OBSERVED AND MODELED SUMMER THERMAL GRADIENTS AND SEA-BREEZE IN SOUTHERN CALIFORNIA

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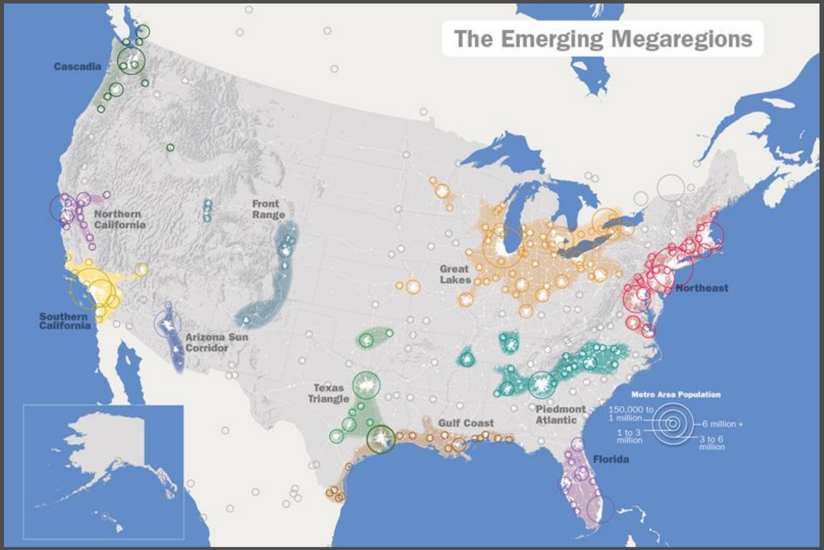
Outline

- MOTIVATION
- SCIENCE QUESTIONS
- METHODOLOGY
- RESULTS
- SUMMARY AND REFLECTIONS
- QUESTIONS AND COMMENTS

Regional Climate in Over-populated Areas (Megapolis)

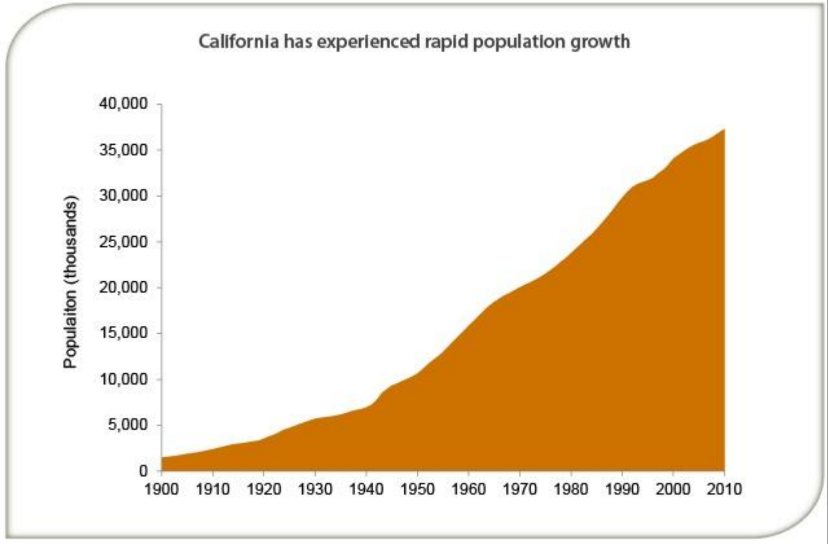
Source: America 2050



- Approx. 70% of US population live in coastal counties (US Census 2010).

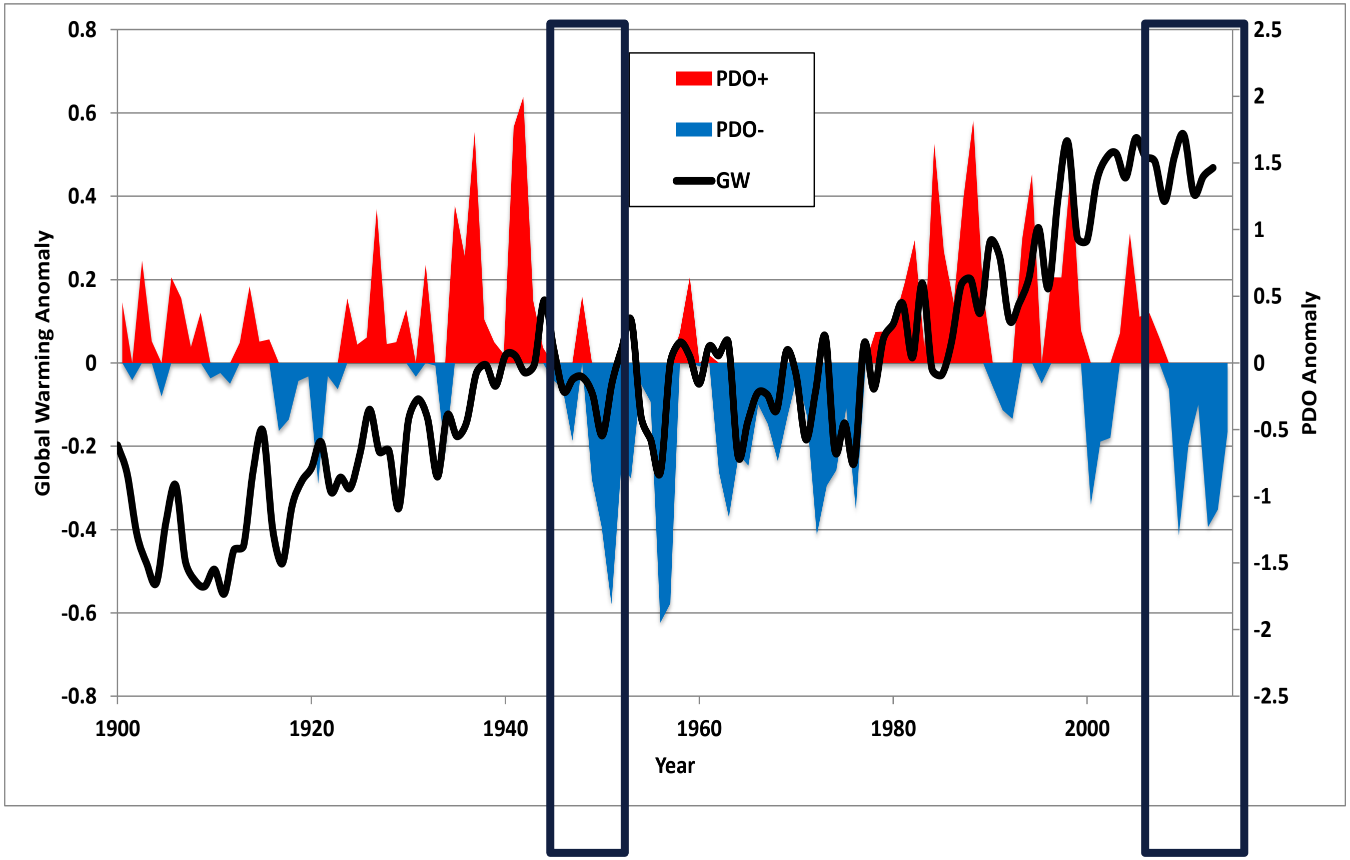
- During the 20th century, California experienced, tremendous population growth (2M in 1900, 10M in 1950 and 37 in 2010).

- City climates are influenced by Urban Heat Island (UHI): warmer urban centers compared to relatively cooler rural surroundings (Oke 1987).



Sources: California Department of Finance estimates; U.S. Census Bureau estimates.
From: Just the Facts: California's Population, PPIC, 2011.

LCLU vs. GHG-Warming



Past
PDO (-)
1950-4

Present
PDO (-)
2009-13

Research questions:

relative contributions to observed climate-trends in coastal-urban areas from GHG-warming &/or LCLU-changes?

1. In coastal/urban regions, what thermal-gradient changes may due to global climate-change
2. How does coastal urbanization (i.e., LCLU-changes) interacts with global climate-change
3. How do these temperature-changes influence coastal-flows
4. What may be the societal-implications of these combined or separate changes

Method-I/HyspIRI Mission (for LCLU construction)

HyspIRI is a global mission, measuring land and shallow aquatic habitats at 60 meters and deep oceans at 1 km every 5 days (TIR) and every 19 days (VSWIR).

