Variability of Aerosol Properties and Mixing-layer Heights from Airborne High Spectral Resolution Lidar, Ground-based Measurements, and the WRF-Chem Model During CARES and CalNex

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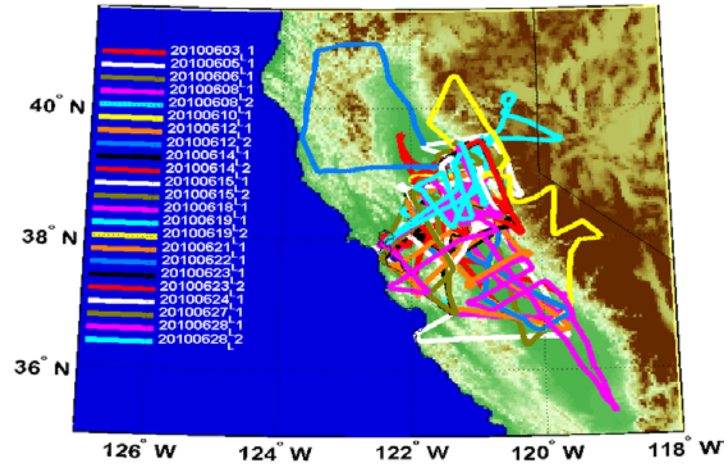
DOE ASR Science Team Meeting

March 2012

NASA LaRC B200 King Air
CalNex & CARES Deployment Summary

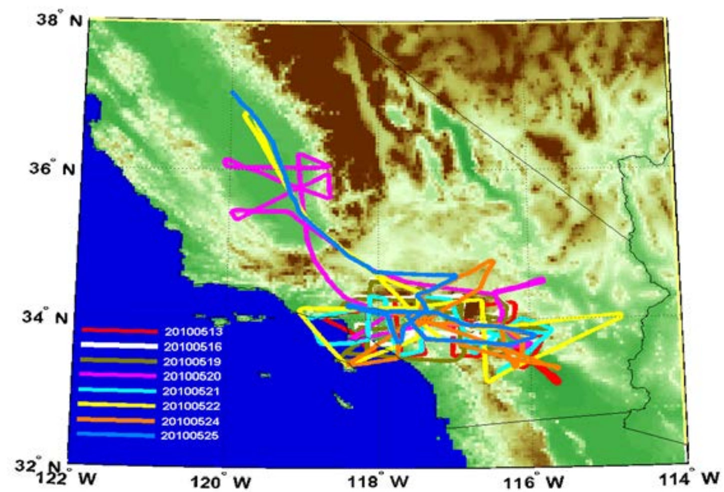
CARES Deployment June 2010

- Sacramento, California
- June 3 -28
- 23 science flights (72.3 hours)
  - 19 with DOE G1
  - 1 with NOAA R/V Atlantis
  - 2 with NOAA P3
  - 6 with NOAA Twin Otter
  - 11 with MODIS and/or MISR satellite overpasses



CalNex Deployment May 2010

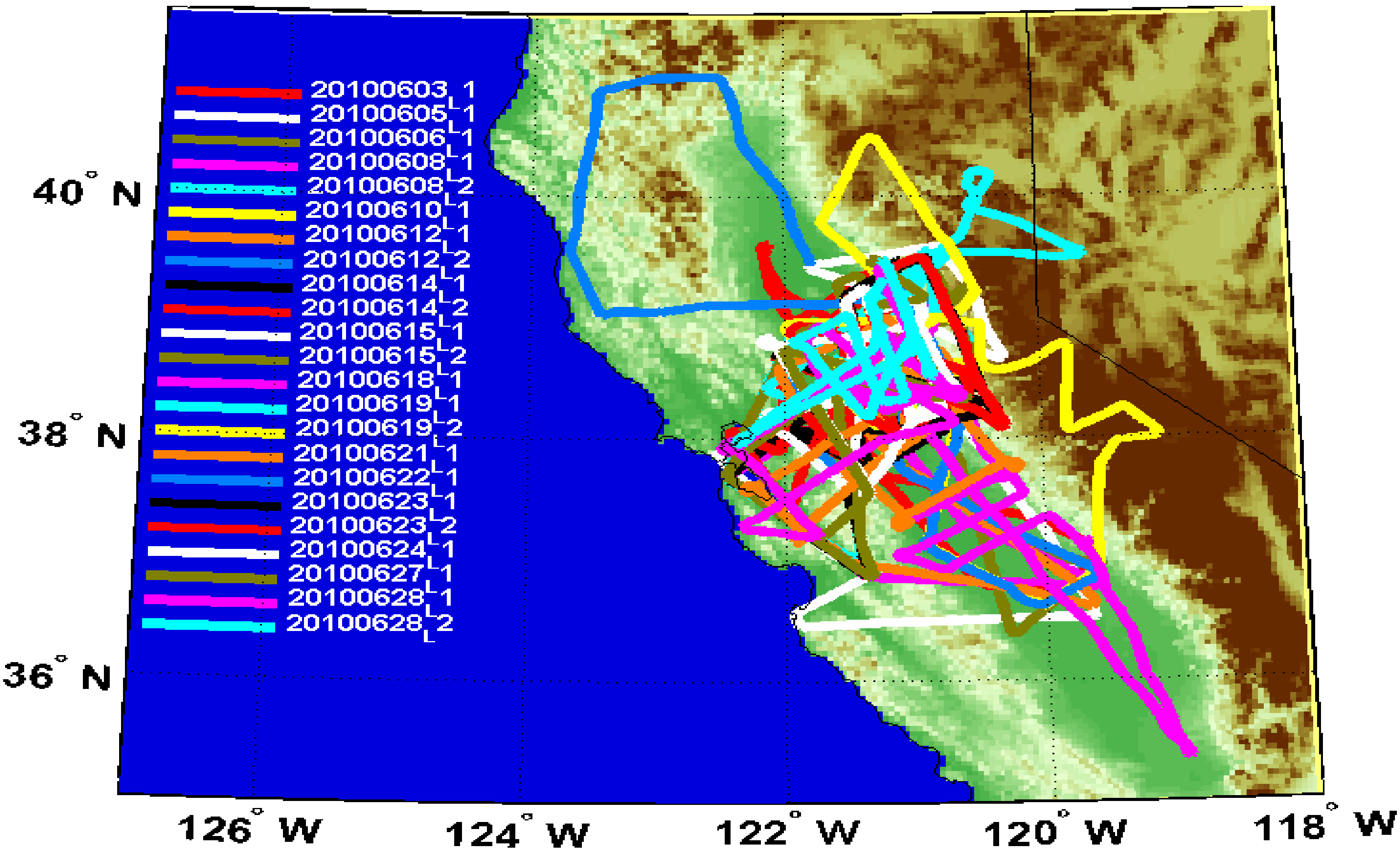
- Ontario, California
- May 13-25
- 8 science flights (28.5 hours)
  - 6 with CIRPAS Twin Otter
  - 2 with NOAA P-3
  - 6 with MODIS and/or MISR satellite overpasses



Instruments deployed for CalNex and CARES

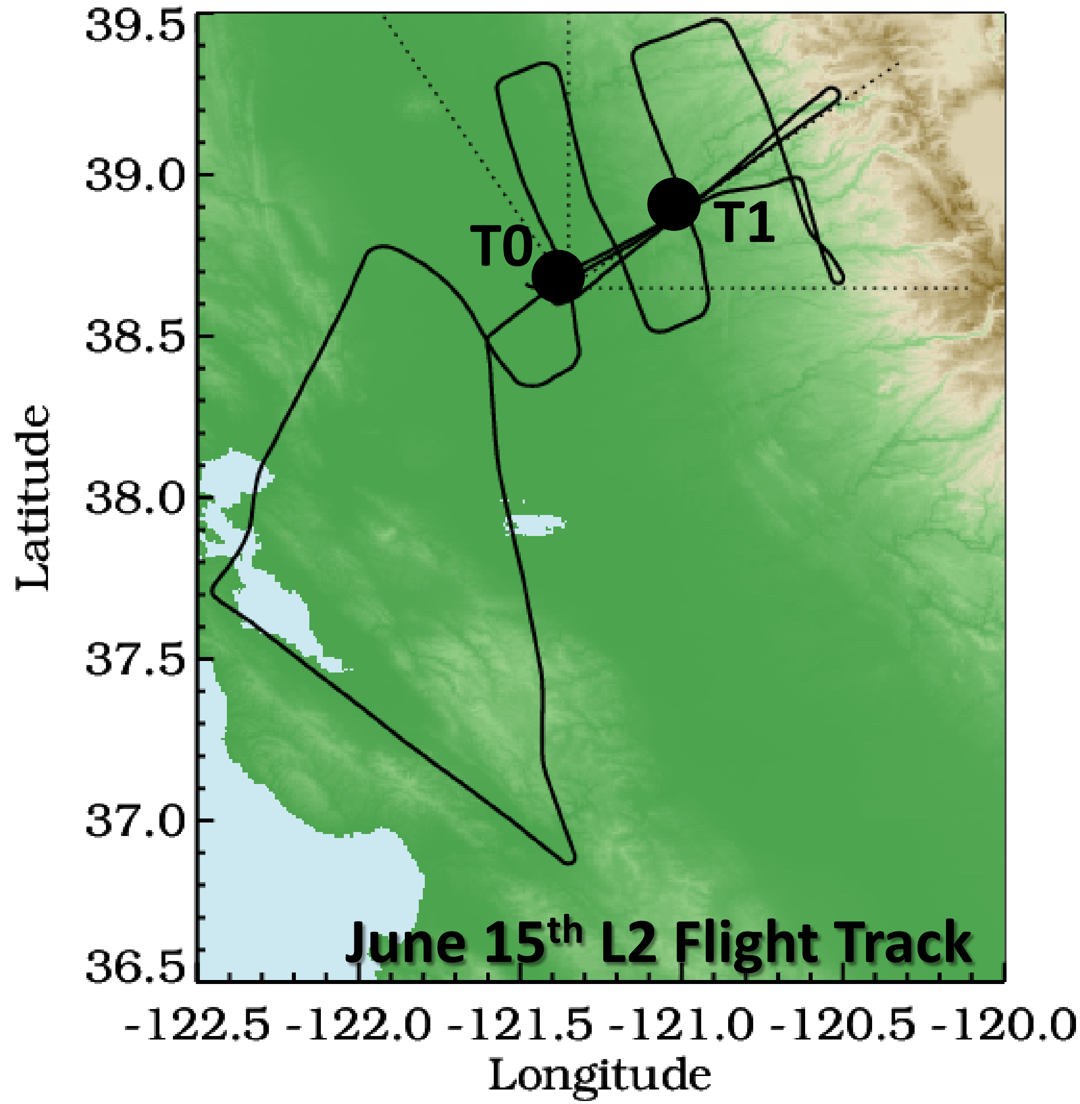
- High Spectral Resolution Lidar (HSRL) (NASA/LaRC)
- Research Scanning Polarimeter (RSP) (NASA/GISS)

CARES Deployment June 2010

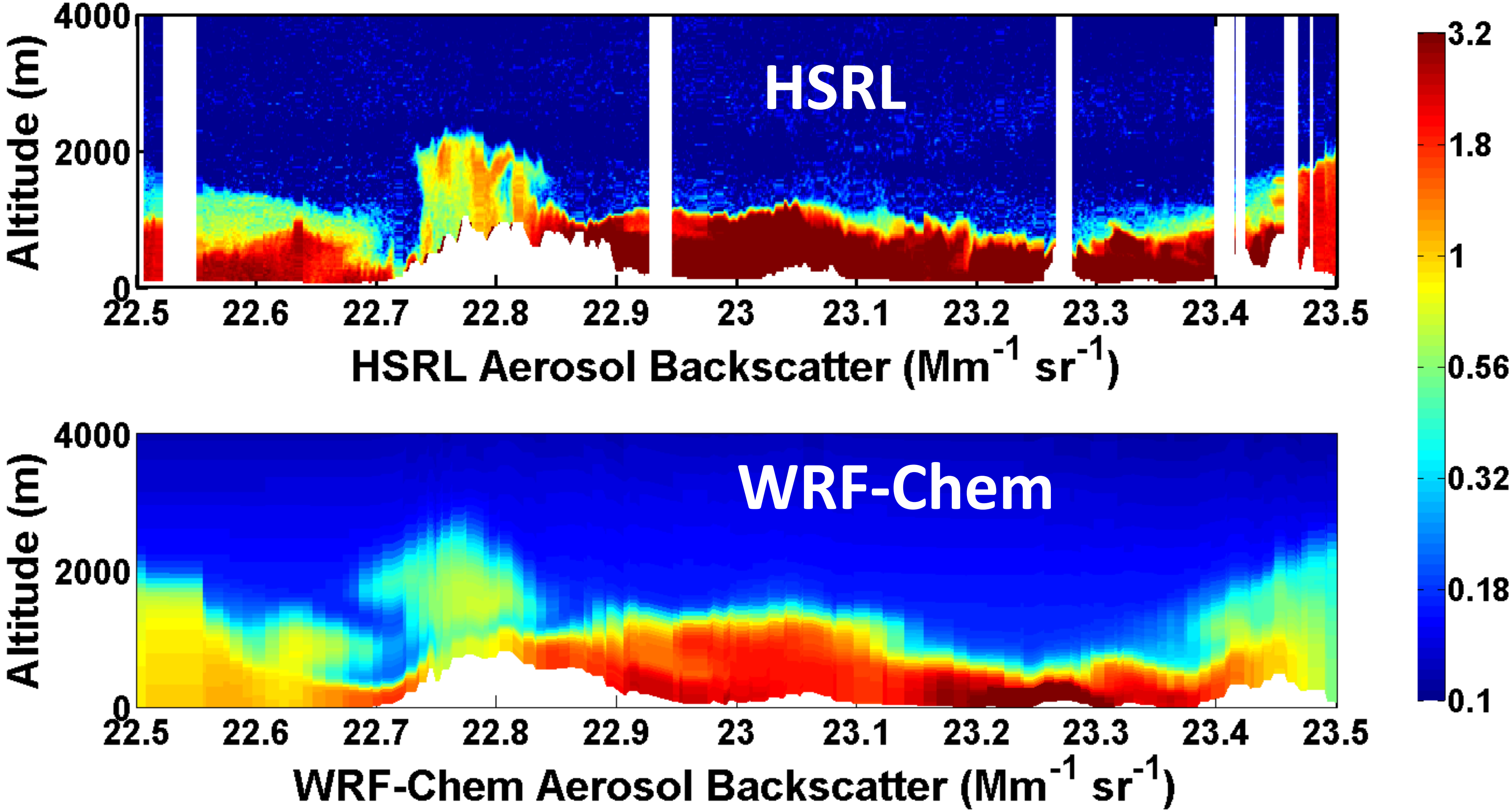


Aerosol Backscatter and Extinction Comparisons

HSRL Flight of June 15 (afternoon flight)

