Thermodynamics Analysis of NLC Formation

대기열역학 발표 6조

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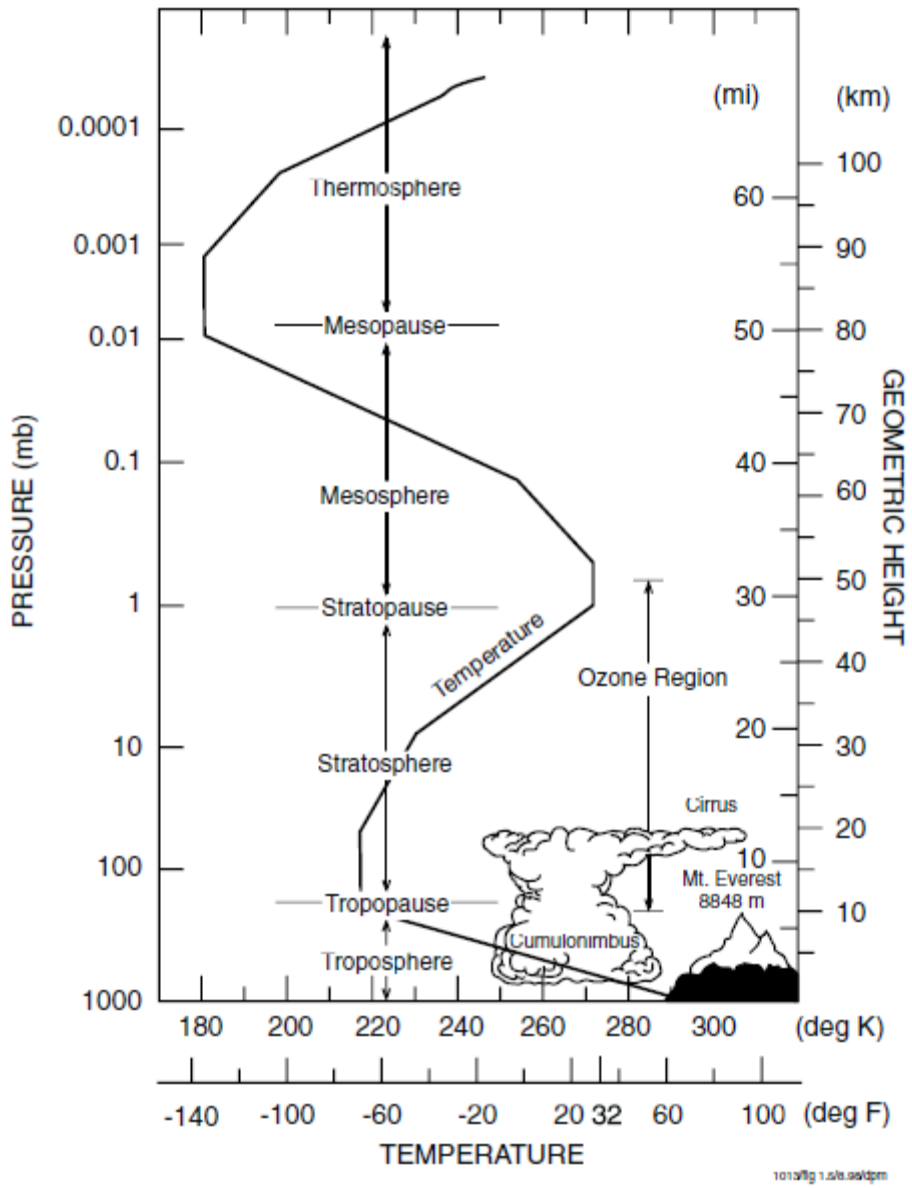
1 Mesosphere / NLC



1
Mesosphere / NLC

Noctilucent Cloud(NLC)

