OCEAN THERMAL ENERGY CONVERSION (OTEC)
Challenges and Opportunities

Gérard Nihous
Associate Professor
Dept. of Ocean and Resources engineering
University of Hawaii

Pacific Economic Cooperation Council

OTEC in a Nutshell

- Heat engine using seawater of different temperatures found at different depths.
- Low thermodynamic efficiencies (≈ 3%) require large physical systems.
- Deep water environment.
- Most of the resource is located offshore.
- Some key components are not modular.

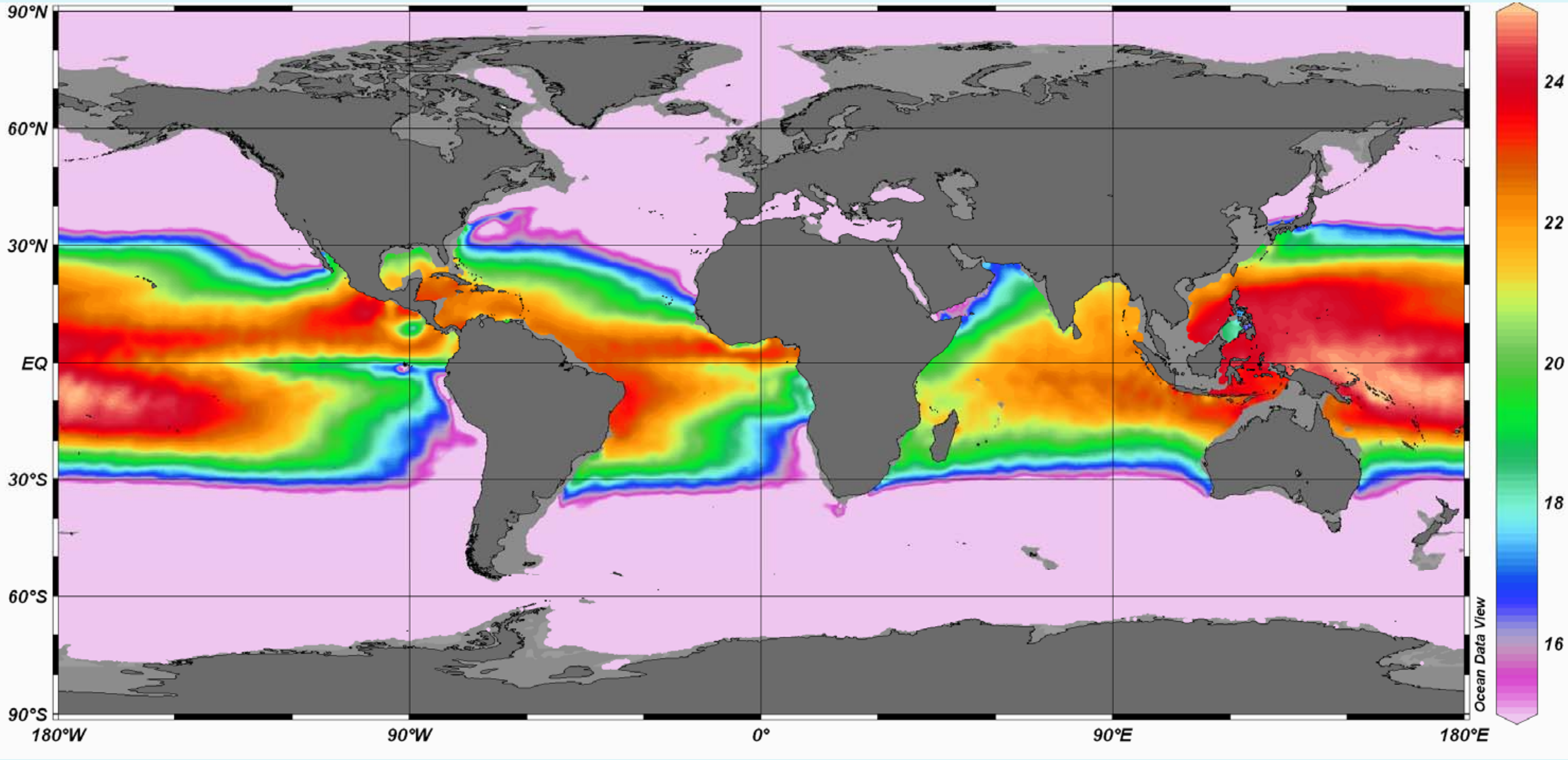
→

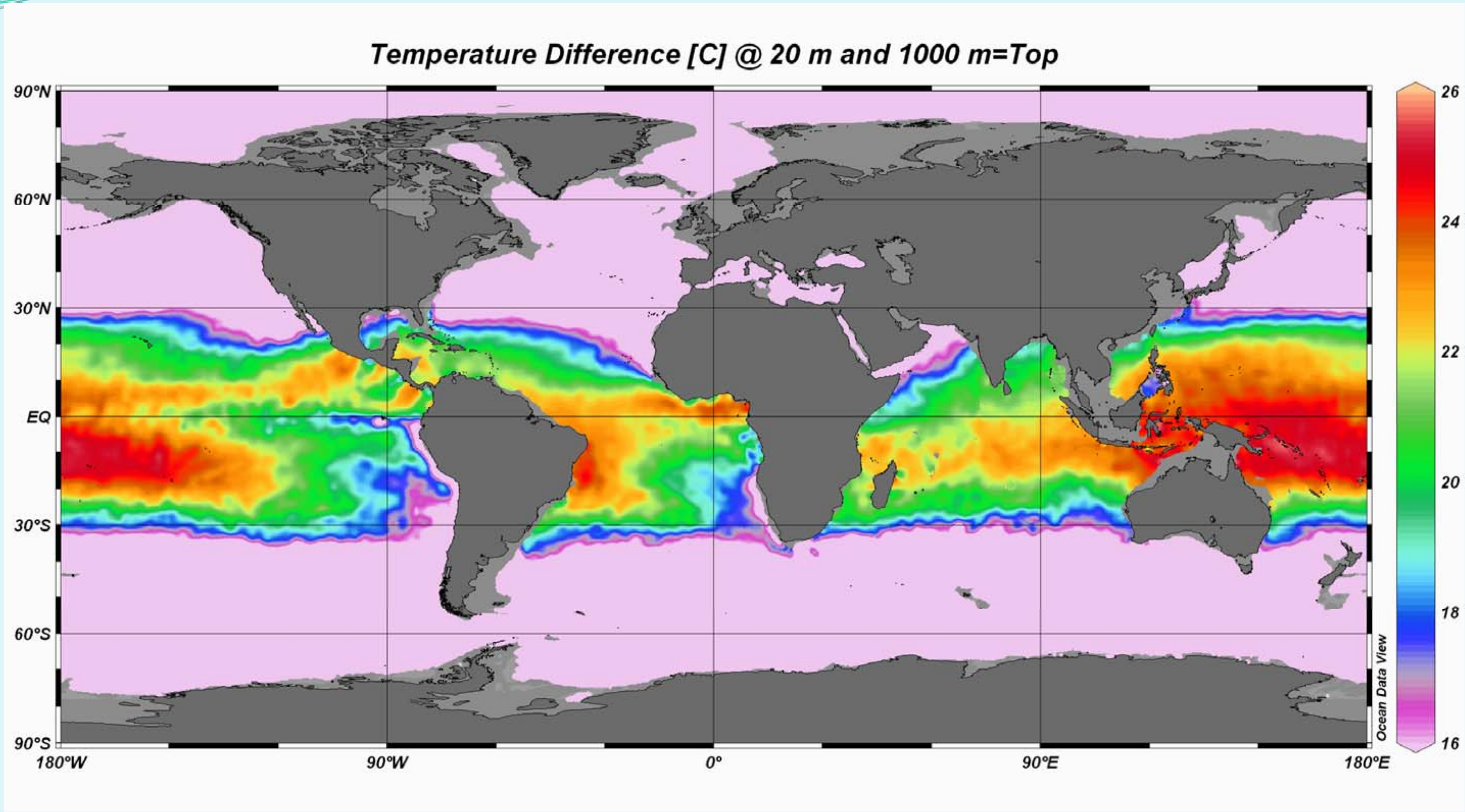
- *Capital intensive technology*
- *Technology development difficult*

WORLDWIDE OTEC THERMAL RESOURCE

Temperature difference between 20 m and 1000 m depths

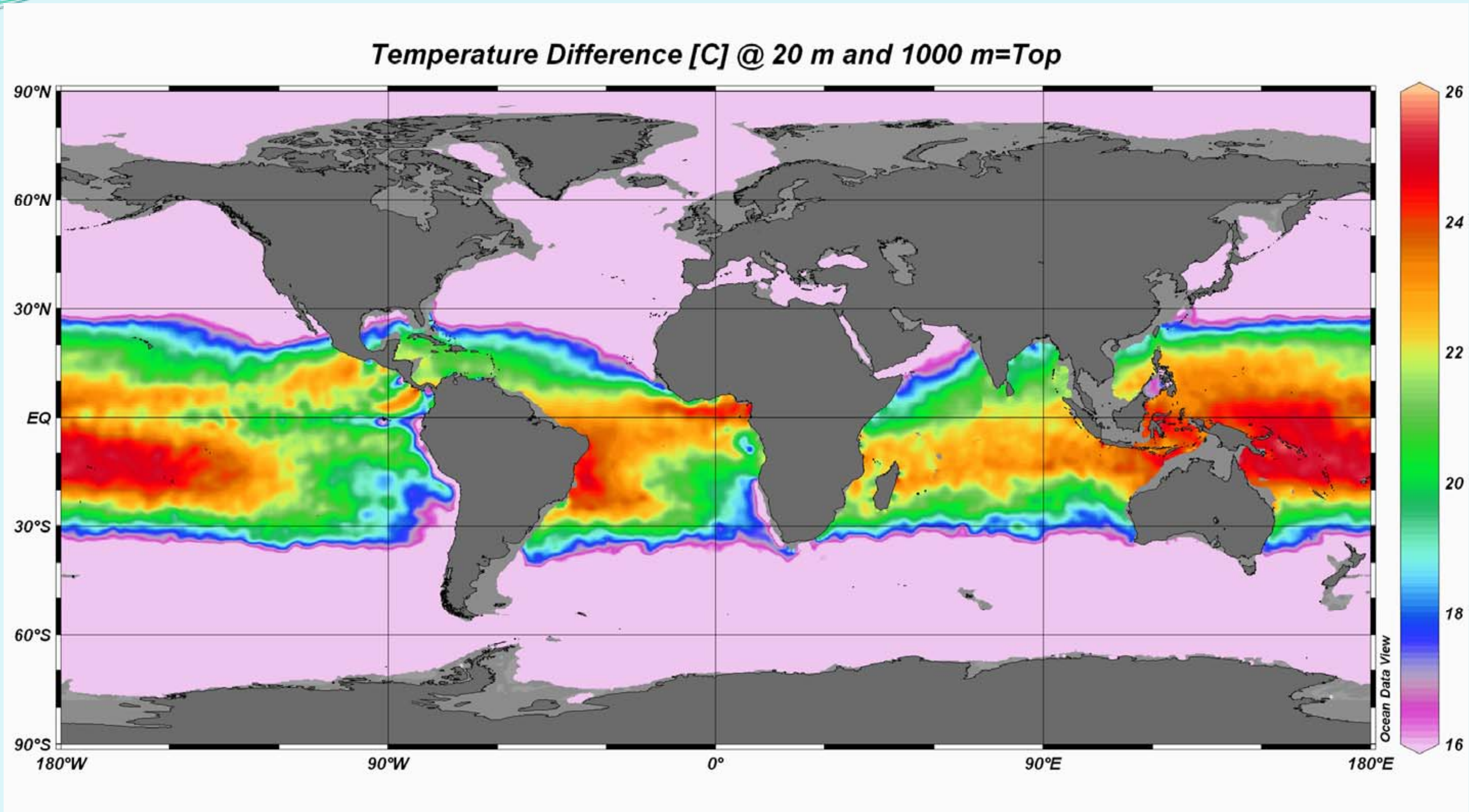
(Nihous, G.C., **2**, 043104, *JRSE*, 2010; from NODC WOA05 database)



