A First Nowcasting System for the Complex Orography of the Canary Islands

David Quintero Plaza, AEMET, Spain. EWGLAM-SRNWP Meeting, September 30th, 2021

Index.

- The Canary Islands and the difficult forecasts for the islands.

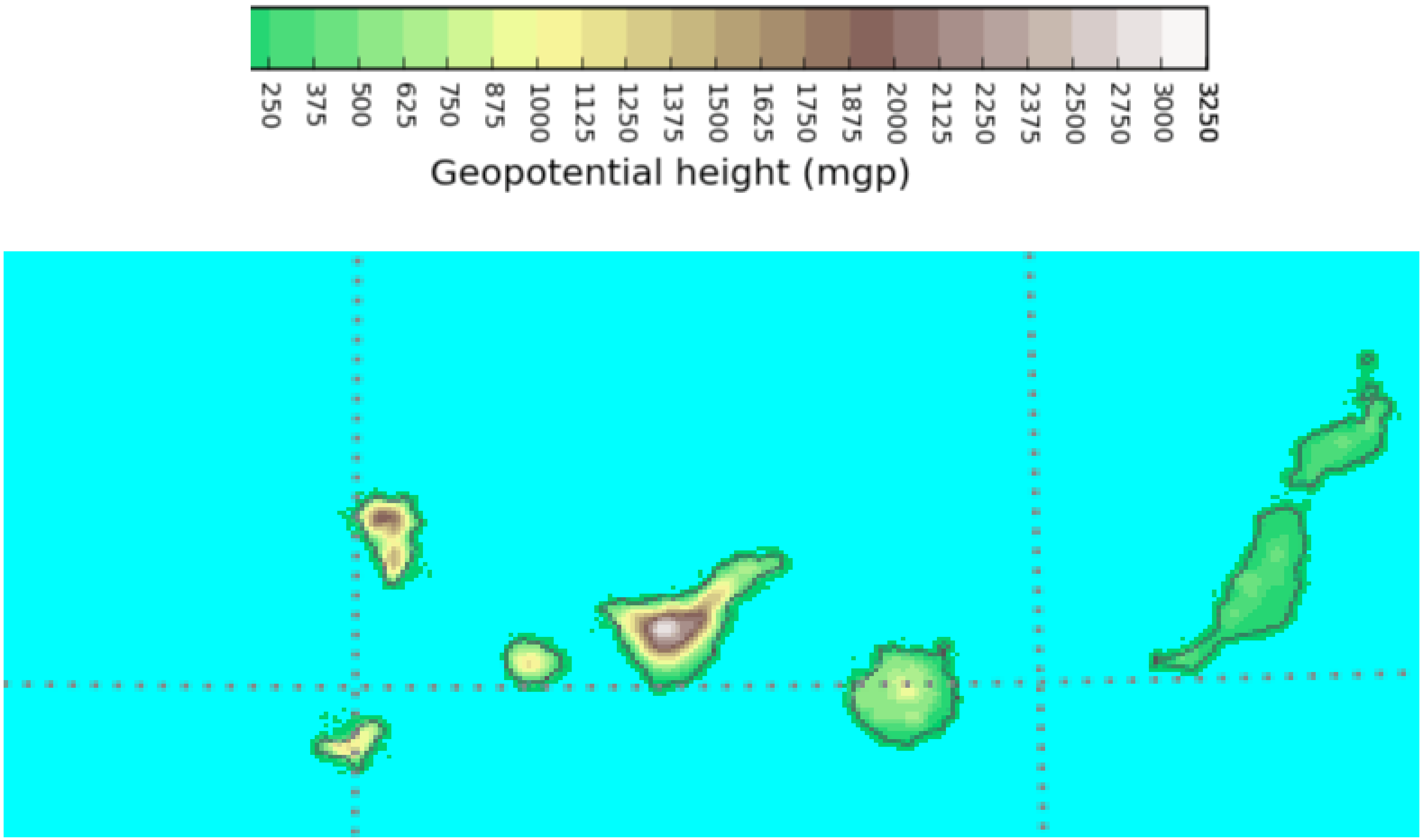
- Optical Flow as a nowcasting tool for the islands. First results and validation.

- Conclusions and future work.

- The islands have a complex, mountainous and fastly changing terrain, with the so called local "micro-climates".

- Even High Resolution Models (Harmonie & gSREPS at 2.5 Km) still show limitations for the islands (not to mention models with less resolution).

- Below: gSREPS orography.



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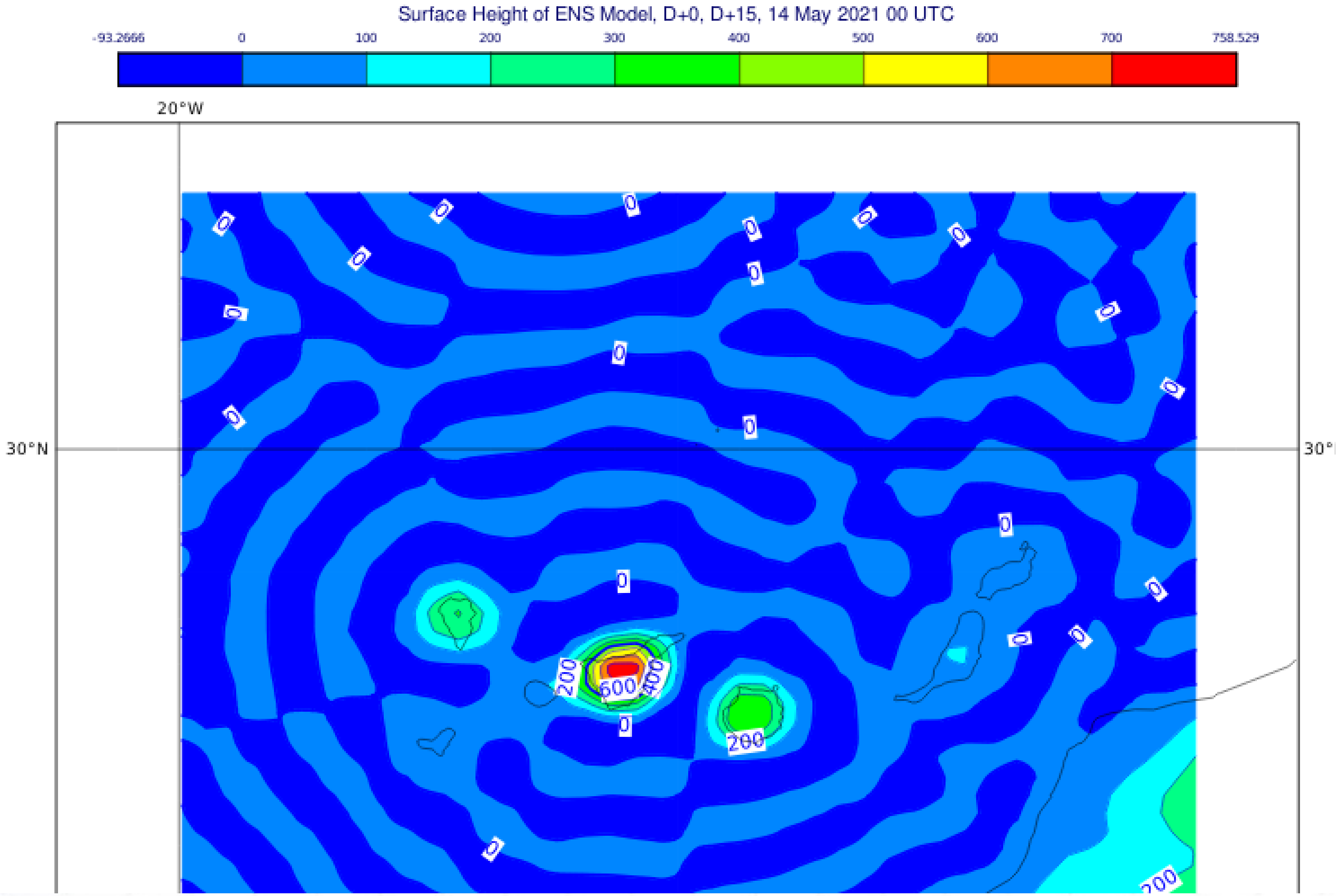
- Below: ECMWF ENS orography.



