



Evaluation of the Inline WRF-HYSPLIT Model for Mesoscale Atmospheric Transport and Dispersion

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1. Introduction and Background

A new, inline framework that combines the Weather Research and Forecasting model (WRF; Skamarock et al. 2008) with the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT; Draxler and Hess 1998) has been developed by the Air Resources Laboratory (ARL). The new "inline" model, WRF-HYSPLIT, has been shown to have some advantages over the traditional "offline" implementation of the HYSPLIT model (Fig. 1), particularly for meso-gamma-scale, short-range, atmospheric transport and dispersion (ATD) predictions (Ngan et al. 2015). Thus, it is of interest to investigate this new inline capability for operational use.

The accuracy of the offline and inline approaches depends on several factors including the meteorological model output frequency and the interpolation of the meteorological and ATD model vertical grids. For example,

- Events characterized by rapid temporal variations may not be well represented by the offline approach, because they require computationally-expensive, high-frequency meteorological outputs.

- Complex vertical wind structures cannot be accurately represented by offline approaches because the HYSPLIT requires the vertical interpolation of meteorological fields into its native, low-resolution grid.

- The new inline WRF-HYSPLIT model implements the HYSPLIT model within WRF computational loops, allowing it to take advantage of the small WRF time-step and its-native vertical grid.

Here, we explore the advantages and disadvantages of this new inline model for a mesoscale dispersion event and identify output frequencies that minimize the offline errors for operational use.

