Boundary Currents and the Coastal Climate Signal: The California Current System

Daniel L. Rudnick
Scripps Institution of Oceanography

SCRIPPS INSTITUTION OF OCEANOGRAPHY UCSD

INSTRUMENT DEVELOPMENT GROUP
SCRIPPS INSTITUTION OF OCEANOGRAPHY

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION NOAA U.S. DEPARTMENT OF COMMERCE

SOUTHERN CALIFORNIA COASTAL OCEAN OBSERVING SYSTEM

CENTRAL & NORTHERN CALIFORNIA OCEAN OBSERVING SYSTEM

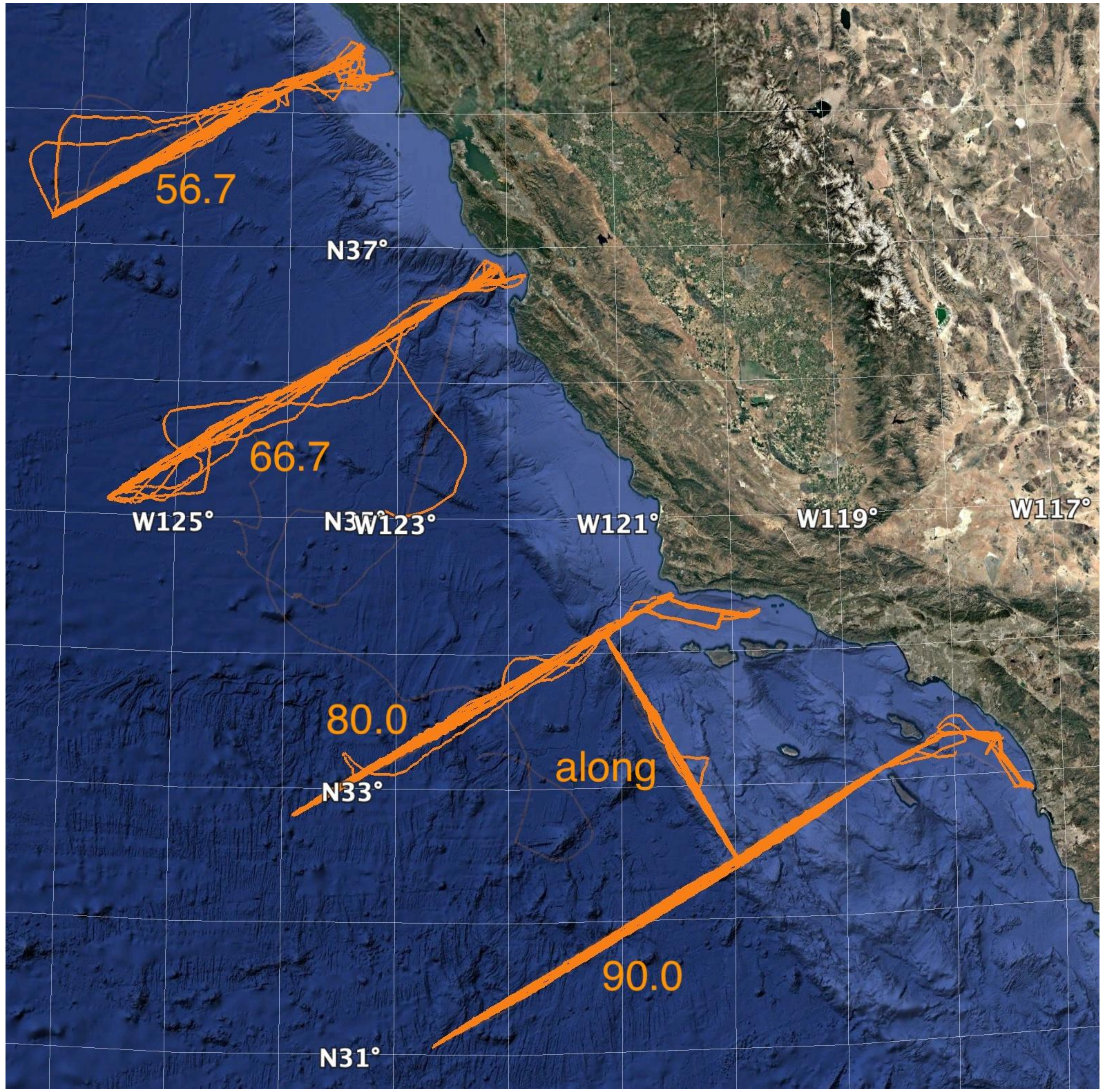
Questions

- What key processes influence coastal climate but remain poorly understood or inadequately represented in models?
  - I will focus on processes, with some opinions about their representation in models.
- What are the current capabilities and limitations of existing models (e.g., global, regional, data-assimilative, coupled, statistical), and in what contexts are they most or least effective?
  - I will not address this question as I am not a modeler.
- What recent observational insights into coastal climate should inform the priorities of the modeling community?
  - I will make some recommendations on what observed processes should be represented in a good model.

Processes

- Focus on the California Current System
- Mean fields
  - Observations and models
- The annual cycle
  - Annual upwelling and the California Undercurrent
- El Niño
  - Mechanisms of warming
- The upwelling cell
  - Evidence for the classic theory of upwelling
- Mesoscale eddies
  - Offshore propagation

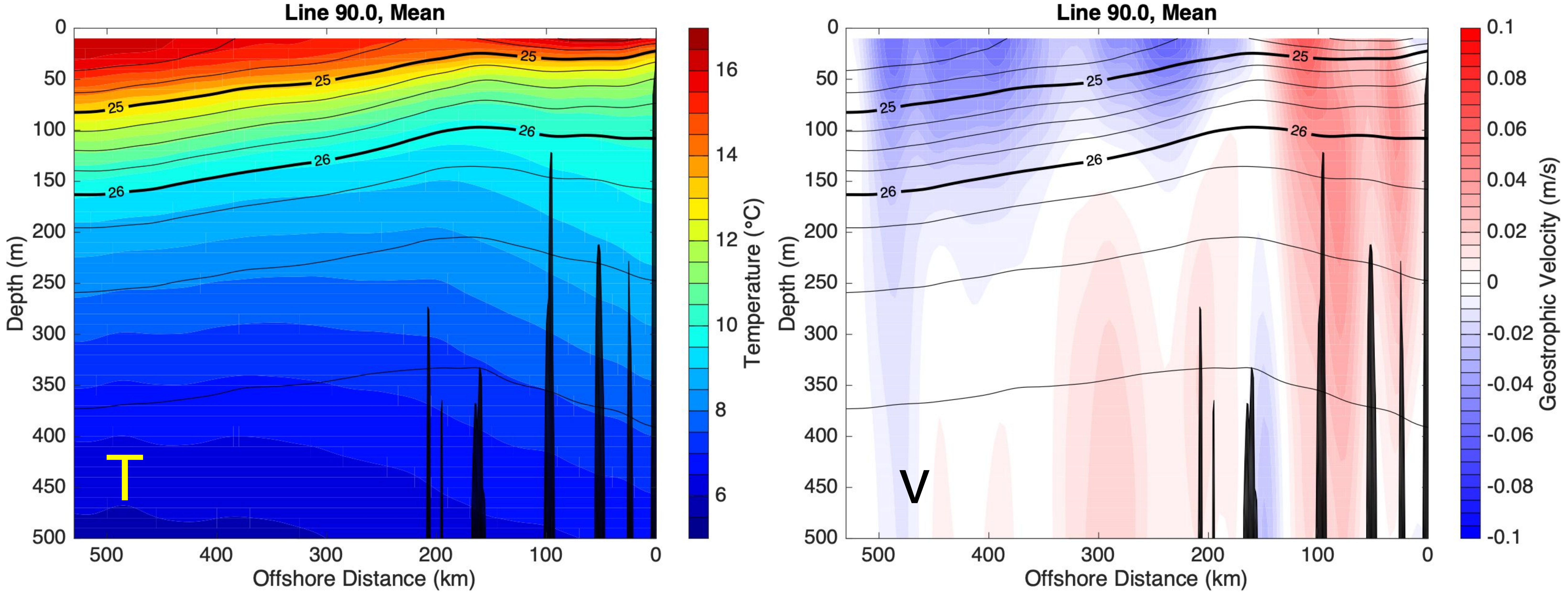
Observations and models in the California Current System

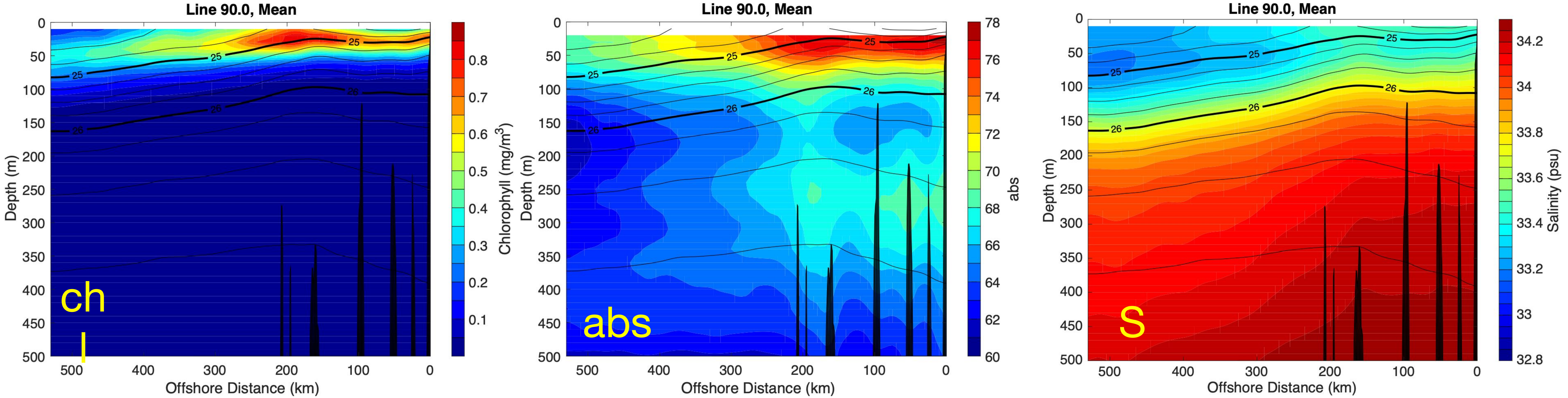


- California Underwater Glider Network (CUGN)
- Climatology with mean, annual, interannual fields
- spraydata.ucsd.edu
- Rudnick et al (2017, Prog Oceanogr.)
- California State Estimation (CASE) assimilating MITgcm
- www.ecco.ucsd.edu/case.html
- Zaba et al. (2018, 2020, JPO)
- ROMS model in the West Coast Operational Forecasting System (WCOFS)
- Kurapov et al. (2017, 2022, JGR)

