# Toward an ARPEGE-based aviation turbulence combined diagnosis

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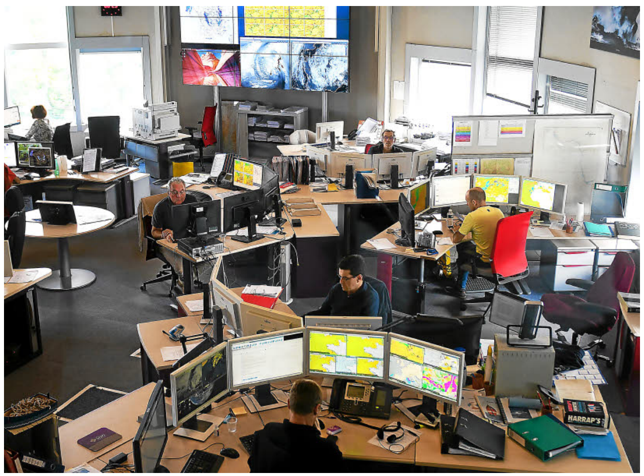
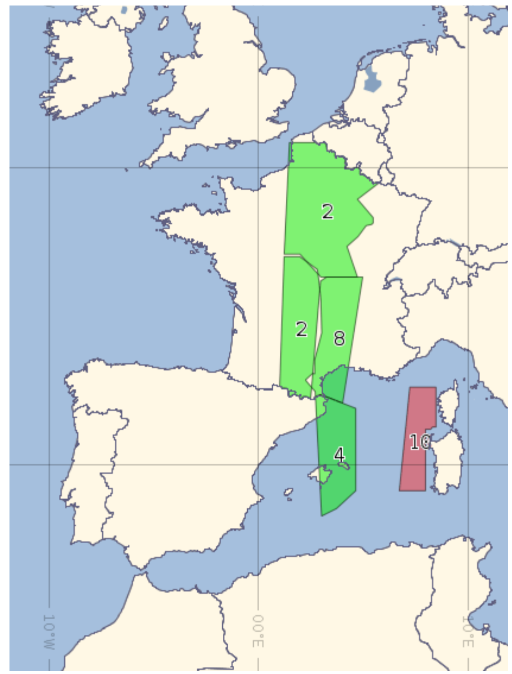
# Aviation turbulence forecasting at Météo-France

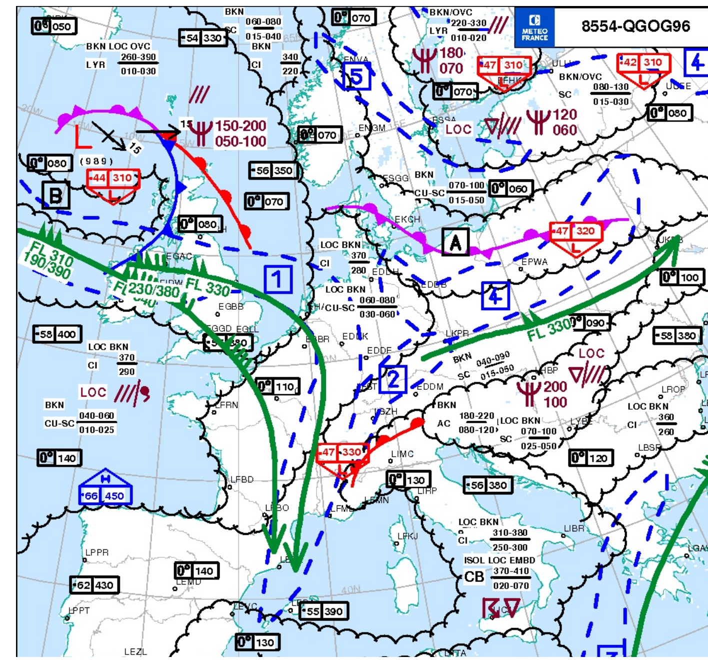
Interactions with French en-route **air traffic control**

