NASA DFRC Climate Change Adaptation Workshop Summary Report

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DFRC Mojave Region Climate Change Adaptation Workshop
Palmdale, California, August 2-3, 2011

Preamble

Executive Order 13514 says: *Each agency Plan shall: … evaluate agency climate-change risks and vulnerabilities to manage the effects of climate change on the agency's operations and mission in both the short and long term…*

In response to this executive order, NASA has developed a Sustainability Working Group under the auspices of the Assistant Administrator of the Office of Strategic Infrastructure (OSI) and a Climate Change Adaptation Science Investigator (CASI) Team under the Associate Administrator for the Science Mission Directorate (SMD). The CASI team provides science input to the OSI Sustainability Working Group on climate change, provides recommendations on needed research to the SMD, and impacts the overall NASA plan for sustainability. The workshop, held by Dryden Flight Research Center (DFRC) at the Dryden Aircraft Operations Facility on August 2-3, 2011, supported the CASI Team objectives by examining the effects of climate change on the facilities and staff of the DFRC from the present through 2080.

A fundamental assumption for this workshop was that climate change impacts on risks/exposures, vulnerabilities, and adaptation steps (Figure 1) focused on the DFRC are broadly applicable to communities and facilities throughout the Mojave Desert region, even though they have different missions and infrastructure. While the DFRC has extensive experience in the conduct of Atmospheric Flight Research and Airborne Science Missions, it has relatively little experience in Climate Change Science. Therefore, NASA contracted with the Nevada System of Higher Education's Desert Research Institute, an organization with extensive research experience in arid landscapes (atmospheric, hydrological and ecological) and in climate change modeling, to conduct the workshop. Additionally, top scientists and institutional policy makers from the entire region were invited to attend the workshop and contribute their expertise (Appendix A). A series of questions was developed and sent to the invited attendees prior to the workshop. Additionally, policy makers were invited to articulate additional questions for the workshop to consider, if they wished.

On the first day, the workshop convened in plenary session to set the objectives and provide the framework for the development of discussions in three groups focused on the discipline areas of Climate Change and Modeling, Hydrology, and Air Quality, e.g., dust emissions (Agenda is provided in Appendix A). Questions under the three scientific areas were organized into the state of the science (i.e., what do we know), what research is needed to be able to increase our confidence in predictions, and what adaptation steps can be taken immediately and in the future? Risks and vulnerabilities were central to all three discussions, and the concept of iterative risk management was introduced. The working groups spent most of the first day working on addressing each of the questions and developing presentations to answer the questions and incorporate the best technical and scientific advice. Consensus was not necessary and the working group presentations attempted to include all participant contributions. The charge was to discuss and document as much knowledge on the topic as possible, within the framework provided. The day closed in plenary with a presentation by each group to all workshop participants to stimulate cross-discipline thought and discussion.

On the second morning, the discipline groups met to refine their presentations and to add cross-disciplinary ideas. These were presented in plenary during a two-hour block just before noon. The workshop closed at noon with a discussion in plenary of the most important points the workshop uncovered. This report is a summary of those findings with some post-workshop contributed material.

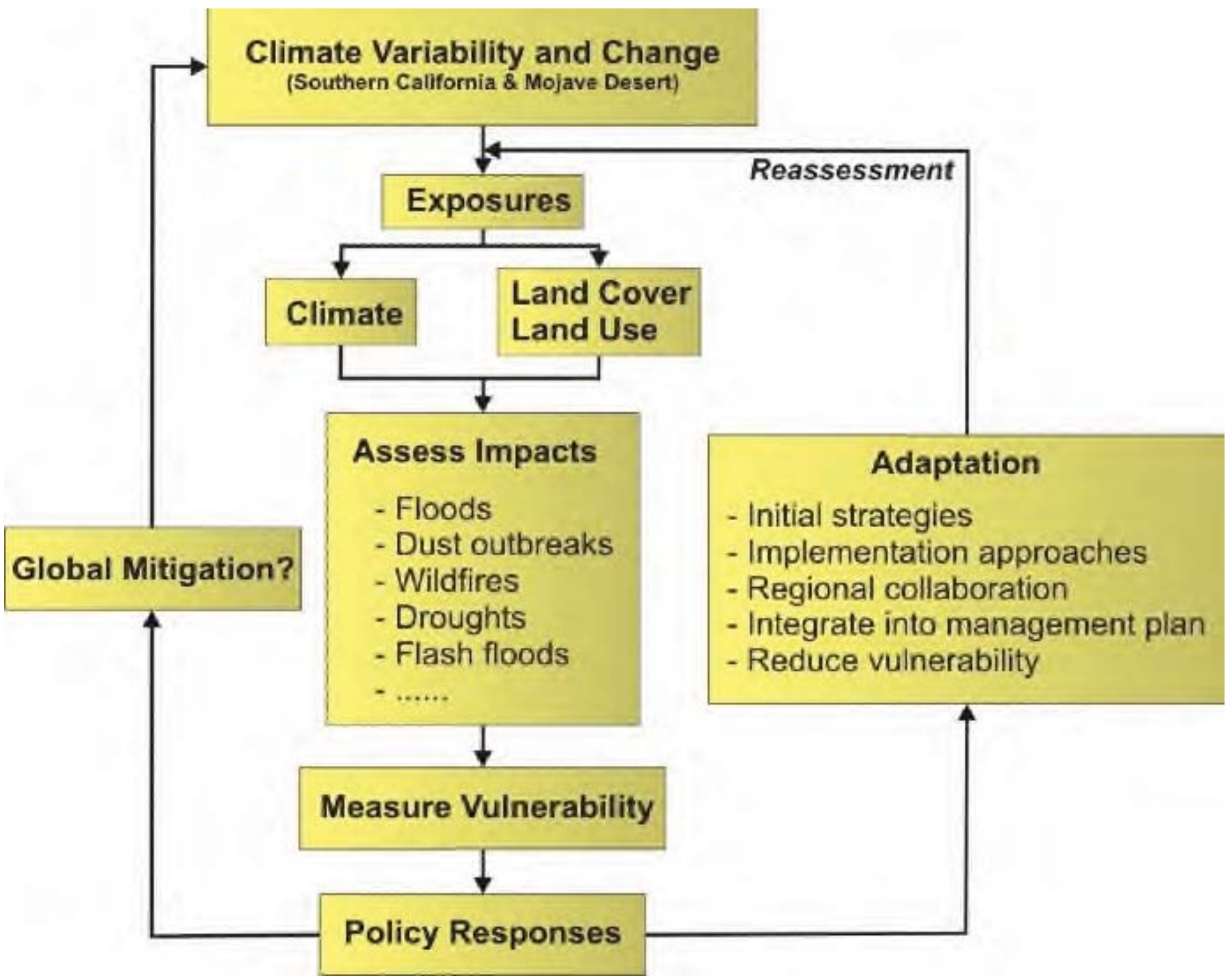

Figure 1. Iterative Risk Management and Adaptation Flowchart.

The workshop questions that participants were asked to consider include:

What is our current knowledge of climate change effects and how they will impact DFRC facilities and people for the present through 2080?

- What are the regional and local vulnerabilities?
- What are the likely stressors?
  - Effect of increasing population within surrounding areas on energy and water demand?
  - Effects of fire?
  - Land use/Land cover change?
  - Commuter traffic
  - Precipitation
  - Temperature
  - Disease
  - Pollution, particularly dust emission & valley fever in this arid environment
- What is the state of subscale climate modeling for the Mojave in general and the Antelope Valley in particular?
- What are the likely effects on ecosystem services/threatened species?
- What is the state of modeling for an Atmospheric River (AR) event and flooding?

What research is necessary to improve predictions and their certainty?

- Modeling
  - Climate
  - Landscape Ecology
- Monitoring
  - Precipitation
  - Temperature
  - Wind
  - LU/LC, other Landscape Variables (ie. surface deformation, etc)
  - Hydrologic Response
  - Air quality (criteria pollutants, toxics, biologicals)

What adaptation and mitigation steps can be taken now?

- Carbon Footprint
- Energy Demand
- Energy Production
- Monitoring
- Workplace
- Water Demand
- Reduction of Aeolian Emissions
- Flood Prevention
- Others?

What steps should be taken in the future?

- •Defensive systems against flood, dust storms, temperature
- •Green Buildings
- •Energy Independence
- •Build flexibility into environmental regulations to accommodate impacts of climate change; e.g., how do we protect endangered species and habitats?
- •Others?

Note: Prior to the start of the workshop, various land and city managers were asked to respond to a survey asking them to list their climate change issues and concerns. Appendix B contains the response from Robert Woods with Environmental Management at Edwards Air Force Base Mr. Woods provided some very thoughtful responses to the survey questions and, therefore, we included his comments in this report for the benefit of all readers.

Background

The NASA Dryden Flight Research Center (DFRC) is located in California at the western end of the Mojave Desert, in the basin and range geologic province (Figure 2). This province is characterized by northwest-southeast trending dry valleys, bounded by arid mountains, some of which are forested at the higher elevations. Seasonally flooded playas are often present in the dry valleys. The Mojave grades into the Sonoran Desert in the east and is bounded by the Sierra and Tehachapi Mountains in the west. The DFRC main campus (Figure 3) is located along the western edge of Rogers Dry Lakebed on Edwards Air Force Base (EAFB), and the auxiliary facility is located at hangar 703, at Site 9 (Figure 4) owned by the Los Angeles World Airways. The facilities are all contained within the Antelope-Fremont Valleys Watershed (USGS Hydrologic Unit Code 18090206). The watershed is bounded on the northwest by the Garlock Fault and on the southwest by the San Andreas. Although not related to climate change, numerous other faults occur within the immediate area, providing high risk for damage to facilities and loss of life from earthquakes, making a multi-hazard analysis necessary to assess vulnerabilities associated with climate change.

Figure 2. Antelope-Fremont Watershed (Basemap – ESRI.com)

Figure 3. Dryden Flight Research Center Main Campus
(located in lower right along the edge of Rogers Dry Lake).

Figure 4. NASA DC-8 over the Dryden Aircraft Operations Facility at Site 9
owned by the Los Angeles World Airways (Bldg 703).

Within NASA, the DFRC key competencies are all related to atmospheric flight. The DFRC supports NASA objectives by conducting: 1) Atmospheric Flight Research using high performance and one-of-a-kind aircraft; 2) operations supporting the space shuttle, the international space station, commercial space flight opportunities, and test of the crew escape vehicle; and 3) Airborne Science Flights that provide worldwide suborbital remote sensing and *in situ* observations from manned and unmanned aerial vehicles. Key infrastructure elements include: 1) the Western Aeronautical Test Range (and associated restricted airspace); 2) a unique Flight Loads Laboratory providing loads testing under both thermal and loads stress, simulation facilities which include hardware-in-the-loop, and fabrication facilities capable of making and maintaining flight hardware to rigorous standards; 3) Space Shuttle landing infrastructure; and 4) large hangars for aircraft maintenance and support. Key environmental enablers for the DFRC mission include a large number of favorable flight test days and the multiple runways on Rogers Dry Lake (Figure 5).

DFRC personnel often live at considerable commuting distances from the Main Campus on EAFB, with an average commute being nearly an hour each way by automobile. Mass transit to work is generally unavailable, due in part to the dispersed nature of the surrounding communities and the necessity of off-hours work to support the varied missions. It is important to understand that the road networks are the primary lifelines to the center. If they become compromised, then the center cannot operate. It is also important to understand that we must consider the vulnerabilities where people live along with the immediate vulnerabilities to the DFRC campus.

Climate variability (e.g., patterns of temperature, precipitation, and wind) impact both the DFRC infrastructure and staff abilities to perform the mission, sometimes enabling mission operations, sometimes restricting them. Winter temperatures can dip below freezing, while summer temperatures often exceed 100 degrees F. Most of the precipitation falls in the winter as frontal rain or snow with a few monsoonal-type thunderstorms forming in the summer. Winter flooding of Rogers Dry Lake, combined with high winds, smooth the surface and minimize cracking and thus make some annual flooding a necessary part of mission capability. Winds are generally in alignment with the hard surface runway and are slightly increased in the spring. Winds in excess of 15 m s^{-1} (i.e., 30 knots or 35 mph) from any direction limit flying in ejection seat aircraft, because of the danger of an ejecting crewmember being dragged by his or her parachute after landing on the ground.

Figure 5. Aerial Image of Rogers Dry Lake showing marked runways.

Workshop Questions

The following sections address the workshop questions and highlight the state of knowledge provided by workshop participants and the DRI scientists who co-authored this report. Each question is addressed by topical area in the following order: subscale (regional) climate modeling; air quality, specifically dust emissions; and hydrology.

1) **What is our current knowledge of climate change effects and how they will impact DFRC facilities and people for the present through 2080?**

Status of Regional Climate Modeling:
Climate scenarios from global climate models (GCM) provide the primary scientific basis for advancing our understanding of climate dynamics and the manifestation of anthropogenic climate change on our planet. GCM output from the CMIP3 (phase 3 of the Coupled Model Intercomparison Project) used for the Intergovernmental Panel on Climate Change fourth Assessment Report (IPCC-AR4; IPCC 2007) addresses the sensitivity of anthropogenic related changes in climate for globally and zonally averaged scales.

These internationally coordinated modeling efforts are designed to relate attributes and distinguish climate change due to natural variability versus anthropogenic forcing, and to characterize and report uncertainty in model results. However, the resolvable GCM spatial scales are too coarse (~100s of km) to enable assessment of climate change impacts at regional and local scales as well as many components of climate subsystems, e.g., basin-scale hydrology or ecosystem response (Giorgi and Mearns 1991; Leung et al. 2006). GCM output that is translated to the scales needed for modeling and value-added decision-making is among the most sought after datasets by public and private agencies interested in advancing climate adaptation measures (IPCC 2007). The increased need for regional climate projections has resulted in a proliferation of efforts to downscale GCM simulated output to assess climate change impact at the regional-to-local level (e.g. Wood et al. 2004; Fowler et al. 2007; Maurer et al. 2007; Moritz et al. 2010).

Downscaling of GCM simulated output generally falls into three categories, i.e., statistical, dynamical, and hybrid statistical-dynamical downscaling, each having their strengths and weaknesses (e.g., Fowler et al. 2007; Abatzoglou and Brown 2011; Mejia et al. 2012). Downscaling methods have limitations in their ability to resolve spatial features, derive meteorological variables, and resolve coupled land-atmosphere feedbacks. Statistical methods are the most commonly used (Wood et al. 2004; Wilby et al. 2004; Gangopadhyay et al. 2011); however, dynamical and hybrid methods are becoming more popular due to their ability to incorporate non-stationary, regional-scale atmospheric processes into downscaled results (Leung et al. 2003). Below is a general description of each of these methods.

Statistical Downscaling:

Statistical downscaling methods are calibrated to historical observations and formulated by applying relationships between large-scale observations and observations from the historical record to GCM simulated output (e.g. GCM output from the CMIP3). The efficiency of statistical downscaling facilitates the use of many different GCM model outputs and scenarios to generate a wide range of climate simulations, which is useful considering GCM model inadequacy and uncertainty. However, a primary limitation of statistical downscaling methods is the lack of historical observations to estimate relationships that are invariant in a changing climate (i.e., stationarity assumption).

The reliability of the statistical downscaling approaches depends on having long-term, accurate observations at individual stations or gridded meteorological field, to develop the statistical relationships. Hence, these methods work best in regions with extensive, existing measurement networks. Statistical approaches have become the most common tool to downscale GCM output over the Western US at spatial scales to the 10s of km. For example, the US Bureau of Reclamation created statistically downscaled climate projections based on CMIP3 GCM output using the bias corrected and spatially disaggregated approach (BCSD) and the bias correction constructed analogues (BCCA), which are the most widely used high-resolution data set to drive hydrologic applications. The BCSD data (with 112 monthly data sets) and BCCA (19 daily data sets) provides 12 km grid size of minimum and maximum temperature and precipitation. The description of these statistically downscaled data sets and their application for hydrological impact studies are presented in Maurer et al. (2007) and Gangopadhyay et al. (2011).

Dynamical downscaling:

Dynamical downscaling refers to the use of Regional Climate Models (RCMs) to produce climate data through regional-scale atmospheric simulations at a spatial scale smaller than the GCMs scale. Typically, RCMs simulate climate at scales between 10 km and 50 km using initial and time-dependent lateral boundary conditions provided by GCMs (e.g. GCM output from the CMIP3), and they require large computational resources relative to statistical approaches. RCMs provide more realistic representation of regional climate processes as compared to statistical downscaling, yet the accuracy depends largely, which also applies to statistical downscaling, on the climatology and variability of the large-scale results provided by GCMs (Piani et al. 2010). When driving RCMs, it may not be critical for a GCM to reproduce local surface climate conditions within the RCM domain, but it must reproduce with a minimum of fidelity, the conditions at the lateral boundaries. This includes the atmospheric general circulation, teleconnection patterns such as ENSO, and other modes of climate variability.

Dynamical downscaling methods are advantageous over GCMs given their ability to resolve processes at sub-GCM grid scales and physically account for mesoscale circulations as well as complex terrain and land cover forcing. Thus, dynamical downscaling is more apt to resolve coupled atmosphere-land-surface interactions that affect climate at local and regional scales (e.g., loss of snow cover amplifying warming). RCMs are particularly strong in simulating atmospheric processes where the influence of the complex terrain and land surface conditions are important. Over the western US these atmospheric processes can include: Santa Ana winds, atmospheric rivers (Leung and Qian 2009), improved simulated winter storm precipitation (Ikeda et al. 2010), and thunderstorms during the summer monsoon (Gutzler et al. 2005).

The North American Regional Climate Change Assessment Program (NARCCAP) is the best example for dynamical downscaling approaches over North America. NARCCAP is a coordinated experiment that provides 50 km of horizontal resolution and 3 hourly parameters (surface and upper air) (Mearns et al. 2009). Using a number of GCM and RCM combinations, NARCCAP provides 9 different members of simulated data sets for historical and future climate projections.

Hybrid and Double-statistical Downscaling:
The hybrid and double-statistical downscaling approaches combine both dynamical and statistical techniques, respectively, to generate climate projections that are appropriately scaled for use in small scale regions. An example includes small scale hydrologic simulations where the inability of a 10km or larger gridded downscaled data sets to adequately resolve important topographic variations within complex orography presents limitations for snow-melt based hydrological systems (Mejia et al. 2012). These downscaling methods involve further post-processing of gridded downscale climate projections to scales on the order of 1 km or even to individual station locations. In the case of downscaling to individual station locations, this process is similar to weather forecasting applications, wherein model output is post-processed to produce site-specific statistical information (Klein and Glahn 1974; Gangopadhyay and Rajagopalan 2005; Vrac et al. 2007). RCM simulations exhibit biases and inaccuracies (Feser et al. 2011), and the statistical downscaling part of the hybrid approach objectively removes such biases by matching observed statistics, while retaining day-to-day variability of the simulated weather phenomena. The hybrid downscaling approach combines the physics-based realism of dynamical downscaling with the computational efficiency of statistical downscaling, whereas the double-statistical approach removes scale and altitude specific biases from gridded statistical downscaled data (e.g., BCSD or BCCA data).

To date, the lack of large ensembles from dynamical downscaling has resulted in the prominence of statistical downscaling methods in climate impact assessment. Hybrid statistical-dynamical downscaling methods that blend the desirable characteristics of different methods may be a means to advances in the delivery of value-added downscaled climate data. Prior studies have highlighted sources of model uncertainty at regional scales through internal variability, emission scenario and model selection (e.g., Hawkins and Sutton, 2009), yet as most impact studies utilize some form of downscaled climate predictions, the relative influence of dynamical downscaling methodology over statistical methods has rarely been explicitly demonstrated. Implementation of various downscaled products would enable assessment and refinement of the most appropriate methodology.

Status of Modeling for Atmospheric River (AR) Events:
Extreme cold-season precipitation accumulation in California is driven by frequency and the intensity of extra-tropical cyclones. When these cyclones tap into tropical sources of warmth and moisture through atmospheric rivers, they are called pineapple expresses and have resulted in the largest storms historically. Atmospheric "rivers" (ARs) are narrow regions of very high water vapor content in mid-latitude flow from over the North Pacific Ocean, sometimes including tropical and subtropical regions, and are historically associated with the most extreme weather episodes on the west coast. Numerous studies have documented the important role that ARs play in major storms and floods in California, Oregon, and Washington (http://www.esrl.noaa.gov/psd/atmrivers/pubs/). Recent results derived from seven CMIP3 GCM simulated outputs show that 21st century projections include more years that capture rare intense ARs (Dettinger 2011). The adequacy of a GCM's ability to simulate ARs is largely related to correct modeling of jet stream characteristics, correct coupling with the tropical environment, and representation of convective and orographic processes. The large-scale environment conducive for ARs is generally considered an area of strength for GCMs; these relatively short-term ARs (~days to weeks) appear to be modulated by the longer period, including intra-seasonal variations (e.g. Madden-Julian Oscillations; Guan et al. 2012) and interannual forcing mechanism (e.g., El Nino Southern Oscillation, Nusbaumer and Noone 2010). On the other hand, fine-scale RCMs have been shown to realistically simulate the local orographic precipitation extremes related to ARs (Leung and Qian 2009; Dettinger et al. 2012). Thus, correctly predicting the climatological effect of AR events, and associated orographic rainfall and flood hazards, depend on the ability of GCMs to simulate atmospheric teleconnection patterns over key oceanic regions, and RCMs' ability to simulate local orographic precipitation processes.

Historical flood events over the region clearly show that copious orographic rainfall is associated with extreme AR events. A particular hypothetical extreme event is the ARkStorm event (Porter et al. 2011), consisting of a 23-day sequence of Atmospheric River storms (e.g., a 500-1000-year flood event) over the southern and northern California. This type of event would result in significant infrastructure damage with large environmental and social-economic consequences. This rare event is plausible in the physical sense and has been motivated by a historical extreme event observed in 1861-62, with a record 45 days of near continuous precipitation. Analogue regional weather simulations using 2km grid spacing of the ARkStorm event suggest rainfall accumulations of approximately 700 mm over the Southern California and and 300 mm in the Sierra Nevada producing extreme catastrophic flood events (Porter et al. 2011; Dettinger et al. 2012). Over the Santa Barbara basin, paleo-flood reconstructions show evidence of recurrent large floods with an approximate 200 yr periodicity (Schimmelmann et al. 2003). While these historical proxies highlight the need of considering relatively frequent extreme flood episodes, future climate projections as investigated by Das et al. (2011) highlight the increase in the likelihood of simulated flood episodes using CMIP3-GCM under a warming climate. These findings suggest that infrastructure adaptation plans should include the ARkStorm rainfall scenarios as a conservative measure to prepare for climate change impacts.

Climate Change Impacts on Ecosystems and Threatened Species:
The Mojave Desert is the driest region in North America with broad temperature extremes from below freezing to over 45˚C. Precipitation is highly variable from year-to-year and season-to-season. During the 2001-2002 hydrologic year in the southern NV region of the Mojave Desert only 27 mm of precipitation occurred throughout the entire year, however, in 2004-2005 this same region received 316 mm (Redmond 2009). A number of studies have been performed to examine the potential effects of climate change on the Mojave Desert ecosystem. Two of these studies include the Nevada Desert FACE (Free Air CO_2 Enhancement) Facility (NDFF) study and the Mojave Global Change Facility (MGCF) study. These studies examined the impact of various climate change factors on Mojave Desert shrubland communities. At NDFF the impact of elevated atmospheric CO_2 (550 $\mu L\ L^{-1}$) was studied for ten years and the MGCF study examined the impact of enhanced summer precipitation, soil crust disturbance and nitrogen deposition over a similar time period. A bibliography of published research from these two studies is included in Appendix C. The key results of these climate change research efforts are summarized in Table 1 (from Smith et al., 2009). The potential new regime that may result from both elevated CO_2 and enhanced precipitation is the likely increase in fire frequency, which would have a large socio-economic impact for the Antelope Valley region.

Table 1. Potential ecological effects of global change in the Mojave Desert (modified from Table 2.4 in Chapter 2 of The Mojave Desert: Ecosystem Processes and Sustainability, 2009, RH Webb, LF Fenstermaker, JS Heaton, DL Hughson, EV McDonald, DM Miller; editors, University of Nevada Press, Reno NV.)

Other results from the NDFF elevated CO_2 experiment revealed the potential for a two-fold increase in the density, biomass and seed production (seed rain) of the exotic grass *Bromus madritensis*, ssp. *rubens* (red brome) during El Niño winters (Smith et al., 2000). Under the same El Niño conditions and exposure to elevated CO_2, native annuals experienced a decrease in density and only a slight increase in biomass and seed production. These results are graphically and pictorially displayed in Figure 6. Increases in *Bromus* invasion and plant density/biomass are associated with a greater risk of fire during the summer monsoon season when lightning strikes are high and senesced *Bromus* provides a ready fuel source for fire ignition and spread.

