Measurement of western U.S. baseline ozone from the surface to the tropopause and assessment of downwind impact regions

O. R. Cooper	U. of Colorado CIRES/NOAA ESRL, Boulder
S. J. Oltmans	NOAA ESRL, Boulder
B. J. Johnson	NOAA ESRL, Boulder
M. Trainer	NOAA ESRL, Boulder
J. Brioude	U. of Colorado CIRES/NOAA ESRL, Boulder
W. Angevine	U. of Colorado CIRES/NOAA ESRL, Boulder
D. D. Parrish	NOAA ESRL, Boulder
T. R. Ryerson	NOAA ESRL, Boulder
I. Pollack	U. of Colorado CIRES/NOAA ESRL, Boulder
P. Cullis	NOAA ESRL, Boulder
M. A. Ives	NOAA/ESRL Trinidad Head Observatory, California
D. W. Tarasick	MSC/Environment Canada, Downsview, Ontario
J. Al-Saadi	Tropospheric Chemistry Program, NASA, Washington DC
I. Stajner	Noblis Inc., Falls Church/NOAA NWS, Silver Spring

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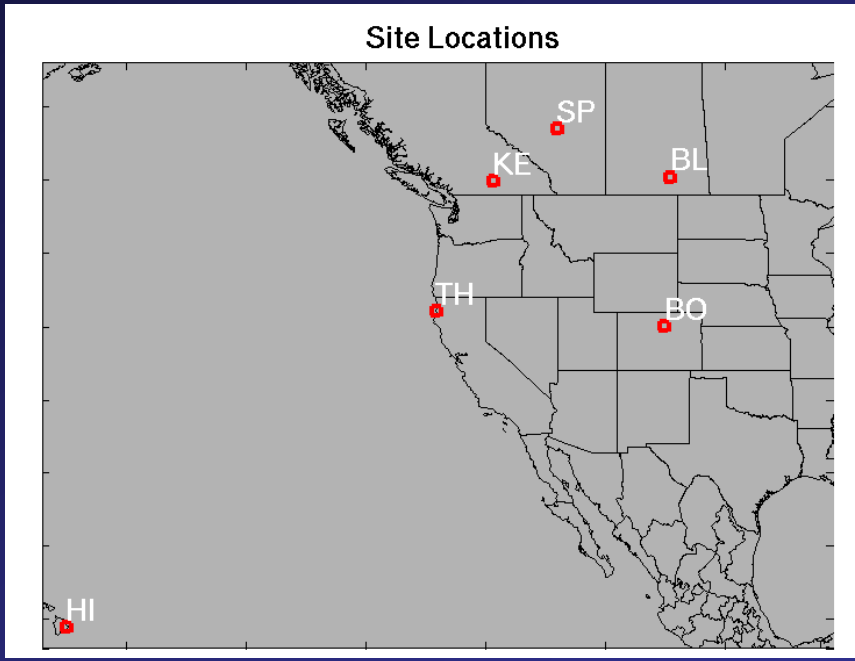
Tropospheric ozone monitoring in western North America

Routine in situ ozone measurements from Earth's surface to the tropopause are made at only 5 ozonesonde sites in western North America

Only Trinidad Head on the west coast is representative of baseline ozone.

baseline ozone - ozone measured at a location with no recent influence from local pollution sources [*WMO GAW definition*].



Science Questions:

1) Is Trinidad Head representative of baseline ozone at other coastal sites?

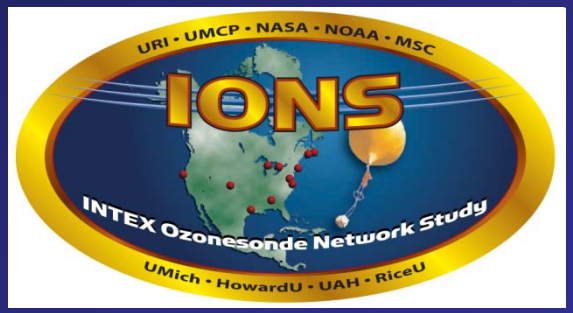
2) What are the anthropogenic NOx emission sources associated with baseline ozone?

3) Once baseline ozone comes ashore, where does it go?

IONS ozonesonde networks

(Intercontinental Chemical Transport Experiment Ozonesonde Network Study)

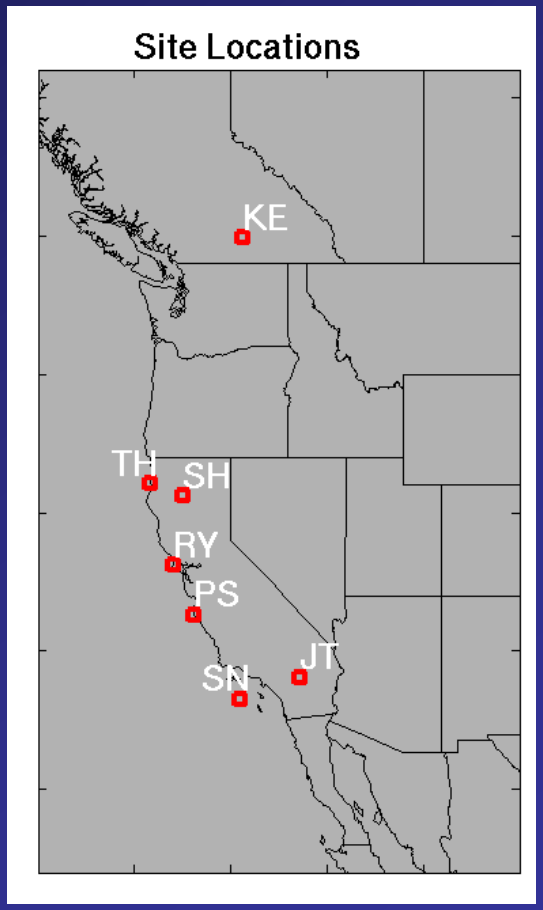
Experiment	Season	Location	Reference
IONS - 2004	Summer	eastern N. America	A. M. Thompson et al., JGR 2007
IONS - 2006	Spring	Central N. America	A. M. Thompson et al, ACP 2008
IONS - 2006	Summer	Central N. America	O. R. Cooper et al., JGR 2007
ARCIONS - 2008	Spring/ Summer	northern N. America	S. J. Oltmans et al., Atmos Environ. 2010
IONS - 2010	Late spring	western N. America	



IONS-2010 ozonesonde network

Near daily ozonesondes were launched from 7 sites between May 10 - June 19, 2010.

A total of 230 sondes were launched, the most in any western North America field campaign aimed at quantifying baseline ozone.



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NOAA ESRL Health of the Atmosphere Program
NASA Tropospheric Chemistry Program
U. S. Navy
Environment Canada
NOAA National Weather Service
National Park Service
California State Parks
Naval Postgraduate School (Monterey)
Federal Aviation Administration

FLEXPART Lagrangian Particle Dispersion Model

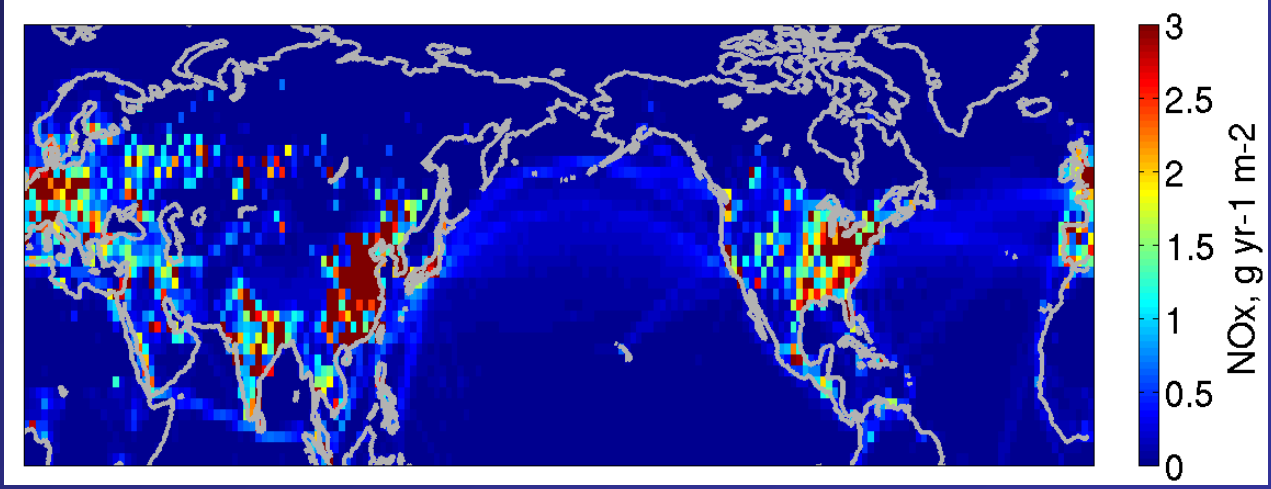
FLEXPART was used to identify air mass sources and receptor regions associated with each ozone measurement

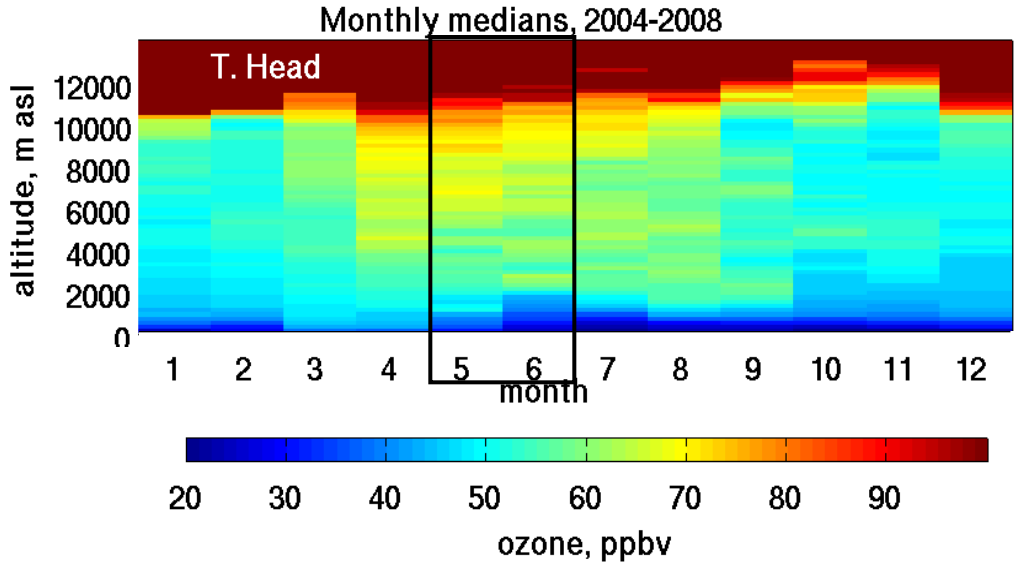
Wind fields: **GFS global 0.5º x 0.5º resolution, 26 vertical levels**
WRF western USA, 12 km resolution, 40 vertical levels

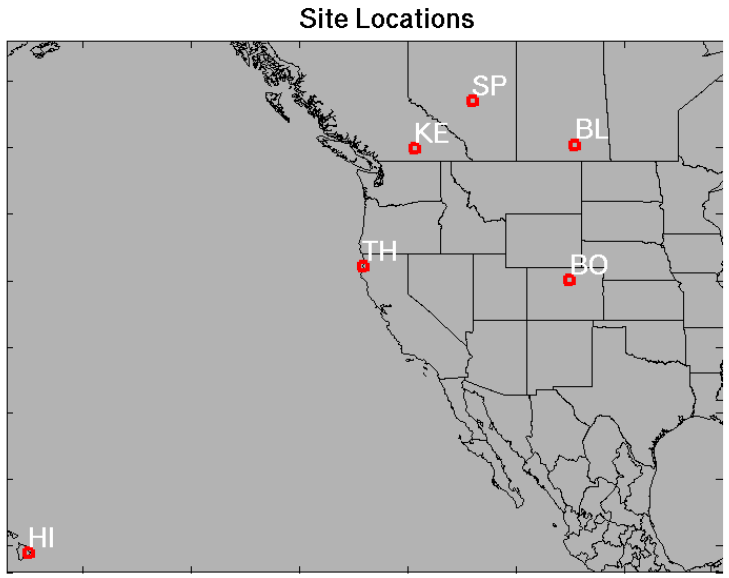
one retroplume and one forward plume were calculated every 200 m along every ozonesonde profile