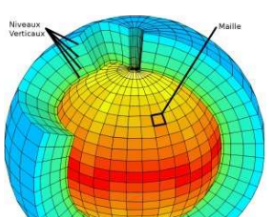


**SIGMETs** for French territories including French Antilles, Polynesia,..




French and European **SIGWX charts** (3H freq)



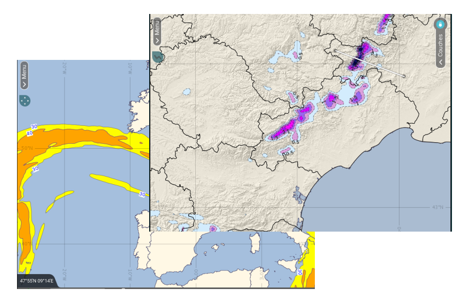




ARPEGE
Météo-France

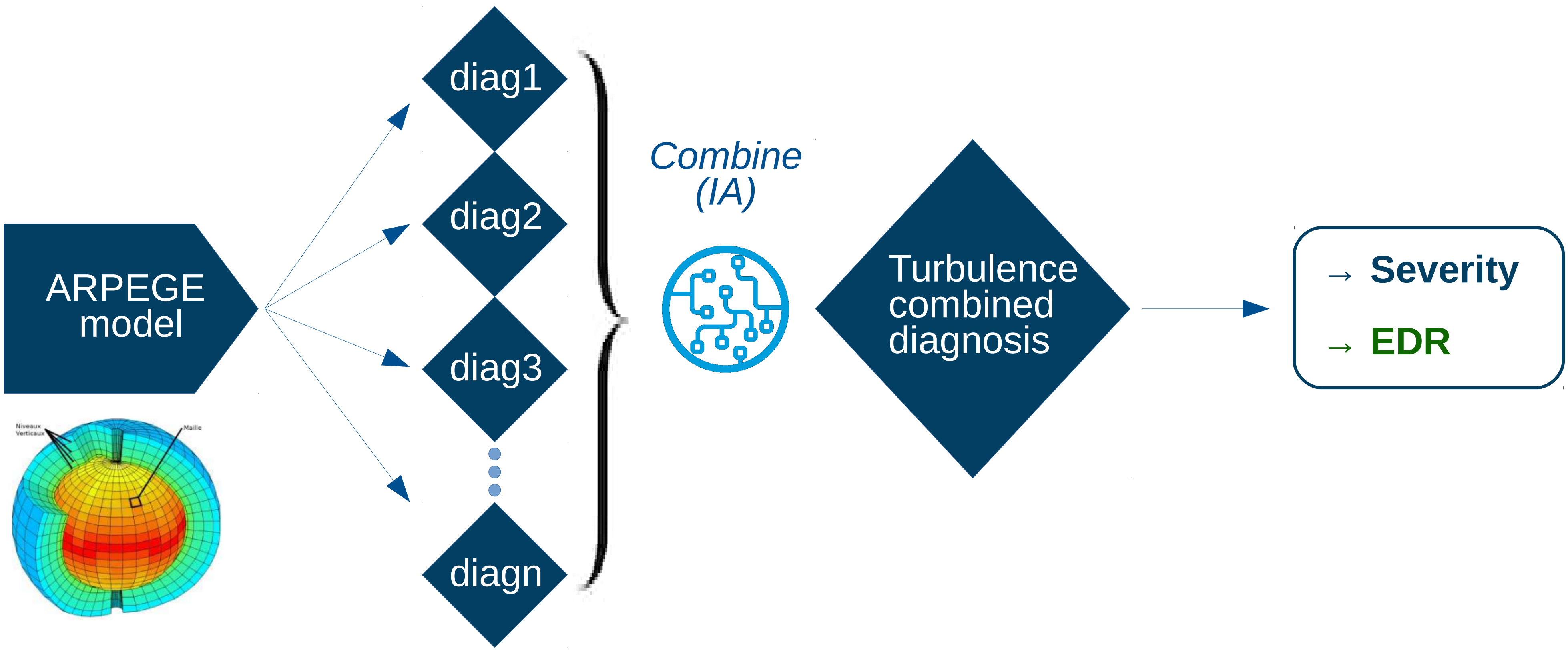
T,Wind, etc...

