Sensitivity Analysis of Coastal Atmospheric Flow with a Nested Adjoint Model

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Nested Models

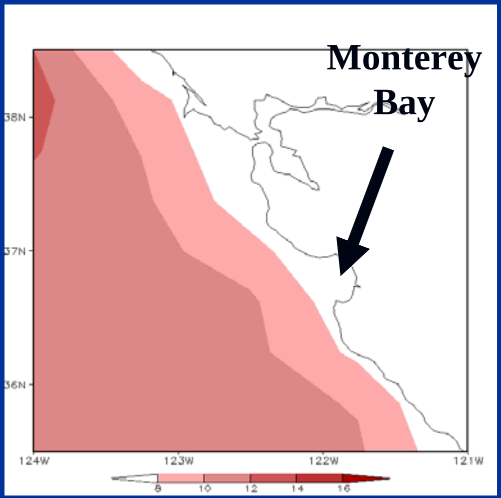
•Balance grid spacing and computational costs

•First proposed for tropical cyclone modeling (Birchfield 1960, Ley and Elsberry 1976)

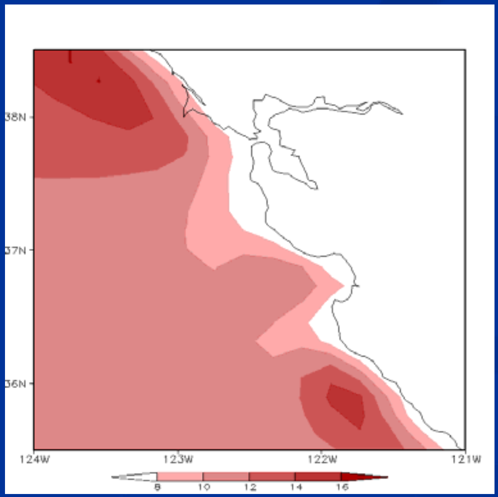
•Current state of the art mesoscale model include multiple nests (COAMPS®, WRF, MM5, RAMS, etc.)

COAMPS 12 h 50 m windspeed Forecast - 0000 UTC 26 July 2007 - 3 nests

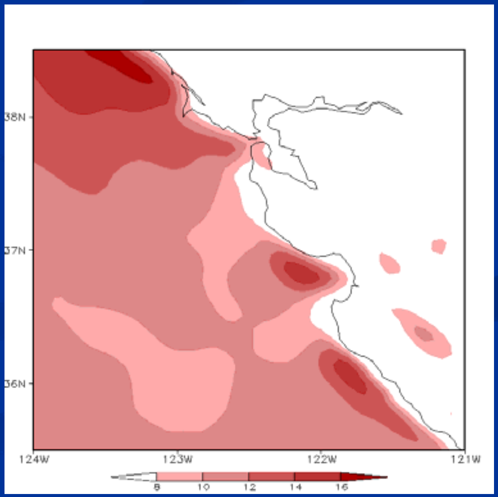
Nest 1- 45 km



Nest 2- 15 km



Nest 3- 5 km

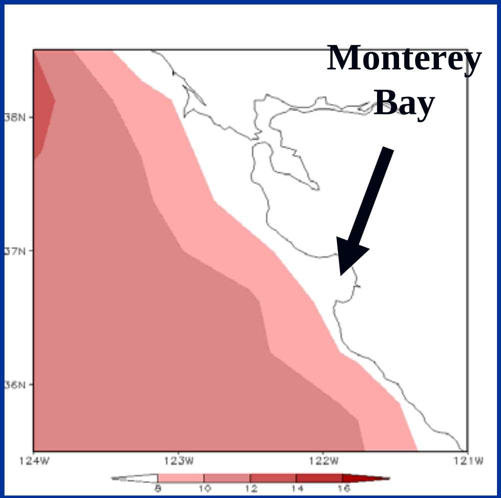


Nested Models

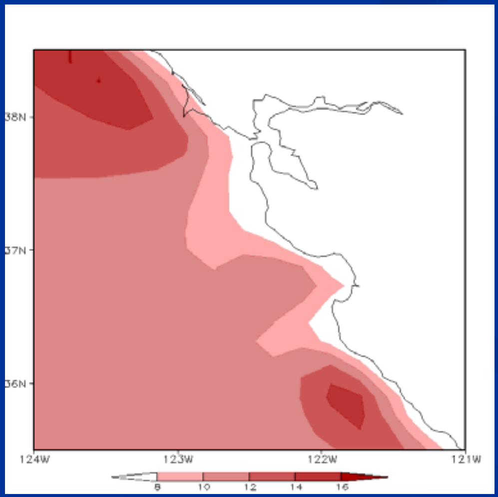
- Summer time flow is channeled by the topography and inversion
- Bays and points modify the primarily NW wind
- Finest nest can resolve some of these flow features

