

Numerical Simulation of Event 191-6 of NASA's Flight Tests

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Outline

- **Introduction**
- **Description of Turbulence Event**
- **TASS Model**
- **Initial Conditions**
- **Results from Model Simulation**
- **Summary**



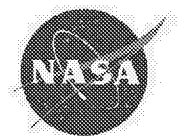
Introduction

- **Numerical Simulation of Event 191-6**
- **Severe Turbulence Encountered by NASA Langley B-757 during Event 191-6**
- **Occurred as B-757 Penetrated Updraft Plumes Near Storm Top**
- **Data Available for Model Validation**
 - **Ground Based Radar (i.e. Nexrad)**
 - **Satellite**
 - **NASA B-757**
 - *In Situ* Winds and Accelerations
 - Onboard Doppler Radar
 - Eyewitness Accounts

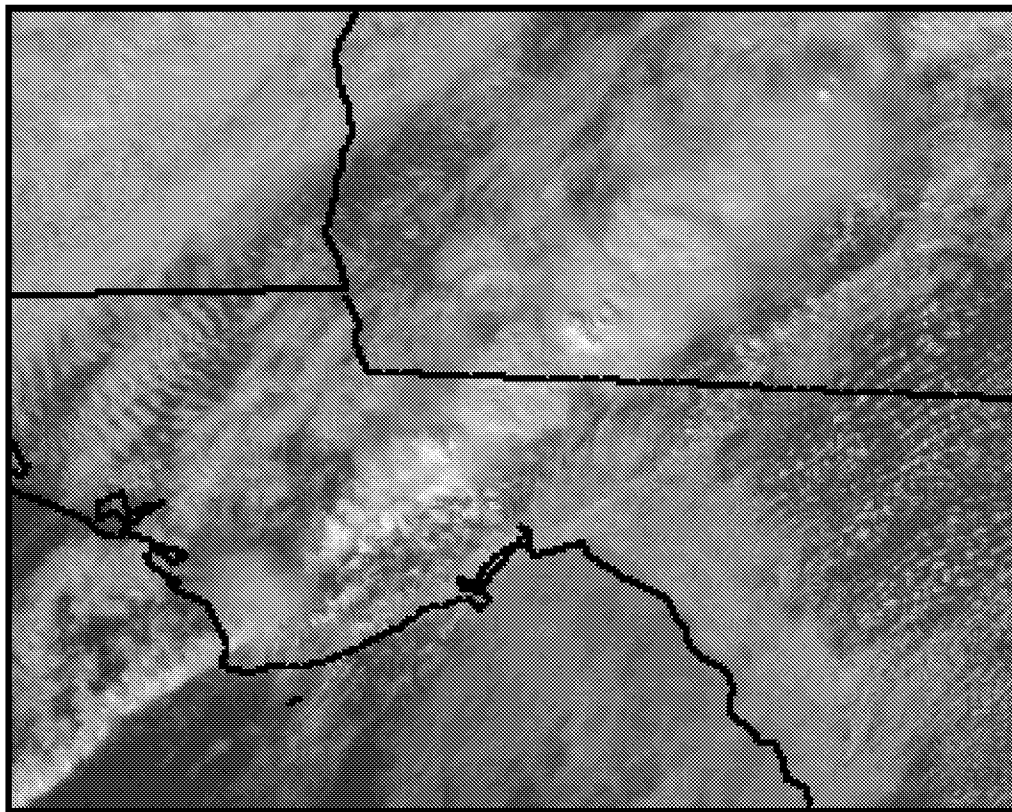


R – 191-6 December 14, 2000

- Severe turbulence encountered ~40 *km* NE of Tallahassee FL (TLH)
- Narrow line of convective cells
 - Peak storm tops: 39,000 *ft* (11.8 *km*)
 - Cell movement: from southwest at 40 *kts*
- 2 significant turbulence events with peak *in situ* measurement:
 - $\sigma_{ng} = 0.44$
 - $\varepsilon^{1/3} = 0.74$



1 km Visible Satellite 1845 Z December 14, 2000



MODELING ROADMAP

- **Step 1: Derive initial sounding based on mesoscale model prediction; configure domain; retrieve and prepare observed data for case verification.**
- **Step 2: Coarse-grid simulation: should capture large scale characteristics of storm: 125x125x70 grid points with horizontal grid size of 200 *m***
- ➔ **Step 3: Fine-grid simulation: 250x250x150 grid points, with grid size of 100 *m***
- **Step 4: Nested grid simulation**
 - 5 km region near cloud top
 - Minimum grid size less than 25 m.
 - Validate results



TERMINAL AREA SIMULATION SYSTEM (TASS)

- **3-D Large Eddy Simulation (LES) Model**
- **Meteorological Framework**
- **Prognostic Equations for:**
 - **3-Components of Velocity**
 - **Potential Temperature**
 - **Water Vapor**
 - **Liquid Cloud Droplets**
 - **Cloud Ice Crystals**
 - **Pressure**
 - **Rain**
 - **Snow**
 - **Hail/graupel**
 - **Dust/insects/tracers**
- **1st-order subgrid turbulence closure with Richardson-number dependency**
- **Surface friction layer based on Monin-Obukhov similarity theory**
- **Cloud microphysics**



TASS -- History

- **Development began in 1983 for NASA/FAA Windshear Program**
- **Recently applied in NASA's Wake Vortex Program for improving airport capacity (i.e. AVOSS)**
- **Generation of data sets for Windshear Sensor Certification**
- **Supported NTSB Investigation of 1994 Charlotte and 1999 Little Rock Aircraft Accidents**
- **Simulations Applied to:**
 - **Cumulonimbus Convection**
 - **Tornadic Storms & Supercell Hailstorms**
 - **Microbursts & Microburst Producing Storms**
 - **Reconstruction of Microburst Windshear Encounters**
 - **Aircraft Wake Vortices**
 - **Atmospheric Boundary Layer**
 - **Flight Turbulence**



