Ingeniería Civil

FACULTAD DE CIENCIAS
FÍSICAS Y MATEMÁTICAS
UNIVERSIDAD DE CHILE

THE WATER ENVIRONMENT AND HUMAN NEEDS: A CASE STUDY INVOLVING THE HYDRODYNAMICS OF A COASTAL LAKE IN SOUTHERN CHILE

Yarko Niño
Department of Civil Engineering, Universidad de Chile

THE WATER ENVIRONMENT AND HUMAN NEEDS

… THIS WIDER SCOPE OF APPROACHING FUTURE PROBLEMS OF THE WATER ENVIRONMENT … WHEN ALL THE COMPLEX ENVIRONMENTAL AND SOCIAL FACTORS MUST BE CONSIDERED IN A GIVEN SYSTEM TO MEET THEM WITH CREATIVE IDEAS AND TECHNOLOGY AT PRESENT STILL LARGELY UNKNOWN …

(A.T. IPPEN, 1970)

THE PLAN

- ➔ EXPLORE A SYSTEM WHOSE HYDRODYNAMICS HAS A STRONG IMPACT ON THE ENVIRONMENT AND WELL-BEING OF LOCAL COMMUNITIES

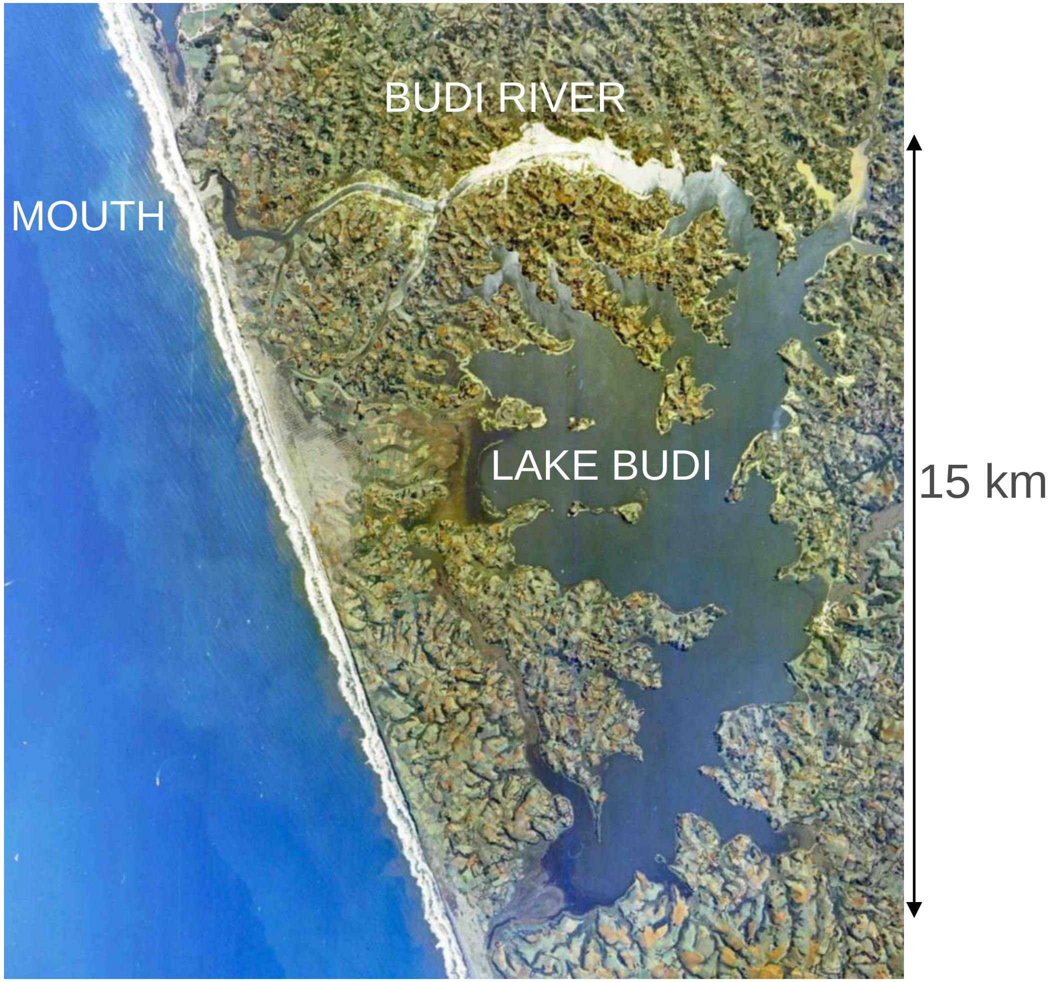
- ➔ IN THE PROCESS DISCUSS ASPECTS OF TRANSPORT AND MIXING IN STRATIFIED FLOWS

- ➔ GO FROM THEORY TO PRACTICE (THROUGH EXPERIMENTS AND NUMERICAL MODELING)

THE SYSTEM

THE SYSTEM

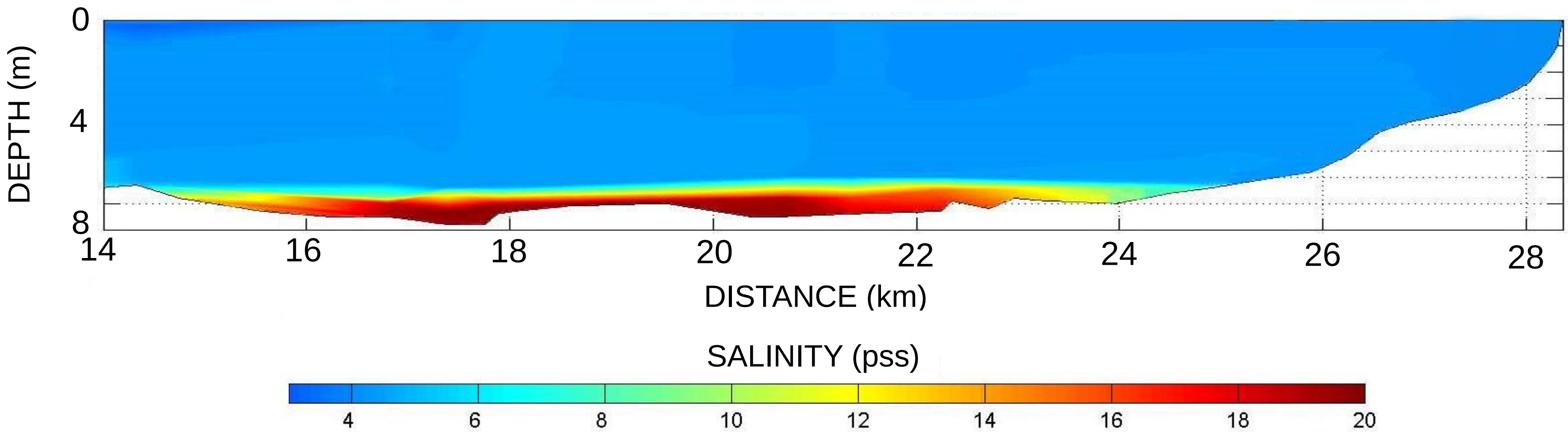
RIVER AND LAKE BUDI

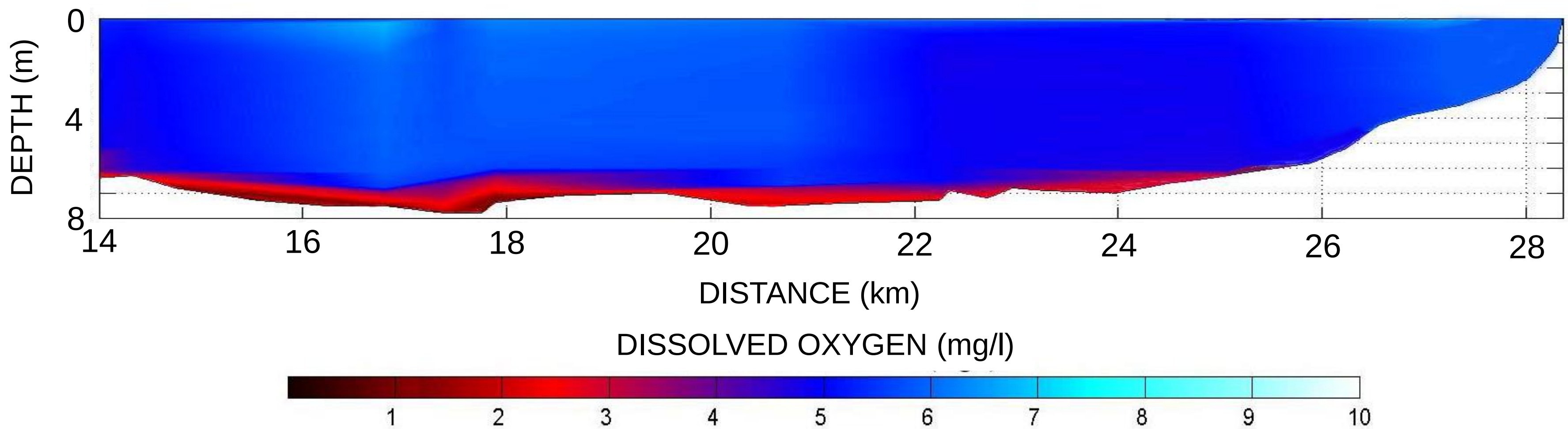


38º 52` 73º 22`

THE SYSTEM

SALINITY STRATIFICATION AND DISSOLVED OXYGEN





THE SYSTEM

BUDI RIVER MOUTH (ICOL)