COAMPS 12 h 50 m windspeed Forecast - 0000 UTC 26 July 2007 - 3 nests

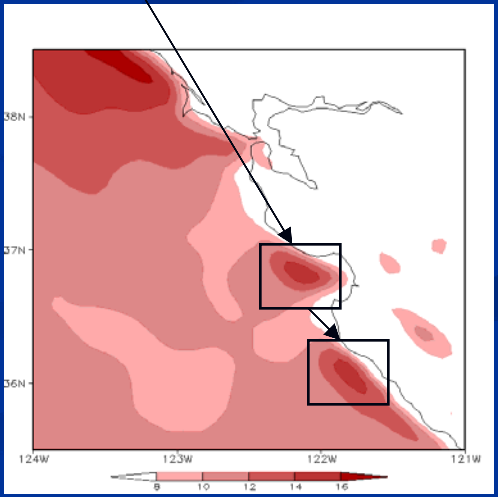
Nest 1- 45 km



Nest 2- 15 km



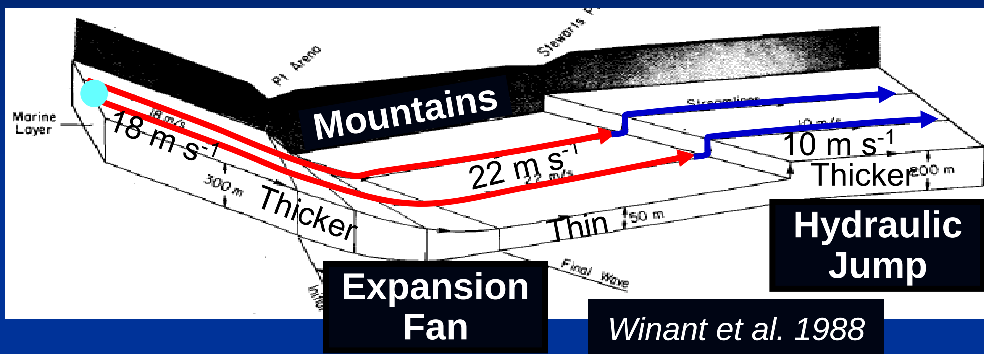
Nest 3- 5 km

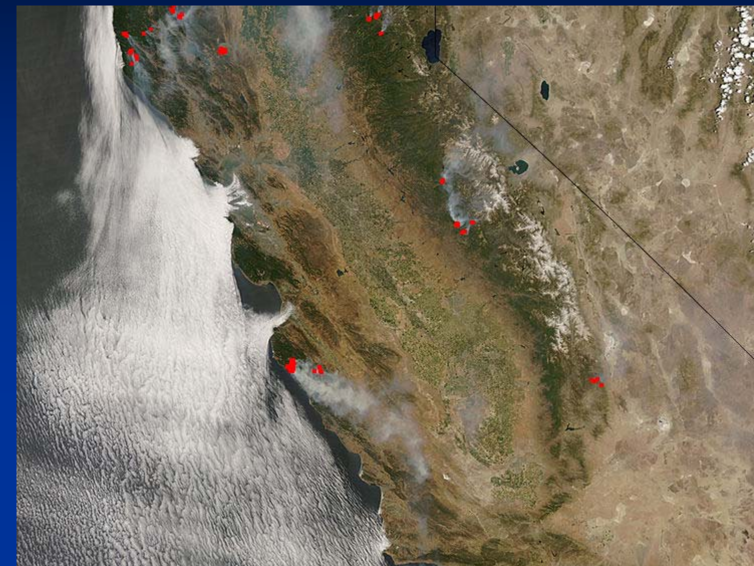


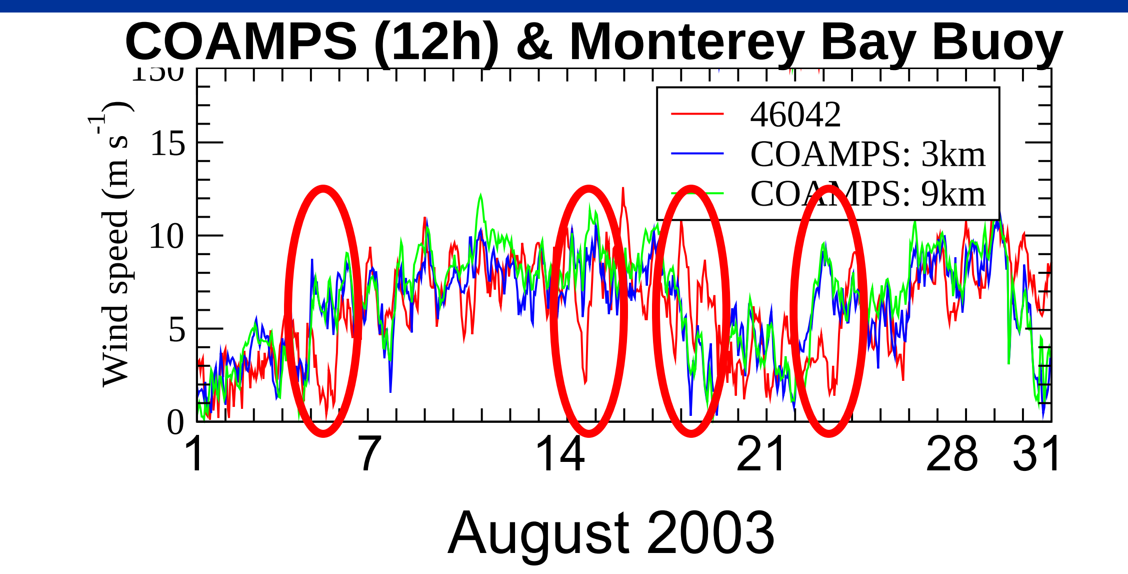
COAMPS® is a registered trademark of the Naval Research Laboratory

