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À VOS CÔTÉS, DANS UN CLIMAT QUI CHANGE

Overview of Météo-France's research activities for aviation safety and climate impact mitigation

Pierre Crispel (CNRM/GMAP)

ISA conference – 23th July 2026 - Toulouse

Outlines

- General information on Météo-France / CNRM research activities
- Research on persistent contrails mitigation
- Research on aeronautical turbulence
- Research on icing hazard
- Other research works of interest concerning aviation

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General information on Météo-France / CNRM research activities

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General information on Météo-France / CNRM research activities

CNRM

Research

- Study of the atmosphere, climate
- **Observations**: new instruments and observation products, campaigns, Assimilation
- **Modelisation**: atmosphere, interfaces (ex. surface)
- Intensive numerical **computing**

Transfer to operations

Operational facilities, feedback

Météo-France

Operations

- Observation systems
- Satellite center
- Operational models
- End-users services and products

Collaborative framework

EUMETNET

EUMETSAT

ECMWF

SAFIRE

ACCORD

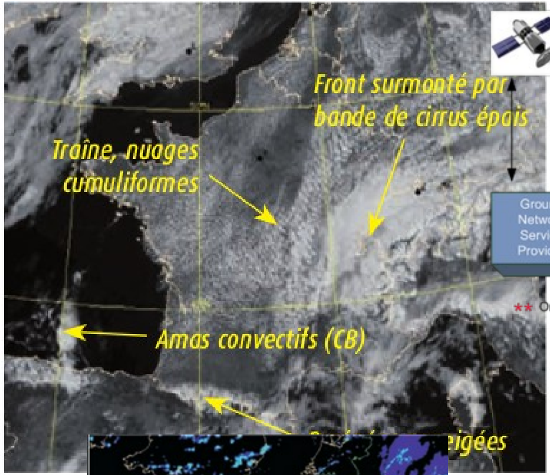
CERFACS

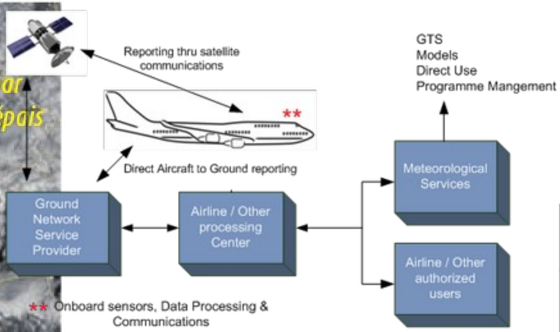
and many others …

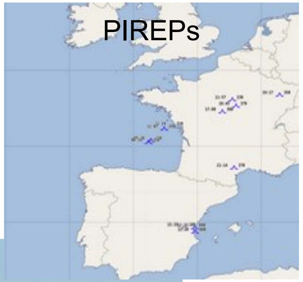
General information on Météo-France / CNRM research activities

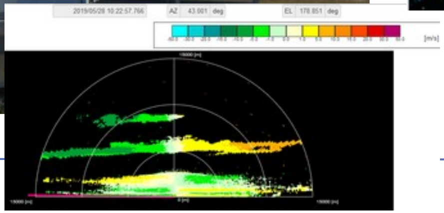
Observations

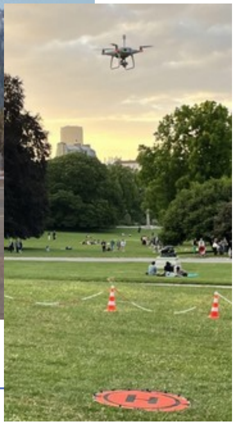
Image visible sur la France







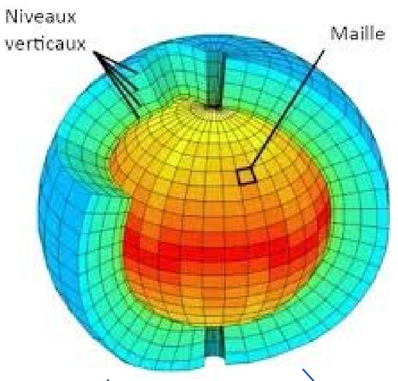




General information on Météo-France / CNRM research activities

Modeling

Global Circulation Models



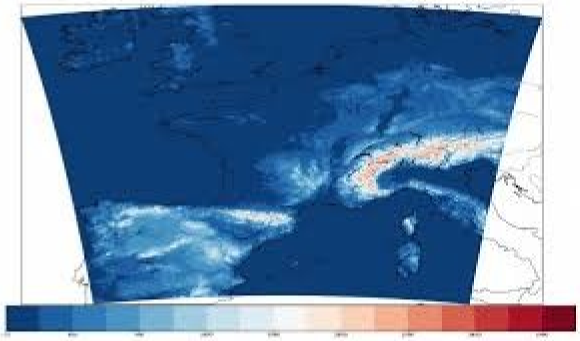
ARPEGE

NWP

Climate
CNRM-CM6-1

ARP-GEM

Limited Area Models



AROME

NWP

Climate
CNRM-AROME

Turbulence scale Model
(Large Eddy Simulation LES)

C. Lac et al.: Overview of the Meso-NH model 1955

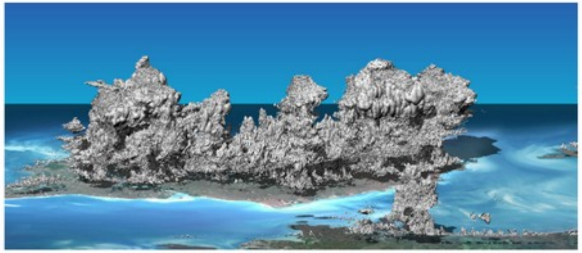


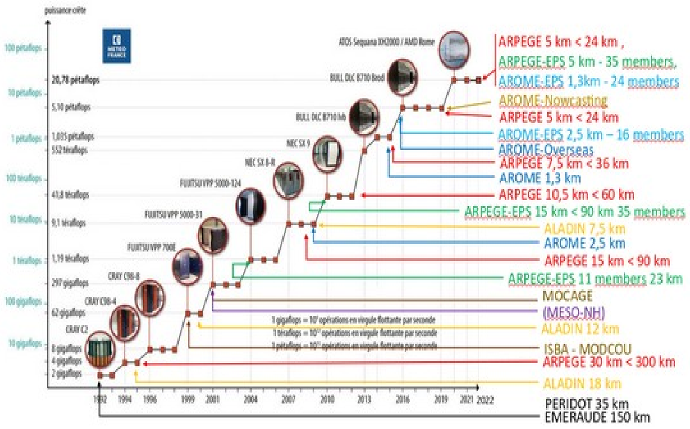
Figure 16. Snapshot of a Meso-NH simulation of Hector the Convector taken from the 1 min cloud envelope animation available at https://youtu.be/xjPumywGaAU (last access: 22 May 2018).

MESO-NH
CNRM / Obs MIP

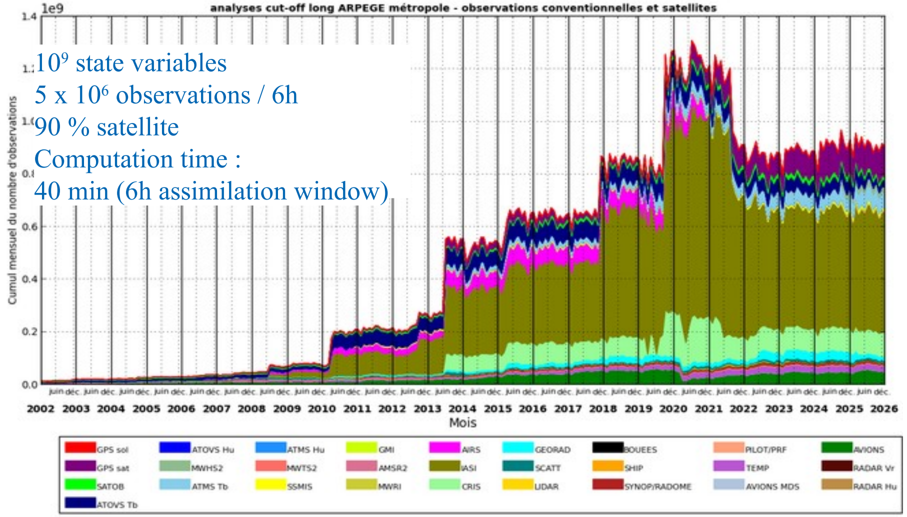
MOCAGE (atmospheric chemistry)

General information on Météo-France / CNRM research activities

Increase of resolution / computation power



New observations to asimilate

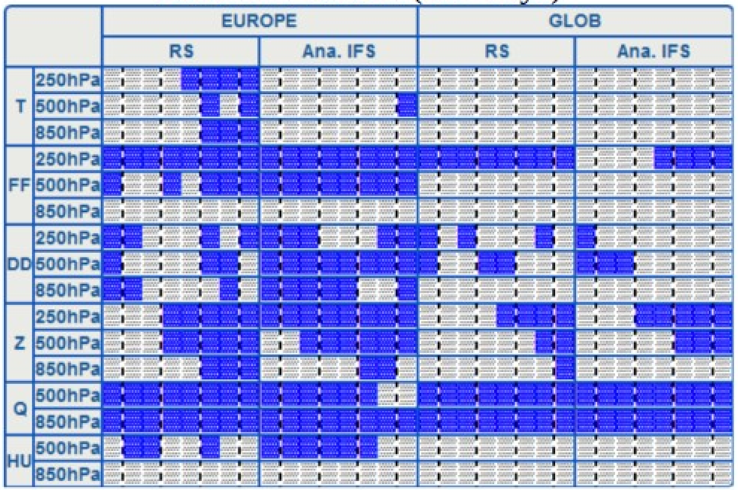


+ improvements in assimilation techniques, dynamical core, physical parametrization (subgrid processes, interfaces)

