Observations, Ray-Tracing, and Data Assimilation in Aerosol Assessment

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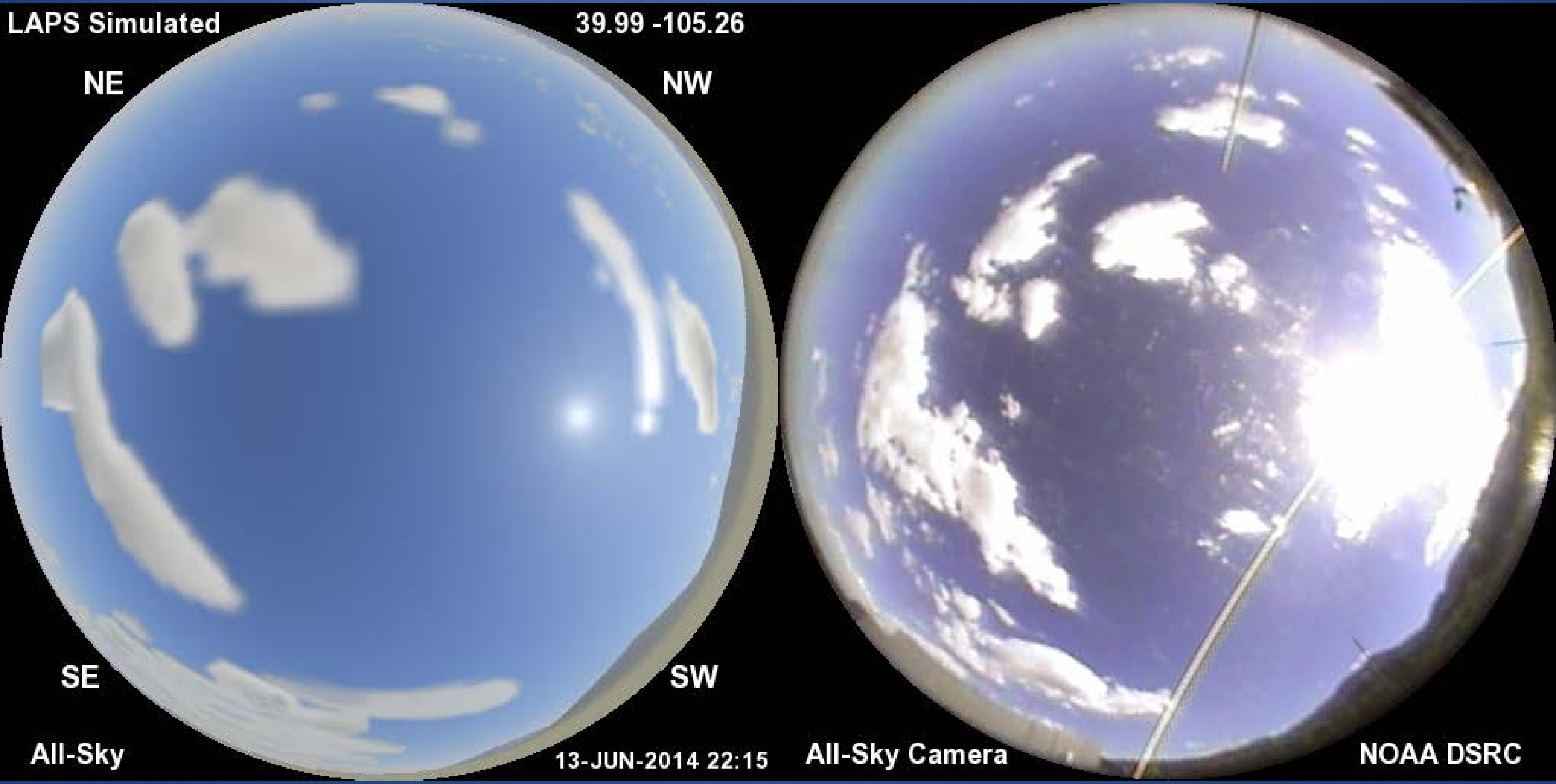
Model Simulated All-Sky Image (left) Compared with All-Sky Camera (right)



A way to peer into the model analysis (or forecast)

Simulated Weather Imagery Purpose

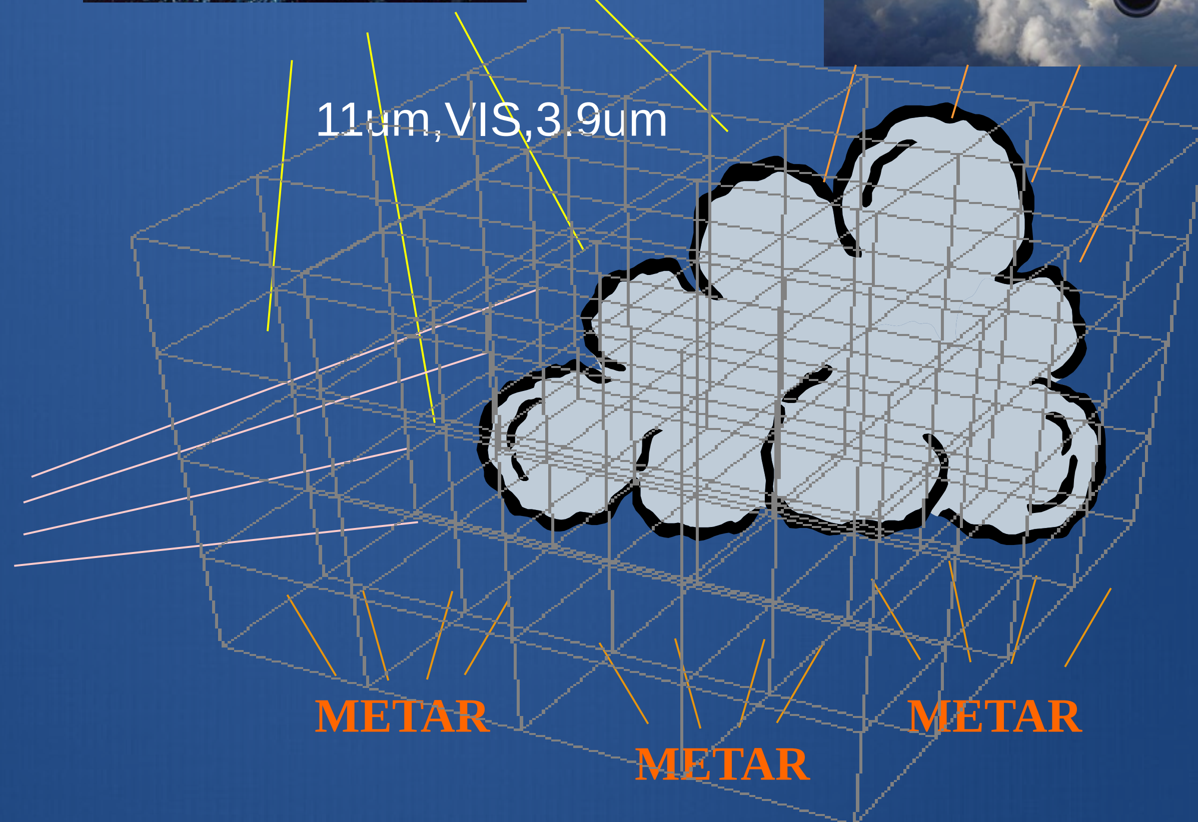
- Helps communicate capabilities of high-resolution real-time model, literally "peering inside"
  - Real-time Analyses
  - Forecasts
- Visually realistic display conveys a lot of information
  - Clouds, Precipitation, Aerosols, Land Surface
- Display output for scientific and lay audiences
  - Connect weather phenomena with what can be seen in the sky (bringing science and art together)
- Helps guide improvements in cloud, etc. analyses and model initialization
  - Sensitive independent validation of both model fields and visualization package
- Potential use as an input for model data assimilation
  - Variational forward model (e.g. GSI or vLAPS)