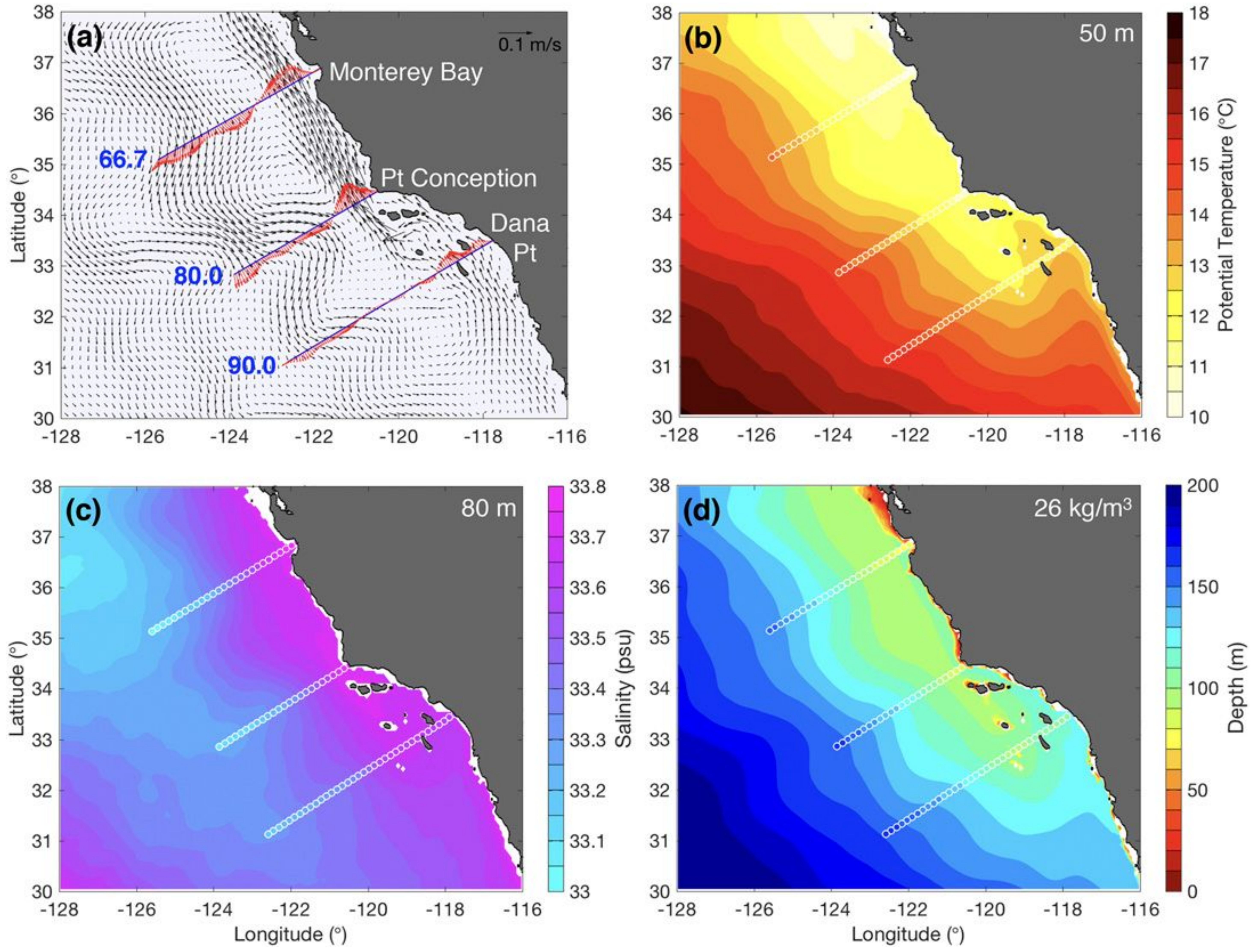
Mean on line 90

- Cores of poleward California Undercurrent
- Equatorward California Current
- Change near edge of bight
- Maximum in chlorophyll fluorescence
- Acoustic backscatter, maxima at surface and depth



