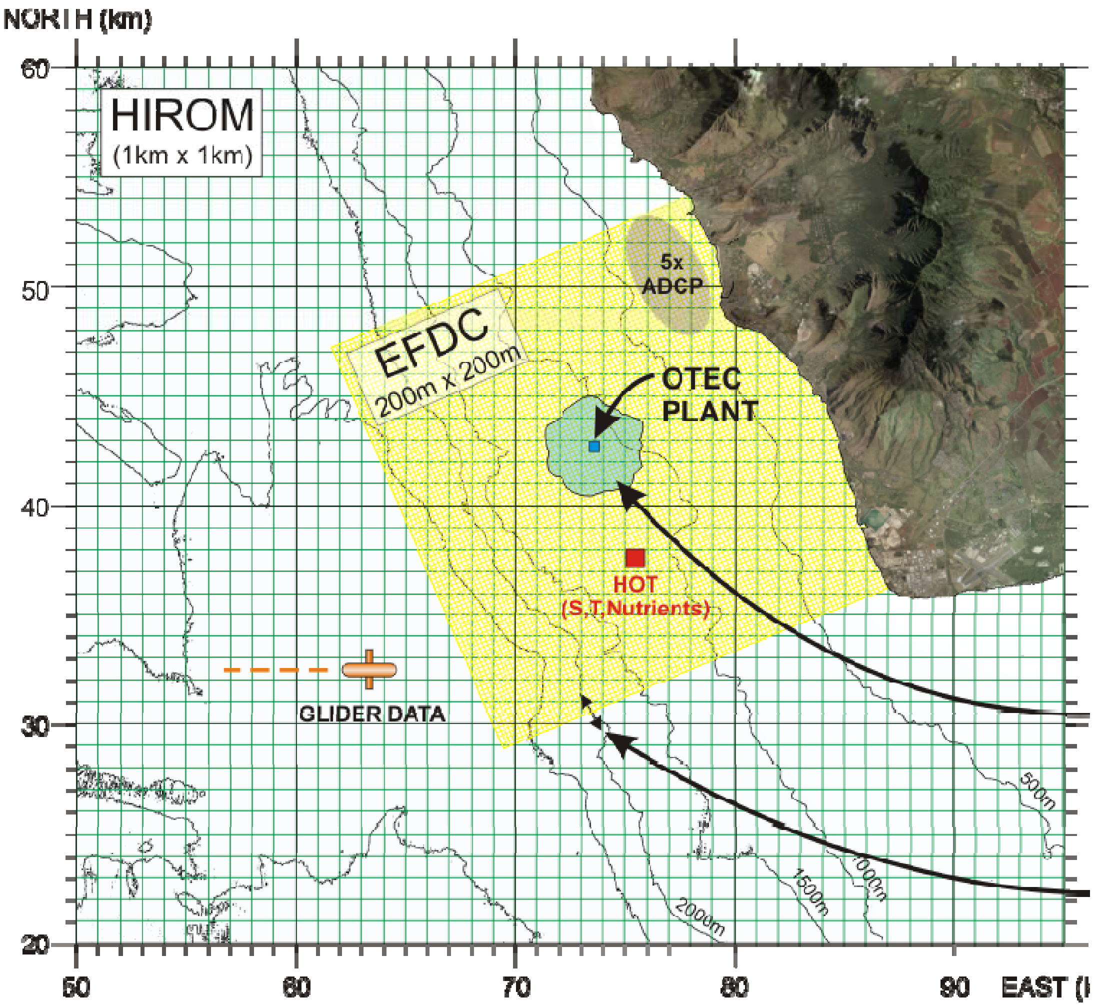
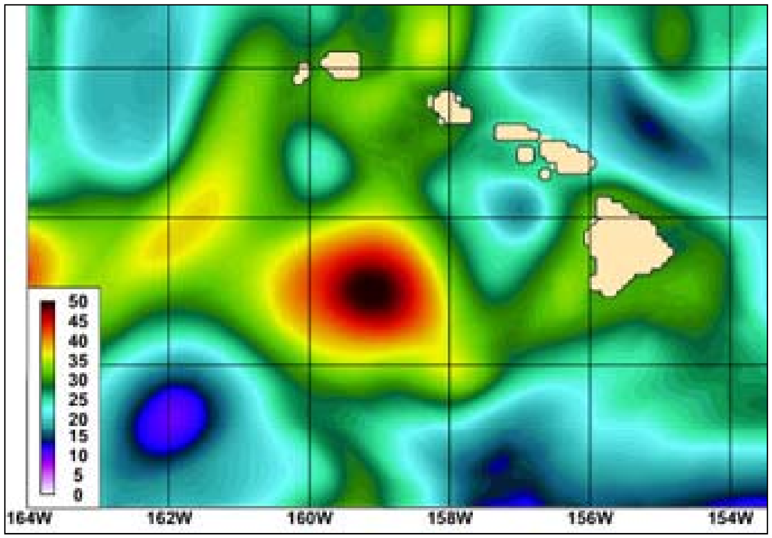
NOAA OTEC Environmental Workshop, June 2010

OTEC Plumes





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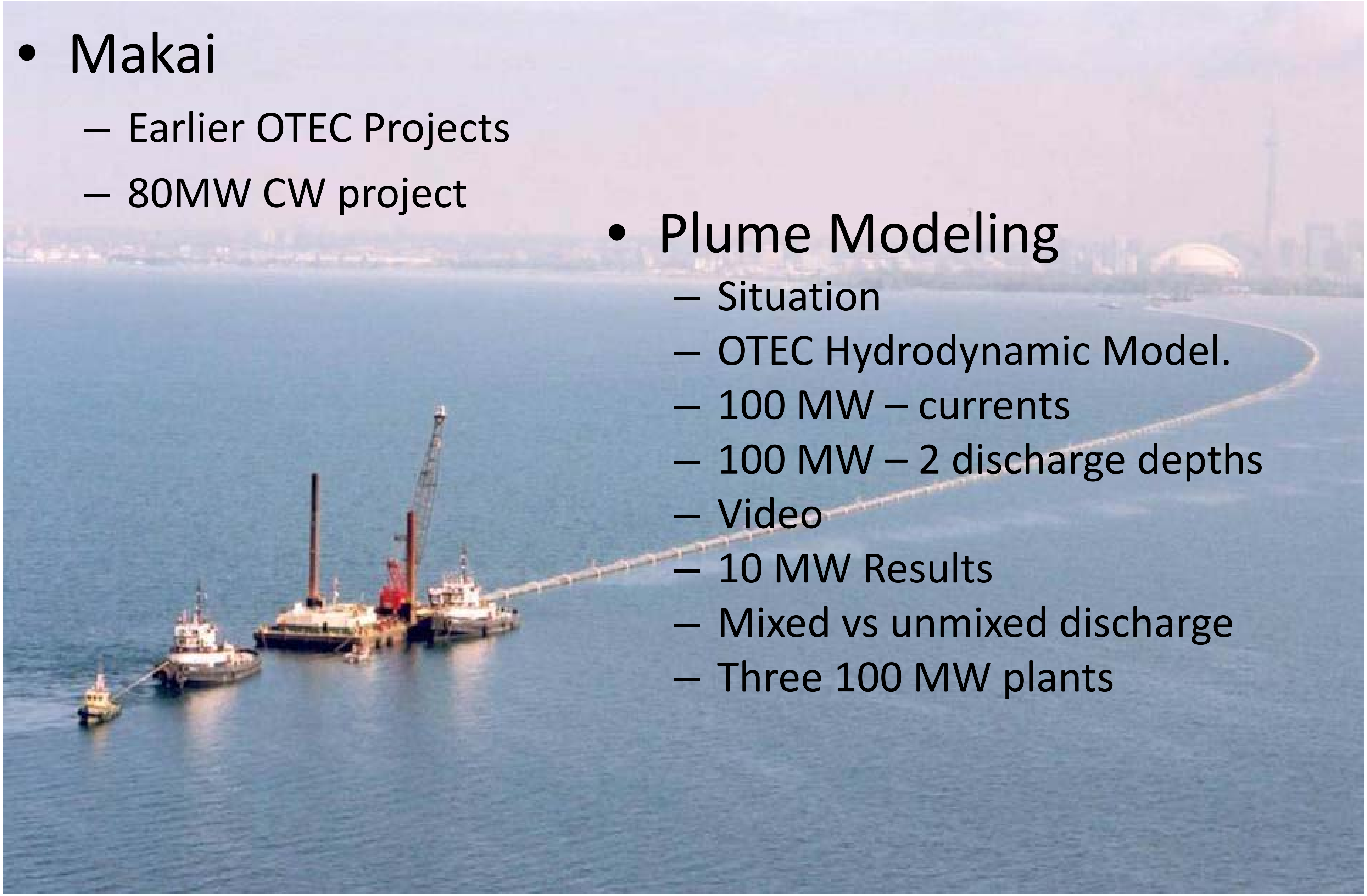
Next Few Minutes



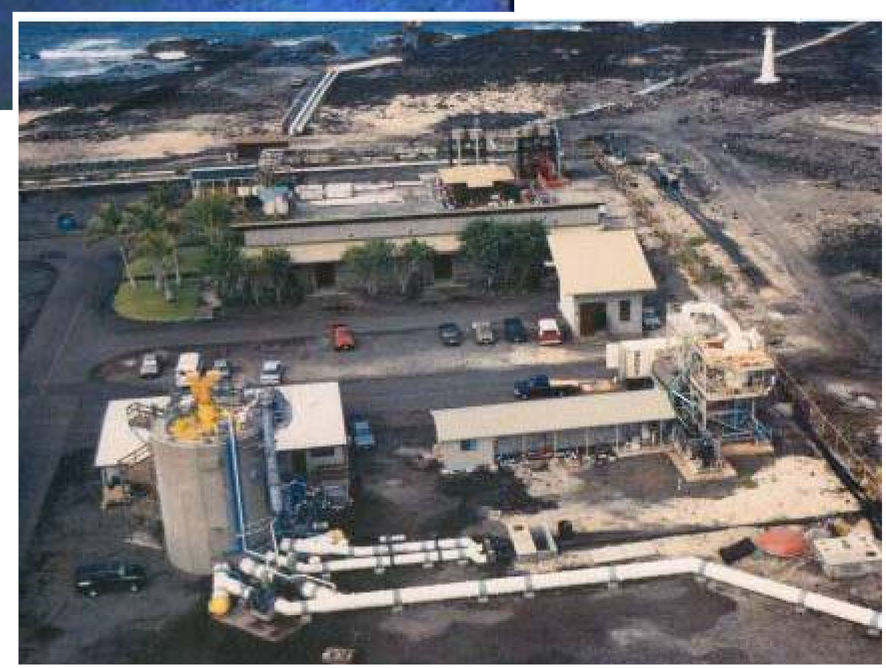
- Makai
  - Earlier OTEC Projects
  - 80MW CW project
- Plume Modeling
  - Situation
  - OTEC Hydrodynamic Model.
  - 100 MW – currents
  - 100 MW – 2 discharge depths
  - Video
  - 10 MW Results
  - Mixed vs unmixed discharge
  - Three 100 MW plants

