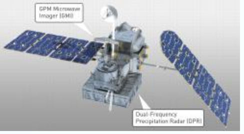

Structure of a winter precipitation system as seen by satellite, ground-based radar, and a WRF simulation

--- with an emphasis on model microphysics comparison

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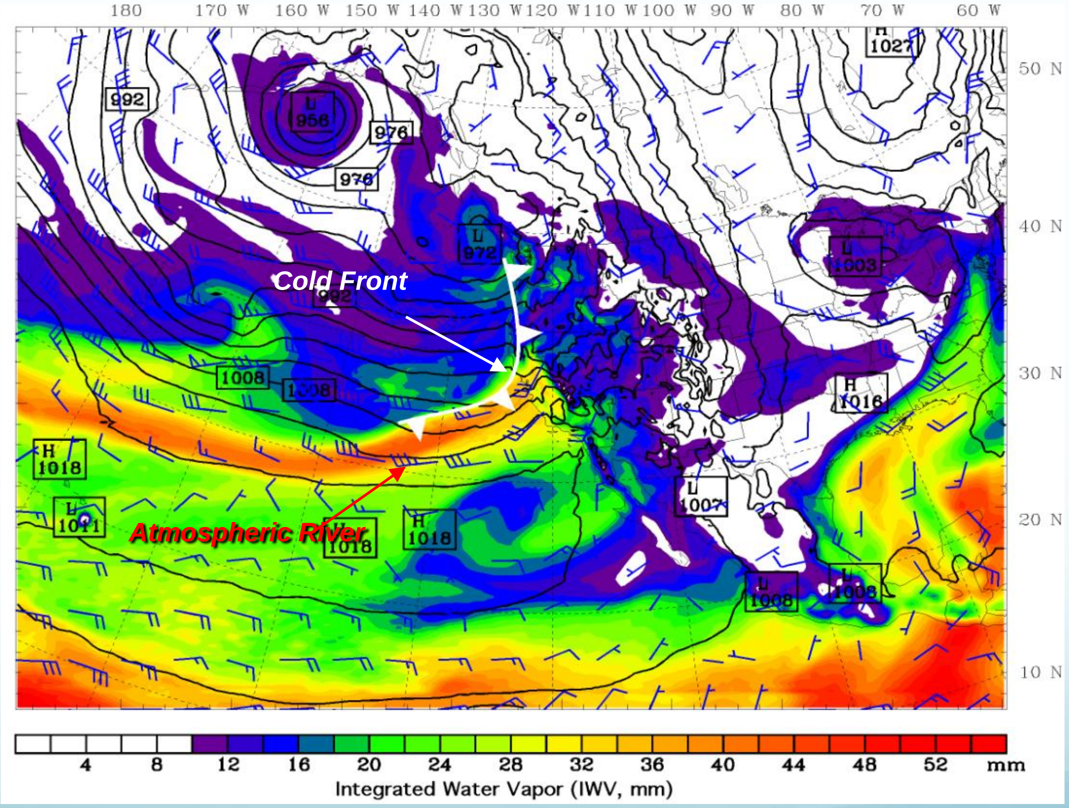
Objective

- Use active and passive microwave measurement
  - to study winter precipitation system
  - to validate model simulations with different microphysics schemes



Integrated Water Vapor (mm), Sea level pressure (contours), winds at 900 mb

Introduction --- How to validate the simulations?

Observations

(TRMM -- no sufficient coverage)

AMSR-E Radiometer
Tb, PCT
(sensitive to: precip. species, mass, PSD,…)

A ground-based Radar
Reflectivity, Doppler Vel.
(sensitive to: precip. species, mass, PSD,…)

Simulations

WRF model
Mass: Qi, Qc, Qs, Qg, Qr
Number con.: Ni, Nc, Ns…
PSD, M-D, and densities

↓

Forward radiative model
same PSD assumption …

↓

Scheme 1	Scheme 2	Scheme 3
Simulated Tb, Reflectivity, Vel.	Simulated Tb, Reflectivity, Vel.	Simulated Tb, Reflectivity, Vel.

Description of Simulations

- WRF ARW V3.1
  - 4 nested domain (1.3, 4, 12, 36 km horizontal resolution, 52 vertical levels, 48 hours integration, output at every 5 min.)
  - 4 microphysics schemes
    - WSM6 (Hong and Lim 2006)
    - Goddard (Tao et al. 1989, Tao and Simpson 1993)
    - Thompson (Thompson et al. 2008)
    - Morrison (Morrison et al. 2009)
- Forward models
  - Goddard Satellite Data Simulator Unit (SDSU) −− Tb
  - Customized reflectivity calculation for each scheme
  - Customized doppler velocity calculation for WSM6 and GODD schemes

Description of Microphysics Schemes

- Bulk scheme (predict mixing ratio and/or number concentration of cloud ice, cloud liq., snow, graupel, rain)
  - Particle Size Distribution (PSD): $N(D) = N_0 D^{\mu} e^{-\lambda D}$, except THOM snow
  - Mass-diameter (M-D) relationship: $m(D) = cD^d$, where $c = \pi\rho_x/6$ and $d=3$ for spheres.

	# of moment	PSD (μ= 0?)			Fixed or Varied N_0 (m^{-4}) ?			M-D (If spheres?)			Bulk density ρ_x (Kg/m^3)		
		Sn	Gr	Ra	Sn	Gr	Ra	Sn	Gr	Ra	Sn	Gr	Ra
WSM6	1	0	0	0	N_{os} (T)	4.e6	8.e6	y	y	y	100.	500.	1000.
GODD	1	0	0	0	1.6e7	4.e6	8.e6	y	y	y	100.	400.	1000.
THOM	1.5		0	0	effective N_{os} (T,q)	N_{og} (q)	N_{or} (n,q)	n	y	y	not a const.	400.	1000.
MORR	2	0	0	0	N_{os} (n,q)	N_{og} (n,q)	N_{or} (n,q)	y	y	y	100.	400.	997.

$$N(D) = \frac{M_2^4}{M_3^3}\left[\kappa_0 e^{-\frac{M_2}{M_3}\Lambda_0 D} + \kappa_1\left(\frac{M_2}{M_3}D\right)^{\mu_s} e^{-\frac{M_2}{M_3}\Lambda_1 D}\right]$$

