Workshop on Atmospheric Dispersion Modeling

Session II

Capabilities

Forecasting Toxic Hazards in Support of Space and Missile Operations at the Eastern and Western Ranges

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Models Currently Used for Operations

- **Rocket Exhaust Effluent Diffusion Model (REEDM) V7.09**

  Used for hot spills

    Normal Launch Applications

    Launch Abort Applications

    Rocket motor test firing

  History

    Development began at MSFC in late 1960's

    Evolved from the NASA Multilayer Diffusion Model

    Initially used to support Space Shuttle launches from KSC

    Hypergolic Accident Release Model (HARM) incorporated into V7.00

    Since 1990, ACTA Inc. has maintained REEDM for use at the Ranges

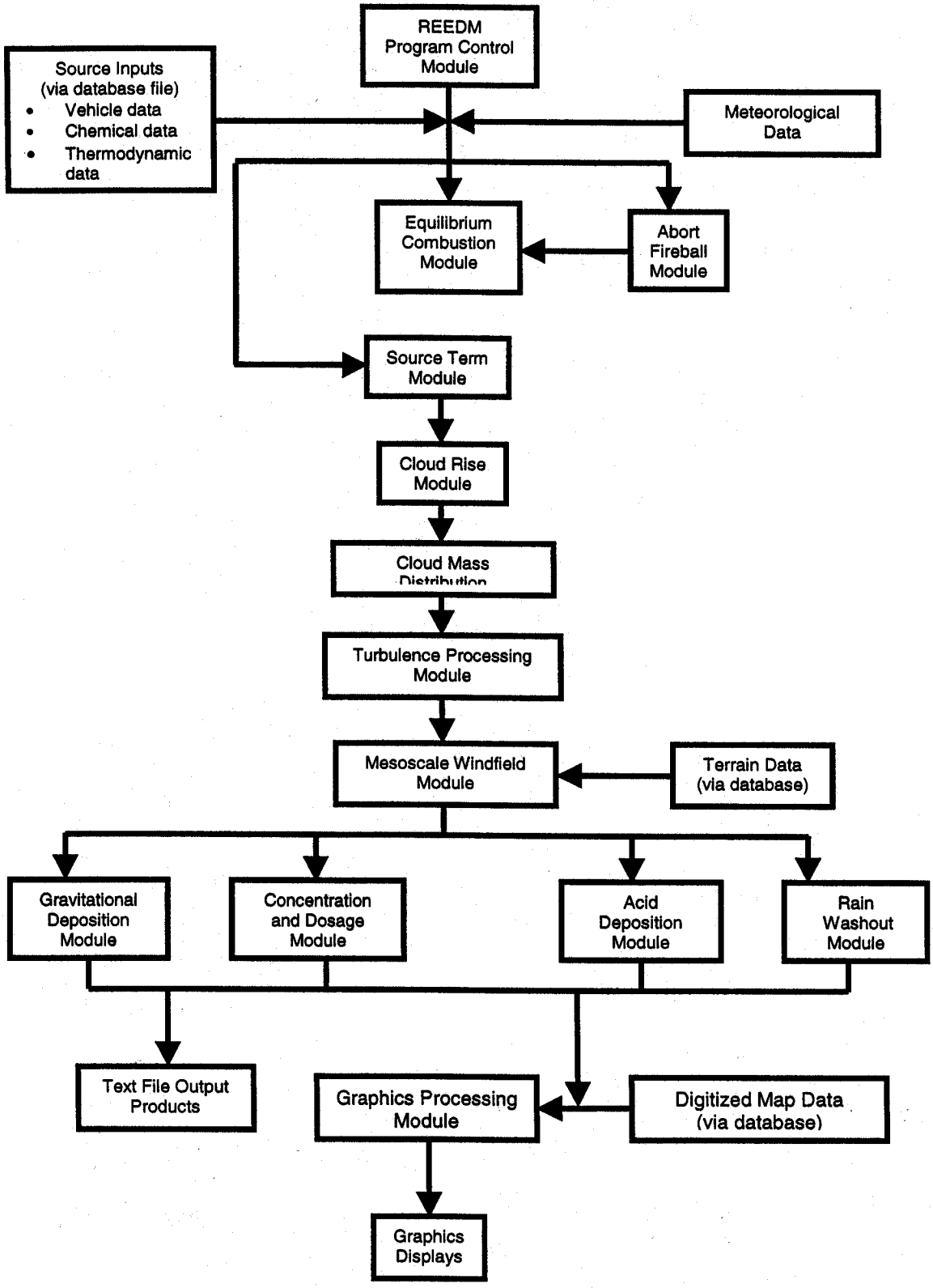
    Version 7.07 incorporated a NASA chemical equilibrium combustion model and an updated liquid propellant fireball model

