National Aeronautics and Space Administration

Feasibility of Modeling HIWC Conditions with the Terminal Area Simulation System

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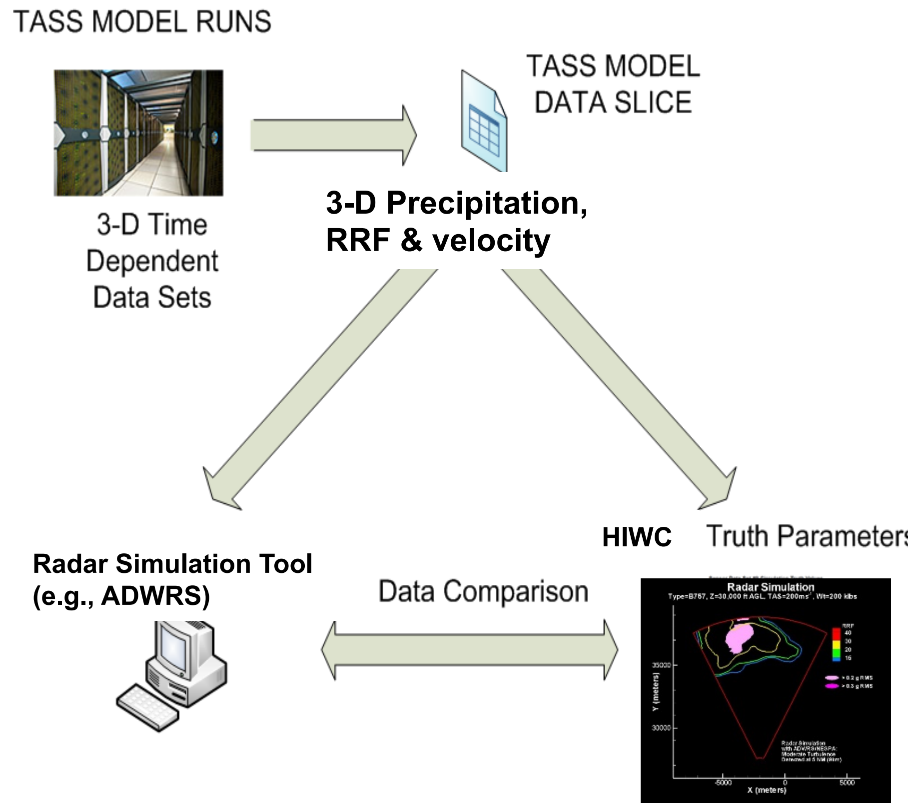
Advanced Air Transport Technology Project
NASA Advanced Air Vehicles Program

Outline

- **High Ice Water Content (HIWC) modeling objectives**
- **Brief description of numerical model and history of application**
- **Description of numerical model**
- **Results from numerical simulations of two cases**
- **Summary**

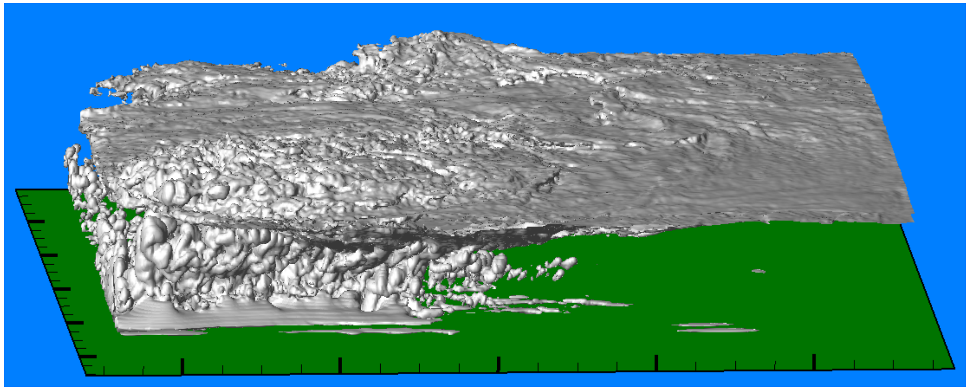
High Ice Water Content (HIWC) Modeling Objective

- **Evaluate feasibility of modeling HIWC events**
  - Select real cases
  - Validate capabilities
- **Characterize HIWC events through numerical modeling studies**
  - Size, duration, elevations of event
  - Water/ice contents
  - Relationship to environment
- **Data for RADAR simulation**
  - Generate realistic numerical data sets for RADAR detection studies
  - Represent three-dimensional HIWC convective system as it evolves within different environments
  - Extract three-dimensional sub-volumes sequenced in time during the evolution of a HIWC Event
  - Provide as input for RADAR simulator studies
  - Post-analysis of extracted data provides "truth" for RADAR simulation studies



TERMINAL AREA SIMULATION SYSTEM (TASS)

- **Time-dependent, 3-D, Large Eddy Simulation (LES) Model**
- **Meteorological Framework**
- **Prognostic Equations for:**
  - **3-Components of Velocity** **- Pressure**
  - **Potential Temperature** **- Rain**
  - **Water Vapor** **- Snow**
  - **Liquid Cloud Droplets** **- Hail / Graupel**
  - **Cloud Ice Crystals** **- Dust / Insects**



- **Subgrid-scale turbulence parameterized with modifications for stratification and flow rotation**
- **Numerics are accurate, highly efficient, *and* essentially free of numerical diffusion**
- **Contains roughly 60 bulk cloud microphysics submodels**
- **Initialization modules for simulation of convective storms, microbursts, atmospheric boundary layers, turbulence, and aircraft wake vortices**
- **Software modifications and re-coding have occurred to take advantage of paradigm shifts in computing platforms**
- **User's guide, version 10.0: NASA TM-2014-218150**

Assumed Particle Size Distributions in TASS

Category	*Size Distribution Intercept (m^{-4})*	*Particle Density ($Kg\ m^{-3}$)*	*Comment*
Cloud Water	**Monodispersed**	**1000**	**Number of drops per volume is an input (constant)**
Rain	$2.25 \times 10^{7} M_r^{0.375}$	**1000**	**Intercept increases with rainwater content, M_r ($g\ m^{-3}$)**
Cloud Ice	**Monodispersed**	**Particle Mass =** $(D_{ic}/4.9\ m\ kg^{-1/2})^2$	**Hexagonal plates**
Snow	$10^{(6.95 - 0.6\ Tc)}$ *for* $2^{o}C > Tc > -40^{o}C$	100 *if* $Tc < -20^{0}C$ $100 + 35/20\ (Tc + 20)$ *if* $Tc > -20^{o}C$	**Intercept increases with decreasing temperature: graupel like snow**
Hail/Graupel	N_{oh}	**900-450**	**N_{oh} is an input (constant)**

Diagnostic of Model Radar Reflectivity Factor *(e.g. Smith et al JAM 1975)*

- **Radar Reflectivity Factor from rain based on Rayleigh Scattering:**

$$Z_R = \int_0^\infty N(D_R)\, D_R^6\, dD_R$$

- **Radar Reflectivity Factor from "dry" snow (similarly for ice crystals and dry hail/graupel)**

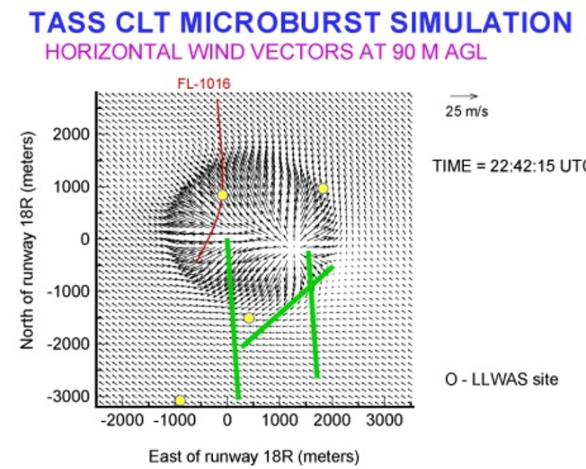
$$Z_S = \frac{|K_I|^2}{|K_W|^2} \frac{\delta_S^2}{\delta_w^2} \int_0^\infty N(D_S)\, D_S^6\, dD_S$$

- **Radar Reflectivity Factor for "wet" hail (accounting for Mie scattering:**

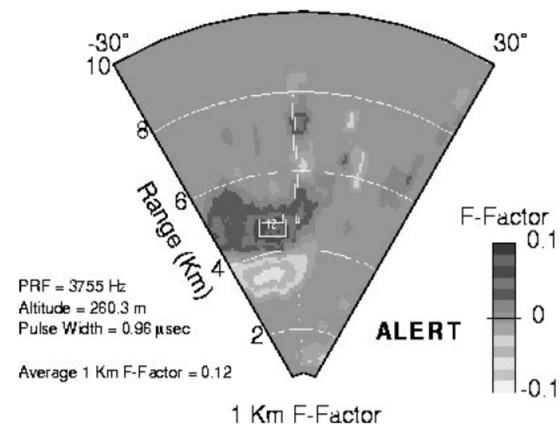
$$Z_{HWet} = \left[\int_0^\infty N(D_H)\, D_H^6\, dD_H\right]^{0.95}$$

