# Quantifying the sensitivity of internal waves in the Philippine Sea

The 9th Workshop on Adjoint Model Applications in Dynamic Meteorology – Cefalu, Siclily
- 10th October 2011 -

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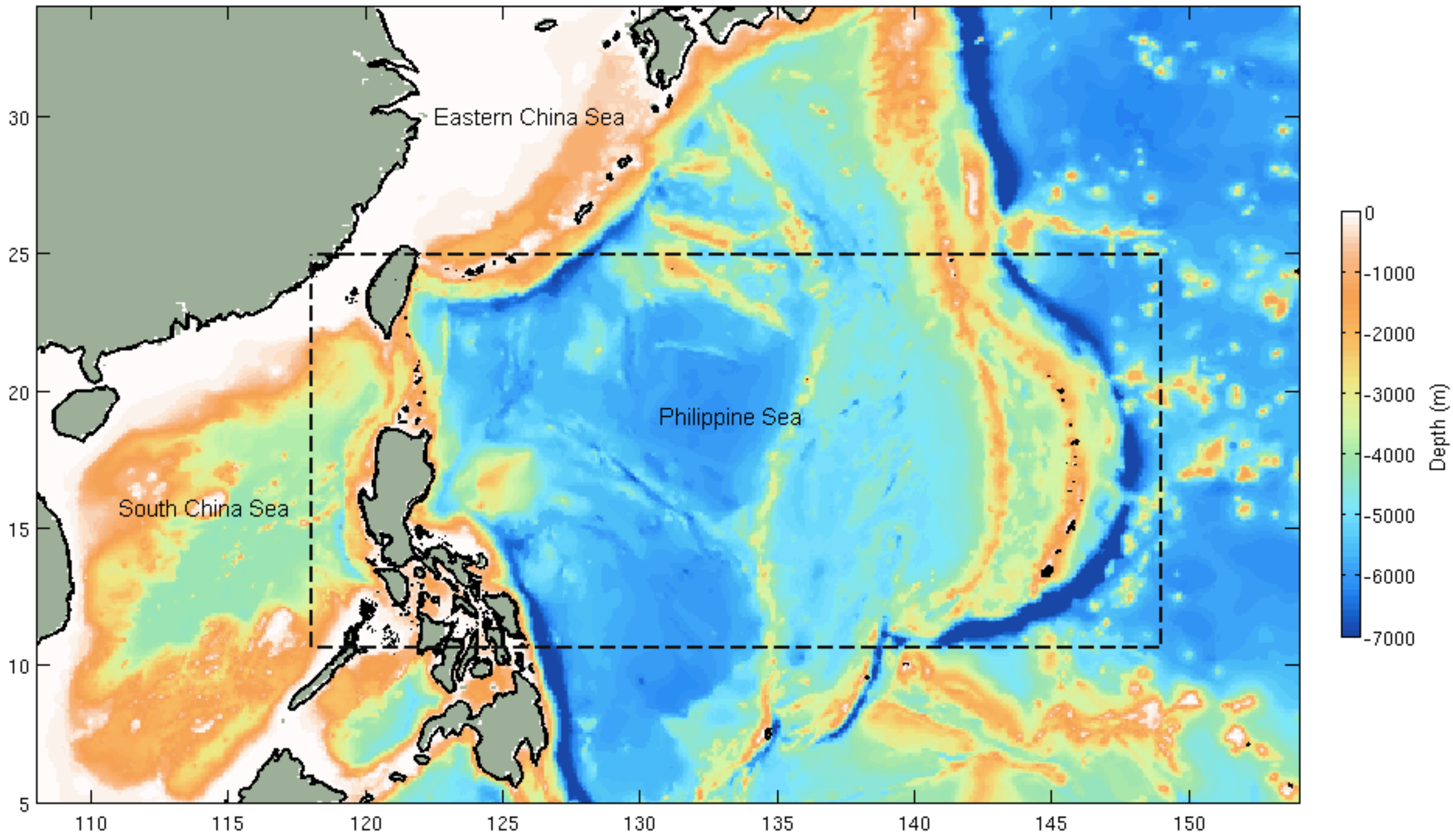
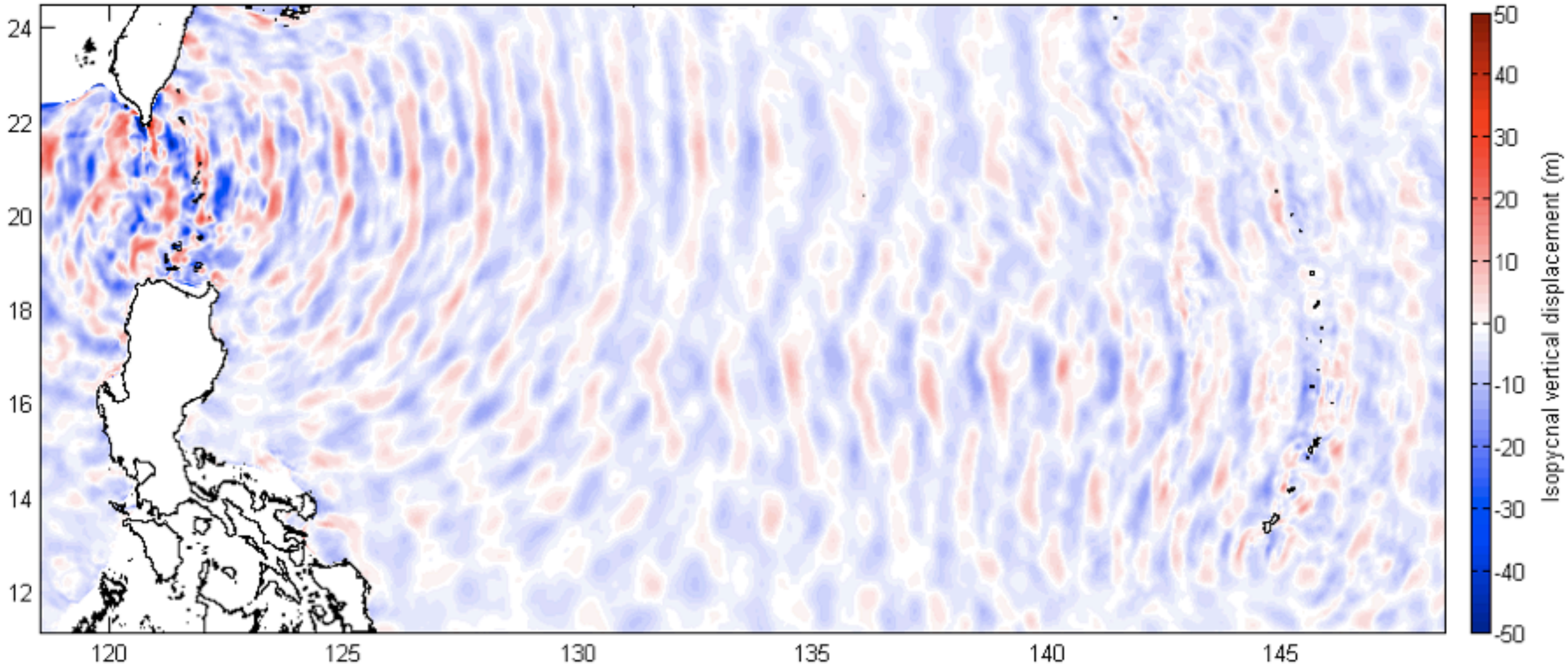
# The Philippine Sea



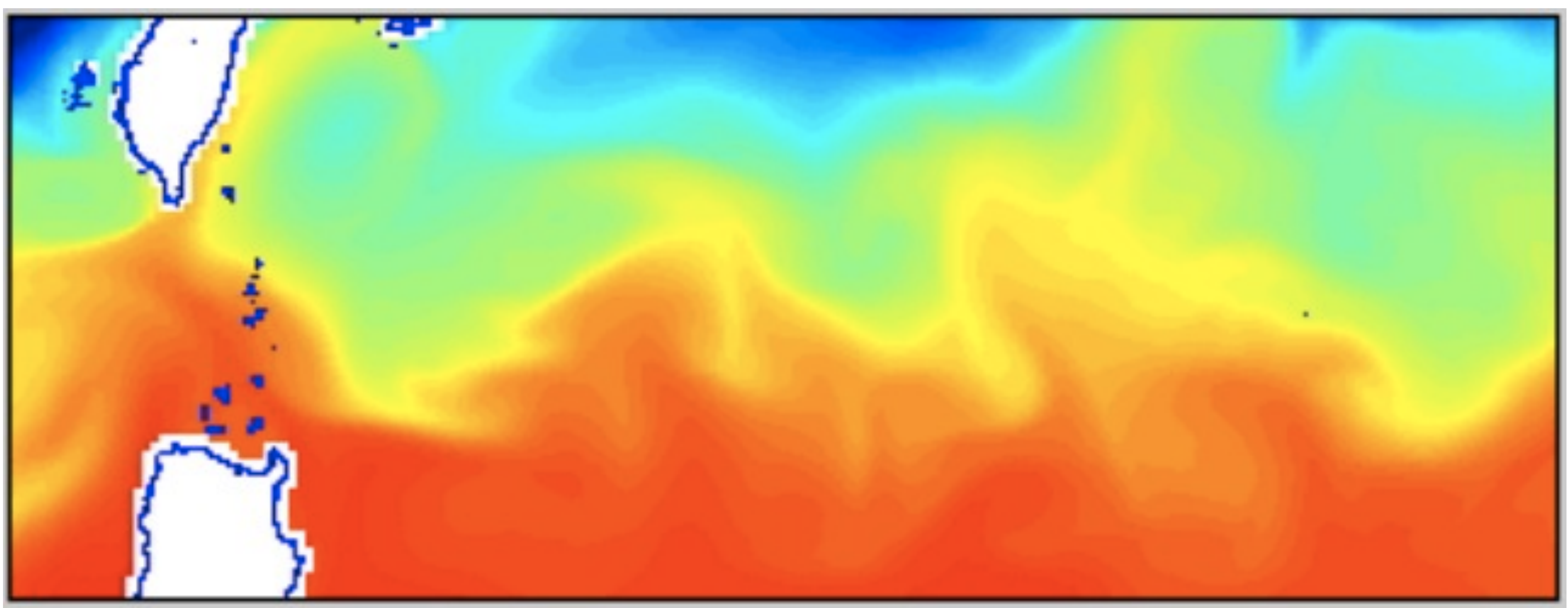
# Internal tides




- Energy loss from the barotropic tide to the open ocean
- Turbulence and mixing of the deep ocean (eg. Kuroshio front and the South China Sea)
- Baroclinic currents