Makai Ocean Engineering - 1973

Mini-OTEC
1978

- Subsea Pipes & Subsea Software
- Mini-OTEC Pipe, Mooring & layout
- Four pipes at NELHA
- Other Studies
- ONR 2005 -> Today
- Another CW project - during question time

NELHA 55” Pipe
2001



250 kW OTEC
1993-1998

OTEC Plume Model

– Ongoing development funded by CEROS

Regional Modeling Studies of 100MW Capacity OTEC Thermal Plumes off West Oahu

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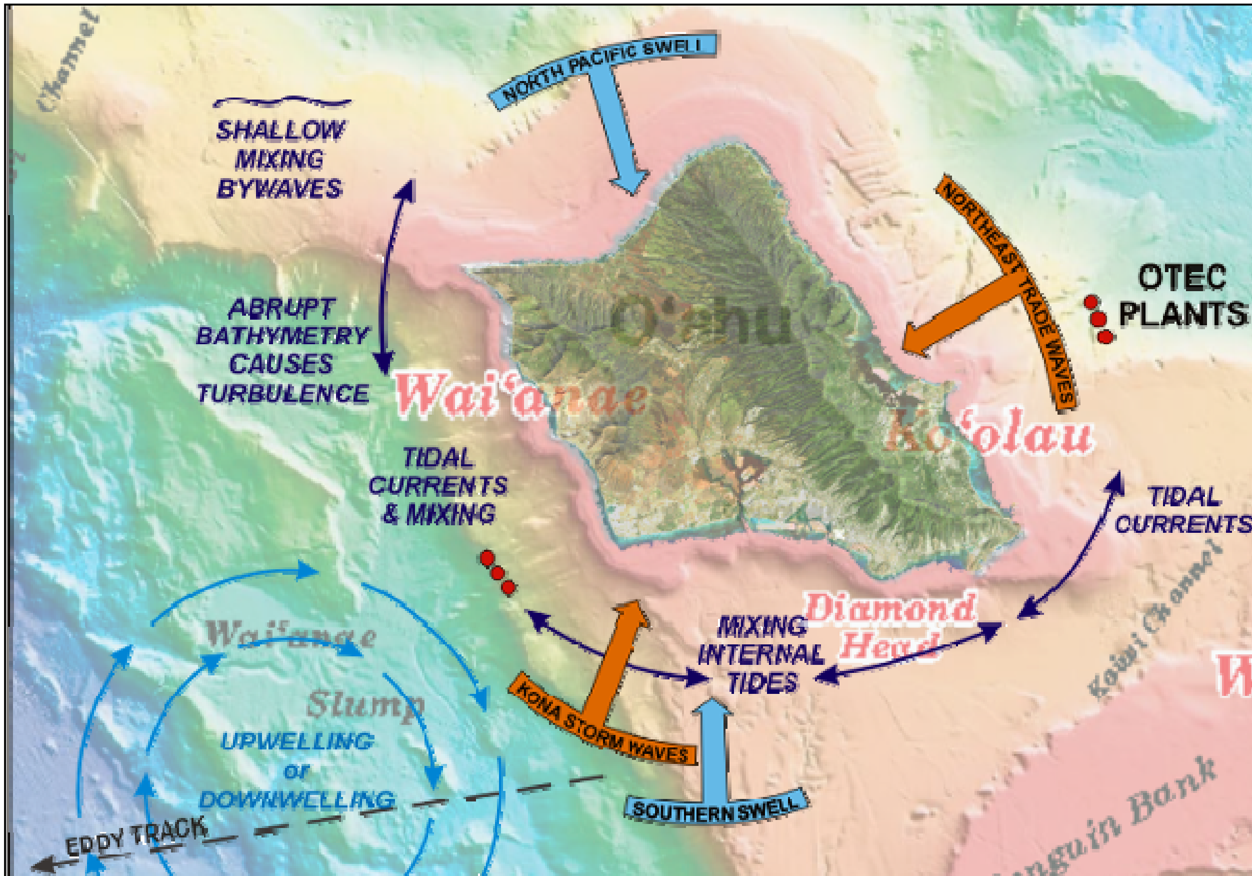
CEROS

DARPA



This effort is sponsored by the Defense Advanced Research Projects Agency and the National Defense Center of Excellence for Research in Ocean Sciences. Content of the information does not necessarily reflect the position or the policy of the Federal Government or the State of Hawaii. No official endorsement should be inferred.

OTEC Design Overview:

What arrangement of:

- Temperature
- Intake depth & velocity
- Discharge depth & and velocity

can be operated in a sustainable manner?

Sustainability = No thermal resource degradation
Sustainability = No adverse nutrient redistribution

Major Flows

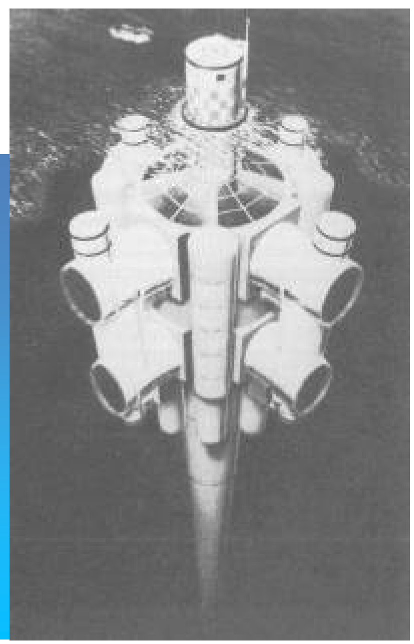
One 100 MW plant:

400 m^3 /sec Warm SW

320 m^3 /sec Deep SW

1000 MW:

2/3 of cubic km per day

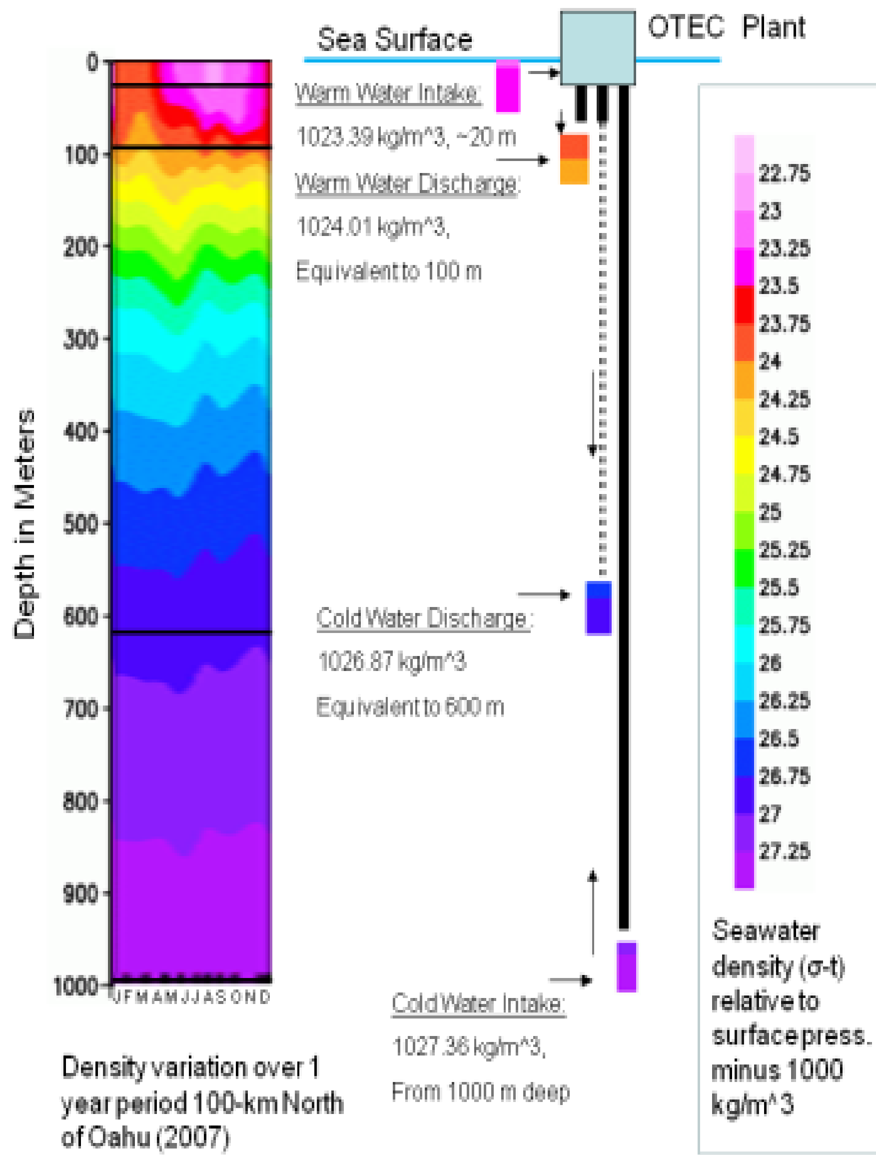


Lockheed Spar 1975

Density of OTEC Intake & Discharge Seawater

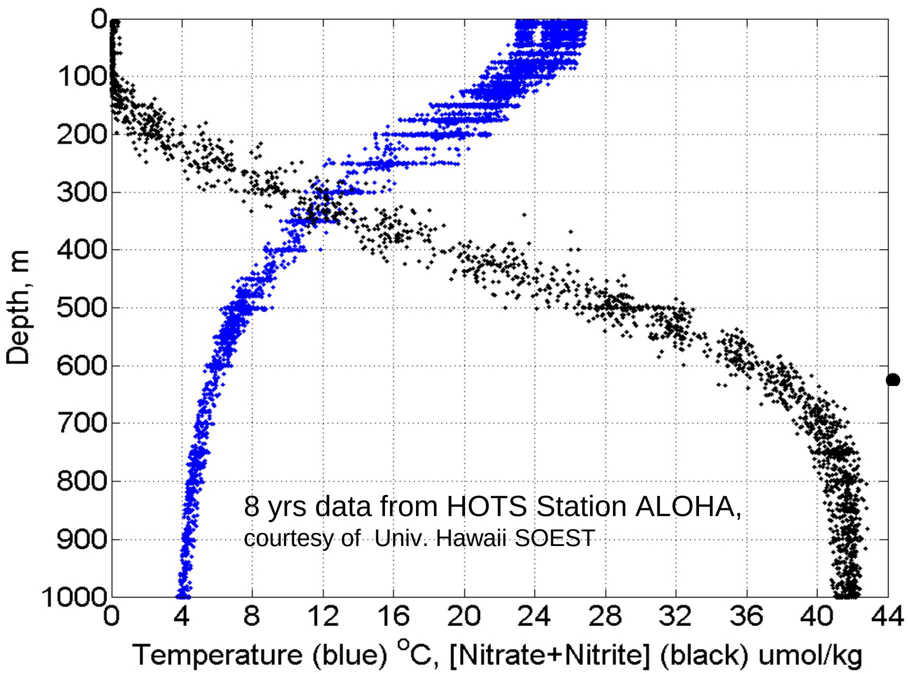
Warm intake water is cooled, becomes more dense.

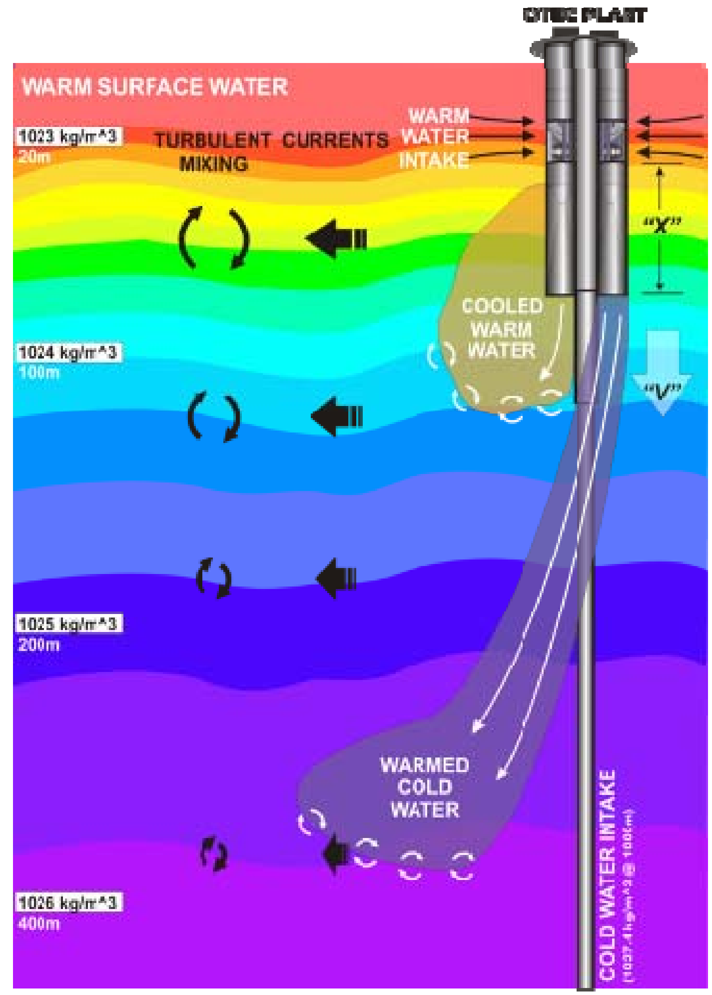
Cold deep intake water is warmed, becomes less dense.



Otec Hydrodynamic Model

- Sophisticated model: Discharge plume, intake flow, geometry, density, & mixing
- Nest the OTEC model inside the dynamic OOS-developed Hawaii Regional Ocean Model

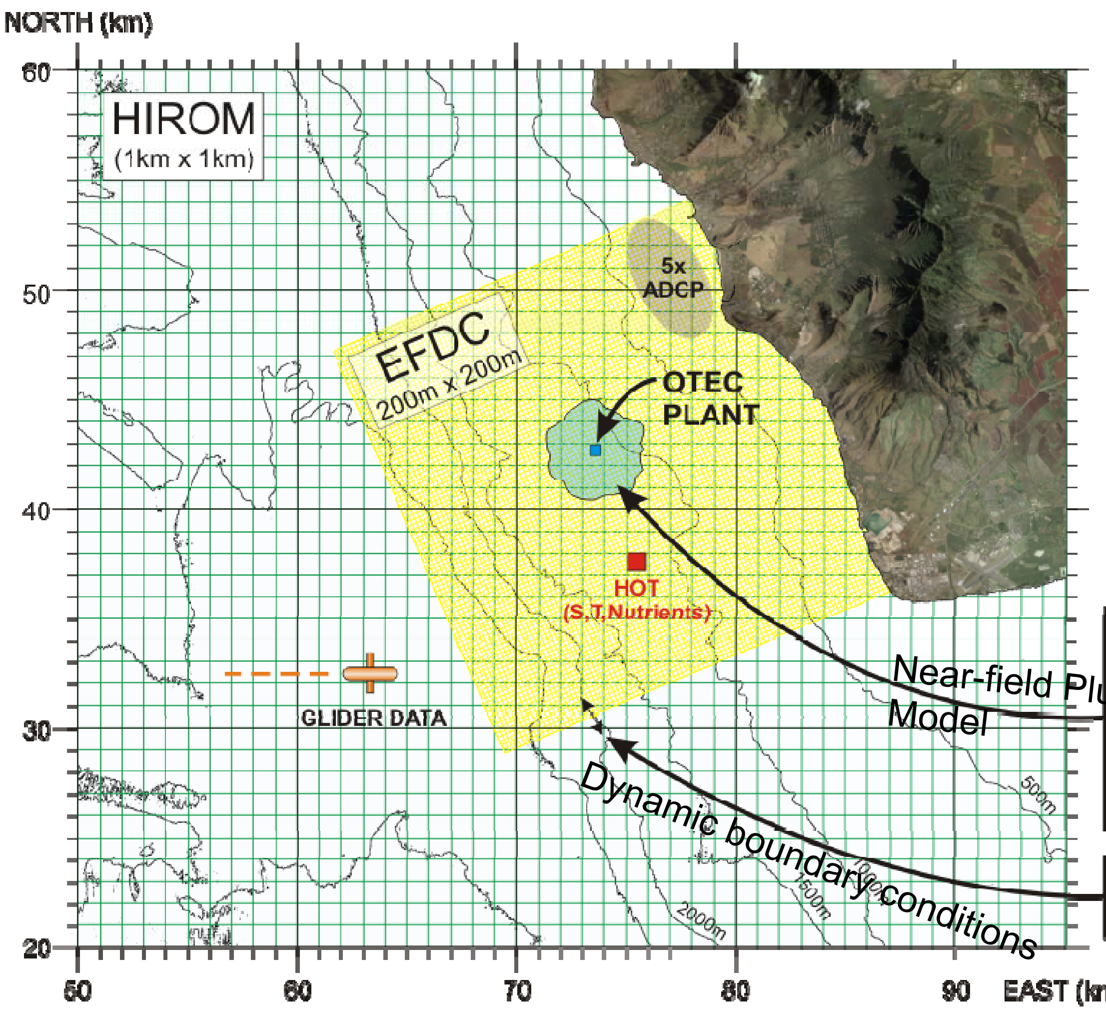


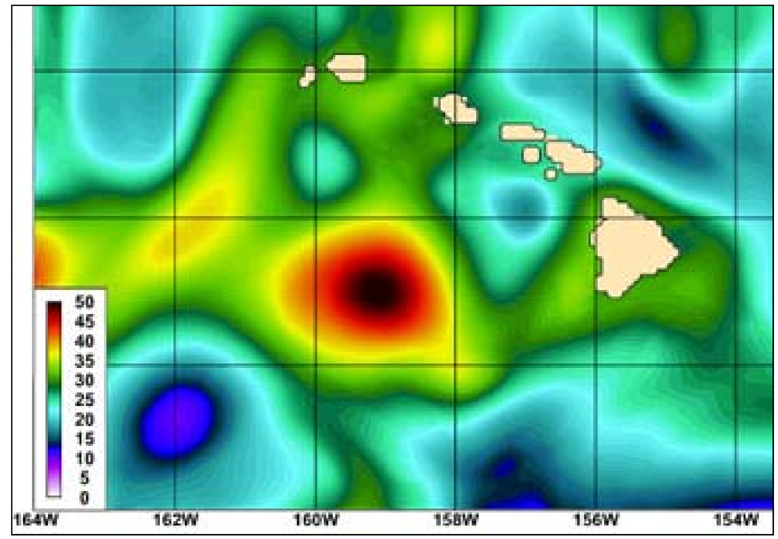


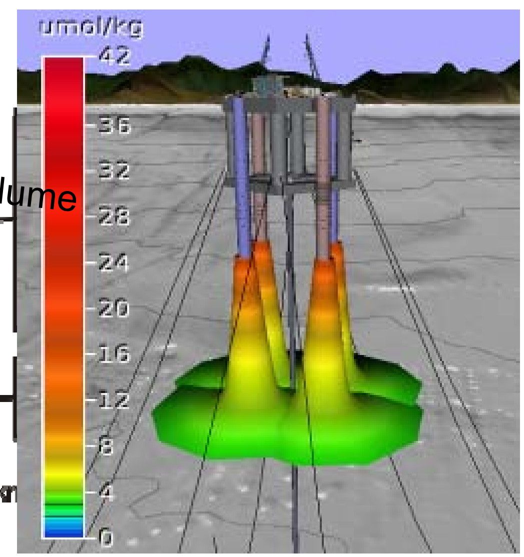
- Use to define the plant(s) geometry, power & spacing for sustainable & economic operation.
  – Nitrate is limiting nutrient in the photic zone, high levels may cause algal blooms
  – Need 40:1 to 20:1 dilution of deep water to reach ambient levels at 100-200m deep

