

Large Scale Urbanization for Climate Studies

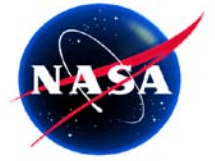
L. Bounoua¹ **J. G. Masek**¹ **C. P. Lidars**² **M. L. Imhoff**¹

¹NASA GSFC Code 614.4, ²NASA GSFC Code 614.3

Irrigation requirement estimation using MODIS vegetation indices and inverse biophysical modeling

M. L. Imhoff¹ **L. Bounoua**¹ **R. Harriss**² and **M. Glantz**²

¹ GSFC Code 614.4, NASA, ²Institute for the Study of Society and Environment, NCAR



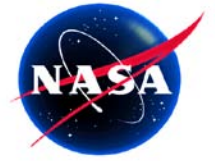
Large Scale Urbanization for Climate Studies

L. Bounoua¹ J. G. Masek¹ C. P. Lidars² M. L. Imhoff¹

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Project Objectives

- 1) Combine well-calibrated high-resolution data from the MODIS instrument and Landsat digital imagery to develop a continental scale land cover map that explicitly accounts for the fractions of impervious surfaces within urban areas
- 2) Develop process algorithms of urbanization suitable for climate studies;
- 3) Use the urban attributes and process algorithms in a land surface model to quantify the impact of urbanization, as a form of land use, on the water, energy and carbon budgets from local to continental scales.



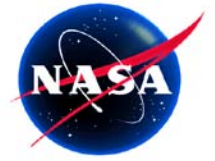
Definition

Large Scale Urbanization

Urbanization is a permanent **form of land use** which affects regional climate through different physical mechanisms:

- 1) the reduction of the fraction of vegetation and the subsequent reduction in photosynthesis and plant's water transpiration and interception loss
- 2) the alteration of water infiltration and surface runoff and their impacts on soil moisture and the water table
- 3) the alteration of surface albedo and its effect on the surface energy partitioning, and
- 4) the modification of the surface roughness and its implication for the turbulent exchanges of water, energy and momentum fluxes.

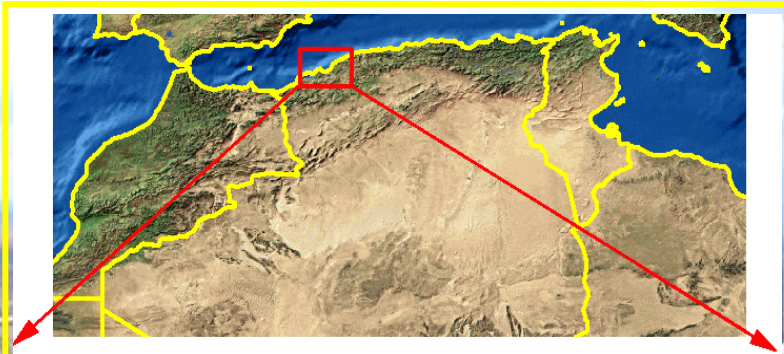
These physical mechanisms are tightly coupled land-atmosphere processes and their alteration may have important impacts on local and regional climate.



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We choose to perform a case study
in a city in a semi-arid region of North
Africa



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Cities are not built the same way nor are they built with the same material



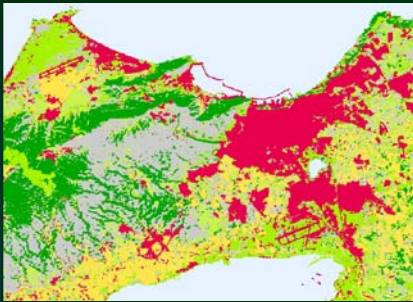
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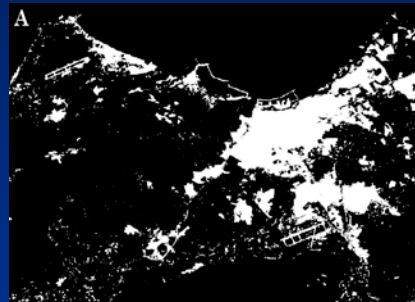
Mapping Approach: Combining Landsat and MODIS

Local Scale

Land Cover, Landsat

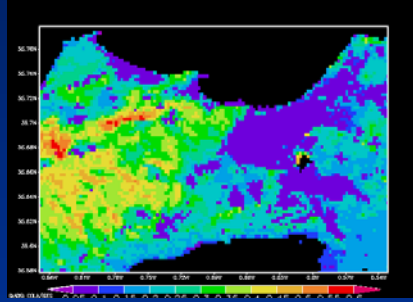


ETM+ derived LC classification
@25x25m (2002)



