Southern California Bight Ocean Temperature Dynamics

A Description and Analysis

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Outline

- Background
- Description of experiment at Catalina Island
  - Long-term temperature measurements
- Determination of vertical diffusion coefficient
- Comparison to CalCOFI data

Background

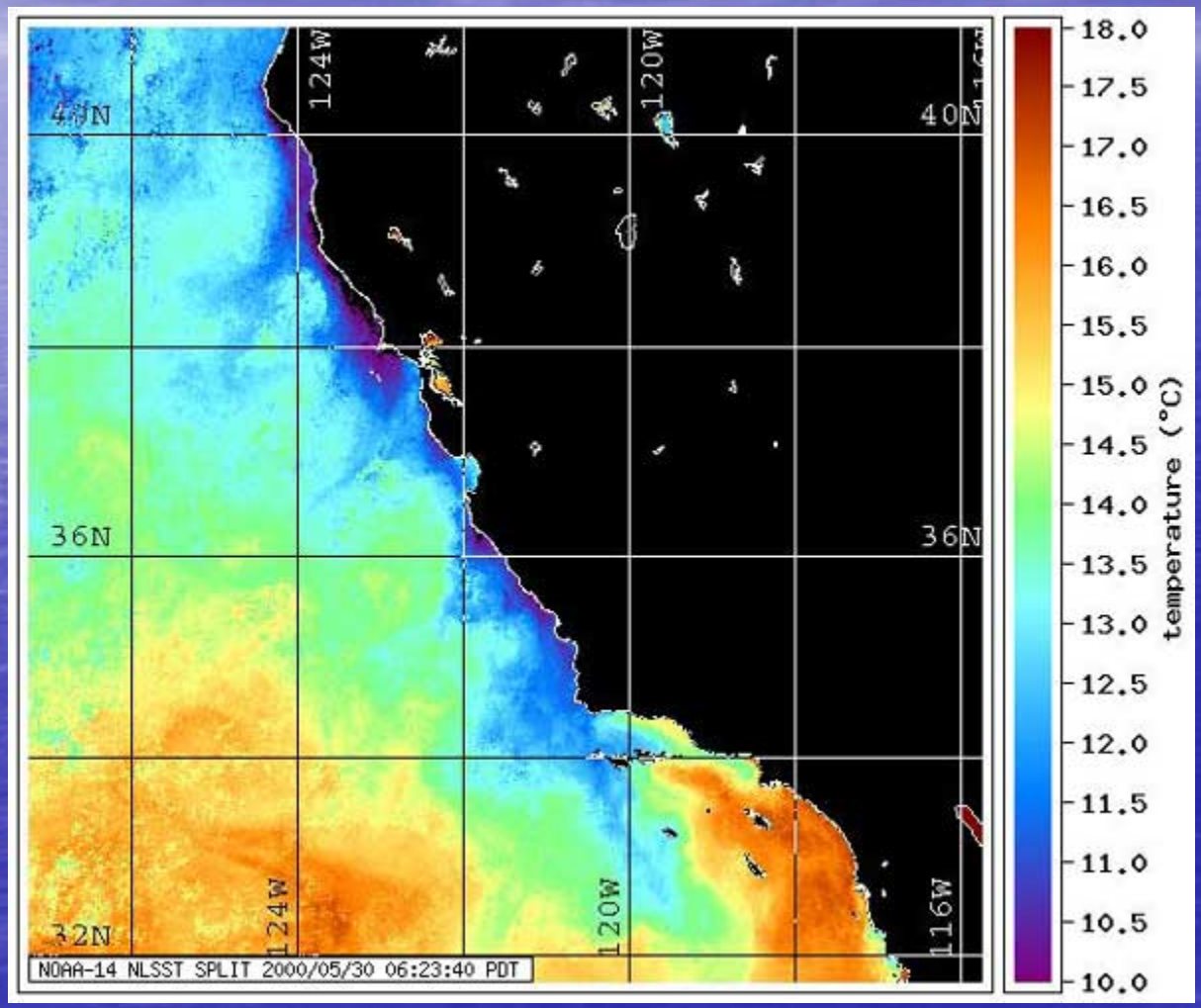
- Volunteer divers set an array of thermographs around Santa Catalina Island and maintained it for over 10 years.
- Provided a unique data set for Southern California.
- Temperature provides a method to examine ocean properties including currents and mixing

Water Properties

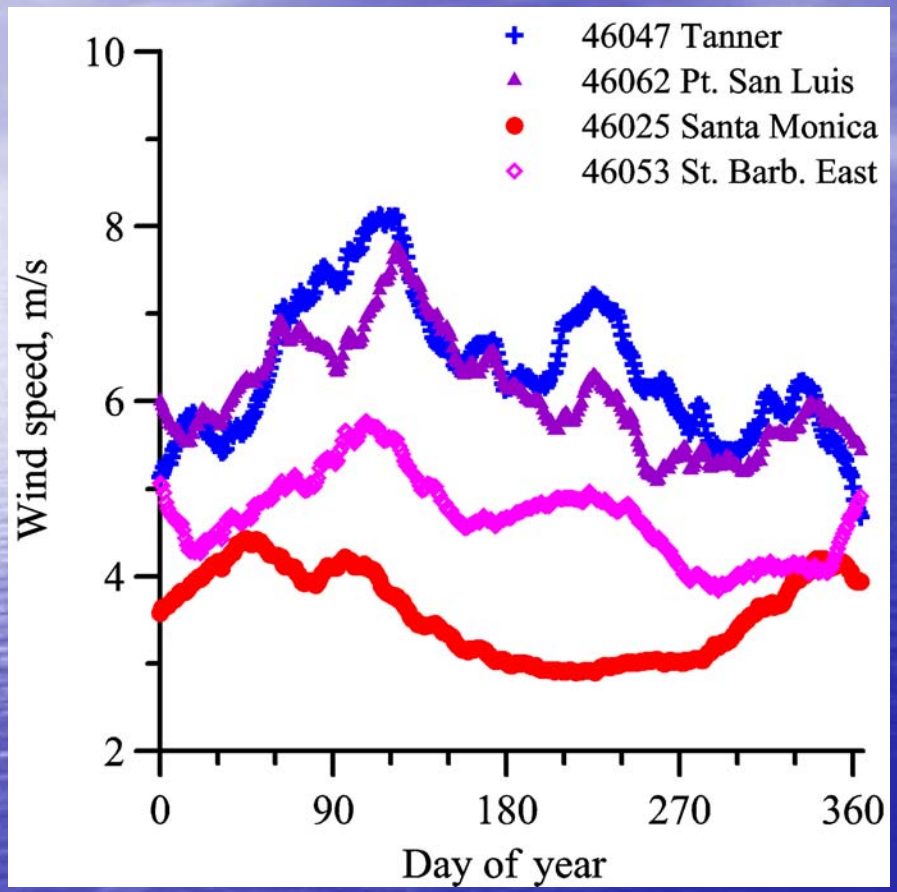
- Water has large heat capacity
  - 4000 J/kg ^{o}C
  - Cube of water 1 m/side increases 1/3 ^{o}C /hr
    - Net flux of 300 W/m^{2}
  - Ocean warms slowly in sun
- Temperature is a tracer for fast variations

