THE CALIFORNIA CURRENT IN THE CLIMATE SYSTEM: ANALYSIS OF OBS.

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« Time-series analysis in Marine science and applications for industry »

Conference in Logonna-Daoulas, France, 17-22 sept. 2012

California Current Introduction

- Eastern boundary: influenced by gyre, coastally trapped waves, local winds
- Productive ecosystem, important fisheries
- Moderates climate for California coast
- Expectations of climate change and other anthropogenic effects

California Cooperative Ocean Fisheries Investigations

- Started 1949
- Reaction to collapse of sardine fishery
  - Due to fishing? Climate?
  - Ecosystem dynamics?
- Partnership:
  - California Department of Fish and Game
  - NOAA Fisheries Service
  - Scripps Institution of Oceanography

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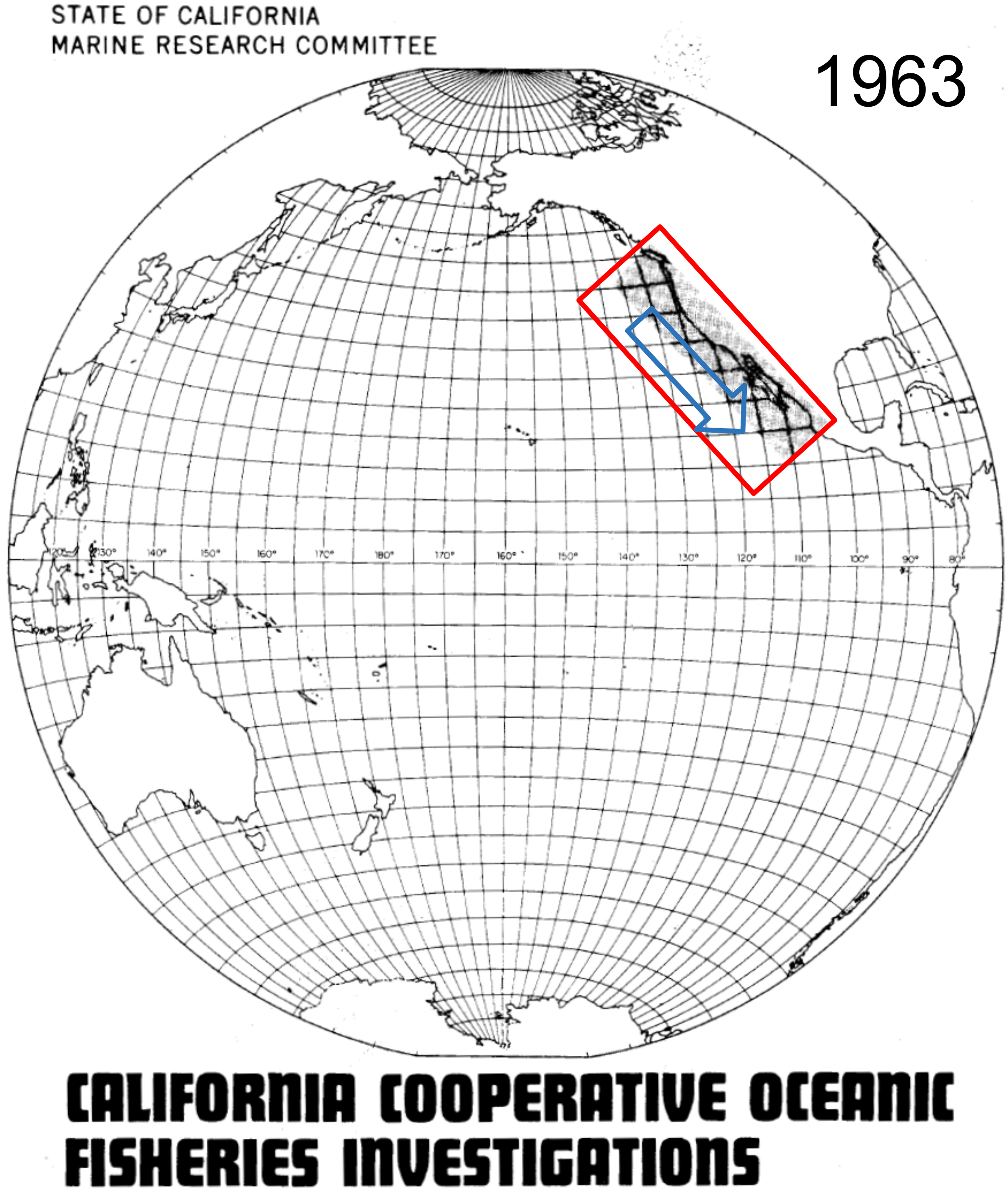
Data collected at depths down to 500 m include: temperature, salinity, oxygen, phosphate, silicate, nitrate and nitrite, chlorophyll, transmissometer, PAR, C14 primary productivity, phytoplankton biodiversity, zooplankton biomass, and zooplankton biodiversity.

1963



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(1949 only)

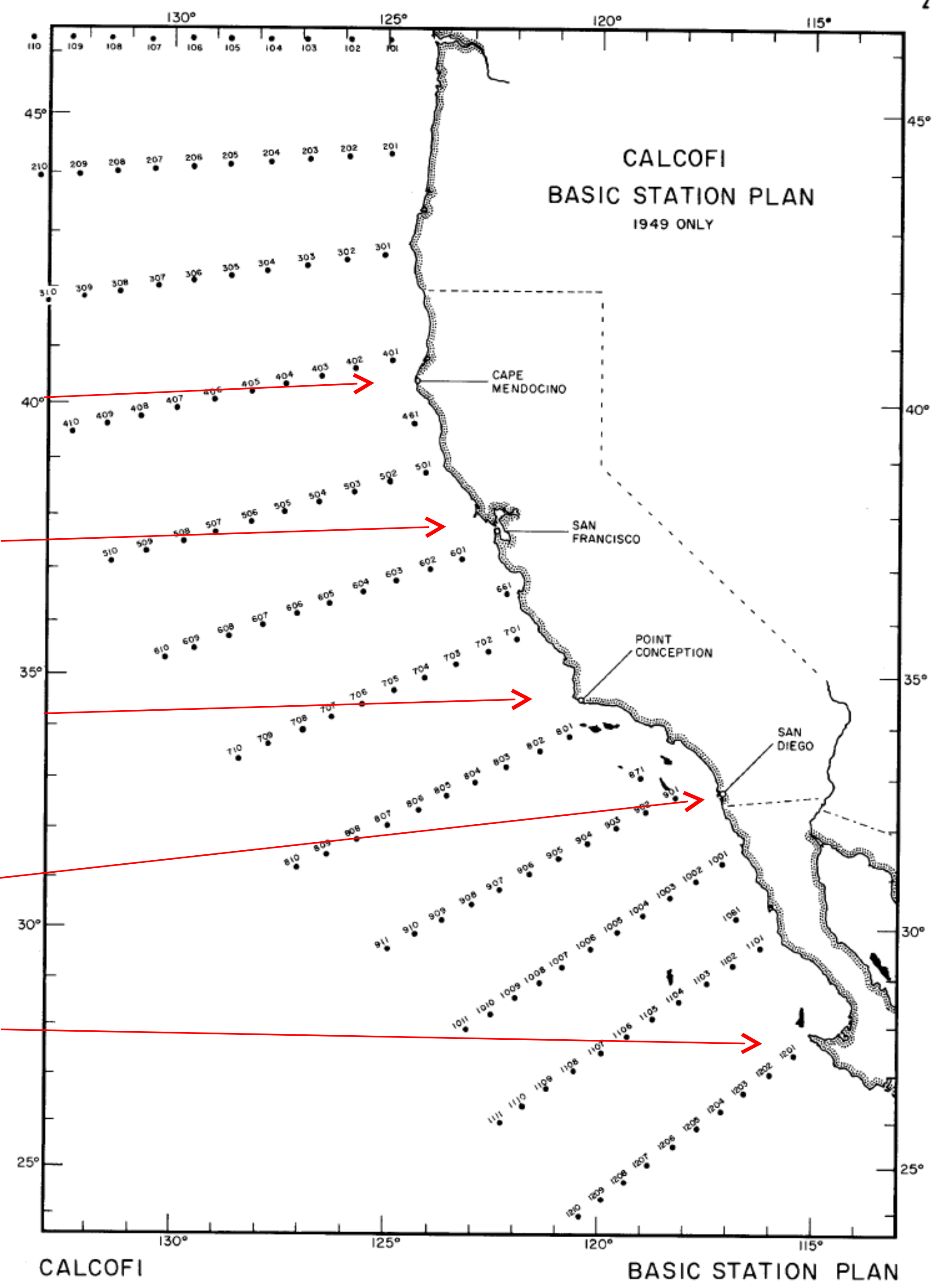
Cape Mendocino

San Francisco

Point Conception

San Diego

Punta Eugenia



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1950-1959

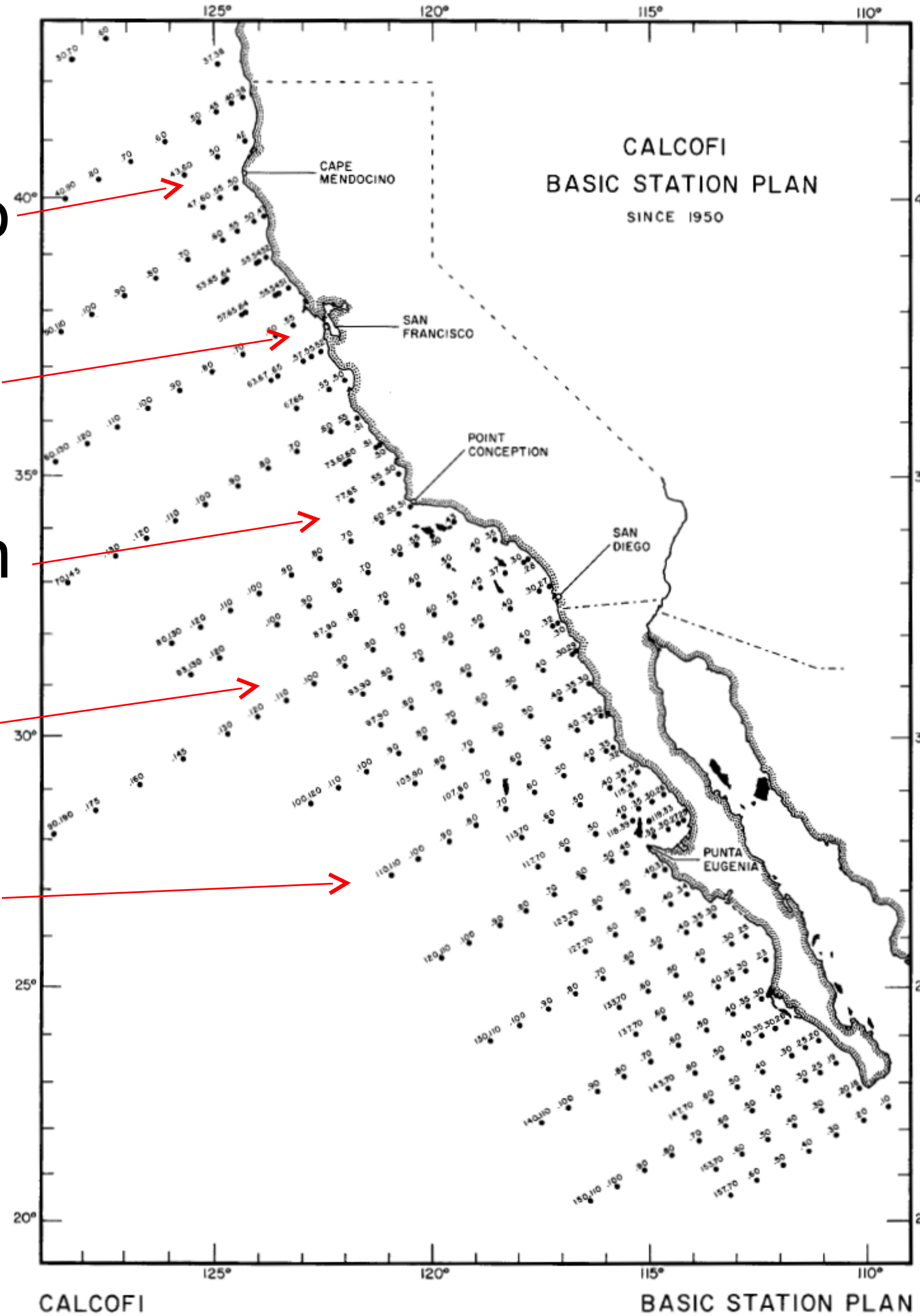
Cape Mendocino

San Francisco

Point Conception

San Diego

Punta Eugenia



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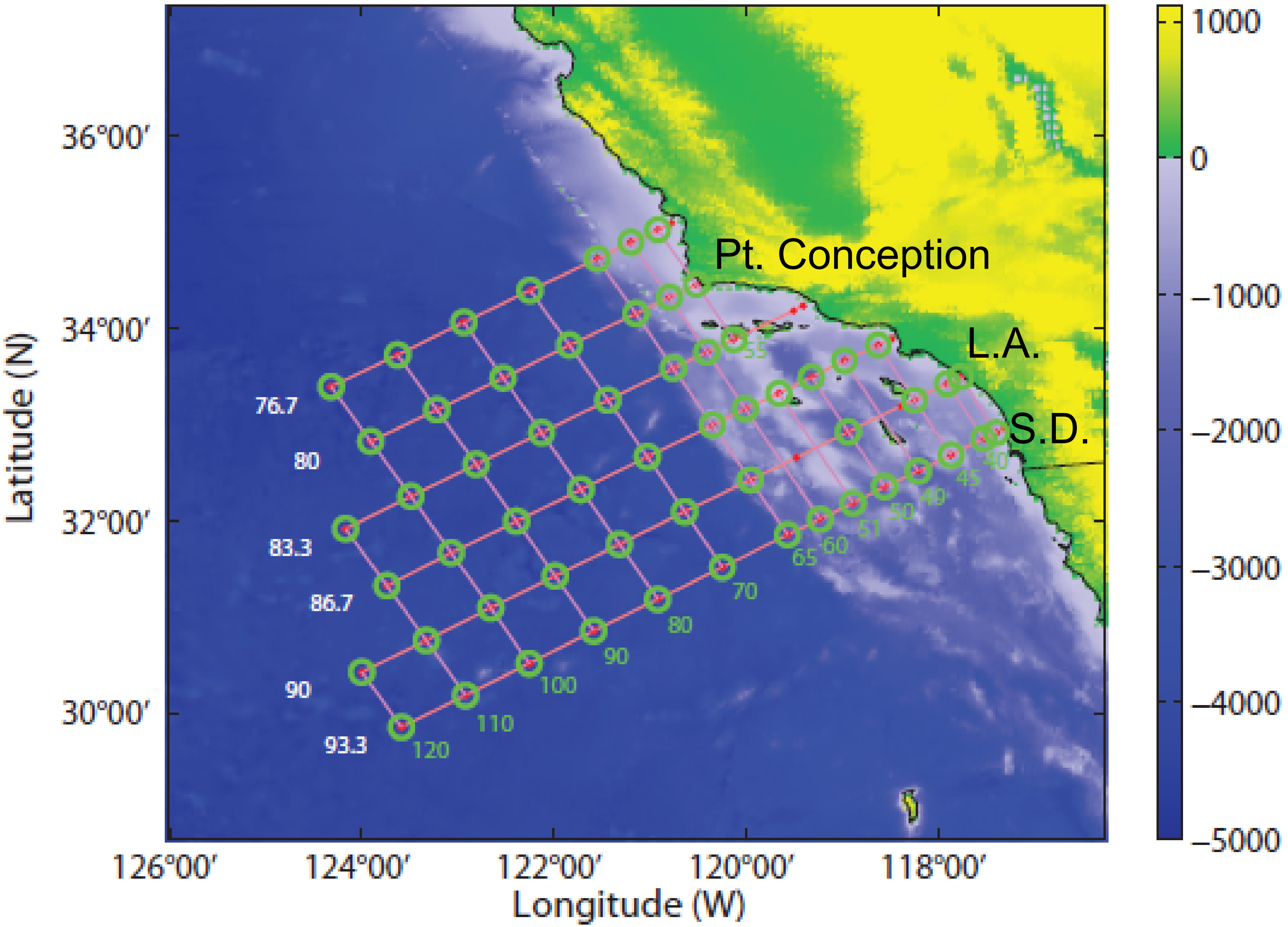
1984– CalCOFI stations (64)



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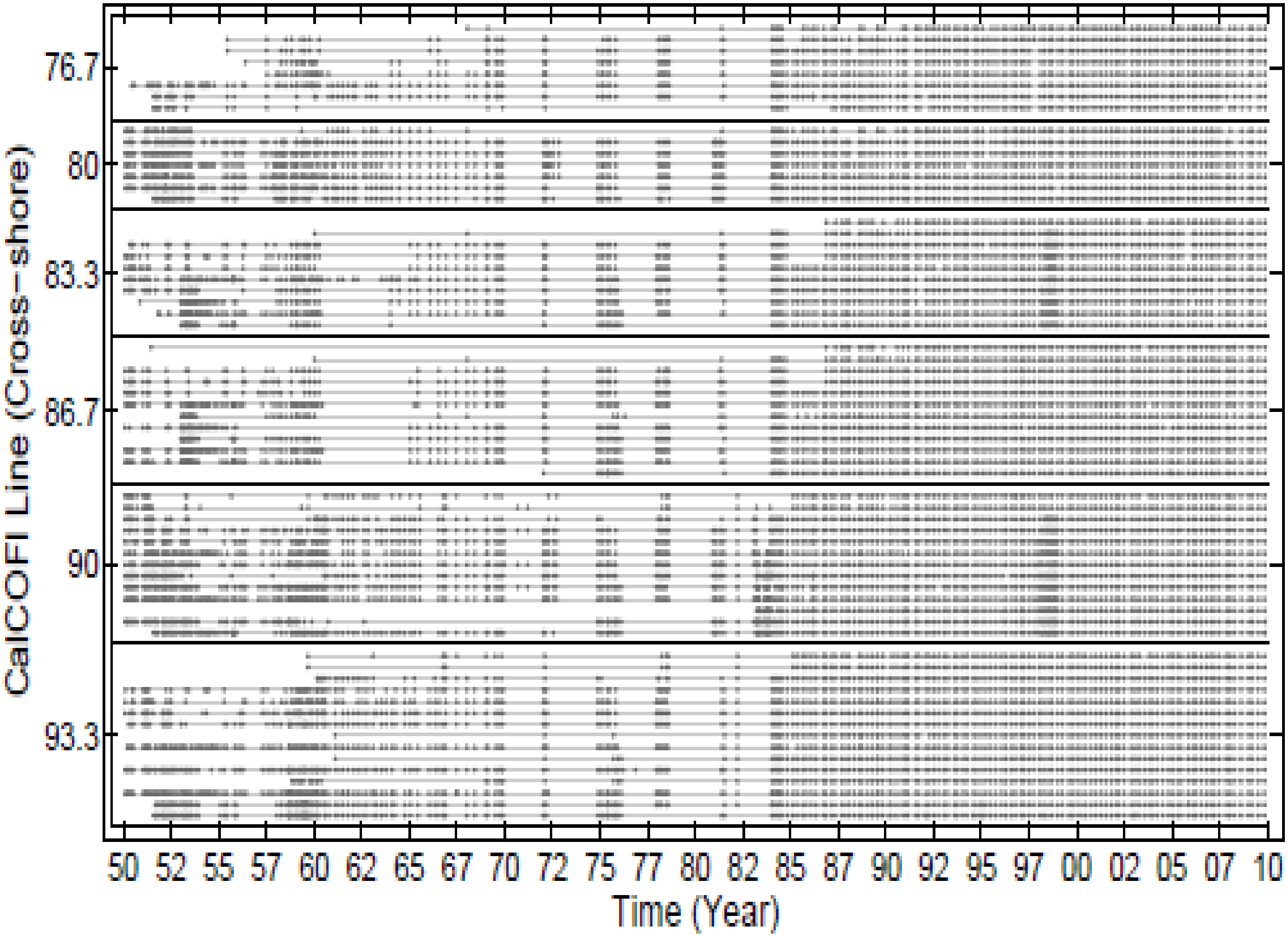
Time Sampling



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Outline

- Green's functions to characterize linearized systems
  - Regression (learn model from obs)
  - Forward or adjoint modeling
- Regression analysis of CalCOFI observations
- State estimation
- Adjoint analysis

Linearized system analysis: Find the Greens functions

y(x,t) = response, f(x',t') = forcing, g(x,t,x',t') = green's function relating forcing at every point in space-time (x',t') to responses at every point in space-time (x,t) (8 dimensions!)

$$y(\mathbf{x},t) = \int_{\mathbf{x}',t'} g(\mathbf{x},t,\mathbf{x}',t')f(\mathbf{x}',t')d\mathbf{x}'dt'$$

written in operator form as $\mathbf{y} = G\mathbf{f}$

Adjoint or tangent linear model yields a row or a column of **G**, respectively (g = solution to linearized equation forced with d-fn)

f(x,t) can be a forcing field or a few time series, as in regression

Linear Regression as a least-squares problem

y = **f G** + **r** (**r** = residual)
Columns of **f** are time series, **G** are weights

correlate with **f'**: <**f' y**> = <**f' f**> **G**
Solve using least-squares:

inv(<**f' f**>) <**f' y**> = inv(<**f' f**>) <**f' f**> **G**
= G if <f' f> is invertible (ideally diagonal)

But <**f' f**> is a sample covariance matrix
With errors and statistical noise, so it
Is difficult to do with most observed time series

Sample covariance is Public Enemy #1

Used in Ensemble Kalman Filter, adaptive beamforming, Adaptive equalization (comms), Adaptive ________,…

Tools: Factorization (e.g. eigenvectors), truncation, localization, regularization, system identification, cross-validation,...

