The evaluation of mixing methods in HYSPLIT using measurements from Sagebrush Tracer Experiment

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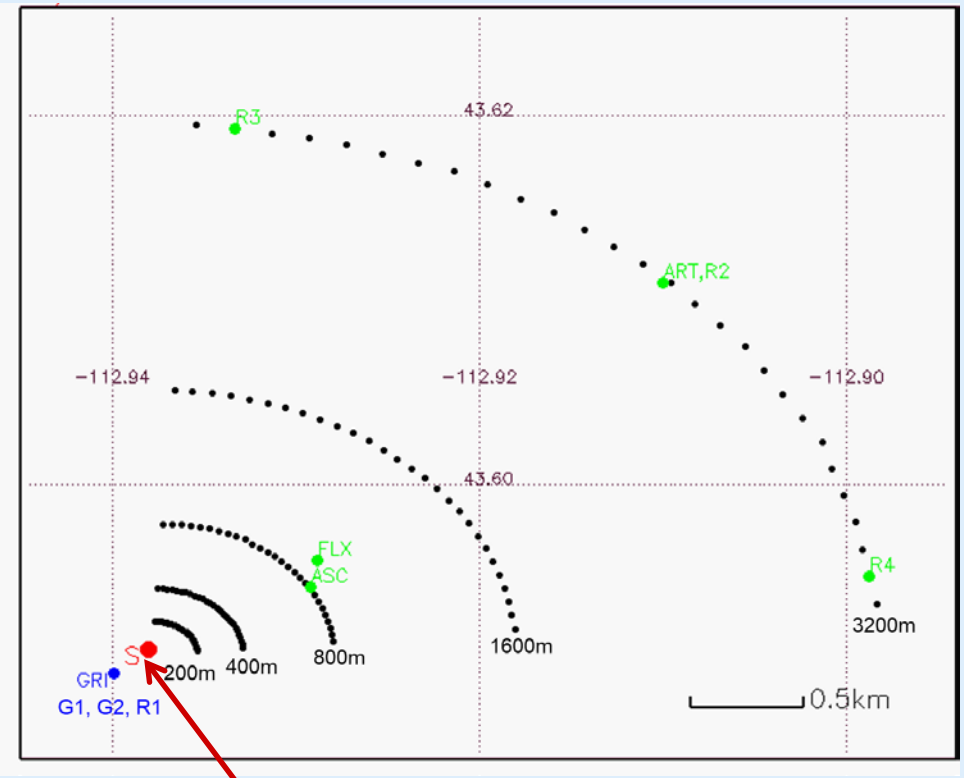
The Objective

To understand the mixing characteristics generated by different estimations of the turbulent velocity variance affecting the dispersion results.

- WRF simulations were conducted for the Sagebrush tracer experiment. The WRF data included variables for computing stability parameters, TKE, and turbulent exchange coefficient.
- HYSPLIT was used to simulate four Sagebrush tracer releases using different mixing options.
- The velocity variances diagnosed in HYSPLIT were compared with observed values while dispersion results were evaluated against the tracer measurements.

The Sagebrush Tracer Experiment

- A controlled tracer experiment was conducted at Idaho National Laboratory during October 2013.
- Releases occurred in five afternoons with neutral conditions/high wind speeds or unstable conditions/low wind speeds.
- Sampling network (black dots) for the tracer concentrations covered distances 200 m – 3200 m from the release location (‘S”) taking samples in 10-min averages.
- Velocity variances were measured at station GRI, FLX, R2, R3, and R4 using 3D sonic anemometer and at station ASC and ART using sodars.



WRF Configuration

	D01	D02	D03	D04	D05
Grid spacing	27 km	9 km	3 km	1 km	0.333 km
IC/BC	3-hourly NARR			D03 nestdown	D04 nestdown
Nesting	2-way nesting			1-way nesting	1-way nesting
Microphysics scheme	WSM3			WSM3	WSM3
Cloud scheme	Grell-Freitas ensemble scheme			None	None
Radiation scheme	RRTMG			RRTMG	RRTMG
PBL scheme	MYNN			MYNN	MYNN
Surface scheme	MYNN			MYNN	MYNN
Land surface model	Noah LSM			Noah LSM	Noah LSM
Nudging	3D nudging[7] (nudge PBL wind)		3D nudging (no PBL wind)	None	None
Time step	90 sec	30 sec	10 sec	3 sec	1 sec
Output frequency for offline HYSPLIT	1 hour	1 hour	5 minutes	5 minutes	5 minutes

Note: HYSPLIT simulations were driven by the WRF data in 0.333 km grid spacing.

HYSPLIT Configuration

- HYSPLIT simulations were driven by WRF data (0.333 km).
- Release duration: 2.5 hours release
  Particle number: 250,000
  Concentration grid: ~100m horizontal grid and 0-25m for the vertical layer

IOP	1	2	3	4	5
Date (Oct 2013)	2nd	5th	7th	11th	18th
Start Time (MST)	1400	1230	1230	1330	1230
End Time (MST)	1630	1500	1500	1600	1500
Emiss rate (g/s)	10.177	9.986	9.930	1.043	1.030
Emiss total (g)	89049	89509	89605	9064	9031
Data points	1343	1341	1388	1313	1363

- IOP1 was excluded because the wind flow patterns caused the tracer plume to go in the opposite direction of the sampling array.
- IOP2 was in an unstable condition with light wind speeds and varying wind directions.
- IOP3 was in a neutral condition with strong southwesterly winds.
- IOP4 and 5 were in a similar synoptic condition - weakly unstable with stationary southwesterly flows and moderate wind speeds.

