Neural Network Cloud Detection Over Antarctica During Nighttime for CERES Edition 5

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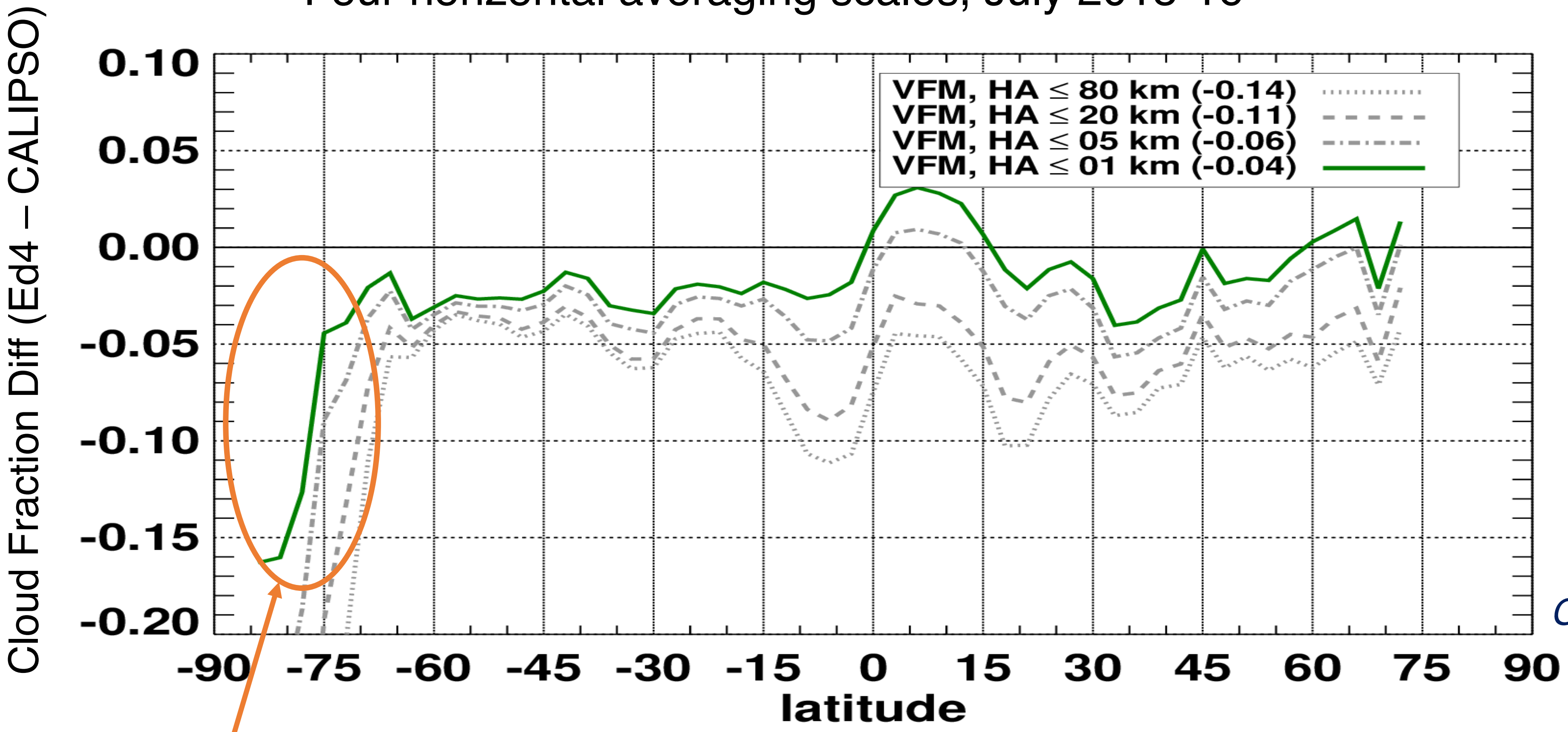
CEREES Earth Radiation Budget Workshop
12-14 October 2022, Hamburg, Germany

Outline

- Motivation
- Methodology
- Neural Network (NN) training and validation data from near nadir Aqua & CALIPSO
- Validation Results
    - Near nadir Aqua-MODIS NN cloud detection, compared to CALIPSO VFM
    - Full swath Aqua-MODIS NN cloud detection, as function of View Zenith Angle (VZA)
    - Consistency between MODIS and VIIRS with NN cloud detection
- Summary & Future Plans

Motivation

Mean nighttime cloud fraction differences, CERES-MODIS Ed4 – CALIPSO VFM
Four horizontal averaging scales, July 2015-16



