CRC1211 Seminar Series, 31.05.2021

Atacama coastal clouds and circulation patterns observed with ground-based remote sensing (A01)

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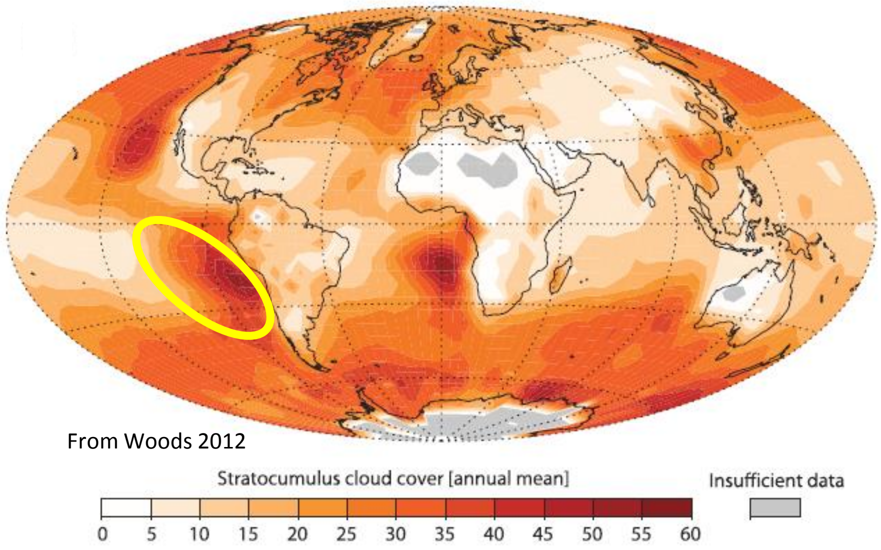
in cooperation with ***Juan Luis García, Pablo Osses McIntyre, Camilo del Río (PUC)***

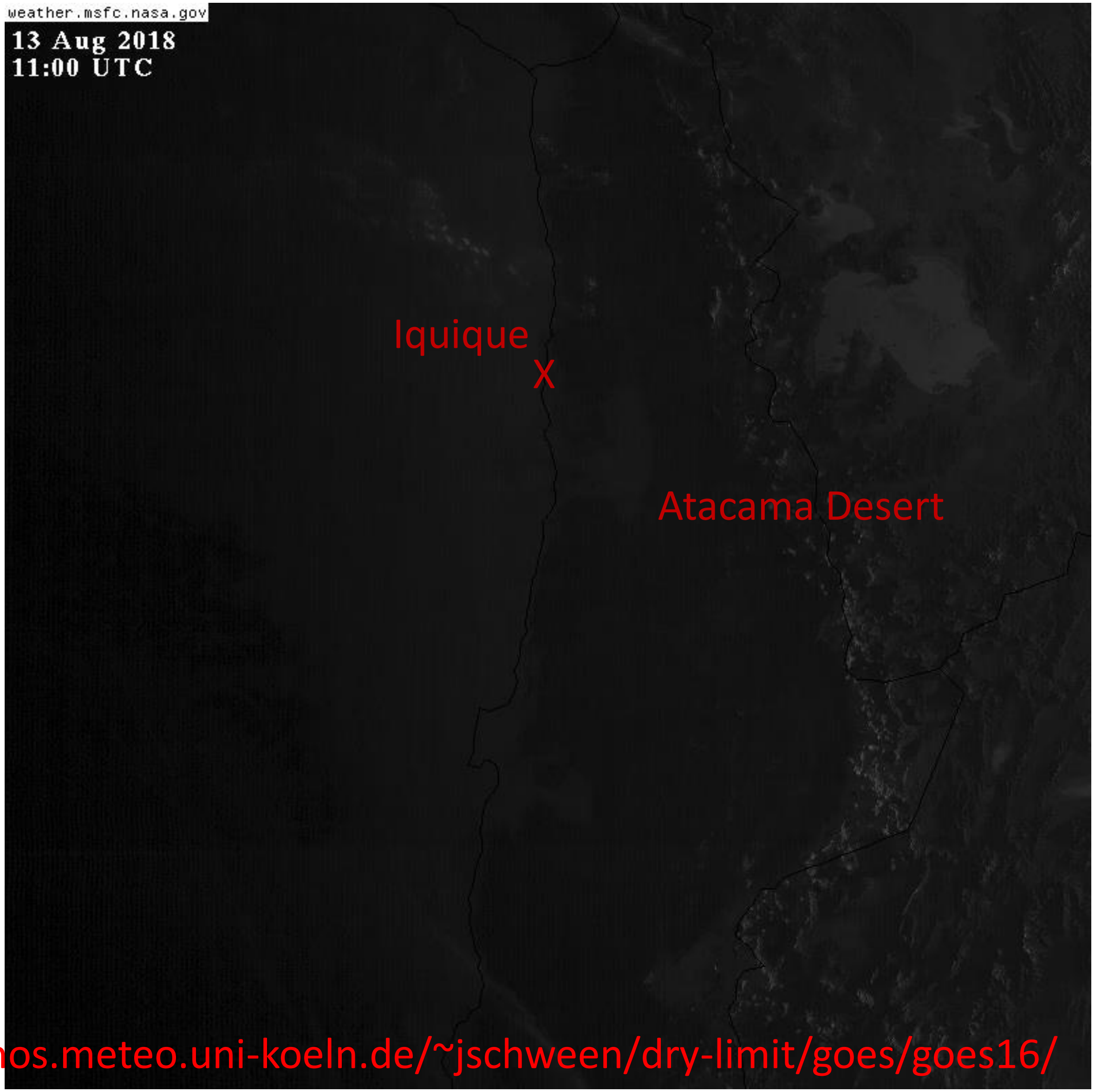
Marine Strato-cumulus (Sc)

- Sc cover large areas along the western coasts of continents → important for **radiation budget** of the planet
- **Provide water** to coastal desert (Namib, Atacama) or dry areas (California)
- **Objective**: understand seasonal and diurnal cycle, relate to external drivers (SST, synoptics, topography)



From Woods 2012

Diurnal cycle of Sc: GOES16



See https://atmos.meteo.uni-koeln.de/~jschween/dry-limit/goes/goes16/

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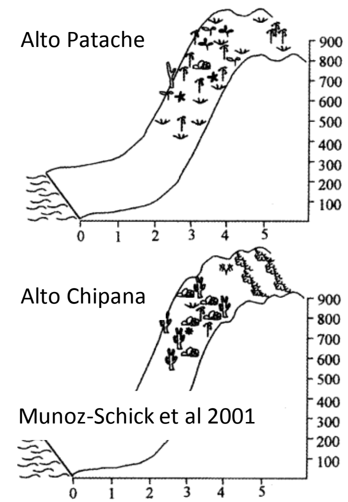
Why investigate **the vertical structure** of Pacific Sc over Chile’s Atacama coastline ?

Pacific Sc and fog

- Sc intercepts the coastal cliff and "Cordillera Costal" as fog
  - Fog oases: Lichens, Cacti, Tillandsia, …
  - Soil: Gypsum – Anhydrite conversions (Talk B. Ritter)
- Height of Sc above ocean defines where fog occurs and is controlled by a variety of parameters



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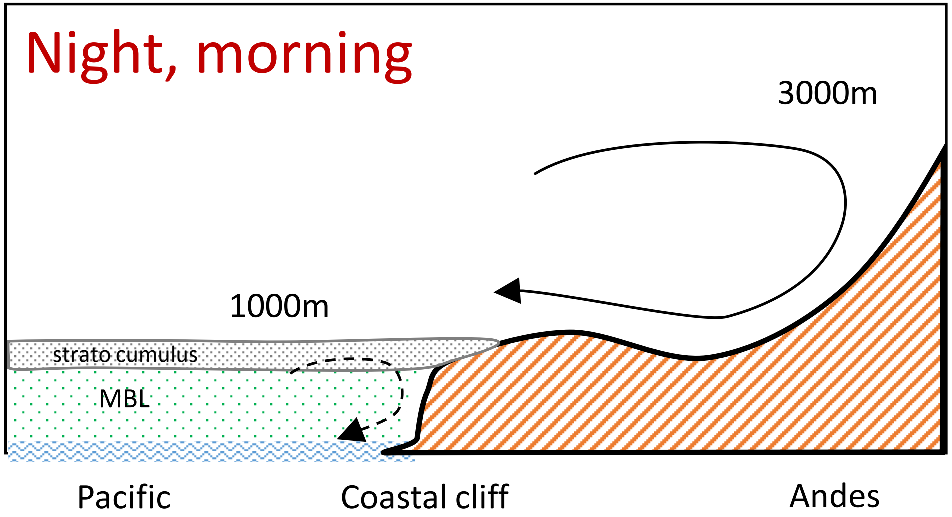
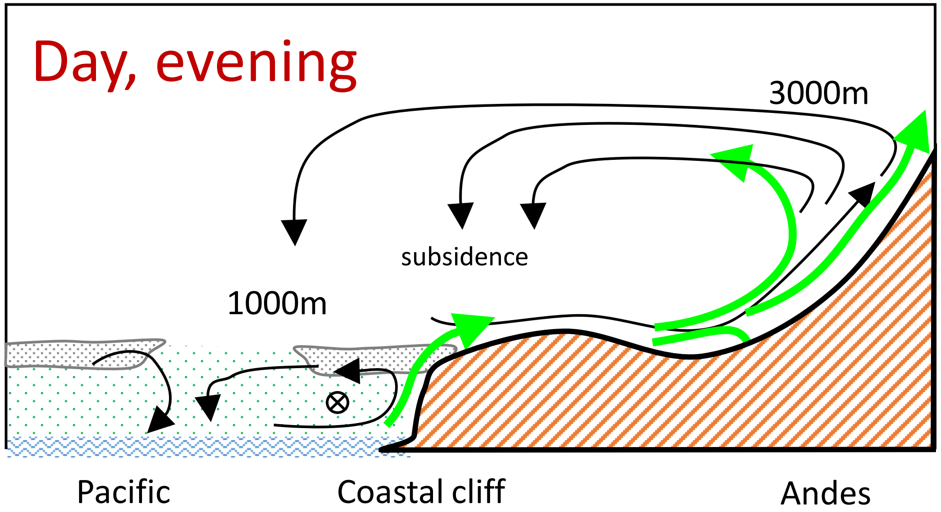
Sc embedded in general circulation patterns



- Down slope winds from the Andes towards coast
- Land-breeze at sea level at coast
- Landward wind at MBL top forces Sc towards coast

Sc embedded in general circulation

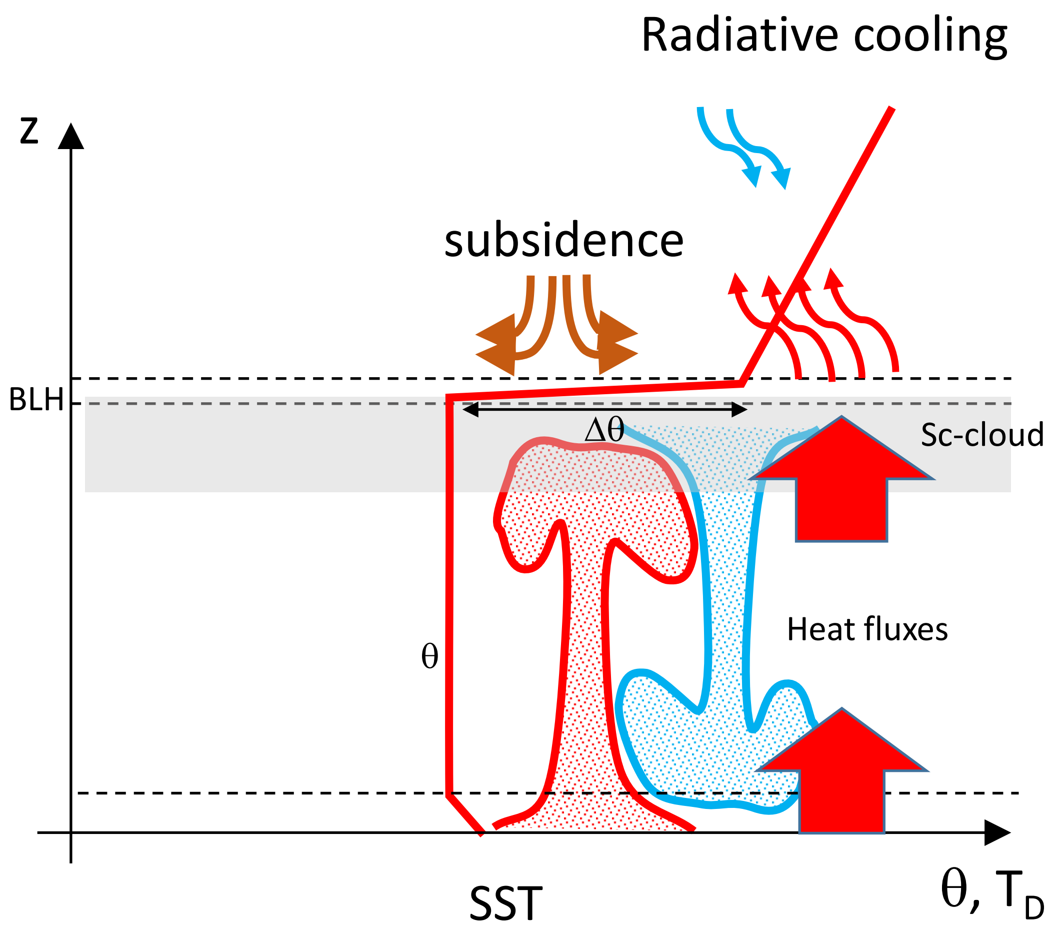
Injection of **moist, aerosol rich air** from Pacific into Atacama Desert



- Rutllant cell: Upslope winds at Andes, with back circulation below ~3 km and subsidence
- Sea-breeze at sea level at coast, sea-ward wind at cloud level
- Warmed air from coastal plain and subsidence dissolves coastal Sc around noon
- Afternoon cooling allows reformation of coastal cloud in rising air of sea breeze circulation

