Blue Waters Applications of 3D Monte Carlo Atmospheric Radiative Transfer

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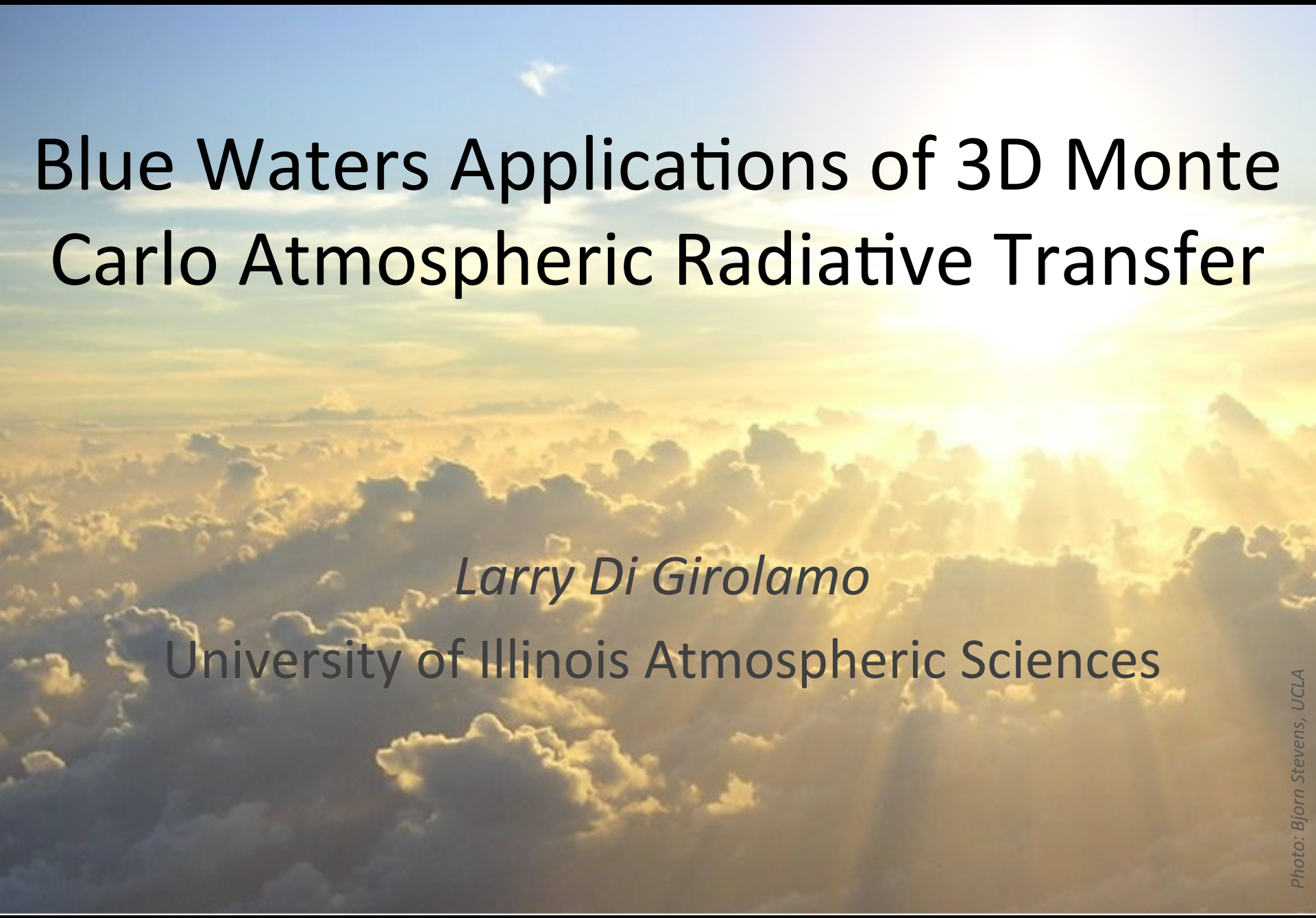
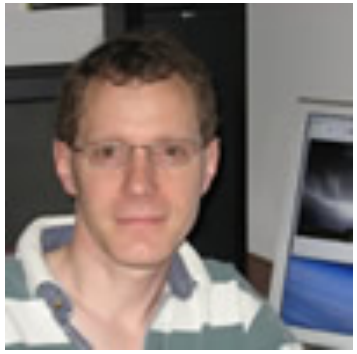


Photo: Bjorn Stevens, UCLA

Acknowledgments



Brian Jewett

Bill Chapman

Allie Jones

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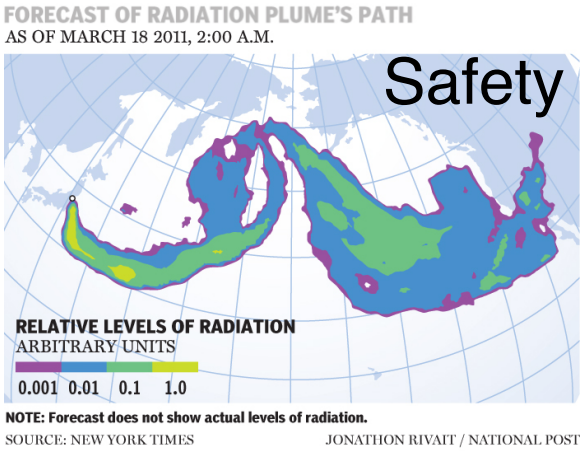
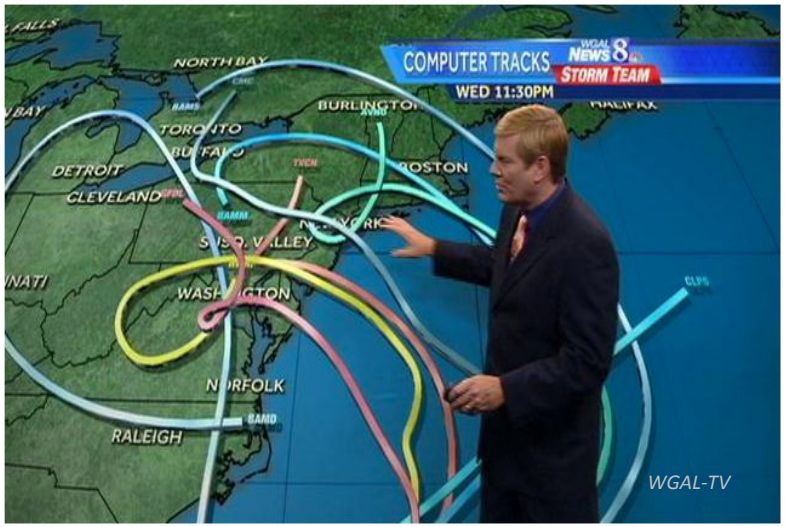
NASA JPL NCSA NSF