Differences between MODIS and each of the VFM cloud fraction estimates

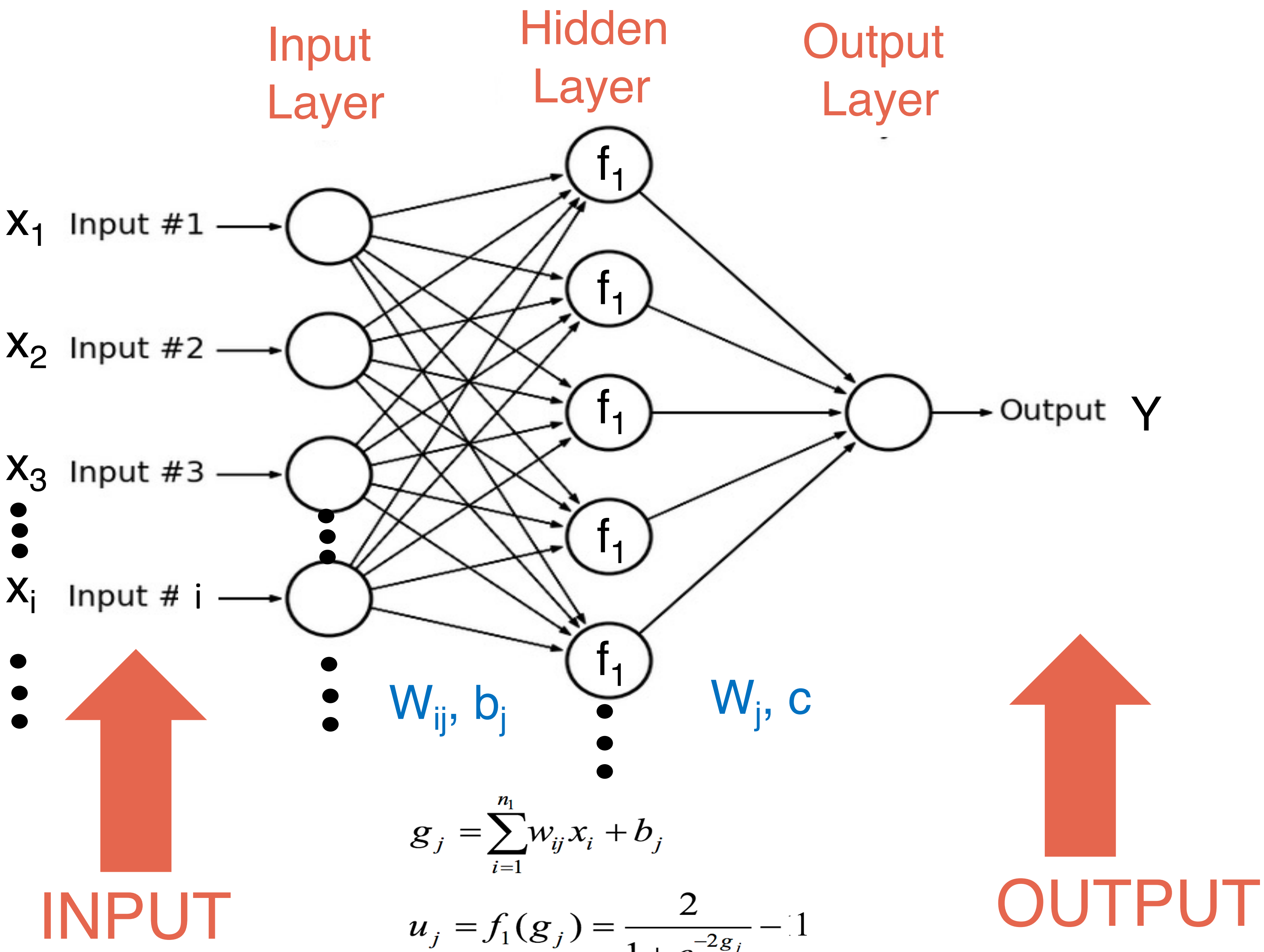
Courtesy of Chris Yost

0.12 underestimate over Antarctica at night

Ed4 Cloud Mask:

- Threshold method, heavily depends on obs. channels & sfc temp
- 3.7, 6.7 and 8.5 μm often stripping at night over Antarctica
- In case of VIIRS, 3.7 saturates (~206 K for I4) nighttime Antarctica
- Large uncertainty of surface temperature at night over Antarctica

Methodology



$$g_j = \sum_{i=1}^{n_1} w_{ij} x_i + b_j$$

$$u_j = f_1(g_j) = \frac{2}{1+e^{-2g_j}} - 1$$

$$y = \sum_{j=1}^{n_2} w_j u_j + c$$

Levenberg-Marquadt optimization used in cloud detection training.

Methodology – Cont.

Input Layer

<u>sfc, Atmos & GEO</u>

- latitude
- longitude
- elevation
- rh1
- rh2
- rh3
- rh4
- rh5
- rh6
- rh7
- rh8

<u>MODIS Radiances</u>

- tb37
- tb85
- tb11
- tb12
- btd3711
- btd8511
- btd1112

Hidden Layer

- *n* = 50 neurons
- 60% for training, 20% for testing, 20% for validation,

Output Layer

<u>Cloud Detection</u>

0 or 1

(Clear or Cloudy)

rh*i* = relative humidity at level *i*
tb*xx* = brightness temperature at wavelength *xx*
btd*xxyy* = brightness temperature difference, bt*xx* - bt*yy*

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Neural Network (NN) training data and validation data from near nadir Aqua & CALIPSO

- Using nadir-matched CALIPSO (V4-20) & Aqua-MODIS C6.1
  - CALIOP 1 & 5 km horizontal averaging vertical feature mask (VFM)
  - Aqua MODIS 1-km matched pixel radiances

- GMAO Product: GEOS 5.4
  8 relative humidity profiles levels: sfc, 850, 700, 500, 400, 300, 200,100 mb

- Antarctica at night
  - Permanent Snow (IGBP = 15)
  - Latitude < -60°,
  - Solar zenith angle > 82.0° (nighttime)

- Seasonal training Data Set. Trained each season separately.

Spring (SH)	**Fall (SH)**	**Winter (SH)**
September, October, November 2008 & 2009	March, April & May 2008	June, July & August 2008
~ 5.2 millions merged pixels	~ 4.3 millions	~ 4.3 millions

- Seasonal Validation Data Set

Spring (SH)	**Fall (SH)**	**Winter (SH)**
September, October, November 2010	March, April & May 2009	June, July & August 2009

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Near nadir Aqua-MODIS NN seasonal cloud fraction, compared to CALIPSO VFM
Antarctica, Nighttime, 2009 – 2010

Neural Net Cloud Detection

Spring (SON, 2010)

NNet \ VFM	clear	cloud
clear	32.2%	7.8%
cloud	8.7%	51.3%

Accuracy 83.5%

*Miss Rate 13%

*Miss Rate = fraction of clouds not detected

Fall (MAM, 2009)

NNet \ VFM	clear	cloud
clear	32.2%	10.3%
cloud	8.5%	49.0%

Accuracy 81.2%

Miss Rate 17.3%

Winter (JJA, 2009)

NNet \ VFM	clear	cloud
clear	32.2%	6.9%
cloud	11.1%	49.8%

Accuracy 82.0%

Miss Rate 12.2%

CERES Ed4 Cloud Detection

Spring (SON, 2010)

Ed4 \ VFM	clear	cloud
clear	32.0%	16.1%
cloud	9.0%	42.9%

Accuracy 74.9%

Miss Rate 27.3%

Fall (MAM, 2009)