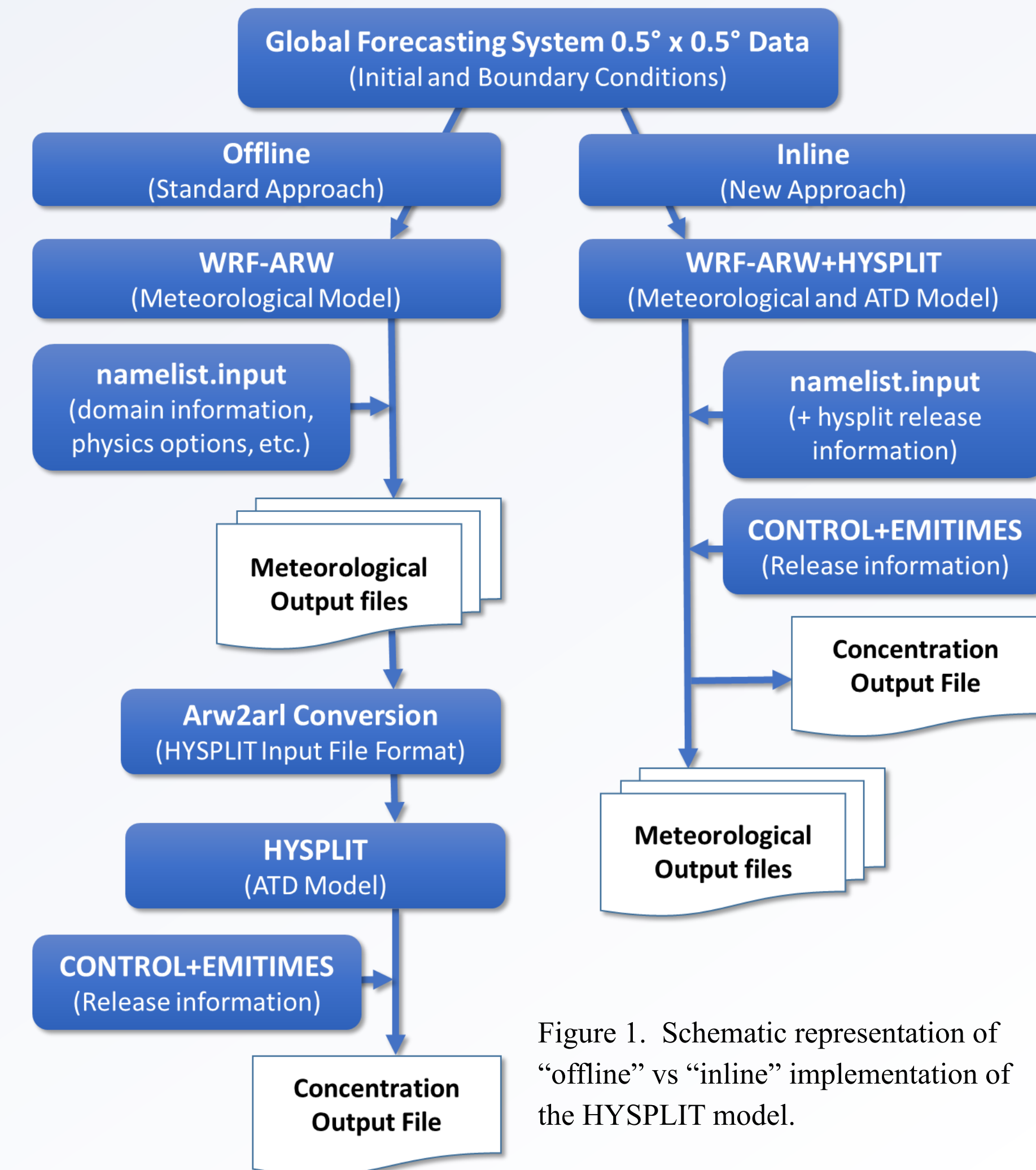


Figure 1. Schematic representation of "offline" vs "inline" implementation of the HYSPLIT model.

2. Experimental Design

Two experiments are conducted using WRF, version 3.7, and WRF-HYSPLIT (Fig 1). The models are configured with four one-way nested domains (Fig 2), and are evaluated for the COSTEX field experiment on 21 October 2010. In this field experiment, 1 kg of perfluorodimethylhexane (PDCH) is continuously released from Colorado Spring, CO from 1900-1930 UTC. Concentration measurements from ten measuring stations, distributed over the Colorado Rockies (Fig. 2b), are available every 30 min from 1900 - 2300 UTC.