R-191-6, 14 Dec 2000, Near Tallahassee FL

TASS Domain Configuration

Physical Domain size

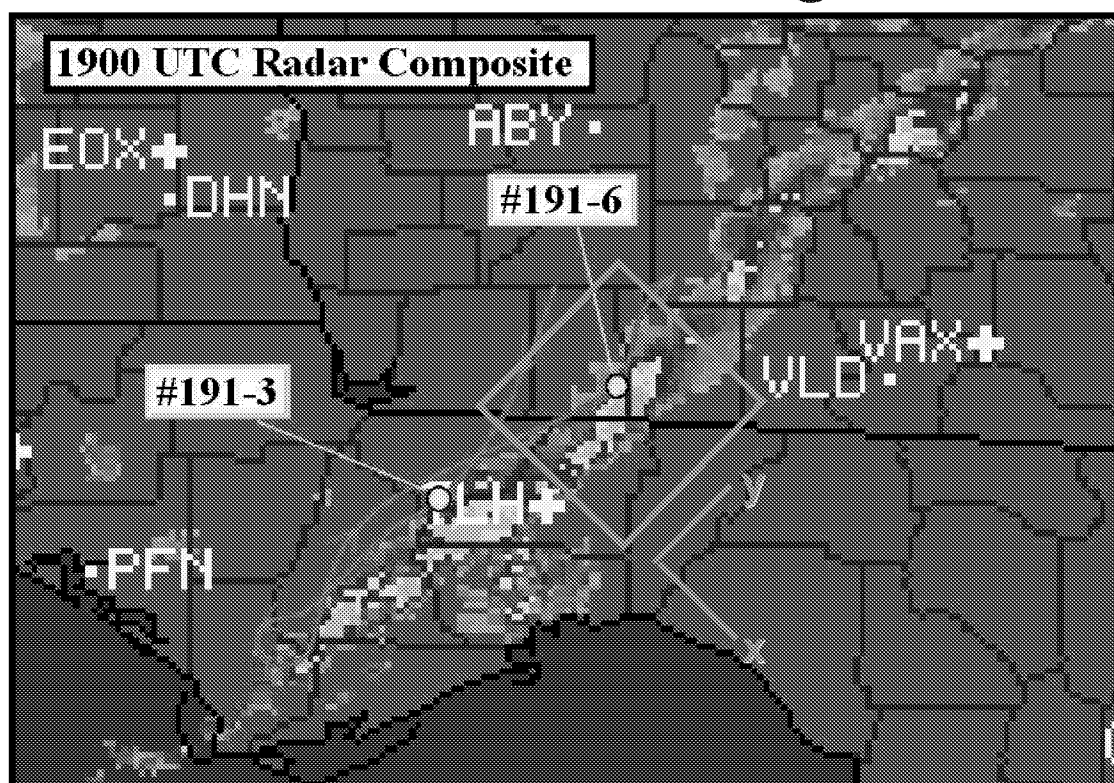
- Horizontal (X, Y): 25 x 25 km
- Vertical (Z): 14 km

Domain orientation and lateral boundary conditions

- Domain rotated 66° clockwise:
 - X – coordinate orthogonal to convective line
 - Y – coordinate along line
- Lateral BC:
 - Periodic boundary at $Y = \{0, X^*\}$,
 - Open at $X = \{0, Y^*\}$
- Computational resolution
 - Horizontal – 100 m (251 x 251 grid points); can resolve horizontal scales down to 400-200 m
 - Vertical – 100 m, stretched grid at $Z < 2100$ m with grid size decreasing to 50 m at $Z = 0$ (148 levels)



TASS Domain Configuration



TASS Simulation of Event 191-6, 14 Dec 2000

TASS Input Data

Input Sounding

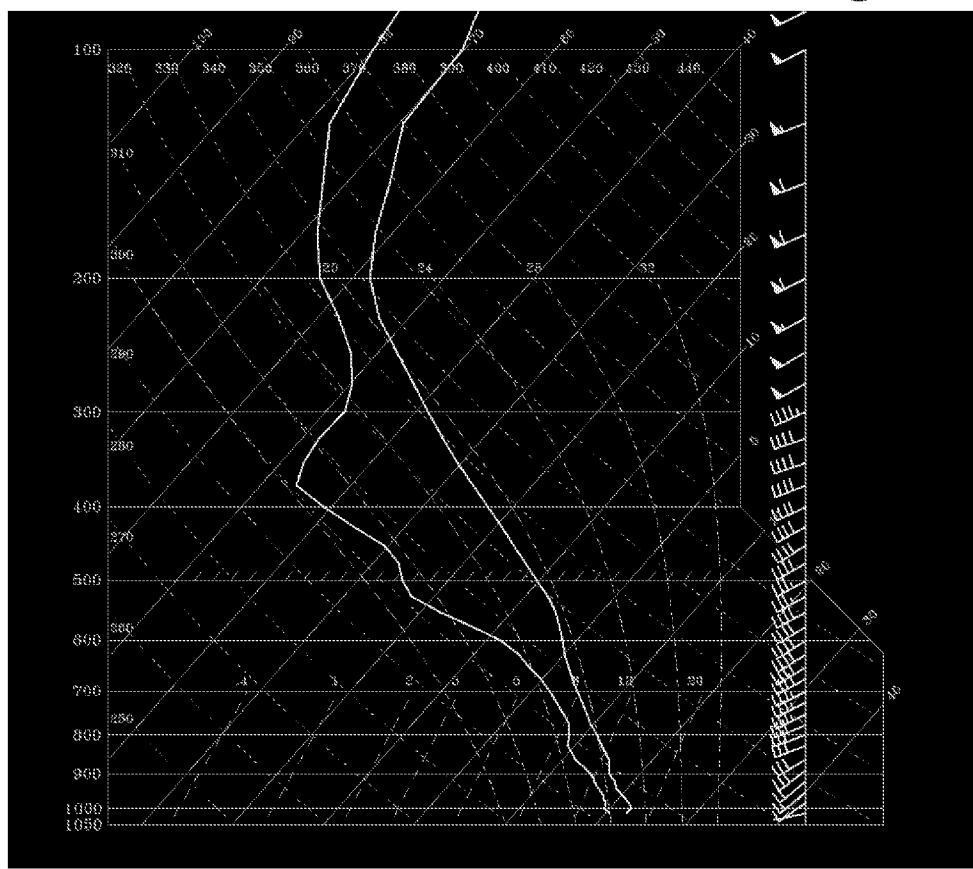
- Environmental winds, temperature, dewpoint, & pressure
- From MASS 6-km forecast at time & location near event
- Boundary layer temperature & moisture from TLH observation

