CEDAR Prize Lecture 2003 (Delivered on June 16)

Climatology and Variability in the Mesopause Region Over Colorado: Sodium Lidar Observation of Temperature and Winds

Chiao-Yao (Joe) She

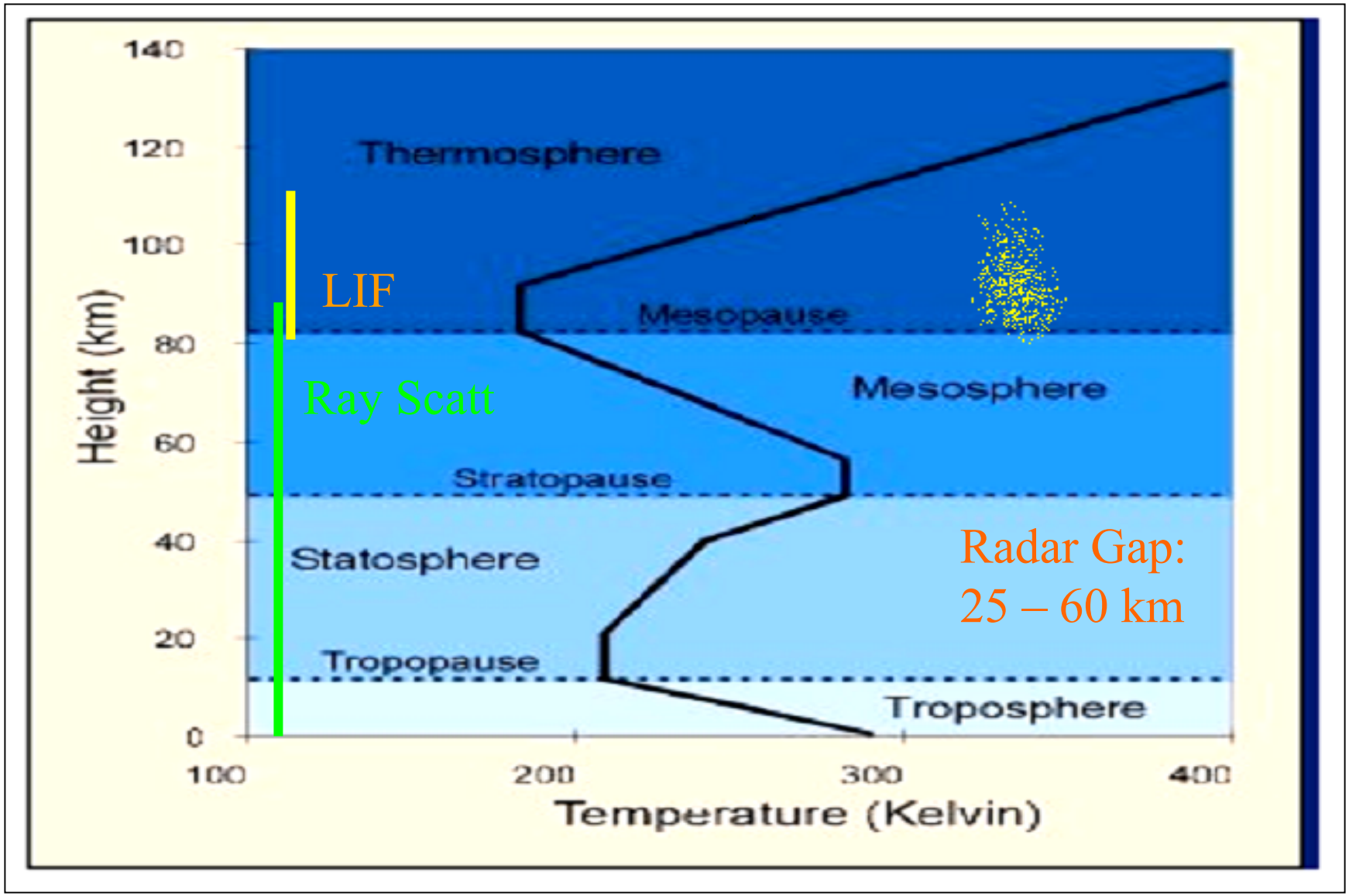
Physics Department

Colorado State University

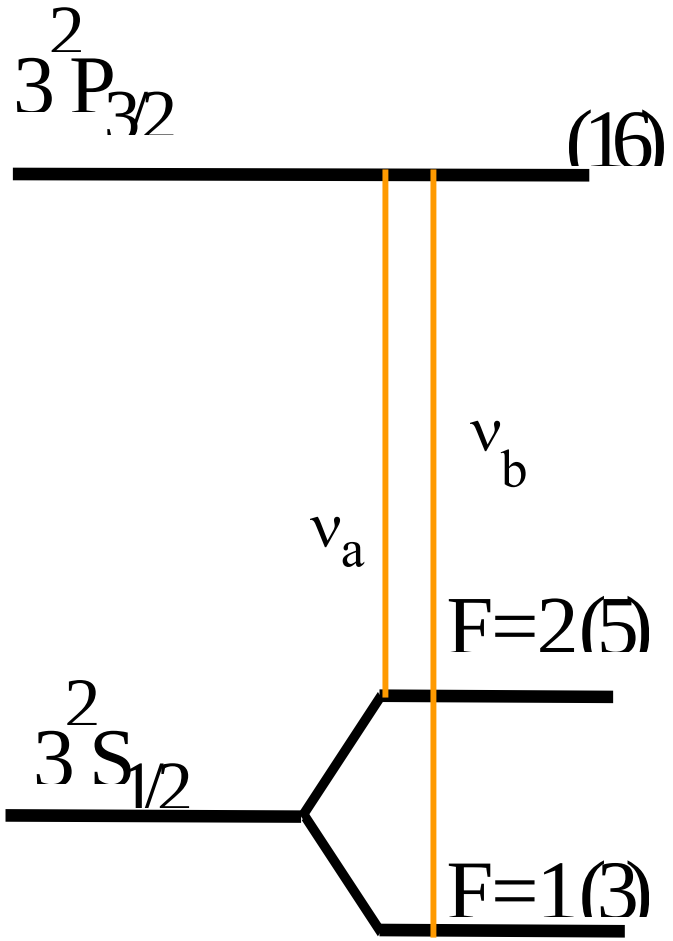
Outline of presentation

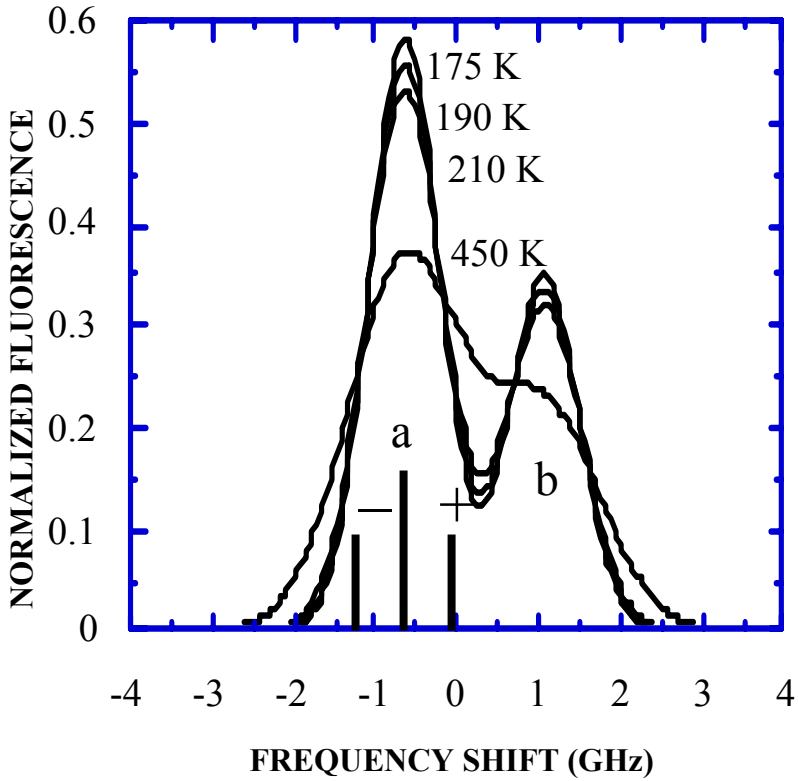
- Ground-based observations of the mesopause region (MLT, 80 – 110km)
  – Na Fluorescence Lidar
- Temp. climatology and long-term change
- Climatology and variability of the diurnal-mean and tidal perturbations - TIMED
- Science enabled and challenges - Examples
- Conclusion, reflection, acknowledgement

Sensing of atmospheric layers from ground



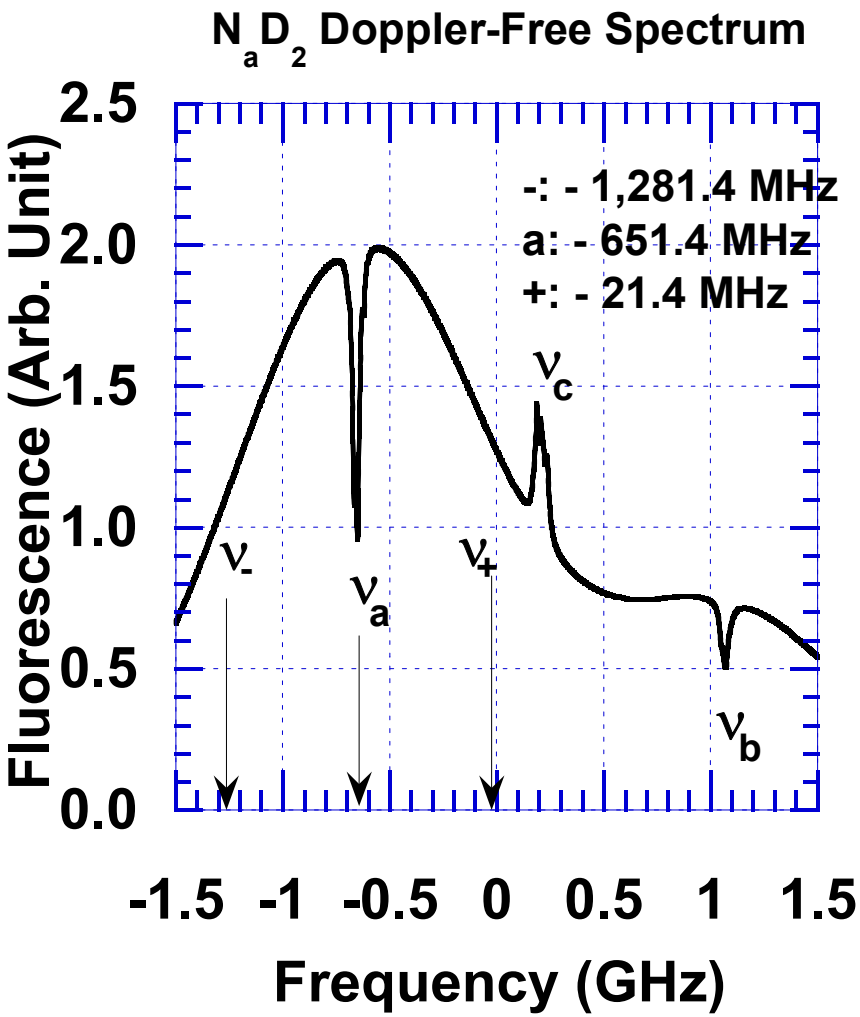
Laser induced fluorescence: NaD_2-T-W measurement