    Current V7.09 revised aspects of REEDM cloud rise algorithms

Table 14-1. REEDM Input and Output File Types

File Type	Type	Default File Name	File Function
Database	Input	RDMBASE	Provide vehicle and site specific data
Chemical	Input	RDMCHEM*	Provide thermodynamic data for the REEDM combustion model
Weather	Input	RAWIND	Provide measured or forecasted weather data
Windfield	Input	none	Allows user to enter a previously generated REEDM windfield solution
Receptors	Input	none	Allows user to define discrete receptor locations
Turbulence	Input	none	Allows user to directly enter turbulence data corresponding to each meteorological level in the Weather input file
Results	Output	RMPRINT	Lists tabular summary of model results
Hazard	Output	REEDSUM*	Provides a 1 to 2 page short summary of the input meteorological data, peak concentration/dosage, and hazard zone parameters
Plots	Output	none	Techtronics format plotter instruction file
Windfield	Output	none	Allows user to save wind vector data at the REEDM terrain grid points (allows the user to run multiple source term scenarios for the same meteorological input without having to rerun the windfield solution each time)
Source	Output	SOURCE.RDM*	Provides a listing of the stabilized cloud disks along with their position, size, and mass composition (used to initialize other dispersion models that lack a buoyant plume rise capability)

* These file names are fixed and cannot be interactively changed by the REEDM user.


REEDM
Program Control
Module
Source Inputs
(via database file)
• Vehicle data
• Chemical data
• Thermodynamic data
Meteorological
Data
Equilibrium
Combustion
Module
Abort
Fireball
Module
Source Term
Module
Cloud Rise
Module
Cloud Mass
Distribution
Turbulence Processing
Module
Mesoscale Windfield
Module
Terrain Data
(via database)
Gravitational
Deposition
Module
Concentration
and Dosage
Module
Acid
Deposition
Module
Rain
Washout
Module
Text File Output
Products
Graphics Processing
Module
Digitized Map Data
(via database)
Graphics
Displays

Models Currently Used for Operations

- **Eastern Range Dispersion Assessment System (ERDAS)**

  Regional Atmospheric Modeling System (RAMS) Model
  Hybrid Particle and Concentration Transport (HYPACT) Model

  Data obtained at 0000 and 1200 UTC

    12-h forecast from Eta model
    Rawinsondes, surface stations & buoys
    Local wind towers
    5 local 915 MHz & 1 local 50 MHz DRWP

  Isentropic analysis using Barnes scheme

  24-h RAMS forecasts generated

  Hourly forecast output available

Models Currently Used for Operations

- **ERDAS RAMS Configuration**

  4 nested grids (2-way interactive on grids 2, 3, 4)