General information on Météo-France / CNRM research activities

cy49 (integration) vs cy48 (oper)

ARPEGE RMSE (500 days)



Lead time

Increased accuracy in Temperature, Humidity, Wind

→ gain in CAT, icing, convection, visibility, etc …

→ new contributions in operational NWP model are available to climate models (and reversly)

~ estimated gain in the last 30 years: 1 day of forecast by decade

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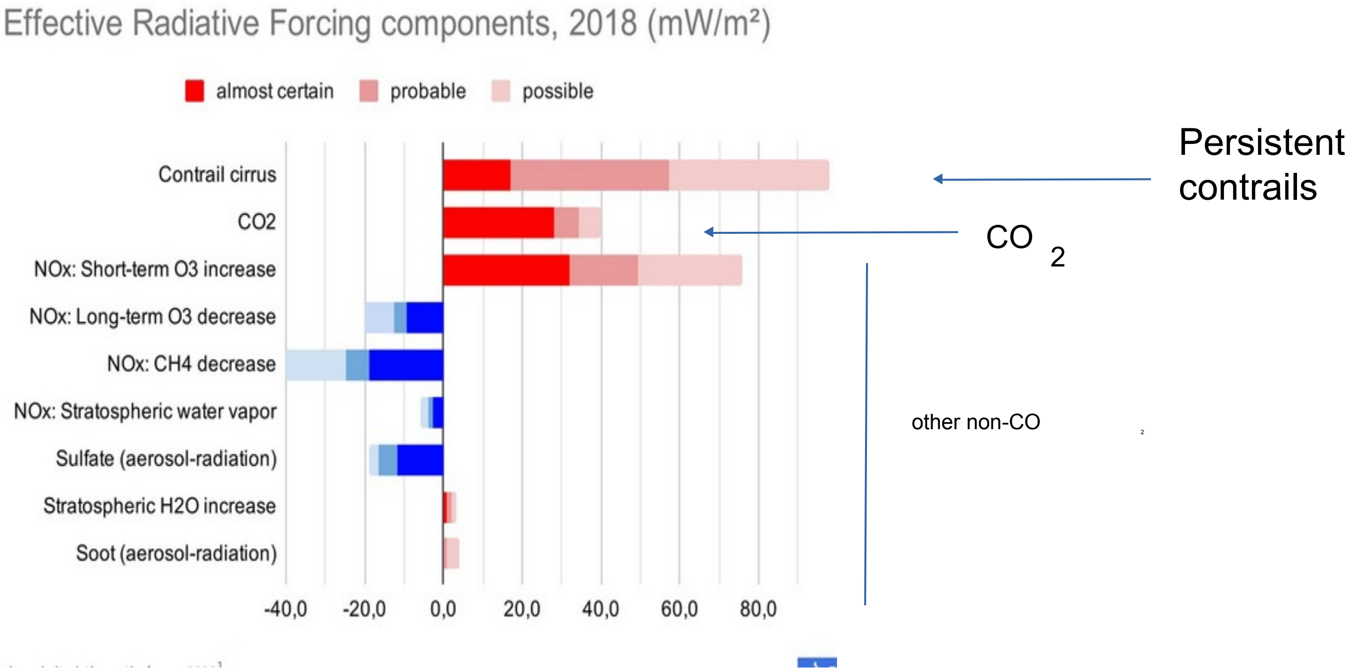
Research on persistent contrails mitigation

Research on persistent contrails mitigation

Source : M. GARCIA

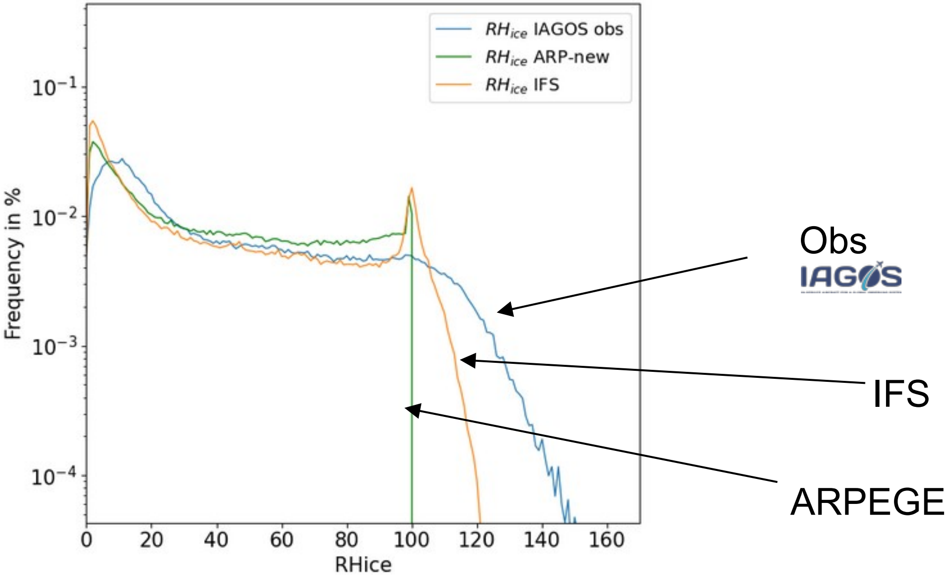


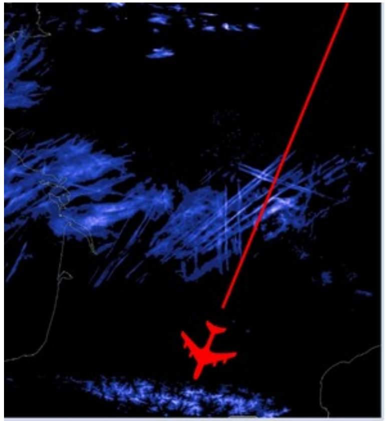
Source : David S. Lee et al., « The contribution of global aviation to anthropogenic climate forcing for 2000

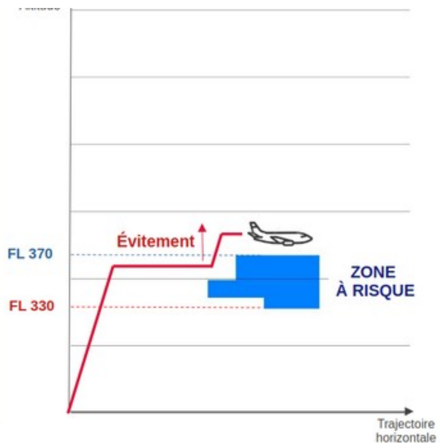
Research on persistent contrails mitigation

Challenges

- Representation of supersaturation w.r.t ice in NWP model
- Verification
- Feasibility of avoidance strategies







Research on persistent contrails mitigation

CICONIA

Led by AIRBUS

SESAR JU

2023-2026

Lead of the WP concerning meteorology

→ Provide data for trials / avoidance / sensitivity studies

→ Allow supersaturation w.r.t. ice in ARPEGE

→ Perform verification of NWP model humidity

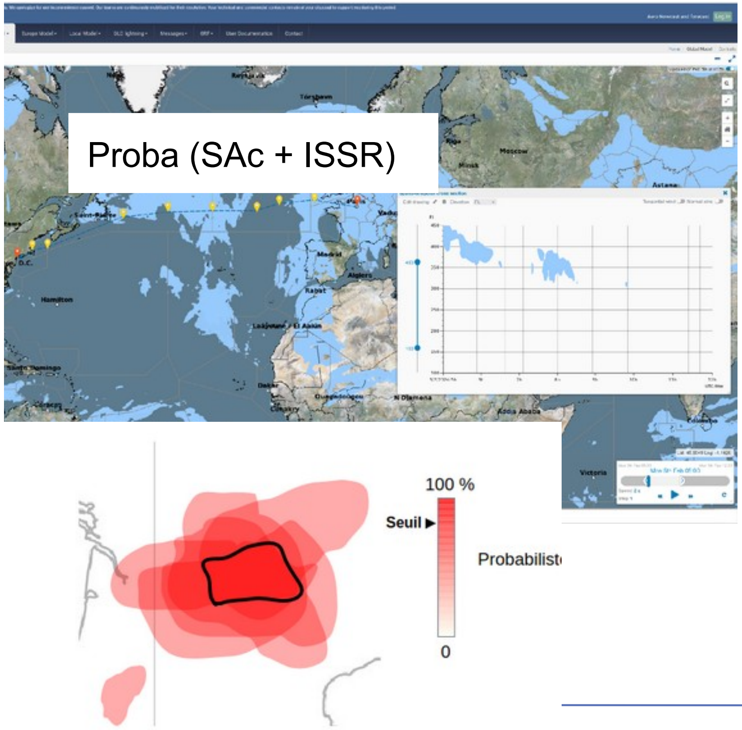
→ Assimilation of RHice observatios with IA techniques ANEMOI framework and fleet equipment assessment