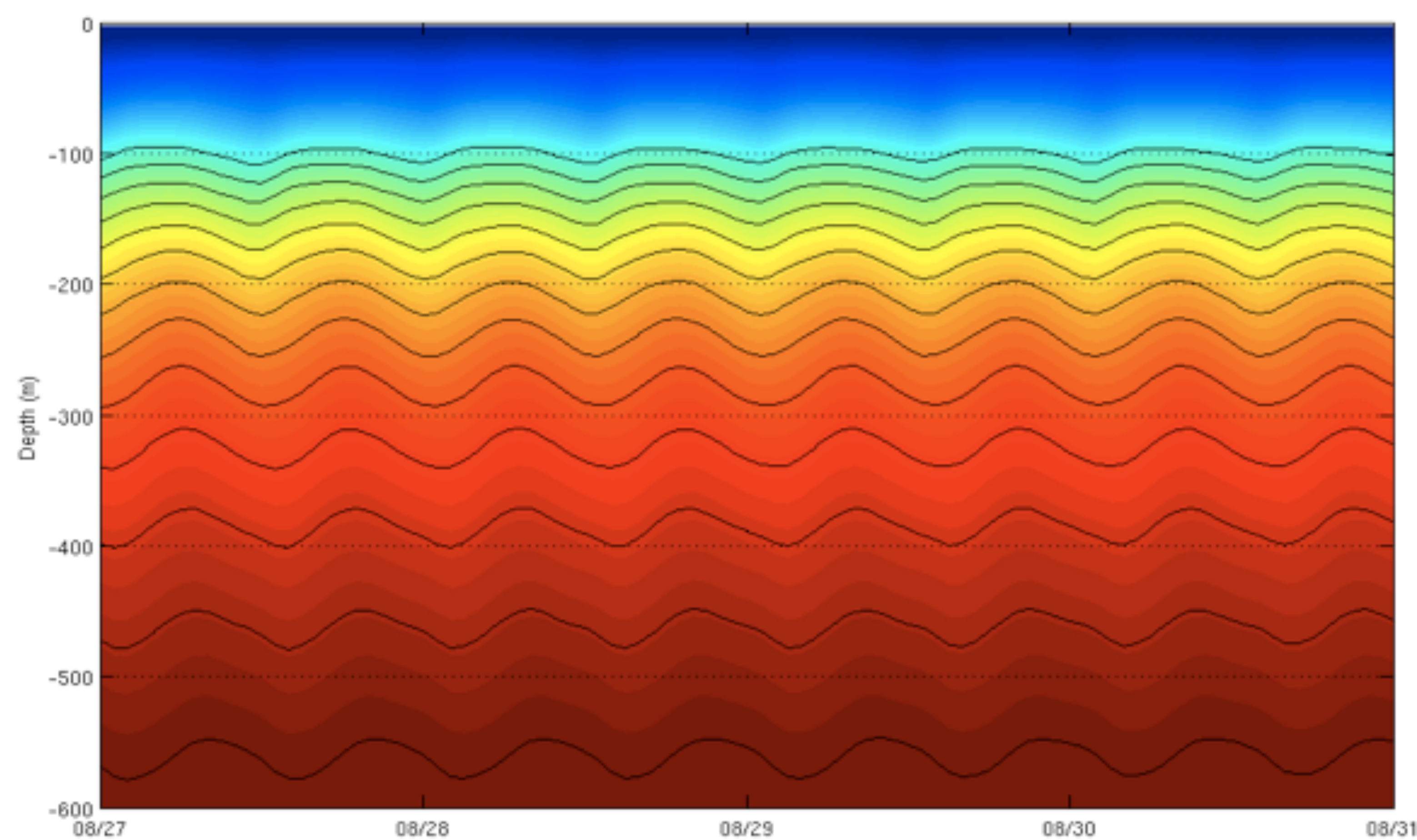
# Predicting and observing the ocean state

- Typically focus on mesoscale
- How do internal waves affect the predictive skill?



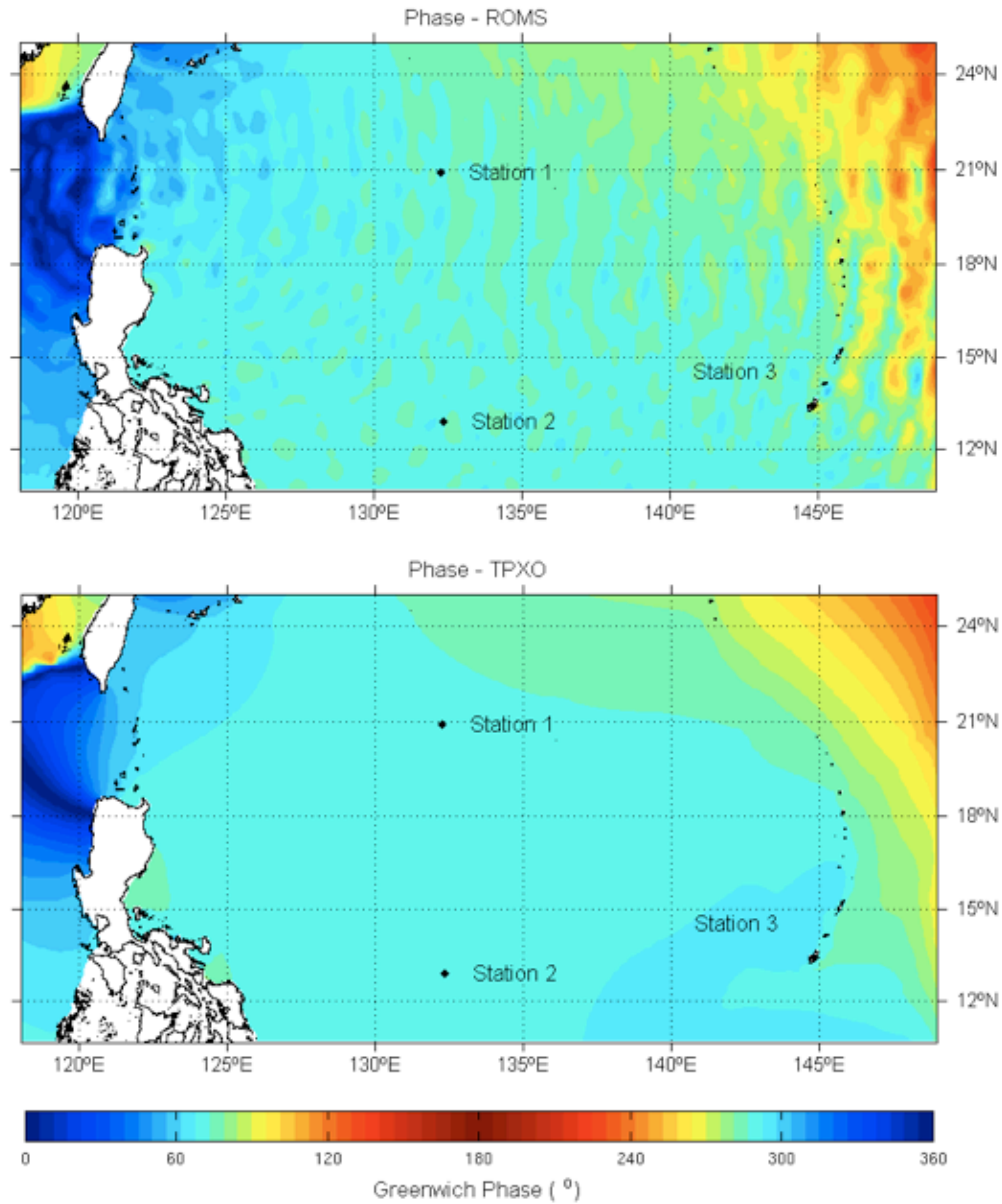
# Predicting and observing the ocean state

- Typically focus on mesoscale
- How do internal waves affect the predictive skill?
  - How does internal tide generation vary?
  - How do internal waves affect observations of the ocean state?



