Using a neural network to retrieve cloud height from Infrared remote sensing measurements in polar regions

Penny Rowe¹

¹NorthWest Research Associates (NWRA)

WAMC June 21, 2021
Motivation

➢ Polar clouds have a strong influence on the radiation budget.
➢ Measurements in polar regions are limited.
➢ Active sensors (e.g. Lidar) can retrieve cloud height but are not always available and sometimes have data gaps.
➢ These gaps can be filled with retrievals from downwelling infrared radiances
  • South Pole: 2001
  • McMurdo: 2016
Measurements

Atmospheric gases, clouds, aerosols

Downwelling Infrared radiance

Ground-based spectrometer
Measurements

Downwelling Radiances
South Pole, 2001/01/01
Measurements

Downwelling Radiances
South Pole, 2001/01/01

<table>
<thead>
<tr>
<th>Wavelength (µm)</th>
<th>17</th>
<th>10</th>
<th>7</th>
<th>5.6</th>
</tr>
</thead>
</table>

- CO₂
- Ozone
- Water vapor
Measurements

Phase (liquid, ice, mixed)

cloud optical depth, effective radius (aerosols)
Measurements

- CO2 slicing: 700 - 813 cm\(^{-1}\)
- MLEV: 750 - 950 cm\(^{-1}\)
Existing Cloud Height Retrievals

Two methods:

➢ MLEV: Minimum Local Emissivity Variance (MLEV; Huang et al., 2004)
➢ Slicing: CO2 slicing/sorting

Existing Cloud Height Retrievals

➢ Both MLEV and slicing rely on the emissivity

\[ \epsilon \approx \frac{R_{\text{obs}} - R_{\text{clr}}}{B_c t_c + R_c - R_{\text{clr}}} \]

➢ Robs = observed radiance
➢ Rclr = clear-sky simulation
➢ Bc = Planck function of cloud temperature
➢ tc = transmittance to cloud base
Emissivities for possible cloud heights. The correct height is where the emissivity is fairly smooth (MLEV) and fairly constant (slicing).

\[ \epsilon \approx \frac{R_{\text{obs}} - R_{\text{clr}}}{B_{\text{c}}t_{\text{c}} + R_{\text{c}} - R_{\text{clr}}} \]
Emissivities for possible cloud heights. The correct height is where the emissivity is fairly smooth (MLEV) and fairly constant (slicing).

\[ \epsilon \approx \frac{R_{\text{obs}} - R_{\text{clr}}}{B_{t}t_c + R_c - R_{\text{clr}}} \]
The two methods don’t always agree

South Pole (optical depths > 0.25)
Can a neural network do better?
Can a neural network find the correct height?

- What should the inputs be?
  - Emissivity?
  - Local emissivity variance (like the MLEV method)?
  - Parameter related to the CO2 slicing method?
  - Other?
- What data should be used, given that we need to know the answers (labels)?
  - Simulated data - we set the cloud heights.
  - Data with known cloud heights from lidar.
Neural Network

• Inputs: emissivity or local emissivity variance
• Outputs: 1 (low or high)
• Hidden layers (0 or 1)
• Loss function (MAE)
• Initial learning rate
• Batch size (default vs. mini-batch): default usually worked best.
Start simple:

- Cloud mask
- Simulated data, no errors
- Radiance differences
- Accuracy: 96-100%
Slightly harder:

- Low or high cloud?
- Simulated data, no errors
- Using LEV (like MLEV)
Slightly harder:

• Low or high cloud?

• Simulated data, no errors

• Using emissivity
Neural network: Accuracy = 99%

- Predicted positive (high) vs. true positive (high)
  - True positives: 56
  - False positives: 1
- Predicted negative (low) vs. true negative (low)
  - True negatives: 49
  - False negatives: 0

MLEV: accuracy = 98%

- Retrieved height (km) vs. True cloud base (km)
  - True negative: 384
  - False negative: 9
  - True positive: 209
  - False positive: 4
Conclusions

• Choice of inputs is extremely difficult for this problem.
  • How do we synthesize all the known information and standardize for different atmospheres?

• Remaining questions:
  • How will it perform with errors added?
  • How will it perform on real data?

• Things to try:
  • Principal component analysis
  • Self-organizing maps
  • Best of the two methods (MLEV and slicing)
Thank you!

Acknowledgements
America Chambers and Evan Shieh for advice on neural networks. Daniel Neshyba-Rowe and Steven Neshyba for help and useful conversations.
South Pole 2001

- Optical depth
- Ice fraction
- Liquid effective radius (µm)
- Ice effective radius (µm)
- Cloud Height