Study of droplet size variability between cloudy and clear air using surface-based hyperspectral observations

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Abstract

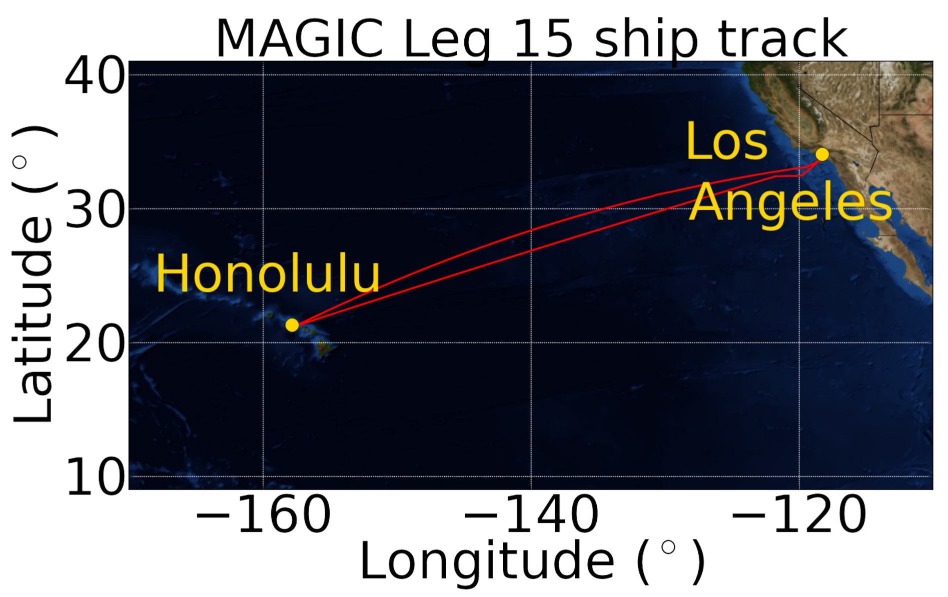
The *Solar Spectral Flux Radiometer* (**SSFR**) was deployed with the *Marine ARM GPCI Investigation of Clouds* (**MAGIC**).

We explore the cloud properties in the cloud transition zone under broken clouds using the shortwave hyperspectral observations of the SSFR.

MAGIC

Campaign to improve our understanding of the stratocumulus to cumulus cloud transition.

ARM AMF deployed on a ship (*Horizon Spirit*) between Los Angeles and Honolulu from 10.1.2012 to 9.30.2013.



Above: The ship track for one leg of the MAGIC campaign. The round trip transit time was roughly 2 weeks.