THE SYSTEM

ARTIFICIAL OPENING




THE SYSTEM

ARTIFICIAL OPENING

SOCIAL AND ENVIRONMENTAL ISSUES

- ➔ LAKE BUDI IS LOCATED IN A REGION OF LOW-INCOME RURAL NATIVE PEOPLE (MAPUCHE) COMMUNITIES
- ➔ MAIN ECONOMIC ACTIVITIES ARE SMALL-SCALE FISHING AND AGRICULTURE
- ➔ IN RECENT YEARS FISHING IN THE LAKE HAS DECLINED FORCING LAND-USE CHANGES FOR AGRICULTURE
- ➔ THIS HAS FORCED EARLIER IN THE YEAR AND MORE FREQUENT OPENINGS OF THE MOUTH BAR AND DECAYING WATER QUALITY IN THE LAKE

RIVER AND LAKE SALINITY INTRUSION DYNAMICS

RIVER AND LAKE SALINITY INTRUSION DYNAMICS

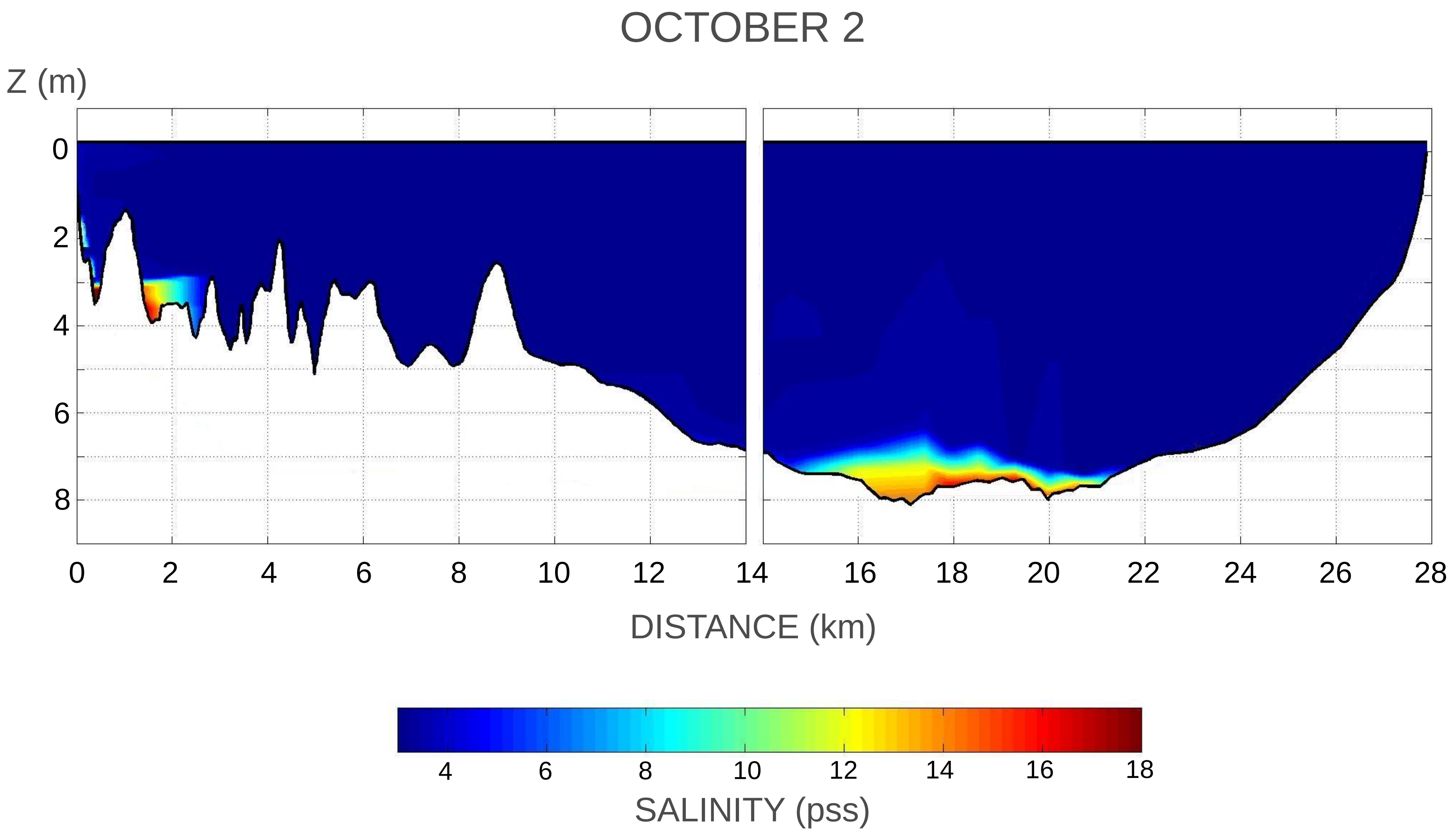
FIELD OBSERVATIONS 2006-2007

➔ 2 MOUTH-BAR OPENINGS IN THE AUSTRAL WINTER OF 2006:
JUNE 22 AND OCTOBER 5

- ➔ OCTOBER 2 (3 DAYS PRIOR 2ND OPENING)
- ➔ OCTOBER 18 (2 WEEKS AFTER 2ND OPENING)
- ➔ DECEMBER 12 (10 WEEKS AFTER 2ND OPENING)
- ➔ JANUARY 29 (17 WEEKS AFTER 2ND OPENING)