Accurate predictions of weather and climate are essential for society…



For many societal and commercial needs, *uncertainties in weather and climate predictions are still too large*



Hurricane Sandy

$68 billion in damage

286 killed in seven countries

Wildly varying forecasts in the days before landfall

Moore, OK tornado

EF5, 210 mph winds

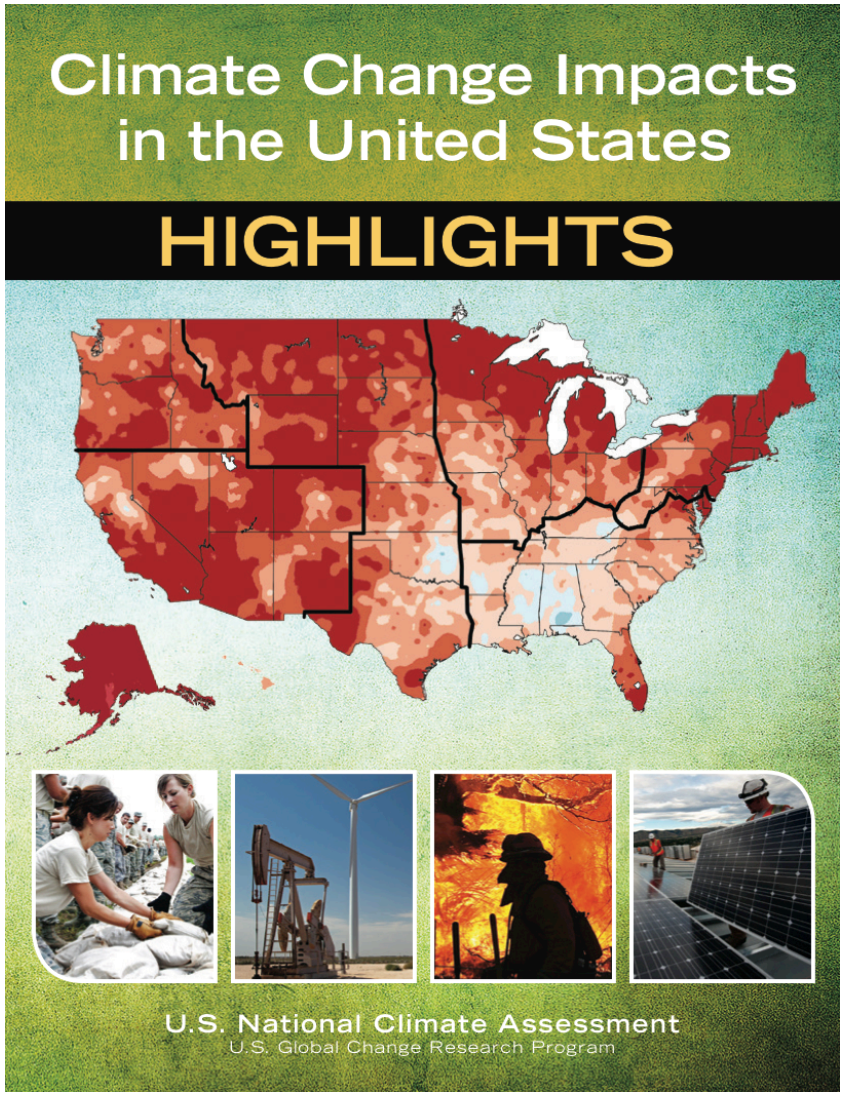
24 deaths, 377 injuries

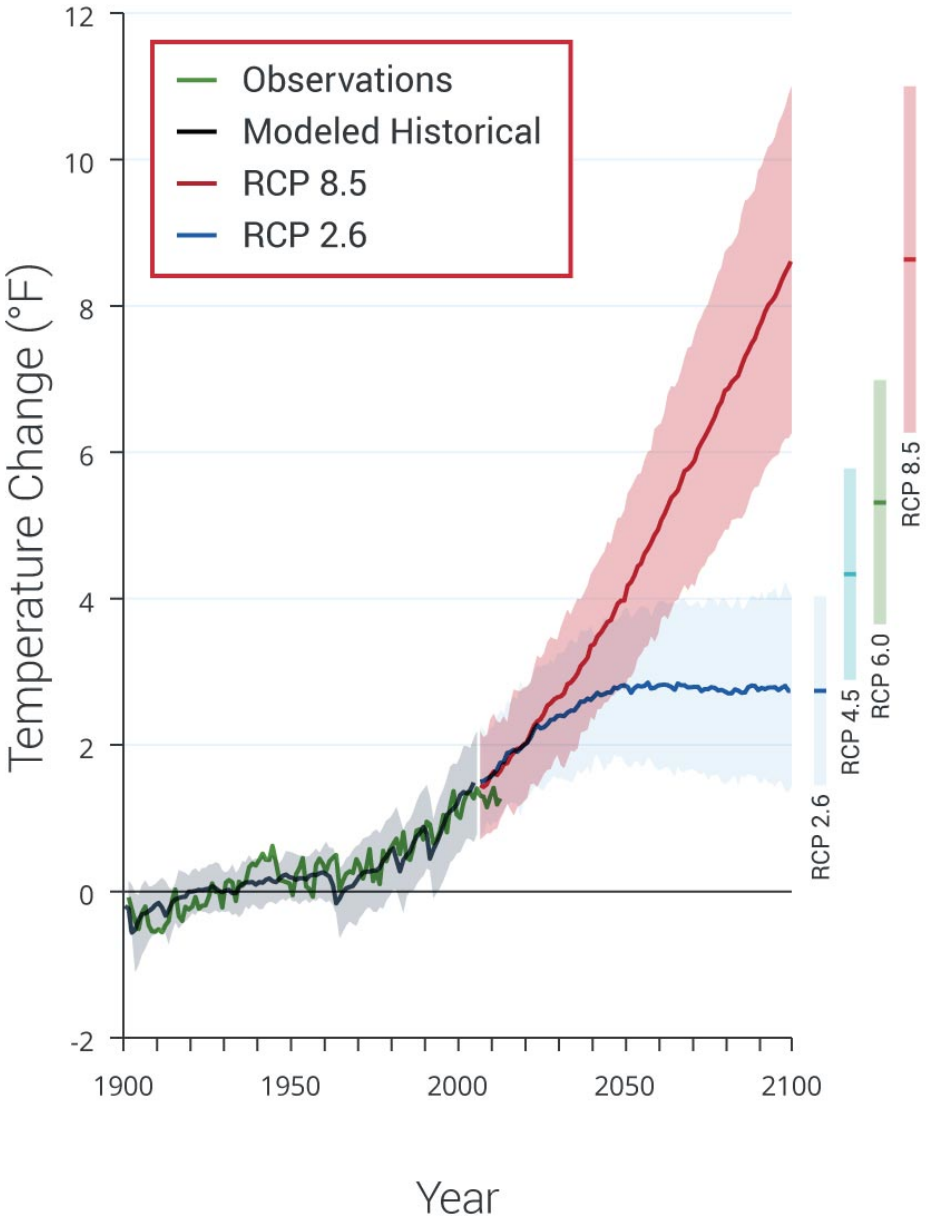
39 minutes on ground, 17 mile path


Tornado kills at least 91 in Oklahoma City suburb

At least 20 kids among the dead; search continues in flattened city

For many societal and commercial needs, *uncertainties in weather and climate predictions are still too large*



