

Wayne State University
Department of Physics & Astronomy
Winter 2008 Nuclear Physics Seminar presents

Louis M. Michaud, P. Eng.

*Vortex Engine
Sarnia, Ontario CANADA*

"The Atmospheric Vortex Engine"

Abstract: *An atmospheric vortex engine (AVE) uses an artificially created anchored tornadolike vortex to capture the mechanical energy produced when heat is carried upward by convection in the atmosphere. The vortex is created by admitting warm or humid air tangentially at the base of a circular wall. The heat source can be waste industrial heat, warm sea water or simply warm humid air. This mechanical energy is produced in peripheral turbines.*

The focus of the seminar will be on thermodynamics. Several different thermodynamic methods of analysis are shown to give consistent results. The mechanisms whereby mechanical energy is dissipated is one of the least well understood and controversial subject in atmospheric science. There is a wide range of opinions on how the entropy required to balance the Earth's entropy budget produced. Ideal cycles are used to show that the primary dissipation mechanism is unrestrained expansion rather than mixing or thermodynamic disequilibrium. The thermodynamic approach is able to unequivocally answer questions that have eluded the traditional atmospheric science methods.

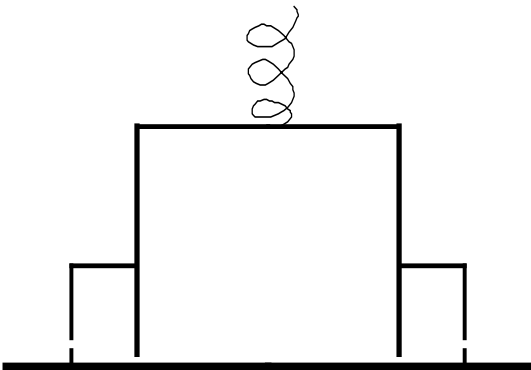
The energy production potential of the atmospheric vortex engine is far greater than that to other solar energy technologies because the solar collector is the earth's surface in its unaltered state; there is no need for a huge solar collector. A vortex engine increases the efficiency of thermal power plants by reducing cold source temperature. The AVE alleviates global warming by reducing the quantity of fuel required to meet energy needs. The AVE remediate global warming by lifting heat above greenhouse gases so that the heat can more easily radiate back to space.

**Friday, January 18, 2008
3 p.m., Room 312 Physics
Refreshments served at 2:30 p.m.**



Atmospheric Vortex Engine

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

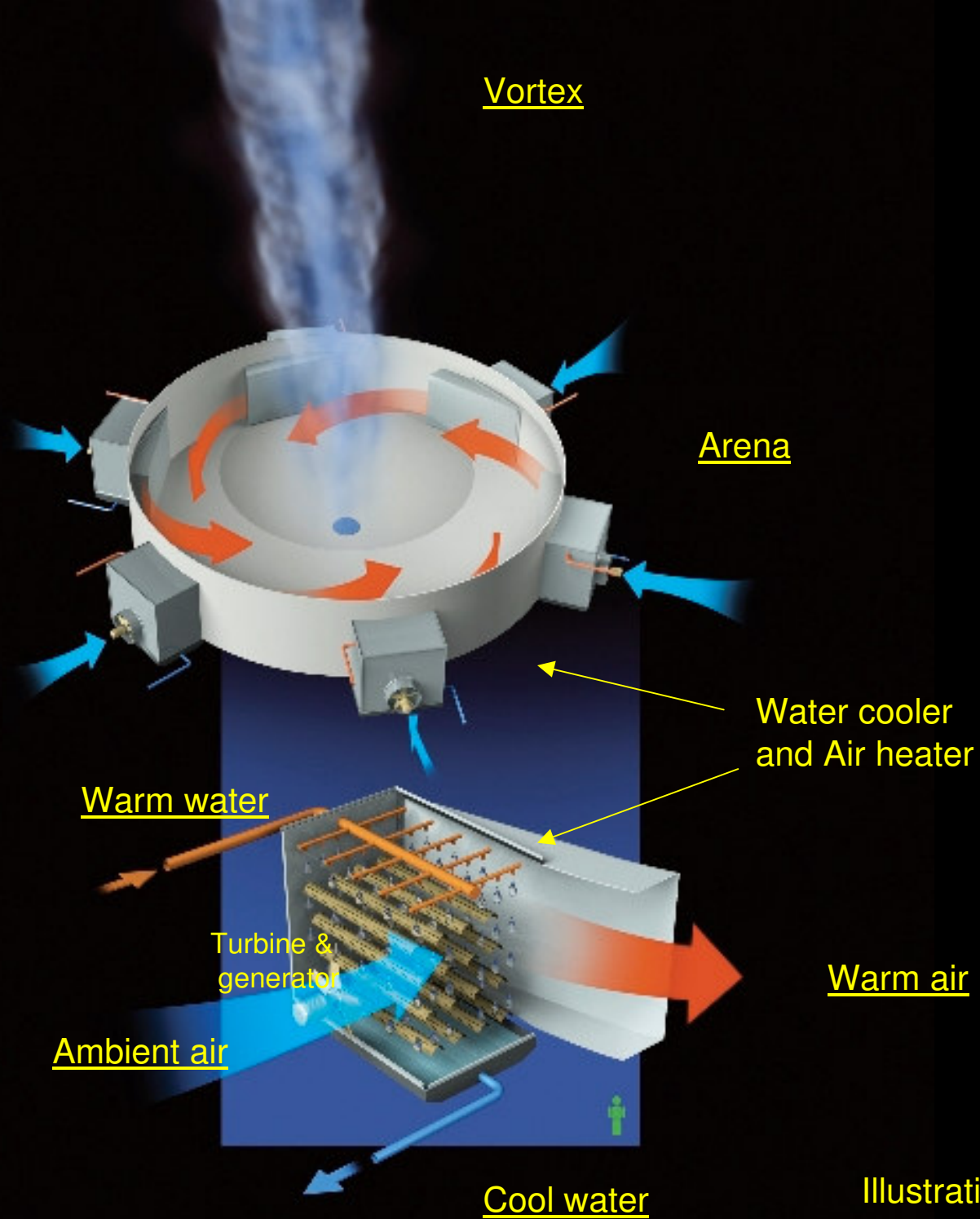
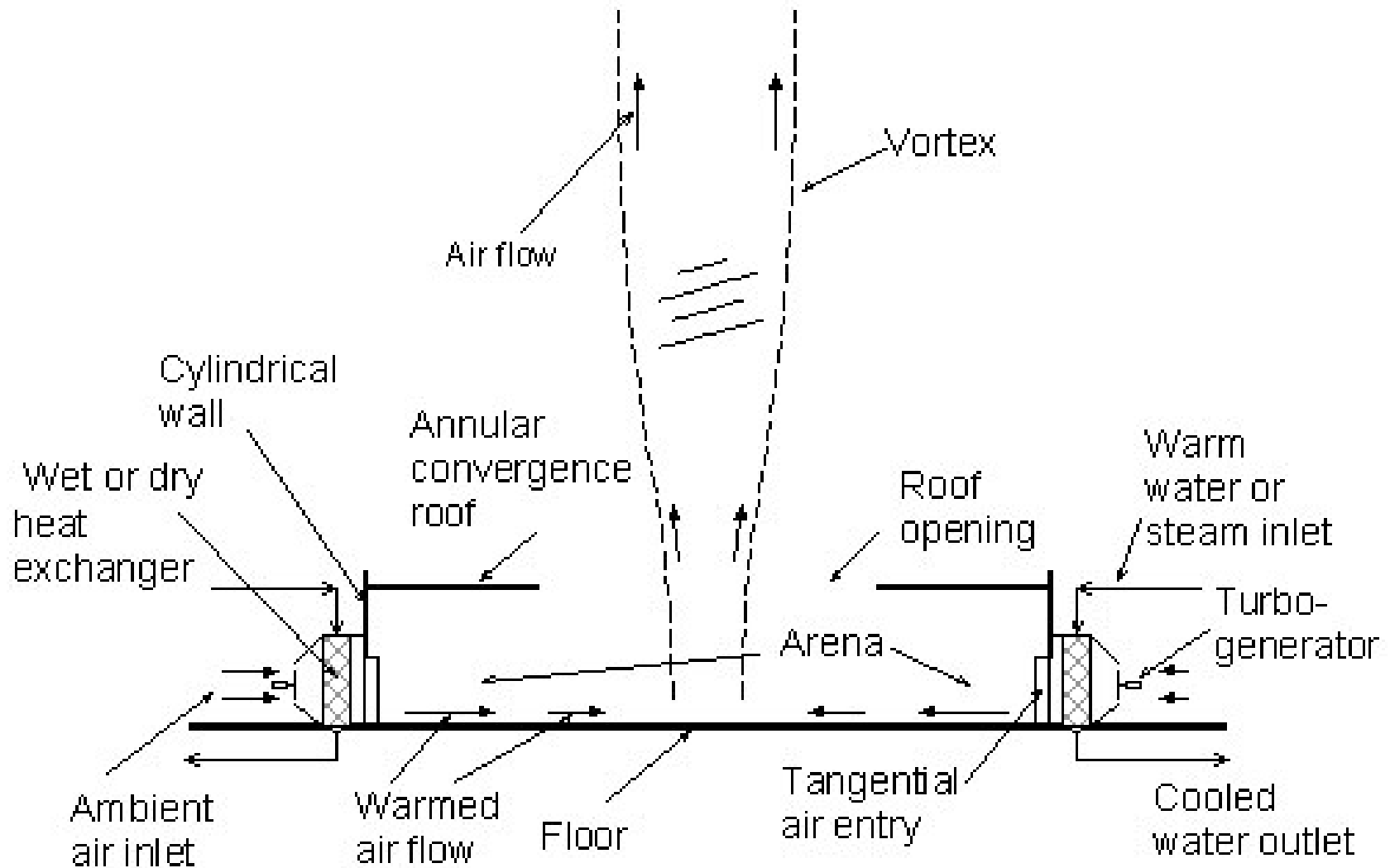
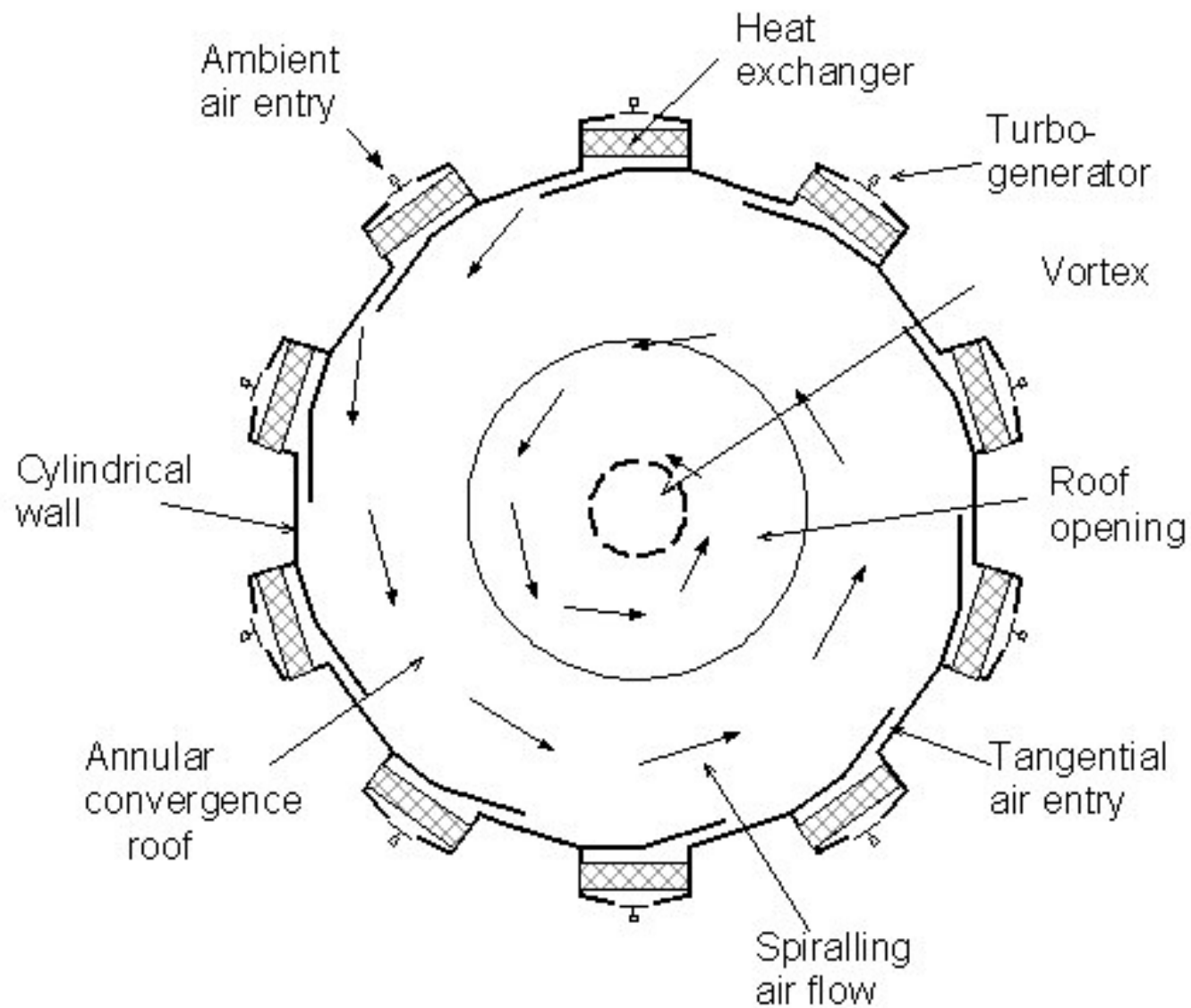


Illustration by Charles Floyd



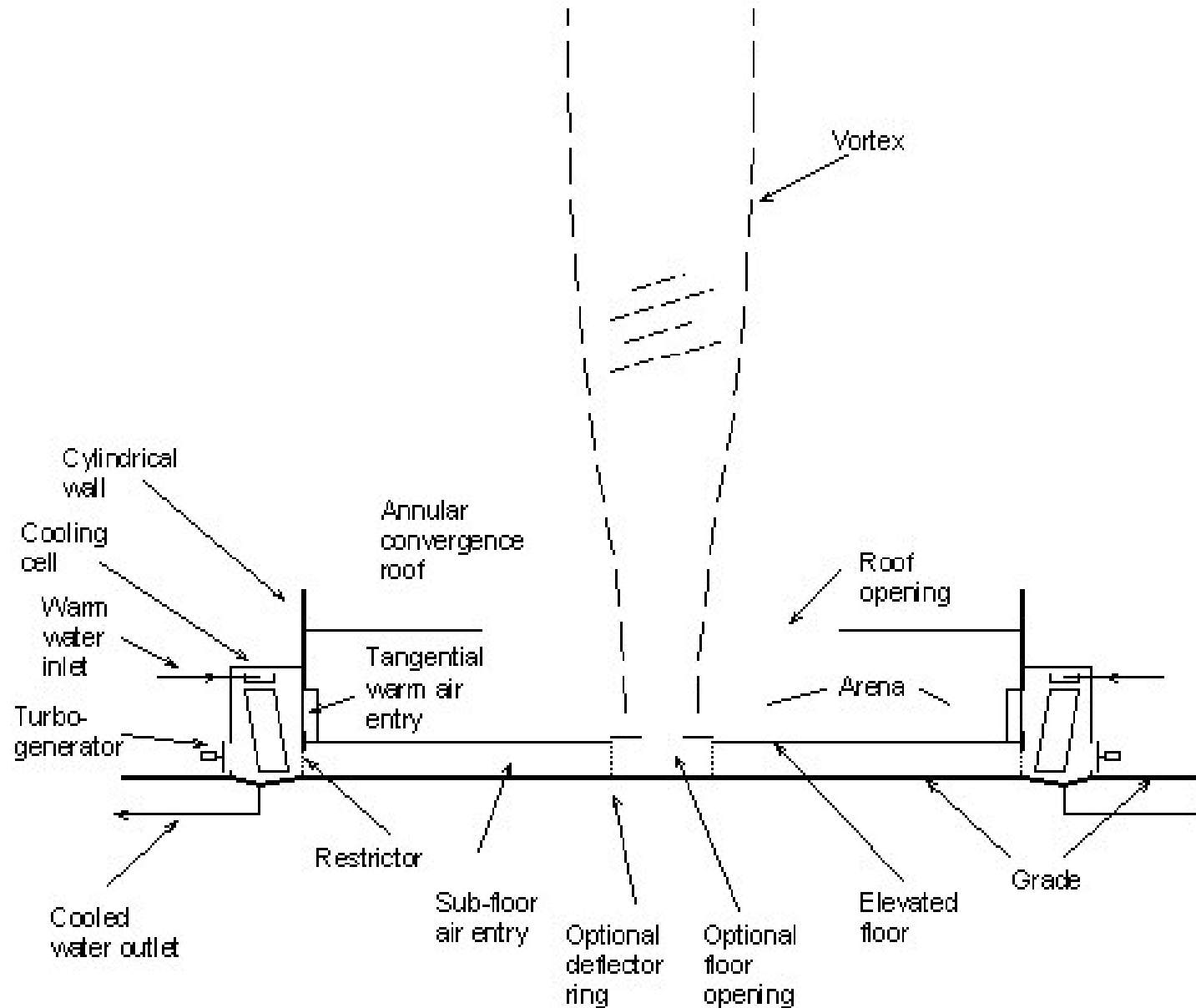
Atmospheric vortex engine side view



Atmospheric vortex engine plan view

Wet cooling tower AVE – Side view

Capacity approximately 200 MW



Electricity from Atmospheric Convection



Manzanares Solar Chimney

200 m high, 10 m diameter
Collector 0.04 sq. km
50 kW, 130 J/kg, 1 Mg/s
Efficiency 0.2%
Spain 1982 to 1989



EnviroMission Solar Chimney

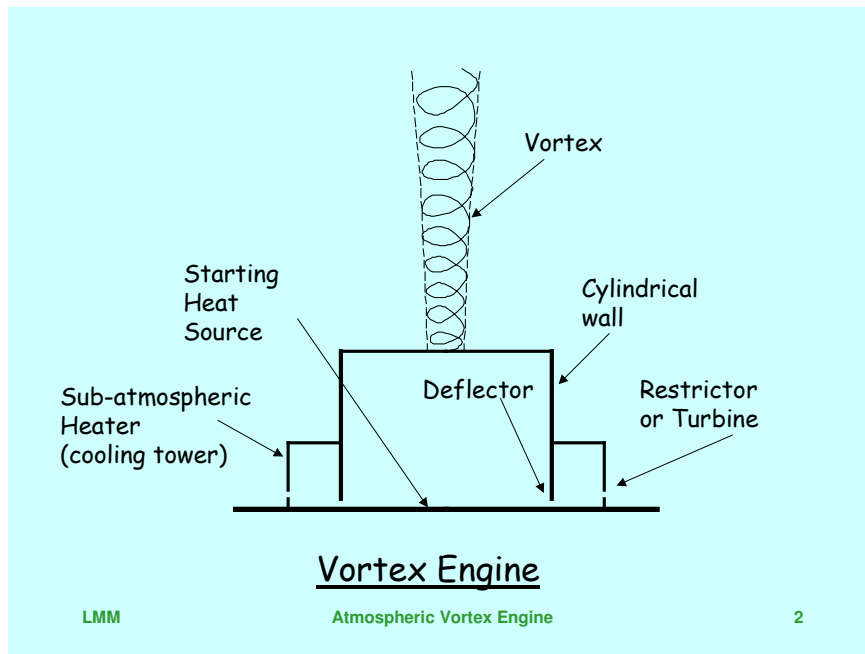
1 km high, 130 m diameter
Collector 40 sq. km
200 MW, 800 J/kg, 300 Mg/s
Efficiency 1.5%
Australia, 2008+

- The AVE eliminates the physical chimney by using a vortex.
- The AVE eliminates the solar collector by using waste heat or natural low temperature heat sources.