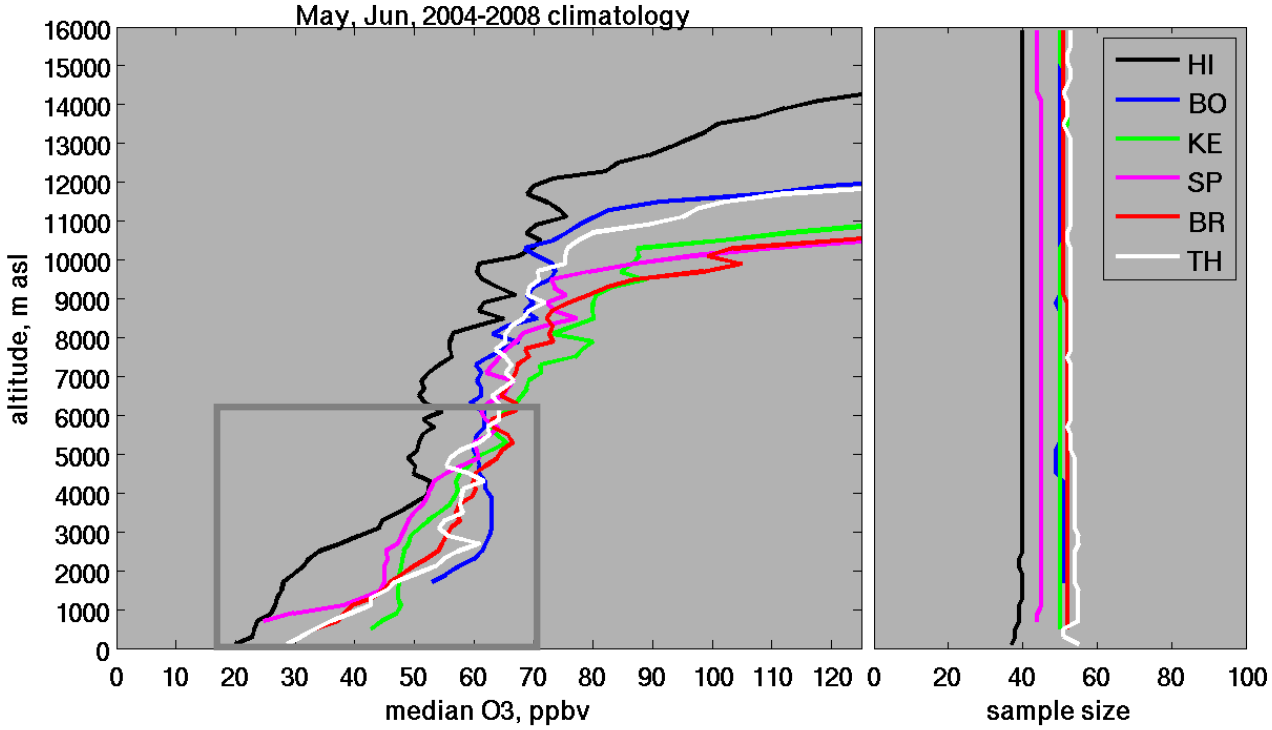
The quantity of a 20-day passive anthropogenic NO_x tracer transported to the ozonesonde measurement locations was calculated

EDGAR 2005 anthropogenic NO_x emission inventory with University of Delaware 2001 international shipping NO_x emissions (J. Corbett)









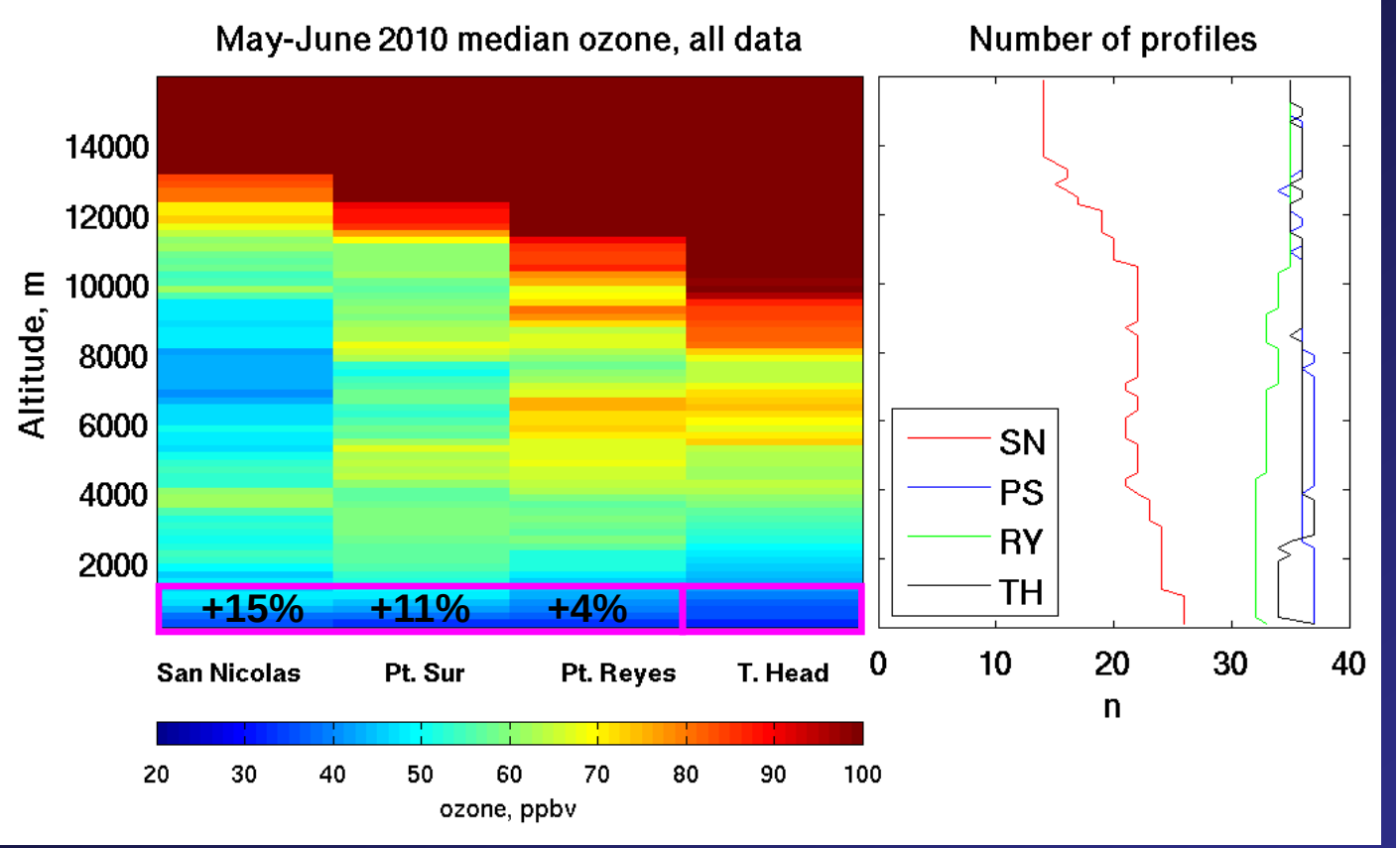
Comparison of 4 inland sites to Trinidad Head of mass of ozone (DU/km) from 0 - 6 km a.s.l.

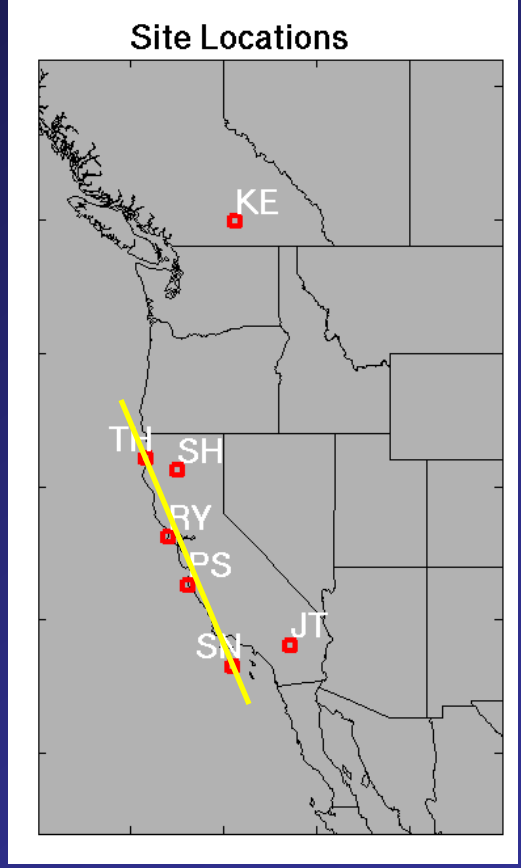
KE = 0%

SP = -7%

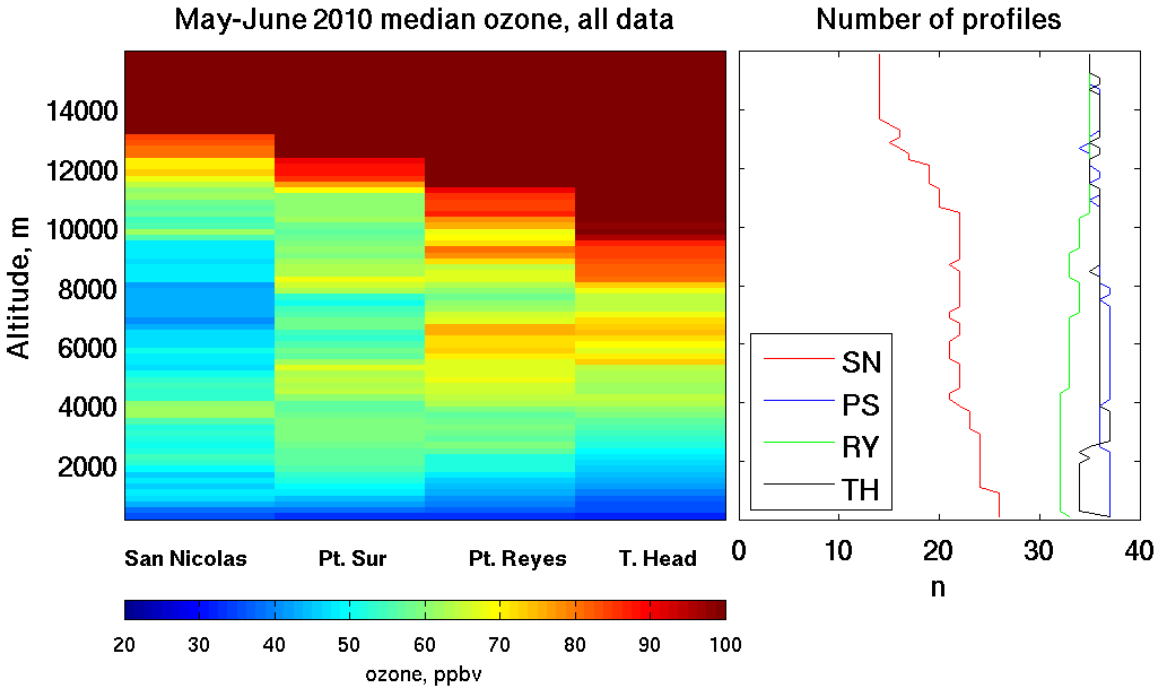
BL = +2%

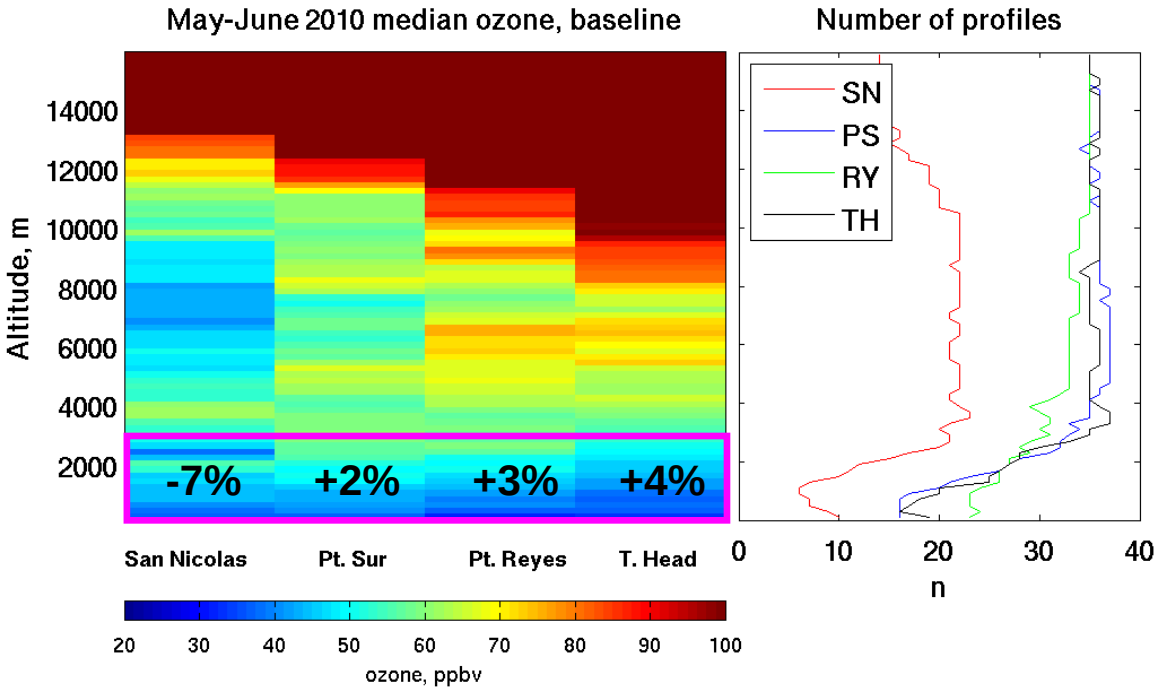
BO = +6%

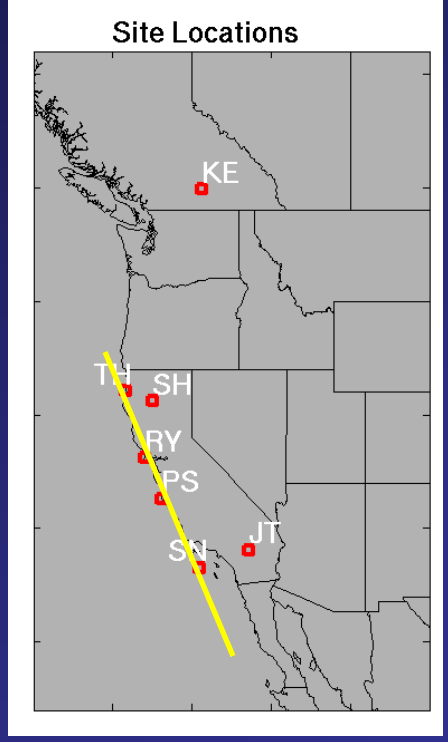




Percent difference in total mass of ozone in the lowest km, for southern sites compared to Trinidad Head.

