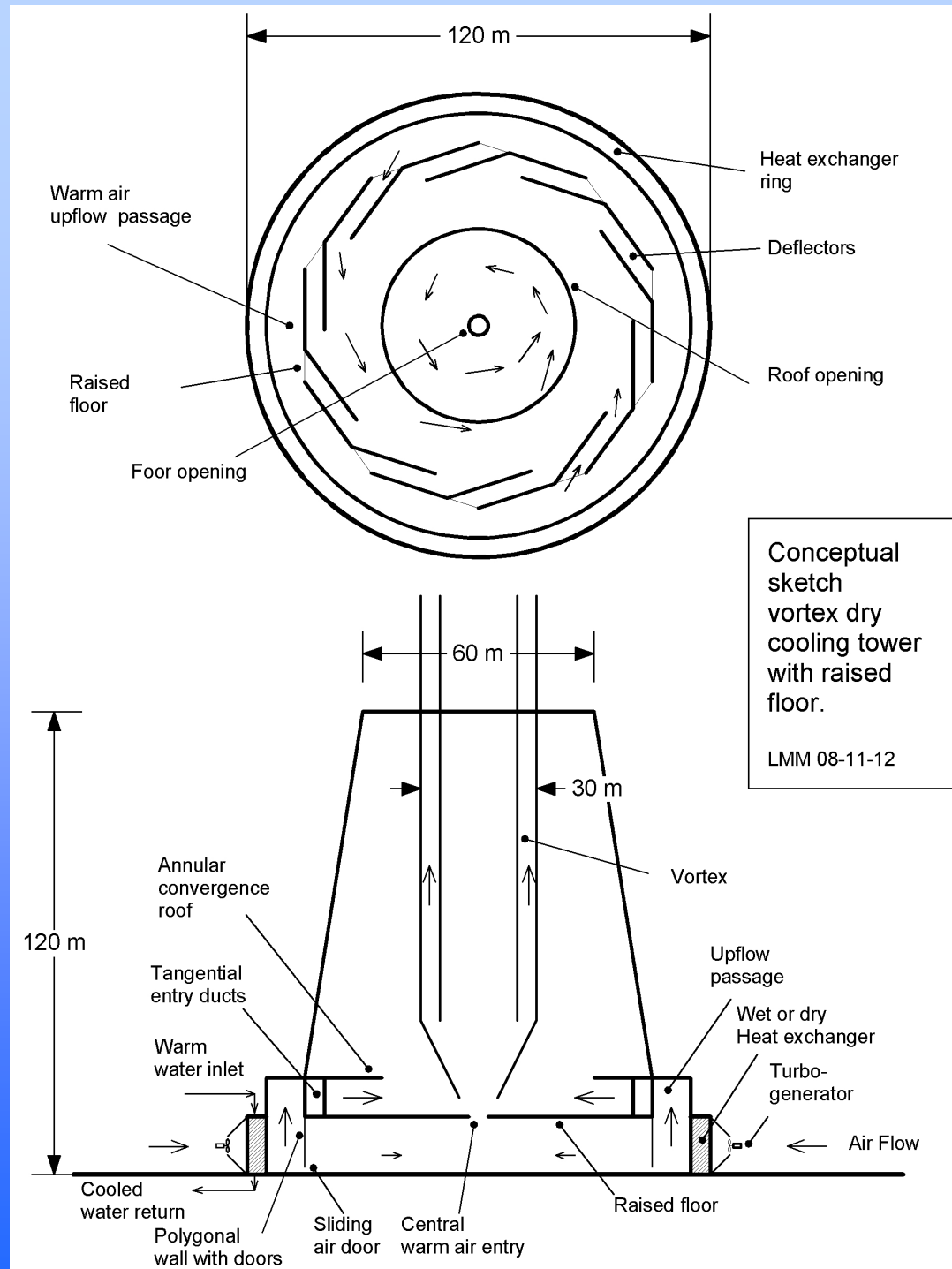
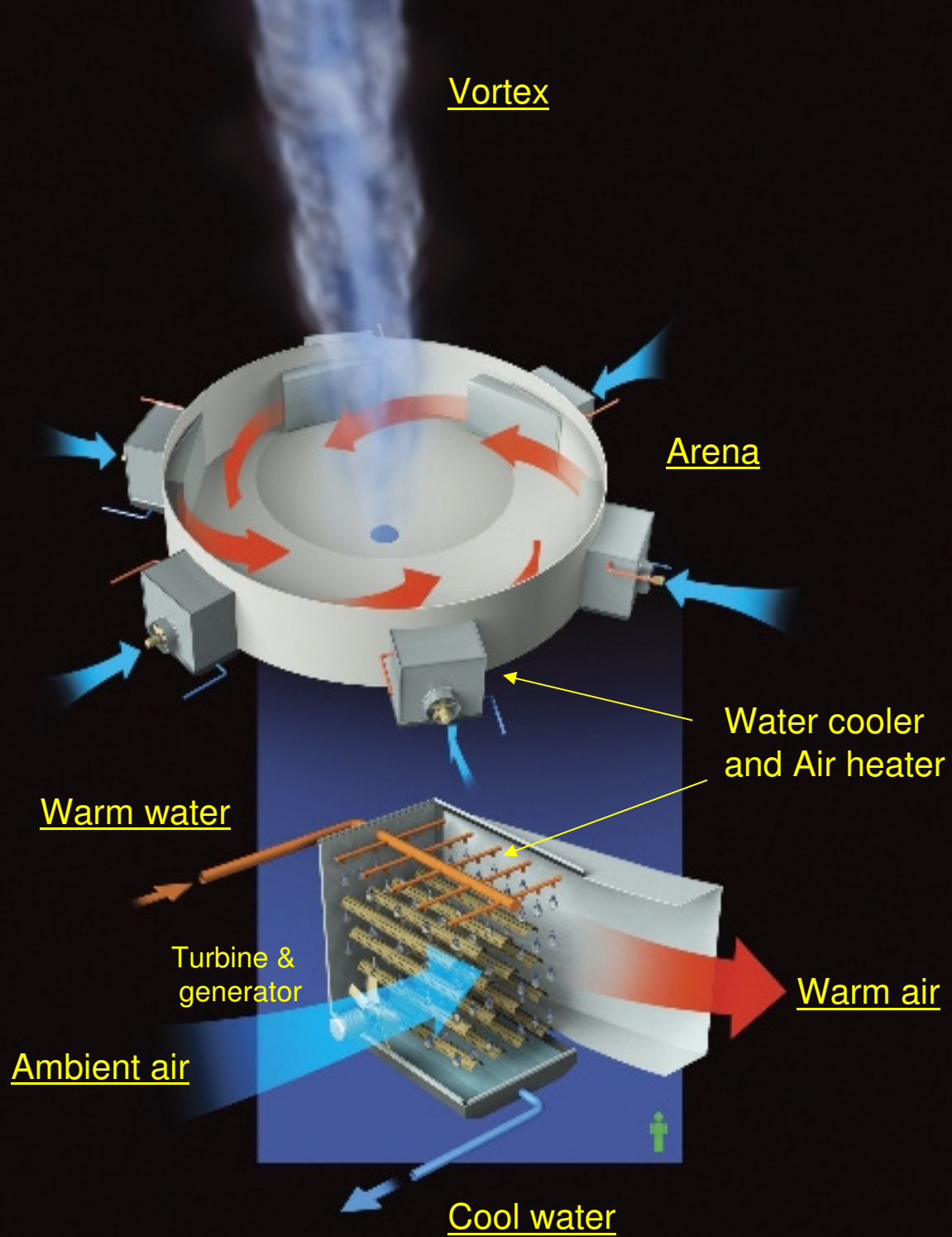




AVE THE FUTURE

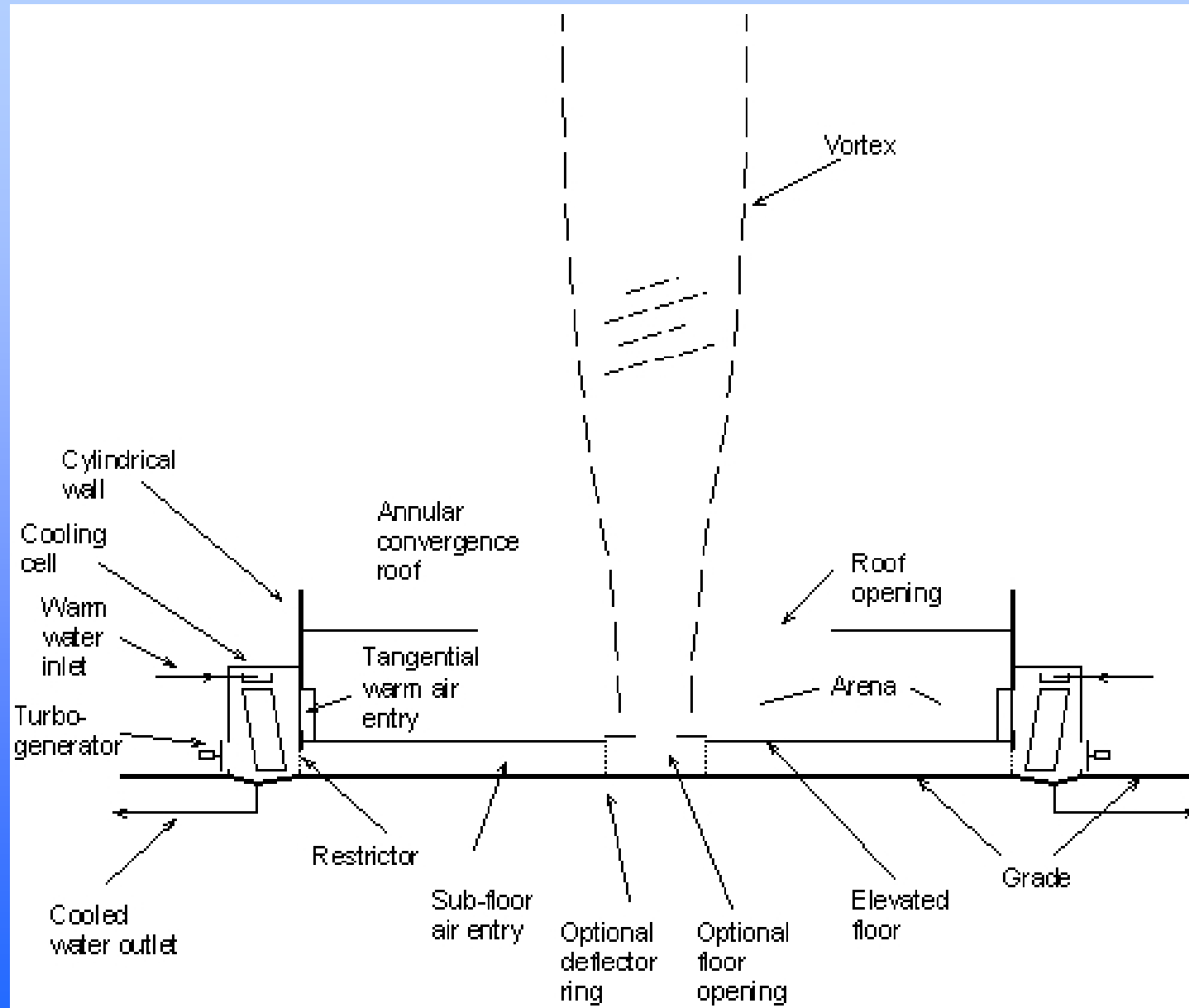
[HTTP://VORTEXENGINE.CA](http://vortexengine.ca)





Wet cooling tower AVE – Side view

Capacity approximately 200 MW



HEIGHT ADVANTAGE OF A VORTEX



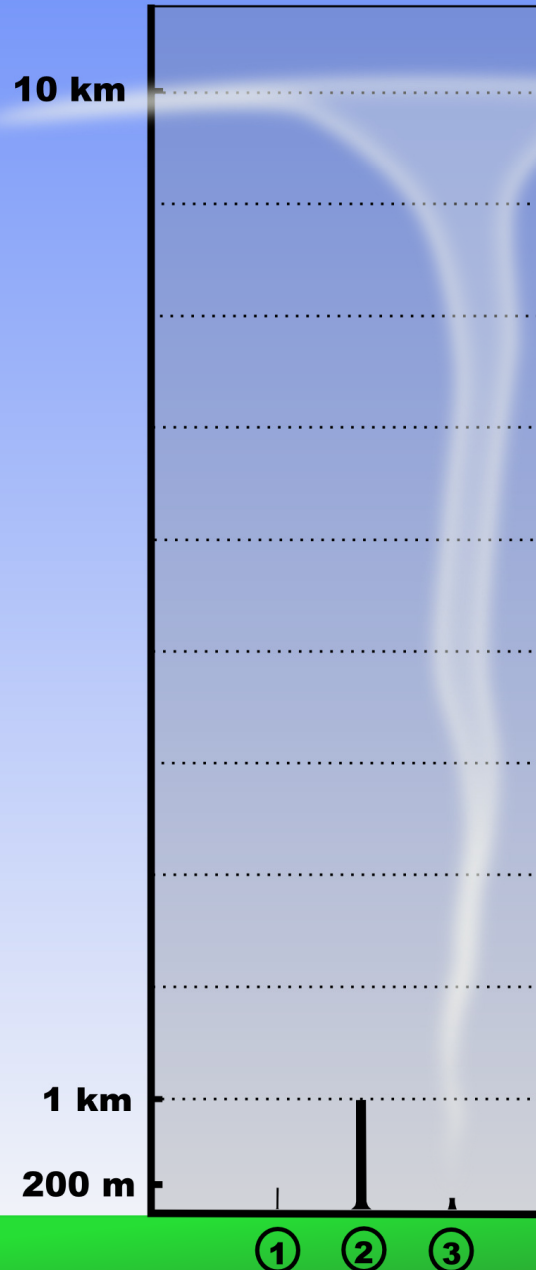
① MANZANARES SOLAR CHIMNEY

Size: 200 m high, Ø10 m
 Collector area: 0.04 km²
 Ambient air temperature: 25 °C
 Inlet air temperature: 45 °C
 Outlet air temperature: 43 °C
 Efficiency: 0.2%
 50 kW, 130 J/kg, 1 Mg/s
 Spain 1982 to 1989



② ENVIROMISSION SOLAR TOWER

Size: 1 km high, Ø130 m
 Collector area: 40 km²
 Ambient air temperature: 25 °C
 Inlet air temperature: 45 °C
 Outlet air temperature: 35 °C
 Efficiency: 1.5%
 200 MW, 800 J/kg, 300 Mg/s
 Australia, 2009+



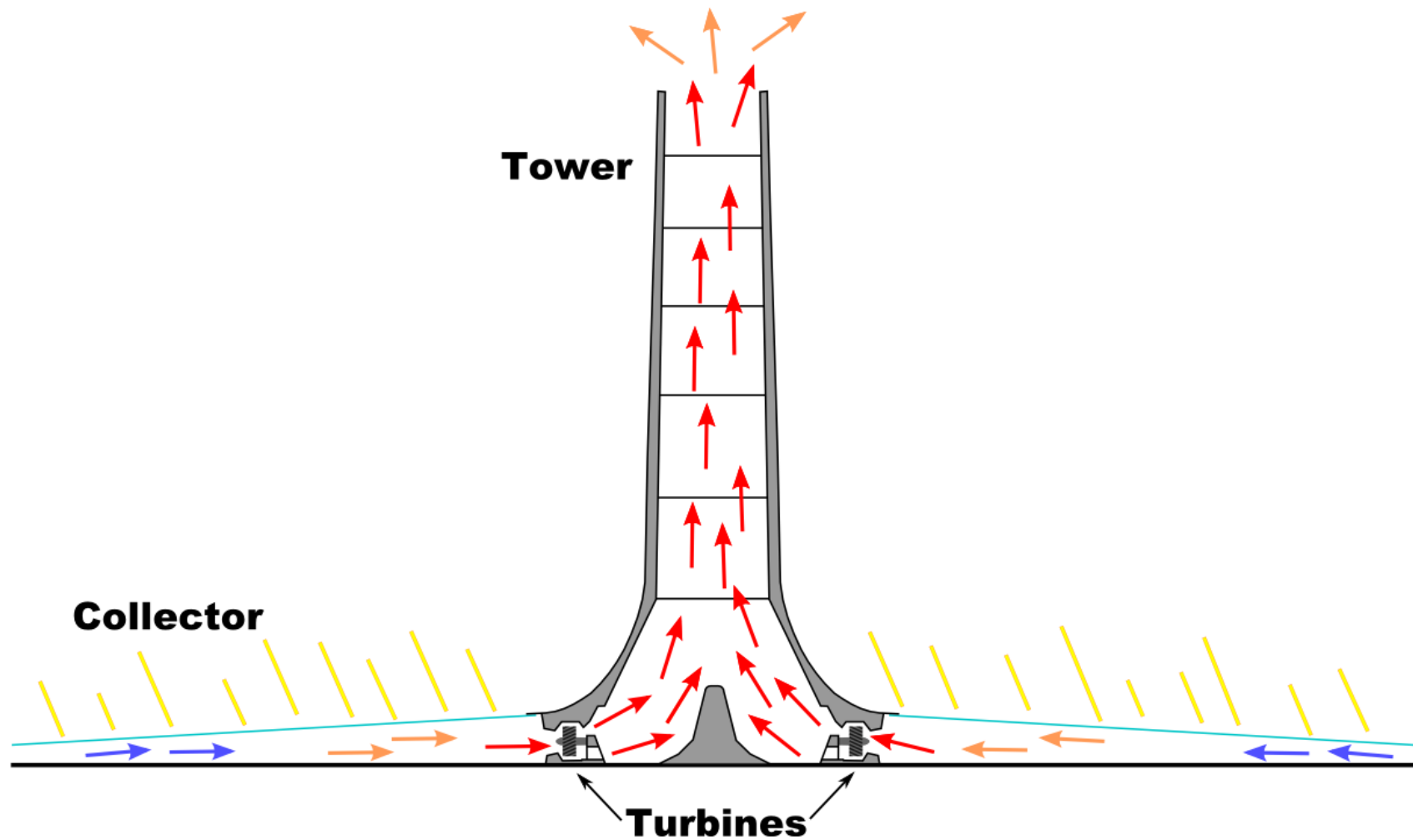
- The AVE replaces the physical chimney with centrifugal force in a vortex
- The AVE eliminates the solar collector by using waste heat or natural low temperature heat sources



③ ATMOSPHERIC VORTEX ENGINE

Size: Structure: 50 m, Ø200 m
 Vortex: 10 km +
 Collector area: NOT REQUIRED
 Inlet air temperature: 25-50 °C
 Outlet air temperature: -60 °C
 Efficiency: 20% +
 200 MW, 10,000 J/kg, 20 Mg/s

Solar Updraft Tower



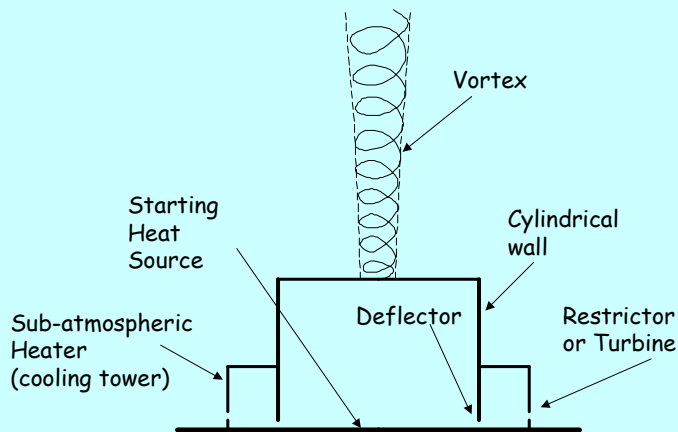
Cooling Towers



Mechanical Draft: \$15 million 40 m tall mechanical draft tower uses 1% to 4% of power output to drive fans. (uses energy)



Natural Draft: doesn't need fans but is 150 m tall and costs \$60 million. (saves energy)



LMM

Atmospheric Vortex Engine

2

Vortex Cooling Tower: \$15 million 40 m tall to function like a natural draft tower. (produces energy!)

