Stochastic RT (SRT) and Potential Benefits of ARM Volume-Scanning Array (AVA)

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Outline

- Stochastic vs Deterministic
- Numerical Averaging
- Analytical Averaging
- Potential AVA Applications

SRT: Why?!

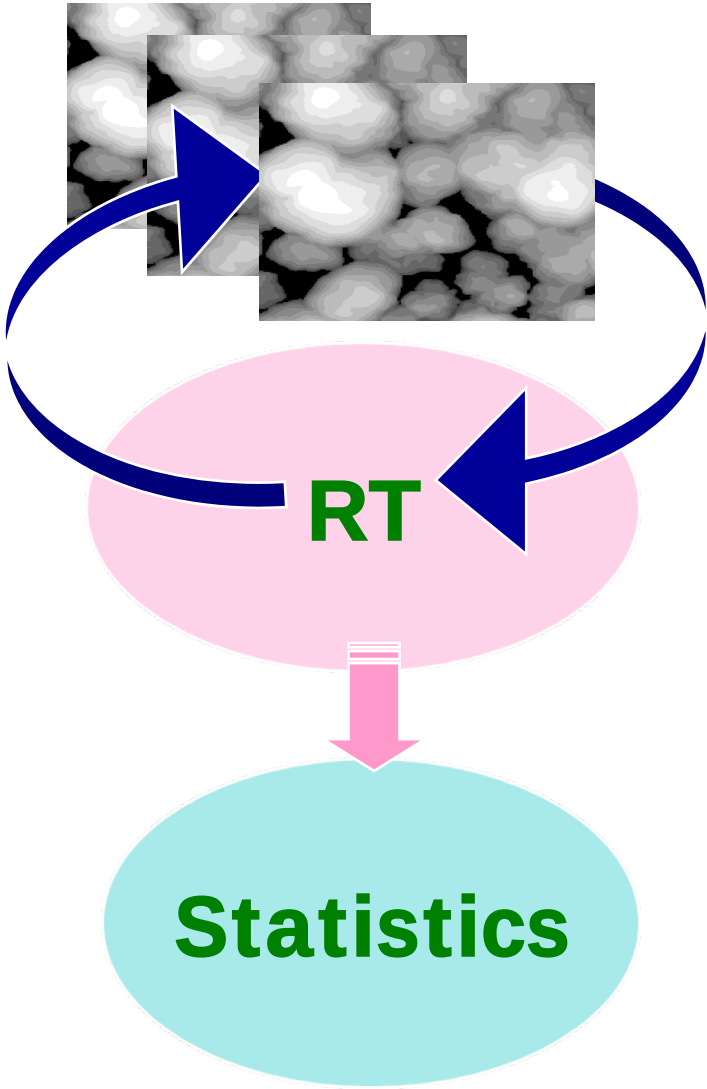
- Mean fluxes are relevant for climate studies
- Mean fluxes depend on basic cloud statistics (mean, variance,...)
- Cloud statistics can be obtained from observations (ARM, NASA)

SRT Equation

- Parameters of SRT are random functions
- Different statistical cloud models have been suggested
- Mean radiative properties can be obtained after numerical or analytical averaging

SRT: Numerical Averaging

- Generate ensemble of 3D cloud fields
- Perform deterministic RT calculations for each field
- Obtain statistics (e.g. mean radiative fluxes)



