Simulated Weather Imagery (SWIm): a Fast 3-D Visible Radiative Transfer Procedure for Visualization and Forward Modeling

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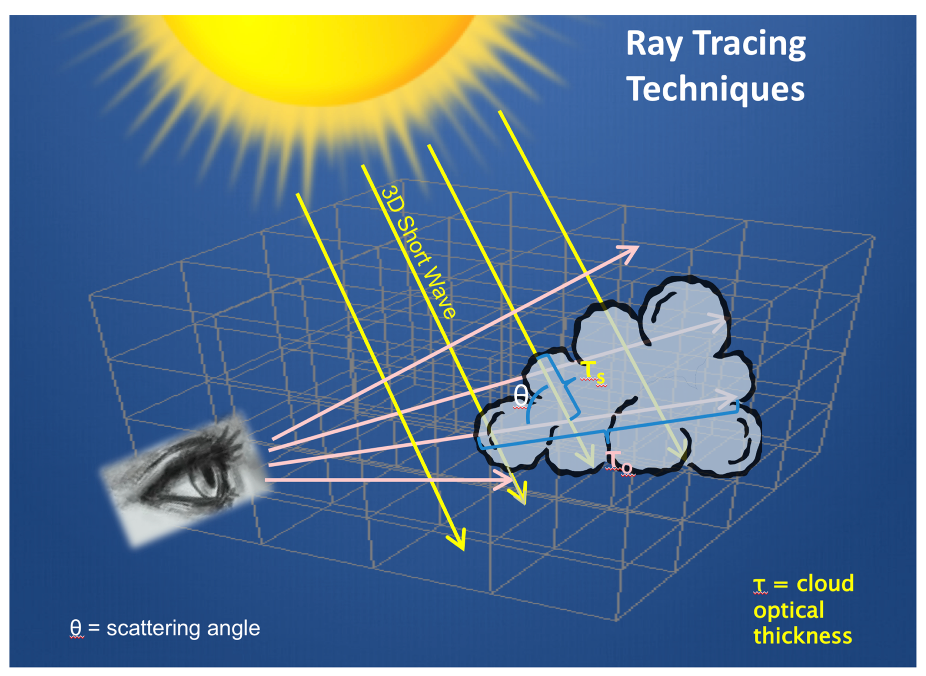
Purpose

Based on analyzed/model states, create visually & physically realistic 3D Simulated Weather Imagery (SWIm)

- Helps communicate capabilities of high-resolution cloud models, literally "peering inside"
- Display output for scientific and lay audiences
- Sensitive **independent validation**
  - cloud microphysics, aerosols, land surface, short wave radiation
- Visual display conveys a lot of information, helping with forecast **communication**
  - public forecast dissemination via web, media
- Helps guide improvements in cloud, etc. analyses and model initialization
- Cameras represent a potential data source for model data **assimilation,** while the sky simulation package can be used as a forward model to translate the model variables into camera-like images