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)

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

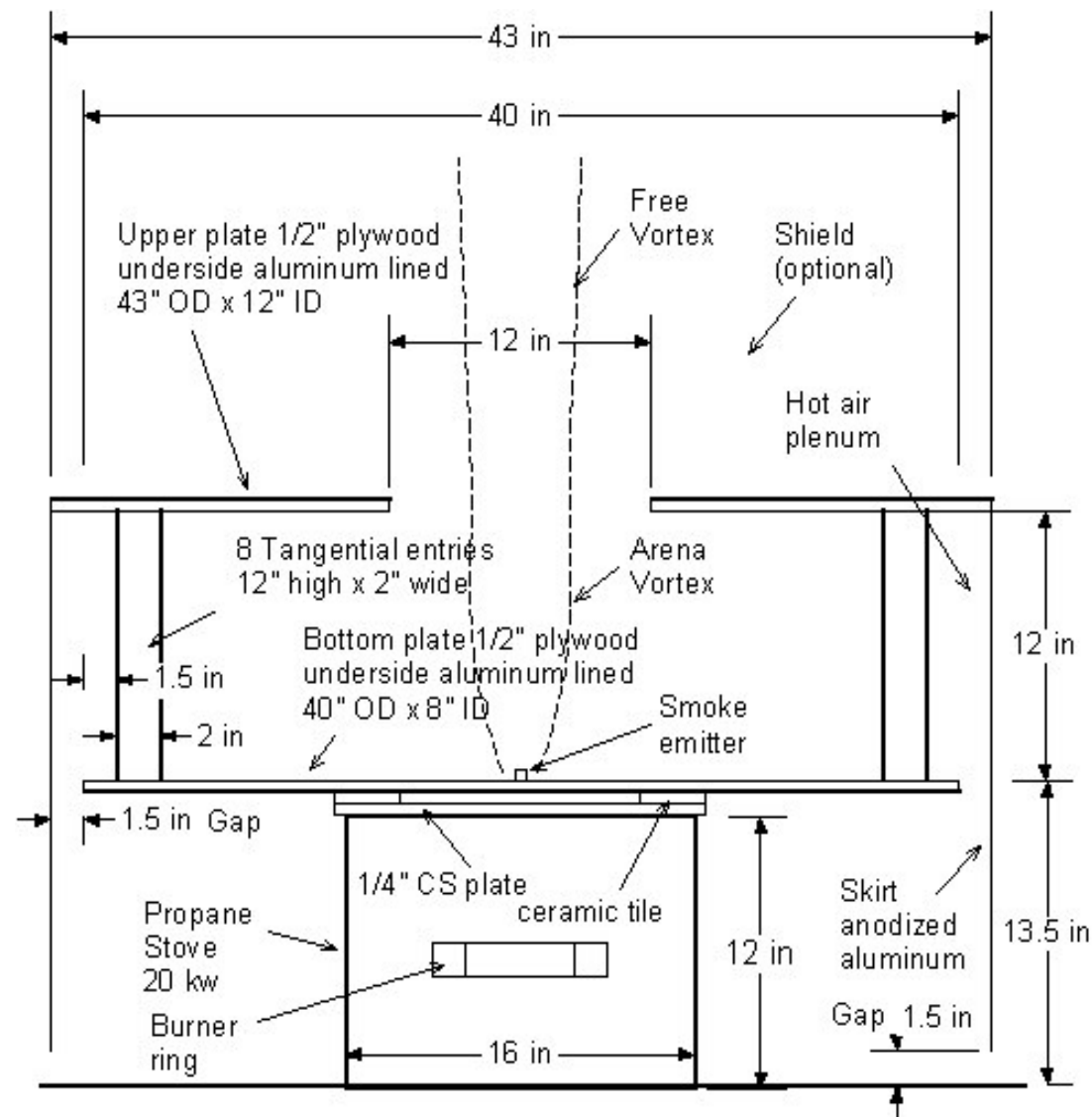
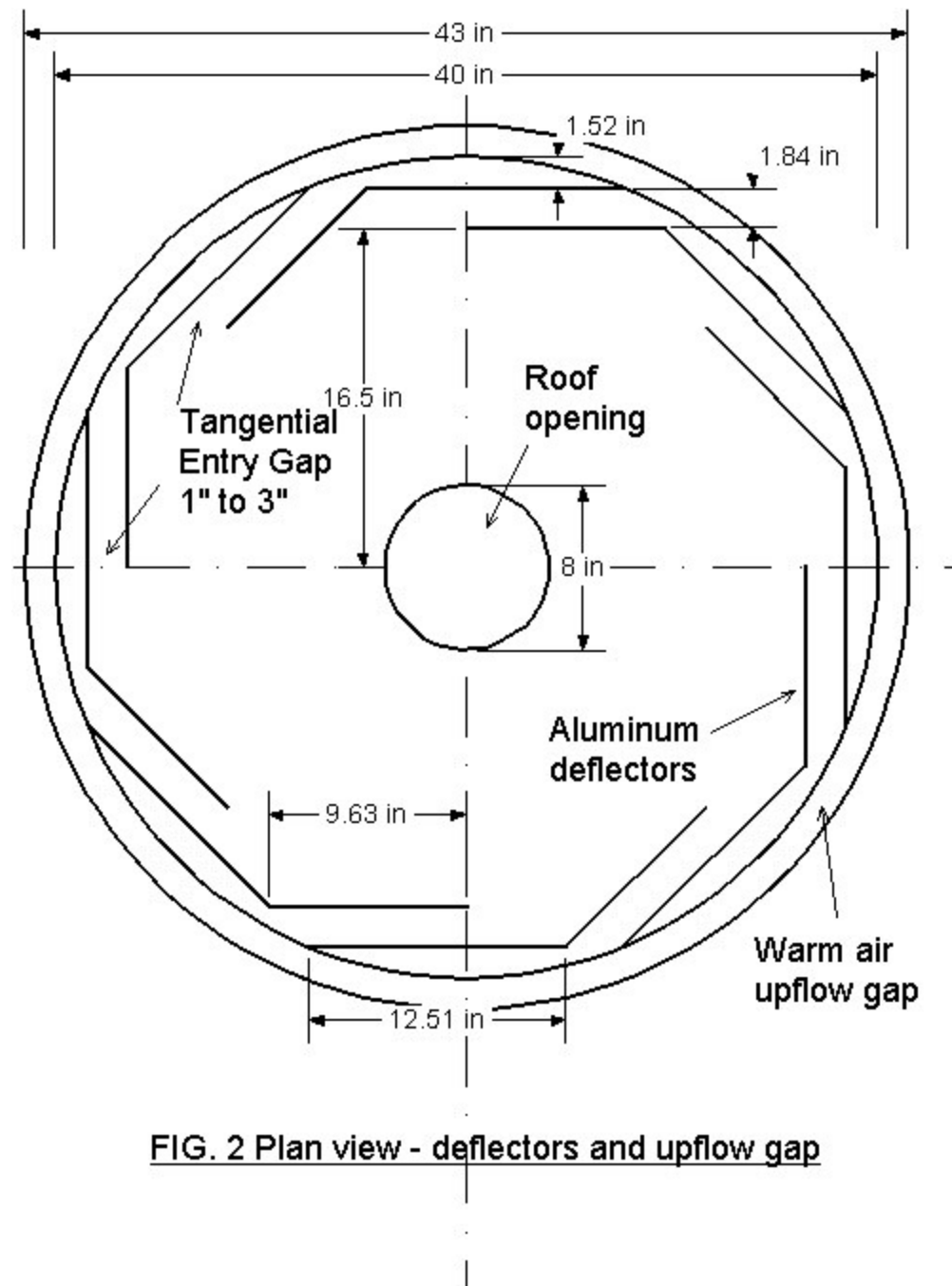


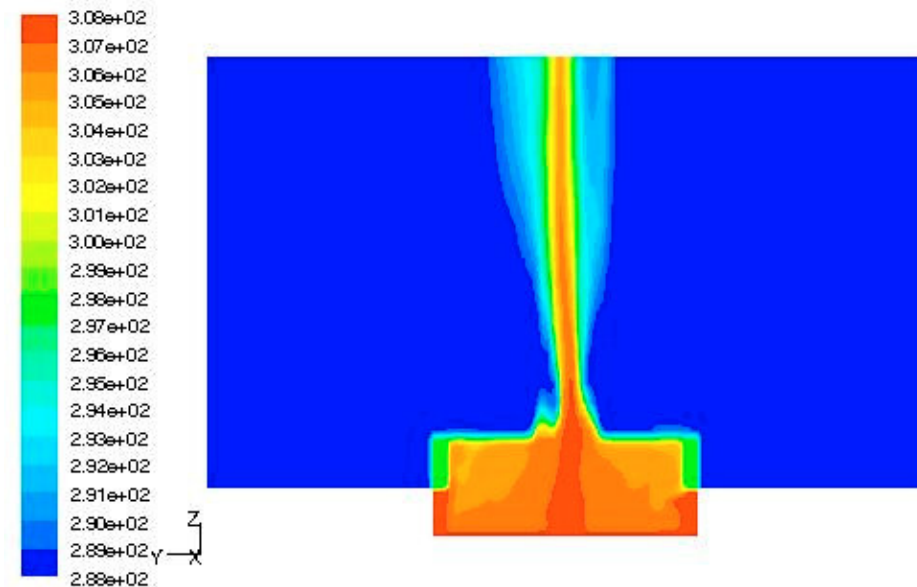
FIG. 1 Model Side

1 meter diameter physical model – top view



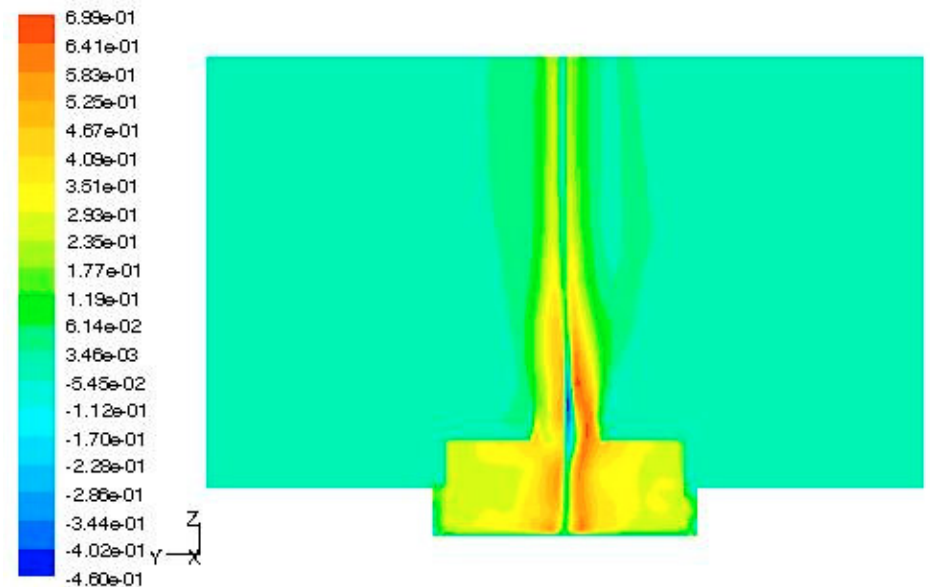
CFD Results

- 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



Contours of Static Temperature (k)

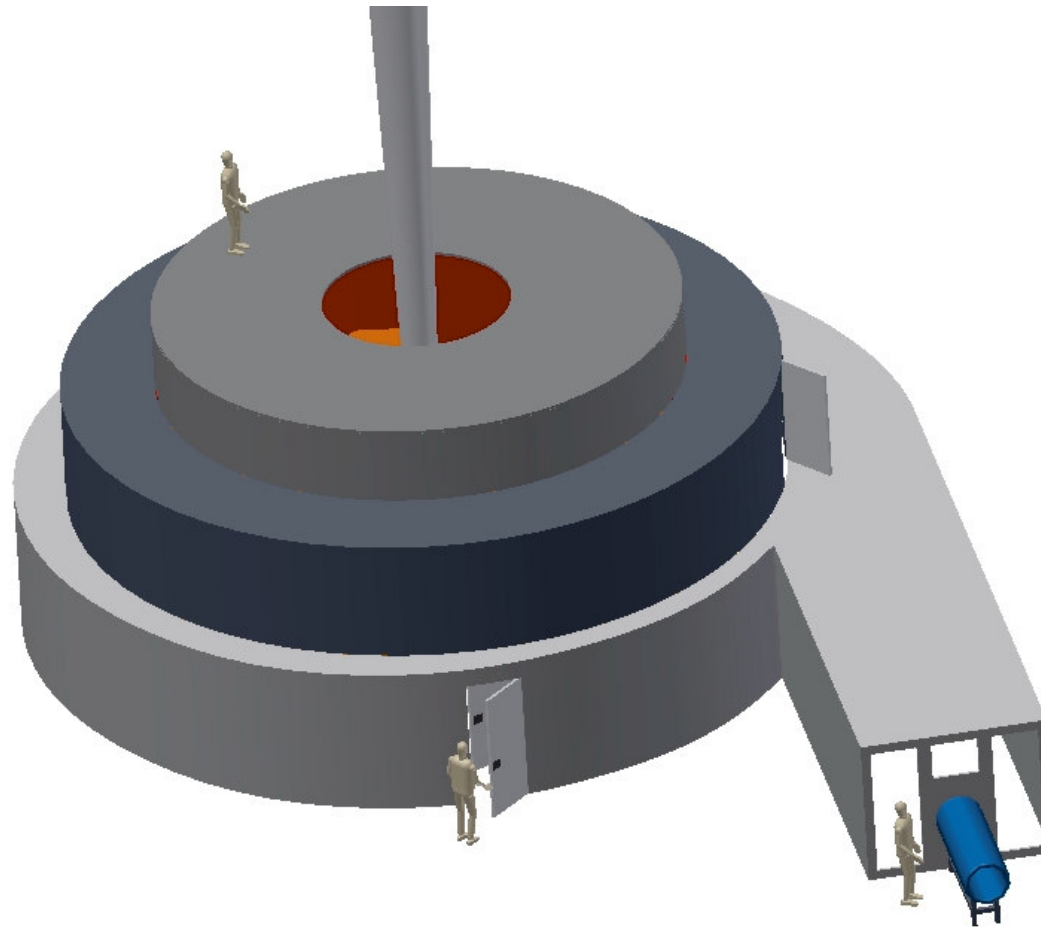
Jan 08, 2007
FLUENT 6.2 (3d, segregated, lam)



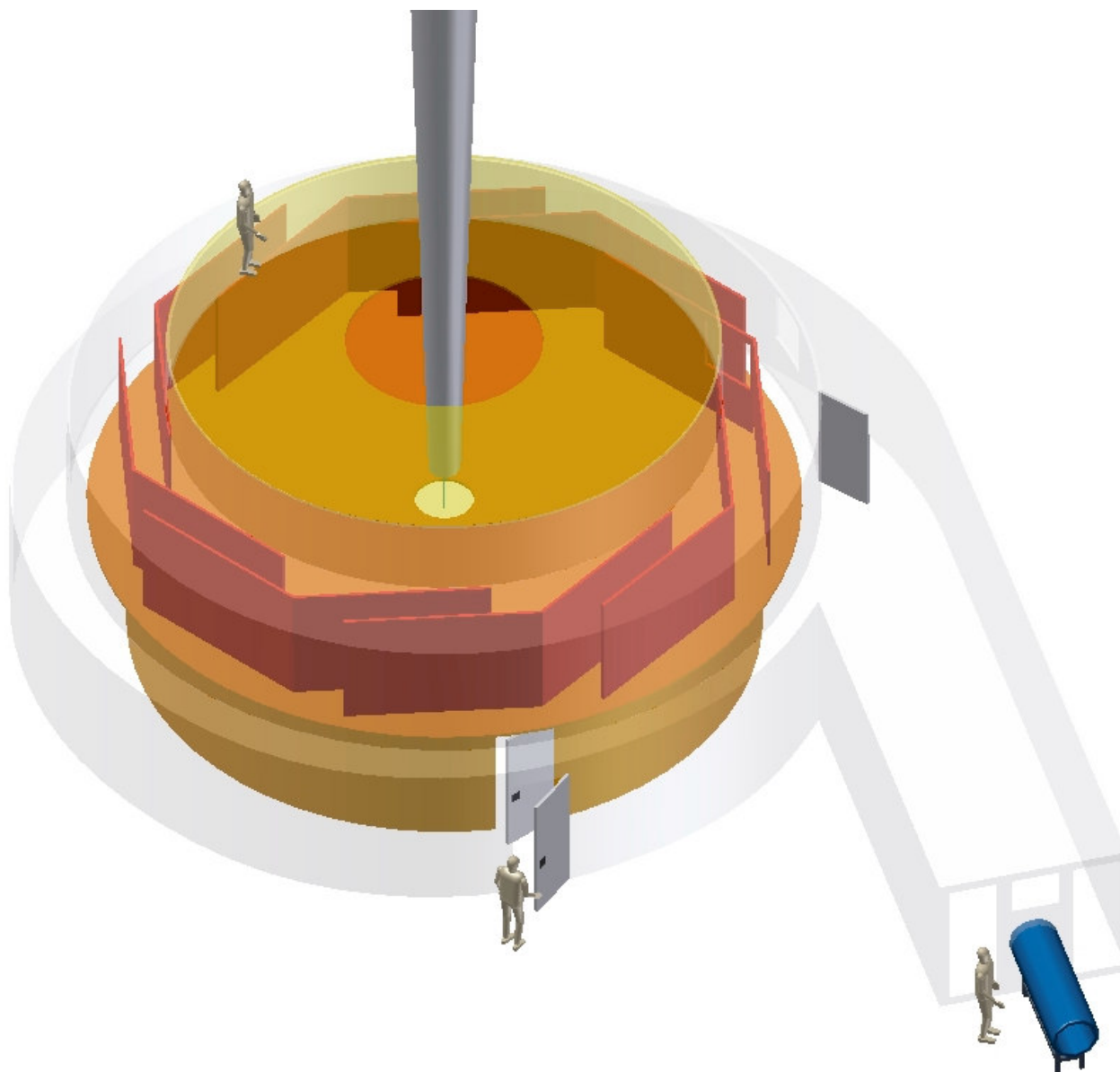
Contours of Tangential Velocity (m/s)

Jan 08, 2007
FLUENT 6.2 (3d, segregated, lam)

Proposed 10 m prototype



Proposed 10 m diameter prototype transparent wall view



Airflow in a Vortex at Altitude

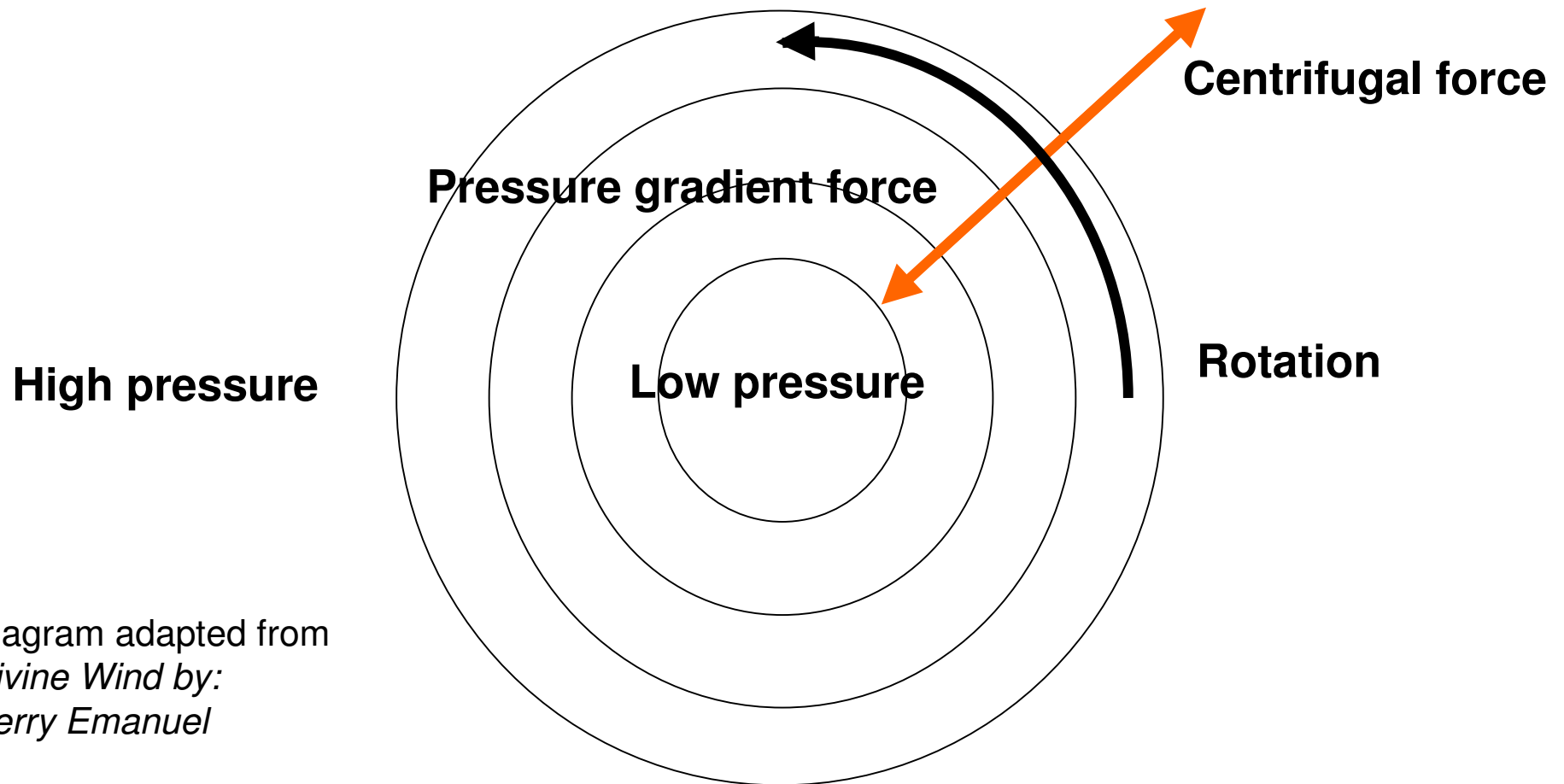
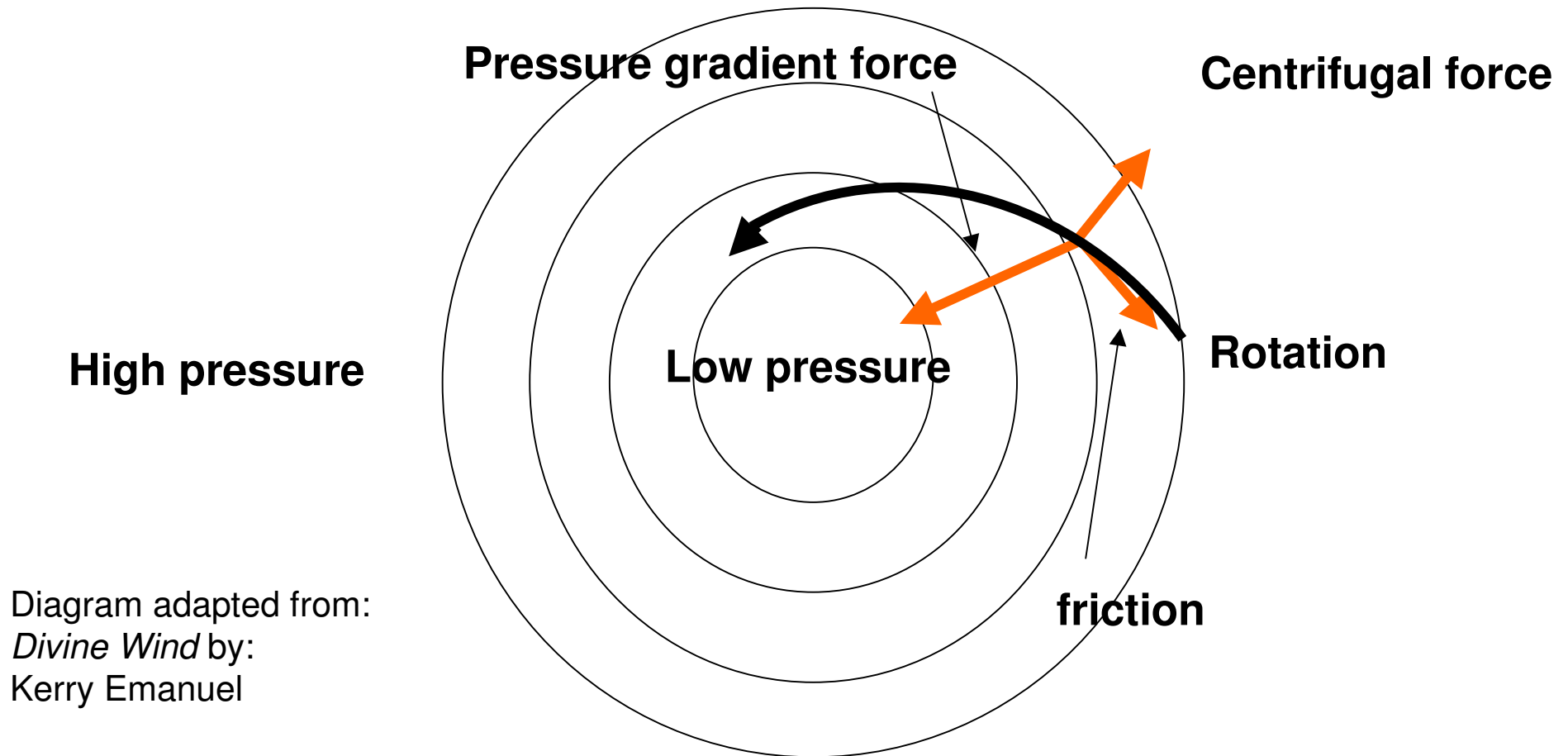


Diagram adapted from
Divine Wind by:
Kerry Emanuel

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.