Individual aviation turbulence diagnoses

Severity maps, contours



# Goal: Computation of diagnoses within the ARPEGE model + combination.




→ Catch several sources of turbulence

→ Final result is EDR = $\varepsilon^{1/3}$

- **ε = Energy Dissipation Rate of eddies.**

# Météo-France & NCAR collaboration

- **Use GTG methodology on ARPEGE outputs**

- **Explore other combination & selection methodologies**

**Model**: ARPEGE 0.25° grid with native vertical levels.

**Observations**: 1 year PIREPs and EDR (2017) **above USA**.

**Preliminary results**

**CAT** at upper levels (FL > 200) in US & Europe.

# Météo-France & NCAR collaboration

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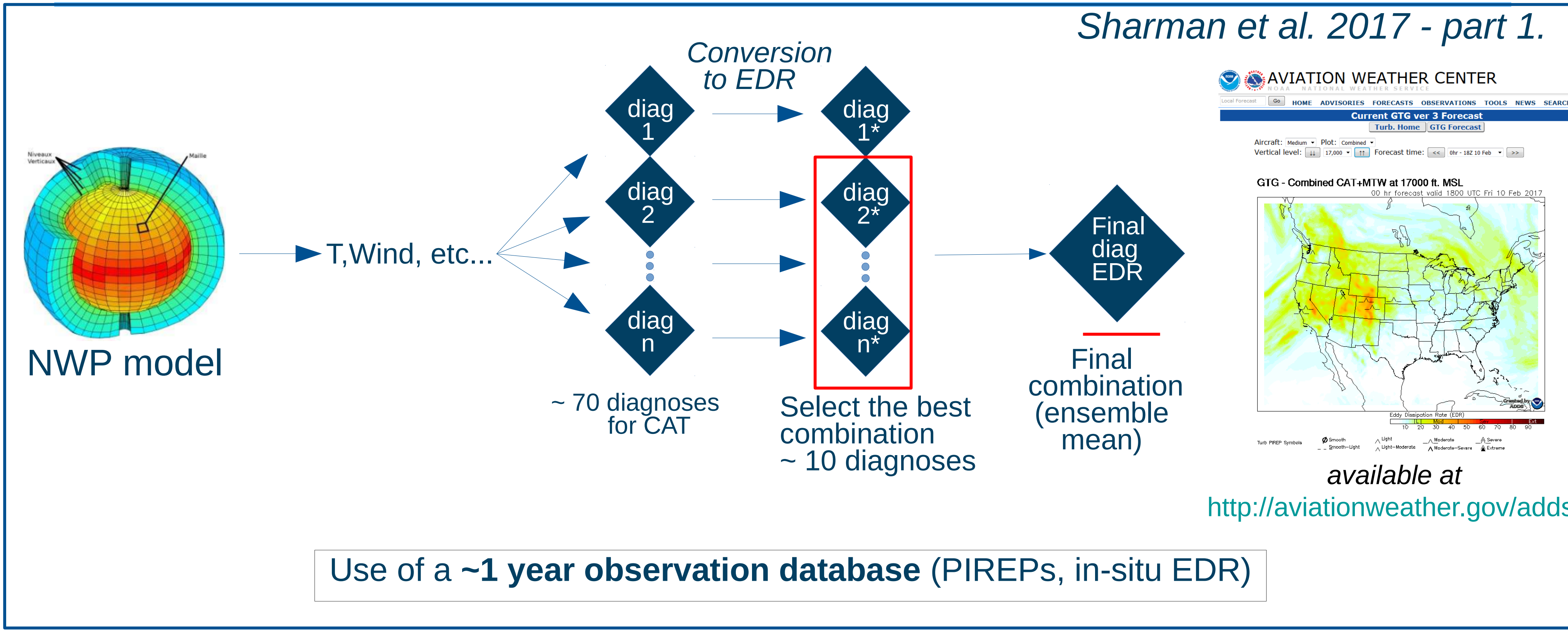
# Combining aviation turbulence diagnoses
# The GTG methodology – NCAR / RAL