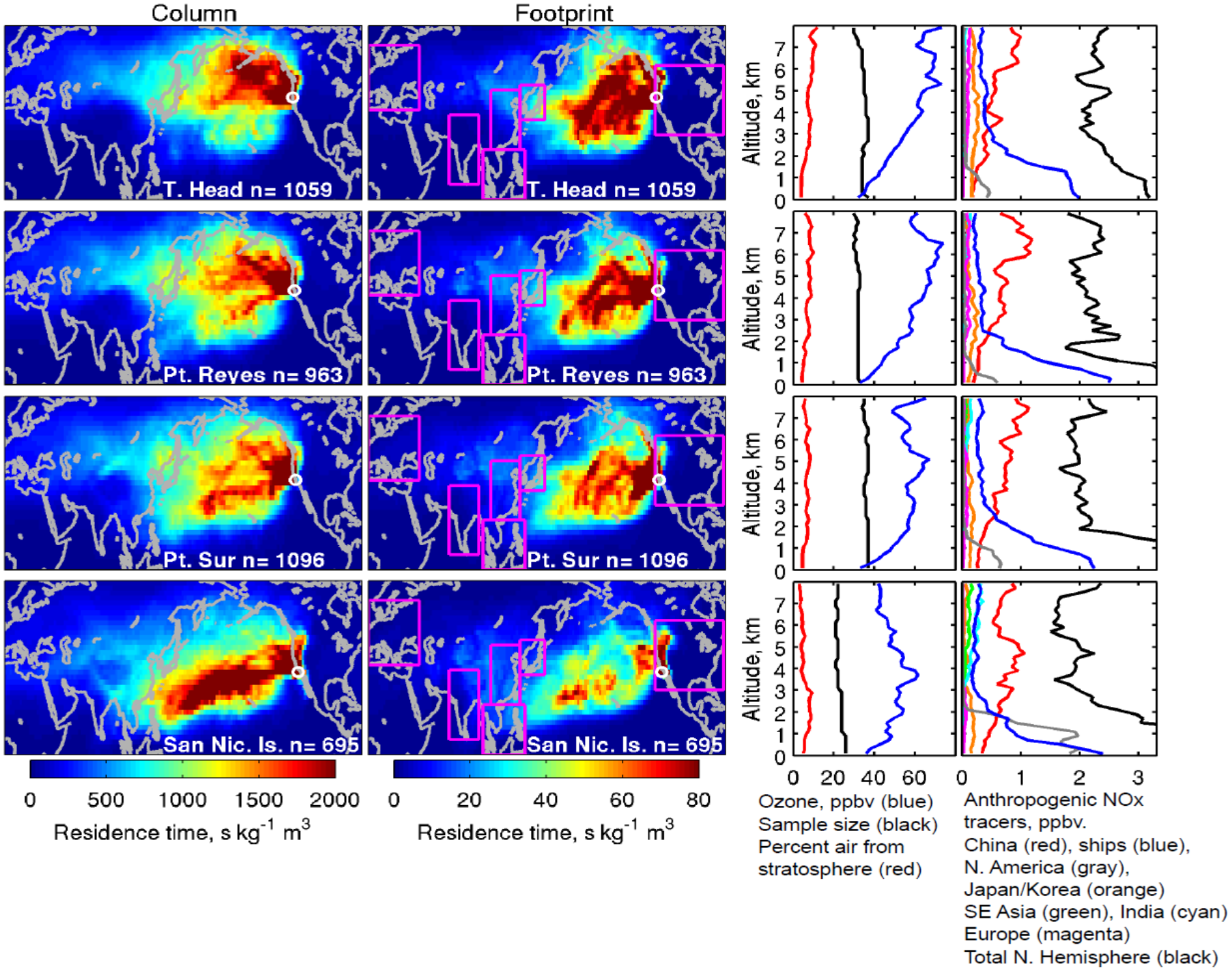


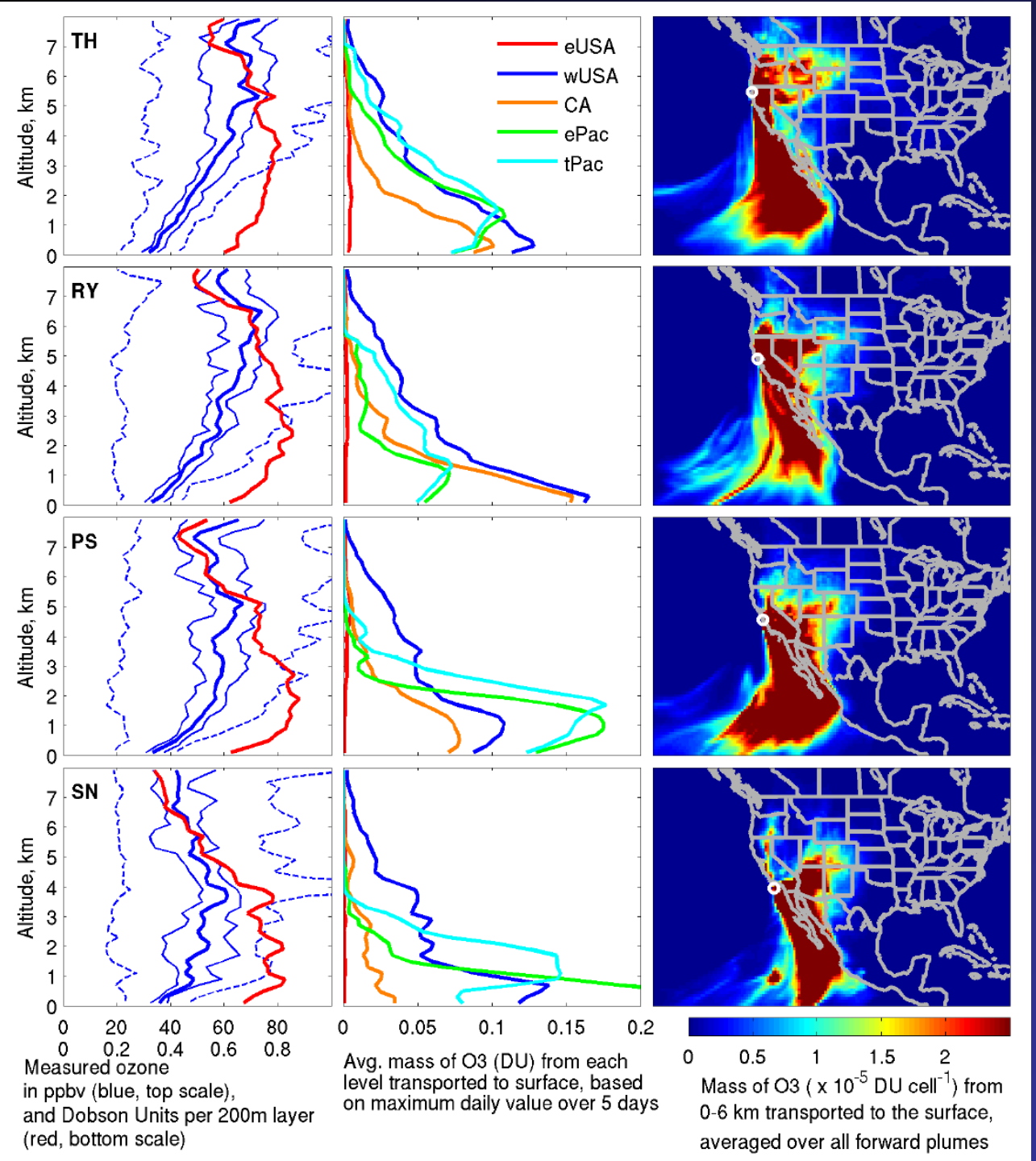


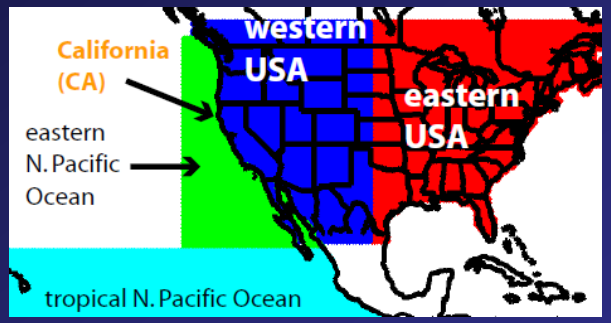


Baseline ozone determined by removing all measurements with a 5-day North America NO_x tracer > 440 pptv.

Change in baseline ozone is calculated in units of DU km^{-1}.


Column
Footprint
T. Head n= 1059
T. Head n= 1059
Pt. Reyes n= 963
Pt. Reyes n= 963
Pt. Sur n= 1096
Pt. Sur n= 1096
San Nic. Is. n= 695
San Nic. Is. n= 695
0 500 1000 1500 2000
Residence time, s kg-1 m3
0 20 40 60 80
Residence time, s kg-1 m3
Altitude, km
0 20 40 60
Ozone, ppbv (blue)
Sample size (black)
Percent air from stratosphere (red)
0 1 2 3
Anthropogenic NOx tracers, ppbv.
China (red), ships (blue),
N. America (gray),
Japan/Korea (orange)
SE Asia (green), India (cyan)
Europe (magenta)
Total N. Hemisphere (black)

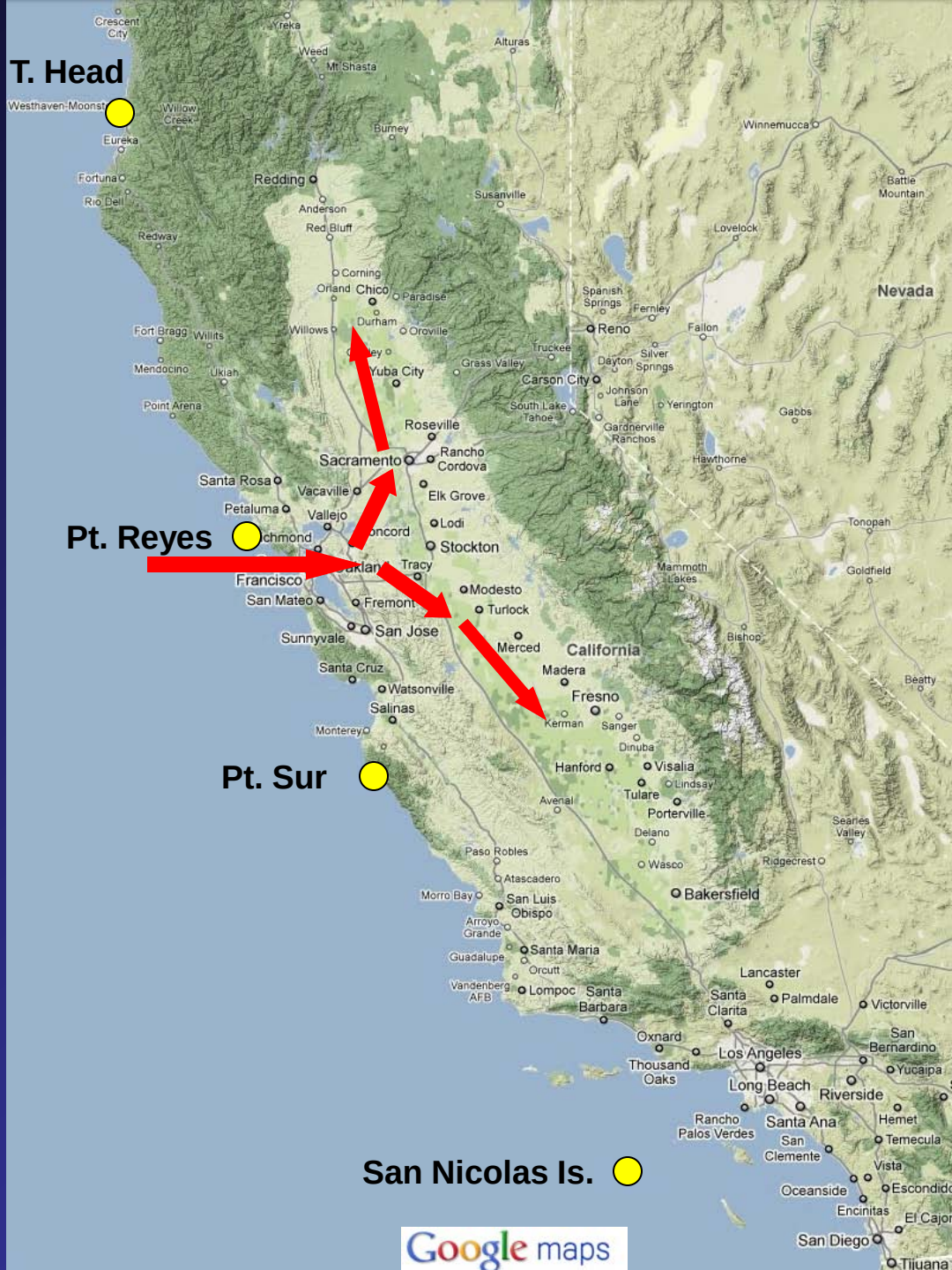

TH
RY
PS
SN
Altitude, km
0
1
2
3
4
5
6
7
eUSA
wUSA
CA
ePac
tPac
0
20
40
60
80
0
0.2
0.4
0.6
0.8
0
0.05
0.1
0.15
0.2
0
0.5
1
1.5
2
Measured ozone
in ppbv (blue, top scale),
and Dobson Units per 200m layer
(red, bottom scale)
Avg. mass of O3 (DU) from each
level transported to surface, based
on maximum daily value over 5 days
Mass of O3 (x 10-5 DU cell-1) from
0-6 km transported to the surface,
averaged over all forward plumes


western
USA
eastern
USA
California
(CA)
eastern
N. Pacific
Ocean
tropical N. Pacific Ocean