- **HyspIRI's VSWIR (Visible Short Wave Infrared)**
- **HyspIRI's TIR (Thermal Infrared)**

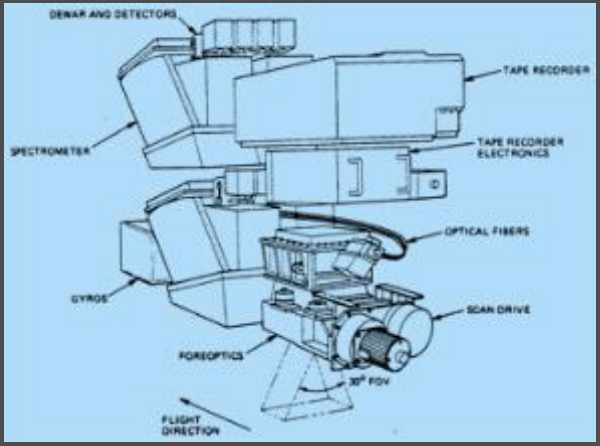
HyspIRI Preparatory Airborne Campaign

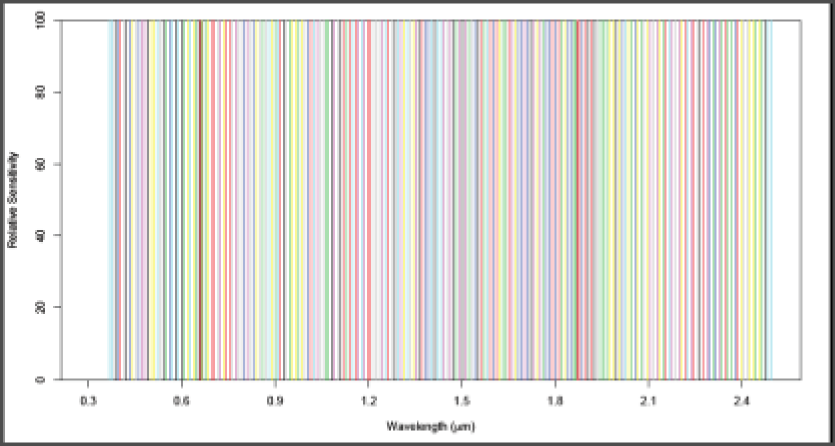
- **Flights in California in 2013 and 2014 along 3 transects from capturing ecological/climatic gradients**
- **Plan to fly these 3 transects 3 times per year for the two years; 3-year awards solicited**

Flight over Southern California. September 24th, 2013

HyspIRI Flightovers Sensors

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

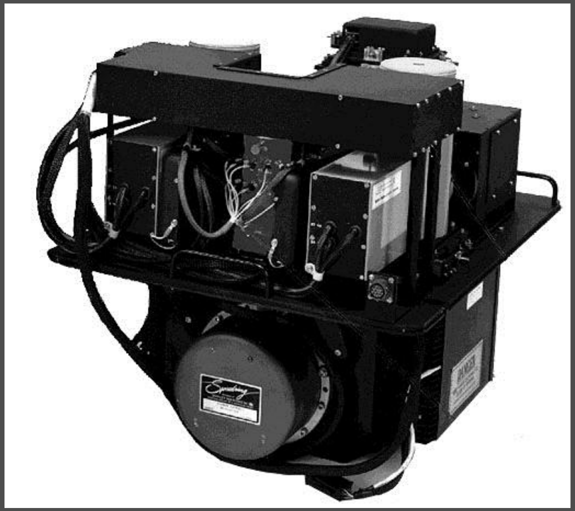


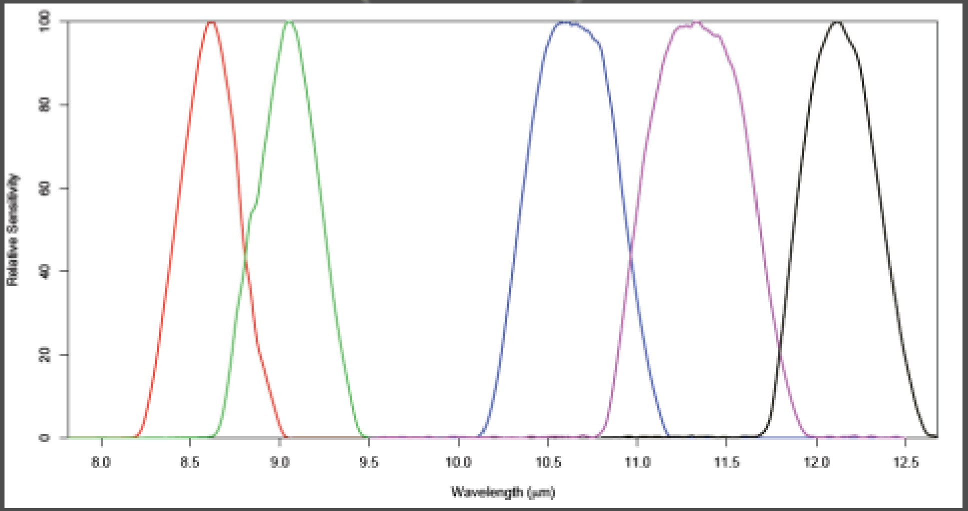


Pixel Resolution: 15 m

Spectral resolution: 224 bands from 380 to 2500 nm (Visible/NIR)

MODIS/ASTER Airborne Simulator (MASTER)