RIVER AND LAKE SALINITY INTRUSION DYNAMICS

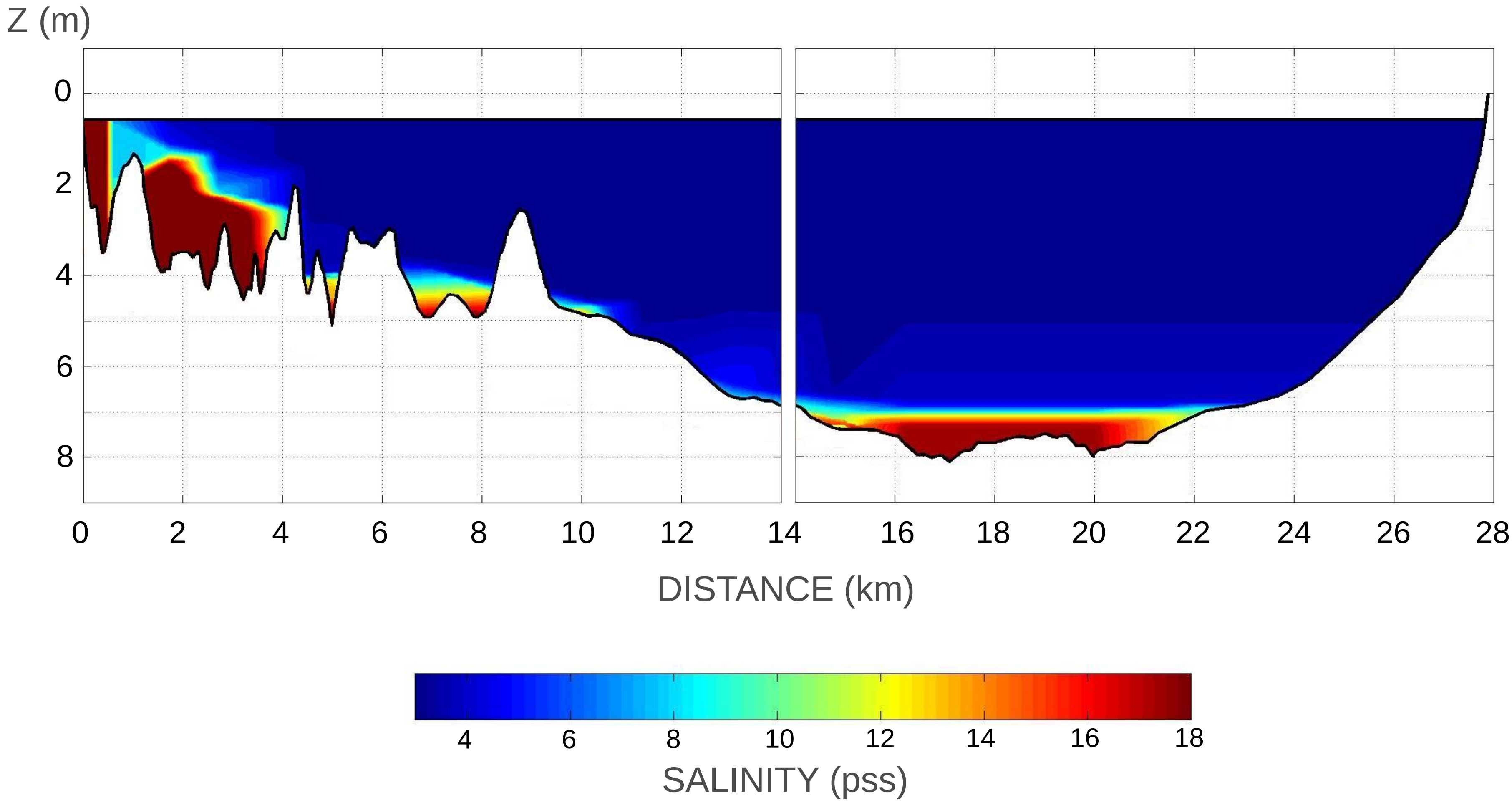
SALINITY STRUCTURE PRIOR 2ND OPENING



RIVER AND LAKE SALINITY INTRUSION DYNAMICS

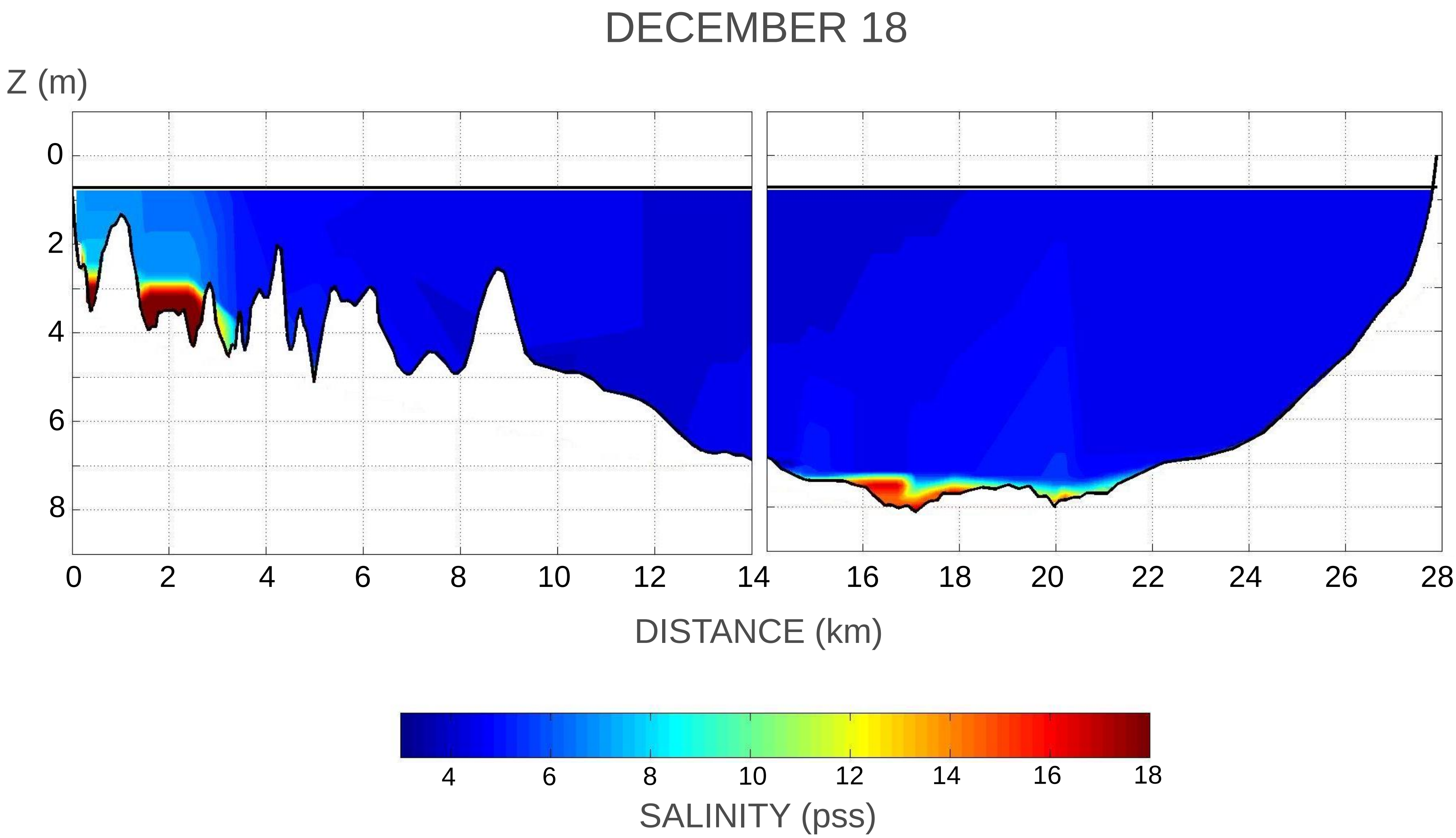
SALINITY STRUCTURE 2WEEKS POST 2ND OPENING

OCTOBER 18



RIVER AND LAKE SALINITY INTRUSION DYNAMICS

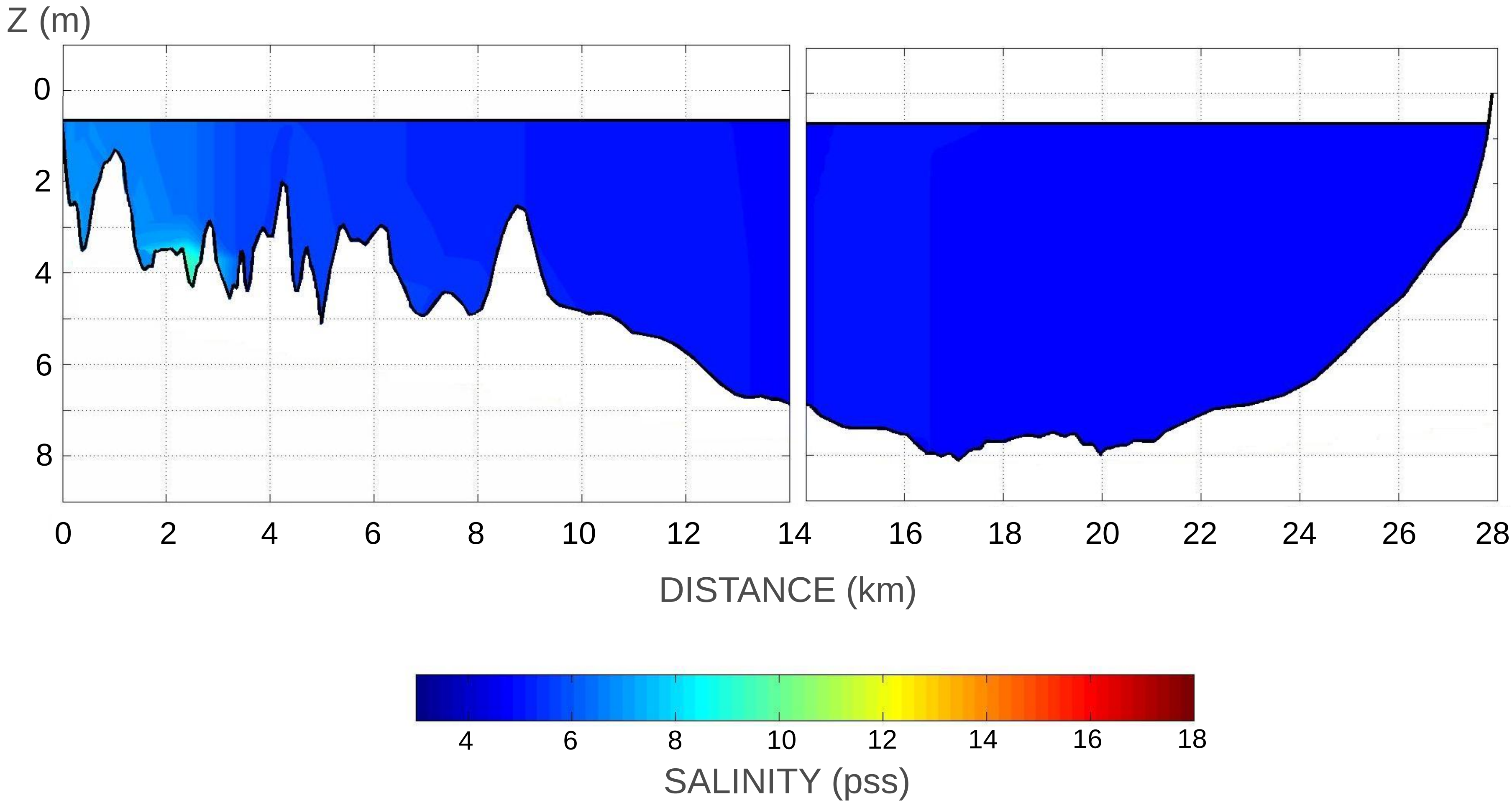
SALINITY STRUCTURE 10 WEEKS POST 2ND OPENING



