Transitions in the wintertime near-surface inversion at Dome C

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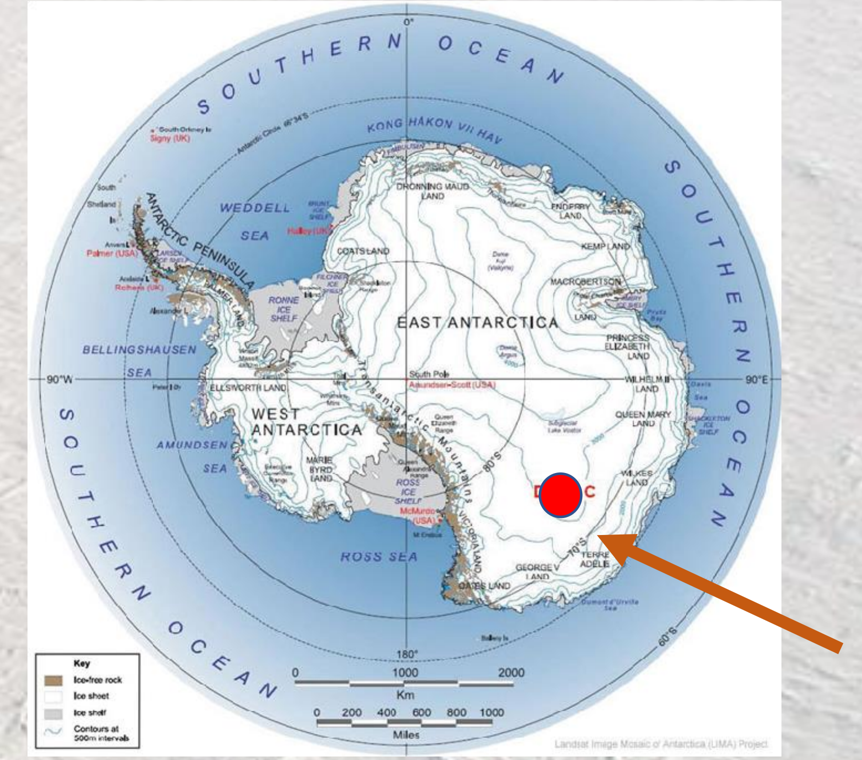
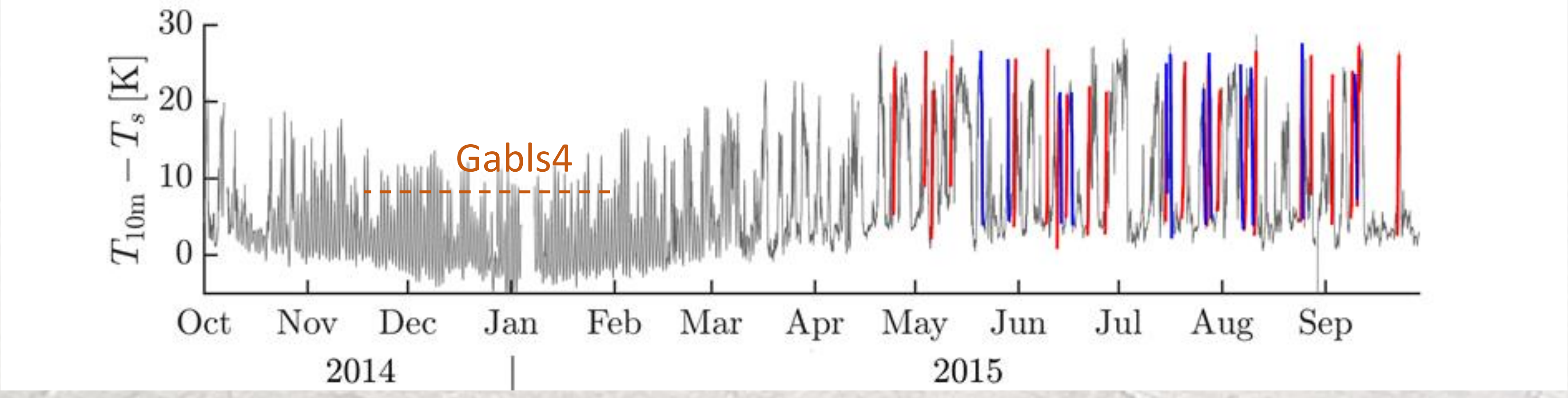
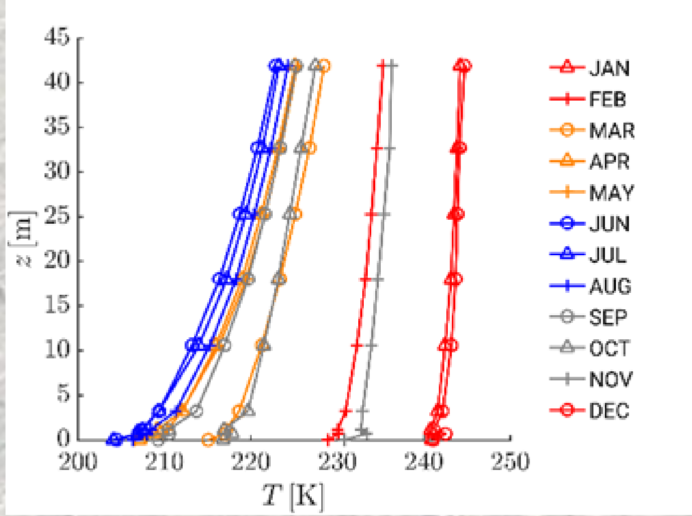
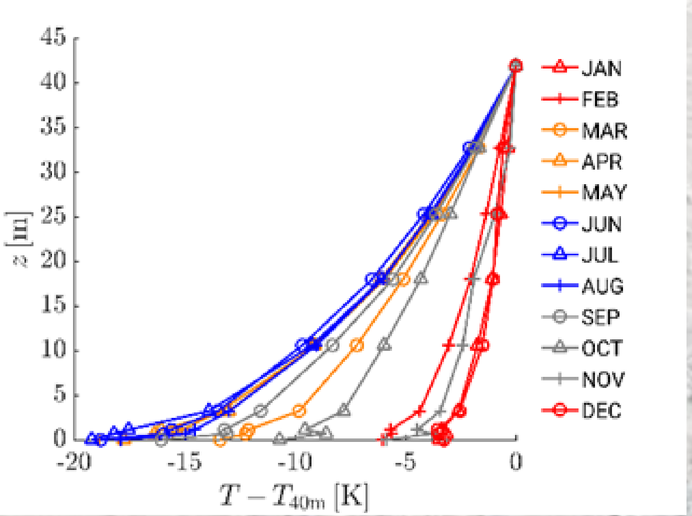