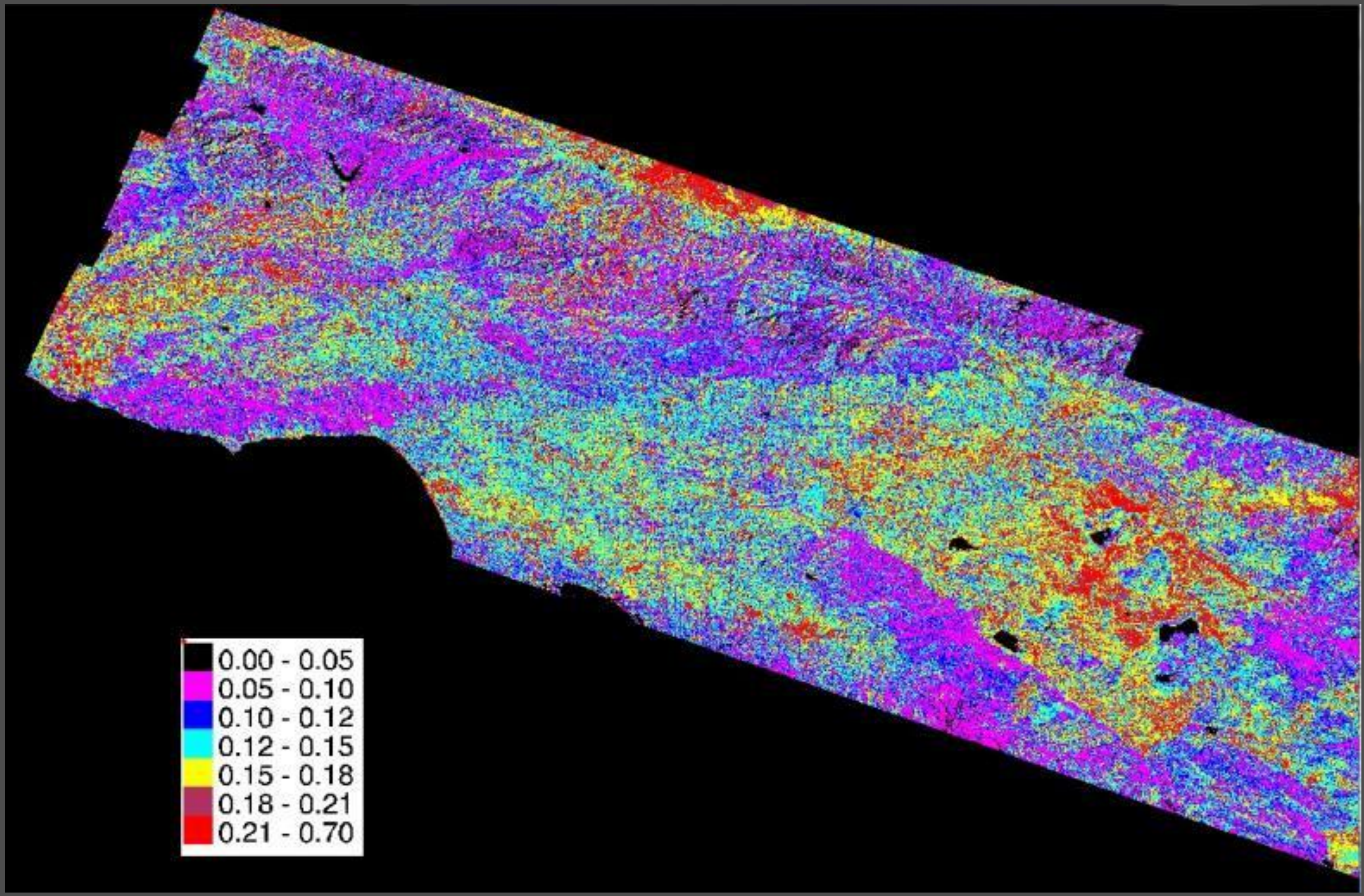




Pixel Resolution: 35 m

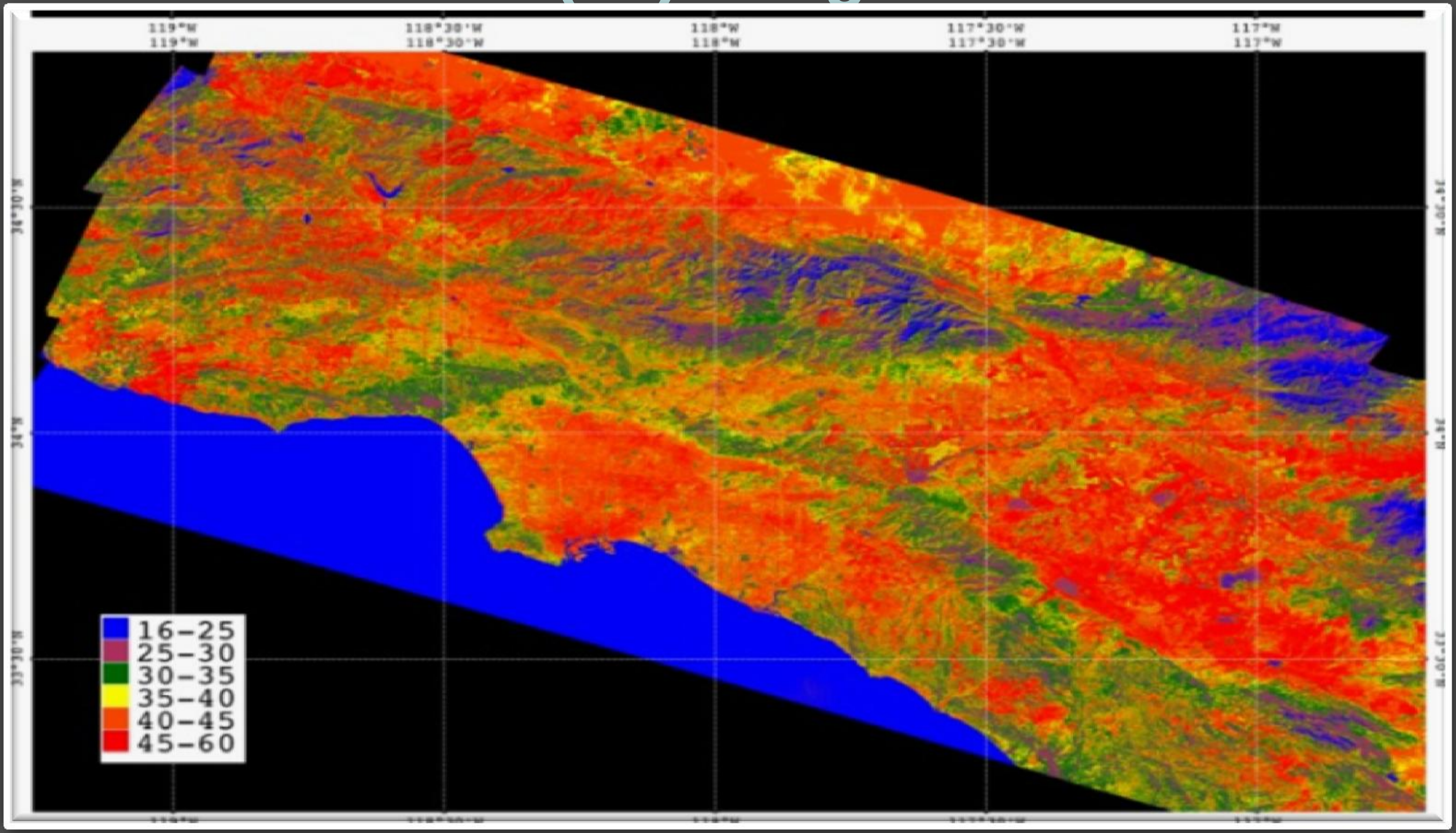
Spectral resolution: 5 bands between 8 and 12.5 µm (TIR)

Mosaicking, Masking, Subsetting and Resampling (Albedo)



Broadband map after mosaicking, masking and subsetting (resolution 15 m)

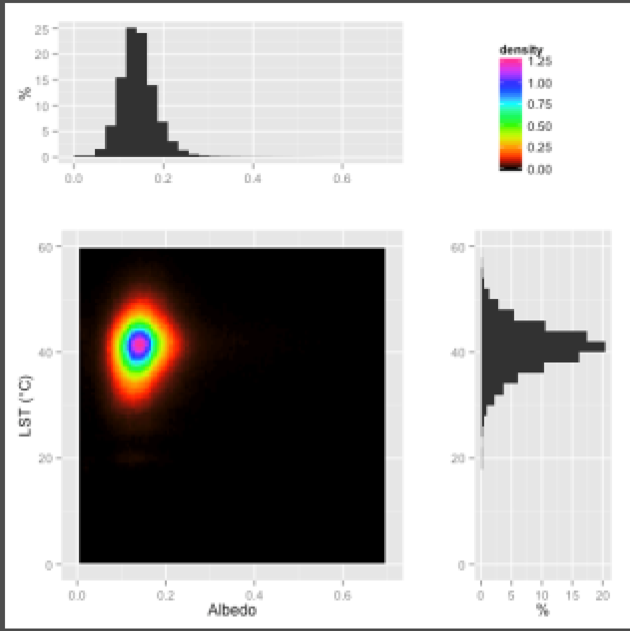
Recent NASA/MASTER SFC T(^{0}C) image for LAX



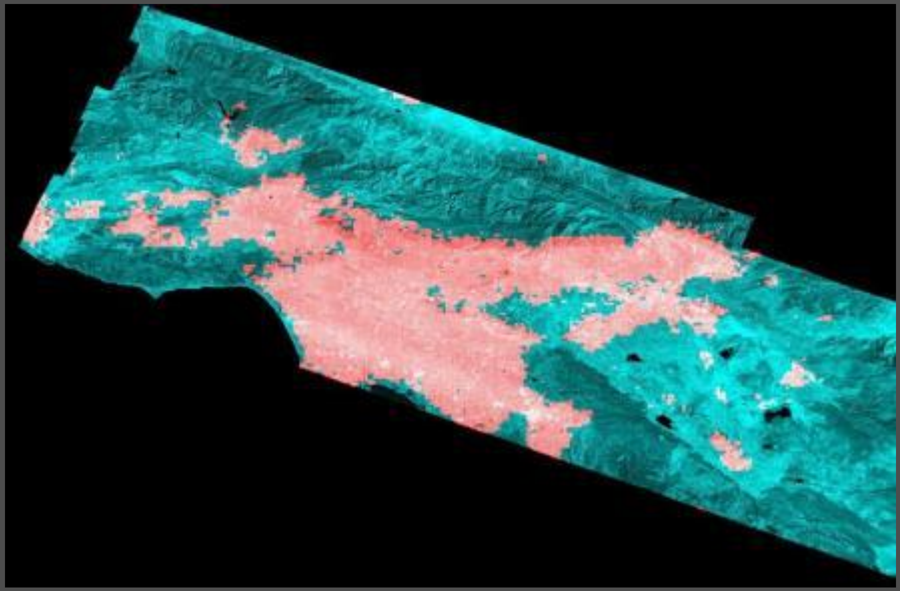
Daytime image of the Master sensor, taken at a 30 meter resolution. 24 September 2013 (1200 LT). Thermal gradients as high as 25^{0}C between vegetation and built areas.

Albedo vs LSTs Densities

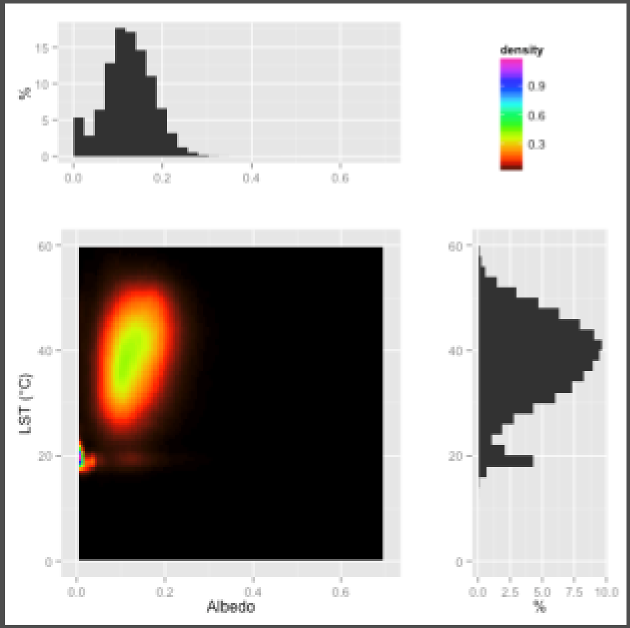
- Larger range of albedos and LSTs for all classes
- Water reflected in low albedo and LST
- Highest density located approximately at albedos 0.14 and LSTs of 40 ˚C



