Making Sense of Multiple Boundary Layer Meteorological Observations during the Jack Rabbit II Chlorine Field Experiment

Steven Hanna

Hanna Consultants, Kennebunkport, Maine

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hannaconsult@roadrunner.com

Acknowledgements

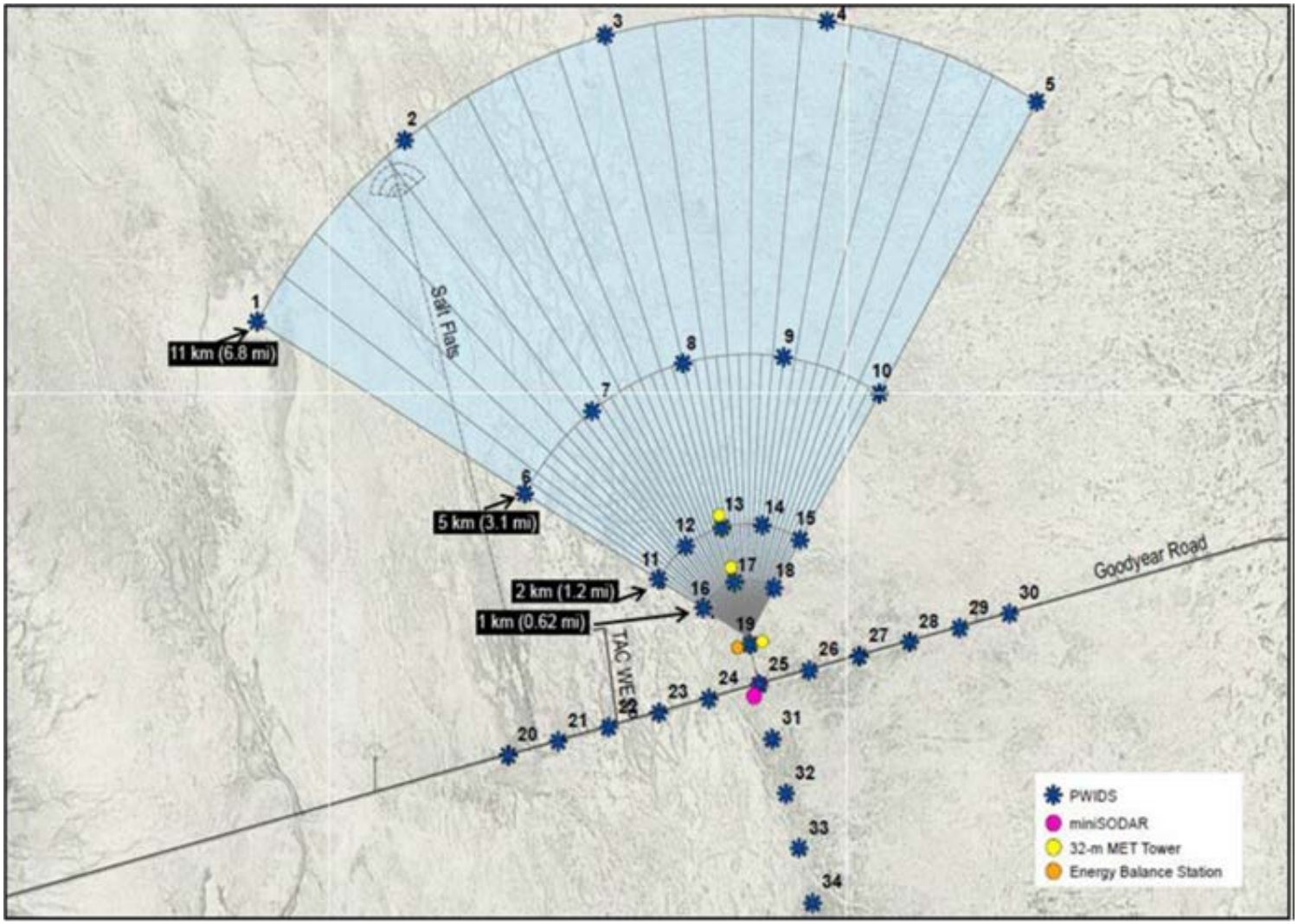
- Sponsored by DTRA
- Many others have been involved in taking and analyzing meteorological data
- Dugway Proving Ground staff owns the met instruments, operates them, and produces final QA/QC'd data archive
- DHS/DTRA committees worked throughout the trials and now (e.g., Shannon Fox, Joe Chang, Tom Mazzola, Tom Spicer and many others)

Can you ever have too many data?

