Using Multiple Scanning Angles to Improve AERI Thermodynamic Retrievals

Jongjin Seo[1], Timothy J. Wagner[2], Jonathan Gero[2], David D. Turner[3], and Tristan L'Ecuyer [1,2]

[1]Department of Atmospheric and Oceanic Sciences, University of Wisconsin–Madison
[2]Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin–Madison
[3]Global Systems Laboratory, National Oceanic and Atmospheric Administration

Contact: jseo47@wisc.edu

Introduction

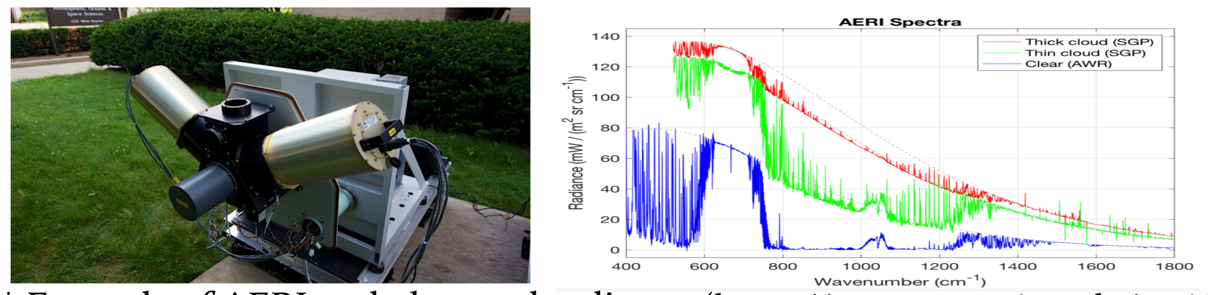
⋆**Motivation**

i. Important to observe thermodynamic profiles in the Planetary Boundary Layer (PBL)

ii. Microwave Radiometer (MWR) and Atmospheric Emitted Radiance Interferometer (AERI)
  a. Have High Sensitivity near the surface and Vertical & Temporal Resolution
  b. Establish World-wide Network (ARM, MWRnet)
  c. Commercially available and Operational Ground-Based Remote Sensing Instruments

iii. MWR community has used Multiple Scanning Angles to Improve Retrievals
  a. Using Multiple Scanning Angles has benefit to retrievals below 1 km (Crewell and Löhnert, 2007).
  b. Additional Angular Information gives a better shape of temperature profiles (Massaro et al., 2015).

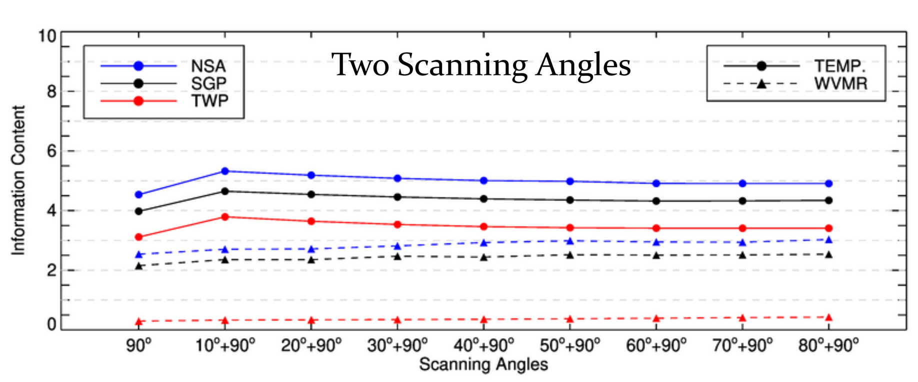
iv. AERI Instrument Characteristics
  a. Developed for the ARM program by SSEC
  b. Spectral Range: 530 – 3050 cm^{-1} (19.0 - 3.3 μm)
  c. Temporal Resolution: 20 s
  d. Radiometric Calibration: Better than 1%