California's coastal topography affects ozone transport:

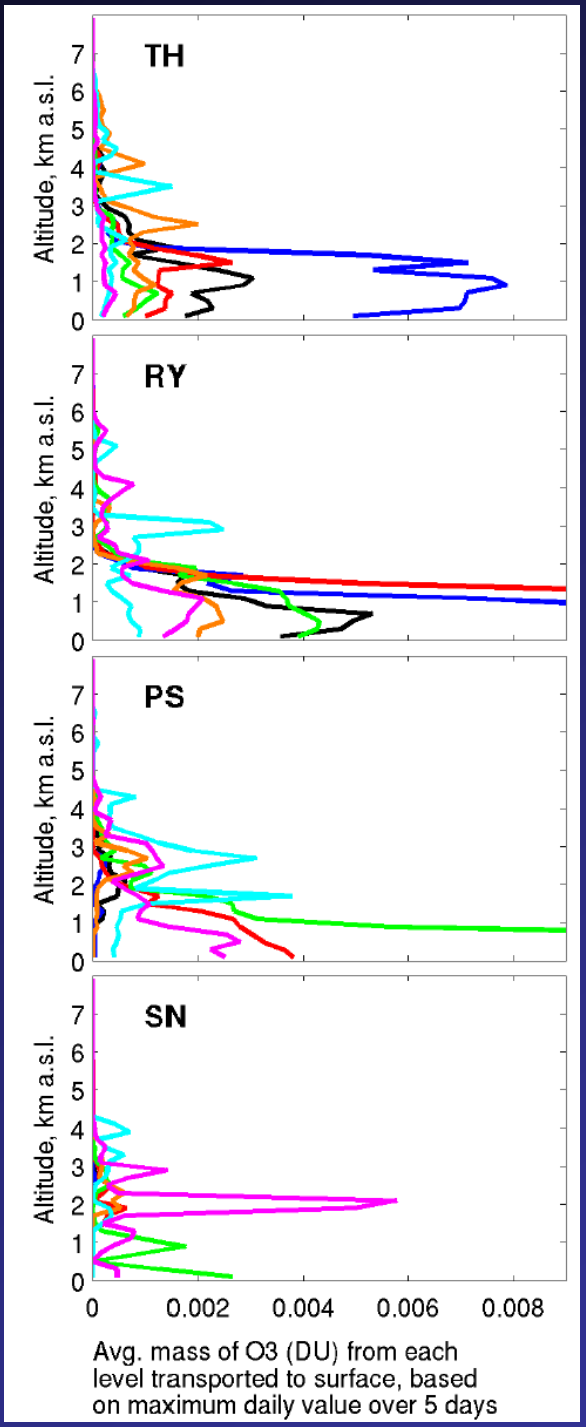
Coastal mountains impede the transport of marine boundary layer air into California at Trinidad Head and Pt. Sur [*Parrish et al.*, 2010].

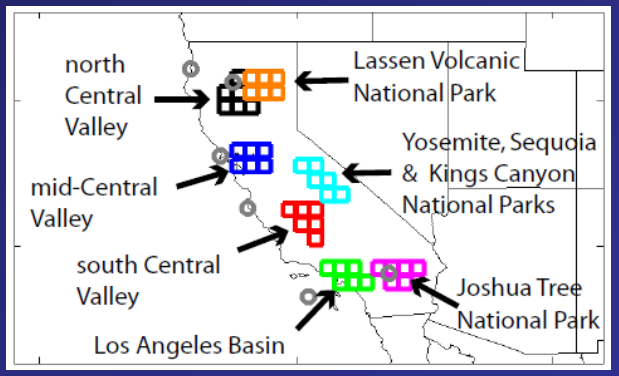
Relatively low topography allows air at Pt. Reyes to enter the Central Valley in the vicinity of The Carquinez Strait [*Bao et al.*, 2008].

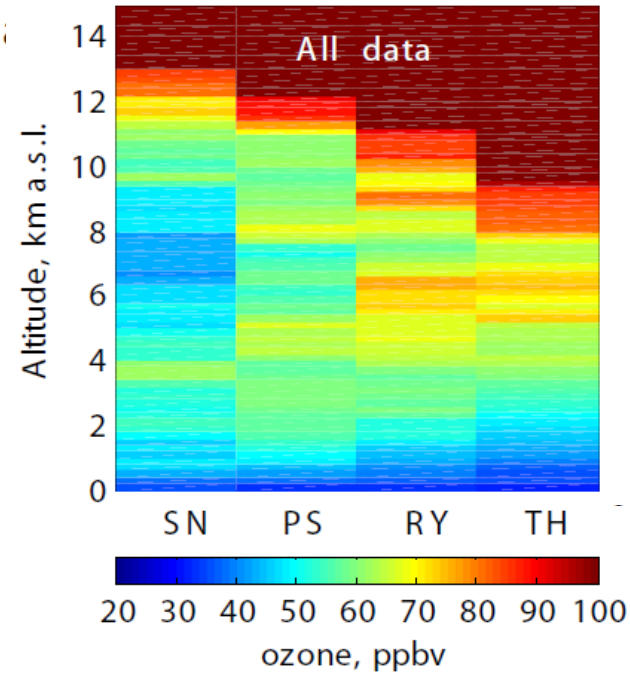


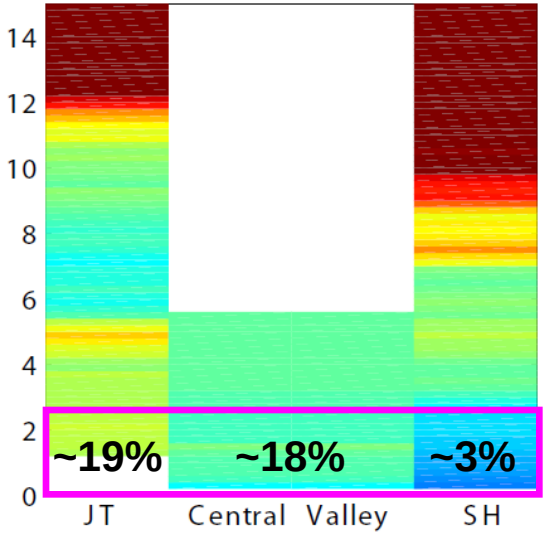
Bao, J.-W. et al. (2008), Observed and WRF-simulated low-level winds in a high-ozone episode during the Central California Ozone Study, *J. Applied Met. Clim., 47*, 2372-2394.

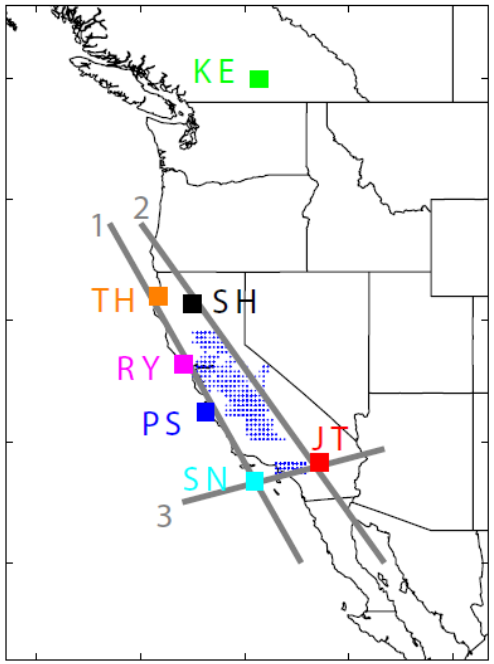
Parrish, D. et al. (2010), Impact of transported background ozone inflow on summertime air quality in a California ozone exceedance area, *Atmos. Chem. Phys., 10*, 10093-10109.

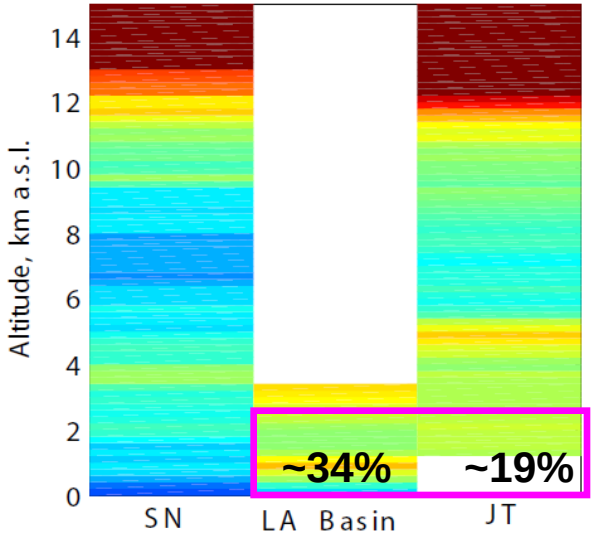

TH
RY
PS
SN
Altitude, km a.s.l.
0
1
2
3
4
5
6
7
0
0.002
0.004
0.006
0.008
Avg. mass of O3 (DU) from each level transported to surface, based on maximum daily value over 5 days

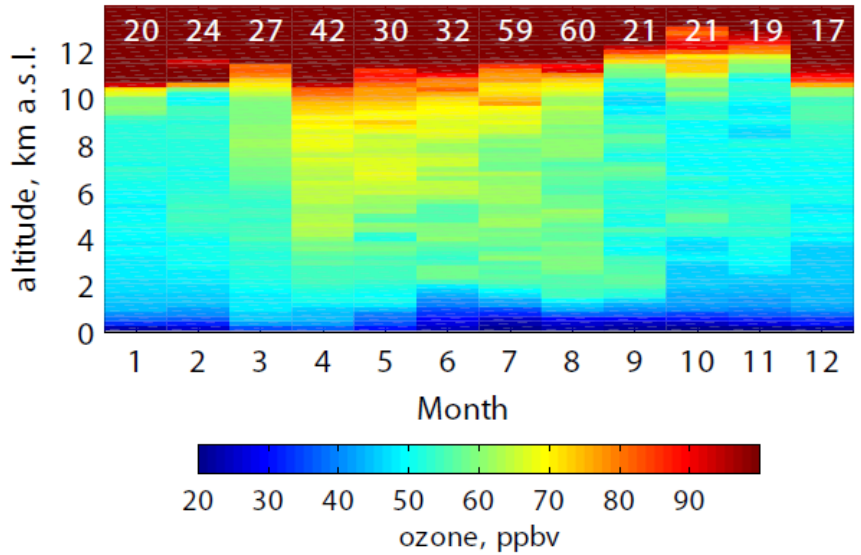

north Central Valley
mid-Central Valley
south Central Valley
Los Angeles Basin
Lassen Volcanic National Park
Yosemite, Sequoia & Kings Canyon National Parks
Joshua Tree National Park

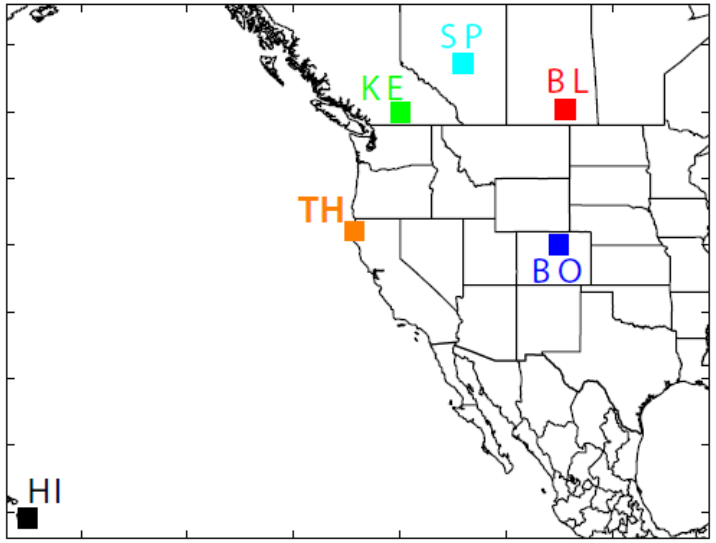

All data
Altitude, km a.s.l.
0
2
4
6
8
10
12
14
SN
PS
RY
TH
20 30 40 50 60 70 80 90 100
ozone, ppbv

