# Stanford Environmental Fluid Mechanics Laboratory VTMX Plans

F. L. Ludwig

Robert Street

# Major Tasks

- Refine and apply existing **Winds On Critical Streamline Surfaces (WOCSS)** objective analysis techniques
- Refine and apply existing **Multiresolution Feature Analysis (MFA)** techniques
- Refine and test new **SubGrid Scale (SGS)** turbulence methodology.

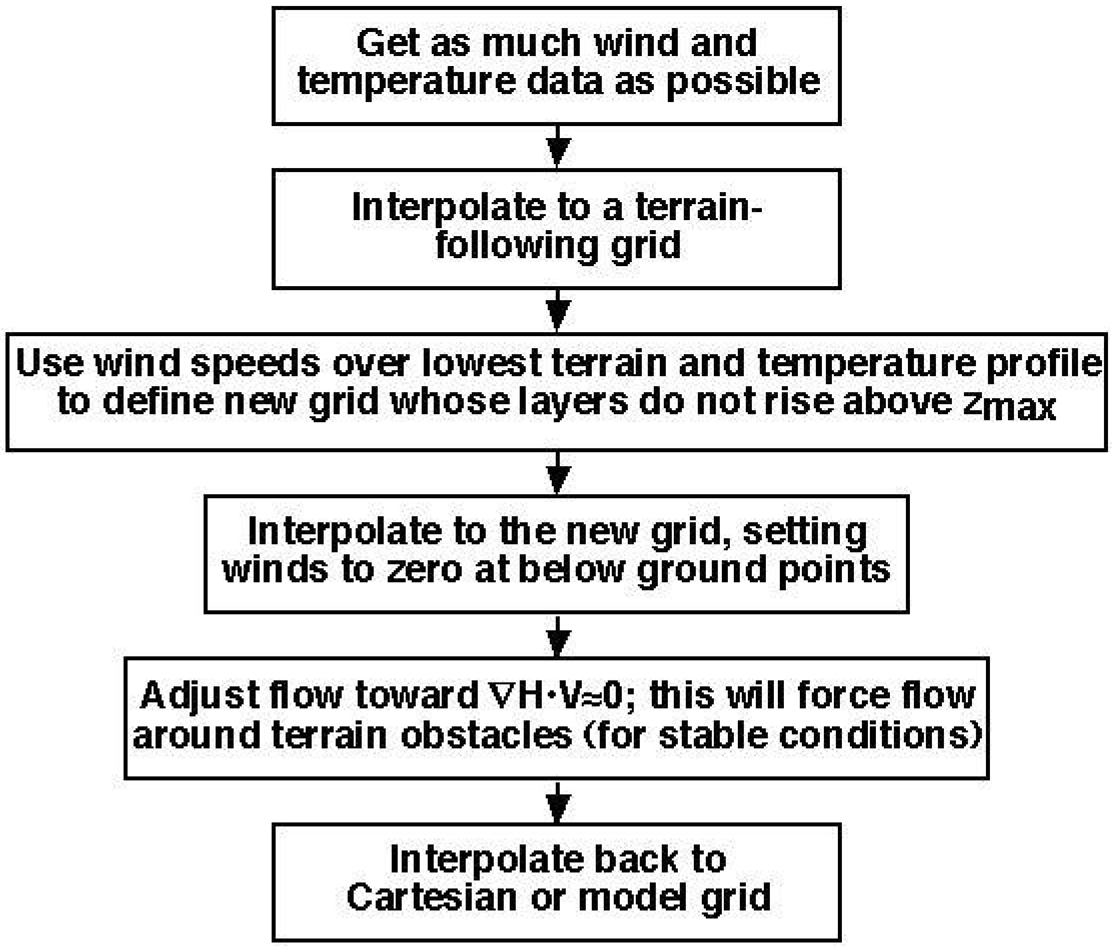
# What I will talk about

- **WOCSS**
  - » Methodology (very brief -- reprints available)
  - » Planned Modifications
  - » Data Sources for Testing -- looking for cooperative field experimenters and modelers
- **MFA**
  - » Methodology (very brief -- reprints available)
  - » Planned Modifications
  - » Data Sources for Testing -- looking for cooperative field experimenters and modelers