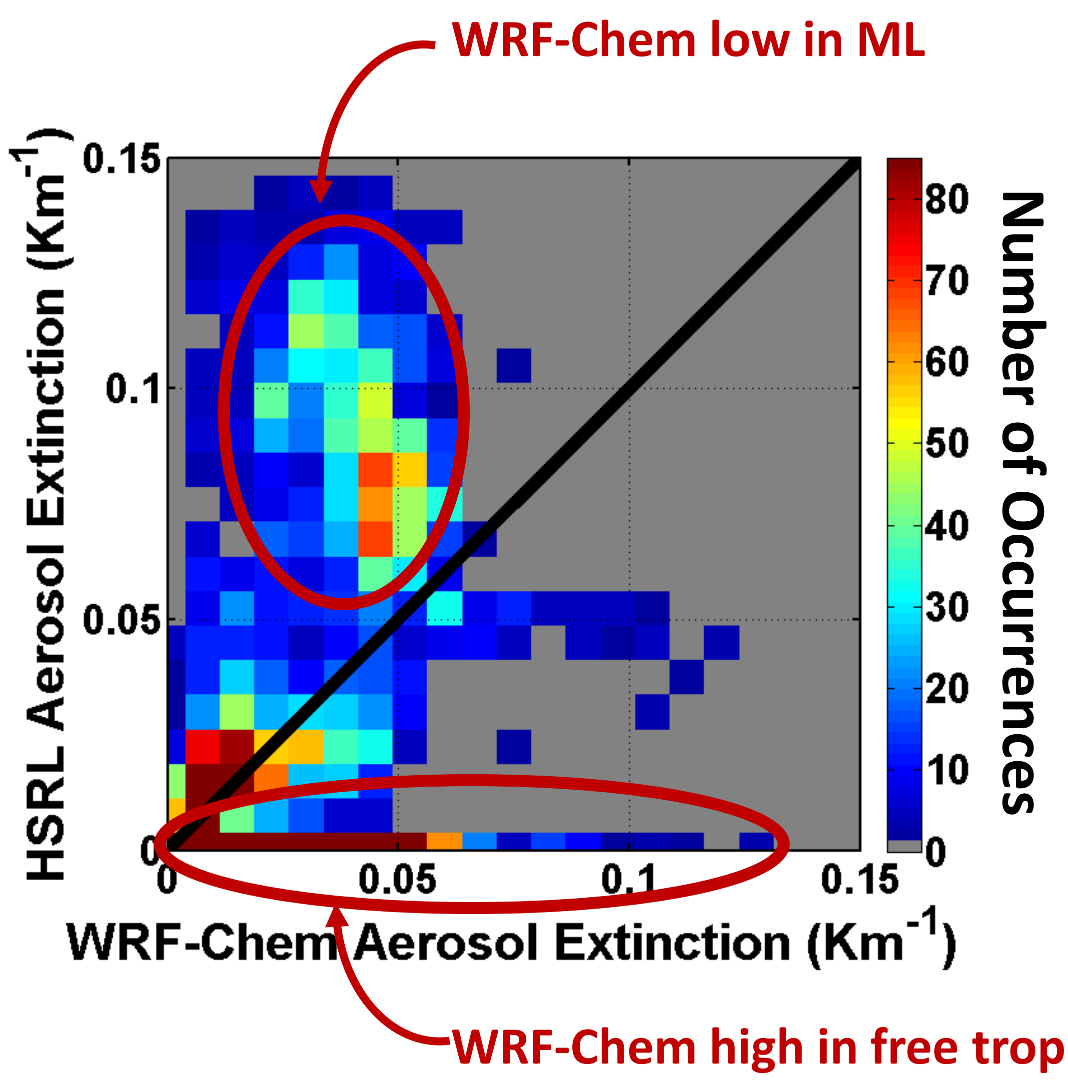


Comparison of Aerosol Properties from WRF-Chem and HSRL during CARES: 6/15/2010 flight 2



**WRF-Chem results are preliminary*

Comparison of Aerosol Extinction from WRF-Chem and HSRL during CARES: 6/15/2010 flight 2



WRF-Chem

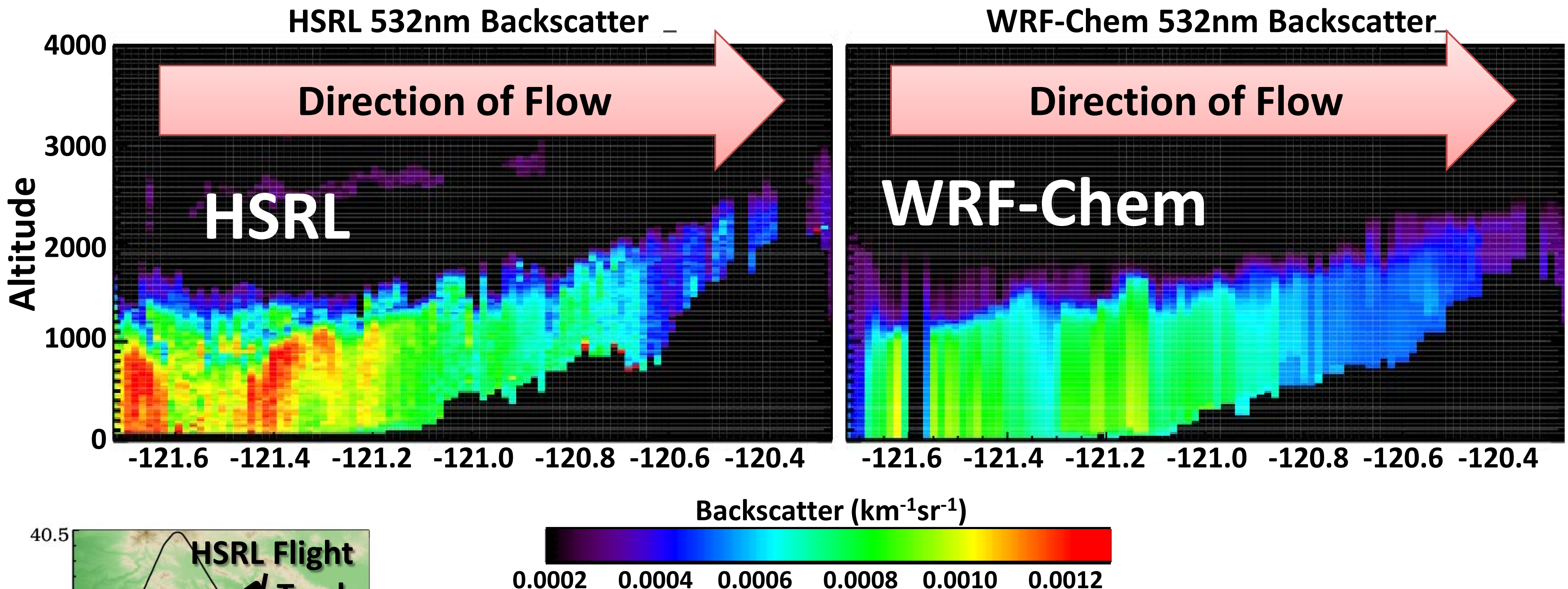
- Too high in the free troposphere
- Too low in BL

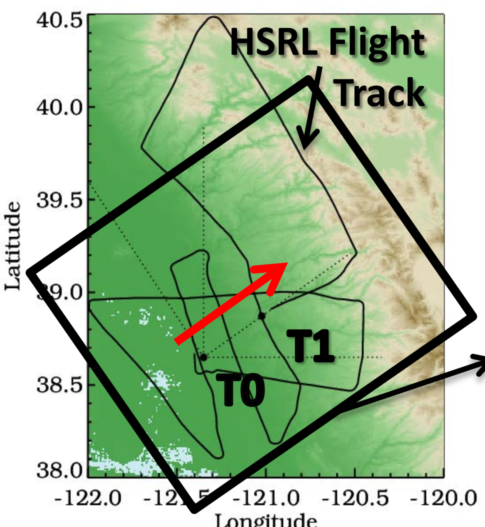
Potential reasons

- Size distribution may not be representative
- Dust not included in model
- Emissions may be inaccurate
- Boundary conditions from MOZART bias loading high in free troposphere

Note: WRF-Chem results are preliminary; additional runs are planned.

Variability of aerosol along direction of flow (6/19/2010 flight 2)





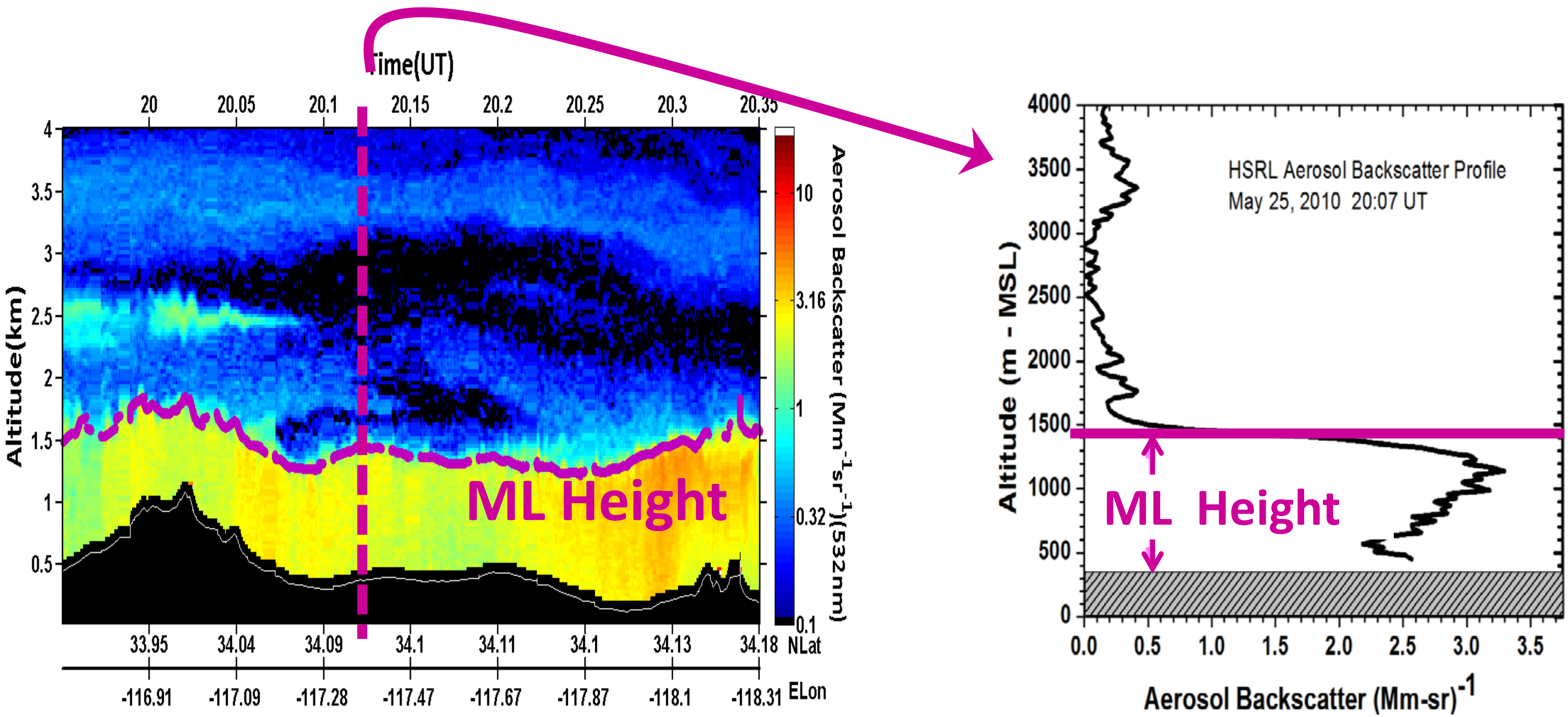
portion of flight track shown in average

- 532nm Backscatter from HSRL and the WRF-Chem were averaged perpendicular to direction of flow for region inside box at left
- WRF-Chem somewhat underestimates HSRL for this case, but show similar trend along flow direction

Mixed Layer Heights

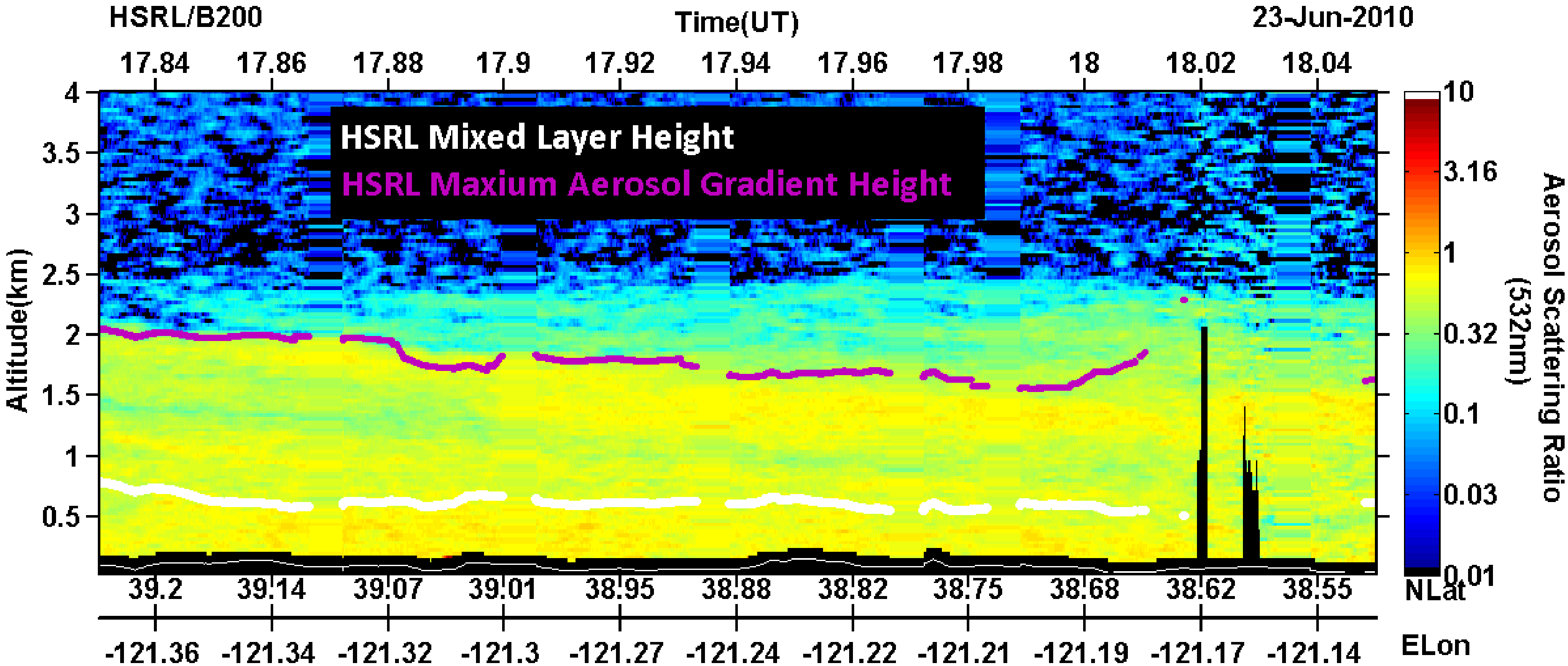
Mixing Layer Height Determined from Aerosol Backscatter Profile