Coastal Flow

Boundary Layer Transitions

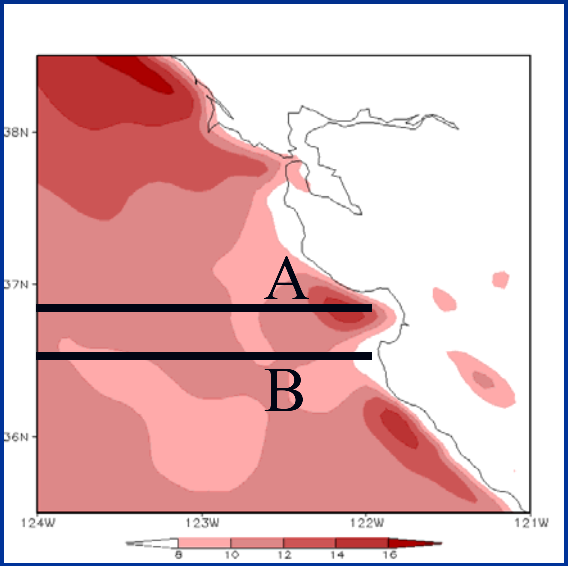




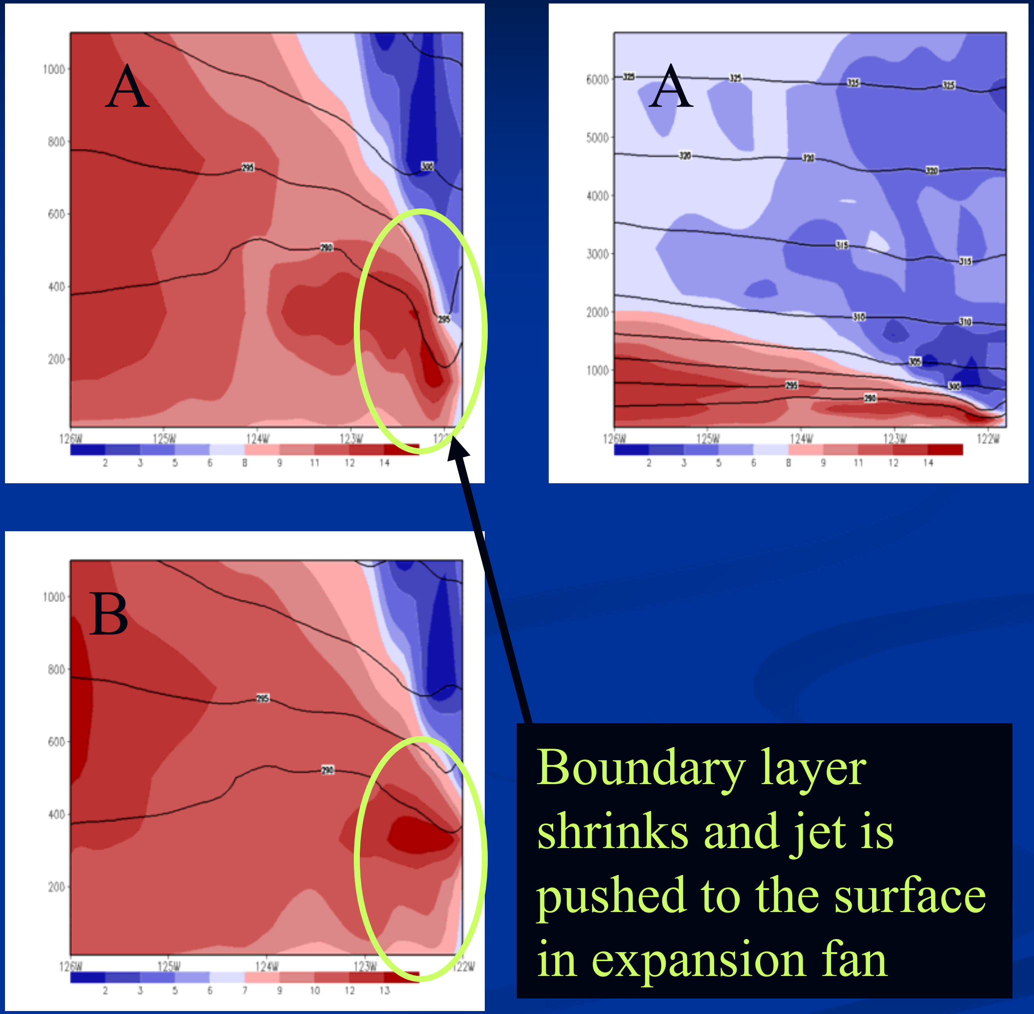


- •Forecasts are skillful overall
- •Episodes of poor forecasts independent of resolution (Error > 5 m/s)

Coastal Flow



COAMPS 12 h 50 m Windspeed (m/s)
0000 UTC 26 July 2007



Cross Sections of θ (contour, K) and Windspeed (shading, m/s)

