Prospect Foundation Symposium on Taiwan under Global Climate Change

(October 23, 2010, Taipei, Taiwan)

Keynote Presenter: Kuo-Nan Liou, University of California, Los Angeles, U.S.A.

Mr. Chairman and distinguished colleagues, I am pleased to have the opportunity to attend the Symposium on "Taiwan under Global Climate Change." First, I would like to thank Vice President George Chen of National Taiwan University, as well as Prospect Foundation Director Liu for the invitation and arrangements.

My talk is concerned with regional climate and climate change. In my opinion, to mitigate societal impact, adapt to climate change and global warming, and achieve sustainability, Taiwan must develop a physically-based, credible regional climate model for projection and prediction studies.

I would like to draw on my experience in California to share with you my concerns and to present a scientific basis for the preceding suggestion. In particular, I will demonstrate the importance of absorbing aerosols, specifically black carbon (BC) and dust particles, in the reduction of snow albedo vis-a-vis aerosols-mountain snow-albedo feedback that has an irreversible impact on regional climate and climate change (Slide 1).

The next 3 slides illustrate the retreat of mountain snow in a number of locations, including Glacier National Park and South Cascade glacier in the United States and Qori Kalis Glacier in Peru, as well as many other glacier retreats. It appears quite evident that the reduction of mountain snow fields over the globe must be related to global warming. However, I submit that the addition of man-made (or anthropogenic) absorbing aerosols must also play a substantial role in this reduction in a non-linear fashion.

Slides 5-7 shows three source types of absorbing aerosols associated with my talk: Emissions from industrial sites and local sources using Los Angeles air pollution as an example (Slide 5); Biomass burning in which southeast Asia and India have been identified and recognized as regions of important sources. Slide 6 displays the BC (soot) concentration measured during the INDOX experiment, which was conducted in March 2001. The dust originated in East Asia and China, as demonstrated in the 2001 perfect dust storm, using the aerosol optical depths determined from the TOMS instrument on board NOAA satellites to display the transport of dust particles (Slide 7).

Slide 8 presents a summary of the sources of BC and dust from China and Southeast Asia. First on BC, China is a significant source of BC production, particularly in recent years. BC is produced by the incomplete combustion of carbonaceous fuels, including fossil fuel and biomass burning. China has been recognized as a major global anthropogenic source for BC aerosols. Coal production during the 1990s was 5 times larger than during the 1960s. About 10% of global carbon emissions in 1990 came from China and this value increased to 12 % in 2000. A projection to 2025 indicated that it would be increased to 18%. In addition to the preceding sources, biomass burning in Southeast Asia has also been recognized as a substantial source of the production of BC. With reference to dust particles, which originate in northwest China (Gobi Desert, Taklamakan Desert, and Tarim basin area) in late March and early April associated with special weather conditions, resulting in extremely dry areas with precipitation less than 200mm. Although dust production is directly related to regional weather systems, it can also be indirectly generated by man-made perturbations, such as deforestation and desertification.

Why are BC and dust particles important in global radiative forcing and the climate system? The first reason is related to their direct radiative interactions with sunlight and thermal infrared radiation emitted from the Earth-atmosphere system, while the second is associated with their indirect effect via formation of clouds and precipitation. The direct effect is determined by absorption and scattering processes (Slide 9). Dust particles are nonspherical and scatter and absorb sunlight, making the determination of their single-scattering properties a difficult issue in radiative transfer and remote sensing. Soot or BC particles are more complicated and some of them have fractal structure with respect to their morphology and composition (Slide 10). Soot is an aggregation of individual monomers, which can be structured in terms of internal and external mixing resulting in open and closed clusters or aggregations. These configurations lead to significant differences in their optical properties and the consequent single-scattering albedo value, a ratio of scattering to extinction cross sections, important in climate study. I will demonstrate this point in a later slide in conjunction with their interaction with snow grains.

In order to understand the transport of BC/dust aerosols from East Asia to the United States, we have analyzed the aerosol optical depths available for MODIS/NASA over the Sierra-Nevada Mountains, a region with snow cover in the winter season, for March and April, during a 9-year period. These results (Slide 11, only 4 years are shown) clearly illustrate the cross-Pacific transport of aerosols in general and BC/dust in particular from East Asia (source regions, red/yellow, 0.7 – 1 optical depths) to the Sierra-Nevada Mountains (green/light yellow, 0.3-0.5 optical depths). The selection of March-April is related to the aerosol activities in East Asia and the issue of snowmelt and water resources in California.

In addition, we have run a simulation using a chemical transport model, referred to as GEOCHEM. This simulation (Slide 12) was conducted for the total aerosol optical depth in March and April for the year 2006; the results of this simulation reinforce the previous satellite aerosol optical depth observations. We need a chemical/aerosol transport model in order to quantify wet and dry depositions of absorbing aerosols onto the snow fields, a subject we are currently working on.

From the preceding discussion, it is evident that through general circulation of the atmosphere, BC and dust originating in East Asia and China have been transported to California. Slide 13 displays a snow scene over the Sierra-Nevada Mountains in Northern California regions.

I wanted to demonstrate that the lower snow albedo values in April compared to those in March is in part caused by absorbing aerosols transported from China and Southeast Asia. For this purpose, we analyzed the monthly mean and standard deviation of snow albedo (ranging from 0.5-0.8, Slide 14) and aerosol optical depth based on satellite observations. We show that the snow albedo in April is consistently lower than in March, whereas the reverse is true for aerosol optical depth. Correlation analysis shows that these two parameters are negatively correlated with a high correlation coefficient and are statistically significant. I fully realize that snow albedo is also correlated with surface temperature in which the month of April is generally warmer than the month of March, as well as the precipitation event, in terms of the days after the snowfall. Nevertheless, I would argue that the decrease in snow albedo with 100% snow cover in April, as compared with March is in part caused by the effect of absorbing BC and dust from East Asia. Of course, more research needs to be done in this area.

In Slide 15, we illustrate the importance of the contamination of snow grains by absorbing aerosols, having carried out light absorption and scattering calculations for the cases involving external and internal mixing of BC and dust particles. These calculations were based on a new theoretical approach we developed, which combined a stochastic process to build aggregates, followed by the geometric photon tracing including reflection/refraction, diffraction, and surface waves. We show that internal mixing produces much larger absorption, as compared with the external counterpart, in terms of a larger single-scattering co-albedo. The subsequent radiative transfer calculations illustrate reduction of snow albedo associated with the contamination of BC and dust particles, depending on their size. Due to its larger absorption, BC has more substantial impact on reducing snow albedo than dust particles.

Slide 16 demonstrates the essence of snow-albedo feedback, a powerful amplification process involving absorbing aerosols. Through the wet and/or direct dry deposition of absorbing aerosols, snow becomes less bright. As a consequence, it will absorb more incoming sunlight, which will lead to surface warming. The loop involving darker snow and absorbing more sunlight forms a powerful feedback that can significantly amplify increase in surface temperature. In this conjunction, we have witnessed powerful ice-albedo feedback in the Arctic and Antarctic.

The next slide (Slide 17) illustrates the global radiative forcings produced by nature and human disturbances of climate change, including greenhouse gases, aerosols, and other forcing elements. Globally BC on snow is shown to have only a small value; without question, however, this forcing must be much more substantial in the regional context.

In the following slide (Slide 18), we present a summary of the impacts of climate change, including global warming produced by greenhouse gases and the effects of absorbing aerosols on snow albedo on the climate of California with reference to a number of key surface climate parameters, including (1) precipitation and snow distribution related to mountain ecosystems and the ski industry, (2) water resources and management, (3) Santa Ana wind events affecting human health and wildfire, (4) runoff and streamflow associated with coastal wetlands, and (5) sea surface temperature pertinent to ocean ecosystems. Indeed, the State of California is particularly vulnerable to global warming and climate change.

In conjunction with the last bullet point, we at the Joint Institute for Regional Earth System Science and Engineering have been working on building a Regional Climate Model to include two new physical processes: parameterization of 3D radiative transfer in mountains/snow field for incorporation in the Weather Research Forecast (WRF) model and the Community Land-Surface Model (CLM); and investigating the impacts of size, shape and composition of soot on solar radiative forcings in terms of the states of external/internal mixing and their interactions with snow grains.

Building global and regional climate models for the prediction and projection of future climate to assess mitigation and adaptation is a challenging and intricate task. All atmospheric and oceanic processes shown in Slide 19 must be physically resolved based on first principle and with uncertainties known in order to have credibility for our computer model, the “Crystal Ball” so to speak, to project and predict our future climate and climate change.

Slide 20 illustrates that global climate models do not have the spatial resolution to adequately represent numerous physical processes, nor the capacity to resolve many physically important and socially relevant processes. IPCC AR4 model projections agree that California will warm in this century, but disagree on whether it will become wetter or drier. This implies that some physical processes have not been adequately represented in global climate models.

I would like to call your attention to the importance of satellite data in climate study. Climate models must be validated for their performance to reproduce past and current climate. As shown in Slide 21, a vast amount of present-day high-resolution satellite data goes unexploited in regards to model development and validation due to much lower GCM grid resolutions. The two upper-left panels show GCM surface temperature with a resolution of about 200 km. The right panels display high resolution satellite observations on the order of 1-5 km of surface temperature and ground cover. Moreover, regional climate models can also facilitate satellite mission development and instrument design for high special and temporal resolutions, a subject associated with innovative technology and its transfer.

Finally, to reinforce my opening statements, in order to mitigate societal impact, adapt to climate change and global warming, and achieve sustainability, Taiwan must develop a physically-based, credible regional climate model for projection and prediction studies. Taiwan is a small island and is particularly vulnerable to global warming and climate change, much more so than the State of California. It has an intricate mountain structure and is surrounded by oceans. Its weather systems are dominated by cold fronts in the winter, monsoons in the spring and typhoons in the summer, along with mesoscale processes coupled with these distinct weather features. Taiwan is covered only by a few grid points in future GCMs (~100 km), as shown in Slide 22. It is quite clear that in order to have a physically-based and realistic discussion on the issues of mitigation and adaptation as well as sustainability, a credible regional climate model must be developed for climate projection and prediction.

Let me stop at this point and thank you very much for your attention.