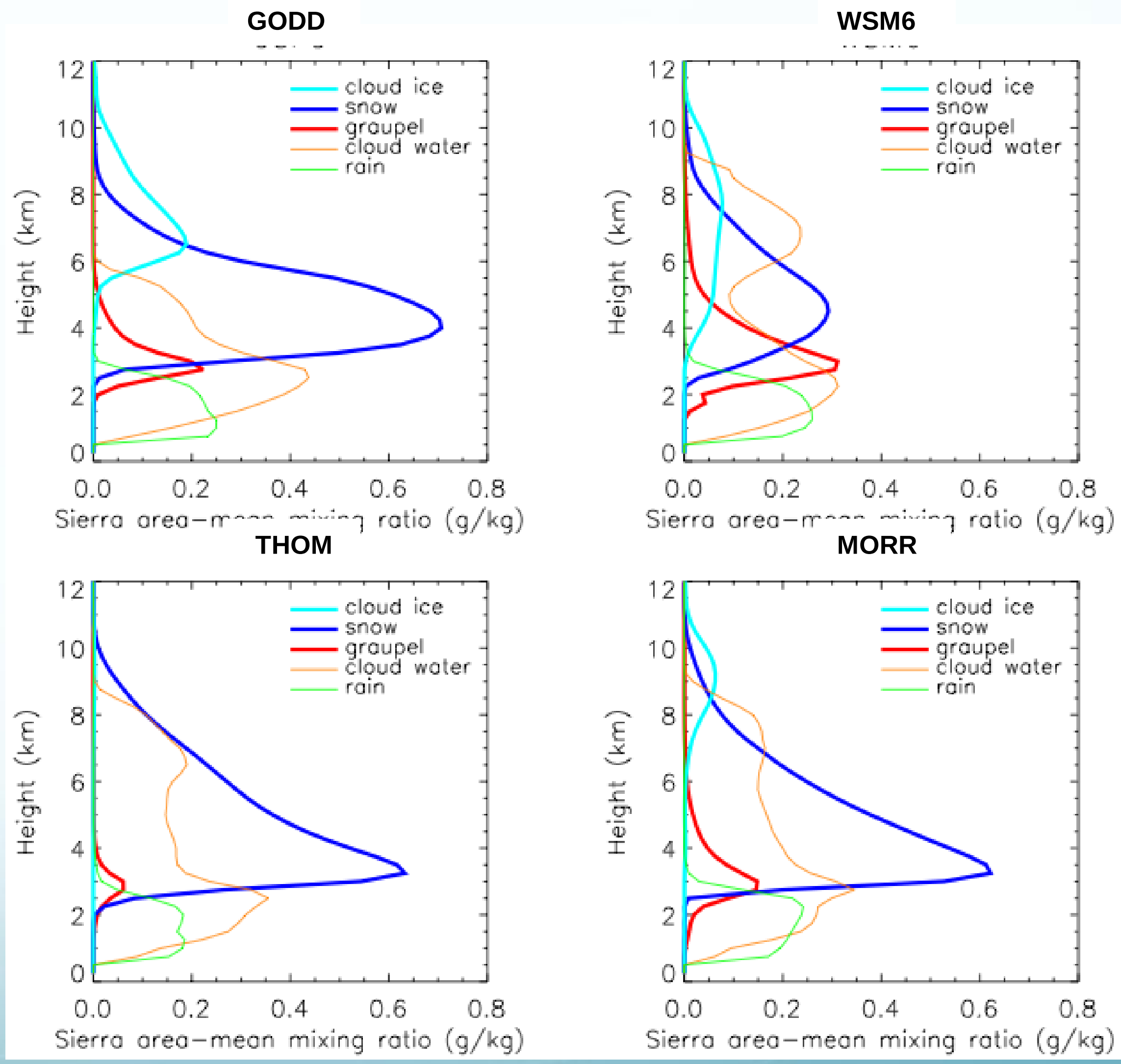
, where $M_n = \int D^n N(D) dD$ is nth moment. (Field et al. 2005)

$m(D) = 0.069 D^2$ (Cox 1988)

Hydrometeor Vertical Profile

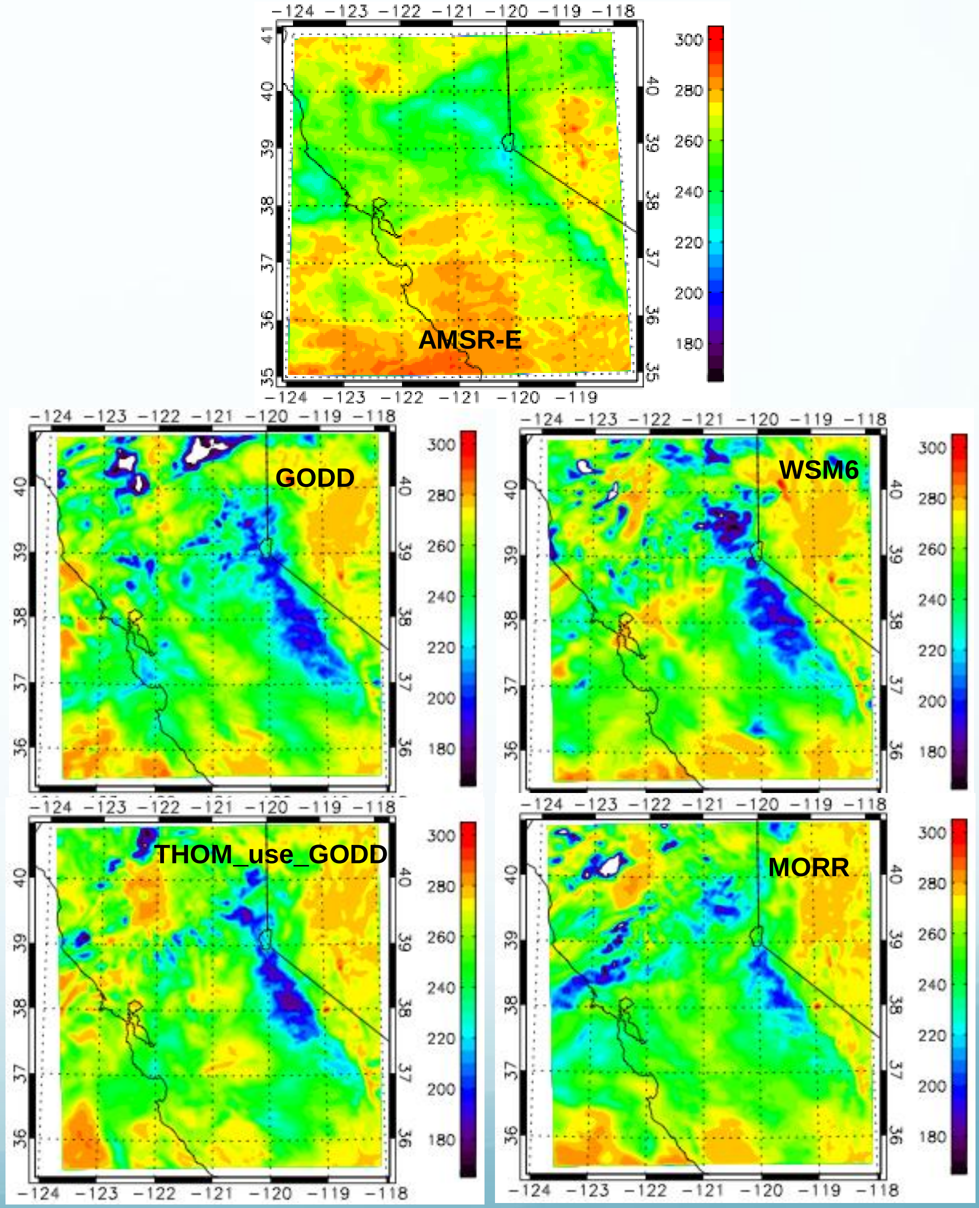
-- Mean mixing ratio profile over Sierra Nevada, at 10 UTC, 31 December, 2005

