Evolution of fog and low stratus observed by satellite

Olivier Atlan $^{1,2}$
Martial Haeffelin $^{1,2}$
Jordi Badosa $^{1,2}$
André Szantai $^{1,2}$
Eivind Wærsted $^{1,2}$

1 : LMD
2 : IPSL
Summary

1. Introduction

2. Case study: two consecutive but divergent fog events

3. Method: definition of satellite indicators

4. Results: follow-up of fog evolution

5. Conclusion
1. Introduction
Objectives & applications

Objectives:
⇒ intraday predictability of
  • fog and low stratus cover
  • ground irradiance: solar panels

Applications:
⇒ transports:
  • security
  • reducing delays
  • €,$: reducing financial losses due to delays & cancellations

=> electricity production forecasts
  • for a better distribution and transmission system management
  • input parameters of storage strategy
  • €,$: pricing & buy and sell opportunities on electricity market
What are the different forecasting methods for:
- fog evolution?
- solar electricity production?

Our approach: combine forecast methods for ground & satellite data

- Statistical methods
- Sky imaging
- Persistence
- Satellite
- Local Numerical Weather Prediction
- Regional/Global Numerical Weather Prediction + post processing
- Regional/Global Climatology
Satellite & ground-based studies complementariness

In both cases, a model-to-prediction approach:
• identify key variables
• quantify order of magnitude and variability
• design conceptual models to transform observations to 0-6 hours forecasts

Ground observations:
From below, local point of view
⇒ numerous instruments
⇒ in-situ & remote-sensing

Geostationary satellite:
From above, wide sightview from space
⇒ fixed point of view
⇒ uninterrupted temporal series of maps

Cloud albedo sequence:

Key dissipation process: surface warming
Ref: Wærsted et al 2017
2. Case study: two consecutive but divergent fog events
Consecutive but divergent fogs: a ground perspective 1/2

27: 2014/10/27
28: 2014/10/28
29: 2014/10/29

Strict definition of fog: horizontal visibility < 1km & water droplets => fog
=> Fog on both 27 & 28th until 9am: same « experience » at ground level
Consecutive but divergent fogs: a ground perspective 2/2

27: 2014/10/27
28: 2014/10/28
29: 2014/10/29

FOG HERE MEANS:
FOG & VERY LOW STRATUS

Model: satellite-to-irradiance
ref Mueller et al 2012

=> GHI max is 4.5 times less by heavy fog compared to clear sky
Consecutive but divergent fogs: a satellite perspective

Predictable at 6 am?

fog dissipation

no fog dissipation

classification derived from CLOUD TYPE satellite product from SAFNWC (EUMETSAT, MeteoFrance)

=> What would be the variables that would enable anticipating fog dissipation?
3. Method: definition of satellite indicators
Selection of three satellite indicators

1. Cloud Type:
   • clusters of pixels: classification of meteorological situations
   • enables monitoring subsets of images with close physical properties
   [satellite product from SAFNWC: EUMETSAT, MeteoFrance…]

2. Cloud Albedo based on visible high resolution channel:
   • ref: Mueller et al 2012
   • contrasted key figure growing with cloud optical depth
   • intermediate key figure for estimating ground irradiance using satellite-to-irradiance models: basis for solar panels applications

3. A new key figure at pixel level:
   • new proxy indicator for surface warming
   • based on variations of 10.8 µm IR channel for two consecutive images
   • notation: $\Delta(BT)$ 10.8 µm (K)
A new proxy indicator for surface warming 1/2

SIRTA-centered images of $\Delta$(BT) 10.8 $\mu$m (K)

- most of the image (green color): uniform signal, variation close to 0
- kind of waves (blue, red, yellow): very strong variations due to high cloud motion

=> seems there is no information about fog based on this $\Delta$(BT) maps
=> is there a « hidden signal » below these high variations?
A new proxy indicator for surface warming 2/2

SIRTA-centered images of $\Delta(BT)$ 10.8 μm (K)

LIGHT FOG
2014 10 27

$|\Delta(BT)| < 1.0$ (K)

9 am

HEAVY FOG
2014 10 28

$|\Delta(BT)| < 1.0$ (K)

warming close from signal for clear sky day

white: filtered part: high cloud motions

cooling

no clear trend

$\Rightarrow$ A warming signal for light fog at 9 am indicates pixel or subpixel clear sky areas
4. Results: follow-up of fog evolution
Evolution of satellite key figures: clear sky

- source: sequence of 11*11 pixels SIRTA-centered maps
- evolution of average of (changing) clear-sky and fog/low stratus clusters/subsets

=> clear sky situations:
  - very low cloud albedo
  - solar-zenith-angle-like $\Delta(BT)$

![Graphs showing clear sky and fog pixel evolutions over time]
Evolution of satellite key figures: clear sky versus light fog

=> dissipating light fog:
1. decreasing cloud albedo
2. increasing clear sky pixels
3. Δ(BT) close from clear-sky pattern
Evolution of satellite key figures: heavy fog versus light fog

⇒ characterisation of heavy fog: 1. high cloud albedo  
   2. no clear sky pixels  
   3. $\Delta(BT)$ without trend
5. Conclusion
Main results

We tested a new approach combining 3 satellite indicators on a case study:

- « cloud type » satellite product
- cloud albedo
- a new satellite key figure based on 10.8 μm channel

New satellite key figure has following properties:

- physical meaning: related to warming/cooling of the surface which is a key variable of fog evolution
- clear contrast for light fog / heavy fog / clear sky
- enables identification of fog dissipation for the case study

LIGHT FOG
9 am
[+ HIGH CLOUDS]

<table>
<thead>
<tr>
<th>Δ(BT)</th>
<th>&lt; 1K</th>
</tr>
</thead>
</table>

HEAVY FOG
9 am
[+ HIGH CLOUDS]

| Δ(BT) | < 1K |
Perspectives

Generalization study:
• check application to hybrid/multilayer situations
• check the results over a larger period of time
• study new key figures

Modeling:
• quantify orders of magnitudes of variables
• quantify variability
• characterize scenarios of evolution for intraday forecast
Thanks for your attention!

olivier.atlan@lmd.polytechnique.fr

Questions?
Bibliography

- Wærsted et al 2017 - Radiation in fog - Quantification of the impact on fog liquid water based on ground-based remote sensing
- Mueller et al 2012 - A new algorithm for the satellite-based retrieval of solar surface irradiance in spectral bands
- Tardif & Rasmussen 2007 - Event-based climatology and typology of fog in the New York City Region