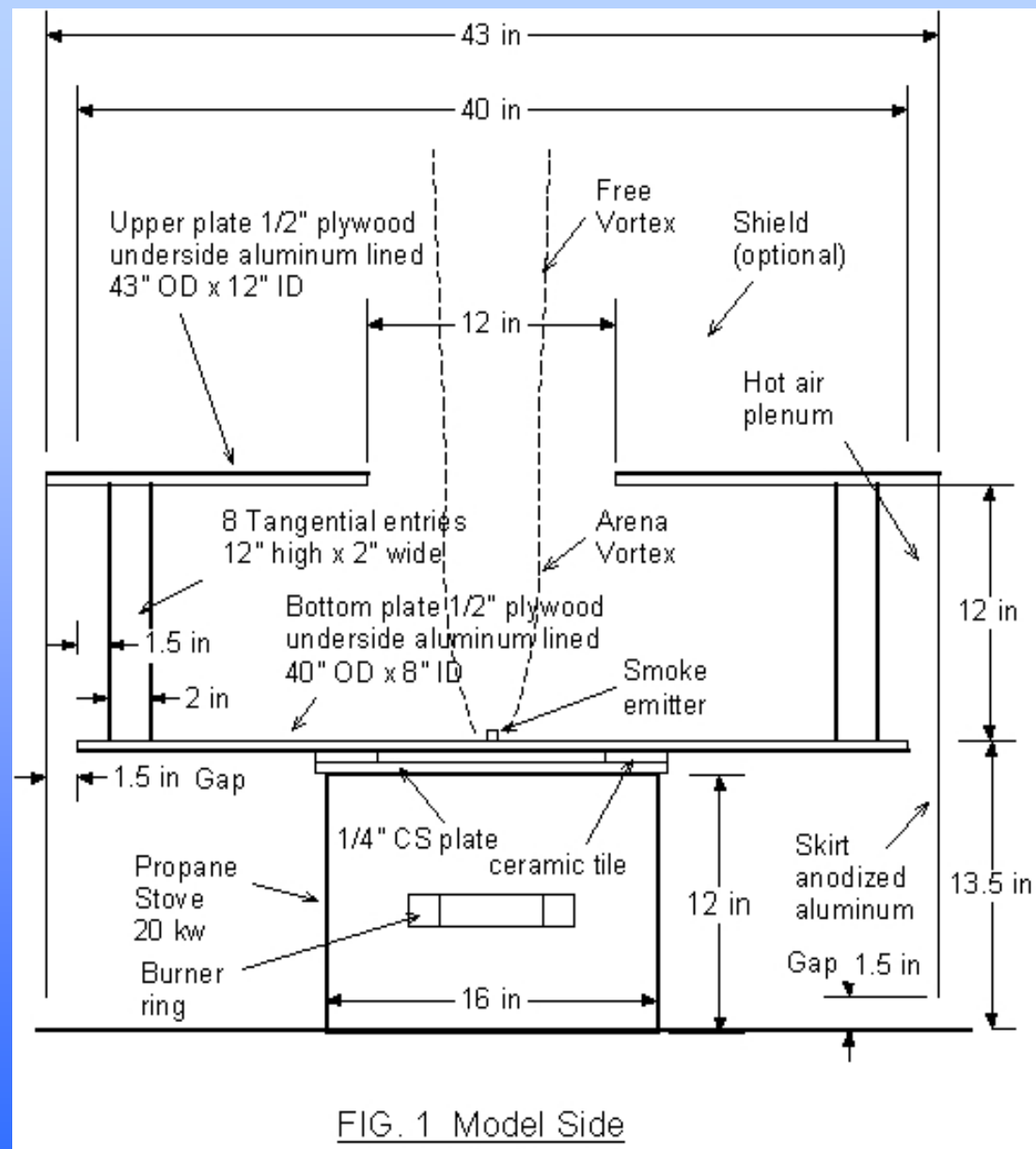
Typical Vortex Engine Size

- Circular wall diameter 50 to 200 m
- Circular wall height 30 to 80 m
- Vortex base diameter 20 to 50 m
- Vortex height 1 to 20 km
- Heat input 1000 MW. 20, 50 MW cooling cells
- Electrical output 200 MW. 20, 10 MW turbines
- Specific work 1000 to 20000 J/kg
- Air flow 20 to 100 Mg/s
- Water flow 40 to 200 Mg/s

Vortex in 1 meter diameter physical model



1 meter diameter physical model – side view



1 meter diameter physical model – top view

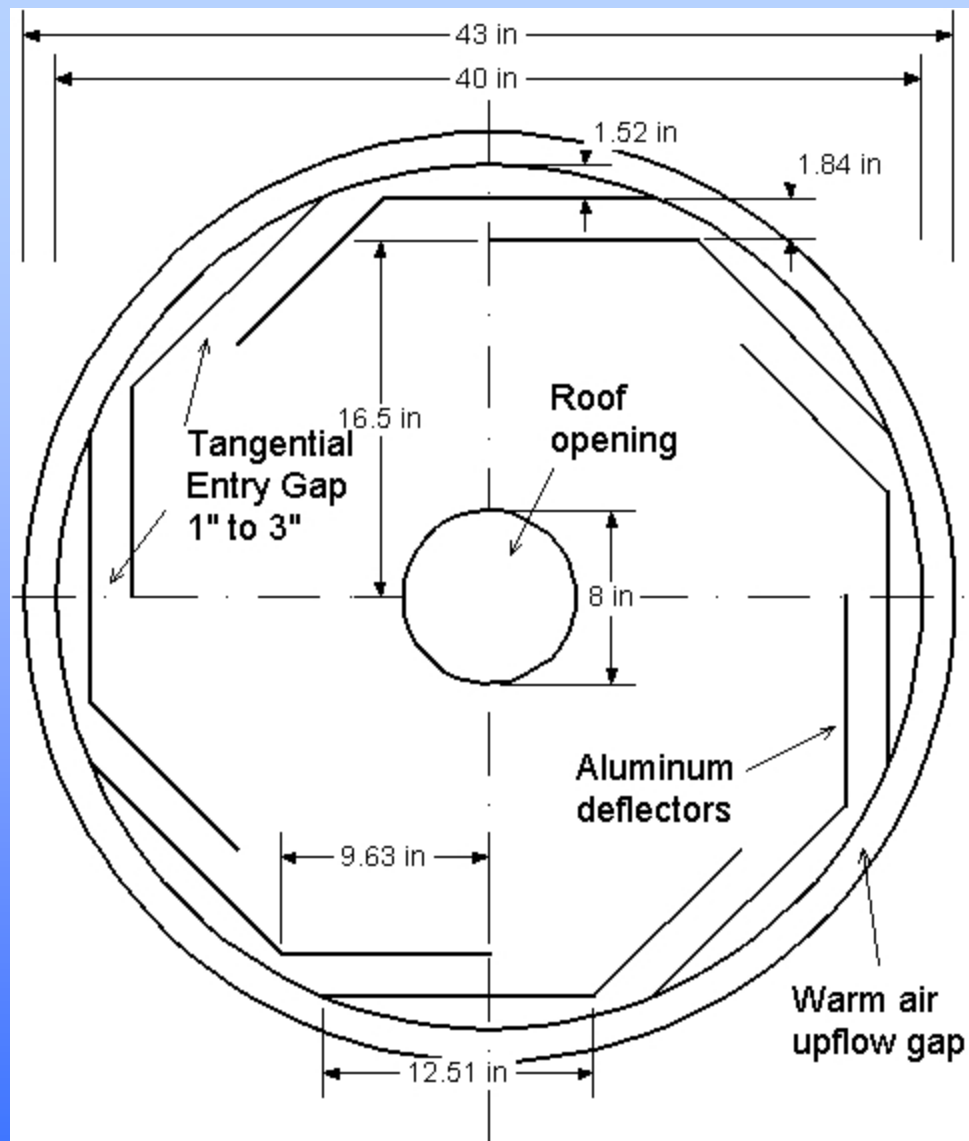
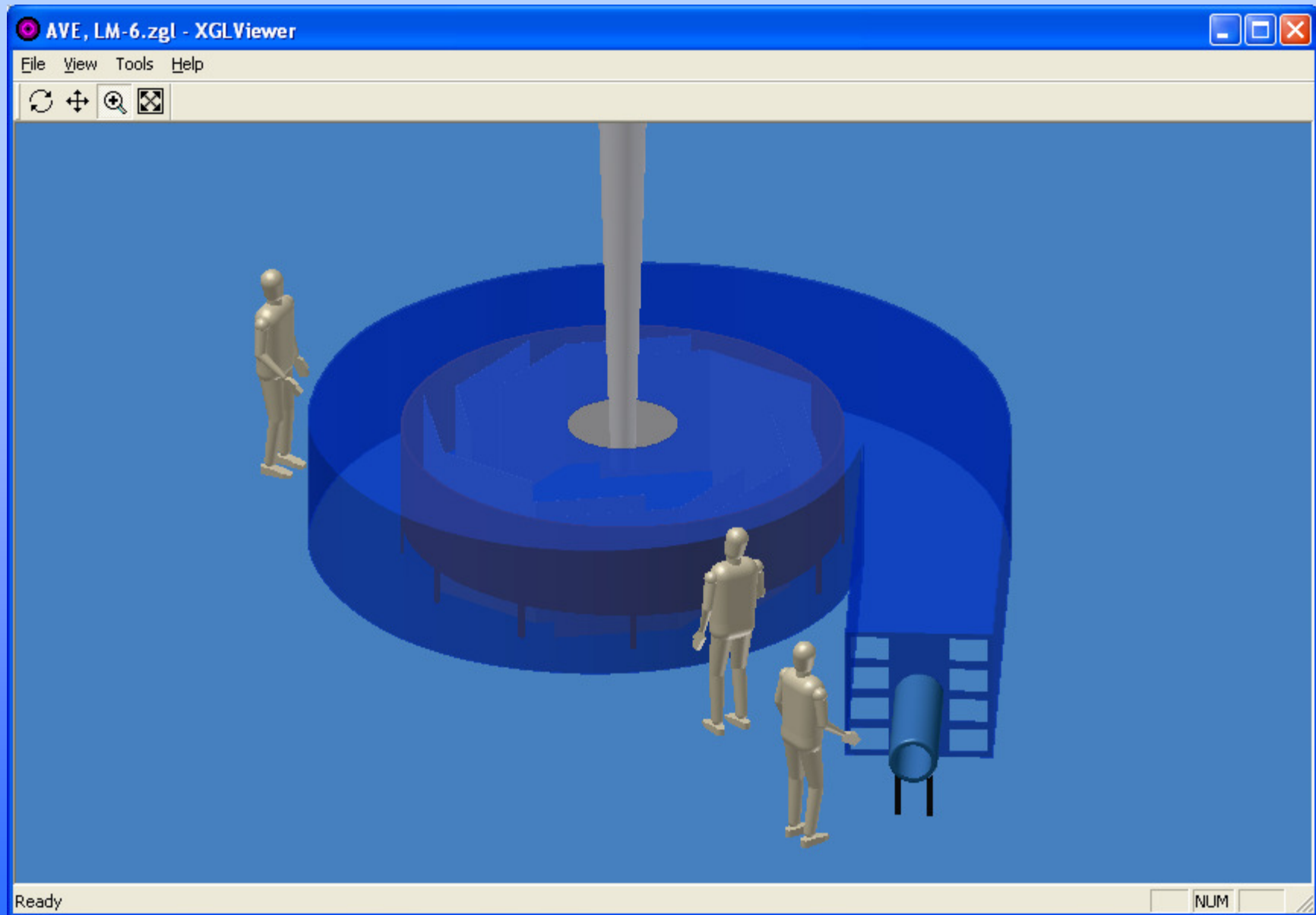


FIG. 2 Plan view - deflectors and upflow gap

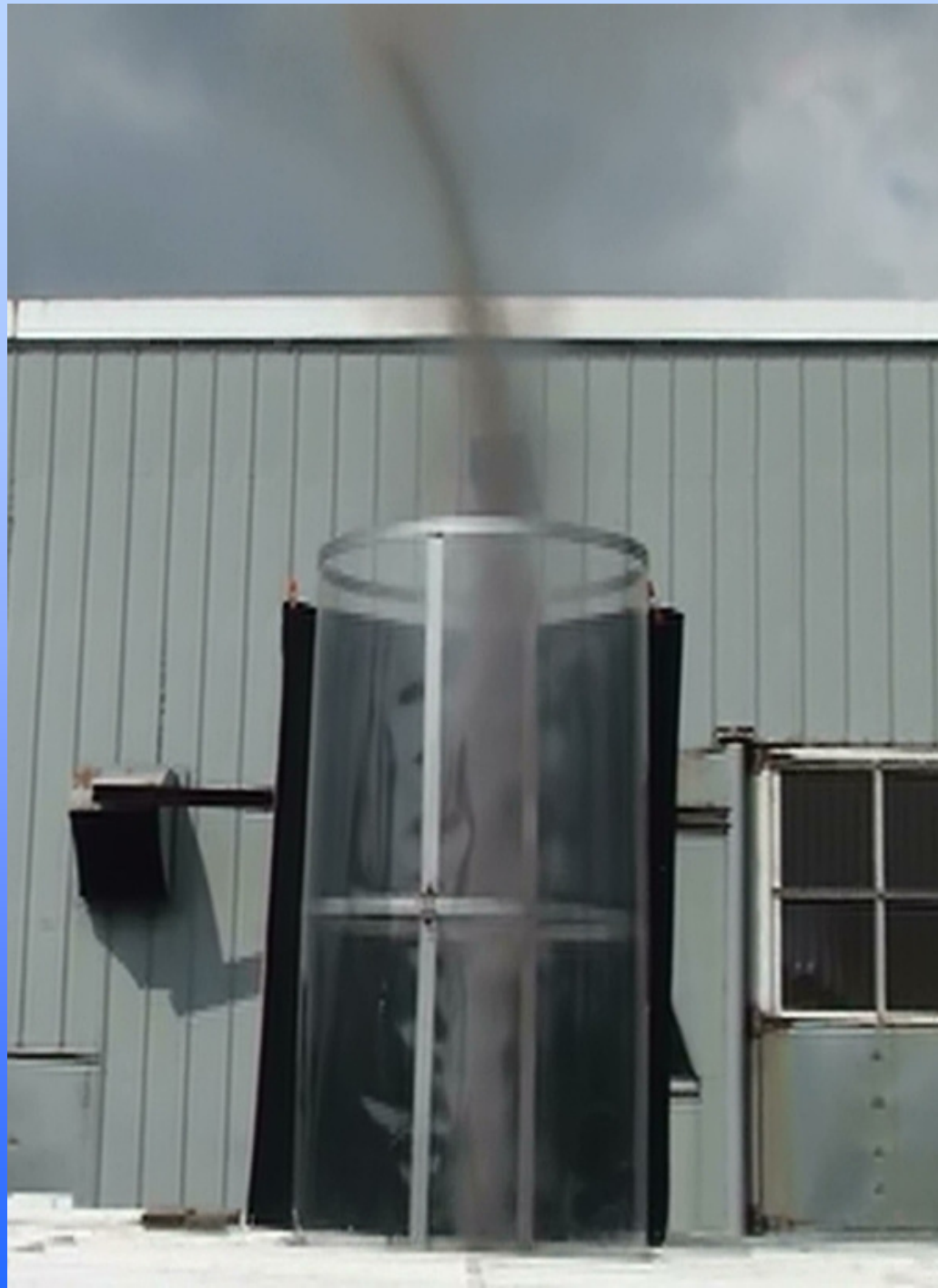
4 m diameter prototype transparent wall view





Petrolia

4 m prototype
vortex



Petrolia

4 m prototype
vortex

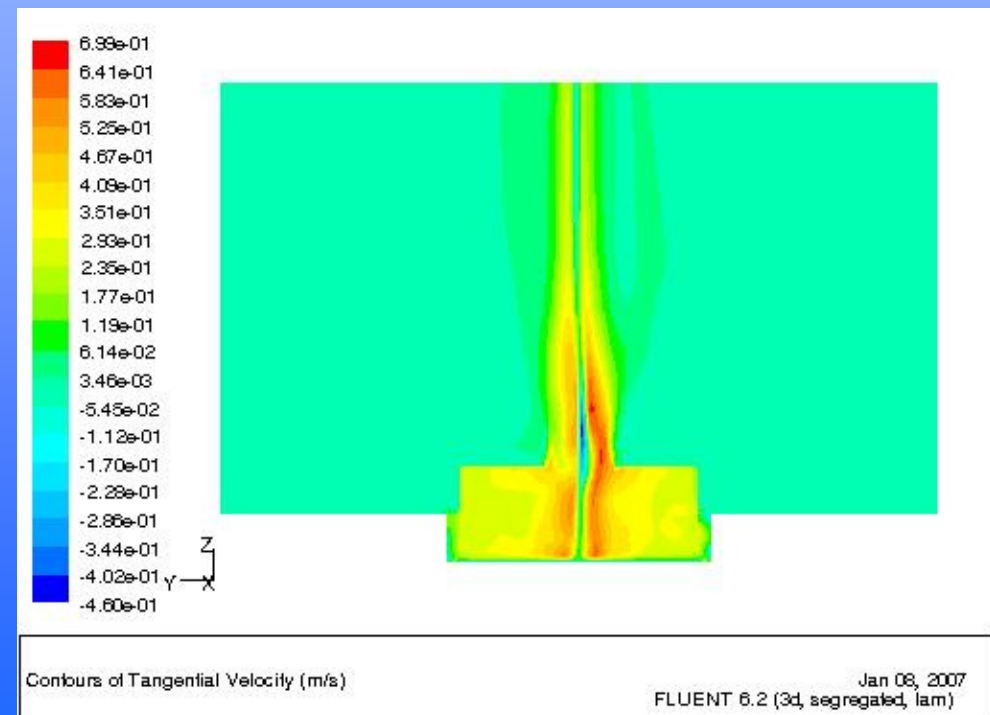
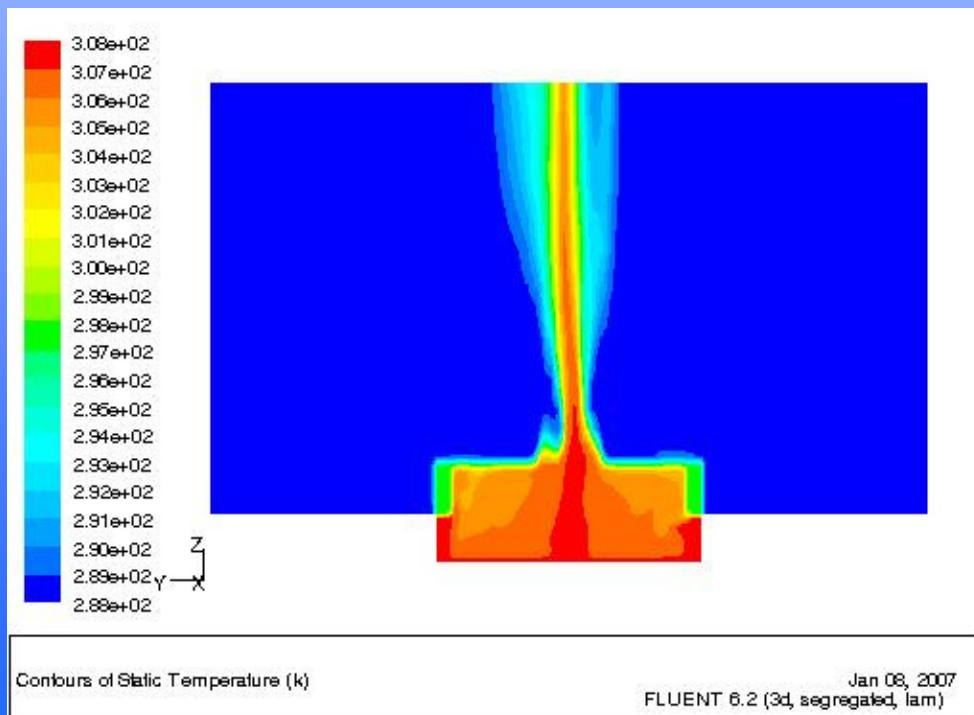


Video available at:

<http://vortexengine.ca/LM6/20080925155414-1.mpg>

CFD Results

- Ontario Centre of Excellence (OCE) and the University of Western Ontario (UWO) Boundary Layer Wind Tunnel Laboratory (BLWTL) recently completed a Computational Fluid Dynamics (CFD) study of the AVE
- Results for a 1 m diameter model simulation with a domain height of 2 m are shown below



