# MMS MODEL DEVELOPMENT STUDY

## Development of the Next Generation Air Quality Models for Outer Continental Shelf (OCS) Applications

**SAC Meeting**

**June 1-2, 2005**

**The Woodlands, Texas**

*Earth Tech, Inc.*
*196 Baker Avenue*
*Concord, Massachusetts 01742*

# Introduction

- Air Quality Model Development for Outer Continental Shelf (OCS) Applications
  - Develop a generalized regulatory model for evaluating air quality impacts from sources located on federal waters on the OCS
    - Short-range (tens of meters) and long range transport (several hundred km)
    - Offshore and coastal impacts
    - Averaging times from 1-hour to one year
    - Criteria pollutants ($SO_2$, $NO_x$, CO, $PM_{10}$), toxic pollutants, sulfate and nitrate (visibility)

# Study Objectives

- Review of existing puff models
- Revise and enhance existing air quality model
  - Easy of use
  - Technical Enhancements
- Conduct sensitivity testing and evaluate model performance
- Develop and package software and documentation

# Overview

- Improvements in datasets for OCS applications
  - Enhanced interface (MM5) and new interfaces (RUC, NAM/Eta, RAMS)
    - 3d and 2d datasets
  - High resolution SST data
  - Standard 1-year MM5 meteorological dataset

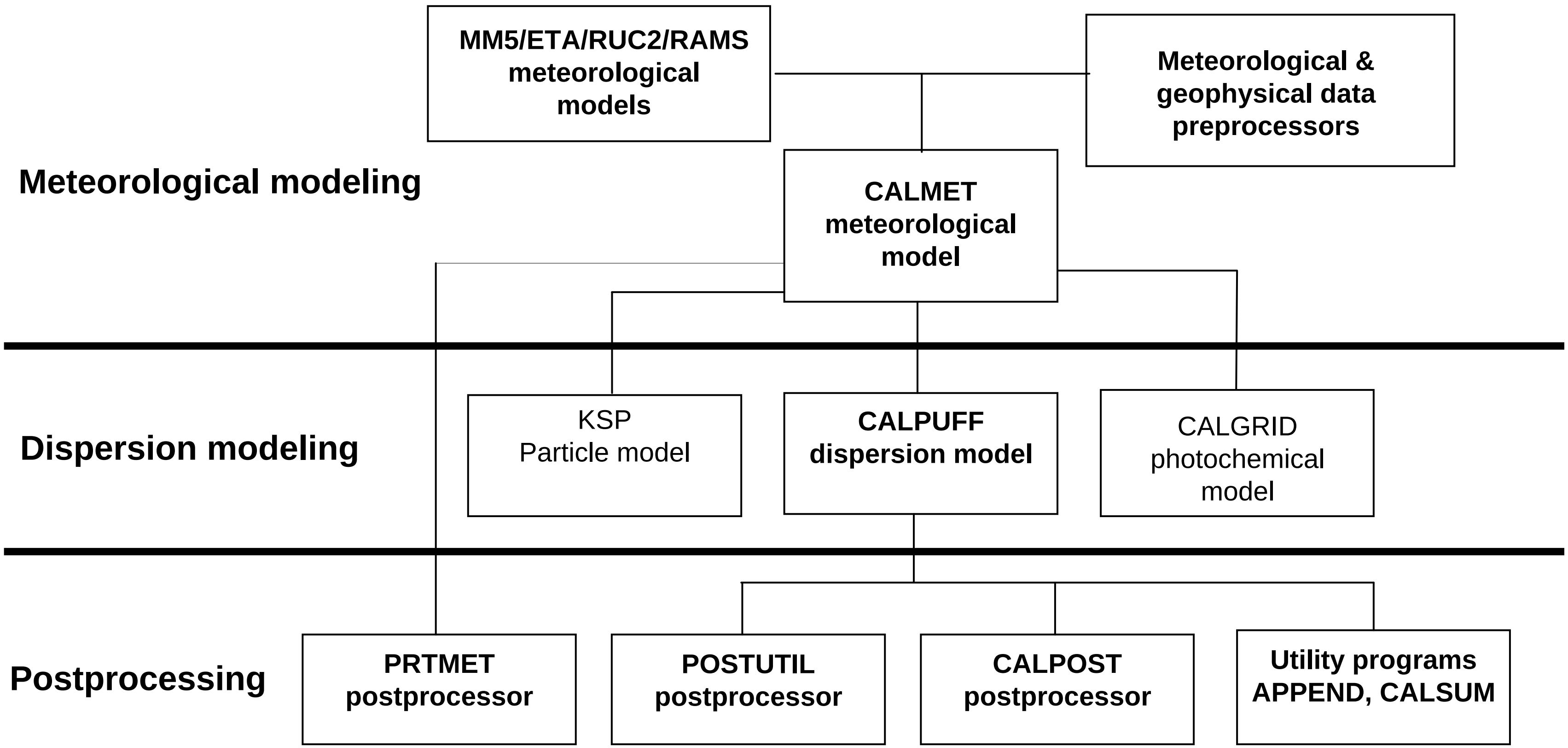
- Ease-of-use enhancements
  - Graphical User Interfaces
  - Graphics – vectors, isopleths, animations

- Technical enhancements to CALPUFF modeling system
  - COARE algorithms
  - Improve mixing height algorithm over water including buoyancy effects
  - Option for AERMOD-like turbulence profiles
  - Subgrid-scale coastline treatment and TIBL growth
  - Non-Boussinesq numerical plume rise for all sources
  - Platform adjustments to building downwash algorithms

# Background

- CALPUFF is a Lagrangian, non-steady-state puff dispersion model
- Achieved status as a U.S. EPA *Guideline Model* (Federal Register, 15 April 2003)
- Recommended by IWAQM (1998) for long-range transport applications
- Recommended by FLAG (2000) for Class I impact assessments and air quality related value impact evaluation

# CALPUFF Modeling System



# CALMET Model

- CALMET boundary layer modules
  - Computes mixing heights, surfaces fluxes, stability and turbulence fields
  - Overland PBL model uses an energy balance approach
  - Overwater PBL model uses a profile method

- CALMET 3-D diagnostic wind field module
  - Uses observations and/or gridded prognostic meteorological fields
  - Wind fields adjusted for fine-scale terrain effects and mass-consistency
    - Slope flows, kinematic effects, terrain blocking effects
    - Divergence minimization
    - Objective analysis procedure to assimilate observational data

