Reprint 1730

透過大氣擴散模式評估大氣懸浮物質的移動與其潛在影響

關錦倫、陳兆偉

第 36 屆粵港澳氣象科技研討會

暨

第 28 屆粵港澳氣象業務合作會議

珠海，2024 年 1 月 29-30 日

Using Atmospheric Dispersion Model for Assessing the Movement and Potential Impact of Atmospheric Suspended Particles

Kam-lun KWAN and Siu-wai CHAN

Hong Kong Observatory

Abstract

To get prepared for potential nuclear accidents, the Hong Kong Observatory has established an Accident Consequence Assessment System (ACAS) to simulate the movement and dispersion of radioactive materials released into the atmosphere and assess its impact on Hong Kong's environment. The atmospheric dispersion model of the ACAS can also be applied to near or long-distance simulation to evaluate the dispersion of other suspended particles in the atmosphere that are of public concern, such as dust, volcanic ash, smoke caused by forest fires, etc., allowing us to estimate the dispersion and deposition of different suspended particles in the atmosphere based on observation data from the ground or satellite with Numerical Weather Prediction (NWP) models. In this article, we demonstrate the operational workflow for dispersion prediction based on recent real-life cases. We also explore the potential application of the tool for the provision of weather services in our region.

第36屆粵港澳氣象科技研討會暨第28屆氣象業務合作會議

透過大氣擴散模式評估大氣懸浮物質的移動與其潛在影響

關錦倫　陳兆偉

香港天文台

摘要

天文台建立了一套事故後果評估系統(Accident Consequence Assessment System),用以模擬放射性物質在大氣中的運動和擴散,並評估對香港環境的影響。這套事故後果評估系統的大氣擴散模型也可以應用於近或遠距離的大氣擴散模擬,評估其他公眾關注的懸浮粒子在大氣中的擴散情況,例如沙塵,火山灰,山火引起的烟霧等等,讓我們可以根據地面及衛星觀測數據和數值天氣預報模式來估算大氣中不同懸浮粒子的擴散和沉積情況。在本文中我們以近年的實例來展示進行擴散評估的運作流程,並探討其對我們區域天氣服務的潛在應用。

1. Introduction

To get prepared for potential nuclear accidents, the Hong Kong Observatory (HKO) has established an Accident Consequence Assessment System (ACAS) to simulate the movement and dispersion of radioactive materials released into the atmosphere and assess the radiological impact of nuclear accident on Hong Kong's environment. ACAS consists of two systems. The first one is Java-based Real-time Online DecisiOn Support (JRODOS) system which uses a dispersion model named Ris∅ Mesoscale PUFF (RIMPUFF). Another one is FLEXible PARTicle (FLEXPART) dispersion model. The atmospheric dispersion model of the ACAS can be applied in near or long-distance simulation to evaluate the dispersion of other suspended particles in the atmosphere that are of public concern, such as dust, volcanic ash, smoke caused by forest fires, etc., allowing us to estimate the dispersion and deposition of different suspended particles in the atmosphere based on observation data and computer prediction models. As a supplement and fast analyzing tool for a long range simulation, HKO also uses HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to analyze the transport trajectories of atmospheric particles.

I. Short range dispersion simulation

For short range atmospheric dispersion simulation, the Observatory’s focus is mainly on the assessment of dispersion of airborne materials and an atmospheric dispersion model called Ris∅ Mesoscale PUFF (RIMPUFF)[1] is employed. RIMPUFF is one of the Lagrangian mesoscale atmospheric dispersion models commonly used in meteorology. The maximum simulation range of the model is 800 km. For operational consideration, the typical domain the Observatory used is at a range of 100 km which has a full coverage of Hong Kong in handling potential nuclear accident from Daya Bay Nuclear Power Plant. The grid resolution of the model is variable, ranging from 0.25 km to 4 km. The model can estimate the concentration of radioactive materials in the air due to an atmospheric release from some points near the ground, its deposition to the surface and the radiation dose to people. Figure 1 is an example of a radioactive plume dispersion simulation with the use of RIMPUFF.