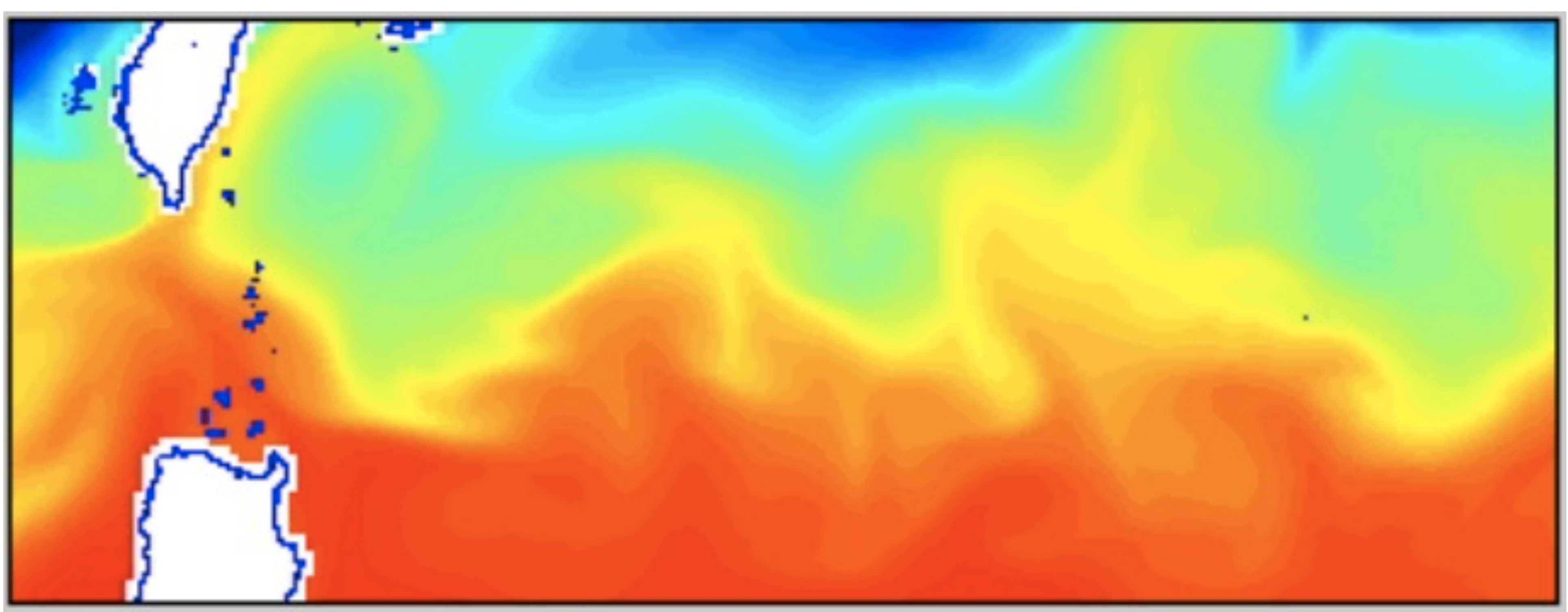
# Tidal Model

- Regional Ocean Modeling System (ROMS)
- Free-surface, hydrostatic, terrain-following, primitive equation ocean model
- 8 km horizontal resolution, 40 sigma-levels
- Boundary forcing from TPXO: $M_2$ Only
- Uniform stratification



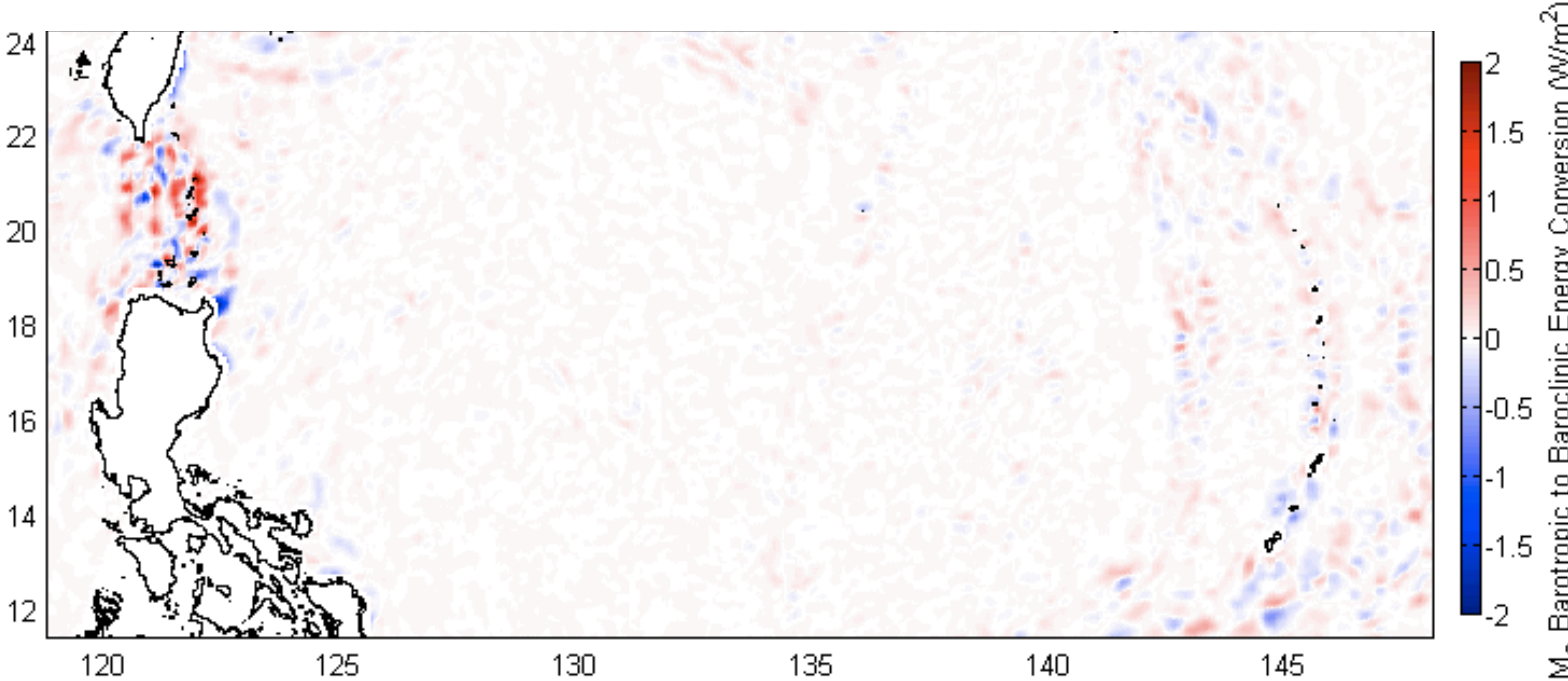
# Mesoscale Model

- Regional Ocean Modeling System (ROMS)
- 12 km horizontal resolution, 25 sigma-levels
- Boundary forcing from global model HyCOM
- Atmospheric forcing from NCEP



# Internal Tide Generation –

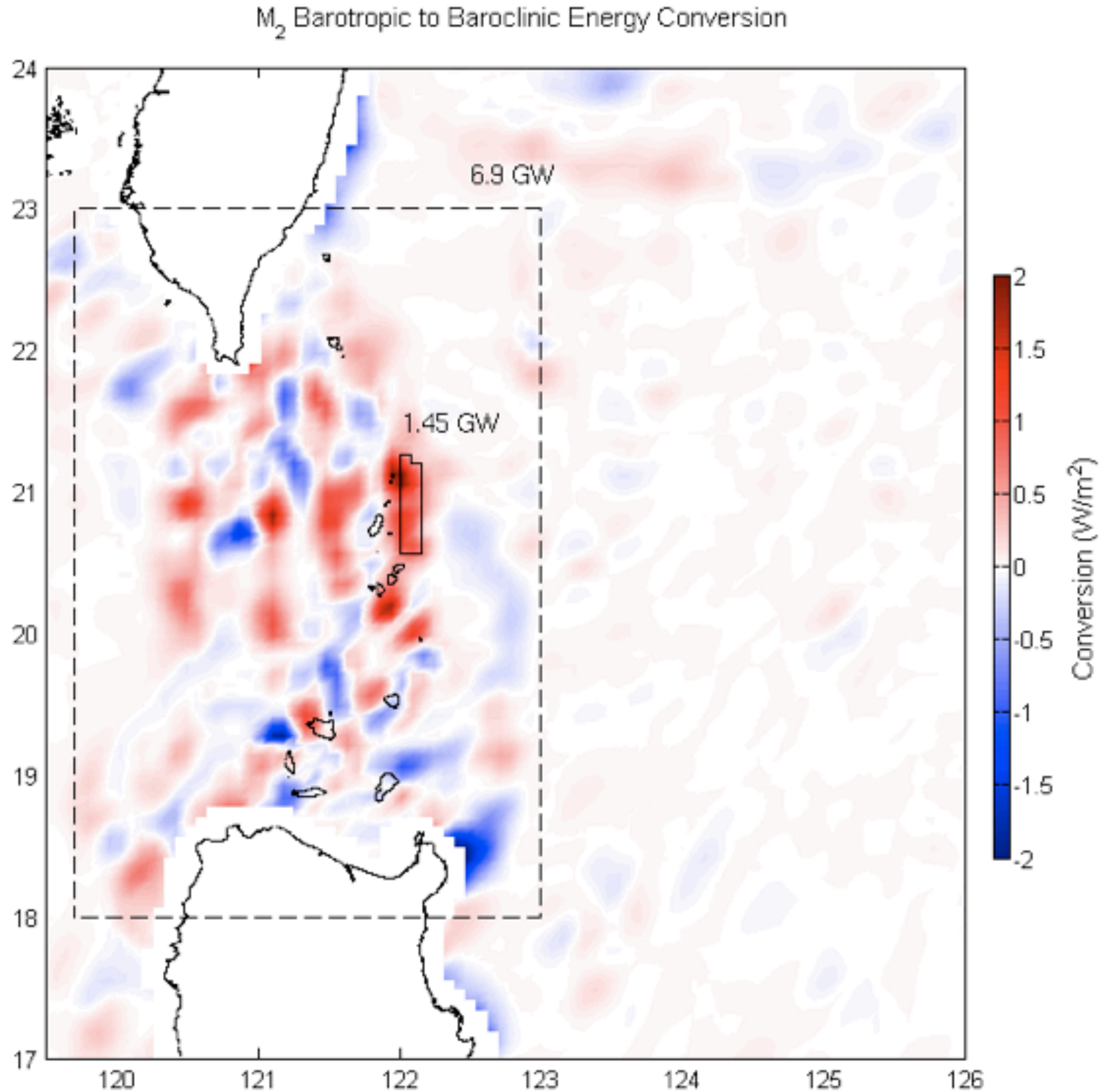
## Barotropic to Baroclinic Energy Conversion




$$Conv = \left\langle \left( P'(-H) - \frac{1}{H}\int_{-H}^{0} P'(z)\mathrm{d}z \right) \cdot \bar{\mathbf{u}}_{\mathrm{M}_2} \cdot \nabla H \right\rangle_{\mathrm{M}_2}$$