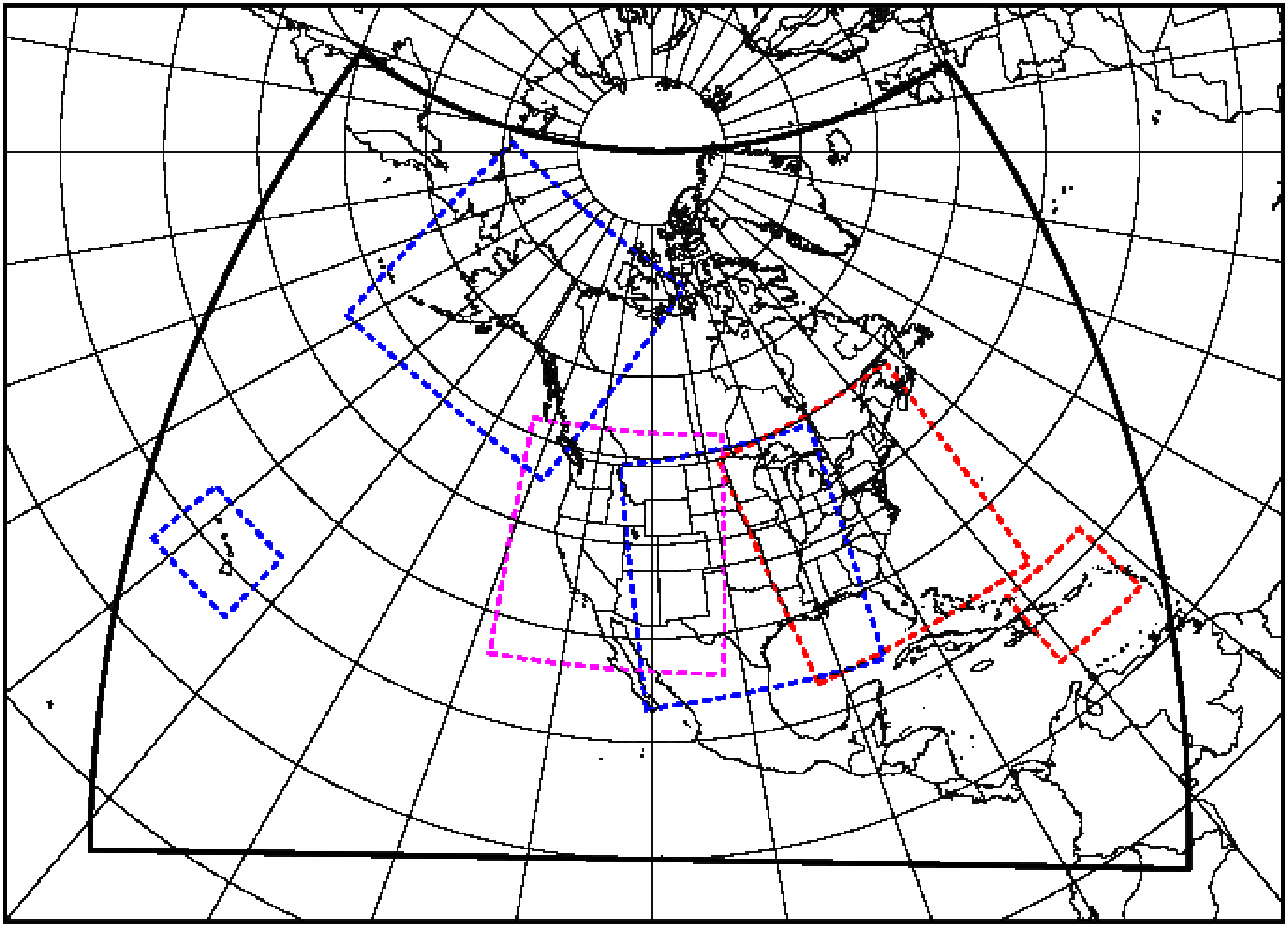
# Improvements in Datasets

- High resolution satellite data in defining SST
- Prognostic model to define conditions, especially in data sparse offshore areas
- Gridded air-water temperature structure (gridded SEA.DAT file)
- Introduction of "no-observations" mode in CALMET
  - Closer coupling of CALMET with prognostic meteorological models
- New interfaces to additional prognostic models such as RUC, NAM/Eta, RAMS in addition to MM5

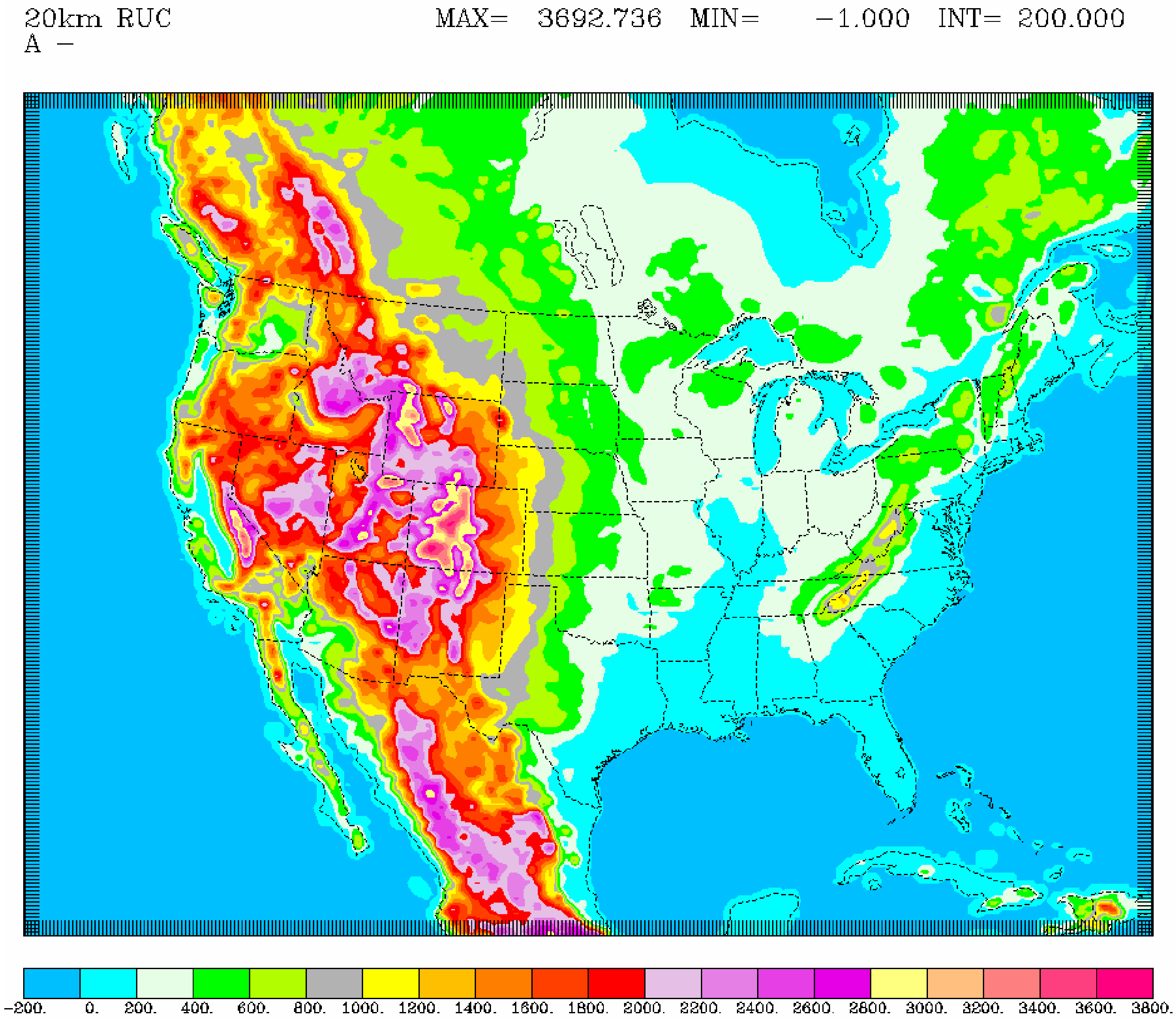
# Standard Meteorological Dataset

- Standard dataset for regulatory applications
  - Consistency of meteorological fields across applications
  - Substantial savings of effort
  - Evaluated dataset with known performance
- MM5 dataset being developed by Penn State under separate MMS contract for the GOM area
  - One year period (Oct 1, 2000 – Sept 30, 2001)
  - Three nests: 36km, <u>12km</u> and 4km nests
  - Using high resolution SST data
- Additional years with MM5 or output from other models
  - New programs developed to interface CALMET to RUC, Eta and RAMS