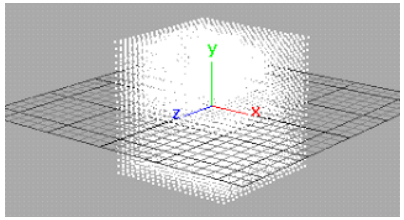


Why do these uncertainties exist?
And can high-performance computing help – and if so, how?

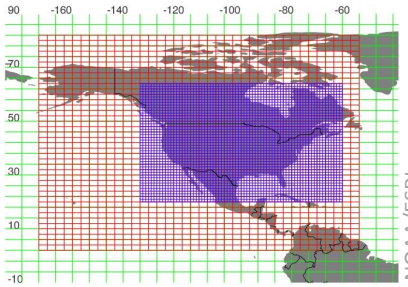
1. Inadequate resolution

Higher spatial *and* temporal resolution helps:

a. resolve smaller-scale phenomena
b. avoid / reduce need for *parameterization, i.e.*, larger-scale estimates of *subgrid* scale phenomena



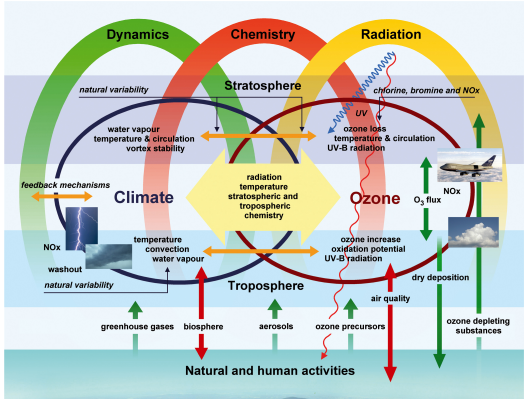
Cliff Mass - blog



NOAA/ESRL

2. Poor representation of physical processes

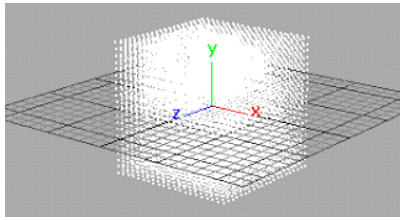
a. turbulence
b. land-atmosphere interactions
c. cloud / precipitation *microphysics*
d. Radiation



atmos.caf.dlr.de - *sciamachy*

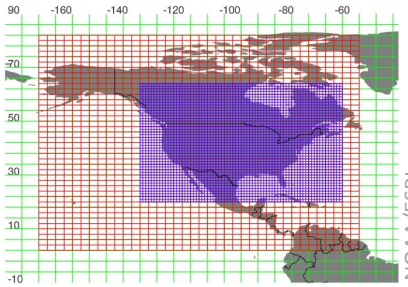
Why do these uncertainties exist?
And can high-performance computing help – and if so, how?

Greater computational resources have *often* been targeted to achieve higher resolution…



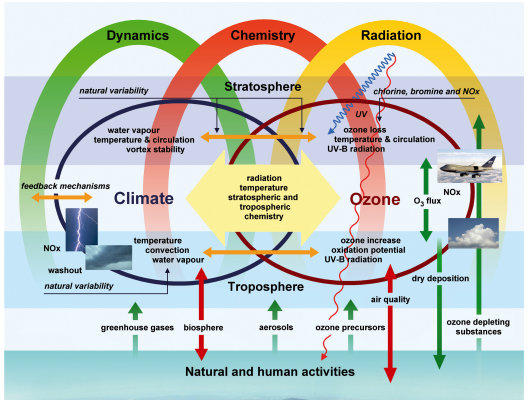
Cliff Mass - blog

… while the inadequate treatment of physical processes has remained largely unchanged.



NOAA/ESRL

Parameterizations based on observations are plagued by inadequate observations.



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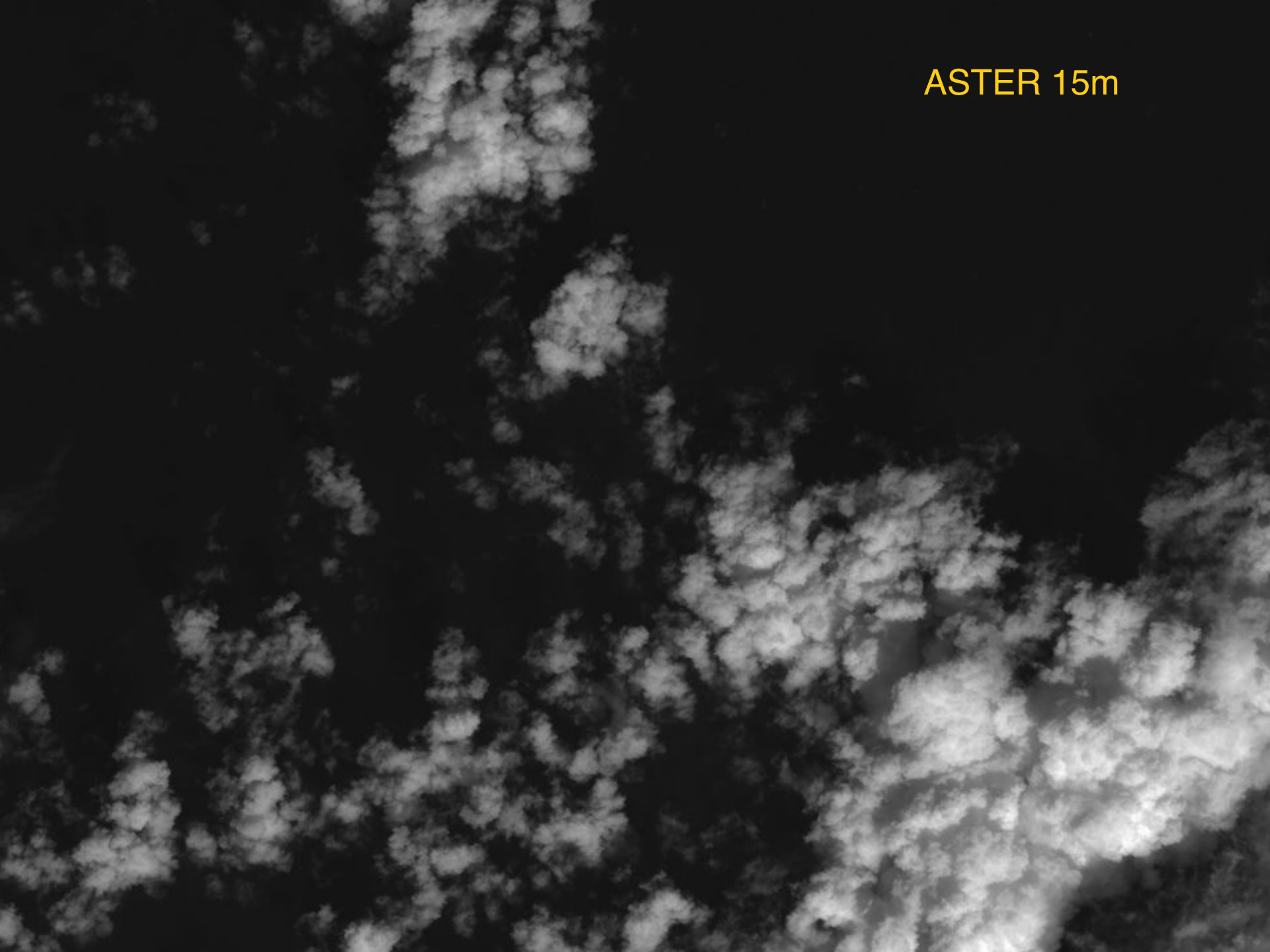
The treatment of clouds and radiation processes have been identified as the largest contributor to model prediction and remote sensing error.