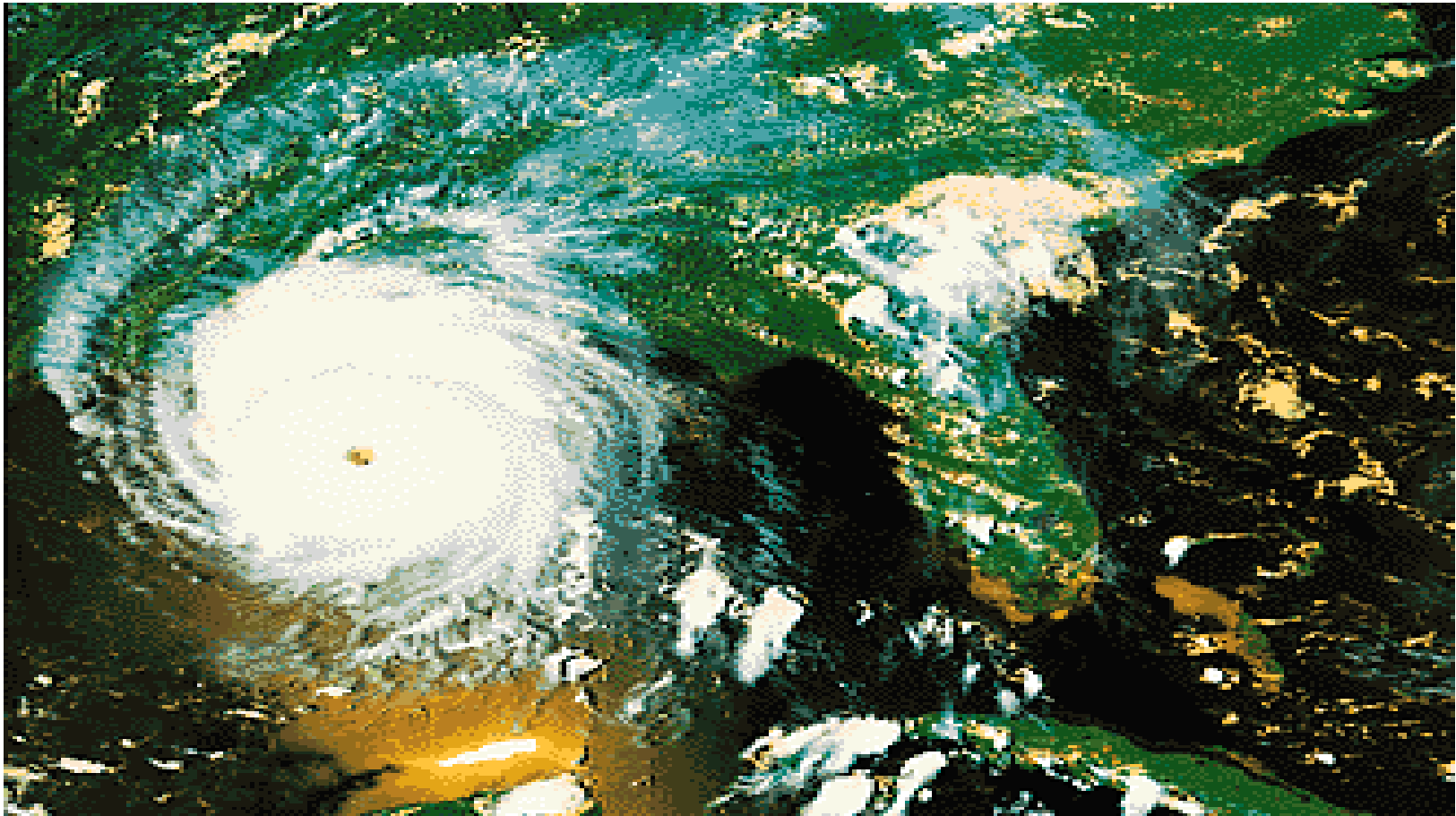
Tornado



Waterspout



Hurricane



NASA

Fire whirls

Accidental ←

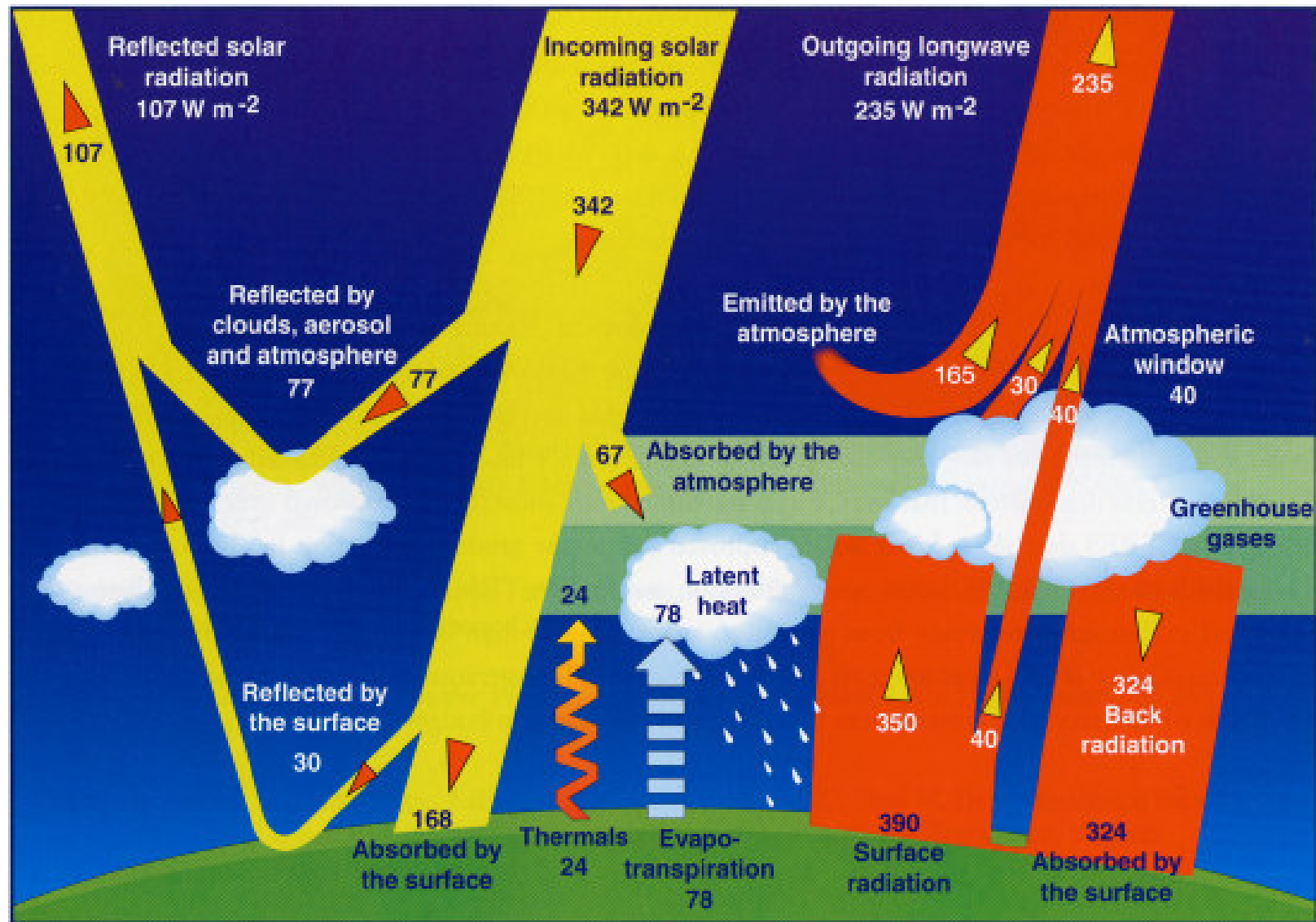
Deliberate ↓



Source: Nate Smith

Entropy

Earth Energy Budget



Earth's Entropy Budget

41, 4 / REVIEWS OF GEOPHYSICS

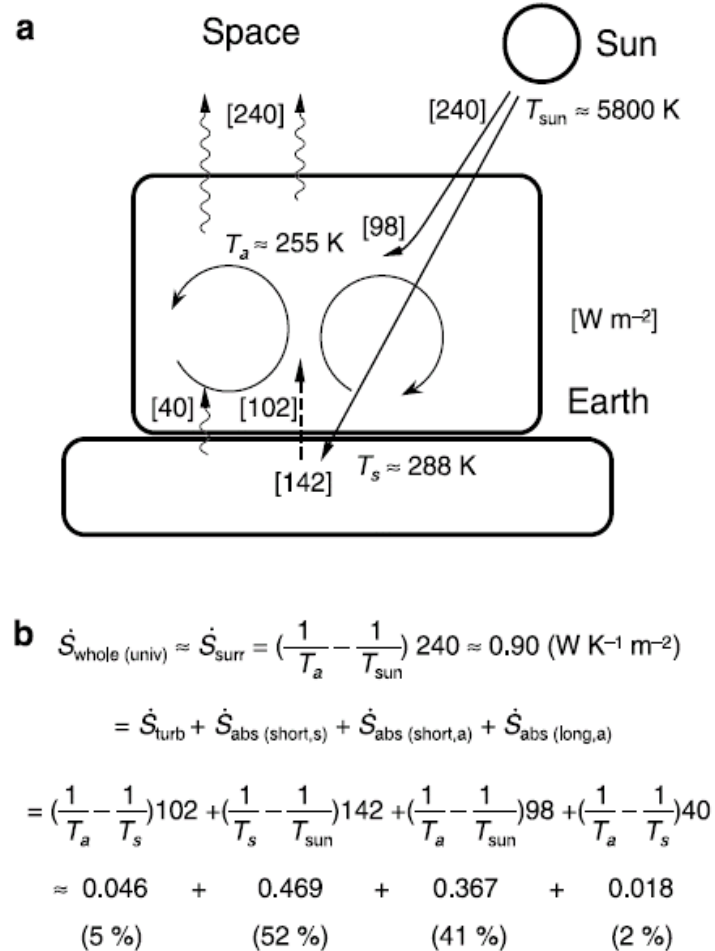
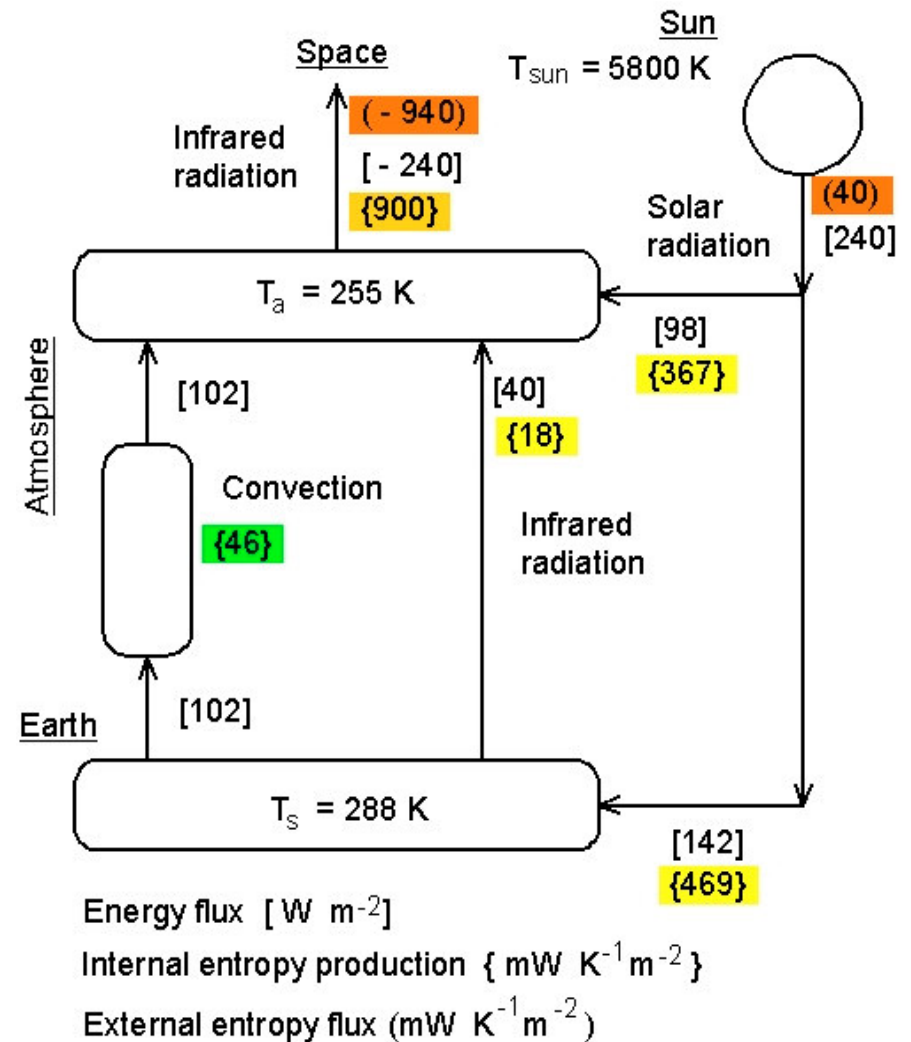


Figure 5. Energy and entropy budgets for the Earth. (a) Global-mean (surface-area mean) energy flux components (i.e., shortwave radiation, longwave radiation, vertical turbulent heat transport), in W m^{-2} . (b) Corresponding rates of entropy production in the whole system (universe) due to the irreversible processes (absorption of radiation, turbulent convection, etc.) in the climate system. The total rate of entropy production is $0.90 \text{ (W K}^{-1} \text{ m}^{-2}\text{)}$.



Source: Ozawa, H. et. al. 2003.

The second law of thermodynamics and the global climate system:
A review of the maximum entropy production principle.
Reviews of Geophysics 41, 4/1018-2003.

Energy and Entropy for Atmospheric convection

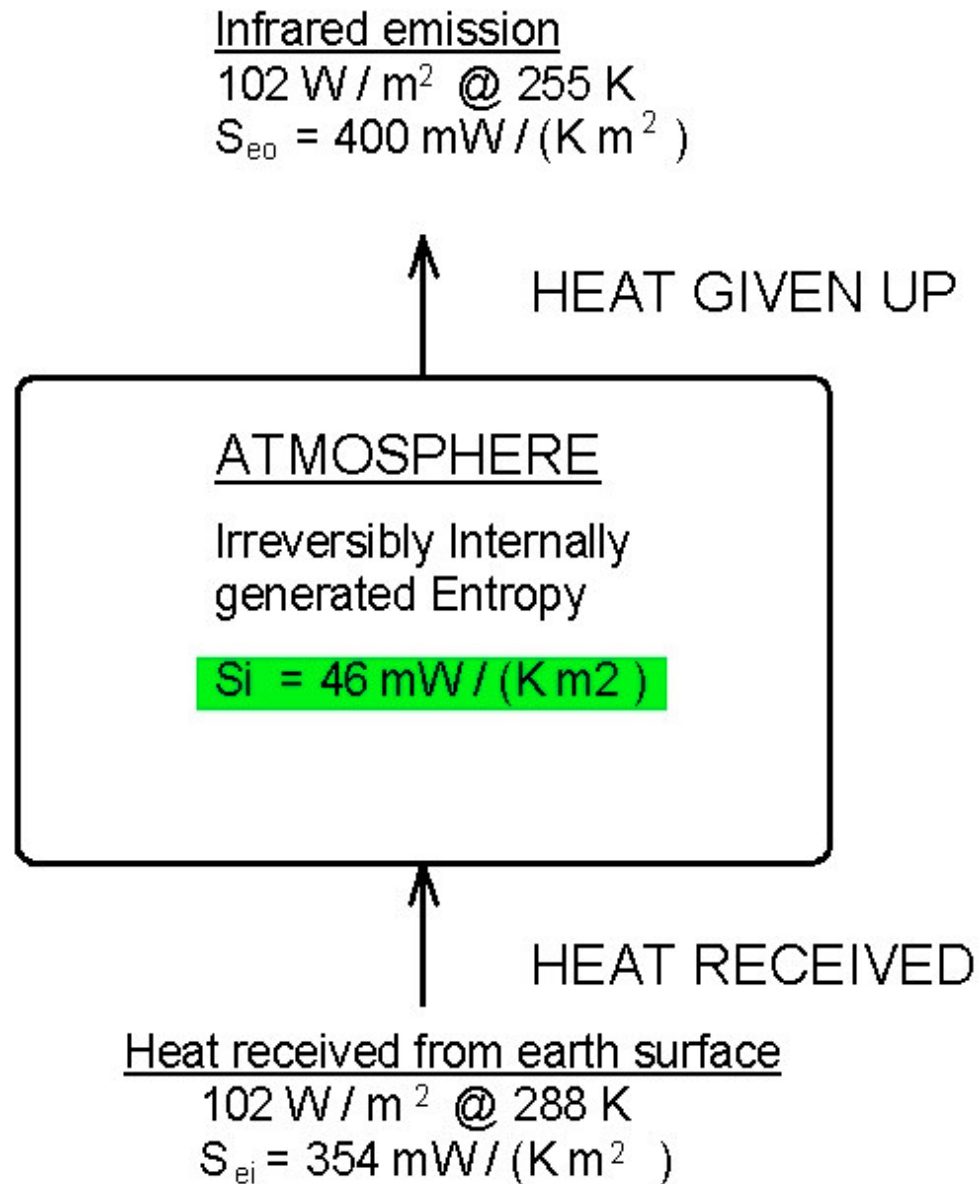


Fig. 2

Energy and Entropy

Heat is carried by a Carnot engine followed by dissipation of the work at cold source temperature.