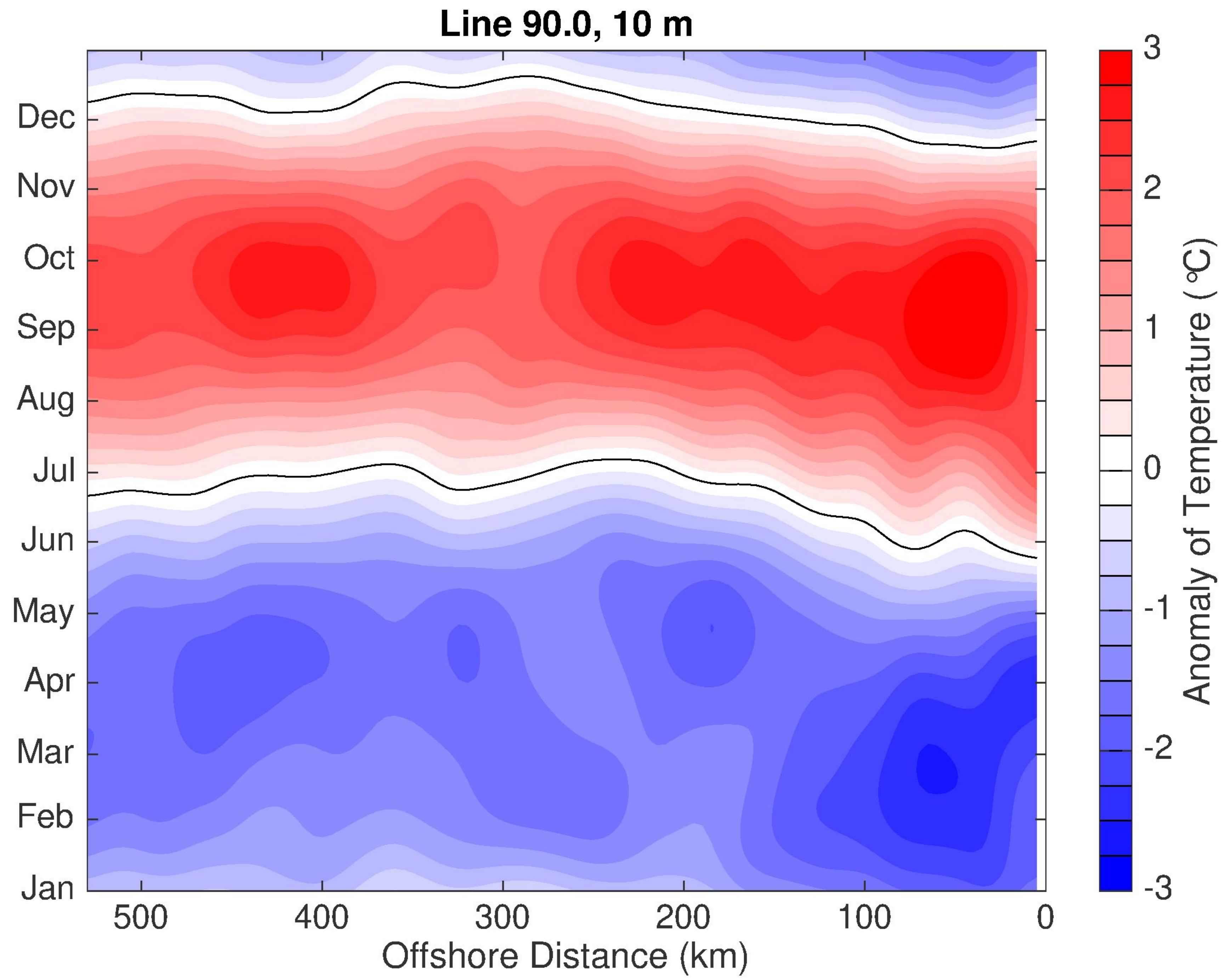


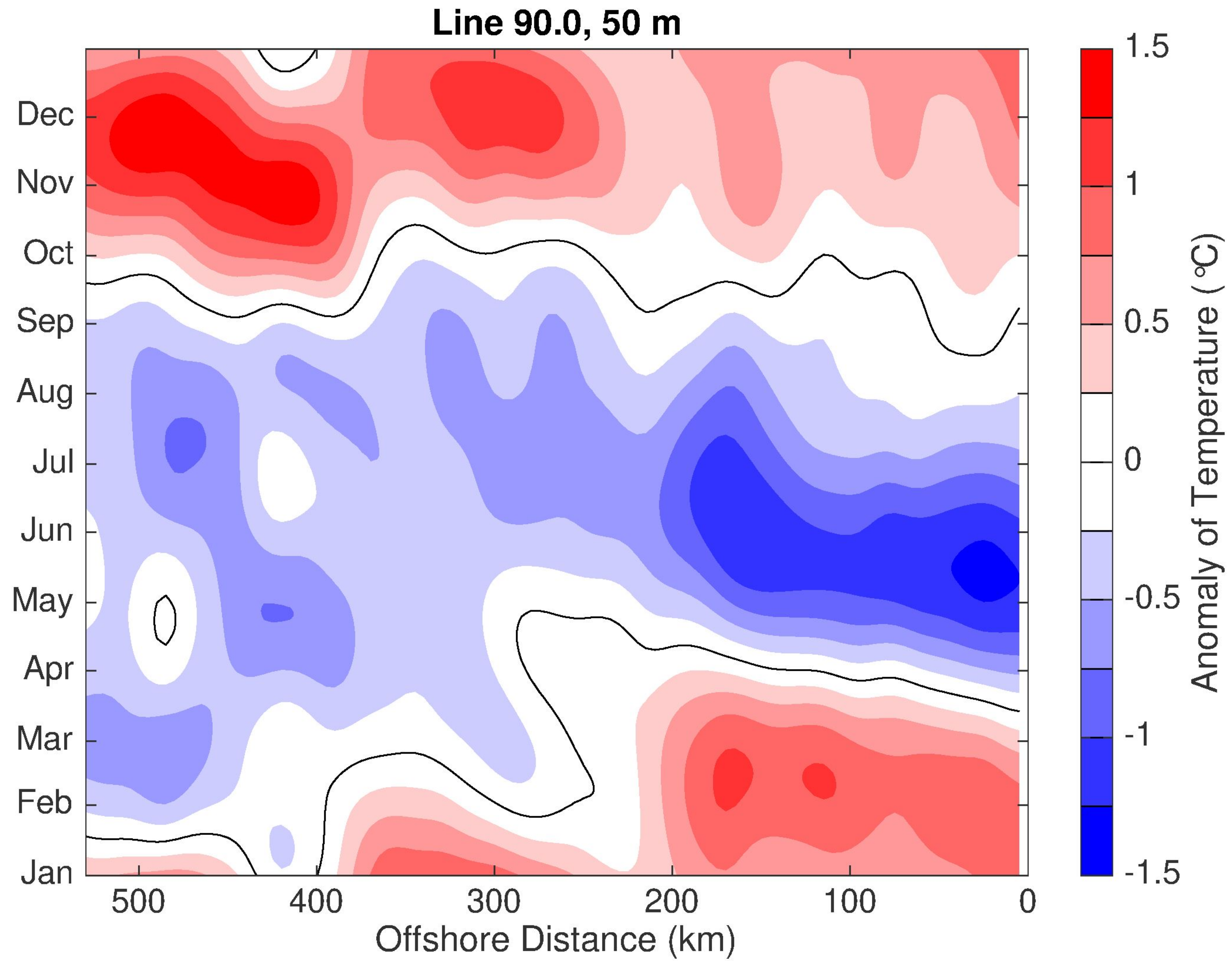
Mean from CUGN and CASE



- Depth-average velocity (not assimilated): California Current and Undercurrent, meanders in 7-year mean
- Potential temperature
- Salinity
- Depth of 26 kg/m^3 isopycnal

Annual cycle of temperature





- 10-m temperature driven by heat flux
- Maximum in late summer
- 50-m temperature driven by wind stress (curl)
- Maximum in winter
- The maximum in winter is relevant to the effects of El Niño, whose effects also peak in winter

Annual cycle: Observed and modeled

Obs

Mod

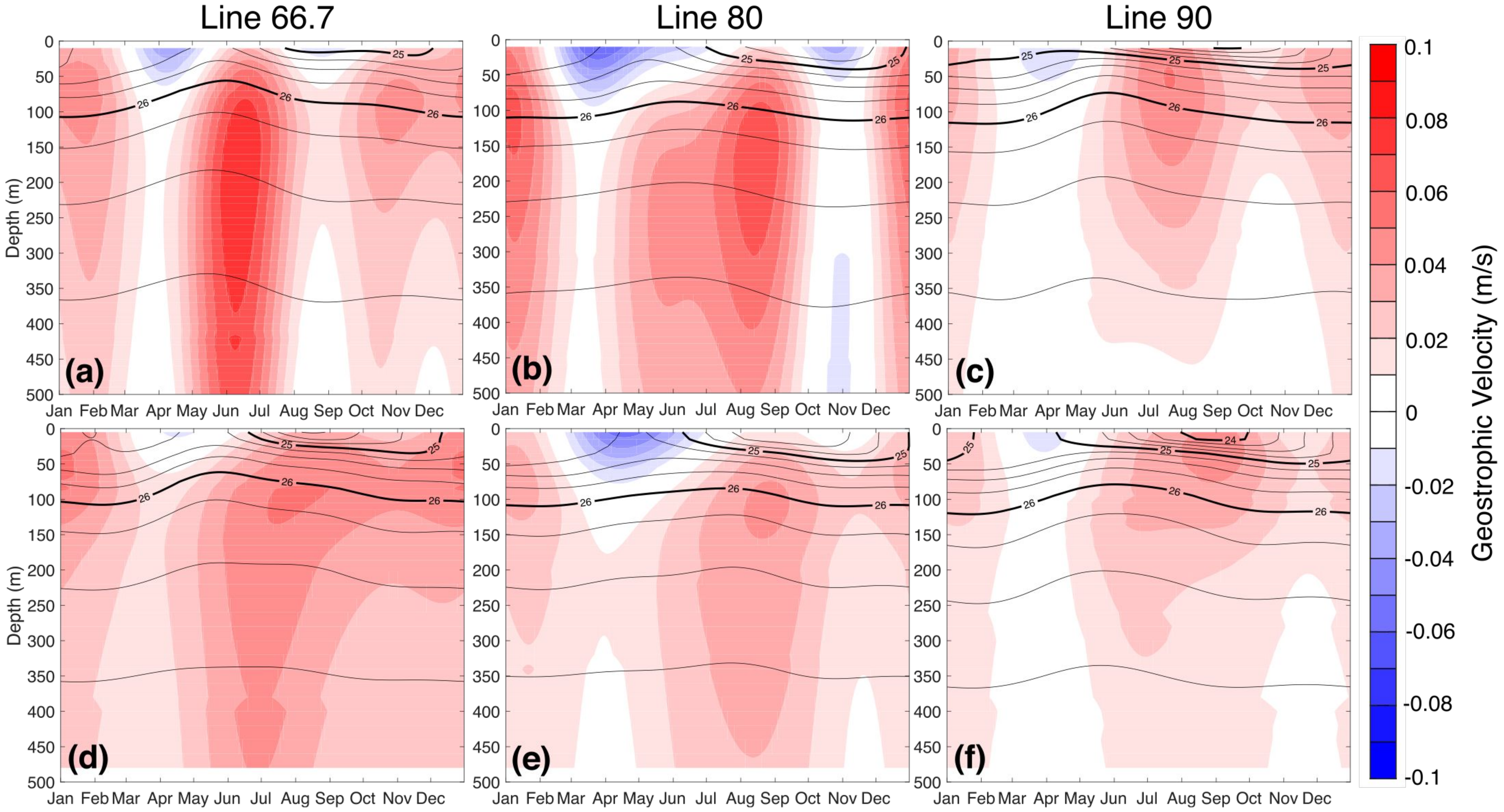
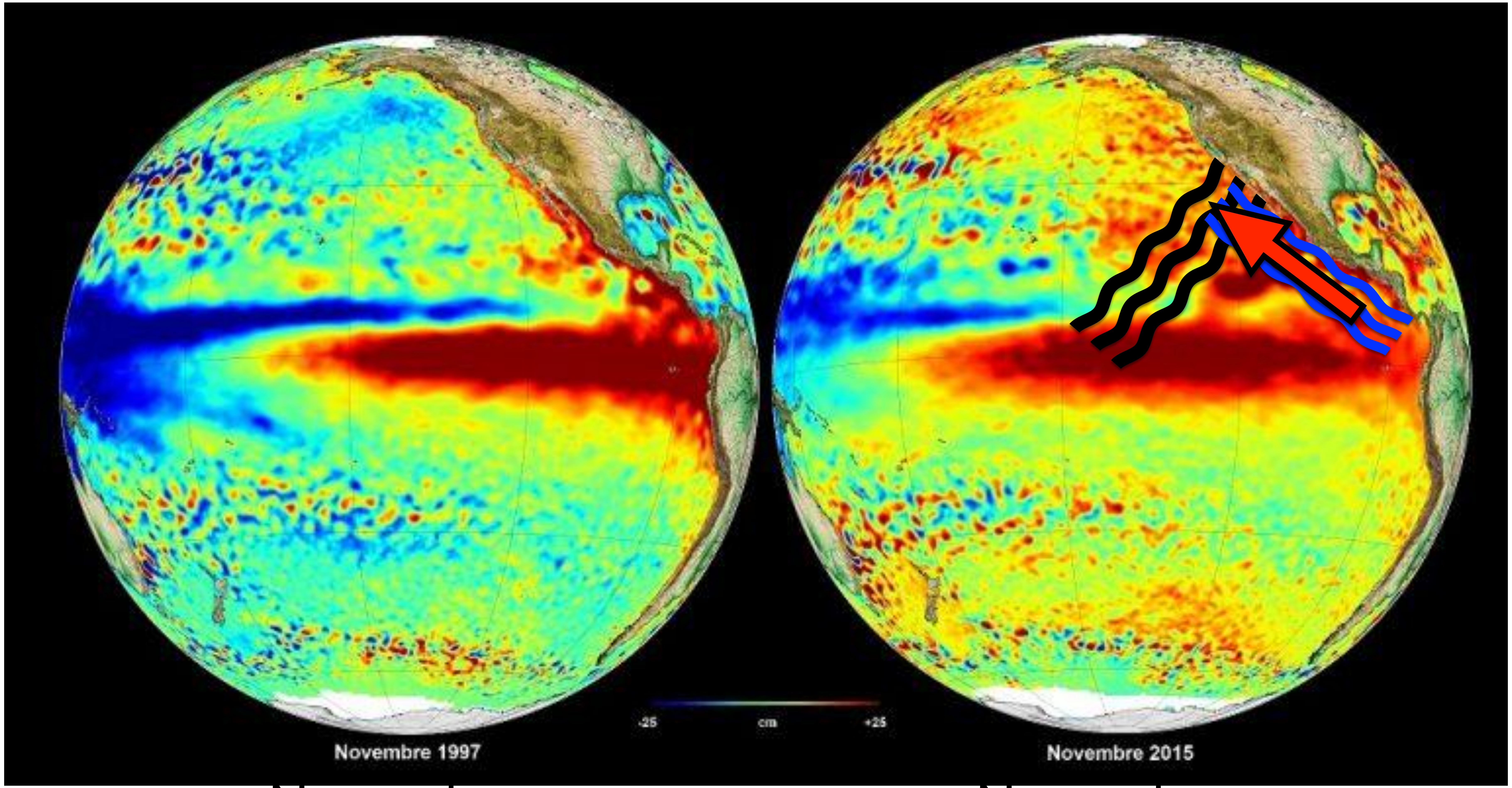