Mechanisms maintaining the Sc

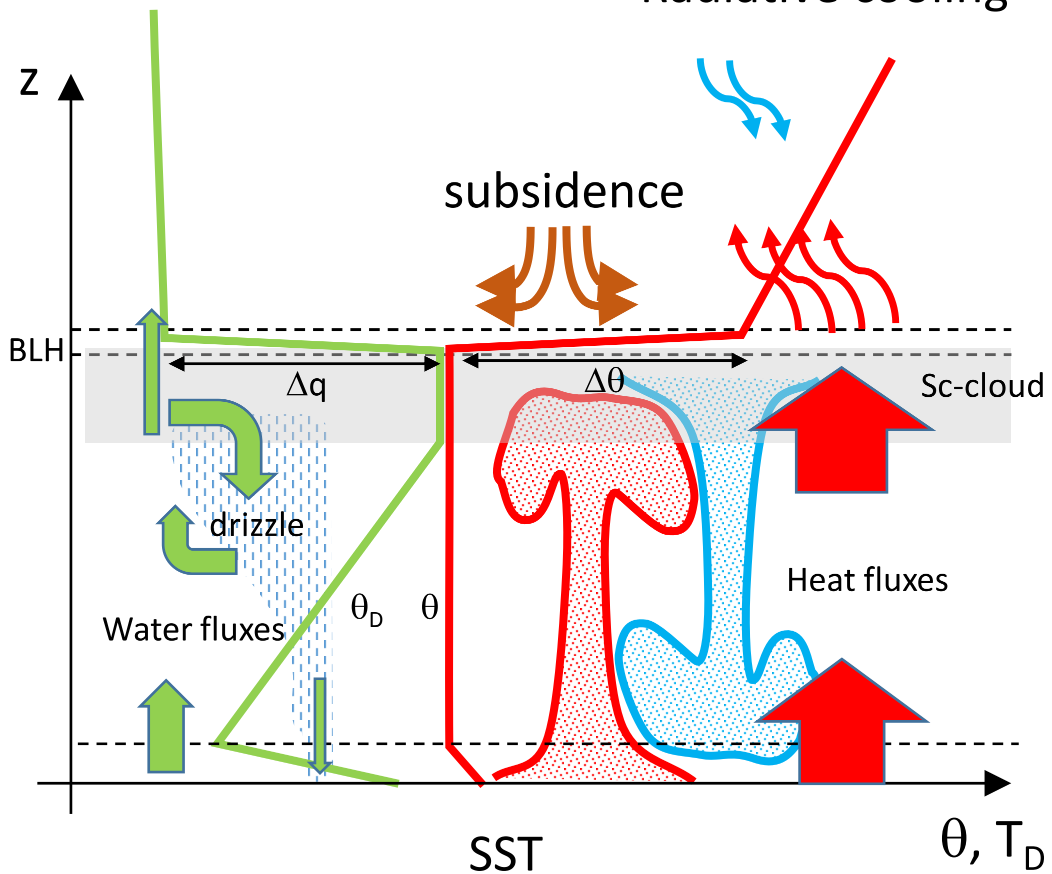
- Radiative cooling at cloud top: generates cold descending plumes → cooling of BL
- When air temperature < SST: warm ascending plumes develop



Mixed Boundary Layer MBL

Mechanisms maintaining the Sc

- Radiative cooling at cloud top: generates cold descending plumes → cooling of BL
- When air temperature < SST: warm ascending plumes develop
- Water source: ascending plumes
- Water sinks: evaporation and drizzle

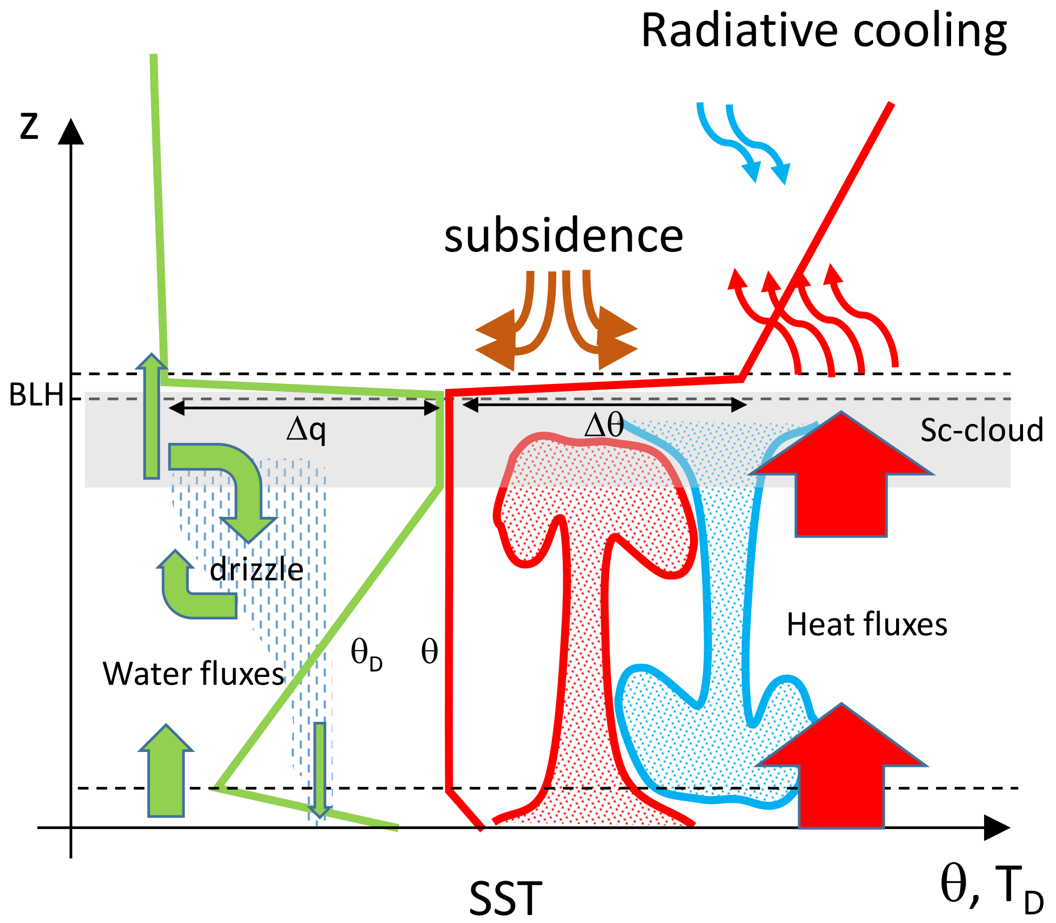


Mixed Boundary Layer MBL

Mechanisms maintaining the Sc

Determining parameters

- IR radiation budget at cloud top
- Strength of subsidence
- Difference $\Delta\theta$ between SST and free troposphere
- Difference humidity Δq BL free troposphere
- Microphysical properties of cloud



Challenge: **continuous observations** of vertical structure, dynamics, thermodynamics and microphysics **missing**

Ground-based remote sensing station at Iquique Airport (2018/2019)

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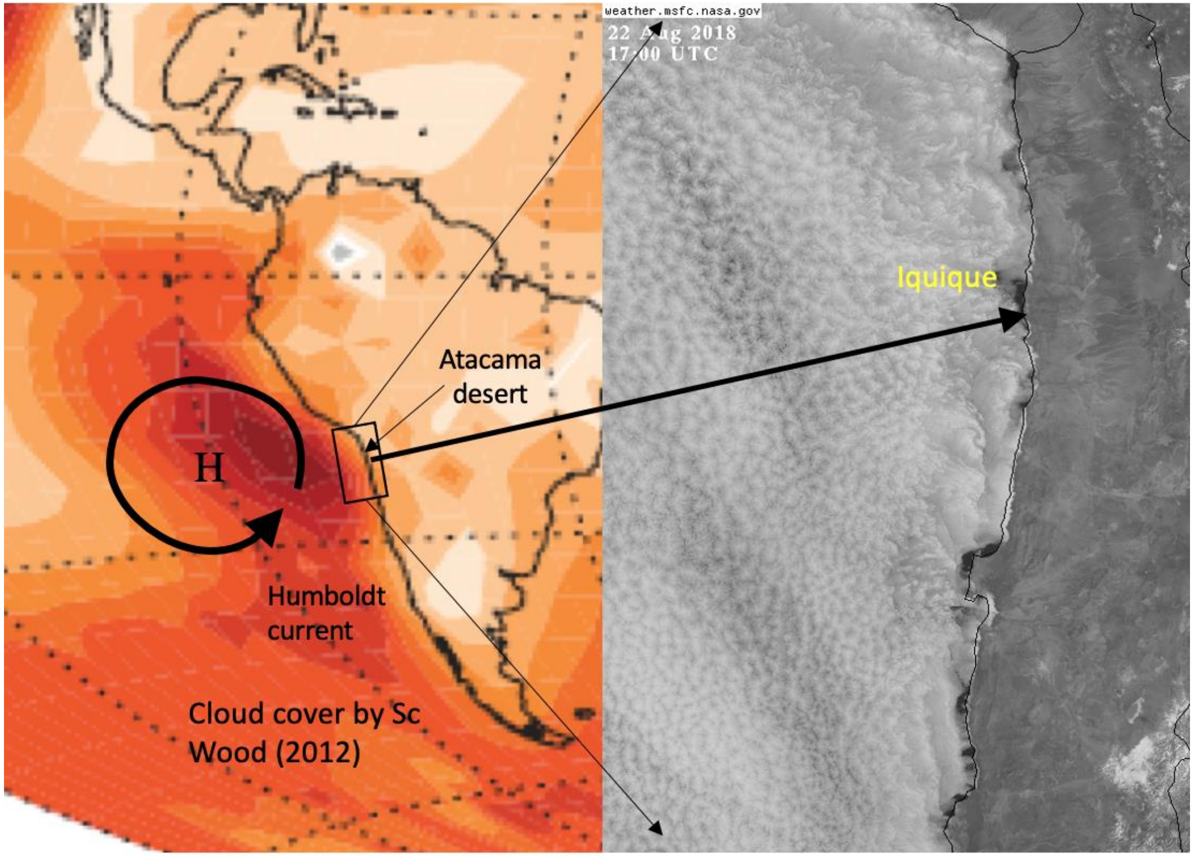
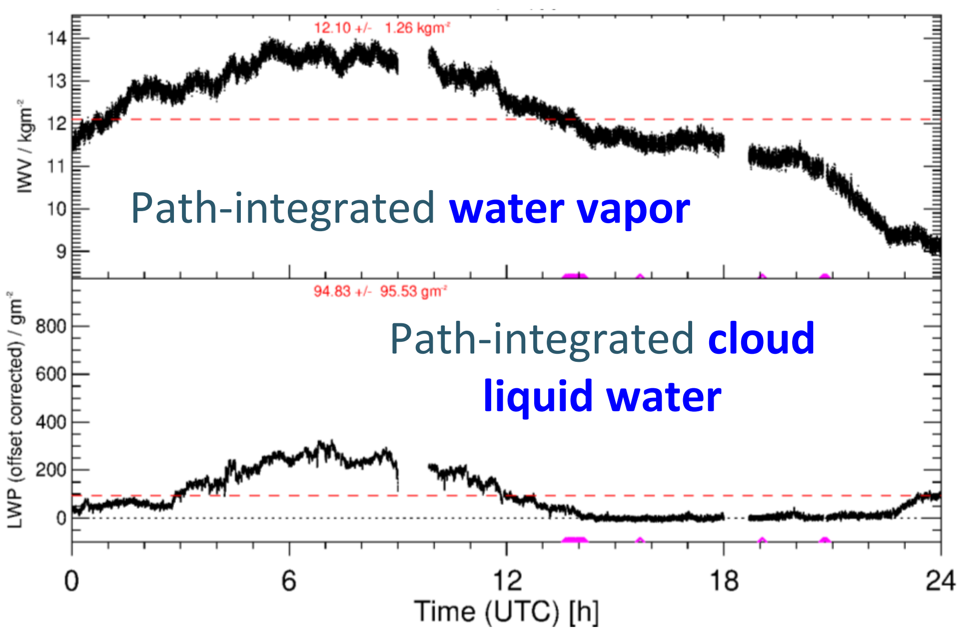
Set-up and location

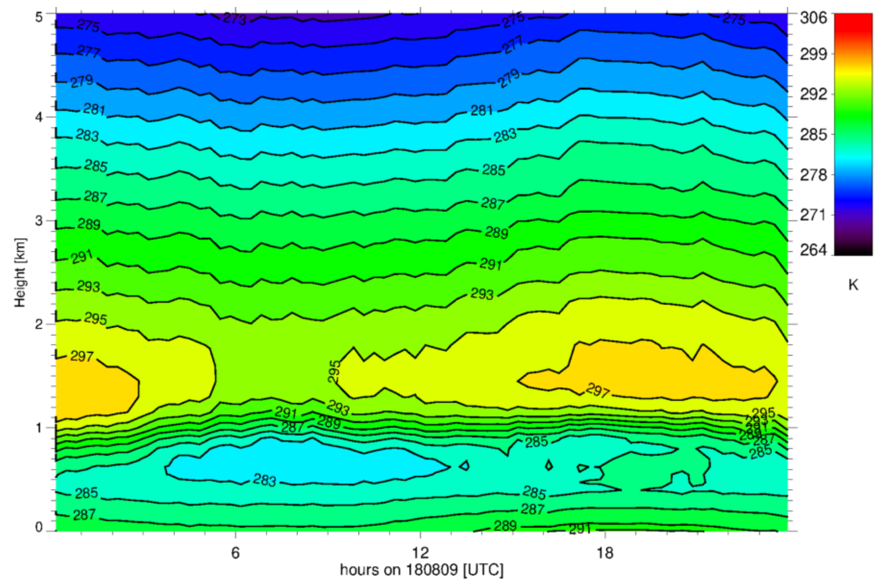


- At Airport Iquique (IQQ) 21.5°S, 70°W, 54 m MSL
- Time period March 2018 – February 2019
- Located on coastal plain 25-50 m MSL extending 30 km to the south

Microwave radiometer

continuous data in all-sky conditions: resolution of seconds to minutes





Temperature profile in the MBL

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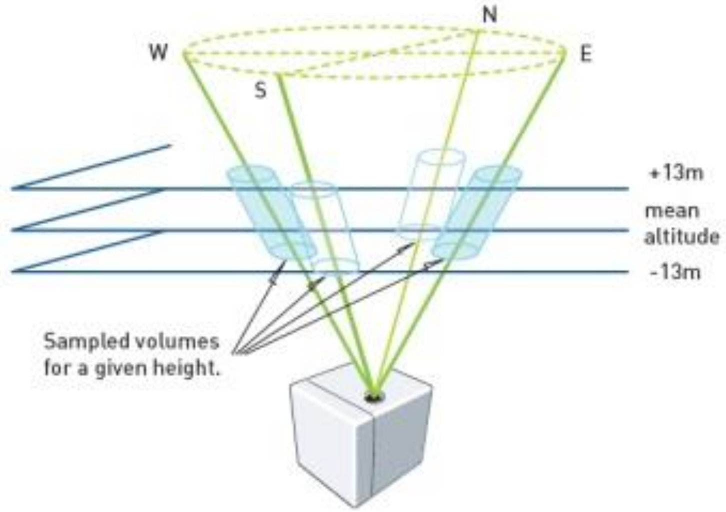
Doppler wind lidar