- HSRL ML heights derived from cloud-screened aerosol backscatter profiles measured by the airborne HSRL
- Automated technique uses a Haar wavelet covariance transform to identify sharp gradients in aerosol backscatter at the top of the ML (Brooks, *JAOT*, 2003)

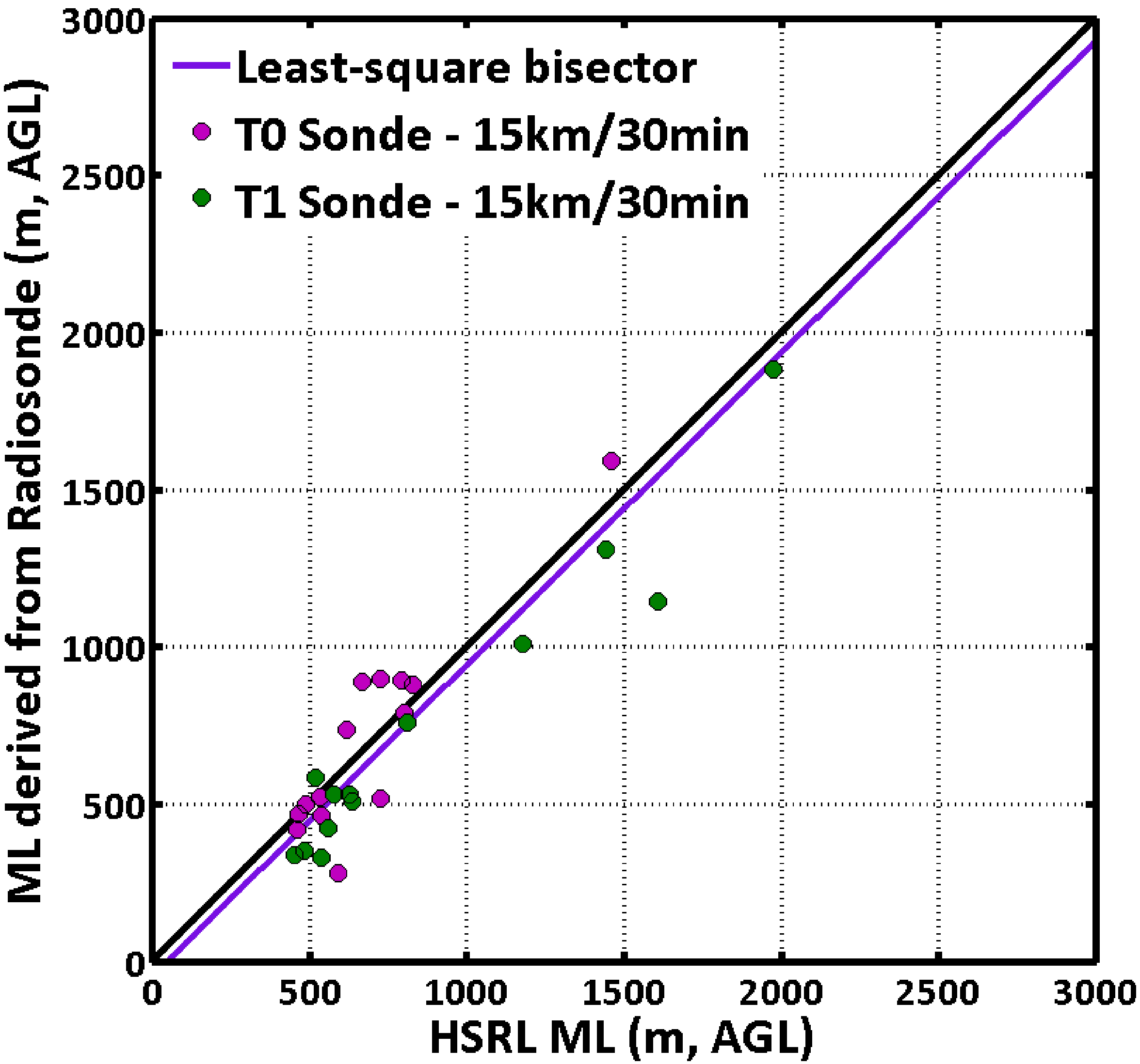


HSRL Mixing Layer Height vs. Maximum Aerosol Gradient

- Mixing layer height related to boundary layer height
- Height of maximum aerosol gradient related to aerosol scale height



Comparison of ML heights from PNNL radiosondes and HSRL during CARES

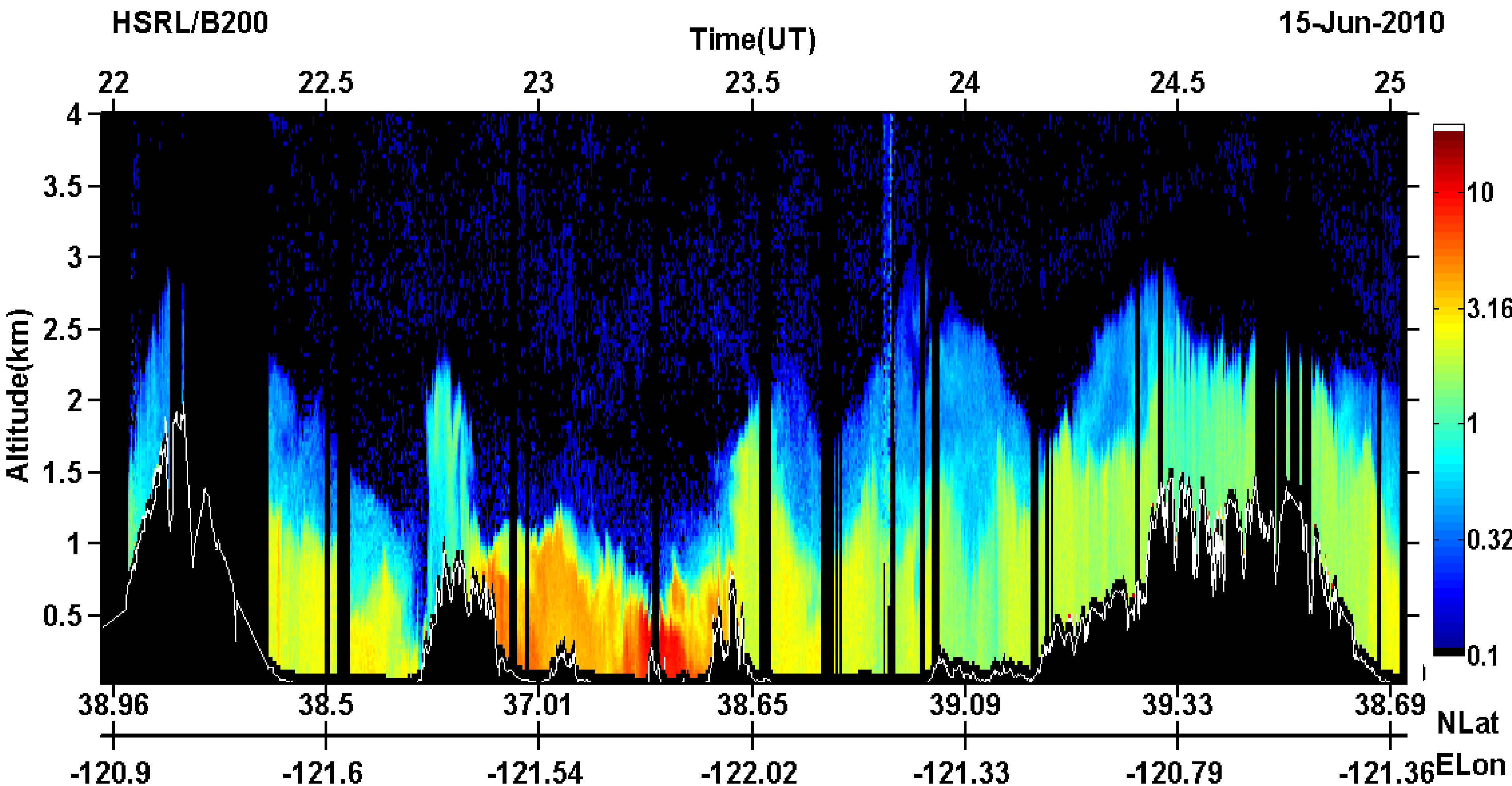


15 km/30 min. Constraints (27 pts)

Least-sq Slope = 0.9219
Least-sq Intercept = 4.4608
R^2 = 0.8626
Bisector Slope = 0.9925
Bisector Intercept = -50.6581
RMS Error = 157.1020 (20.8713%)
Bias Diff = 56.5439 (7.5120%)

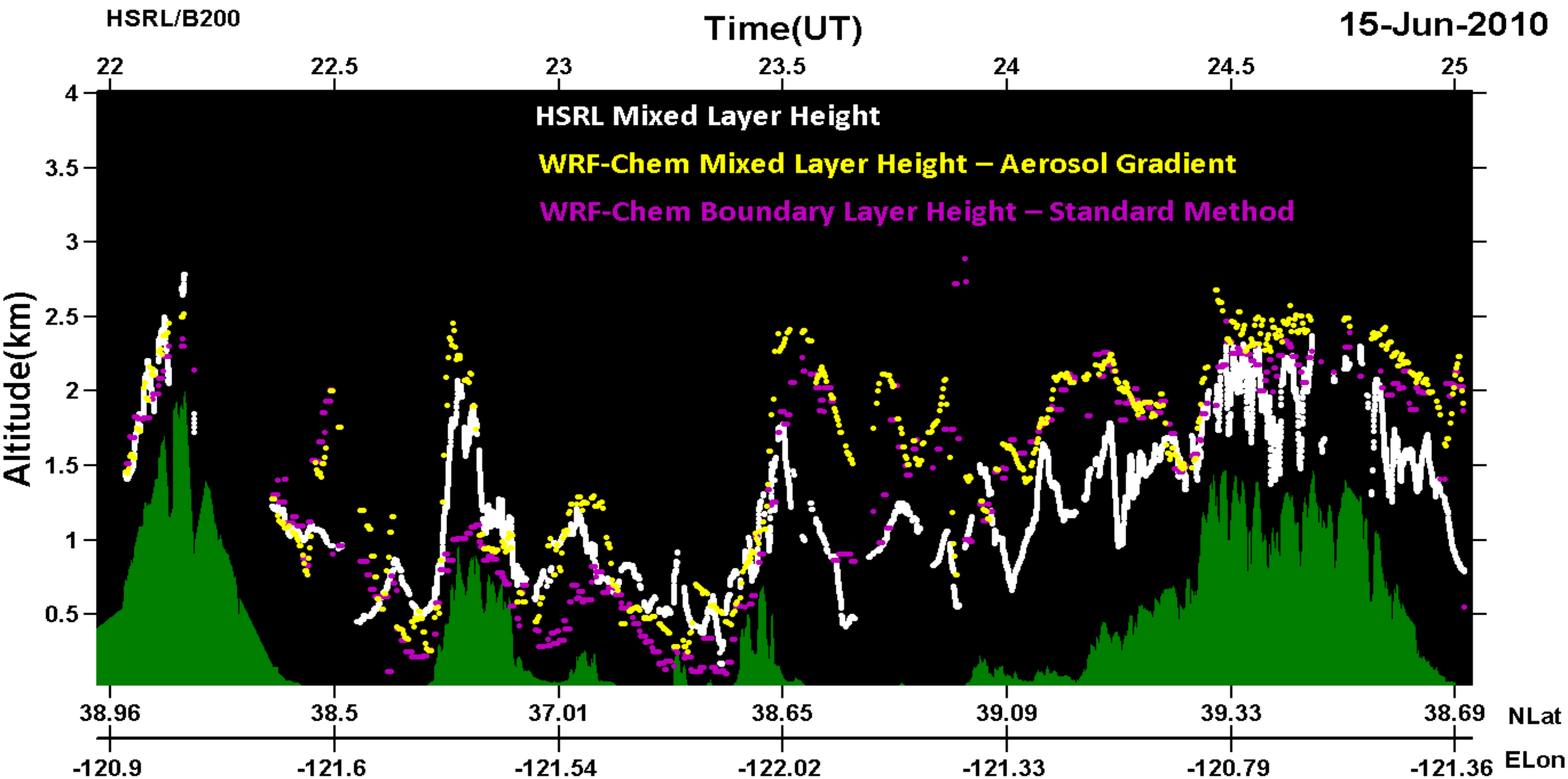
HSRL ML heights and radiosonde-derived ML heights show good agreement when HSRL was within 15 km and 30 minutes of the launch site

HSRL-derived aerosol backscatter for the 15 June 2010 afternoon flight



Aerosol Backscatter ($Mm^{-1}sr^{-1}$)(532nm)