<**f’ y**> is also noxious, similar techniques are used (e.g. CCA)

Besides small ensemble size, **f** and **y** are contaminated with noise, so there are errors in the “model”

One solution: physics

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Seasonal cycle: 6 harmonics, sine and cosine

$$\mathbf{f}'_s = \begin{bmatrix} \cos\sigma_1 t_1 & \cdots & \cos\sigma_1 t_N \\ \vdots & \ddots & \vdots \\ \cos\sigma_K t_1 & \cdots & \cos\sigma_K t_N \\ \sin\sigma_1 t_1 & \cdots & \sin\sigma_1 t_N \\ \vdots & \ddots & \vdots \\ \sin\sigma_K t_1 & \cdots & \sin\sigma_K t_N \end{bmatrix},$$

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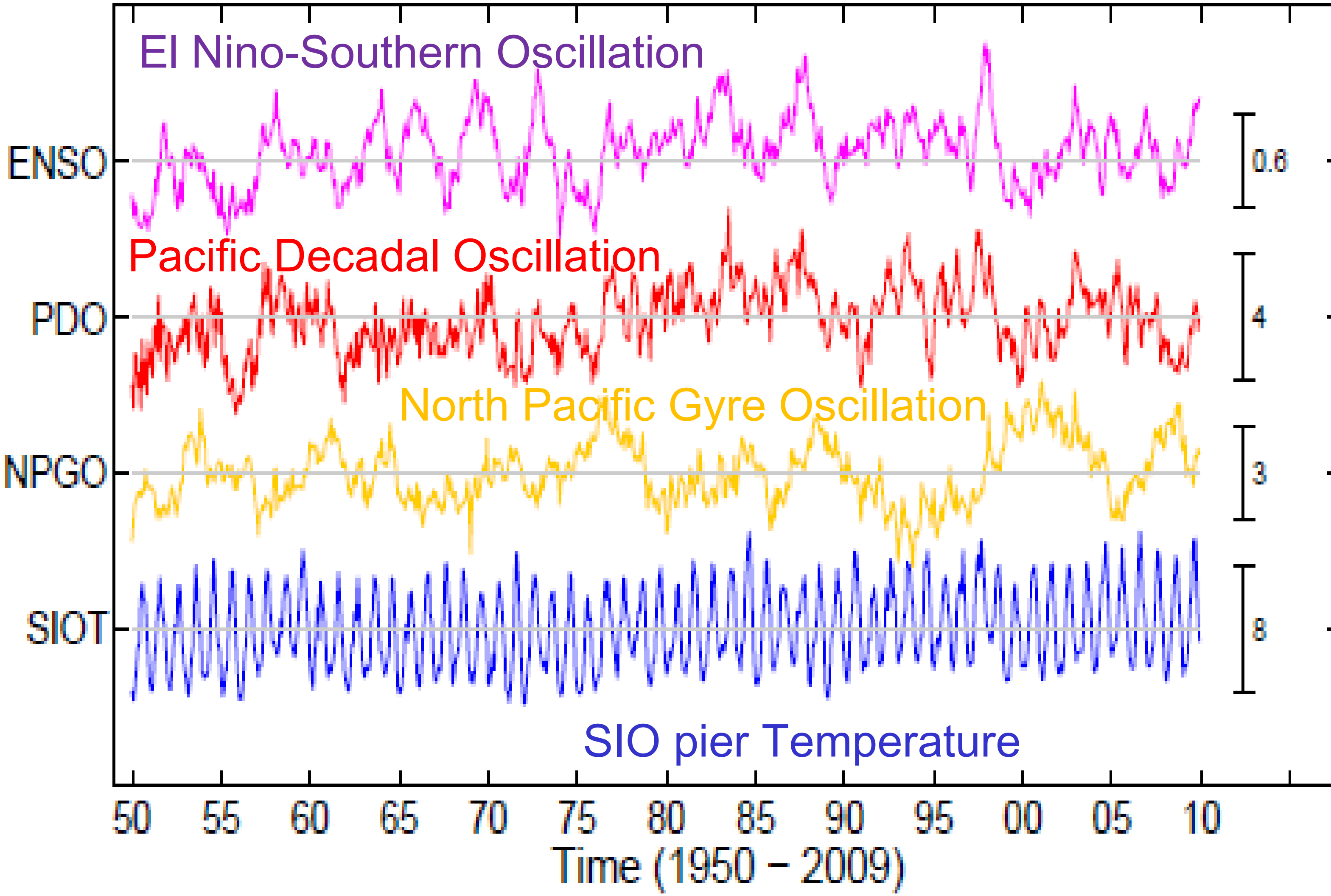
Climate forcing functions for Regression (pre-orthogonal)



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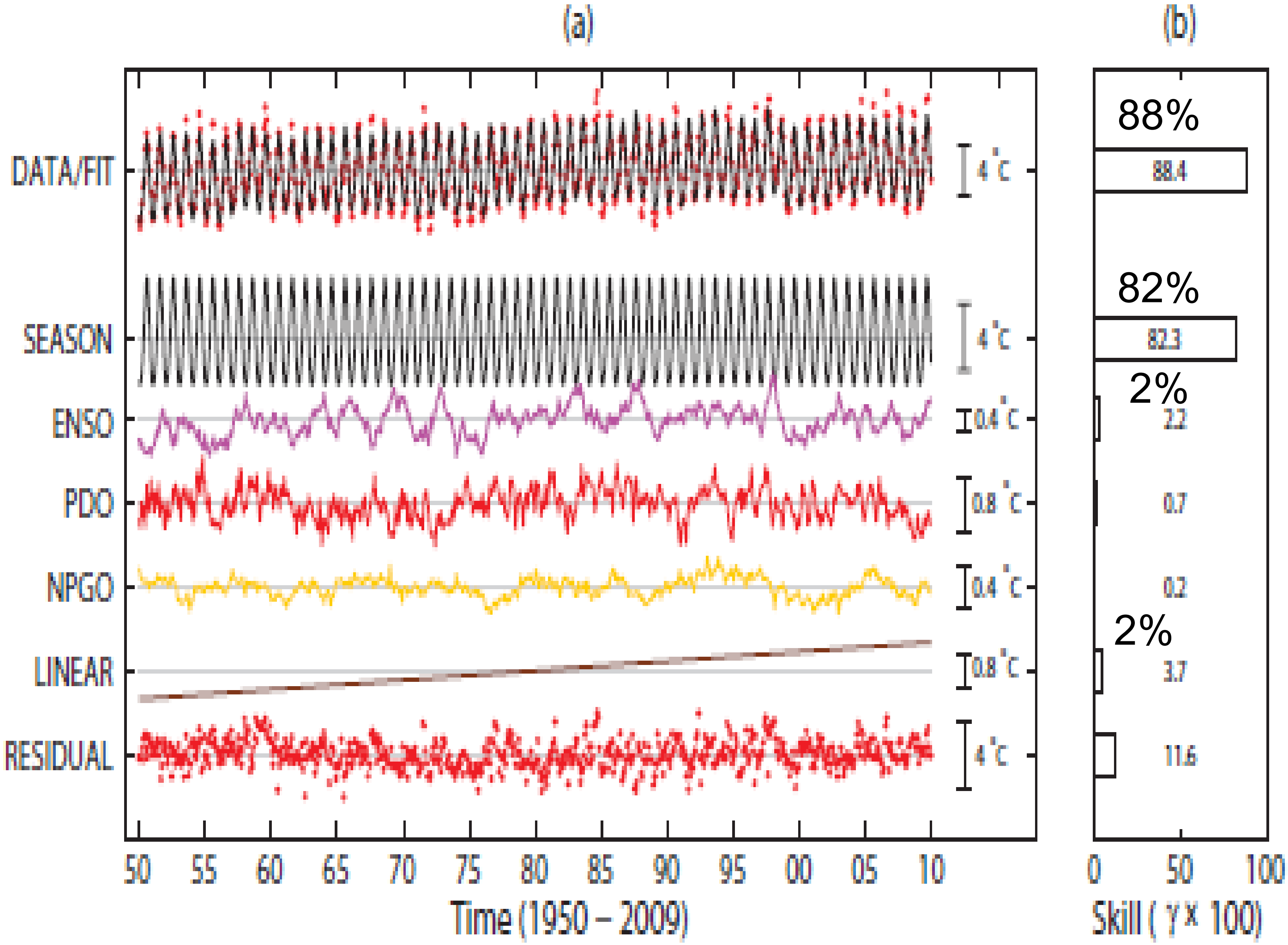
Decomposition of SIO Pier T



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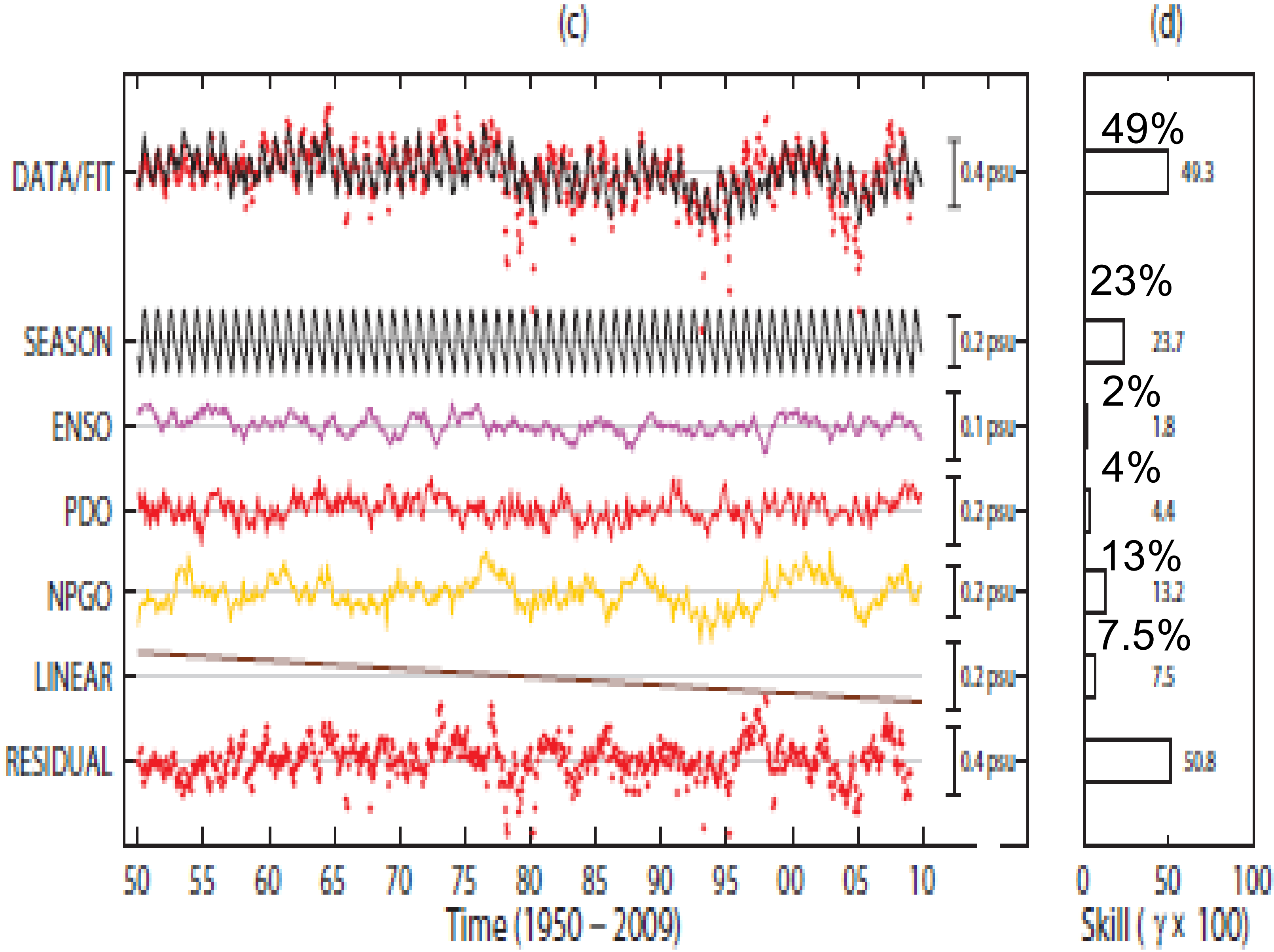
Decomposition of SIO Pier S



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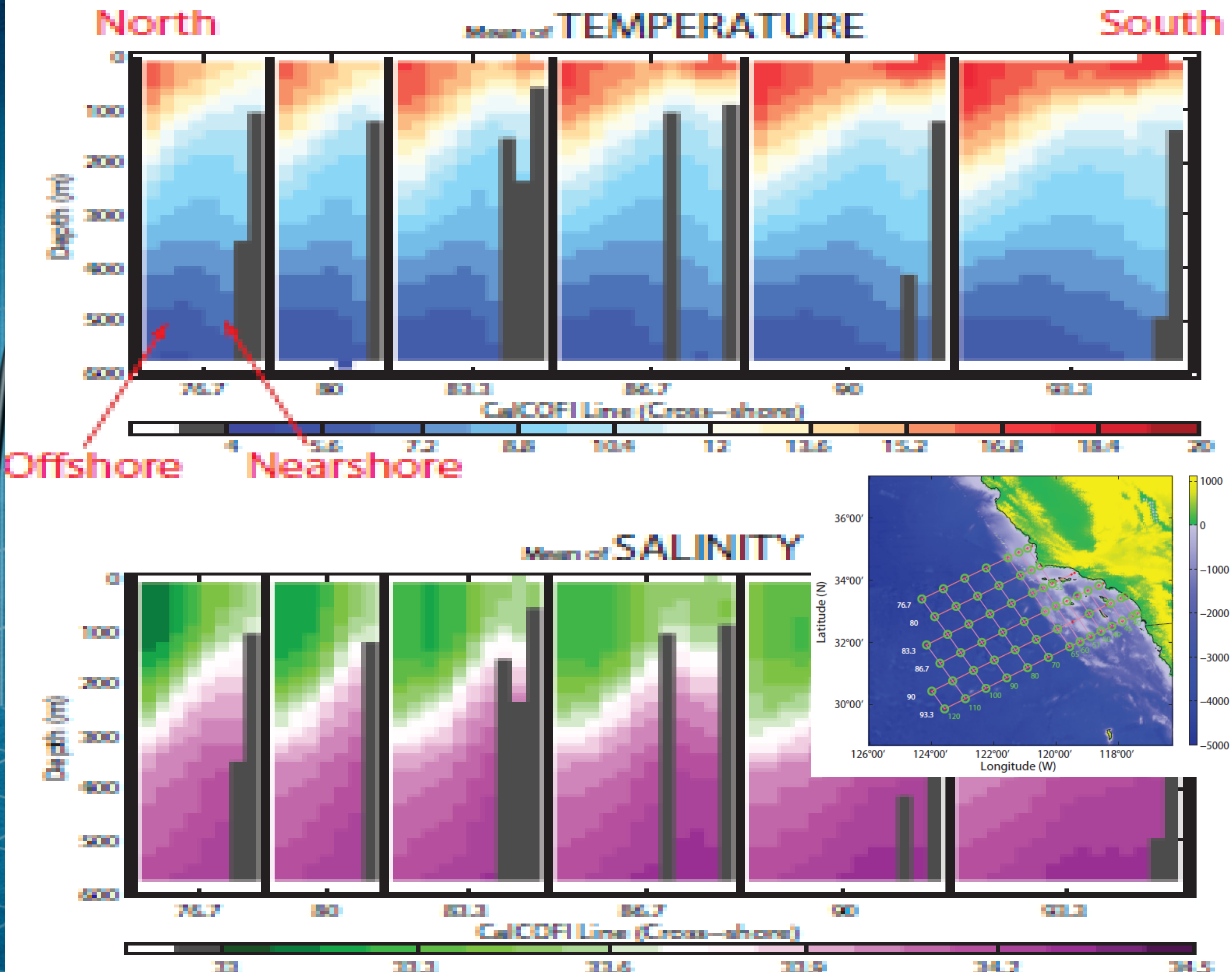