Photograph courtesy of Stephen Hudson

From summertime diurnal cycles to polar winter





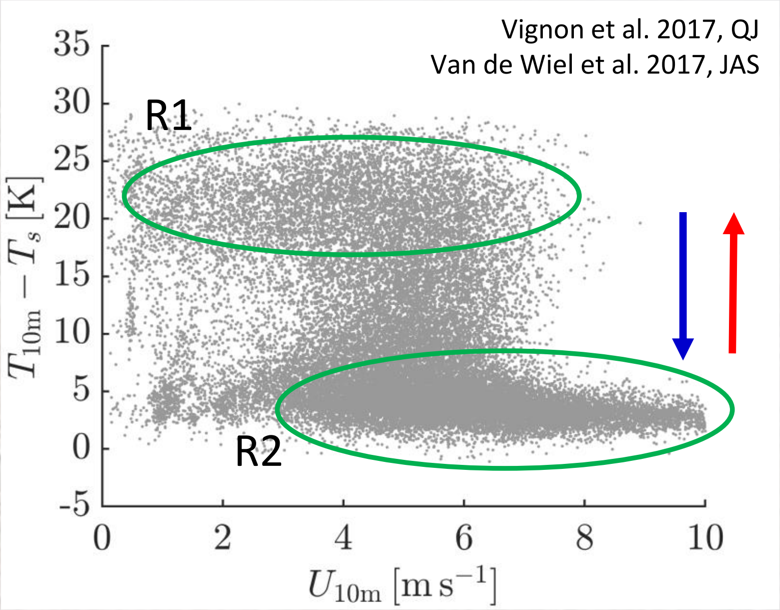


Aim

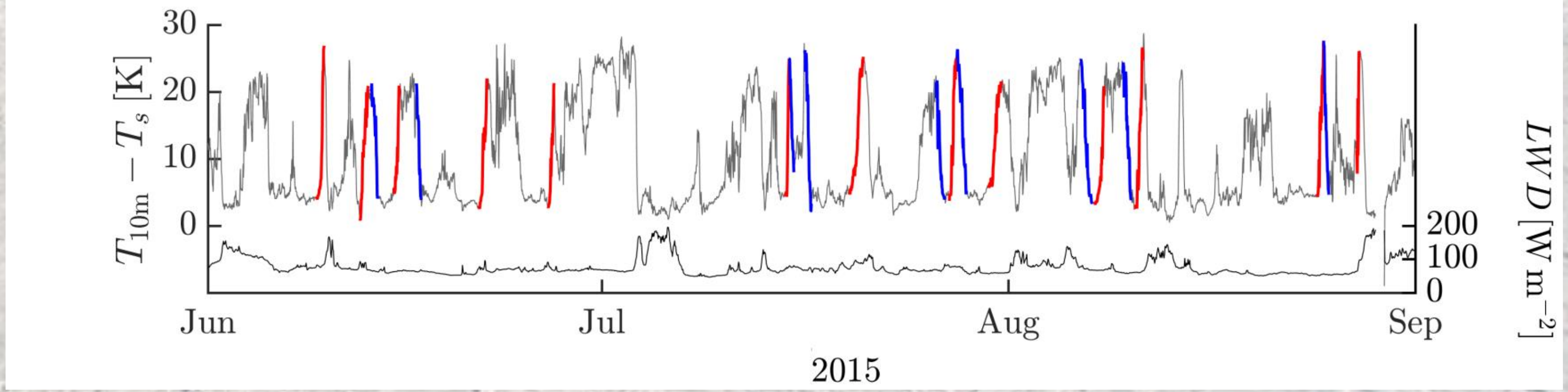
Study the sudden transitions between contrasting SBL regimes

R1: Weak wind, very strong inversion (25 K / 10 m)

R2: Strong wind, weak inversion (< 5 K / 10 m)



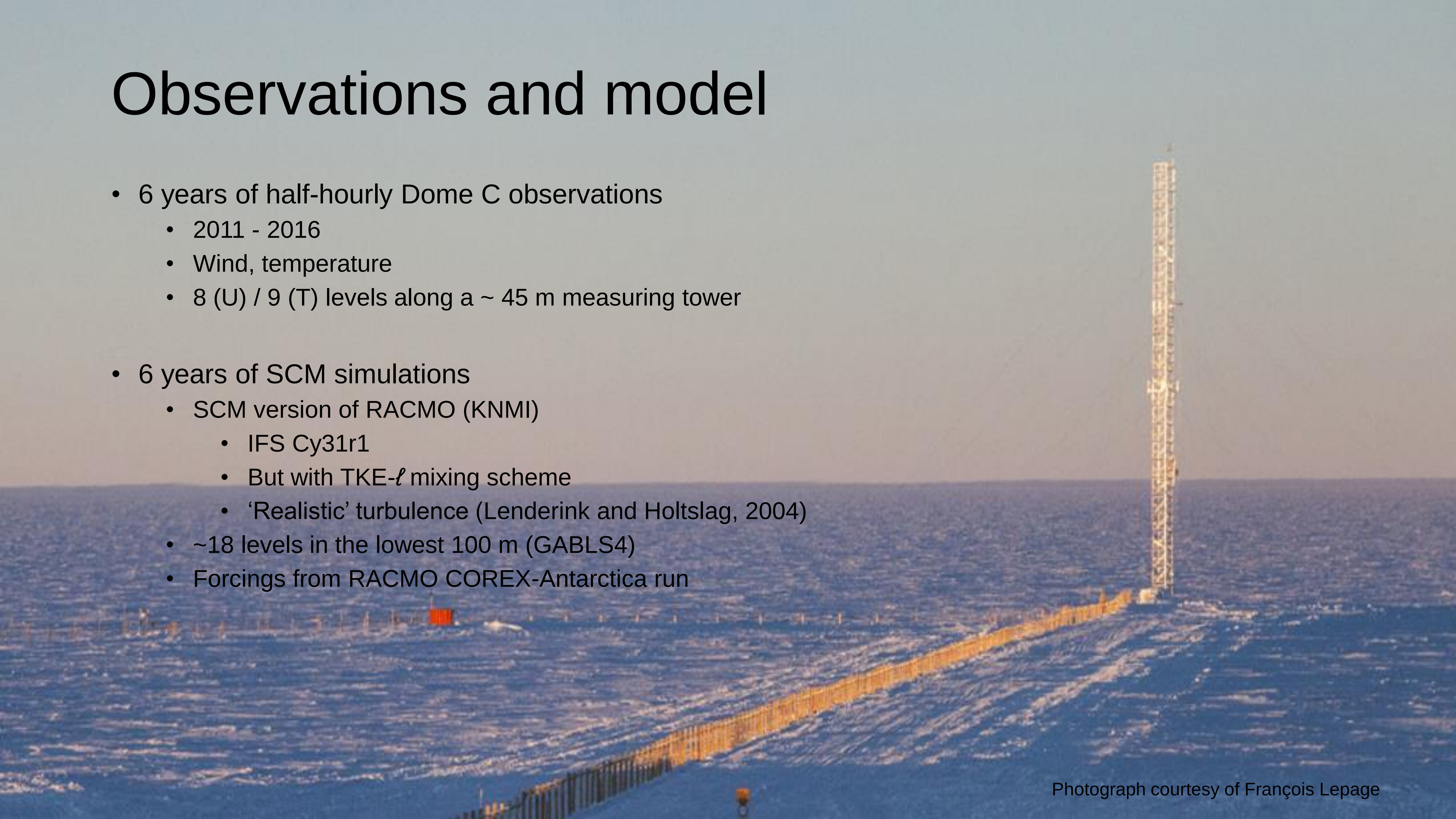
1. Understand the dynamics between wind and temperature
   - What explains the strong non-linearity?
2. Assess the performance of an atmospheric model
3. Disentangle underlying mechanisms



Observations and model

- 6 years of half-hourly Dome C observations
  - 2011 - 2016
  - Wind, temperature
  - 8 (U) / 9 (T) levels along a ~ 45 m measuring tower

- 6 years of SCM simulations
  - SCM version of RACMO (KNMI)
    - IFS Cy31r1
    - But with TKE-ℓ mixing scheme
    - ‘Realistic’ turbulence (Lenderink and Holtslag, 2004)
  - ~18 levels in the lowest 100 m (GABLS4)
  - Forcings from RACMO COREX-Antarctica run