  Full microphysics on grids 1-4

  Kuo-type cumulus parameterization on grids 1-3

  3D non-hydrostatic

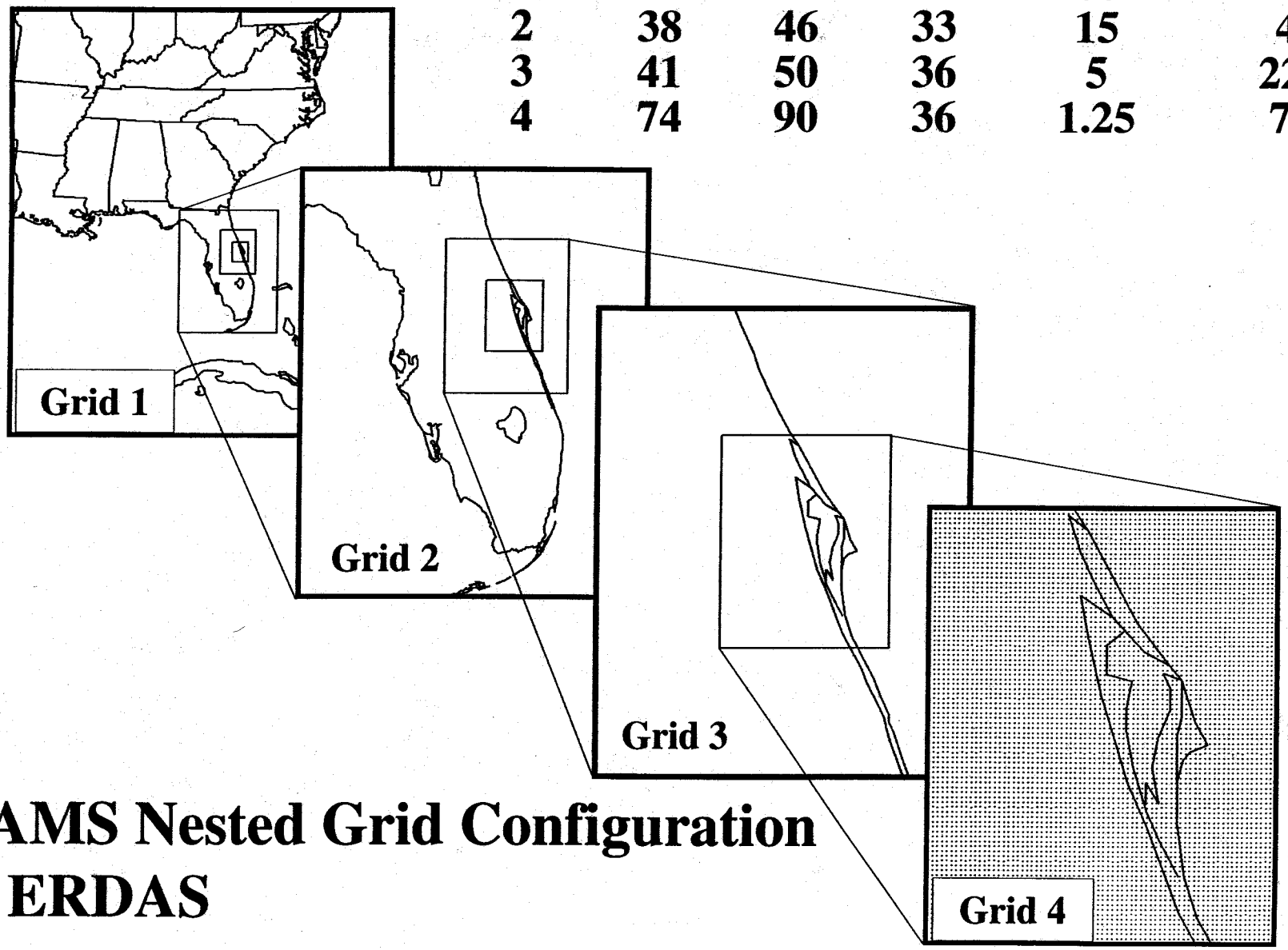
  Mellor-Yamada TKE

  Chen and Cotton radiative parameterization

  Vegetation temperature / moisture model (11 soil layers - fixed initial soil moisture)

  Lateral BC: nudged by 12-36 h Eta forecasts

Grid	nx	ny	nz	dx (km)	dt (s)
1	36	40	33	60	45
2	38	46	33	15	45
3	41	50	36	5	22.5
4	74	90	36	1.25	7.5



RAMS Nested Grid Configuration in ERDAS

Models Currently Used for Operations

- **Hybrid Particle and Concentration Transport Model (HYPACT)**

  Tracks a large set of particles as they are advected through a spatially and temporally varying wind field

  Dispersive effects of small scale eddies included by adding a random, turbulent component to the wind

  Can handle complex 3-D wind fields

  Can use observed winds blended with RAMS predicted winds

  Can disperse stabilized abort cloud source term provided by REEDM

  ERDAS provides excellent graphics for viewing 3-D plume structure

Models Currently Used for Operations

- **Ocean Breeze/Dry Gulch (OB/DG) Model**

  Restricted to cold spills (no fire or explosion)

  Depends on OB/DG diffusion prediction equation

    Empirical statistical best fit to tracer data

    Tracer data collected from Ocean Breeze (Cape Canaveral, FL), Dry Gulch (Vandenberg AFB, CA), and Prairie Grass (O'Neill, NB) tests