Concatenated cross-shore lines

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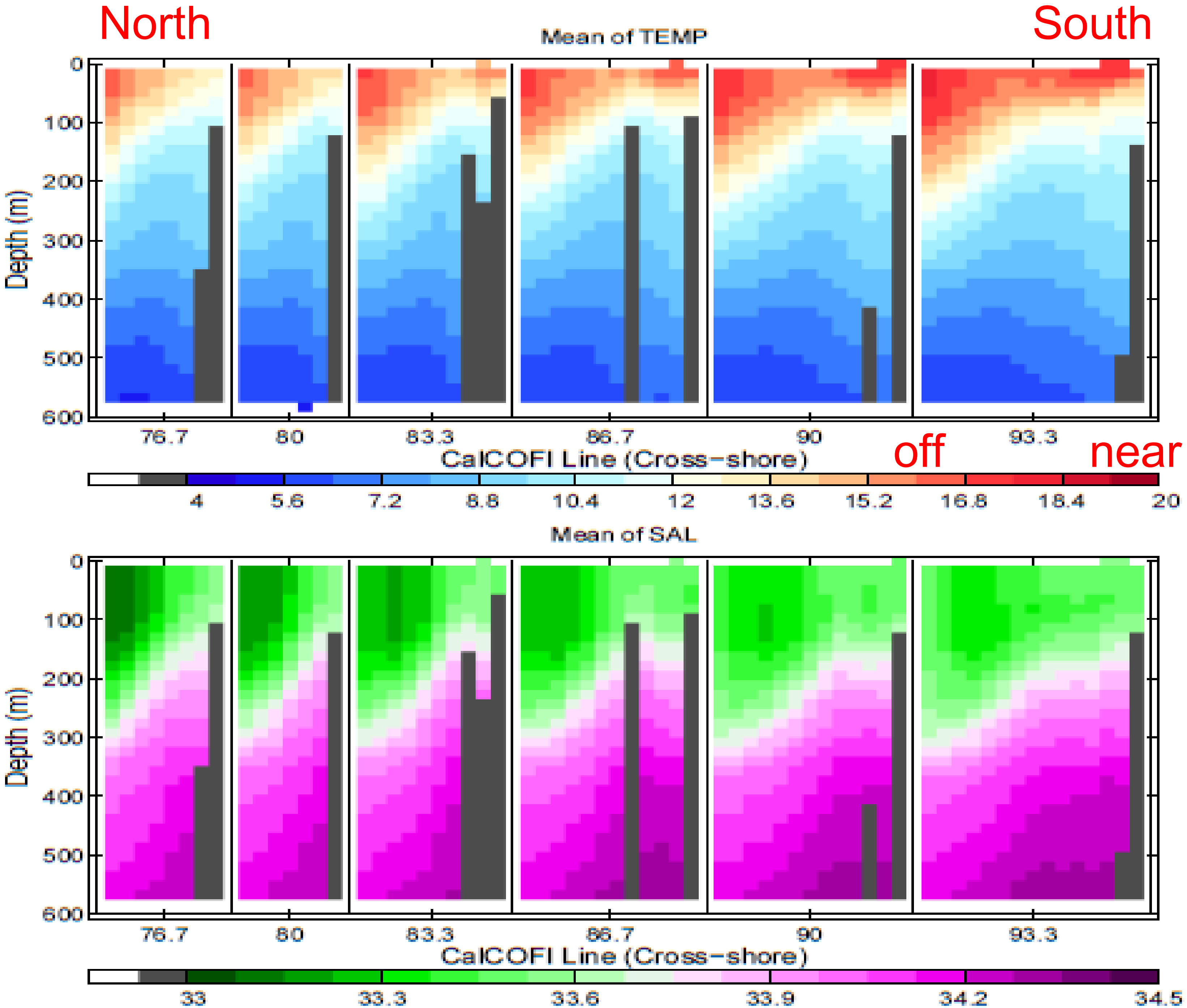

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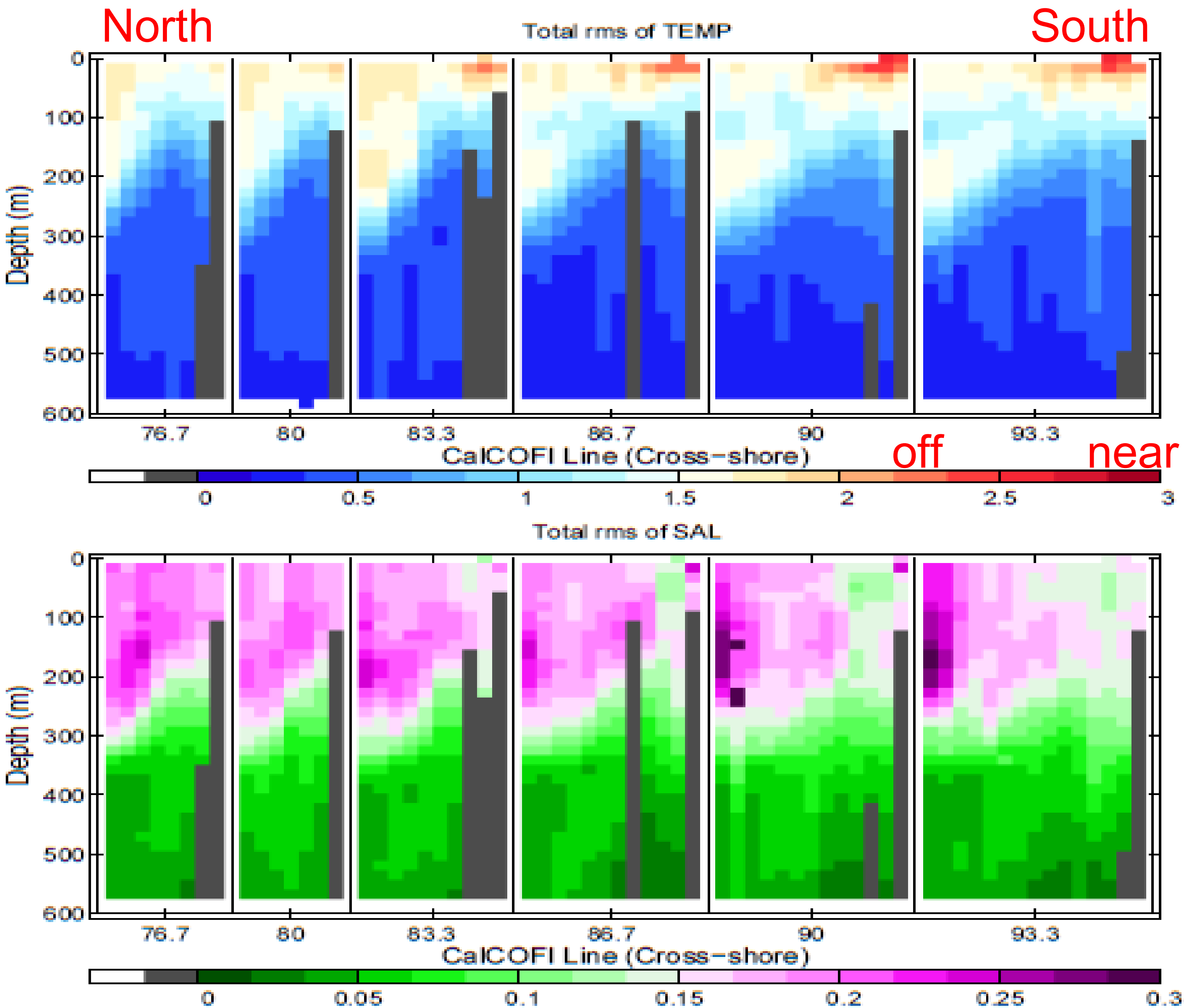

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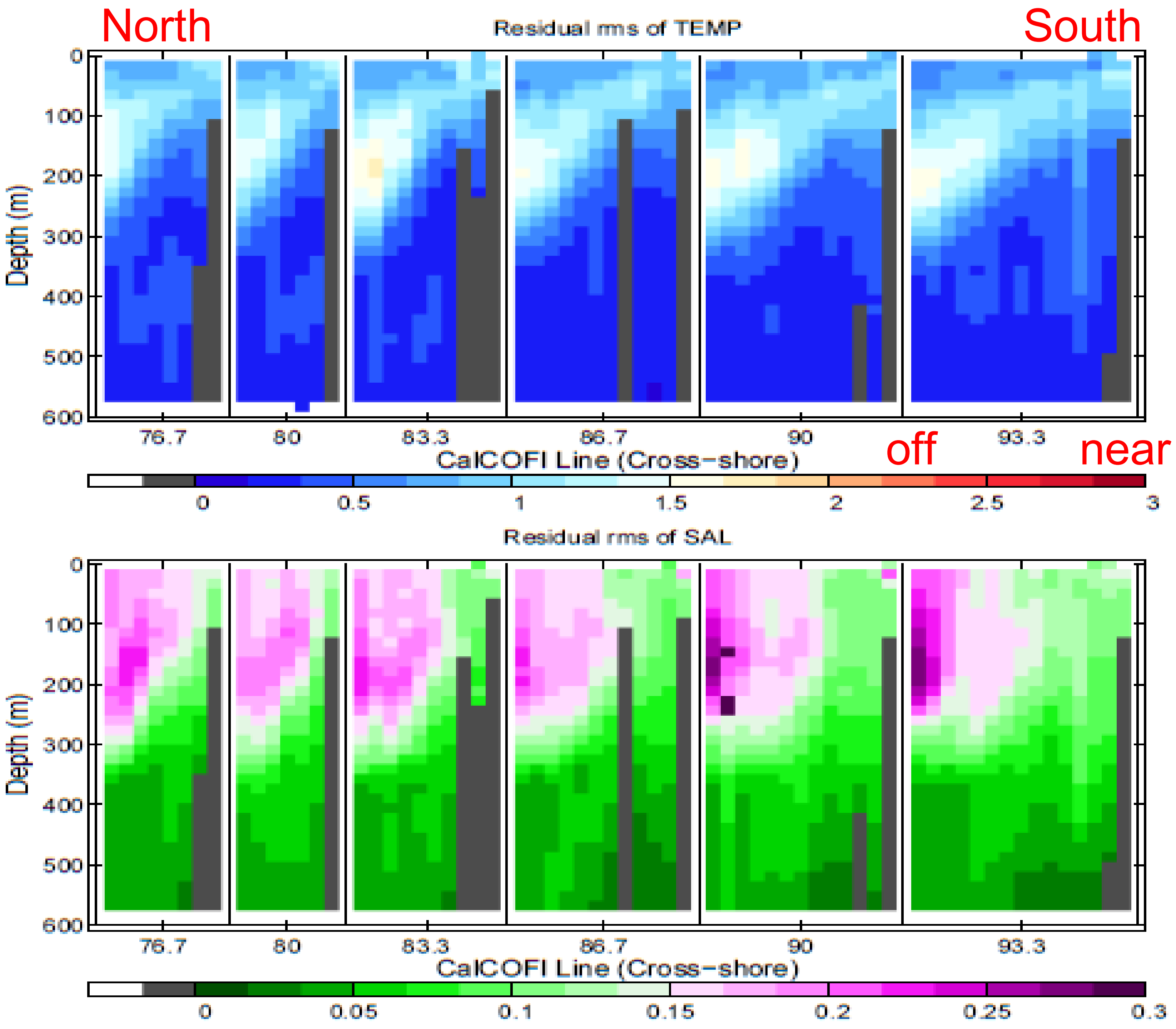

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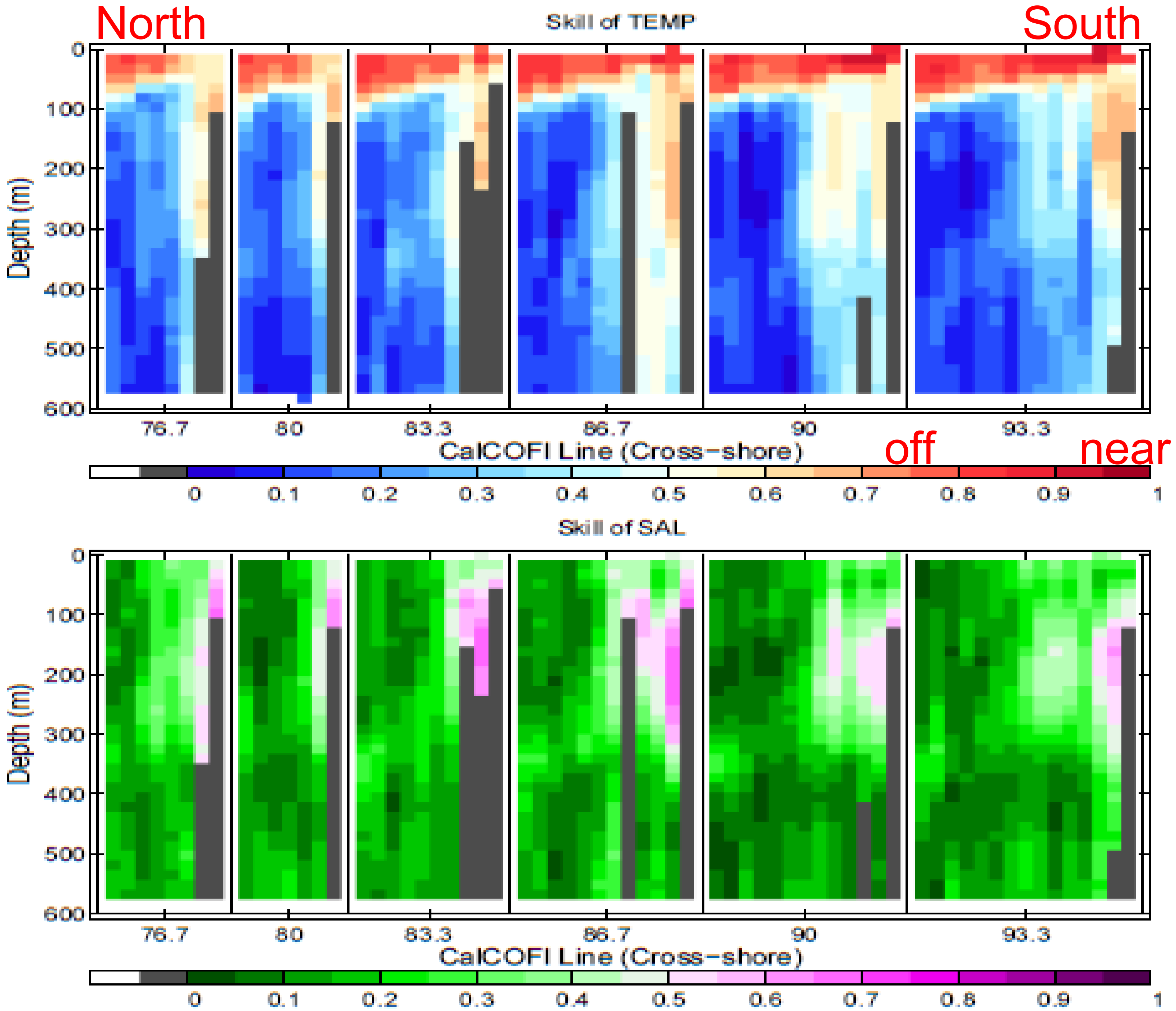

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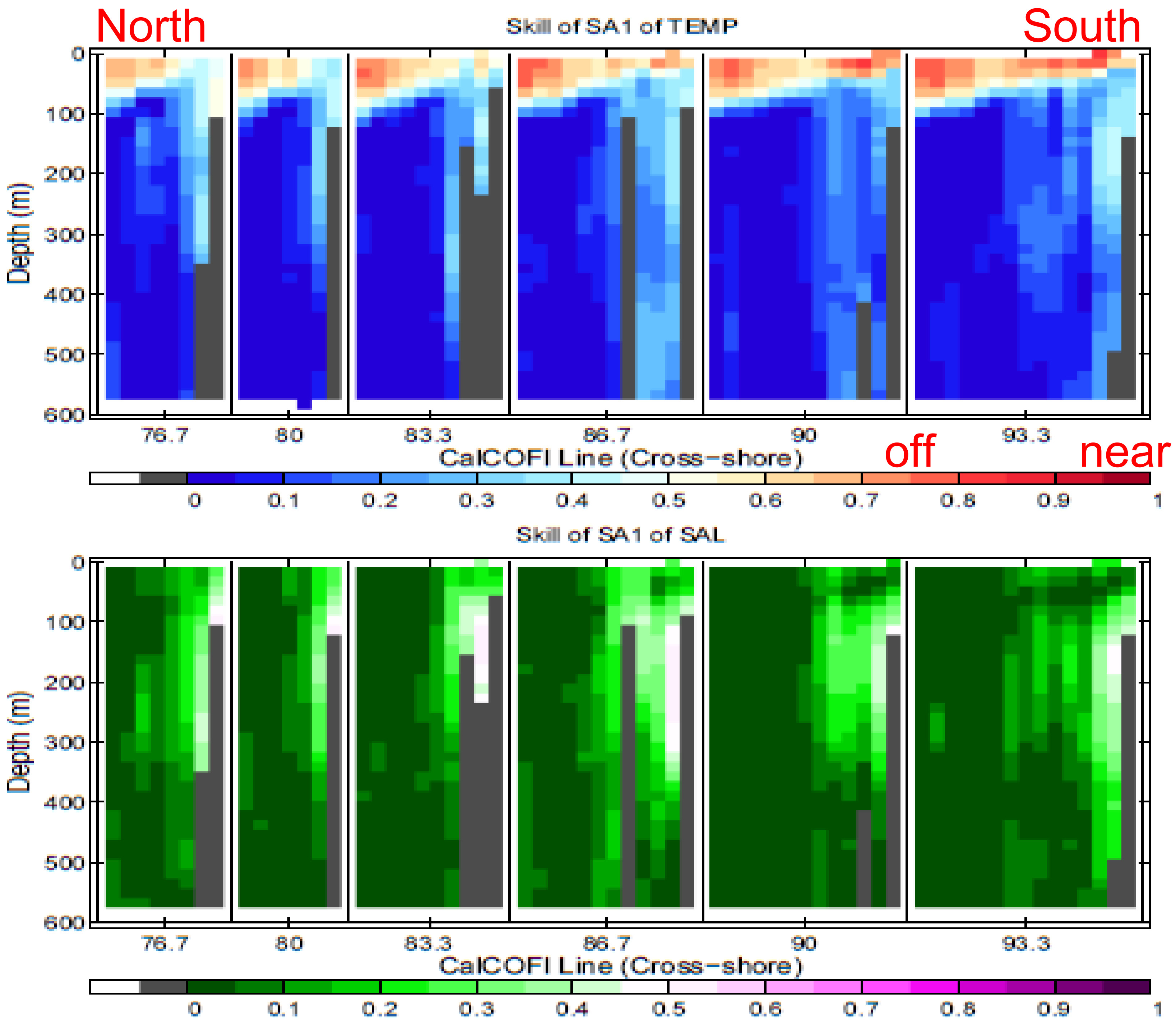