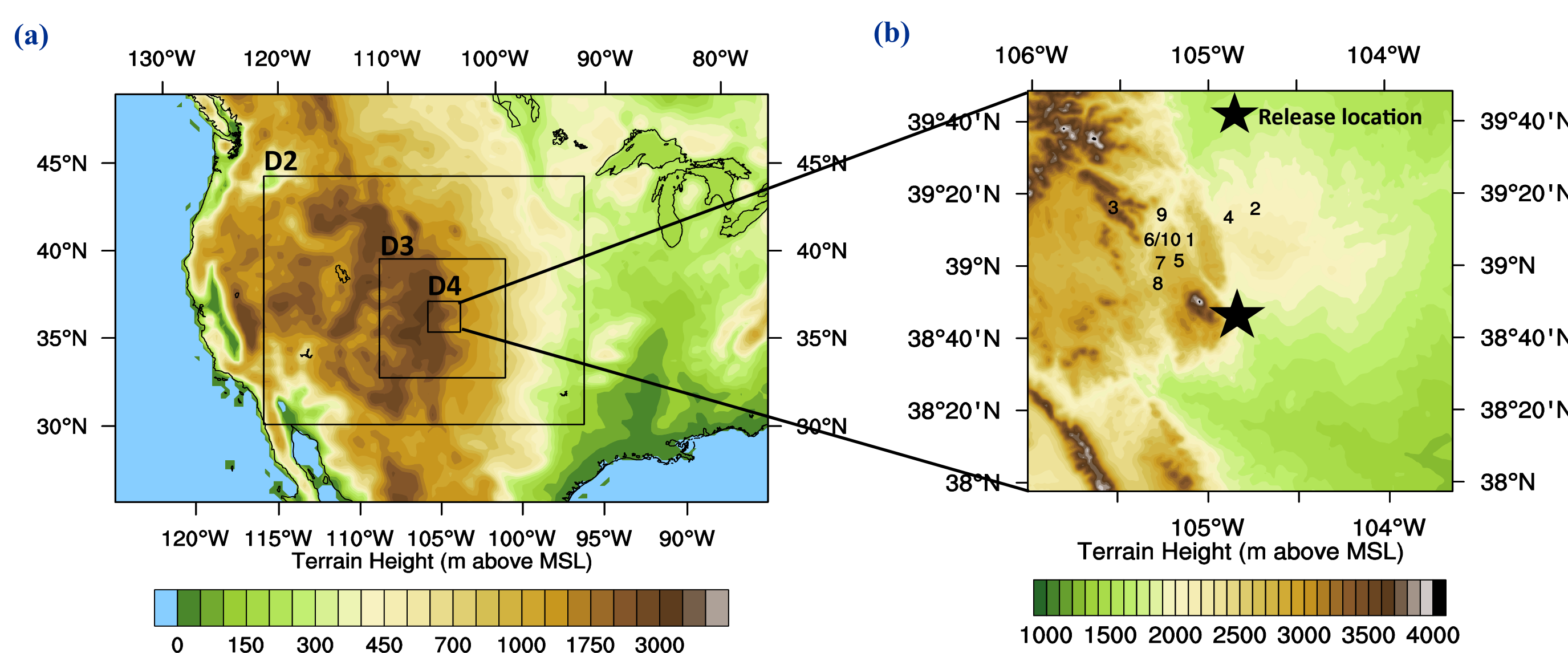


Figure 2. (a) Mean sea level model terrain (m, shaded according to scale) for the 27-km (D1), 9-km (D2), 3-km (D3), and 1-km (D4) domains. (b) Release site and array of measuring stations for the tracer release on 21 October 2010.

3. Results

Inline concentration forecasts starting at 1900 UTC are compared against offline simulations using the same ATD configurations. Offline ATD simulations are conducted using 5, 10, 15, 20, 30, and 60 min meteorological model output frequency. Model comparisons and verification statistics are provided for D2 and D3.

