Inline Coupling of WRF-HYSPLIT: model development and evaluation using tracer experiments

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Overview

Development of inline coupling of a Lagrangian model, HYSPLIT and WRF-ARW

- ❖ Using high temporal frequency of met data
- ❖ Using the same vertical coordinate system as the met model
- ❖ No temporal and vertical interpolation of met data

Evaluation of the inline WRF-HYSPLIT with two controlled tracer experiments

- ❖ Cross-Appalachian Tracer Experiment (CAPTEX; regional scale)
- ❖ Atmospheric Studies in Complex Terrain (ASCOT; fine scale, complex terrain)

(Ngan et al. 2015)

Early online releases – http://journals.ametsoc.org/doi/pdf/10.1175/JAMC-D-14-0247.1

Met and dispersion models

WRF-ARW

- Fully compressible Euler nonhydrostatic
- Arakawa C-grid and time-dependent terrain-following hydrostatic pressure coordinate

HYSPLIT

- Lagrangian model
- Simple air parcel trajectory AND complex dispersion/deposition simulations using particle or puff approaches
- Following the horizontal grid of the met input and using terrain-following coordinate
- Being run in offline mode using diverse met data (WRF, MM5, NARR, ECMWF, etc)
- Application for identifying source-receptor relationship of pollutants and for dispersion predictions (i.e. nuclear incidents, volcanic eruptions, wild fire, dust, etc)

(Stein et al. 2015)

Early online releases – http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-14-00110.1

WRF-HYSPLIT coupling

	Inline HYSPLIT	Offline HYSPLIT
Source of met. input	WRF-ARW	Varying met data (WRF, NARR, etc); Need conversion programs for each
Met. input frequency	At WRF’s time step No temporal interpolation	WRF’s output (hourly or minutely) Need interpolation
Vertical grid	Using WRF’s terrain-following hydrostatic vertical coordinate No vertical interpolation	HYSPLIT internal terrain-following coordinate Need interpolation
Horizontal grid	Following WRF’s grid	Following the grid of met input
Disk usage	Dispersion output and WRF output based on users’ request	Large cost of data storage if high temporal resolution data are needed
Multiple simulations	Requires repeating met simulation	Met simulation is run only once

Cross-Appalachian Tracer Experiment (CAPTEX)

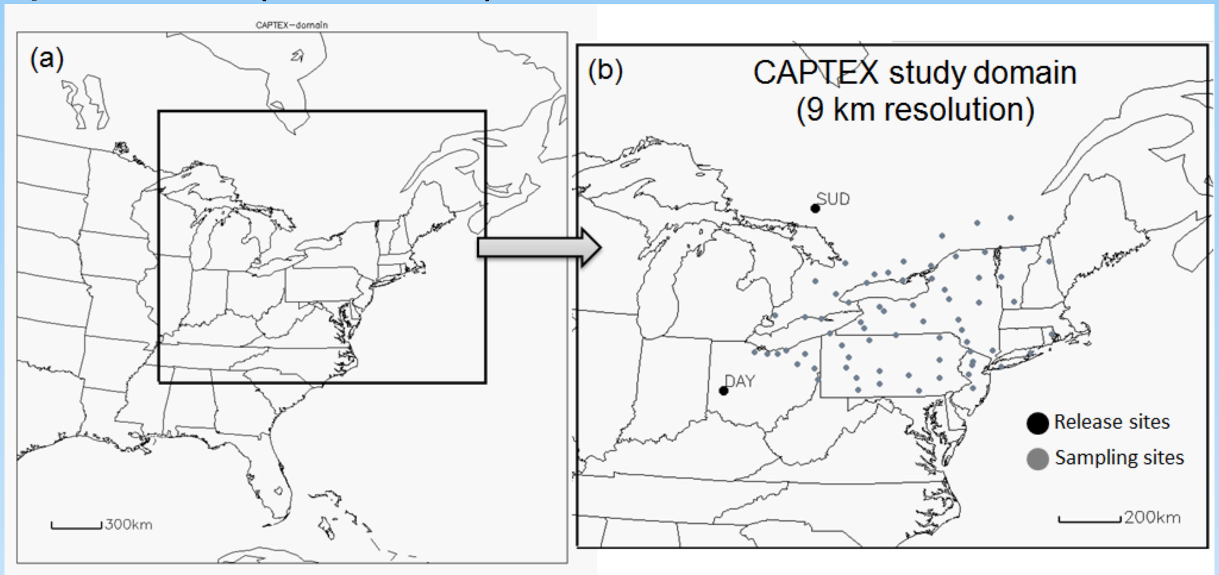
Regional scale (1000-km transport)