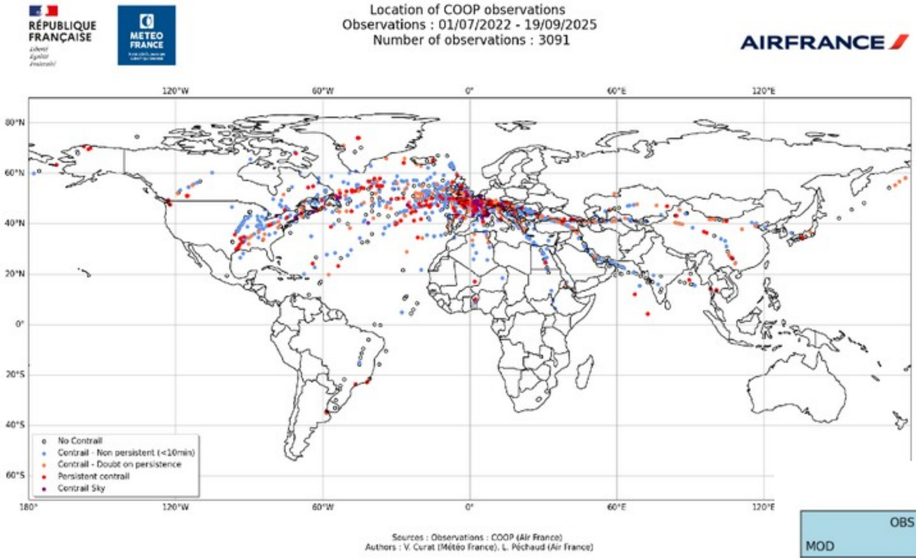
→ Contrail properties by LIDAR measurements - DSO

Research on persistent contrails mitigation

WIMCOT demonstration product with IFS-EPS

→ Verificiation with Air France COOP program (observation of contrails) since 2023

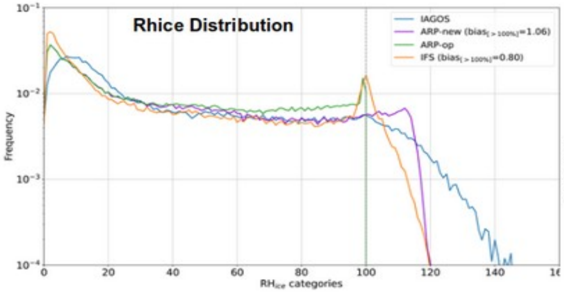


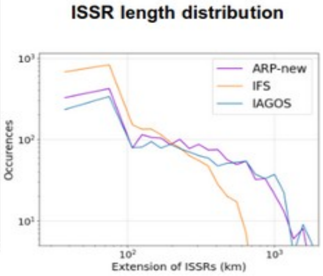


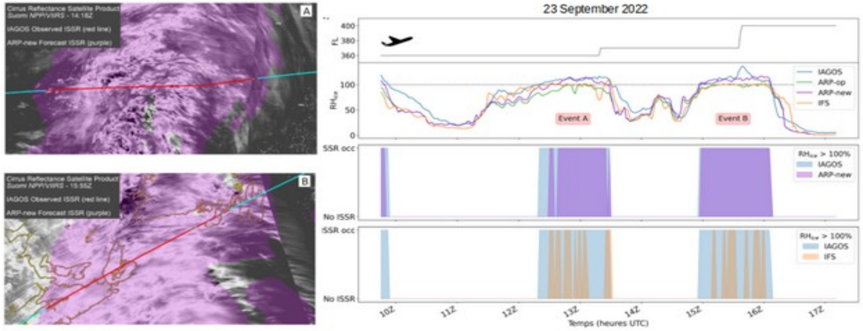
MOD \ OBS	COTRA	NO COTRA
COTRA	190	85
NO COTRA	55	1601

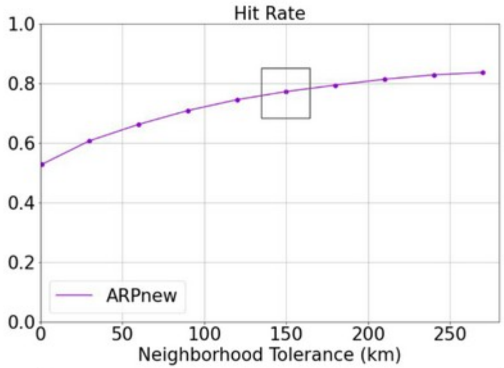
Research on persistent contrails mitigation

CICONIA : Supersaturation w.r.t. ice in **ARPEGE** and spatial verification (Arriolabengoa et al 2025 - ACP)

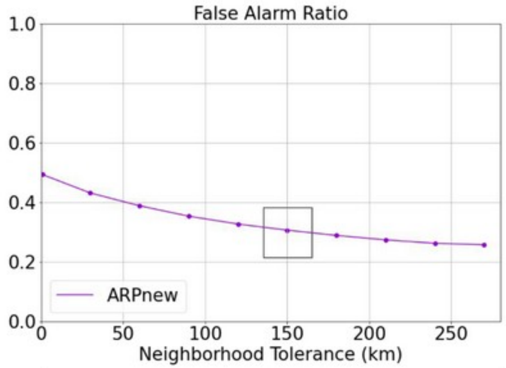








When an ISSR was observed, an ISSR was forecast in a 150 km (10 min) neighbourhood in **77%** of the cases.



When an ISSR was forecast, no ISSR was observed in a 150 km (10 min) neighbourhood in **31%** of the cases.

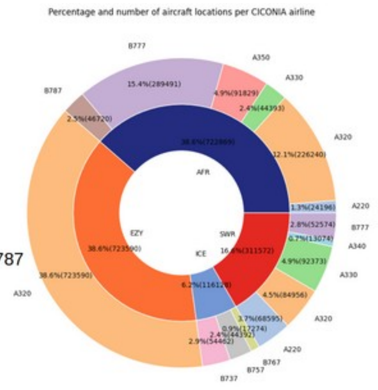
Research on persistent contrails mitigation

Data fusion Obs / model with IA techniques (ANEMOI framework)

Fleet equipment scenario

- Number of positions
  - Single aisle :
    - ~ 1 M A320
    - ~ 70 000 A220 ?
    - ~ 120 000 ICE
    - Total : 1,2 M
  - Long range :
    - 390000 B777 + B787
    - 240000 A330 + A340 + A350
    - Total : 630 000

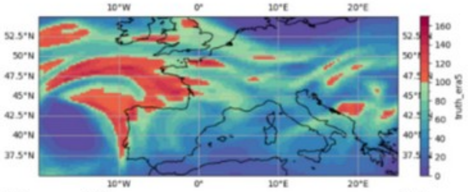
CICONIA



Scenario 1 (0%)	Scenario 2 (50%)	Scenario 3 (100%)	Scenario 4 Single Aisle	Scenario 5 Long range

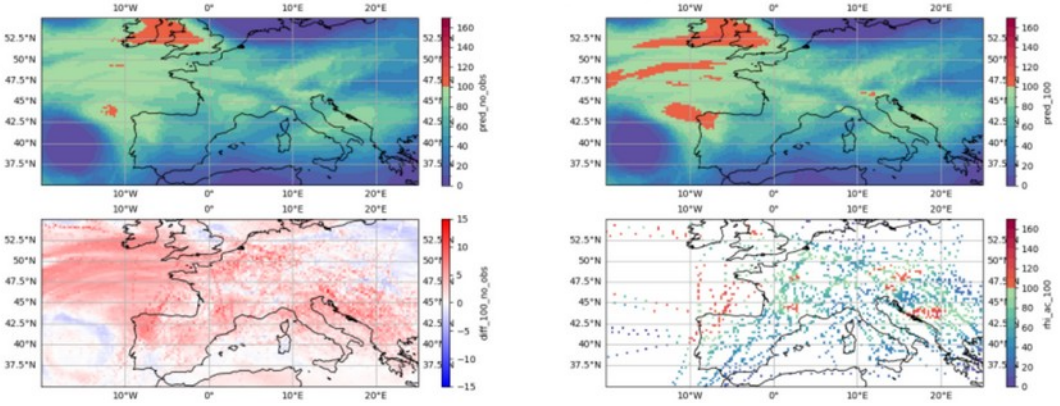
→ Signal on RMSE reduction when fleet equipment rises, but need to be consolidated

TARGET



NO ASSIM

WITH ASSIM



Suzanne Angeli

Perspectives

Internal work

→ Supersaturation in the operational model ARPEGE, ARPEGE-ENS (2028)

→ WIMCOT probabilistic product based on ARPEGE-ENS

Research on persistent contrails mitigation

Perspectives

Internal work
→ Supersaturation in the operational model ARPEGE, ARPEGE-ENS (2028)
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2026-2029

CICONIA-MET (SESAR)

→ Impact of assimilation of RHice observations in ARPEGE model

→ Fleet scenario equipment

→ NWP intercomparison

→ Definition of the met-service and communication on uncertainties

Research on persistent contrails mitigation

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Internal work
→ Supersaturation in the operational model ARPEGE, ARPEGE-ENS (2028)
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2026-2029

POETIC (DSNA) Dassault – *currently suspended*

→ ISSR caracterization in AROME microphysics module, and transfer in ARPEGE.