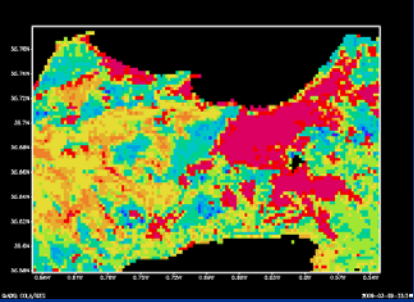
Impervious surface areas
@25x25m

NDVI, MODIS

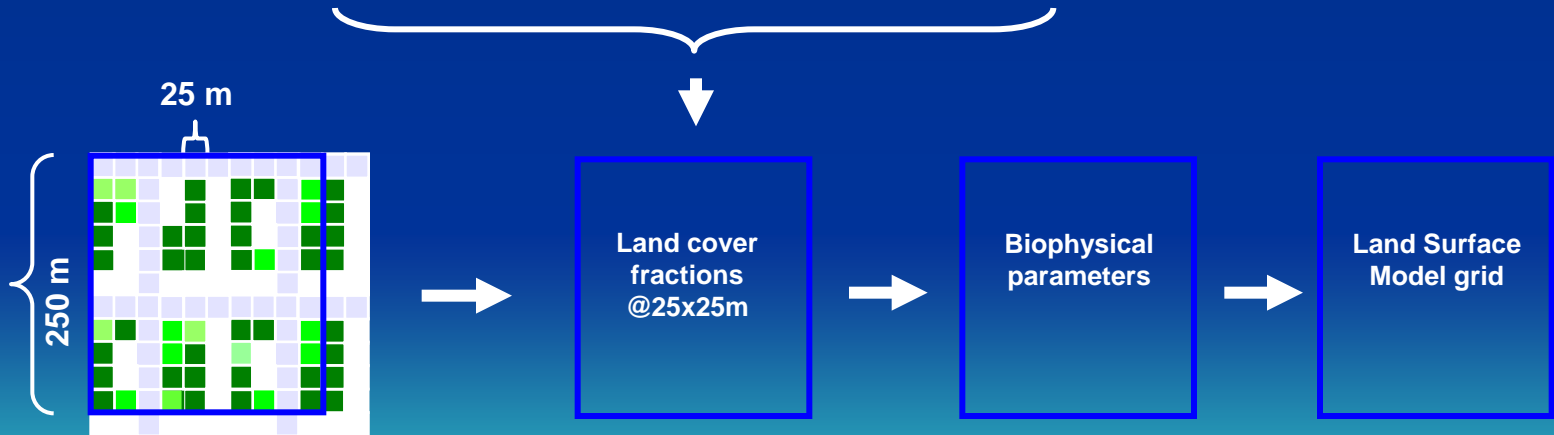


16-day MODIS NDVI @ 250 m

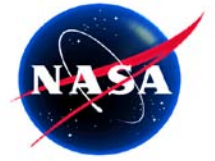
Climate



Hourly Meteorology @ 250 m



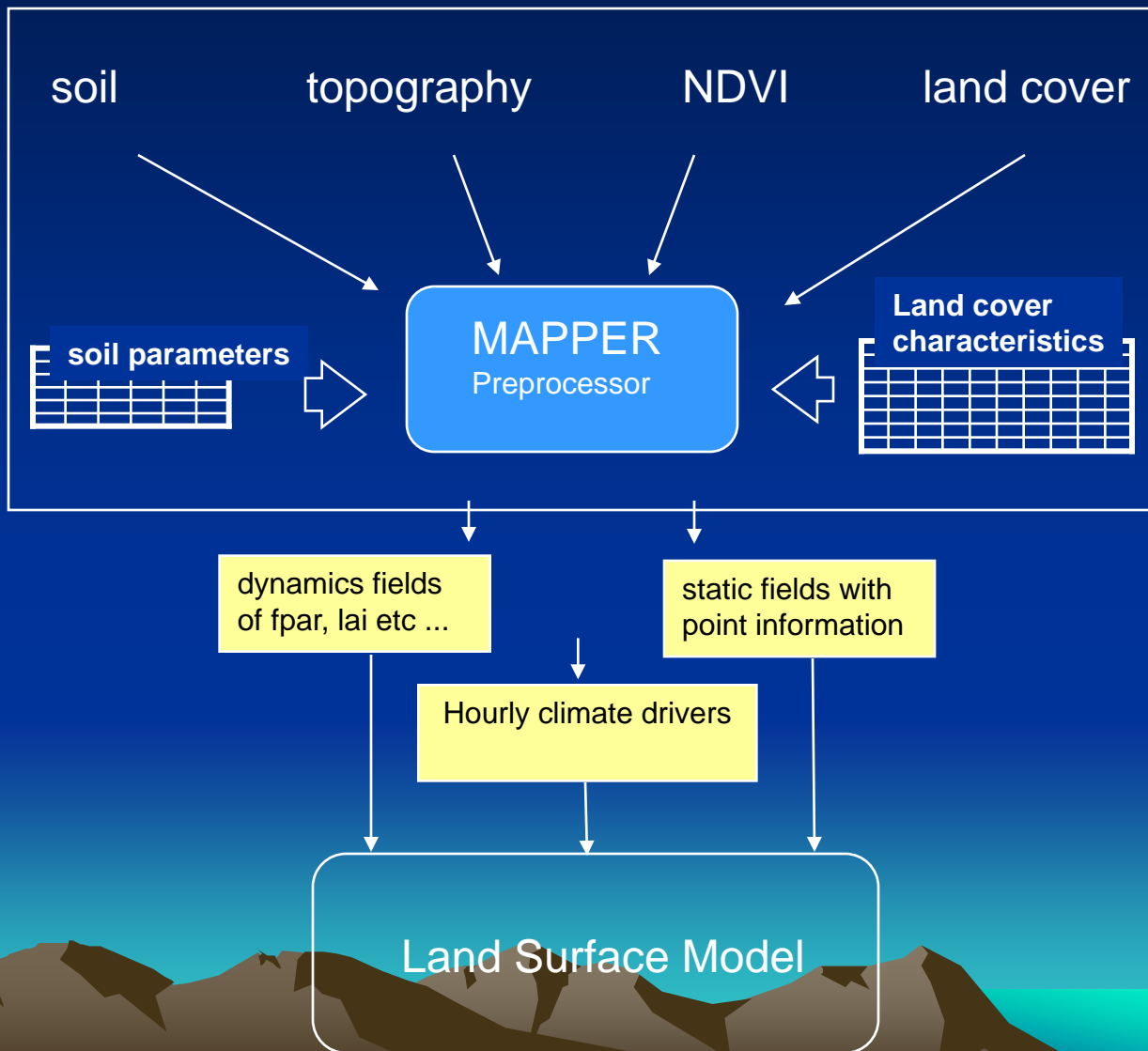
We develop a land use map discriminating impervious surfaces from other types and use it in a land surface model to assess the impact of urbanized land on surface energy, water and carbon budgets.

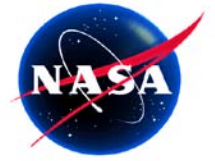


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Model and Data

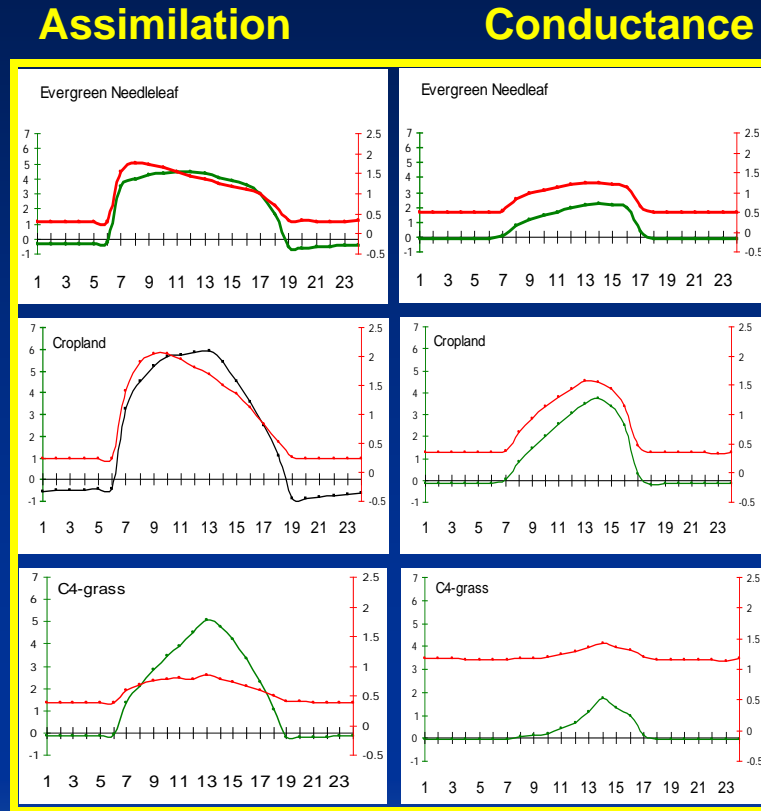




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Diurnal Response

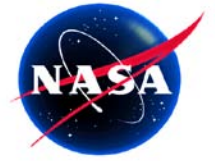


Summer (JJA)

Winter (DJF)

Canopy assimilation (green) in $\mu\text{moles}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and conductance (red) $\text{m}\cdot\text{s}^{-1}$ at a selected grid cell for 3 land cover types (4- Forest, 7-Grassland, Cropland). For the urban type assimilation and conductance are insignificant.

Different land cover types respond differently to the same forcing depending on their physiological, morphological and optical attributes and therefore have different interactions with local climate.



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Diurnal Response

average 26.38 °C

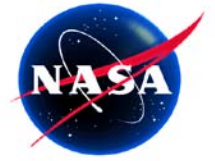
average 26.43 °C

average 26.93 °C

Composite diurnal temperature cycles for the summer (JJA).

Land use	Type 4	Type 7	Urban	Type 9	Type 11	Type 12	Weighted
Fraction (%)	4	5	6	3	10	71	100
Tmin	18.87	19.08	19.68	19.18	19.09	19.18	19.17
Tmax	33.25	33.39	34.70	33.61	33.47	33.43	33.44
Tmean	26.38	26.34	26.93	26.47	26.36	26.45	26.43
Nighttime Tmean	24.09	23.88	24.18	23.92	23.87	24.08	24.04
Daytime Tmean	28.66	28.80	29.67	29.01	28.85	28.82	28.83
DTR	14.38	14.32	15.02	14.43	14.38	14.25	14.28
Difference Tmax	1.45	1.31	0.00	1.09	1.23	1.27	1.26
Difference Tmin	0.81	0.60	0.00	0.50	0.59	0.50	0.51

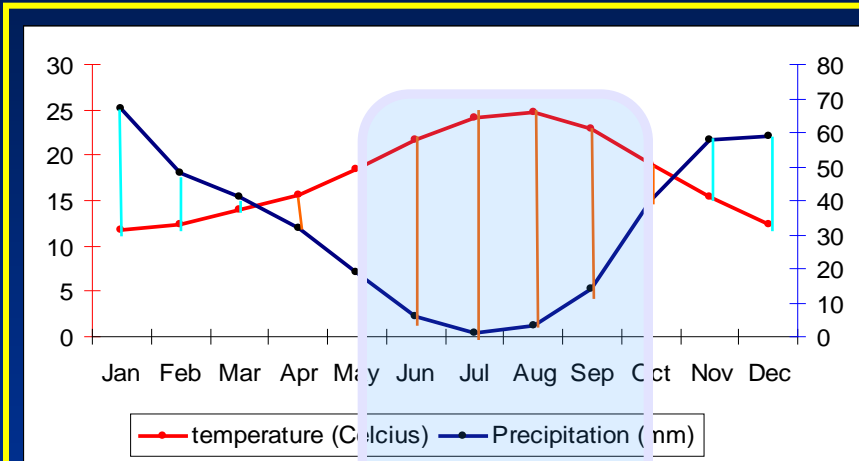
During summer, the urban class results in an additional warming of 1.45°C during daytime and 0.81°C at night compared to that simulated for needleleaf trees under similar climate conditions.