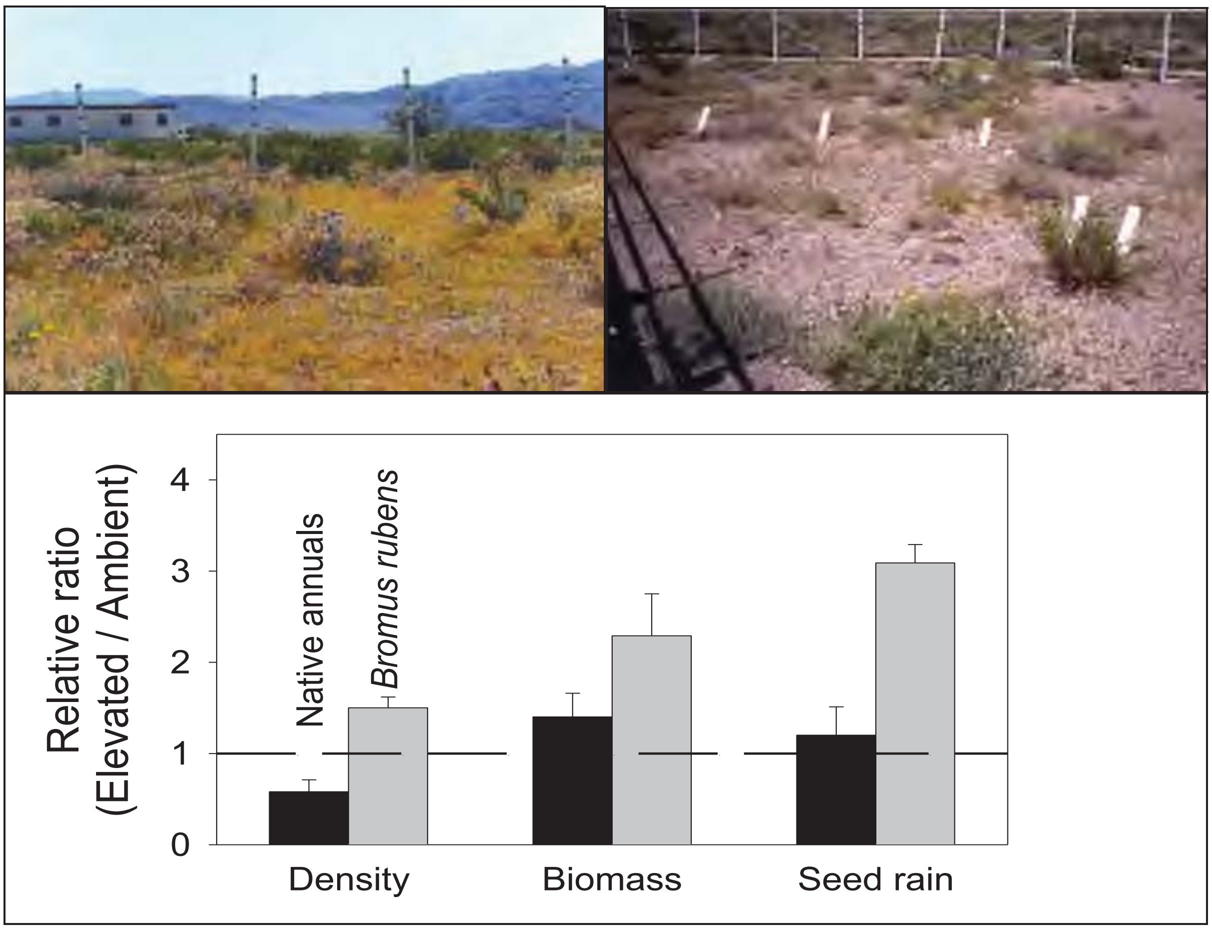

Figure 6. The effects of an elevated atmospheric CO_2 treatment are compared with ambient CO_2 annual productivity following an El Niño winter. The photograph on the left shows the enhanced annual plant productivity in an elevated atmospheric CO_2 treatment plot and the photograph on the right depicts plant productivity in an ambient CO_2 plot. The graph at the bottom displays the ratio of elevated to ambient CO2 treatment plant densities, biomass and seed rain for native annuals (black bar) and the invasive grass Bromus madritensis, ssp. rubens. The ratio is "1" for no difference between elevated and ambient measurements. Values less than "1" indicate a negative response to elevated CO_2 and values larger than "1" indicate a positive effect of elevated CO_2 on plant density, biomass and seed rain; figure adapted from Smith et al., 2000.

The increase in invasive grasses simultaneous with decreases in native annual plant numbers under increasing atmospheric CO2 also raises concerns about the loss of threatened and endangered (T&E) plant species and food sources for T&E animal species. Table 2 provides a list of T&E plant and animal species that likely occur in Antelope Valley. This list was extracted from the California Department of Fish and Game's California Natural Diversity Database (CNDDB). Because species are listed by county in this database, the county lists for the three counties that cover portions of Antelope Valley were extracted, namely Kern, Los Angeles and San Bernardino Counties. From these county lists, only the Federally and State listed T&E species were extracted from the database. It must be noted that each of these counties encompasses additional areas beyond Antelope Valley and therefore some of these species listed in Table 2 might not occur in Antelope Valley for natural species range reasons.

Table 2. A list of threatened and endangered plant and animal species in Kern, Los Angeles and San Bernardino Counties, which cover portions of Antelope Valley.

Species Name	Common Name
Acanthoscyphus parishii var. *goodmaniana*	Cushenbury oxytheca
Acmispon argophyllus var. *adsurgens*	San Clemente Island bird's-foot trefoil
Acmispon dendroideus var. *traskiae*	San Clemente Island lotus
Ambystoma californiense	California tiger salamander
Ammospermophilus nelsoni	Nelson's antelope squirrel
Amphispiza belli clementeae	San Clemente sage sparrow
Anaxyrus californicus	arroyo toad
Aquila chrysaetos	golden eagle
Arenaria paludicola	marsh sandwort
Astragalus albens	Cushenbury milk-vetch
Astragalus brauntonii	Braunton's milk-vetch
Astragalus jaegerianus	Lane Mountain milk-vetch
Astragalus pycnostachyus var. *lanosissimus*	Ventura Marsh milk-vetch
Astragalus tener var. *titi*	coastal dunes milk-vetch
Astragalus tricarinatus	triple-ribbed milk-vetch
Atriplex tularensis	Bakersfield smallscale
Batrachoseps simatus	Kern Canyon slender salamander
Batrachoseps stebbinsi	Tehachapi slender salamander
Berberis nevinii	Nevin's barberry
Brodiaea filifolia	thread-leaved brodiaea
Buteo swainsoni	Swainson's hawk
Castilleja cinerea	ash-gray paintbrush
Castilleja grisea	San Clemente Island paintbrush
Catostomus santaanae	Santa Ana sucker

Species Name	**Common Name**
Caulanthus californicus	California jewel-flower
Cercocarpus traskiae	Catalina Island mountain-mahogany
Charadrius alexandrinus nivosus	western snowy plover
Charadrius montanus	mountain plover
Charina umbratica	southern rubber boa
Chelonia mydas	green turtle
Chloropyron maritimum ssp. *maritimum*	salt marsh bird's-beak
Chorizanthe parryi var. *fernandina*	San Fernando Valley spineflower
Coccyzus americanus occidentalis	western yellow-billed cuckoo
Deinandra mohavensis	Mojave tarplant
Delphinium variegatum ssp. *kinkiense*	San Clemente Island larkspur
Desmocerus californicus dimorphus	valley elderberry longhorn beetle
Dipodomys ingens	giant kangaroo rat
Dipodomys merriami parvus	San Bernardino kangaroo rat
Dipodomys nitratoides nitratoides	Tipton kangaroo rat
Dipodomys stephensi	Stephens' kangaroo rat
Dithyrea maritima	beach spectaclepod
Dodecahema leptoceras	slender-horned spineflower
Dudleya cymosa ssp. *agourensis*	Agoura Hills dudleya
Dudleya cymosa ssp. *marcescens*	marcescent dudleya
Dudleya cymosa ssp. *ovatifolia*	Santa Monica dudleya
Elanus leucurus	white-tailed kite
Empidonax traillii extimus	southwestern willow flycatcher
Eremalche kernensis	Kern mallow
Eremogone ursina	Big Bear Valley sandwort
Eriastrum densifolium ssp. *sanctorum*	Santa Ana River woollystar
Erigeron parishii	Parish's daisy
Eriogonum kennedyi var. *austromontanum*	southern mountain buckwheat
Eriogonum ovalifolium var. *vineum*	Cushenbury buckwheat
Eriogonum thornei	Thorne's buckwheat
Eucyclogobius newberryi	tidewater goby
Euphilotes battoides allyni	El Segundo blue butterfly
Euproserpinus euterpe	Kern primrose sphinx moth
Fritillaria striata	striped adobe-lily
Galium catalinense ssp. *acrispum*	San Clemente Island bedstraw
Gambelia sila	blunt-nosed leopard lizard
Gasterosteus aculeatus williamsoni	unarmored threespine stickleback
Gila elegans	bonytail

Species Name	**Common Name**
Glaucopsyche lygdamus palosverdesensis	Palos Verdes blue butterfly
Gopherus agassizii	desert tortoise
Gulo gulo	California wolverine
Gymnogyps californianus	California condor
Haliaeetus leucocephalus	bald eagle
Helianthemum greenei	island rush-rose
Lanius ludovicianus mearnsi	San Clemente loggerhead shrike
Laterallus jamaicensis coturniculus	California black rail
Lithophragma maximum	San Clemente Island woodland star
Malacothamnus clementinus	San Clemente Island bush-mallow
Martes pennanti (pacifica) DPS	Pacific fisher
Melanerpes uropygialis	Gila woodpecker
Micrathene whitneyi	elf owl
Monolopia congdonii	San Joaquin woollythreads
Nasturtium gambelii	Gambel's water cress
Navarretia fossalis	spreading navarretia
Oncorhynchus mykiss irideus	southern steelhead - southern California DPS
Opuntia basilaris var. *treleasei*	Bakersfield cactus
Orcuttia californica	California Orcutt grass
Passerculus sandwichensis beldingi	Belding's savannah sparrow
Pentachaeta lyonii	Lyon's pentachaeta
Perognathus longimembris pacificus	Pacific pocket mouse
Phacelia stellaris	Brand's star phacelia
Physaria kingii ssp. *bernardina*	San Bernardino Mountains bladderpod
Poa atropurpurea	San Bernardino blue grass
Polioptila californica californica	coastal California gnatcatcher
Pseudobahia peirsonii	San Joaquin adobe sunburst
Ptychocheilus lucius	Colorado pikeminnow
Rallus longirostris yumanensis	Yuma clapper rail
Rana draytonii	California red-legged frog
Rana muscosa	Sierra Madre yellow-legged frog
Rhaphiomidas terminatus abdominalis	Delhi Sands flower-loving fly
Sibara filifolia	Santa Cruz Island rock cress
Sidalcea pedata	bird-foot checkerbloom
Siphateles bicolor mohavensis	Mohave tui chub
Sorex ornatus relictus	Buena Vista Lake shrew
Sternula antillarum browni	California least tern
Synthliboramphus hypoleucus	Xantus' murrelet

Species Name	Common Name
Taraxacum californicum	California dandelion
Thamnophis gigas	giant garter snake
Thelypodium stenopetalum	slender-petaled thelypodium
Urocyon littoralis catalinae	Santa Catalina Island fox
Urocyon littoralis clementae	San Clemente Island fox
Vireo bellii arizonae	Arizona bell's vireo
Vireo bellii pusillus	least Bell's vireo
Vulpes macrotis mutica	San Joaquin kit fox
Xantusia riversiana	island night lizard
Xerospermophilus mohavensis	Mojave ground squirrel
Xyrauchen texanus	razorback sucker

Status of Dust Emission Research:
An introduction of this topic is presented prior to the discussion on current knowledge to provide the reader with a basic understanding of the topic.

Introduction:
The delivery of dust-sized particles (<70 µm) to the atmosphere is a process driven by the fluid properties of wind (Figure 7). There is a complex interplay, however, between the resisting and driving forces that control the release and entrainment of these particles and the vertical flux of dust. The dust can be entrained from soil when the surface is susceptible and the shearing force of the wind is sufficient to entrain particles. Entrainment of dust into the wind also occurs when sand-sized particles are moved along the surface in a series of jumps and hops called saltation. The saltating particles impact the surface and eject dust sized particles (Figure 8). Dust can also be released to the airflow as aggregates of sediment breakdown during the vigorous transport process. Key concepts in dust emissions or wind erosion in general are the threshold, or initiation, of transport and the flux of particles from the surface into the atmosphere by the driving forces of wind and saltation. The critical surface controls affecting threshold and the magnitude of the emissions are moisture content, roughness (whether vegetation or large solid elements), and crusting, which can be formed by biotic and abiotic processes. The flux of emissions once initiated scales as a power function of the wind shear, but the actual magnitude of the flux is controlled to a high degree by the surface's ability to release the dust.

Disturbance of a surface can both increase the probability that emissions will occur as well as increase the magnitude of emissions from that surface. The increase in the probability of emissions is a result of the lowering of the threshold velocity, making the surface more susceptible (e.g., Belnap and Gillette, 1997). The strength of dust emissions are related principally to the particle size distribution of the sediments (i.e., soil texture), soil moisture content, salt and clay mineral bond strengths, and the roughness of the surface. Disturbance can alter or modify these properties to various levels of severity. Research has indicated that, in general, disturbance increases emissions as compared to the undisturbed surface by an order of magnitude.

Figure 7. Dust storm created by high speed winds flowing out from a thunder cell, known as a Haboob (Idso, 1973) observed at the NASA DSFC (NASA Dryden Photographs).

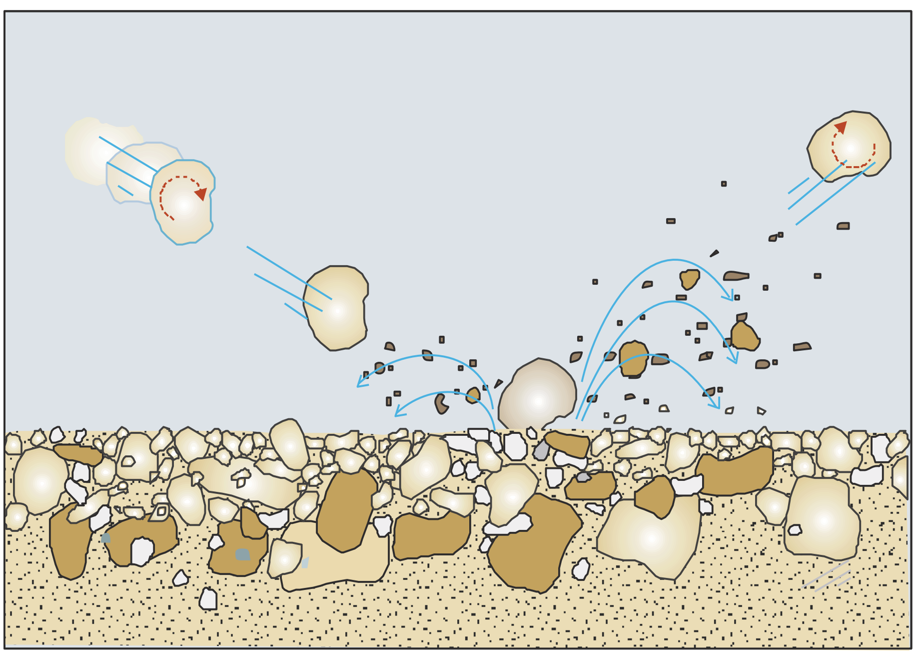

Figure 8. Diagrammatic representation of dust emissions caused by sand particles in active transport striking a susceptible surface releasing dust-sized particles (image courtesy of W.G. Nickling).

The propensity of desert surfaces to release dust to the atmosphere changes through time and at different scales. Short term changes in susceptibility, e.g., over the course of a day can be affected by changing relative humidity (Ravi and d'Odorico, 2005; McKenna Neuman and Sanderson, 2008). Changes in the minerals that form through evaporative processes that create crusts in the sediments and soils change on seasonal patterns driven by variations in temperature and moisture (Gill et al., 2002). The strength of the crust will determine, in large part, the resistance of the sediments to entrainment by the wind. Buck et al. (2009) observed that the nature of the salt crusts affected their susceptibility to erosion, even if the mineral component was the same. The nature of the crystal form (i.e., crystal habit) can be disruptive, enhance salt heave, lessen the degree of interlocking precipitates, and form loose, efflorescent crusts that are highly emissive. Different environmental conditions can cause the same minerals to help form crusts that are highly resistant to wind erosion. To date very little research has been carried out to characterize the seasonal cycling of mineralogy, mineral habit evolution, and their effect on dust emission potential.

Longer term cycles tied to changes in global circulation and sea currents likely play a larger role in altering the dust cycle in the Mojave Desert than the daily and seasonal controls described above. Okin and Reheis (2002) noted that changes in the El Niño/La Niña cycles (or El Niño Southern Oscillation, ENSO) had a marked effect on dust emissions in the southwest US. According to their study, there is an increase in dust events in the years following a strong La Niña and El Niño years, which was corroborated by Reheis (2006). The link is created through changed rainfall patterns brought about by these cycles. Okin and Reheis (2001) note that the probability of an increased frequency of dust events occurs when annual precipitation, or annual precipitation/potential evapo-transpiration ratio (P/PE) falls below the 10^{th} percentile. The response of the Mojave under decreased precipitation (La Niña event) is to produce lower amounts of vegetation in the winter months, which endures through to the next winter. The reduced vegetation cover represents a loss of protection of the surface and an ability to resist high spring winds, so there is a greater probability for wind erosion and dust emissions to occur (threshold wind speed is lower). Okin and Reheis (2001) note that an anomalously high input of precipitation (strong El Niño) can also increase dust storm frequency likely due to delivery of sediments by fluvial processes, or their re-working, increasing the available supply of dust into areas prone to wind erosion (i.e., playas and their margins).

Under the conditions of a moderate El Niño, dust storm frequency can be reduced. During moderate El Niño events precipitation amounts are likely to increase, which stimulates plant grow that can persist through to the next season or longer. The enhanced vegetation cover provides additional protection of the surface, even if the plants die, which serves to raise the threshold wind speed required to cause wind erosion and dust emissions to occur. These cycles of dust emission frequency in southern US deserts are likely to stay tuned to the ENSO cycles, and so will be influenced by how these coupled atmospheric and oceanic processes evolve in a changing climate. An exception to this occurred in the winter of 2010-2011, in which an unusual strongly meridional jetstream provided increased precipitation to Southern California in a usually dry La Niña year. A significant research question that is pertinent here is "what is the stability of these natural modes that have been identified, in the face of an evolving climate"?

Current Knowledge of Climate Change Impacts on Dust Emissions:
Most climate forecasts for the southwestern US convey an overall drier climate (Seager and Vecchi, 2010 and references therein) that is nonetheless characterized by more severe, less frequent precipitation events as compared to the climate over the past century (Seager et al., 2007 and Knapp et al., 2008). These changes will have several first-order effects on the dust emission processes in the southwestern US. These effects can be roughly grouped into impacts of changes in wind regime, changes in sediment supply, and changes in vegetation cover. The nature of these effects can be characterized, but the direction that they will force the aeolian sediment transport system to take is less certain.

The most easily understood impact is that associated with changes in wind regime. If all other parameters were held constant, increases in surface wind speeds result in increases in dust emissions. In cases where the supply of dust is not limited at the surface, increases in wind speed result in additional dust emissions that are proportional to the wind speed raised to some power that is larger than unity (typically 2-6). In reality, the timing of high wind events and their duration can have a more profound effect than the relative magnitude of events. For example, a comparatively vigorous wind event can result in comparatively low dust emissions if the event occurs during a period when the soil is moist or has recently developed a protective surface crust. Conversely, a relatively mild wind event can lead to comparatively vigorous dust emissions, if it occurs when soil conditions are more favorable for aeolian sediment transport. Thus, changes in wind regime must be considered in the context of other limiting or enabling variables.

Vegetation cover, or lack of it, can be the difference between a severe wind erosion event and one that is either not noteworthy or absent altogether. Surface roughness in the form of vegetation extracts momentum from the wind aloft. On balance, this reduces the influence of the wind on the surface by some multiple that is dependent on the type and density of the vegetation. In settings with thick vegetation, the windblown sediment transport system may be shut down altogether. In recent decades, invasive grasses such as cheat grass have flourished in parts of the Mojave Desert. Typically, these annuals are very responsive to precipitation on fairly short time scales. A wet year generally results in a thick grass cover. When present, grasses tend to protect the soil surface from wind erosion. However, grasses can be problematic from a wind erosion perspective as well. First, the presence of grasses markedly increases the probability of wildfires in the Mojave. Depending on the severity of the fire, entire communities of native shrubs may be eradicated or weakened. These shrubs, less responsive to short term environmental changes and, therefore less intermittent than grasses, serve as a year-round, constant vegetative cover. Their loss from a landscape renders the soil surface vulnerable to wind erosion during periods when grasses are also absent (e.g., prolonged drought). Second, invasive grasses directly compete for the same resources as native shrubs and can stress and displace shrubs, resulting in the same lack of constant, long-term vegetative protection for the underlying soil.

Changes in precipitation frequency and severity can affect the supply of sediment available for wind erosion as well as the biotic and abiotic crusts that protect soil surfaces from wind erosion. Playa basins form over millennia through alluvial processes that erode material at high elevations. Eroded material is transported downstream and undergoes a size sorting process. Hillslopes are steeper at the high elevations and essentially flat at the basins. As surface runoff loses energy as it gets closer to the basin, coarse materials are the first to deposit and only the finest materials are able to complete the journey to the lake bed. If precipitation events change in intensity and duration, the calculus of what size materials deposit at what point along the downslope gradient also changes. Through the process of saltation, sand bombardment can give rise to very high levels of dust emissions. Changing the spatial distribution of sand can give rise to changes in the distribution of surfaces that are susceptible to dust emissions. Alternatively, more energetic precipitation events may simply transport more dust-sized material to the lake bed, providing a reservoir that is capable of supplying greater quantities of dust.

Another effect of changing precipitation patterns, or more directly changes in hydrology influenced by precipitation, is that the ability of the soil surface to support biotic or abiotic crusts may be altered. Abiotic crusts form through cohesion of sediment by salts and other chemicals. Altering the mix of chemical constituents can alter the robustness of abiotic crusts. Similarly, the delivery of nutrients or the severity of water erosion may have a direct impact on the viability of biotic crusts.

Status of Hydrological Research:

Climate change will lead to increases in both the variability and the uncertainty of hydrologic processes in the future. Climate change predictions for the Southwestern U.S. are for overall drier conditions, with less precipitation and more droughts, and the extremes of the new climate condition are expected to be greater than they are now. Precipitation events may be less frequent, but they will be of increased magnitude and intensity, resulting in altered watershed rainfall-runoff responses and thus producing more floods and debris flows. Droughts will be more severe and last for longer periods of time.

Flood hazard mitigation, based on a traditionally static approach, will need to be re-evaluated, as the “100-year” design storm evolves with climate change (Miller, 2009; Milly et al., 2008). Ecosystems that support threatened and endangered species habitat will change in response to less precipitation, affecting future facility siting needs and airfield and range operations. Land uses will change as watershed rainfall-runoff responses are altered, both in terms of water availability for agricultural uses, as well as for areas that become subject to risk by flooding or debris flows.

Specific impacts of the predicted climate change condition to the DFRC include three major categories: Rogers Lake inundation, EAFB access obstructions, and Rogers Lake lakebed fracturing and fissuring. The depth, frequency, and duration of lakebed inundation will change as precipitation events become more likely to result in flooding. Airfield and lakebed operations will be affected or shut down, possibly for much longer time periods than under current climate conditions (Figure 9). Increased inundation depths will result in flooding of more shoreline areas, impacting both current facilities as well as limiting future facility siting opportunities. Ponded water on the lakebed will result in habitat impacts as more migratory birds are drawn to the airfield, resulting in increased bird strike hazards to aircraft.

Figure 9. Lakebed inundation near DFRC in 1983 (NASA Dryden Photo, 1983) (left); Lakebed airfield inundation of Rogers Lake (Motts and Carpenter, 1970) (right).

The Main Gate (Rosamond Boulevard), South Gate (Lancaster Boulevard), and the North Gate are all subject to flooding, resulting in partial or complete roadway closures. Rosamond Boulevard, although somewhat elevated, crosses Rosamond Lake, another playa lakebed on EAFB. Ponded water crosses beneath the roadway through culverts, although the outside lanes of the roadway have been inundated, and thus, closed in the past (Figure 10). Lancaster Boulevard has been in the past overtopped by excessive drainage from Buckhorn Lake (a third playa lakebed) that typically crosses in culverts beneath the roadway to Rogers Lake. At the North Gate, the railroad underpass section of the roadway frequently floods, limiting access to this gate.