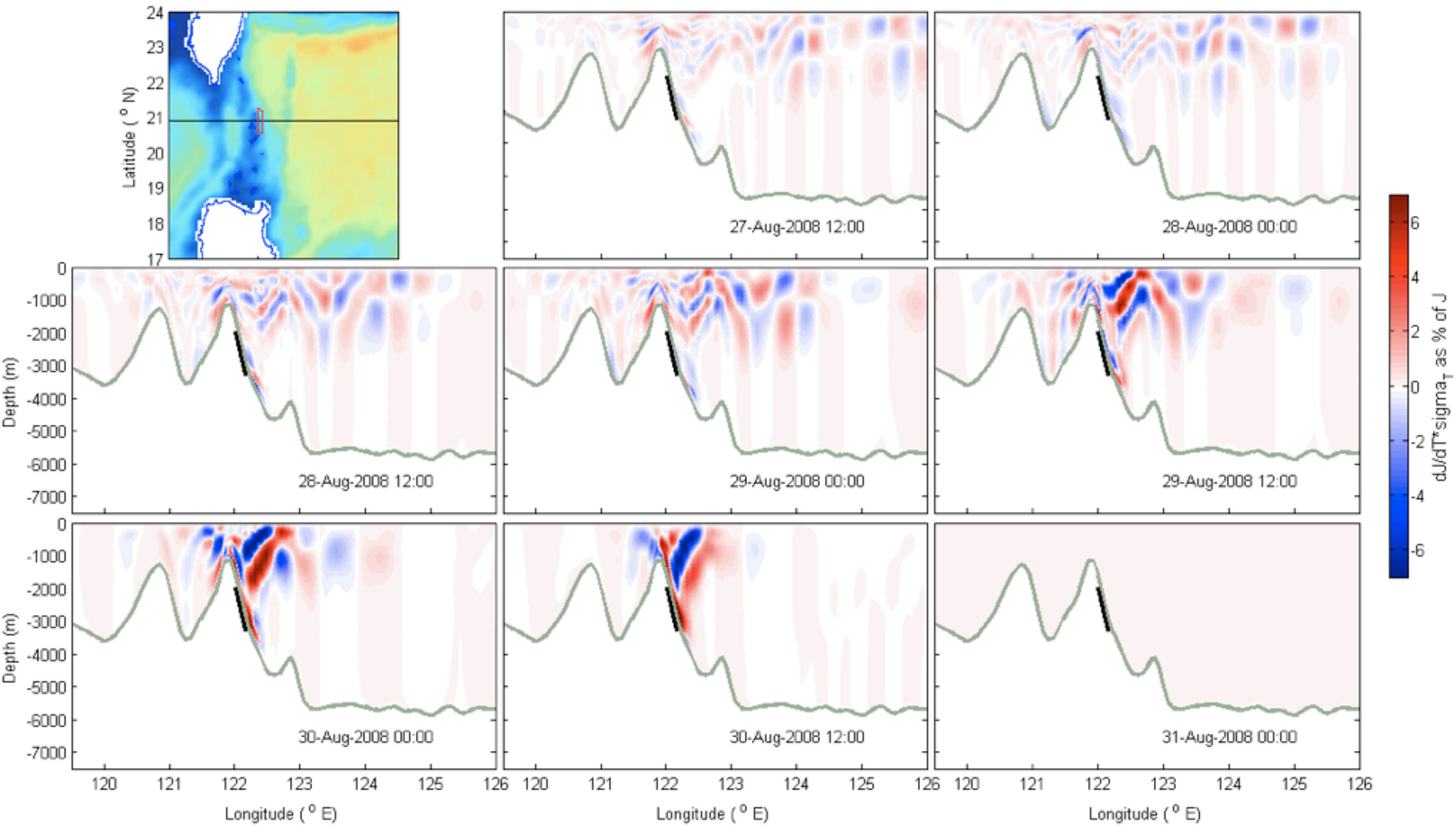
$$P'(z) = P(T(z), S(z), z) - \langle P(T(z), S(z), z) \rangle$$