→ Support for trials and flight measurements / verification

→ Rhice at very high altitude

Research on persistent contrails mitigation

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2026 Call for bursary E-AI Eumtenet programme Klima / Météo-France

→ Altitude caracterization in contrail satellite detection algorithme

→ Nowcasting of persistent contrail risk area

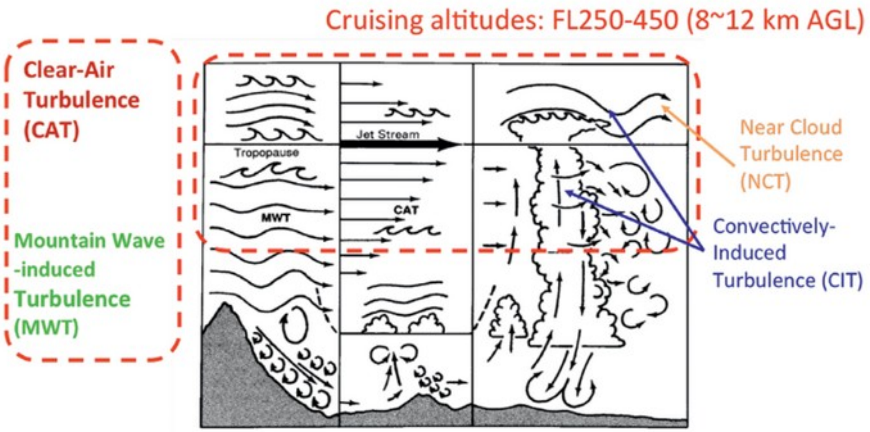
Research on aeronautical turbulence

Turbulence

http://en.wikipedia.org/wiki/Image:Wavecloudsduval.jpg

Impactful phenomena for en-route (injuries)

→ several situations for CAT triggering

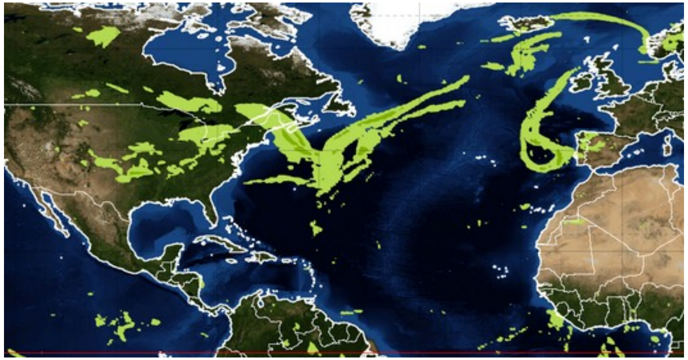


Kim et al. 2018

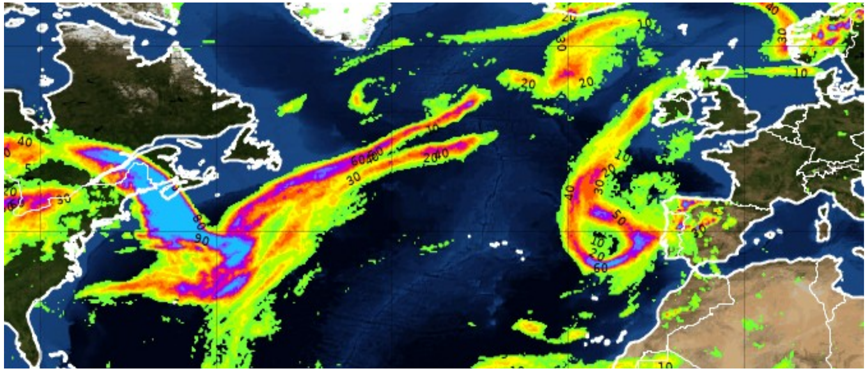
Turbulence

State of the Art

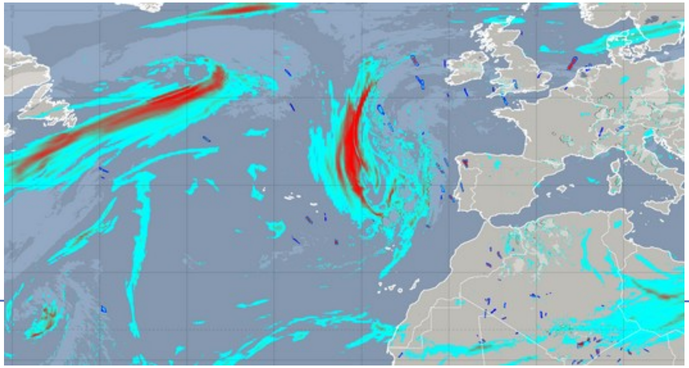
CAT-EDR diagnostic computed on native ARP resolution (op. 2019)
(combined indices - GTG methodology Sharman et al.)



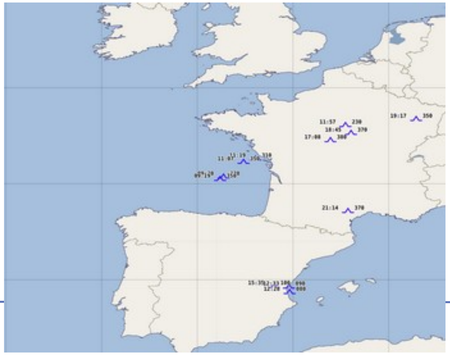
Probabilistic CAT-EDR based on ensemble (op. 2024)



Satellite diagnostics (tropopause folding + gravity waves)



PIREPS, In-situ EDR

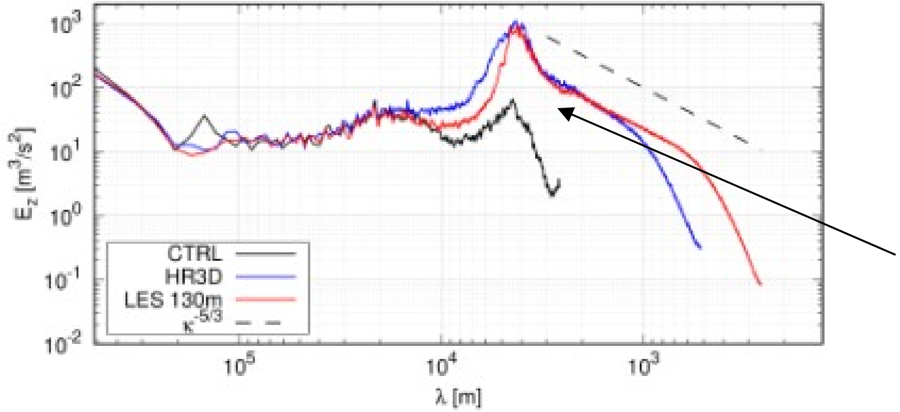


Turbulence

Challenges

- Aeronautical turbulence is a subgrid scale phenomena (~ 100m)
- Under-estimation of turbulence with current subgrid scale turbulence parametrization in NWP models in the UTLS (stable conditions)

→ Improving TKE parametrization gives an overall benefit for the model (in particular in the UTLS)

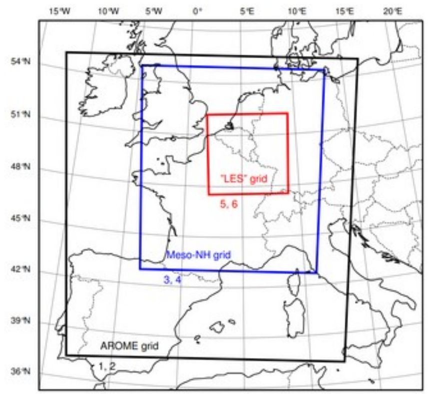


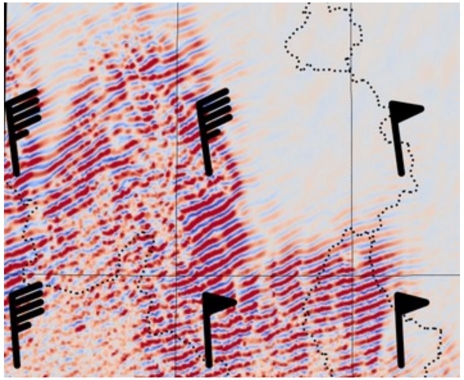
MesoNH
(AROME settings)

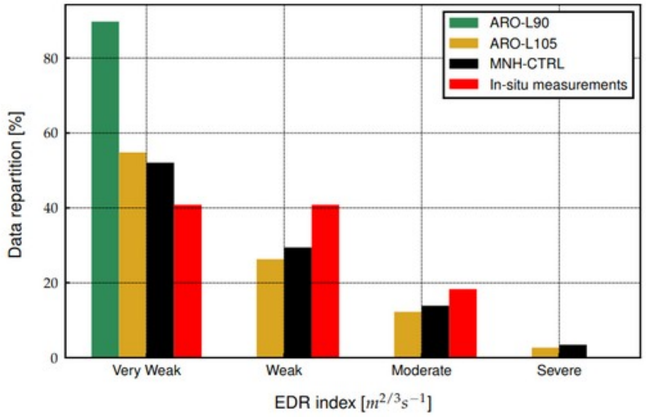
Thèse - Léo Rogel (CNRM)

Turbulence

Impact of resolution and test of a 3D turbulence scheme against LES (PHD + article Rogel et al 2023)







- Increase in AROME resolution (next cycle op 2028 after HPC change)

- **Perspectives**:
  - horizontal shear production terms in TKE equation in AROME (next cycle op 2028 after HPC change)
  - → currently tested for low levels & hectometric resolution.

  - other possibilities for a better TKE representation (e.g. flow depency for turbulence dissipation computation)

Climate trends

Collaboration with CERFACS
→ classical CAT diagnostics in ARPEGE-Climat

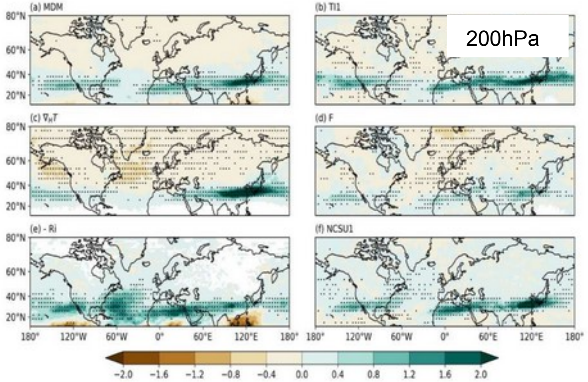


Figure 3.11 – Projected changes in MOG-CAT frequency at ΔT=2°C for (a) the multi-diagnostic mean (MDM), (b) Turbulence Index 1 (TI1), (c) horizontal temperature gradient ($\nabla_H T$), (d) Frontogenesis function (F), (e) negative Richardson number (- Ri), and (f) North Carolina State University index 1 (NCSU1). Changes are estimated from the multi-model ensemble mean. The black dots in (a) indicate those grid points where all CAT indices agree on the sign of the change, while in (b-f) they indicates where more than 80% of models agree on the sign of the change. Units are in %.

