

Urban Impacts on Precipitation

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**Based on research of Drs. Susan van den Heever and
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- **In this talk I overview our modeling studies of urban impacts on precipitation.**
- **This includes the effects of urban land-use and aerosol pollution.**

How we treat aerosol activation in RAMS

Cloud Droplet Nucleation

Number nucleated obtained from lookup table as a function of

{
CCN number concentration
Vertical velocity
Temperature

Lookup table generated previously (offline) from detailed parcel-bin model

$$N_{c1} = N_{ccn} S_w^b$$

$$N_{c2} = N_{gccn} ; S_w > 0.0$$

Ice Crystal Nucleation

Ice nucleation follows the approach described by Meyers et al. (1992):

$$N_i = N_{IN} \exp [12.96 (S_i - 1)]$$

$T < -5^\circ\text{C}$; $r_v > r_{si}$ (supersaturation with respect to ice), and $T < -2^\circ\text{C}$; $r_v > r_{sl}$ (supersaturation with respect to liquid).

Secondary ice particle production model in RAMS is based on Mossop (1976). In MKS units, the formula is:

$$N_i = 9.1\text{e-}10 \times B \times N_{24} \times (N_{13})^{.93}$$

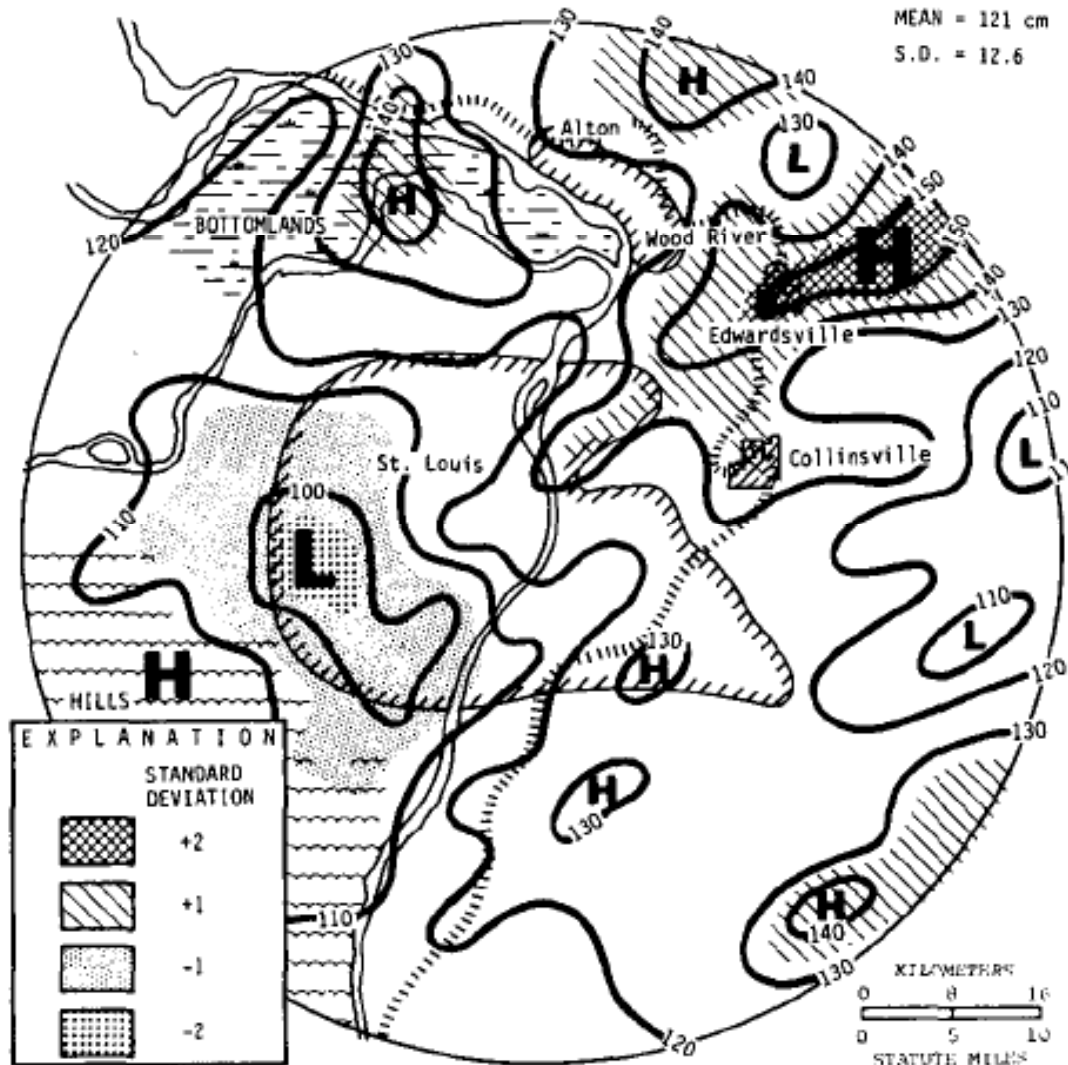
where B increases linearly from 0 to 1 as ice temperature T increases from -8 C to -5 C, B decreases linearly from 1 to 0 as T increases from -5 C to -3 C, and B is zero at other ice temperatures. N_i is the number of ice particles produced per second, N_{24} is the number of cloud droplets larger than 24 μm in diameter that are collected by ice each second, N_{13} is the number of cloud droplets smaller than 13 μm in diameter that are collected by ice each second.