- Regarding the nowcasting: 3 possibilities,
    - Fast Integration Models.
    - Optical Flow.
    - Neural Networks and other Machine Learning approaches.

- The variable chosen was **SRI (Surface Rainfall Intensity)**, an estimated value of the instant precipitation using data from all the vertical, as offered by the IRIS SIGMET-VAISALA radar, **each 10 minutes**.

- The nowcasting method chosen was Optical Flow, more especifically, *rainymotion*, by Georgy Ayzel: https://rainymotion.readthedocs.io/en/latest/

- Beware of the limitations: radar located at 1778 meters above sea level!

- Optical Flow:

Estimate motion between 2 small instants of time. Assume conservation of brigthness:

$$I(x,y,t) = I(x+\Delta x, y+\Delta y, t+\Delta t)$$

Taylor expanding at first order and taking limits: $\frac{\partial I}{\partial x}V_x + \frac{\partial I}{\partial y}V_y + \frac{\partial I}{\partial t} = 0$

One equation, 2 unknowns (V's, *aperture problem*): extra assumptions needed.

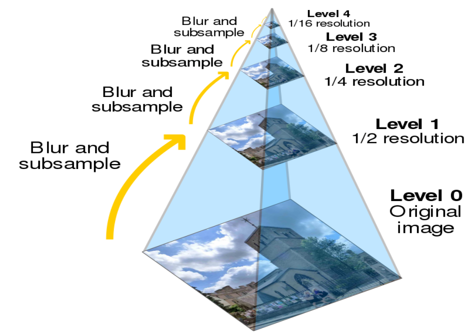
Typical assumption: Lucas-Kanade => flow constant in some region. The problem now has more equations that unknowns (over-determined). Solved with least squares.

$$\begin{aligned} I_x(q_1)V_x + I_y(q_1)V_y &= -I_t(q_1) \\ I_x(q_2)V_x + I_y(q_2)V_y &= -I_t(q_2) \\ &\vdots \\ I_x(q_n)V_x + I_y(q_n)V_y &= -I_t(q_n) \end{aligned}$$

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \sum_i I_x(q_i)^2 & \sum_i I_x(q_i)I_y(q_i) \\ \sum_i I_y(q_i)I_x(q_i) & \sum_i I_y(q_i)^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i I_x(q_i)I_t(q_i) \\ -\sum_i I_y(q_i)I_t(q_i) \end{bmatrix}$$

- Optical Flow:

rainymotion has 2 approaches: Sparse and Dense. Sparse: look for corners and evaluate and propagate velocity through Lucas-Kanade.



Dense (Kroeger et al., 2016): from coarse to fine (pyramid):

1) Create regular grid with overlapping patches

2) Find velocity of displacement (Lucas-Kanade)

$$\mathbf{U}_s(\mathbf{x}) = \frac{1}{Z}\sum_i^{N_s} \frac{\lambda_{i,\mathbf{x}}}{\max(1, ||d_i(\mathbf{x})||_2)} \cdot \mathbf{u}_i$$

3) Weighted averaging of displacements

$$Z = \sum_i \lambda_{i,\mathbf{x}} / \max(1, ||d_i(\mathbf{x})||_2)$$

(λ = 1 means overlap between patch i and point x, d measures difference of intensities)

4) Variational "energy" minimization of U (ψ(E) α E)

$$E(\mathbf{U}) = \int_\Omega \sigma\Psi(E_I) + \gamma\Psi(E_G) + \alpha\Psi(E_S)\, d\mathbf{x}$$

$$E_I = \mathbf{u}^T \bar{\mathbf{J}}_0 \mathbf{u} \quad \bar{\mathbf{J}}_0 = \beta_0 (\nabla_3 I)(\nabla_3^T I)$$

$$E_G = \mathbf{u}^T \bar{\mathbf{J}}_{xy} \mathbf{u}$$

$$\nabla_3 = (\partial x, \partial y, \partial z)^T$$

$$E_S = ||\nabla u||^2 + ||\nabla v||^2$$

$$\bar{\mathbf{J}}_{xy} = \beta_x(\nabla_3 I_{dx})(\nabla_3^T I_{dx}) + \beta_y(\nabla_3 I_{dy})(\nabla_3^T I_{dy})$$

- Optical Flow:

Dense propagates velocity allowing for rotation (semi-Lagrangian field) or with a constant vector, using times *t* and *t-1*.