OTEC Plume Modeling Technique

•Nested within University of Hawaii Regional Ocean Model (HiROM)
•EFDC domain forced with Temperature, Salinity, U,V, and $Z_{surface}$
•Coupled with near-field plume model

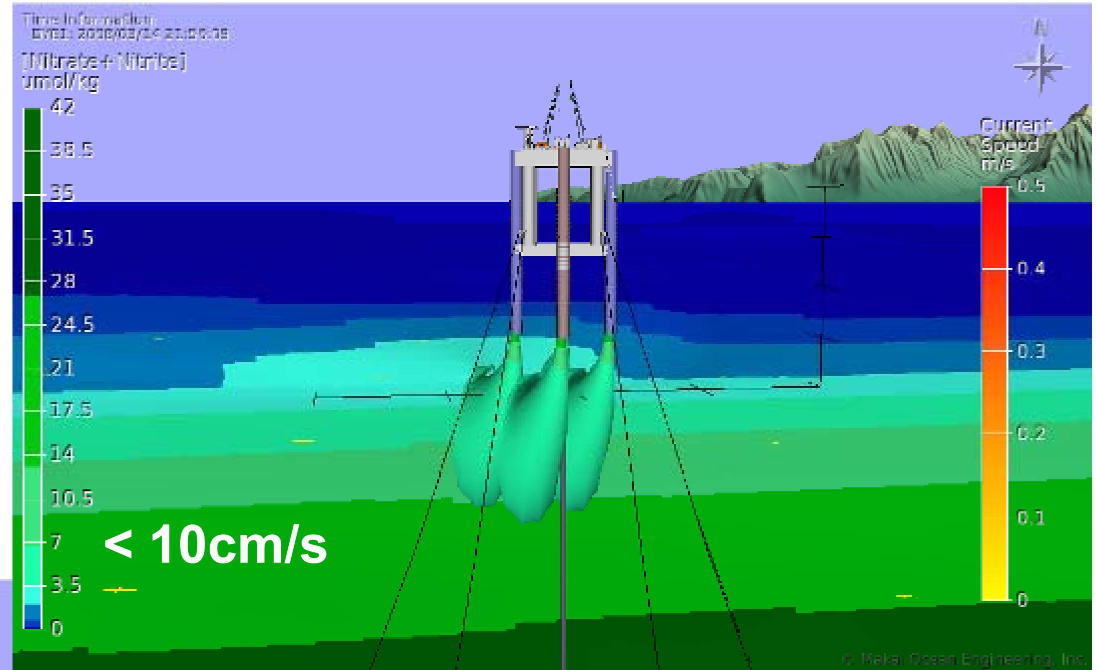


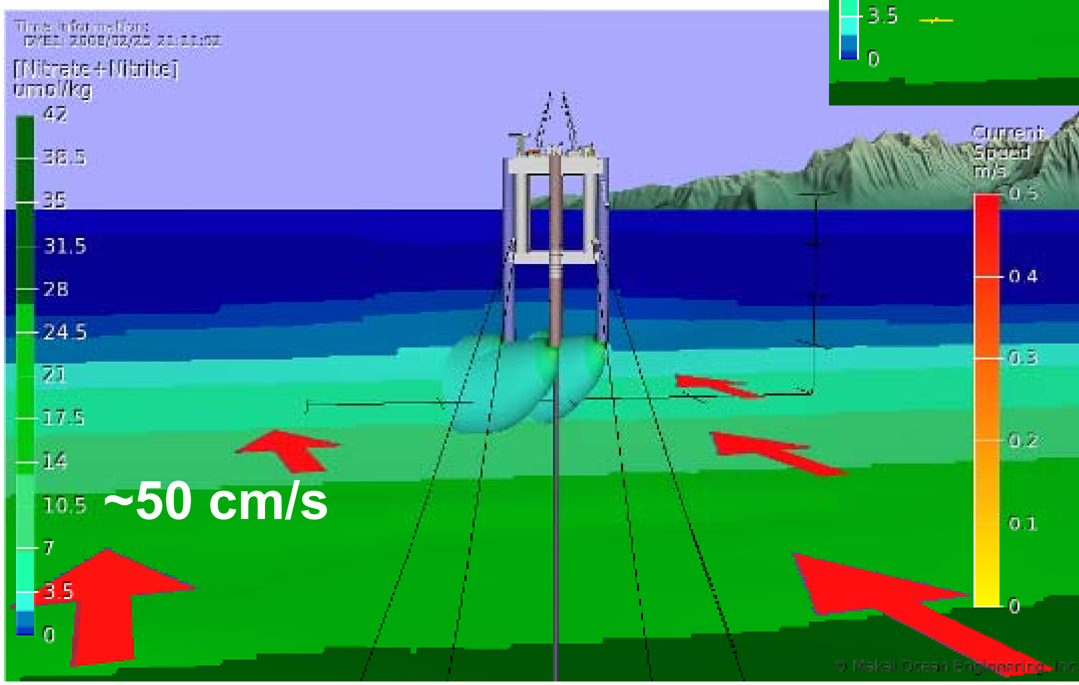




Effects of Current on Near-Field Plume

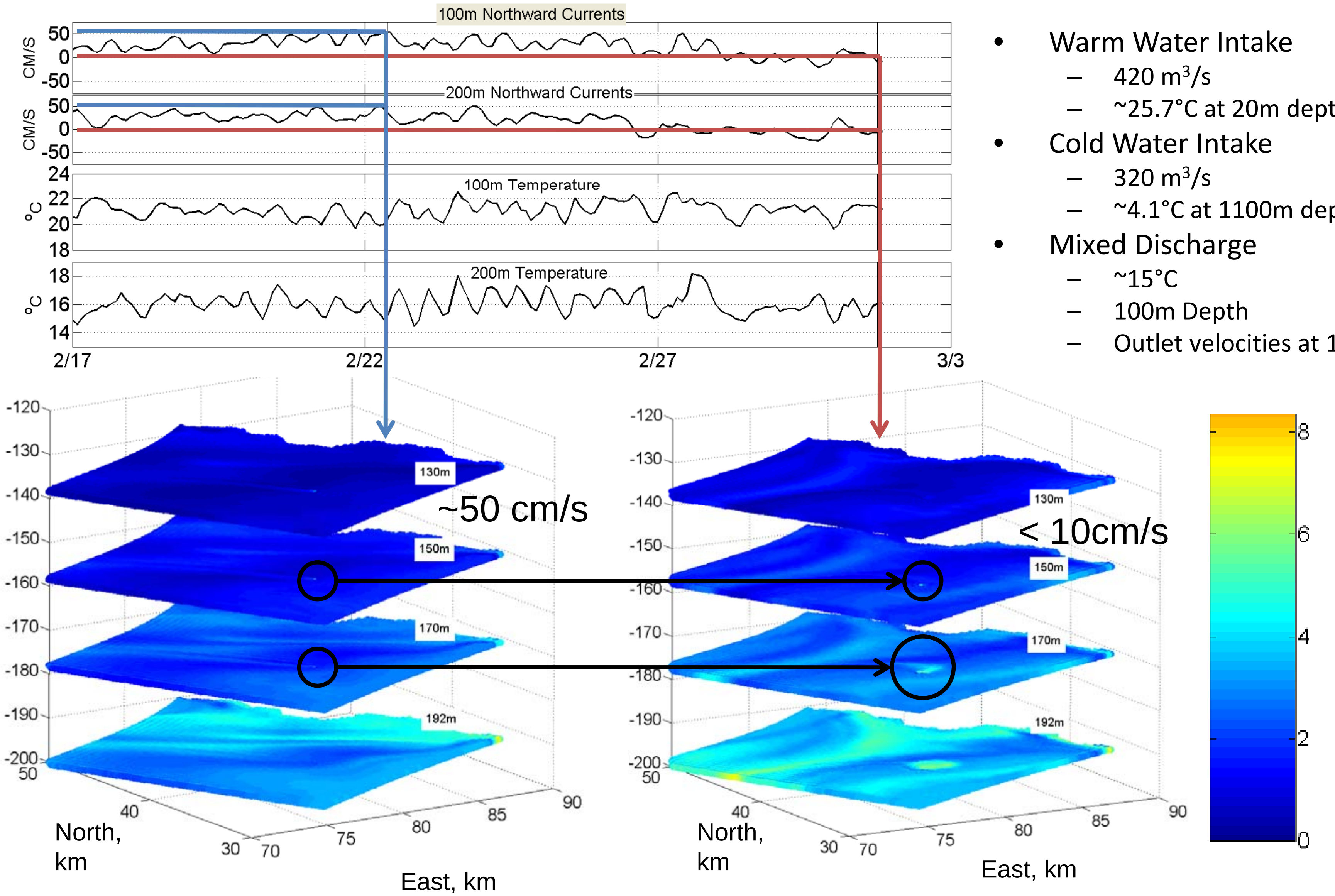
- Increases in current strength (0-70cm/s) cause a significant increase in the mixing and entrainment of near-field plumes, resulting in shallower terminal depths with a greater dilution