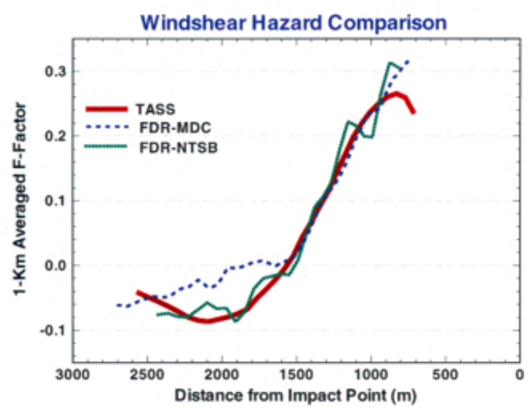
TASS -- History

- Development began in 1983 for NASA/FAA Windshear Program
- Validated and verified in simulations of cumulus convection, severe local storms, tornadic supercells, microburst wind shear, atmospheric boundary layer turbulence, convective induced turbulence, aircraft wake-vortex transport and decay
- Produced data sets for FAA certification of onboard windshear sensors (1993). Delivered to RTCA
- Supported NTSB investigations of 1994 Charlotte, 1999 Little Rock accidents, as well as the 2001 American Airlines flight 587 crash at JFK



Radar Simulation Using TASS Generated Data



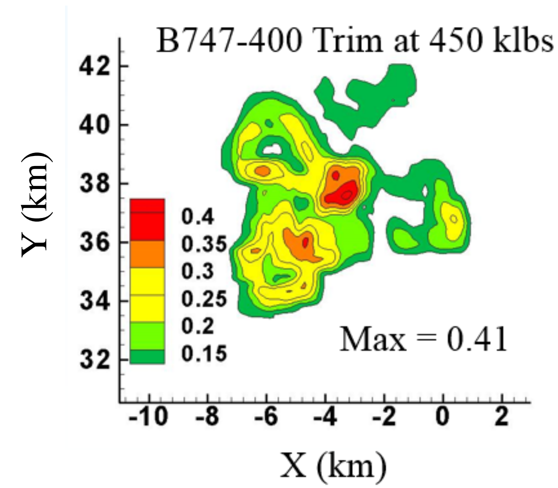


F-Factor Comparison from 1994 CLT Accident

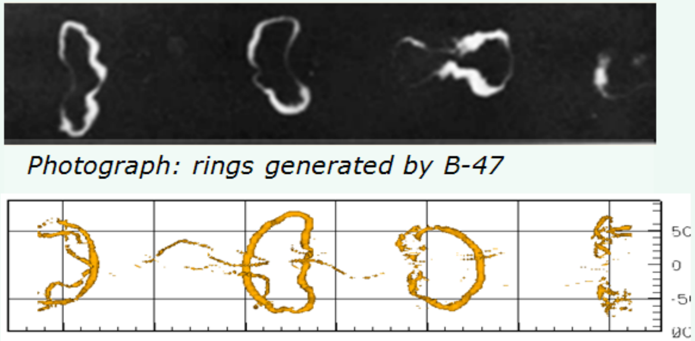
TASS – History (continued)

- Used in NASA/FAA program to study convectively induced turbulence and improve aviation safety (2000-2006)
  - Produced data sets for testing and certification of onboard turbulence RADAR systems. Delivered to RTCA
- Used in wake vortex studies for improving airport capacity (1993-2014)
  - Provided guidance for development of wake vortex fast-time prediction models: e.g., the TASS derived algorithm for wake prediction (TDAWP)
  - TASS generated data sets used in development and evaluation of Lidar wake detection software

TASS Simulated Turbulence Intensity – RMS-g Load



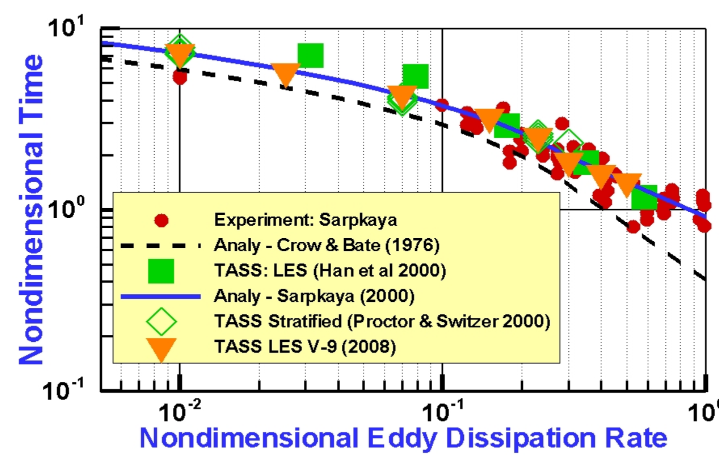
Ring vortices following vortex linking



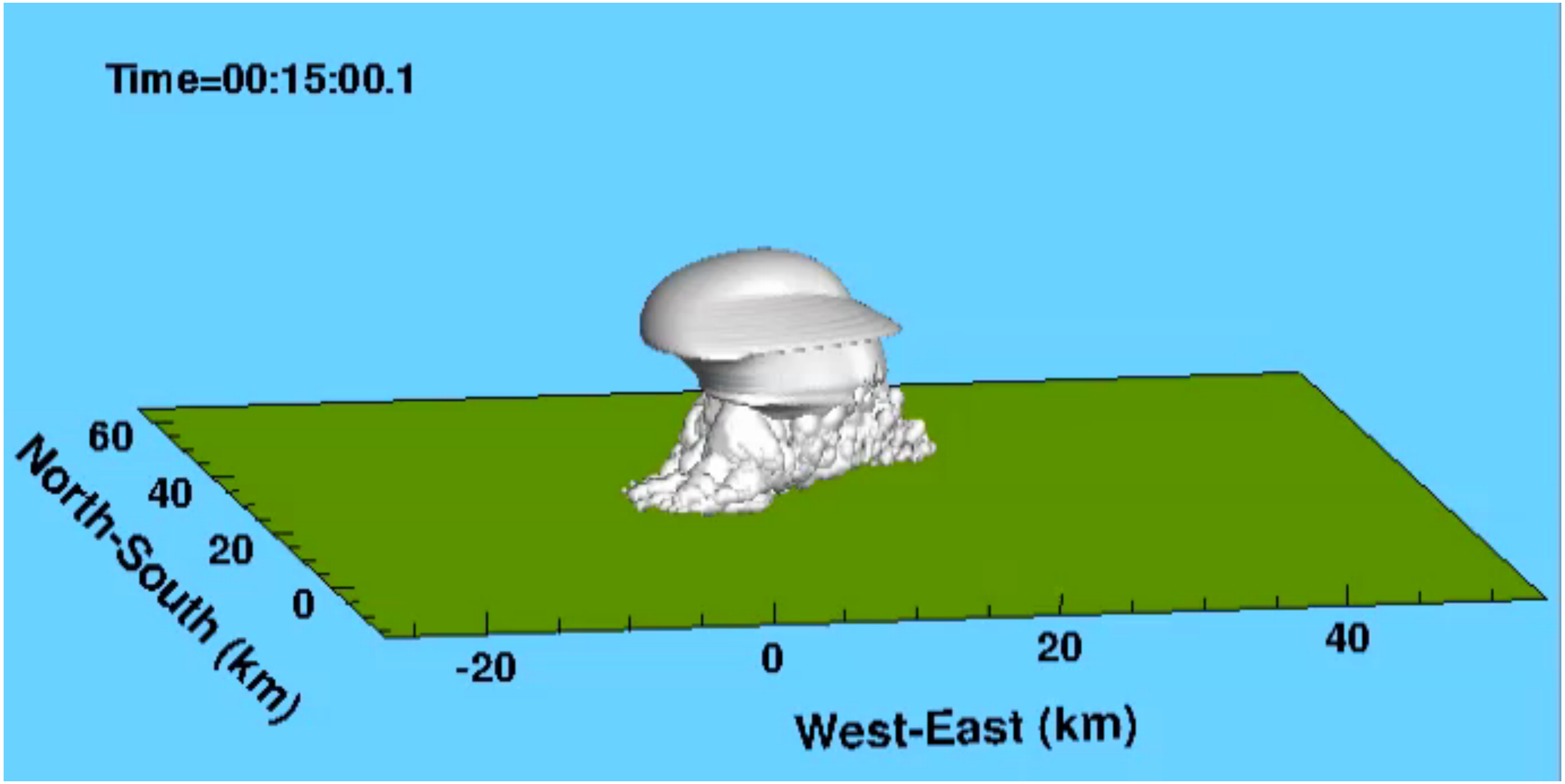
Photograph: rings generated by B-47

From TASS simulation

Vortex Time to Linking vs Turbulence Intensity



TASS Simulation: Time Evolutions of a Tornadic Supercell *(AIAA Paper 2012-0557)*



Feasibility Study: TASS Simulation of Darwin and Louisiana HIWC Events

- Two Cases examined from:
  - Darwin, Australia, 23 January 2014, HIAC campaign
  - Offshore Louisiana, 19 August 2015, HIWC campaign
- Both cases associated with coastal mesoconvective systems and measured ice water contents exceeding 2 $g\ m^{-3}$
- Cases simulated with Large-Eddy-Simulation (LES) cloud-scale model