Why radiation?
And can high-performance computing help – and if so, how?

All environmental prediction models (from Cloud Resolving to NWP to Climate Models) and most remote sensing algorithms use a 1-D (plane-parallel) radiative transfer assumption resolution.

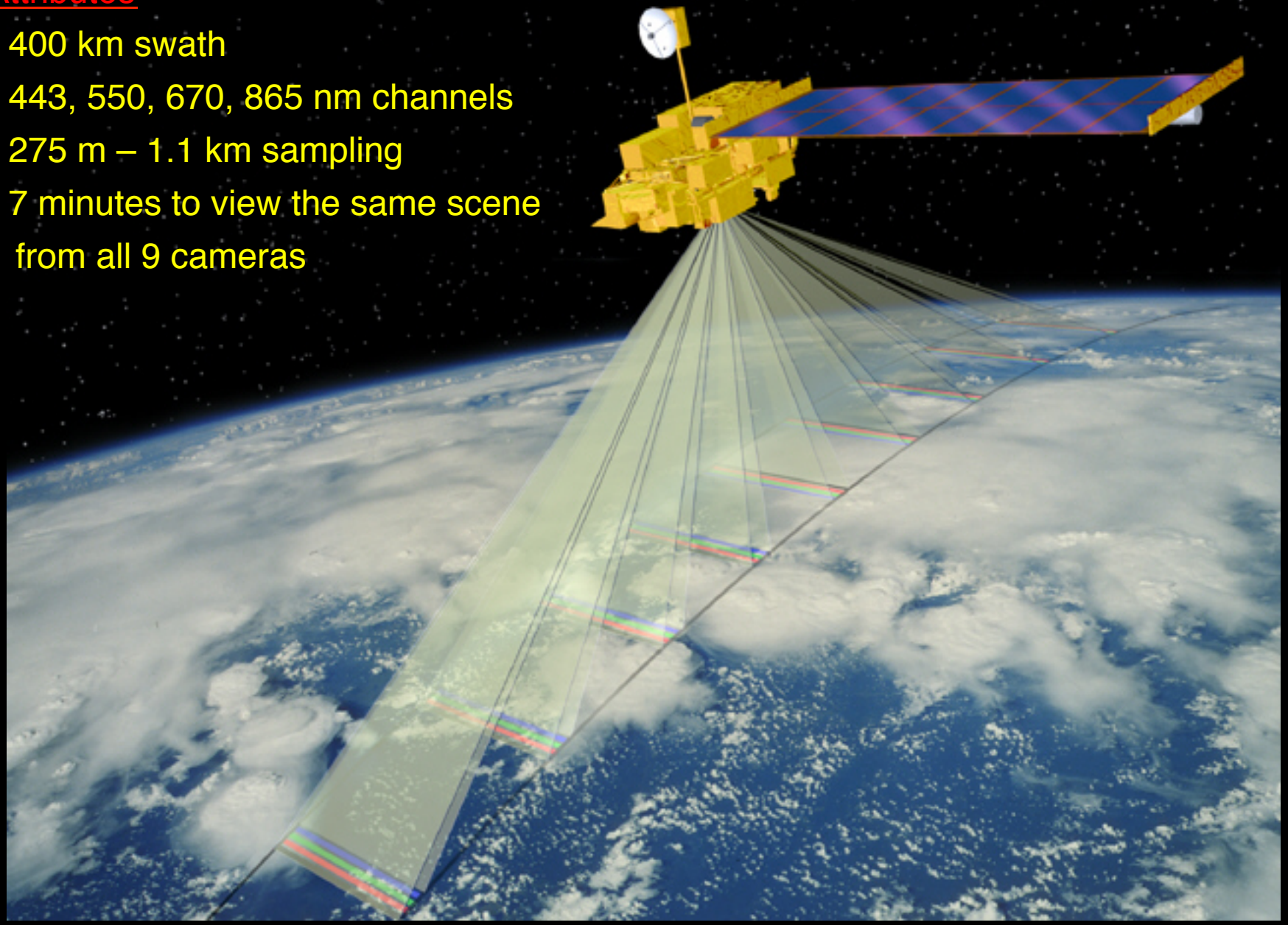
- **Computationally faster than full 3D radiative transfer**
  - **1D RT calculations takes ~ half the compute time in prediction models**
  - **3D RT would take > 99% of the compute time in prediction models**

- **1D leads to a tangible satellite remote sensing solution for cloud properties with single-view, spectral measurements**
  - **No operational satellite remote sensing solution that fully accounts for 3D RT exists**