- GODD
  - More snow, shallower cloud liq.
- WSM6
  - Least snow, most graupel
- THOM
  - Least cloud ice, least graupel
- MORR
  - Moderate graupel



Observed and simulated PCT89

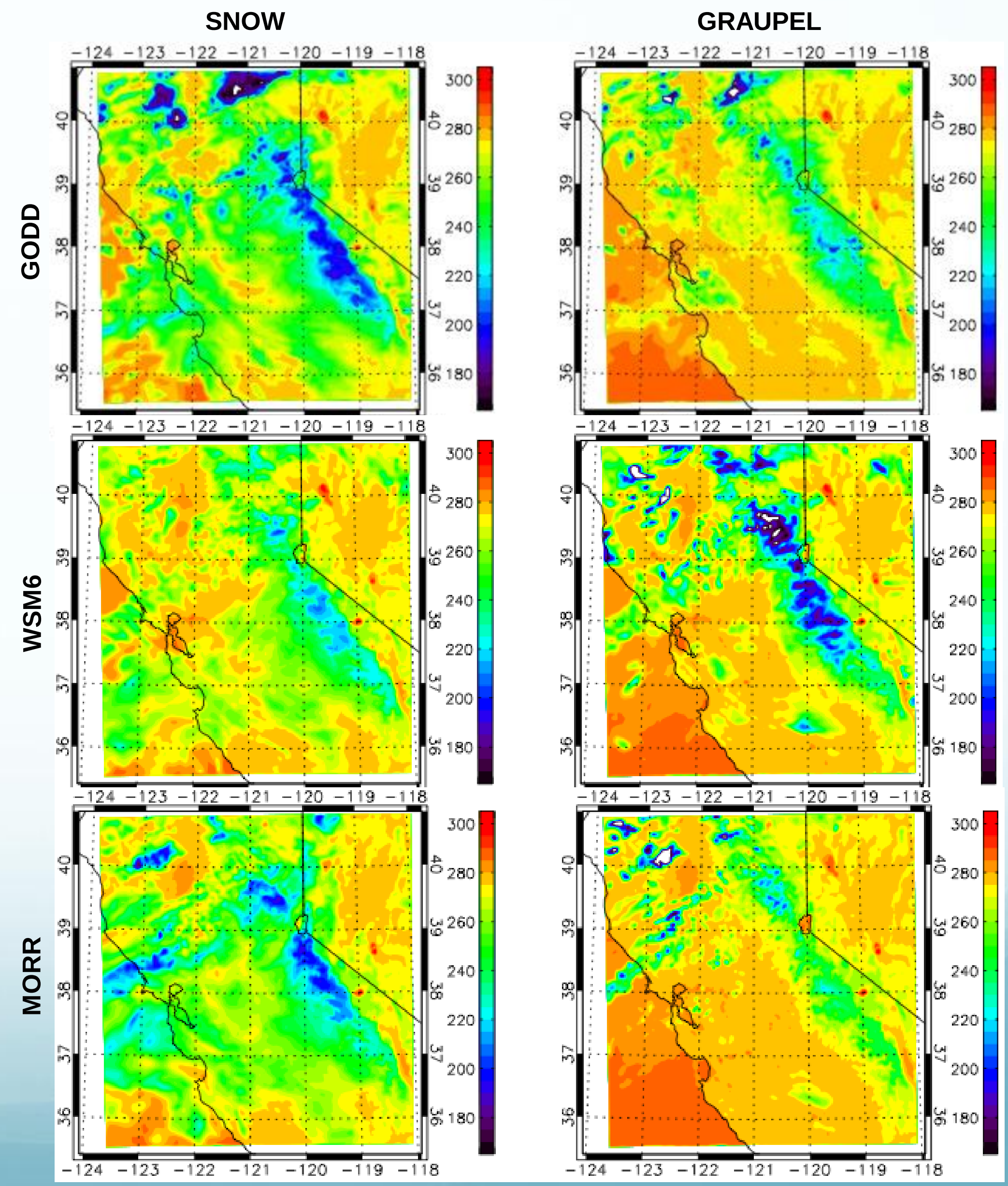
- AMSR-E
  - Cold PCT −− snow and grauple near coastal region and over Sierra Nevada range
- 4 simulations
  - Generally too cold PCT −− too much precip. ice scattering
  - GODD and WSM6 are similar, despite diff. in snow and graupel profiles
  - MORR −− closer to Obs.
  - THOM (Note: estimated using GODD PSD assumptions) −− too much ice scattering