Photograph courtesy of François Lepage

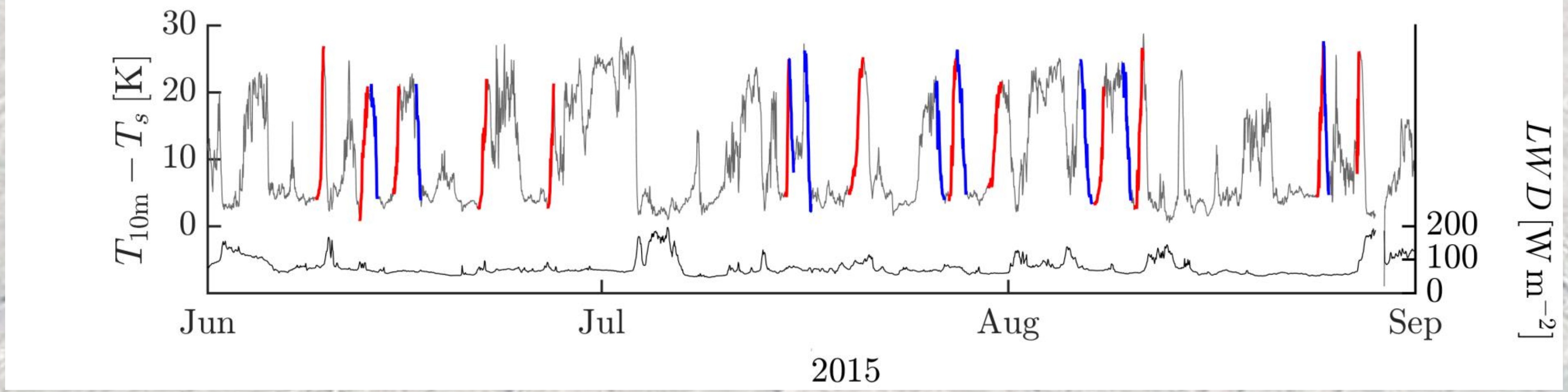
Approach

→*Select all relevant transition cases and study composite time-series and profiles*

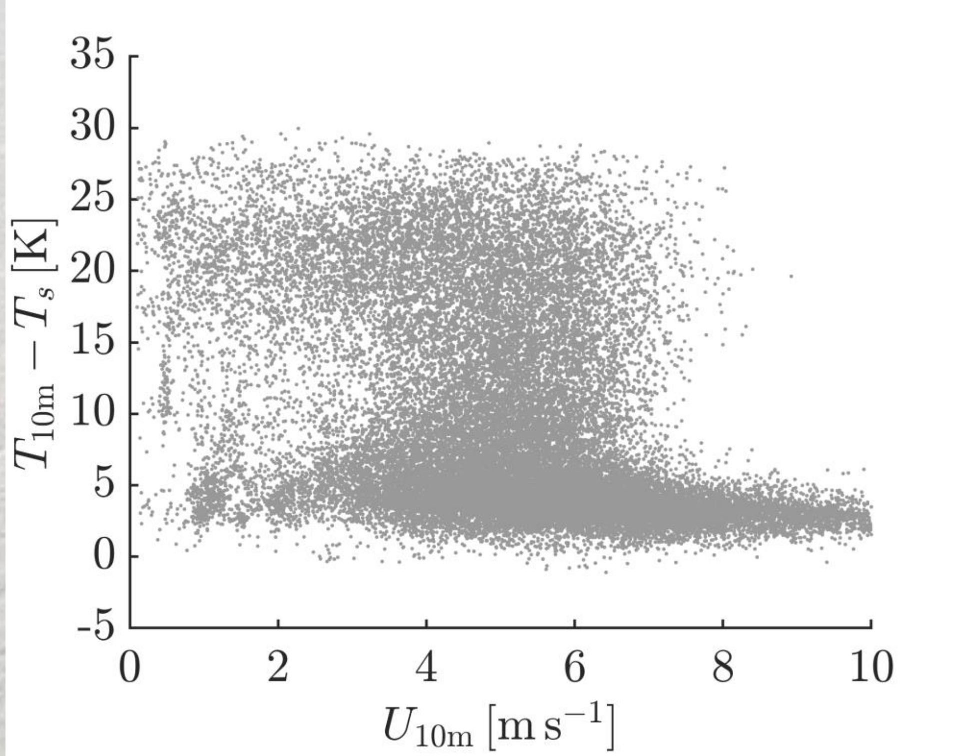
- Extended winter period: April - September
- Jump in $T_{10m} - T_s > \pm 15$ K
- $LW_d < 100$ W / m^2
- Define t = 0 h @ t for which $\Delta T = (\Delta T_{max} + \Delta T_{min})$ /2

  … or in other words: t = 0 h half-way the inversion jump

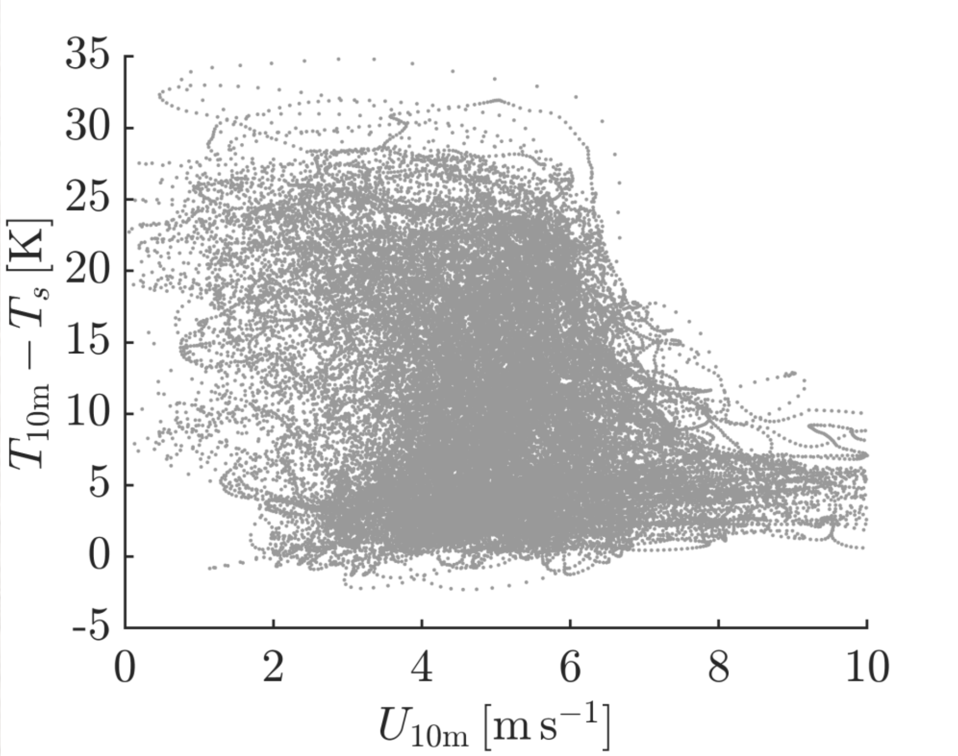
Color coding: inversion formation (***red***)
inversion erosion (***blue***)