- Warm Water Intake
  - 420 m^3/s
  - ~25.7°C at 20m depth
- Cold Water Intake
  - 320 m^3/s
  - ~4.1°C at 1100m depth
- Mixed Discharge
  - ~15°C
  - 100m Depth
  - Outlet velocities at 1m/s

Effects of Current on Far-Field Plume: Shallow, narrow, and diluted vs. deep, wide, and concentrated



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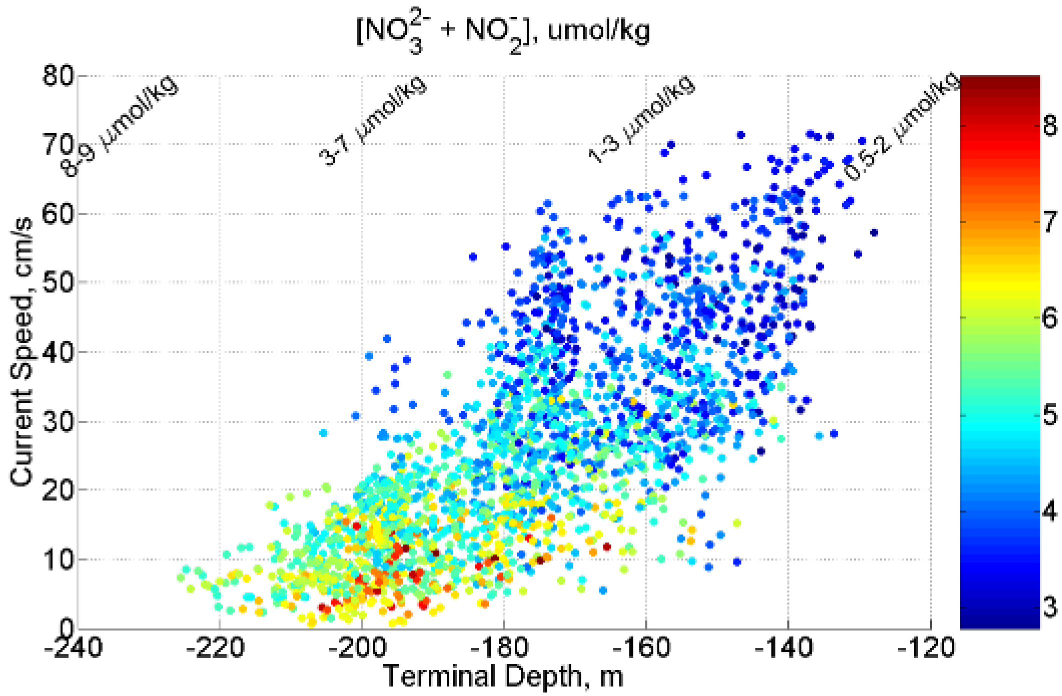
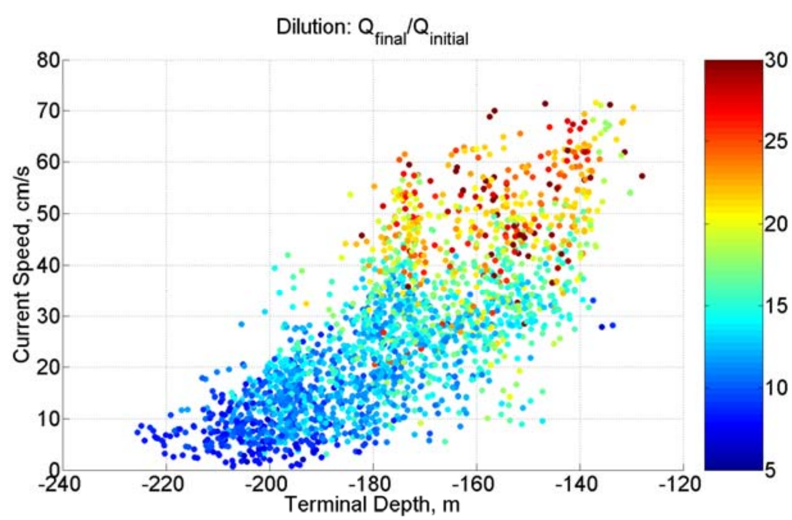
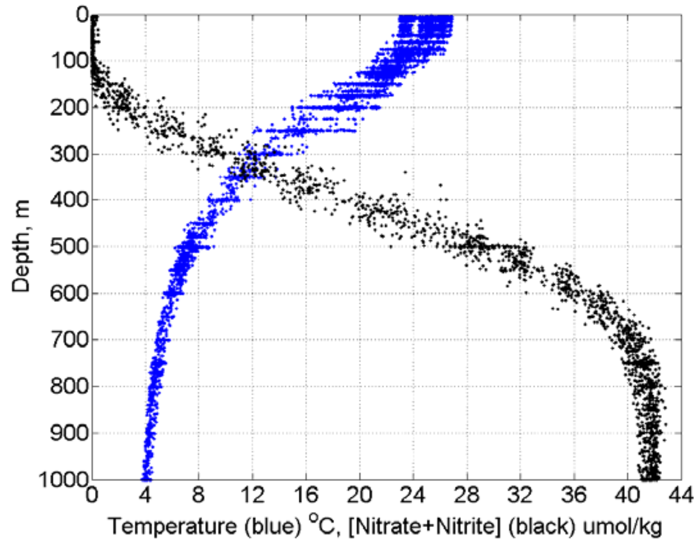




Results: Nutrients from 100MW Plant (w/ mixed discharge)



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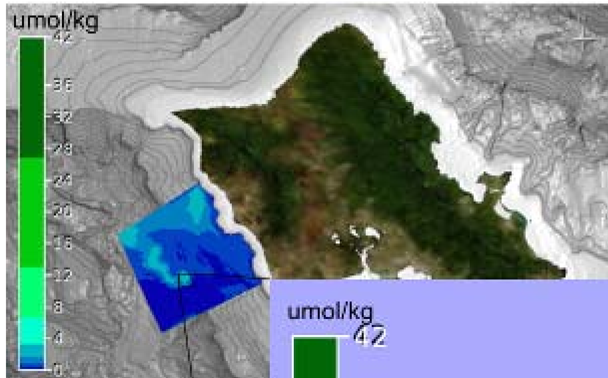
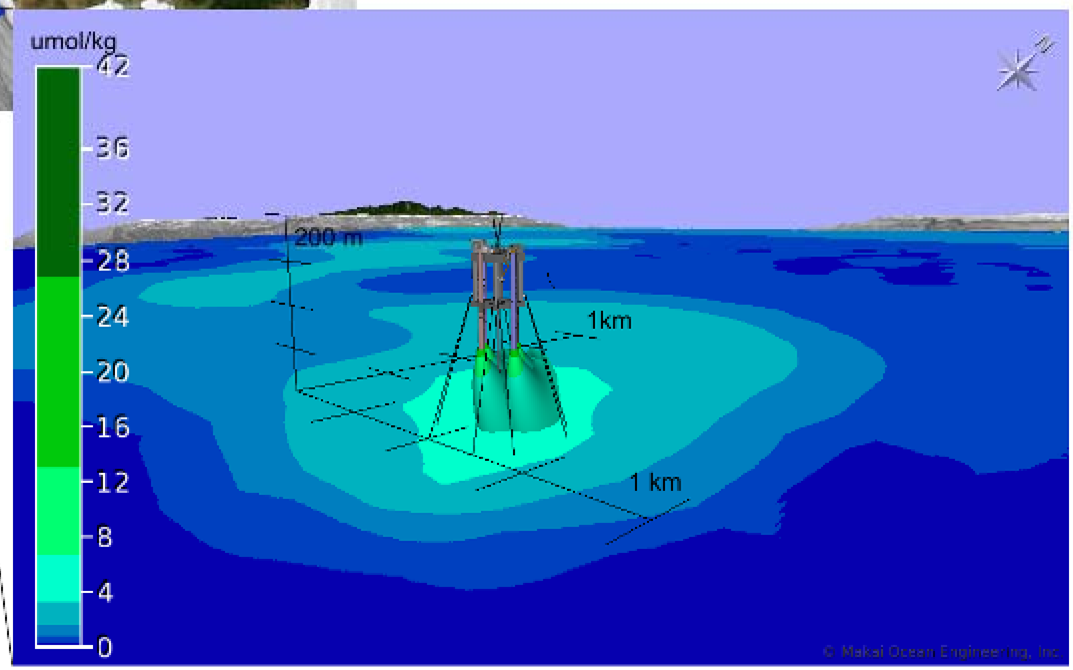


•Plumes sink and mix, finding a neutral buoyancy at 150m, well below the mixed layer depth.

•Plumes spread out horizontally at their equilibrium depth, remaining within a constant density layer.