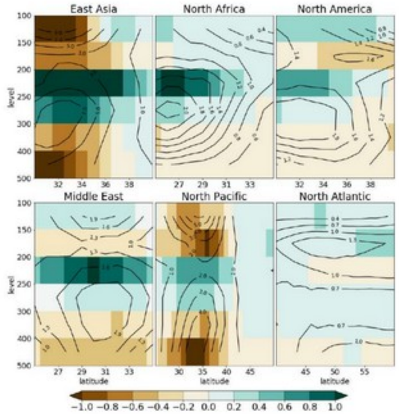


Figure 3.18 – Changements projetés de la structure verticale de la MOG-CAT dans les différentes régions sélectionnées avec ΔT=2°C (en couleurs). La climatologie de la MOG-CAT est indiquée avec les contours noirs. Les changements sont estimés à partir de la moyenne multi-diagnostic multi-modèle. Les unités sont exprimées en %.

Foudad et al. 2024 (Phd + article)

Perspectives

→ Post Doc (ISA)

- Work with a combined CAT-EDR diagnostic
- Multi-level approach

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Research on icing

Icing

Supercooled Water Droplets

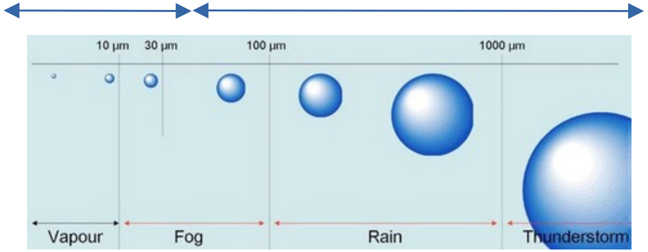
https://www.flickr.com/photos/63366024@N00/3168468245/in/dateposted/

→ Accretion of water supercooled droplets on wings or engine surfaces

→ New certification criteria for **SLD Icing** (annex O)

Classical icing <50um
(annex C)

SLD
(annex O)



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Icing

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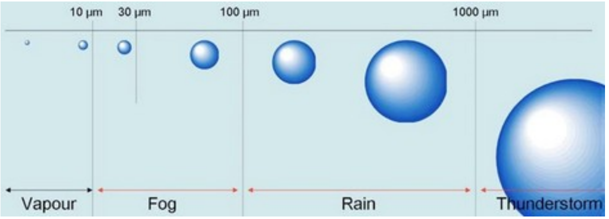
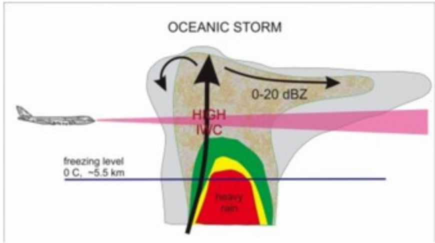


High Ice Crystals Content (Engine icing)

→ ingestion of high concentration of small icecrystals in engines

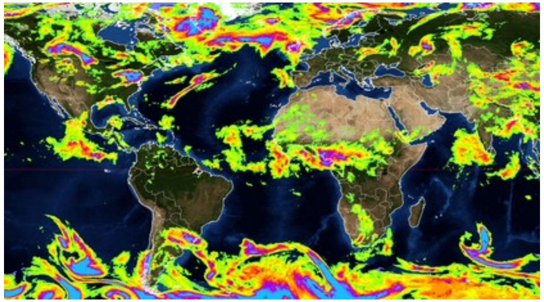


Icing

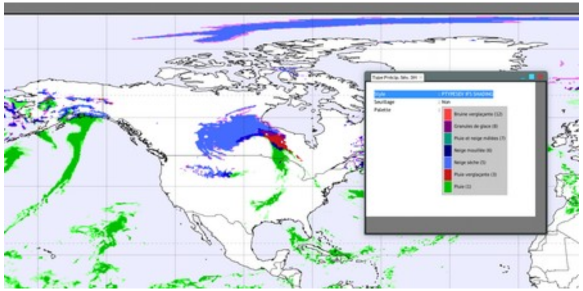
State of the Art

ICEP diagnostic

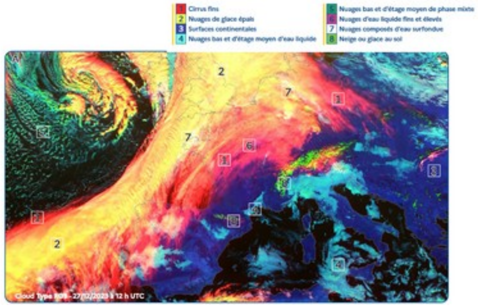
Probabilistic diagnostic

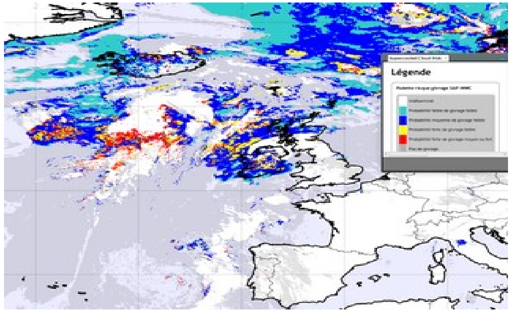


FZRA/FZDZ (ground)

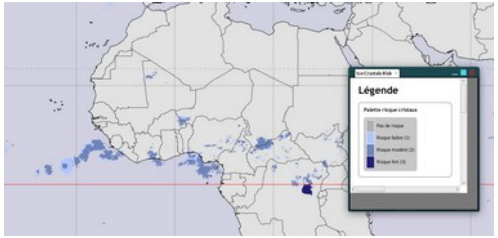


Satellite

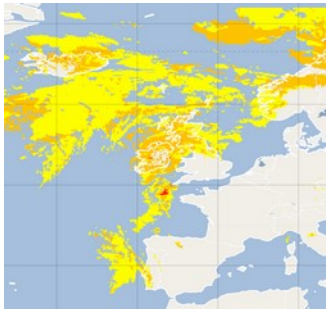




Ice Crystal risk (CMIC - NWC-SAF)



SIGMA (sat / radar / NWP model fusion)



Icing

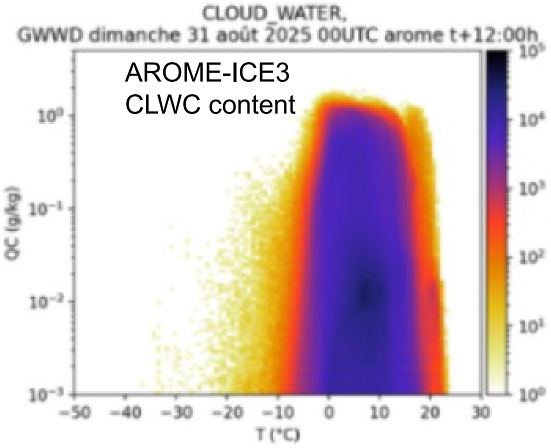
Challenges

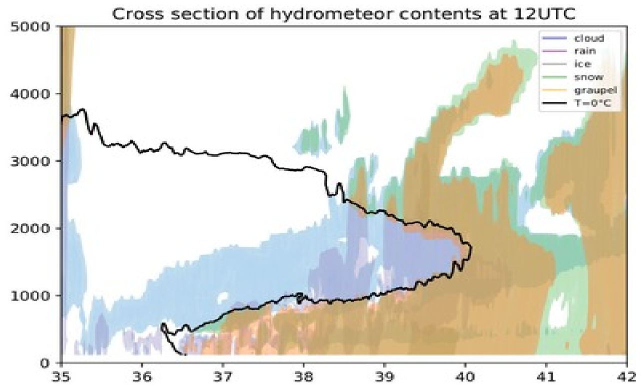
Under-representation of supercooled liquid water contents (in AROME-ICE3, and also in AROME-LIMA 2mom, ARPEGE)

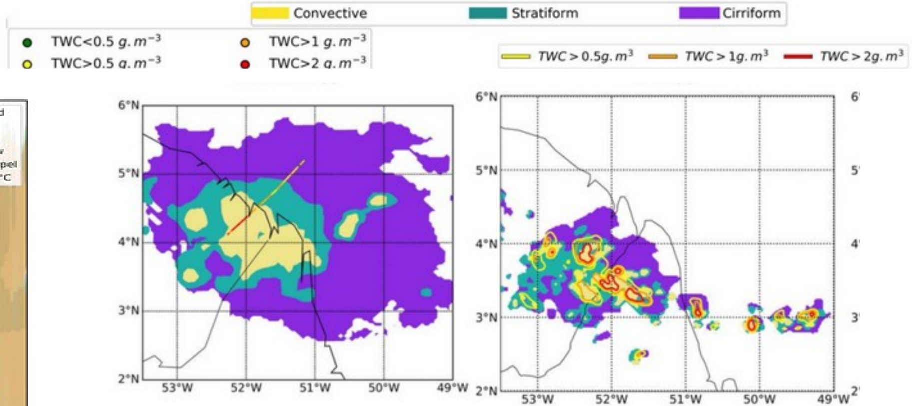
Calibration of supercooled liquid water diameter in AROME-LIMA-2mom