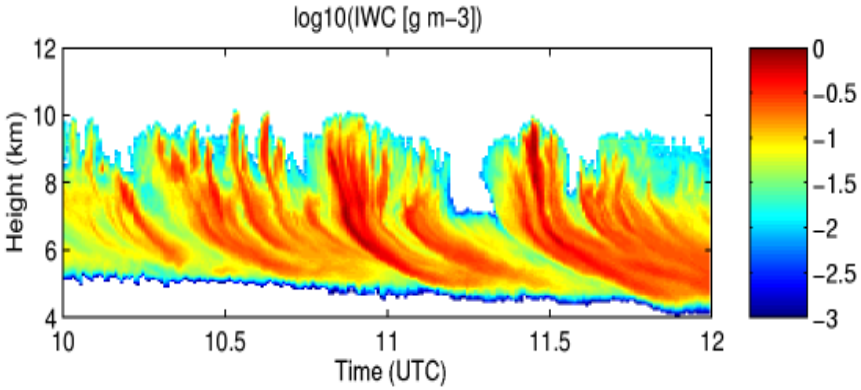
Surrogate Clouds Generating

- Barker and Davies, 1992
- Cahalan, 1994
- Evans and Wiscombe, 2004
- Raisanen et al., 2005
- Hogan and Kew, 2005
- Venema et al., 2006

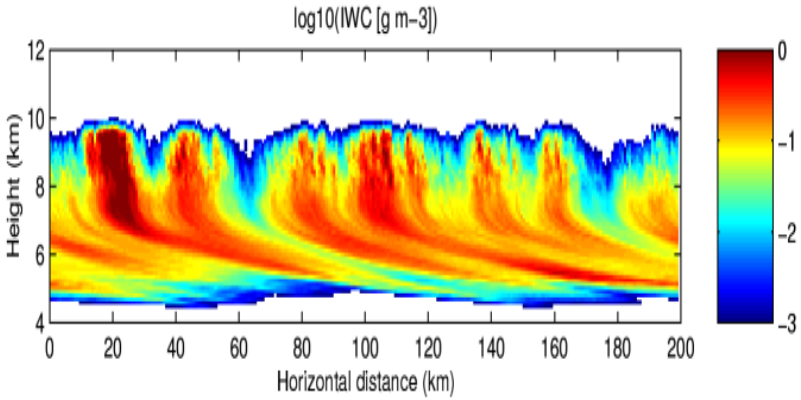
Statistics:

- One-point (PDF, ...)
- Two-points (Power Spectra,..)

Observations



Simulations



Hogan and Kew, QJRMS, 2005

Numerical Averaging

- Advantage:

  Statistics of radiation can be obtained for given surrogate clouds

- Disadvantage:

  Computationally expensive

Analytical Averaging

Analytical equations link statistics of clouds and radiation

- Advantage:

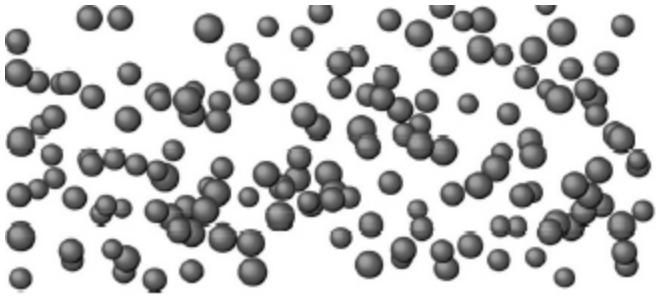
  Computationally efficient

- Disadvantage:

  Relatively simple cloud models

Analytical Averaging: Models

- Stephens et al., 1991
- Evans, 1993
- Cahalan et al., 1994
- Gabriel and Evans, 1996
- Barker et al., 1996
- Petty, 2002



Petty, JAS, 2002:

- Macroscopic “Cloudlets” distributed randomly

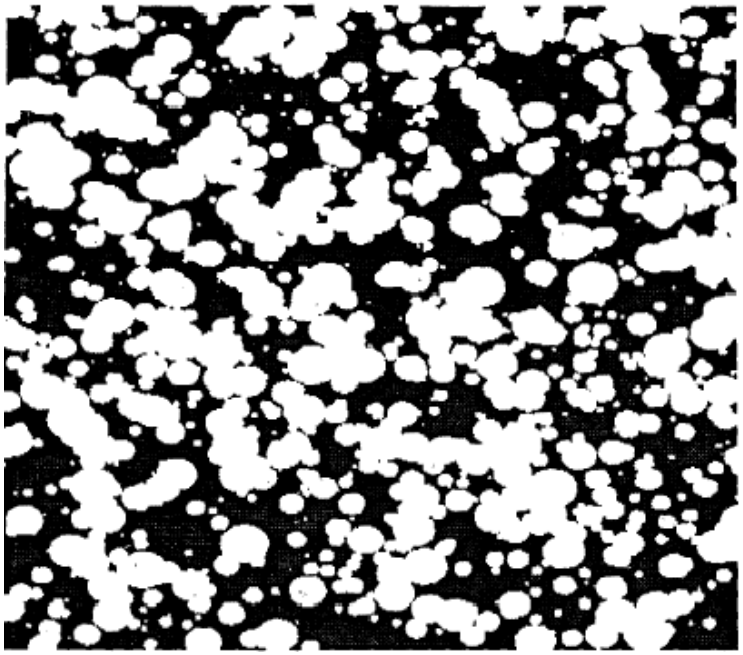
Cloud Statistics (PDF,...)

Averaged Fluxes

Cloud Models: Markovian

- Avaste and Vainokko, 1973
- Pomraning, 1986,1991
- Titov, 1990, 1995

- Byrne et al., 1996
- Lane et al., 2002



Zuev and Titov, JAS, 1995:

- Clouds distributed with exponential distribution function

Mean, Correlation Function

Averaged Fluxes, Radiances

Analytical Averaging: Example

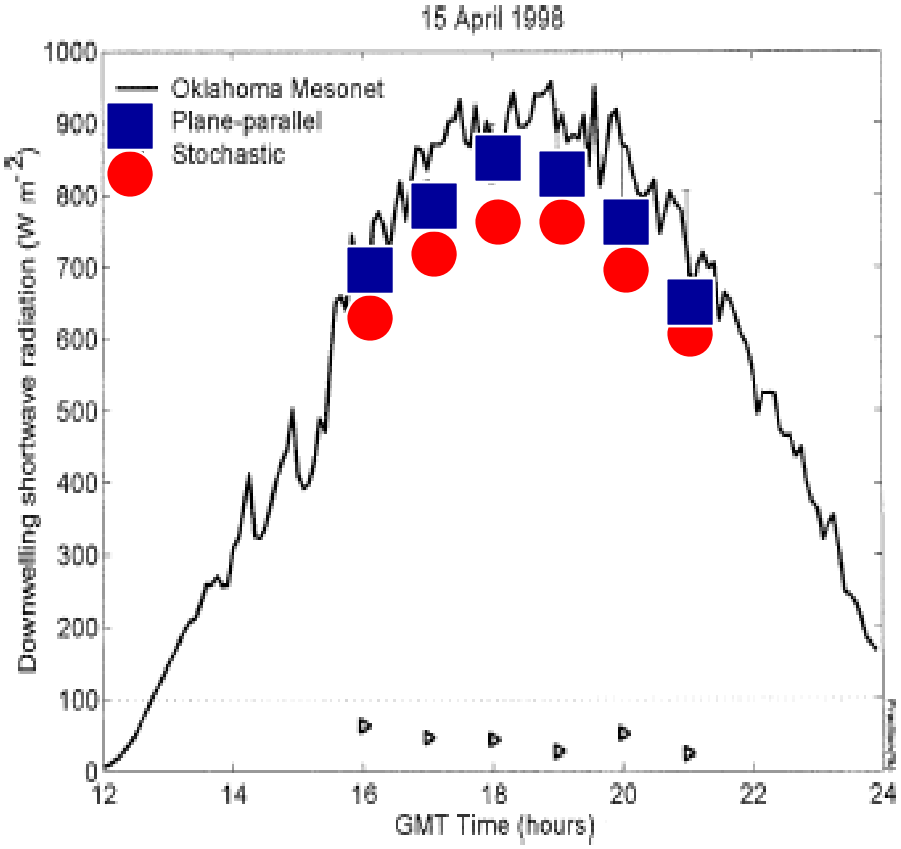
Ensemble-averaged Intensity (Direct):