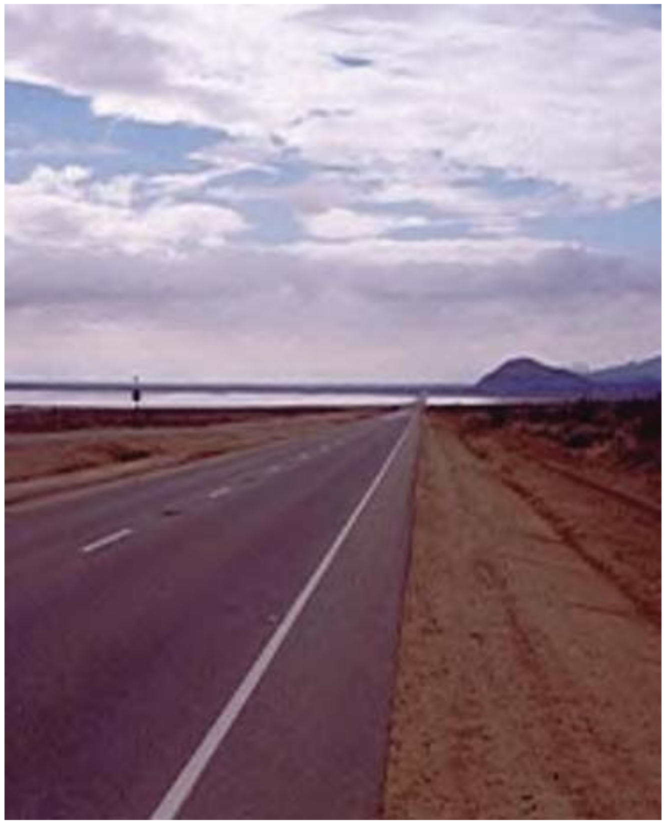

Figure 10. Water is seen on both sides of Rosamond Boulevard where it crosses Rosamond Lake, February 2003 (Miller, 2009).

Long-term drought conditions have both directly and indirectly caused lakebed fracturing and fissuring of the Rogers Lake lakebed (Motts, 1970; Galloway et al., 2003) (Figure 11). As lakebed sediments are subject to long-term drought, subsurface sediments desiccate, causing subsurface voids and cracks that eventually propagate to the surface. In addition, population and agricultural demands on groundwater supplies cause increased groundwater withdrawals from Antelope Valley, resulting in subsidence and additional fracturing on the lakebed. Regardless of the cause, these features reduce the availability of the lakebed for airfield operations.

Figure 11. A lakebed fissure resulting from both long-term drought conditions and groundwater withdrawal resulted in closure of the lakebed Space Shuttle runway on Rogers Lake during January 1991 (Galloway et al., 2003).

Water resources in the Antelope Valley region are overtaxed now, and will become increasingly so in the future as the population grows, resulting in even more impacts to lakebed conditions and available water supplies for DFRC operations. Increasing population densities in the valley will add further strain on the available water resources, resulting in greater groundwater withdrawals. Future housing densities also will result in increased impervious surfaces in the valley, resulting in greater runoff response from even lesser, more frequent precipitation events, and thus more flooding in general and of the playa lakebeds. Urban development will expand outwards to the edges of the valley, where encroachment of both groundwater recharge areas and undisturbed habitat will occur. Energy resources will be limited both by the increased demand of an increasing population density, by the decreased water volume in river systems (i.e., the Colorado River), and by reservoir operations that are restricted by habitat and recreational use requirements.

2) What research is necessary to improve predictions and their certainty?

Research Needed to Improve Regional Climate Modeling and Uncertainty:
Predictions of regional climate are becoming an increasingly important source of information to develop regional responses, particularly for environmental planning and natural resource management. These decisions can be improved if reliable information is provided by climate scenarios of future projections. As mentioned earlier, downscaled GCMs can be used to create these climate scenarios along with strategic decisions under a changing climate regime. Regional Climate Modeling is a tool that helps to bridge the gap between GCM output and regional response. The hope is that future climate prediction from RCMs will improve as models begin to explicitly resolve processes on ever-finer scales (Hurrel et al. 2009). However, this can lead to an increase in uncertainty due to: an additional model layer and the numerous complex processes that no model can ever be expected to perfectly simulate; scale interactions and resolution; physical parameterizations and other structural model errors; initial and boundary conditions inherited from the GCMs; and inter-model variability (Fronzek and Carter 2007; Foley 2010). Additional uncertainties are related to knowledge gaps in climate sensitivity and feedbacks and formulations of human influences (e.g. emissions of green house gases) and their responses (Pielke et al 2009).

Continued efforts are needed to quantify and reduce uncertainty within and across models to increase the accuracy of projections. Assessment of model related uncertainties has been a significant part of past and ongoing research efforts by different research institutions (e.g. PRUDENCE, Christensen et al. (2007); NARCCAP, Mearns et al. (2009); WRCP-CORDEX, http://www.meteo.unican.es/en/projects/CORDEX). Using a probabilistic concept, a number of multi-model or perturbed physics ensembles based on RCMs can be designed and created to quantify the effects of uncertainty by simulating climate system processes (Murphy et al, 2007; Foley 2010). In other words, for one particular variable or location, a single model may perform well, but when considering all aspects of climate and uncertainty, an ensemble of model outputs tends to improve certainty (Tebaldi and Knutti, 2007). In spite of their uncertainties, RCM ensembles can provide valuable and robust information for the decision-making process. By working with a range of models rather than looking at single model output, decision-makers can build strategies that represent a range of plausible futures.

Analyses and simulations of extreme weather events using a more targeted “case studies” approach is an important complementary alternative for impact assessment rather than just measuring change in climate and extreme events from global climate model simulations forced to future emission scenarios. RCMs can be utilized to study the accuracy, exposure and vulnerability around a worst case sequence of observed weather events. For example, simulation of ARkStorm-like events, and understanding the effect in the regional environment and its threat to society, could provide valuable information for mitigation and adaptation measures. However, we first need to investigate the sensitivity of simulations of such AR events to model selection, resolution, physical parameterizations, and boundary conditions. While such case studies are not predictions, the range of solutions provided by a set of RCM(s) configurations constitute a conservative measure based on predictive judgments about the interactions of possible events manifested in the past. This research strategy can potentially produce regional and sub-regional climate scenarios based on basic understanding of physical processes and quantification of simulations skills of extreme events.

Research Needed to Improve Dust Emission Assessment and Uncertainty:
Related to the discussion above, the following are areas where additional information would help reduce the uncertainty of future response of the aeolian dust emissions system in response to changes in climate. An important first step is to obtain a baseline understanding of the source areas of present day windblown dust. This includes determining the locations of dust hot spots, determining the collection of characteristics common to these locations, and identifying the potential for dust emissions from other locations that may become hot spots in the future. Important characteristics include soil texture, degree and type of crusting (biotic vs abiotic, seasonal vs. perennial), soil moisture as a function of other hydrological inputs (e.g., rainfall history, proximity to water table, salt content).

Another, perhaps equally important effort is the characterization of vegetative and biological soil crust (BSC) cover over basin areas where current and future dust emissions may be expected. Specifically, a vegetation and BSC survey would establish the baseline plant and BSC community that can be compared to future surveys and inform on the direction that the plant species and BSC cover in the area are heading in terms of distributions and densities. In addition, a survey would enable the estimation of the shear stress protection that is currently offered by vegetation and BSC cover. This information can add certainty to a basin-specific model of the aeolian sediment transport system.

Dust Emission Modeling:
The research needs described above also feed explicitly into the further development of dust emission models that operate at the meso-scale, which will be important to evaluate regional dust effects on visibility impairment, air quality, and radiative transfer under current and changing climate regimes.

A main focus and potential weakness in dust emission models is that the emission process is highly sensitive to meteorological, surface, and soil properties. Dust emissions are a sporadic and spatially heterogeneous phenomenon (Laurent et al., 2009), which is locally controlled on spatial and temporal scales (Tegen and Schepanski, 2009). Therefore predicting the magnitude and spatio-temporal patterns of dust emission is challenging for regional dust models, so the acquisition of local and regional scale data, as described here, is critical.

A meso-scale dust emission model requires information on the dust source, with different schemes using data linked to characteristics of topography (Ginoux et al., 2001), hydrology

(Tegen et al., 2002), geomorphology (Zender et al., 2003), surface reflectance retrieved from MODIS (Westphal et al., 2009), and UV-visible albedo (Morcrette et al., 2009). Dust sources must also be ascribed a threshold wind friction speed for which a number of schemes are available (e.g., Iverson and White, 1982; Shao and Lu, 2000). A local or regional and seasonally resolved data base would also serve to constrain this critical parameter as moisture content plays an important role in addition to particle size.

The driving force of a dust emission model is based on wind data and the means to generate the wind friction speed (u_*, m s^{-1}), which is used to generate the horizontal and vertical fluxes of saltation (sand-sized particles moved by the wind) and dust. It is assumed that the vertical flux scales proportionally with the dust flux and this proportion can be taken as a function of the soil texture (e.g., Tegen et al., 2002). Sedimentation must be accounted for at the bottom layer of the model due to dry deposition (e.g., Zhang et al., 2001) and wet scavenging and convective mixing. To couple the aerosol and the radiation processes an acceptable radiative transfer model including aerosol effects must be integrated into the model. It must be recognized here that dust aerosols are not well-characterized for their optical properties, which will affect the quality of the radiative transfer estimates. There is opportunity to collect and quantify Mojave Desert dust aerosol optical properties as part of the climate adaptability process.

There are a number of available dust emission models each with their own strength and weaknesses. For example, Pérez et al. (2011) provide a detailed description of an operationalized meso-scale dust model. An effort should be undertaken as part of the process evaluating climate change adaptability at NASA DRFC to evaluate which model could best be adapted to serve the needs of developing an understanding of the regional effects of dust under a changing climate. This should be a high research priority for the climate adaptability assessment.

<u>Research Needed to Improve Hydrological Assessment and Uncertainty:</u>
The key to the future is often said to be found in the past. Review of historic archaeological records, including oral histories and historic photographs, for information pertaining to the local effects of the 1861 storm and other significant precipitation events, as analogs to the ARkStorm, will provide key information as to the flooding created by these types of storms. In addition, paleohydrology studies, including paleoflood and fluvial geomorphologic observations, should be conducted in the field to determine playa lakebed inundation depths, channel flowpaths, etc. Field studies should address the "coupled processes" or landscape ecology involved in a system-wide view of flooding, including land use, vegetation cover, drainage pathways, geomorphic surfaces, critical infrastructure interdependencies, etc.

Current remote sensing techniques, modeling, and *in-situ* measurements are important methods to integrate information. Remote sensing allows one to gather data where monitoring does not exist, and allows calibration of models of these non-monitored watershed areas to *in-situ* measurement points (Miller et al., 2011). For example, when both precipitation and flow gage records are available from a nearby watershed, they can be used to calibrate hydrologic models of adjacent ungaged watersheds, where remote sensing measurements indicate that land use, geomorphic soil conditions, and vegetation cover conditions are similar.

Hydrologic modeling is a tool that allows for a system-wide perspective to be taken, both in terms of spatial and temporal scales. On a spatial scale, models can range from thousands of kilometers to a local scale of a few kilometers, representing continental droughts to local flooding, respectively. Temporally, models can represent paleoclimates or current climate patterns, over hundreds to thousands of years. Environmental changes in both climate oscillations and land use changes over decades can be described. Seasonal forecasts of climate, hydrologic, and drought conditions can be made in terms of months or weeks, or daily weather and flood forecasting can be made. However, to create an ongoing hydrometeorological prediction system very high resolution regional atmospheric modeling simulations are needed to couple with hydrologic models.

Long-term monitoring is used to validate and calibrate climate change models that use existing (i.e., historical) data sets. However, throughout the Southwestern U.S., precipitation and stream gages are sparse, and long-term records are thus limited, and generally consist of many years of “zero” measurements. Implementation of long-term *in-situ* measurements and monitoring is recommended to integrate with remote sensing and modeling efforts.

3) What adaptation and mitigation steps can be taken now?

<u>Adaptation and Mitigation for Climate Change:</u>
During the workshop, the climate change modeling group discussed a number of facility adaptation steps, but for climate change modeling as an individual topic, adaptation and mitigation are not applicable. The topics discussed overlapped with the other working groups and include: efforts to retrofitting air conditioning units to the most power and water efficient models available; developing on-site renewable energy; maintaining clean drainage systems to allow free flow of water during flood events; and increasing the ability of federal agencies to take advantage of energy saving performance contracts and alternative energy financial incentives.

<u>Adaptation and Mitigation for Dust Emissions:</u>
There are actions that can be taken to reduce the potential for or the severity of dust events in the region of NASA DFRC. As the weather and climate are beyond human control, actions to mitigate dust must be directed towards the surfaces that have the potential to emit dust. First and foremost mechanical disturbances of surfaces must be minimized. As described earlier disturbance increases the probability of an event occurring, because lower wind speeds are required. It also increases the strength of the emissions when they occur due to enhanced production of dust-sized particles. A management plan can be developed that promotes a

minimum impact of disturbance of the playa surface, without compromising the NASA DFRC mission.

Along with a strategy to reduce mechanical disturbance of the soil, actions that seek to preserve or increase native species abundance in the surrounding landscape will provide protection of surfaces that are susceptible to wind erosion and dust emissions. Vegetation protects the surface by covering part of it, absorbing momentum that reduces the shear stress acting on the bare areas, and traps particles that are in motion removing their contribution to the dust emission process. Similar to promoting vegetation growth, conditions that promote biotic crust preservation and propagation would aid in keeping crusts intact.

<u>Adaptation and Mitigation for Hydrological Risks:</u>
Several steps can be taken now to mitigate the adverse effects of flooding on DFRC facilities and operations. Lakebed airfield operation schedules can be modified to avoid predicted periods of likely lakebed inundation or fracturing by extended droughts. Increases in the "factor of safety" for flood mitigation structures (i.e., overdesign flood mitigation structures) are simple engineering design adaptations that can be made now. Flood mitigation structures are currently designed with a specific factor of safety built in to ensure that most predicted or unforeseen risk is limited. As climate conditions change, and precipitation events become more intense, resulting in greater flooding, these current factor of safety items will be somewhat lessened, and will eventually be overwhelmed. By increasing the safety factor to above general engineering design standards, mitigation structures built now or in the next few years will provide protection for a much longer time period, even without a precise knowledge of exact future climate conditions. In addition, an inclusion of an additional freeboard depth factor above the estimated 100-year ponded lakebed depth (Miller, 2009) will somewhat account for predicted increased flooding of the lakebed, as well as changes in wind speeds, direction, and frequency that will move water over the lakebed; thus, allowing avoidance of those areas of shoreline that may be expected to be flooded in the future. A straightforward example of this would be to move electrical utilities from the floor of the hangars to a higher position in the building. If inundation occurred, then the primary electrical services would be above the water level.

The DoD and NASA both have incentives to reduce both energy and water resource consumption so as to comply with federal mandates and to leverage limited budgets. The incorporation of LEED building standards will help to reach these goals by reducing both energy and water use in future buildings.

4) What steps should be taken in the future?

Future Steps to Adapt/Mitigate for Climate Change Modeling:
During the workshop the climate change modeling group discussed a number of facility mitigation steps, but for climate change modeling as an individual topic, adaptation and mitigation are not applicable. The modeling group did discuss the importance of improved management plans for human populations and urban development of desert regions. Some of the ideas discussed for improving management plans included off-grid electricity generation, incentives for decreased water use, improving green building codes and limiting the urban infrastructure footprint to a sustainable level based on current and future water availability.

Future Steps to Adapt/Mitigate for Dust Emission:
To allow NASA DFRC to develop responses to mitigate effects to their operations that arise from dust emissions on the playa and in the vicinity of their operations several actions are recommended that are enhancements to the general monitoring of the environment. It would be advisable to begin a monitoring of the state of the playa surface to provide information on its potential to emit dust. The potential for dust emissions to occur will be principally driven by the larger climatic cycles of moisture delivery to the area (amount and timing) and temperature. These cycles will combine to influence the delivery of sediments by hydrologic flows (channelized and un-channelized) to surfaces that are then exposed to wind. The role of temperature will be to influence the speed at which sediments reach conditions of dryness that make them susceptible to entrainment, and also the strength of the crusts that form by affecting the mineral habits of the salts forming upon evaporation of available water.

To monitor the state of the playa and its dust emission potential a monitoring program that systematically measures the emission potential and key environmental parameters could be established. It is suggested that two parallel monitoring actions be considered. The first is based on using the Portable In Situ Wind Erosion Laboratory (PI-SWERL, Etyemezian et al., 2007) to measure dust emission potential as it relates to wind speed and in combination with measurements of surface conditions to characterize: particle size distribution of surface sediments, salt content, mineralogy (as a function of particle size), and observations of disturbance (disturbed versus undisturbed). The PI-SWERL is a system which is being used as a primary tool to characterize and evaluate windblown dust emissions from natural and artificial soil surfaces (e.g., Kavouras et al. 2009, Kuhns et al. 2010, Gillies et al., 2010). PI-SWERL is a portable device that aims to fulfill many of the same measurement functions that until now have required the use of larger portable field wind tunnels (e.g., Sweeney et al., 2008). Unlike large (10 m or longer) field wind tunnels, the PI-SWERL does not meet many of the scaling criteria that are theoretically required for realistic simulations of aeolian sediment transport processes. However, recent research, and cross calibration with a large portable field wind tunnel indicates that the PI-SWERL does provide a reliable measure of windblown dust emission potential (Sweeney et al. 2008). The measurement of playa emission potential should be carried out systematically through time (i.e., through all seasons) to begin to develop an understanding of the changes of emission potential and their links with climate and hydrological cycles.

The second monitoring action suggested is the establishment of measurement devices on the playa that can record local wind speed and direction and particle transport (both sand- and dust-sized) to provide real time information on the initiation of emission events, the associated environmental conditions, and their temporal characteristics. It is also recommended that dust concentration be measured, particularly the size fraction that is regulated by the US EPA as an air pollutant (i.e., particles ≤10 µm aerodynamic diameter, PM_{10}). This should be established in conjunction with the NOAA-sited meteorological station that is to be established at the DFRC.

Future Steps to Adapt/Mitigate for Hydrological Risks:

In conjunction with the monitoring plan developed for dust emissions, a system of flow gages with corresponding precipitation gages is suggested to be installed along the major contributing drainages to Rogers Lake, near the lakebed. These gages will allow a quantitative estimate of runoff volume reaching the lake, as well as provide local precipitation data and supplement the overall watershed gage network. In addition, a series of ultrasonic depth sensors could be installed at strategic locations on the lakebed to determine ponded water depth. If these instruments are paired with wind measurement instrumentation, the movement of water by wind on the lakebed can be monitored. The wind and water measurements can also be used to study the drying of surficial lakebed sediments that lead to dust emissions and fissuring of the lakebed surface.

To prevent long-term lakebed inundation that disrupts airfield operations, off-channel floodplain storage in upstream reaches of the drainages that contribute significant runoff to Rogers Lake could be developed. Such storage would attenuate the flood wave timing and flood depths on the lakebed, and limit the duration of inundation, which impacts operations. In addition, if wetlands are incorporated into off-channel floodplain storage mitigation efforts, both storm- and wastewater bioremediation is possible; thus, improving water quality as well as reducing flooding.

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Appendix A
NASA/DFRC Climate Change Adaptation Workshop Agenda and Attendee List

Date: August 2-3, 2011
Location: NASA/DFRC Facility at Palmdale Airport (DAOF Conference Facility)

August 2, Tuesday

08:00-08:20 Registration

08:20-08:45 Workshop welcome by Dr. Thomas H. Mace, Senior Science Advisor, NASA/DFRC

08:45-10:00 Plenary – Discussion of workshop questions and goals

10:00:10:15 Break

10:15-12:00 Discipline specific group discussions:
- Air Quality (dust emissions) (Rm 234)
  - Pollutants (dust, spores, ozone, smoke)
  - Monitoring network
- Hydrology (Rm 211)
  - Subsidence
  - Flooding
  - Altered Landscapes (LU/LC, fire)
  - Monitoring
- Climate (Rm 334)
  - Subscale modeling for the Mojave region
  - Climate change effects on temperature, precipitation and wind
  - Atmospheric Rivers

12:00-13:00 Lunch

13:00-15:00 Continuation of group discussions

15:00-15:15 Break

15:15-17:00 Plenary: groups provide a verbal summary of key discussion topics followed by a discussion of impacts on infrastructure and human health/activities as well as possible mitigation plans

August 3, Wednesday

08:00-09:45 Summary report and presentation preparation by each topic group

09:45-10:00 Break

10:00-12:00 Summary presentation to Policy Makers followed by a question and answer period

12:00-12:15 Optional tour of DFRC Aircraft Hangar

NASA/DFRC Climate Change Adaptation Workshop Attendees

Name	Organization
Barraclough, Jonathan	NASA, DFRC
Bendrick, Gregg	NASA, DFRC
Bryson, Robert "Bob"	Mojave National Preserve
Carrillo, Carlos	University of Arizona
Cox, Dale	USGS, Sacramento, CA
Crowley, Dan	NASA, DFRC
Doklestic, Dea	Yale University
Duke, Fon Allan	Desert Managers Group
Etyemezian, Vic	Desert Research Institute
Fenstermaker, Lynn	Desert Research Institute
Flores, Gemma	NASA, DFRC
Gillies, Jack	Desert Research Institute
Hughson, Debra	Mojave National Preserve
Iraci, Laura	NASA, Ames
Martin, Jennifer	NASA, DFRC
McKee, Jerry	NASA, DFRC
Mejia, John	Desert Research Institute
Miller, Julie	Desert Research Institute
Moll, Gary	Antelope Valley Conservancy
Morgan, Dan	NASA, DFRC
Munoz-Arriola, Francisco	Scripps Institution of Oceanography
Myers, Jeri	NASA, DFRC
Okin, Greg	University of CA, Los Angeles (UCLA)
Pantana, Laura	Edwards AFB
Rademacher, Thomas	Edwards AFB
Reed, Wendy	Antelope Valley Conservancy
Reinke, Danny	Edwards AFB
Smith, Barbara	NASA, DFRC
Torres, John	NASA, DFRC
Vechil, Jack	NASA, DFRC
Watts, Stephen	Edwards AFB
Wood, Robert	Edwards AFB
Young, Gwen	NASA, DFRC

Appendix B

Landholder Agency Survey on Climate Change Management Issues

1) In your city planning endeavors, do you consider potential climate change impacts? If yes, are there any questions you have about climate change modeling efforts?

Edwards AFB is actively considering how climate change is impacting our mission. In the last 25 years we have witnessed changes in the plant communities on the base caused by changes in the weather patterns, increases in the amount of Nitrogen in the atmosphere, and the introduction of invasive plant species following the traffic on Highway 58, 395, and 14. The climate change models need to predict ecological changes as well as precipitation and temperature.

2) What do you believe are the critical environmental hazards that currently have the largest potential impact for city planning and human health?

The regional changes in precipitation patterns will release more water in shorter periods of time, this changes the plant and animal population. The minor changes in temperature and moisture will change the ability of insects and other vectors to support and transmit diseases in new areas. West Nile, Plague, White Nose Bat Syndrome, Newcastle disease and Hanta virus are just a few of the diseases that might move into areas where the weather previously controlled their establishment.

Equally important will be the immediate change in desert flora following fires. The desert plants are being pushed out by invasive grasses that compete for the available water. These grasses allow fire to spread quickly; destroying Desert plants that are not fire adaptive. When a range fire burns the desert plants, they do not quickly reestablish themselves. Instead, more grasses and mustard plants take over.

3) Are there any environmental hazards that you believe will have a more significant impact in the future?

As the desert plants and animals change to adapt to the new climatic conditions, these new stresses will result in rapid declines in their population, distribution and health. The Endangered Species Act, both federal and state, do not have escape clauses to "not list species that are being impacted by the weather". Edwards AFB is tracking the population health of 18 plant and animal species that could become listed as endangered. The mitigation lands that we are now setting aside to protect various species will eventually not have the habitat necessary to support the species we bought the land for. Consider that Joshua Tree National Park will not have any live Joshua Trees in 50 years.

4) What climate/environmental data or information is currently lacking that would help you with planning/management decisions?

The changes to the climate will be subtle and gradual. But changes to cropping patterns, animal migrations, and the diversity of plant life in the desert and mountains potentially will be much more rapid. The gross climate data need to feed flora and fauna models. The birds and insects and bats have a very significant role in pollination. California has a very significant agricultural business. Changes to the availability and timing of precipitation and the timing of temperature changes will contribute to significant changes in pollinators and in the farm yields.

5) Are there any additional questions that you would like to see addressed at the NASA/DFRC Climate Change Adaptation Workshop?

