The Evaluation of turbulent mixing in HYSPLIT using measurements from controlled tracer experiments

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INTRODUCTION

HYSPLIT, a dispersion model developed by NOAA's Air Resources Lab, has different options to estimate the turbulent mixing depending on the availability of stability and turbulent parameters in the meteorological data used to drive the dispersion simulation. This study aims to understand the mixing characteristics generated by different estimations of the turbulent velocity variance. We conducted HYSPLIT simulations performed with different turbulent mixing parameterizations and driven by WRF meteorological data for two controlled tracer experiments – the Project Sagebrush phase 1 (**PSB1**) and the Cross Appalachian Tracer Experiment (**CAPTEX**). The velocity variance was compared with measurements taken during PSB1 and dispersion results were evaluated with tracer concentrations from both controlled experiments.

Mixing options in HYSPLIT

*a) Beljaars and Holtslag (labeled as "**BH**")*

Following Beljarrs and Holtslag (1991), the model computes the vertical mixing coefficient according to the normalized profiles for heat/momentum and other stability parameters. The velocity variance is then computed as a function of the diagnosed mixing coefficient and the Lagrangian time scale.

*b) Kantha-Clayson (labeled as "**KC**")*

Following Kantha and Clayson (2000), the turbulent velocity variance is defined as a function of friction velocity, convective velocity scale, and boundary height.

*c) Turbulent Kinetic Energy (labeled as "**TKED**")*

The model partitions the TKE obtained from WRF to vertical and horizontal components using the anisotropy ratio (default 0.18).

*d) Turbulent Exchange Coefficient (labeled as "**EXCH**")*

The turbulent exchange coefficient from WRF is divided by the turbulent time scale (100 s).

Statistical Evaluation for HYSPLIT results

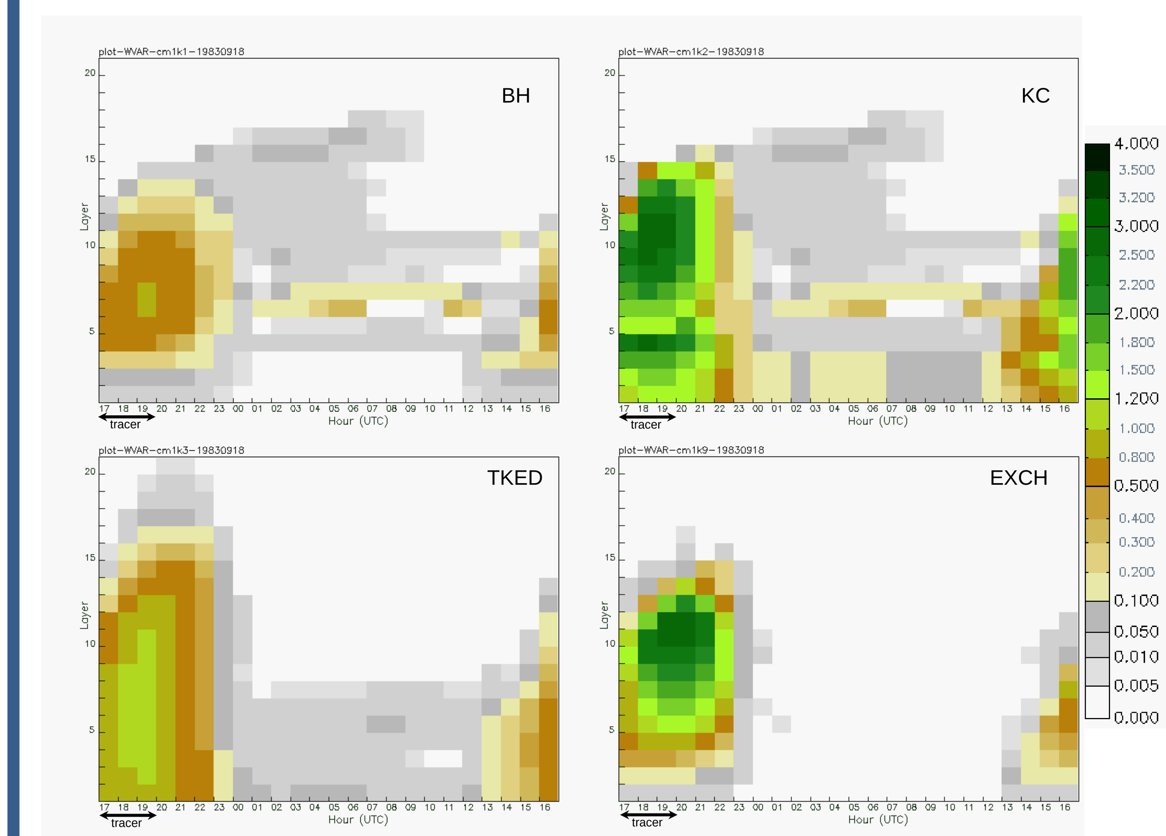
Rank, a cumulative statistical score (range between 0-4), (Roland, 2006)