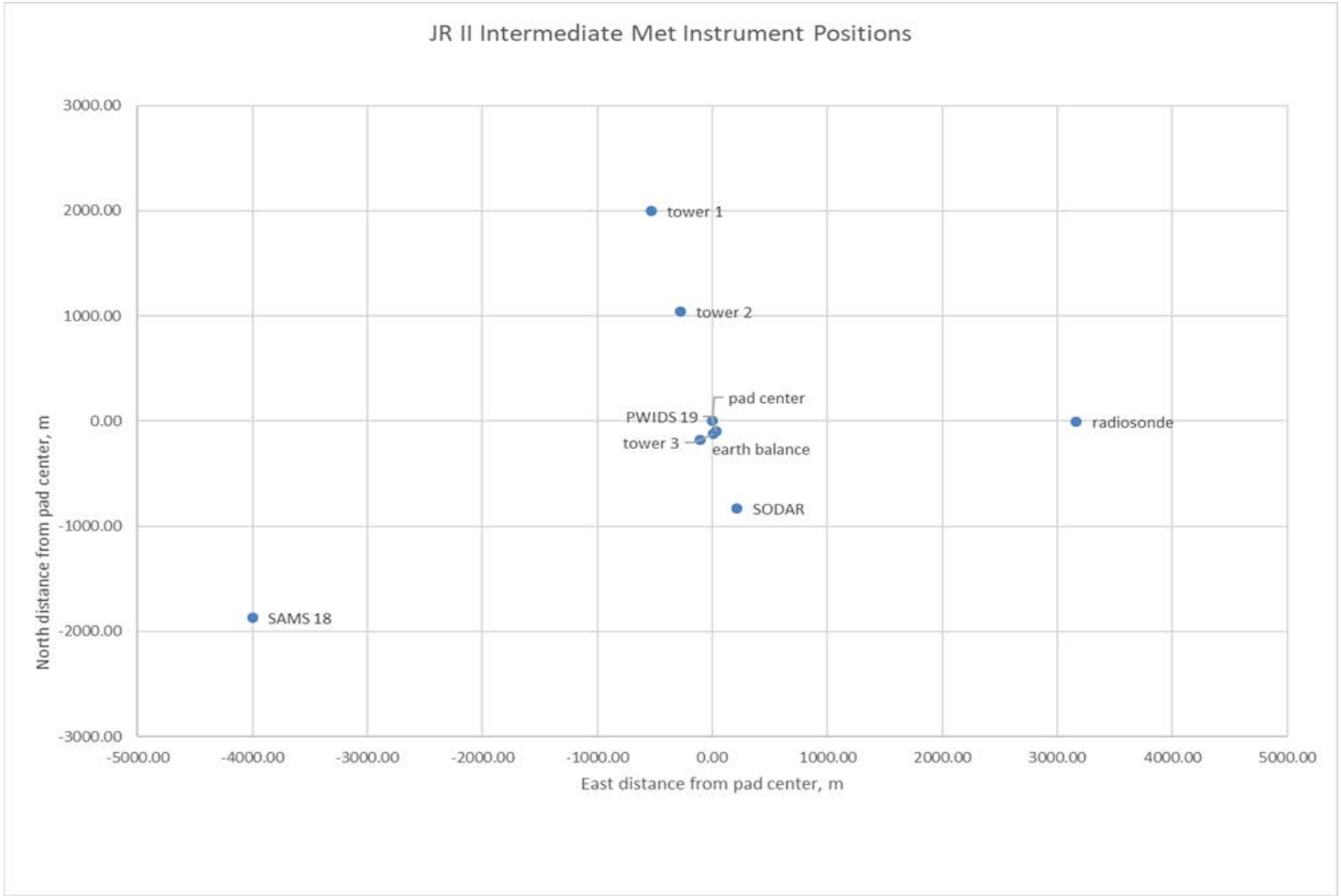
Yes, if you are trying to prepare basic meteorological inputs for a dense gas dispersion model

Here we discuss met data collected at Dugway Proving Ground, Utah, for the Jack Rabbit II chlorine release trials

Near-surface met instrument locations, in and around the JR II sampling grid (arcs at 1, 2, 5, and 11 km).