Airflow in a Vortex at Altitude

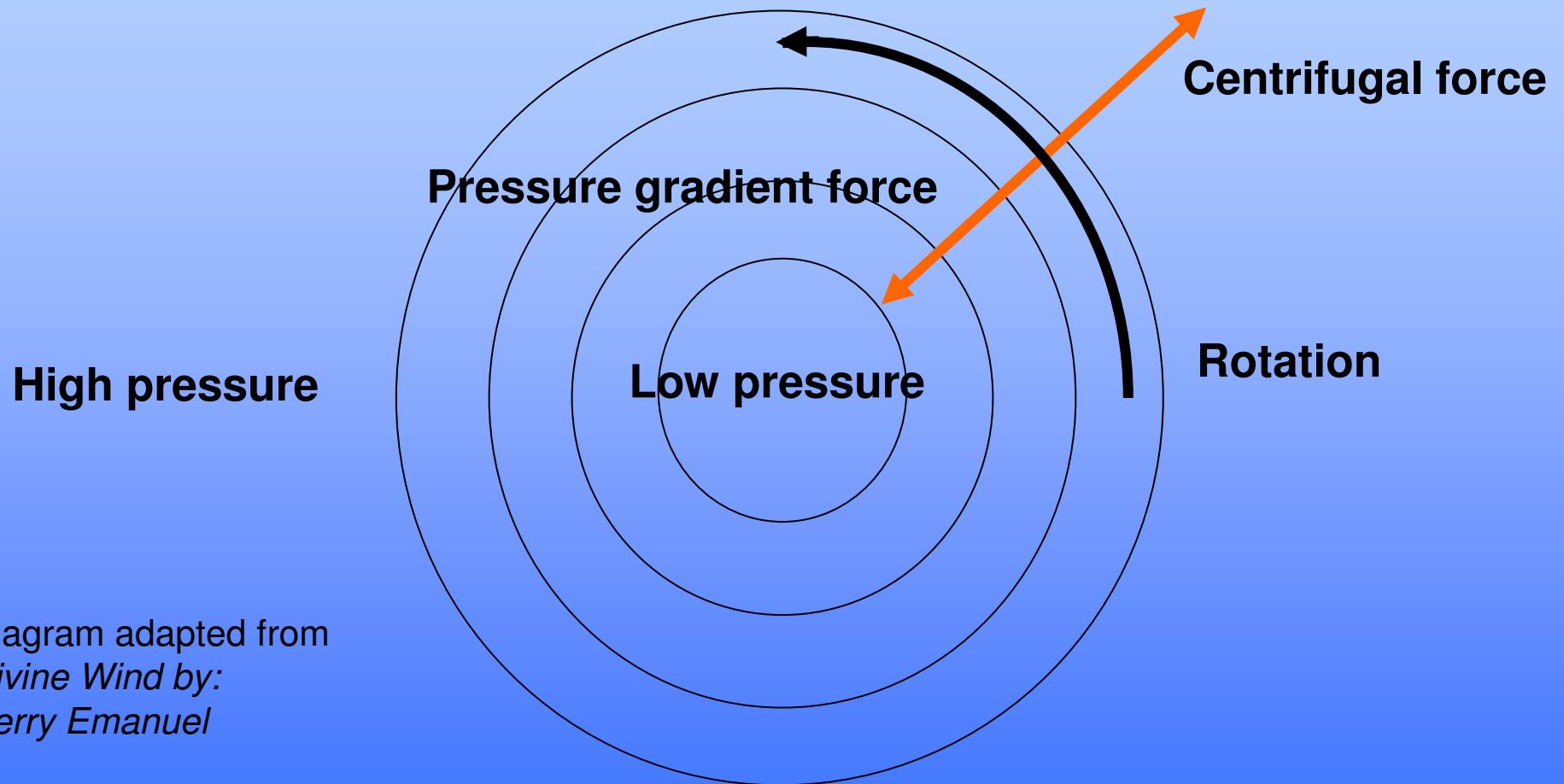
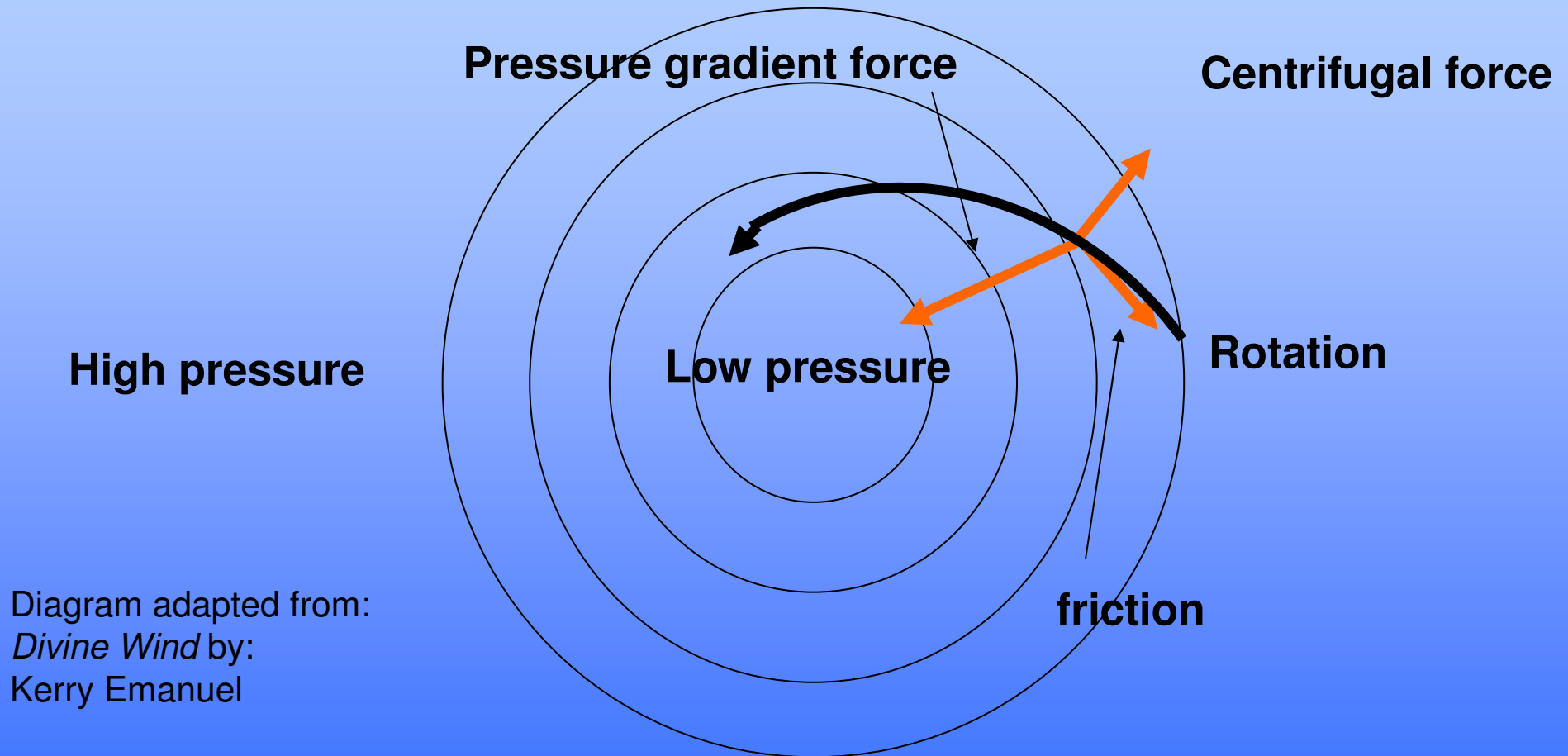


Diagram adapted from
Divine Wind by:
Kerry Emanuel

At altitude, the pressure gradient force (inwards) exactly equals the centrifugal force (outwards). The air rotates without a significant radial component

Airflow in a Vortex at Ground Level



Near the ground, friction acts to reduce the rotational velocity and hence the centrifugal force. The air spirals towards the centre.

Natural Vortices

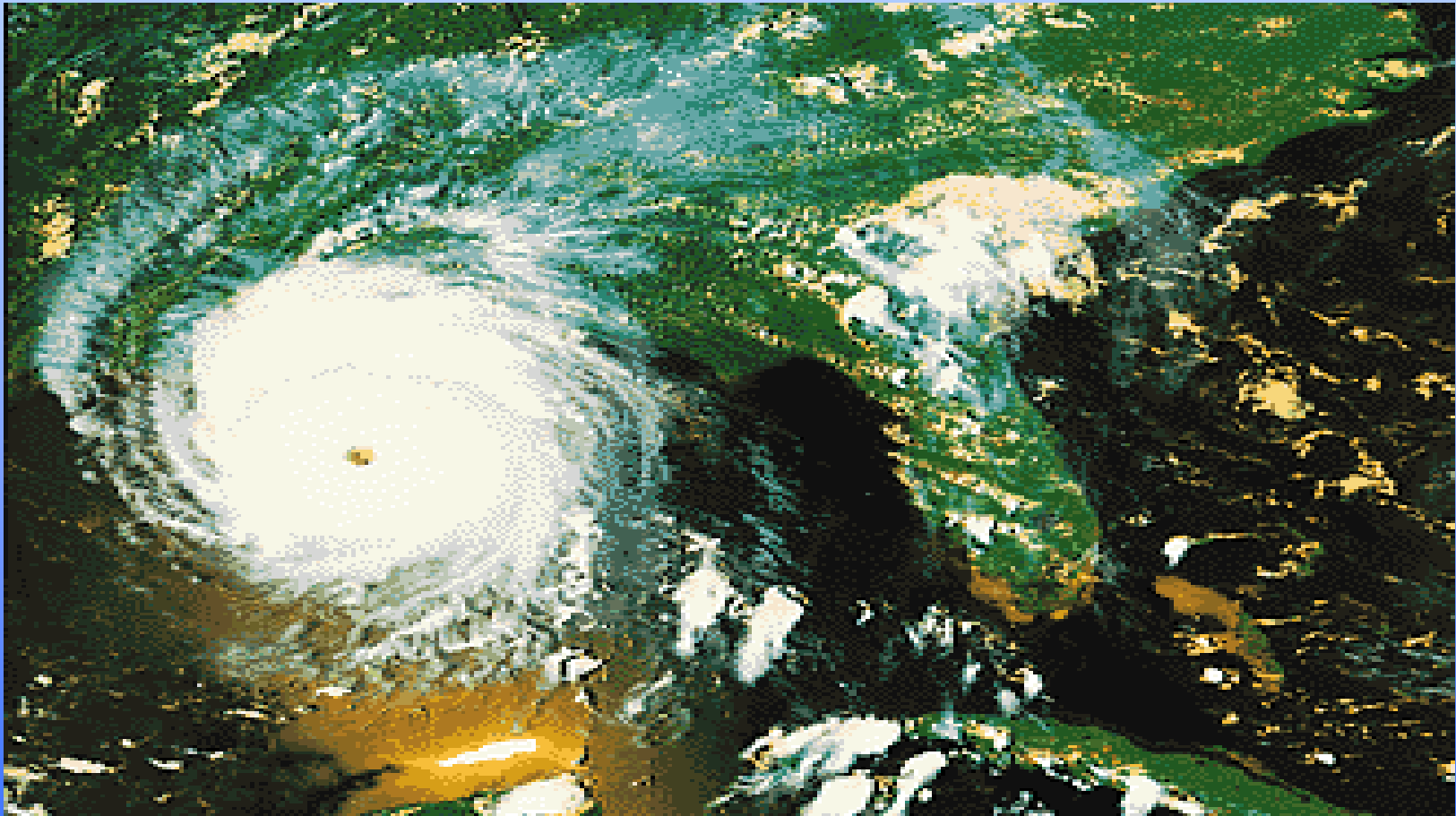


Tornado



Waterspout

Hurricane



NASA

Fire whirls

Accidental ←

Deliberate ↓

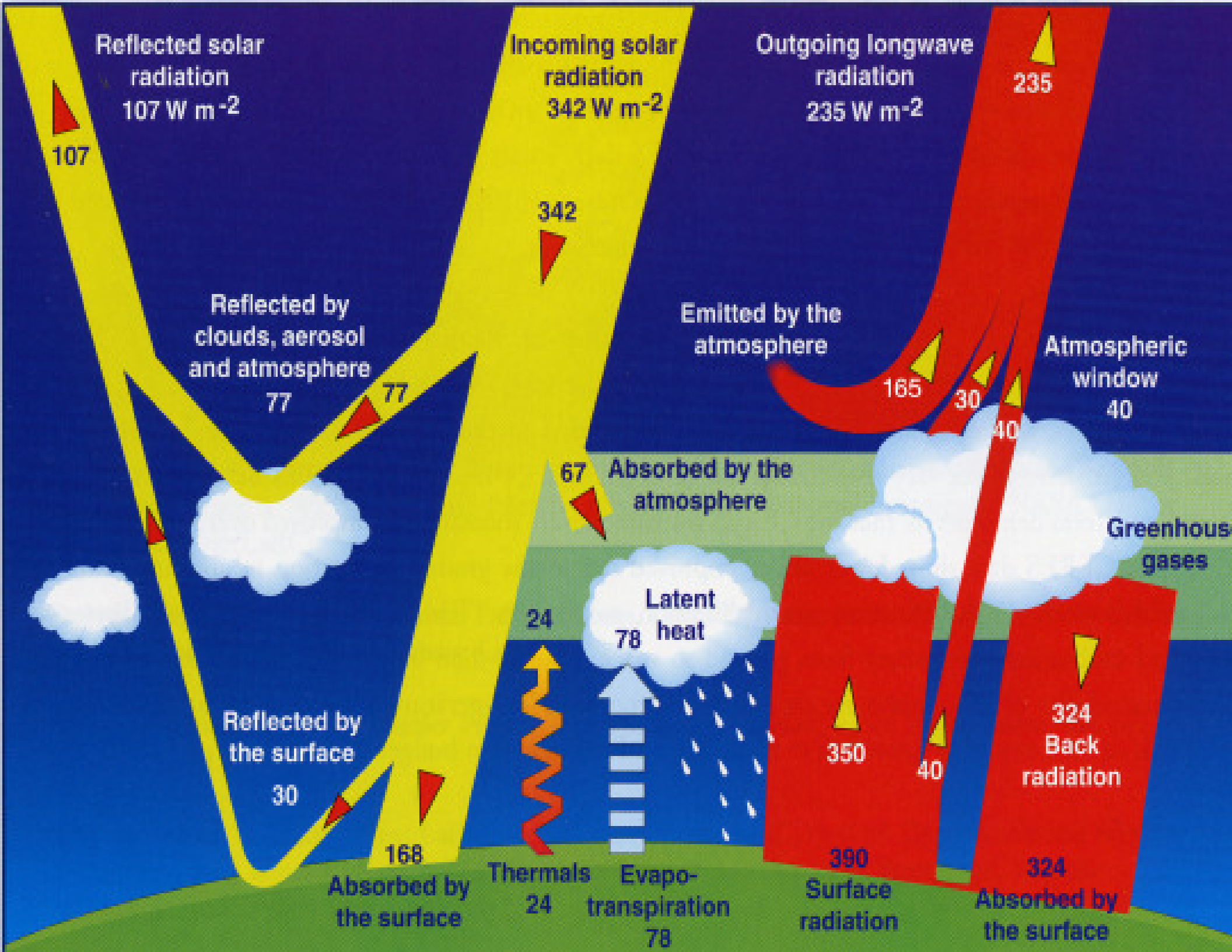


Source: Nate Smith

Courage



Source: Nate Smith



Energy Production Potential of the Atmospheric Vortex Engine

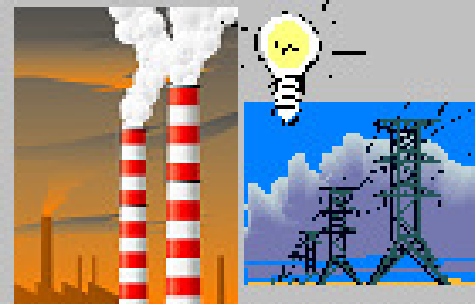
Atmospheric Vortex Engine
mechanical energy production
potential = 6,000 TW (Ref 3)
(Carnot Efficiency 12% $\times$ 52,000
TW = 6,000 TW)

Total incoming
solar radiation =
174,000 TW
(Ref 1)

Atmospheric
upward heat
convection =
52,000 TW
(Ref 1)

Total global energy production rate = 15 TW (Ref 2)

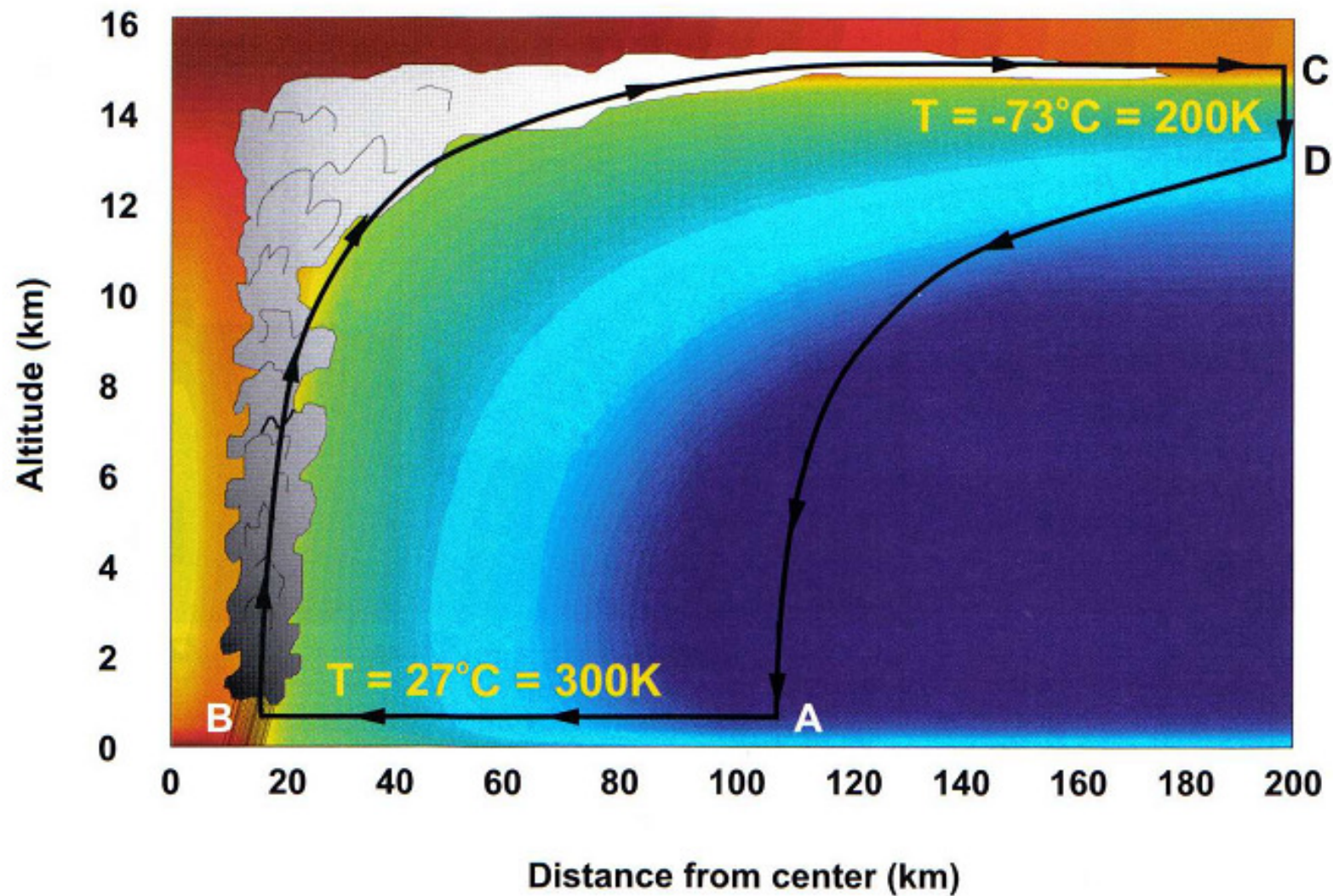
Total global electrical energy
production rate = 2 TW (Ref 2)