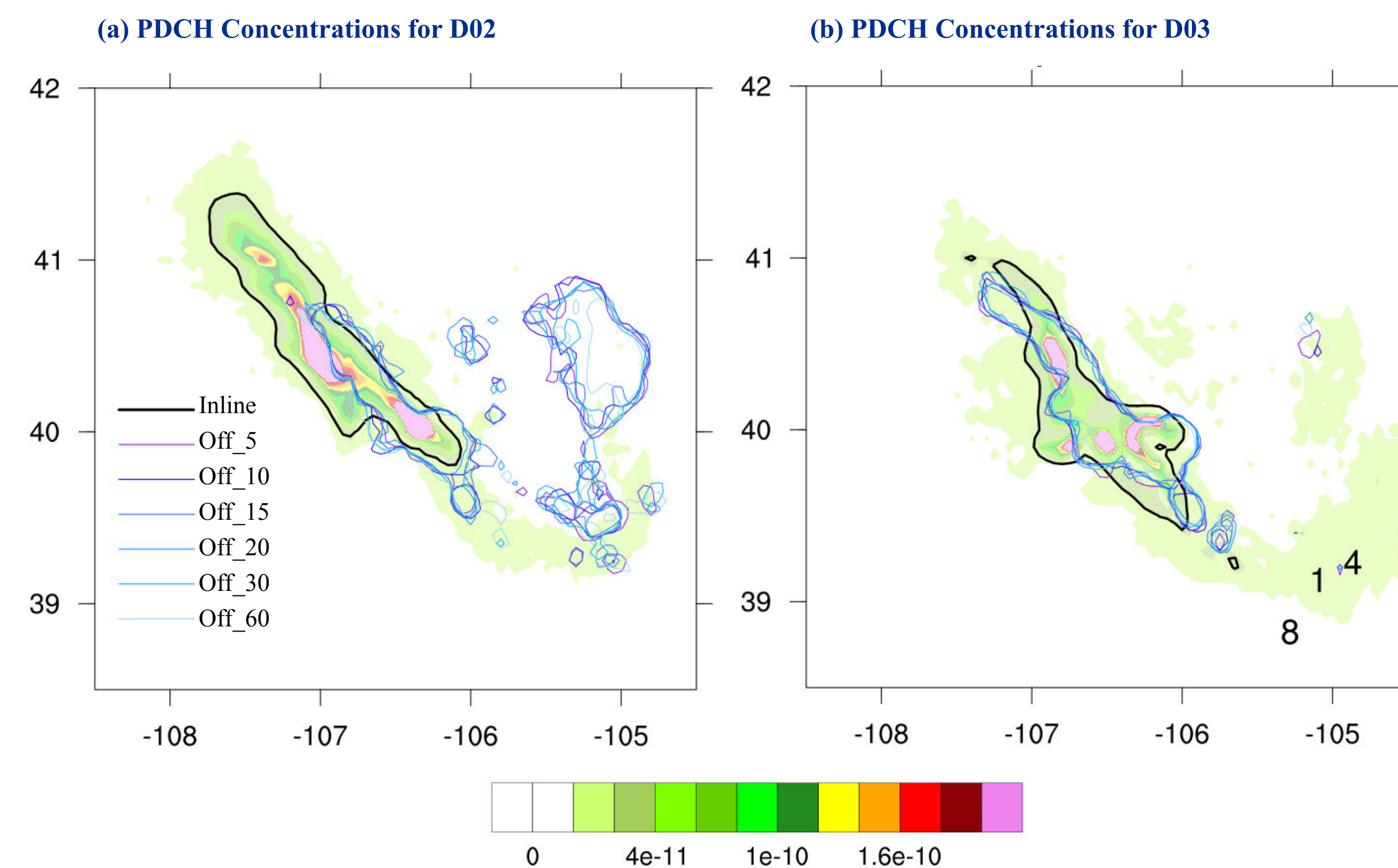


Figure 3. PDCH concentrations from the inline model (colored according to scale) and inline and off line concentration contours ($2 \cdot 10^{-11} \text{ kg/m}^3$) 12 hours after release time for (a) D02 and (b) D03. The locations of stations 1, 4, and 8 are provided.

Verification Metrics: Model comparisons are conducted using verification metrics developed by Draxler (2006). The rank is given by

$$\text{Rank} = R^2 + 1 - \frac{|FB|}{2} + \frac{FMS}{100} + \left(1 - \frac{KSP}{100}\right)$$

where correlation coefficient (R), the fractional bias (FB), figure of merit in space (FMS), and the Kolmogorov-Smirnov parameter (KSP) are given by

$$R = \frac{\sum(M_i - \bar{M})(P_i - \bar{P})}{\sqrt{\sum(M_i - \bar{M})^2 \sum(P_i - \bar{P})^2}}, \quad FB = \frac{2(\bar{P} - \bar{M})}{(\bar{P} + \bar{M})}, \quad FMS = 100 \frac{N_p \cap N_m}{N_p \cup N_m}, \quad \text{and } KSP = \max|D(M_k) - D(P_k)|$$

and M and P are true and predicted values, N is the number of samples, and D is the cumulative distribution over a range of k values.