- Composed of small ice particles(diameter ~100 nm)
- Builds up nearby mesopause(75~85km), thin stratiform cloud
- Mesosphere pressure<Triple point pressure(=6.11mb): no liquid form of water exists
- Nuclei in mesosphere move towards high latitudes(specific procedure not examined)
- Formation is favorable in extremely low temperature(nearby -120°C)
- Formed usually during summer in high latitudes(50~66.5°)
- Seldom seen in Arctic, Antarctic circles due to midnight sun(shed by sunlight)
- Mesosphere is colder in summer than in winter
  - ✓Ascending current in summer/descending current in winter
  - ✓Ascending current results in low temperature and more moist air due to expansion(Mesopause anomaly)
- Recent southern advance of NLCs(nearby 40°) allegedly caused by global warming
  - ✓ CO_2, CH_4 cause greenhouse effect: blocking radiation energy flowing out from troposphere
  - ✓ Increase in GHG results in mesospheric temperature decline
  - ✓ Temperature decline derives more formation of NLCs in lower latitudes

2
Data 수집

Altitude (km)	*Temperature* (K)	*Scale Height* (km)	*Pressure* (hPa)	*Concentration* (cm^{-3})	*Potential Temperature*[2] (K)
0	288	8.4	1013.3	2.55 (19)[1]	288
5	256	7.5	540.5	1.53 (19)	307
10	223	6.5	265.0	8.61 (18)	327
15	217	6.4	121.1	4.04 (18)	398
20	217	6.4	55.3	1.85 (18)	498
25	222	6.5	25.5	8.33 (17)	636
30	227	6.6	12.0	3.83 (17)	807
35	237	6.9	5.7	1.74 (17)	1043
40	250	7.3	2.3	6.67 (16)	1426
45	264	7.7	1.5	4.12 (16)	1702
50	271	7.9	8.0 (-1)	2.14 (16)	2091
55	261	7.6	4.3 (-1)	1.19 (16)	2405
60	247	7.2	2.2 (-1)	6.45 (15)	2757
65	233	6.8	1.1 (-1)	3.42 (15)	3170
70	220	6.4	5.2 (-2)	1.71 (15)	3709
75	208	6.1	2.4 (-2)	8.36 (14)	4374
80	198	5.8	1.1 (-2)	4.03 (14)	5205
85	189	5.5	4.5 (-3)	1.72 (14)	6416
90	187	5.5	1.8 (-3)	6.98 (13)	8250
95	188	5.5	7.6 (-4)	2.93 (13)	10613
100	195	5.7	3.2 (-4)	1.19 (13)	14098
105	209	6.1	1.5 (-4)	5.20 (12)	18767
110	240	7.0	7.1 (-5)	2.14 (12)	26690
115	300	8.8	4.0 (-5)	9.66 (11)	39313
120	360	10.5	2.5 (-5)	5.03 (11)	53963

[1] read 2.55 (19), for example, as 2.55×10^{19}.
[2] calculated with $p_0 = 1013$ hPa.

T(z), p(z)

Day # / Altitude, km / Lat, deg	H_2O VMR, ppmv (Nedoluha et al., 2007)	H_2O VMR, ppmv (this work)
076/50.0/45.0 S	7.0±0.2	7.1±0.7
076/60.0/45.0 S	7.7±0.3	7.5±0.8
076/70.0/45.0 S	5.9±0.2	5.8±0.9
265/50.0/45.0 S	6.7±0.3	6.9±0.7
265/60.0/45.0 S	6.2±0.6	5.9±0.6
265/70.0/45.0 S	4.1±0.7	3.3±0.5
340/50.0/45.0 S	6.9±0.3	7.2±0.7
340/60.0/45.0 S	7.1±0.2	7.3±0.7
340/70.0/45.0 S	5.6±0.3	6.0±0.9
076/50.0/19.5 N	6.4±0.2	6.6±0.7
076/60.0/19.5 N	6.7±0.2	6.7±0.7
076/70.0/19.5 N	4.9±0.3	4.5±0.7
186/50.0/19.5 N	6.2±0.2	6.5±0.7
186/60.0/19.5 N	7.0±0.3	6.7±0.7
186/70.0/19.5 N	5.7±0.4	5.8±0.8
265/50.0/19.5 N	6.7±0.2	6.6±0.7
265/60.0/19.5 N	7.0±0.3	6.9±0.7
265/70.0/19.5 N	5.8±0.6	5.8±0.8
Below this line: comparisons with Sonnemann et al. (2009)		
076/50.0/69.2 N	4.5±0.3	4.5±0.5
076/60.0/69.2 N	4.0±0.3	3.7±0.4
076/70.0/69.2 N	2.2±0.2	2.6±0.4
076/80.0/69.2 N	1.4±0.2	1.6±0.4
186/50.0/69.2 N	7.0±0.5	6.2±0.6
186/60.0/69.2 N	6.5±0.5	6.0±0.6
186/70.0/69.2 N	6.7±0.6	5.7±0.8
186/80.0/69.2 N	3.6±0.6	4.5±1.0
265/50.0/69.2 N	7.5±0.5	6.5±0.6
265/60.0/69.2 N	6.5±0.7	6.0±0.6
265/70.0/69.2 N	5.0±0.6	4.7±0.6
265/80.0/69.2 N	2.5±0.5	3.0±0.6