Sky & Weather Simulation Ingredients

- 3-D cloud / hydrometeor analyses (or forecasts)
  - Cloud liquid / ice, rain, snow, graupel
  - LAPS / HRRR systems developed at ESRL/GSD (e.g.)
  - Typical grid resolution = 500m – 3km
- Land Surface (3-color spectral reflectance - including snow cover)
- Aerosol parameters
  - Optical depth (~.03-.30)
  - Scale height (~750-3000m)
  - Size distribution
- Locations of sun, moon, planets, stars
- Nighttime city lights (via VIIRS), airglow
- Specify vantage point – easily movable
  - Latitude, longitude, elevation / altitude (surface to lunar distance)
  - Viewing window up to full 360º sphere (virtual reality)

Cloud analysis (e.g. from LAPS)

First Guess →



(Albers et. al. 1996)

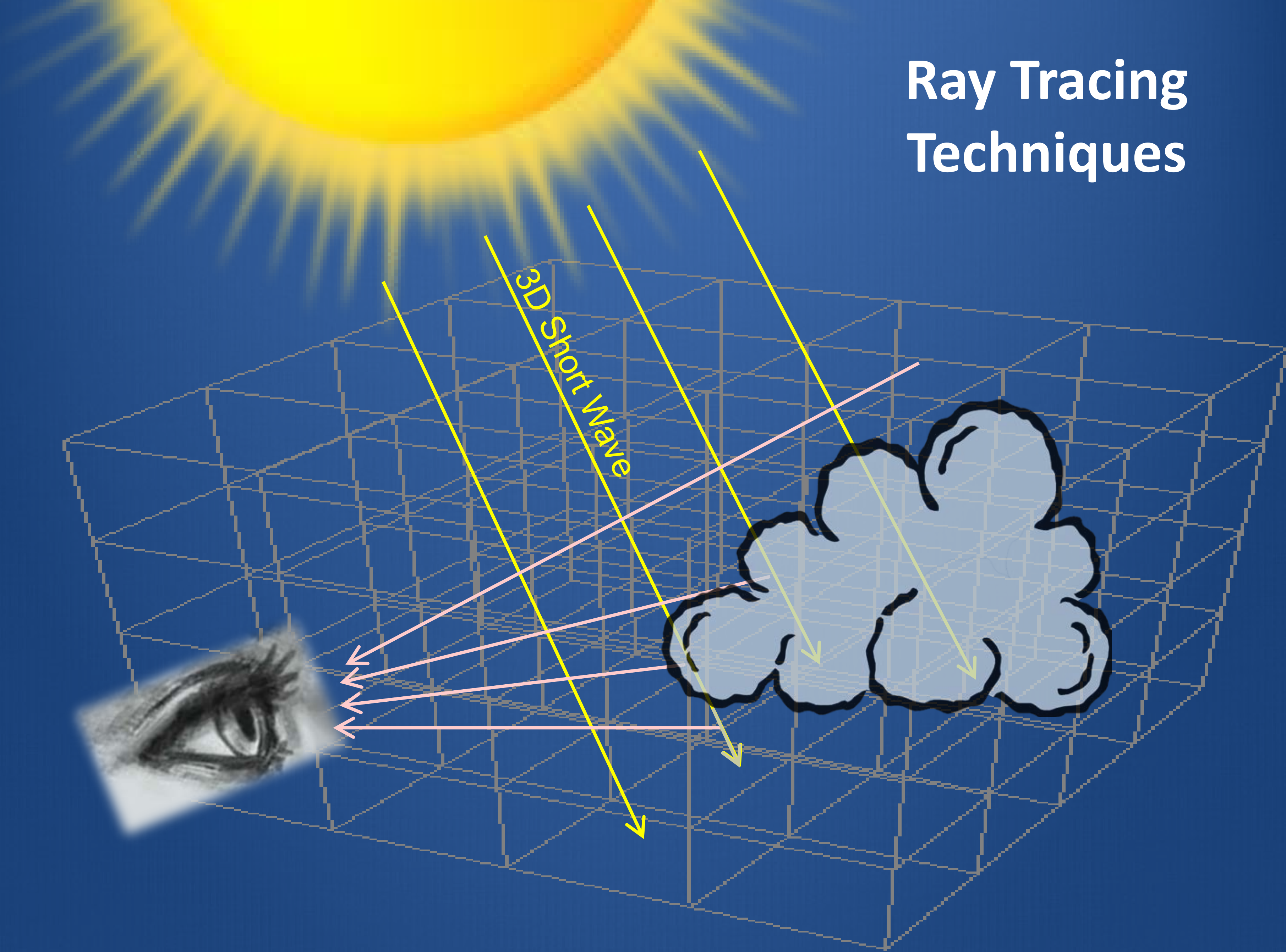
DSRC Rooftop “Moonglow” Camera

Acknowledgement to Kirk Holub (GSD) as camera engineer

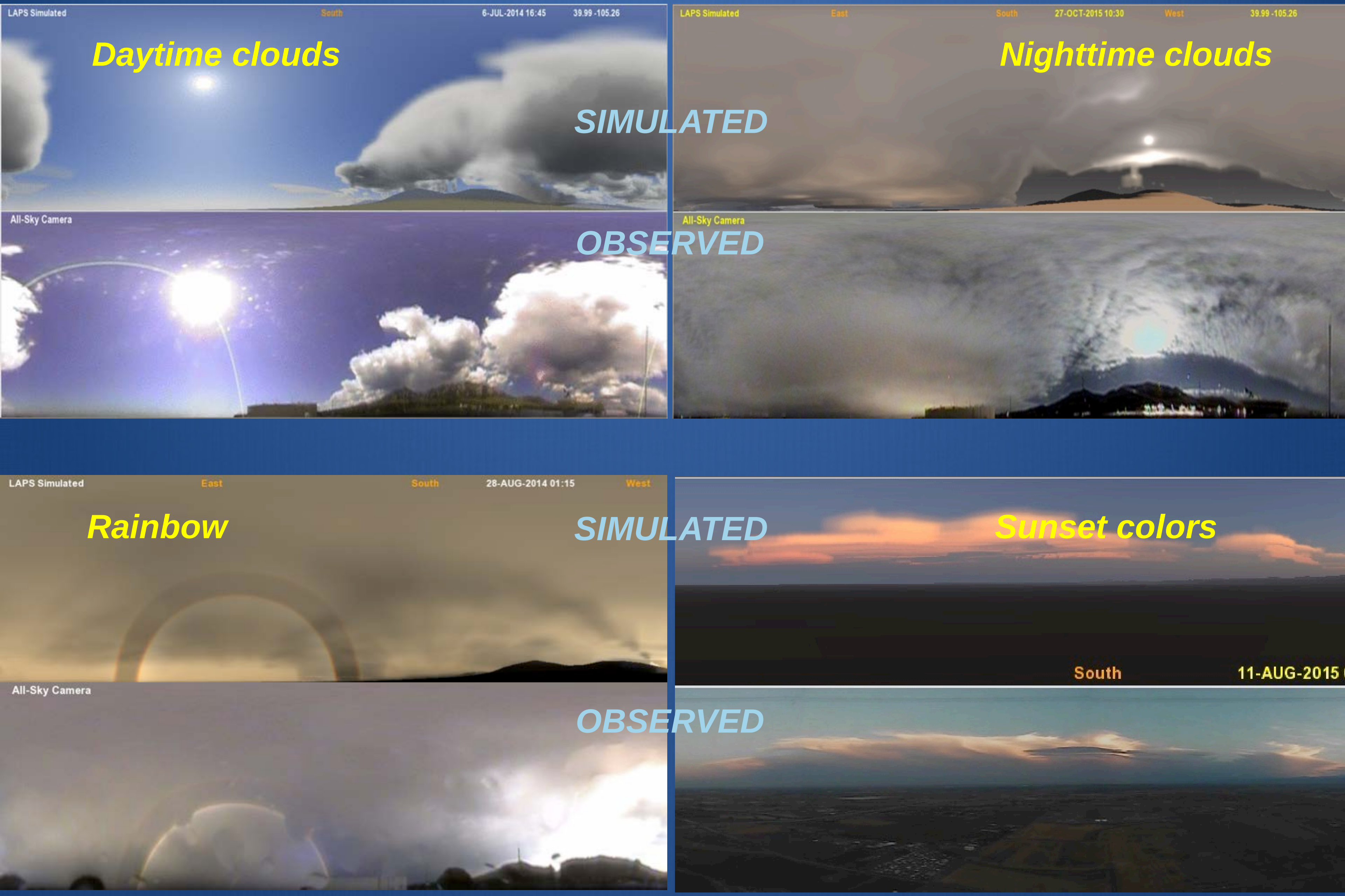
Other cameras:

- Mt. Evans webcam (Meyer-Womble Observatory Univ. of Denver)
- Longmont Astronomical Society
- 300m BAO Tower (Erie, CO)