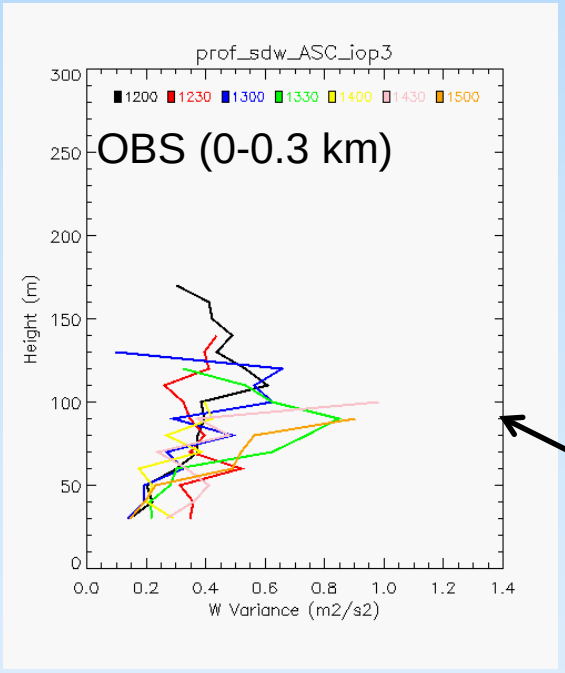
Mixing options in HYSPLIT

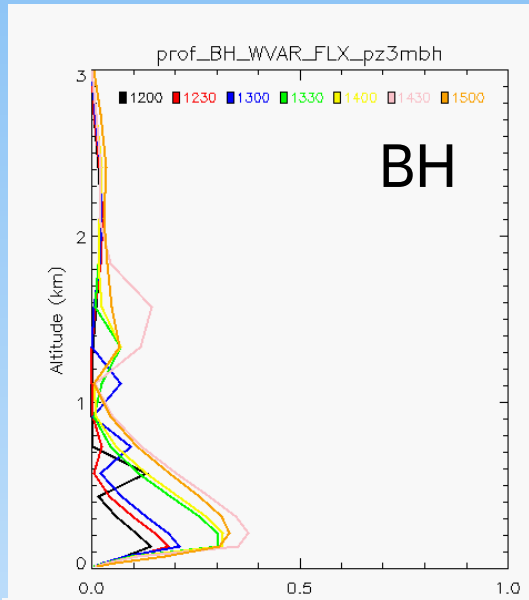
- **BH** – Beljaars and Holtslag (1991), computing mixing coefficient from heat/momentum profiles and stability parameters, and then convert it to the velocity variance.
- **KC** – Kantha and Clayson (2000), computing the velocity variance based on the friction velocity, convective velocity scale, and PBL height.
- **TKED** – scaling the TKE field from WRF to vertical and horizontal velocity variances.
- **EXCH** – using the turbulent exchange coefficient from WRF, divided by the Lagrangian time scale to obtain the vertical velocity variance. Scale the vertical variance to horizontal variance with a factor of 2.353 (from the KC mixing option).
- **EXCH-obs** – same as EXCH, but with a scaling factor of 5.3276 based on measured velocity variances.

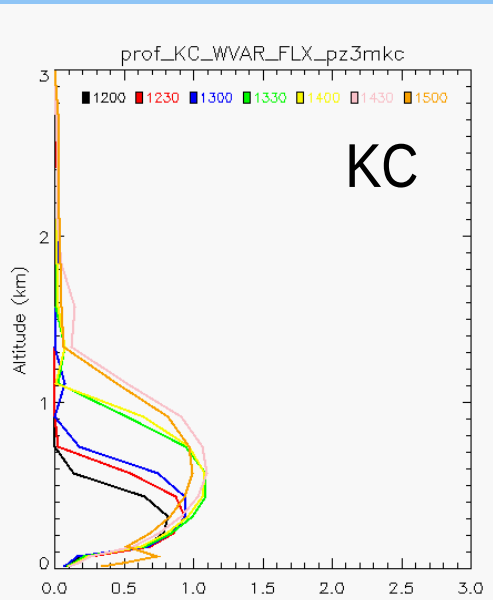
IOP 3 (neutral conditions with strong southwesterly winds)
Vertical velocity variance profile (0-3 km) at different hours (12-15 MST)

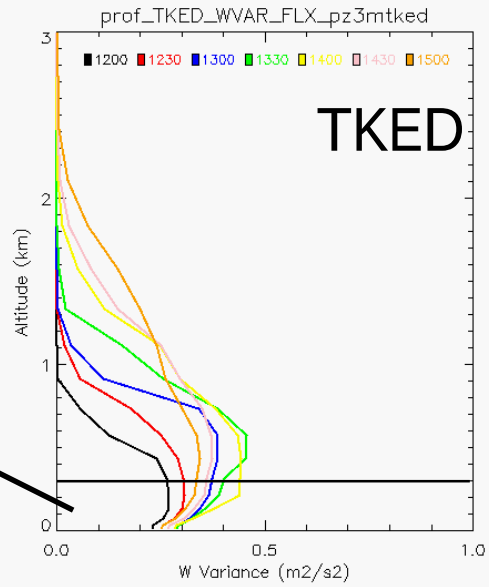
Height of max w-variance at ~ 0.3-0.6km
(BH had it lower than 0.3 km)
Max values of w-variance:
- KC and EXCH are bigger ~1.0 m^2/s^2
- TKED is smaller ~0.4 m^2/s^2
- BH is the smallest 0.2-0.3 m^2/s^2

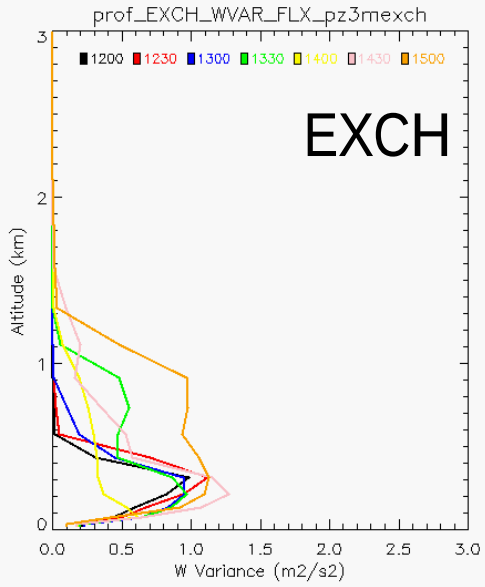
KC and EXCH had stronger mixing and larger gradient near the surface (0-0.3 km).