~2-3 days events

Six releases at SUD and DAY

Inert perfluorocarbon tracer

Mid-Sep to Oct 1983



Atmospheric Studies in Complex Terrain (ASCOT)

Fine scale and complex terrain

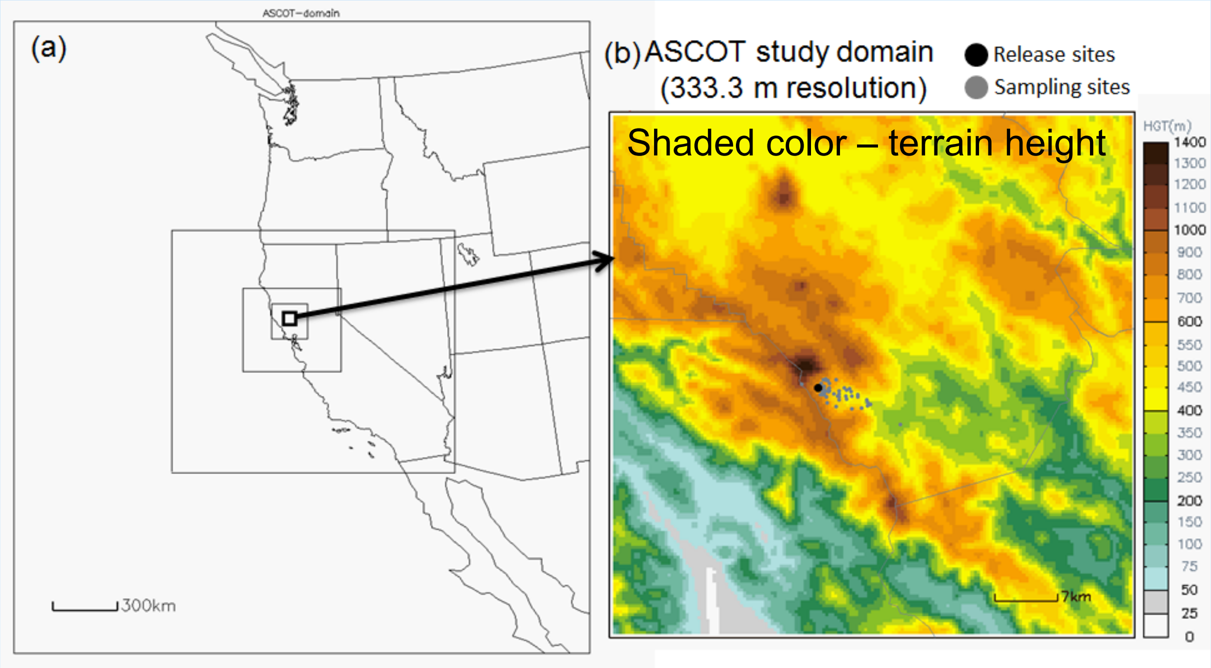
(nocturnal drainage flows)

~10 hours

Five releases at night

Inert perfluorocarbon tracer

Mid-Sep 1980



Model Configuration

	CAPTEX (six releases)	ASCOT (five releases)
Study area	NE USA and Canada	Northern California
Study goal	1000-km scale transport	Nocturnal drainage flows
Study period	Mid-Sep to Oct 1983	Sep 1980
Nested domain for WRF	2 (27- and **9-km**)	5 (27-, 9-, 3-, 1- and **0.333-km**)
Vertical layers	27 (1st mid-layer at **~16m**)	33 (1^{st} mid-layer at **~8m**)
Microphysics	WSM3	WSM3
Sub-grid cloud scheme	Grell-Devenyi ensemble	None
Radiation	RTTM and Dudhia	RTTM and Dudhia
PBL scheme	YSU	YSU
Surface scheme	Similarity theory (MM5)	Similarity theory (MM5)
Land-surface model	Noah LSM	Noah LSM
Nudging	3D nudging	None
Model time step	60 second	1 second
WRF output frequency	Hourly	5 minutes
Particle number for dispersion *	50,000	250,000
Grid spacing for concentration *	~27 km	~ 11 m
Height of concentration level *	100 m	50 m