- LIDAR principle: send out laser pulses and measure **backscattered** light
- Measures **Doppler effect** on small particles (e.g. aerosols)
  - along-sight Doppler velocity
  - scanning configurations allows to derive 3D **wind vector** as a function of height

- Vertical resolution 30m
- Maximum height: cloud base or "end" of aerosol layer



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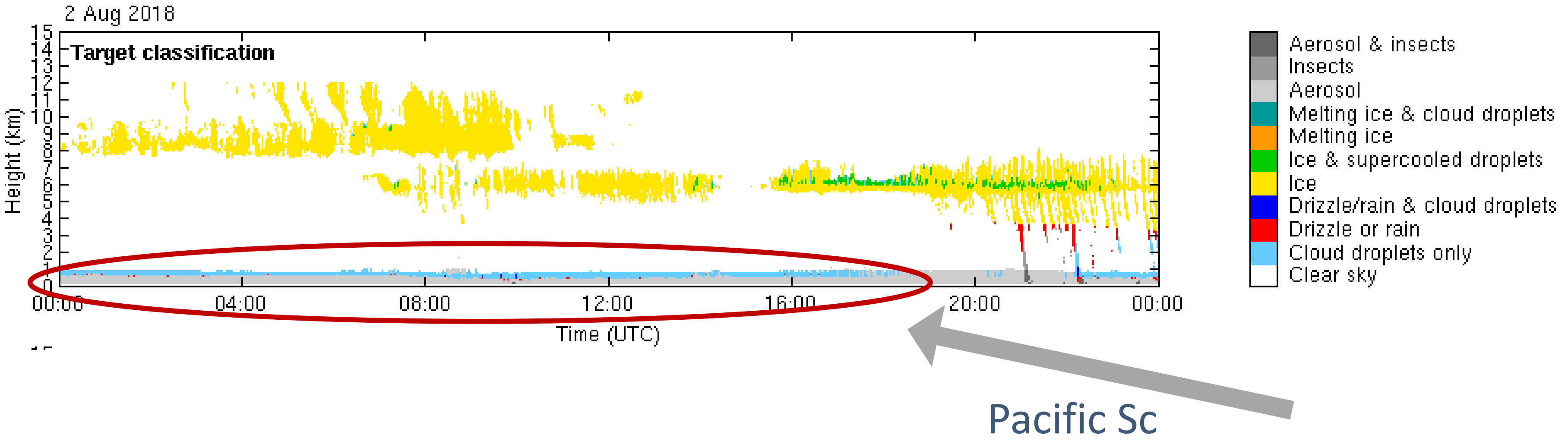
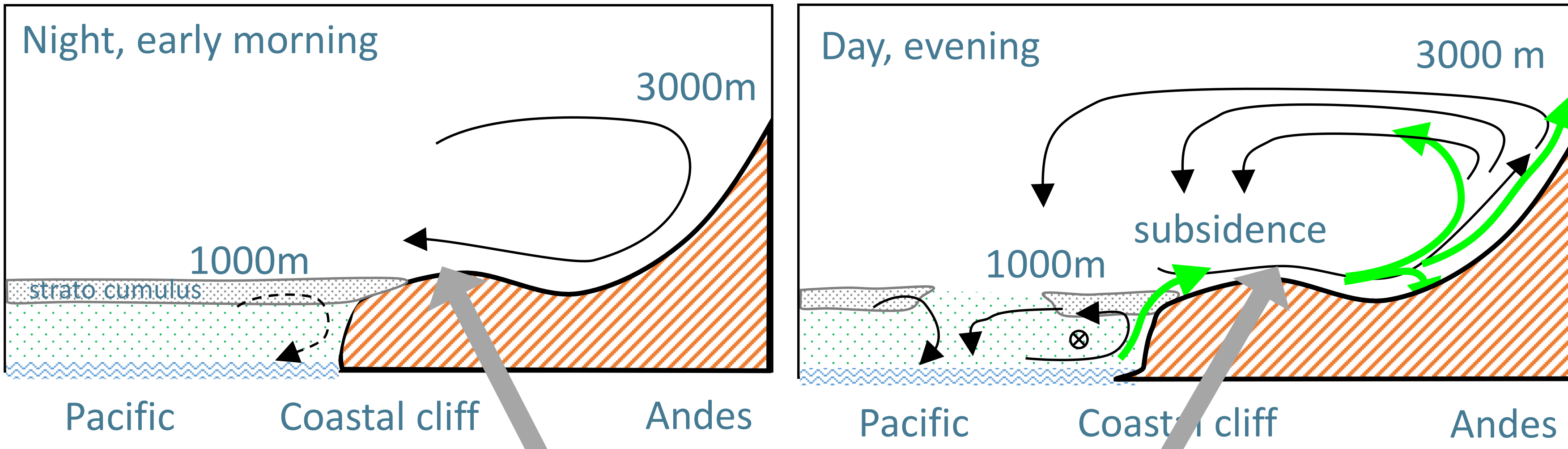
Cloud radar + lidar

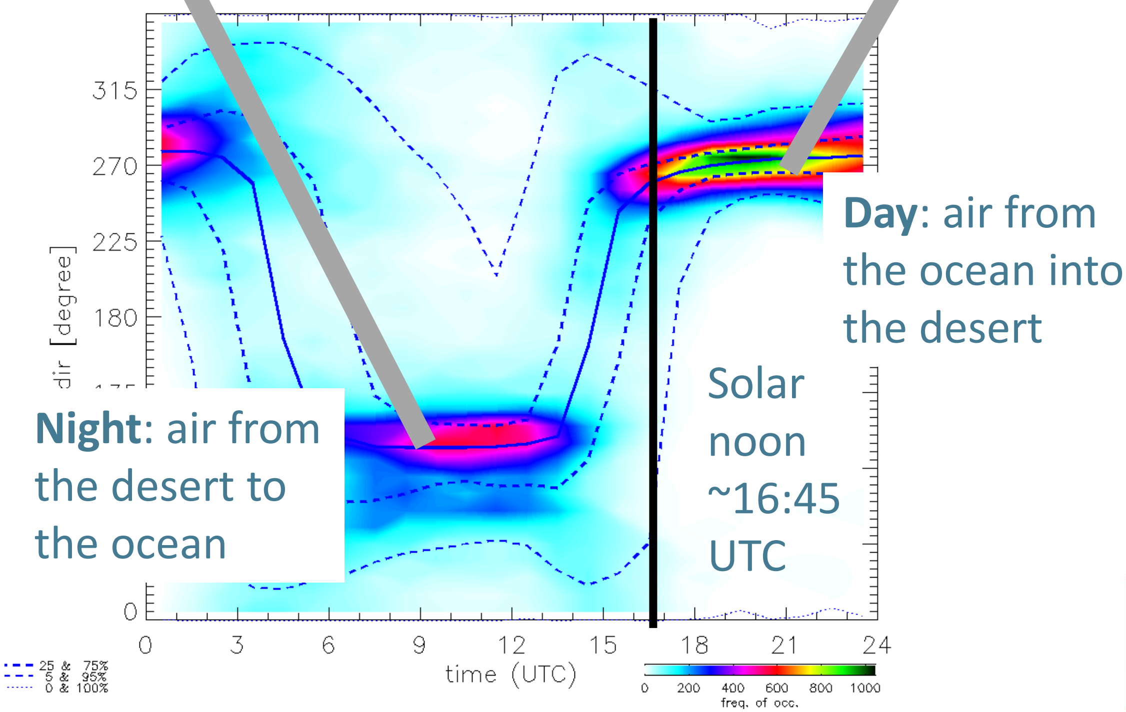
- Cloud radar: works like a rain radar, just upward looking a sensitive to much smaller droplets
- Cloudnet classification algorithm
- Allows to discriminate “targets” in the vertical column up to 15 km



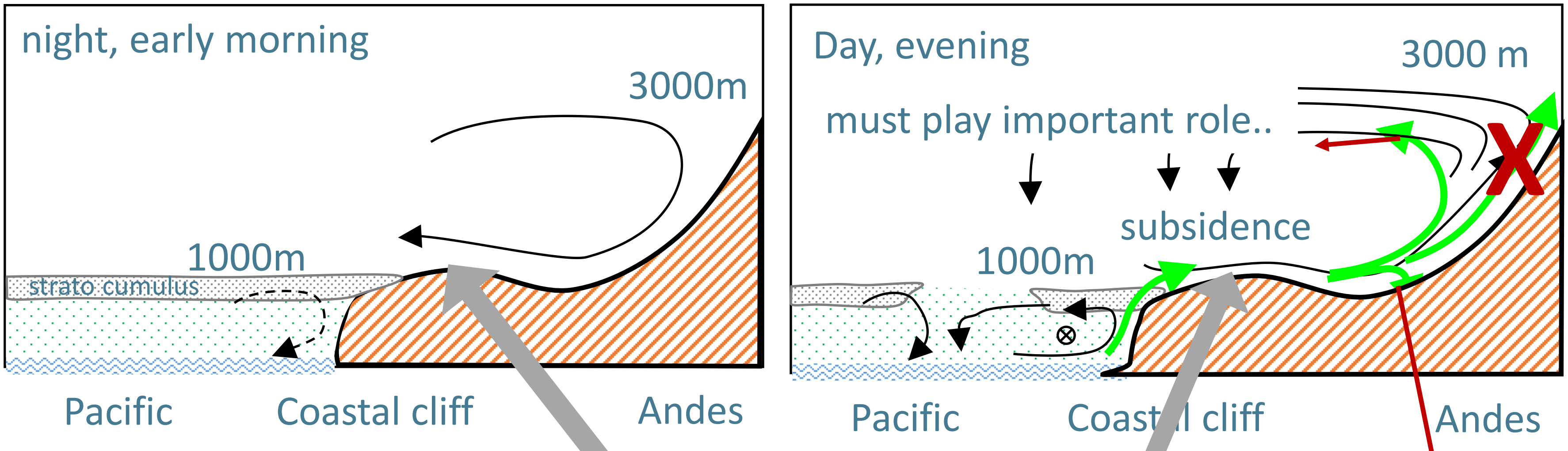
Diurnal cycle of local circulation patterns



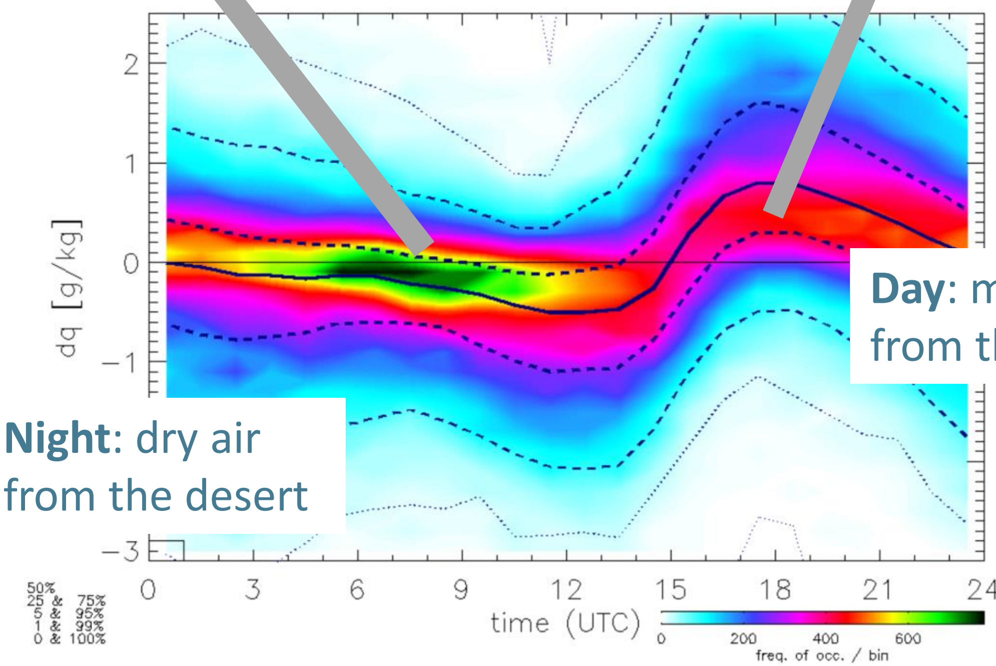
Diurnal cycle wind direction (FOC colored)



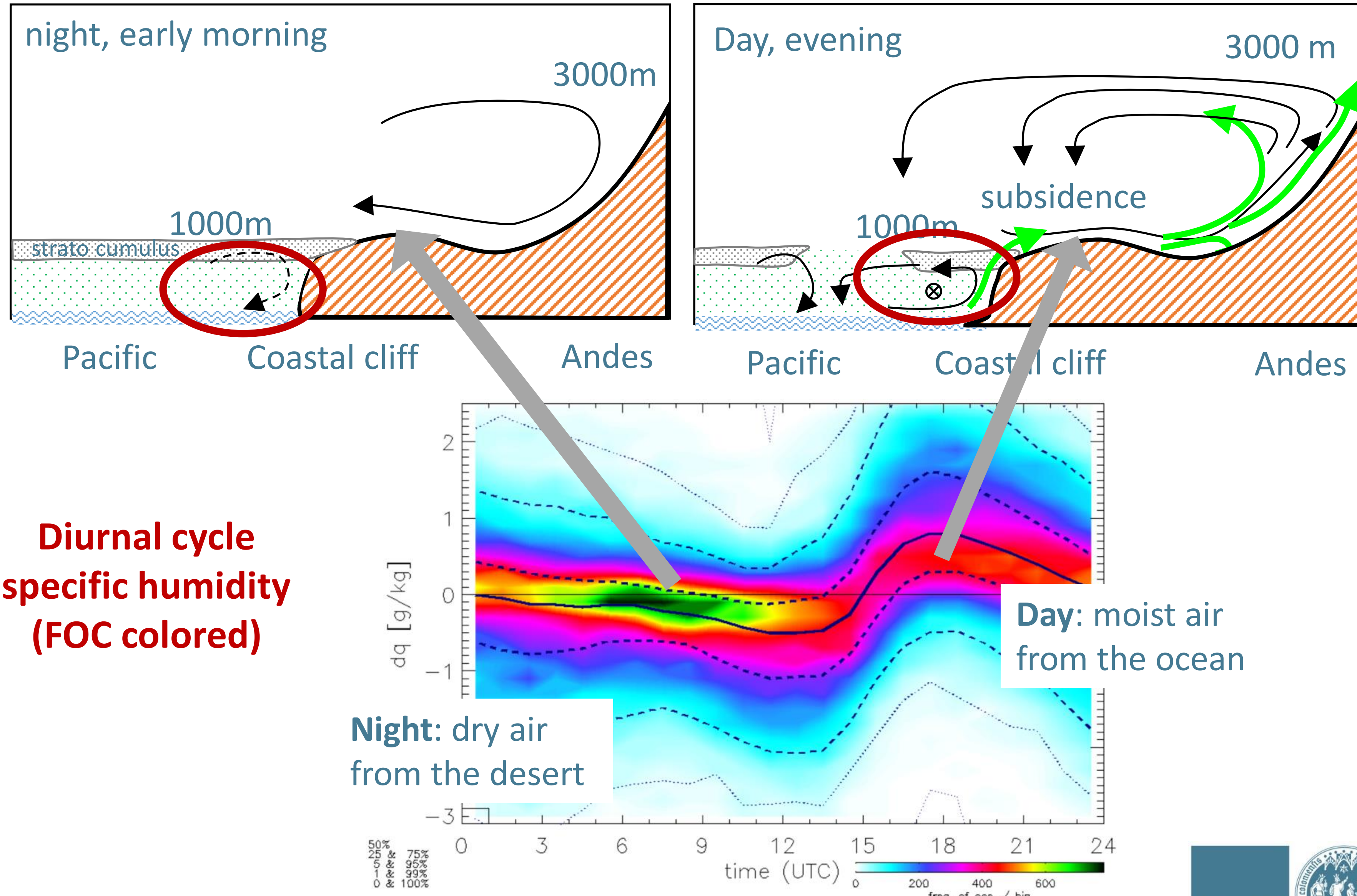
Diurnal cycle of local circulation patterns



