Impact of Sea Breeze Fronts on Urban Heat Island & Air Quality in Texas

Xiao-Ming Hu
Center for Analysis and Prediction of Storms, School of Meteorology
University of Oklahoma

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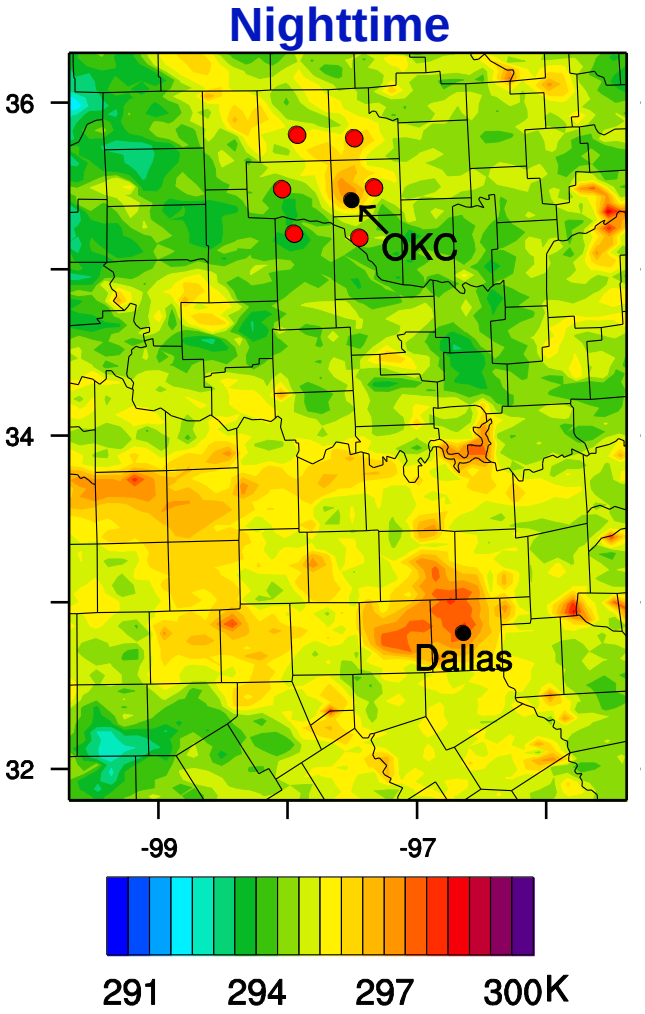
at Ocean Univ. of China

MODIS-derived land surface temperature

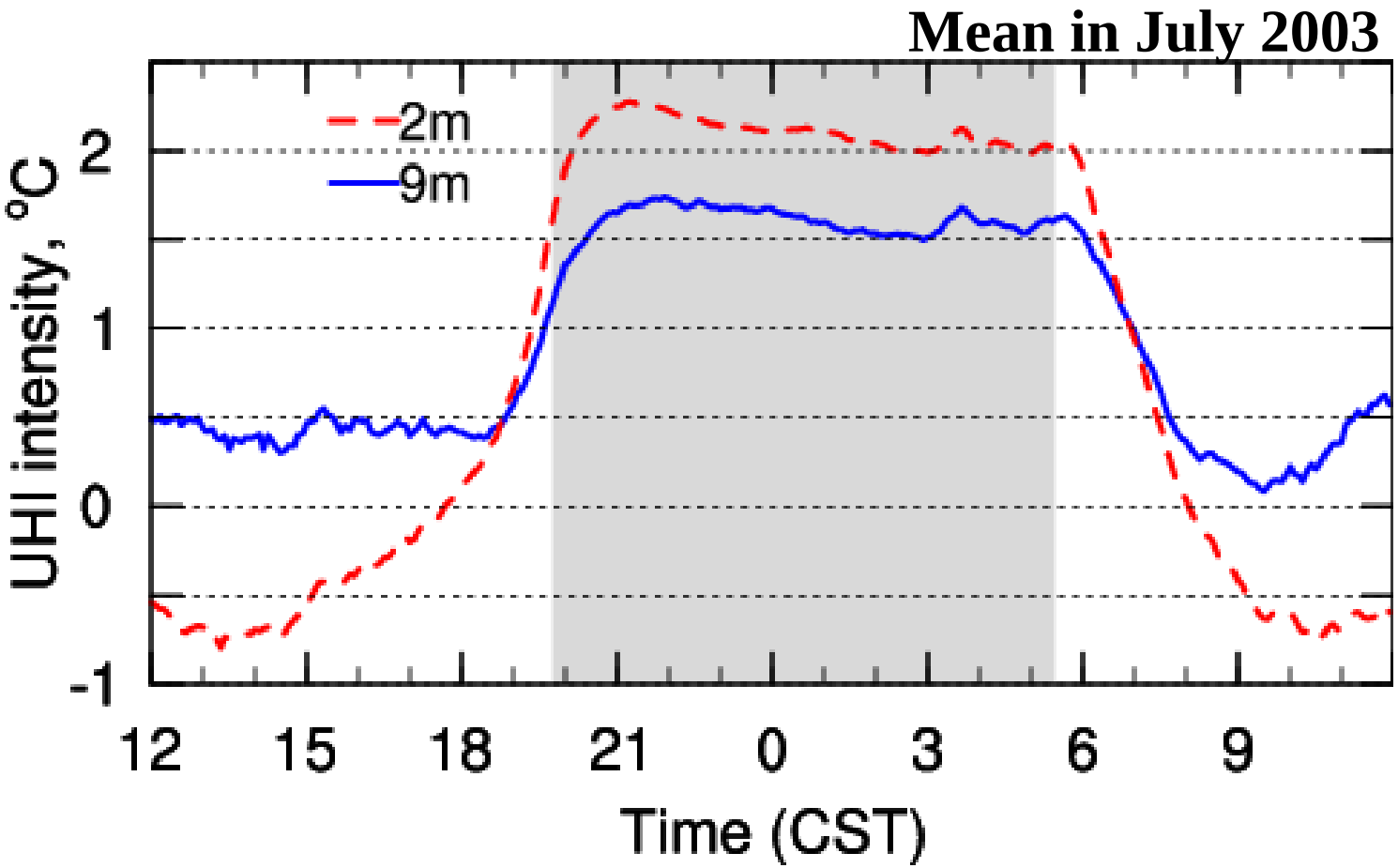


Hu et al. (2013, JAMC)

UHI is prominent during nighttime

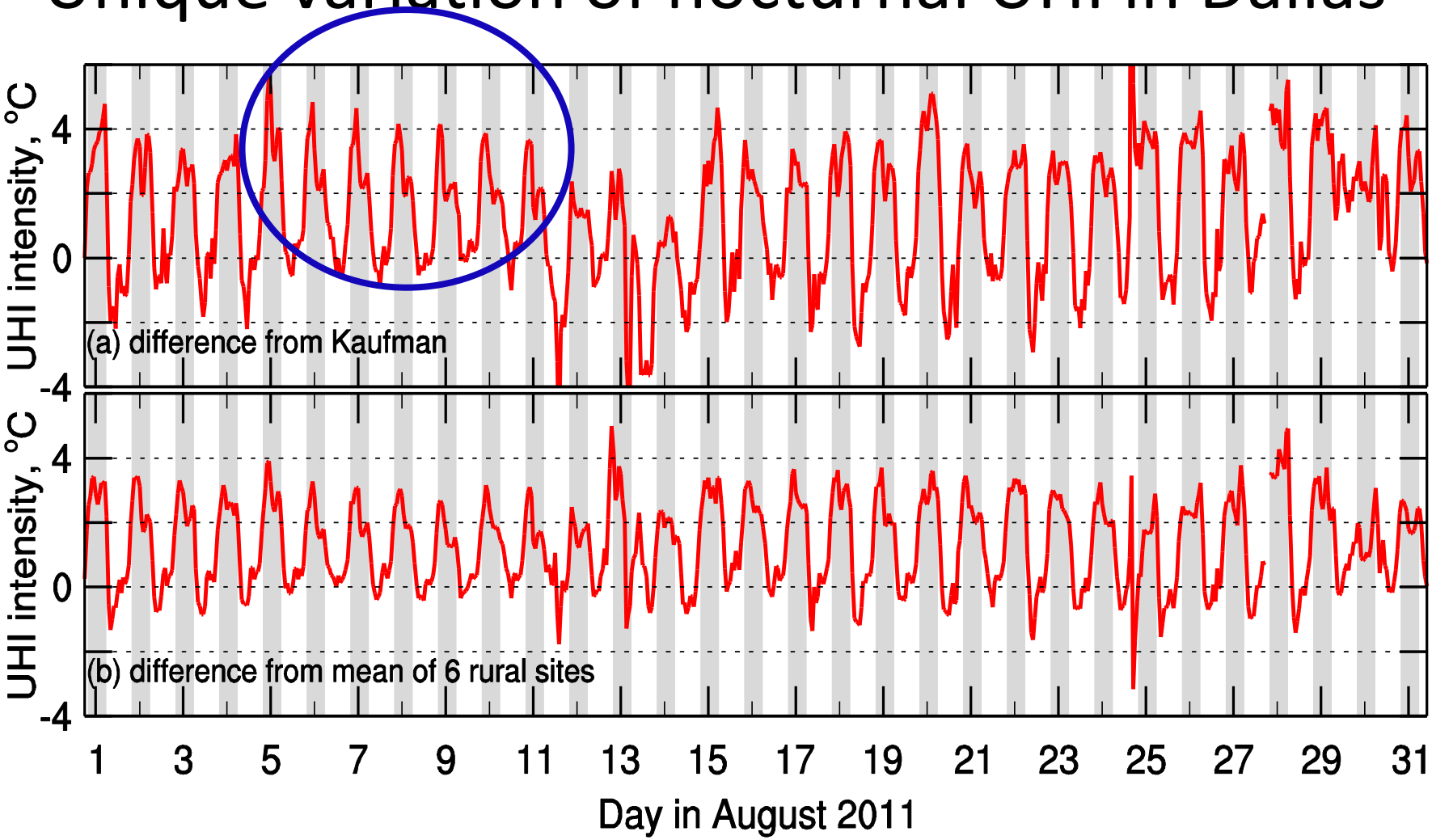
UHI intensity = T at urban location – T at rural sites

Diurnal variation of UHI intensity in OKC



UHI intensity normally increases around sunset quickly and then stays at a roughly constant level throughout the night.

Unique variation of nocturnal UHI in Dallas



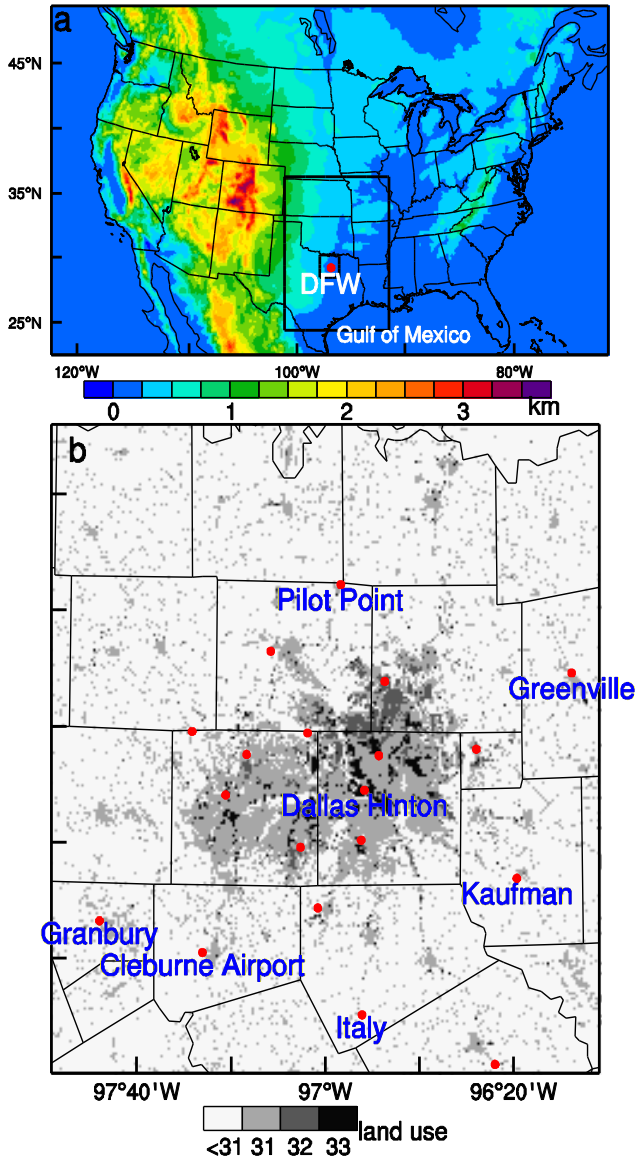
Sharp decrease ("collapse") of the nocturnal UHI intensity

Motivations/objectives of this study

Hu and Xue (2015, MWR, conditionally accepted)

- Understand such a unique temporal variation of the nocturnal UHI intensity in Dallas
  - Mountain-Plain solenoid
  - Sea breeze
  - Nocturnal warming events
- Investigate WRF model capability to reproduce UHI
- Impact on air quality

Model domains and configurations

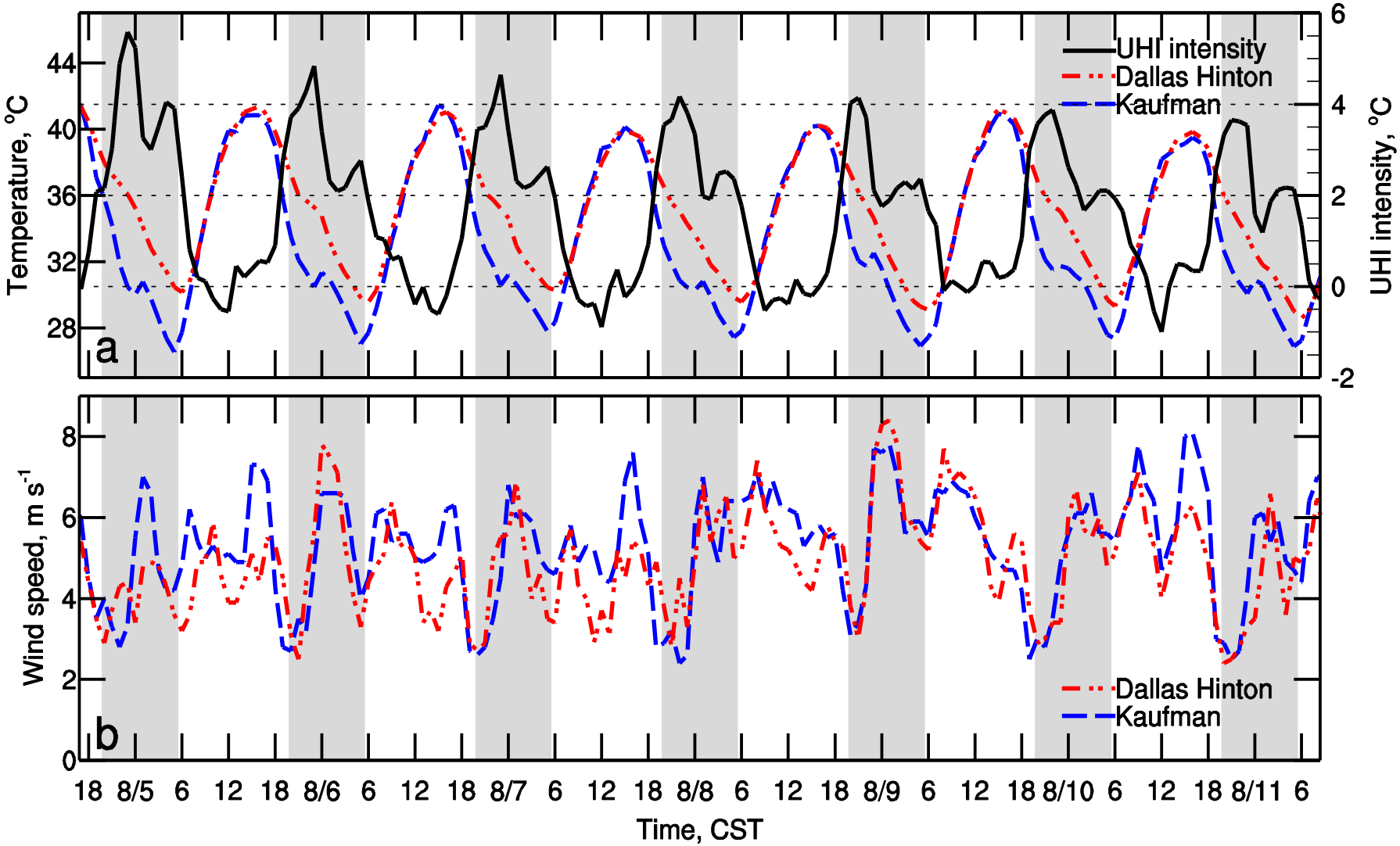


- WRF3.6.1
- 12->4->0.8km
- NOAH+Urban canopy model
- Boundary layer scheme: YSU
- Simulation period: August 7-8 2011

UHI intensity = T at Dallas Hinton – T at Kaufman
to be consistent with Winguth (2013, JAMC)