The linkage between science and political science is missing. Our laws and regulations controlling land use, conservation, endangered species, commercial fishing, anadromous fish, fire management and outdoor recreation are based on the premise that the environment we see today will be the environment we will always see. Flood plains will change; some shrinking, some expanding. Does FEMA have a mandate to re-calculate the 100 yr flood plain very often? When the flood plain changes, does the zoning change, or the redevelopment and infrastructure investment strategies change? If an animal becomes scarce because the habitat changed, do we delineate the critical habitat that must be preserved based on historic values, or on what the ecological-climate change model predicts will be the future habitat? Climate Change Adaption will be managed with regulation of investment strategies and land use controls.

Submitted by: Robert W. Wood, Environmental Management, Edwards AFB, (661) 277-1407

Appendix C
Mojave Desert Climate Change Bibliography

Nevada Desert FACE Facility Peer-reviewed Publications
Submitted / In press

Coe KC, Sparks JP. Physiological ecology of the desert moss *Syntrichia caninervis* after long-term exposure to elevated CO_2: changes in photosynthetic thermotolerance? Oecologia (submitted).

Housman DC, Killingbeck KT, Evans RD, Charlet TN, Smith SD. Foliar nutrient resorption in two Mojave Desert shrubs exposed to free-air CO_2 enrichment (FACE). Journal of Arid Environments (submitted).

LuoY, Melillo J, Niu S, Beier C, Clark J, Classen A, Davidson E, Dukes J, Evans RD, Field C, Czimczik C, Keller M, Kueppers L, Norby R, Pelini S, Pendall E, Rastetter E, Six J, Smith M, Tjoelker M, Torn M. . Coordinated approaches to quantify long-term ecosystem dynamics in response to global change. Global Change Biology (accepted).

McCalley CK, Strahm BD, Sparks KL, Eller ASD, Sparks JP. The effect of long-term exposure to elevated CO_2 on nitrogen gas emissions from Mojave Desert soils. JGR-Biogeosciences (submitted).

2011

Aranjuelo I, Ebbets AL, Evans RD, Tissue DT, Nogues S, van Gestel N, Ebbert V, Adams, WW III, Nowak RS, Smith SD (2011) Photosynthetic and carbon allocation responses after long-term exposure to elevated [CO_2] in two Mojave Desert shrubs. Physiological Ecology 167:339-354.

Brinda JC, Fernando C and Stark LR (2011) Ecology of bryophytes in Mojave Desert biological soil crusts: effects of elevated CO_2 on sex expression, stress tolerance, and productivity in the moss Syntrichia caninervis Mitt. Pages 169-189 *in* Tuba Z, Slack N, Stark L (eds.), *Bryophyte Ecology and Climate Change*. Cambridge University Press.

Cable JM, Ogle K, Lucas RW, Huxman TE, Loik ME, Smith SD, Tissue DT, Ewers BE, Pendall E, Welker JM, Charlet TN, Cleary M, Griffith A, Nowak RS, Rogers M, Steltzer H, Sullivan PF, van Gestel NC (2011). The temperature responses of soil respiration in deserts: a seven desert synthesis. Biogeochemistry DOI 10.1007/s10533-010-9448-z.

Ferguson SD, Nowak RS (2011) Transitory effects of elevated atmospheric CO_2 on fine root dynamics in an arid ecosystem do not increase long-term soil carbon input from fine root litter. New Phytologist 190(4):953-967.

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Clark NM, Apple ME, Nowak RS (2010) The effects of elevated CO_2 on root respiration rates of two Mojave Desert shrubs. Global Change Biology 16:1566-1575.

Jin VL, Evans RD (2010) Microbial ^{13}C utilization patterns via stable isotope probing of phospholipid biomarkers in Mojave Desert soils exposed to ambient and elevated atmospheric CO_2. Global Change Biology 16:2334-2344.

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Shen W, Reynolds JF, Dafeng H (2009) Responses of dryland soil respiration and soil carbon pool size to abrupt vs. gradual and individual vs. combined changes in soil temperature, precipitation, and atmospheric [CO_2]: a simulation analysis. Global Change Biology, 15:2274-2294.

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NASA/DFRC Workshop on Climate Change Adaptation

Thomas Mace, ed.

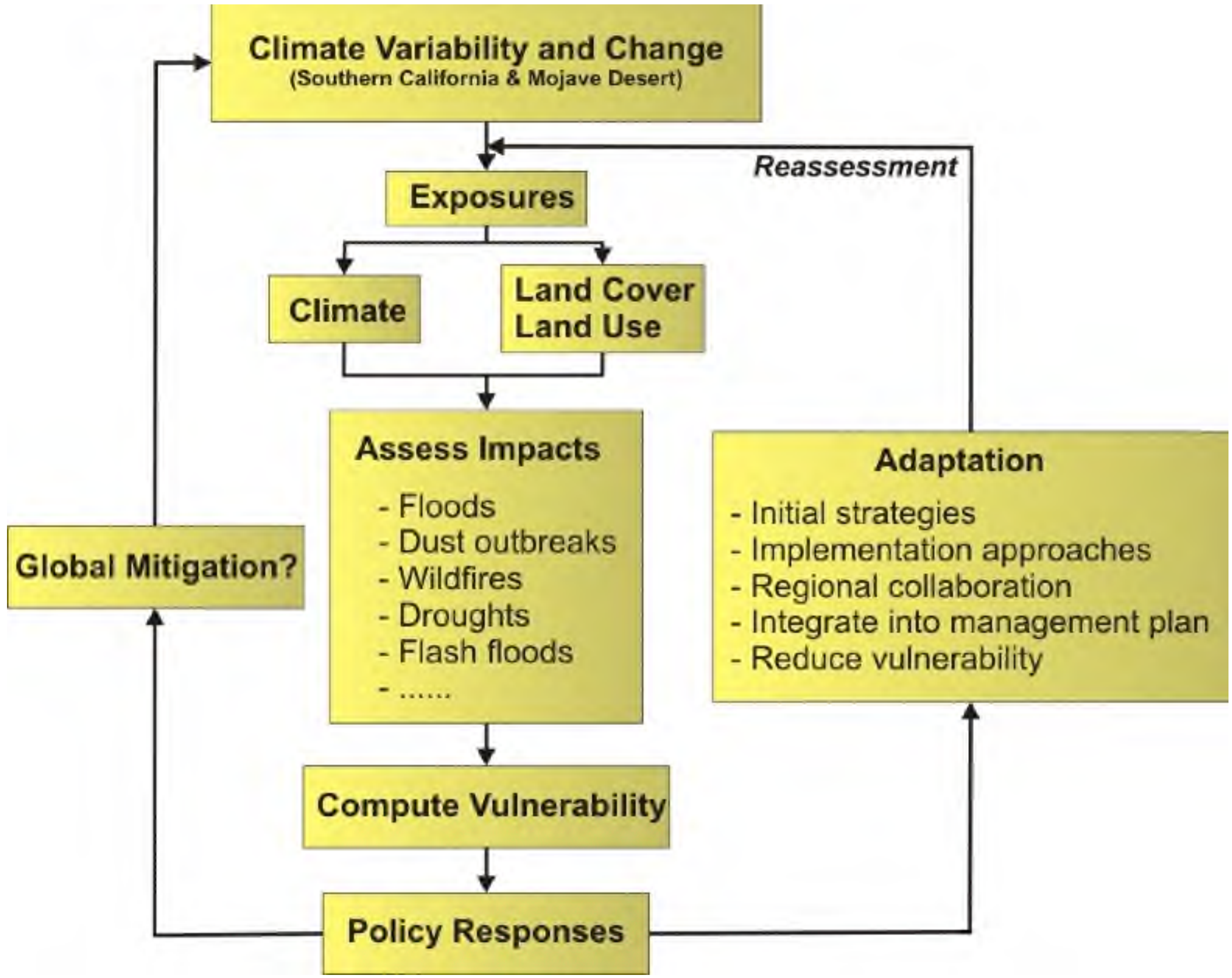
NASA/DFRC Workshop on Climate Change Adaptation

Assessing Climate Variability and Change

Vulnerability to Climate Variability and Change

$$\text{Vulnerability} = \frac{(\text{sensitivity} \times \text{exposure})}{\text{adaptation}}$$

- **Exposure**: Harm in the system (?) due to environmental hazard.
- **Sensitivity** is the level to which a system is affected, either adversely or beneficially, by climate-related exposure.
- **Adaptation**: capacity to adjust.

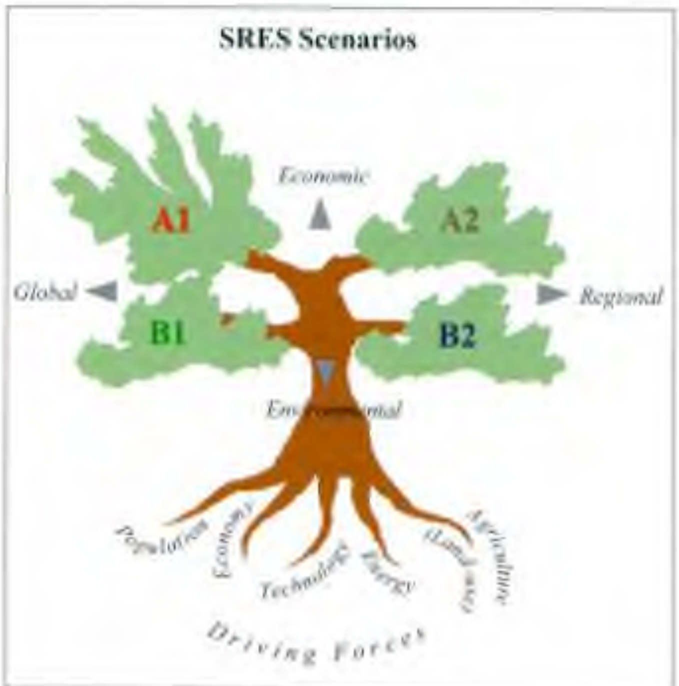


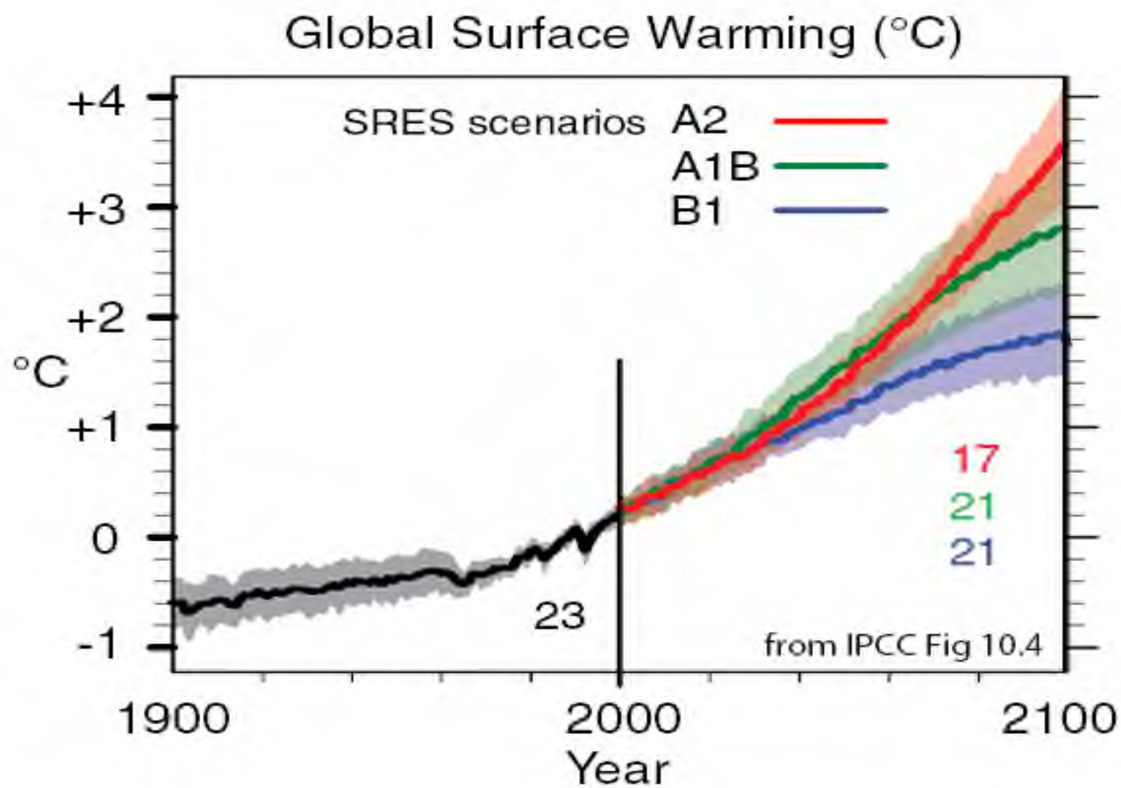
Climate Variability and Change
(Southern California & Mojave Desert)
Exposures
Reassessment
Climate
Land Cover
Land Use
Assess Impacts
- Floods
- Dust outbreaks
- Wildfires
- Droughts
- Flash floods
- ......
Adaptation
- Initial strategies
- Implementation approaches
- Regional collaboration
- Integrate into management plan
- Reduce vulnerability
Global Mitigation?
Compute Vulnerability
Policy Responses

Climate Change

- Our role is to understand and assess some of the possible impacts of climate change.
- Climate Change is well understood by scientists:
  - We know the role that green house gases play in warming the atmosphere
  - Many of these gases come from human emissions
- The hardest part to understand is the impact that Climate Change would produce in many components of the climate systems at regional and local scales

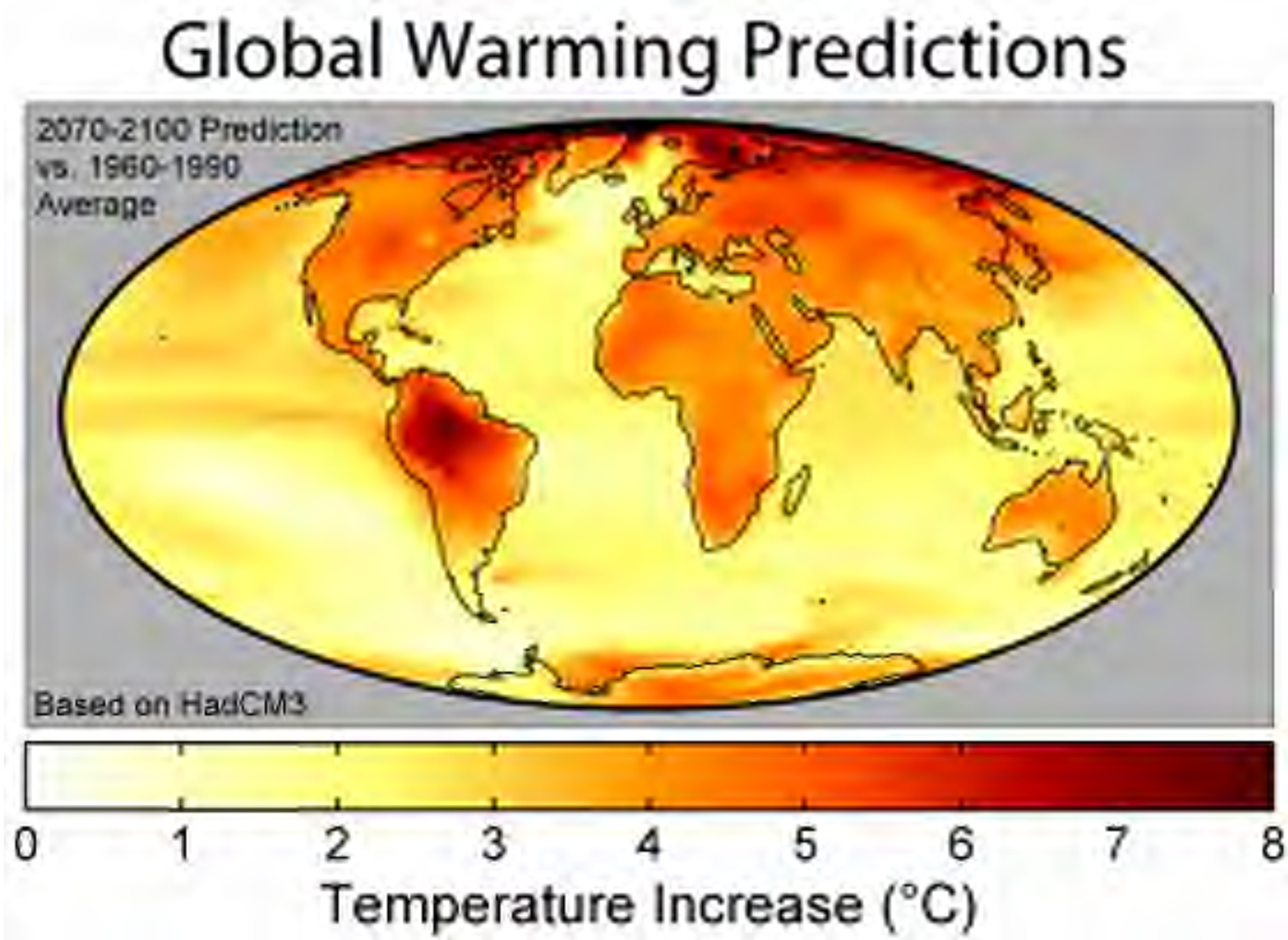
Special Report on Emissions Scenarios - SRES





Figures adapted from http://www.ipcc.ch/index.htm

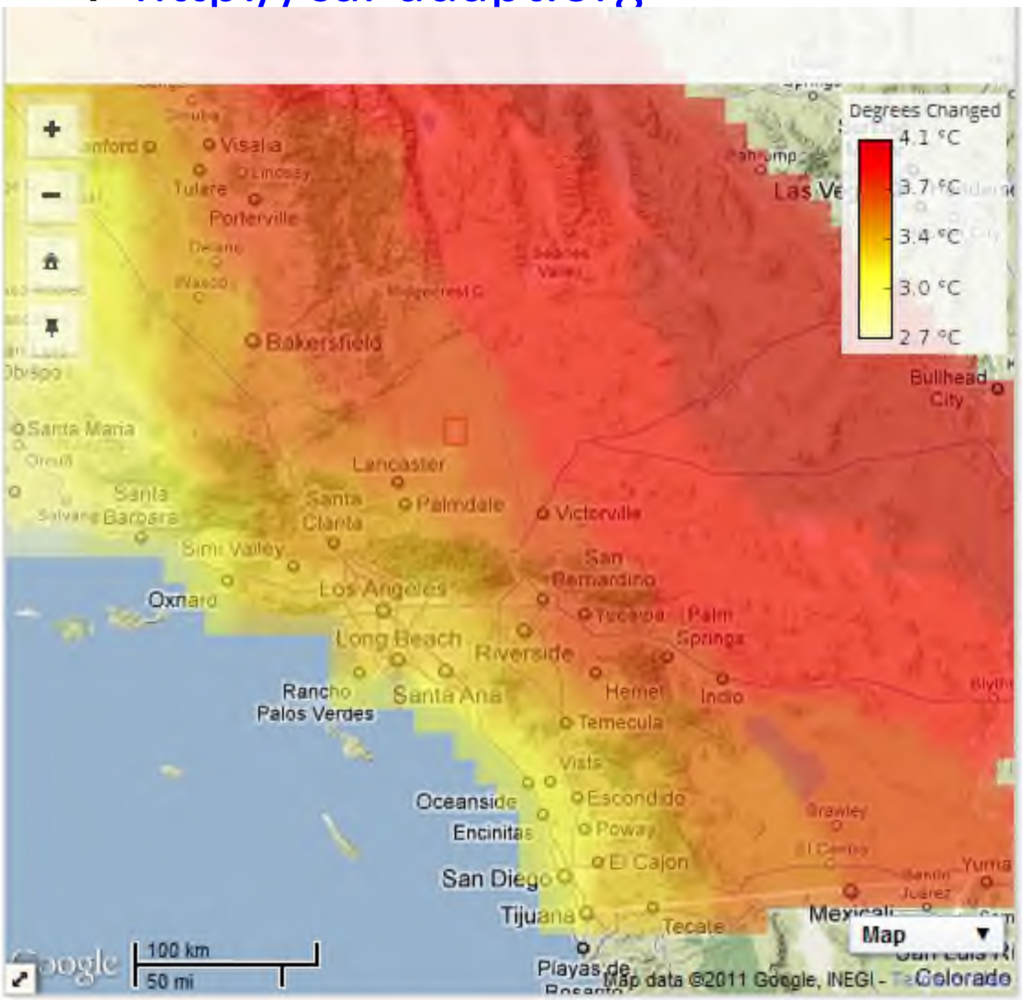
- Scenarios of socio-economical and environmental factors translated into the GCM driving forces: greenhouse gas and aerosol emissions.

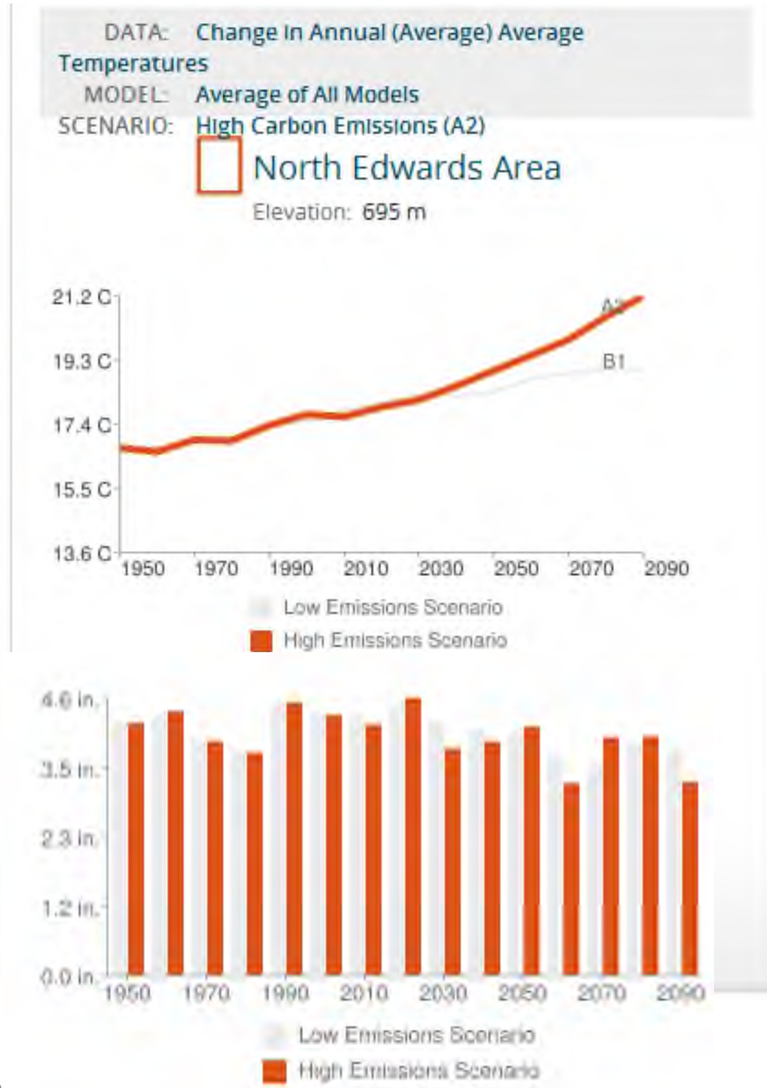


Predicted distribution of temperature change due to global warming from Hadley Centre HadCM3 climate model.