Diurnal cycle specific humidity (FOC colored)



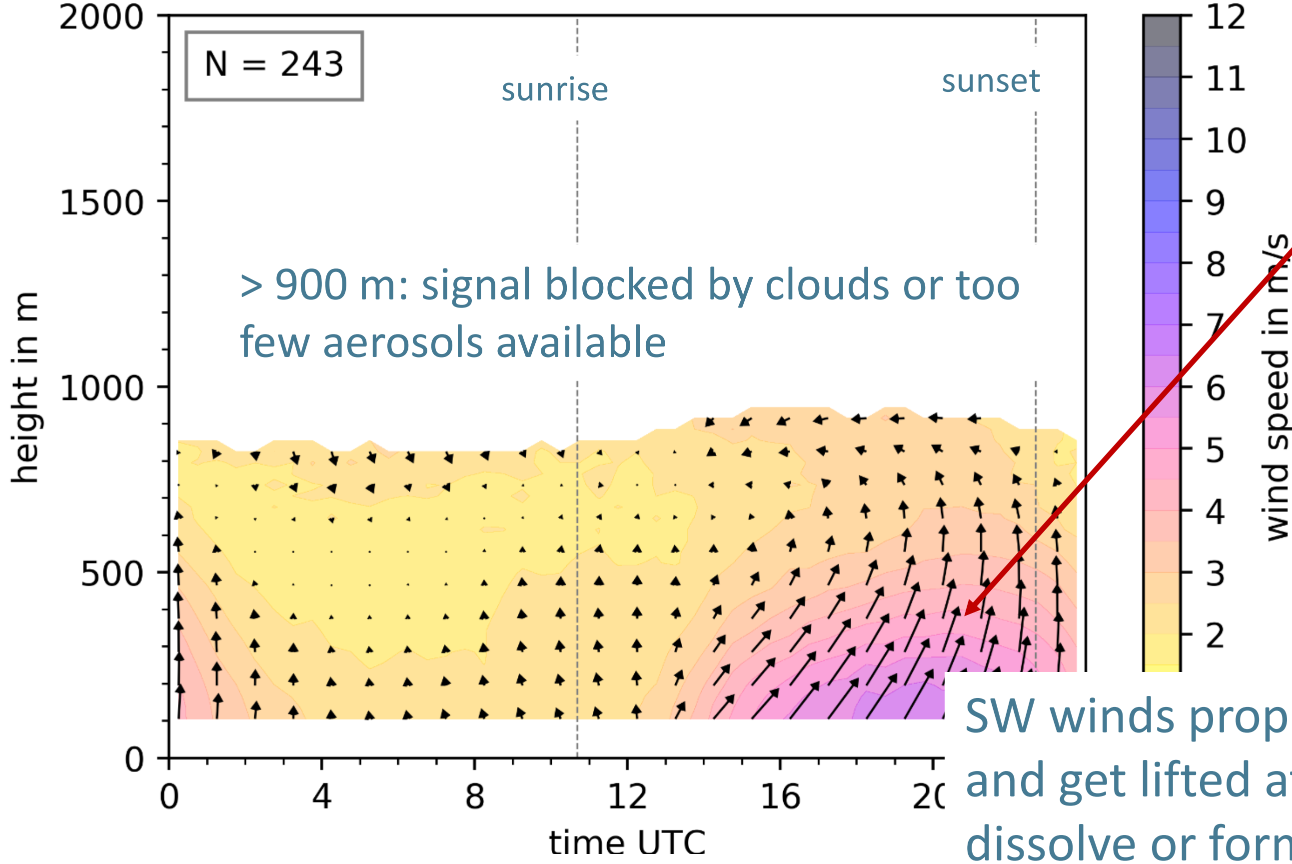
Diurnal cycle of local circulation patterns



Diurnal cycle specific humidity (FOC colored)

Diurnal cycle of wind (Doppler lidar)

“Coastal cliff circulation”



Strong low SW winds, turning to S → SE → E with height at cloud base

SW winds propagate land-inward and get lifted at coastal cliff to dissolve or form clouds..

Generally low winds at night…

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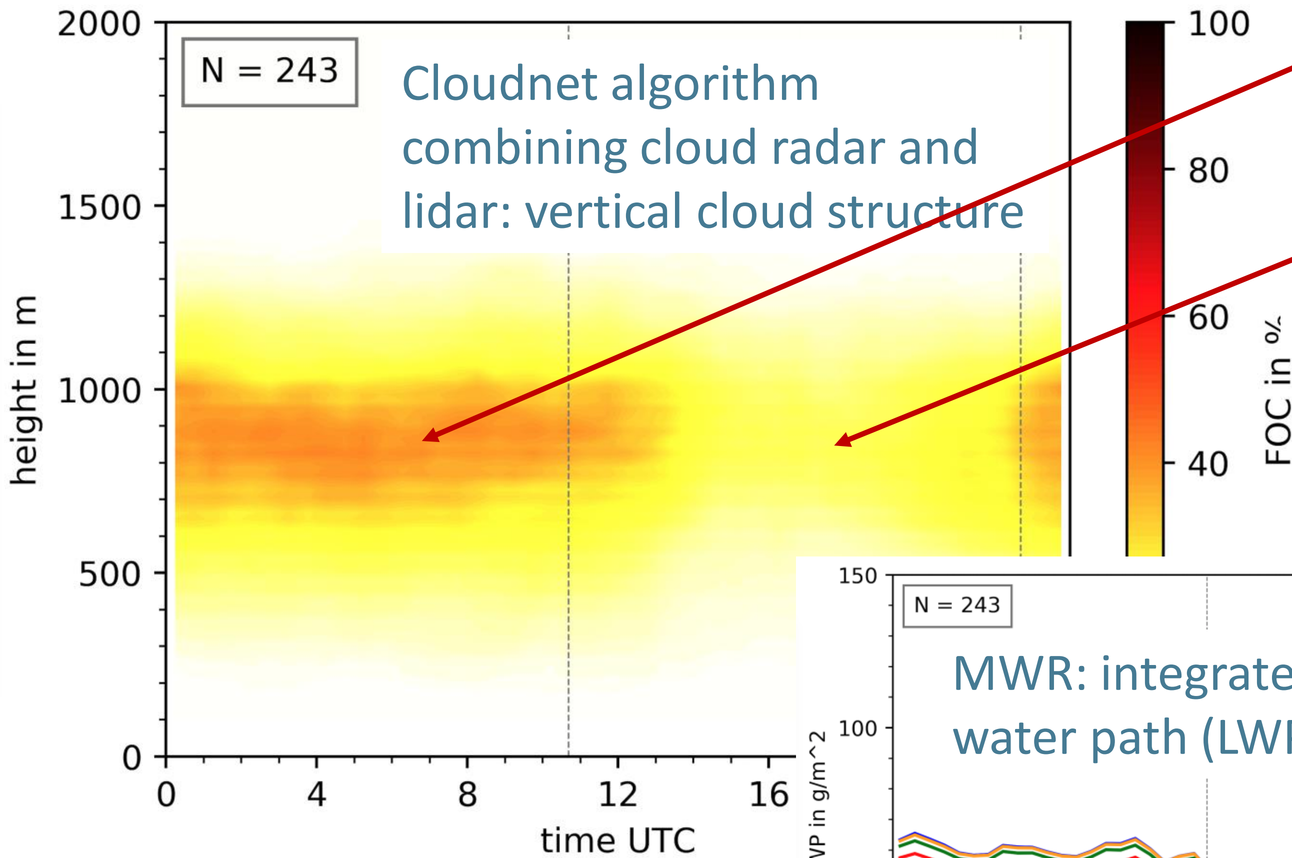
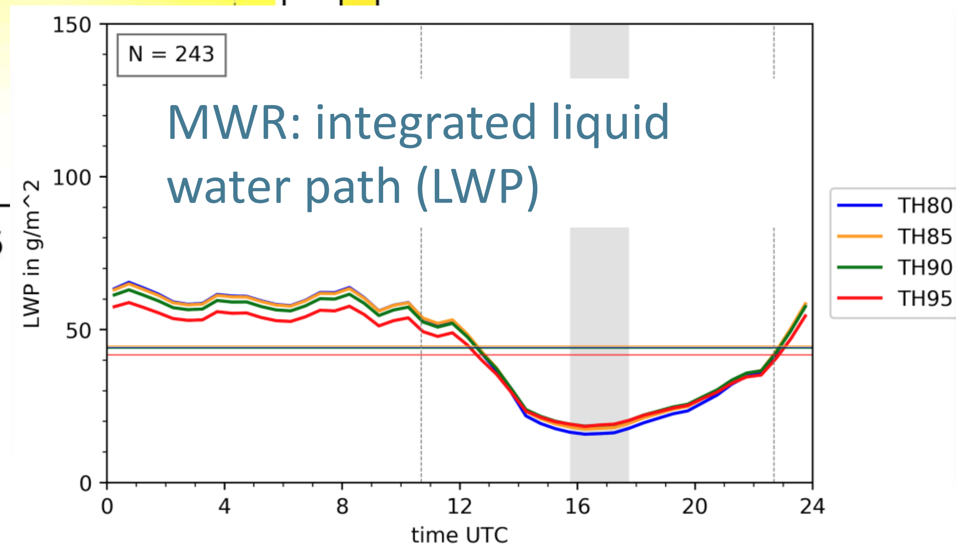
Diurnal cycle of clouds (Cloudnet)



Cloudnet algorithm combining cloud radar and lidar: vertical cloud structure

Maximum cloud occurrence *per height* at night (60%), minimum at day (20%)



MWR: integrated liquid water path (LWP)

Maximum LWP (60 gm^{-2}) during night, minimum during day (20 gm^{-2})

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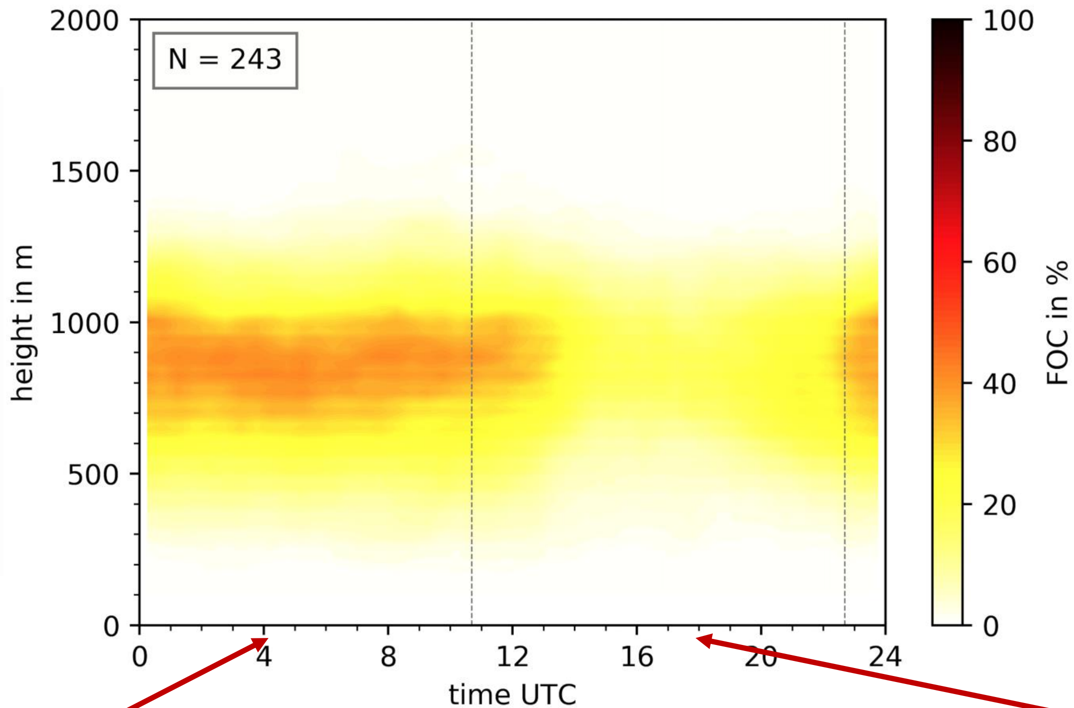
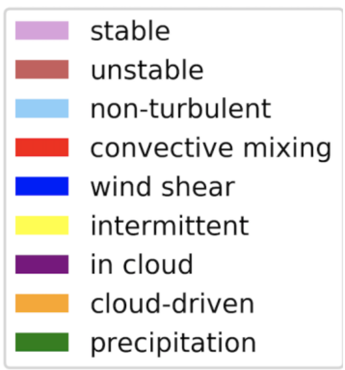
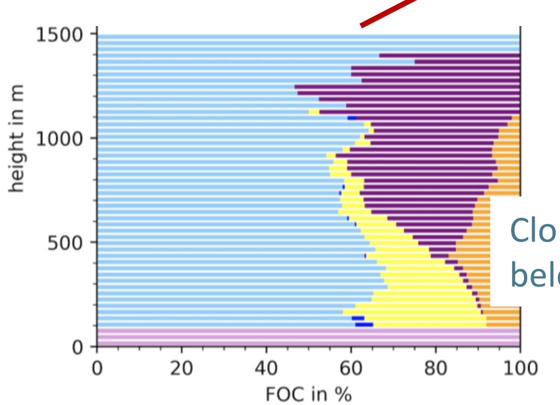
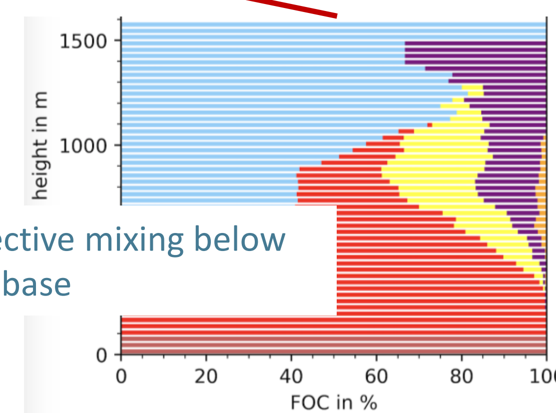
Cloud environment: Turbulent mixing below







Cloud-driven turbulence below cloud base



Convective mixing below cloud base

Different nature of the MBL clouds!