Subset of met instruments used in this paper. Outside of this domain are a 924 MHz profiler (18 km ESE) and a 449 MHz profiler (35 km E)

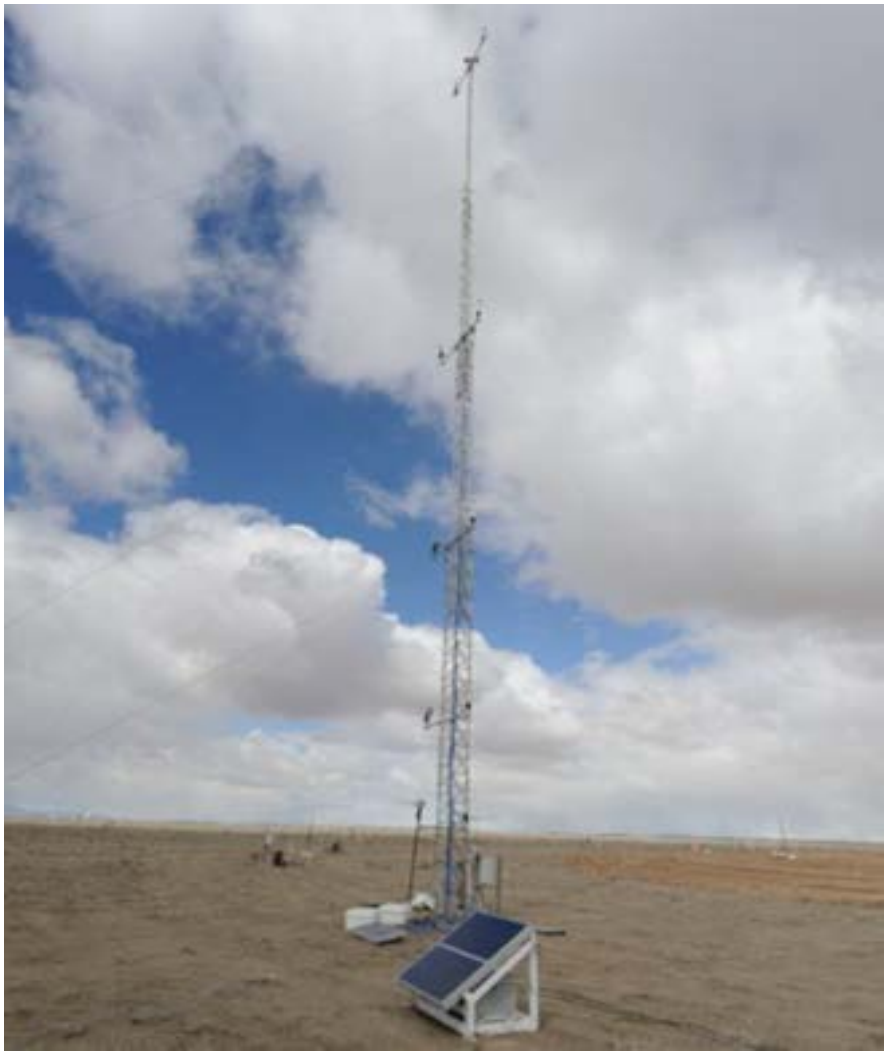


Domain is 6 km N-S and 10 km E-W

32 m meteorological tower used at Tower 1, 2, and 3 locations

Winds are measured by aerovanes and by sonic anemometers at each level

Energy balance station is in foreground



Objectives

- Recommend abridged set of Jack Rabbit II (JR II) meteorology observations for use by several groups in dispersion modeling
- Start with huge data archive
- Produce met data that are sufficient for dispersion model inputs (but no more)
- Will be part of Modelers Data Archive (MDA) for future evaluations

Dugway Proving Ground Area. Note broad playa 60 miles wide by 100 miles long oriented SSE to NNW

----40 miles-----

Transient and spatially-variable JR II meteorology

- Early morning releases and chlorine cloud transport across 11 km domain occurred during transition period from stable night to unstable day
- Mesoscale wind variations in time and space often are present
- Large wind direction shear between drainage wind from SSE at surface and synoptic westerlies at 1000 m