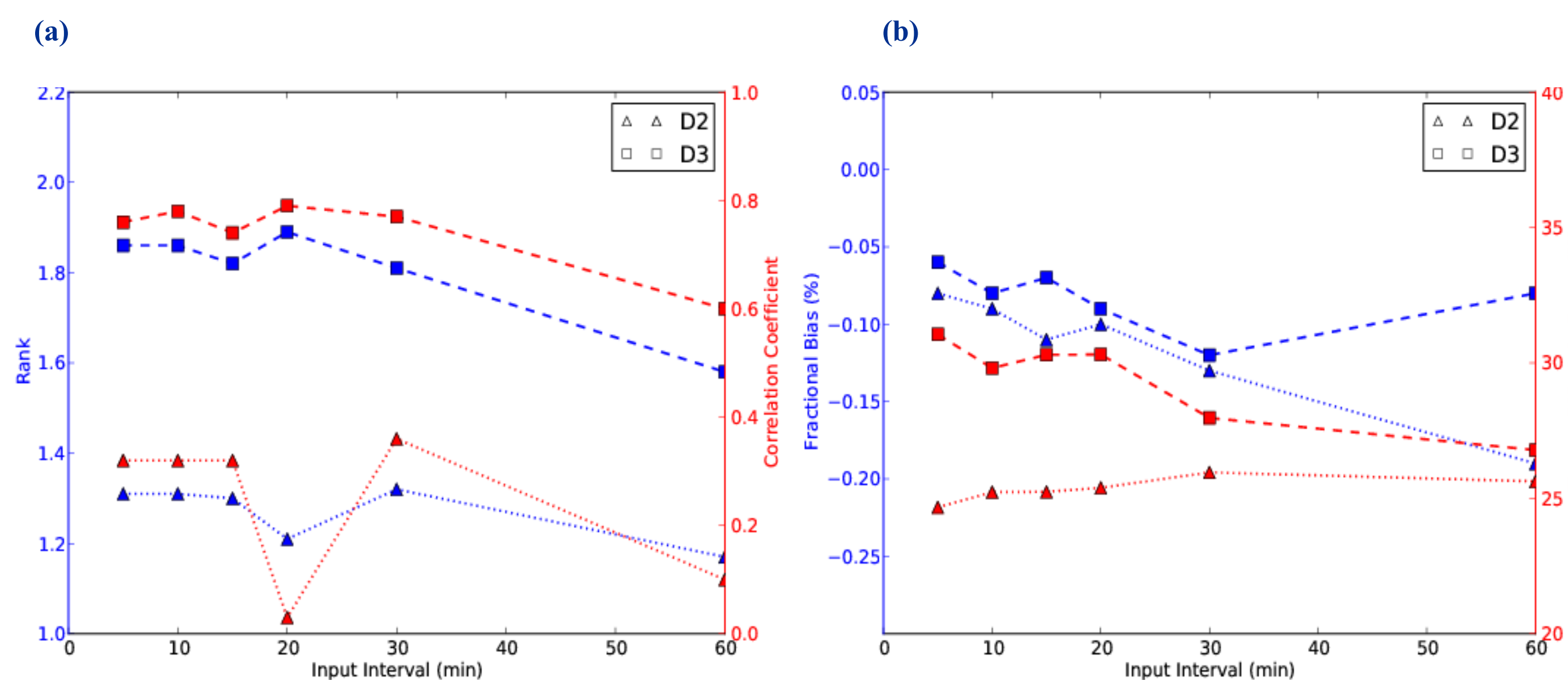


Figure 4. Verification metrics of the inline versus online HYSPLIT forecasts for D2 and D3 at 5, 10, 15, 20, 30, and 60 min input frequency. (a) Rank and correlation coefficient and (b) fractional bias and figure of merit in space (%).

