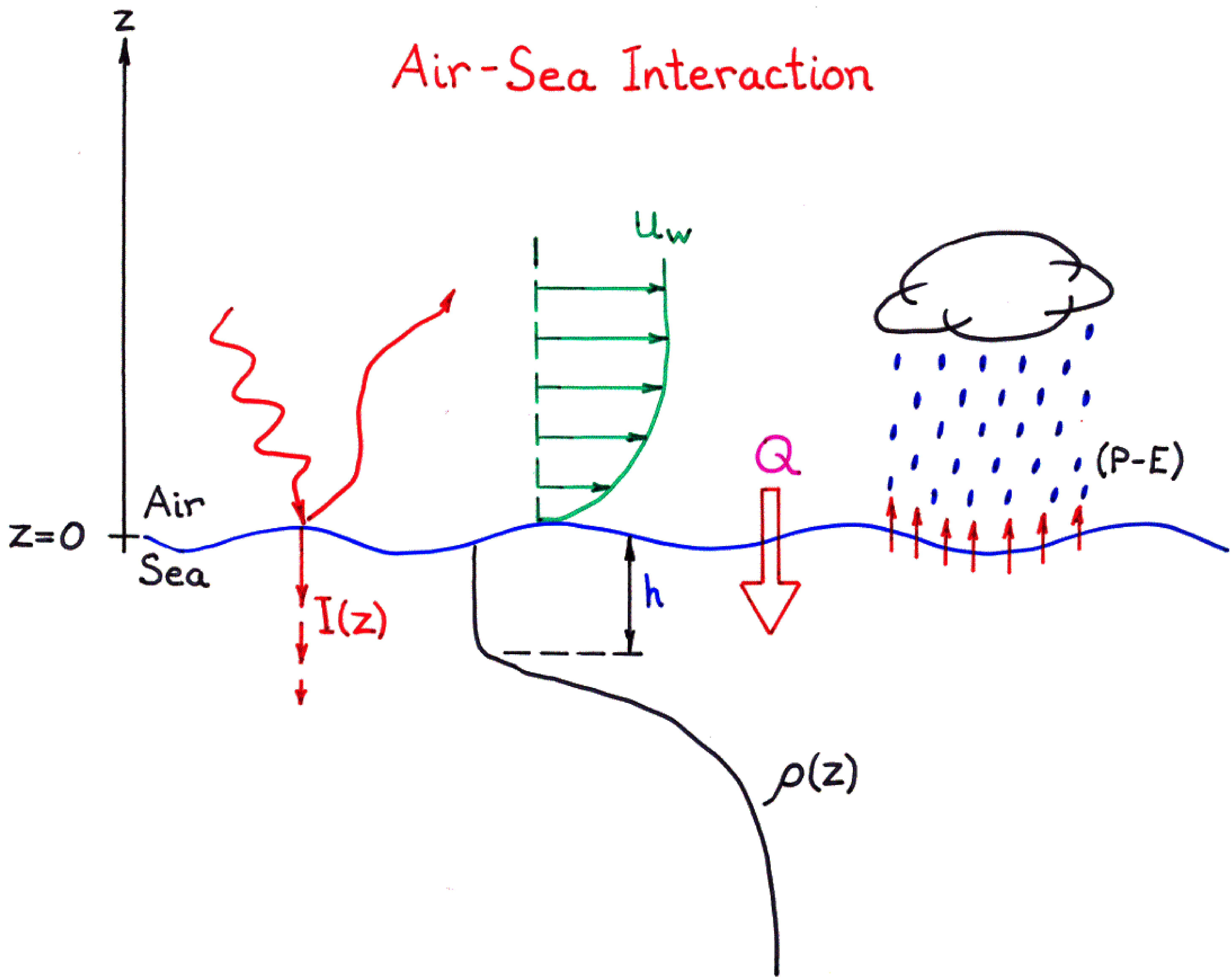
Mixed-Layer Simulations At OWS Bravo: The Role Of Salinity In The Mixed-Layer Dynamics