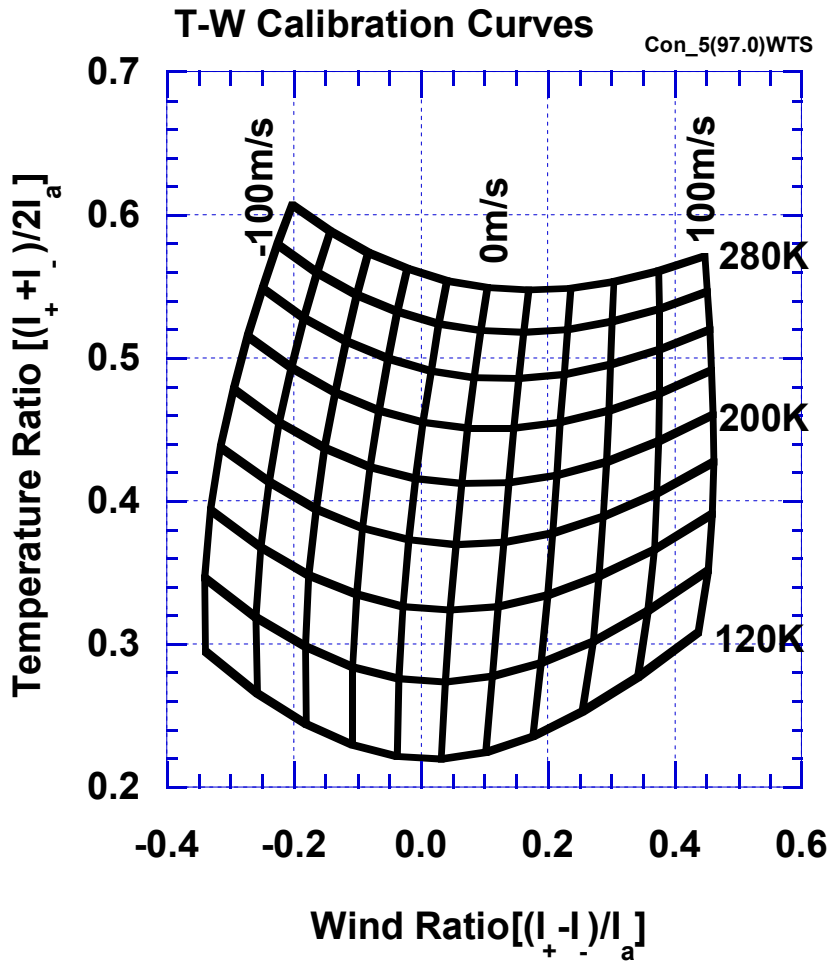




1nm ~ 1050 GHz; 1MHz ~ 0.6m/s

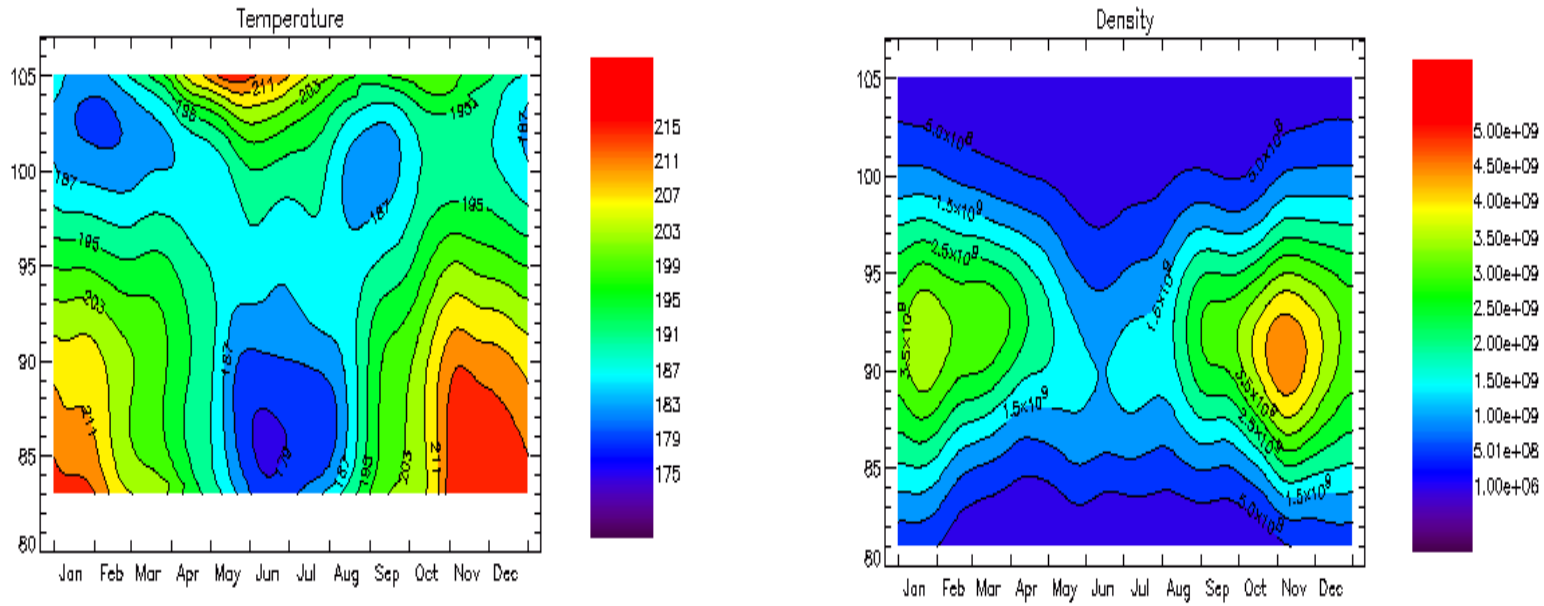
- $\mathbf{R_T = (I_+ + I_-) / 2I_a}$
- $\mathbf{R_W = (I_+ - I_-) / I_a}$


$N_a D_2$ Doppler-Free Spectrum
-: - 1,281.4 MHz
a: - 651.4 MHz
+: - 21.4 MHz
ν_c
ν_-
ν_a
ν_+
ν_b
Fluorescence (Arb. Unit)
2.5
2.0
1.5
1.0
0.5
0.0
-1.5 -1 -0.5 0 0.5 1 1.5
Frequency (GHz)


T-W Calibration Curves
Con_5(97.0)WTS
-100m/s
0m/s
100m/s
280K
200K
120K
Temperature Ratio [(I+ +I-)/2Ia]
0.7
0.6
0.5
0.4
0.3
0.2
-0.4 -0.2 0.0 0.2 0.4 0.6
Wind Ratio[(I+ -I-)/Ia]