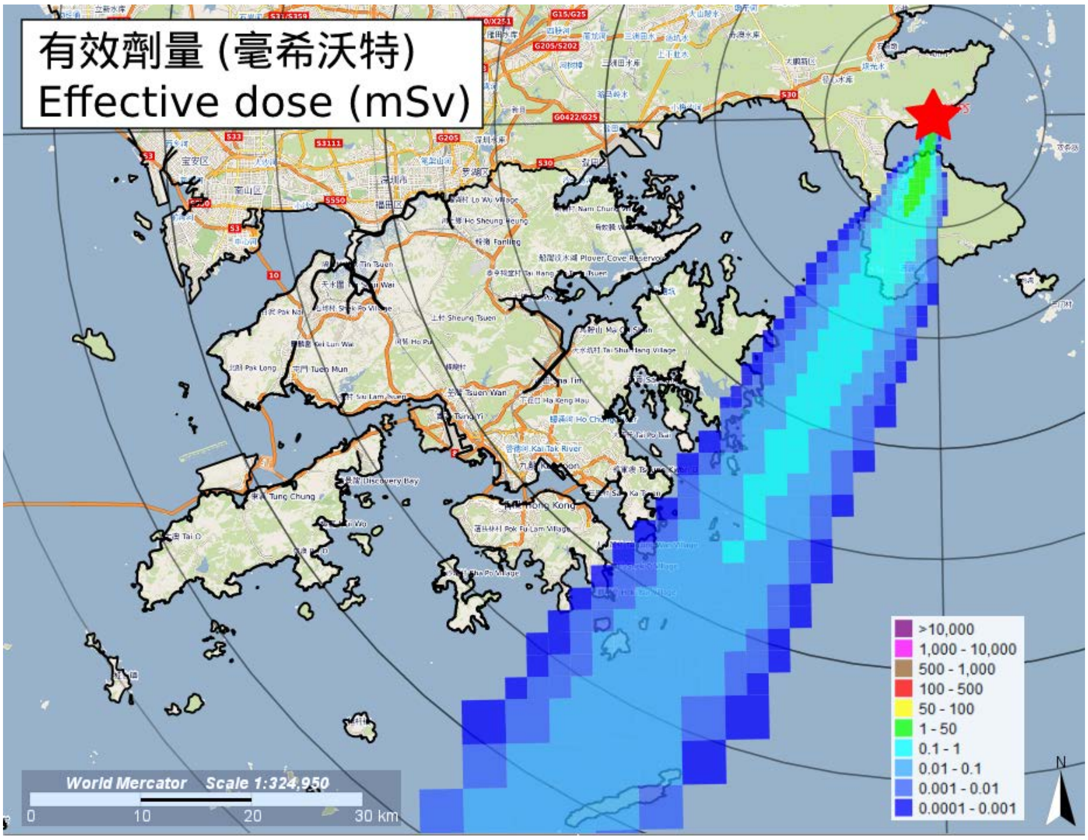

Figure 1 - Plume dispersion simulation for a hypothetical release of radioactive materials in the atmosphere from Daya Bay Nuclear Power Plant for 72 hours forecast

II. Long range dispersion simulation

For long range atmospheric dispersion simulation, the Observatory employs the FLEXible PARTicle (FLEXPART) [2] atmospheric dispersion model. FLEXPART is a particle dispersion model that can simulate long range atmospheric dispersion up to thousands of kilometers from the source. Figure 2a is an example of the FLEXPART atmospheric particle dispersion simulation.

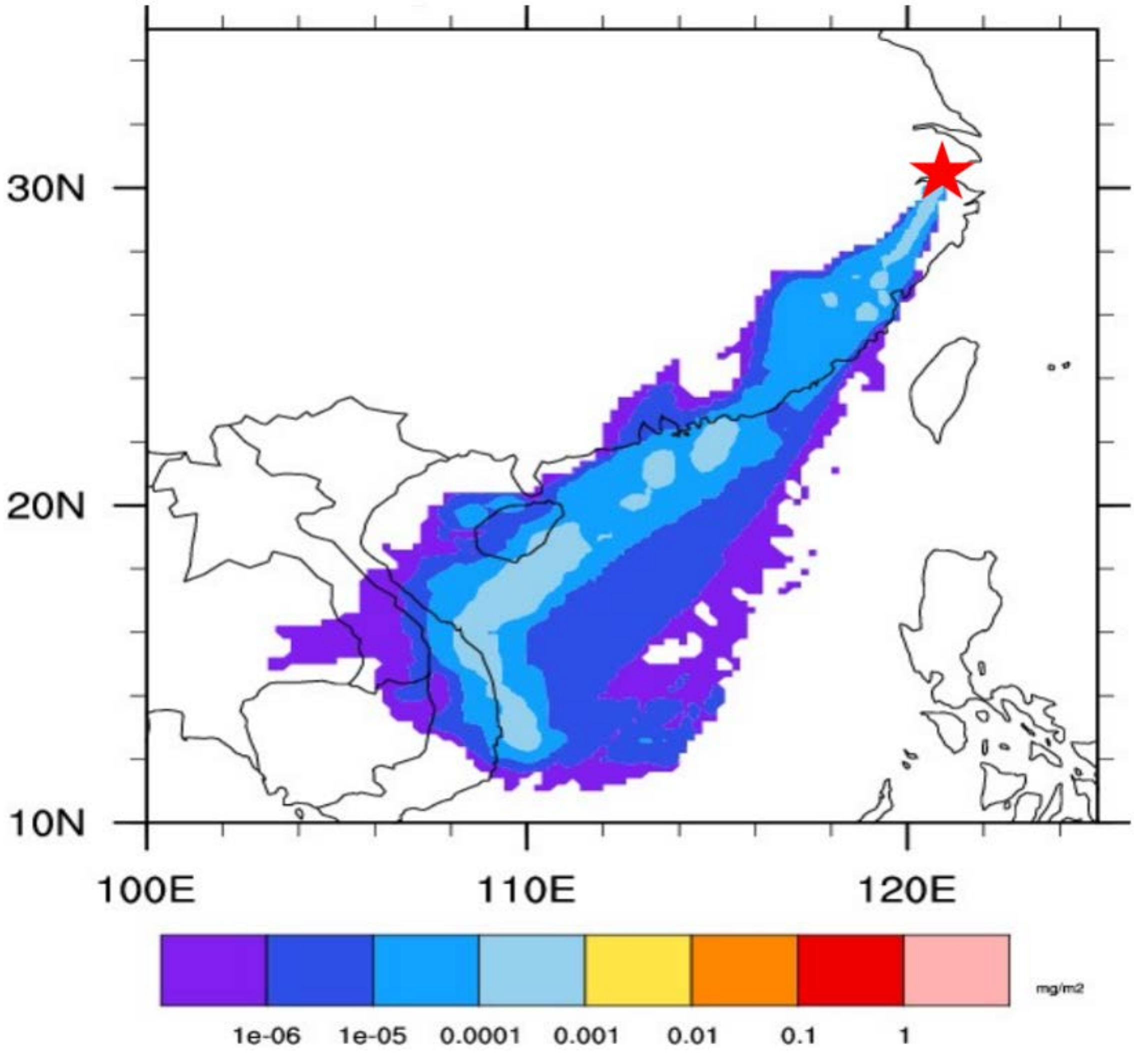

Figure 2a - Atmospheric particle dispersion simulation for a hypothetical release near the ground from Qinshan Nuclear Power Plant Station for 72 hours forecast

Besides dispersion simulation, HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) [3] model is also a commonly used tool for the long range atmospheric particle transport simulation up to global scale, and able to produce forecast trajectories. Figure 2b shows the forecast trajectories of air from three different heights, originated from the location of the nuclear power plant in Fukushima, Japan.