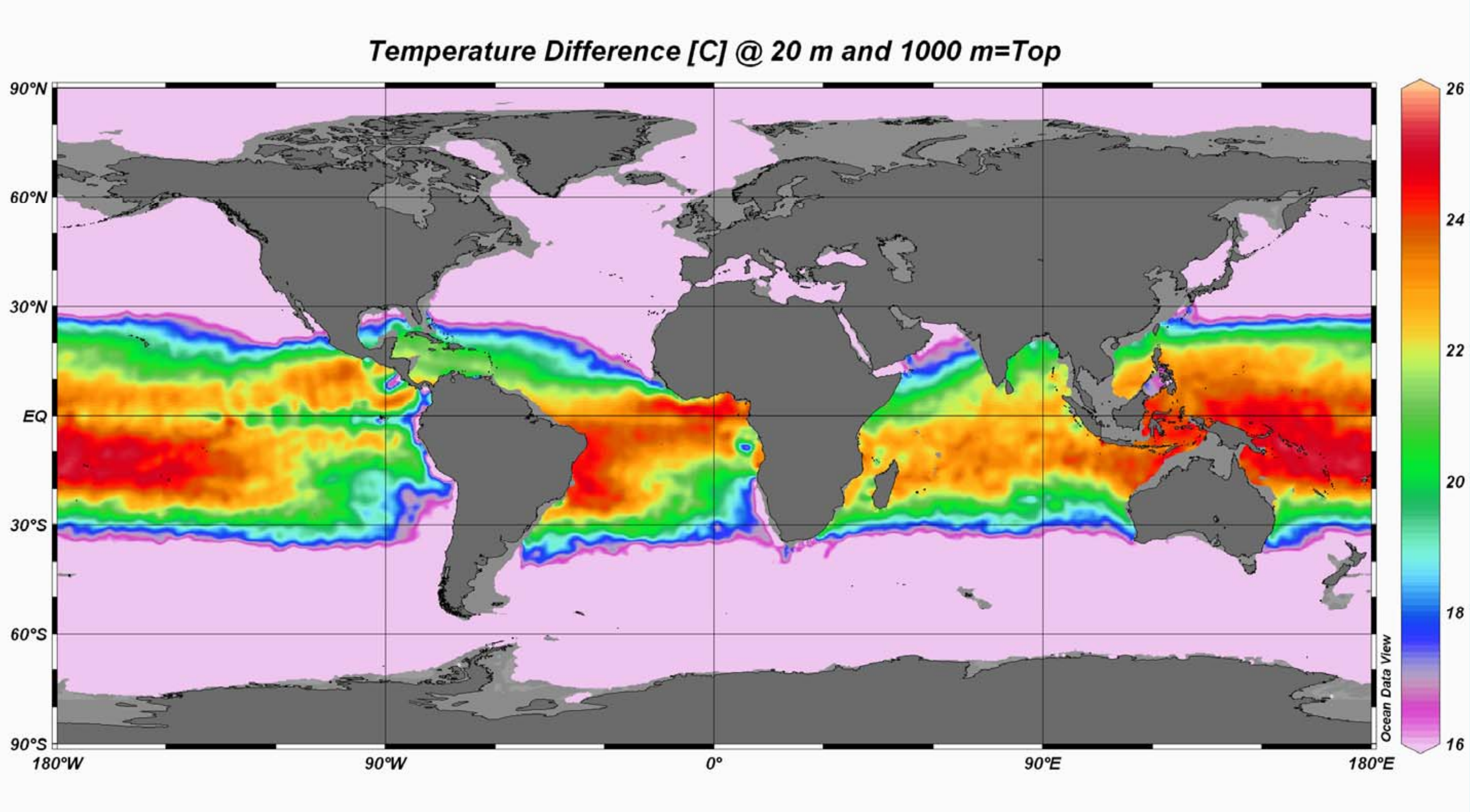


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

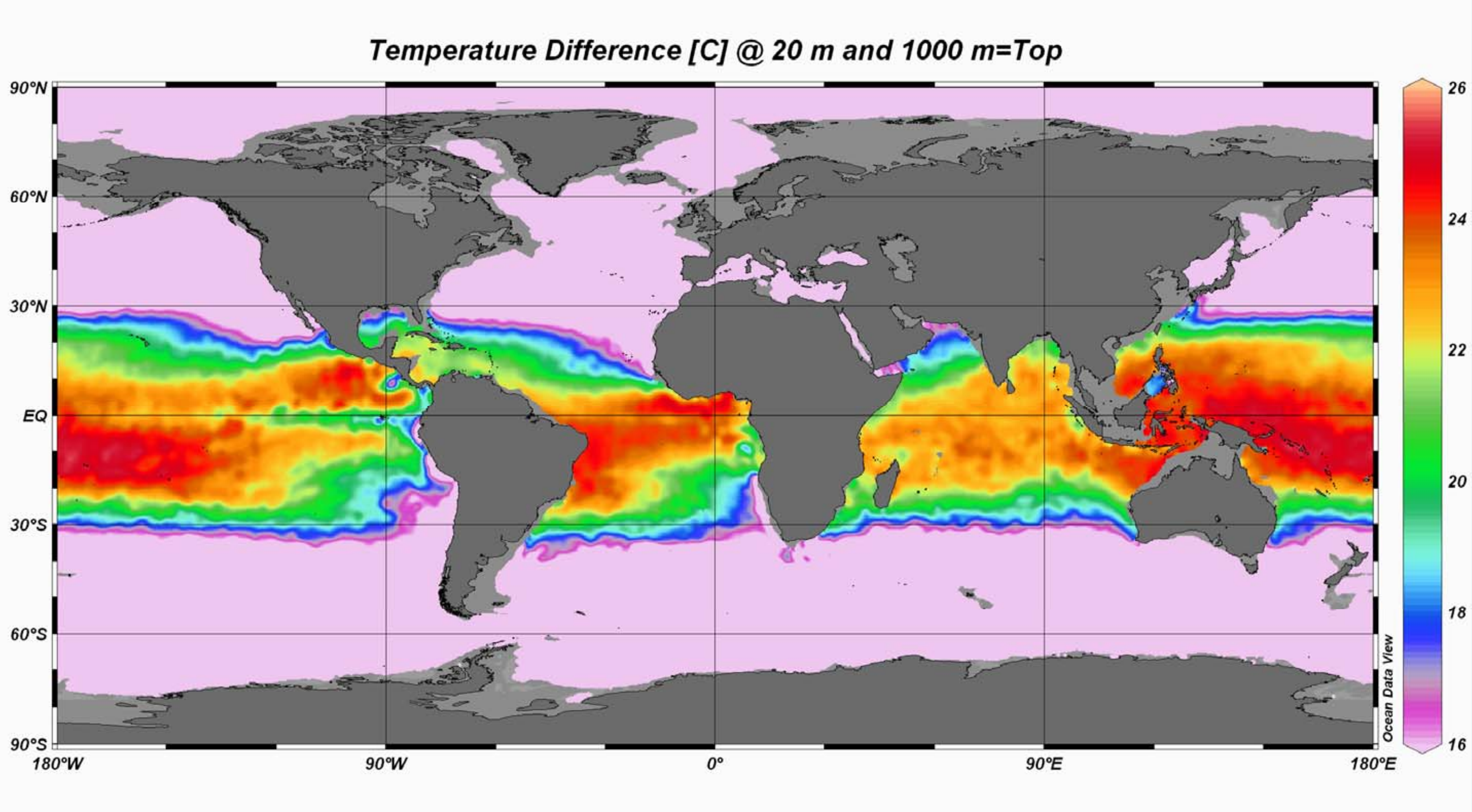
January


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

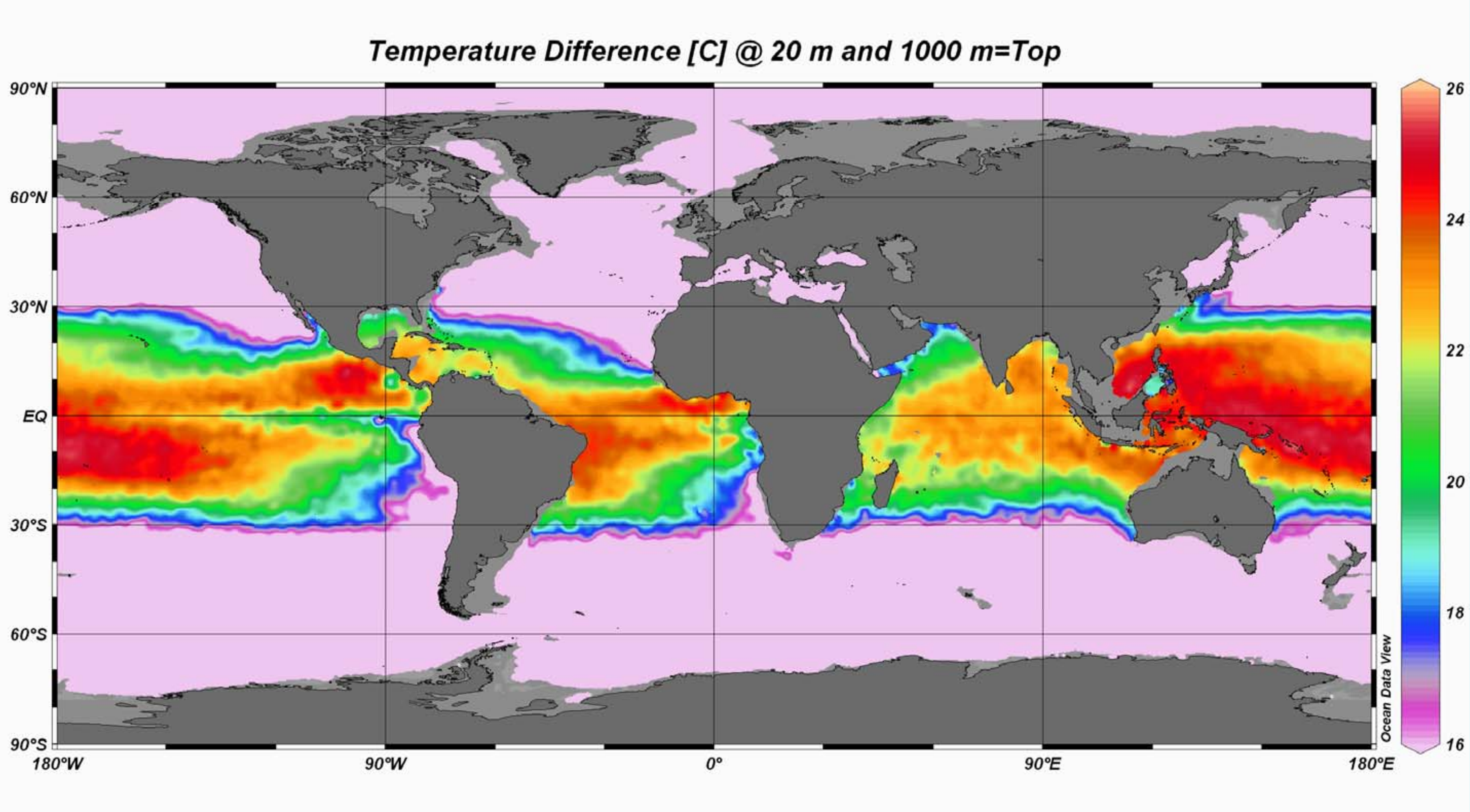
February


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

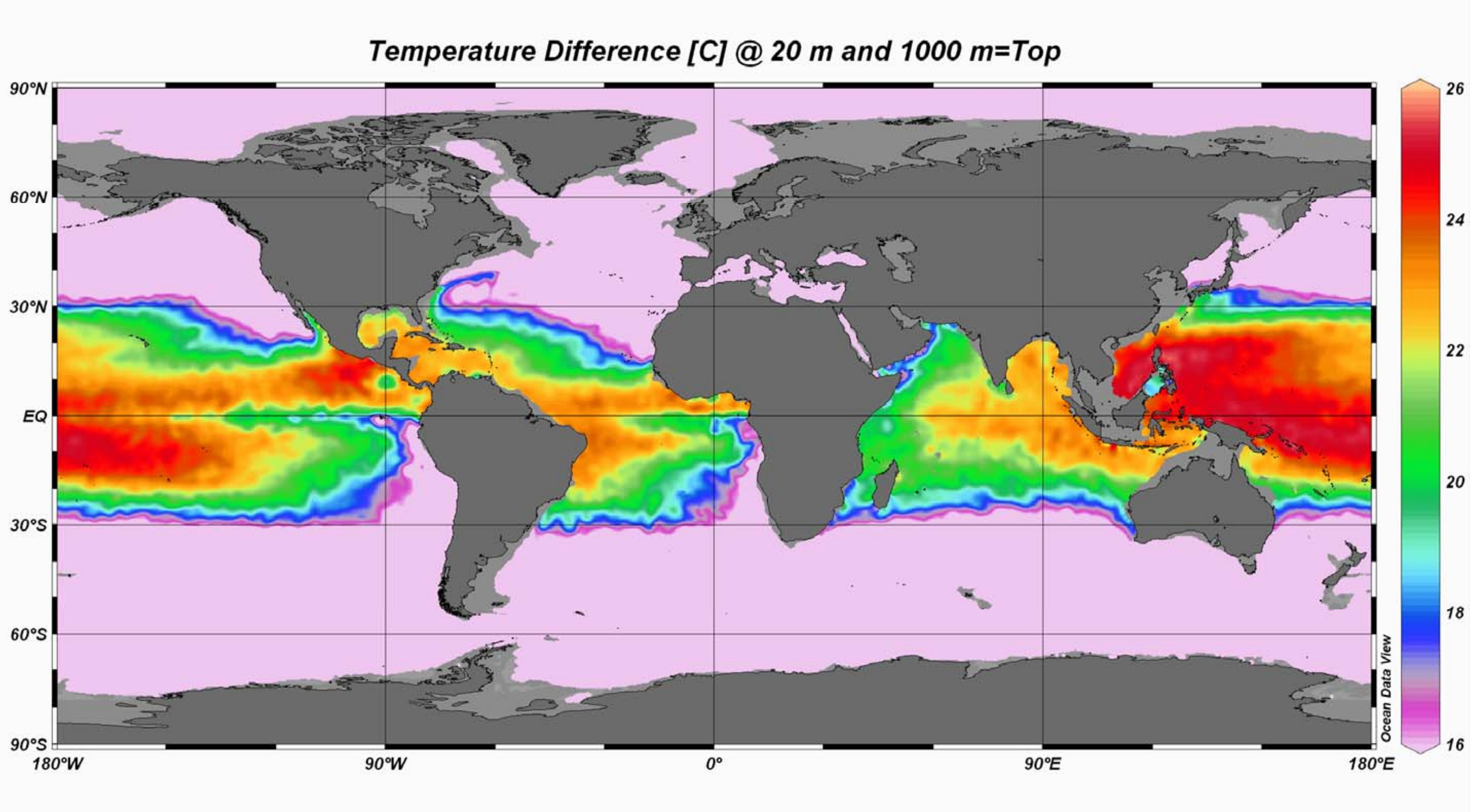
March


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

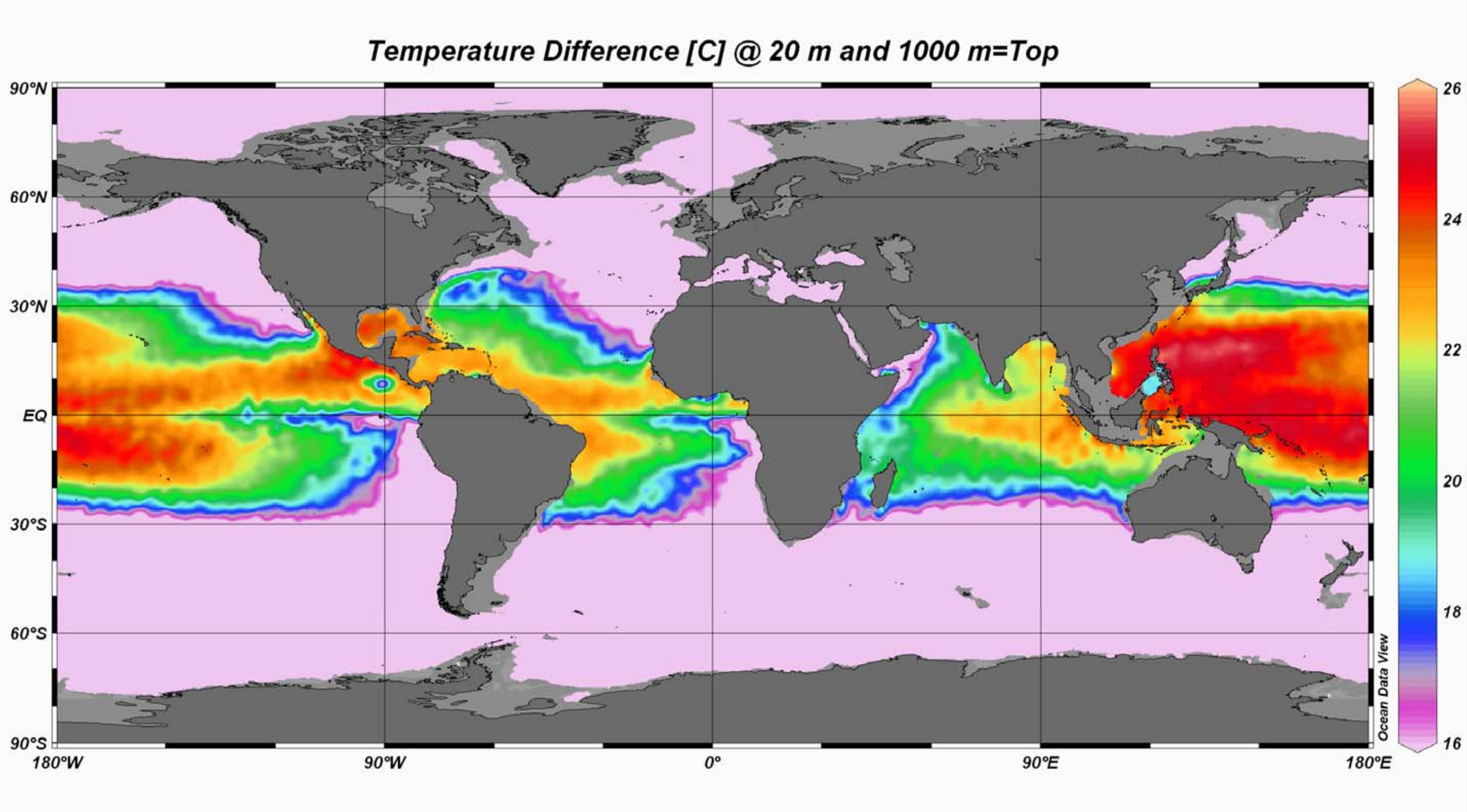
April


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

May