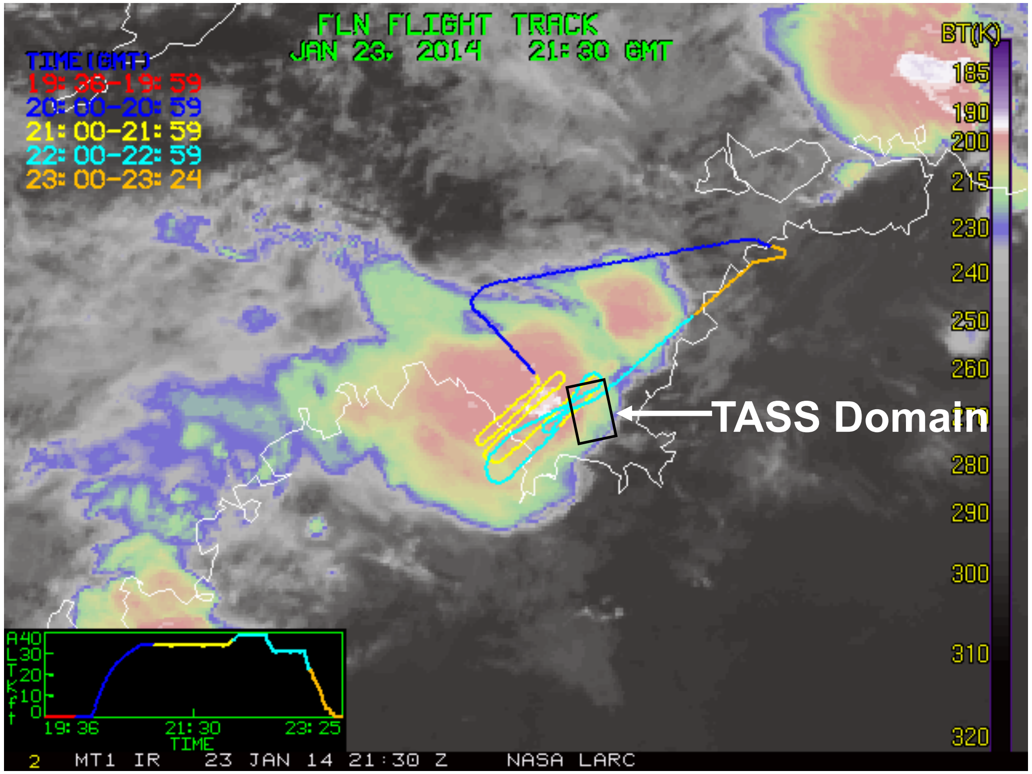
APPROACH

- Approach is to simulate specific convective elements within the mesoconvective systems, since systems are too large for full simulation with adequate grid resolution
- Horizontal and vertical grid size selected as 150*m*
- Model left & right boundaries are periodic
- Initialization guidance obtained from satellite and radar data
- Environment defined from nearby modeled or observed atmospheric soundings

Case 1: TASS Simulation of Darwin HIWC Events

- **Initialized from atmospheric sounding launched at Darwin, on 24 January 2014, 0000 UTC**
- **Weakness: the actual system was over a 100 *km* from Darwin and formed several hours earlier**
- **Domain configured offshore over the Timor Sea (southwest of Darwin) – within convectively active region**

Infrared satellite imagery showing cloud top temperatures of a mesoconvective system offshore of Northern Australia on 23 Jan 2014 (Courtesy NCAR Field Catalogue)



Case 1: Darwin 0000 UTC 24 Jan 2014 – Model Setup

Grid size: $\Delta x = \Delta y = \Delta z = 150m$

Grid points: 304 x 403 x 124

X*,Y*,Z*: 45*km* x 60*km* x 18*km*

Integration time$_{max}$ = 3*hr* 10min

$\Delta T_{pert} = 1.0K$

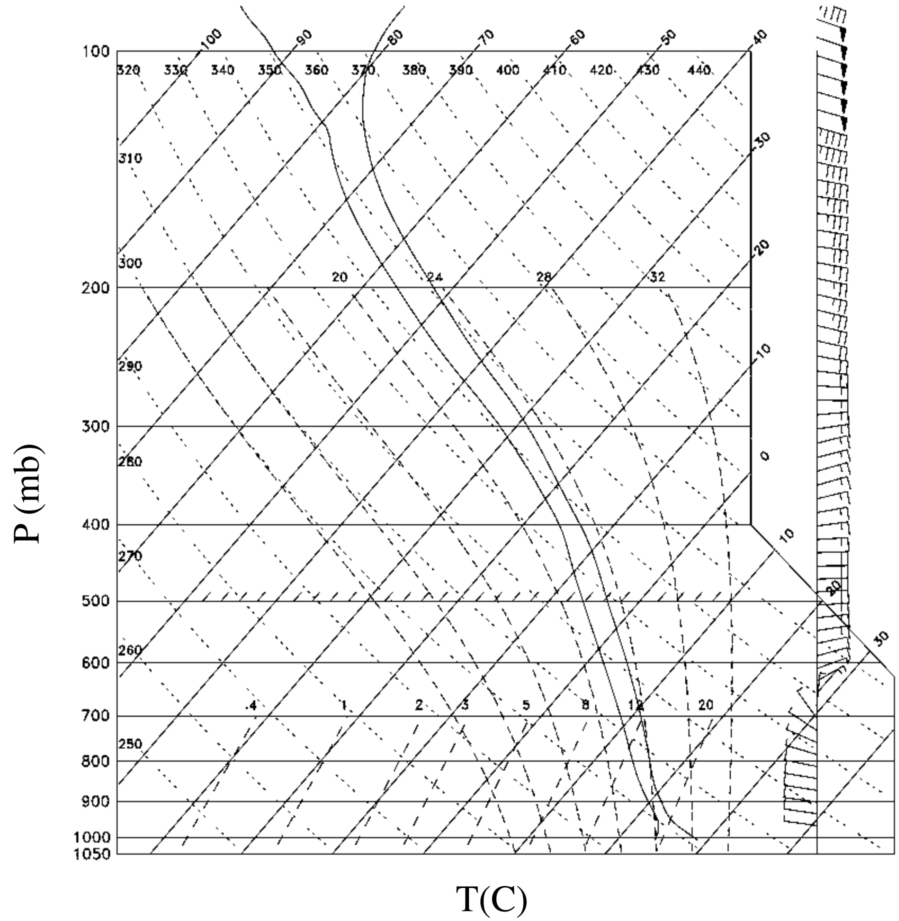
$R_{pert} = 12000m$, $H_{pert} = 1000m$

Ncld = 75 droplets cm^{-3}

Grid rotated -12° (ie Y – coordinate at 348°)