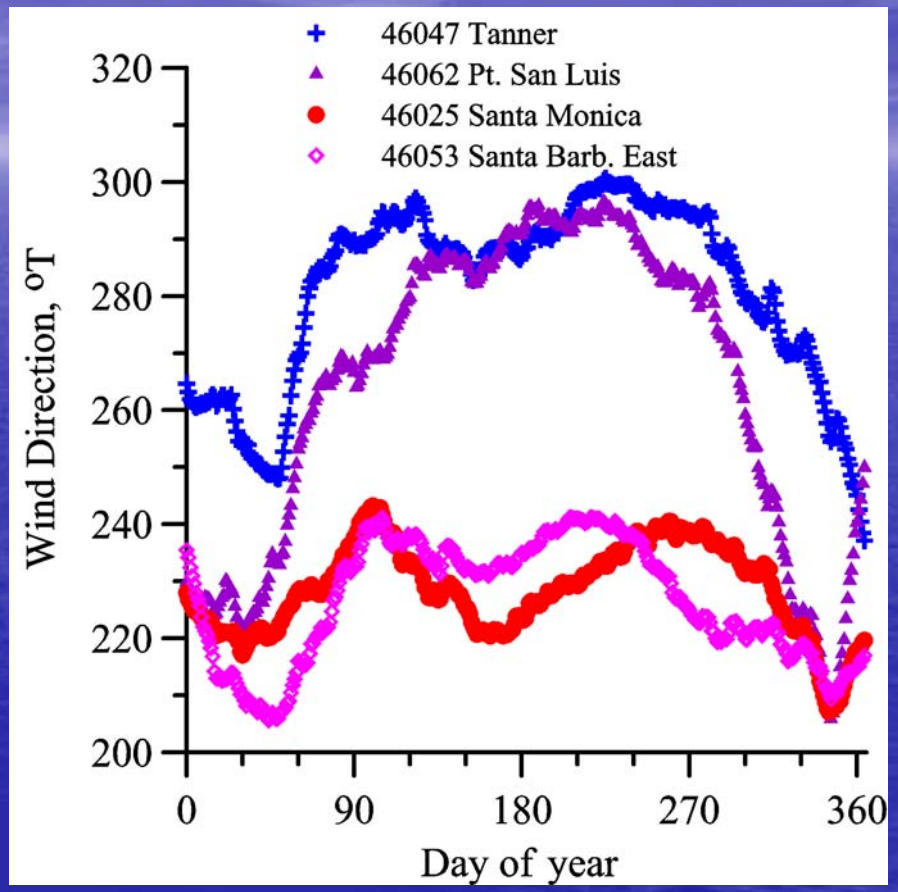
Sea Surface Temperature

Upwelling off California



Wind speed and direction Comparison

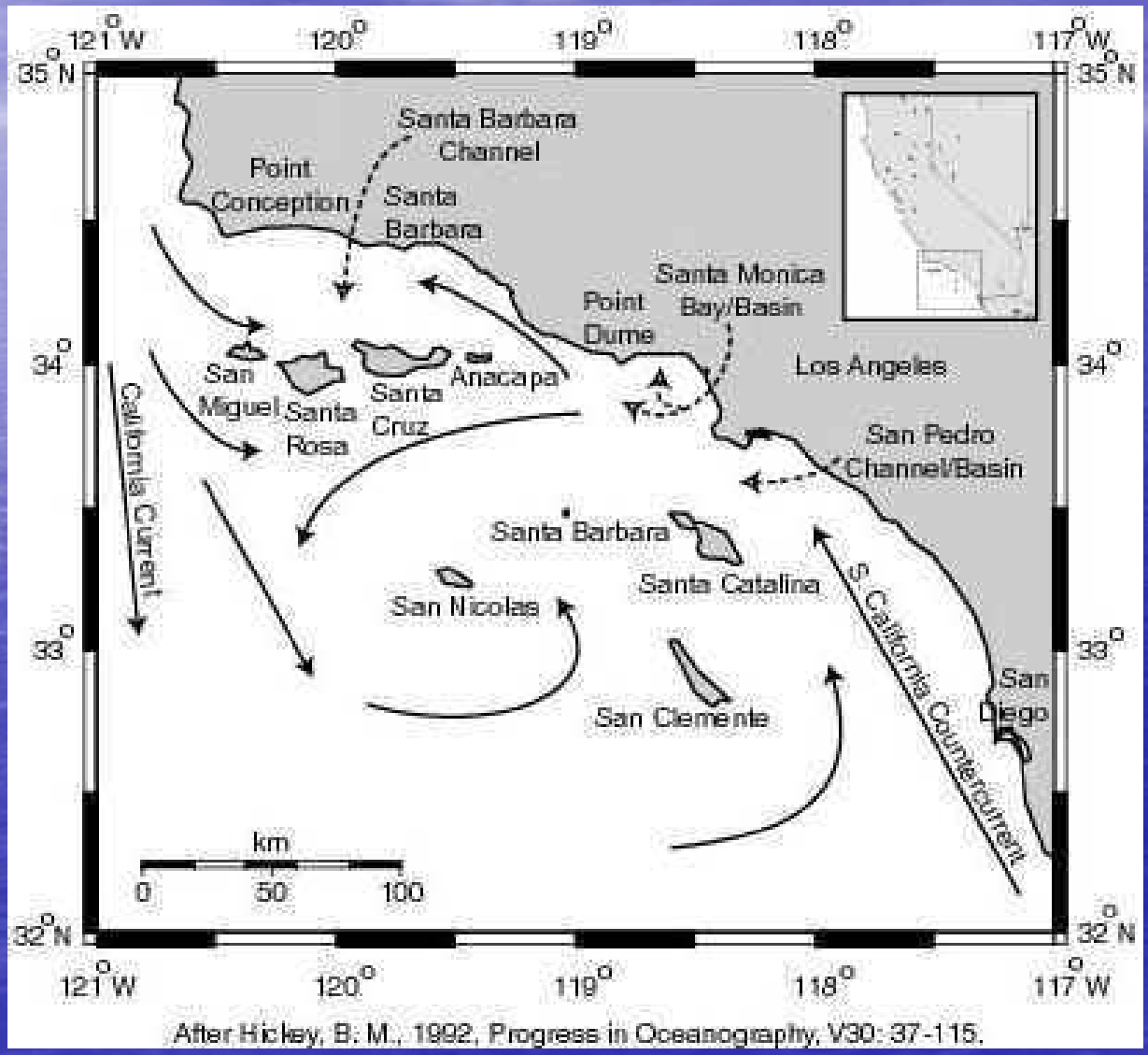




Winds consistently slower in the SCB than north of Pt. Conception.
Winds consistently from the southwest in the SCB.
North of Pt. Conception, winds are from the northwest in Spring/Summer.

Southern California Bight

Circulation in the Bight



After Hickey, B. M., 1992, Progress in Oceanography, V30: 37-115.

Experiment Description

- An array of underwater thermographs was deployed and has been maintained around Catalina Island at various depths and sites since 1992.

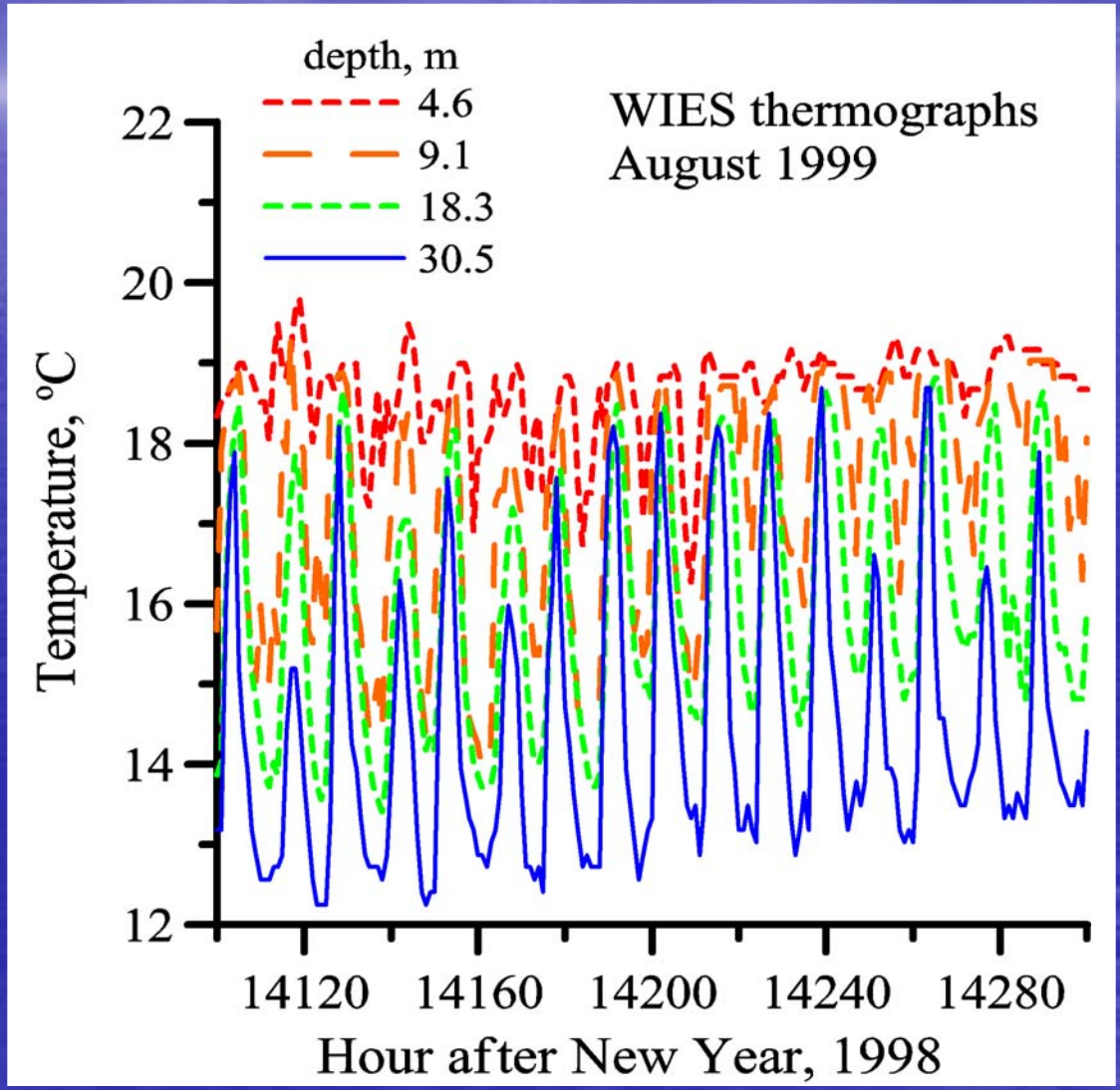
Site	Location	Depths of Instruments (m)
1	WIES	5, 9, 18, 30
2	Pumpernickel	12
3	Italian Gardens	12
4	Casino Point	12
5	East End	5, 9, 18
6	Little Harbor	5, 9, 18
7	Cactus Bay	5, 9, 18

Analysis Procedure

- Data are vetted for quality
- Short-term trends examined
- Smoothed with 31-day boxcar filter
  - Reduces tidal-induced variations
- Data from 4 sites around Catalina compared and then combined
- Long-term trends examined

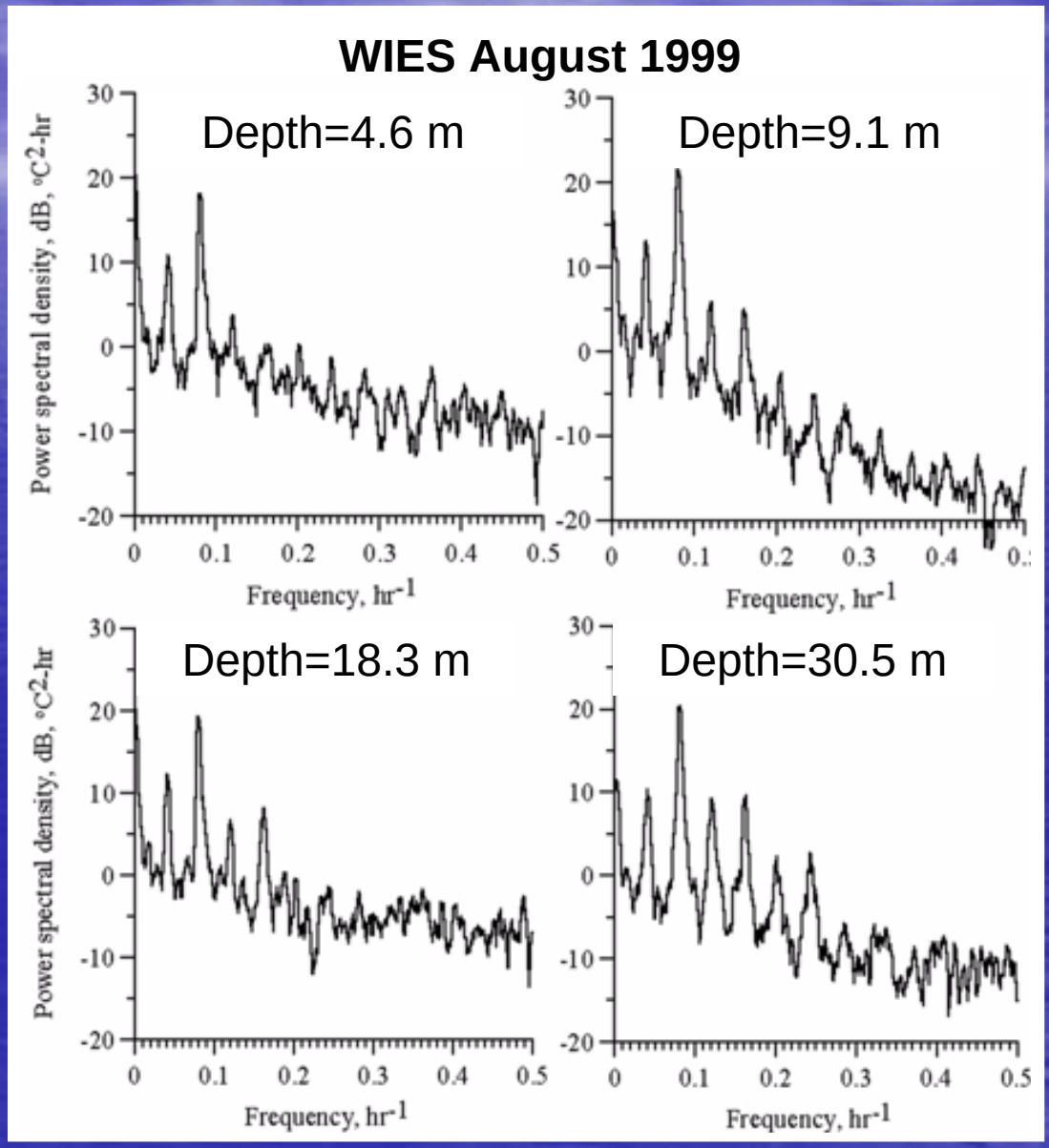
Short-term Variations
Sample 200-Hour Time Series