Regional Climate Change: The Role of Light-Absorbing Aerosols and Snow-Albedo Feedback

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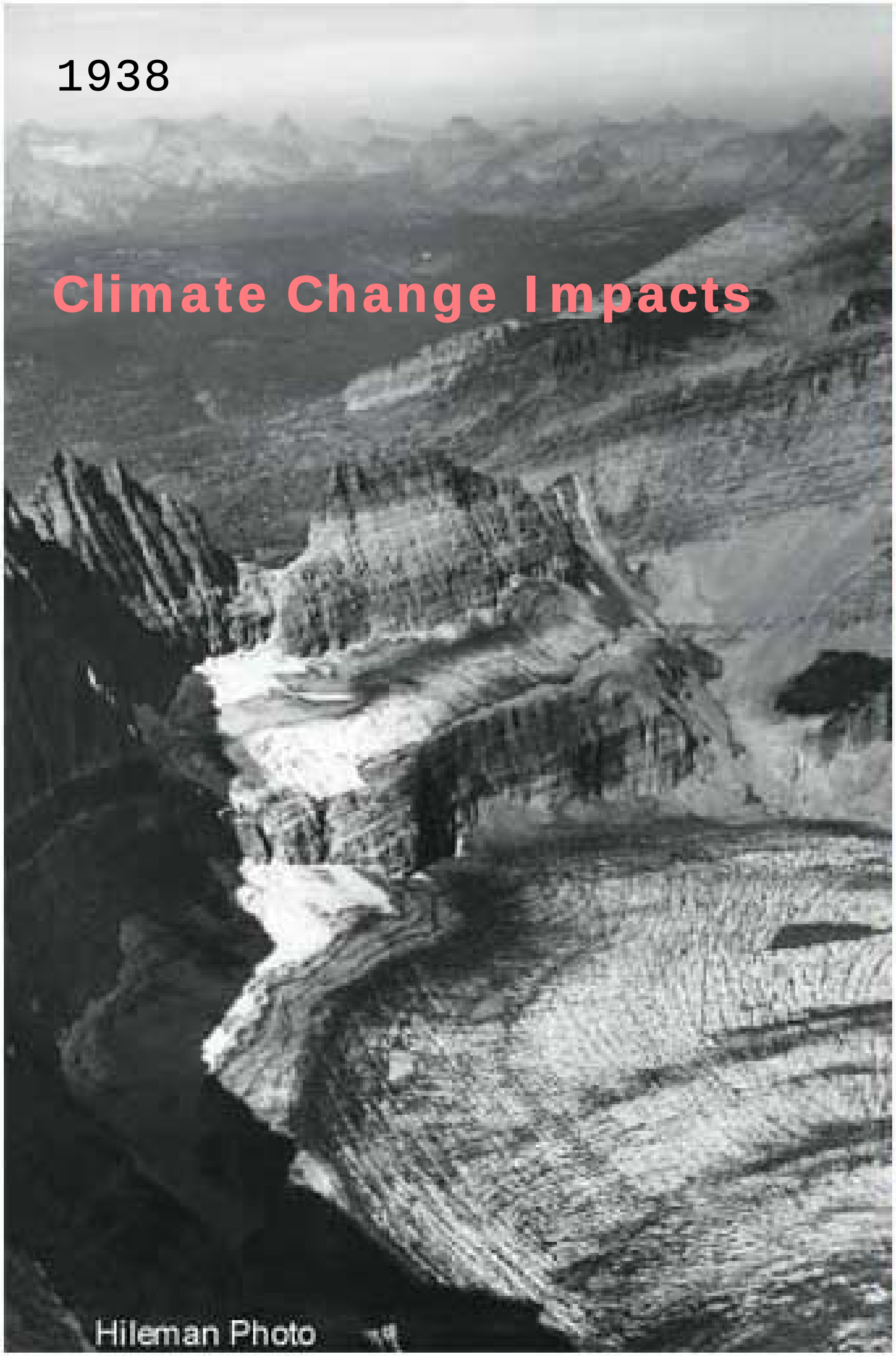
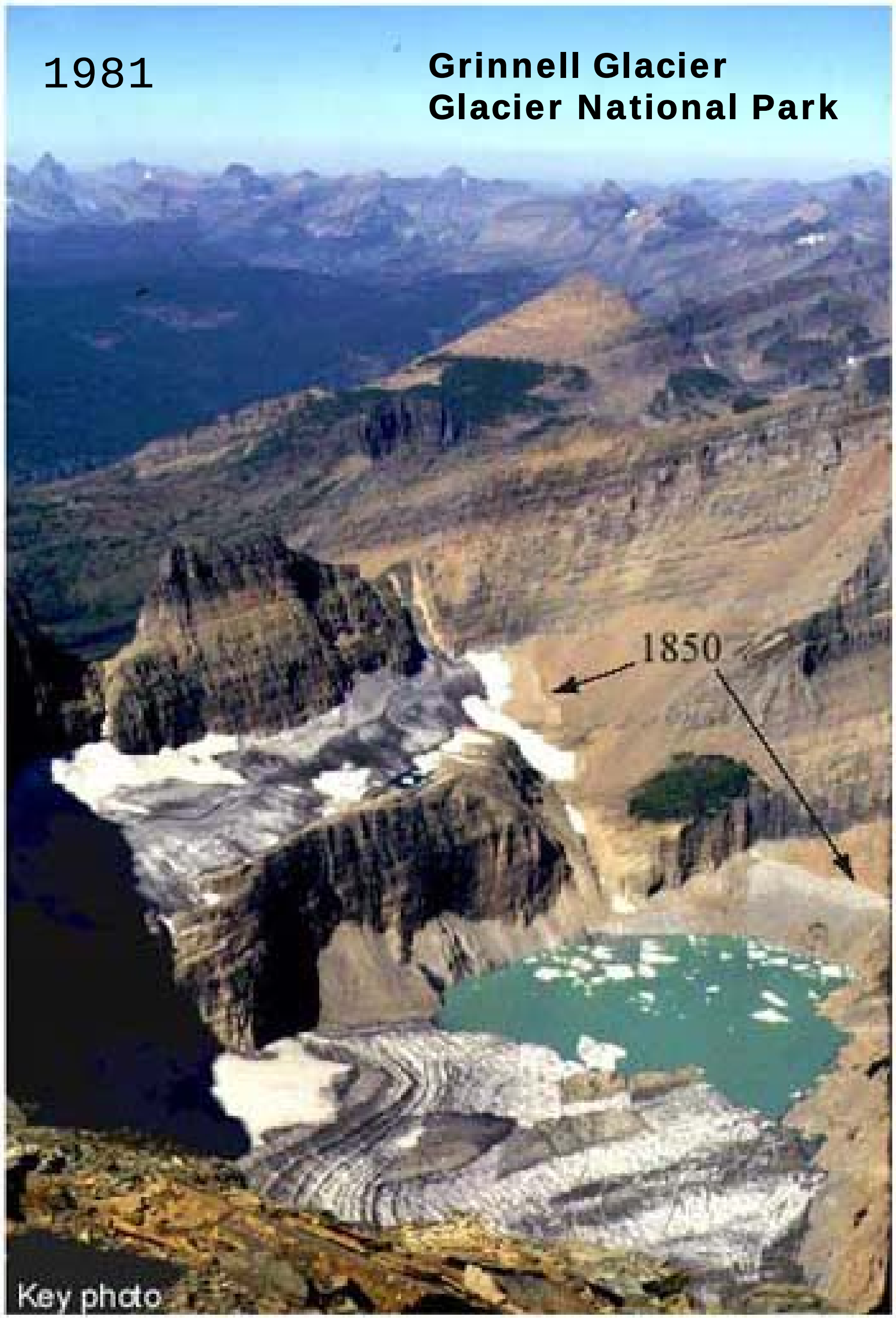
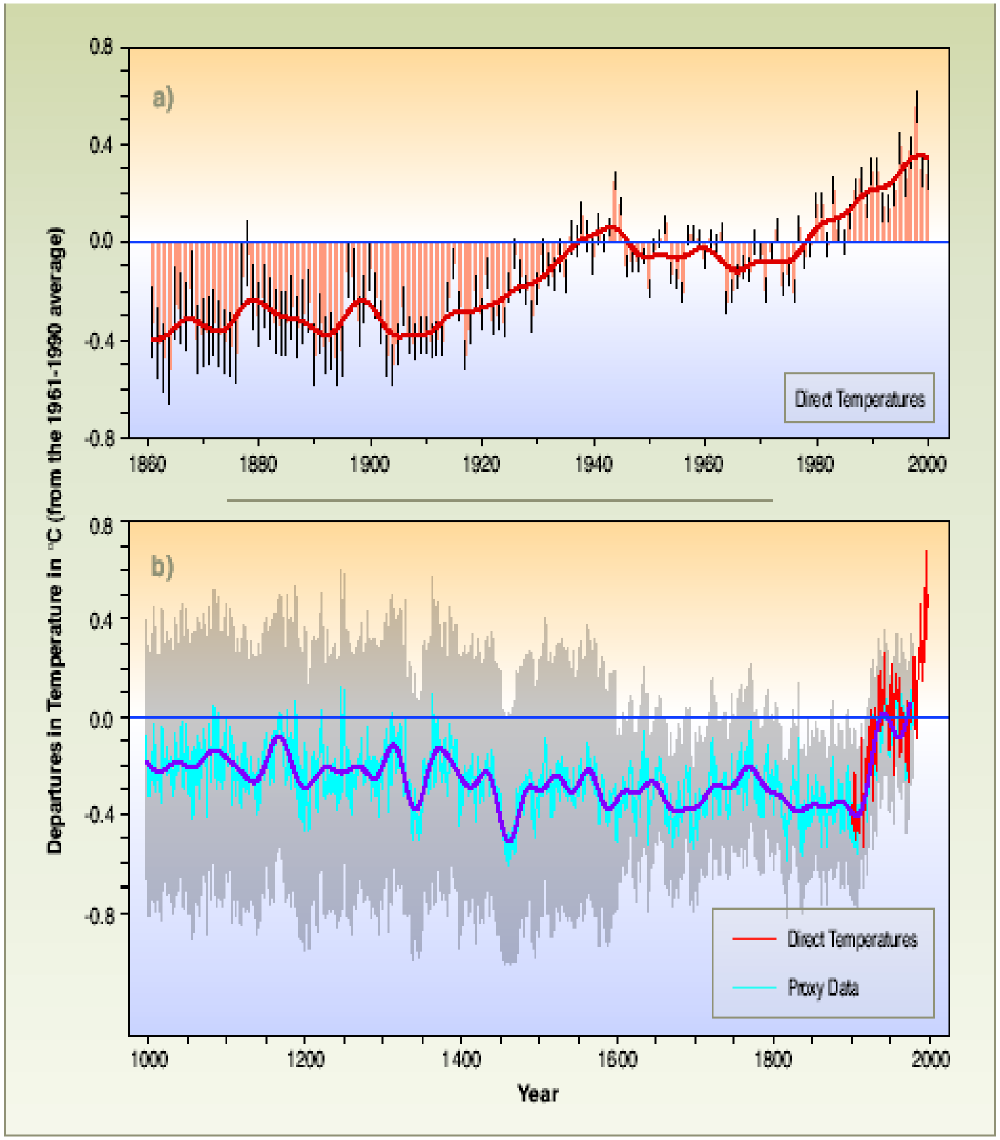
*With contributions from W. L. Lee, Y. Takano, Q. Li, Y. Gu, P. Yang, and J. Kim

- ❑ Regional Climate Change and Mountain Snow
- ❑ Absorbing Aerosols: Black Carbon (BC) and Dust
- ❑ Transport of BC and Dust from EA to CA: Some Evidence of Snow Albedo Reduction in the Sierras in Spring
- ❑ The Concept of Snow-Albedo Feedback
- ❑ Climate Change Impacts on California: Need of a Regional Climate Model
- ❑ Taiwan Under Global Climate Change: Some Perspectives