Ray Tracing Techniques



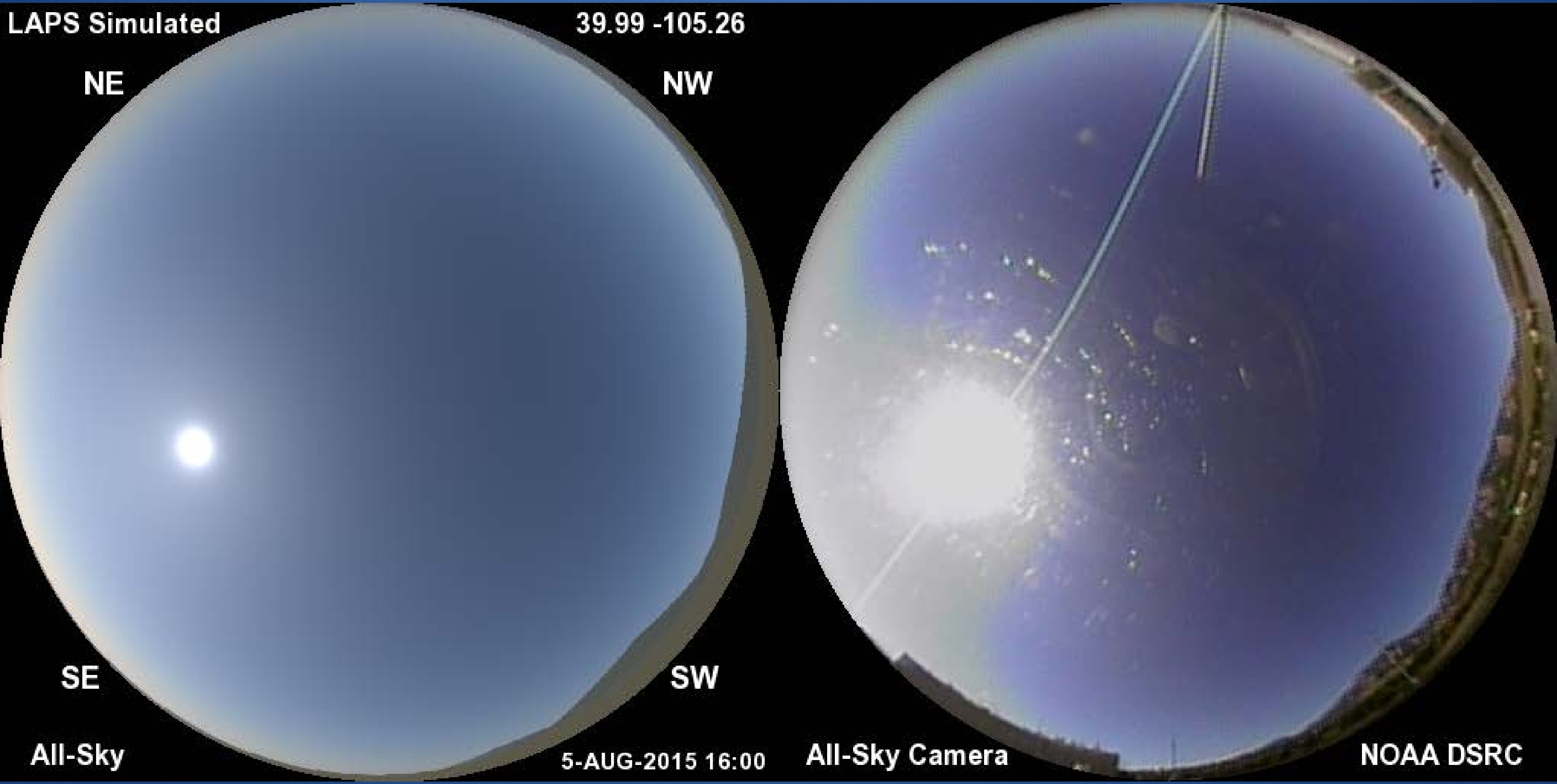
FOUR SIMULATED vs OBSERVED COMPARISONS



Ray Tracing Techniques

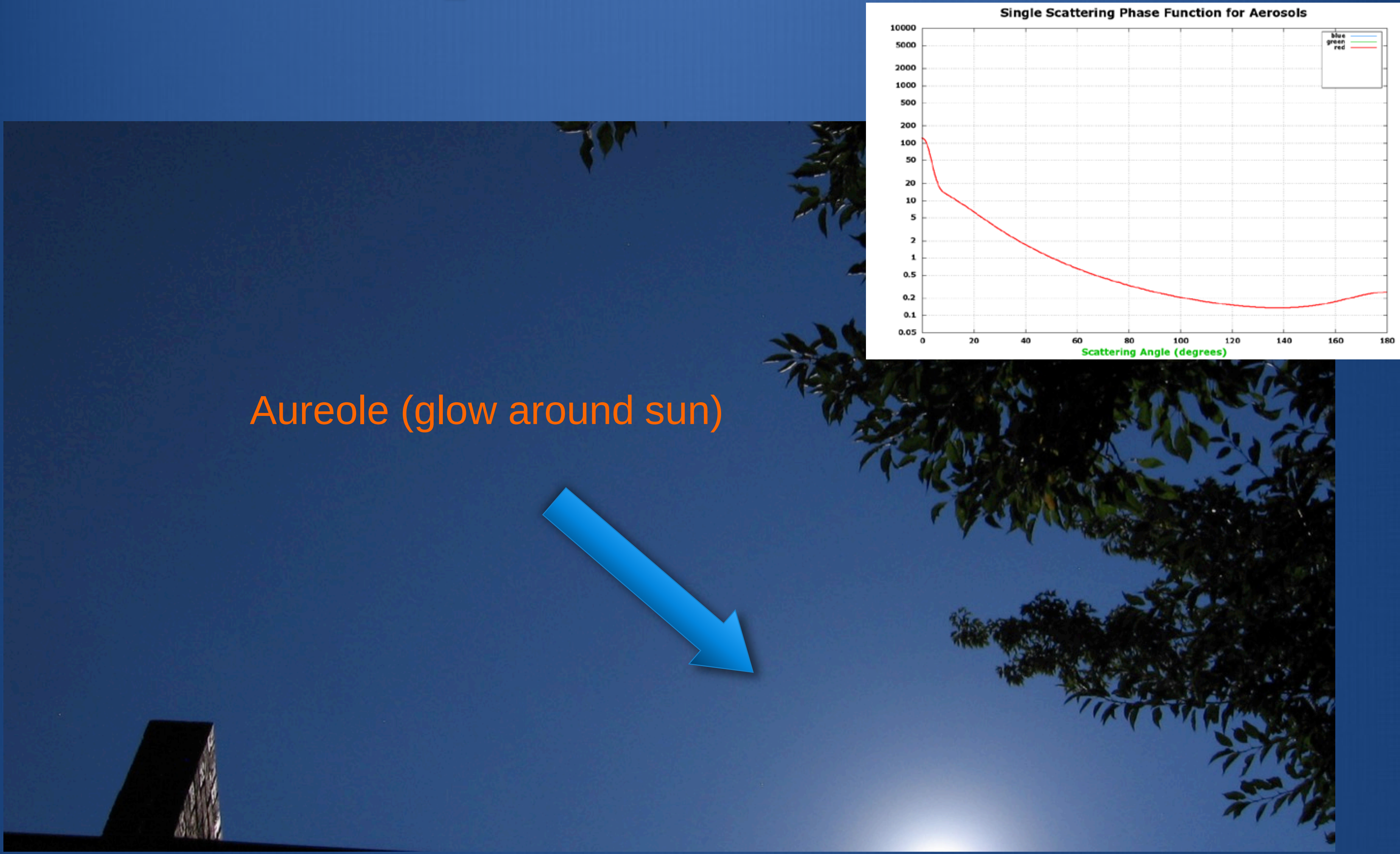
- Determine 3-D short wave radiation field
- Light scattering by hydrometeors, aerosols, gases
  - Cloud liquid / ice, rain, snow, graupel
  - Determine optical thickness along light ray paths
  - Rayleigh and Mie scattering
  - Single / Multiple scattering phase functions
  - Calculated using 3 colors
  - Shadowing effects and terrain
- Light scattering by land / water / snow surface
  - Spectral albedo and reflectance (BRDF) used
  - Spectral Solar Irradiance fields (GHI, DNI) - Renewable Energy Link
  - Terrain slope considered