Meteorology inputs needed by dispersion models

- **Simple similarity or Gaussian or slab (single met site)**
  - ***A***. Winds (speed and direction), stability class, T, RH
  - ***B***. Winds, fluxes (sensible heat H_s, momentum (u*)), z_o, L, mixing depth z_i, T, RH, land use type; possibly include vertical profiles.
- **Lagrangian puff or particle**
  - ***A***. Above list plus network of met sites across the domain (input to diagnostic mass consistent wind model)
  - ***B***. NWP (e.g., WRF) time varying outputs on 3D grid
- **CFD**
  - Requires initial conditions and boundary conditions
  - Usually an upwind met profile is used; can link with WRF

Summary JR II Table

Trial	day	start time	end time	release	Q	Jet or pool	wind speed	wind dir	Avg T
		MDT	for jet or pool	duration	kg/s	mass	near source	near source	near source
			MDT	s		Qtot	at z = 2 m	degrees	C
						kg	m/s		
1	8/24/2015	7:35:46 AM	7:36:44 AM	22.2	204.7	4545	1.5	147	17.5
2	8/28/2015	9:24:21 AM	9:25:10 AM	32.4	252.8	8192	4.7	176	23.0
3	8/29/2015	7:56:55 AM	7:57:31 AM	20.3	225.0	4568	3.8	170	22.9
4	9/1/2015	8:39:33 AM	8:40:16 AM	28.8	243.6	7017	1.8	196	22.6
5	9/3/2015	7:29:09 AM	7:29:59 AM	33.6	248.4	8346	1.5	242	21.5
6	8/31/2016	8:23:35 AM	8:24:10 AM	33.2	252.8	8392	2.4	147	22.3
7	9/2/2016	7:56:00 AM	7:56:35 AM	36.4	236.8	8620	4.0	150	18.7
8	9/11/2016	9:01:45 AM	9:02:45 AM	30.0	78.93	2368	2.1	120	15.8
9	9/17/2016	8:05:00 AM	8:08:00 AM	132.6	133.5	17700	2.6	162	11.2
7 dump	9/2/2016	8:11:00 AM	8:16:00 AM	300	1.507	452	4.0	150	18.7
8 dump	9/11/2016	9:16:45 AM	9:21:00 AM	300	22.51	6754	2.9	129	15.8

Meteorological Instruments Used to Make Recommendations

Met instruments JR II analyzed in preparation of met summary tables							positions referenced to pad center		
Note: RASS (temperature profiles) are taken by the 449 and 924 profilers									
name	meteorological variables	measurement heights (m)	Easting (m)	Northing (m)	Elevation (m)		east (m)	north (m)	distance from pad (m)
SODAR	WS, WD	30, 40, ...400	288324.4	4444804.0	1294		215.2	-830.0	857.4
Radiosonde	WS, WD, T, RH	sfc to many km	291270.6	4445629.8	1294		3161.4	-4.1	3161.4
Profiler_449	WS, WD, T	170 m to 2 km	320904.1	4443286.8	NR		32794.9	-2347.1	32878.8
Profiler_924	WS, WD, T	170 m to 2 km	306428.4	4439222.8	1294		18319.2	-6411.2	19408.7
Earth_Balance	sfc fluxes, WS, WD, turb	sfc and 2.5 m	287999.9	4445458.5	1294		-109.3	-175.5	206.7
Tower 3	WS, WD, turb, fluxes	2, 4, 8, 16, 32	288114.1	4445517.6	1294		4.9	-116.4	116.5
Pad Center			288109.18	4445633.95	1295.47		0.0	0.0	0.0
Tower 2	WS, WD, turb, fluxes	2, 4, 8, 16, 32	287833.6	4446675.3	1294		-275.6	1041.3	1077.2
Tower 1	WS, WD, turb, fluxes	2, 4, 8, 16, 32	287577.4	4447630.1	1294		-531.8	1996.2	2065.8
PWIDS19	WS, WD	2	288138.9	4445541.6	1294		29.7	-92.3	97.0
SAMS18	WS, WD	10	284109.0	4443763.1	1294		-4000.2	-1870.8	4416.1

How to narrow down the met recommendations

- We are emphasizing the time period beginning with the chlorine release time and extending for 20 or 30 minutes.
- During this time period the cloud will travel about 500 to 1500 m downwind
- We are focusing on met instruments as close as possible to the release point