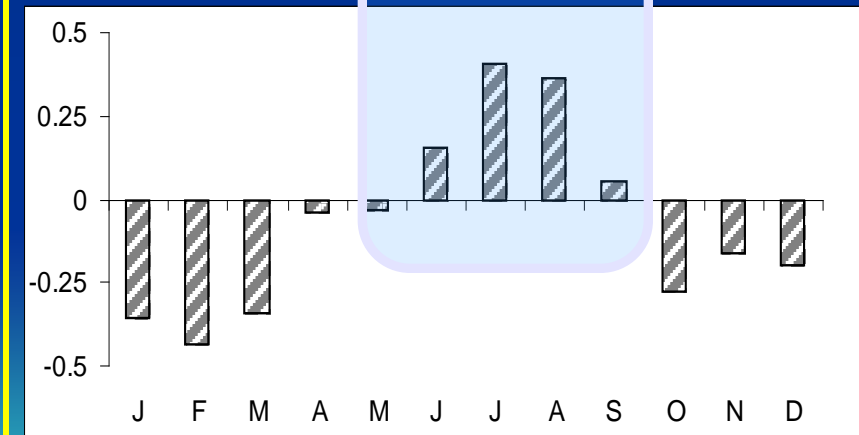
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Monthly Response



Observed temperature and Precipitation climatology



Monthly mean difference between the urban temperature and the average for all other classes (0.5°C).

In this semi-arid region, the growing season is not clearly defined as in temperate latitudes. The temperature and precipitation are out of phase. Precipitation is maximum during winter when the temperature is still relatively cold and partially inhibits vegetation growth.

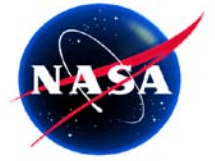
The difference between the surface temperature of urban and non urban areas is largely modulated by albedo and transpiration. These two factors may either work in tandem or offset each other depending on the season.

During summer:

- the warming due to lack of evapotranspiration dominates the cooling effect of high albedo in urban areas compared to non urban areas which still maintain some transpiration.

During winter:

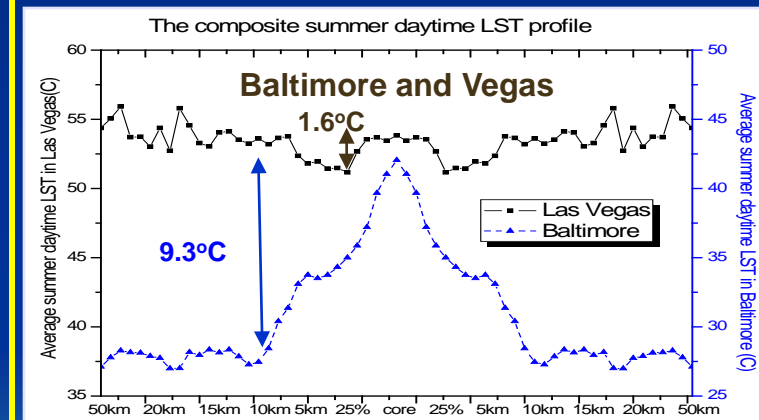
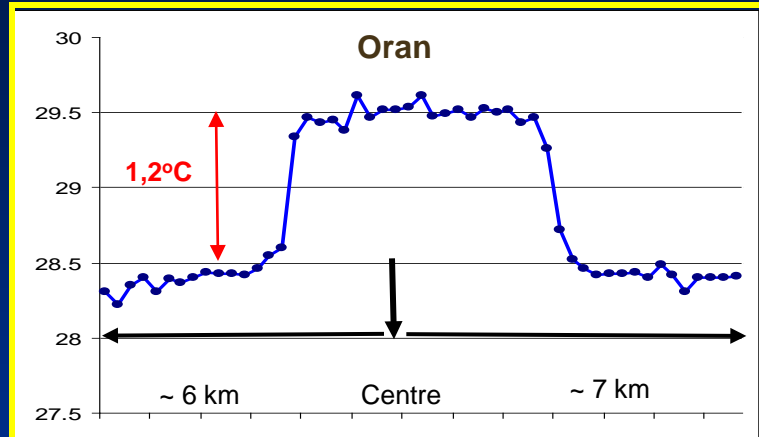
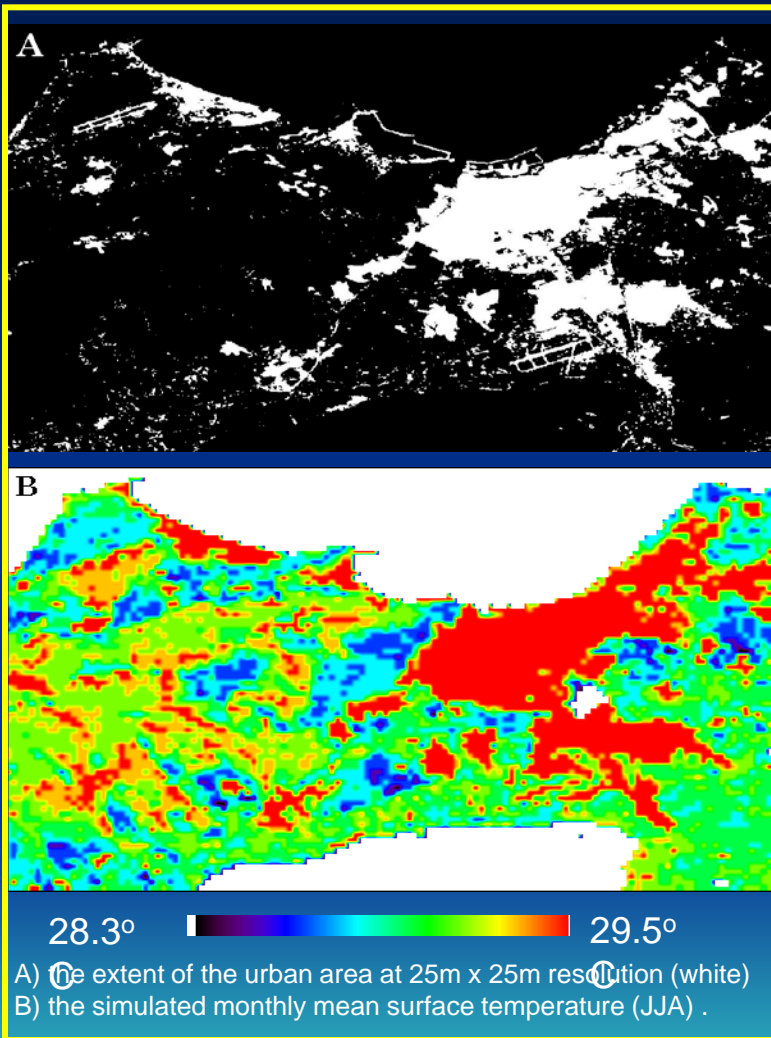
In addition to high albedo, urban soils are exposed and evaporation takes place at potential rate; thus exacerbating the cooling compared to non urban areas in which transpiration is limited by cold temperatures, thus shunting most of the absorbed energy into sensible heating.



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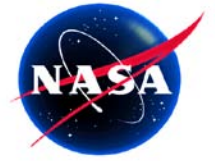
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Monthly Response



Composite averaged JJA daytime modeled surface temperature for A) Oran and B) LST profile from MODIS across urban zones in Baltimore and Las Vegas.

Unlike in temperate latitudes where urbanization creates a marked Heat Island effect, for this semi arid region, urbanization contributes a monthly mean warming of about 1.2 °C during the summer months.

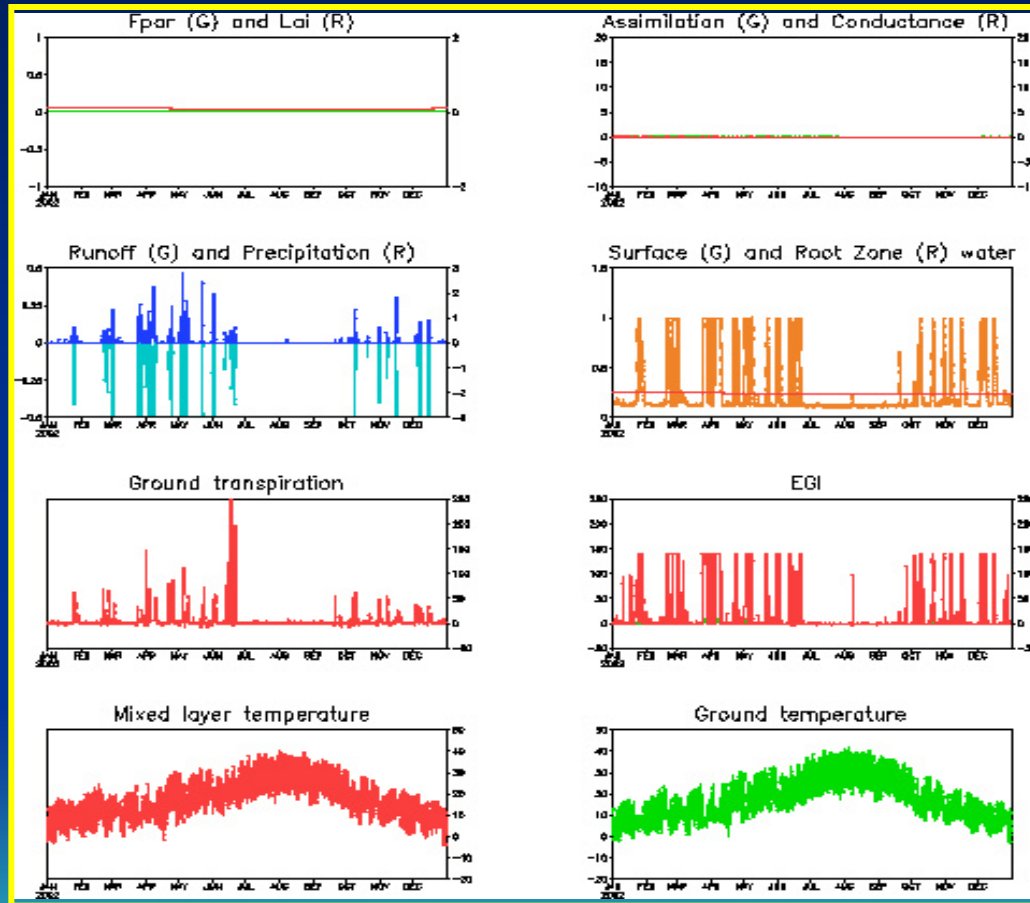


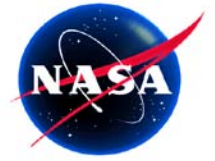
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Annual Response