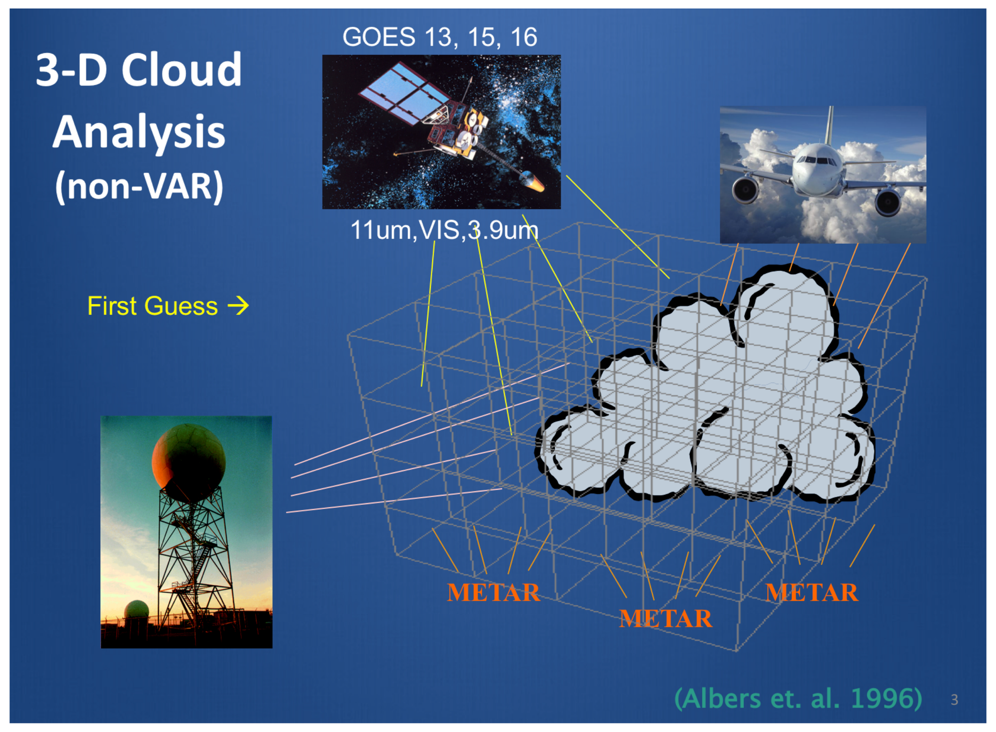
Simulation Ingredients

- 3-D 500m Resolution Gridded Cloud / Hydrometeor Analyses (cloud liquid, ice, rain, snow)
- Various models (analyses/forecasts) and resolutions
  - tested with LAPS – (a proxy for the RUA), HRRR, FIM, NAVGEM, RAMS
- Specification of Aerosols (3-D extinction coefficient)
- Atmospheric Pressure (for gas component)
- Vantage points can be ground-, air-, or space-based
- Location of Sun and other light sources (moon, planets, stars, artificial lights)
  - works day and night

Simulated 3h Forecast, Seward AK

- Above example from HRRR developed at ESRL
- Can be implemented in weather offices for forecaster use and public dissemination

Three-Dimensional Cloud Analysis (non-variational)

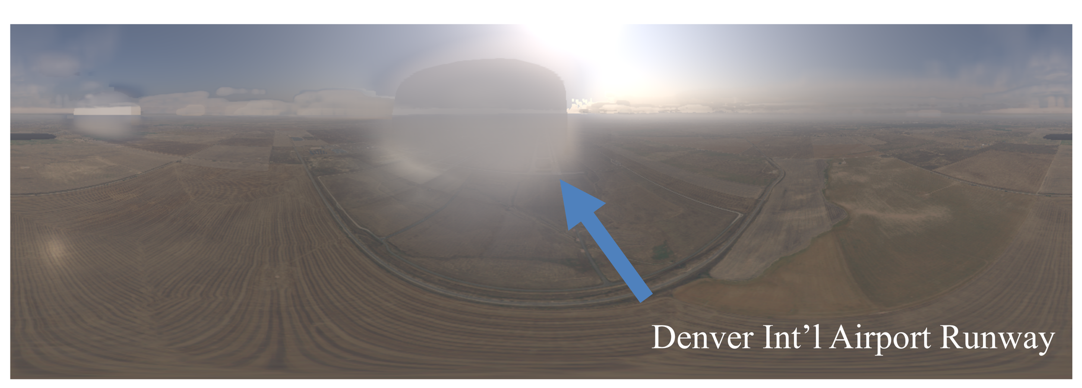


Visualization Technique

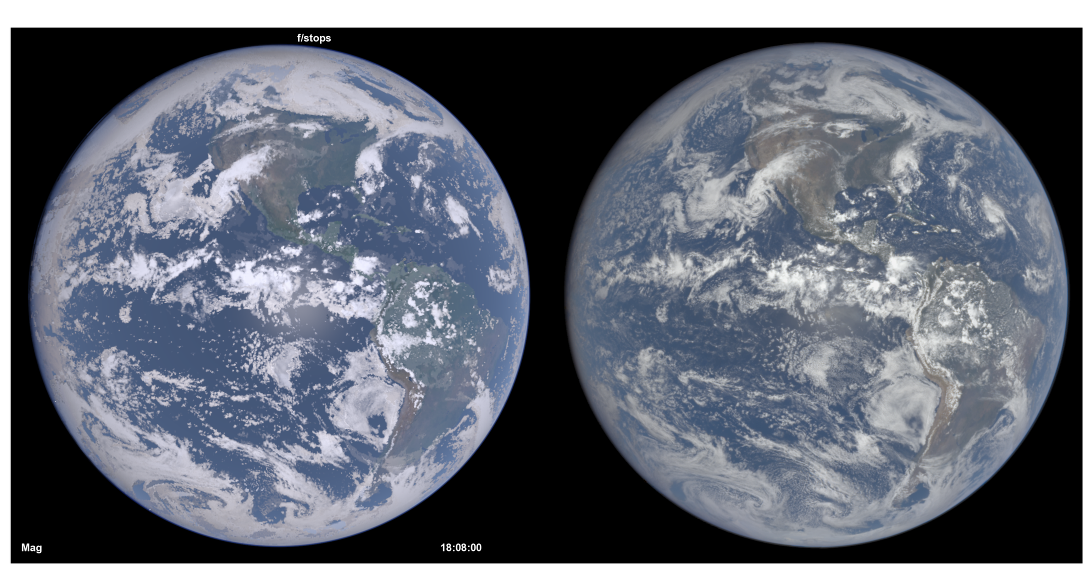
- Illumination of clouds, air, and terrain pre-computed
  - Simplified **3-D radiative transfer - 3 visible** wavelengths
- Sky brightness based on sun and other light sources
- Ray Tracing from vantage point to each sky location
- Scattering by intervening clouds, aerosols, gas (via effective particle radius and optical thickness)
- Terrain included where present along sight lines
- Physically and empirically based for best efficiency (produces RGB images and spectral radiances)
- Examples below use LAPS cloud analysis (as a proxy for the Rapid Update Analysis - RUA)

