Cluster Analysis of Air Quality Data for CCOS Study Domain

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Overview

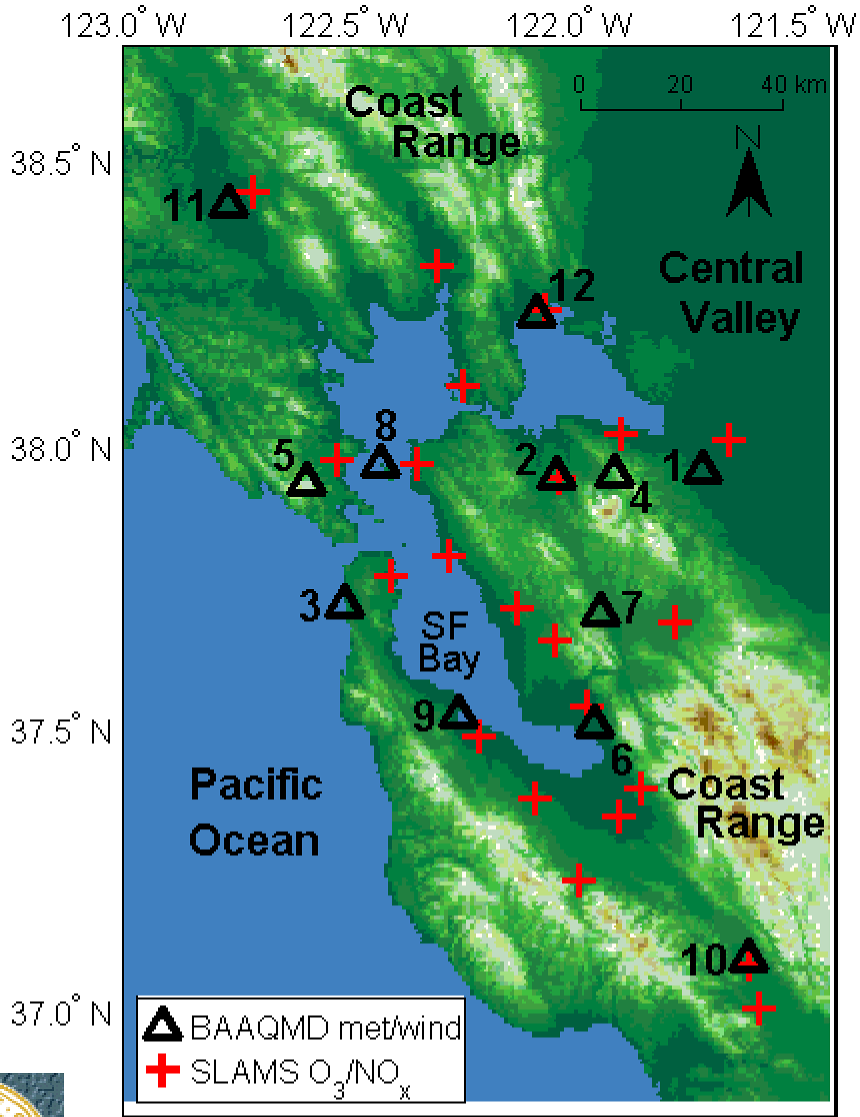
- Project: Cluster Analysis for CCOS Domain
  I. Intra-basin analyses: wind patterns & synoptic regimes
  II. Meteorological response of O_3 levels
- Intra-basin analyses:
  - Completed Bay Area analysis
    - Strong synoptic influence; seabreeze cycles
  - Completed North SJV wind field clustering
    - Synoptic & ventilation effects
  - Completed Central SJV wind field clustering
    - Synoptic & mesoscale (Fresno eddy) effects
  - Completed South SJV wind field clustering
    - Synoptic effects; mesoscale variability difficult to capture
  - Completed Sacramento Valley & Mountain Counties analysis
    - Synoptic effects; mesoscale conditions
- New work, PM analysis for Bay Area
- Conclusions and recommendations

Cluster Analysis for CCOS

- Scope of 2-year project
  I. Intra-basin wind field cluster analyses
    - Requires continuous, hourly surface wind data
    - Days grouped by diurnal wind field patterns
    - Reveals synoptic regimes and mesoscale flow patterns

  II. Inter-basin analysis
- Study Domain
  - 6 CCOS air basins
    - San Francisco Bay Area
    - SJV: split into North, Central, & South
    - Sacramento Valley
    - Mountain Counties
  - 1996-2004 ozone seasons (1 May – 31 October)

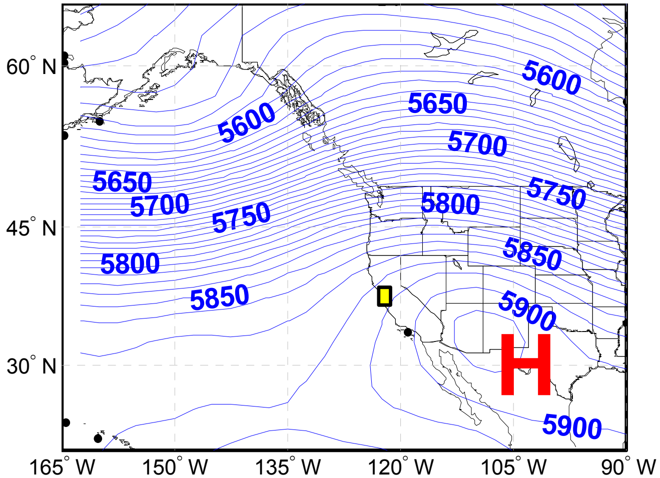
San Francisco Bay Area



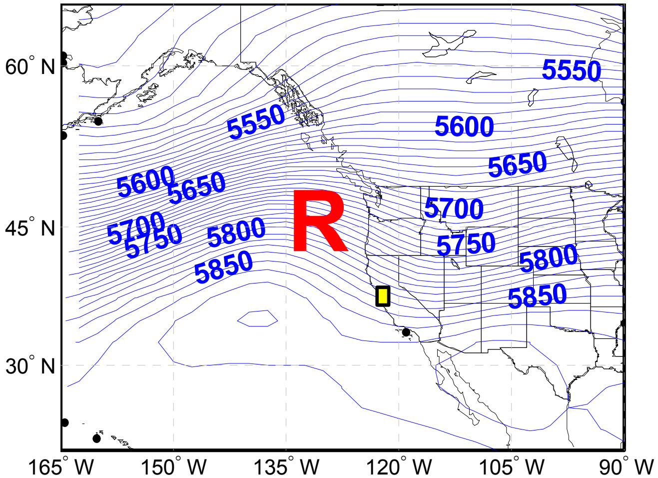
Surface Wind Monitors

1	Bethel Island	-2 m
2	Concord	24 m
3	Fort Funston	57 m
4	Kregor Peak	577 m
5	Mt. Tamalpais	762 m
6	NUMMI	9 m
7	Pleasanton	99 m
8	Pt. San Pablo	70 m
9	San Carlos	1 m
10	San Martin	85 m
11	Santa Rosa	29 m
12	Suisun	5 m

SFBA clusters = synoptic regimes

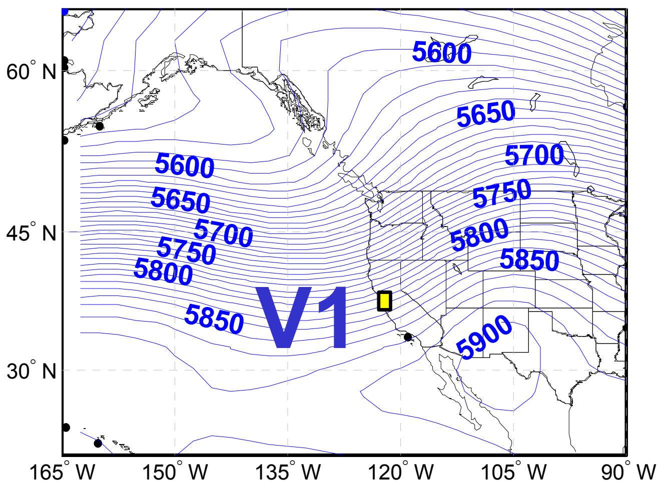


Onshore High: 353 d, 13% episodes

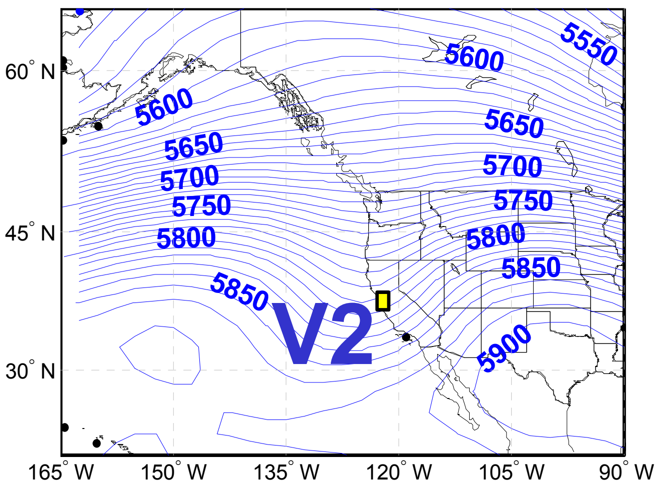


Offshore High: 86 d, 13% episodes

Weaker Trough: 309 d, 0% episodes



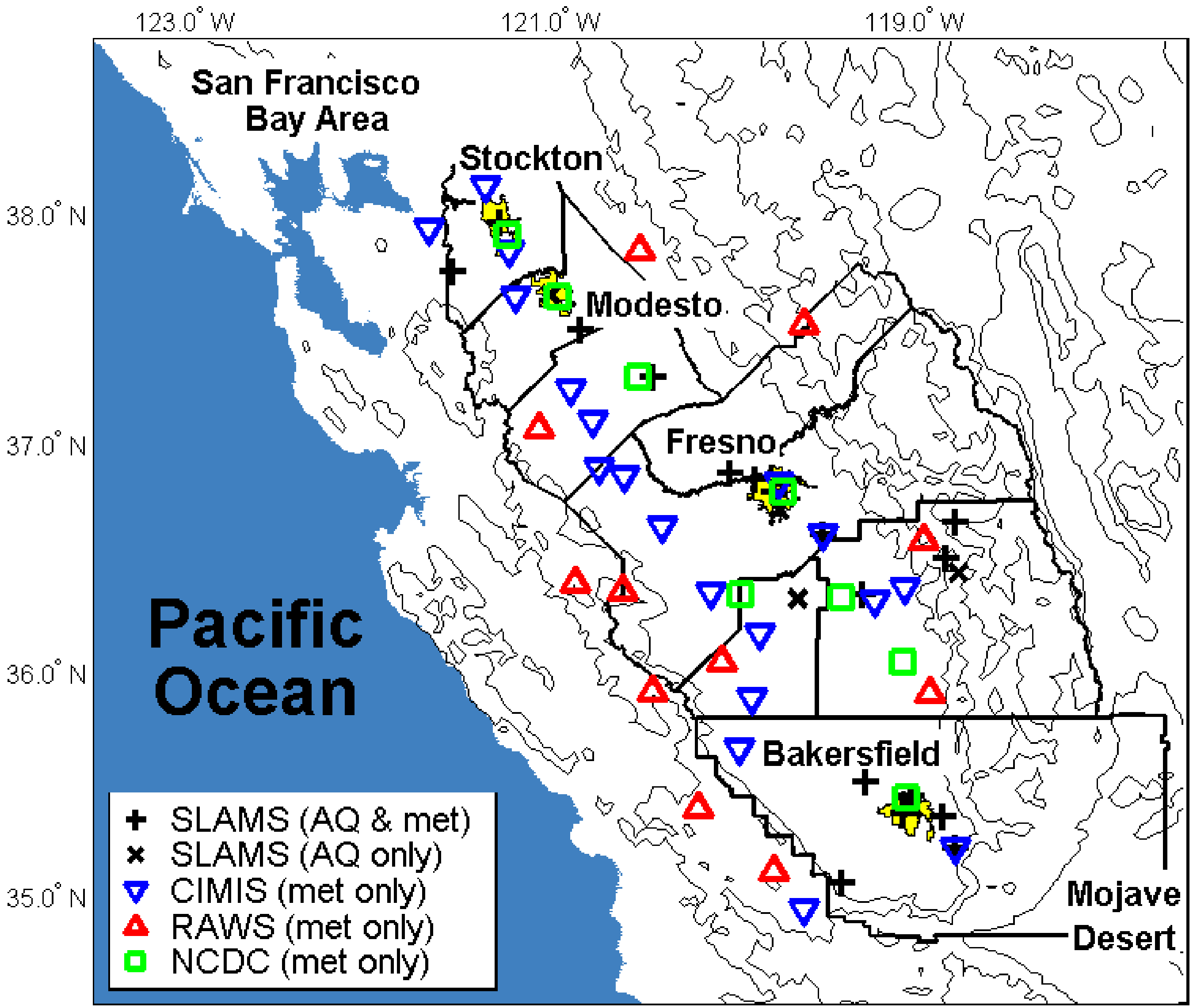
Deeper Trough: 309 d, 0% episodes



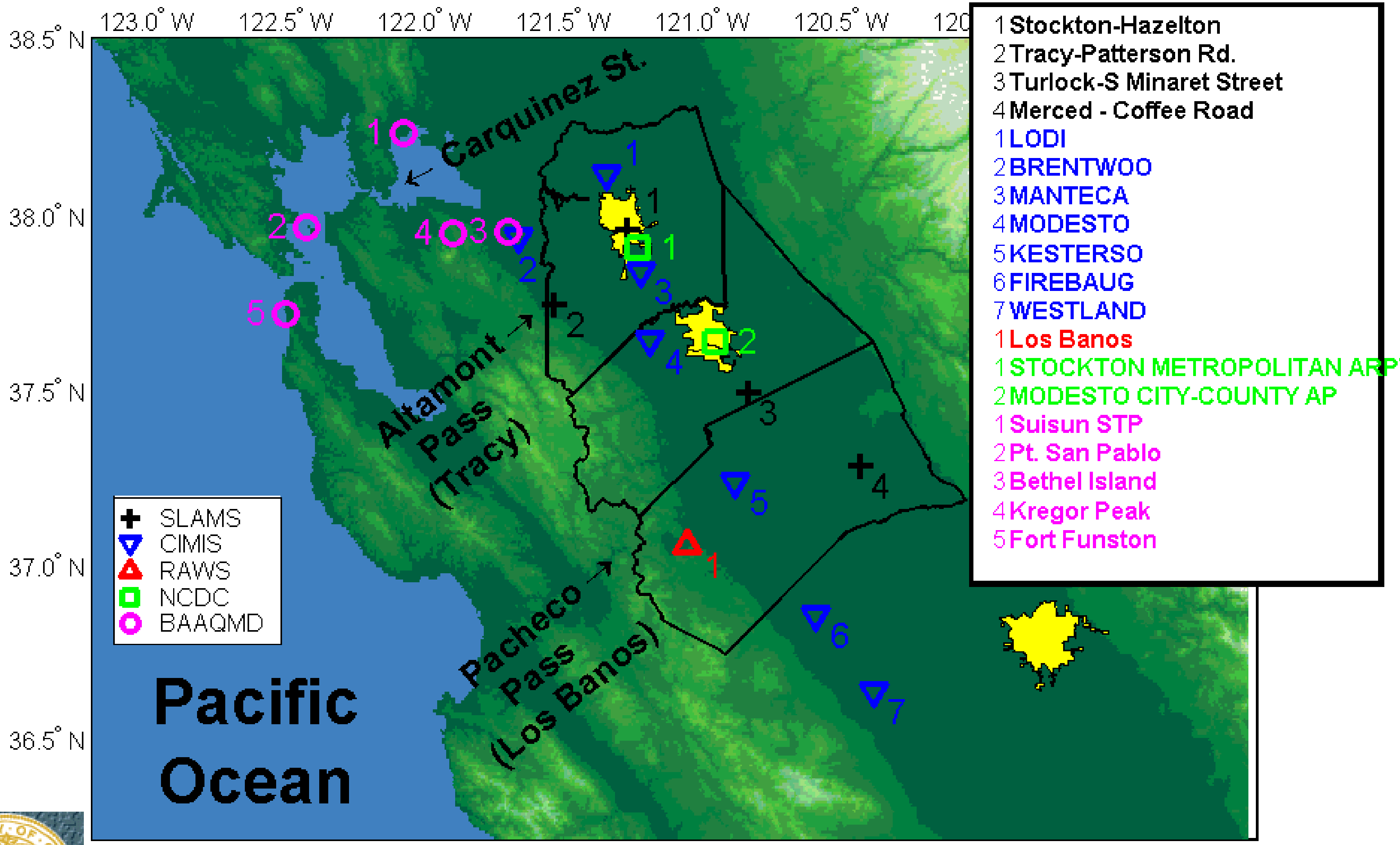
Conceptual Model for SFBA

- **R** transitions rapidly to **H**
  - Severe, multi-day episodes
  - Reverse **H**→**R** does not occur
  - Polar low may "save" SFBA from episode
- Persistence of **H** indicates stability
  - Displaced by sufficiently deep trough (e.g. **V2**)
  - Bulk of episodes during persistent **H**
- Transitions from **V1** & **V2** driven by global met.
  - Troughs may persist for long periods; low O_3 levels
  - Transition to **H** or **R** will occur unless O_3 season ends