Ed4 \ VFM	clear	cloud
clear	31.7%	17.6%
cloud	9.0%	41.7%

Accuracy 73.4%

Miss Rate 29.7%

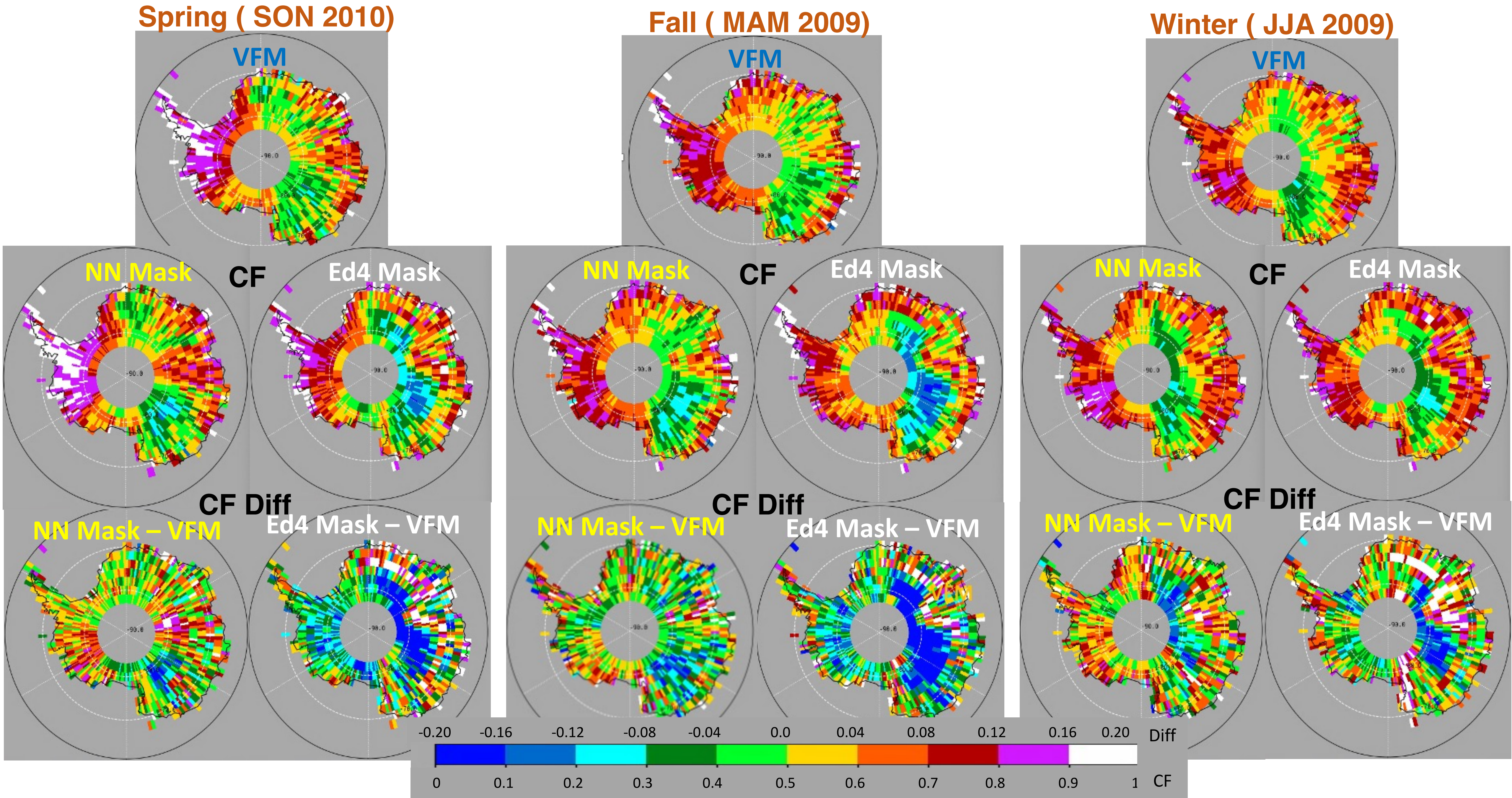
Winter (JJA, 2009)

Ed4 \ VFM	clear	cloud
clear	30.8%	12.6%
cloud	12.5%	44.1%

Accuracy 75.0%

Miss Rate 21.5%

Nadir Aqua-MODIS NN seasonal cloud fraction compared to CALIPSO VFM, Antarctica, Night, 2009-2010

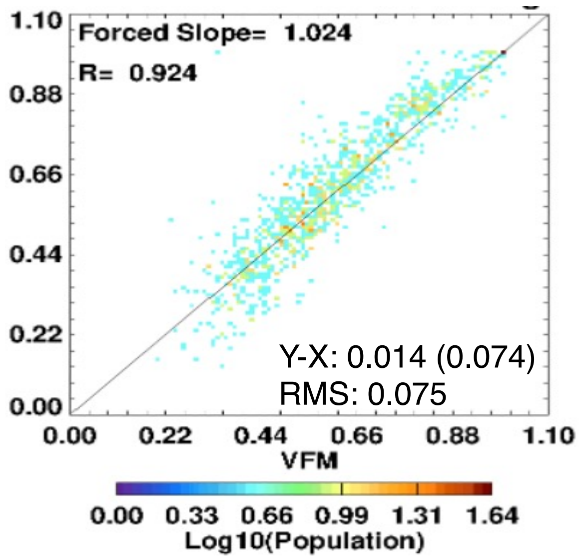


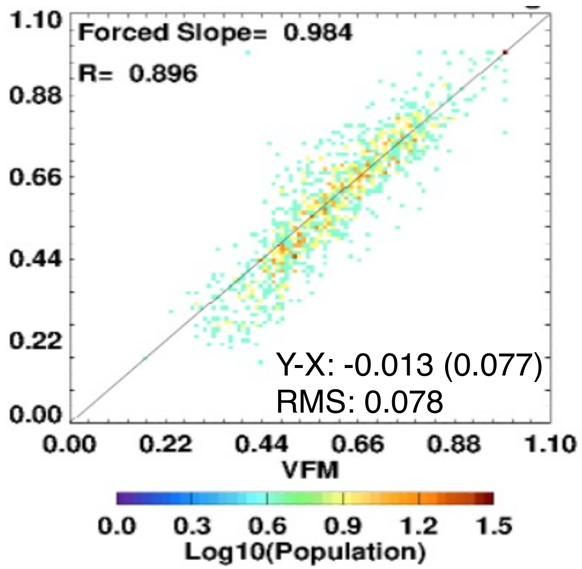
Regionally Averaged Cloud Fraction, Antarctica, Nighttime, 2009 – 2010