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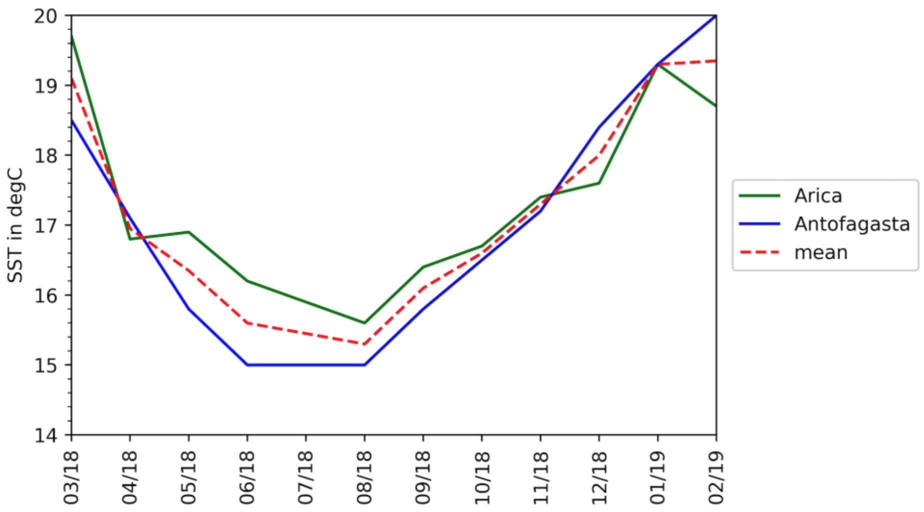
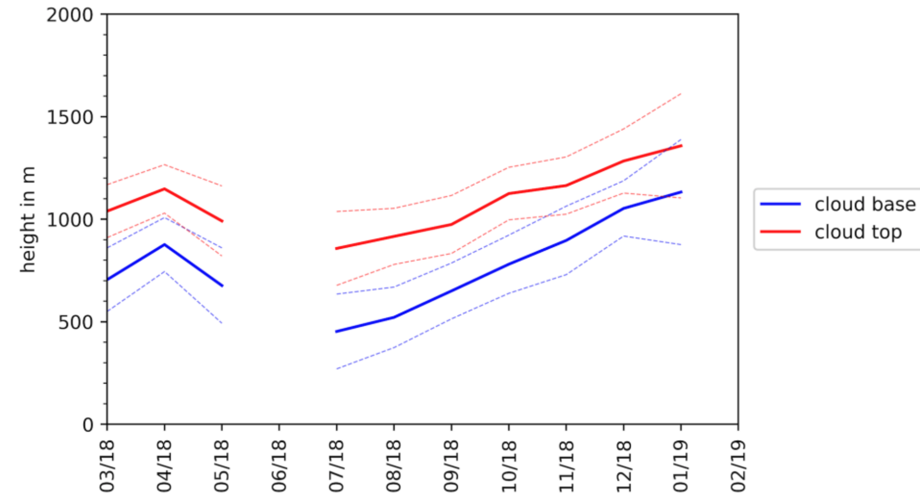
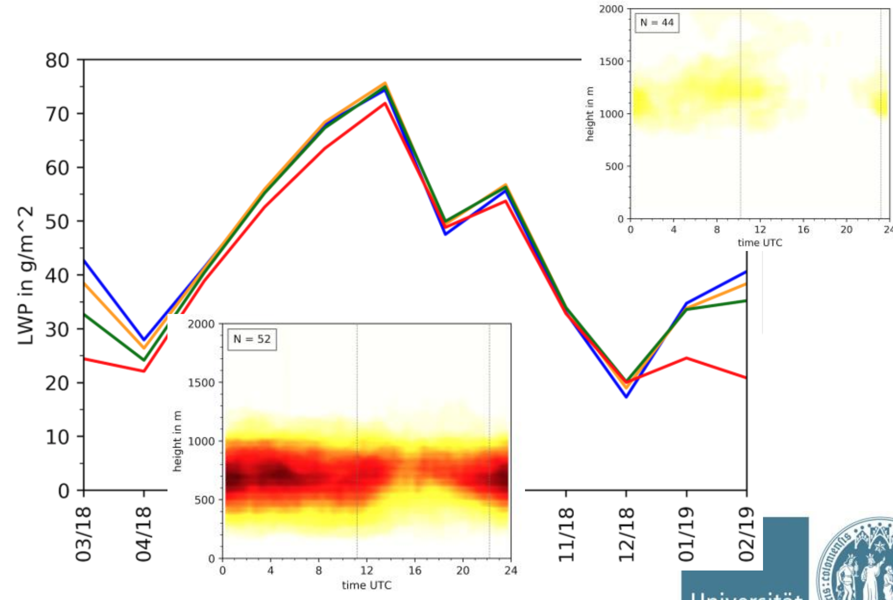
Annual cycle of Atacama coastal clouds





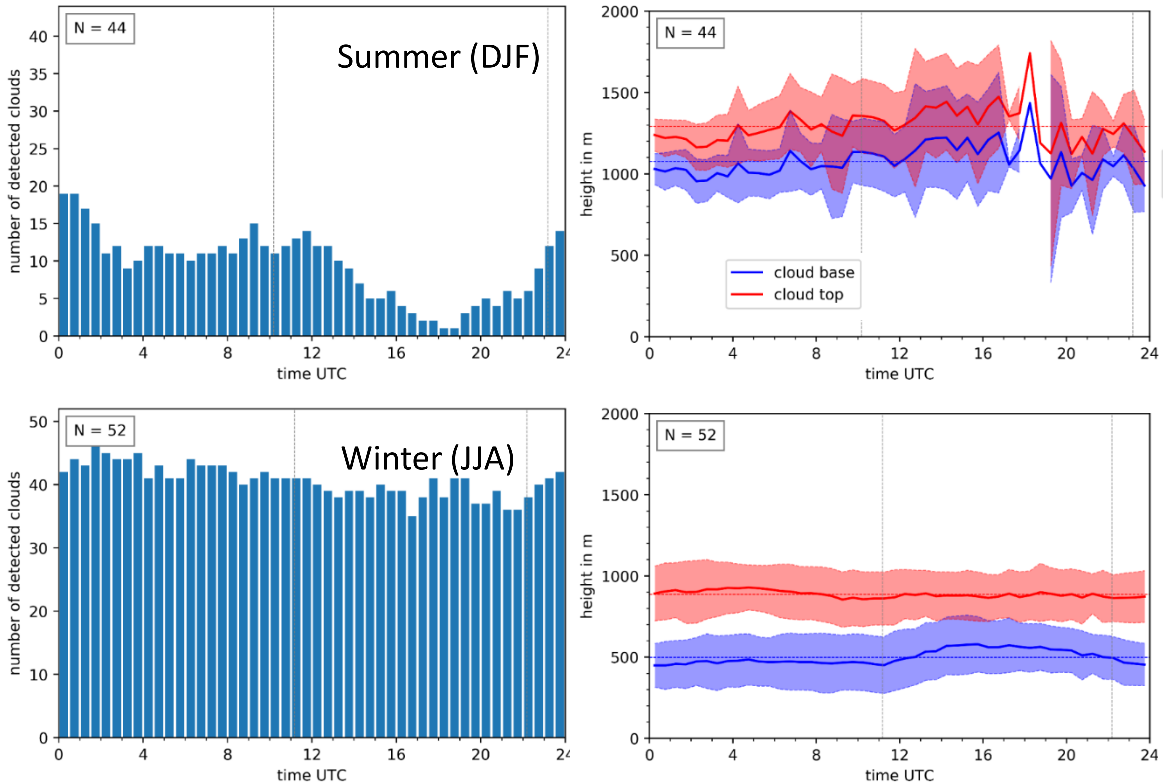
Winter: low SST, strong subsidence, low ABL → low, abundant, thick clouds, high LWP



Summer: “opposite conditions”

Sc occurrence in different seasons

- Much less frequent in summer than in winter
- Higher and more variable in summer



Winter

- Cloud top fairly constant, slight decrease during day
- Cloud base higher during day
- Clouds are “eaten” from the bottom
- Sea breeze circulation & surface heating at coastal plain

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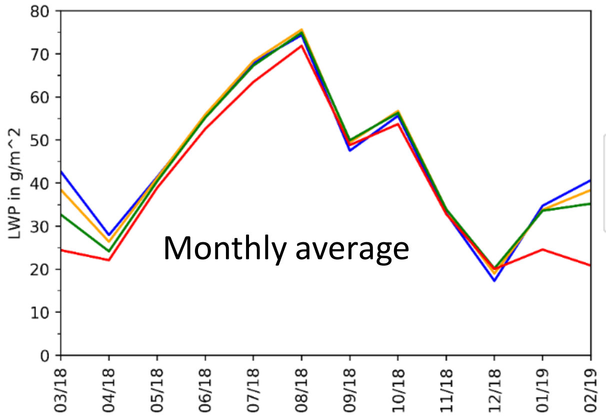
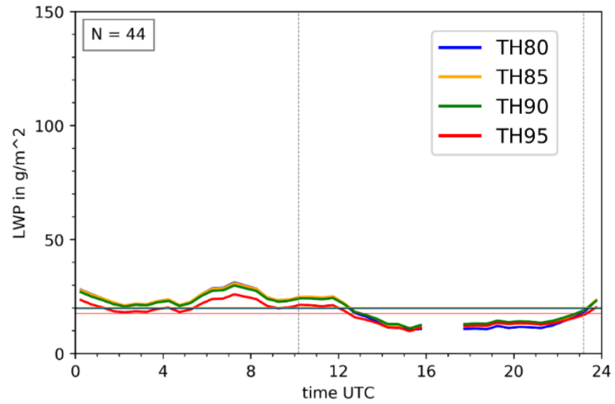
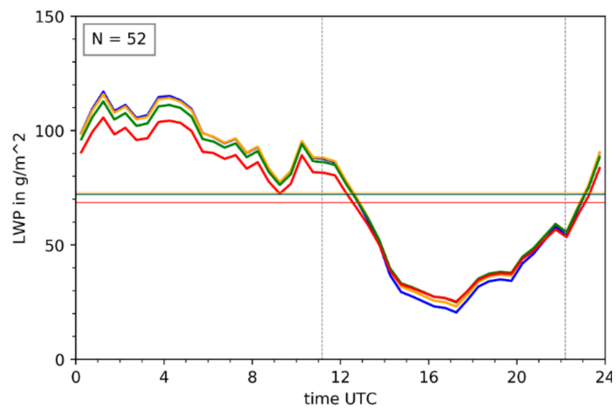
LWP in different seasons





Diurnal course
Summer (DJF)



Diurnal course
Winter (JJA)

- Max LWP in winter
- Min LWP in summer
- Largest daily amplitude in winter with max in first half of night

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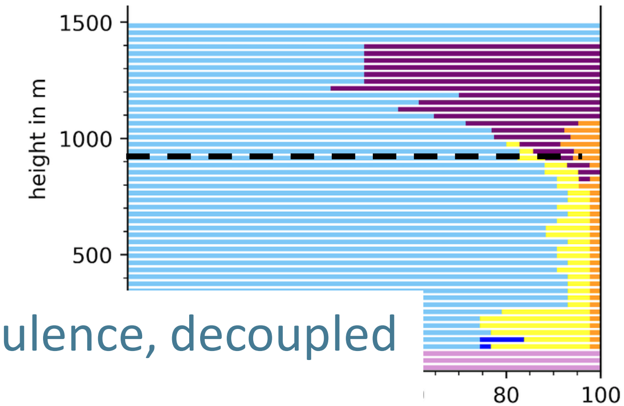
Turbulent mixing in different seasons

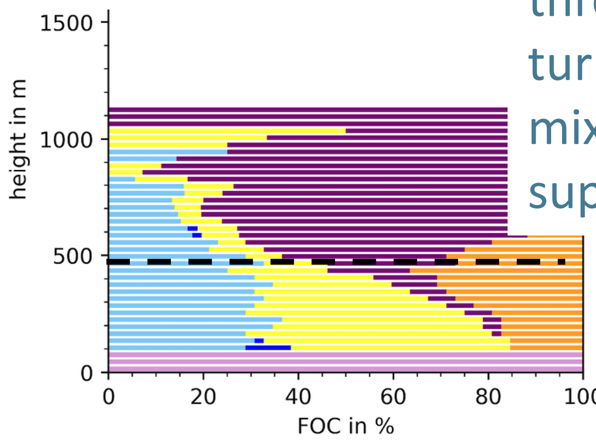
Summer (high clouds)

Winter (low clouds)