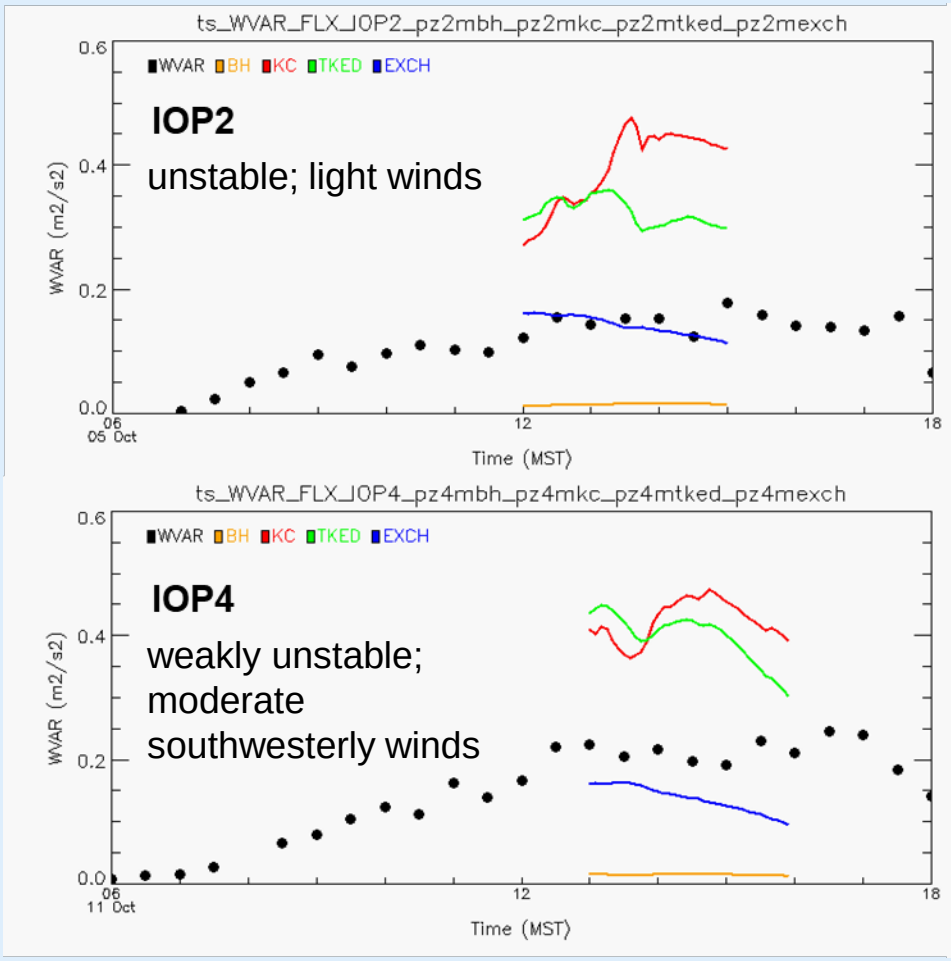


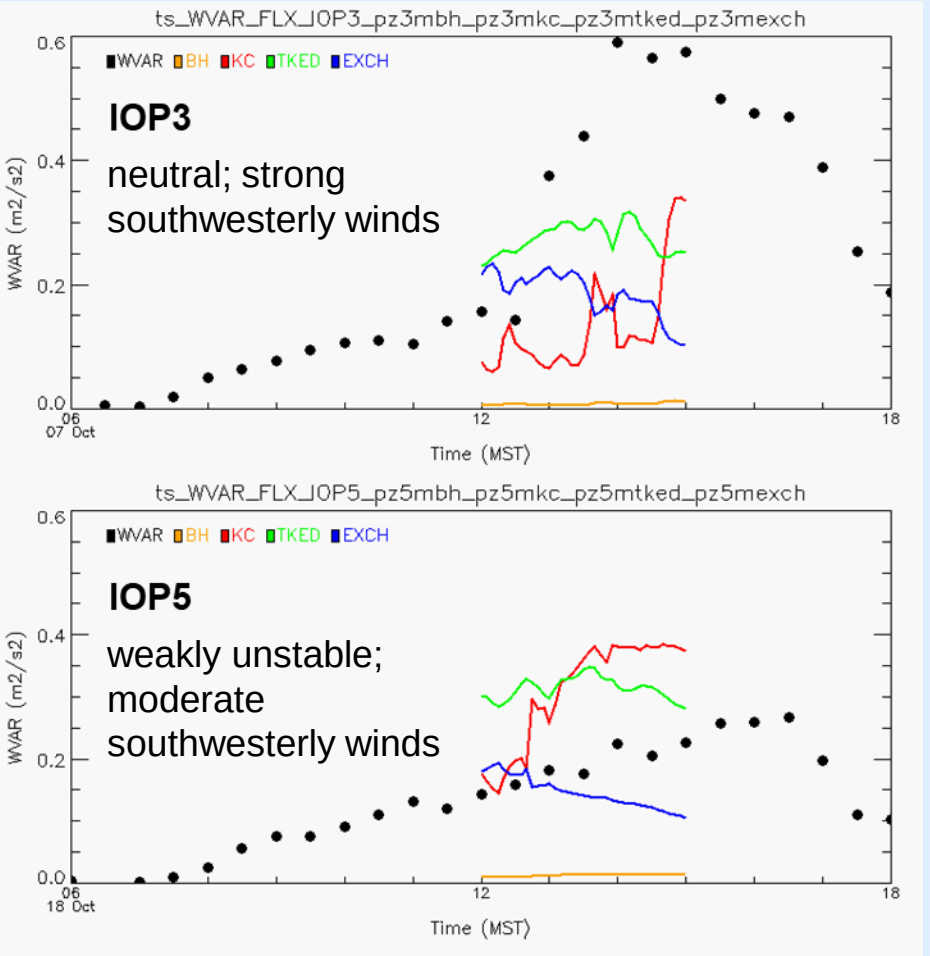






Time series of **vertical** velocity variances at FLX station (3.2 m)





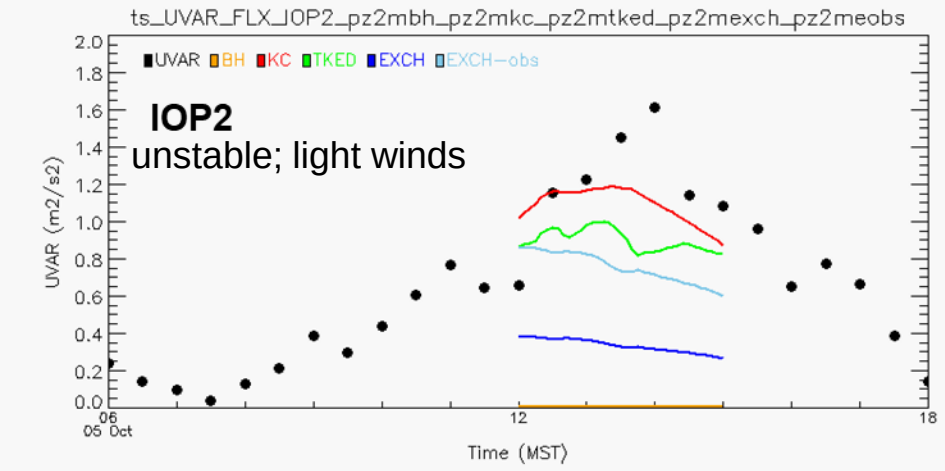
The KC and TKED mixing overestimated the vertical velocity variance
The BH significantly underestimated it while the EXCH mixing slightly underestimated it.

