Definition of the Mesoscale

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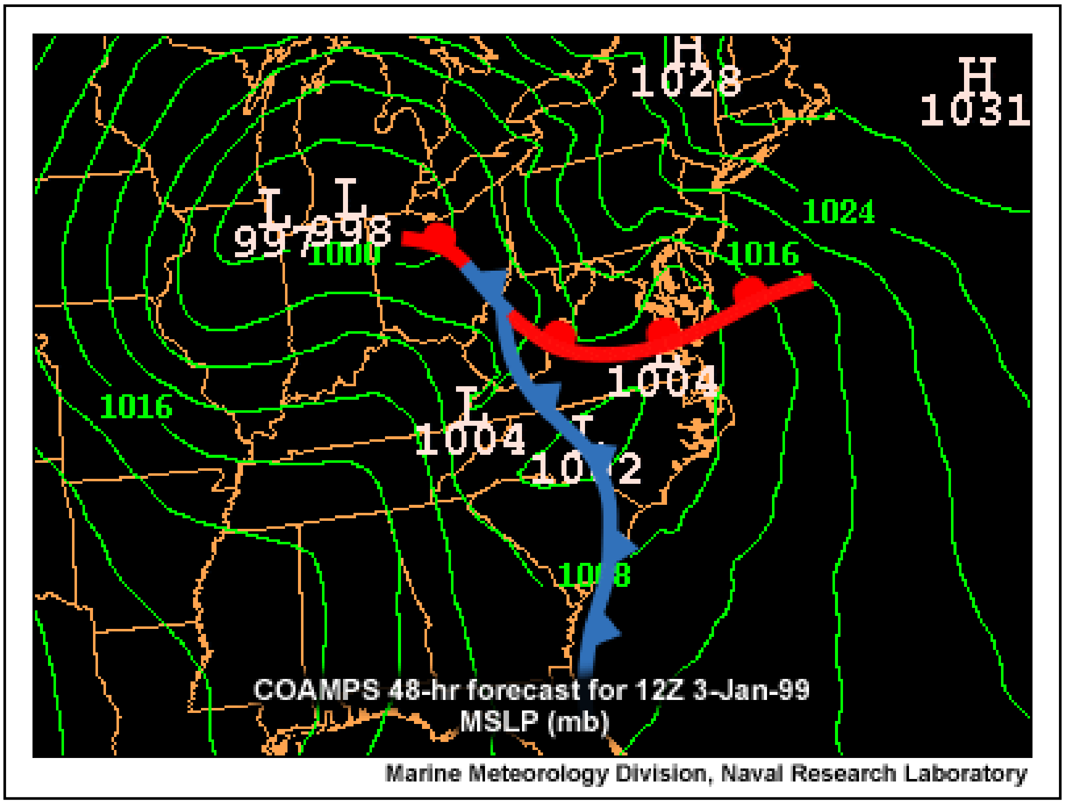
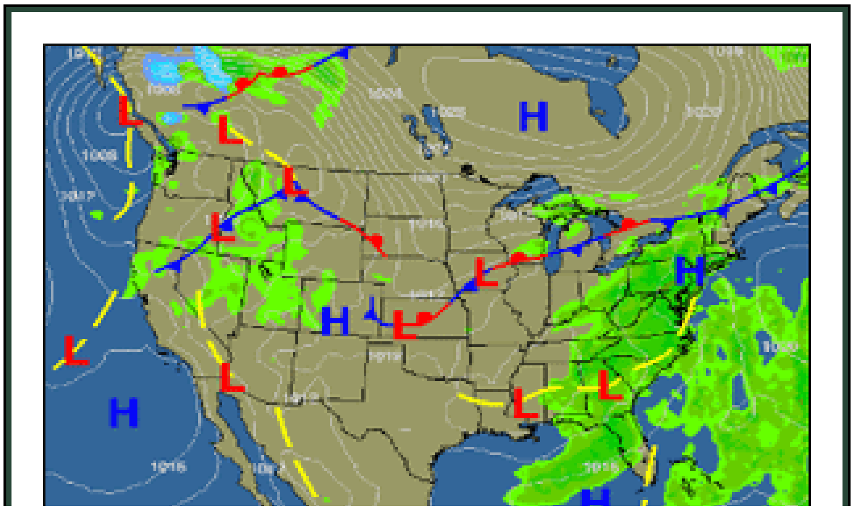
What is Mesoscale Meteorology?