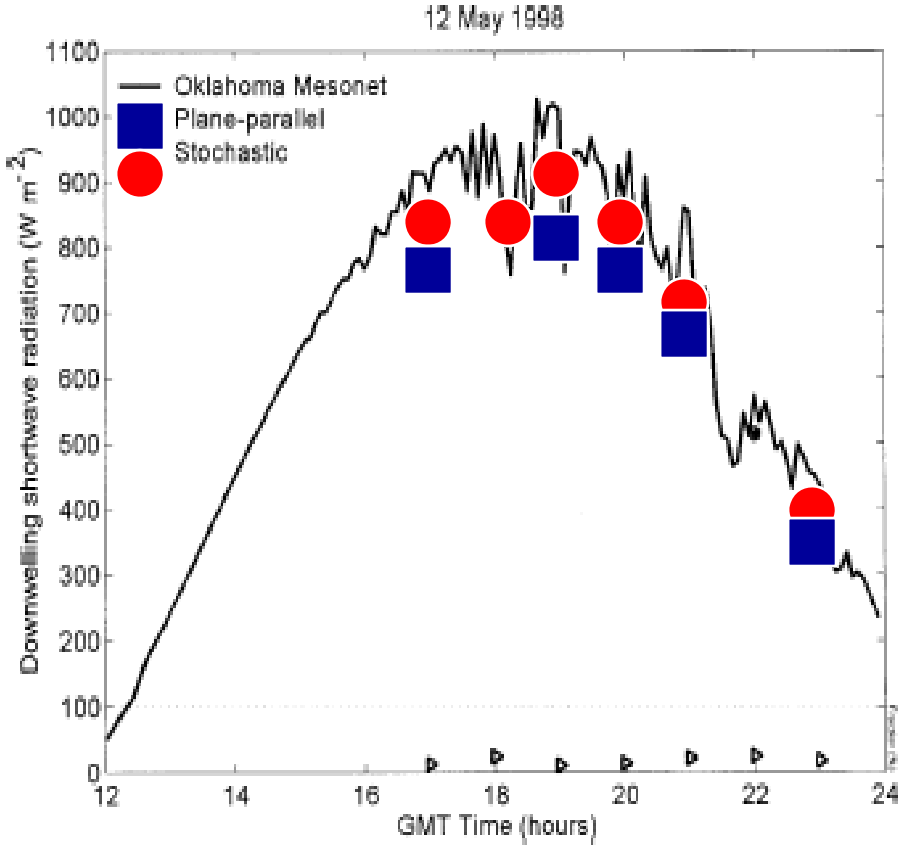
$$I(s) = I(0)\left[\, f \exp(-s/l_1) + (1-f)\exp(-s/l_2)\,\right]$$

where $f,\ l_1,\ l_2$ are functions of

- 2 optical (σ clear sky, cloudy)
- 2 geometrical (CF, *correlation* scale)

Markovian Approach: Validation*





- SRT is worse (better) on April 15 (May 12)

* Lane, Goris, and Somerville, *Climate*, 2002

Discrepancy: Possible Reasons

- Vertical variability of clouds
- Anisotropy of cloud fields
- Limited ability of model and observations to capture them

Markovian Approach: Generalization*

- Represent 3D broken clouds as set of interrelated cloud layers:
  - inverse-exponential expression

- Improved ability of model to capture vertical/horizontal variability of clouds:
  - random/maximum overlaps
  - correlation scales in x-, y- and z-directions

