Multi-sensor Retrievals of Cloud Properties

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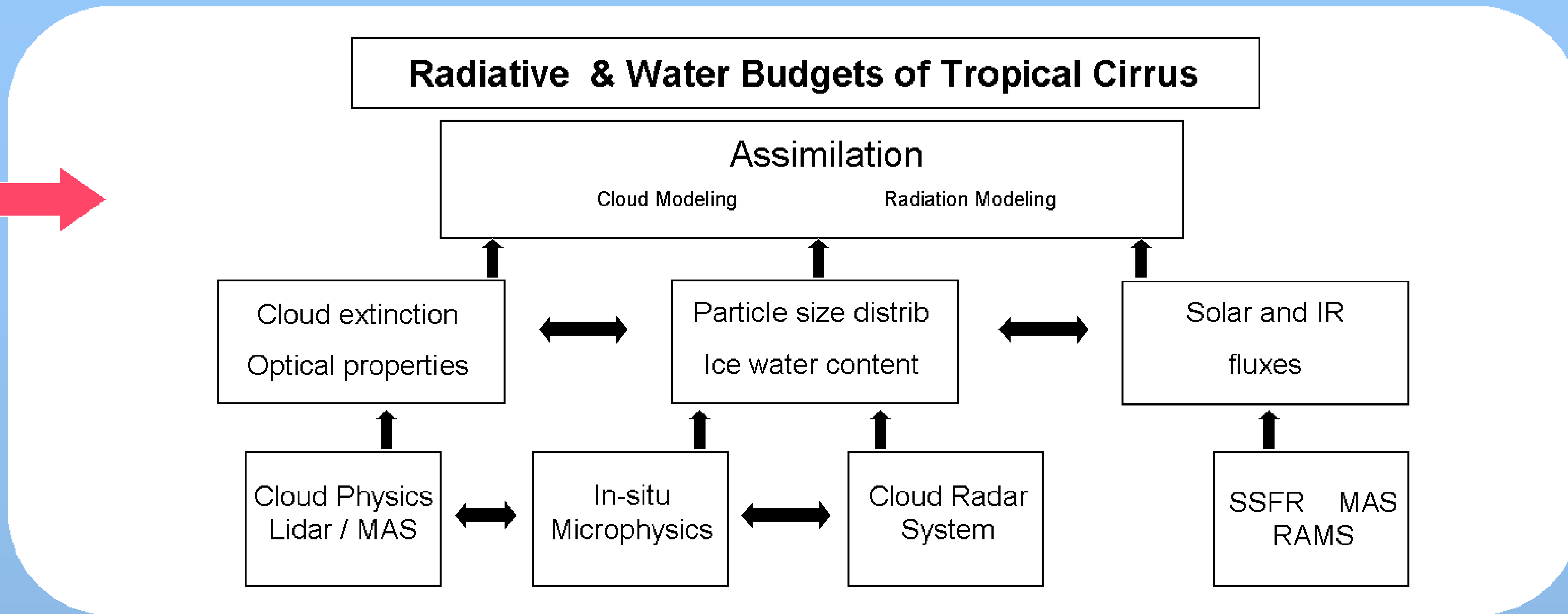
Colorado State University
Knowledge to Go Places

Objectives & Approach

Our goal is to document the radiative and water budgets of tropical cirrus, relate one to the other and each to governing environmental factors.

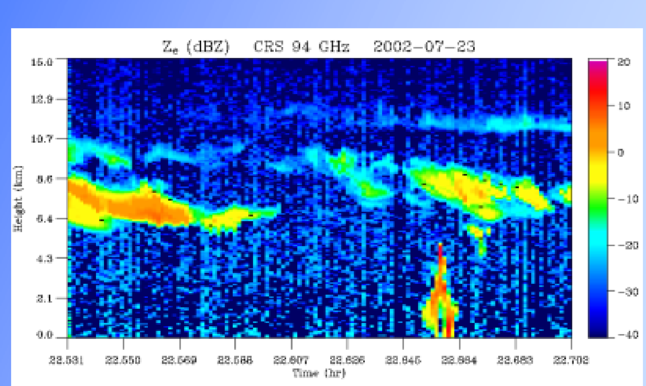
Our approach is to 'assimilate' multiple sources of CRYSTAL data, obtained from multiple platforms. Included in this approach are the:

- **Inversion of lidar data to obtain profiles of visible extinction**
- **Inversion of MAS data to obtain bulk cloud optical properties**
- **Inversion of mm radar data, combined with optical depth to obtain ice contents and microphysics.**
- **Evaluate these using *in-situ* microphysical data**
- **Use these data to simulate the radiative budgets of cirrus and compare to relevant measured fluxes**
- **Use these data to evaluate cloud model simulations of selected cases and explore relationships between convection and cirrus**



Preliminary Example: 2002 Jul 23

Radar Microphysics Retrievals



CRS radar reflectivity factor observed from the ER-2.

- The radar retrieval is formulated in an optimal estimation approach where the measurements, y, are expressed in terms of a forward model that is a function of the quantity to be retrieved, x, and associated errors, ε_y and ε_F :

$$y = F(x,b) + \varepsilon_y + \varepsilon_F$$

- Inversion proceeds through minimization of a cost function, where the forward model is constrained by a column visible optical depth estimate from the Cloud Physics Lidar (CPL).

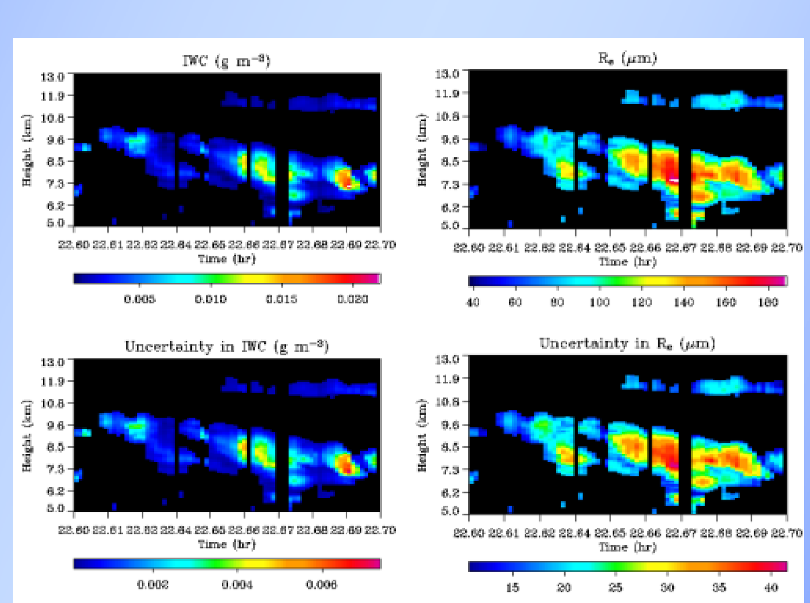
The Forward Model

- Assume ice crystal size spectra follows the gamma distribution. Further assume that number concentration, N_t, and spectrum width, ν, are constant with height.
  - Knowns: Reflectivity Z (height), τ_{column}
  - Unknowns: Diameter D_n (height), $\overline{N}_t$

$$Z_{ray} = \int_0^\infty D^6 n(D) dD \longrightarrow Z = \frac{\Gamma(6+\nu)}{\Gamma(\nu)} \overline{N}_t D_n^6 f_{Mie}(D_n)$$

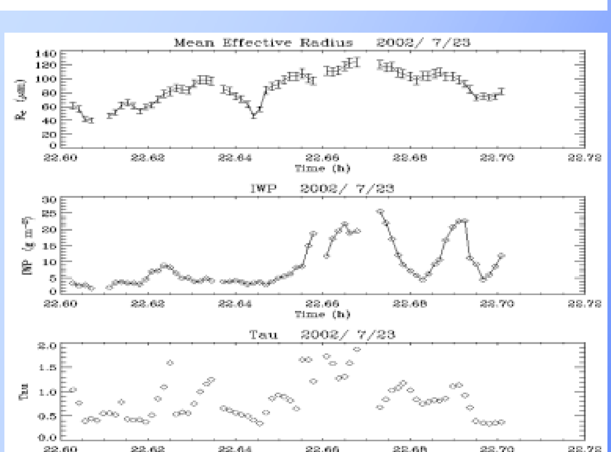
$$\tau = \int_{z_b}^{z_t} \sigma_{ext}(z) dz \longrightarrow \tau = \frac{\pi}{2} \frac{\Gamma(2+\nu)}{\Gamma(\nu)} \int_{z_b}^{z_t} \overline{N}_t D_n^2 dz$$