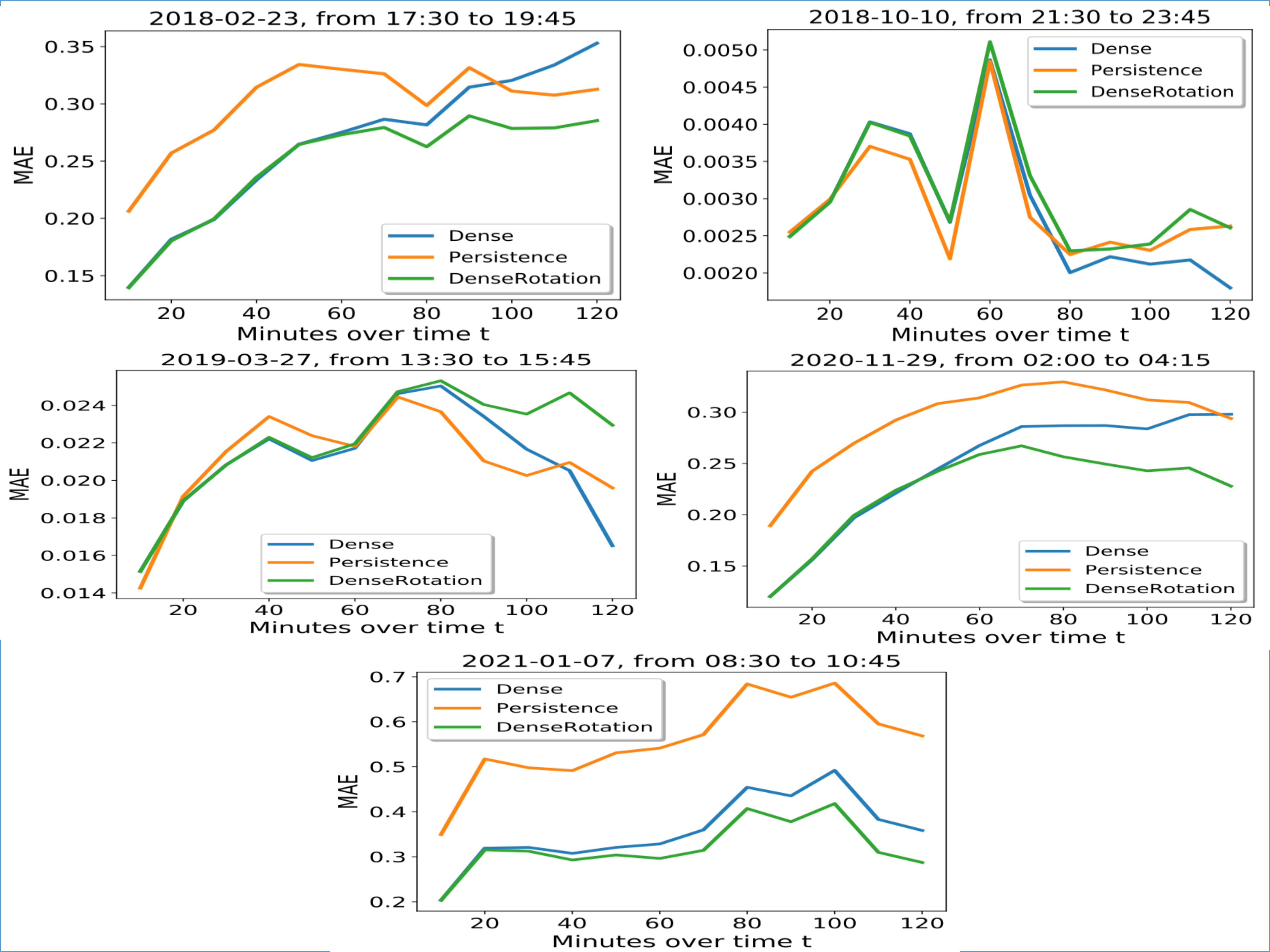
After propagating pixels to *t+n*, with the calculated velocities, new intensities are interpolated between *t* and *t+n* with **inverse distance weighting**.

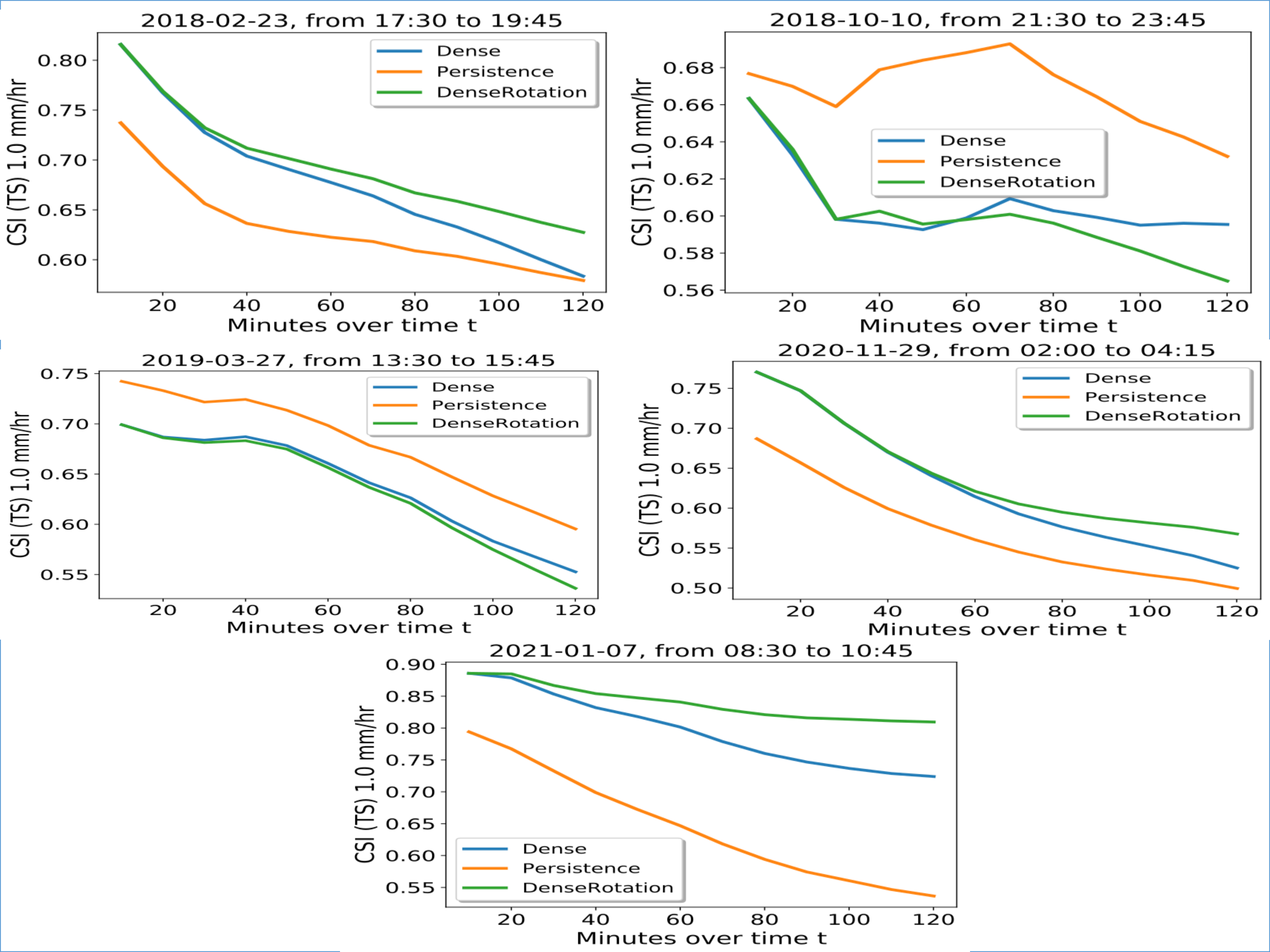
rainymotion offers other options and tweaking of the parameters.