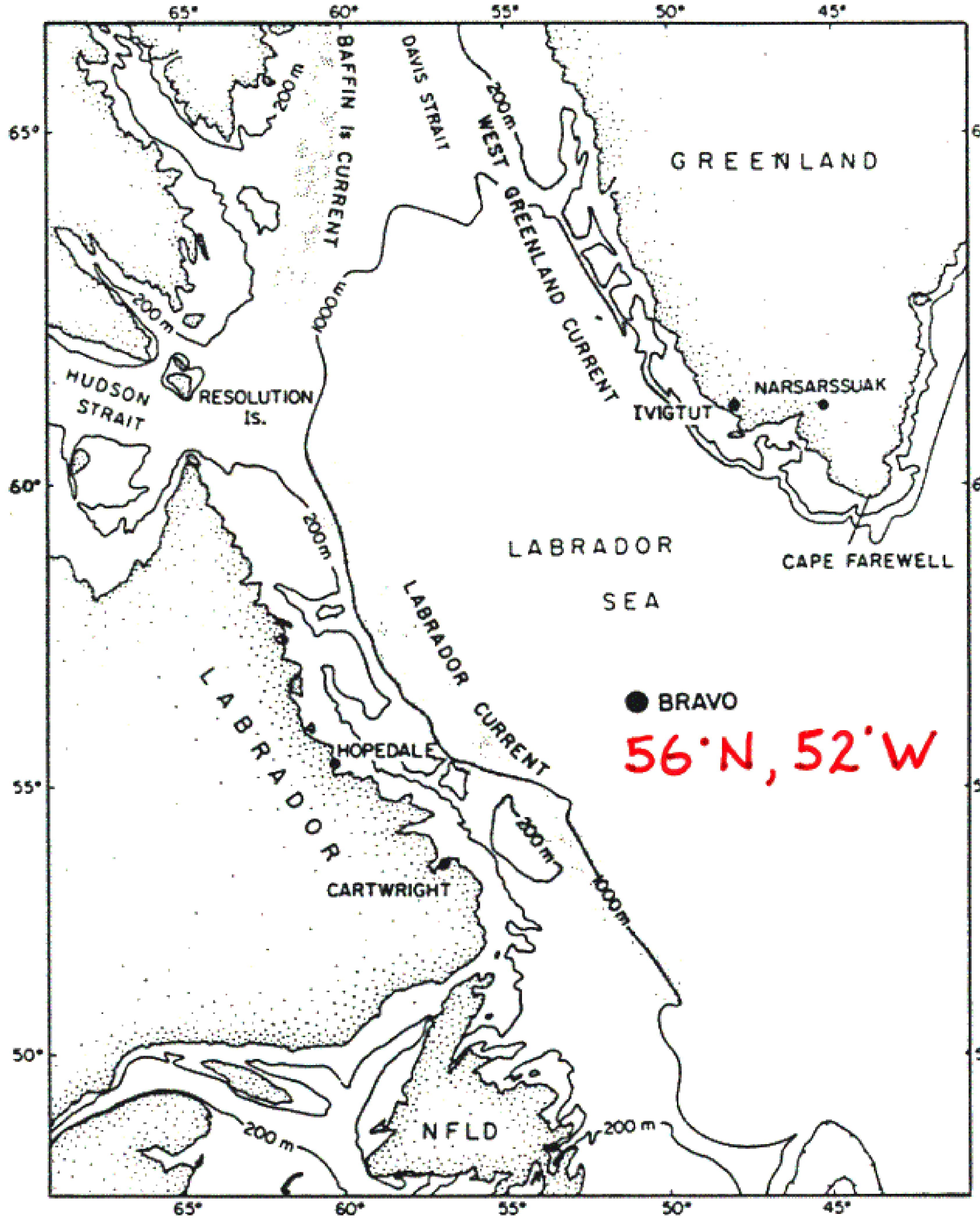
By: Serge D'Alessio
E-Mail: sdalessio@math.uwaterloo.ca

Department of Applied Mathematics
University of Waterloo
Waterloo, Ontario

With:
C.L. Tang & B.M. DeTracey
Bedford Institute of Oceanography
Department of Fisheries and Oceans
Dartmouth, Nova Scotia



Air-Sea Interaction
z
Air
z=0
Sea
I(z)
uw
h
ρ(z)
Q
(P-E)



Location of OWS Bravo

Source: Lazier, Atmos. Ocean, 1980

GOVERNING EQUATIONS

$$\frac{\partial \overline{U}}{\partial t} = f\overline{V} - \frac{\partial(\overline{u'w'})}{\partial z}$$

$$\frac{\partial \overline{V}}{\partial t} = -f\overline{U} - \frac{\partial(\overline{v'w'})}{\partial z}$$

$$\frac{\partial \overline{T}}{\partial t} = \frac{1}{\rho_0 c_p}\frac{\partial I}{\partial z} - \frac{\partial(\overline{T'w'})}{\partial z}$$

$$\frac{\partial \overline{S}}{\partial t} = -\frac{\partial(\overline{s'w'})}{\partial z}$$

At OWS Bravo $f = 1.2128 \times 10^{-4}[1/s]$, $\rho_0 = 1027[kg/m^3]$ and $c_p = 4190[J/kgK]$.