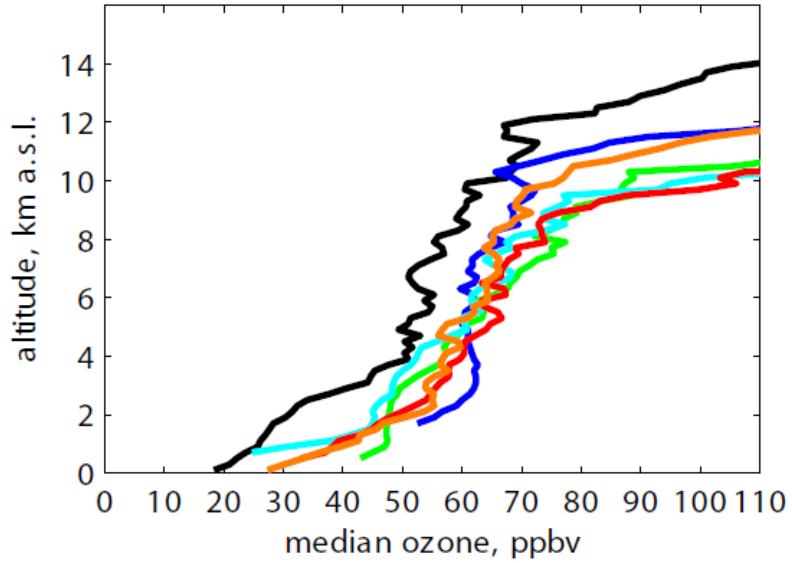

~19%
~18%
~3%
JT
Central Valley
SH

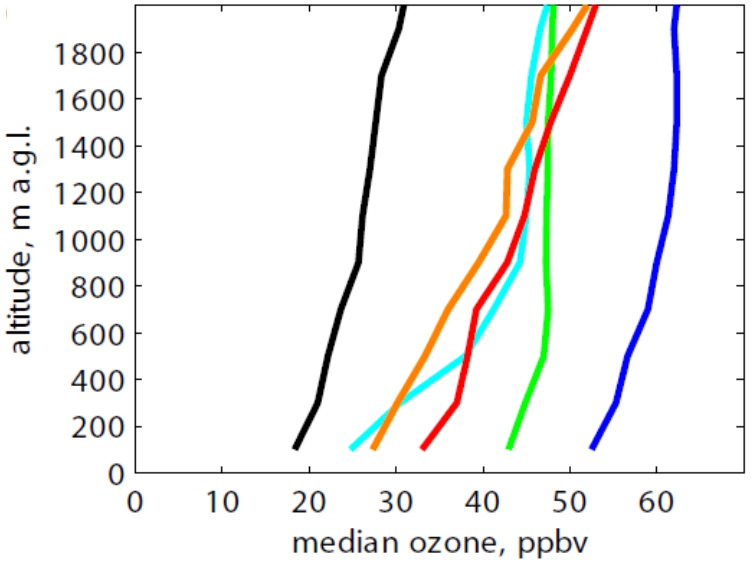

KE
1
2
TH
SH
RY
PS
JT
SN
3

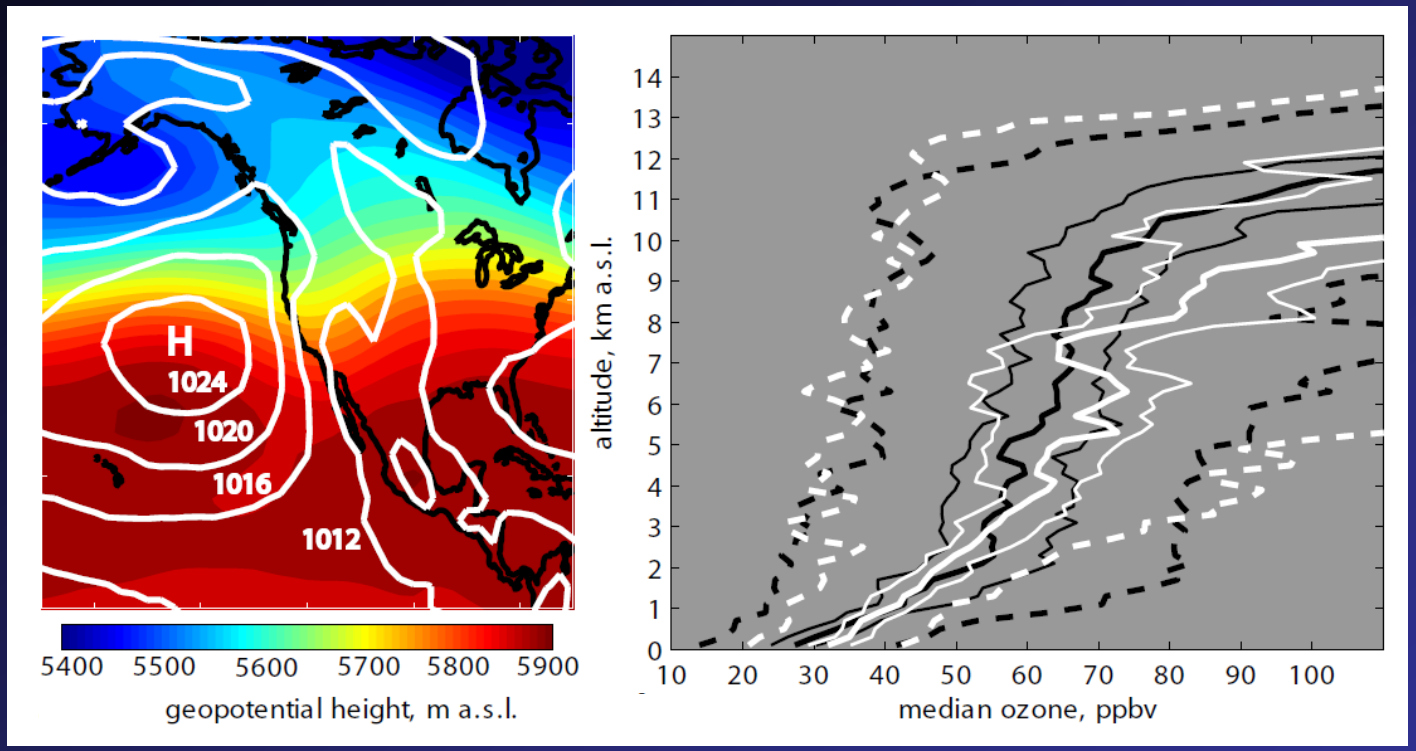

Altitude, km a.s.l.
0
2
4
6
8
10
12
14
~34%
~19%
SN
LA Basin
JT

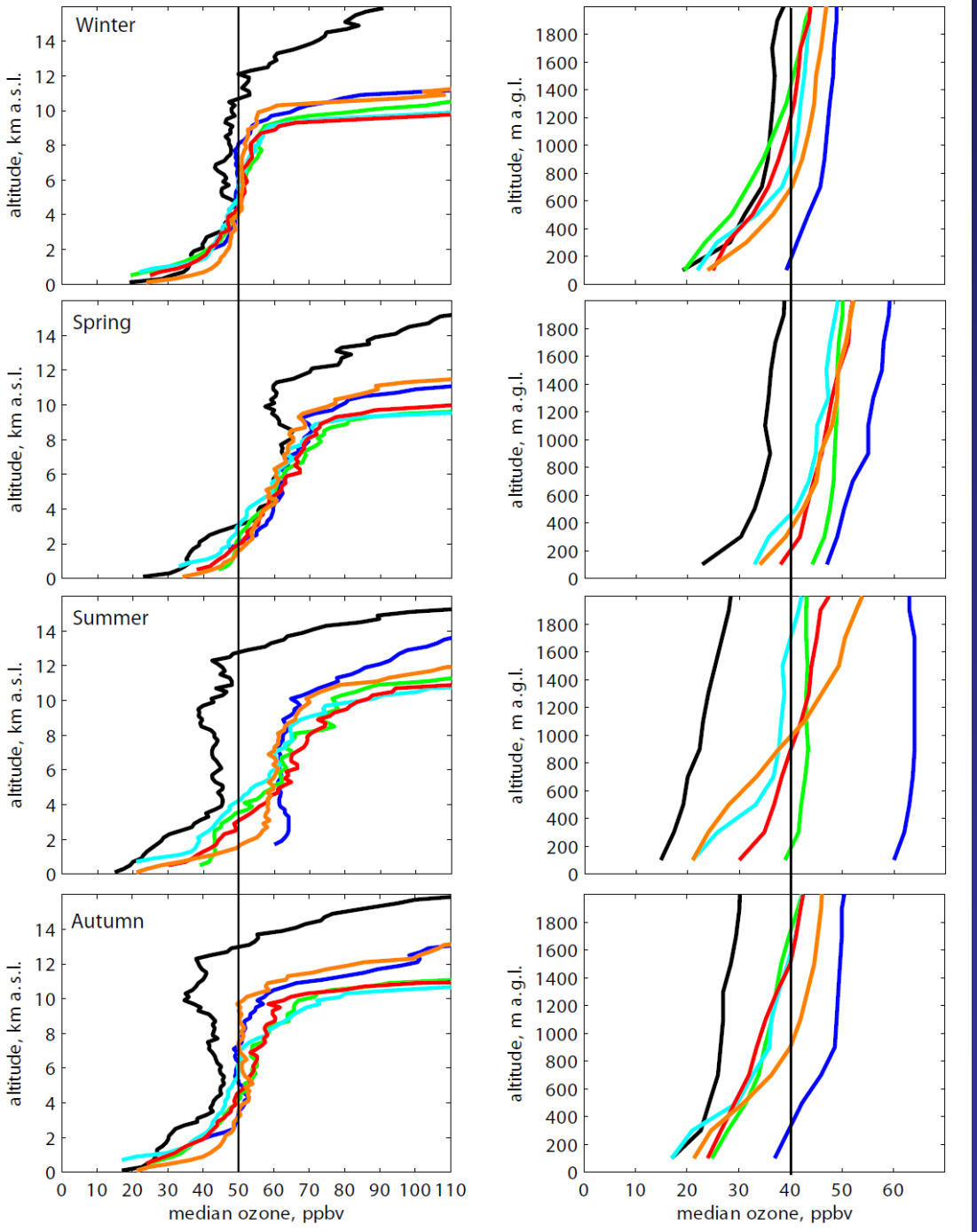

20 24 27 42 30 32 59 60 21 21 19 17
altitude, km a.s.l.
0 2 4 6 8 10 12
1 2 3 4 5 6 7 8 9 10 11 12
Month
20 30 40 50 60 70 80 90
ozone, ppbv

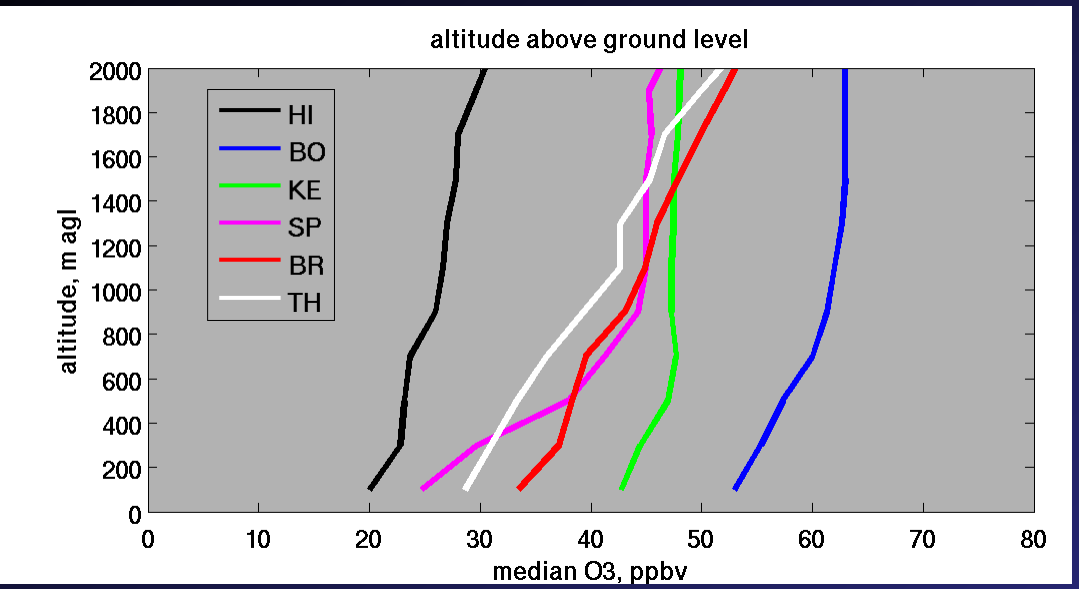

SP
KE
BL
TH
BO
HI

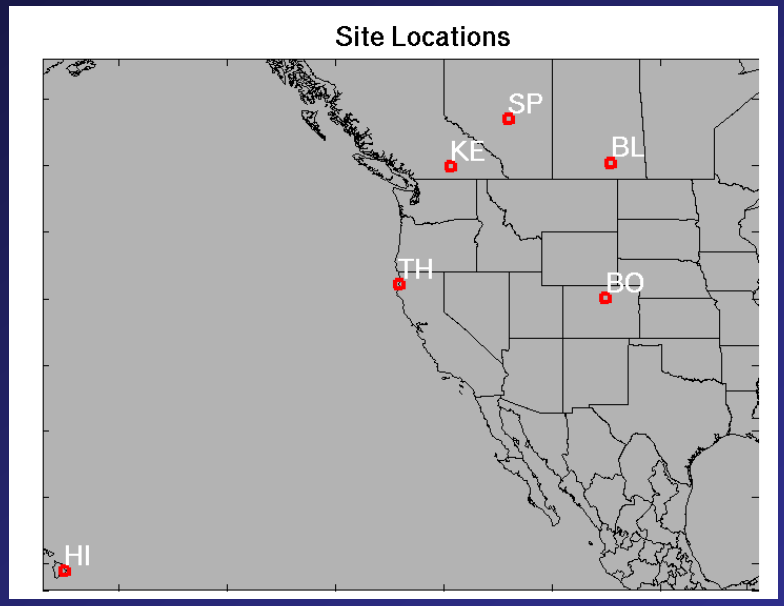

altitude, km a.s.l.
0 2 4 6 8 10 12 14
0 10 20 30 40 50 60 70 80 90 100 110
median ozone, ppbv


altitude, m a.g.l.
0 200 400 600 800 1000 1200 1400 1600 1800
0 10 20 30 40 50 60
median ozone, ppbv


H
1024
1020
1016
1012
5400
5500
5600
5700
5800
5900
geopotential height, m a.s.l.
altitude, km a.s.l.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
10
20
30
40
50
60
70
80
90
100
median ozone, ppbv


Winter
Spring
Summer
Autumn
altitude, km a.s.l.
altitude, m a.g.l.
median ozone, ppbv
median ozone, ppbv