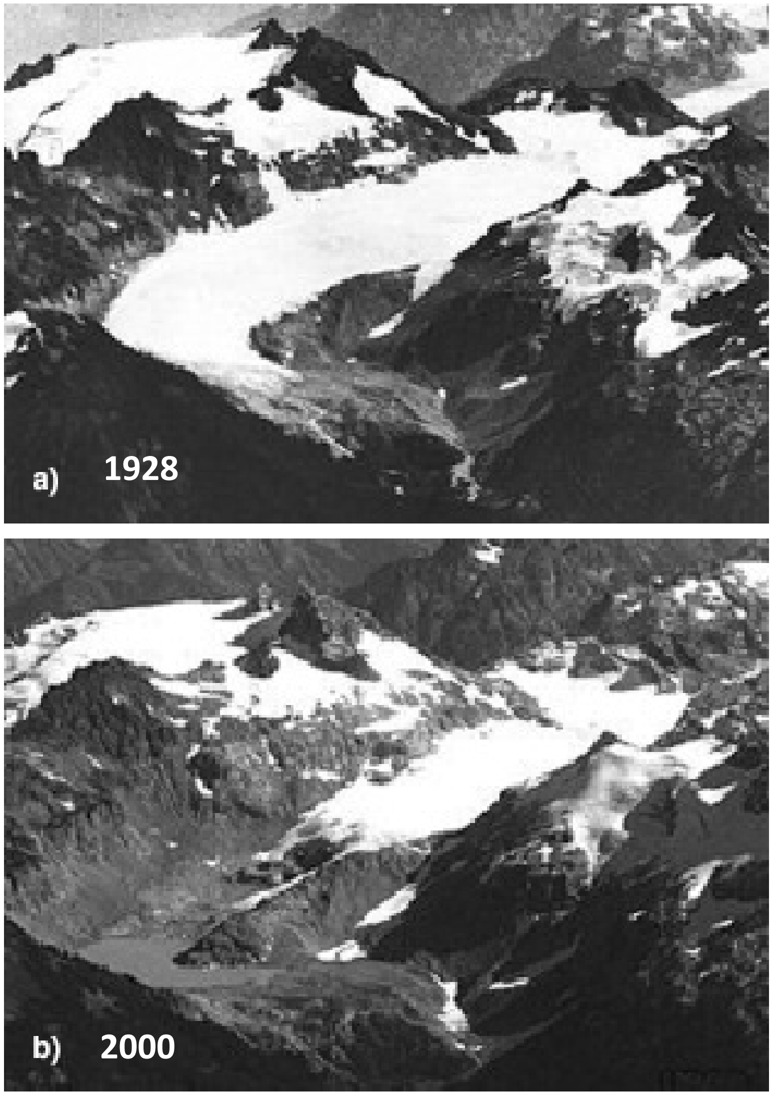

1938
Climate Change Impacts
Hileman Photo


1981
Grinnell Glacier
Glacier National Park
1850
Key photo

Strong Evidence for Global Warming



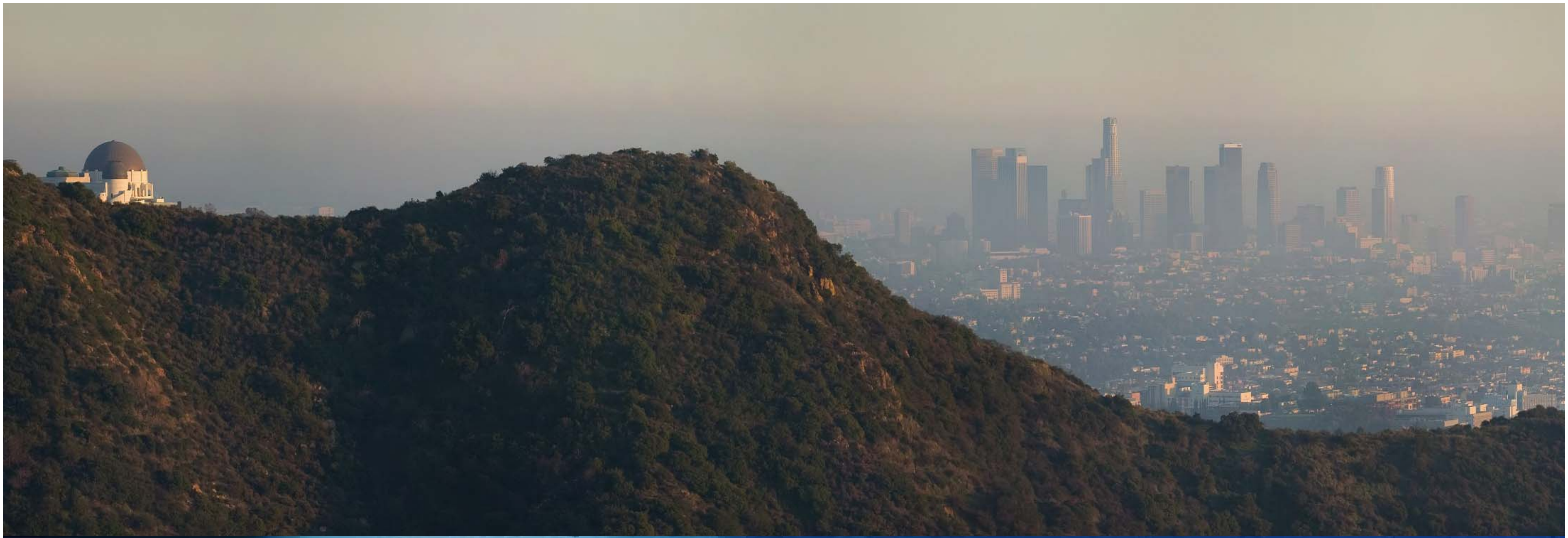
From US Climate Change Science Program

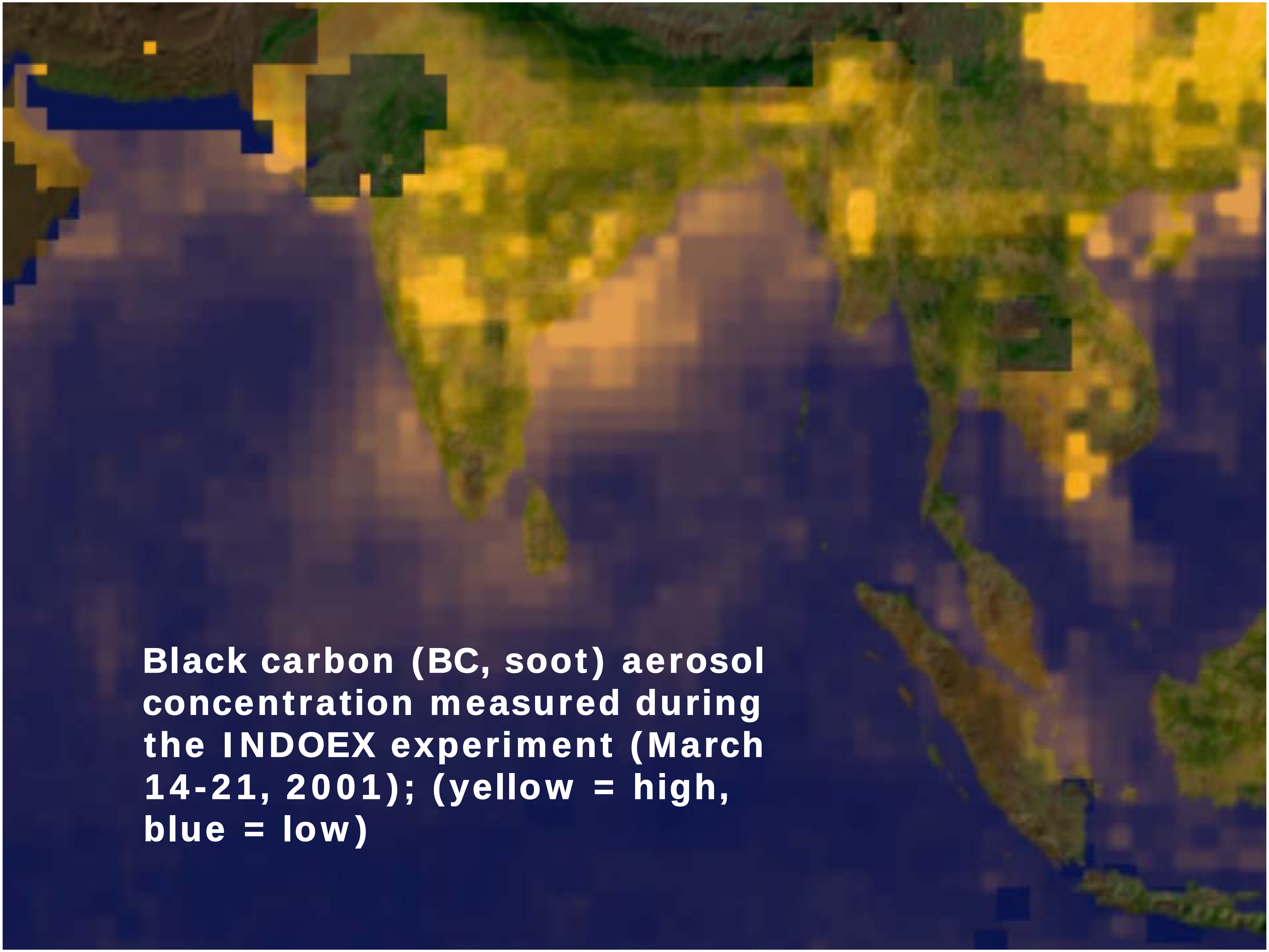


South Cascade Glacier, Washington

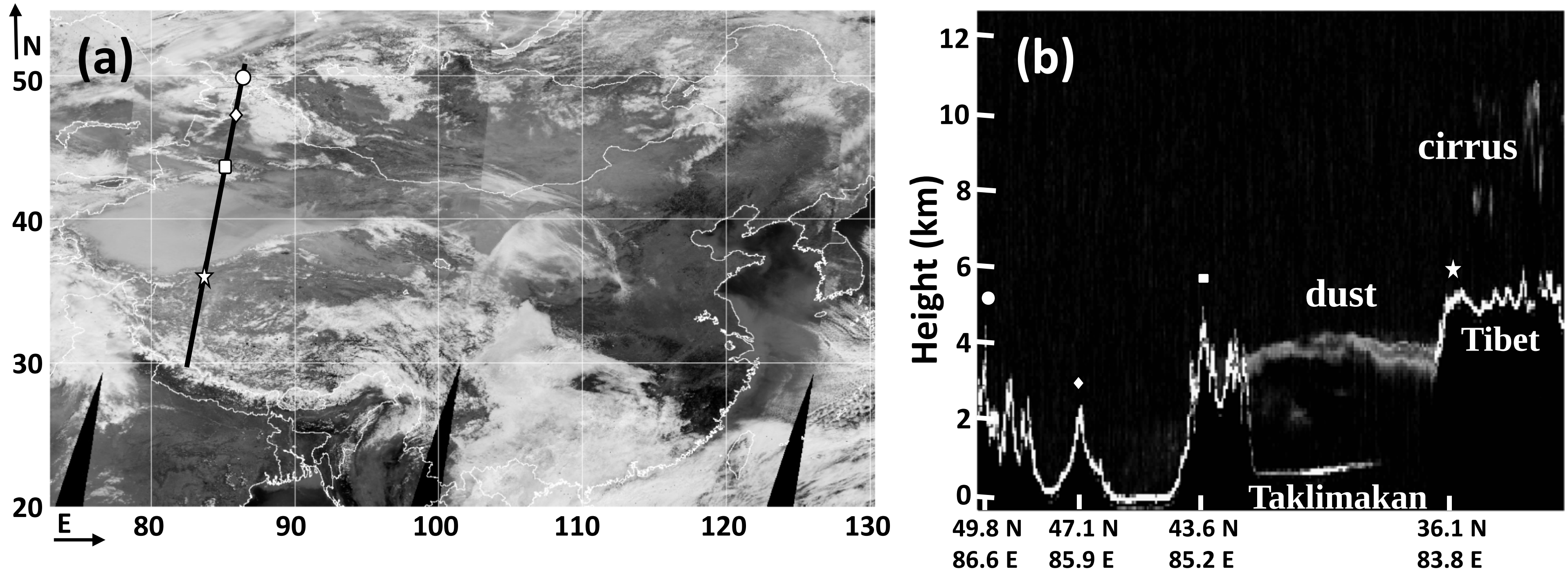
Mountain glaciers all over the world are in retreat. This is the Qori Kalis glacier in Peru in 1978.

The same glacier in the year 2000. The lake covers 10 acres.

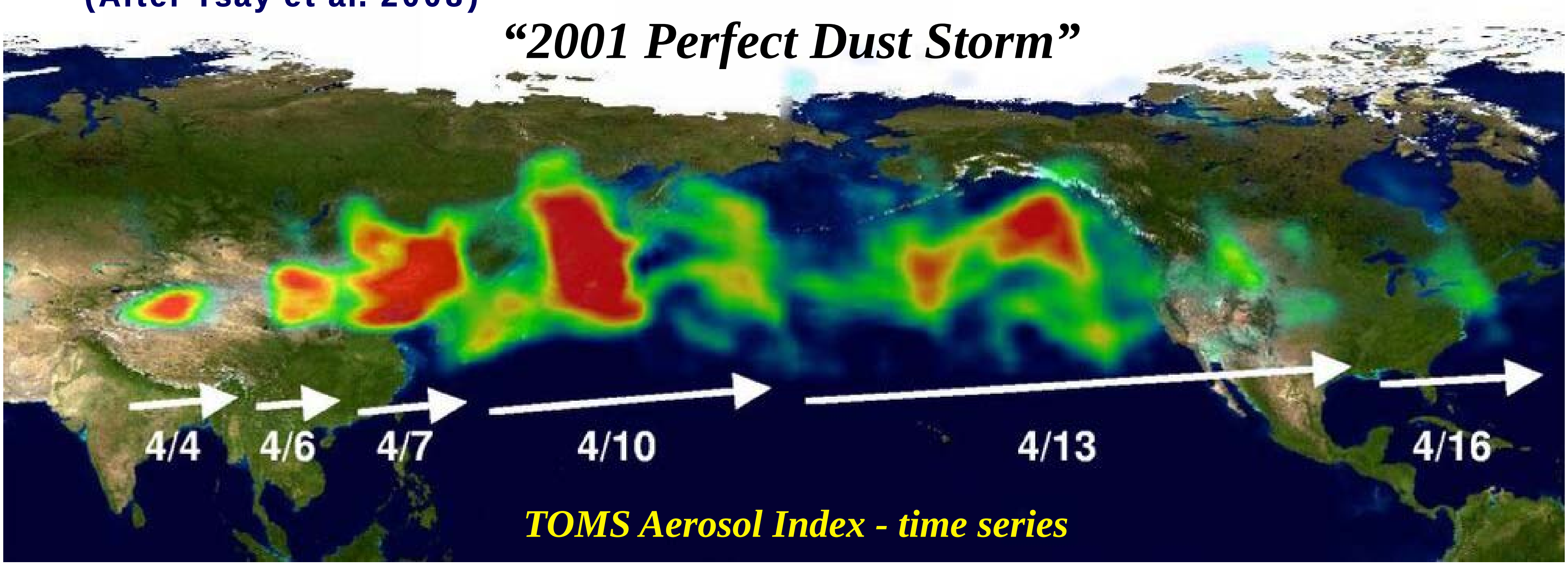




Black carbon (BC, soot) aerosol concentration measured during the INDOEX experiment (March 14-21, 2001); (yellow = high, blue = low)



(After Tsay et al. 2008)



Black Carbon (BC) and Dust Particles from China and Southeast Asia

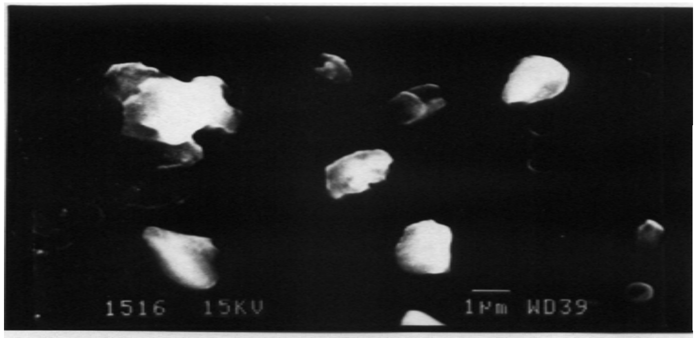