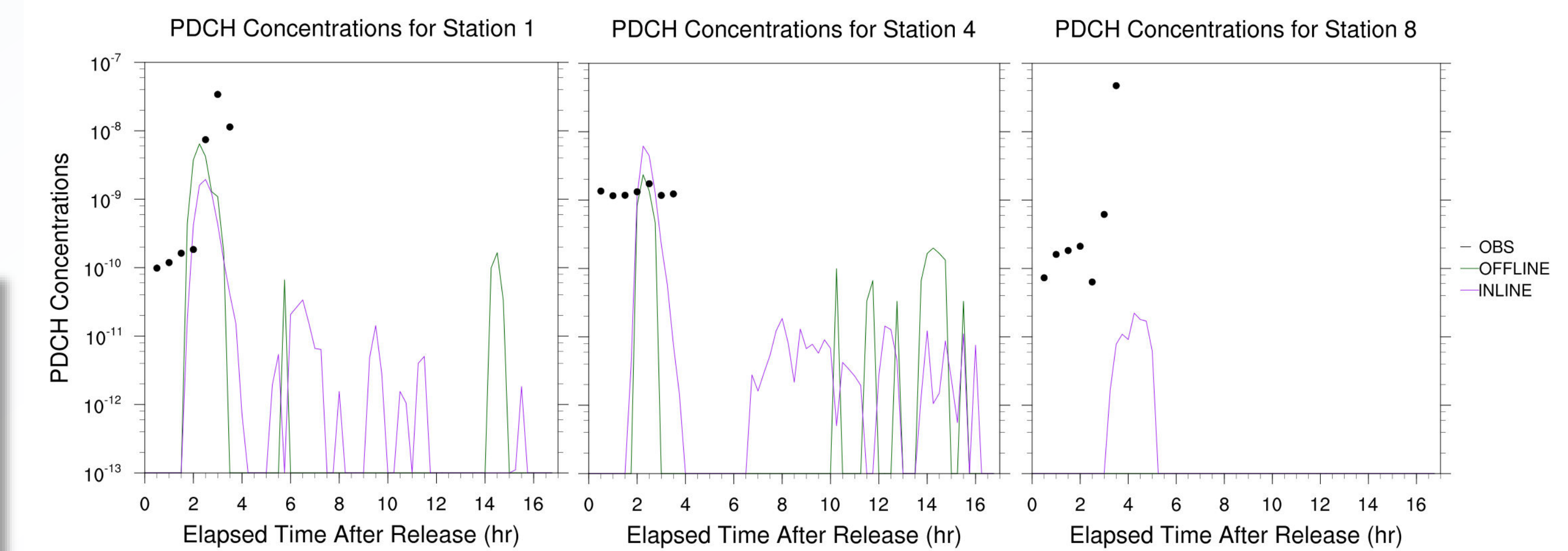


Figure 5. Observed (dot) and forecasted (solid lines) PDCH concentrations at multiple stations using a 15 min output frequency.

Parallel Scalability Analysis: The computational speedup ratio (S) and parallel efficiency (E) are estimated by

$$S = \frac{T_1}{T_N} \quad \text{and} \quad E = \frac{S}{N}$$

where N is the number of processors utilized, T_N is the computational speed for N processors, and T_1 is the computational speed for $N=1$.