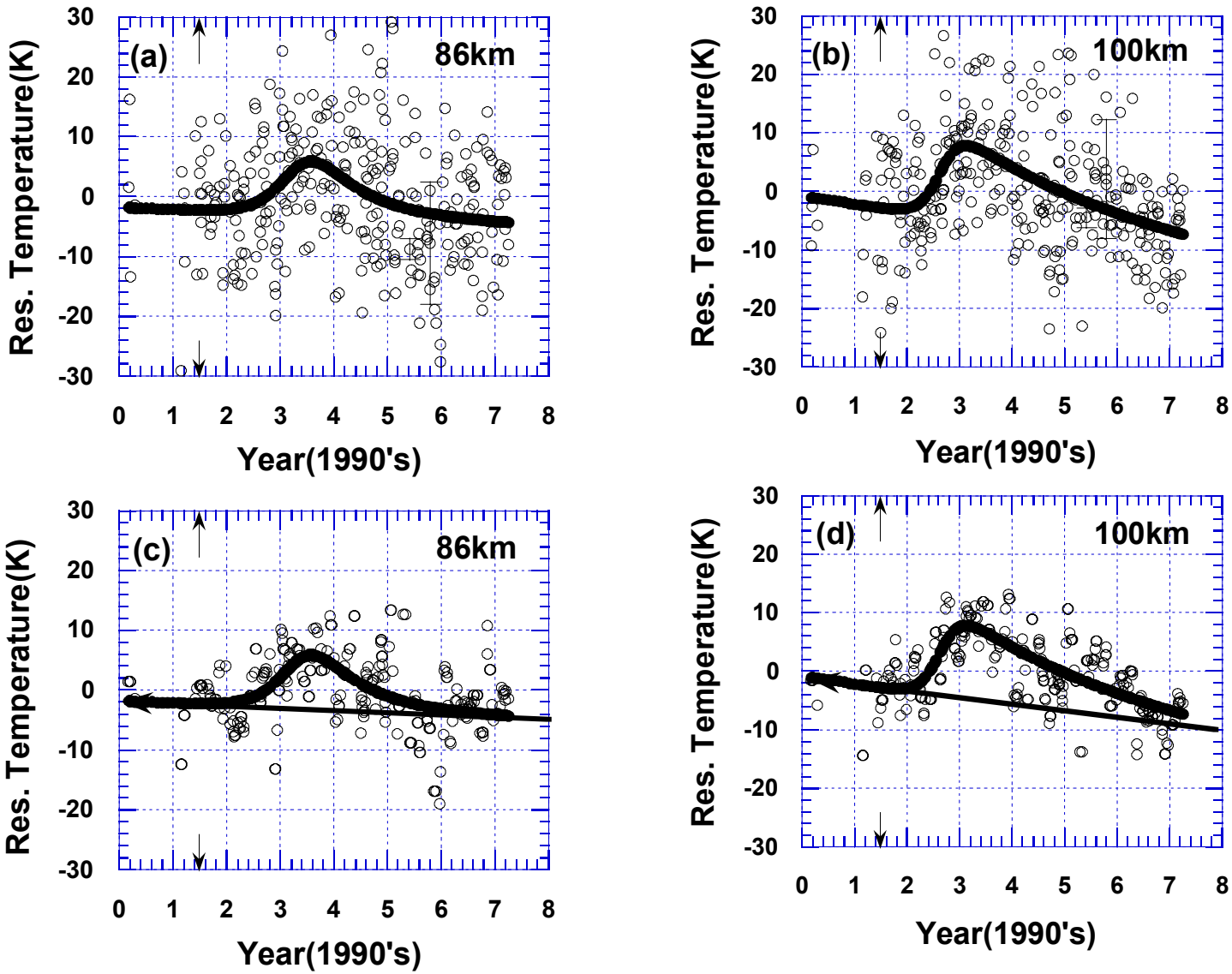
1MHz ~ 0.6m/s

Climatology – Two-level Mesopause

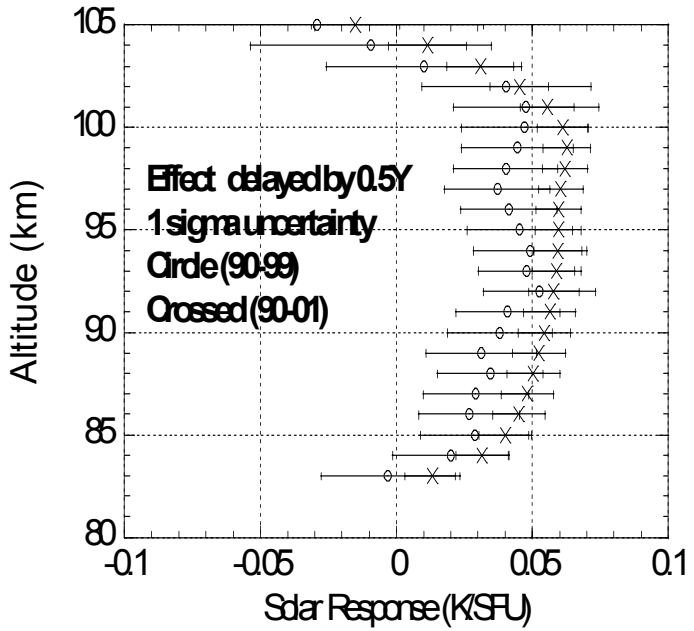


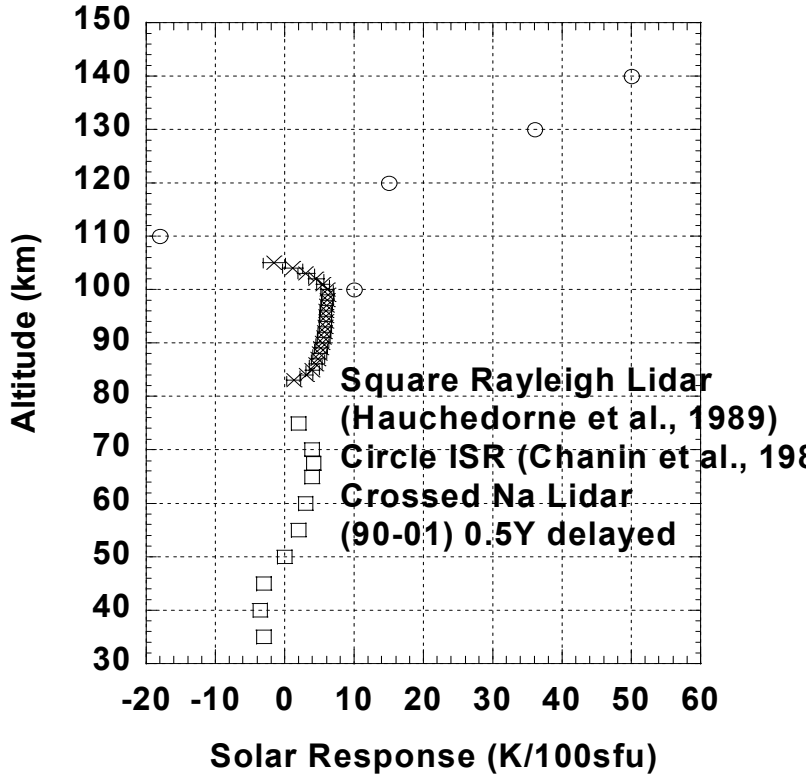
Eight-year Fort Collins climatology of 3.7 km and 1 month smoothed nocturnal temperature (left) and Na density (right) – She et al. GRL 2000

Episodic Warming Between 1990 and 1997



Solar Cycle Effect in Middle Atmospheric Temperature





Long-term change – She and Krueger, ASR (in press)

T, U, V over full diurnal cycles

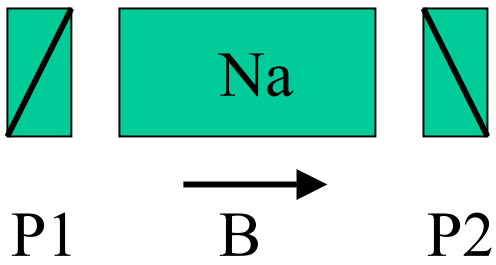
Dynamics observed from a single station:

Field variables (temperature, zonal and meridional winds) as a function of altitude and local time in a 24-hour continuous day:

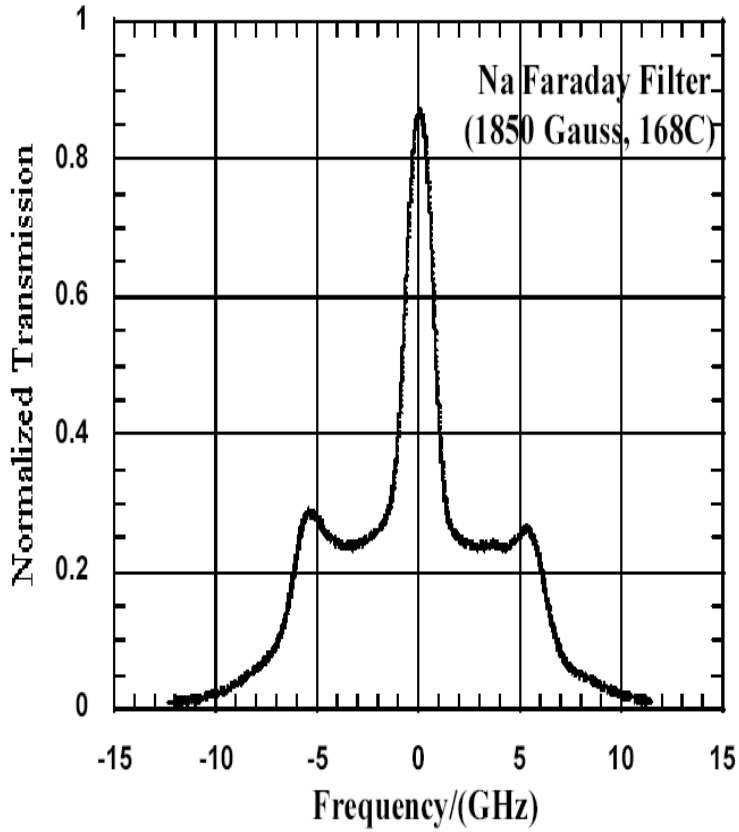
$$\Phi^{T,U,V}(z,t)=\overline{\Phi^{T,U,V}(z)}+\sum_j A_j^{T,U,V}(z)\cos\left(\frac{2\pi j(t-\tau_j^{T,U,V})}{24}\right)+R^{T,U,V}(z,t)$$

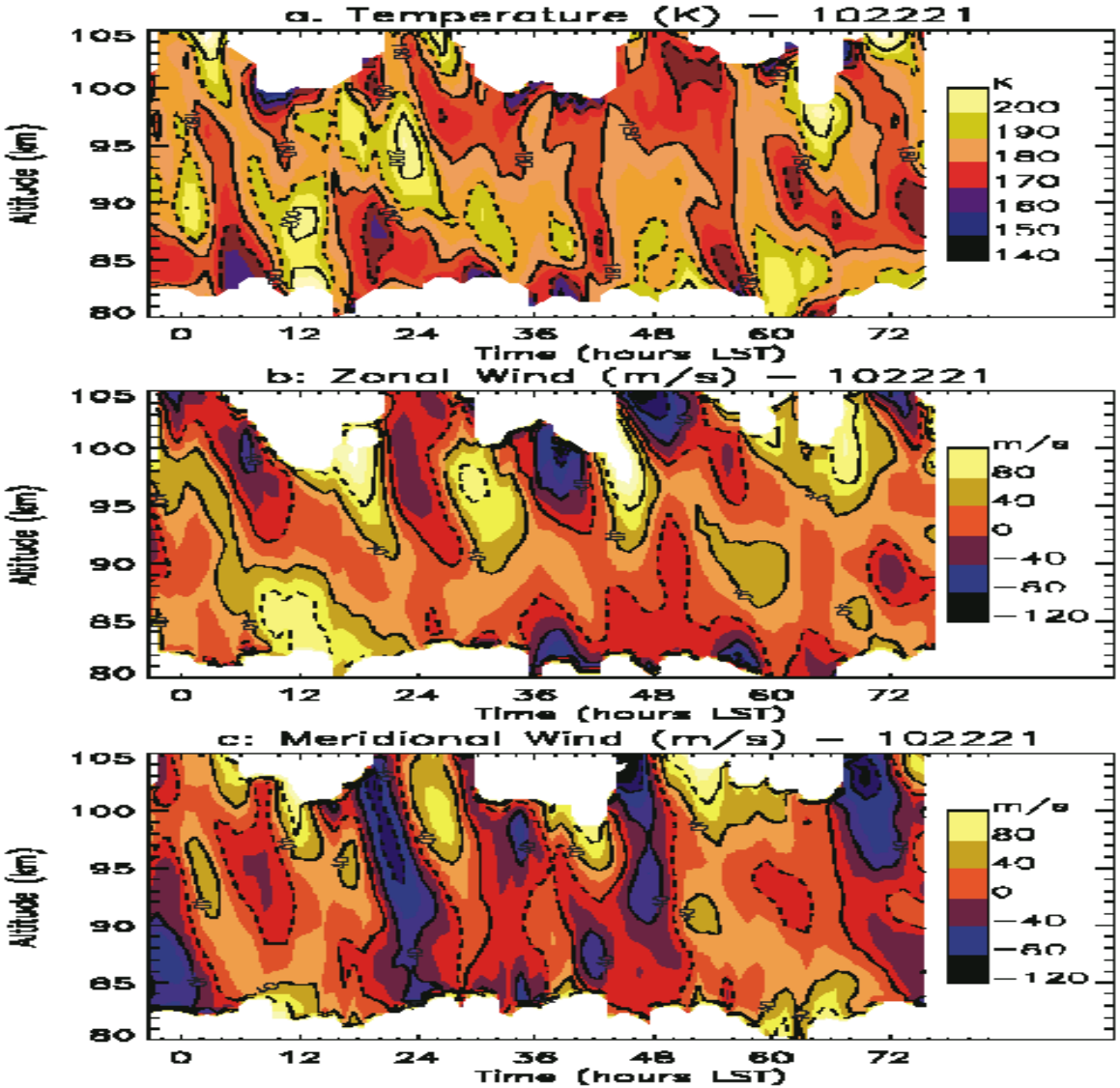
All terms determined solely from data

Sodium Faraday Filter
Rejection of sky background



A heated sodium cell in axial magnetic field between two crossed polarizers





Simultaneous T, U, V contours; August 9th to 12, 2002

Day-to-day variability

–Planetary wave modulation and nonlinear interactions

Example: July 17 - August 12 [83(N)+108(D)]