- **BC:** Incomplete combustion of carbonaceous fuels, including fossil fuel and biomass burning

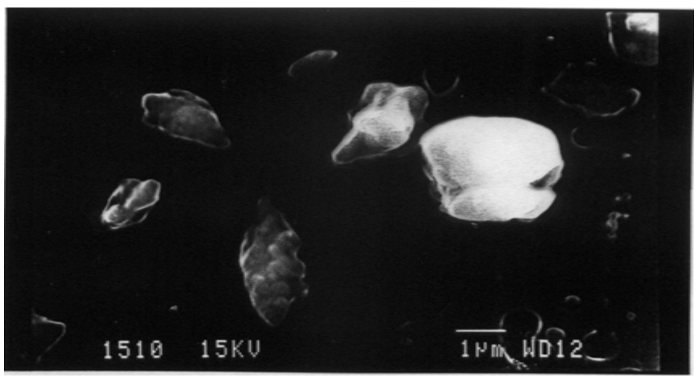
- China: 80% of its energy from coal combustion
  Recognize as a major global anthropogenic source for BC aerosols: Coal production during the 1990s was 5 times larger than that during the 1960s
  ~10% of the global carbon emission in 1990
  ~12% in 2000
  ~18% in 2025 (projection)
- Southeast Asia: Biomass burning

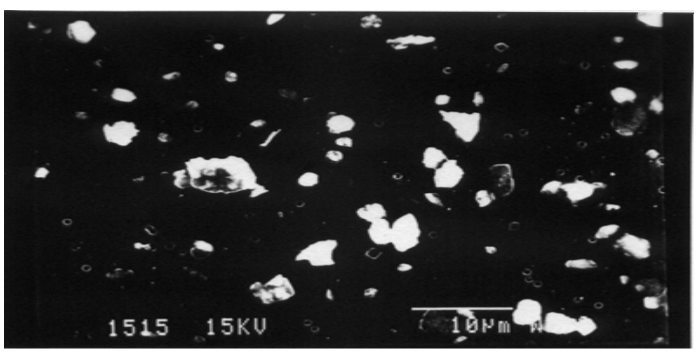
- **Dust:** Originating in northwestern China (Gobi Desert, Taklamakan Desert, and Tarim basin area) in late March and early April (extremely dry areas < 200mm precipitation, and special weather conditions)

Light Scattering and Absorption by Dust and Black Carbon: Fundamental to the Understanding of Aerosol Climate Forcings