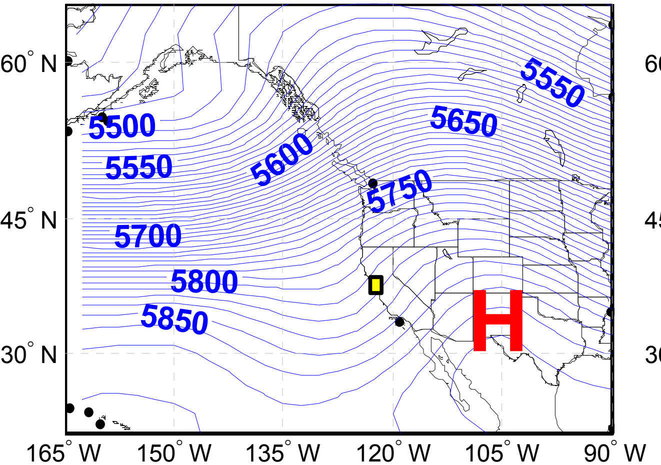
San Joaquin Valley

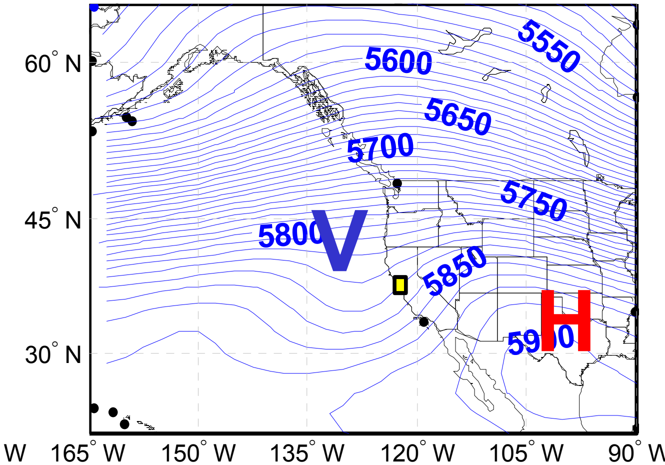


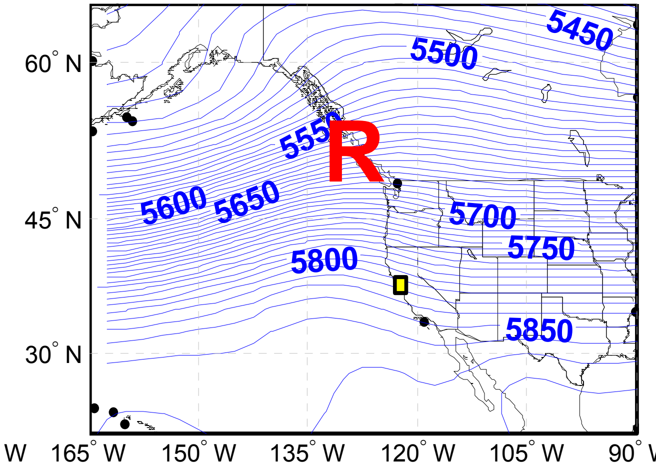
N-SJV Wind Monitors



N-SJV clusters = synoptic regimes

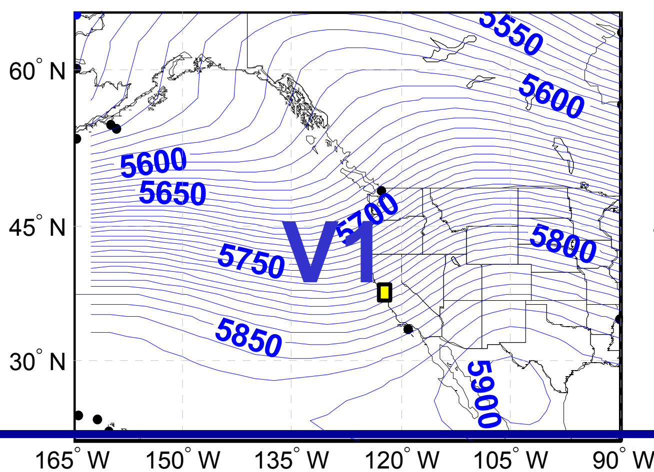


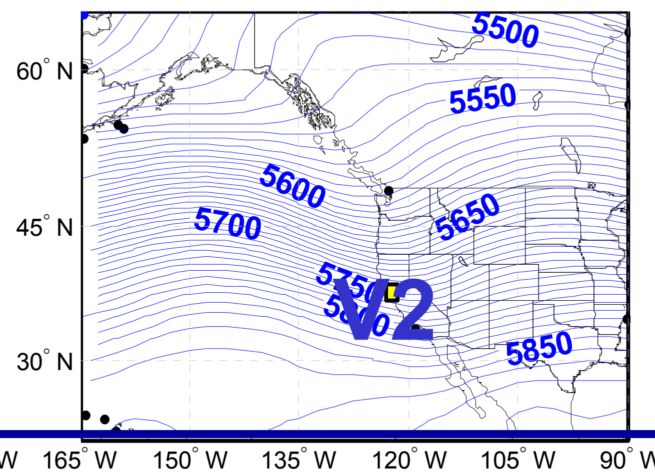




H: 179 days, 42% H/V: 212 days, 25% R: 264 days, 19%

V1: 299 days, 12% V2: 108 days, 6%





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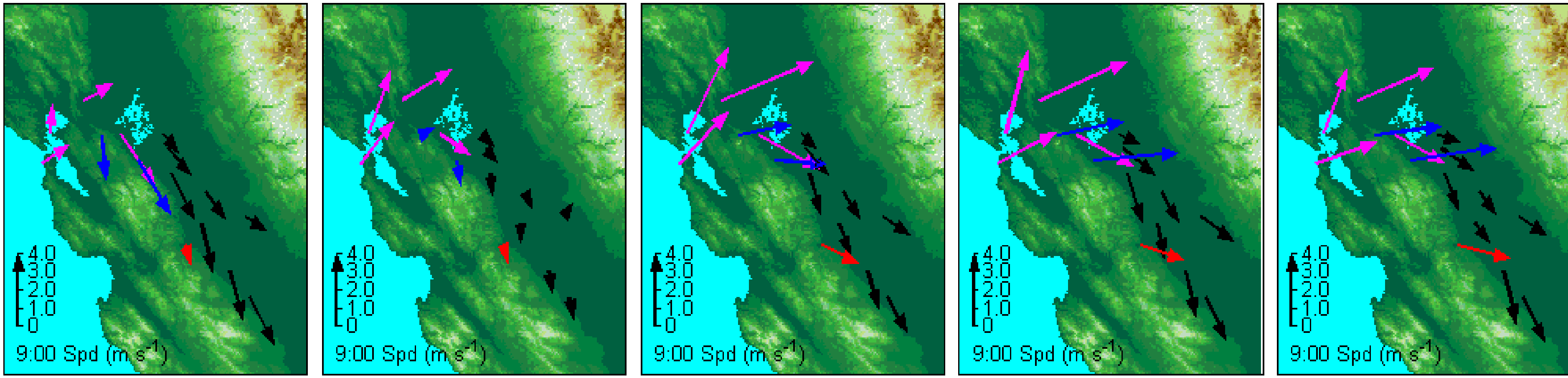
N-SJV 0900 PST Wind Field



R **H** **H/V** **V1** **V2**

Increasing marine ventilation: R < H < H/V < V1 < V2

Magenta: Carquinez Strait— Ft. Funston, Pt. San Pablo, Suisun, Bethel Is.

Blue: Altamont Pass— Kregor Peak, Tracy

Red: Pacheco Pass— Los Banos

Black: SJV floor

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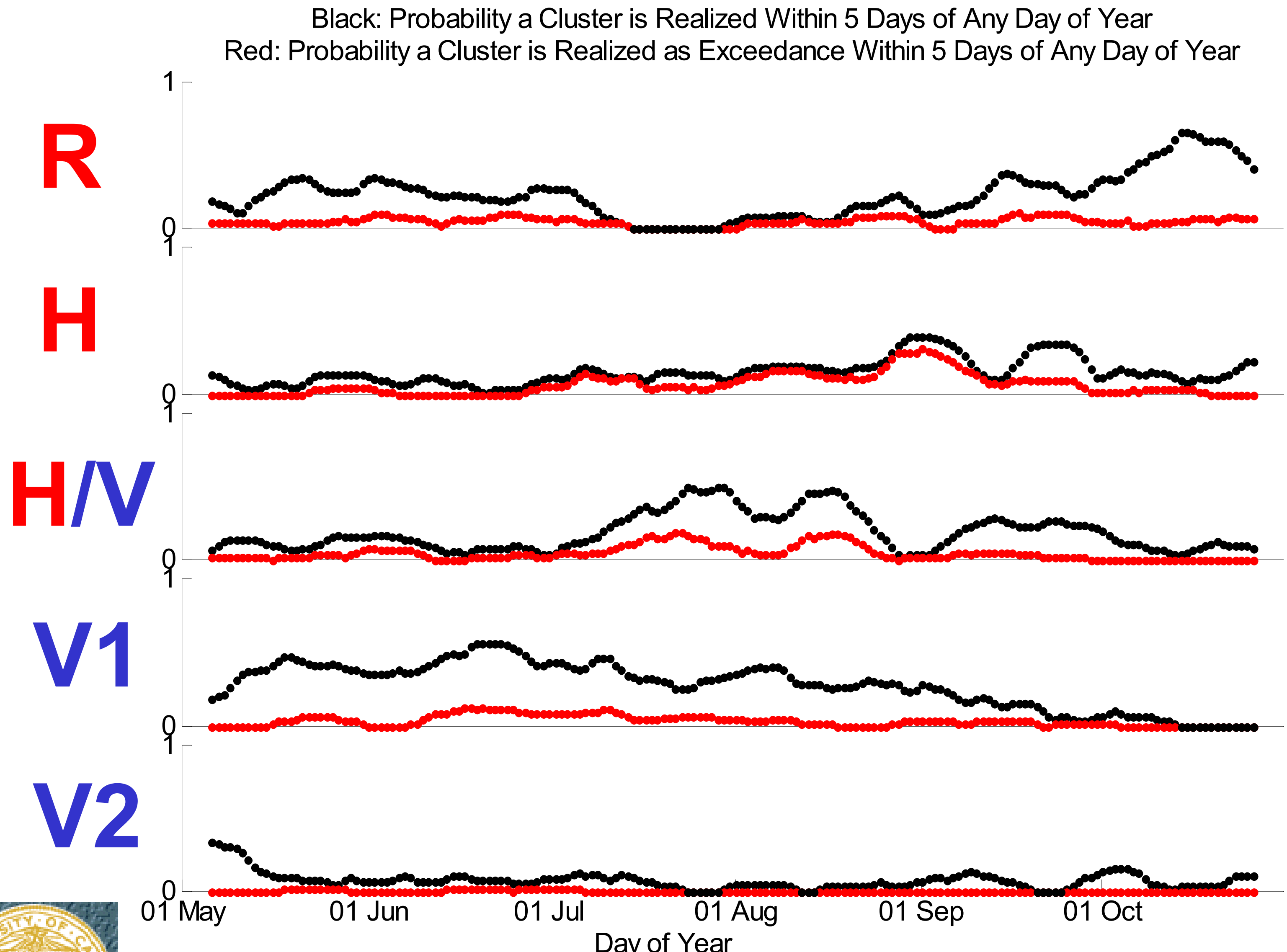
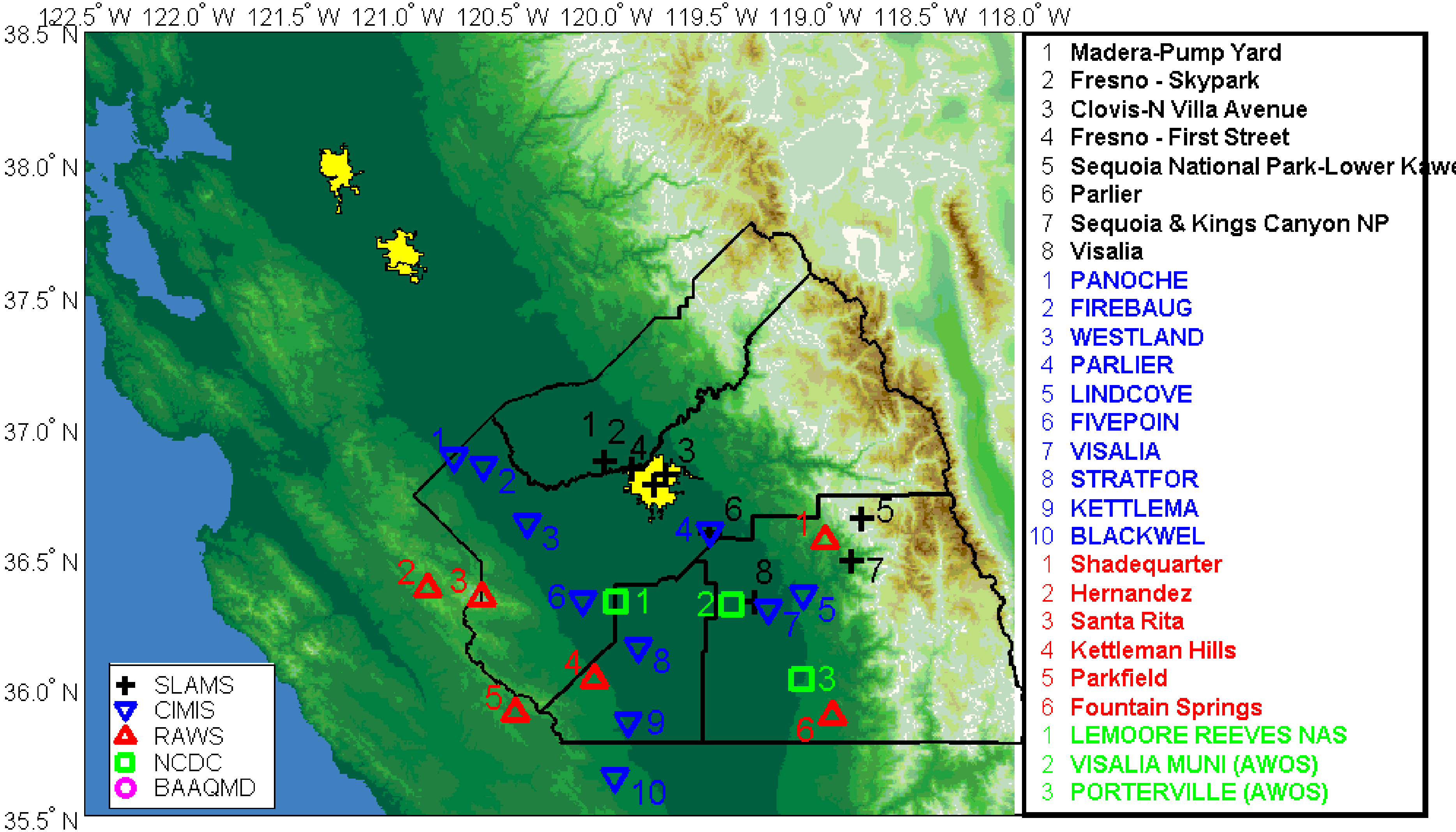
N-SJV Seasonal Distribution



N-SJV Conceptual Model

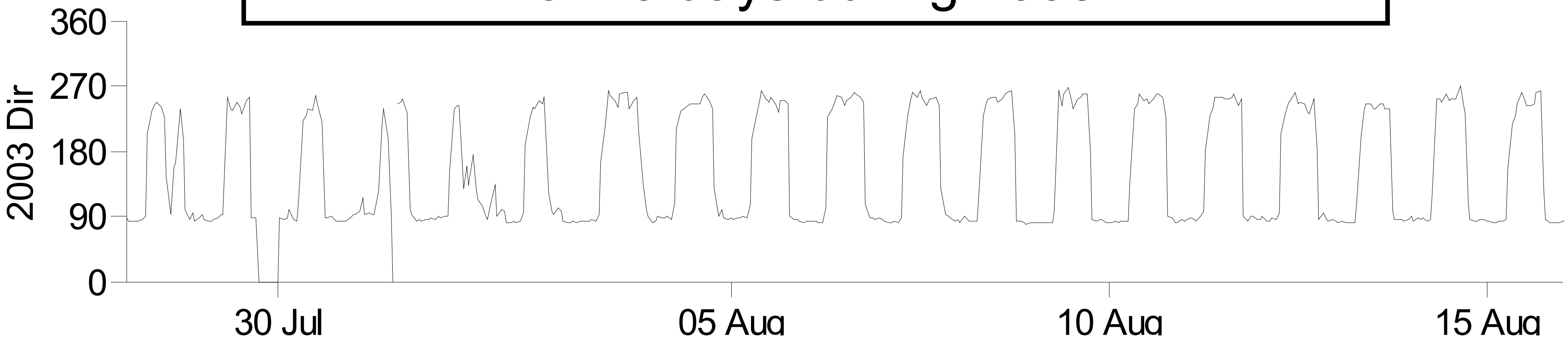
- $\alpha = 0.05$
  - R ⟷ H/V disfavored
  - Clusters occur in different seasons (trivial result)
- $\alpha = 0.15$
  - R ⟶ H favored
  - H ⟶ H/V favored
  - H/ V ⟶ V favored
  - V ⟶ R favored
- Compare to Bay Area
  - Transitions significant at $\alpha < 0.02$
  - Stronger synoptic influence than N-SJV

Central SJV Wind Monitors



Upslope/Downslope Cycle

Wind direction at SLAMS Sequoia monitor
for 20 days during 2003.



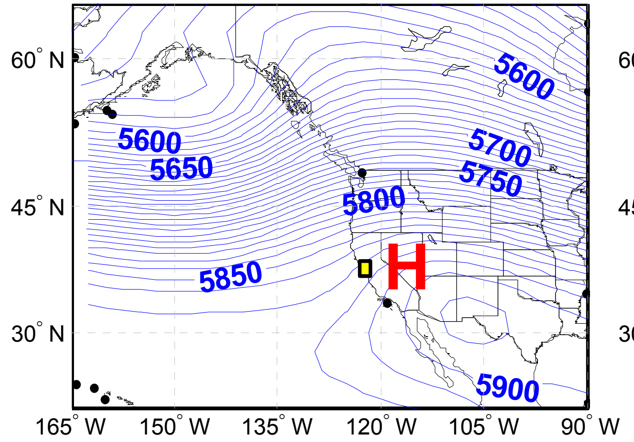
Flow switches from easterly to westerly.

Daytime upslope flows; nighttime drainage flows

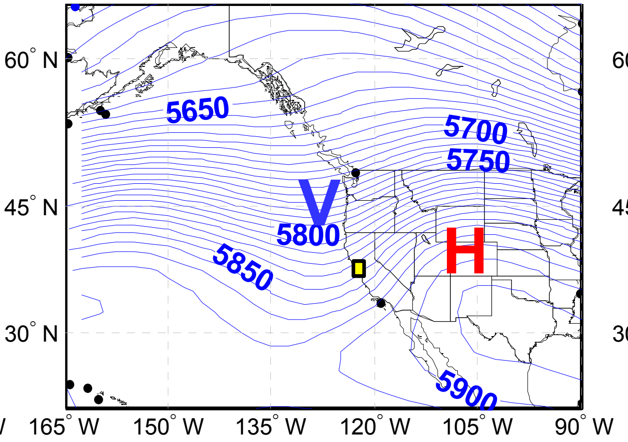
Diurnal cycle largely captures local effects.

Signal is not well modeled by clustering algorithm.