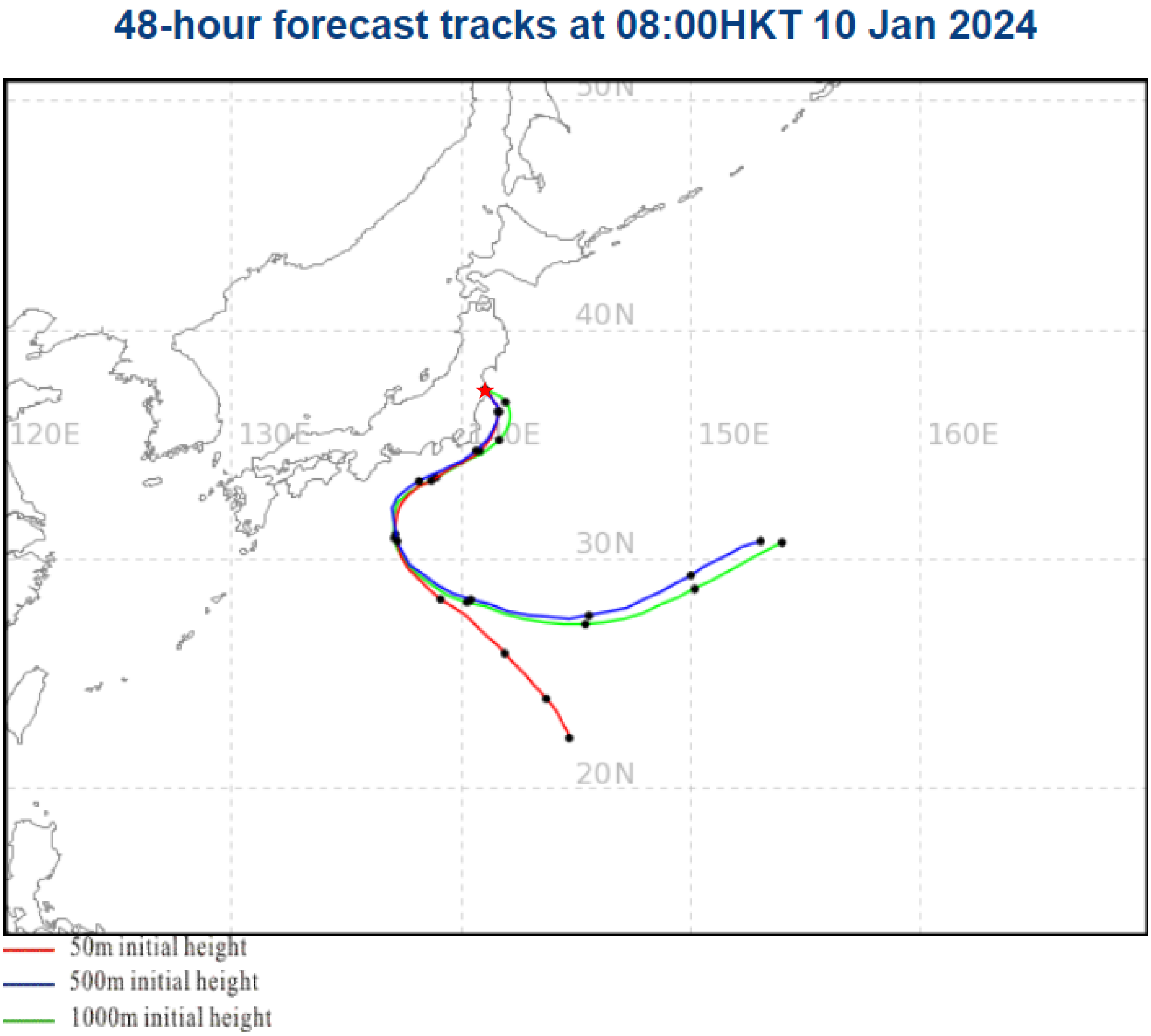

Figure 2b shows the forward forecast trajectories of airborne particulate from three heights from the location of the nuclear power plant in Fukushima, Japan for 48 hours forecast

2. Operational examples

Atmospheric dispersion models can be applied to various atmospheric environmental events. Models can perform simulations based on the potential source term of the suspended particulates and its specific properties (e.g. transformation and decomposition) to assess the dispersion of the air-borne particulates in the atmosphere. We try to apply the technique to the following real or hypothetical cases in the atmospheric environmental assessment operations.

I. Hypothetical release from Zaporizhzhya nuclear power plant (“ZNPP”) at Ukraine

We set up this scenario for assessing a hypothetical release from ZNPP. Figure 3a and 3b show the dispersion simulation of a hypothetic release of Cs-137 at ZNPP by FLEXPART. The system can be automated to perform dispersion model run every 12 hours when a new set of United States National Centers for Environmental Prediction (NCEP) global model numerical weather prediction data is received.