ASTER 15m

Multi-angle Imaging SpectroRadiometer Attributes

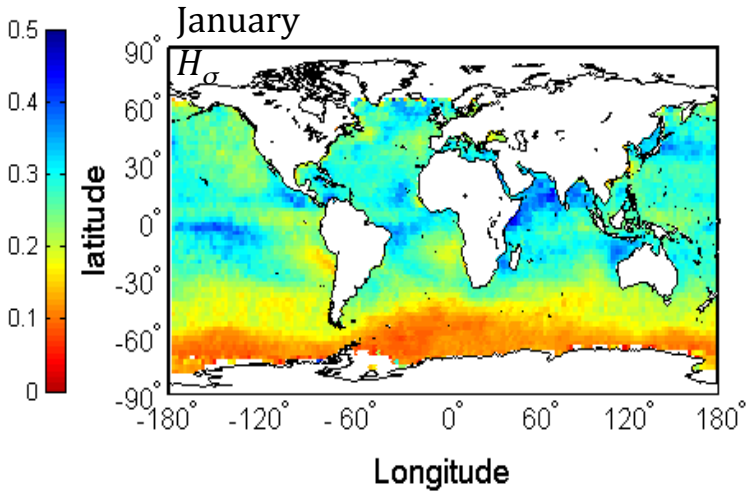
- 400 km swath
- 443, 550, 670, 865 nm channels
- 275 m – 1.1 km sampling
- 7 minutes to view the same scene from all 9 cameras

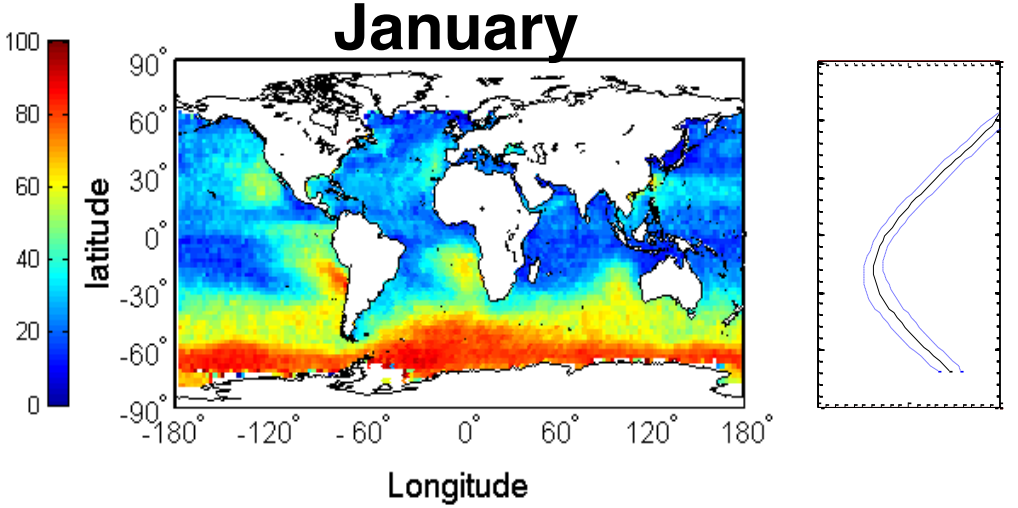


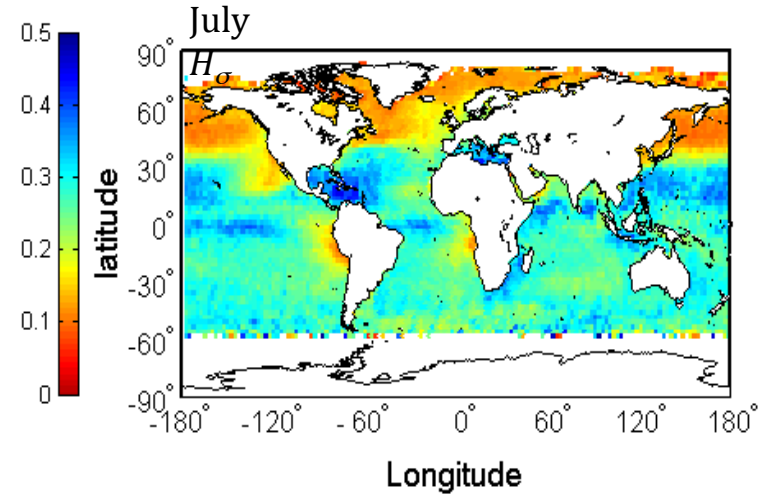
Average texture of clouds

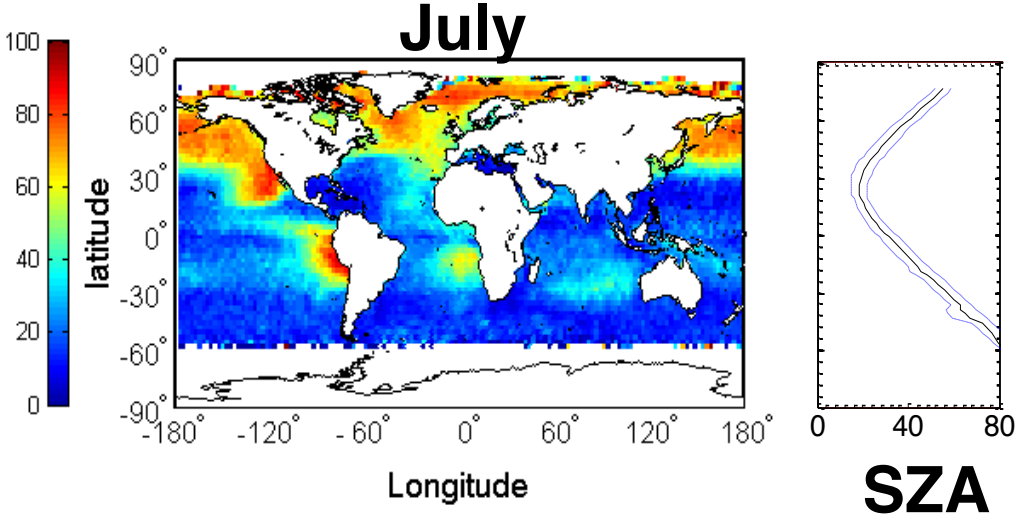
(smooth to rough)

Fraction of observations with angular distribution of scattered sunlight that is within 5% of the plane-parallel expectation









Di Girolamo et al. (2010)

Questions we are addressing with Blue Waters

- **What are the radiative heating rates for real (i.e., 3D) clouds and their impact on dynamics?**