w(z)

3

z_{LCL}, T_{LCL} 계산

사용 수식

$$e_{sw} = 6.11\exp(19.83 - \frac{5417}{T})$$

$$w = \frac{\varepsilon e}{p - e}$$

$$r = \frac{e}{e_{sw}}$$

$$T_{LCL} = \frac{1}{\frac{1}{T - 55} - \frac{\ln r}{2840}} + 55$$

$$T_{dew} = \frac{T}{\frac{-TR_v \ln r}{l_s} + 1}$$

$$z_{LCL} = z + \frac{T - T_{dew}}{8}$$

R_v=461.51J/Kg*K

l_s= 2.8345*10^6J/Kg

3 z_{LCL}, T_{LCL} 계산

실제 값

Z = 50km $T = 271K$ w =6.2*10^{-6}

$$e_{sw} = 6.11 \exp\left(19.83 - \frac{5417}{271}\right) = 5.212mb$$

$$6.2 * 10^{-6} = \frac{0.622e}{8 * 10^{-1} - e}$$ e = 7.974*10^{-6}mb

$$r = \frac{7.974*_{10^{-6}}}{5.212} = 1.530*10^{-6}$$

$$T_{LCL} = \frac{1}{\frac{1}{271 - 55} - \frac{\ln 1.530 * 10^{-6}}{2840}} + 55 = 162.014K$$

$$T_{dew} = \frac{271}{\frac{-271 \ln 1.530*10^{-6}}{2.8345*10^{6}}+1} = 170.351\text{K}$$

$$z_{LCL} = 50 + \frac{271 - 170.351}{8} = 62.581Km$$

$\varepsilon = 0.622$

$p = 8 * 10^{-1}$mb

R_v=461.51J/Kg*K

l_s= 2.8345*10^6J/Kg

3 z_{LCL}, T_{LCL} 계산

실제 값

Z = 60km $T = 247K$ w =6.0*10^{-6}

$$e_{sw} = 6.11 \exp\left(19.83 - \frac{5417}{247}\right) = 0.741mb$$

$$6.0 * 10^{-6} = \frac{0.622e}{2.2 * 10^{-1} - e}$$ e = 2.122*10^{-6}mb

$$r = \frac{2.122*_{10^{-6}}}{0.741} = 2.841*10^{-6}$$

$$T_{LCL} = \frac{1}{\frac{1}{247-55} - \frac{\ln 2.841*10^{-6}}{2840}} + 55 = 158.306K$$

$$T_{dew} = \frac{247}{\frac{-247 \ln 2.841*10^{-6}}{2.8345*10^{6}}+1} = 163.185\text{K}$$

$$z_{LCL} = 60 + \frac{247 - 163.185}{8} = 73.851Km$$

$\varepsilon = 0.622$

$p = 2.2 * 10^{-1}$mb

R_v=461.51J/Kg*K

l_s= 2.8345*10^6J/Kg

3 z_{LCL}, T_{LCL} 계산

실제 값

Z = 70km $T = 220K$ $w = 5.7*10^{-6}$

$$e_{sw} = 6.11 \exp\left(19.83 - \frac{5417}{220}\right) = 0.0506mb$$

$$5.7 * 10^{-6} = \frac{0.622e}{5.2 * 10^{-2} - e}$$ e = $0.478*10^{-6}$mb

$$r = \frac{0.478*10^{-6}}{0.0506} = 9.44*10^{-6}$$

$$T_{LCL} = \frac{1}{\frac{1}{220-55} - \frac{\ln 9.44*10^{-6}}{2840}} + 55 = 153.71K$$

