Multi-Episodic and Seasonal Evaluation of the Impacts of Heat Island Control and Solar Power Generation on Meteorology and Air Quality

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GOALS OF THE PROJECT

1. Multi-episodic and seasonal evaluation modeling of the impacts of heat-island control on meteorology and air-quality in California
   - Evaluation under broad range of meteorological conditions – versus episodic / worst-case scenarios
   - Threshold effect
   - Ozone meteorology characterization – CART
   - Detailed urban morphological characterization
   - Mesoscale modeling / Meso-urban modeling (meteorology, emissions, and AQ)
   - Emissions equivalence
   - UHI control via high albedo (relevance to Title 24 cool roofs, AB32 early action plan)

2. Scoping the impacts of large-scale solar arrays deployment in urban areas
   - Quantifying potential impacts – what are the issues?
   - Proposing mitigation measures and recommendations for next steps
   - Extension to solar power plants (heat-pollution plumes)

PROJECT STATUS

Heat-island component of project

- Status: work in progress
- Initial results expected in December time frame
- Current: Meteorological and AQ modeling of perturbations scenarios
- LULC characterization completed
- Base case meteorology completed
- Base case air-quality completed
- Models performance evaluation completed

Solar component of project

- Work will begin in 2011

PROJECT STATUS

- Analysis of ground-level ozone data (California) at monitor level
- CART analysis at monitor and county levels using years 2000-2005 in addition to years 1995-2005
- Classification trees as well as regression trees
- Ranking of AQ monitors by ozone peaks and dates
- Initial selection of episode-regions and season-regions
- Screening of episodes for fire and / or smoke events and finalization of episodes selection
- Synoptic and CART analysis of weekdays separate from weekends
- Full model data sets for all episode-regions and seasons (surface/land-use/morphology, meteorology, emissions, air quality)
- Meteorological (mesoscale, meso-urban), emissions, and photochemical modeling

URBAN HEAT ISLANDS

Symptoms:

- Surface temperature + 10-20K
- Air temperature + 1-6K
- Velocity ± 2-5 m/s
- Mixing, Turbulence

Impacts on / exacerbation of:

- Energy use
- Emissions (NOx, VOC, CO2, ..)
- Photochemical production of O3
- Heat waves
- Thunderstorms, precipitation, and heat pollution plumes
- Local impacts of GCC (heat waves, AQ, emissions, energy use)

Potential ramifications / regulatory:

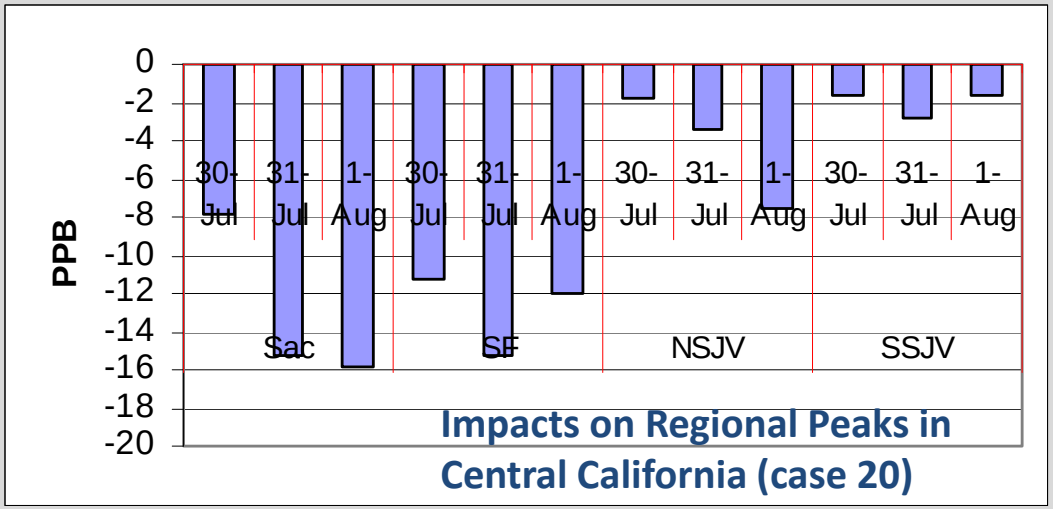
Inaccurate accounting for impacts of urban meteorology and UHIs (under a range of met conditions and scenarios of future growth) on emissions and photochemistry can bias attainment demonstration

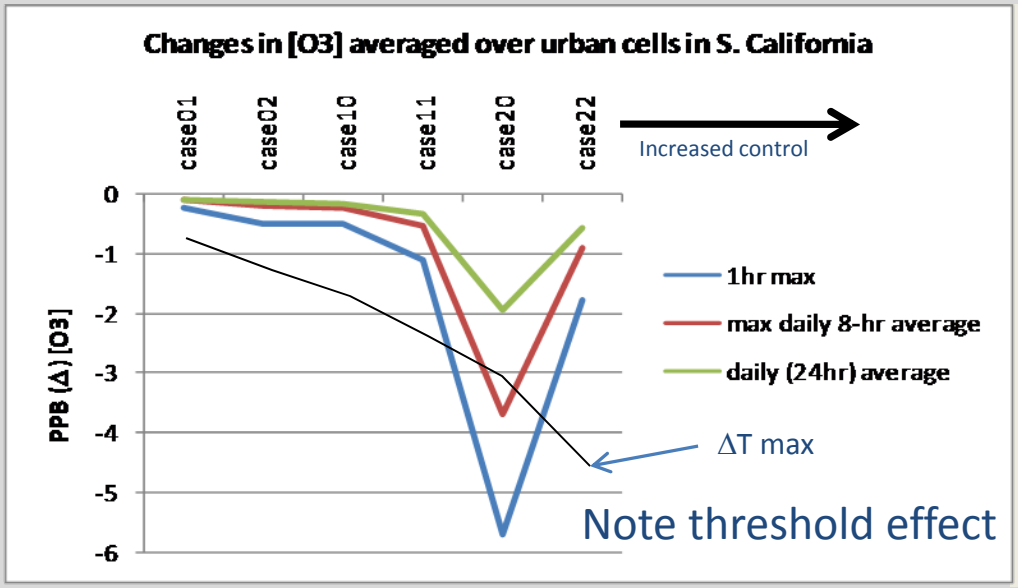
Current regulatory / SIP modeling is not sufficiently resolved within the UCL or urban areas in general, thus can underestimate the urban effects.

Climate change will impact air-quality control; thus UHI mitigation can become a viable additional control strategy in the future (expected local impacts of GCC ~ magnitude of UHI) -- thus should be evaluated

REGULATORY EPISODES

AQ Benefits of increased urban albedo





Southern California

Changes in [O3] averaged over urban grid cells in Southern California: Simulated UHI control for August 5th.

Case##

albedo ∈ 0,1,2

veg cover ∈ 0,1,2

0: none
1: moderate
2: high

REGULATORY EPISODES

AQ Benefits of increased urban albedo: Sacramento

Base-case peak (simulated)				Δ [O3] (ppb) at location of peak	
		Time of peak (LST)	Location of peak (see Figure 9)	At time of peak	Max Δ [O3] at any time
	Peak (ppb)			Albedo - basecase	Albedo - basecase
July 29	103	1600	A	-8.7	-8.7 (at1600)
July 30	113	1600	B	-10.9	-11.1 (at 1700)
July 31	96	1400	C	-8.1	-10.6 (at 1300)
August 1	117	1500	D	-22.2	-22.2 (at 1500)
August 2	101	1600	E	-6.7	-9.2 (at 1700)

Source: Taha 2008.
Atmospheric Environment

Changes in [O3] at time of 1-hr base-case peak, and other times, on each day of the July-August 2000 episode in the Sacramento **uMM5 domain** (resulting from increased urban albedo), corresponding to a decrease of up to 2-3 C in air temperature.

NON-WORST-CASE CONDITIONS (non-regulatory episodes)

Determinants of AQ at a locale: Various spatial and temporal scales
Aspects addressed in this study:

- Global
- Synoptic → qualitative analysis, e.g., weather maps, mesoscale modeling
- Local / upper air → Meteorology CART analysis vs. ozone at monitor and county levels, modeling
- Surface-level flow and surface meteorology → mesoscale modeling and obs. data
- Coupling / Non-coupling of source / receptor → mesoscale modeling and trajectory analysis
- Urban, UHI, Micrometeorology → meso-urban modeling
- Emissions, trends, and controls → emission inventories
- Meteorology-dependent emissions: esp. biogenics → BVOC modeling

OZONE METEOROLOGY
AQ and MET CART ANALYSIS

Profilers:
KOAK, VAFB, PMNAS, CLNWS, EAFB, SNNOF

Counties:

SFBA

AL = Alameda
CC = Contra Costa
SC = Santa Clara
SJ = San Joaquin

SoCAB

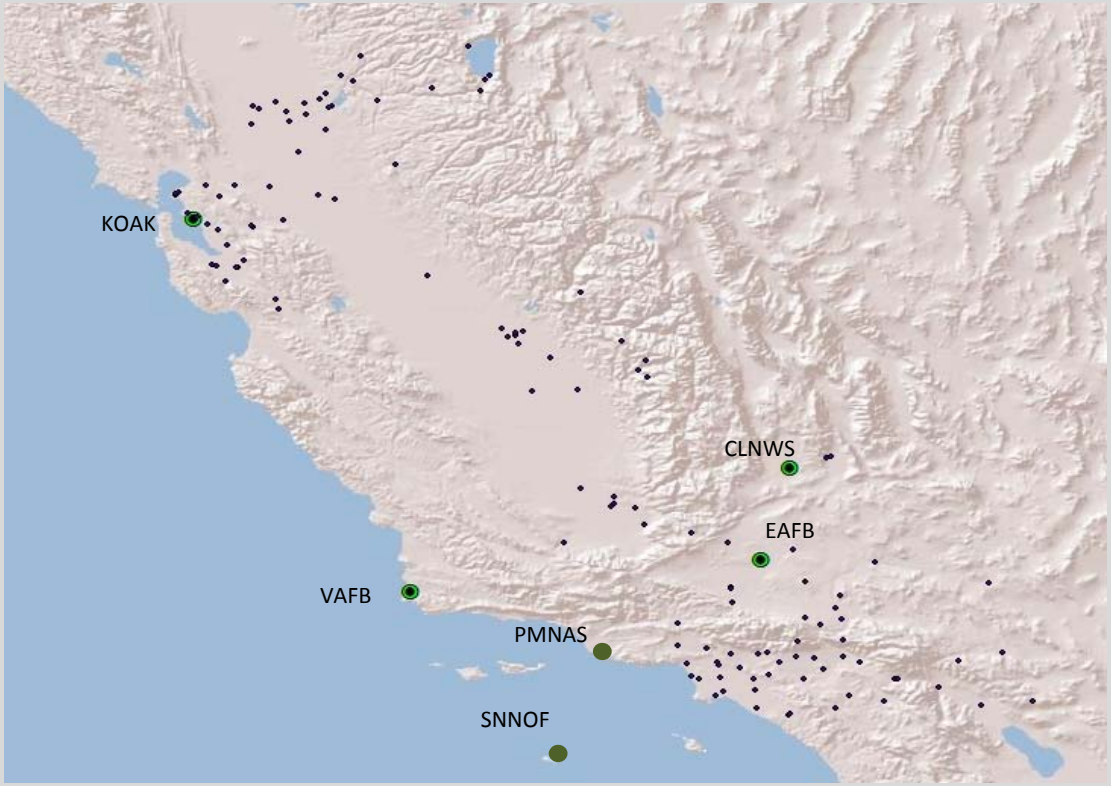
SB = San Bernardino
RS = Riverside
OR = Orange
LA = Los Angeles

Fresno-Bakersfield

FR = Fresno
KR = Kern
KI = Kings
TU=Tulare

Sacramento

SA = Sacramento
PL = Placer
YO = Yolo
ED = El Dorado

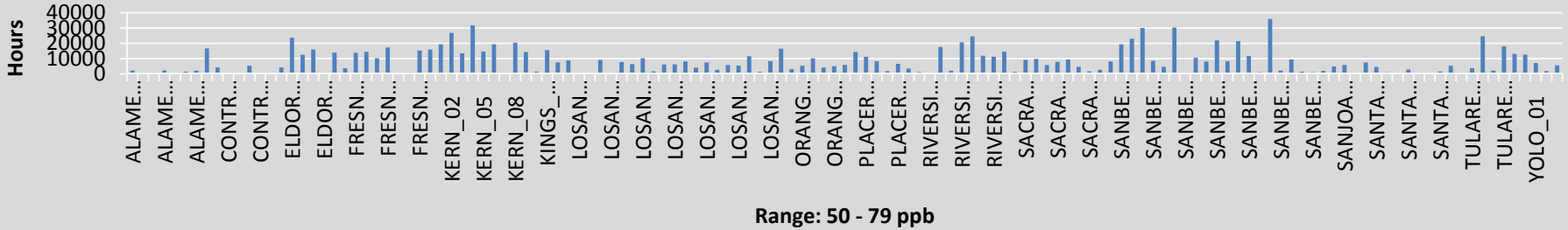


Surface ozone monitors and rawinsonde stations **continuous** 1995-2005

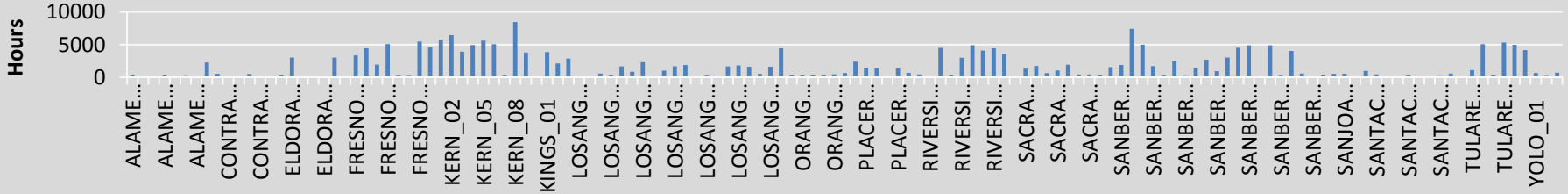
134 AQ Monitors data analyzed

YOLO	0004, 0005, 1003
PLACER	0002, 0004, 0006, 0007, 3001
ELDORADO	0010, 0011, 0012, 0013, 0020, 2003
SACRAMENTO	0002, 0006, 0010, 0011, 0012, 0013, 1001, 5002, 5003
CALAVERAS	0001
SANJOAQUIN	0009, 1002, 3002, 3003
SANTACLARA	0002, 0004, 0005, 1001, 1002, 2004, 2005, 2006, 2007
CONTRACOSTA	0002, 0003, 0010, 1002, 1003, 1004, 3001
ALAMEDA	0003, 0005, 0006, 0007, 0010, 1001, 2001
MERCED	0003
FRESNO	0007, 0008, 0010, 0242, 0243, 0244, 4001, 5001
KINGS	1004
KERN	0007, 0008, 0010, 0011, 0014, 0232, 1005, 5001, 6001, 9000
TULARE	0005, 0006, 0007, 0008, 0009, 2002
ORANGE	0001, 0007, 1003, 2001, 2022, 5001
SANBERNARDINO	0001, 0005, 0012, 0014, 0015, 0017, 0217, 0306, 1004, 1234, 2002, 4001, 4003, 9000, 9002, 9003, 9004, 9006, 9007, 9008
LOSANGELES	0002, 0016, 0030, 0031, 0113, 0206, 1002, 1103, 1201, 1301, 1601, 1701, 2005, 4002, 5001, 5005, 6002, 6012, 9002, 9006, 9033
RIVERSIDE	0002, 0003, 0008, 0012, 1002, 2002, 5001, 6001, 8001, 9001, 9003

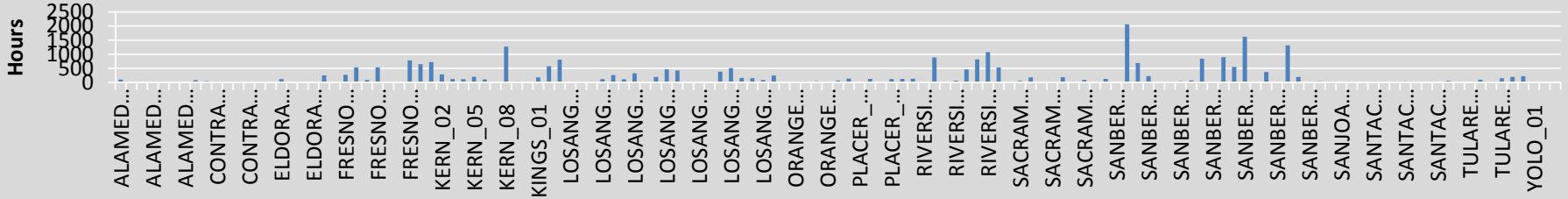
Hours 30-ppb binned O3 (1995-2005) 134 monitors