Recommended basic meteorology including stability

Trial	Release time					
	UTC (MDT = UTC - 6)	Mixing Height (m AGL)	Wind speed at z = 2 m m/s	1/L 1/m	Pasquill stab class	Comments on vertical temperature gradients
1	8 24 15 1336	1000	1.5	0.068	E or F	2 C inversion over 32 m at T3
						RASS shows 9 C inversion between surface and 400 m
2	8 28 15 1524	1000	4.7	-0.0472	C or D	Slightly unstable lapse rate over T3
					for z < 50 m	RASS shows 2.5 C inversion from about 170 to 400 m
3	8 29 15 1357	1000	3.8	0.0497	D or E	32 m tower shows 1.8 C inversion
						RASS shows 5 C inversion between surface and 400 m
4	9 1 15 1440	1000	1.8	-0.0055	D or E	Slightly stable or isothermal on the 3 towers
						RASS shows 2 C inversion up to 800 m
5	9 3 15 1329	1000	1.5	0.0176	E	0.5 C inversion to 8 m
						Isothermal to 300 m
6	8 31 16 1424	1000	2.4	0.056	E	1 C inversion over 16 m on T3 tower
						RASS shows 3.5 C inversion from surface to 400 m
7	9 2 16 1356	1000	4.0	0.0229	D or E	0.8 C inversion over 16 m on T3 tower
						RASS shows 4 C inv from surface to 100m, isothermal to 250 m
8	9 11 16 1502	1000	2.1	-0.1632	C at z < 8m	Towers show unstable lowest 8 m then inv above
					E above	RASS shows 5 C inv sfc to 200m, isothermal above
9	9 17 16 1405	1000	2.6	0.0382	E	1 C inversion lowest 16 m on T3,
						then another 5 C inv to 250 m. Adiabatic above 250 m.

Trials ordered by release time (transition from stable to unstable)

Trial	Date and release time	Sensible	WS		cloud	T gradient	Pasquill	1/L
	UTC	heat flux	2 m		cover	on tower	Stab Class	1/m
	(MDT = UTC - 6)	C m/s	m/s		tenths	C	by SH	
5	9 3 15 1329	-0.0300	1.5		7	0.5 C inv	E	0.0176
1	8 24 15 1336	-0.0055	1.5			2 C inv	E/F	0.068
7	9 2 16 1356	-0.0159	4.0		0	0.8 C inv	D/E	0.0229
3	8 29 15 1357	-0.0272	3.8		8	1.8 C inv	D/E	0.0497
9	9 17 16 1405	-0.0072	2.6		0	1 C inv	E	0.0382
6	8 31 16 1424	-0.0034	2.4		3	1 C inv	E	0.056
4	9 1 15 1440	0.0010	1.8		1	slight stable	D/E	-0.0055
8	9 11 16 1502	0.0253	2.1		0	unst < 8 m	C	-0.1632
2	8 28 15 1524	0.0391	4.7		3	slight unst	C/D	-0.047

Recommended u*, H, L and horiz and vert turbulence

TIMESTAMP UTC (end time) 30 min avg	Release time UTC	Avg of T3 sonic at 2 m and EBS at 2.5 m Recommended for modeling u* m/s	Hs K m/s	L m from Hs and u*	1/L (1/m)	sighor m/s	sighor/u*	sigw m/s	sigw/u*
8/24/2015 14:00	Trial 1 1336	0.103	-0.0055	14.7	0.0678	0.536	5.205	0.107	1.035
8/28/2015 15:30	Trial 2 1524	0.222	0.0391	-21.2	-0.0472	0.953	4.299	0.246	1.105
8/29/2015 14:00	Trial 3 1357	0.193	-0.0272	20.1	0.0497	1.345	6.946	0.212	1.102
9/1/2015 15:00	Trial 4 1439	0.136	0.0010	-182.8	-0.0055	0.658	4.908	0.130	0.961
9/3/2015 13:30	Trial 5 1329	0.284	-0.0304	56.9	0.0176	1.756	6.376	0.279	0.968
8/31/2016 14:30	Trial 6 1424	0.093	-0.0034	17.8	0.0560	0.416	4.824	0.647	1.161
9/2/2016 14:00	Trial 7 1356	0.210	-0.0159	43.6	0.0229	0.781	3.735	0.247	1.178
9/11/2016 15:30	Trial 8 1502	0.128	0.0253	-6.13	-0.1632	0.719	5.790	0.148	1.170
9/17/2016 14:30	Trial 9 1405	0.138	-0.0072	26.2	0.0382	0.638	4.656	0.150	1.087