- A trend of decreasing temperature with depth.
- Cyclic fluctuations that increase in amplitude with depth.
  - 6 ^{o}C at 30 m
  - smaller modulations at 5 m
- Major fluctuations have a period of about 12 hours.
- Rectification - warm surface water is transported to depth

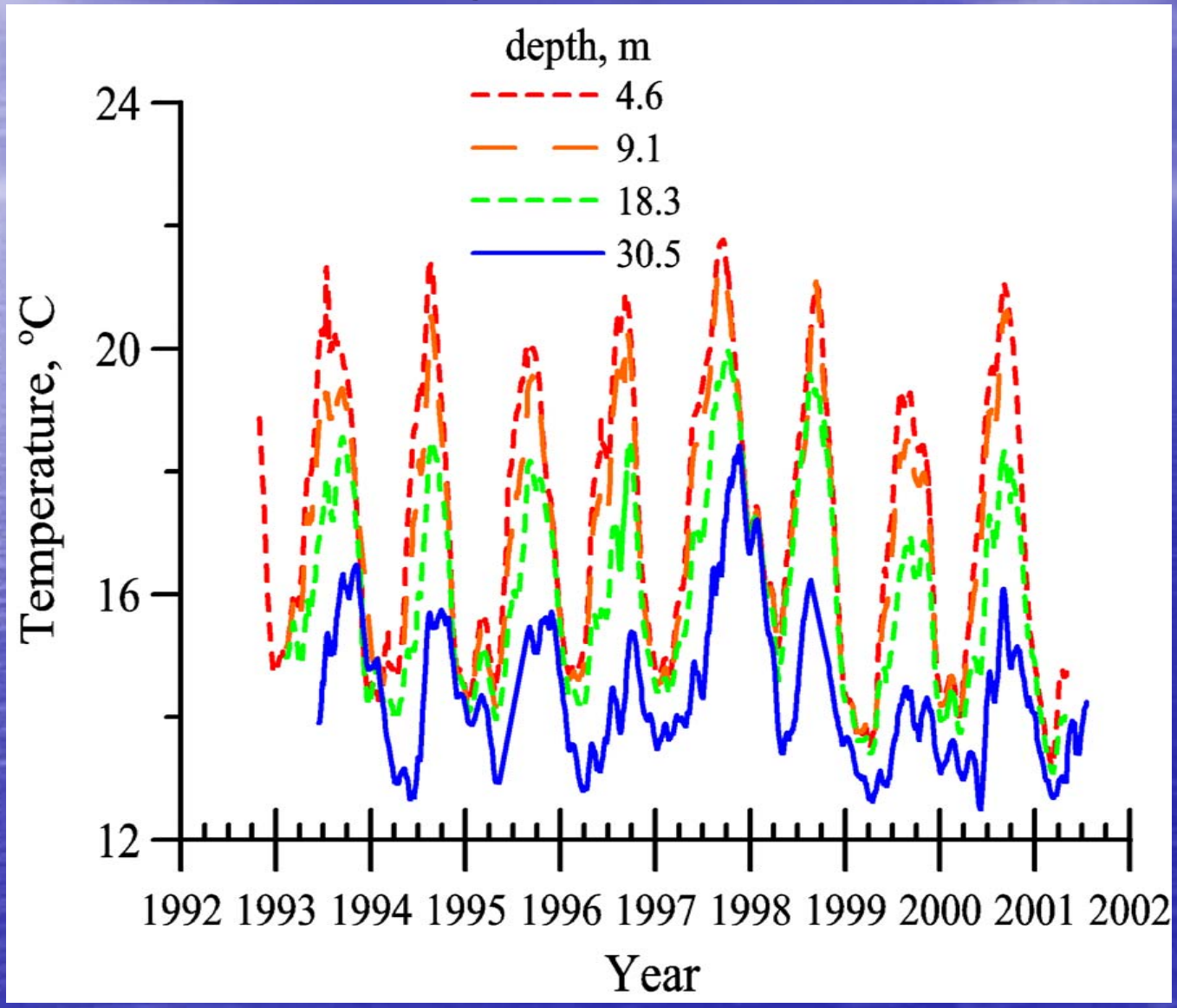


Power Spectral Densities

- Well-defined spectral peaks at every depth
- Largest peak at f=0.08/hr (12.3 hr period) = M_2 semidiurnal tide
- Second largest peak at f=0.041/hr = diurnal period
- Additional peaks at “ultrasemidiurnal” periods (8.3, 6.1, 5.0, and 4.1 hrs) (these peaks not found in LA Harbor PSD)
- Summer more energetic than winter by 10 dB

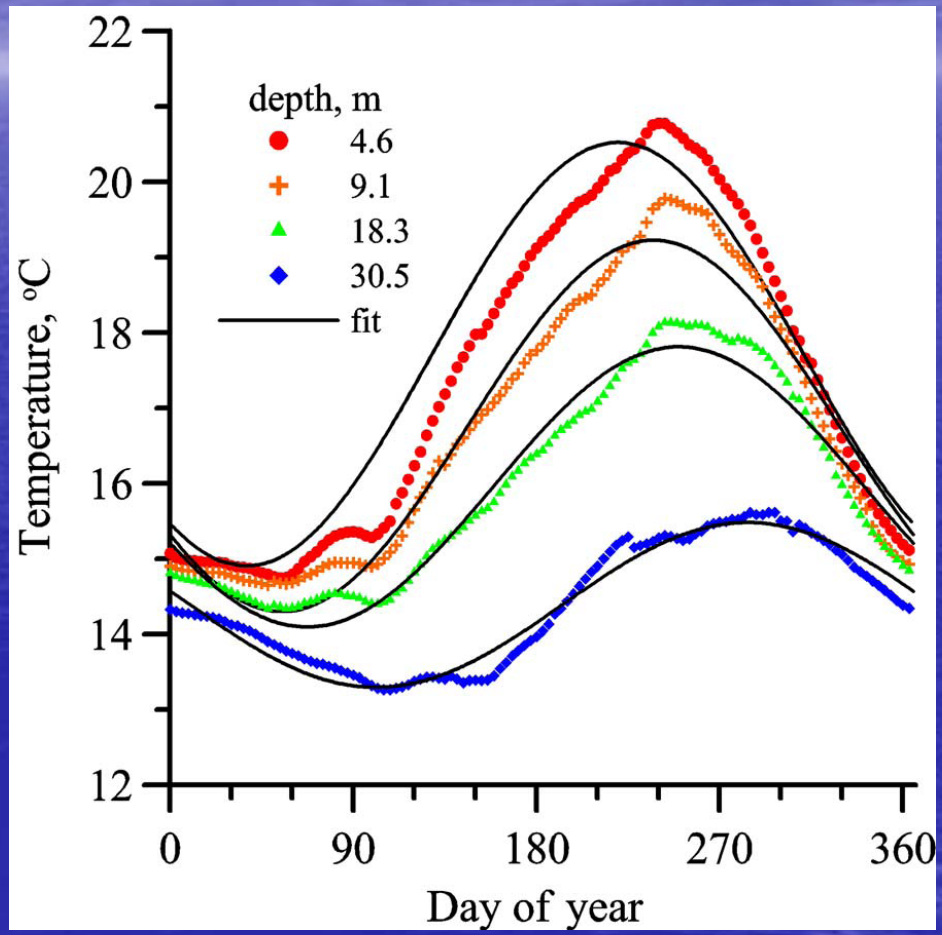


Yearly Variations



Intra-annual temperature modulation

- Average daily temperatures from all years
- Fit the modulation with a sinusoid with an annual period and mean temperature
  - Amplitude and phase determined empirically
- 53 days between 4.6-m phase and 30.5-m phase



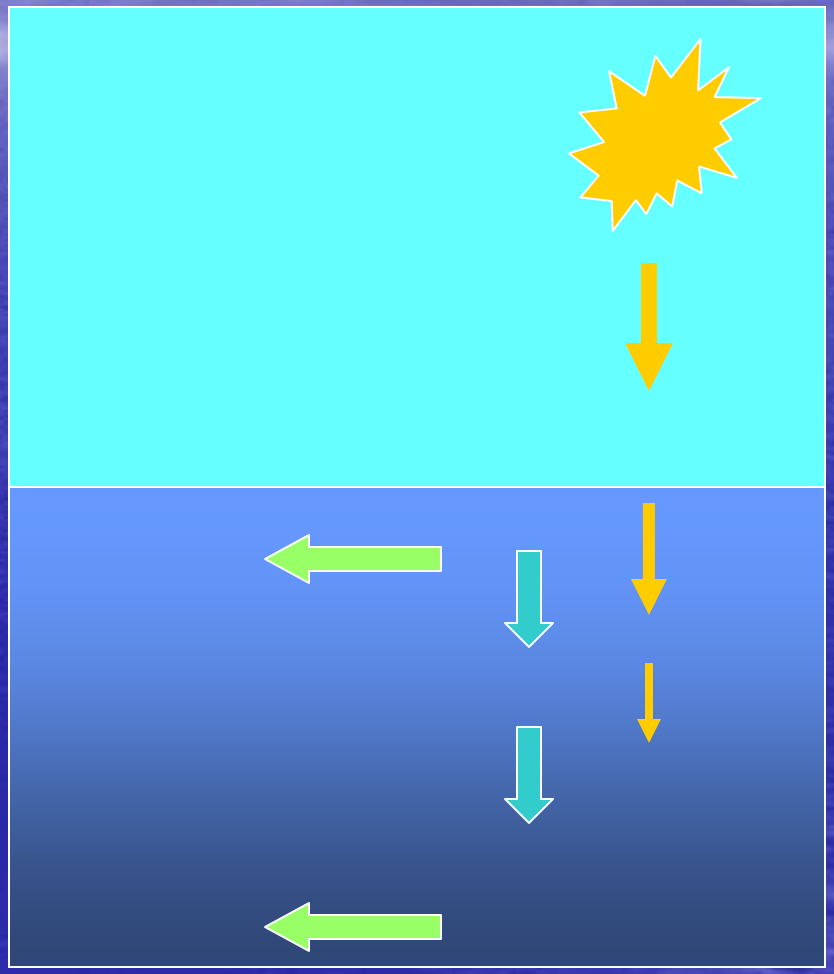
Vertical Diffusion

- The intra-annual variation appears to be a diffusion phenomena
- Molecular heat diffusion is too slow
- Review ocean internal, vertical dynamics

Vertical Eddy Diffusion

- Parcels of water mix and diffuse
- Effective diffusion rate is much larger than molecular rate
- Nutrients, heat, salinity diffuse at same rate.
- Eddy diffusion is mitigated by density gradients.