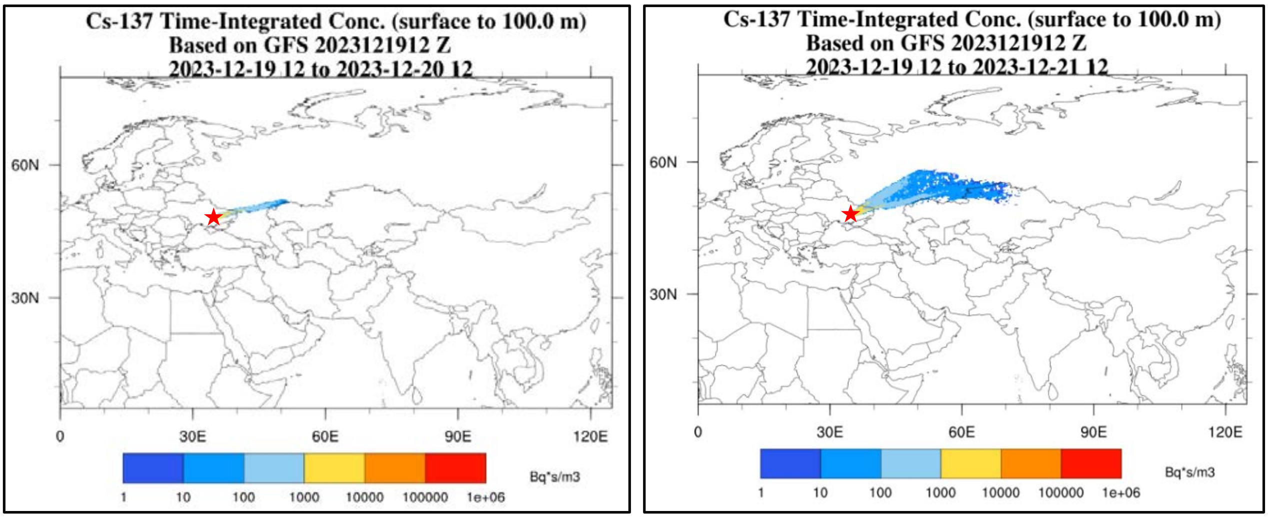

Figure 3a and 3b - FLEXPART dispersion simulation of a hypothetic release of Cs-137 from the ZNPP for 24 and 48 hours forecast

II. Forest Fire in Canada in early June 2023

In early June 2023, a large-area forest fire occurred over the eastern part of Canada. The fire produced intense smoke and the smoke moved immediately to southeast to affect the northeastern part of USA. Over 1,000 flights were delayed in New York due to the smoke. Figure 4a and 4b show the dispersion simulation of smoke particulates by FLEXPART. Figure 4c shows the smoke as observed by satellite.

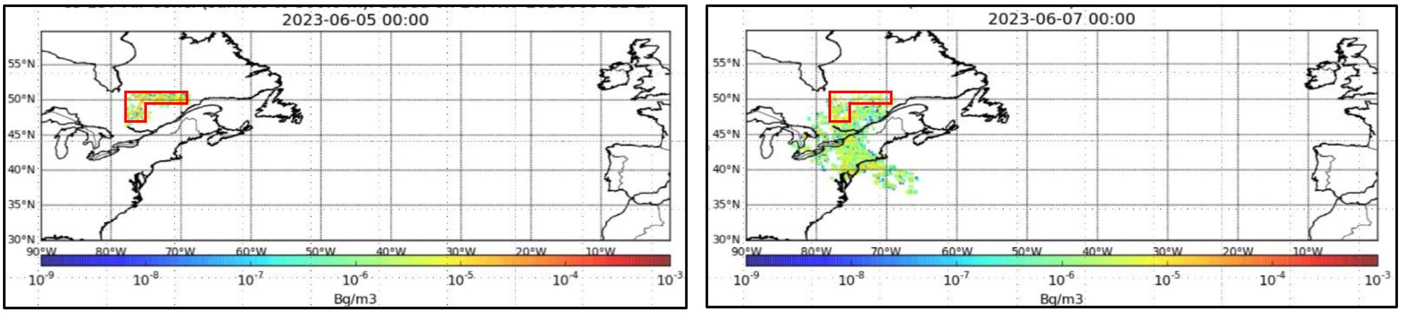

Figure 4a and 4b - FLEXPART dispersion simulation of smoke particulates for 12 and 36 hours forecast (red border indicating the estimated boundary of forest fire on 4 June 2023)

