BBHRP Assessment Part 2:
Cirrus Radiative Flux Study Using Radar/Lidar/AERI Derived Cloud Properties

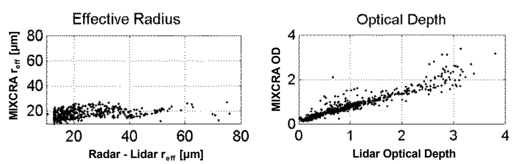
David Tobin, Lori Borg, David Turner, Robert Holz, Daniel DeSlover, Hank Revercomb, Bob Knuteson, Leslie Moy, Ed Eloranta, Jun Li
Space Science and Engineering Center, University of Wisconsin-Madison

Introduction:
Previous related work by our group has focused on closure of the clear sky flux problem and providing assessment of and improvements for BBHRP in that regard (see Part 1). Here, our analyses are extended to include uniform cirrus clouds. We present results of a cloud flux closure study where observed top-of-atmosphere and surface flux measurements are compared with computed fluxes for uniform cirrus cloud events at the Southern Great Plains site. The flux and heating rate calculations use cloud properties derived from various sources including radar and a combined radar/lidar/AERI cloud algorithm.

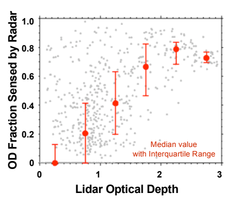
Approach:
- Derive cloud properties using radar reflectivity and Raman lidar extinction
  - Used W-band radar since MMCR transmitter was problematic
  - Cloud properties averaged to 5-min intervals
- Derive cloud properties from the AERI (MIXCRA retrieval algorithm)
- Compute infrared radiative fluxes and heating rates with RRTM
  - A. MWR-scaled interpolated radiosonde profiles
  - B. Radar-only cloud properties (Microbase logic, which is Z-IWC power law, R_e as function of T)
  - C. Radar + lidar cloud properties (direct measurements of extinction and particle size)
    - Radar + lidar following Donovan et al when both instruments see cloud simultaneously
    - Microbase logic when only radar sees the cloud
    - Lidar extinction and assumed R_e when only lidar sees the cloud
  - D. MIXCRA-retrieved optical depth and effective radius using Lidar boundari
    - Extinction and particle size assumed constant with height
- Ice habit assumed to be hexagon columns, assumed Ebert and Curry parameterization in RRTM
- Compare computed fluxes to observations at:
  - E. Top of atmosphere (TOA) -- GOES derived values
  - F. Surface (SFC) -- best-estimate flux product (BEFLUX)

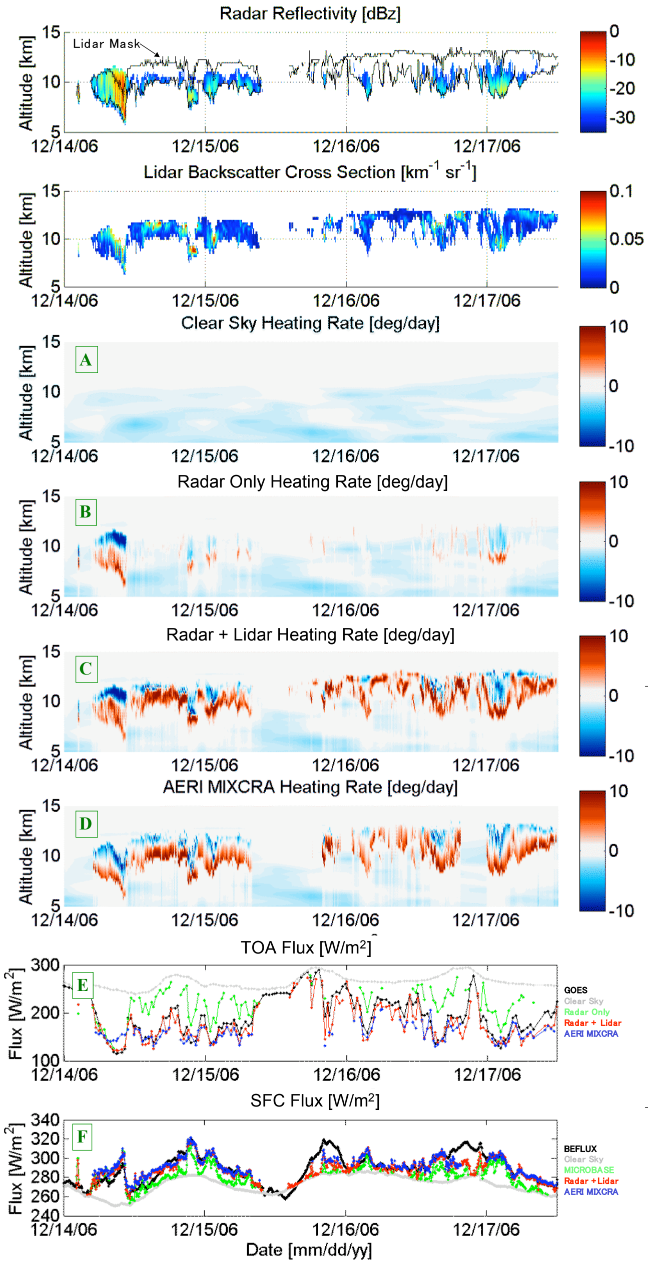
Comparison of Cloud Properties:

- MIXCRA and radar+lidar optical depths show good correlation
- Radar+lidar r_{eff} distribution is much larger than MIXCRA r_{eff}

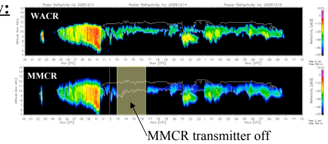


- For lidar OD < 1, radar typically sees only a small fraction of the cirrus optical depth
- Even for OD ~ 3 (limit of lidar), radar still sees only ~80% of total cirrus optical depth
- How does the result from this 3-day case study extend to the larger dataset?

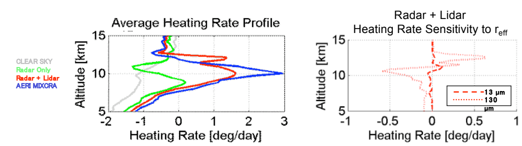


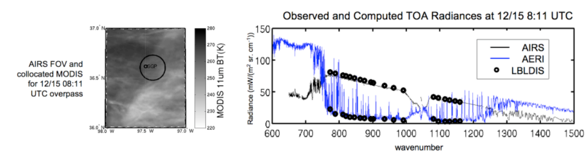


MMCR and WACR Reflectivity:
- MMCR transmitter was intermittent in this period
- WACR used in our analysis
- Note reflectivity differences
- Both have similar sensitivities

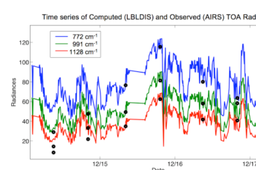


Discussion:
- Cirrus is prevalent above SGP, occurring 25% - 35% of the time
- Different instruments have different sensitivities
  - Radar sensitive to 6th moment of size distribution
  - Lidar sensitive to 2nd moment of size distribution
  - AERI sensitive to ratio of 3rd and 2nd moments of size distribution
- Resulting differences in atmospheric heating rate calculations are large for different cloud properties
- Note that standard ARM BBHRP product uses Microbase (with MMCR)
- **Radar alone misses significant upper level cirrus resulting in large errors in computed fluxes and heating rates**
- **Accurate characterization of thin cirrus in BBHRP requires lidar extinction plus radar or AERI plus lidar boundaries**
- **Vertical distribution of extinction and particle size are significantly less important than optical depth in computing heating rates**





Example of Radiance Closure:
- Spectral resolution provides enhanced sensitivity to assumptions (ice habit, atmospheric state, size distribution, etc.)
- Compute radiance with LBLDIS
- Compare with AIRS and AERI obs
- Homogeneity in AIRS field-of-view important (will need MODIS)
- Considerably less uncertainty in radiance obs (esp. TOA) than in flux
- Closure with direct radiance obs will be used to interpret flux analysis



Future:
- Use AIRS and AERI radiance analyses to assist in the BBHRP flux closure study (analogous to our clear sky approach in Part 1)
- Evaluate satellite retrieved cloud properties in this same framework
- Extend radiative closure analysis to the shortwave
- Extend cirrus case study timeline and include liquid and mixed-phase clouds