Urban



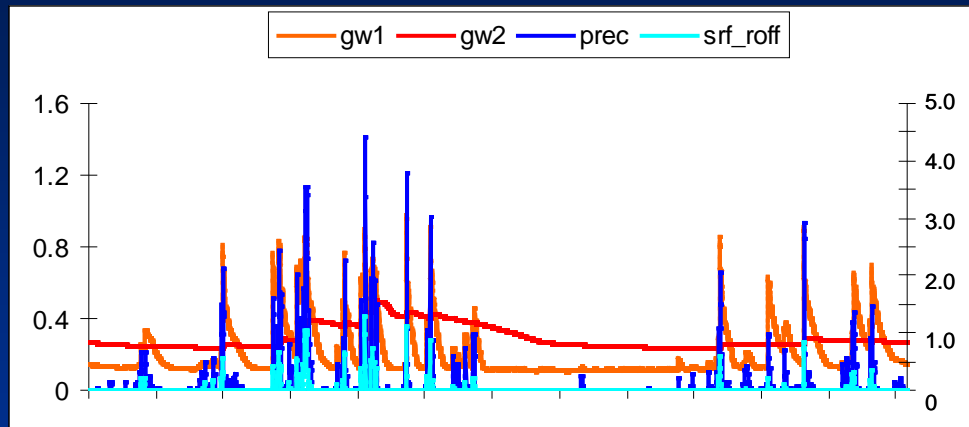


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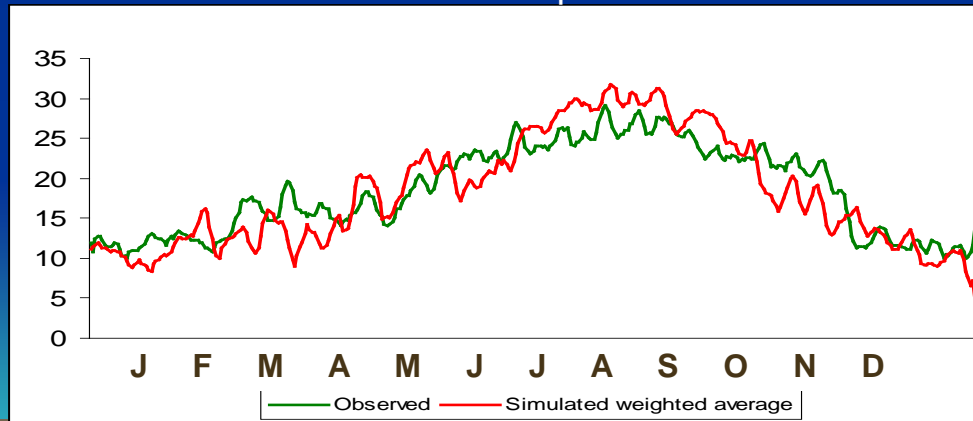
Annual Response Weighted Average

Surface Hydrology



Annual weighted hourly evolution of simulated surface layer (GW1), root zone layer (GW2) soil moisture (%), surface runoff (*100) and observed precipitation in mm.hr⁻¹

Surface Temperature



Five day running-mean observed temperature at a single station in the study area and the domain averaged weighted mean simulated daily temperature (Celsius) for 2002.



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Carbon Budget and Urban Scenarios

Scenario 1: Business as usual

urbanization grows to reach 50% of the total area expanding equally on the available land but excluding forests.

Scenario 2: Smart Growth

urbanization grows to reach 50% of the total area excluding forests, all remaining vegetation is replaced by newly introduced *platane* trees.

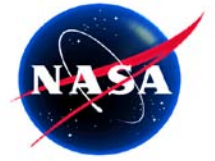
Fractional coverage of each land cover type. * represents the current situation.

Simulations	Forest	Grassland	Urban	Shrubs	Bare	cropland	<i>Platane tree</i>	Total
Control*	15.73	8.61	21.67	23.69	14.23	16.07	0	100
Scenario 1	15.73	1.53	50	16.60	7.15	8.99	0	100
Scenario 2	15.73	0	50	0	0	7.12	27.15	100

July mean temperature and total annual gross carbon uptake

July mean	Control (C)	Scenario 1 (S1)	Scenario 2 (S2)	S1 - C	S2 - C	S2 -S1
Temperature (C)	29.44	29.57	28.55	+0.13	-0.89	-1.02
Carbon uptake (g)	1.94 E+12	1.26 E+12	2.70 E+12	-0.60 E+12	+0.76 E+12	+1.44 E+12

Remarkably, despite the increase of 50% in urban area in scenario S2, the mean July temperature is cooler than the control by about 0.89°C and the carbon uptake increases by 0.76 10⁶ metric tons or 39% more than the current configuration. Scenario 2 is much more advantageous than scenario 1; it allows a reasonable urbanization growth, keeps a fraction for agricultural lands and increases forested areas. Most importantly, it reduces the surface temperature by about 1°C and more than doubles the carbon uptake compared to scenario S1.

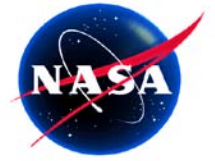


Concluding Remarks

In this and other arid and semi arid regions, urbanization is increasing at a high rate (Oran, 17% per decade) and is taking place in most fertile agricultural lands.

1. Urban albedo is higher than that of the surrounding regions.
2. The difference between the surface energy budgets in urban and non urban areas is modulated mostly by **albedo and transpiration**.
3. The Urban Heat Island – UHI effect is not as marked as for urban areas embedded in temperate forests.
4. For July, the UHI is **1.45 °C** during daytime and **0.81°C** at night with a monthly average UHI of **1.2 °C**
4. The hydrological cycle is practically ‘shut down’ during summer and characterized by important runoff during precipitation events (winter-Spring).
5. The carbon cycle is relatively weak, 1.94E+12 grams of carbon per year.
6. Increase in forested areas along with urban growth may **increase carbon sequestration** and **mitigate** some of the urban warming.

More details can be found in: Impact of Urban Growth on Surface Climate: A Case Study in Oran, Algeria **Bounoua L., A. Safia, J. Masek, C. Peters-Lidard, and Marc L. Imhoff**, JAMC, Volume 48, Issue 2, 217,231;DOI: 10.1175/2008JAMC2044.

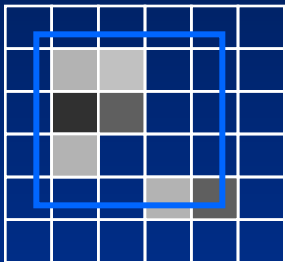


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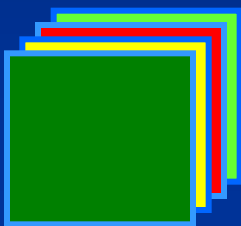
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Continental Scale

NLCD 30m
% impervious



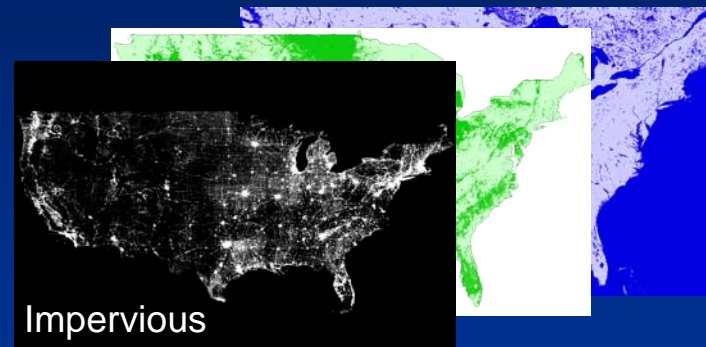
MODIS 1km LC



MODIS 1km NDVI

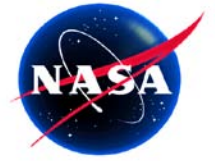


FVC in a CMG (0.05 Deg.)