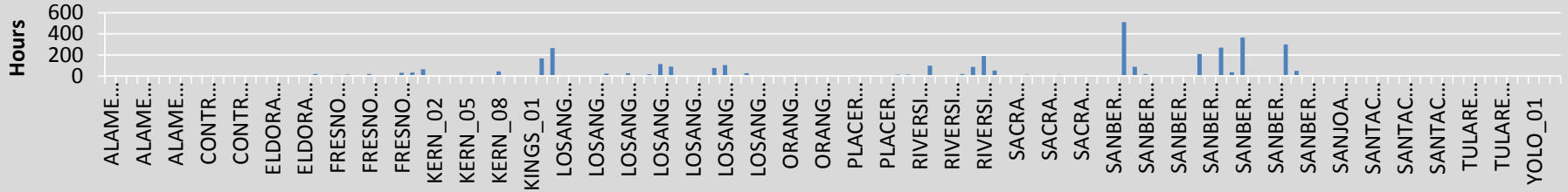
Range: 50 - 79 ppb



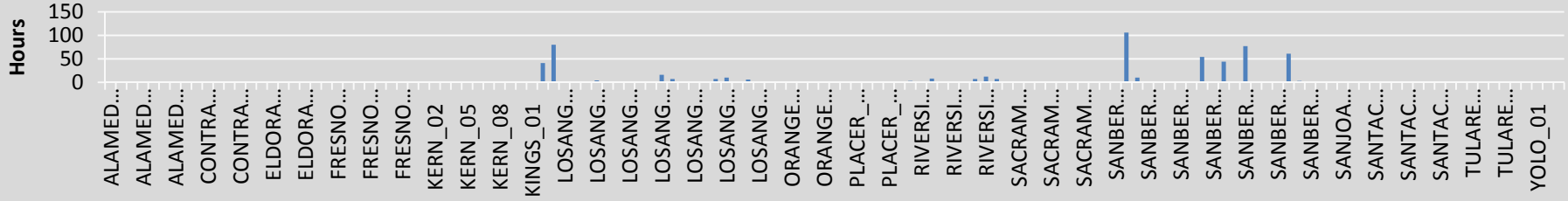
Range: 80 - 109 ppb



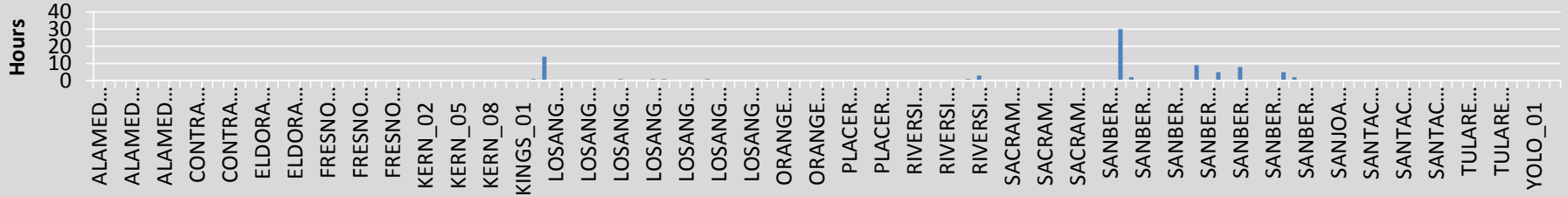
Range: 110 - 139 ppb



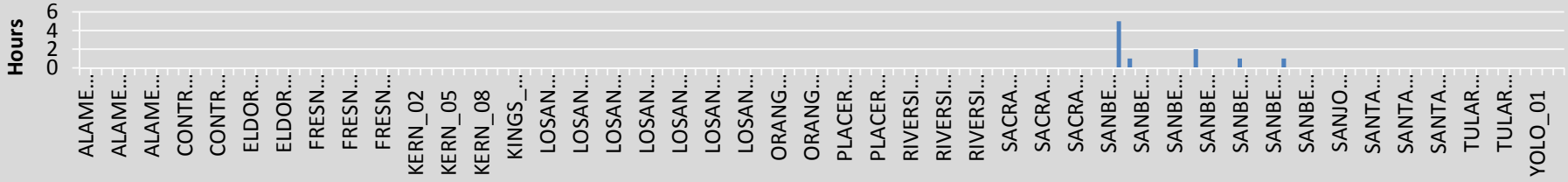
Range: 140 - 169 ppb



Range: 170 - 199 ppb

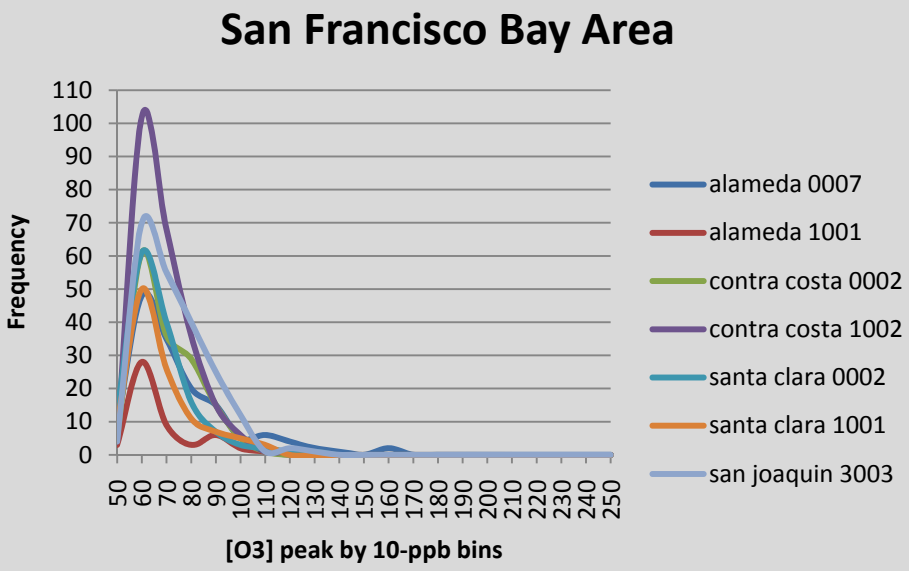


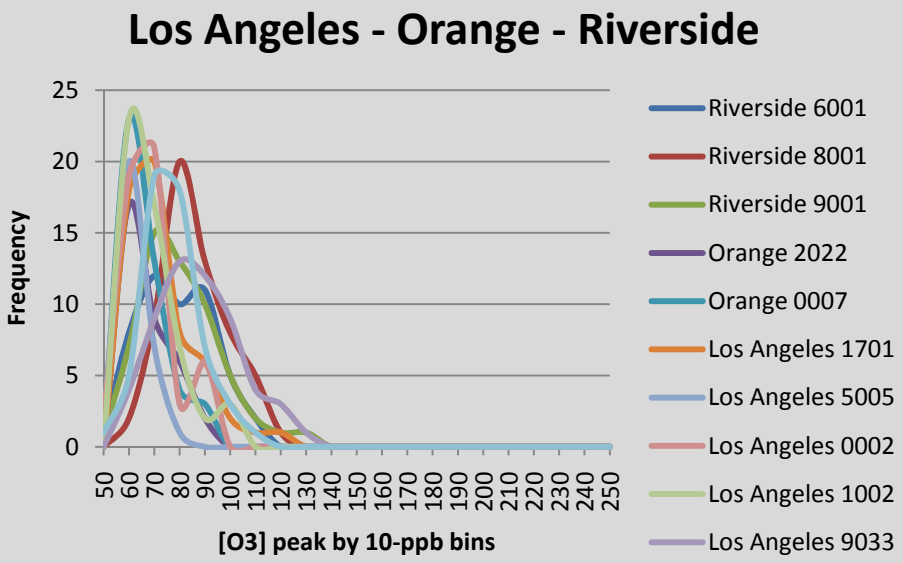
Range: 200 - 229 ppb

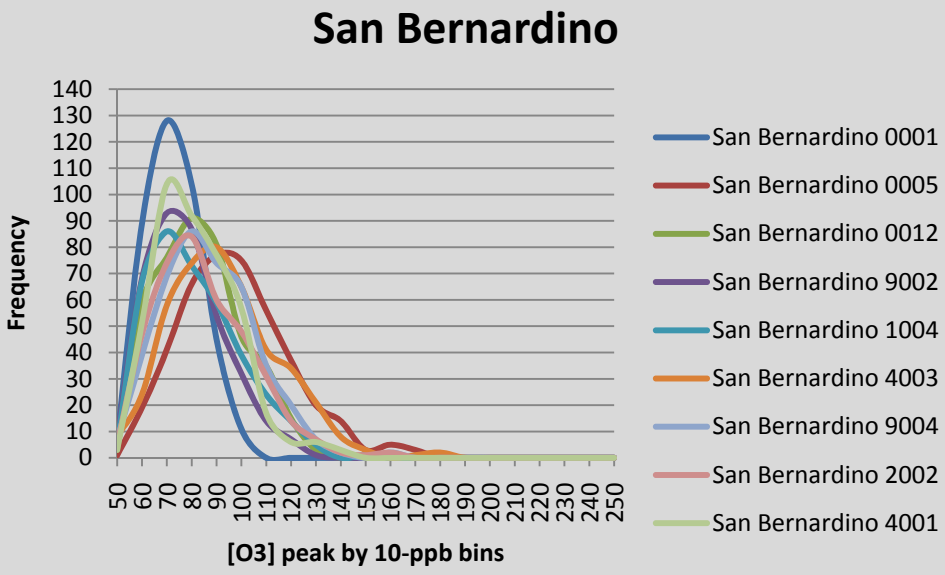


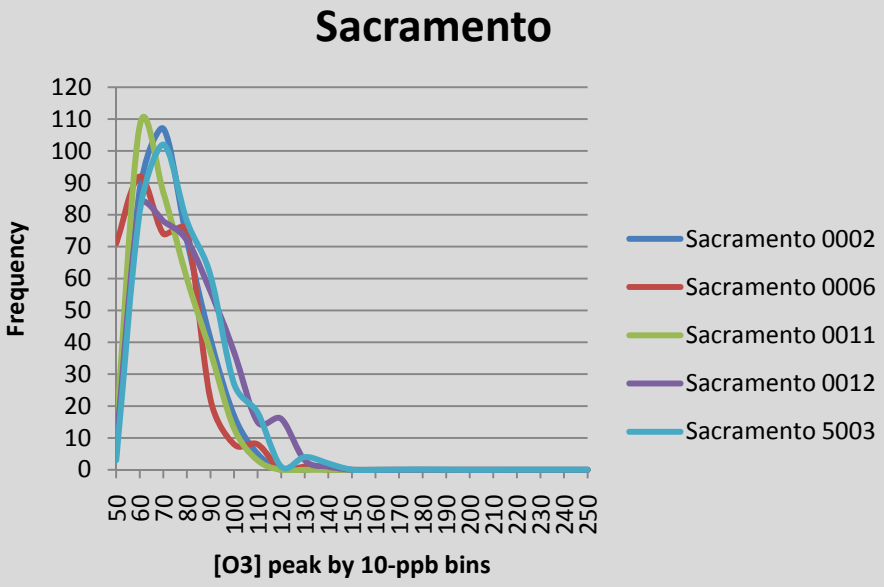
Range: 230 - 260 ppb

1-hr peak (ppb) -- Weekdays -- Years 2000-2005 – Period: 15 May - 30 August

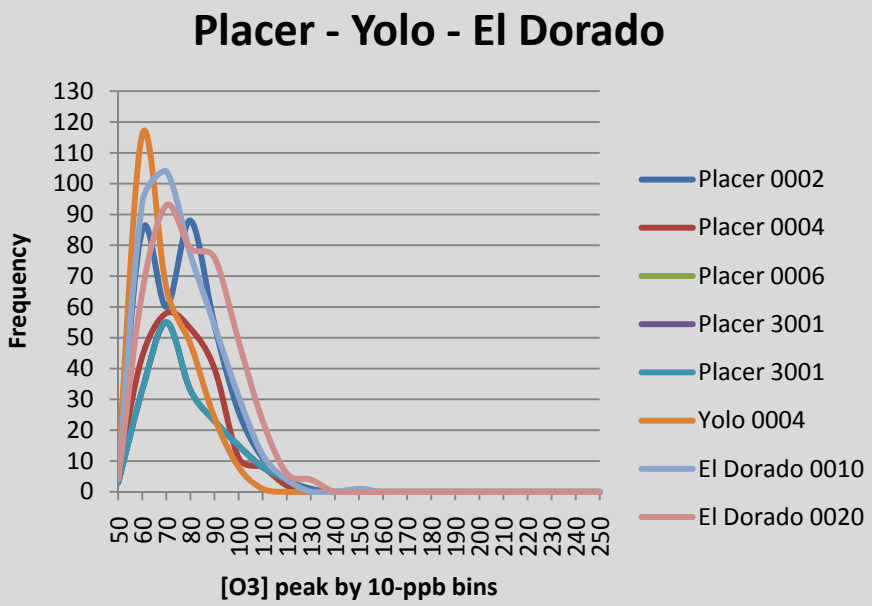


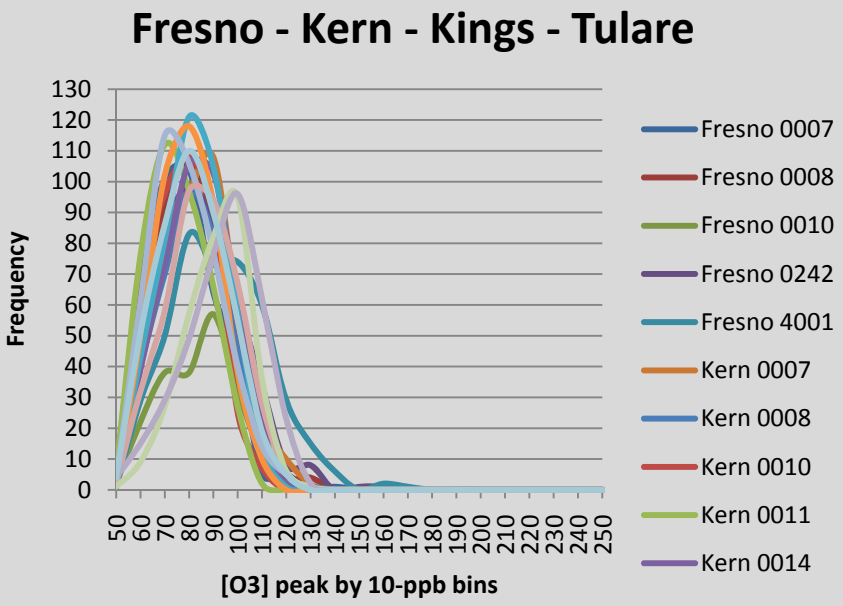






1-hr peak (ppb) -- Weekdays -- Years 2000-2005 – Period: 15 May - 30 August





RANKING OF MONITORS BY O3 1-HR PEAK

South Coast / Los Angeles Basin

San Bernardino County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	4003	172-174	1	4003	147	1	4003	119-124
2	0005	158-163	2	0005	135-140	2	0005	112-116
3	2002	156-158	3	2002	131	3	2002	109-113
4	9004	151-154	4	9004	128-129	4	9004	107-112
5	0012	145	5	0012	125-126	5	0012	102-107
6	1004	142	6	1004	118-122	6	1004	100-105
7	4001	138-140	7	4001	121	7	4001	99-104
8	9002	125	8	9002	107-110	8	9002	90-95
9	0001	94-99	9	0001	84-89	9	0001	74-79

Riverside County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	0012	141	1	0012	118-119	1	0012	100-102
2	9001	129	2	9001	109-113	2	9001	92-97
3	5001	125	3	5001	106-107	3	5001	90-92
4	8001	119	4	8001	103-106	4	8001	88-93
5	6001	104	5	6001	88-93	5	6001	78-82
6	2002	92-97	6	2002	86-88	6	2002	75-79

Los Angeles County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	6012	155	1	6012	134	1	6012	108-112
2	9033	120-123	2	9033	103	2	9033	89-94
3	1201	112-113	3	1201	95-98	3	1201	83-87
4	1701	111	4	1701	95-96	3	1701	83-87
5	0016	97-102	5	0016	87-88	4	0016	76-81
6	1002	94-96	6	1002	82-83	5	1002	74-75
7	0002	86-90	7	0002	82	6	0002	69-74
8	2005	82-86	8	2005	73-77	7	2005	66-71
9	5005	75	9	5005	65-69	8	5005	60-65

Fresno - Bakersfield

Fresno County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	4001	164	1	4001	137	1	4001	114-118
2	0242	155	2	5001	113-117	2	0242	108-113
3	5001	134	3	0007	111-114	3	5001	95-100
4	0007	132	4	0008	105-110	4	0007	94-99
5	0008	121-125	5	0010	100-103	5	0008	90-95
6	0010	114-119	NA	0242	NA	6	0010	86-90

Kern County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	0007	121-126	1	0007	105-110	1	0007	90-95
2	0008	123	2	0008	103-108	2	0008	88-93
3	0014	111-115	3	0014	97-102	3	0014	84-89
4	0232	107-111	4	0232	93-98	4	0232	81-86
5	5001	106-111	4	5001	93-98	4	5001	81-86
6	6001	104-109	5	6001	92-97	5	6001	80-85
7	0010	103-108	6	0010	93-96	6	0010	79-84
8	0011	103-107	7	0011	91-95	6	0011	79-84

