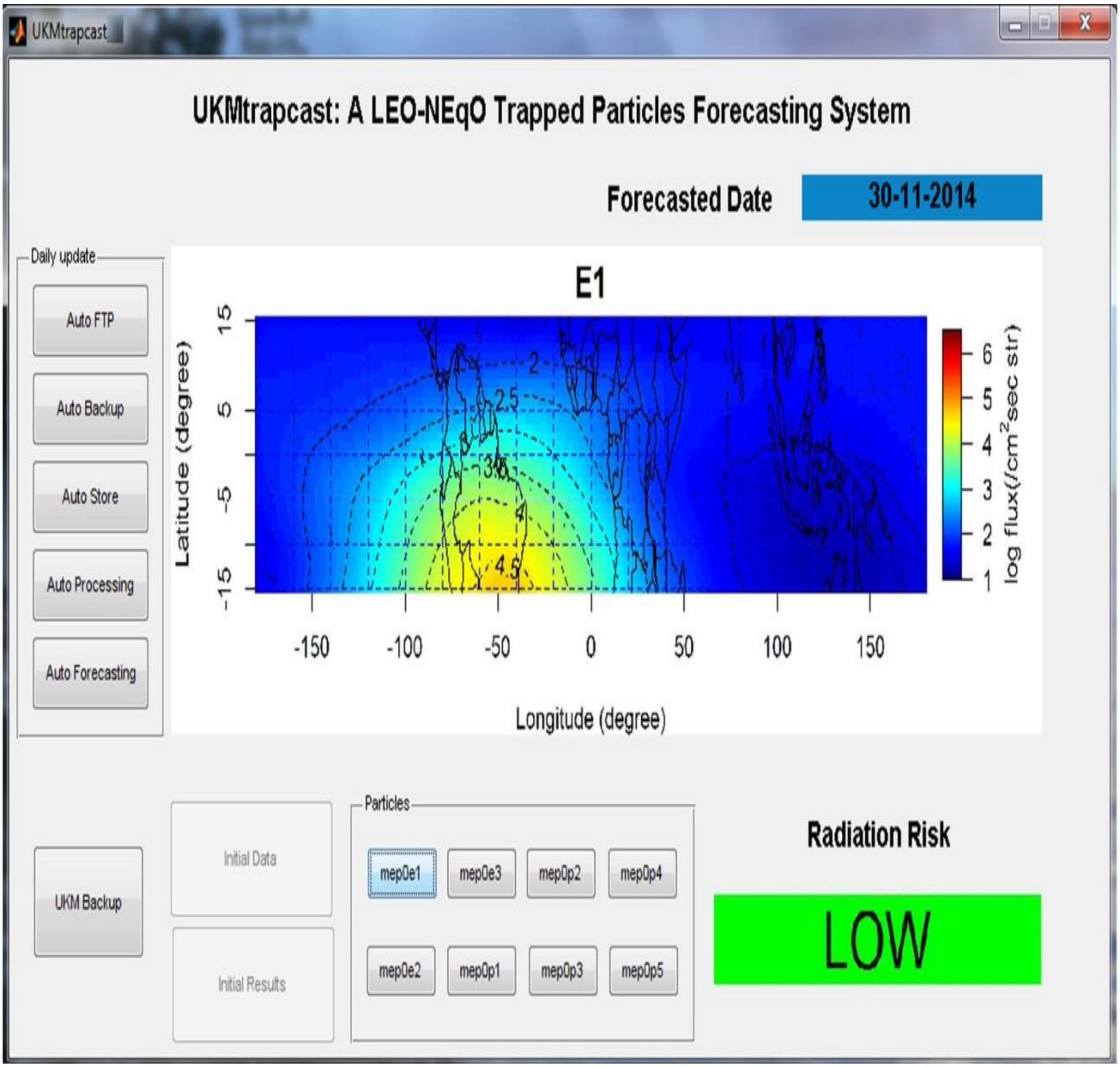
Result



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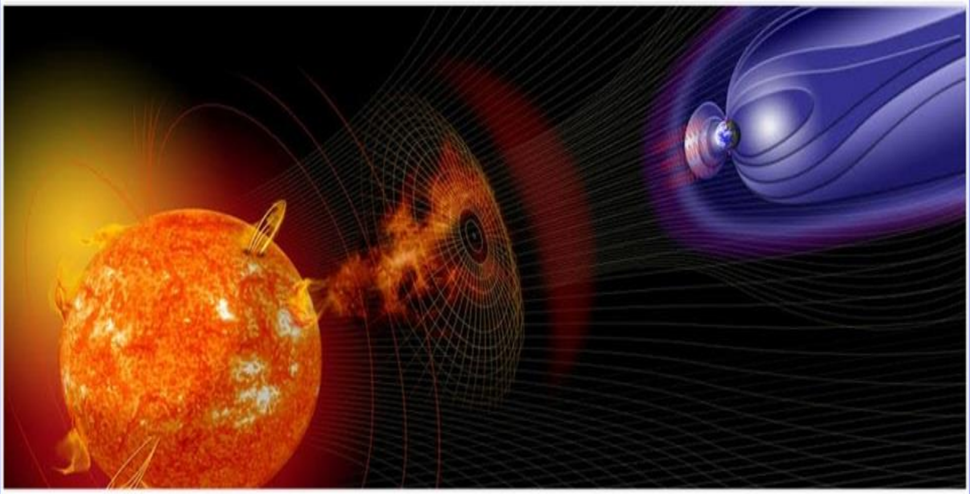
Result