Convection initiated at model time zero

- Spheroidal thermal impulse
 - Peak amplitude 2.0° C
 - Dimensions – 4 km horizontal x 2.1 km vertical



MASS TLH sounding



TASS Simulation of Event 191-6, 14 Dec 2000

Simulated Storm Characteristics

- Near solid line of convection
- Overshooting tops to 11.5 *km* (38,000 *ft*)
- Cell motion: 19 *m/s* (37 *kts*)
- Moderate rainfall at surface (no hail)
- Persistent multi-cell type convection
- Turbulence associated with storm tops
- Cloud top rise rates about 10 – 12 *m/s* (30-40 *ft/s*)

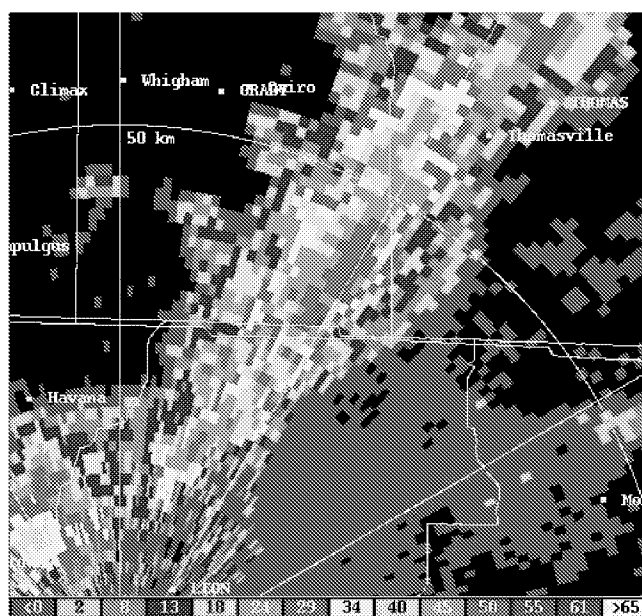


Table 3. Model Comparison

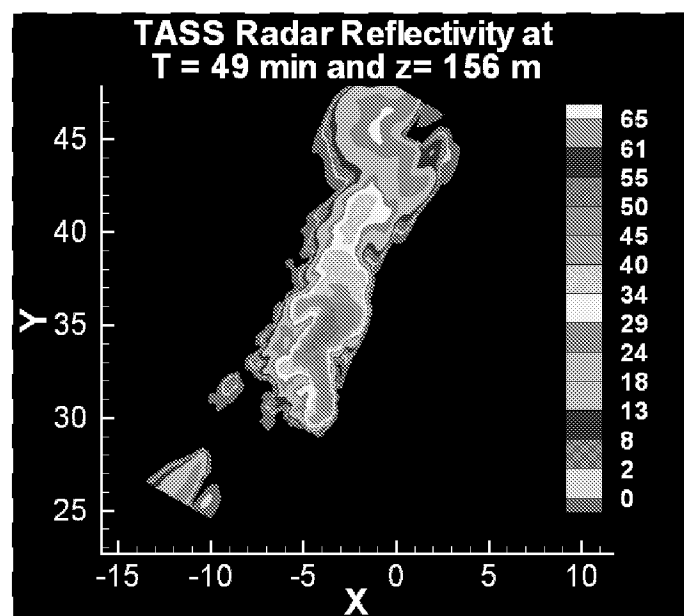
Variable	TASS		Observed	
Peak Storm Tops	11.5 km		11.8 km	
Peak Radar Reflectivity at Ground	53.5 dBz		55 dBz	
Peak Radar Reflectivity at $z=9$ km	38.9 dBz		40 dBz	
Cell Motion (toward)	ENE at 19 m/s		ENE at 17 m/s	
Width of Convective Line near Ground Level (based on 20 dBz)	6 km		8 km	
Peak Vertical Velocity at Flight Level ($z \sim 10.3$ km)	Max 17 m/s	Min -11 m/s	Max 18 m/s	Min -15 m/s
Peak Eddy Dissipation Rate ($m^{2/3}/s$)	0.86		0.74	
Horizontal Scale of Turbulence Patch at Flight Level	5 km		6 km	

*from 1 Hz *in situ* data

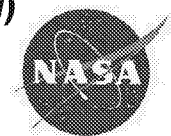
Radar reflectivity near ground (dBz)



**PPI Display From TLH Nexrad
(1.4° tilt)**



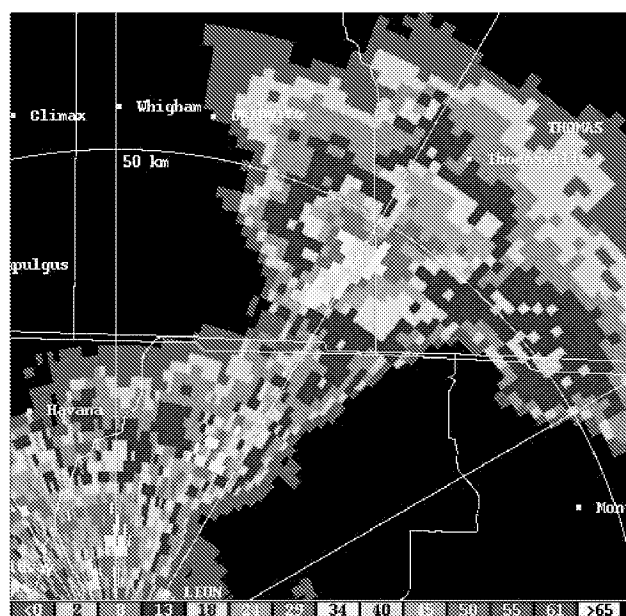
**TASS
(Horizontal Cross Section)
(major tick every 5 km)**