Tulare County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	0009	121-126	1	0009	105-110	1	0009	90-95
2	0008	119-121	2	0008	101-106	2	0008	87-92
3	2002	120	3	2002	101-105	2	2002	87-92
4	0006	111-115	4	0006	97-102	3	0006	84-89

RANKING OF MONITORS BY O3 1-HR PEAK

Sacramento Valley

Sacramento County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	0006	134	1	5003	117	1	0006	95-100
2	5003	129-134	2	0006	114-116	1	5003	95-100
3	0012	129-132	3	0012	111-	2	0012	94-99
4	0002	131	4	0011	91-96	3	0002	93-98
5	0011	108	NA	0002	NA	4	0011	79-84

Placer County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	0006	130	1	0006	110	1	0006	93-98
2	0002	120-125	2	0002	106-108	2	0002	90-95
3	3001	114-118	3	3001	99-104	3	3001	85-90
4	0004	112-115	4	0004	97-101	4	0004	84-89

El Doarado County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	0010	141	1	0010	117-119	1	0010	99-104
2	0020	121-126	2	0020	105-108	2	0020	90-95
3	0012	78-82	3	0012	70-75	3	0012	64-69

San Francisco Bay Area

Alameda County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	0007	151-152	1	0007	128	1	0007	107-111
2	0003	134	2	1000	86-91	2	1001	78-81
3	1001	99-102	3	2001	81-84	3	2001	76
4	2001	95	NA	0003	NA	NA	0003	NA

Contra Costa Counry

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	1002	130	1	0002	87-91	1	1002	93-98
2	3001	111	NA	1002	NA	2	3001	81-86
3	0002	98-103	NA	3001	NA	3	0002	77-81

Santa Clara County

top 20%			2nd 20%			3rd 20%		
Rank	Monitor	O3 range	Rank	Monitor	O3 range	Rank	Monitor	O3 range
1	0002	120-121	1	0002	104	1	0002	87-89
2	2006	113-117	2	2006	101-102	2	2006	85-90
3	1001	102-106	3	1001	89-94	3	1001	80-81

Initial episode selections		Final episodes
1. Fresno – Bakersfield		
2002 / 7 / 10 through 2002 / 8 /15	(top 20%)	7/10 – 7/22; 8/8 – 8/11
2000 / 8 / 2 – 25	(2nd 20%)	8/4 – 8/8; 8/11 – 8/18
2002 / 7 / 10 – 12	(2nd 20%)	stands
2000 / 6 / 14 – 27	(3rd 20%)	stands
2001 / 5 / 18 – 31	(3rd 20%)	stands
2002 / 8 / 8 – 20	(3rd 20%)	stands
2. Sacramento Valley		
2005 / 7 / 13 – 14	(top 20%)	stands
2003 / 6 / 3 – 27	(2nd 20%)	stands
2001 / 6 / 20 – 22	(2nd 20%)	stands **
2000 / 7 / 19 through 2000 / 8 / 22	(3rd 20%)	7/19 – 8/1; 8/4 – 8/8; 8/11 – 8/18
2002 / 7 / 4 – 19	(3rd 20%)	stands
2005 / 7 / 25 through 2005 / 8 / 4	(3rd 20%)	stands
3. San Francisco Bay Area		
2000 / 6 / 14 – 15	(top 20%)	stands
2003 / 6 / 25 through 2003 / 7 / 17	(2nd 20%)	stands
2002 / 7 / 1-2	(3rd 20%)	stands **
4. Los Angeles Basin		
2003 / 7 / 9 – 15	(top 20%)	stands
2001 / 5 / 22 through 2001 / 6 / 8	(2nd 20%)	stands **
2003 / 7 / 9 – 24	(2nd 20%)	stands
2000 / 5 / 23 through 2000 / 6 / 16	(3rd 20%)	stands
2001 / 8 / 13 – 17	(3rd 20%)	stands **
2005 / 7 / 12 – 26	(3rd 20%)	stands