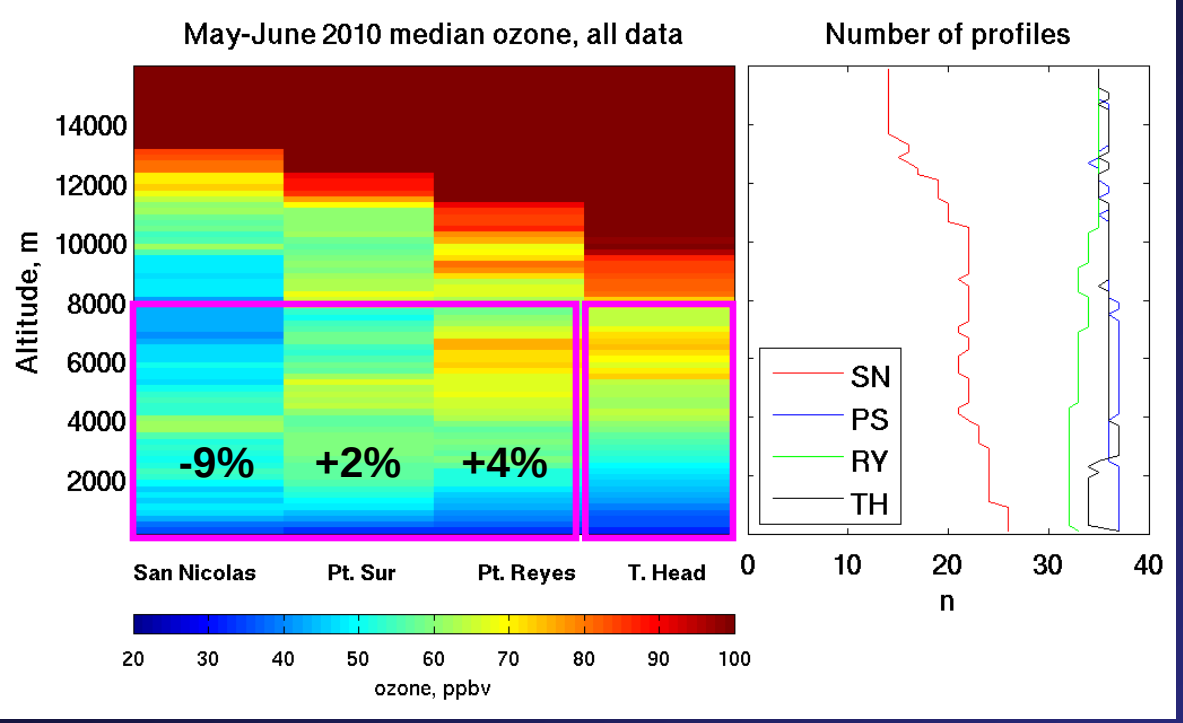
Comparison of 4 inland sites to Trinidad Head of mass of ozone (mPa/km) from 0 - 2 km a.g.l.