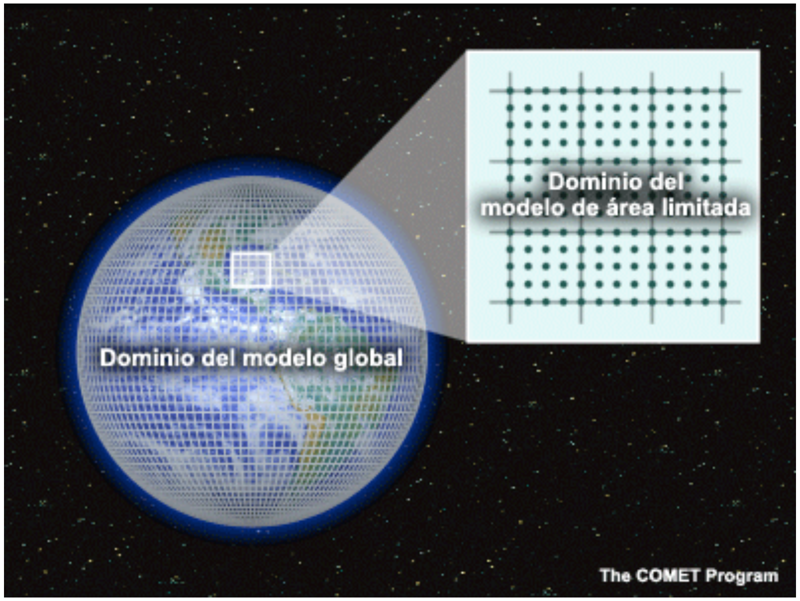
Change in Annual Average Temperatures

- http://cal-adapt.org

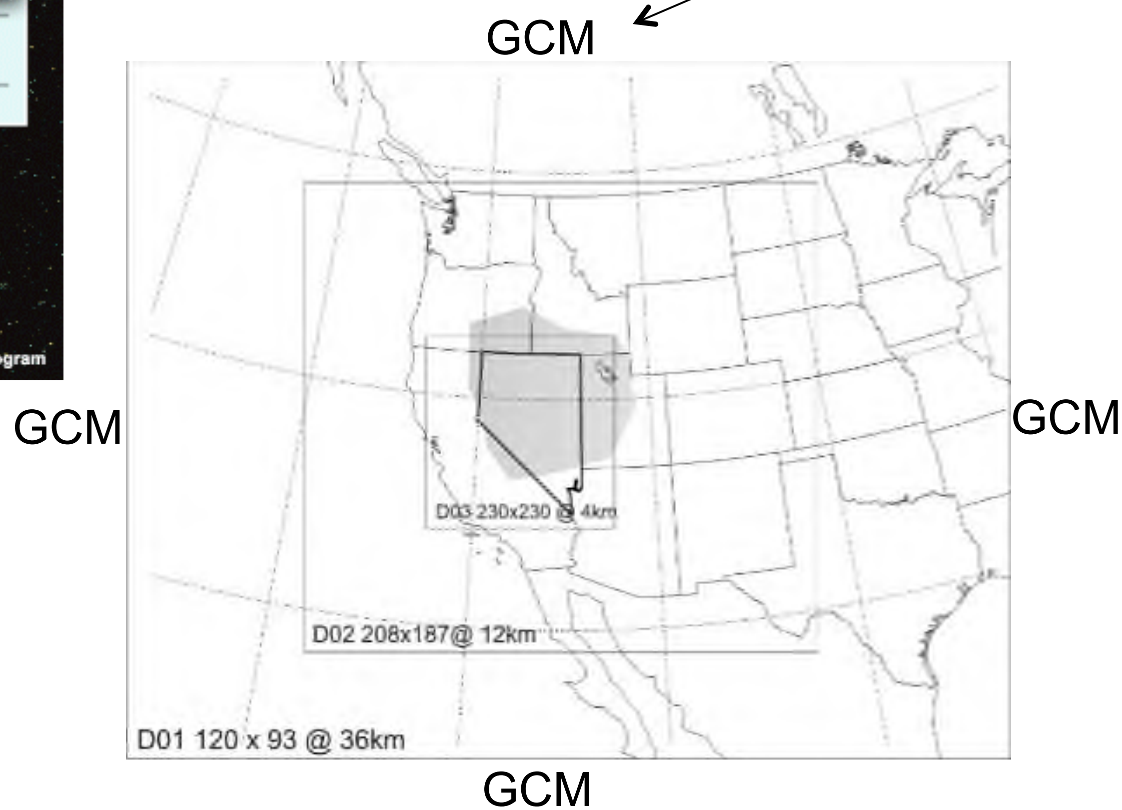




Regional Climate Modeling



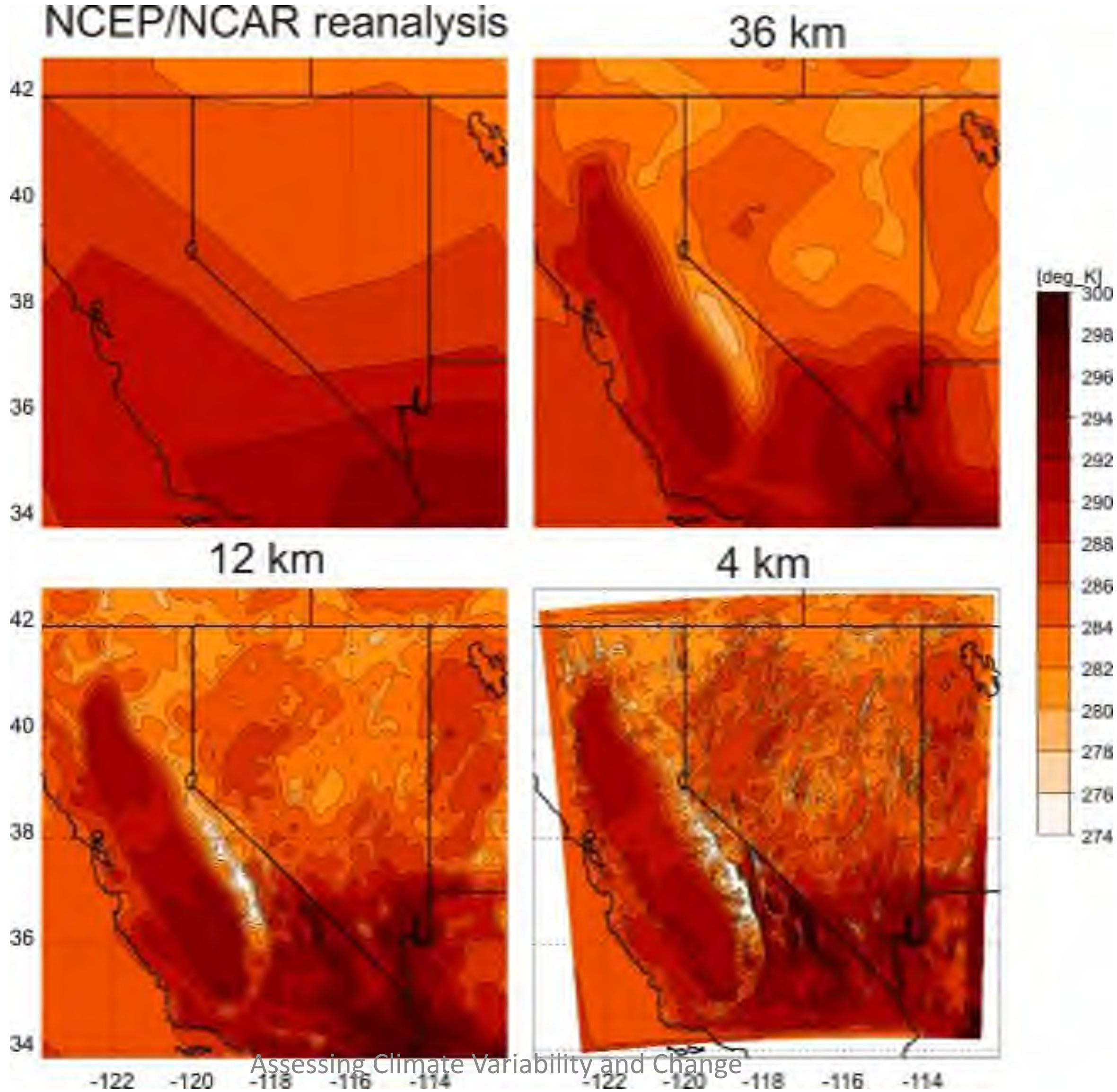
Global Climate Model (GCM) provides the lateral boundary conditions (LBC) for the RCM



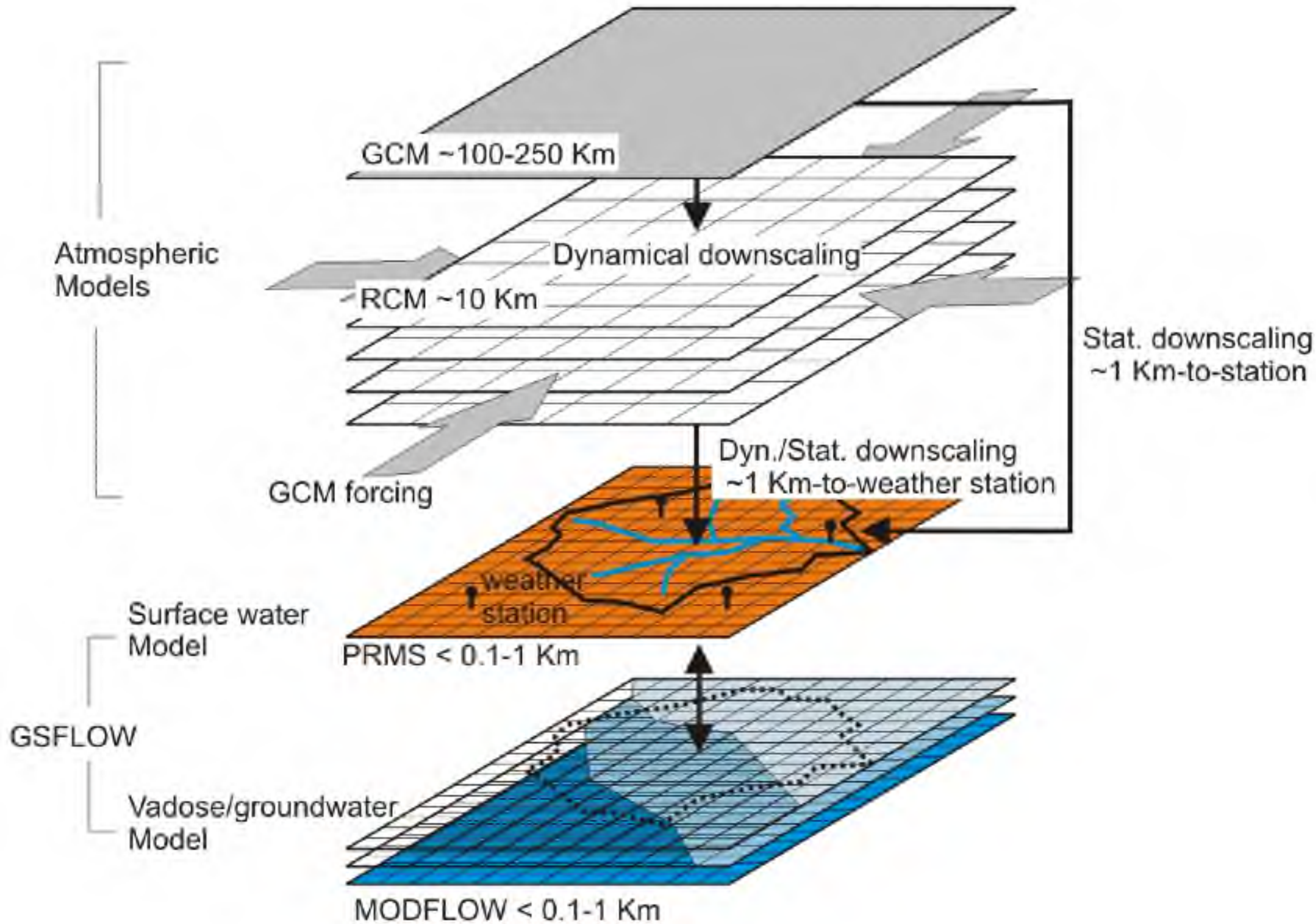
It is impractical to run Atmospheric and Oceanic **GCMs** (AGCM and OGCM) at scales of ~ 10km

Nested RCM for dynamical downscaling over SW North America at 36 km grid size, the Great Basin (Tri-State area) at 12km grid size, and Nevada at 4km grid size. Gray shading represents approximate location of the Great Basin region.

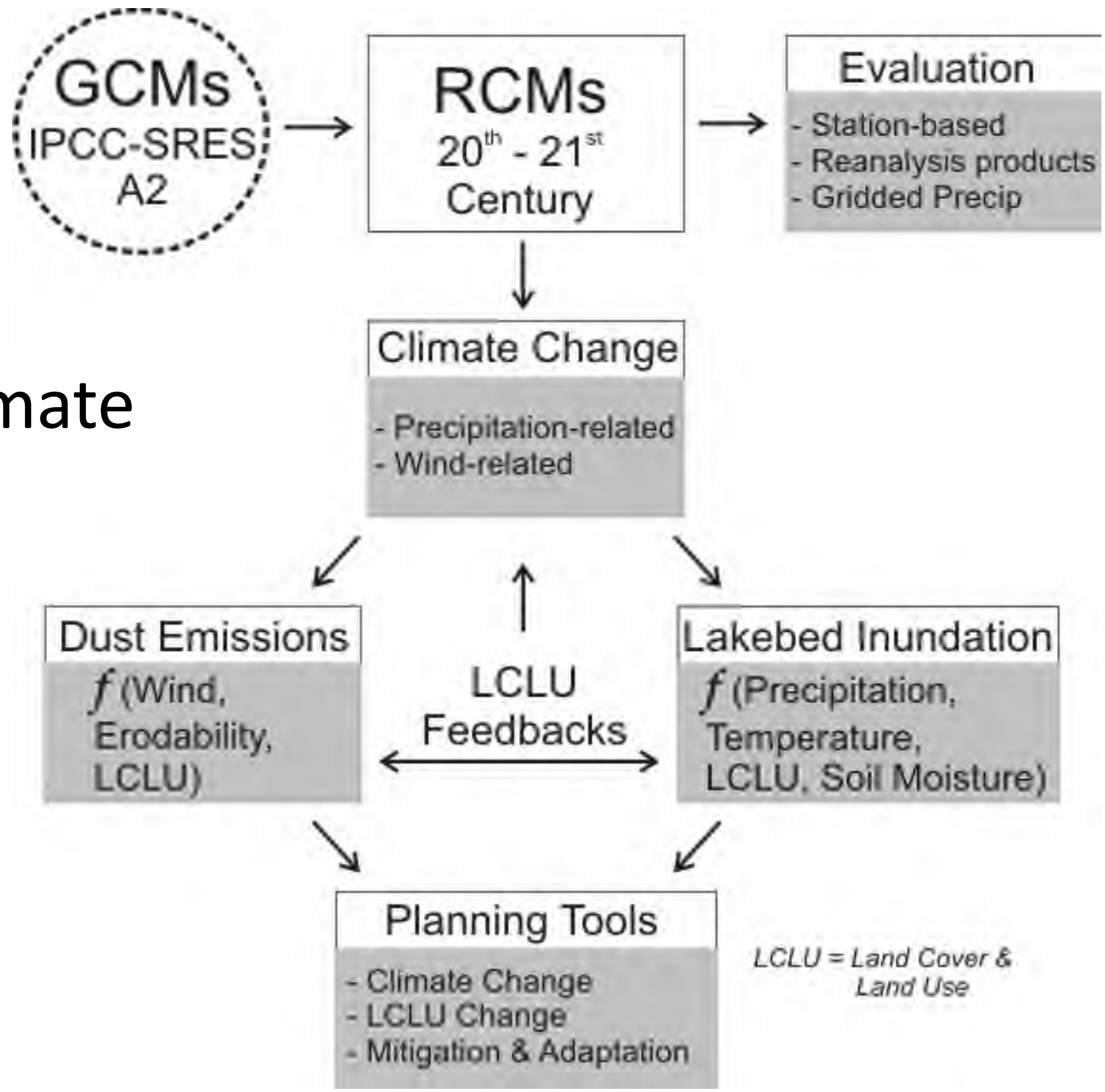
Example of downscaling from GCM ~250km to Regional 4km - Mean Temperature



Integration of Regional Climate Model with Hydrological and Groundwater Models



Combining downscaled Climate Projections and Impact Studies



Climate Vulnerabilities

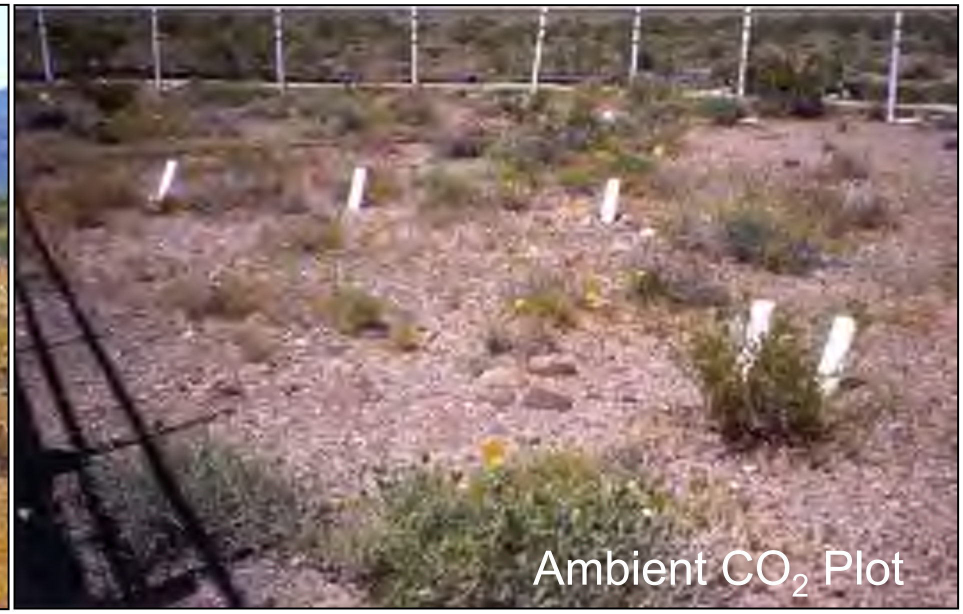
- ! Effects of variability and extreme events will:
  - –!Impact transportation via flooding, debris flows and dust storms
  - –!Impact most human "life-lines" in addition to transportation (e.g., communications, gas lines...)
  - –!Potential for large economic impacts as a result of isolation between Antelope Valley and rest of southern CA
  - –!Difficult to plan/engineer for an ARkStorm type event; very high cost for some engineering changes
  - –!Impact to ecosystem and resulting impact to human infrastructure

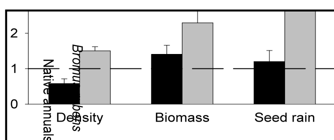
Environmental/Ecosystem Climate Change Responses and Hazards

- !Ecosystem impacts and wildfires
- !Atmospheric Rivers (AR) in the westerlies and related flood episodes.
- !Dust and Santa Ana Winds

Impact of Elevated CO_2 on Productivity of Annuals (Native vs Invasive)

Nature 408, 79 - 82 (2000); doi:10.1038/35040544





Potential ecological effects of global change in the Mojave Desert

Table 2.4 from: Chapter 2; The Mojave Desert: Ecosystem Processes and Sustainability (2009) RH Webb, LF Fenstermaker, JS Heaton, DL Hughson, EV McDonald, DM Miller (editors), University of Nevada Press, Reno NV.

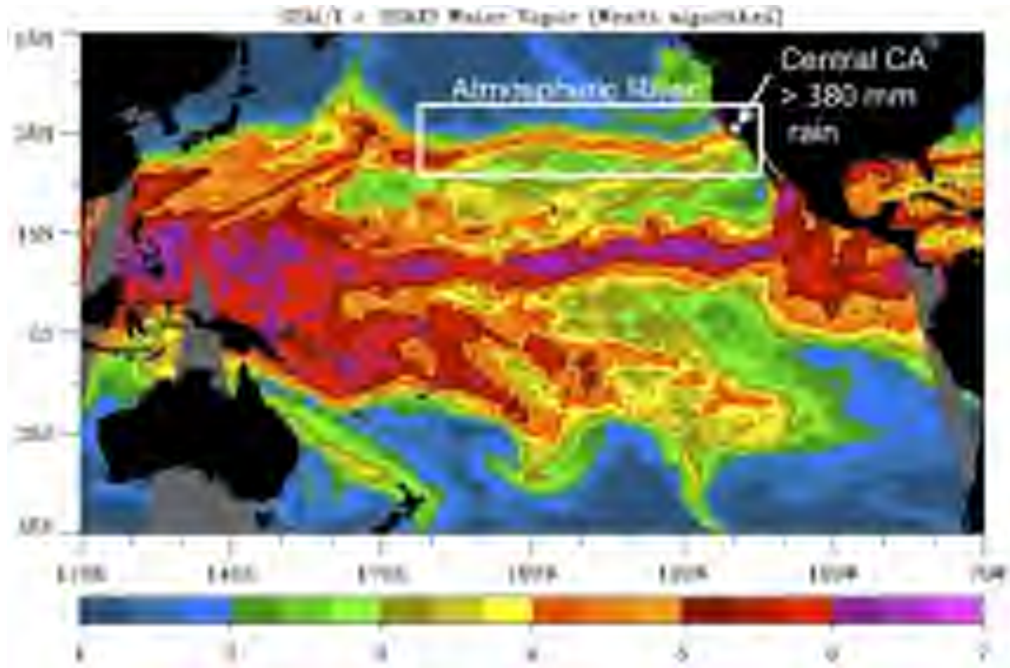
External Variable	Functional Response	Potential New Regime
Elevated CO_2	↑ plant production ↑ plant invasion	↑ desert productivity ↑ fire frequency
↑ Temperature	Species range shifts	Community disequilibrium
Altered Precipitation:		
Wetter winter	↑ exotic production	↑ fire frequency
Wetter summer	↑bunchgrass production	Semiarid ecosystem-type
Drier	↑ mortality	Species-poor system
↑ N-deposition	↓ N-fixation ↑ plant production	↓ of N-fixing species ↑ desert productivity

Wildfires: Land Cover Change + Climate Variability

- Invasive weeds fuel Mojave Desert fires (e.g. Red Brome)
- Invasive grass fills the gaps between shrubs allowing fires to spread more quickly.
- Competition between native shrubs and invasive plants.
- Invasive plants appear to be more resilient than native plans under increasing temperatures and shifting precipitation regimes.
- Invasives thrive during rainy years (increased biomass, density and seed production). Particularly dangerous for wildfires when wet years are followed dry years.
- Land use disturbances often enhance growth of invasive species.
- “Wildfires are happening more often and are much bigger (132% compared to previous 25years) in certain parts of the Mojave now than in the past because of the grass invasion” – USGS.

AR & Floods (Dettinger)

- On October 14, 2009 an atmospheric river channeled water vapor from a decaying typhoon over the western North Pacific, across nearly the entire width of the ocean basin, to deposit copious rains over the central coast of California (M. Dettinger, http://urbanearth.gps.caltech.edu/winter-storm/)
- Science article on the subject: [Rivers in the Sky are Flooding the World with Tropical Waters](#).



Dettinger, M. D. Climate change, Atmospheric Rivers, and Future California Floods. California Extreme Precipitation Symposium. ARWI, 2009.