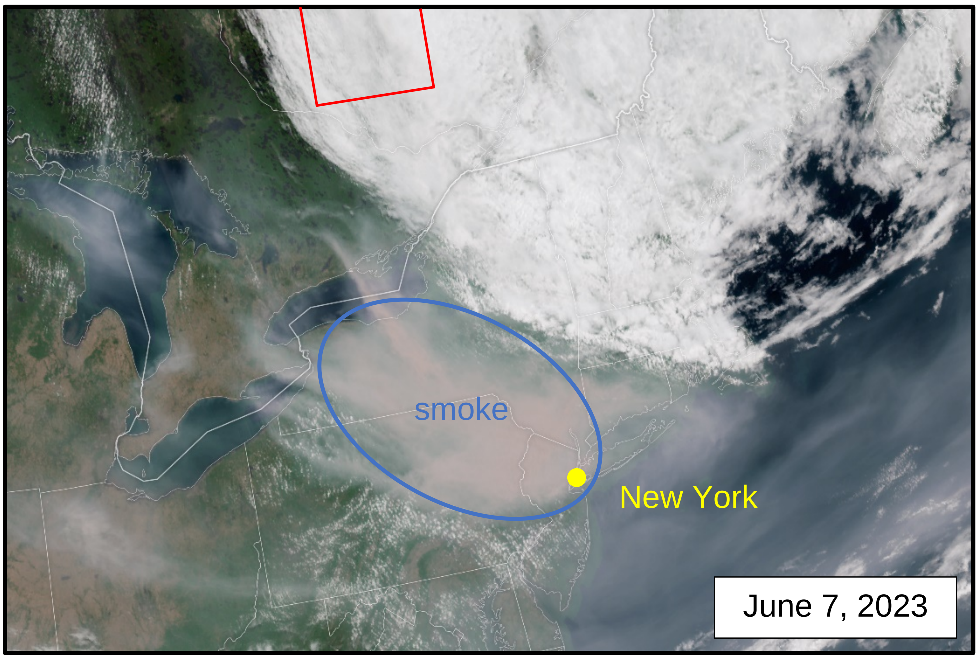

Figure 4c show the smoke observed by satellite (NASA GOES-16 satellite) and red border indicating the estimated boundary of forest fire

With the forest fire sustained over the region, the intense smoke drifted further downstream across the Atlantic Ocean and reached western Europe in late June 2023. Figure 5a - 5d show the dispersion simulation of smoke particulates reaching western Europe by FLEXPART. Figure 5e shows the smoke observed by satellite over the region.

With the dispersion simulation results, aviation forecasters can predict the affected areas and prepare SIGMET weather charts to facilitate flight planning or re-routing by pilots and civil aviation authorities.

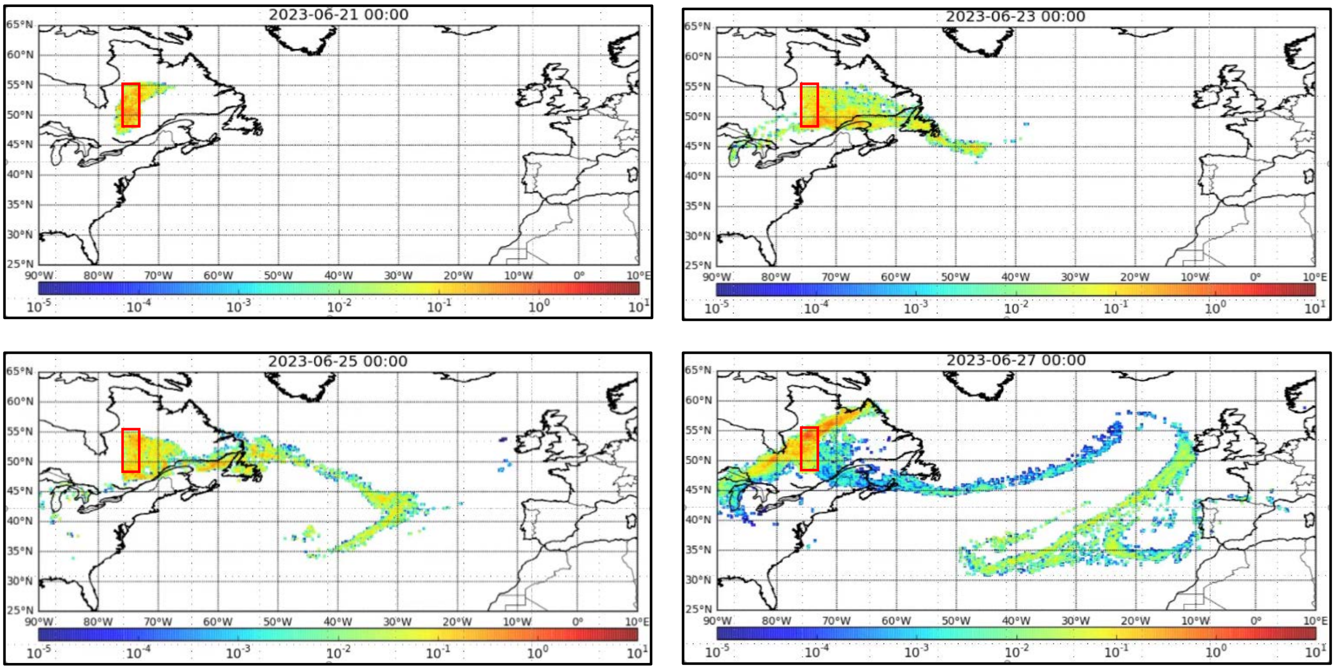

Figure 5a - 5d - FLEXPART dispersion simulation of smoke particulates reaching western Europe for day+1, +3, +5 and +7 forecasts (red border indicating the estimated boundary of forest fire on 20 June 2023)