BOUNDARY CONDITIONS

Surface flux conditions at $z = 0$:

$$\overline{u'w'}_0 = -\frac{\tau_x}{\rho_0}, \; \overline{v'w'}_0 = -\frac{\tau_y}{\rho_0}$$

$$\overline{T'w'}_0 = -\frac{Q}{\rho_0 c_p}$$

$$\overline{s'w'}_0 = -\overline{S}_0(E - P)$$

Bottom boundary conditions at $z = -D$:

$$(\overline{U}, \overline{V}) \rightarrow (0, 0)$$

$$\overline{T} \rightarrow \overline{T}_\infty$$

$$\overline{S} \rightarrow \overline{S}_\infty$$

EXTERNAL PARAMETERIZATIONS

Equation of State: (Friedrich & Levitus, J.P.O., 1972)

$$\sigma(T,S) = C_1 + C_2 T + C_3 S + C_4 T^2 + C_5 ST + C_6 T^3 + C_7 ST^2$$

$$C_1 = -7.2169 \times 10^{-2}, C_2 = 4.9762 \times 10^{-2}, C_3 = 8.0560 \times 10^{-1}$$

$$C_4 = -7.5911 \times 10^{-3}, C_5 = -3.0063 \times 10^{-3}$$

$$C_6 = 3.5187 \times 10^{-5}, C_7 = 3.7297 \times 10^{-5}$$

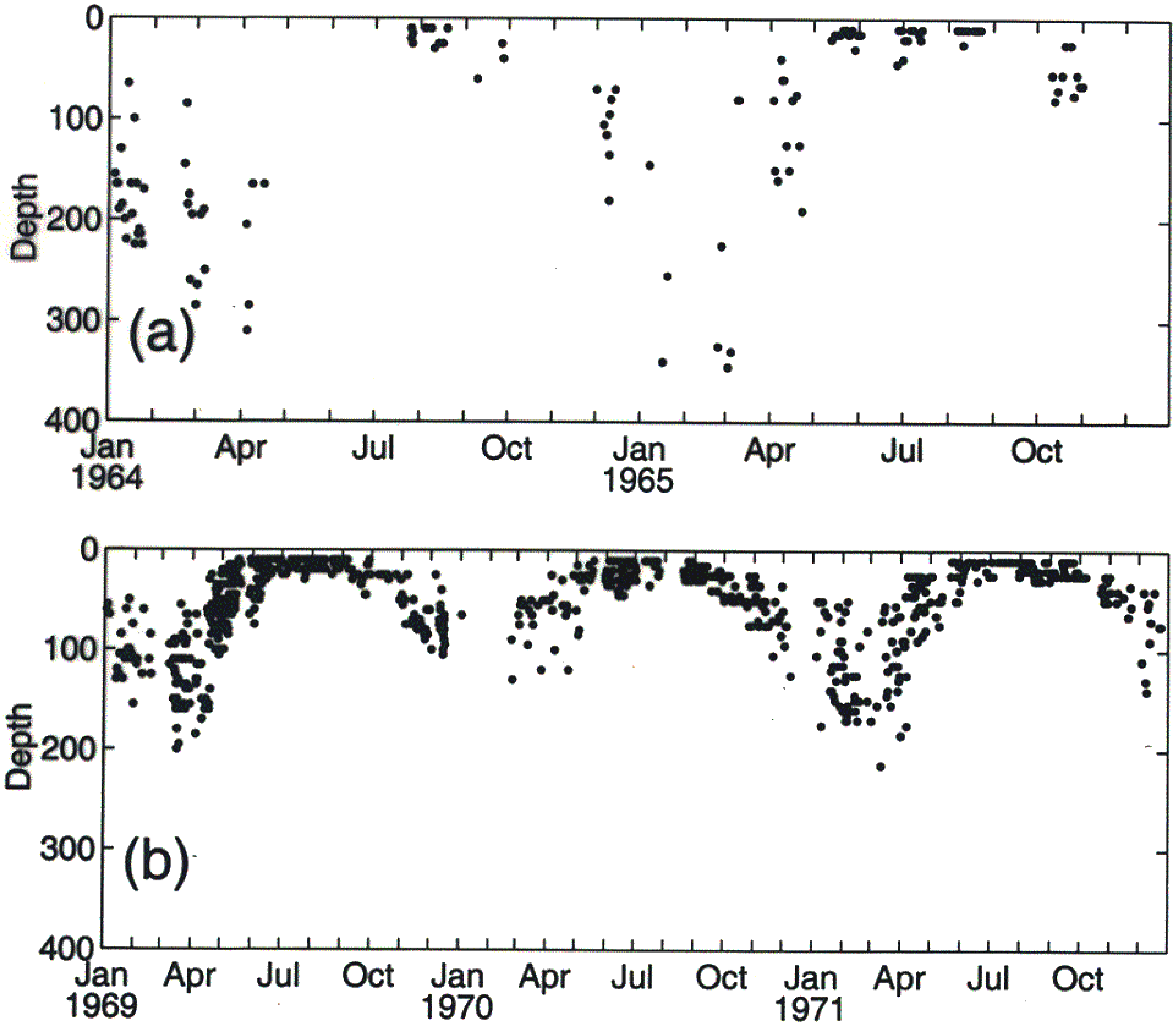
$$\alpha = -\frac{1}{\rho_0}\frac{\partial \sigma}{\partial T}, \ \beta = \frac{1}{\rho_0}\frac{\partial \sigma}{\partial S}$$