# Adjoint sensitivity of conversion



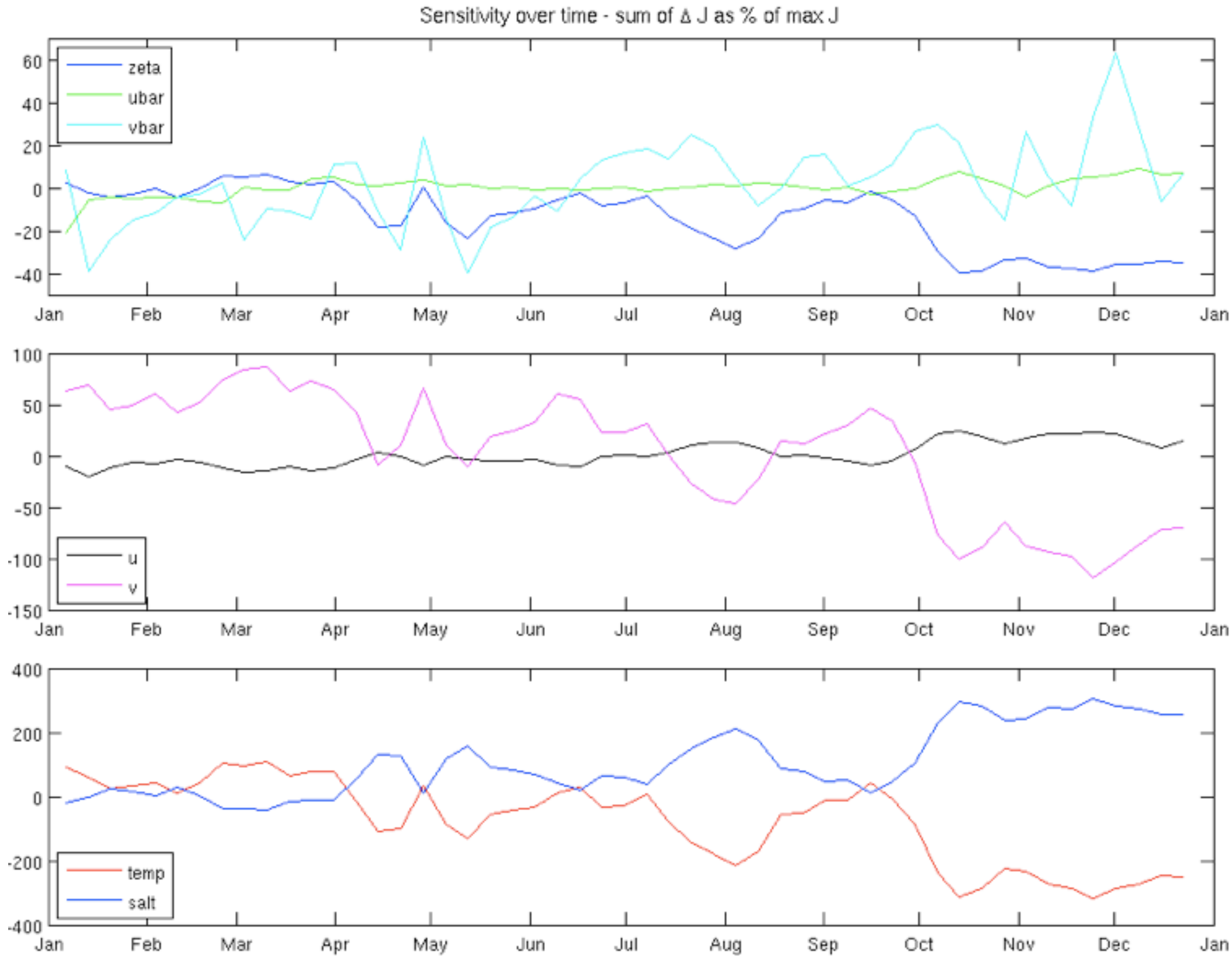

$$J = \frac{1}{TA} \int_A \int_T (P' - P_s)_{bot} * W_{bt,bot} \, dA \, dt$$

# Sensitivity to temperature - tidal



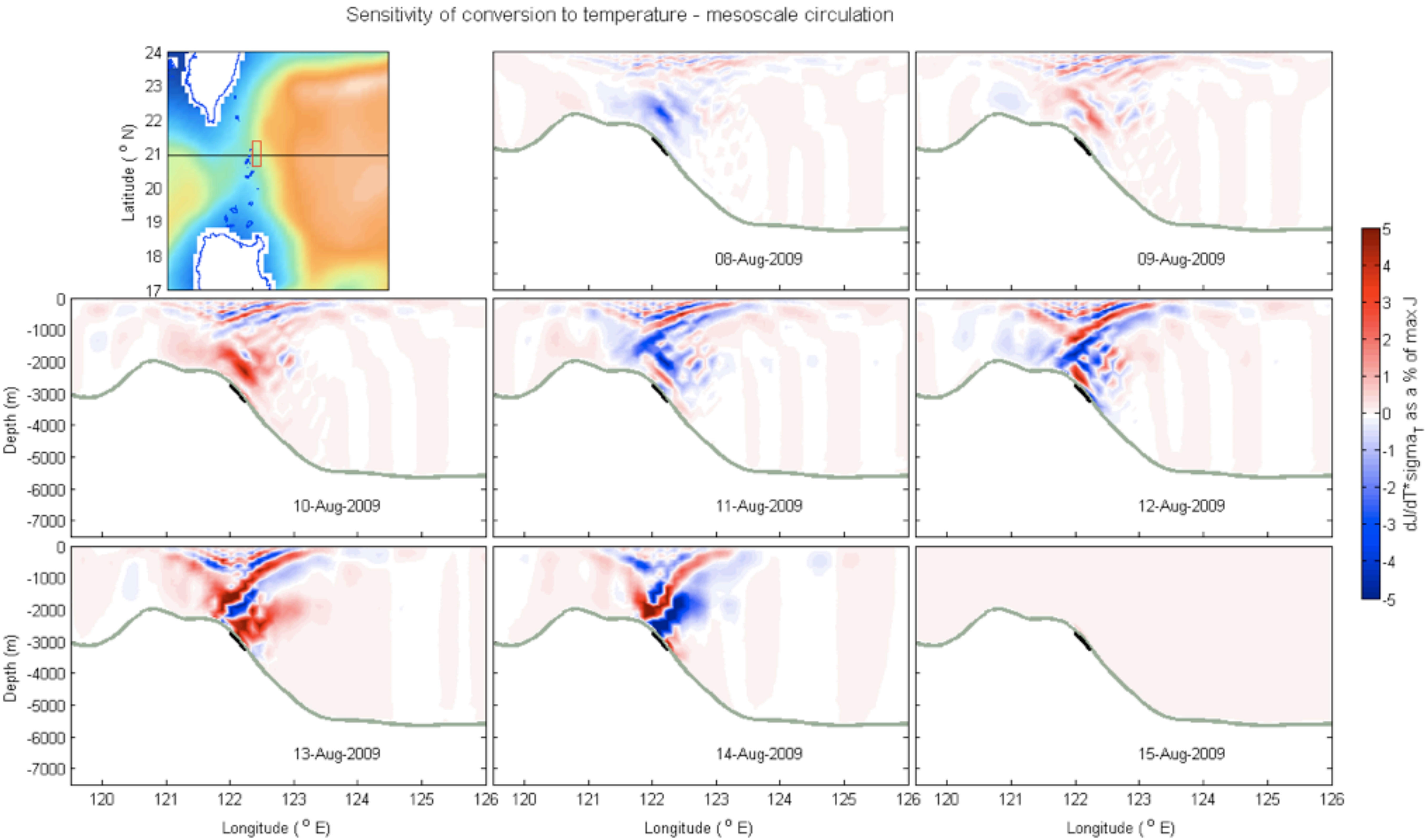

$$\Delta J = \partial J / \partial T * \sigma_T$$

# Sensitivities to varying mesoscale

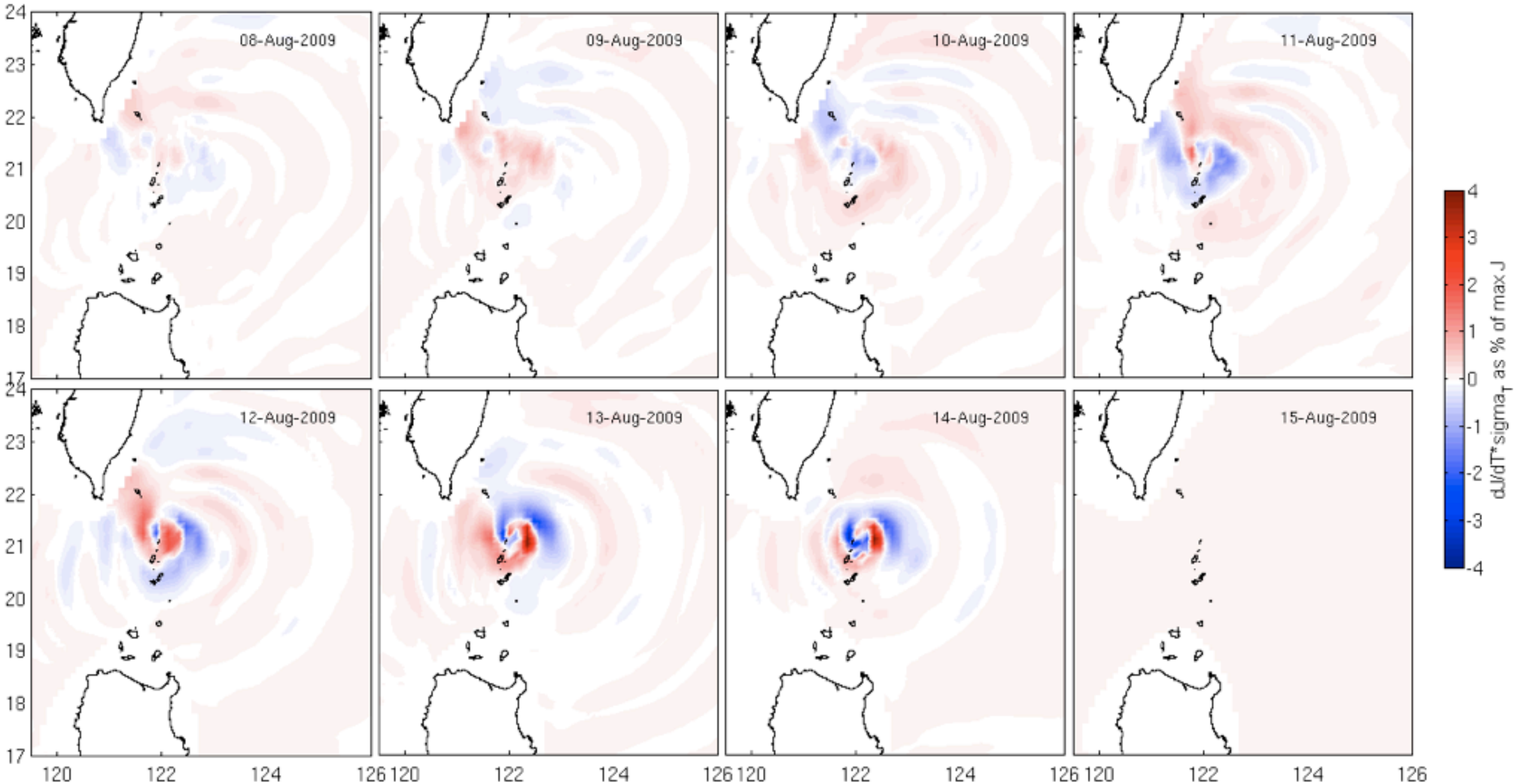



$$\Delta J = \sum_A \partial J / \partial var * \sigma_{var}$$

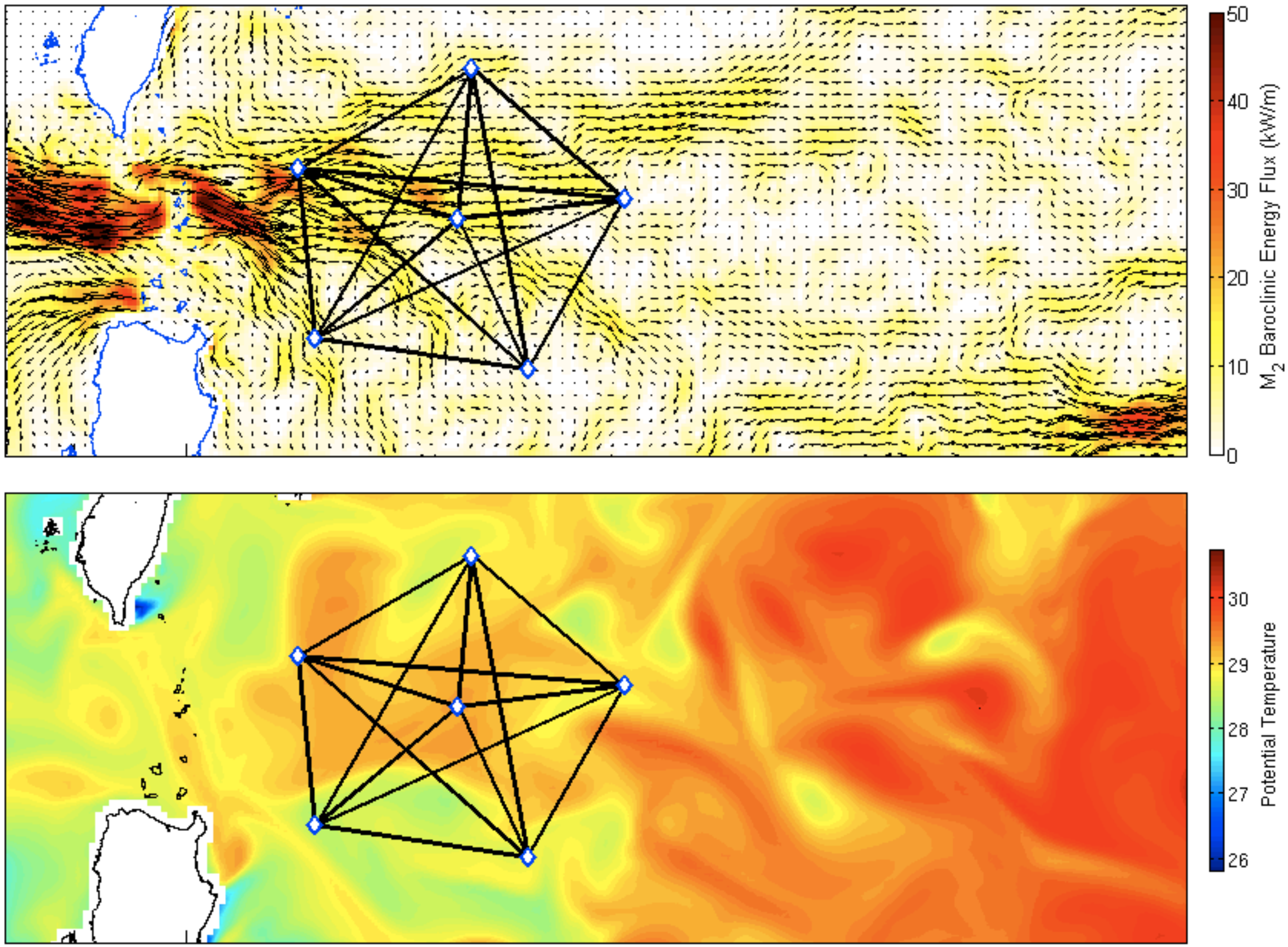
# Sensitivity to temperature - mesoscale