Observed and modeled transition events

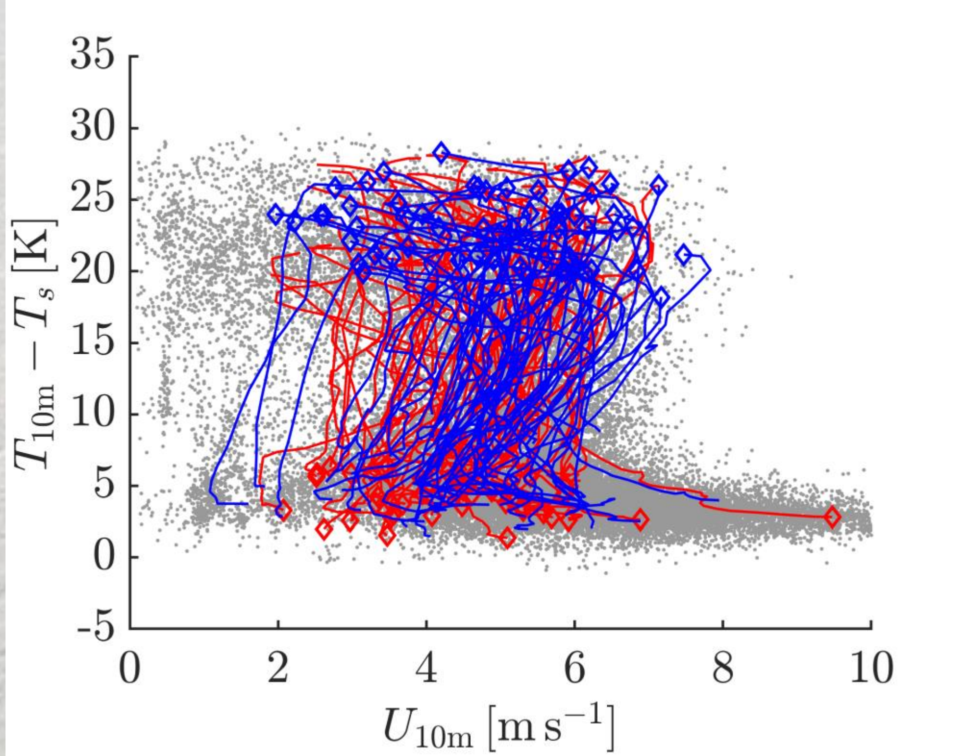


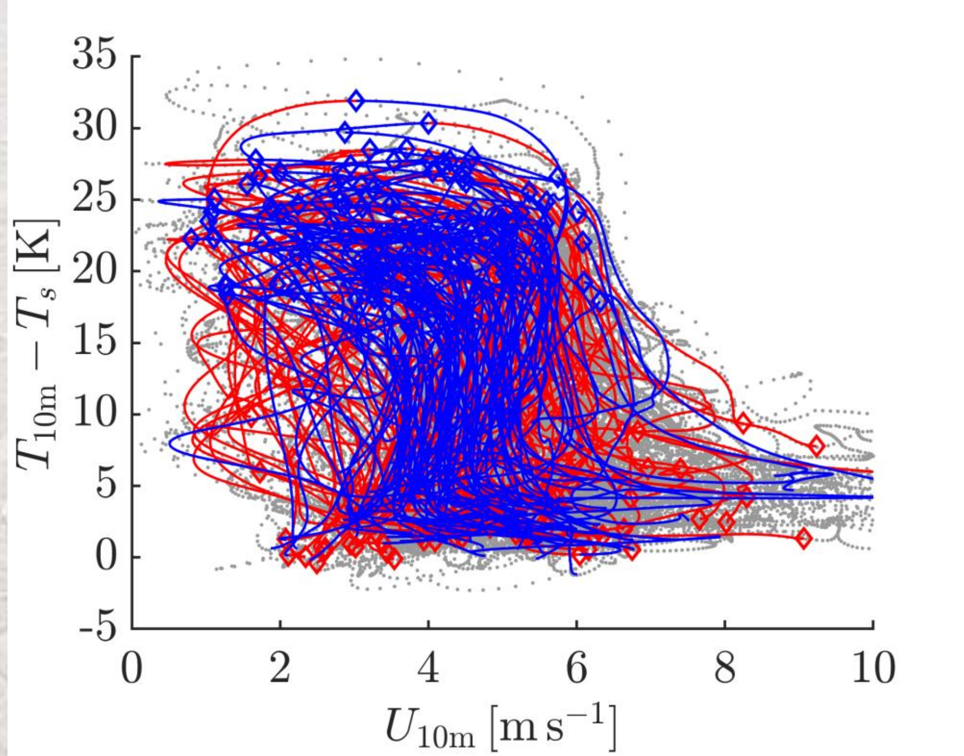
Observations



Model

Observed and modeled transition events

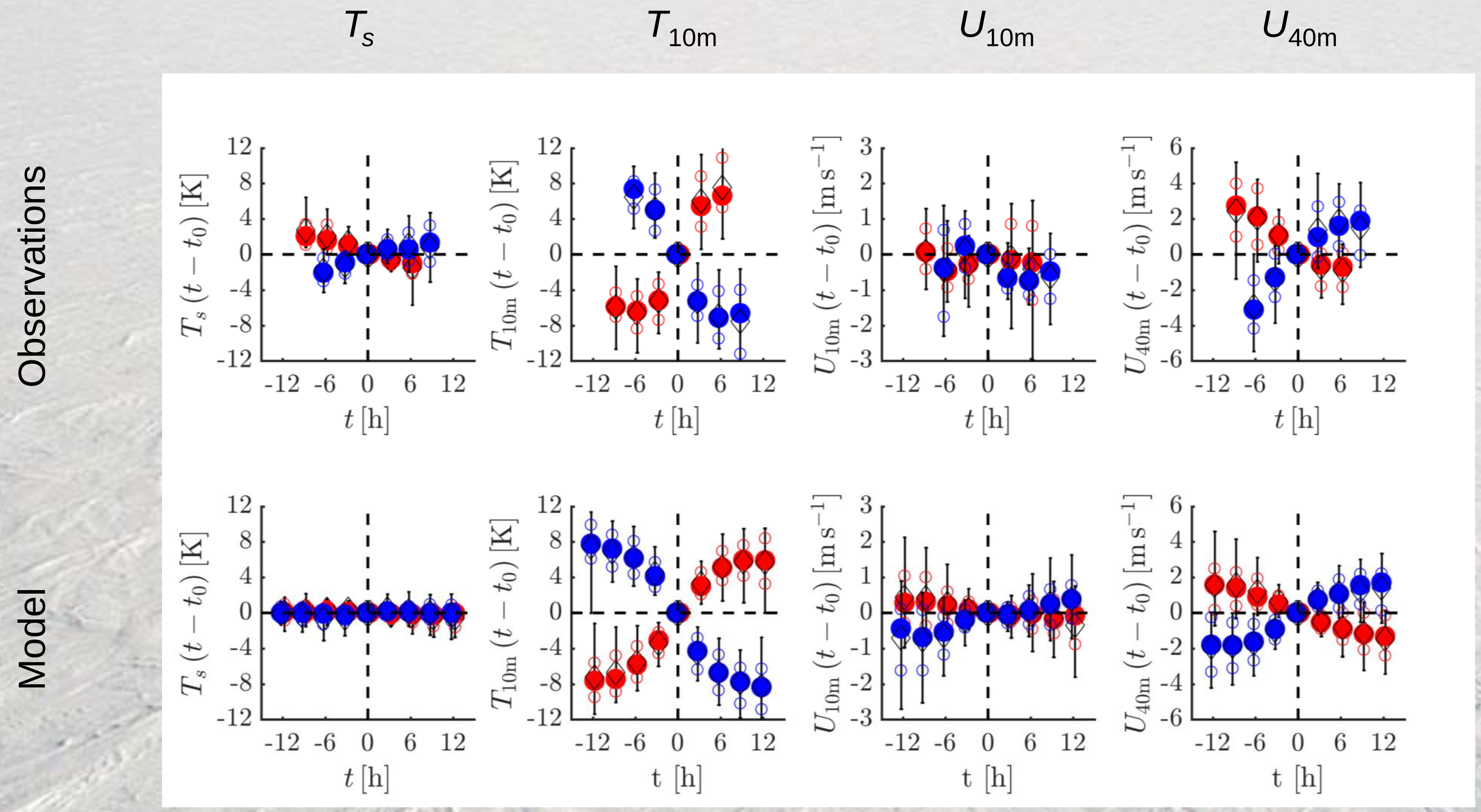




	Observations	Model
# cases :	76	106
# cases :	62	110

Composite time series

Color coding: inversion formation (***red***)
inversion erosion (***blue***)