Daylight Clear Sky



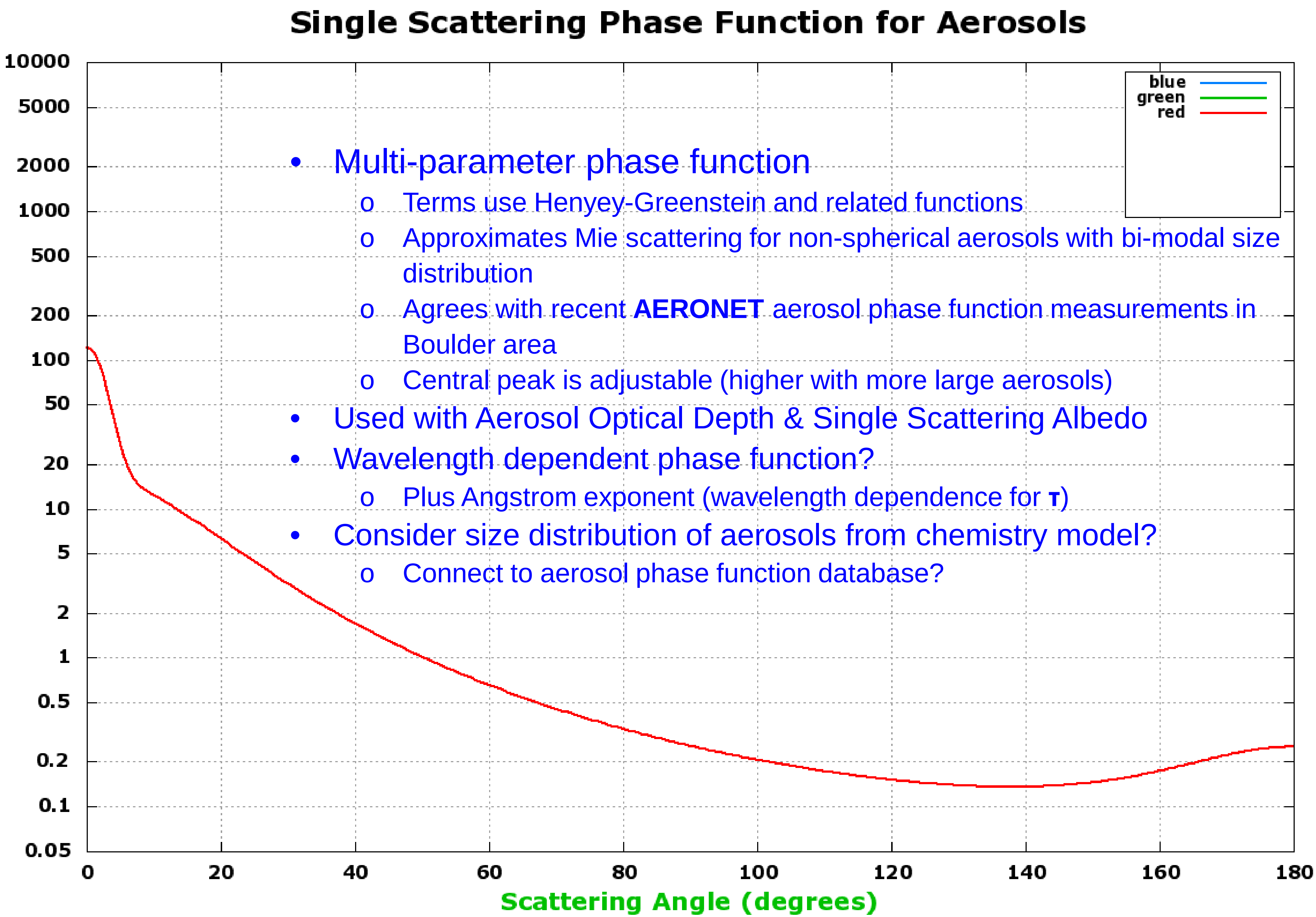
- Low aerosol content (**τ~.05**) with aureole around the sun
- Bimodal aerosol size distribution contributes to condensed aureole
- Standard gamma brightness function to match camera image
- Image brightness proportional to actual scene enhances realism

Closeup of Solar Aureole



Aerosols modeled with vertical extinction coefficient profile and scattering phase function. Phase function and Angstrom exponent depend on size distribution