# Sensitivity to temperature - mesoscale

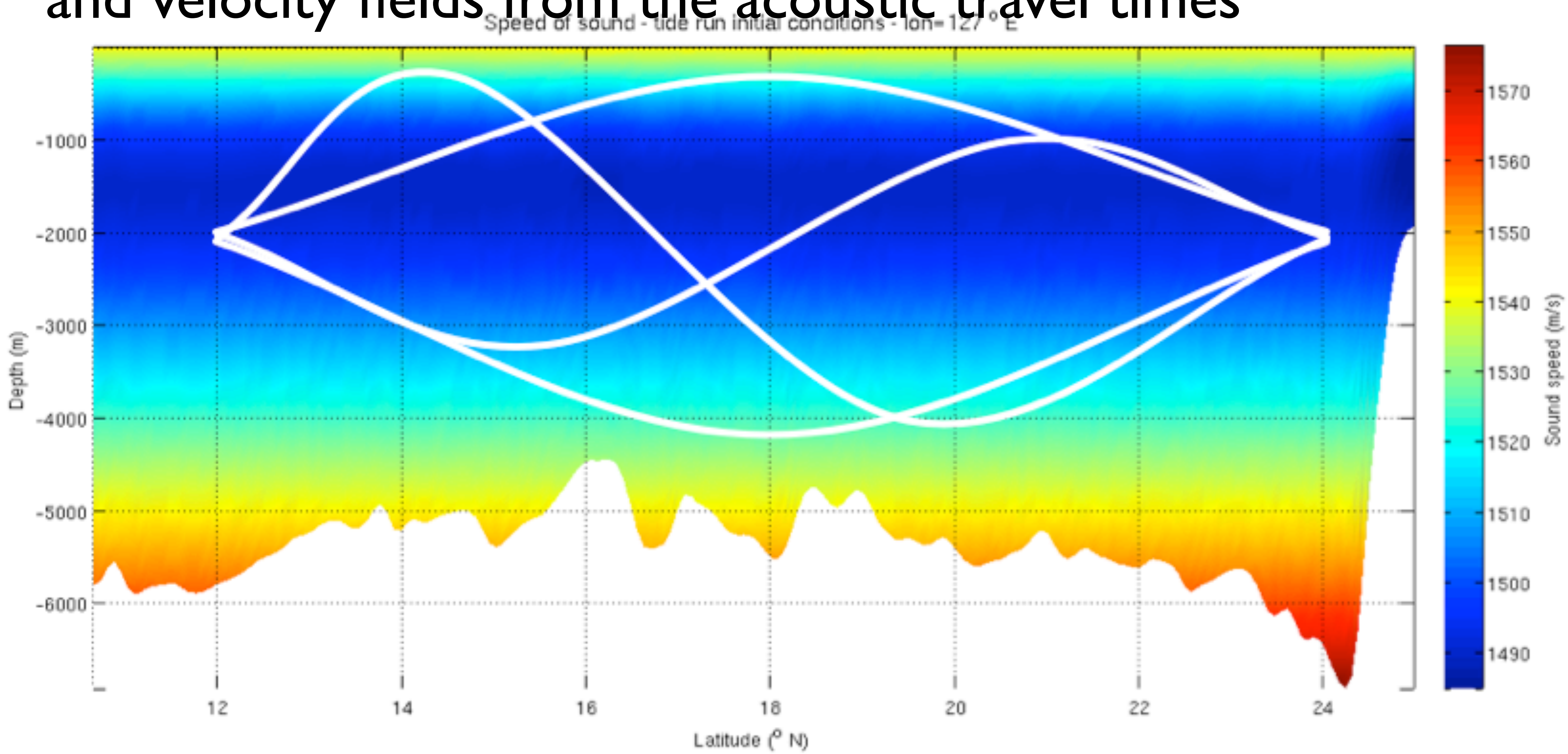


# Observations of the Ocean using Acoustic Tomography

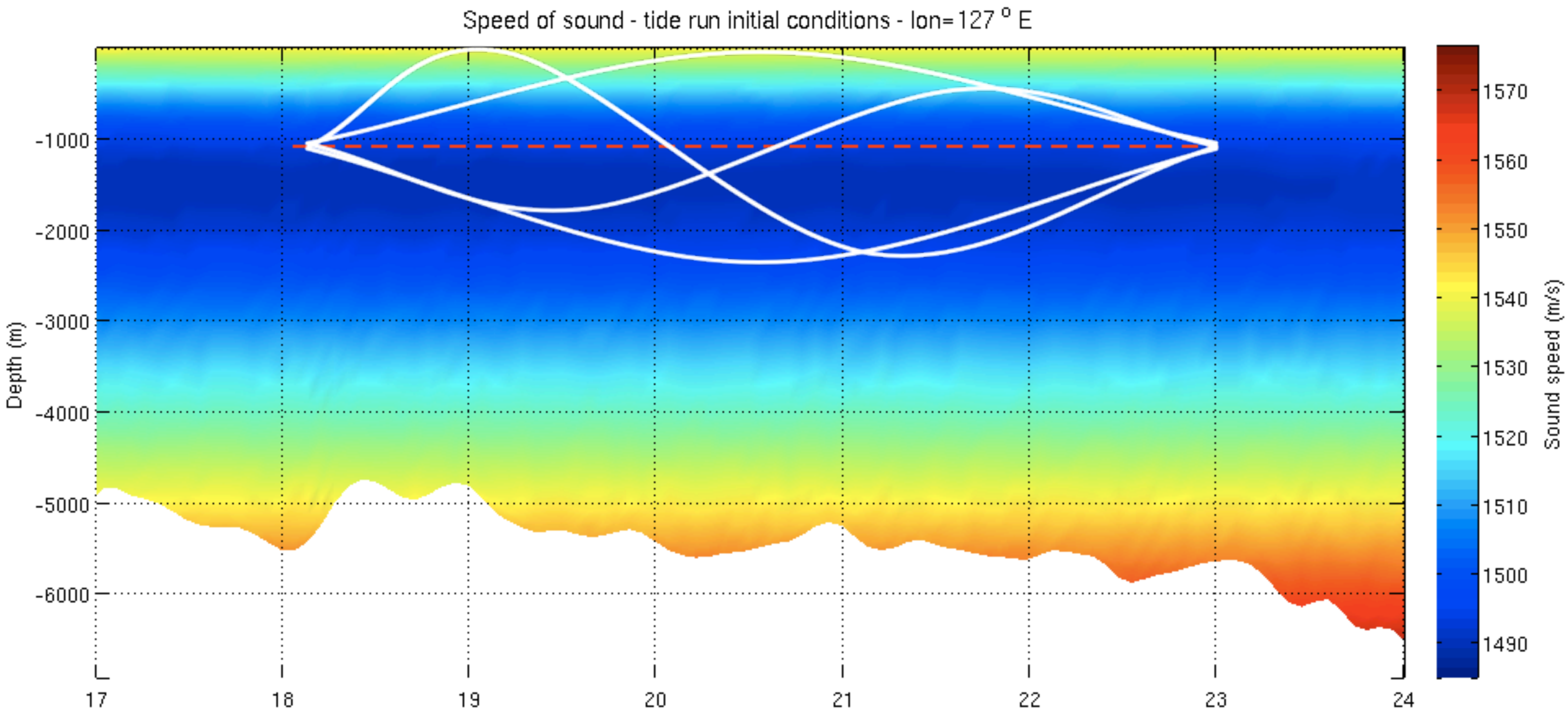


# Acoustic tomography

- Speed of sound function of temperature and pressure
- Acoustic signals travel along a set of ray paths, multiple arrivals at the receiver
- Inverse problem -  reconstruct the sound speed (temperature) and velocity fields from the acoustic travel times