References:

- (1) Tremberth and NASA
- (2) US Department of Energy
- (3) L.M. Michaud

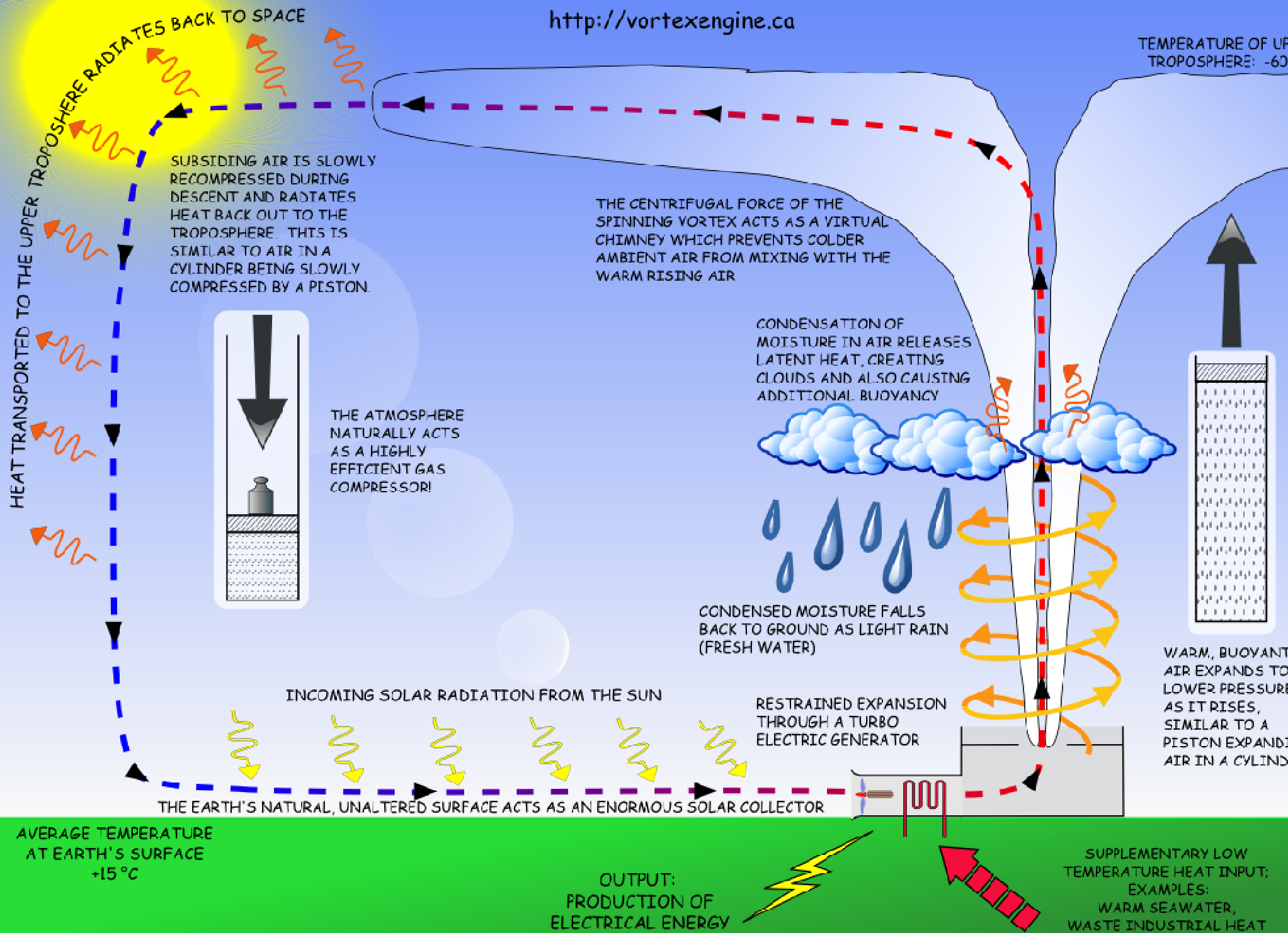
A hurricane viewed as a Carnot cycle



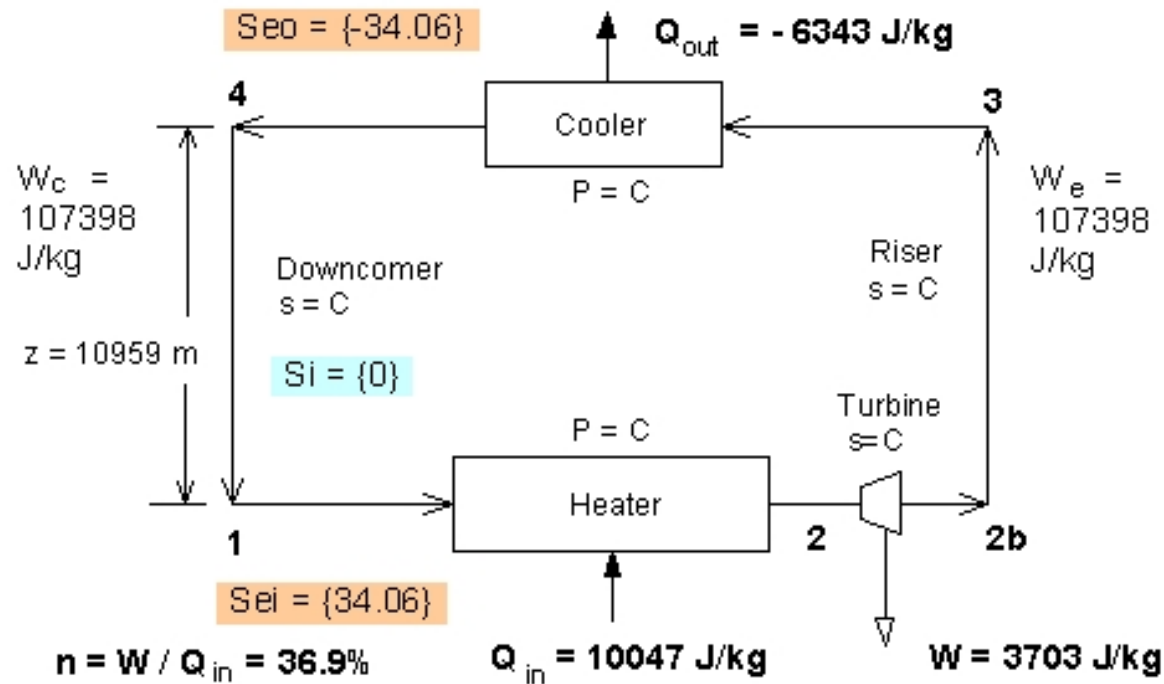
Efficiency $n = 1 - T_c / T_h = 1 - 200/300 = 33\%$

THE AVE POWER CYCLE

<http://vortexengine.ca>



Gravity Power Cycle

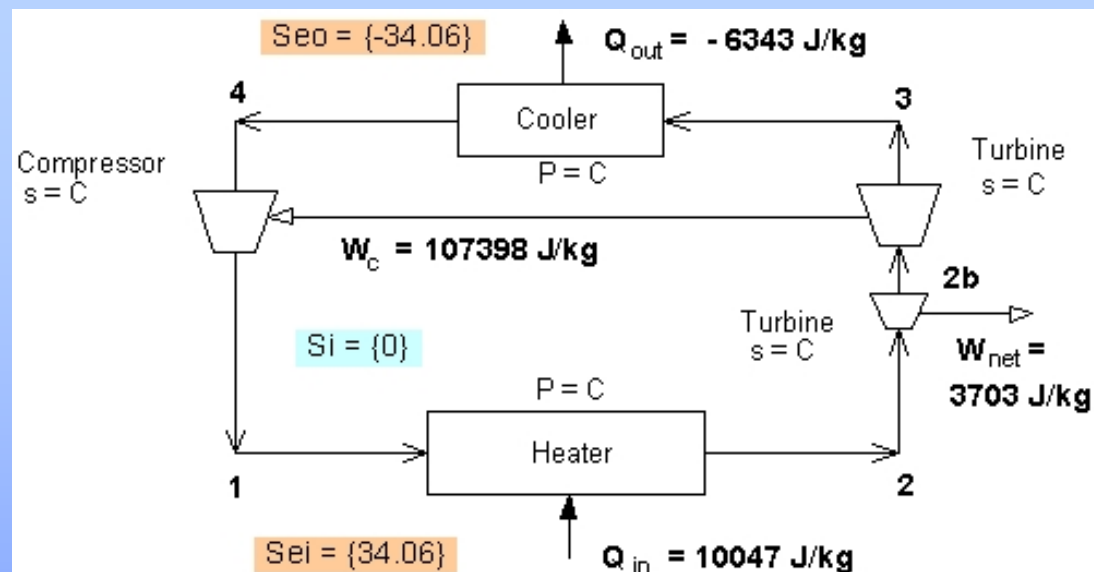


State	P (kPa)	T (K)	s (J/ K kg)	h (J/kg)	gz (J/kg)	h+gz (J/kg)
1	100	290	60.14	16929	0	16929
2	100	300	94.20	26975	0	26975
2b	95.77	296.31	94.20	23272	0	23372
3	20	189.42	94.20	-84126	107398	23372
4	20	183.10	60.14	-90467	107398	16929

Gravity cycle - Case 1

Cooling at constant pressure, dry air, reversible.
Height based on lapse rate of 9.75 K/km

Brayton gas-turbine power cycle



$$W_{net} = Q_{in} - Q_{out} = 10047 - 6343 = 3703 \text{ J/kg}$$

$$n = 1 - T_3 / T_2 = 1 - T_4 / T_1 = 1 - (P_3 / P_2)^{R/C_p}$$

$$n = 1 - T_4 / T_1 = 1 - 183.1 / 290.0 = 36.9 \%$$

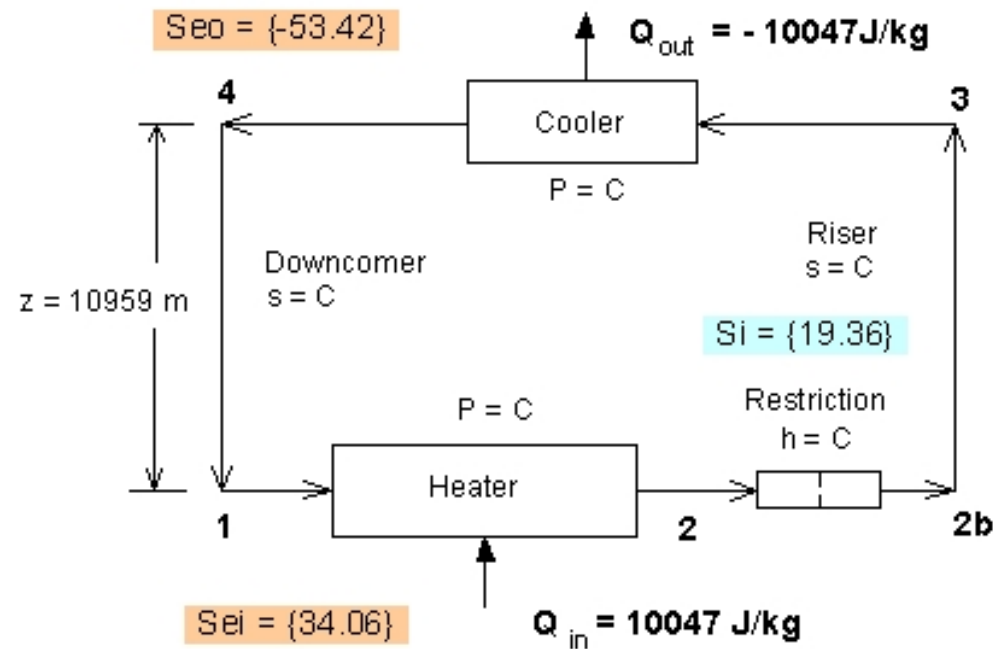
$$W_{net} = n Q_{in} = 0.369 * 10047 = 3703 \text{ J/kg}$$

State	P (kPa)	T (K)	s (J/ K kg)	h (J/kg)
1	100	290	60.14	16929
2	100	300	94.20	26975
2b	95.77	296.31	94.20	23272
3	20	189.42	94.20	-84126
4	20	183.10	60.14	-90467

Brayton gas-turbine power cycle

Case 1 process conditions

Irreversible Gravity Cycle



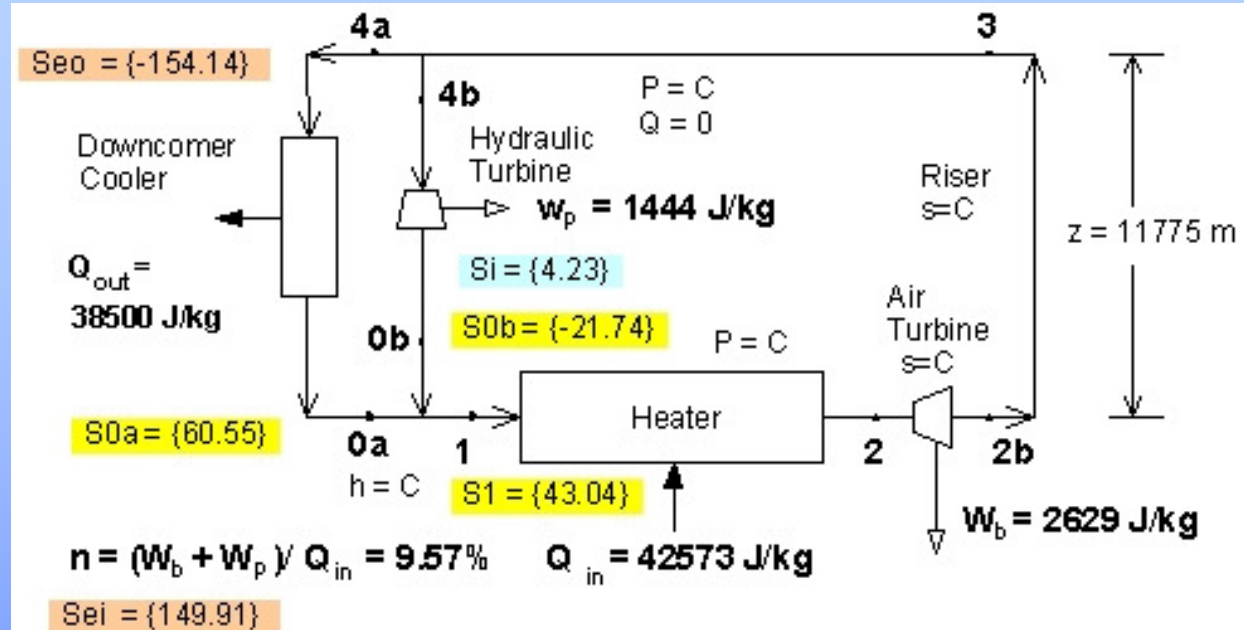
State	P (kPa)	T (K)	s (J/ K kg)	h (J/kg)	gz (J/kg)	h+gz (J/kg)
1	100	290	60.14	16929	0	16929
2	100	300	94.20	26975	0	26975
2b	93.48	300	113.56	26975	0	26975
3	20	193.10	113.56	-80424	107398	26975
4	20	183.10	60.14	-90467	107398	16929

Gravity Cycle - Case 1 - Irreversible

Constant pressure cooling, Pure air

Height based on lapse rate of 9.75 K /km

Gravity Cycle Air-Water System



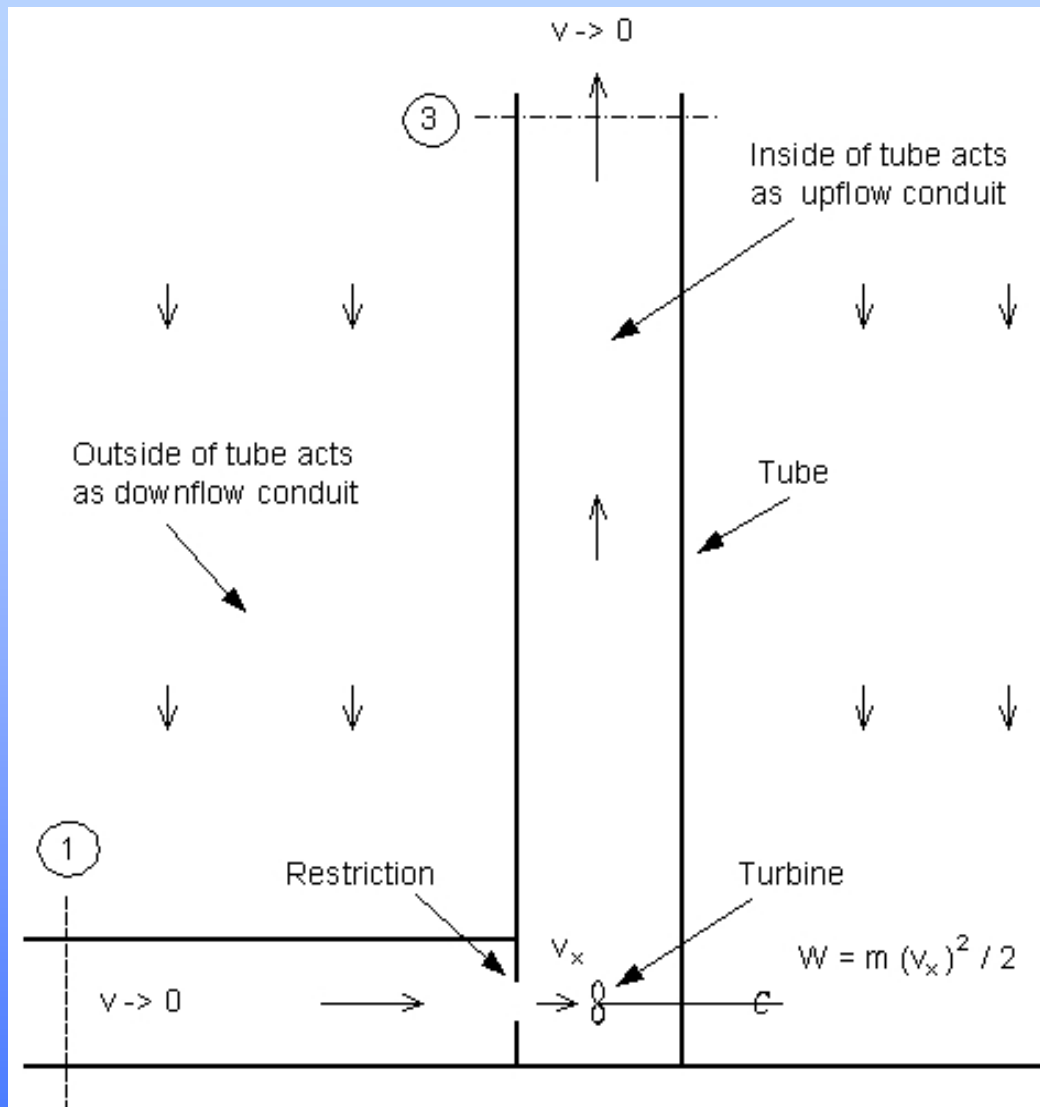
State	P (kPa)	T (K)	r (g/kg)	s (J/ K kg)	h (J/kg)	gz (J/kg)	h+gz (J/kg)
1	100	274.12	12.55	43.04	11278	0	11278
2	100	295	12.55	192.95	53851	0	53851
2b	96.99	292.44	12.55	192.95	51222	0	51222
3	20	213.46	12.55	192.95	-65622	116844	51222
4a	20	213.46	0.03	214.69	-59884	115399	55515
0a	100	290	0.03	60.55	17017	0	17017
4b	20	213.46	12.52	-21.74	-5738	1444	-4294
0b	100	213.46	12.52	-21.74	-5738	0	-5738

Gravity Cycle - Case 3a

Downcomer cooling, moist air

Height based on lapse rate of 6.5 K /km

Single Tube Gravity Cycle



Single tube gravity cycle.

The inside of the tube acts as the upflow conduit.

The outside of the tube acts as the downflow conduit.

The cross sectional area of the conduit has no effect on ideal cycles because the velocity is assumed to approach zero except at the turbine.