Blue Waters offers the first opportunity to address this question

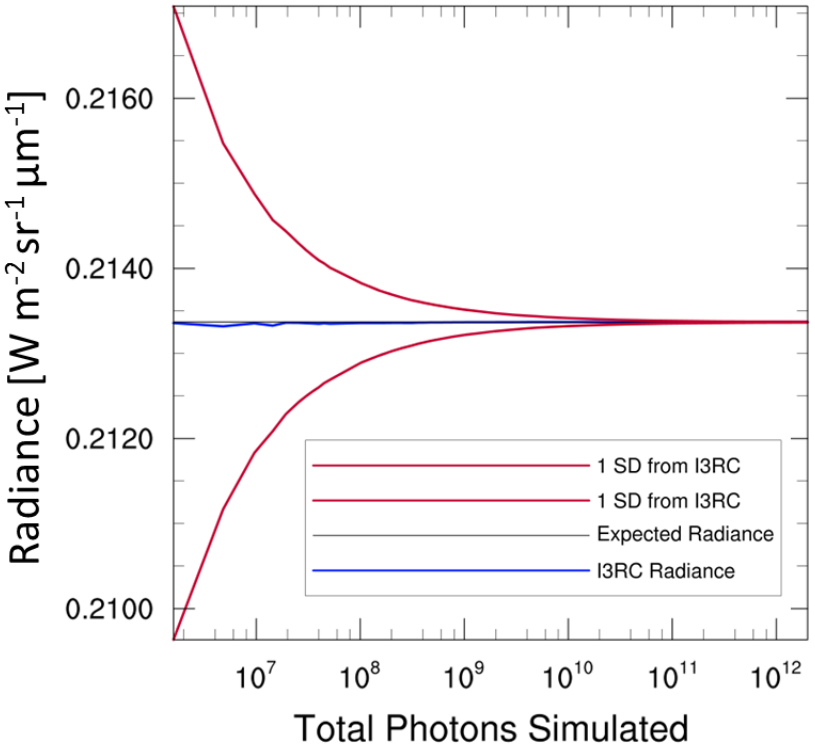
- **How do we overcome the computational challenges of properly calculating radiative heating rates dynamically within weather and climate models?**

- **How do we solve remote sensing problems for retrieving cloud and aerosol microphysical properties in the face of 3D radiative transfer (i.e., no plane-parallel assumption)?**

Blue Waters Radiative Transfer Model

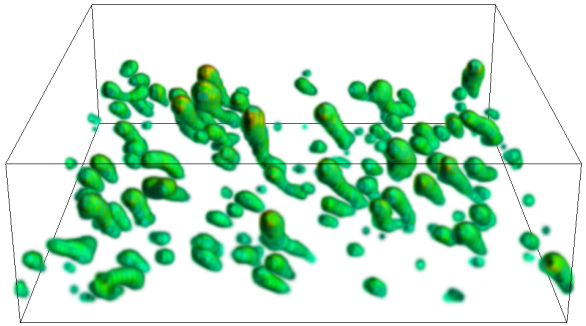
- **Open Source Community Atmospheric 3D Radiative Transfer Model (there's only one): NASA/DOE "I3RC" Monte Carlo RTM (Cahalan *et al*. 2005; Pincus and Evans 2009)**
  - **Solar source only**
  - **Lots of nice tools for building atmospheric domains**
  - **Within I3RC model "consensus mean benchmarks" of participating inter-model spread of 3.5%**

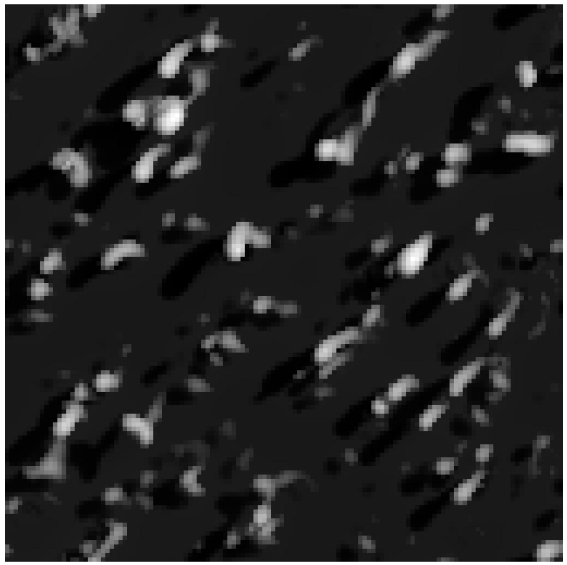
- **High photon (low noise ~ 0.00005%) Blue Waters benchmarking against several analytical solutions and reciprocity revealed numerous minor coding issues within I3RC that have been identified and resolved.**
- **Added thermal source, specify heterogeneous surface, track order of scattering, end simulation after achieving specified error threshold, ...**
- **Currently adding spectral integration needed for broadband heating rates**



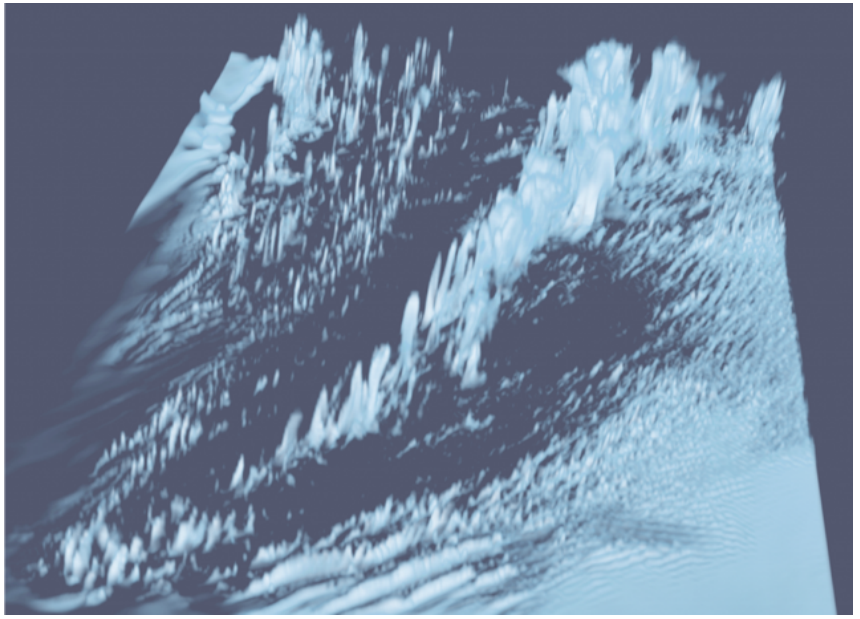
Weather Research and Forecasting (WRF)

- Yamaguchi and Feingold (2012)
- Optimized on **Blue Waters**
- WRF-I3RC Domain Converter Tool



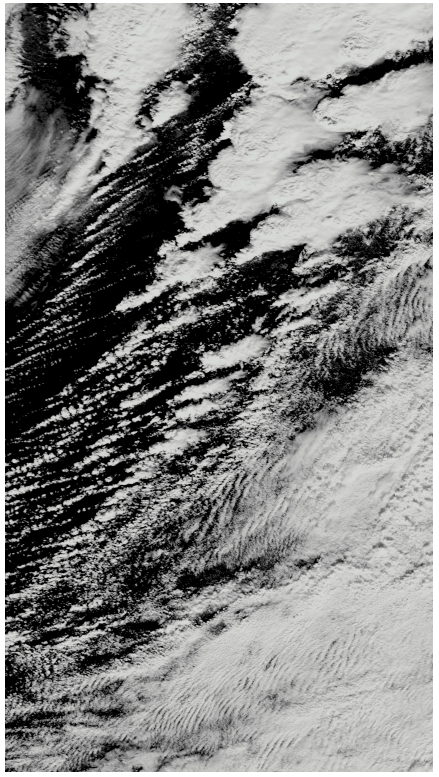


12 km



Largest 3D RT simulation?