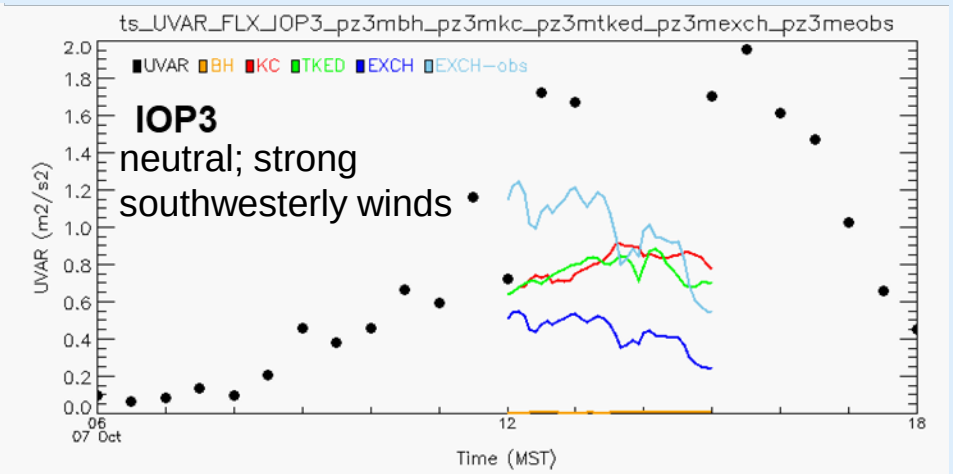
Ratio of horizontal and vertical velocity variances

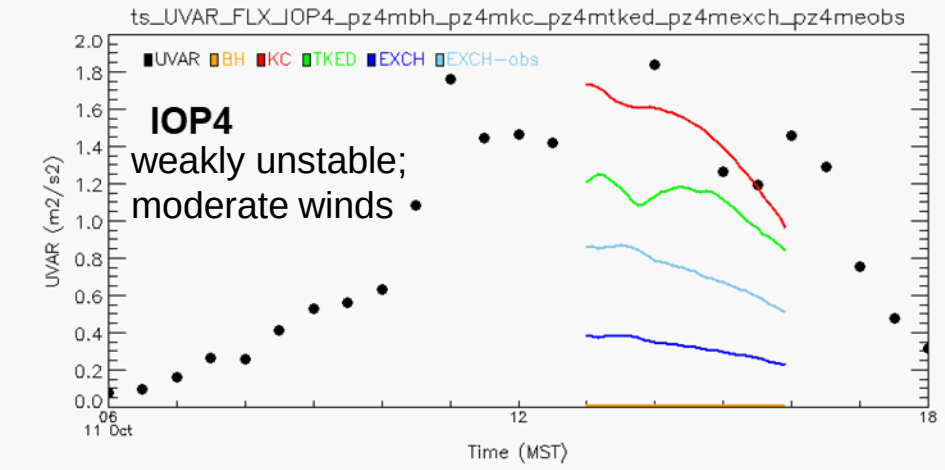
Station name	Measurement Height (m)	All data in October	Data on the day of IOPs	Data during 12-18UTC on IOP days
G1	4	3.7041	4.1874	4.5567
G2	30	2.4748	2.6607	2.6127
R1	45	1.8743	1.8830	1.9990
R2	3.2	4.2582	4.5396	4.5487
R3	3.2	4.4776	5.1804	5.3276
R4	3.2	4.6456	5.6300	5.8733
FLX	3.2	3.9803	4.6829	5.3066
ASC	30	-	1.5909	1.8236
	40	-	1.4331	1.5430
	50	-	1.4335	1.4650
	60	-	1.3115	1.3045
	70	-	1.1898	1.2175
	80	-	1.1499	1.1052
	100		1.0902	1.0343

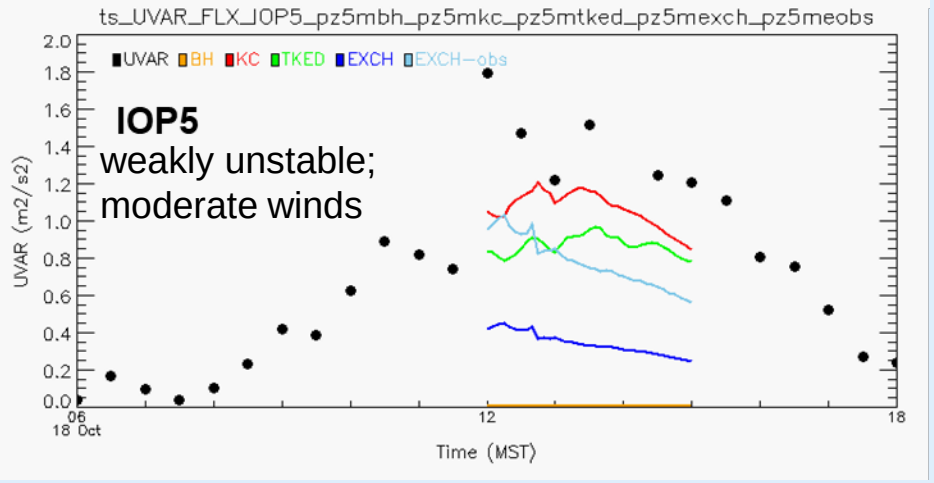
Note: The fifth simulation (labeled as "EXCH-obs") used 5.3276 scaling the vertical to horizontal component for the velocity variance.

Time series of **horizontal** velocity variances at FLX station (3.2 m)









The scaling factor used in the BH mixing was too small causing significant underestimation of the u-variance.
KC and TKED mixing had reasonable u-variances with a small underestimation.
The u-variance in “EXCH-obs” (using larger scaling factor) was closer to the measured values than that in ‘EXCH”.

Dispersion Evaluation

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^2 = Square of linear correlation coefficient