AVE Combined Cycle Power Plant

Cold Source – upper troposphere

$T_L = -60^\circ\text{C}$
(213 K)

Qout
780 MW

Heat Engine

Wout
195 MW

Qin
975 MW

$T = 30^\circ\text{C}$
(303 K)

Qout
975 MW

Heat Engine

Wout
525 MW

Qin
1500 MW

$T_H = 540^\circ\text{C}$
(813 K)

Stage 2: Atmospheric Vortex Engine

Carnot Efficiency

$$n_c = 1 - T_L / T_H = 1 - 213/303 = 29.7\%$$

Typical Efficiency (Estimated)

$$n = 20\%$$

Overall Efficiency
(Thermal Power Plant +
Atmospheric Vortex Engine
combined)

$$n = (525 + 195) / 1500 = 48\%$$
$$W_{\text{total}} = 525 + 195 = 720 \text{ MW}$$

$$\text{Incremental Efficiency Increase} = (525 + 195) / 525 = 37.1\%$$

Stage 1: Thermal Power Plant (Coal)

Carnot Efficiency

$$n_c = 1 - T_L / T_H = 1 - 303/813 = 62.7\%$$

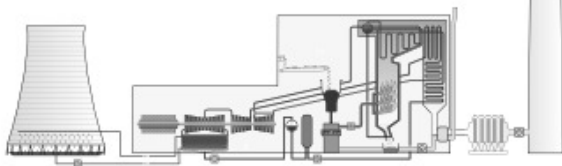
Typical Efficiency

$$n = 35\%$$



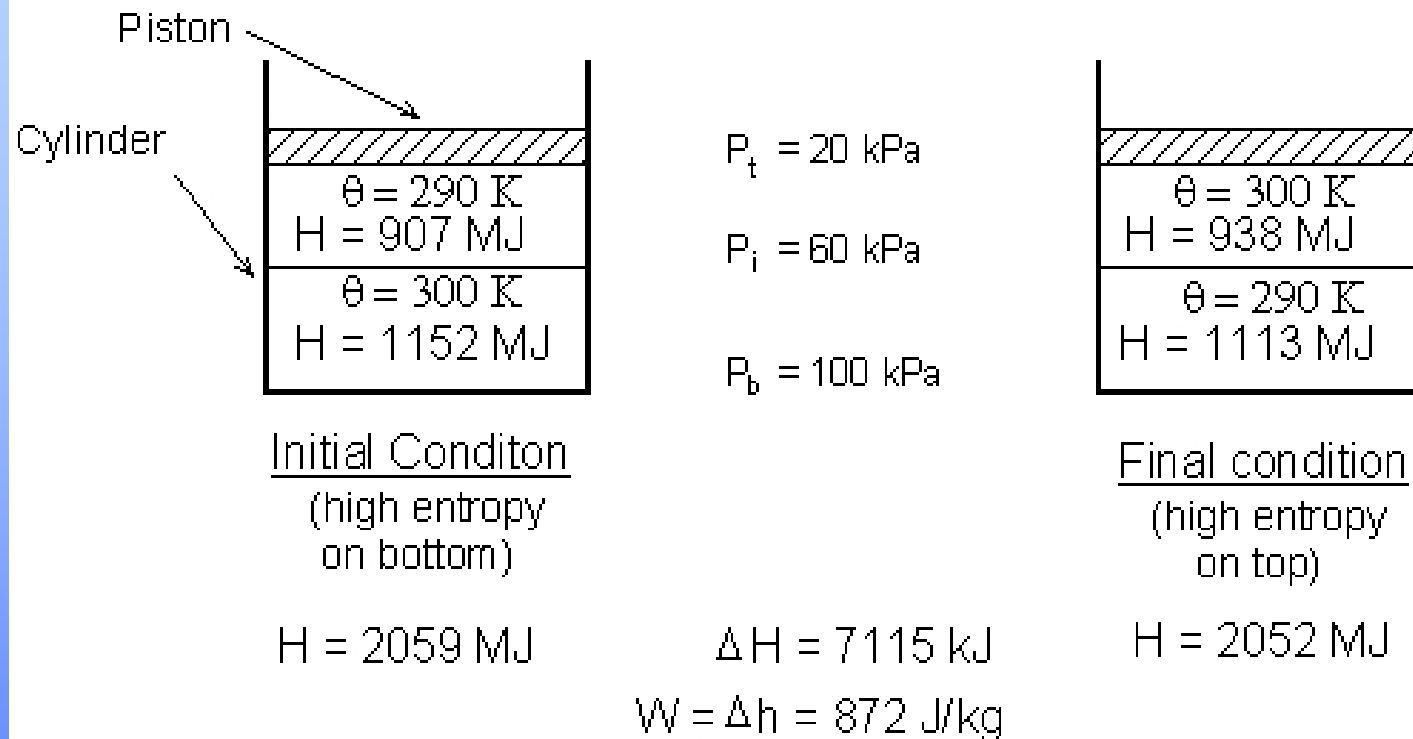
AVE heat source
EQUALS
waste heat rejected
from thermal power
plant at condenser
temperature

Thermal
Power Plant
(Coal)



Hot Source - superheated steam

Margules re-arrangement of large air masses initially on top of one another.



The work corresponds to a velocity of 42 m/s

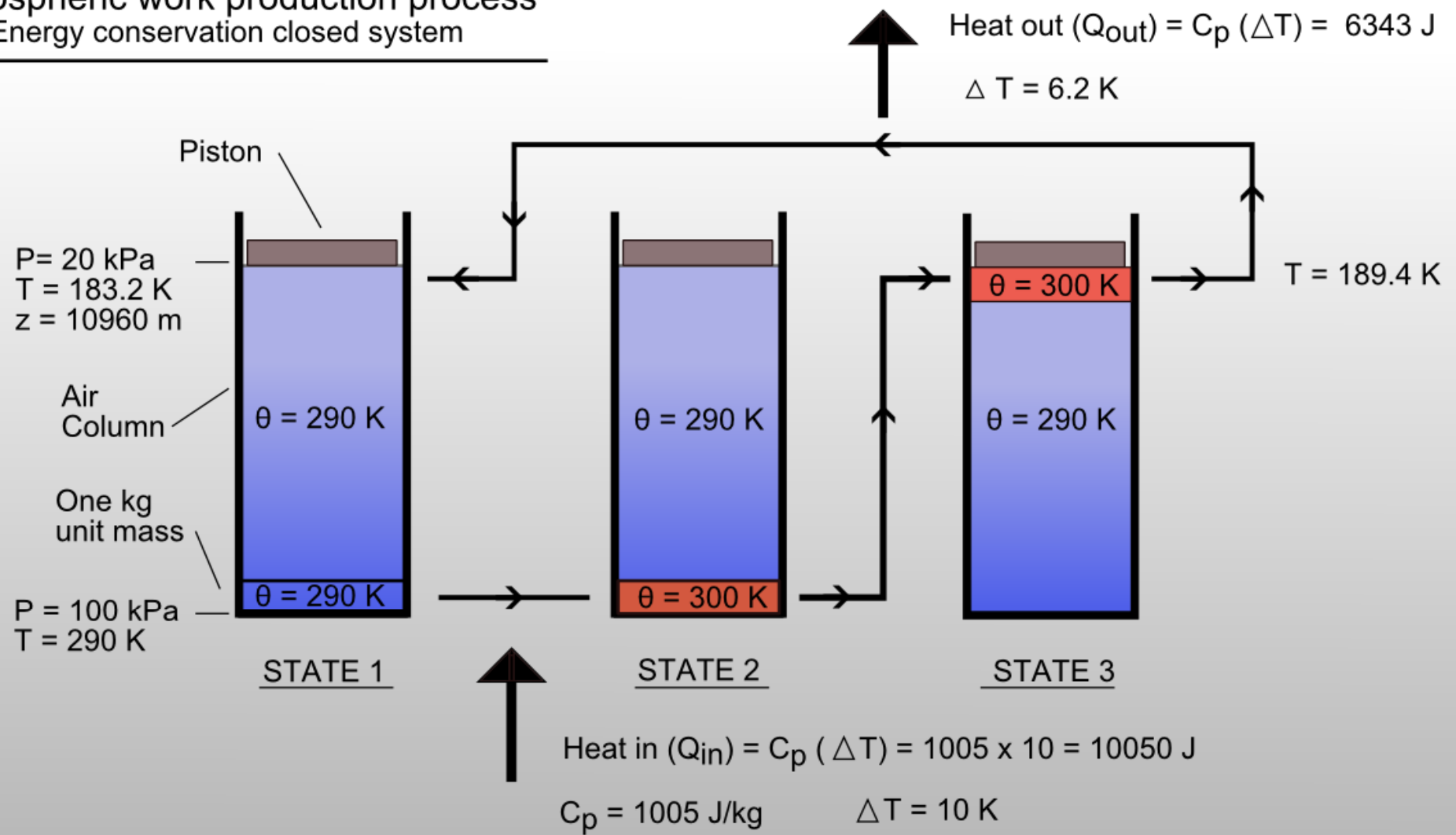
$$m = (P_b - P_t)/g = 8163 \text{ kg}$$

Notes:

Closed piston covered isolated thermodynamics system
Mass based on column area of one square meter

Atmospheric work production process

Energy conservation closed system



1. Heat received minus heat given up

$$W = Q_{in} - Q_{out} = 10050 - 6343 = 3703 \text{ J}$$

2. Heat in multiplied by the Carnot efficiency

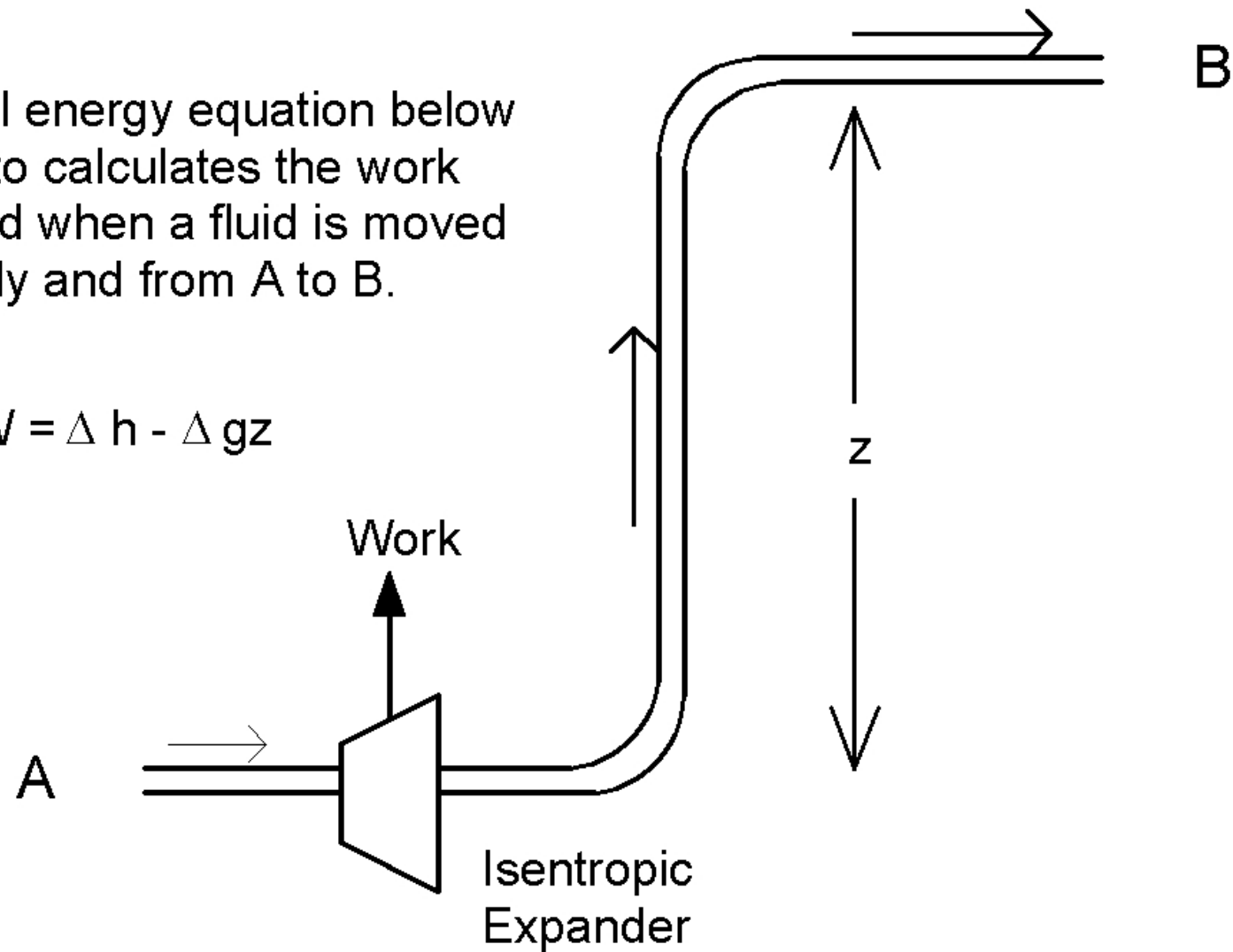
$$W = Q_{in} (1 - T_{out} / T_{in}) = 10050 (1 - 183.2 / 290) = 3703 \text{ J}$$

3. Total energy equation

$$W = \Delta h - \Delta gz = 1005 (300 - 189.4) - 9.8 (10960) = 3703 \text{ J}$$

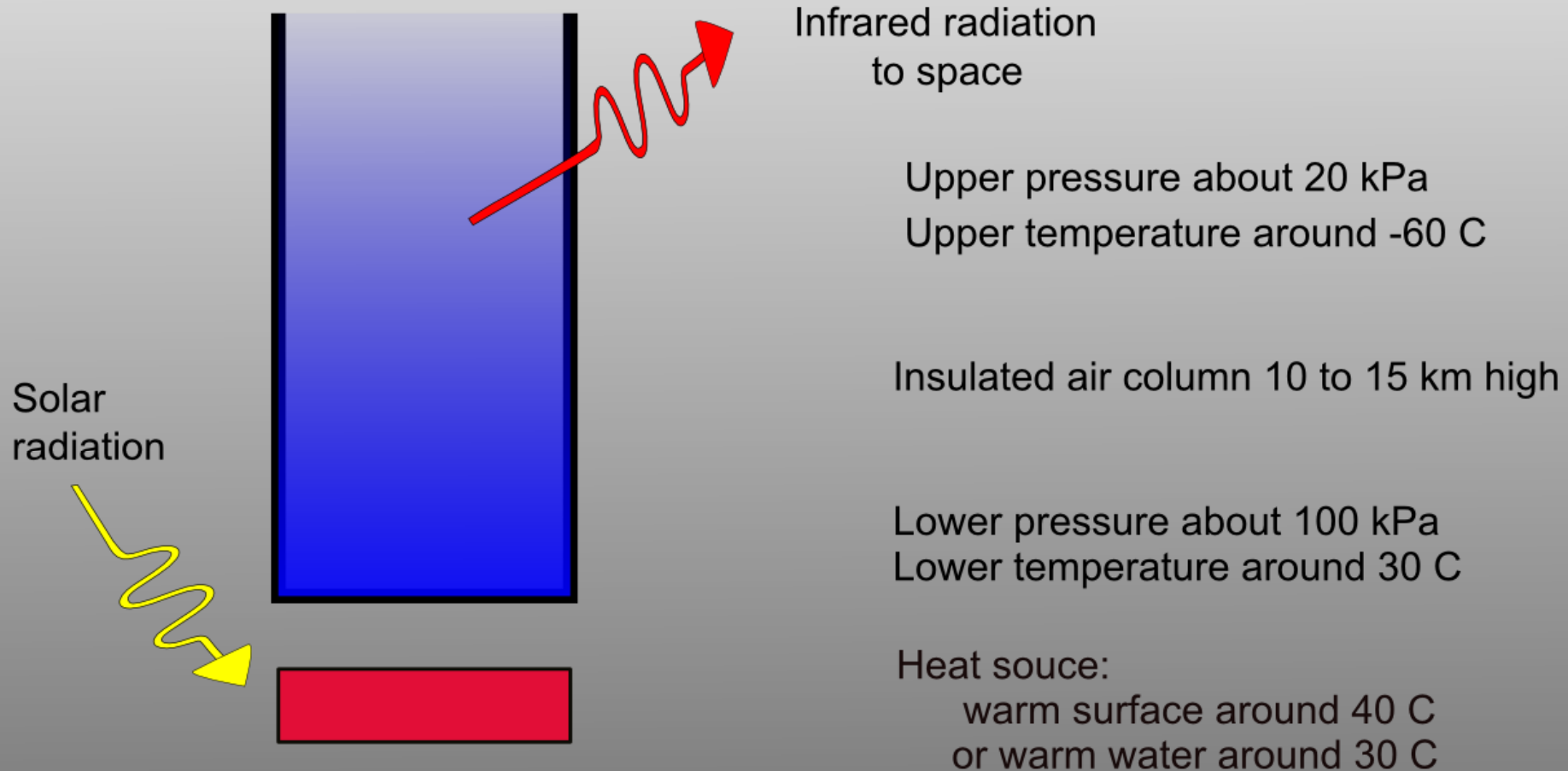
The total energy equation below is used to calculate the work produced when a fluid is moved reversibly and from A to B.

$$W = \Delta h - \Delta gz$$



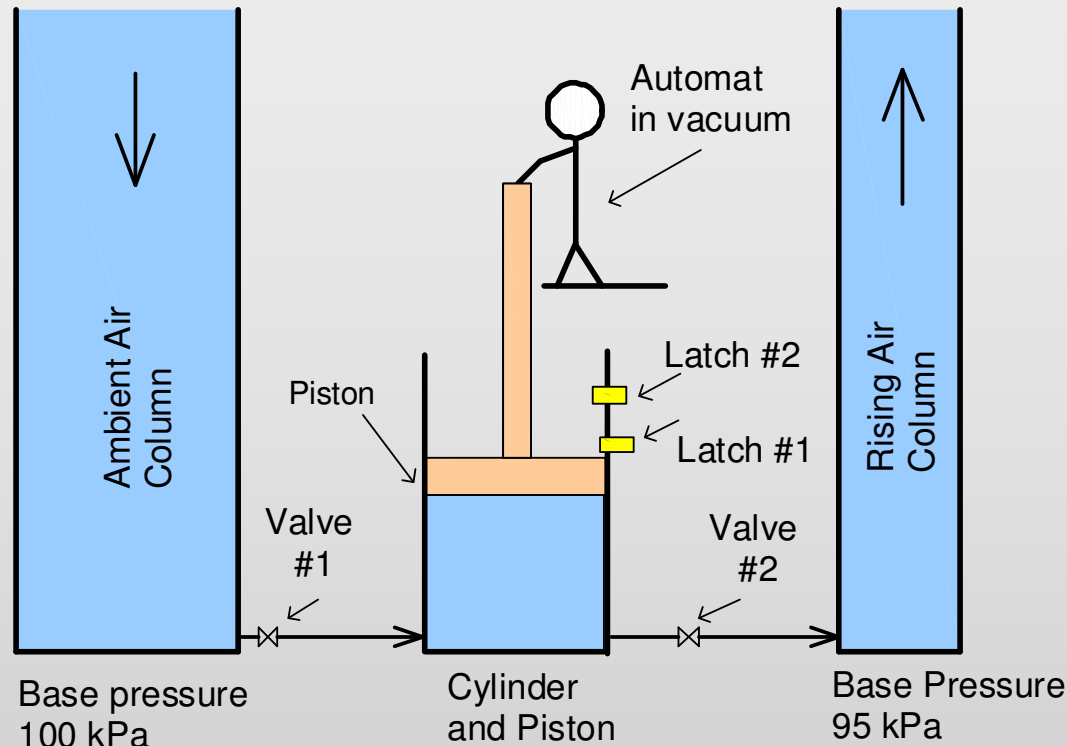
Atmospheric work production process

Basic requirements



Heat to work conversion efficiency equals
Carnot efficiency based on average temperatures
at which heat is received and given up.