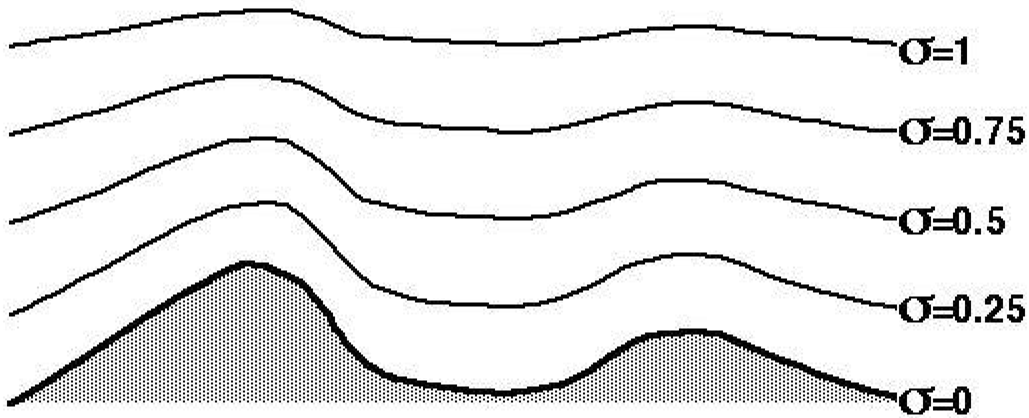
# What I will talk about (concluded)

- **SGS modeling ideas**
  - » Brief -- I will be talking about an area where Bob Street is the expert
  - » Testing plans -- looking for cooperative modelers.

# WOCSS Overview



# Interpolate to a terrain-following grid




- Interpolate winds at surface & at topmost levels.
- Fit u & v profiles between lower and upper surfaces.
- Determine deviations from profiles for intermediate observations.
- Interpolate these deviations on the flow surfaces.
- Add profile and deviation values to get intermediate winds.

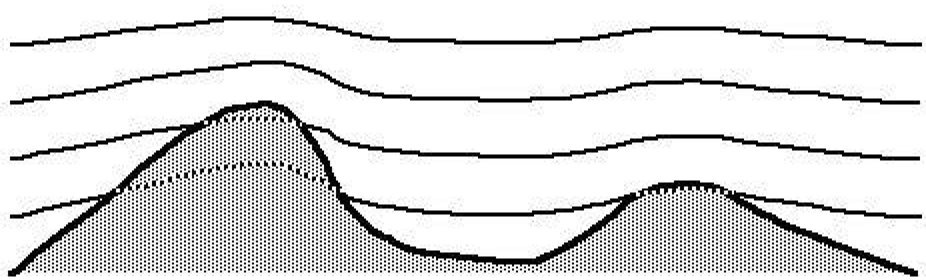
$$u(z)=[u(z)]_{profile}+[\Delta u(z)]_{interpolated}$$