Extinction of Solar Radiation: (Paulson & Simpson, J.P.O., 1977)

$$\frac{I(z)}{I_0} = Re^{z/l_1} + (1-R)e^{z/l_2}$$

At OWS Bravo the water optical type is **very clear**.

$$R = 0.4 \ , \ l_1 = 5m \ , \ l_2 = 40m$$



Observed Mixed-Layer Depth

HEAT AND SALT BALANCE

Integrating the temperature and salinity equations from $z = -D$ to $z = 0$ gives

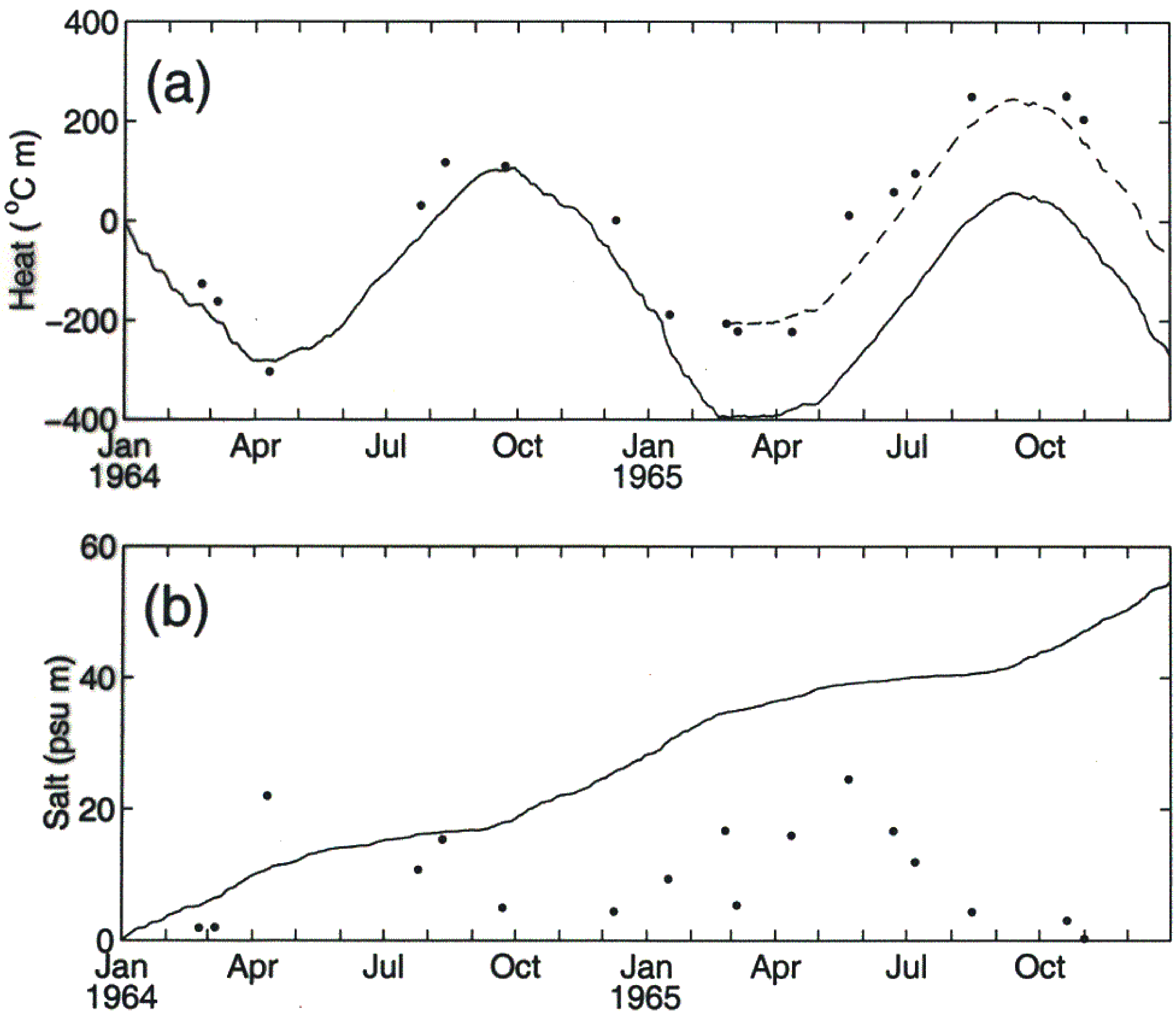
$$\frac{d}{dt}\int_{-D}^{0} \overline{T} dz = \frac{1}{\rho_0 cp}[Q + I_0]$$