# NAM (Eta) Modeling Domains



# RUC Modeling Domain

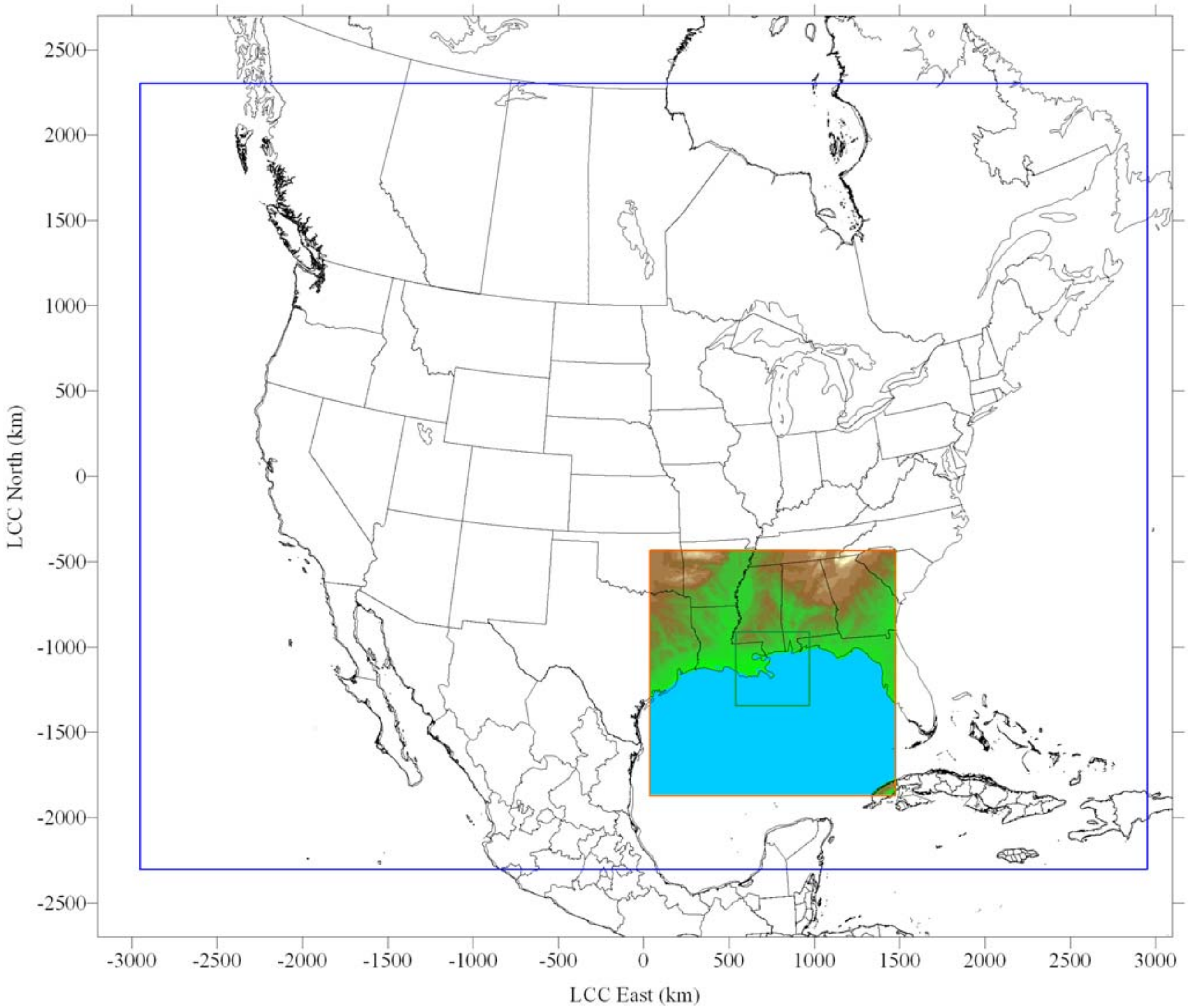


# Summary of Eta/RUC Operational Runs

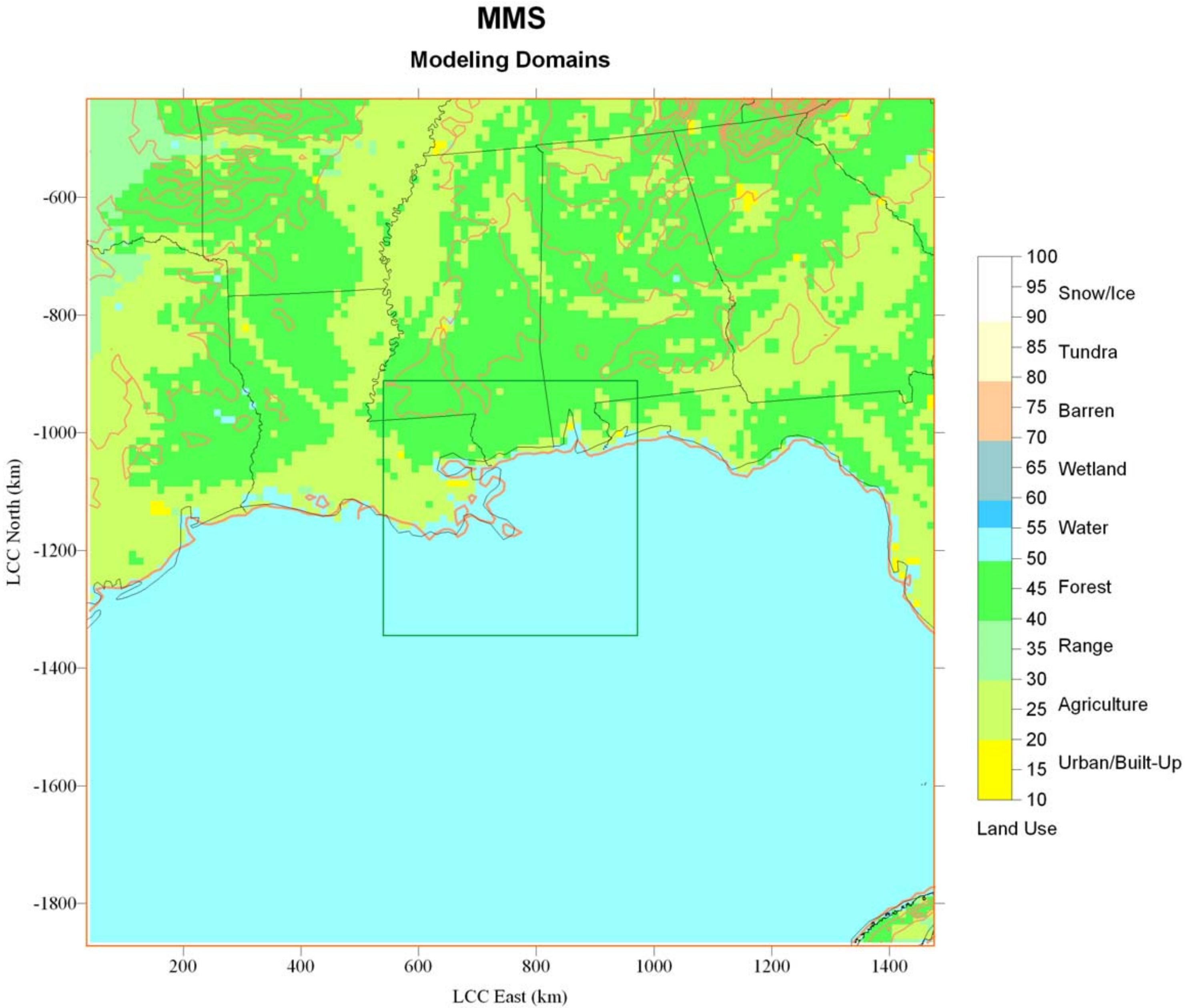
| Model | Horizontal Resolution (km) | Vertical Resolution | Run Frequency | Output Interval | | Forecast Length |
|---|---|---|---|---|---|---|
| | | | | Analysis | Forecast | |
| ETA | 12 | 60 Levels | 4 per day | 6-hours | 3-hours | 84 Hours |
| ETA | 8 | 60 Levels | 4 per day | 6-hours | 3-hours | 48 Hours |
| RUC | 20 | 50 Levels | 24 per day | 1-hour | 1-3 hour | 12-Hours |