By now many of you have become accustomed to seeing mesoscale numerical model products from the Navy's Coupled Oceanographic and Atmospheric Mesoscale Prediction System (COAMPS) or the National Weather Service Mesoscale Model (MM5). While the term "mesoscale" may be familiar, perhaps the actual definition and application of Mesoscale Meteorology is still not second nature.

Synoptic scale meteorology



Traditionally, operational forecasters have been trained in synoptic scale meteorology. This type of meteorology deals with analyzing and forecasting meteorological features of scales in excess of 2000 km. Features such as troughs, ridges, highs, lows and frontal boundaries are well understood. Over time, forecasters developed rules of thumb to derive sensible weather parameters, such as temperature, wind, icing, turbulence, and precipitation from synoptic models. They also developed a sense of the strengths and weaknesses of synoptic numerical models.

Mesoscale meteorology

But what about smaller weather features? How many forecasts are “busted” by a sub-synoptic, topographically forced weather feature hidden within the main synoptic pattern?


NCAR / UCAR / NSF

What if we knew just how quickly a vorticity maximum would move through our forecast area? If we did, we could nail the thunderstorm forecast.

What if we had a better handle on the wind-funneling effect of the terrain? We could provide a more precise Santa Ana, Mistral, or Taiwan Strait advisory.

These scenarios require the knowledge of sub-synoptic, or mesoscale meteorology.

How is mesoscale forecasting different from synoptic?

Synoptic and mesoscale models: 2 tools in the same toolbox. Synoptic model “hammer” guides the meso-model “chisel.”

Synoptic and mesoscale models are two tools in the same toolbox.

Synoptic model initial and boundary conditions serve as the “hammer” to guide the meso-model “chisel.” The hammer is useful by itself, especially for rough work. On the other hand, the chisel is pretty much worthless without the hammer.

Meteorological forecasting, especially mesoscale processes and local, sensible weather elements will always have a bit of “art” implied. No matter how skillful the model, you will always be required to apply the "artist's eye" to derive specific conditions over your region of concern.

Classification of the Mesoscale

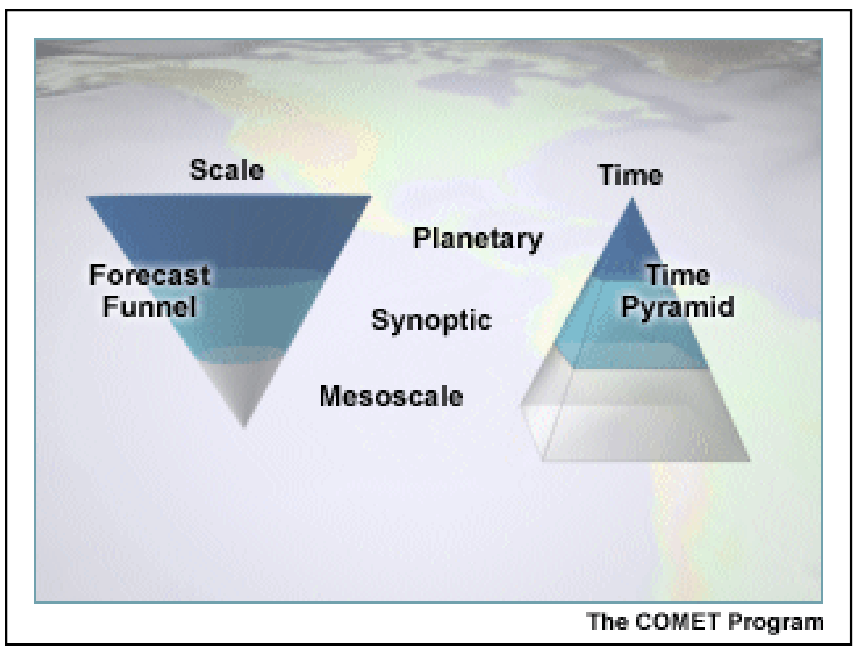
Nomenclature	Dimensions		Typical WX Feature
Mesoscale-alpha (a)	200 - 2000 km	6 hrs - 2 days	Jet stream, small hurricanes, weak anticyclones

Mesoscale-beta (b)	20 - 200 km	30 mins - 6 hrs	Local wind fields, mountain winds, land/sea breeze, mesoscale convective complexes (MCCs), large thunderstorms
Mesoscale-gamma (c)	2 - 20 km	3 - 30 mins	Most thunderstorms, large cumulus, extremely large tornadoes

Fujita (1986)

Synoptic meteorological processes such as fronts, highs, and lows are associated with wavelengths of greater than 2000 km and normally persist for days to weeks. Mesoscale features range from near synoptic scales (mesoscale-alpha) down to individual cloud cells with dimensions of 1–20 km and life spans less than one hour (mesoscale-gamma). Current technology, both in the military and civilian sectors, is concentrating on mesoscale-gamma. For example, the Coupled Oceanographic and Atmospheric Mesoscale Prediction System (COAMPS) model at Fleet Numerical Meteorology and Oceanography Center, Monterey CA, is run for several regions at 27 km grid-cell spacing (mesoscale-beta). Regional centers in direct support of tactical customers normally run local COAMPS regions at 9 and 6 km grid-cell sizes, approaching upper mesoscale-gamma range.