METROMEX Revisited

- **METROMEX was a comprehensive project in the 1970's in the St. Louis, MO area. Findings from that study were:**
 - **Area-averaged precipitation increase is 25% during the afternoon and evening over the city and the surrounding countryside east and northeast of the city.**
 - **The frequency of thunderstorms increased by 31% and hailstorms by 45% and the average size of hailstones increased.**

TOTAL SUMMER RAINFALL, 1971-1975

MEAN = 121 cm
S.D. = 12.6



The hypotheses explaining these observations:

- **Urban Increases in CCN and IN Concentrations and Spectra.**
- **The Glaciation Mechanism.**
- **Impact of Urban Landuse on Precipitation and Weather.**

Our modeling approach

- **Select a case study day from recent records in which ordinary thunderstorms prevailed.**
- **Introduce into RAMS urban land-use data derived from METROMEX observations.**
- **Introduce into RAMS enhanced CCN and GCCN concentrations derived from METROMEX observations.**
- **Only limited IN measurements were made which suggested no increase and a possible decrease.**

Urban Land-use studies

- **This is based on the MS thesis of Chris Rozoff and published as Rozoff et al. (2003).**
- **Urban land-use was modeled with the Town Energy Budget (TEB) model (Masson, 2000).**
- **TEB uses a generalized urban canyon with separate energy budgets for roads, roofs, and walls. The hydrology includes impermeable roofs and roads, with runoff into sewers. Water vapor from automobiles and industry can also be taken into account.**

Table 3.4: Urban characteristics used by TEB

Parameter	Value
Fractional area covered by buildings	0.5
Fractional area covered by roads	0.5
Building height (m)	15
Building aspect ratio (height/length)	1
Canyon aspect ratio (height/width)	1
Roughness length (m)	0.8
Roof layers 1, 2, and 3 thicknesses (cm)	5, 40, 5
Wall layers 1, 2, and 3 thicknesses (cm)	2, 12.5, 2
Road layers 1, 2, and 3 thicknesses (cm)	5, 10, 100
Roof, wall, and road albedos	0.15, 0.25, 0.08
Roof, wall, and road emissivities	0.9, 0.85, 0.94

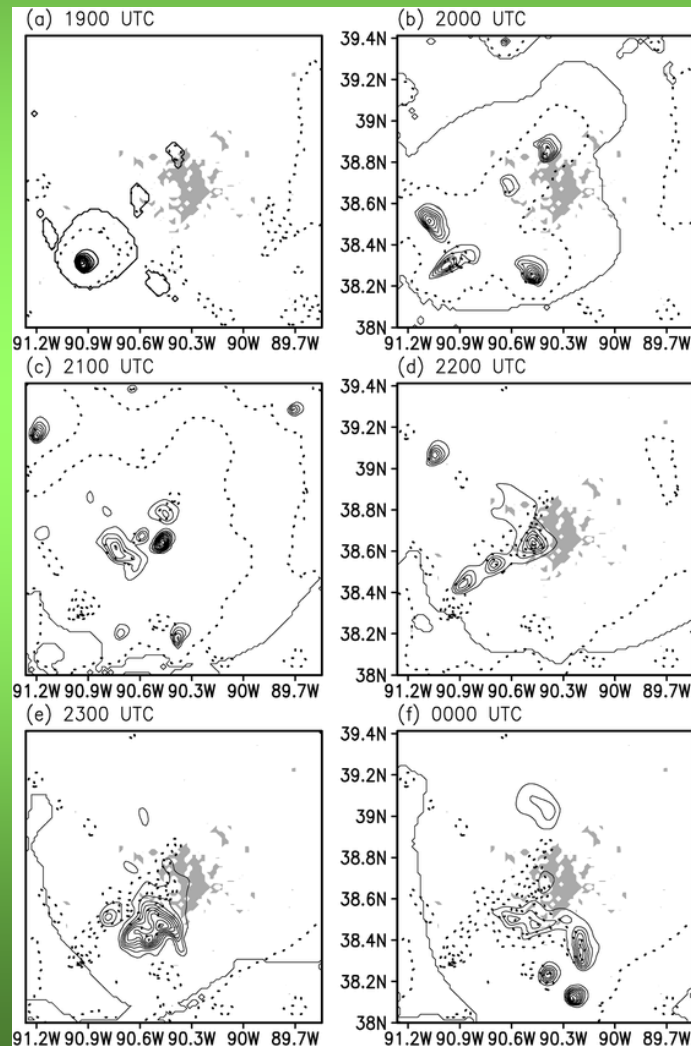
RAMS setup

- **Three nested grids were used with the finest grid spacing being 1.5km.**
- **RAMS is initialized with the EDAS for 8 June 1999.**
- **AVHRR are used for the surrounding countryside and Landsat Thematic Mapper (TM), National Land Cover Data (NLCD) are used over the urban area.**