www.ukm.my/ukmtrapcast/index.html

UKMtrapcast

A LEO-NEqO Trapped Particles Forecasting System

Introduction   Trapped Particles ▾   About



Home

Trapped particles are a major cause of satellite anomalies, and the risk is higher for satellites in equatorial low earth orbit (LEO) because of their frequent passes through the South Atlantic Anomaly (SAA). We developed a system for forecasting the distribution of trapped particle fluxes in equatorial LEO near Equatorial orbit (NEqO) based on a hierarchical Bayesian spatio-temporal (HBST) statistical model. This model is applicable to low- and medium-energy electrons and protons in all conditions of solar activity. We also used dynamic rather than static data. A Gaussian process (GP) model, a simple HBST model, was developed using the NOAA 15,16,18,19 and METOP02 satellites data, which categorized particle energies as > 30 keV (mep0e1), > 100 keV (mep0e2), > 300 keV (mep0e3) for electrons and 30-80 keV (mep0p1), 80-240 keV (mep0p2), 240-800 keV (mep0p3), 800-2500 keV (mep0p4), 2500-6900 keV (mep0p5) and > 6900 keV (mep0p6) for protons over Equatorial region. Our forecast region is located from -15° to 15° of latitude and from -180° to 180° of longitude. The area was gridded into a 5x5 size of longitude and latitude and consisted of six latitude layers to ease computational process. Ten percent of grids in each layer were selected as validation points which were not involved in HBST model fitting. The forecast result was then interpolated using a Kriging technique to estimate the particle distribution. Statistical and visual validations showed good indicators, with average values of the mean absolute error (MAE) and relative bias (rBIAS) remaining below 1 and a mean percentage error (MAPE) below 20%. Based on the results, the contribution of this work is a method for predicting the trapped particle flux distribution at medium LEO altitudes.

Background
Methodology
References

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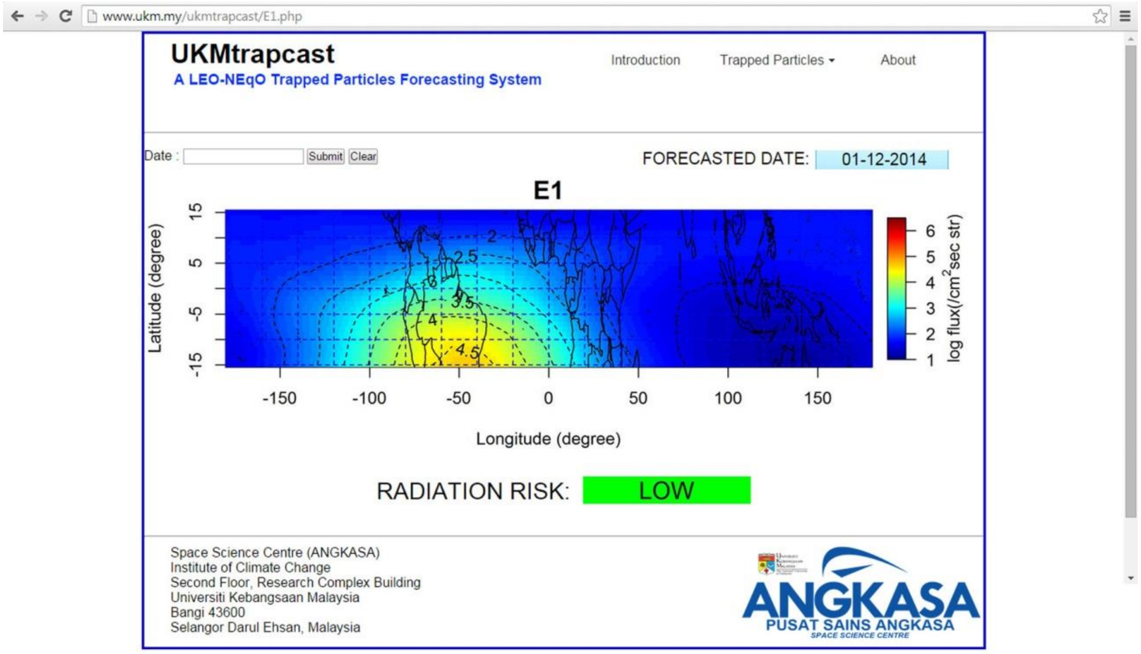
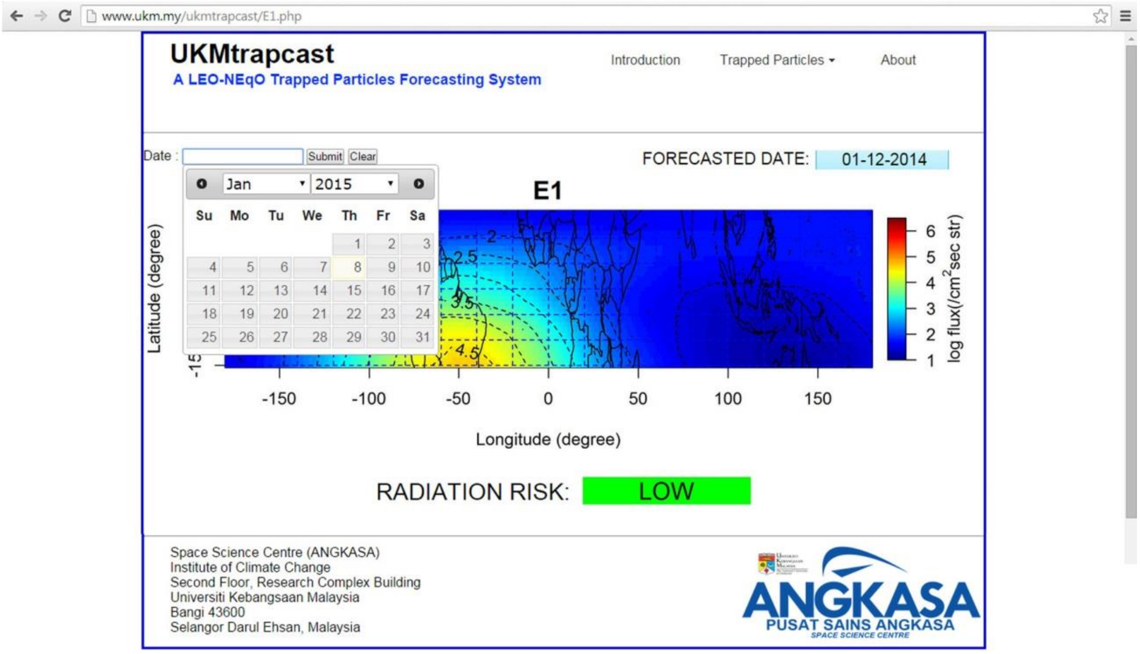
Result