Reversible and Irreversible Expansion



Constrained reversible expansion - Work is produced - No Latch

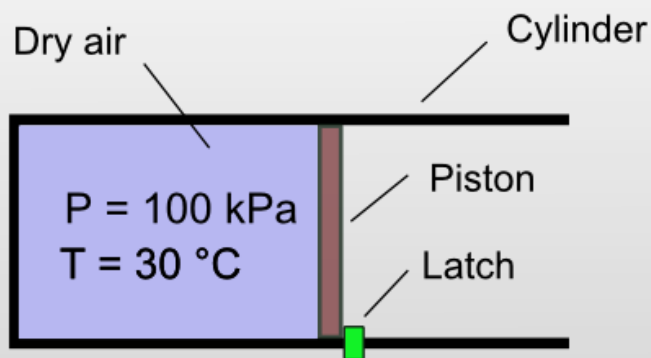
1. Start with piston at bottom of the cylinder, open valve #1,
2. Automat raises piston and let 1 kg of air at 100 kPa in cylinder,
3. Close valve #1,
4. Automat raises piston until cylinder pressure decreases to 95 kPa,
5. Open valve #2,
6. Automat pushes piston to the bottom of the cylinder.

The air temperature decreases.

Unconstrained irreversible expansion - No work is produced - Two Latches

- 1-3. As above except after step 3. set latch #1 and #2, set latch #2 so that the final pressure is 95 kPa,
4. Automat lets go of the piston,
5. Let go latch #1, piston snaps against latch #2 without doing any work,
6. Automat pushes piston to the bottom of the cylinder.

The air temperature does not decrease.

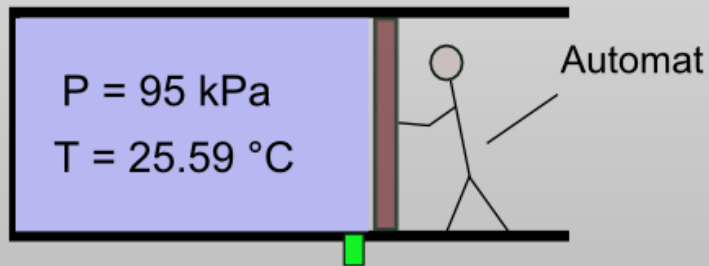


INITIAL CONDITION

Work production requires that expansion be restrained

Ambient pressure: $P = 95 \text{ kPa}$

Initial pressure difference: 5 kPa

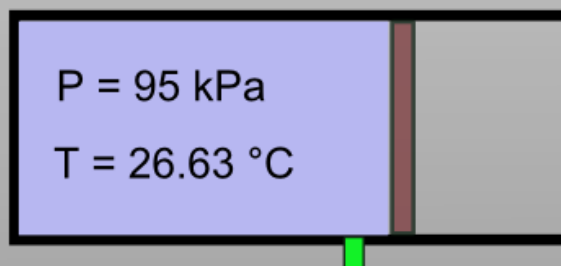


AFTER RESTRAINED
ISENTROPIC EXPANSION

Work against environment 3085 J

Work against automat 1346 J

Total work 4431 J



AFTER UNRESTRAINED
EXPANSION

Work against environment 3384 J

Total work 3384 J

Loss work 1047 J

Additional enthalpy of the air 1047 J

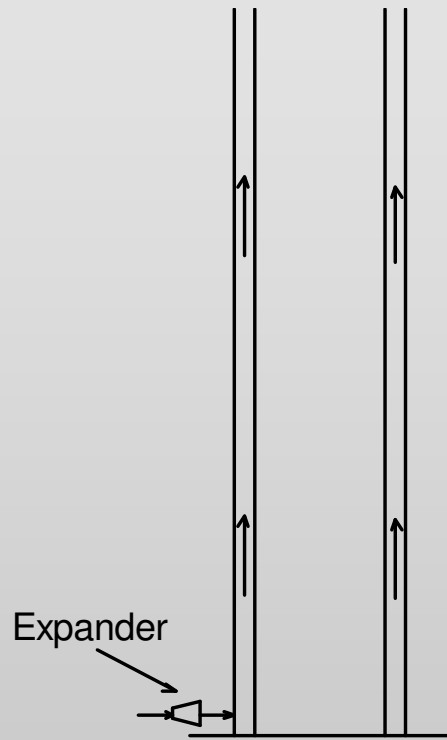
Capturing work of expansion produced when the latch lets go requires that the expansion be restrained, otherwise the energy remains in the cylinder.

Approximately 22% of the work of expansion is lost no matter how small the initial pressure difference.

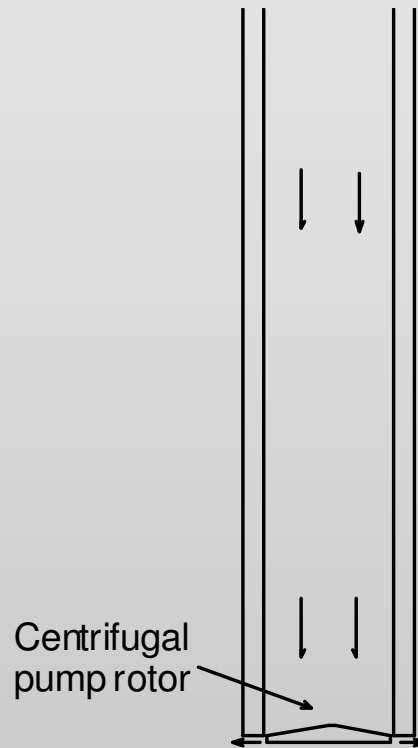
Annular Tube



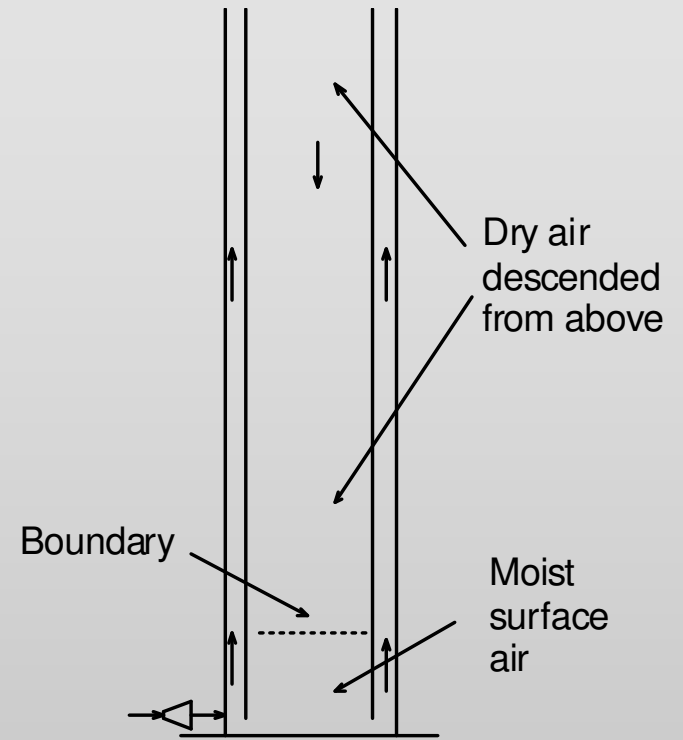
Circular
upflow
tube



Annular
outer
upflow
tube



Circular
inner
downflow
tube



Dual tubes
outer upflow
inner static

A vortex as a dual annular tube

Three types of continuous lifting processes



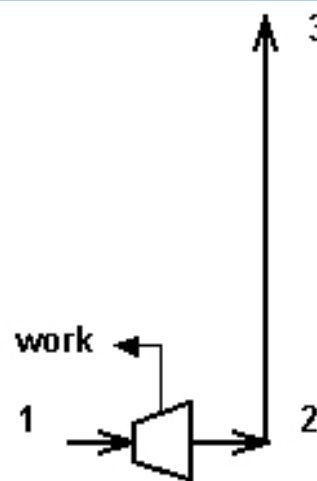
USUAL

Isenthalpic Lifting

$$h_3 = h_2 - gz$$

$$s_3 > s_1$$

Irrespective of where dissipation occurs.
Irrespective of whether of whether dissipation is due to resistance to flow or unrestrained expansion.



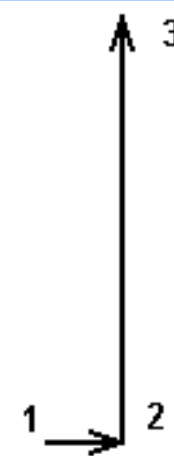
APPROACHABLE

Isentropic Lifting

$$s_3 = s_2 = s_1$$

$$w = h_1 - h_2$$

Requires an isentropic expander.
Requires a shaft to get the work out of the system.



IMPOSSIBLE

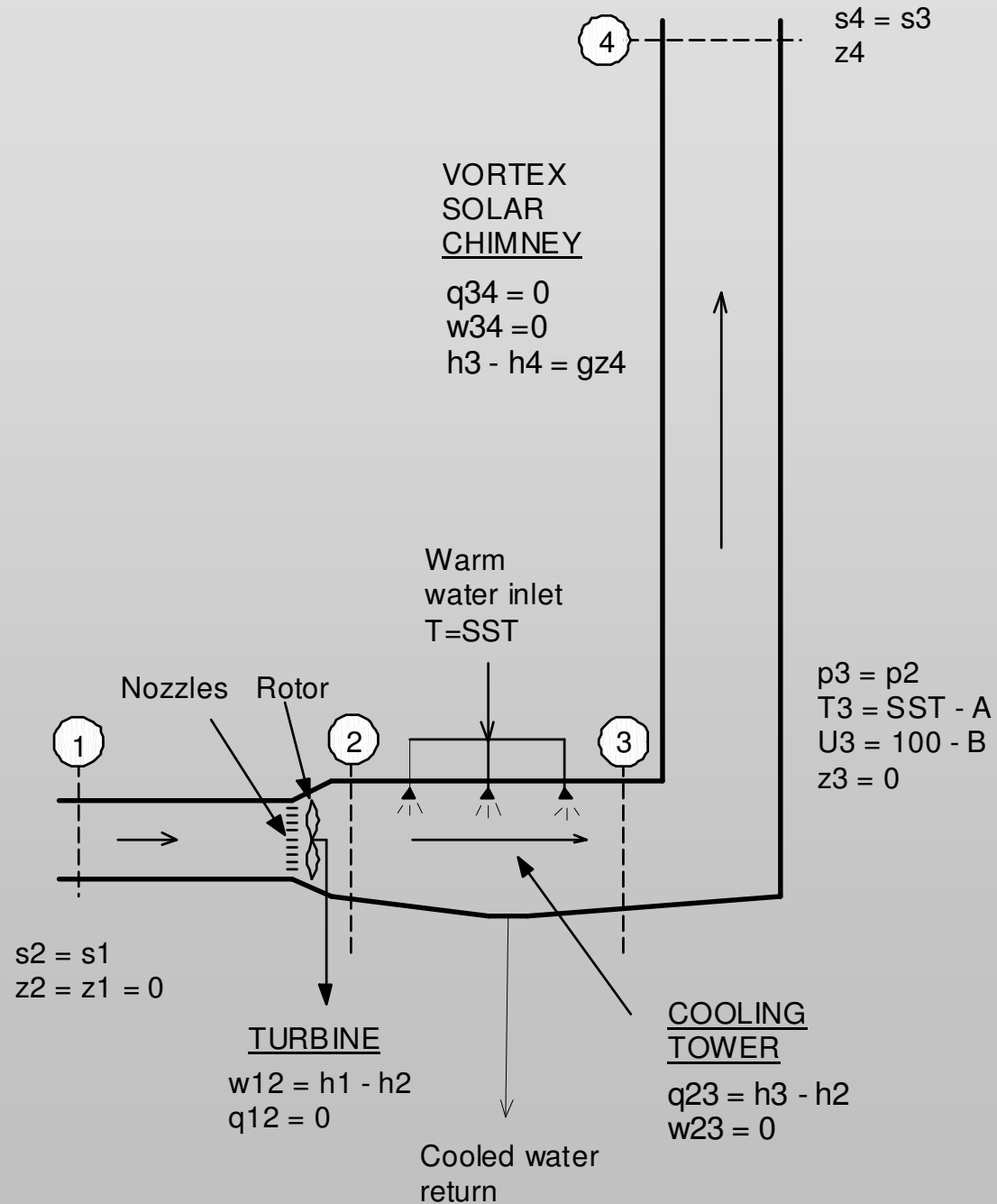
Isentropic Lifting

$$s_3 = s_2 = s_1$$

$$w = 0$$

Isentropic expansion without device for taking work out of the system is impossible except in one case ($w \neq 0$).
It is the basis of most atmospheric models.

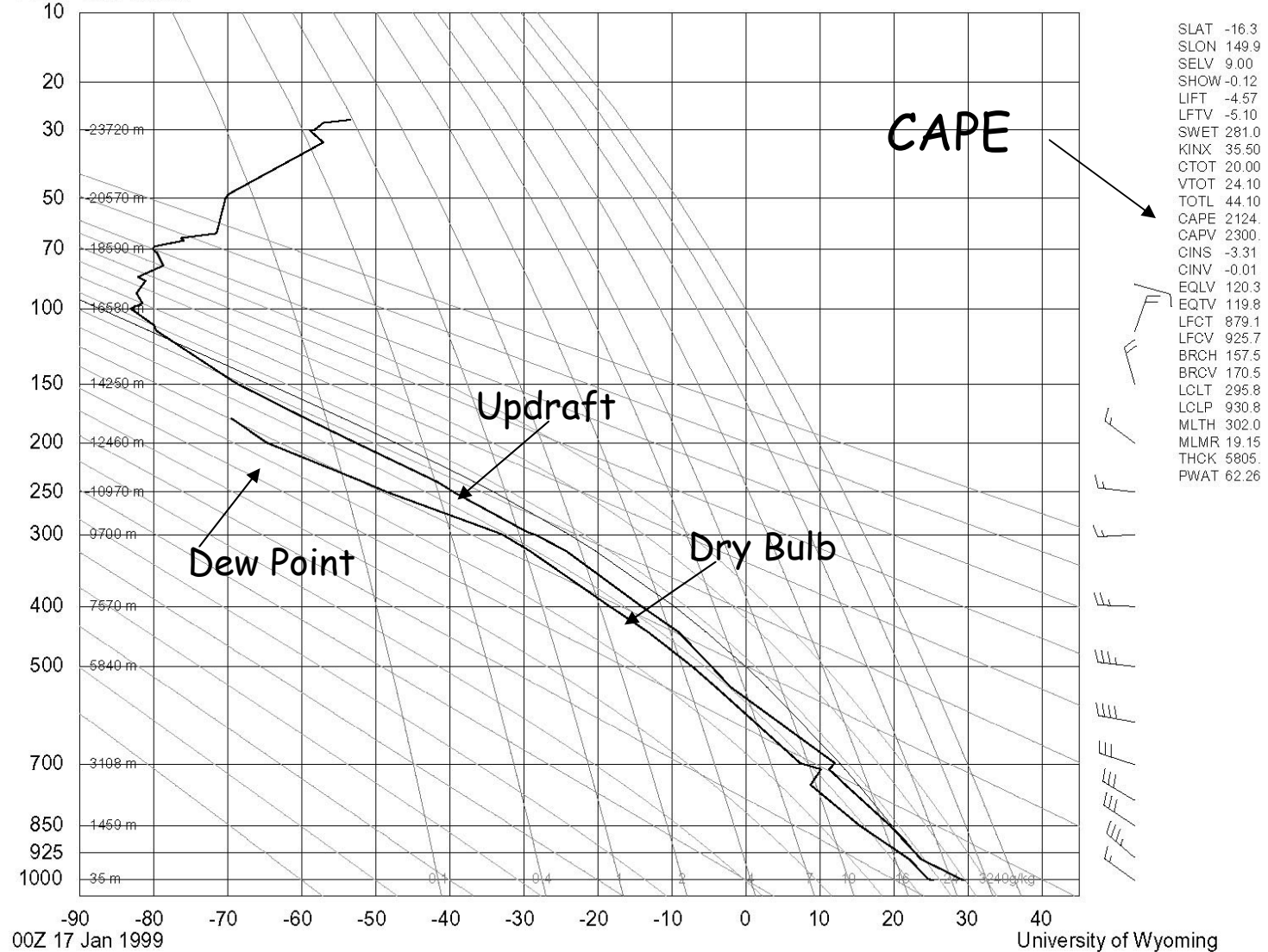
Thermodynamic Calculation Method



Willis Island Sounding

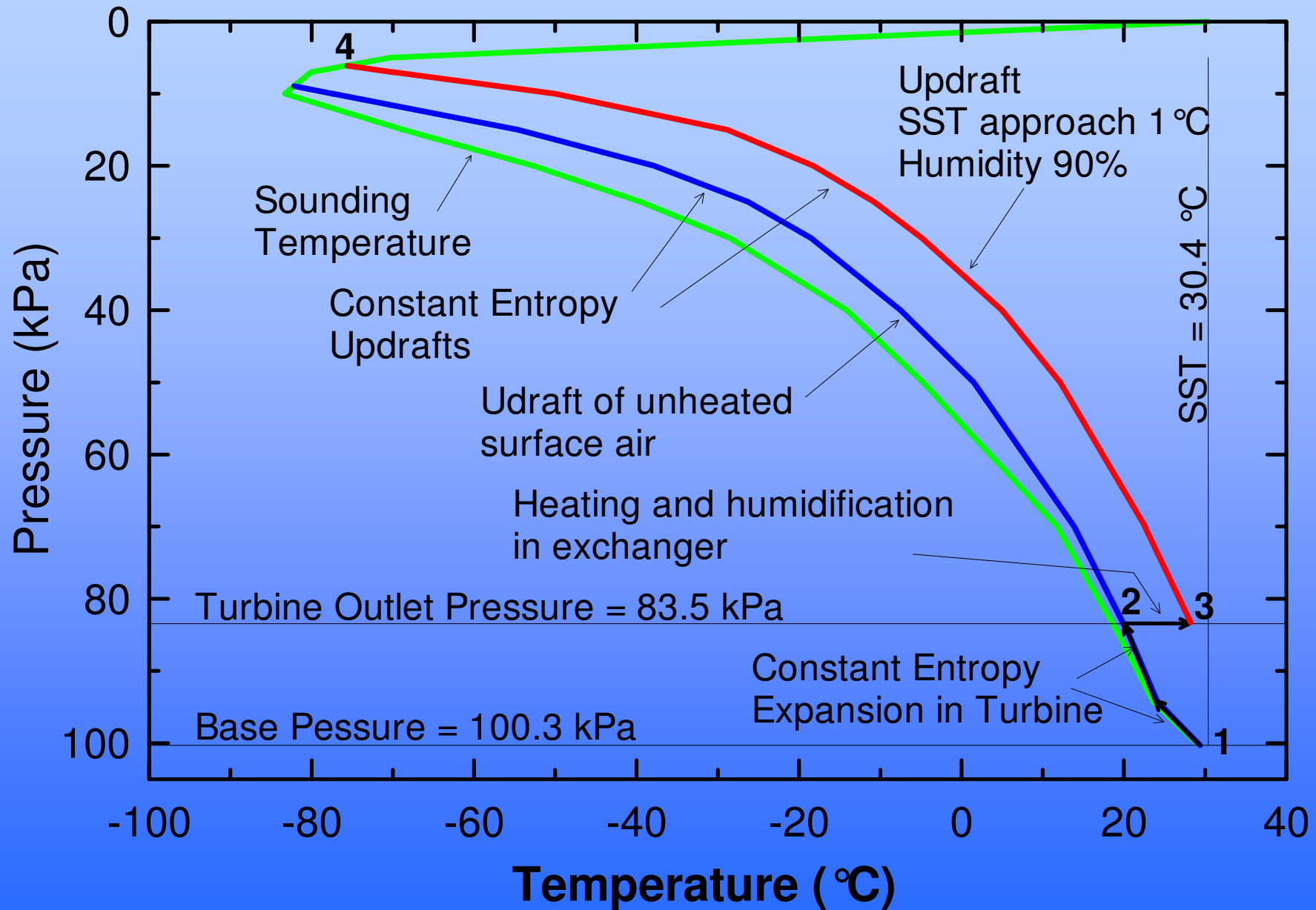
Pressure
(hPa)

94299 Willis Island



Temperature (C)

Willis Island sounding and updraft temperatures



Typical Energy Calculations - SST 30.4 C

Vortex solar chimney energy calculations for a range of temperature and humidity approach to sea surface temperature (SST). Ambient surface air conditions: $P_1 = 100.3$ kPa, $T_1 = 29.4$ °C, $U_1 = 77.5\%$, $r_1 = r_2 = 20.50$ g kg⁻¹, $s_1 = s_2 = 287.0$ J kg⁻¹ K⁻¹, $h_1 = 81920$ J kg⁻¹. Heights based on 17 January 1999, 0000Z Willis Island sounding. Approach based on SST = 30.4 °C.