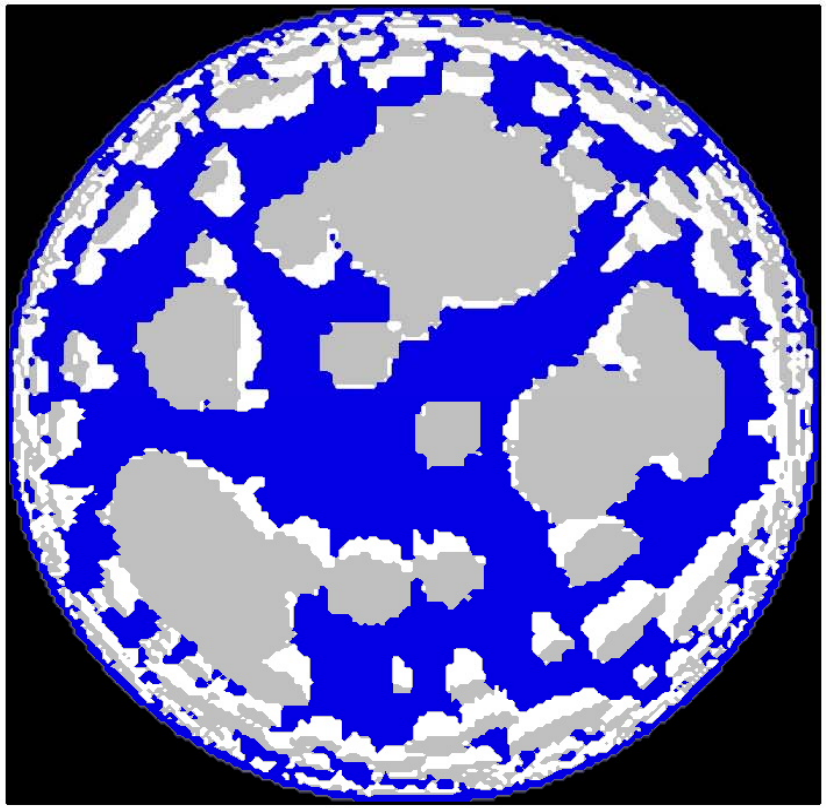
* Kassianov, 2003; Kassianov et al., 2003; 2005

Problem

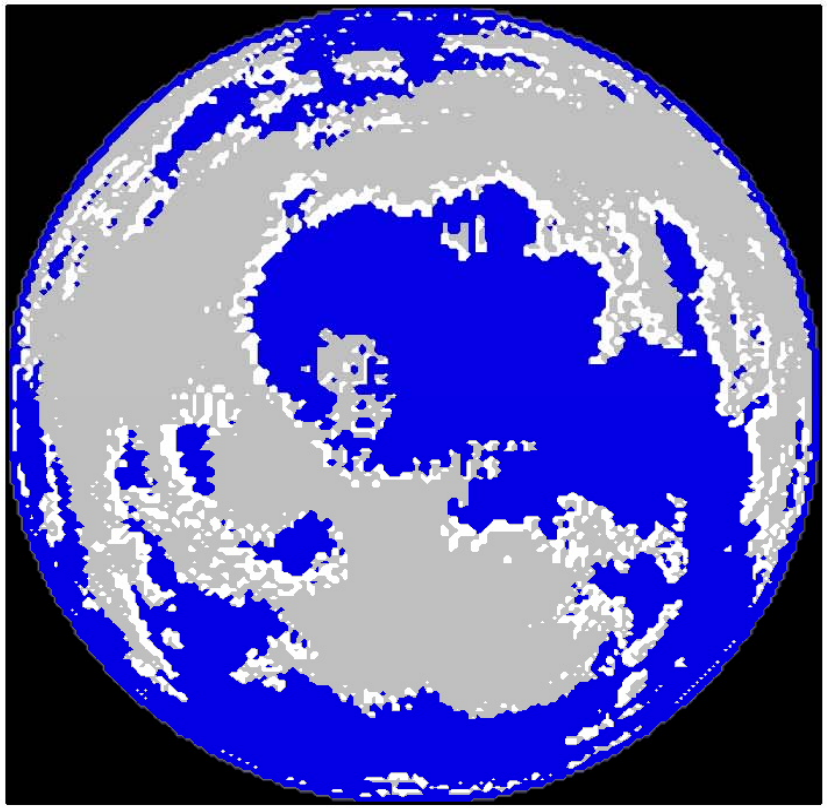
- Fluxes are sensitive to 3D cloud statistics:
  - vertical overlap, horizontal anisotropy, ...
- Cloud models capable of incorporating these 3D statistics
- However, cloud observations are 2D:
  - horizontal fields (satellite data)
  - time-height cross-cut (radar data)