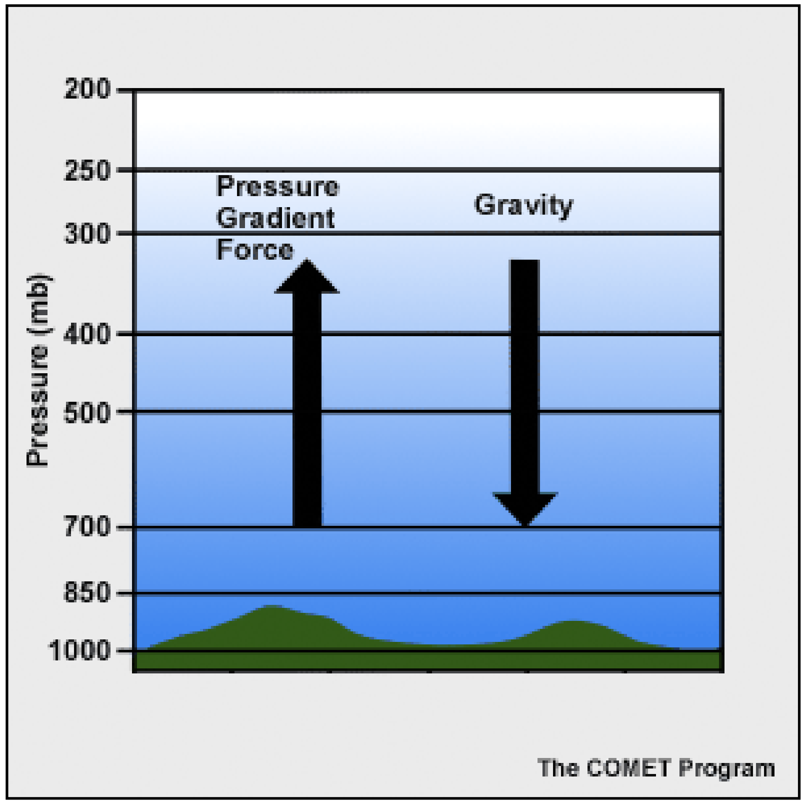
The Forecast Funnel and the Time Pyramid



Notice the inverted relationship between the Forecast Funnel and the Time Pyramid. Operational forecasters will still be required to maintain their expertise in planetary and synoptic meteorology while developing their mesoscale skills. However, due to increasing complexity, forecasters will have to shorten the time spent on planetary and synoptic analysis in order to devote more time and effort on an in-depth study of mesoscale features.

When dealing with mesoscale processes, you need to be aware that geostrophic and hydrostatic approximations cannot be relied upon. Geostrophic equilibrium exists when there is a balance between the Coriolis and horizontal pressure forces. In the extratropical latitudes and free atmosphere, geostrophic balance can give acceptable results for synoptic-scale motions, but not mesoscale.