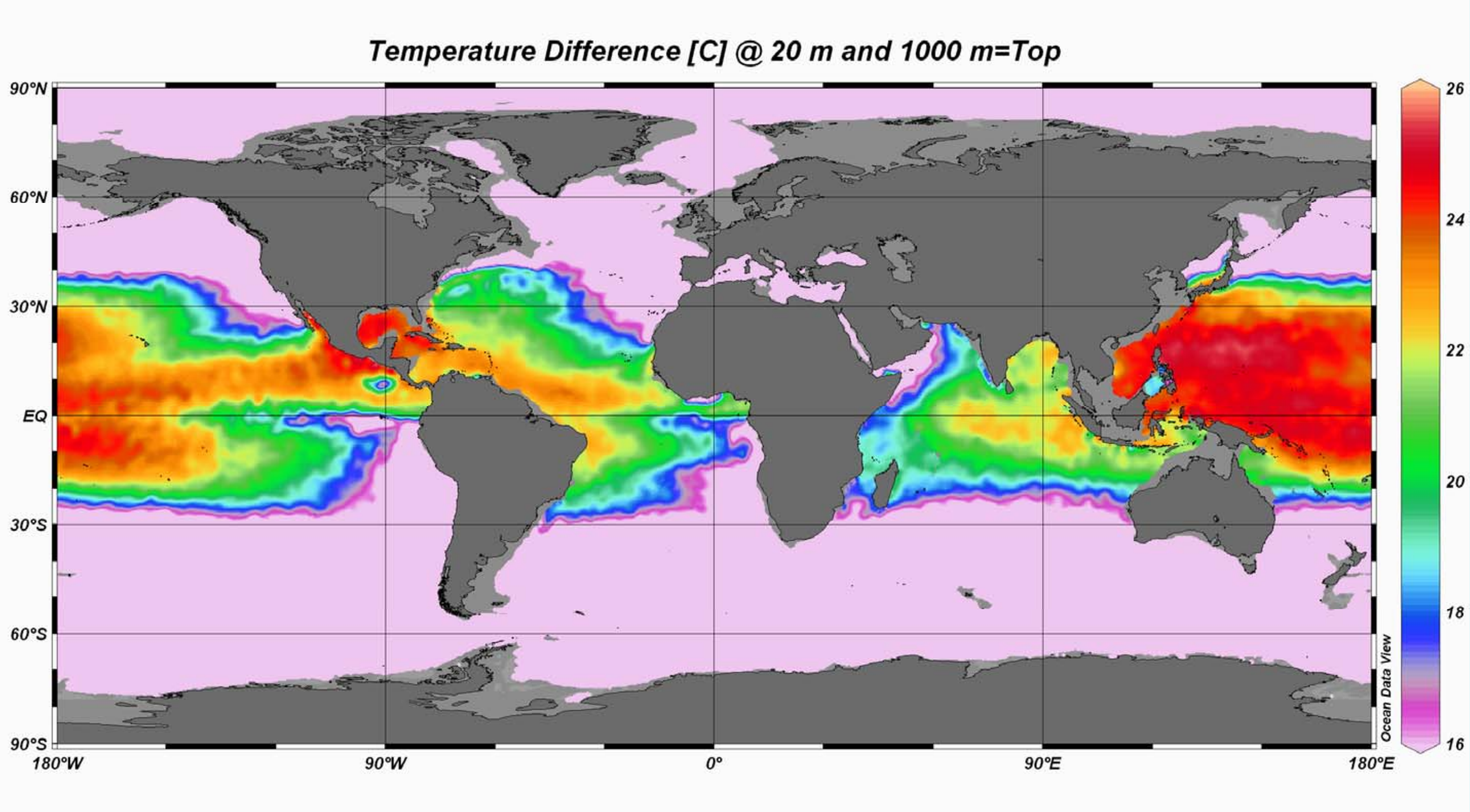

Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

June

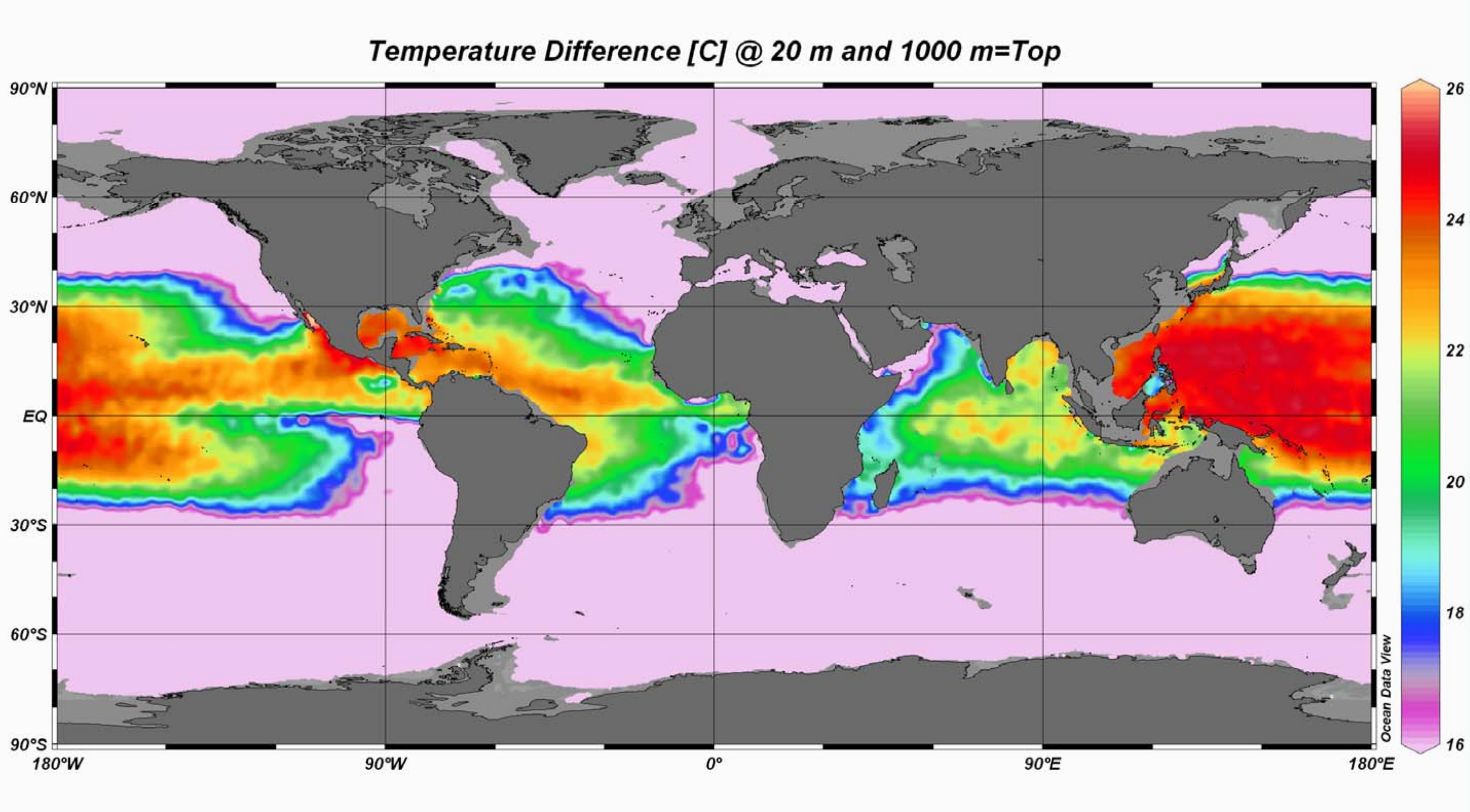


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

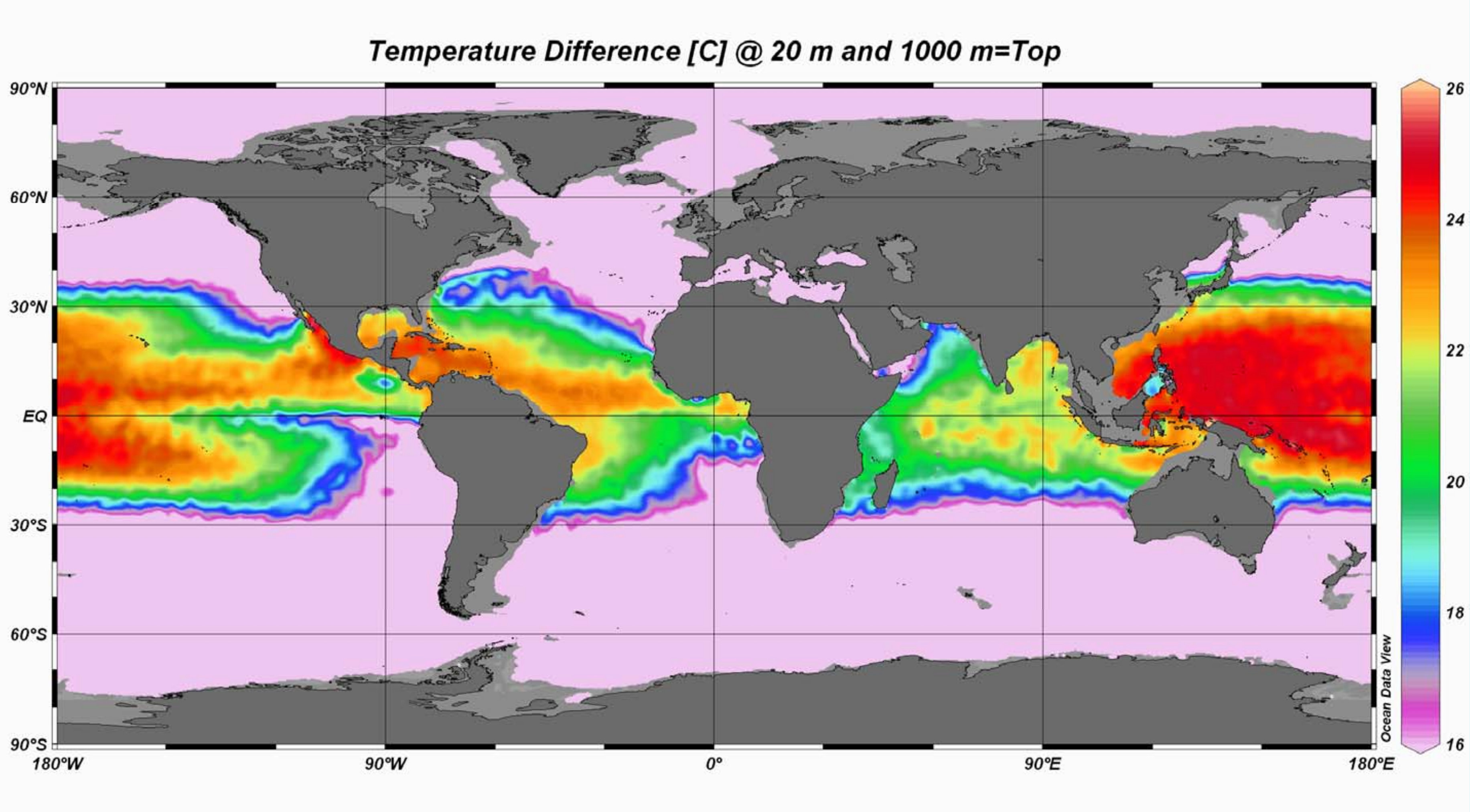
July


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

August

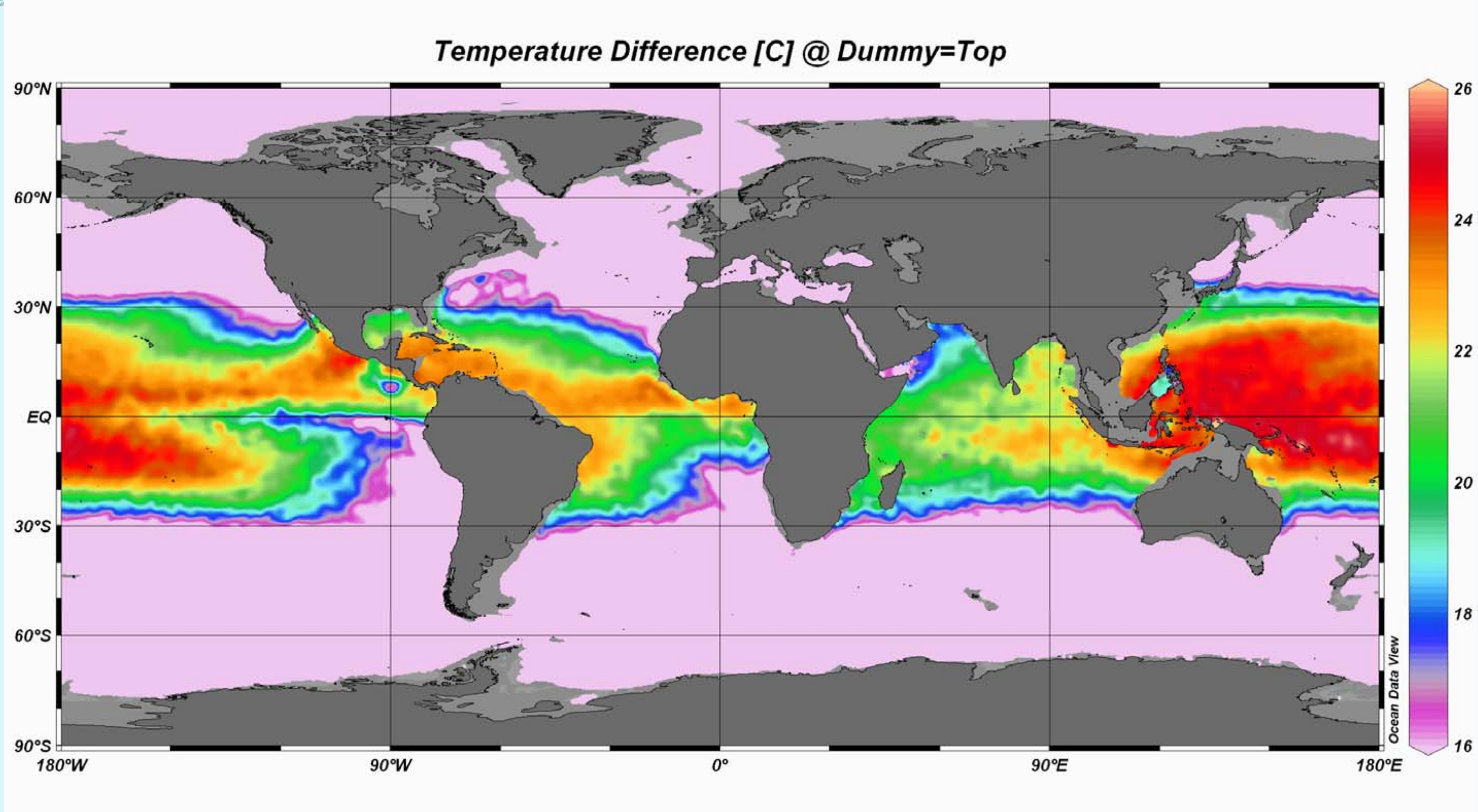

Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

September

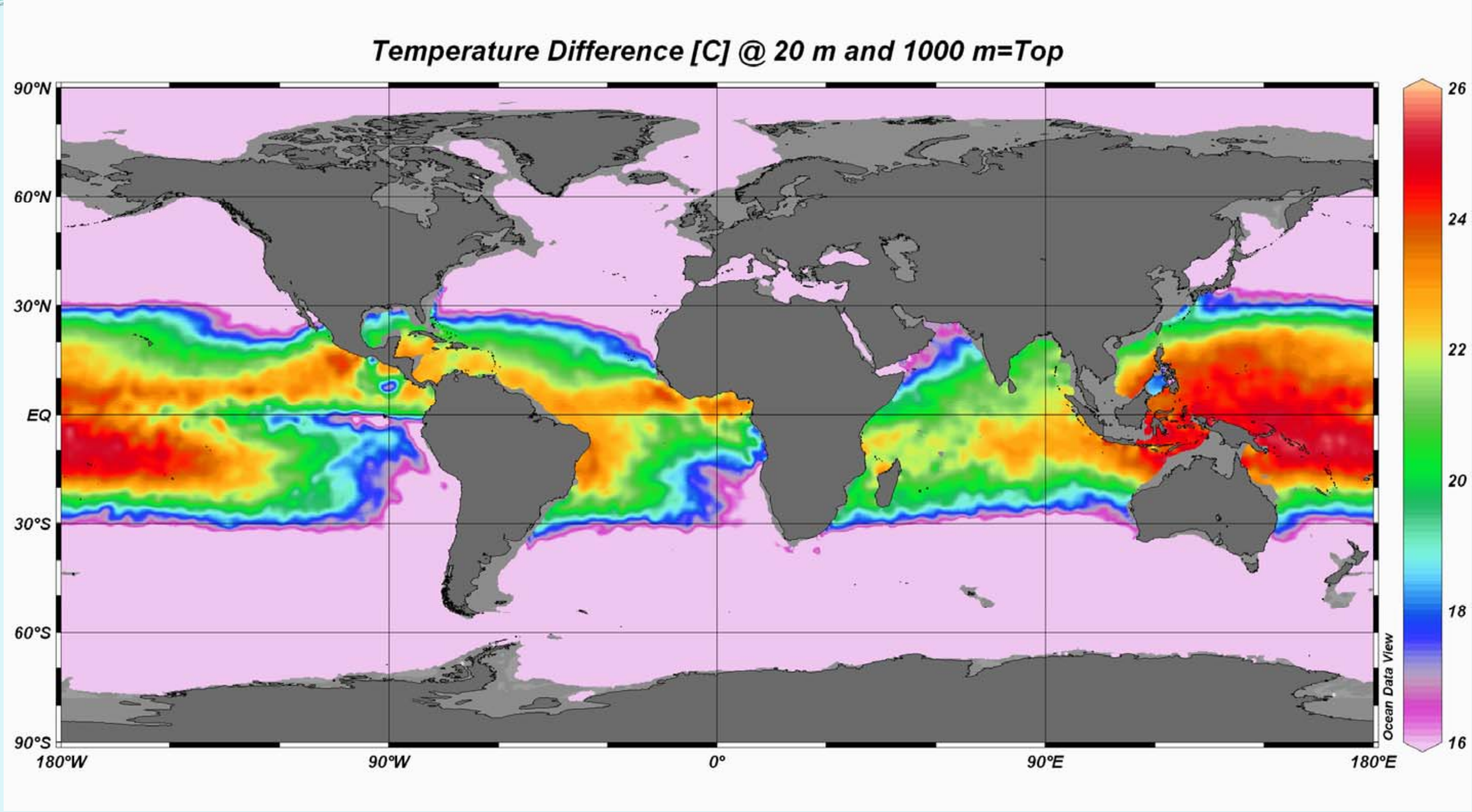


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

October


