Boundary layer, cloud, and aerosol variability in the southeast Pacific coastal marine stratocumulus during VOCALS-REx

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03/21/2011
Scientific objectives:

- Characterize variations of the coastal BL, clouds, and aerosols
- The first-hand evidence of cloud-aerosol-turbulence interactions in the coastal marine Sc

VOCALS--Hypothesis 1a: Aerosol-Cloud-Drizzle Interactions

From VOCALS Program Summary
CIRPAS Twin Otter Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Observations/Purpose</th>
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<tbody>
<tr>
<td>Standard met</td>
<td>Winds, temp, dewpoint, cloud liquid water, sfc temp</td>
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<tr>
<td>Turbulence Probes</td>
<td>High speed wind, temp, and moisture (Djamal Khelif)</td>
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<td>94 GHz Doppler FMCW radar</td>
<td>Cloud properties; in-cloud turbulence</td>
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<tr>
<td>CPCs</td>
<td>Ultrafine aerosols</td>
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<tr>
<td>PCASP</td>
<td>Aerosols 0.1-3 μm</td>
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<td>CAS</td>
<td>Clouds 2-40 μm</td>
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<td>CIP</td>
<td>Drizzle 25-1500 μm</td>
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<td>CCN-200</td>
<td>CCN (fast-2-point; slow-6 points)</td>
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<tr>
<td>Phased Doppler Interferometer</td>
<td>Cloud-drizzle 2-150 μm (Patrick Chuang)</td>
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<td>Photo-Acoustic Soot Spectrometer</td>
<td>Bulk soot absorption</td>
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<td>SP2-Black Carbon; DMT</td>
<td>BC mass and ratio to total particles;</td>
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Date

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Synoptic Conditions

- Subtropical high, a low-level trough, and a mid-latitude trough
- ~ Oct. 29 – Nov. 4 and an intense mid-latitude disturbance. (Rahn and Garreaud, 2010; Toniazzo et al., 2011)
• Generally solid cloud
• Relatively low LWP and $R_e \rightarrow$ thin and polluted cloud
• QuikSCAT surf. wind: $4.1 \pm 1.5 \text{ ms}^{-1}$, $175^\circ$ (Southerly wind)
• Average Div: $\sim 3 \times 10^{-6} \text{ s}^{-1}$
Cloud Liquid Water Path

Oct. 19 GOES10 Ch1
Cloud Liquid Water Path

![Graph showing LWP (gm^-2) over different dates with error bars.]

- **Dates**: 1016, 1021, 1026, 1031, 1105, 1110
- **Axes**: LWP (gm^-2)
- **Legend**:
  - Grey bars: TO
  - Pink dots: GOES10

![Map showing locations at 17.5°S, 20°S, 22.5°S, 75°W, 70°W.]

- **Map Details**:
  - Oct. 24
  - Orange circle highlighting an area of interest.
Cloud Liquid Water Path

![Graph showing LWP (gm^-2) for different dates and locations. The graph includes bars for different dates (1016, 1021, 1031, 1105, 1110) and points for TO and GOES10. The y-axis represents LWP in gm^-2, ranging from 0 to 250. The x-axis lists dates from Nov. 1, with a map indicating locations at 17.5°S, 20°S, and 22.5°S, 75°W, and 70°W. The graph shows variability in LWP across the dates and locations.]
Cloud Liquid Water Path

![Graph showing LWP (gm^-2) for different dates and locations.](chart)

- **Dates:** 1016, 1021, 1026, 1031, 1105, 1110
- **Locations:** 17.5°S, 20°S, 22.5°S, 75°W, 70°W

**Legend:**
- **TO**
- **GOES10**
Cloud Liquid Water Path

![Graph showing LWP (gm^-2) vs Date]

- **Dates:** 1016, 1021, 1026, 1031, 1105, 1110
- **LWP (gm^-2):** 0, 50, 100, 150, 200, 250
- **Legend:**
  - Gray bars: TO
  - Pink dots: GOES10

![Map indicating Nov. 12 and geographical coordinates]

- **Geographical Coordinates:**
  - 17.5°S
  - 20°S
  - 22.5°S
  - 75°W
  - 70°W

**Nov. 12**
Boundary Layer Structure

- Well mixed BL with strong inversion
- Relatively low wind speed with strong vertical wind shear
- Some complications involving wind shear within the BL, moist layers above, strong decoupled BL with cumulus below
Turbulence structure

- Relatively weak turbulence in the BL
- Entrainment rates (average of 1.5±0.6 mms$^{-1}$)
- Cloud top radiative cooling

Vertical vel. variance  total water flux  heat flux
BL Variations

- Inversion height varied between 1000 and 1500 m
- SST gradually increased
- the 30-m fluxes
Aerosol and Cloud Properties

The diagrams illustrate the number concentration over time, with different symbols representing different properties:

- PCASP above inversion
- CCN above inversion
- Subcloud PCASP
- Cloud droplet
- CCN

The x-axis represents dates, and the y-axis shows the number concentration per cubic centimeter.
Aerosol Indirect Effect

\[ \frac{d\ln N_d}{d\ln CCN} = 0.92, 0.72 \]

\[ \frac{d\ln N_d}{d\ln N_a} = 1.07, 0.86 \]
LWP and Sub-cloud CCN

(Zheng et al. GRL 2010)
Conclusions

• Typical non-drizzling, well-mixed stratocumulus topped BL on days when synoptic and meso-scale influences are small
• Aerosol variability driven by boundary layer flow and processes.
• Entrainment rates and turbulence were weaker than that in the BL over the open ocean west of Point Alpha and the BL off the coast of the NE Pacific (Bretherton et al. 2010; Stevens et al. 2005).
• During the typical well-mixed BL days, the LWP increased with the CCN concentrations (Zheng et al. GRL 2010)
• On the other hand, meteorological factors and the decoupling processes can have large influences on the cloud LWP variations