Six full diurnal coverage: 198, 210, 211, 221, 222, 223

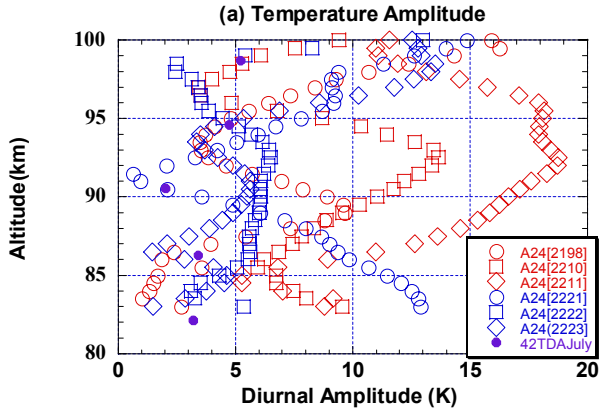
Questions:

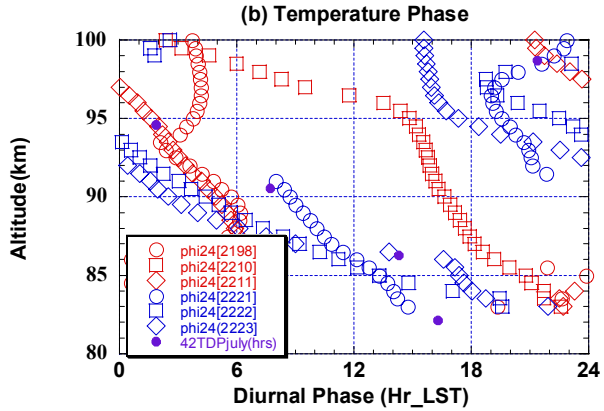
What is the extent of day-to-day variability?

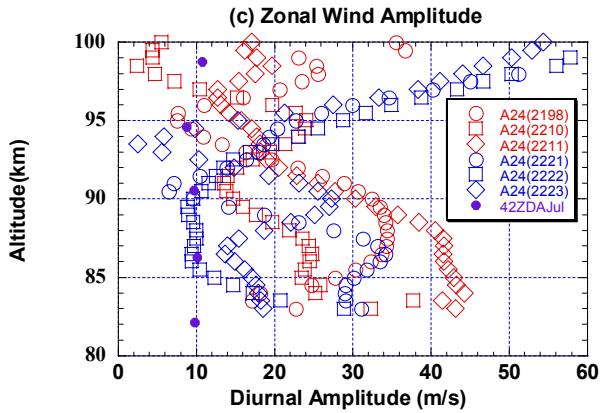
–On diurnal (and other periods) perturbations (tides)

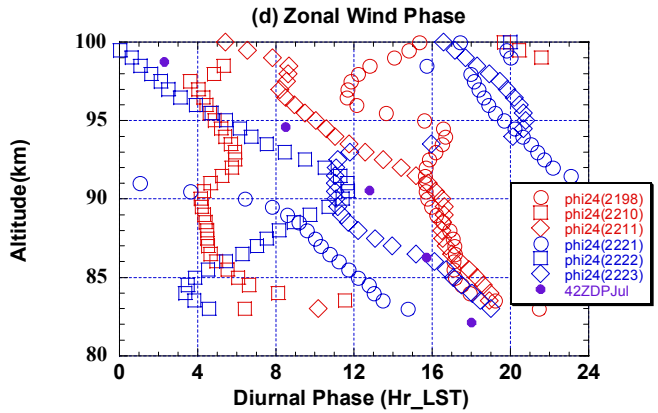
–**And** on the mean-state (diurnal-mean)

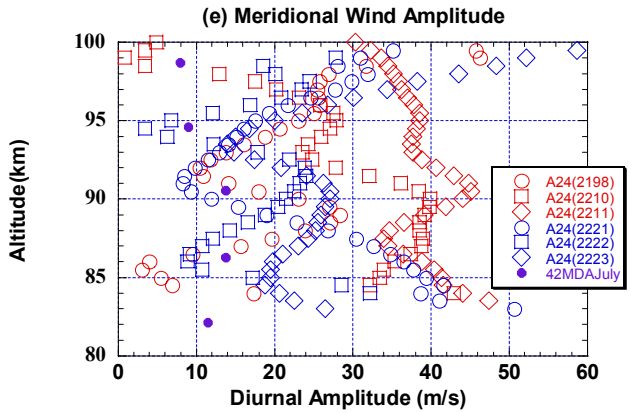
Do individual full diurnal-cycle data average (converge) to the mean?

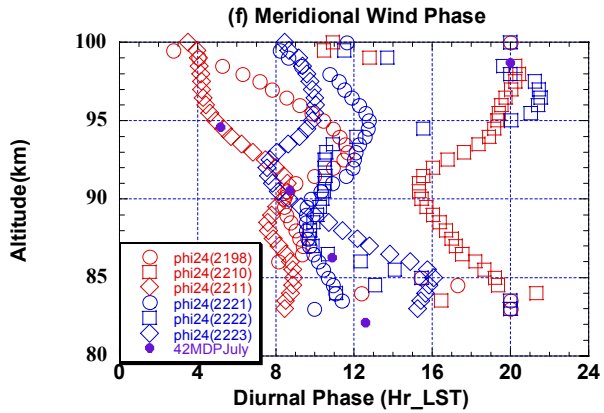

(a) Temperature Amplitude
Altitude(km)
Diurnal Amplitude (K)
A24[2198]
A24[2210]
A24[2211]
A24[2221]
A24[2222]
A24[2223]
42TDAJuly

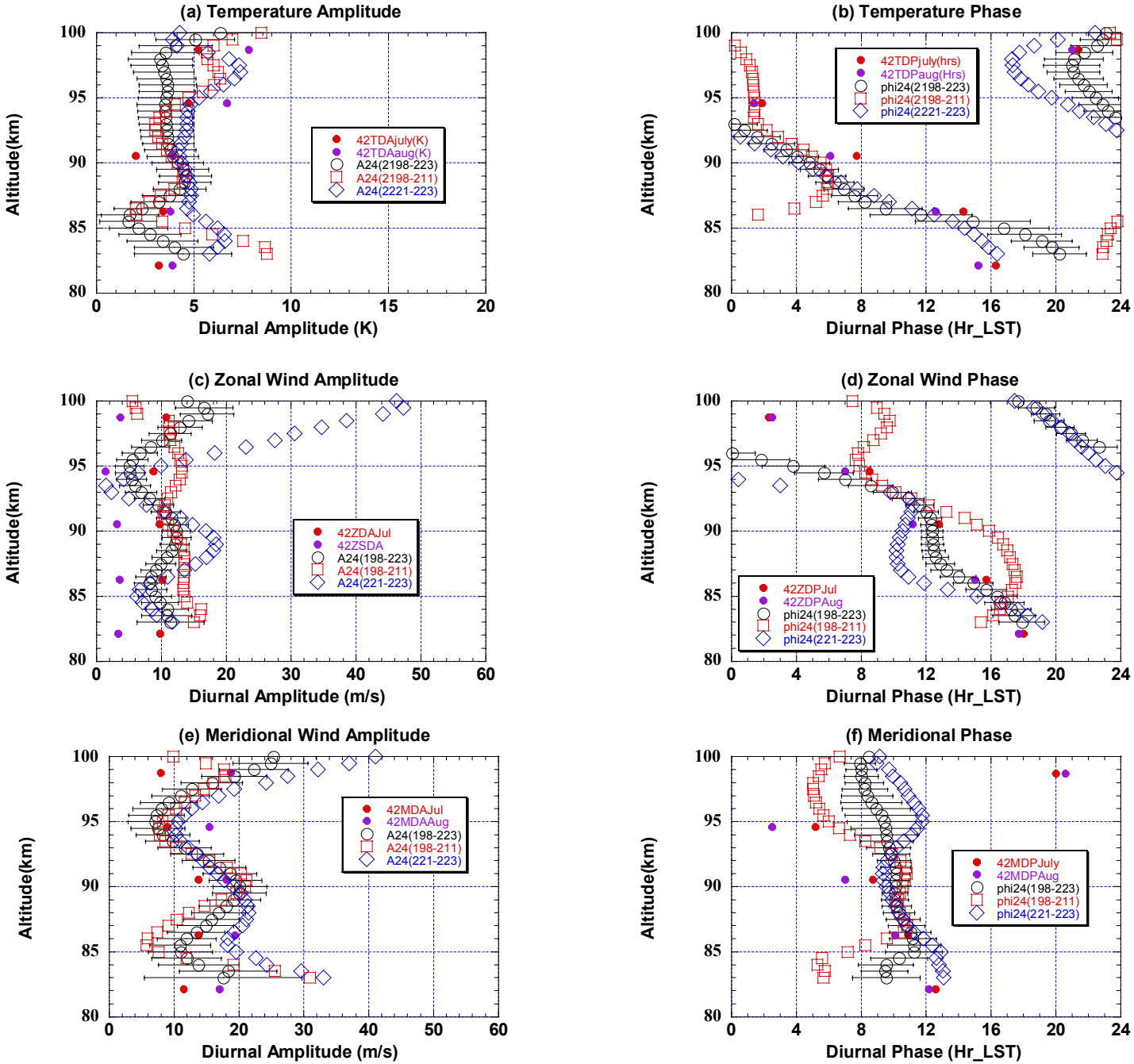

(b) Temperature Phase
Altitude(km)
Diurnal Phase (Hr_LST)
phi24[2198]
phi24[2210]
phi24[2211]
phi24[2221]
phi24[2222]
phi24[2223]
42TDPjuly(hrs)


(c) Zonal Wind Amplitude
Altitude(km)
Diurnal Amplitude (m/s)
A24(2198)
A24(2210)
A24(2211)
A24(2221)
A24(2222)
A24(2223)
42ZDAJul