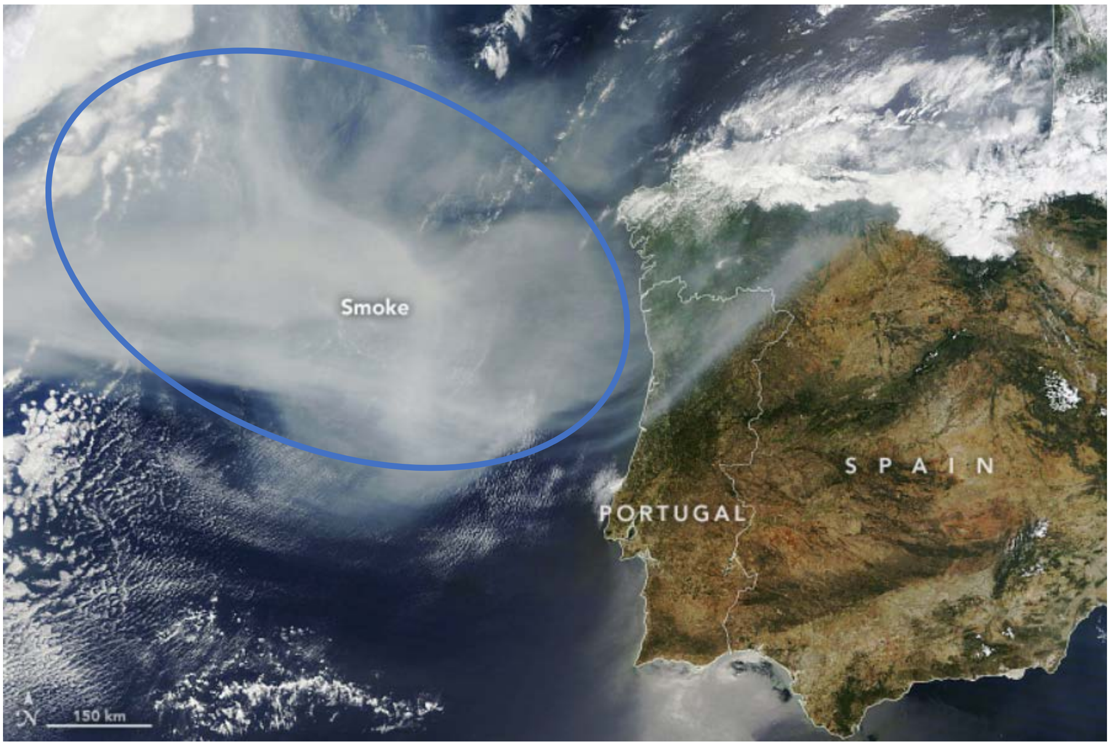

Figure 5e show the smoke originated from Canada observed over the eastern part of

Atlantic Ocean by satellite at 26 June 2023 (MODIS of NASA Terra satellite)

III. Simulations of Hunga Tonga-Hunga Ha'apai volcanic eruption in January 2022

The Hunga Tonga-Hunga Ha'apai volcano had severe eruption on 15 January 2022. The volcanic ash moved west towards Australia. Figure 6a - 6d show the volcanic eruption with the ash moving west to Australia (Japan Meteorological Agency [JMA] Himawari 8/9 satellite imagery).