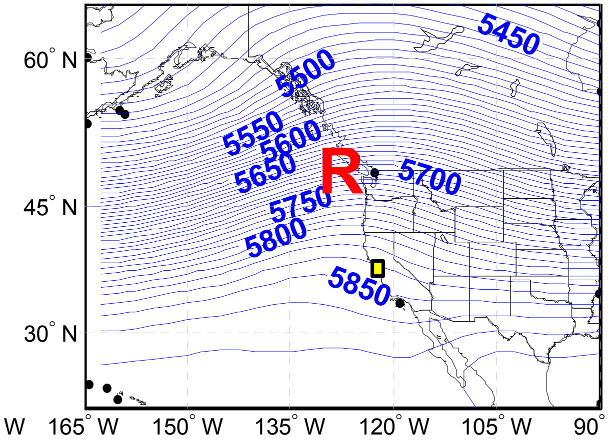
C-SJV clusters = synoptic regimes



H: 203 days

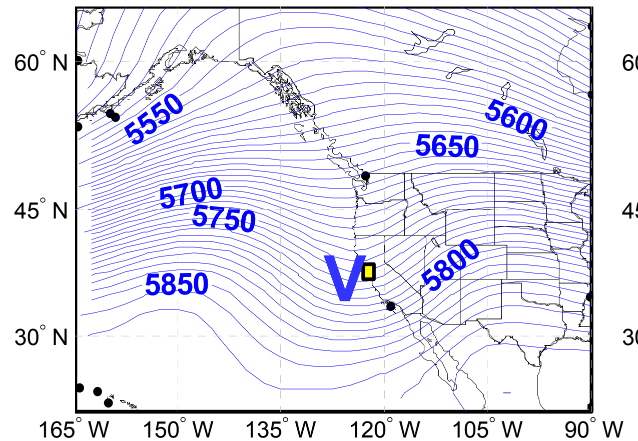


H/V: 169 days

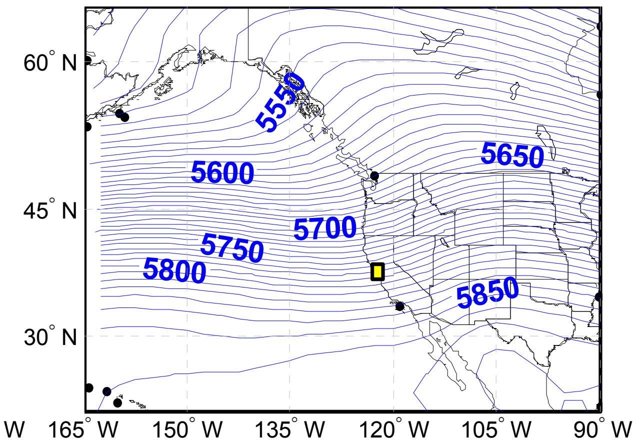


R: 341 days

V: 279 days



V/I: 378 days



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C-SJV 8-hr O_3 Exceedances

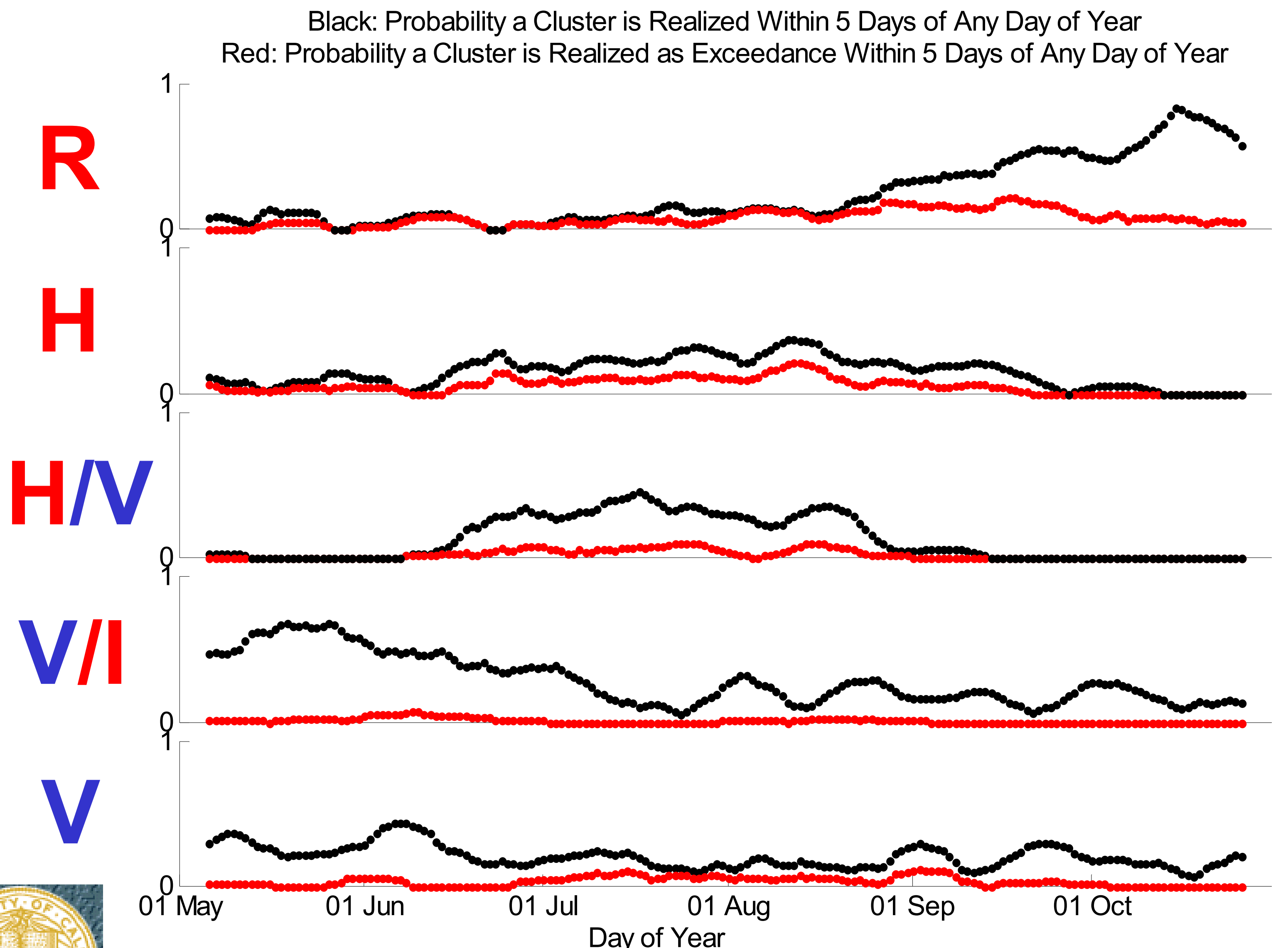
Percentage of days in each cluster that are 8-hr O_3 exceedances

	V	V/I	H/V	H	R
	279 d	378 d	169 d	203 d	341 d
Total	40%	32%	64%	92%	59%
SJV floor	29%	17%	34%	84%	52%
Parlier	20%	15%	28%	73%	43%
Clovis	18%	6%	12%	62%	33%
Sequoia	25%	25%	57%	64%	33%
SJV floor & Sequoia	14%	10%	27%	56%	26%

Ventilated regime episodes favor Sequoia.

Anti-cyclonic regime episodes favor SJV floor.

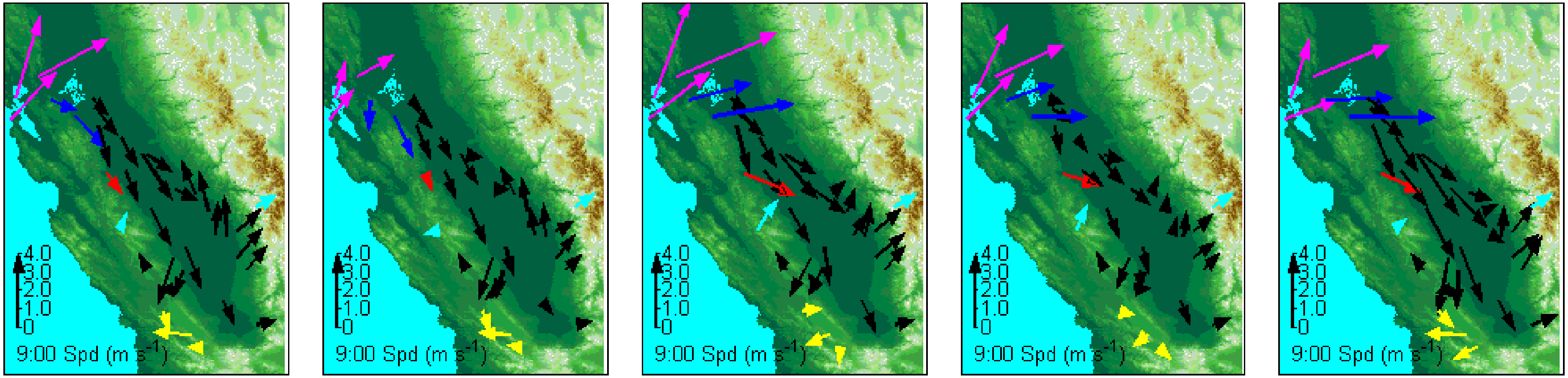
C-SJV Seasonal Distribution



C-SJV Conceptual Model

- Direct transitions between H, R, and V occur infrequently
- H/V and V/I are "intermediate" states
  - C-SJV is buffered from synoptic effects
  - Synoptic transitions have less effect on O_3 levels than for N-SJV (than for Bay Area)
- Mesoscale effects important for C-SJV

The Fresno Eddy



H **R** **H/V** **V** **V/I**

Decreasing eddy strength: H > R > H/V > V > V/I

Magenta: Carquinez Strait— Ft. Funston, Pt. San Pablo, Suisun

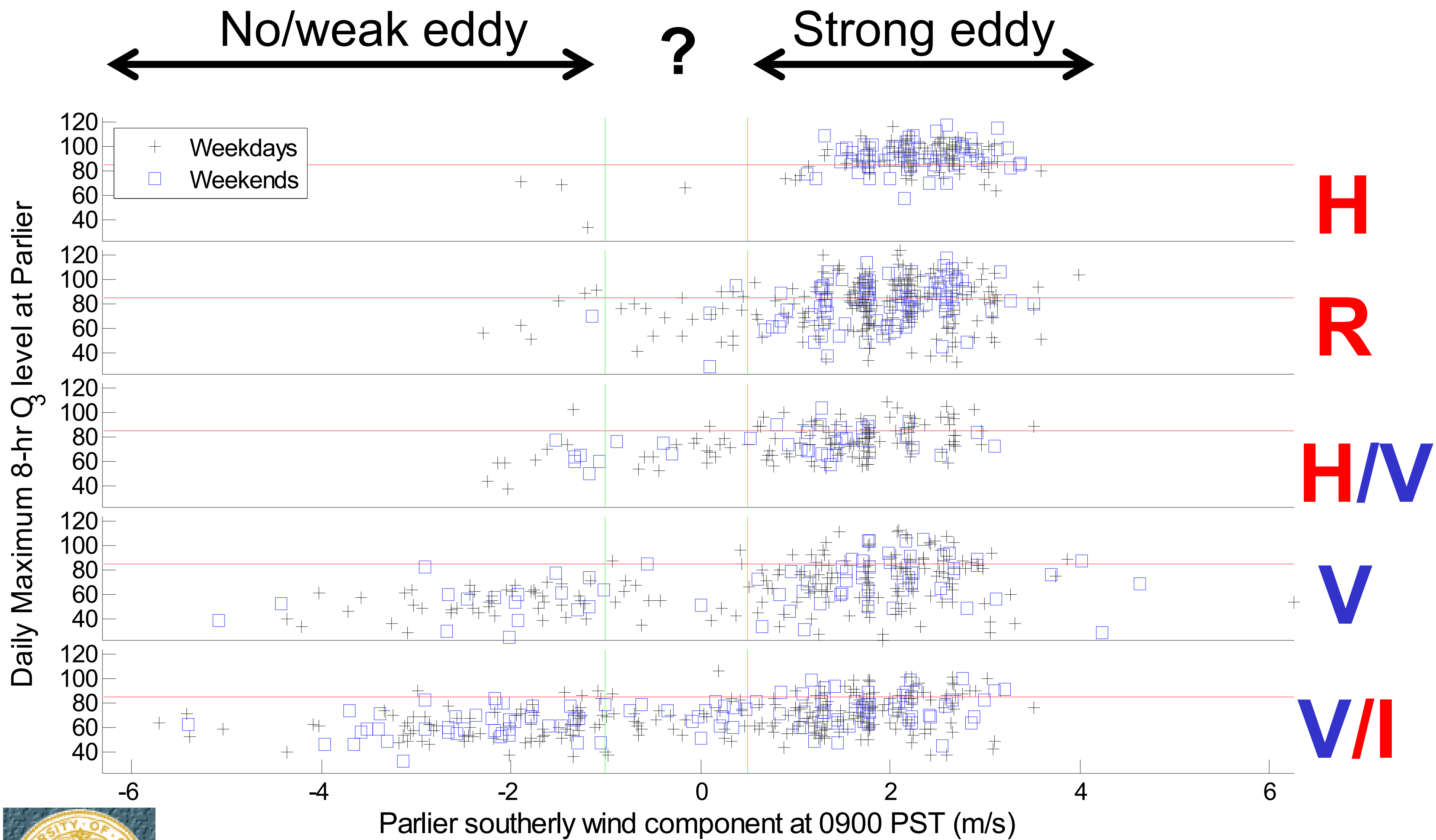
Blue: Altamont Pass— Kregor Peak, Tracy

Red: Pacheco Pass— Los Banos

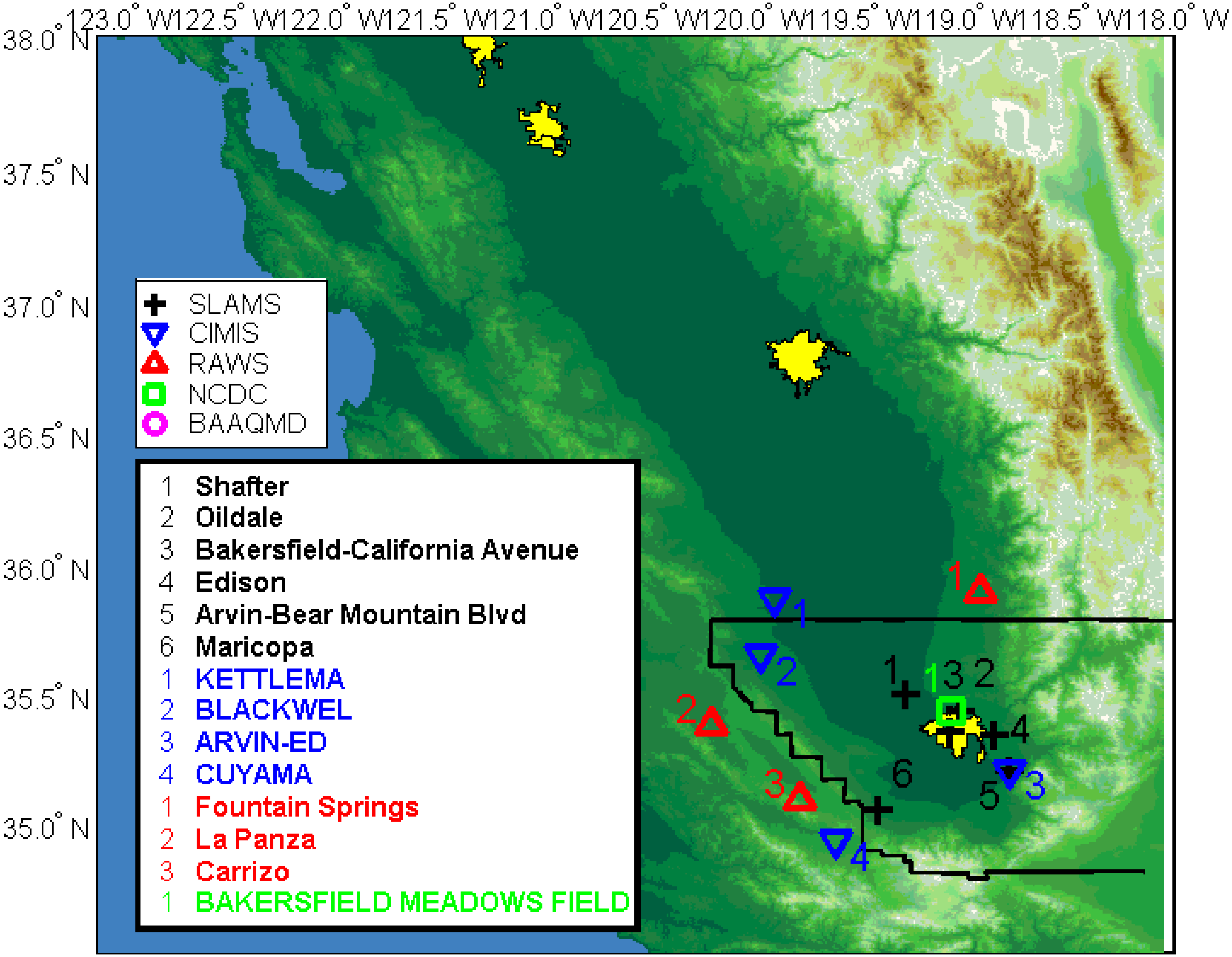
Cyan: Hernandez (west) & Sequoia (east)