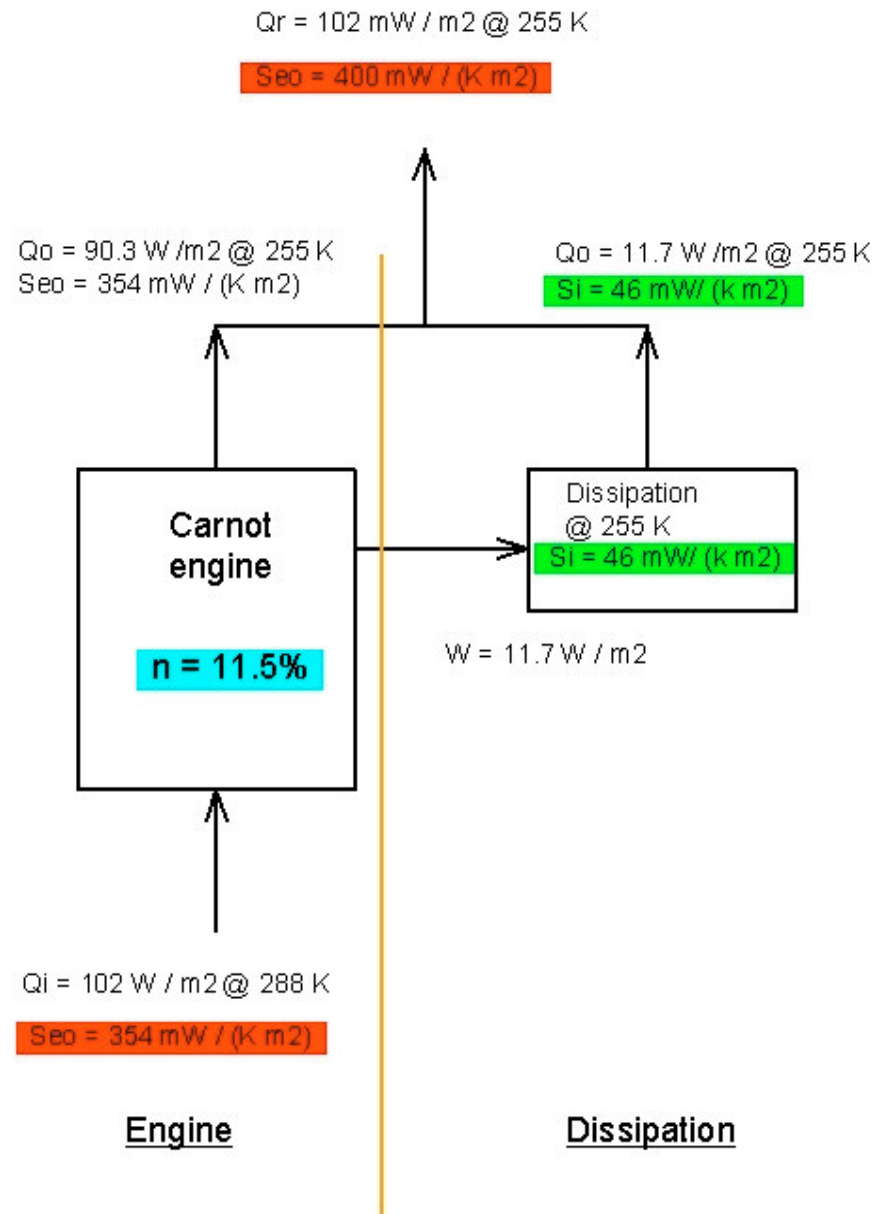
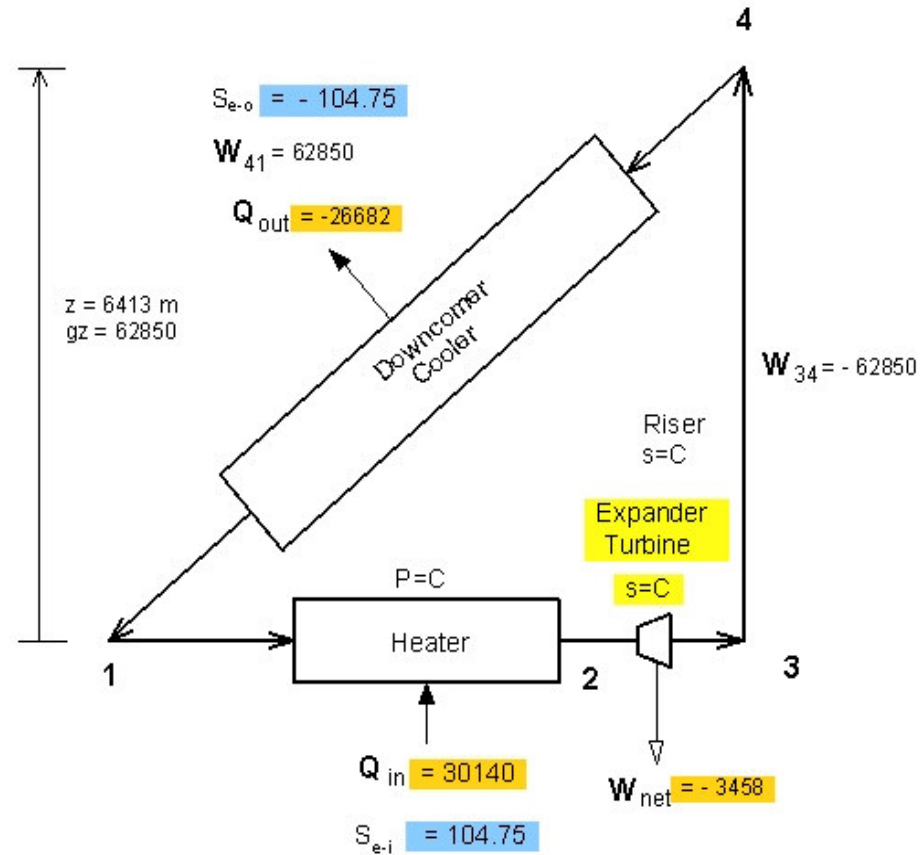


Fig.
3



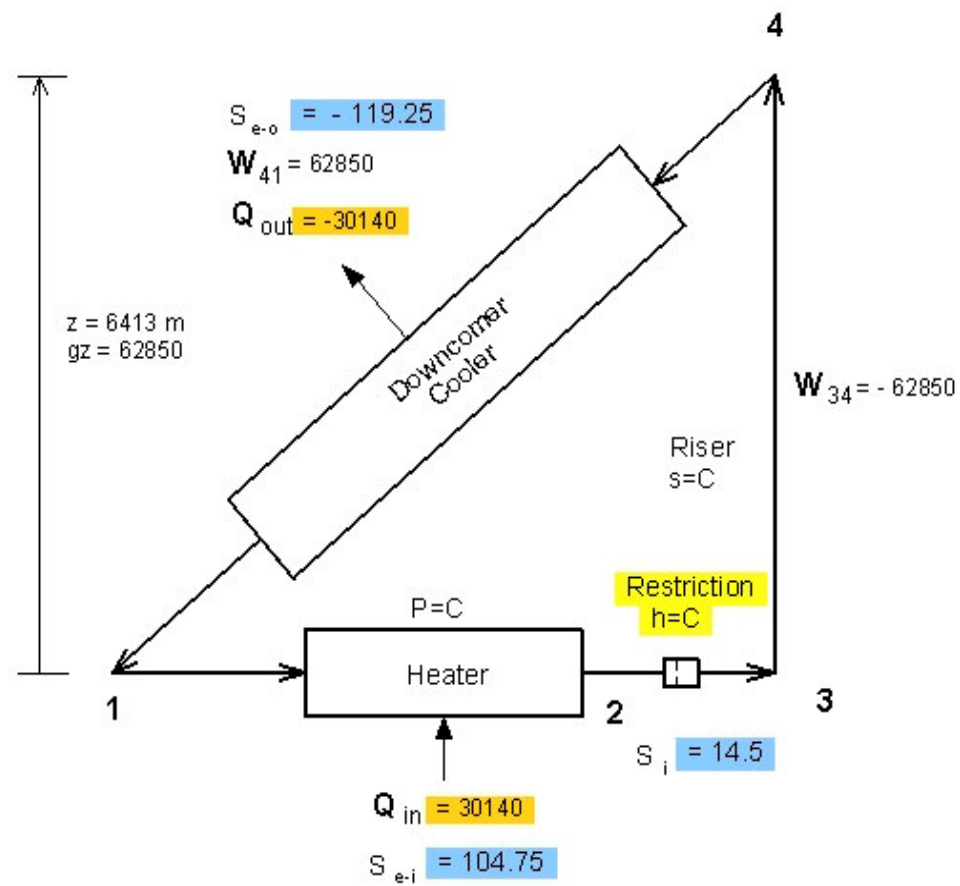
State	P (kPa)	T(K)	s (J/K-kg)	h (J/kg)	Duty (J/kg)
1	100	273	-0.55	-150	30140
2	100	303	104.20	29989	-3458
3	96.08	299.6	104.20	26531	-62850
4	42.32	237	104.20	-36319	36168

$T_h = 288 \text{ K}$ $T_c = 255 \text{ K}$ Efficiency = 11.47%

Gravity power cycle - Reversible - Pure Air

Based on: Michaud, L. 2000: Thermodynamic Cycle of Atmospheric Upward Heat Convection. Meteorol. Atmos. Phys. 72, 29-46

Fig. 4



State	P (kPa)	T(K)	s (J/K-kg)	h (J/kg)	Duty (J/kg)
1	100	273	-0.55	-150	30140
2	100	303	104.20	29989	0
3	95.07	303	118.70	29989	-62850
4	42.32	240.4	118.70	-32903	32710

$$T_h = 288 \text{ K}$$

$$T_c = 256.7 \text{ K}$$

$$\text{Efficiency} = 0 \%$$

Gravity power cycle - Irreversible - Pure Air

Based on: Michaud, L. 2000: Thermodynamic Cycle of Atmospheric Upward Heat Convection. Meteorol. Atmos. Phys. 72, 29-46

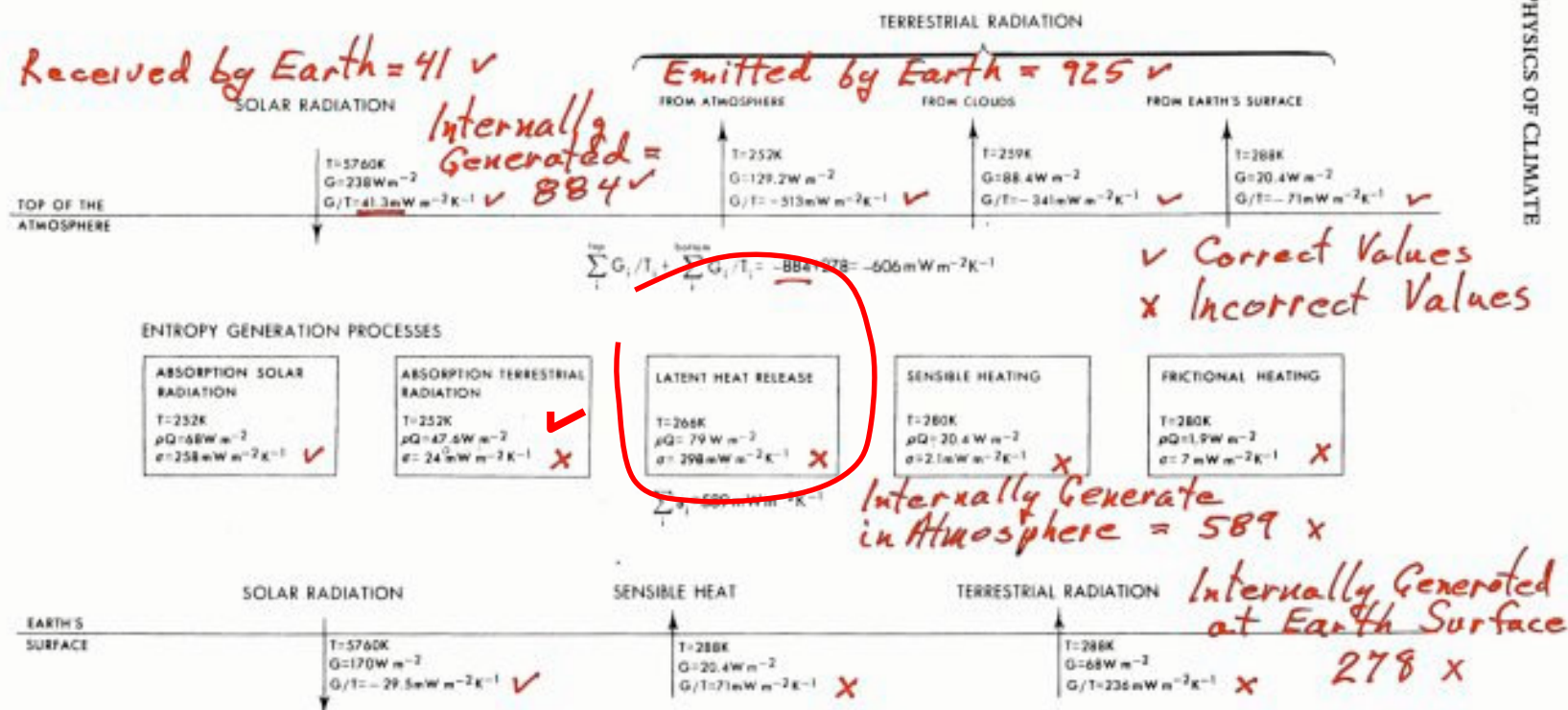


FIGURE 15.2 Entropy budget of the global atmosphere estimated for annual-mean conditions. Shown are the equivalent temperature T^* in K, the energy flux G in W m^{-2} , and the entropy flux G/T^* in units of $\text{mW m}^{-2}\text{K}^{-1}$ for each energy component at the top of the atmosphere and at the earth's surface. A positive (negative) sign is used when the atmosphere gains (loses) entropy. The boxes in the middle of the figure contain for each component estimates of the atmospheric temperature at which the absorption takes place in K, the rate at which energy is absorbed ρQ in W m^{-2} , and the rate of entropy production σ in units of $\text{mW m}^{-2}\text{K}^{-1}$ (from Peixoto *et al.*, 1991).

An Early Earth Entropy Budget

in: Kleidon, A. and Lorenz, R. D. (eds.) Non-equilibrium thermodynamics and the production of entropy: life, Earth, and beyond. Springer Verlag, in press.
 © 2004 Springer Verlag, Heidelberg. ISBN: 3-540-22495-5

1 Entropy Production by Earth System Processes

5

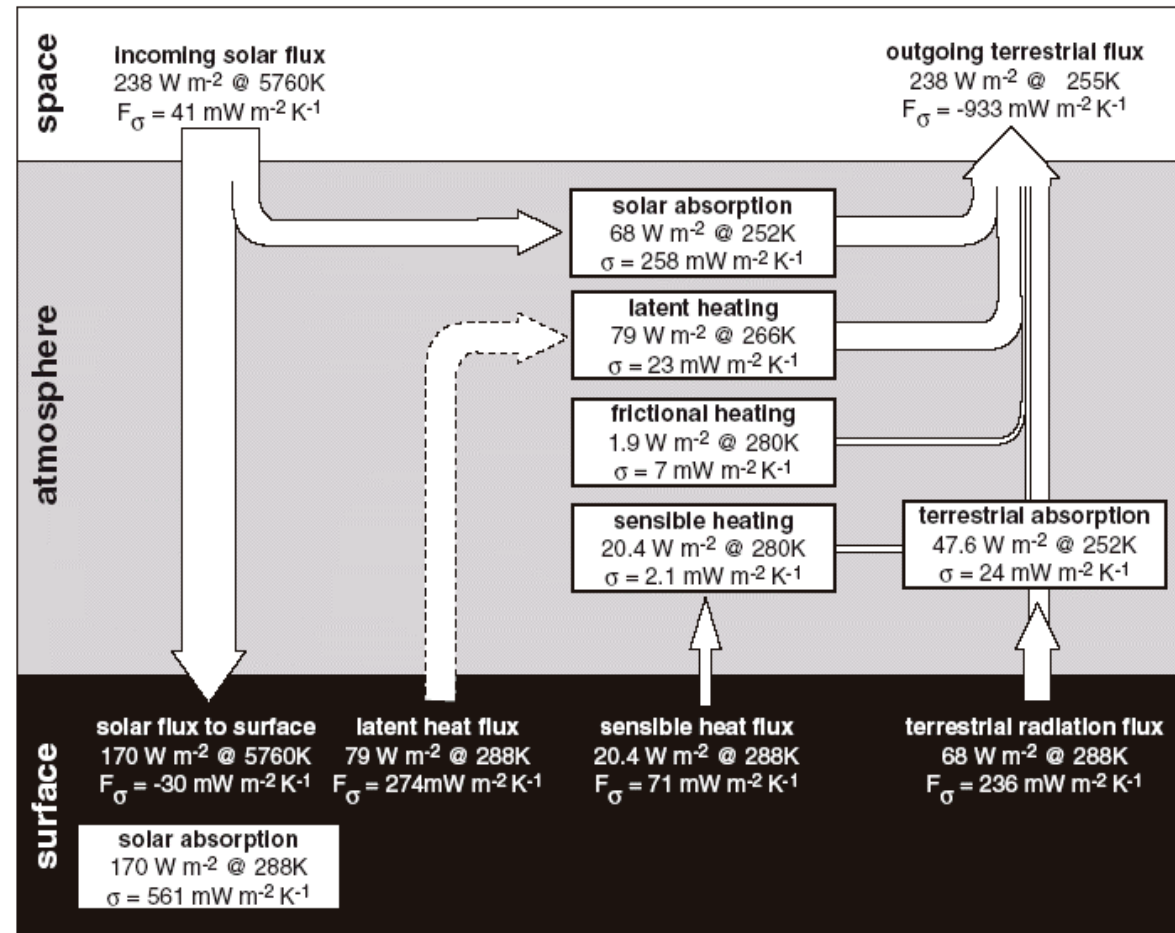


Fig. 1.2. Global budget of entropy production by diabatic Earth system processes. Based on Peixoto et al. (1991). Note that the latent heat flux has been corrected from Peixoto et al.'s estimate

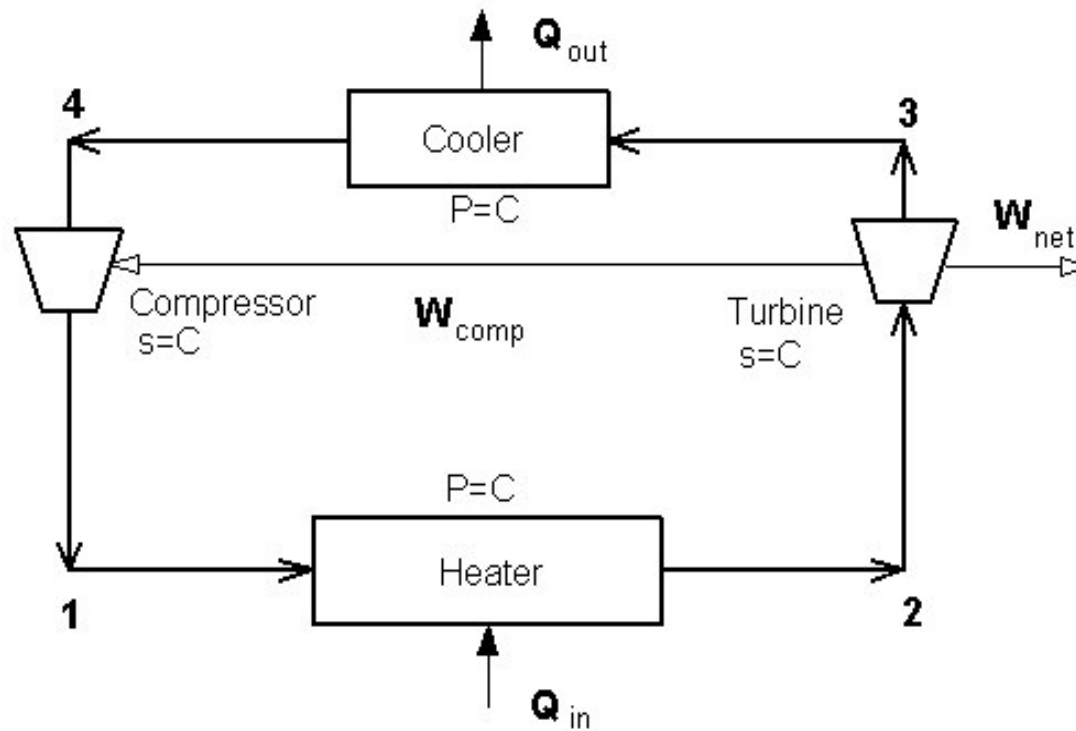
Courage



Source: Nate Smith

Thermodynamics

Brayton - one turbine



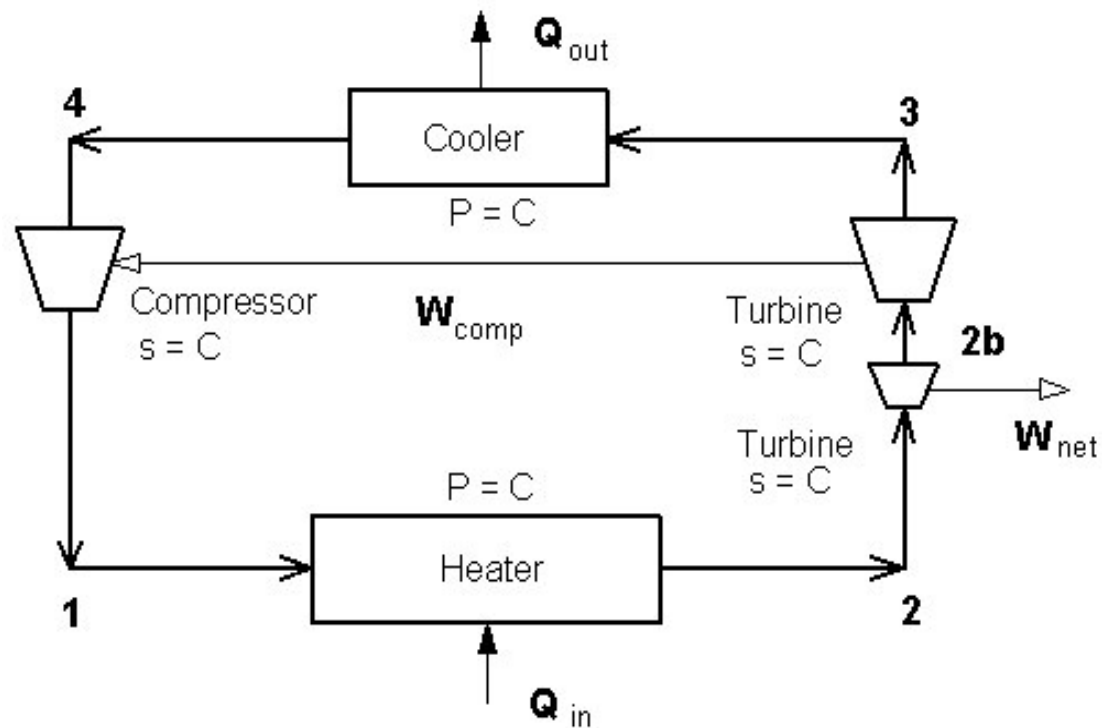
$$W_{\text{net}} = Q_{\text{in}} - Q_{\text{out}}$$