$sighor^2 = sigu^2 + sigv^2$

u* can be large due to wind speed trends (e.g., Trial 5)

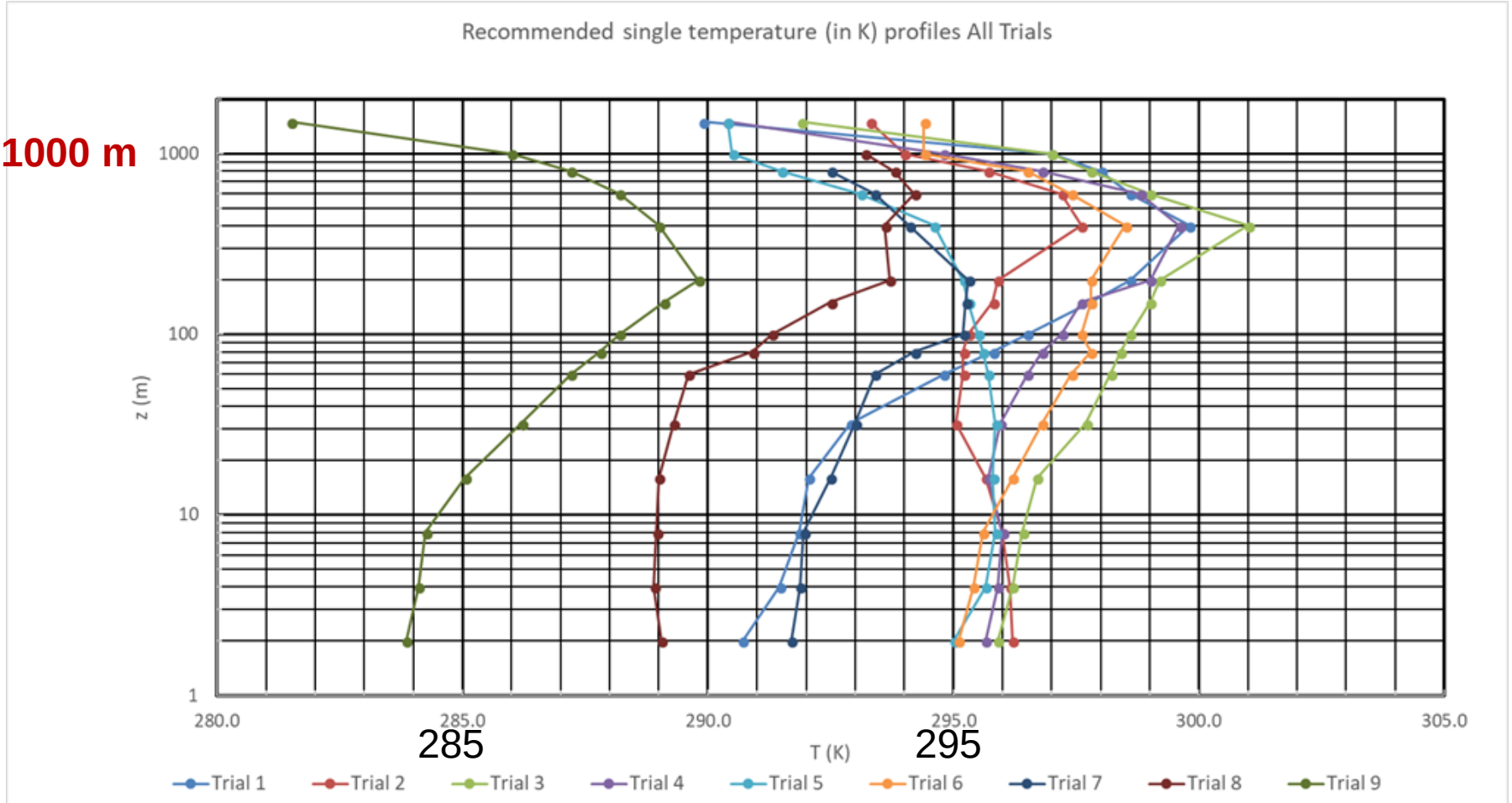
Surface roughness length z_o

- z_o is calculated for each 30 min time period from neutral wind profile formula, using observed 2 m u (wind speed) and u* on upwind 32 m tower
- Median value is z_o= 0.0005 m = 0.5 mm
- Valid for desert playa upwind of and surrounding 182 m by 122 m gravel pad, release pad, and CONEX array