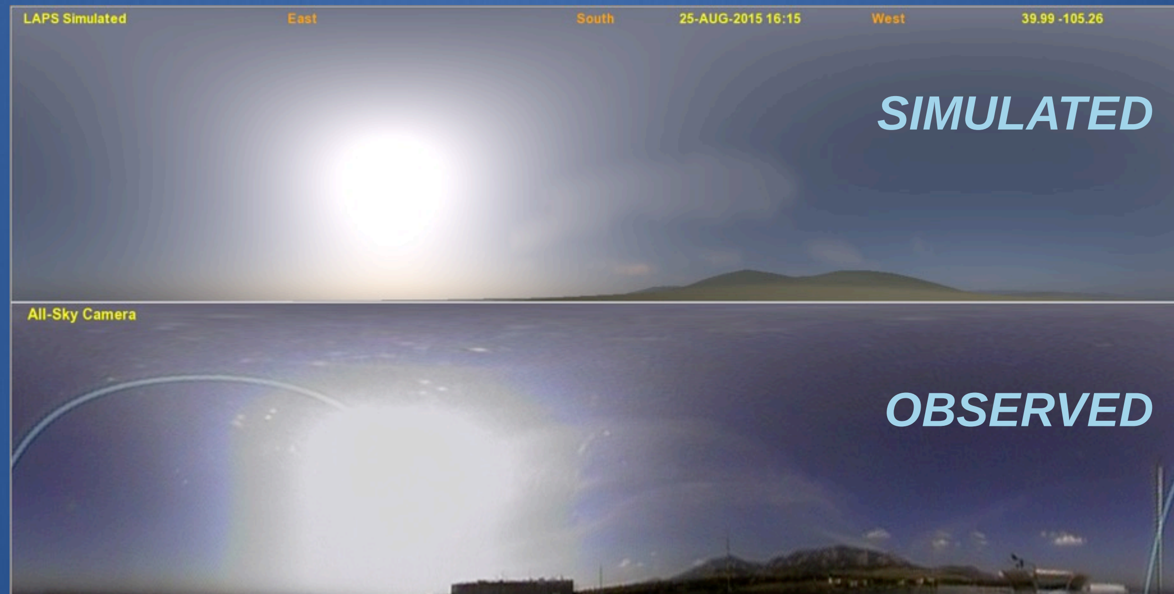
Aerosol Scattering Phase Function



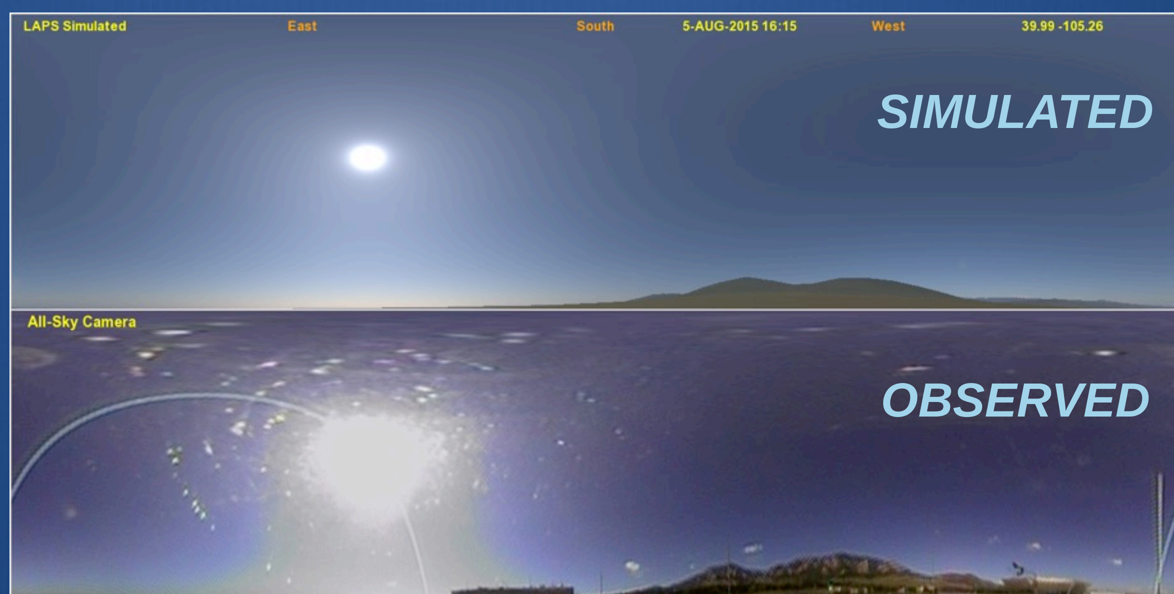
- Multi-parameter phase function
  - Terms use Henyey-Greenstein and related functions
  - Approximates Mie scattering for non-spherical aerosols with bi-modal size distribution
  - Agrees with recent **AERONET** aerosol phase function measurements in Boulder area
  - Central peak is adjustable (higher with more large aerosols)
- Used with Aerosol Optical Depth & Single Scattering Albedo
- Wavelength dependent phase function?
  - Plus Angstrom exponent (wavelength dependence for **τ**)
- Consider size distribution of aerosols from chemistry model?
  - Connect to aerosol phase function database?