→ Discrimination FZRA/FZDZ/Classical icing

Calibration of ice crystals contents in stratiform and cirriform parts of convective systems (ARPEGE / AROME)







OBS (sat)

AROME-ICE3 (sat)

Icing

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
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METEO FRANCE
À VOS CÔTÉS, DANS UN CLIMAT QUI CHANGE

ICICLE

In-Cloud Icing and Large-Drop Experiment

Winter 2019

LEA Leading Edge Atmospherics

Federal Aviation Administration

National Research Council Canada

NCAR

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Collect data in a wide variety of icing and non-icing conditions
– Small-drop and **large-drop**

Event type (across) Parameter (down)	*FZDZ aloft down to sfc*	*FZDZ aloft only*	*FZDZ Seed-Feeder*	*FZRA*	*Classical PL*	*Deep Glaciated*	*Shallow StCu*	*High LWC / MVD 30-40 mic*	*Typical App C*	*Clear Air*
Priority	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
% flight hr	15	10-15	10	15	5	5	10-15	5-10	5-10	5
Time (hr)	18	12-18	12	18	6	9	12-18	6-12	6-12	9
Frequency (1-10)	5	5	4	3	2	9	6	3/1	9	10
Sampling Diff. (1-10)	5	5	6	8 (Z vs MEA)	9 (narrow)	1	3 (Z vs MEA)	7 (small) / 9 (rare)	2	1
Tmin range (°C)	-5 to -13	-5 to -13	-5 to -13 / -20	-2 to -10	-2 to -12	-30	-5 to -20	-4 to -13	-5 to -20	0 to -30
Dominated by	Liquid	Liquid	Liquid/SN mix	Varies	Mixed PCP	Snow	Liquid	Liquid	Liquid/Mix	None
LWC (gm^{-3})	0.1-0.4	0.1-0.4	0.1-0.4	0.1-0.3	0.1-0.2 (FZRA)	0-0.2	0.2-0.8	>1.0 / 0.1-0.4	0.1-0.4	0.0
MVD (mic)	20-250	20-250	20-250	20-2500	20-2500	10-20	10-25	12-20 / 30-40	15-25	N/A
Dmax (mic) Liquid	200-500	200-500	200-500	>500	>500	20-30	15-30	15-25 / 35-60	20-30	N/A
Depth (kft)	1-5	1-5	1-5	0.2-1.0	0.3-1.5 (FZRA)	3-40	1-3	2-6 / 1-5	1-5	N/A
Length (nm)	10-200	10-200	10-200	10-100	5-50	20-100+	20-200	5-25 / 10-100	20-500	5-100+
Width (nm)	10-200	10-200	10-200	50-250	50-250	20-100+	20-200	5-50 / 10-100	20-500	5-100+
Duration (h)	2-10+	2-10+	2-10+	2-24+	2-24+	2-24+	2-24+	0.5-3 / 2-24+	4-24+	2-24+
Sfc Wx Type	FZDZ	DZ/-SN/None	FZDZ/-SN	FZRA, PL, RA	FZRA, PL, RA	SN, RA	None/-SN	SHRA / Varies	None	None

Bernstein et al.

Icing

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Priority	1	2	3	4	5	6	7	8	9	10
% flight hr	15	10-15	10	15	5	5	10-15	5-10	5-10	5
Time (hr)	18	12-18	12	18	6	9	12-18	6-12	6-12	9
Frequency (1-10)	5	5	4	3	2	9	6	3/1	9	10
Sampling Diff. (1-10)	5	5	6	8 (Z vs MEA)	9 (narrow)	1	3 (Z vs MEA)	7 (small) / 9 (rare)	2	1
Tmin range (°C)	-5 to -13	-5 to -13	-5 to -13 / -20	-2 to -10	-2 to -12	-30	-5 to -20	-4 to -13	-5 to -20	0 to -30
Dominated by	Liquid	Liquid	Liquid/SN mix	Varies	Mixed PCP	Snow	Liquid	Liquid	Liquid/Mix	None
LWC (gm^{-3})	0.1-0.4	0.1-0.4	0.1-0.4	0.1-0.3	0.1-0.2 (FZRA)	0-0.2	0.2-0.8	>1.0 / 0.1-0.4	0.1-0.4	0.0
MVD (mic)	20-250	20-250	20-250	20-2500	20-2500	10-20	10-25	12-20 / 30-40	15-25	N/A
Dmax (mic) Liquid	200-500	200-500	200-500	>500	>500	20-30	15-30	15-25 / 35-60	20-30	N/A
Depth (kft)	1-5	1-5	1-5	0.2-1.0	0.3-1.5 (FZRA)	3-40	1-3	2-6 / 1-5	1-5	N/A
Length (nm)	10-200	10-200	10-200	10-100	5-50	20-100+	20-200	5-25 / 10-100	20-500	5-100+
Width (nm)	10-200	10-200	10-200	50-250	50-250	20-100+	20-200	5-50 / 10-100	20-500	5-100+
Duration (h)	2-10+	2-10+	2-10+	2-24+	2-24+	2-24+	2-24+	0.5-3 / 2-24+	4-24+	2-24+
Sfc Wx Type	FZDZ	DZ/-SN/None	FZDZ/-SN	FZRA, PL, RA	FZRA, PL, RA	SN, RA	None/-SN	SHRA / Varies	None	None

Bernstein et al.

SENS4ICE

2019-2023

SENS4ICE:
- development, test, validation, and maturation of SLD detection principles.
- **Collect SLD measurement in flight test**

Conditions flight by flight (EU)

Flightnum	ID	SM DP POS	DZ	RA	SM DP Icing	FZDZ	FZRA	MIXED	Glac	Clear	Unknown	All
as230008	1	0,05 %	0,00 %	0,00 %	0,95 %	0,00 %	0,00 %	0,27 %	0,27 %	2,39 %	0,00 %	3,92 %
as230009	2	0,09 %	0,00 %	0,00 %	2,98 %	0,00 %	0,00 %	2,75 %	0,28 %	2,63 %	0,00 %	8,73 %
as230010	3	0,03 %	0,03 %	0,03 %	0,27 %	0,00 %	0,00 %	0,36 %	0,01 %	2,31 %	0,07 %	3,11 %
as230011	4	0,04 %	0,04 %	0,02 %	0,14 %	0,00 %	0,00 %	0,66 %	0,07 %	2,23 %	0,05 %	3,25 %
as230014	5	0,14 %	0,46 %	0,03 %	0,53 %	0,07 %	0,00 %	2,50 %	0,18 %	1,76 %	0,02 %	5,69 %
as230015	6	0,04 %	0,00 %	0,00 %	4,18 %	0,01 %	0,00 %	0,10 %	0,00 %	3,42 %	0,00 %	7,75 %
as230016	7	0,01 %	0,00 %	0,00 %	0,29 %	0,00 %	0,00 %	0,16 %	0,66 %	5,27 %	0,02 %	6,41 %
as230017	8	0,41 %	0,23 %	0,12 %	2,15 %	0,00 %	0,00 %	1,05 %	0,05 %	3,01 %	0,03 %	7,06 %
as230018	9	0,21 %	0,84 %	0,13 %	1,45 %	0,65 %	0,00 %	2,91 %	0,44 %	3,84 %	0,32 %	10,79 %
as230019	10	0,16 %	1,50 %	0,22 %	1,38 %	0,25 %	0,00 %	3,60 %	1,68 %	2,94 %	0,25 %	12,00 %
as230020	11	0,23 %	0,21 %	0,00 %	0,88 %	0,00 %	0,00 %	0,07 %	0,43 %	4,08 %	0,02 %	5,93 %
as230021	12	0,30 %	0,29 %	0,07 %	0,86 %	0,19 %	0,00 %	2,59 %	2,04 %	1,82 %	0,14 %	8,31 %
as230022	13	0,14 %	0,26 %	0,11 %	0,43 %	0,03 %	0,00 %	3,38 %	1,45 %	2,26 %	0,15 %	8,21 %
as230023	14	0,03 %	0,37 %	0,22 %	0,50 %	0,10 %	0,00 %	2,14 %	0,68 %	4,73 %	0,07 %	8,84 %
All		**1,88 %**	**4,23 %**	**0,96 %**	**16,98 %**	**1,32 %**	**0,00 %**	**22,54 %**	**8,25 %**	**42,68 %**	**1,15 %**	**100,00 %**

Percentage of each condition across measurements data
(take off and landing are suppressed)
Some ferry phase are included.