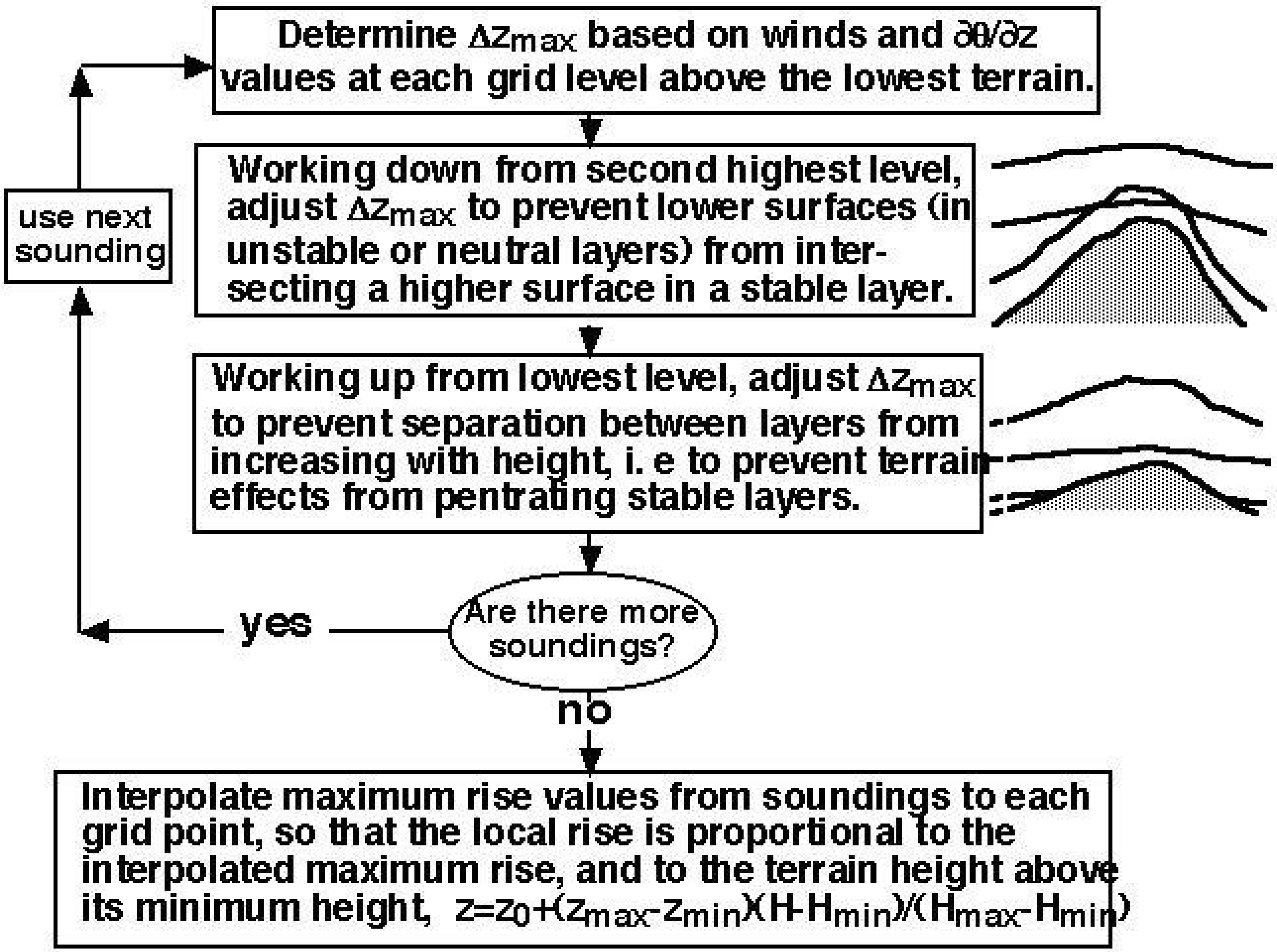
# Temperature sounding(s) & winds determine maximum possible rise.

We use the critical streamline equation:

$$Z_{max} - z_o = V_o \left( \frac{g}{\overline{T}} \frac{d\theta}{dz} \right)^{-\frac{1}{2}}$$

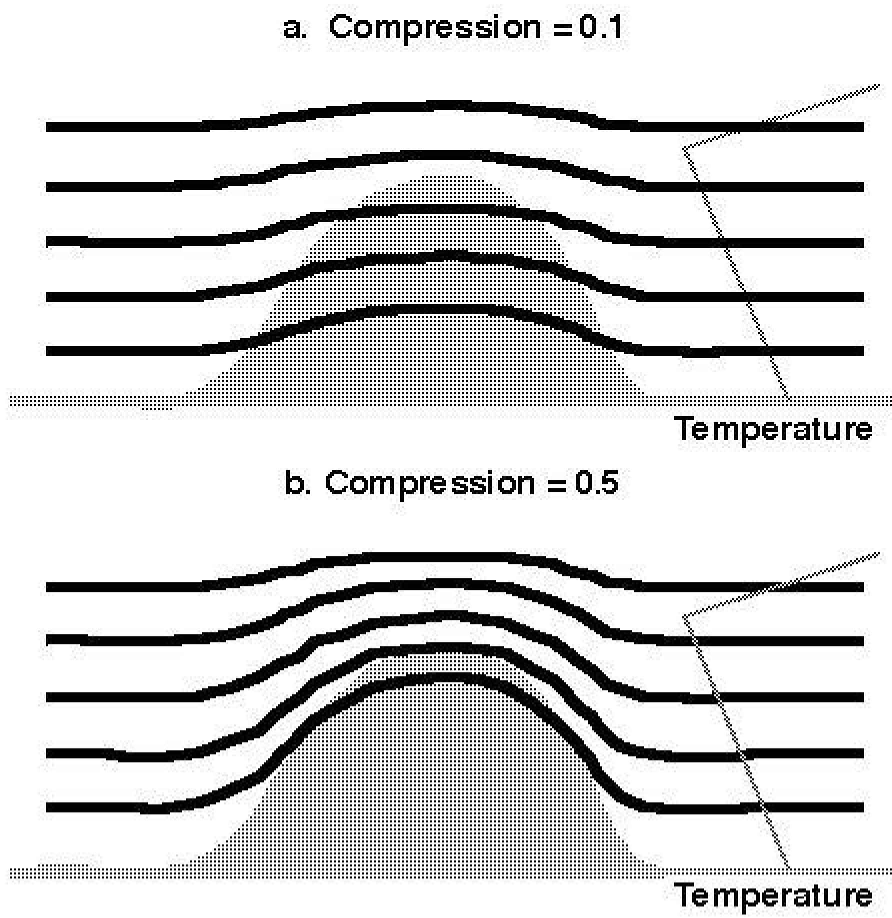
Equates potential energy gained from change of height to kinetic energy at starting level.