Smoke Event Comparisons

AOD ~ 0.23



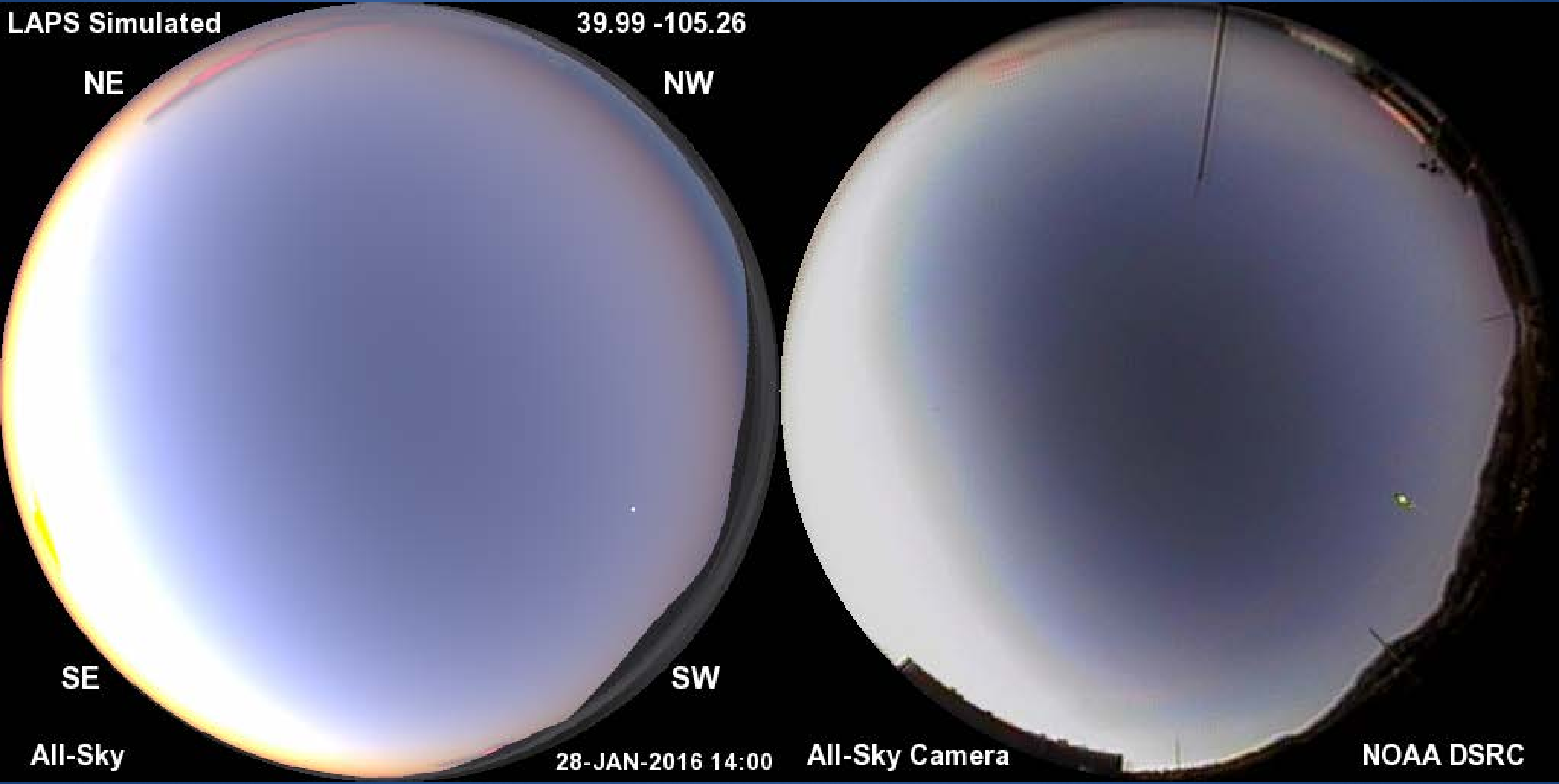
AOD ~ 0.05



Twilight Comparison – BAO Tower

Colors relate to handling of multiple scattering & ozone absorption
Stratospheric (and tropospheric) aerosols can affect twilight appearance

Twilight Comparison – Fisheye View



Colors relate to handling of multiple scattering & ozone absorption
Stratospheric (and tropospheric) aerosols can affect twilight brightness

Nighttime Comparison atop 300m BAO Tower in Erie, CO

SIMULATED

OBSERVED

Lunar aureole is bright in this example

VIIRS stable nightlights used in simulation

Good alignment of city lights on larger scales

City lights show aerosol scattering localized over Denver (observed)