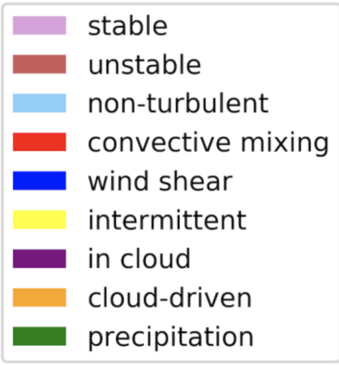
high turbulence, clouds coupled to surface through cloud driven turbulence → well mixed, high moisture supply

night

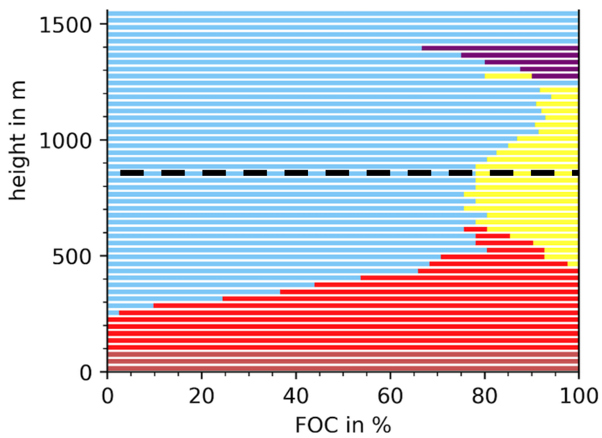


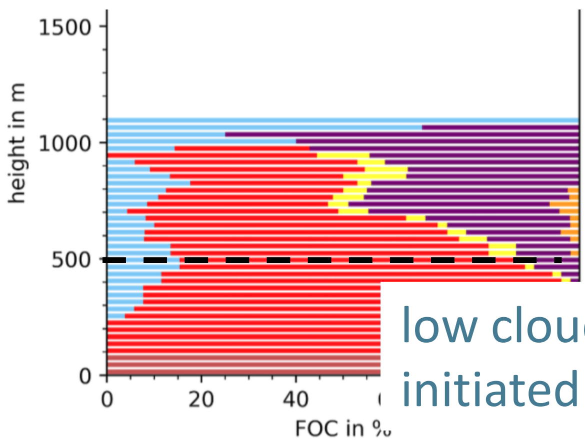


low turbulence, decoupled clouds



day





low clouds almost always initiated by convection

convection seldomly leads to condensation

Important “take home” messages

- Ground-based profiling well suited for **high-resolution MBL monitoring** at the Atacama coastline
- Observed structure of **coastal circulation cell** fits to theory; however strong daytime and weak nighttime winds..
- Clear **diurnal and seasonal cycle** in all **cloud-related properties**
- Sc are thicker, lower and contain more water in winter than in summer
- Strongest Sc water supply to desert typically at night
- **Different cloud sustaining mechanisms** during night (cloud top driven) and day (surface driven)

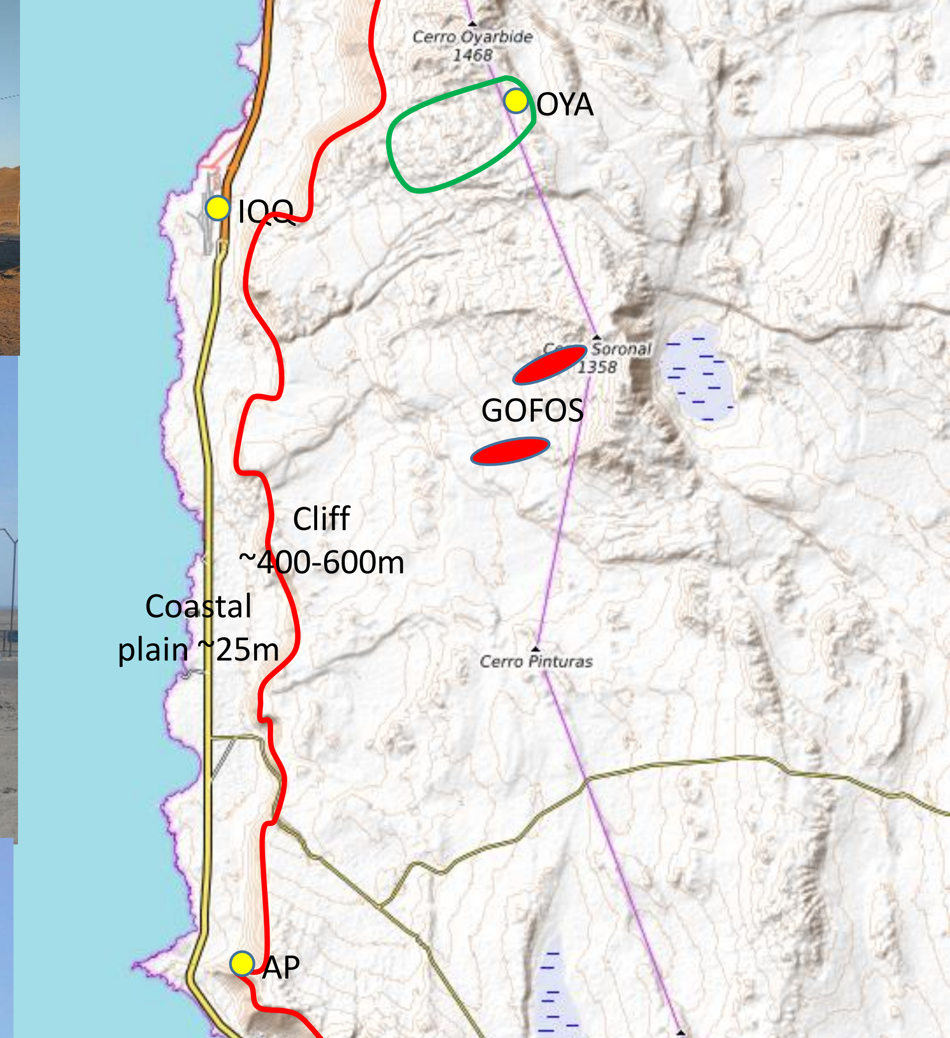
Next steps…

- Add water vapor MWR observations around 2600 m MSL (Paranal)
- Perform regional high-resolution Large Eddy Simulations (~50 m)
- Evaluate LES with observations

Looking for a more complete picture for the Atacama moisture supply: Where (and how…) does the water go??

Thank you for your attention!


Radiometer Physics
A Rohde & Schwarz Company
RPG-HATPRO-G5


Cerro Oyarbide
1468
OYA
IOQ
Soronal
1358
GOFOS
Cliff
~400-600m
Coastal
plain ~25m
Cerro Pinturas
AP

Data in Database(s) :

Data from **Iquique** Mar2018-Feb2019

- "**Wind profiles**"
- "**Boundary layer classification**"
  = turbulence classification
- "**Mixing layer height**"
  different method, Schween et al 2014
- "**Cloudnet data**" @ https://cloudnet.fmi.fi/

Meteo station data:

- Raw data under ‘weather data’ in data base
- "**Fog and Meteo data**" start > Mar.2017 -- Sept 2019
  quality controlled meteo data and derived fog occurence
  data from nearly all stations

MBL turbulence classification

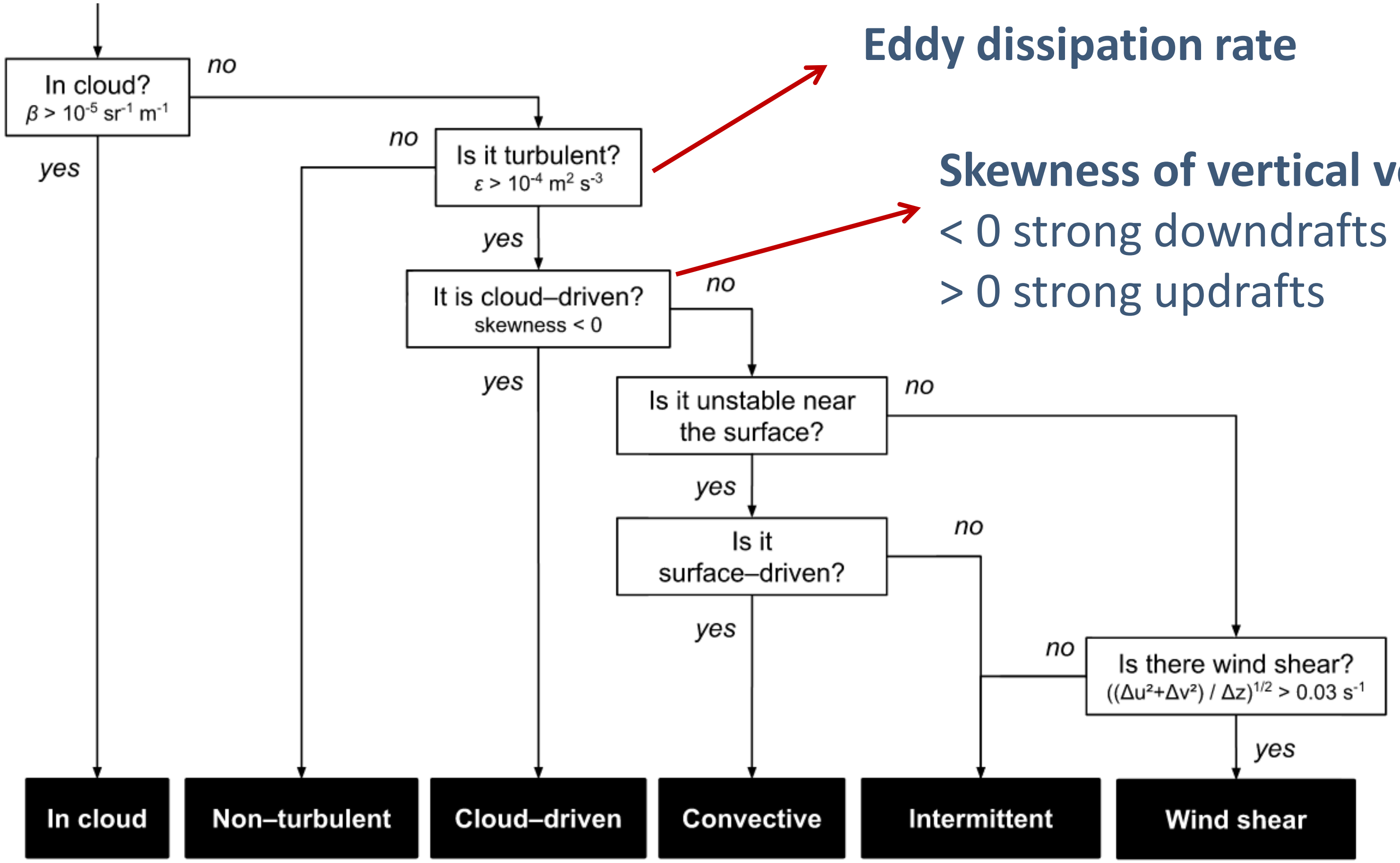


Figure 2. Schematic of the atmospheric boundary layer turbulent mixing source decision tree.

Eddy dissipation rate

Skewness of vertical velocity

< 0 strong downdrafts

> 0 strong updrafts

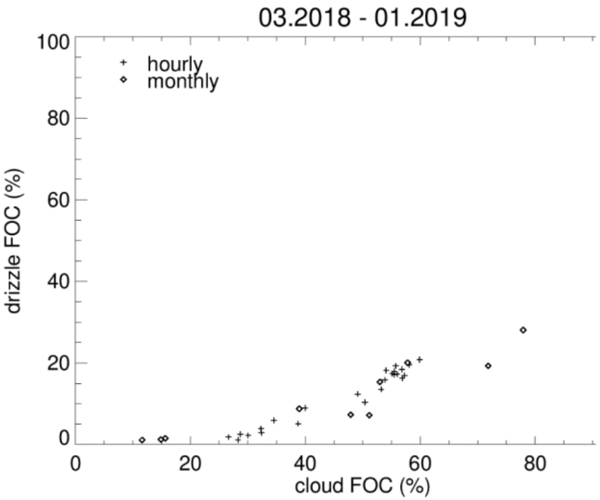
Manninnen and Marke et al., JGR, 2018

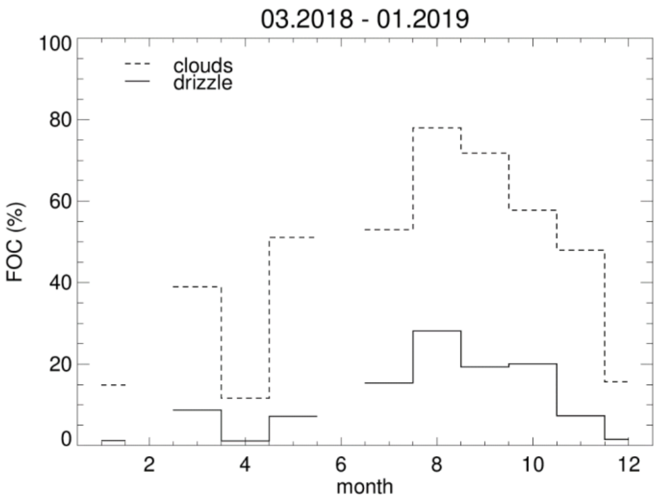
Drizzle: Frequency of occurence

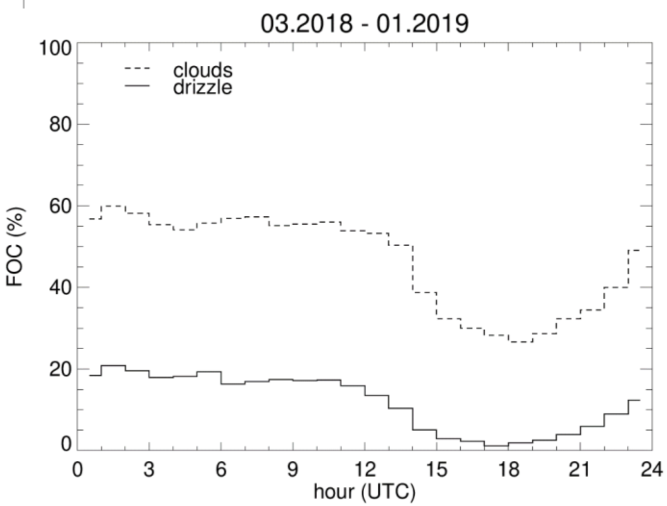
drizzle most frequent in end-summer to spring, nearly no in winter

Most drizzle during night

strongly coupled to foc of clouds







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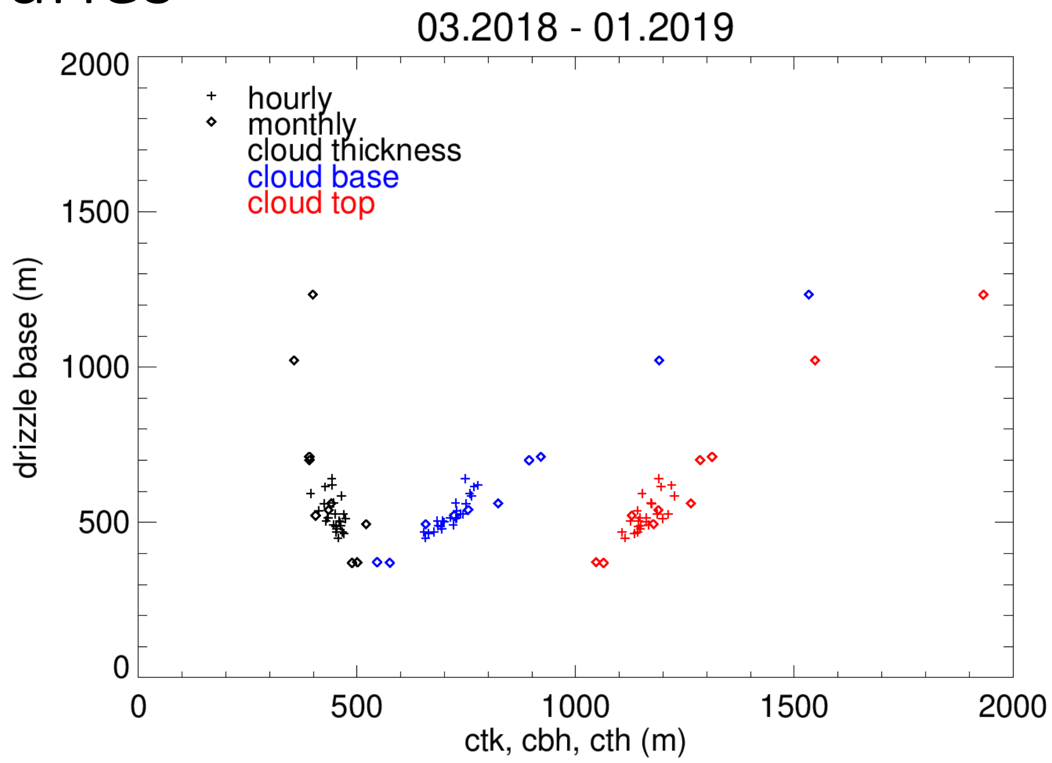
Drizzle and cloud boundaries