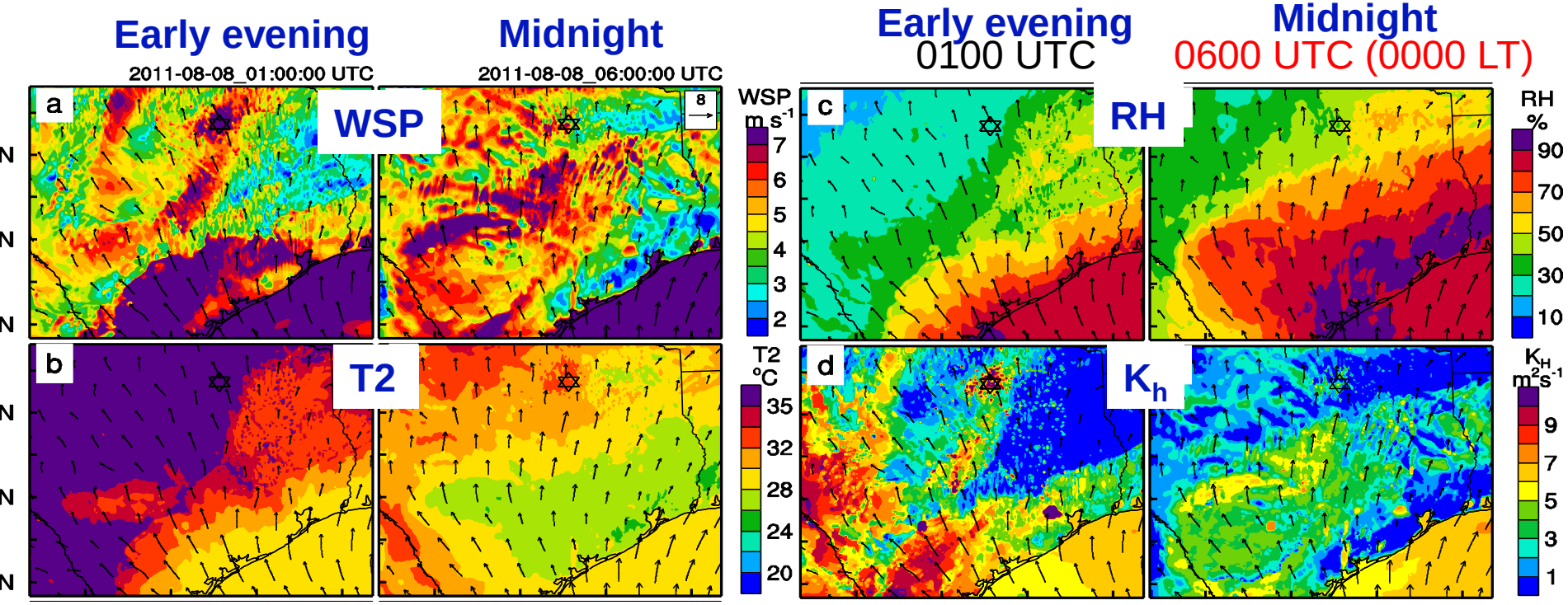
WRF/Chem for air quality impact

Observed variation of UHI, T, wind speed



Collapses of UHI coincided with wind maximum and rural nocturnal warming events

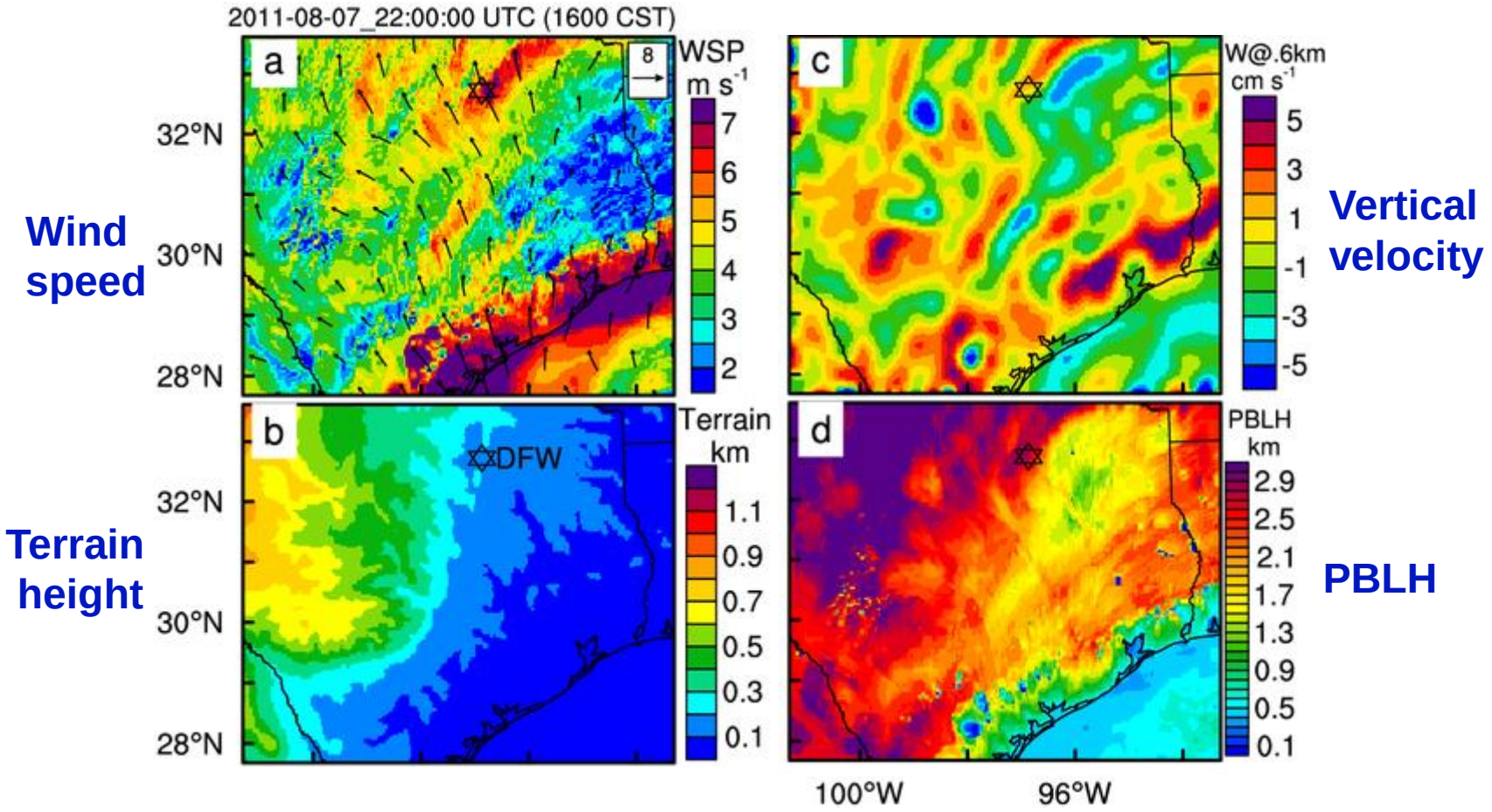
Map of wind, T2, RH, K_h at 00 and 06 UTC



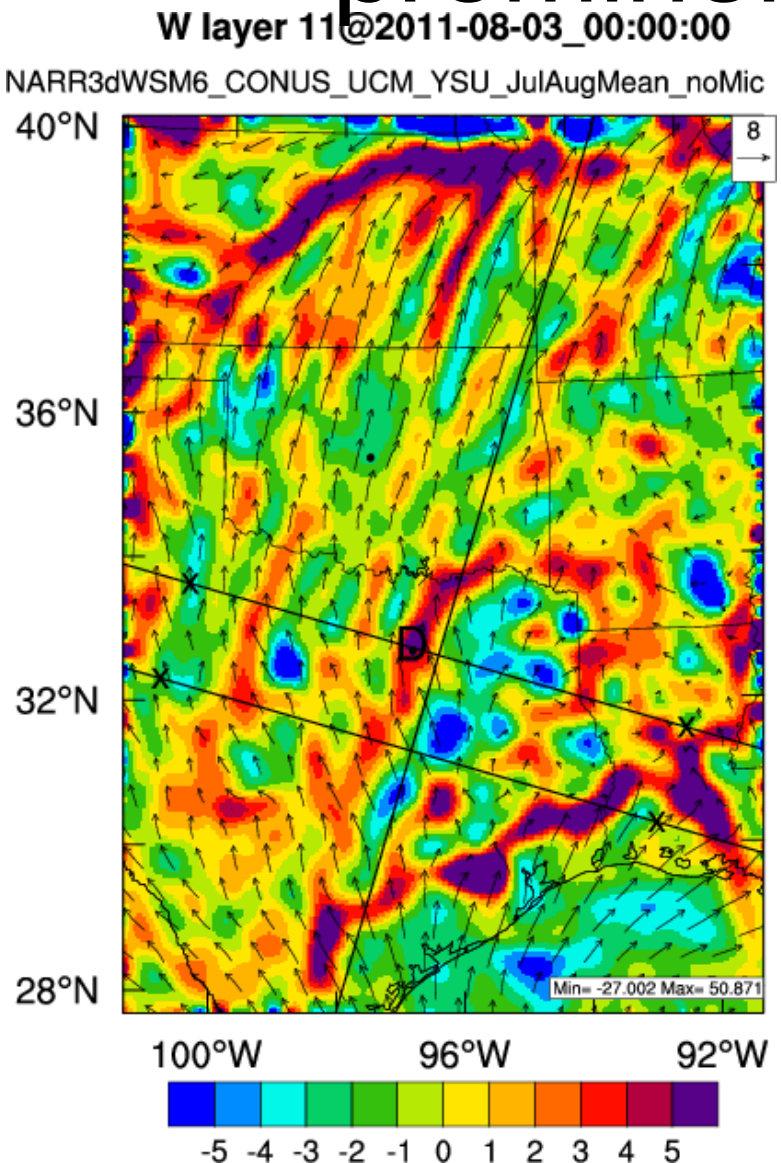
Indications of a sea breeze front:

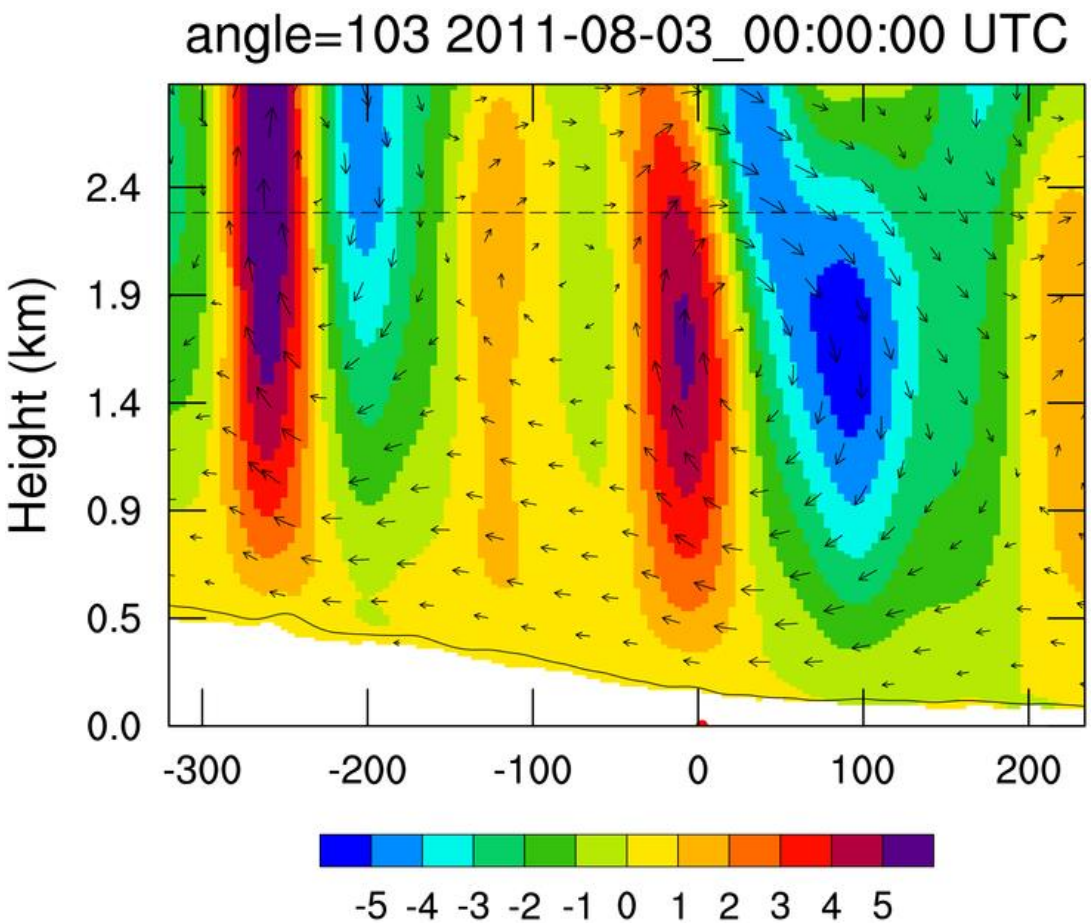
Cooler and moister air behind the front with stronger momentum and vertical mixing

Mountain-Plain Solenoid induced wind maximum band

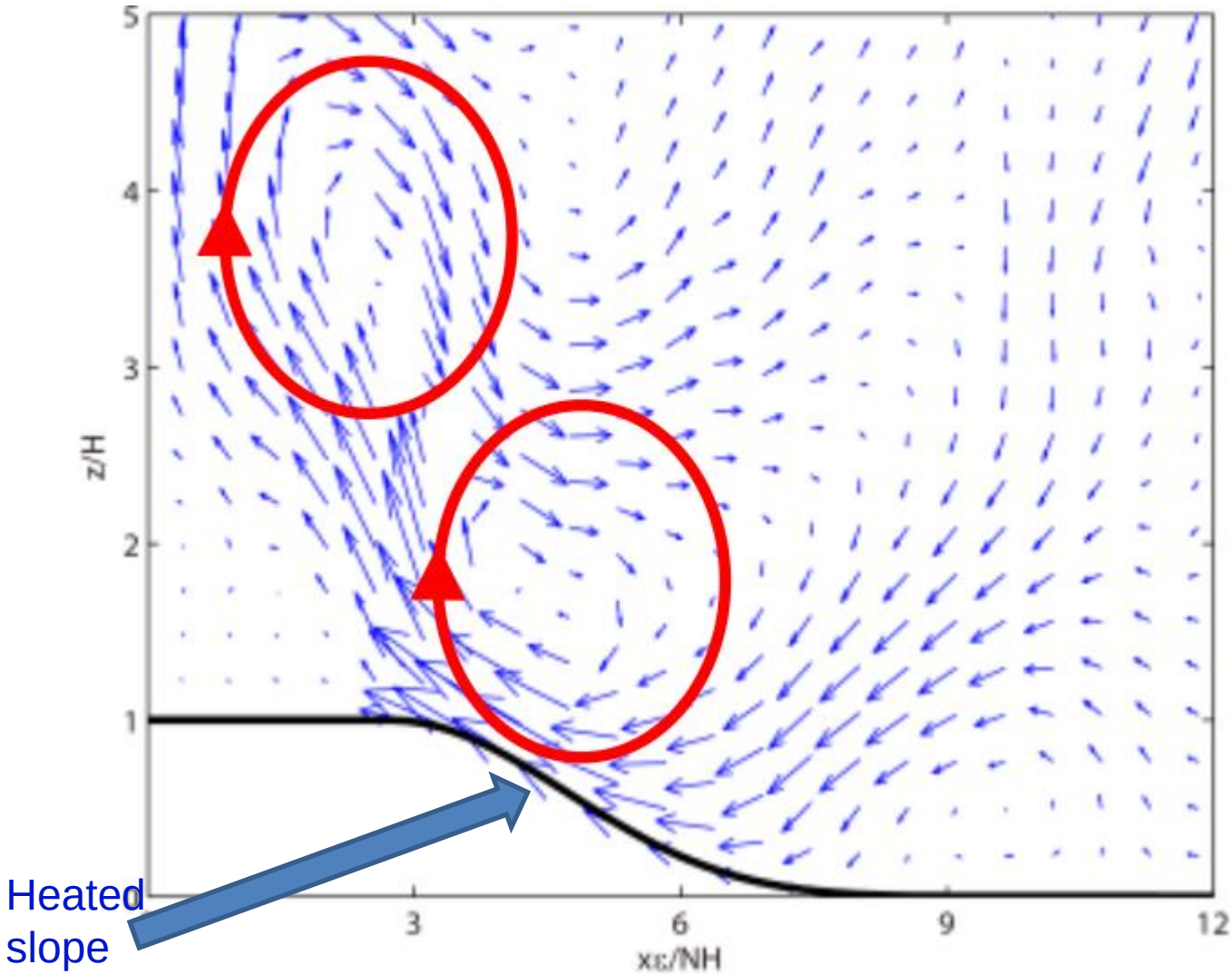


Mountain-Plain Solenoid was prominent in Aug. 2011





Confirmed by 2D idealized simulations



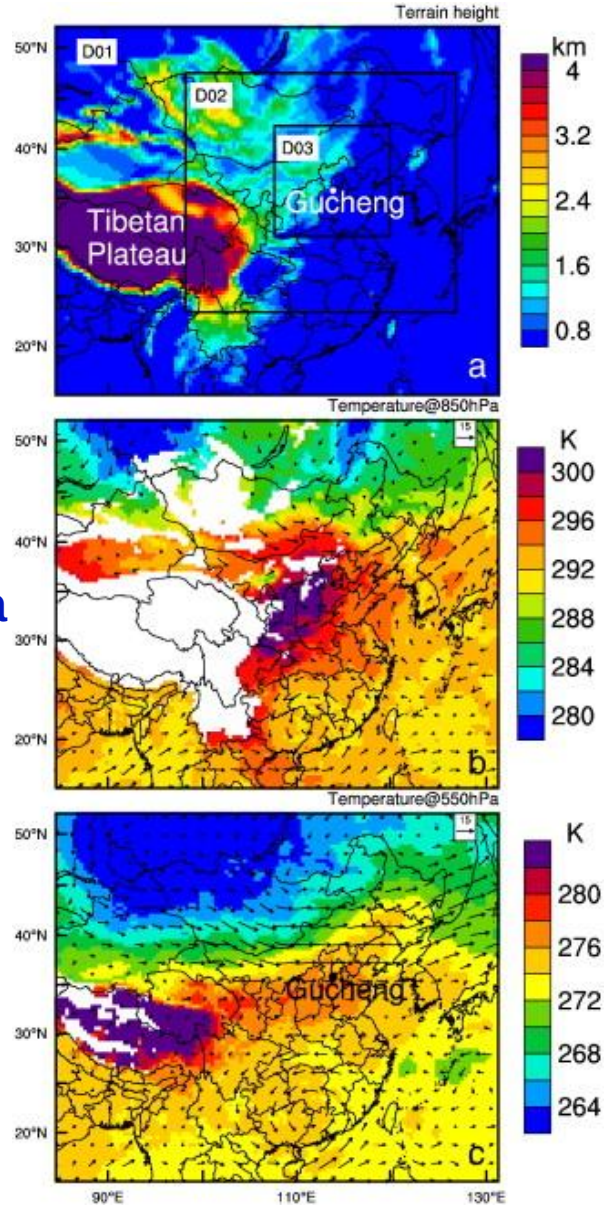
Two circulation cells along a heated slope
simulated using a 2D model from Qian et al. (2012, JAS)

Similar as North China Plain?