  Equation solved for downwind distance to exposure limits

  Concentrations assume a Gaussian distribution in the cross-wind direction

  Assumes a fixed constant evaporation rate for each chemical class

Models Currently Used for Operations

- **Air Force Toxic Chemical Dispersion Model (AFTOX)**

  Used only at the Western Range

  A Gaussian puff model

  Can calculate 3-D concentration field

  Can account for buoyancy effects in an elevated plume

  Can simulate the reflection of a plume trapped below an inversion

  Mean wind concept still used

Range Dispersion Monitoring System (RDMS)

- **Ranges need a real-time RDMS**

  Purpose

    Observe actual toxic cloud location and concentration
    Predict future location and concentration of the cloud
    Fully validate and refine current predictive models

  Possible Components

    Remote Sensing
      Radar
      Lidar
      Cameras (visible and IR)

    In-Situ Measurements
      Ground-based fixed or mobile sensors
      Airborne sensors

- **Current limited capability from WSR-88D weather radar**

RADAR DESCRIPTION

- Weather Surveillance Radar 1988-Doppler (WSR-88D), also known as NEXRAD

  -- S-band wavelength 10.7 cm
  -- Operating power 750 kW, peak power 1 MW
  -- Parabolic antenna 28 ft diameter
    --- Produces a 1 degree conical beam
    --- Maximum speed of rotation 5 rpm
    --- Predetermined elevation steps depend on mode of operation
  -- Two modes of operation
    --- Storm mode to detect precipitation
      ---- Antenna turns rapidly
      ---- Elevation steps 0.5 to 19.5 degrees
      ---- Full volume scan cycle takes 5-6 minutes
    --- Clear-air mode when no precipitation is within range
      ---- Antenna turns more slowly
      ---- More powerful pulse of energy
      ---- Elevation steps limited to 0.5, 1.5, 2.5, 3.5, and 4.5 degrees
      ---- Full volume scan cycle takes 10 minutes

- WSR-88D in Melbourne, FL detected the abort plume from the Delta rocket failure at Cape Canaveral on 17 Jan 97

DELTA II ABORT

- Vehicle exploded at 1438 feet altitude after 12.5 seconds of nominal flight on 17 Jan 97

- Stages 2, 3 and payload drifted to 2500 feet before command destruct

- Abort cloud components

  -- Upper portion formed by second-stage hypergolic fuel
  -- Lower portion formed by
    --- Nominal launch plume
    --- Burning SRM fragments which fell back to the ground
    --- Remains of first-stage RP-1 fuel (which mostly vaporized)
    --- Debris particles from the explosion