Partitioning simulated PCT89

−− snow vs. graupel

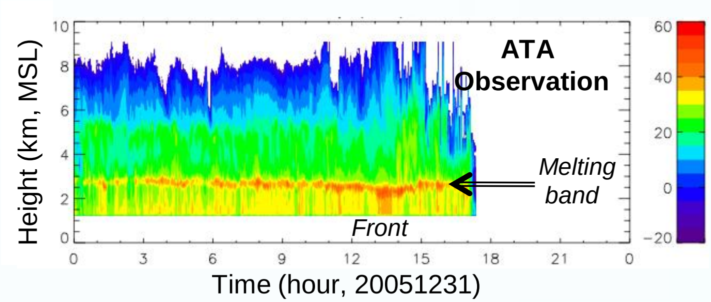
- GODD
  - Snow contribute more −− dominant mass of snow
- WSM6
  - Graupel contribute more −− graupel is more efficient in scattering
- MORR
  - Snow contribute more −− dominant mass of snow

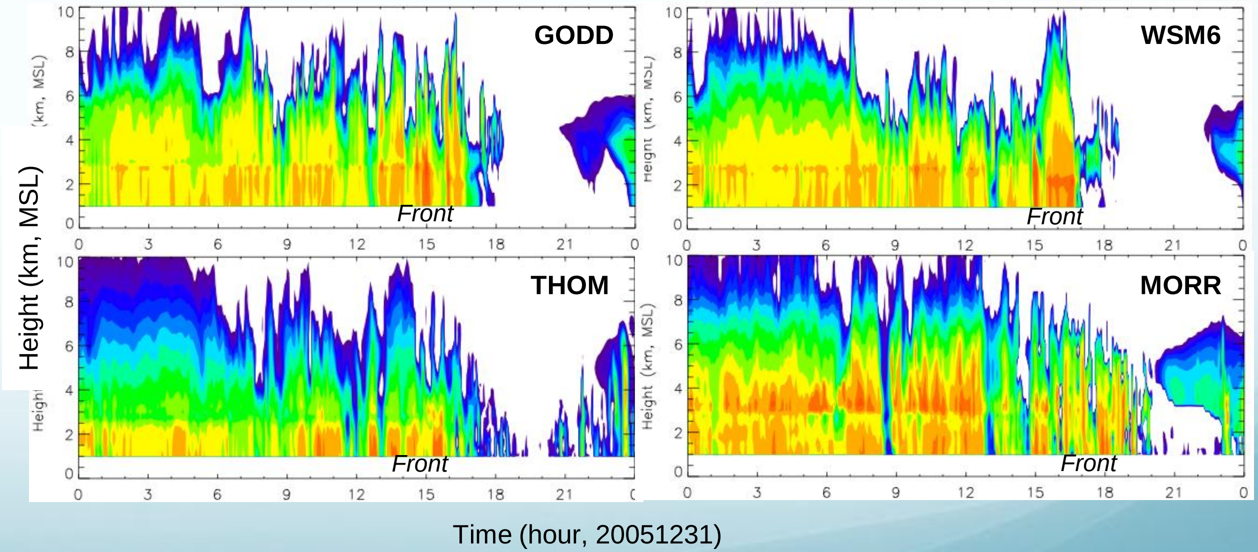


Observed and simulated reflectivity

−− At Alta, CA, time − height plot, 31 December, 2005

- S-prof
  - Melting band and front passage
  - Rain (25 − 45 dBZ), snow (< 30 dBZ)
- 4 simulations
  - Melting band ?
  - Front passage is captured
  - Reflectivity magnitude
    - GODD and WSM6: rain layer is OK, too strong in snow layer
    - THOM −− comparable to Obs.
    - MORR is too strong in both snow and rain layers





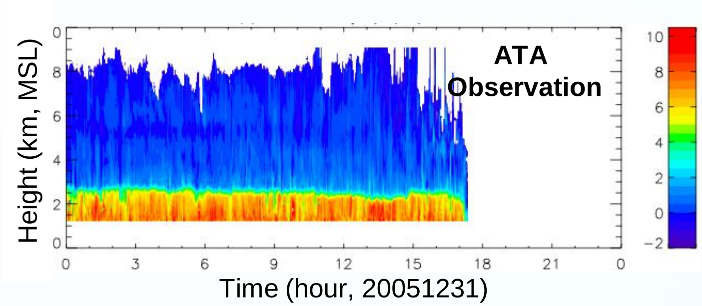
Obs. and sim. Doppler Velocity (DopVel)

- Methodology on Doppler Velocity simulation for S-prof
  - DopVel = Vt + w
  - In WRF, Vt is mass/number-weighted, however, Vt is reflectivity-weighted in Obs.

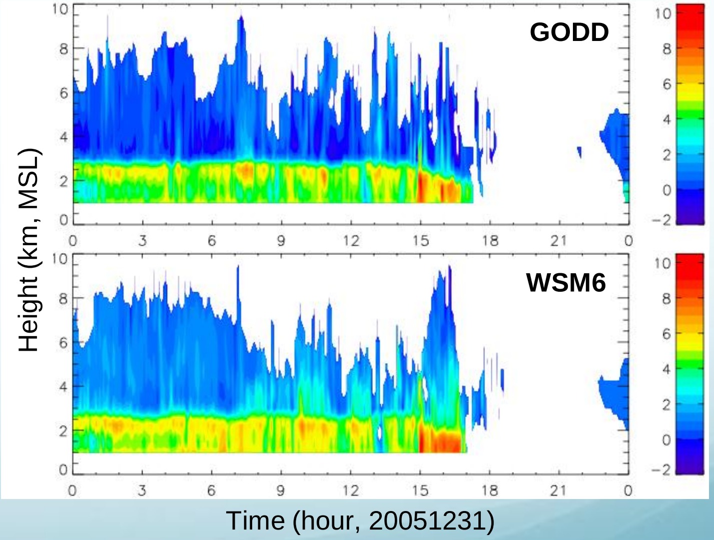
$$Vt = Vt_{s+g+r} = \frac{\int N_s\sigma_s(D)V_s(D)dD + \int N_g\sigma_g(D)V_g(D)dD + \int N_r\sigma_r(D)V_r(D)dD}{\int N_s\sigma_s(D)dD + \int N_g\sigma_g(D)dD + \int N_r\sigma_r(D)dD}$$

, where $V_x = a_x D^{b_x} (\frac{\rho_0}{\rho})^{0.5}$ is the particle fall velocity.

a_x and b_x varies in diff. schemes



- 2 simulations
  - DopVel in both schemes are slower than obs. in the rain layer
  - GODD –– comparable to Obs. in snow layer
  - WSM6 –– faster than Obs. in snow layer