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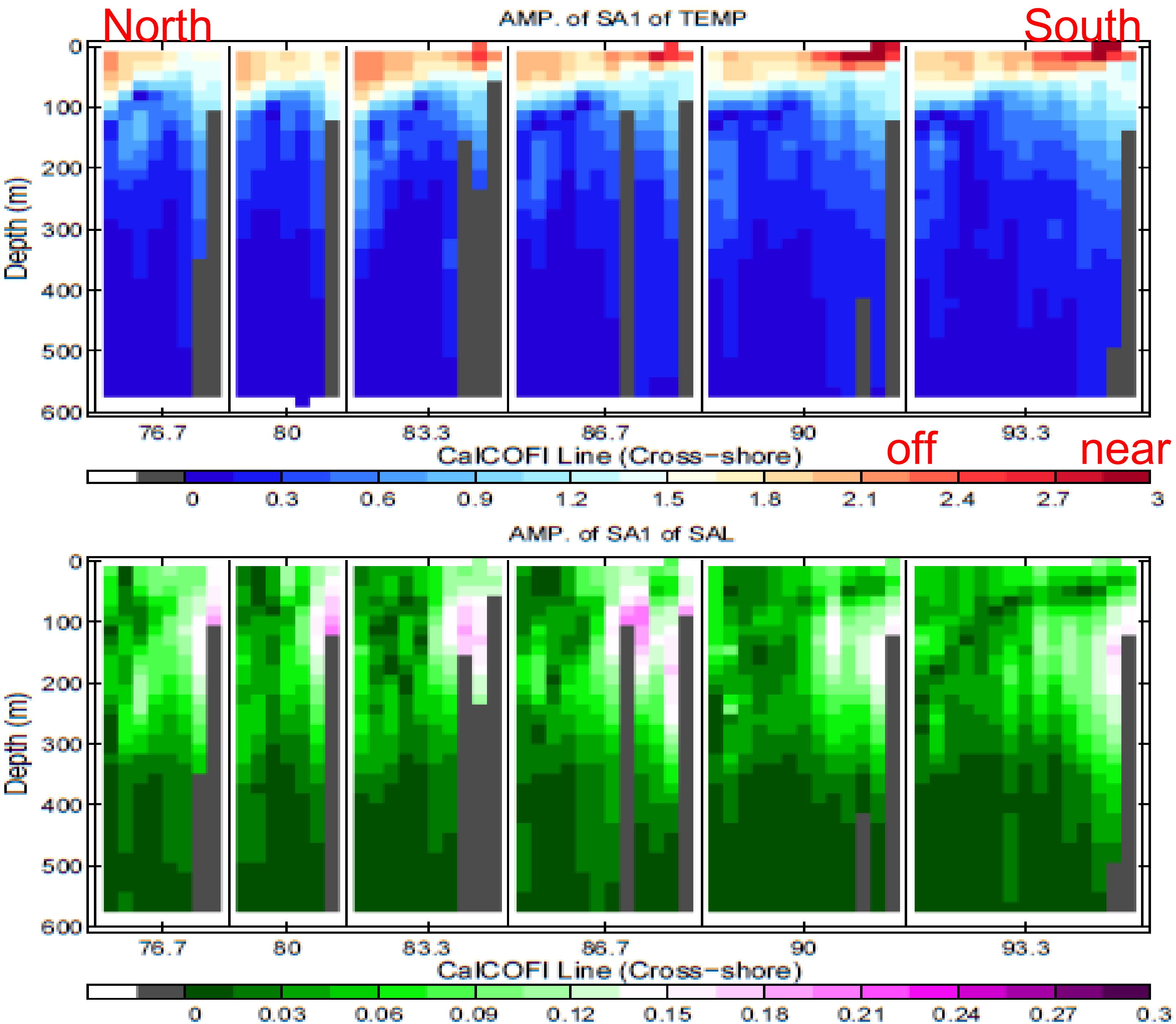

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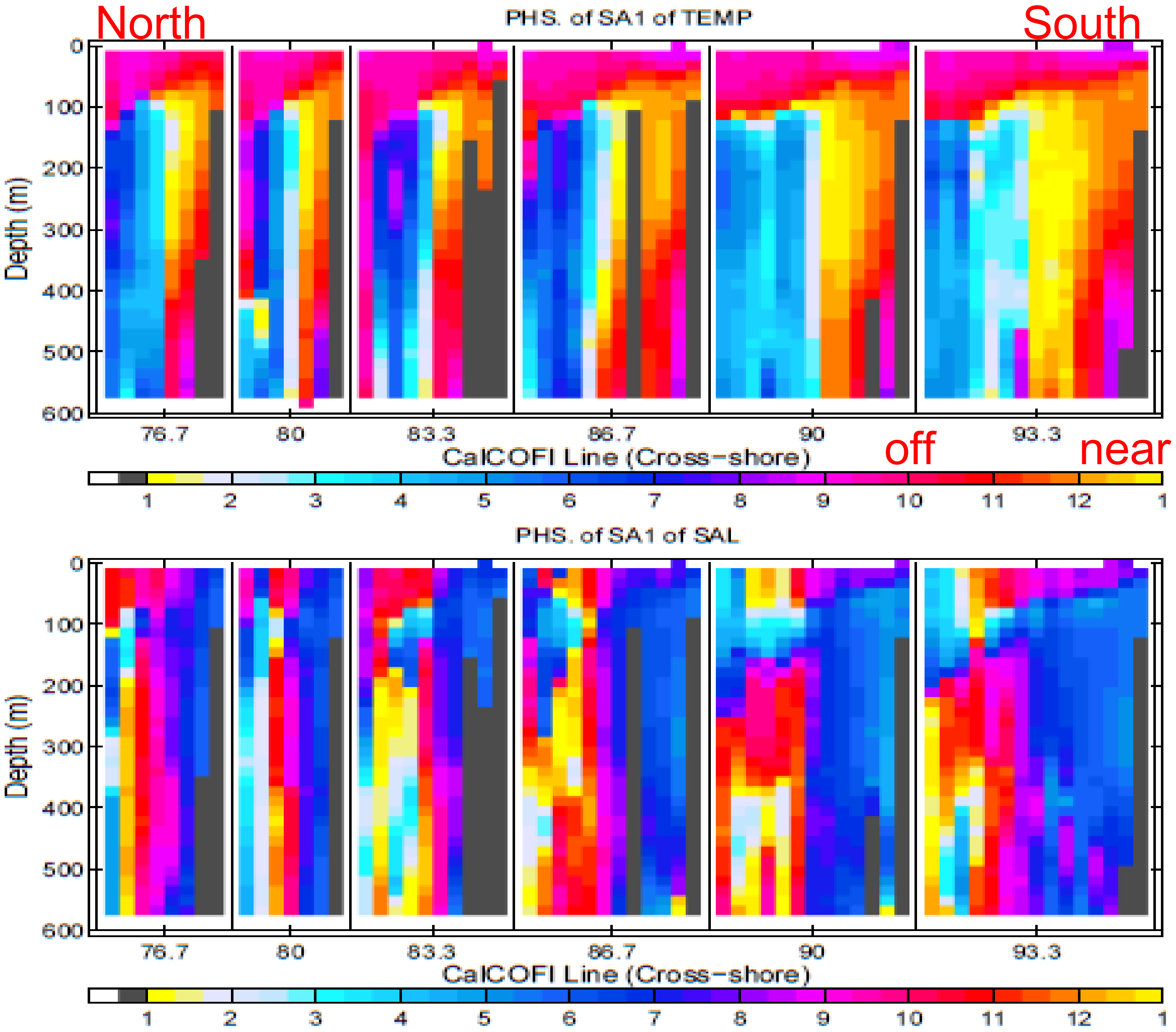

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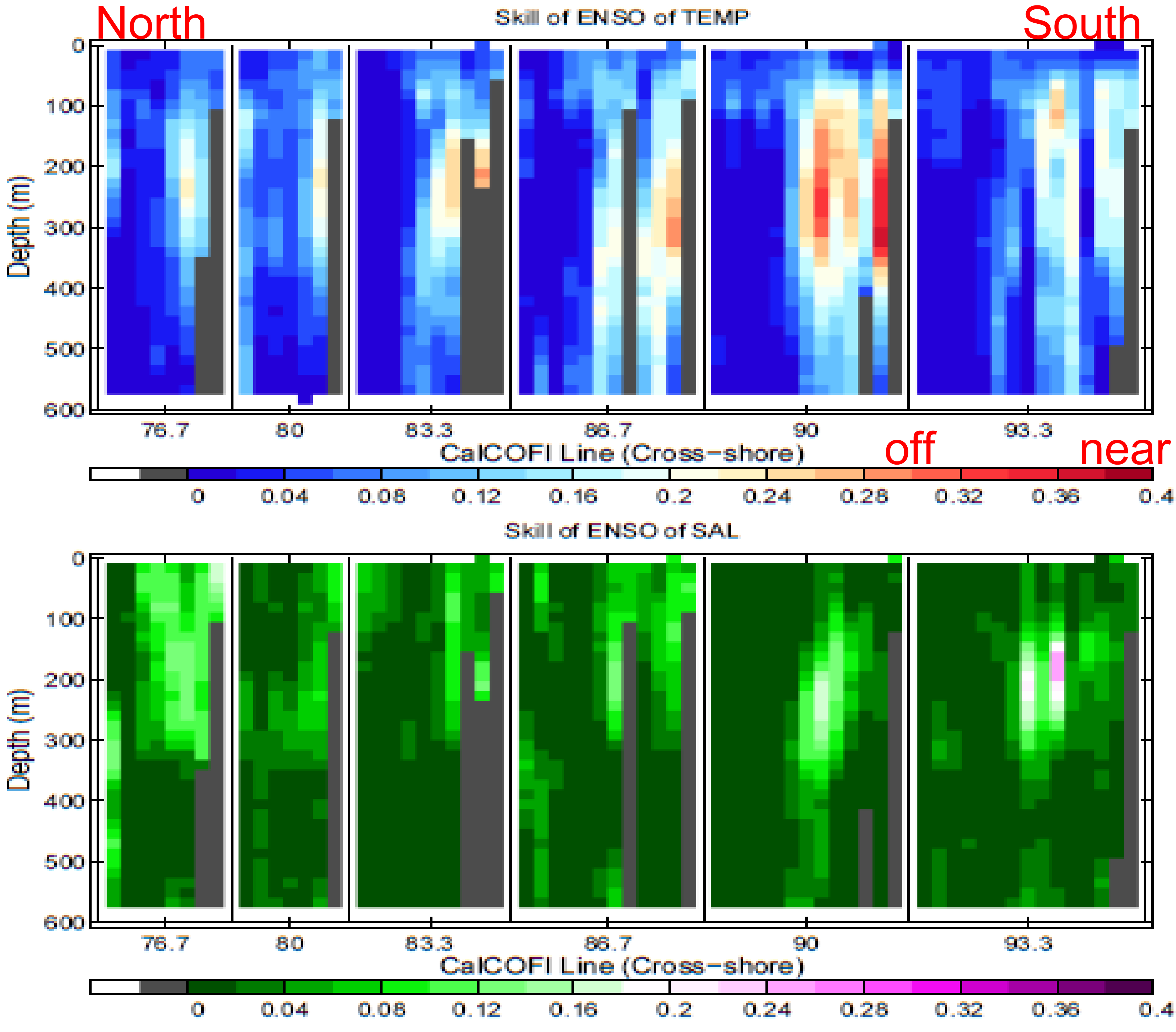

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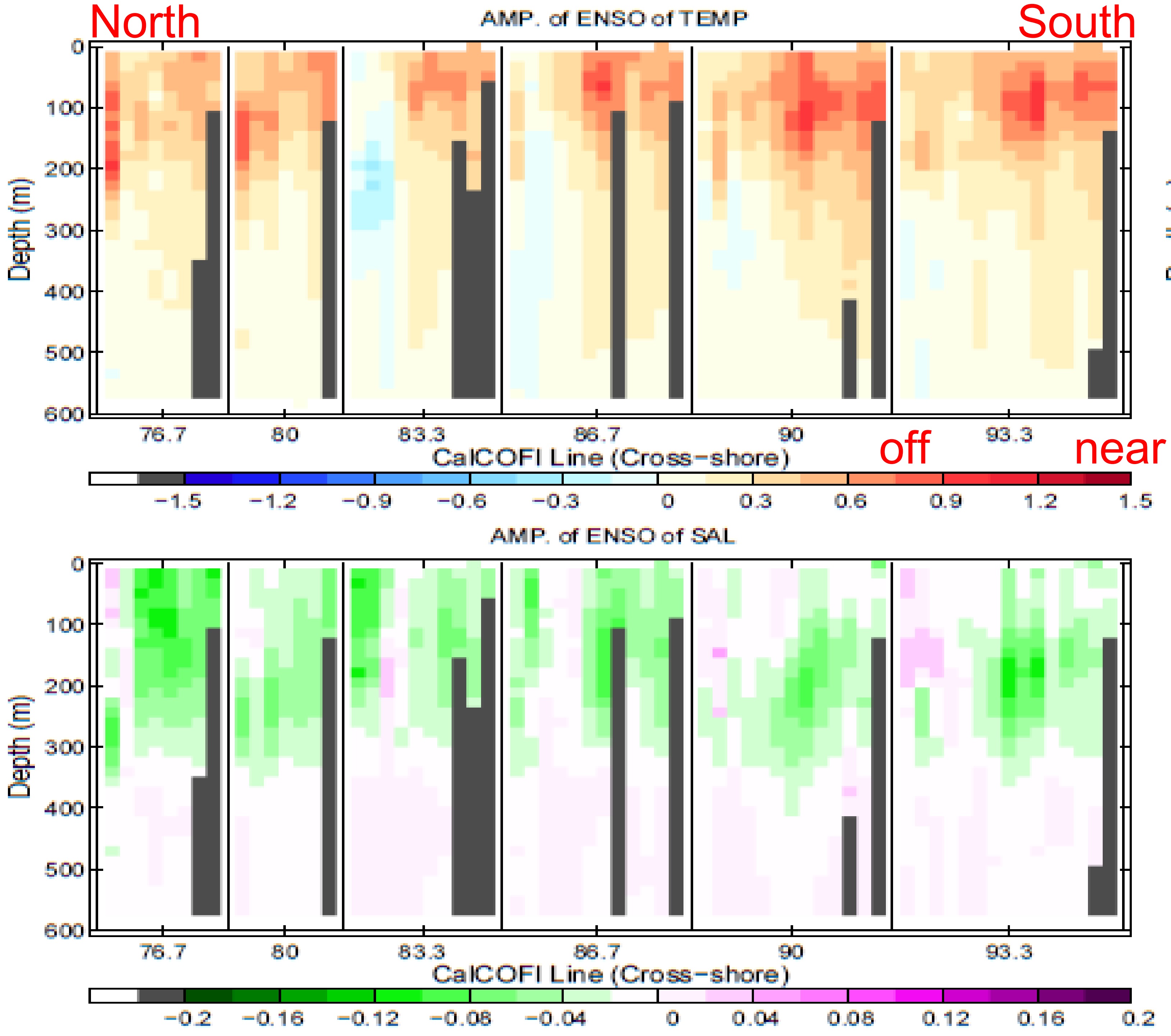

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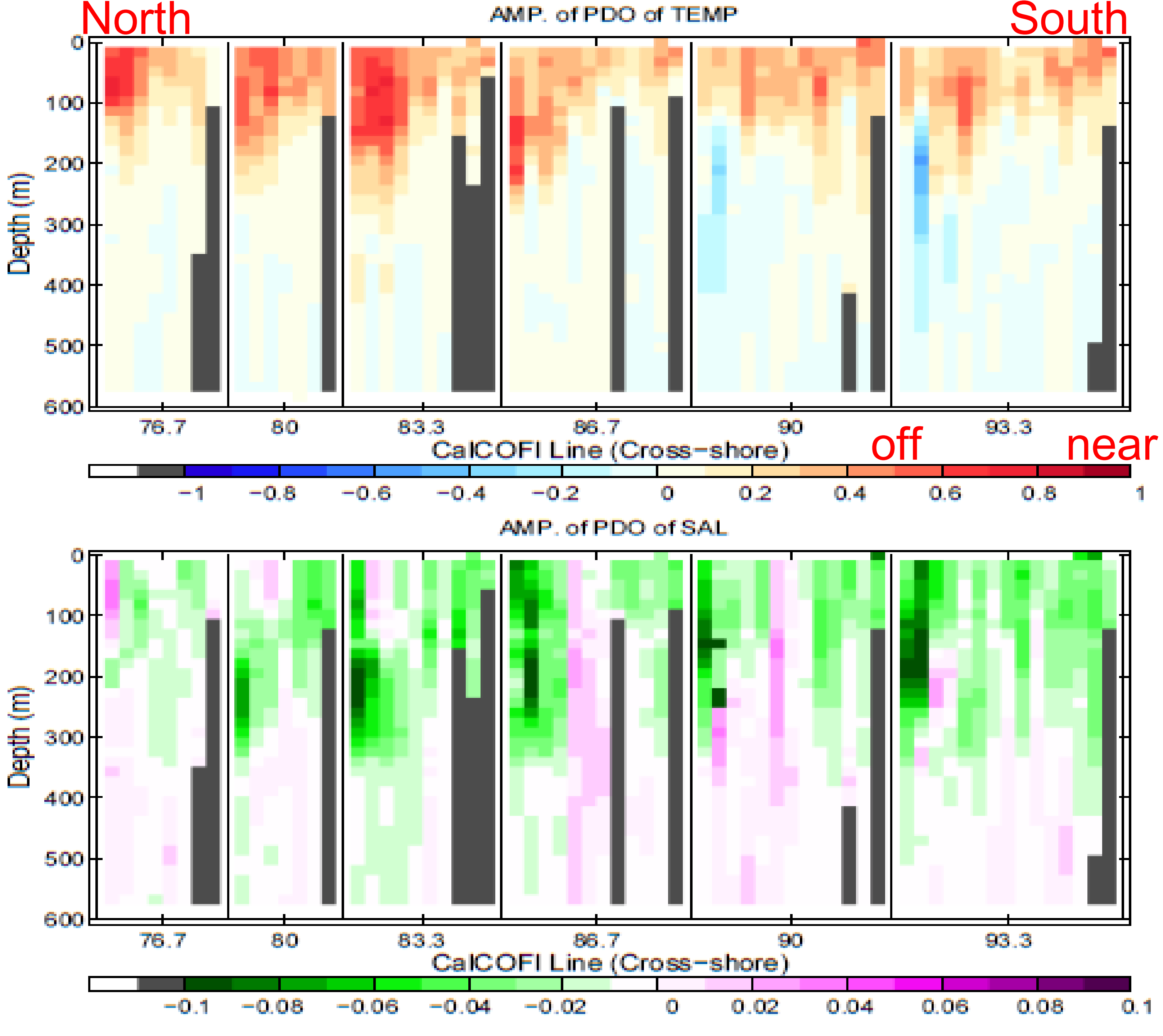

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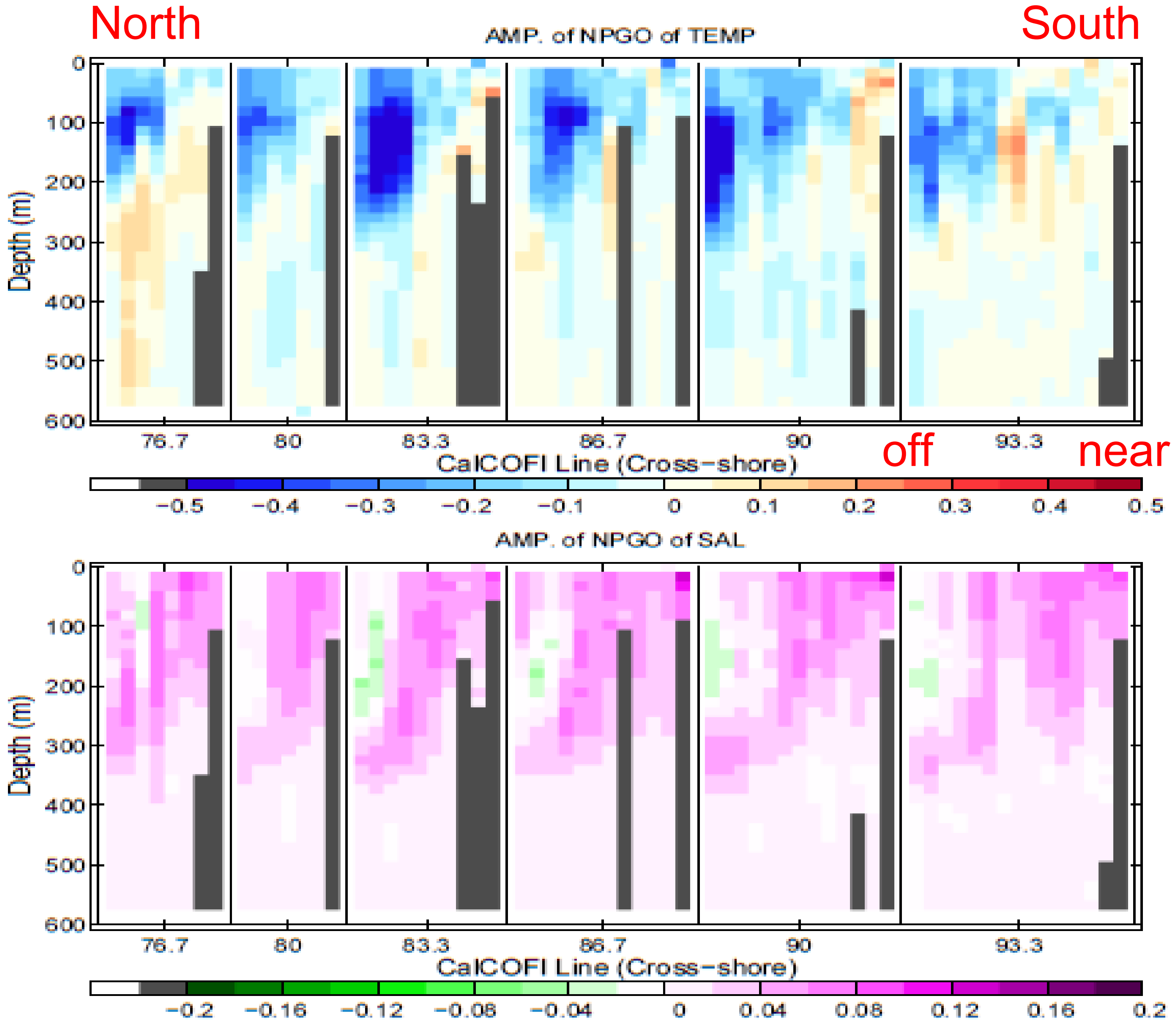

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Conclusions from CalCOFI regression

- Seasonal cycle direct response small below 50 m
- Annual baroclinic Rossby wave propagation to west
- ENSO influences upper ocean temperatures near shore, PDO influences offshore
- NPGO influences primarily Salinity (Emanuele DiLorenzo and others)

What are the mechanisms?