# MMS

## Modeling Domains




(LCC Origin Lat. = 40.0 N, Origin Lon. = 97.0 W, Parallel 1 = 33.0 N, Parallel 2 = 45.0 N, Datum = WGS-84)




(LCC Origin Lat. = 40.0 N, Origin Lon. = 97.0 W, Parallel 1 = 33.0 N, Parallel 2 = 45.0 N, Datum = WGS-84)

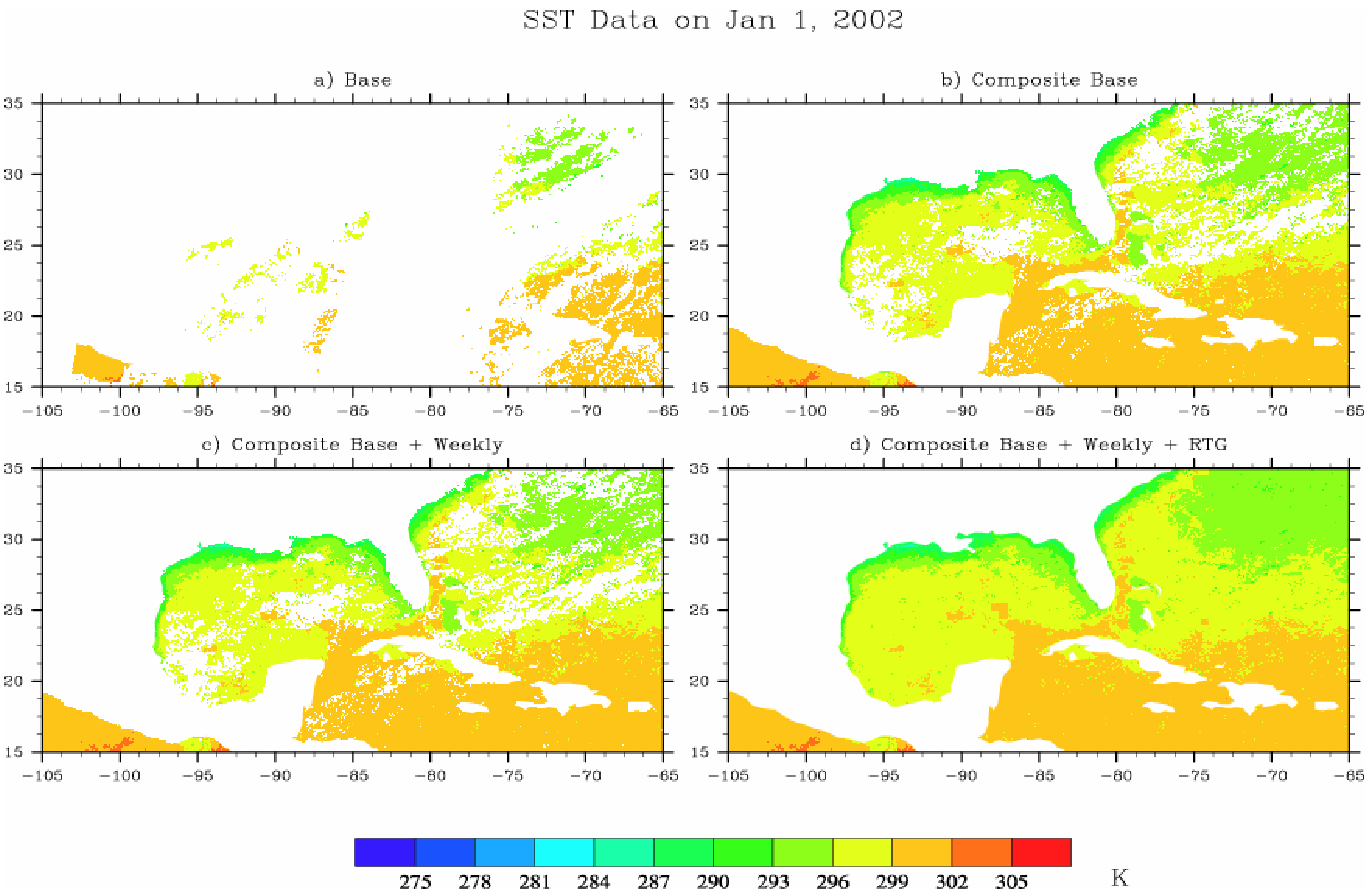
# Satellite SST Datasets

- Final Analysis Data (FNL)
  - 1 deg x 1 deg data
  - Available 4 times daily
  - Data assimilation
- Real-time, global SST Analysis (RTG)
  - 0.5 deg x 0.5 deg
  - Available daily
  - Analysis of satellite measurements, surface obs and interpolation
- Moderate Resolution Imaging Spectroradiometer (MODIS)
  - 4km data
  - Daily and weekly
  - Satellite measurements

# Development of MODIS SST Dataset

- Any given satellite pass has potentially large amounts of missing data due to clouds
- Procedure being tests:
  - Base:  Satellite data for Day: n
  - Composite: Fill missing cells iteratively with data for day n+1, n-1, n+2, n-2, n+3, n-3
  - Composite + weekly: Fill missing cells with data from weekly MODIS dataset
  - Composite + weekly + RTG: Fill any remaining missing data with daily RTG data

# Illustration of Steps in Developing SST Dataset



# Evaluation of MM5 Performance

- Conducted by Penn State
- Initial results presented in Jan 2005 for three model configurations
  - Analysis nudging, RTG SST data
  - Observations nudging added
  - Obs nudging + 4-km MODIS SST data
- Results indicated improvements in both winds and temperature fields as obs nudging added and again when high resolution SST data added
- Evaluation is ongoing

# Convective Boundary Layer

- New convective mixing height  parameterization:
  - Batchvarova and Gryning (1990, 1994)

- 2 options overland:
  - Maul-Carson (original)  (when positive buoyancy flux)
  - Batchvarova and Gryning (when positive buoyancy flux)

- 3 options over water:
  - Mechanical OCD always
  - Maul-Carson (original)  (when positive buoyancy flux)
  - Batchvarova and Gryning (when positive buoyancy flux)

- Above convective mixing height lapse rates:
  - Land: observed ( UP.DAT soundings)  or prognostic (e.g. MM5)
  - Water: observed (SEA.DAT or constants) or prognostic (e.g. MM5)

# New convective boundary layer input parameters

- IMIXH : convective boundary layer parameterizations
  - 1: Maul-Carson for land and water cells
  - -1: Maul-Carson for land cells only – Original OCD mixing height overwater (old CALMET)
  - 2: Batchvarova and Gryning for land and water cells
  - -2: Batchvarova and Gryning for land cells only - Original OCD mixing height overwater

- THRESHW: threshold buoyancy energy flux per meter of marine boundary layer required for boundary layer growth over water (default: 0.05 $W/m^2$ /m)

- THRESHL: threshold buoyancy energy flux per meter of land boundary layer required for boundary layer growth over land (default: 0.05 $W/m^2$ /m)

- ITWPROG: overwater lapse rates above the current OW mixing height
  - 0 : use SEA.DAT air/sea temperatures and lapse rates for the marine BL growth
  - 1 : use SEA.DAT air/sea temperatures and MM5 lapse rates