Temperature Difference [C] @ Dummy=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

November


Temperature Difference [C] @ 20 m and 1000 m=Top
90°N
60°N
30°N
EQ
30°S
60°S
90°S
180°W
90°W
0°
90°E
180°E
26
24
22
20
18
16
Ocean Data View

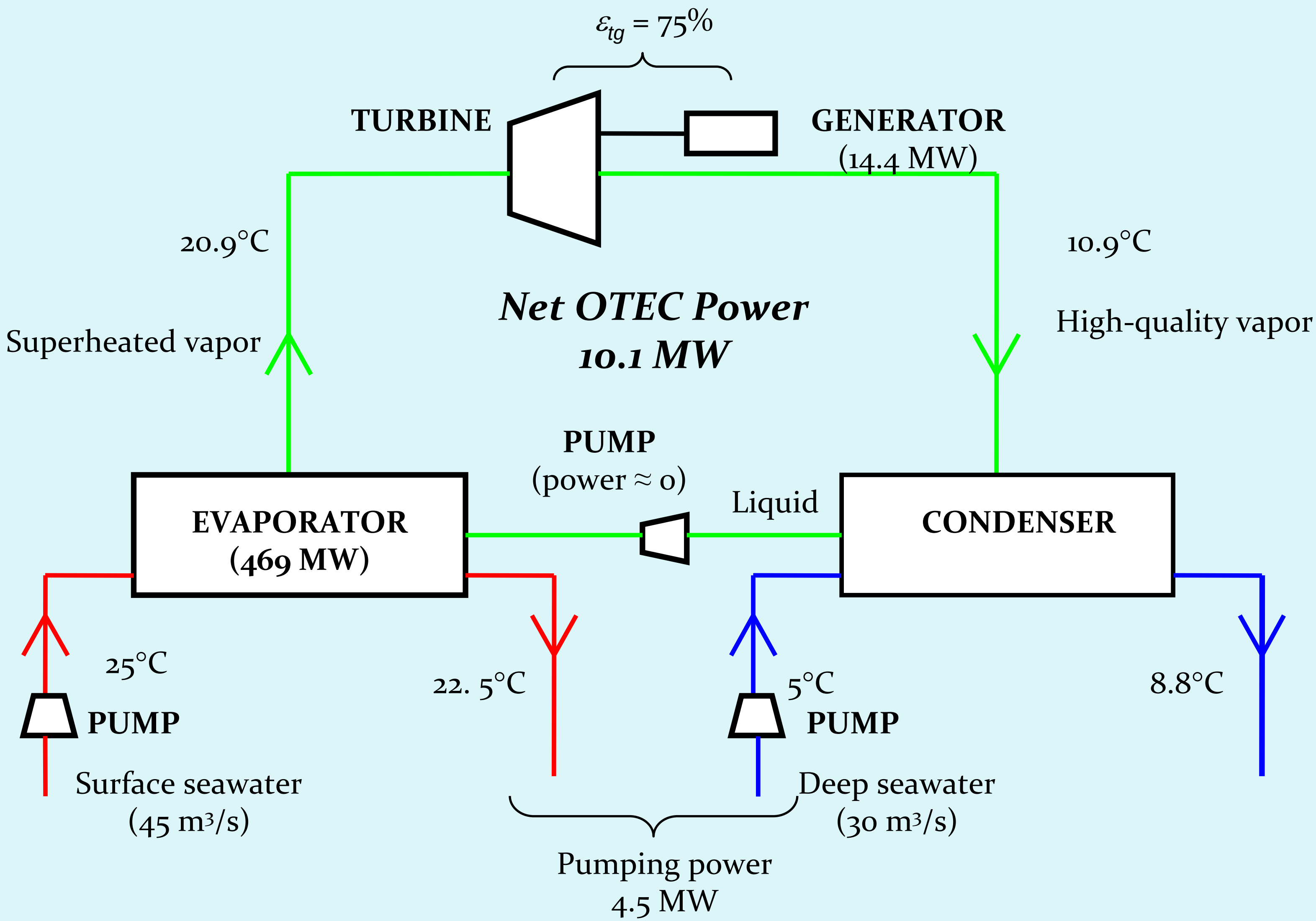
December

- OTEC is one of the few renewable energy technologies with *baseload* (high capacity factor) potential.

- An oceanic area of over 100 million km^2 is concerned.

- The geopolitical distribution of OTEC resources is not ideal to promote technological development.