Terrain height

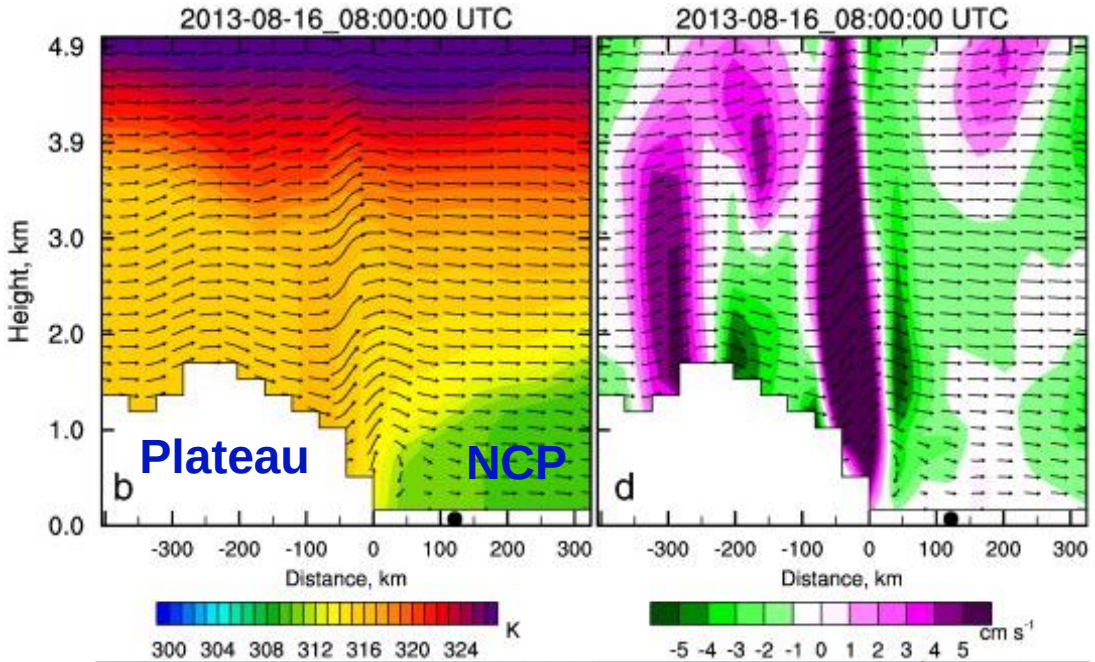
T@850hPa

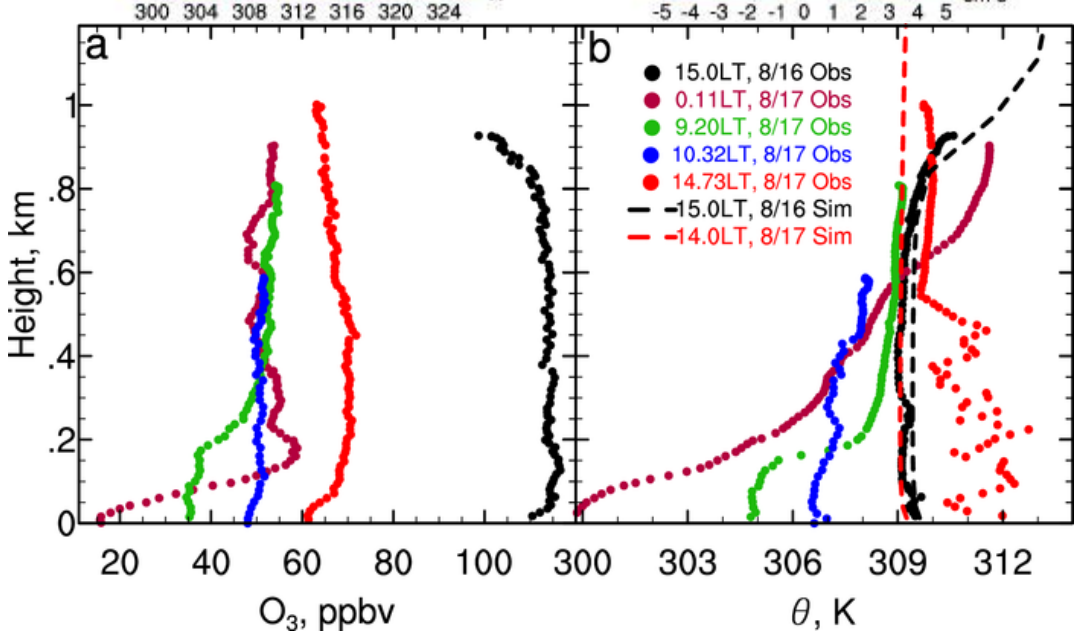
T@550hPa



The Plateau acts as a heated source in Summer (Hu et al., 2014, STE)

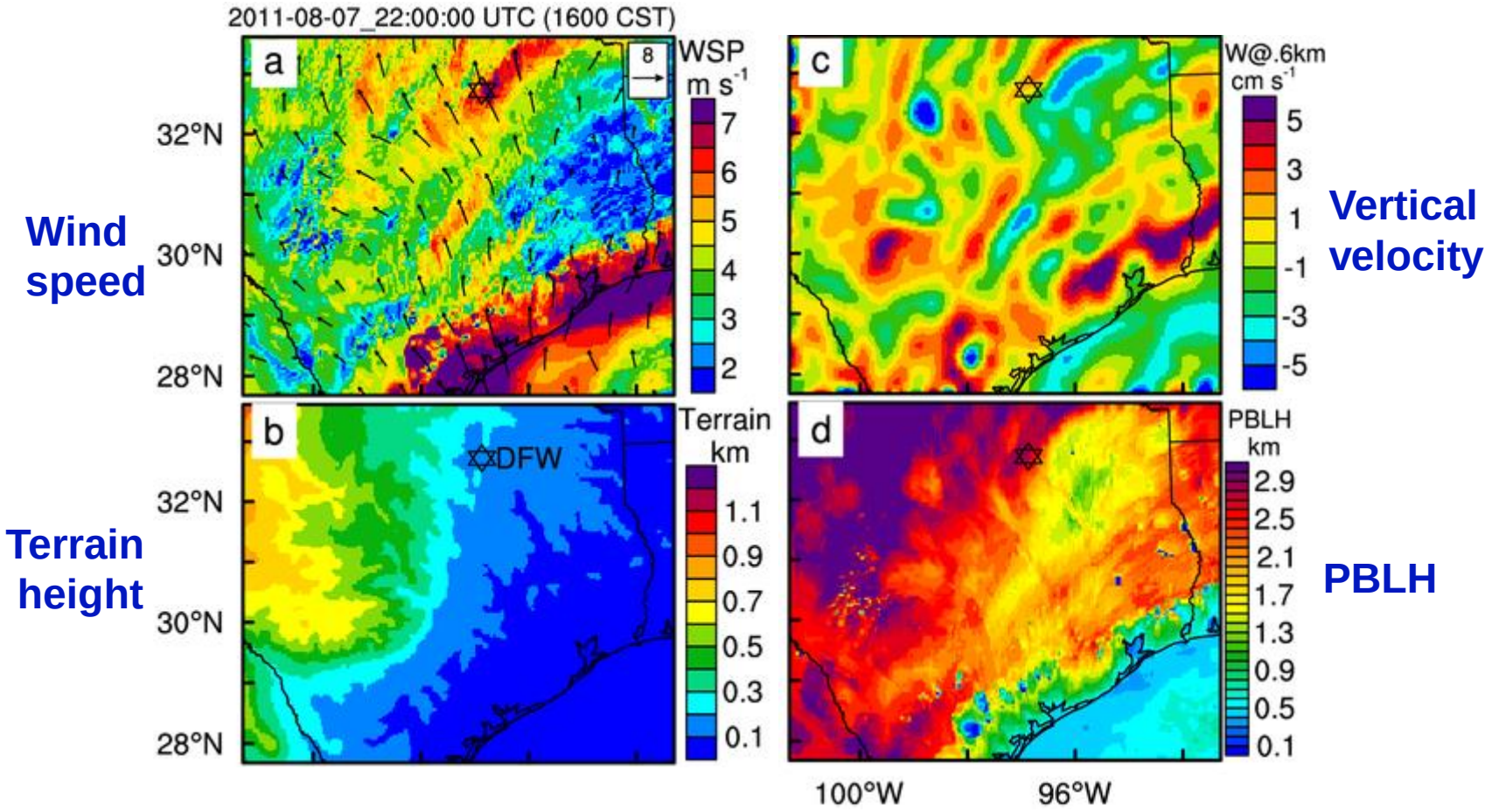
Impact of Mountain-Plain solenoid on boundary layer



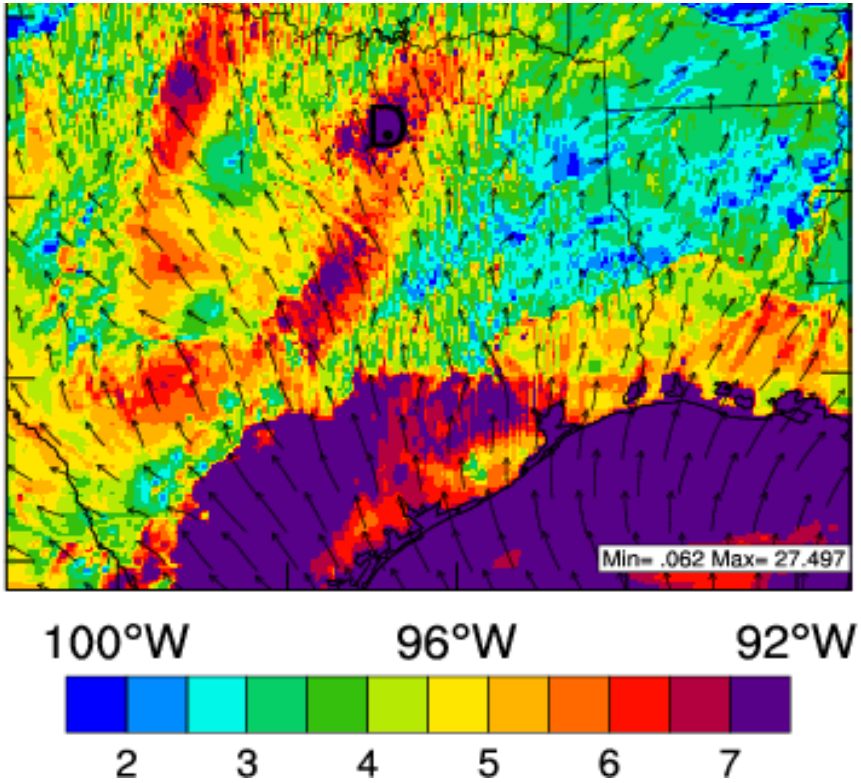


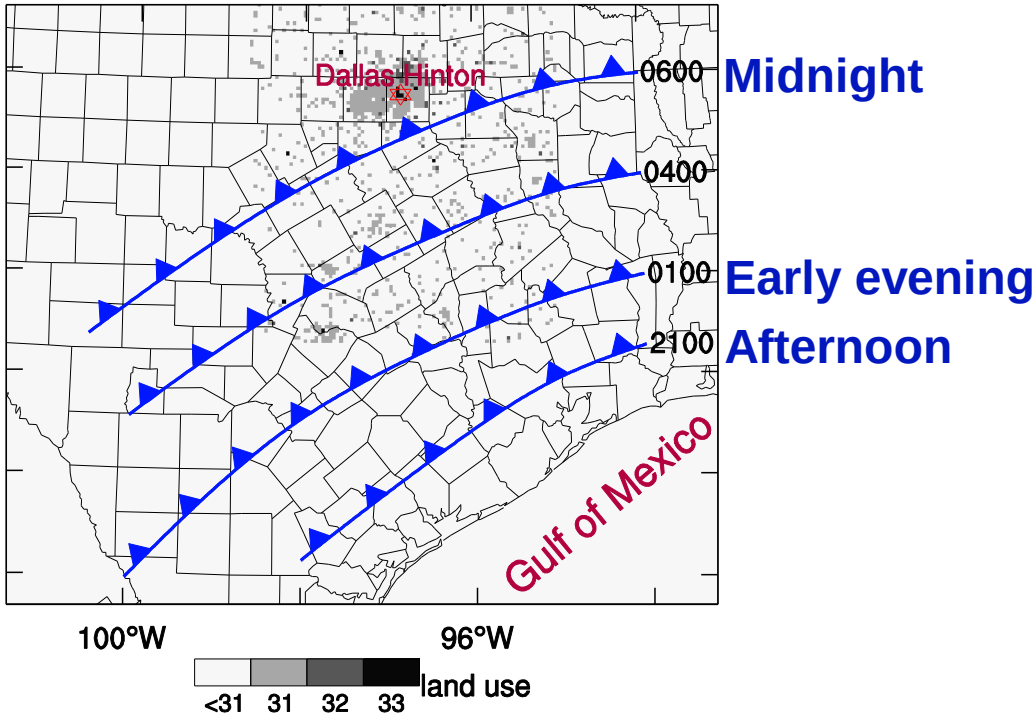
Mountain-Plain solenoid suppress boundary layer development and enhance air pollution (Hu et al., 2014, STE)