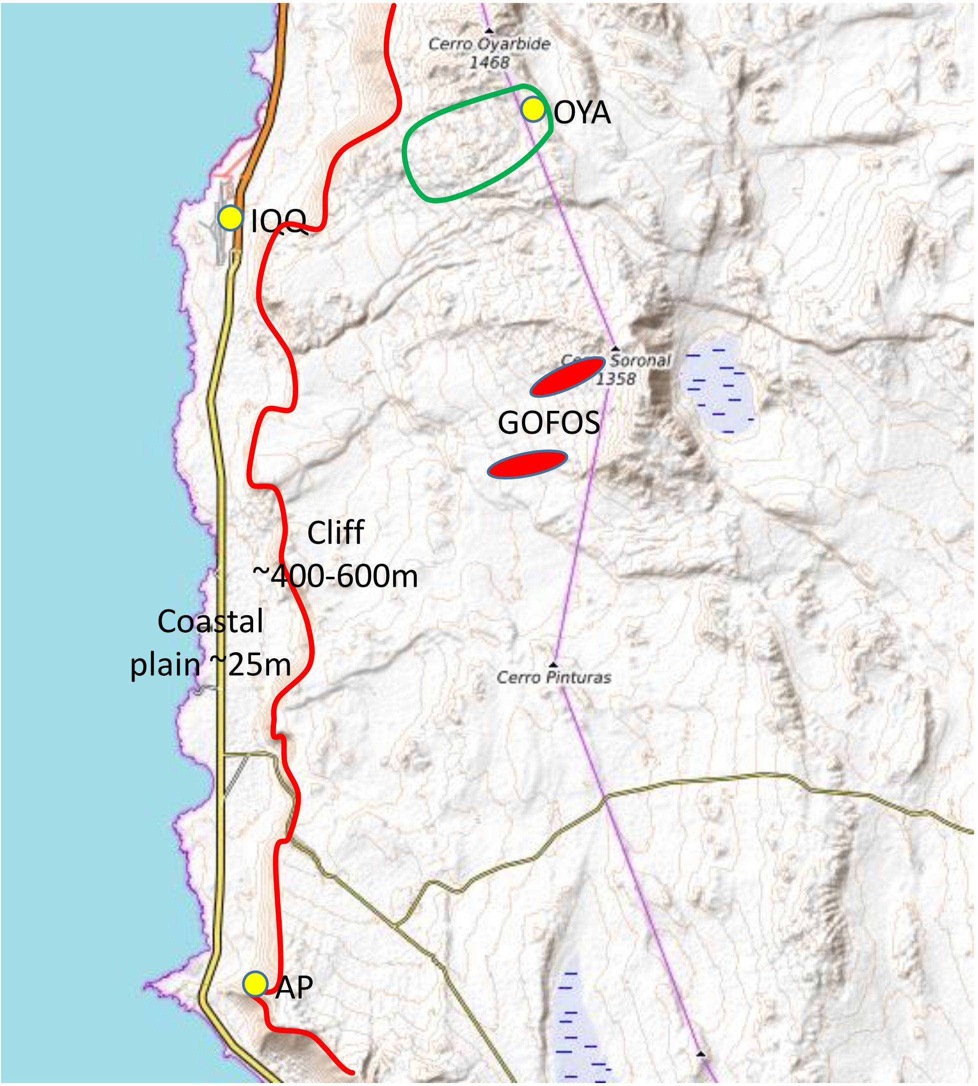
drizzle does not reach ground

the lower cloud base and the thicker the cloud the further down reaches the drizzle



Research area around IQQ

- Below Oryabide Tillandsia field (meteo station), several fog collectors
- GOFOS system for cloud/fog detection (cooperation Univ. Heidelberg, PUC Santiago)
- 36 km N of Alto Patache desert research station, fog oasis, meteo station



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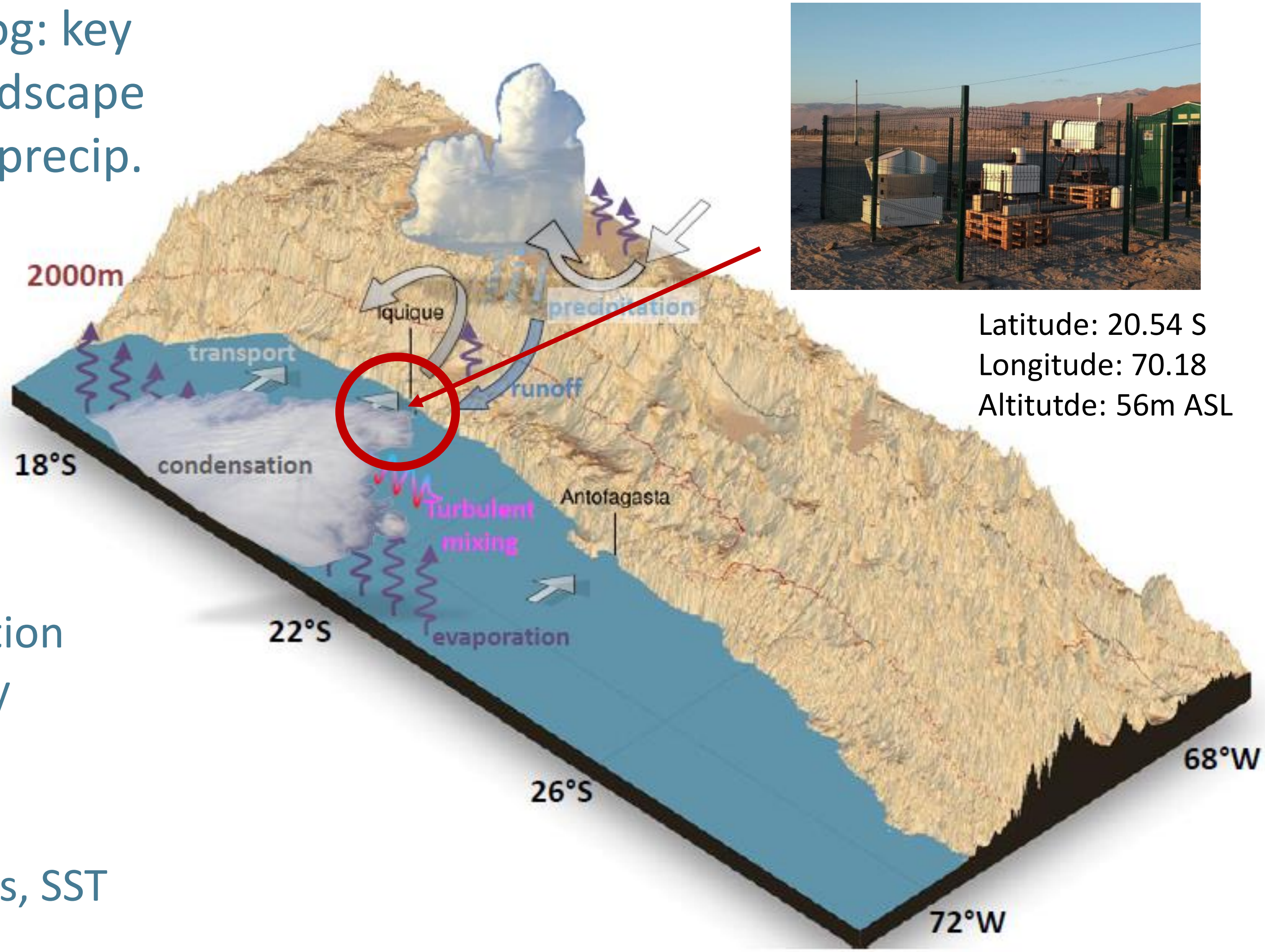
Status: atmospheric vertical profiling

- Radiosondes (“weather balloons")
  - Closest in Antofagasta (~350 km)
  - Temporal coverage: 1x daily
- Aircraft (AMDAR, E-AMDAR..)
  - Limited to areas around large airports & no humidity yet
- Satellites
  - Geostationary → no vertical resolution
  - Polar orbiters → ~2x daily overpasses only
  - General problem in resolving the ABL: variable surface emissivity and low vertical resolution

Moisture Supply to the Atacama Desert

Water vapor and fog: key for biology and landscape evolution (annual precip. < 1 mm / year!)



Latitude: 20.54 S
Longitude: 70.18
Altitutde: 56m ASL

What controls the moisture supply?

- Land-sea circulation superimposed by synoptic activity
- Orography
- Seasonal changes, SST patterns, ENSO…