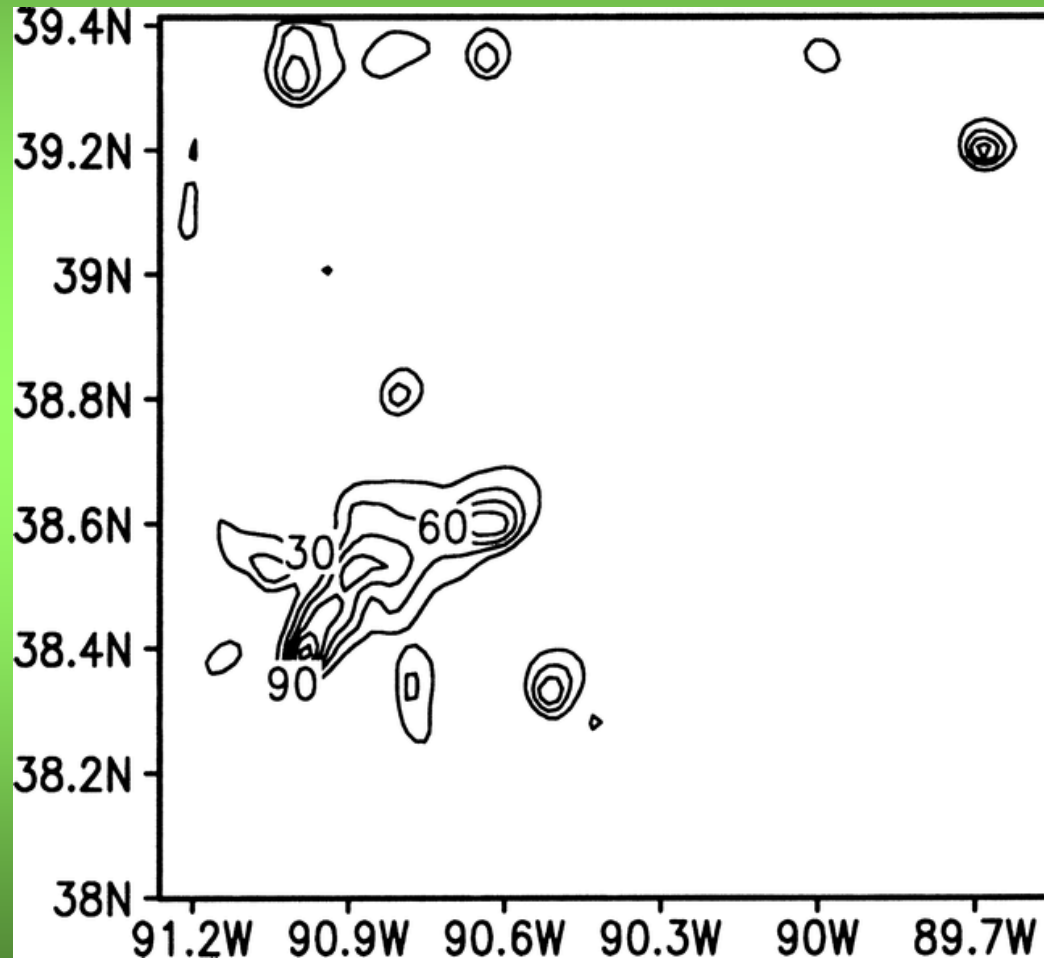
Simulations with and without:

- **Urban radiative and energy fluxes.**
- **Urban roughness.**
- **Local topography.**

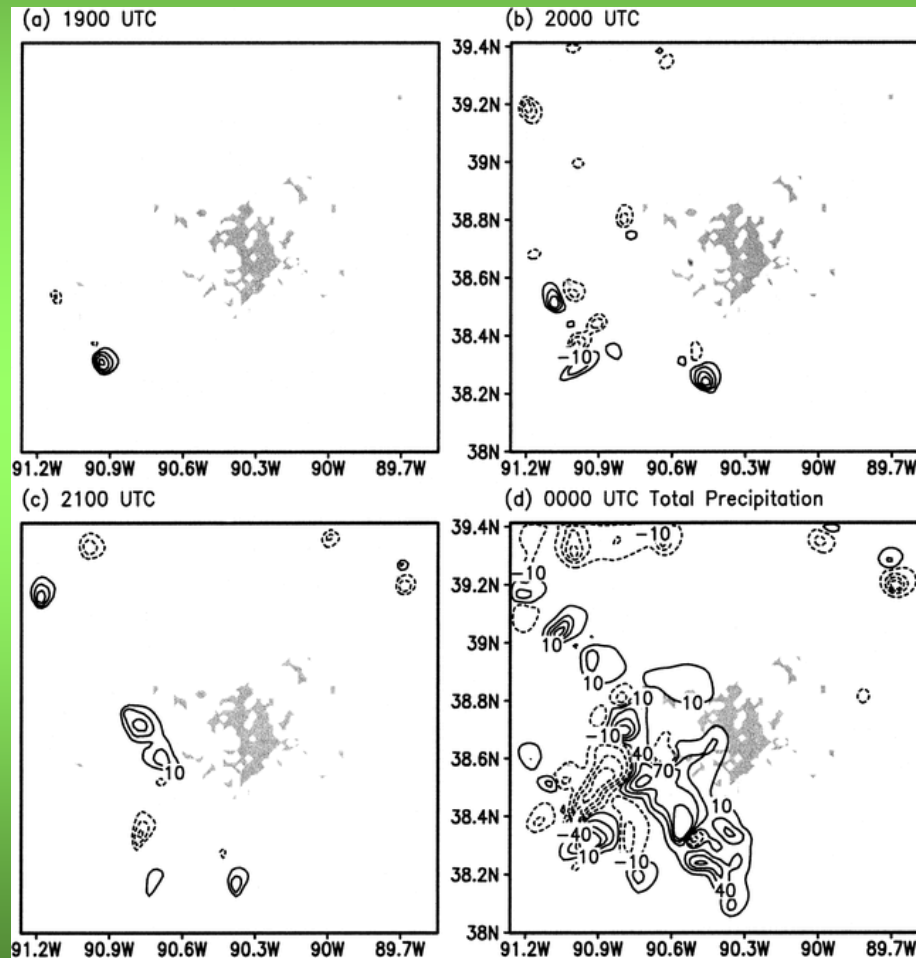
Vertically integrated condensate and precipitation (dashed)



Total precipitation (mm) at 0000UTC



Difference field between urban and all rural land-use



Major findings:

- **Topography impacts the development of storms around St. Louis, especially over the foothills of the Ozarks.**
- **The urban heat island plays the largest role in urban thunderstorm modification. Its convergence is greatest on the leeward side of the city, where storms initiate.**
- **Urban momentum flux (i.e., frictional convergence) alone barely affects the outcome of convection. Its convergence is greatest on the windward side of the city.**
- **Urban momentum flux, when interacting with the UHI, offsets the timing of convection initiated by the urban heat island.**

Urban aerosol influences—
METROMEX revisited
based on van den Heever and
Cotton (2007)

Experiment Design

- In the CONTROL experiment, RAMS is initialized homogeneously with rural CCN and GCCN concentrations.
- In the sensitivity tests, a continuous source of urban CCN and / or GCCN concentrations are used within the lowest 500m over the urban region. The sensitivity tests are otherwise identical to the CONTROL experiment.
- These experiments were repeated in which the urban region was removed while the aerosol characteristics were maintained.

AEROSOL CONCENTRATIONS

- **High background:**

Rural: CCN: 1200 cc⁻¹; GCCN: 0.1 cc⁻¹

Urban: CCN: 2000 cc⁻¹; GCCN: 0.2 cc⁻¹

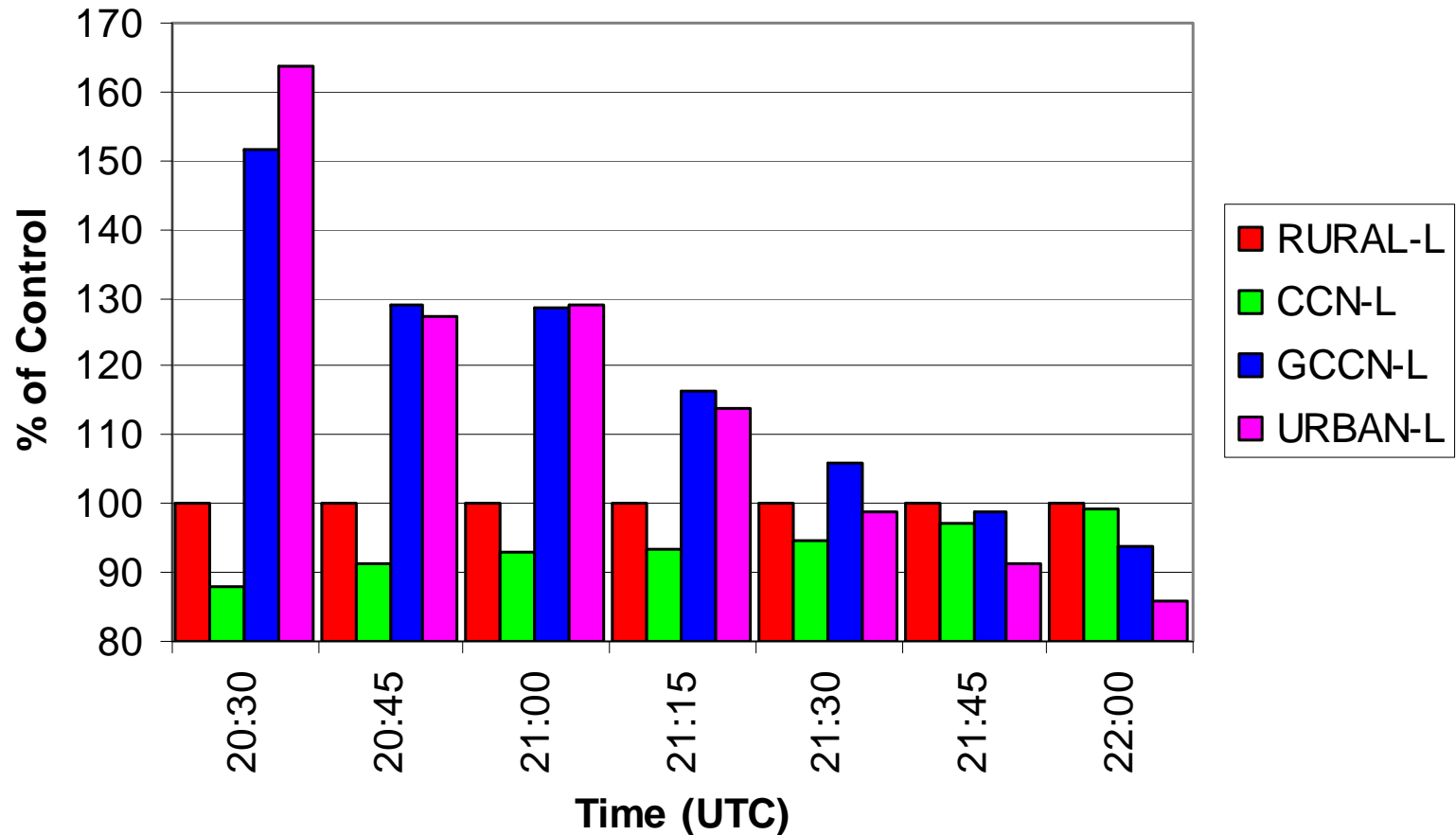
- **Low background:**

Rural: CCN: 800 cc⁻¹; GCCN: 0.01 cc⁻¹

Urban: CCN: 2000 cc⁻¹; GCCN: 0.2 cc⁻¹

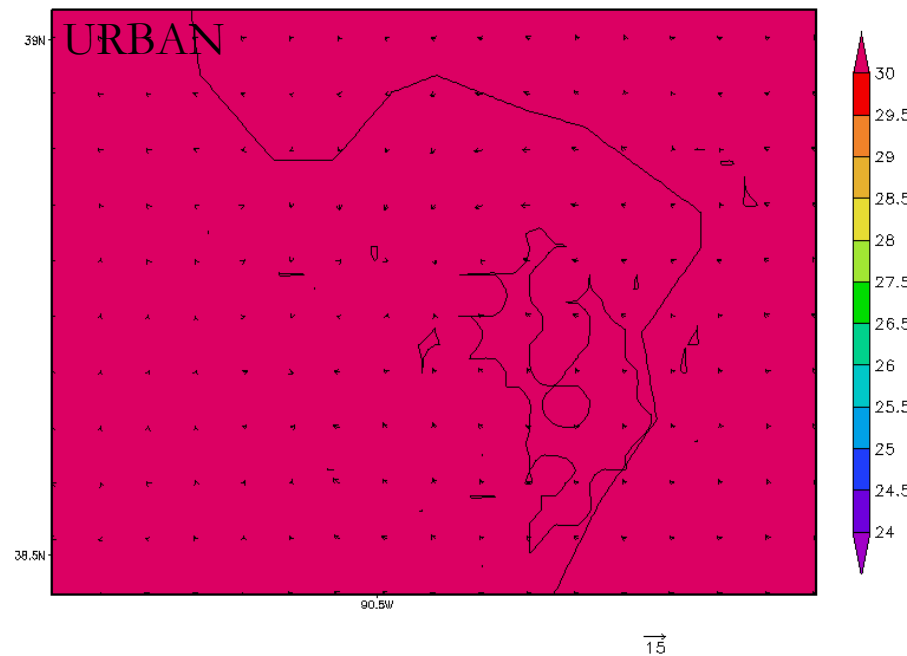
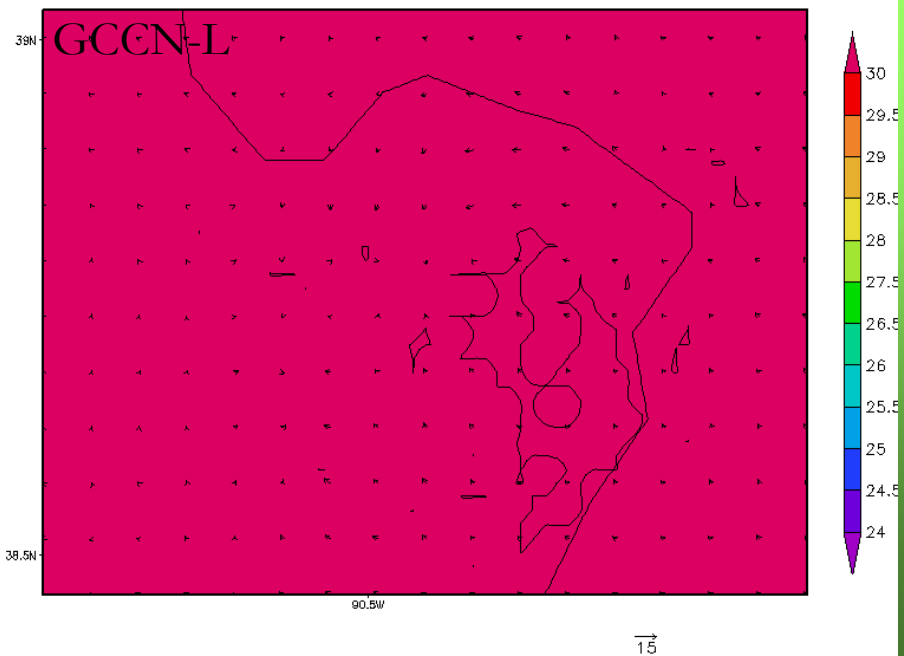
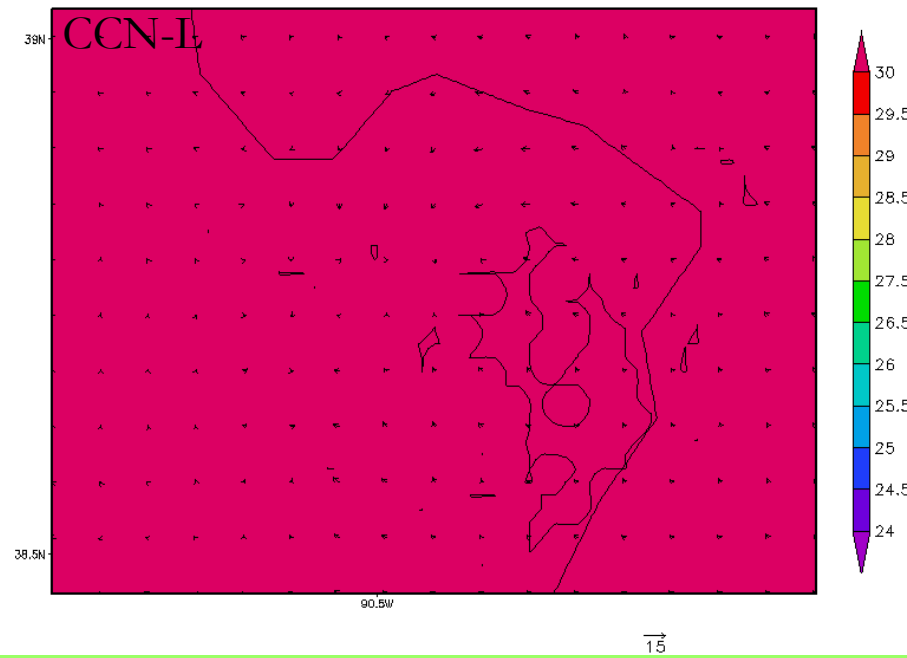
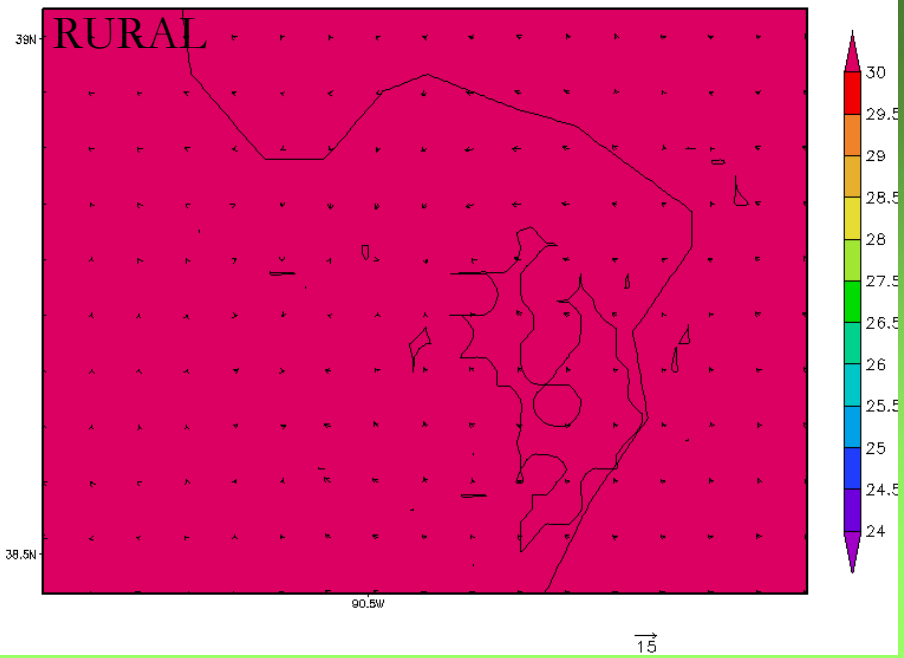
Downwind Precipitation Low Background Concentrations