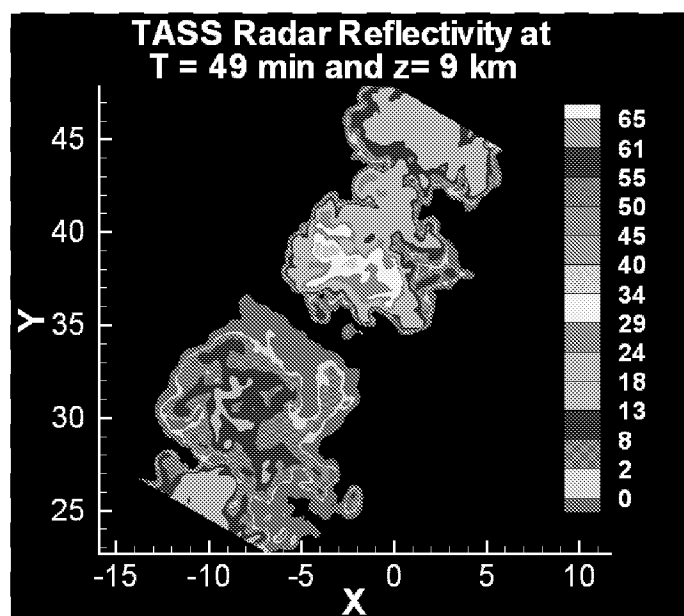
Upper-Altitude Structure of Convective Line

NASA/CP—2002-210964

525



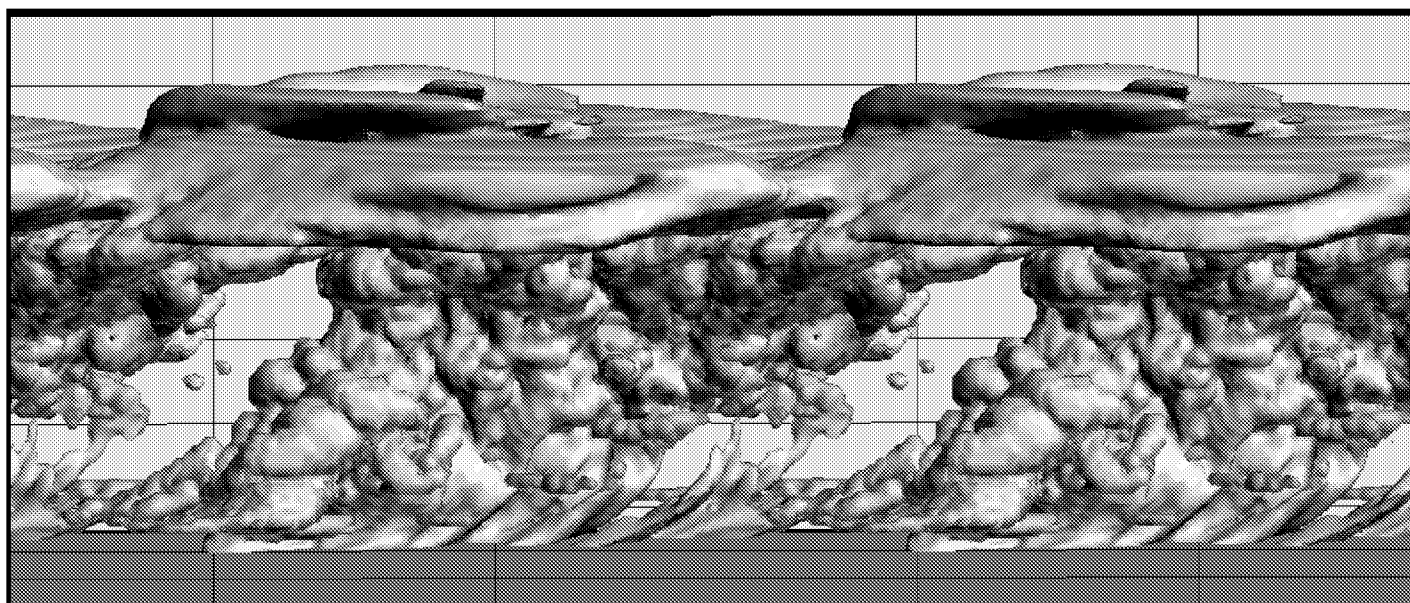
**PPI Display From TLH Nexrad
(9.8° tilt)**