$$\frac{d}{dt}\int_{-D}^{0} \overline{S} dz = -\overline{S}_0[P - E]$$

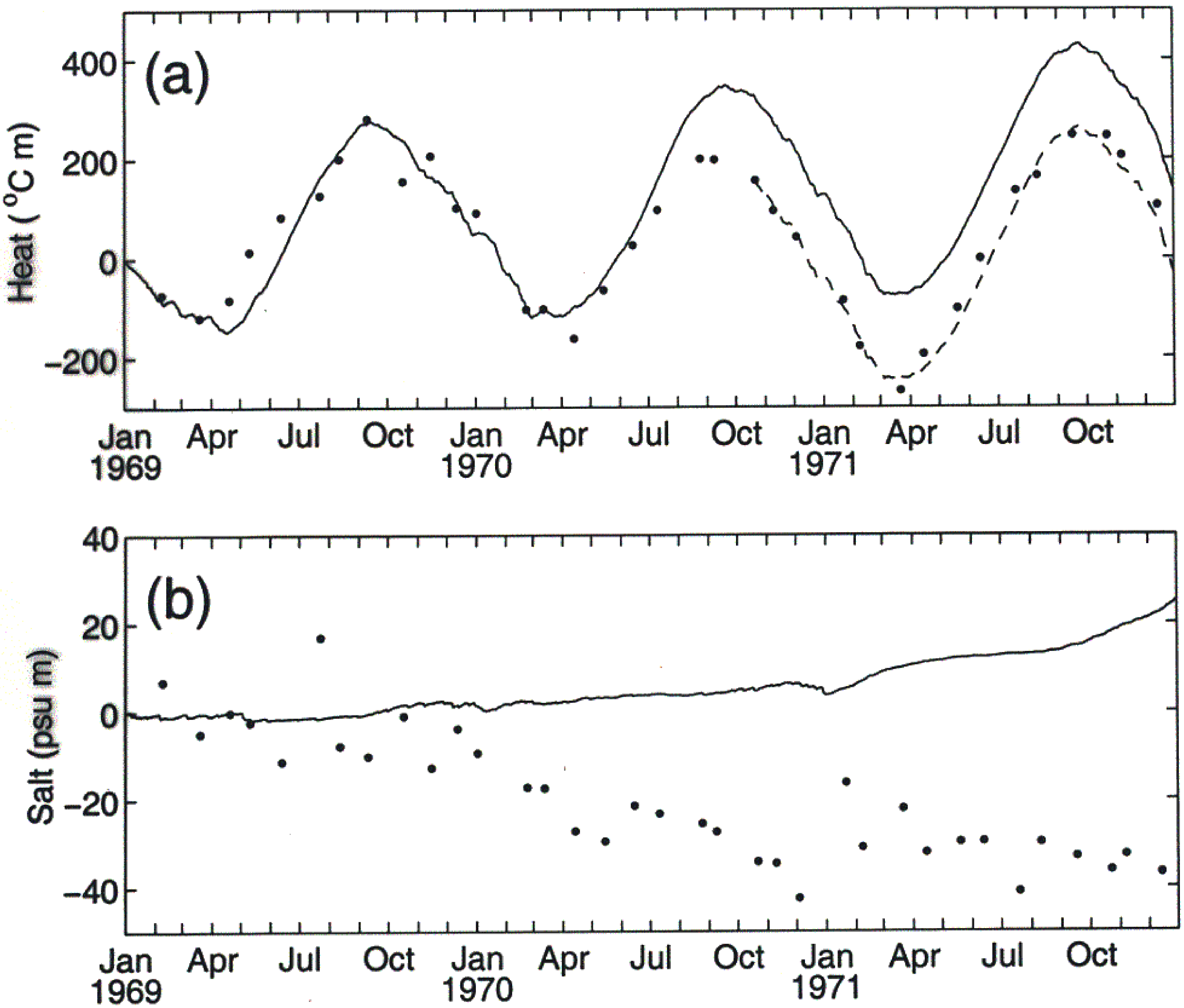
Integrating again in time yields

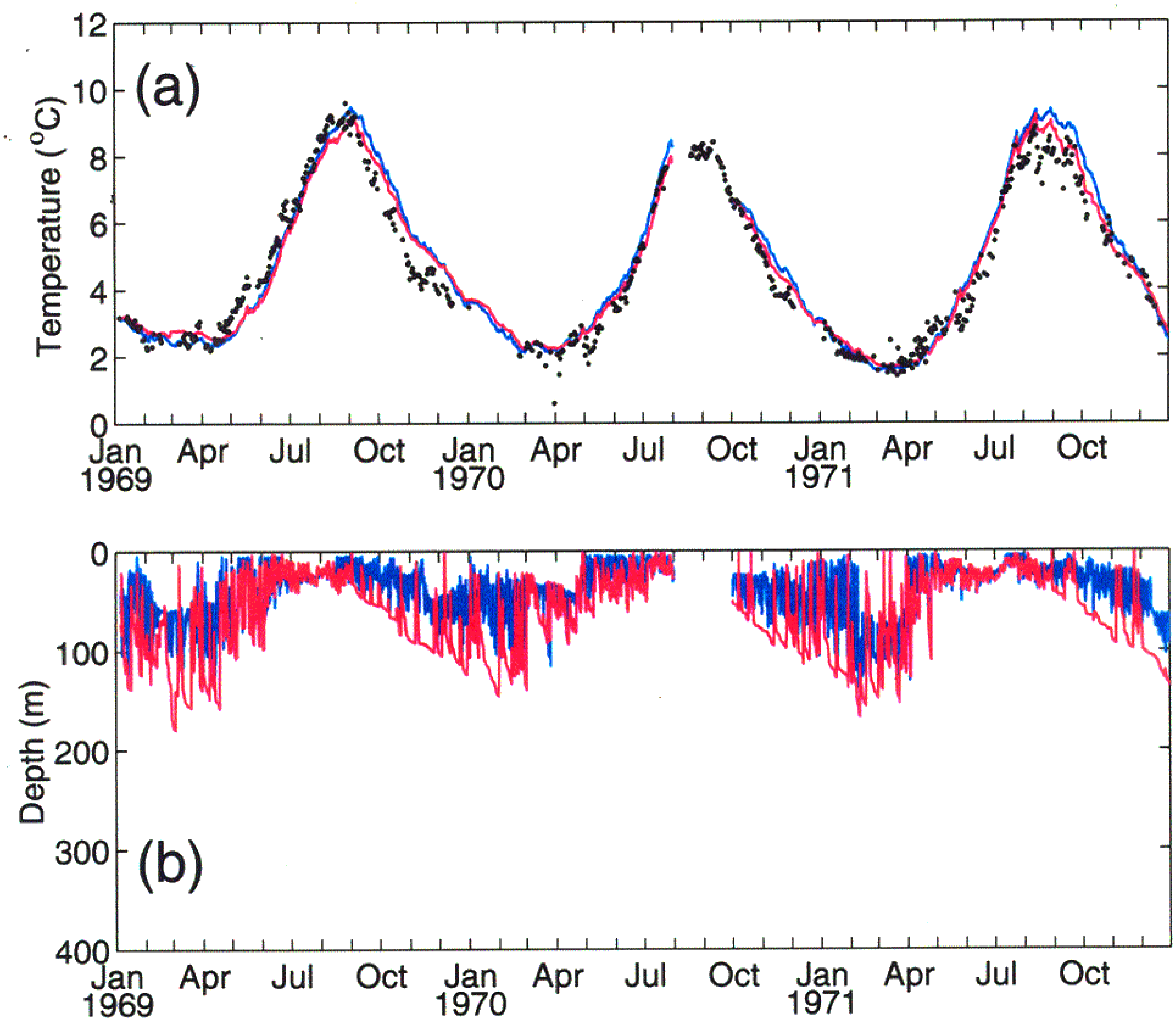
$$\int_{-D}^{0} \overline{T}(t) dz - \int_{-D}^{0} \overline{T}(t=0) dz = \frac{1}{\rho_0 cp}\int_{0}^{t}[Q + I_0] dt$$

$$\int_{-D}^{0} \overline{S}(t) dz - \int_{-D}^{0} \overline{S}(t=0) dz = -\overline{S}_0 \int_{0}^{t}[P - E] dt$$