- Surface heat flux?
- Wind stress?
- Local or remote?
- ENSO Kelvin waves, Coastally trapped waves?
- Need a model to get the dynamical Green's function, and need a good state estimate to linearize around

State Estimation for CCS

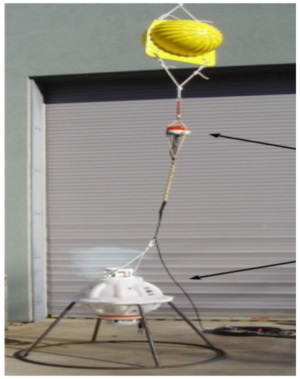
- Fit model to observations using 4D-Var (adjoint)
- Adjust initial conditions, boundary conditions, and forcing (within error bars)
- Estimate is a free forward run of the model that should match the observations (within error bars)
- Dynamically consistent reanalysis for research and fisheries use

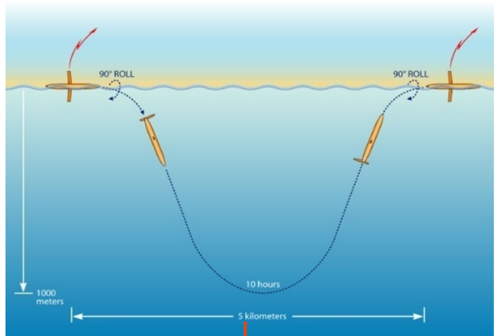
MITgcm configuration

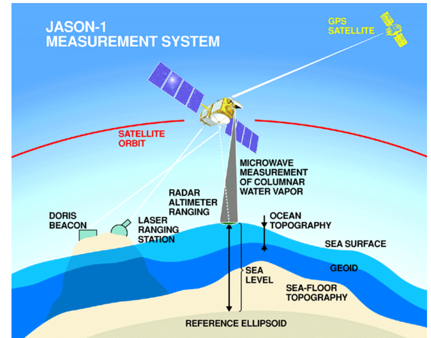
- Domain: 130W-coast, 27N-40N
- Resolution: 1/16*1/16, 72 z-levels with high resolution in the upper ocean
- Surface forcing is derived from NCEP NAM model (1/12 degree)
- Open boundary conditions and initial conditions: global OCCA 1x1 product
- Long assimilation window: 2007-2010

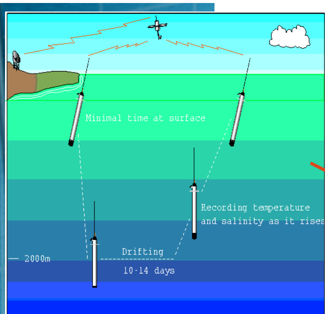
Observations

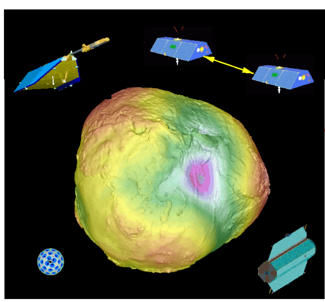
- Along-track altimeter sea surface height
- Temperature and salinity profiles from Argo, gliders, XBTs, and elephant seals
- Geoid constraints from GRACE
- SST from TMI and AMSR-E (microwave)
- 2 Moorings with T and S profiles
- 5 Inverted echo sounder moorings
- Others to be added, e.g. HF-radar

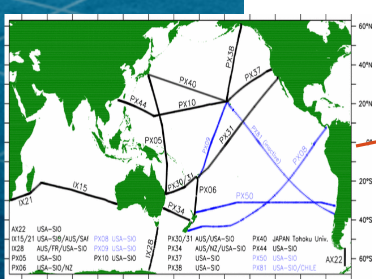



90° ROLL
90° ROLL
10 hours
1000 meters
5 kilometers


JASON-1
MEASUREMENT SYSTEM
GPS SATELLITE
SATELLITE ORBIT
MICROWAVE MEASUREMENT OF COLUMNAR WATER VAPOR
RADAR ALTIMETER RANGING
LASER RANGING STATION
DORIS BEACON
OCEAN TOPOGRAPHY
SEA SURFACE
GEOID
SEA LEVEL
SEA-FLOOR TOPOGRAPHY
REFERENCE ELLIPSOID


Minimal time at surface
Recording temperature and salinity as it rises
Drifting
2000m
10-14 days




PX38
PX37
PX40
PX44
PX10
PX05
PX31
IX15
IX21
PX30/31
PX06
PX34
PX50
IX28
AX22
60°N
40°N
20°N
20°S
40°S
60°S

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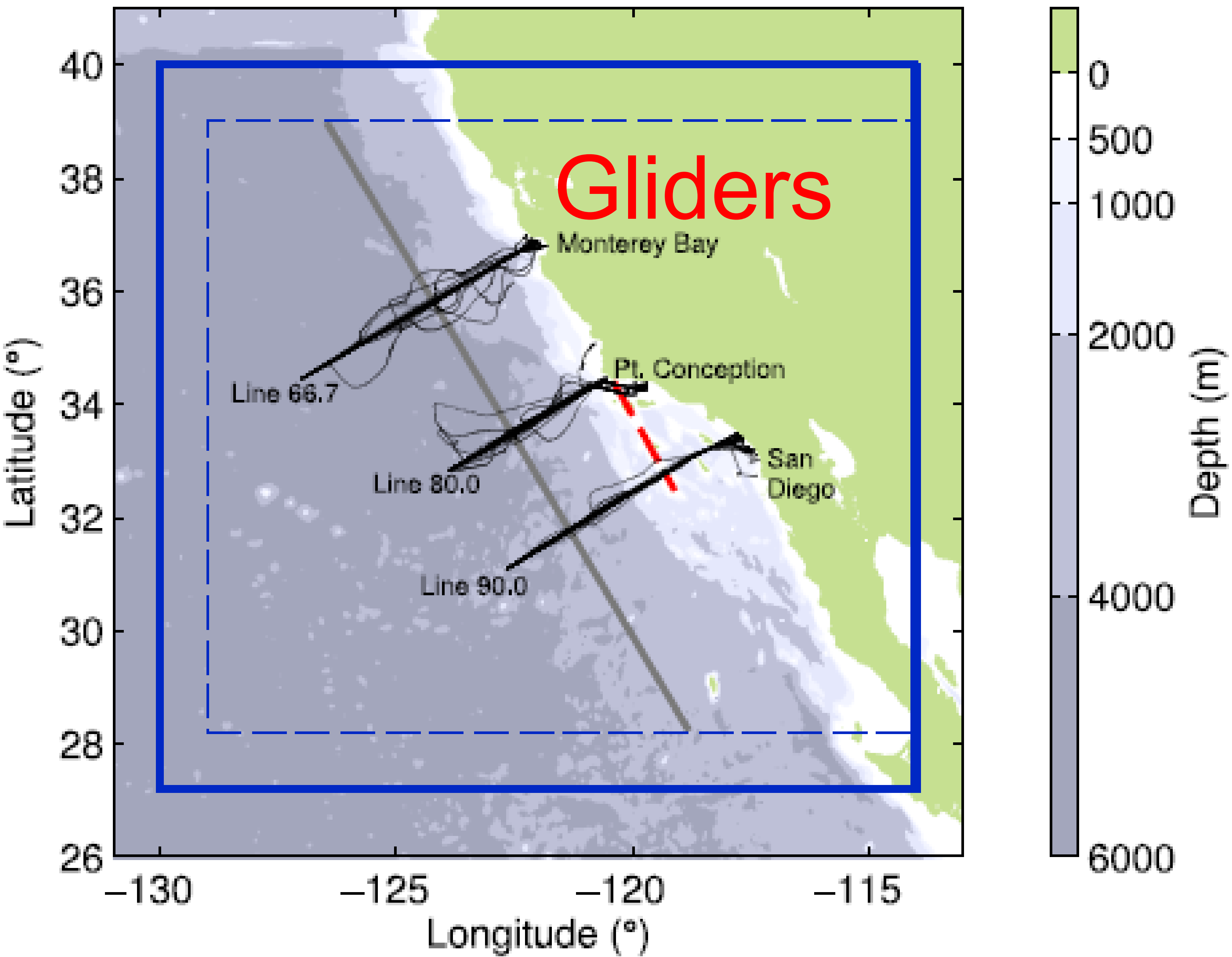
TODD ET AL.: THERMOHALINE STRUCTURE OFF CALIFORNIA



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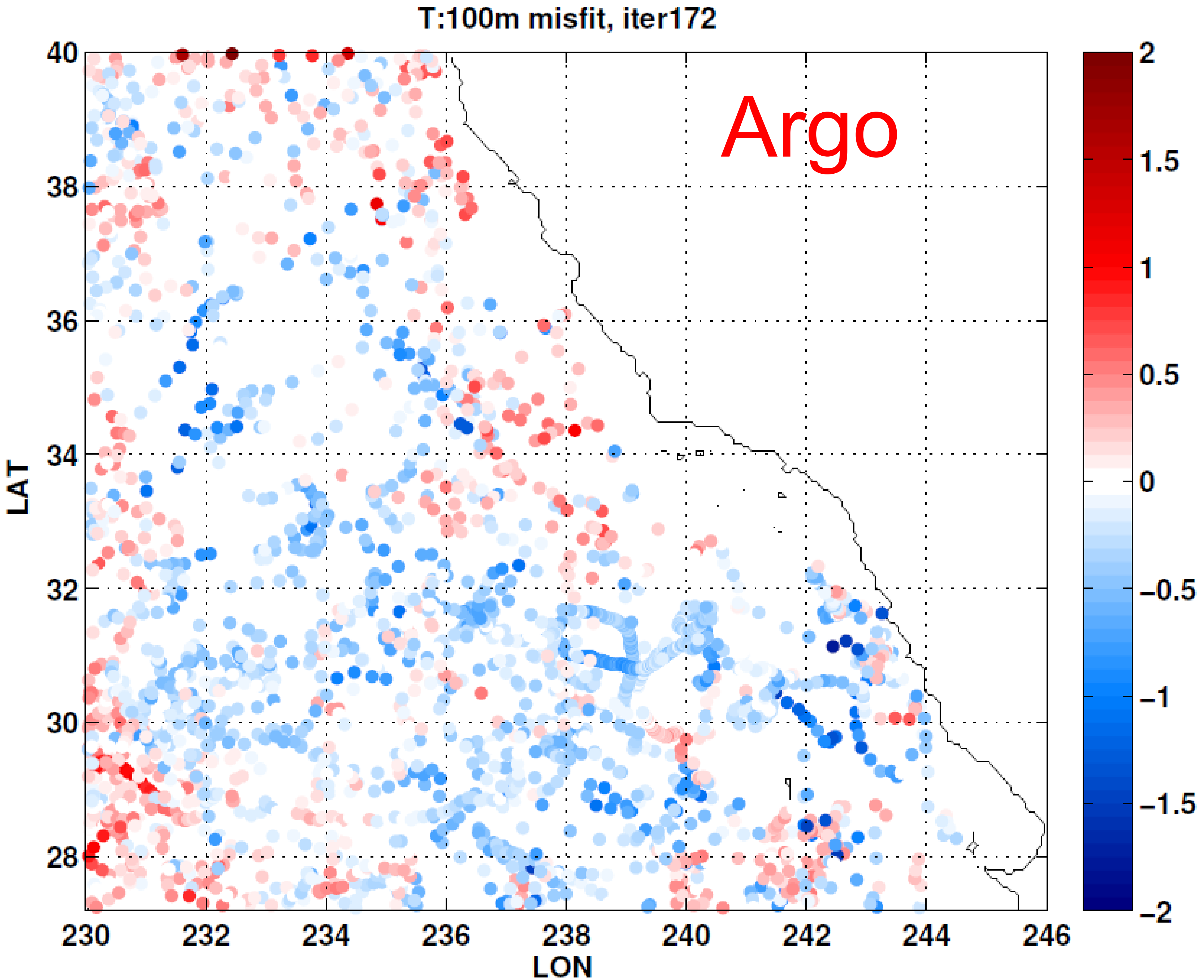

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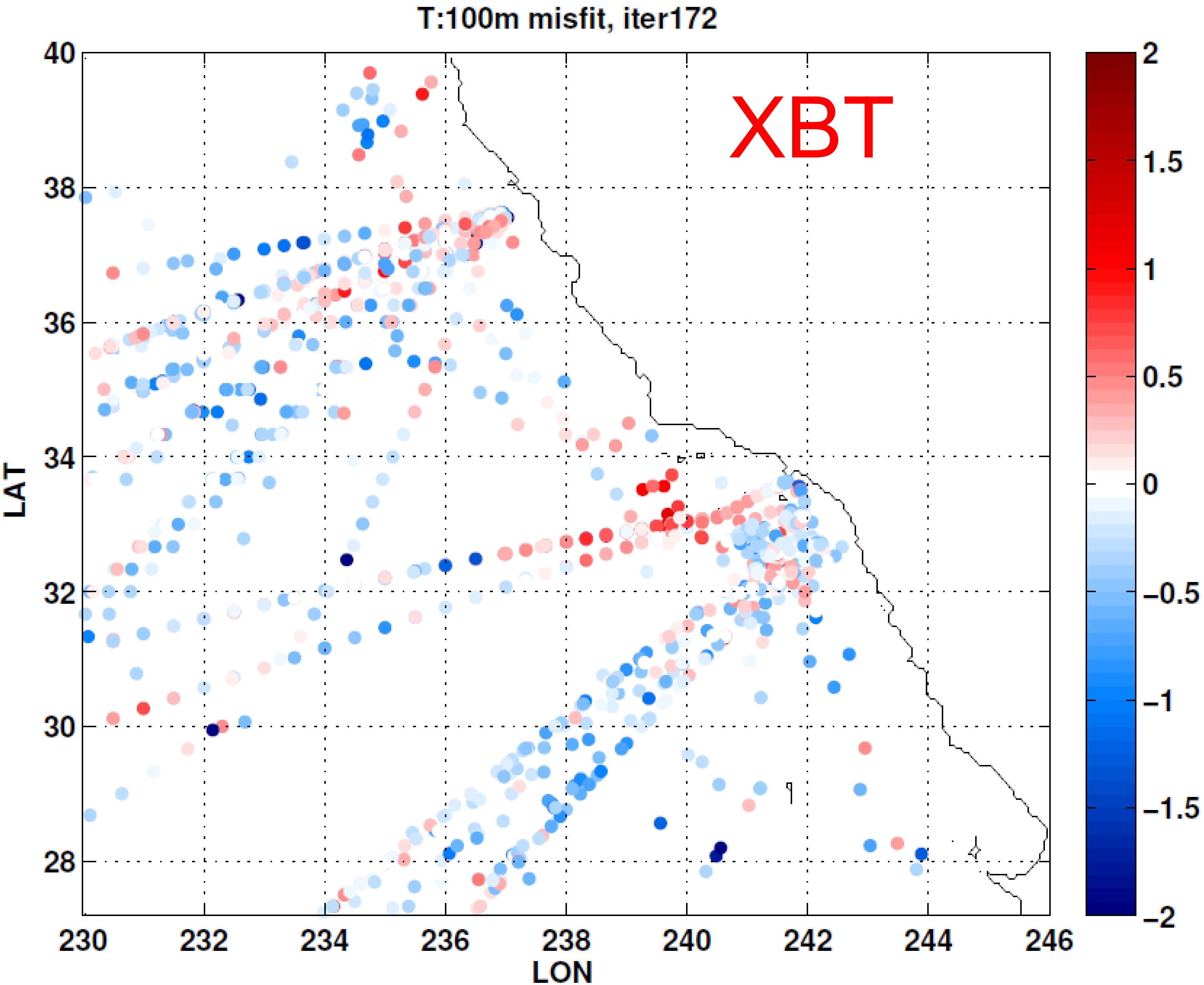