FIG. 10. Annual cycles of geostrophic velocity averaged over the inshore 150 km of (a),(d) line 66 and (b),(e) 80 and 200 km of (c),(f) line 90 and plotted as a function of time and depth for (top) glider-measured and (bottom) modeled values.

Zaba et al. (2018)

- Semi-annual cycle in California Undercurrent observed by CUGN and simulated by CASE
- Qualitative agreement
- Differences could be important to the assessment of climate variability
- Gomez-Valdivia et al. (2017, JGR) attribute the semi-annual cycle to coastally-trapped waves

El Niño: Sea Surface Height



November 1997

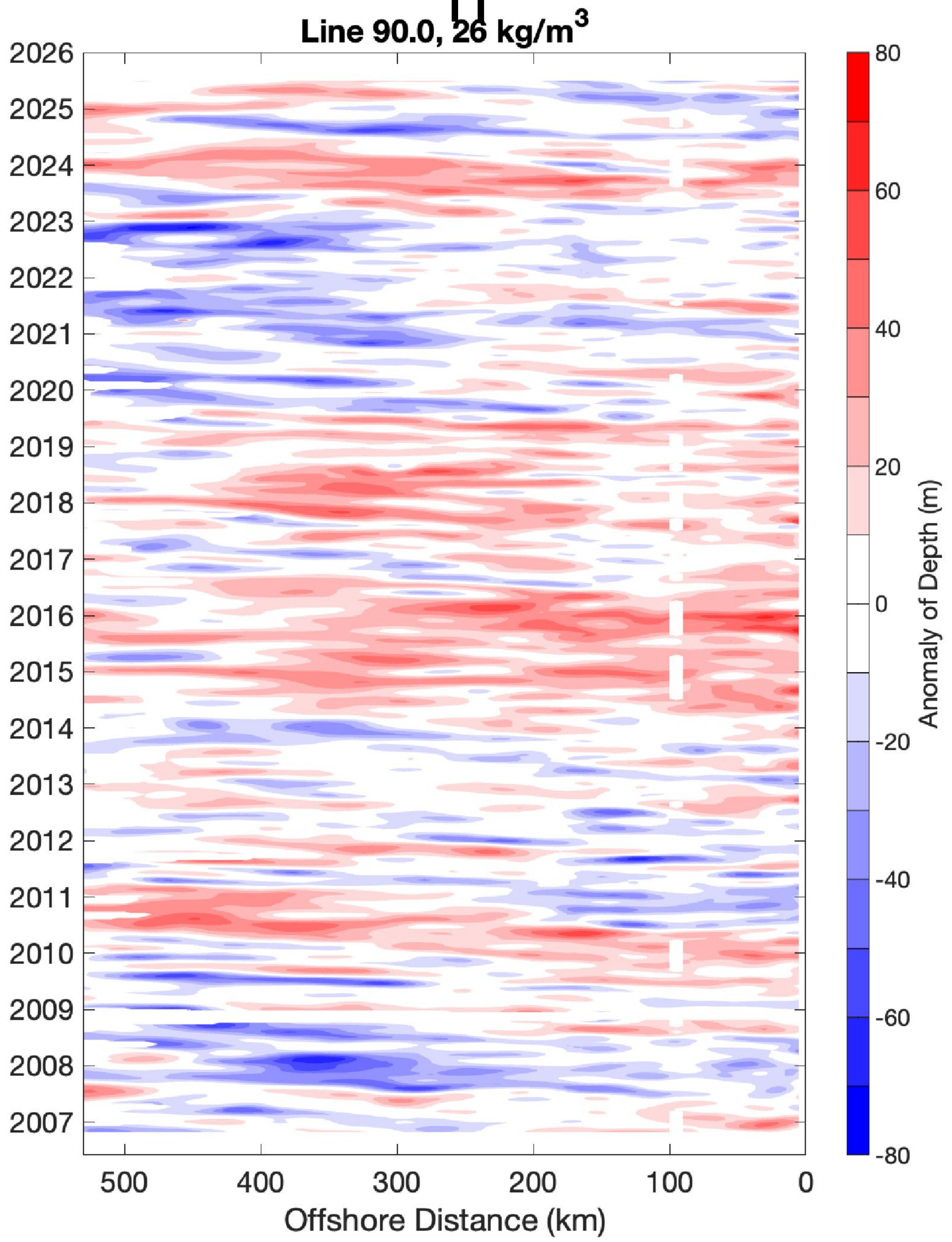
November 2015

CNES

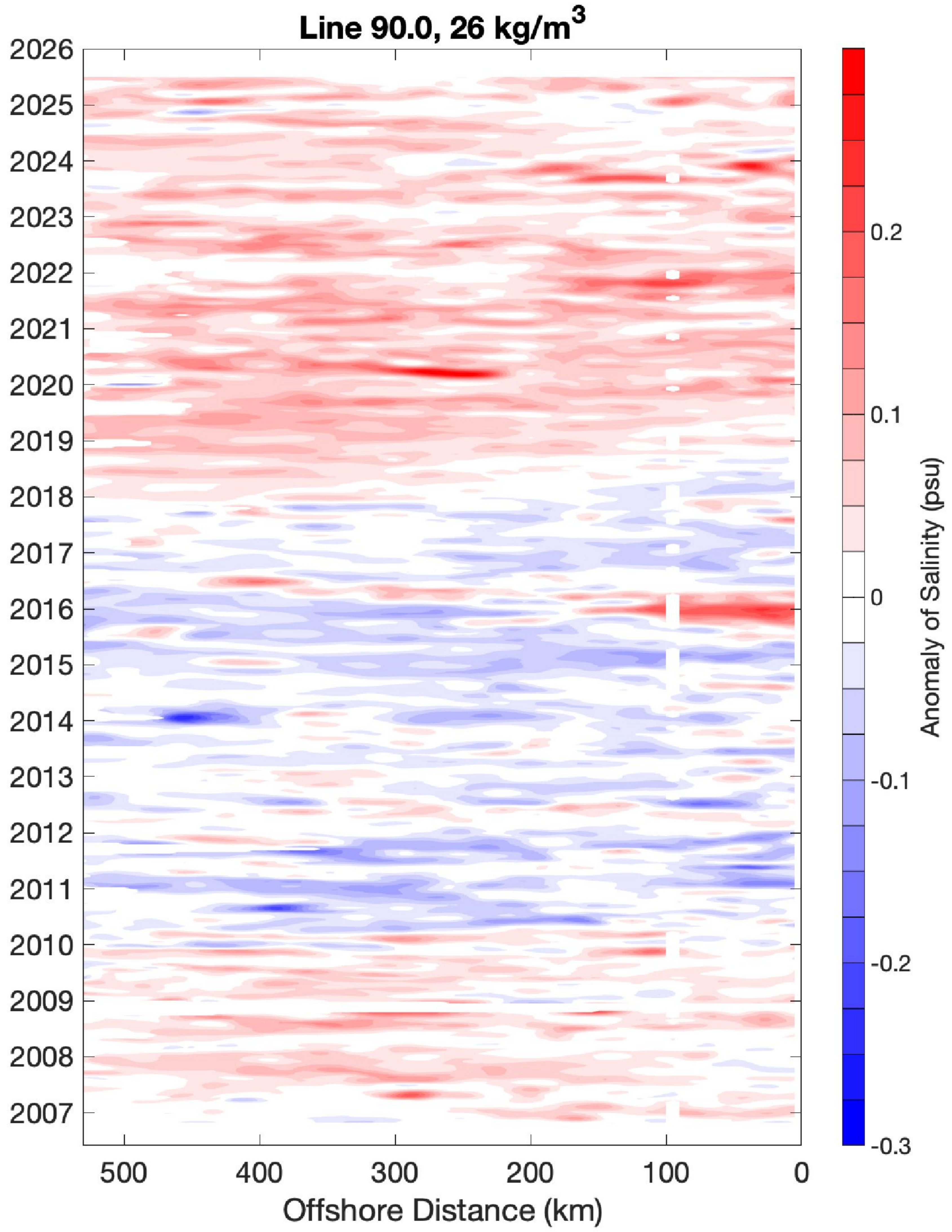
- Effects of El Niño reaches West coast of US
  - Atmospheric teleconnection
  - Oceanic teleconnection
  - Oceanic advection