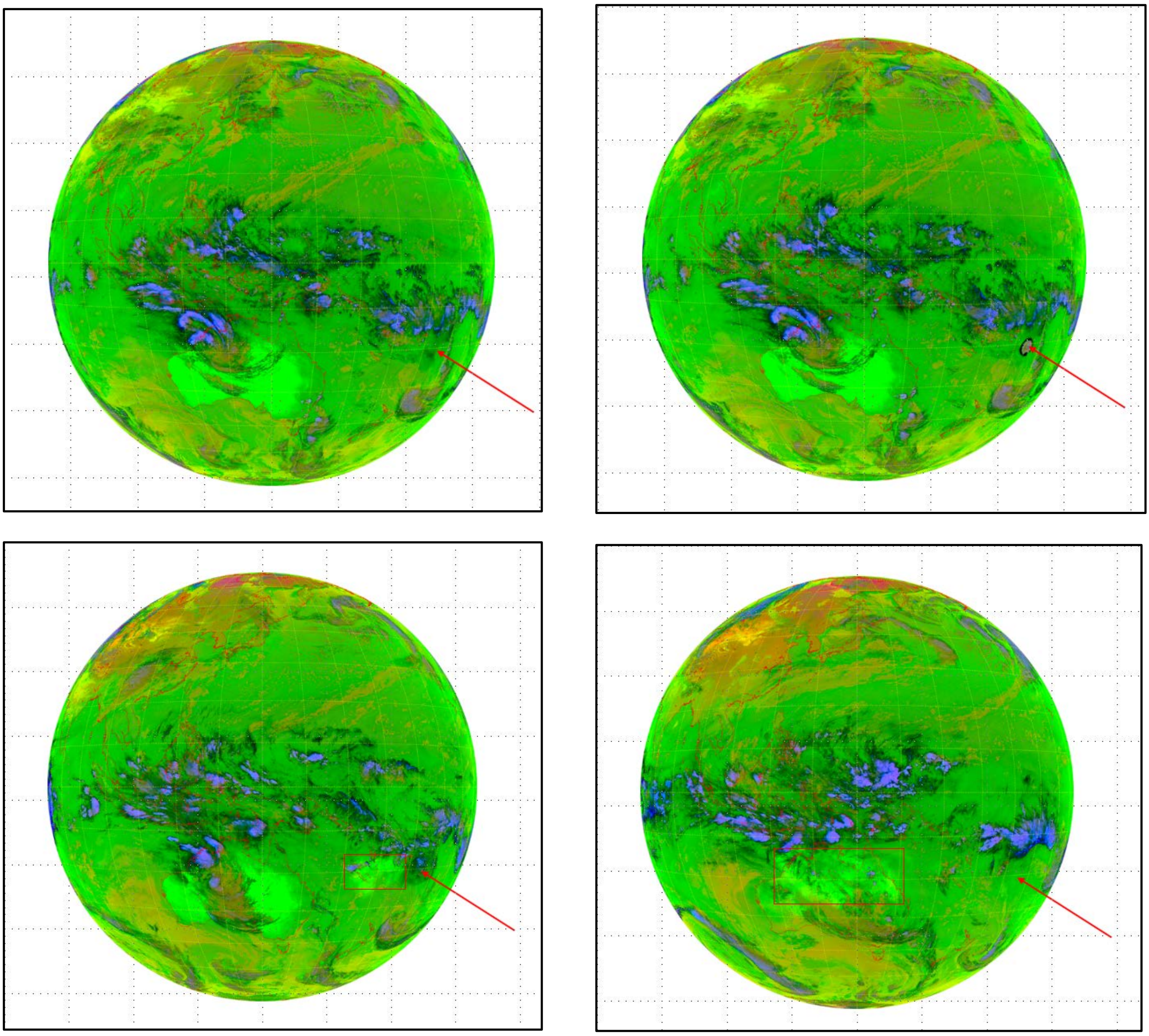

Figure 6a - 6d show the volcanic eruption and the movement of the ash towards

Australia by Japan Himawari 8/9 Satellite dust channel (Arrow denoting the volcano).

To simulate the trajectory of the volcanic ash, HYSPLIT with release height at 20 km, estimated by the satellite cloud top, was used to simulate the westward trajectories at high-attitude. The trajectories matched the satellite observations. The severe eruption released a large amount of ash to the stratosphere. The ash was transported westward with strong easterlies to Australia. The high density volcanic ash is dangerous to the flight cruising. Similar to the previous case of forest fire, the simulation results and thus the relevant aviation products can facilitate aviation users planning the flight routes to avoid the ash. Figure 6e shows the HYSPLIT trajectories simulation.

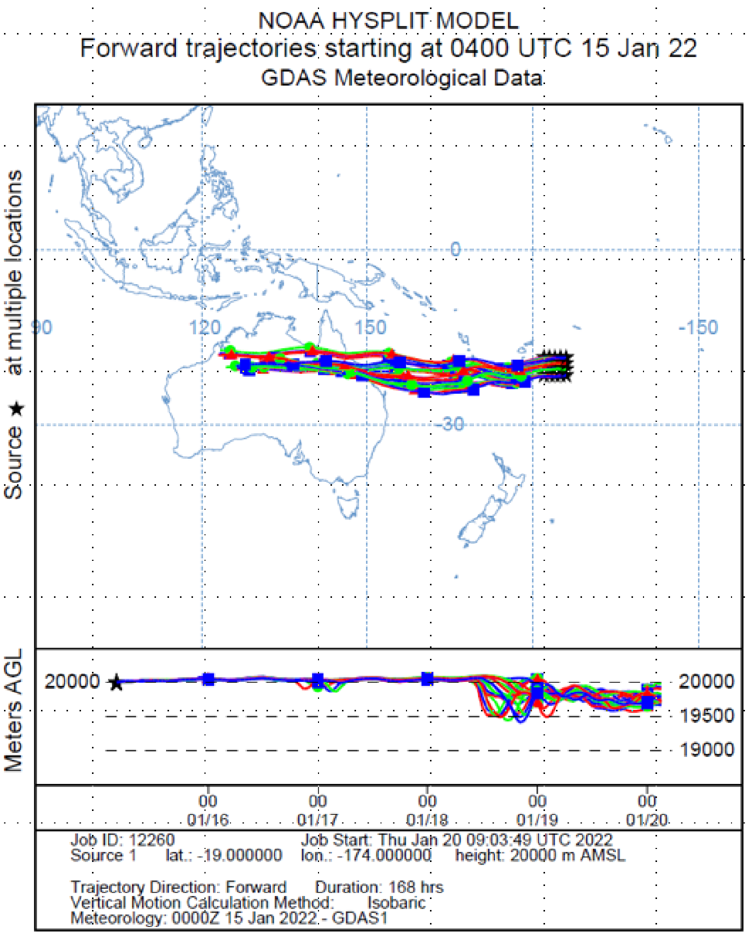

Figure 6e shows the HYSPLIT trajectories simulation at the grid points around Hunga Tonga-Hunga Ha'apai volcano for 168 hours forecast.

IV. Dust storm in northern China in early April 2023

In early April 2023, northern China was affected by the dust storm. Figure 7a shows the dust storm dispersion simulation by FLEXPART. Figure 7b shows the position of atmospheric dust observed at that time by the JMA Himawari 8/9 satellite. Some atmospheric dust was covered by high clouds around the eastern China and the Yellow Sea. The simulation result shows resemblance with the actual situation as depicted in the satellite image.