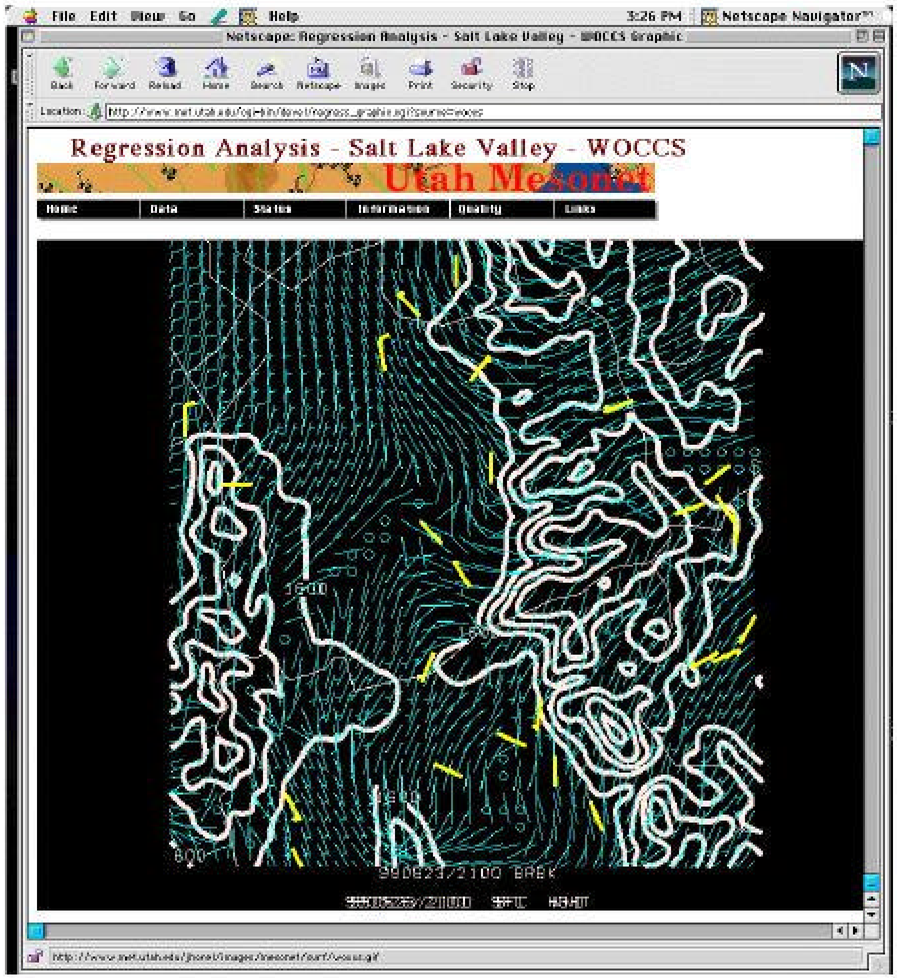


Determine Δzmax based on winds and ∂θ/∂z values at each grid level above the lowest terrain.
Working down from second highest level, adjust Δzmax to prevent lower surfaces (in unstable or neutral layers) from inter-secting a higher surface in a stable layer.
Working up from lowest level, adjust Δzmax to prevent separation between layers from increasing with height, i. e to prevent terrain effects from pentrating stable layers.
Are there more soundings?
yes
use next sounding
no
Interpolate maximum rise values from soundings to each grid point, so that the local rise is proportional to the interpolated maximum rise, and to the terrain height above its minimum height, z=z0+(zmax-zmin)(H-Hmin)/(Hmax-Hmin)

# Treatment of levels below inversion



# A version of the analysis code is already on line in the Salt Lake City area



# Other WOCSS uses

- Could be used for screening and planning
  - » Reasonably fast -- a 103×108×15 took ~1 minute on MacIntosh 65MHz Power PC.
  - » Also can be used to drive plume models.
- Could be useful during field effort.
  - » Already running in Salt Lake area.
  - » Might be useful for mobile monitoring.