<u>Properties</u>	<u>Case 0</u> <u>$q_{23} = 0$</u>	<u>Case 1</u> <u>$A=3, B=10$</u>	<u>Case 2</u> <u>$A=1, B=10$</u>	<u>Case 3</u> <u>$A=1, B=5$</u>	<u>Case 4</u> <u>$A=0, B=0$</u>
$P_2 = P_3$ (kPa)	95.80	91.38	83.42	81.02	74.62
$P_1 - P_2$ (kPa)	4.50	8.92	16.88	19.28	25.68
T_2 (°C)	25.47	23.10	19.99	18.99	16.14
U_2 (%)	94	103	115	119	131
h_2 (J kg ⁻¹)	77820	73670	65720	63200	56150
$T_3 = \text{SST} - A$ (°C)	25.47	27.4	29.4	29.4	30.4
$U_3 = 100 - B$ (%)	94	90	90	95	100
$r_3 = r_4$ (g kg ⁻¹)	20.50	23.25	28.87	31.43	38.35
h_3 (J kg ⁻¹)	77820	86840	103320	109840	128590
$s_3 = s_4$ (J K ⁻¹ kg ⁻¹)	287.0	331.3	413.5	444.1	531.1
P_4 (kPa)	10	10.0	7.0	7.0	5.0
T_4 (°C)	-77.39	-68.01	-69.91	-63.21	-62.77
z_4 (m)	16570	16570	18580	18580	20560
h_4 (J kg ⁻¹)	-87890	-79330	-84020	-77970	-80630
$h_4 + gz_4(1+r_4)$	77820	86840	103320	109840	128590
$q_{23} = h_3 - h_2$ (J kg ⁻¹)	0	13170	37590	46650	72440
$w_{12} = h_1 - h_2$ (J kg ⁻¹)	4090	8250	16190	18720	25770
v_x (m s ⁻¹)	90	128	180	193	227
$\Delta w_{12}/\Delta T_3$	n/a	4050	base	n/a	n/a
$\Delta w_{12}/\Delta U_3$	n/a	n/a	base	512	n/a
$\Delta w_{12}/\Delta r_3$	n/a	n/a	base	1000	n/a
$\Delta w_{12}/\Delta q_{23}$	n/a	32.8%	base	28.1%	28.2%

Hurricane Isabel Dropwindsonde Soundings

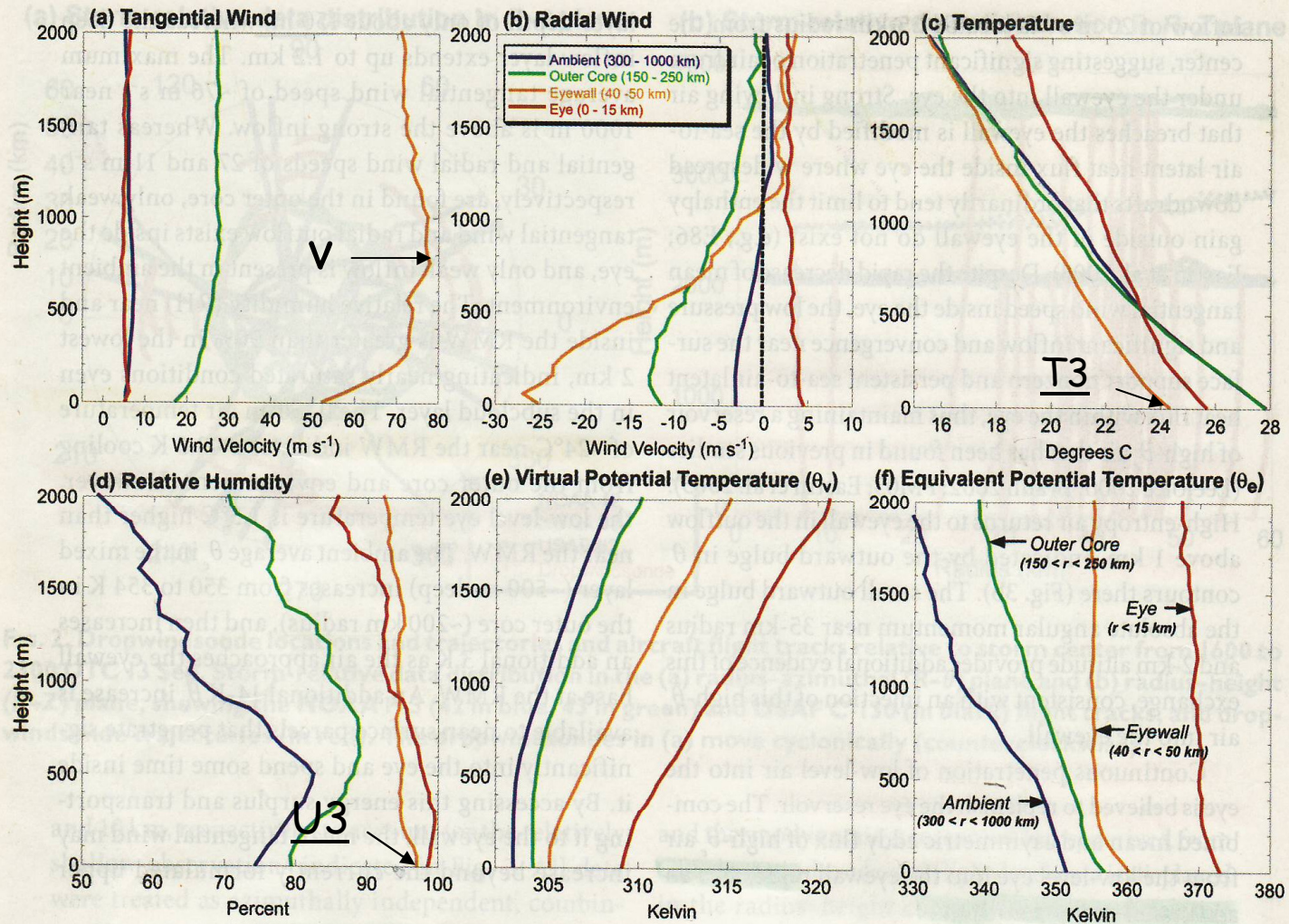


FIG. 4. Low-level (0-2 km) mean soundings from dropwindsonde observations for the eye (0-15-km radius, red), nominal eyewall (40-50-km radius, orange), outer core (~200 km radius, green), and ambient environment (300-1000-km radius, blue) during 1600-2300 UTC 13 Sep. (a) Tangential wind (m s^{-1}), (b) radial wind (m s^{-1} ; inflow/outflow transition indicated by dashed line), (c) temperature ($^{\circ}\text{C}$), (d) RH (%), (e) θ_v (K), and (f) θ_e (K).

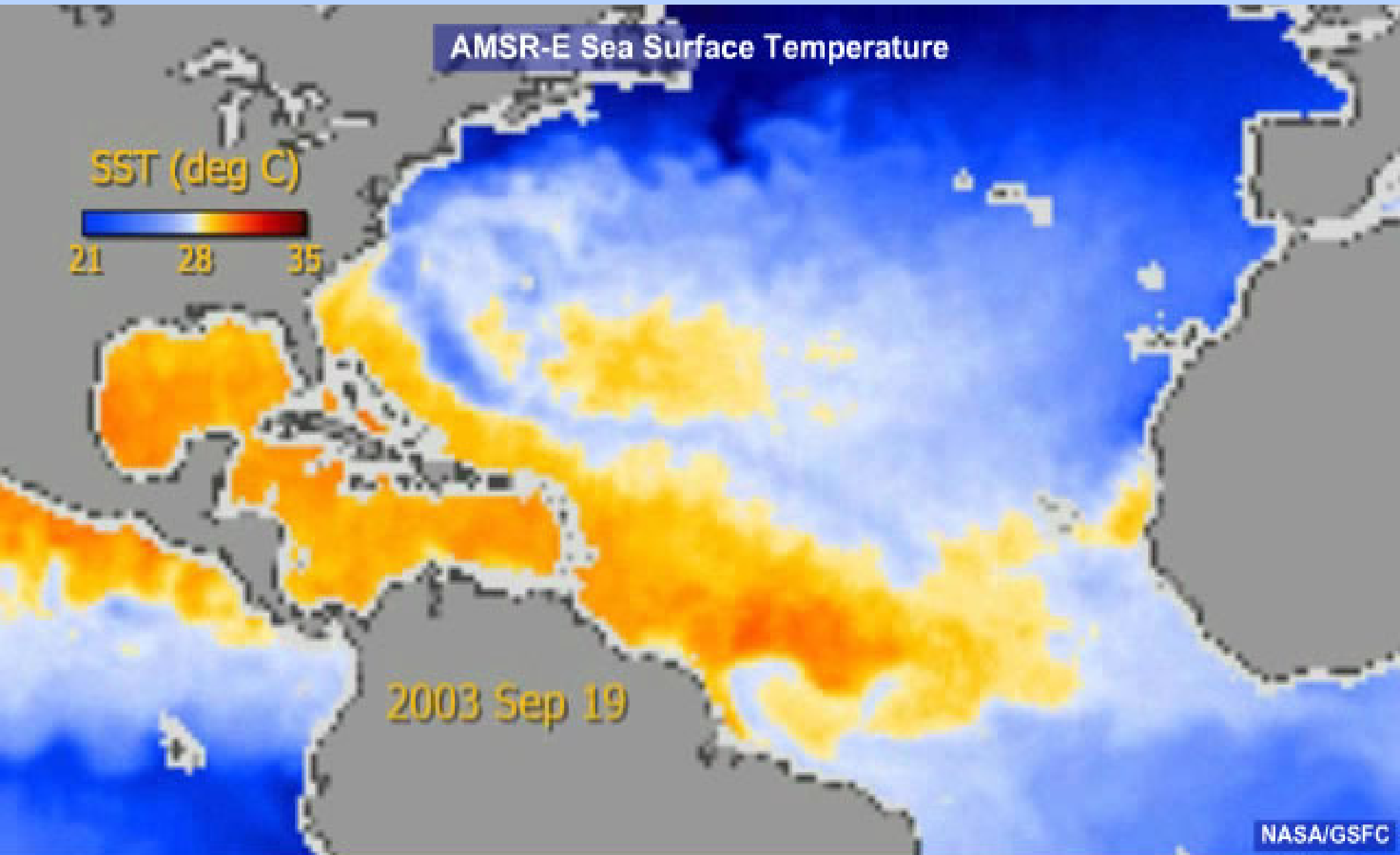
Hurricane Isabel Intensity SST 25 to 26.5 C

Temperature approach 1 C - Relative humidity 97%

Surface air properties: $P_1 = 101.1$ kPa, $T_1 = 27.8$ °C, $U_1 = 80$, $r_1 = r_2 = 19.06$ g kg⁻¹, $h_1 = 76572$ J kg⁻¹, $s_1 = s_2 = 266.8$ J K⁻¹kg⁻¹.

Eyewall SST (°C)	25.0	25.5	26.0	26.5
$P_2 = P_3$ (kPa)	99.14	97.72	96.01	94.36
T_2 (°C)	26.12	24.90	23.41	22.72
U_2 (%)	86.8	92.2	99.3	101.75
h_2 (J kg ⁻¹)	74830	73557	72005	70490
T_3 (°C)	24	24.5	25.0	25.5
U_3 (%)	97	97	97	97
$r_3 = r_4$ (g kg ⁻¹)	18.69	19.57	20.55	21.57
$h_3 = h_4 + (1+r_4)$ gz	71686	74434	77459	80590
$s_3 = s_4$ (J K ⁻¹ kg ⁻¹)	256.2	269.7	285.2	300.8
P_4 (kPa)	15.0	10.0	10.0	10.0
T_4 (°C)	-61.45	-80.92	-77.72	-74.42
T_{4V} (°C)	-65.32	-84.69	-81.65	-78.61
T_{4A} (°C)	-62.9	-80.1	-80.1	-80.1
z_4 (m)	14220	16570	16570	16570
h_4 (J kg ⁻¹)	-70275	-91130	-88264	-85299
ΔP_{12}	1.96	3.38	5.09	6.74
$W = h_1 - h_2$	1742	3015	4567	6081
v (m/s)	59.0	77.6	95.6	110.3
n (%) = $\Delta W_{12}/\Delta Q_{23r}$	n/a	base	33.9	33.2
n (%) = $1 - T_4/T_3$	28.8	35.4	33.5	33.5

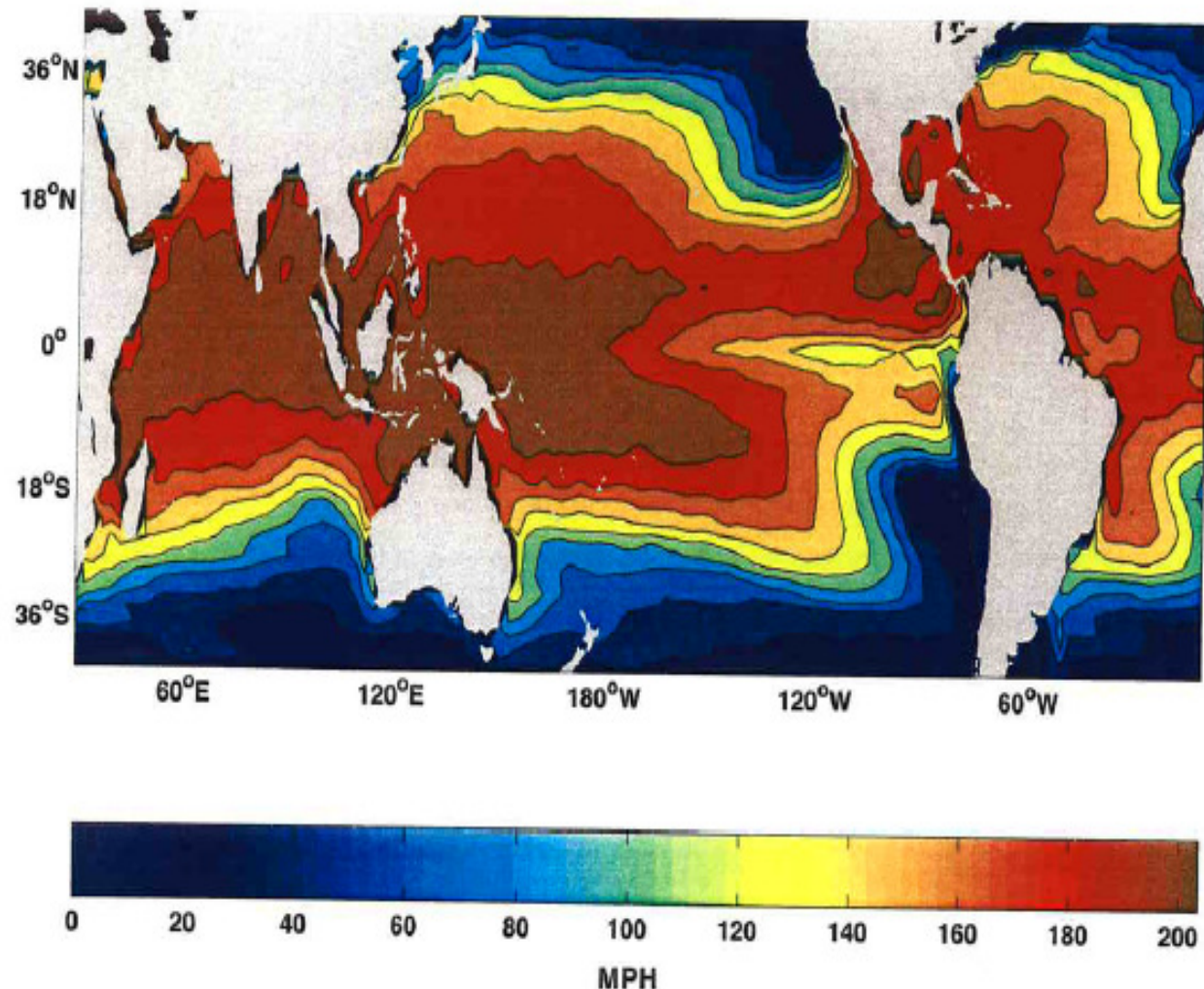
Hurricane Isabel effect on sea surface temperature as observed from satellite



The Carnot Potential Wind Speed

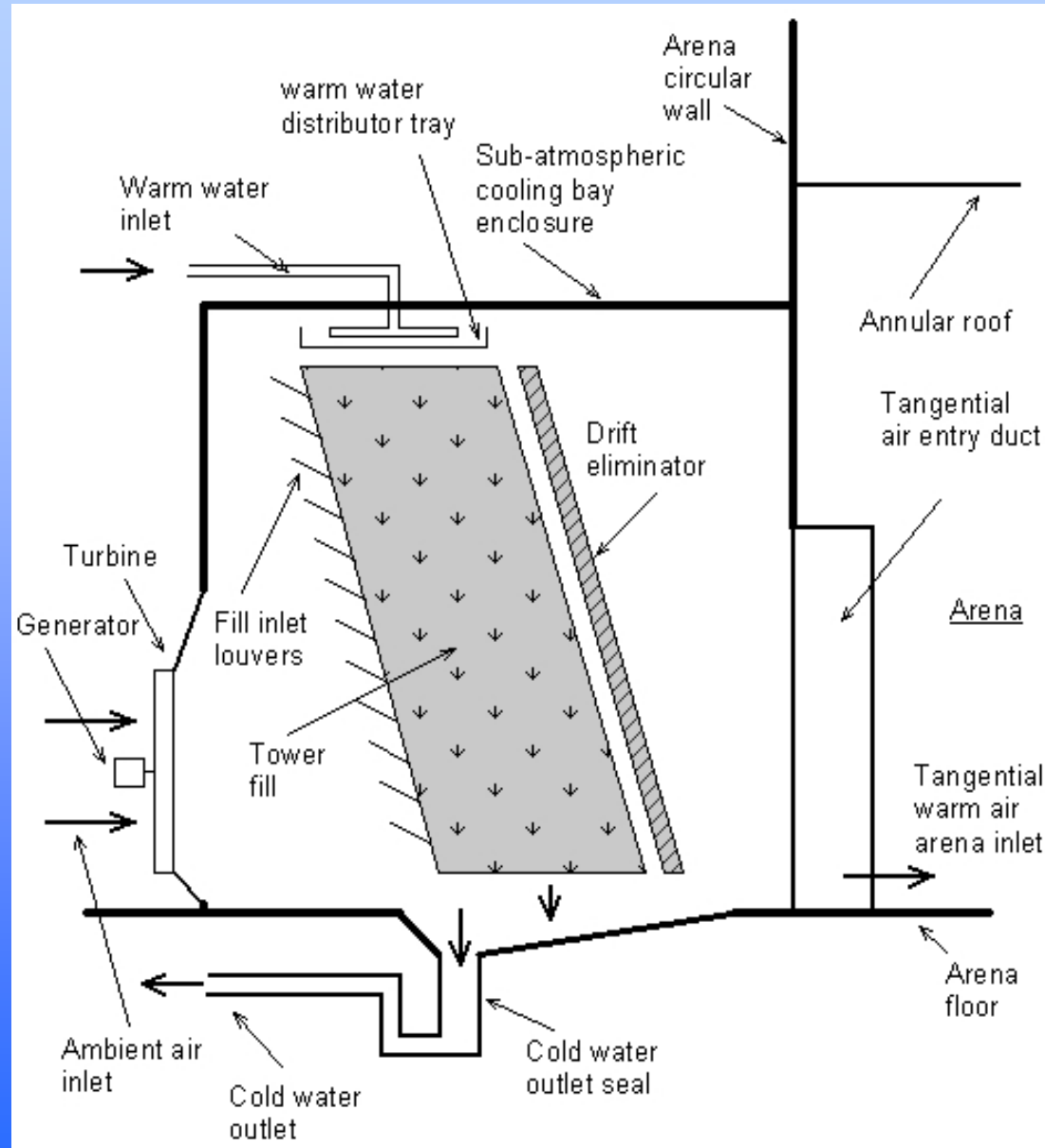
Map showing the maximum wind speed in MPH achievable by tropical cyclones over the course of an average year according to Carnot's theory of heat engines.