Ralph, F. M., Neiman, P. J., Wick, G. A., Gutman, S. I., Dettinger, M. D., Cayan, D. R., and A. B. White. Flooding on California's Russian River: Role of atmospheric rivers. Geophysical Research

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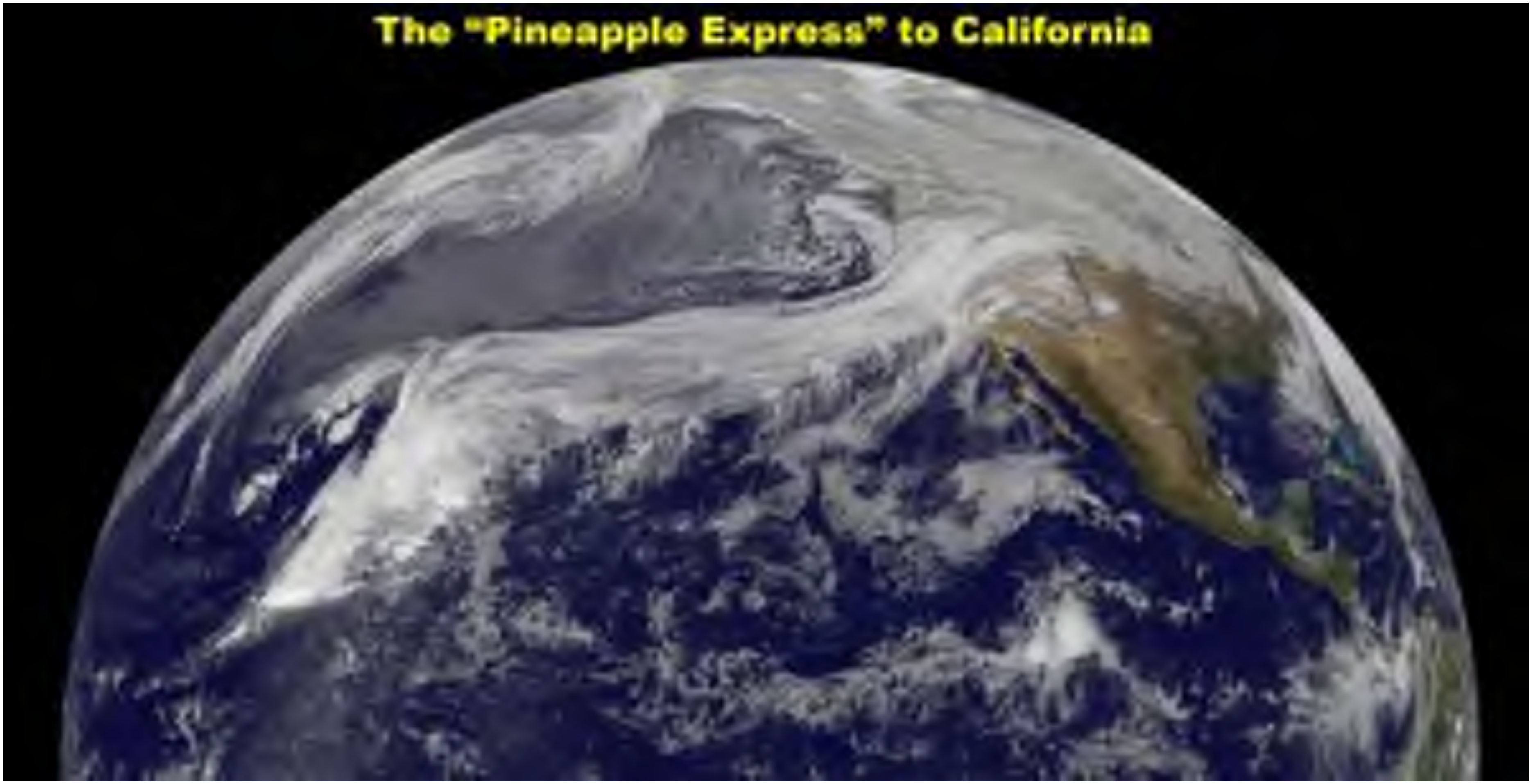
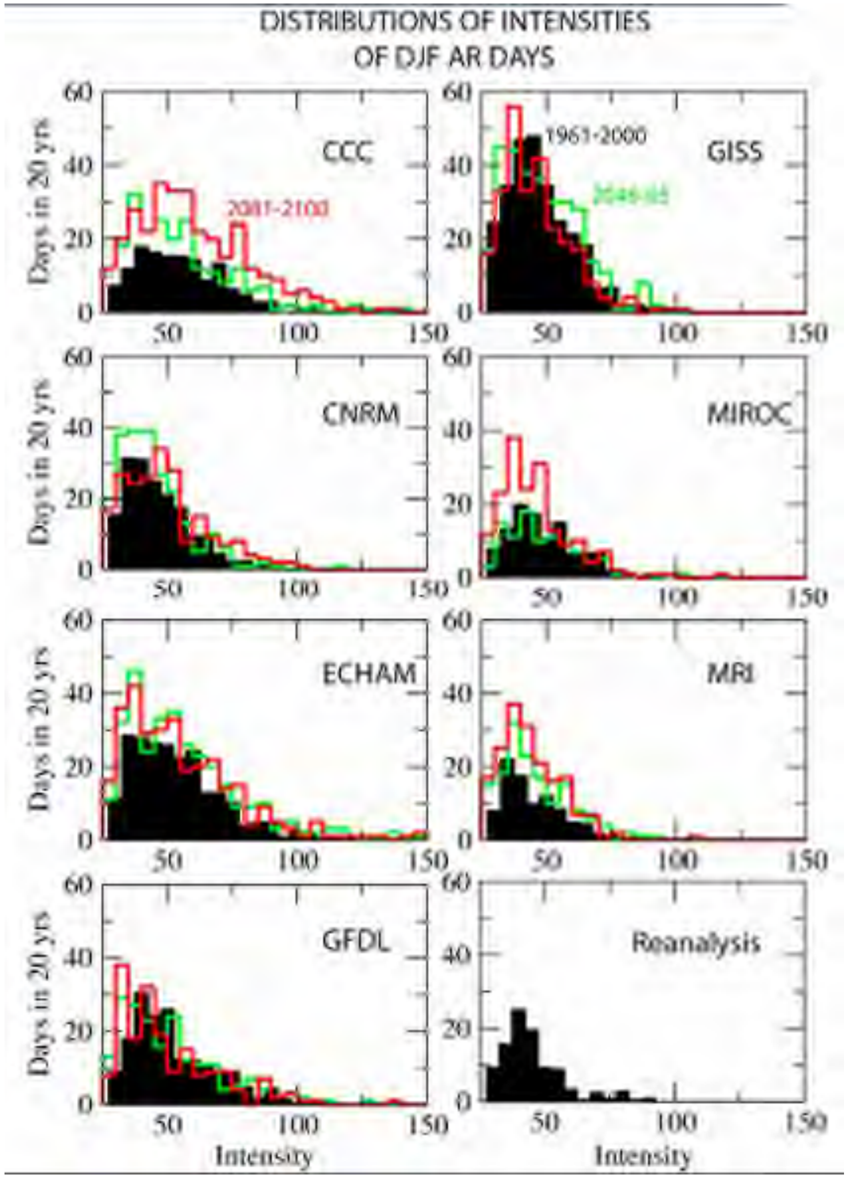
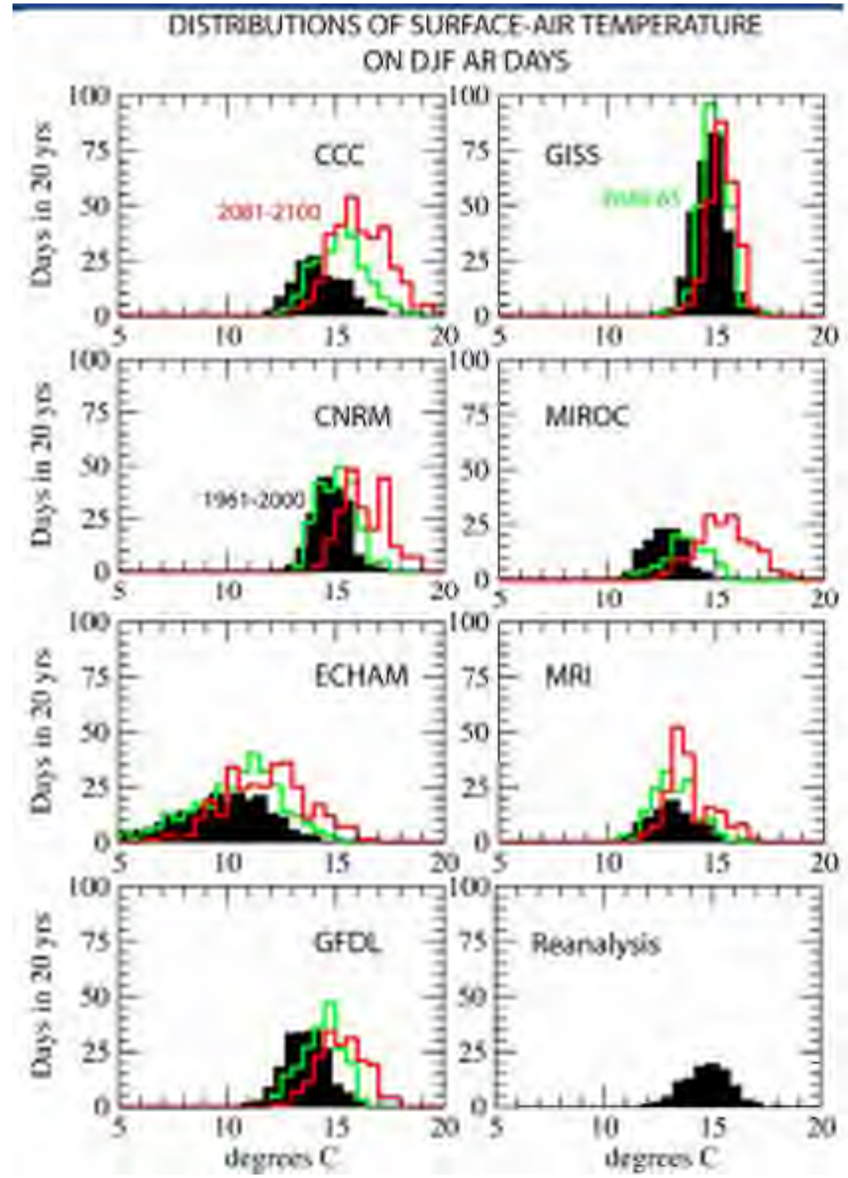


Source: http://www.ouramazingplanet.com

"Not only do atmospheric rivers (Pineapple Express) play a crucial role in the global water budget, they can also lead to heavy coastal rainfall and flooding, and thus represent a key phenomenon linking weather and climate" Ralph et al. 2006, GRL.





Models predict little change in mean intensities, but more extreme outliers

Broad warming of AR storms

From Dettinger et al. 2009

Current Knowledge

- Confusion in understanding of difference between ARkStorm and Atmospheric Rivers
  - ARkStorm event is one plausible storm event and appear to occur on average every 200 yrs with primary effect on coastal areas; high precip over several days resulting in catastrophic flooding and wind disaster
  - Atmospheric Rivers (AR) occur more frequently (4-5 every winter) and typically deliver less intense storms than ARkStorm event
  - Might not see increase in precipitation in Antelope Valley, but might see increased runoff from precip in surrounding mountains
  - Uncertain how an ARkStorm event would impact Mojave Desert region

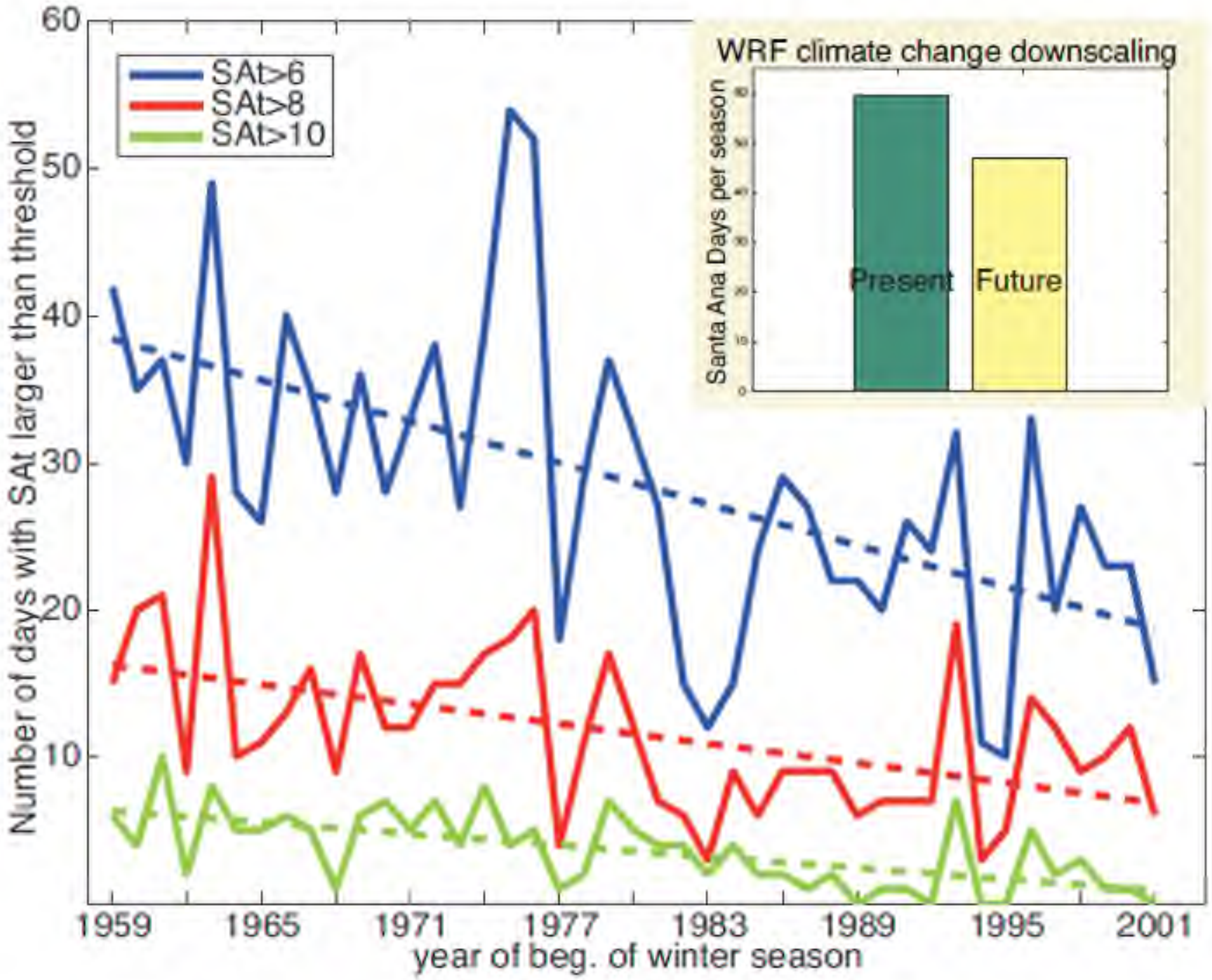
ARkStorm like event

- ARkStorm event (Porter et al. 2011, USGS report) 23-day Atm River.
- Related to 500-1000-year flood event
- Significant infrastructure damage with large environmental and social-economic consequences.
- Plausible in the statistical sense & via past observations, e.g., 1861-62, 45-day event of near continuous precipitation. Analogue simulations of the ARkStorm event suggest rainfall accumulations from 87 mm to over 1.5m, with higher elevations receiving the most rainfall.
- USGS modeled ARkStorm event is a conservative measure to prepare for climate change impacts.

Atmospheric River Projections:
From Dettinger et al. 2009

- The future of landfalling atmospheric rivers (AR) is important for the future of flood hazards AND water resources in California
- Projections of 21st century climate suggest:
  - More years with several ARs, fewer years with few ARs
  - Moister ARs with weaker upslope winds
  - Overall average intensities will not change much but occasionally much stronger than historical ARs
  - ARs warmer by about +2C on ensemble avg
  - AR season will extend

Santa Ana Winds



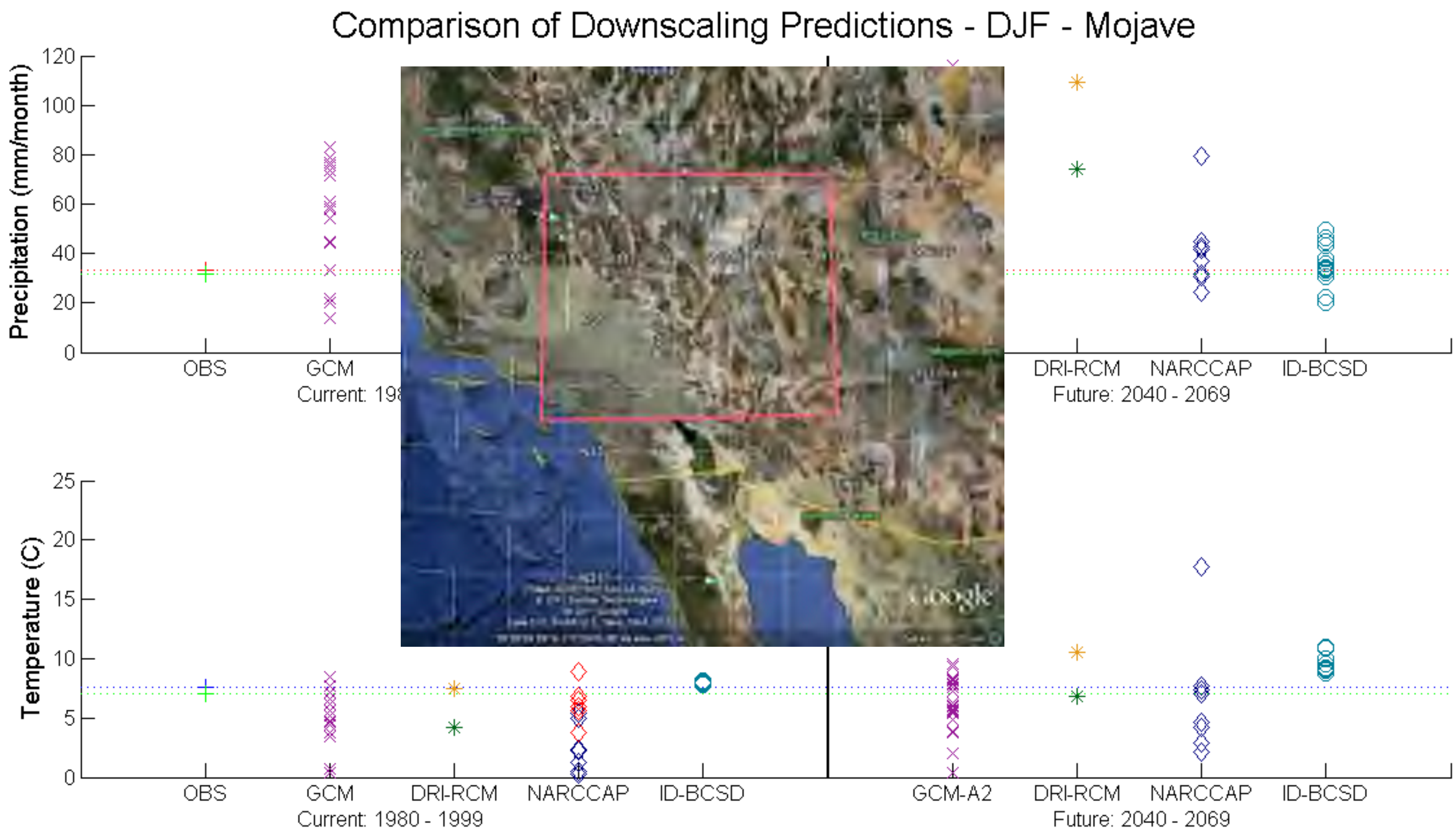
From Hughes et al, 2011

Significant decrease of Santa Ana wind frequency

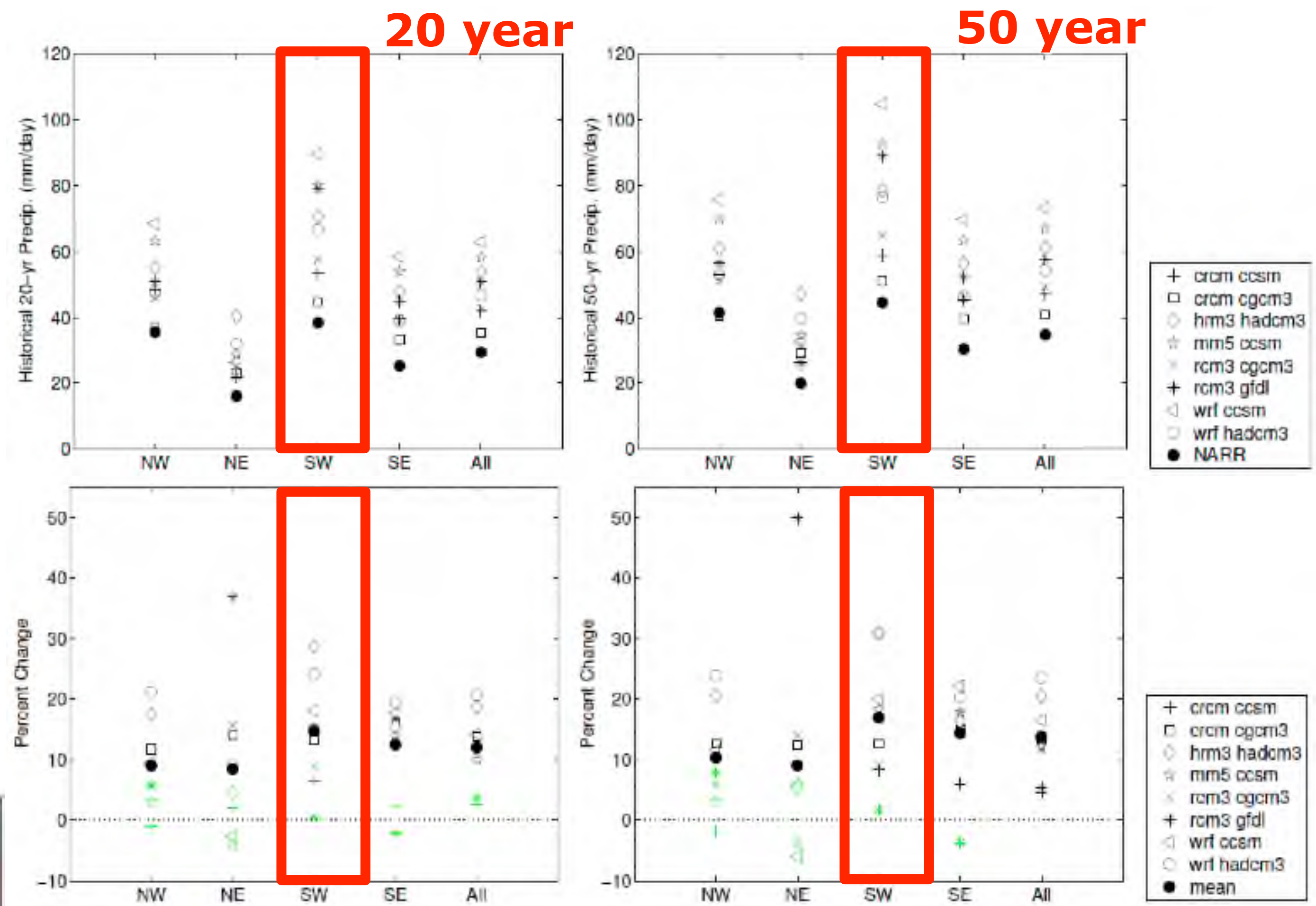
Current Knowledge: Regional Climate Datasets: 20th & 21st centuries

	GCMs	NARCCAP	BCSD	Mod_BCSD	MACA	DRI-RCM	DRI Statistical Downscaling
Method	Global A-O coupled models	Dyn. downscaling using 6-7 different RCMs	Stat. downscaling	Stat. downscaling Z_Scores	Multivariate Adaptive Constructed Analog	Dyn. downscaling using WRF	Stat. downscaling of GCM and DRI-RCM
Institution	PCMDI-CMIP3	NCAR/Mult.	LLNL, BoR, S. Clara Univ. (SCU), and Clim. Central (CC)	Univ. Idaho	Univ. Idaho	DRI	DRI
Drivers	GHG, Aerosol, Volcanic erupions, astronomical.	4 GCMs	16 GCMs	16 GCMs	16 GCMs	2 GCMs	2+ GCMs
Emissions Scenarios	A1, A2, B1, B2 and variants	A2	B1, A1b, A2	B1, A1b, A2	A1B	A2	B1, A1b, A2
Grid Size	~100 km	50 km	12 km	8 km	4 km	36 and 12 km	4 km to Point based
Coverage	Global	North America	US , Parts of Canada and Mexico	US, Parts of Canada and Mexico	Western US	Western US	Western US
Parameters	Most Atm. & Oceanic variables	Most Atm. variables at: surface and multiple vertical levels	Precip., T_{min}, and T_{max}	Precip., T_{min}, and T_{max}	Precip., T_{min}, and T_{max}	Most Atm. variables at: surface and multiple vertical levels	Precip., T_{min} and T_{max}
Data Availability	Monthly, 6 hourly (some), or by request	3 hourly	Monthly/Daily coming soon (Aug, 2011)	Monthly	Daily	1 hourly	Daily -monthly

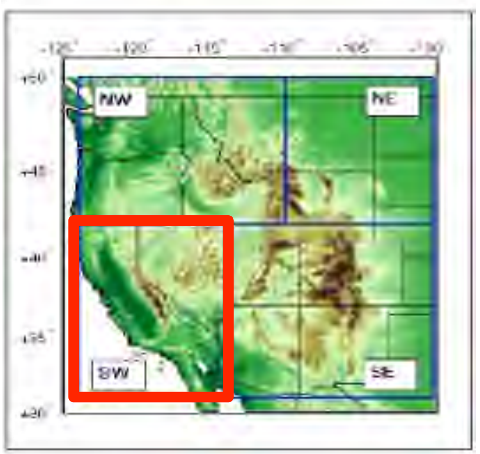
Regional Climate Projections



20 and 50 year return Period



Dominguez et al. (2011), submitted



SW region has the highest intensity of extreme events

Remarks on Regional Climate Modeling

Lots of efforts to downscale Climate Modeling data for regional and local impact studies: California, Arizona, and Nevada research groups are dealing with this problem.

Scenarios show warming and dryer conditions by the end of the 21st century.

More years with lots of ARs, fewer with few.

Frequency of extreme wind events are projected to decrease.

Future Climate Modeling Research

- Need for more spatial and temporal detail with an acceptable level of certainty
- What is the range in variability for temperature and timing/amount of precip
- Need to include topography to help improve reliability of models
- Scales of needs for specific land owners within a mosaic of land owners and land uses
- Develop collaboration network for data acquisition and monitoring

Climate Adaptation/Mitigation

- Keep drainage systems clean to minimize flood impacts
- AC (building cooling) utilizes the most power and water
- Budget constraints can limit progress; need for agencies to enter into:
  - Energy Saving Performance Contracts
  - Utility Company Savings Contracts
- Use of renewable energy for cooling
- Improve alternative financial incentives and their assessability for Federal agencies
- Tie improved decision making to improved forecasting and modeling

Climate – Future Steps

- Plan for major precipitation events and enable capture of precip/runoff for future use
- Don't build in areas that will flood and don't depend on levees
- Regulations need to have flexibility to allow achievement within a changing climate
- Regulatory mandates must be adjustable to funding levels and agency missions

Climate – Future Steps Cont.