Comparison of ML heights from the WRF-Chem model and HSRL during CARES



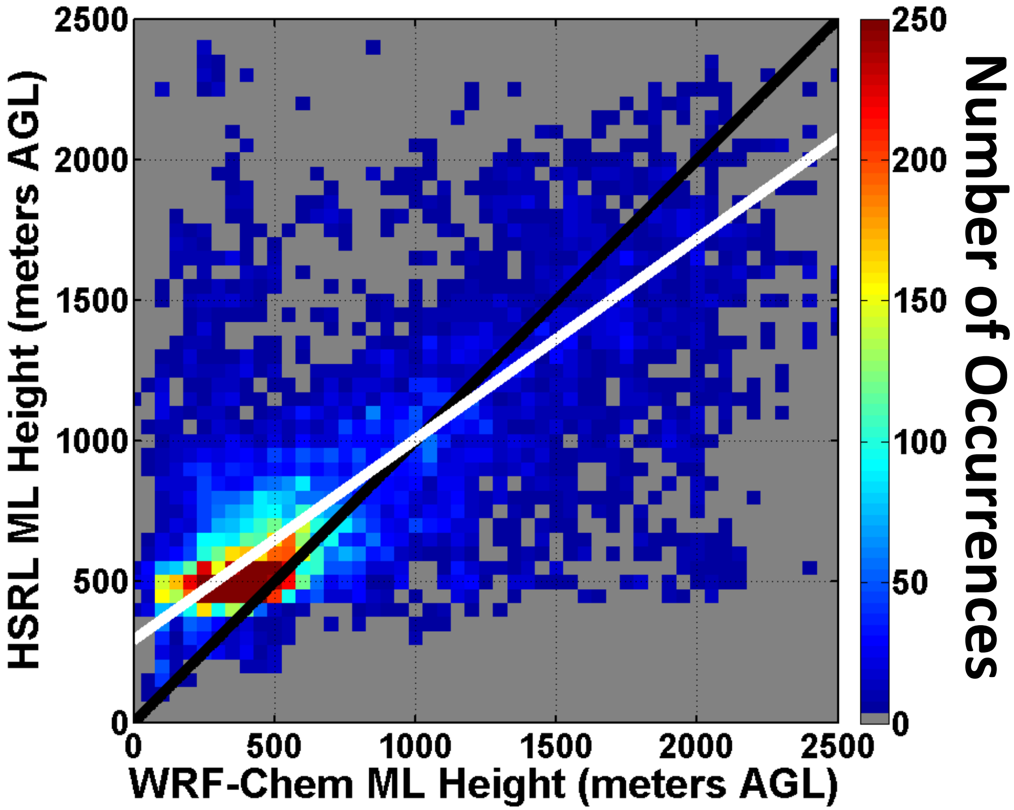
*Green filled area denotes terrain

*WRF-Chem BLH – Standard Method is Preliminary

Comparison of mixed layer heights from the WRF-Chem model and HSRL during and CARES

ML height comparison across all CARES flights:

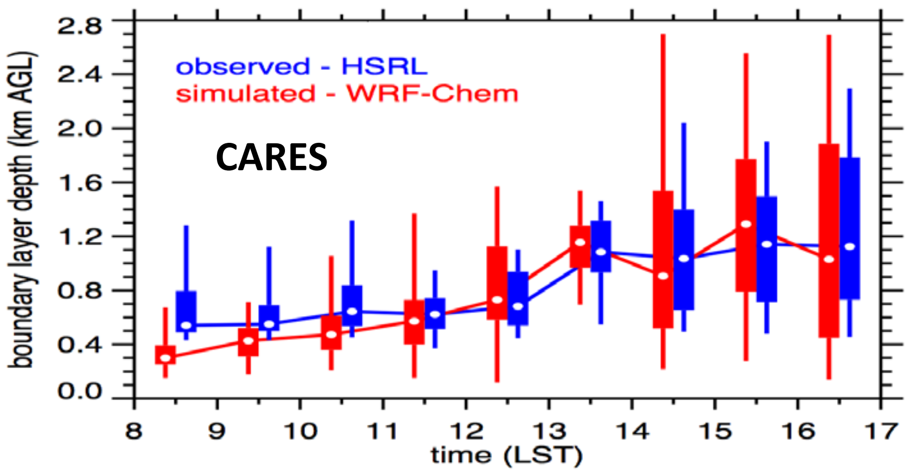
Bisector Slope = 0.71
Bisector Intercept = 292
R^2 = 0.37

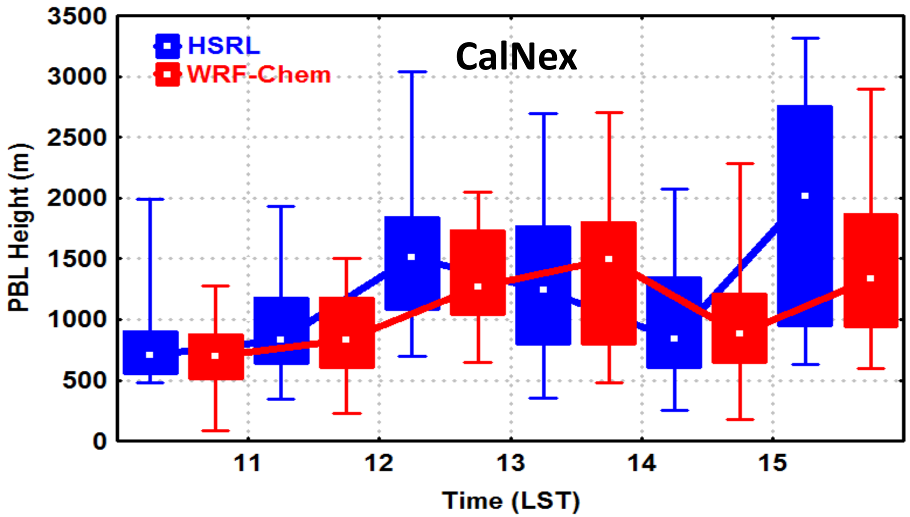


- Comparisons of WRF-Chem and HSRL ML height shows rough agreement between the model output and the airborne measurements across most flights
- Influence of differences in ML height calculation methods being explored

WRF-Chem data are preliminary

Good agreement between HSRL and WRF-Chem on the temporal evolution of ML

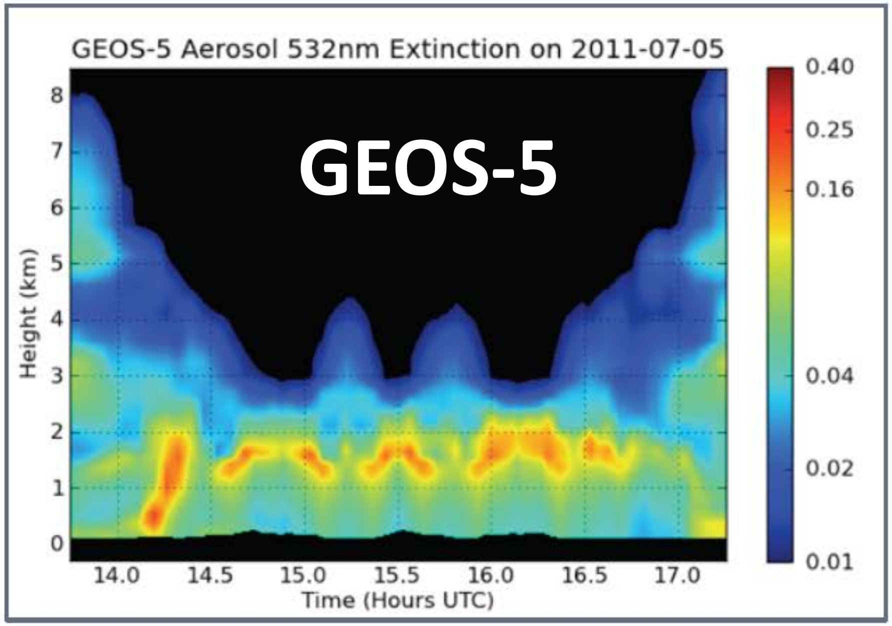


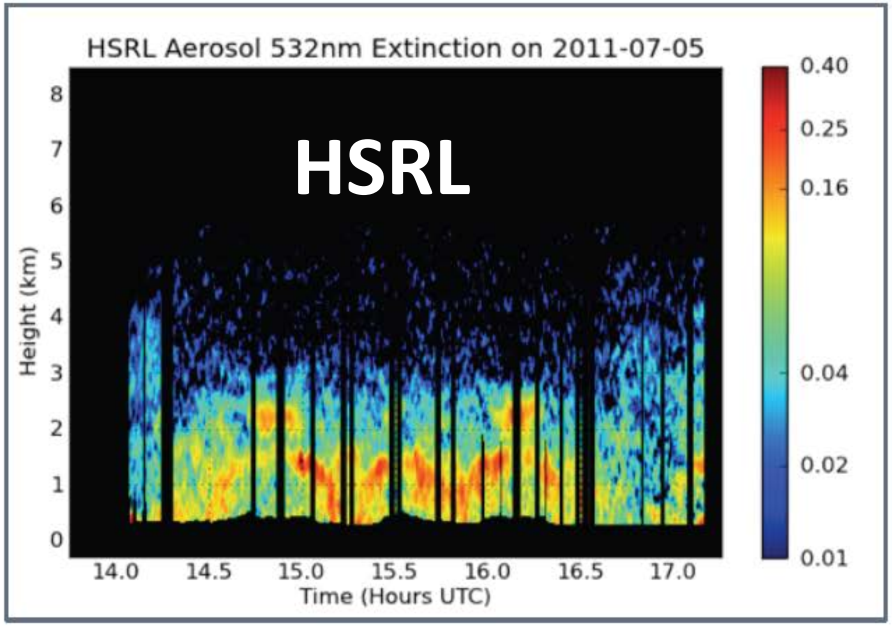


- Plots show ***observed*** and ***simulated*** mixing layer depth along the B-200 flight (top figure, from Fast, et al., *ACP*, 2012)

- Filled boxes denote the 25^{th} and 75^{th} percentiles and vertical lines denote the 5^{th} and 95^{th} percentiles. Lines connecting the white dots denote the median value for each hour

Comparison of HSRL data with GEOS-5 model during DISCOVER-AQ





PBL height data from HSRL has were crucial for diagnosing issues with the land surface in the NRT GEOS-5 system.

- Correcting the soil moisture
- Prescribing observed precipitation

Plot from Alindo da Silva, et al., “Evaluation of GEOS-5 PBL and Aerosols During DISCOVER-AQ,” DISCOVER-AQ Workshop, February 14-16, 2012.

Summary

- **NASA HSRL data products being used for:**
  - **Model evaluations**
  - **Vertical context of in situ measurements**
  - **Aerosol typing**
  - **Partitioning of AOD above/below mixed layer**
- **Comparisons with WRF-Chem ML heights, backscatter, and extinction currently underway**
- **HSRL mixed layer heights are available for several ASP/ASR missions:**
  - **MaxMex, MaxTex, CHAPS, RACORO, CalNex, and CARES**
- **HSRL will deploy on the summer portion of TCAP campaign**
  - **Anticipate doing similar evaluation of WRF-Chem**

Backup Slides

Mixing Layer Height Methodology

Radiosonde Potential Temperature

- ML heights derived from radiosondes launched at the T0 and T1 sites during CARES
- Automated technique uses a modified Heffter method to determine the inversion in the potential temperature profile (Heffter, AMS Conf Proc., 1980; Hayden, AE, 1997)
- Heffter chose two constraints to determine the mixing layer from a potential temperature profile
  - 1. Lapse rate:

$$\frac{\Delta\theta}{\Delta z} \geq 0.005\ {}^{o}K/m$$

  - 2. Inversion temperature difference:

$$\theta_{top} - \theta_{base} \geq 2^{o}K$$

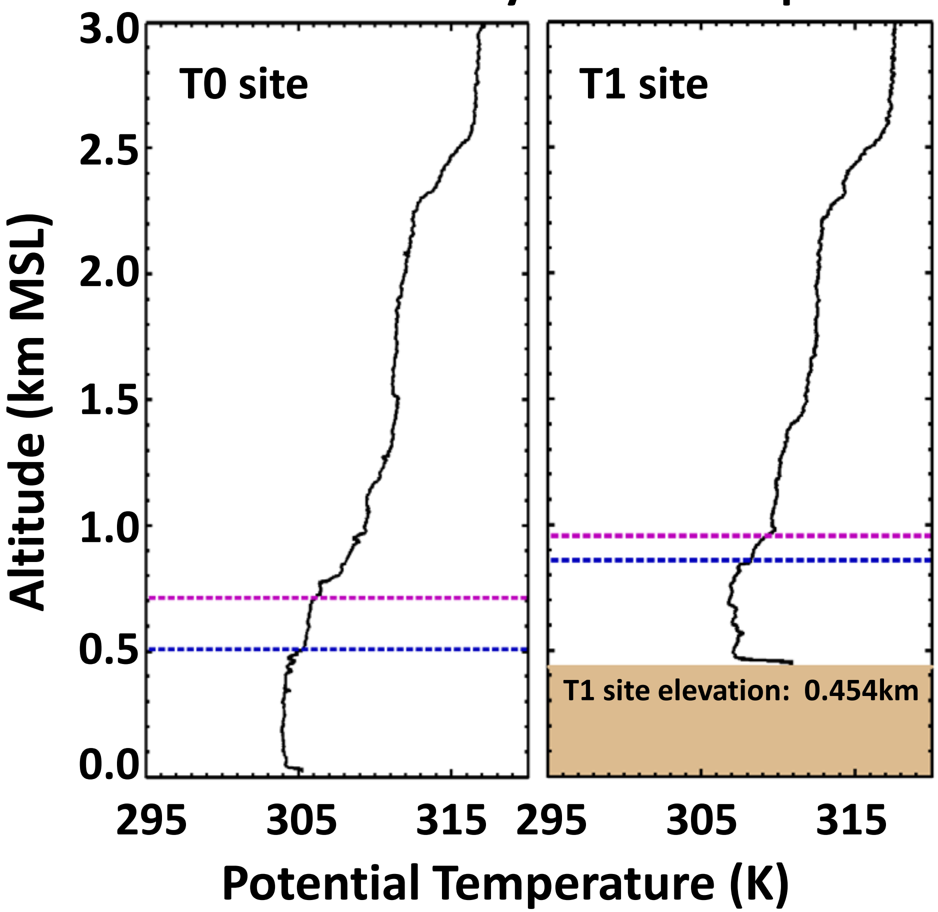
- Hayden et al. modified this for complex terrain using a lapse rate of 0.002 °K/m and an inversion temperature difference of 1°K