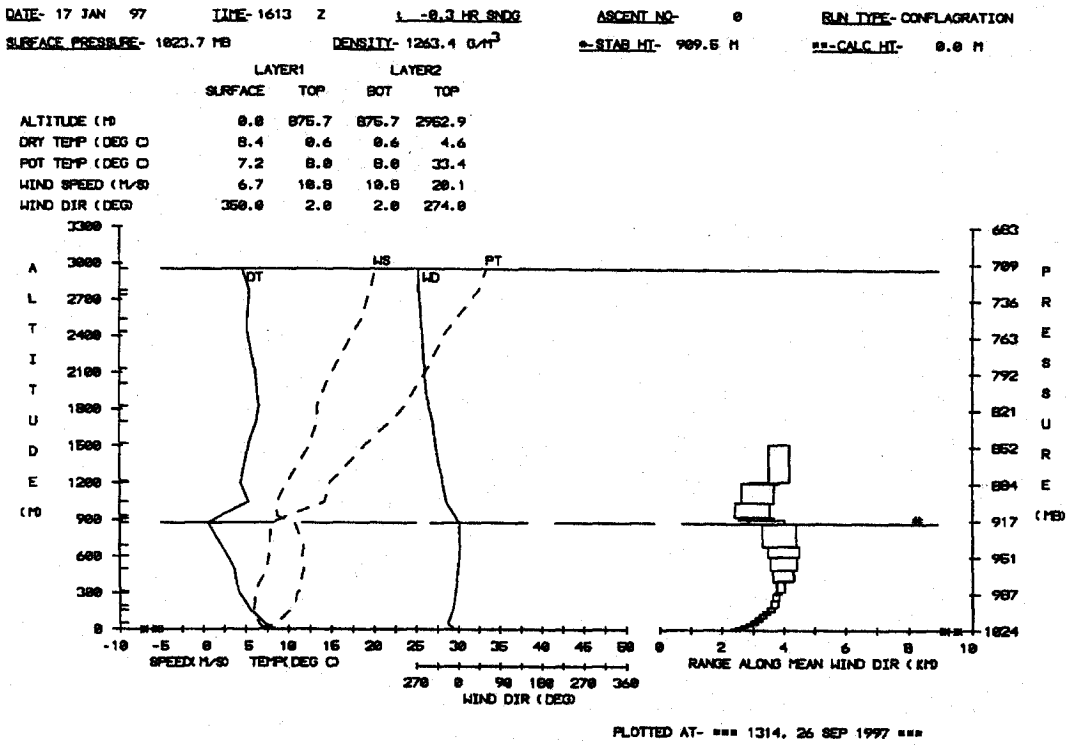


Figure 1: REEDM meteorological summary plot 1613 Z, 17 January 1997.

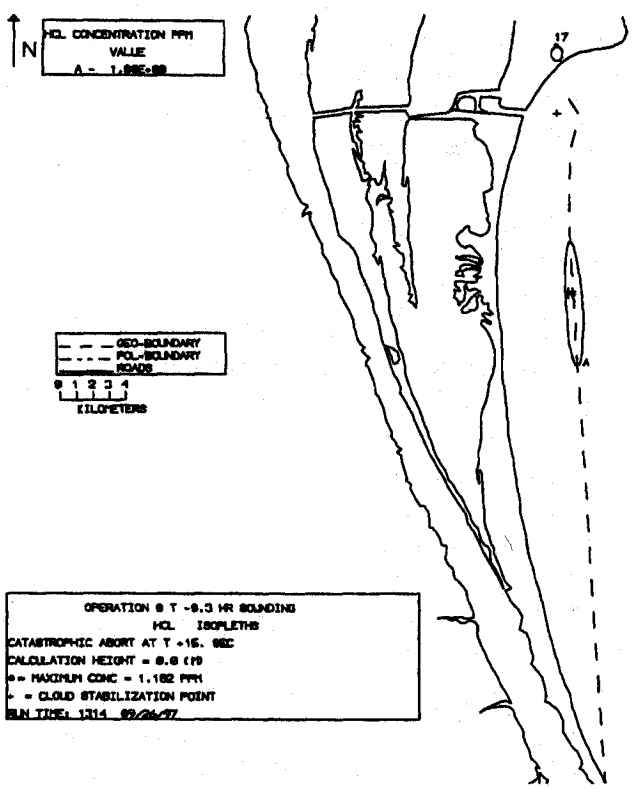


Figure 2: REEDM plume track and ground-level concentration of HCl from Delta II failure.

RADAR RETURNS FROM DELTA II ABORT

- Radar in clear-air mode
- Scan at 0.5 degrees ended prior to launch and showed no echoes over Cape Canaveral
- Scan at 1.5 degrees starting at 1628 Z (1128 EST) detected the initial abort cloud
- Higher elevation scans show rapid evolution of the cloud
- Scan at 4.5 degrees shows separate echoes

  -- Cloud below inversion moving south
  -- Cloud above inversion moving southeast

- After 30 minutes the strongest echo near PAFB, 11 nm from CX-17A
- Cloud tracked for more than 4 hours
- No HCl concentrations determined

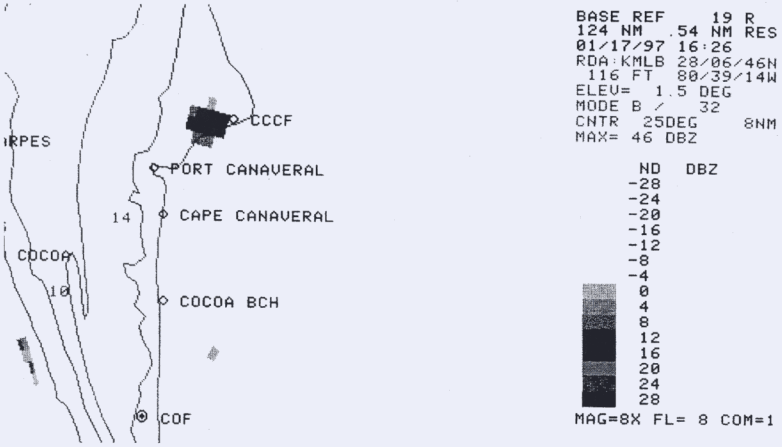


Figure 3: Radar image of abort cloud over CX-17A immediately after abort.