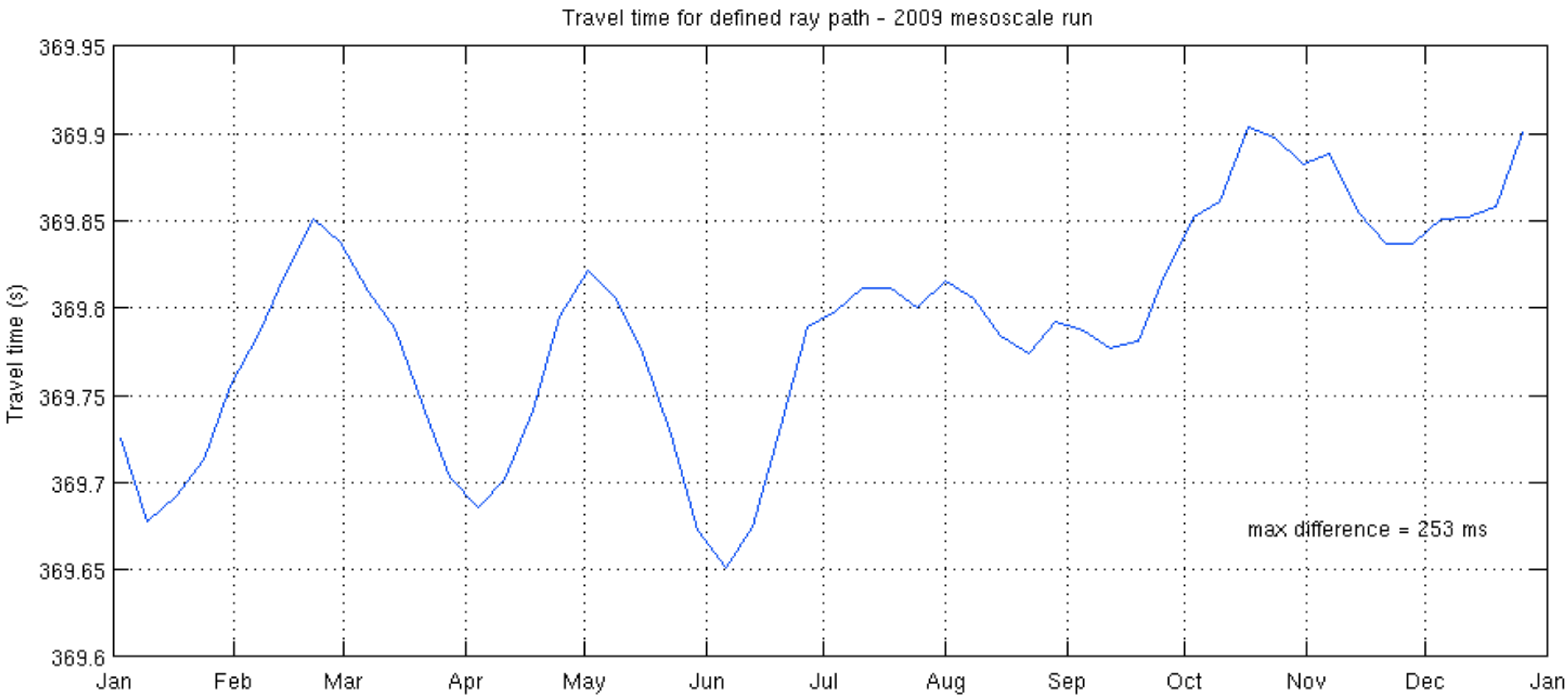


# Adjoint sensitivity of travel time

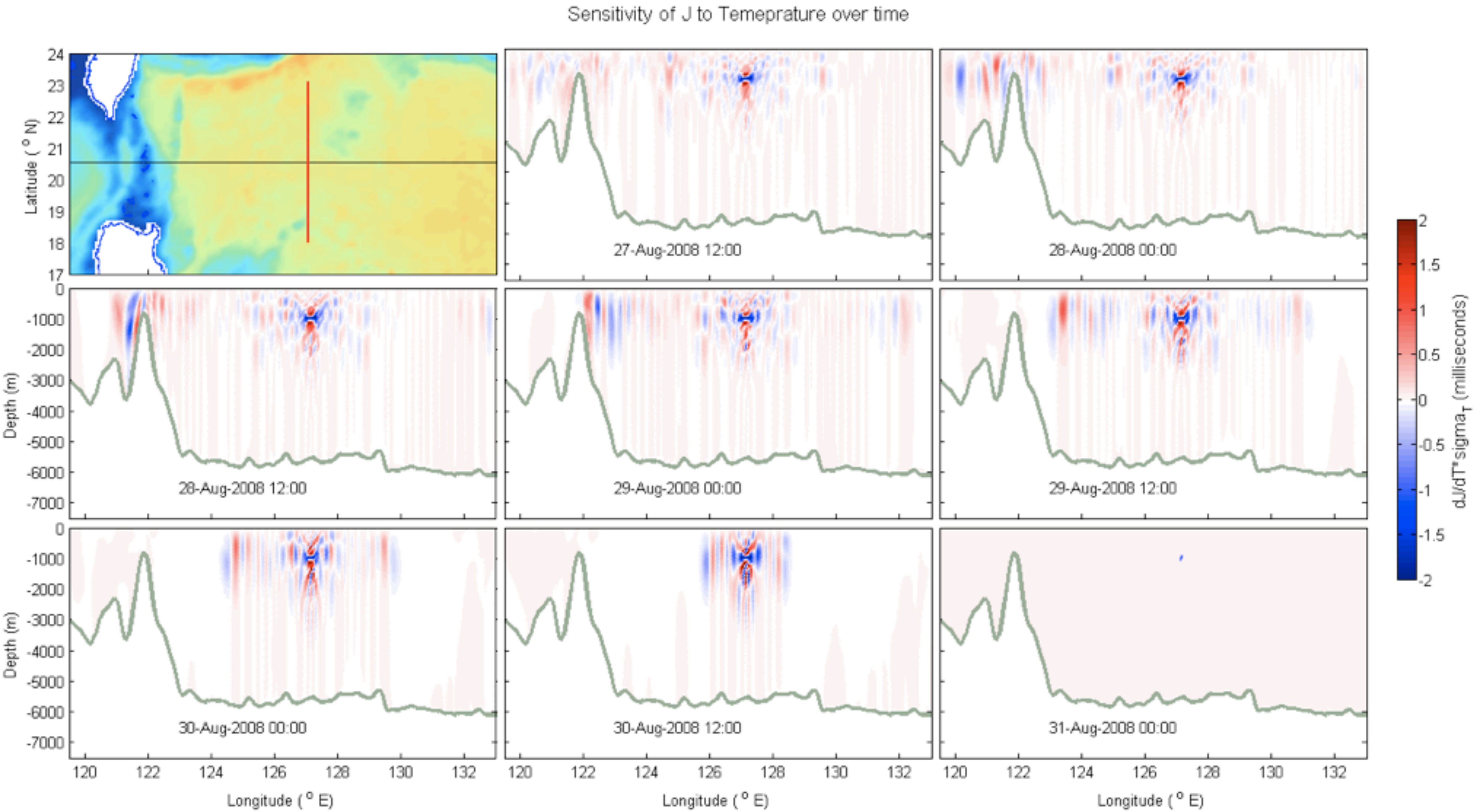



$$J = \int_l \frac{1}{c_{sound}}\, dl$$

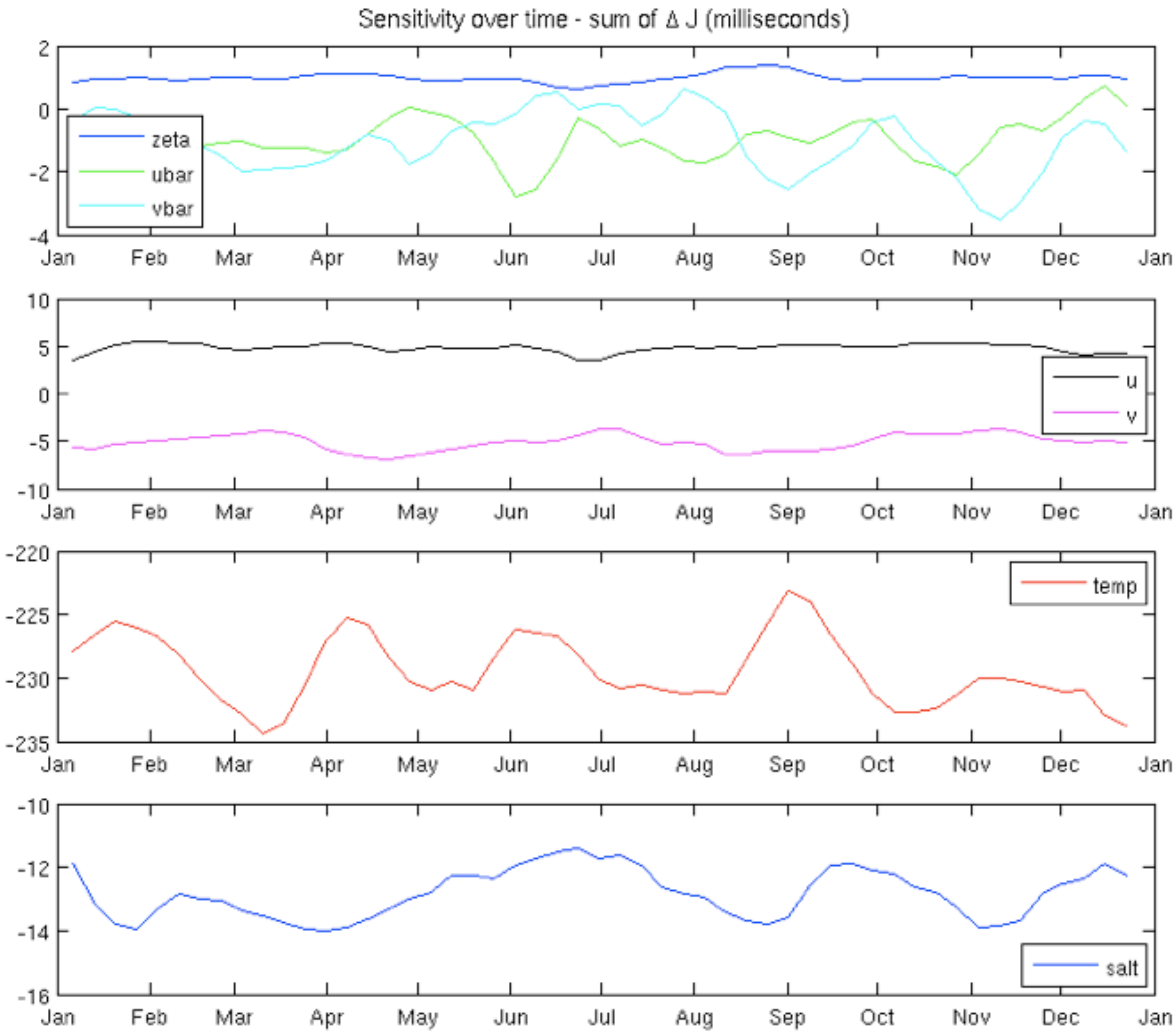
# Travel time variation with mesoscale



# Sensitivity to temperature - tidal

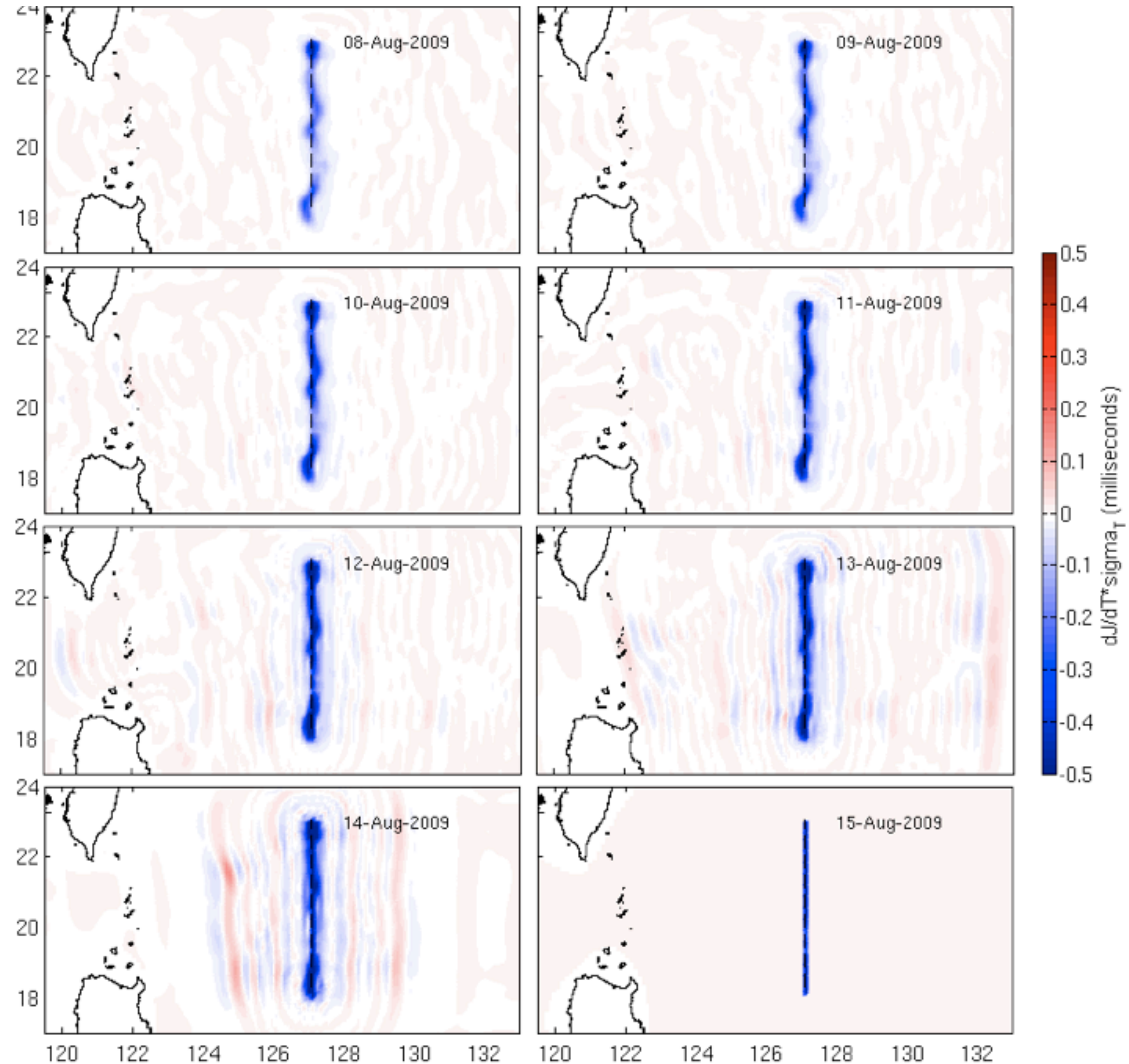


# Sensitivities to varying mesoscale




$$\Delta J = \sum_{A} \partial J / \partial var * \sigma_{var}$$