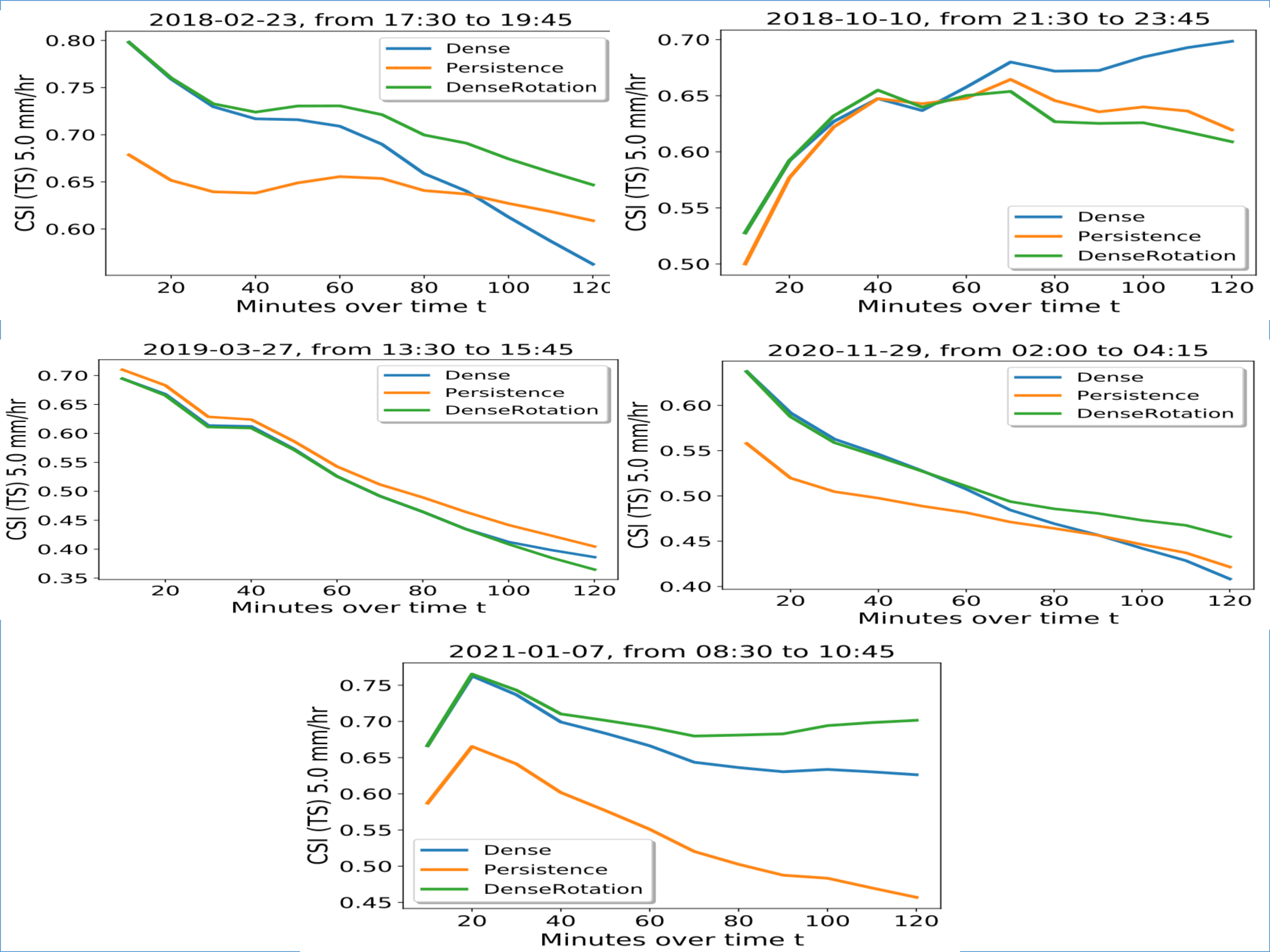
- **Our results:** 5 heavy rainfall situations under study. Scores: CSI (accuracy; higher => better) and MAE (error; lower => better).

CSI = hits/(hits+misses+false alarms)

MAE = $(1/N)\Sigma|obs - fcst|$


2018-02-23, from 17:30 to 19:45
MAE
0.35
0.30
0.25
0.20
0.15
20 40 60 80 100 120
Minutes over time t
Dense
Persistence
DenseRotation
2018-10-10, from 21:30 to 23:45
MAE
0.0050
0.0045
0.0040
0.0035
0.0030
0.0025
0.0020
20 40 60 80 100 120
Minutes over time t
Dense
Persistence
DenseRotation
2019-03-27, from 13:30 to 15:45
MAE
0.024
0.022
0.020
0.018
0.016
0.014
20 40 60 80 100 120
Minutes over time t
Dense
Persistence
DenseRotation
2020-11-29, from 02:00 to 04:15
MAE
0.30
0.25
0.20
0.15
20 40 60 80 100 120
Minutes over time t
Dense
Persistence
DenseRotation
2021-01-07, from 08:30 to 10:45
MAE
0.7
0.6
0.5
0.4
0.3
0.2
20 40 60 80 100 120
Minutes over time t
Dense
Persistence
DenseRotation


2018-02-23, from 17:30 to 19:45
CSI (TS) 1.0 mm/hr
0.80
0.75
0.70
0.65
0.60
20
40
60
80
100
120
Minutes over time t
Dense
Persistence
DenseRotation
2018-10-10, from 21:30 to 23:45
CSI (TS) 1.0 mm/hr
0.68
0.66
0.64
0.62
0.60
0.58
0.56
20
40
60
80
100
120
Minutes over time t
Dense
Persistence
DenseRotation
2019-03-27, from 13:30 to 15:45
CSI (TS) 1.0 mm/hr
0.75
0.70
0.65
0.60
0.55
20
40
60
80
100
120
Minutes over time t
Dense
Persistence
DenseRotation
2020-11-29, from 02:00 to 04:15
CSI (TS) 1.0 mm/hr
0.75
0.70
0.65
0.60
0.55
0.50
20
40
60
80
100
120
Minutes over time t
Dense
Persistence
DenseRotation
2021-01-07, from 08:30 to 10:45
CSI (TS) 1.0 mm/hr
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
20
40
60
80
100
120
Minutes over time t
Dense
Persistence
DenseRotation