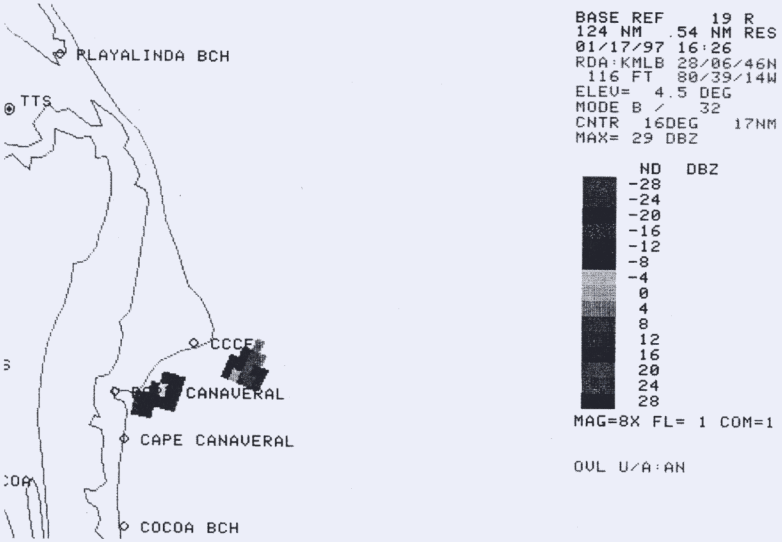


Figure 4: Radar image of abort clouds 6 minutes after abort.

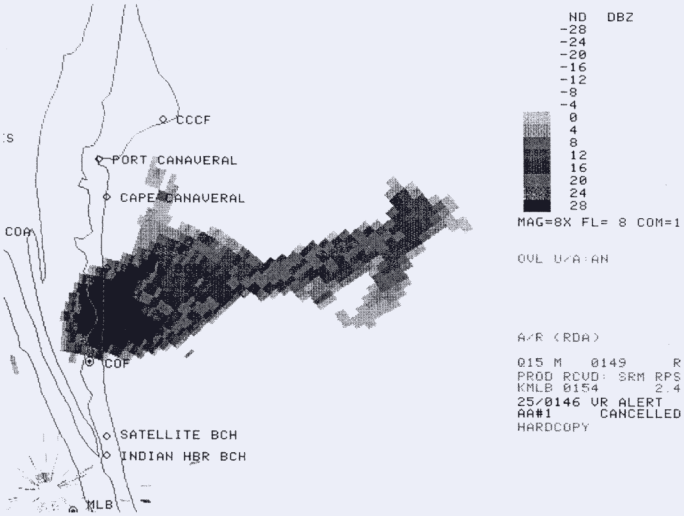


Figure 5: Delta rocket abort cloud 30 minutes after abort.

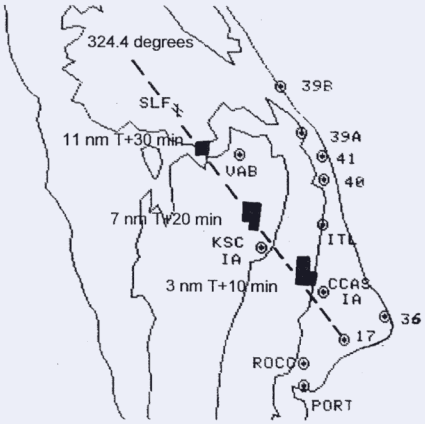
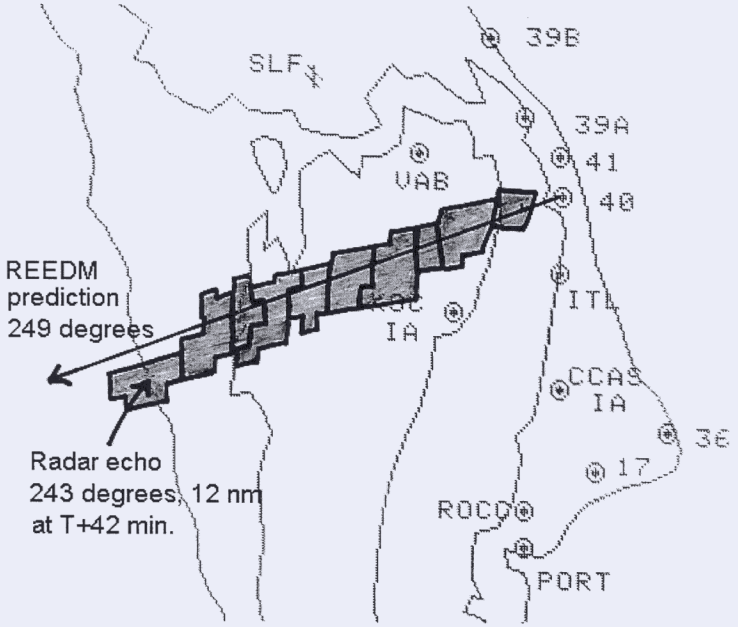