Mountain-Plain Solenoid induced wind maximum band



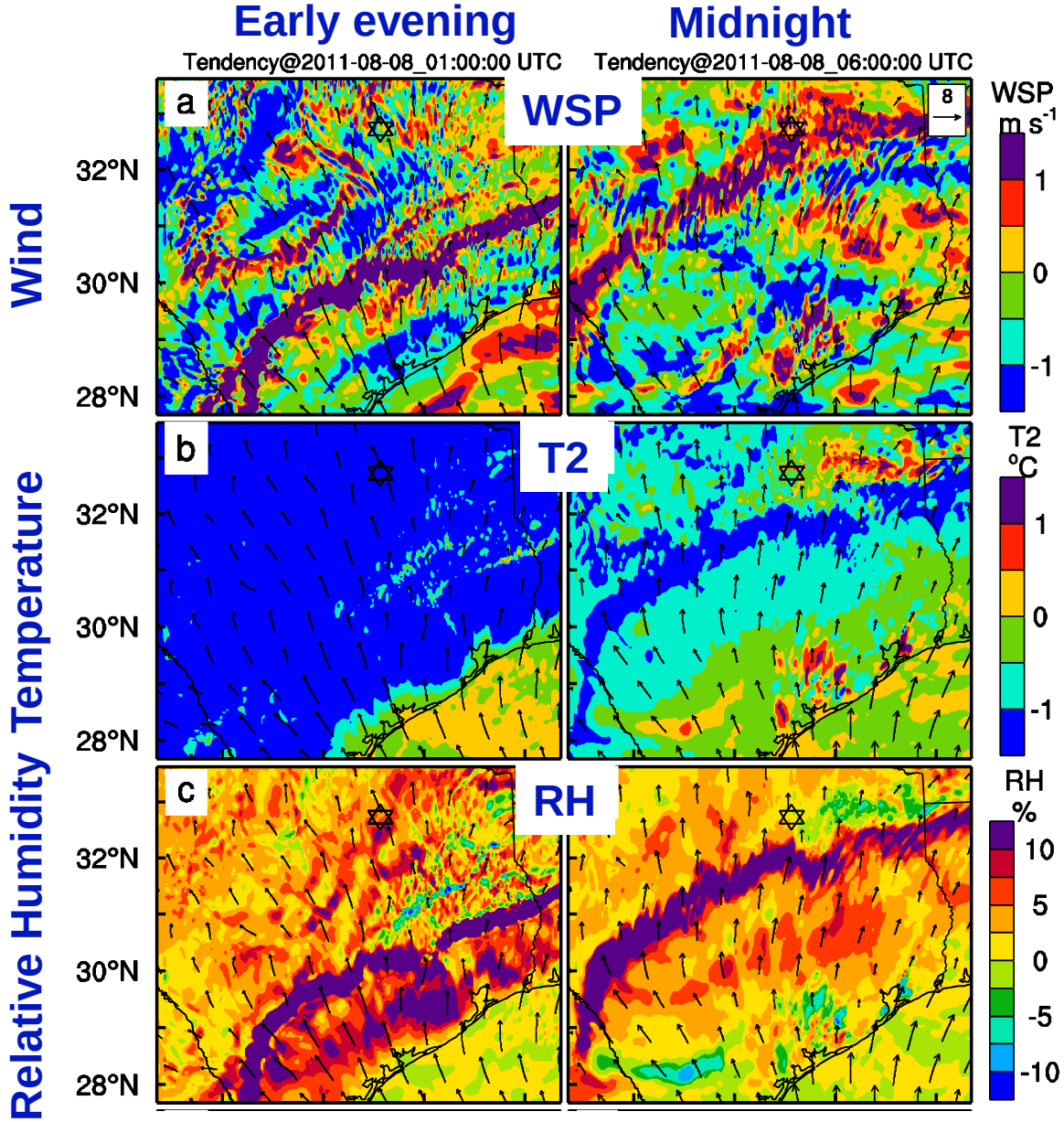
Inland penetration of the sea breeze front





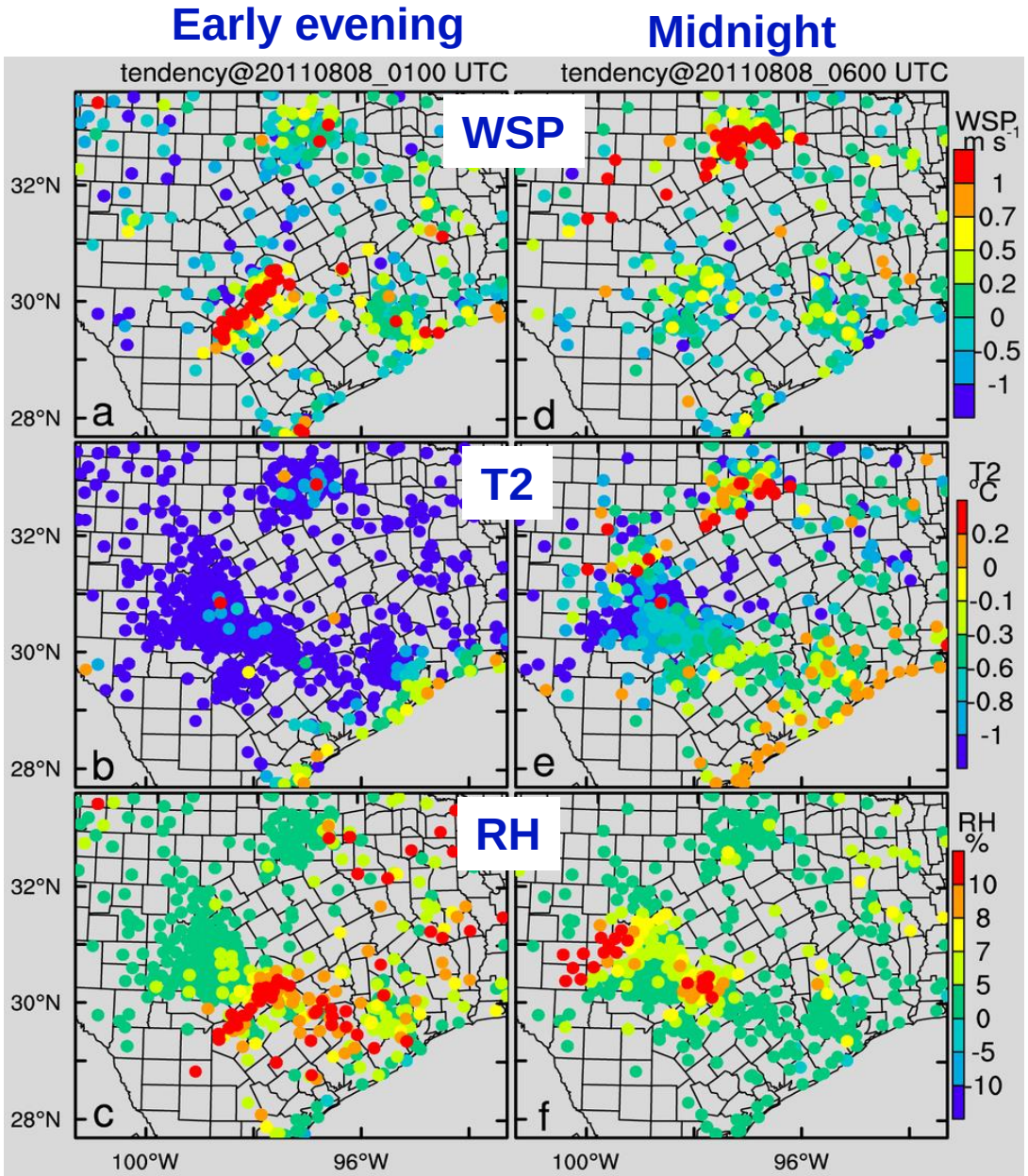
The sea breeze front approached Dallas around midnight (0600 UTC)

Tendency: difference between current and next hours



The inland penetration of sea breeze front can be clearly illustrated in the tendency of WSP, T2, RH.

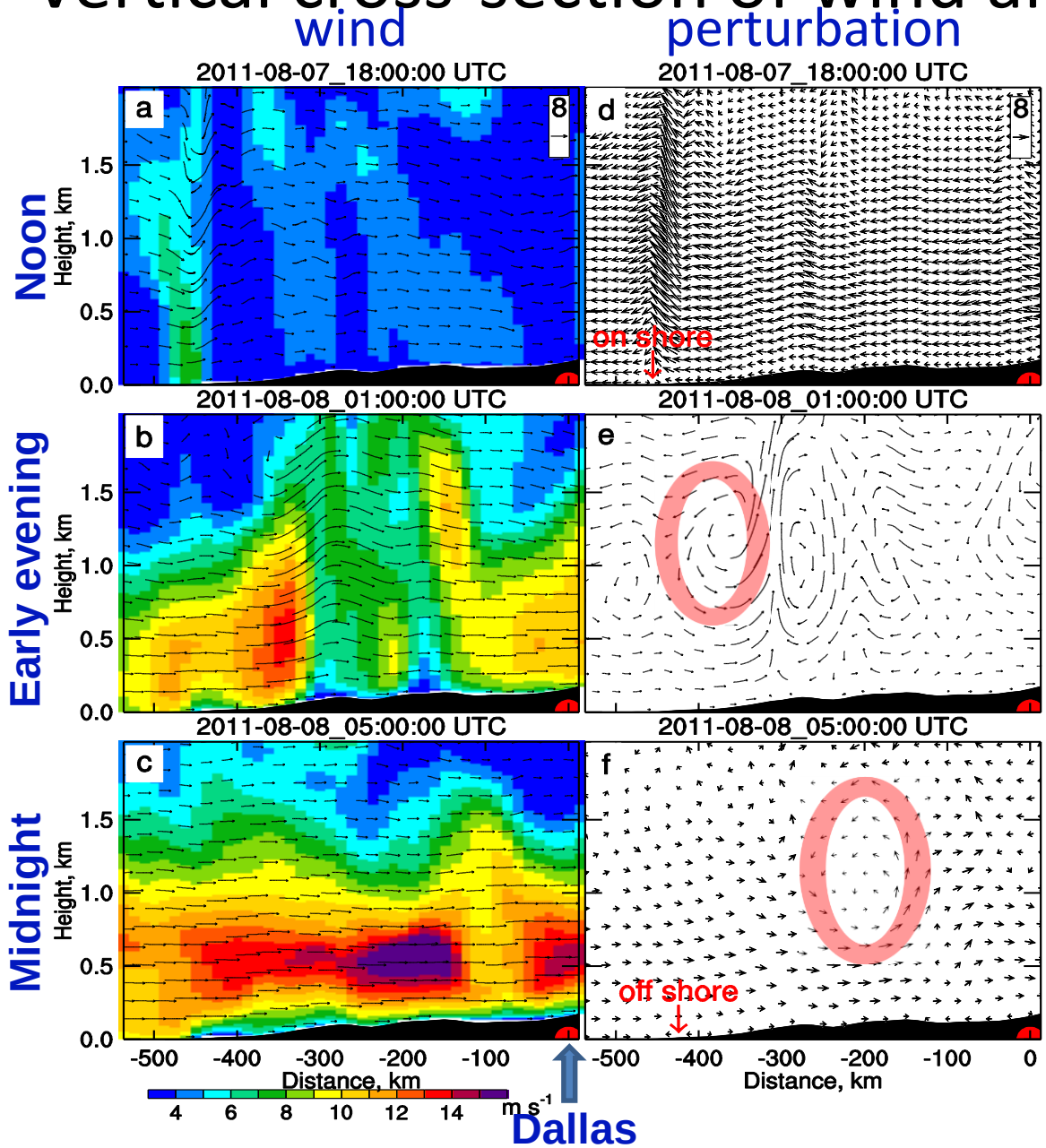
Observed tendency in MADIS data



MADIS integrated data from many providers

In the spatial distribution of tendency, the small scale local heterogeneity in instantaneous values is removed and only the spatial information of temporal variation is remaining.

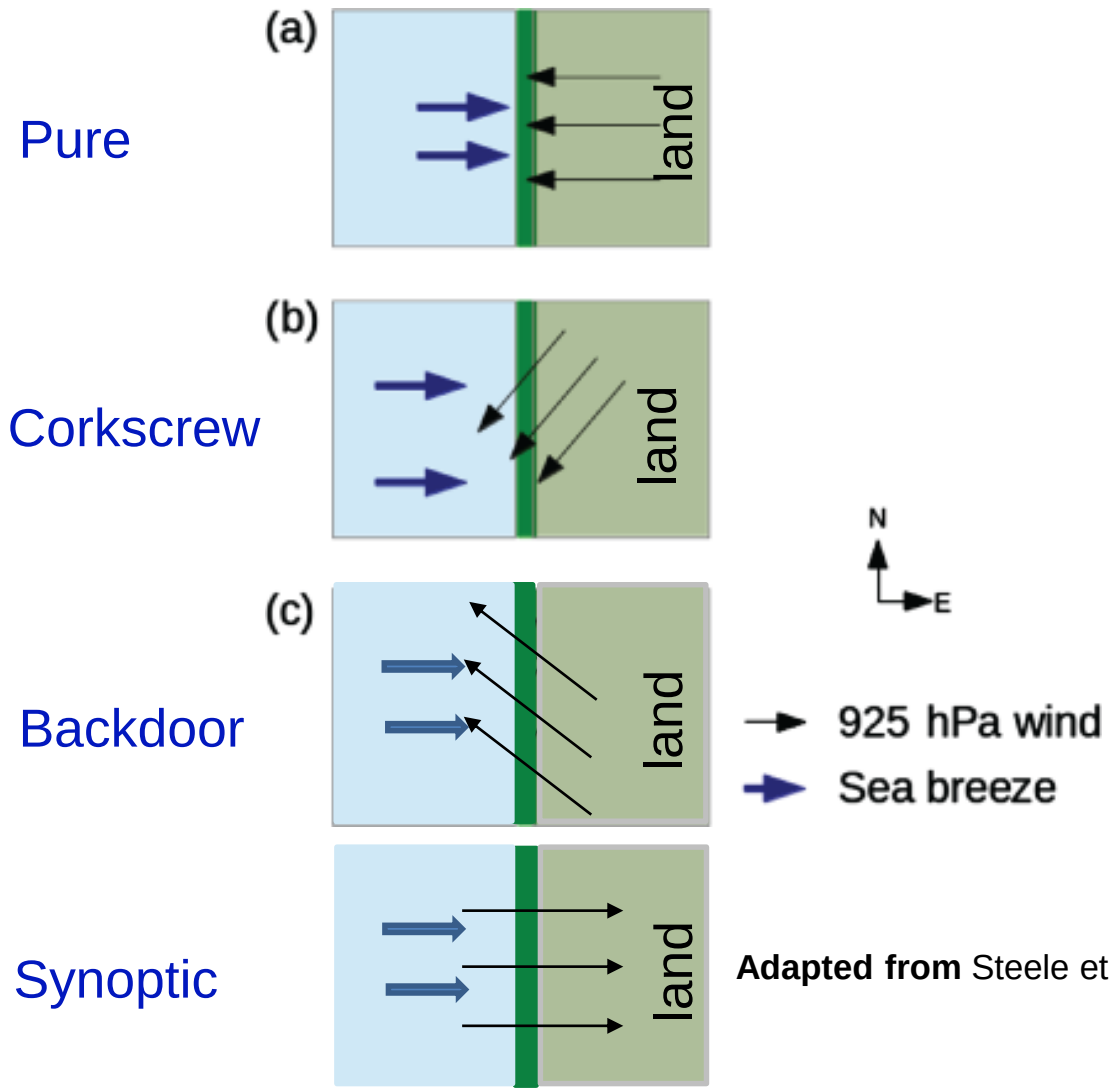
Vertical cross-section of wind and its perturbation



Sea breeze develops in the morning and is advected by Low-Level Jet at night

Synoptic sea breeze

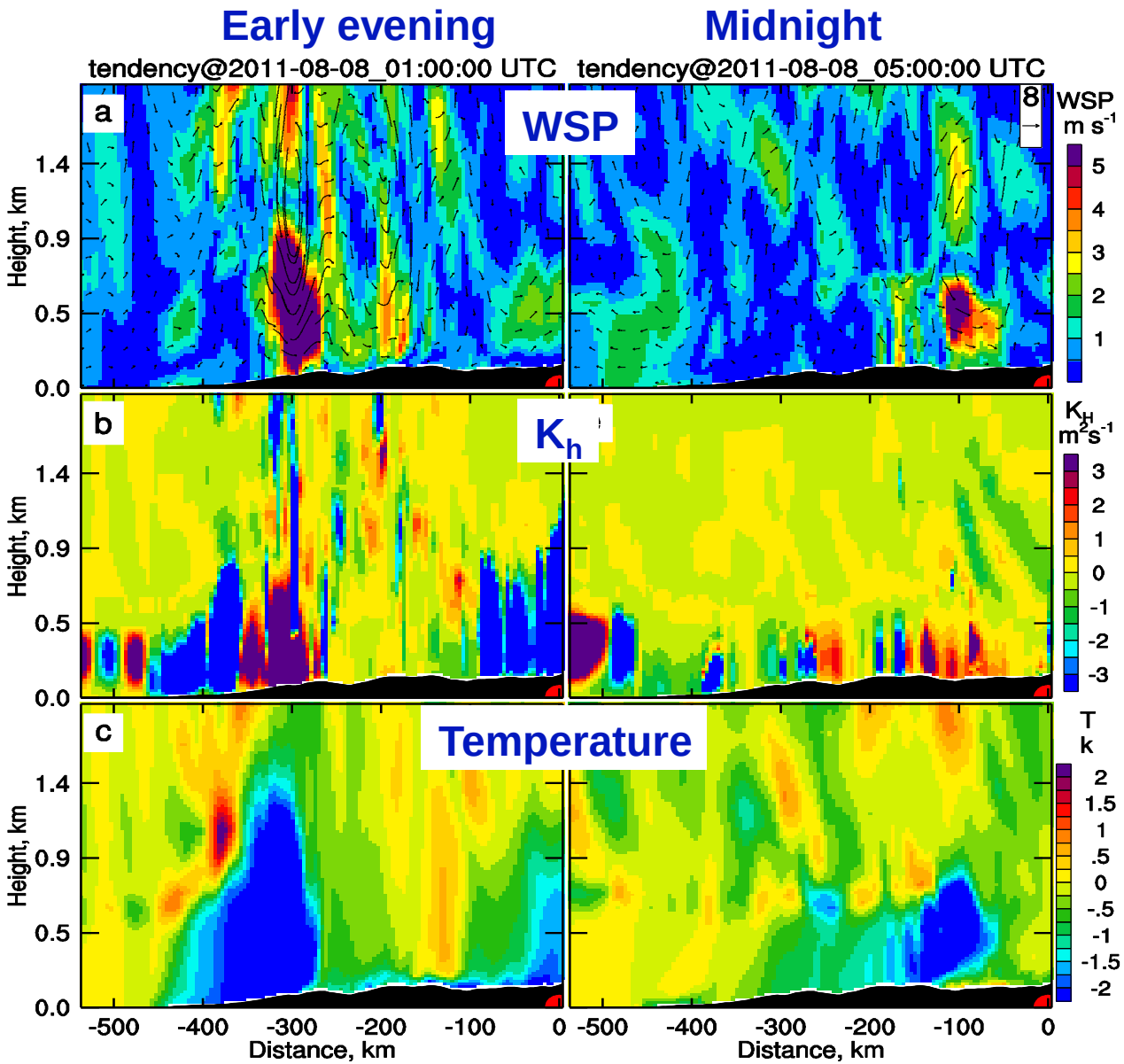
Categories of Sea Breeze



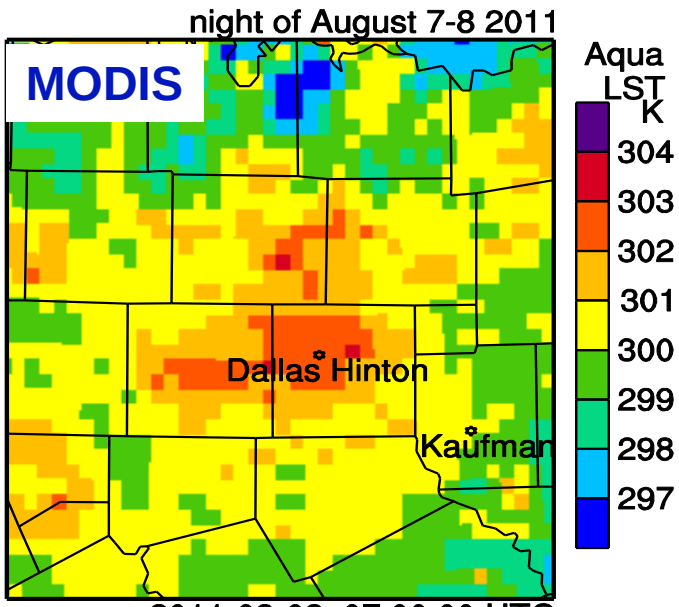
Adapted from Steele et al. (2014, QJ)