Fractional ndvi in a CMG (0.05 Deg.)

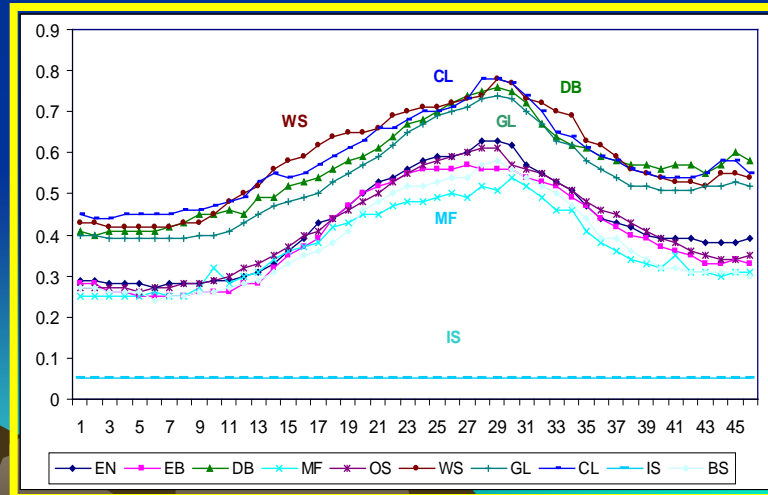
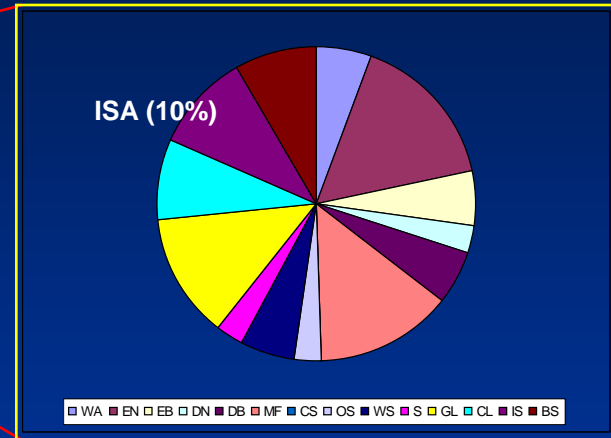
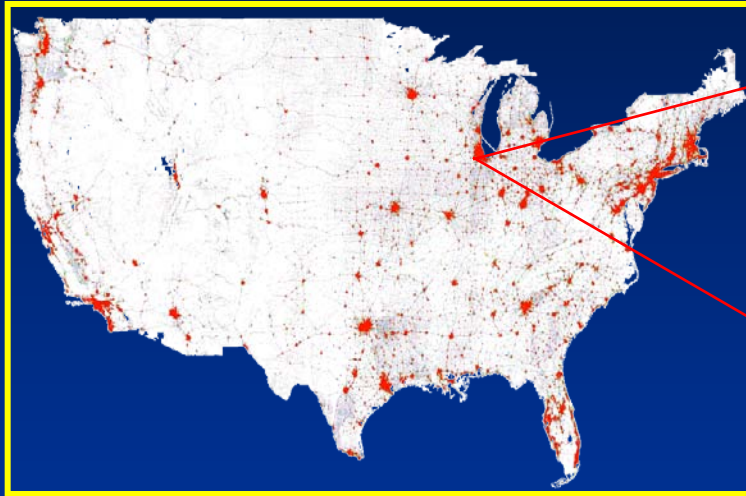




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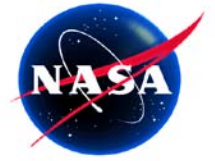
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Mapping Approach: Combining Landsat and MODIS



Biophysical parameters:

- FPAR
- LAI
- Greenness Fraction
- Snow Free Albedo
- Zero Plane displacement
- Roughness
- Aerodynamic resistance



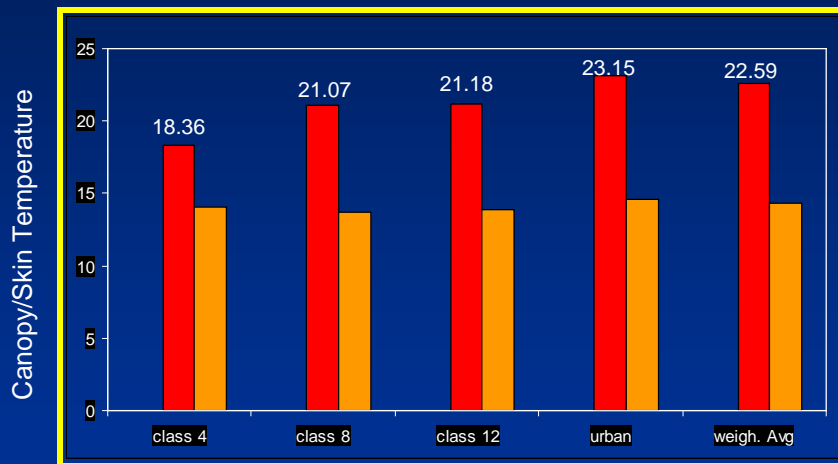
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Preliminary model results

Chicago

July mean daytime/nighttime average temperature



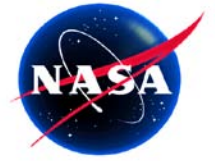
Class	Forest	Shrubs	Cropland	Urban	Weighted
Fractions (%)	4.2	2.8	20	73	100
Mean Temperature (urban – class)	4.79	2.08	1.97	0	0.56
Mean DTR	5.27	6.55	6.30	8.13	7.63

At 100% impervious, the model response results in a latent heat reduction of **100Wm⁻² (10.7 cm for July)** and an increase in sensible heat of about **65 Wm⁻²**.

A study covering regional scale Eastern U.S suggests that at 100%, urbanization decreases annual evaporation by **22 cm** and increases SH by **13 W.m⁻²**.

End





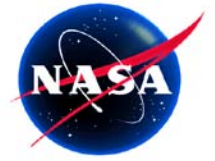
Irrigation requirement estimation using MODIS vegetation indices and inverse biophysical modeling

M. L. Imhoff¹ L. Bounoua¹ R. Harriss² and M. Glantz²

¹ GSFC Code 614.4, NASA, ²Institute for the Study of Society and Environment, NCAR

Project Objective:

This work explores an *inverse modeling approach* using satellite-derived biophysical attributes (LAI, FPAR) and the *Simple Biosphere model - SiB2* to quantify the minimum amount of water required to sustain unstressed photosynthetic production for crops in semi-arid and arid regions.



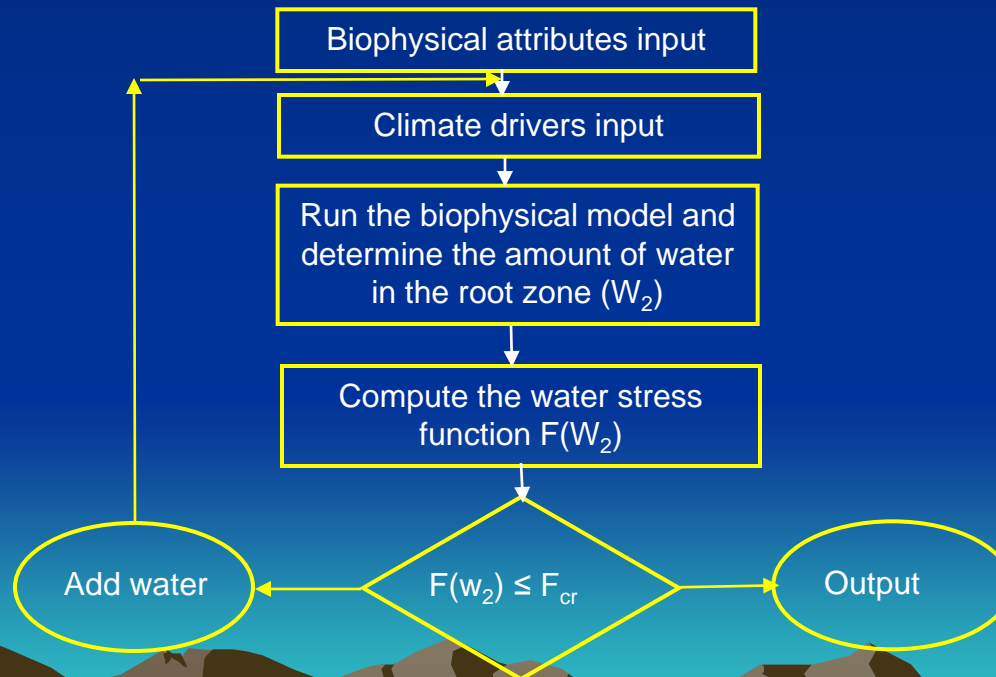
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Algorithm

MODIS data are used to estimate the seasonal cycle of LAI, FPAR and other biophysical parameters of a crop canopy. The inverse modeling approach consists of comparing the carbon and water flux modeled under both equilibrium (in balance with prevailing climate) and non-equilibrium (irrigated) conditions.