WRF-Chem simulated ML

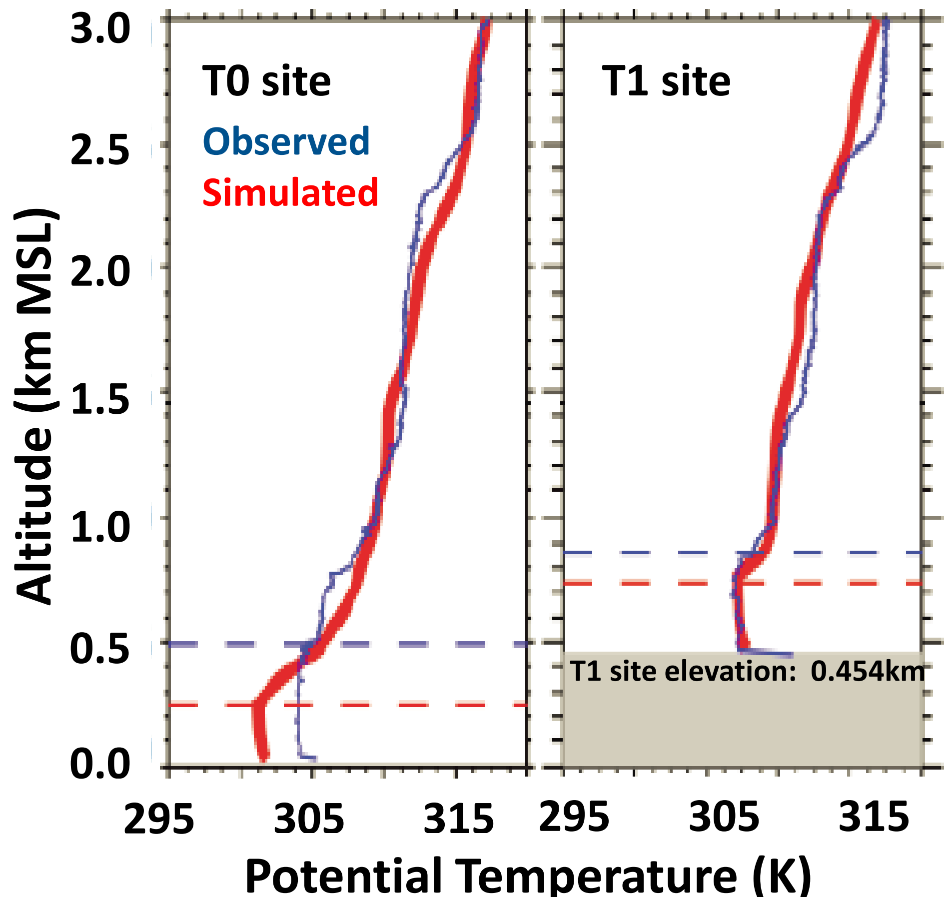
- The estimated boundary-layer depth is based on the gradients of potential temperature and humidity (Fast et al., ACP, 2012)

Mixing Layer Height Radiosonde Case
June 28th at 17 UTC (9 LST)

Heffter & Hayden Technique



WRF-Chem



T0 Site ML

Heffter : 0.715 km
Hayden : 0.51 km

T1 Site ML

Heffter : 0.959 km
Hayden : 0.859 km

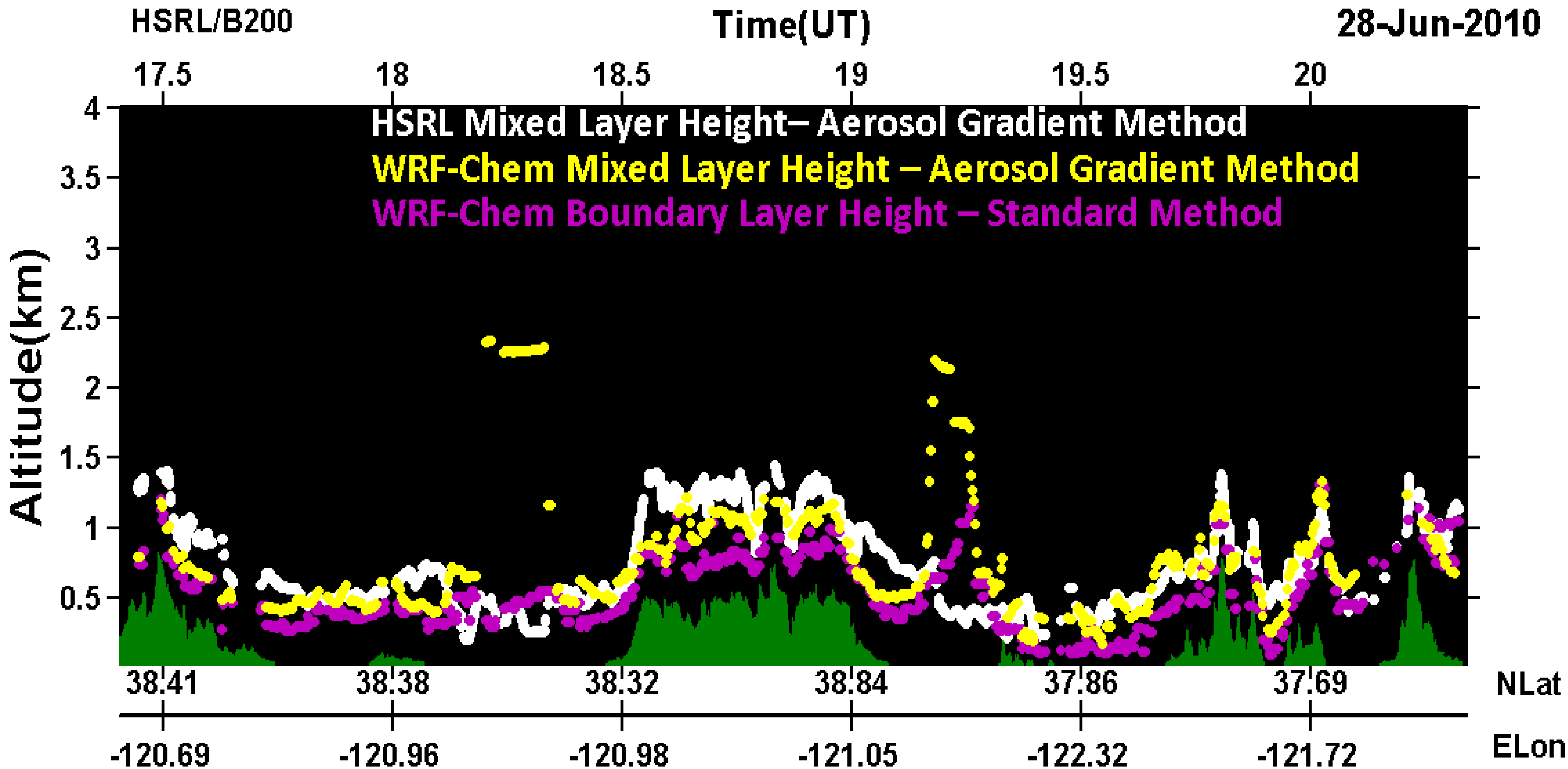
T0 Site ML

Observed: ≈0.50 km
Simulated: ≈0.25 km

T1 Site ML

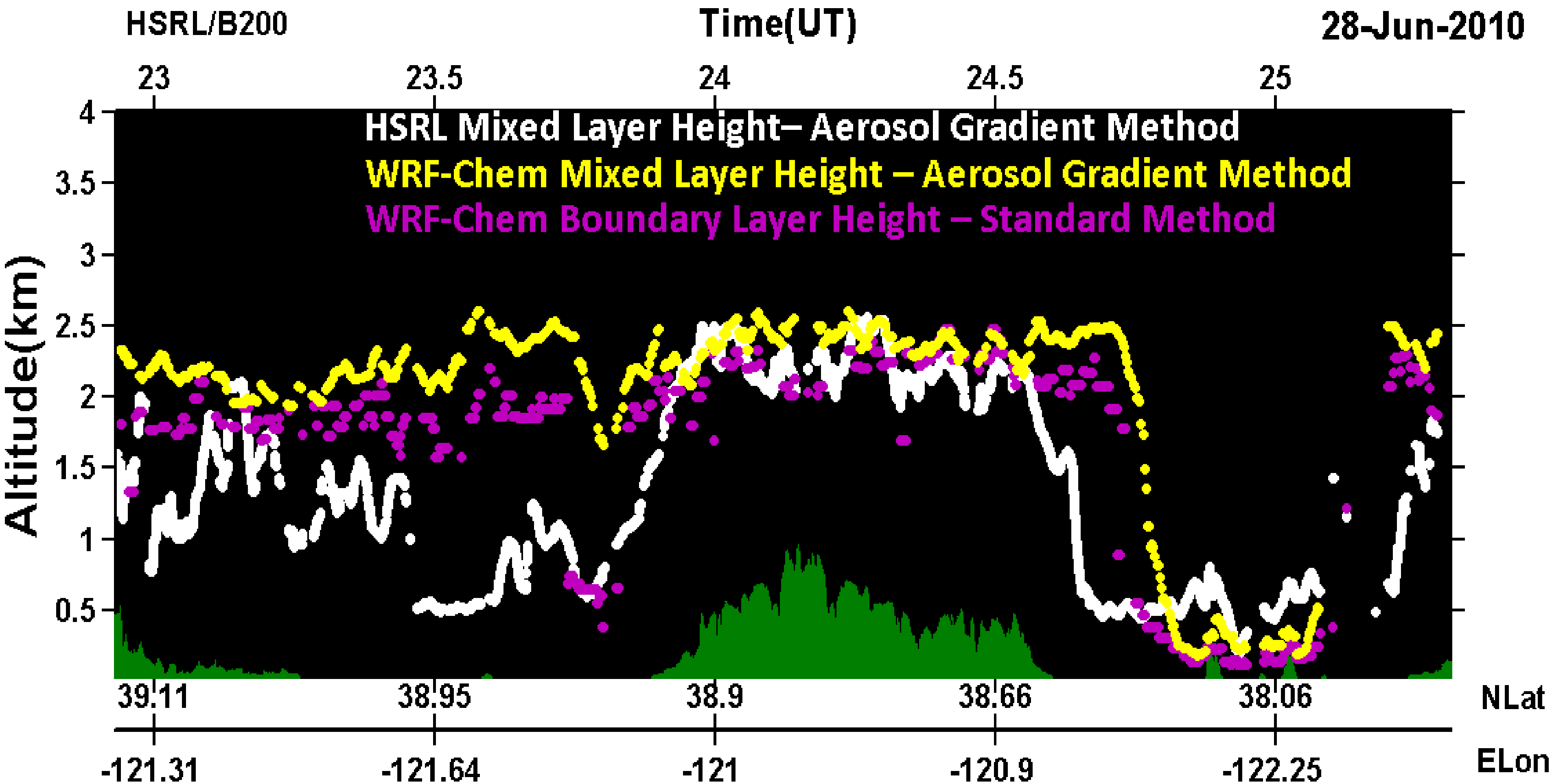
Observed: ≈0.88 km
Simulated: ≈0.73 km

Comparison of ML heights from the WRF-Chem model and HSRL during CARES



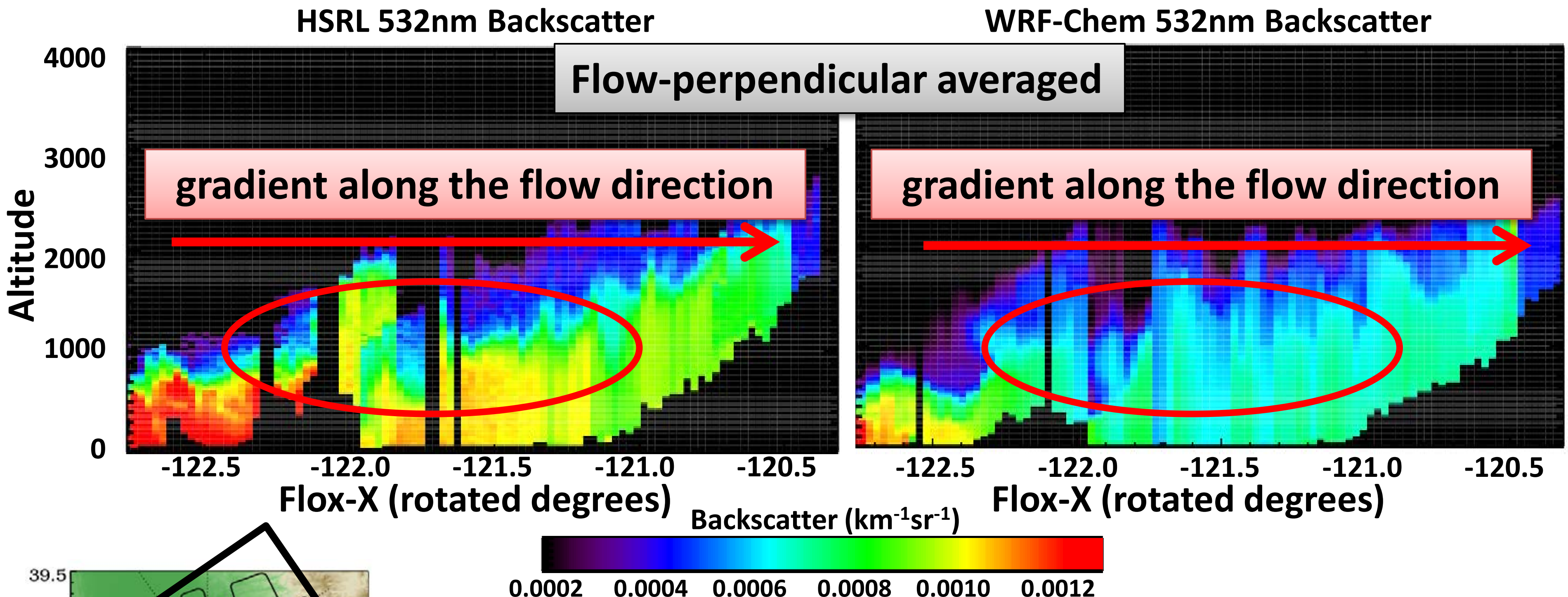
*Green filled area denotes terrain

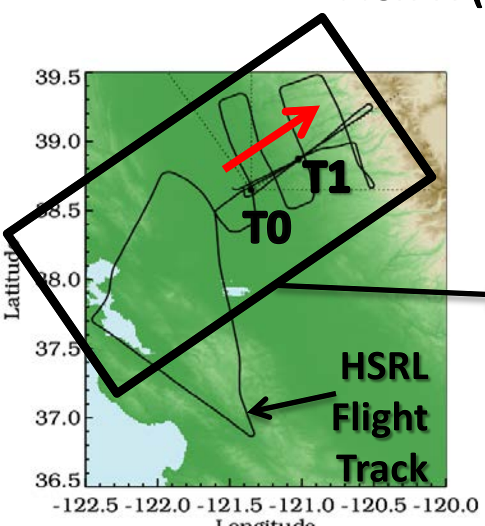
Comparison of ML heights from the WRF-Chem model and HSRL during CARES