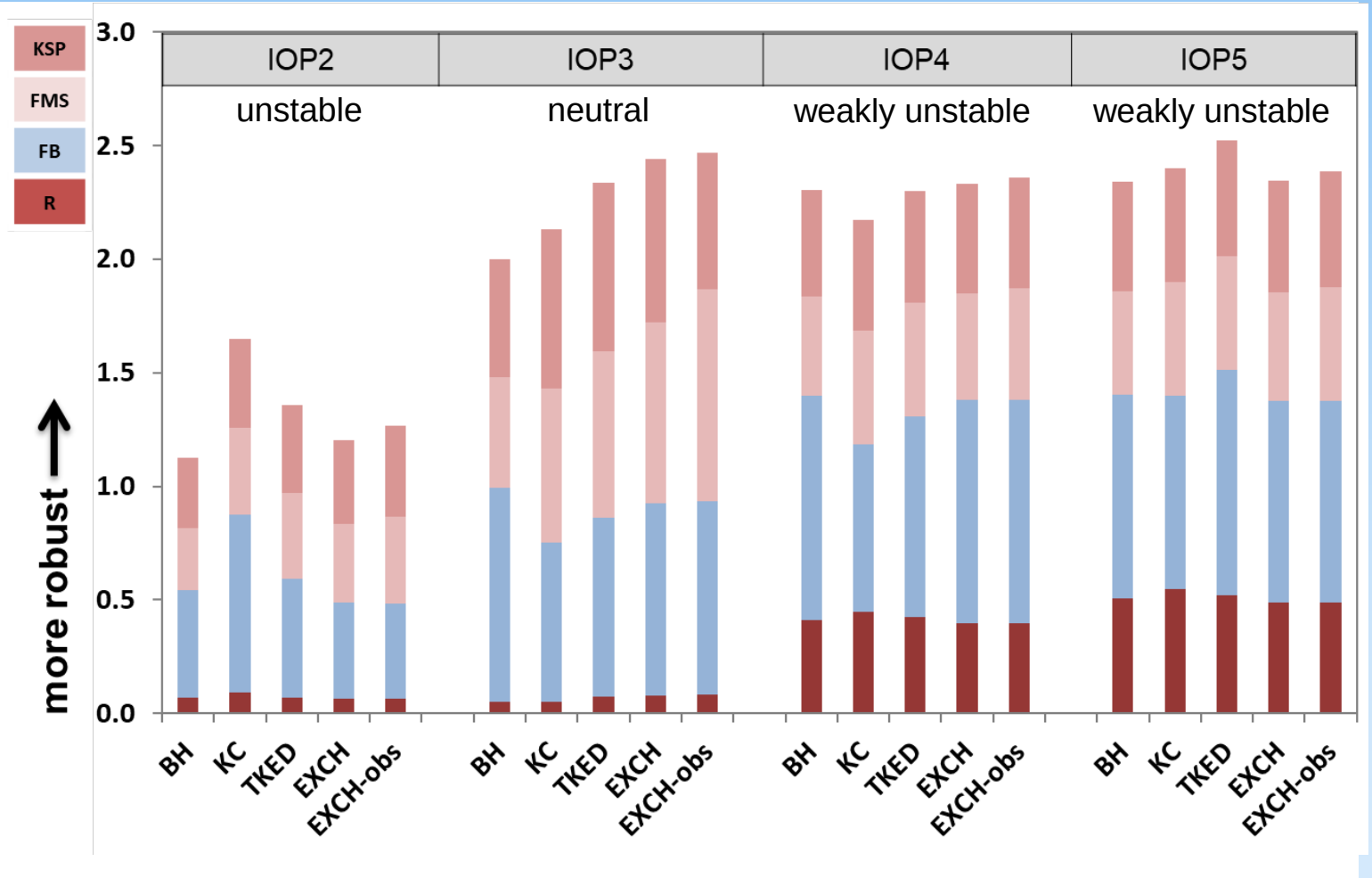
FB=Fractional Bias defines a normalized measure of bias

FMS = Figure of Merit in Space defines a percentage of overlap between measured and predicted areas

KS = Kolomogorov-Smirnov parameter defines the maximum difference between two cumulative distributions

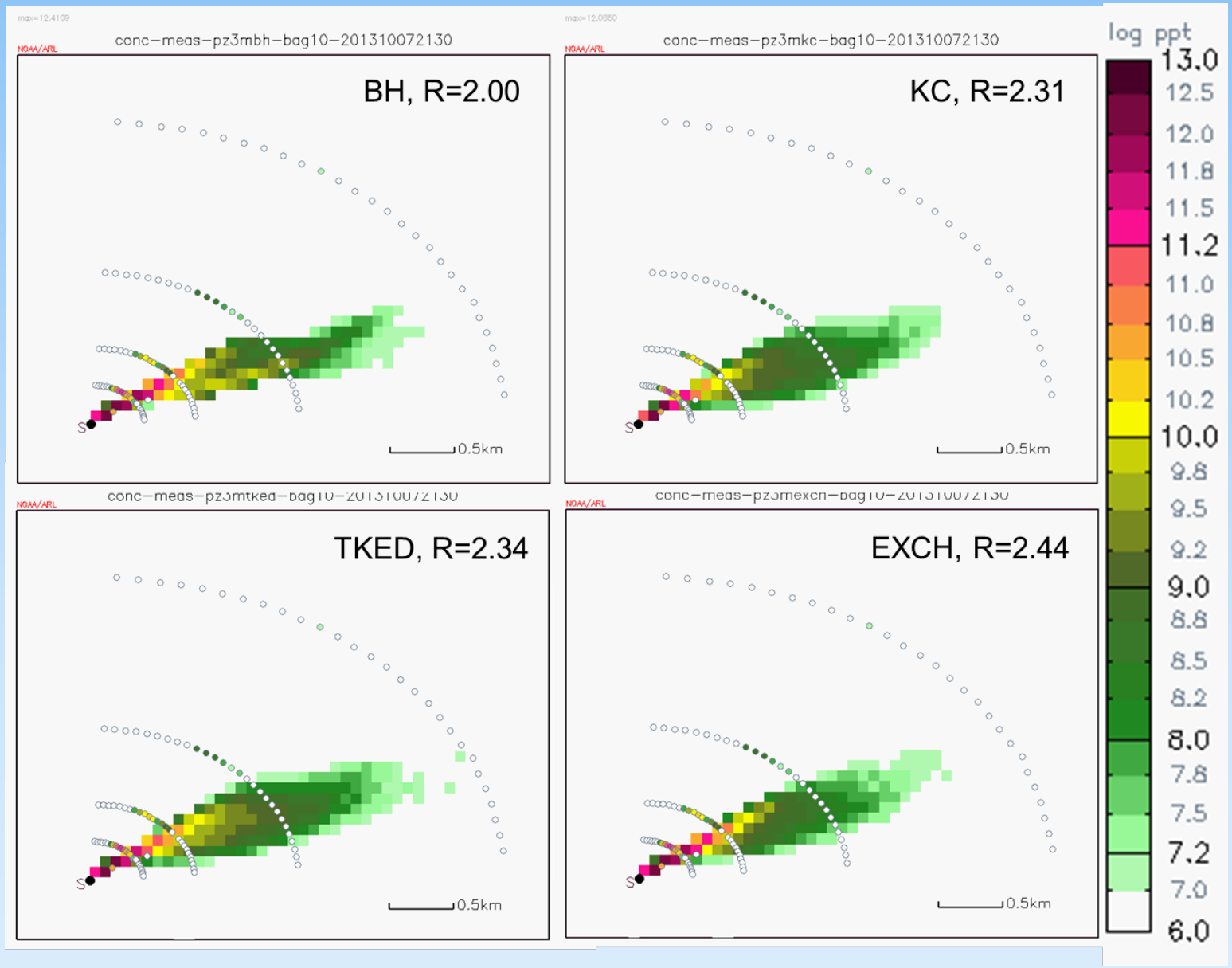
Statistical summary of HYSPLIT simulations