Urban Only classes

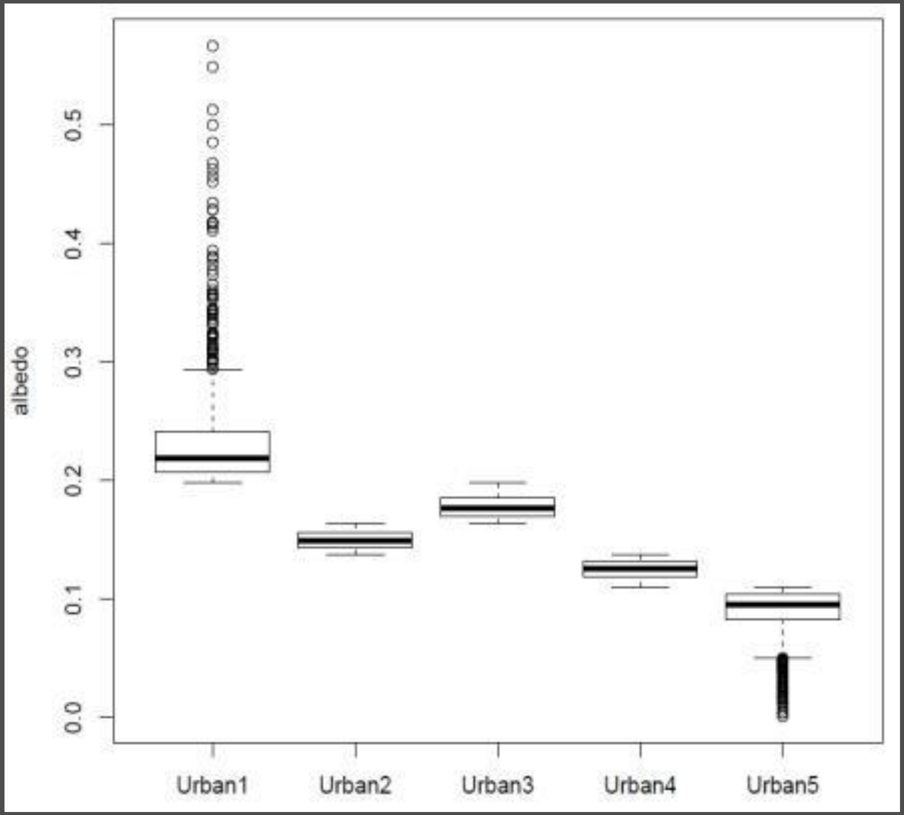


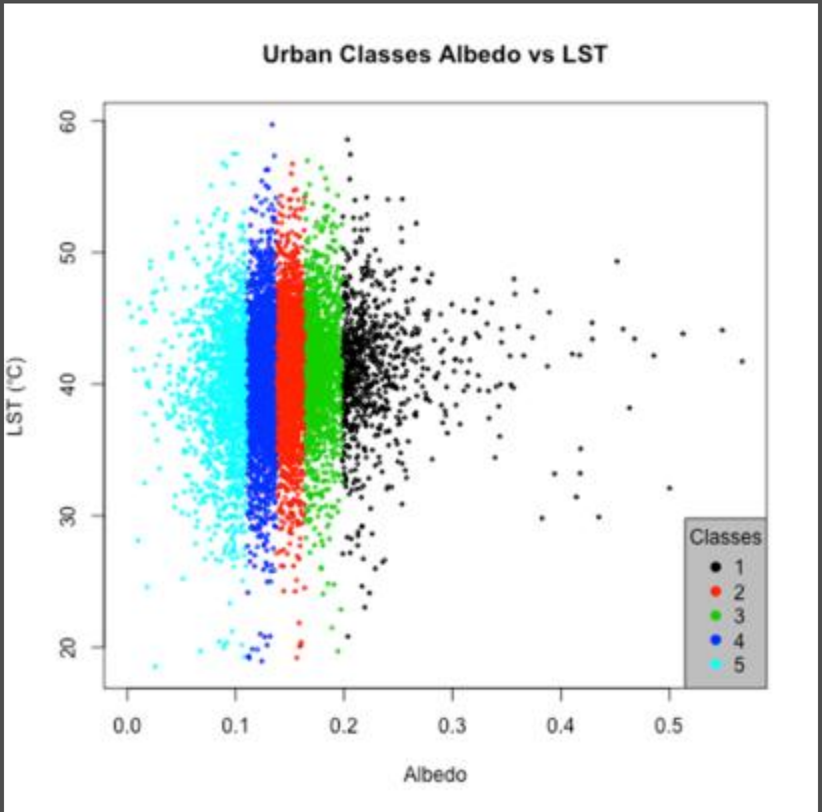
Urban LCLUs according to MODIS IGBP LCLU scheme (in red)



Non-Urban Only classes

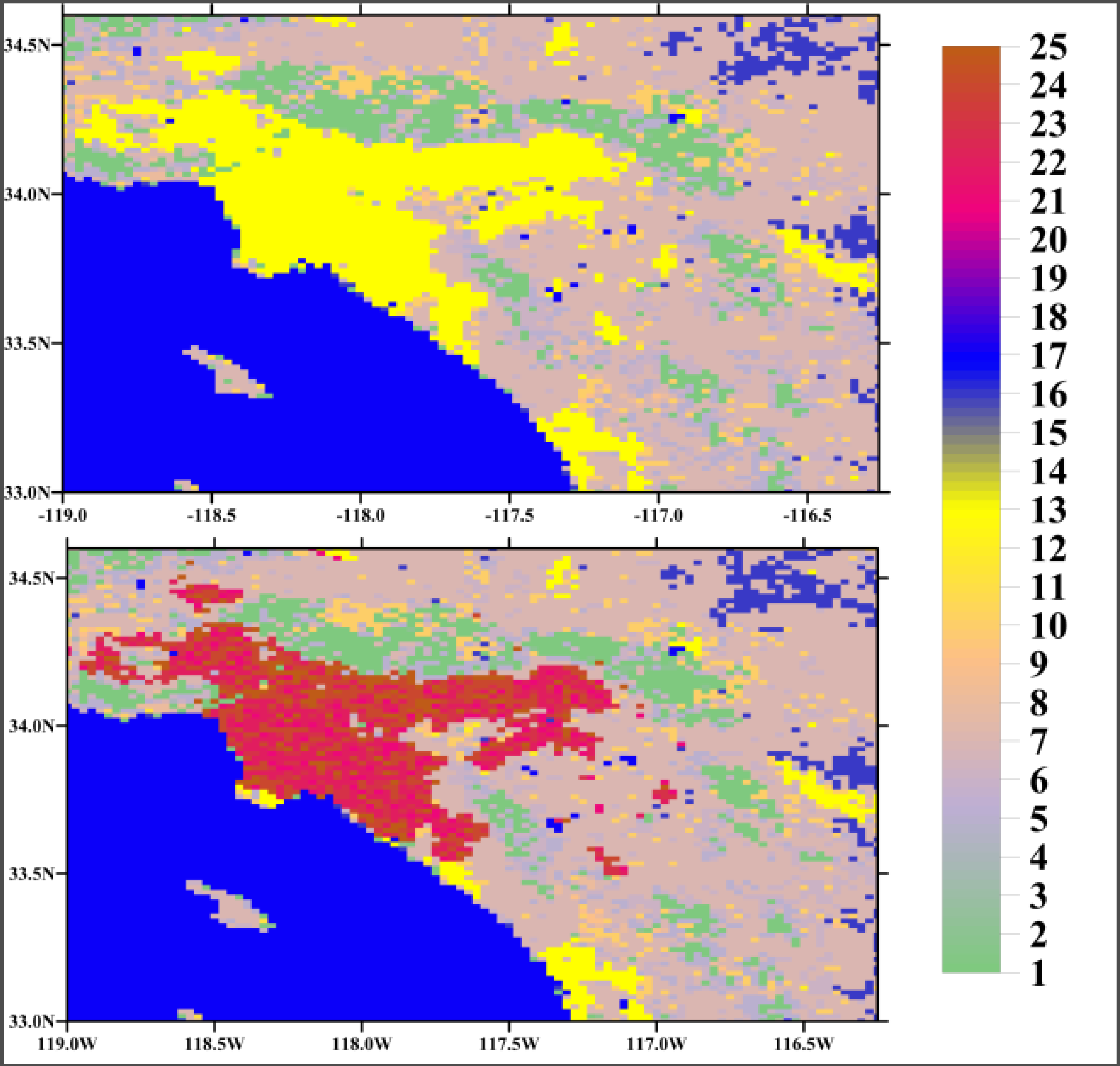
Urban LCLU Classification (New Classes Specifications)





Category name	Category Number in MODIS IGBP scheme	Albedo range
Urban 1	21	0.20 – 0.57
Urban 2	22	0.14 – 0.16
Urban 3	23	0.16 – 0.20
Urban 4	24	0.11 – 0.14
Urban 5	25	Less than 0.11