SSFR

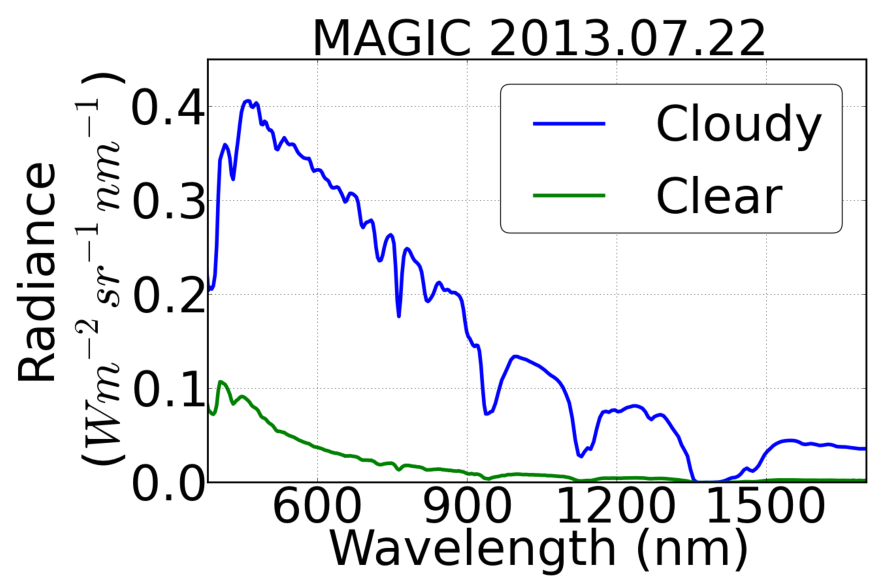
SSFR Observations

- Deployed on 7.6.2013
- Operates at 1 Hz
- FOV ~3°
- WL range: 350-1700nm

Above: Deck of the *Horizon Spirit* with the SSFR circled in red.

Sample zenith radiance spectra from the SSFR during the MAGIC campaign.

Cloudy signal is higher due to increased scattering.



Cloud transition zone (CTZ)

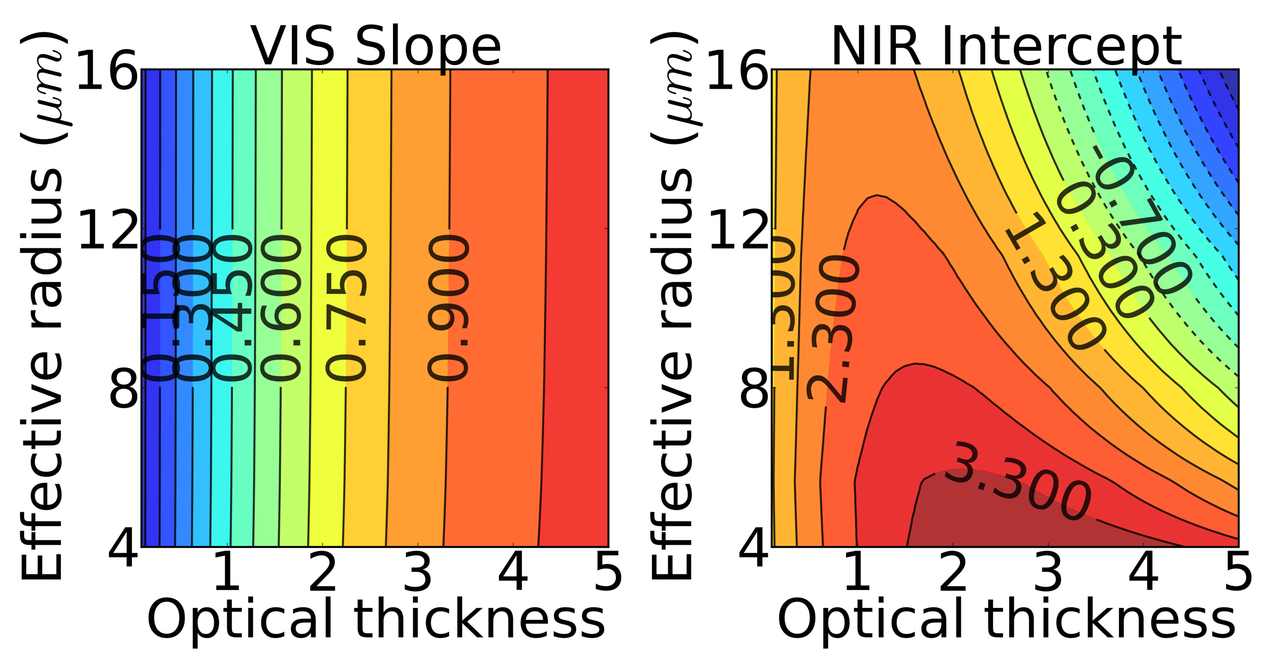
- Region between visible cloud and cloudless skies.
- A mix of aerosols, water vapor, and cloud droplets.
- Difficult to quantify due to its optically thin nature and 3D and adjacency effects
- Widespread, with half of all clear sky pixels closer than 5 km from clouds.[2]

Cloud properties in the cloud transition zone

Spectra in the CTZ can be approximated as a linear combination of a known cloudy spectrum and a known clear spectrum with a spectrally invariant slope (m) and y-intercept (b)[3,4].

$$\frac{I(t,\lambda)}{I(t_{\text{known\_clear}},\lambda)} = \frac{I(t_{\text{known\_cloudy}},\lambda)}{I(t_{\text{known\_clear}},\lambda)} m(t) + b(t)$$

Cloud optical thickness (τ) and effective particle radius (r_{eff}) can be retrieved using m fit in VIS and b fit in NIR.