RIVER AND LAKE SALINITY INTRUSION DYNAMICS

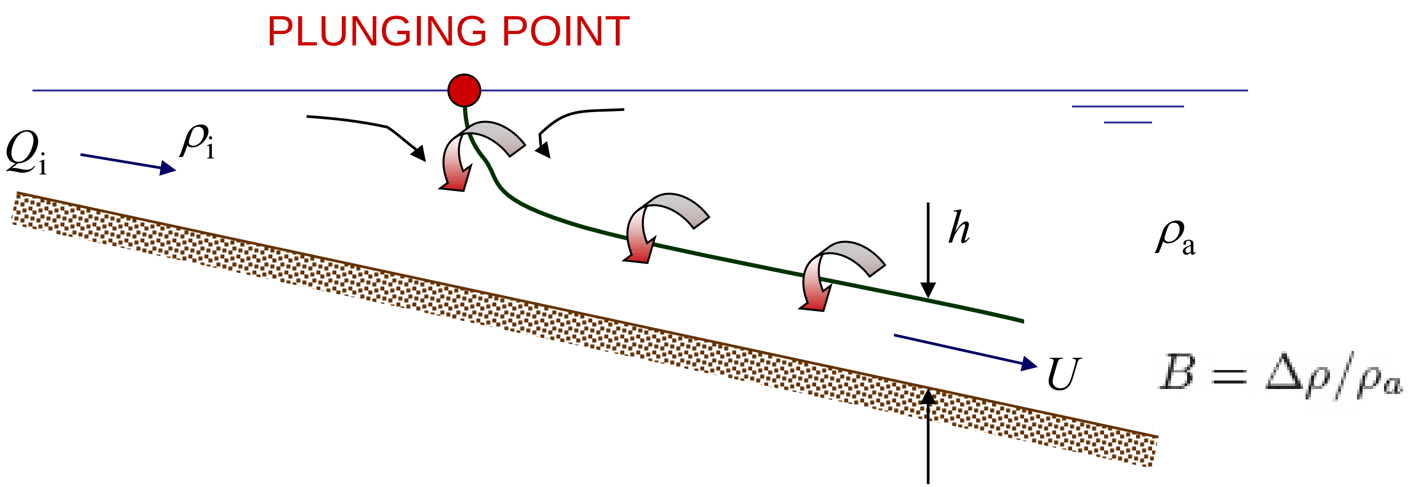
SALINITY STRUCTURE 17 WEEKS POST 2ND OPENING

JANUARY 29 COMPLETE MIXING!

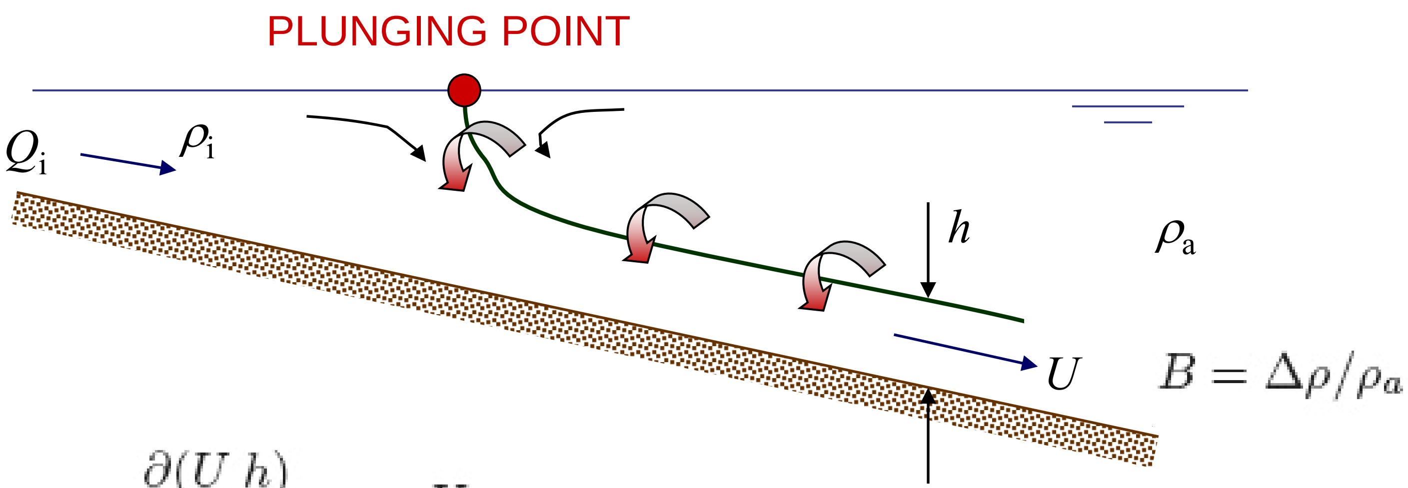


SALINITY INTRUSION: PLUNGING AND DENSITY CURRENT

SALINITY INTRUSION: PLUNGING AND DENSITY CURRENT



SALINITY INTRUSION: PLUNGING AND DENSITY CURRENT



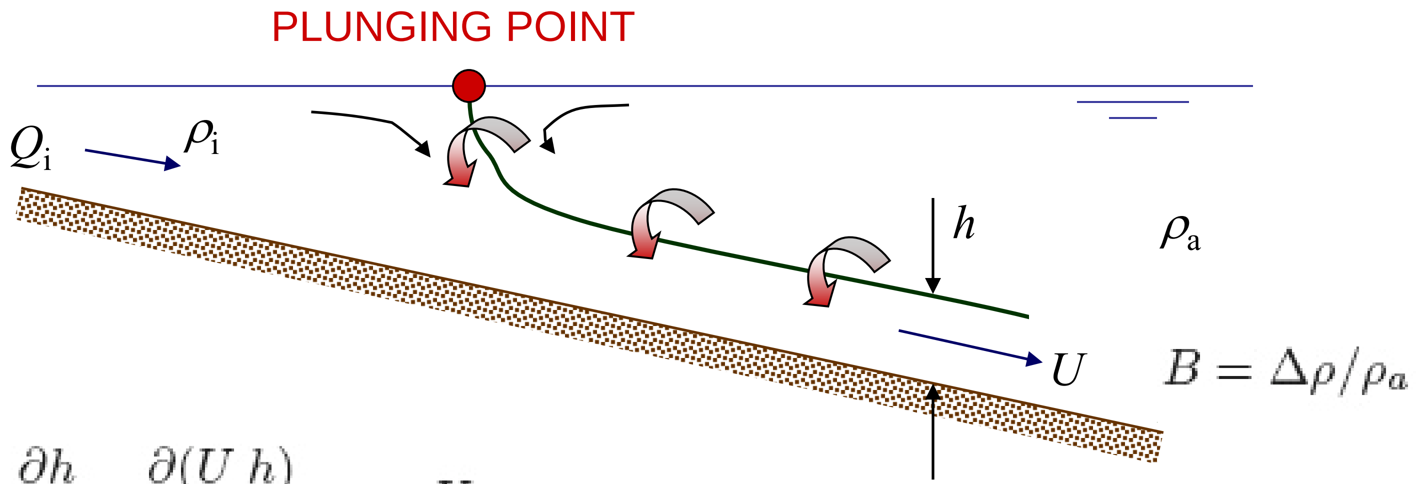
$$\frac{\partial(U\,h)}{\partial x} = e_w\,U$$

$$\frac{\partial(U^2\,h)}{\partial x} = S_1\,g\,B\,h\,S - \frac{1}{2}\,S_2\,g\,\frac{\partial(B\,h^2)}{\partial x} - c_f\,U^2$$

$$\frac{\partial(U\,B\,h)}{\partial x} = 0$$

ELLISON & TURNER (1959)

SALINITY INTRUSION: PLUNGING AND DENSITY CURRENT



$$\frac{\partial h}{\partial t} + \frac{\partial (U\,h)}{\partial x} = e_w\,U$$

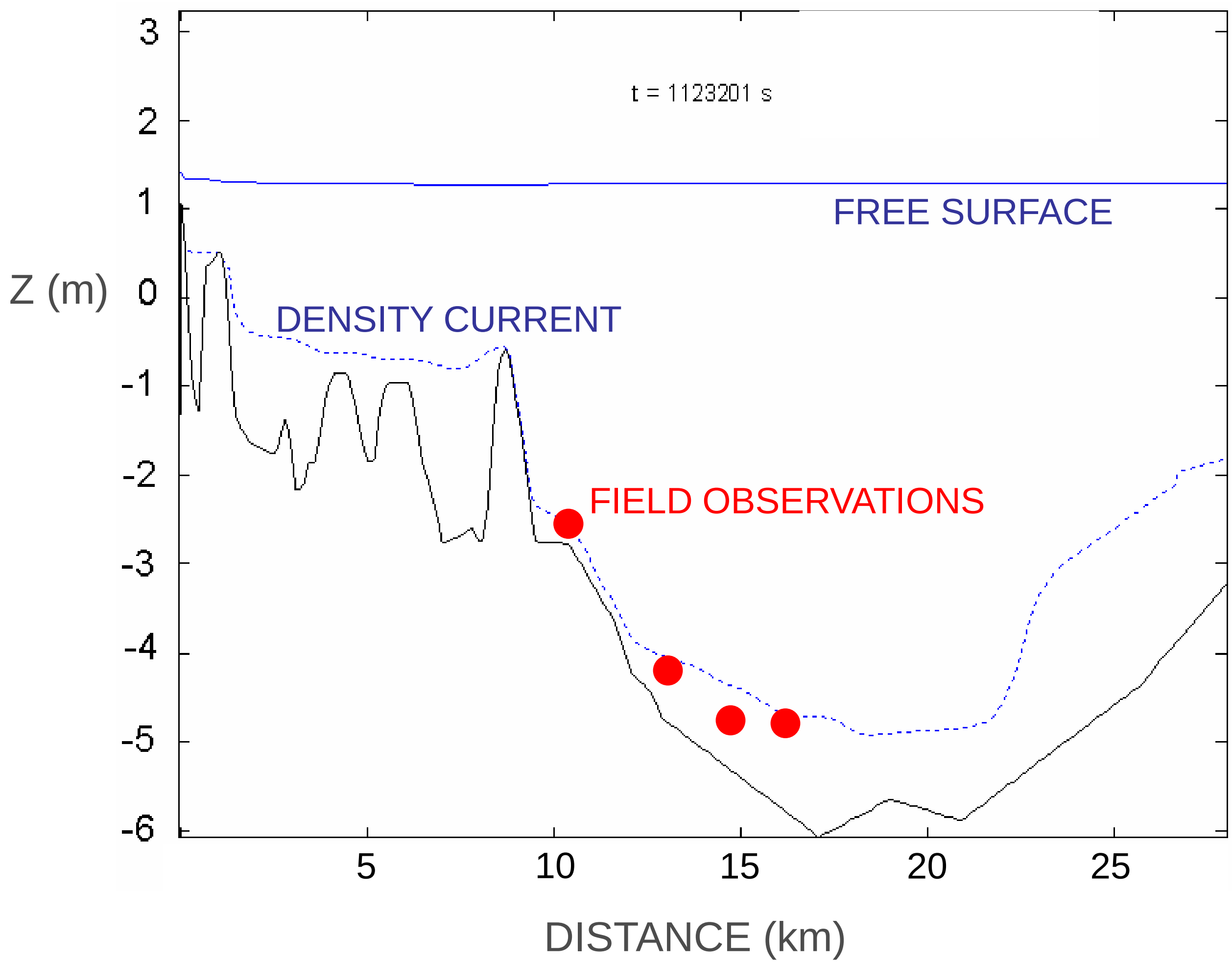
$$\frac{\partial (U\,h)}{\partial t} + \frac{\partial (U^2\,h)}{\partial x} = S_1\,g\,B\,h\,S - \frac{1}{2}\,S_2\,g\,\frac{\partial (B\,h^2)}{\partial x} - c_f\,U^2$$