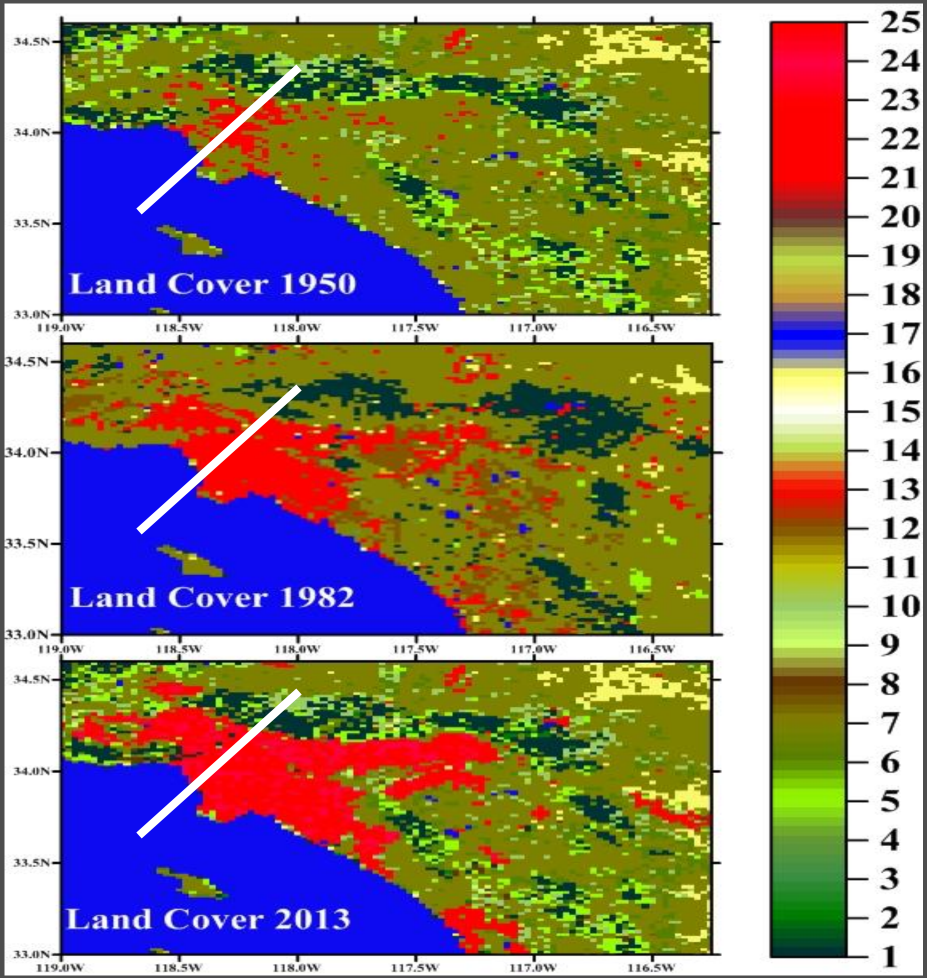
Land Surface Models Specifications



Default LSM

Updated LSM

Land Surface Models



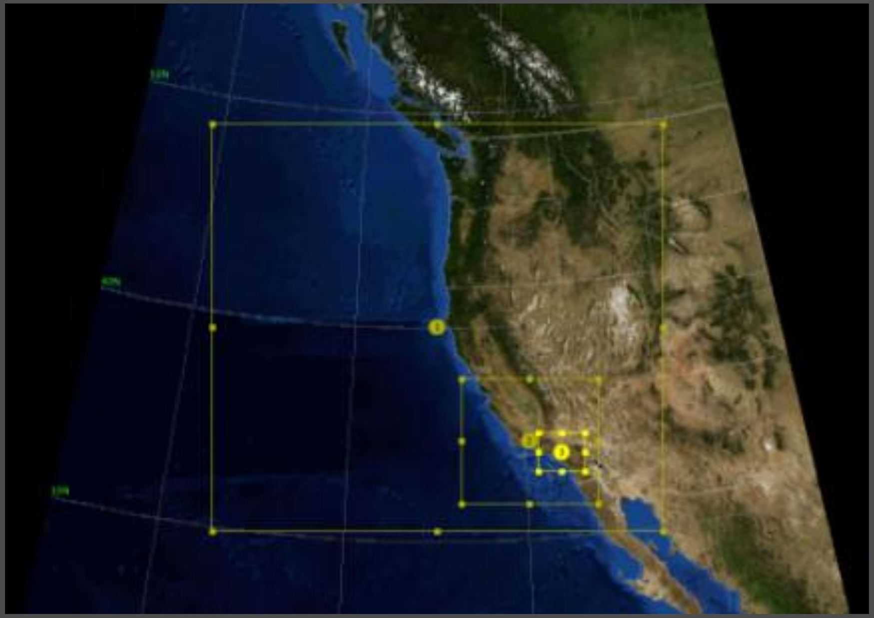
Land Cover (1-20) Classes 1950: USGS Historical Maps

Land Cover (1-20) Classes 1982: USGS Aerial Photography

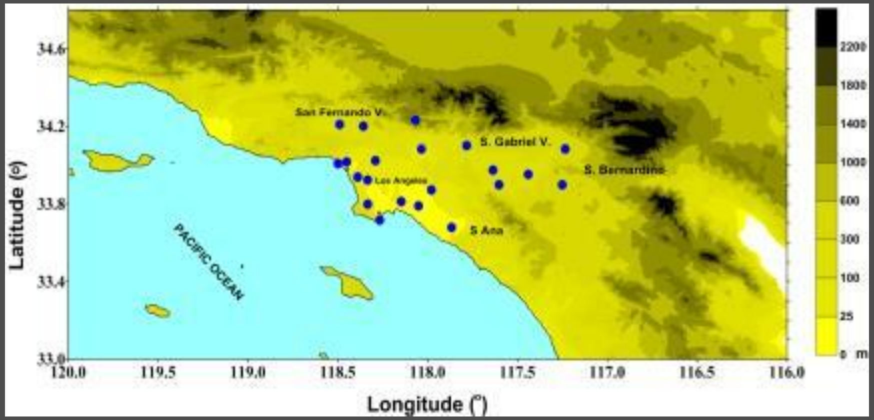
Land Cover 2013 (1-25) Classes: MODIS IGBP + new urban classes from NASA HyspIRI

Urban land-classes in red (13 & 21-25)
White-lines indicates plane of temperature and wind z-sections in following slides