Periodic BC at x = X^0 and X*,

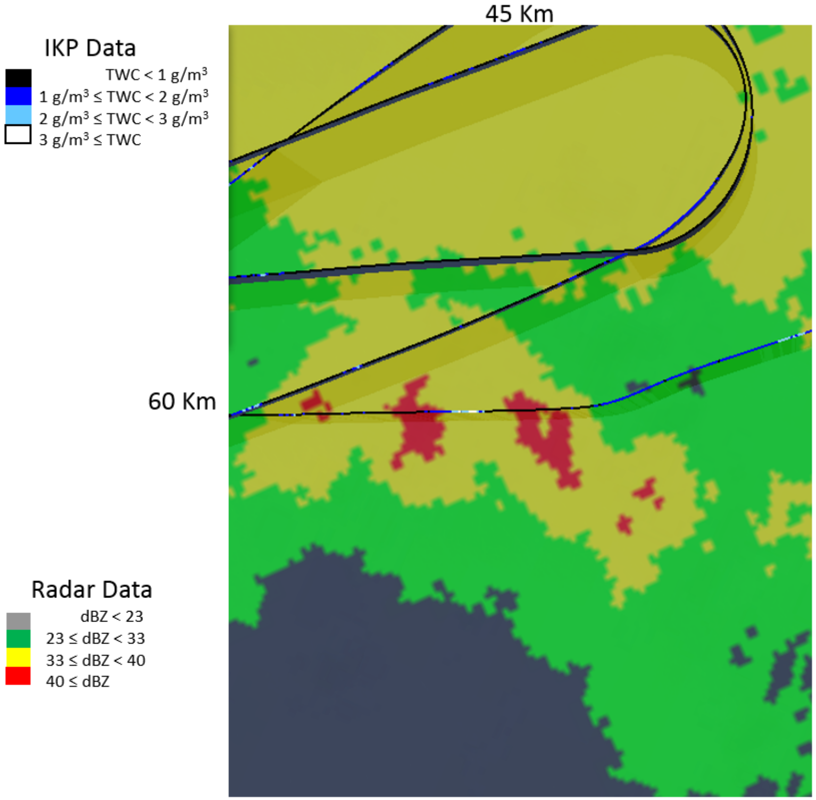
Open BC at y= Y° and Y*

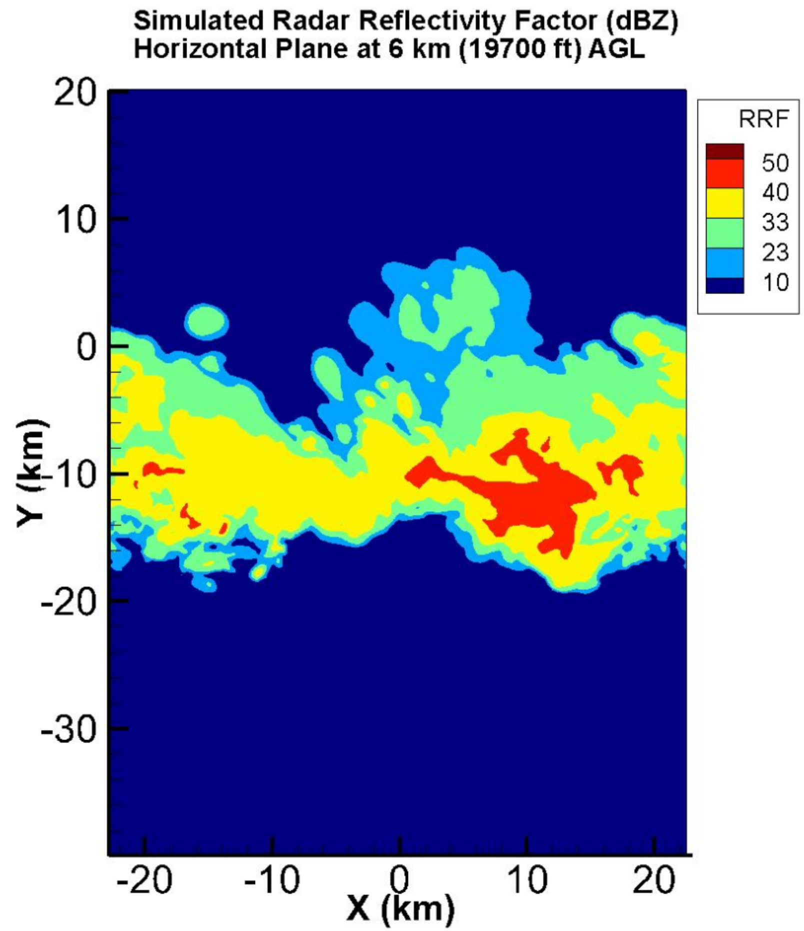


TASS Initialization Sounding

Comparison: Between Airborne and TASS Simulated RADAR Reflectivity

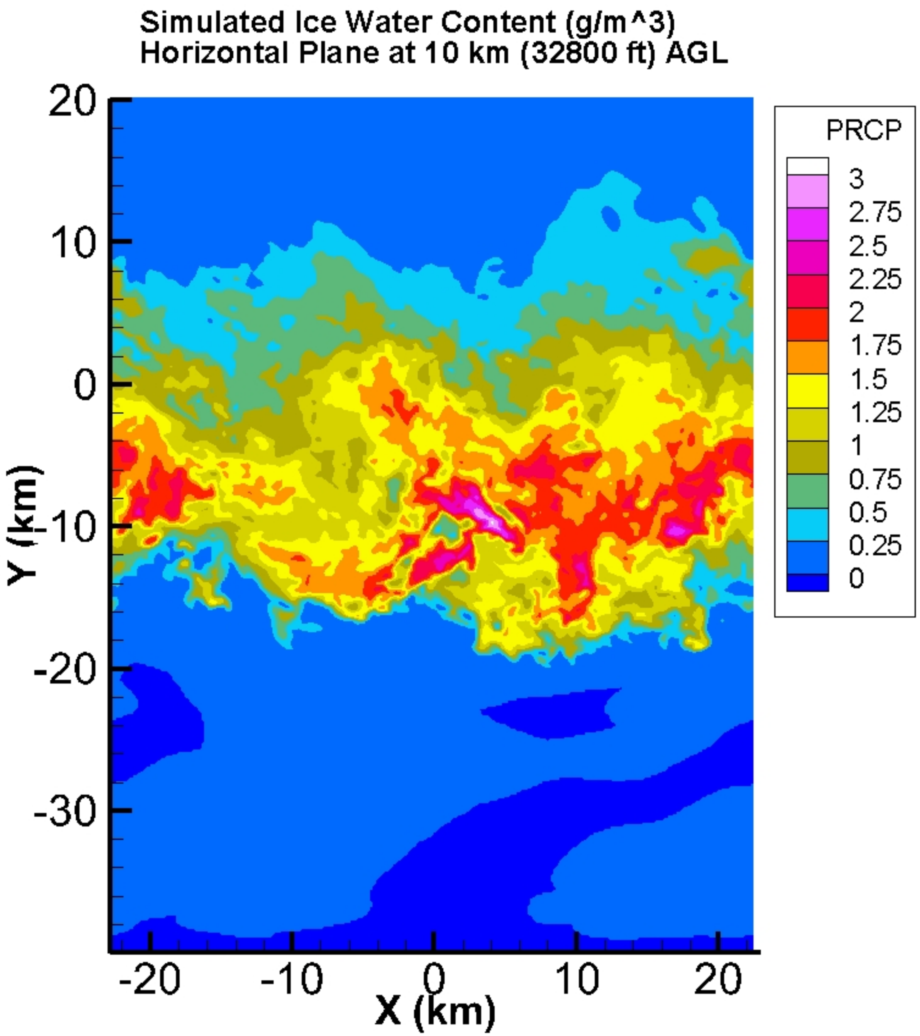
Airborne Radar -4 deg tilt

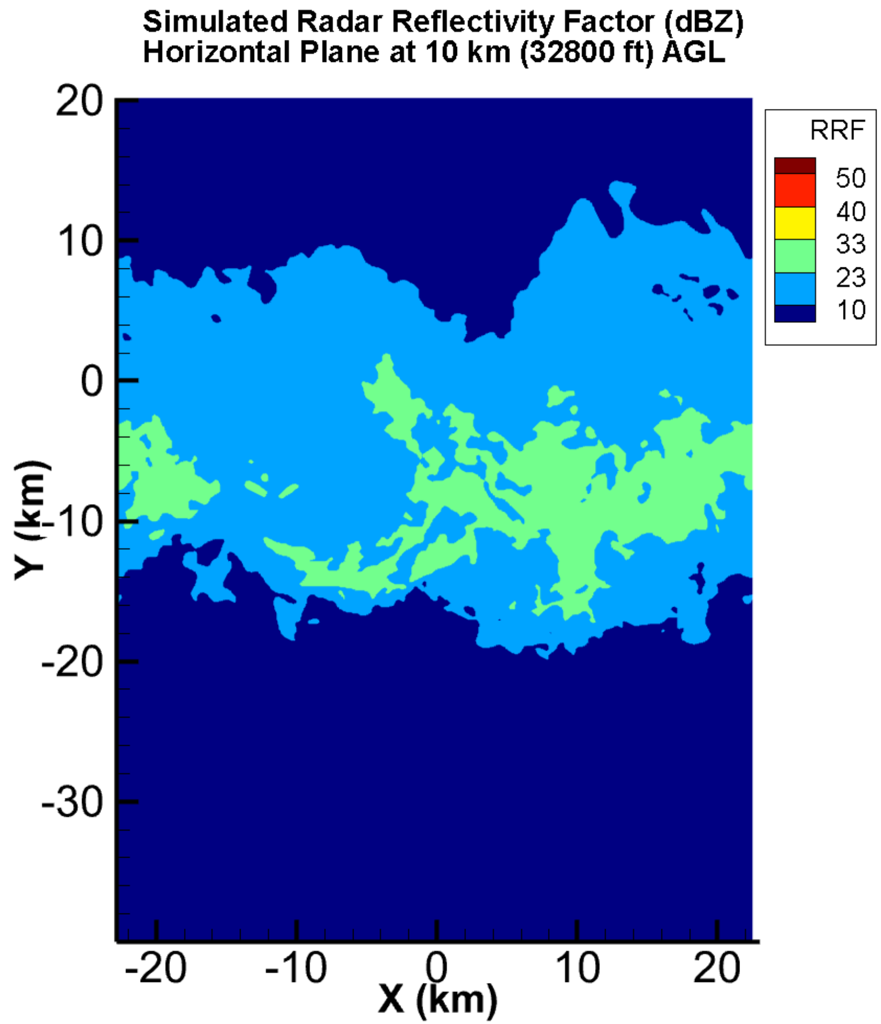




60*km* x 45*km* window, rotated -12 deg

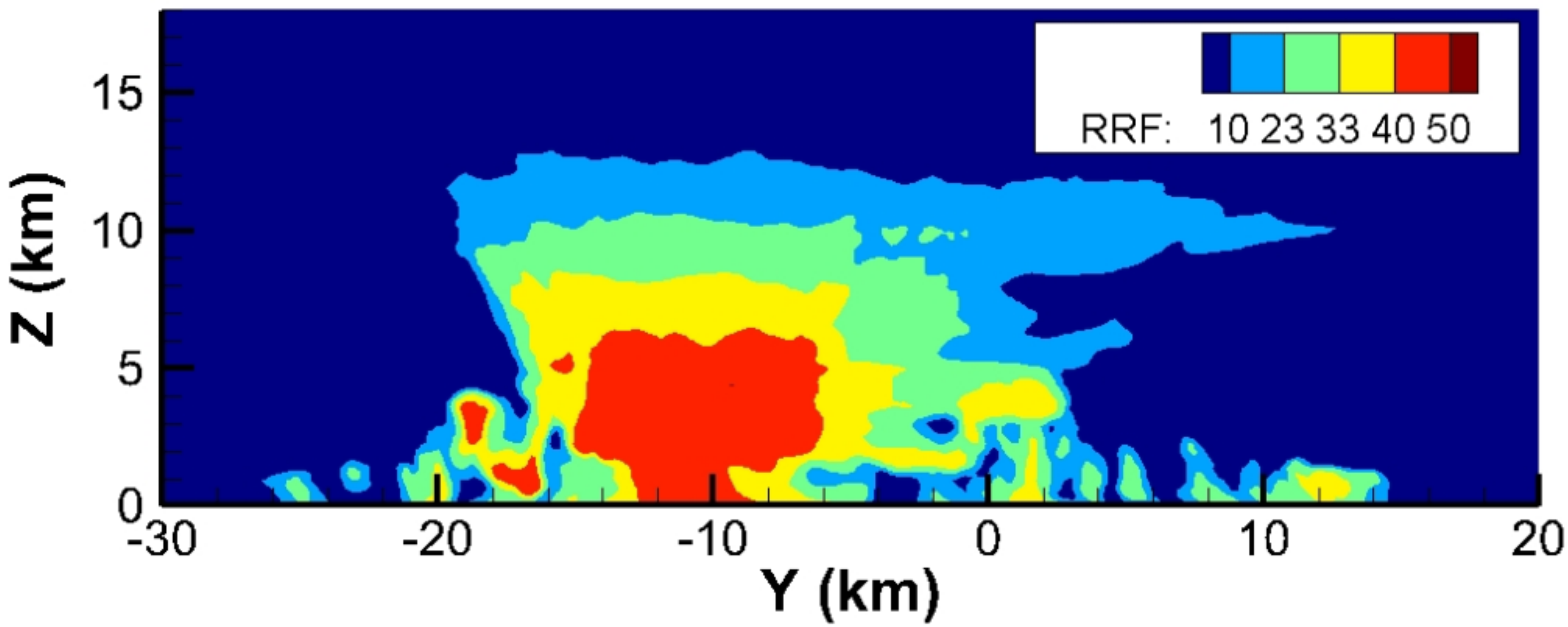
Darwin: TASS Simulation