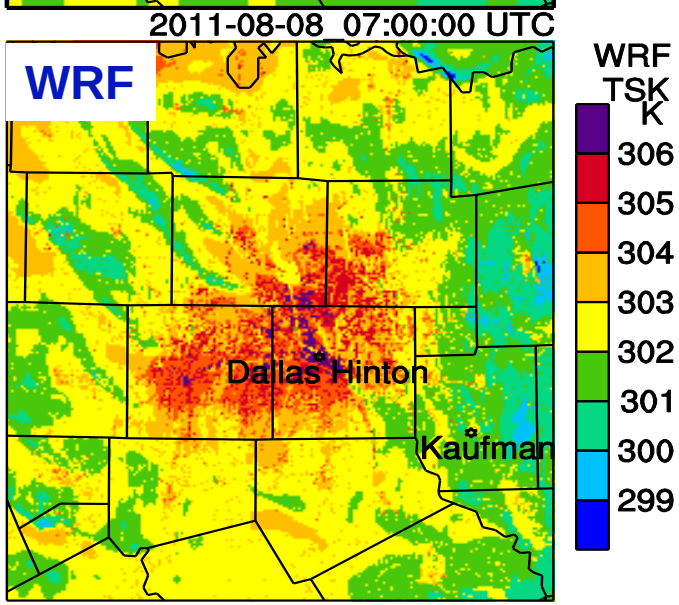
Synoptic sea breezes were less studied previously

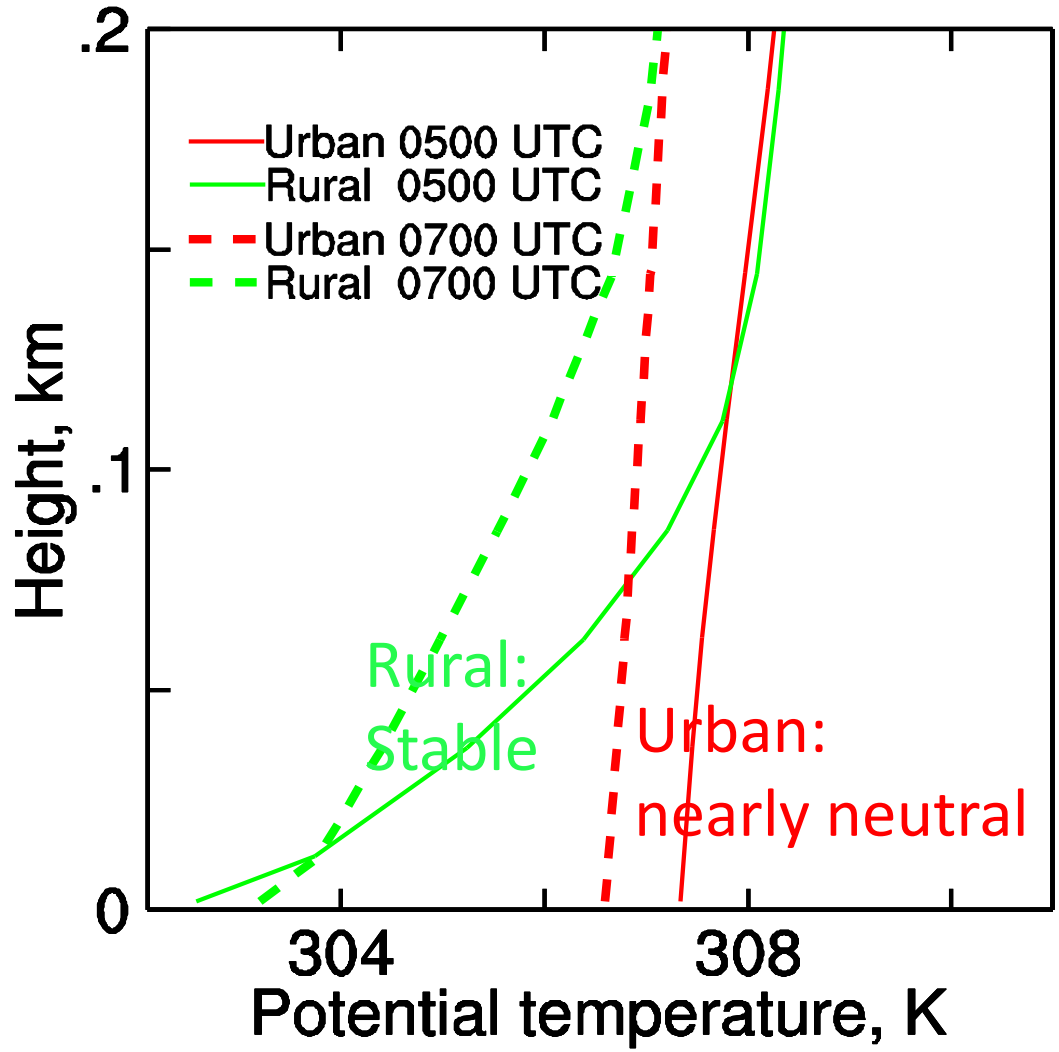
Vertical cross section of tendency of WSP, K_h, T



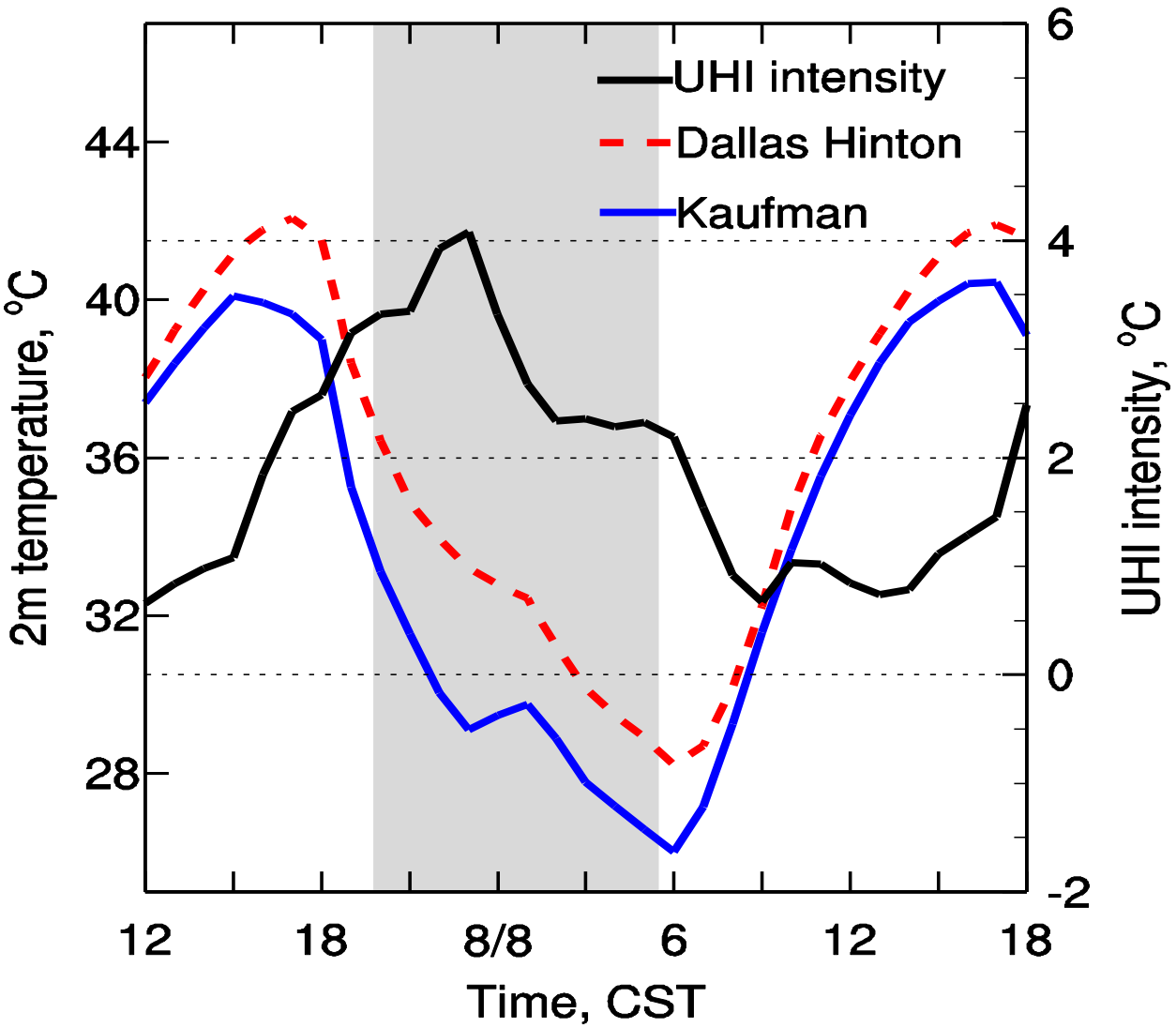
Different response to the front in rural and urban