Yellow: Carrizo Plain

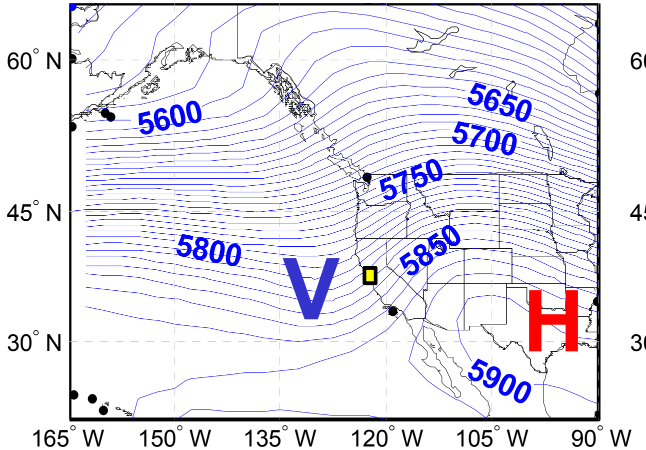
Eddy Strength and O_3 Levels

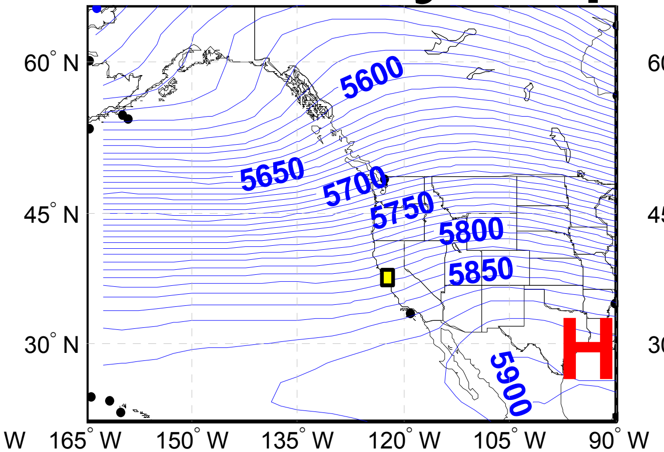


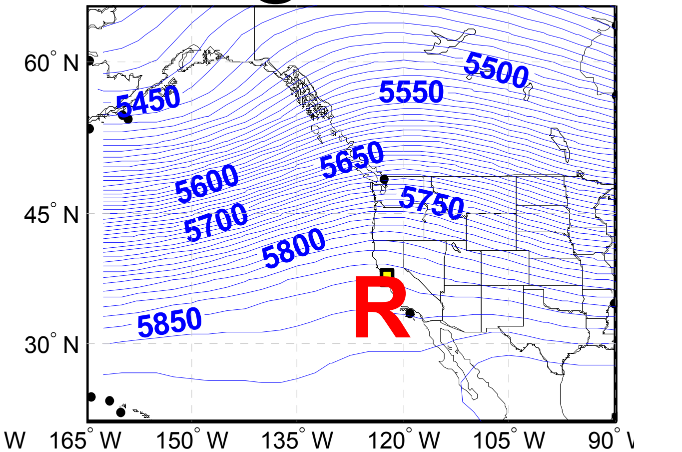
S-SJV Wind Monitors



S-SJV clusters = synoptic regimes







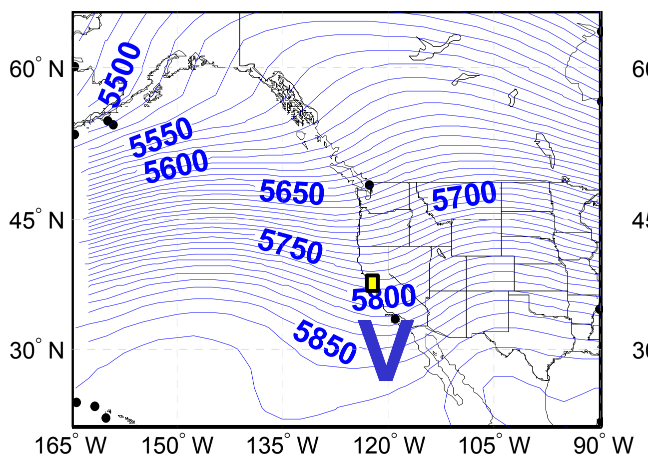
H/V: 206 days, 64%

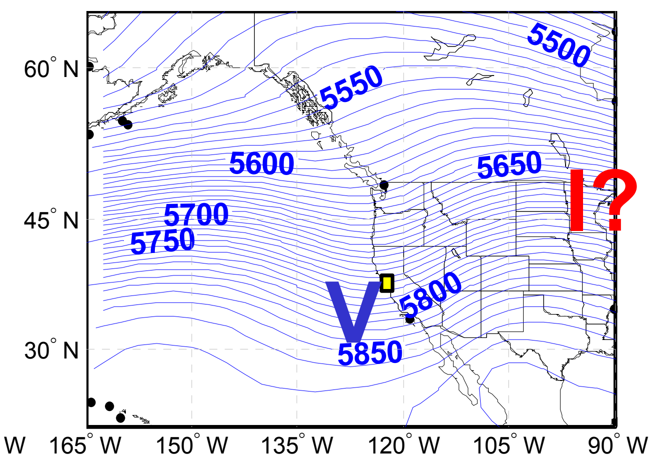
H: 354 days, 58%

R: 373 days, 62%

V: 160 days, 36%

V/I: 317 days, 22%





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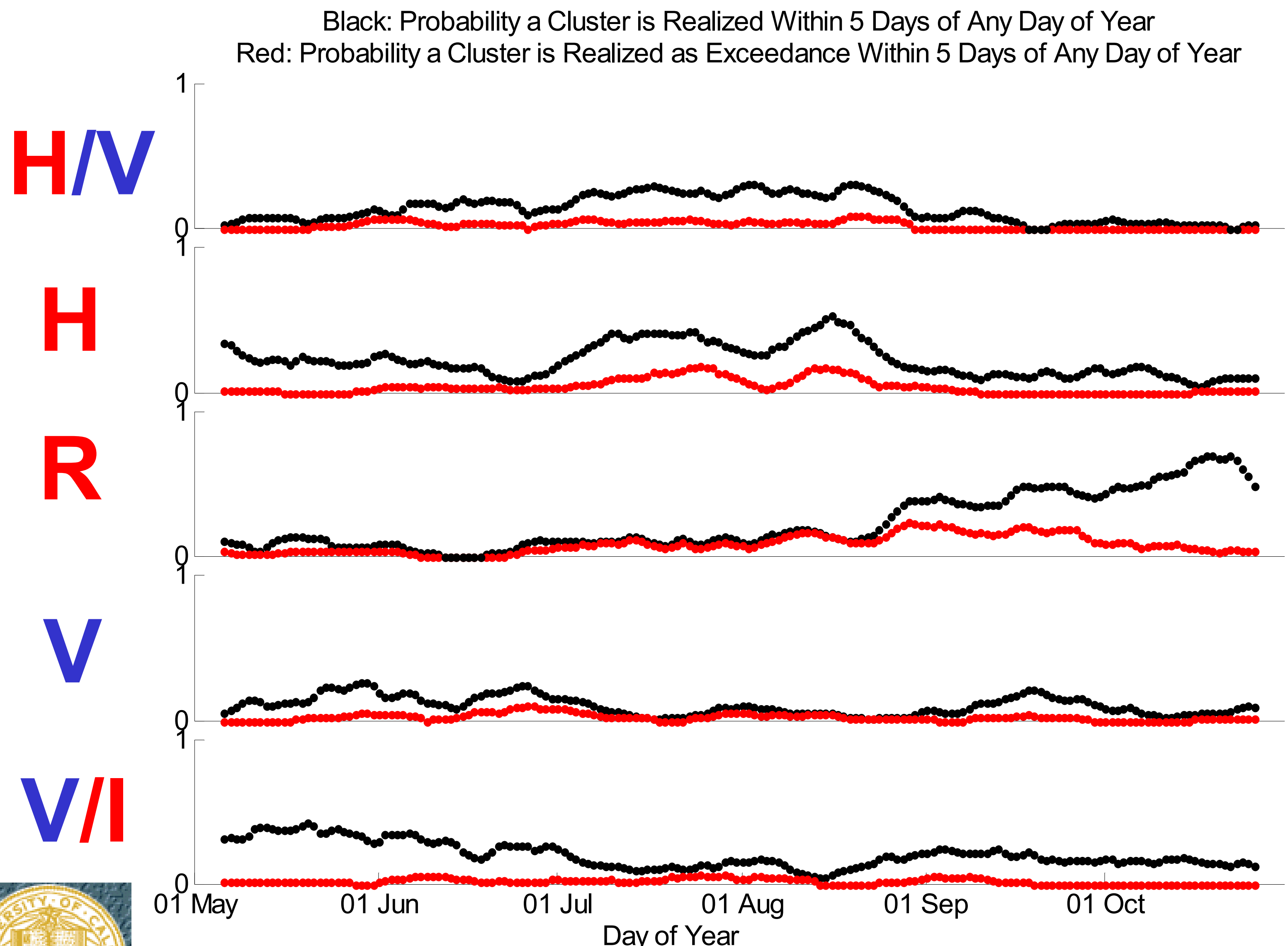
S-SJV Seasonal Distribution



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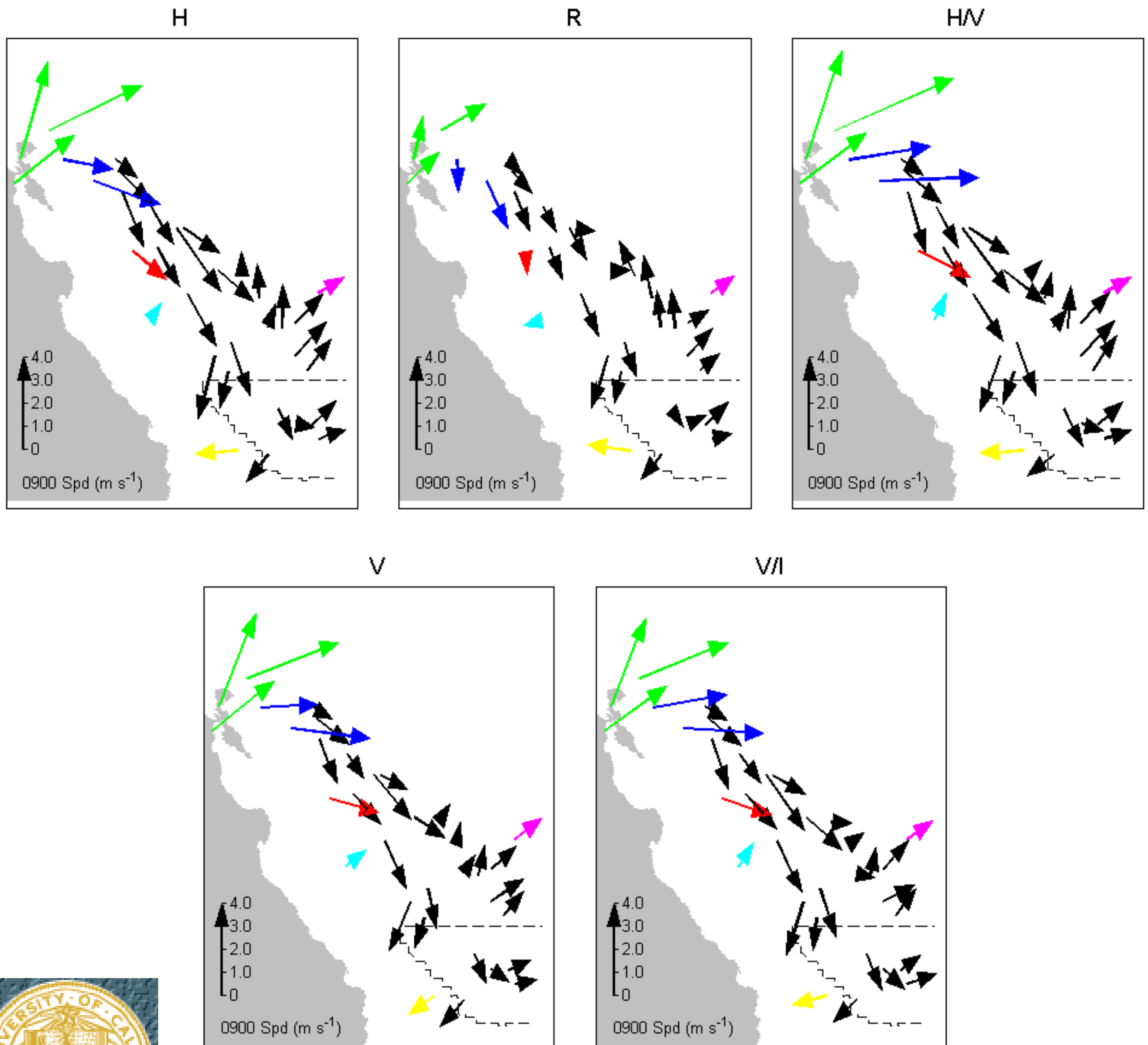
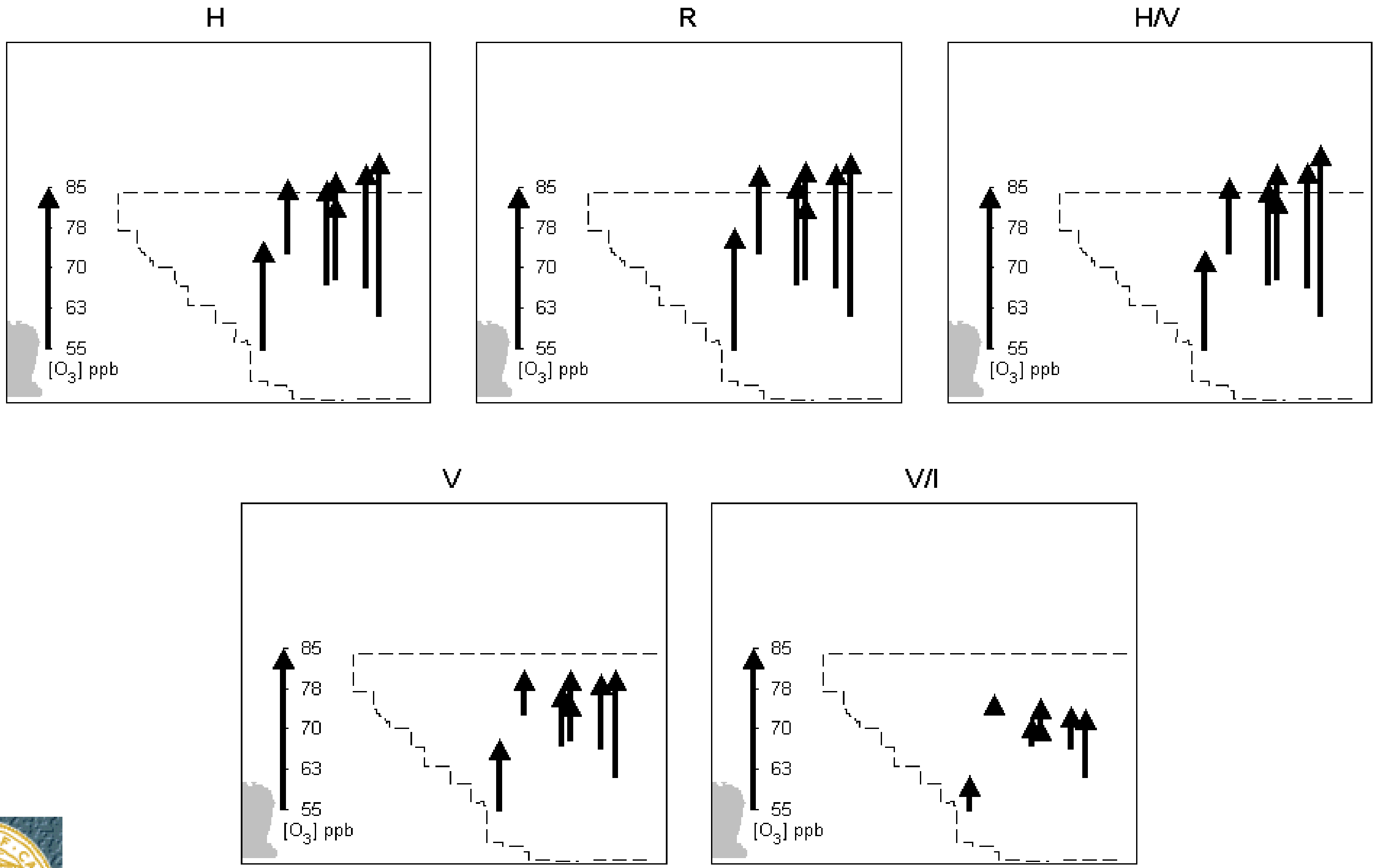
S-SJV 0900PST Wind Field

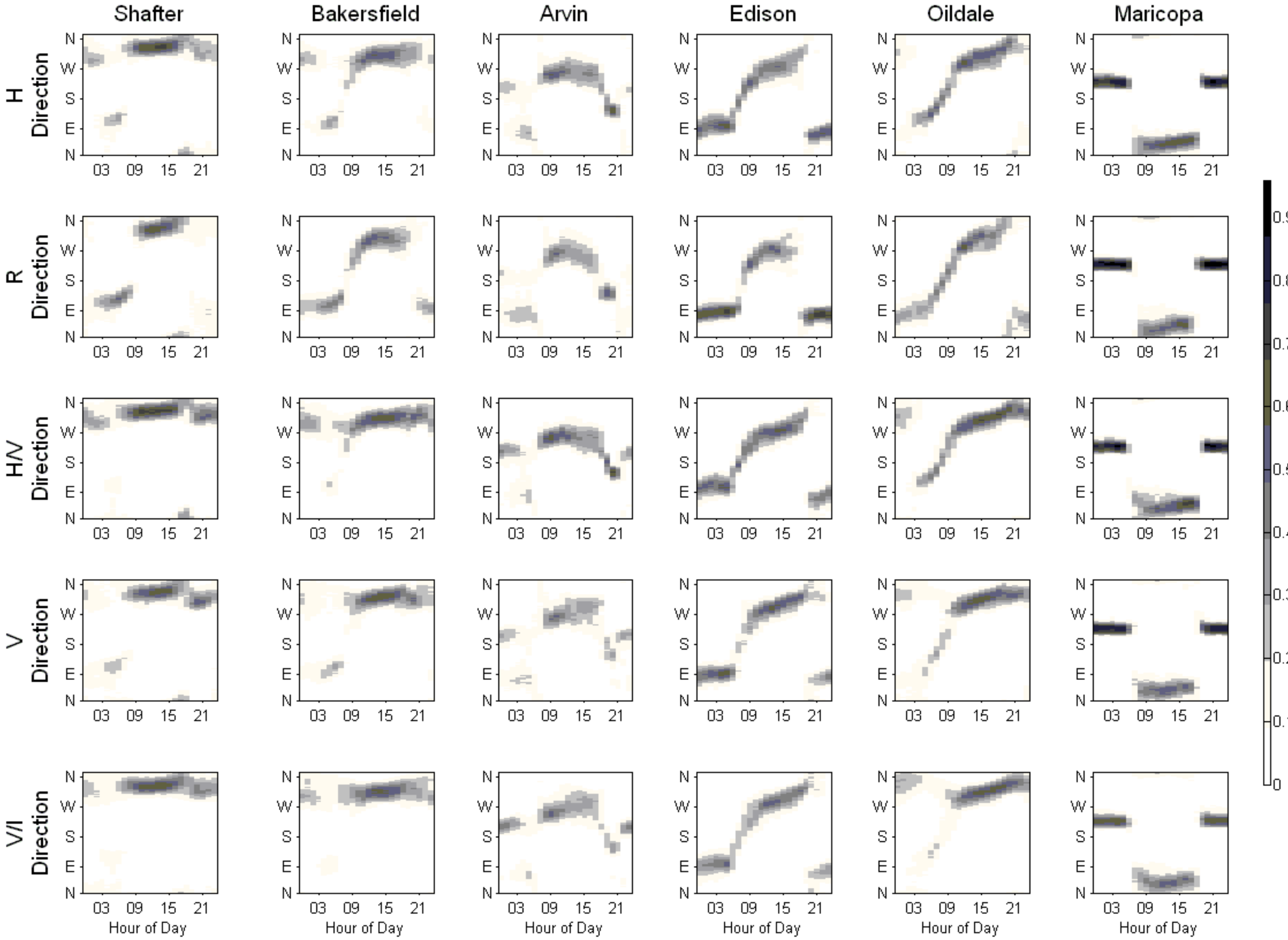


- Marine ventilation and SJV exit flows.
- No marine air penetration for R.
- Southerly component at Edison.
- Highest wind speeds for H/V