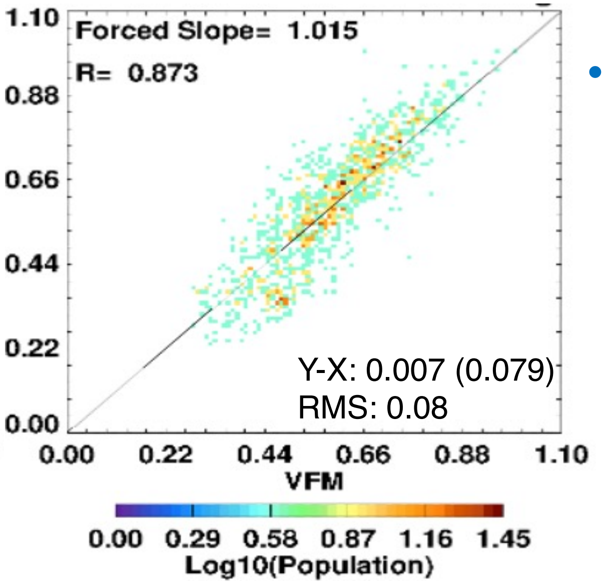
Spring (SON 2010) | **Fall (MAM 2009)** | **Winter (JJA 2009)**

Neural Net Cloud Detection

NN Mask

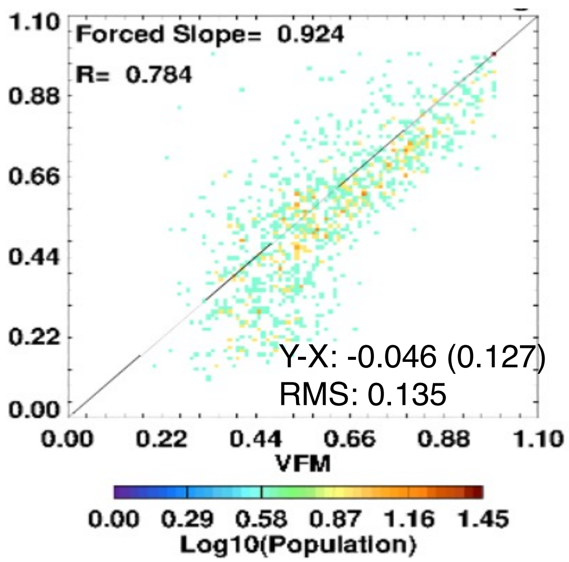


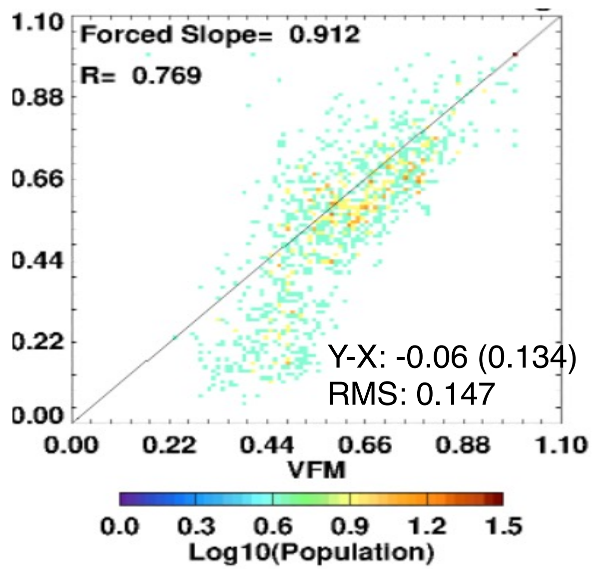


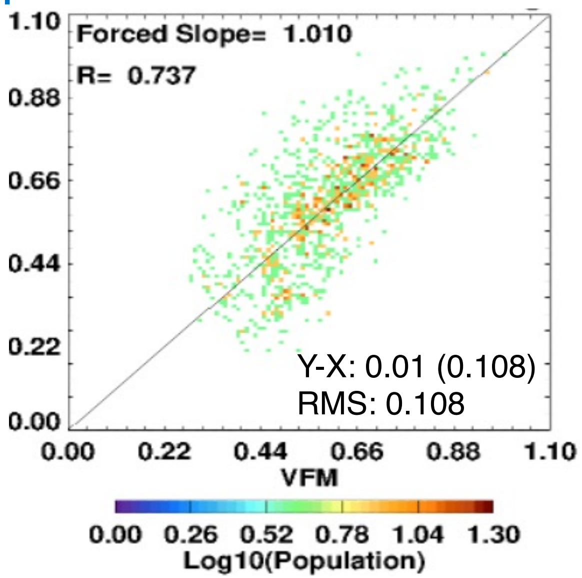


CERES Ed4 Cloud Detection

Ed4 Mask







- Correlation to CALIPSO:
  NN Mask: 0.92 (Spring)
  0.90 (Fall)
  0.87 (Winter)
  much higher than
  Ed4: 0.78 (Spring)
  0.77 (Fall)
  0.74 (Winter)

- RMS against CALIPSO:
  NN Mask: 0.075 (Spring)
  0.078 (Fall)
  0.080 (Winter)
  a little less half of
  Ed4: 0.135 (Spring)
  0.147 (Fall)
  0.108 (Winter)