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

R – correlation coefficient
FB – fractional bias,
FMS – figure of merit in space
KSP – Kolmogorov-Smirnov parameter

RESULTS FOR CAPTEX

CAPTEX, consisted of six 3-h releases aimed to simulate the **long-range transport** and diffusion of pollutants. Six releases took place from Dayton, Ohio during the afternoon (#1-4) and Sudbury, Ontario, Canada during the nighttime (#5 and #7). The sampling network provided 3- and 6-h average tracer concentration for three-day periods.



Time series of vertical velocity variance profiles from HYSPLIT using different mixing options for Sep 18th 17 UTC – 19th 16 UCT, 1983 (CAPTEX #1). Unit: m^2s^{-2}.

The KC and EXCH mixing had the max w-variance at the 10th layer (~900 m) during the afternoon hours. The TKED option generated flat profile while the EXCH had large gradients near the surface.

During the nighttime, close to zero w-variance values were produced by the EXCH mixing because of using a Lagrangian time scale which was used for the daytime unstable condition.

The statistical rank for all six episodes shows that the TKED mixing had good performance while the BH option produced the worst results.

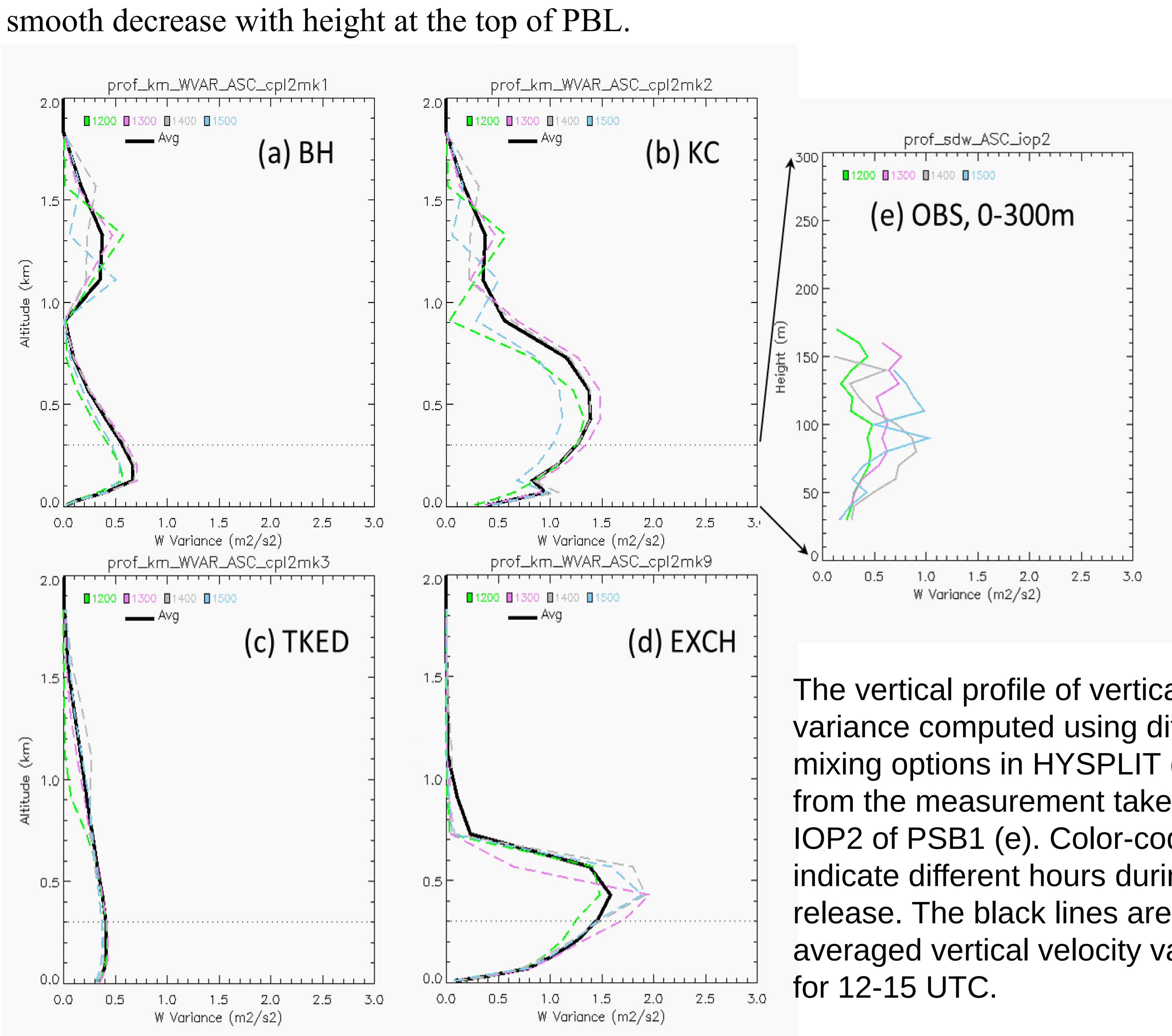
The statistical Rank of HYSPLIT results using different mixing options.
[a]All data points from six releases are used.

Release	BH	KC	TKED	EXCH
R1	2.49	2.50	2.62	2.38
R2	2.78	2.72	2.73	2.79
R3	1.98	1.95	2.11	2.13
R4	2.14	2.18	2.16	2.49
R5	2.64	2.52	2.65	2.68
R7	2.25	2.36	2.33	2.12
All[a]	2.35	2.49	2.51	2.44