Simulated vs Observed
Heat & Salt Budgets

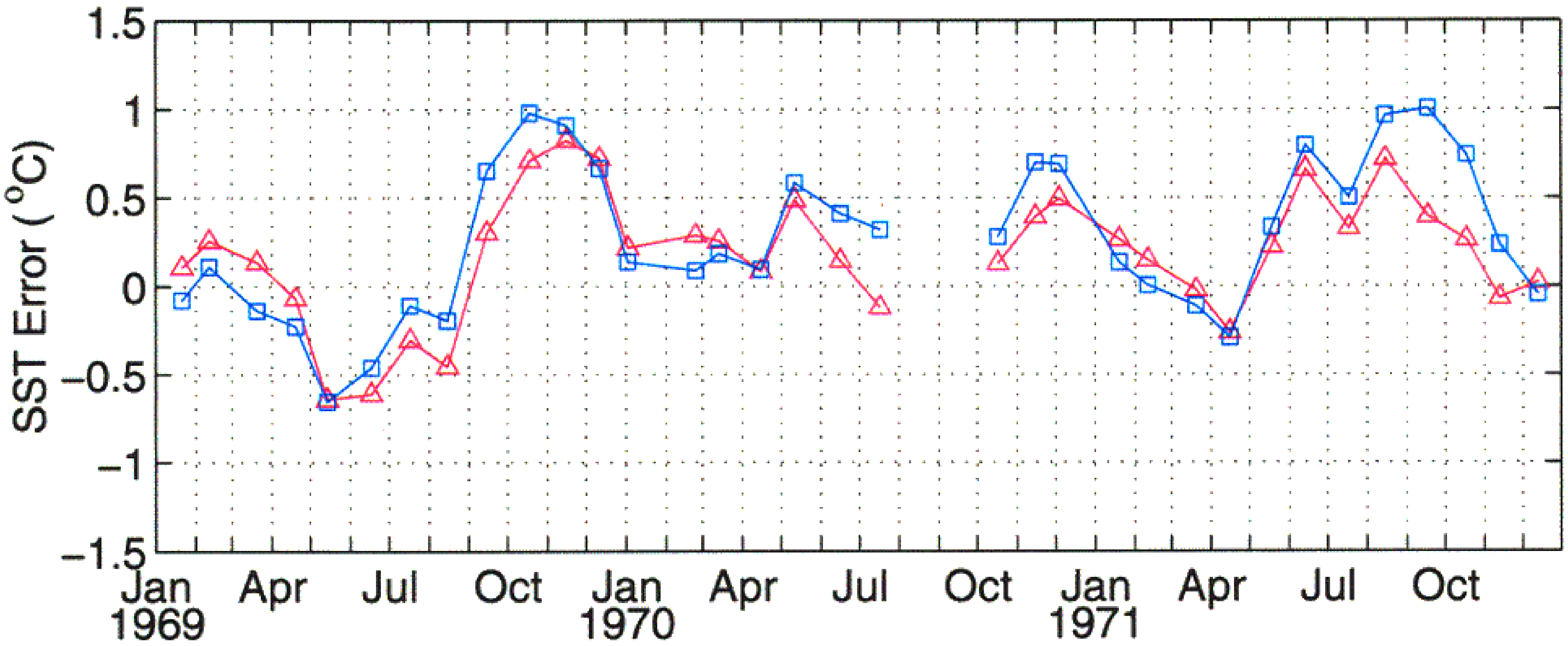

(a)
Heat (°C m)
400
200
0
−200
Jan 1969
Apr
Jul
Oct
Jan 1970
Apr
Jul
Oct
Jan 1971
Apr
Jul
Oct
(b)
Salt (psu m)
40
20
0
−20
−40
Jan 1969
Apr
Jul
Oct
Jan 1970
Apr
Jul
Oct
Jan 1971
Apr
Jul
Oct