Above: Contour plot of slope fit over visible (right) and intercept fit over near infrared wavelengths (right)

Goal: Develop a ***qualitative*** algorithm using the above relationship to study changes in particle size at the cloud edge and through the cloud transition zone.

Steps

1) Decreasing VIS Slope indicates decreasing τ through the cloud transition zone
2) Increasing NIR Intercept indicates a decreasing r_{eff}.

Monte Carlo simulations show that the NIR Intercept correctly predicts the relative change in droplet size in 75% of the cases.

References

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[2] T. Varnai and A. Marshak. Global CALIPSO observations of aerosol changes near clouds. IEEE Geoscience and Remote Sensing Letters, 8(1):19–23, January 2011.

[3] A. Marshak, et al. Spectral invariant behavior of zenith radiance around cloud edges observed by ARM SWS. Geophysical Research Letters, 36(16), August 2009.

[4] J. C. Chiu, et al. Physical interpretation of the spectral radiative signature in the transition zone between cloud-free and cloudy regions. Atmospheric Chemistry and Physics, 9(4):1419–1430, February 2009.

[5] P. J. McBride, et al. A spectral method for retrieving cloud optical thickness and effective radius from surface-based transmittance measurements. Atmospheric Chemistry and Physics, 11(14):7235–7252, 2011.

Summary

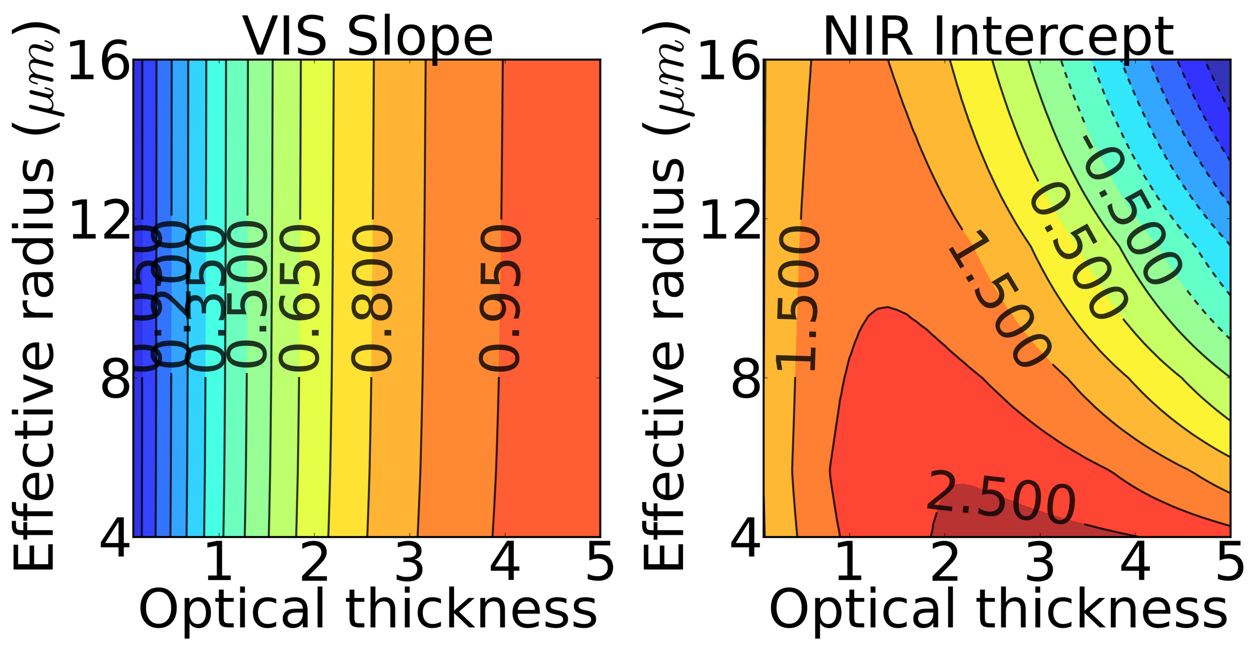
A qualitative algorithm was developed that predicts the relative change in droplet size through the cloud transition zone with a confidence level of 75%