# CALPUFF UPGRADES

- Building downwash adjustment for elevated (platform) structures with an open area between the surface and the bulk of the structures. Currently implemented for ISC downwash.
- Option for computing gridded turbulence profiles using the AERMOD subroutines.
- Option to specify Lagrangian time-scale for lateral plume growth functions
- AERMET version of SURFACE and PROFILE met data files
- Numerical plume rise for hot plumes (e.g., flares)

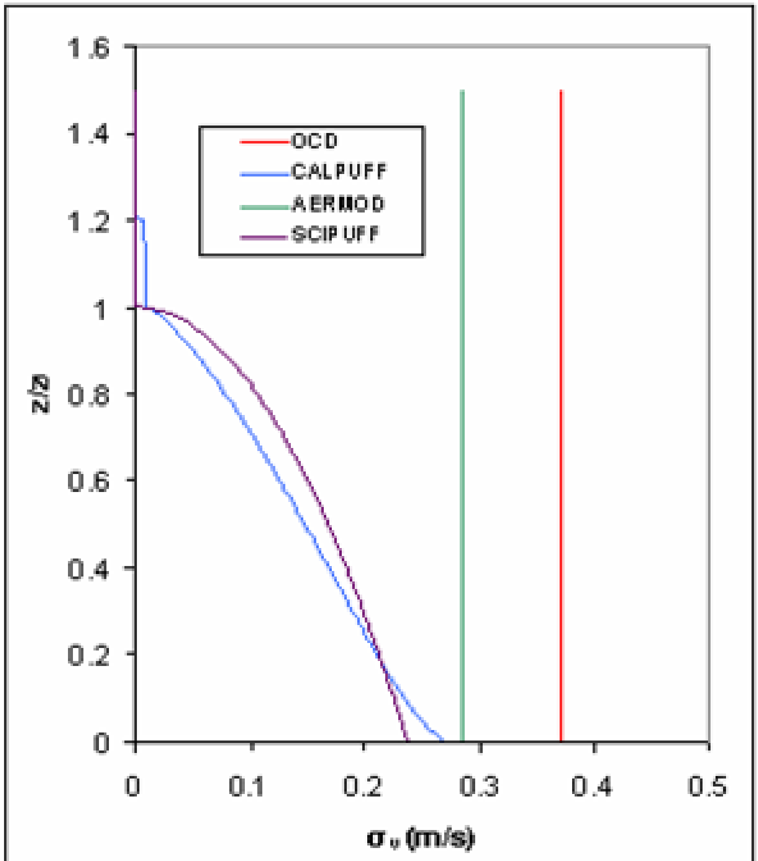
# AERMOD Turbulence Option

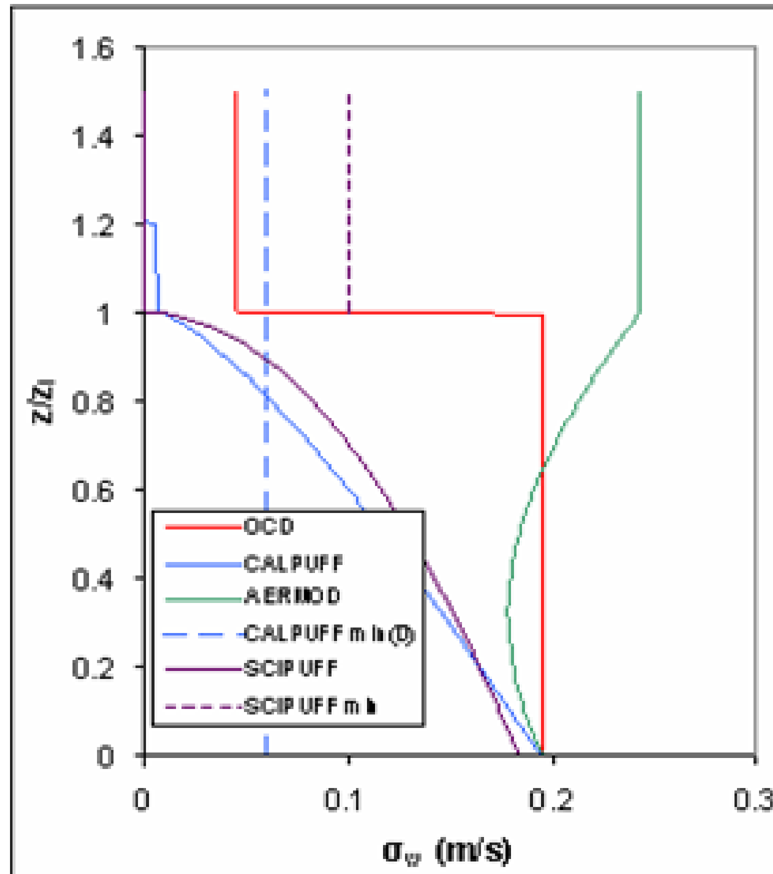
- Compared OCD, CALPUFF, SCIPUFF and AERMOD algorithms for computing profiles of sigma-v and sigma-w from surface layer parameters
  - CALPUFF and SCIPUFF include similar vertical structure within the surface layer;  AERMOD and OCD use constant sigma-v(z)
  - AERMOD includes a residual sigma-w aloft for the stable BL
  - Include option for AERMOD profiles

- New control file variable to allow switching of turbulence schemes from standard CALPUFF scheme to AERMOD scheme
  - Method used to compute turbulence sigma-v & sigma-w using micrometeorological variables  (MCTURB)
  - 1 = Standard CALPUFF subroutines
  - 2 = AERMOD subroutines

# AERMOD Turbulence Option

(Example for L=50 m, u_star=0.15 m/s)



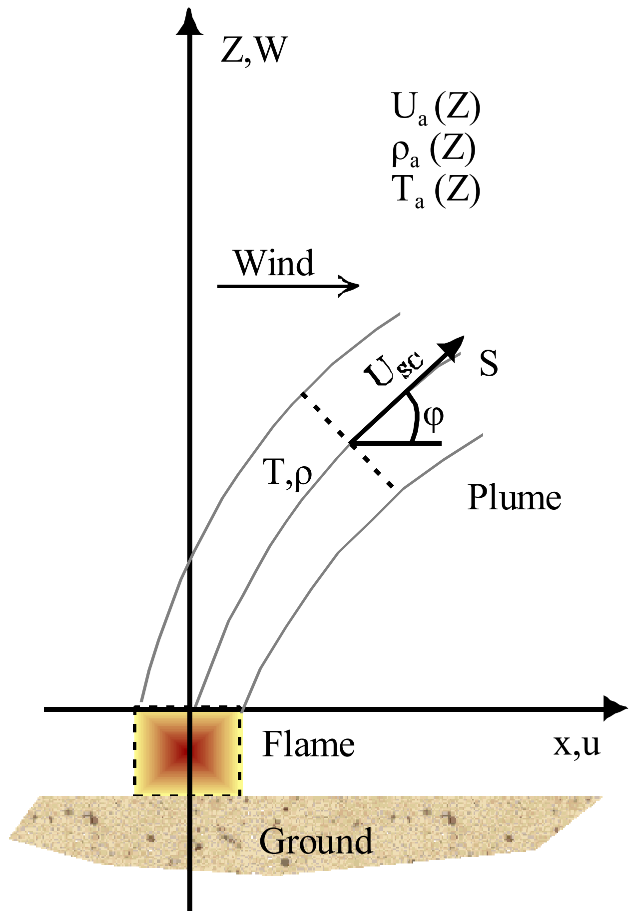
# Numerical Plume Rise

- Numerical solution to conservation and state equations in non-Boussinesq form (used for high temperature sources such as flares or fires)