Figure 6: Radar positions of a Delta II normal launch cloud overlaid on REEDM predicted track.

NOMINAL LAUNCH CLOUDS

- Nominal launch clouds do pose a possible toxic threat
  - -- REEDM has predicted HCL > 100 ppm
- Radar track of nominal launch clouds examined after Delta II abort cloud detected
- Delta II launch cloud tracked for 30 minutes on 23 Jul 97
- Titan IVB launch cloud tracked for more than 42 minutes on 15 Oct 97
- Most other vehicle launch clouds tracked since then
  - -- Average track 16 minutes
  - -- Average distance 8.9 km
- Good agreement between radar position and REEDM prediction
  - -- Average difference 9.4 degrees in direction and 1.1 km in distance



Radar positions of a Titan IVB normal cloud overlaid with REEDM predicted track

Model Evaluation Efforts

- **Air Force Model Validation Program (MVP)**

  SF_6 tracer release sessions

    Three sessions at Cape Canaveral (Jul 95, Nov 95, Apr-May 96)

    One session at Vandenberg AFB (May 97)

    Surface and elevated (from blimp) tracer release

    Fixed and mobile surface samplers, aircraft sampling aloft

    Extensive meteorological data collection

  Launch plume imaging

    Multiple IR camera locations

    Track plume rise and dispersion

    Determine cloud stabilization altitude

    Estimate air entrainment rate

  Launch plume HCl measurements by Geomet instrumented aircraft

Model Evaluation Efforts (AMU)

- **NASA/KSC's Applied Meteorology Unit**

AMU evaluated prototype ERDAS RAMS

Recommended changes included in current ERDAS

RAMS model upgrade
Finer resolution on inner forecast grid
Full cloud microphysics

AMU evaluating current ERDAS to validate new configuration

Objective component (May – August 1999)

Point verification of 4-grid RAMS configuration
Bias, RMS Error, Standard Deviation of error
T, T_d, Wind direction & Speed
All available observational data on grid 4
Surface land, buoy, & rawinsonde sites on grids 1-3

Model Evaluation Efforts (AMU cont.)

Subjective Component (grid 4 only)

Central Florida east coast sea breeze (May – Aug 1999)

Occurrence, onset & propagation (13 local wind towers)
Compare with RAMS forecasts at 13 wind towers

Precipitation verification

Occurrence (Doppler radar 1-h rain rates)
Compare with forecast rain (any measurable rain in model)

Initial Results

Temp. & Dew point: Cool, dry daytime bias, RMS Error 4.5 °C
Wind Dir: 50-70° RMS error, Unbiased
15-20° observational variability (Merceret 1995)
Largest during nighttime hours (light wind regimes)
Smallest error during quiescent regimes
10-15° model error, Post sea breeze ~ 30°
Anomalous precipitation forecasts → Large wind errors
Wind Speed: Positive bias in 4-grid forecasts
RAMS: Excellent in forecasting onset and movement of sea breeze

Model Evaluation Efforts (AMU cont.)

Future work

1999-2000 cool-season verification

- Cold fronts and associated precipitation
- Low temperatures and low-level inversions

2000 warm-season evaluation

- First thunderstorm of the day
- Additional sea breeze verification
- Precipitation verification