A simplified OTEC process diagram

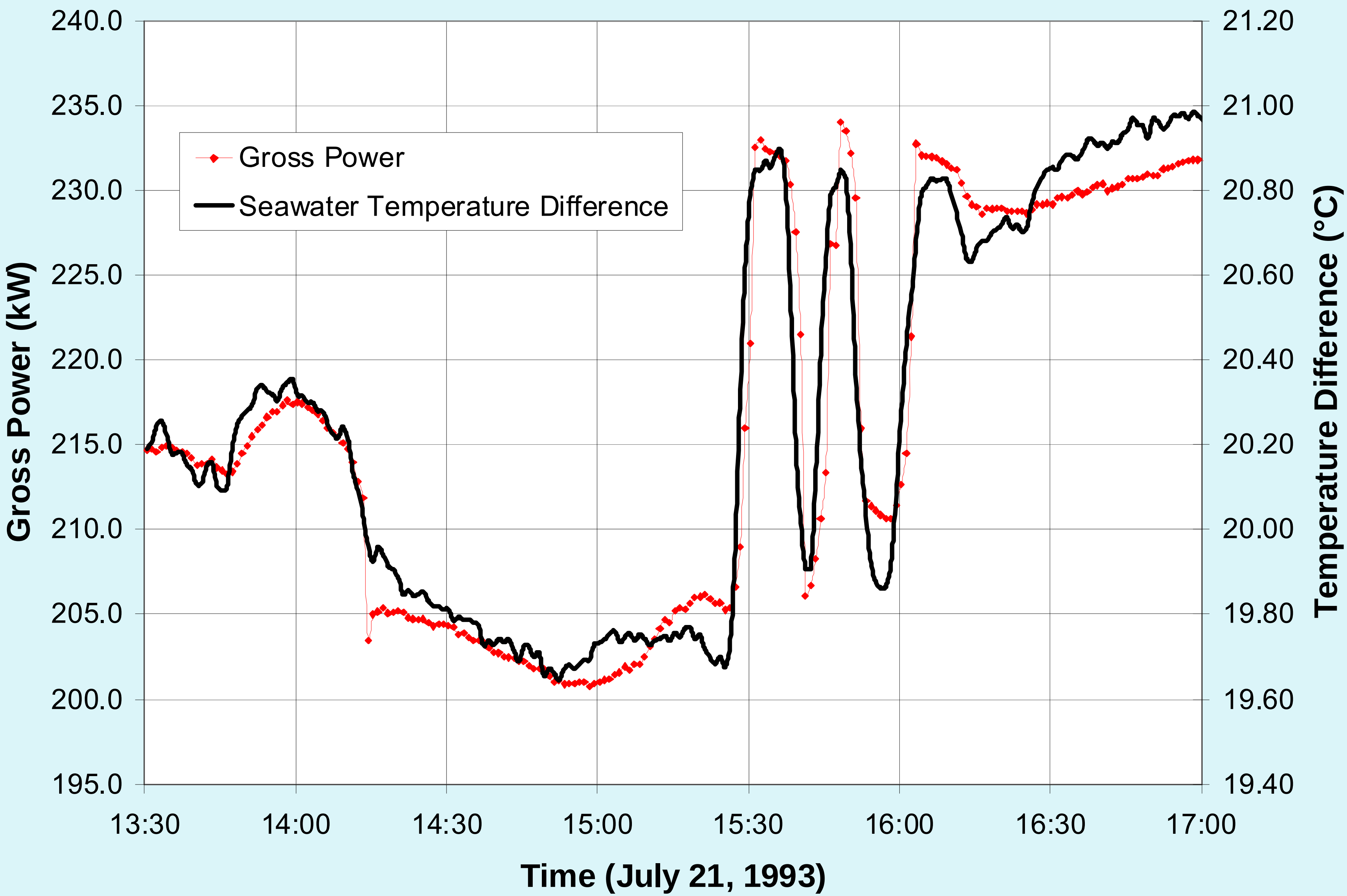


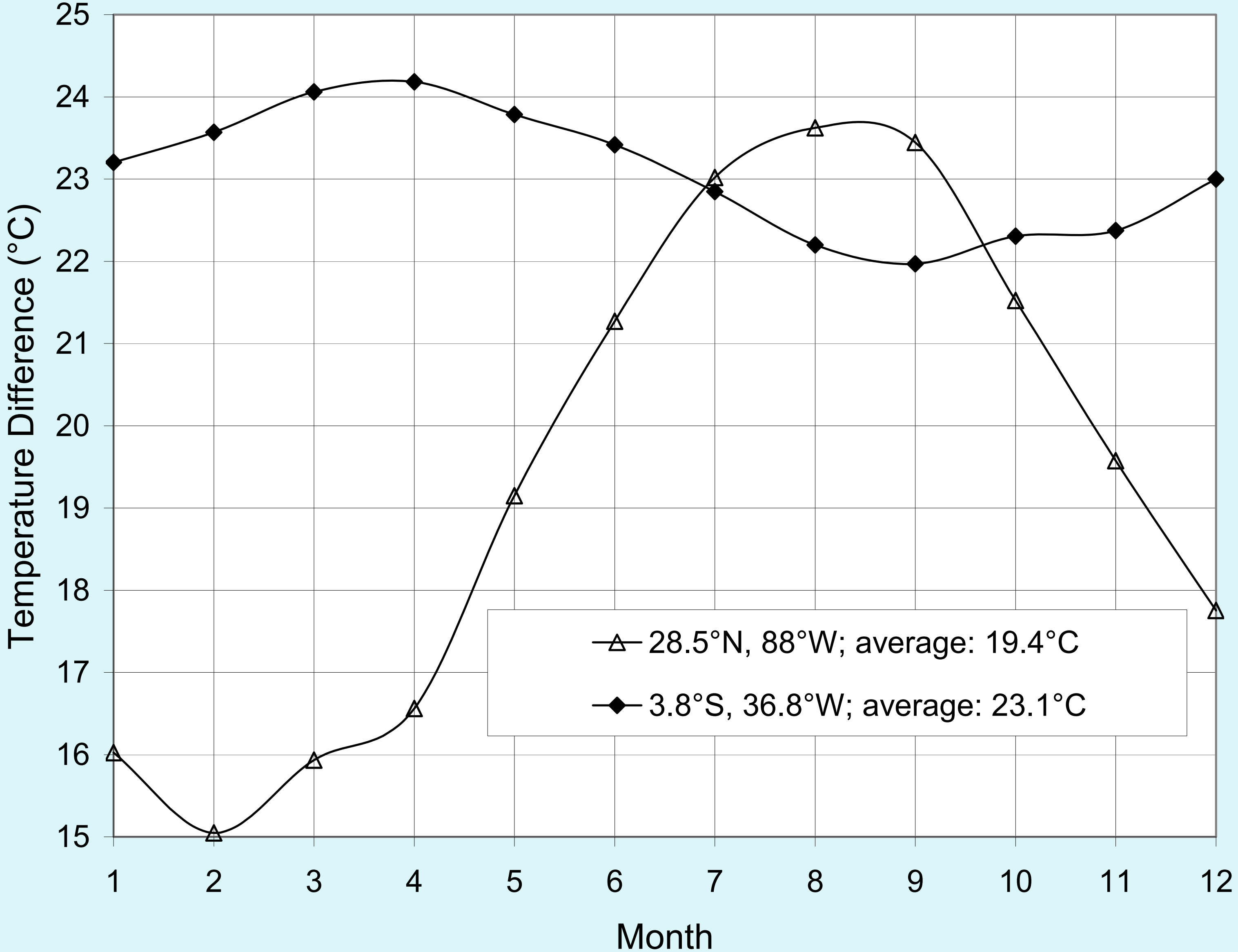
- OTEC operates with a marginal thermal resource.
- It is quite sensitive to the stability of the thermal resource.

  1°C change in $\delta T \approx 15\% \ P_{net}$!
- It is characterized by a high seawater flow rate intensity (of order 7 m^3/s per net MW).
- The Cold Water Pipe represents a technological frontier.

210 kW Open-Cycle OTEC Net Power Producing Experiment, Hawaii (1993-1997)

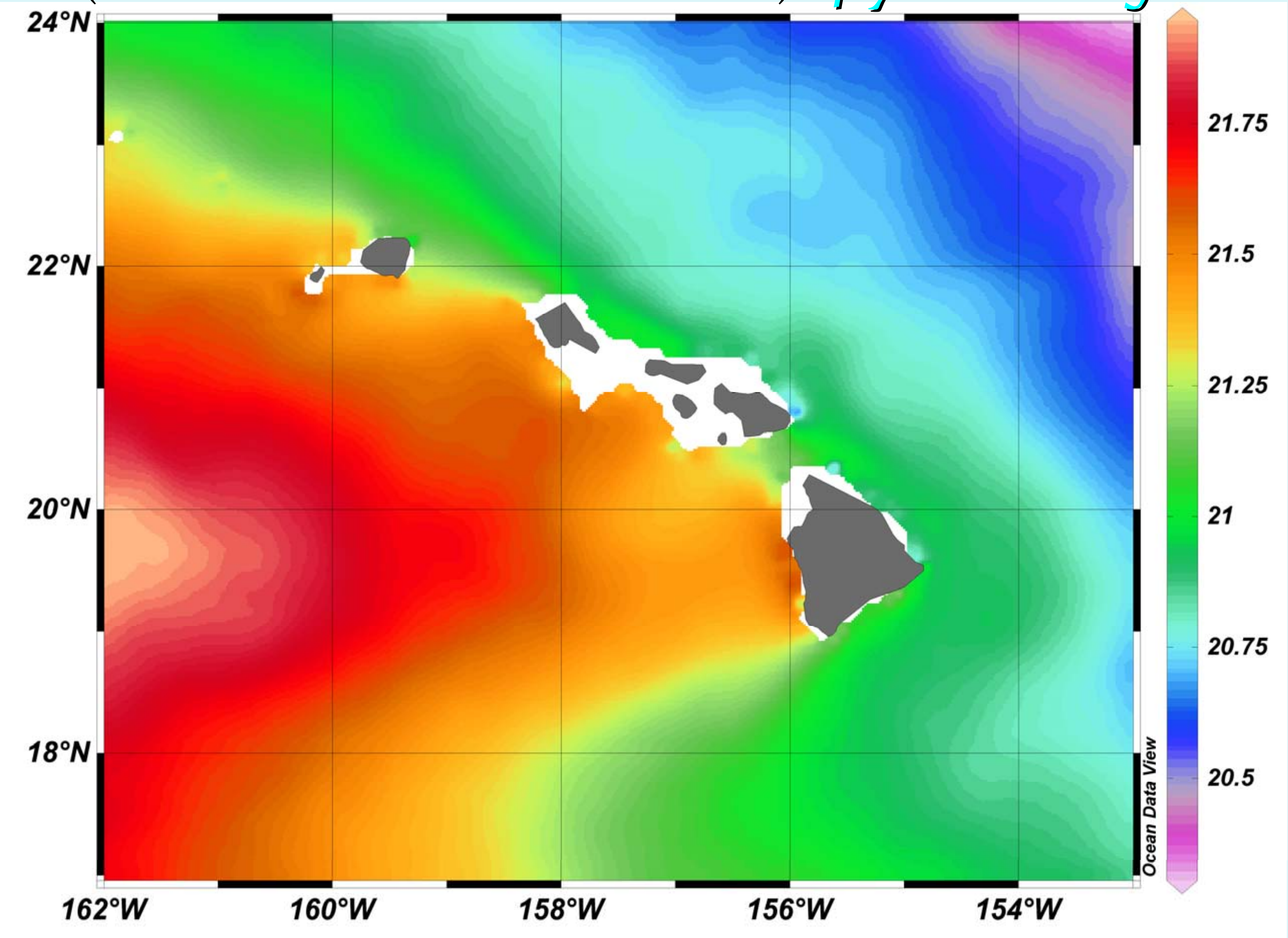
210 kW OC-OTEC Experimental Plant (Keahole Pt.)