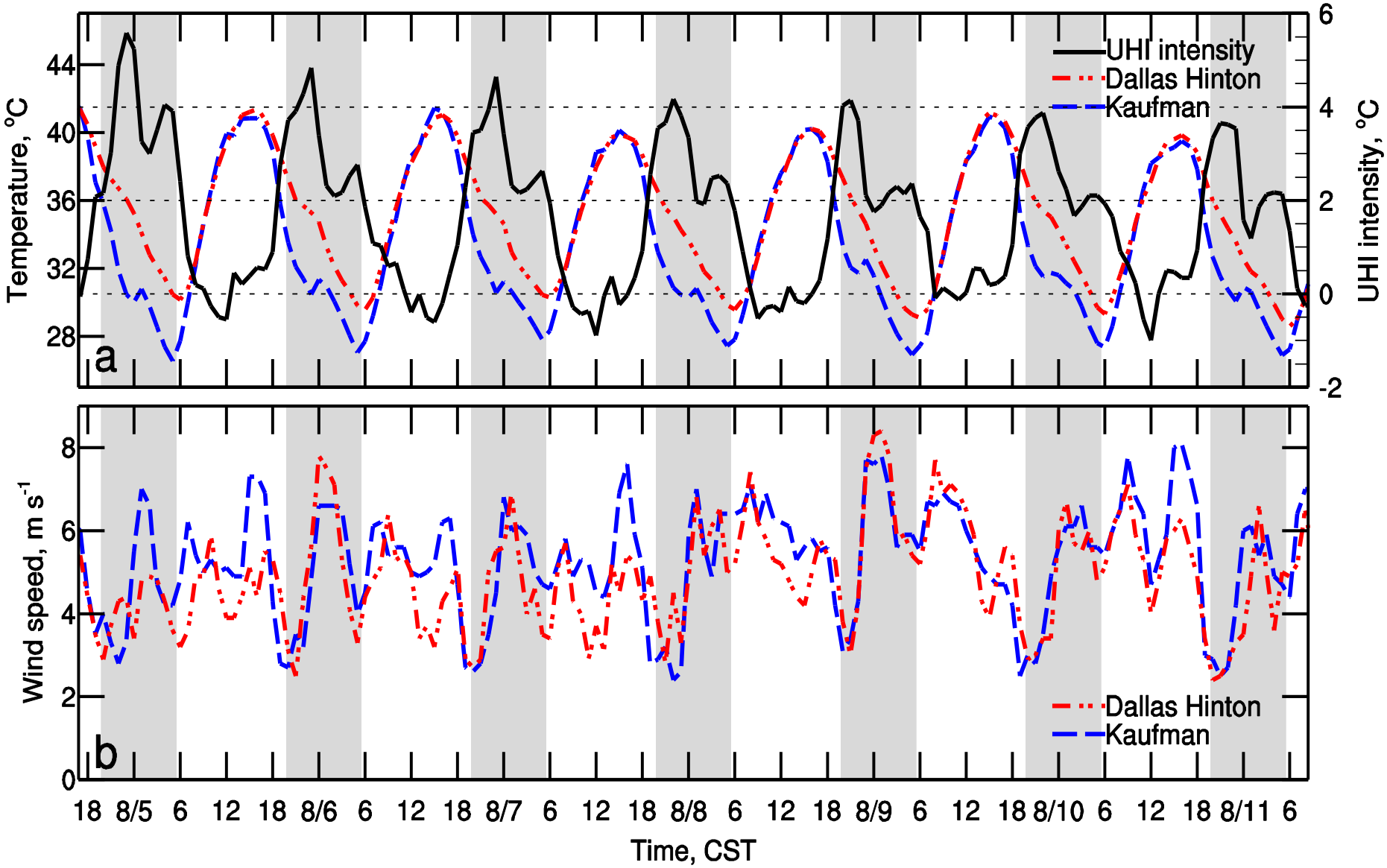


Simulated variation of T, and UHI intensity

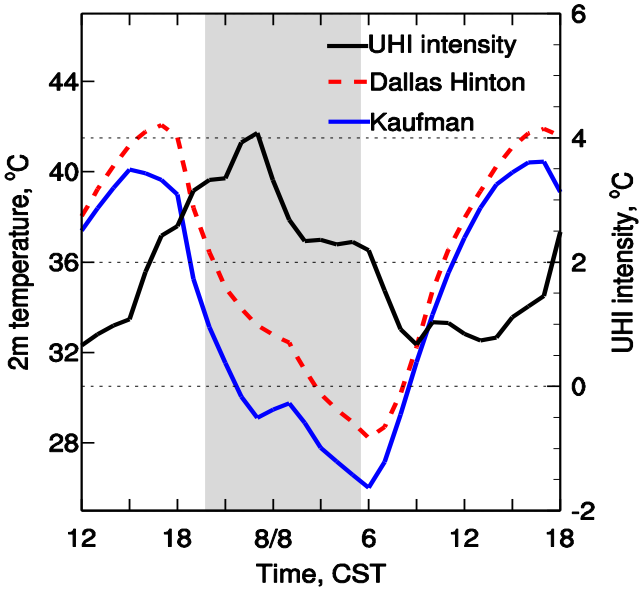


Nocturnal warming in rural and non-warming in urban led to collapse of UHI

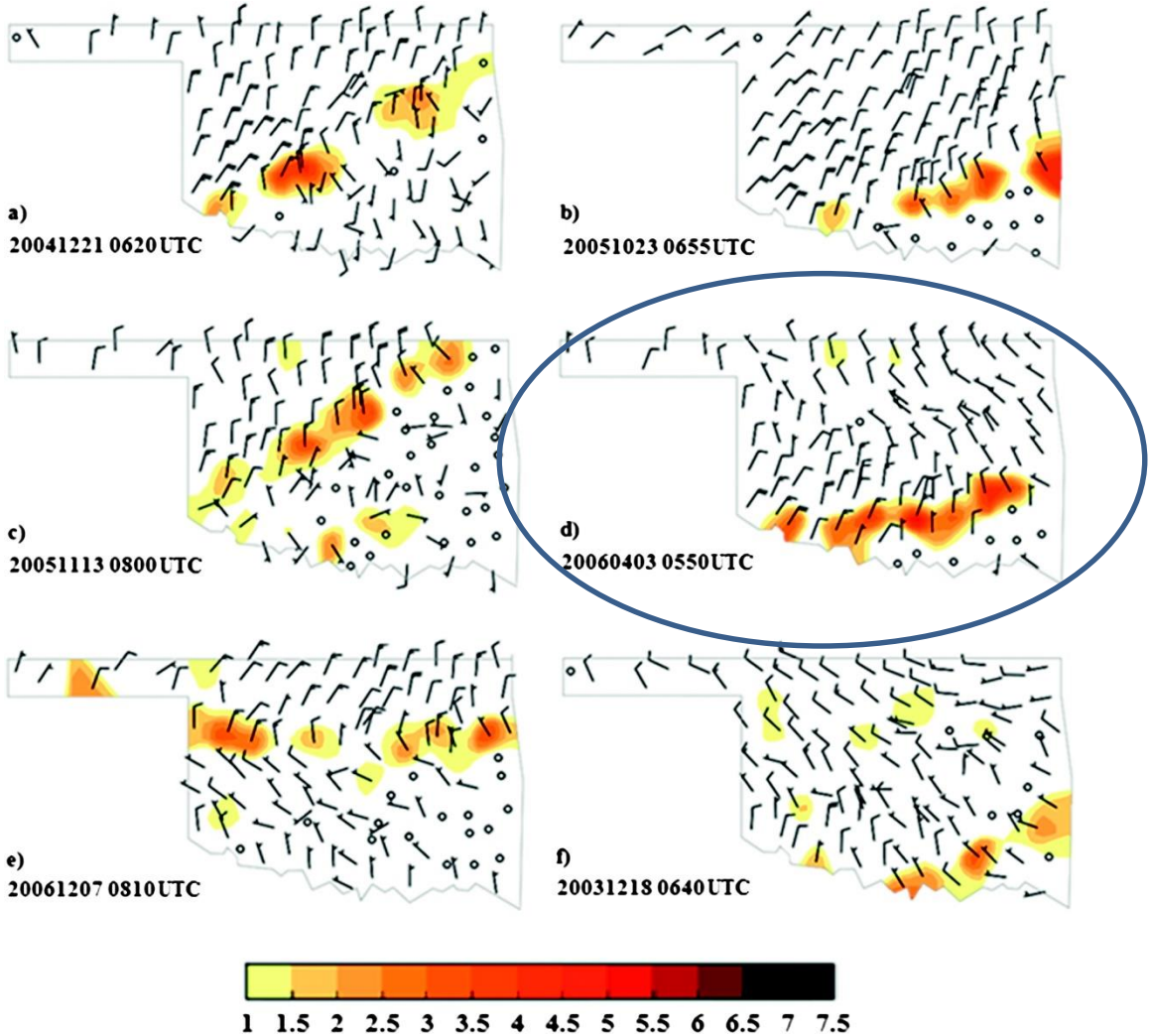
Observed variation of UHI intensity in Dallas



Nocturnal warming events reported previously

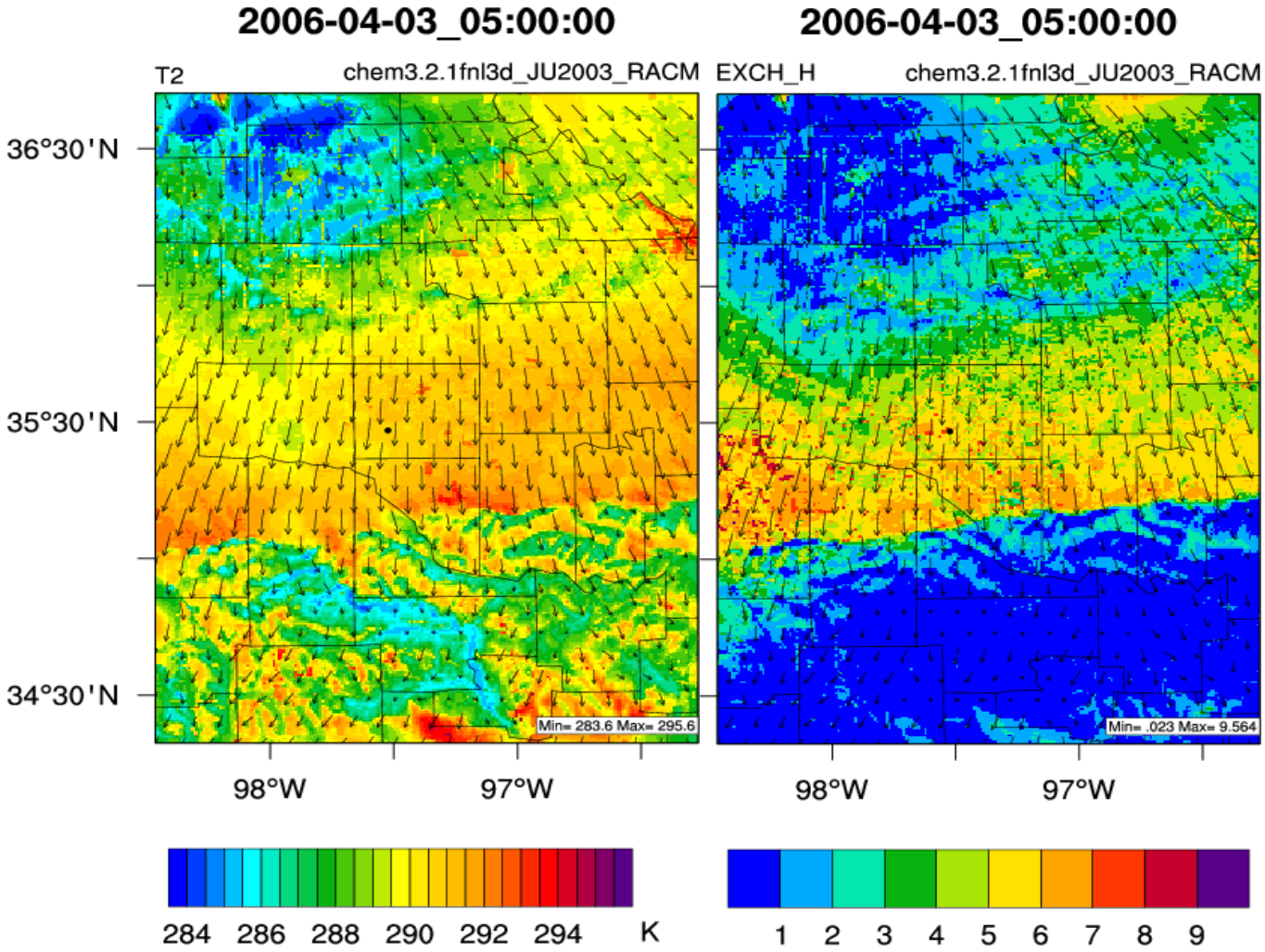


Induced by sea breeze



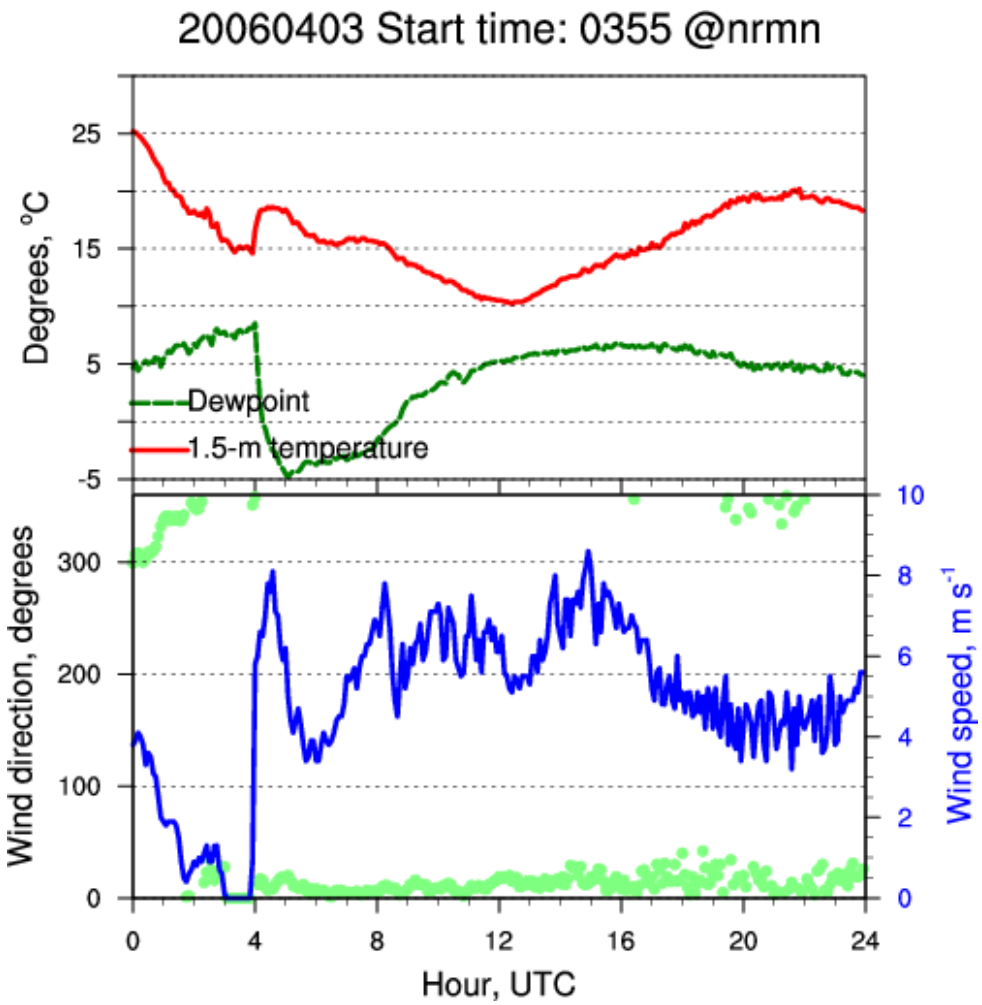
Induced by **synoptic cold fronts** (Nallapareddy et al., 2011)

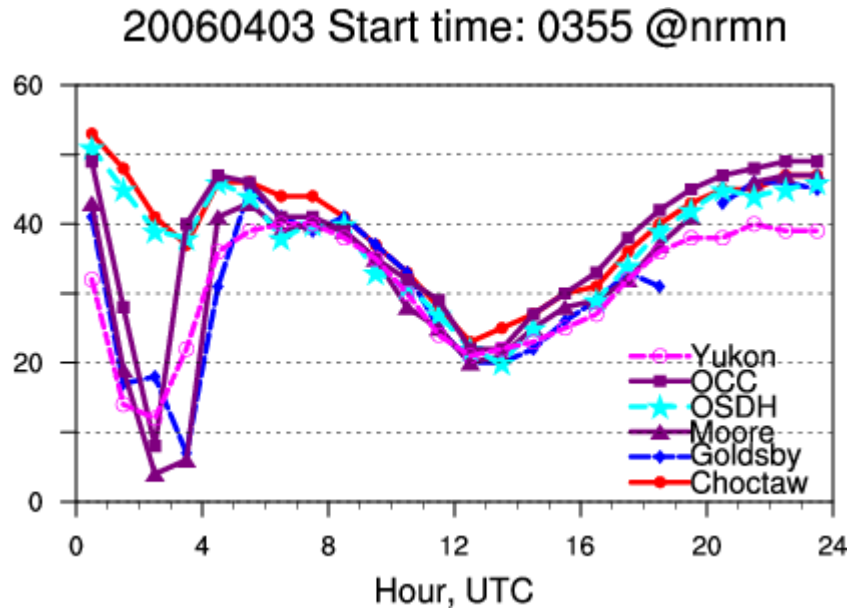
T2 and vertical mixing coefficient at the leading edge of a cold front



Enhanced vertical mixing associate with cold fronts led to surface warming (Hu,2013,JGR)

Nocturnal warming events and O_3 maximum induced by a cold front





O_3 increased by 40 ppb when the nocturnal warming event occurred (Hu, 2013, JGR)

Conclusions

1.“collapse” of nocturnal UHI intensities occurred frequently around midnight in August 2011 in Dallas.

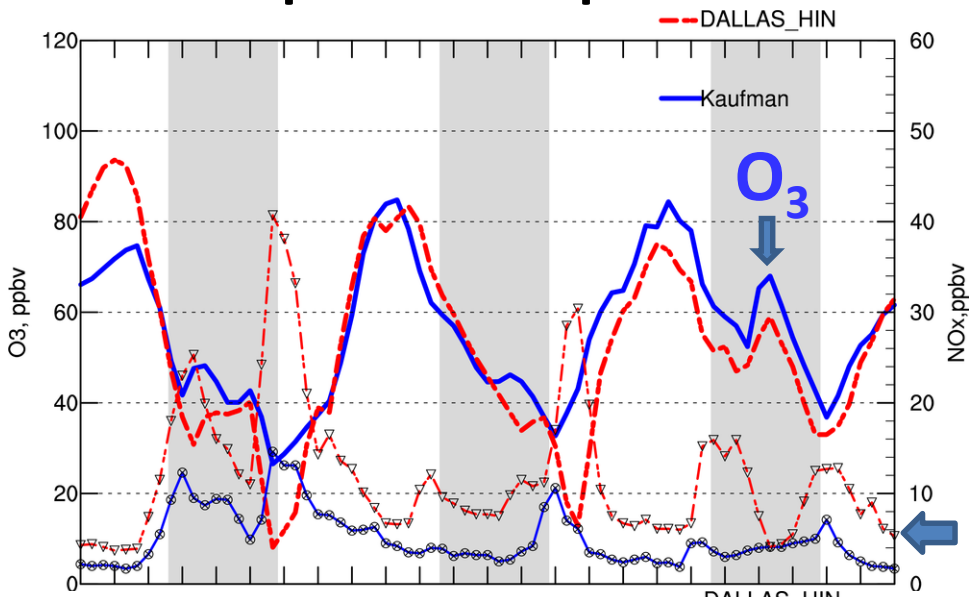
2. Synoptic sea breeze circulation cells can be advected to Dallas and influence its UHI, such a sea breeze category is rarely studied in the past.

Conclusions

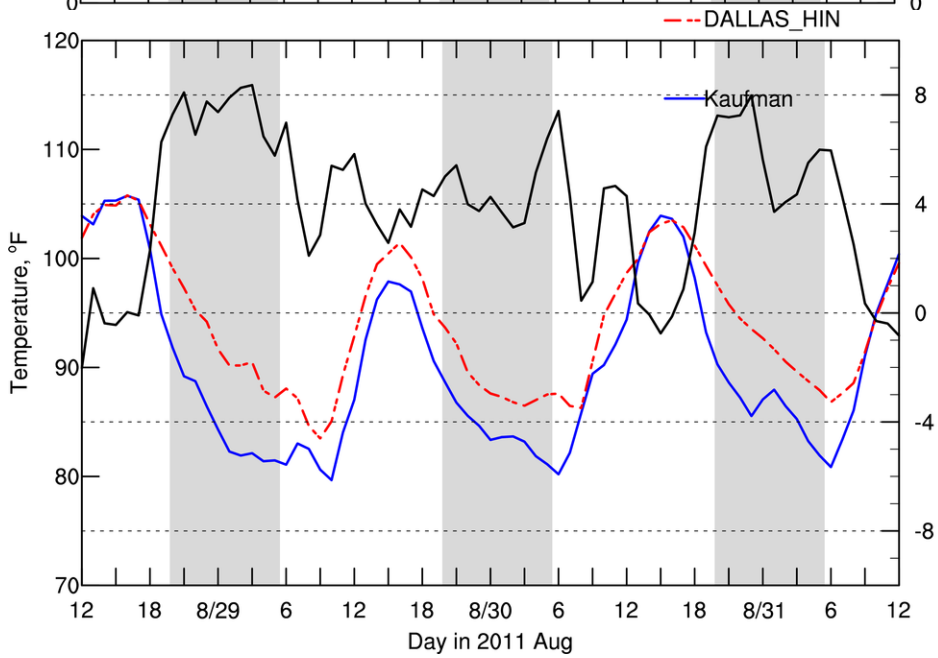
3. Sea breeze frontal passage induced nocturnal warming events in rural area, while it did not alter urban boundary layer much, leading to collapse of UHI.