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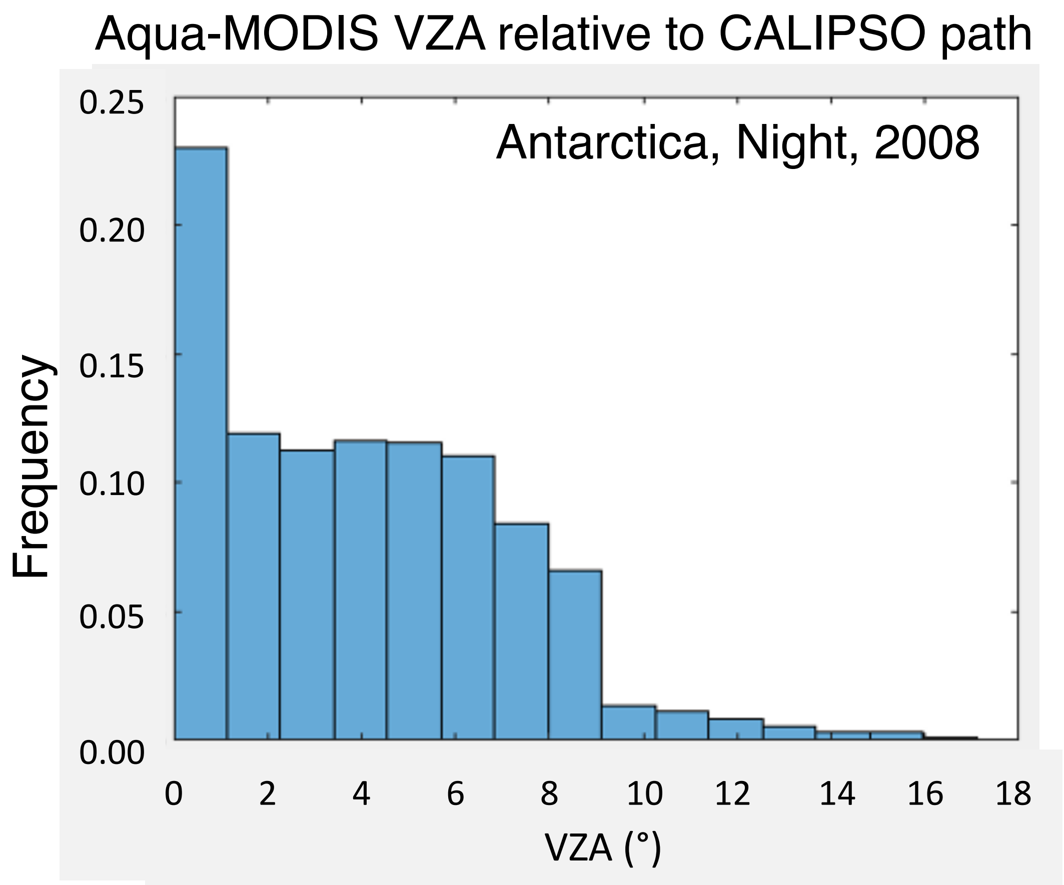
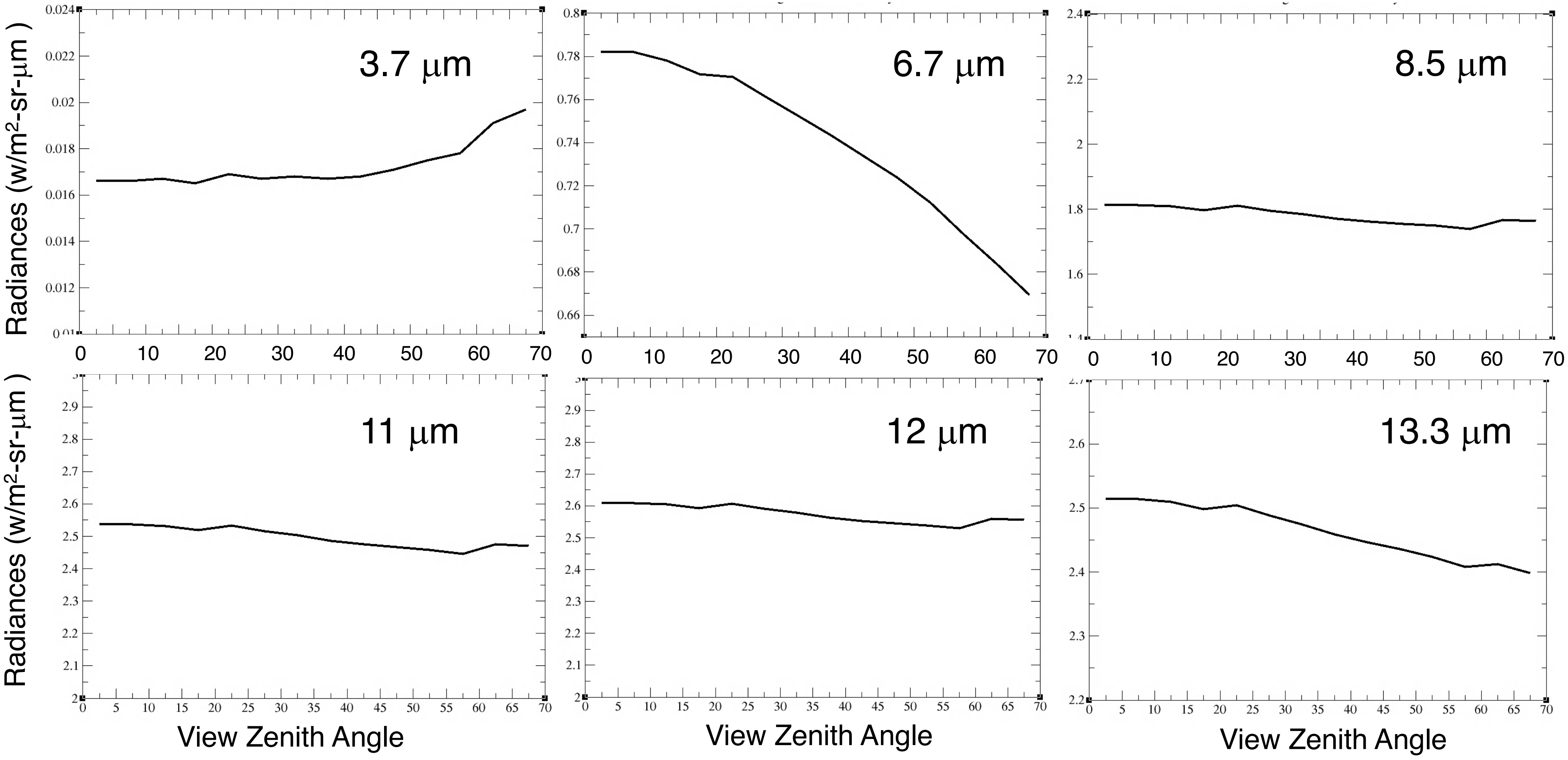
Creating a Full Swath Retrieval: Variations of radiances with VZA



- NN trained with near-nadir VZA
- MODIS radiances change w/VZA, expect some misinterpretation of off-nadir radiances by NN Mask
- In absence of off-nadir matches, we attempt to make radiance sets “appear” as nadir radiances