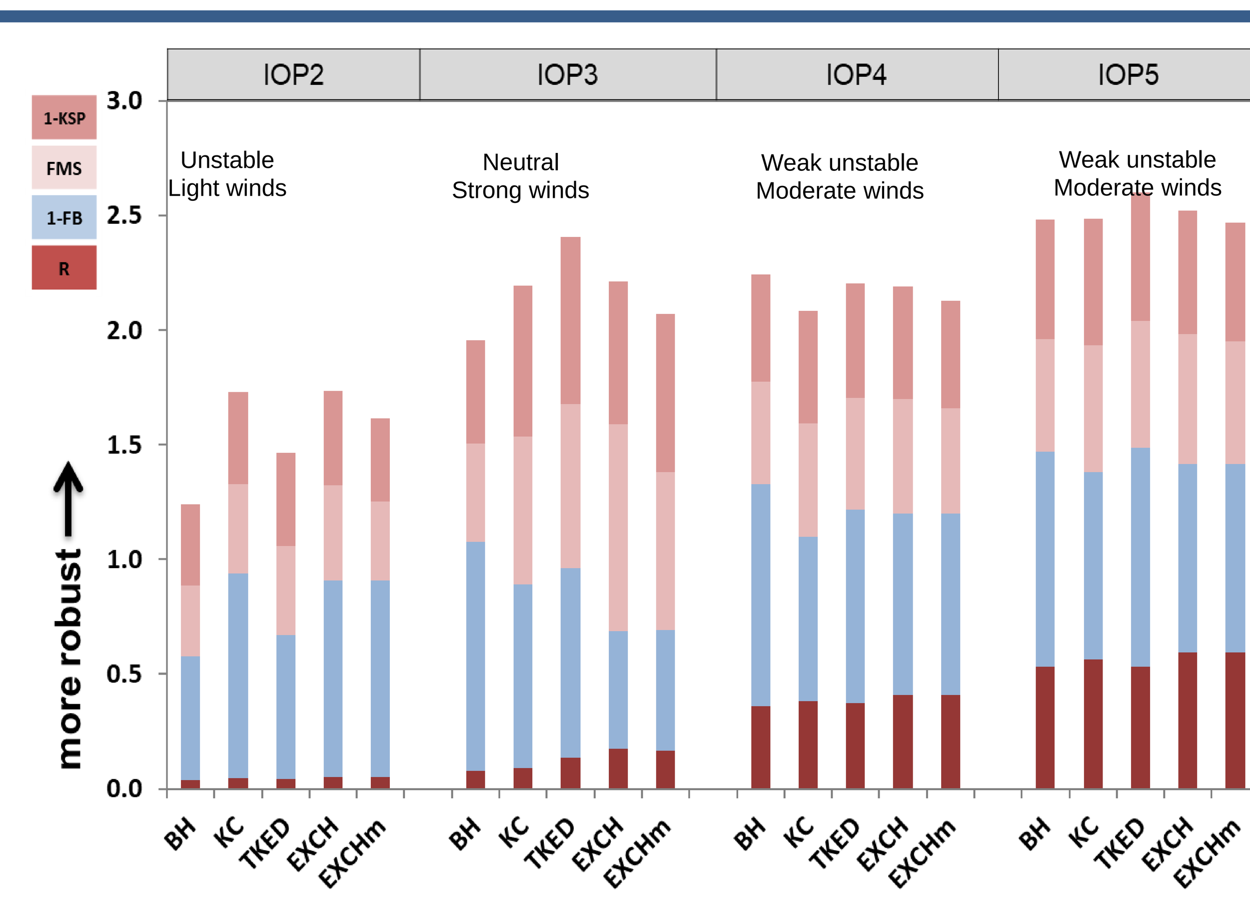
RESULTS FOR PSB1

PSB1 consisted of five tracer releases (IOPs) aiming for the **sub-kilometer scale transport** in afternoons with near neutral or unstable stability conditions. The sampling network for measuring tracer concentrations was set within a 3-km range from the release taking in 10-minute averages.

The KC and EXCH option generated w-variance profiles with larger max values at higher altitudes than the other two methods did. The profile of TKED had the smallest max values among all and a smooth decrease with height at the top of PBL.