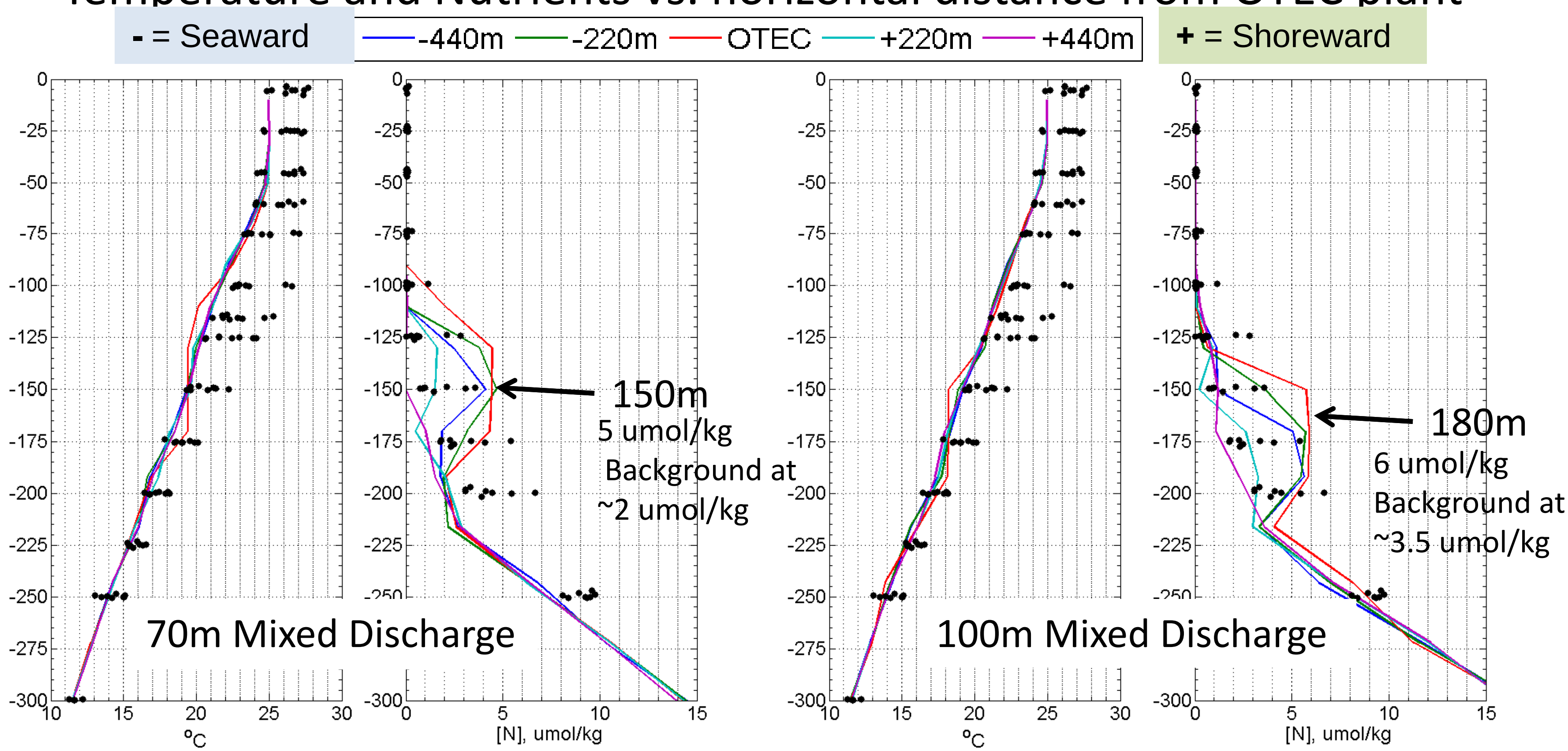


Slice taken at 150m. Day 7. 100MW-70m mixed discharge.

Horizontal Slice at 150m Showing [Nitrate+Nitrite]

Results: 70m vs. 100m Deep Mixed Discharge

Temperature and Nutrients vs. horizontal distance from OTEC plant



Summary of Embedded Plume Model Results

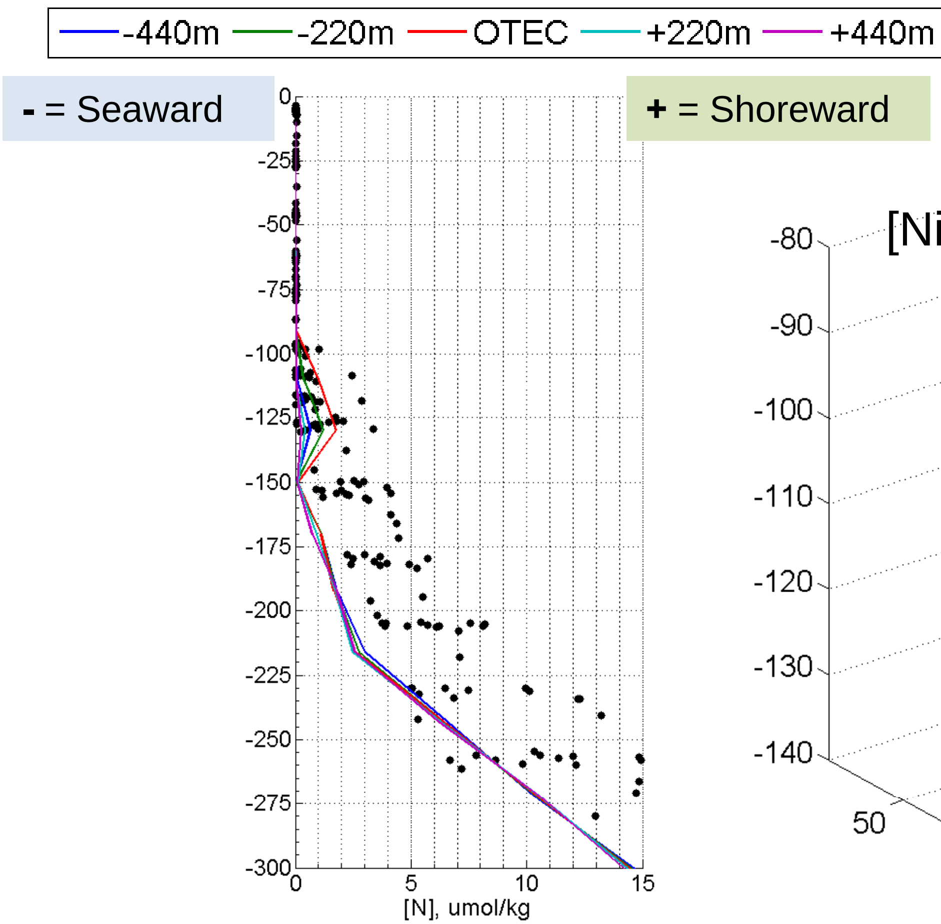
Discharge Depth (m)	Discharge Radius (m)	Discharge Velocity (m/s)	Entrainment (Qf/Qi)	Equilibrium Depth (m)	Final Plume $[NO_3+NO_2]$ (umol/kg)	Typical $[NO_3+NO_2]$ (umol/kg)
70	15.35	1	9.5	**150**	5.1	2.2
105	15.35	1	8.8	**186**	6.2	3.7

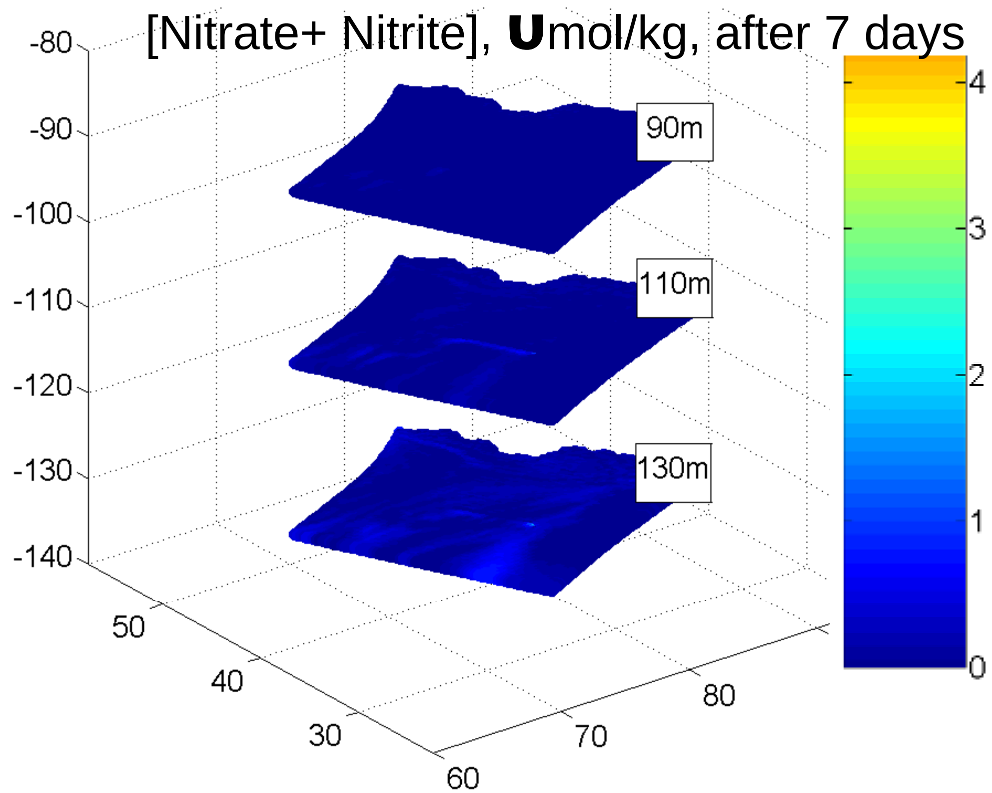
Movie

10 MW Pilot Plant: Mixed Discharge

Equilibrium Depth	130m
Terminal Nitrate	~2.2 Mmol/kg
(ambient Nitrate)	~0-3Mmol/kg
Entrainment (Qf/Qi)	16.5

- Warm Water Intake
  - ~25.7°C at 20m depth
  - 44.8 m3/s
- Cold Water Intake
  - ~4.1°C at 1100m depth
  - 35.6 m3/s
- Mixed Discharge
  - ~15°C at 70m depth
  - 1 m/s outlet velocity