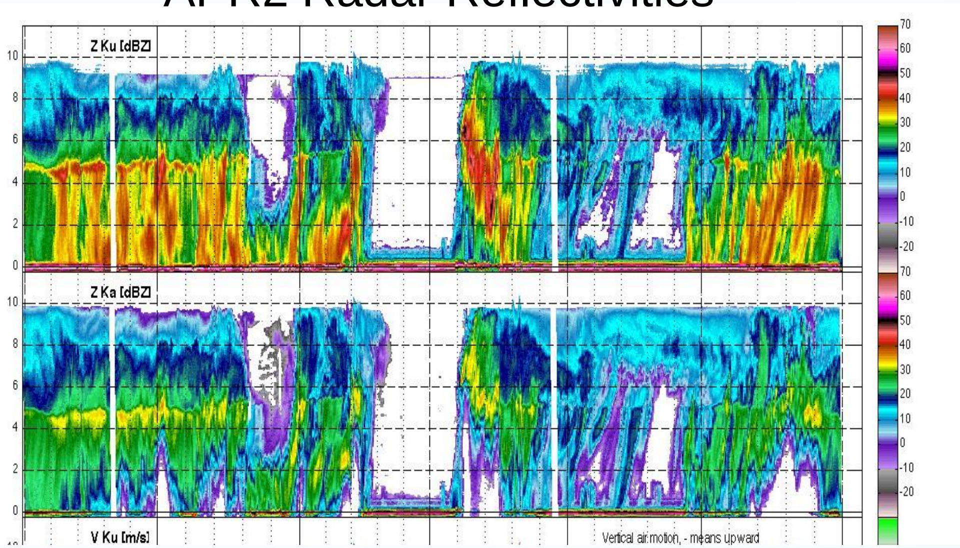
Summary

- Most schemes used produce deep layers of supercooled cloud water and too much ice aloft
- Some evidence that rain fall speeds are not large enough (dBZ larger, fall speeds smaller than observed)
- Ice fall speeds larger than observed, but so too are ice amounts. Likely from too much graupel
- Most schemes produce too much scattering at 89 GHz, but not clear what is the role of RTM

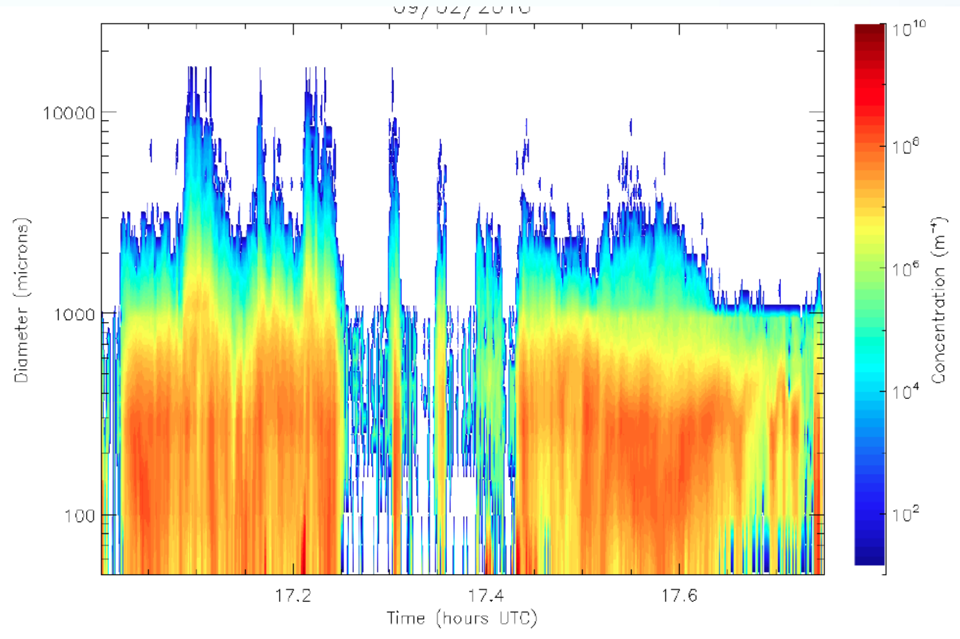
GRIP 2010

- Dual-frequency Doppler radar data (APR-2 on DC8, HIWRAP on Global Hawk)
- With appropriate reflectivity calculations, modeled hydrometeor mixing ratios, size distributions can be evaluated
- Cases: Earl, Karl, Matthew