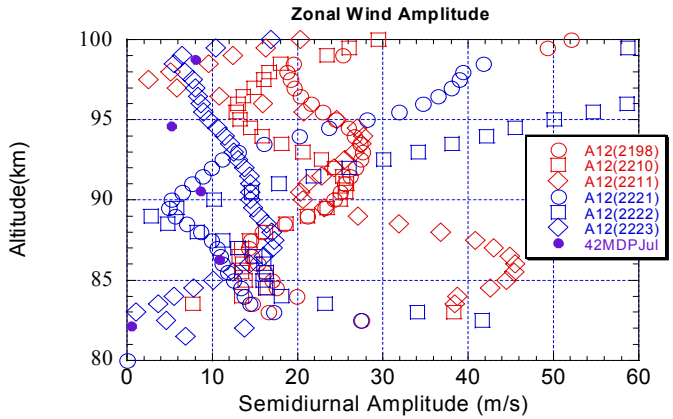

(d) Zonal Wind Phase
Altitude(km)
Diurnal Phase (Hr_LST)
phi24(2198)
phi24(2210)
phi24(2211)
phi24(2221)
phi24(2222)
phi24(2223)
42ZDPJul

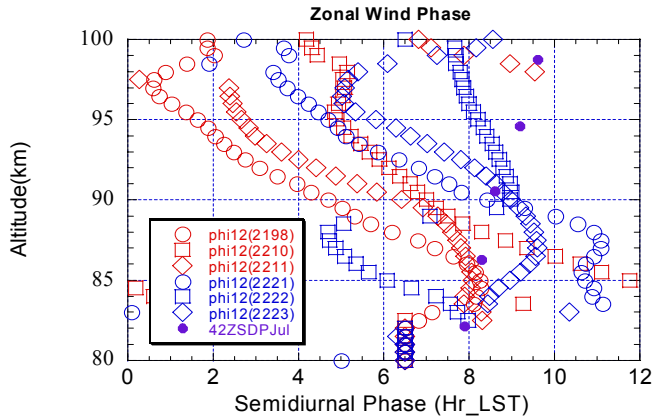

(e) Meridional Wind Amplitude
Altitude(km)
Diurnal Amplitude (m/s)
A24(2198)
A24(2210)
A24(2211)
A24(2221)
A24(2222)
A24(2223)
42MDAJuly

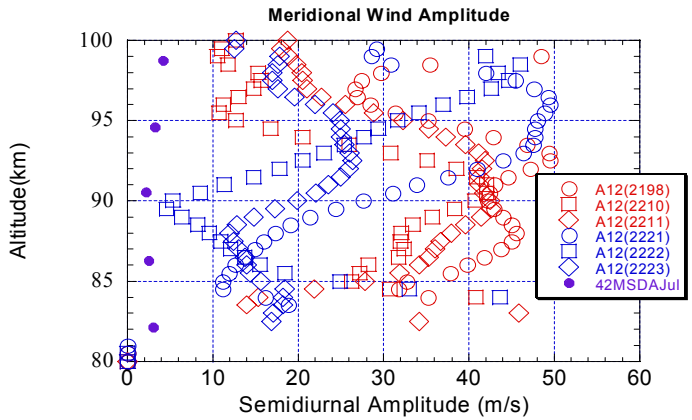

(f) Meridional Wind Phase
Altitude(km)
Diurnal Phase (Hr_LST)
phi24(2198)
phi24(2210)
phi24(2211)
phi24(2221)
phi24(2222)
phi24(2223)
42MDPJuly

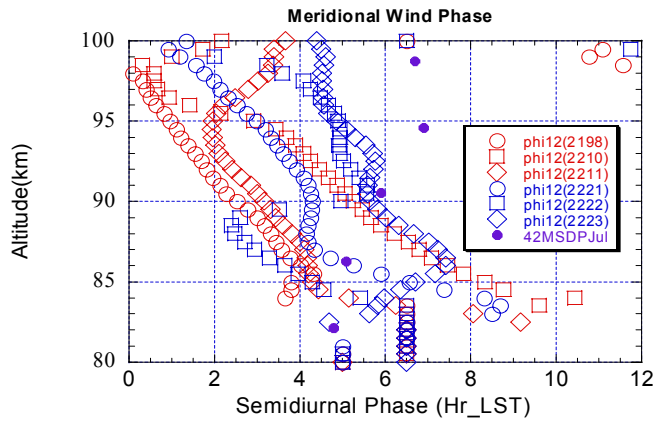

(a) Temperature Amplitude
Altitude(km)
Diurnal Amplitude (K)
42TDAjuly(K)
42TDAaug(K)
A24(2198-223)
A24(2198-211)
A24(2221-223)
(b) Temperature Phase
Diurnal Phase (Hr_LST)
42TDPjuly(hrs)
42TDPaug(Hrs)
phi24(2198-223)
phi24(2198-211)
phi24(2221-223)
(c) Zonal Wind Amplitude
Diurnal Amplitude (m/s)
42ZDAJul
42ZSDA
A24(198-223)
A24(198-211)
A24(221-223)
(d) Zonal Wind Phase
42ZDPJul
42ZDPAug
phi24(198-223)
phi24(198-211)
phi24(221-223)
(e) Meridional Wind Amplitude
42MDAJul
42MDAAug
A24(198-223)
A24(198-211)
A24(221-223)
(f) Meridional Phase
42MDPJuly
42MDPAug
phi24(198-223)
phi24(198-211)
phi24(221-223)

Zonal and Merid. Wind Semidiurnal Tides; Individual Days

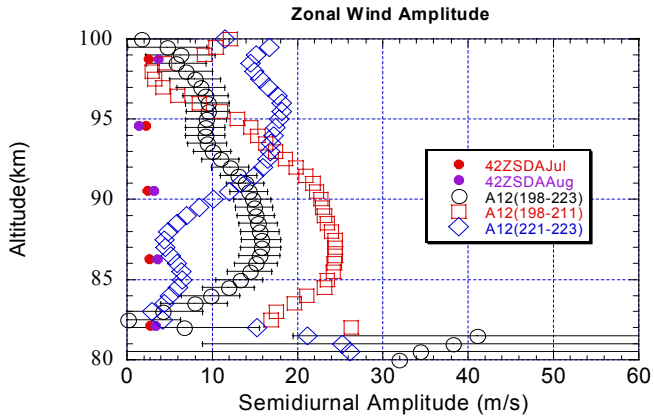


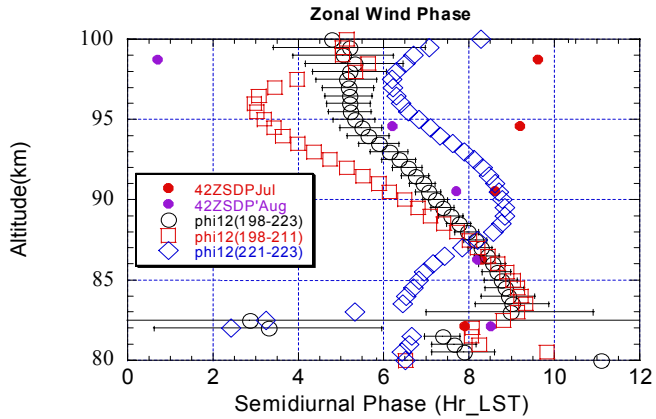


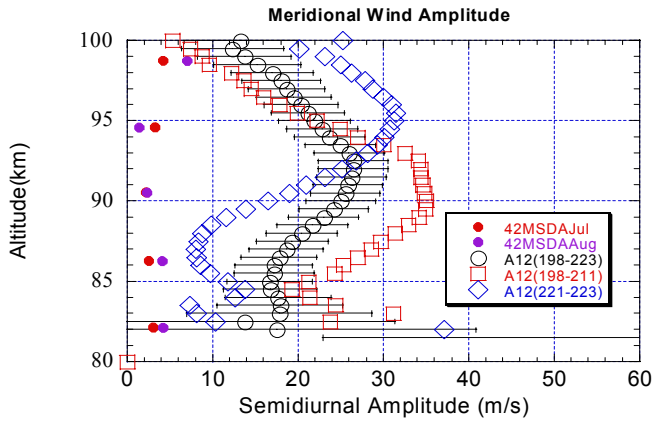


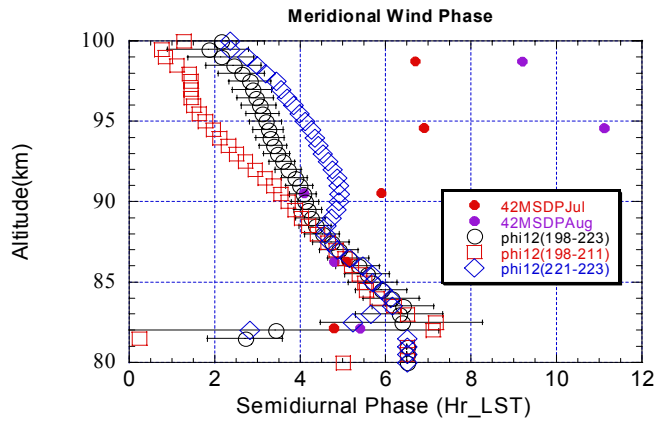


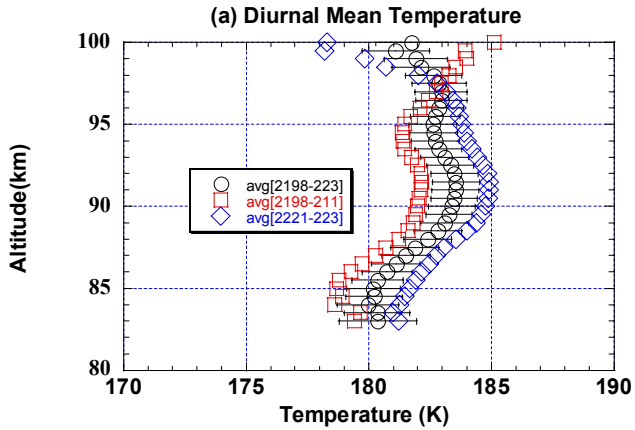
Zonal and Merid. Wind Semidiurnal Tides; 3-day means