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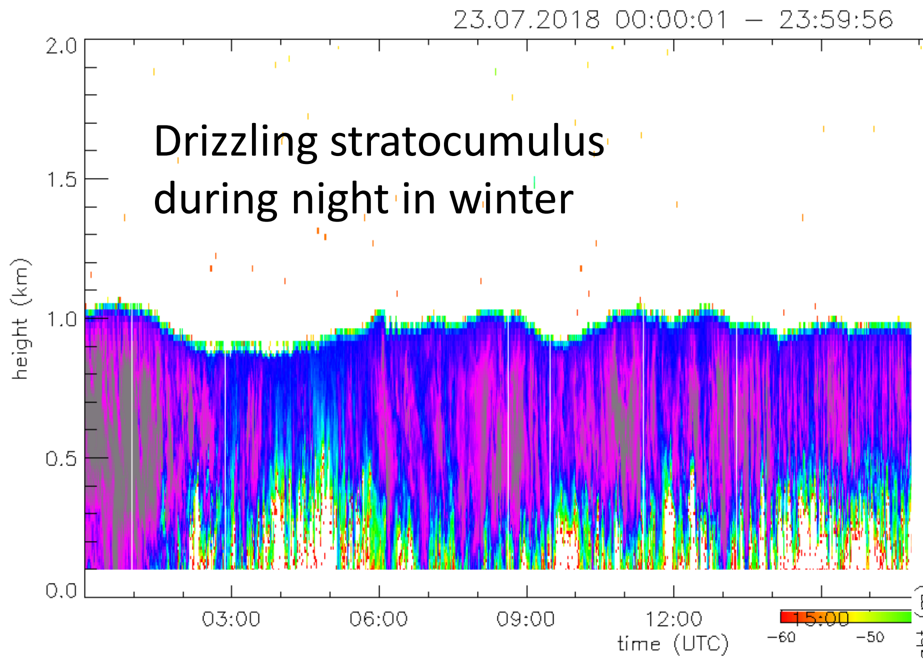
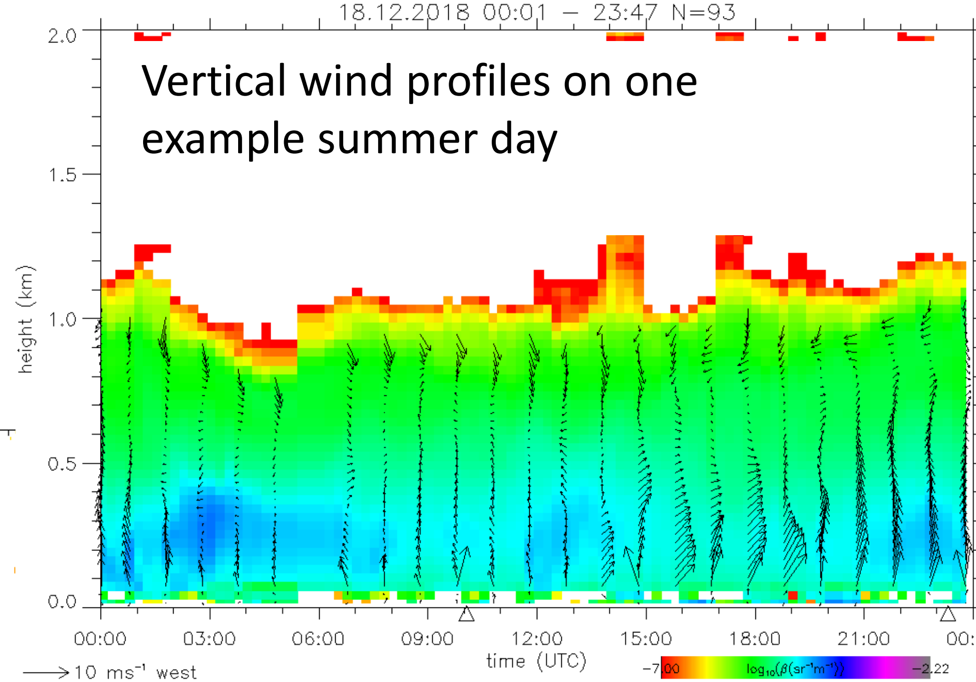
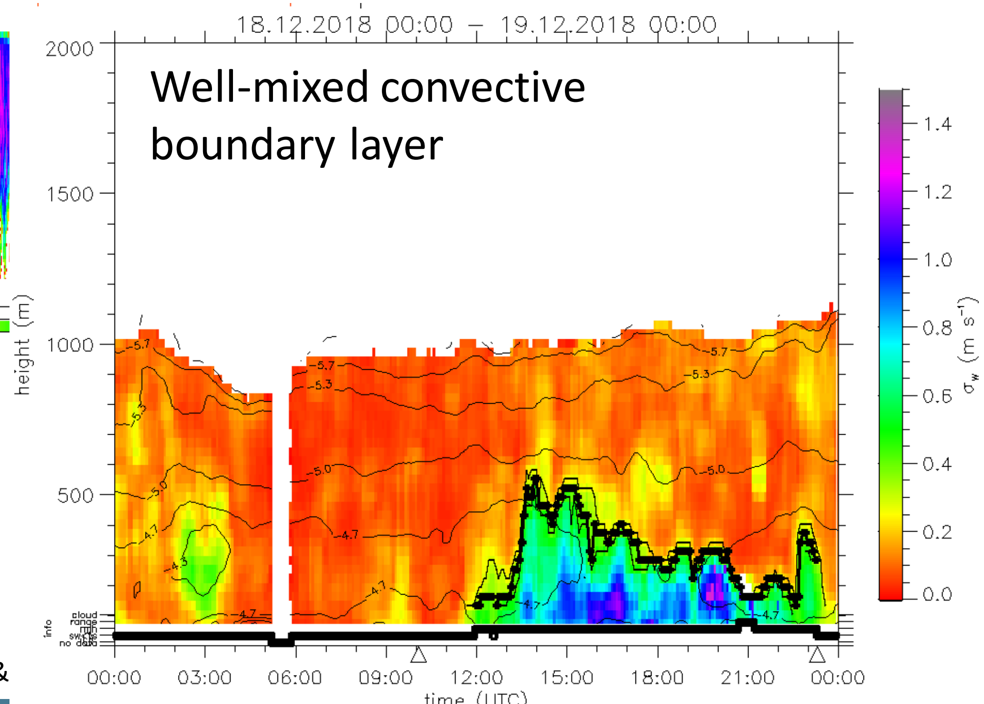
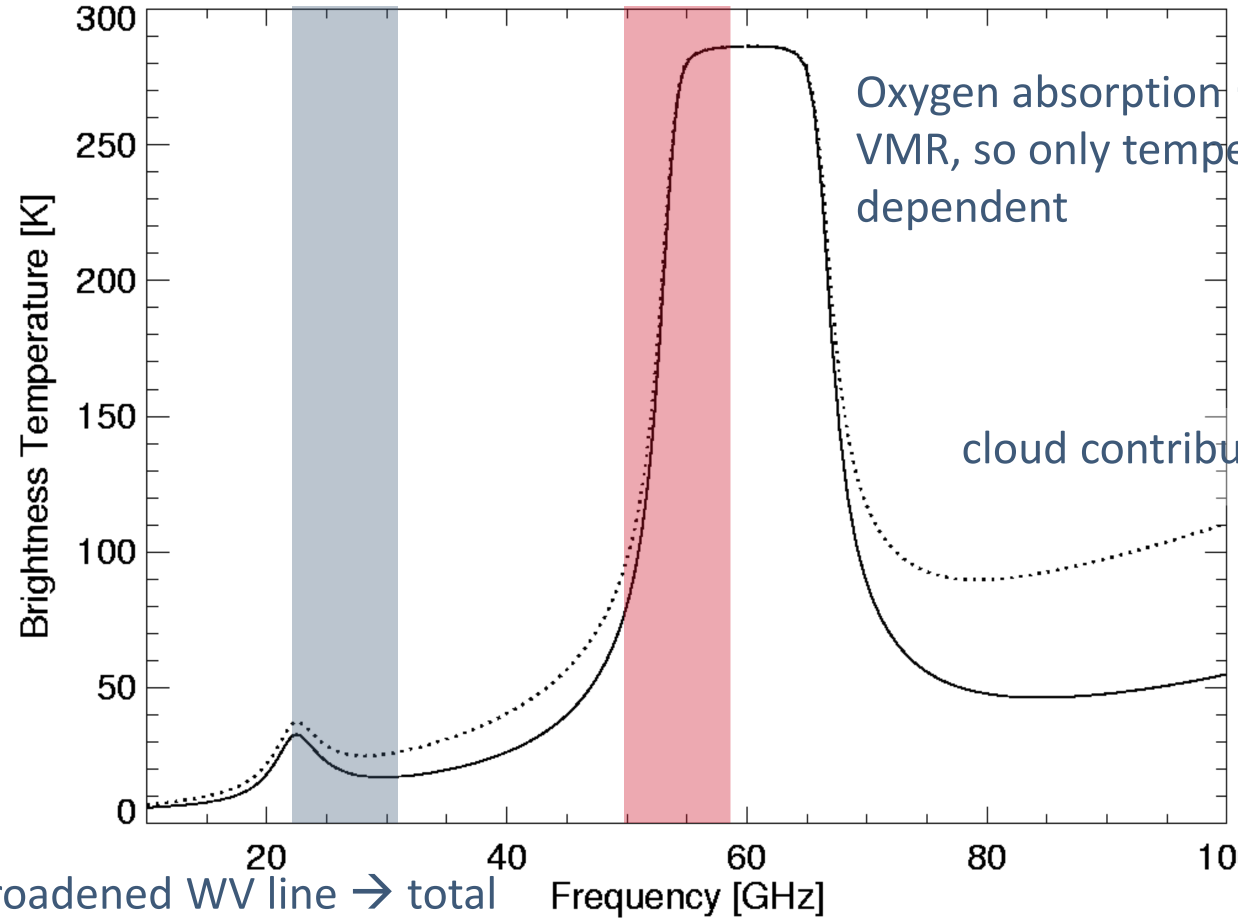
Iquique Campaign: extended from 3 months to nearly one year







MW-profiling: How does it work theoretically?

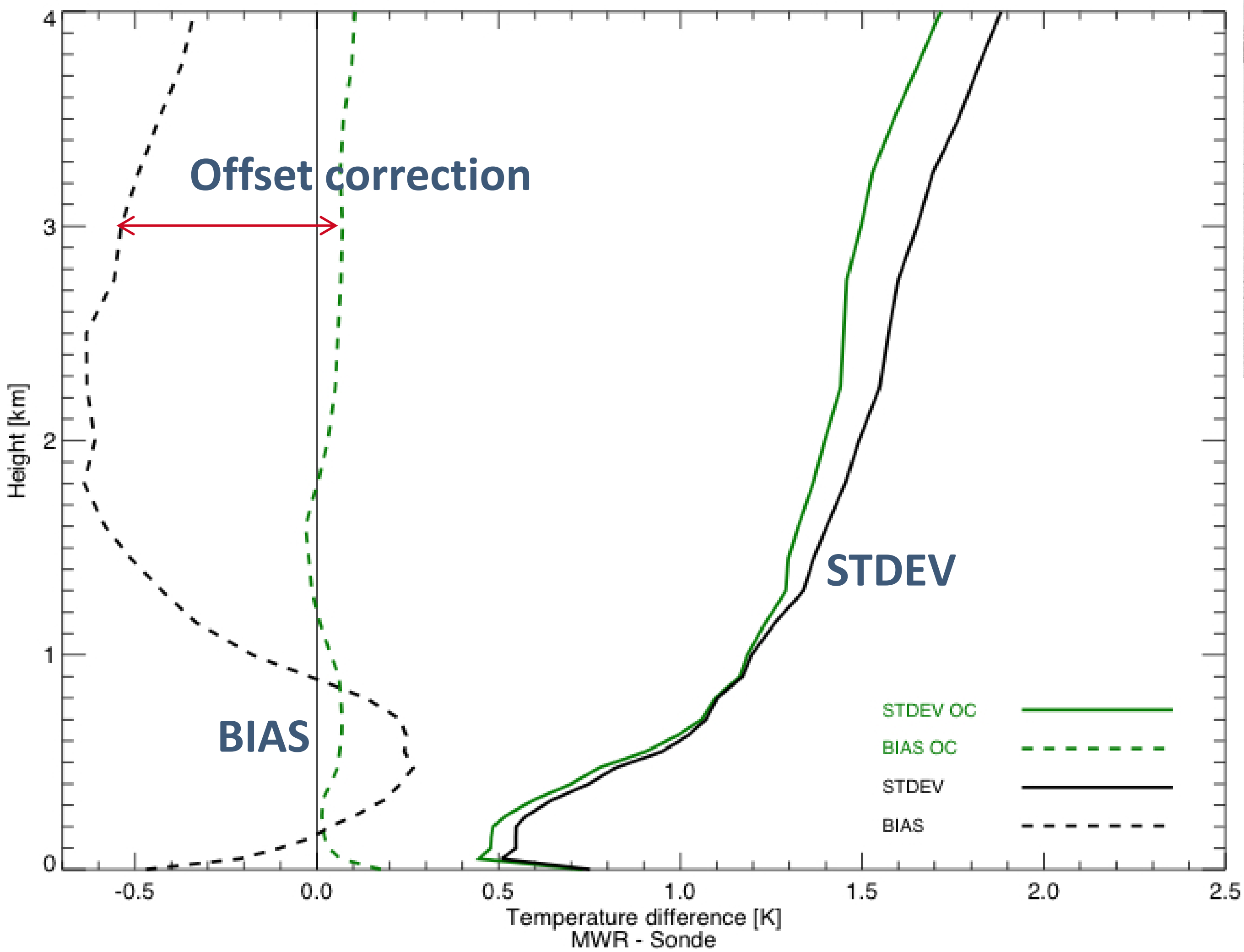


Oxygen absorption → constant VMR, so only temperature dependent

cloud contribution

pressure broadened WV line → total water vapor & weak profile information

Temperature profiling accuracies (radiosonde reference)



- BIAS issue: improved calibration loads
- STDEV: better instrument stability

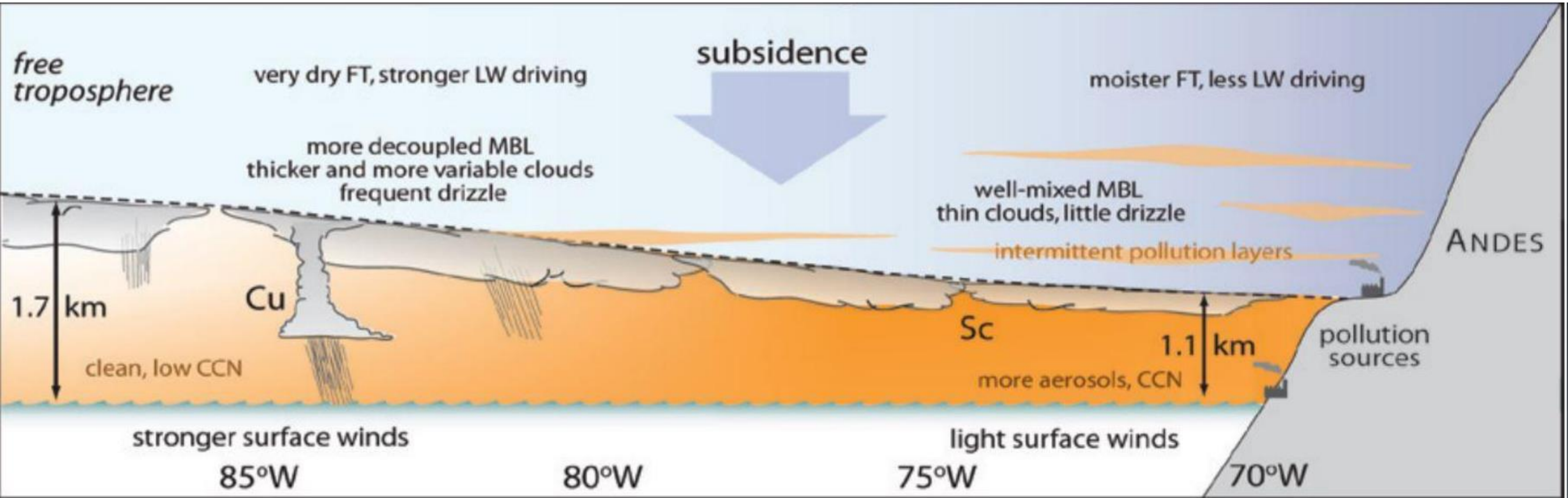
WP1: Characterizing Land-Sea Circulation Patterns

Hypothesis: The diurnal cycle induced land sea circulation is the dominating mode for moisture variability.

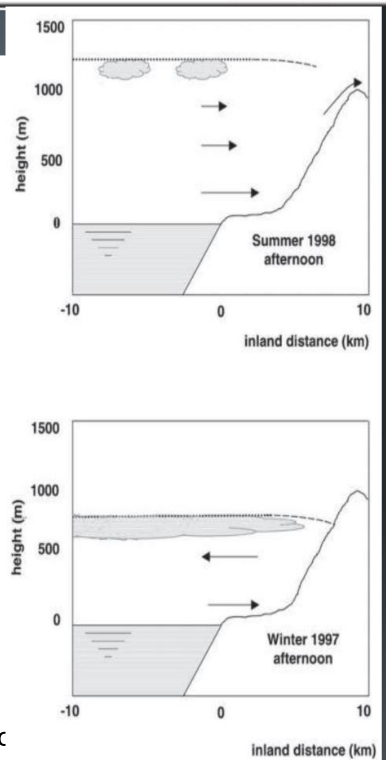
- Exploit the growing record of data from climate station network
- Understand the effects of fog, drizzle and boundary layer moistening at the coastal cliff using unique remote sensing data
- Investigate details of local water vapor transport using unique data set of scanning microwave measurements from astronomy (Costal Cordillera)

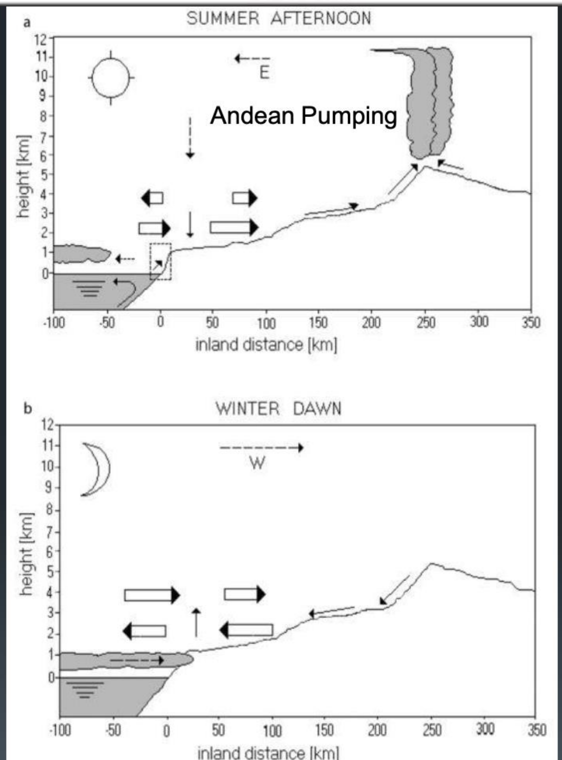
- Analyse the synoptically superimposed variability due to moist intrusions („atmospheric rivers“, cut-off lows) jointly with A03

→ Link to vegetation (!)



Mechoso et al. (2014)





Rutllandt et al. (2003)