Ground-based Panoramic Camera Validation

Simulated Aerial 360 Panoramic View



Simulated Earth vs. DSCOVR / EPIC



Clear Air (Gas/Aerosol) Sky Brightness

- Source can be sun or moon
- Rayleigh Scattering by N_2,O_2 Molecules (blue sky)
  - Minimum brightness 90 degrees from light source
- Ozone (O_3) absorption
  - Contributes to blue zenithal sky with low sun or twilight
- Mie Scattering by Aerosols
  - Multi-parameter (e.g. Henyey-Greenstein) phase functions
- Cloud/Terrain shadows can show crepuscular rays
- Night-time sky brightness from other light sources
  - Planets, stars, airglow, surface lighting
- Earth shadow geometry considered during twilight
  - Secondary scattering reduces contrast

Cloud / Precip Scattering

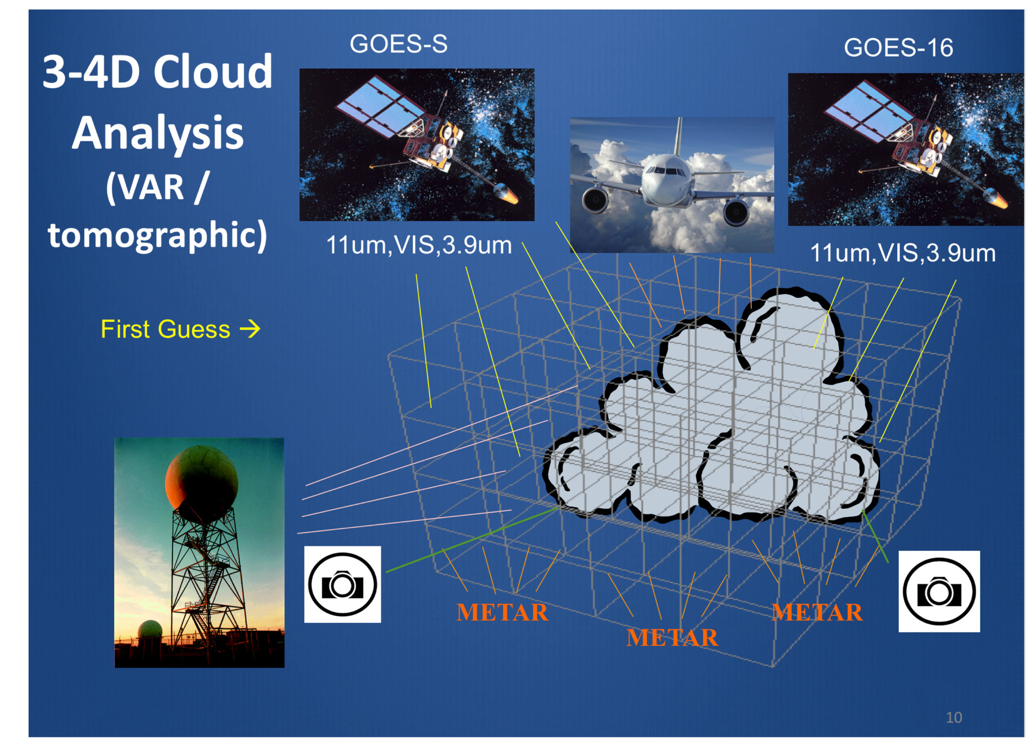
- Mie scattering phase function means thin clouds are brighter near the sun (with "silver lining")
- Thick clouds are the opposite, being lit up better when opposite the sun
- Phase function has forward peak with single scattering
  - flattens with multiple scattering parameterization
- Rayleigh scattering by clear air reddens distant clouds
- Rainbows included in scattering phase function