Method-II/Atmospheric Model (WRF) Setup for Validation



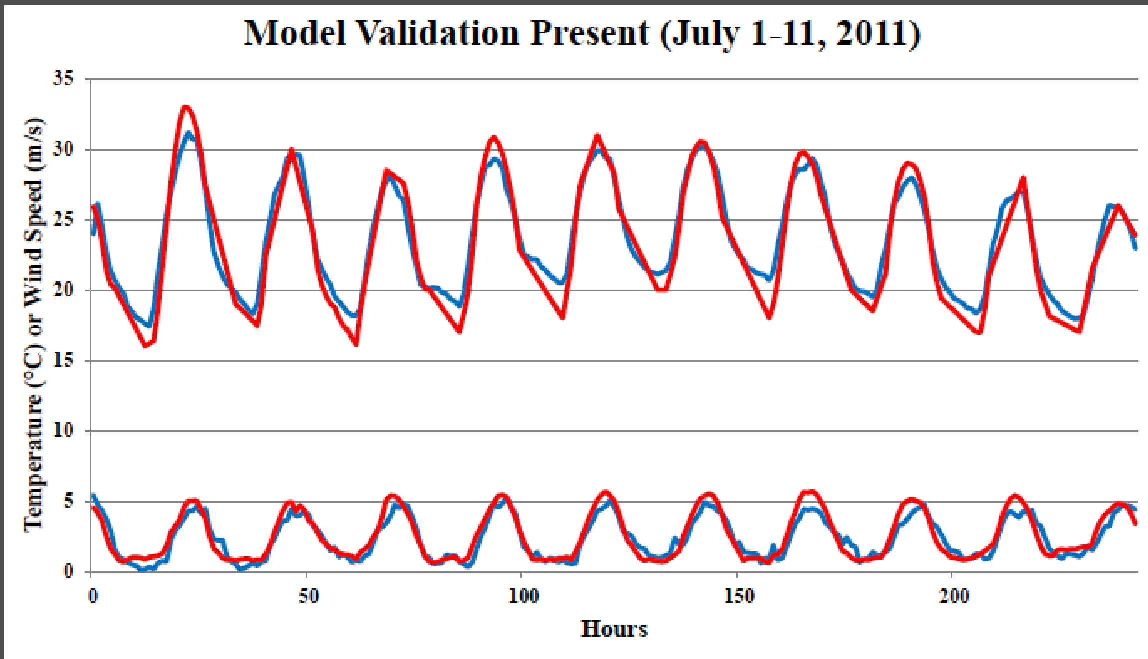
Nested Domains

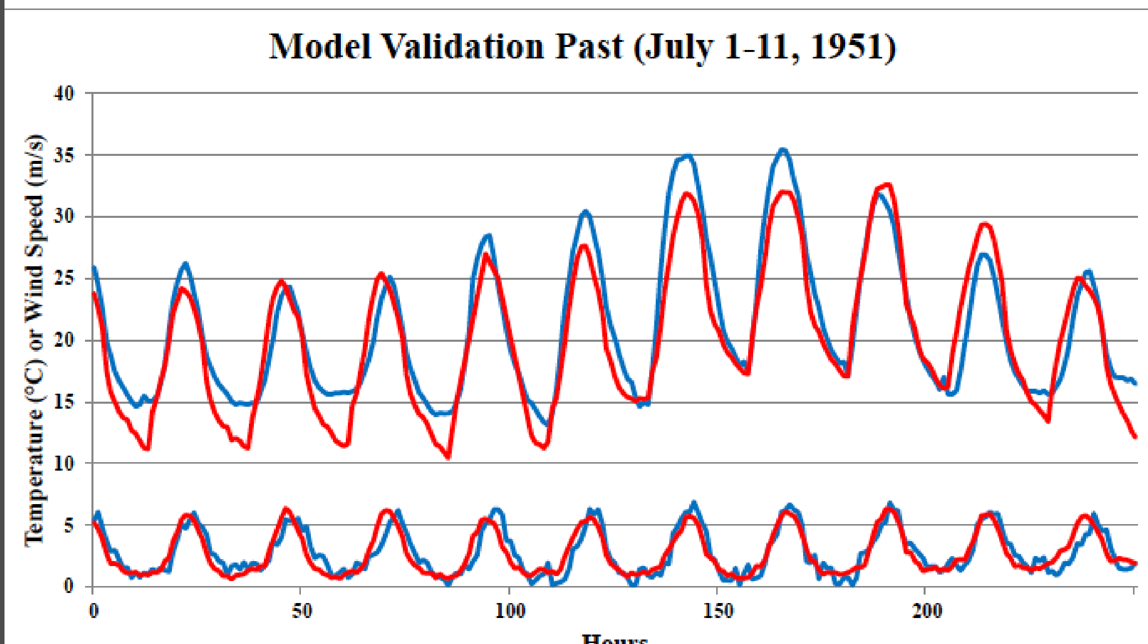


18 surface meteorological stations (in blue), which provide hourly: temperature, wind speed, wind direction and sea-level pressure.

- Three two-way nested domains with a grid spacing of 16, 4 and 1 km are defined on a Lambert Conformal Projection.
- Initial and boundary conditions from NCEP/NCAR Reanalysis
- PBL Parameterization: MYNN 2.5 level TKE.
- Radiation Schemes: RRTM and Dudhia scheme.
- Unified Noah land-surface model.
- Landuse categories : (20) from MODIS IGBP plus 5 new urban classes.

WRF Model Validation: Surface Variables With Different LCLUs





- **Modeled (red) and observed (blue) hourly averaged [over the 18 METAR stations for: 1-10 July 2011 (top) and 1-10 July 1951 (bottom)]: (top) 2-m air temperatures (˚C) and (bottom) surface wind speeds (m/s).**

What are the large-scale, regional & local factors that influence coastal temperatures in SoCal?

Method-III/Factor Separation in Numerical Simulations Method (Stein and Alpert, 1993)

Calculation of the individual and combined contribution of each factor(s) to the predicted total change in any given atmospheric field.

f: value of any predicted field
ψ_i: factor that influence f
We want to predict the fraction of f that is induced by factor $\hat{f}_i$ i:

Method for 2 factors

$$\hat{f}_0 = f_0$$
$$\hat{f}_1 = f_1 - f_0$$
$$\hat{f}_2 = f_2 - f_0$$
$$\hat{f}_{12} = f_{12} - (f_1 + f_2) + f_0$$

Where:
f_0: Simulation without factors any factors
f_1: Simulation with factor 1 without factor 2
f_2: Simulation with factor 2 without factor 1
f_{12}: Simulation with factors 1 and 2

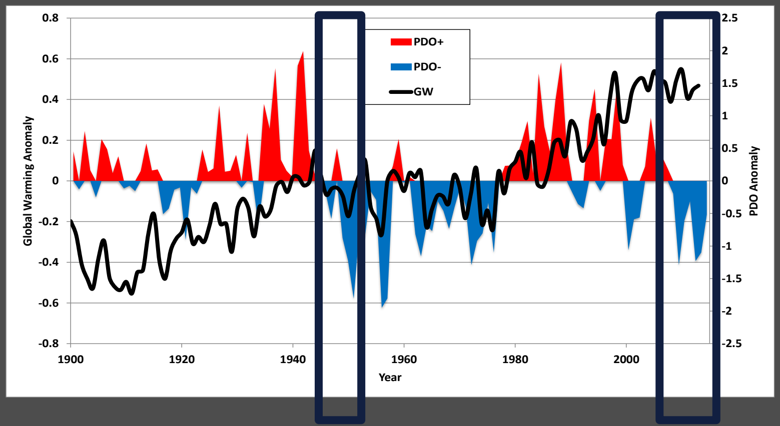
In our study:

f: Maximum temperatures and surface winds
ψ_1: Large scale forcing
ψ_2: LCLU

Significance of changes in T_{max} is evaluated through t-tests at 5% Significance level.

Simulation	LCLU	Atmospheric Conditions
f_0	Past	Past
f_1	Past	Present
f_2	Present	Past
f_{12}	Present	Present

Ensemble: LCLU vs. GHG-Warming



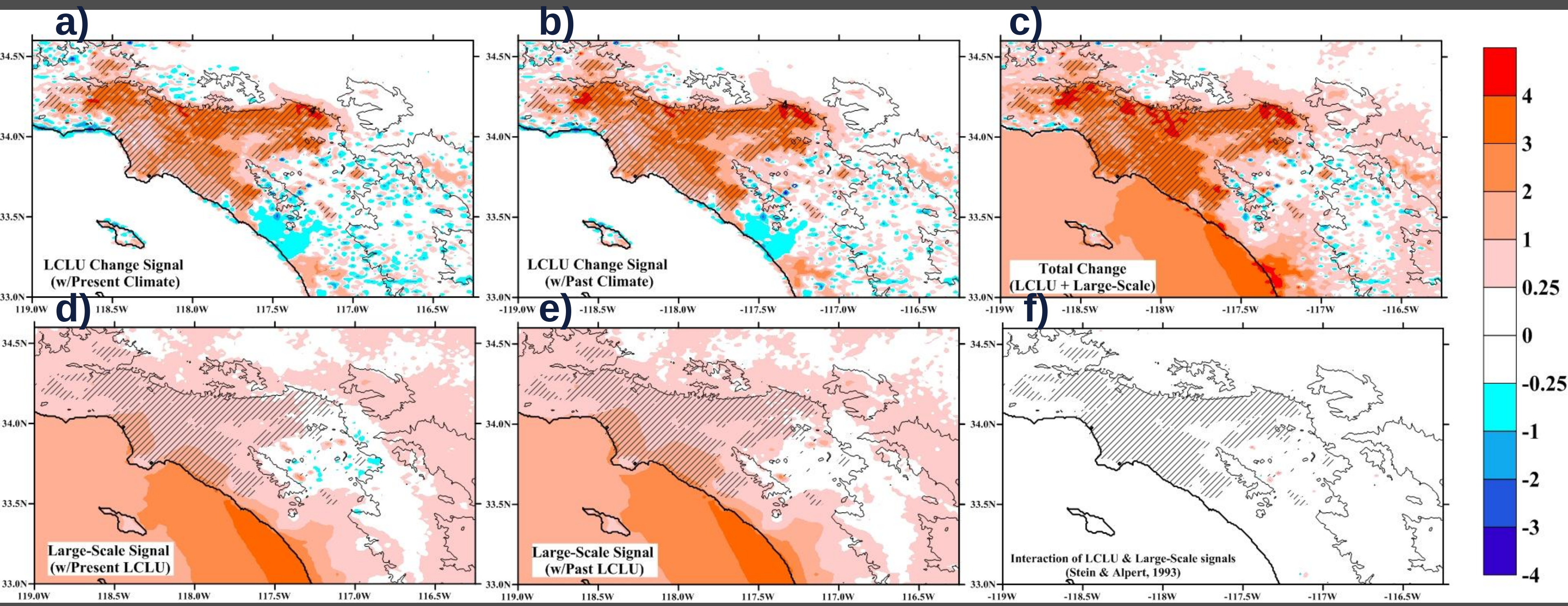
Past	Present
PDO (-)	PDO (-)
1950-4	2009-13

Simulation Identification	LCLU	Atmospheric Conditions
Past2	Past	Pre GW
Past1	Past	Post GW
Present2	Present	Pre GW
Present1	Present	Post GW

- **5-yr simulations each year during summer (JJA).**
- **40% of current LA county population in 1950.**
- **50% increase in population between 1950 & 1960.**
- **Same PDO phase.**