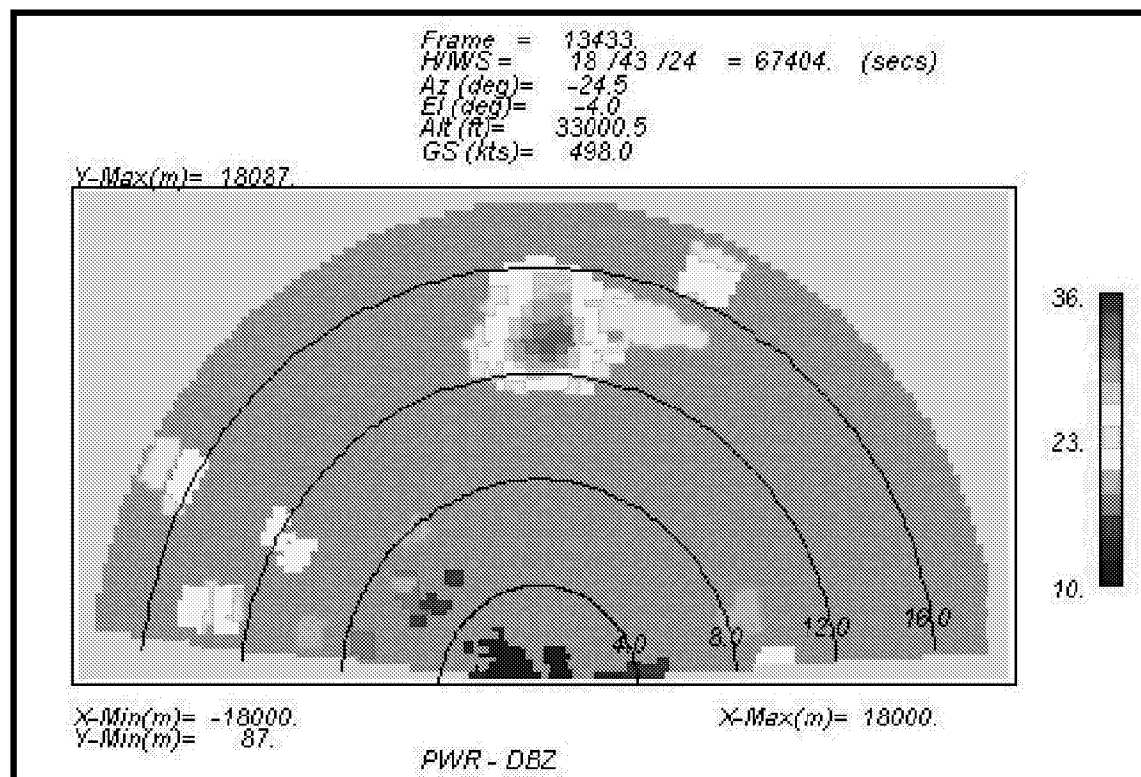
**TASS
(Horizontal Cross Section
at 9 km AGL)**



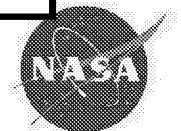
TASS Simulation of Convective Line viewed from southeast (cloud/precipitation surfaces)



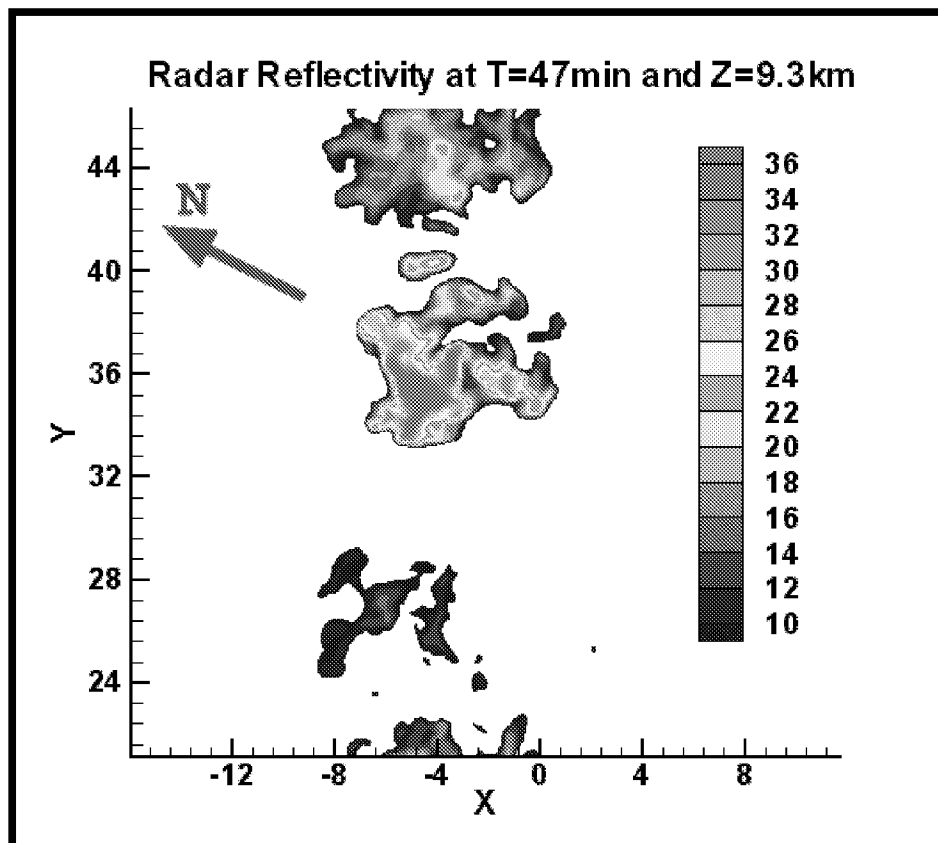
Radar reflectivity from onboard turbulence radar (dBz) at -4° tilt. (Range rings every 4 km)



