Lecture 30. Further Consideration on Lidar Data Inversion

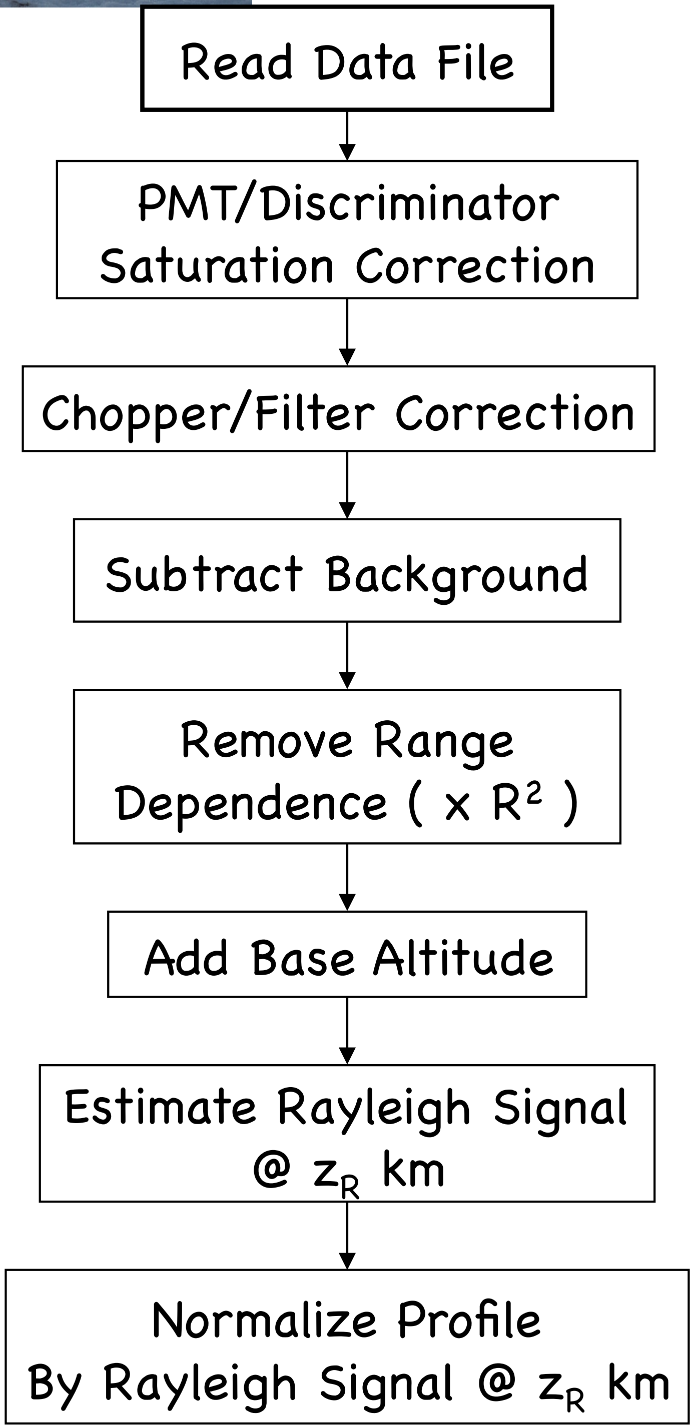
- Aerosol and Cloud Lidar

-- Finish Remaining of Lecture 29

- Resonance Doppler lidar data processing

-- Further consideration on T_c

-- Na density derivation



Preprocess Procedure and Profile-Process Procedure for Na/Fe/K Doppler Lidar

- Read data: for each set, and calculate T, W, and n for each set
- PMT/Discriminator saturation correction
- Chopper/Filter correction

Integration

- Background estimate and subtraction
- Range-dependence removal (xR^2, not z^2)
- Base altitude adjustment
- Take Rayleigh signal @ z_R (Rayleigh fit or Rayleigh mean)
- Rayleigh normalization $$N_N(\lambda,z) = \frac{N_S(\lambda,z) - N_B}{N_S(\lambda,z_R) - N_B} \frac{z^2}{z_R^2}$$

Main Process

- Subtract Rayleigh signals from Na/Fe/K region after counting in the factor of T_C

Main Process Step 1: Starting Point

1. Set transmission (T_c) at the bottom of Na layer to be 1
2. Calculate the normalized photon count for each frequency

$$N_{Norm}(\lambda,z) = \frac{N_S(\lambda,z) - N_B}{N_S(\lambda,z_R) - N_B} \frac{z^2}{z_R{}^2} \frac{1}{T_c^2(\lambda,z)} - \frac{n_R(z)}{n_R(z_R)}$$