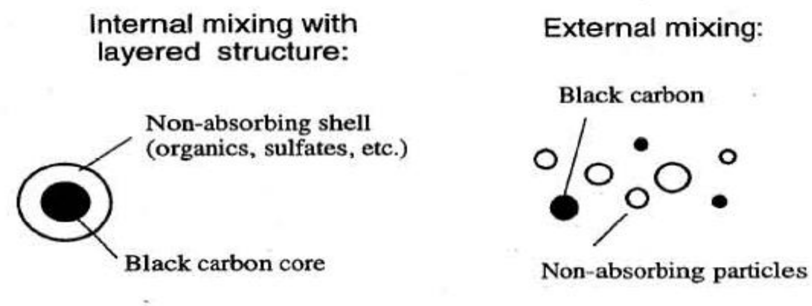
Dust

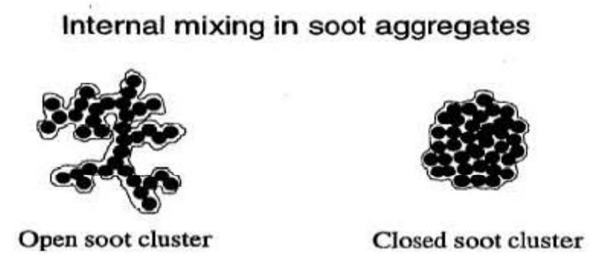


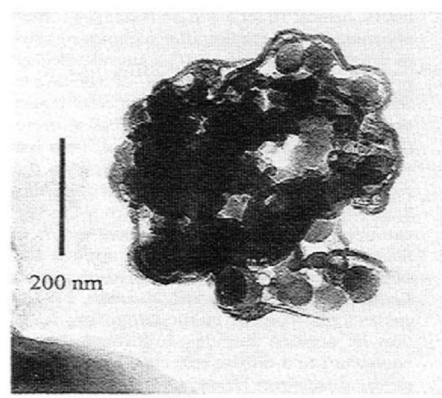


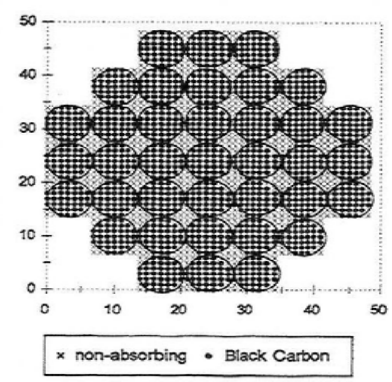


Black Carbon

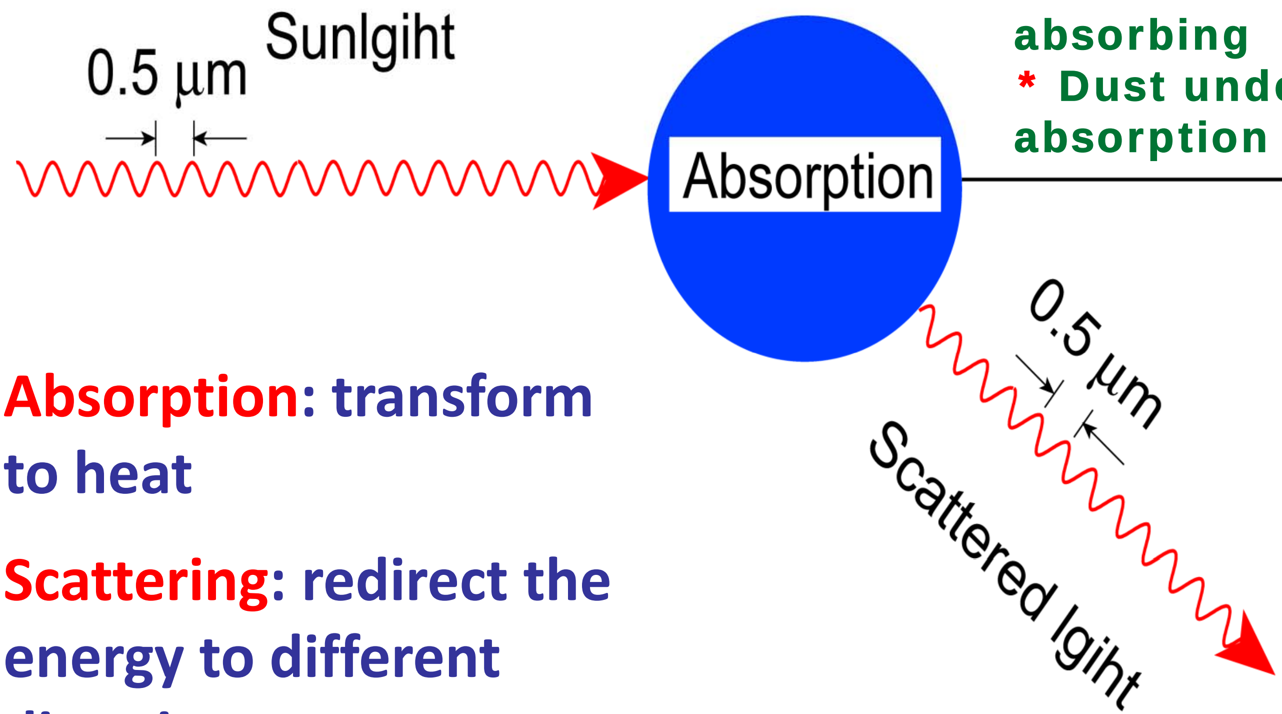








Light Scattering and Absorption by Aerosols: Direct Radiative Forcing

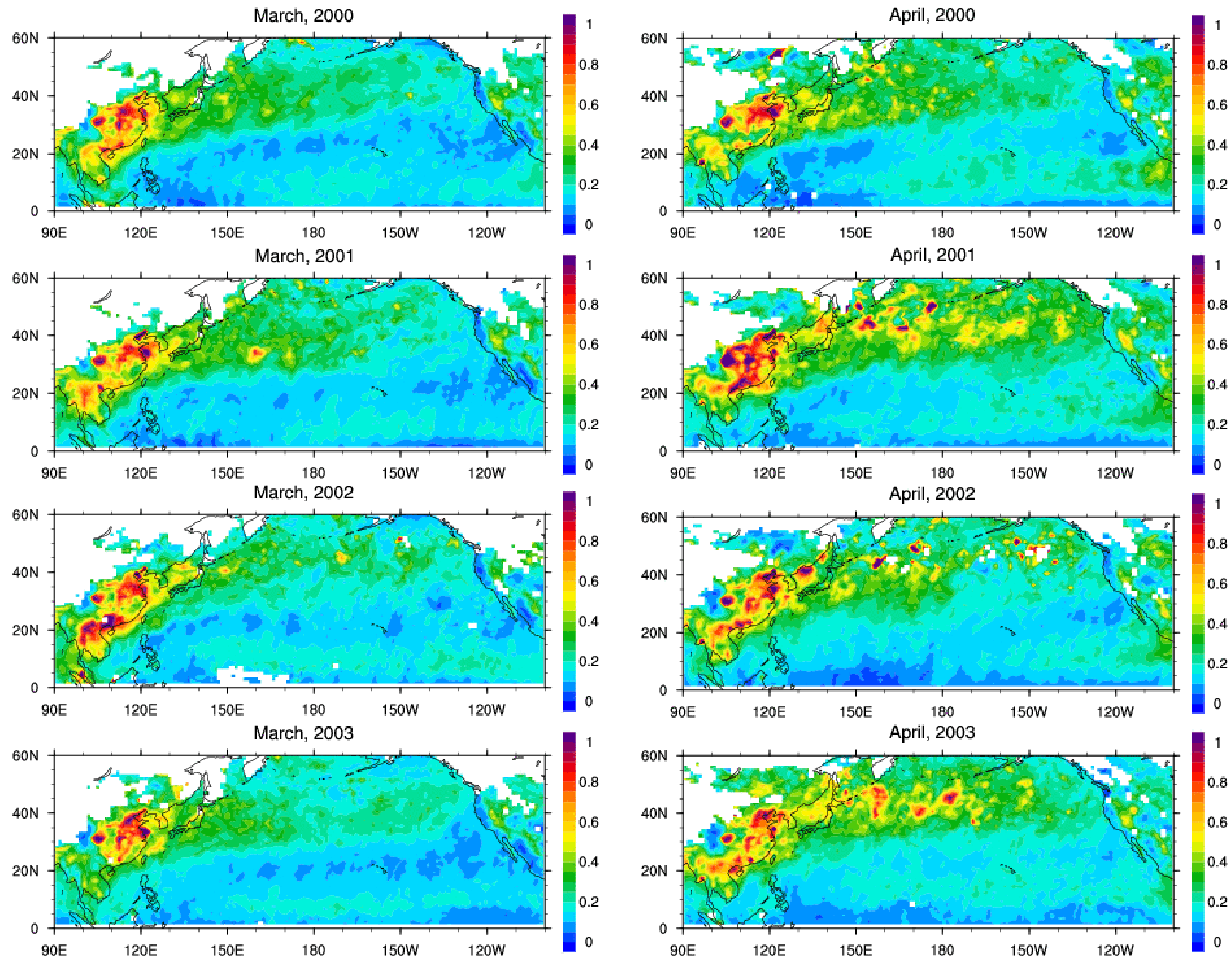


* Black carbon is highly absorbing
* Dust undergoes absorption and scattering

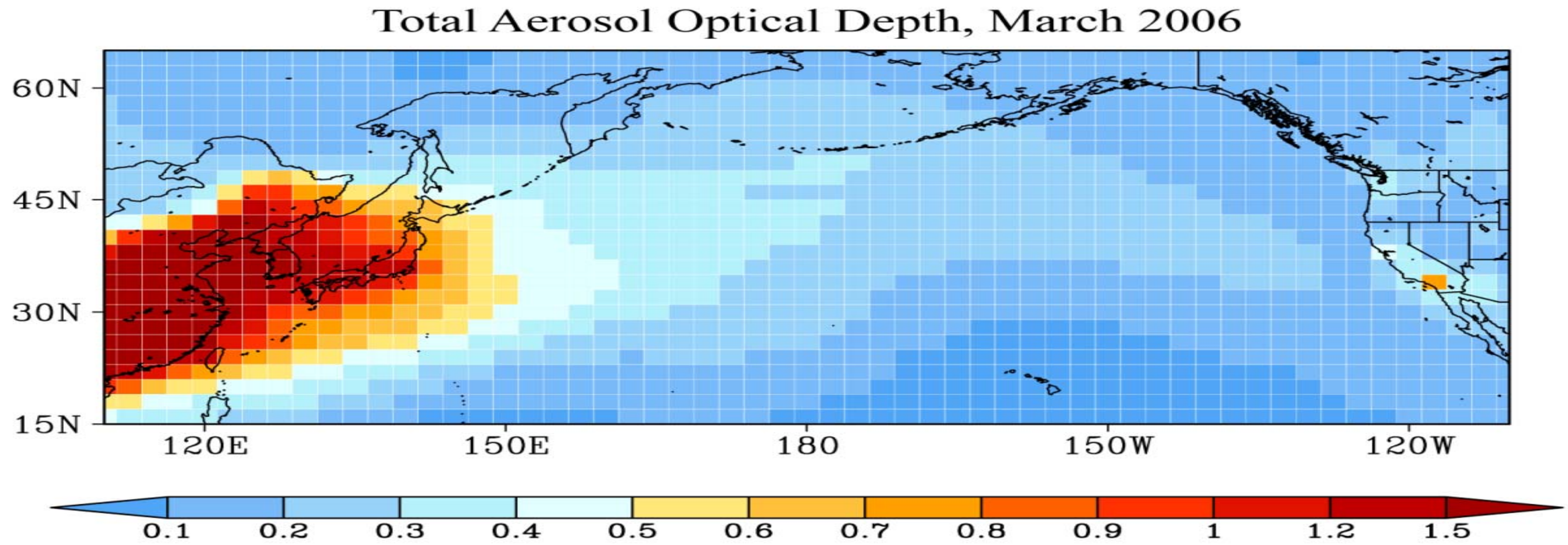
Absorption: transform to heat

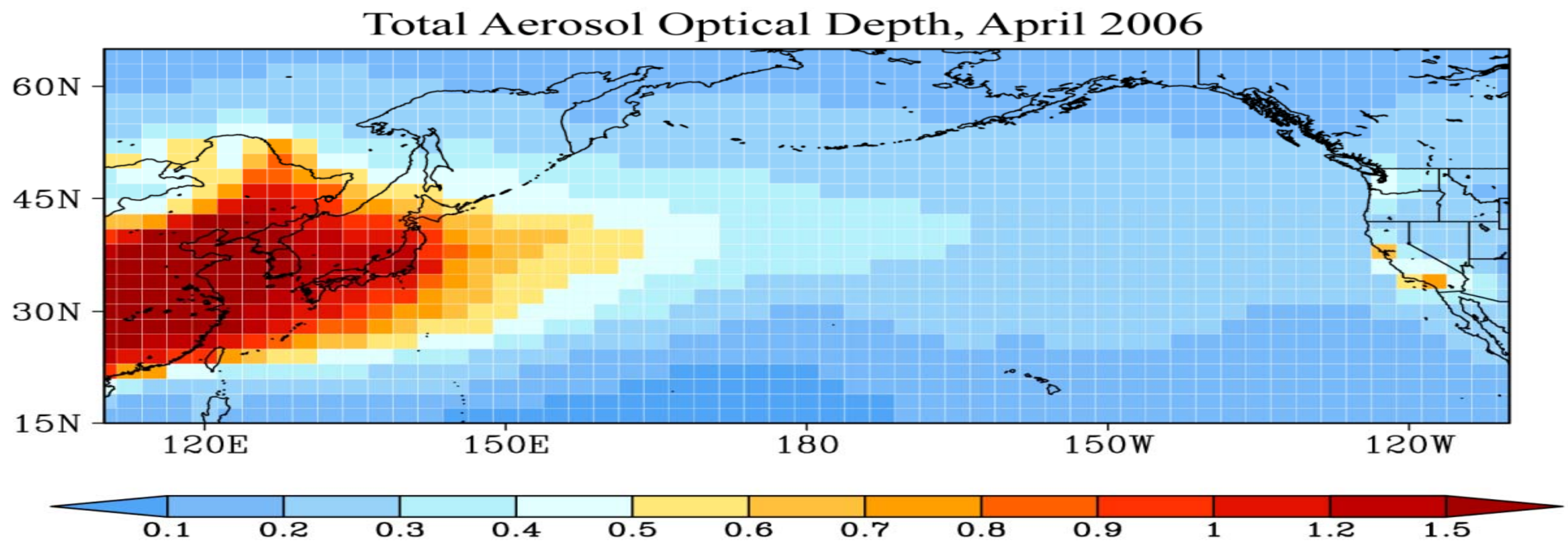
Scattering: redirect the energy to different directions

Aerosol optical depths determined from MODIS of NASA satellites for March and April, 2000-2008, a 9 year period, illustrating the transport of absorbing aerosols from China and Southeast Asia across the Pacific to the United States.