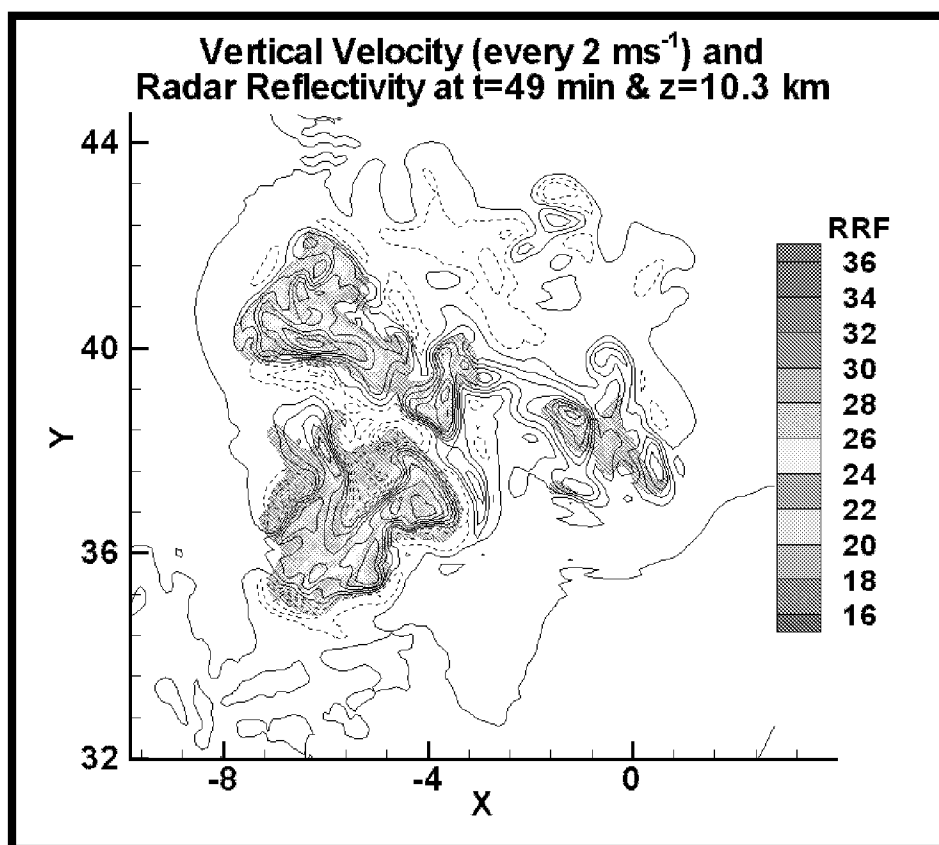
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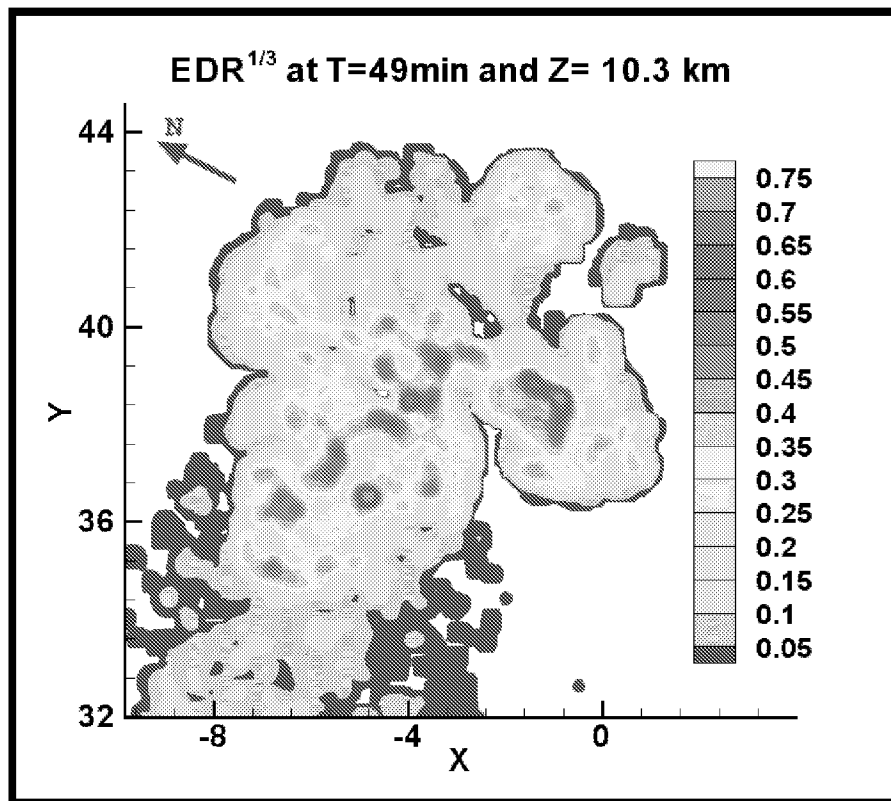
**TASS radar reflectivity (dBz) at 9.3 *km* altitude
corresponding to time and location of echo in previous slide
(major ticks every 4 *km*)**



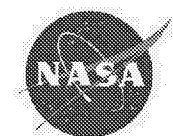
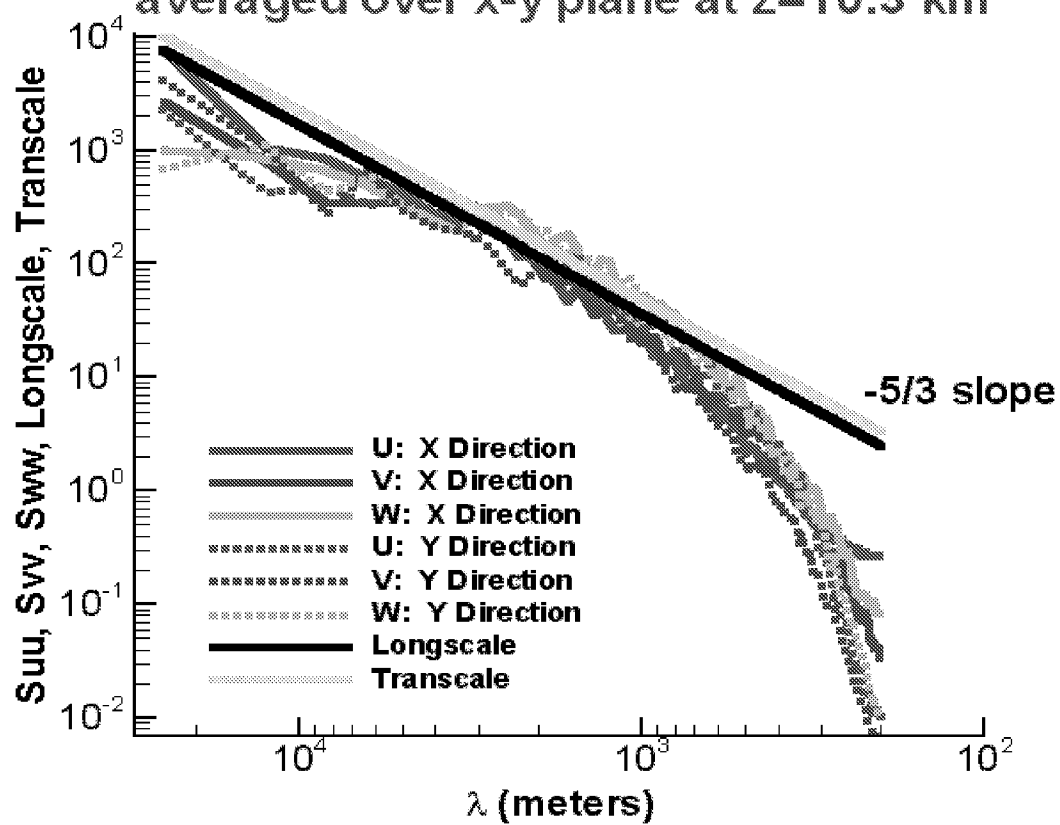
TASS radar reflectivity (dBz) at 10.3 km altitude
(major ticks every 4 km)