APR2 Radar Reflectivities

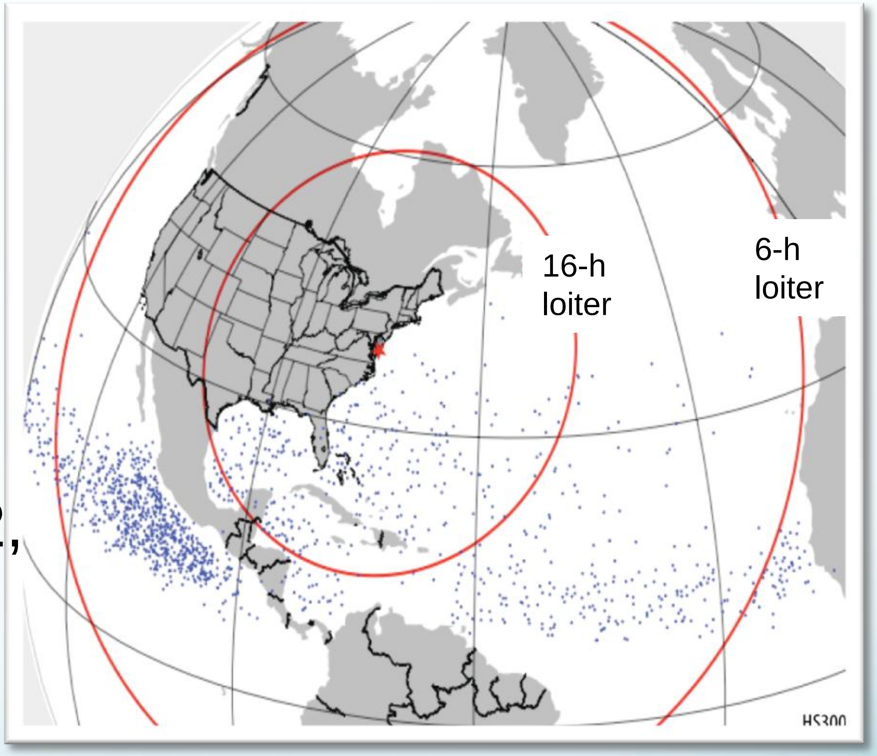


Particle Concentrations



Hurricane and Severe Storm Sentinel (HS3) Overview

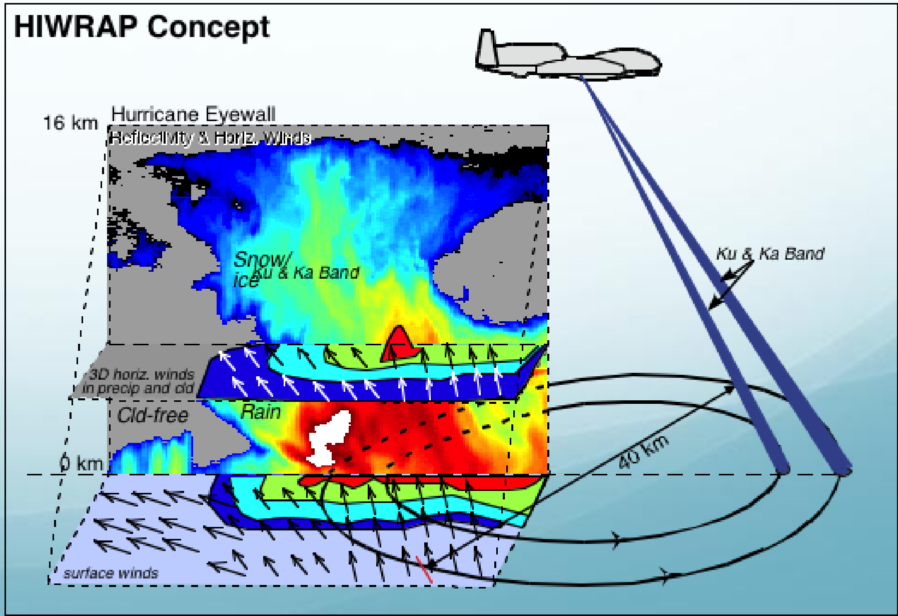
- Two aircraft, one equipped for the storm environment, one for over-storm flights
- Deployments of GHs from the East Coast, likely Wallops Flight Facility in VA
- One-month deployments in 2012, 2013, and 2014, 300 flight hours per deployment
- 3-year mission ensures adequate sampling of a wide variety of conditions



Dots indicate genesis locations. Range rings assume 26-h flights.

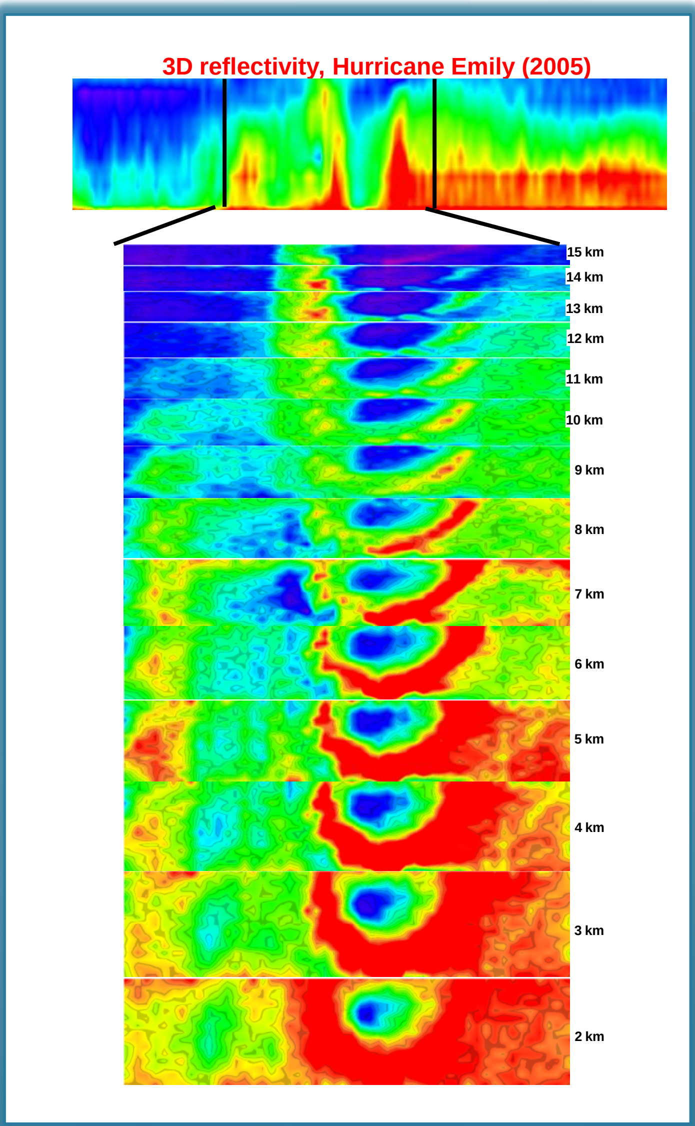
High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

- Instrument PI: Gerald Heymsfield, NASA/GSFC
- Data: Calibrated reflectivity, Doppler velocity, 3D reflectivity and horizontal winds, ocean surface winds in precipitation free areas
- Horiz., vertical resolution=
  - 1 km, 200 m for dBZ, Doppler velocity
  - 1 km, 500 m for horiz. winds
  - 2 km for surface winds