COAMPS

- Coupled Ocean Atmosphere Mesoscale Prediction System

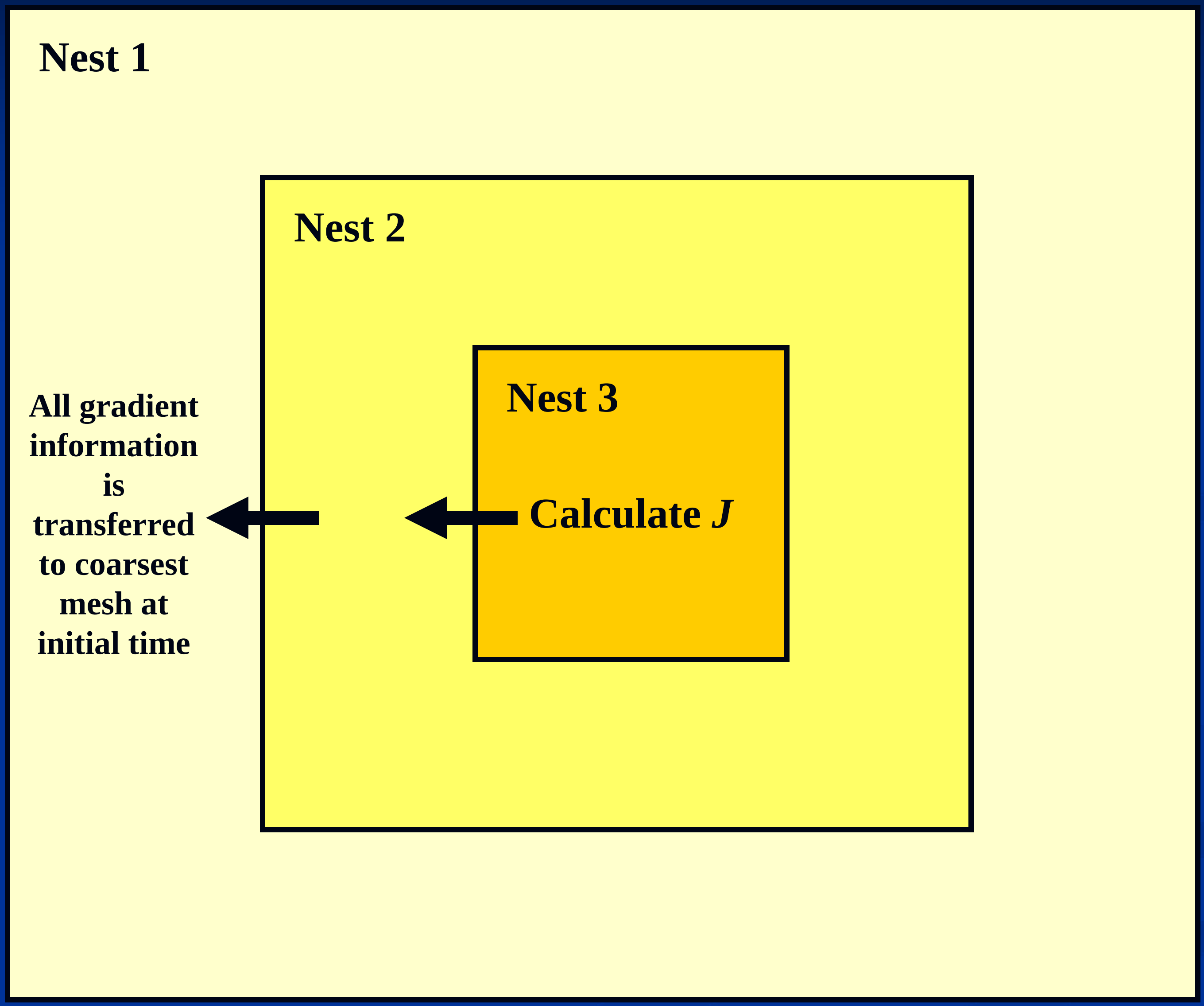
- Relocatable Limited Area Model for US Navy

- Distributed Memory Architecture

- Adjoint/Tangent Linear Model include parameterizations for TKE, surface fluxes, Kuo cumulus, moist physics (no radiation)

- Experimental Setup: 109x109x30 point in each of 3 telescoping nests
  45-15-5 km horizontal grid spacing
  1200 UTC 25 July 2007
  J is Kinetic Energy in a small volume

Adjoint Nested Model



Sensitivities are modified by grid spacing

$$\frac{1}{\Delta x \Delta y \Delta \sigma_z} \frac{\partial J}{\partial x_n}$$

Adjoint Nested Model

- Adjoint written for boundary communication and interpolation (fine nest – coarse nest)

- Removed single nest dependence in the adjoint model

- Expensive (trajectory saved for each nest) – 3 time steps for each subsequent finer mesh

Sensitivities are modified by grid spacing

$$\frac{1}{\Delta x \Delta y \Delta \sigma_z} \frac{\partial J}{\partial x_n}$$

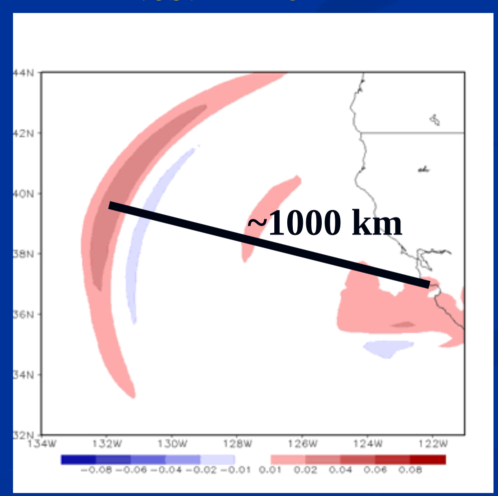
Acoustic Waves

- COAMPS is nonhydrostatic and compressible – slow and fast time step
- Smaller gradient values quickly pass through boundaries to coarser nest
- Move at speed of sound (300 m/s)
- Easy to see before main sensitivity area passes through the boundary
- Divergence damping filters acoustic modes
    - Has a much larger effect on adjoint fields than in the nonlinear model
    - Problems with stability in forward model so it is not implemented