3. Take ratios R_T and R_W from normalized photon counts

$$R_T = \frac{N_{Norm}(f_+, z) + N_{Norm}(f_-, z)}{N_{Norm}(f_a, z)} \qquad R_W = \frac{N_{Norm}(f_+, z) - N_{Norm}(f_-, z)}{N_{Norm}(f_a, z)}$$

4. Estimate the temperature and wind using the calibration curves computed from physics

Main Process Step 2: Bin-by-Bin Procedure

5. Calculate the effective cross section using temperature and wind derived

6. Using the effective cross-section and T_C = 1 (at the bottom), calculate the Na density.

$$n_c(z) = \left[\frac{N_S(\lambda,z) - N_B}{N_R(\lambda,z_R) - N_B} \cdot \frac{z^2}{z_R^2} \frac{1}{T_c^2(\lambda,z)} - \frac{n_R(z)}{n_R(z_R)} \right] \cdot \frac{4\pi\sigma_R(\pi,\lambda) n_R(z_R)}{\sigma_{eff}(\lambda) R_B(\lambda)}$$

7. From effective cross-section and Na density, calculate the transmission T_C for the next bin.

$$T_c(\lambda,z) = \exp\left(-\int_{z_{bottom}}^{z} \sigma_{eff}(\lambda,z) n_c(z) \mathrm{d}z\right) = \exp\left(-\sum_{z_{bottom}}^{z} \sigma_{eff}(\lambda,z) n_c(z) \Delta z\right)$$

Main Process

Load Atmosphere n_R, T, P Profiles from MSIS00

Start from Na layer bottom
E ($z=z_b$) = 1
Calculate Nnorm ($z=z_b$) from photon counts and MSIS number density for each freq

$$N_{Norm}(\lambda,z) = \frac{N_S(\lambda,z)-N_B}{N_S(\lambda,z_R)-N_B}\frac{z^2}{z_R{}^2}\frac{1}{T_c^2(\lambda,z)} - \frac{n_R(z)}{n_R(z_R)}$$

Calculate R_T and R_W from N_{Norm}

Are ratios reasonable?

- Yes → Find T and W from the Table (using the Look-up Table Calibration) → Calculate Na density $n_c(z)$
- No → Set to nominal values or MSIS: T = 200 K, W = 0 m/s → Calculate Na density $n_c(z)$

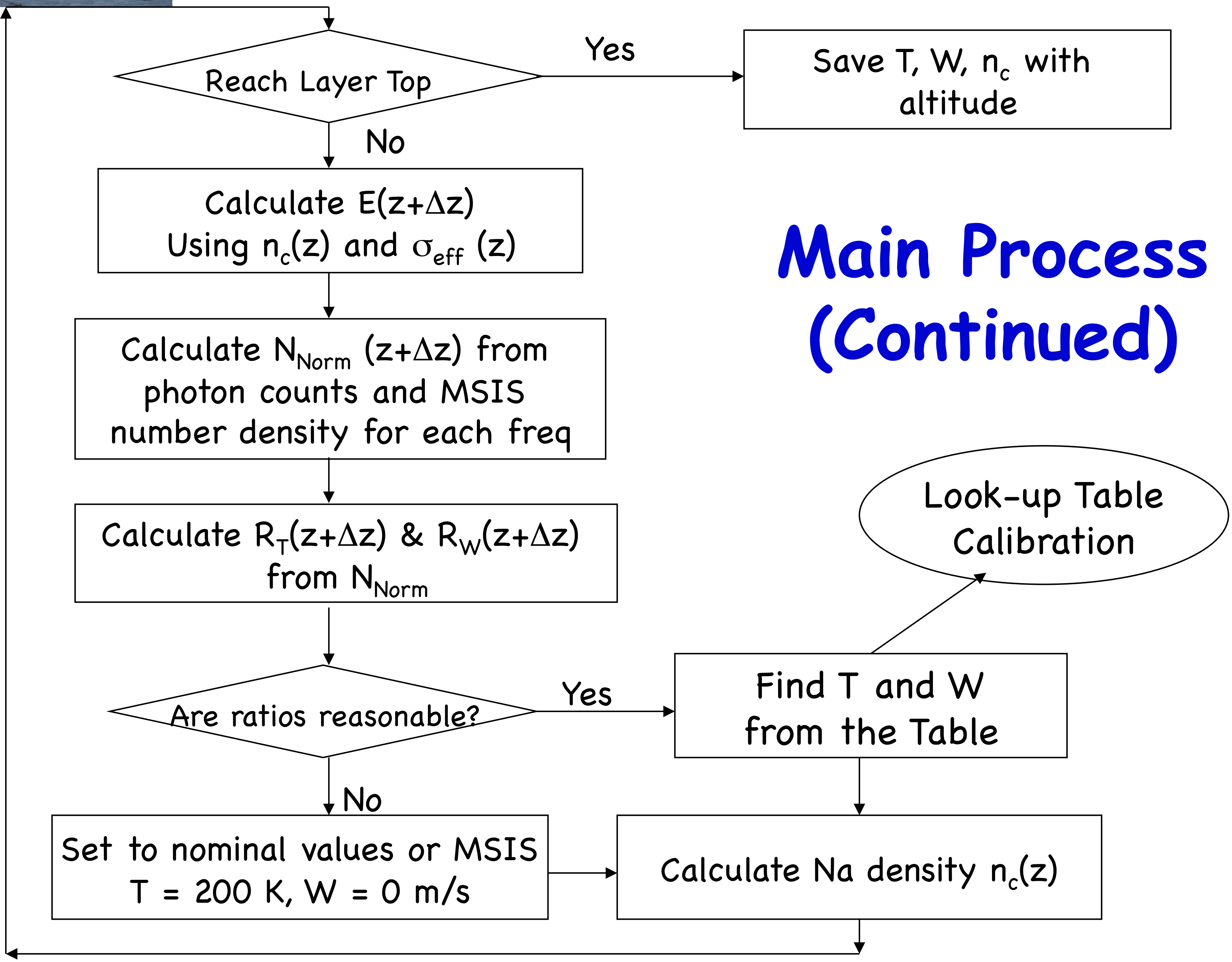
Create look-up table or calibration curves From physics