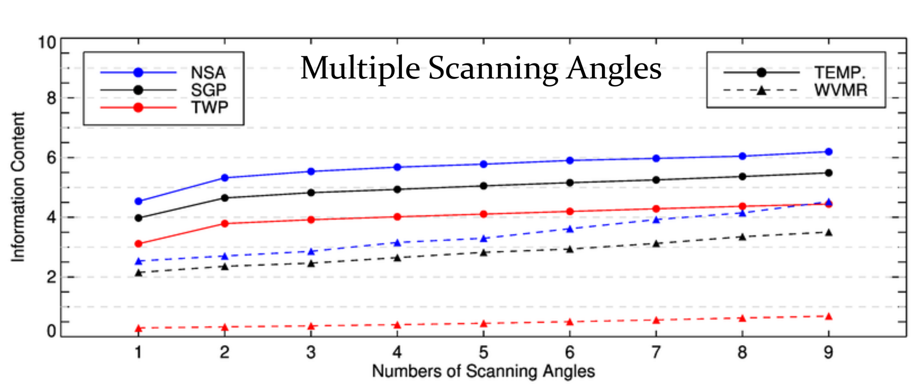


* Example of AERI and observed radiance (https://www.ssec.wisc.edu/aeri/)

Synthetic Experiment

⋆ **Information Content**





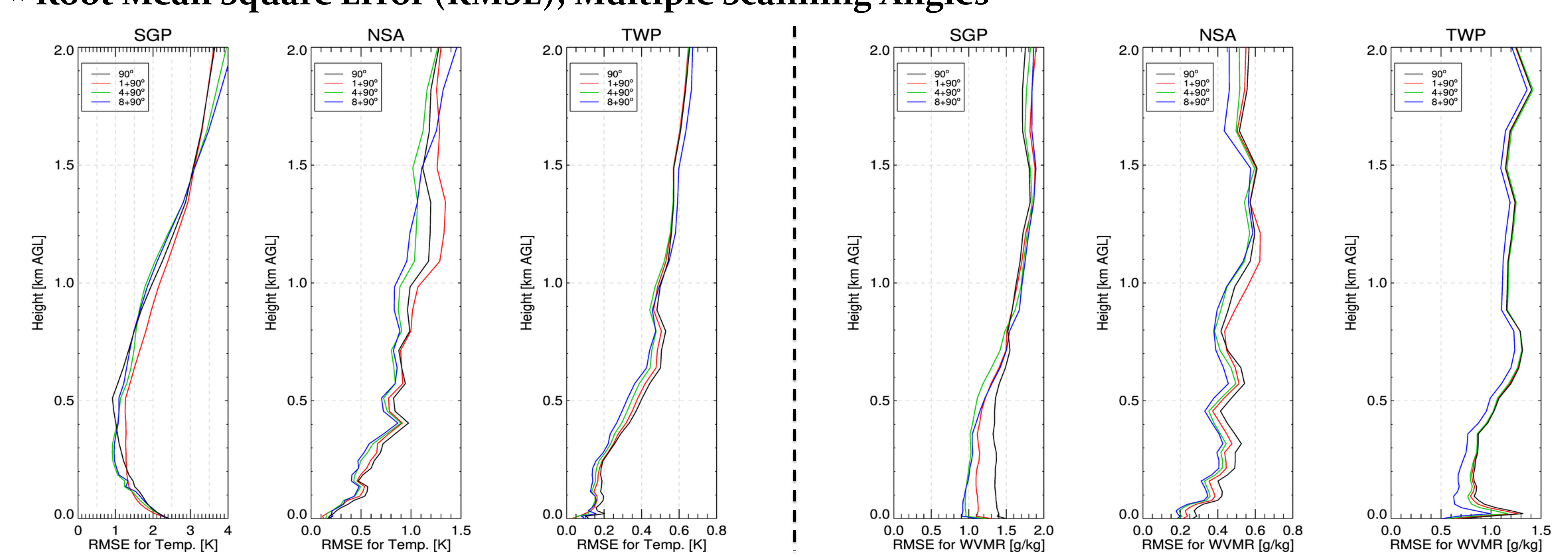
Mean Information Content at 4 km

Temp.	90°	10+90°	80+90°	Wvmr	90°	10+90°	80+90°
SGP	3.85	**4.52**	4.19	SGP	1.94	2.14	**2.27**
NSA	4.27	**5.02**	4.50	NSA	2.21	2.36	**2.61**
TWP	3.11	**3.79**	3.40	TWP	0.29	0.33	**0.42**

Temp.	90°	4+90°	8+90°	Wvmr	90°	4+90°	8+90°
SGP	3.85	4,91	**5.30**	SGP	1.94	2.53	**3.09**
NSA	4.27	5.48	**5.82**	NSA	2.21	2.88	**3.84**
TWP	3.11	4.10	**4.44**	TWP	0.29	0.45	**0.69**