- Solar radiation
  - Absorbed
  - Diffused
  - Advected



No-Advection Model

- Simple model forced by local solar insolation:

$$\frac{\partial T}{\partial t} - \kappa \frac{\partial^2 T}{\partial z^2} = C e^{-\beta z} e^{-i\omega t}$$

β is absorption coefficient

κ is vertical diffusion coefficient

assume time dependent and independent terms

$L(z,t) = L_0 + L_1(t)$ surface energy flux

$T(z,t) = T_0(z) + T_1(z,t)$ temperature variation

Solutions

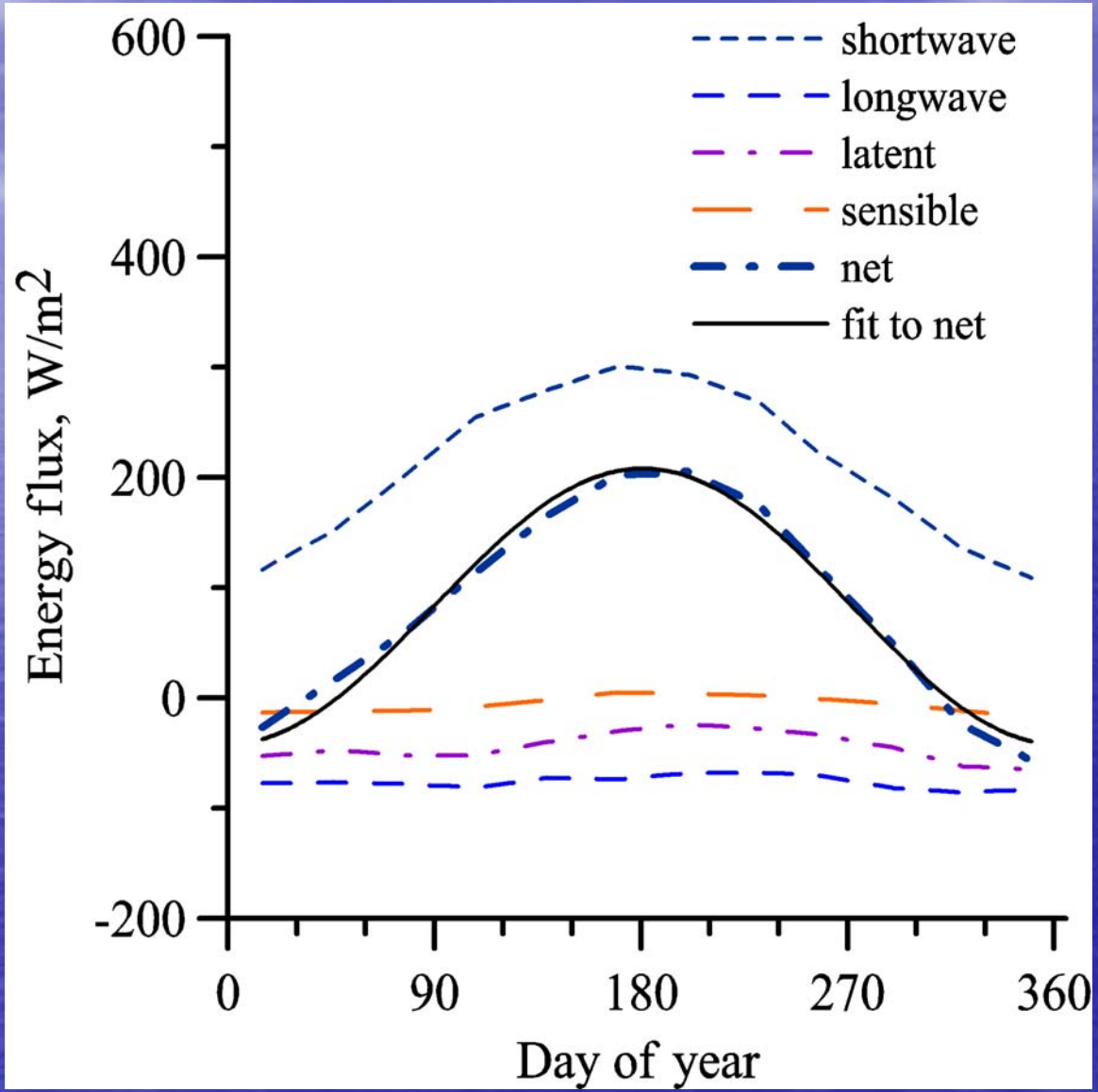
$$\frac{\partial T_0}{\partial z} = \frac{L_0}{c_p \rho \kappa}$$

$$T_1(z,t) = \frac{C'}{2i\alpha}\left[\frac{e^{-\beta z} - e^{i\alpha z}}{(i\alpha+\beta)} + \frac{e^{-\beta z}}{(i\alpha-\beta)}\right]e^{-i\omega t}$$

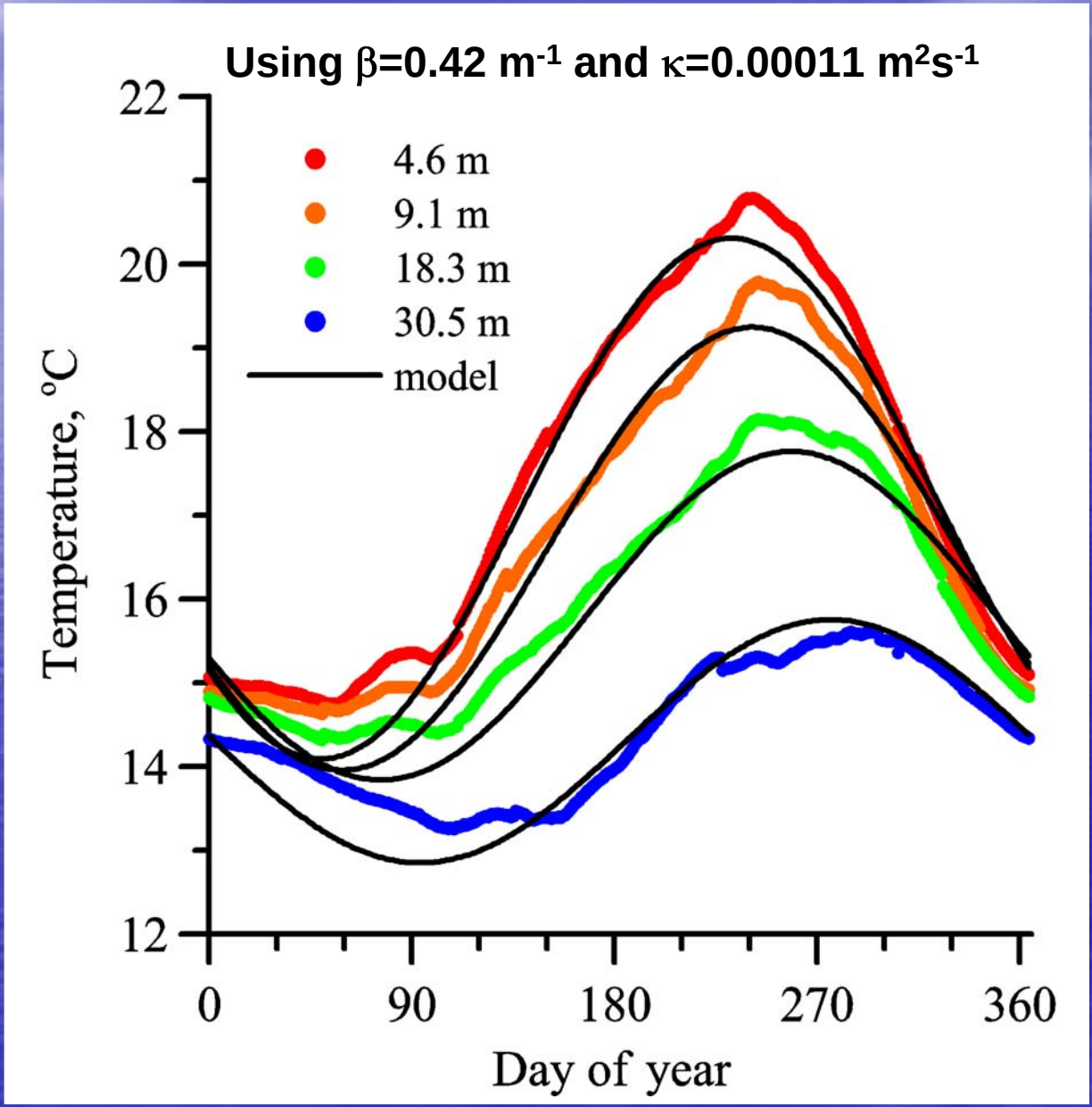
where

$$C' = \frac{L_1 \beta}{c_p \rho \kappa} \qquad \alpha = \frac{i\omega}{\kappa}$$

Energy fluxes for Catalina Island



Intra-annual temperature modulation



- Solutions to both DC and modulated equations yield the same vertical temperature diffusivity