$$R_T = \frac{\sigma_{eff}(f_+,z)+\sigma_{eff}(f_-,z)}{\sigma_{eff}(f_a,z)}$$

$$R_W = \frac{\sigma_{eff}(f_+,z)-\sigma_{eff}(f_-,z)}{\sigma_{eff}(f_a,z)}$$

Look-up Table Calibration

Main Process (Continued)



Derivation of T_c (Transmission Caused by Constituent Extinction)

- T_c (caused by constituent absorption) can be derived from

$$T_c(\lambda,z) = \exp\left(-\int_{z_{bottom}}^{z} \sigma_{eff}(\lambda,z) n_c(z)\,\mathrm{d}z\right) = \exp\left(-\sum_{z_{bottom}}^{z} \sigma_{eff}(\lambda,z) n_c(z)\Delta z\right)$$

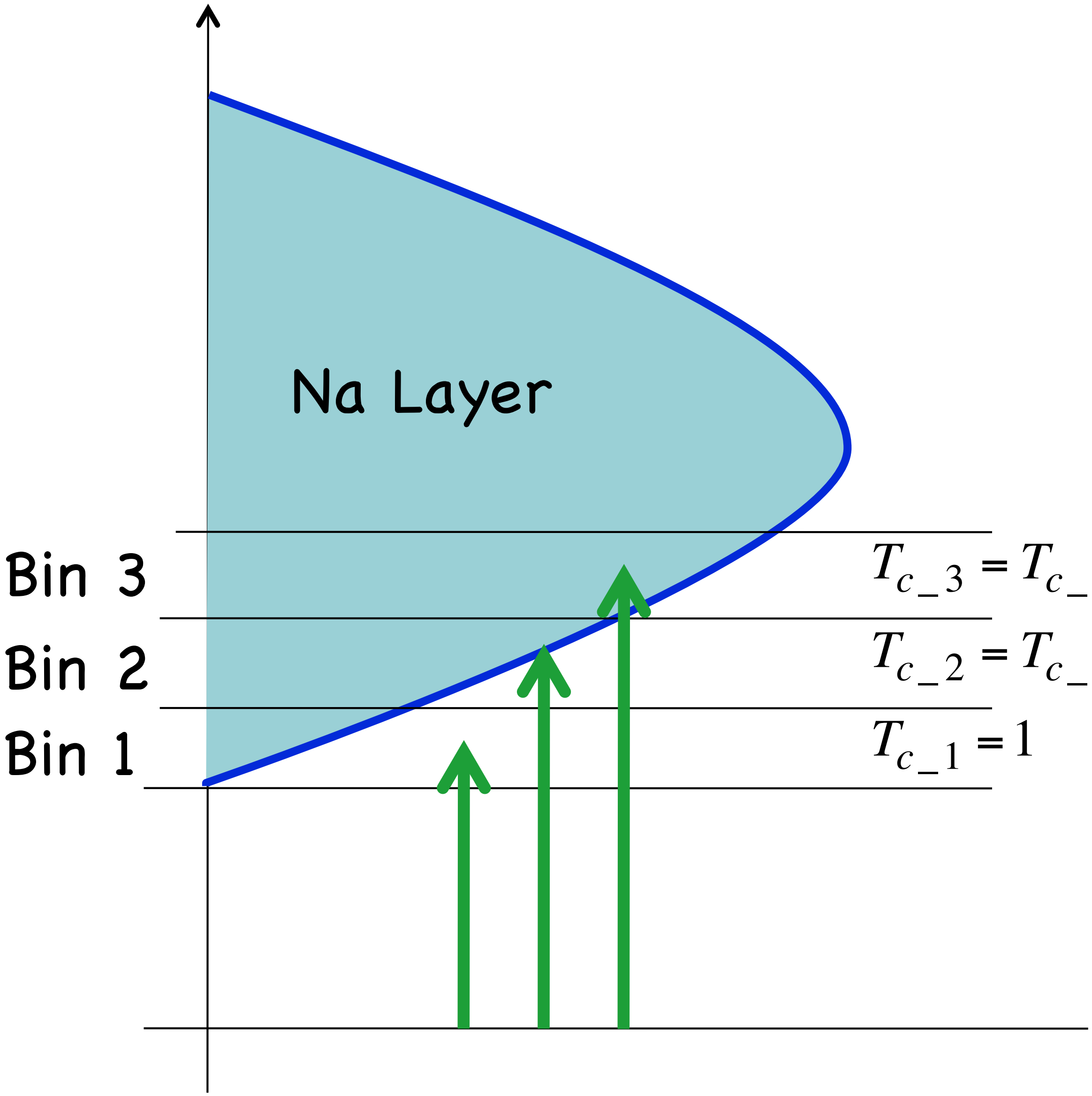
+

$$n_c(z) = \left[\frac{N_S(\lambda,z)-N_B}{N_R(\lambda,z_R)-N_B}\cdot\frac{z^2}{z_R^{\,2}}\frac{1}{T_c^{\,2}(\lambda,z)} - \frac{n_R(z)}{n_R(z_R)}\right]\cdot\frac{4\pi\sigma_R(\pi,\lambda)n_R(z_R)}{\sigma_{eff}(\lambda,z)R_B(\lambda)}$$

$$\sigma_e = \sqrt{\sigma_D^2 + \sigma_L^2}$$

$$T_c(\lambda,z) = \exp\left(-\sum_{z_{bottom}}^{z}\left[\frac{N_S(\lambda,z)-N_B}{N_R(\lambda,z_R)-N_B}\cdot\frac{z^2}{z_R^{\,2}}\frac{1}{T_c^{\,2}(\lambda,z)} - \frac{n_R(z)}{n_R(z_R)}\right]\cdot\frac{4\pi\sigma_R(\pi,\lambda)n_R(z_R)}{R_B(\lambda)}\Delta z\right)$$

A Step in the Main Process: Estimating Transmission (T_c)