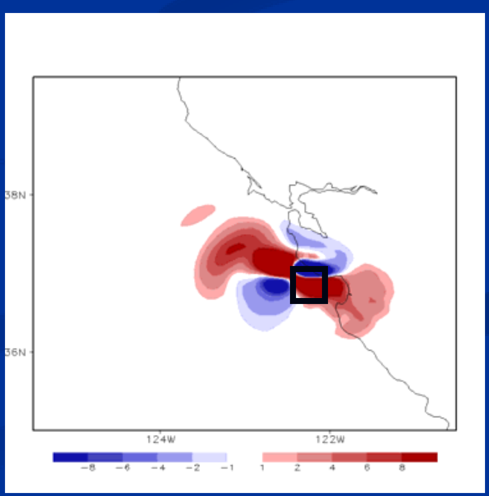
- 1 hr adjoint fields
- 1000 km / 1 hr ~ 300 m/s
- Acoustic wave signal is smaller then main sensitivity signal

$$\frac{\partial KE}{\partial u}$$

Nest 2 - 15 km



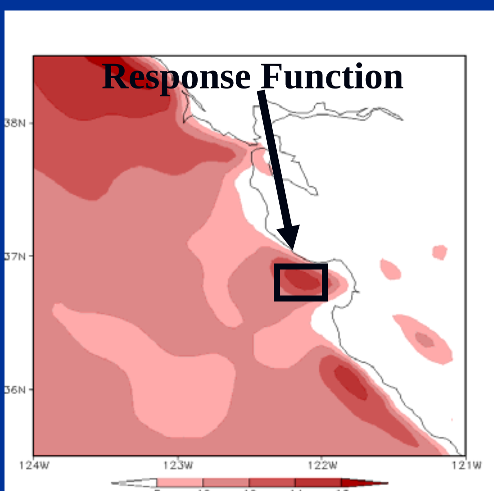
Nest 3 - 15 km



Adjoint Sensitivity

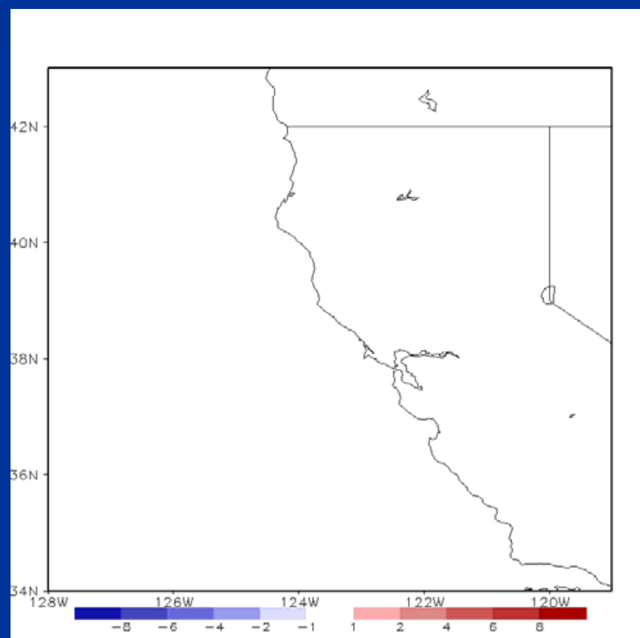
Response function is KE in 5 lowest model levels (100 m) near Monterey Bay
0000 UTC 26 → 1200 UTC July 25 2007 (12 h adjoint run)

$\frac{\partial KE}{\partial u}$ 2300 →1200 UTC, z ~ 300 m, multiplied by 10^{14}