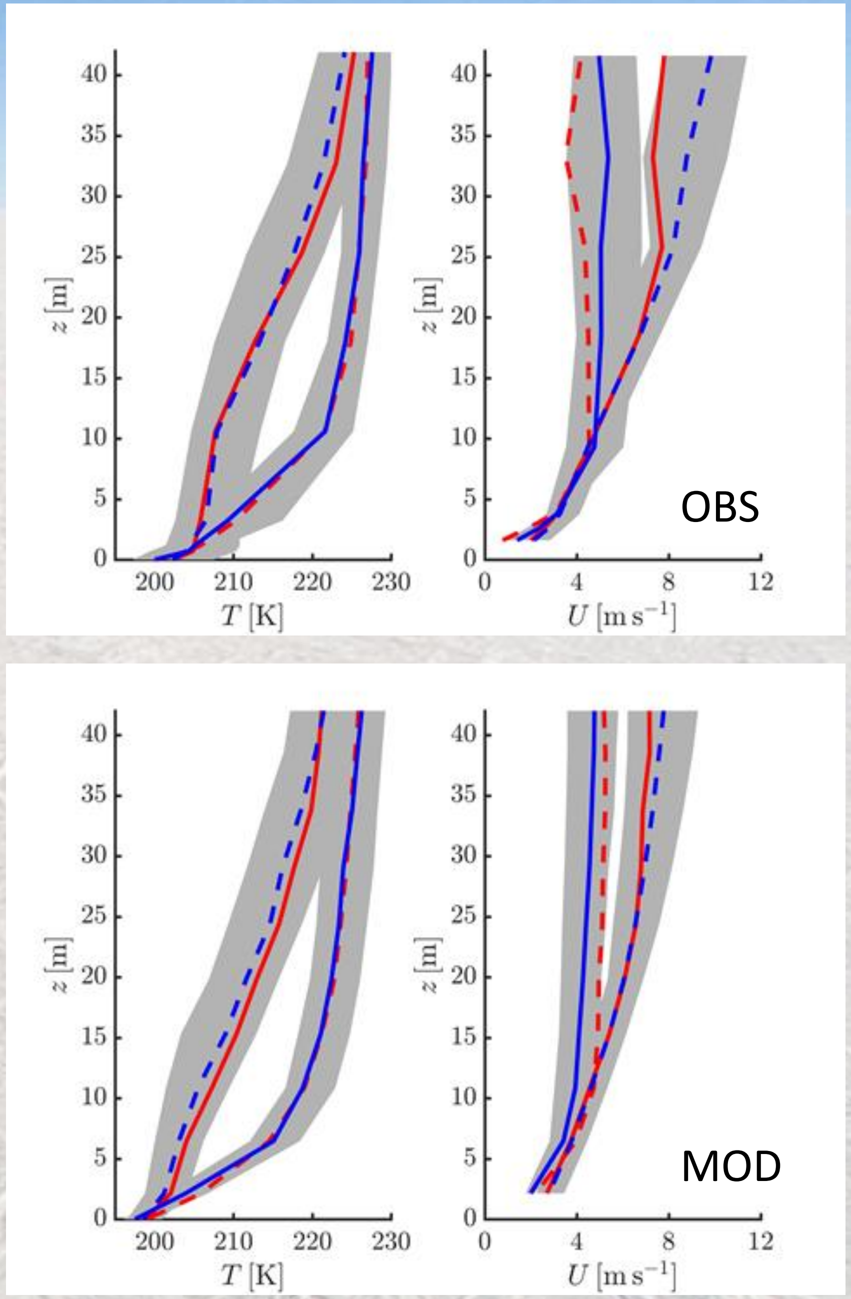
Composite profiles

- At t = -6 h (solid lines) and t = 6 h (dashed lines)
- Inversion formation and erosion

- Weakly stable regime:
  - Convex-Concave-Convex T profile
  - Wind speed increases continuously with height

- Very stable regime:
  - Exponential T profile
  - Wind speed constant for z > 10 m

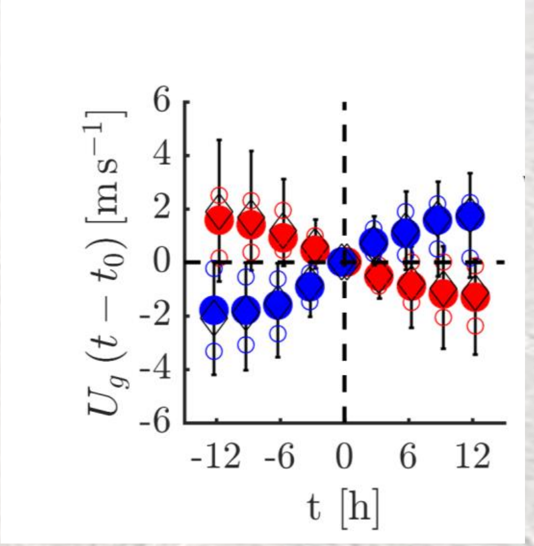
- Model profiles mimic observation really well!



Use model output to diagnose mechanisms

What explains the observed dynamics?

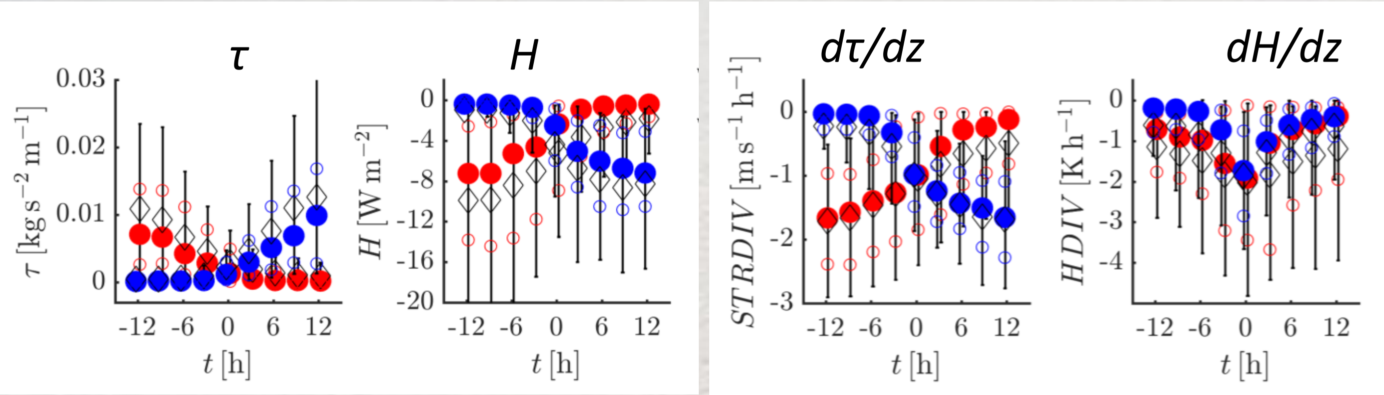
- No turbulence observations available
- Utilize good correspondance model and observations
  → How does the model 'do it'?
- Focus on
  - Large-scale forcing
  - Role of stress divergence
  - Heat budget



Color coding: inversion formation (***red***)
inversion erosion (***blue***)