  $\sim 10^{-4}\ m^2\ s^{-1}$

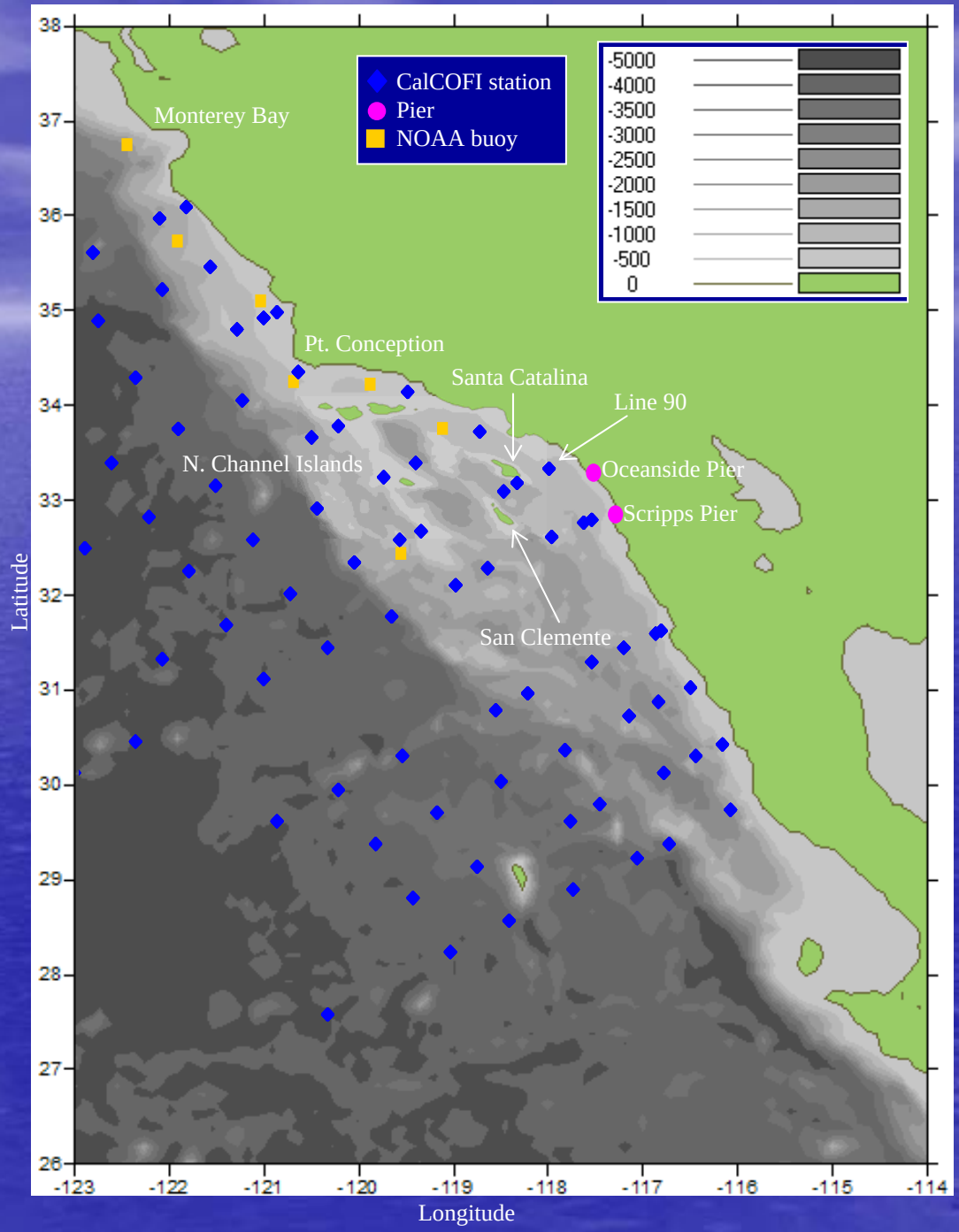
- Is the no-advection assumption valid?

Investigation of no-advection

- Gather data from other sources
  - California Cooperative Oceanic Fisheries Investigation (CalCOFI)
  - Channel Island National Park (ChINP)
  - Scripps Institution of Oceanography
  - NOAA buoys