Accumulated Precipitation as % of the Control (RURAL-L) -
Low Background Concentrations



Accumulated Volumetric Precipitation (acre-feet) for entire Grid 3

Time	Rural	CCN	GCCN	Urban
20:00	0	0	0	0
21:00	13956	13748	14411	14490
22:00	36338	35900	35173	35299
23:00	63409	63964	61451	58227
00:00	74370	75499	72511	69914



Summary of deep convection simulations

- **Urban land-use has the biggest control on locations and amounts of precipitation.**
- **Overall both CCN and GCCN concentrations are important to cloud responses to varying aerosols.**
- **For deep convective clouds the nonlinear interactions between varying aerosol amounts and cloud dynamics can lead to responses in terms of rainfall amounts that are quite unpredictable. Short term responses may increase rainfall whereas longer-term responses can decrease rainfall.**

**Simulation of the interaction
between aerosols and clouds,
precipitation over the Gulf of
Mexico and Houston**

New NOAA Grant:

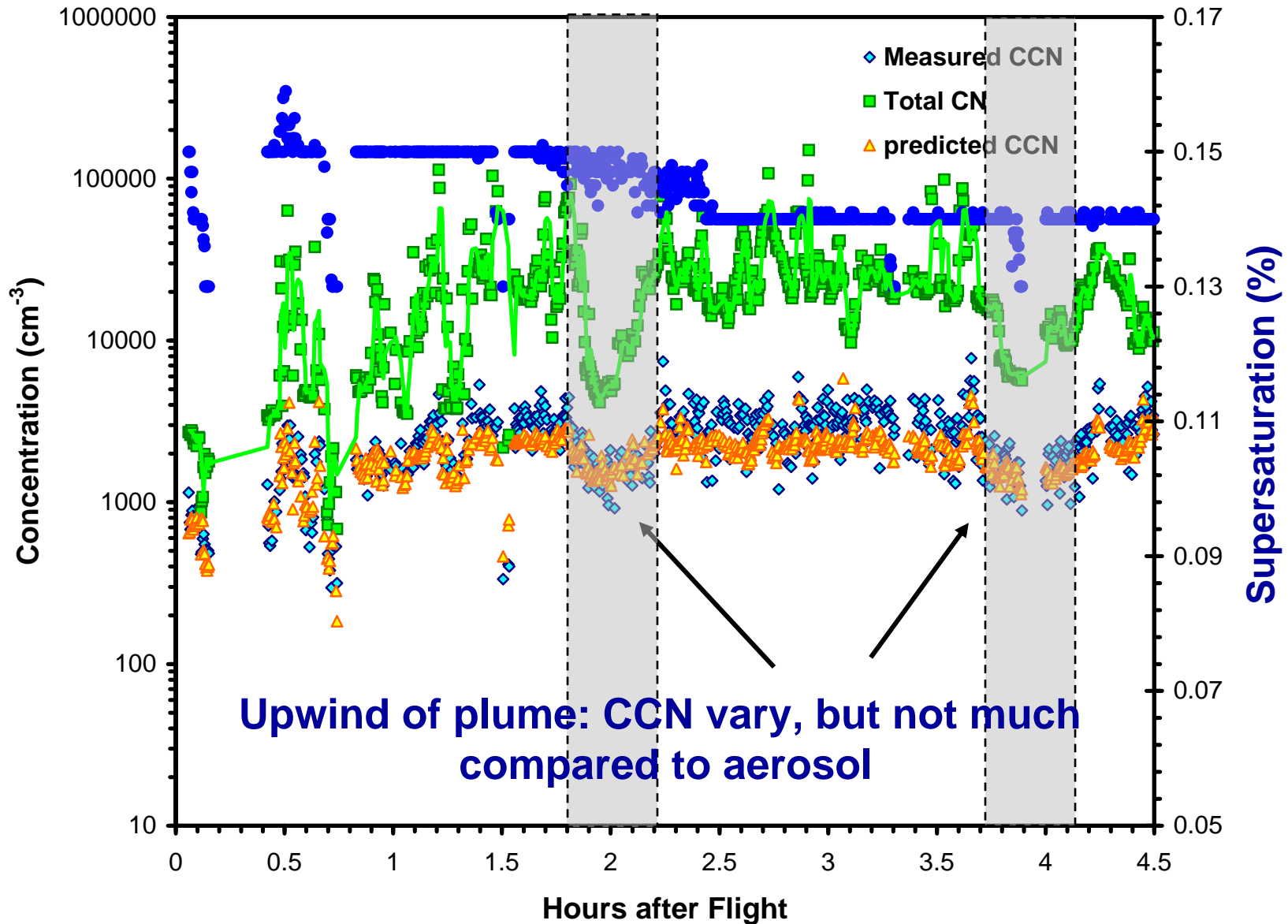
RAMS initialized with observed aerosol concentrations from the *GoMACCS 2006 field campaign.*