- **Numbers of Scanning Angles**: 1 = 90°, 2 = 10+90°, …, 4+90° = 10+20+30+40+90°, 8+90° = 10+20+…+70+80+90°

⋆ **Root Mean Square Error (RMSE); Multiple Scanning Angles**



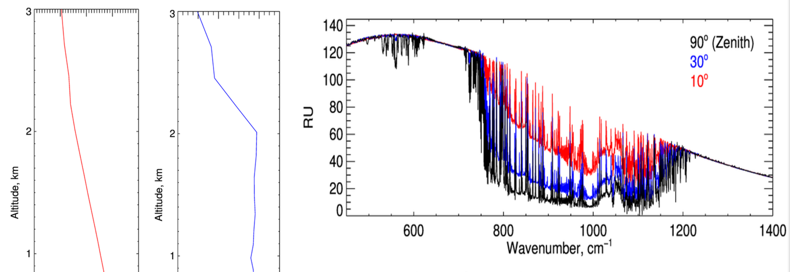
⋆ **Acknowledgements**

Thank Jonathan Gero, Timothy Wagner, David Turner and Tristan L'Ecuyer.

Methodology

⋆**Data resources**

i. Synthetic Experiment
  a. Simulate Radiances Using Radio Soundings at ARM sites (SGP, NSA, and TWP)
  b. Make *A Priori* profiles using 10 years Radio Sounding at ARM sites
  c. Clear sky and Horizontal Homogeneity of Atmosphere are assumed.
  d. Atmospheric Limb views (10, 20, 30, 40, 50, 60, 70, 80°), Zenith view (90°)



i. Example of Radio Sounding at SGP
ii. Simulated Radiance with LBLRTM
  a. Atmospheric Limb views (10, 30°)
  b. Zenith view (90°)

ii. ARM Cloud Aerosol Precipitation Experiment (ACAPEX) Campaign (M-AERI)
  a. Aimed to improve understanding of precipitation process at Western U.S
  b. Pacific Ocean and West of California (14 January 2015 – 12 February 2015)
  c. Make *A Prior* profiles using 10 years Radio Sounding at Oakland and San Diego
  d. Atmospheric Limb views (20, 25, 30, 35°), Zenith view (90°), Dwell period: ~ 4 min
  e. Cloud Filtering: Use Ceilometer, Total Sky Imager data (TSI), and Brightness temperature at 11 μm.

Marine-AERI

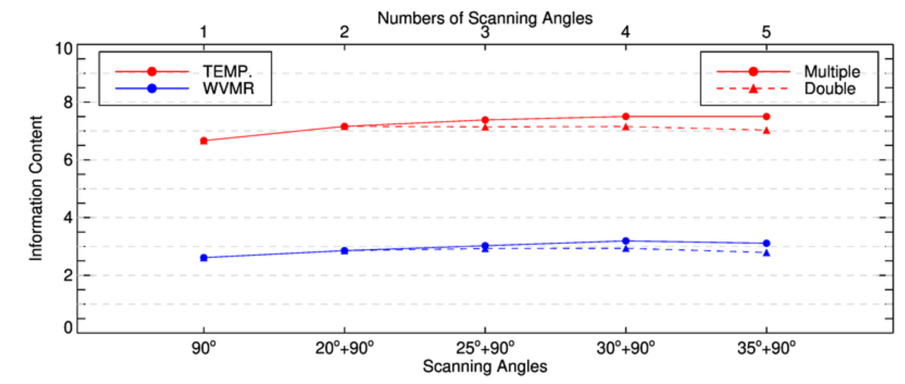
⋆ **Method**

i. Optimal Estimation Method
  a. $X^{n+1} = X^n + [(1+\gamma)S_a^{-1} + K_n^T S_\epsilon^{-1} K_n]^{-1}[K_n^T S_\epsilon^{-1}(Y - F(X^n)) - S_a^{-1}(X^n - X_a)]$ (Rogers, 2000)
  X^n, X_a: State Vector at *n iteration, A priori*, S_ϵ, S_a: Error Covariance of Measurement, *A Priori*, γ: Damping Factor
  Y: Observed Radiance, $F(X^n)$: Calculated Radiance using LBLRTM, K_n: Jacobian Matrix $\left[\frac{\partial F(X^n)}{\partial X^n}\right]$

ii. Information Content (or Degree of Freedom for Signal)
  a. The number of independent pieces of information from the observation used in the solution
  b. Trace of Averaging Kernel $A = (K^T S_e^{-1} K + S_a^{-1})^{-1} \bullet (K^T S_e^{-1} K)$