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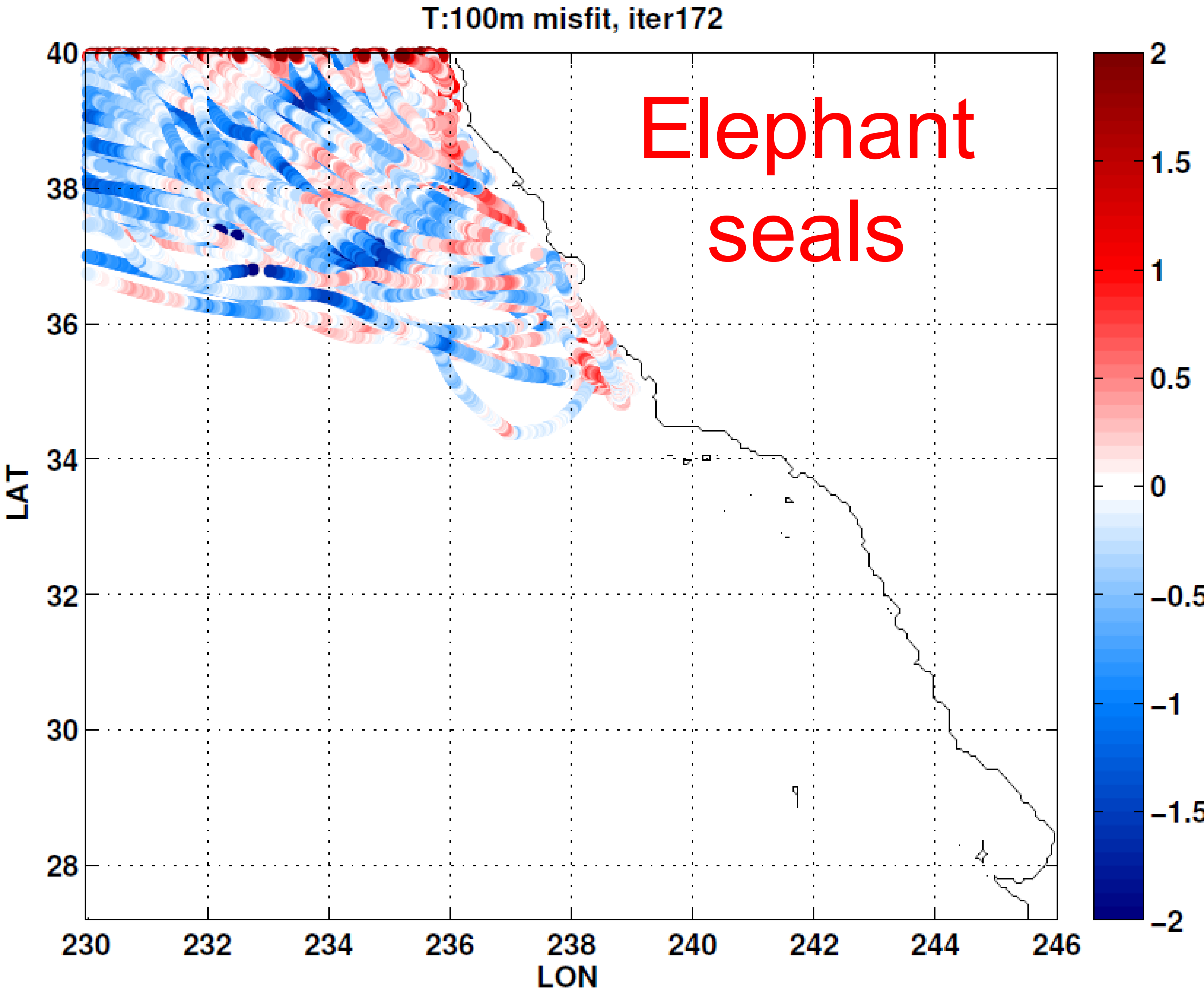

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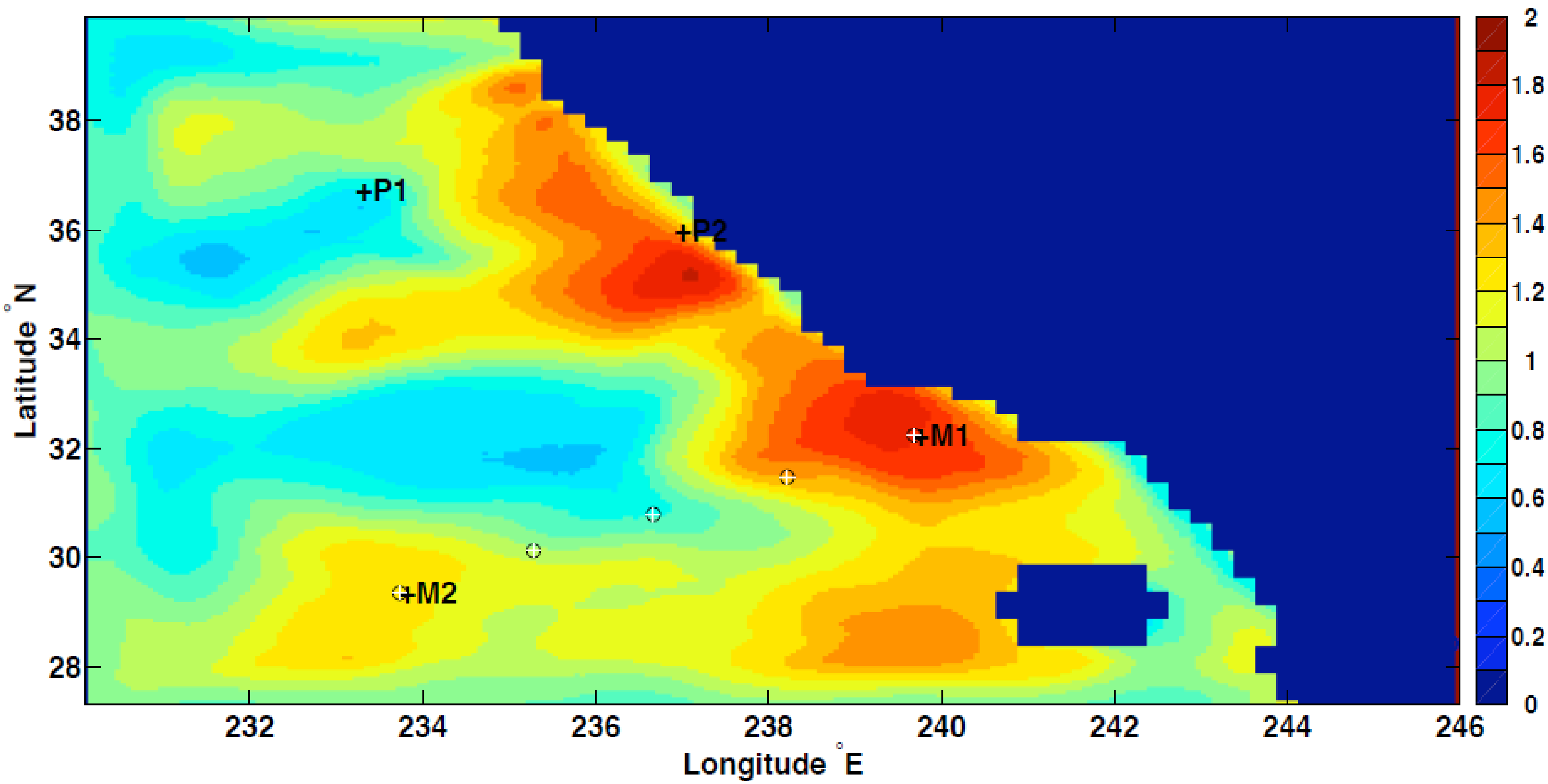
RMS difference with TMI at start



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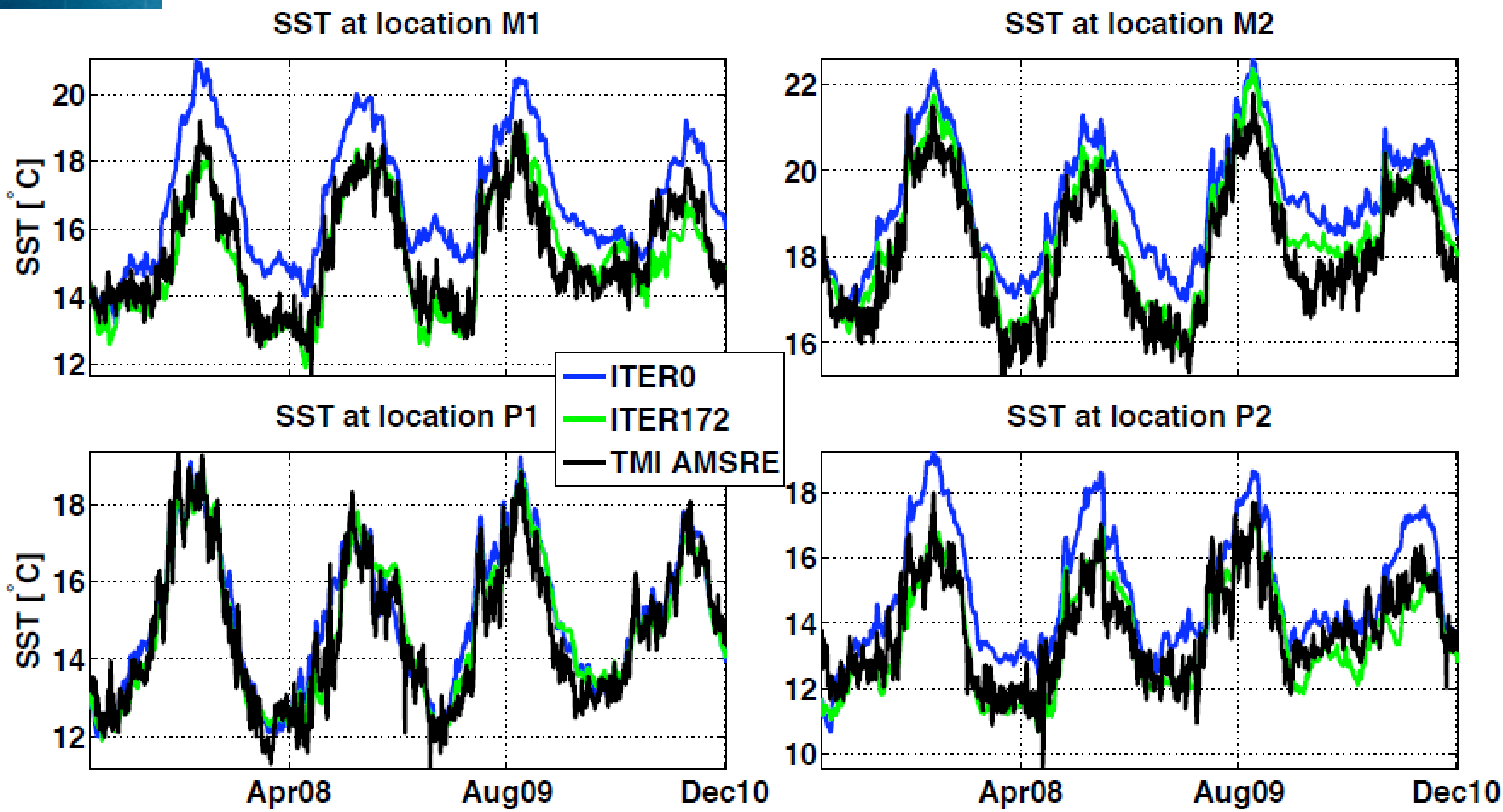
SST agreement before and after at a few points



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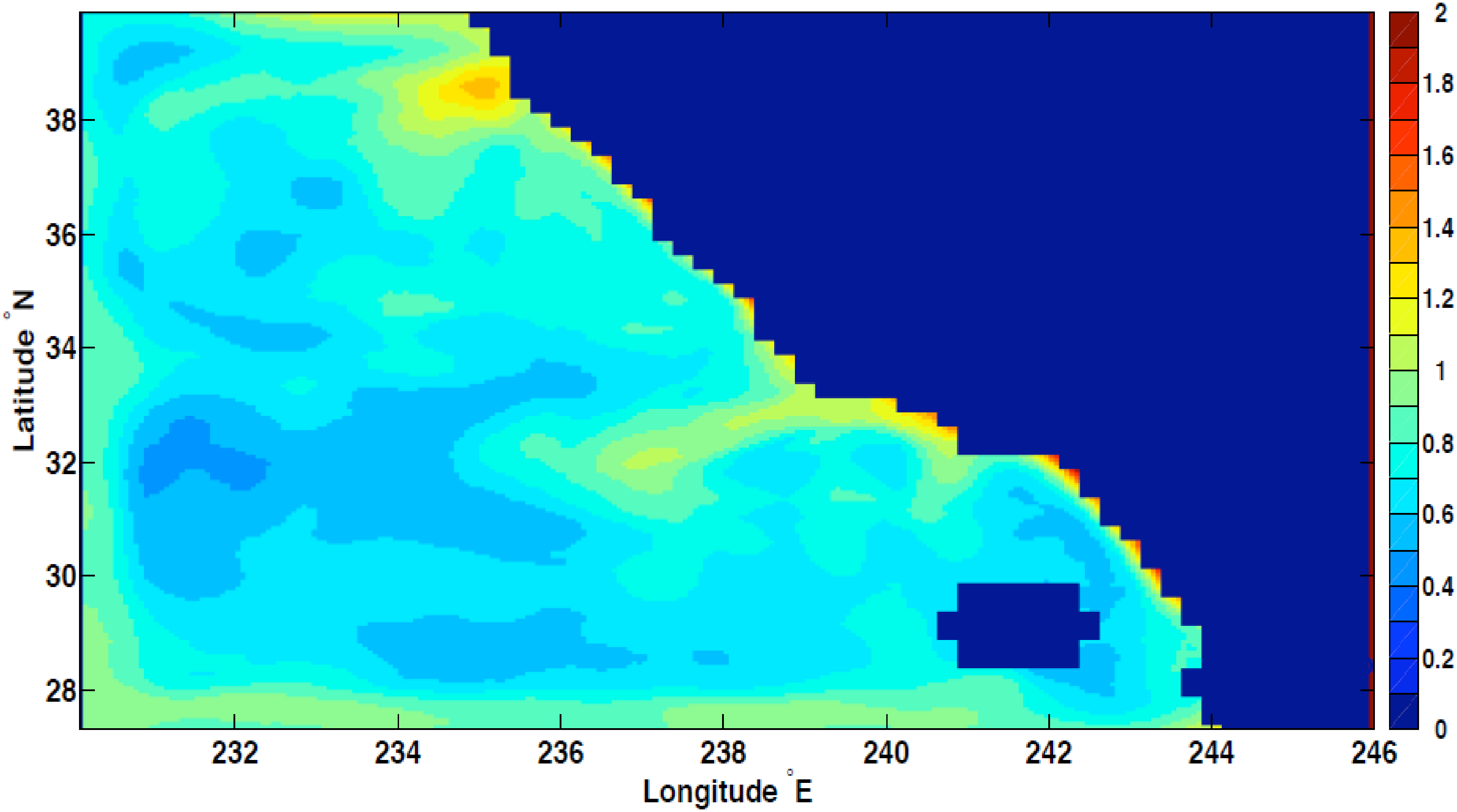
RMS difference with TMI after 172 iterations



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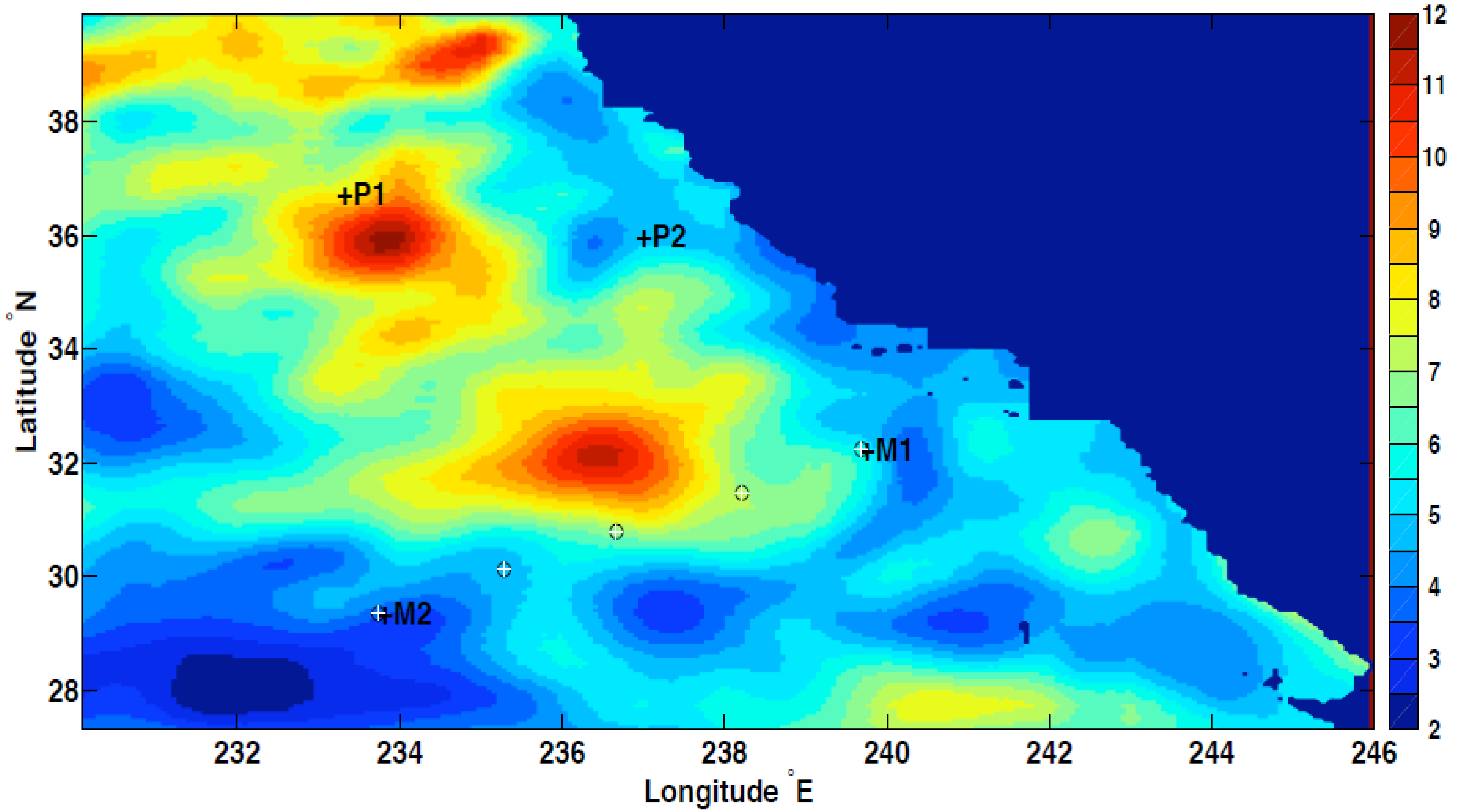
RMS difference with AVISO at start