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

$$W_{\text{net}} = n Q_{\text{in}}$$

Brayton gas-turbine power cycle
One turbine

Brayton - two turbines



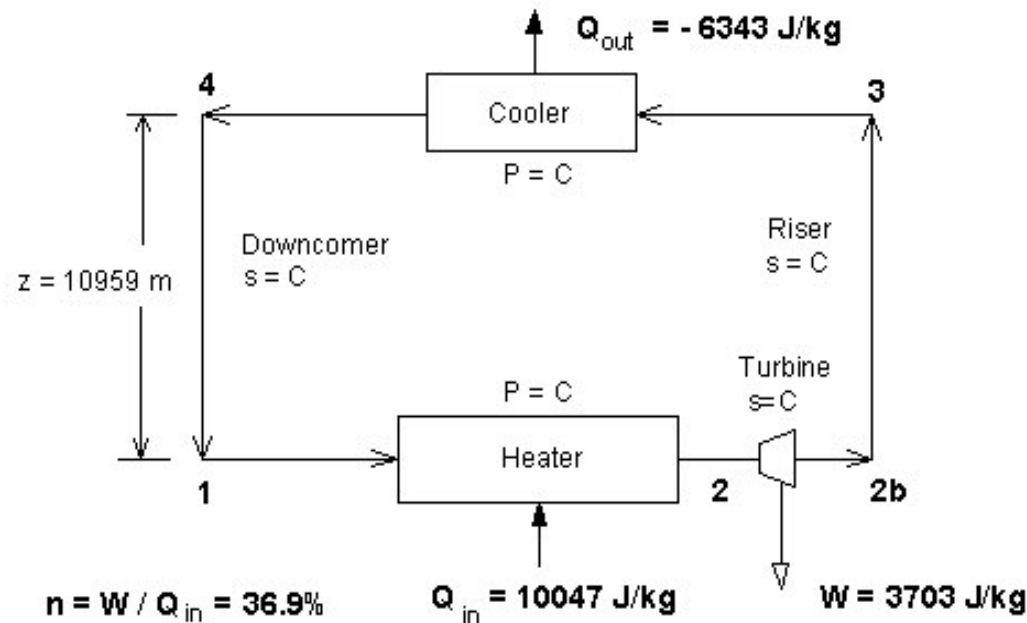
$$W_{net} = Q_{in} - Q_{out}$$

$$n = 1 - T_4 / T_1$$

$$W_{net} = n Q_{in}$$

Brayton gas-turbine power cycle
Two turbines

Gravity cycle - Case 1 reversible

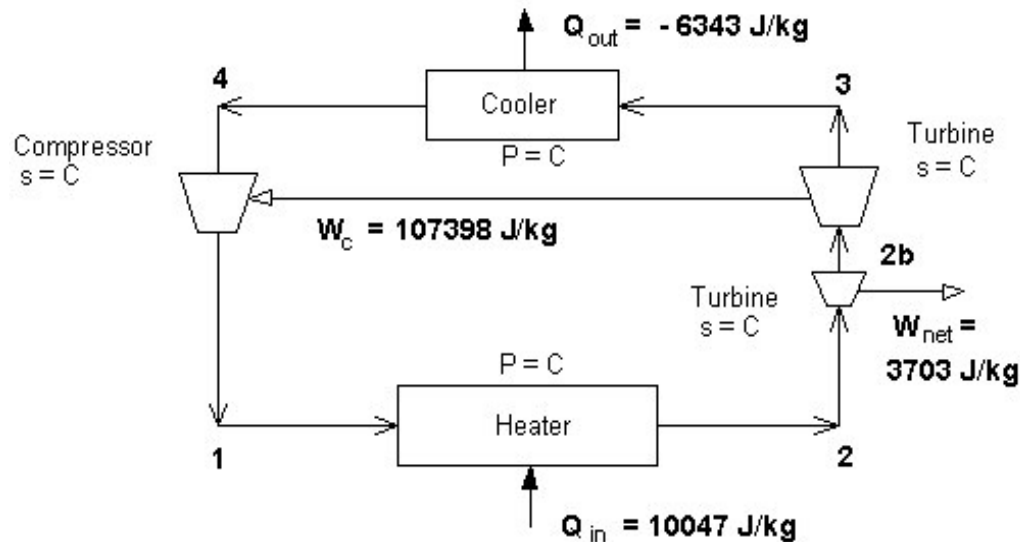


State	P (kPa)	T (K)	s (J/ K kg)	h (J/kg)	gz (J/kg)	h+gz (J/kg)
1	100	290	60.14	16929	0	16929
2	100	300	94.20	26975	0	26975
2b	95.77	296.31	94.20	23272	0	23372
3	20	189.42	94.20	-84126	107398	23372
4	20	183.10	60.14	-90467	107398	16929

Gravity cycle - Case 1

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

Brayton - Case 1



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

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

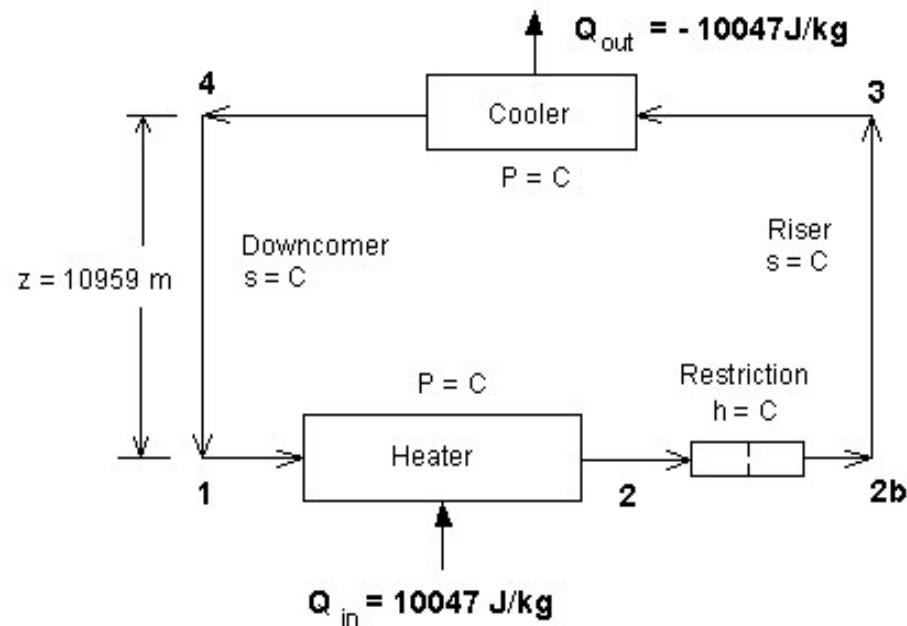
$$W_{\text{net}} = n Q_{\text{in}} = 0.369 * 10047 = 3703 \text{ J/kg}$$

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

Gravity cycle - Case 1 irreversible

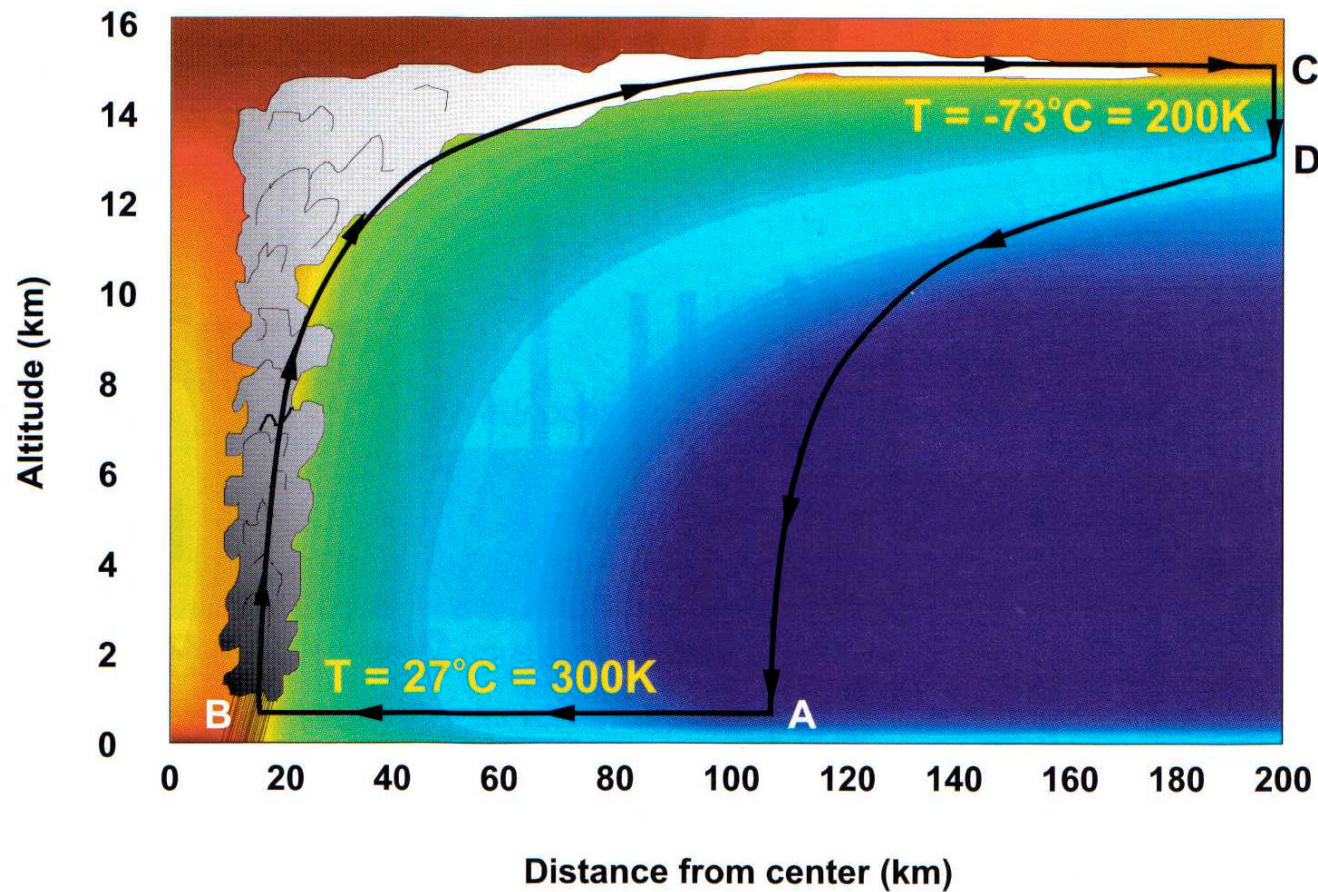


State	P (kPa)	T (K)	s (J/ K kg)	h (J/kg)	gz (J/kg)	h+gz (J/kg)
1	100	290	60.14	16929	0	16929
2	100	300	94.20	26975	0	26975
2b	93.48	300	113.56	26975	0	26975
3	20	193.10	113.56	-80424	107398	26975
4	20	183.10	60.14	-90467	107398	16929

Gravity Cycle - Case 1 - Irreversible

Constant pressure cooling, Pure air
Height based on lapse rate of 9.75 K /km

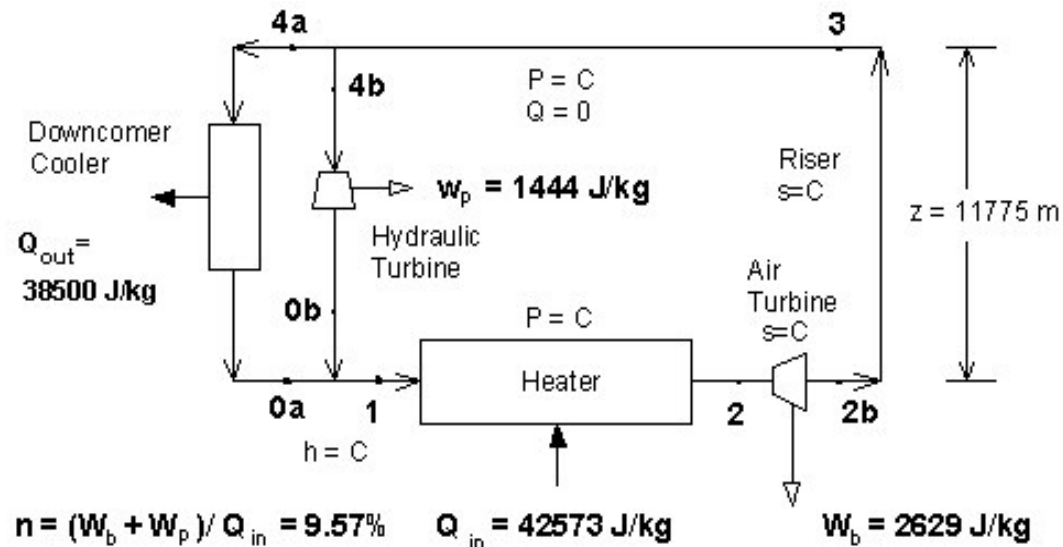
A hurricane viewed as a Carnot cycle



$$\text{Efficiency} = 1 - T_c / T_h = 33\%$$

Source Divine Wind by Kerry Emanuel

Gravity cycle - Case 3

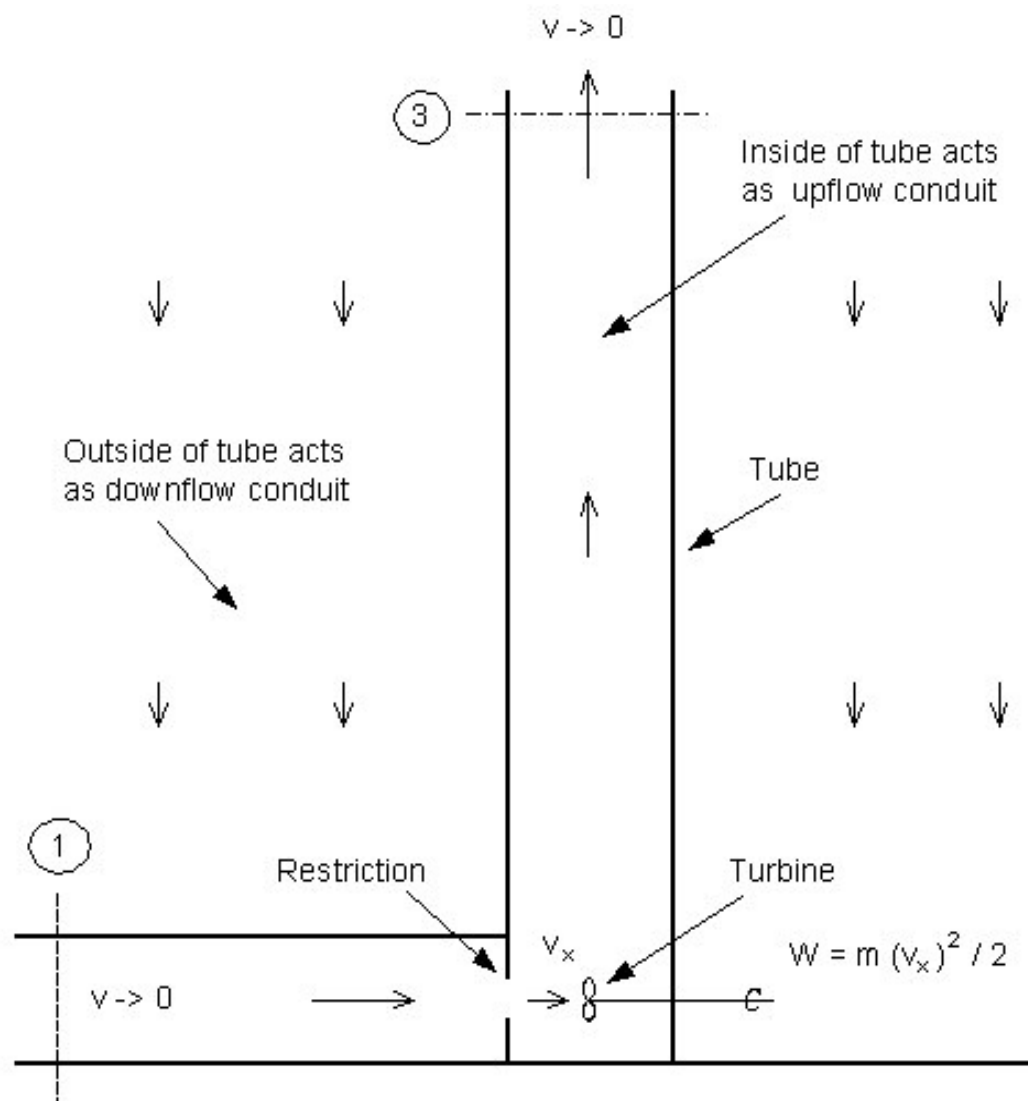


State	P (kPa)	T (K)	r (g/kg)	s (J/ K kg)	h (J/kg)	gz (J/kg)	h+gz (J/kg)
1	100	274.12	12.55	43.04	11278	0	11278
2	100	295	12.55	192.95	53851	0	53851
2b	96.99	292.44	12.55	192.95	51222	0	51222
3	20	213.46	12.55	192.95	-65622	116844	51222
4a	20	213.46	0.03	214.69	-59884	115399	55515
0a	100	290	0.03	60.55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

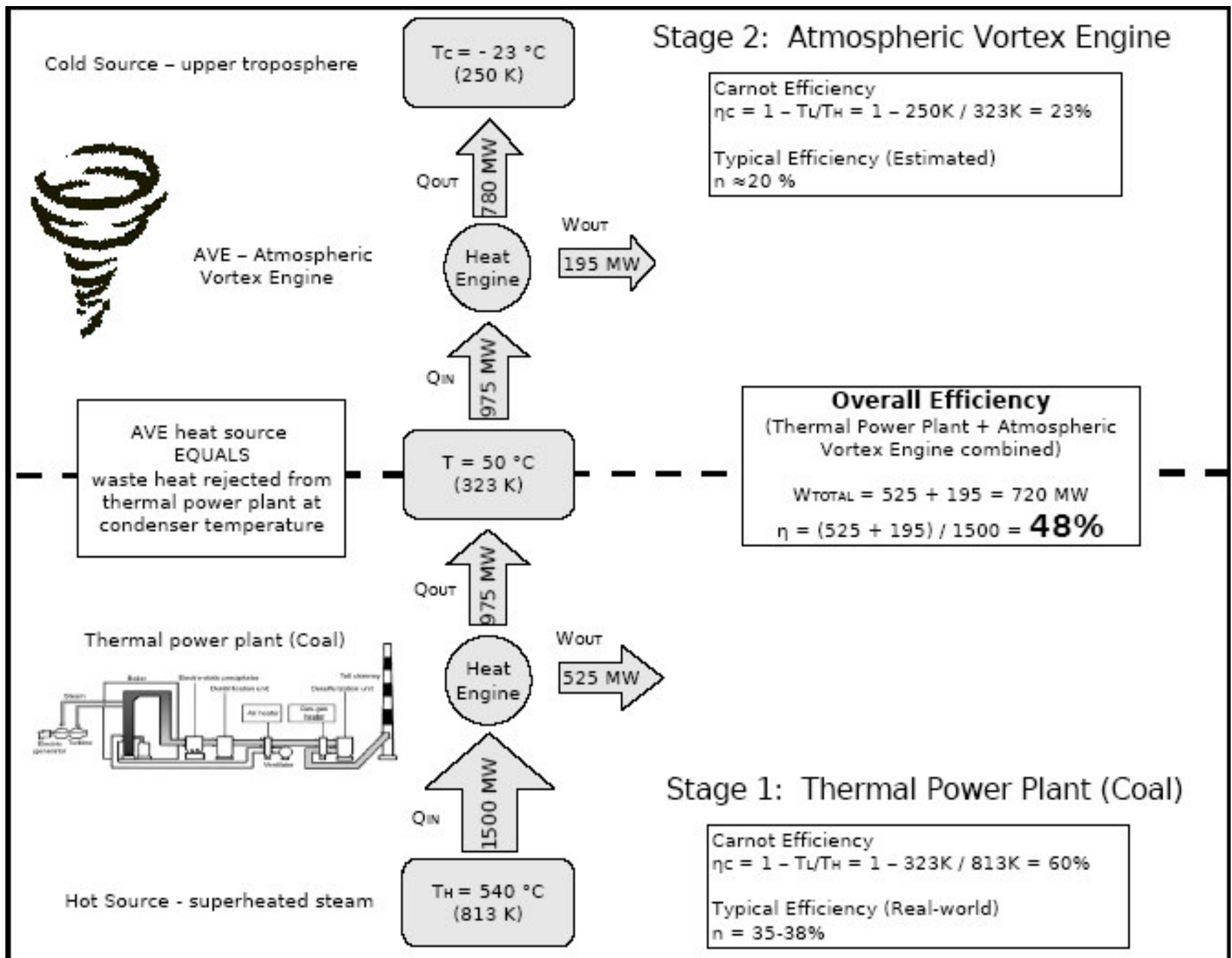


Single tube gravity cycle.

The inside of the tube acts as the upflow conduit.

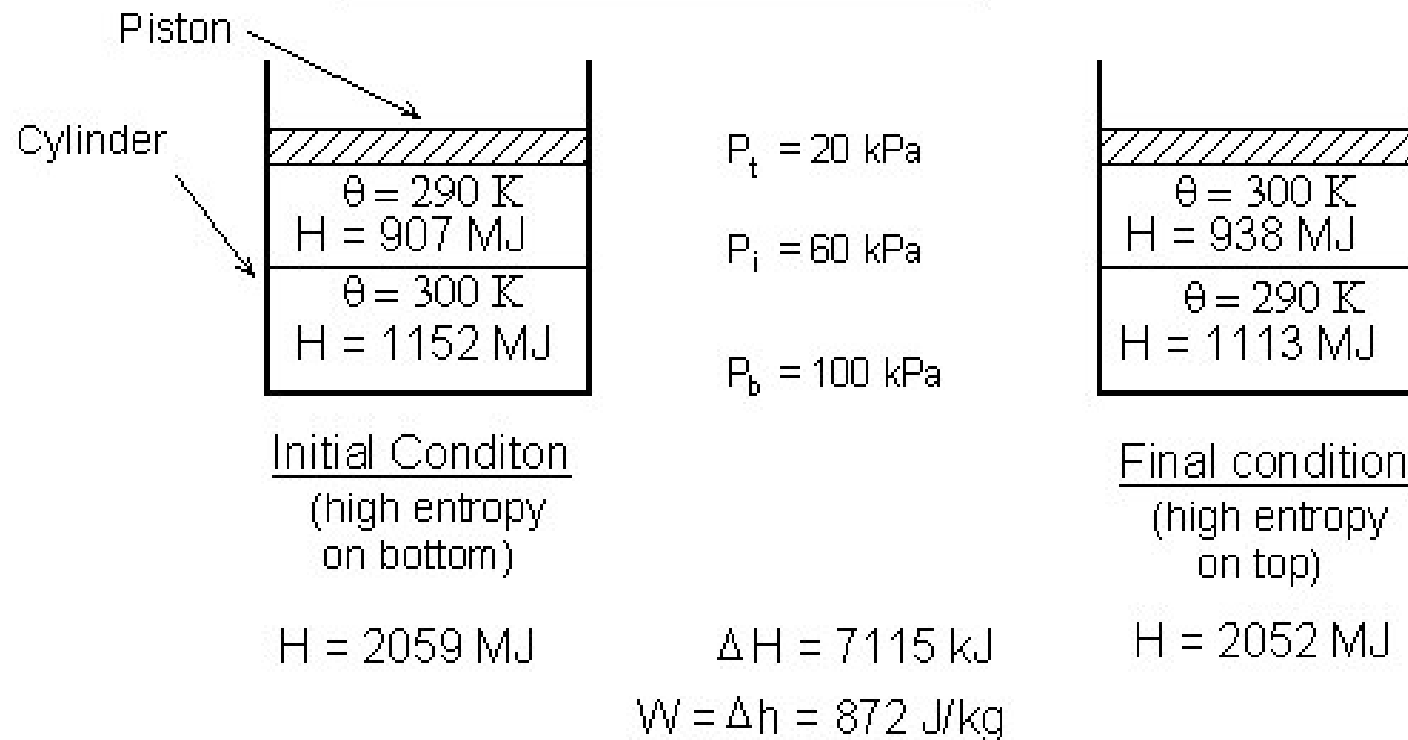
The outside of the tube acts as the downflow conduit.