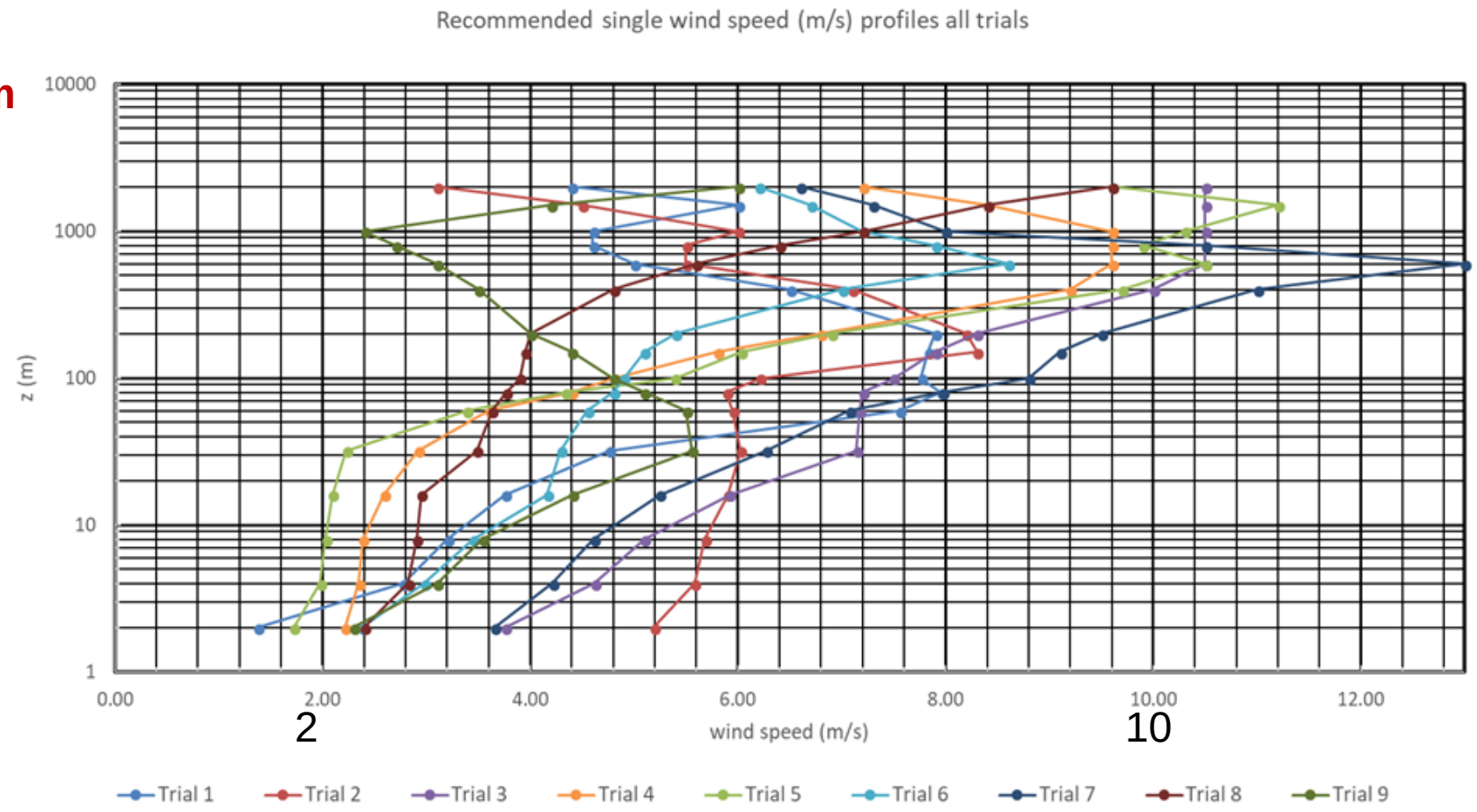
Vertical profile recommendations

- Profiles from 32 m towers, radiosonde, minisodar, 449 and 924 MHz wind profilers, RASS
- Tables for WS, WD, T for each trail
- 16 levels from 2 m to 2000 m
- Plots of data in tables (variable vs z)
- Separate tables and plots for each trial and variable and instrument