We postulate that the degree to which irrigated lands vary from equilibrium conditions is related to the amount of irrigation water used.

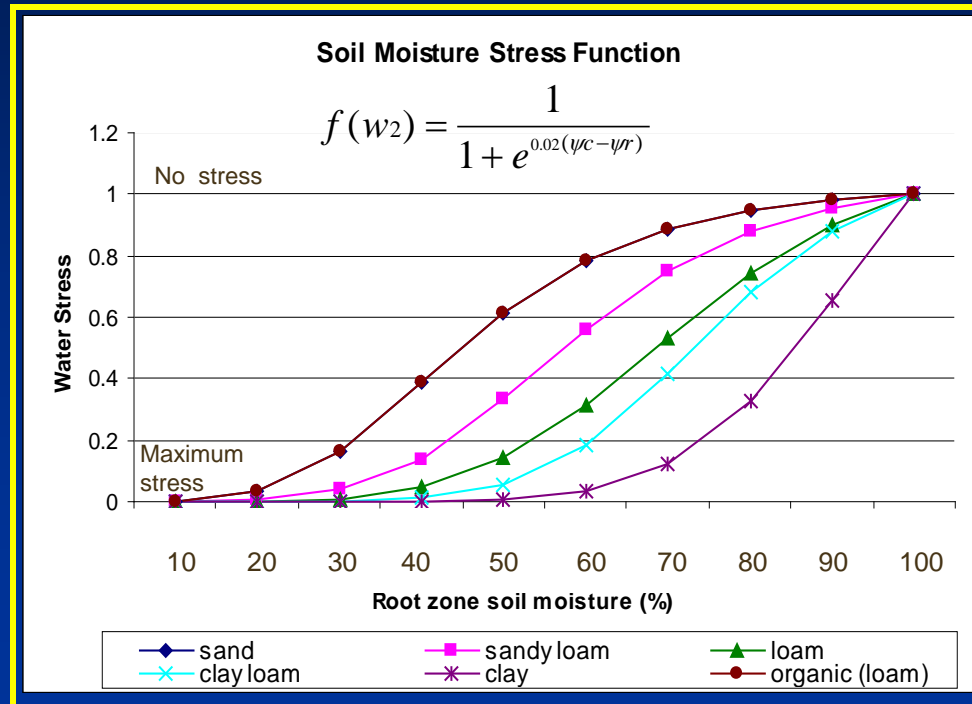




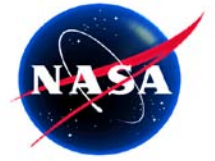
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Water stress function



The water stress function depends on the root zone soil moisture potential and the critical water potential both of which are soil type dependent (1). Where w_2 is the soil moisture in the root zone layer expressed as a fraction of saturation, Ψ_c and Ψ_r represent the critical water potential and the root zone soil moisture potential expressed in meters, respectively; and where $\Psi_r = \Psi_s W_2^{-b}$ with Ψ_s being the soil moisture potential at saturation and b an empirical parameter. The soil moisture stress function is then used to scale photosynthesis and the stomatal conductance. In SiB2, the water stress varies between 1 and 0, with 1 representing no stress. It inhibits photosynthesis by half when the soil moisture potential reaches the critical value.



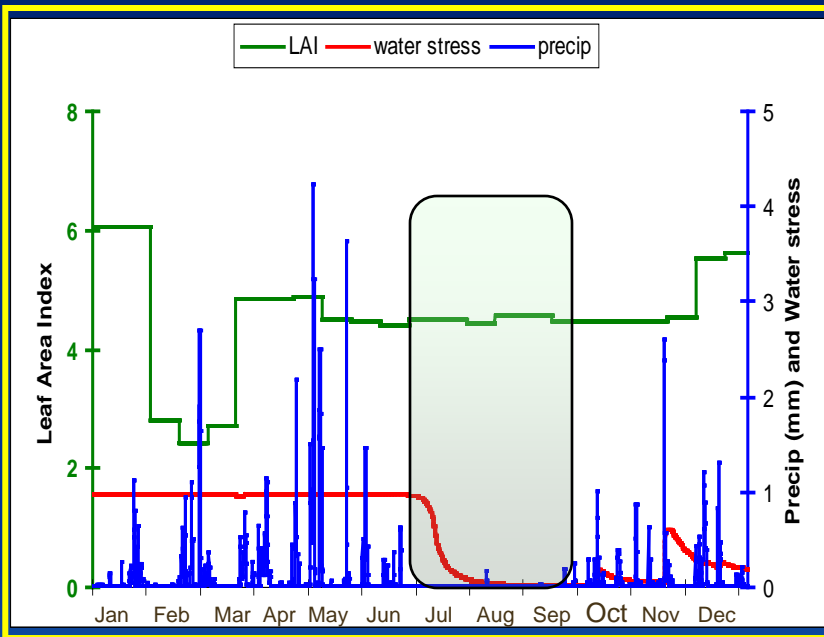
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Climate-Vegetation Imbalance

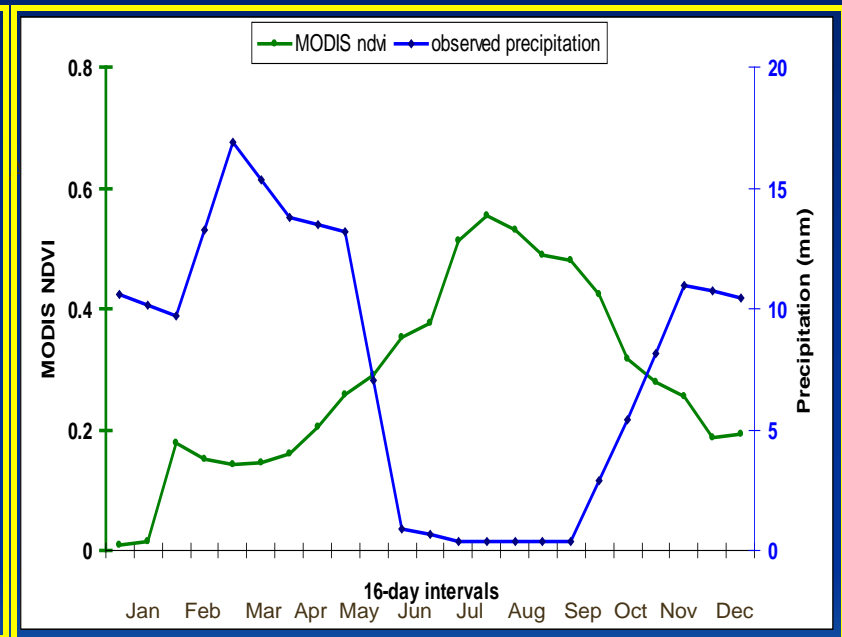
We implement the algorithm in the model and apply it to cropland areas in semi-arid test regions.

Eastern Mitidja, North Africa

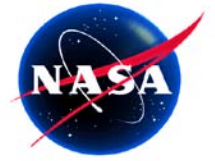


North East Algeria, (Mitidja), 2005. 21 small adjacent private farms based on extensive vegetable farming where the irrigated area is less than 50%. Irrigated area ~ 1.0 ha. Gravity is used as the irrigation technique. Water delivered from **Aquifer**. Reported irrigated water for vegetable crops **1900 m³.ha⁻¹ yr⁻¹**