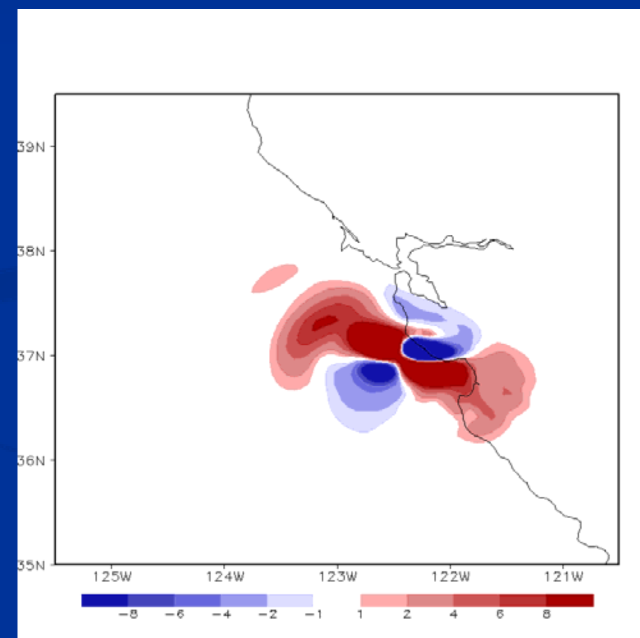


COAMPS 12 h 50 m Windspeed (m/s)
0000 UTC 26 July 2007

Nest 2 - 15 km



Nest 3 - 5 km

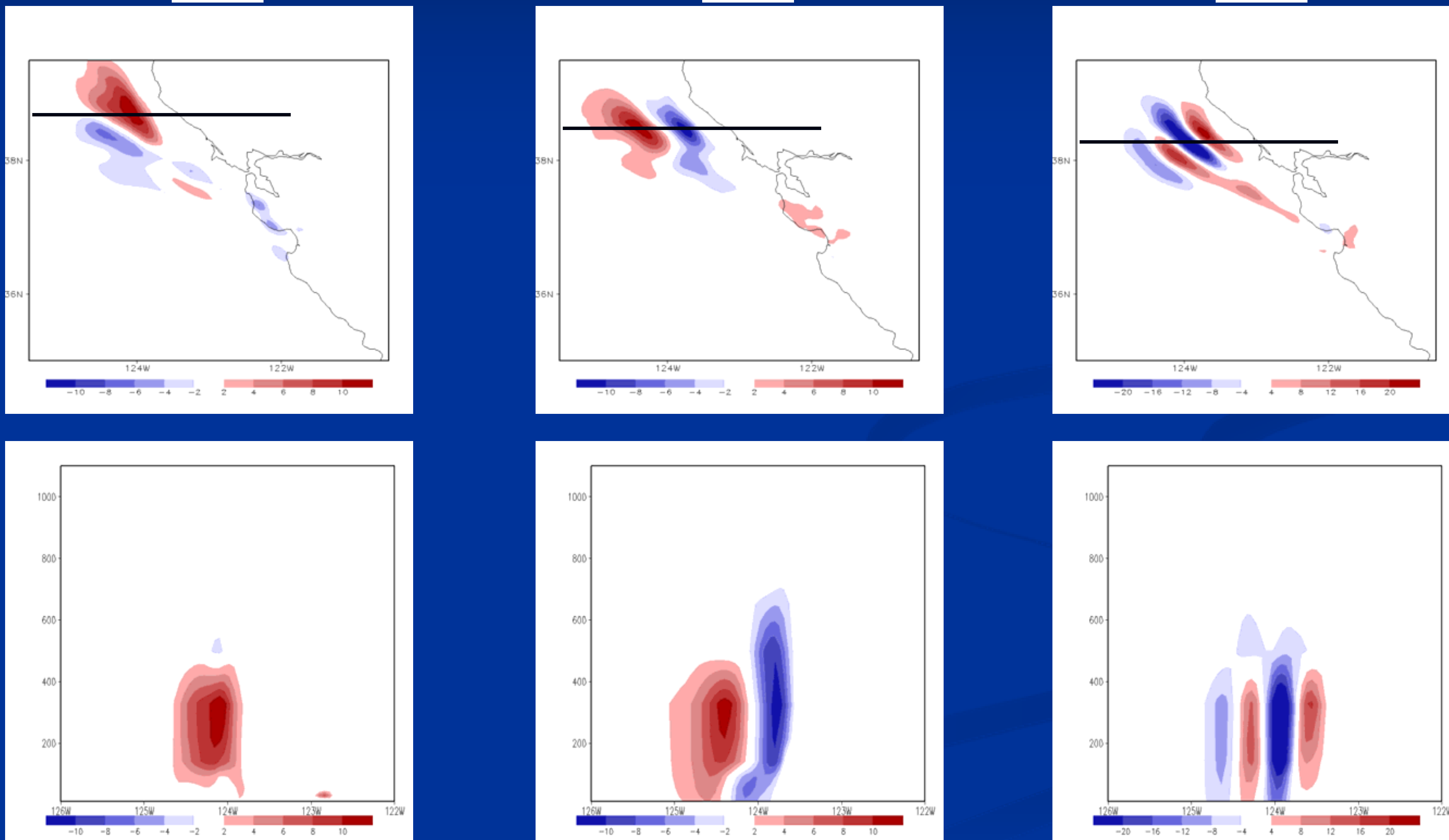


- Gradient information is not passed to Nest 1 through boundaries
- Largest sensitivities stay trapped in the coastal boundary layer
- Sensitivities move ~ 500 km / 12 hr – corresponding to advective speed

Adjoint Sensitivity

1800 UTC 25 July 2007, z ~ 300 m

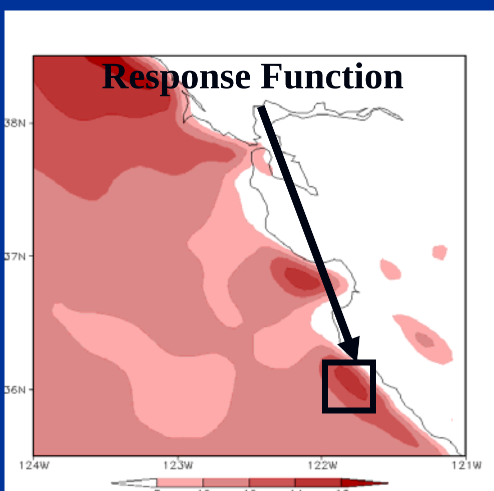
$\frac{\partial KE}{\partial u}$ $\frac{\partial KE}{\partial v}$ $\frac{\partial KE}{\partial \theta}$