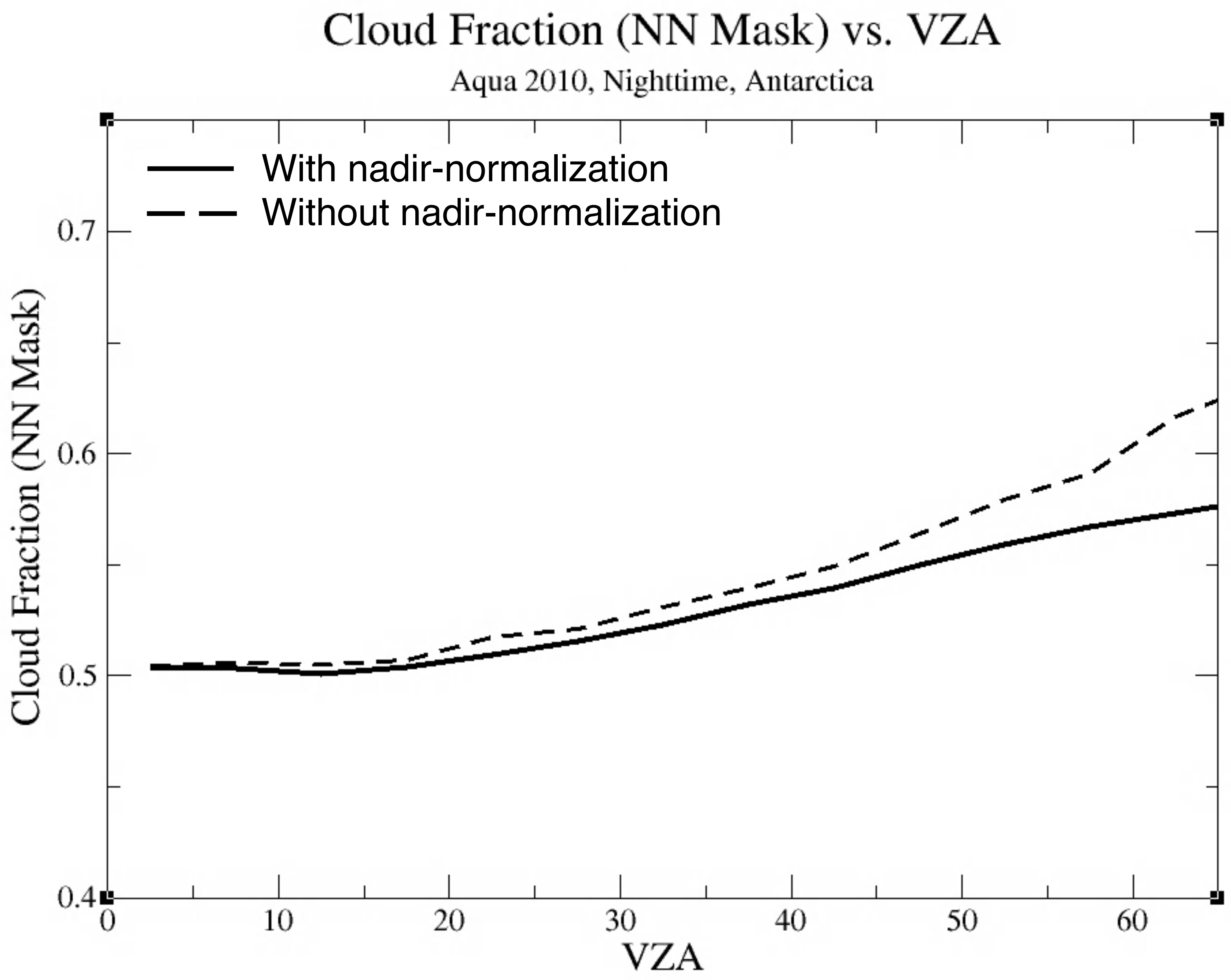
Creating a Full Swath Retrieval: Variations of radiances with VZA

Mean JAJO 2019 radiances as function of Aqua-MODIS VZA for nighttime over Antarctica



- Calculate VZA dependence of radiance using full swath data
- Normalize observed radiances to the near-nadir view by creating correction factors
- Apply corrections to observed radiances making them “nadir-like” radiances
- Perform NN cloud detection retrieval using corrected or nadir-normalized radiances

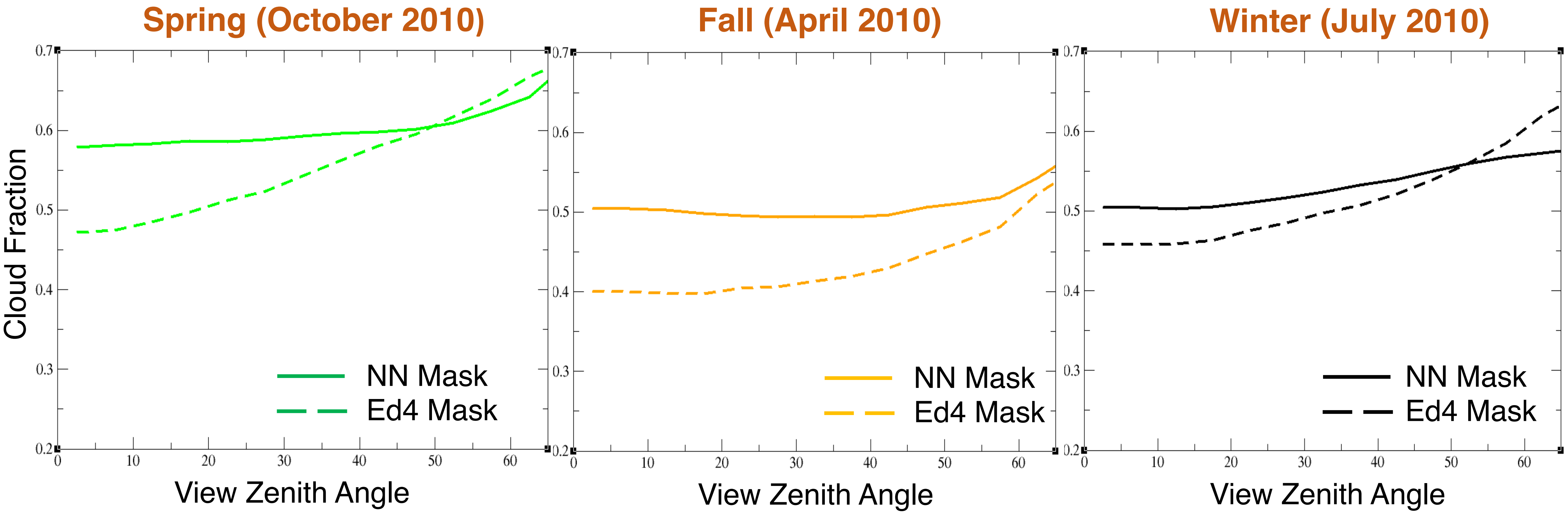
Impact of Using Nadir Normalization Approach



- Normalization decreases the rise of cloud amount with VZA
- Need further study to determine which approach is more accurate

Full swath seasonal MODIS NN cloud fraction, compared with CERES MODIS Ed4
Antarctica, Nighttime, 2010

NN Mask: Apply nadir trained Neural Net to full swath Aqua-MODIS, with nadir normalized radiances