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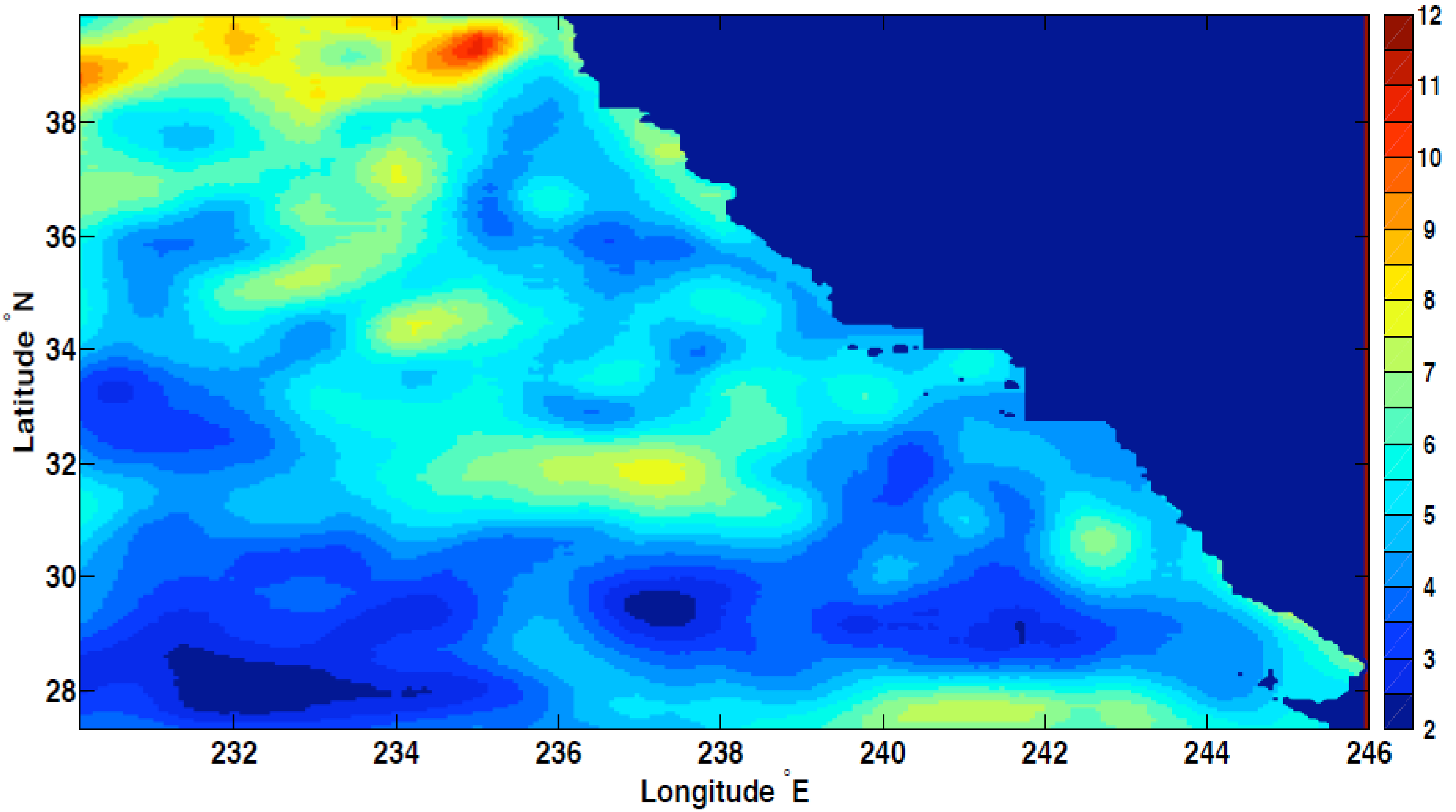
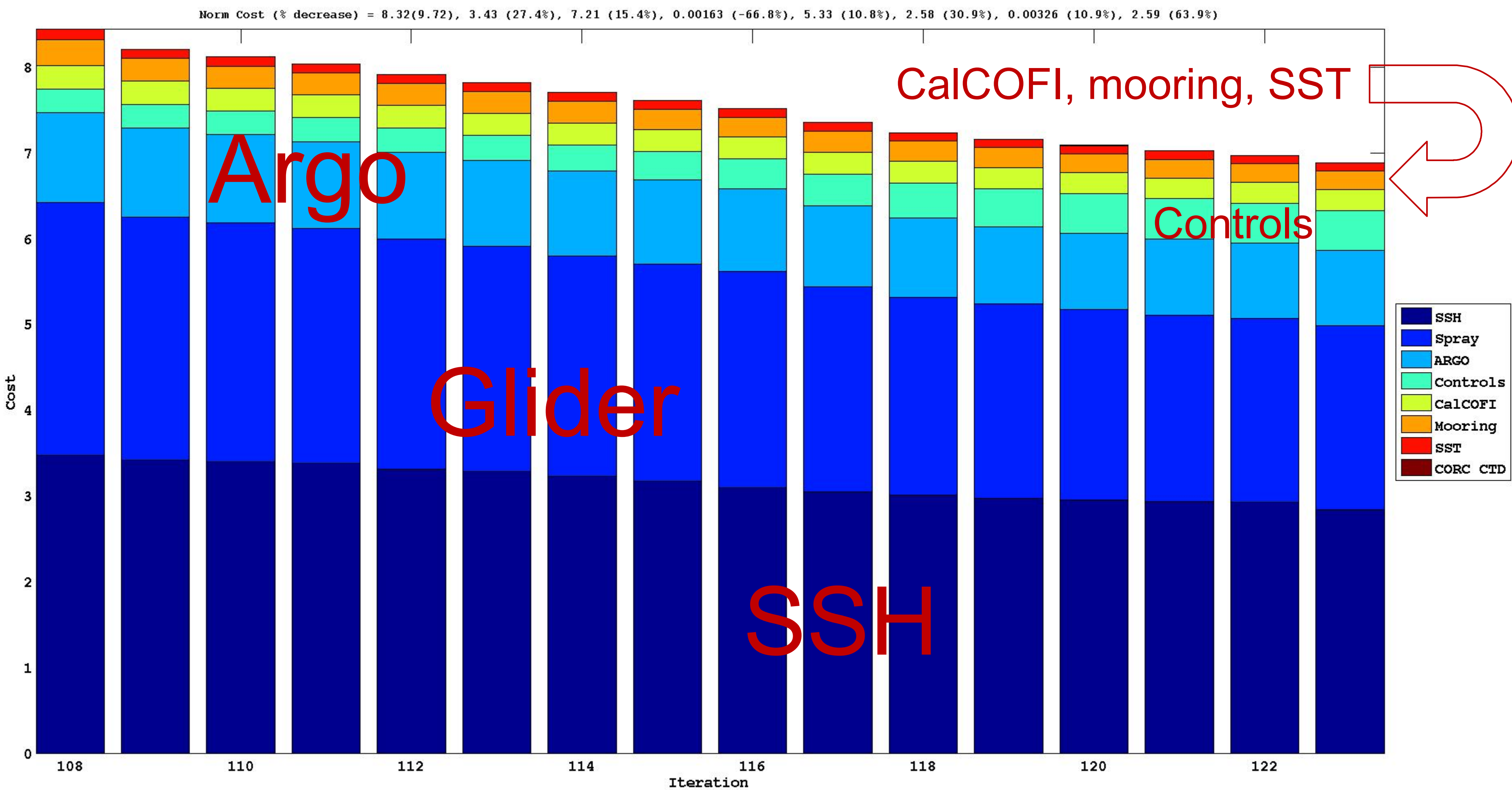
RMS difference with AVISO after 172 iterations



Cost decrease Iter 108-123

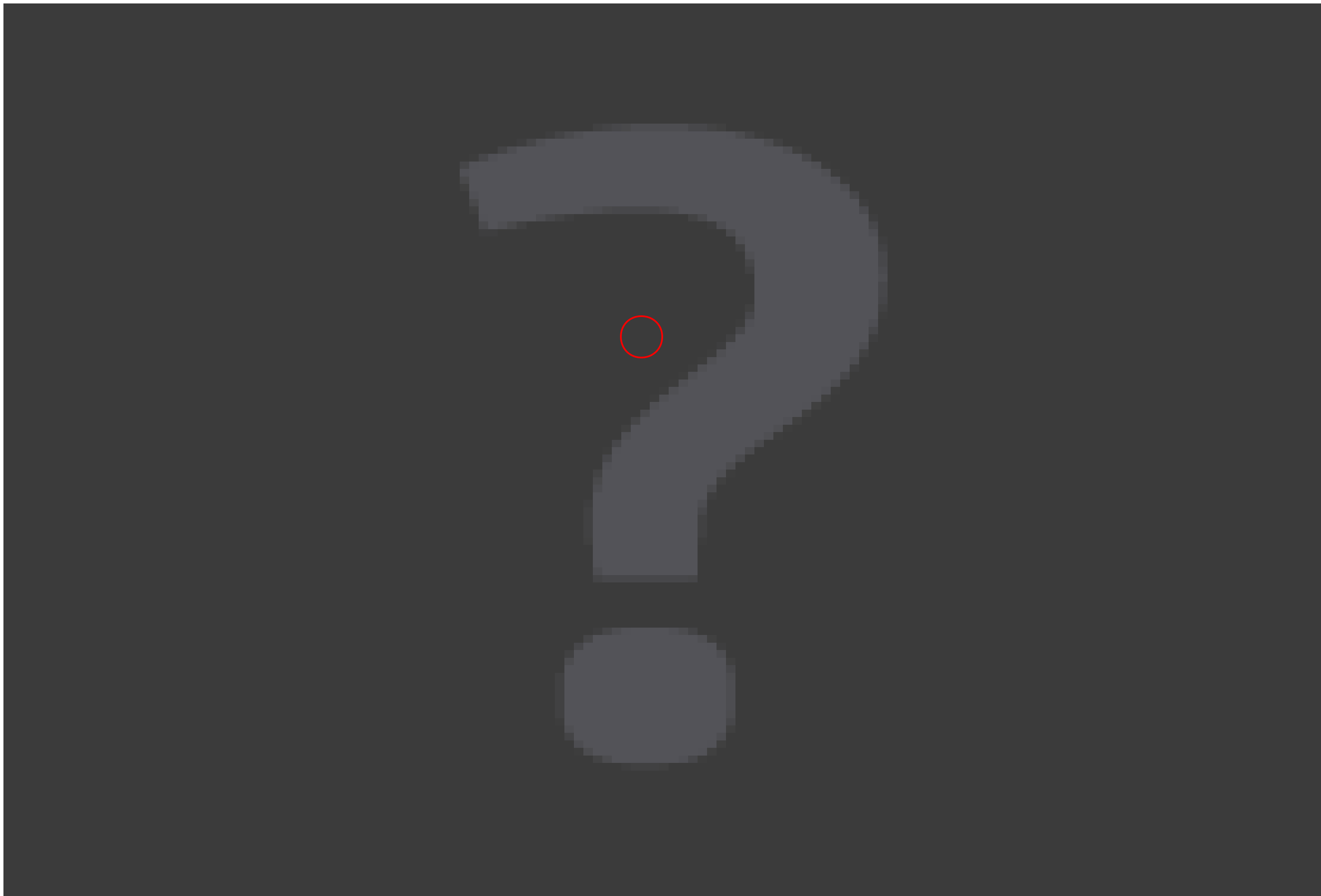


MITgcm adjoint runs

- Cost function J = sea surface height at San Luis Obisbo (simple, part of transport)
- Derive adjoint Sensitivity $\partial J / \partial x$, where x can be forcing fields, open boundary conditions etc. Showing only $\partial J / \partial \tau^x$, $\partial J / \partial \tau^y$

- Adjoint is a linearization around the chosen forward model trajectory.
  - It can vary with model state.
  - If it varies too much (non-linearity), it may not be useful
  - The sensitivity estimated by the adjoint is comparable to that obtained with regression, but without statistical noise

Port San Luis tide gauge



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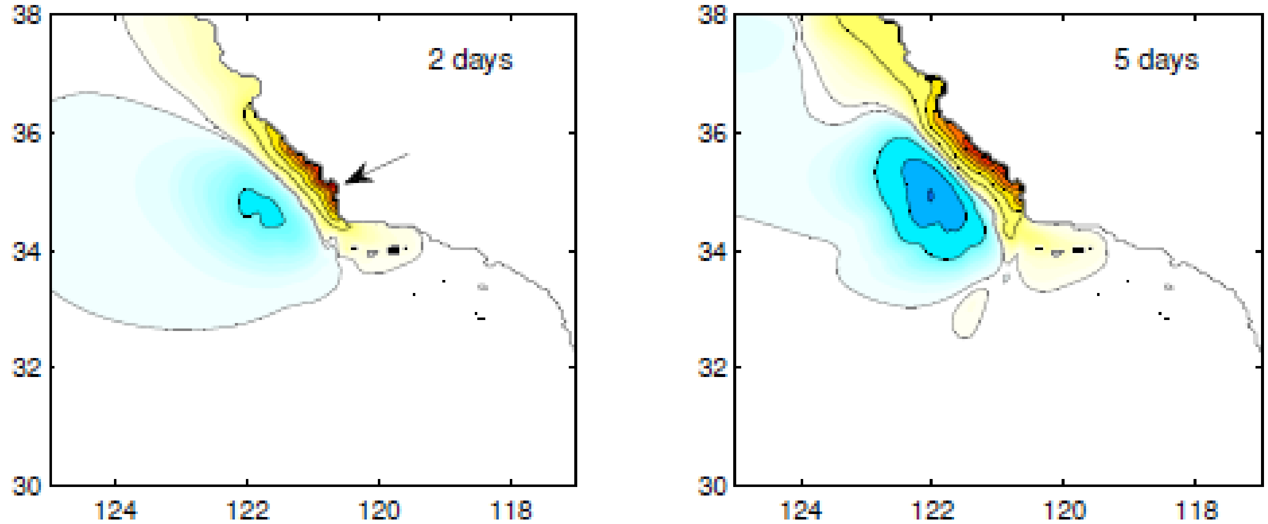
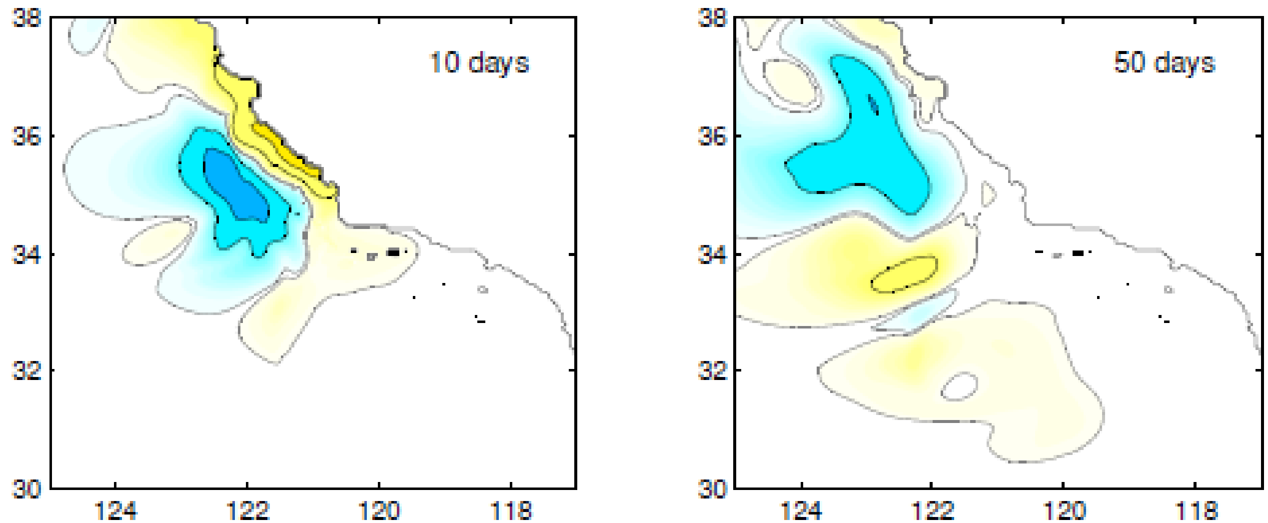
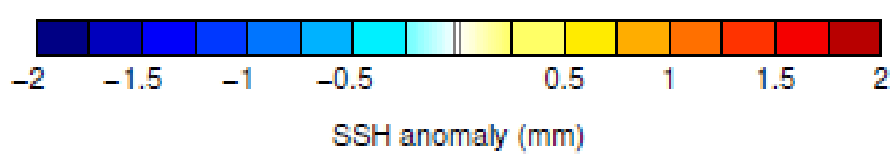
SSH



Response to positive along-coast wind impulse



4 day duration, max at 2 days, linear impulse



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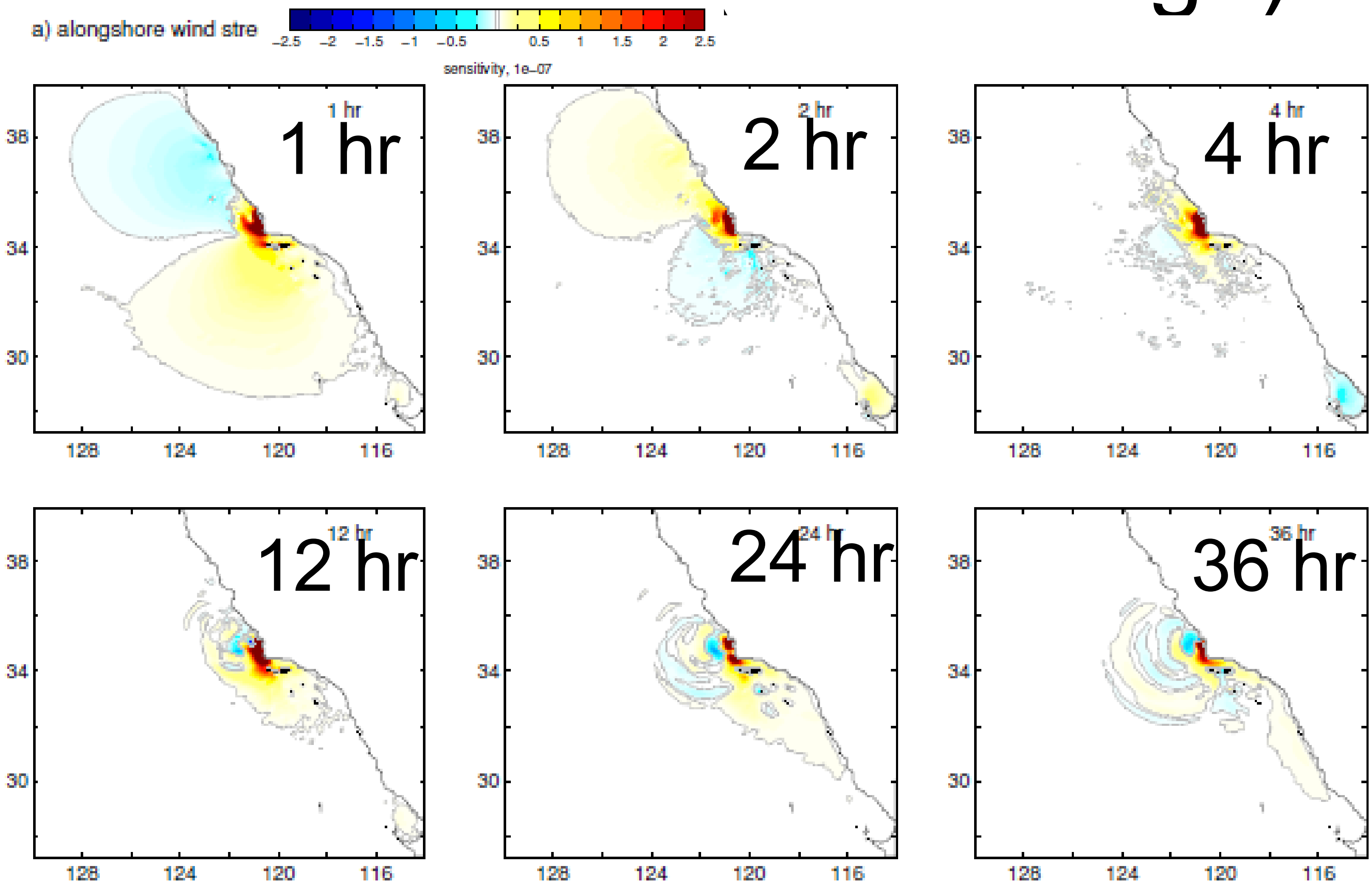
Sensitivity to alongshore wind: first few hours (storm surge)