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.



Work Production in the Atmosphere

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



The work corresponds to a velocity of 42 m/s

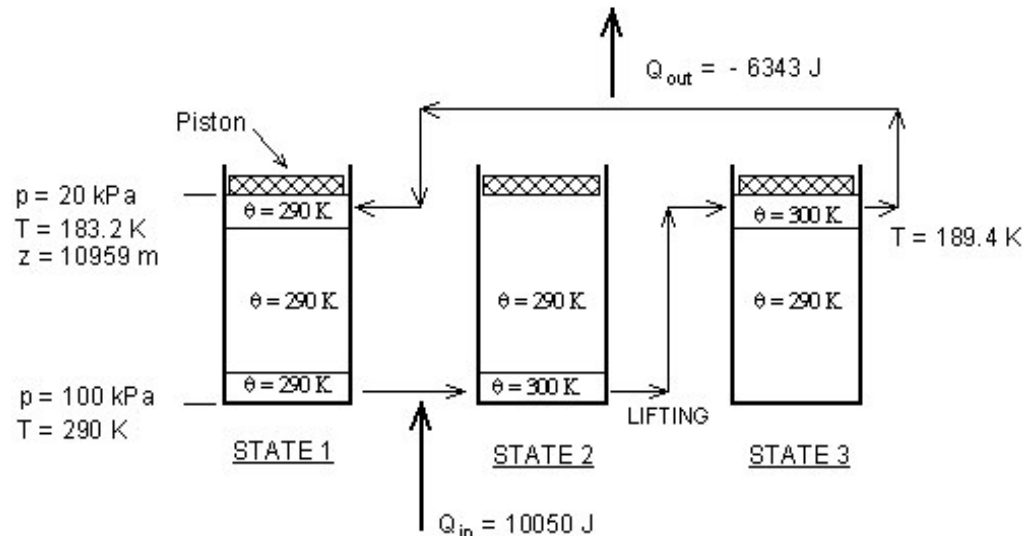
$$m = (P_b - P_t)/g = 8163 \text{ kg}$$

Notes:

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

Thin Layer

Work production when a thin layer is raised



The work per unit mass can be calculated using **five** methods giving the same result.

1. Heat received minus heat given up

$$W = Q_{in} + Q_{out} = 3703 \text{ J}$$

2. Heat received multiplied by the Carnot efficiency based on the temperatures at which the heat is received and given up.

$$W = Q_{in} (1 - T_{out}/T_{in}) = 10050 (1 - 183.2/290) = 10050 * 0.368 = 3703 \text{ J}$$

Corresponds to a velocity of 86 m/s.

3. Previous Margules' equation for the enthalpy of large air mass.

4. Total energy equation: $W = \Delta h - \Delta gz$

5. Standard meteorological Convective Available Potential Energy (CAPE) equation.

$$W = \sum g (\rho_a - \rho_p) \Delta z$$

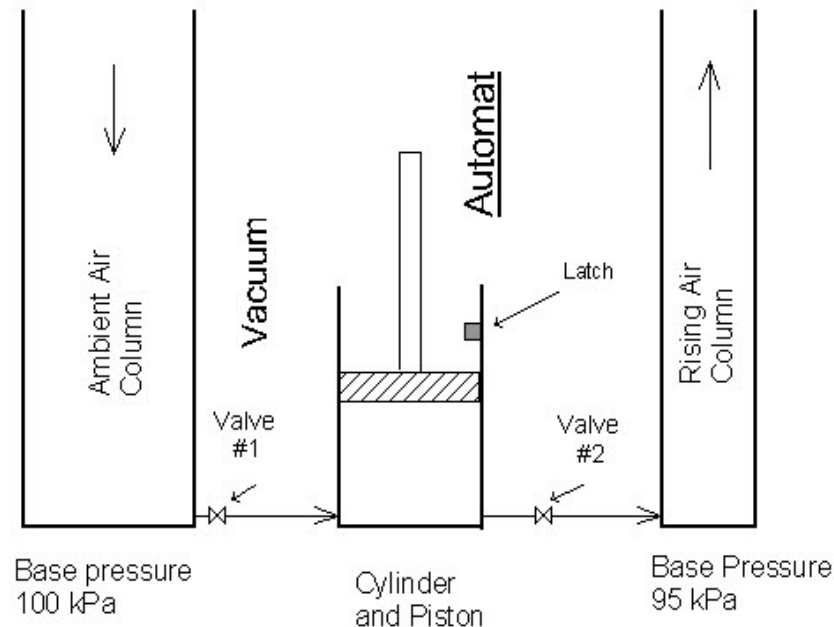
$$W = \sum g [(T_p - T_{wa}) / T_p] \Delta z$$

The work per unit mass raised is approximately four times higher than in the Margules mass on top of one other case because the air is raised approximately twice as high and because the work is allocated to the raised air only.

The work is related to the heat received and to the temperature at which heat is received by the Carnot efficiency, which is not evident when using large air masses.

Transfer System

Reversible or Irreversible Transfer Cylinder



Reversible transfer procedure:

1. Open valve #1,
2. Automat raises piston to 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 air out of cylinder.

Note: air temperature decreases and work is produced.

Irreversible transfer procedure:

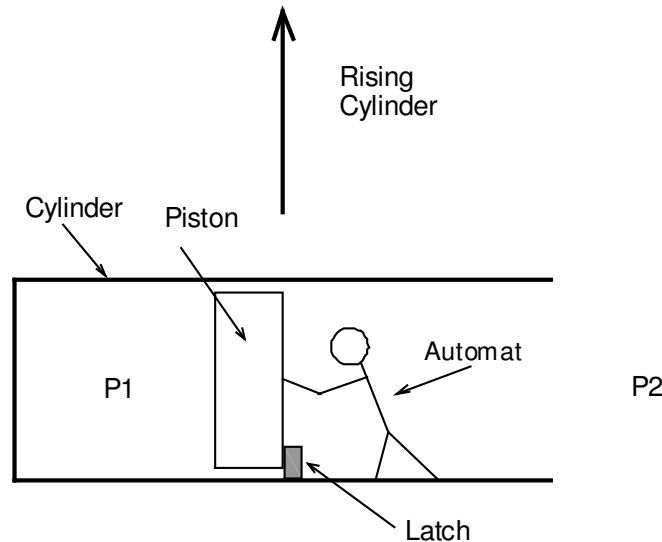
As above except after step #3 set a latch at position that will allow pressure to drop to 95 kPa.

4. Automat lets go of the piston, it snaps against the latch without doing any work.

Note: Air temperature does not drop, no work is produced.

Rising Cylinder

Reversible Expansion and the Automat



Rising Horizontal cylinder

Air rises in a weightless cylinder with a latched piston.

When the latch is let go, the work required to push away the ambient air is less than the work that could be produced by isentropic expansion, therefore the excess work becomes heat.

Capturing the work requires that the expansion take place in mechanical equilibrium.

Without the automat to capture the work any work beyond the work required to push the ambient air away is lost.

Rising cylinder expansion can be of three kinds

Expansion of pure air initially at 100 kPa and 30 C to 95 kPa.

- A. Isentropic expansion: $T_2=25.6$ C, $W=4431$ J/kg
- B. Unlatch against 95 kPa: $T_2=26.63$ C, $W=3384$, $W_{\text{loss}}=1047$ J/kg
- C. Unlatch against 0 kPa: $T_2=30$ C, $W=0$, $W_{\text{loss}}=4431$ J/kg

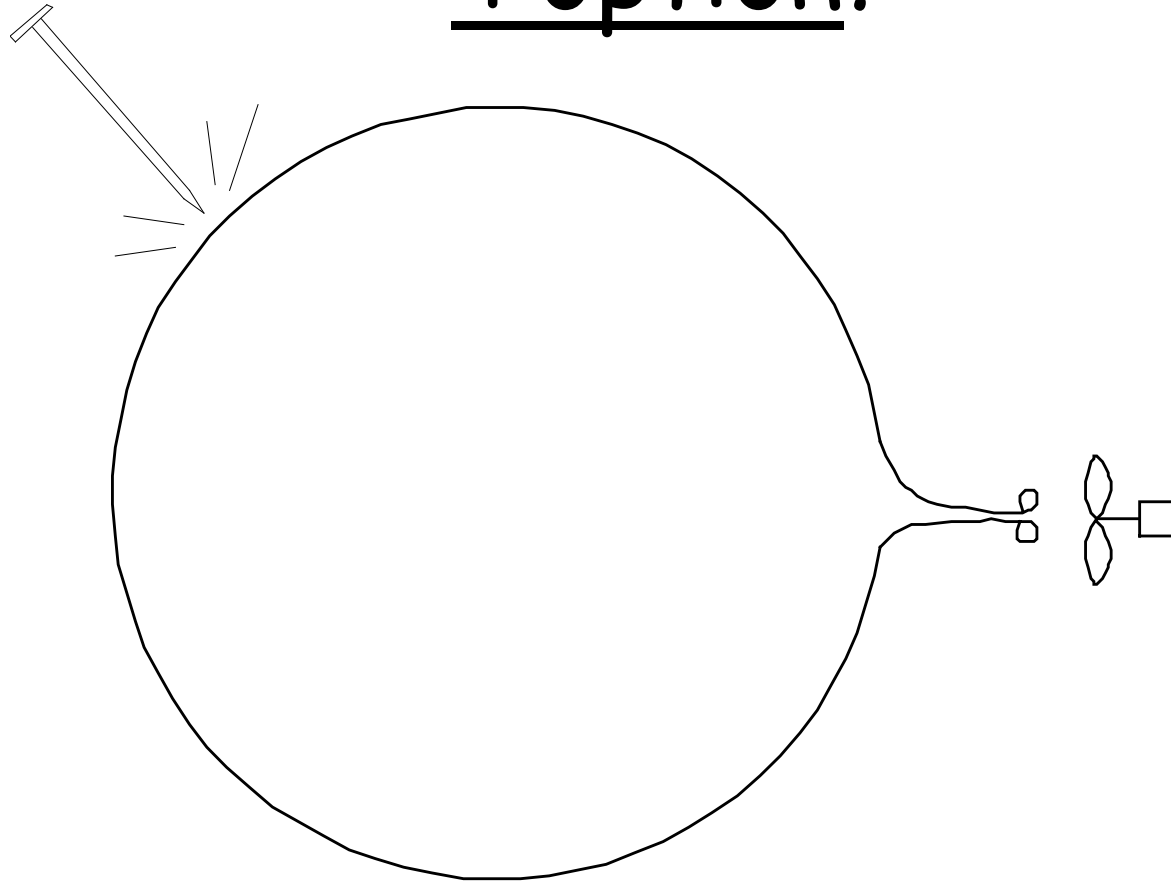
B is equivalent to popping a balloon. No organized velocity is produced; the POP sound provides indication of the work dissipation.

B is what happens to a rising air mass. If there is no mean for capturing the work while the air expands, the work reverts to heat.

Approximately 20% of the work that would produced with isentropic expansion is lost irrespective of the change in pressure.

I.e. 20% of the work would be lost if the pressure change had been from 100 to 99.9 kPa.

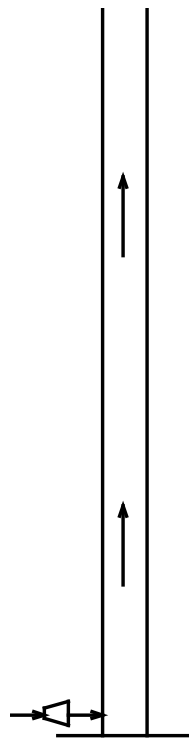
Energy dissipation when the balloon is punctured - Poption?



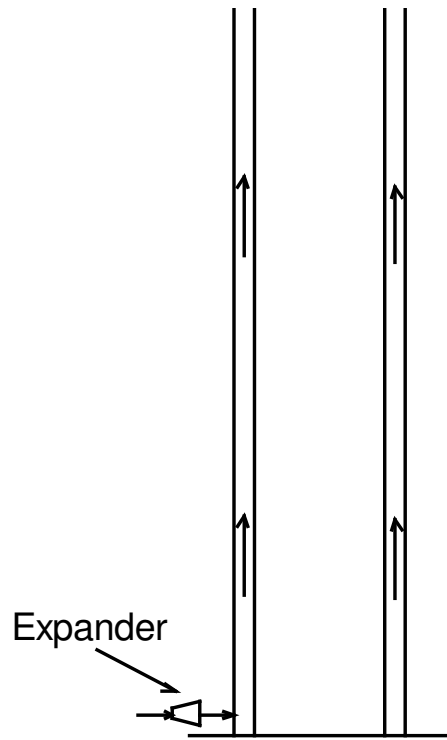
POP

What happens to the kinetic energy of the jet which could be captured by the turbine if the balloon is punctured?

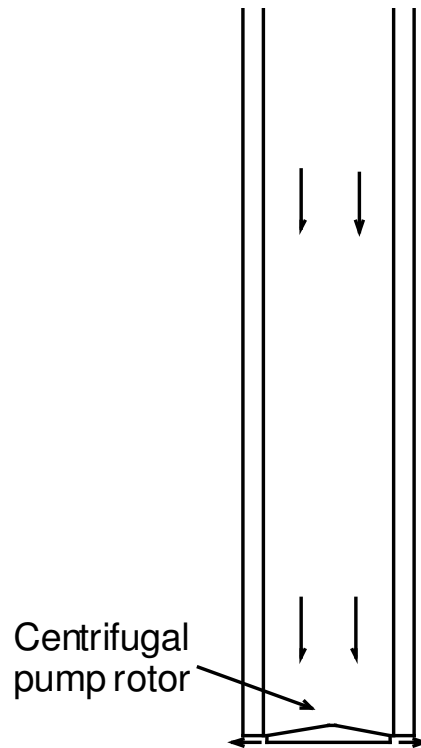
Annular Tube



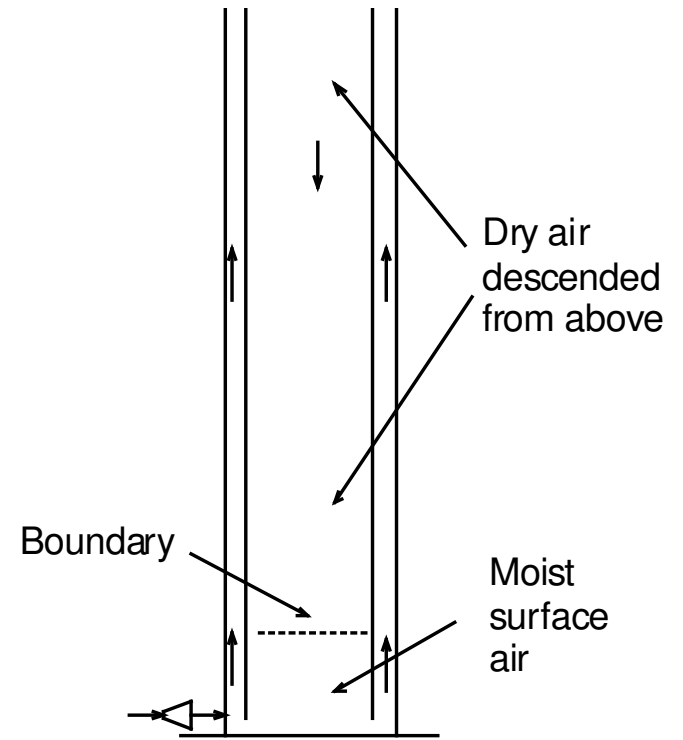
Circular
upflow
tube



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



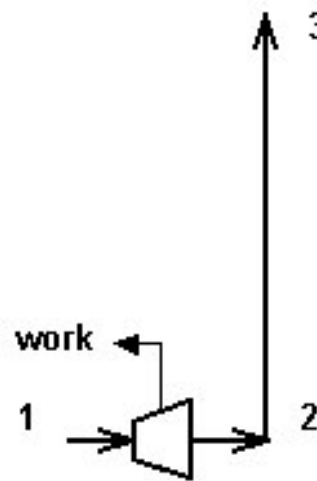
USUAL

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

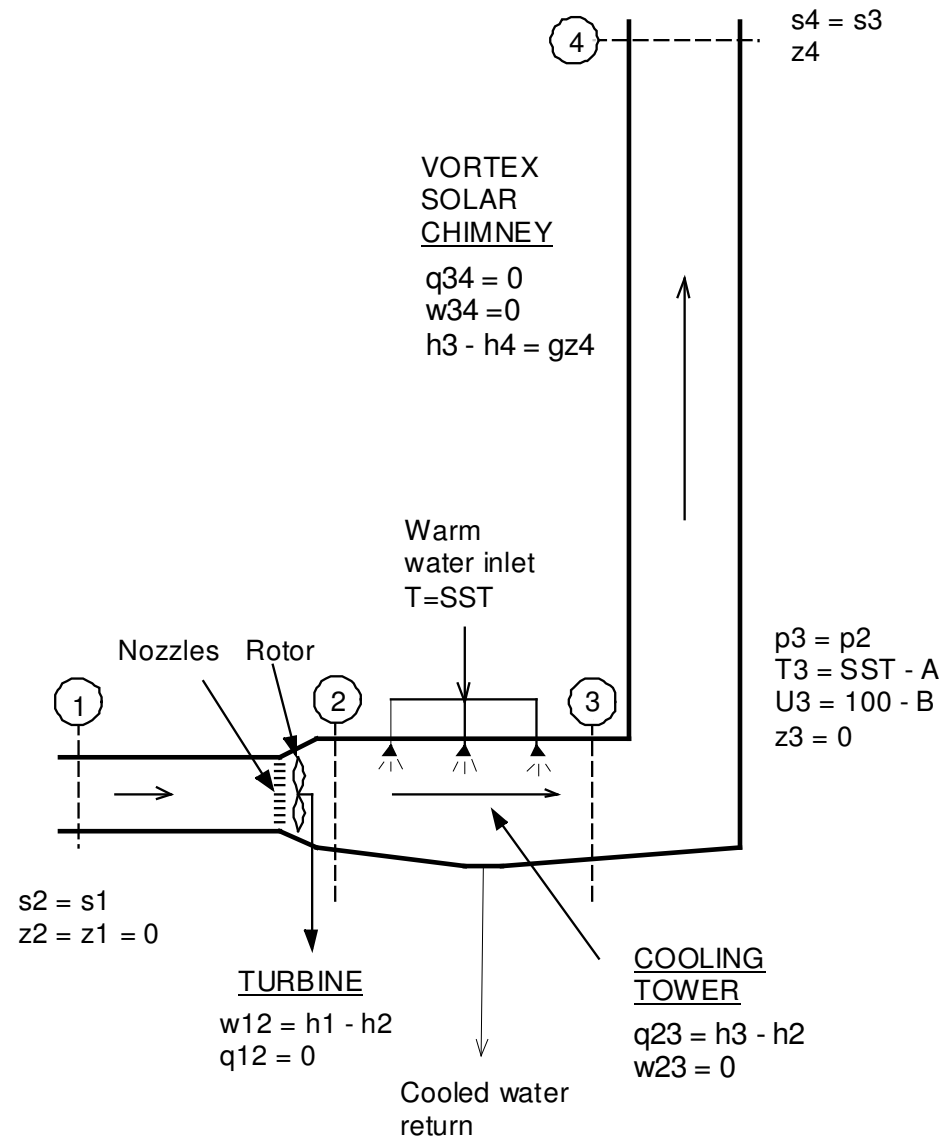
$$s_3 = s_2 = s_1$$

$$w = 0$$

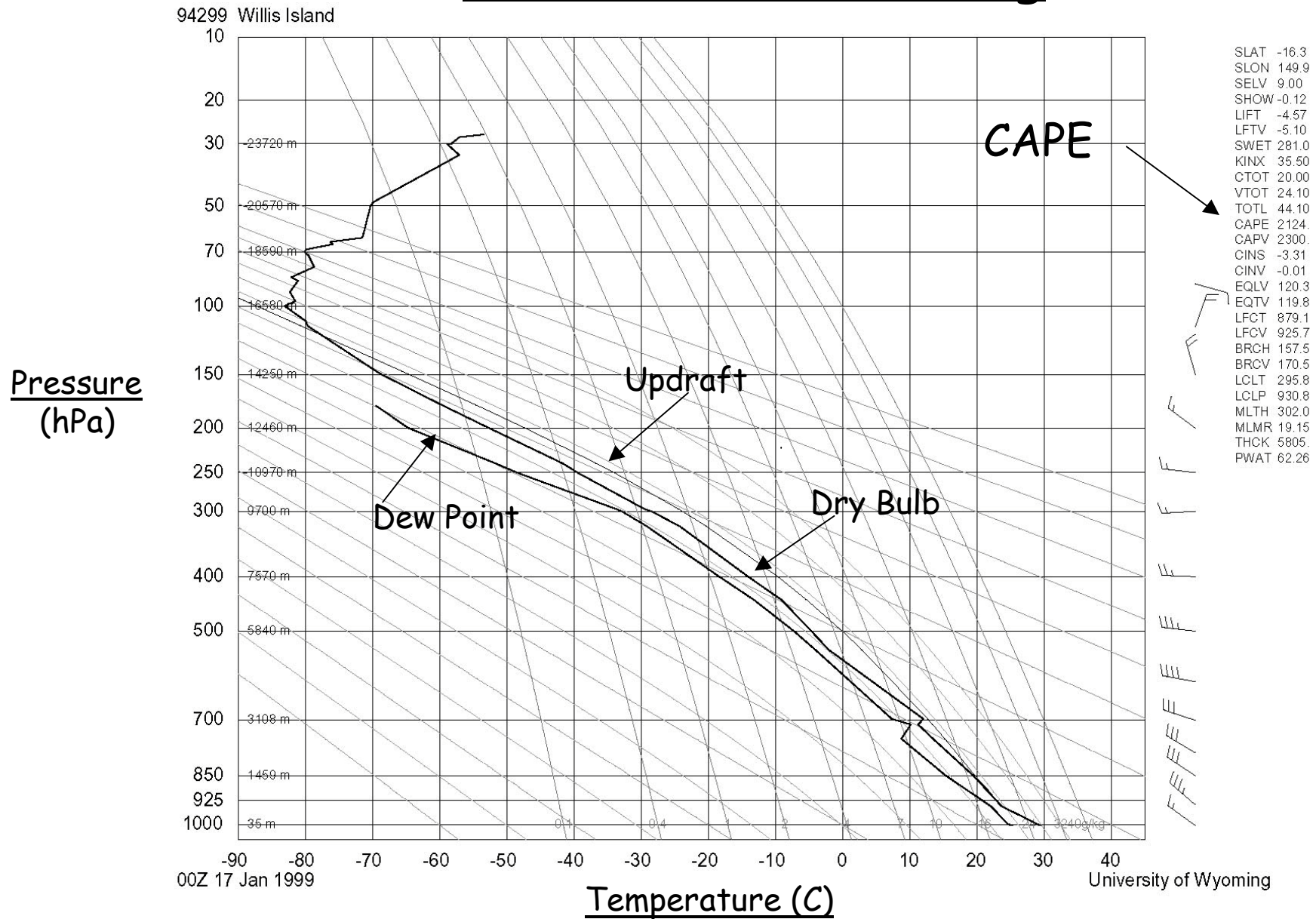
Isentropic expansion without device for taking work out of the system is impossible except in one case ($w=0$).
It is the basis of most atmospheric models.