2018-02-23, from 17:30 to 19:45
CSI (TS) 5.0 mm/hr
Minutes over time t
Dense
Persistence
DenseRotation
2018-10-10, from 21:30 to 23:45
CSI (TS) 5.0 mm/hr
Minutes over time t
Dense
Persistence
DenseRotation
2019-03-27, from 13:30 to 15:45
CSI (TS) 5.0 mm/hr
Minutes over time t
Dense
Persistence
DenseRotation
2020-11-29, from 02:00 to 04:15
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Minutes over time t
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Persistence
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2021-01-07, from 08:30 to 10:45
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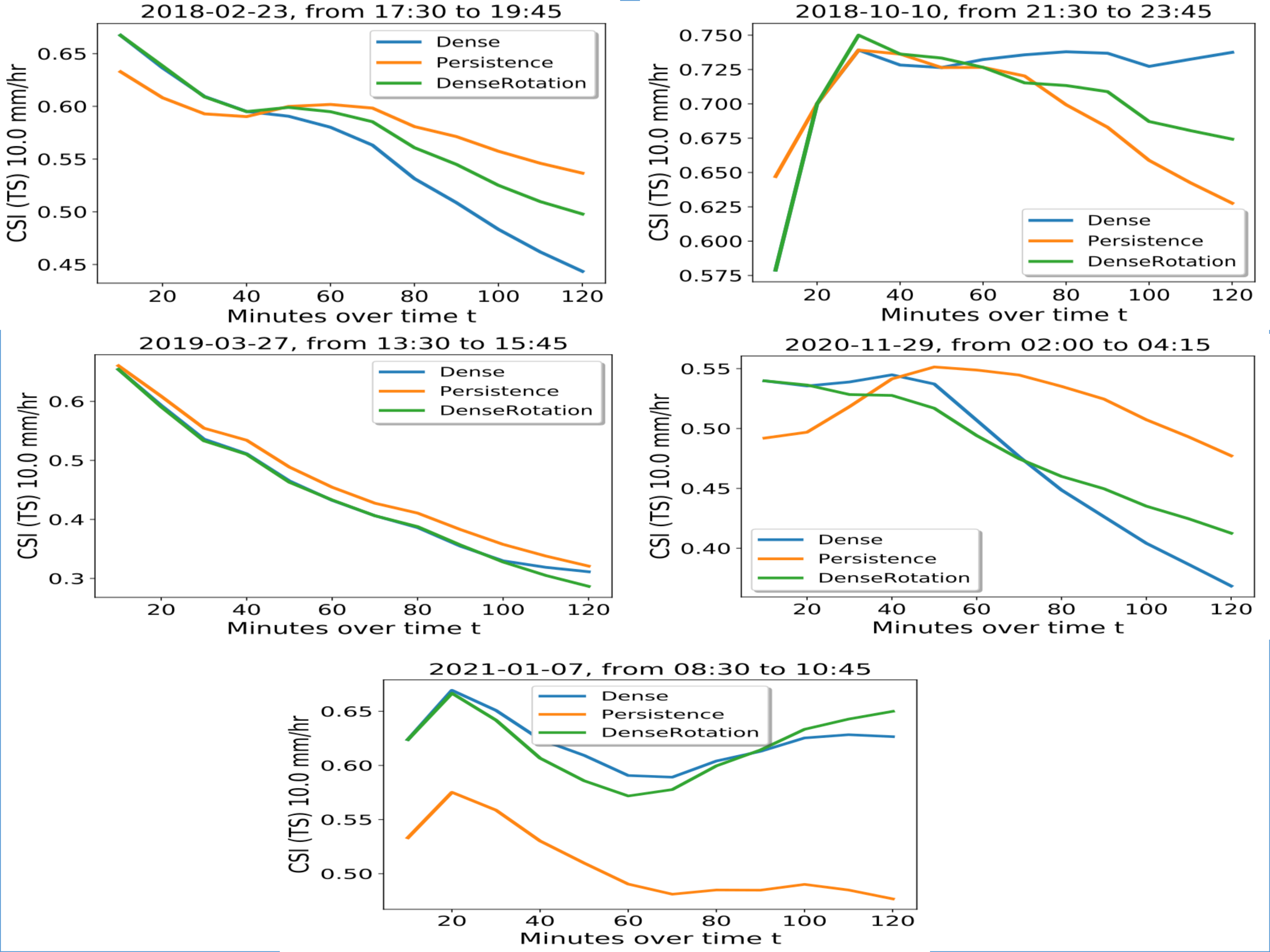
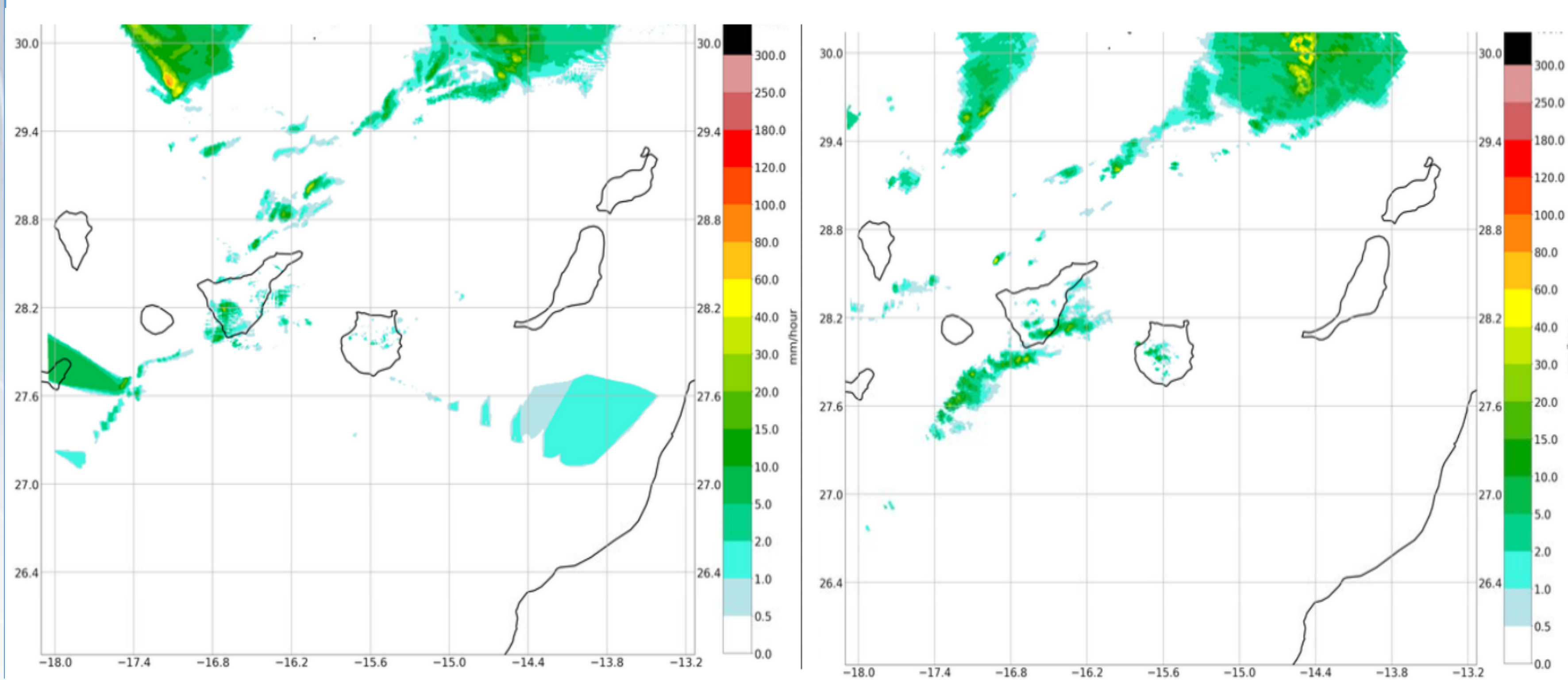
Minutes over time t
Dense
Persistence
DenseRotation