**

Very small/marginal fires, distant, and downwind of sub-regions of interest

5. Seasonal: <May – October> of years 2006, 2007, 2008, and 2009 for all domains

6. Regulatory episodes: July-August 2000, July 1999, July 1997

OZONE METEOROLOGY: CART ANALYSIS

- Ozone meteorology regimes: e.g., for high, average, marginal ozone
- **Meteorology data:** Synoptic weather maps, rawinsonde/upper air data, 4D analyses (e.g., NNRP), surface networks data (EPA AIRS/AQS -- Aerometric Information Retrieval System / Air Quality System), NCAR data (e.g., ds472), CCOS and SCOS intensive, NWS data
- **Air quality data:** Ground-level O3 from 134 monitors in following California counties:
  - North-central: Yolo, Placer, El Dorado, Sacramento, Calaveras
  - Central: San Joaquin, Santa Clara, Contra Costa, Alameda, Merced, Fresno, Kings, Kern, Tulare
  - Southern: Orange, San Bernardino, Los Angeles, Riverside

CART ANALYSIS

Selected rawinsonde/upper-air data sites for initial analysis:

- KOAK – Oakland International Airport
- VAFB – Vandenberg AFB / Lompoc
- PMNAS – Point Mugu Naval Air Station
- EAFB – Edwards AFB
- CLNWS – China Lake Naval Weapons Center
- SNNOF – St. Nicolas Island / Naval Outlying Field

Splitting variables and settings used to date:

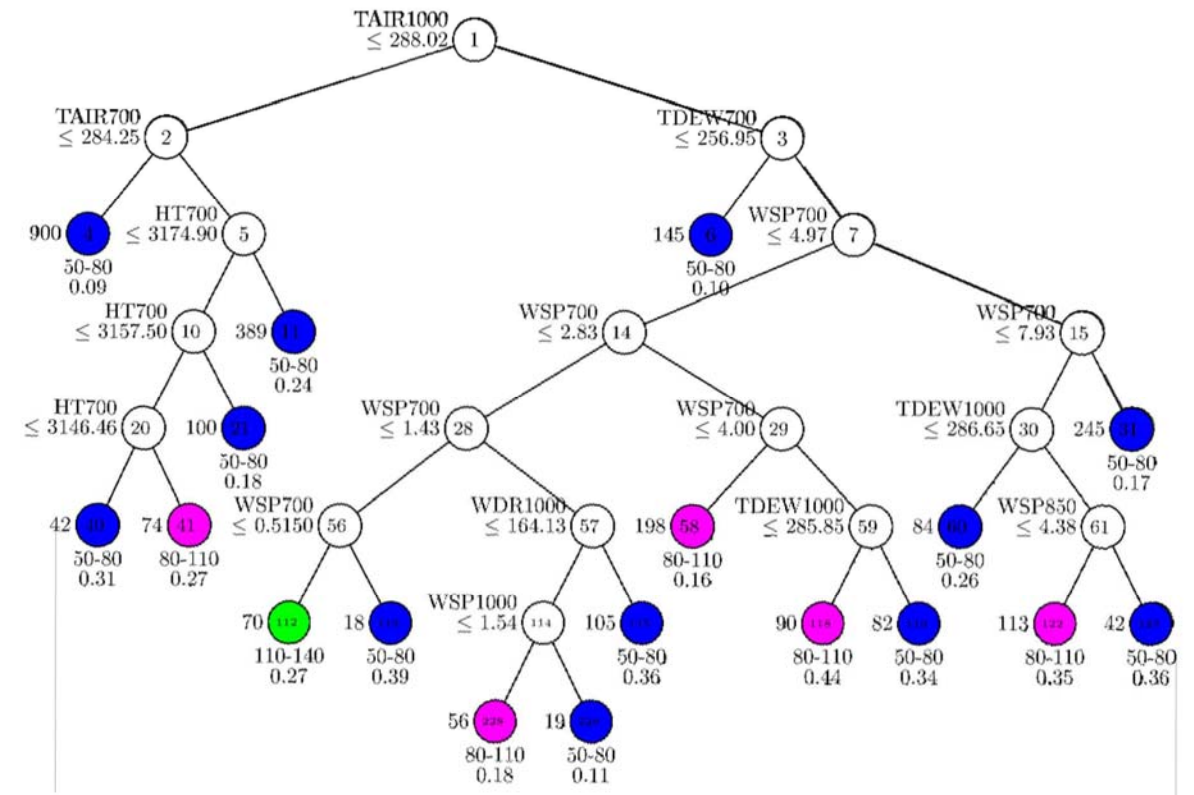
- Variables from above sites, at 1000, 850, and 700 mb
- Temperature, Dew point, Wind speed, Wind direction, Geopotential/pressure height
- Data from 1995 through 2005, Then 2000 through 2005
- 30 ppb O3 bins for initial analysis
- Trees pruned to varying degrees of SE and minimum node data
- Discrimination between weekend and weekdays in CART generation
- Two days running averages (1200 UTC) for variables
- Both classification and regression trees were generated

Of note:

- Horie et al. used 1200Z averaged over two days; Tair850, Tair900, RHsfc, RH900, WSPsfc
- Other researchers simply used geopotential height as a surrogate for all other variables
- BAAQMD and UC Davis used cluster analysis of surface winds for Bay Area ozone
- Bornstein et al. characterized the large-scale flow / synoptic conditions of CCOS2000/SCOS1997 field intensives

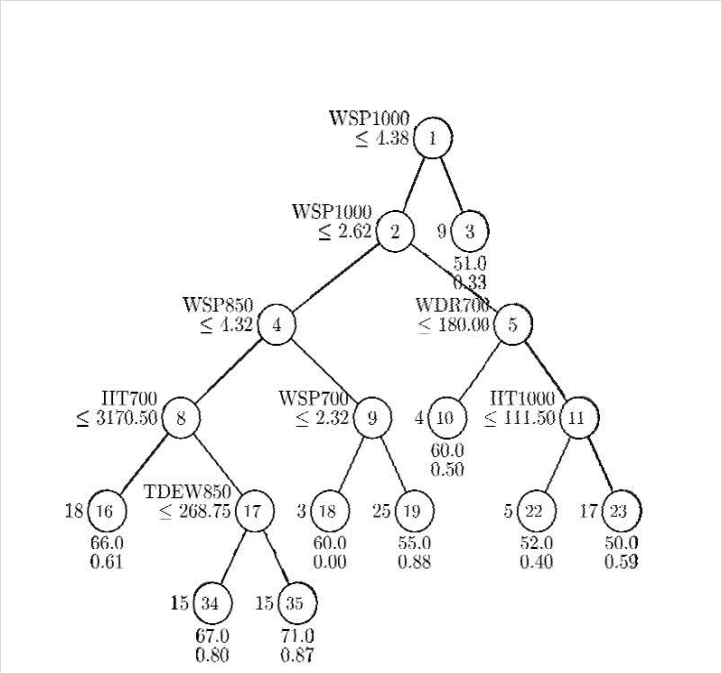
TREE EXAMPLES: CLASSIFICATION

Sample Alameda County ozone vs. KOAK profiler 1200 UTC

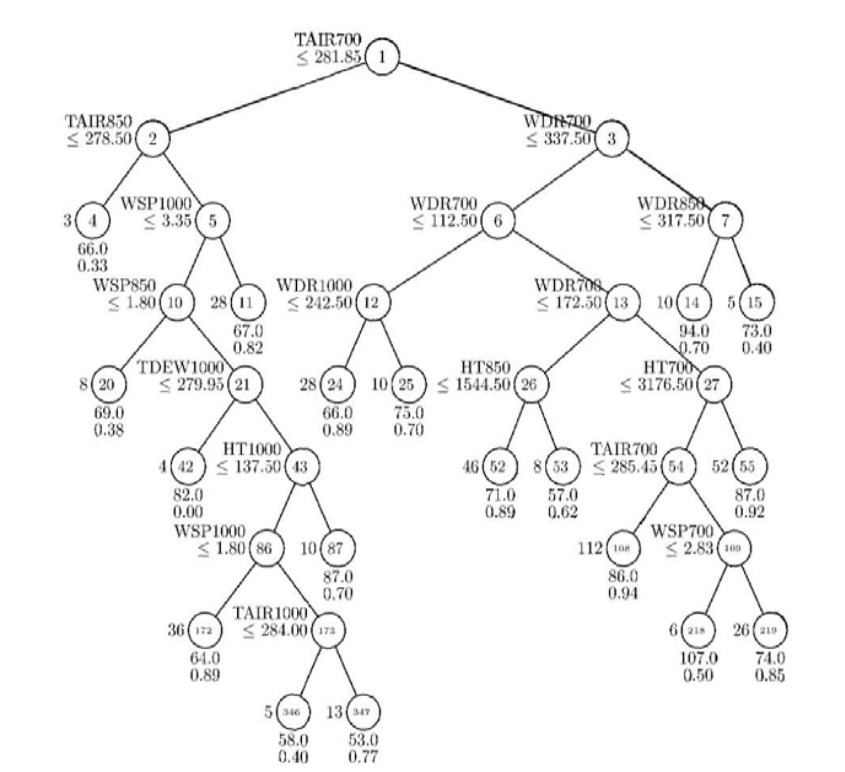


O3 bin	Frequency	Of which	Tair 1000	Tair 700	WSP 700	Tdew 700	HT 700
110-140	2.5 %	100% occurs →	> 288 K		< 0.5 m/s		
80-110	19.2 %	14 % occurs →	< 288 K	> 284 K			> 3146
		11 %	> 288 K		< 2.83 m/s	> 257 K	
		37 %	> 288 K		< 4.00 m/s		
		16 %	> 288 K		< 4.90 m/s		
		21 %	> 288 K		< 7.93 m/s		
50-80	78.3 %	66% occurs →	< 288 K				
	.....	.....	.....	.....	.....	.....	.....