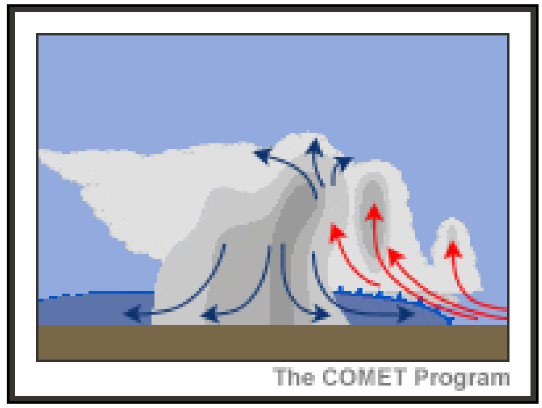
Hydrostatic Equilibrium



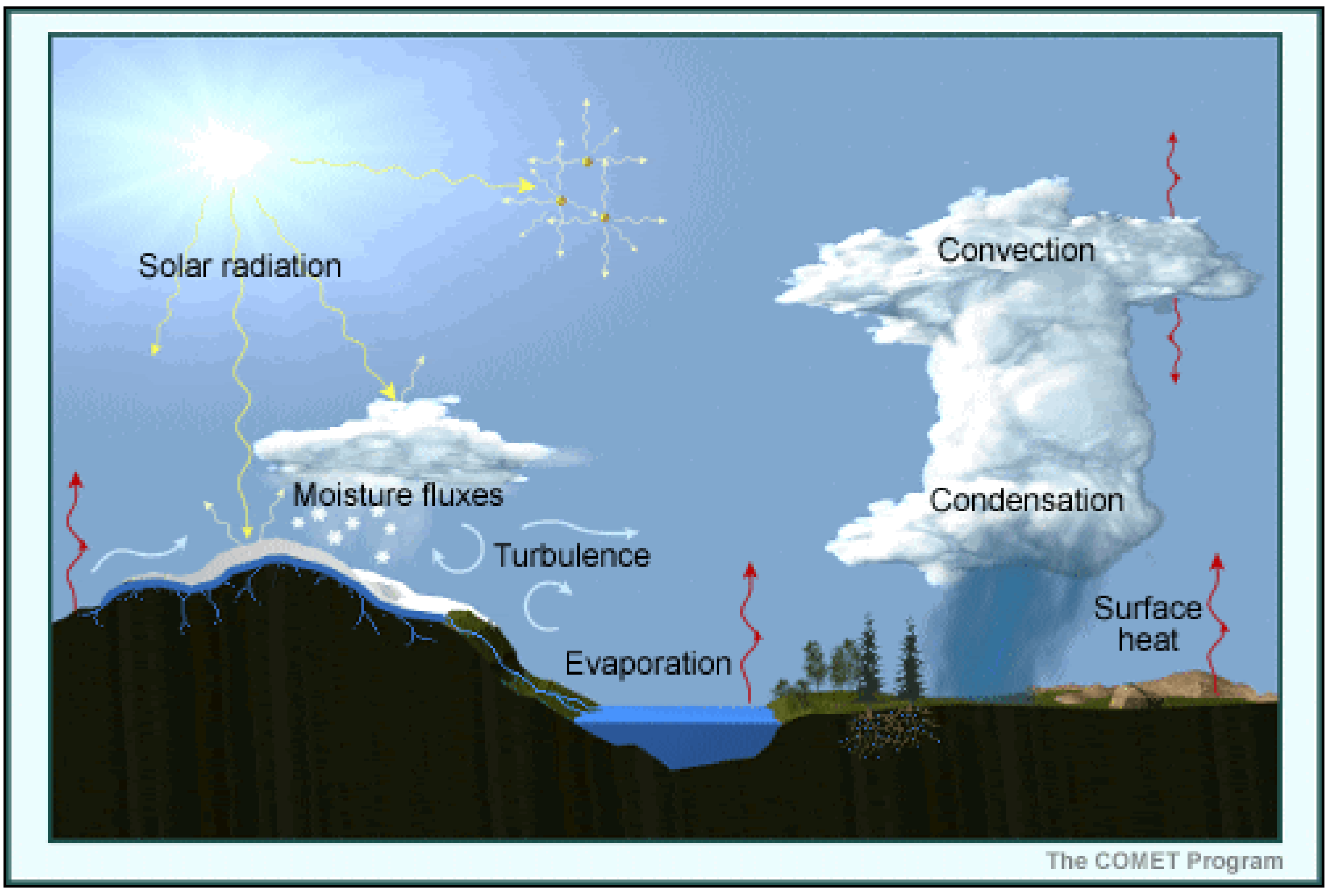
One of the keys to mesoscale processes is the role of non-hydrostatic processes. Hydrostatic models assume, as their name indicates, a reliance on "Hydrostatic Equilibrium." The atmosphere is in hydrostatic equilibrium when the pressure gradient force drawing air upwards, from higher pressures near the surface to lower pressures aloft, is balanced by the force of gravity pulling air back down to the surface.

Non-hydrostatic processes and mesoscale meteorology

On a synoptic scale and even upper mesoscale-alpha, the atmosphere is very nearly in hydrostatic equilibrium. Consequently, synoptic scale parcels of air rise and fall very slowly relative to their horizontal motions. However, this is not true for the lower mesoscale-beta and especially for mesoscale-gamma. Here, vertical velocities, driven by processes including buoyancy and topographic effects, can approach or even exceed horizontal velocities (over short distances). As a result, mesoscale meteorology is frequently determined by non-hydrostatic processes.