# Things we are considering doing

- **Change interpolation scheme.**
  - » Need to be able to include temperature and wind information from more arbitrary points.
  - » 3-d multiquadric seems to have right properties.
- **Try to include slope heating/cooling effects**
  - » specify nonzero $\nabla_H \cdot V$ at low levels.
- **Change the way we calculate vertical motion**
  - » Integrate $\nabla_H \cdot V$ upward to get better mass consistency.

# Overview of MFA

Successively filter wind field, resulting in a set of wind fields of varying resolution

↓

Define wind features of some physical significance

↓

Use features as filters on each of the wind fields from first step to generate feature intensity fields at the different resolutions

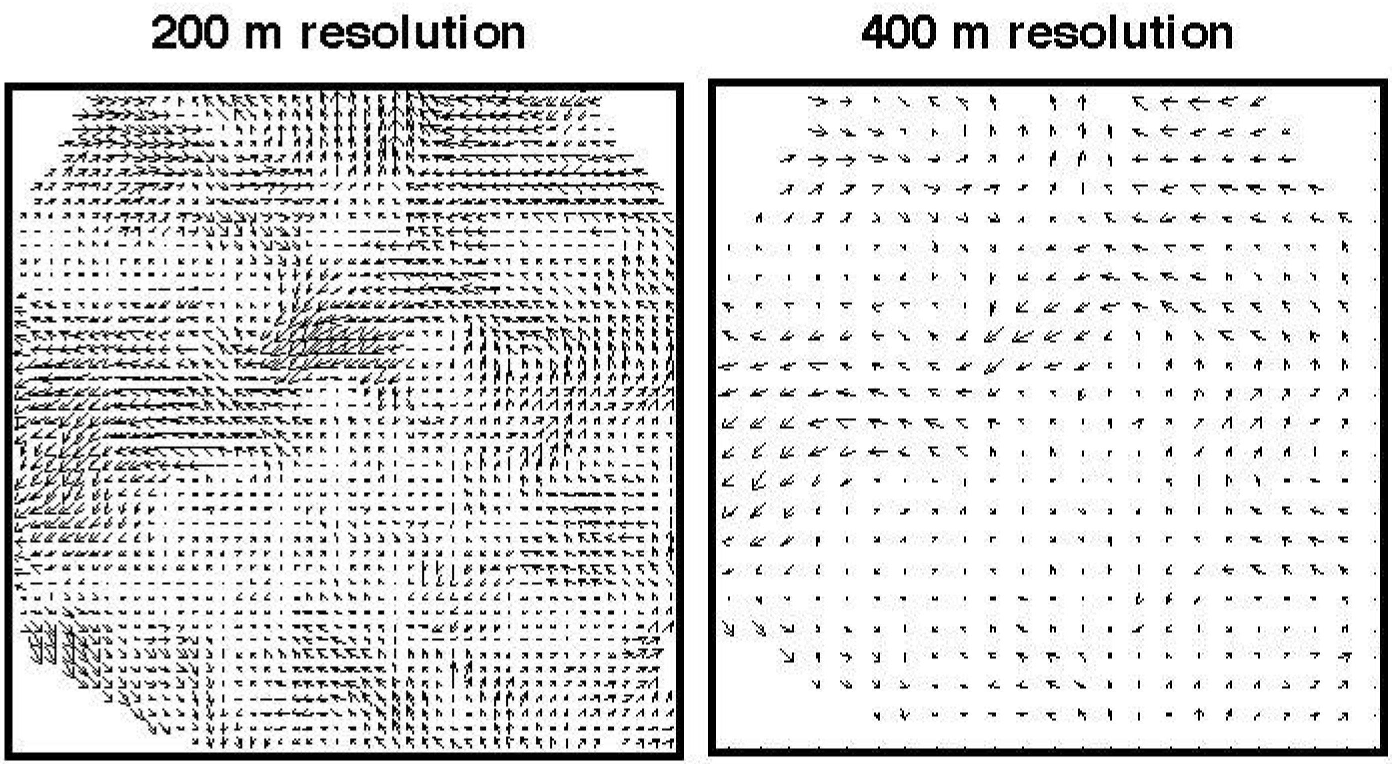
↓

Compare frequencies (at different resolutions) of peaks exceeding selected thresholds to estimate support dimension