Adjoint Sensitivity

Response function moved south of Monterey Bay

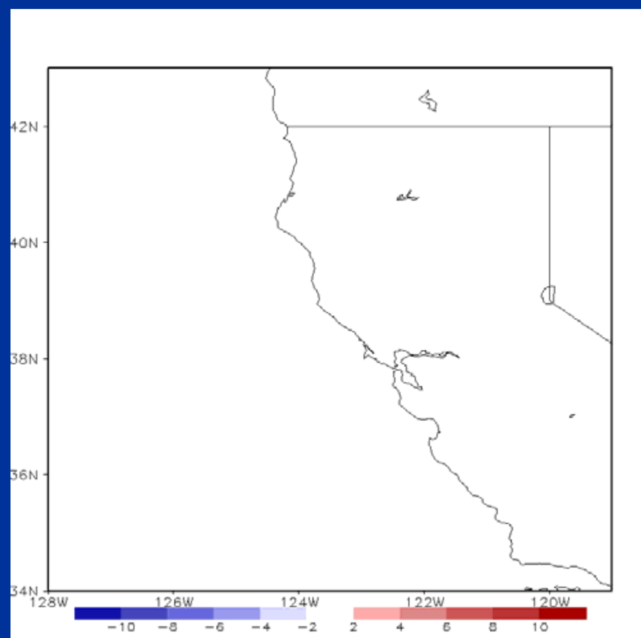
$\frac{\partial KE}{\partial u}$ 2300 $\rightarrow$1200 UTC, z ~ 300 m, multiplied by 10^{14}



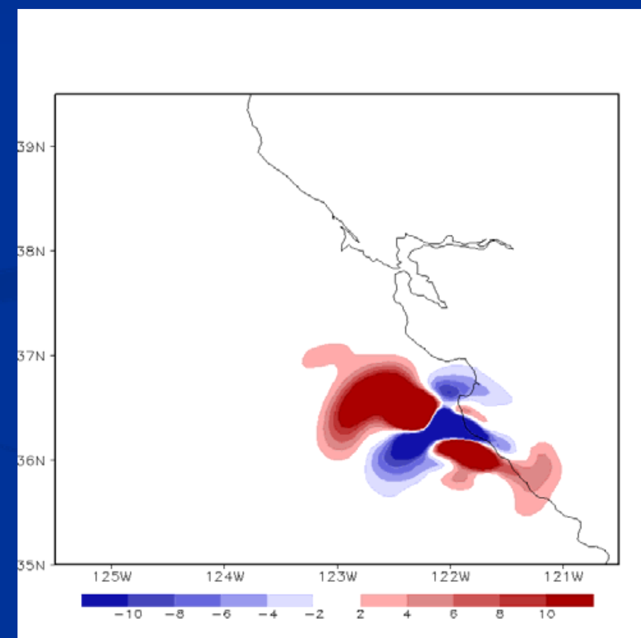
COAMPS 12 h 50 m Windspeed (m/s)

0000 UTC 26 July 2007

Nest 2 - 15 km



Nest 3 - 5 km

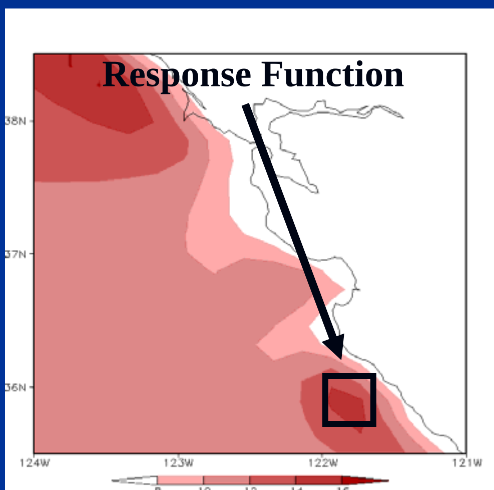


- Similar to previous case, gradient stays close to the coast and moves with similar speed

Adjoint Sensitivity

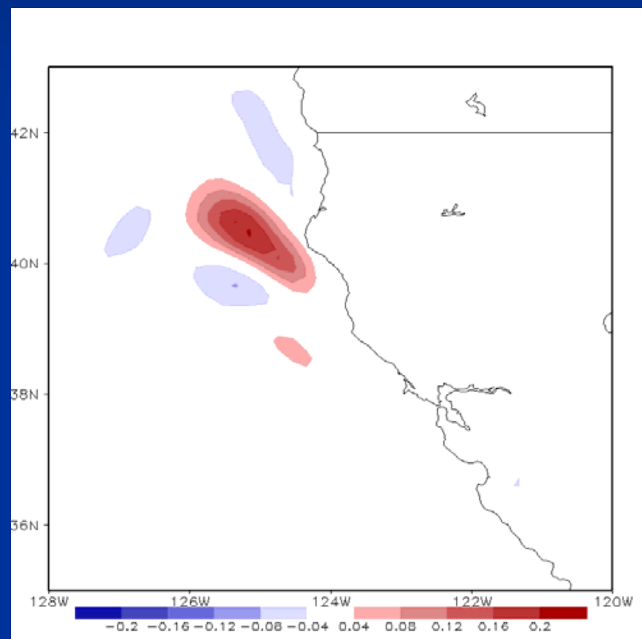
2 Nests vs. 3 Nests

Nest 2 (15 km)