We examine relative impacts of Houston area land-use, urban aerosol sources, Gulf of Mexico aerosol sources and surrounding non-urban aerosol sources.

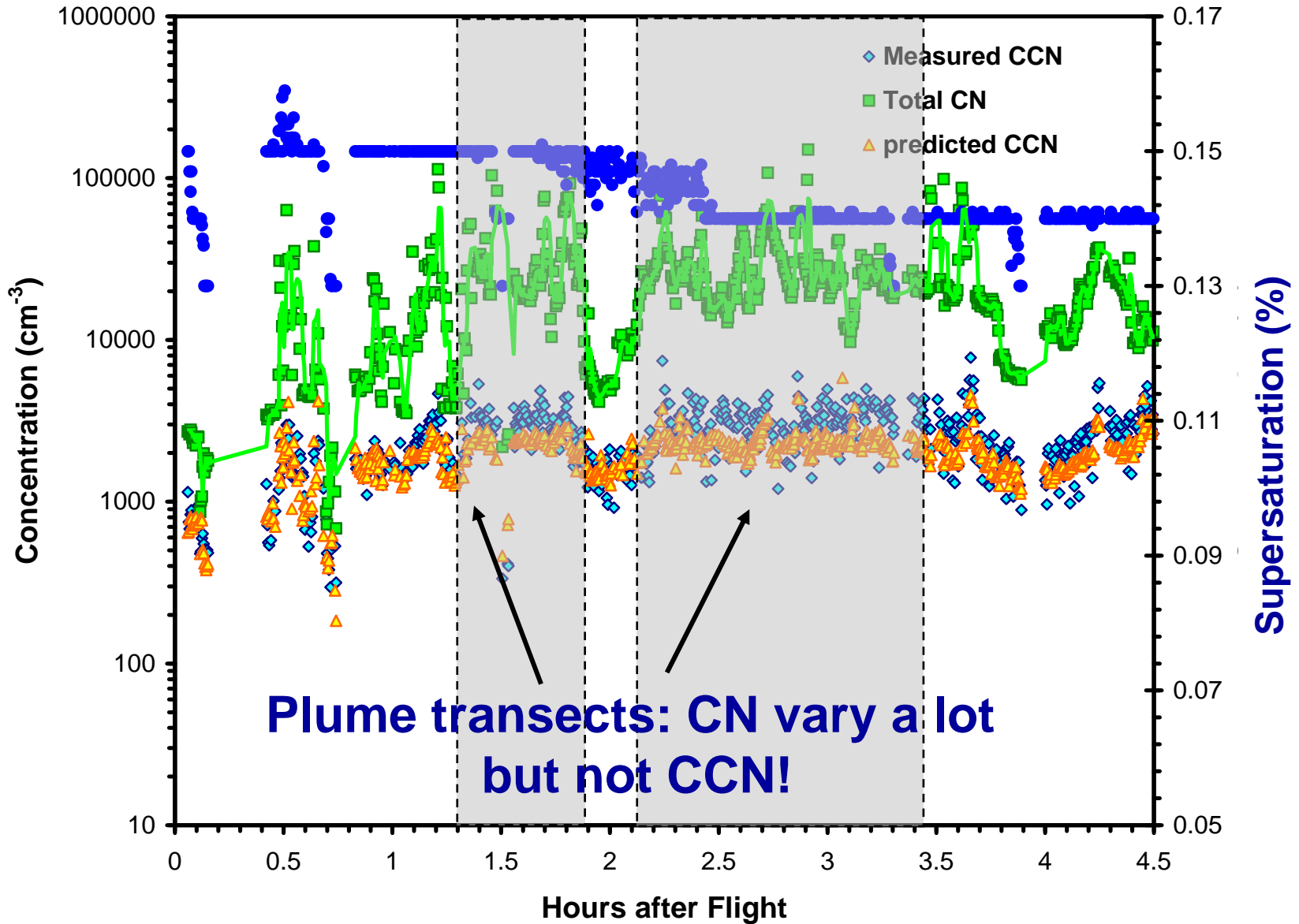
Sample Houston area CCN

- Data provided by Athanasios Nenes

September 20 Flight (P3 data)