*Green filled area denotes terrain

Distribution and Transport of aerosols during CARES – June 15 L2 Case

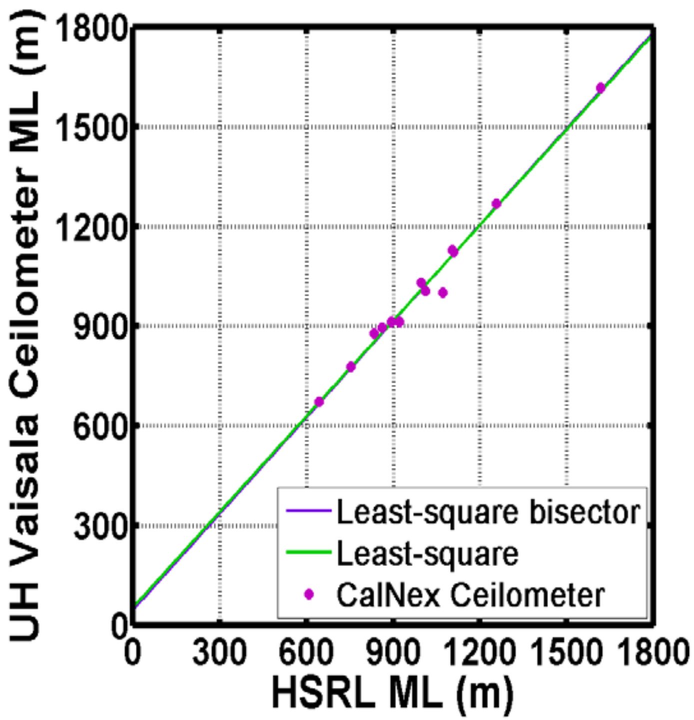




portion of flight track shown in average

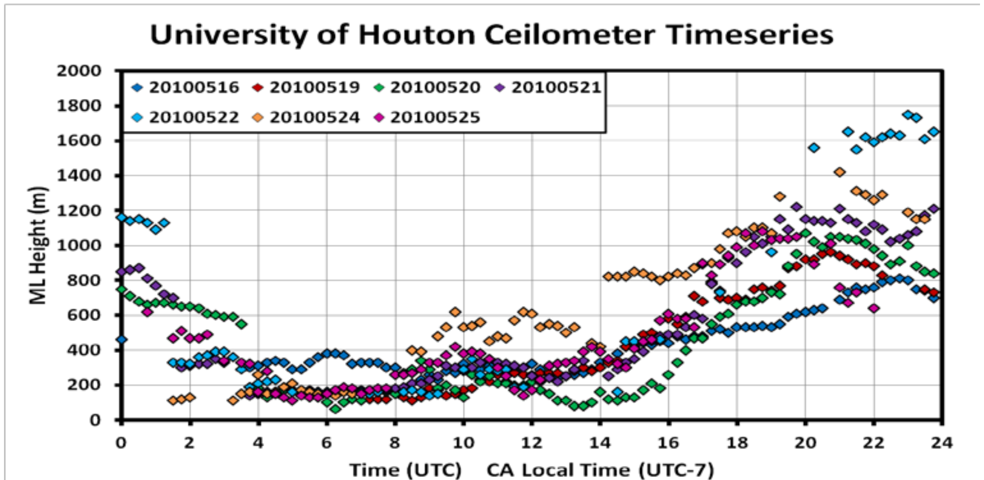
- 532nm Backscatter from HSRL and the WRF-Chem model demonstrate aerosol distribution and transport in the Sacramento region
- WRF-Chem somewhat underestimates HSRL for this case, but show similar patterns

Comparison of ML heights from UH ceilometer and HSRL during CalNex



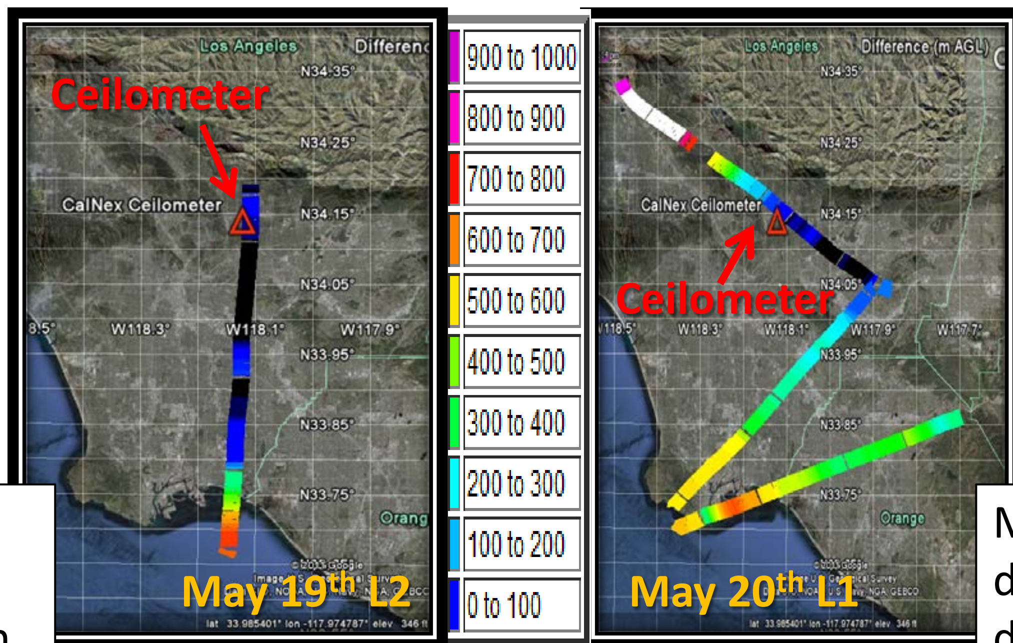
- HSRL ML heights matched with ceilometer-derived ML heights at the times when HSRL was within 15 km and 15 min. of the ceilometer measurements
- **Least-Sq R = 0.9931**
- **RMS Error = 30.9 (3.06%)**

- Ceilometer data shows that the ML did not grow rapidly in 30 min, so the HSRL values provide a snapshot of ML heights in the region



Comparison of ML heights from UH ceilometer and HSRL during CalNex

- The HSRL measurements included a large portion of the Los Angeles basin and we were able to study whether the ceilometer values could be applied to the entire area
- Ceilometer ML heights, which were also computed from aerosol gradients, were subtracted from the HSRL ML heights within ± 15 min. of the aircraft overpass, and data were limited to ground altitudes of 500 m or less, i.e., the basin area

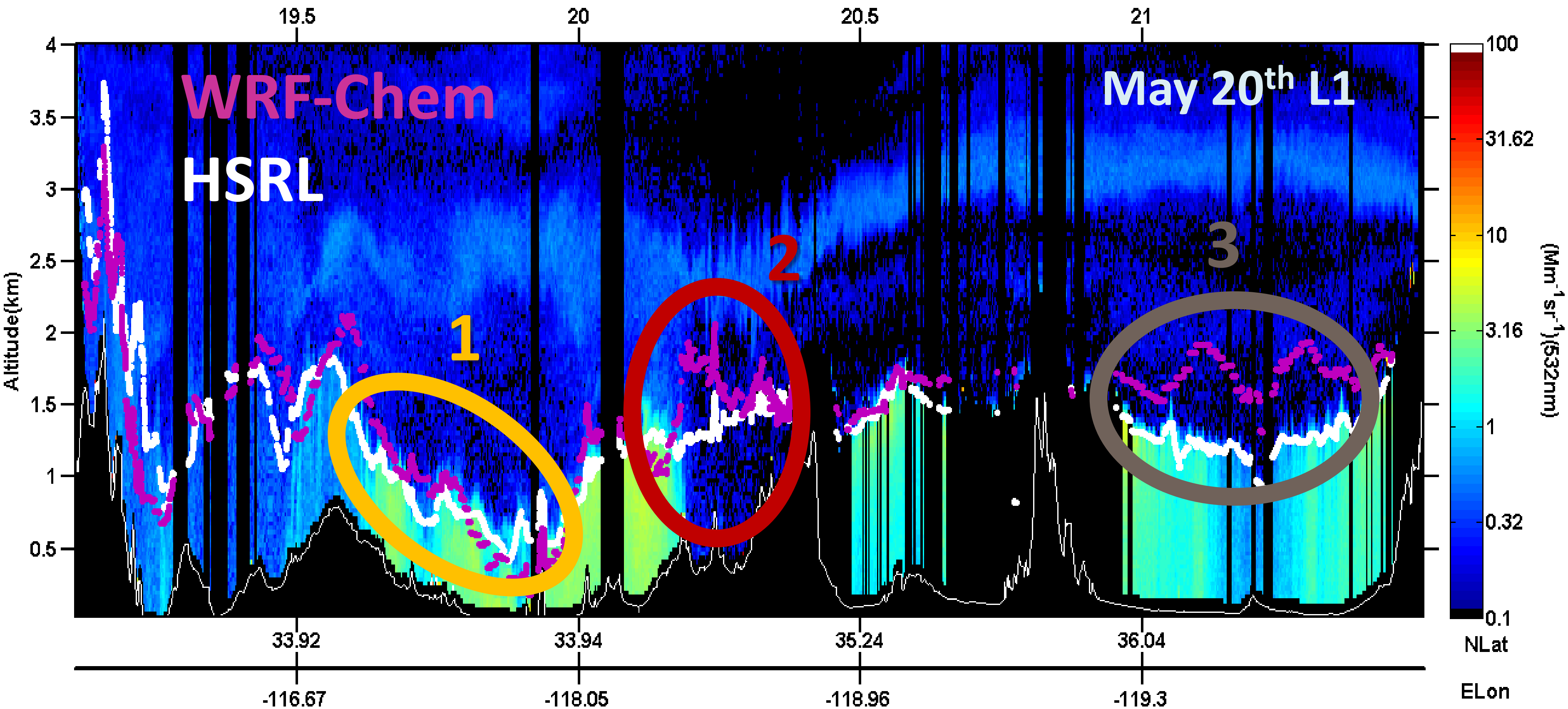


During some flights, ceilometer data correlated closely with ML heights throughout the region

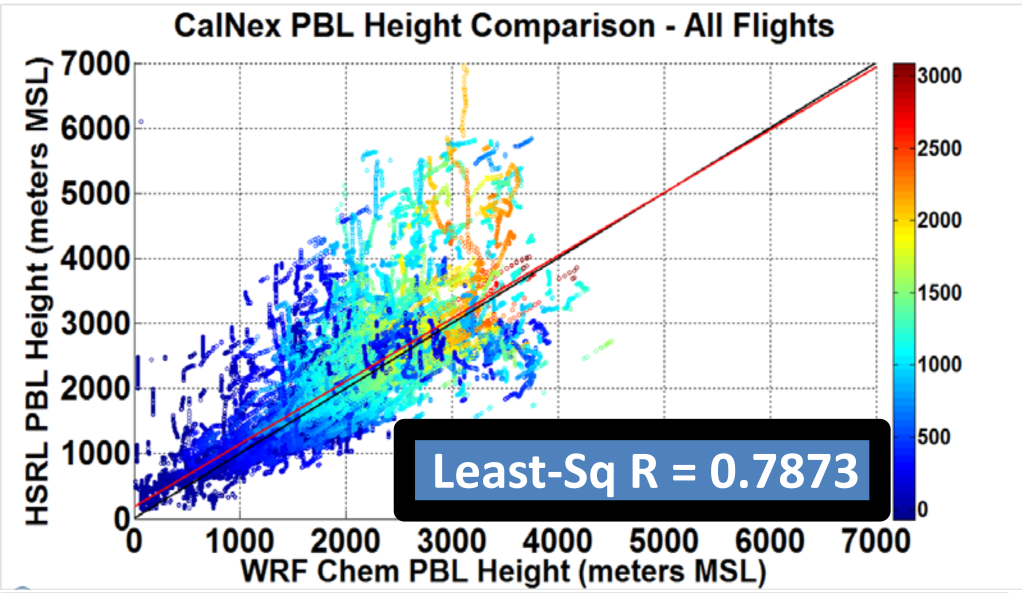
ML heights did show differences on some days up to 1000 m or more, at times very close to the ceilometer

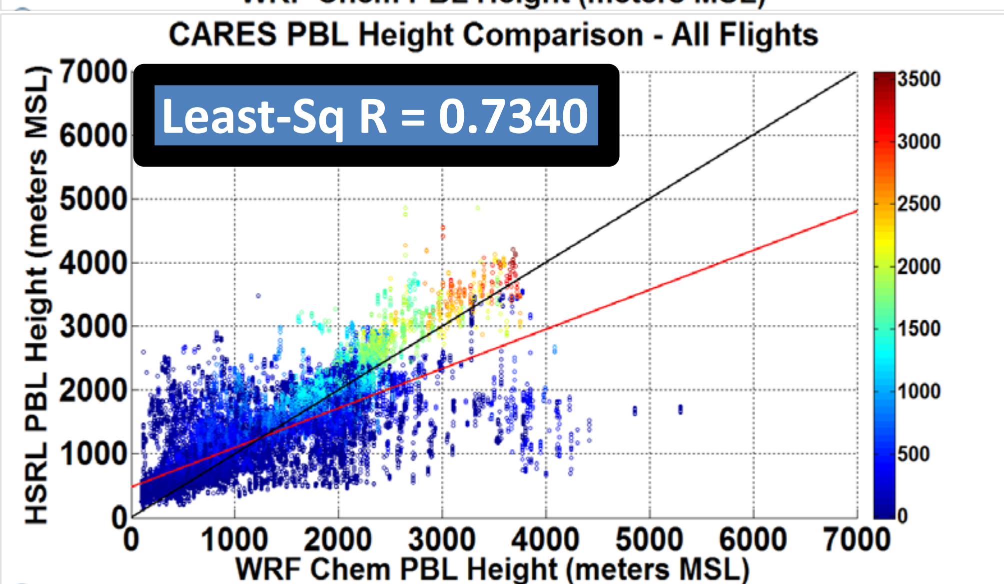
Comparison of ML heights from the WRF-Chem model and HSRL during CalNex and CARES

- While the WRF-Chem and HSRL ML heights tend to agree (1), the algorithms can differ in low aerosol loading conditions (2) and other situations (3), perhaps related to temperature gradients
- These discrepancies can be understood by assessing aerosol properties