- Initial properties at release
  - temperature
  - effective vertical velocity
  - effective radius

- Explicitly accounts for vertical structure of atmosphere
  - wind speed profile
  - wind direction profile
  - temperature (density) profile

# SCHEMATIC FOR A PLUME IN A CROSSWIND



# Numerical Plume Rise Conservation Eqns

- Mass

$$\frac{d}{ds}(\rho u_{sc} r^2) = 2r\alpha\rho_a\left|u_{sc} - u_a\cos\phi\right| + 2r\beta\rho_a\left|u_a\sin\phi\right|$$

- Momentum - along-wind

$$\frac{d}{ds}(\rho u_{sc} r^2 (u - u_z)) = -r^2\rho w\frac{du_a}{dz}$$

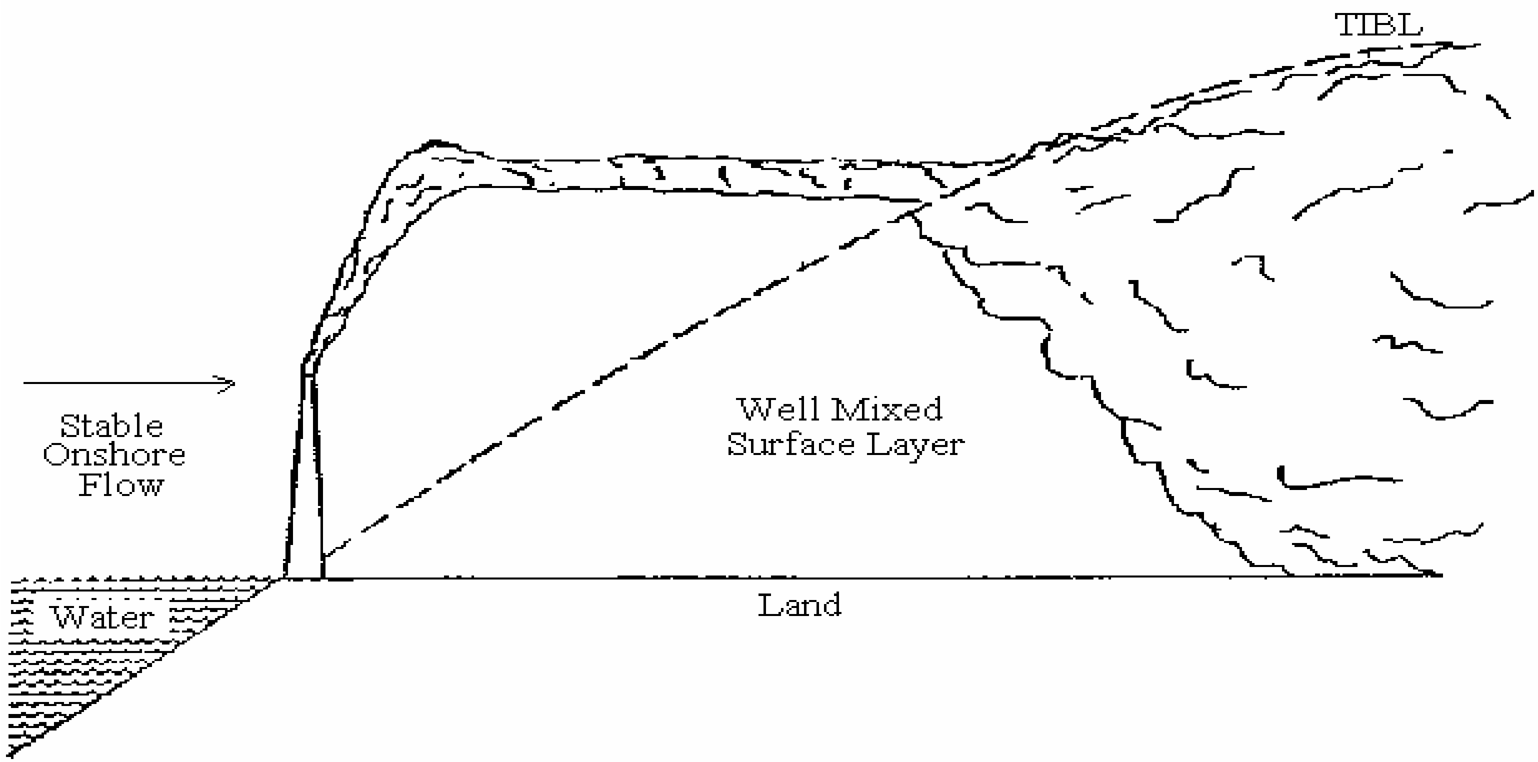
- Momentum – vertical

$$\frac{d}{ds}(\rho u_{sc} r^2 w) = g r^2 (\rho_a - \rho)$$

- Energy

$$\frac{d}{ds}\left[\rho u_{sc} r^2 (T - T_a)\right] = -\left(\frac{dT_a}{dz} + \frac{g}{c_p}\right)\rho w r^2 - R_p r\left(T^4 - T_a^4\right)$$

# Plume Fumigation



# TIBL

- OCD
  - Piece-wise linear mixed layer height is prescribed along the direction from the source to a receptor with distance measured from the coast
  - $h = 0.1\ x$ for $x \le 2000$m
  - $h = 200 + 0.03\ (x-2000)$ for $x \ge 2000$m)
  - Designed to approximate a generic TIBL without inputs for wind speed, heat flux, marine layer lapse rate

# TIBL

- CALMET
  - 2-Step mixing height procedure
  - (1) Gridded mixing height field computed using local grid-cell properties
  - (2) Advective averaging scheme controlled by user inputs smoothes transitions by averaging heights along flow
  - Provides robust treatment of coastal-zone transitions, recognizing difference in along-shore / on-shore / off-shore situations

# TIBL

- CALPUFF
  - Sub-grid TIBL option refines the gridded mixing height structure in coastal zones using the TIBL model of Garrett (1992)

$$\frac{dh}{dx} = \frac{(1 + 2\beta)H}{\gamma \rho c_p u h}$$

  - Model is applied along the puff trajectory using local grid cell properties.
  - For steady conditions,