Mary Velayat, Eurasia



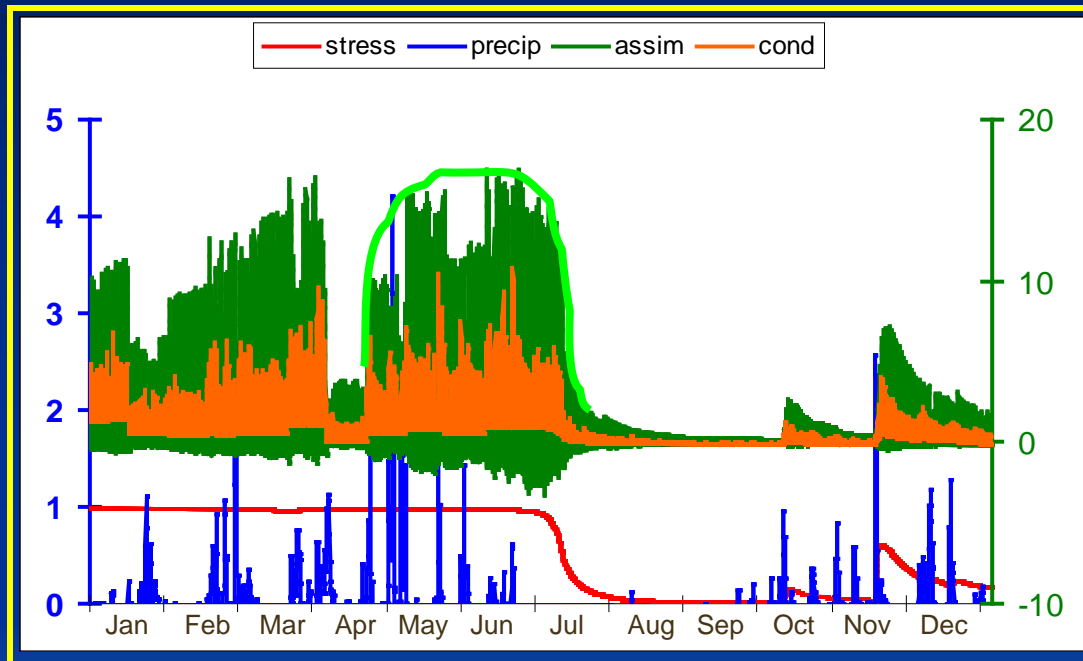
Southeast Turkmenistan (Mary Velayat), 2005. Size is about (700mx500m). cotton is sowed in late March to early April, heavily irrigated in late July and August. Harvested and gathered in November. Water delivered from the **Murgab** river. 2005. Well fertilized. Reported irrigated water for cotton **7000-7500 m³.ha⁻¹ yr⁻¹**



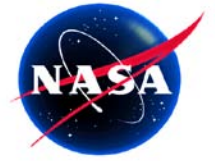
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Model Response - Control



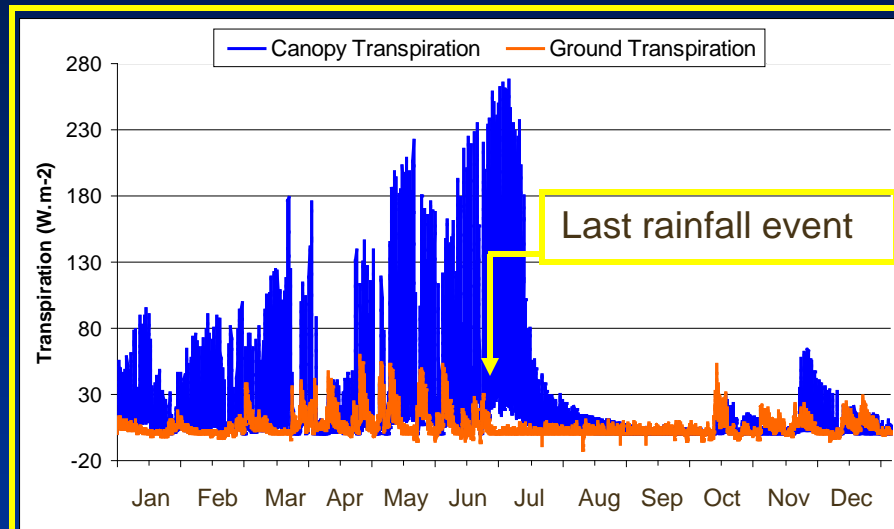
Canopy assimilation and conductance (right axis); Precipitation and Water stress (left axis)



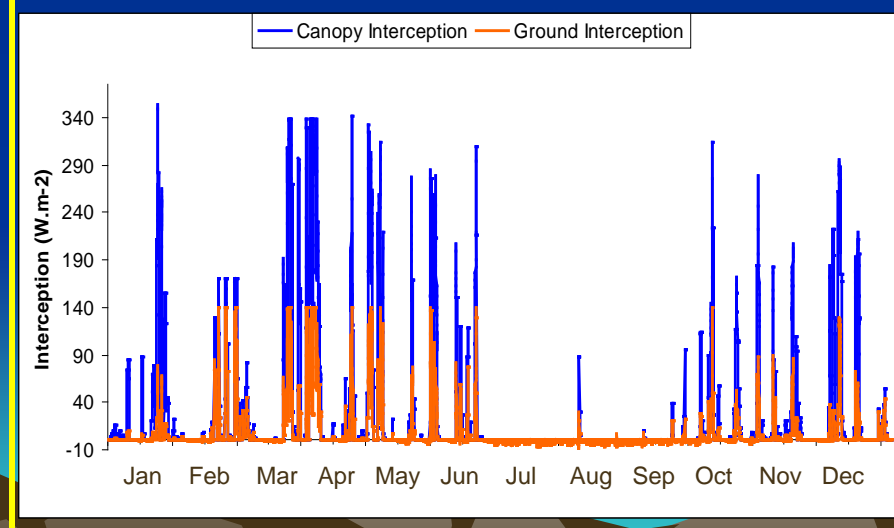
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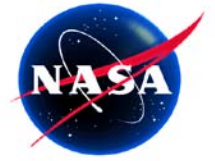
Model Response - Control



It takes about 3-4 weeks after the last rain event for the water stress to completely shut the stomata and inhibit plant's transpiration.



Canopy and ground interception stop immediately with the last rain event.



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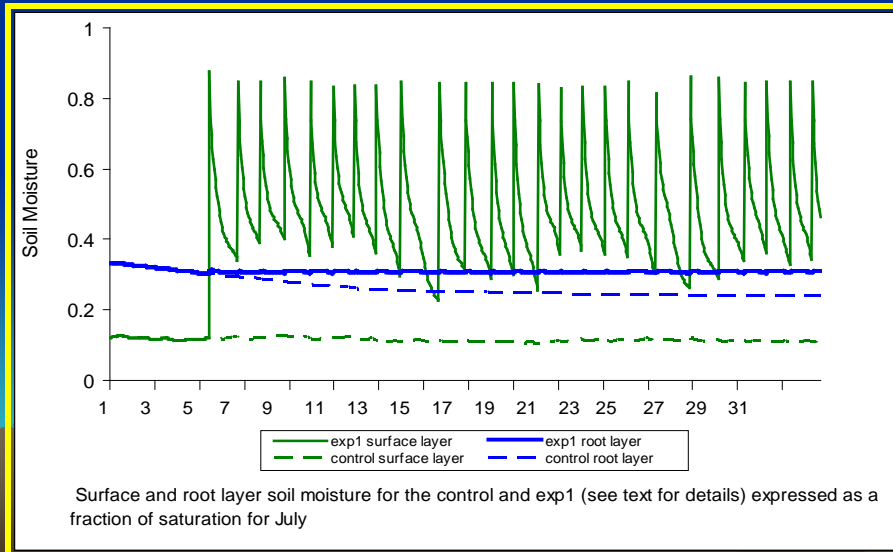
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Model Response

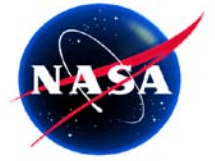
July Control and Spray Irrigation



Irrigation has maintained a water stress level around the 0.9 threshold and provided a maximum amount of about 1.4 mm of water per occurrence with an average frequency of occurrence of 24.6 hours.



Since water is added directly on top of the canopy, it first saturates the canopy interception store, fills the surface layer and then infiltrates into the root zone. The water content in the first layer almost mirrors the irrigation pattern. As water is added however, the moisture content in the root zone slowly builds up and maintains values significantly higher than those obtained during the control simulation