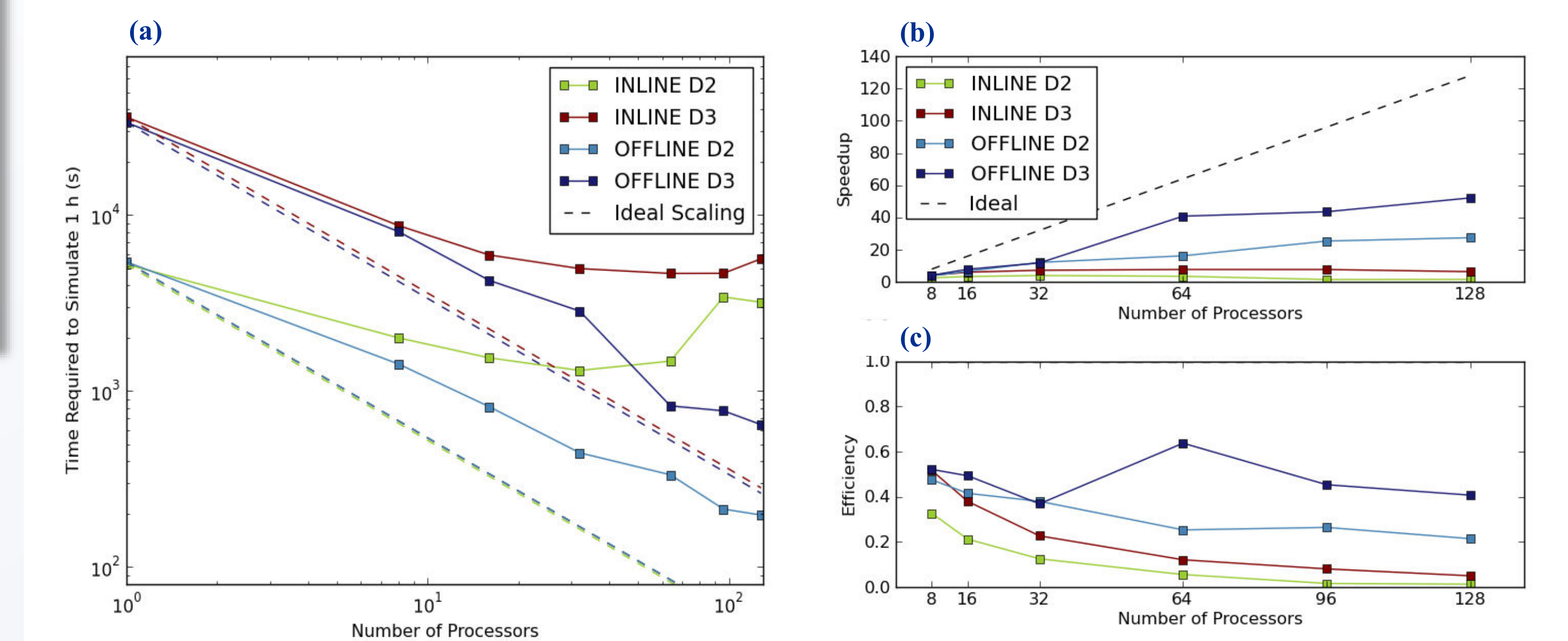


Figure 6. Parallel scalability analysis. (a) Time (seconds) required to simulate one model hour as a function of the number of processors. (b) Speedup and (c) efficiency computed against a single processor, as a function of the number of processors.

4. Conclusions

Based on this preliminary investigation of the inline WRF-HYSPLIT for operational use, it is concluded that

- The inline has some advantages reproducing the observed concentrations over the offline implementation of HYSPLIT.
- Comparisons for multiple output frequencies show that the skill of the offline approach to reproduce the inline plume does not generally vary for intervals less than 20 min, regardless of domain resolution.
- The operational implementation of the new inline model presents numerous challenges, including increased computational cost and the requirement of new, computationally-expensive WRF simulations in order to change the parameters of the release (e.g., release height, number of particles, material, etc.).

Overall, the inline model provides a unique platform for ATD predictions. Better model performance could be expected as future developments, e.g., the parallelization of the code and the use of additional WRF prognostic fields, are implemented. Future work will investigate the sensitivity of the inline model to physics options (e.g., planetary boundary layer), vertical resolution, and dispersion at synoptic and sub-kilometer scales.

References:

- Draxler, R. R., and G.D. Hess, 1998: An overview of the HYSPLIT_4 modeling system for trajectories, dispersion, and deposition. *Aust. Meteor. Mag.*, **47**, 295-308.
- Draxler, R.R., 2006: The Use of Global and Mesoscale Meteorological Model Data to Predict the Transport and Dispersion of Tracer Plumes over Washington, D.C. *Wea. Forecasting*, **21**, 383-394.
- Ngan, F., A. Stein, and R. Draxler, 2015: Inline Coupling of WRF-HYSPLIT: Model Development and Evaluation Using Tracer Experiments. *J. Appl. Meteor. Climatol.*, **54**, 1162-1176.
- Skamarock, W. C., and Coauthors, 2008: A description of the Advanced Research WRF Version 3. NCAR Tech. Note NCAR/TN-475+STR, 125 pp.

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