TREE EXAMPLES: REGRESSION



Santa Clara monitor 1001 vs KOAK



San Bernardino monitor 0012 vs PMNAS

Trees generated: one for each of the 134 monitors, for 2 periods: 1995-2005 and 2000-2005, with varying degrees of pruning, and for both classification and regression

MODELS and DATA

1. Mesoscale meteorology
   - PSU NCAR MM5
   - WRF
2. Meso-urban meteorology
   - uMM5
3. Emissions
   - SMOKE / BEIS3
4. Air quality / photochemistry
   - CAMx
   - CMAQ
5. Land use / land cover
   - NUDAPT
   - Urban morphology
   - USGS

- NCAR NNRP analyses
- Observational upper air and surface

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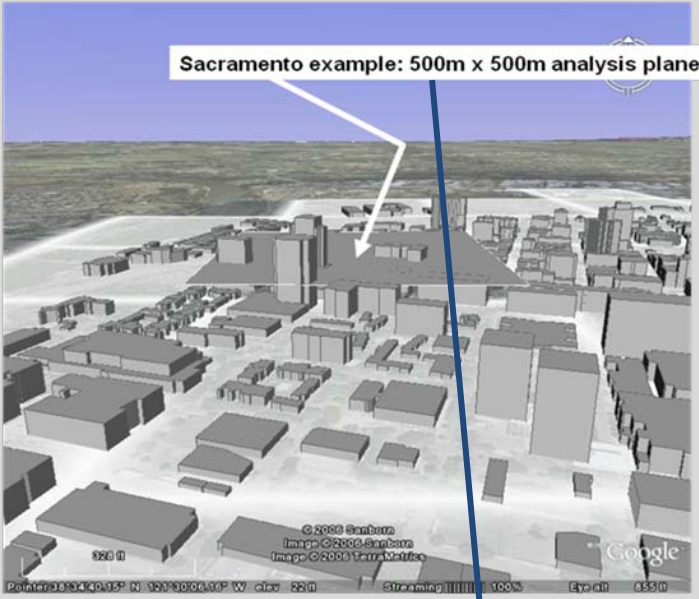
- Observational upper-air and surface
- Local network data
- Morphology and canopy parameters

- Emission inventories
- Observed air-quality (ic/bc)
- Land-use, roughness, deposition
- CCOS 1999, 2000
- SCOS 1997 – 2005

Meso-urban modeling: uMM5



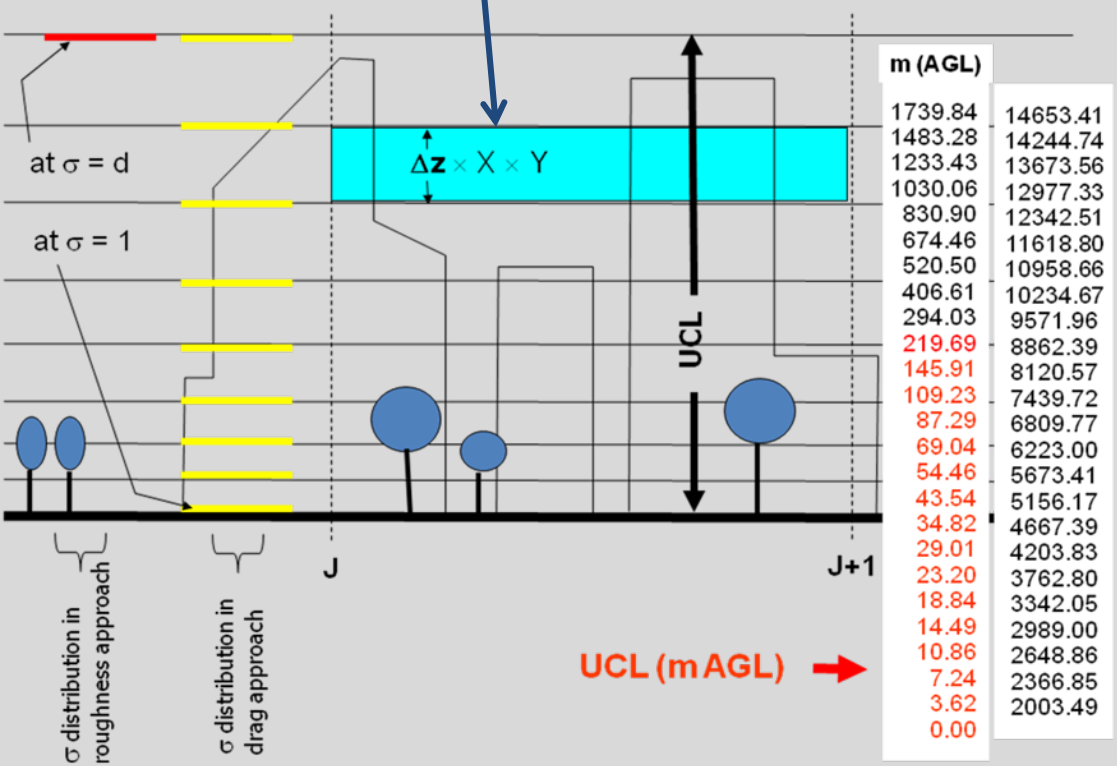
$$\frac{\partial \rho u_i}{\partial t} = F_{g(ui)} + \underbrace{F_{ui}^{j}}_{1} + \underbrace{\sum_j D_{ui}^{j}}_{2}$$

$$\frac{\partial \rho \theta_L}{\partial t} = F_{g(\theta L)} + \underbrace{H_j}_{3} + \underbrace{Q_f}_{4}$$

$$\frac{\partial \rho q}{\partial t} = F_{g(q)} + \underbrace{S_j}_{5}$$

$$\frac{\partial E}{\partial t} = \frac{\partial u_i E}{\partial x_i} + \left\{ k_m \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right] S_{air} + \underbrace{F_E^{bui}}_{6} \right\} + \left\{ \frac{g}{\theta_v} \langle w \theta_v \rangle + \underbrace{H_E}_{7} \right\}$$

$$- \frac{1}{\rho} \frac{\partial (\rho \langle wE \rangle)}{\partial z} - \varepsilon + \underbrace{\sum_j w_E^j}_{8} - \underbrace{\sum_j D_E^j}_{9}$$

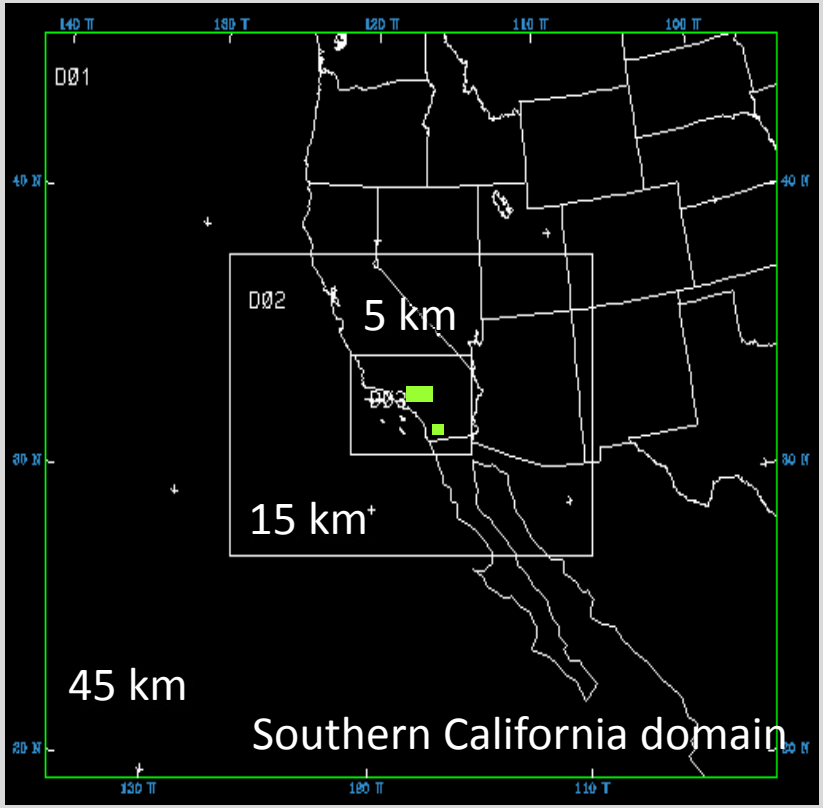


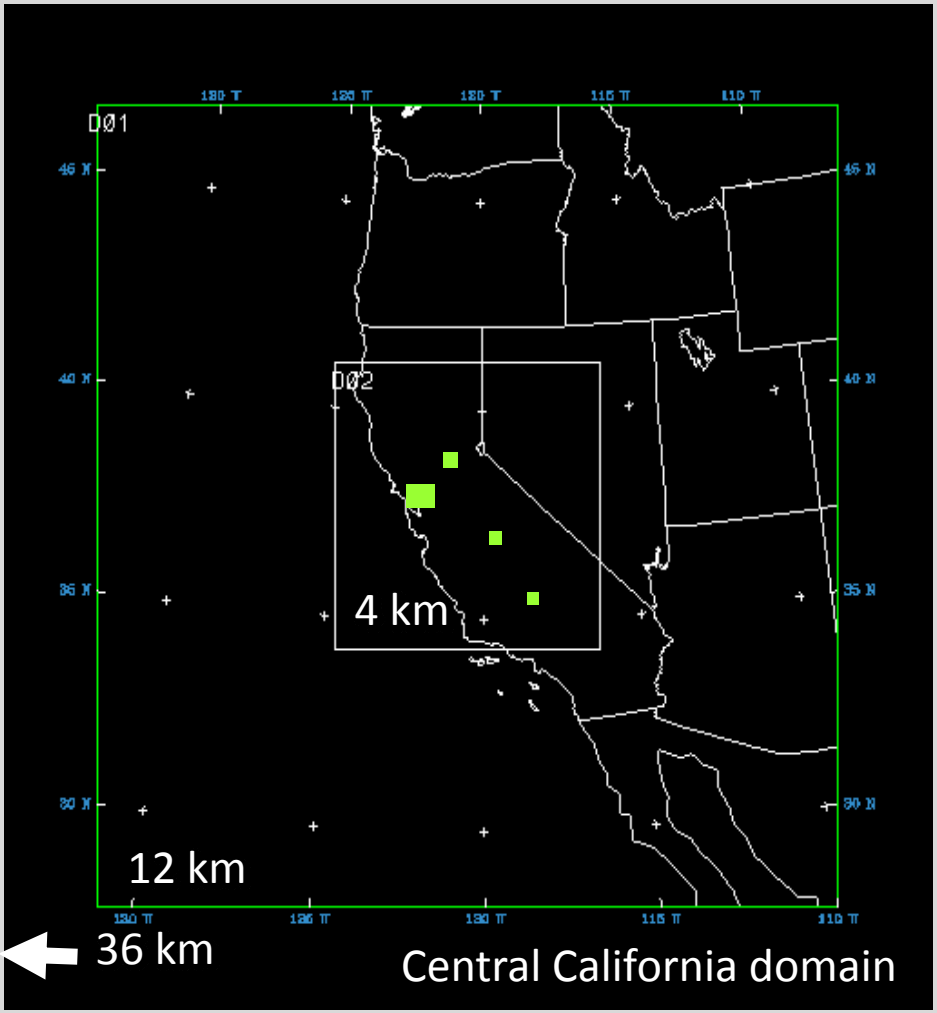
+ Urban geometry / effective albedo / radiation trapping