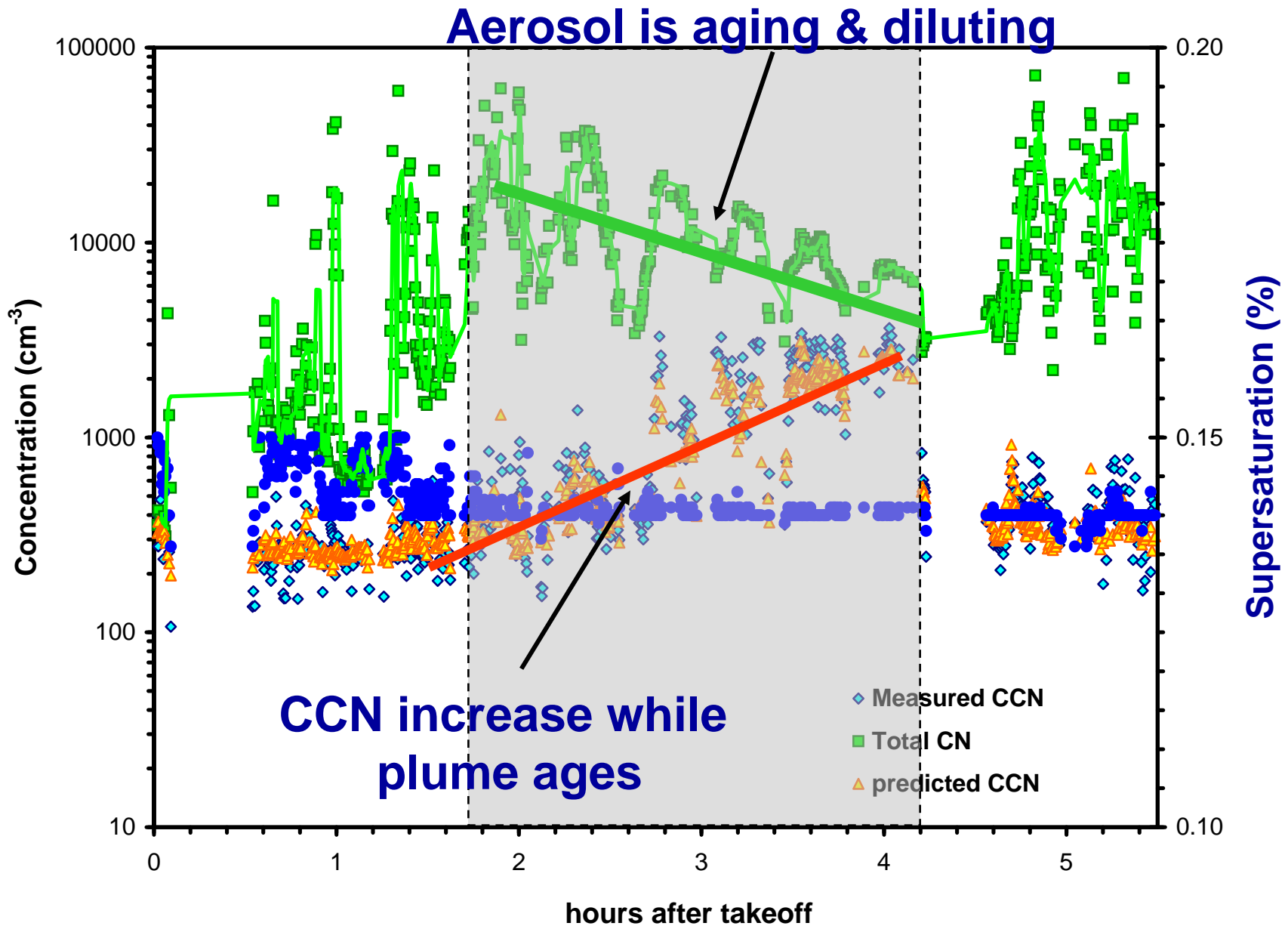


September 20 Flight



September 21 Flight

~ 100 km



The following ensemble of simulations are planned:

- **Simulation of the mesoscale evolution excluding Houston urban land-use but using clean background CCN and GCCN concentrations for the Gulf and urban-free countryside, and no direct aerosol radiative heating. We expect that the pure sea-breeze circulation will be the main driving force.**
- **Simulation of the mesoscale evolution including Houston urban land-use but using clean background CCN and GCCN concentrations and no direct aerosol radiative heating.**

- **Simulation of the mesoscale evolution excluding Houston urban land-use, excluding urban enhancement of CCN and GCCN, but including direct aerosol radiative heating.**
- **Simulation of the mesoscale evolution excluding Houston urban land-use, excluding aerosol direct radiative heating, but with urban enhancement of CCN and GCCN and control aerosols in the surrounding countryside and over the Gulf.**
- **Simulation of the mesoscale evolution including Houston urban land-use and including aerosol direct radiative heating, but excluding urban enhancement of CCN and GCCN concentrations.**

- **Simulation of the mesoscale evolution including Houston urban land-use, including aerosol direct radiative heating, and including urban enhancement of CCN, but excluding urban enhancement of GCCN.**
- **Simulation of the mesoscale evolution including Houston urban land-use, including aerosol direct radiative heating, including urban enhancement of GCCN but excluding urban enhancement of CCN.**
- **Simulation of the mesoscale evolution including Houston urban land-use, including aerosol direct radiative heating, and including urban enhancement of GCCN and CCN concentrations.**

Expectations

- **We expect that urban land-use over Houston will be the dominate control of clouds and precipitation.**
- **But, given that sea breeze air masses will transport relatively clean air into the Houston region, we expect that Houston Urban area aerosol pollution will have a stronger impact than we found over St. Louis.**