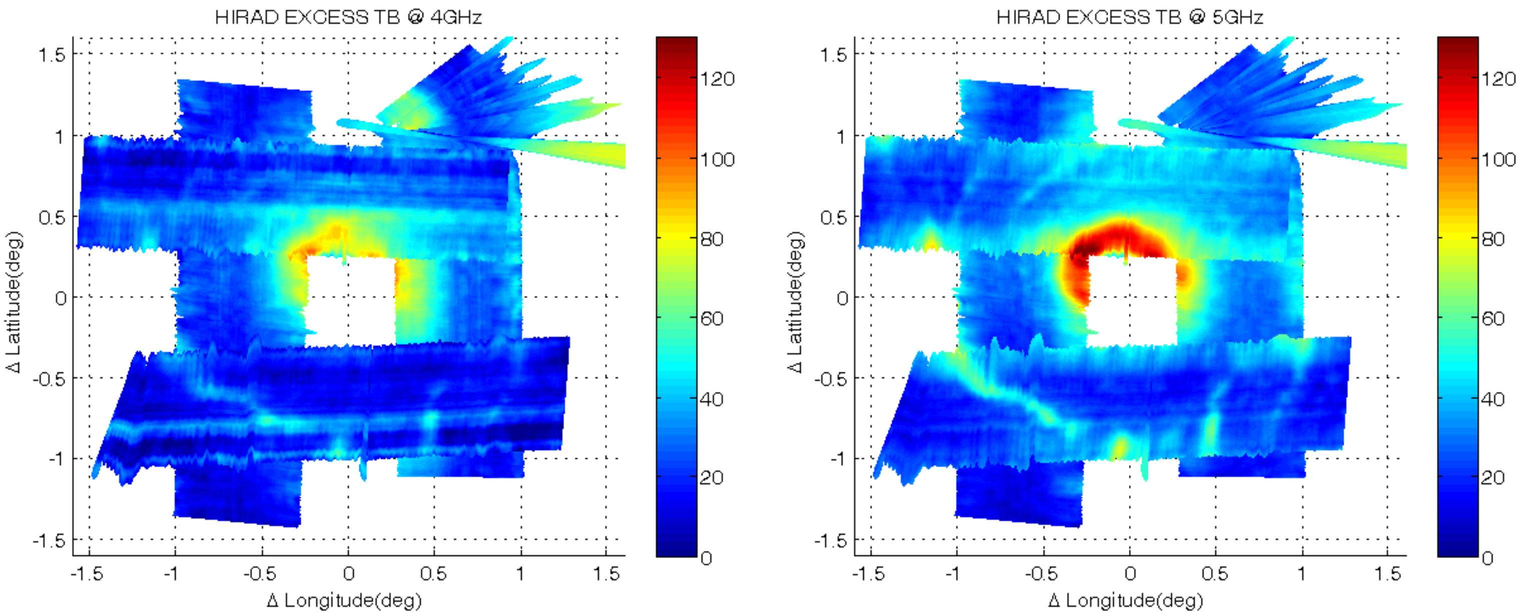
High-Altitude MMIC Sounding Radiometer (HAMSR)

- Instrument PI: Bjorn Lambrigtsen, JPL
- Data: Calibrated brightness temperature; vertical profiles of temperature and water vapor and liquid water; precipitation structure
- Horiz., vertical resolution=2km, 1-3 km



Hurricane Imaging Radiometer (HIRAD)

- Instrument PI: Tim Miller, NASA/MSFC
- Data: Surface wind speed, rain rate, and temperature; brightness temperature fields at 4 frequencies
- Technology similar to NOAA's SFMR, but scans cross track instead of just nadir
- Horiz. resolution=~1.5-2.5 km

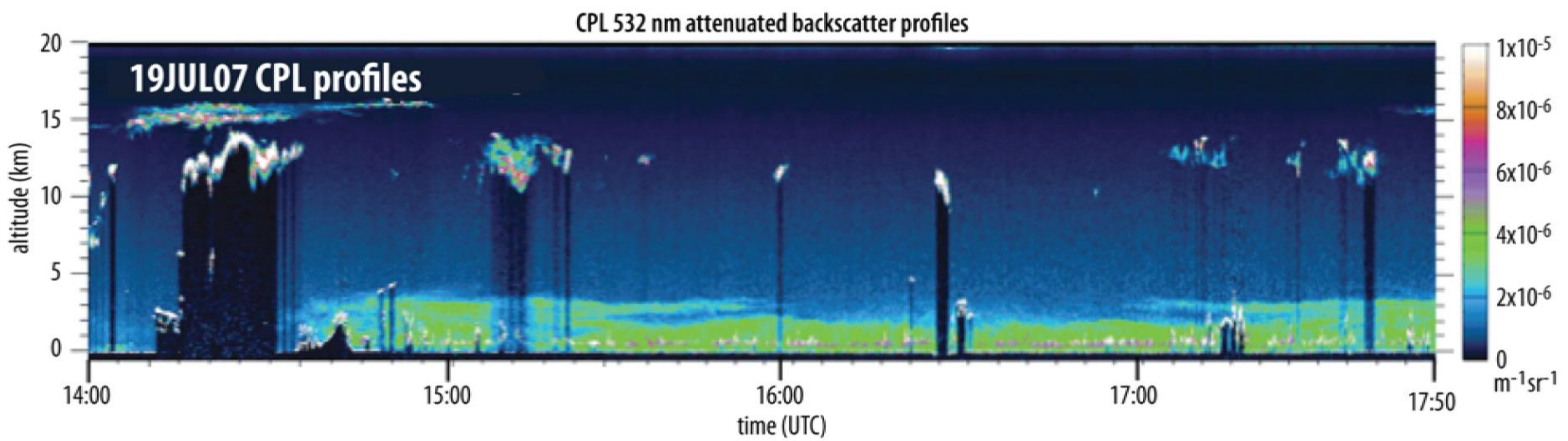


Example from Hurricane Earl flight during GRIP

Cloud Physics Lidar

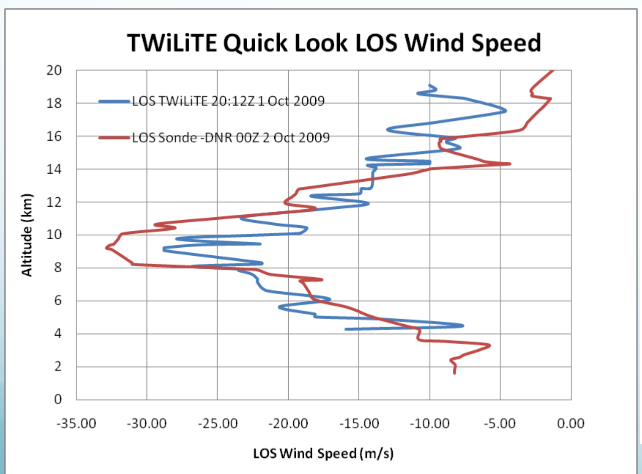
- Cloud/aerosol lidar (CALIPSO simulator)
- Instrument PI: Matt McGill, NASA/GSFC
- Data: Profiles of atten. backscatter, cloud/aerosol boundaries, optical depth, extinction, depolarization