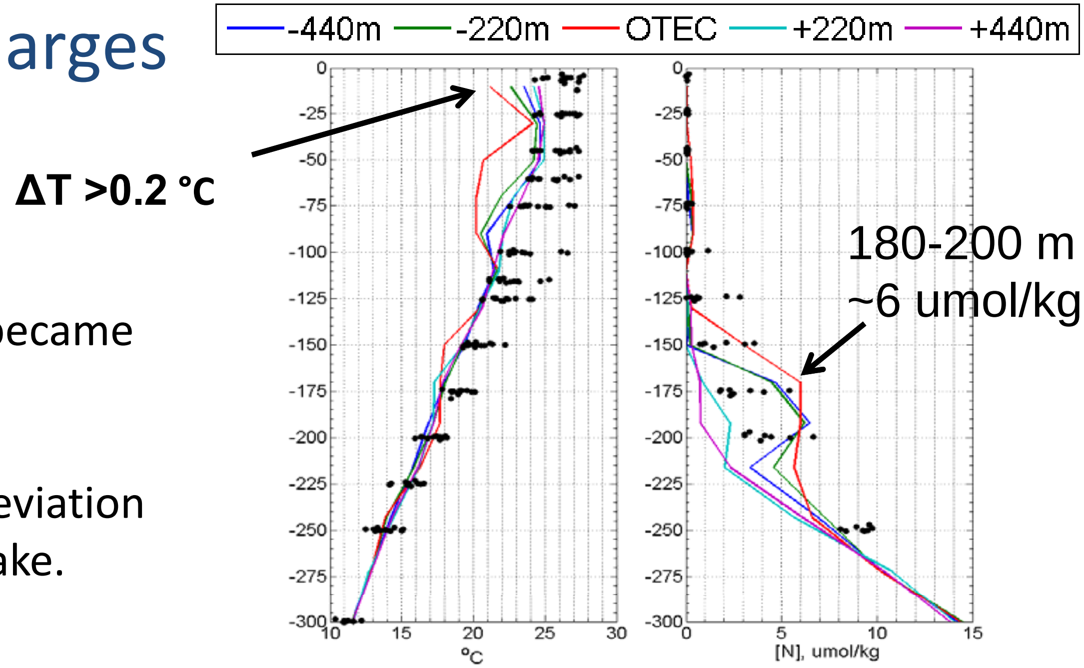


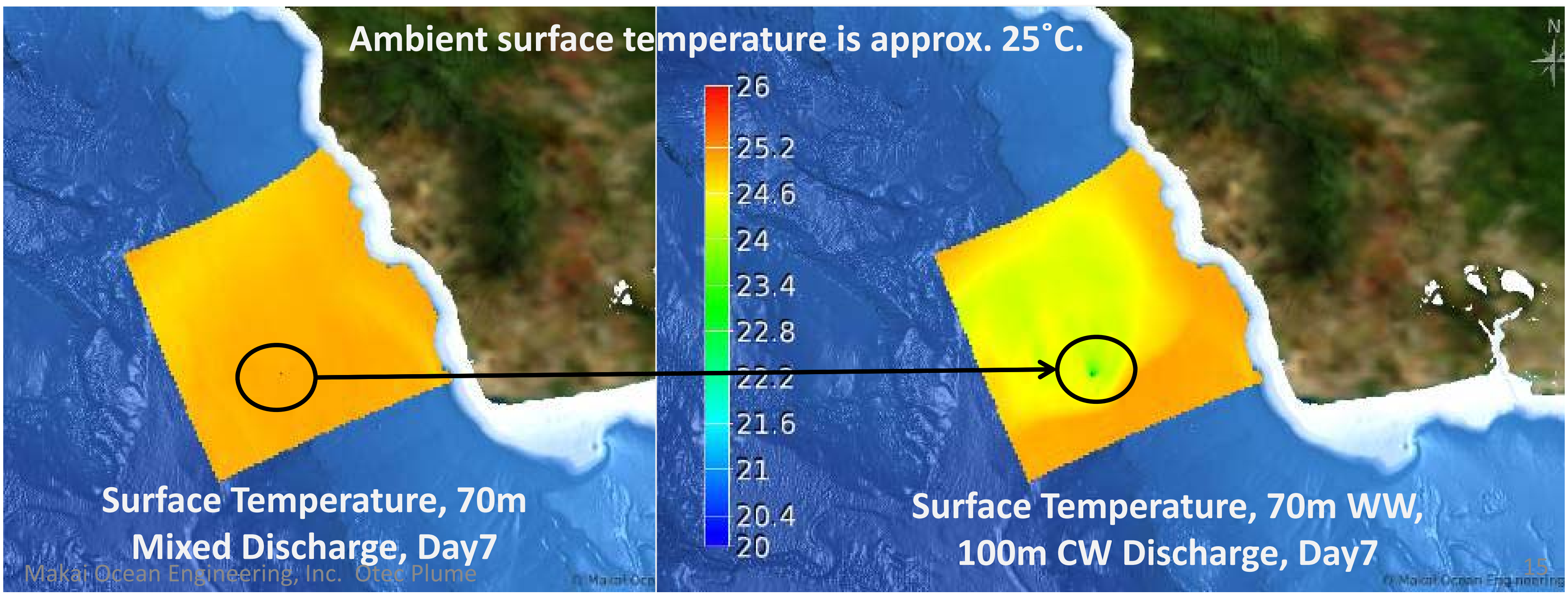


Mixed vs. Separate Discharges

- Cold Water discharge
  - ~7.5 °C at 100m, at 1 m/s
- Warm Water discharge
  - Started ~23.0 °C at 70m, at 1 m/s, became cooler as 7 days passed.

- Unmixed warm discharge: 0.3 °C wide deviation on surface, uneconomic 23°C at WW intake.
- Mixed discharge: No discernible effect.