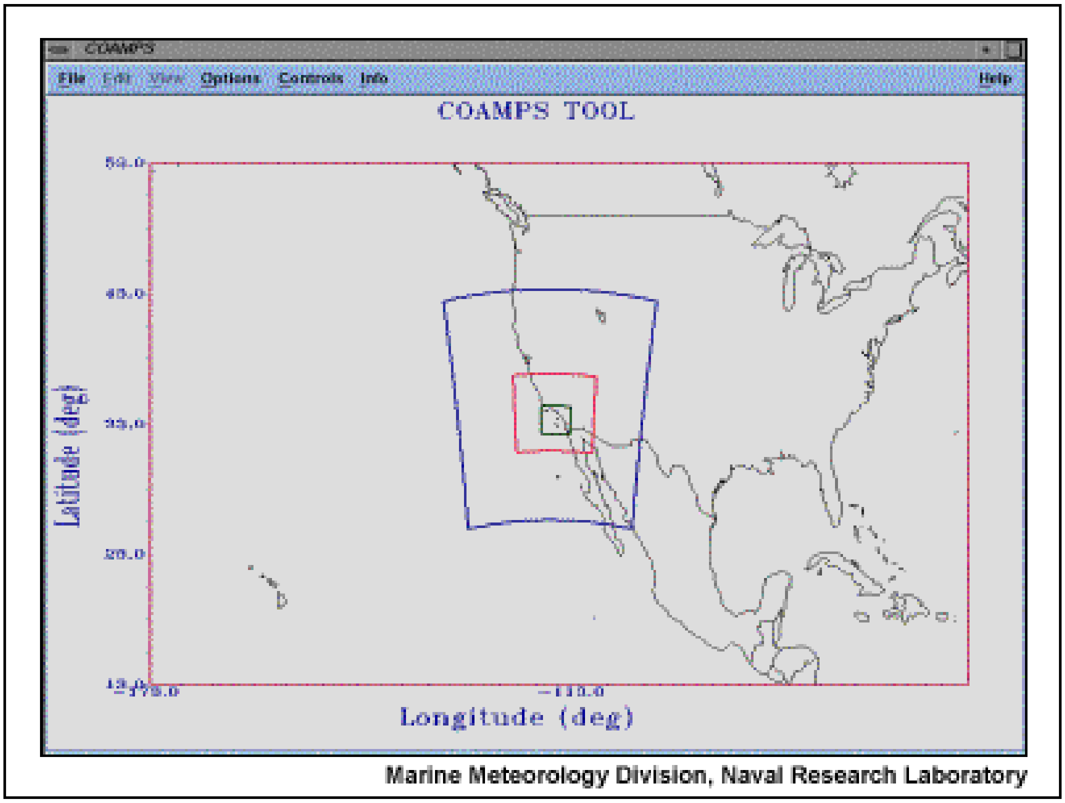


Atmospheric Processes with Non-hydrostatic Effects



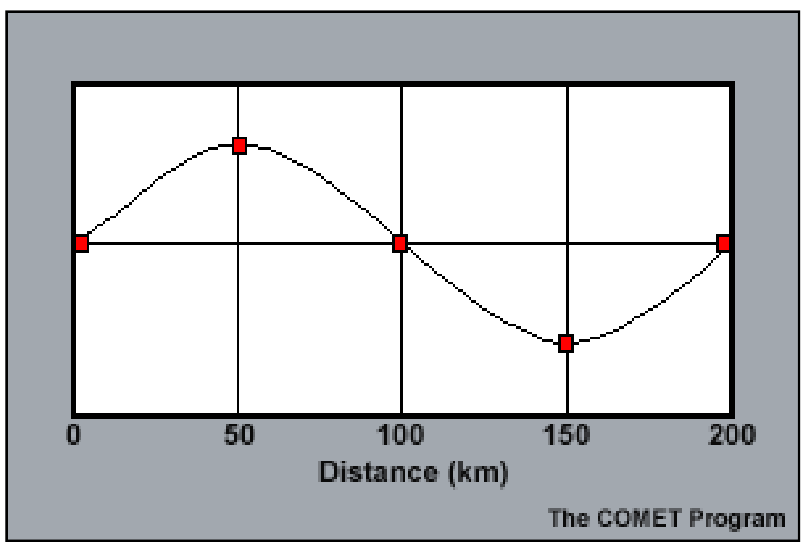
This figure illustrates many of the atmospheric processes that have non-hydrostatic effects. These include surface and atmospheric heat and moisture fluxes, turbulence, convection, evaporation, and condensation. For features less than 10-20 km, meteorological models must incorporate these non-hydrostatic processes.

