Mini Lidar School –
Na lidar for measuring temperature and wind

- Historical temperature measurements in England and Andenes, Norway
- Doppler effect: Physics for narrowband lidars
- How does CSU Na lidar measure temperature and wind?
- Science example – Searching for the global mesopause thermal structure
- Climatology – understanding of mean states and tides, and provide challenge to modelers
- Provide background states for imager and rockets
- Future research directions – Cluster instrumentation.
Historical temperature measurements

Demonstration of Doppler temperature measurement via a tunable dye laser
Nonlinear fit to spectrum

Fricke and von Zahn, JATP (1985)

Fig. 1  

\[ a \text{, Ratio of the sodium to Rayleigh scattered signals as a function of laser frequency for 1,200 laser shots on 30 January 1979, together with the theoretical lineshape which provides the best fit to the data.} \]
\[ b \text{, The probability } P(x^2, 4) \text{ as a function of temperature for the curve-fitting in } a. \]

Gibson, Thomas, and Bhattachacharyya, Nature (1979)

Five years of science observation with a number of excellent science publications plus climatoloy studies in Lübken/Zahn (1991)
Doppler Effect for LOS wind with Cabannes scattering and for mesopause temperature and wind with LIF

Cabannes scattering:
\[
\nu = \nu_L \left(1 - \frac{2u}{c}\right) = \nu_L - \frac{2u}{\lambda_L}
\]

Frequency analysis (or converting to intensity)

LIF = Absorption + Re-emssion

Abs: \(\nu_a = \nu_0 = \nu_L - \frac{u}{\lambda_0}\); Re-emission:

\(\nu_e = \nu_0 - \frac{u}{\lambda_0} = \nu_0 - (\nu_L - \nu_0) = 2\nu_0 - \nu_L\)

Frequency analysis doesn't work

Int. depends on T and LOS wind
Laser induced fluorescence: T-W measurement

\[ \begin{align*}
3^2 \text{P}_{3/2} & \quad \text{(16)} \\
3^2 \text{S}_{1/2} & \quad \text{F}=1(3) \\
& \quad \text{F}=2(5)
\end{align*} \]

1 nm = 35 cm\(^{-1}\); 1 cm\(^{-1}\) = 30 GHz

\[ \begin{align*}
R_T &= (I_+ + I_-) / 2I_a \\
R_W &= (I_+ - I_-) / I_a
\end{align*} \]
We use DFS to lock the laser at $v_a$ and AOM to get to $v_+$ and $v_-$.  

$$R_T = \frac{(I_+ + I_-)}{2I_a}$$

$$R_W = \frac{(I_+ - I_-)}{I_a}$$
Observation Under Sunlit Conditions
Sodium Faraday Filter: Rejection of sky background

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

Chen et al., 1993 and 1996
Raw Photon Files
(35cm telescope)
Mesopause temperature structure: Double minima?

Luebken/Zahn (1991)

She et al. (1993)

She et al. (1995)

States and Gardner (1998)
Global mesopause thermal structure

Von Zahn et al. (1996)

She et al. (2000)

Mertens et al. (2000)
September 2003

Diurnal Cycle Observations

Planetary-GW interactions

She et al., GRL, 2004
Mean state \((T, U, V)\) and GCM comparison, Fig.4 of Yuan et al., JGR, 2008

The observed results are in qualitative agreement with our current understanding of the mesopause region thermal and dynamical structure, with two-level mesopause, zonal wind switching directions and “residual” meridional flow. Note: Difference from model less than that between models.
Movie showing the ripple traversed Na Lidar North beam
Ripples observed on Sep 04 (left), and on Sep 06 (right), 2002. Also shown are short-period gravity waves with propagation directions indicated.

Was atmosphere unstable when a ripple was observed? If so, was it convectively or dynamically unstable?
Tidal-period perturbations

Altitude-time plot of temperatures (top) and zonal wind (bottom) contours. The temperature data shows a strong vertical temperature gradient between 85 and 90km on Sep 03/04. The zonal wind shows unusually strong 12hr perturbation between 85 and 95km on Sep 05/06. Li, She, Williams et al., JGR, 2005
Extreme gradients at ALOMAR (69°N) July 02, 2002

Un-usual indeed!  Fritts et al. (2004),  She et al. (2006)

Trigged by famous southern hemisphere stratospheric warming?
Future Research Requires Correlative Observations and Cluster Instrumentations

- CRRL: CTC + 3 Na Lidar sites:
  - ALOMAR, Norway (69N, 12E)
  - CSU (41N, 105W) → USU (42N, 112W)
  - ALO, Cerro Pachon, Chile (30S, 70W)
- All stations have radar and other optical instrument
- Still needs a station near equator.
- All national ISR centers could use a state-of-the-art lidar

Thank You for your attention