Dispersion results driven by WRF data using different mixing options



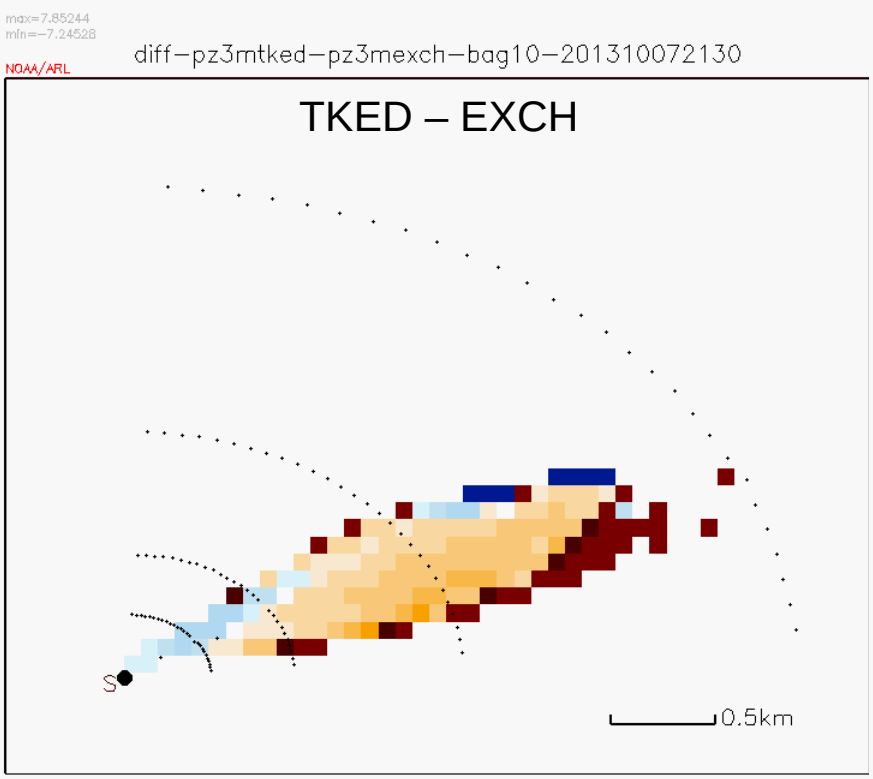
The rank for EXCH-obs is slightly better than EXCH.
The dispersion results for IOP4 and 5 were less sensitive to the mixing option than IOP2 and IOP3.

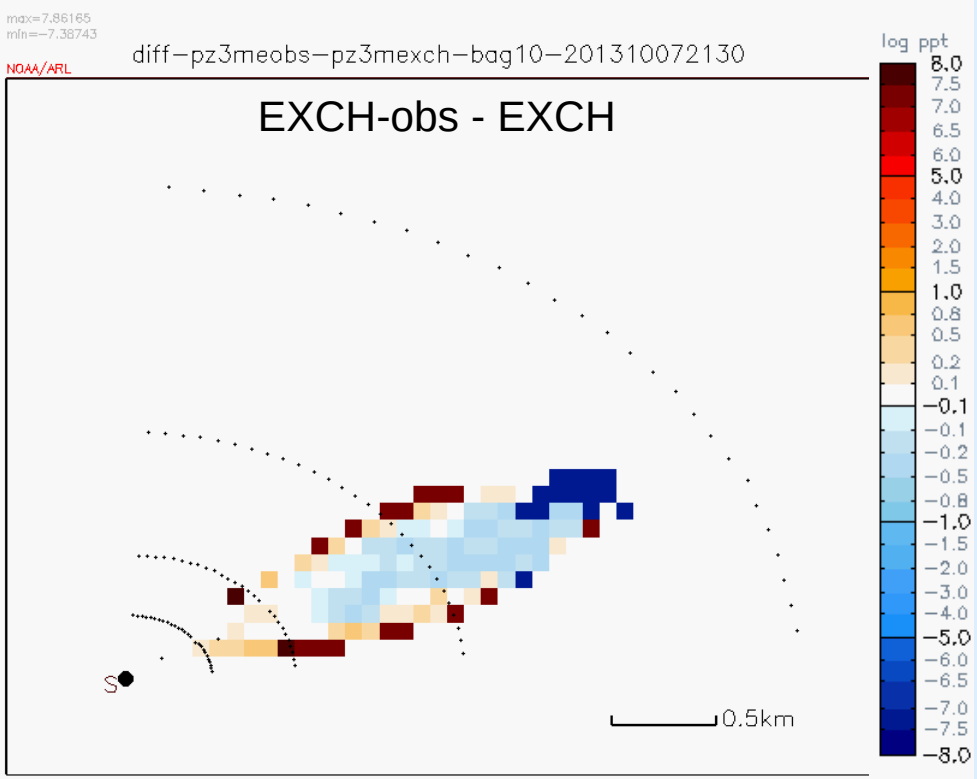
Spatial plot of tracer concentrations for **IOP3** at 1430 MST



The larger horizontal velocity variance in the EXCH-obs generated a wider plume than the one in the EXCH simulation.

Difference plots for IOP3 (1430 MST)





The TKED plume moved further away from the source location than EXCH plume.
Near the source (200 and 400 arcs), EXCH had higher concentrations than TKED.

The larger horizontal velocity variance in the EXCH-obs generated a wider plume than the one in the EXCH simulation.

Summary

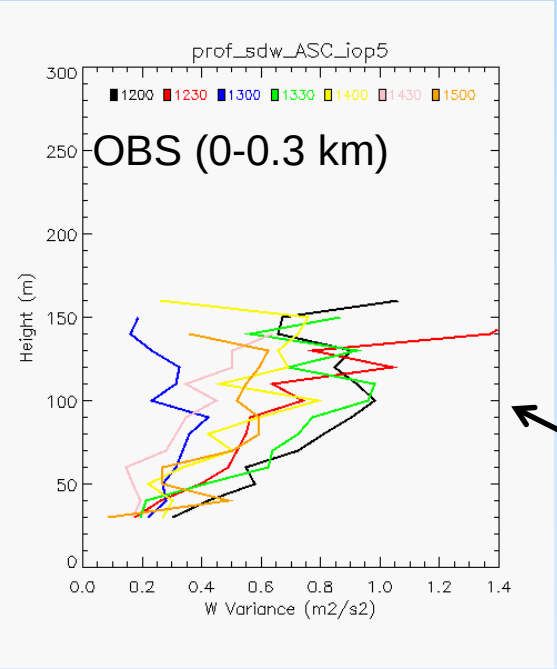
- Dispersion simulations driven by WRF data in a high spatial resolution were conducted for the Sagebrush experiment and evaluated with tracer measurements.
- The velocity variances estimated by four mixing options in HYSPLIT were compared with observations taken during the tracer episodes.
- The KC and TKED mixing overestimated the vertical velocity variance while the mixing options of BH (significantly) and EXCH (slightly) underestimated it in the comparison of the measurement at 3.2 m height.
- The dispersion results for IOP4 and 5 (weak unstable conditions with moderate winds) were less sensitive to the mixing option than the runs for IOP2 (unstable with light winds) and IOP3 (neutral with strong winds).
- The plume generated by TKED mixing moved further away from the source location than the one driven by EXCH mixing. The larger horizontal velocity variance in the EXCH-obs generated a slightly wider plume than the one in the EXCH simulation.