A Brief Word about Mesoscale Model Resolution



Those familiar with either the COAMPS or MM5 models are also aware of increasing grid-point spacing with the available triple-nested products. Where do these models get their initial or boundary conditions? All "mesoscale" models rely on relatively coarse-resolution "global" models with grid-point spacing of 50-81 km to provide them with initial and boundary conditions. Remember, the chisel is no good without the hammer.

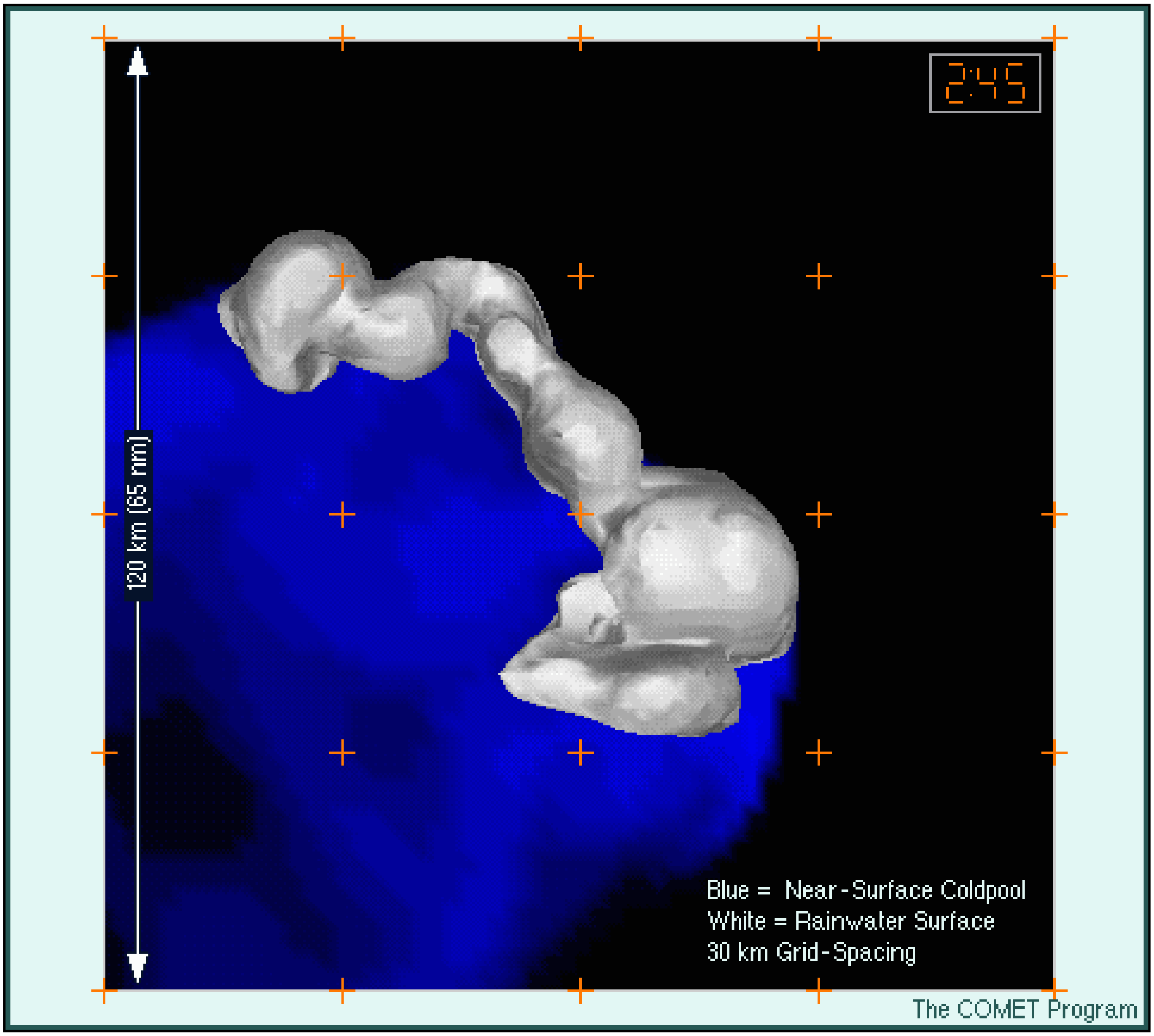
Why is "grid-point resolution" important?



For any numerical model to analyze a simple wave-form, five grid points are required to resolve the wave's structure. So, if we are dealing with a 50-km model (that is, the horizontal distance between any two grid points is 50 km) the model will only be able to completely analyze waves or systems of 200 km and greater.