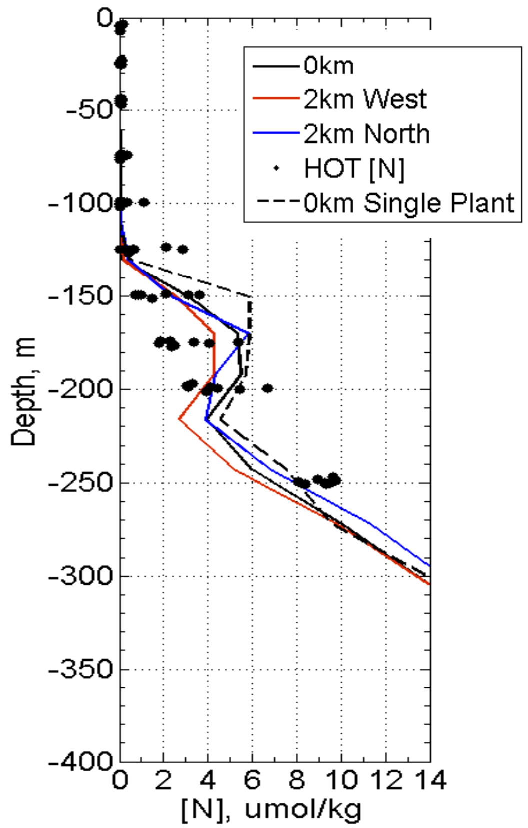


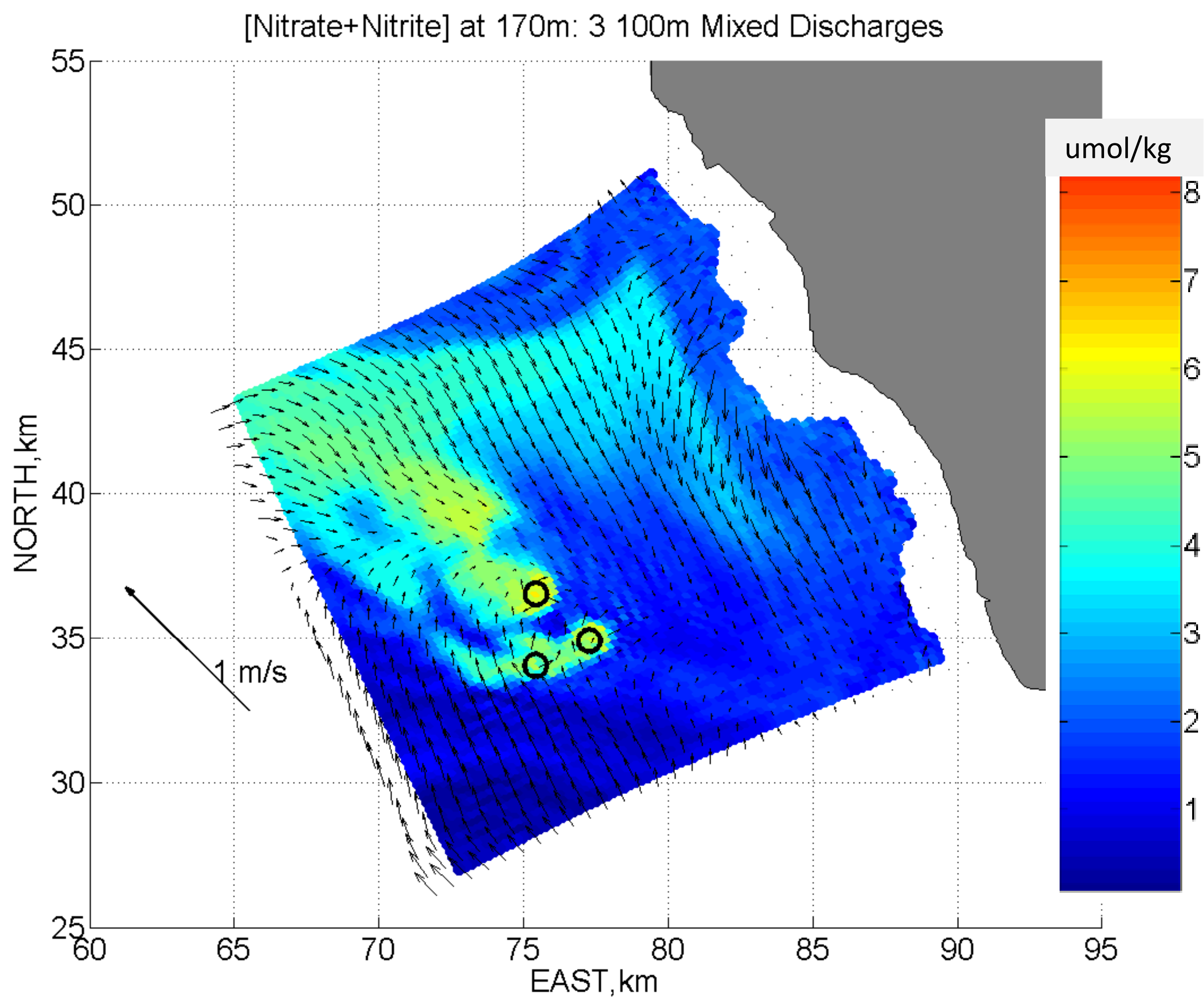


Three 100MW Plants, 2.2 km spacing, 100m Mixed Discharge

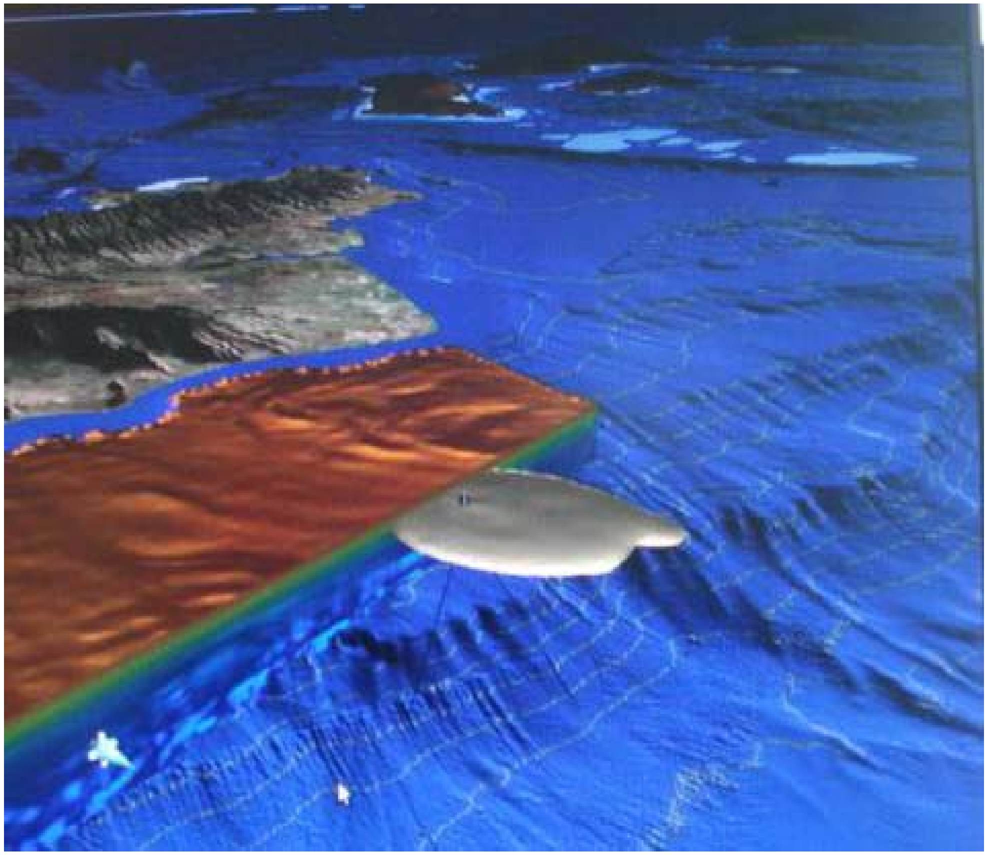
- No significant increase in [N] at OTEC plants when compared with operating a single 100MW OTEC plant with 100m discharge
- Horizontal scale of plume is modified by increased number of facilities

Nitrate profiles at each location after 7 days





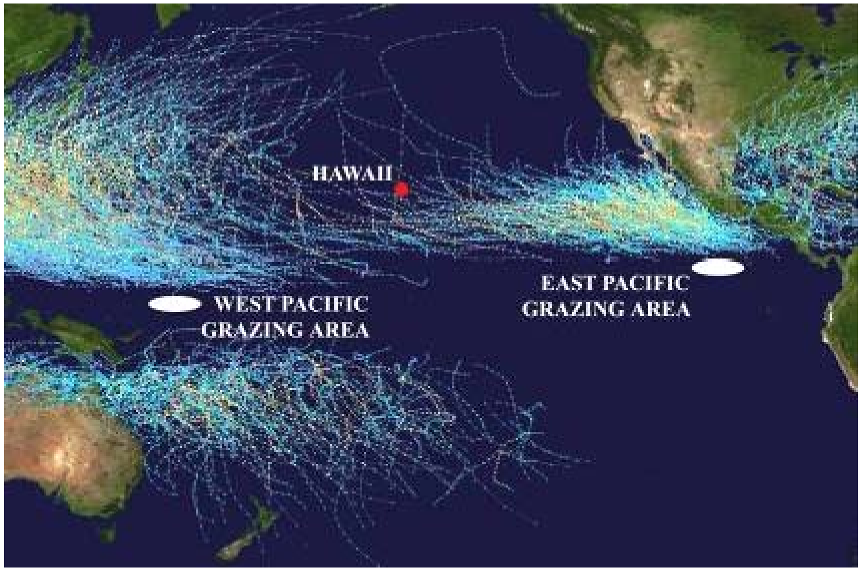
Conclusions & Questions



- A realistic, dynamic plume model has been developed for single and multiple offshore OTEC plants.
- The plume model is helping us make design decisions.
- Designs for mixed discharge plumes seem more sustainable (T & N) than unmixed discharge plumes.
- Mixed discharge OTEC plants will raise nutrient levels, but remain below the photic zone and within natural variability.
- Further biogeochemical modeling would be useful.

Thank you for attending.   Questions?

2040 A Massive Energy Source ?



- Similar vision as 1980 OTEC Act

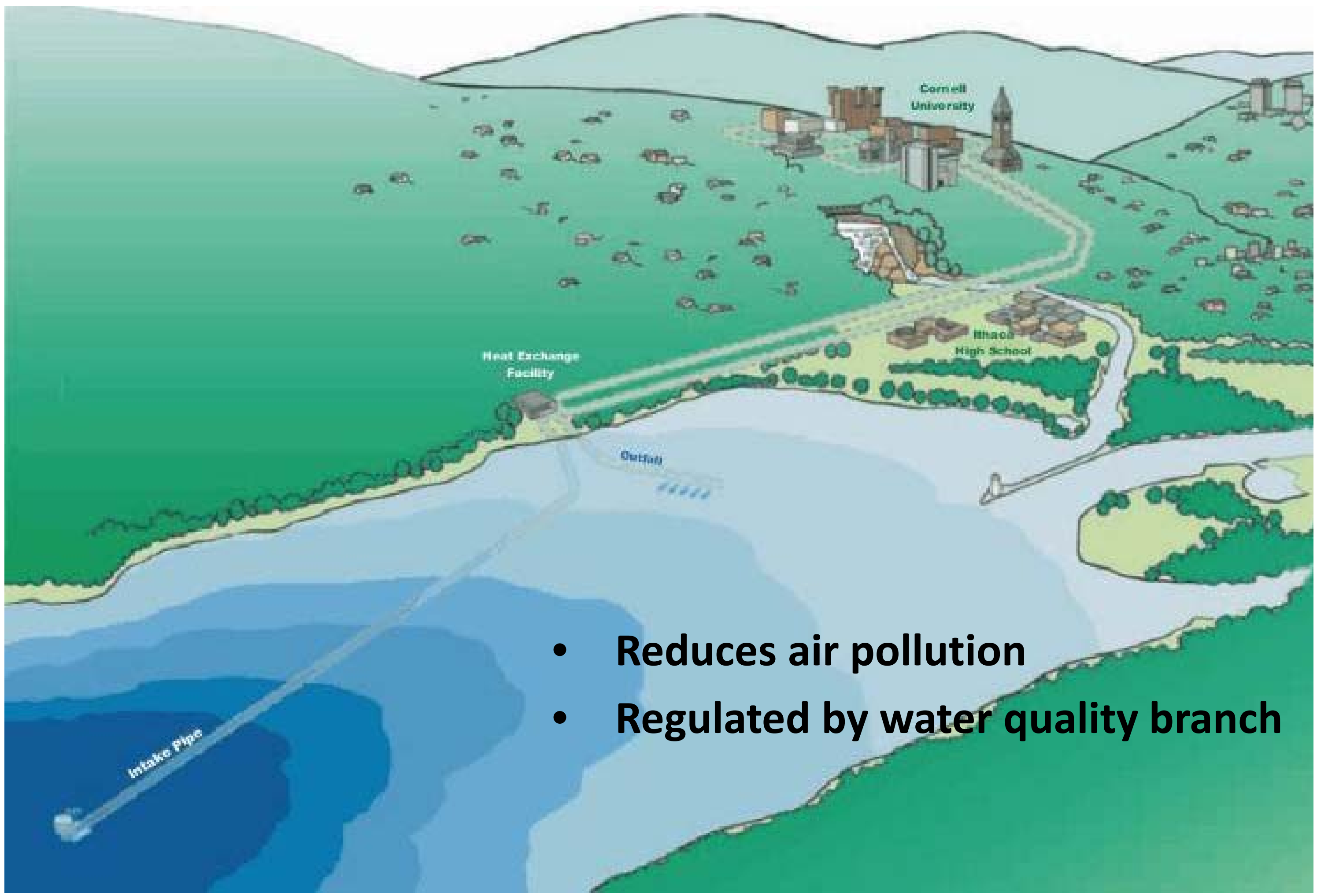
TABLE 1: HYDROGEN PRODUCTION FROM DOMESTIC RESOURCES TO PRODUCE 40 MILLION SHORT TONS OF HYDROGEN FUEL FOR 150 MILLION VEHICLES

Resource	Needed for Hydrogen Annually	Resource	Footprint Required
Reforming and / or Partial Oxidation			
Natural Gas	95 million tons	49 years	400 plants
Coal	310 million tons	89 years	280 plants
Biomass	400-800 million tons	n/a	400 - 600 plants
Water Electrolysis or Thermo-Chemical			
Wind	555 GW_e	n/a	North Dakota Class 3 Wind
Solar	740 GW_e	n/a	3750 sq. miles
Nuclear (electrolysis)	216 GW_e	n/a	200 plants
Nuclear (thermo-chemical)	300 GW_{th}	n/a	125 plants
Above information is condensed from [3].			
OTEC	216 GW_e	n/a	500 - 1000 plants

1998
Cornell University – Cayuga Lake, NY

- 1.6m dia pipe,
- Use 1.2 m^3/sec
- Saves 20MW
- Rejects 4 hr of sunlight to Lake
- Electric power plant on same lake
- Awards galore

- 2004 Permit Renewal ???



- **Reduces air pollution**
- **Regulated by water quality branch**