S-SJV 8-hr Ozone Spatial Distribution

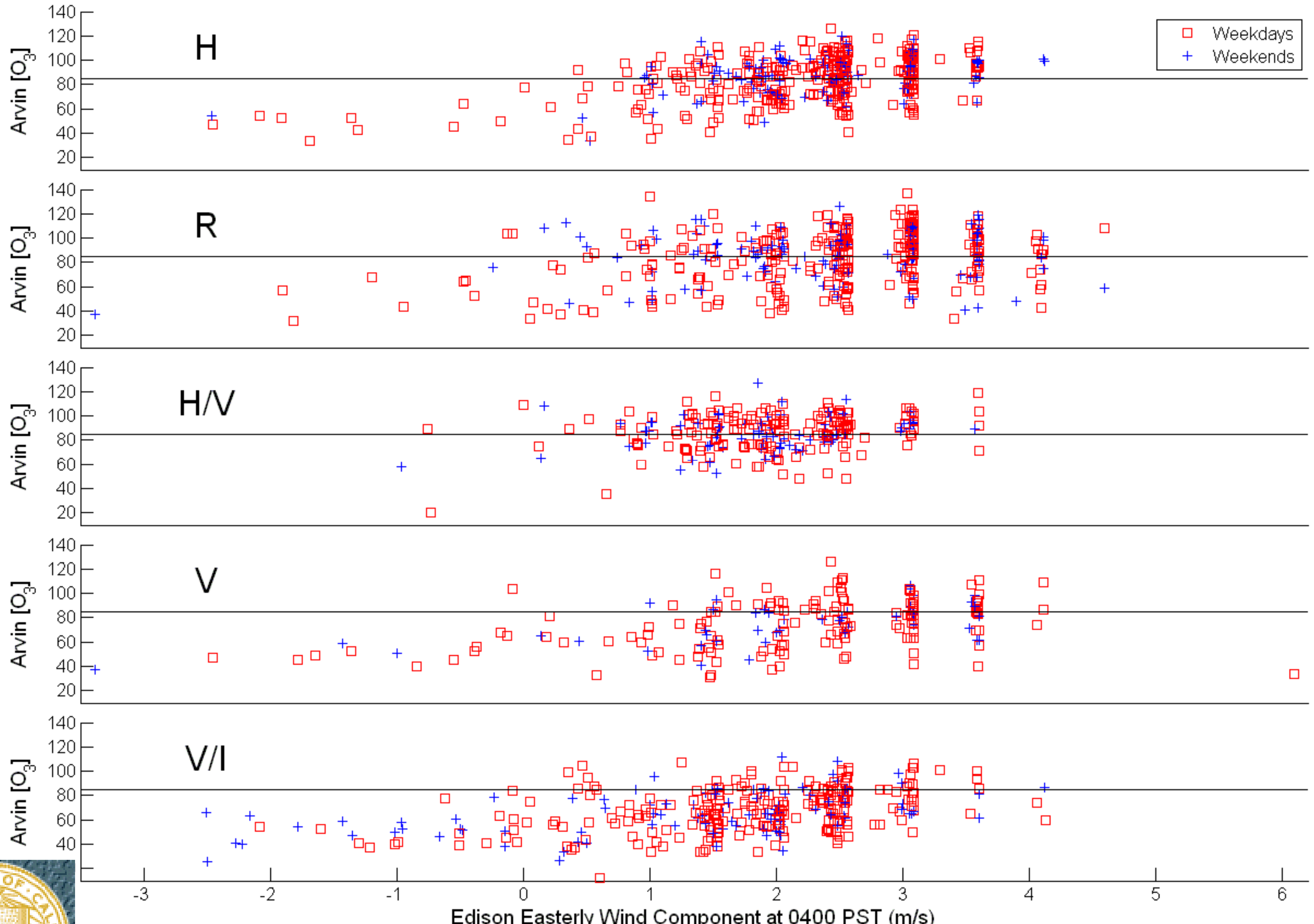


Wind Direction Distribution



- Flow reversal under anticyclonic clusters.
- Arvin captures local downslope flows from Tehachapi.
- Bakersfield shows superposition of marine penetration and easterly flows.

Flow Reversal and Ozone Levels



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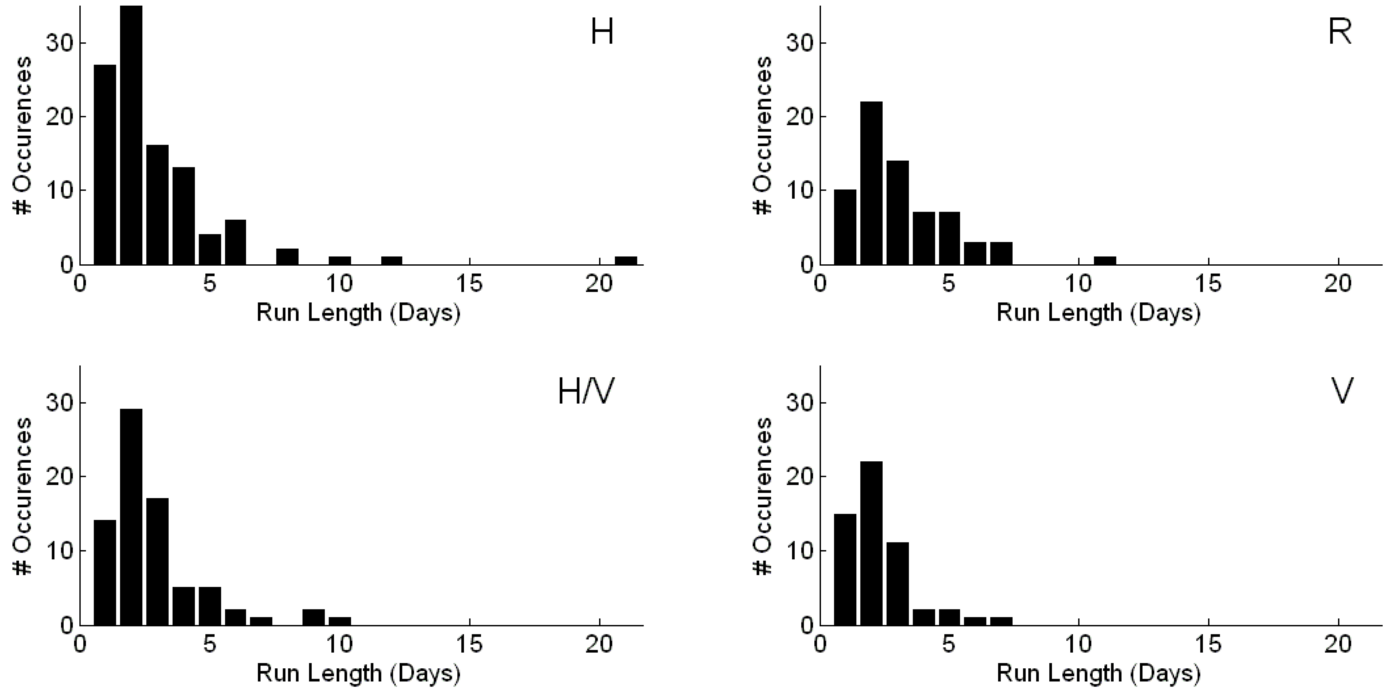
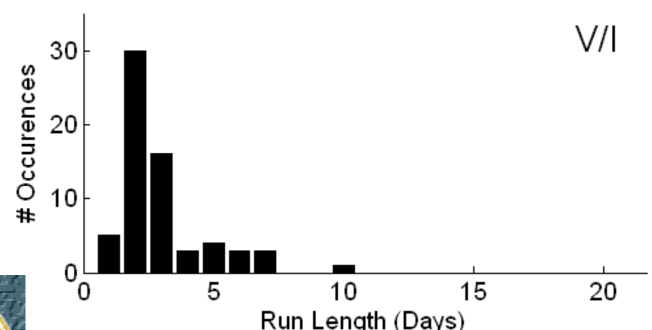
Distribution of Cluster Run-lengths

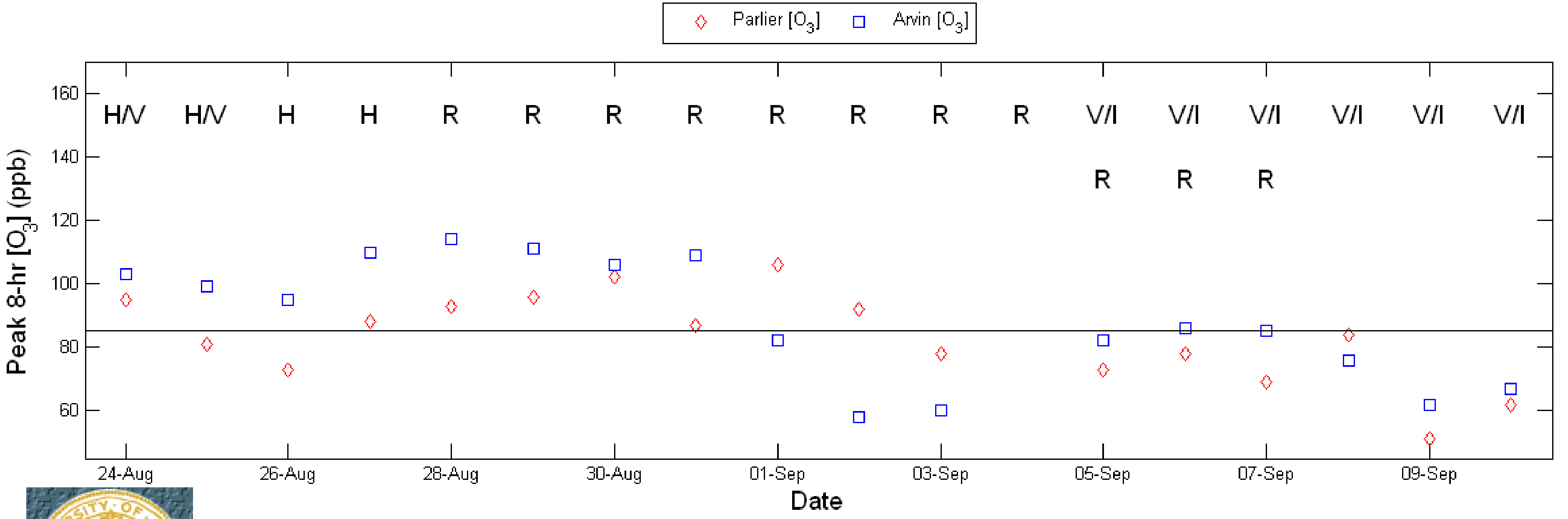




- Clusters less persistent when compared to other two sub-regions. Decreased synoptic influence.

S-SJV Cluster transitions

- Transitions from H to R or H/V. (Contrast to C-SJV for H/V)
- Transition from R to V or H. (Expanding low P vs offshore ridge)
- V to V/I (intensification of cyclonic conditions)



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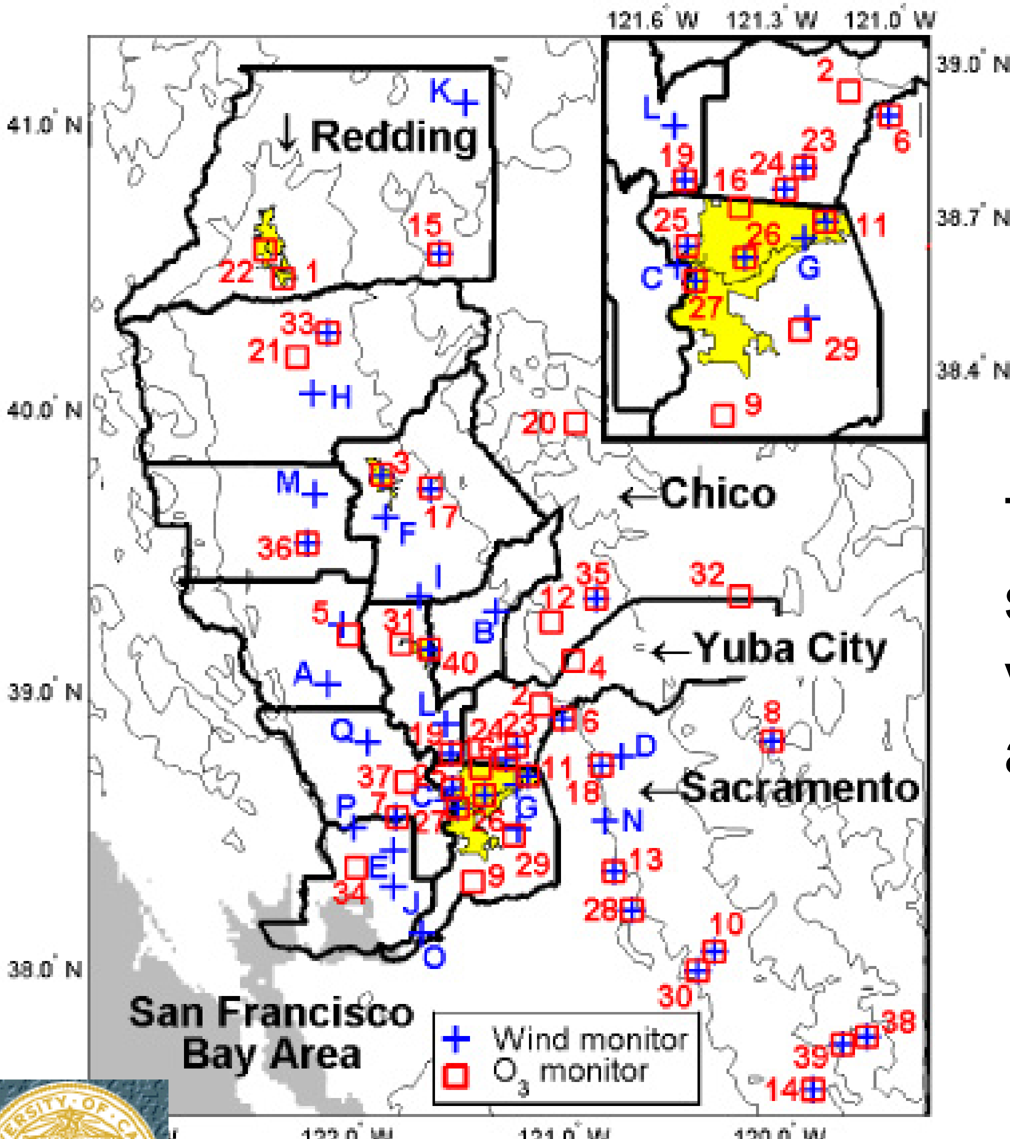
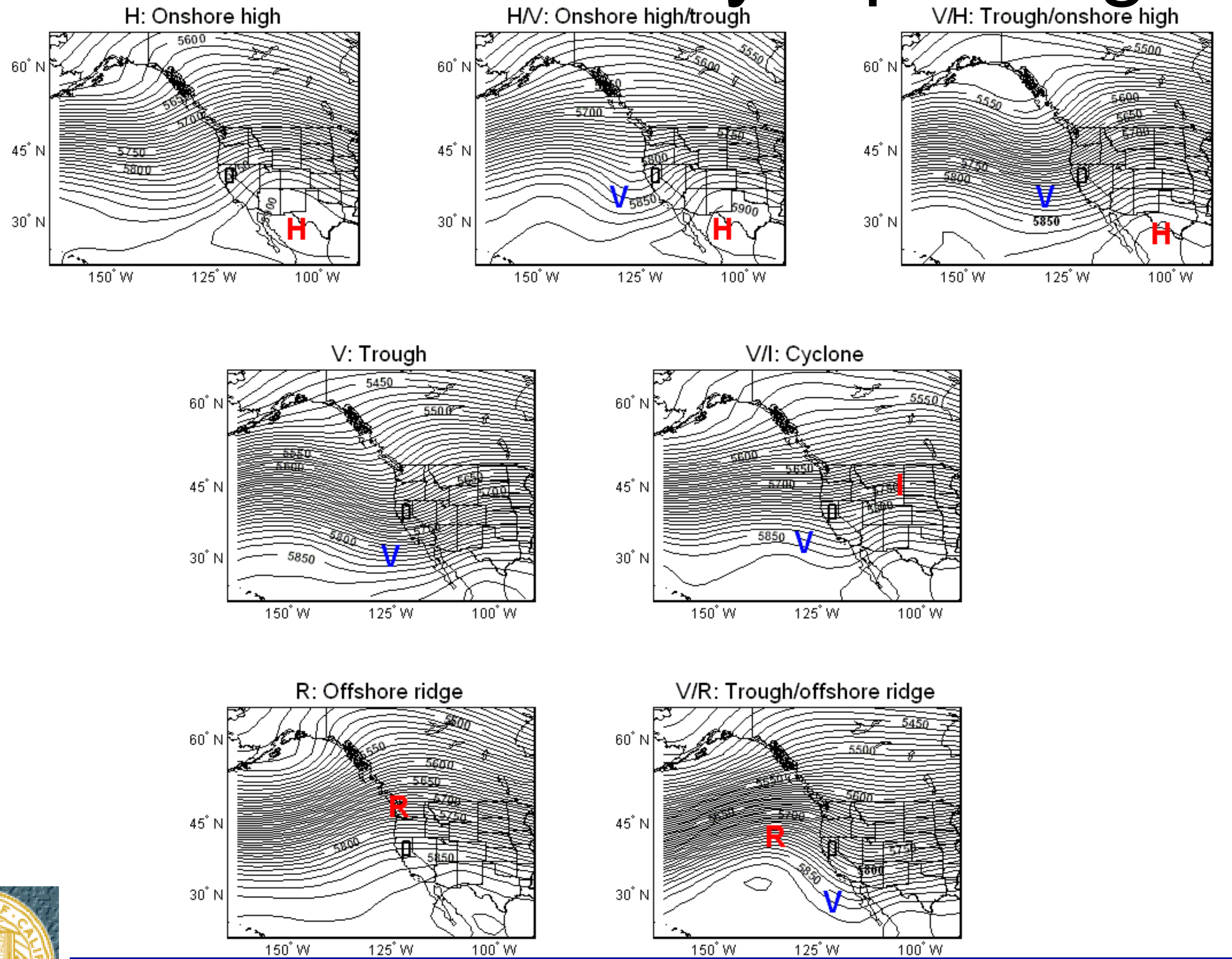
Sacramento Valley / Mountain County



The spatial extent of the study domain and siting of various meteorological and ozone monitors.