WRF's physics

Inline's time step

offline Met data

HYSPLIT's setup

Statistical metrics

Rank, a cumulative statistical score (range between 0-4)

$$Rank = R^2 + 1 - \left|\frac{FB}{2}\right| + \frac{FMS}{100} + \left(1 - \frac{KSP}{100}\right)$$ (Draxler 1987)

Correlation coefficient (R) $R = \sum (M_i - \bar{M})(P_i - \bar{P}) / \sqrt{\sum (M_i - \bar{M})^2 \sum (P_i - \bar{P})^2}$

Fractional bias (FB) $FB = 2(\bar{P} - \bar{M}) / (\bar{P} + \bar{M})$

Figure of merit in space (FMS; %) $FMS = 100 N_p \cap N_m / N_p \cup N_m$

Kolmogorov-Smirnov parameter (KSP; %) $KSP = Max|D(M_k) - D(P_k)|$

NOTE: “M” – measured tracer concentrations

“P” – predicted tracer concentrations

N is number of samples and “D” is the cumulative distribution

Comparison for CAPTEX

Six episodes of the CAPTEX – evaluation with measurement data

Inline and offline results were very similar.

About 300 samples (~200 samples in #7) were available for each CAPTEX release ➔ limited in space and time

DAY site (Ohio)

SUD site (Canada)

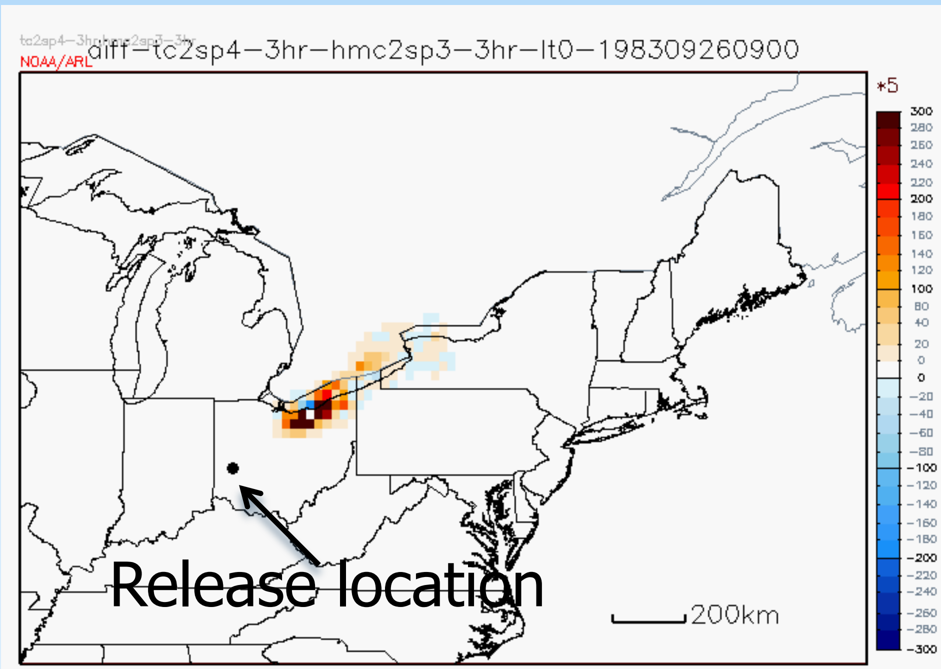
Release #	HYSPLIT version	Rank	R	FB	FMS	KSP
R1	Inline	2.68	0.56	0.05	39.32	4.00
	Offline	2.65	0.56	0.05	38.79	2.00
R2	Inline	3.06	0.65	0.01	72.69	8.00
	Offline	3.07	0.68	-0.04	71.24	8.00
R3	Inline	1.90	0.68	1.35	28.45	17.00
	Offline	1.92	0.68	1.31	27.71	16.00
R4	Inline	2.30	0.08	-0.01	39.00	9.00
	Offline	2.29	0.08	0.03	39.22	9.00
R5	Inline	2.55	0.79	0.52	33.75	14.00
	Offline	2.56	0.77	0.51	34.18	13.00
R7	Inline	2.38	0.34	-0.35	47.46	4.00
	Offline	2.42	0.34	-0.32	51.72	5.00