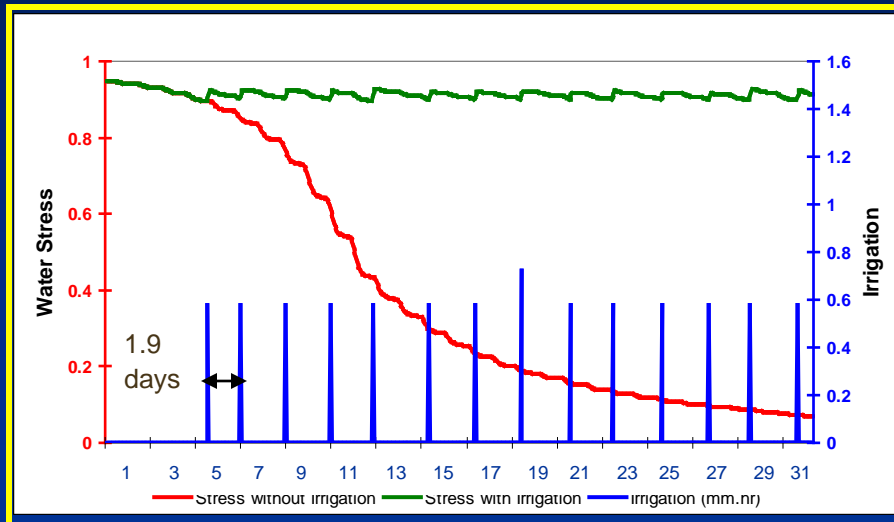


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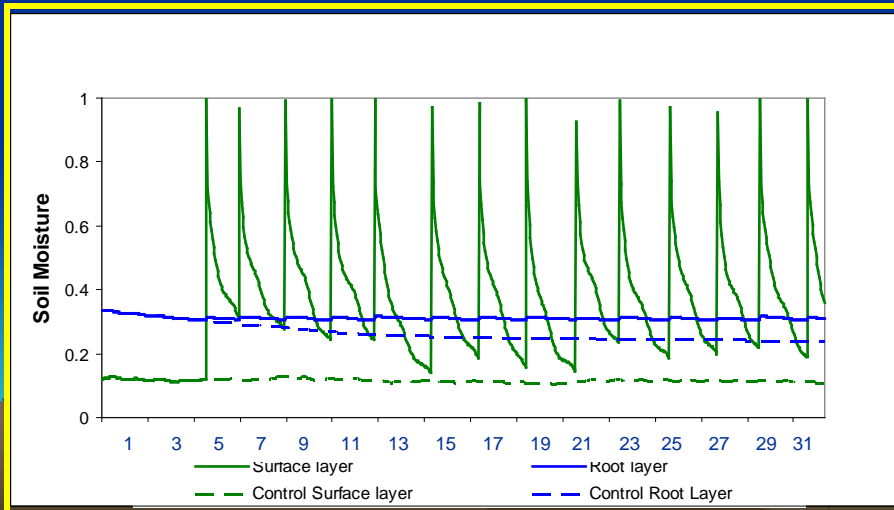
Model Response

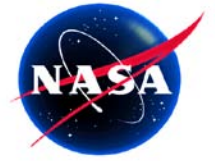
July Control and Drip Irrigation



The use of the drip irrigation method Reduced both the canopy and ground interception compared to spray irrigation.

Thus method results in less frequent irrigation events (about every 48 hours) with an average water requirement amount of about 0.6 mm per occurrence, that's about 43% of that simulated for spray irrigation.





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Validation

Eastern Mitidja, North Africa

Mary Velayat, Eurasia

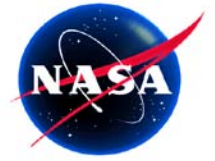
Irrigated Crop (ha)			
Potato	0.164	Sweet Peppers	0.077 eggplant 0.067
Carrot	0.192	Turnip	0.038 Zucchini 0.365
French Beans	0.096		

Irrigated Crop (ha)	
Cotton	100.

	Water Delivery Type	H ₂ O (m ³ ha ⁻¹ yr ⁻¹)
Data collection Laoubi and Yamao (2008)	All	1904.20
EXP1	Spray	1170.00 61.5 %
EXP2	Drip	300.00 16%

	Water Delivery Type	H ₂ O (m ³ ha ⁻¹ yr ⁻¹)
Data collection Jahan Kariyeva (2008)	All	7000-7500
EXP1	Spray	4095.00 56.5%
EXP2	Drip	1365.00 19%

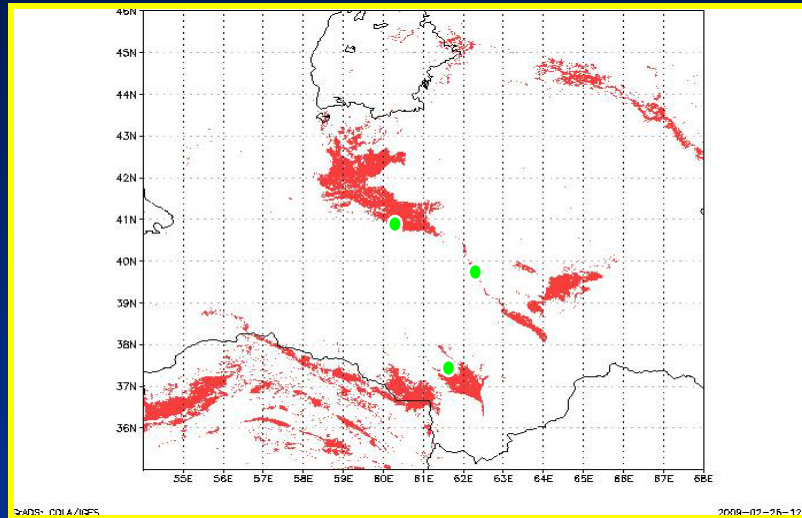
The approach provides a physiological benchmark water requirement for observed canopies to which reported irrigation water use can be compared in order to improve both estimates and delivery systems. The technique can also be expanded to assess water vulnerability of both crops and natural ecosystems as a result of climate change.



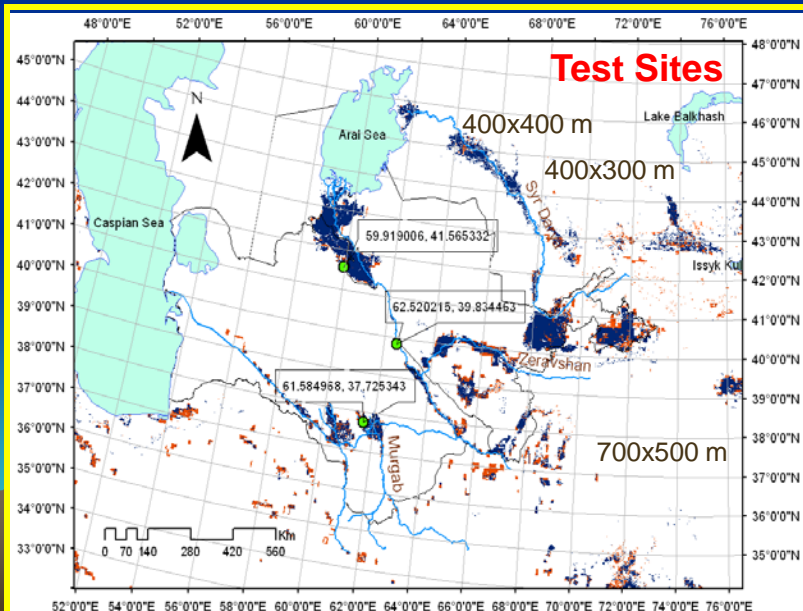
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Cropland distribution from MODIS



Observed Cropland from field experiment

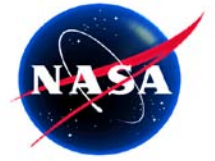


- The Green spots identify areas where crop rotation data and water usage have been collected.
- Dark blue and orange areas identify irrigated croplands, where dark blue (double crops) and orange (single crops) in one calendar year.

(source: International Water Management Institute's (IWMI) Global Irrigated Area Map (GIAM) dataset).

End

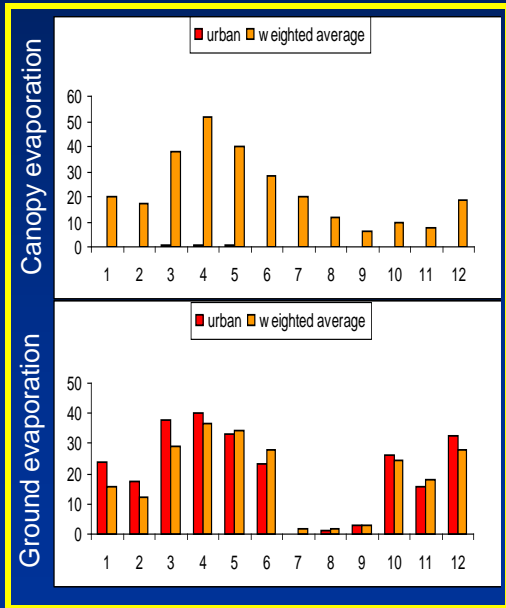




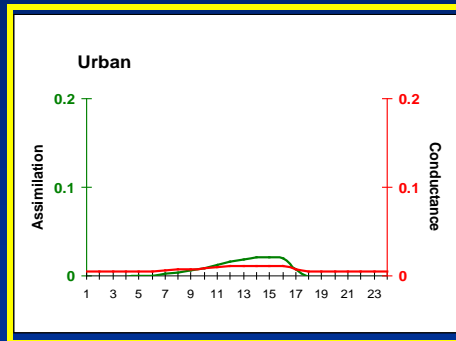
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Urban Evaporation



Urban Assimilation and Conductance



Urban precipitation and runoff