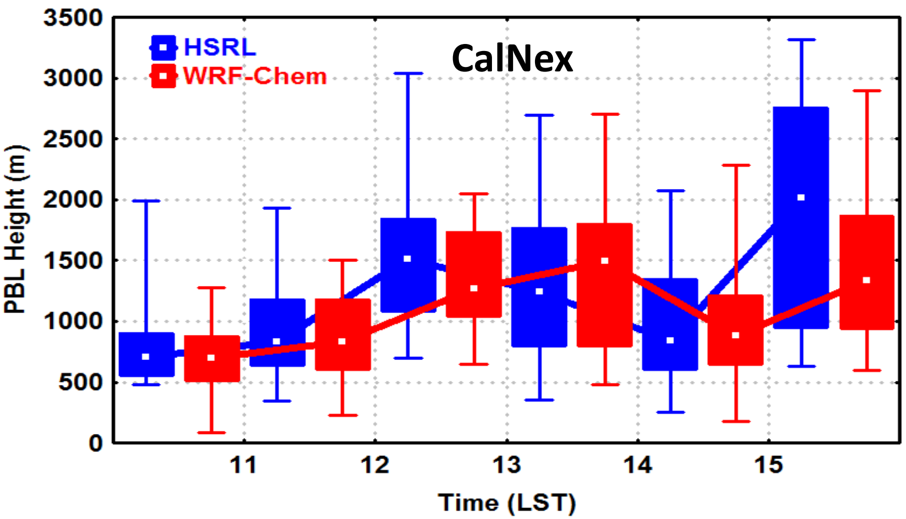
Comparison of ML heights from the WRF-Chem model and HSRL during CalNex and CARES

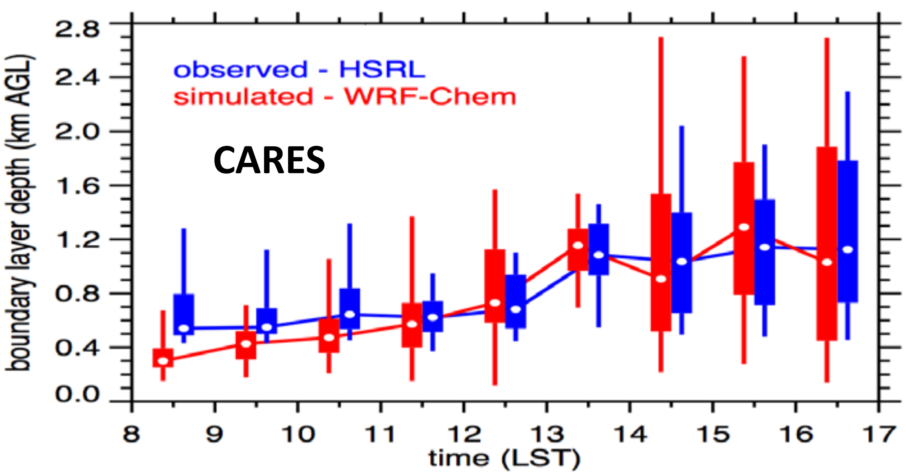




- Preliminary WRF-Chem and HSRL ML height comparisons show reasonable agreement between the model output and the airborne measurements across most flights, as shown by the following scatter and regression plots
- Ground altitude (MSL) is shown by color, with higher altitude mountainous regions shown in orange and red

Comparison of ML heights from the WRF-Chem model and HSRL during CalNex and CARES

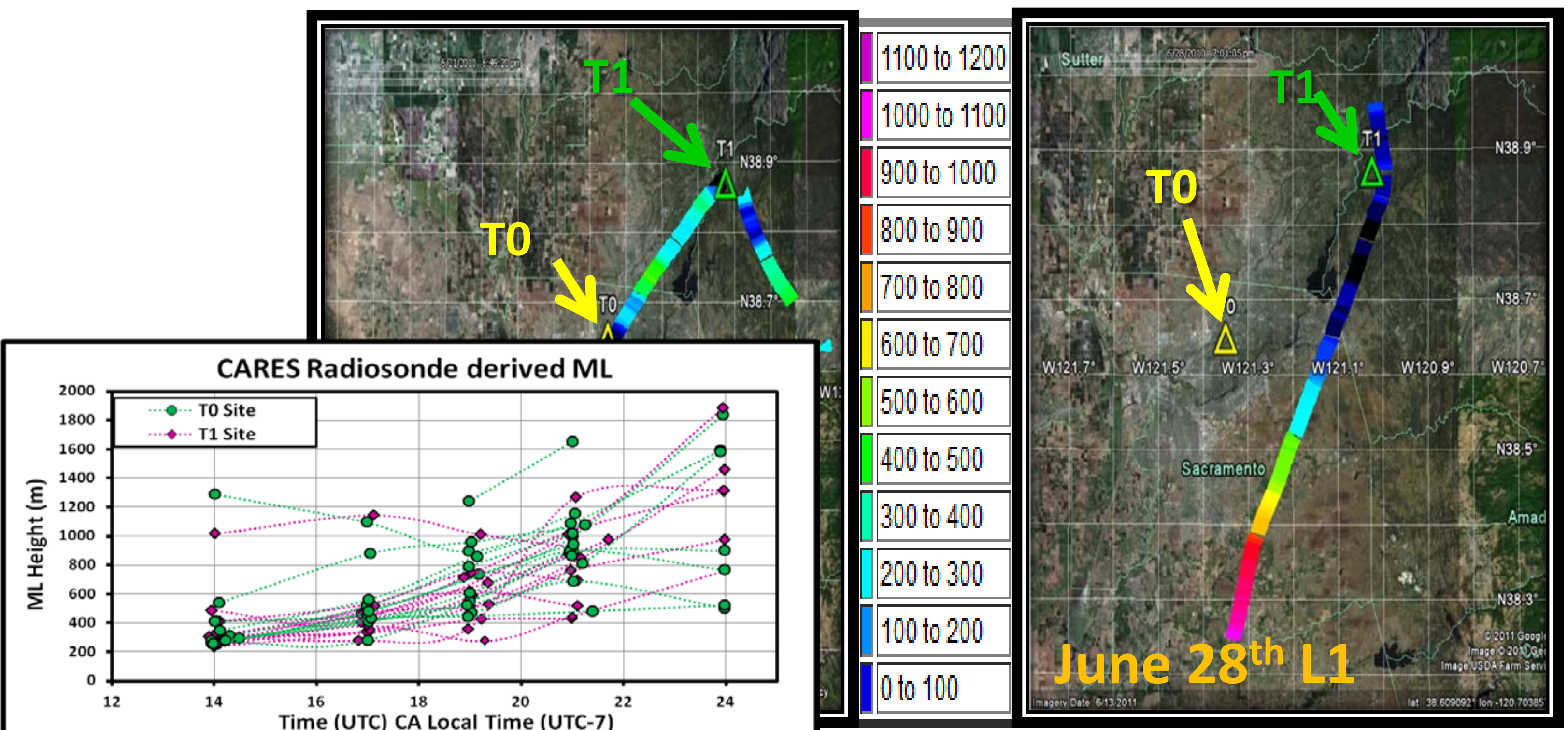




- Plots show ***observed*** and ***simulated*** mixing layer depth along the B-200 flight paths over and around the Los Angeles (top figure), and Sacramento (bottom figure, from Fast, et al., *ACP*, 2012) areas in terms of percentiles for each hour of the day over the entire campaign
- Filled boxes denote the 25th and 75th percentiles and vertical lines denote the 5th and 95th percentiles. Lines connecting the white dots denote the median value for each hour

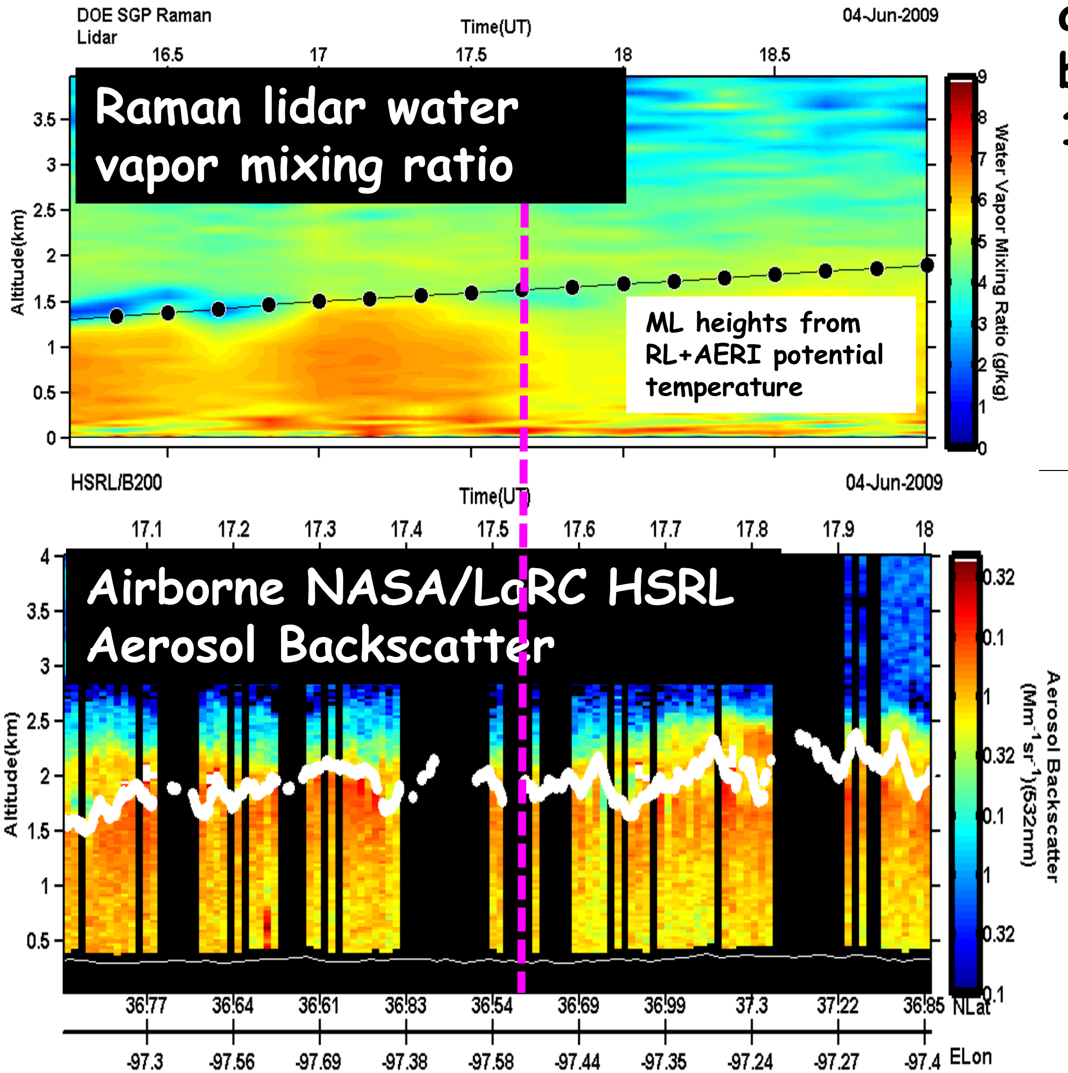
Comparison of ML heights from PNNL radiosondes and HSRL during CARES

- Radiosonde ML heights were subtracted from the HSRL ML heights within ± 15 min. of the aircraft overpass
- ML heights from T0 and T1 at times differ widely from ML heights measured across the surrounding region, even when the ML height was not growing rapidly