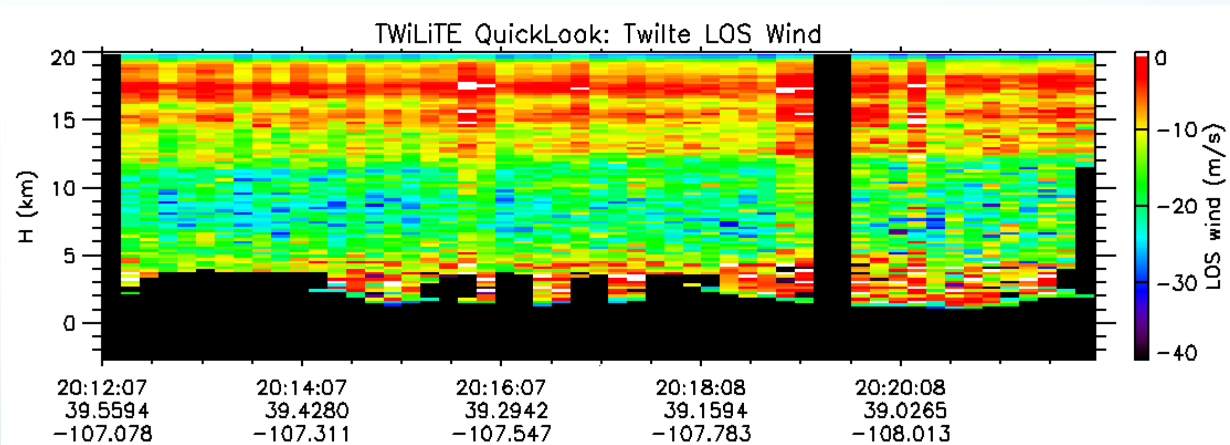
- Horiz., vertical resolution=200 m, 30 m



TWiLiTE Wind Lidar

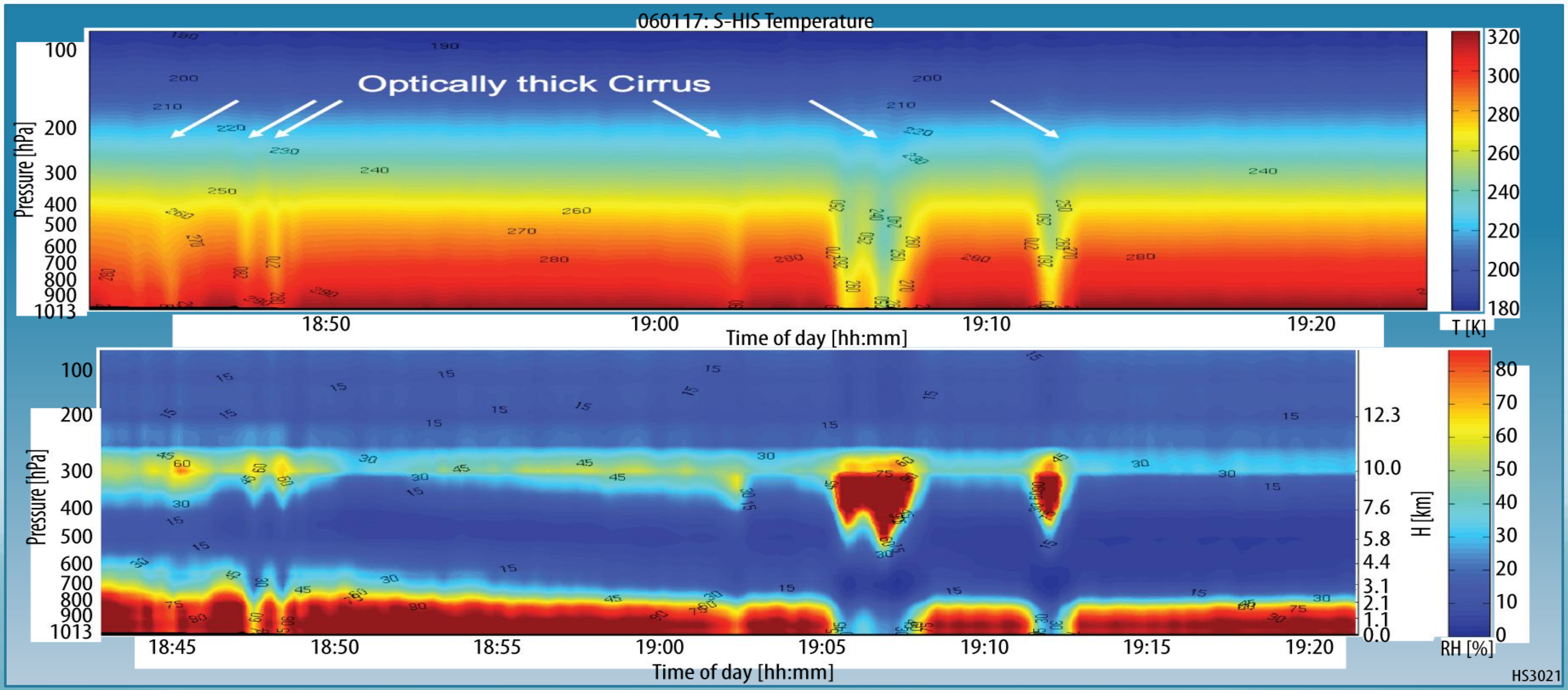
- Instrument PI: Bruce Gentry, NASA/GSFC
- Data: Profiles of backscatter intensity, Doppler velocity, horizontal winds in clear-sky conditions
- Will fly as part of HS3 in 2013-14 only due to NGC schedule, wind pod availability
- Horiz., vertical resolution=~2 km radial winds, 8 km for retrieved horizontal winds, 250 m





Scanning High-resolution Interferometer Sounder

- Instrument PI: Hank Revercomb, Univ. Wisconsin
- Data: IR TB spectra; Cloud-top temperature, height; sfc skin temperature; profiles of temperature and water vapor <u>in clear-sky conditions</u>
- Horiz., vertical resolution=2 km, 1-3 km



Dropsondes (AVAPS)

- Instrument PI: Gary Wick, NOAA
- Data: High-resolution vertical profiles of temperature, humidity, pressure, winds
- Potentially up to 89 drops per flight
- New design has flown on GH
  - Test flights (low, mid, high alt.) completed 2/4/11
  - NOAA science flights ongoing