Spatial Variability: Example*

Cumulus clouds



Stratocumulus clouds



Fluxes represent *hemispherical* (3D) observations

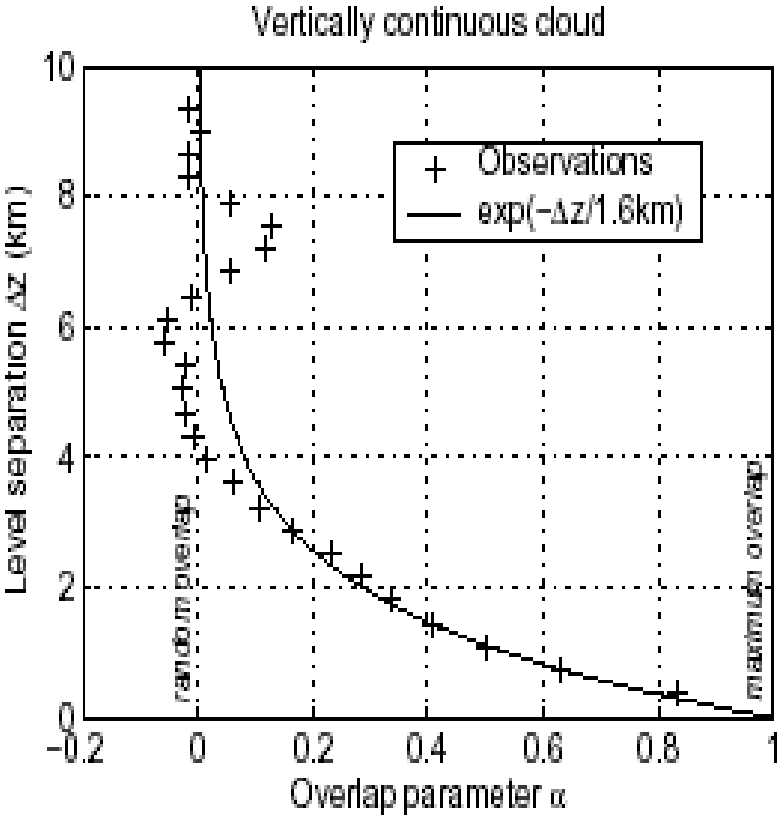
To predict fluxes accurately, we need 3D cloud statistics

* Kassianov et al., 2005

Potential AVA Applications

- Provide 3D statistics of cloud fields:
  - vertical overlap, horizontal anisotropy, ...
- Apply AVA-derived cloud statistics to improve/develop cloud models
- Validate model predictions (e.g., mean fluxes) with observations