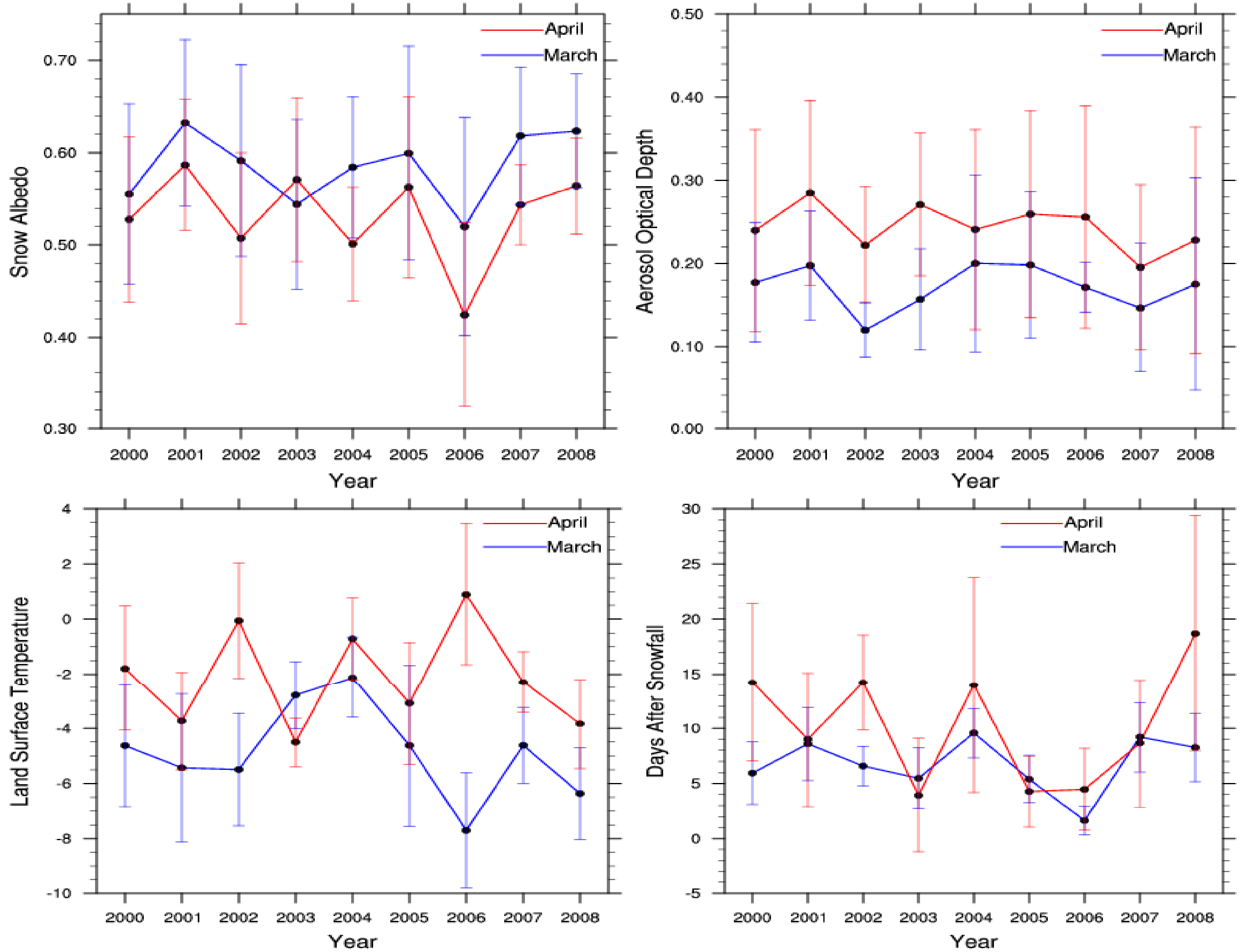
Total aerosol optical depths for March and April, 2006 simulated from a chemical transport model, illustrating the effects of absorbing aerosols generated in China on the west coast of the United States (courtesy of Q. Li, UCLA).