↓

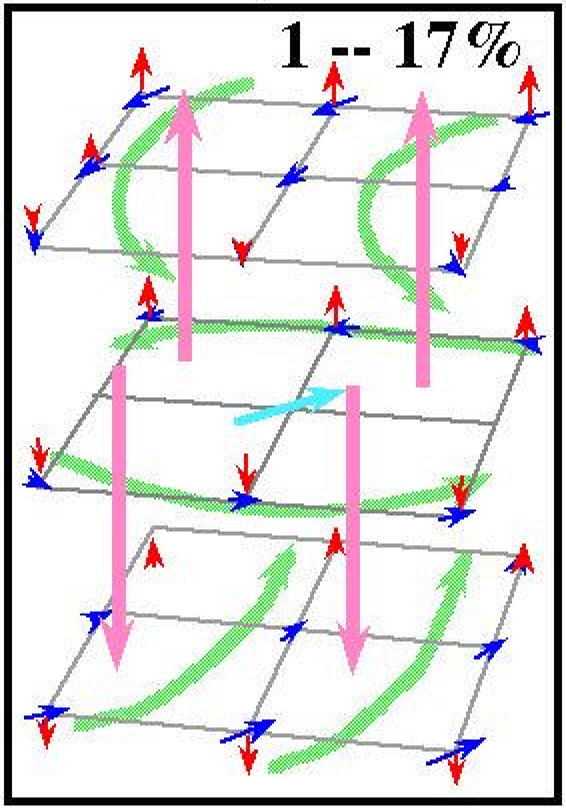
Look at relationships between locations and intensities of peaks at different resolutions -- could be very useful for domain decomposition and SGS modeling