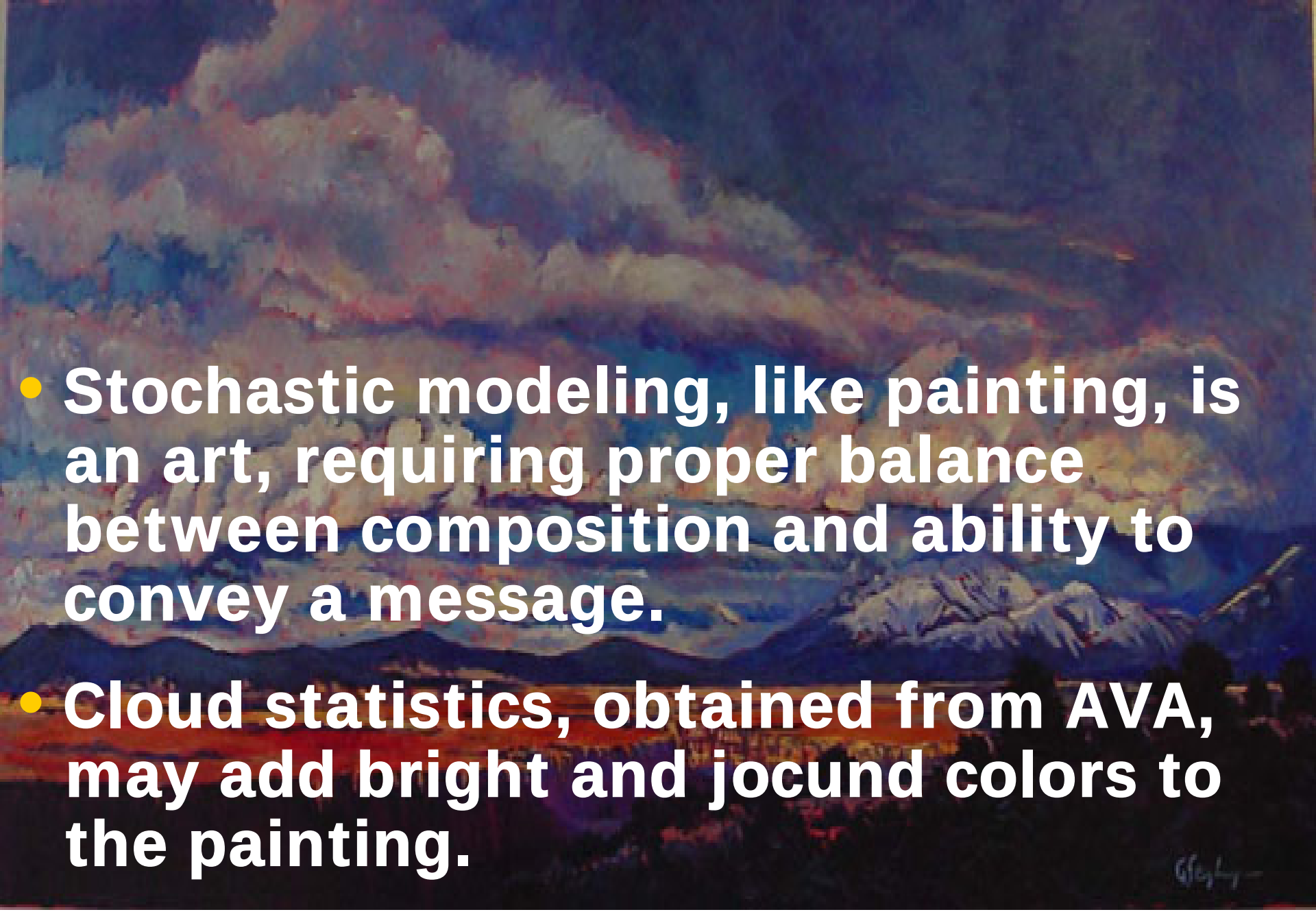
3D Cloud Statistics & AVA



- Vertical Overlap *: inverse-exponential expression

* Illingworth and Hogan, 2000

- How sensitive is overlap parameter to viewing direction?
- How strong is variability of directional CF?
- Effective SW/LW CF vs directional CF



- Stochastic modeling, like painting, is an art, requiring proper balance between composition and ability to convey a message.
- Cloud statistics, obtained from AVA, may add bright and jocund colors to the painting.

Graeme Stephens cloud painting

Thank you!