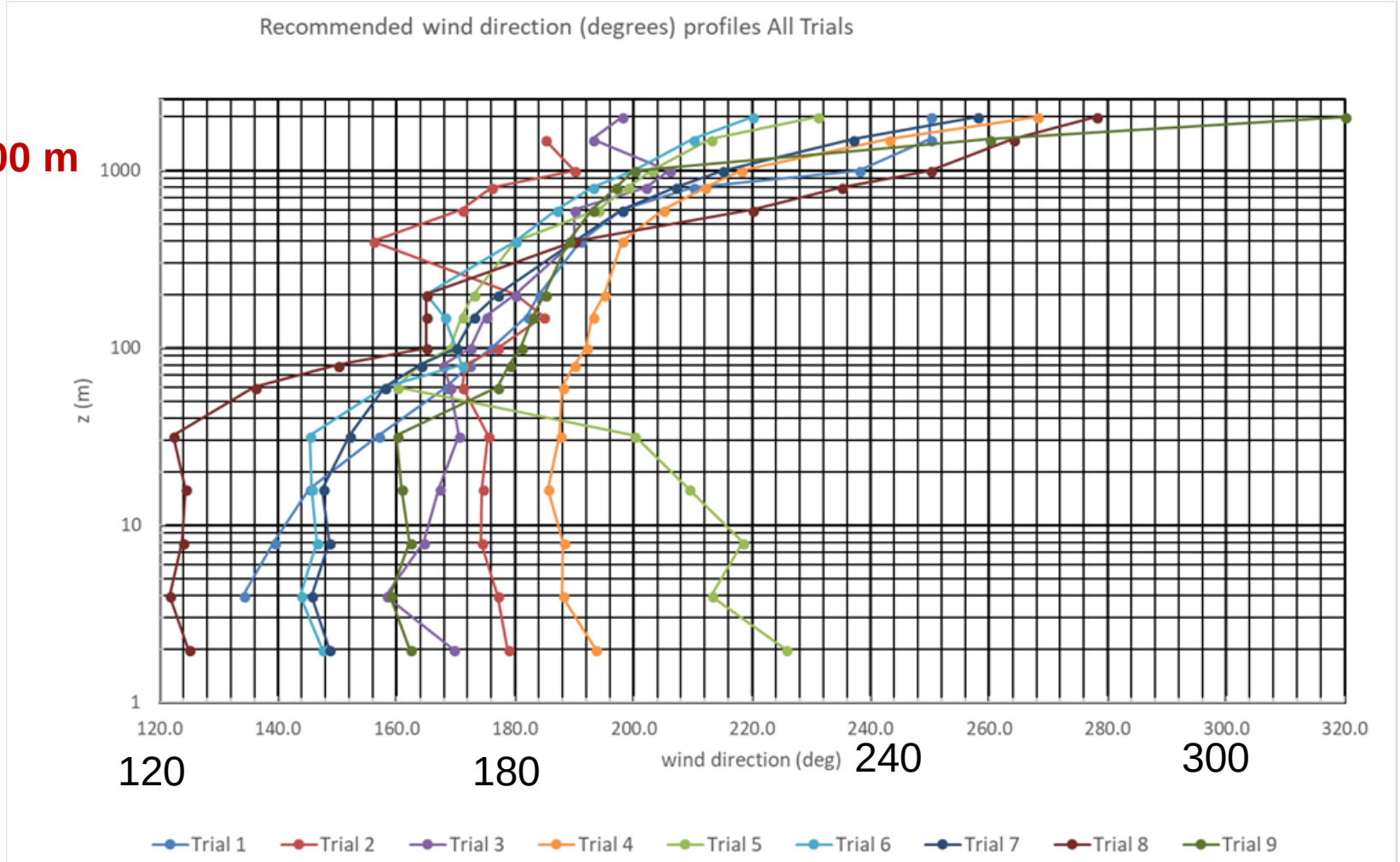
Rec T profiles for each trial



Rec WS profiles for each trial



Rec WD profile for each trial



Modelers were allowed to modify meteorological recommendations

- Most of the 17 models used the meteorology summaries shown above
- Some modelers preferred to derive their own met parameters (e.g., u*, L) and this was allowed
- Special high resolution WRF runs were made by DPG, but were not used in the model comparison

Status of model comparison

- The initial comparison of 17 models with JR II observations for Trials 1, 6, and 7 is complete
- A special issue of *Atmospheric Environment* is underway
- Future extension of the comparison to all trials