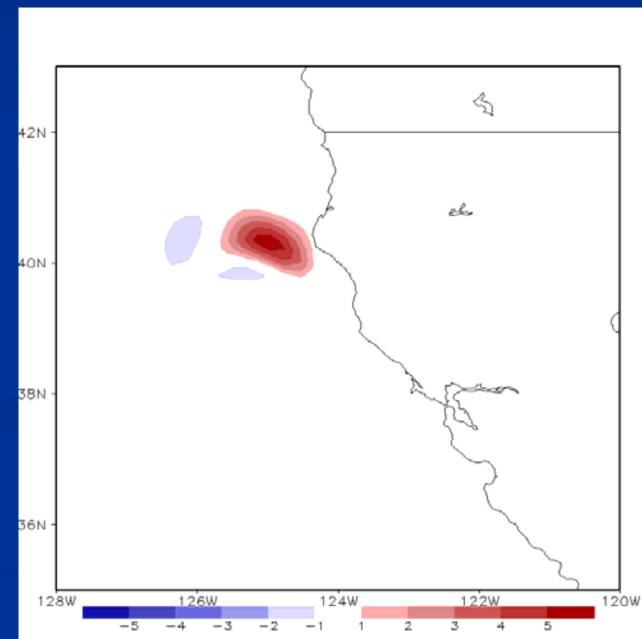


COAMPS 12 h 50 m Windspeed (m/s)
0000 UTC 26 July 2007

2 Nests



3 Nests



$\frac{\partial KE}{\partial u}$ 1200 UTC 25 July 2007, z ~ 300 m, multiplied by 10^{14}

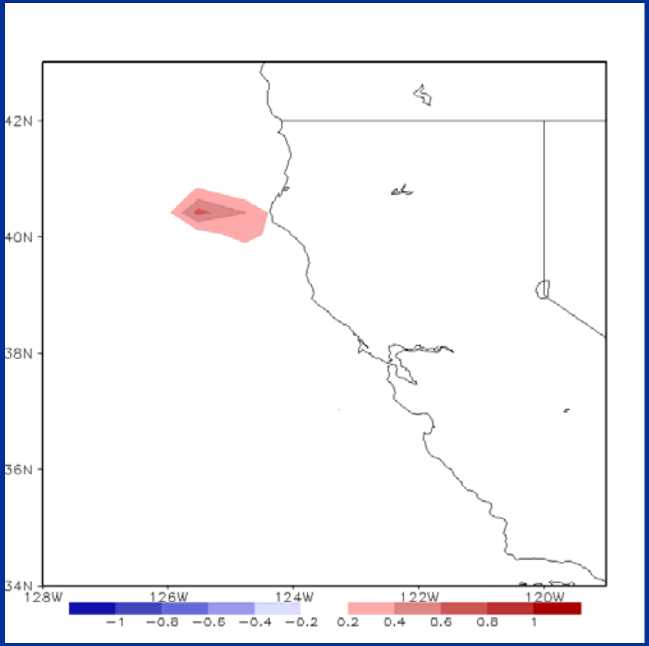
•Similar pattern, magnitude is larger for the 3 nest case

Perturbation Growth

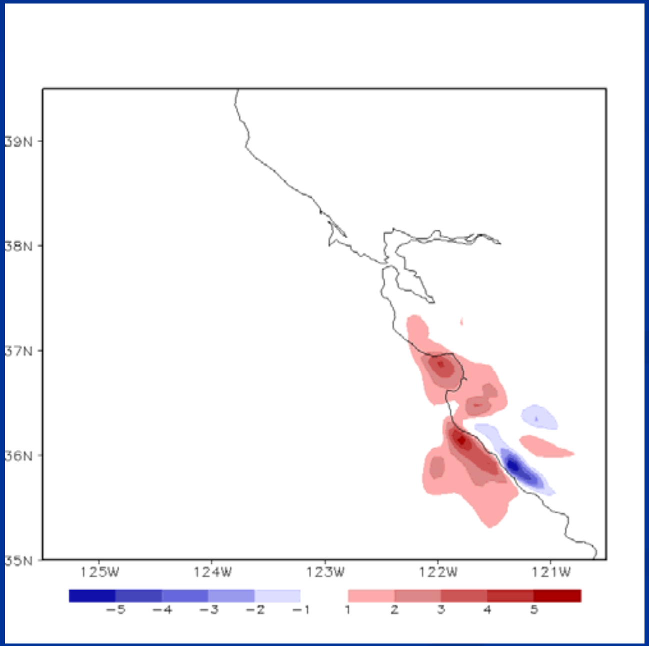
Adjoint Based Perturbations

$$x_j' = \frac{s}{w_j}\frac{\partial J}{\partial x_j}$$

w_j: weighting parameter
s: scaling parameter (u_{max}<1 m s^{-1})



Initial *u* perturbation – Nest 1
z ~ 300 m - 1200 UTC July 25 2007



TLM *u* 12 h forecast – Nest 3
z ~ 50 m - 0000 UTC July 26 2007

Summary

•Adjoint nested model passes information from fine scale mesh to coarse mesh

•Smaller grid spacing → larger sensitivity

•Largest gradient values move with advective speed in the boundary layer jet

•Sensitivities indicate that surface wind maxima depend on the strength of the upstream northwesterly flow in the jet and the boundary layer temperature

•Perturbation growth ~ 5 times