Aircraft measurement comparison

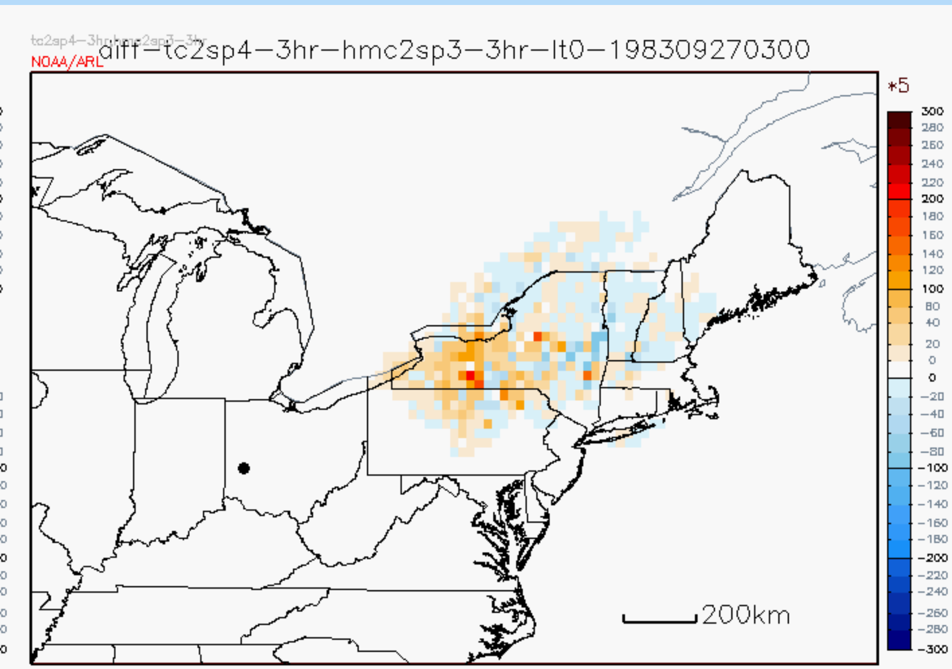
CAPTEX #2

Difference plot of tracer concentration (inline-offline)