Calculations

Thermodynamic Ideal Cycle Equivalent



Willis Island Sounding



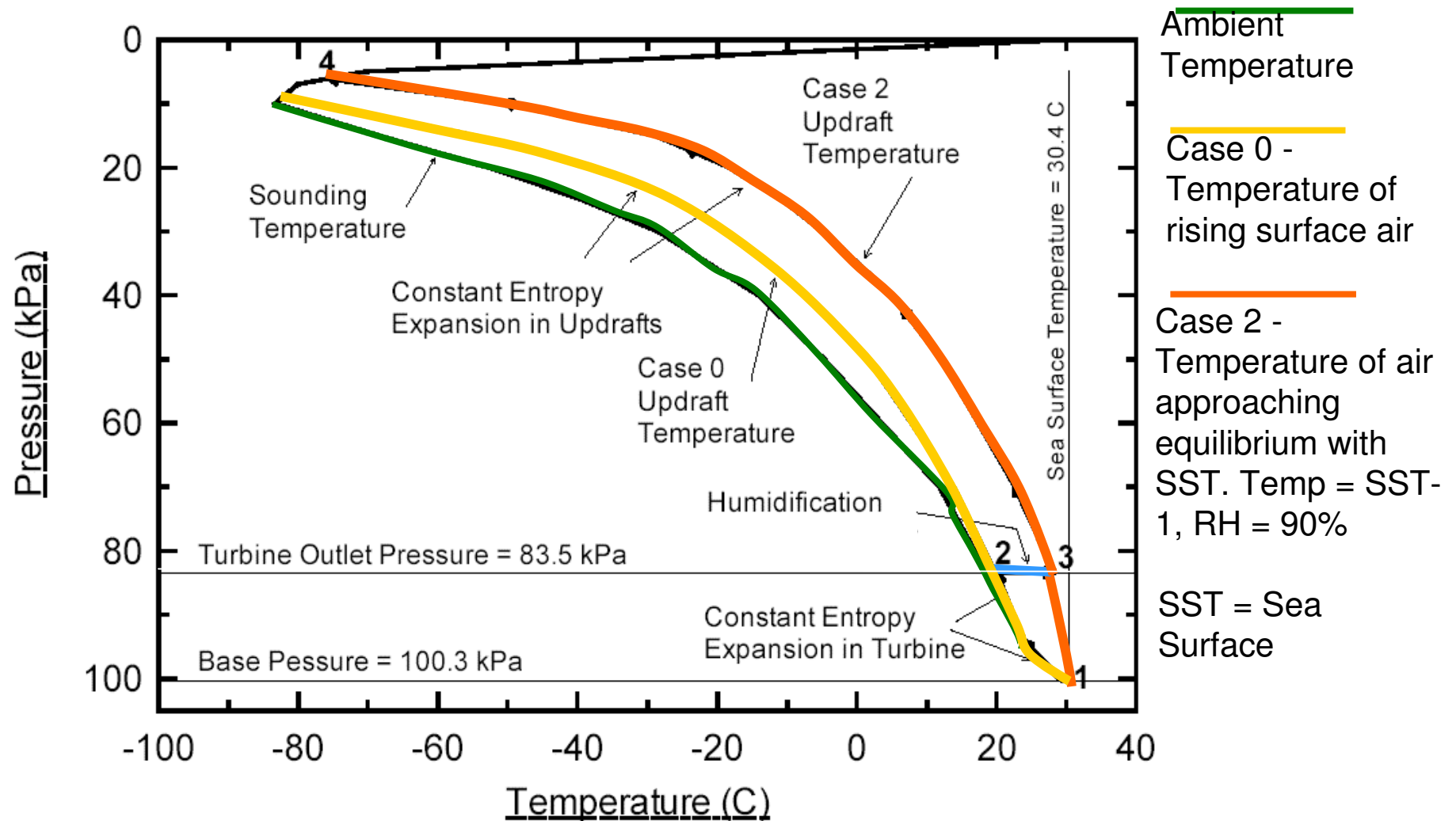


Fig. 3 Willis Island sounding and updraft temperatures

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

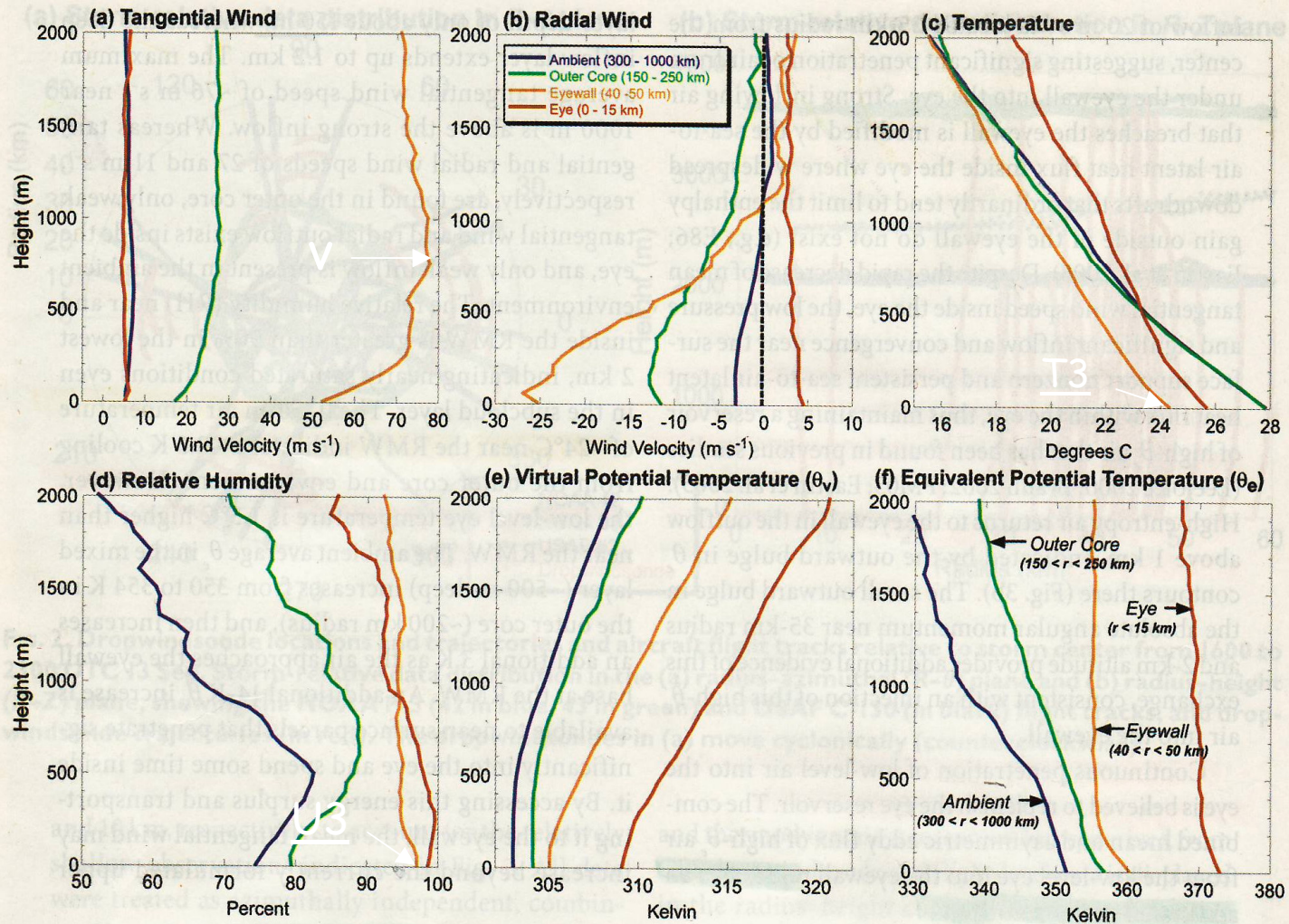


FIG. 4. Low-level (0–2 km) mean soundings from dropwindsonde observations for the eye (0–15-km radius, red), nominal eyewall (40–50-km radius, orange), outer core (~200 km radius, green), and ambient environment (300–1000-km radius, blue) during 1600–2300 UTC 13 Sep. (a) Tangential wind (m s^{-1}), (b) 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).

Table 1. Hurricane Isabel Maximum Potential Intensity (TEE-MPI). Distant 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 humidity approach $B = 3\%$, $U_3 = 100 - B = 97\%$.

Temperature approach $A = 1$ °C

Eyewall SST (°C)	25.0	25.5	26.0	26.5
<u>Rising air properties:</u>				
$P_2 = P_3$ (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)	-81.45	-80.92	-77.72	-74.42
T_{4V} (°C)	-85.32	-84.69	-81.65	-78.61
T_{4A} (°C)	-82.9	-80.1	-80.1	-80.1
z_4 (m)	14220	16570	16570	16570
h_4 (J kg ⁻¹)	-70275	-91130	-88264	-85299
<u>Base Pressure Reduction (kPa)</u>				
ΔP_{12}	1.96	3.38	5.09	6.74
ΔP_2	n/a	base	1.71	3.36
<u>Work (J kg⁻¹)</u>				
$W = h_1 - h_2$	1742	3015	4567	6081
ΔW	n/a	base	1552	3086
<u>Velocity (m s⁻¹)</u>				
$v = (2W)^{0.5}$	59.0	77.6	95.6	110.3
Δv (%)	n/a	base	18.0	32.7
<u>Sensitivity</u>				
$\Delta P_3/\Delta T_3 = 3.36$ kPa/K				
$\Delta W/\Delta T_3 = 3076$ J kg ⁻¹ /K				
$\Delta v/\Delta T_3 = 32.7$ m s ⁻¹ /K, versus 2 m s ⁻¹ /K for E-MPI method.				
<u>Heat Supplied (J kg⁻¹)</u>				
Q_{23r}	-3144	877	5454	10100
Q_{12l}	-4886	-2138	887	4018
ΔQ_{23r}	n/a	base	4577	9223
<u>Incremental Efficiency</u>				
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

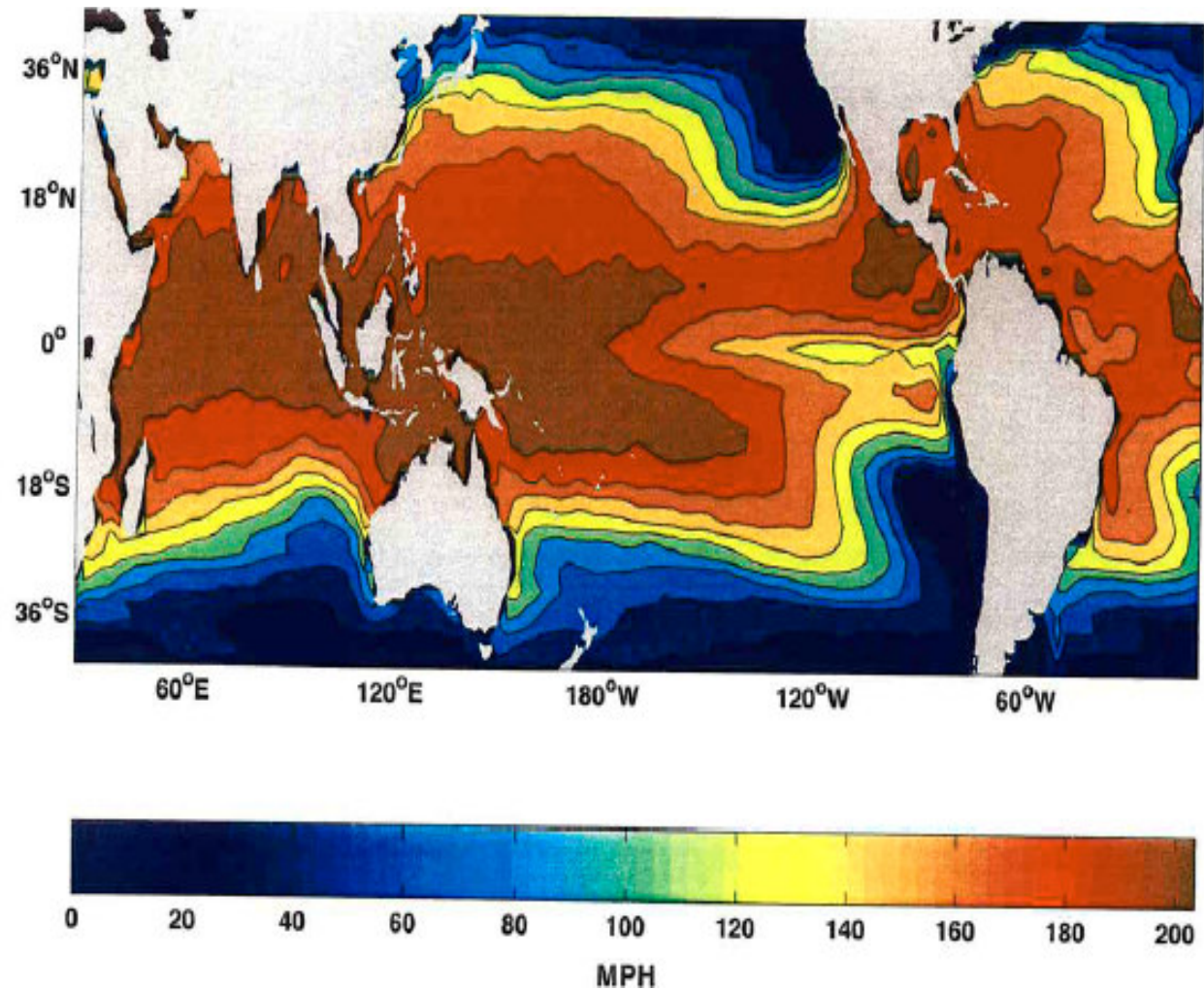
Hurricane Isabel Intensity SST 25 to 26.5 C

Temperature approach 1 C
Relative humidity 97%

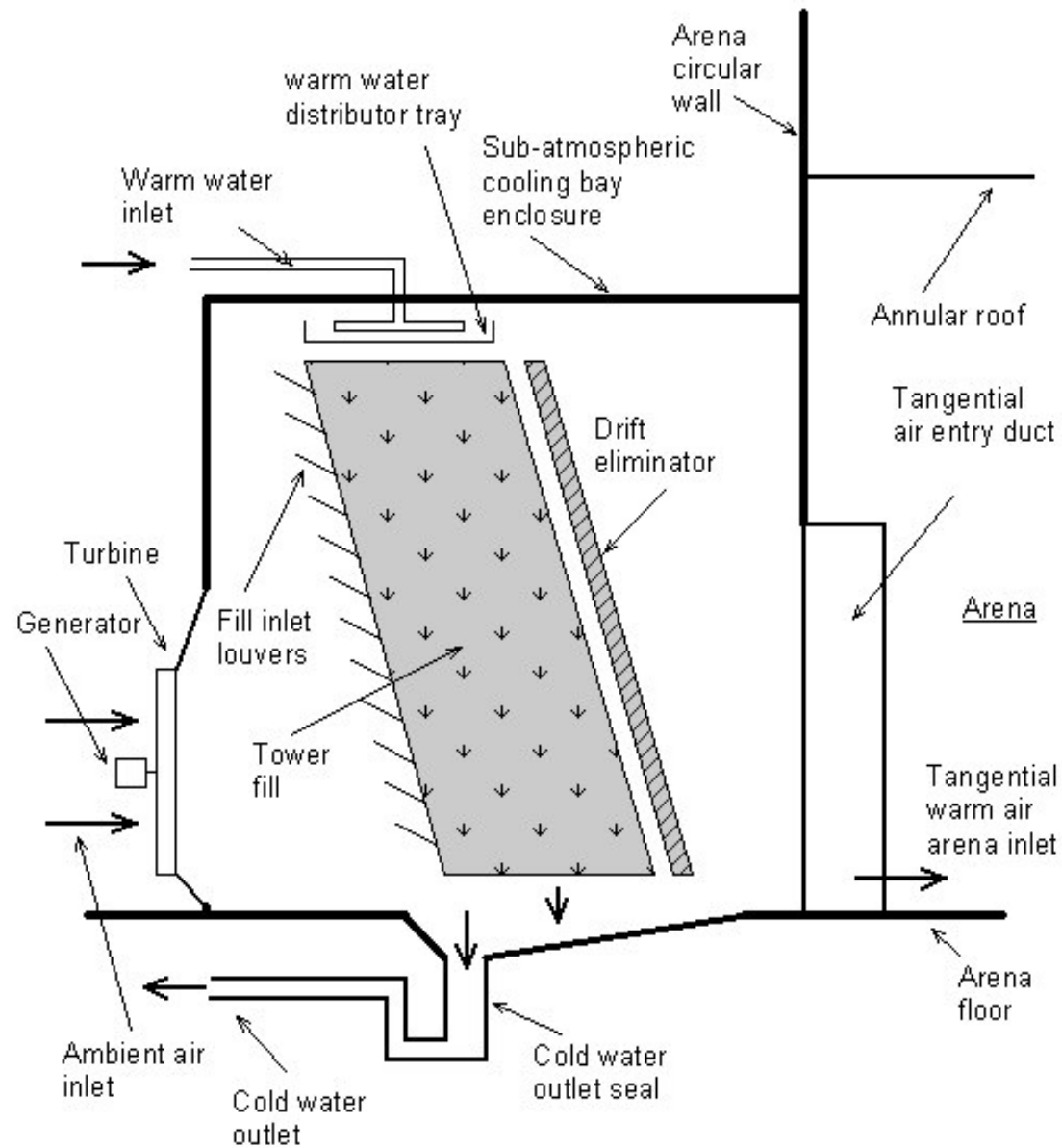
The Carnot Potential Wind Speed

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.