2018-02-23, from 17:30 to 19:45
CSI (TS) 10.0 mm/hr
Minutes over time t
Dense
Persistence
DenseRotation
2018-10-10, from 21:30 to 23:45
CSI (TS) 10.0 mm/hr
Minutes over time t
Dense
Persistence
DenseRotation
2019-03-27, from 13:30 to 15:45
CSI (TS) 10.0 mm/hr
Minutes over time t
Dense
Persistence
DenseRotation
2020-11-29, from 02:00 to 04:15
CSI (TS) 10.0 mm/hr
Minutes over time t
Dense
Persistence
DenseRotation
2021-01-07, from 08:30 to 10:45
CSI (TS) 10.0 mm/hr
Minutes over time t
Dense
Persistence
DenseRotation

- To give an example: SRI from *rainymotion* at 09:10 UTC, 2021-01-07, with SRI from 07:50 and 08:00 (left); observed SRI at 09:10 (right).



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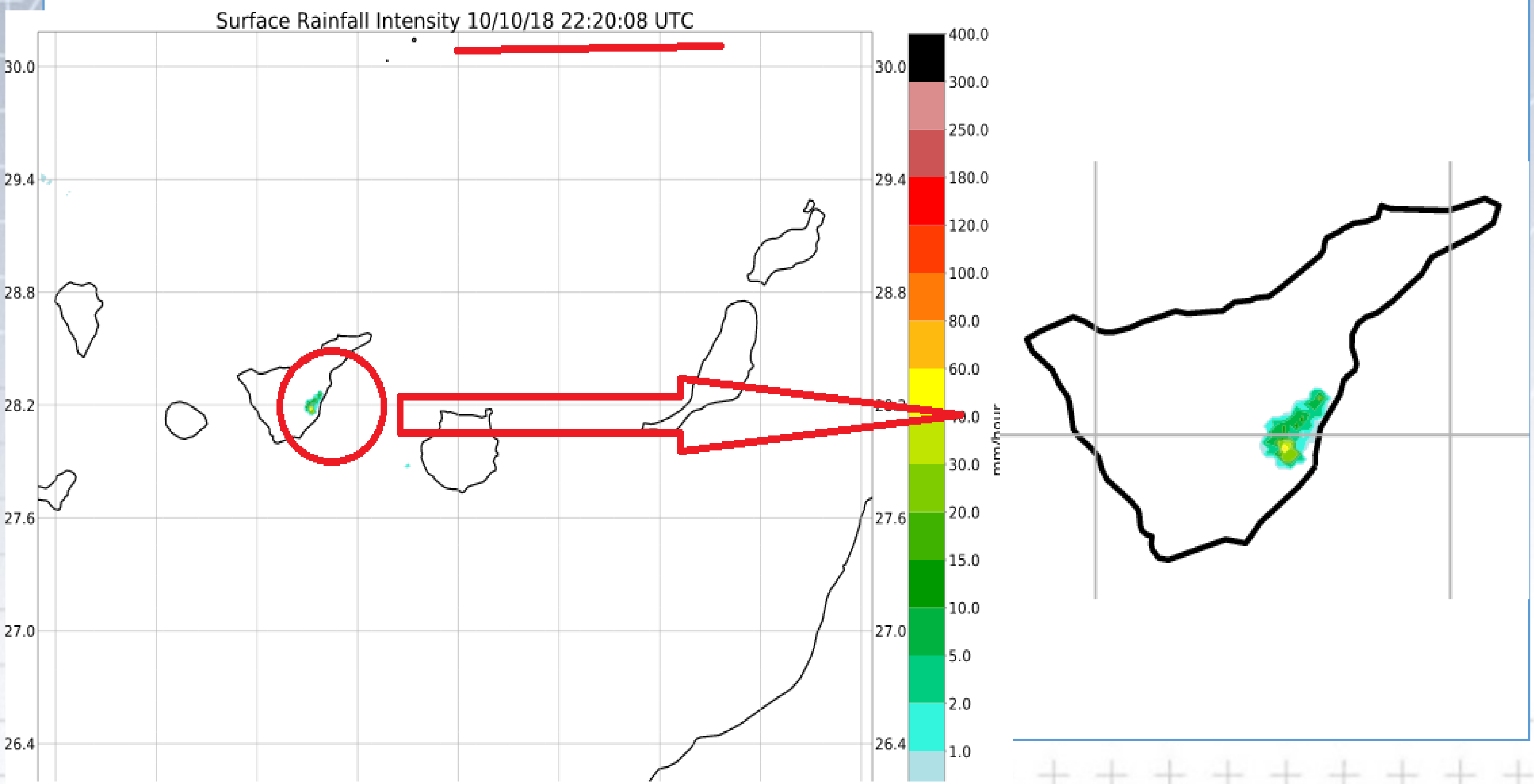
- What did it happen when persistence was the best choice? Observations at 2018-10-10. It seems we were under *very* localized and static conditions.