1983/9/26 09z



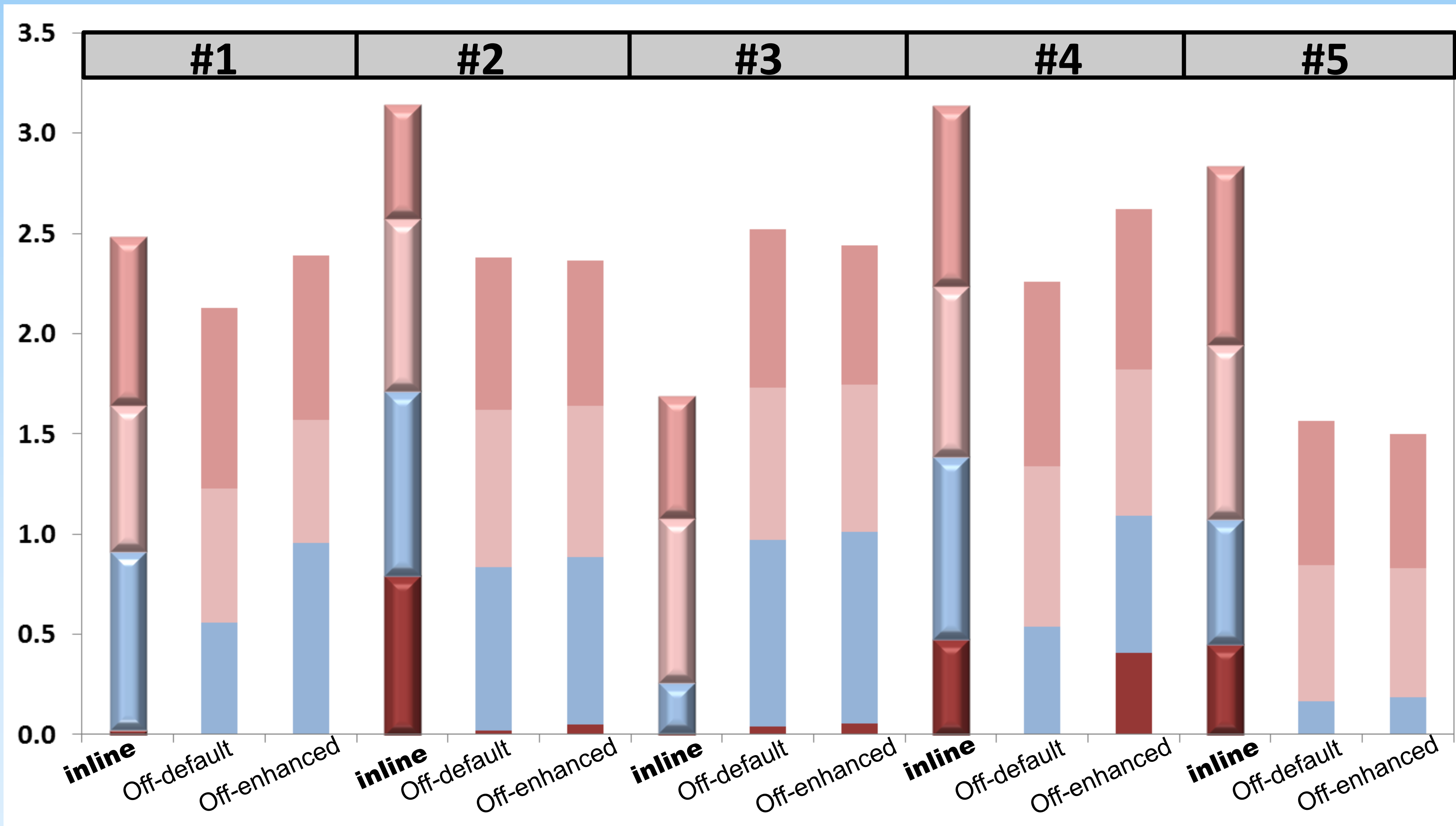
1983/9/27 03z



HYSPLIT vertical layers used in inline and offline runs

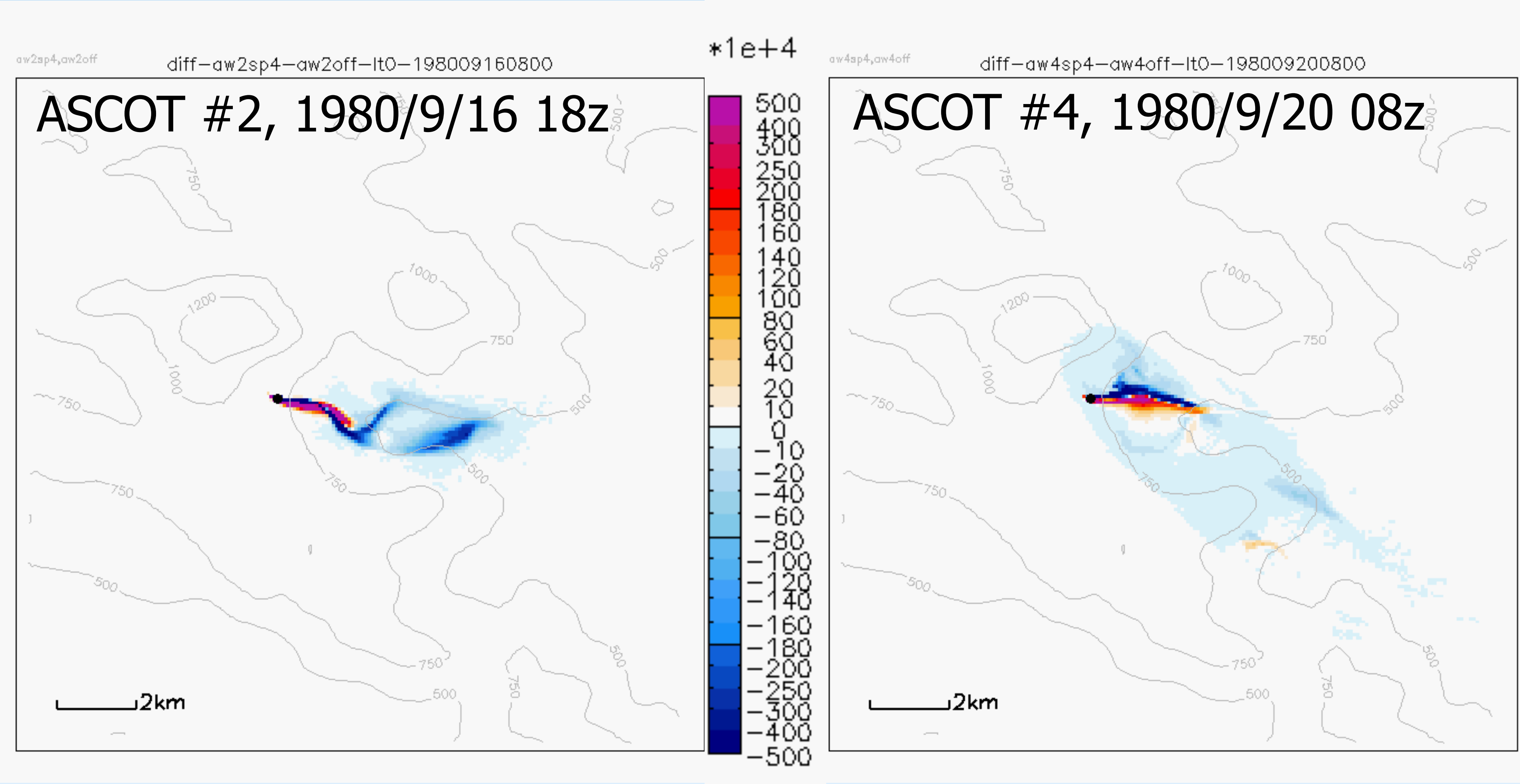
Layer	Inline layer height (m)		Offline (default) layer height (m)	Offline (enhanced) layer height (m)
	CAPTEX	ASCOT		
1	15.3	7.8	10	5
2	54.0	23.7	30	16
3	116.3	43.4	70	33
4	195.0	67.1	130	56
5	274.3	98.8	210	86
	"inline"		"off-default"	"off-enhanced"