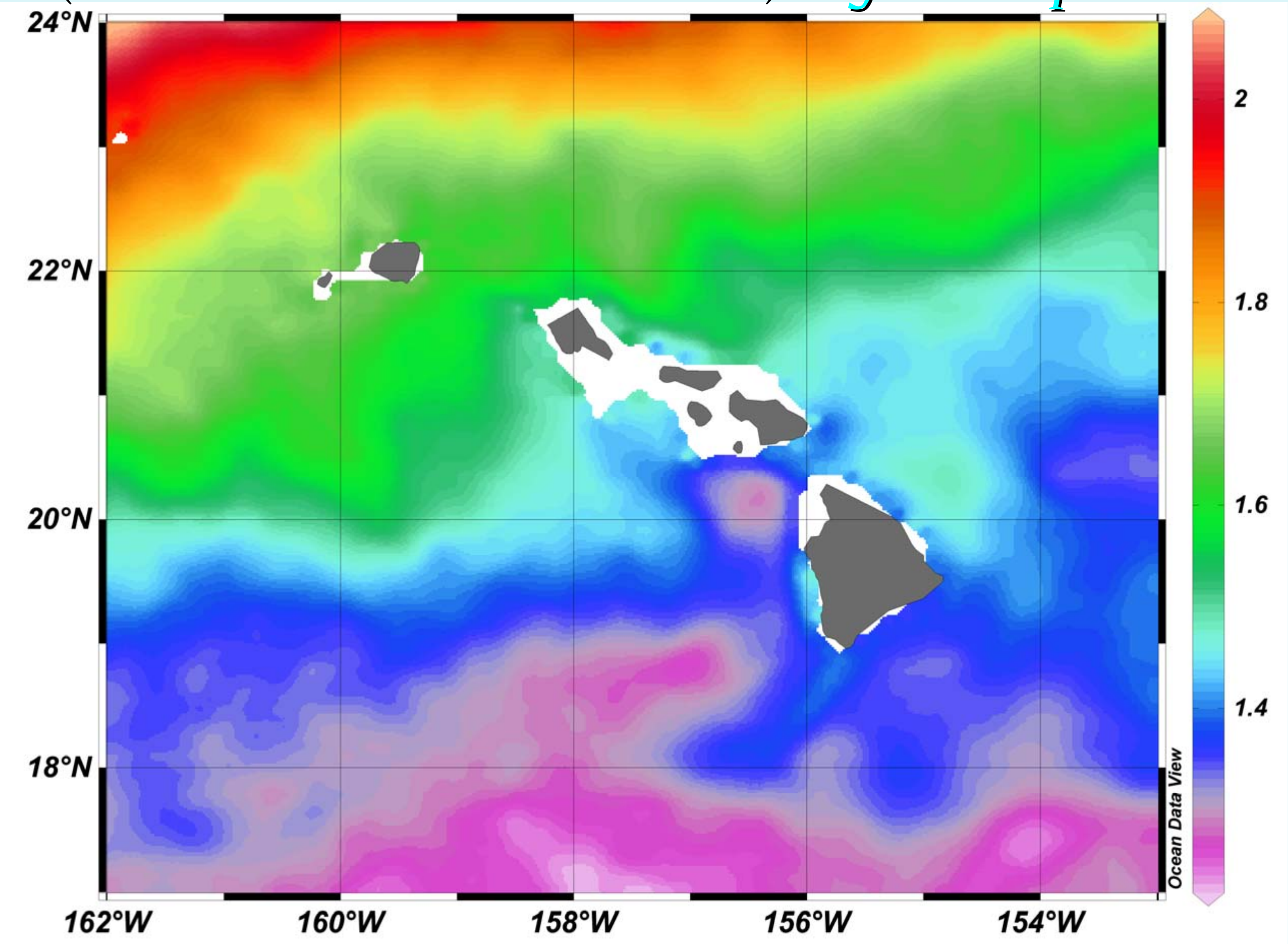


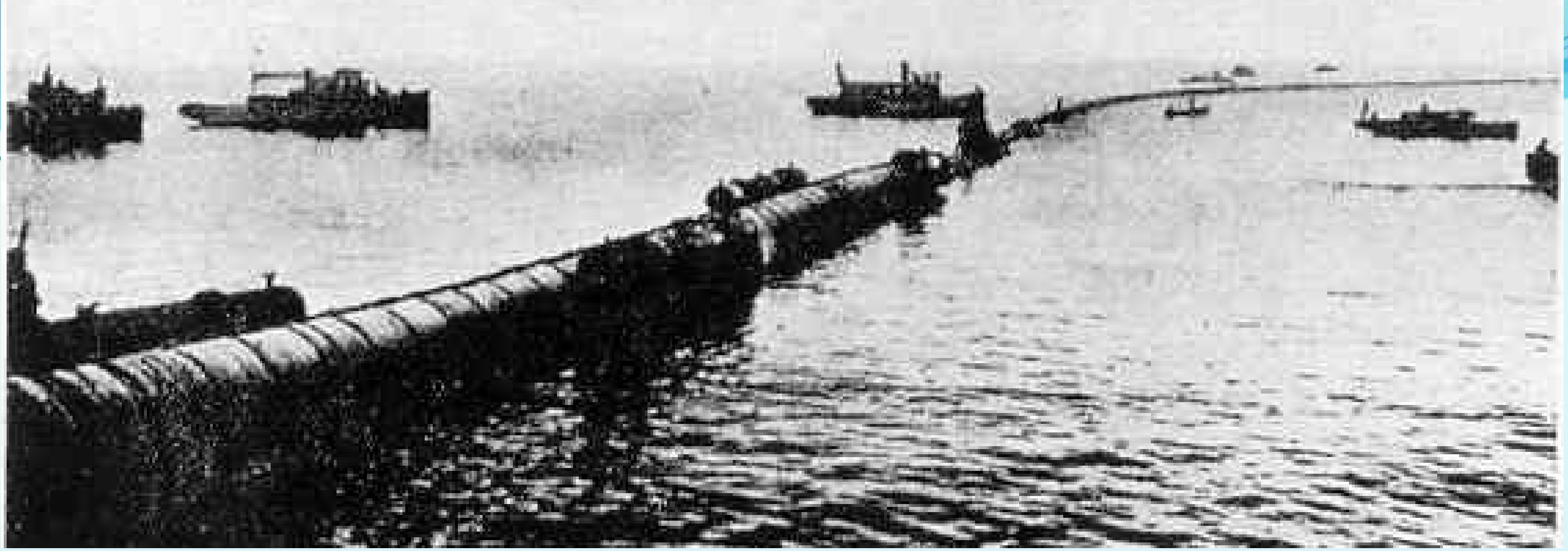
Temperature Difference (°C)
25
24
23
22
21
20
19
18
17
16
15
1
2
3
4
5
6
7
8
9
10
11
12
Month
28.5°N, 88°W; average: 19.4°C
3.8°S, 36.8°W; average: 23.1°C

OTEC THERMAL RESOURCE IN HAWAII
Temperature difference between 20 m and 1000 m depths (HYCOM +NCODA Simulations): *4-year average*

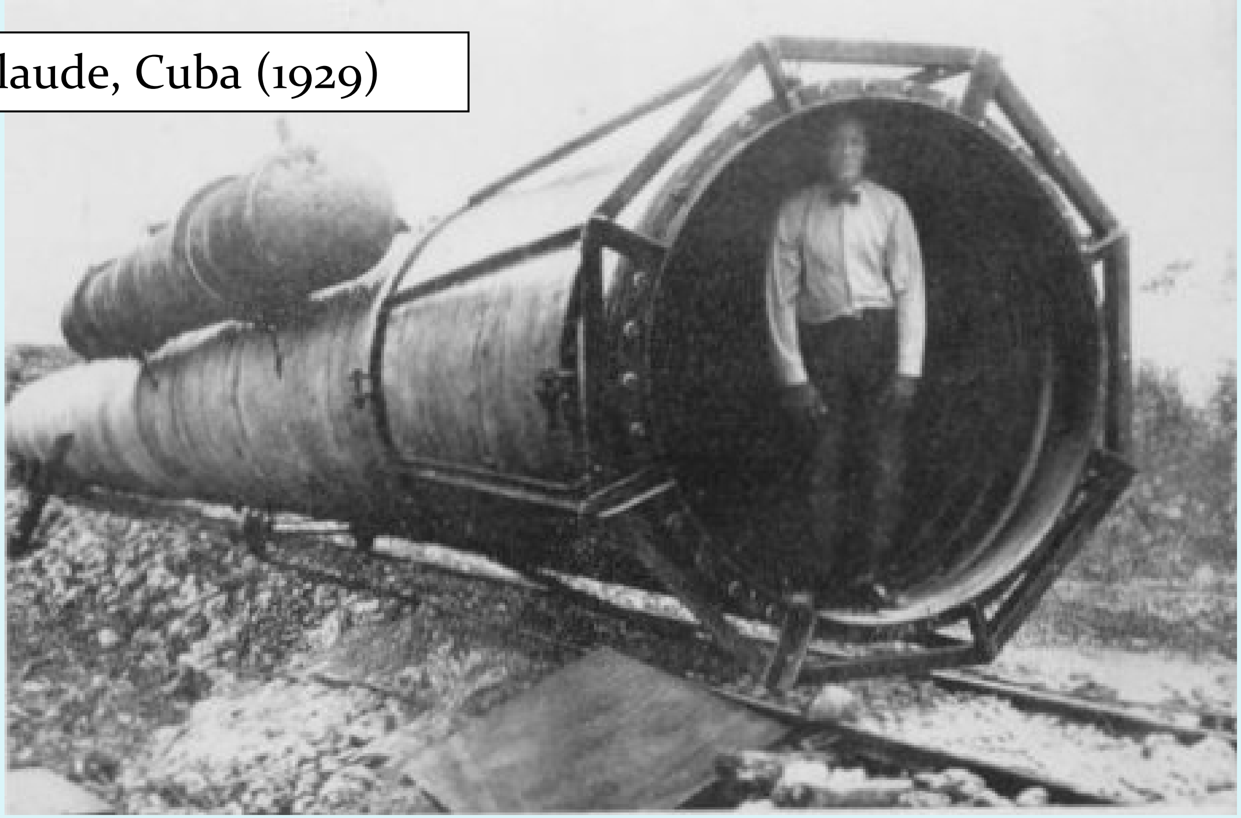


OTEC THERMAL RESOURCE IN HAWAII
Temperature difference between 20 m and 1000 m depths (HYCOM +NCODA Simulations): *signal amplitude*

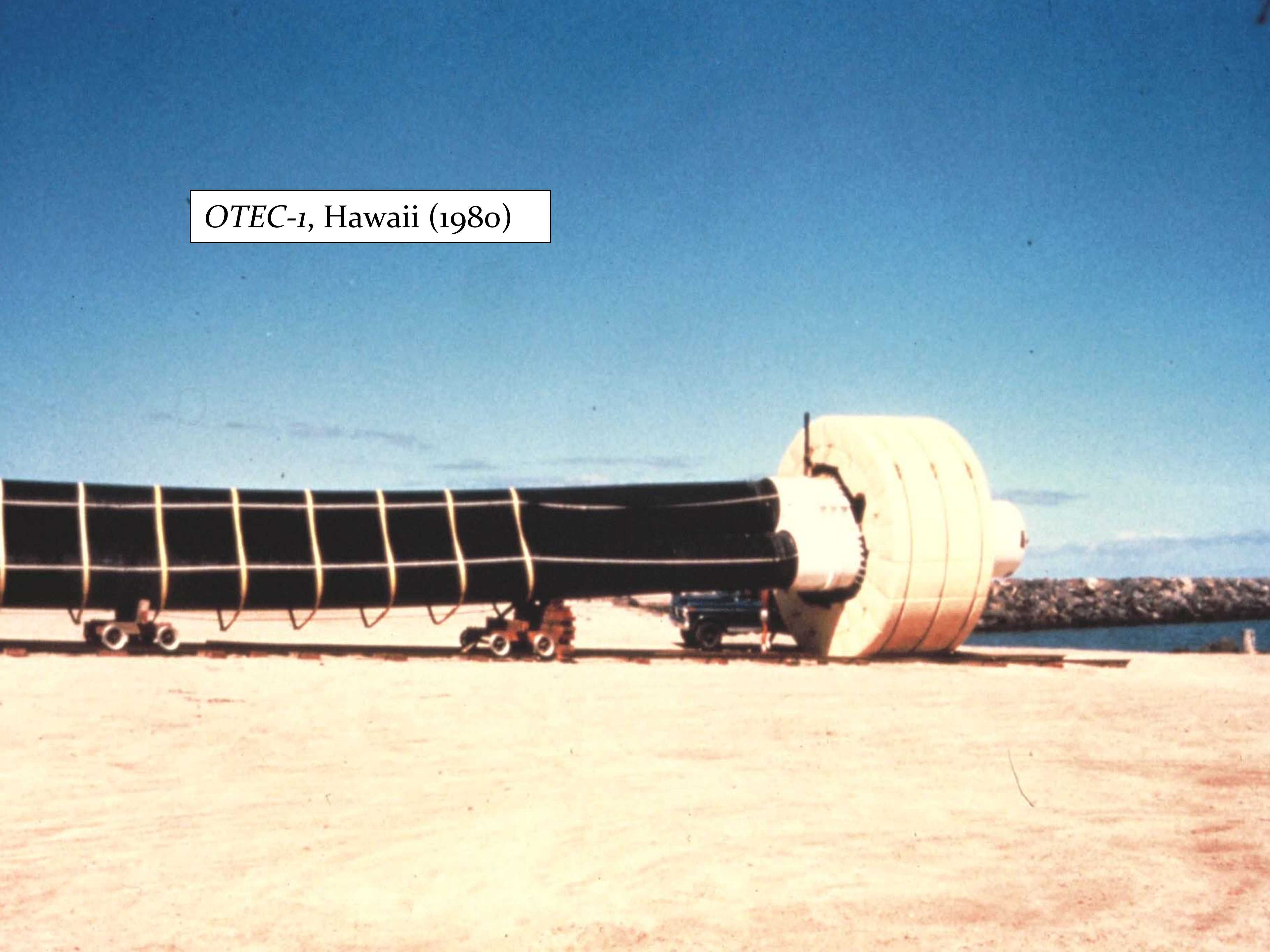




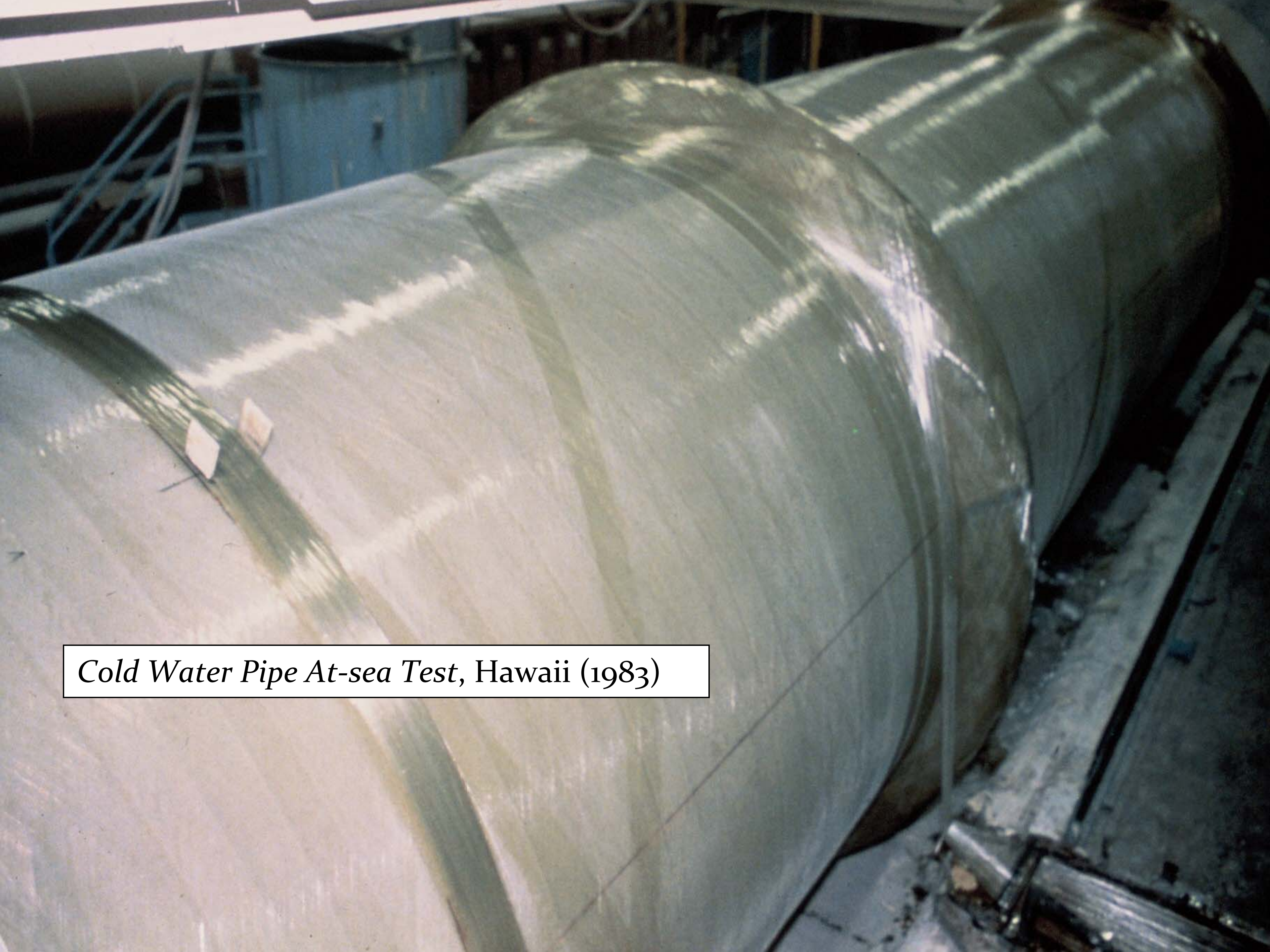
Georges Claude, Cuba (1929)