Climate variability on an isopycnal

Dept
h



Salinity



- El Niños: 2009-10, 2014-16, 2023-24
- Anomalously deep isopycnal caused by local winds, coastally-trapped waves
- Extended period of deep isopycnals related to large scale changes in North Pacific
- High salinity in 2015-16 caused by advection
- Decadal variability in salinity suggests larger scale changes in source water

Interannual variability: Observed and modeled

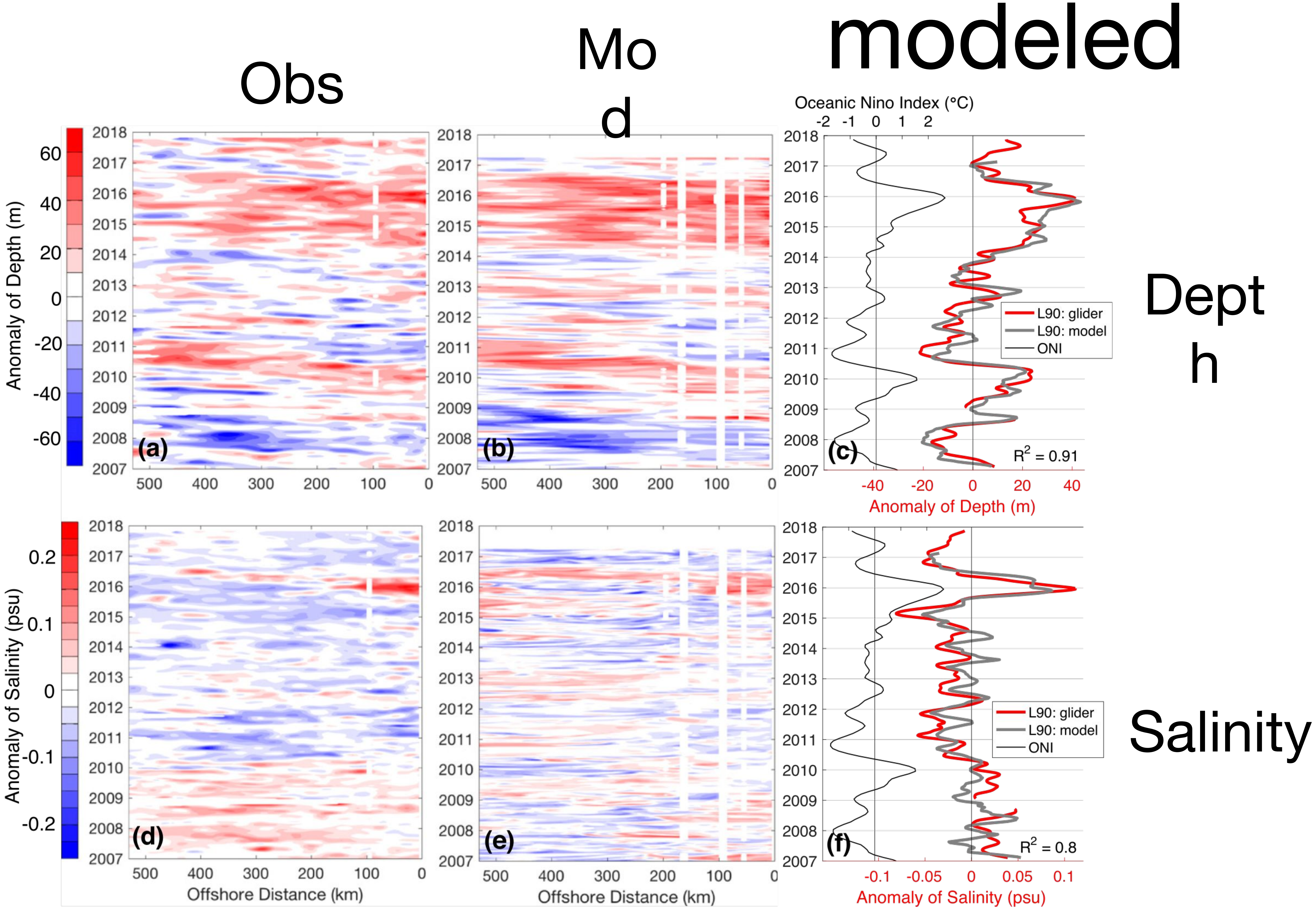


FIG. 15. Anomalies of (a)–(c) 26.0 kg m^{-3} isopycnal depth anomaly (positive indicates deep) and (d)–(f) 26.0 kg m^{-3} isopycnal salinity anomaly along line 90. The Hovmöller plots show the (left) glider-measured and (center) modeled anomalies. The (right) line plots show the glider-measured (colored) and modeled (gray) anomalies averaged over the inshore 200 km of line 90. The oceanic Niño index is plotted on an offset axis in black in (c) and (f).

Zaba et al. (2018)

- Qualitative agreement in depth and salinity of 26 kg/m^3 isopycnal
- Main signals of El Niño reproduced
- Decadal variability perhaps less well modeled

Coastally trapped waves and advection

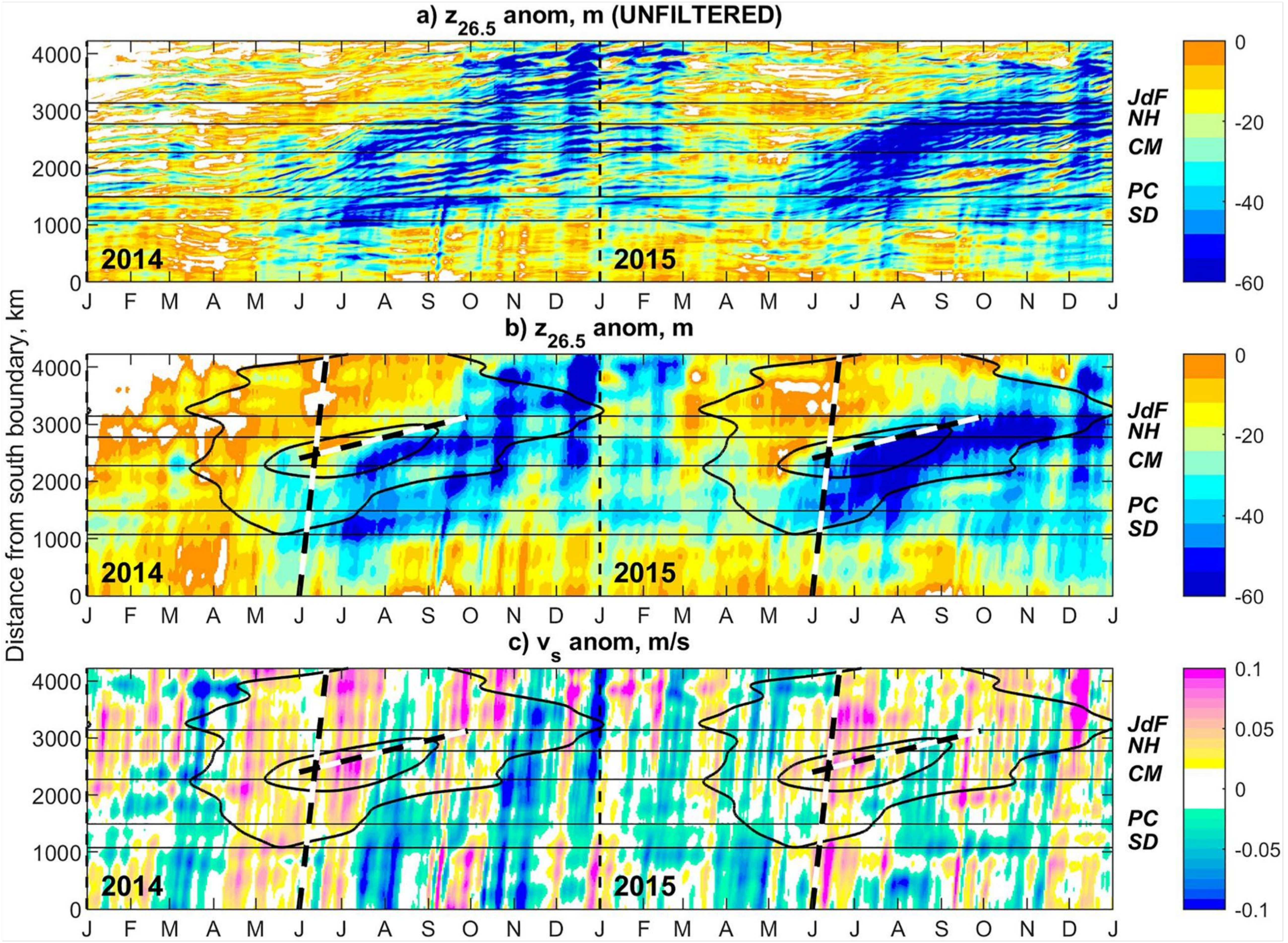
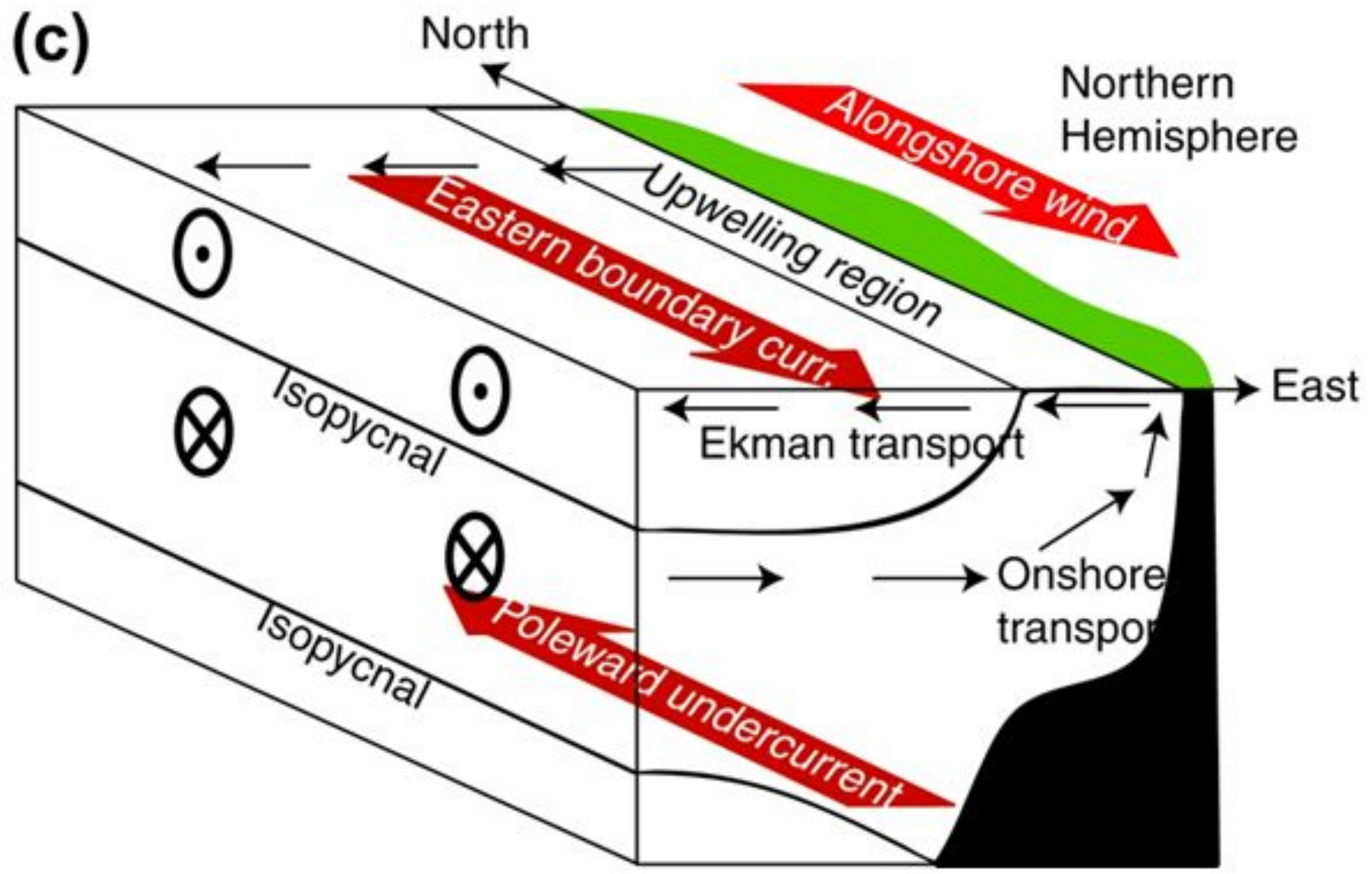