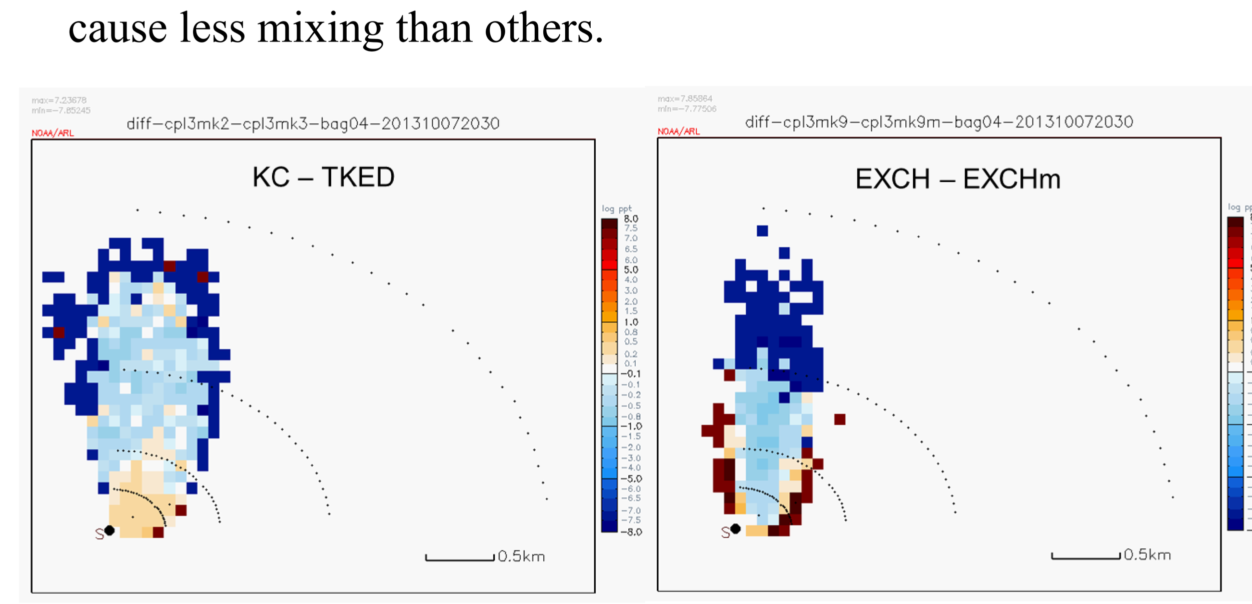


The vertical profile of vertical velocity variance computed using different mixing options in HYSPLIT (a-d) and from the measurement taken during IOP2 of PSB1 (e). Color-code lines indicate different hours during the release. The black lines are the averaged vertical velocity variance for 12-15 UTC.



The statistical Rank of HYSPLIT results using different mixing options. For the mixing option using WRF's exchange coefficient, we conducted two simulations "EXCH" and "EXCHm" by applying the max and min ratio of horizontal and vertical component of measured velocity variance.

The model performed differently with different mixing options for four episodes that no mixing option always produced a better result. The range of statistical scores for IOP4 and IOP5 was smaller than those for the other two IOPs. For IOP3, the BH case had the worst FMS because the model plume was narrow near the source location due to the small velocity variance. The underestimation of the turbulence in the KC mixing option due to the negative bias in predicting wind speeds (also the friction velocity) might cause less mixing than others.



Difference plot of tracer concentrations for IOP3 at 2020 UTC on October 7th, 2013. Small dots are location of the sampling network.

Near the source (200 and 400 arcs), KC had higher concentrations than TKED. The larger horizontal velocity variance in the EXCH generated a wider plume than the one in the EXCHm simulation.

SUMMARY

- This study is the first attempt to evaluate HYSPLIT's turbulent mixing with the measurements of the turbulent velocity variance and the corresponding dispersion results with tracer concentration observations.
- The "EXCH" mixing method is newly added to HYSPLIT with using the WRF meteorology. It computes the turbulent mixing by dividing the exchange coefficient by the Lagrangian time scale.
- The plumes generated by the BH and TKED method (weaker mixing) had higher concentrations near the surface than those driven by the KC and EXCH option (stronger mixing). `
- The statistical rank for the dispersion result using the TKED option was slightly better than others while the BH mixing generated results with a roughly worse rank.
- No mixing option always outperformed the other options. HYSPLIT users can select a mixing option according to the scenario and availability of meteorological fields, and use different options to generate dispersion ensembles.
- The uncertainty of using different mixing methods is discussed. For the KC and BH mixing, errors due to the process of re-diagnosing variables may be carried to the dispersion simulation but no extra variable is required. The TKED and EXCH methods depend on the mixing variables that are not commonly available in meteorological model output or reanalysis products, and are usually not well evaluated.

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