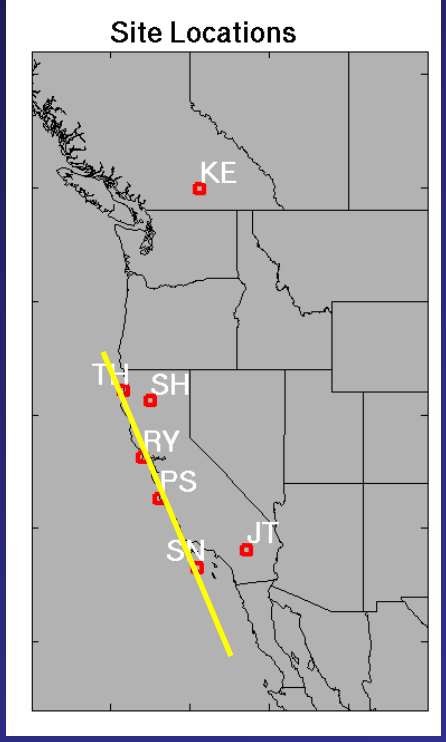
KE = +14%

SP = -5%

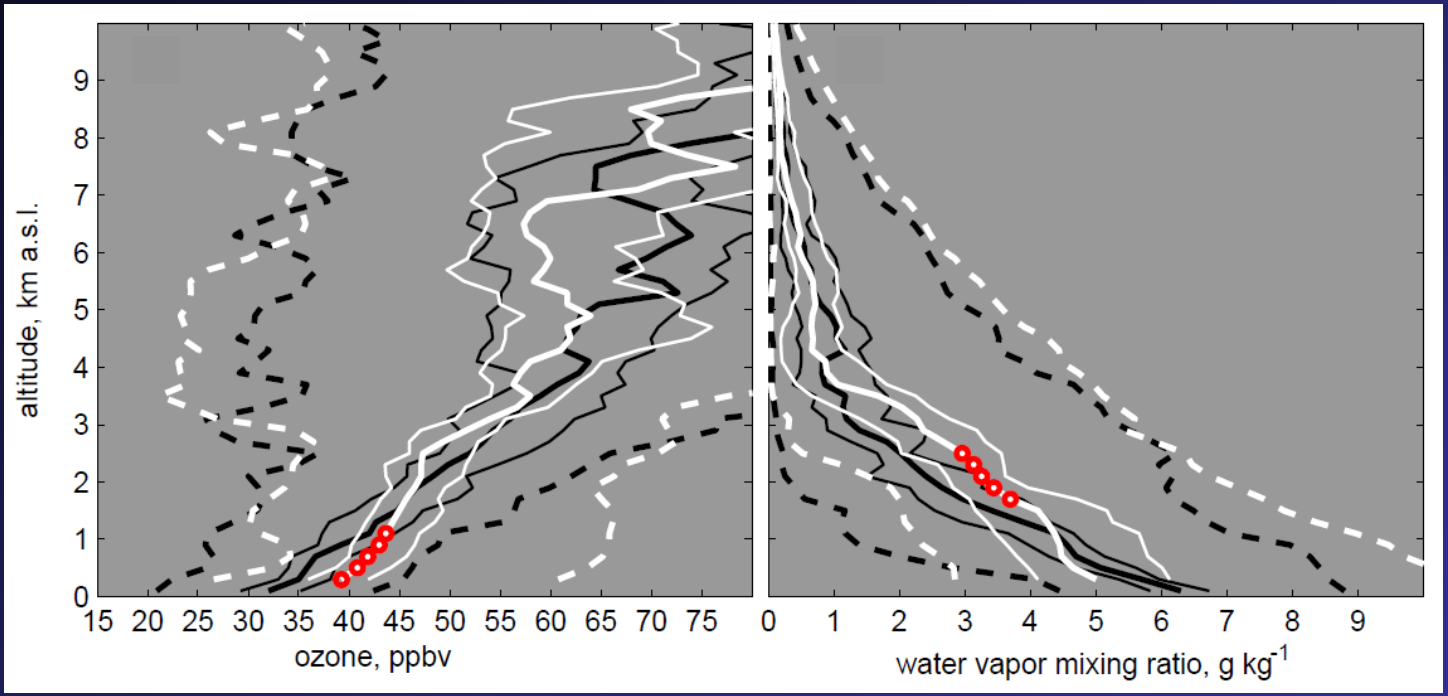
BL = +4%

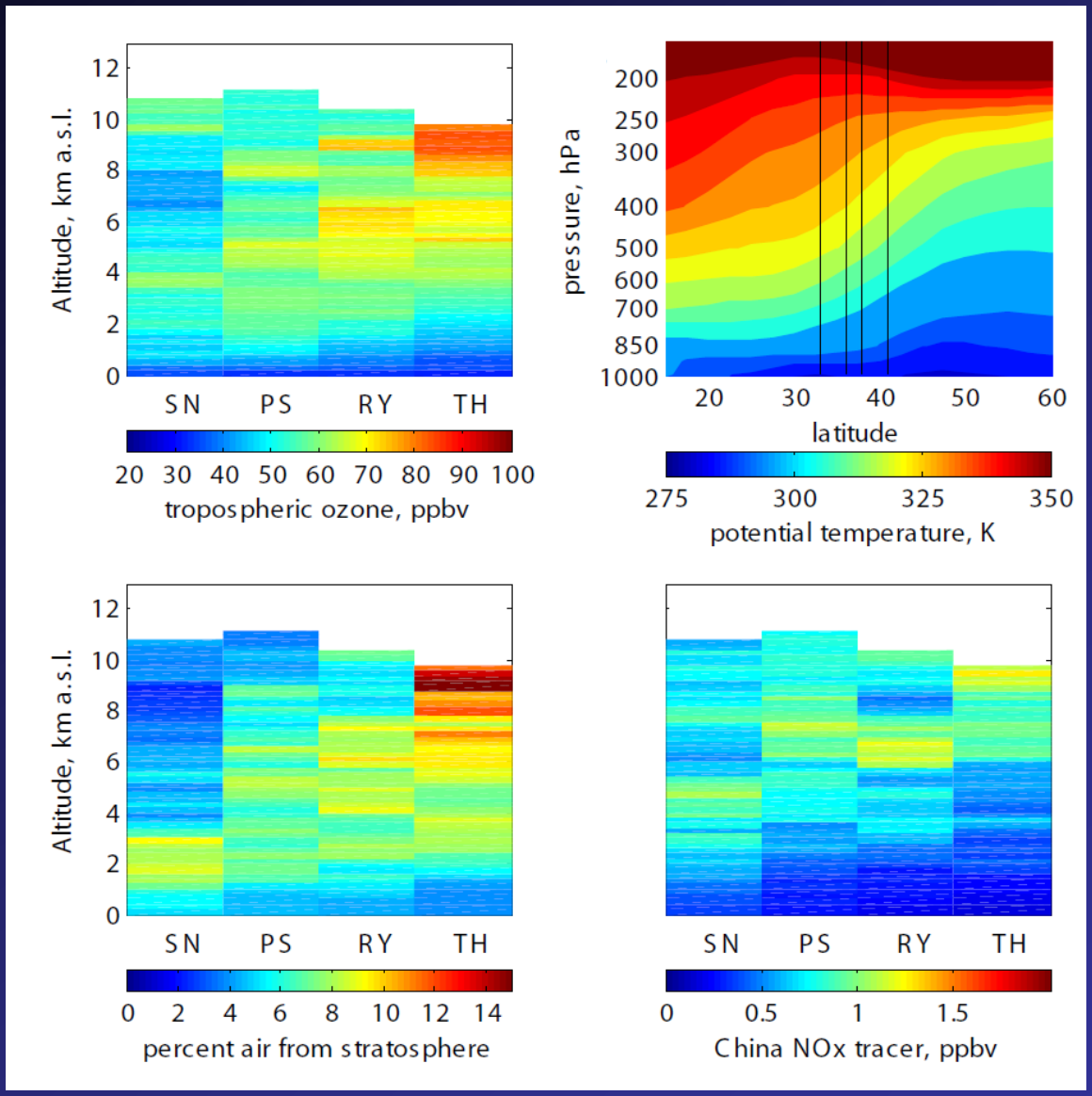
BO = +26%

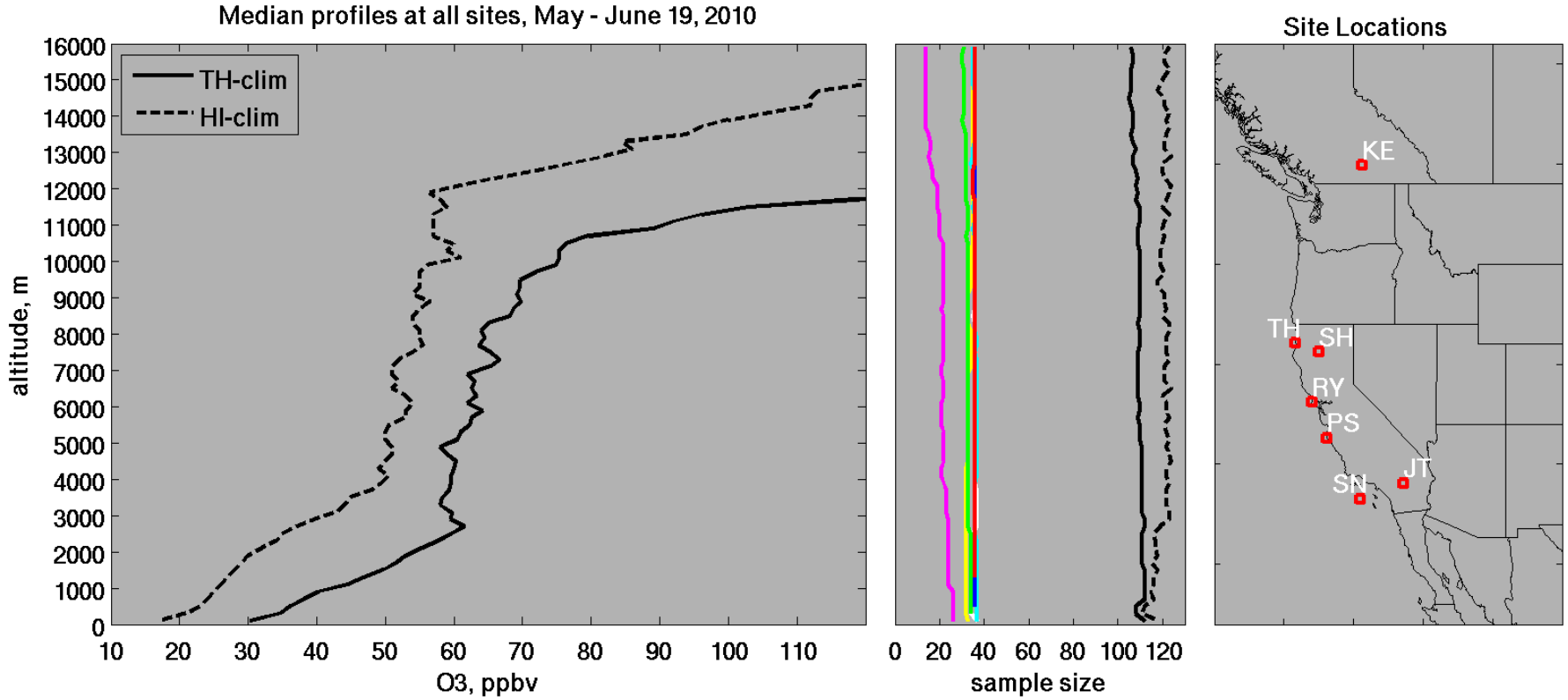


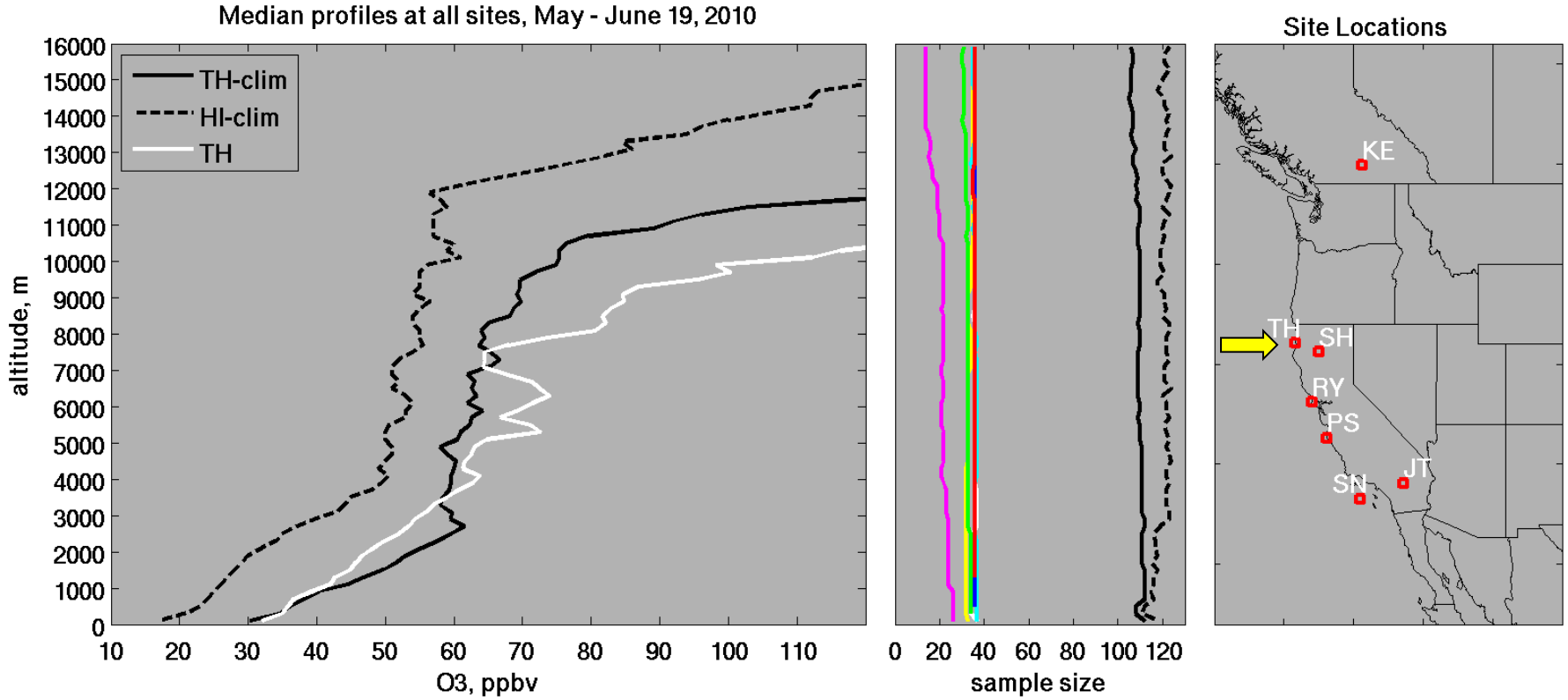


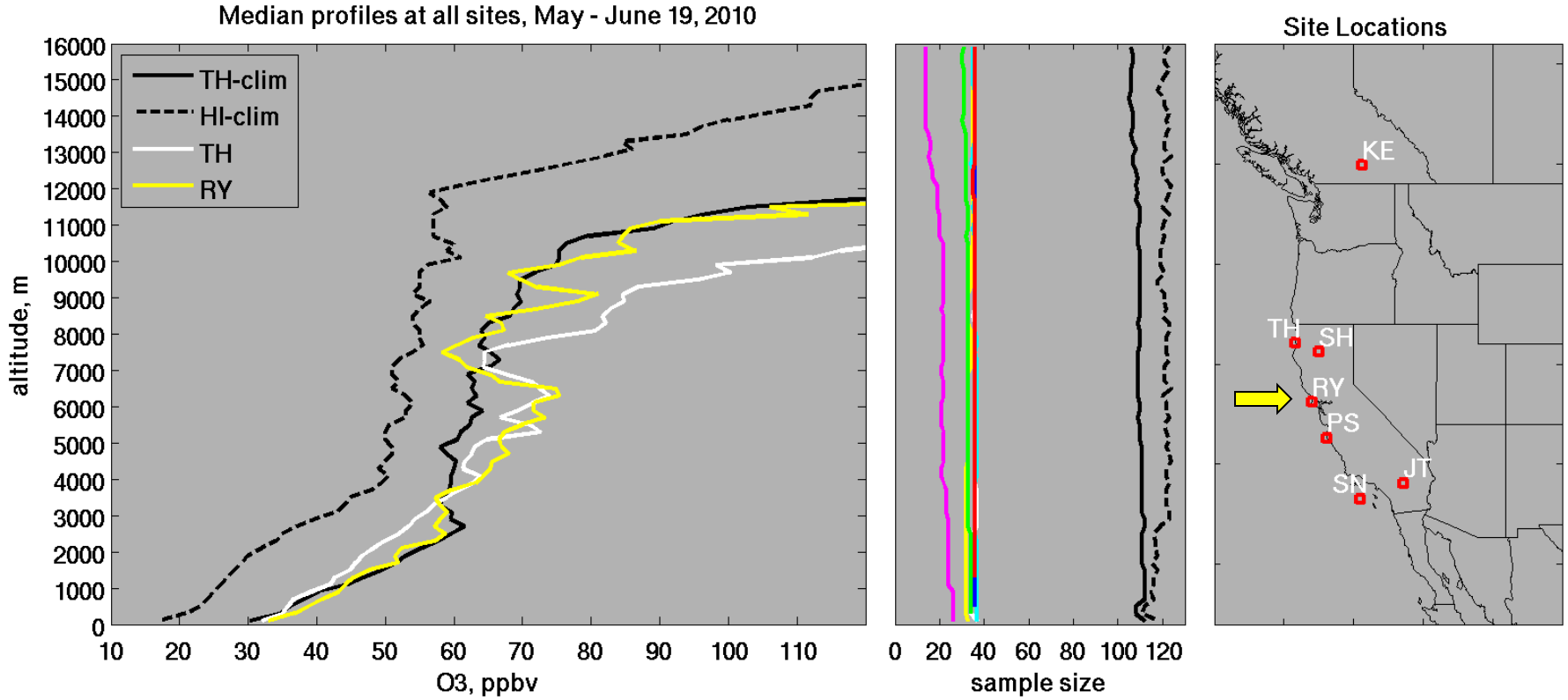
Percent difference in total mass of ozone per km (0-8 km), for southern sites compared to Trinidad Head.

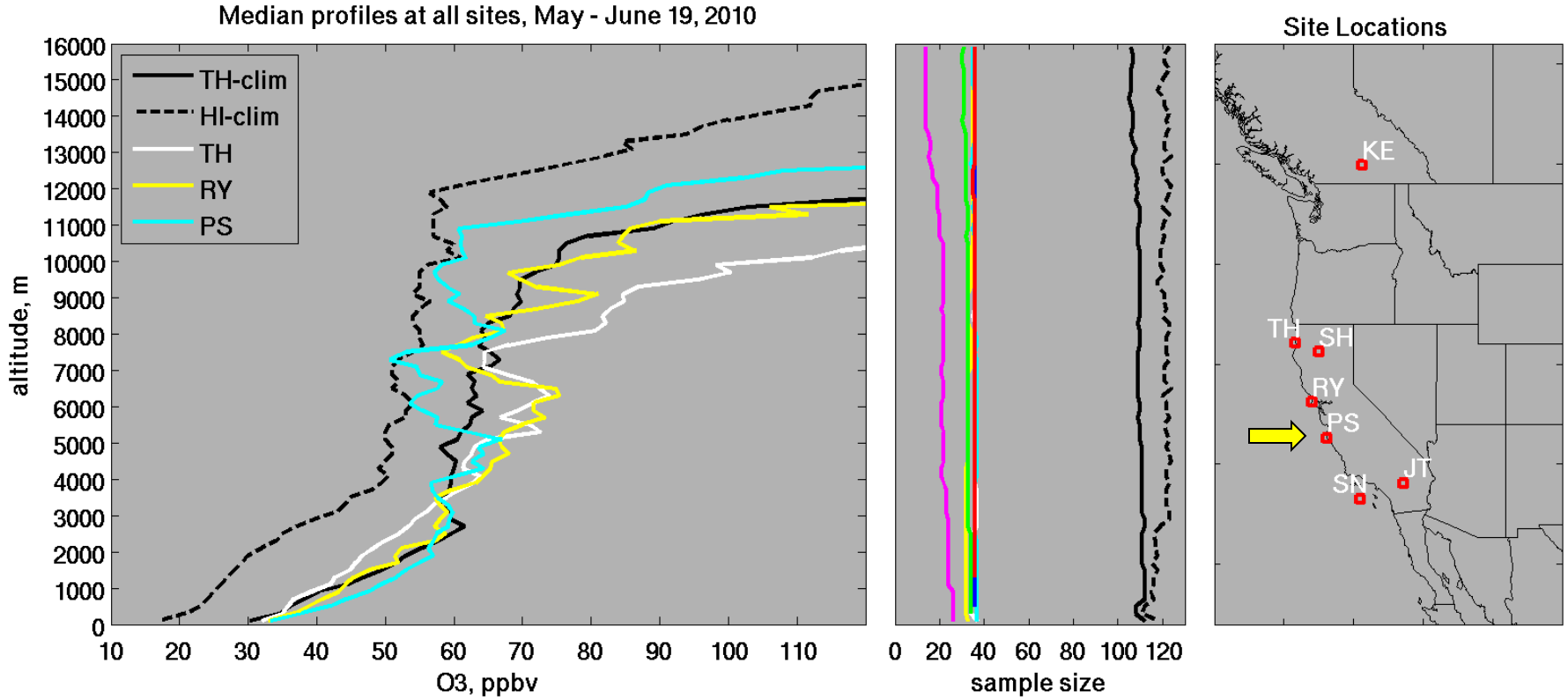

altitude, km a.s.l.
0
1
2
3
4
5
6
7
8
9
15 20 25 30 35 40 45 50 55 60 65 70 75
ozone, ppbv
0 1 2 3 4 5 6 7 8 9
water vapor mixing ratio, g kg-1

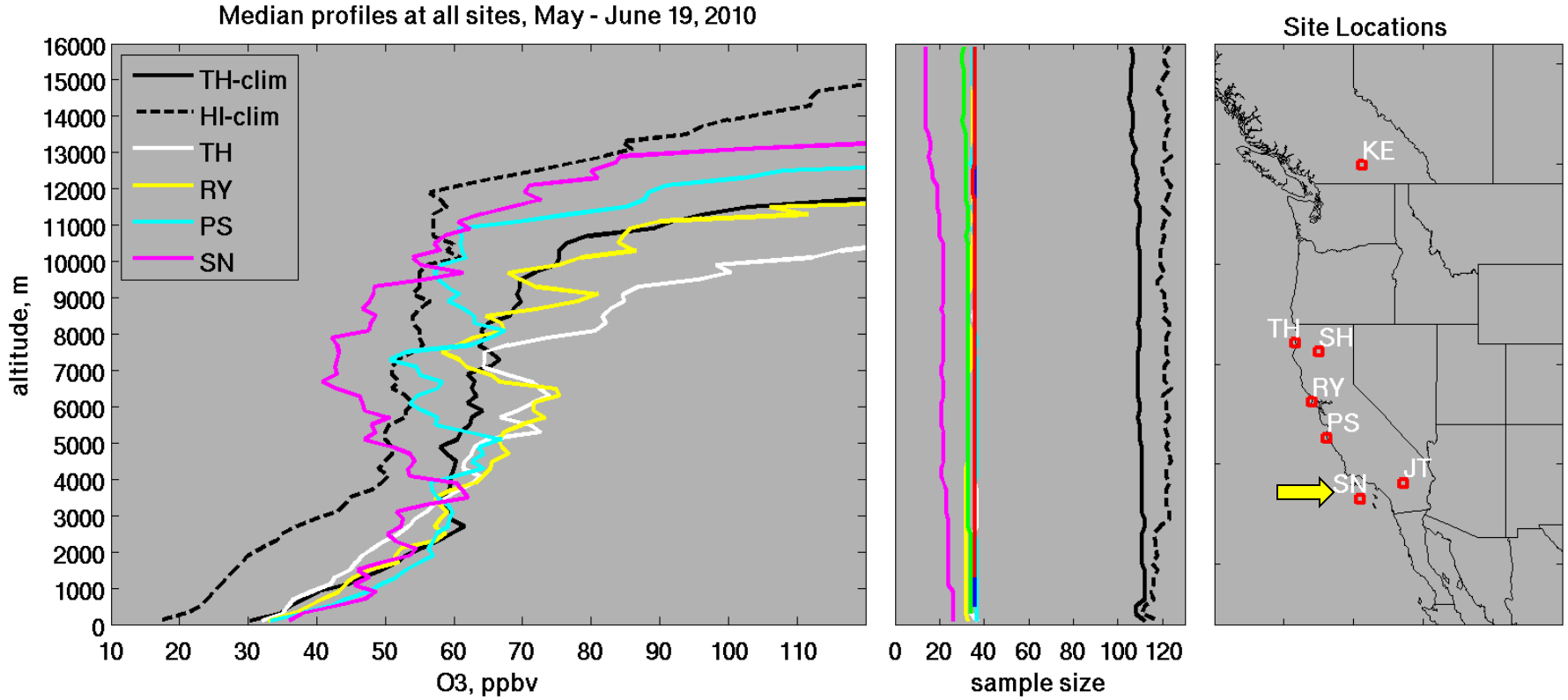

Altitude, km a.s.l.
12
10
8
6
4
2
0
SN
PS
RY
TH
20 30 40 50 60 70 80 90 100
tropospheric ozone, ppbv
pressure, hPa
200
250
300
400
500
600
700
850
1000
20 30 40 50 60
latitude
275 300 325 350
potential temperature, K
Altitude, km a.s.l.
12
10
8
6
4
2
0
SN
PS
RY
TH
0 2 4 6 8 10 12 14
percent air from stratosphere
SN
PS
RY
TH
0 0.5 1 1.5
China NOx tracer, ppbv