# Sensitivity to temperature - mesoscale



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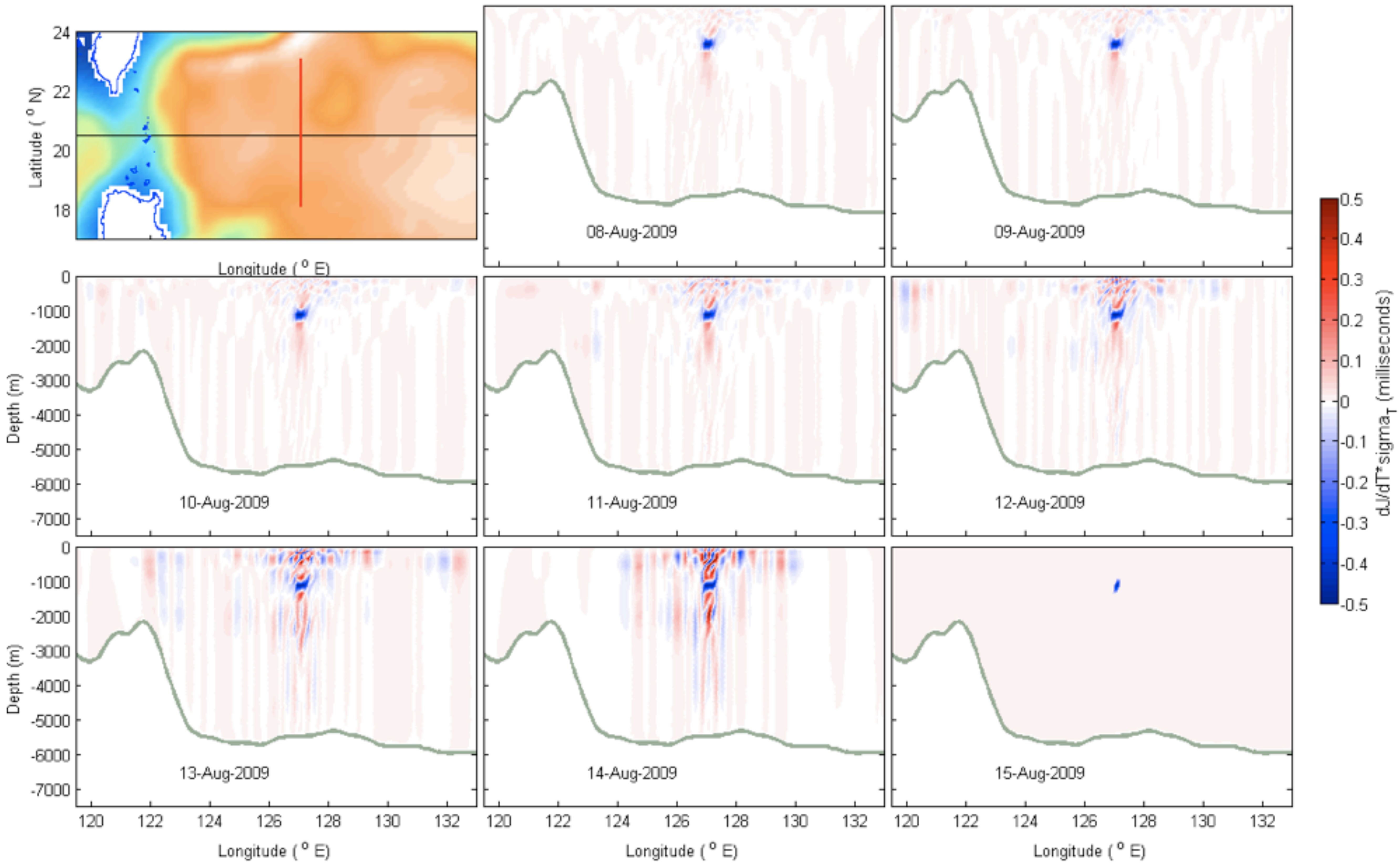

# Conclusions

- Mesoscale changing generation of internal tides
- Internal tides important impact on acoustic travels times

Next Steps -

- Assimilation of acoustic data – need to include internal tides
- Sensitivities for different ray paths where we have surface and bottom bounces – are internal waves still significant?