# Dual doppler wind -- unsmoothed and smoothed

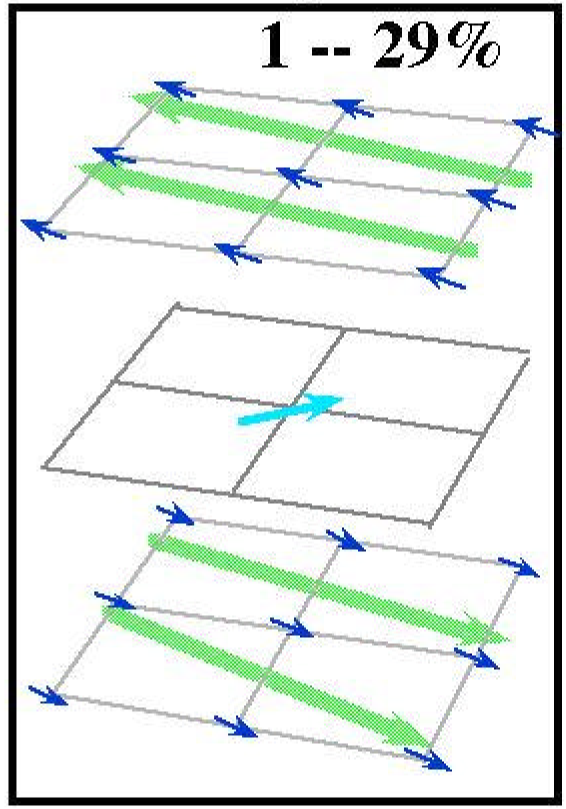


# MOST IMPORTANT SMALL SCALE MOTION PATTERNS

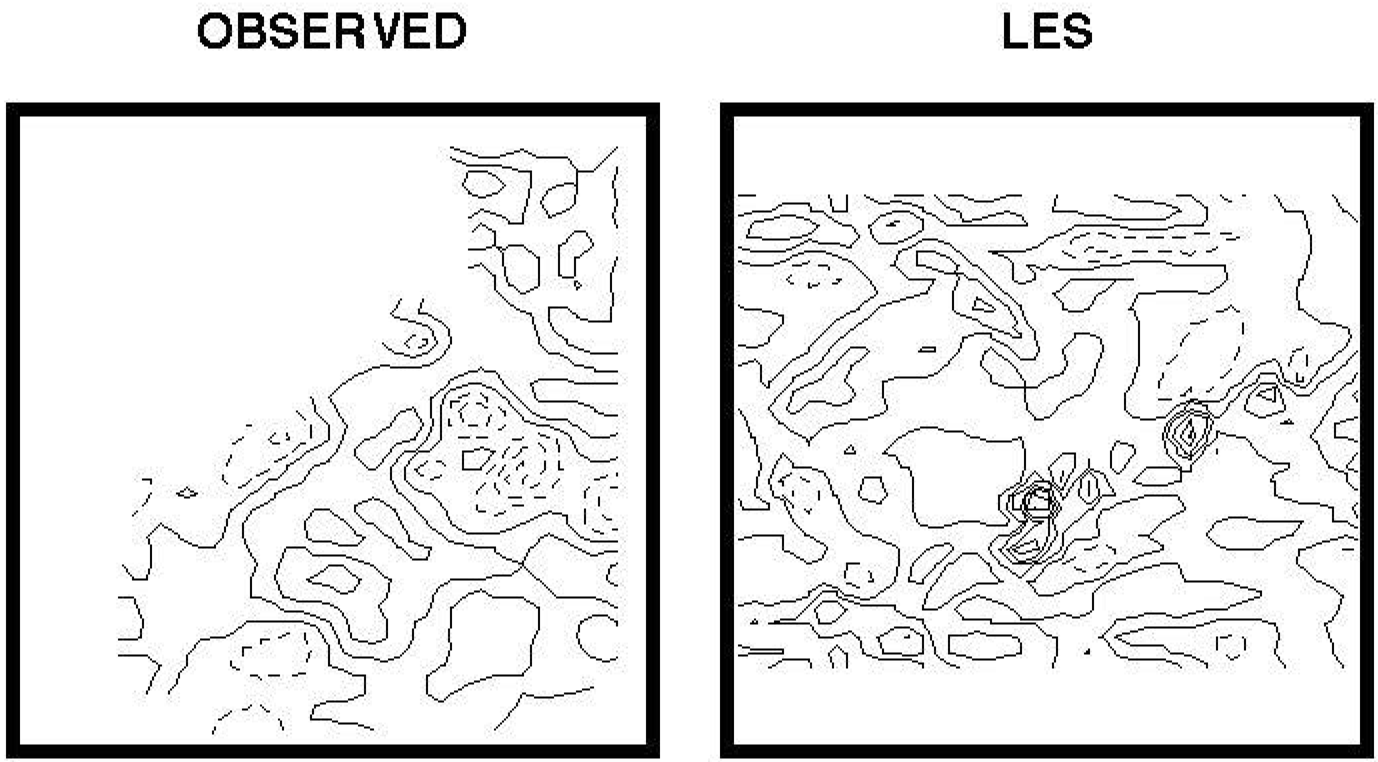
OBSERVED
22 June 1984, 1316-1333 MST




LES SIMULATION representing
22 June 1984, 1322 MST



# FEATURE INTENSITIES (EOF 1) IN HORIZONTAL PLANE AT 300 m



# How might we use MFA to model VTMX in the stable PBL?

- **Identify model-resolvable features associated with VTMX.**
- **Identify spatial relationships between resolvable features and volumes where mixing takes place.**
  - » Introduce nested grid or domain decomposition at appropriate places.
  - » Guidance for subgrid scale (SGS) modeling, e.g. location and magnitude of dissipation.
- **Use flow properties (e.g. vorticity, helicity, the stress tensor) to guide the design of analysis filters (features).**

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# The leap from MFA to subgrid scale (SGS) turbulence modeling

It's not such a long leap -- both involve relating what is going on a one scale to what's happening at a smaller scale.

Consider the SGS stress tensor:

$$\tau_{ij} = \overline{u_i u_j} - \overline{u}_i \overline{u}_j$$

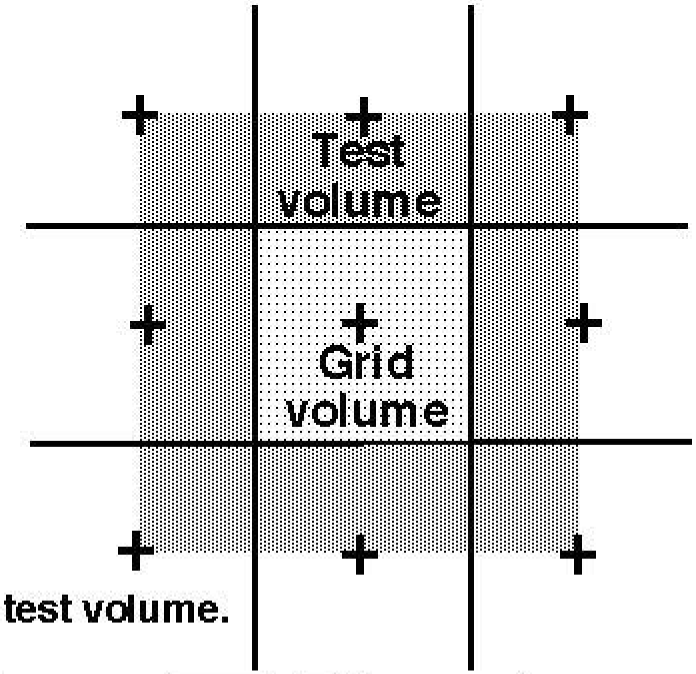
resolved: $\overline{u}_i \overline{u}_j$

unresolved: $\overline{u_i u_j}$

A basic assumption of LES (and other) models is that the calculated values are the filtered values over a model volume element.