$$T_{dew} = \frac{220}{\frac{-220 \ln 9.44*10^{-6}}{2.8345*10^{6}}+1} = 155.537\text{K}$$

$$z_{LCL} = 50 + \frac{220 - 155.537}{8} = 78.125Km$$

$\varepsilon = 0.622$

$p = 5.2 * 10^{-2}$mb

R_v=461.51J/Kg*K

l_s= $2.8345*10^{6}$J/Kg

3 z_{LCL}, T_{LCL} 계산

실제 값

Z = 80km $T = 198K$ $w = 5.7*10^{-6}$

$$e_{sw} = 6.11 \exp\left(19.83 - \frac{5417}{198}\right) = 0.00328mb$$

$$6.2 * 10^{-6} = \frac{0.622e}{1.1 * 10^{-2} - e} \qquad \text{e} = 0.0798*10^{-6}\text{mb}$$

$$r = \frac{0.0798*_{10^{-6}}}{0.00328} = 2.4*10^{-5} \qquad T_{LCL} = \frac{1}{\frac{1}{198-55} - \frac{\ln 2.4*10^{-5}}{2840}} + 55 = 148.19K$$

$$T_{dew} = \frac{198}{\frac{-198 \ln 2.4*10^{-5}}{2.8345*10^{6}}+1} = 147.483\text{K}$$