$$\frac{\partial Bh}{\partial t} + \frac{\partial (U\,B\,h)}{\partial x} = 0$$

ELLISON & TURNER (1959)

SALINITY INTRUSION: PLUNGING AND DENSITY CURRENT

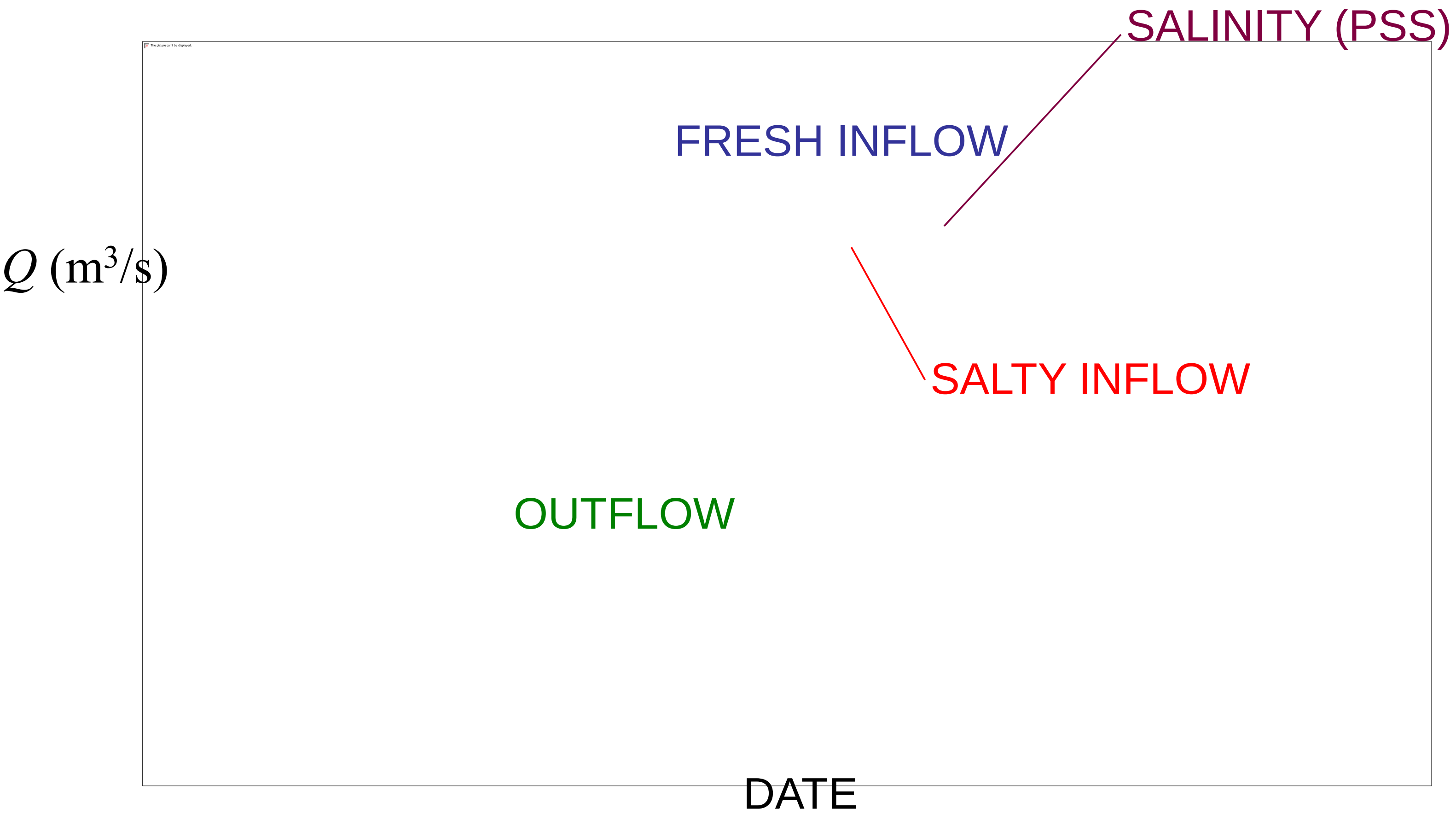
DENSITY CURRENT IN THE LAKE (2 WEEKS POST 2ND OPENING)



SALINITY INTRUSION: PLUNGING AND DENSITY CURRENT

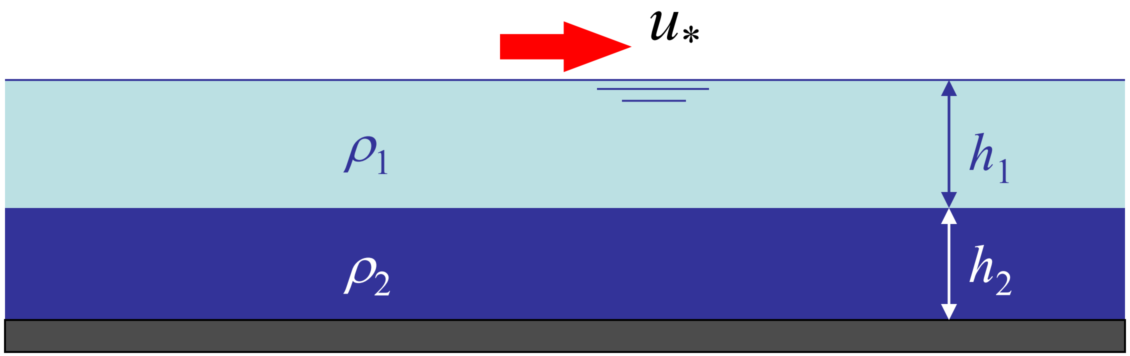
EXCHANGE FLOWS

DAILY MEAN FLOW RATES



MIXING IN STRATIFIED FLUID

WIND MIXING IN TWO-LAYER FLUID



$$Ri_* = \frac{g\,(\rho_2 - \rho_1)/\rho_0\, h_1}{u_*^2}$$

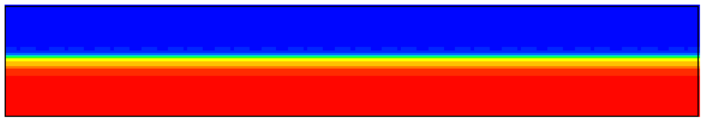
WIND RICHARDSON NUMBER

MIXING IN STRATIFIED FLUID

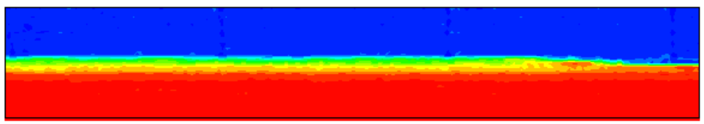
EXPERIMENTS (NIÑO ET AL., 2003)

DENSITY MAPS, $Ri_* = 82.6$

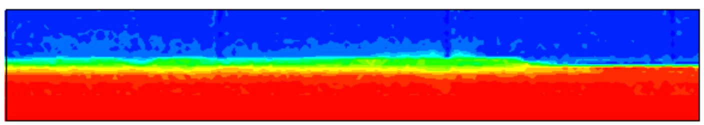
$t = 0$



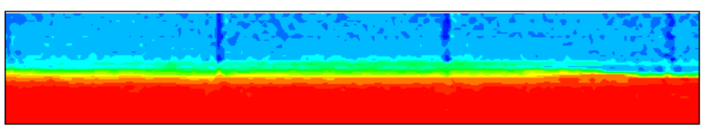
$t = 3$ min



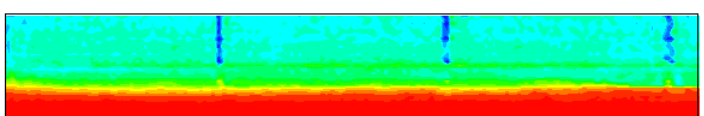
$t = 15$ min



$t = 50$ min



$t = 120$ min



ENTRAINMENT VELOCITY

$$\boxed{\frac{dh_1}{dt} = u_e}$$

MIXING IN STRATIFIED FLUID

EXPERIMENTS (NIÑO ET AL., 2003)