•! Better management plans for human populations and development in the desert

–!Off-grid electricity

–!Incentives for decreased water use

–!Improved “green” building codes

–!Limit development/infrastructure footprint

•! DO NOW; don’t wait


Air Quality (aka Dust Emissions)

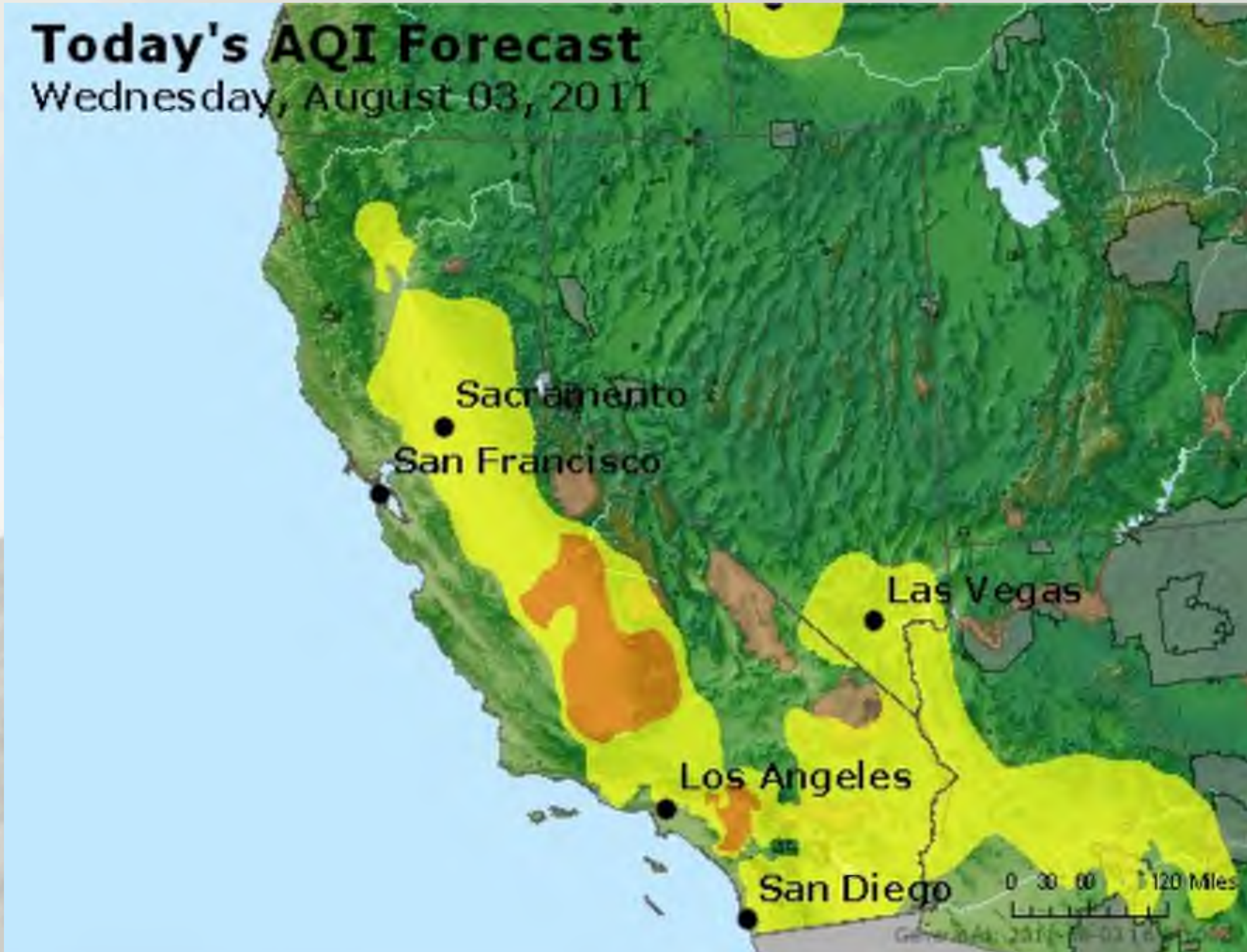
Team Members

- DoD/Air Force Flight Test Center
- DRI (Desert Research Institute)
- Mojave National Preserve
- NASA/Ames Research Center
- NASA/Dryden Flight Research Center
- UCLA

Scope

- Dust, wildfire smoke, ozone, visibility impacts
- Wildfire
  - Invasives increase due to precipitation; temperatures favor invasives
  - Positive feedback through native
  - Tertiary impact though as creates endangered species
- Ozone: Air quality models
- Therefore, our focus is on DUST

Ozone Impacts



Visibility Impairment

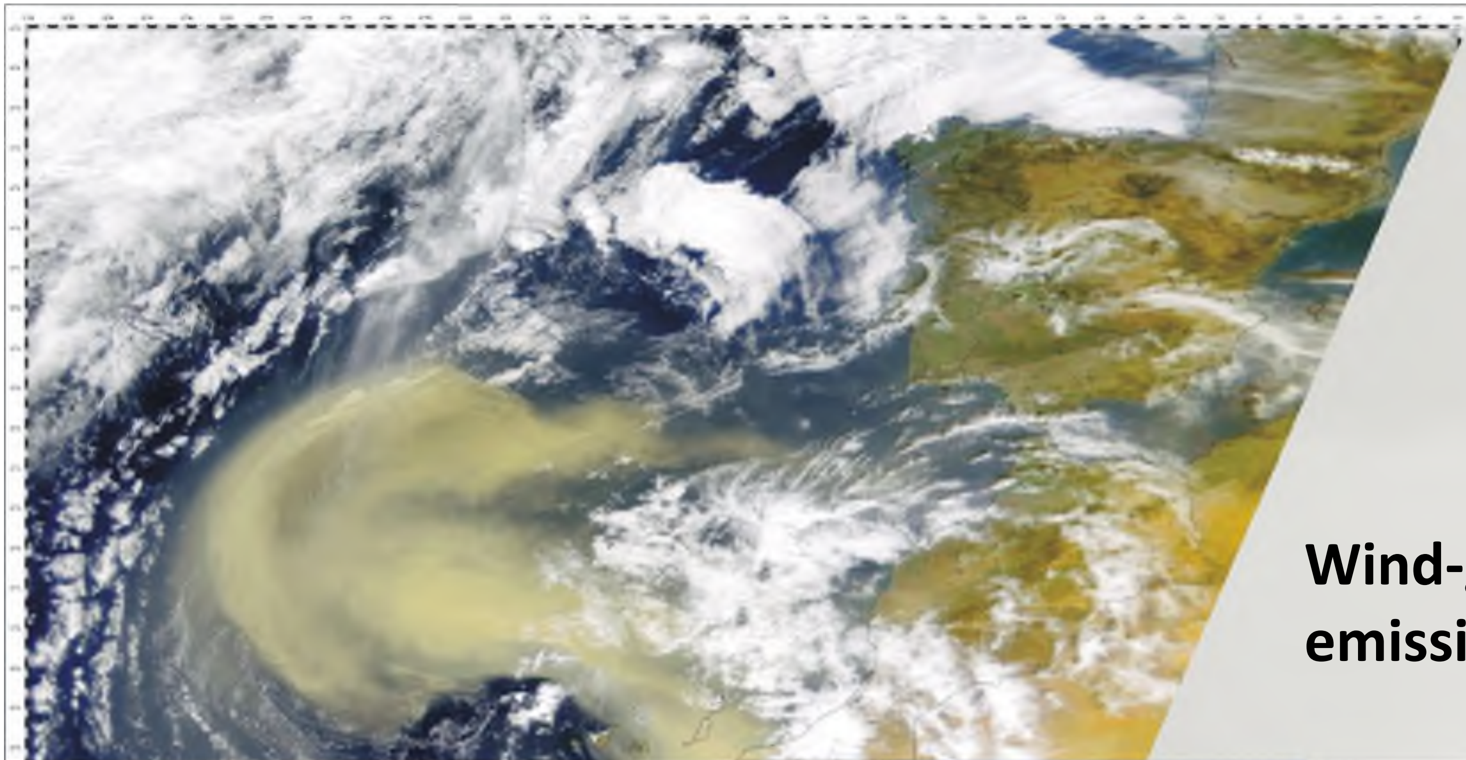
Approach

- Current Knowledge
- What adaptation and mitigation is recommended now?
- What Research / Monitoring is recommended?
- Overlap with Hydrology and Climate
- Top Recommendations

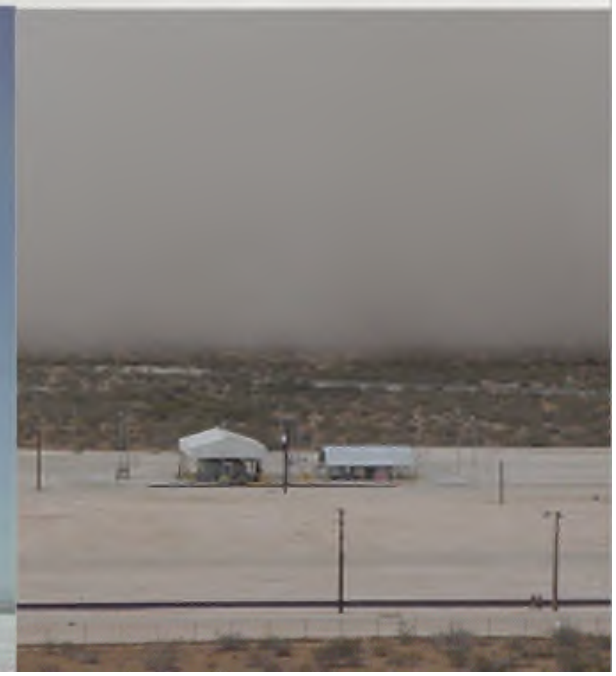
Current Knowledge

- Greatest impact to area: dust and smoke
- Relationship between ENSO (El Nino Southern Oscillation) and dust emissions in 1 year
- Relationship between vegetation and dust:
  - temperature
  - precipitation
- Temperature and precipitation cycles → direct effect on soil crust strength
- Disturbance of soil
- Valley fever: dust-borne disease endemic to region, prefers alternating wet / dry seasons; likely to increase with temperature
- Invasives: generally reduce dust but increase fire probability

Human-generated dust emissions

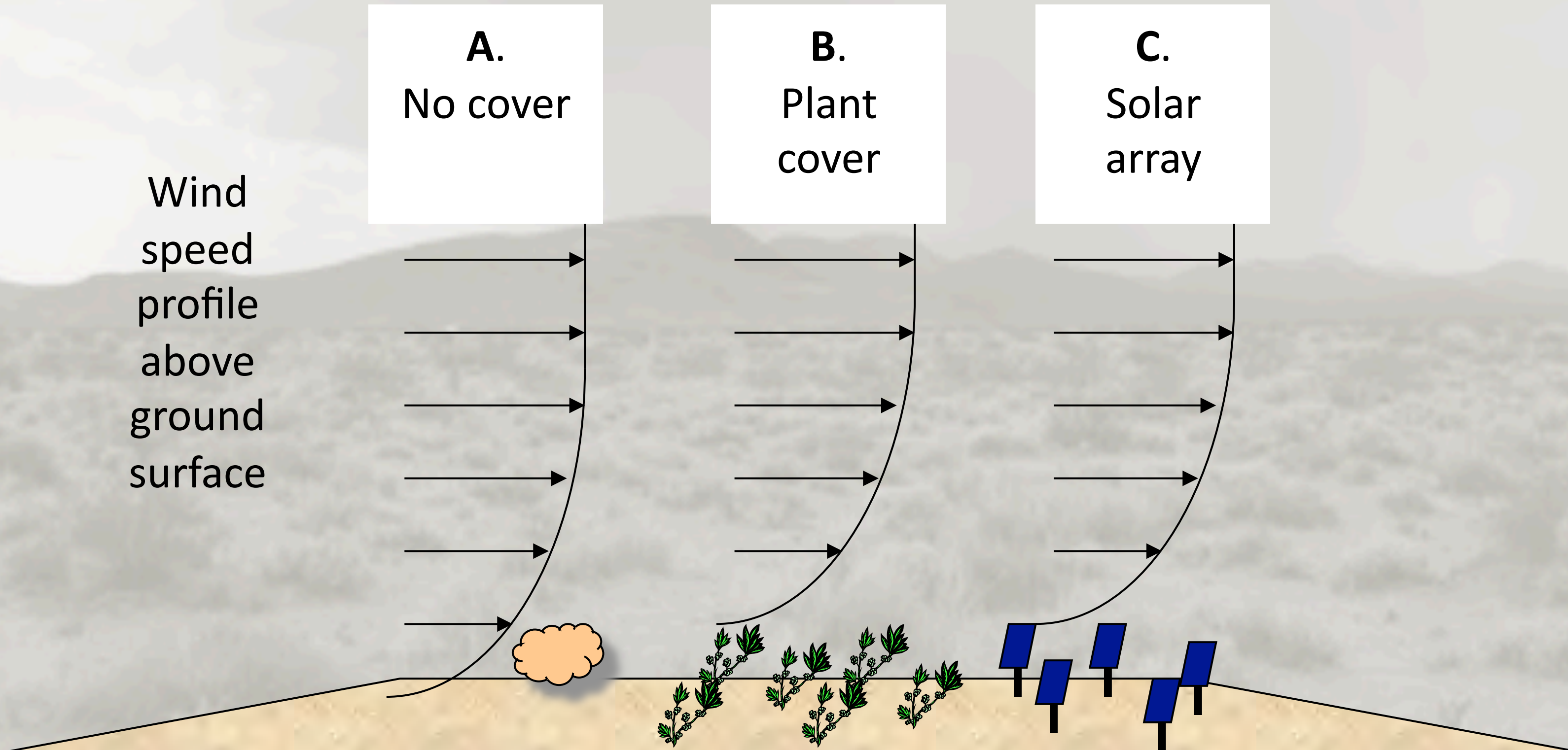


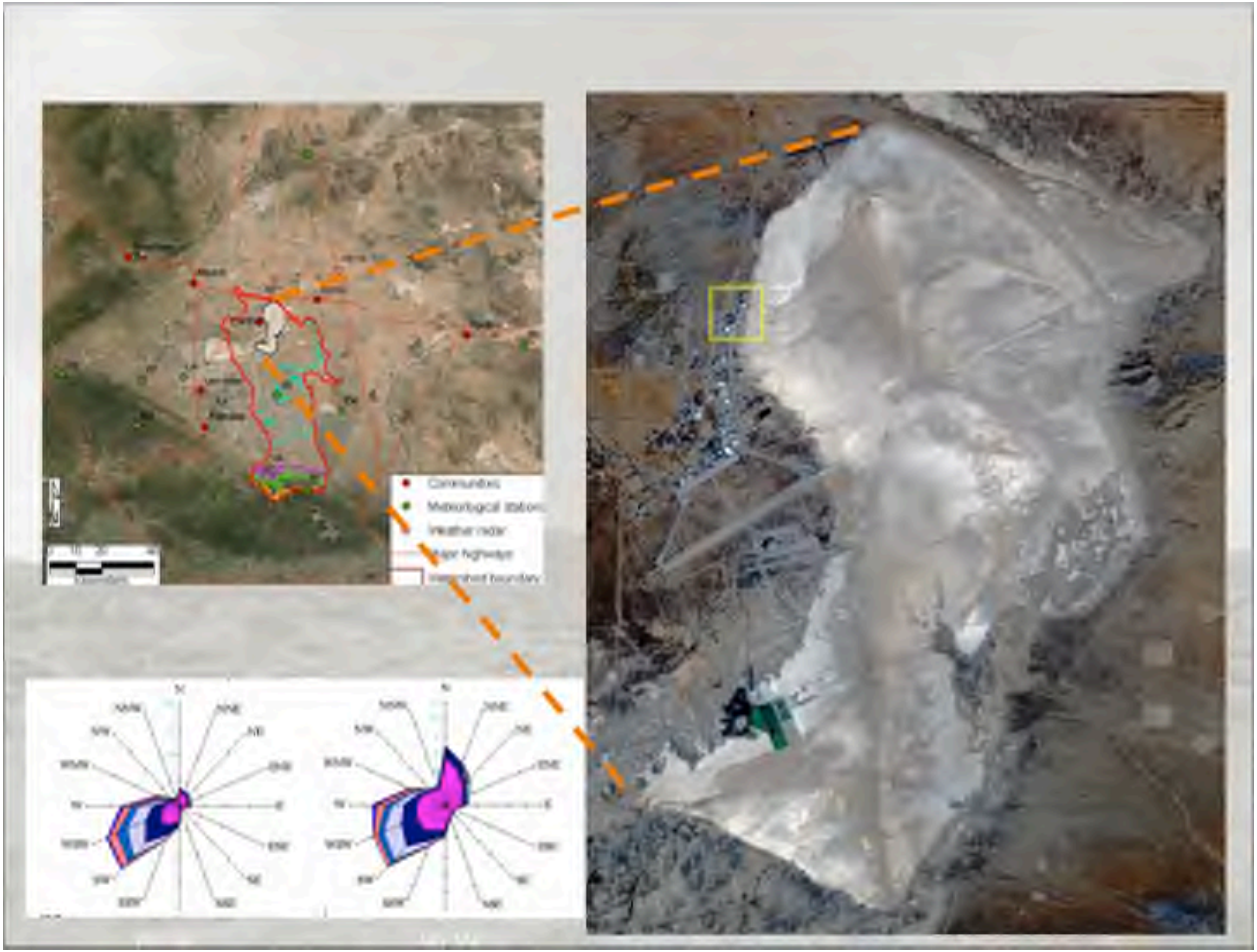
Wind-generated dust emissions



•! Current Knowledge

How it Works: Wind-blown dust occurs when wind from aloft imparts energy to the soil at the ground and raises dust clouds (A). Vegetation on the surface protects the soil from the shearing action of wind (B). Solar arrays can be spaced to serve the same function as vegetation (C).




Communities
Weather radar
Major highways
Watershed boundary

Wildfire

Wildfire

Recommended Adaptation and Mitigation

- Adaptation: live with it
  - Scheduling, forecasting, seasonality
  - Maintenance impacts: air handling, etc.
  - Adaptive adaptation: change acceptable thresholds for work environment based on outside climate (thermostats to 78 in summer)

- Mitigation: try to fix
  - Reduce soil disturbance / optimal mitigation
  - Support conservation efforts: soil, air quality
  - Engineered fire suppression
  - Engineering dust reduction such as chemically treating grounds around solar farm
  - Expanded advisories: for dust, etc.



Recommended Research / Monitoring

- Model air quality impacts, especially ozone, PM 2.5
- What surface treatments can mitigate emissions?
  - Engineered approach effectiveness such as solar farm
- Review retrospective short-term and long-term records of particulate matter vs wind vs hydro vs vegetation cover
- New NOAA climate monitoring platform coming to Edwards AFB, near NASA – what is it? Can new monitoring be included?
- Conduct new monitoring
  - Permanent station for measurement of sand movement
  - Vegetation density document, perhaps EAFB remote sensing and ground tracking and species
  - Lakebed erodibility, chemistry, mineralogy, Valley Fever baseline, salt characteristics
  - Use spectrometers for measurement that don't require soil disturbance

Overlap with Hydrology and Climate

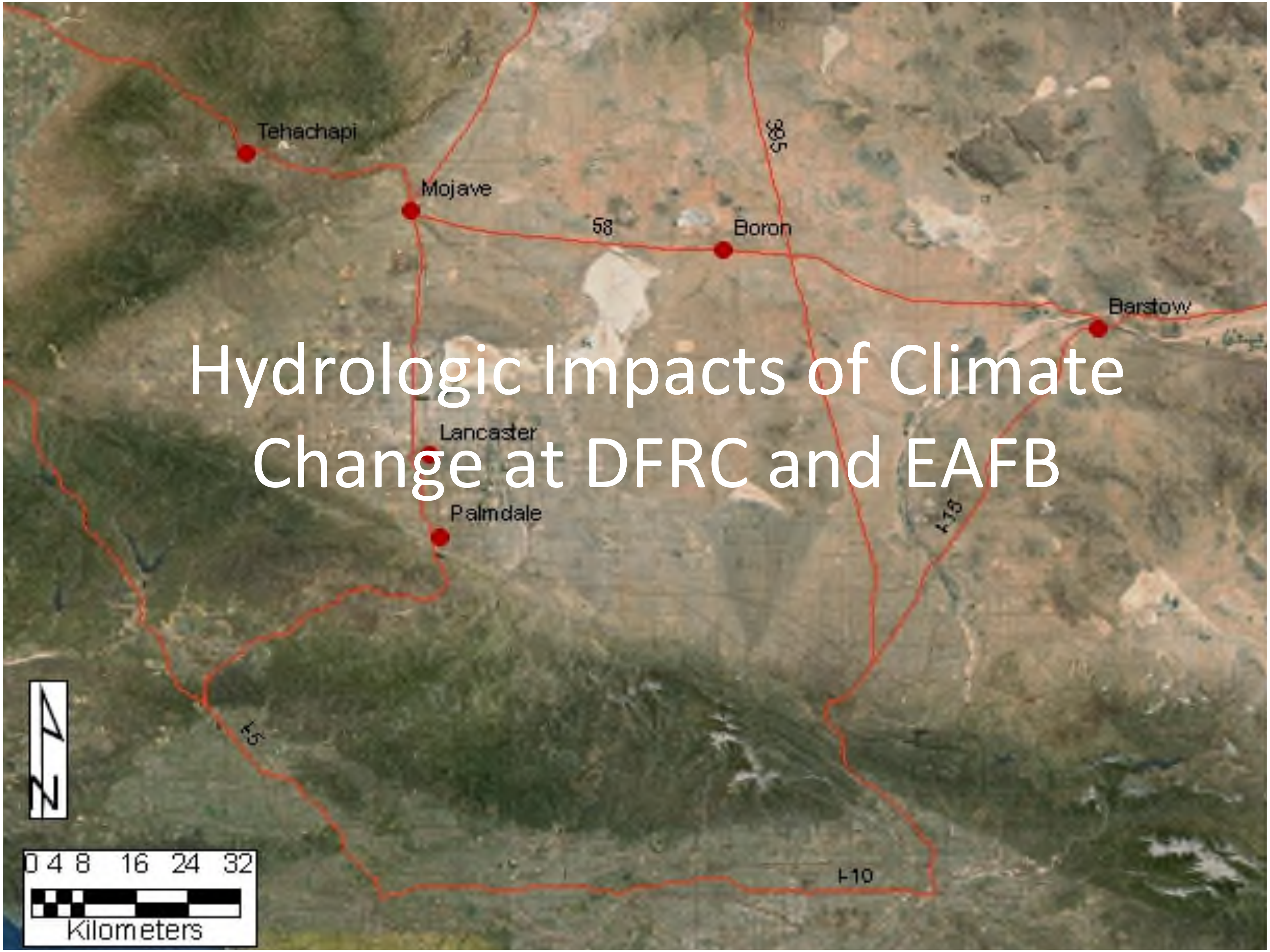
- Hydrology
  - Urban / agricultural runoff to lakebed
  - Fluvial delivery of sediment to the lakebed
  - Depth to ground water at lakebed
  - Changes in chemical composition of sediment

- Climate
  - Dust and climate feedback on a regional scale
  - Precipitation, temperature
  - Wind distributions
  - Global climate and air quality models in conjunction with the Santa Ana winds
  - Inter-annual variability of wetness / dryness, extreme events

Top Recommendations

- Consider mitigations to reduce soil disturbances
- Gain better understanding of aeolian (wind-blown) dust emission system in Antelope Valley
  - Characterize soil, wind distributions, vegetation density, lakebed erodibility
    - Review existing information
    - Consider new monitoring
  - Use new information to evolve mitigations

Hydrologic Impacts of Climate Change at DFRC and EAFB



Hydrologic Impacts - Outline

- Current knowledge
- EAFB/DFRC Site-Specific Impacts
- Stressors to Hydrologic Resources
- Hydrologic Research:
  - Linking remote sensing techniques, modeling, and in-situ measurement
- Hydrologic Adaptation/Mitigation
- Hydrology – Future Steps
- Conclusions

Current Knowledge

- Climate change will lead to increase in both *variability* and *uncertainty*:
  - Precipitation Events
    - Depths, frequency, magnitude, intensity
  - Flood Events
    - What is the "new" 100-year design storm/flood?!
    - Current EAFB 100-year, 24-hour design storm = 3.55 inches

- Ecosystem changes
  - Threatened and endangered species habitat will change → how does that affect future facilities siting and airfield and range operations?