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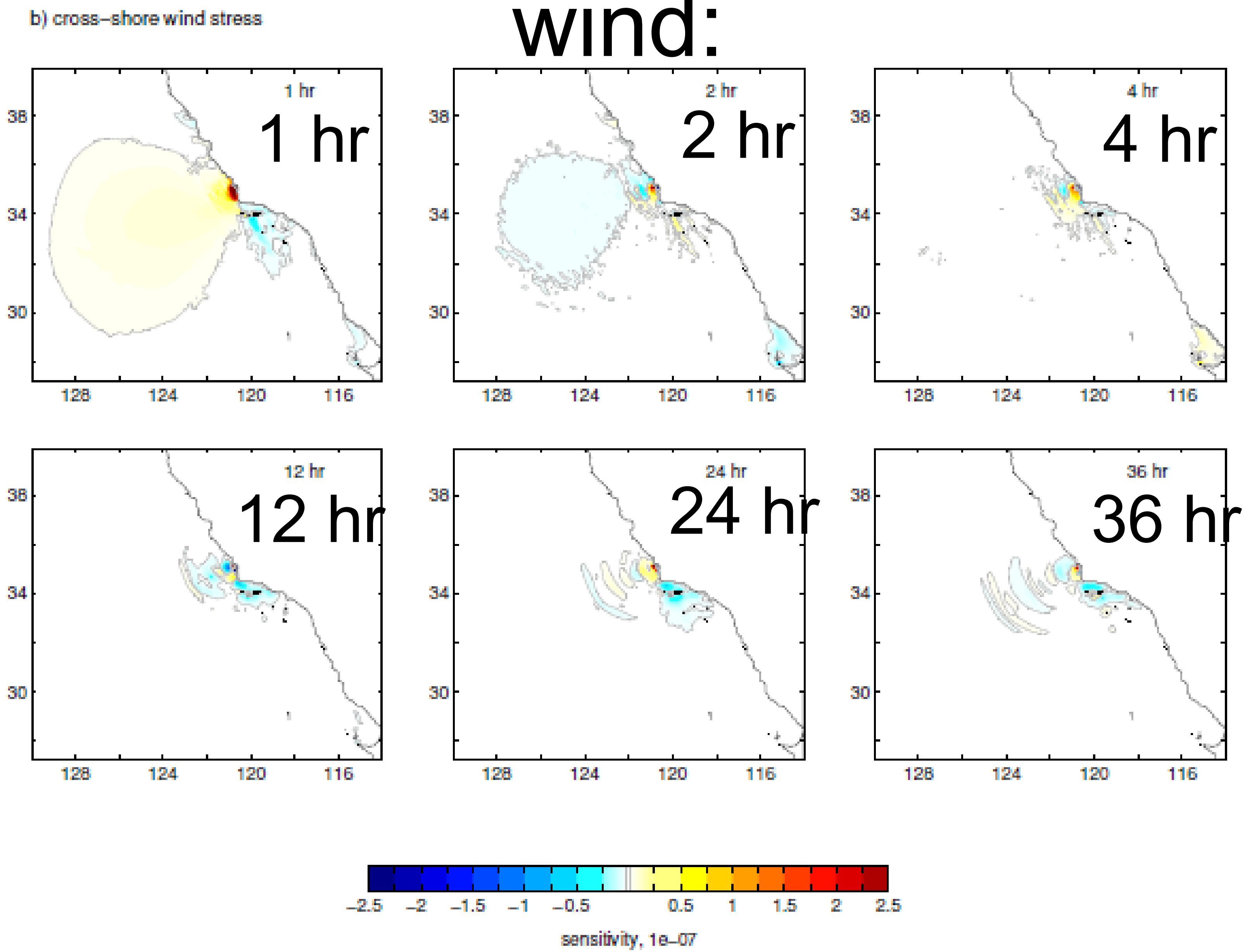
Sensitivity to cross-shore wind:



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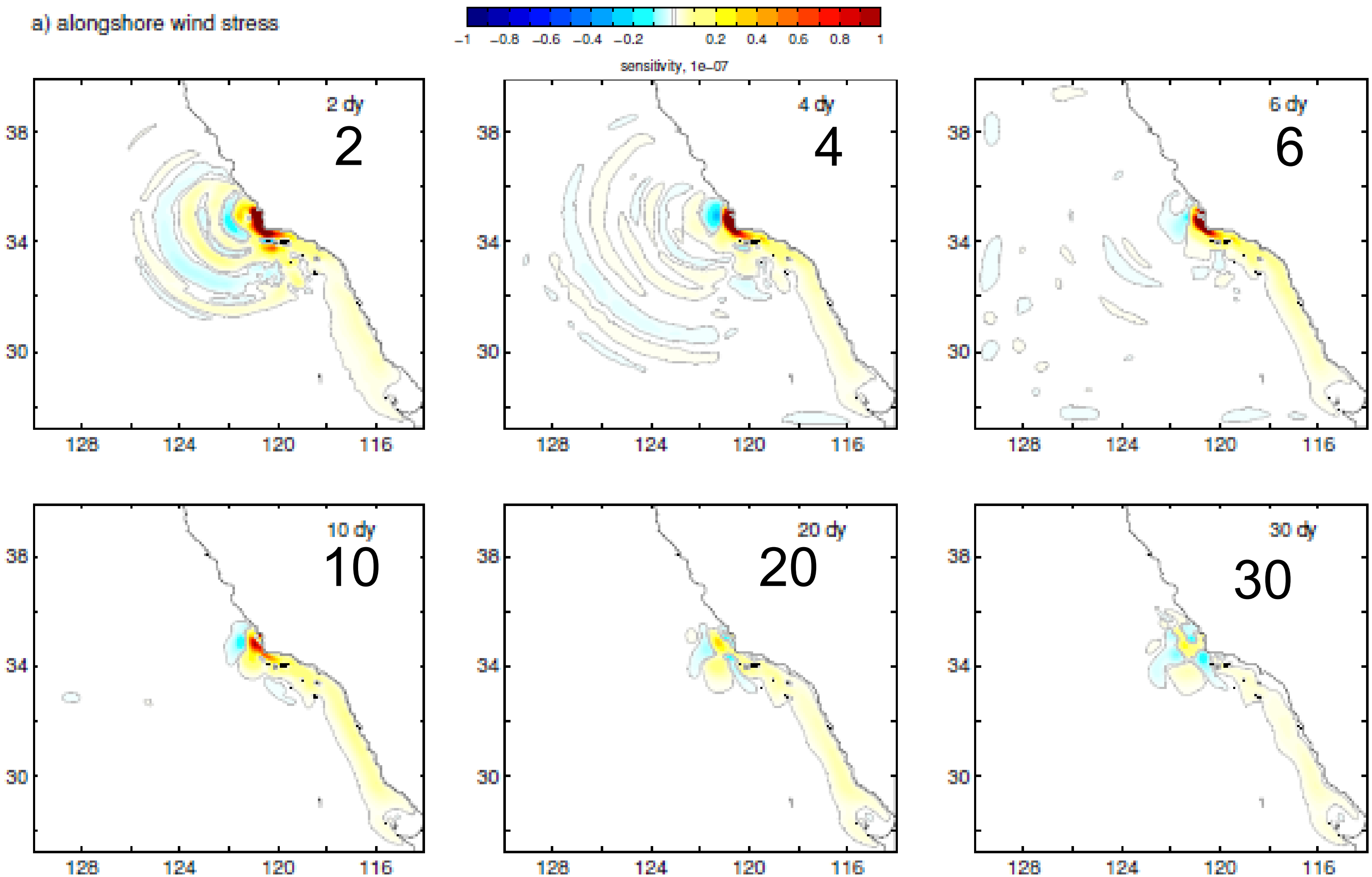
Alongshore: 2 to 30 days



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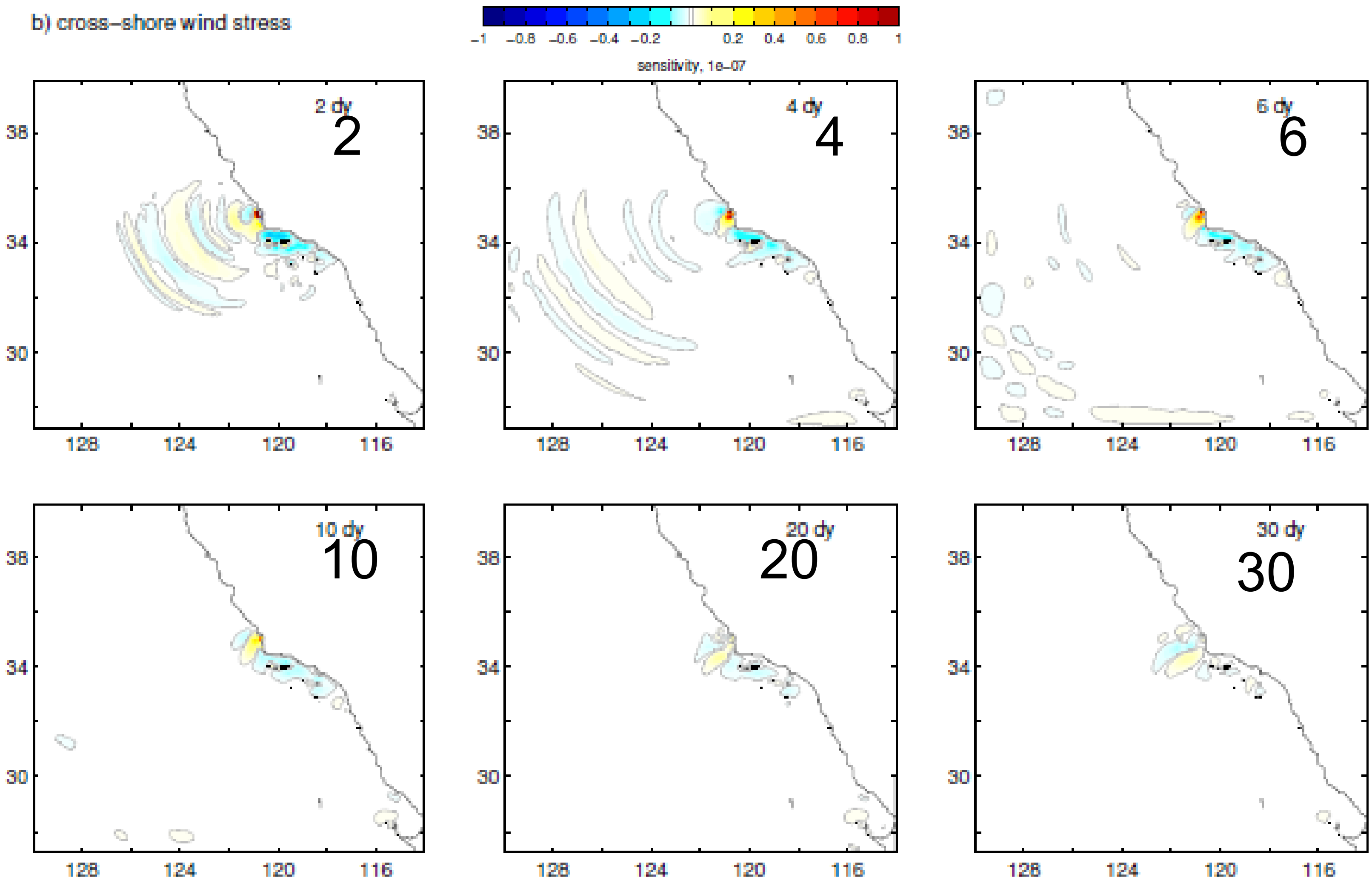
Cross-shore: 2 to 30 days



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Conclusions from adjoint

- Influence propagates primarily in coastal waveguide (as expected)
- Short-term response shows storm surge sensitivity and barotropic waves
- Longer-term response shows baroclinic waves
- Influence of ocean state (nonlinearity) is significant (not shown)

References

- Xuebin Zhang, Bruce Cornuelle, and Dean Roemmich (2011) Adjoint sensitivity of the Nino-3 surface temperature to wind forcing, Journal of Climate.
- Xuebin Zhang, Bruce Cornuelle, and Dean Roemmich (2012) Sensitivity of western boundary transport at the mean North Equatorial Current bifurcation latitude to wind forcing. Journal of Physical Oceanography

References, Continued

- Todd, Robert E., Daniel L. Rudnick, Matthew R. Mazloff, Bruce D. Cornuelle, and Russ E. Davis, (2012), Thermohaline structure in the California Current System: Observations and modeling of spice variance. JGR
- Todd, Robert E., Daniel L. Rudnick, Matthew R. Mazloff, Russ E. Davis , and Bruce D. Cornuelle, (2011) Poleward flows in the southern California Current System: Glider observations and numerical simulation. JGR

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Merci ! Questions?

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Extra slides

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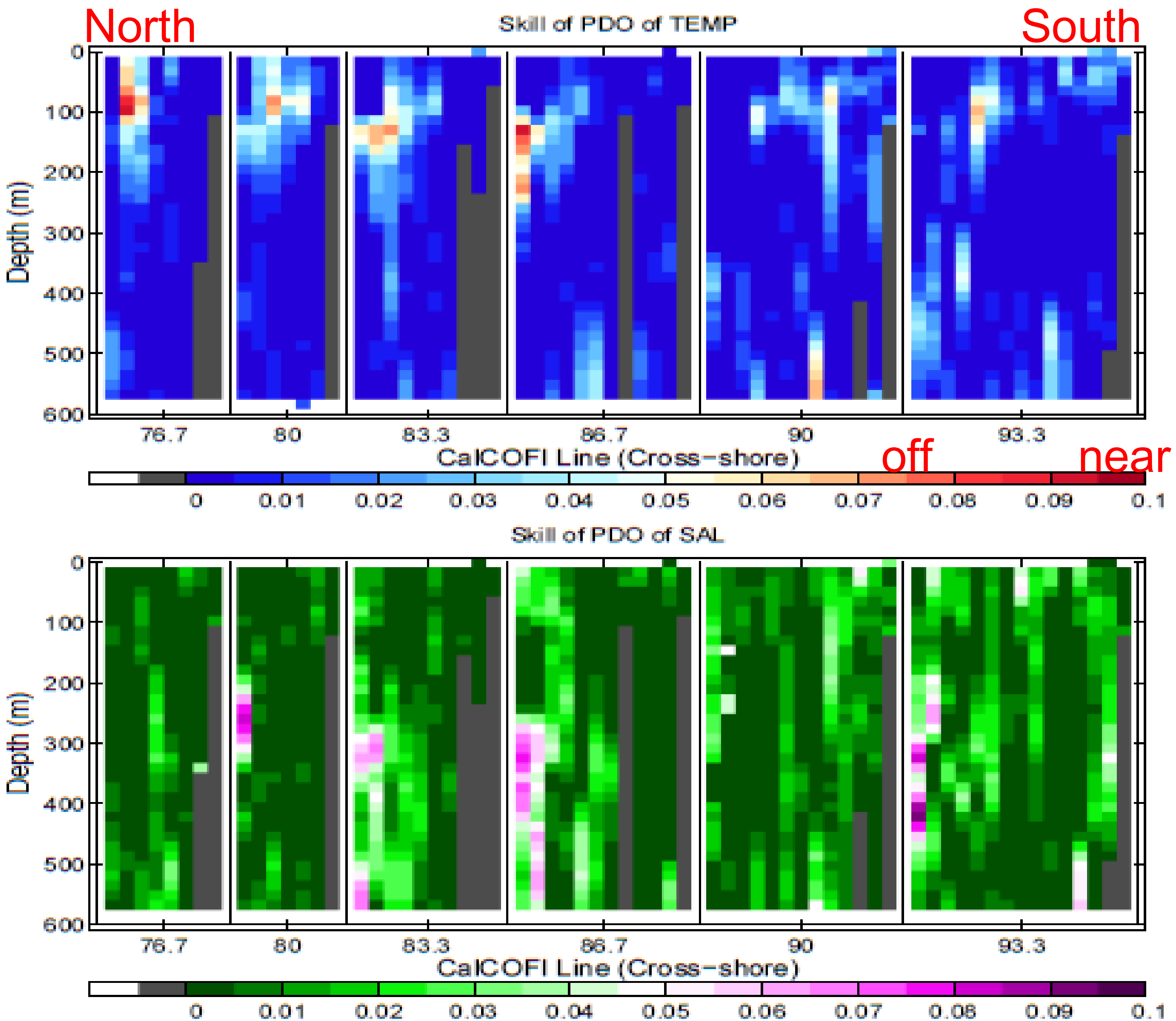

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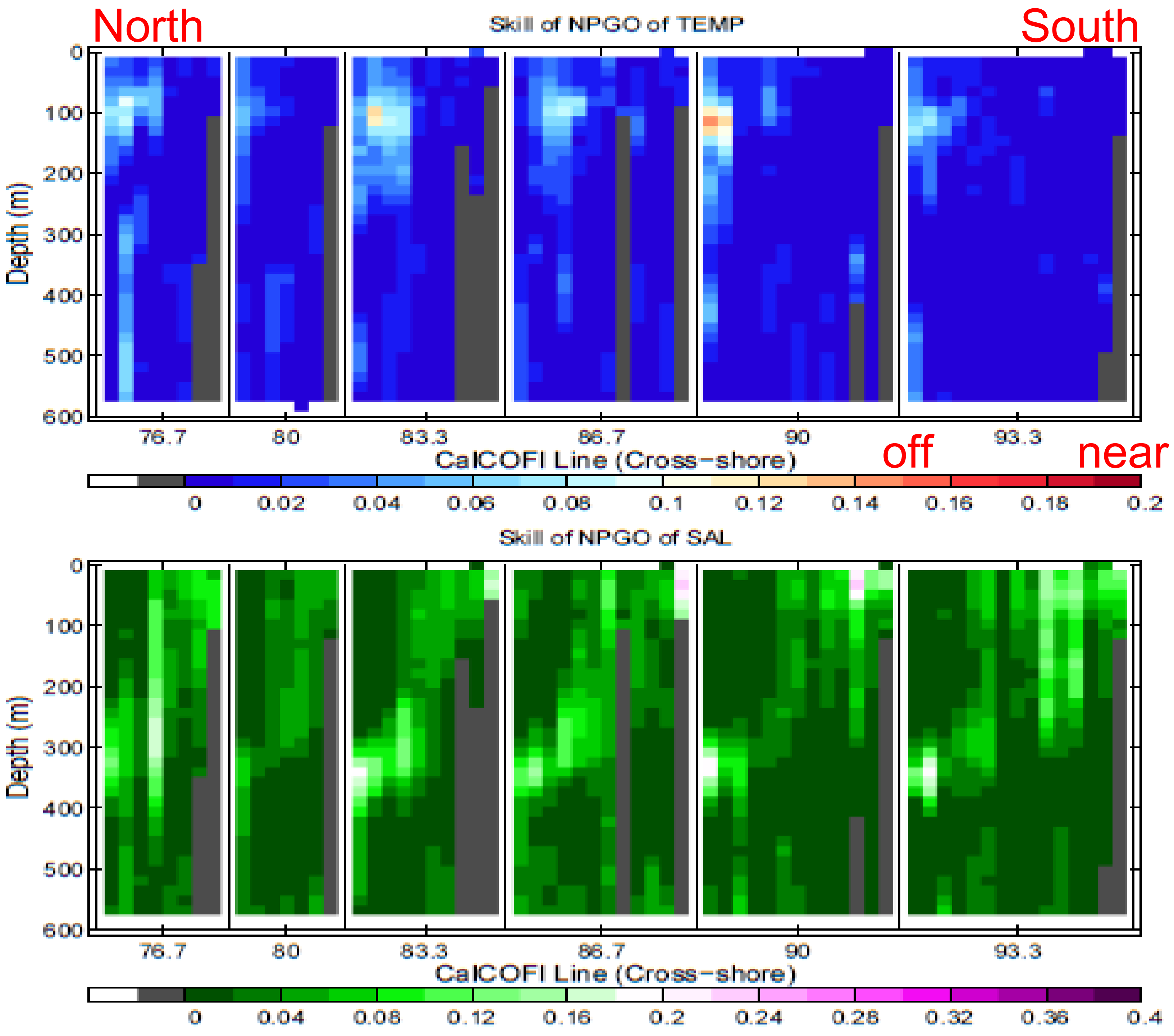

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