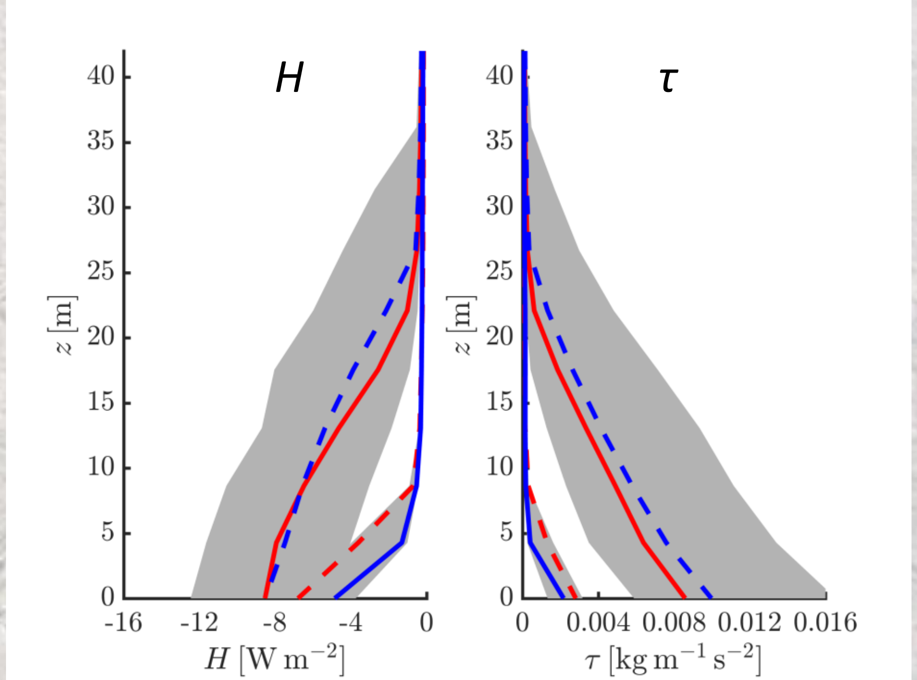
Turbulent fluxes (@ 10 m)

Color coding: inversion formation (***red***)
inversion erosion (***blue***)

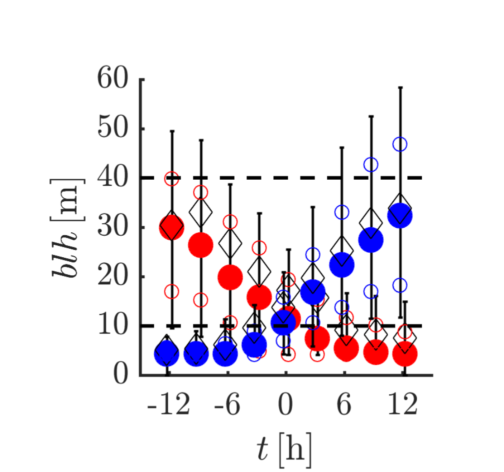


Fluxes and flux divergence at 10 m above the surface

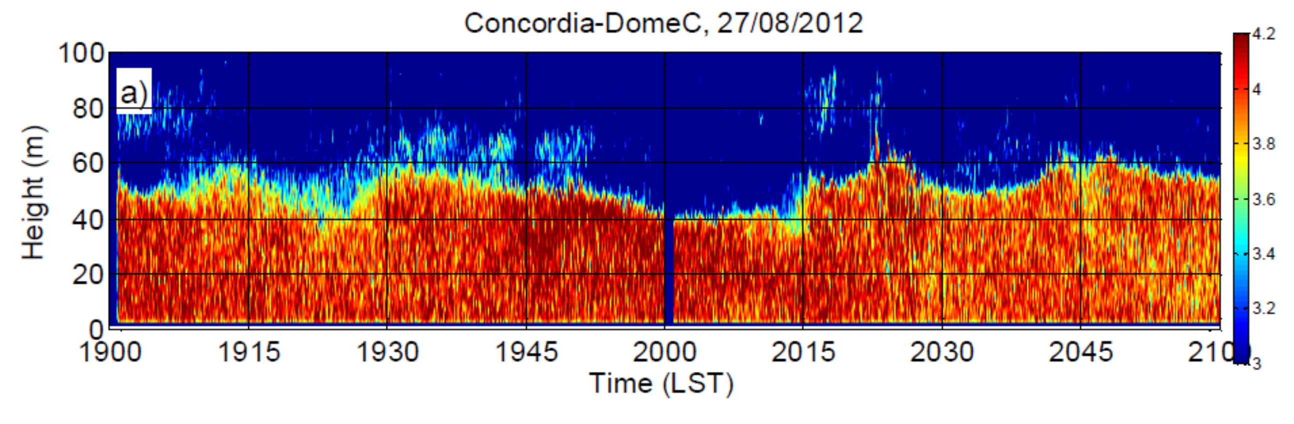
- Weakly stable regime:
  - Deep turbulent layer
  - Flux divergence at 10 m
- Very stable regime:
  - Shallow turbulent layer
  - No flux-divergence at 10 m
- Strong cooling at 10 m around t = 0 h