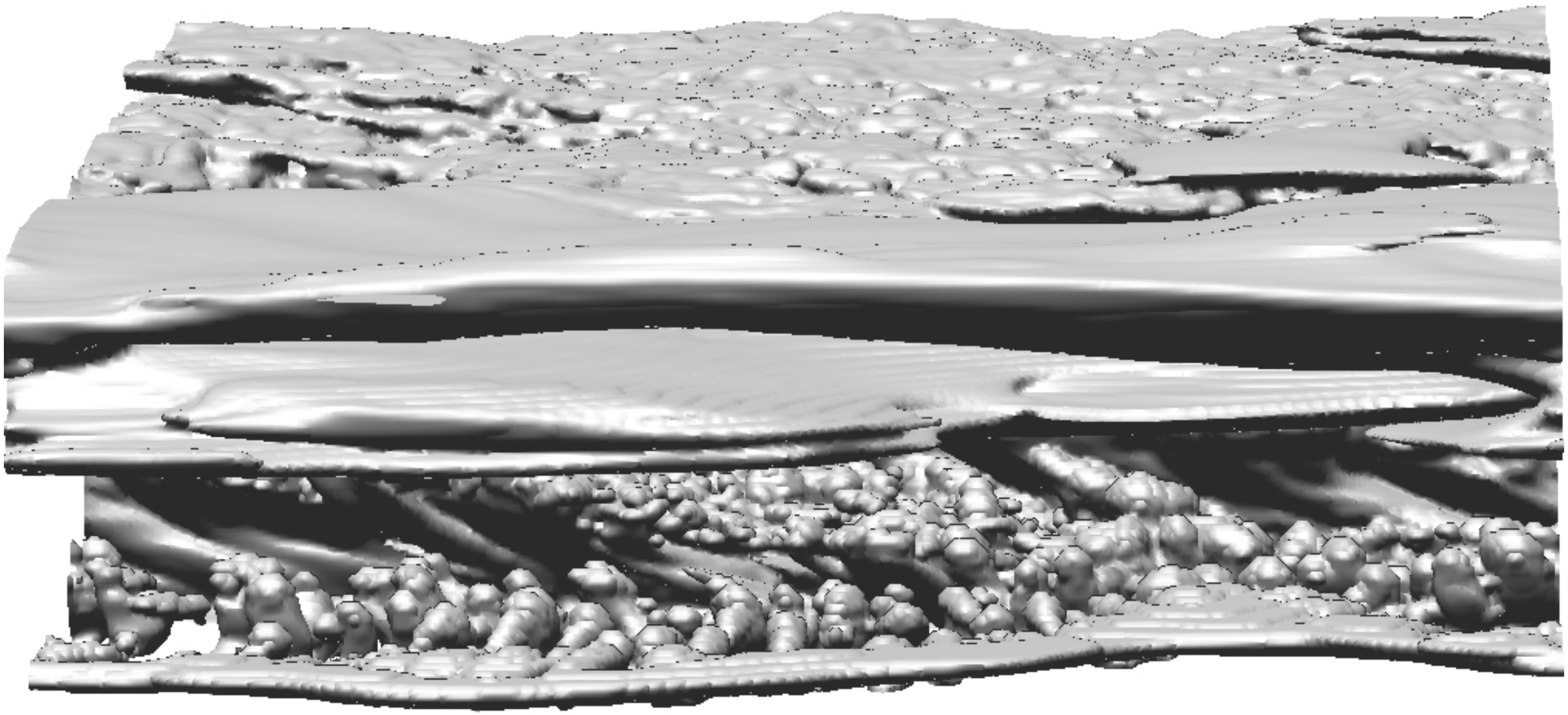
- **Large areas of HIWC with RRF less than 30 dBZ**
- **Sustained areas (over 25*km* wide) of ice water greater than 1.0 *g/m³* and with peak values at 3 *g/m³***

TASS RADAR Reflectivity Factor: y-z cross section at x= 10 *km*



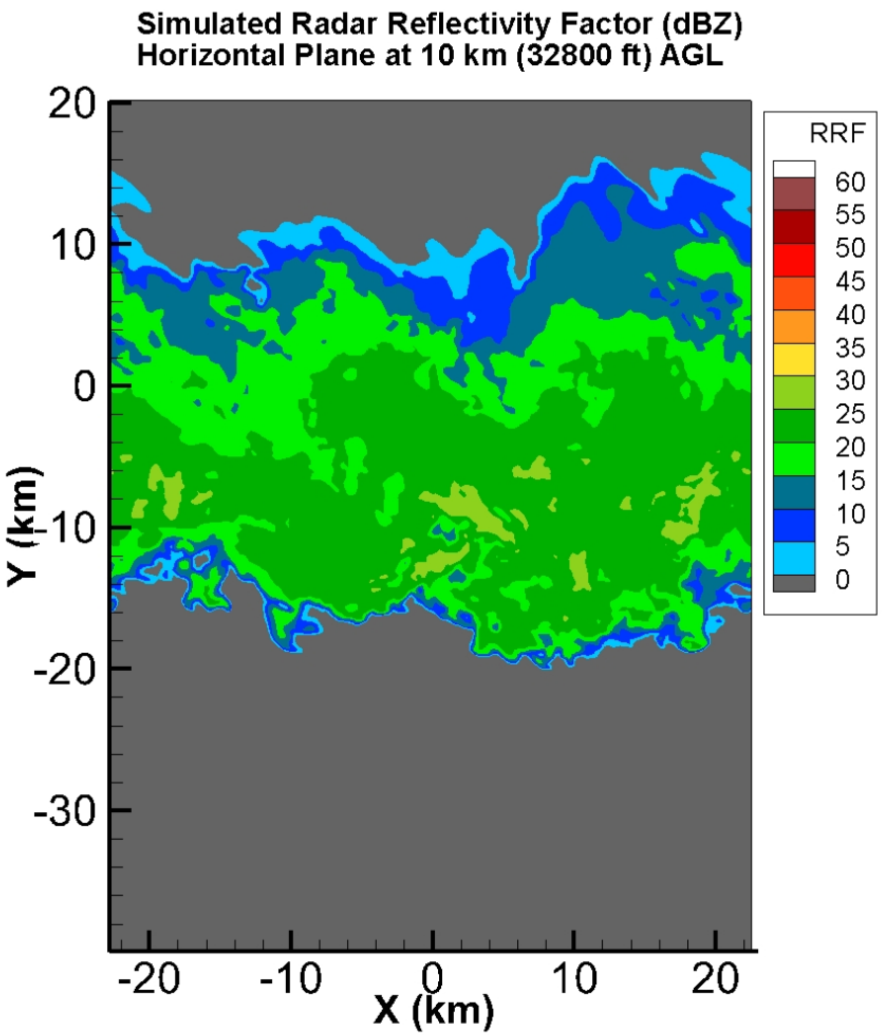
- **Most RADAR reflectivity in excess of 40 dBZ confined to lower 7*km* of storm**
- **Weak RADAR reflectivity factor at flight level (~10*km* AGL)**