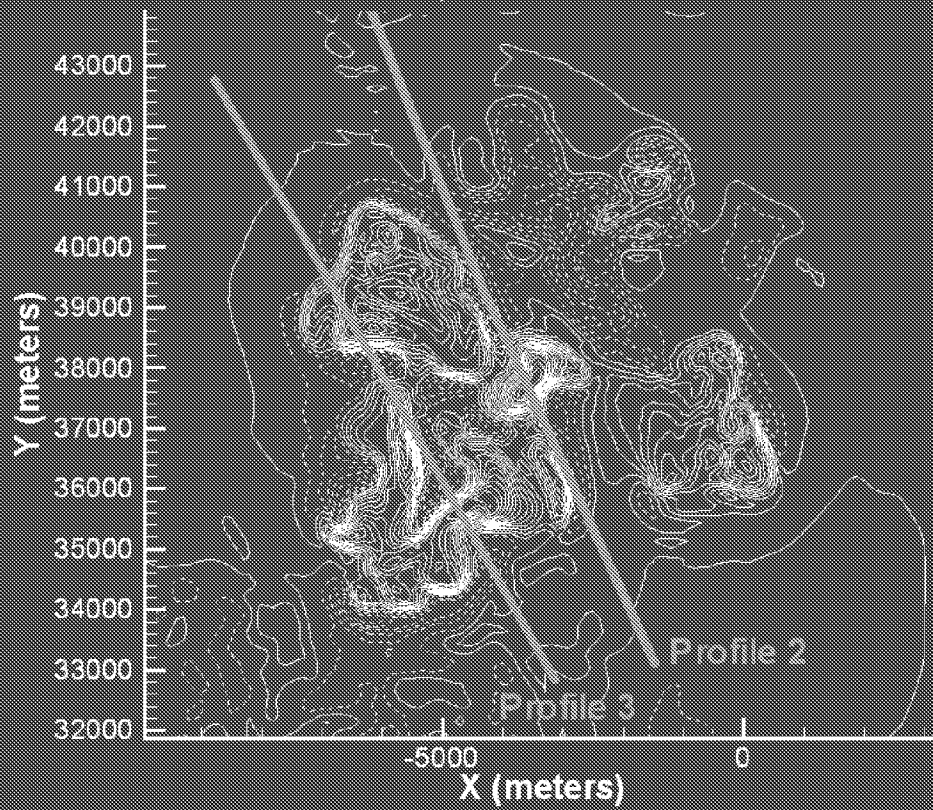
TASS Eddy Dissipation Rate to the 1/3 power ($\text{m}^{2/3}/\text{s}$) at time and location corresponding to previous slide.