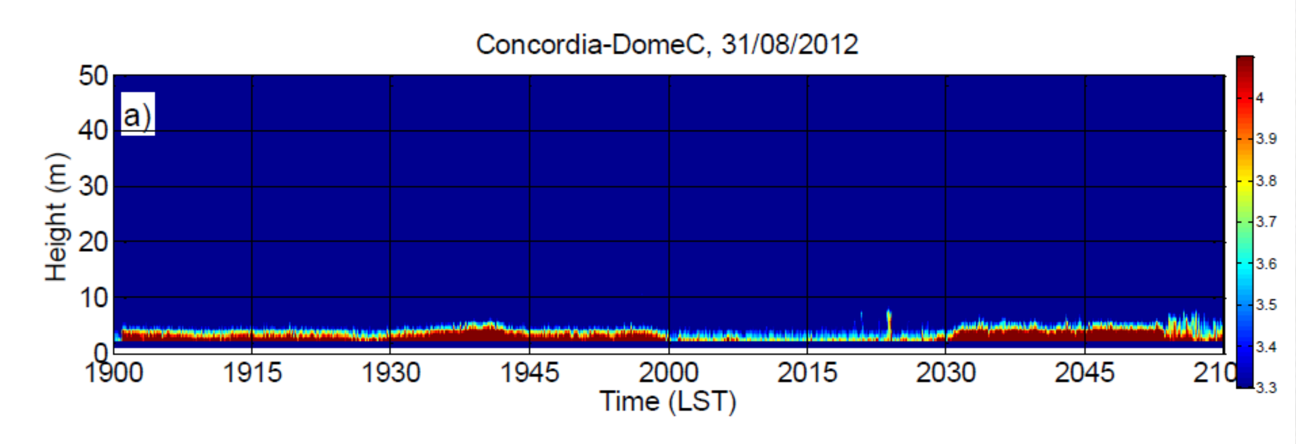


Depth turbulent layer



BLH crosses 10-m level



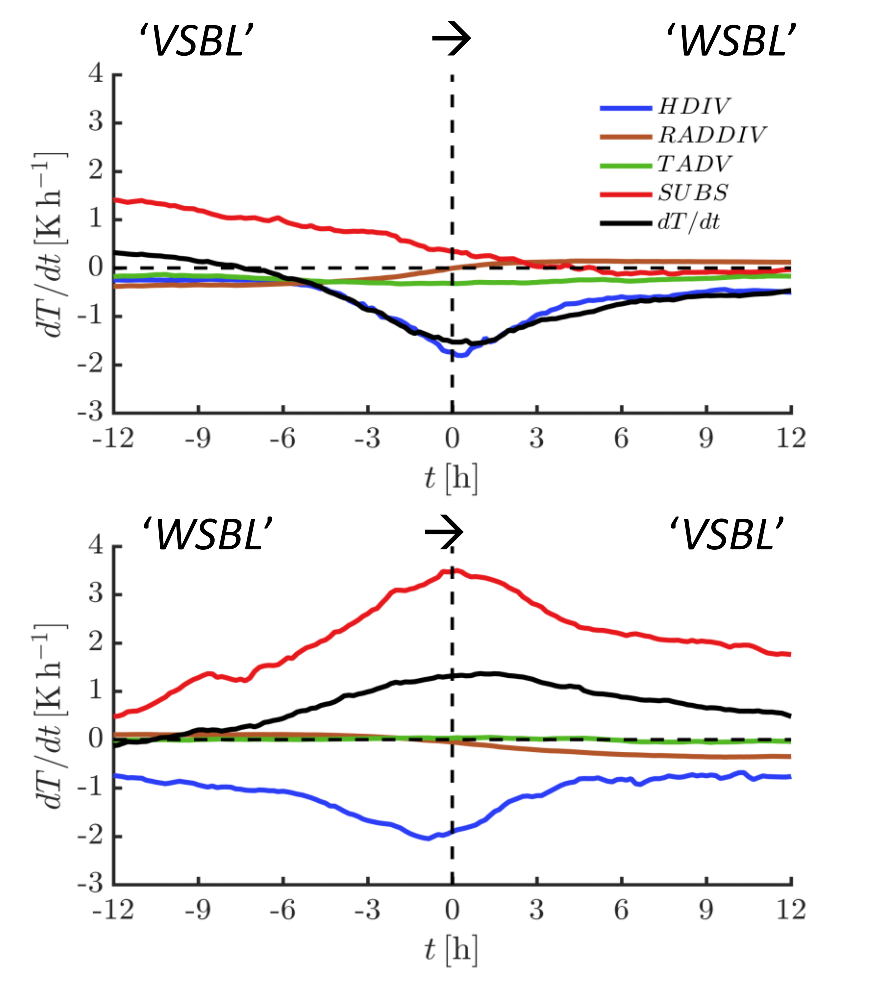


Courtesy of Igor Petenko

Heat budget at 10 m height during transition

Erosion

Formation



$$\rho c_p \partial_t T = \underbrace{-\rho c_p (u\partial_x T + v\partial_y T)}_{\text{Horizontal Advection}} \underbrace{-\rho c_p w \partial_z T + \omega}_{\text{Subsidence}}$$

$$\underbrace{-\partial_z SW}_{\text{SW}} \underbrace{-\partial_z LW}_{\text{LW}} \underbrace{-\partial_z (THF)}_{\text{Turbulence}}$$

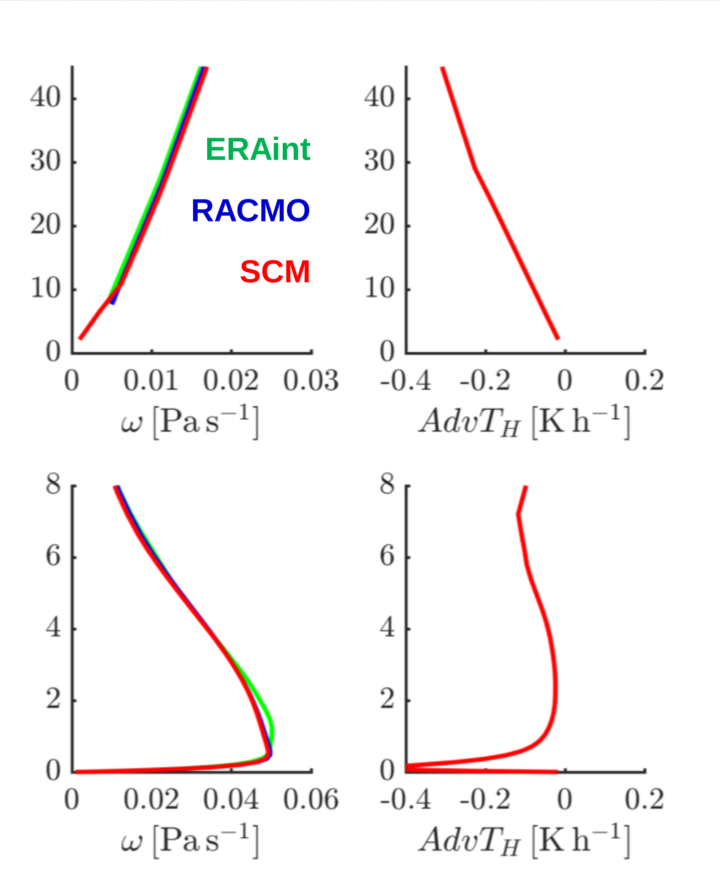
- Erosion of the inversion; cooling at 10 m due to
  - Heat flux divergence
  - Subsidence heating decreases
- Formation of the inversion; warming at 10 m due to
  - Subsidence heating
- Role of radiation divergence and horizontal advection is small