- NN Mask has much smaller vza dependency than Ed4 Mask, for all seasons.
- Near nadir, NN Mask detects more clouds (10-11% for Spring & Fall, 5% for winter) than Ed4 mask
- The cloud fraction differences between NN and Ed4 decrease as increasing VZA, up to vza ~ 55^{o}

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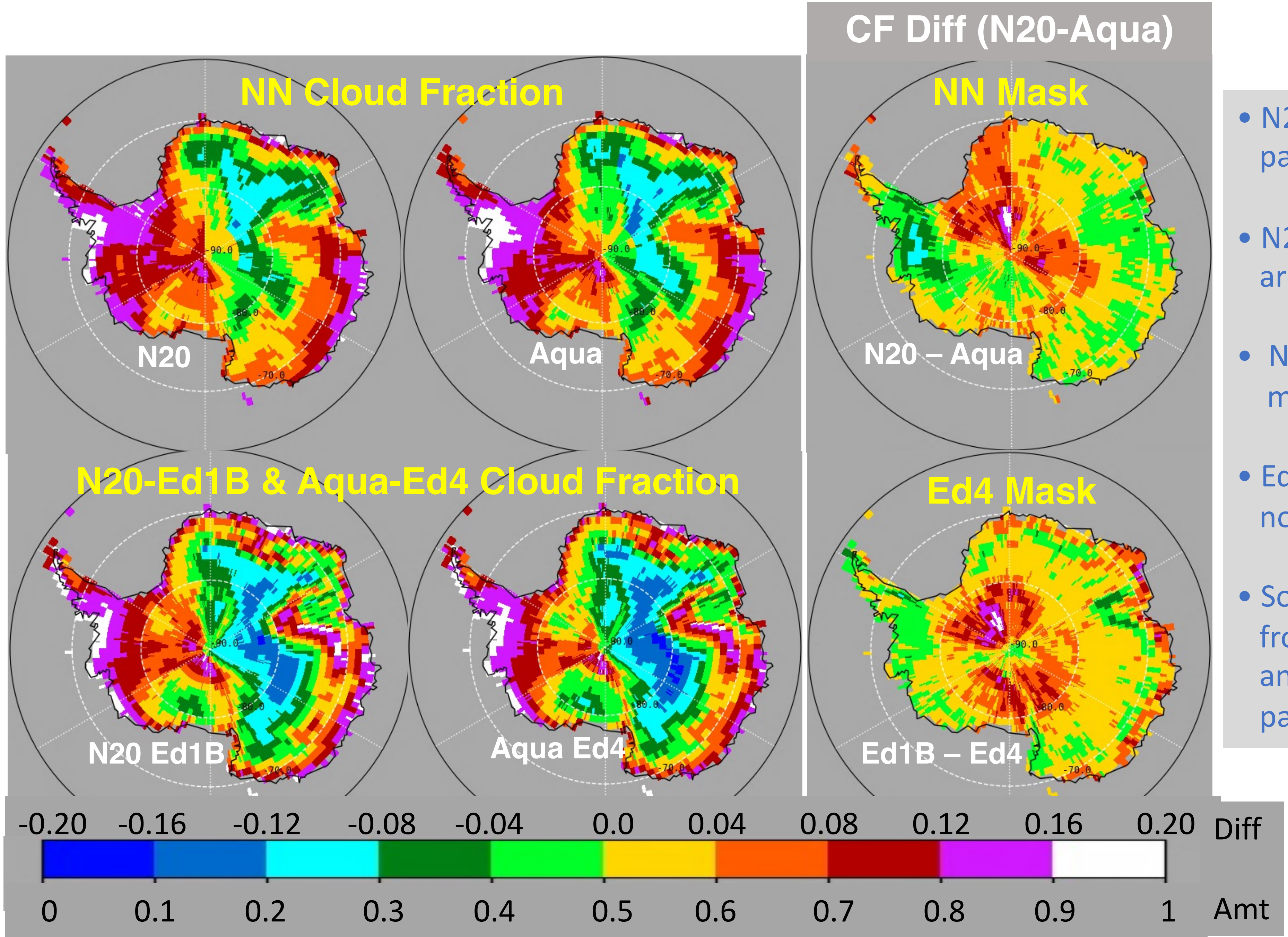
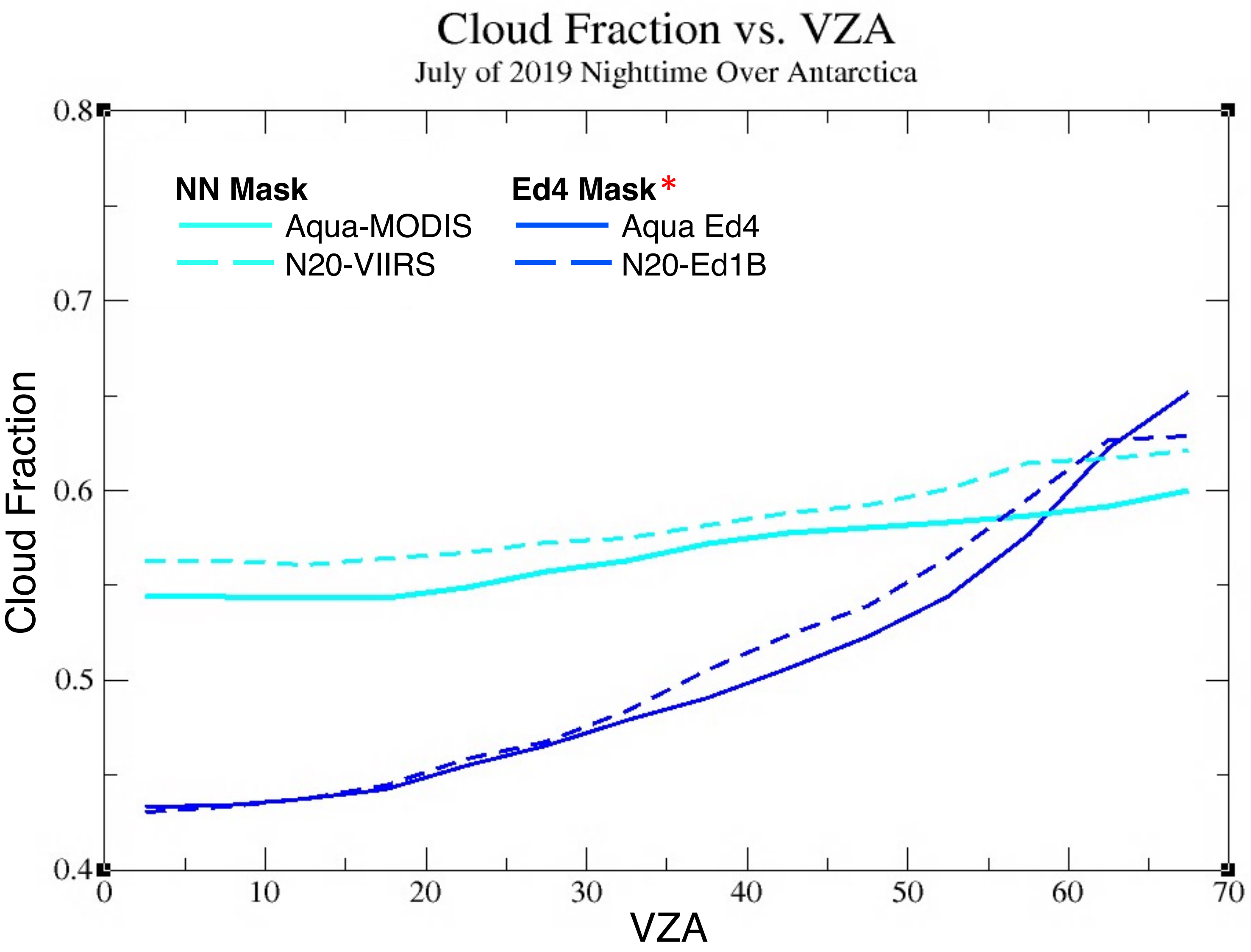
NN Cloud Fraction from Aqua-MODIS and NOAA20-VIIRS, Night, Antarctica, July 2019