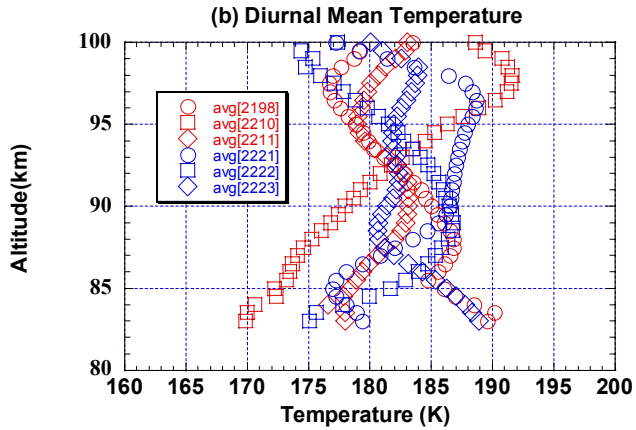


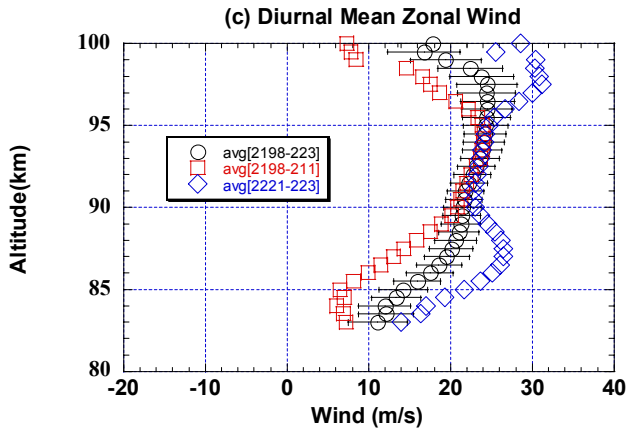


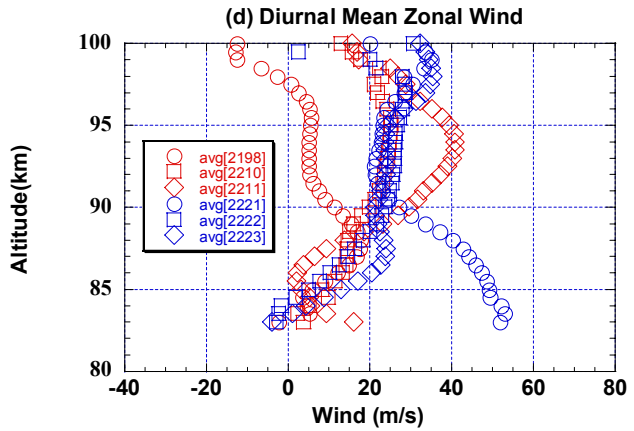


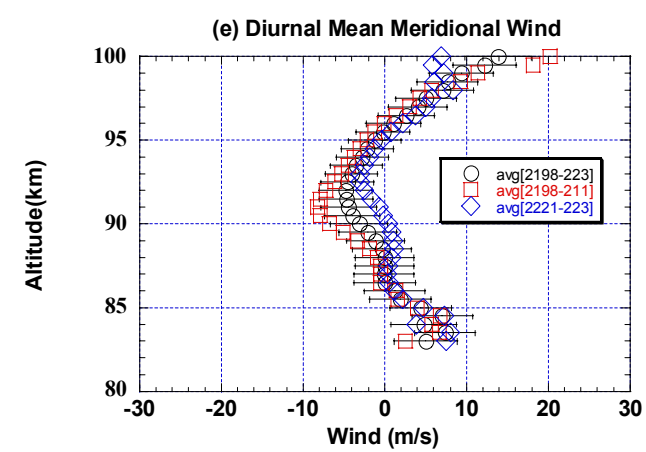


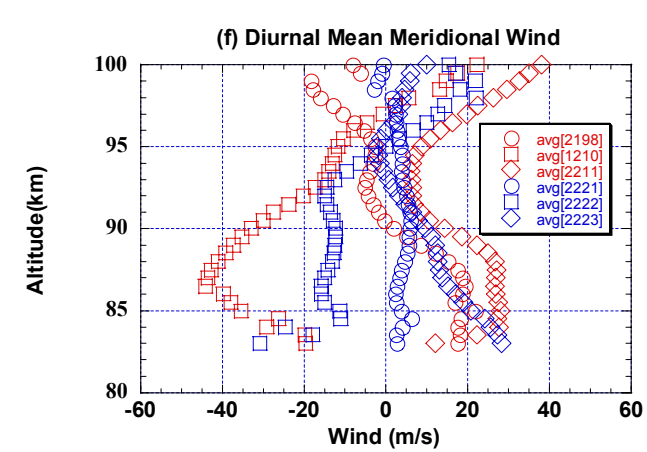

(a) Diurnal Mean Temperature
Altitude(km)
Temperature (K)
avg[2198-223]
avg[2198-211]
avg[2221-223]


(b) Diurnal Mean Temperature
Altitude(km)
Temperature (K)
avg[2198]
avg[2210]
avg[2211]
avg[2221]
avg[2222]
avg[2223]

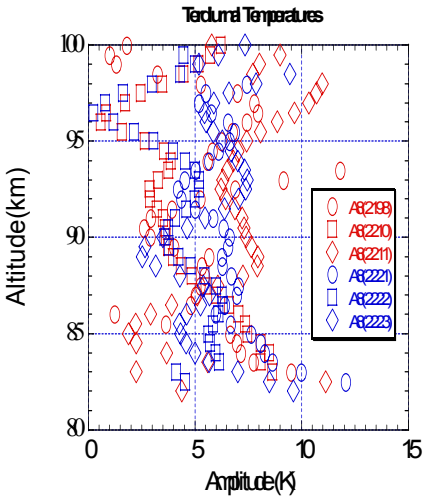

(c) Diurnal Mean Zonal Wind
Altitude(km)
Wind (m/s)
avg[2198-223]
avg[2198-211]
avg[2221-223]

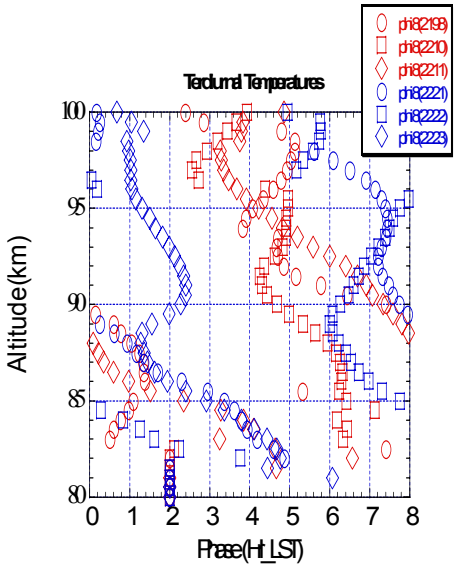

(d) Diurnal Mean Zonal Wind
Altitude(km)
Wind (m/s)
avg[2198]
avg[2210]
avg[2211]
avg[2221]
avg[2222]
avg[2223]

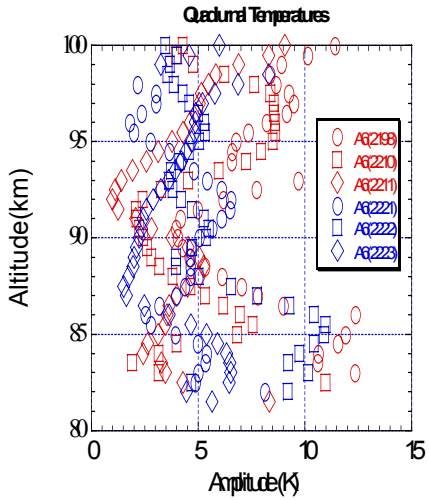

(e) Diurnal Mean Meridional Wind
Altitude(km)
Wind (m/s)
avg[2198-223]
avg[2198-211]
avg[2221-223]

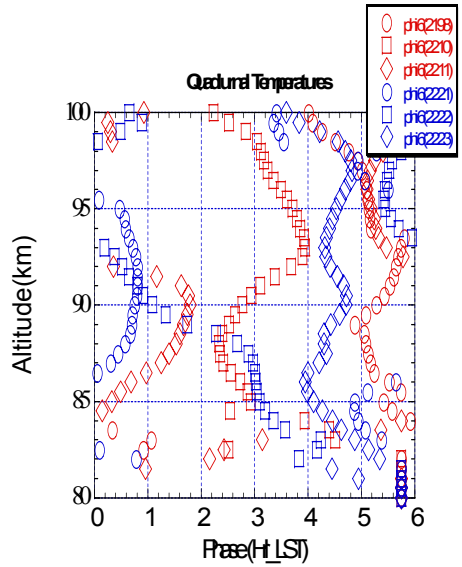

(f) Diurnal Mean Meridional Wind
Altitude(km)
Wind (m/s)
avg[2198]
avg[1210]
avg[2211]
avg[2221]
avg[2222]
avg[2223]

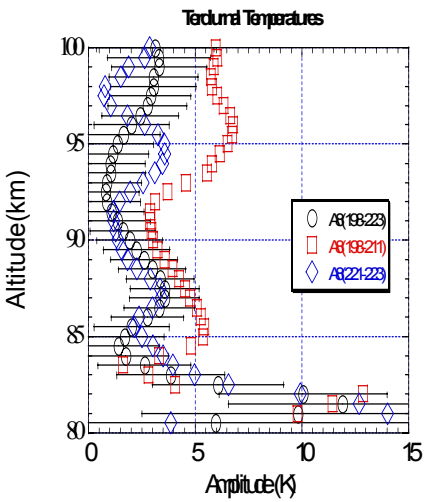
Temperature, T, terdiurnal and quadiurnal tides and variability

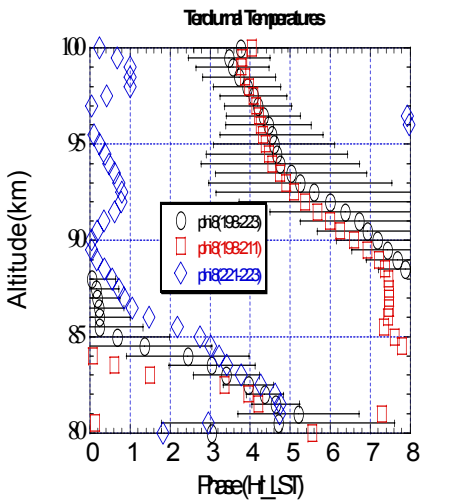


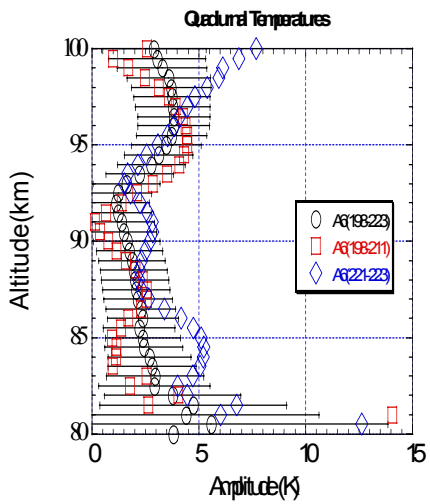


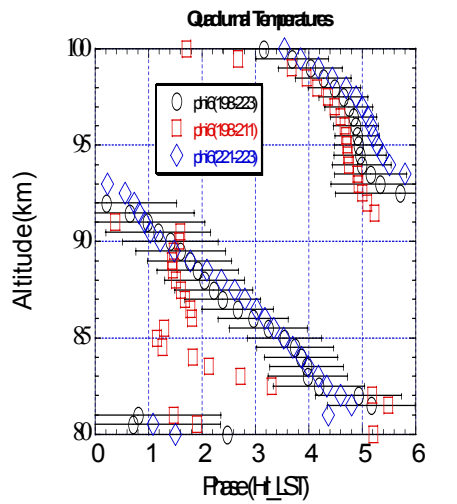












•What are the causes of the observed variability?