Not discussed today

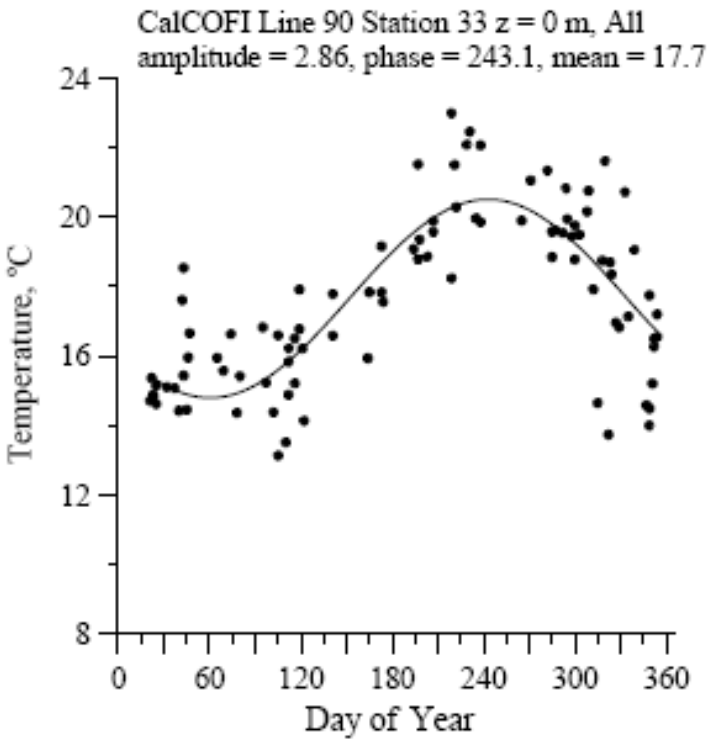
CalCOFI stations



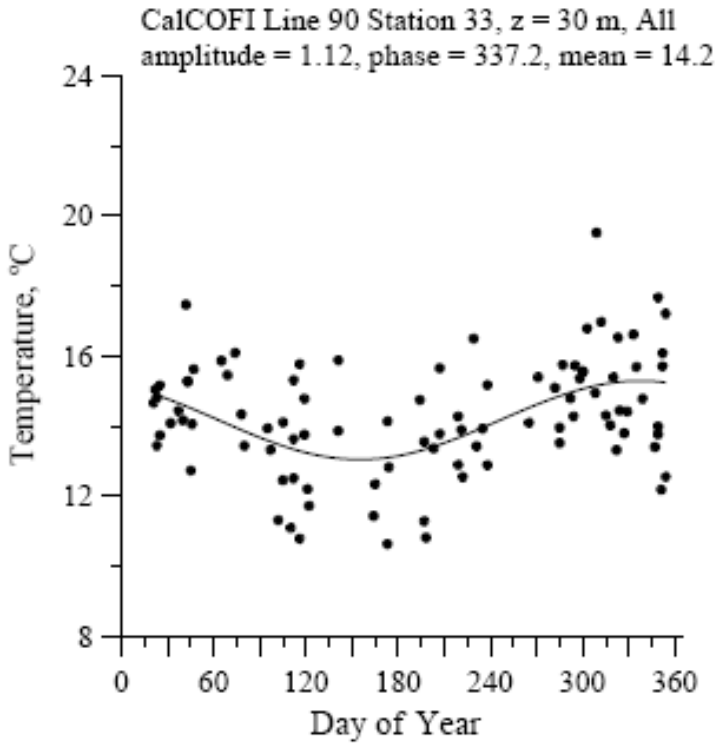
CalCOFI intra-annual variation

single station in center of SCB

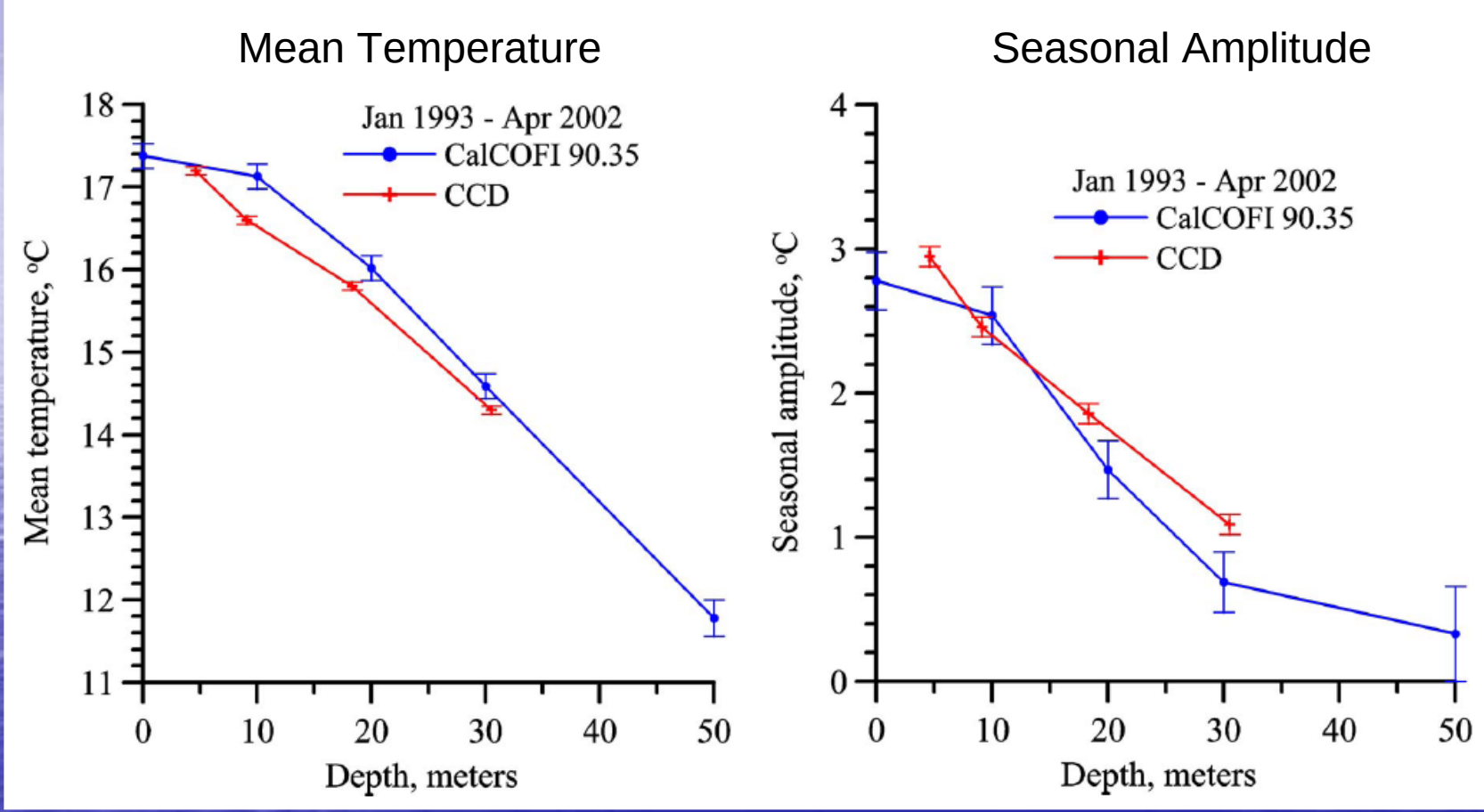
Depth=0 m



Depth=30 m

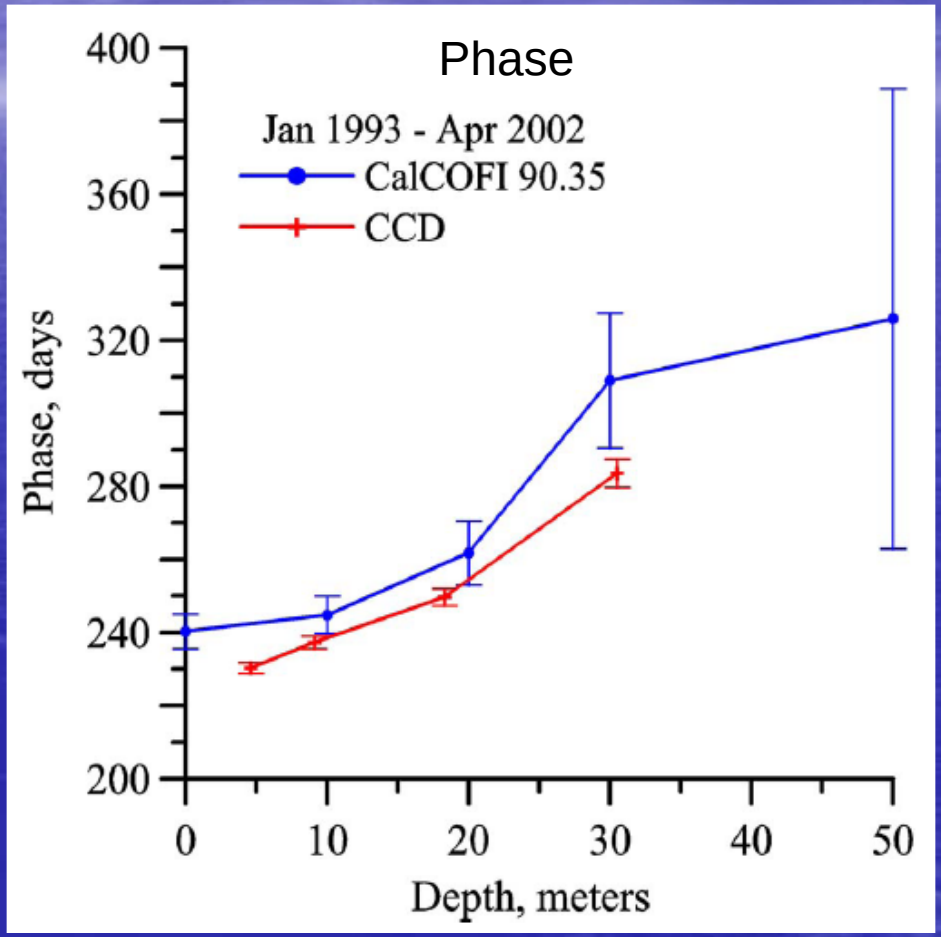


Comparison of CalCOFI and CCD



Comparison of CalCOFI and CCD

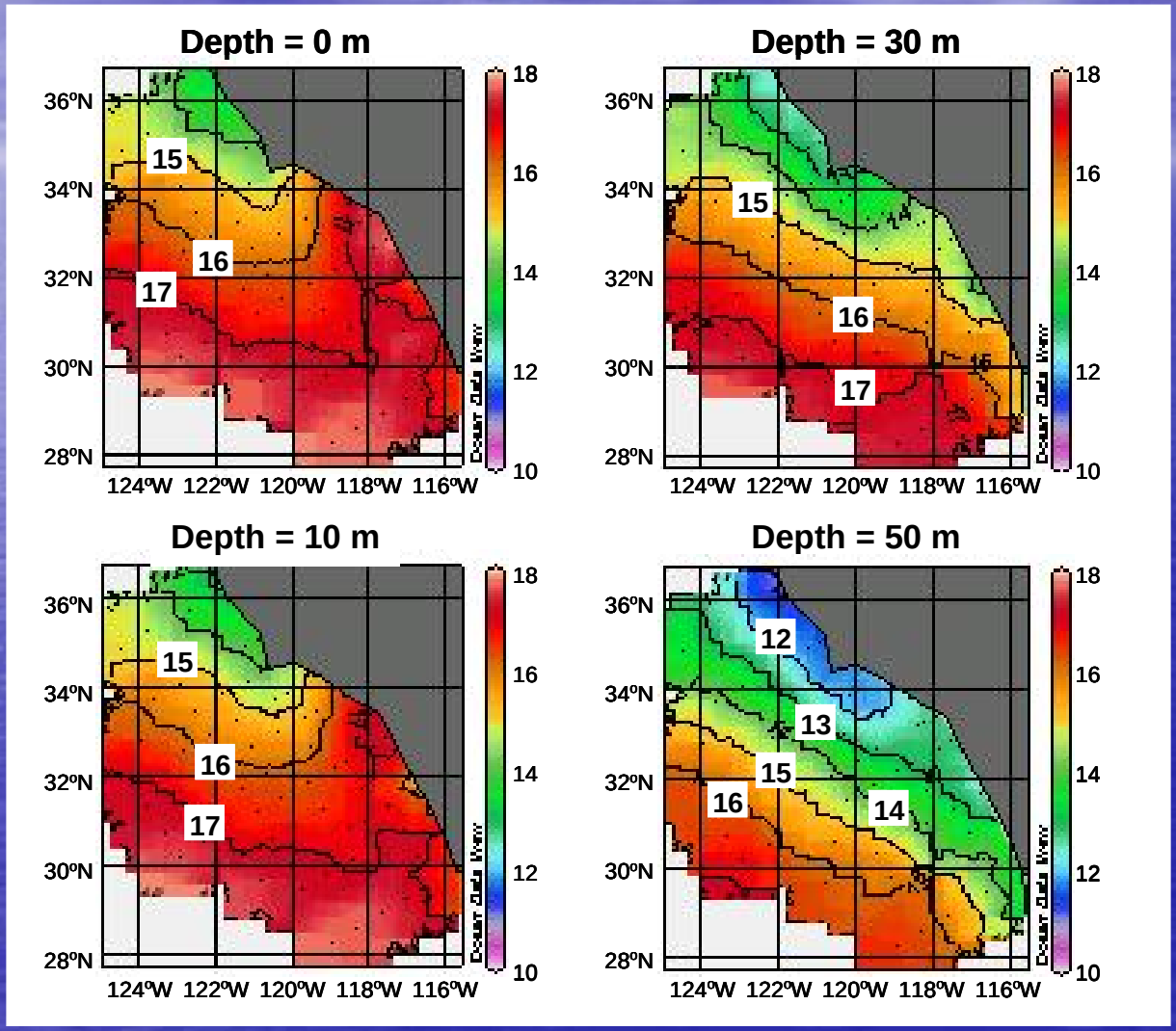
- CCD phase is systematically lower than that of CalCOFI
- Causes?
  - CCD data smoothed with zero-phase filter (no)
  - CalCOFI interpolation scheme (no)
  - Internal waves at Catalina exhibit rectification: accounts for 10 days, but decreases CCD mean temp and seasonal amplitude by 0.3°C (wrong way)



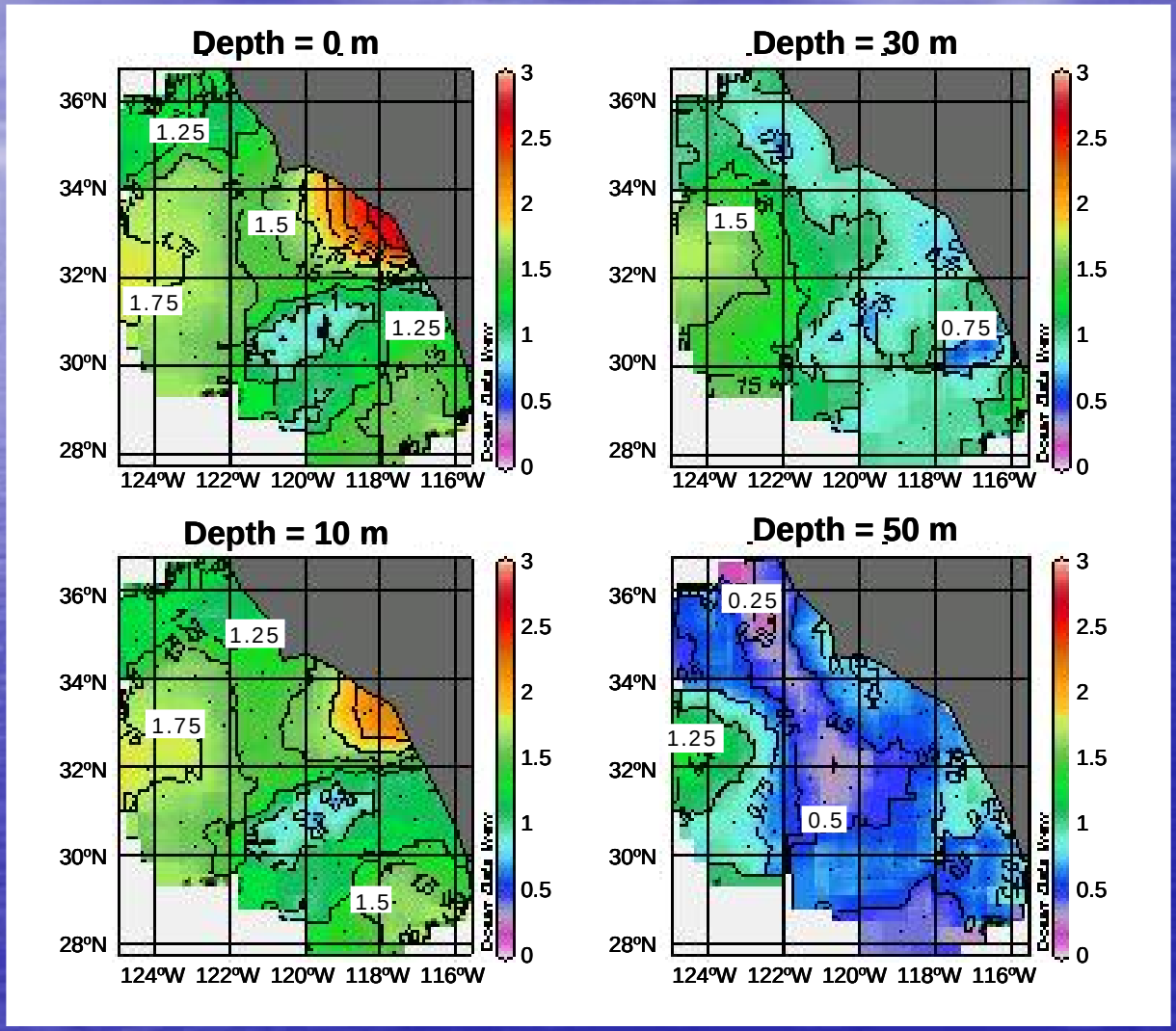
Consistency Checks

- Similar measurements using CalCOFI data by Lynn, Bograd and Lynn, and Nezlin et al.
- Other datasets gave similar fits as CCD data:
  - Channel Islands National Park
  - NOAA buoys
  - Scripps and Oceanside piers