358 km



Earth's Clouds are Getting Lower… "The sky is falling!"

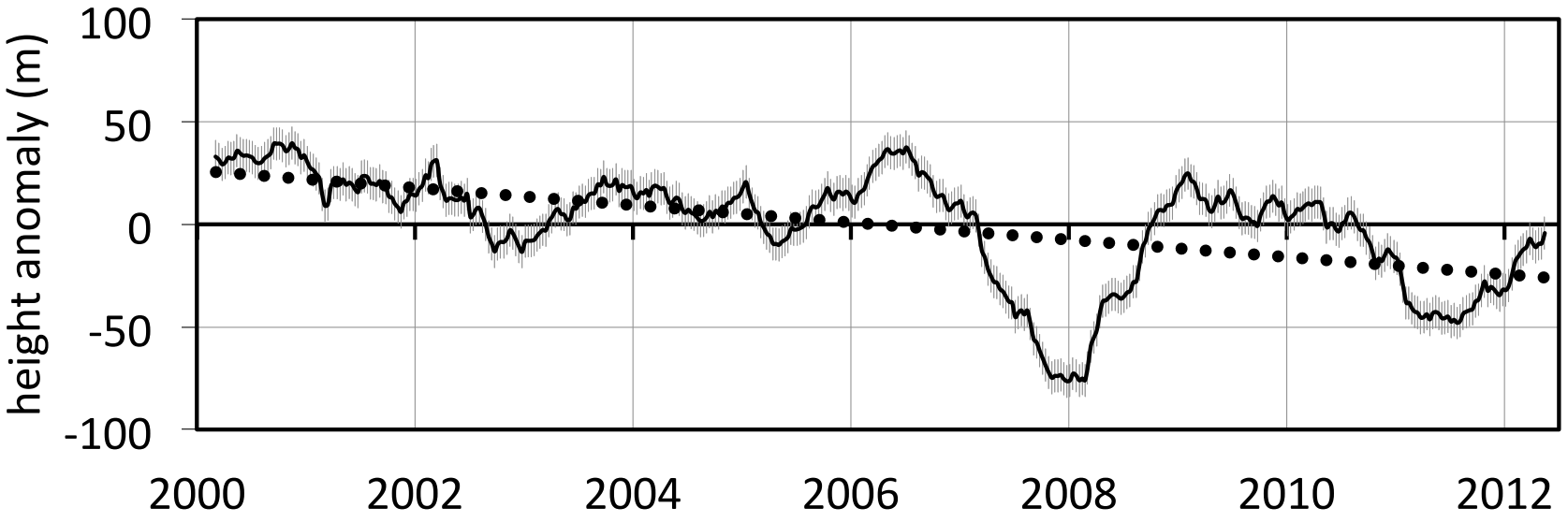


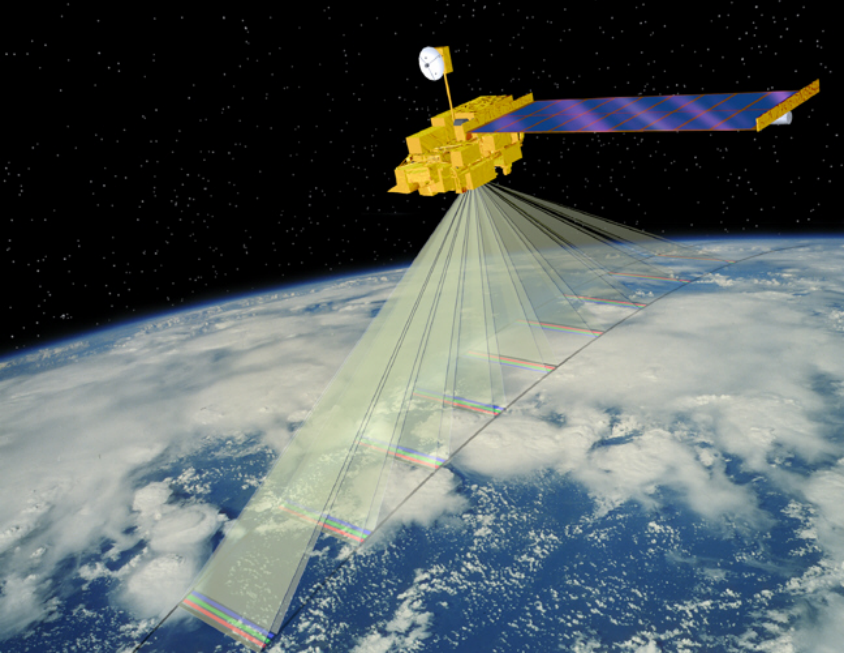
FIGURE 1. Global effective height anomalies from MISR, March 2000 to May 2012. The dotted line indicates a linear regression with slope –45 ±19 m/decade.

From Davies (2013)