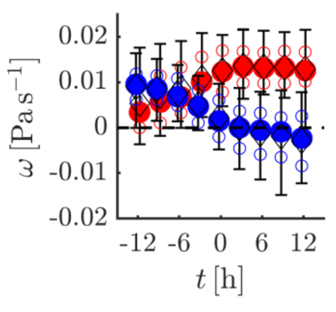
Subsidence heating

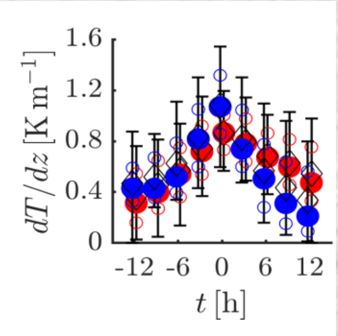
Average wintertime profiles

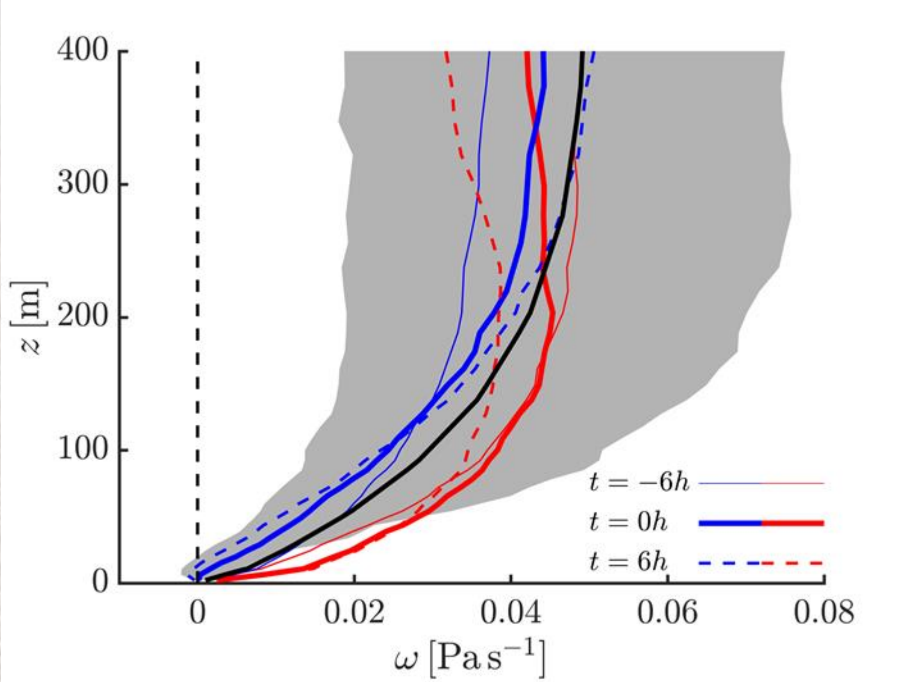
40 m

8 km



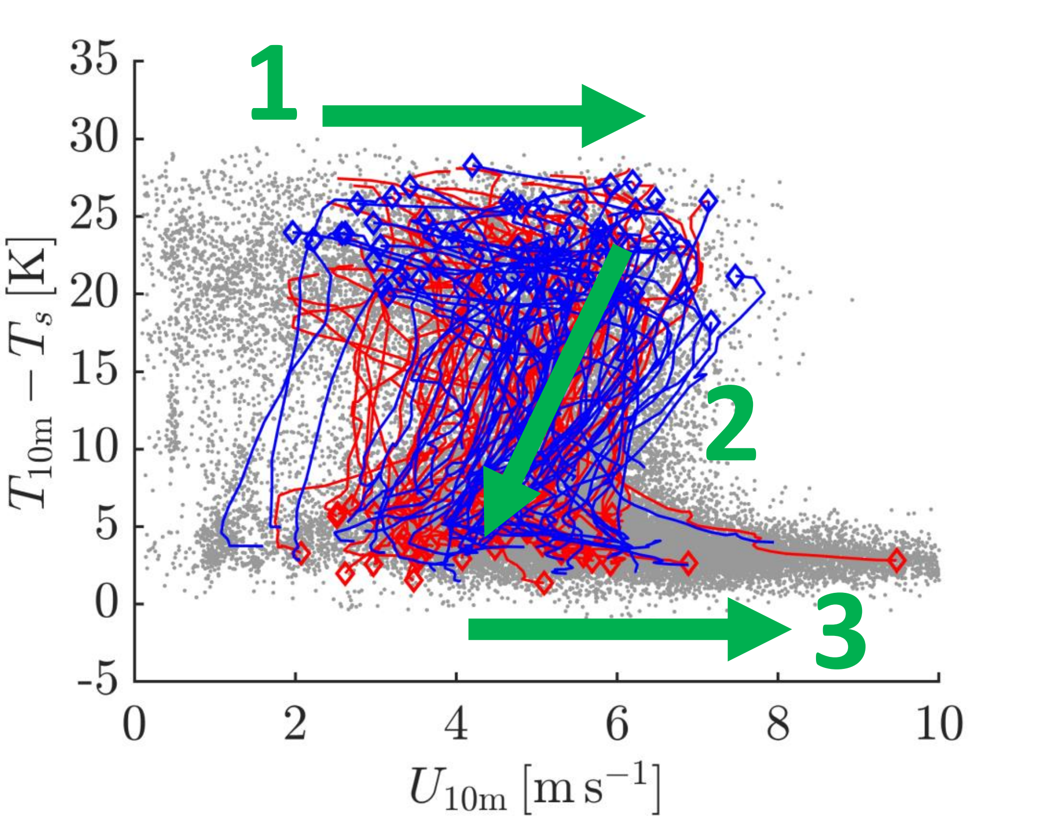






For reference: a $d\theta/dz = 1$ K/m and a $\omega = 0.01$ Pa/s (or -0.001 m/s) give a subsidence heating of 3.6 K/h.

Explaining the non-linearity (inversion erosion case)



1. Geostrophic forcing increases
   - 10 m wind increases
   - BL depth (<10m) start to increase
   - Inversion is in very stable state

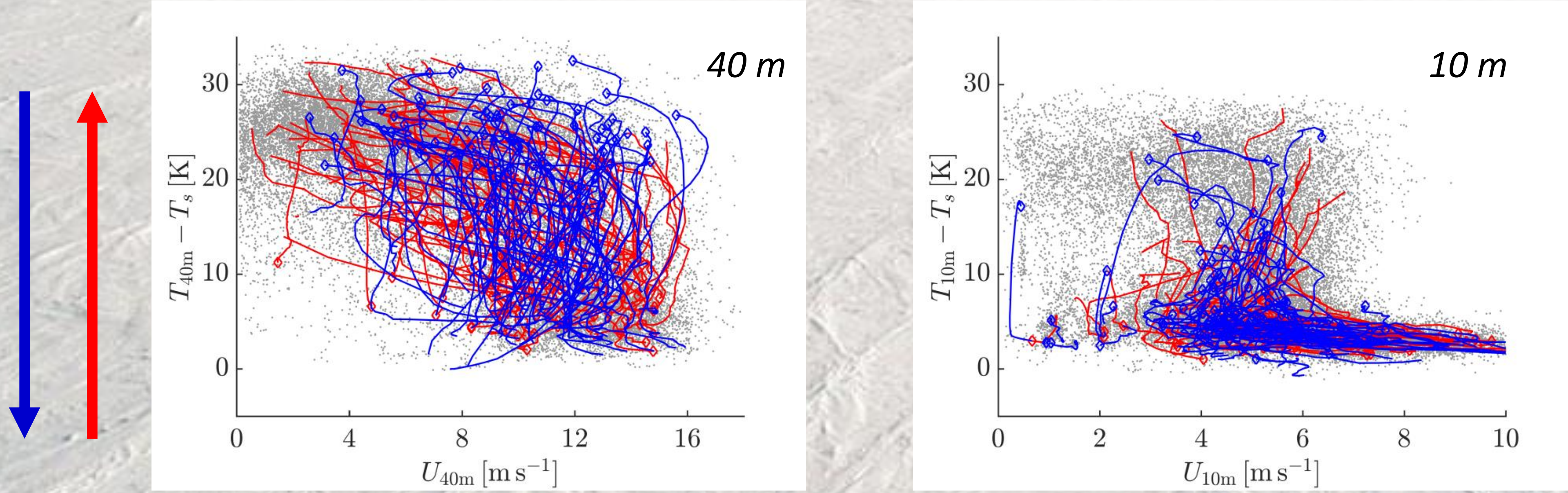
2. BL depth crosses 10 m level
   - Stress divergence slows down 10m wind (effectively counteracting the increase in forcing
   - Heat flux divergence cools T_{10m}

3. Geostrophic forcing increases further
   - BL depth (> 10m) becomes deeper and deeper
   - 10-m wind increases again
   - Inversion is in weakly stable state

What about transitions in the 40-m inversion?

- At 40 m, the same mechanism is in play
- Transitions (> 15 K) occur for stronger forcing
- 10-m inversion already in weakly stable state

→ Stronger forcing → deeper turbulent layer → thicker layer coupled to the surface



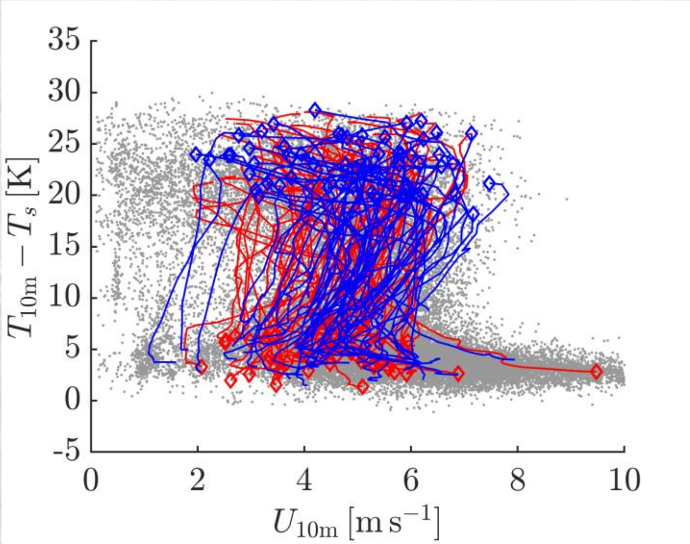
Conclusions

- Regime transitions occur within 6 to 12 h

- Variation is in T_{10m}, not in T_s
- Model results reproduce wind and temperature profiles

- Transitions are driven by large scale (geostrophic) forcing and subsidence heating
- Non-linearity results from interplay between large-scale forcings, the depth of the turbulent layer, and turbulent flux divergence

- Even at 10 m above the surface subsidence heating plays important role



→ Baas et al. 2018: Transitions in the wintertime near-surface temperature inversion at Dome C, Antarctica. Submitted to QJRMS.