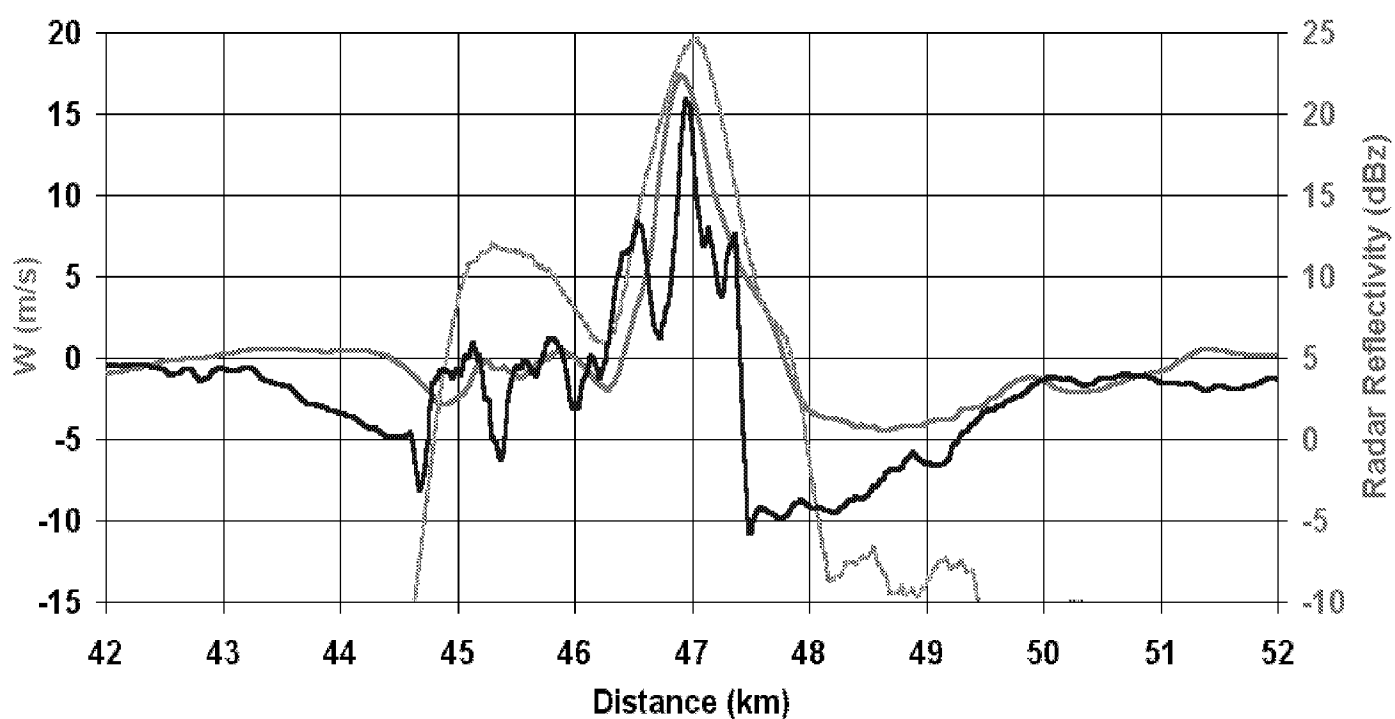


**Spectra: TASS Simulation of R-191-6, $\Delta=100$ m
averaged over x-y plane at $z=10.3$ km**

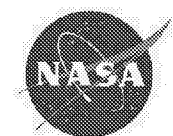


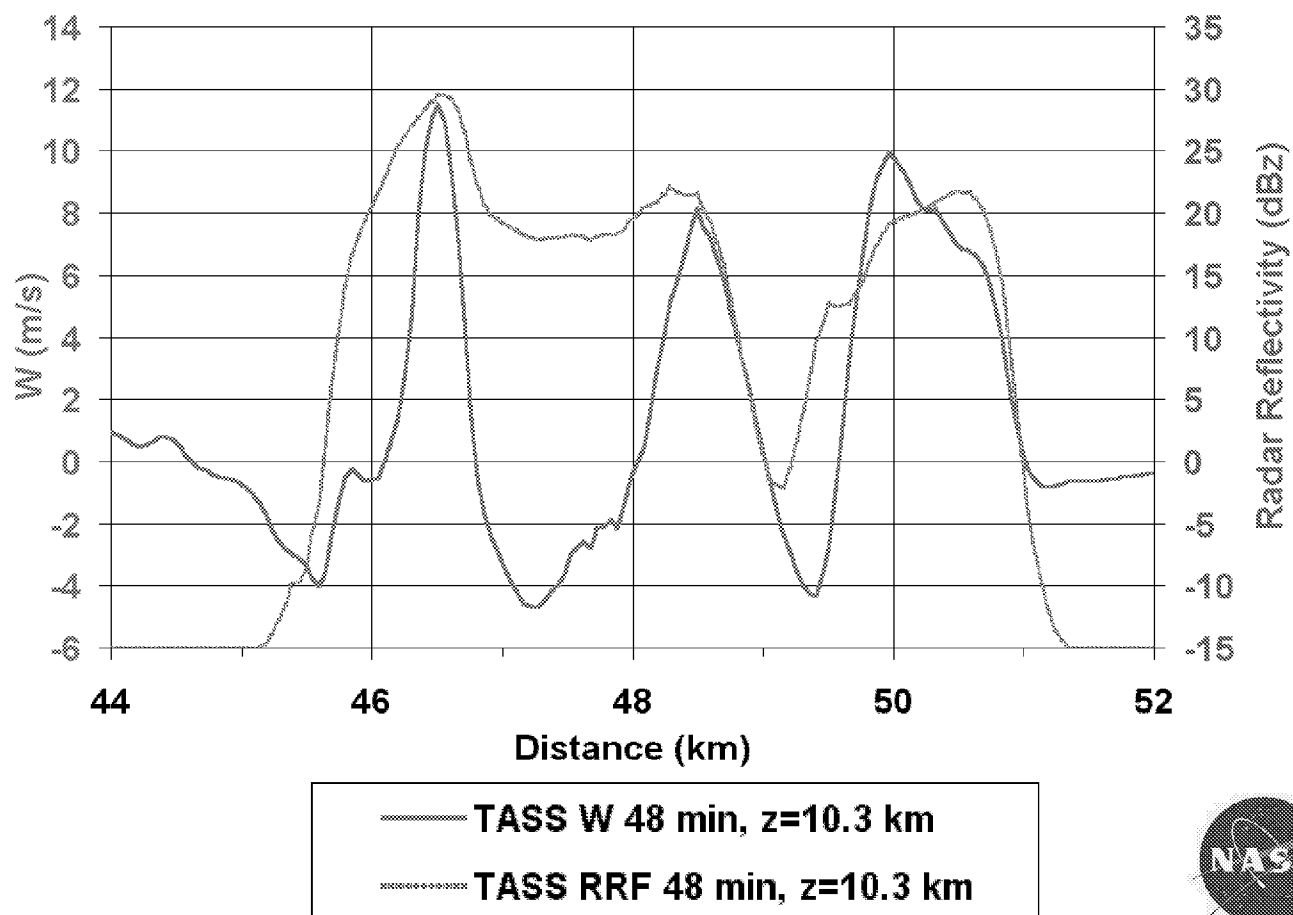
TASS Vertical Velocity every 1 m/s
T=48 min, Z=10.3km



Profile 2: Comparison of TASS with *In Situ*

— TASS W 48 min, $z=10.3$ km
... TASS RRF 48 min, $z=10.3$ km
— 100 m mov. avg (W (191-6 In Situ))



Profile 3: Comparison of TASS with *In Situ*

Summary

- **Observed Large-Scale Features Captured by 100 m Simulation, Although Details of Storm Structure Differ from Measurements**
- **Turbulence Associated with Buoyant Plumes in Upper-Levels of Storm**
- **Turbulence and Strong Vertical Velocity may Occur within Weak Radar Reflectivity**
- **Downdraft Regions may Contain Weaker Radar Reflectivity than Updraft Regions (at flight level)**



Future/Ongoing Work

- **Finer Grid Resolution Needed to Capture Important Scales of Motion that Affect Aircraft Normal Load Accelerations**
- **Data Set from this Case Delivered to NCAR for Addition of Small-Scale Karman Turbulence**
- **A Nested-Grid with Grid Size of 25 m to be Applied in Future Simulation**