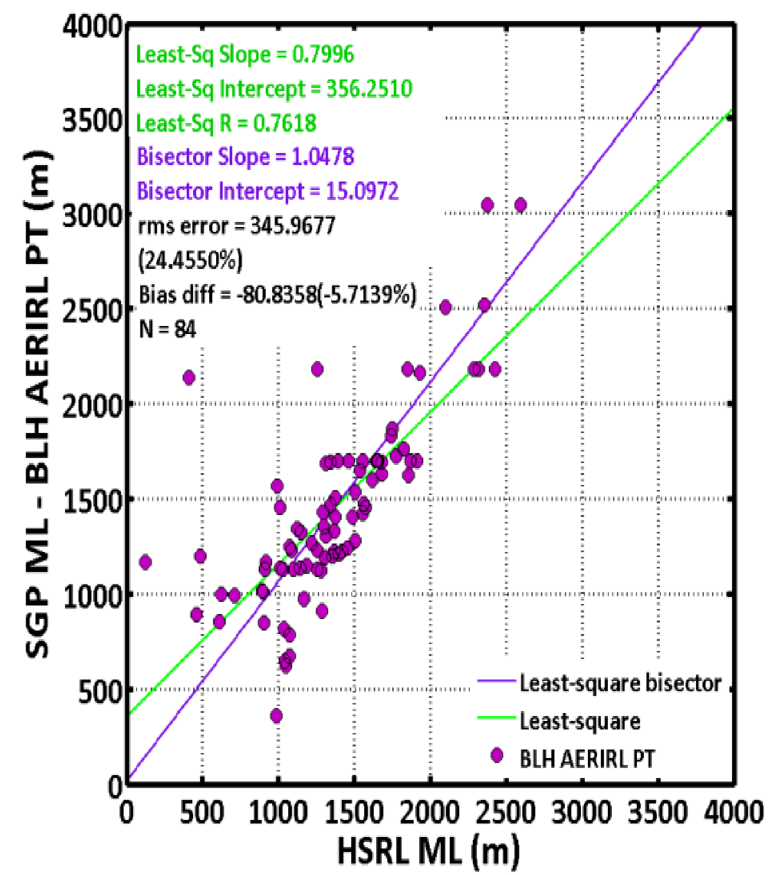


Comparison of Raman lidar and airborne HSRL ML heights

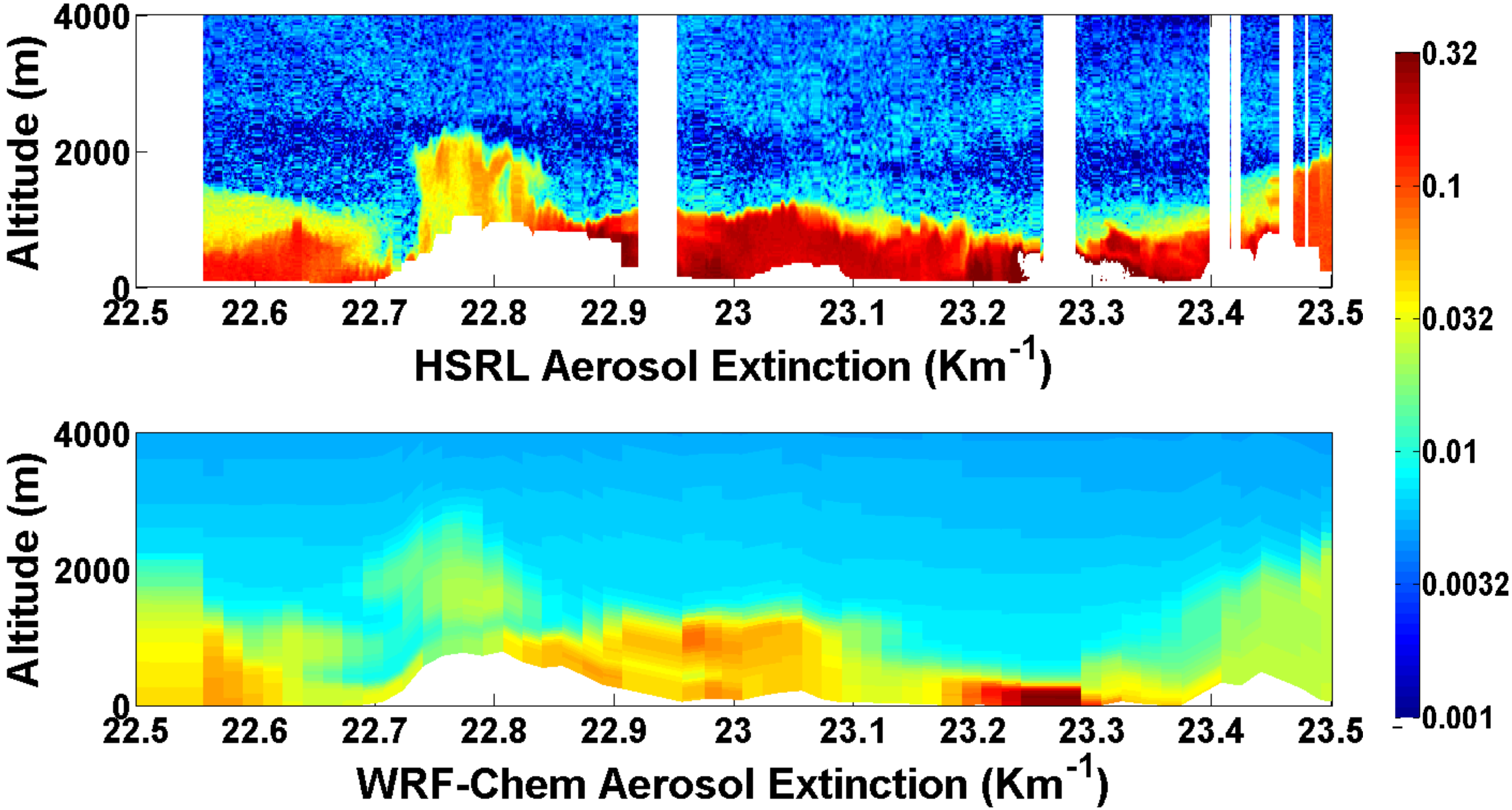
June 4, 2009 (RACORO)



ML heights from RL+AERI potential temp. profiles and airborne HSRL aerosol backscatter measurements within 10 km and 10 min of SGP



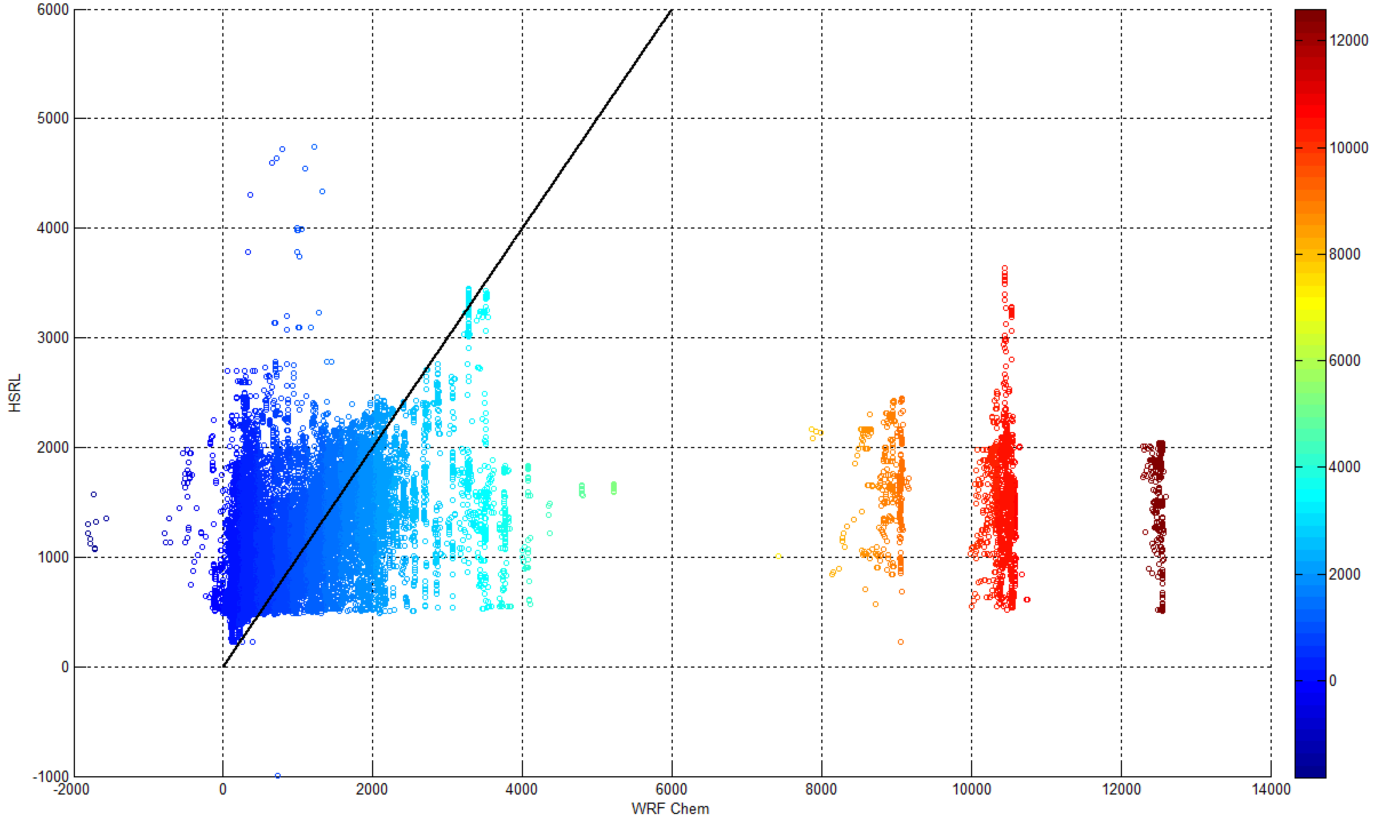
Comparison of Aerosol Properties from WRF-Chem and HSRL during CARES: 6/15/2010 flight 2



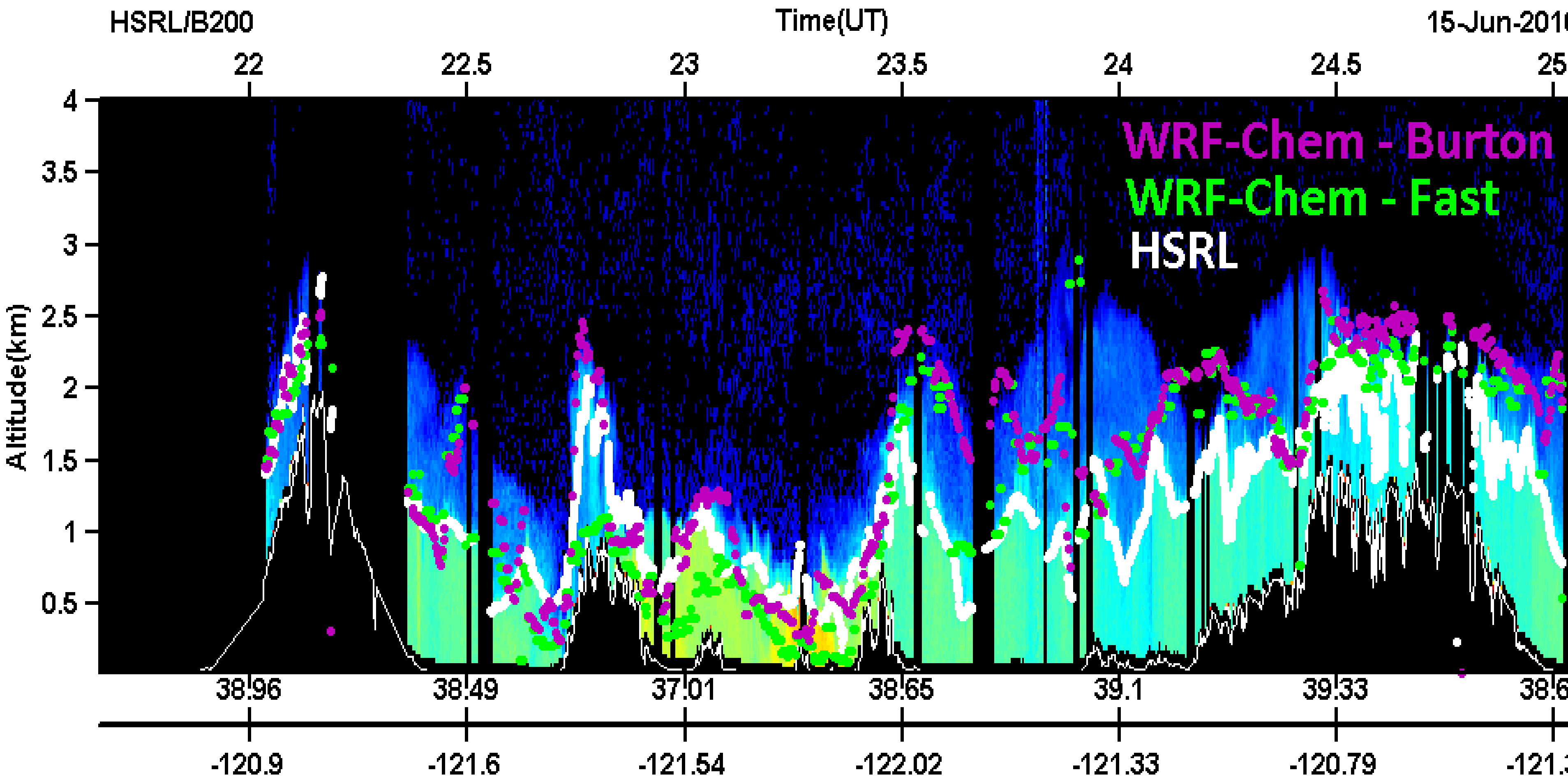
**WRF-Chem is Preliminary*

Comparison of ML heights from the WRF-Chem model and HSRL during and CARES

- WRF-Chem has many non-physical outliers at very high altitudes (shown in orange to red below). These are an obvious error and are removed from comparisons with HSRL



Comparison of ML heights from the WRF-Chem model and HSRL during CARES



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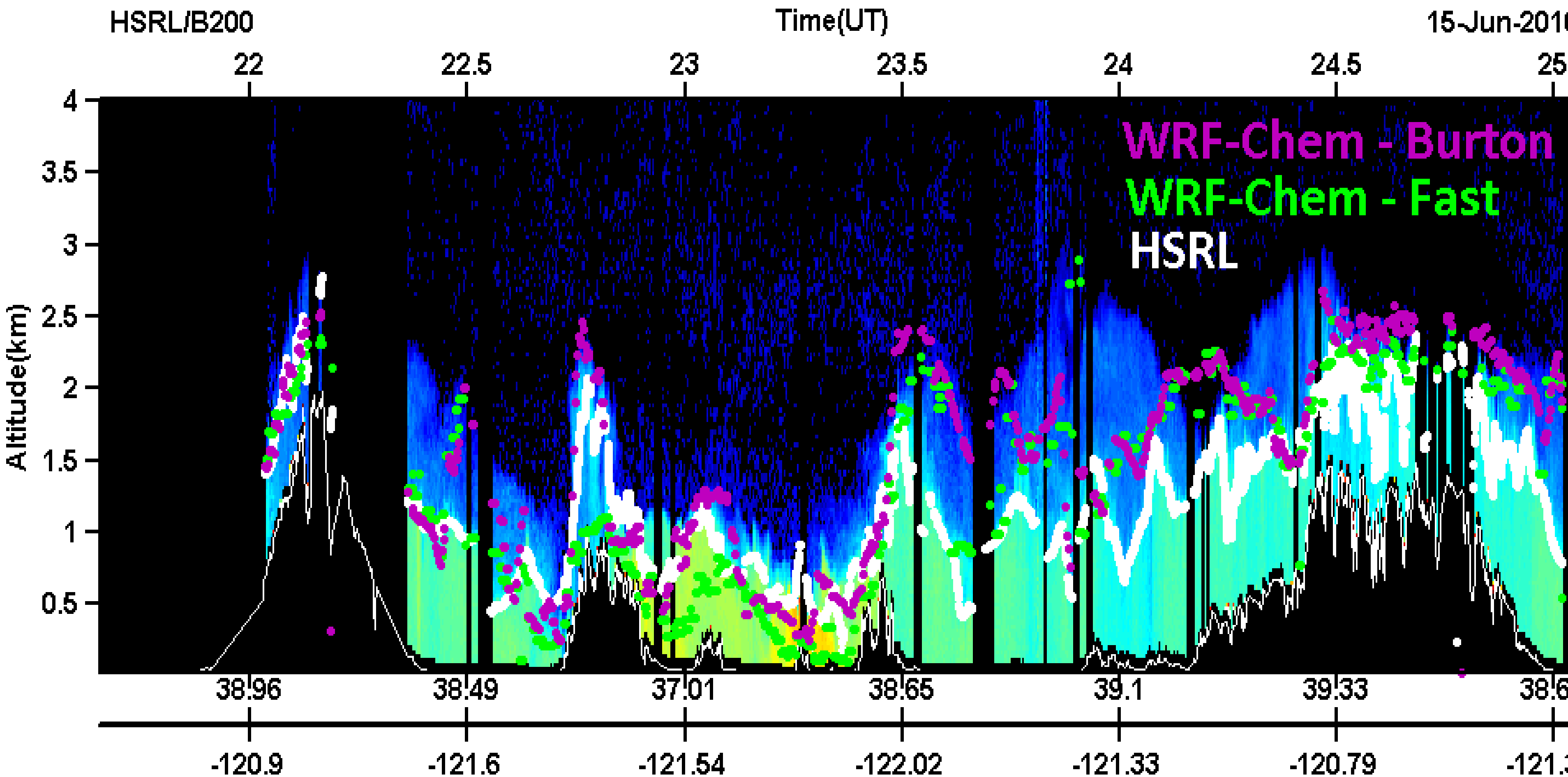
*WRF-Chem BLH – Standard Method is Preliminary

Comparison of ML heights from the WRF-Chem model and HSRL during CARES



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