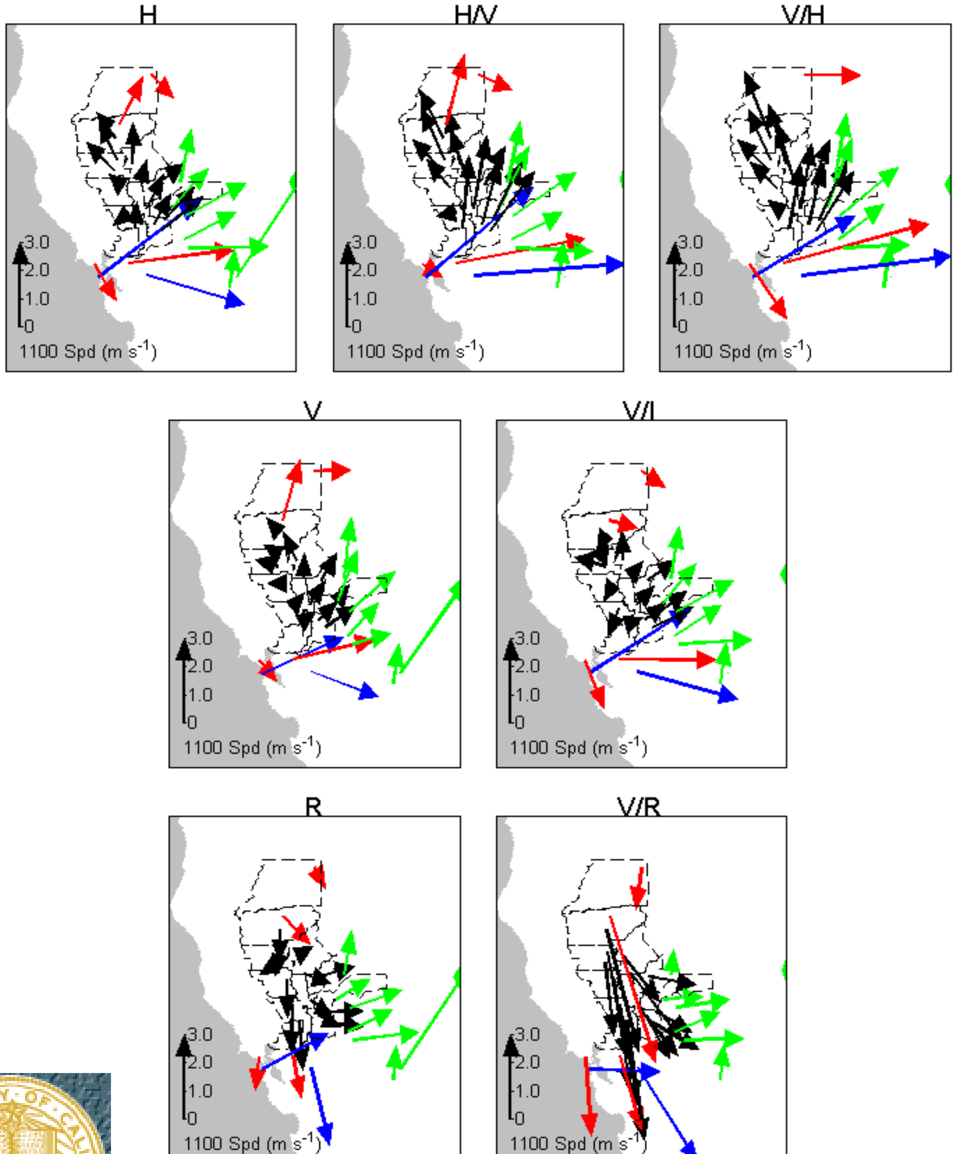
SV/MC clusters = synoptic regimes



Ozone Response

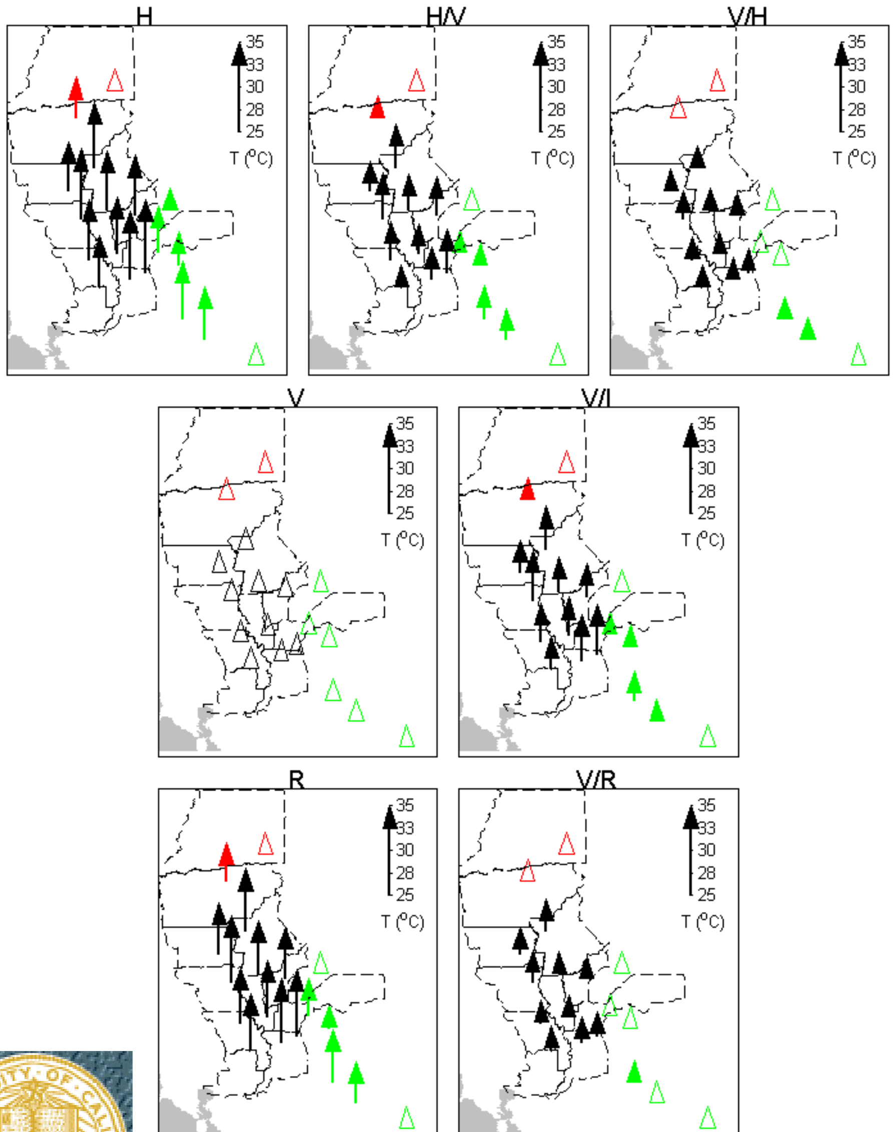
Cluster Label	# Days	% Exceedances SV	% Exceedances MC	Synoptic Feature(s)
H	397	28%	43%	Onshore anticyclone
H/V	203	17%	29%	Onshore anticyclone (dominant) with trough
V/H	198	6%	12%	Trough (dominant) with onshore anticyclone
V	228	3%	4%	Trough pattern
V/I	171	12%	23%	Cyclone with inland ridge
R	302	35%	40%	Offshore ridge of high pressure
V/R	200	3%	11%	Offshore ridge with trough

1100 PST Wind Field



- H/V highest wind speeds.
- Upslope/Downslope winds.
- Westerly/South westerly flows for H,H/V,V/H V vs northerly flows for R, V/R.
- Reduced mixing depth, thermally induced flows cause increased exceedances.

Cluster Averaged Temperature Field

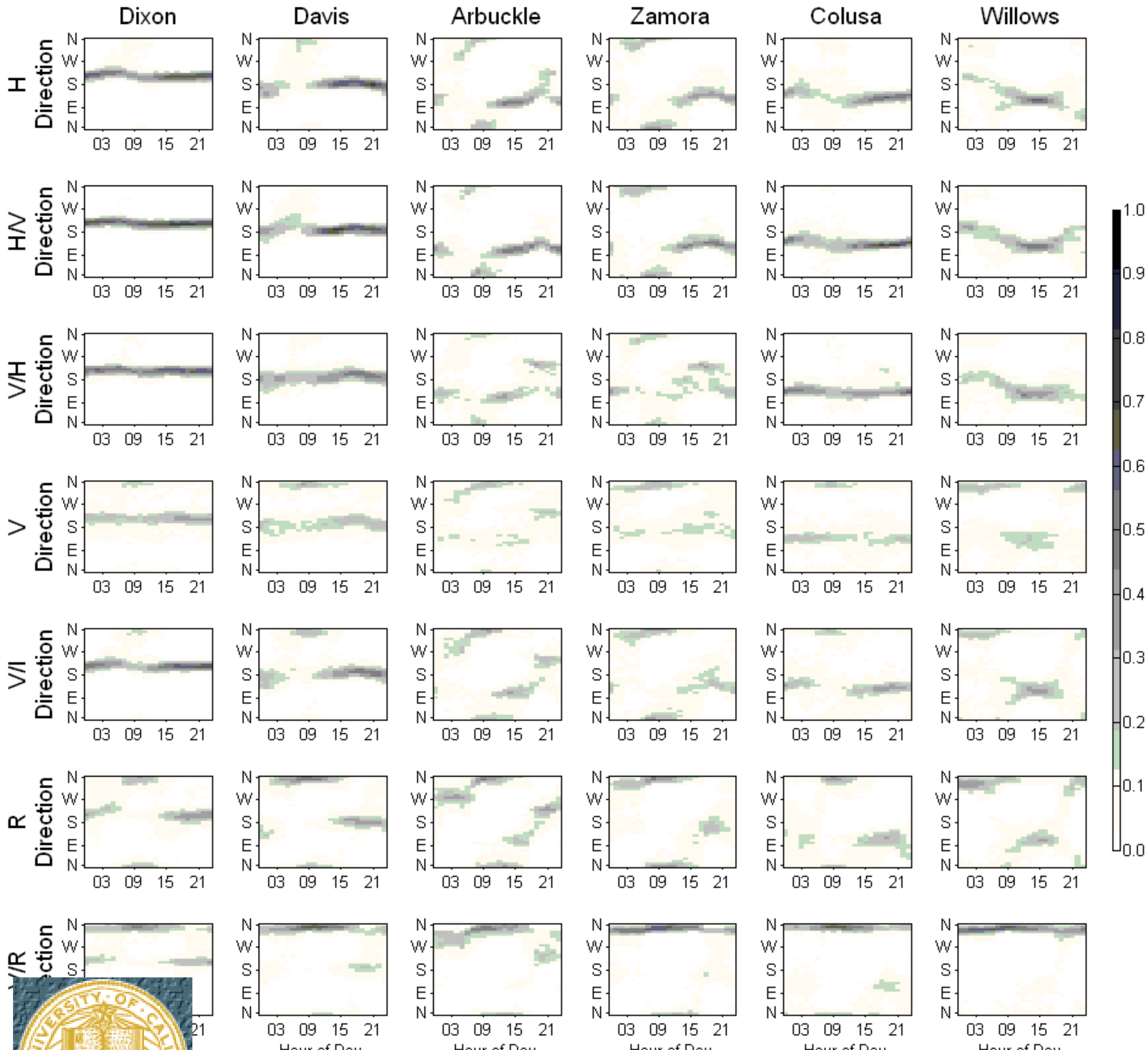


- H and R have the highest temperatures.
- V, V/R and V/H lowest.

Red – Elevated Sites

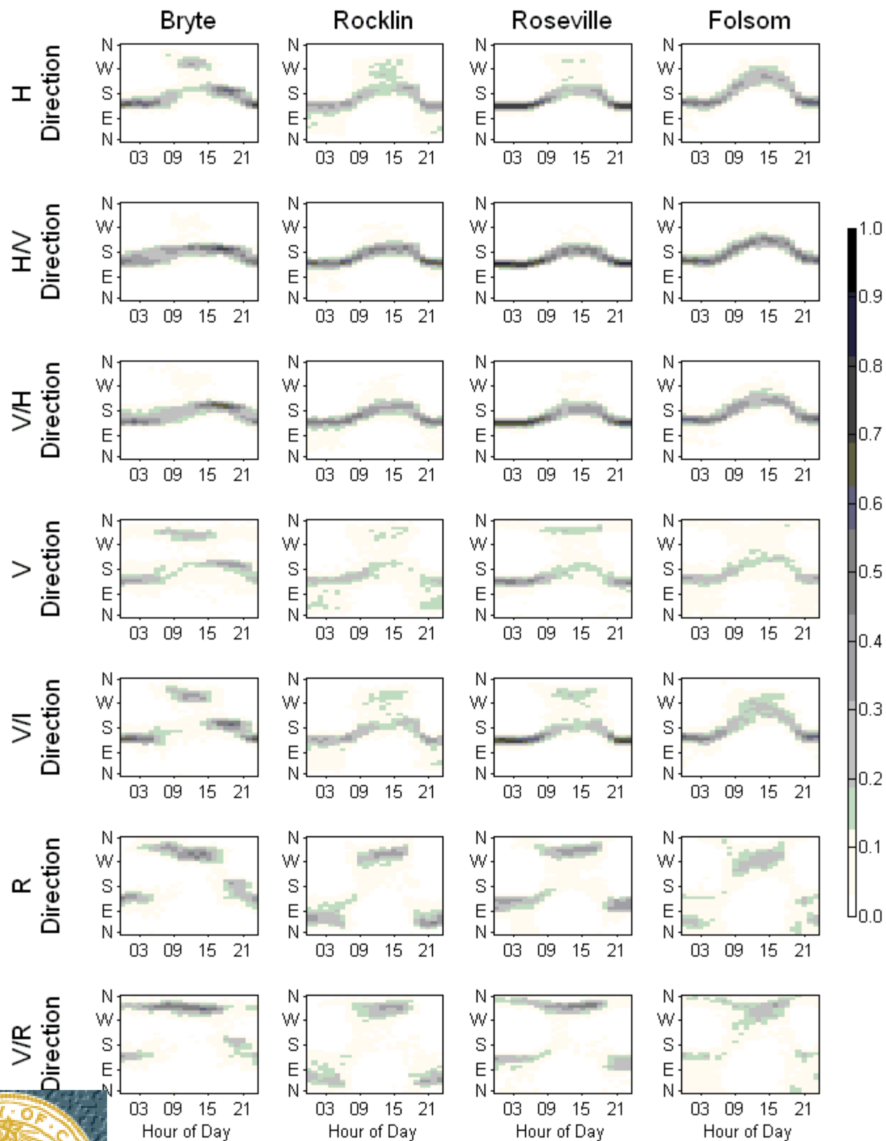
Green – Mountain County Sites

Wind Direction distribution – Schultz Eddy



- The extent and strength in various regimes.
- No pronounced effect on ozone air quality.

Sacramento Upslope/Downslope Flows

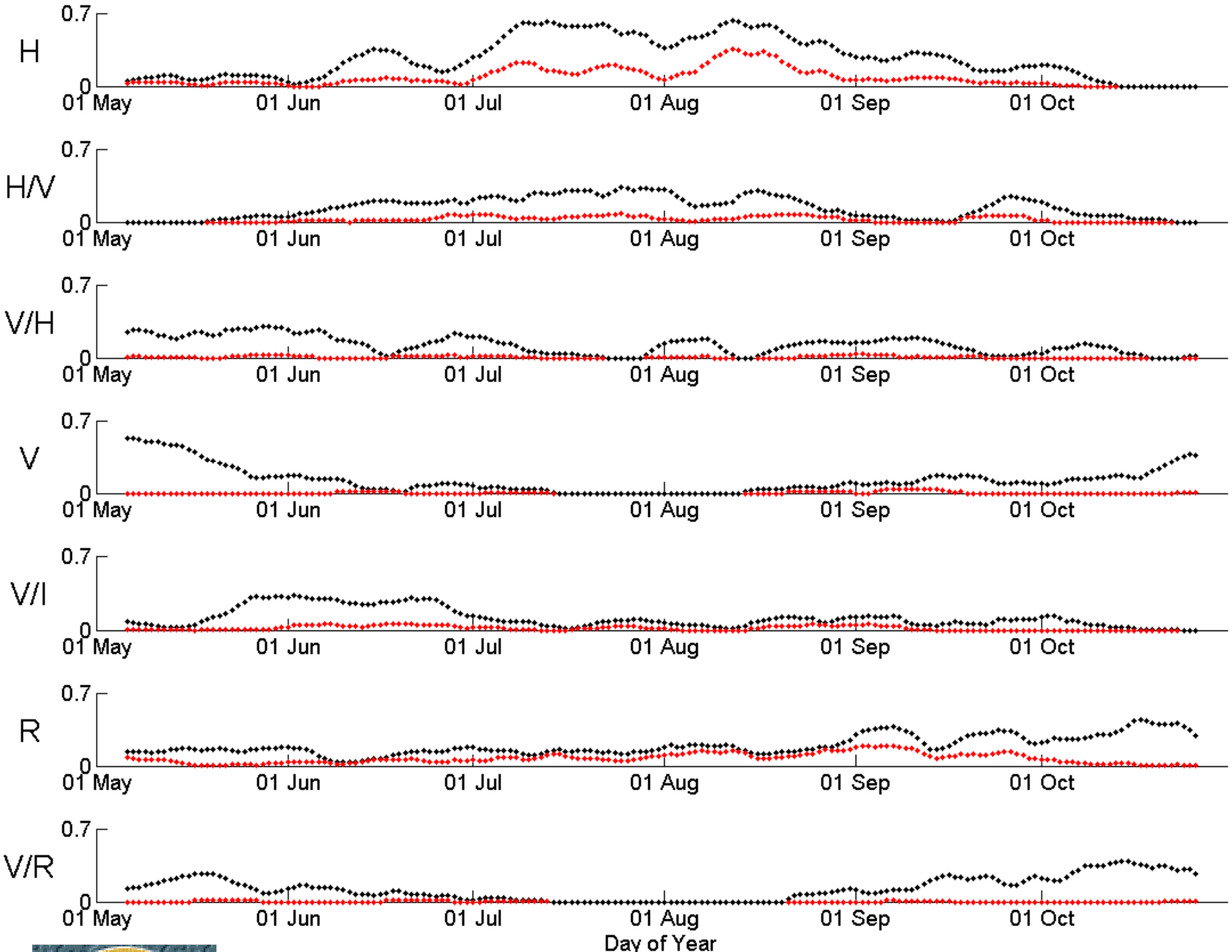


- Upslope/downslope flows strong for H and R.
- Daytime upslope flows represent an important transport mechanism between the Sacramento Area and the downwind SV and MC receptor locations.

Air Quality Response to Flow Patterns

- R and H are most prone to triggering exceedences but their spatial influence varies. R leads to exceedences more east of Sacramento while H causes exceedences most often at Folsom and less frequently in Sloughhouse and Elk Grove.
- R and H exceedences in MC are distinguished by both latitude and elevation.
- V/H and H/V show similar exceedence behavior in and to the east of Sacramento. However, H/V experiences higher O_3 levels at locations distant from Sacramento.