- Land use changes
  - Watershed rainfall-runoff response altered

EAFB/DFRC Site-Specific Impacts

- Lakebed Inundation
  - Depth, frequency, and duration
    - Impacts airfield and lakebed operations – for how long?
    - Impacts future facility siting
    - Impacts habitat as birdstrike hazard increases

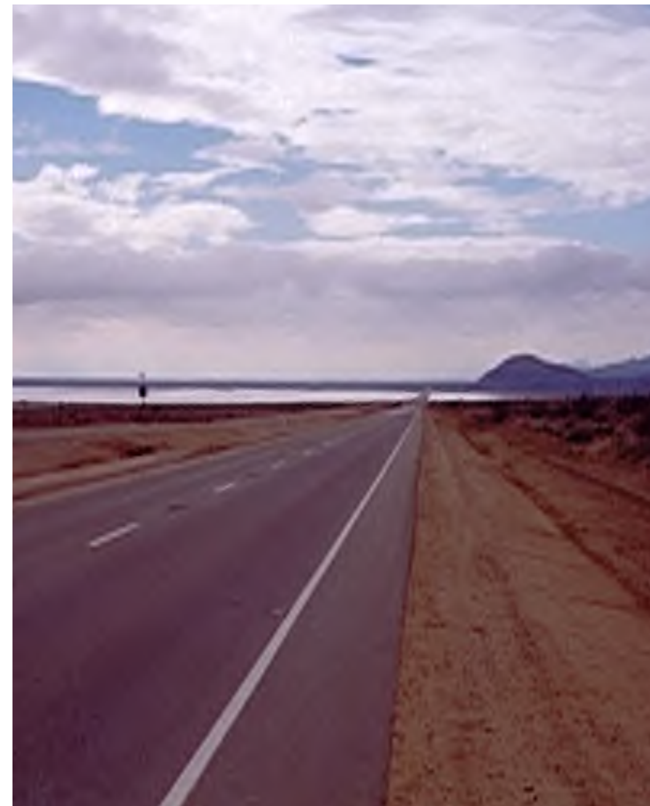
Lakebed inundation near DFRC, 1983 (NASA Dryden Photo, 1983)

Lakebed airfield inundation (Motts and Carpenter, 1970)

EAFB/DFRC Site-Specific Impacts

- Base access obstructed
  - *Main Gate*: Rosamond Blvd overtopped by inundation of Rosamond Lake
  - *South Gate*: Lancaster Blvd overtopped by Buckhorn drainage to Rogers Lake
  - *North Gate*: Railroad underpass floods

Drainage from Buckhorn at Lancaster Blvd, February 2003 (Miller *et al*., 2009)



Water on both sides of Rosamond Blvd, February 2003 (Miller *et al*., 2009)

EAFB/DFRC Site-Specific Impacts

- Lakebed Fracturing/Fissuring
  - Related to long-term drought conditions
    - Sediments desiccate and cracks propagate to surface
    - Groundwater withdrawal causes subsidence and additional fracturing on the lakebed
    - Impacts lakebed airfield operations
      - Reduced availability of lakebed

Fissure on Rogers Lake resulted in closure of lakebed Space Shuttle runway, January 1991 (USGS Circ.#1247, 2003)

Stressors to Hydrologic Resources

- Overtaxed water resources – now vs future
- Hydropower Energy Resources
  - Hydropower resources are impacted by decreased water volume and reservoir operations that are restricted by habitat requirements and recreational uses
- Increasing population density
  - More drain on limited resources, increased impervious surfaces, encroachment on habitat and groundwater recharge areas

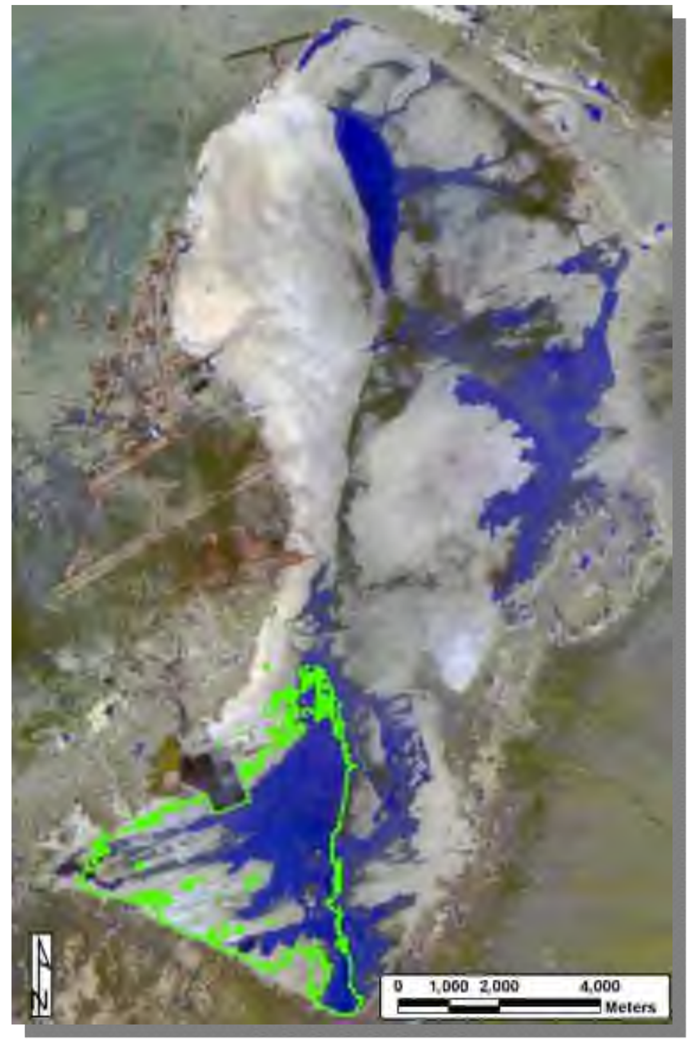
Hydrologic Research Needs

- Review historical records of local effects of 1861 storm (as an analog of ARKSTORM)
  - Archaeological records
    - Oral histories
    - Historic photos
  - Paleohydrology/Paleoflood/Fluvial Geomorphology

- Establish new ways of looking at existing data
  - System-wide view in terms of "coupled processes"
  - Landscape ecology

Hydrologic Research

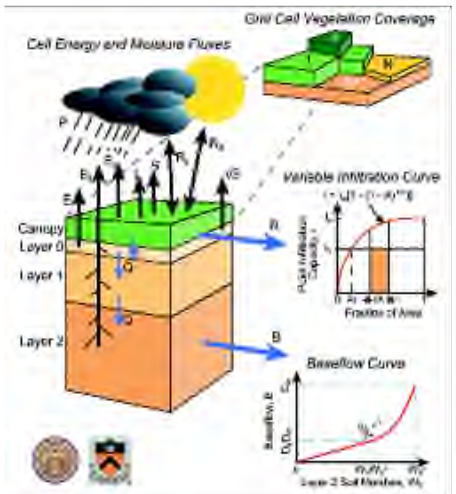
- Remote Sensing Techniques, Modeling, and *in-situ* measurements
  - Integrates information
  - Gathers data where monitoring does not exist
  - Calibrate models to measurement points



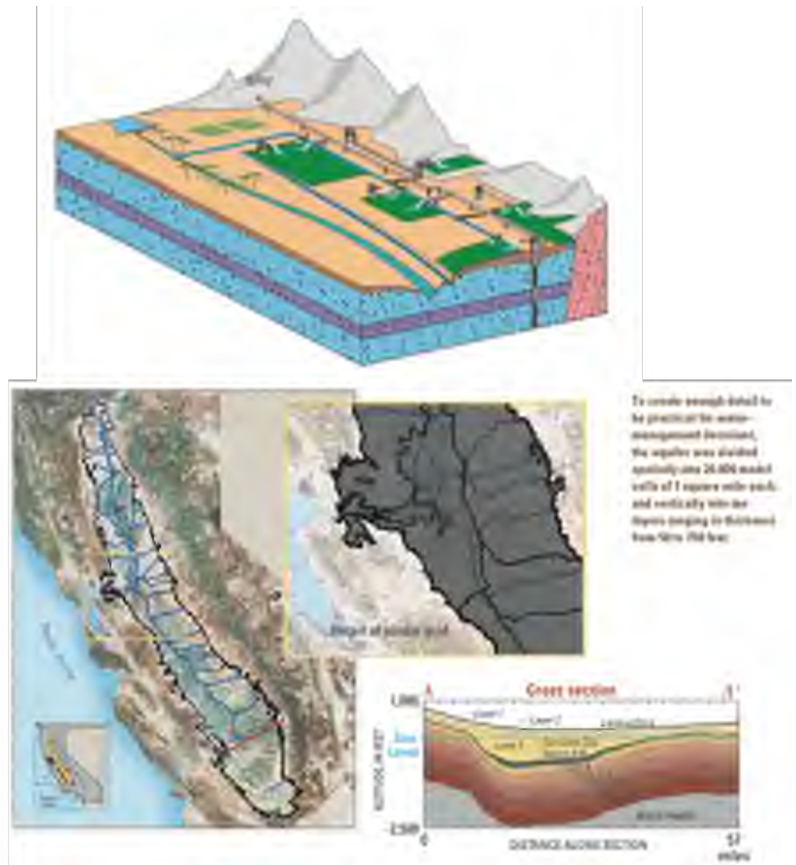
Landsat image, April 2003, Rogers Lake

Hydrologic Modeling - Tools

- Integrating modeling, remote sensing and *in situ* observations

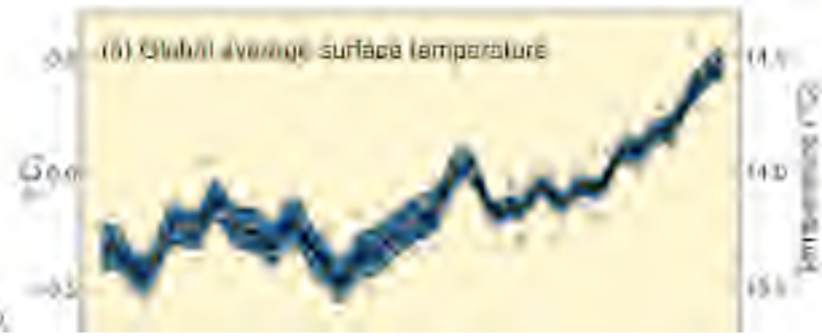


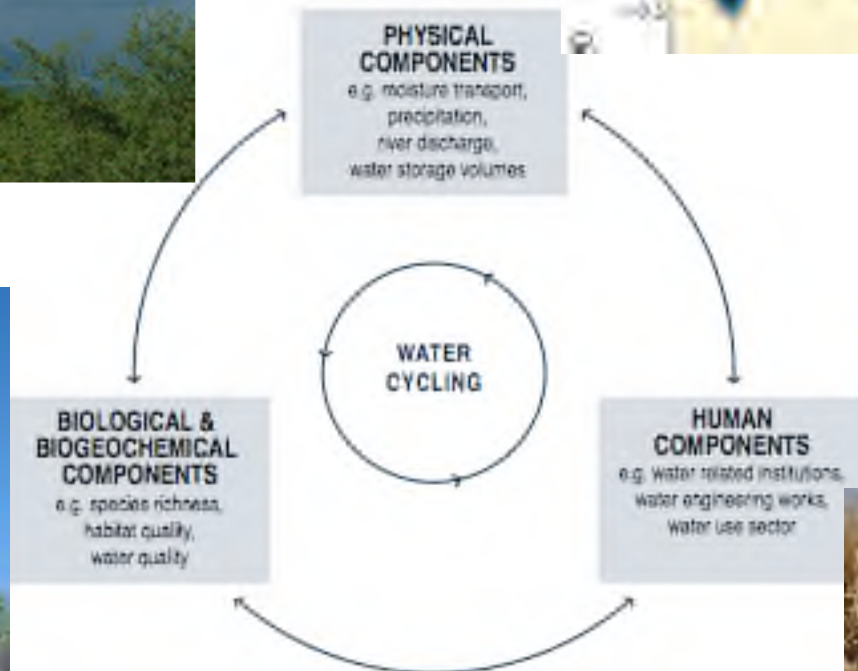
Variable Infiltration Capacity (VIC) Model



MODFLOW-Farm Process

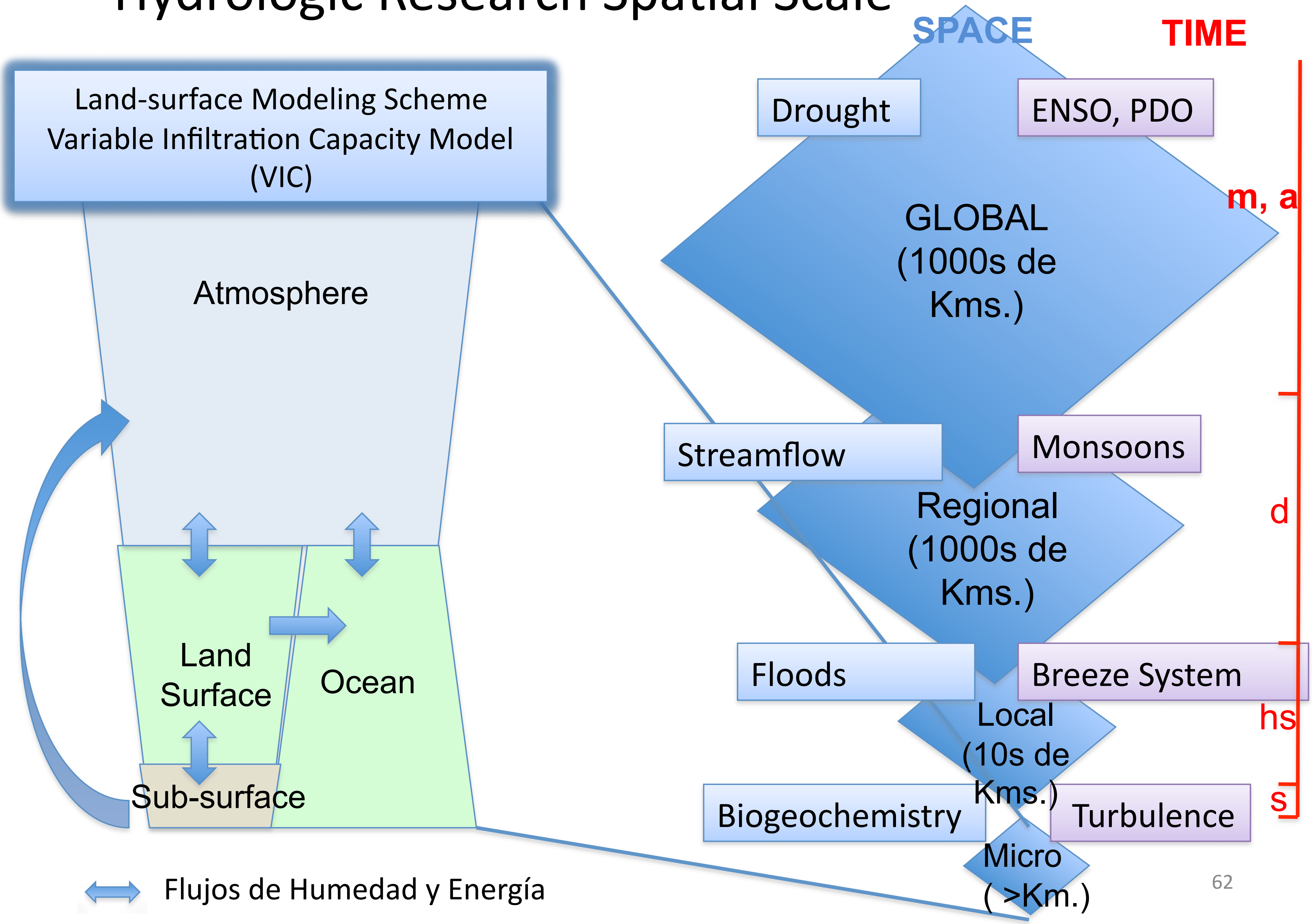
Hydrologic Modeling - Systems Perspective



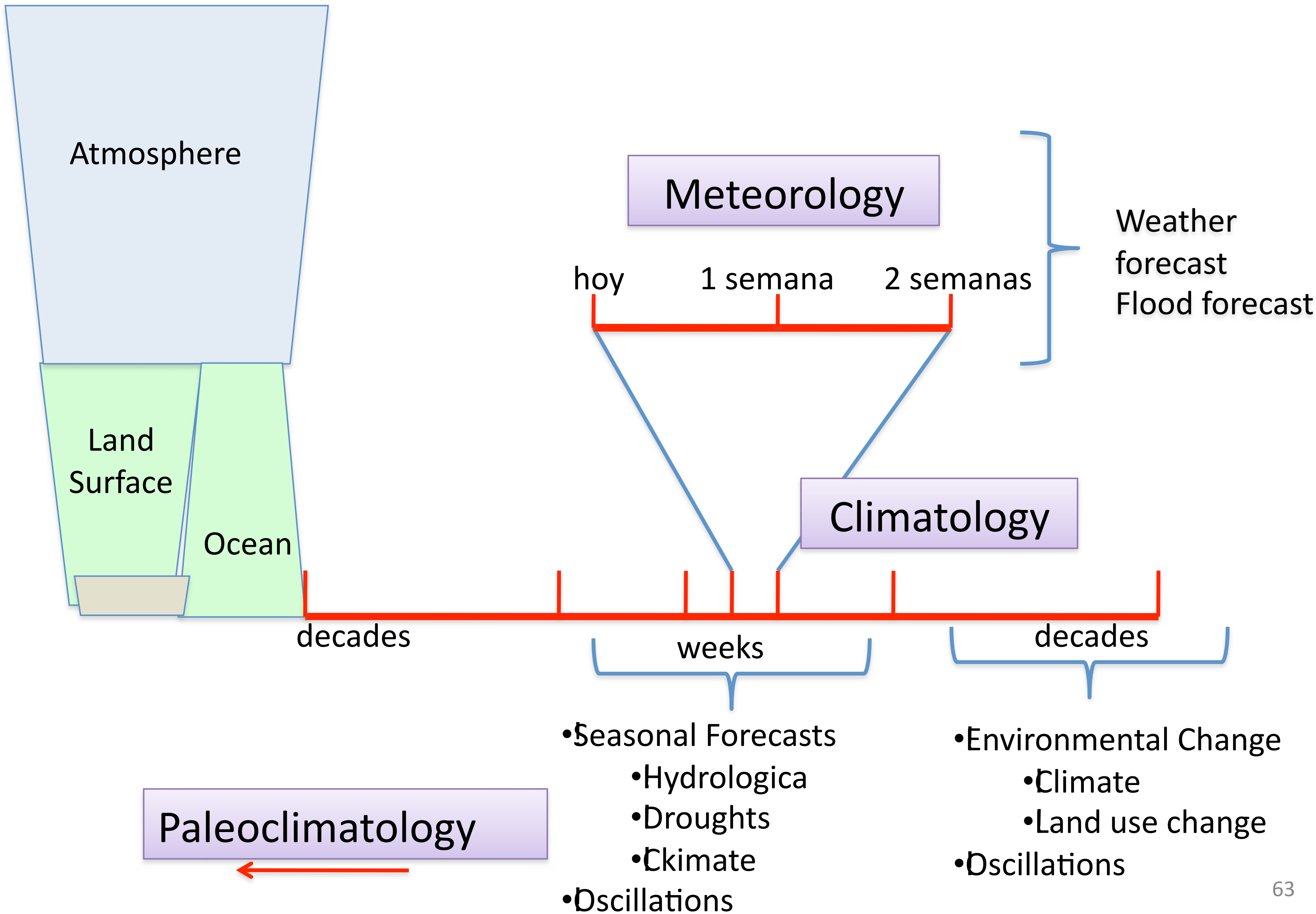


http://www.gwsp.org/

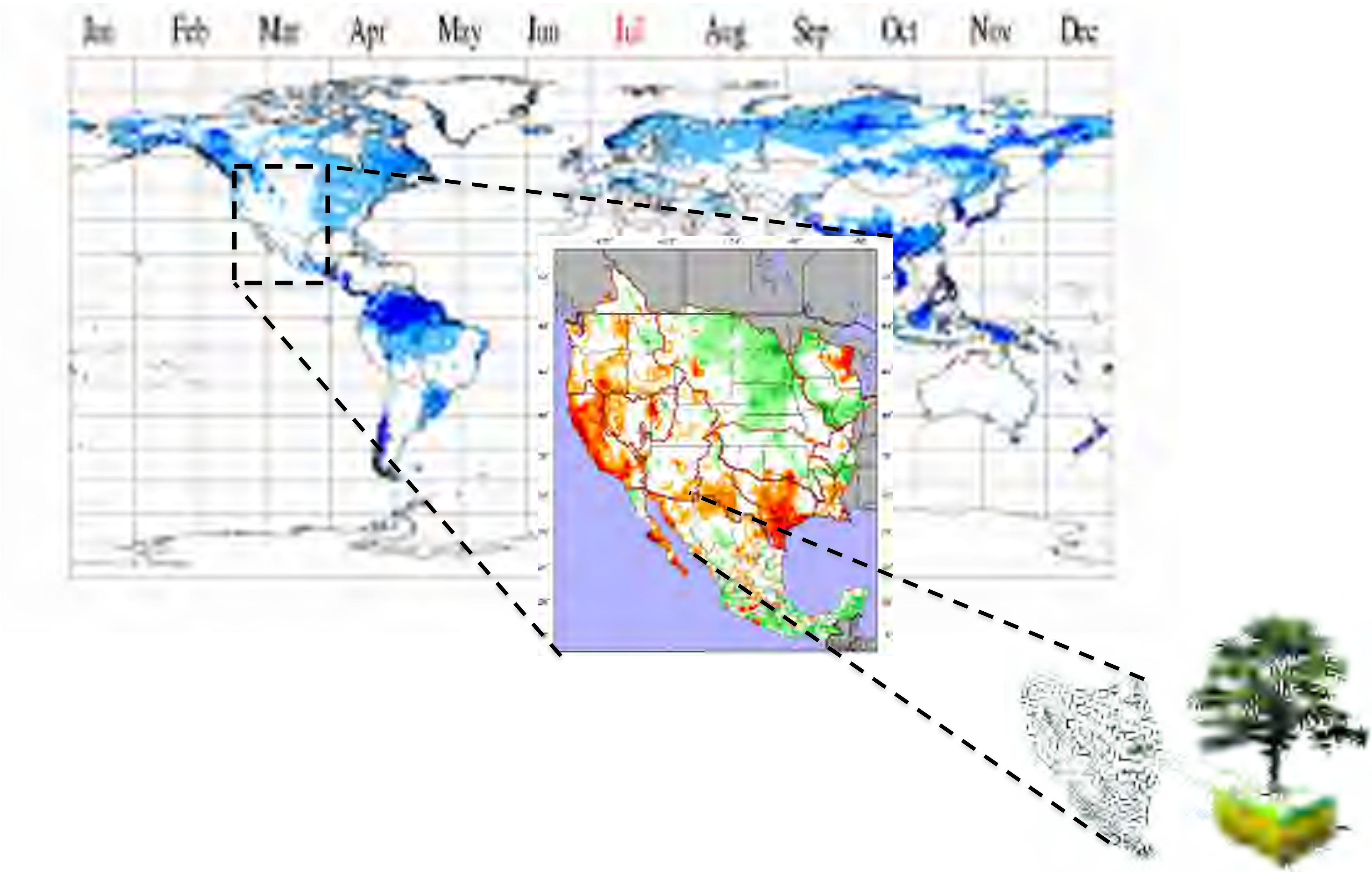
Hydrologic Research Spatial Scale



Hydrologic Modeling -Temporal Scale



Hydrologic Modeling -Tools



Hydrologic Research - Monitoring

- Long-term monitoring is used to validate and calibrate climate change models that use existing (*i.e.,* historical) data sets
- Precipitation and stream gages are sparse
- Long-term records are limited and consist of many years of zero measurements
- Propose to install additional gages and tie to remote sensing for data in ungaged watersheds

Hydrologic Adaptation/Mitigation

- NASA/DOD incentives to reduce resource use:
  - Federal mandates for sustainability
  - Leverage limited budgets

- Modify operation schedules to account for predicted periods of likely lakebed inundation or fracturing by extended droughts

- Increase "factor of safety" in flood mitigation structures (i.e., overdesign flood mitigation structures)

- LEED building standards
  - Now cost-effective to reduce energy and water use

Hydrology – Future Steps

- Flood and water quality mitigation
  - Increase factor of safety in future mitigation design
  - Increase off-channel floodplain storage
  - Increase wetlands used for bioremediation of stormwater and wastewater

Wetlands, Las Vegas Wash

Flood mitigation: Levee construction

Conclusions

- Current climate patterns are already impacting missions
- Future climate patterns will increase the risk to our missions requiring adaptation
- Current natural resources are already overtaxed, future growth makes situation worse
- Antelope Valley policymakers must:
  - Incorporate the changing environment in planning
  - Protect Antelope Valley water resources

Hydrology– important points

- Public education and leadership
- Building climate change into public planning
- Address specific problems without emphasizing climate change in the discussion