Hence, the filtered values $u_i$ and $u_j$ are calculated by the code, but the filtered value for the velocity product is not.

# The leap from MFA to subgrid scale (SGS) turbulence modeling (continued)




One possible approach is to look at the SGS stress, $T_{ij}$, for a larger, "test," volume that includes the smaller grid volume of interest, as done by Zang et al. (1993).

$$T_{ij} = \widetilde{\overline{u}_i \overline{u}_j} - \tilde{\overline{u}}_i \tilde{\overline{u}}_j$$

$\sim$ indicates filtering over the test volume.

This approach uses a dynamic mixed model to evaluate:

$$\tau_{ij} = \overline{\overline{u}_i \overline{u}_j} - \overline{\overline{u}}_i \overline{\overline{u}}_j - 2C\Delta^2 |\overline{S}| \overline{S}_{ij}$$

but produces an SGS model where C is evaluated dynamically (Lilly's least squares method) at each point in time and space using the resolved flow variables inside the "test" volume. (over test vol after determined)

# Taylor series approach
# (after Katopodes, Street & Ferziger, 1999)

Taylor series expansion of velocity:

$$\mathbf{u}_i(X') \approx \mathbf{u}_i(X) + (\mathbf{x}_j' - \mathbf{x}_j)\frac{\partial \mathbf{u}_i}{\partial \mathbf{x}_j} + \frac{1}{2}(\mathbf{x}_j' - \mathbf{x}_j)(\mathbf{x}_k' - \mathbf{x}_k)\frac{\partial^2 \mathbf{u}_i}{\partial \mathbf{x}_j \partial \mathbf{x}_k} + \cdots$$

Spatially filter (top hat): $\bar{u}_i(x) \approx u_i(x) + \frac{\Delta^2}{24}\nabla^2 u_i(x) + \mathcal{O}(\Delta^4)$

Invert: $u_i(x) \approx \bar{u}_i(x) - \frac{\Delta^2}{24}\nabla^2 u_i(x) + \mathcal{O}(\Delta^4)$

# Taylor series approach (cont.)

Use the result back in itself to get:

$$u_i(x) \approx \bar{u}_i(x) - \frac{\Delta^2}{24} \nabla^2 \bar{u}_i(x) + \mathcal{O}(\Delta^4)$$

Substituting $u_i$ expansion in expression for $\tau_{ij}$:

$$\begin{aligned} \tau_{ij} &= \overline{u_i u_j} - \bar{u}_i \bar{u}_j \\ &\approx \left( \overline{\bar{u}_i \bar{u}_j} - \bar{\bar{u}}_i \bar{\bar{u}}_j \right) - \frac{\Delta^2}{24} \Big[ \overline{\bar{u}_i \nabla^2 \bar{u}_j} + \overline{\bar{u}_j \nabla^2 \bar{u}_i} - \\ &\qquad \left( \bar{\bar{u}}_i \nabla^2 \bar{\bar{u}}_j + \bar{\bar{u}}_j \nabla^2 \bar{\bar{u}}_i \right) \Big] + \mathcal{O}(\Delta^4) \end{aligned}$$

We now have an expression for $\tau_{ij}$ that can be used in the filtered N-S equations, and all its terms are resolved and computable. The approach has been shown to equal the best alternative dynamic models, e.g the Zang et al. mixed model

# SGS model development efforts

- Develop a version that can be adapted for use in existing mesoscale or LES models
- Work with modelers to help incorporate SGS scheme into their models
- Work with modelers to test the SGS scheme and interpret results

# What we have in hand

- Working objective analysis scheme.
- Working MFA scheme.
- Preliminary versions of SGS models.

# What we will be doing with objective analysis methodology

- Refine objective analysis to allow more general data inputs.
- Applying and testing objective analysis on data sets from other VTMX participants (and elsewhere)
- We could also assist by using it for screening and planning purposes.

# What we will be doing with MFA methodology

- Obtaining field data and model outputs for applying and testing MFA.
- Refine and augment MFA to clarify spatial relationships between features occurring at different scales.
- Attempt to incorporate these spatial relationships into domain decomposition, and SGS methods.

# What we will be doing with SGS model development

- Use MFA findings to improve SGS approach
- Develop and test SGS model with existing EFML LES models
- Work with VTMX researchers to help them use new SGS techniques in their models.
- Work with other VTMX researchers to test new SGS techniques and interpret results