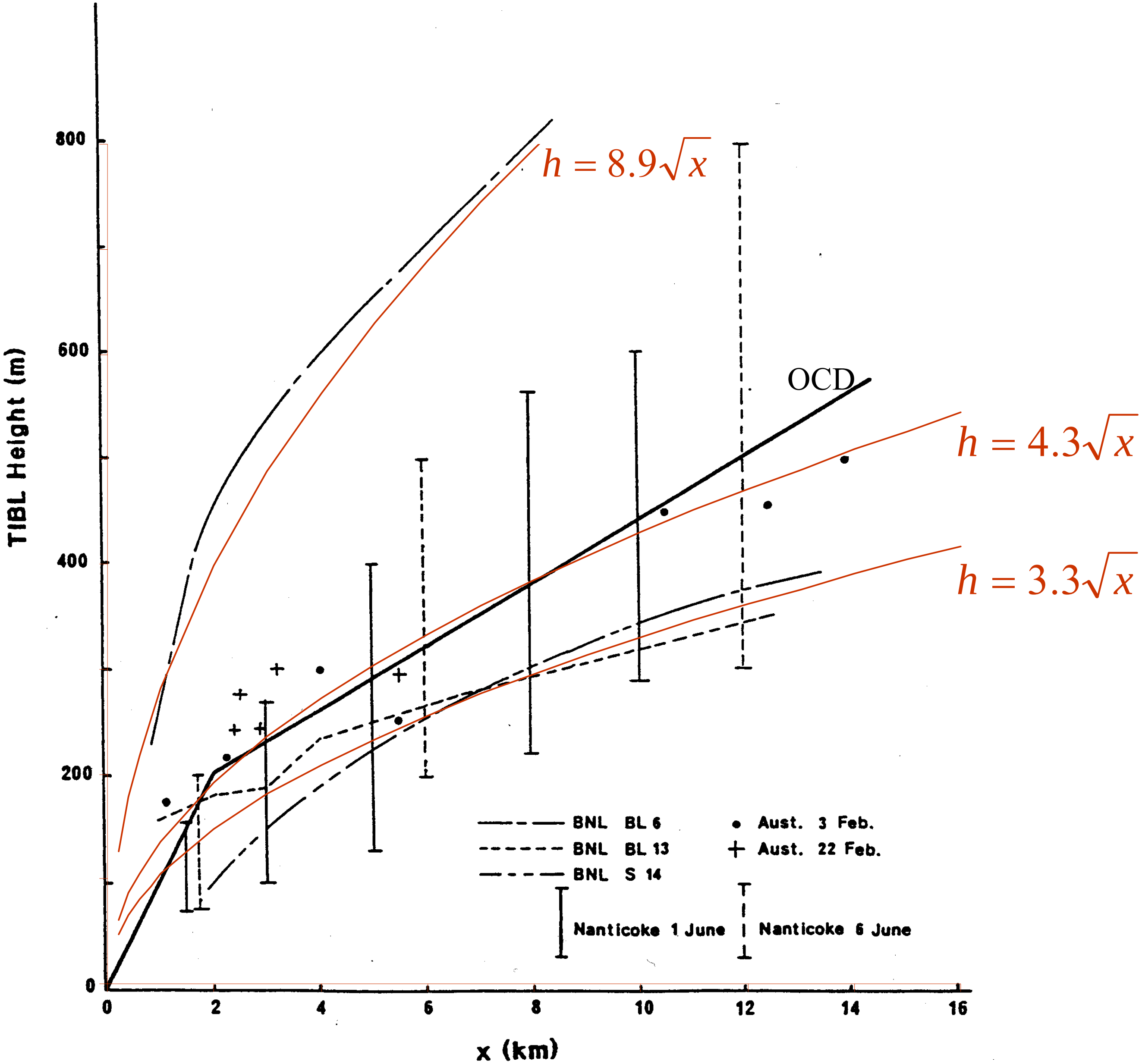
$$h = \sqrt{\frac{2(1 + 2\beta)H}{\gamma \rho c_p u} x}$$

# TIBL

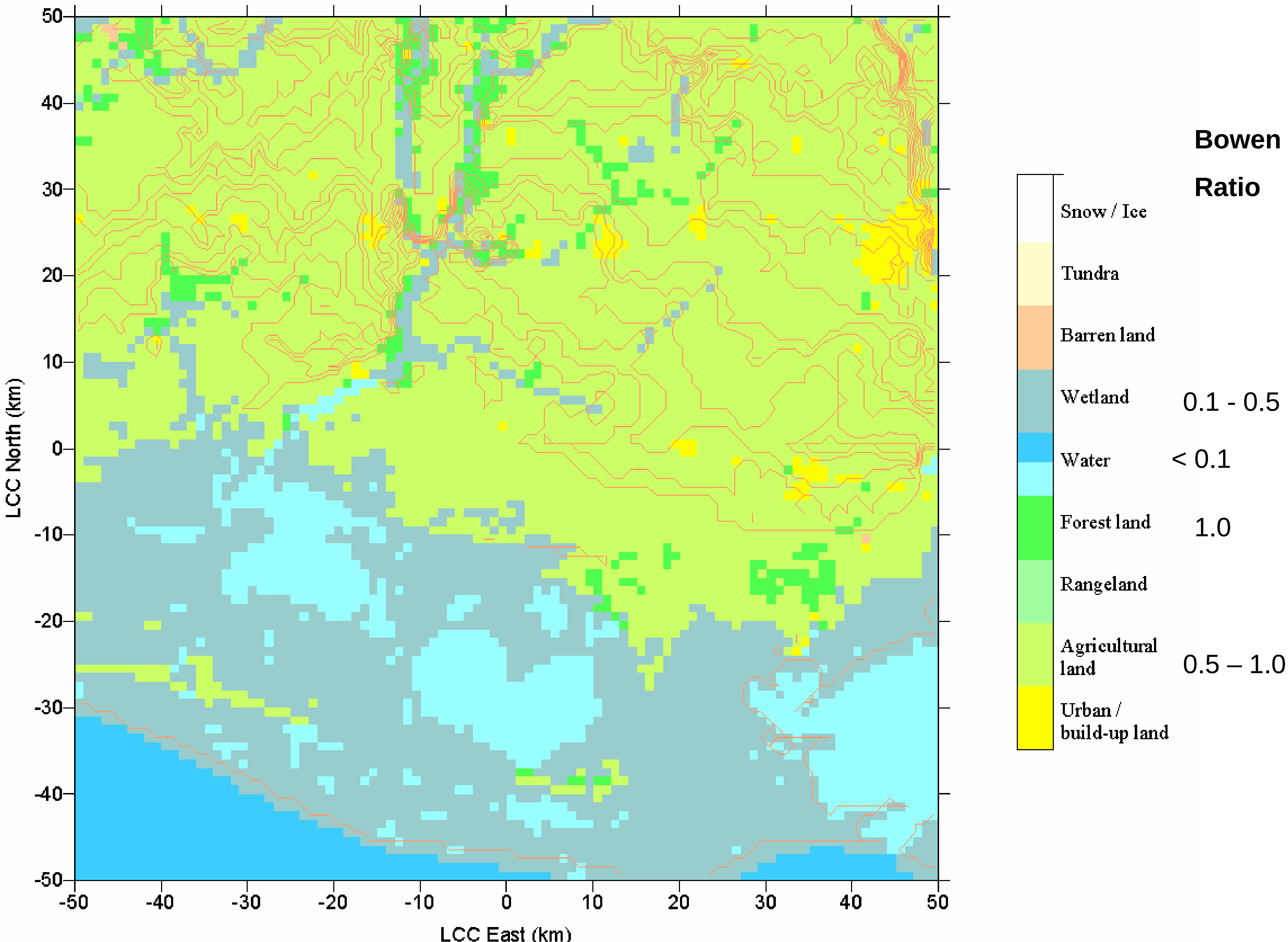
- CALPUFF (Coastal Zone Representation)
  - Gridded land use includes wetlands and inland water bodies
  - Properties tied to land use includes roughness length and Bowen Ratio
  - Sensible heat flux (H) is proportional to Bowen Ratio
  - Computed TIBL growth rate will respond to coastal zone properties:

$$\frac{dh}{dx} = \frac{(1 + 2\beta)H}{\gamma \rho c_p u h}$$

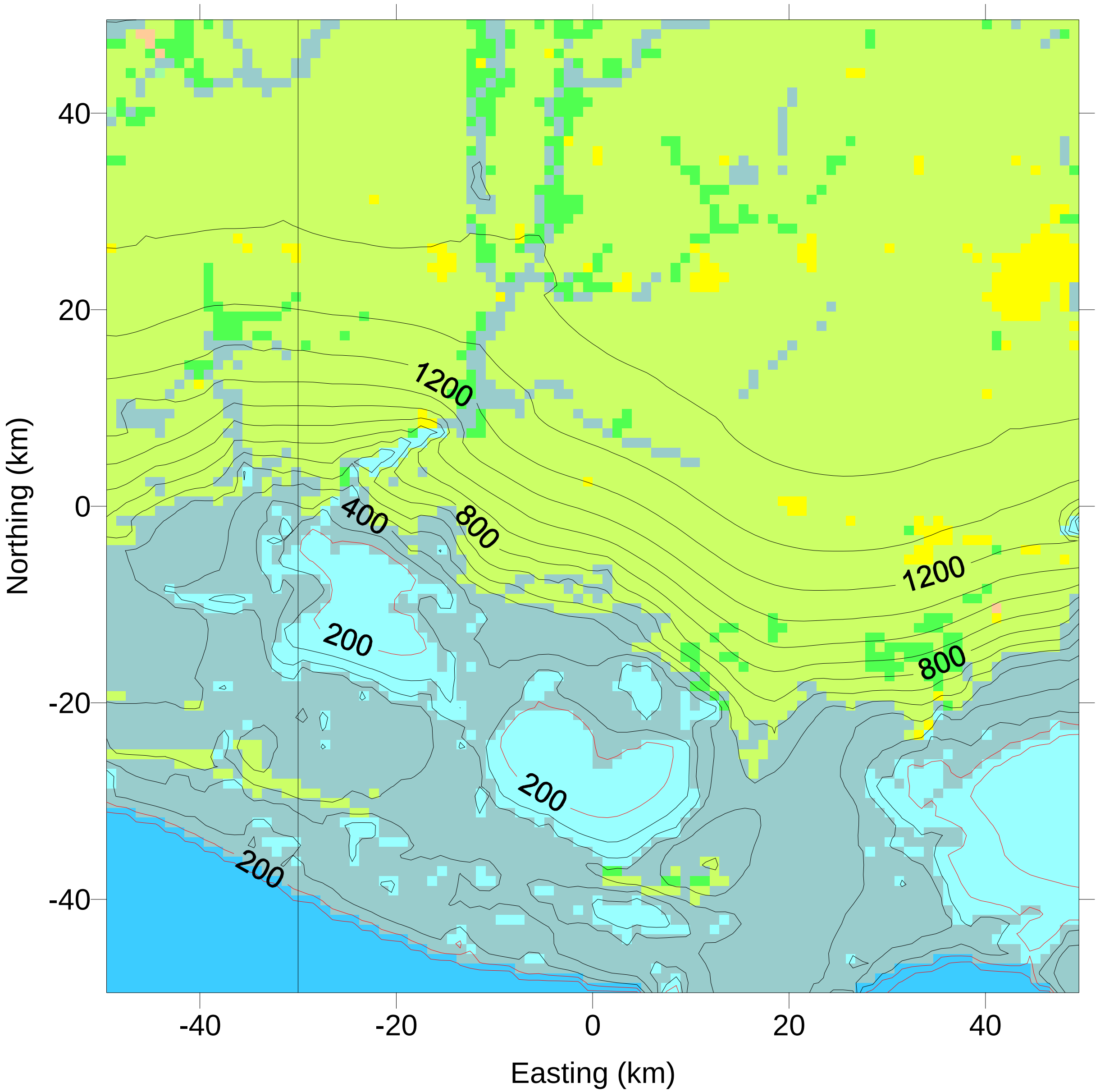
*OCD TIBL Comparison with Field Data*



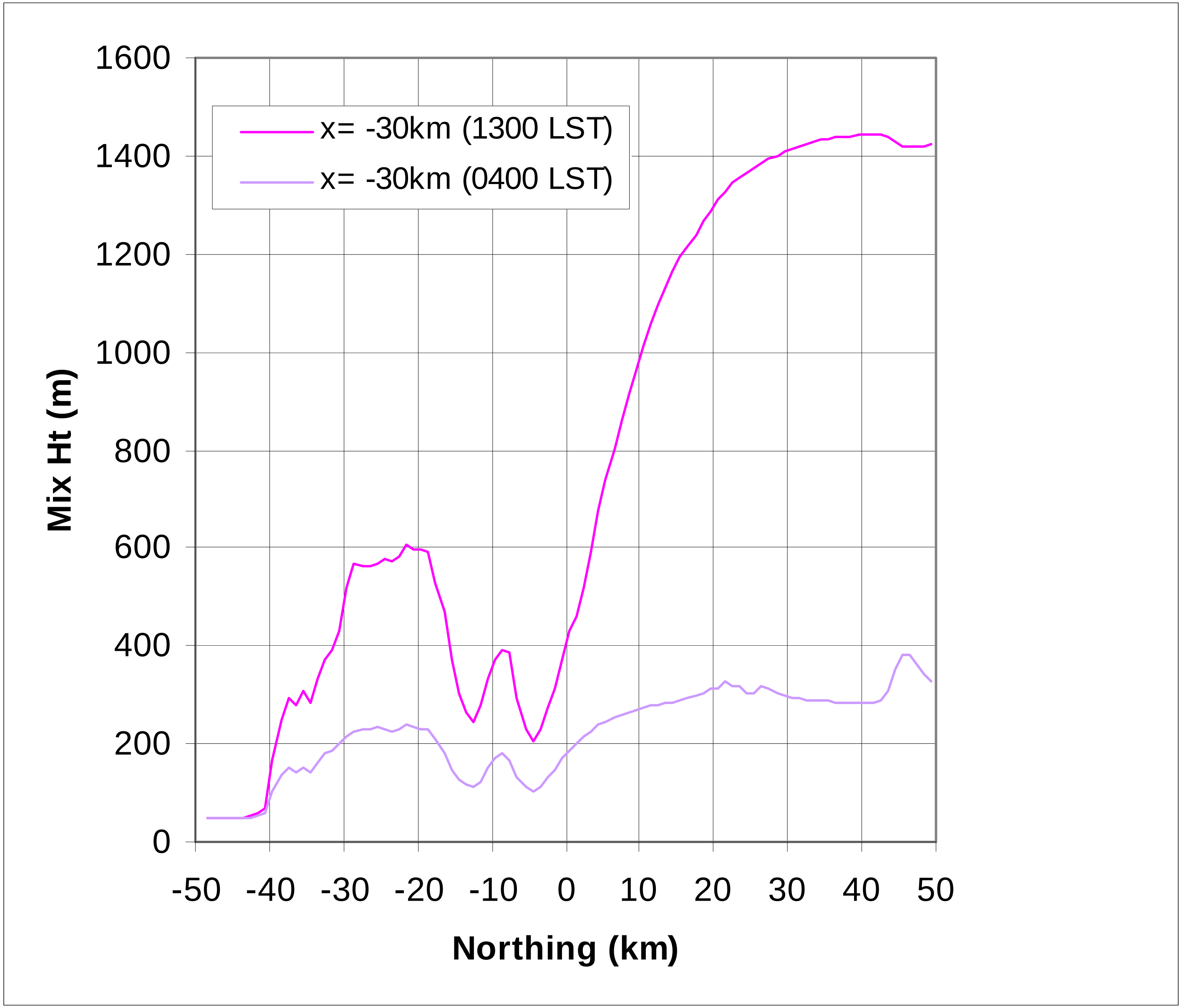
# Land Use and Terrain in Lake Charles, LA area



# Computed Mixing Heights (m) 1300 LST



# Mixing Heights along X=-30km



# Conclusions

- Improvements made in datasets for OCS applications
  - Use of prognostic datasets important in data sparse areas offshore
  - Enhancements to allow better use of prognostic meteorological datasets
  - Addition of new interfaces to allow new options for data sources (MM5 + RUC, Eta, RAMS)
  - High resolution SST data developed based on MODIS 4km data
  - Standard 1-year MM5 meteorological dataset to be prepared for regulatory use
- Enhancements made to facilitate use of CALPUFF for regulatory applications
- Technical enhancements to CALPUFF modeling system
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End