- N20 NN mask yields regional patterns similar to Aqua NN mask
- N20/Aqua NNmask similarities are quite encouraging
- N20 – Aqua NN differences mostly greatest over west
- Ed1B – Ed4 difference patterns not the same as for the NNmask
- Some discrepancies expected from channel spectral differences and remaining calibration issues, particularly at low temps, 3.7 µm

Cloud Fraction VZA dependency from Aqua-MODIS and NOAA20-VIIRS Nighttime, Antarctica, July 2019



- Some VZA dependence expected
  - cloud sides, multiple layers, etc.
- Cloud fraction VZA dependence much flatter with the nadir normalization approach
  - validate using matched VIIRS/CALIOP
- NN gives consistent 1-3% difference between VIIRS and MODIS
- Ed4 mask yields near nadir agreement between VIIRS & MODIS with 1-2% differences at higher VZA

*N20 Ed1B uses 6.7 & 13.3 μm from fusion data (Baum et al, 2019a)

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Summary

- Neural net trained seasonal cloud masks detect additional ~ 9% of cloud amount missed by threshold methods (Aqua Ed4 and N20 Ed1B)

- The agreement with CALIPSO is:
  NN Mask: 83.5% (Spring), 81.2% (Fall), and 82% (Winter), much improved from
  Ed4: 74.9% (Spring), 73.4% (Fall), and 75% (Winter)
    - Results comparable to those of White et al. 2021 (a convolutional NN) for permanent snow

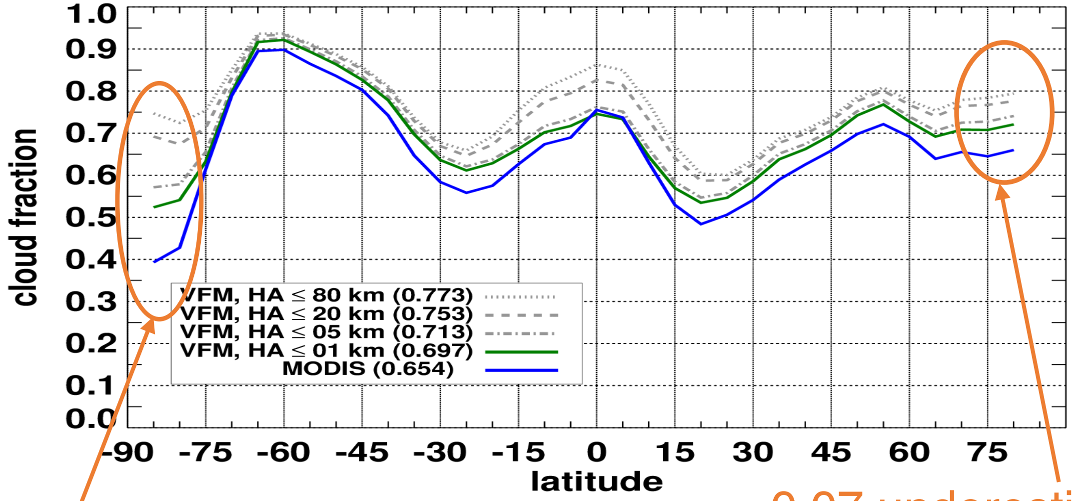
- Neural net trained cloud detections do not use 6.7 and 13.3 μm as input parameters, which are the crucial channels for Ed4 and N20 Ed1B (fusion data, Baum et al, 2019a).

- After applying nadir normalizations, neural net cloud detections in full swath data have much less view angle dependency (less than 10%) than that of Aqua Ed4 and N20 Ed1B (~ 40%)
    - Need to verify with matched VIIRS & CALIOP data

- When applying nadir Aqua & CALIPSO trained neural net to NOAA20 VIIRS, the consistency between Aqua and NOAA20 is similar to Ed4 & NOAA20 Ed1B, ~ 1-3% globally & could be large regionally
    - Should account for any calibration differences, especially for 3.7-μm

Future Plans

Mean zonal cloud fractions from MODIS Ed4 and CALIPSO for four horizontal averaging scales, JAJO 2015-16.



Courtesy of Chris Yost

- Arctic cloud fraction at night is underestimated by ~0.07 in Ed4
  - Extend neural net training to Arctic (both Arctic Ocean and Greenland) at night, as well as ice shelves in Southern Ocean adjacent to Antarctica.
- Current neural net training used **GMAO G5.4**. CERES plans to use either **GMAO GEOS-IT** or **R21C** in Ed5
  - Will need to re-train with the new atmospheric relative humidity data.
- Validate & train with VIIRS using VZA input term, and test 3.7 μm with M12, saturates ~ 200K (I4 206 K).
- Examine effect of using some spatial context in the input.