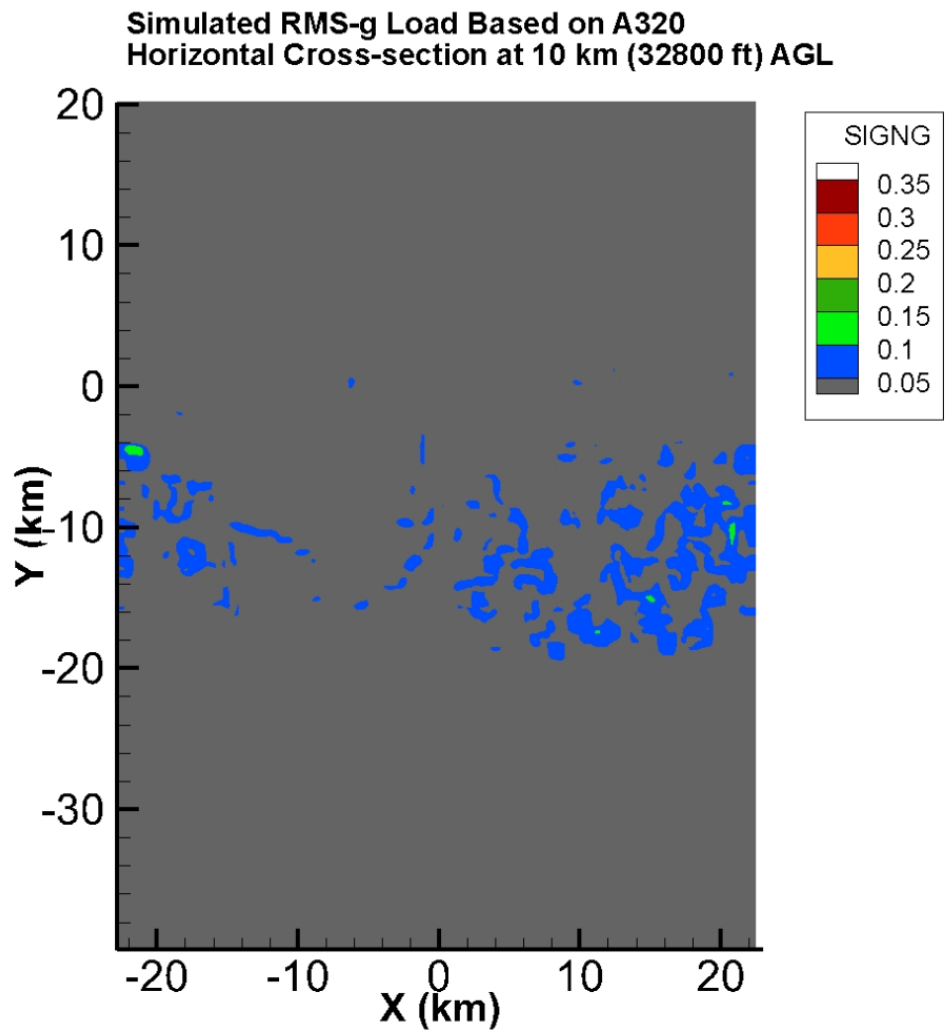
TASS Darwin Simulation: 3-D Cloud



- Viewed from South
- Multiple pulsing convective cells feed canopy overhang
- Overhanging cloud canopy much larger than active cells

TASS Darwin Simulation





- **Simulation shows very light turbulence at flight level near vicinity of HIWC event**

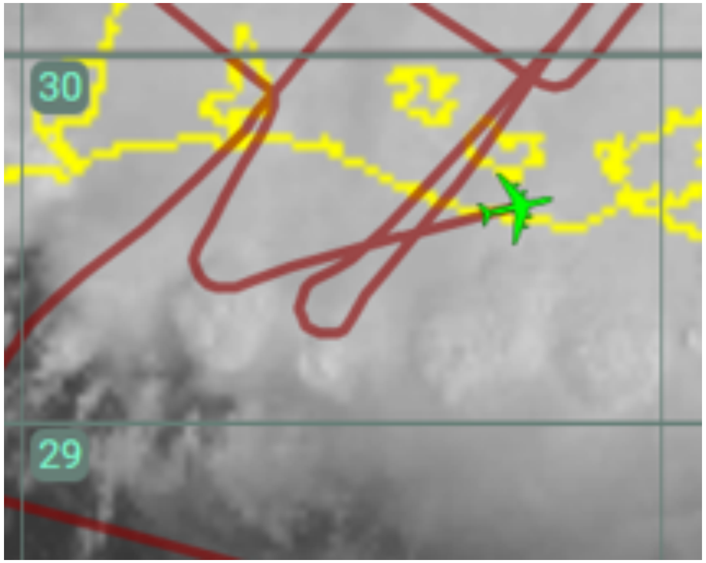
Case 2: TASS Simulation of Coastal Louisiana HIWC Event

- **One of the events investigated during the recent HIWC DC-8 Flight Campaign**

- **Again, TASS domain confined to small region of the mesoconvective system**
  - **Domain configured offshore of Louisiana over the Gulf of Mexico**

- **Initialized from an atmospheric sounding obtained from the Operational NCEP Rapid Refresh(RAP) weather prediction model**
  - **Sounding for 19 August 2015, 1400 UTC**
  - **Location: 29 N, 91.2 W**

Visible satellite imagery showing convective cells along southern edge of mesoconvective system on 19 Aug 2015



Case 2: Offshore Louisiana Coast 0000 UTC 24 Jan 2014 –TASS Setup

Grid size: $\Delta x = \Delta y = \Delta z$ = 150m

Grid points: 204 x 353 x 124

X*,Y*,Z*: 30*km* x 52.5*km* x 18*km*

Integration time$_{max}$ = 2*hr* 50*min*

ΔT_{pert} = 1.0*K*

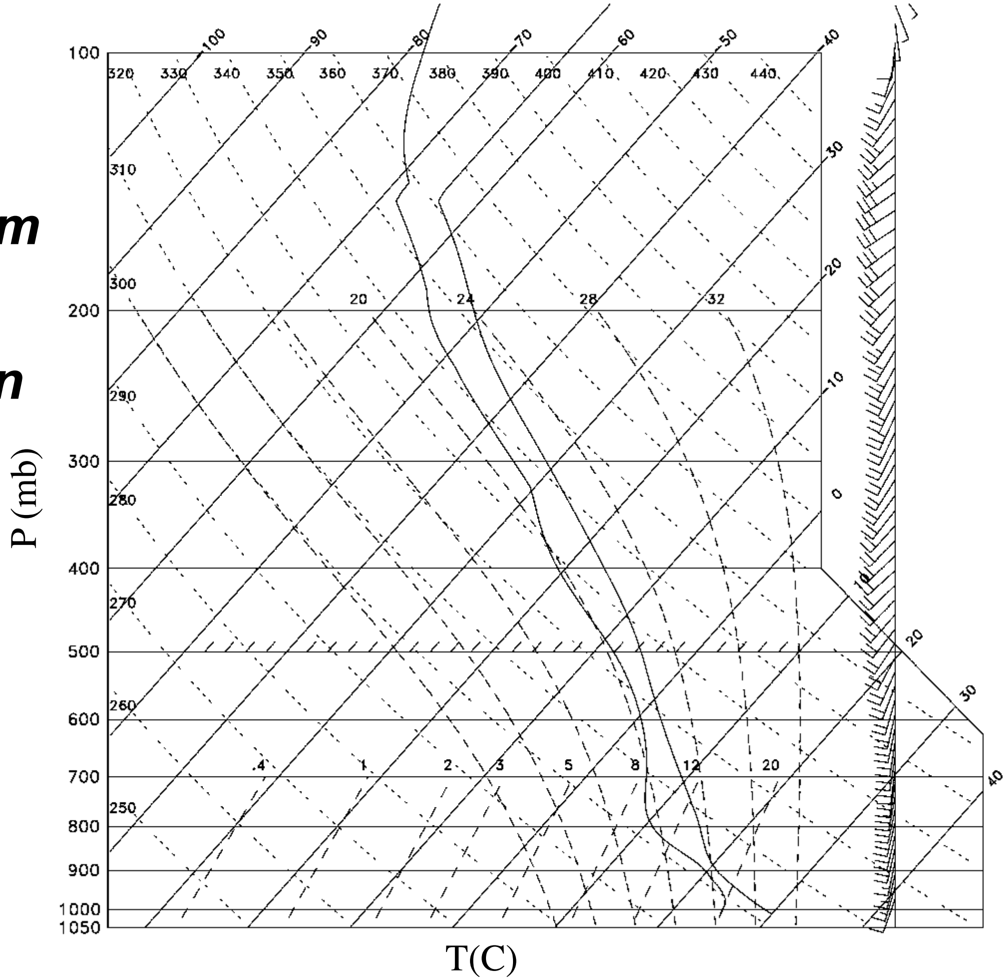
R_{pert} = 3000*m*, H_{pert} = 1000*m*

Ncld = 75 droplets *cm*$^{-3}$

Grid rotated -15° (ie Y – coordinate along 345°)