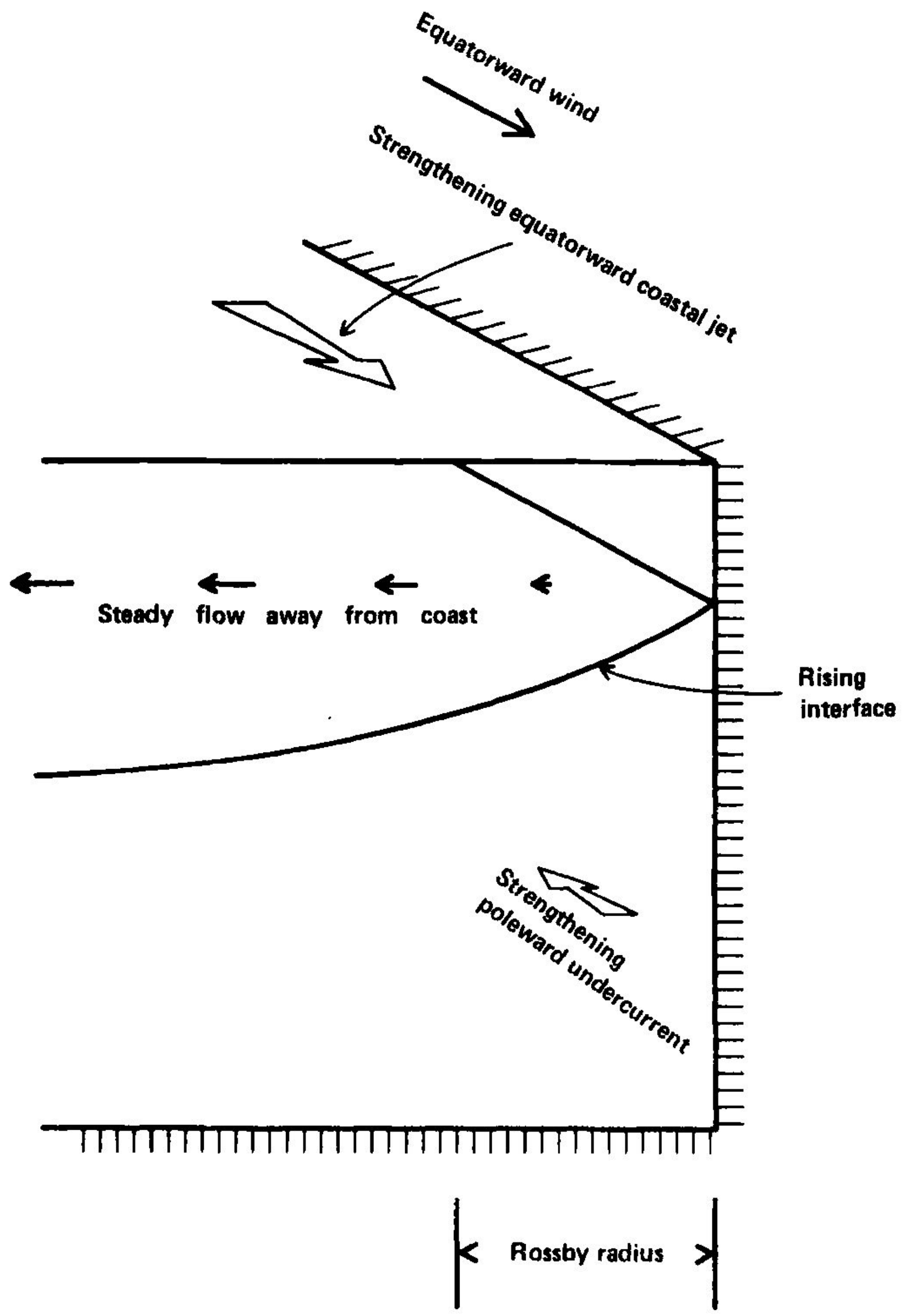
Figure 11. The anomalies in the along-slope properties in time versus along-slope distance, a close-up on 2014–2015: (a) $z_{26.5}$, without the low-pass filter in the alongshore direction, (b) $z_{26.5}$ (filtered), (c) v_s (filtered). Black contours show the annual cycle in $z_{26.5}$ (−200 and −160 m) from Figure 9a. Black-white guide lines are 2.5 and 0.07 m s^{-1}, characteristic of the CTW speed and the along-slope current, respectively. Horizontal lines are San Diego (SD, 32.7°N), Point Conception (PC, 34.4°N), Cape Mendocino (CM, 40.4°N), Newport, OR (NH, 44.6°N), and Juan de Fuca Strait (JdF, 48.4°N). In (a)–(b), the white areas are the positive anomalies.