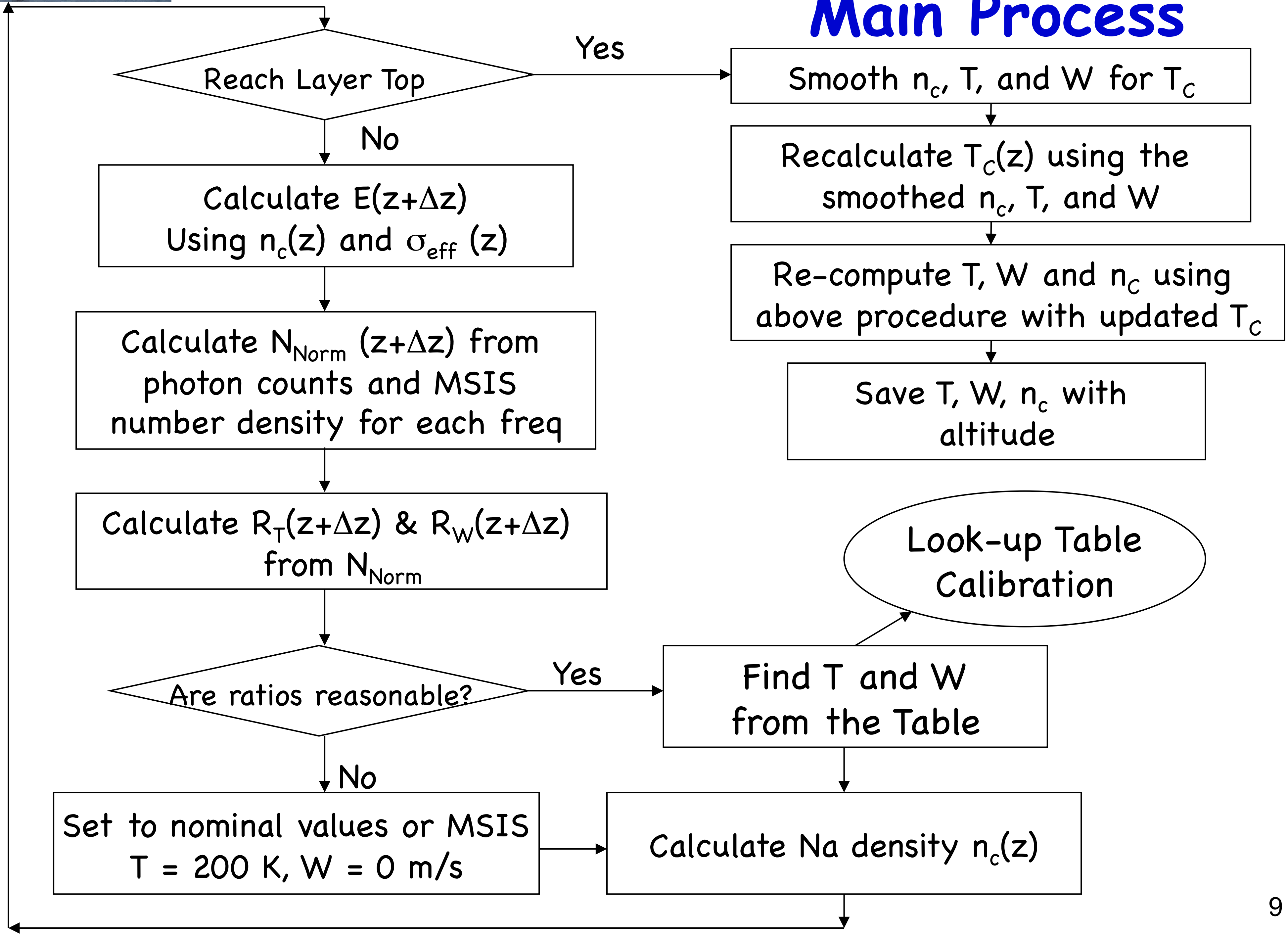


$$T_{c\_3} = T_{c\_2} \times \exp(-\sigma_{eff\_2} \cdot n_{c\_2} \cdot \Delta z)$$

$$T_{c\_2} = T_{c\_1} \times \exp(-\sigma_{eff\_1} \cdot n_{c\_1} \cdot \Delta z)$$

$$T_{c\_1} = 1$$

Main Process



Na Density Derivation

- The Na density can be inferred from the peak freq signal

$$n_{Na}(z) = \frac{N_{norm}(f_a,z)}{\sigma_a} 4\pi n_R(z_R)\sigma_R = \frac{N_{norm}(f_a,z)}{\sigma_a} 4\pi \times 2.938 \times 10^{-32} \frac{P(z_R)}{T(z_R)} \cdot \frac{1}{\lambda^{4.0117}}$$

- The Na density can also be inferred from a weighted average of all three frequency signals.
- The weighted effective cross-section is

$$\sigma_{eff\_wgt} = \sigma_a + \alpha\sigma_+ + \beta\sigma_-$$

where α and β are chosen so that

$$\frac{\partial\sigma_{eff\_wgt}}{\partial T} = 0; \qquad \frac{\partial\sigma_{eff\_wgt}}{\partial v_R} = 0$$

- The Na density is then calculated by

$$n_{Na}(z) = 4\pi n_R(z_R)\sigma_R \frac{N_{norm}(f_a,z) + \alpha N_{norm}(f_+,z) + \beta N_{norm}(f_-,z)}{\sigma_a + \alpha\sigma_+ + \beta\sigma_-}$$

Na Density Derivation

- The Na density can be inferred from the peak freq signal

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- The Na density can also be inferred from a weighted average of all three frequency signals as explained above.

- The Na density can also be inferred from each individual frequency, and in principle, all three frequencies should give identical results of Na density.

$$n_{Na}(z) = \frac{N_{norm}(f_\pm, z)}{\sigma_\pm} 4\pi n_R(z_R)\sigma_R = \frac{N_{norm}(f_\pm, z)}{\sigma_\pm} 4\pi \times 2.938 \times 10^{-32} \frac{P(z_R)}{T(z_R)} \cdot \frac{1}{\lambda^{4.0117}}$$