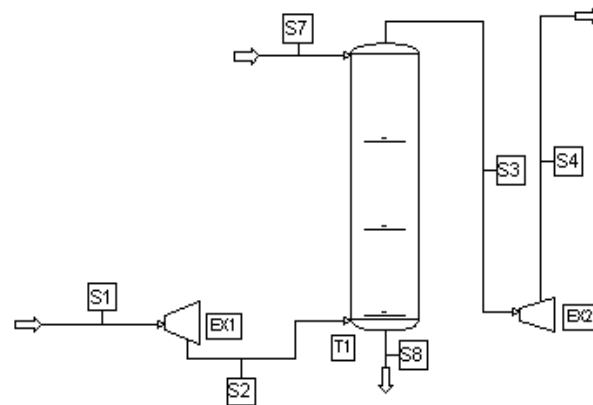
Source: *Divine Wind* by Kerry Emanuel



Cooling Tower Cell

(water cooler & air heater/humidifier)





CALCULATOR

$$WK_NET = EX2_WK - M3 \cdot g \cdot z$$



CONTROLLER

Vary P2 until $WK_NET = 0$

Stream Name		S1	S2	S3	S4	S7	S8
Phase		Vapor	Mixed	Vapor	Mixed	Liquid	Liquid
Pressure	KPA	100.30	75.47	75.47	5.00	100.00	75.47
Temperature	C	30.00	16.66	31.14	-62.63	33.00	24.68
Total Sp. Enthalpy	KJ/KG	47.528	23.218	95.437	-106.050	122.777	85.842
Total Sp. Entropy	KJ/KG-C	6.507	6.507	6.718	6.718	5.106	4.984
Total Mass Rate	KG/SEC	1020.500	1020.500	1039.928	1039.928	2000.000	1980.572
Total Enthalpy	M*WATT	48.502	23.694	99.247	-110.284	245.555	170.015

Calculator Name		CA1
EX1 WORK (MW)		24.81
EX2 WORK (MW)		209.53
Heat Duty (MW)		75.54
Height (m)		20560

Pro II Simulation

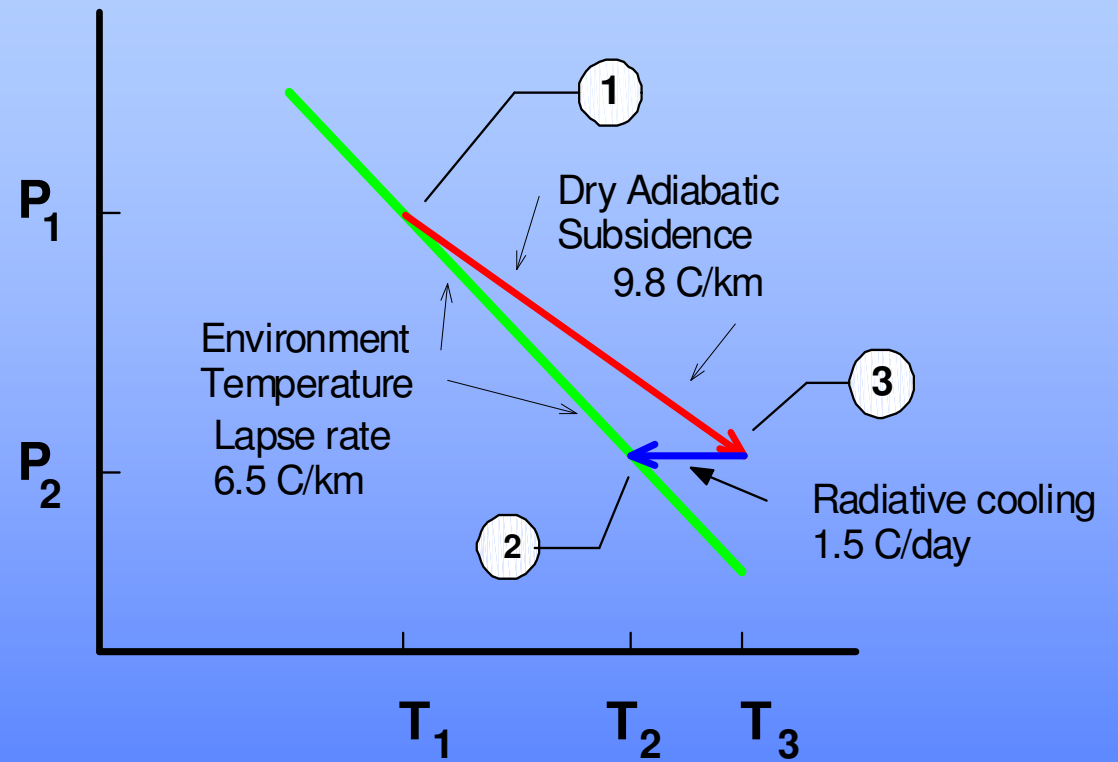
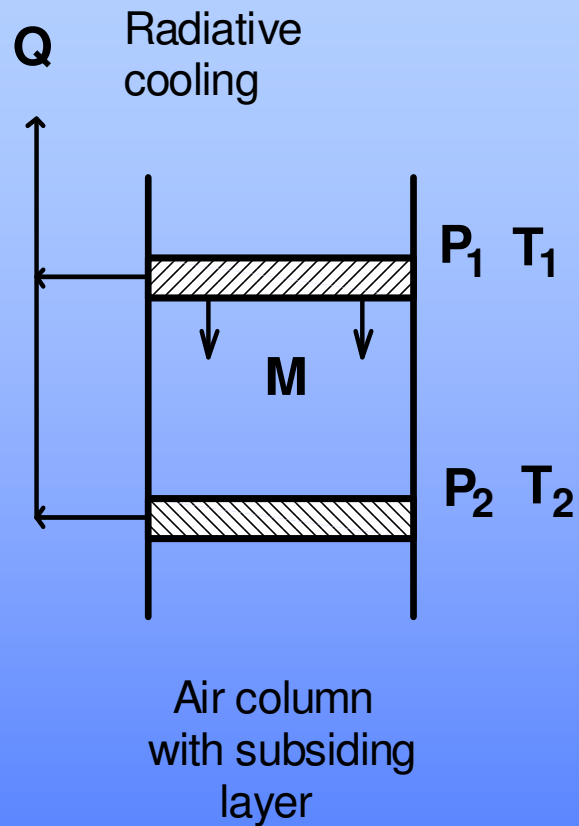
Simulation Highlights

<u>Water Temperature (C)</u>	<u>Power (MW)</u>
25	0
26	30
33	250
40	400

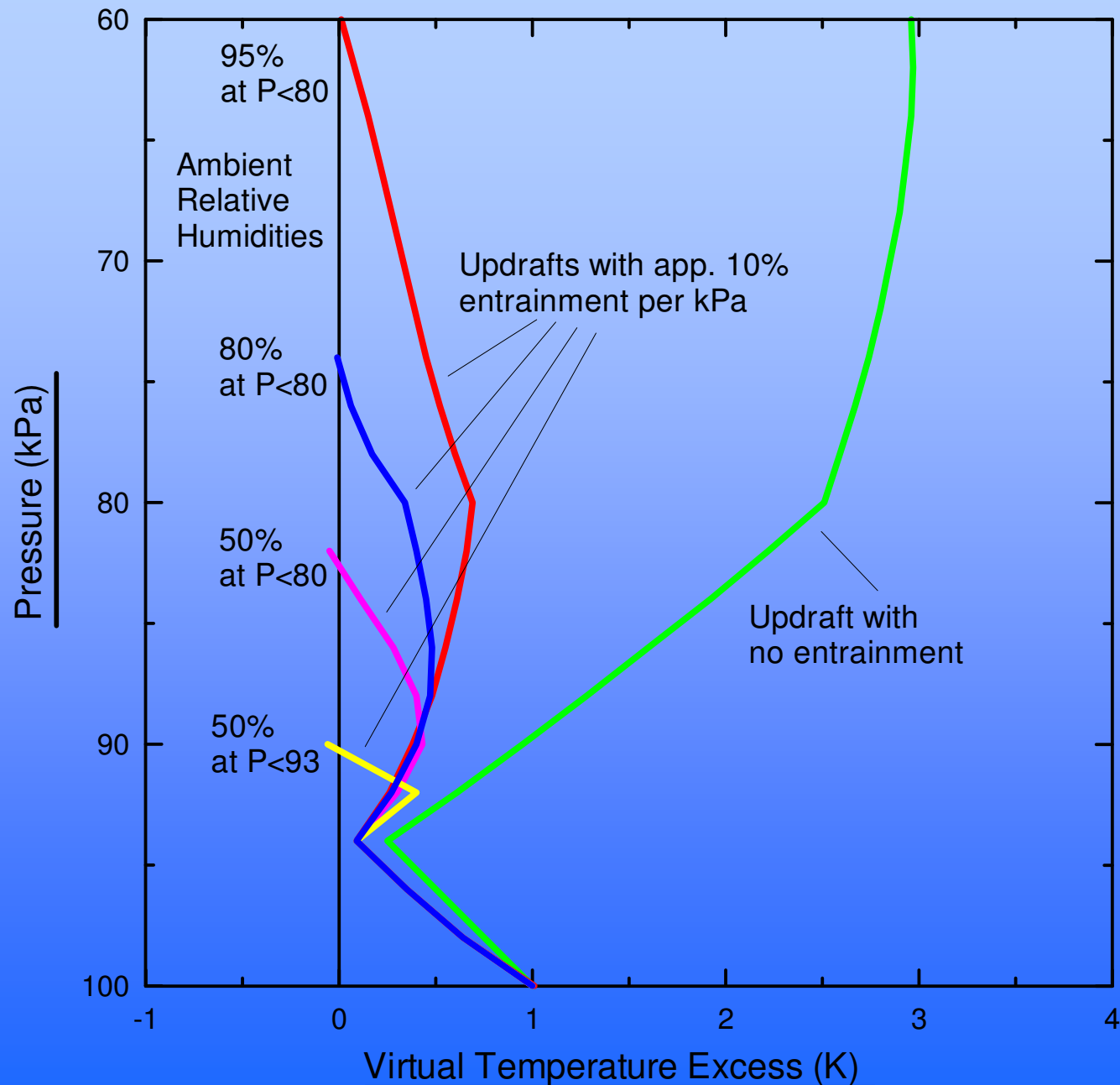
Note: based on an air flow of 10 tonnes/s (12 times Manzanares flow)

- Large change in elevation are required to achieve significant efficiency.
 - Manzanares 200 m 0.6%
 - SolarMission 1000 m 3%
 - Vortex Engine 18000 m 25%

Subsidence warming and radiative cooling



Effect of entrainment and ambient relative humidity on updraft buoyancy



A Comparison of the Earth's Stored Energy Resources

Crude Oil Reserves

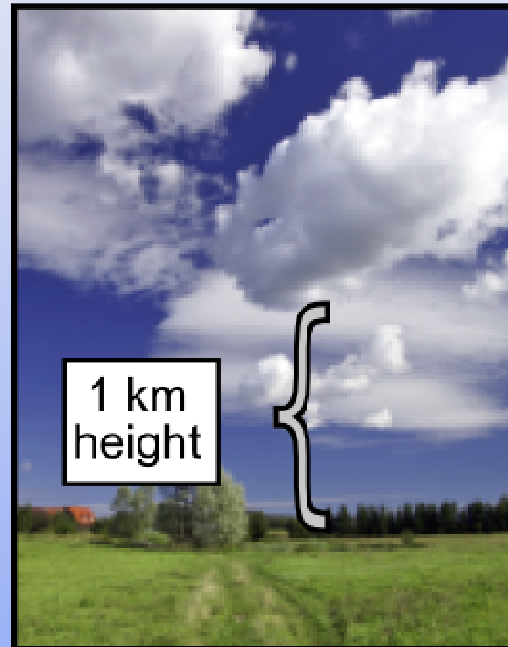


$7.3 \times 10^{21} \text{ J}$



Latent heat of water vapor

in the bottom kilometer of the atmosphere



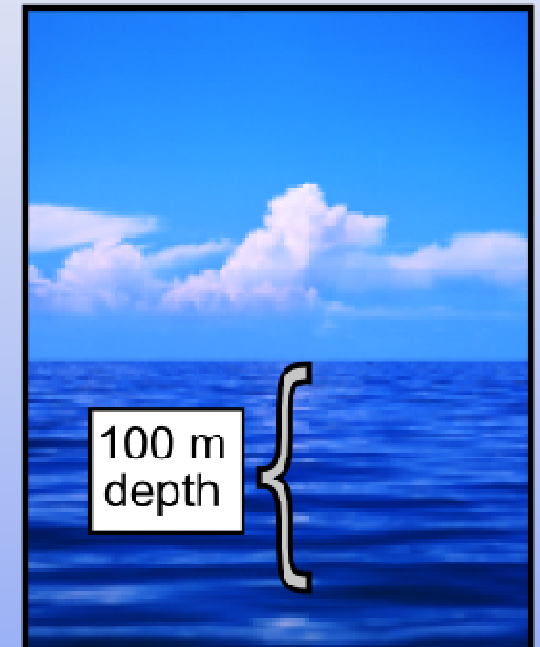
1 km
height

$13 \times 10^{21} \text{ J}$



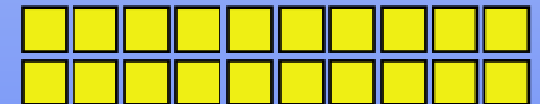
Heat content of tropical ocean water

100 m layer, 3°C



100 m
depth

$130 \times 10^{21} \text{ J}$



Replenishment times

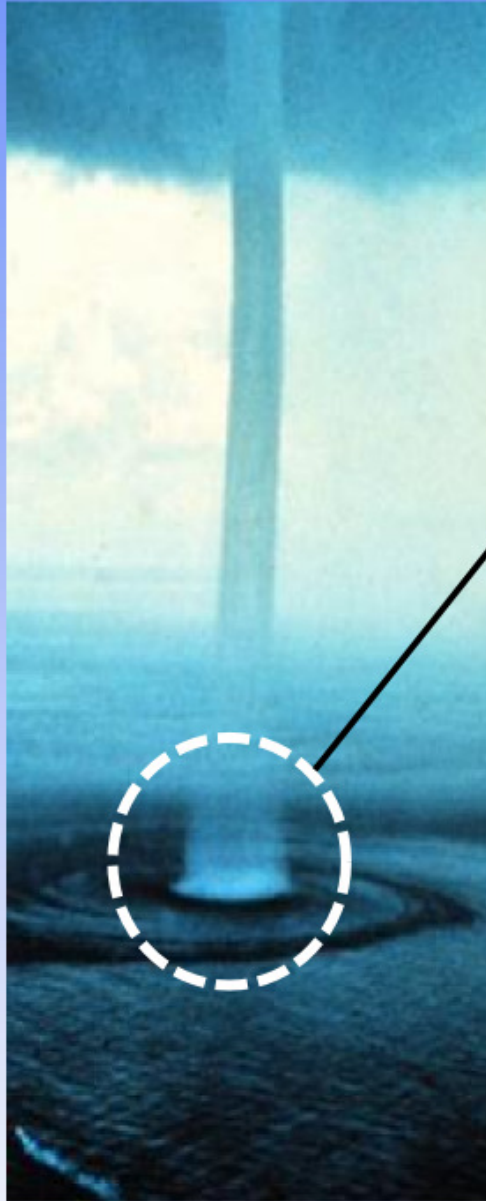
10^8 years

10 days

100 days

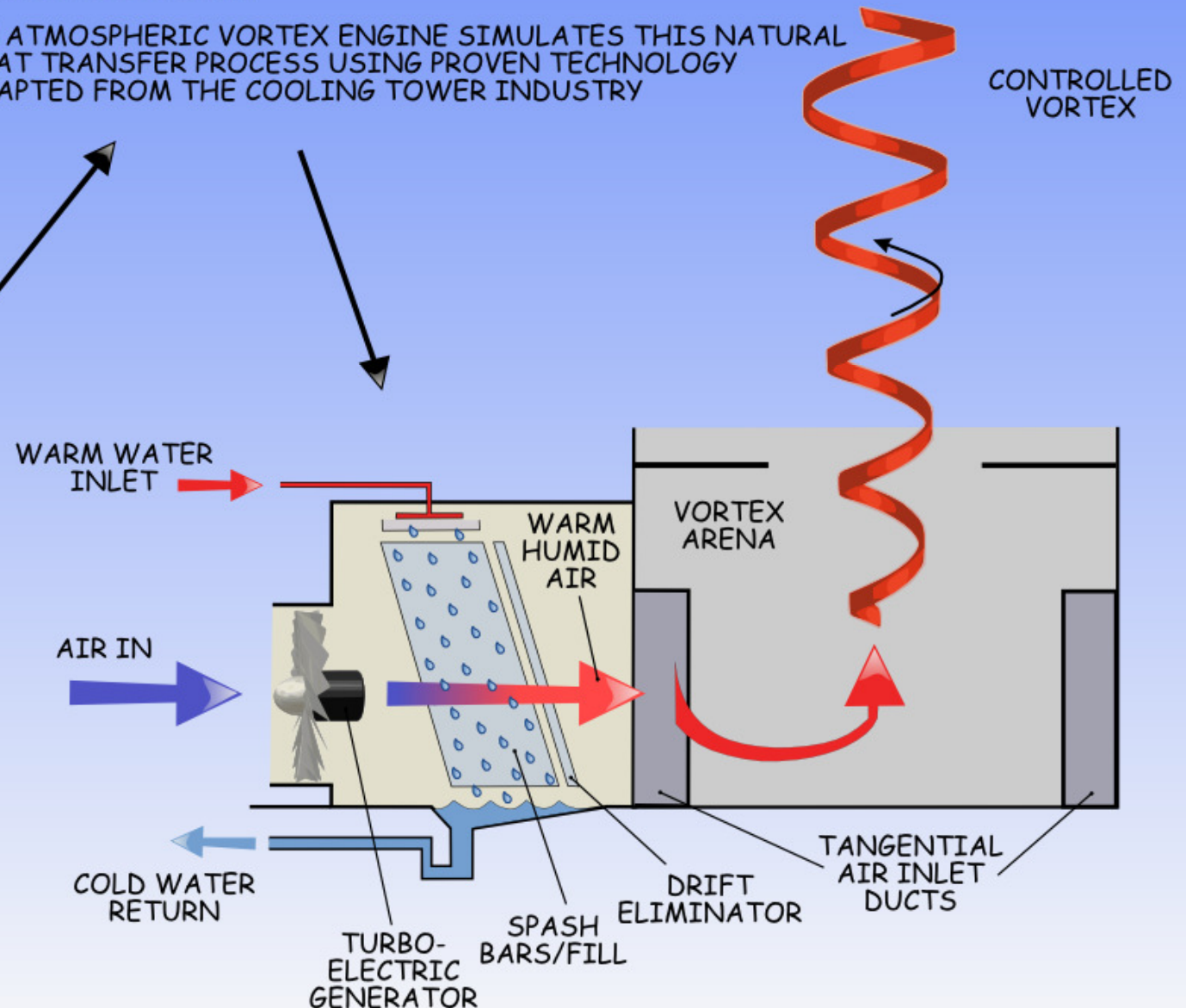
SIMULATION OF HEAT TRANSFER IN A WATERSPOUT USING COOLING TOWER TECHNOLOGY

<http://vortexengine.ca>



AT THE BASE OF A NATURAL WATERSPOUT, SPRAY FROM WARM SEA WATER TRANSFERS SENSIBLE AND LATENT HEAT TO THE RISING AIR COLUMN.

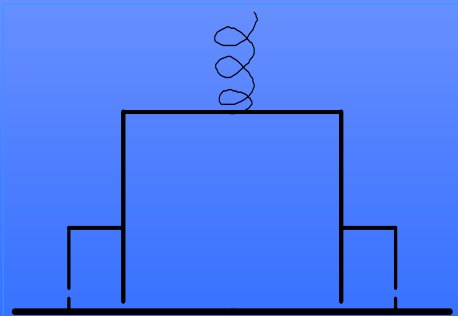
AN ATMOSPHERIC VORTEX ENGINE SIMULATES THIS NATURAL HEAT TRANSFER PROCESS USING PROVEN TECHNOLOGY ADAPTED FROM THE COOLING TOWER INDUSTRY





Atmospheric Vortex Engine

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For more information visit:
<http://vortexengine.ca>