- ROMS model that forms dynamical basis for WCOFS
- Evidence of propagation by waves and currents
- Kurapov et al. (2022, JGR)

Coastal upwelling, the classic picture



DPO, Talley et al., 2011



Gill, 1982
Yoshida, 1955

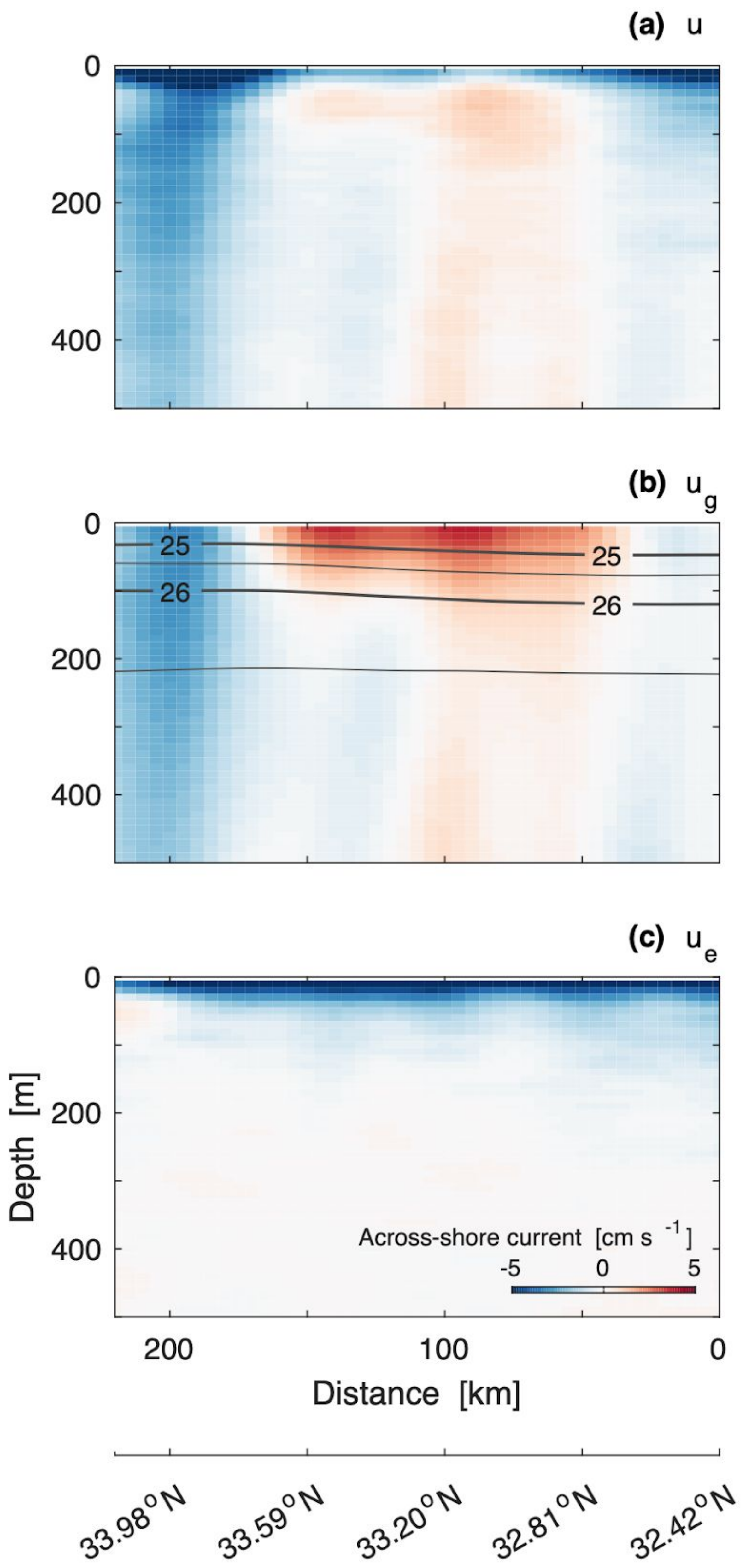
- Alongshore wind blows surface layer offshore
- In the simplest model, a problem when the surface leaves the coast
- Temporal intermittence, alongshore variability, eddies
- After wind stops, return of warm water is not symmetric, with alongshore advection important (Send et al, 1987)

Mean across-shore velocity

ADCP

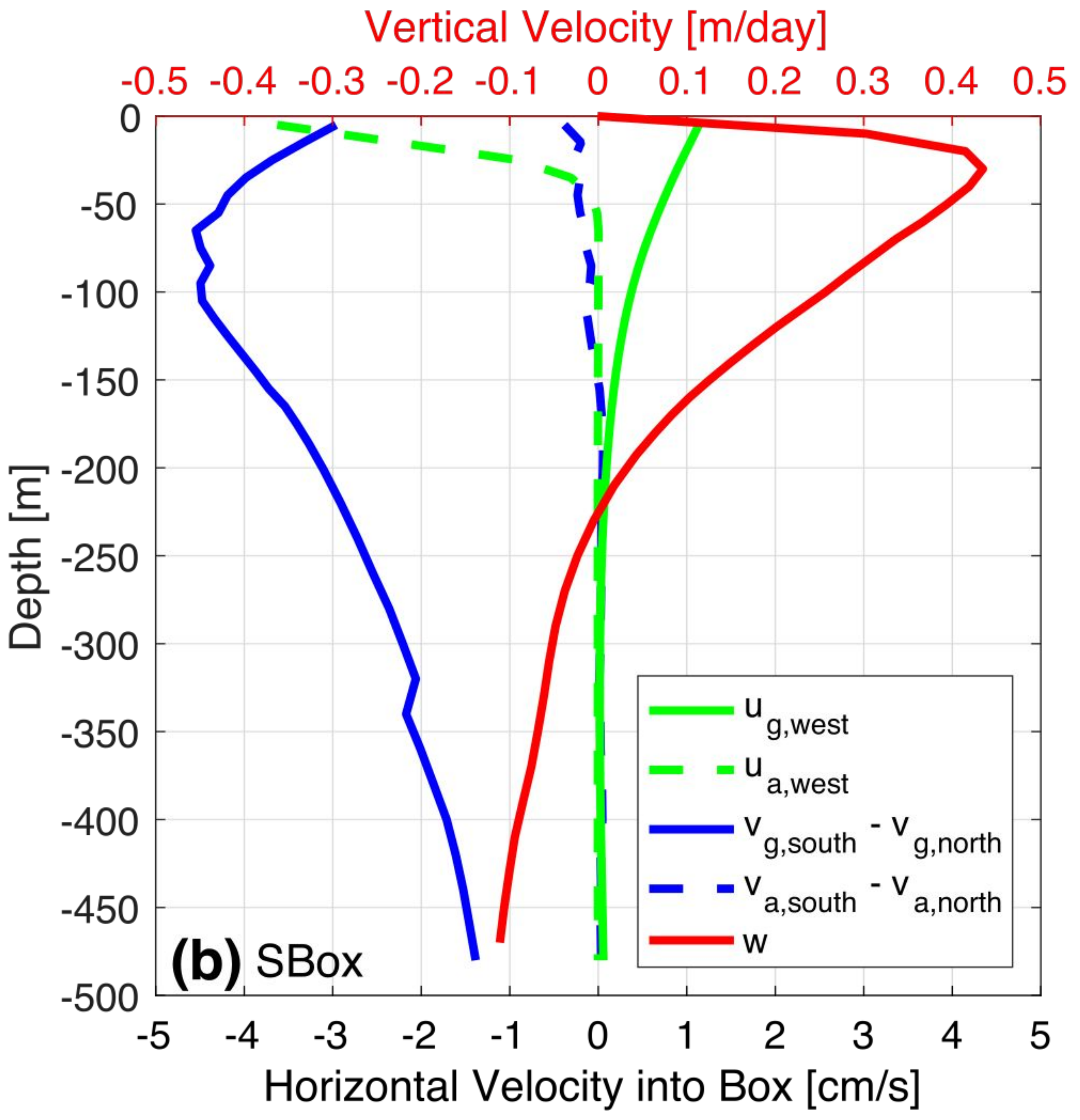
Geostrophic

Wind-driven

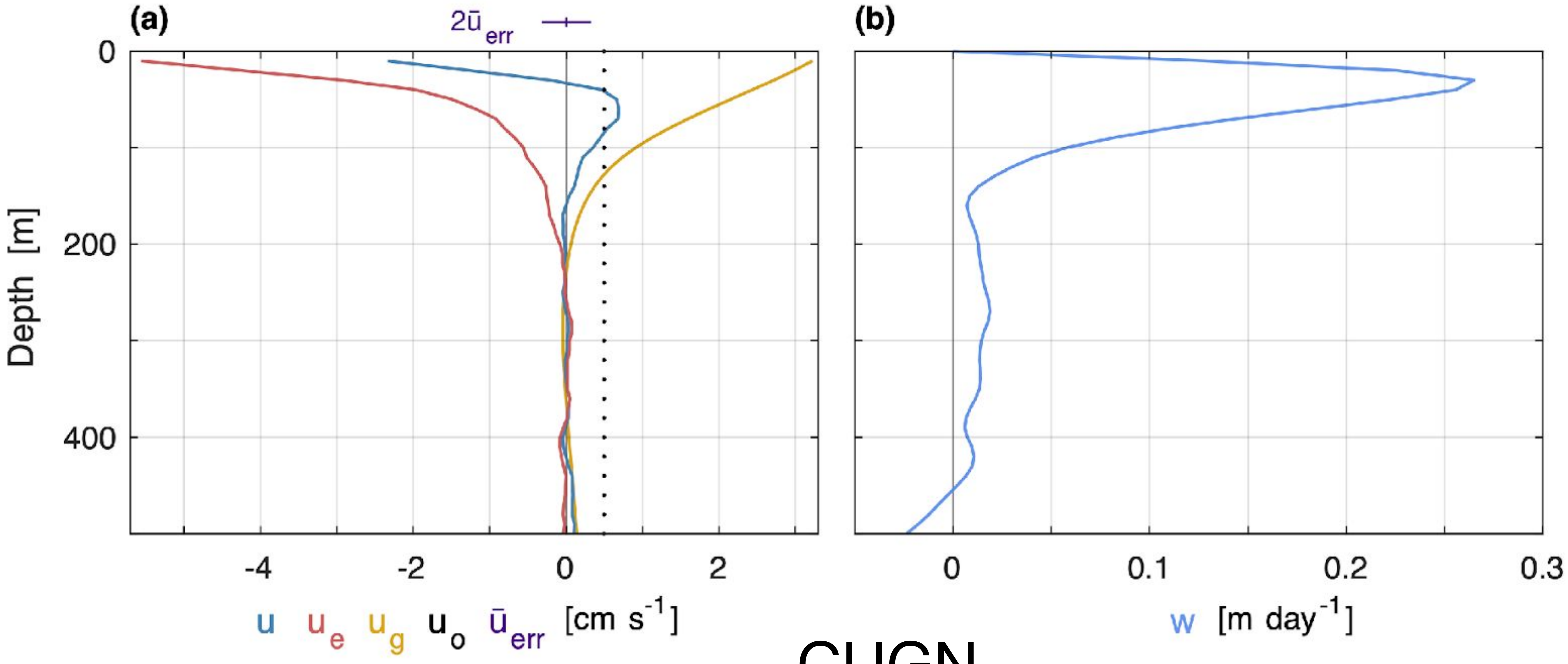


- Observed ADCP velocity has overturning cell in middle of section, offshore flows at ends caused by meander in Undercurrent
- The geostrophic velocity includes this alongshore variability
- Remainder is interpreted as wind-driven, and is stronger near surface
- Johnston & Rudnick (2025, ms in prep)