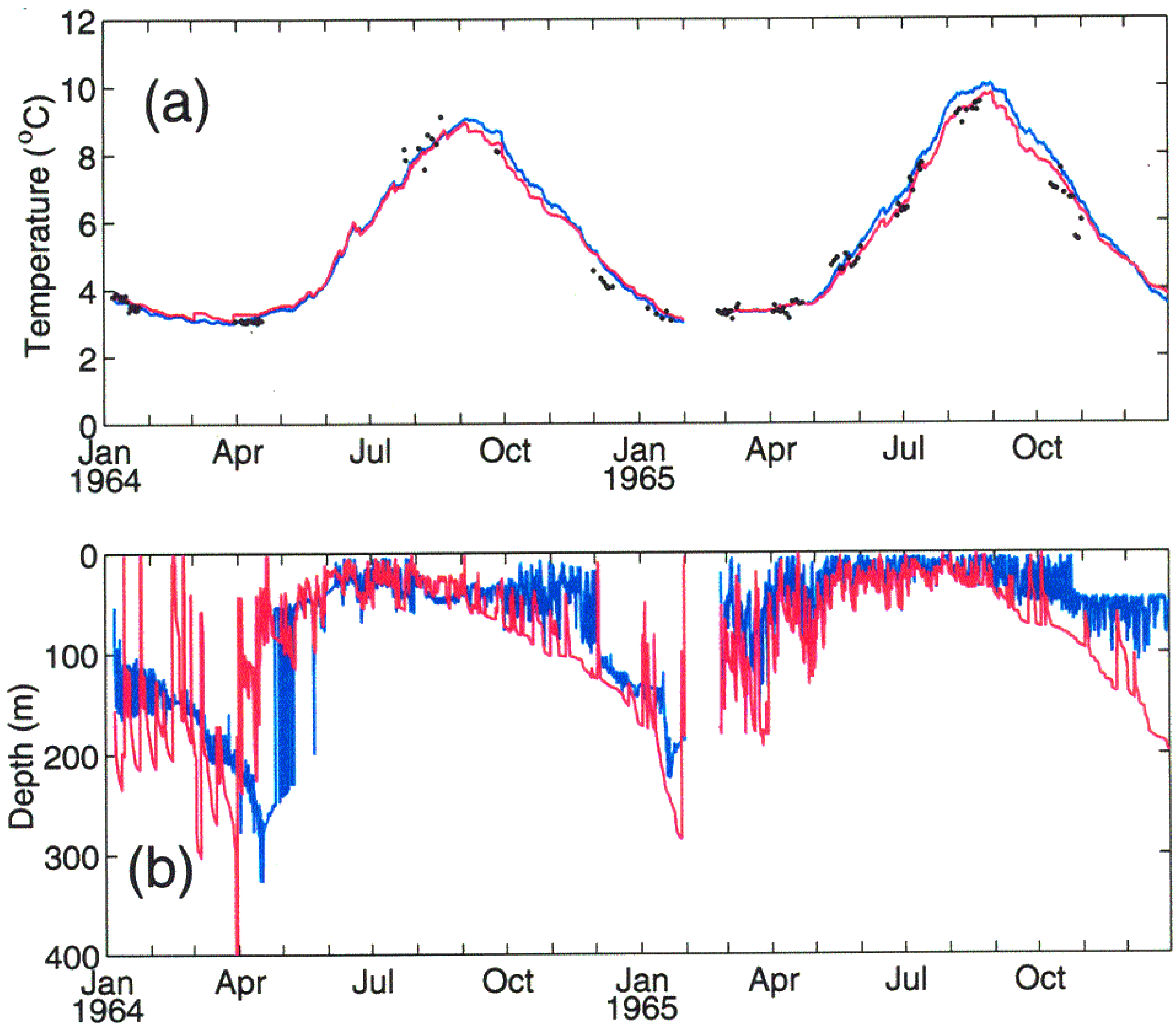
Simulated vs Observed Sea-Surface Temp. & Mixed-Layer Depth

red line: simulation using Bulk Model

blue line: simulation using Turbulence Closure Model



1.5
1
0.5
0
−0.5
−1
−1.5
SST Error (°C)
Jan 1969
Apr
Jul
Oct
Jan 1970
Apr
Jul
Oct
Jan 1971
Apr
Jul
Oct



(a)
Temperature (°C)
12
10
8
6
4
2
0
Jan 1964
Apr
Jul
Oct
Jan 1965
Apr
Jul
Oct
(b)
Depth (m)
0
100
200
300
400
Jan 1964
Apr
Jul
Oct
Jan 1965
Apr
Jul
Oct

SUMMARY

- 1-D models cannot simulate salinity well at OWS Bravo
- simulations of SST and MLD improve as the salinity is more realistically specified
- salinity is an important factor controlling mixed-layer properties during the cooling phase (winter - spring)
- for period 1964-1965, max MLD is $300m$ and min SST is $3°C$
  for period 1969-1971, max MLD is $200m$ and min SST is $2°C$
- the difference in max MLD and min SST is mainly a salinity effect