Even with COAMPS running at 9-km resolution, the model will only be able to completely analyze systems that extend greater than 36 km. We will be studying mesoscale features such as Coastal Barrier Jets and Gap Winds that may require model grid-point resolutions of 1-2 km.

Example of "grid-point resolution"

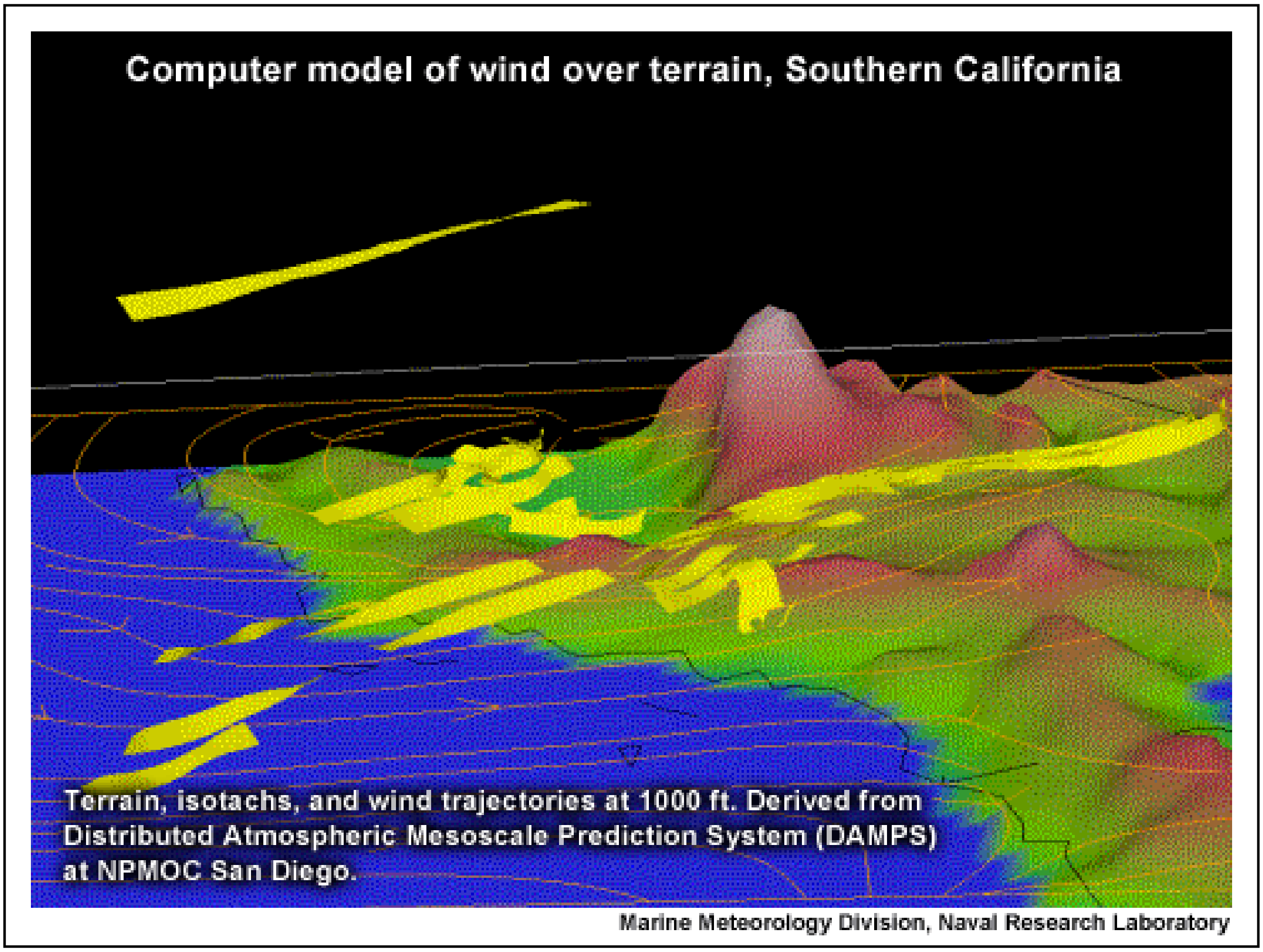


Even as we increase the resolution (that is, decrease the distance between successive grid-points), many important mesoscale processes can be missed.

Here we have a grid-point field at 30 km spacing. What you are seeing is the build-up of a convective rain shaft and near surface cold air temperatures. As this process is developing, the model is missing the majority of the information due to the limited interface with actual grid-points.