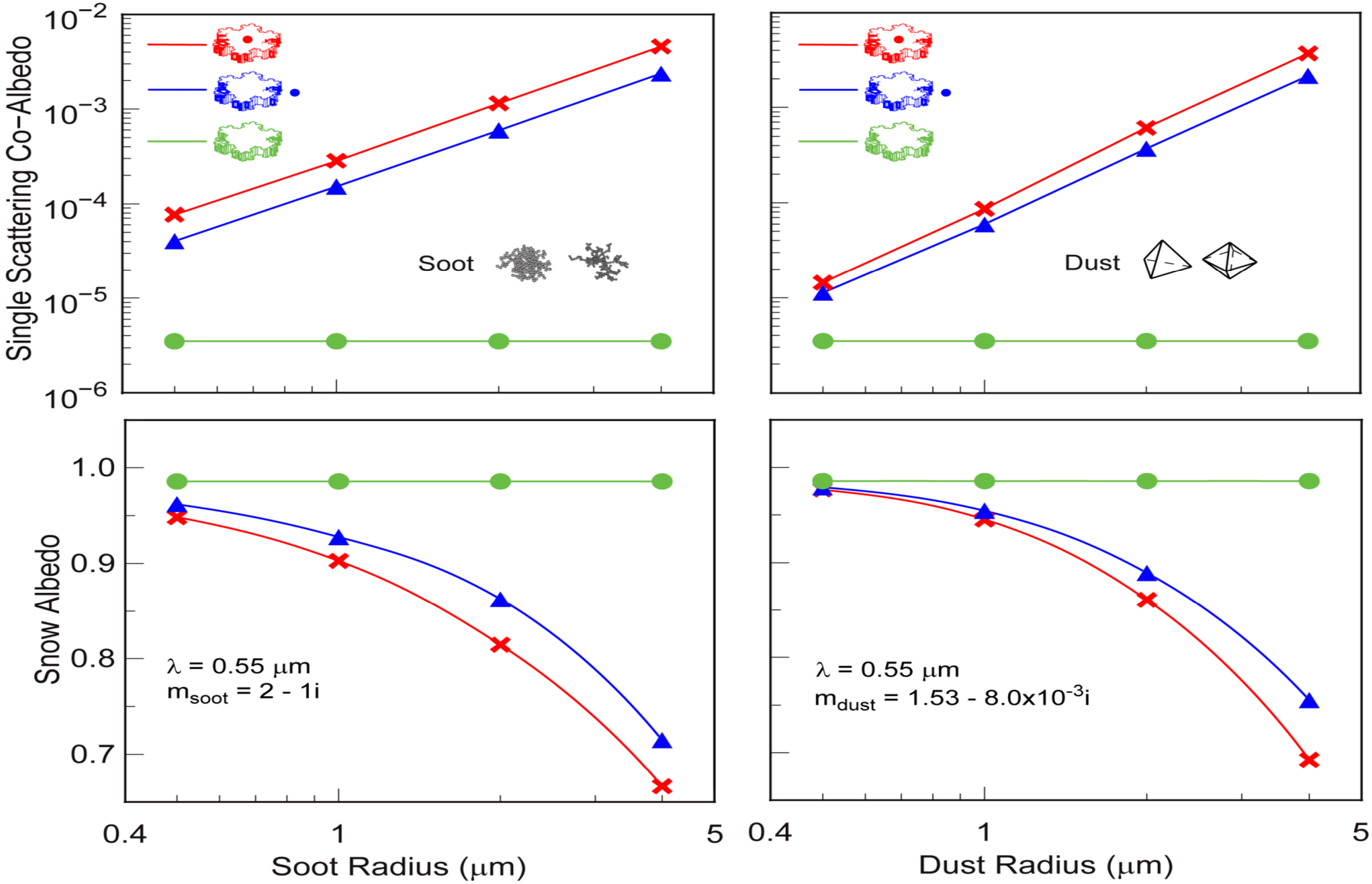



Sierra Nevada Mountains:
BC/Dust-Snow Impact on Regional Climate

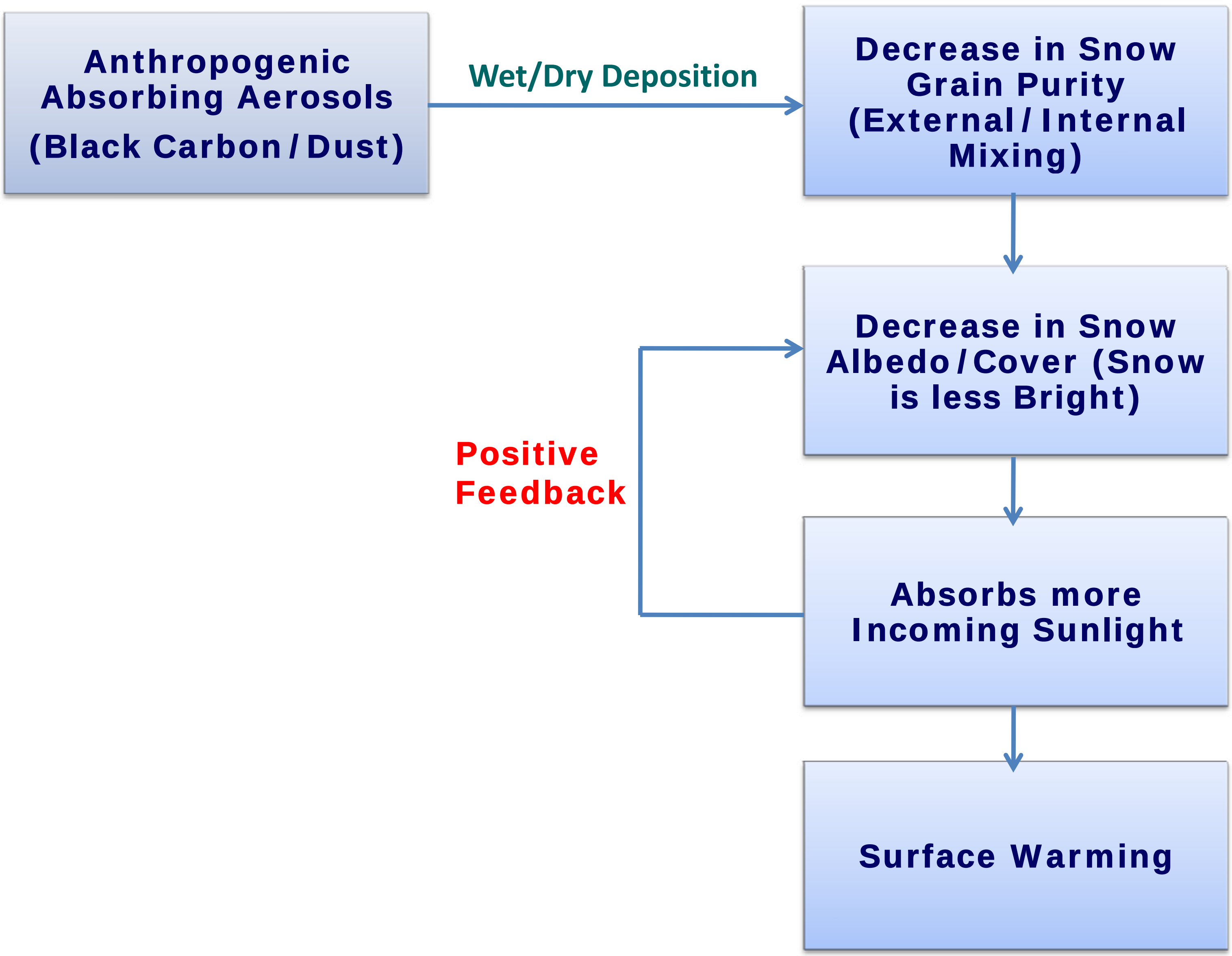
Monthly mean snow albedo and aerosol optical depth over the Sierra Nevada Mountains for March and April, 2000 to 2008.



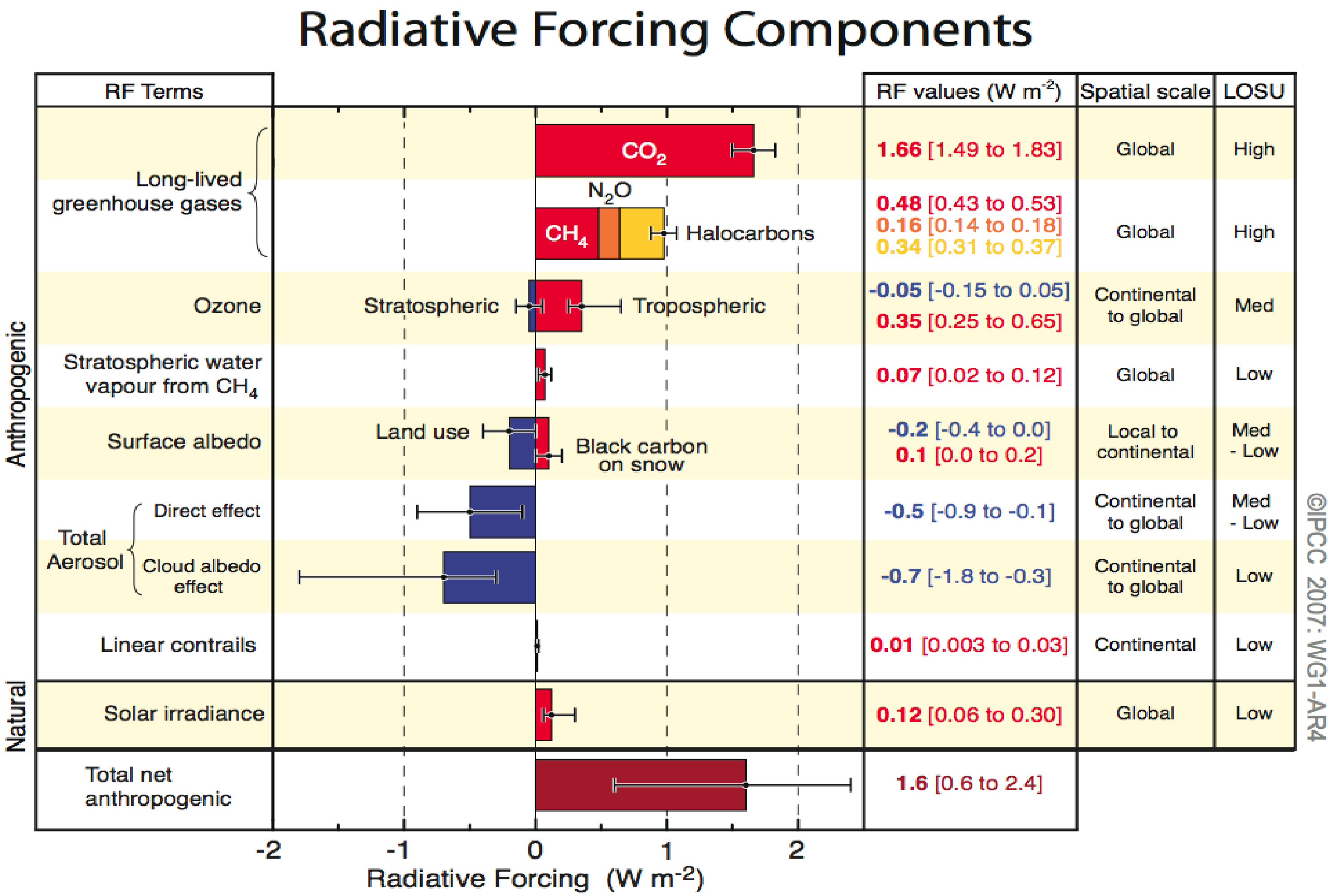
Single-scattering co-albedo (the ratio of absorption and extinction coefficients) and snow albedo as a function of soot and dust equivalent radii for a snow grain (snowflake, see attached) of 50 μm in diameter. Large differences in snow albedo are shown with absorbing aerosol contamination.



An Illustration of Snow-Albedo Feedback due to Absorbing Aerosols



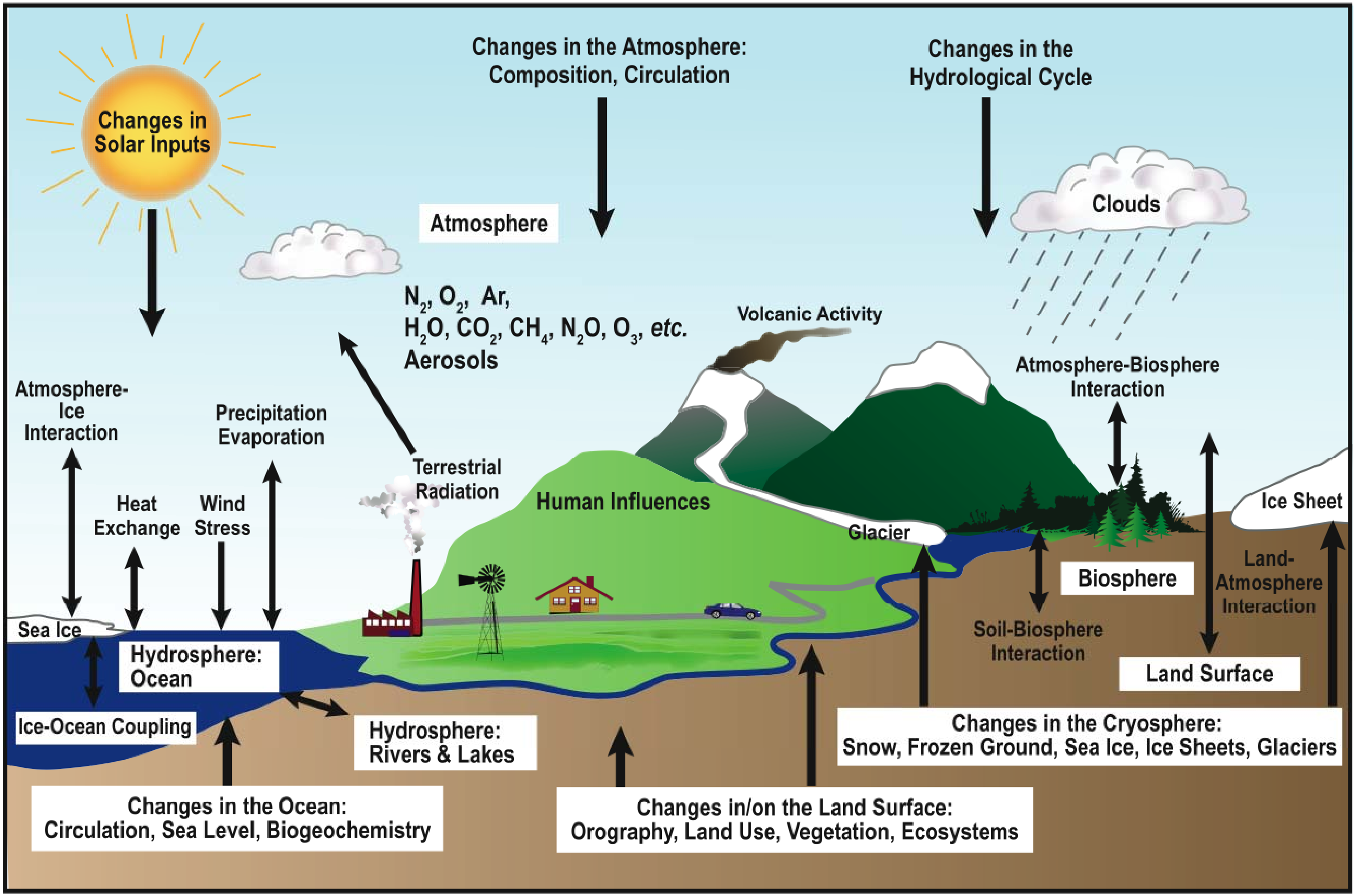
Human and Natural Drivers of Climate Change