CalCOFI Mean temperature at depth

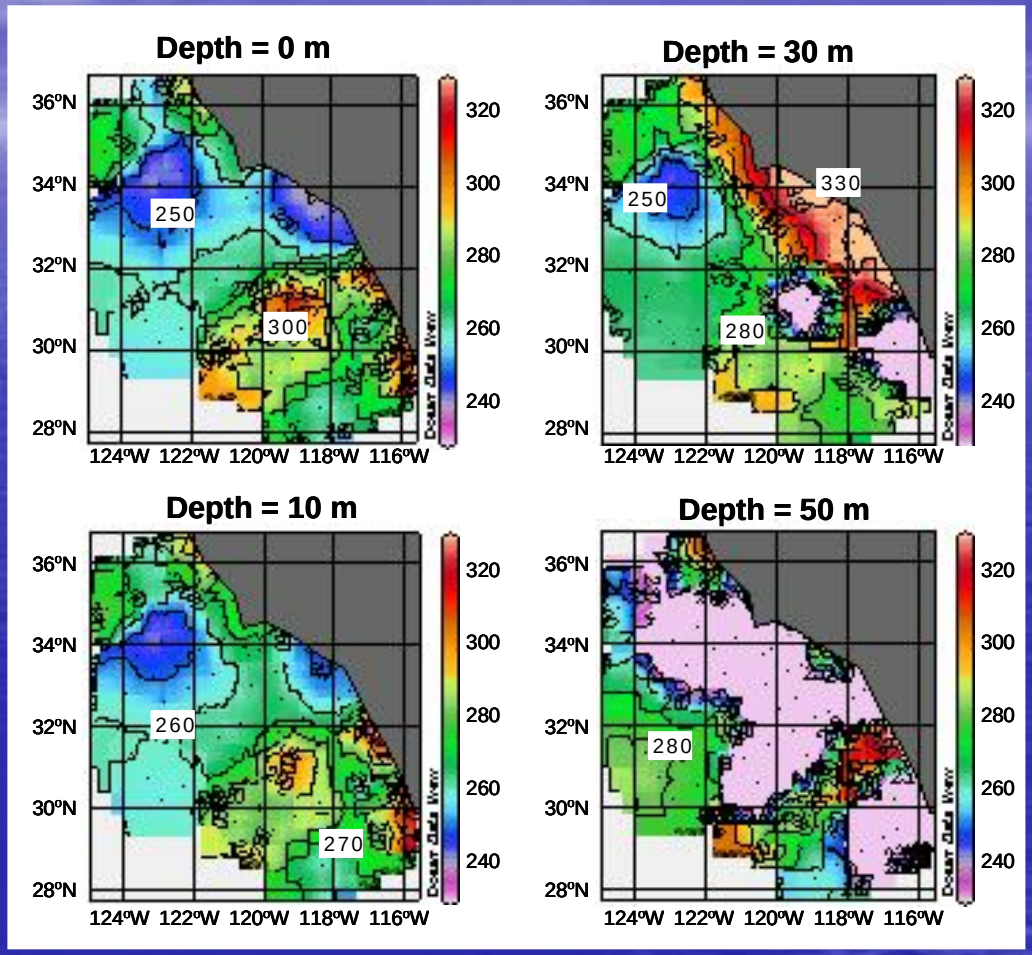


CalCOFI Seasonal Amplitude



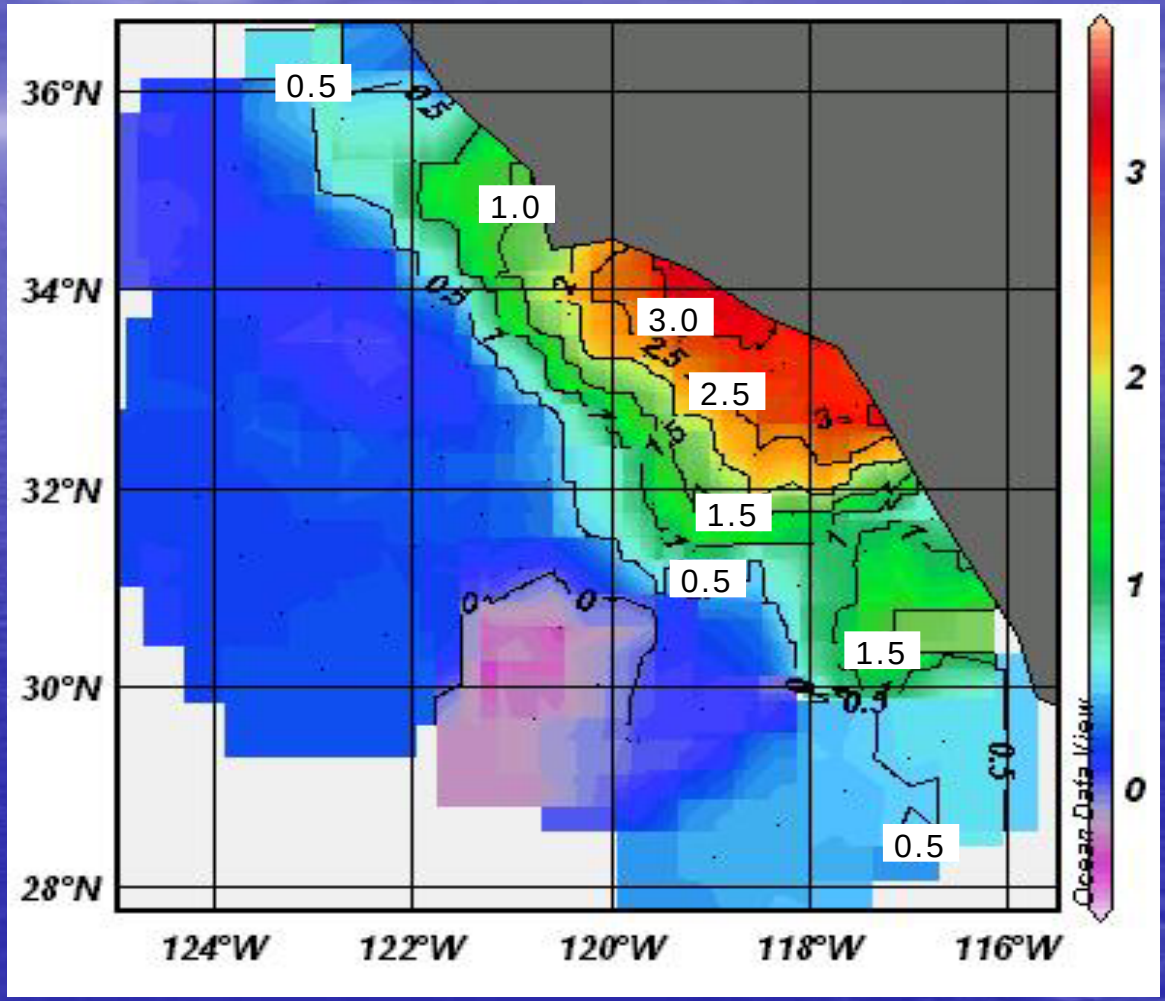
CalCOFI Temperature Phase (days)

- Surface water warms earliest in center of SCB and near Pt. Conception
- 10-m water delayed in warming in center of SCB; no delay in CCS and off Pt. Conception
- 30-m water warms latest in center of SCB
- Data are aliased at 50-m

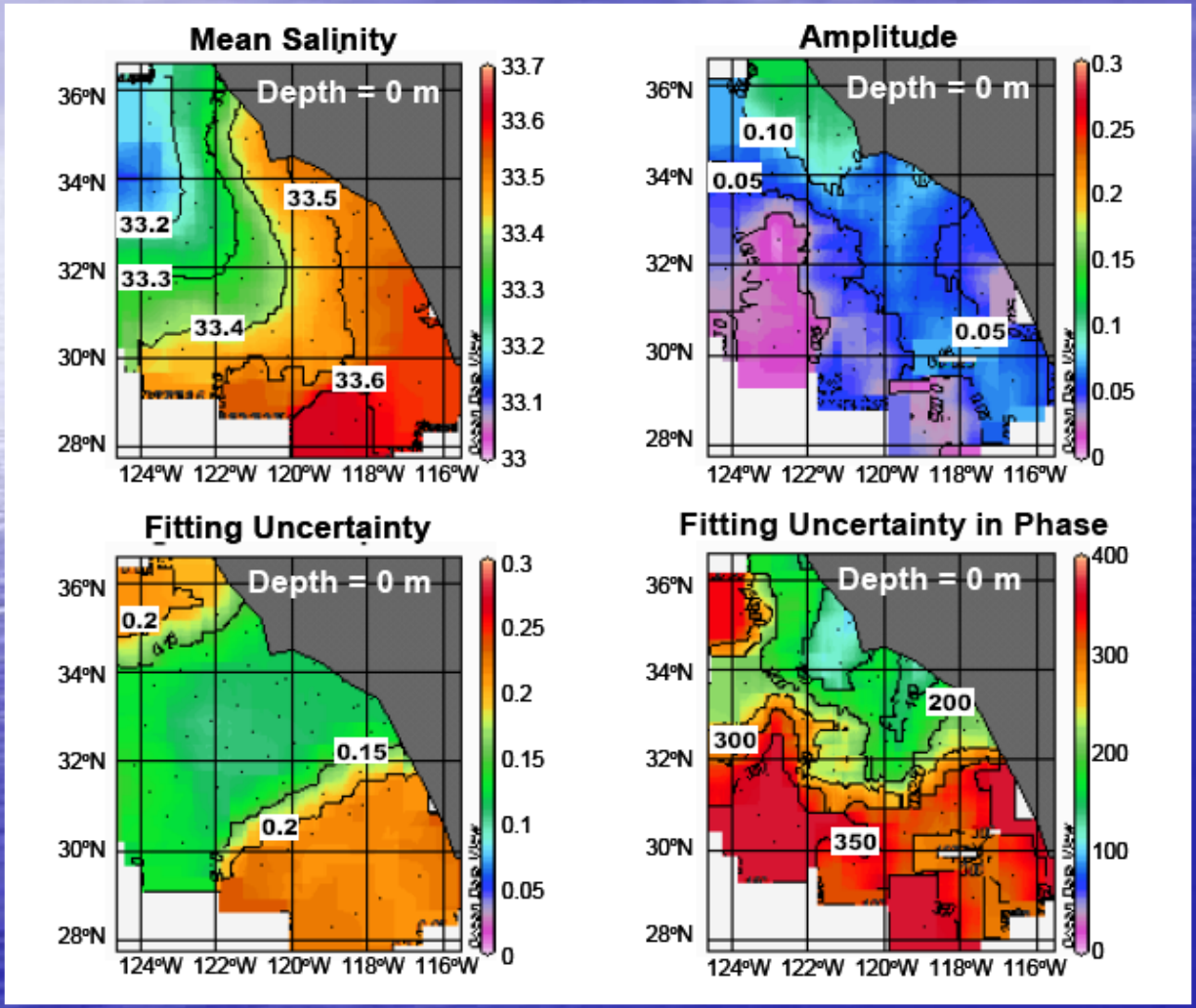


CalCOFI Phase Gradient (Days/meter)