Mini-OTEC, Hawaii (1979)

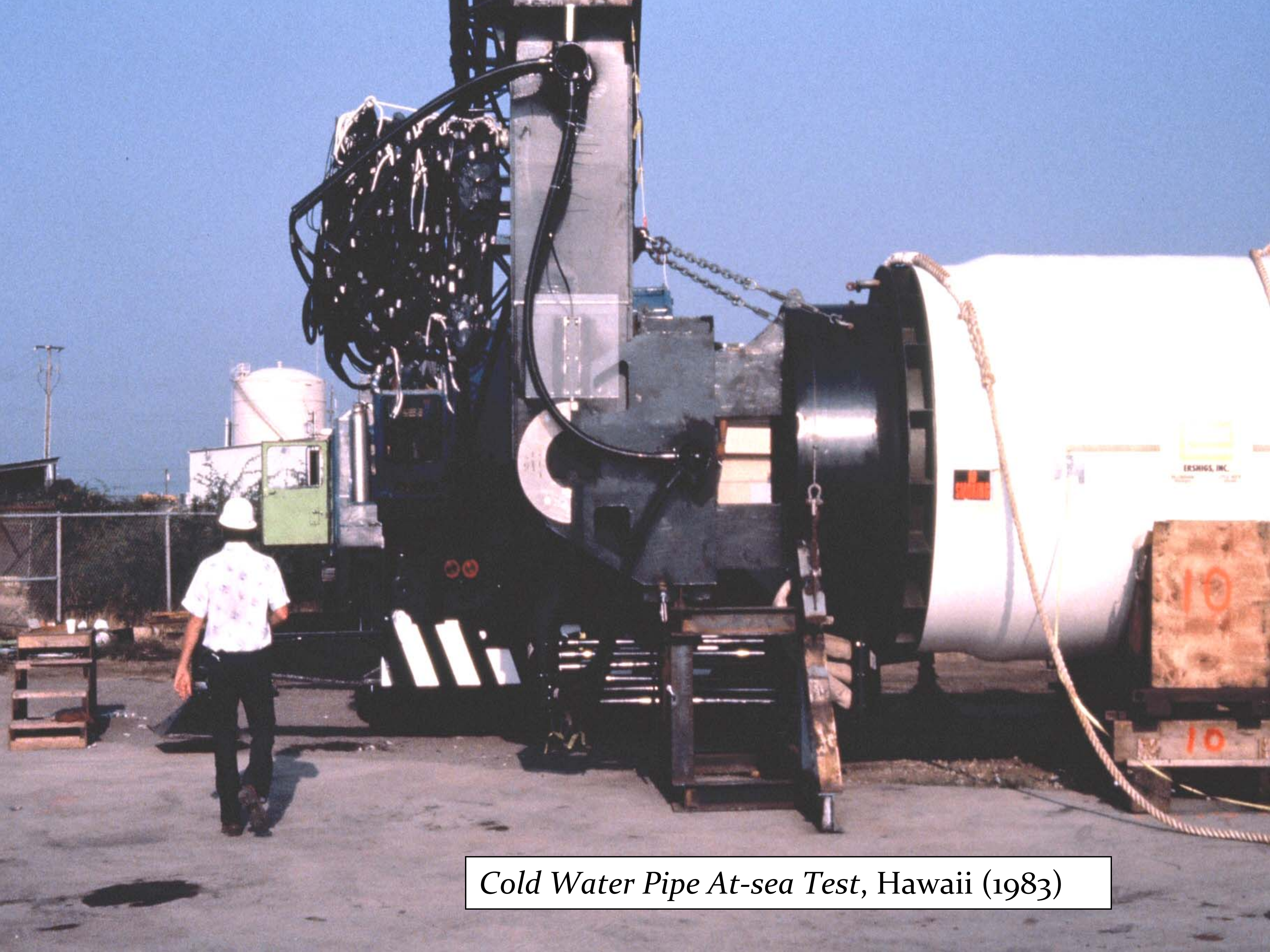


OTEC-1, Hawaii (1980)



Cold Water Pipe At-sea Test, Hawaii (1983)

Cold Water Pipe At-sea Test, Hawaii (1983)

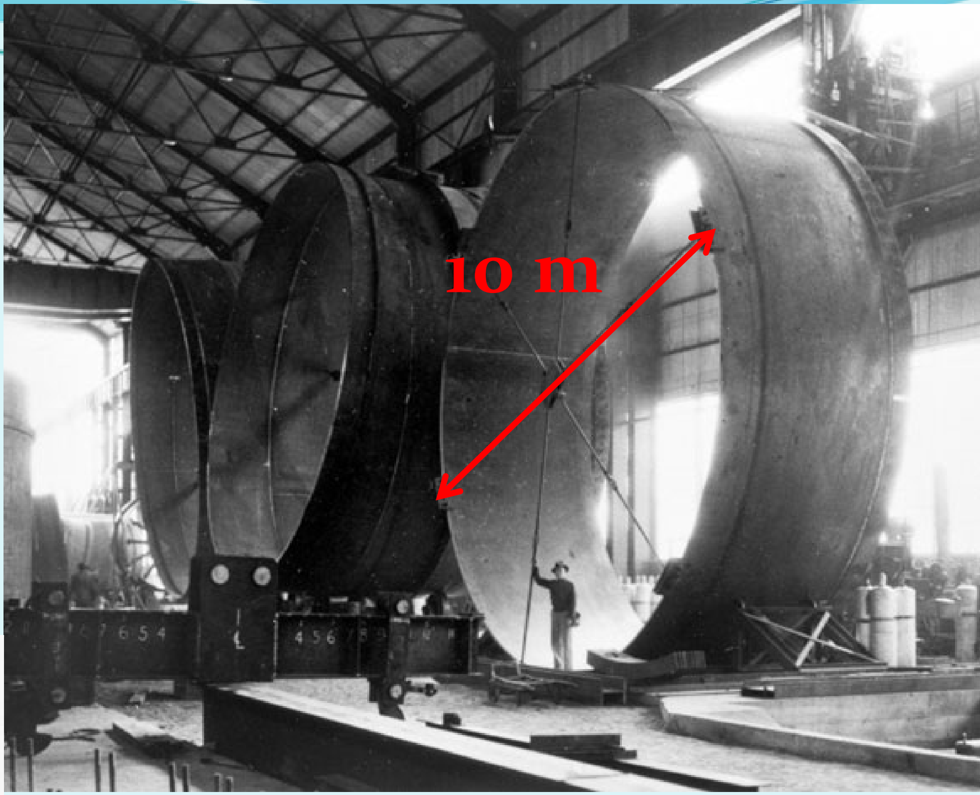


Cold Water Pipe At-sea Test, Hawaii (1983)

Cold Water Pipe At-sea Test, Hawaii (1983)

Cold Water Pipe At-sea Test, Hawaii (1983)

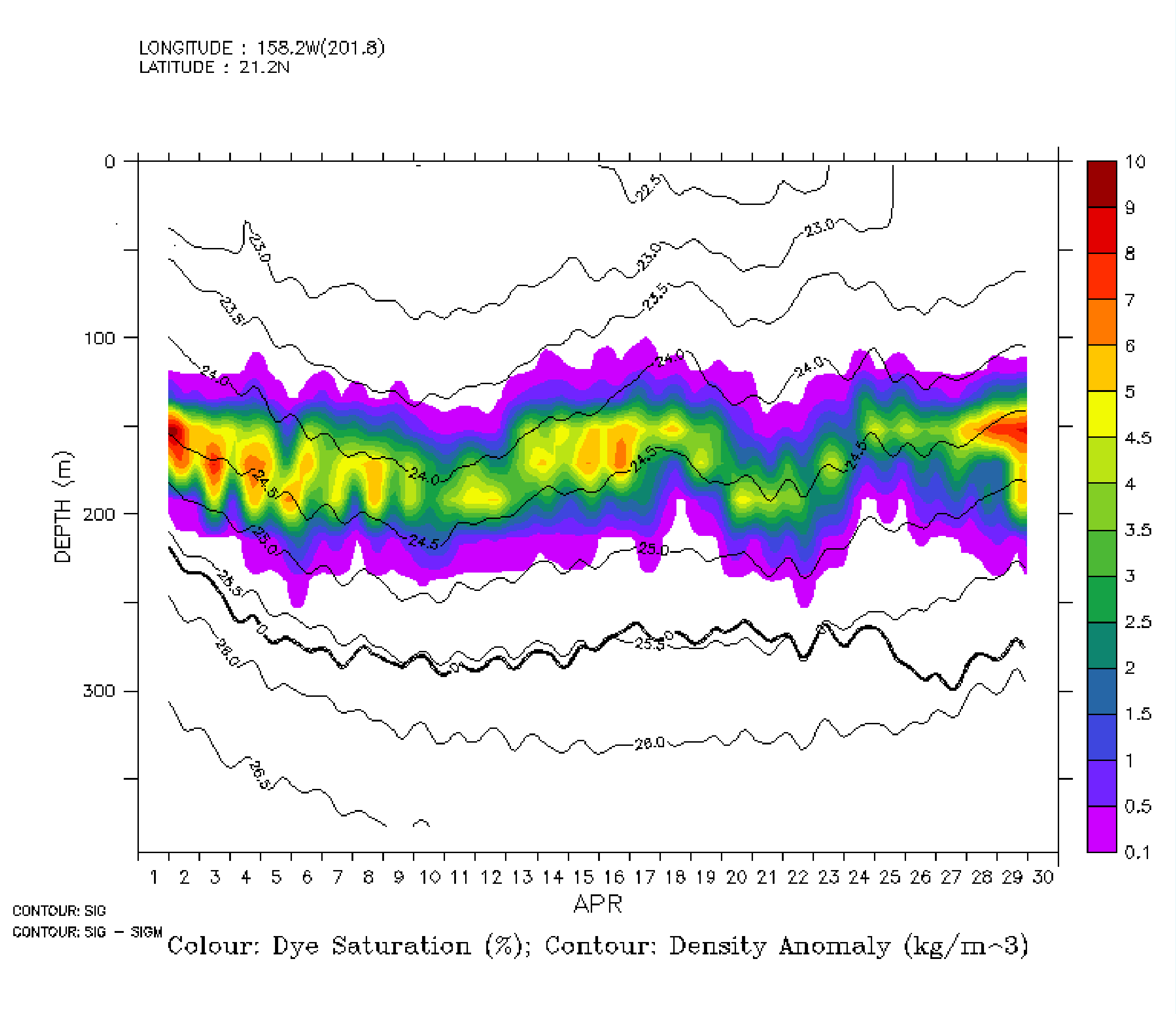
Penstock pipe from Hoover Dam construction (1934)



