

M.S. Defense Announcement
Joe Kelly
Monday, March 20, 2023, at 2:30 p.m.

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March 20, 2023
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Defense
ATS Large Classroom (101 ATS) or [Teams](#)

Post Defense Meeting
ATS Main 2nd Floor Conference Room (209 ATS)

Committee:
Christine Chiu (Adviser)
Steven Miller
Chandra Venkatachalam (Electrical and Computer Engineering)

Fast 3D Radiative Transfer of Shortwave Reflectance for Synergistic Remote Sensing Applications

Marine stratocumulus clouds are a critical component of Earth's radiation budget and remain a key source of uncertainty in climate projections. Better representing these clouds and their interactions with radiation, precipitation and aerosols in models necessitates observations of three-dimensional (3D) cloud fields. While passive satellite observations provide critical information on cloud properties globally, their retrievals lack information on vertical structure. Most retrieval methods also assume one-dimensional (1D), plane parallel clouds, leading to significant retrieval errors for both stratocumulus and cumulus regimes. In contrast, observations from active sensor allow us to probe cloud vertical structure but are limited in coverage. Clearly, combining active and passive satellite observations provides an excellent opportunity for us to reconstruct the 3D cloud fields.

To provide 3D cloud fields that do not suffer from errors introduced by plane-parallel assumption, 3D radiative effects must be incorporated during the retrieval process. In this thesis, the impact of the 3D radiative effects on the 1D retrievals is quantified with a focus on contrasting illuminated and shadowed pixels. It is found that shadowed pixels had a larger magnitude of mean optical depth bias (-11) than illuminated pixels (2) at high sun angles, and the inverse at low sun angles, with a bias of -5 for shadowed pixels and 12 for illuminated pixels. Effective radius was most strongly shifted at low sun angles, with a bias of mean $1.5 \mu\text{m}$ in shadowed pixels and $-3 \mu\text{m}$ for illuminated pixels. By incorporating 3D radiative effects, the range of the errors in retrieved optical depth is greatly reduced from $[-50, 100]$ to $[-30, 40]$.

We also highlight a potential real-world test case to evaluate our retrievals against the Variability of the American Monsoon System (VAMOS) Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-REx). In-situ cloud were calculated from the Cloud Droplet Probe and was based on one vertical cloud profile and three longer periods of in-cloud data from within 1 hour of the A-Train overpass. This

cloud profile was subadiabatic, although the cloud droplet number concentration was reasonably constant with height, and cloud liquid water content still increased roughly linearly with height to about 0.3 g/m³. Applying the retrieval method to real-world data proved challenging due to the limited vertical information provided by satellites of clouds near the surface and due to inherent uncertainties of comparing cloud fields at different times. This vertical cloud information poorly correlated in height with that from in-situ observations.

Last, we have used a convolutional neural network to create a 3D shortwave radiative transfer emulator for stratocumulus cloud fields. This emulator was trained on selected cloud fields from the Large Eddy Simulation (LES) and applies to a specific set of solar and viewing geometry and aerosol conditions. The emulators had 3D errors from truth lower than 10% at viewing nadir and consistently achieved 15th and 85th percentile errors of less than $\pm 9\%$ for all setups. This type of emulator could be integrated into a number of remote sensing applications and allow for 3D effects to be cheaply integrated into radiative transfer.

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