Jaron et al. (SAE)

Icing

ICICLE

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Collect data in a wide variety of icing and non-icing conditions
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Priority	1	2	3	4	5	6	7	8	9	10
% flight hr	15	10-15	10	15	5	5	10-15	5-10	5-10	5
Time (hr)	18	12-18	12	18	6	9	12-18	6-12	6-12	9
Frequency (1-10)	5	5	4	3	2	9	6	3/1	9	10
Sampling Diff. (1-10)	5	5	6	8 (Z vs MEA)	9 (narrow)	1	3 (Z vs MEA)	7 (small) / 9 (rare)	2	1
Tmin range (°C)	-5 to -13	-5 to -13	-5 to -13 / -20	-2 to -10	-2 to -12	-30	-5 to -20	-4 to -13	-5 to -20	0 to -30
Dominated by	Liquid	Liquid	Liquid/SN mix	Varies	Mixed PCP	Snow	Liquid	Liquid	Liquid/Mix	None
LWC (gm⁻³)	0.1-0.4	0.1-0.4	0.1-0.4	0.1-0.3	0.1-0.2 (FZRA)	0-0.2	0.2-0.8	>1.0 / 0.1-0.4	0.1-0.4	0.0
MVD (mic)	20-250	20-250	20-250	20-2500	20-2500	10-20	10-25	12-20 / 30-40	15-25	N/A
Dmax (mic) Liquid	200-500	200-500	200-500	>500	>500	20-30	15-30	15-25 / 35-60	20-30	N/A
Depth (kft)	1-5	1-5	1-5	0.2-1.0	0.3-1.5 (FZRA)	3-40	1-3	2-6 / 1-5	1-5	N/A
Length (nm)	10-200	10-200	10-200	10-100	5-50	20-100+	20-200	5-25 / 10-100	20-500	5-100+
Width (nm)	10-200	10-200	10-200	50-250	50-250	20-100+	20-200	5-50 / 10-100	20-500	5-100+
Duration (h)	2-10+	2-10+	2-10+	2-24+	2-24+	2-24+	2-24+	0.5-3 / 2-24+	4-24+	2-24+
Sfc Wx Type	FZDZ	DZ/-SN/None	FZDZ/-SN	FZRA, PL, RA	FZRA, PL, RA	SN, RA	None/-SN	SHRA / Varies	None	None

Bernstein et al.

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as230010	3	0,03 %	0,03 %	0,03 %	0,27 %	0,00 %	0,00 %	0,36 %	0,01 %	2,31 %	0,07 %	3,11 %
as230011	4	0,04 %	0,04 %	0,02 %	0,14 %	0,00 %	0,00 %	0,66 %	0,07 %	2,23 %	0,05 %	3,25 %
as230014	5	0,14 %	0,46 %	0,03 %	0,53 %	0,07 %	0,00 %	2,50 %	0,18 %	1,76 %	0,02 %	5,69 %
as230015	6	0,04 %	0,00 %	0,00 %	4,18 %	0,01 %	0,00 %	0,10 %	0,00 %	3,42 %	0,00 %	7,75 %
as230016	7	0,01 %	0,00 %	0,00 %	0,29 %	0,00 %	0,00 %	0,16 %	0,66 %	5,27 %	0,02 %	6,41 %
as230017	8	0,41 %	0,23 %	0,12 %	2,15 %	0,00 %	0,00 %	1,05 %	0,05 %	3,01 %	0,03 %	7,06 %
as230018	9	0,21 %	0,84 %	0,13 %	1,45 %	0,65 %	0,00 %	2,91 %	0,44 %	3,84 %	0,32 %	10,79 %
as230019	10	0,16 %	1,50 %	0,22 %	1,38 %	0,25 %	0,00 %	3,60 %	1,68 %	2,94 %	0,25 %	12,00 %
as230020	11	0,23 %	0,21 %	0,00 %	0,88 %	0,00 %	0,00 %	0,07 %	0,43 %	4,08 %	0,02 %	5,93 %
as230021	12	0,30 %	0,29 %	0,07 %	0,86 %	0,19 %	0,00 %	2,59 %	2,04 %	1,82 %	0,14 %	8,31 %
as230022	13	0,14 %	0,26 %	0,11 %	0,43 %	0,03 %	0,00 %	3,38 %	1,45 %	2,26 %	0,15 %	8,21 %
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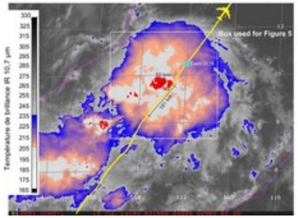
All		**1,88 %**	**4,23 %**	**0,96 %**	**16,98 %**	**1,32 %**	**0,00 %**	**22,54 %**	**8,25 %**	**42,68 %**	**1,15 %**	**100,00 %**

Percentage of each condition across measurements data
(take off and landing are suppressed)
Some ferry phase are included.

Jaron et al. (SAE)

HAIC – High Altitude Ice Crystals

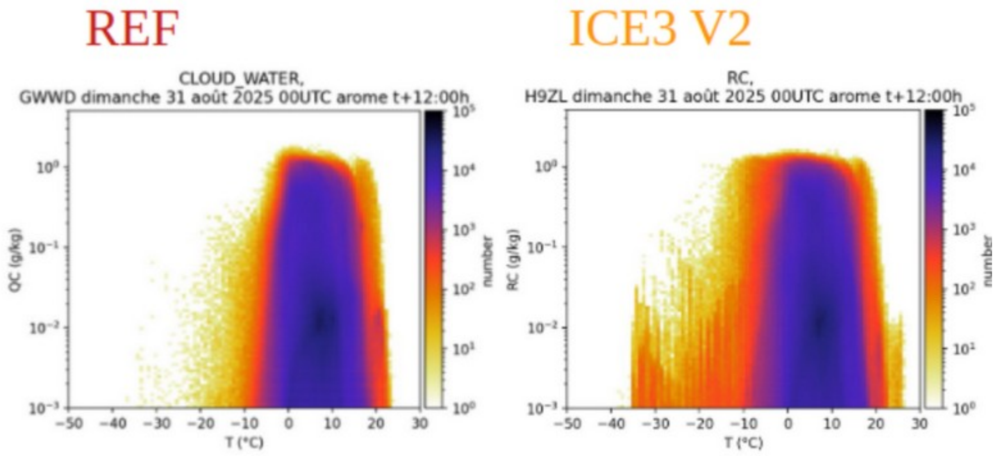
2014-2015



Icing

Calibration of AROME-ICE3 (1 moment) microphysics for supercooled liquid water representation → based on ICICLE

Rémi Dupont et al. 2024
Phd + Article, Clément Strauss

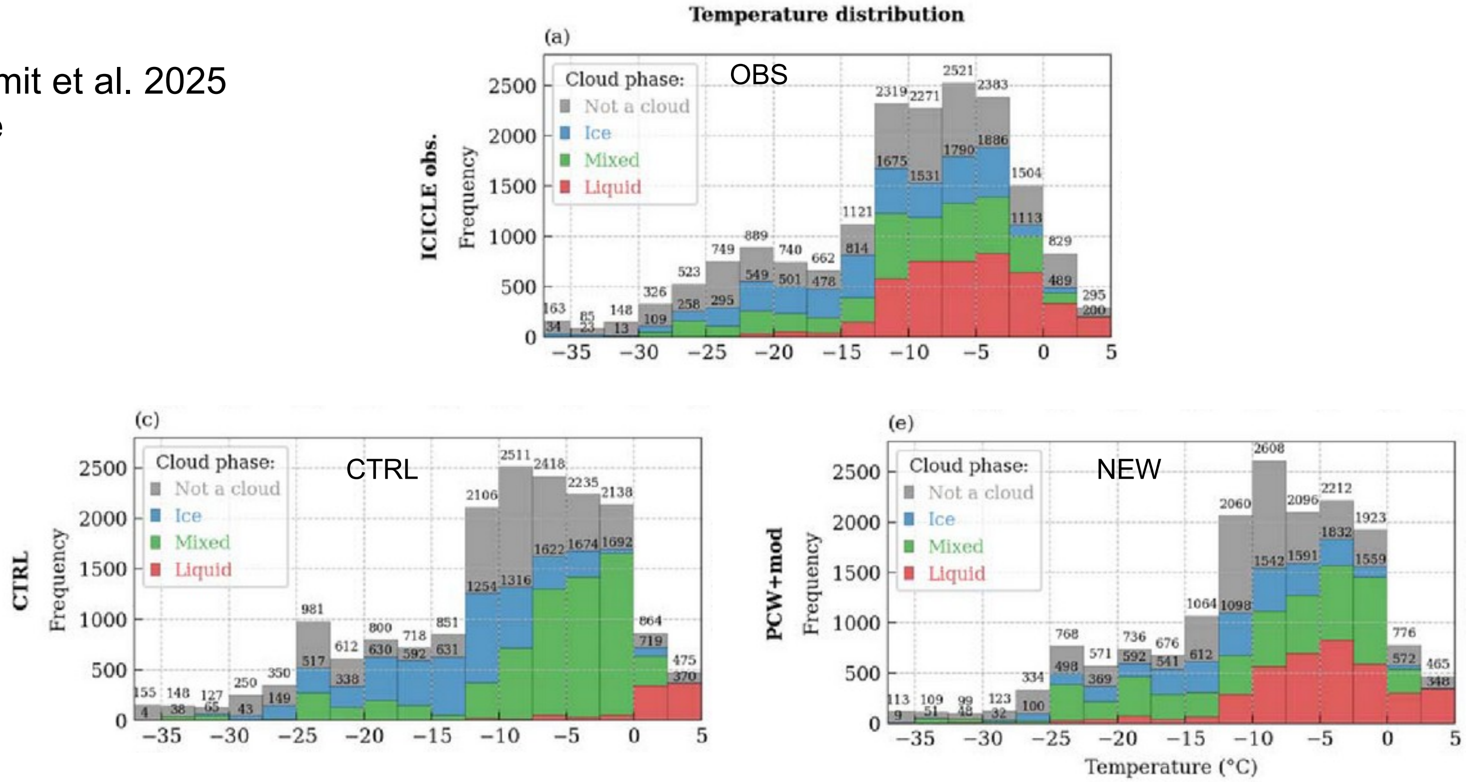


Rémi Dupont et al. 2024, Clément Strauss

Icing

Calibration of AROME-LIMA (2 moment) microphysics for supercooled liquid water representation → based on ICICLE