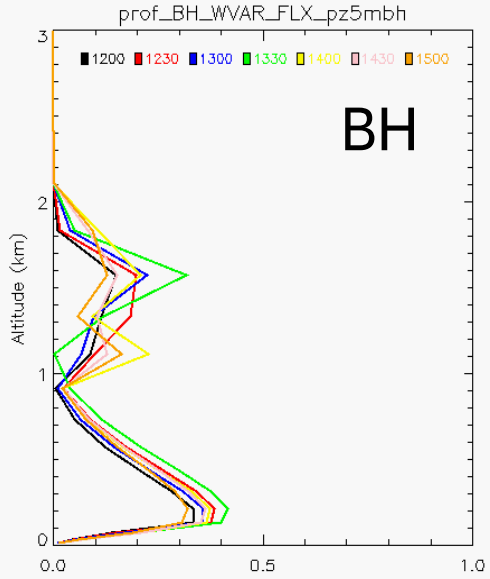
IOP 5

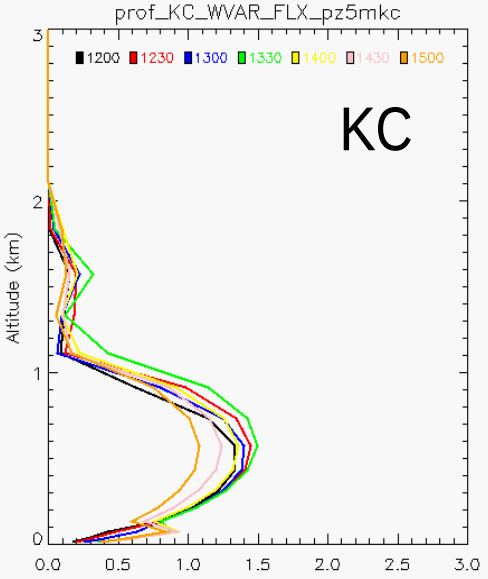
Vertical velocity variance profile (0-3 km) at different hours (12-15 MST)

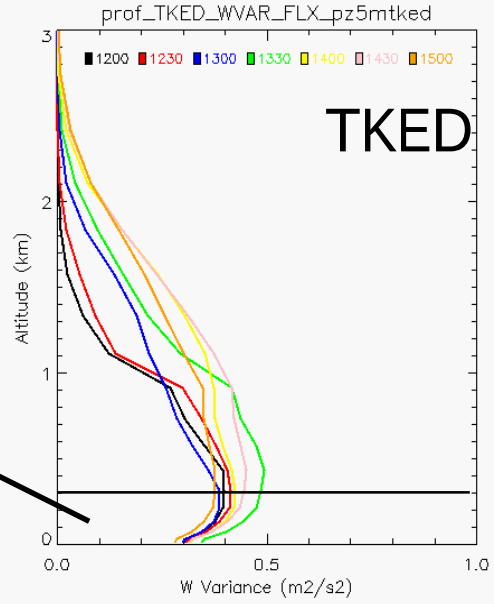
Height of max w-variance at ~ 0.3-0.5km
Max values of w-variance:
- KC and EXCH are bigger ~1.5 m^2/s^2
- TKED is smaller 0.4-0.5 m^2/s^2
- BH is the smallest ~0.4 m^2/s^2

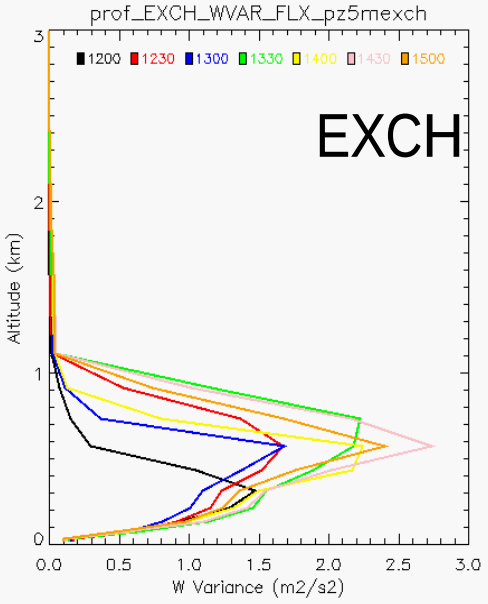
KC and EXCH had stronger mixing and larger gradient near the surface (0-0.3 km).