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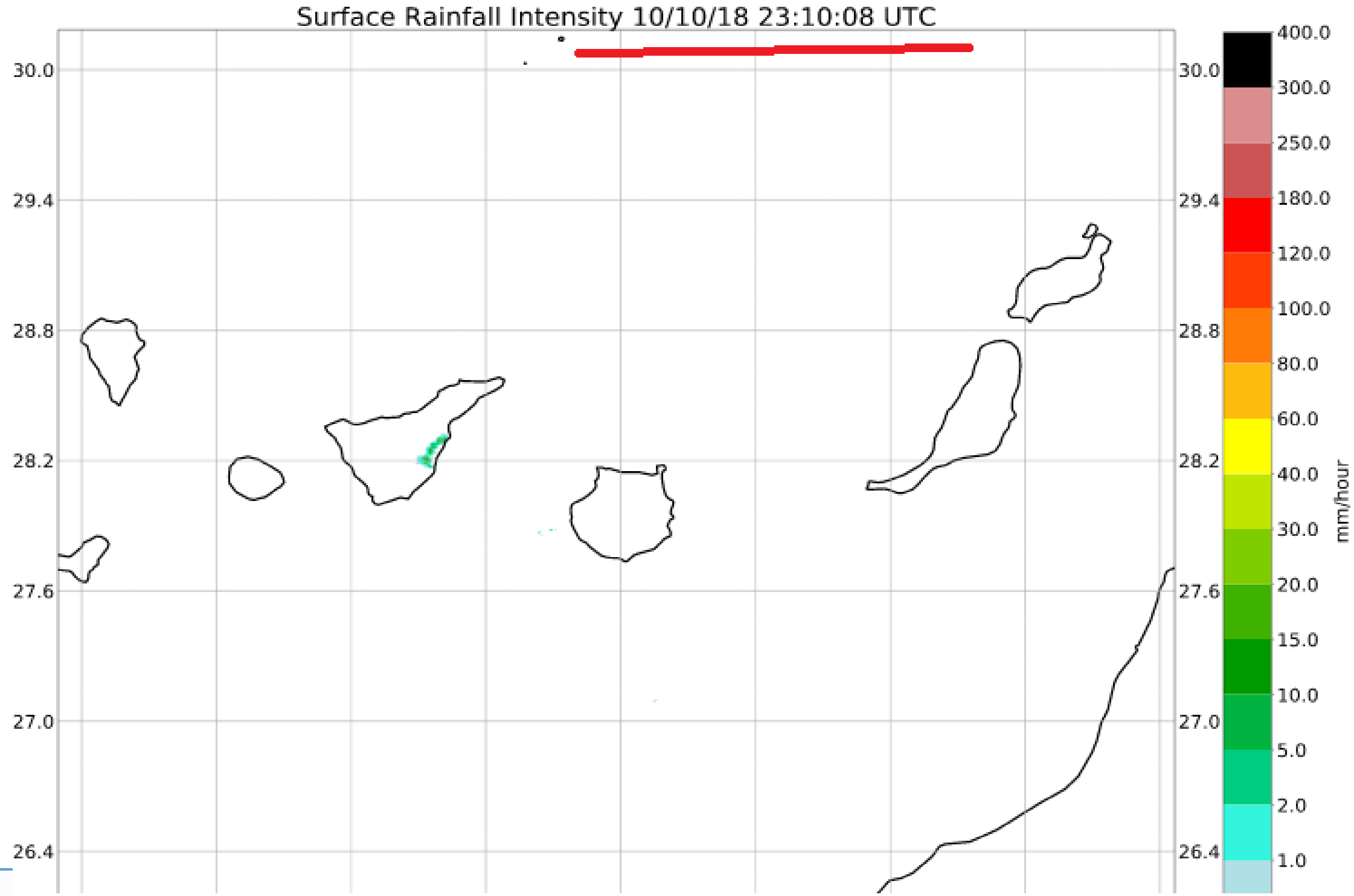

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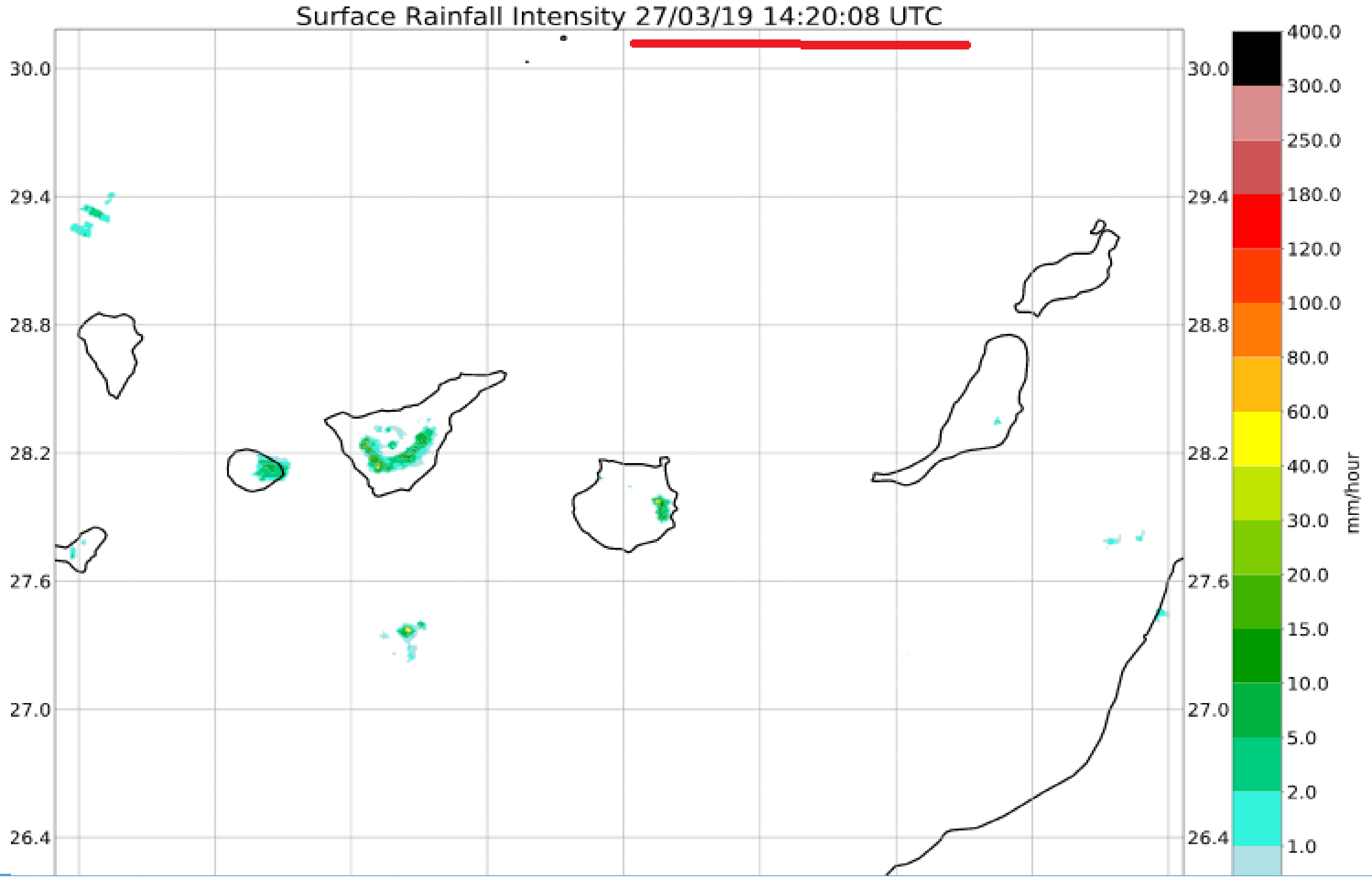
- What did it happen when persistence was the best choice? It seems we were under *very* localized, very intense precipitation. Observations event 2019-03-27:



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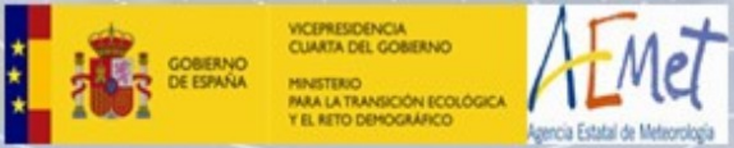
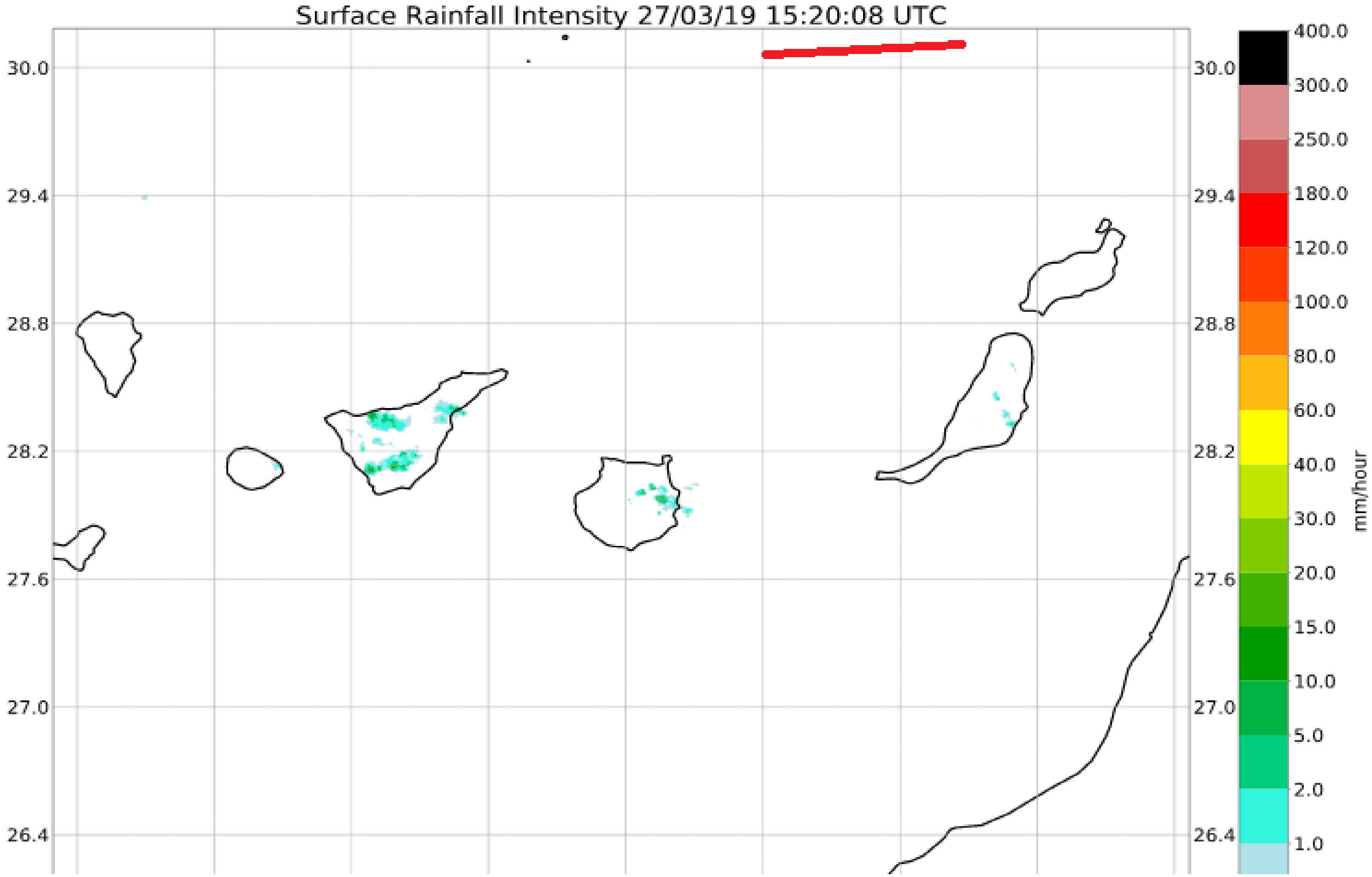


- **What did it happen when persistence was the best choice?** It seems we were under *very* localized, very intense precipitation. Observations event 2019-03-27:



- CONCLUSIONS AND FUTURE WORK:

- Optical flow with *rainymotion* is a good nowcasting system in the complexities of the Canary Islands. Possibly a nice choice for a cheap and fast nowcasting.

- It seems that DenseRotation is slighlty better than Dense (different to G. Ayzel's original paper, probably due to the complex orography of the islands).

- Persistence seems to be better for very local and/or static precipitation systems. But errors with Dense do not seem significative.

- Radar limitations in the Canary Islands: SRI each 10 min, 1778 meter above mean sea level.

- Future work: more advanced method with neural networks (RainNet...)

References:

P. 3: By Iven Gummelt - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4040284

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P. 7: Optical flow: https://en.wikipedia.org/wiki/Optical_flow. Lucas-Kanade: https://en.wikipedia.org/wiki/Lucas%E2%80%93Kanade_method

P. 8: Kroeger T., Timofte R., Dai D., Van Gool L. (2016) Fast Optical Flow Using Dense Inverse Search. In: Leibe B., Matas J., Sebe N., Welling M. (eds) Computer Vision – ECCV 2016. ECCV 2016. Lecture Notes in Computer Science, vol 9908. Springer, Cham. https://doi.org/10.1007/978-3-319-46493-0_29

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