Ensemble: LCLU vs. GHG-Warming

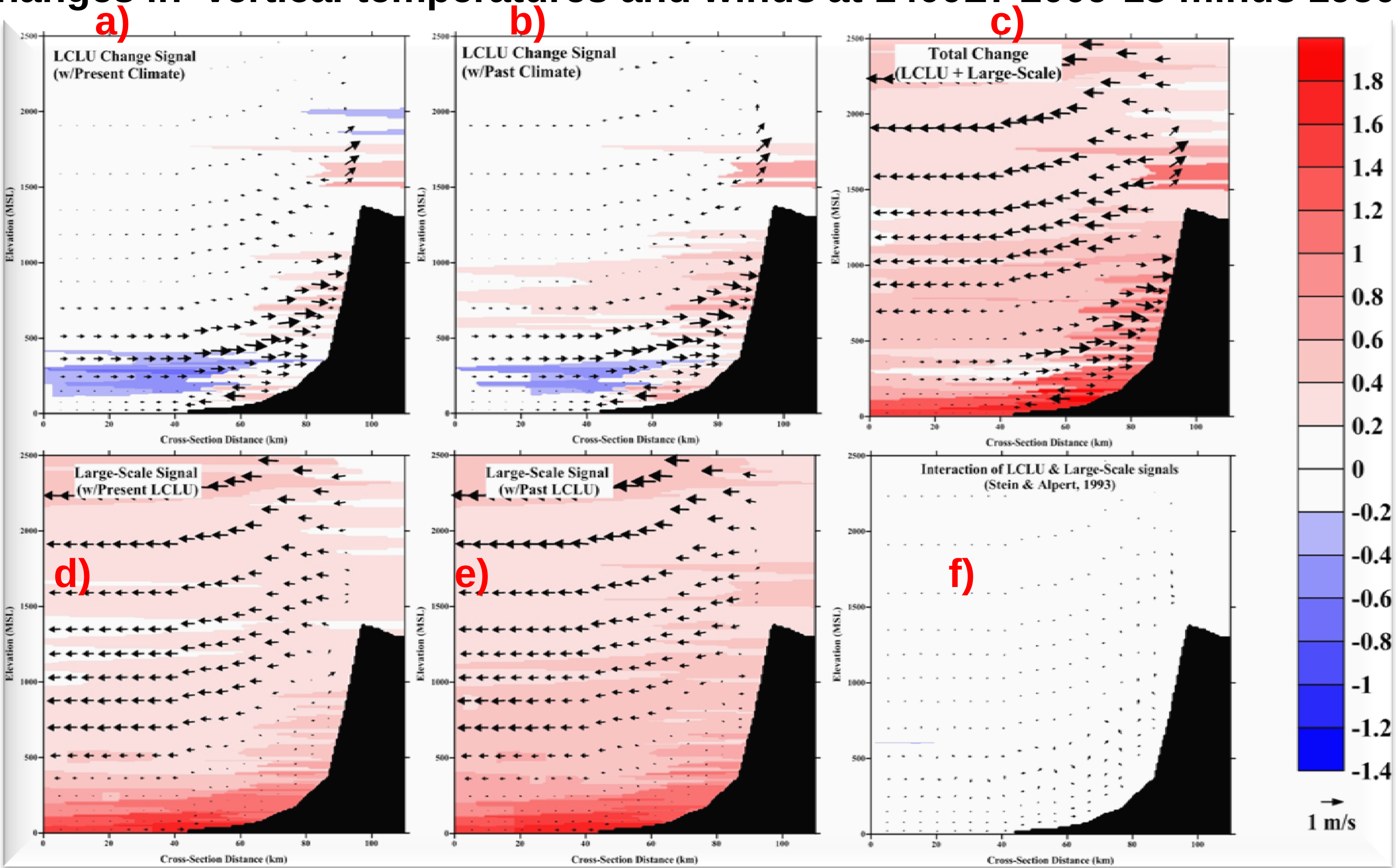
Changes at 2 PM PST in T_{max}: 2009-13 minus 1950-54 (GHG-Warming vs. LCLU)
Hatched areas: 2013urbanized; White-areas: non-significant changes, at p >5% signif. Level; Black lines indicate 700m and 2000 m MSL topography contours



- **GHG-WARMING:** max-effect (panels d and e) up to 2°C/60-years in coastal areas.!
- **URBANIZATION:** max-warming (up to 4°C/60-years) in urban areas (panels a and b)
- **TOTAL CHANGE (panel c):** both contribute to warming, but regional-warming dominates.
- **NON-LINEAR INTERACTIONS (panel f): mostly** insignificant, as total-change is their linear sum.

Ensemble: LCLU vs. GHG-Warming

Changes in vertical temperatures and winds at 1400LT 2009-13 minus 1950-54



- Large-scale warming (panel d & e) dominates most temperature-changes, but
- UHI-growth creates land-sea temp-gradient that generates significant coastal-cooling (a & b), but not below 100 m.
- Changed-speeds (panel c) dominated by changed-LCLU (a & b) b// inversion (<less 600 m) with increased onshore sea-breeze, except near surface where decreases are from increased urban z_0.
- Above PBL (> 600 m), large-scale (d & e) dominates (c) with (increased) offshore return flow no longer suppressed.

What are the large-scale, regional and local factors that influence coastal temperatures in California?

Factors on SoCAB T_{max} changes

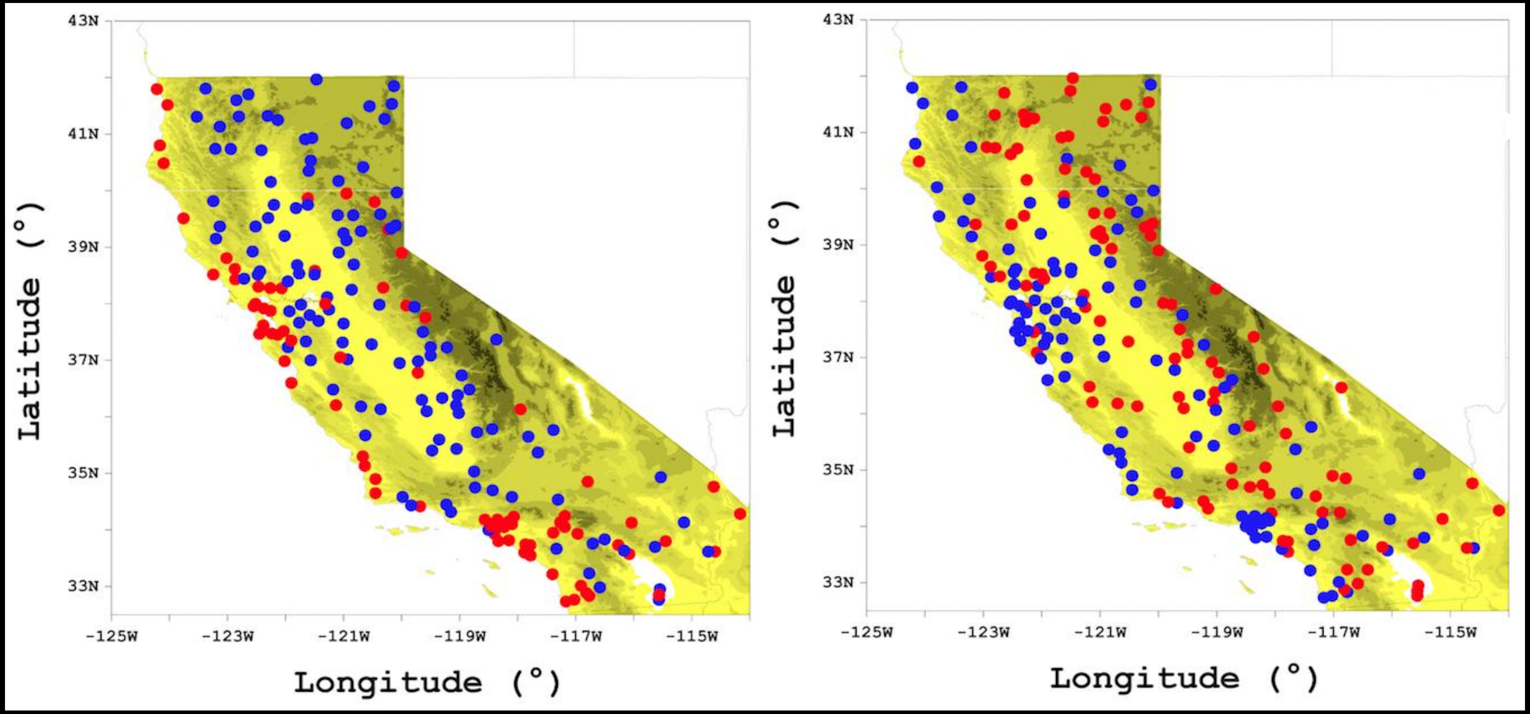
Time Scale	Region	Factor	
		GHG-Warming	UHI
Long-term (60-yr)	Coastal	Warming (~ 1.5°C/60-yr)	Warming (~ 1.5°C/60-yr)
	Inland-Urban	Warming (~ 1°C/30-yr)	Main driver (max warm. 4°C/30-yr)

Summary & Reflections

- Remote sensors (SR & LR) can be combined with climate-data & modeling-tools to analyze UHI-impacts over coastal metropolitan areas.
- SoCAB long-term thermal trends are defined by **both** GHG and UHI-warming.
- Regional T_{max} trends are mostly dominated by large-scale factors. UHI influences are more significant at urban-inland areas.
- Coastal/urban regions are particularly sensitive to climate changes, and respond **in unique ways** to global/regional environmental changes and to local dynamics.
  - The assumption of positive-feedback, may not be correct.
- The complex D(LCLU+Climate) for coastal urban environments requires both: Long-term climate records (SSTs; UA) & long term land surface properties *at urban scale resolutions*.
- **Future research** will focus on discerning the impacts of decadal oscillations in modulating/amplifying (GW+LCLU) combined signals.

What may be the impact of Decadal Oscillations?