(KRANENBURG, 1985; MONISMITH, 1986)

The picture can't be displayed.

$$\boxed{\frac{u_e}{u_*} = \frac{0.07}{Ri_*}}$$

u_e/u_*

Ri_*

LET'S DO SOME THEORY IPPEN'S STYLE

(e.g., HARLEMAN & IPPEN, 1966)

MIXING IN STRATIFIED FLUID

BULK MIXING EFFICIENCY

(TSENG & FERZIGER, 1998)

$$\Gamma_{mix} = \frac{dPE/dt}{dK/dt}$$

GAIN IN PE

$$\frac{d(PE/A)}{dt} = \frac{1}{2}\, g\, (\rho_2 - \rho_1)\, h_1\, \frac{dh_1}{dt}$$

WIND INPUT

$$\frac{d(K/A)}{dt} = \rho_0\, u_*^2\, u_s$$

$$k = \frac{u_s}{u_*}$$

FRICTION FACTOR

$$\boxed{\frac{u_e}{u_*} = 2\, k\, \Gamma_{mix}\, \frac{1}{Ri_*}}$$

$\Gamma_{mix} \approx 0.0018$ (0.2%)

MIXING IN STRATIFIED FLUID

LET'S TRY A DIFFERENT APPROACH!

MIXING IN STRATIFIED FLUID

TKE BALANCE

$$\frac{DK}{Dt} = Diffusion + P + G - \epsilon$$

$$P + G - \epsilon = 0$$

MIXING EFFICIENCY

$$\gamma_{mix} = -\frac{G}{\epsilon}$$

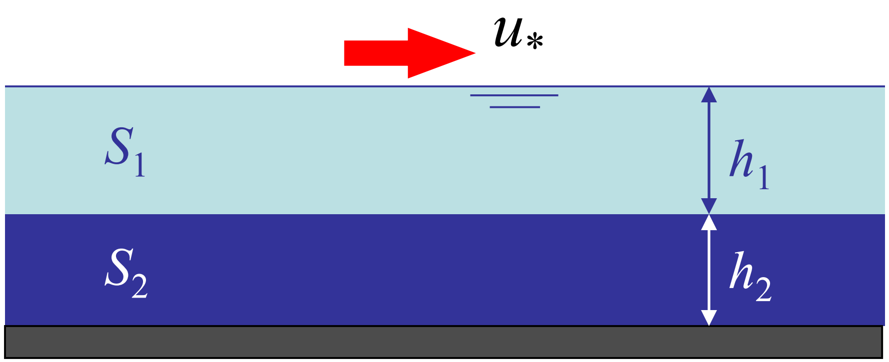
≈ 0.15 (WÜEST & LORKE, 2003)

$$G = D_t \left(\frac{-g}{\overline{\rho}} \frac{\partial \overline{\rho}}{\partial z} \right)$$

TURBULENT DIFFUSIVITY

$$D_t = \frac{\gamma_{mix}\, \epsilon}{N^2}$$

MIXING IN STRATIFIED FLUID



$$\frac{\partial S}{\partial t} = \frac{\partial}{\partial z}\left(D_t \frac{\partial S}{\partial z}\right)$$

$$\frac{\partial (h_1 S_1)}{\partial t} = -\left(D_t \frac{\partial S}{\partial z}\right)_{int} = S_2\, u_e$$

$$(\rho_2 - \rho_0)\, u_e = -D_t \left(\frac{\partial \rho}{\partial z}\right)_{int}$$

$$-\frac{\rho_0}{g} N^2$$

$$\frac{\gamma_{mix}\, \epsilon}{N^2}$$

$$\boxed{\frac{u_e}{u_*} = \gamma_{mix}\, \epsilon^* \frac{1}{Ri_*}}$$

$$\epsilon^* = \frac{\epsilon\, h_1}{u_*^3}$$

VALUE?

MIXING IN STRATIFIED FLUID

K-ε MODEL WITH BUOYANCY EFFECTS

z/H

VELOCITY

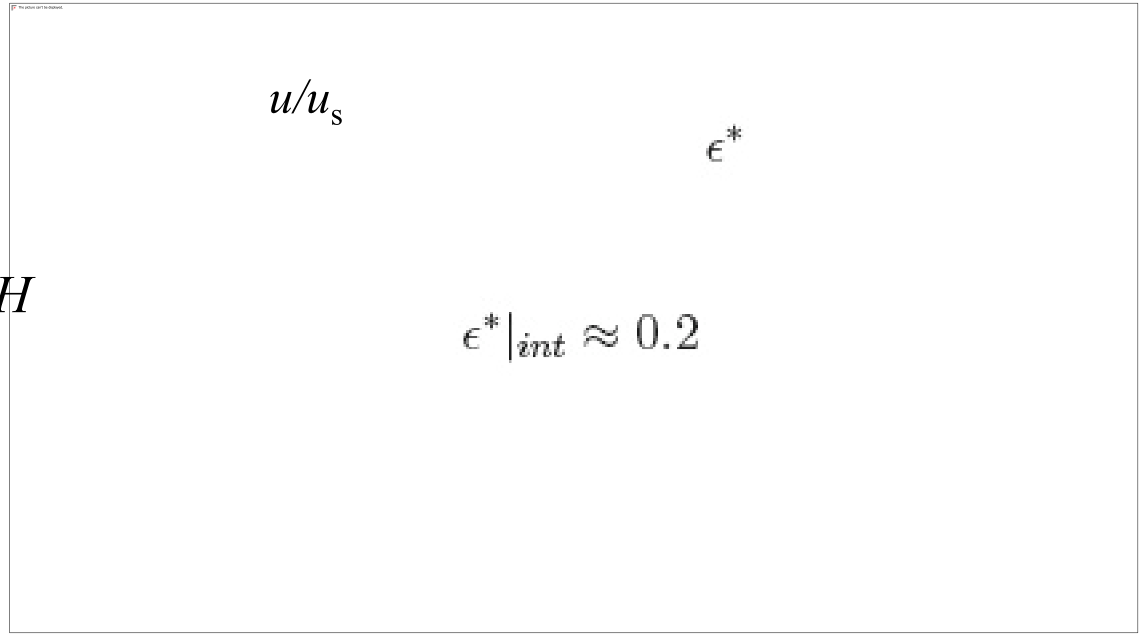
u/u_s

z/H

TKE

K/u_s^2

K-ε MODEL WITH BUOYANCY EFFECTS



$$\frac{u_e}{u_*} = \gamma_{mix}\,\epsilon^*\,\frac{1}{Ri_*}$$

$$\gamma_{mix}\,\epsilon^*|_{int} \approx 0.03 < 0.07$$

MIXING IN LAKE BUDI

MIXING IN LAKE BUDI

ENTRAINMENT VELOCITY

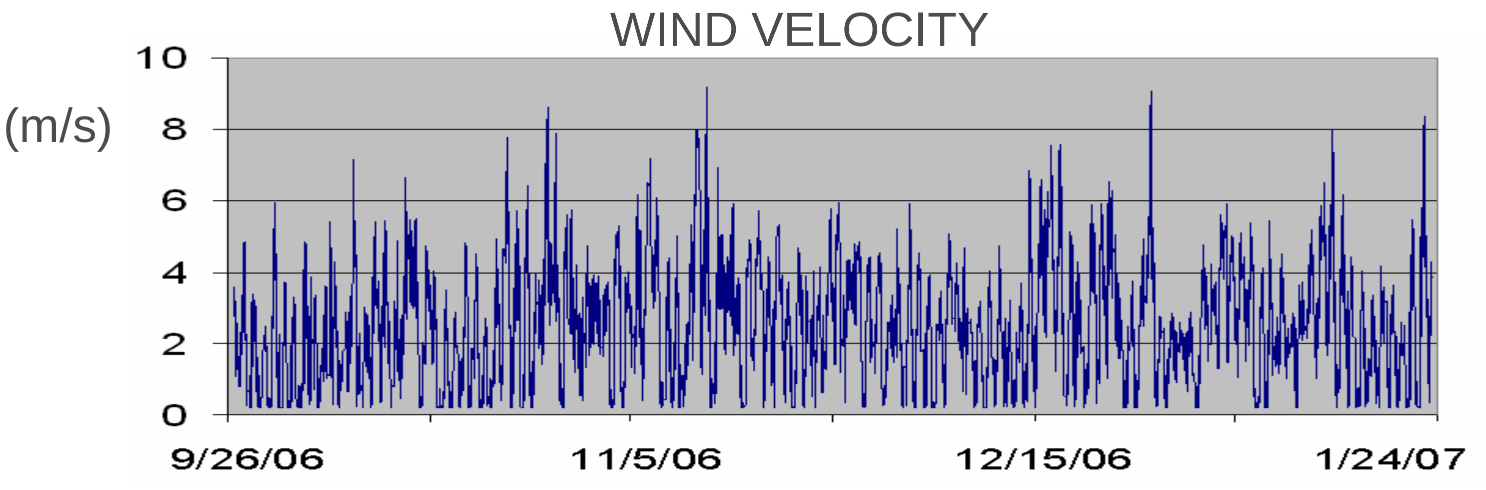
The picture can't be displayed.