$$z_{LCL} = 50 + \frac{198 - 147.483}{8} = 86.314Km$$

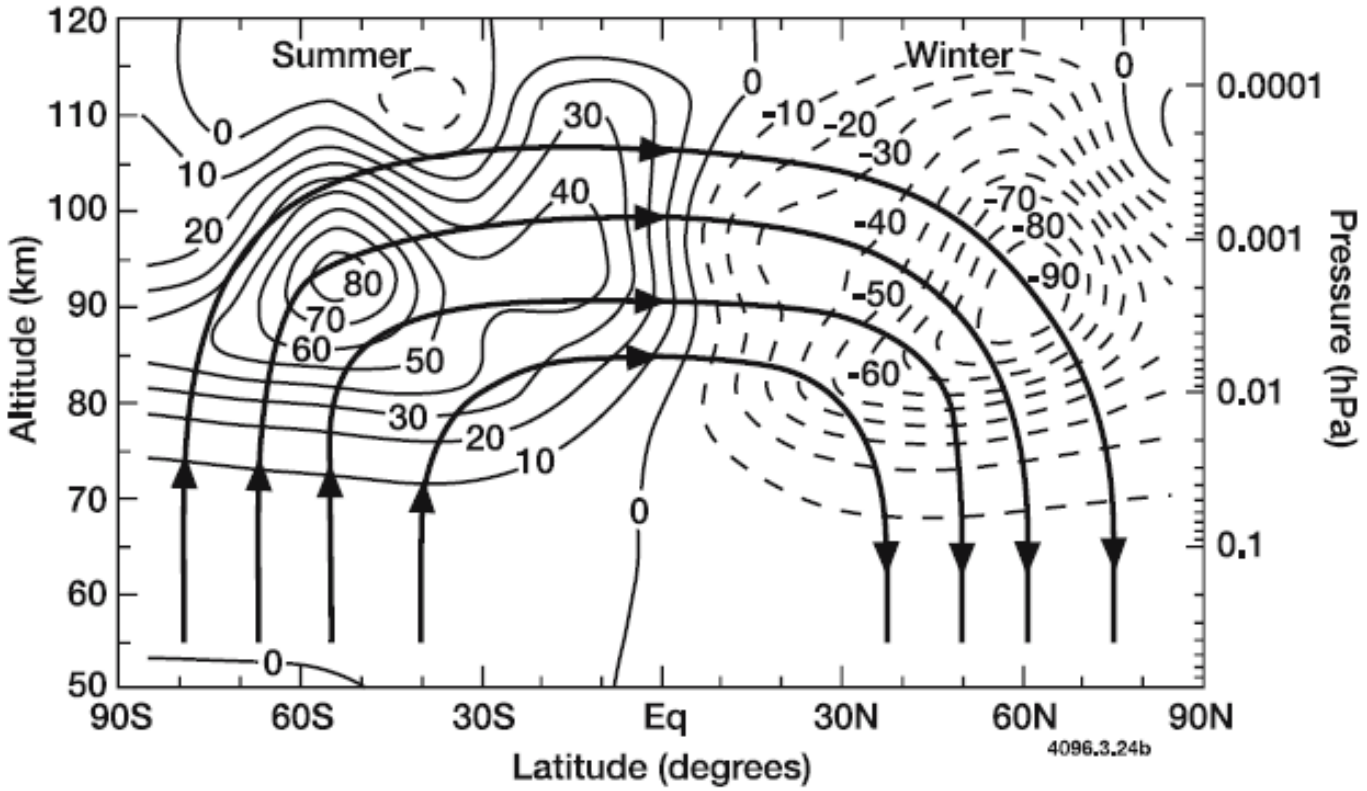
$\varepsilon = 0.622$

$p = 1.1 * 10^{-2}\text{mb}$

R_v=461.51J/Kg*K

l_s= 2.8345*10^6J/Kg

4
결과 분석


Summer
Winter
Altitude (km)
Pressure (hPa)
Latitude (degrees)
120
110
100
90
80
70
60
50
90S
60S
30S
Eq
30N
60N
90N
0.0001
0.001
0.01
0.1
0
10
20
30
40
50
60
70
80
-10
-20
-30
-40
-50
-60
-70
-80
-90
4096.3.24b

4
결과 분석

$$\Gamma_s = \frac{g}{c_p}\frac{1 + l_s\omega_{sw}/RT}{1 + l_s^2\omega_{sw}/c_pR_vT^2} \cong \frac{g}{c_{pd}}\frac{1 + l_s\omega_{sw}/RT}{1 + l_s^2\omega_{sw}/c_pR_vT^2}$$

$$\omega_{sw} = 6 \times 10^{-6}, \qquad T = 160K$$

$$\Gamma_s = \frac{9.8}{1005}\frac{1+\frac{2.8345\times10^6\times6\times10^{-6}}{287\times160}}{1+\frac{(2.8345\times10^6)^2\times6\times10^{-6}}{1005\times461.51\times160^2}} \cong 0.0097K/m = 9.7K/km$$

계산한 습윤단열감률을 이용하여 고도에 따른 구름의 온도를 구할 수 있다.