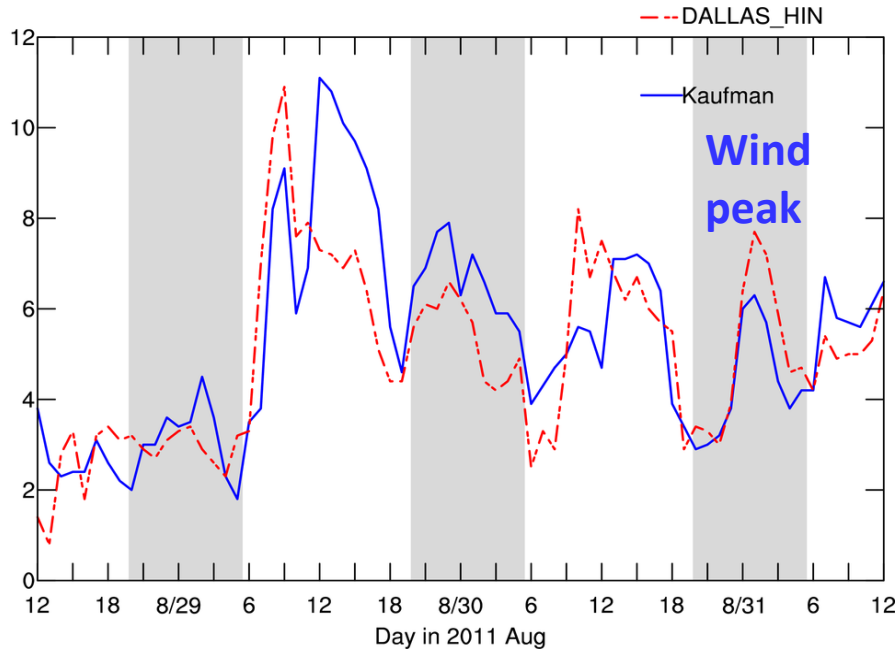
Nocturnal warming events were reported before, but as a result of synoptic cold fronts. In both cases the mechanism is similar, i.e., enhanced vertical mixing associated with momentum fronts plays a dominant role.

Unique temporal variation of nocturnal O_3

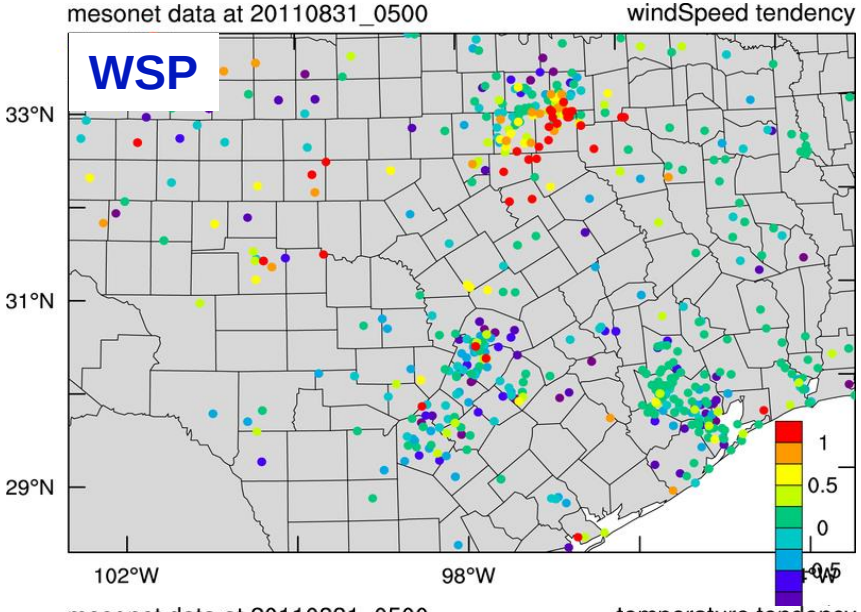


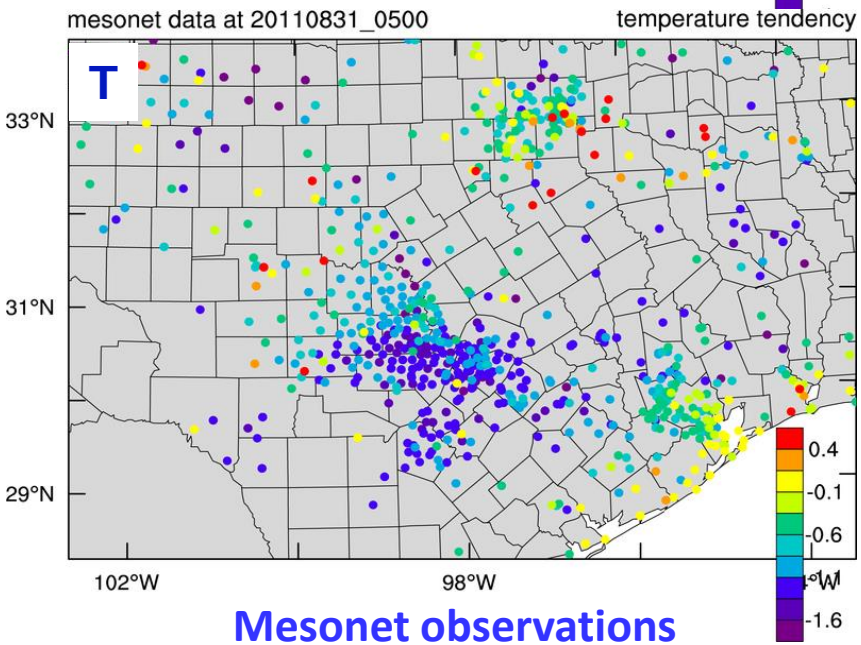
Nighttime O_3 maxima associated with collapse of UHI