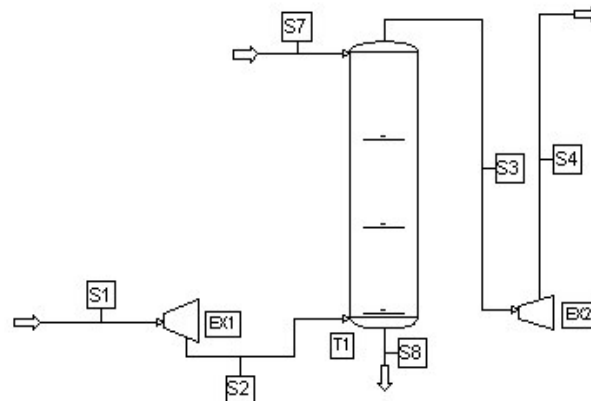
Source: *Divine Wind* by Kerry Emanuel



Cooling Tower Cell (water cooler & air heater/humidifier)



Pro II Simulation



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)		20580

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 and Entrainment

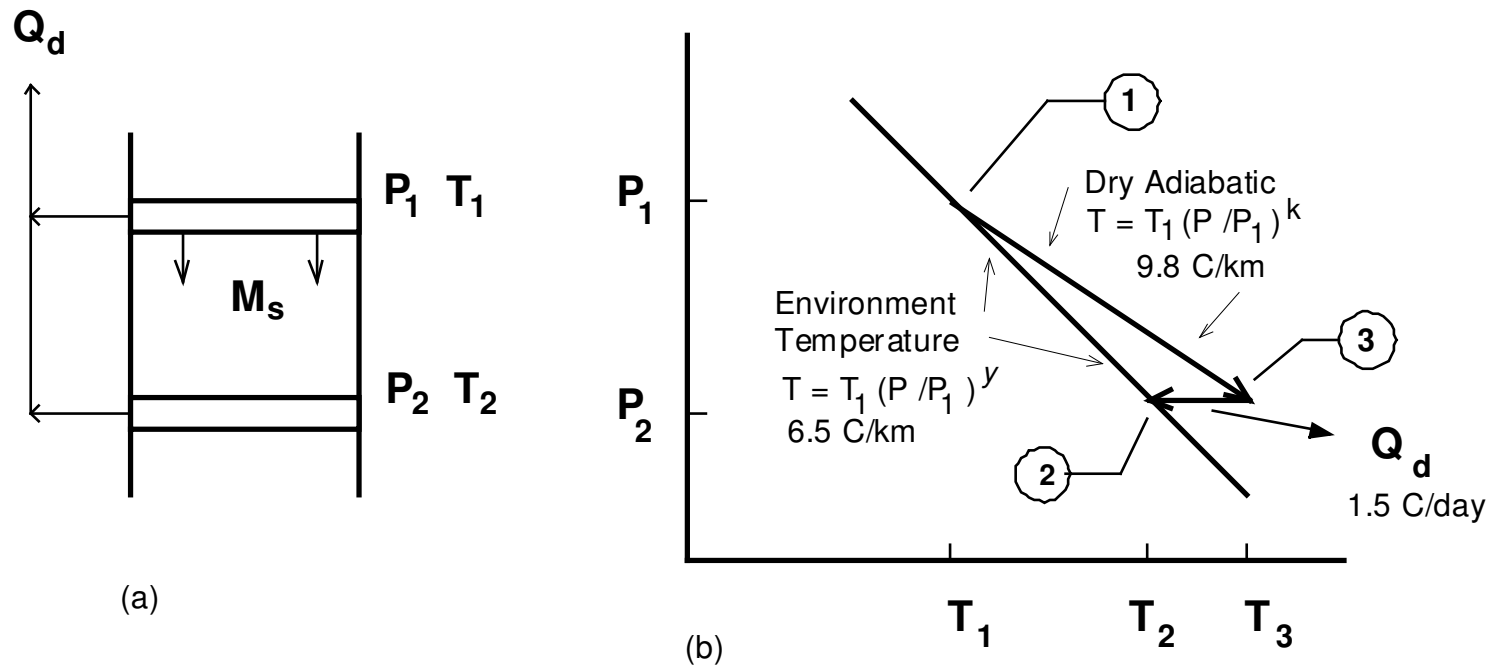


Fig. 2 Without cooling the temperature of the subsiding layer would exceed the temperature of the environment.

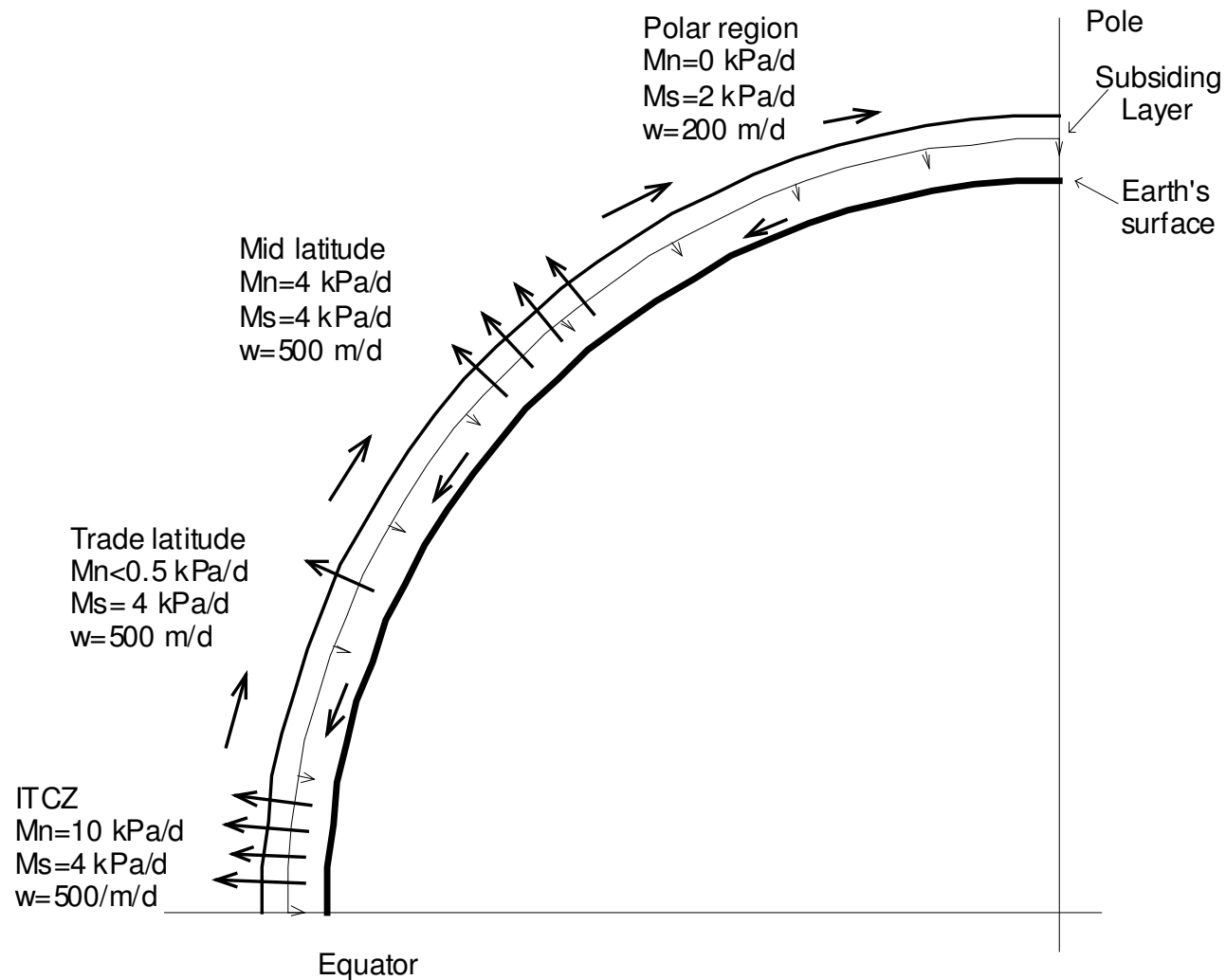
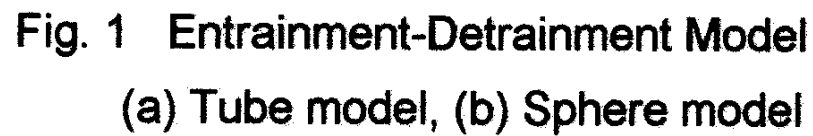


Fig. 7 Subsiding Layer General Circulation Model.
 The drafts are redistributed by meridional flow as required to compensate for radiative cooling. The layers which are penetrated by drafts subside at roughly uniform velocity. The mass fluxes apply to layers at mid troposphere level.



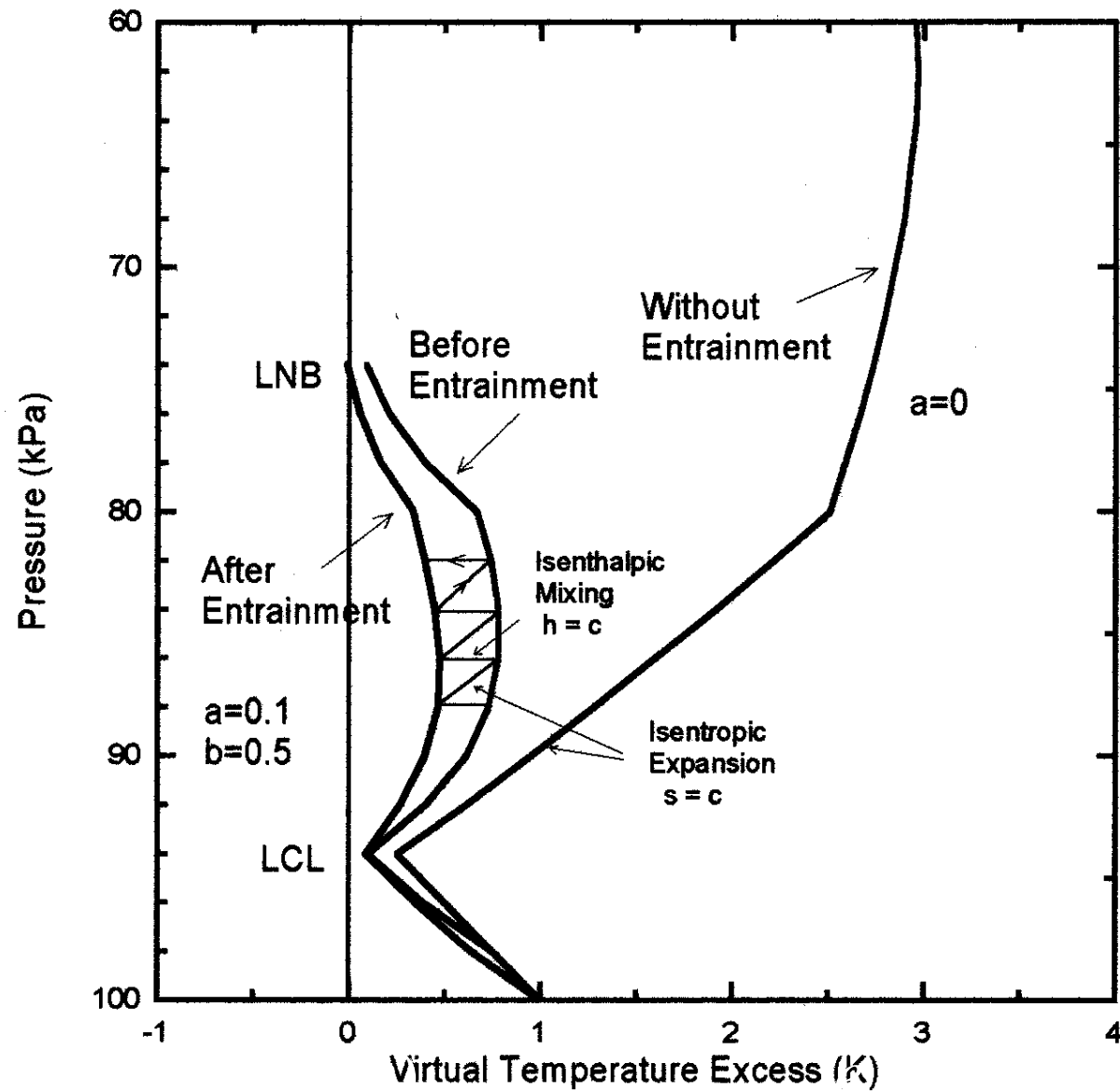


Fig. 2 Virtual temperature excess base case, $a=0.1$, $b=0.5$.

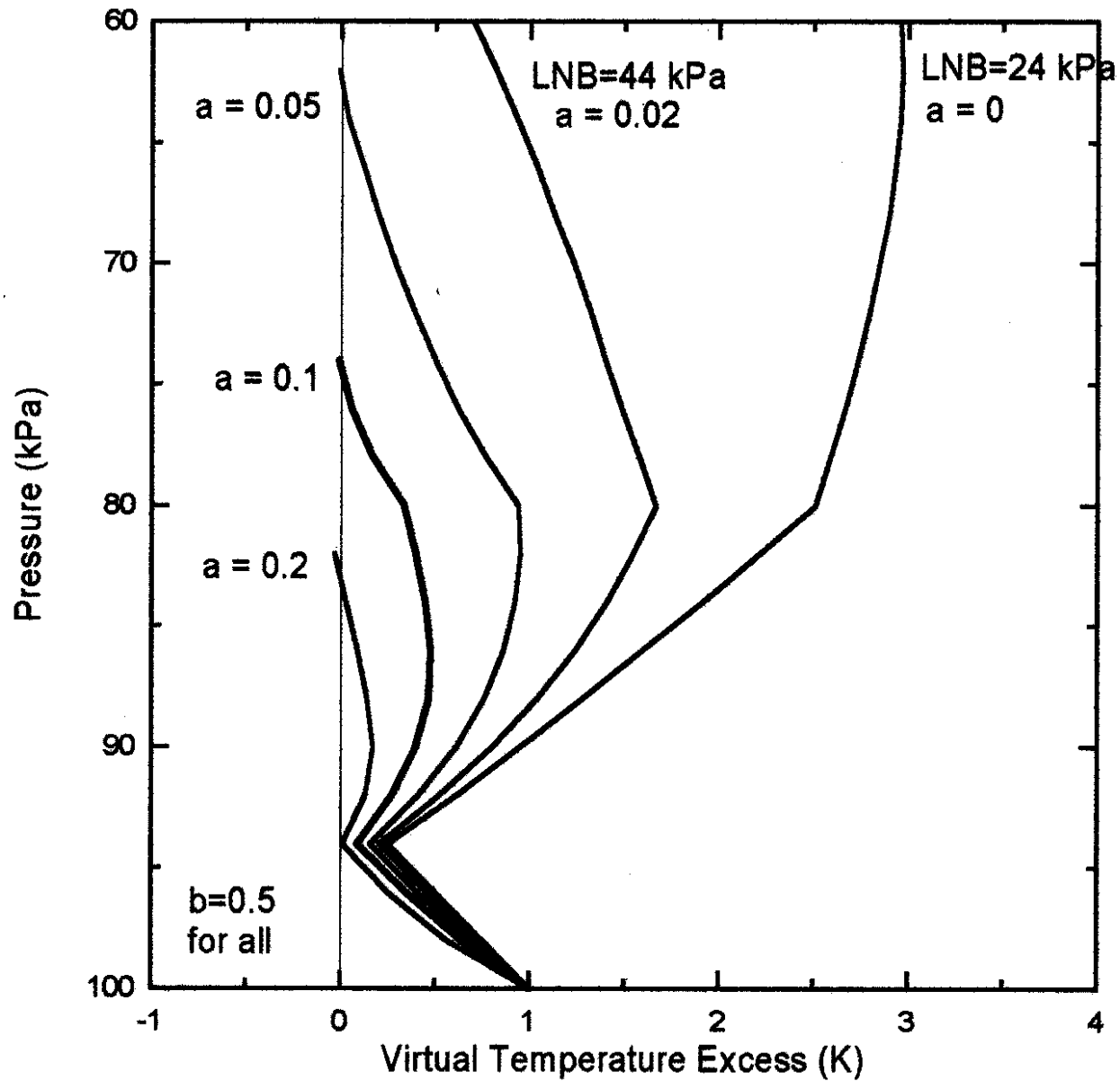


Fig. 3 Effect of entrainment factor, $b=0.5$.

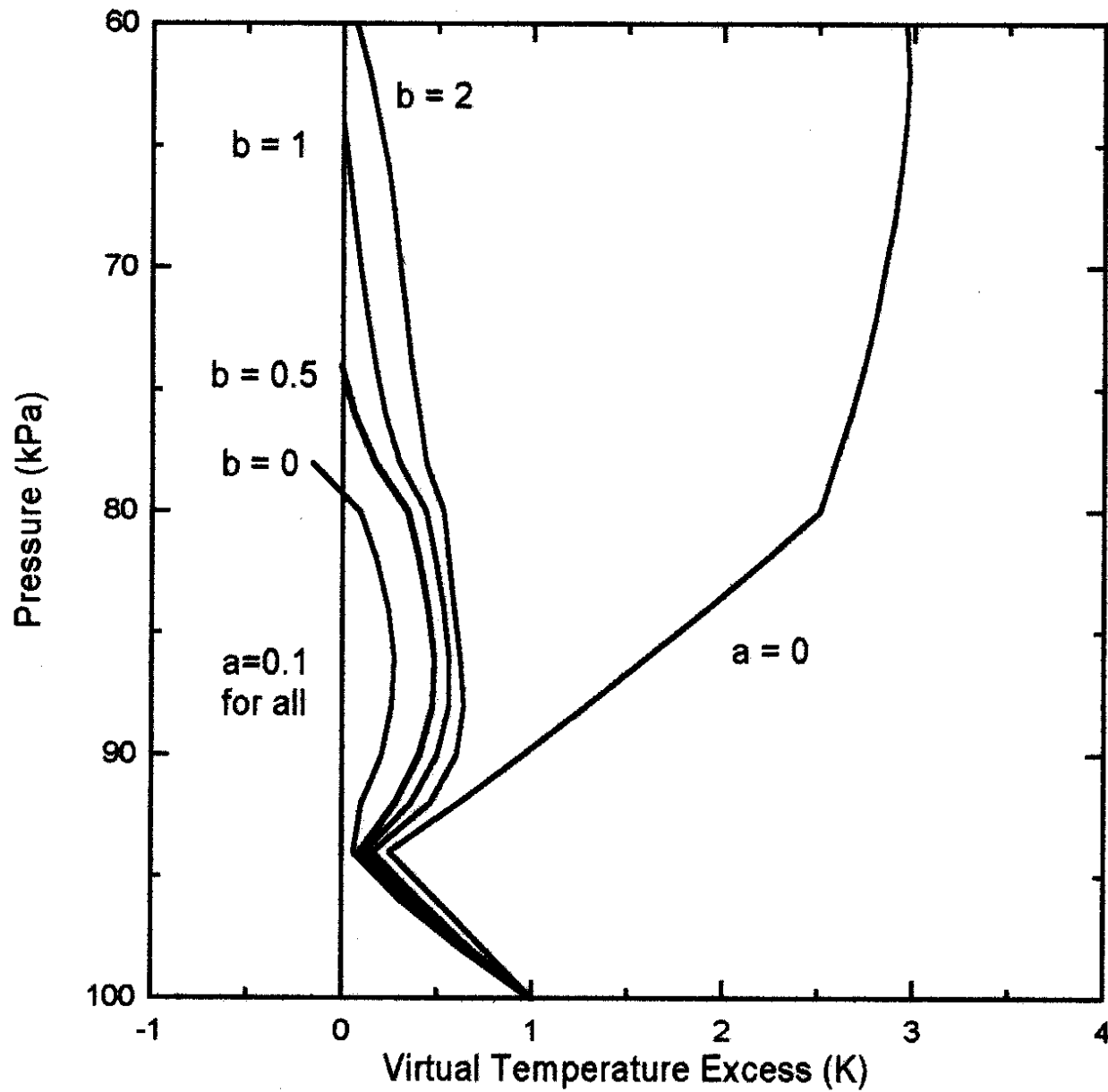


Fig. 4 Effect of entrainment exponent, $a=0.1$

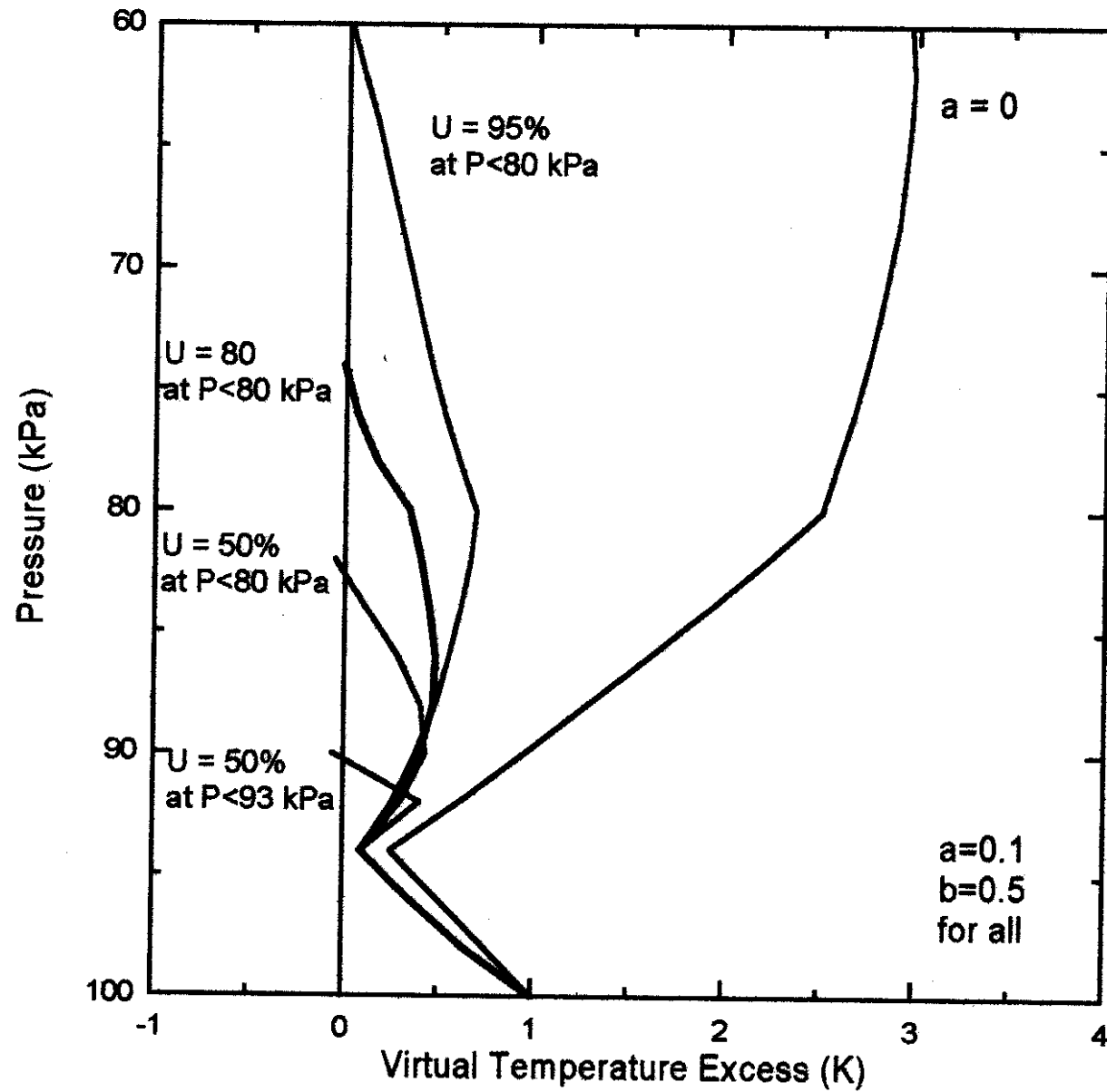


Fig. 5 Effect of environmental relative humidity, $a=0.1$, $b=0.5$.