z/H

S (pss)

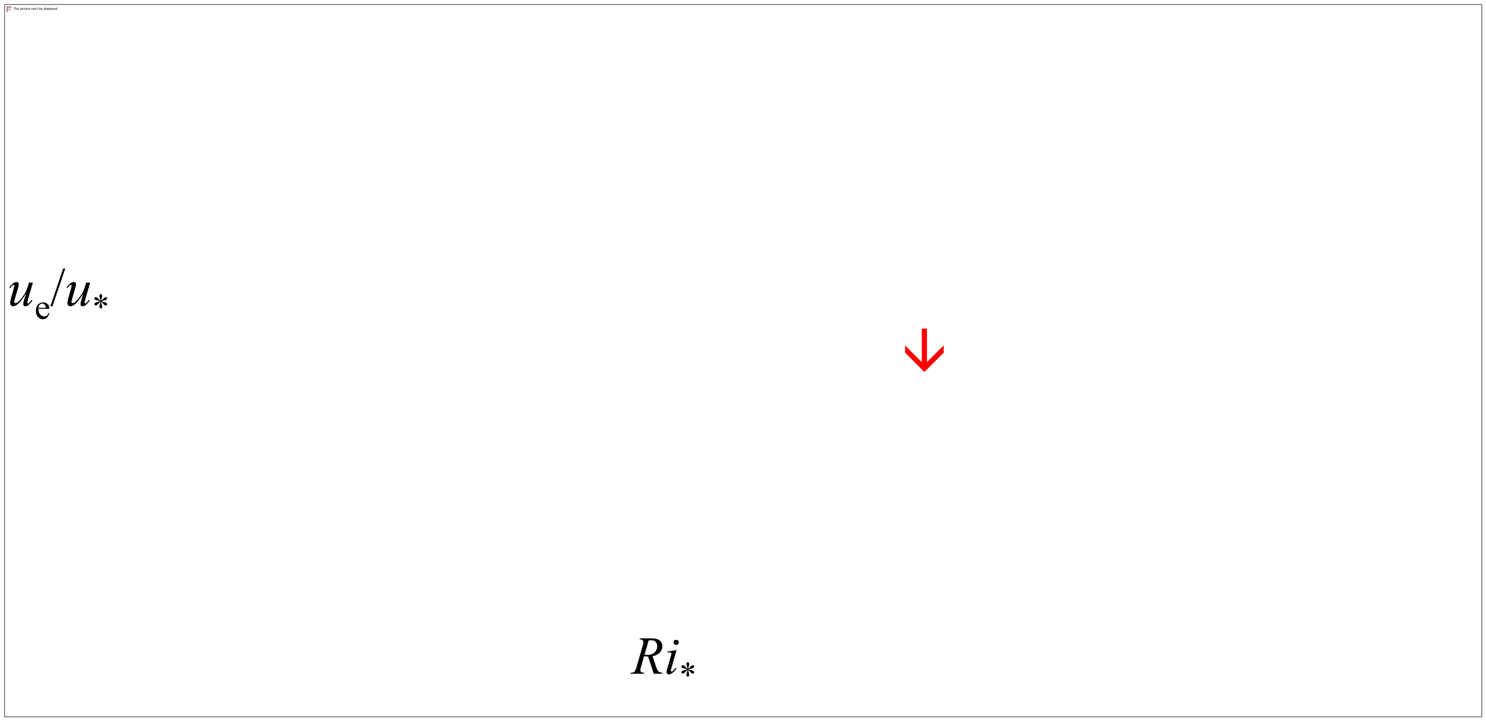
MIXING IN LAKE BUDI

ENTRAINMENT VELOCITY

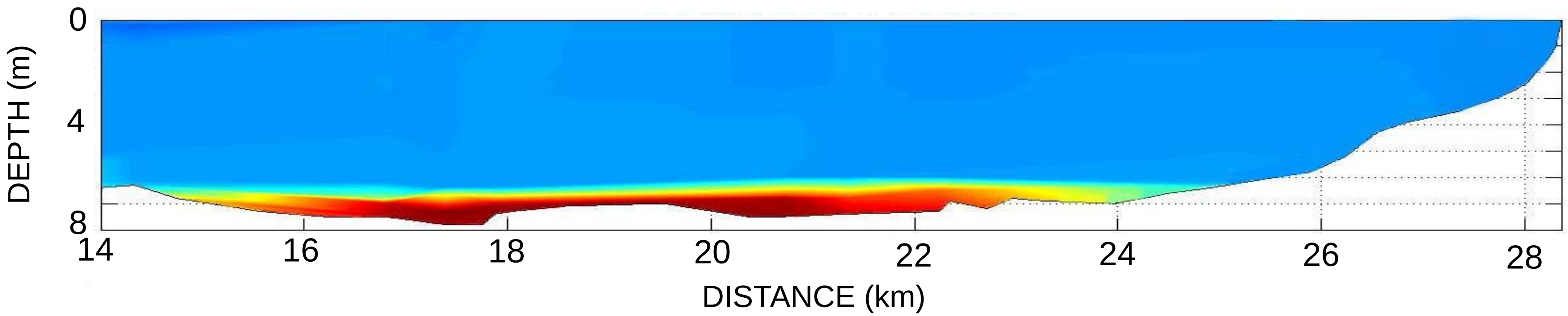


→ $u_e/u_* \approx 2\times10^{-5}$ $Ri_* \approx 2.2\times10^{4}$

MIXING IN LAKE BUDI



MIXING IN LAKE BUDI



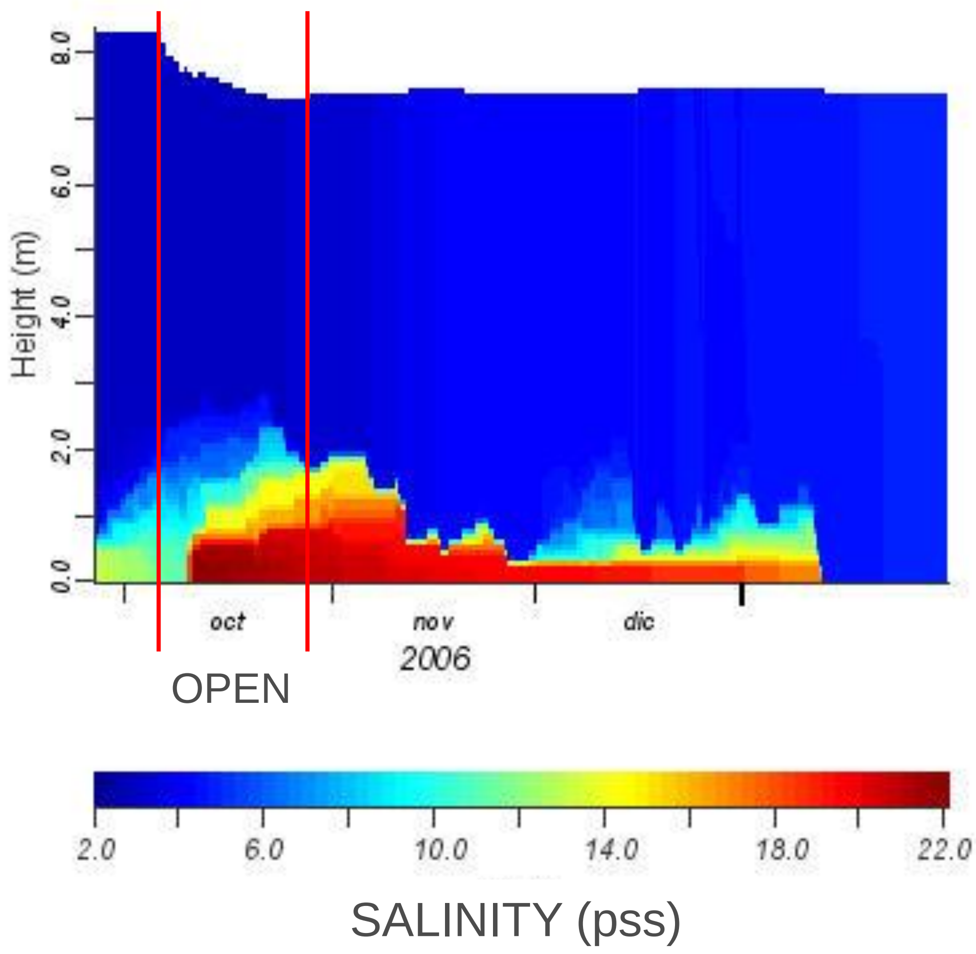
MIXING DUE TO BENTHIC BOUNDARY LAYER TURBULENCE