The qualitative approach is not strongly dependent on the cloud properties of the known clear spectrum.

The case from MAGIC, shows a decreasing effective radius through the transition zone, supporting the homogeneous mixing scenario.

What if the “known clear” isn't clear?

The following look up table results from using a “known clear” spectrum calculated with τ=0.1 and r_{eff}=8 micron.



Above: Contour plot of slope fit over visible (right) and intercept fit over near infrared wavelengths (right). Spectra were normalized by a known clear with optical thickness = 0.1 and effective radius = 8 micron.

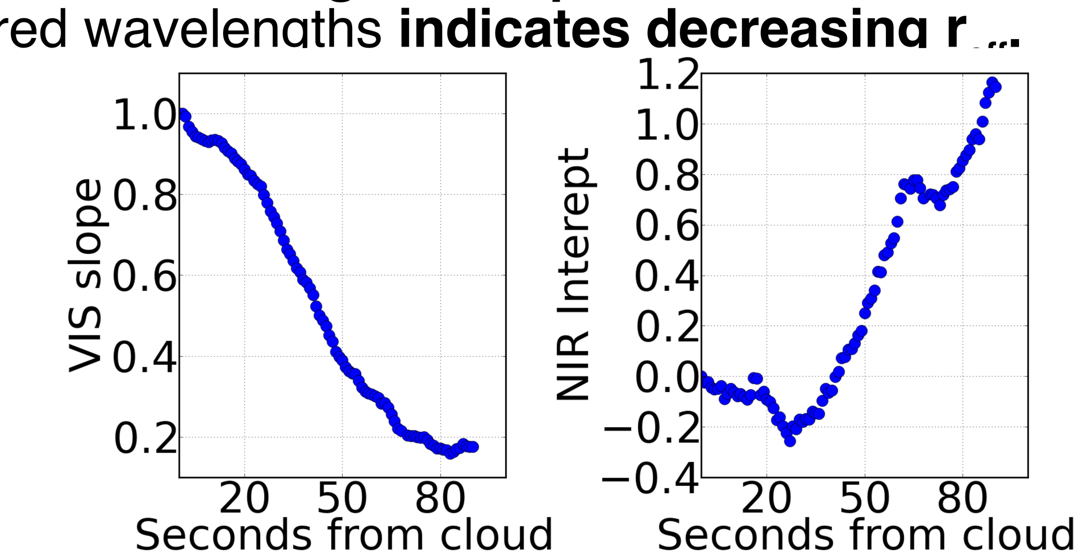
The slope and intercept change, but the overall shape does not.

The change in r_{eff} can still be predicted with 75% confidence with this cloud contamination of the known clear spectrum.

An example from MAGIC

Left Panel: **Decreasing slope** from line fit over visible wavelengths **indicates decreasing τ** and a transition from cloudy to clear sky.

Right Panel: **Increasing intercept** from line fit over near infrared wavelengths **indicates decreasing r_{eff}**.



This example shows, with 75% confidence, that the effective radius remains unchanged, initially, and is then decreasing, supporting a homogeneous mixing scenario.