Effects of Climate Change on California: A Research Frontier

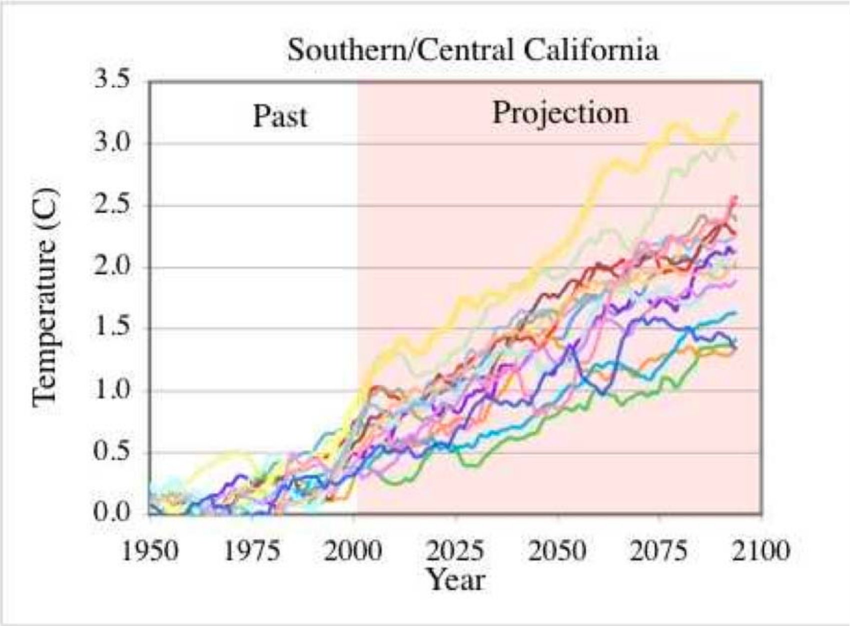
- Precipitation and snow distribution (mountain ecosystems, ski industry)
- Water resources and management
- Santa Ana events (human health, wildfire)
- Runoff/streamflow (coastal wetlands)
- Sea surface temperatures (ocean ecosystems)
- Building a regional Earth system model: Mountains/snow and absorbing aerosols

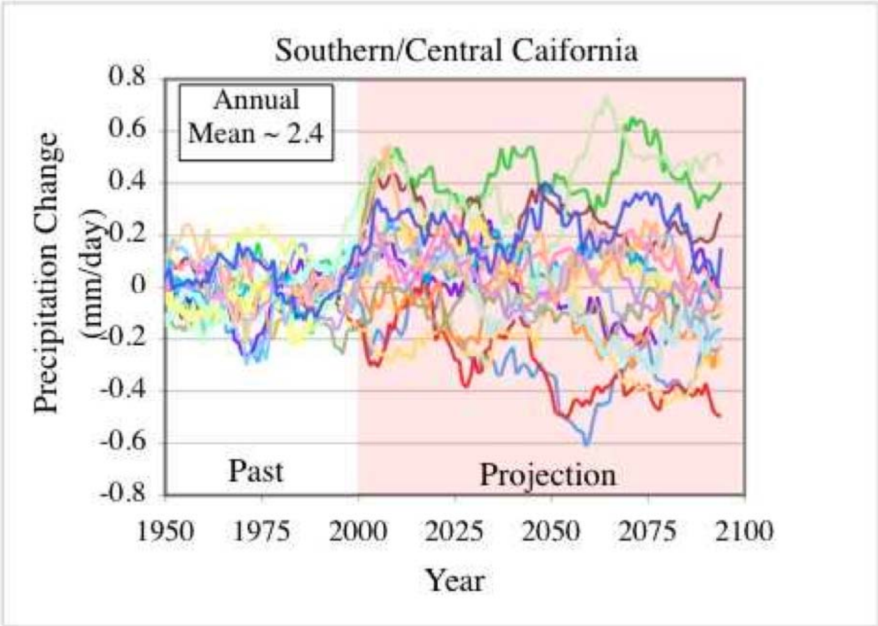
Climate Models



Regional Climate Modeling

Global Climate Models (GCMs) used for climate projections (e.g., IPCC, ~200x200km^2) do not have the resolution to adequately represent many physical processes (e.g., topography, land-sea effects, soil & vegetation variations, cloud systems) nor the capacity to represent many physically important and socially relevant processes (e.g., streamflow, atmospheric composition, water quality).

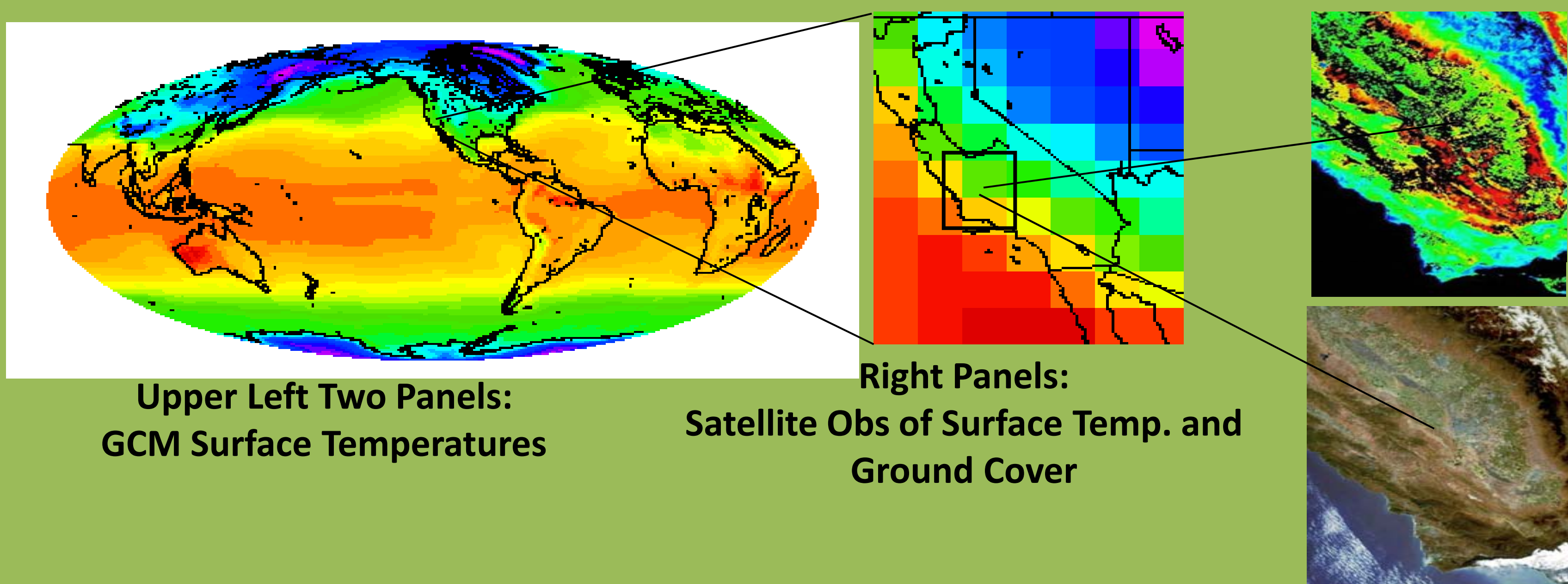




IPCC AR4 model projections agree that California will warm in this century but disagree on whether it will become wetter/drier. This implies that some physical processes are inadequately represented in GCMs.

Satellite Observations

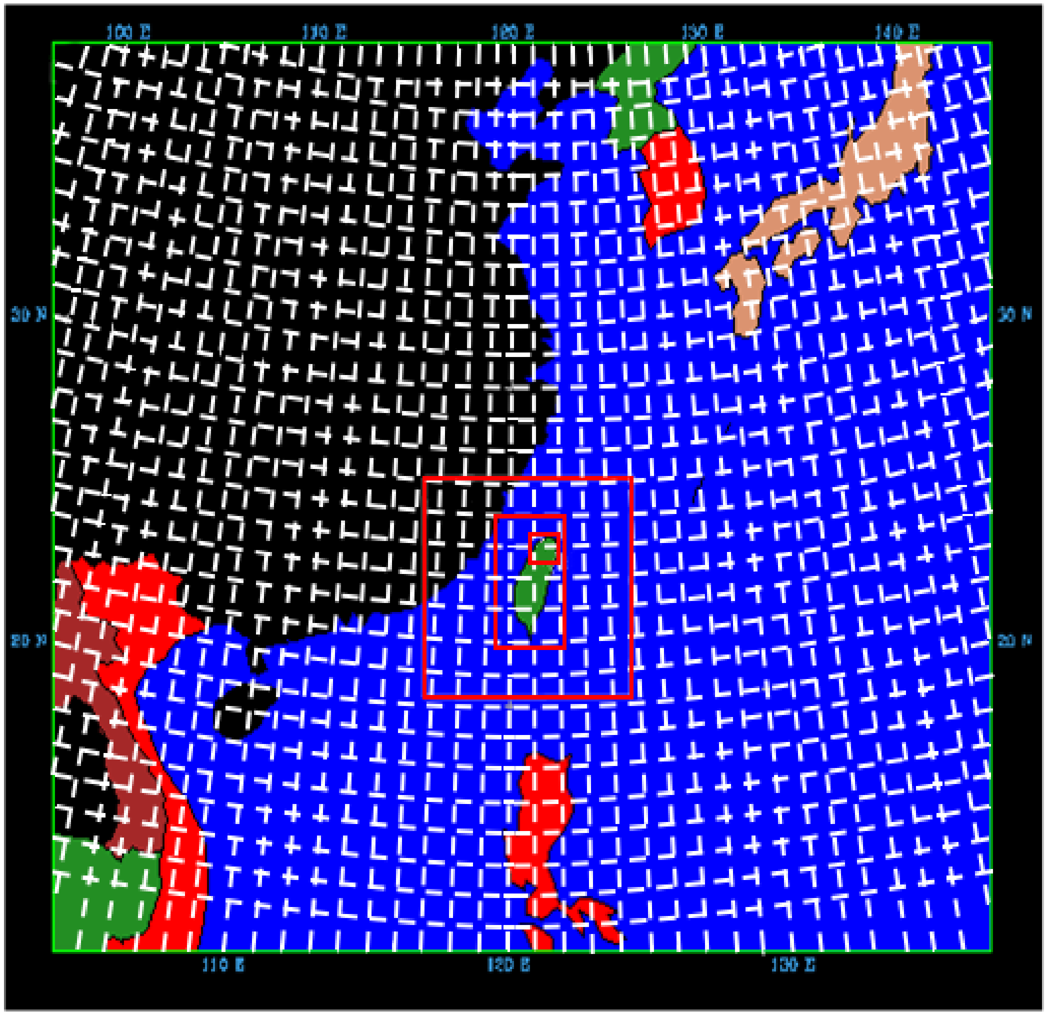
- A vast amount of present-day high-resolution satellite data goes unexploited in regards to model development and validation due to the much lower GCM grid resolution.
- These products are not often used synergistically in a single modeling context to more thoroughly constrain and validate a given model.
- RESMs can facilitate satellite mission development and instrument design by better quantifying spatial/temporal dependencies of variance characteristics of both the signal and noise of processes relevant to the target retrievals.



Upper Left Two Panels:
GCM Surface Temperatures

Right Panels:
Satellite Obs of Surface Temp. and Ground Cover

Global and Regional Climate Models (Horizontal Resolutions)



*Prepared by Drs. Chia Chou, Chuan-Yao Lin, and Wei-Liang Lee (Academia Sinica)

To mitigate societal impact, adapt to climate change and global warming, and achieve sustainability, Taiwan must develop a physically-based, credible regional climate model for projection and prediction studies.

- Current global climate models (coupled the atmosphere and oceans), horizontal resolution ~100 × 100 km² (AR4 / IPCC)
- Regional models, horizontal resolution (WRF, 3 × 3 – 27 × 27 km²): mountain features and coastal oceans must be accounted for
- Coupling between the two (downscaling)