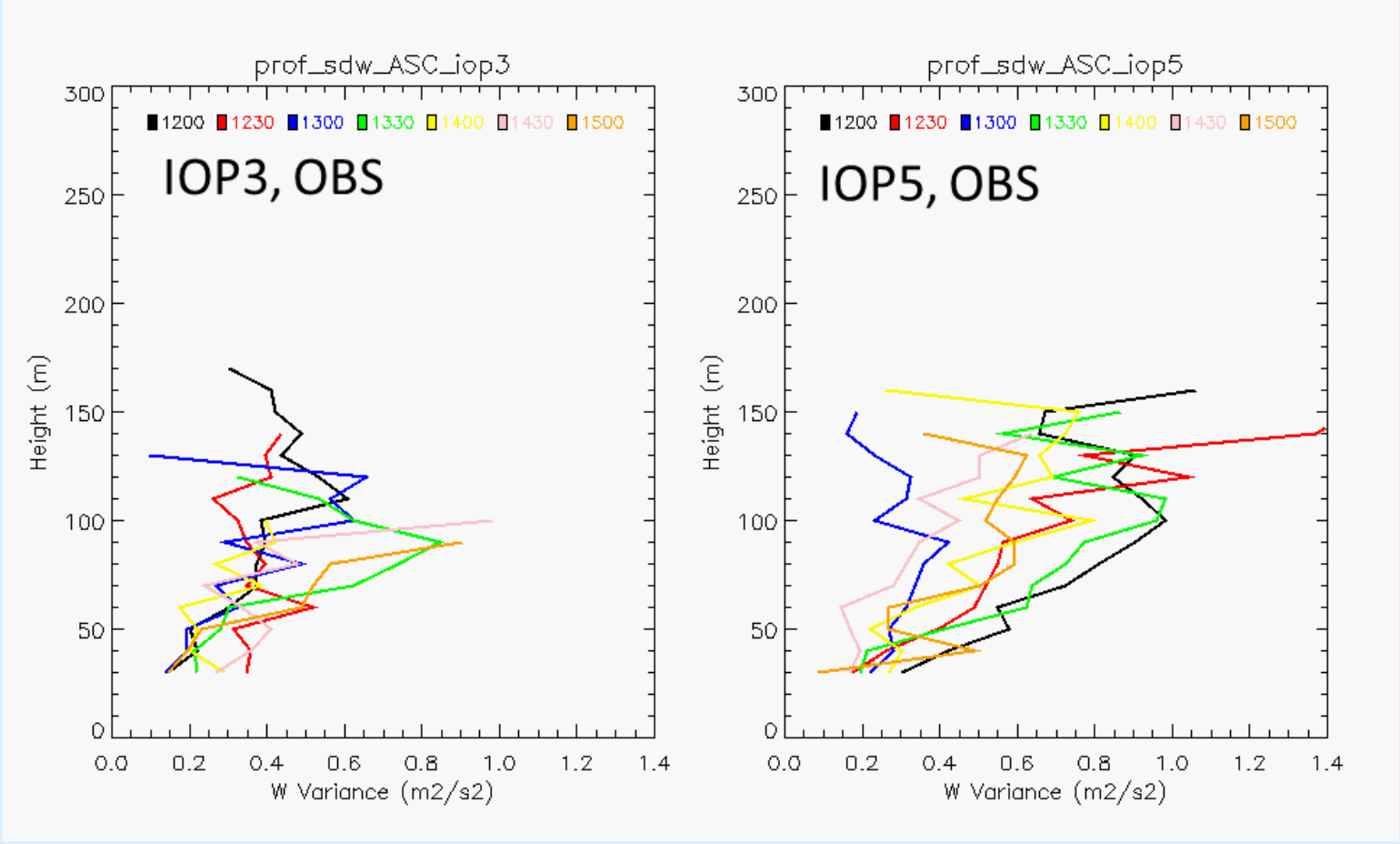






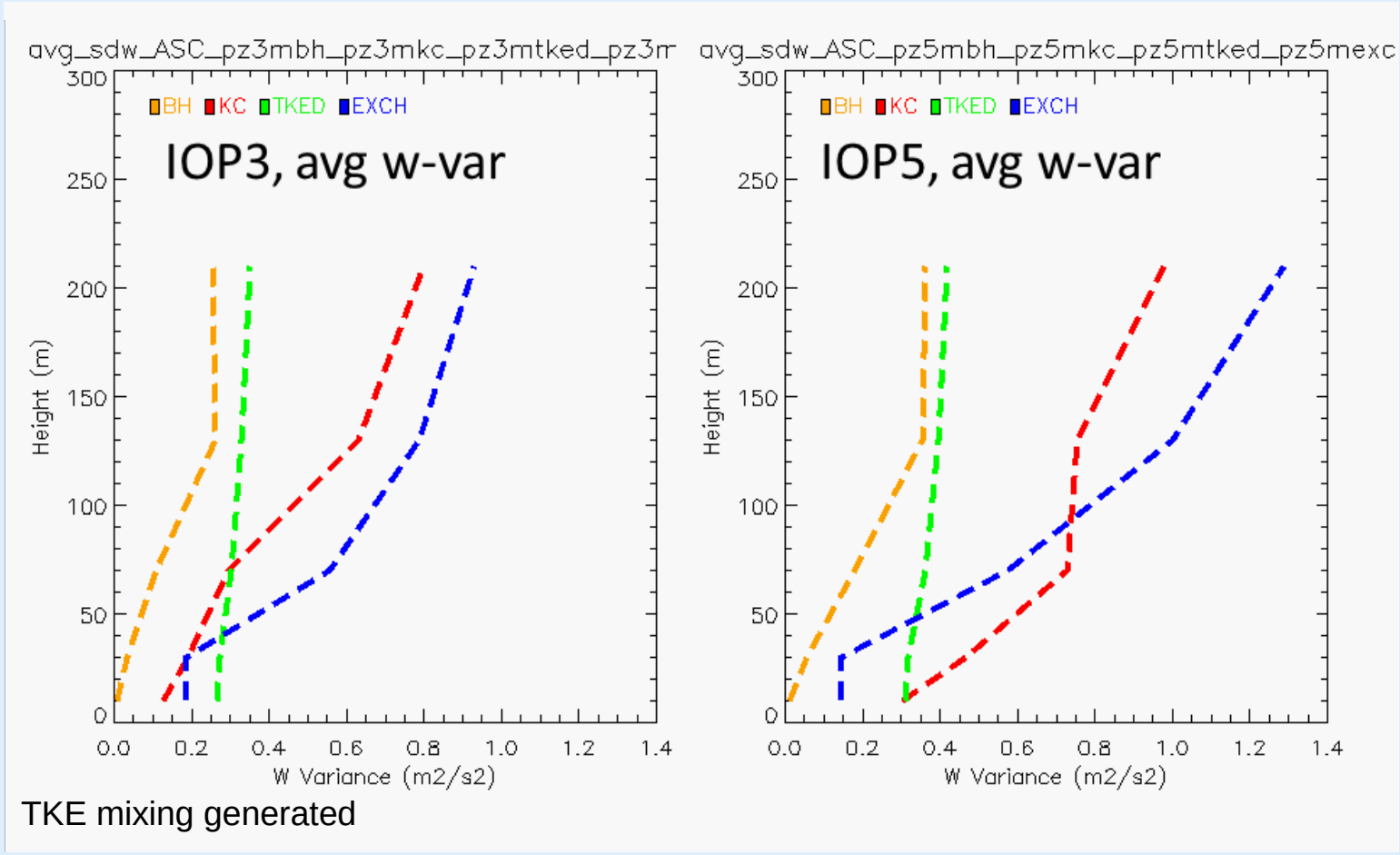
Vertical profiler of vertical velocity variance

Measurements were taken at the ASC station at heights 30 – 200 m, in the afternoon (12 – 15 MST) of IOP3 and IOP5.



Averaged vertical profiler of vertical velocity variance

The vertical velocity variance profilers at the ASC station were generated by four mixing options in HYSPLIT averaging over 12 – 15 MST on the days of IOP3 and IOP5.



TKE mixing generated

Spatial plot of tracer concentrations for **IOP2** at 1340 MST