+ Urban soil model (SM2-U)

Source: Taha 2008.
Boundary-Layer Meteorology

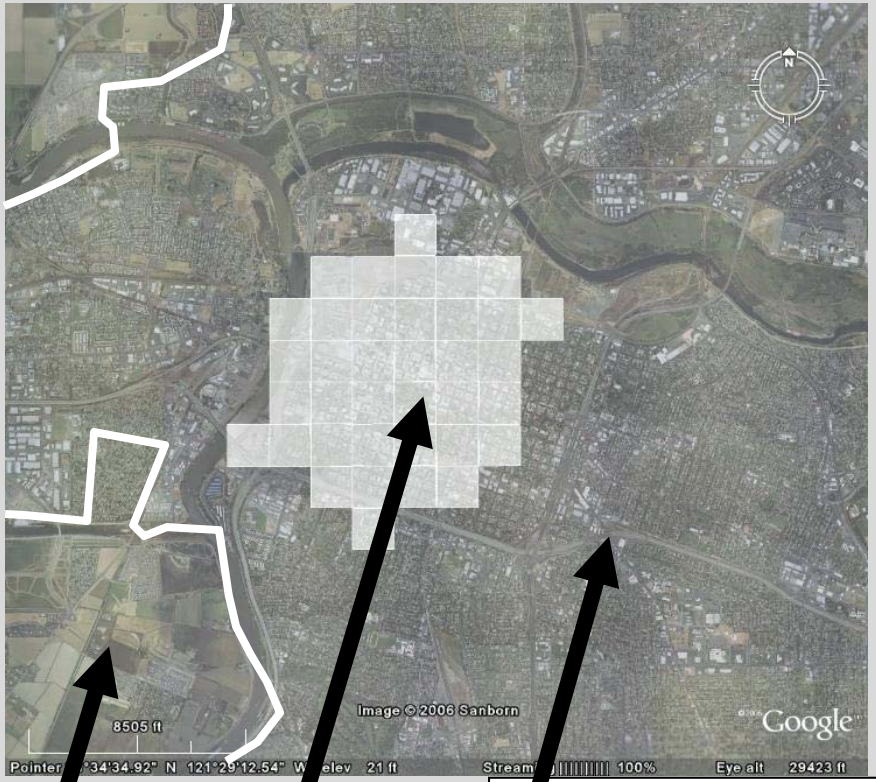
MODELING DOMAINS

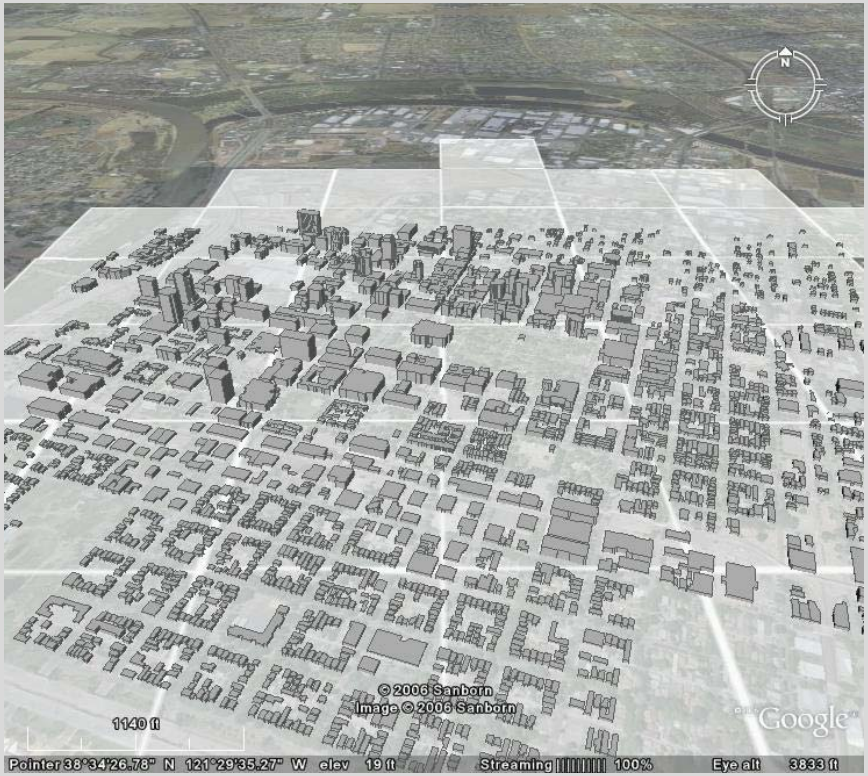




- Mesoscale modeling domains
- Meso-urban (1-km) modeling domains

DEVELOPMENT OF URBAN MORPHOLOGY





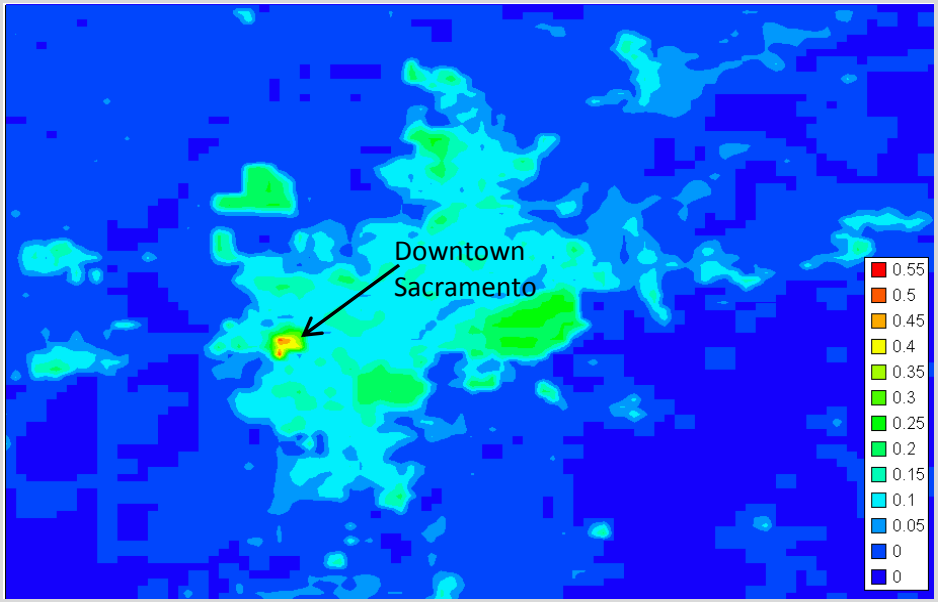
Urban statistical region

Urban morphology region

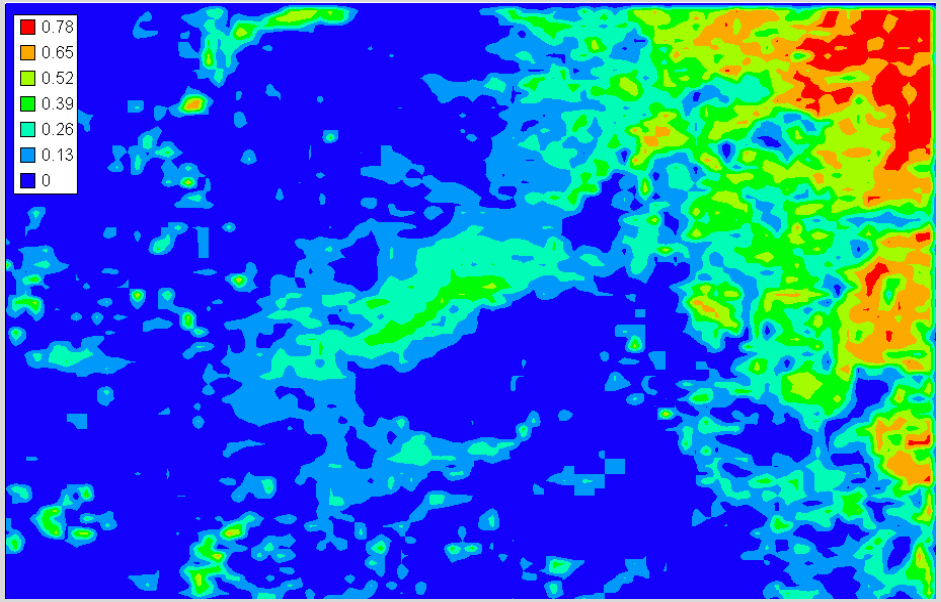
Non-urban land-use (e.g., USGS) region

UCP / MORPHOLOGY CHARACTERIZATION

Sacramento example:
1-km building plan-area density, $m^2\ m^{-3}$, at 2m AGL



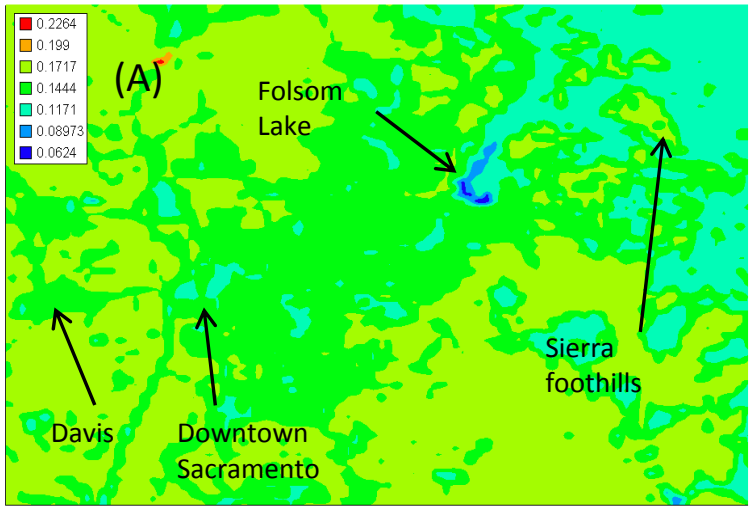
Sacramento example:
1km vegetation plan-area density, $m^2\ m^{-3}$, at 2m AGL

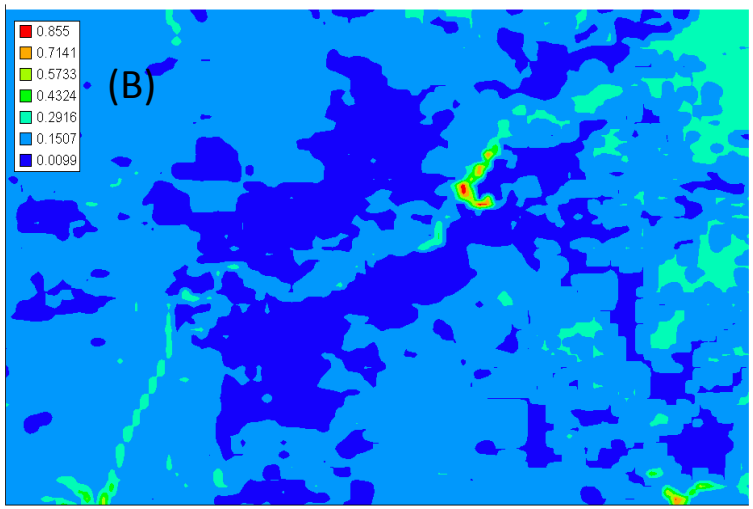