- Maximum phase gradient in inner SCB: 3 days/m
- In CCS, phase gradient is less than 0.5 days/m



CalCOFI Salinity Measurements and Fits



Phase uncertainties
> 100 days

⇨ **No reliable seasonal signal**

CalCOFI results

- Inner bight has different dynamics than elsewhere off the coast
  - Annual amplitude exceeds the lateral gradient.
    - Temperature gradient is not advected
  - Salinity gradient but no seasonal signal indicates little advection in inner bight

Implications

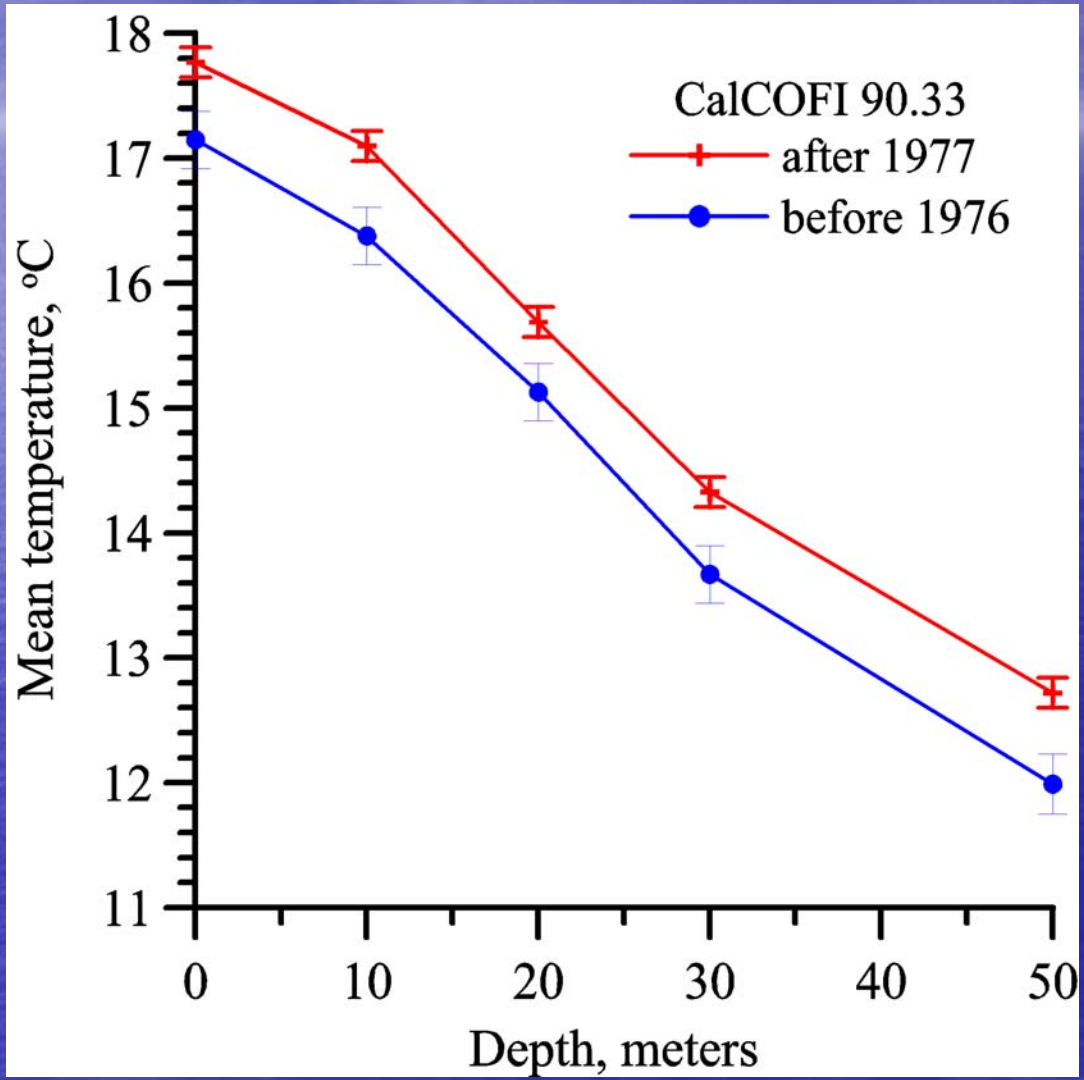
- Water is not exchanged in the SCB as rapidly as once thought.
- Diffusion rate not large enough to remove heat energy.
- Strong horizontal eddy field
  - Entrains water longer in the inner Bight yet provides net current flow

More to the Story

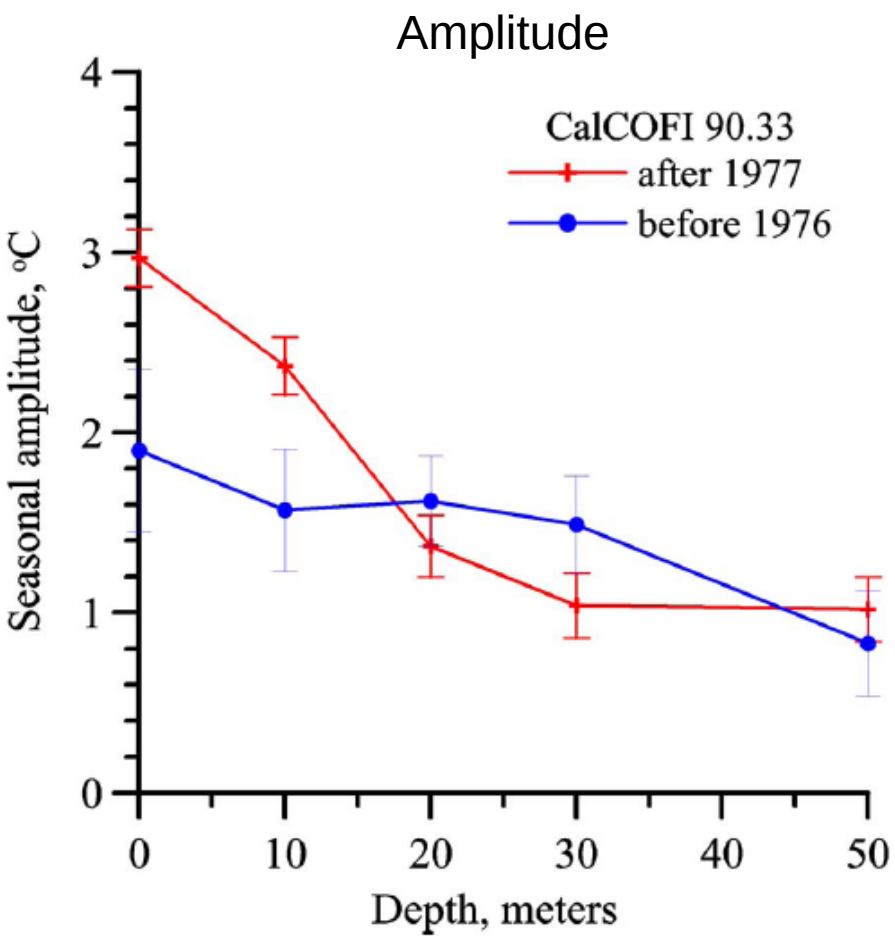
- Open-ocean measurements of diffusion are difficult to make:
  - Dump a tracer at a specified depth
  - Measure the tracer at other depths
- Tracer experiments at 70 m indicate a diffusion coefficient a factor of 10 smaller then the CCD data.
- Recent work off Florida in shallow water measured a vertical diffusion coefficient similar to the CCD-measured coefficient.
- Seasonal warming in center of SCB may explain Di Lorenzo's outward-propagating waves

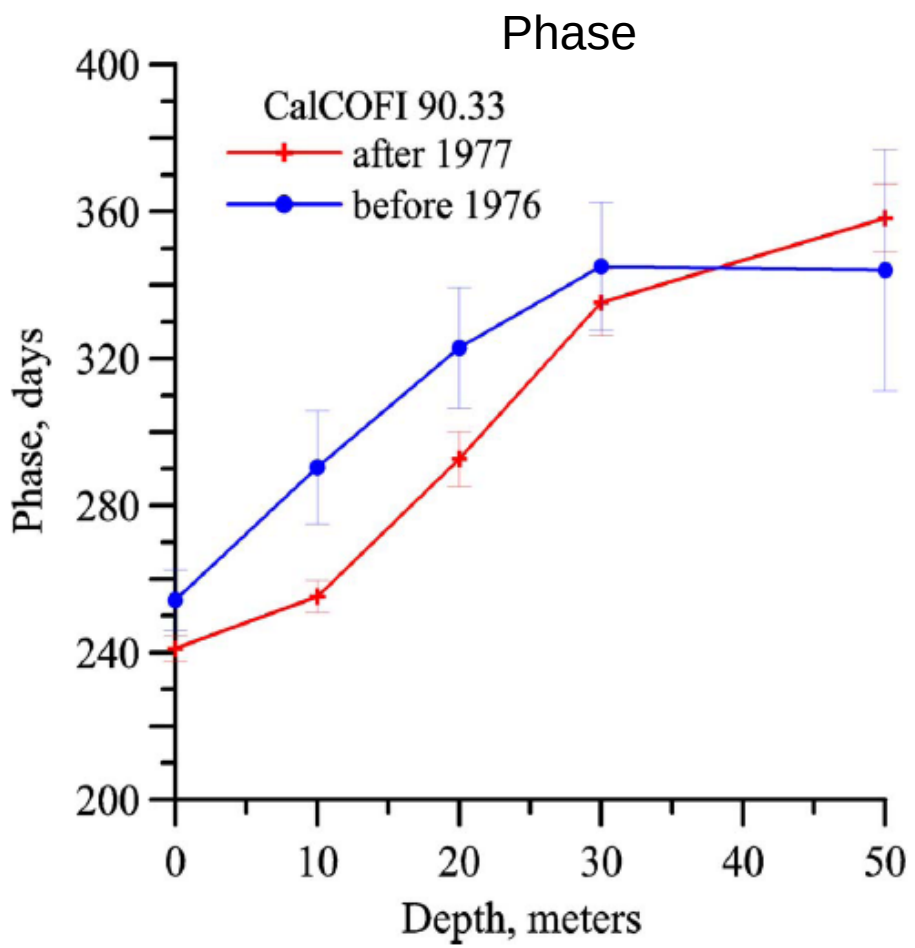
other material

Evidence of Regime Shift



Regime Shift





Extended Thermograph Array