Topography profoundly influences mesoscale meteorology

- Land-sea breezes
- Gap winds
- Coastal barrier jets
- Upslope/downslope winds



At a mesoscale, terrain profoundly affects meteorology and sometimes plays a dominant role. At model resolutions of 20 km and less, topographic effects are critical to understanding the local effects on the forecast. Land-sea breezes, venturi (gap) effects through mountainous regions, coastal barrier jets, and upslope and downslope winds require high resolution topography to be accurately modeled.

Current Digital Elevation Models (DEMs) give a good approximation of the topography. Mesoscale models, such as COAMPS, incorporate this digitized topography into our forecast fields. It is important that the resolutions of the Digital Elevation Model and meteorological model match closely for an accurate and meaningful forecast.

The depiction above shows yellow ribbons reflecting the wind trajectories at 1000 feet. Note the funneling through the mountain passes

To what other sensible weather elements should we apply our "Mesoscale" knowledge?

Evaporation, transpiration, and fog

Whether you are forecasting for a coastal station, onboard an afloat platform, or hundreds of miles inland, forecasting fog can be the most difficult part of your job. Of primary concern is safety of flight, surface navigation, or even vehicle highway safety. Most difficult is forecasting the exact location and timing of fog events.

Subtle variations in temperature and humidity profoundly affect the formation and distribution of fog. Mesoscale variations in temperature and humidity are driven by local evaporation and transpiration. For example, the presence of a lake or snow cover or the type of vegetation in an area may affect the fields of temperature and humidity. Consequently, mesoscale analysts need to look at resolutions of 1-2 km to be able to discern whether or not a fog event will extend into their local region.

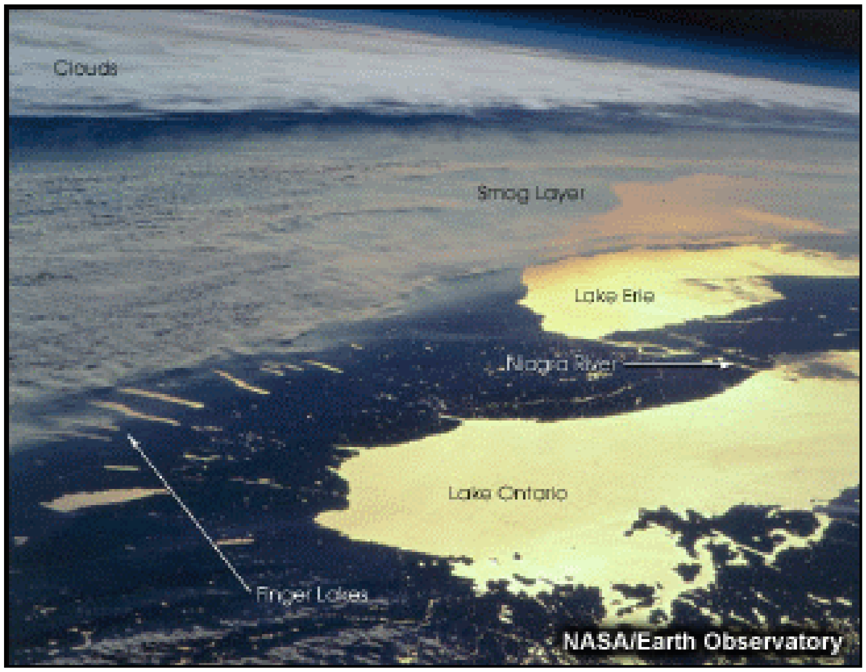
Natural and man-made effects

Volcanic eruptions

Forest fires


National Interagency Fire Center

Smog



Natural and man-made effects play a significant role in mesoscale meteorology. For example, volcanic eruptions, forest fires, and even smog can affect sensible weather. Unfortunately their sporadic nature or limited scale make them extremely difficult to incorporate into numerical models and nearly impossible to forecast with accuracy.

Effects on fleet operations

Fog and low clouds limit flight operations

Gustiness affects helicopter operations

Precipitation degrades electromagnetic and electro-optic refractivity

Local winds enhance the generation of ocean waves

Disruption of the ocean thermal stratification and underwater acoustics.

Military forecasters have the additional burden of coupling their weather forecasts to actual effects on weapons, platforms, and sensors. For example,

- Fog and low clouds limit flight operations
- Gustiness affects helicopter operations
- Precipitation degrades electromagnetic and electro-optic refractivity
- Local winds enhance the generation of ocean waves
- Offshore winds may lead to increased upwelling that locally disrupts the ocean thermal stratification and underwater acoustics.

Some critical, tactical considerations will require an even higher resolution "microscale" study. However, with a good handle on mesoscale meteorology, a forecaster is well-equiped to forecast most weather events.