Longer time scale (2-day to weeks):Planetary waves

Shorter time scale (5-min to hours): Gravity waves

•To assess variability, we need

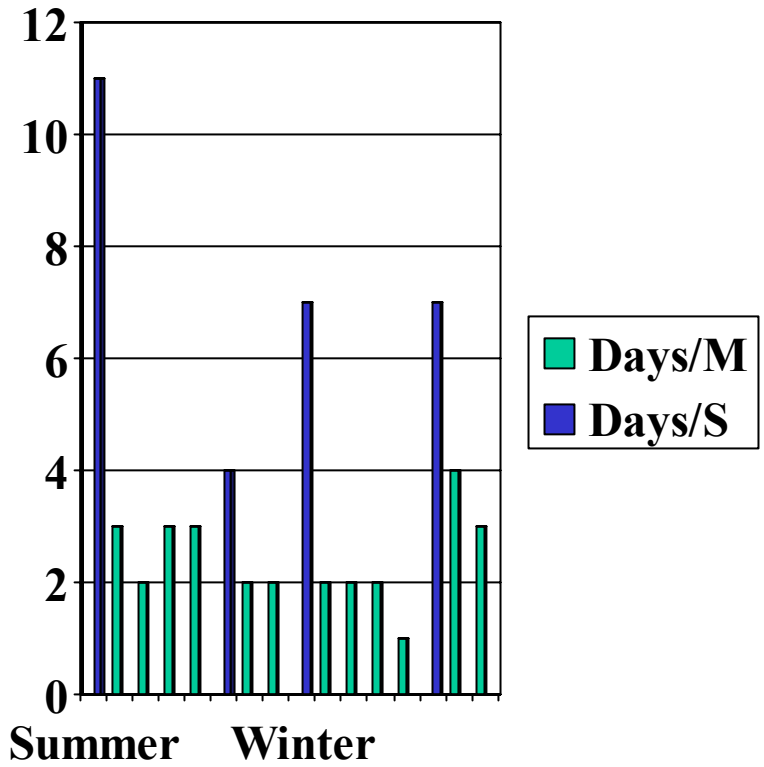
To avoid **aliasing** in analysis, use full DC data

To have sufficient data to converge to climatology

Sufficient data: minimum 3 days (if lucky), 1 week to ten days would be better

One year of observation completed May 2002 to April 2003

- Simultaneous T,U,V observations.
- Acquired a total of 1,388 hours of data with 634 hours under sunlit conditions.
- Only 29 sets (696 hours) of full diurnal-cycle data.



Are non-24hr continuous data useful, say for tidal study?

MLT (80-110km) Science Enabled

Dynamics (80-110km) studies in ↑-order of difficulty, with signal depending on season and time of the day

•Dynamical structure:

Temperature, T, and horizontal winds, u and v

•Gradients and stabilities:

Väisälä-frequency, N, and Richardson number, Ri

•Perturbations and waves : T', u' and v'

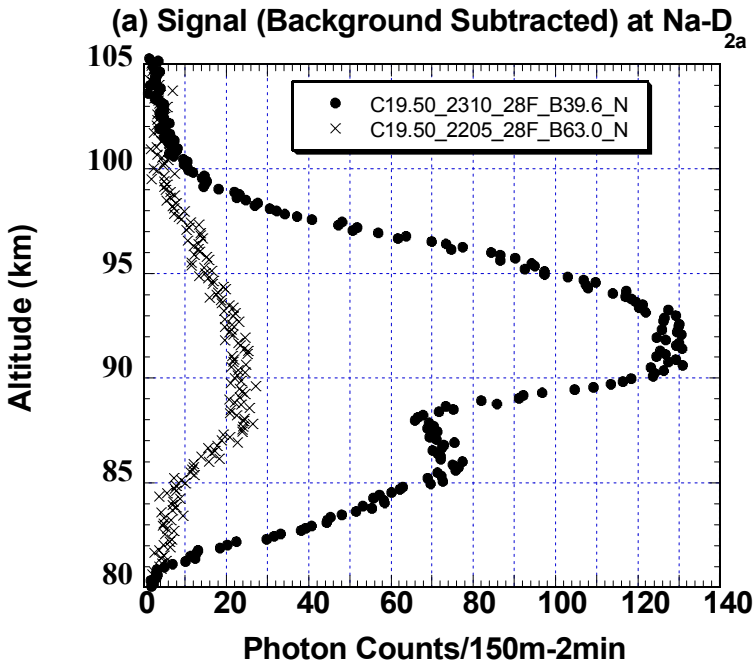
•Vertical gradients of fluxes:

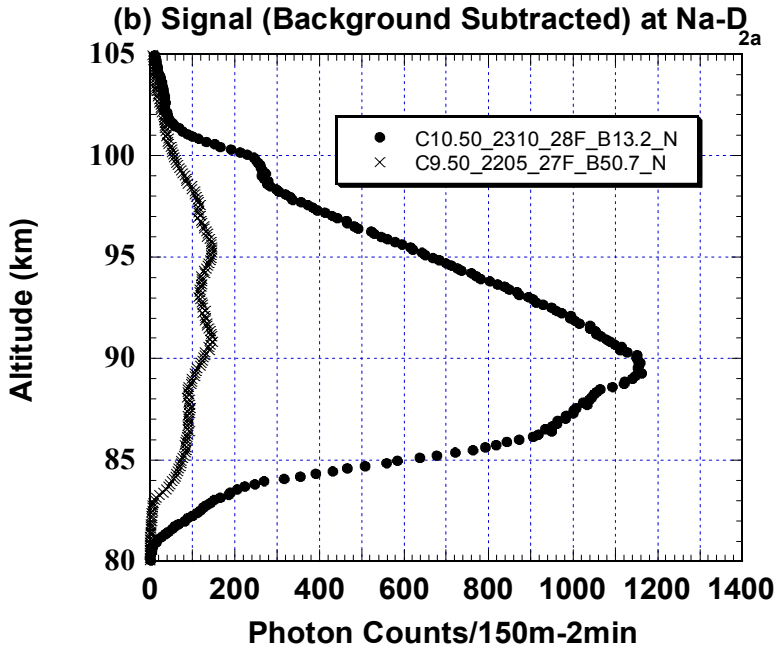
Momentum flux, <u'w'>and heat flux, <w'T'>

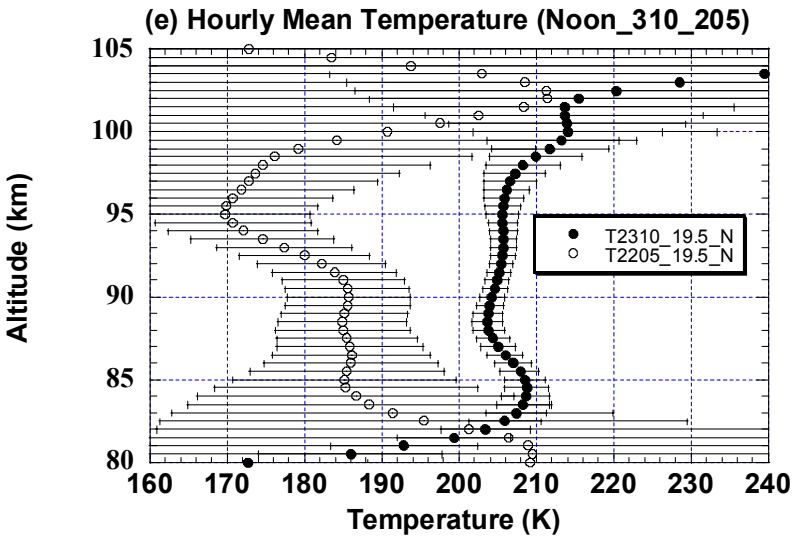
Sodium density and chemistry:

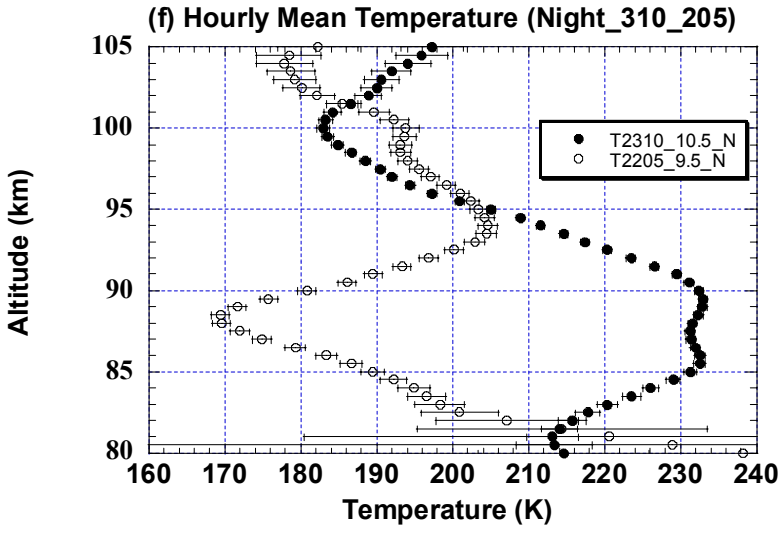
Sporadic sodium and polar summer goodies (PMSE and NLC)

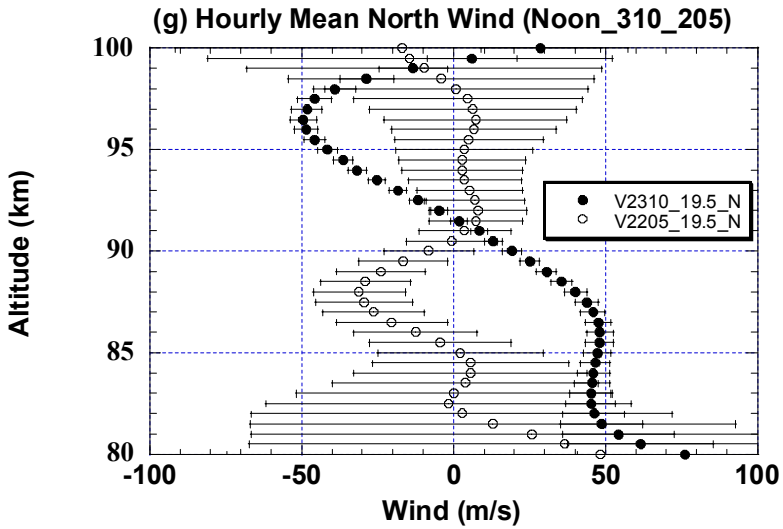
Hourly-mean photon-count profiles under different clear-sky observing conditions