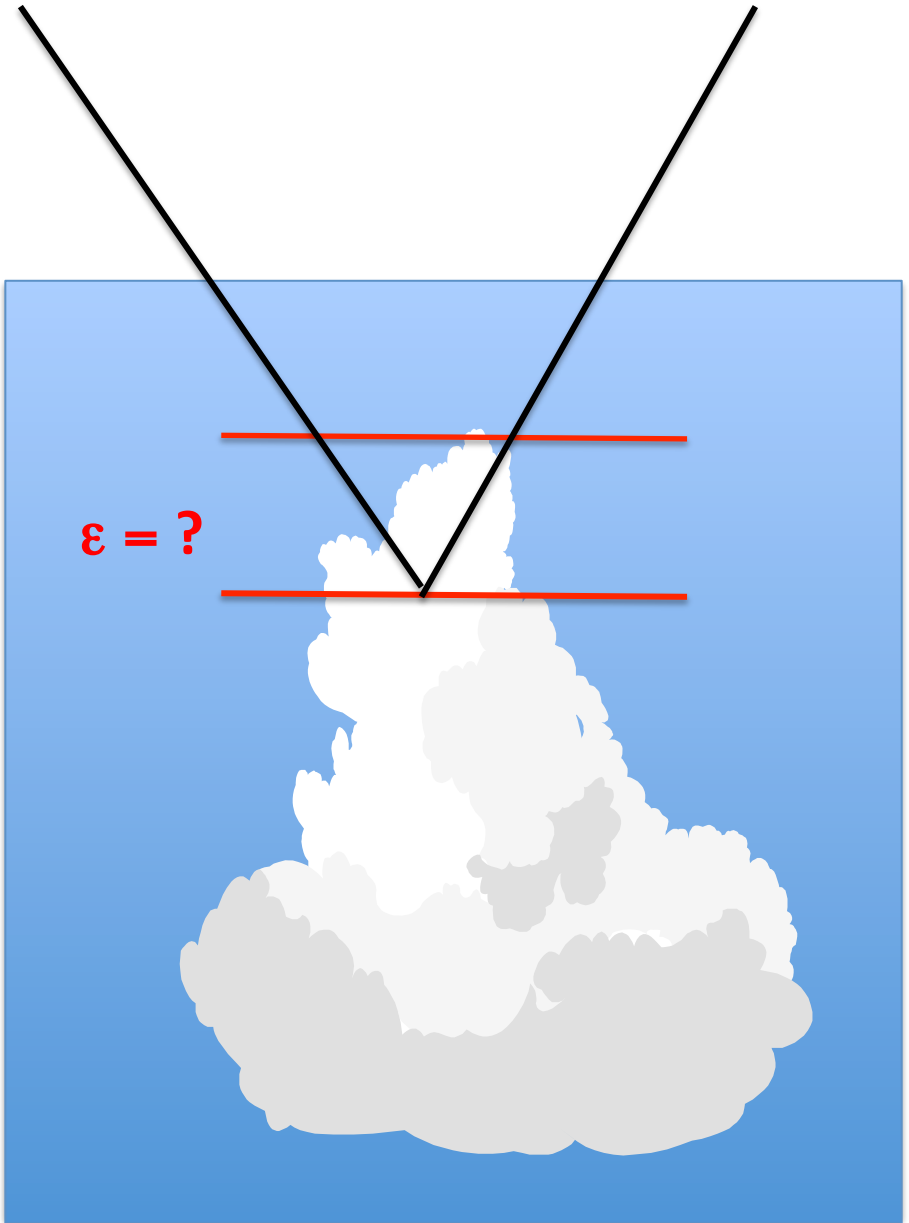
Implication: a negative feedback on the climate system via greater radiative cooling to space

Equilibrium surface temperature response to observed CTH changes – 0.35 K

Equilibrium surface temperature response to observed changes in CO_2 + 0.09 K



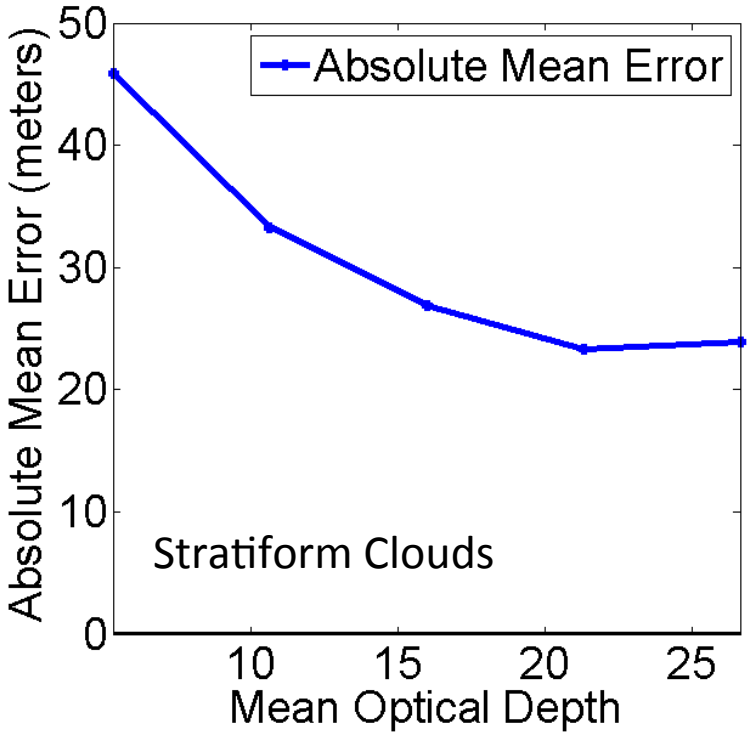
MISR Stereo-derived cloud top heights

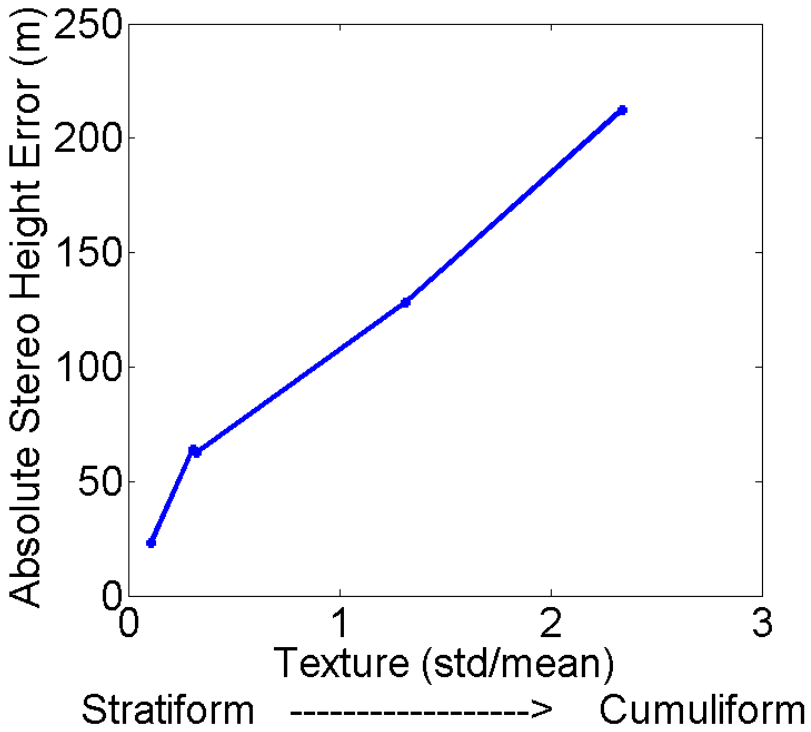


Error depends on…

- **3D distribution of cloud properties**
- **Sun-View geometry**
- **Resolution**
- **Wavelength**

Early and Incomplete Results





Perhaps it's the texture and optical thickness of the clouds that are changing, not just the heights?

Climate models need to be careful in using stereo height changes as a benchmark

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These questions will take decades to fully address…

… but we hope to have some early results to share by the end of the year.