(a)



(b)

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Result-Validation

Event	Particles	Date	T+1 (MAPE units in percentage)
Quiet	mep0e1	12-Mar-09	11.24
		13-Mar-09	11.86
		14-Mar-09	11.68
	mep0e3	12-Mar-09	14.19
		13-Mar-09	14.57
		14-Mar-09	15.19
	mep0p2	12-Mar-09	13.16
		13-Mar-09	11.1
		14-Mar-09	12.19
	mep0p4	12-Mar-09	18.66
		13-Mar-09	24.22
		14-Mar-09	17.45

Quiet Period to validate: 12-14 March 2009

Result-Validation

Event	Particles	Date	T+1 (MAPE units in percentage)
Severe	mep0e1	23-Jan-12	10.8
		24-Jan-12	11.36
		25-Jan-12	11.82
	mep0e3	23-Jan-12	15.7
		24-Jan-12	13.68
		25-Jan-12	12.07
	mep0p2	23-Jan-12	11.71
		24-Jan-12	14.11
		25-Jan-12	14.72
	mep0p4	23-Jan-12	17.28
		24-Jan-12	25.12
		25-Jan-12	20.58

Severe Period to validate: 23-25 January 2012
Proton Flux 6310 pfu, Flare Class M8/Long Period

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Discussion

- The accuracy of 75-90% for both quiet and severe days.
- The values of all validation parameters of all particles for both periods are relatively stable.
- Indicates that the variability of trapped particles fluxes distribution is quite stable even for severe days.
- The Kriging interpolation technique with high quality of estimation indicated by the values of variances which tend to zero.
- The merger between R and Matlab -> non-executable programs -> still need R and Matlab installed in our computer

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Discussion

- The consumption of memory is quite high.
- In some case the program halted to run after operating for several days -> lack of memory of our computer comparing to the R packages needed.
- Challenge from NOAA data -> the termination of NOAA 17 satellite in April 2013, NOAA 16 in June 2014, and NOAA 15 in December 2014.
- Finally, start from January 2015, the NOAA server just released three satellites data, i.e.: NOAA 18, 19 and METOP 02 with zero size -> termination of our system temporarily.

Conclusion

- The HBST-GP model was successful to deliver our first objective -> accuracy is about 75-90% -> during quiet and severe periods .
- The employment of Kriging interpolation technique also succeeded to deliver our second objective -> The variance results that tended to zero
- The third objective has been gained by the successful development of UKMtrapcast system and display the results on a web based system (www.ukm.my/ukmtrapcast) to provide an easy looking of our system result.

Future Works

- Embedding our system in more robust computer and changing UKMtrapcast platform from Matlab to Java -> unifying the R packages to Java library -> reduce the memory consume -> UKMtrapcast stand-alone program.
- Finding new alternative data for become the input of our system -> suggest data from Japan Aerospace Exploration Agency (JAXA) satellites which are quite similar with the NOAA data.
- Considering to apply our estimation system in the McIlwain (L, B) coordinate
- Adding the feature of radiation dose calculation

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THANK YOU