Comparison for ASCOT



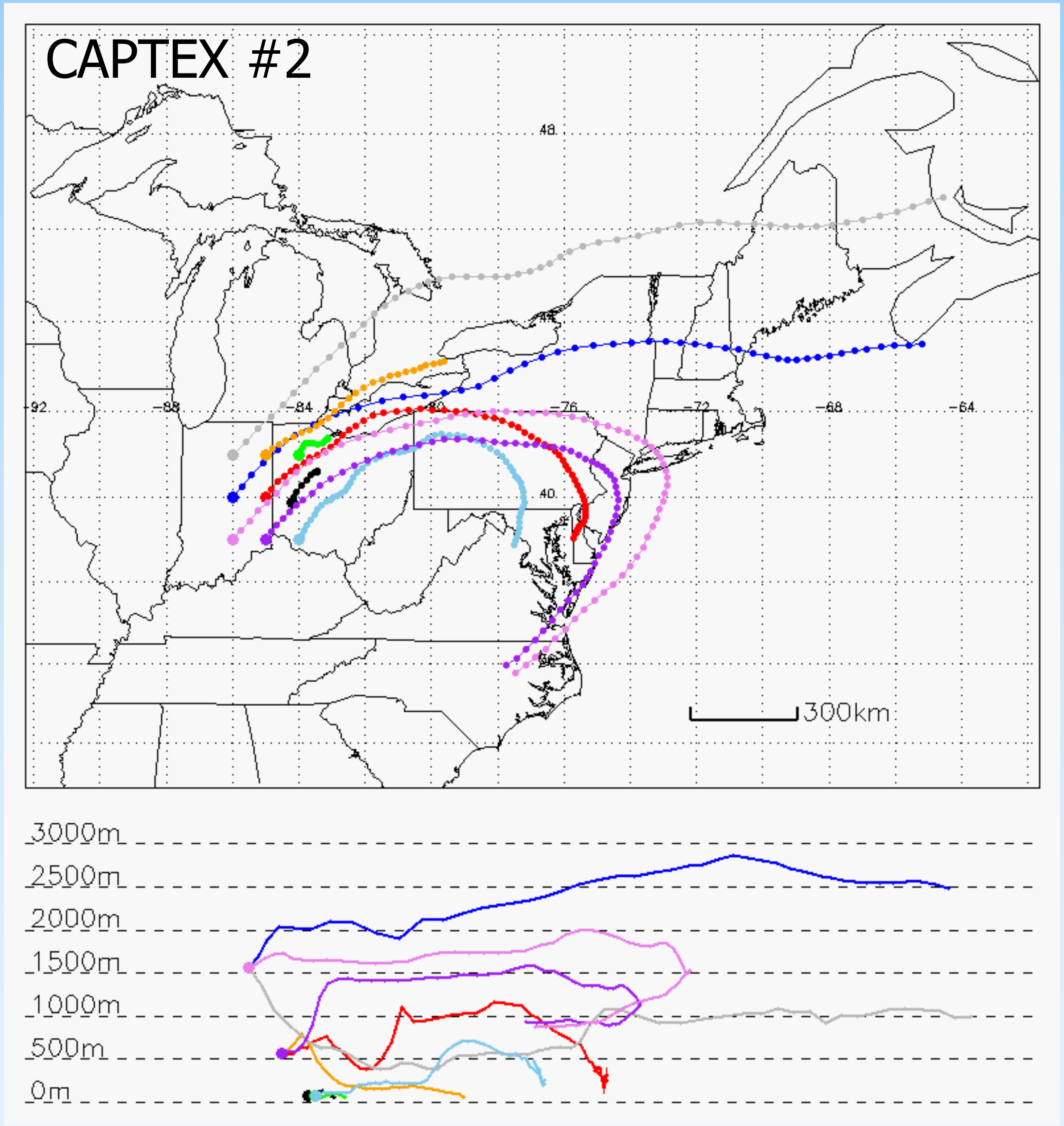
$$Rank = R^2 + 1 - |FB/2| + FMS/100 + (1 - KSP/100)$$

Difference plot of tracer concentration (inline-offline)



Contour – terrain height

Forward trajectory generated by inline HYSPLIT



Summary

- A Lagrangian dispersion model, HYSPLIT, has been coupled (inline) to the WRF model. The inline HYSPLIT includes dispersion, trajectory, deposition (dry and wet) and radioactive decay.
- Compared to the offline approach, the inline HYSPLIT takes advantage of higher temporal frequency of meteorological variables, with no time interpolation required between WRF's output hours , and it uses the same vertical coordinate as the WRF model.
- The inline coupling system is especially beneficial for an ASCOT type of application because the drainage flow occurred over an area of complex terrain and over a short time period (less than 10 hours) and in fine spatial resolution.

Future Work

- For model development

The inline HYSPLIT will be also tested using others parameters from WRF-ARW most relevant to plume mixing, stability, and convection.

We seek for collaboration with NCAR to include the inline HYSPLIT to the WRF model repository.

- For model evaluation

Inline dispersion simulations will be run for other tracer experiments for an urban environment and other complex terrain studies.

ex: METREX – tracer experiment in DC area
COSTEX – tracer experiment in Colorado

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