Variational Cloud Assimilation

- Development underway with variational cloud analysis and hot-start
- Satellite testing with radiance based forward models (e.g. CRTM), or NESDIS Cloud Optical Depth Retrieval (with simpler forward model)
- Hot-start constrained more consistent clouds and water vapor, temperature, etc.
- Simultaneous analysis consistent with observational data along with model microphysics, radiation, & dynamics
- Use cameras, satellites, radars, METARs, etc.
- **Full spatial, temporal,** and **spectral** use of High Resolution **GOES-16/17** visible & IR at 1-5 minute time steps for sub-kilometer scale models used for Warn-On-Forecast.
- Fits analysis to observed satellite & camera radiance (using correlation and/or direct radiance)
- 3D- and 4DVAR implementation utilizes model microphysics and dynamical constraints

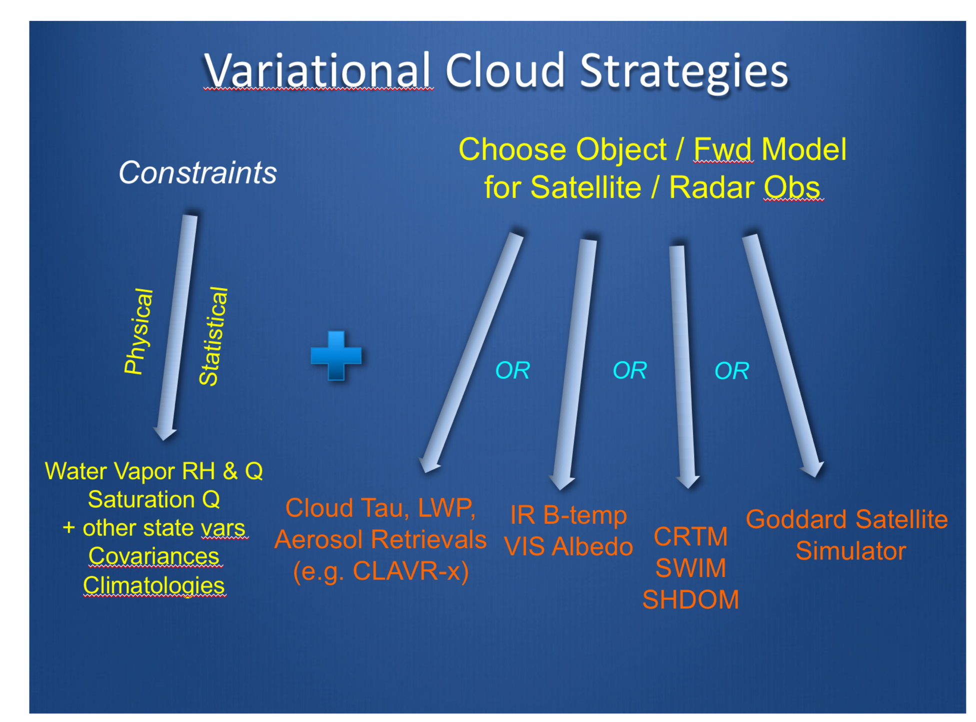
Tomographic Variational Analysis

- Will use **multiple vantage points** to help constrain 3-D cloud structure
- Considers **multiple scattering** in visible light, along with IR channels to diagnose optical and microphysical properties deep within clouds



Modular Software Design

- Forward Models
  - CRTM (mainly for IR – in 2D)
  - SWIM and SHDOM can augment CRTM in 3-D (particularly for visible light)
- Physical and Statistical Constraints added in a modular manner
  - Temperature vs hydrometeor type
  - RH vs hydrometeor content
  - Covariances with state variables
- Applications (incorporating **modular components** into **JEDI** variational framework for minimization and model interfacing)
  - Pre-convective environment (Cu fields)
  - Active convection (Thunderstorm evolution)
  - Solar Energy – detailed cloud and irradiance forecasting)



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