Across-shore, vertical velocity from CUGN, CASE

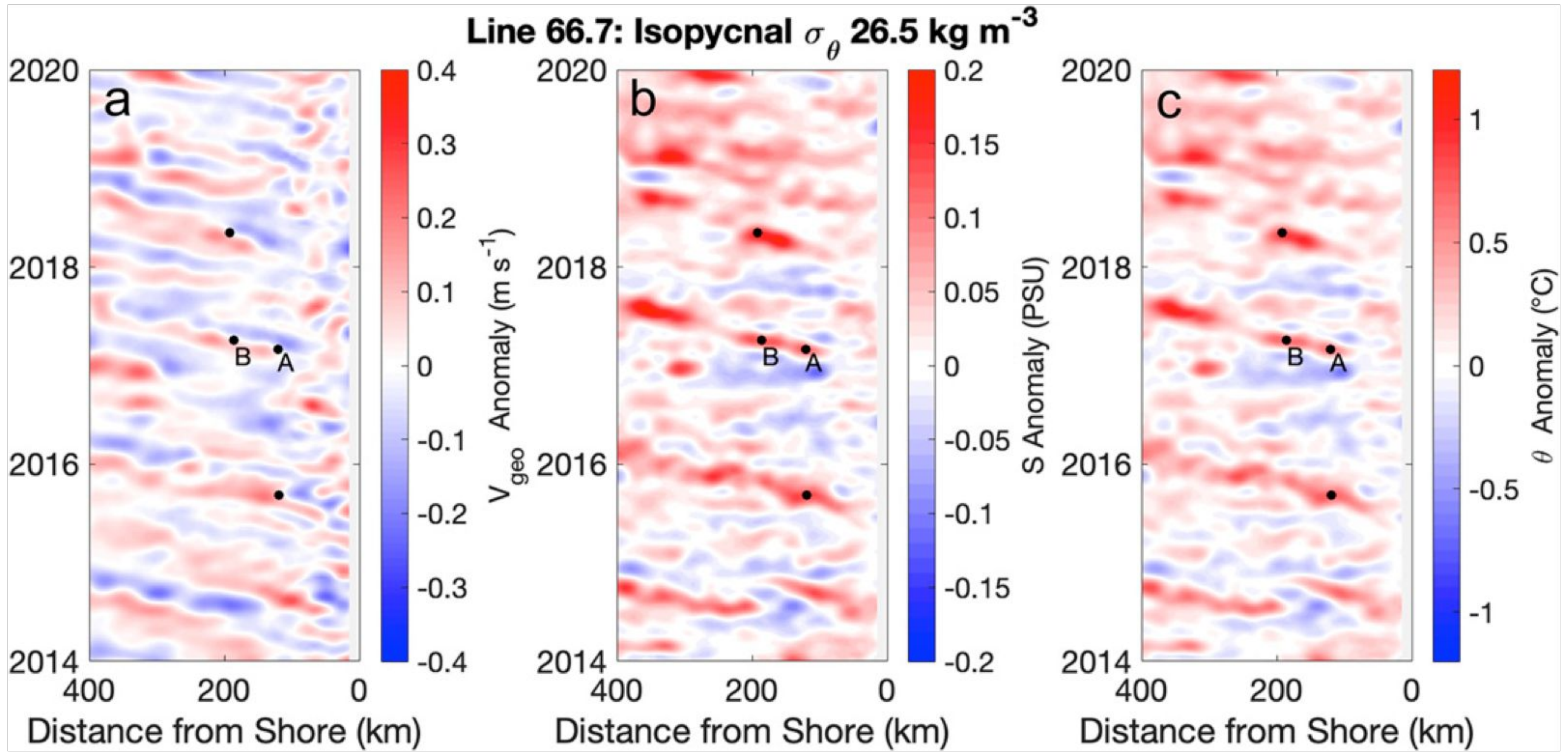


CASE
Zaba et al. (2020)

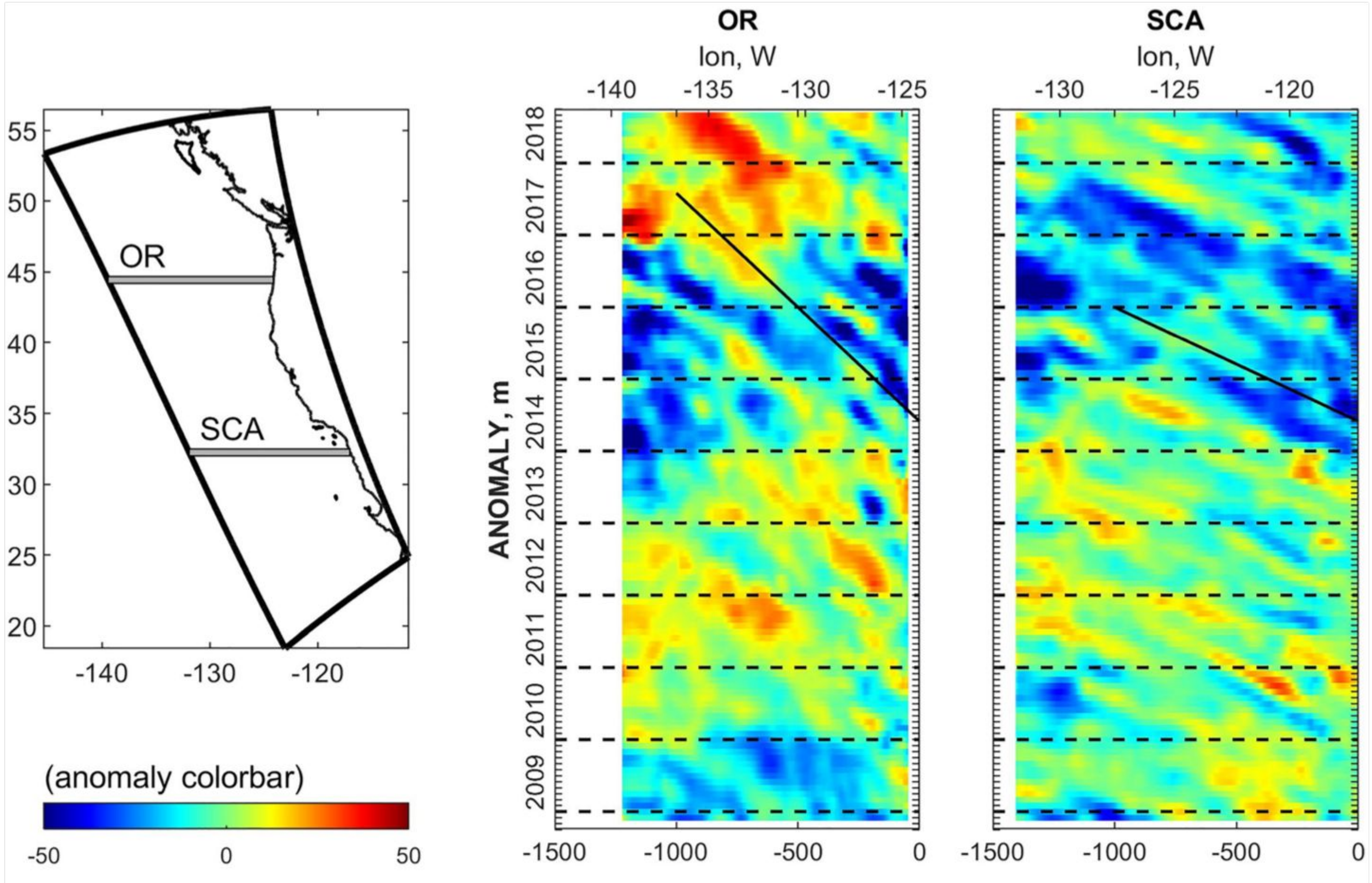


CUGN
2025

Mesoscale eddies



Observations
Ren and Rudnick (2022)



Model
Kurapov et al (2022)

- Offshore propagation of anomalies on the 26.5 kg/m^3 isopycnal
- Speeds of 1-2 cm/s
- Consistent with baroclinic Rossby waves

Conclusions

- Models largely do have the physics required to simulate coastal climate processes
- Improvement should focus on having the necessary data for initialization
- A recent CLIVAR workshop, Optimizing Ocean Observing Networks for Detecting the Coastal Climate Signal had this recommendation:

  Recommendation 2: Improve access to coastal ocean information.

  Observations from the coastal ocean observing system should be integrated with model-based reanalyses and forecasts, and the resulting data products must be made available in a standardized manner that is freely accessible for broad societal use.
- An observing/modeling system for coastal climate should be our end goal.