$$T_{LCL} = 150.95K, \qquad z_{LCL} = 82.2195km \ \ (average\ of\ 70 - 80km)$$

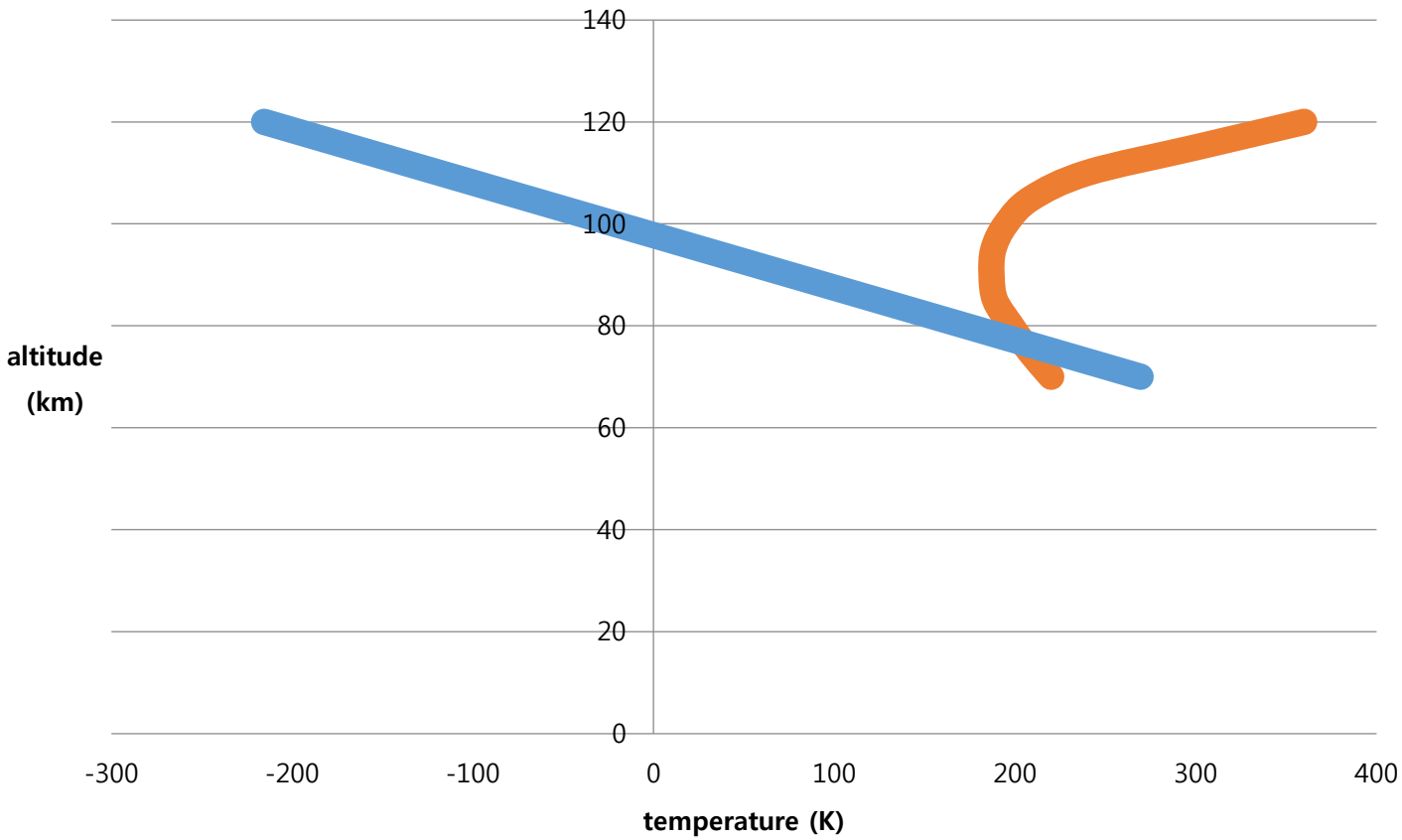
$$\frac{T - 150.95}{z - 82.2195} = -9.7$$

$$T = -9.7z + 948.48$$

4
결과 분석

	A	B	C	D	E	F	G	H	I
1	h	Tsurr	Tparcel		Tsurr	h		Tparcel	h
2	70	220	269.48		220	70		269.48	70
3	75	208	220.98		208	75		220.98	75
4	80	198	172.48		198	80		172.48	80
5	85	189	123.98		189	85		123.98	85
6	90	187	75.48		187	90		75.48	90
7	95	188	26.98		188	95		26.98	95
8	100	195	-21.52		195	100		-21.52	100
9	105	209	-70.02		209	105		-70.02	105
10	110	240	-118.52		240	110		-118.52	110
11	115	300	-167.02		300	115		-167.02	115
12	120	360	-215.52		360	120		-215.52	120

4
결과 분석



Cloud temperature

Environment temperature

5
결론

1. 중간권에서 구름을 만드는 공기덩이를 강제로 상승시키는 원동력은 성층권계면에서의 부등가열보다는 75km 고도에서부터 발달하는 상승기류

2. 중간권에서 생성된 구름은 안정하기 때문에 위로 발달하지 못한 층운형 구름이 된다.

Q&A 및 참고문헌

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대기열역학 6조 발표

감사합니다.