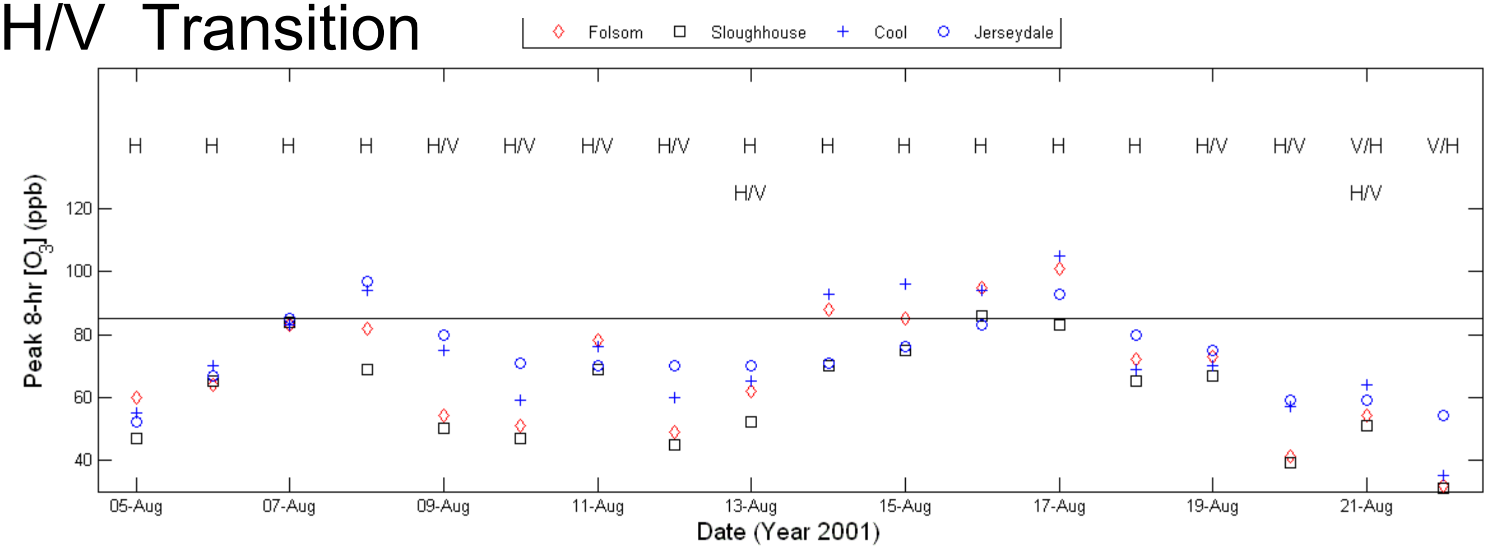
SV and MC Seasonal Distribution



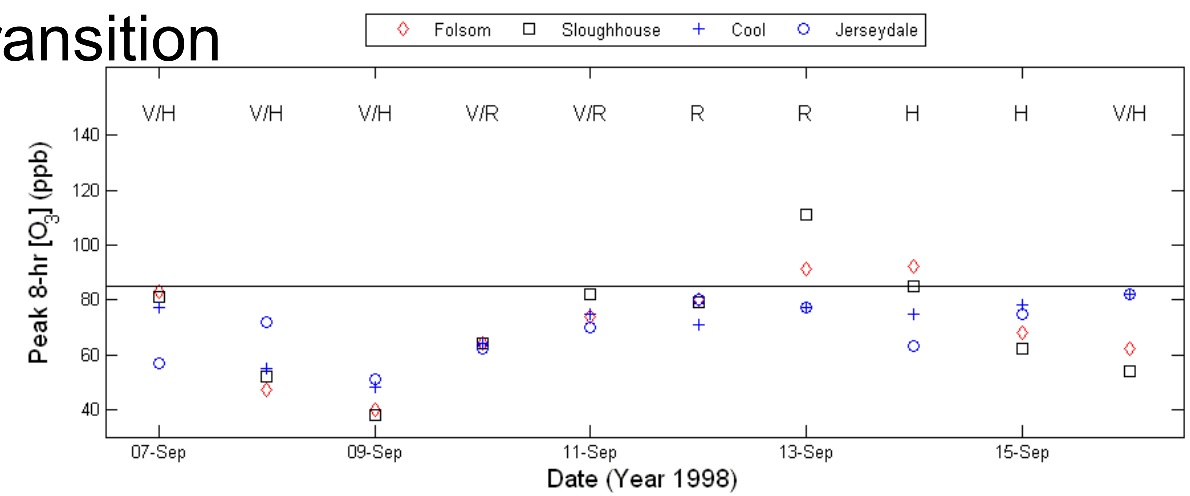
- H & H/V in core season
- R & V/R towards the ends.
- R during the core is the expanding onshore anticyclone.
- V/I primarily occurs in Jun-Jul.
- V favored towards the ends.

Dynamic Transitions

H ⟷ H/V Transition



V/R ⟶ R ⟶ H Transition



Summary

- Synoptic states and mesoscale patterns are identified for all CCOS air basins.
- Each air basin has unique ozone response influenced by meteorology
- Mesoscale patterns play a critical role in SJV and SV ozone response

PM Study for SF Bay Area

- Goal and purpose of study
- Description of meteorological and air quality data
- Cluster analysis of wind field measurements
- Identification of synoptic regimes
- Description of regional conditions
- Relationships between PM levels and meteorology
- Example results: Dec 27, 2000 – Jan 7, 2001 PM episode

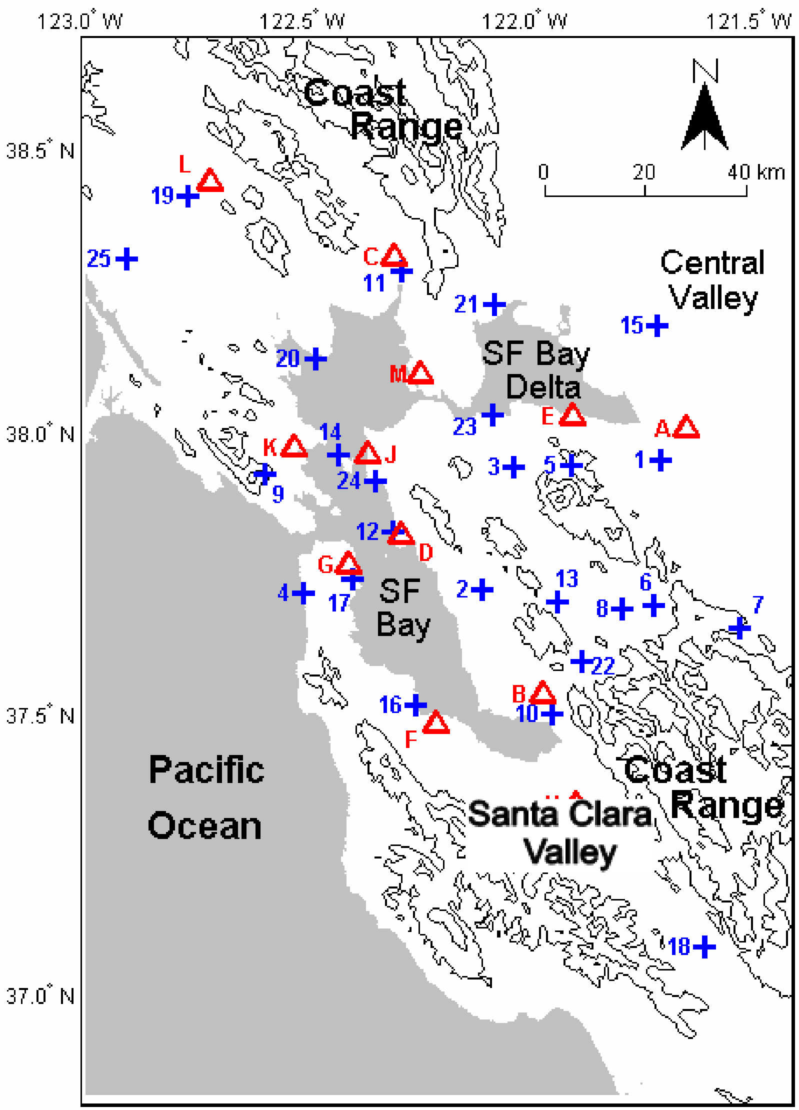
Goals and Purpose of Study

- Goal
  - Identify meteorological patterns affecting transport and dispersion of PM in the San Francisco Bay Area, CA
  - Distinguish conditions favoring primary and secondary PM buildup
- Purpose
  - Use meteorological classification for air quality model evaluation
    - Does model performance vary with meteorological conditions?
    - Is model performance robust across different PM episodes?

Meteorological and Air Quality Data

- Wind data
  - Study period: 1996-2007 (Nov 1 – Mar 31)
  - 26 sites monitoring wind speed and direction
- PM data
  - $PM_{2.5}$ and PM_{10} measurements available on a 3-day or 6-day schedule
  - Speciated $PM_{2.5}$ data at San Jose on a 6-day schedule
- Other data
  - Surface temperature and precipitation data
  - NCEP/NCAR Reanalysis weather maps

San Francisco Bay Area, CA



Meteorological Stations (+)

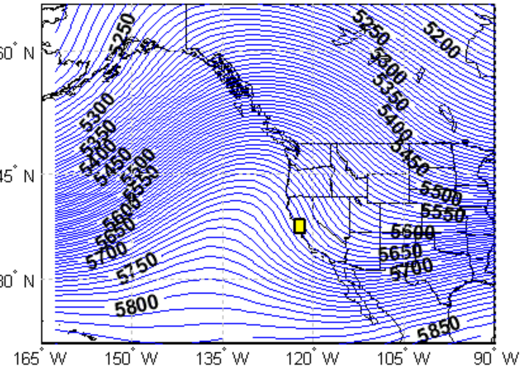
1. Bethel Island
2. Chabot
3. Concord
4. Fort Funston
5. Kregor Peak
6. Livermore Lab
7. Livermore Lab Site-300
8. Livermore Rincon
9. Mt. Tamalpais
10. NUMMI
11. Napa STP
12. Oakland STP
13. Pleasanton STP
14. Pt. San Pablo
15. Rio Vista
16. San Carlos
17. San Francisco STP
18. San Martin APT
19. Santa Rosa APT
20. Sonoma Baylds
21. Suisun STP
22. Sunol
23. Tesoro(Golden Eagle)
24. UC Richmond
25. Valley Ford

PM Monitors (Δ or +)		BAM	$PM_{2.5}$	PM_{10}
A	Bethel Island			6-day
2	Concord		1-day	6-day
B	Fremont		3-day	6-day
8	Livermore	1-day	3-day	6-day
C	Napa			6-day
D	Oakland	1-day		
E	Pittsburg			6-day
F	Redwood City	1-day	3-day	6-day
G	San Francisco	1-day	1-day	6-day
H	San Jose-4th St	1-day	1-day	6-day
I	San Jose-Tully		1-day	6-day
J	San Pablo			6-day
K	San Rafael			6-day
L	Santa Rosa		3-day	6-day
M	Vallejo	1-day	3-day	6-day