$$\epsilon^* \approx O(\frac{1}{\kappa}) \sim 2.5$$

SIMULATION OF LAKE BUDI HYDRODYNAMICS

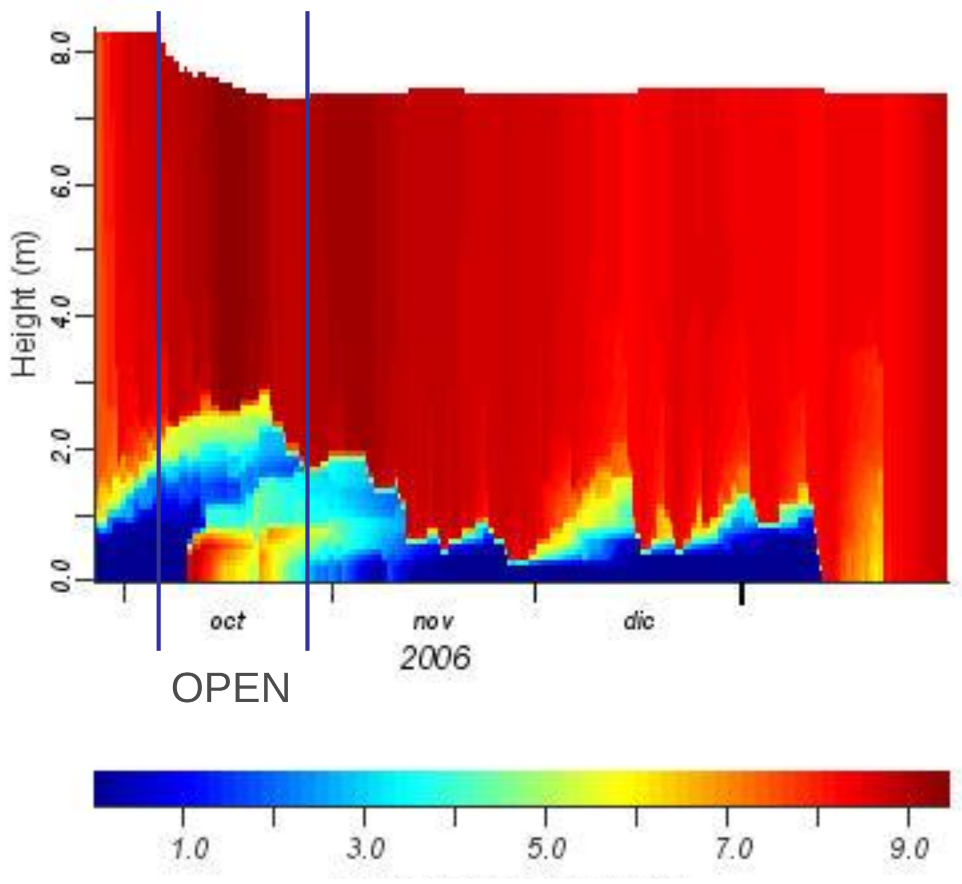
SIMULATION OF LAKE BUDI HYDRODYNAMICS

MODELING SALINITY INTRUSION AND MIXING



SIMULATION OF LAKE BUDI HYDRODYNAMICS

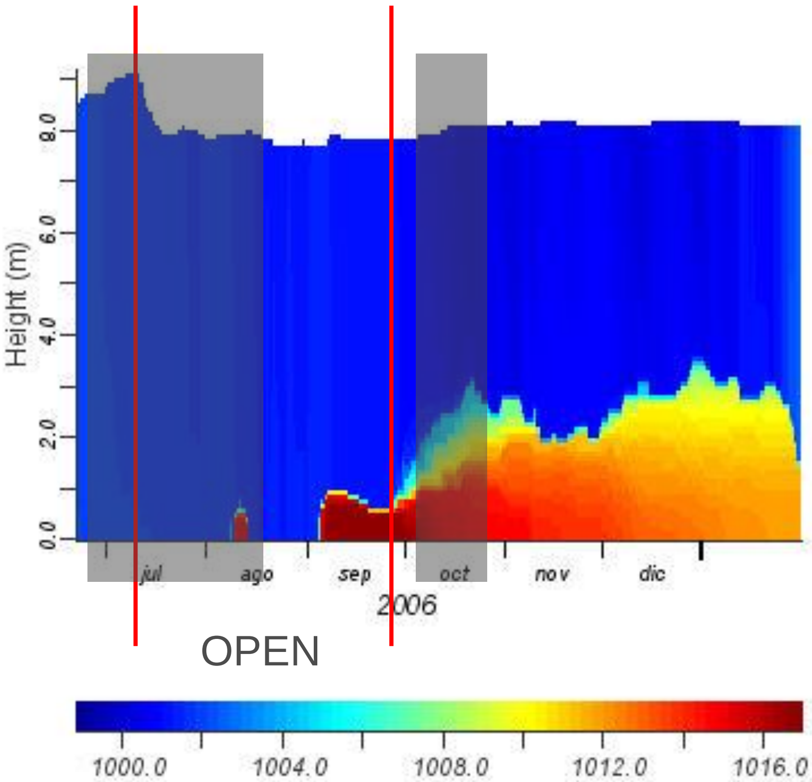
MODELING DISSOLVED OXYGEN CONCENTRATION



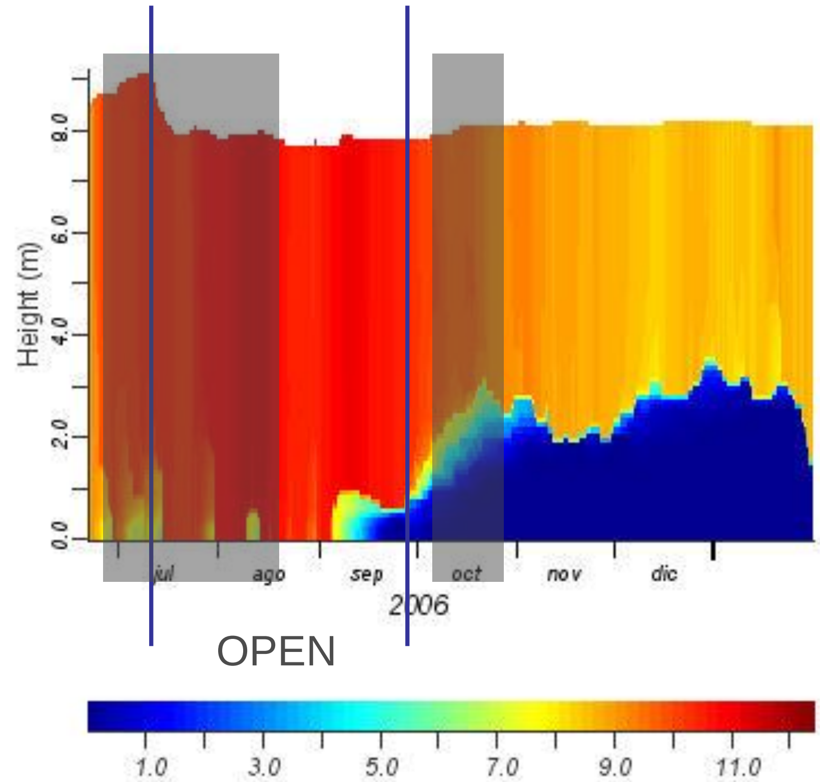
DISSOLVED OXYGEN CONCENTRATION (mg/l)

SIMULATION OF LAKE BUDI HYDRODYNAMICS

PREDICTION IN THE CASE OF NATURAL MOUTH BAR OPENING



DENSITY (kg/m^3)



DISSOLVED OXYGEN CONCENTRATION

FINAL REMARKS

➔ PRESENT MOUTH BAR MANAGEMENT WOULD NOT BE COMPATIBLE WITH FISH ECOLOGICAL DYNAMICS

➔ BETTER PRACTICE MUST COMPATIBILIZE FLOODING PROTECTION, WATER QUALITY, LAKE ECOLOGY, AND LOCAL COMMUNITIES WELFARE

➔ RESEARCH IS FUN BUT IS MORE FUN WHEN IT IS PUT AT THE SERVICE OF PROTECTING AND IMPROVING SOCIAL AND ENVIRONMENTAL CONDITIONS

THANKS TO:

FELIPE SANDOVAL
CLAUDIA RODRIGUEZ
MANUEL CONTRERAS

MIXING IN LAKE BUDI

TURBULENT INTENSITY PARAMETER (IVEY ET AL., 2008)

$$I = \frac{\epsilon}{\nu N^2}$$

$$I = \frac{\epsilon}{\nu N^2} = \epsilon^* \frac{Re_*}{Ri_*} \frac{L_i}{h_1}$$

$$Re_* = \frac{u_* h_1}{\nu}$$

$$L_i = \frac{\Delta\rho}{-(d\rho/dz)}$$

LAKE BUDI

$Re_* \approx 3\times10^4$

$Ri_* \approx 2\times10^4$ → $I \approx 0.15$

$L_i/h_1 \approx 0.2$

EXPERIMENTS NIÑO ET AL. (2003): $I \approx$ 1-15

WUEST & LORKE (2005): $I \approx$ O(1) AT LAKES THERMOCLINE

MIXING IN LAKE BUDI

TURBULENT INTENSITY PARAMETER (IVEY ET AL., 2008)

$$I = \frac{\epsilon}{\nu N^2}$$

I RANGE	REGIME
I < 7	MOLECULAR
7< I < 100	TRANSITIONAL
I > 100	ENERGETIC

CHECK!

MIXING DUE TO BENTHIC BOUNDARY LAYER TURBULENCE

$$\epsilon^* \approx O(\frac{1}{\kappa}) \sim 2.5$$