California Summer T_{max} Trends: Cooling (blue) & Warming (red)



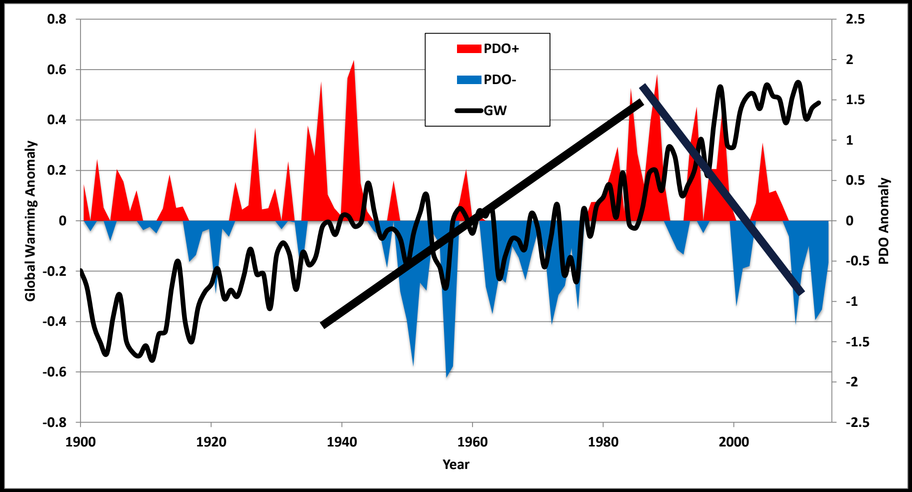
- **Increasing PDO (1950-1985):**

  Coastal-warming (81%) and inland-cooling (82%)

- **Decreasing PDO (1982-2013):**

  Coastal-cooling (64%) and inland-warming (75%)

- **Coastal locations positively correlated with PDO.**
- **Inland locations negatively correlated with PDO.**



Thank you!

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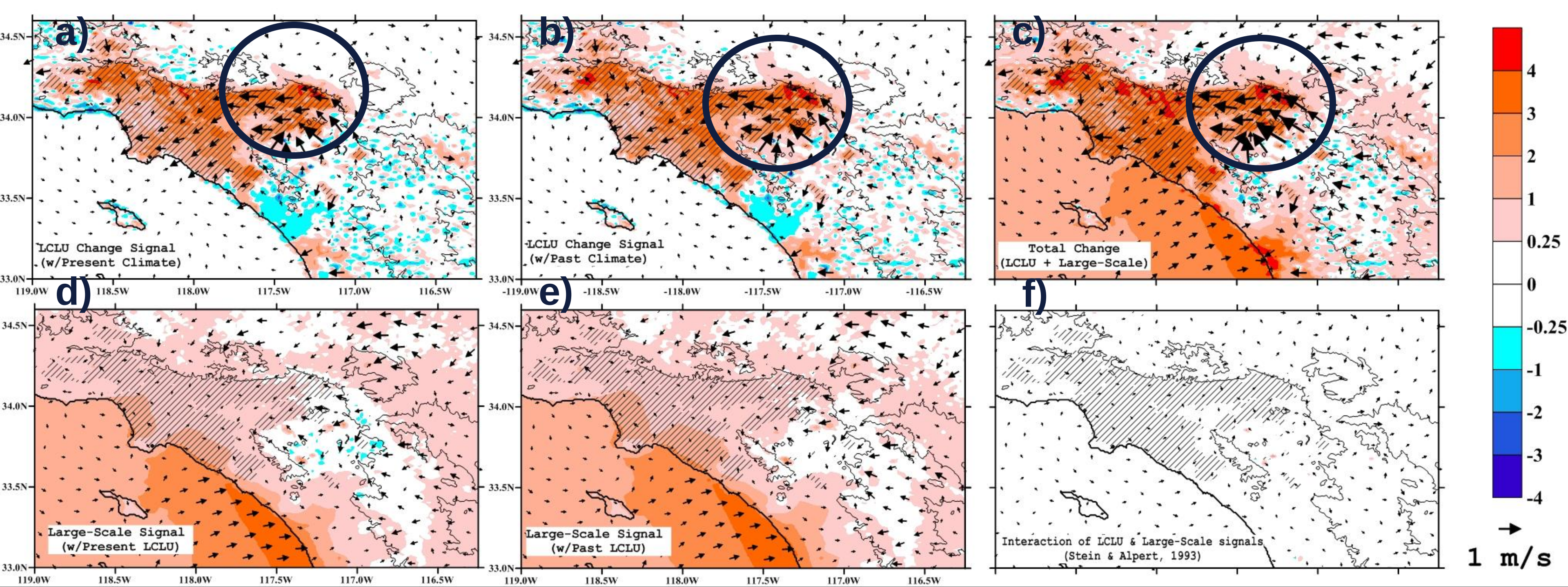
Ensemble: LCLU vs. GHG-Warming

Same T_{max} colors as in previous slide, but with arrows as vector-change in 10-m wind speed (2009-13 minus 1950-54, i.e., GHG Warming vs. LCLU)



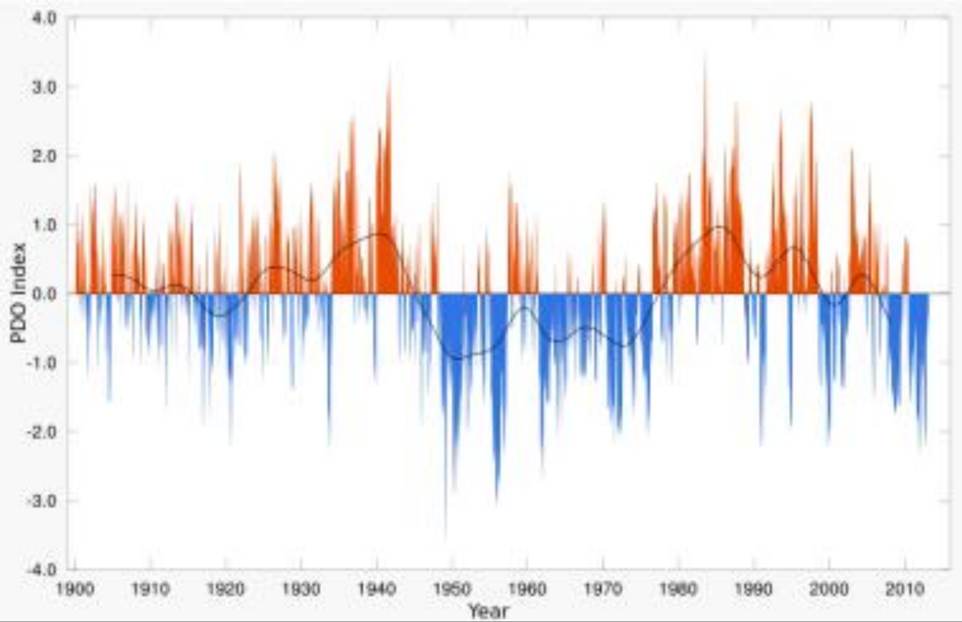
- **Onshore arrows: increased wind speed, as 2 LST wind is generally a a converging local zone with a developing onshore breeze.**
- **Offshore arrows increased flow due to large-scale forcing.**
- **Higher changes in total wind speed (panel c) occur indicating that the total decrease (increase) in on-shore (sea-breeze) magnitude is due mostly to changes in LCLU (panels a and b).**

PDO Index Definition

1) First, monthly-mean global-average SST-anomalies (from the long-term 1900-92 average) are removed from local monthly values (on a 5° grid-box basis), to separate local-variability from global-warming signals.
2) Second, "first principal-component analysis" is applied to these anomalies in the Pacific Ocean poleward of 20°.

PDO Regime-Shifts

- **1924-5:** change to warm phase (Deser et al. 2004).
- **1945-6:** change to cool phase (Deser et al. 2004).
- **1976-7:** change to warm phase (Hare and Mantua 2000).
- **1997-8:** change to cool phase, within a significant internal warm-phase period (Di Lorenzo et al. 2005; Chavez et al. 2003).



Source: http://jisao.washington.edu

Urban LCLU Classification

- The new urban classes were determined by use of the CLARA algorithm on albedos and the best number of classes was assessed by using the average silhouette criterion.

- The CLARA (Clustering for Large Applications) algorithm extents the k-medoids approach for a large number of objects by clustering a sample from the dataset and then assigning all objects in the dataset to these clusters (Kaufman and Rousseeuw, 1990).

- The silhouette width is a measure of dissimilarity between one point and all other points of the same cluster. Observations with a large s(i) (almost 1) are very well clustered, a small s(i) (around 0) means that the observation lies between two clusters, and observations with a negative s(i) are probably placed in the wrong cluster.

Number of Classes	Average Silhouette
3	0.47
4	0.49
5	0.54
6	0.52
7	0.51
8	0.51
9	0.50

The optimum number of classes is 5 according to the average silhouette

Overall Data Process Flow

- Calculation of Broadband albedo (AVIRIS)
- Geo-reference land surface temperature and emissivity (MASTER)

Offset Correction

Mosaicking

Masking

Subseting

Broadband albedo
Land Surface Temperature (LST)

Resample to 1km and layer stacking

Generation of new/updated land classes

Analysis of subregions

Update surface characteristics in WRF

New Land Surface Model