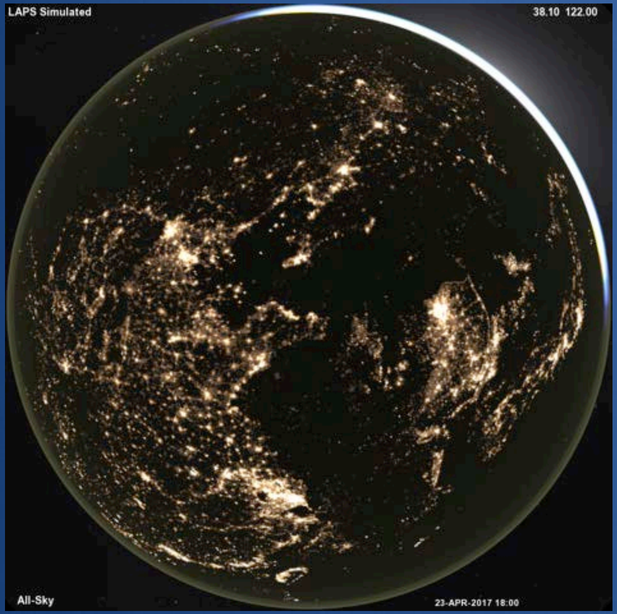
Aerosol Observation Platforms

- **Camera**
  - o **Scattered light intensity & phase function**
- **Nephelometer**
  - o **In-situ spectral measurement of extinction coefficient (AirPhoton)**
- **Aeronet**
  - o **Spectrophotometry yields spectral phase function**
  - o **Provides AOD, Angstrom exponent, size distribution**
- **Other Spectrophotometry**
  - o **Solar / Moon / Star extinction vs zenith angle**
  - o **Yields AOD and potentially vertical / horizontal distribution**
  - o **Airmass calculation is non-linear vs *sec*(z) near the horizon from Earth curvature and aerosol scale height**
- **Small Telescope**
  - o **Concurrent star extinction measurements throughout sky**

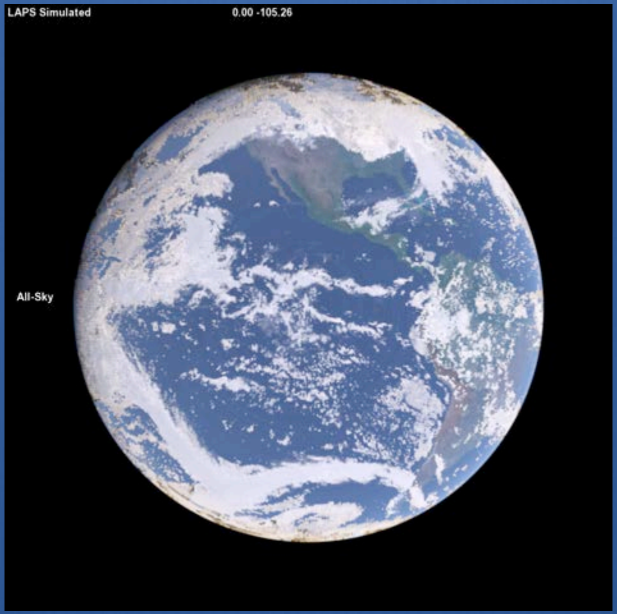
Aerosol Observation Platforms (cont)

- Balloon / Glider
  - Miniaturized Aeronet like package - experimental at ESRL/CSD
- LIDAR
- Satellite

Miscellaneous Simulations



Twilight / Airglow 790km up
+ City Lights, Zodiacal Light, Galactic Glow



Earth global view
Compare with DSCOVR / Himawari

Lunar Eclipse
Sensitive to stratospheric aerosols, ozone, clouds

Martian Sky – Mainly Dust

Future Directions

- Improve ray-tracing techniques
  - Monte Carlo methods?
- Improve scattering phase functions
- Connect with microphysics packages and chemistry models
  - Details on hydrometeor & aerosol species
  - FIM global model and WRF-Chem

Variational Cloud / Aerosol Analysis

- Variational cloud analysis currently under development
  - based on existing LAPS and GSI cloud analyses
- Simultaneous solution with all types of data + constraints
- Use satellite radiance (e.g. CRTM) or algorithm products (e.g. CWP, AOD)
  - radiances may blend more naturally with other types of data
- Radars used for precipitating hydrometeors
- Appropriate forward models and constraints
  - constraints between state variables and hydrometeor fields
- Will use all-sky cameras + all aerosol obs as input data

The sky is the limit!

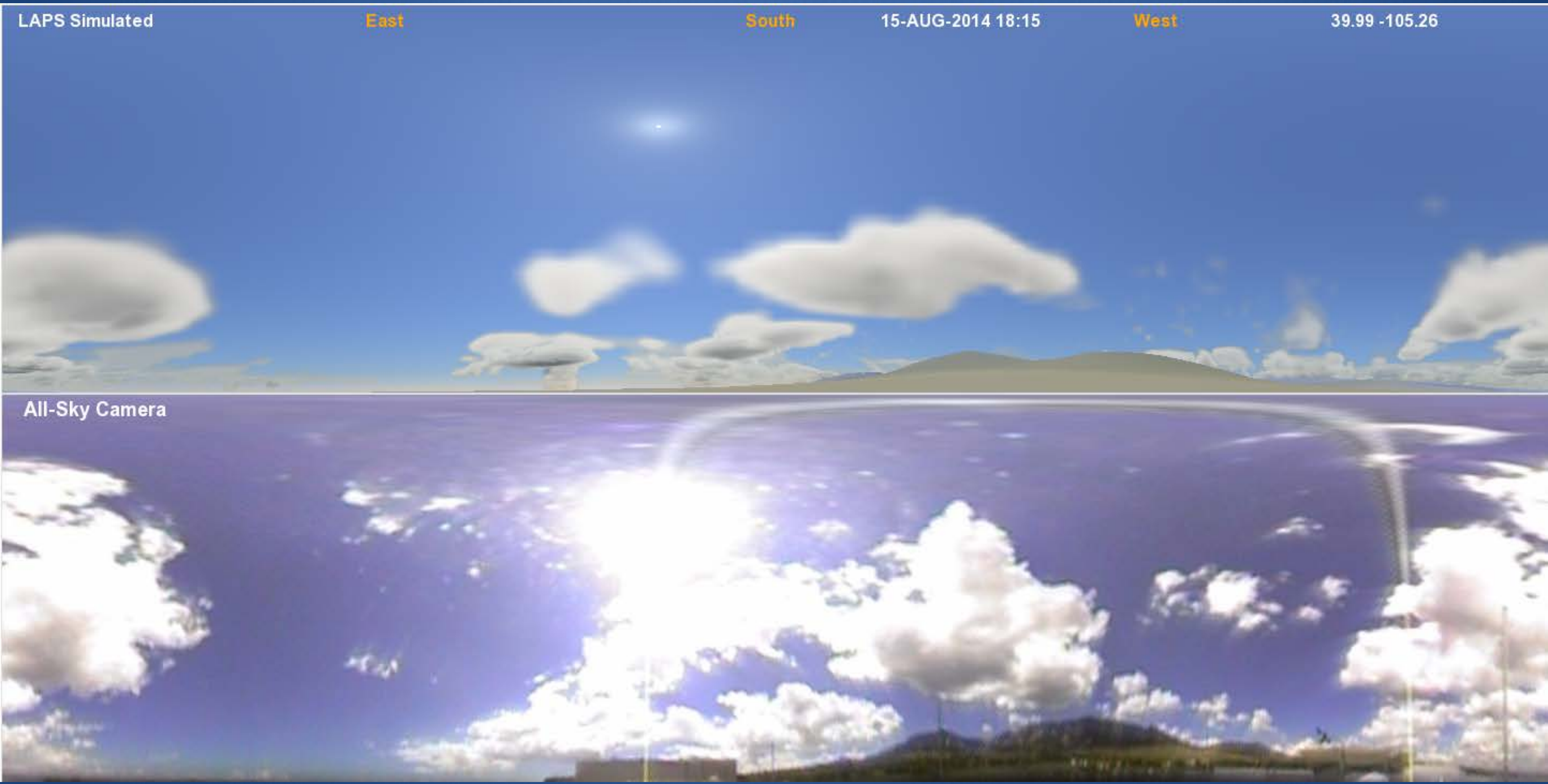
“Launch” into the stratosphere (40km up), 360º spherical view