Retrieved Ice Water Content and Particle Radius



Retrieved IWC, eff radius

Uncertainties ~ 20 – 35%

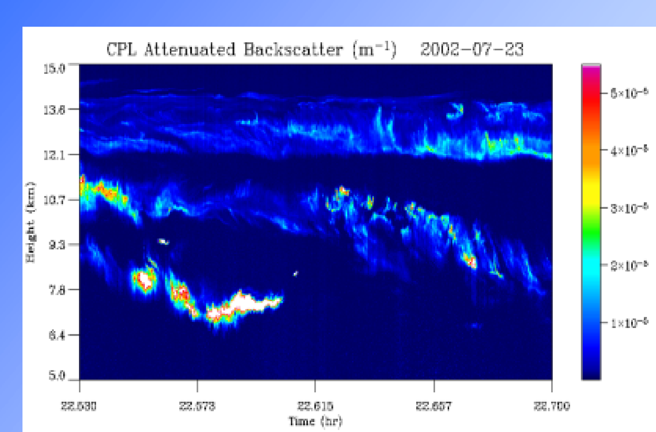


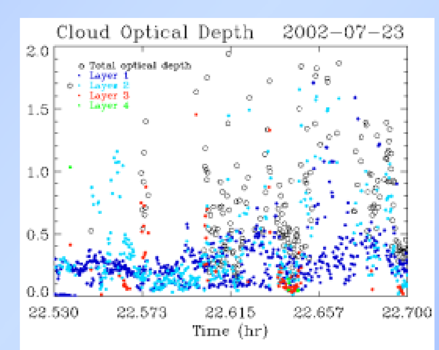
Mean effective radius

Ice water path

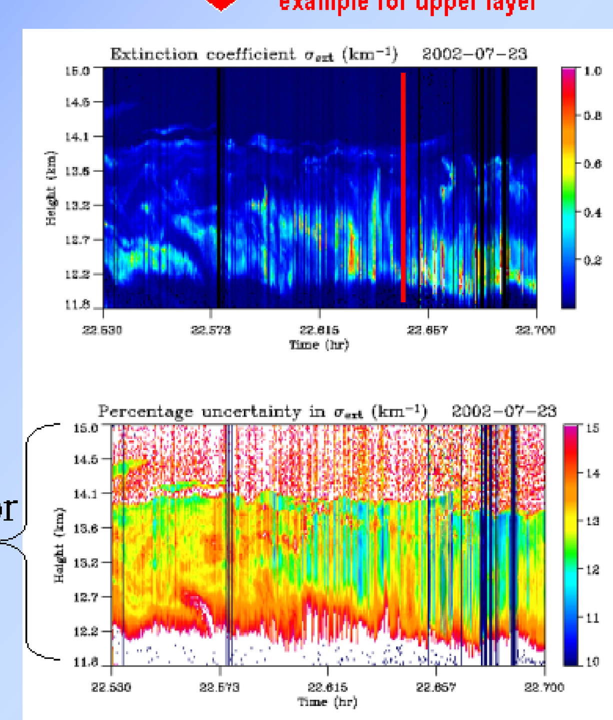
Optical depth

Lidar Retrieval of Cirrus of Extinction Coefficient





Extinction profiles retrieved from lidar backscatter: example for upper layer

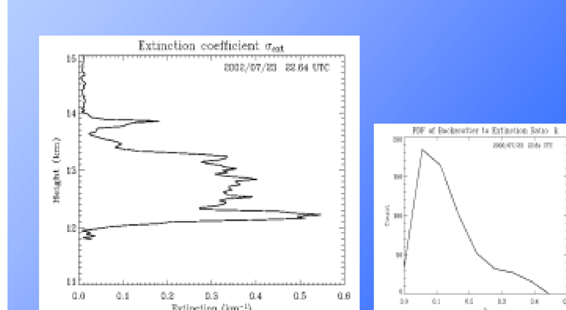


Error

The lidar equation is inverted by an optimal estimation technique to obtain a vertical profile of extinction:

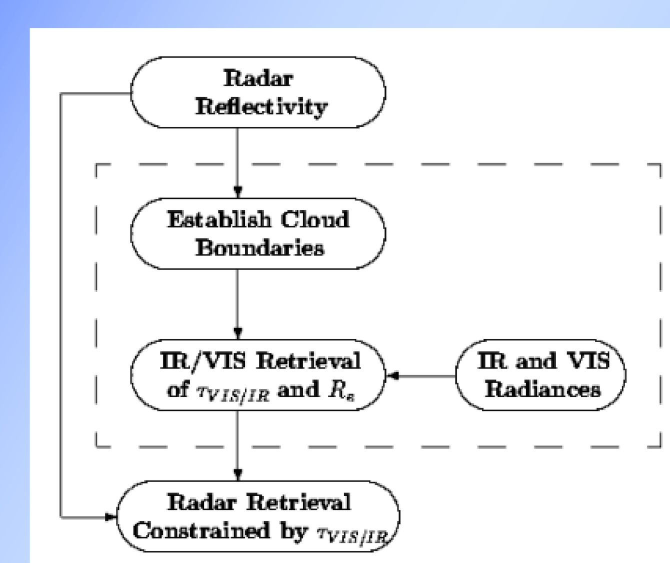
$$\ln\left(C \times P(R) R^2\right) = \ln\left[\beta_{ray}(R) + \beta(R)\right] - 2\int_0^R \left[\eta(r')\sigma(r') + \sigma_{Ray}(r')\right] dr'$$

The retrieval is constrained by visible optical depth and retrieves a vertically averaged value of the backscatter to extinction ratio, k.



MAS Retrievals

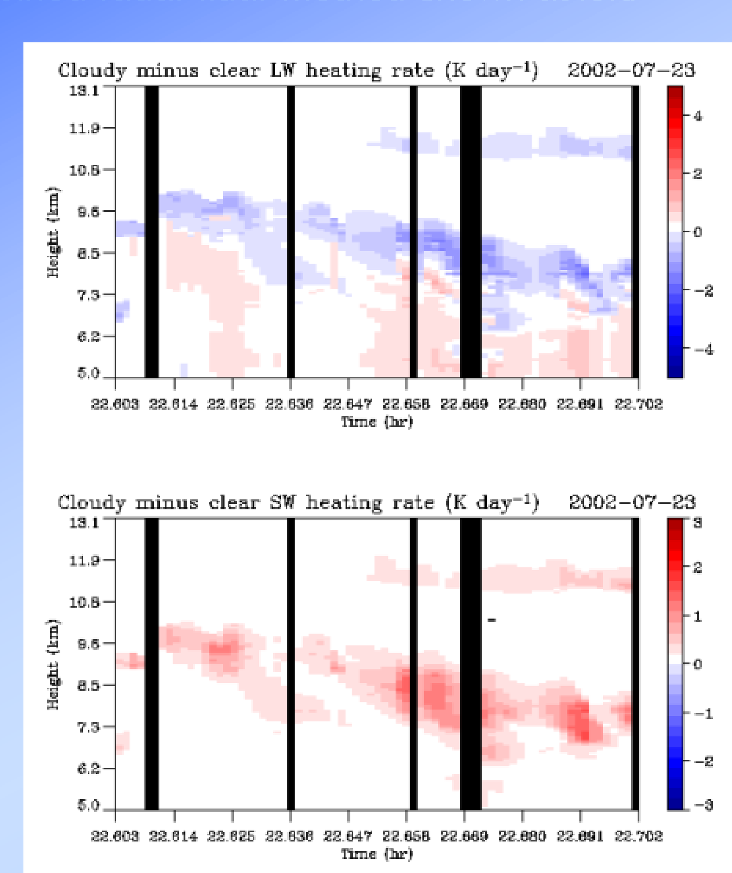
MAS data will be used in conjunction with active measurements from either radar or lidar to determine cloud particle effective radius and optical depth. The optimal estimation retrieval developed by Cooper et al. (2003) for infrared radiances is currently being expanded to include visible and nir wavelengths both to maximize information content and to insure retrieved cloud properties are consistent with all available MAS measurements.