Periodic BC at x = X^0 and X*,

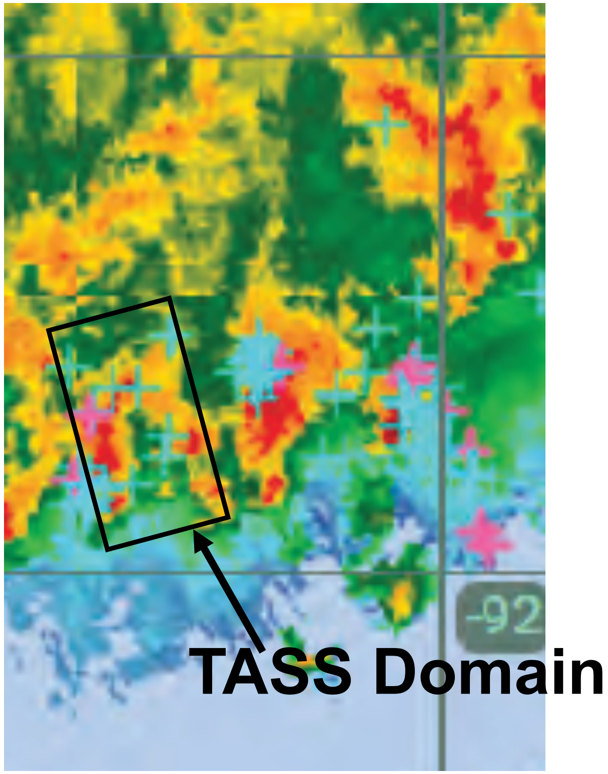
Open BC at y= Y° and Y*

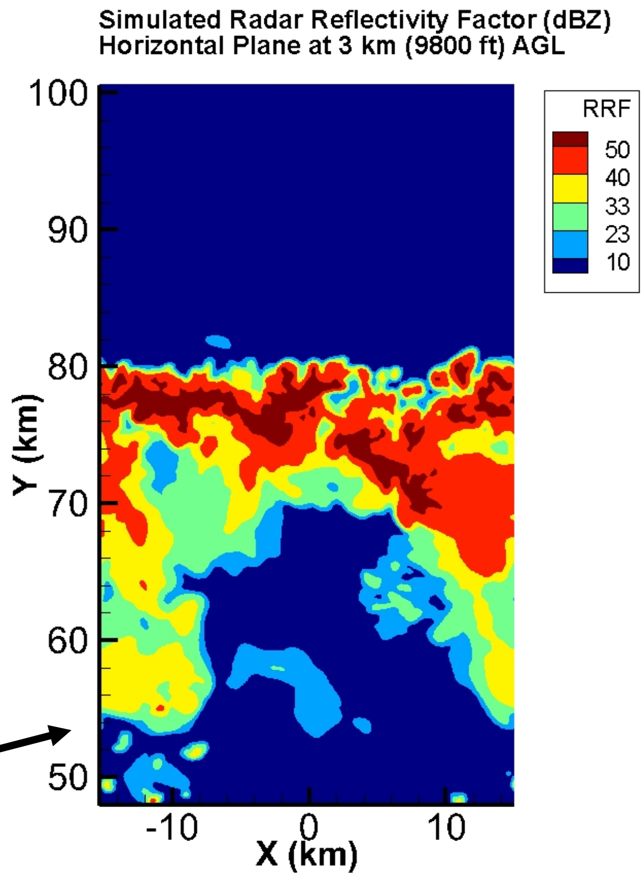


TASS Initialization Sounding -- Extracted from RAP 1400 UTC 29 N, 91.2W

Louisiana Case: Domain and Radar Reflectivity

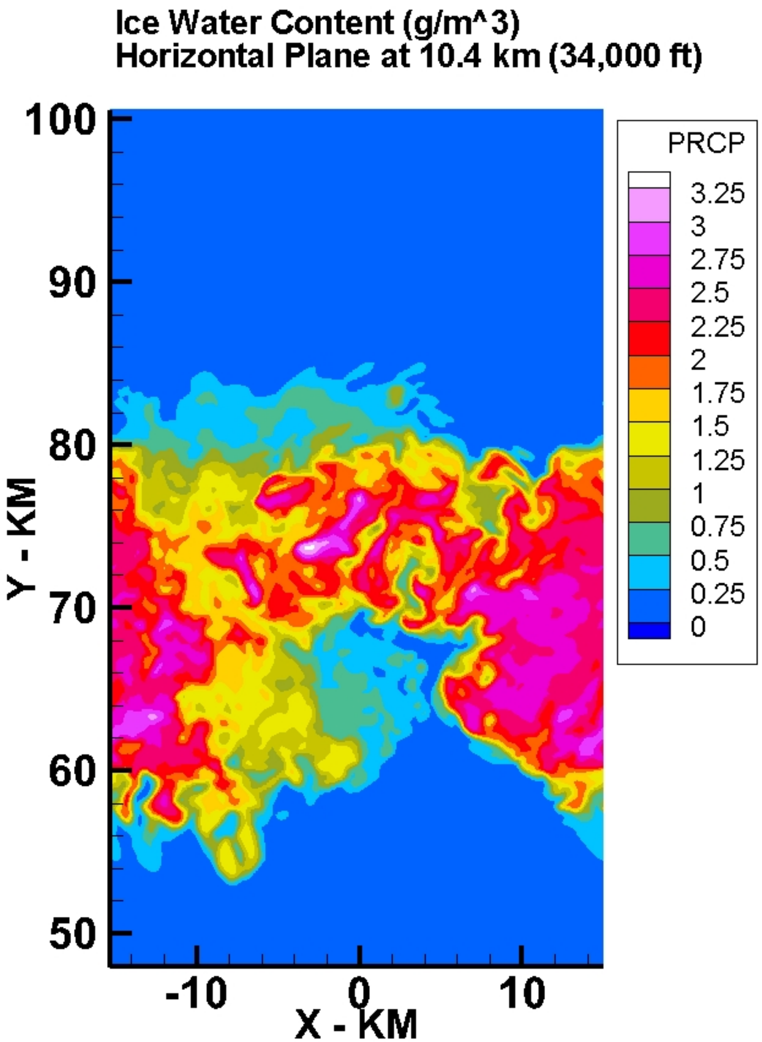
Nexrad Radar composite – along Louisiana Coast