More at laps.noaa.gov/allsky/allsky.cgi OR steve.albers@noaa.gov

Backup Slides

Cylindrical Panorama Comparison

(1/4 degree resolution)

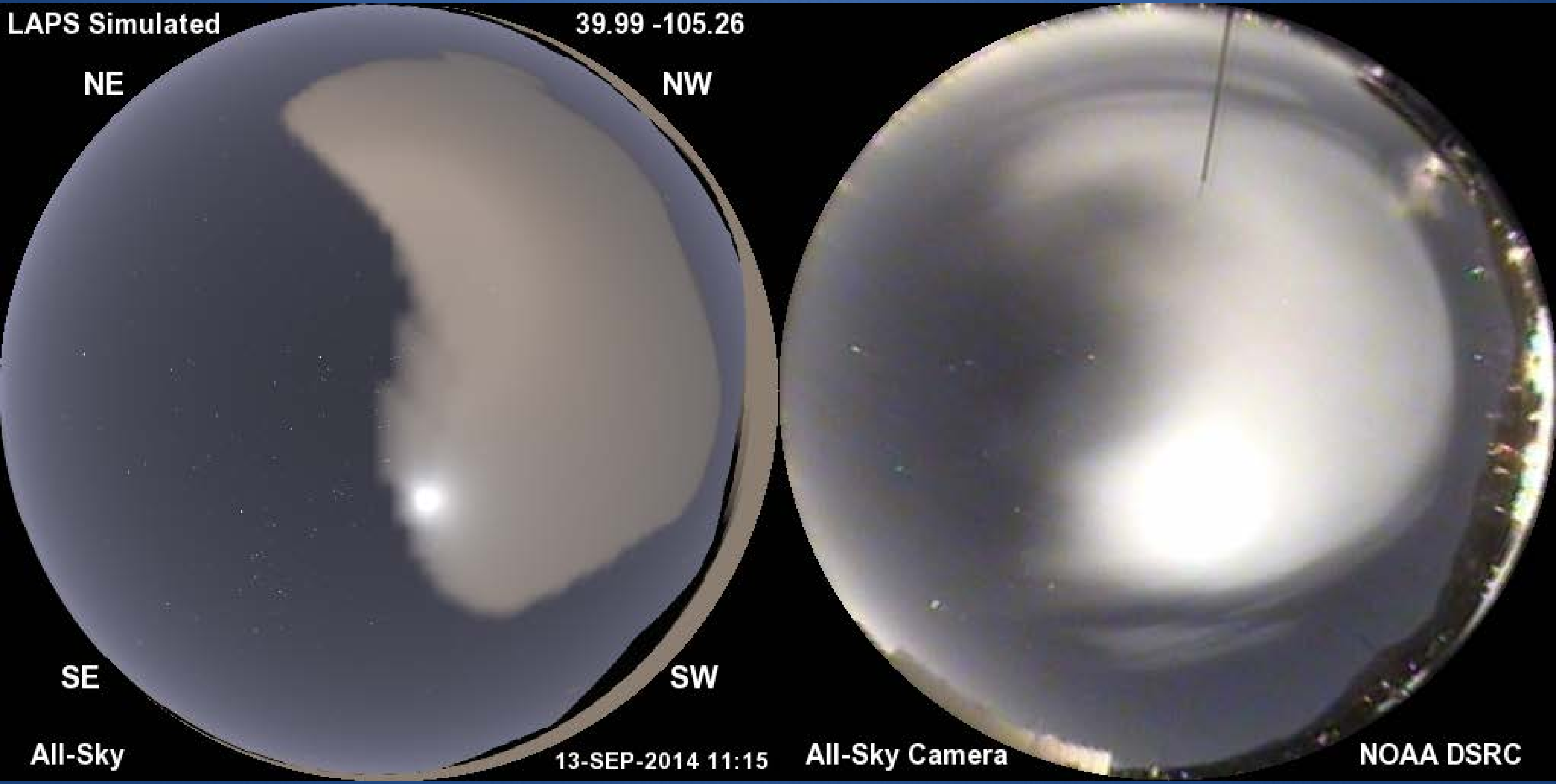


Top: simulated sky via LAPS analysis (independent of camera)
Bottom: observed sky ("Moonglow" camera atop ESRL)

Future Directions - II

- More cameras, via NOAA's observing systems?
  - Add to ASOS?
  - FAA camera networks (e.g. Alaska)
  - Airborne cameras?
  - CSTAR / AWIPS
- Data assimilation with variational cloud and GSI analysis
  - Efforts underway to use GSI cloud/hydrometeor analysis (used in HRRR/RAP) with all-sky forward model for nowcasting.
  - Use derived METAR, cloud mask, image correlation, or spectral radiances
  - Check applicabilty of available RTMs

Nighttime Clouds (and stars)



Illumination by moonlight and artificial surface lighting


LAPS Simulated
South
20-APR-2014 20:15
39.99 -105.26
The sky is the limit!


All-Sky Camera
More at laps.noaa.gov/allsky/allsky.cgi