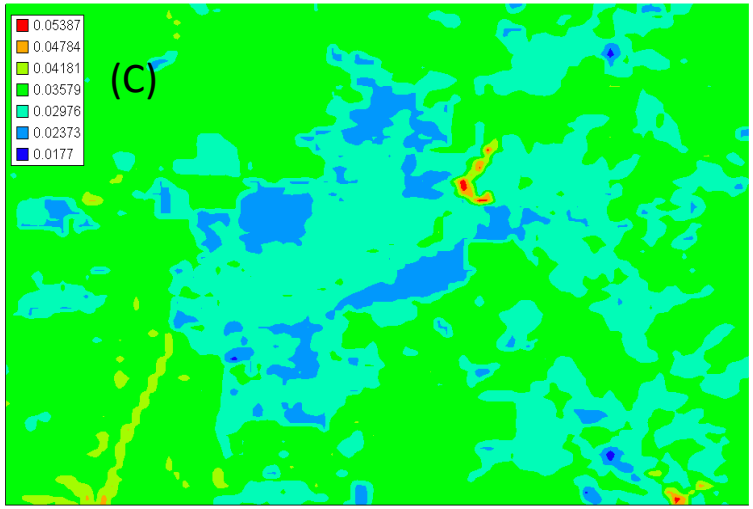
ALTOSTRATUS

PHYSICAL CHARACTERIZATION

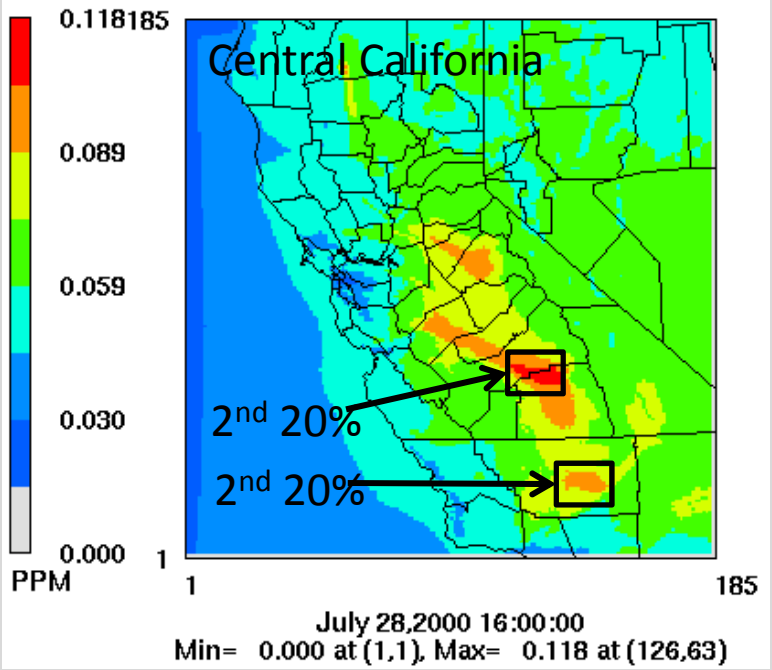
Sacramento example:
1-km albedo (A), soil moisture content (B), and thermal inertia J m^{-2} K^{-1} $s^{-0.5}$ (C)

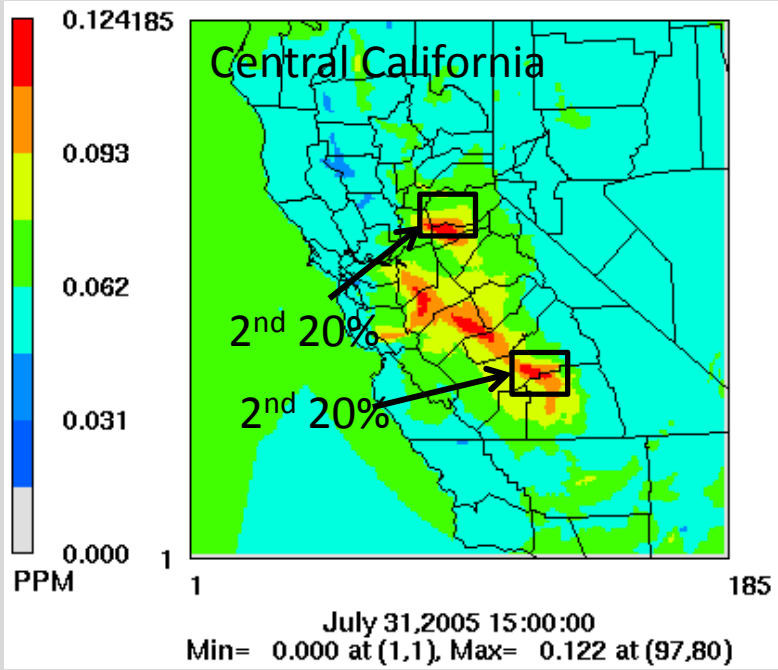


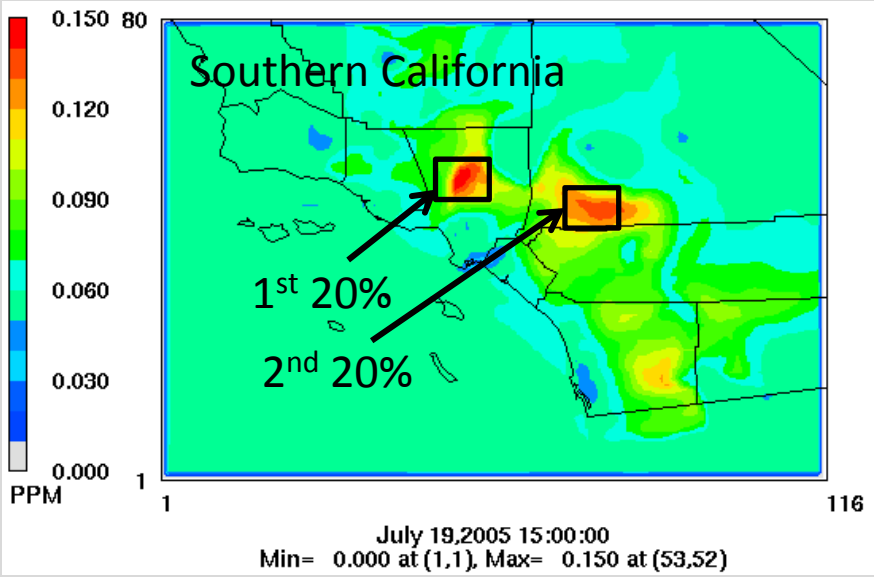




SAMPLE BASE MODELING RESULTS







NEXT STEPS

- Complete mesoscale and meso-urban modeling
- Develop emission-reduction equivalence for heat island control
- Analyze the meteorological and AQ impacts of urban solar arrays (and solar power plants)
- Develop guidelines for mitigation

THANK YOU!

NOTE: This presentation is for work in progress. Results and findings can change.