The retrieval of cloud microphysical properties from MAS as described above can easily be incorporated within the work of Benedetti et al. (2003) to determine the vertical profiles of cirrus cloud properties. Cloud boundary information from the radar is used to determine the optical depth constraint, which in turn, is used to scale the radar reflectivity. See Cooper et al. Poster.

Radiative Heating Rates

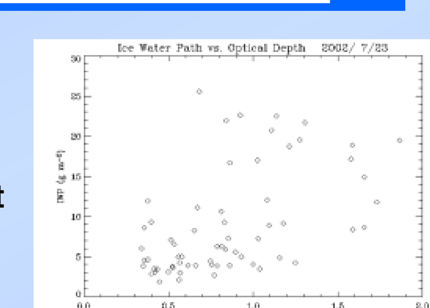
Longwave and shortwave cloud heating rates can be derived from cloud ice distributions retrieved through the combined radar-lidar method shown at left.



Cloudy minus clear-sky heating rates derived from the two-stream BUGSrad model developed at CSU.

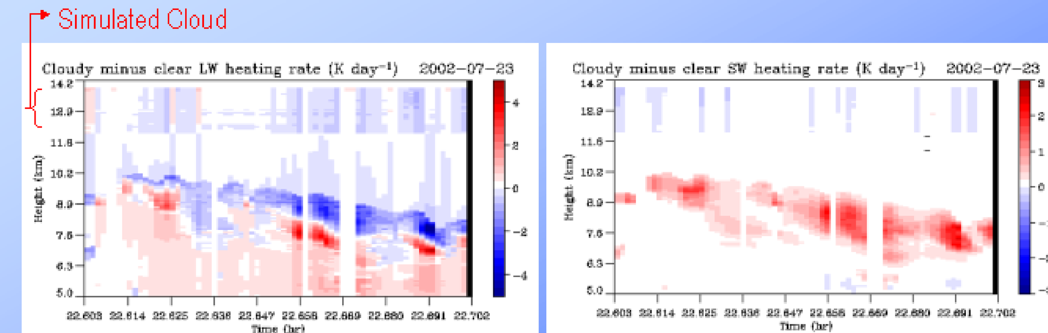
Heating rates: Lidar versus Radar

For the segment shown at left, a high altitude tenuous cirrus layer was continually detected by lidar but only intermittently visible to the radar. What is the difference in cloud heating rate between these two cases?



The cloud observed by the lidar was simulated using lidar-estimated visible optical depth to estimate the ice water path of the cloud. Heating rates were then calculated using BUGSrad:

$$\tau_{Ray} \approx \frac{3}{2\rho_i} \frac{IWP}{r_r}$$



It is apparent that the presence of the tenuous cirrus detected by the lidar is associated with a mean layer heating rate of approximately – 0.5 K day^{-1}.

Radar IWC Algorithm

Benedetti, A., G.L. Stephens, and J.M. Haynes, 2003: Ice cloud microphysics retrievals from millimeter radar and visible optical depth using an estimation theory approach. *To appear in J. Geophys. Res.*

Lidar algorithm

Stephens, G.L., R.J. Engelen, M. Vaughan, and T.L. Anderson, 2001: Toward retrieving properties of the tenuous atmosphere using space-based lidar measurements. *J. Geophy. Res.*, *106*, 28143-28157.

Radiative Heating Algorithm and Example Approach

L'Ecuyer, T.S. and G.L. Stephens, 2003: The tropical oceanic energy budget from the TRMM perspective. Part I: algorithm and uncertainties. To appear in *J. Climate.*

Stephens, G.L., P.M. Gabiel, and PT Partain, 2001: Parameterization of atmospheric radiative transfer. Part I: validity of simple models. *J. Atmos. Sci.*, 58, 3391-3410.

Optical Properties

Cooper, S.J., T.S. L'Ecuyer, and G.S. Stephens, 2003: The impact of explicit cloud boundary information on ice cloud microphysical property retrievals from infrared radiances. *Submitted to J. Geophys. Res.*