More 'Twists' from the High Seawater Flow Rate Intensity of OTEC

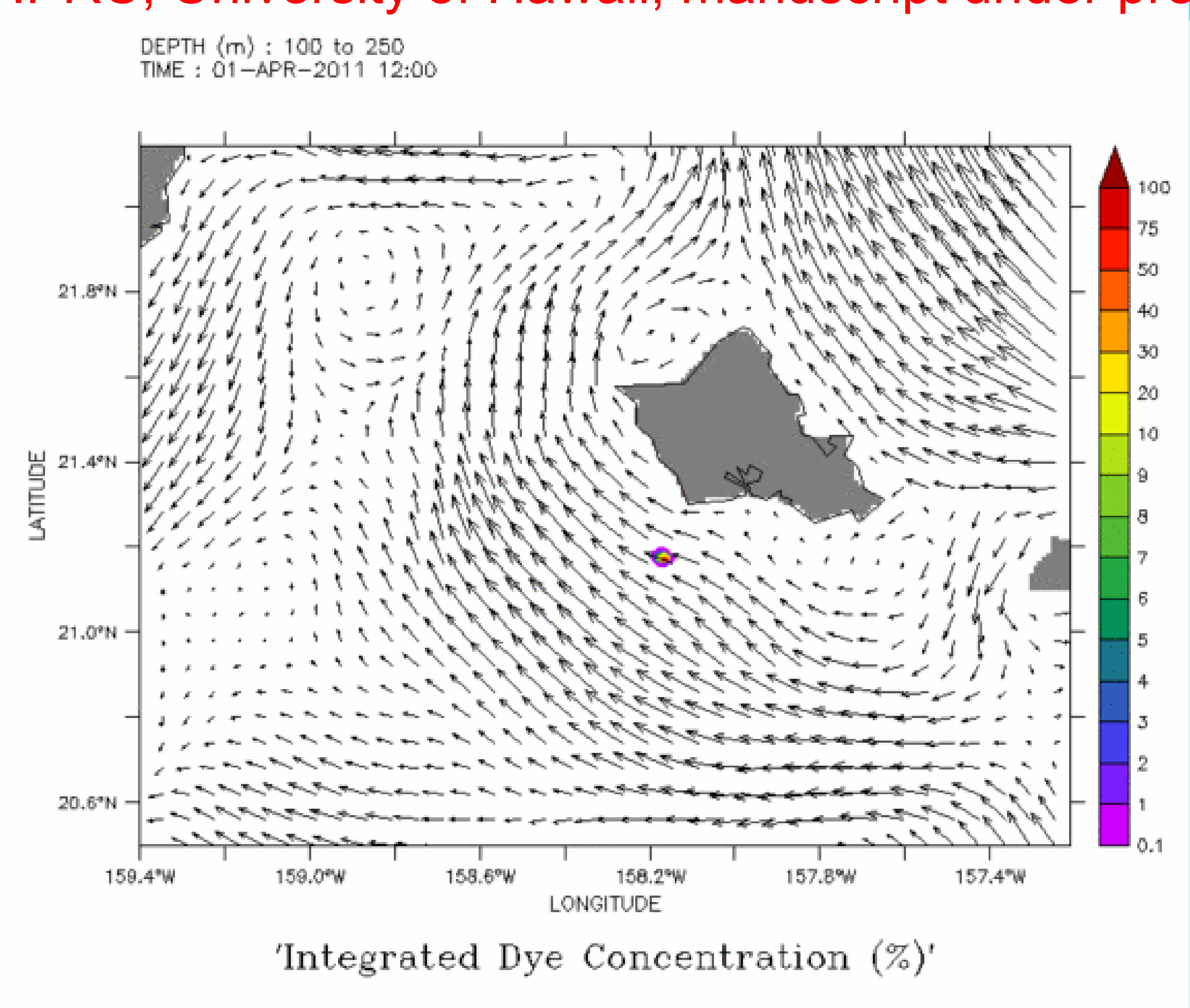
- Modeling the evolution of effluents from large OTEC plants is challenging and computationally demanding (e.g., ongoing work by Jia *et al.*, University of Hawaii).
- The tantalizing possibility of an opportunistic boost of the marine food web should be investigated.
- Global OTEC resources appear to be 'self-limited' from interactions with the thermal structure of the water column (ongoing work by Rajagopalan and Nihous, University of Hawaii).
- A global OTEC production of 5 to 10 TW would have little impact, although the maximum is much greater.

Jia *et al*., IPRC, University of Hawaii, manuscript under preparation



Vertical profile of dye at the mass source grid cell for the base experiment. Thick black line indicates the density of mixed warm and cold water intakes before discharge.

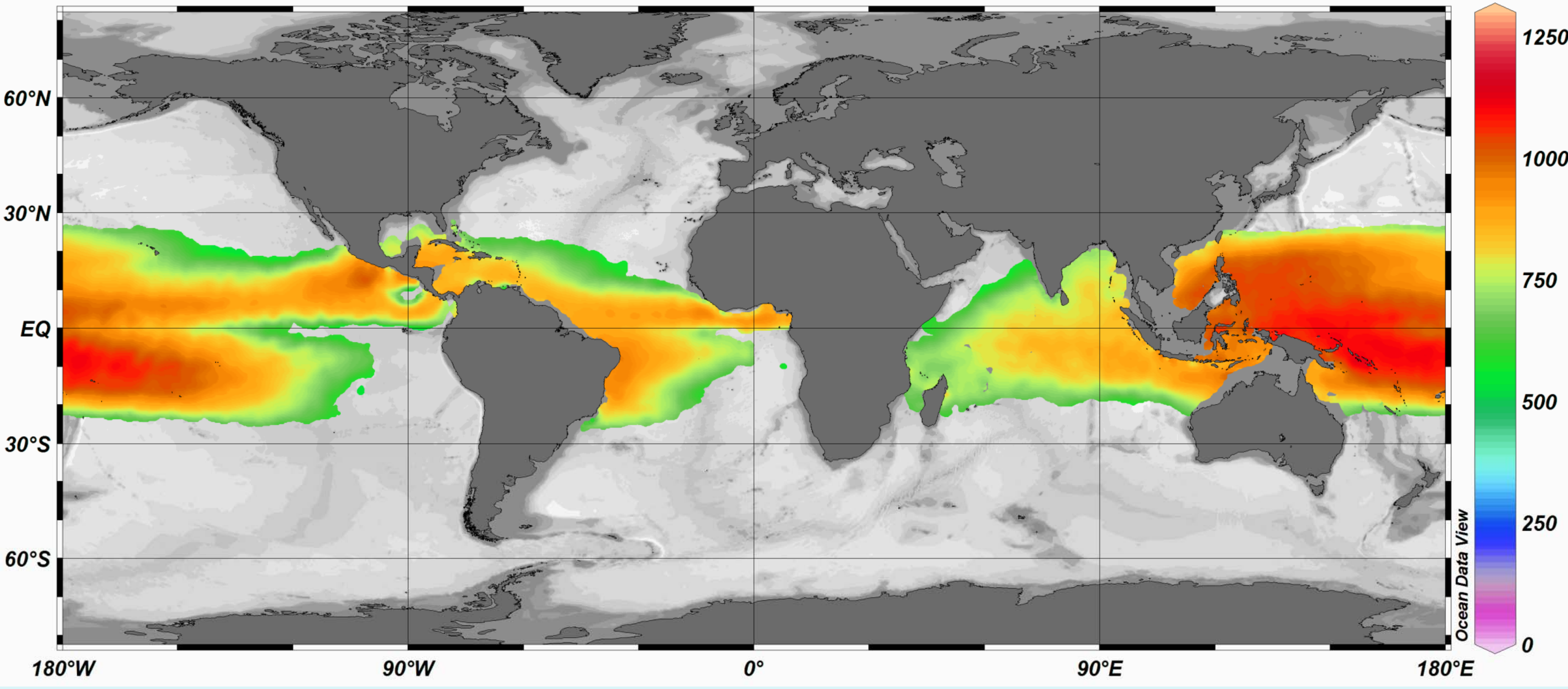
Jia *et al*., IPRC, University of Hawaii, manuscript under preparation



Vertically integrated dye concentration. Arrows represent vertically averaged flow in the same depth range (100-250 m). Base case flow rates.

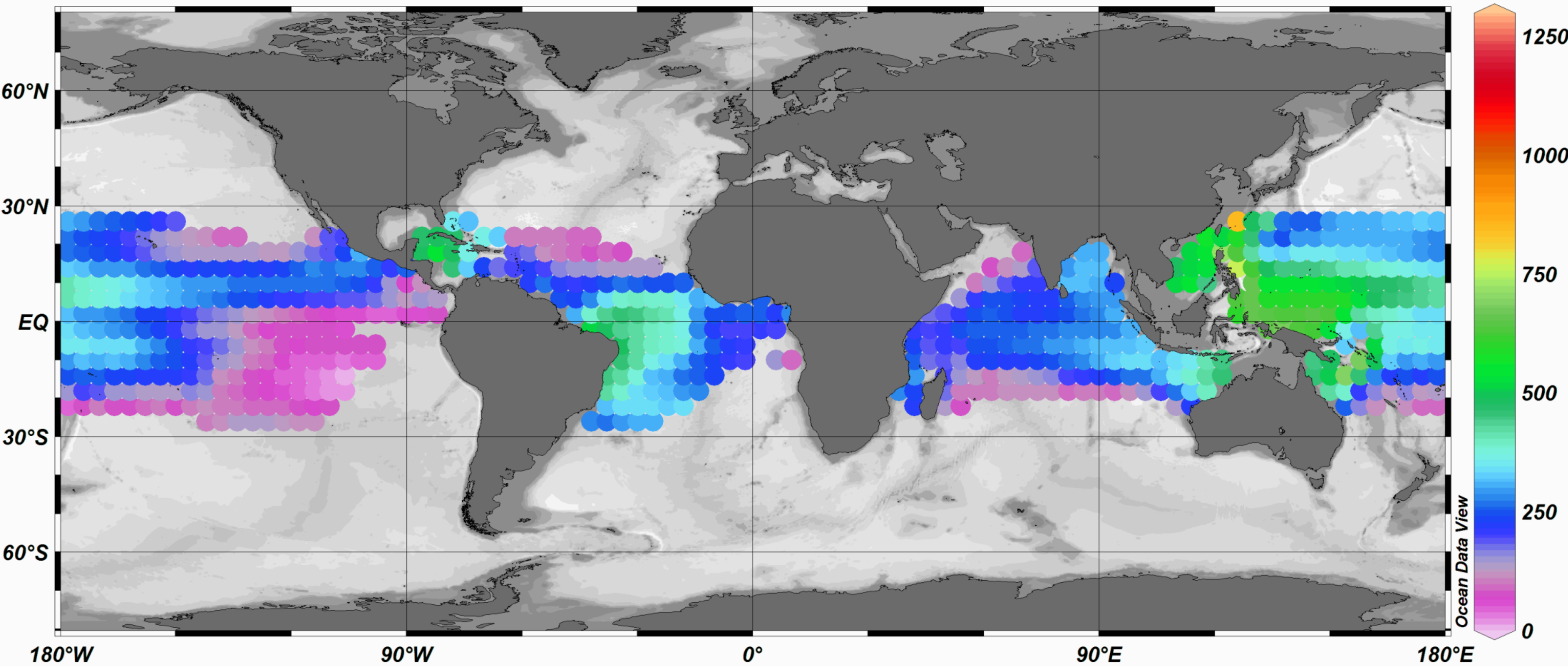
Rajagopalan and Nihous, ORE, University of Hawaii, manuscript submitted to *Renewable Energy* (February 2012)

OTEC Power density (kW/km^2) at global maximum
No interaction

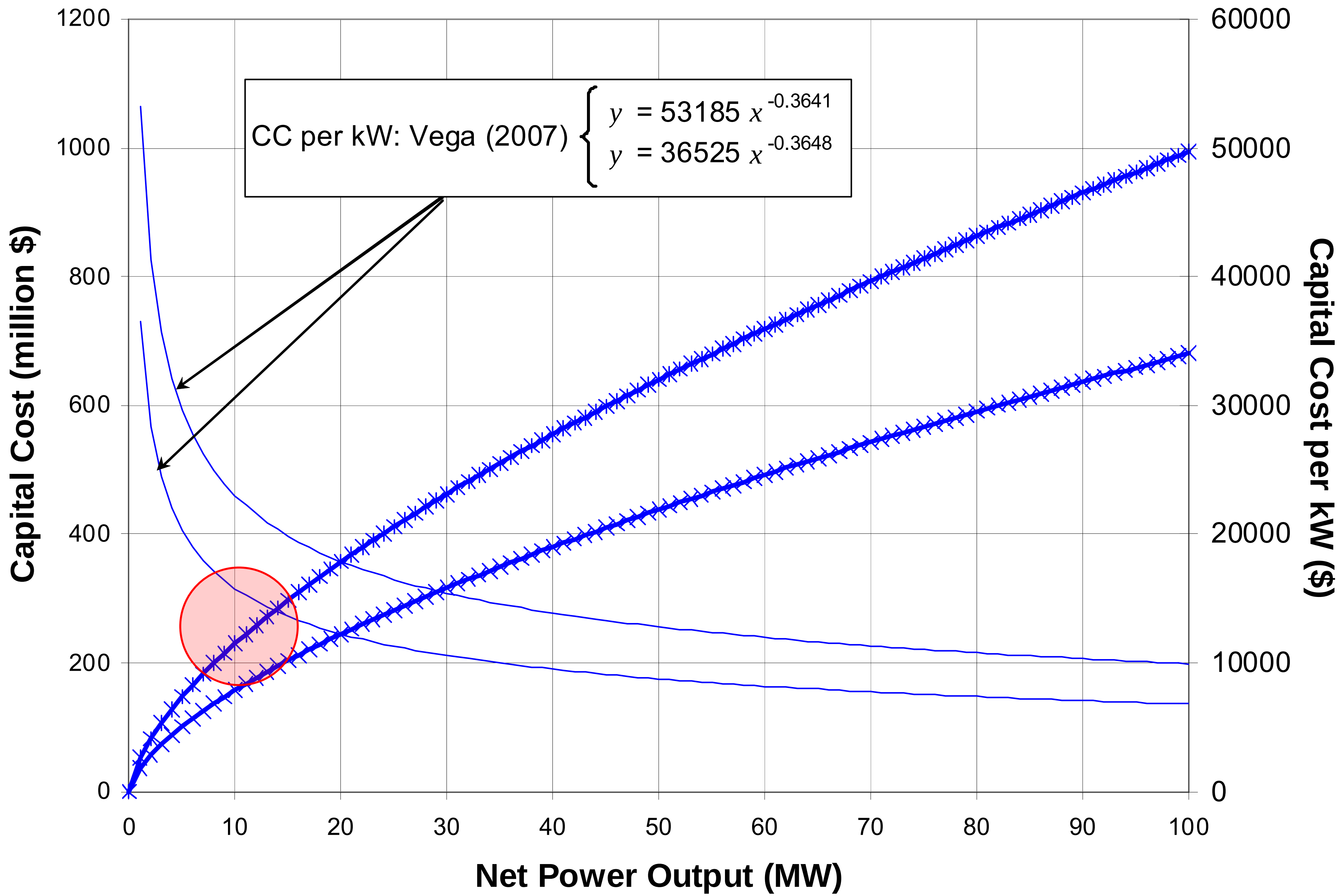


Rajagopalan and Nihous, ORE, University of Hawaii, manuscript submitted to *Renewable Energy* (February 2012)

OTEC Power density (kW/km^2) at global maximum
Full coupling



OTEC Cost Summary



- The technological development of OTEC is an ‘unfinished business’.
- Scaled-up (and scalable) floating pilot systems must provide operational record.
- At a cost of 200 to 300 millions ($), these 5 to 10 MW systems are not attractive in a market-driven context.
- Governmental ‘willpower’ or a concerted effort from multiple stakeholders are likely necessary to move forward.