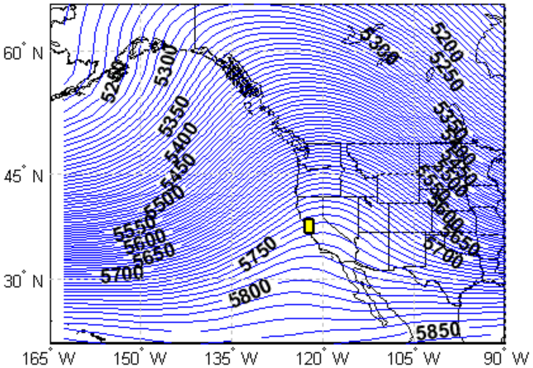
500-hPa Cluster Composites

Anticyclonic Clusters

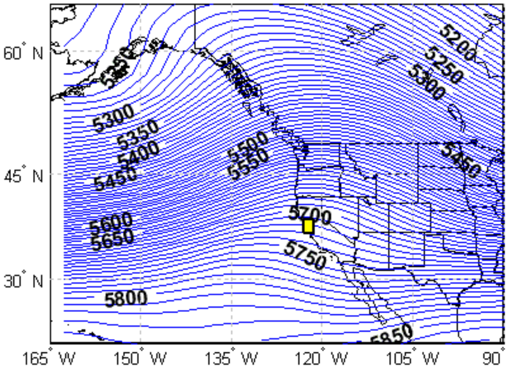
R1 (offshore ridge)
219 days



R2 (shoreline ridge)
422 days

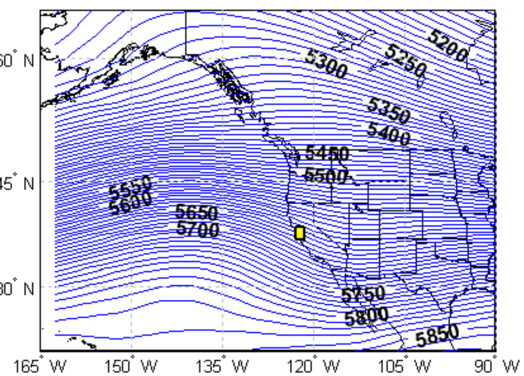


R3 (weakened ridge)
279 days

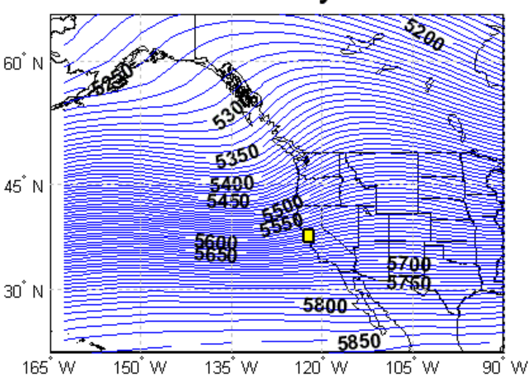


Cyclonic Clusters

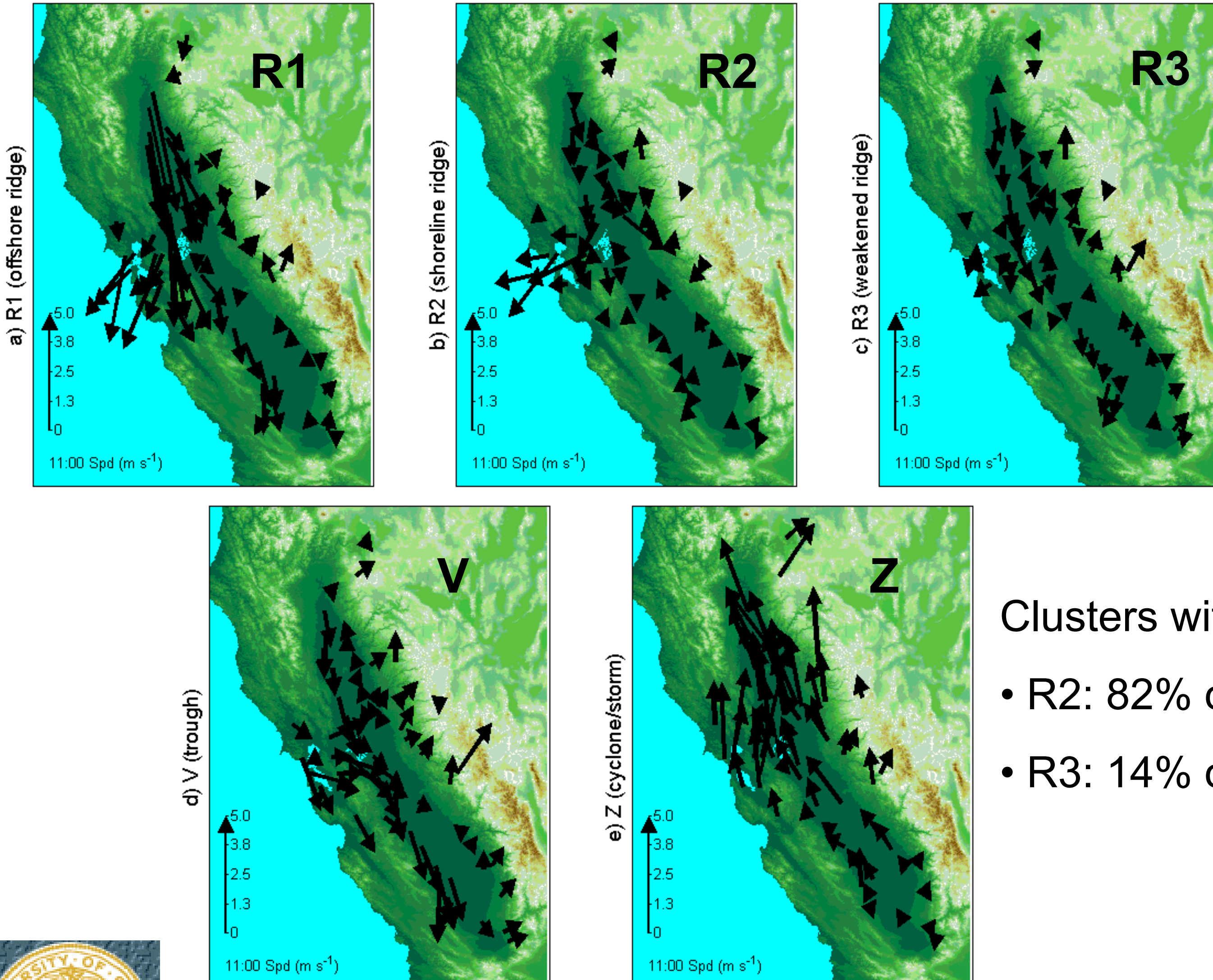
V (trough)
413 days



Z (cyclone/storm)
489 days



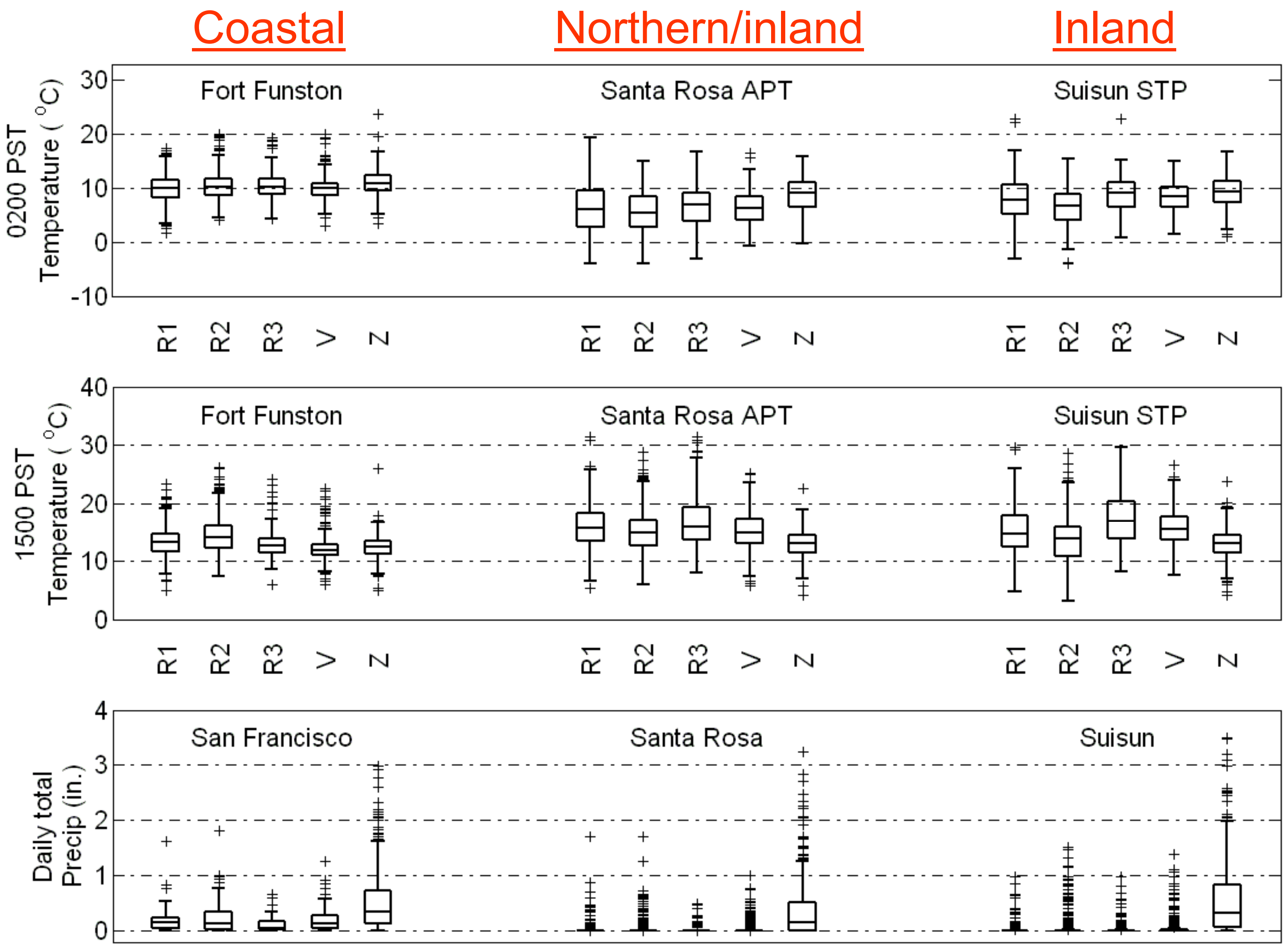
Surface Air Flow Patterns



Clusters with $PM_{2.5}$ exceedances

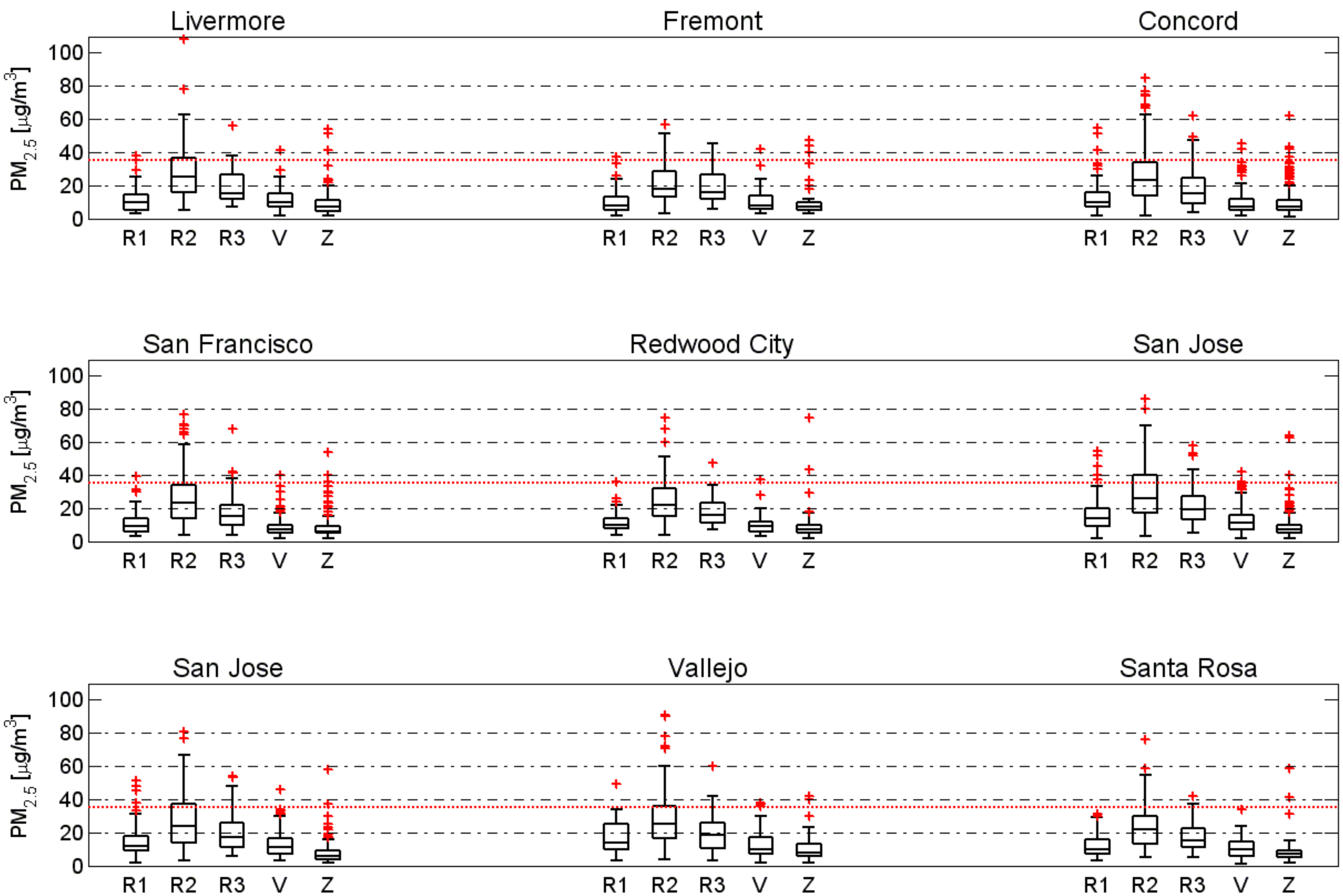
- R2: 82% of days
- R3: 14% of days

Temperature / Precipitation Response



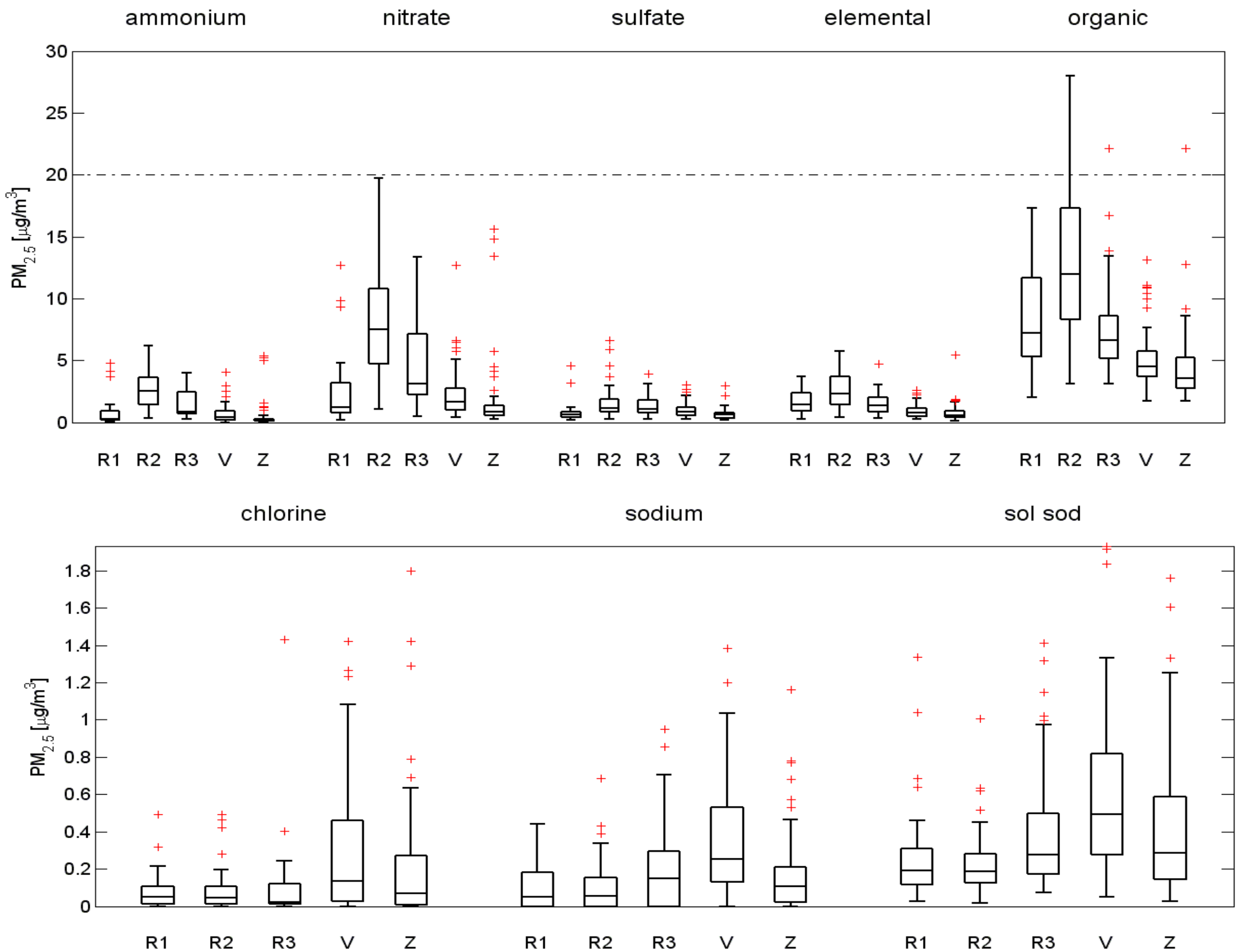
- R2 has reduced overnight temperatures at inland sites
- Z accounts for most of the annual precipitation in the Bay Area

$PM_{2.5}$ Response for Clusters



- PM_{10} response is similar

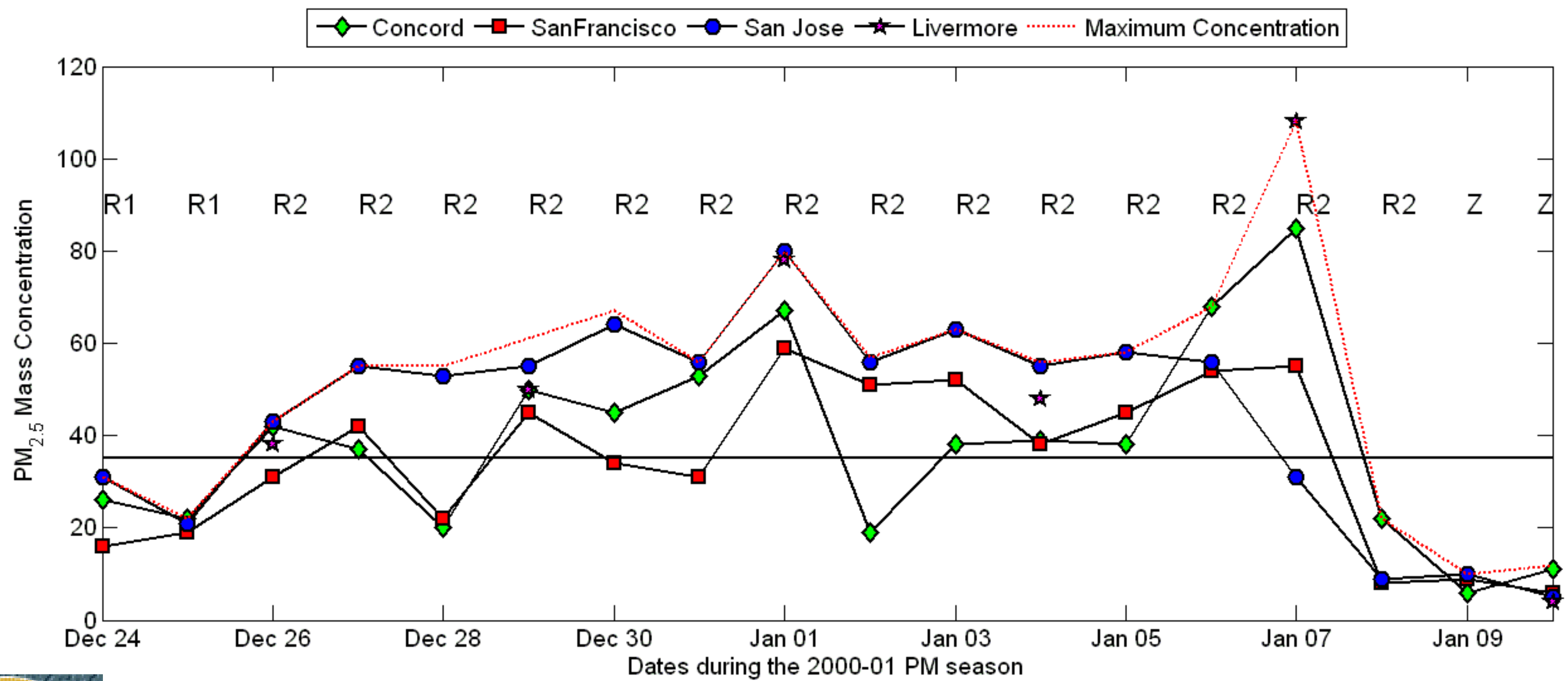
Speciated $PM_{2.5}$ Response for Clusters



- Dominant species response similar as for total $PM_{2.5}$
- Cl and Na levels are highest under marine air flows (V and Z)

Example Results

- PM levels increase over 2-3 days and level off under conducive conditions
- PM levels rapidly decline upon transition to Z



Department of Chemical Engineering and Materials Science

Summary

- Bay Area PM levels are strongly impacted by meteorology
  - Large scale synoptic influences
  - Regional thermal effects
- Total PM levels indicate dispersion varies by cluster
  - R2 and R3 trigger the bulk of exceedances
  - R1 has strong winds and moderate PM levels
  - V and Z have the lowest PM levels
- Speciated $PM_{2.5}$ data indicate source-receptor relationships vary by cluster
  - R3 has the highest proportion of secondary $PM_{2.5}$
  - V and Z have the most sea spray
- PM_{10} responds similarly to $PM_{2.5}$

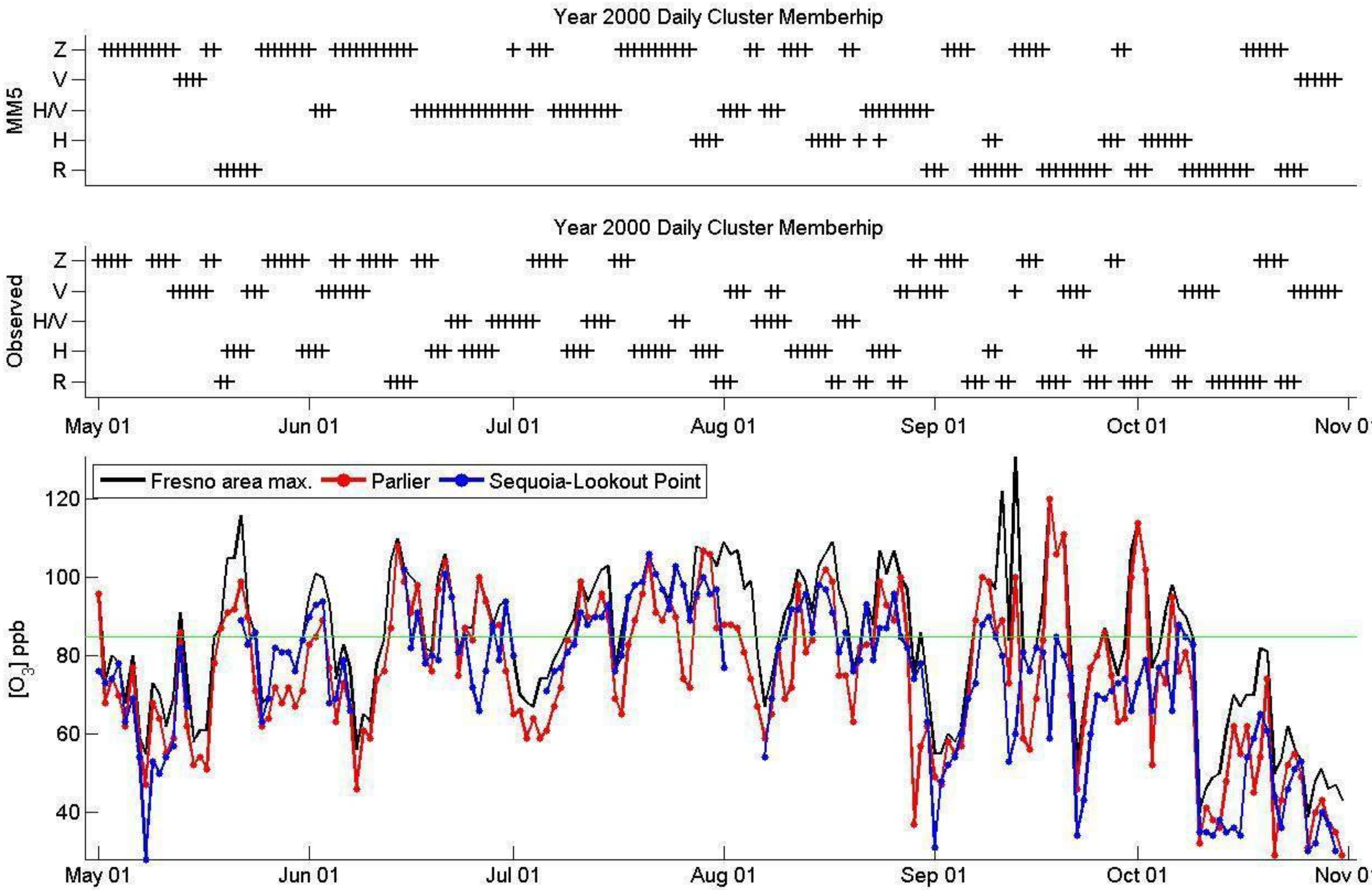
Recommendations and Future Directions -1

- Inter-basin analysis: transport analysis for identified met regimes using a (back-trajectory) transport model.
  - Transport through gaps in Coastal Range
  - Transport patterns from major source areas
- El Nino effects
- Wild fire analysis
- Vertical analysis

Recommendations and Future Directions -2

- Meteorological influences on PM levels.
  - Meteorological classification
  - Search for key meteorological parameters affecting PM
  - Investigation of marine boundary layer effects
  - Effect of meteorology of PM sensitivity to emissions
  - Validation of MM5 and WRF models

MM5 Evaluation - Preliminary



Recommendations and Future Directions -3

- Modeling for control strategy development.
  - Episode selection
  - Prediction of PM levels
  - Meteorologically disaggregated source apportionment
  - Combined control strategy development for PM and ozone
  - Effects of local, regional and inter-basin transport

Recommendations and Future Directions -4

- Inter-annual variability and climate change impacts for PM.
  - Trend analysis
  - Effect of climate change on ambient PM exposure

References

1. Beaver, S., and A. Palazoglu, “Influence of Synoptic and Mesoscale Meteorology on Ozone Pollution Potential for San Joaquin Valley of California,” *Atmospheric Environment*, submitted (2008).
2. Beaver, S., and A. Palazoglu, “Hourly Surface Wind Monitor Consistency Checking over an Extended Period of Observation,” *Environmetrics*, 19, 1-17 (2008).
3. Beaver, S., S. Tanrikulu, and A. Palazoglu, “Cluster Sequencing to Analyze Synoptic Transitions Affecting Regional Ozone,” *J. Applied Meteorology and Climatology*, 47(3), 901-916 (2008).
4. Beaver, S. and A. Palazoglu, “A Cluster Aggregation Scheme for Ozone Episode Selection in the San Francisco, CA Bay Area,” *Atmospheric Environment*, 40, 713-725 (2006).
5. Beaver, S. and A. Palazoglu, "Cluster Analysis of Hourly Wind Measurements to Reveal Synoptic Regimes Affecting Air Quality," *J. Applied Meteorology and Climatology*, 45(12), 1710–1726 (2006).