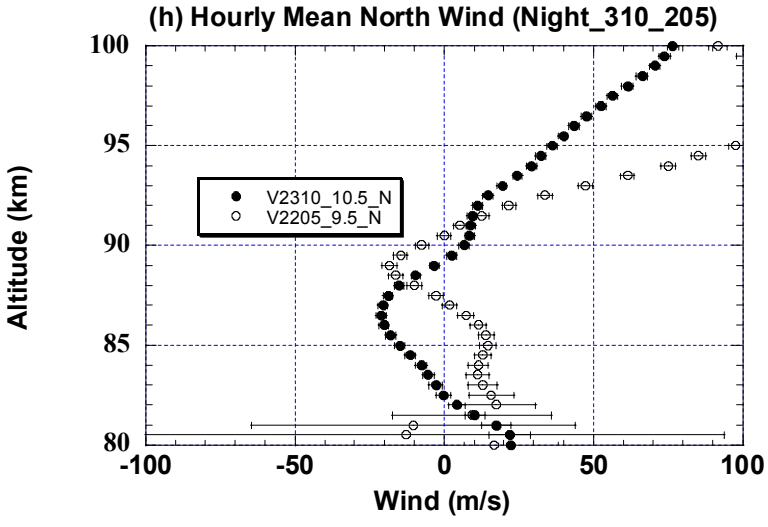





(e) Hourly Mean Temperature (Noon_310_205)
Altitude (km)
Temperature (K)
T2310_19.5_N
T2205_19.5_N
105
100
95
90
85
80
160
170
180
190
200
210
220
230
240


(f) Hourly Mean Temperature (Night_310_205)
Altitude (km)
Temperature (K)
T2310_10.5_N
T2205_9.5_N
105
100
95
90
85
80
160
170
180
190
200
210
220
230
240


(g) Hourly Mean North Wind (Noon_310_205)
Altitude (km)
Wind (m/s)
V2310_19.5_N
V2205_19.5_N
100
95
90
85
80
-100
-50
0
50
100


(h) Hourly Mean North Wind (Night_310_205)
Altitude (km)
Wind (m/s)
V2310_10.5_N
V2205_9.5_N
100
95
90
85
80
-100
-50
0
50
100

Hourly-mean measurement uncertainty under different clear-sky observing conditions with a Na lidar (35-cm telescope, PA=0.06Wm^2)

- Summer noon

Range: 84-97km

Delta: <20K, <30m/s

- Summer night

Range: 84-100km

Delta: <2K, <3m/s

- Winter noon

Range: 82-98km

Delta: <5K,<10m/s

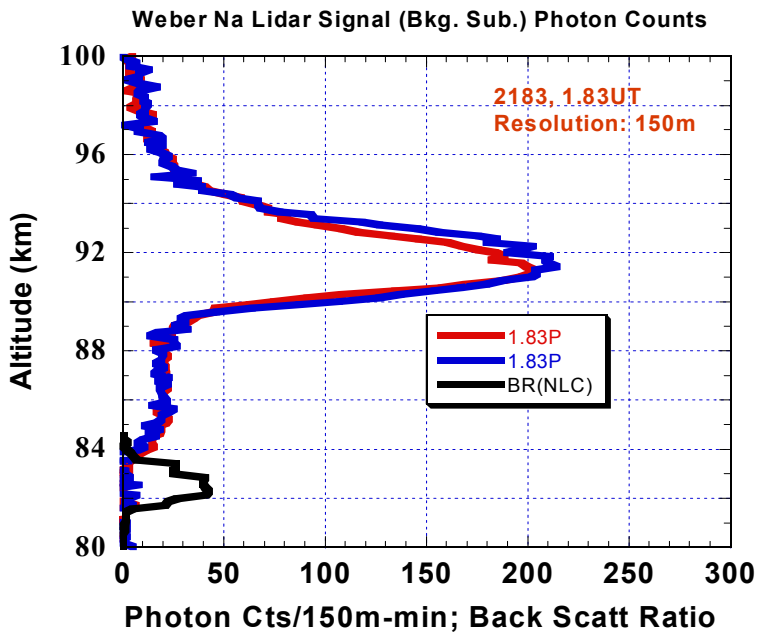
- Winter night

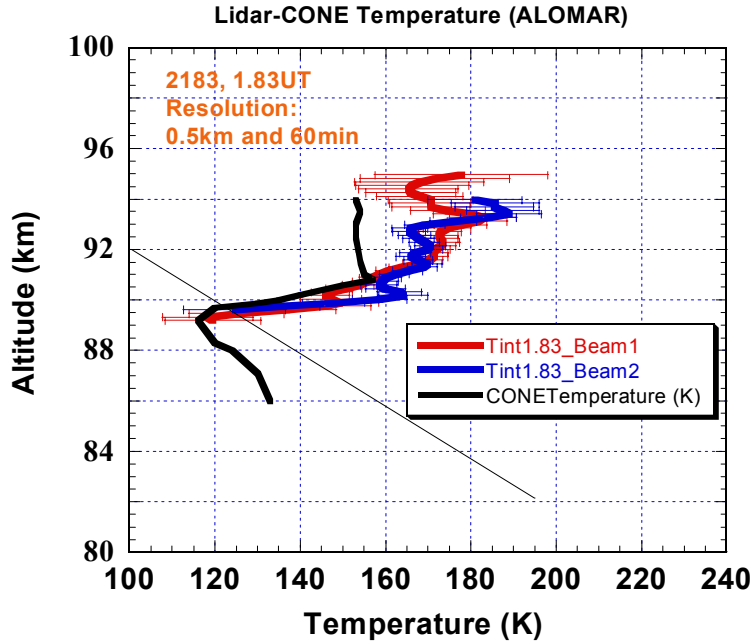
Range: 84-100km

Delta: <1K, <2m/s

Polar Summer Mesopause – A Challenge

ALOMAR Weber Sodium Lidar (July 2, 2002, 1.83 UT)





Red (blue) are Lidar porofiles with West (East) pointing 20deg from Zenith
Black are: CONE temperatures, Rapp & Luebken, priv. comm. 2003
NLC BSR, Baumgarten & von Zahn, priv. comm. 2003

Conclusions

- Thermal structure: Two-level mesopause
- Long-term Natural variability: Impact on trend study
- Full diurnal cycle observation: **True** daily mean, aliasing-free analysis, **Reliable** variability assessment
- Considerable variability; Solar and tidal forcing prevailed; Multi-day profiles converged to climatology
- Climatological means agreement with GCM, and the diurnal (not semidiurnal) perturbations with GSWM00
- Limited by photon noise, polar summer challege
- winter night for **gravity waves, and fluxes** studues

Near Future

To upgrade Fort Collins system:

- A newly designed Faraday filter to increase signal 2X
- Acquire two 30" telescopes to replace the existing Celestron 14” to gain another factor of 4.6.

To continue present operation till end of 2005:

•Enough data for reliable assessment of climatology and variability (assist TIMED, combined with radar data elsewhere) of diurnal-mean as well as tidal components

•Gravity wave study with tide-removed winter observations

•Continue to encourage collaboration and use of lidar data for science study

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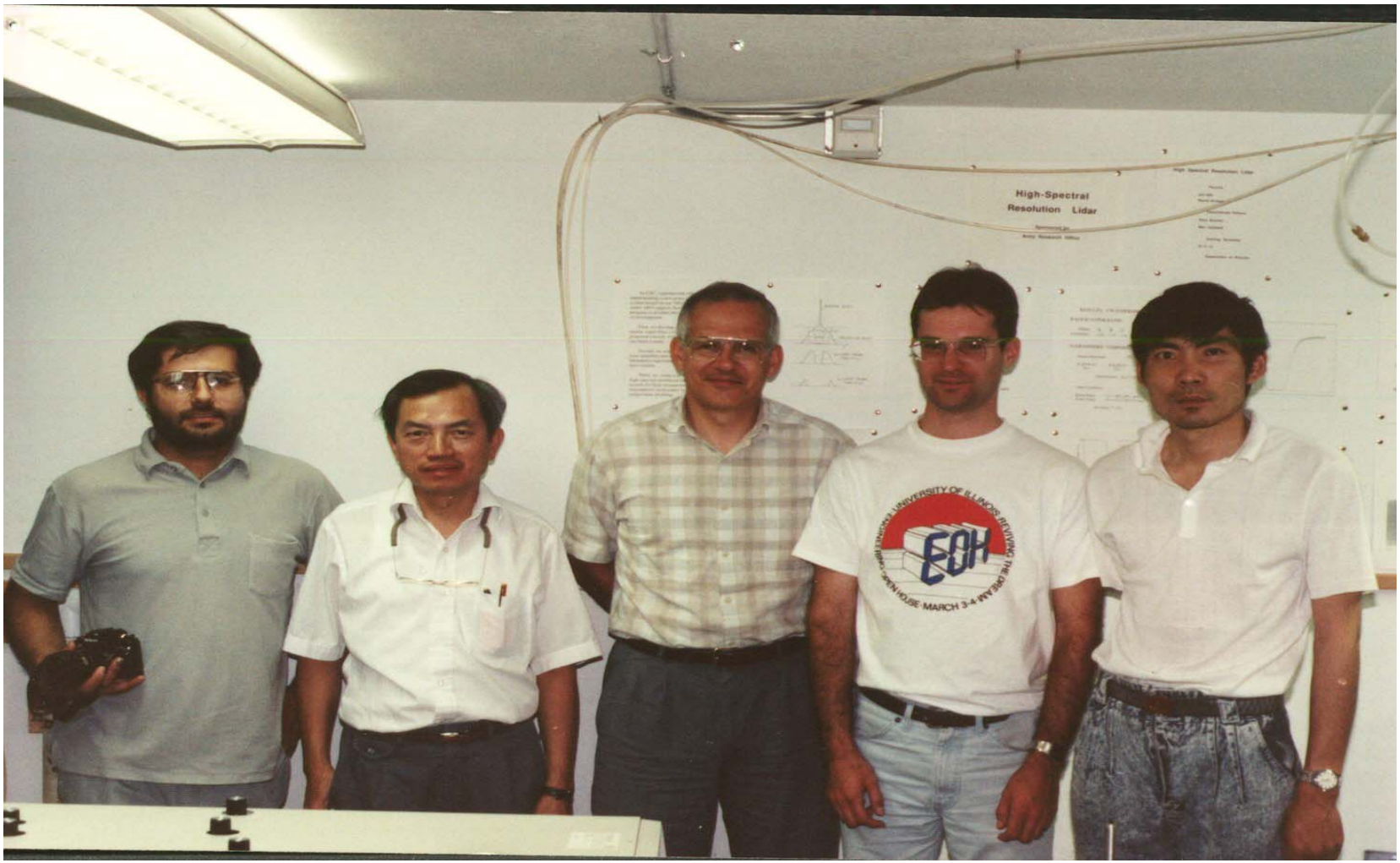
The first Na temperature measurement in Fort Collins, CO
Team Photo, August 25th, 1989



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Construction of a high-tech observatory, 1993? 1994?

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