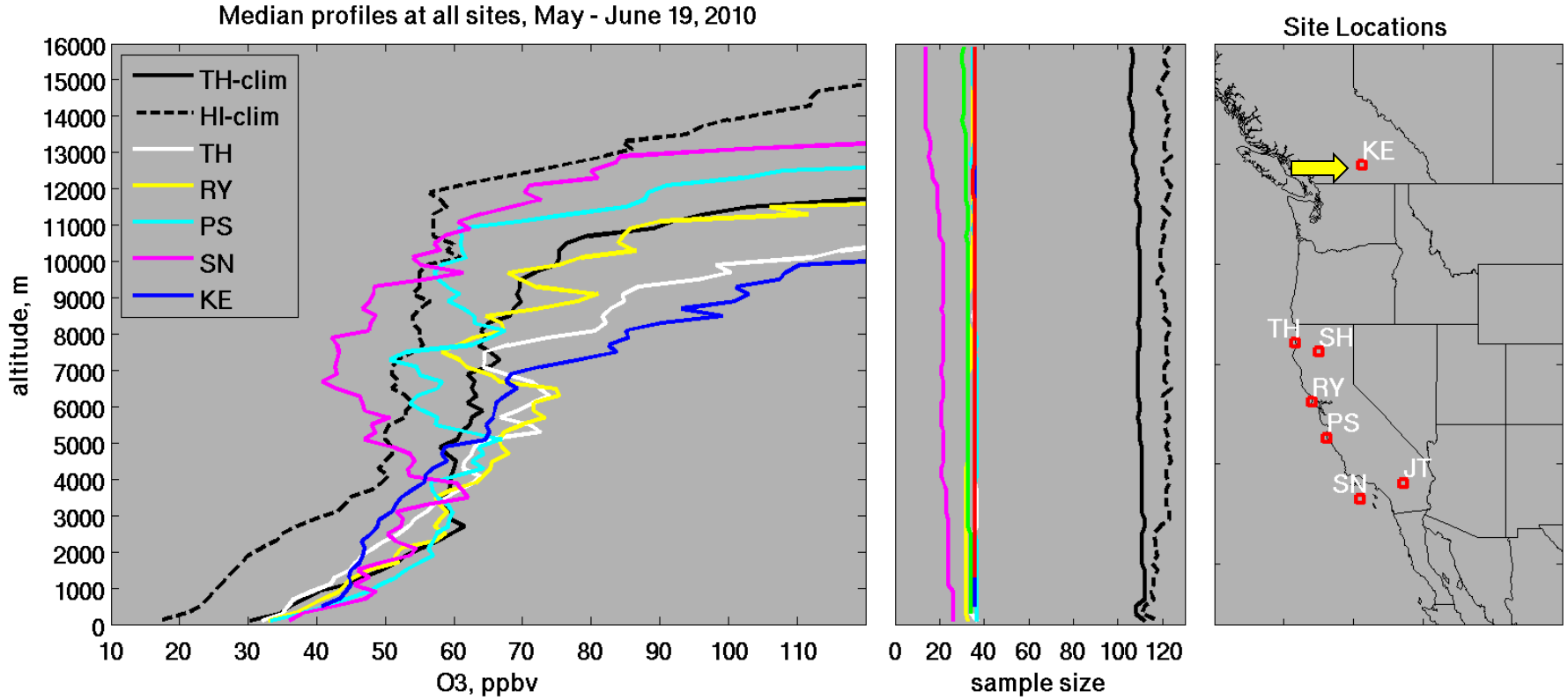

Median profiles at all sites, May - June 19, 2010
TH-clim
HI-clim
altitude, m
O3, ppbv
sample size
Site Locations
KE
TH
SH
RY
PS
JT
SN

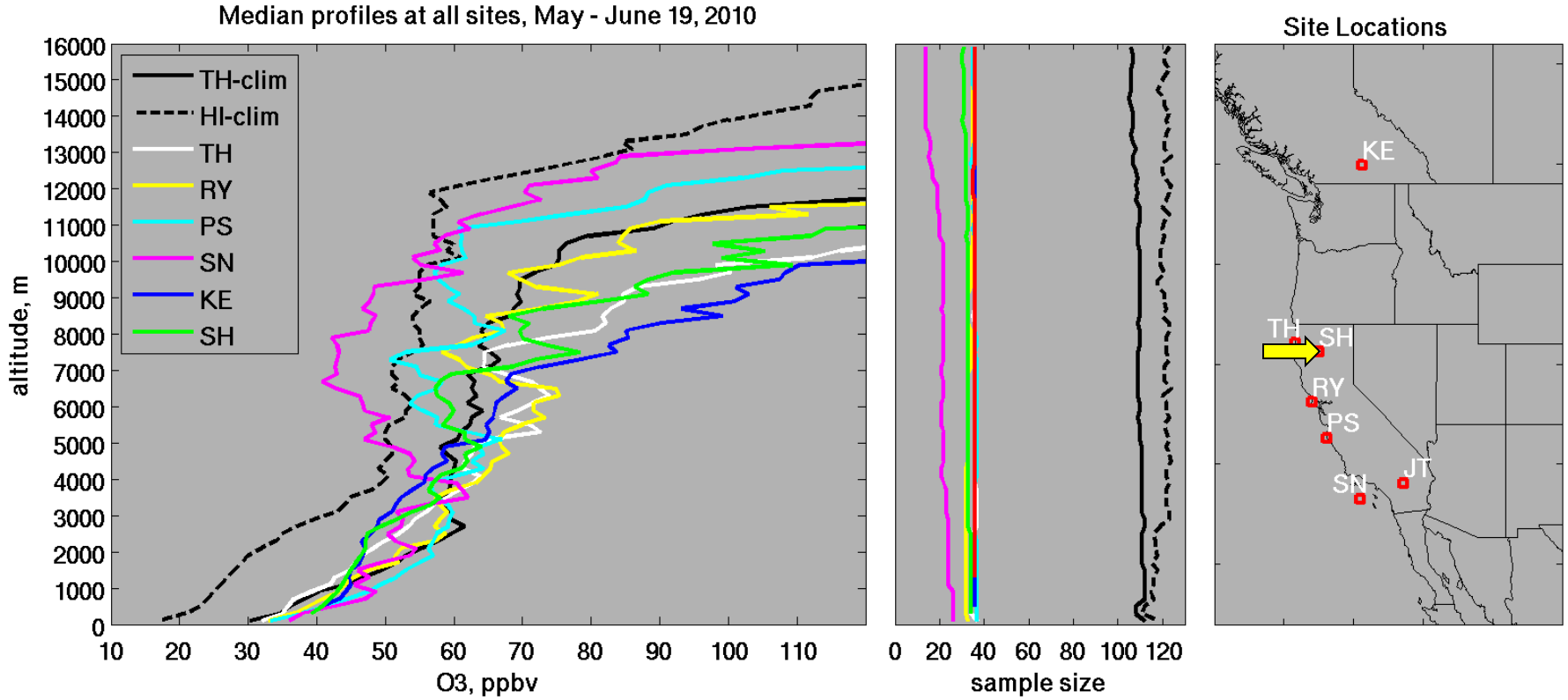

Median profiles at all sites, May - June 19, 2010
TH-clim
HI-clim
TH
altitude, m
O3, ppbv
sample size
Site Locations
KE
TH
SH
RY
PS
JT
SN

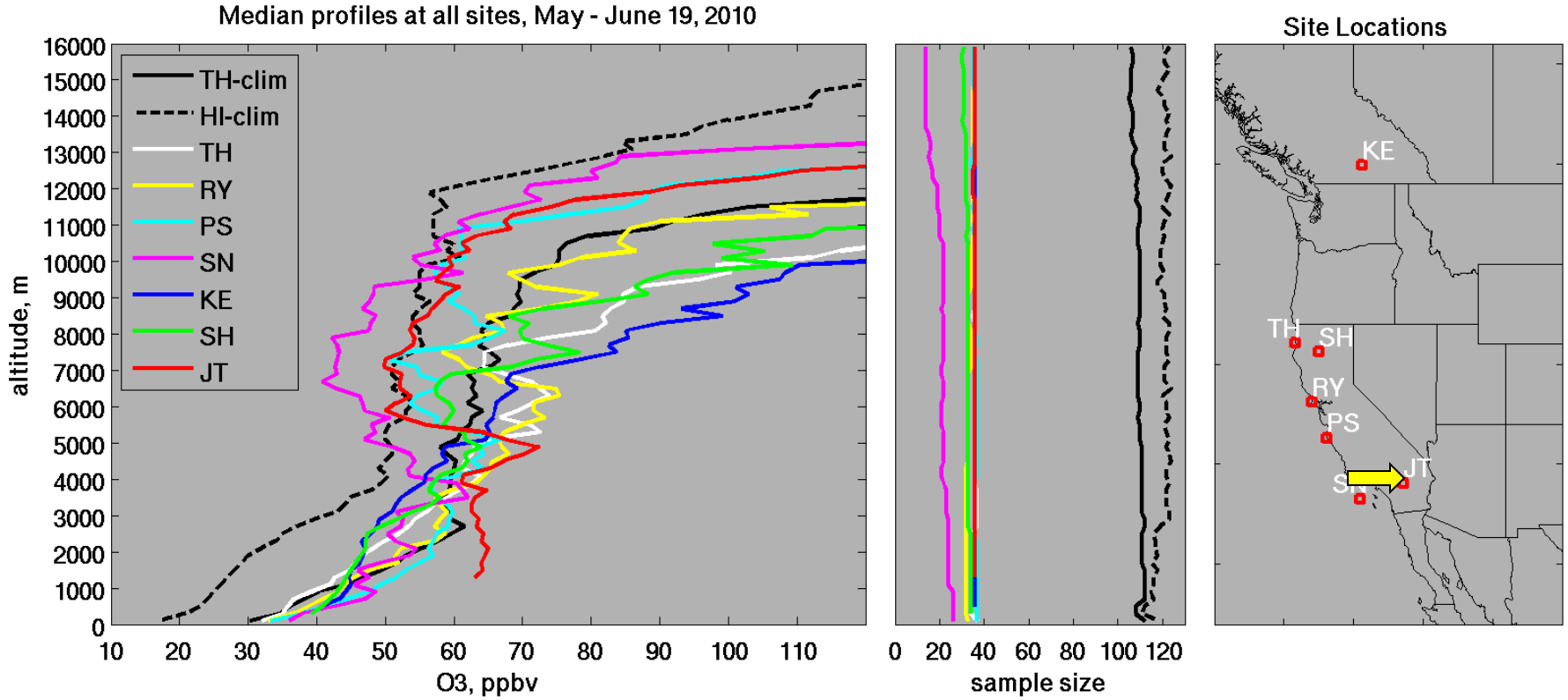

Median profiles at all sites, May - June 19, 2010
TH-clim
HI-clim
TH
RY
altitude, m
O3, ppbv
sample size
Site Locations
KE
TH
SH
RY
PS
JT
SN


Median profiles at all sites, May - June 19, 2010
TH-clim
HI-clim
TH
RY
PS
altitude, m
O3, ppbv
sample size
Site Locations
KE
TH
SH
RY
PS
JT
SN


Median profiles at all sites, May - June 19, 2010
TH-clim
HI-clim
TH
RY
PS
SN
altitude, m
O3, ppbv
sample size
Site Locations
KE
TH
SH
RY
PS
JT
SN


Median profiles at all sites, May - June 19, 2010
altitude, m
O3, ppbv
sample size
TH-clim
HI-clim
TH
RY
PS
SN
KE
Site Locations
KE
TH
SH
RY
PS
JT
SN


Median profiles at all sites, May - June 19, 2010
altitude, m
O3, ppbv
sample size
TH-clim
HI-clim
TH
RY
PS
SN
KE
SH
Site Locations
KE
TH
SH
RY
PS
JT
SN


Median profiles at all sites, May - June 19, 2010
altitude, m
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
TH-clim
HI-clim
TH
RY
PS
SN
KE
SH
JT
10 20 30 40 50 60 70 80 90 100 110
O3, ppbv
0 20 40 60 80 100 120
sample size
Site Locations
KE
TH
SH
RY
PS
JT
SN