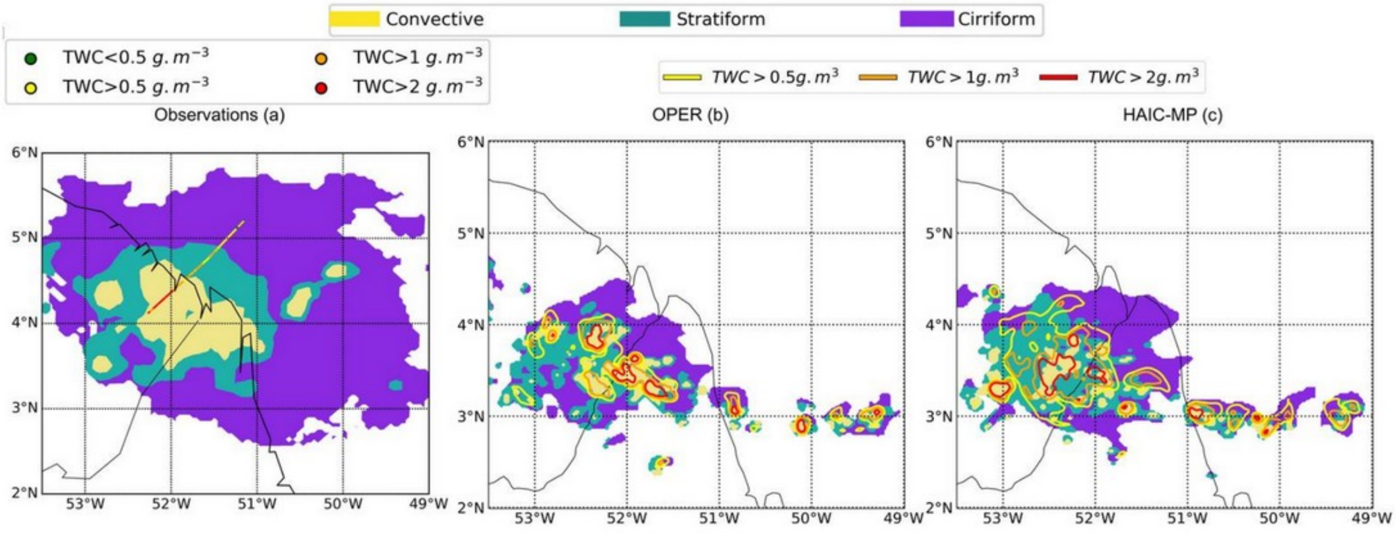
M. July-Wormit et al. 2025
Phd + Article



Icing

Calibration of ARPEGE / AROME-ICE3 microphysics for ice crystals → based on HAIC

J. Wurtz et al. 2023
Phd + Article



Icing

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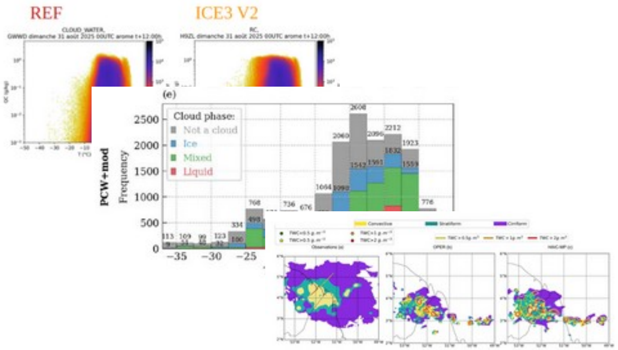

- Calibration of AROME-ICE3 microphysics (next cycle op 2028 after HPC change)

- Calibration of Next-Gen LIMA microphysics

Perspectives:

- Improve icing severity diagnostic AROME/ARPEGE
- → provide SLD diagnostic in AROME (and ARPEGE?)

- Upgrade of SIGMA (Nowcast) with MTG new products

- Improve IC representation in ARPEGE ?

Application in climate study

CERFACS in collaboration with Météo-France
→ operational Icing Index in ARPEGE-Climat

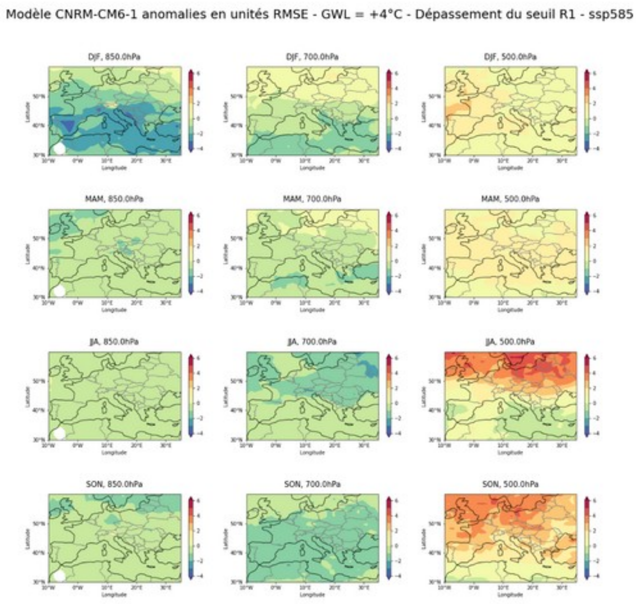

FIGURE 8 – Anomalies maximales en fonction de la saison et de l'altitude, pour GWL = +4°C et ssp585 ; modèle CNRM-CM6-1

Icing

Application in climate study

CERFACS in collaboration with Météo-France
→ operational Icing Index in ARPEGE-Climat

Modèle CNRM-CM6-1 anomalies en unités RMSE - GWL = +4°C - Dépassement du seuil R1 - ssp585

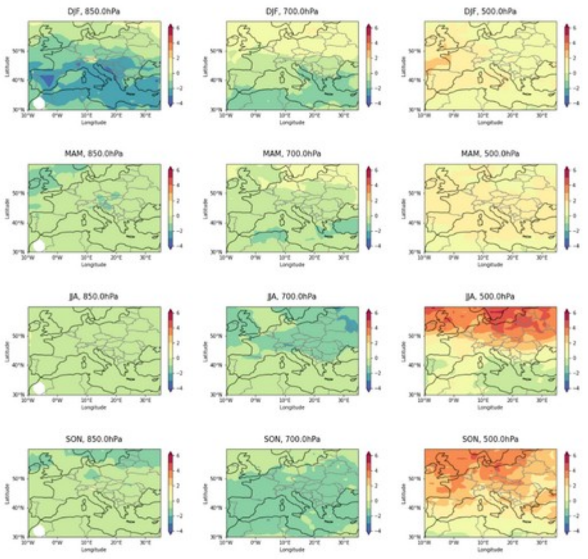

FIGURE 8 – Anomalies maximales en fonction de la saison et de l'altitude, pour GWL = +4°C et ssp585 ; modèle CNRM-CM6-1

In collaboration with AIRBUS (work in progress)

Climatology and future trends in SLD icing

→ Use of LIMA microphysics to calibrate & verify SLD diagnostics in reanalyses and climate models

ICECAP (submitted SESAR), SLUSH project (submitted Horizon, Clean Aviation - waiting)

Application in climate study

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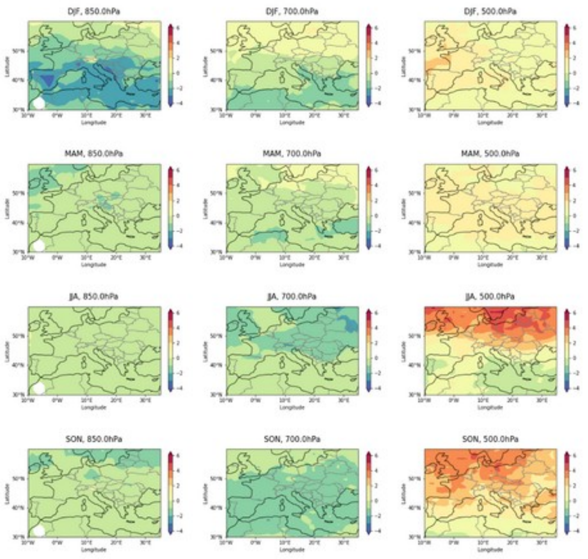
Modèle CNRM-CM6-1 anomalies en unités RMSE - GWL = +4°C - Dépassement du seuil R1 - ssp585



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ICECAP (submitted SESAR), SLUSH project (submitted Horizon, Clean Aviation)

EN-ICCA group (climate change for Aviation) – report on state-of-the-art for icing

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METEO FRANCE
À VOS CÔTÉS, DANS UN CLIMAT QUI CHANGE

Other research works of interest concerning aviation

- Low visibility events: research on the representation of fog in NWP model (e.g. A. Salomé, M. Fathalli, G. Thomas) based on SOFOG3D campaign (ANR)

- Temperature, Wind: MODE-S assimilation in NWP AROME (2024) and ARPEGE models (2026) (V. Pourret)

- VULCLIM : *Vulnérabilité des aéroports face au changement Climatique* (DGAC) in collaboration with Météo-France climate services department.

- AI Techniques:
  - Nowcast (e.g. visibility, satellite products)
  - Subgrid physical parametrization in ARP-GEM climate model (B. Balogh, D. Saint-Martin)
  - Diagnostics (e.g. CAT, Visibility)
  - NWP model emulators (AI-AROME, ARPEGE nudged)
  - Downscaling
  - Ensemble generation
  - Assimilation (Ariadna Perelló Achfari PhD)

- Climate models at kilometric scale:
  - Limited Area Climate models: CNRM-AROME (convection - Caillaud et al. 2021)
  - Fast climate models / high resolution at global scale : ARP-GEM2 (D. Saint-Martin, O. Geoffroy)

Thank you for your attention

pierre.crispel@meteo.fr