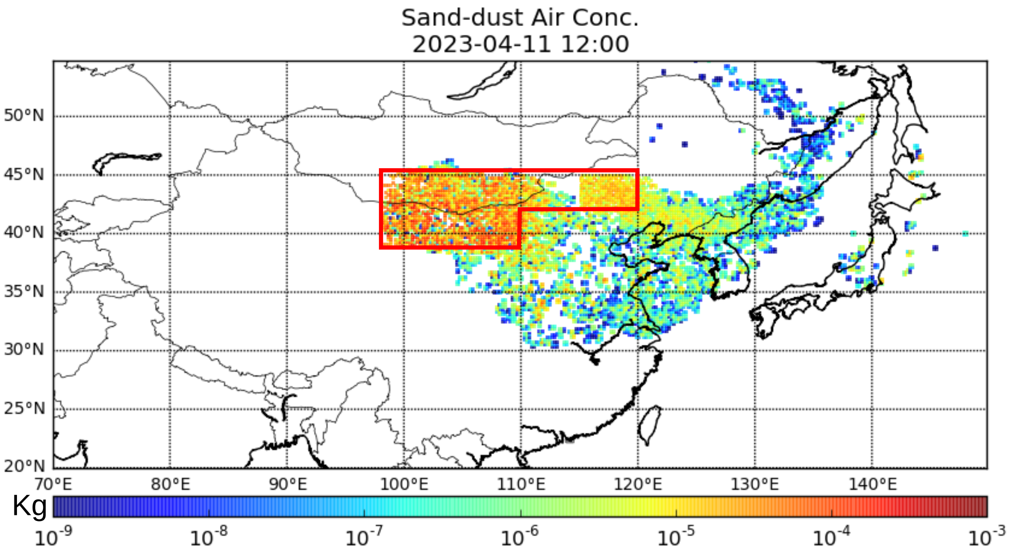

Figure 7a FLEXPART simulation of dust dispersion in the atmosphere for the day + 4 forecast (red border indicating the observed dust area on day 0)

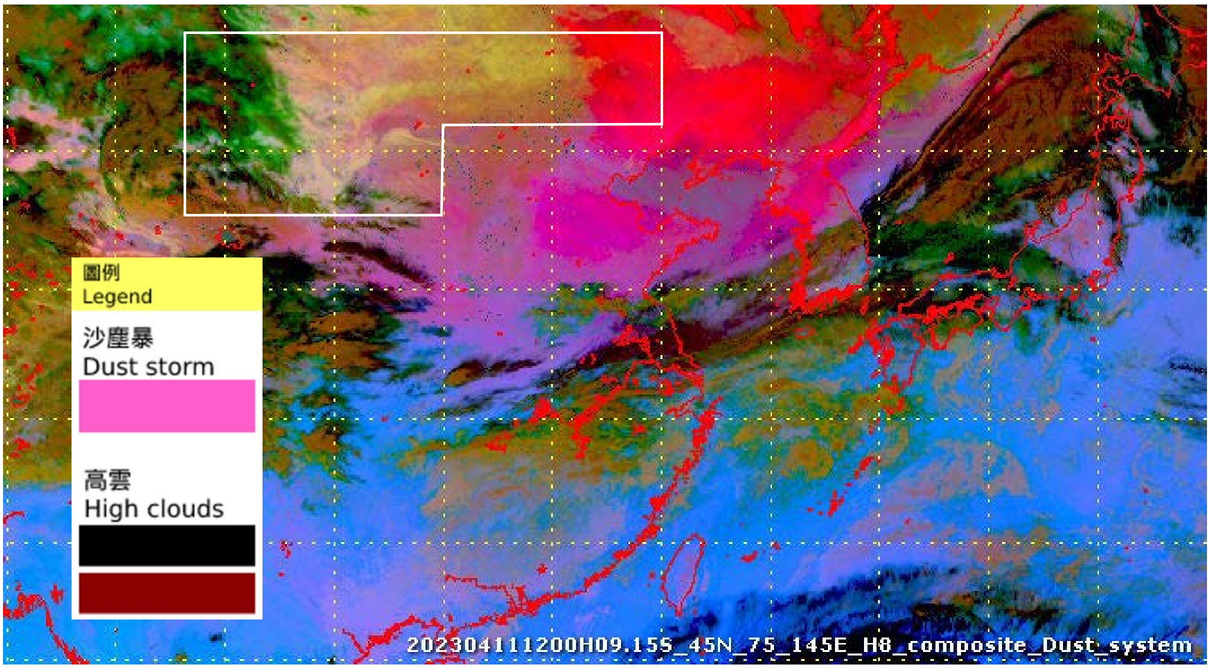

Figure 7b Dust storm as observed by the JMA Himawari 8/9 satellite spreading

over the eastern China and the Yellow Sea (white border indicating the origin of dust on day 0)

3. Way forward

In some physical phenomena, erupted particles have a distribution of size. For examples, the volcanic eruption or sand/dust storm events release a mixture of particles in different sizes and other parameters. Simulation of these events requires the understanding of the ratio of different particles in the release source and other parameters of those particles. In FLEXPART, the species of the released source in the model can be customized with parameters by users. The parameters of the released source were specified in terms of its density, mean diameter, diameter variation in percentage, scavenging coefficient, and dependency on precipitation rate. In HYSPLIT model, there are also settings for the mixture composition including ash particles' mass fraction, diameter, density and shape factor. More studies are required to build appropriate preset parameters for the volcanos and specific areas.

Besides, comparison between the dispersion outputs based on input from different NWP model, e.g. ECMWF, NCEP, can be carried out to evaluate their effectiveness in emergency assessment. The use of multiple NWP data sources can enhance the resilience of the ACAS, as well as benefit the compiling of ensemble products, which can generally provide more information on uncertainty than a single model approach.

Reference

[1] Søren Thykier-Nielsen, Sandor Deme, Torben Mikkelsen. Description of the Atmospheric Dispersion Module RIMPUFF, RODOS(WG2)-TN(98)-02, 1999

[2] Stohl, A., C. Forster, A. Frank, P. Seibert, and G. Wotawa, 2005: Technical Note : The Lagrangian particle dispersion model FLEXPART version 6.2. Atmospheric Chemistry and Physics, 5, 2461-2474.

[3] Stein, A.F., Draxler, R.R, Rolph, G.D., Stunder, B.J.B., Cohen, M.D., and Ngan, F., (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system, Bull. Amer. Meteor. Soc., 96, 2059-2077.

[4] Olesen, H.R., 2005. User's Guide to the Model Validation Kit. National Environmental Research Institute, Denmark, pp. 72. Research Notes from NERI no. 226.