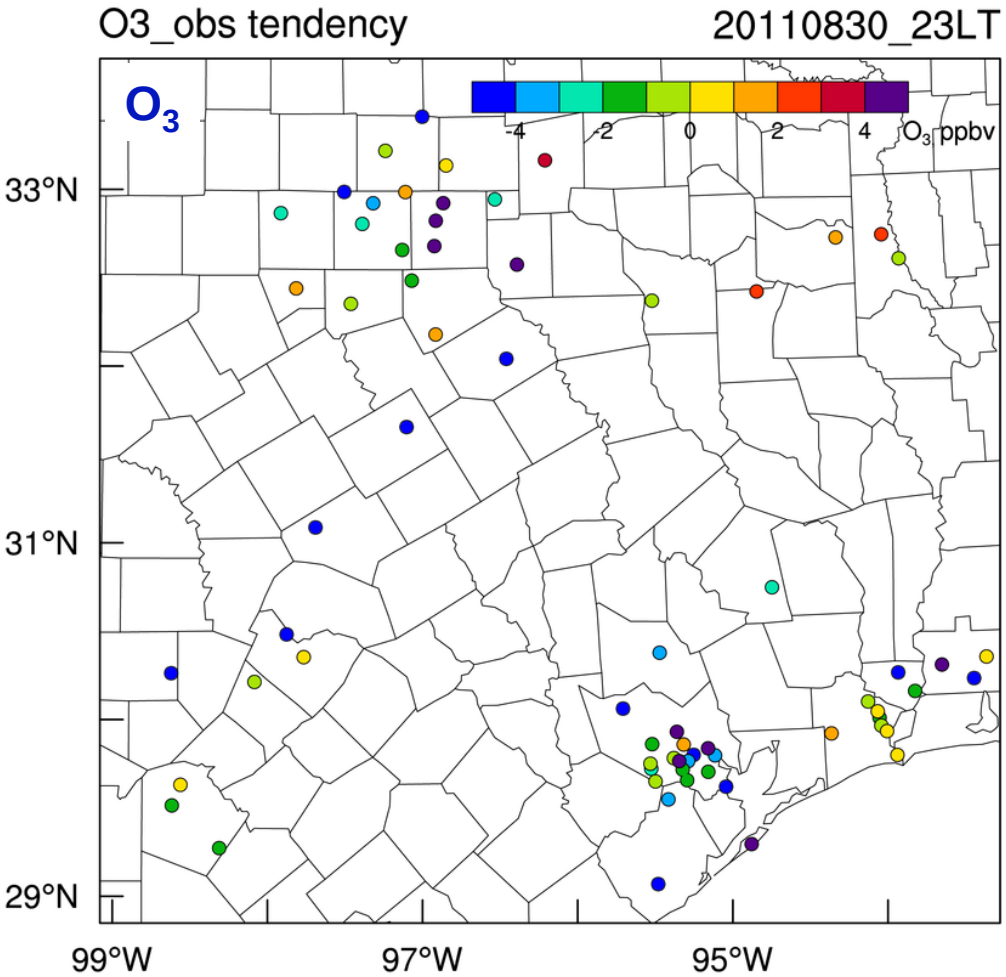


Induced by sea breeze frontal passage? tendencies





Mesonet observations



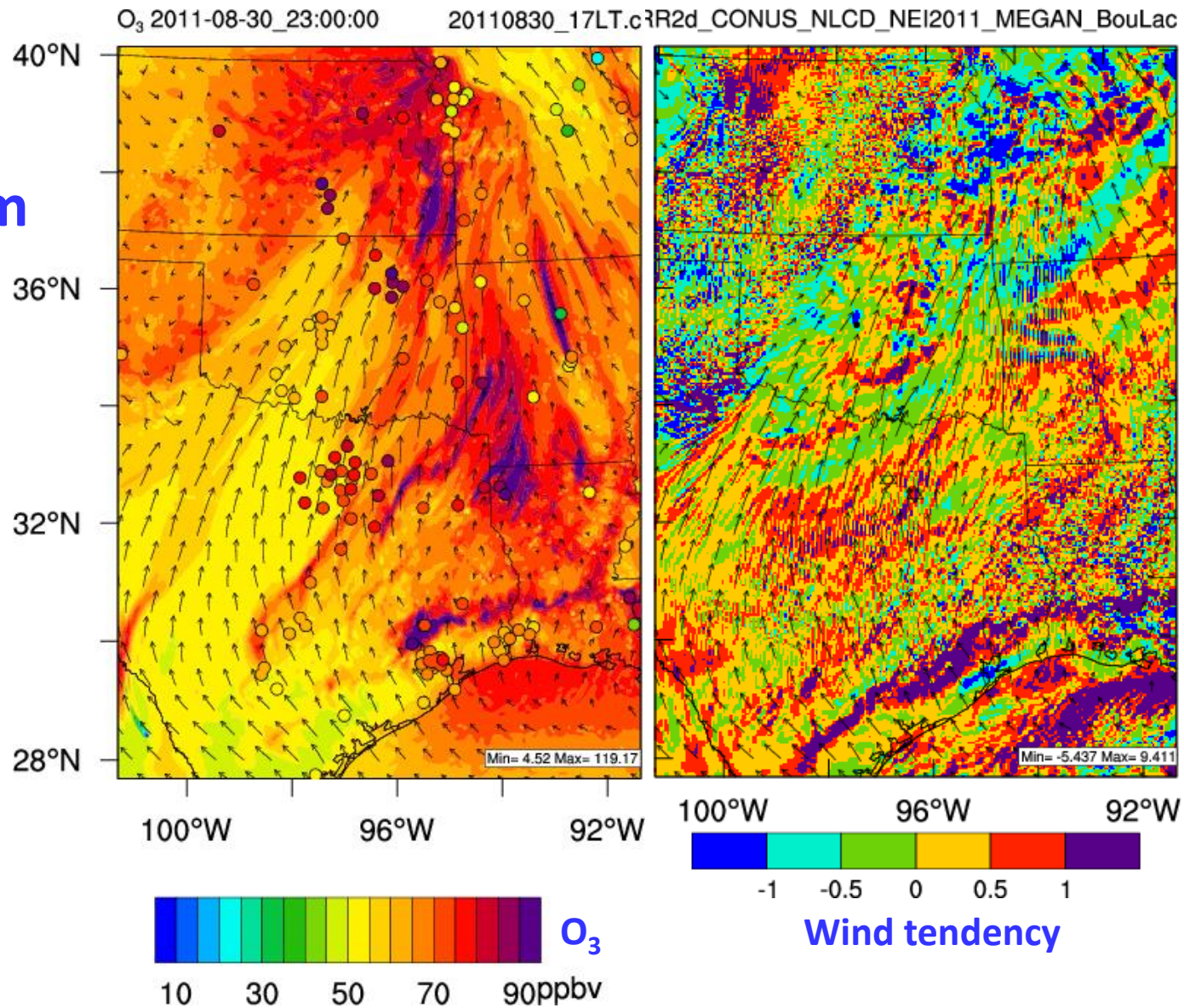
EPA AQS observations

Impact of sea breeze fronts on O_3 in the afternoon

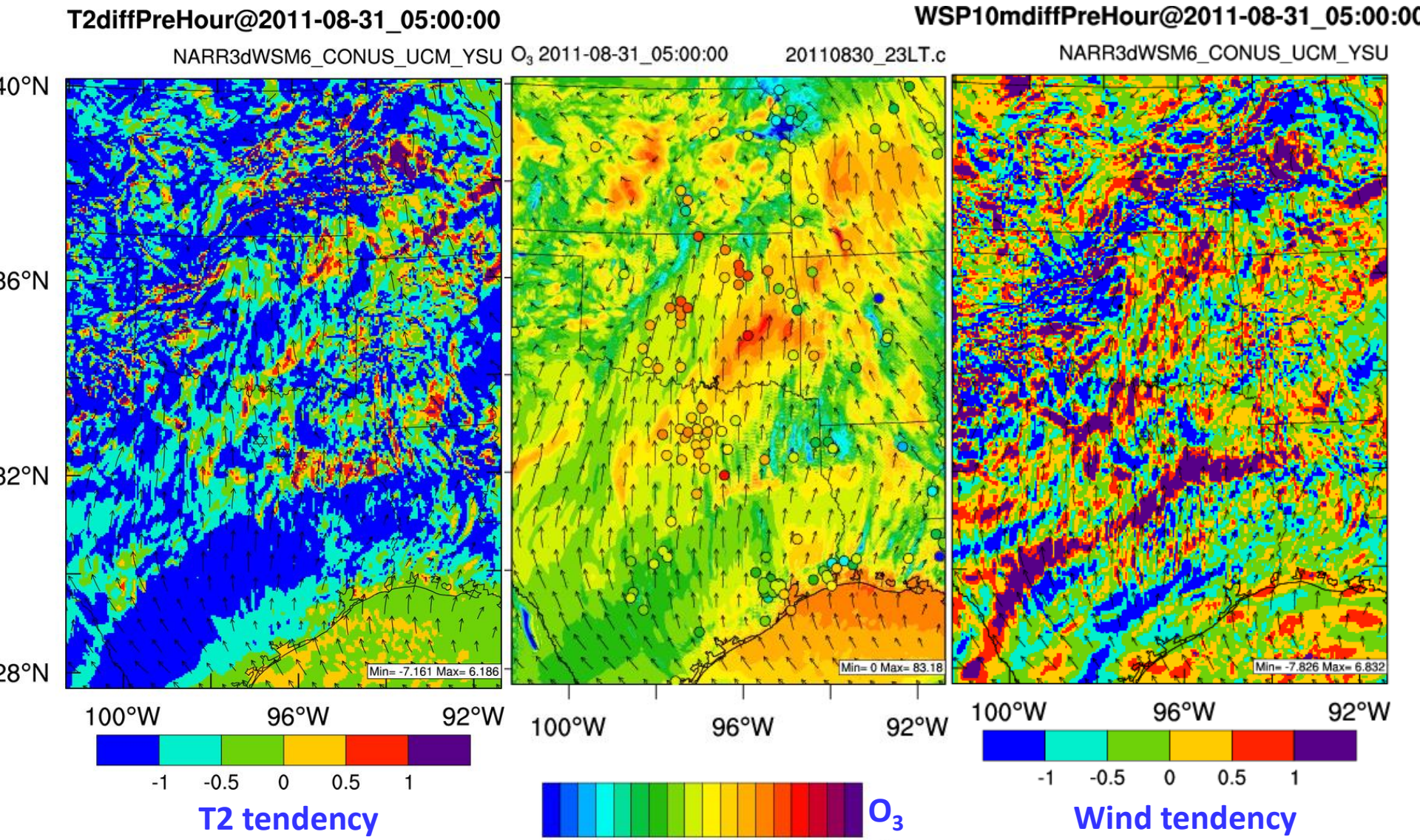
WRF/Chem 3.7

Emission:
NEI2011
MEGAN

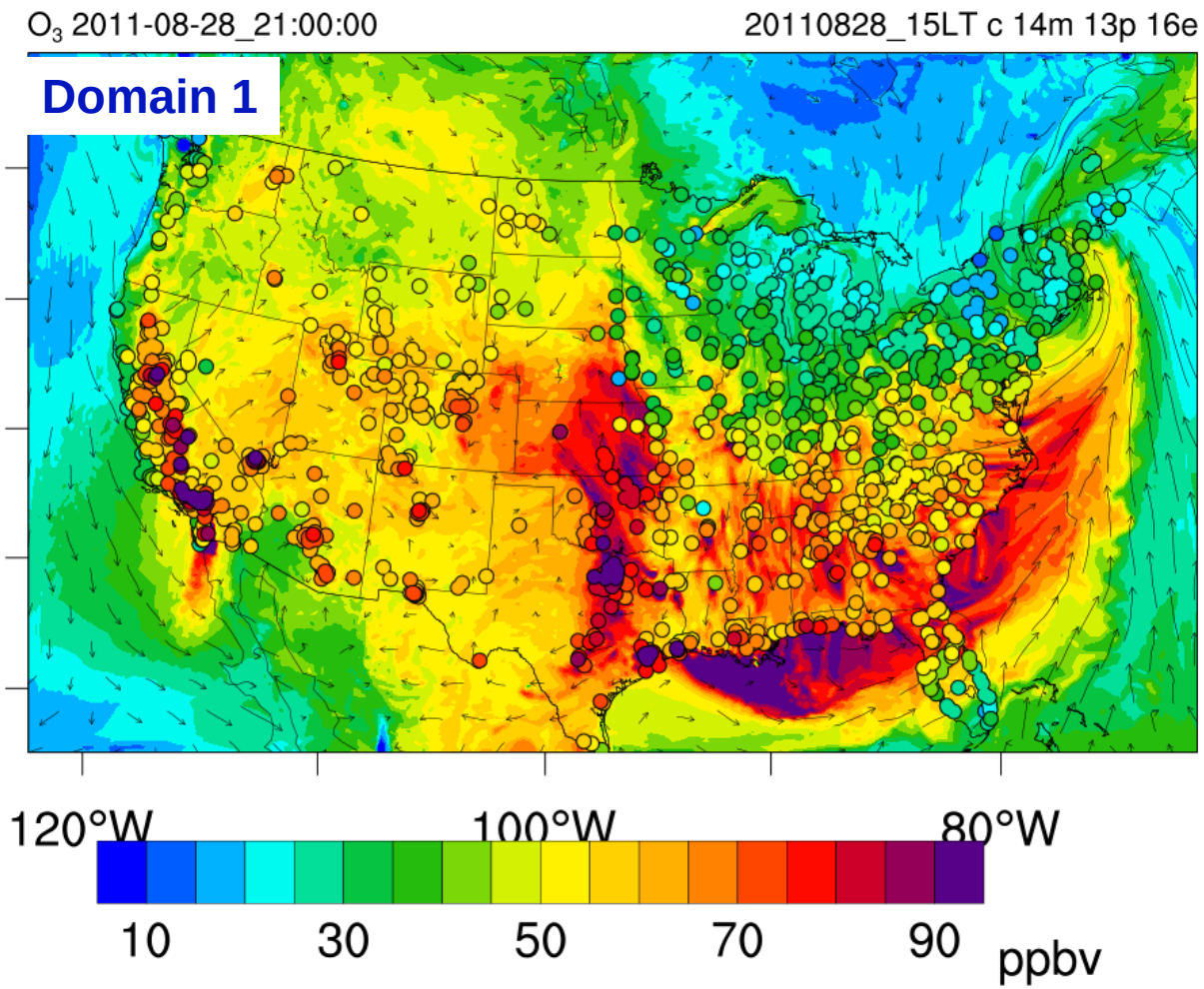
IC/BC:
NARR

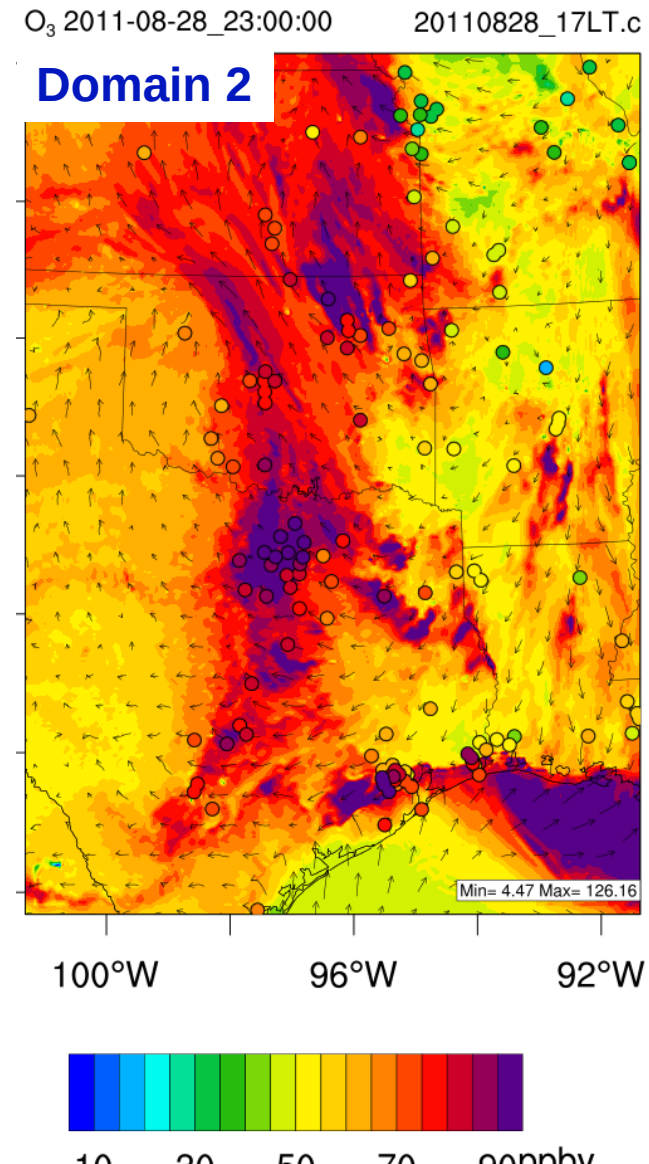


Impact of sea breeze front on O_3 at night



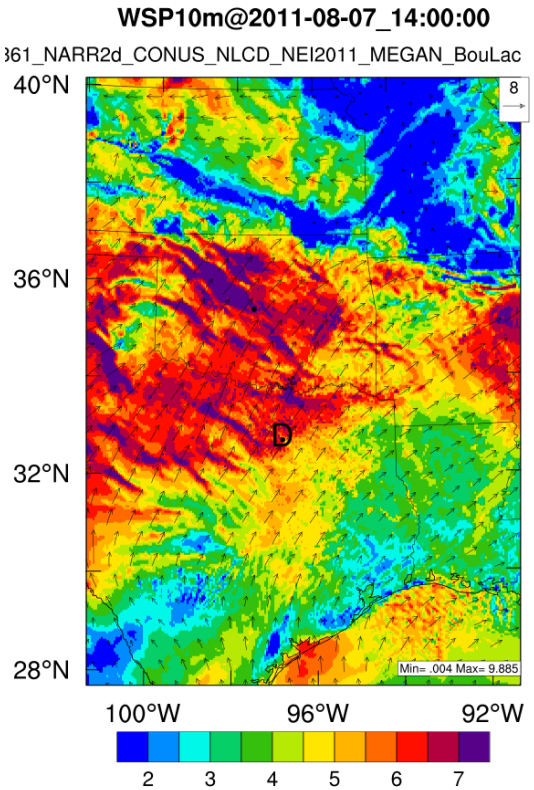
Impact of Hurricane on O_3?



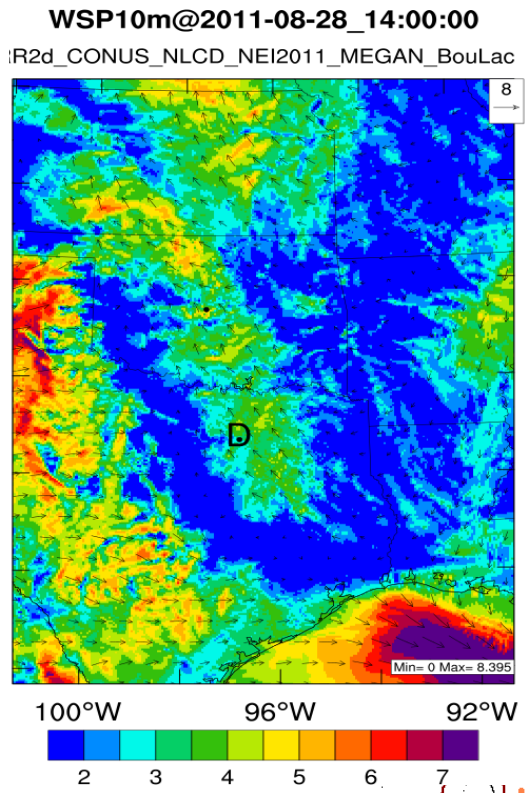


Weak wind zone around Dallas?

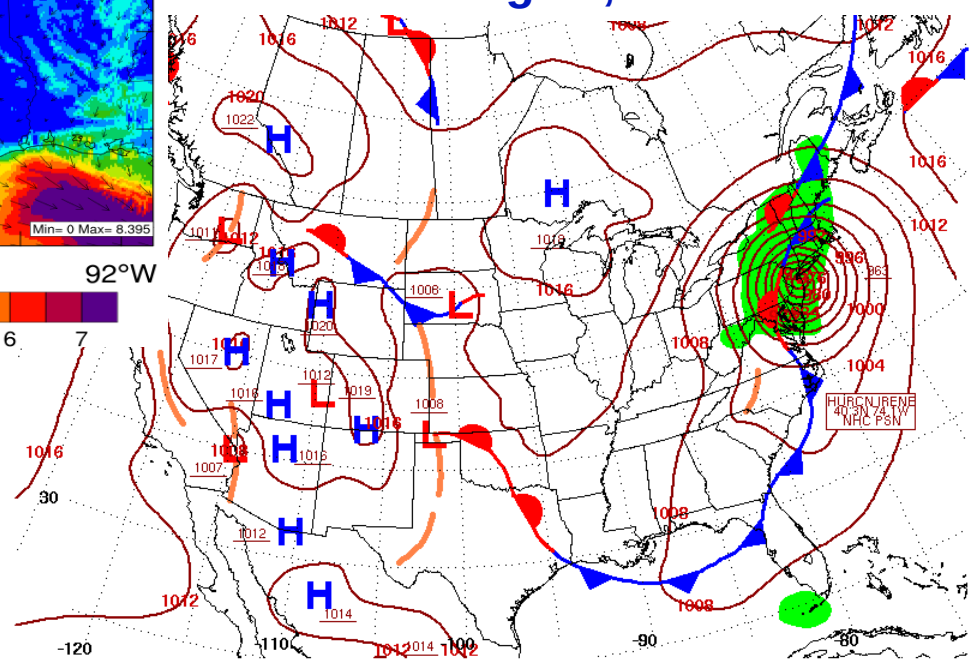
No Hurricane



Hurricane



Aug 28, 2010



Aug 25-30, interesting episode

Area	Monitoring Site	POC	August 2011																															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	F
Dallas-Fort Worth																																		
	Ft. Worth Northwest C13/AH302	2	54	65	64	55	50	45	45	36	45	41	41	39	31	69	56	47	53	52	54	61	60	54	50	56	82	81	86	87	73	66	58	
	Keller C17	2	69	80	80	68	63	58	55	48	57	49	50	48	40	76	70	58	67	62	64	73	74	68	63	70	100	97	95	103	88	78	70	
	Frisco C31/C680	1	86	80	92	78	65	61	54	52	62	47	42	45	43	68	77	57	68	67	71	79	65	73	70	71	91	92	78	89	83	76	72	
	Midlothian OFW C52/A137	1	50	63	61	56	50	42	41	40	42	37	43	36	29	74	58	46	49	57	58	66	57	47	54	60	65	72	95	81	80	71	60	
	Denton Airport South C56/A163/X157	1	73	86	86	77	66	62	59	52	54	53	45	48	44	70	74	61	70	60	67	72	74	76	63	66	102	87	81	98	90	76	71	
	Arlington Municipal Airport C61	1	55	66	67	58	50	44	44	39	44	38	43	37	26	74	61	45	49	54	56	63	53	51	53	57	69	73	92	83	77	68	59	
	Dallas North No.2 C63/C679	1	81	78	87	69	58	53	48	46	50	41	41	38	44	68	68	50	59	64	64	75	67	64	64	67	90	98	88	86	82	73	67	
	Rockwall Heath C69	1	80	76	91	69	56	48	46	42	47	42	44	40	57	61	67	36	45	54	54	67	59	49	52	56	65	79	73	65	64	66	56	
	Grapevine Fairway C70/A301/X182	1	71	83	86	73	60	NV	NA	NV	56	44	45	42	37	68	71	53	64	61	64	71	69	68	62	67	98	91	87	97	81	72	64	
	Kaufman C71/A304/X071	1	58	65	65	57	60	54	44	36	40	42	41	41	47	60	60	54	50	56	60	66	65	50	58	52	62	76	81	68	73	74	64	
	Granbury C73/C681	1	45	59	60	55	48	41	41	37	43	39	49	35	37	67	51	44	49	51	52	59	53	48	50	53	61	70	82	80	71	67	56	
	Eagle Mountain Lake C75	1	55	70	67	59	53	49	48	37	45	47	39	38	36	74	59	49	59	52	55	62	65	59	52	56	84	75	79	85	73	63	58	
	Parker County C76	1	52	67	69	63	56	50	50	41	49	47	58	39	45	70	62	55	61	58	59	67	68	59	56	61	84	78	88	93	82	72	63	
	Cleburne Airport C77/C682	1	50	60	60	56	50	43	41	38	43	41	44	38	37	74	50	43	48	54	56	62	52	50	52	57	67	69	90	82	75	67	56	
	Dallas Hinton St. C401/C60/AH161	3	70	75	75	61	52	48	44	41	43	35	41	33	34	68	59	45	40	52	55	67	60	55	55	58	79	88	90	84	76	66	58	
	Dallas Executive Airport C402	1	60	70	69	55	48	41	40	37	42	34	41	32	30	69	58	44	47	55	59	67	58	51	56	57	71	78	96	82	82	73	63	
	Greenville C1006/A198	1	70	67	80	64	52	49	46	38	44	36	41	45	38	69	74	50	54	61	65	71	64	54	58	59	73	83	77	73	66	76	66	
	Pilot Point C1032	1	78	88	91	84	75	68	60	60	64	56	42	51	50	71	91	65	75	67	74	79	64	79	72	67	91	87	79	92	81	83	77	
	Italy C1044/A323	1	43	54	56	52	44	38	33	37	36	35	43	33	34	58	57	47	46	55	57	66	57	49	53	59	62	NV	83	75	79	71	60	
	Corsicana Airport C1051	1	54	64	61	56	58	51	40	37	39	42	43	38	27	64	61	53	57	59	61	67	58	57	59	57	63	69	84	70	76	78	66	
Houston-Galveston-Brazoria																																		
	Houston East C1/G316	2	61	49	43	39	29	31	27	29	23	27	29	29	27	36	36	40	52	68	68	62	48	55	53	54	58	97	80	92	97	80	65	
	Houston Aldine C8/AF108/X150	2	71	57	49	45	34	32	29	32	30	29	33	32	29	32	43	46	56	69	74	64	44	61	62	63	59	100	78	70	73	86	69	
	Channelview C15/AH115	3	60	43	37	39	28	29	24	28	25	28	26	29	28	39	34	33	46	69	66	55	40	52	50	47	56	73	78	77	93	68	55	
	Northwest Harris Co. C26/A110/X154	2	64	64	50	42	37	37	30	30	27	34	39	36	29	29	42	48	57	63	70	71	44	65	56	NV	NA	80	79	75	79	100	83	
	Hou.DeerPrk2 C35/235/1001/AFH139FP239	1	39	33	27	29	22	23	21	23	22	24	24	24	23	33	28	32	44	54	55	54	37	44	42	42	52	80	83	82	92	79	59	
	Seabrook Friendship Park C45	1	42	32	26	32	23	23	21	23	21	22	23	23	21	28	25	26	37	43	49	52	34	39	37	40	52	65	84	76	83	76	55	
	Houston Bayland Park C53/A146	1	47	41	35	31	24	24	23	25	23	22	27	23	26	33	30	34	43	51	58	50	32	39	39	37	46	88	79	98	99	71	63	
	Conroe Relocated C78/A321	1	63	64	56	51	48	49	33	36	34	44	45	49	34	32	60	63	72	62	61	60	47	66	66	56	60	71	77	64	72	78	62	
	Houston Regional Office C81	1	47	39	33	30	NV	25	23	24	20	22	25	23	22	34	30	34	45	56	59	54	40	43	44	45	45	97	80	99	96	76	65	
	Manvel Croix Park C84	1	41	39	31	28	25	24	24	26	21	25	27	25	23	32	27	34	43	49	55	52	32	35	36	34	47	89	88	98	84	73	65	
	Clinton C403/C304/AH113	3	44	37	30	27	21	24	22	21	18	21	23	22	21	35	26	30	41	53	55	54	41	40	42	44	42	90	78	92	90	69	59	
	Houston North Wayside C405	1	61	52	44	39	29	30	27	27	25	26	28	29	27	36	39	39	51	66	69	62	47	54	56	57	49	99	80	74	84	80	66	
	Houston Monroe C406	1	38	31	26	25	22	21	19	22	18	21	22	20	19	27	24	28	37	47	46	47	33	31	31	37	38	76	75	81	76	71	55	
	Lang C408	2	60	48	41	36	29	28	27	29	26	28	32	29	27	34	40	39	50	59	63	60	41	57	48	49	50	94	77	77	72	78	62	
	Houston Croquet C409	2	45	39	33	30	25	25	23	25	22	24	26	23	24	32	28	33	41	49	55	49	30	36	38	35	45	80	79	101	85	67	62	
	Houston Westhollow C410	1	46	43	37	32	26	27	23	23	20	26	28	27	23	30	28	33	44	49	55	50	35	39	NV	37	46	81	75	93	92	67	60	

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