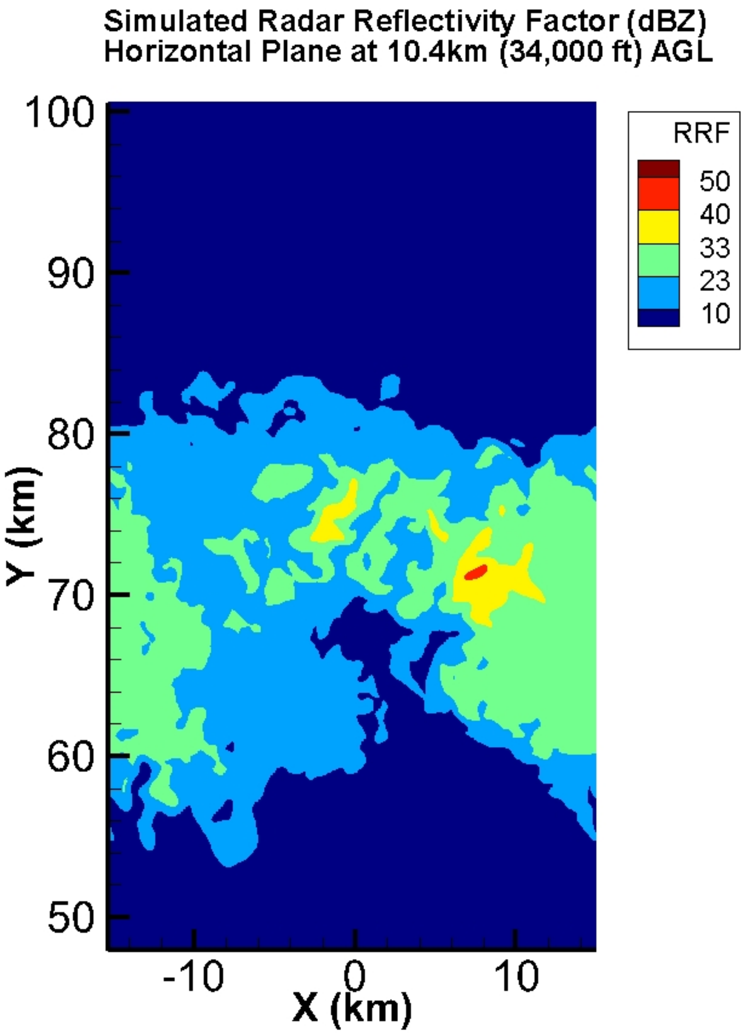




52.5 km x 30 km window, rotated -15 deg

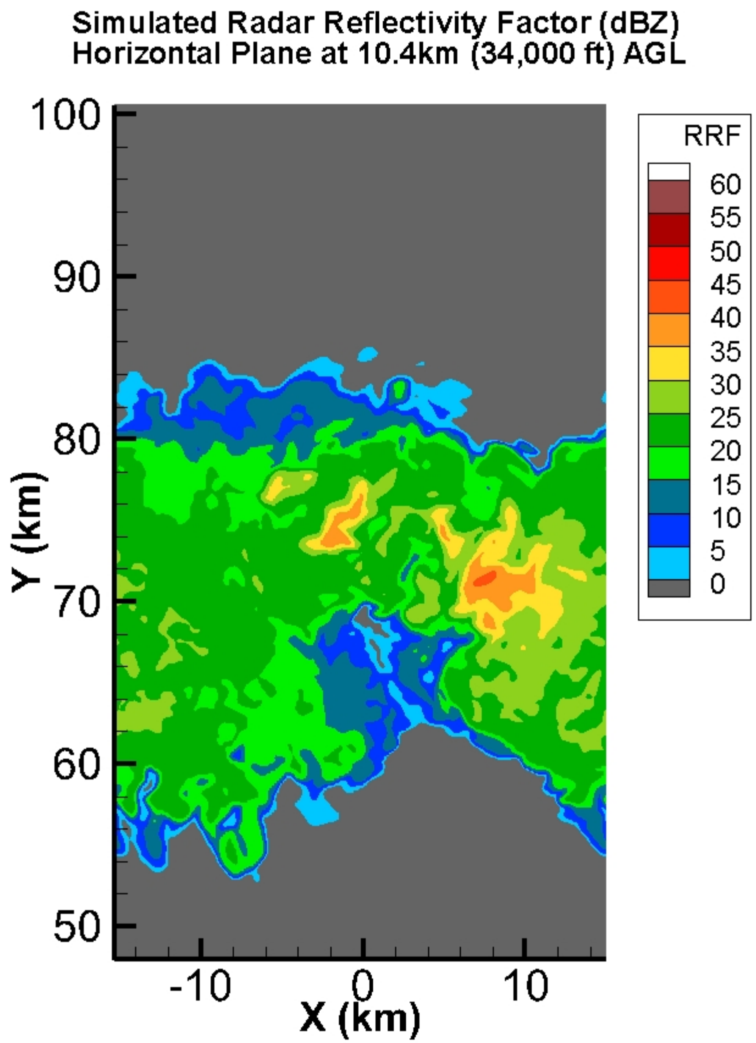
TASS Louisiana Simulation

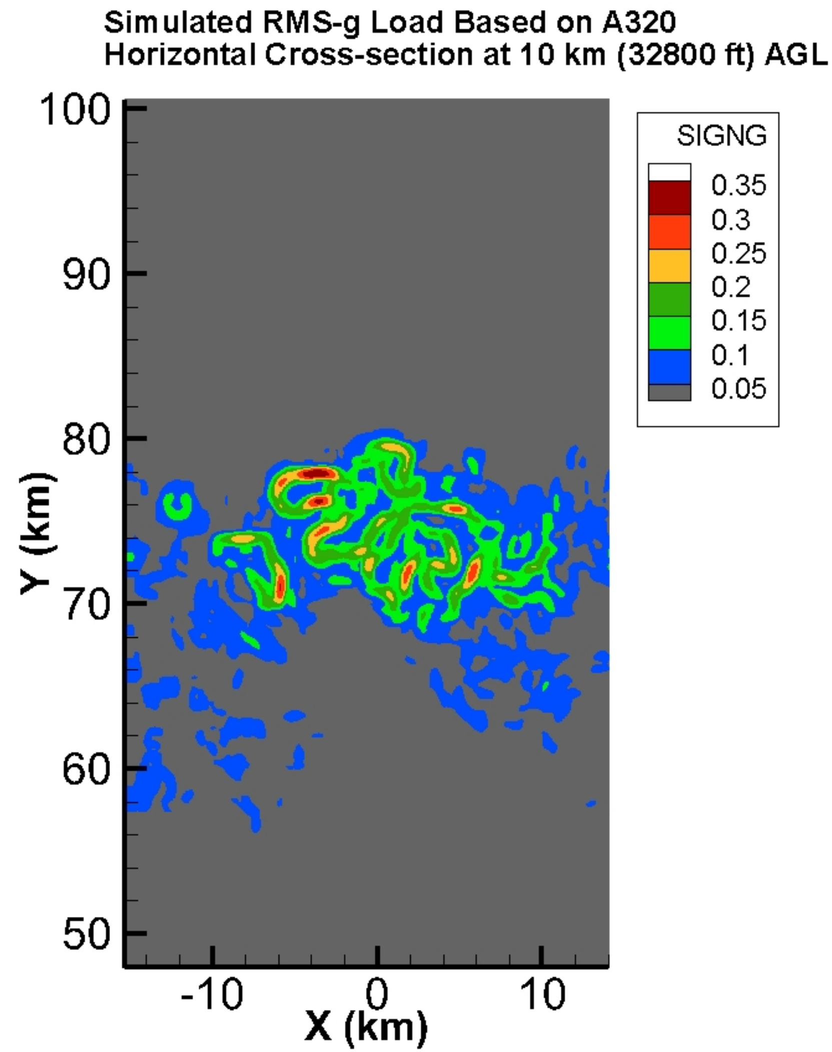




- Large areas of HIWC with RRF less than 30 dBZ
- Sustained areas (over 20*km* wide) of ice water greater than 2.0 g/m^3 and with peak values at 3.3 *g/m^3*

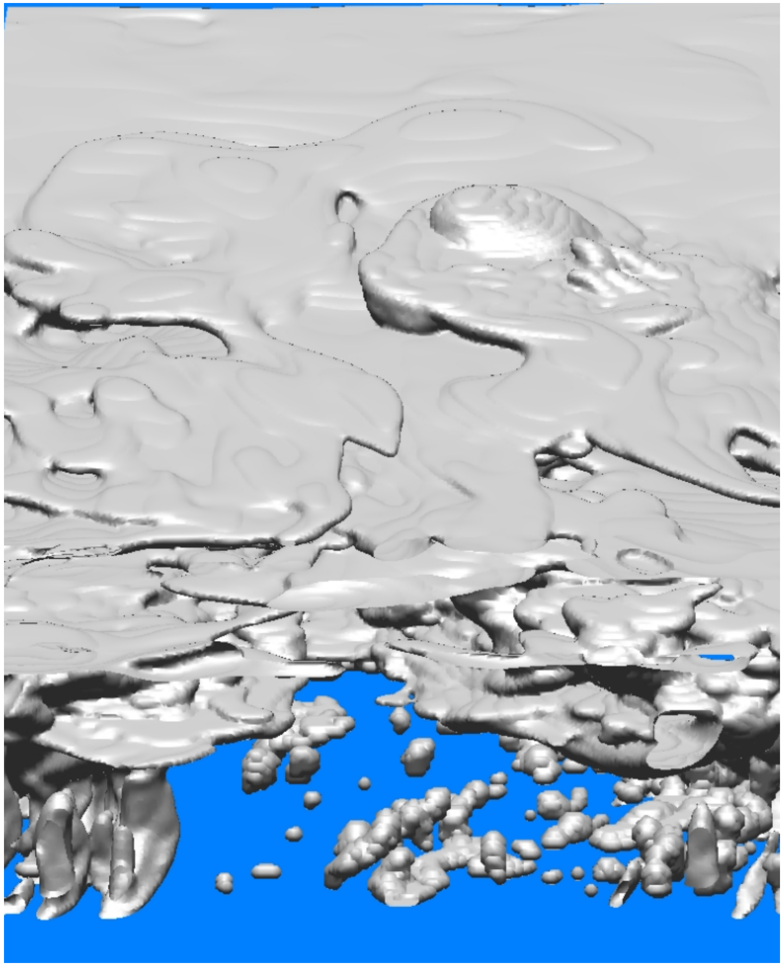
TASS Louisiana Simulation





- **Simulation shows some turbulence at flight level near vicinity of HIWC event**

TASS Louisiana Simulation: 3-D Cloud



- Full domain viewed from above and from South.
- Multiple pulsing convective cells with overshooting tops feed canopy overhang

Summary

- Two cases are shown to demonstrate the feasibility of simulating HIWC events with a high-resolution convective cloud model
- HIWC conditions were demonstrated to occur in regions with low RADAR reflectivity
- Peak ice water contents in excess of 3 $g\ m^{-3}$ were simulated at flight level. Consistent with measurements from the HIWC flight campaigns
- Simulations demonstrate large mesoconvective system canopies maintained by ensembles of pulsing convective cells