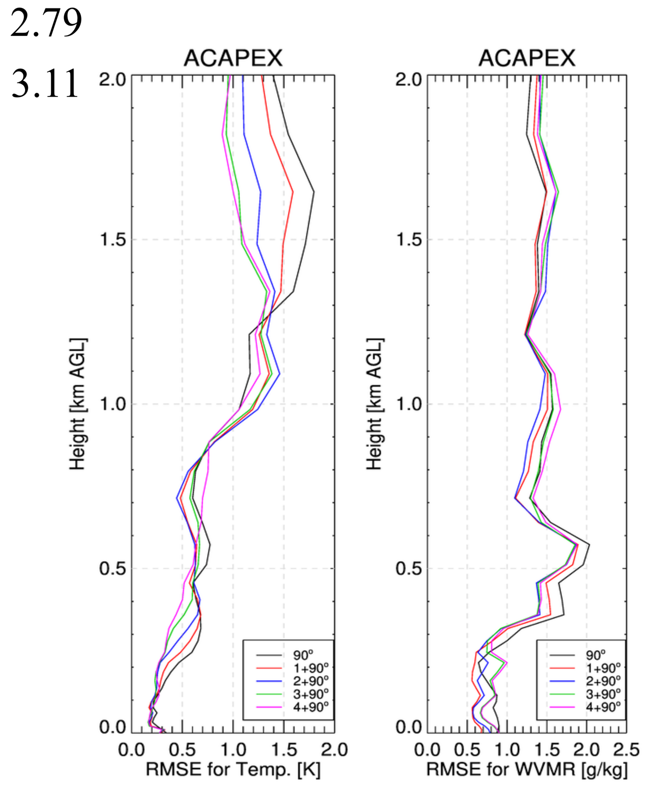
ACAPEX Campaign

⋆ **Information Content**



	90°	20+90°	25+90° / 2+90°	30+90° / 3+90°	35+90° / 4+90°
Temp.	6.67	7.16	7.14 / 7.38	7.16 / 7.50	7.03 / 7.50
Wvmr	2.61	2.85	2.93 / 3.02	2.93 / 3.19	2.79 / 3.11

Numbers of SAs
2+90° = 20+25+90°
3+90° = 20+25+30+90°
4+90° = 20+25+30+35+90°



⋆ **Root Mean Square Error (RMSE); Multiple Scanning Angles**

i. Using multiple scanning angles improves the temperature retrievals.
  a. Zenith with four low scanning angles has the best RMSE.
  b. within 0.5 K below 1 km and 1.0 K at 2 km of the radio soundings

ii. Using multiple scanning angles has benefit of retrieving water vapor mixing ratio.
  a. Zenith with 20 degree has the best RMSE.
  b. within 0.5 g/kg near the surface and 1.5 g/kg above 500 m of the radio soundings.
  c. Multiple scanning angles haven't necessarily good RMSE.

⋆ **Future Work**

i. Using M-AERI data during Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) Campaign

ii. Investigating multi-spectral channels with multiple scanning angles to improve AERI retrievals

iii. Retrieving thermodynamic profiles in both clear and cloudy condition, and Cloud information

⋆ **References**

Crewell, S., and Lohnert, U., 2007: Accuracy of Boundary Layer Temperature Profiles Retrieved With Multifrequency Multiangle Microwave Radiometry. *IEEE Trans. Geosci. Remote Sens.*, **45**, 2195-2201.

Massaro, G., Stiperski, I., Pospichal, B., and Rotach, M. W., 2015: Accuracy of retrieving temperature and humidity profiles by ground-based microwave radiometry in truly complex terrain. *Atmos. Meas. Tech.*, **8**, 3355-3367

Rogers, C. D., 2000: Inverse Methods for Atmospheric Sounding: Theory and Practise (Series on Atmospheric Oceanic, and Planetary Physics), vol. 2. Sigapore: World Scientific, 233 pp