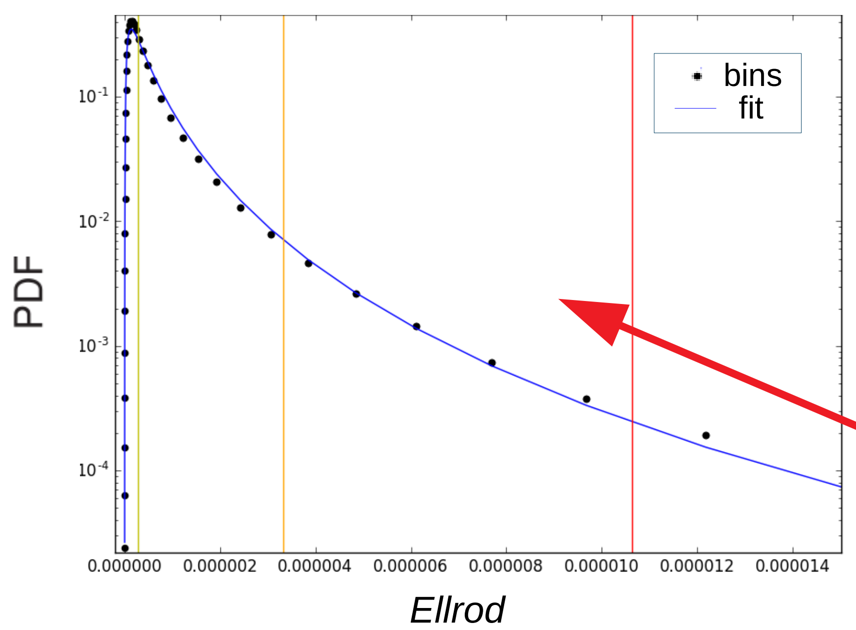



- Same process for different sources: CAT, MTW, CIT, LLT, at low mid & upper levels
- Final combinations directly computed in operational mode
- Aims to be used by Washington and London WAFC for SIGWx charts production *(Kim et al. 2018)*

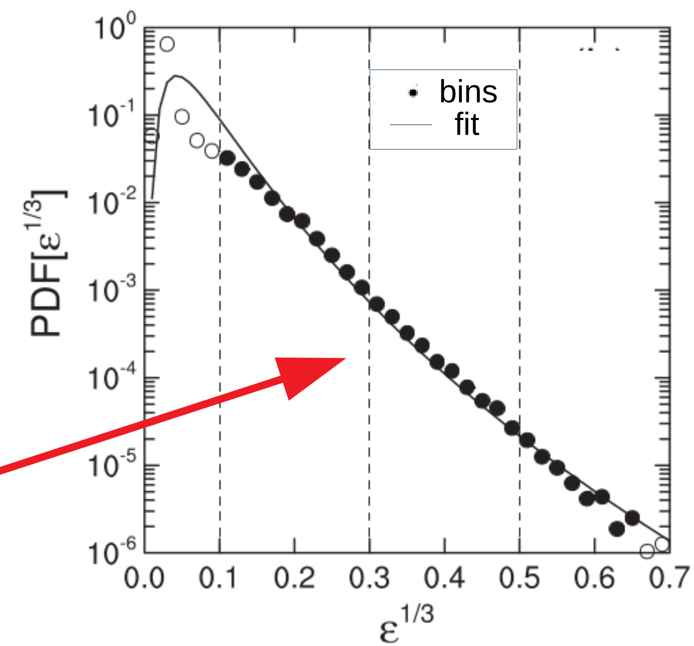
# 1. GTG pre-processing step: Conversion of individual diagnoses to EDR

Ex: **Ellrod turbulence diag** climatology – year 2017
*ARPEGE - CONUS 0.25°*

**In-situ EDR** climatology
*Sharman et al. 2014*




Lognormal distributions

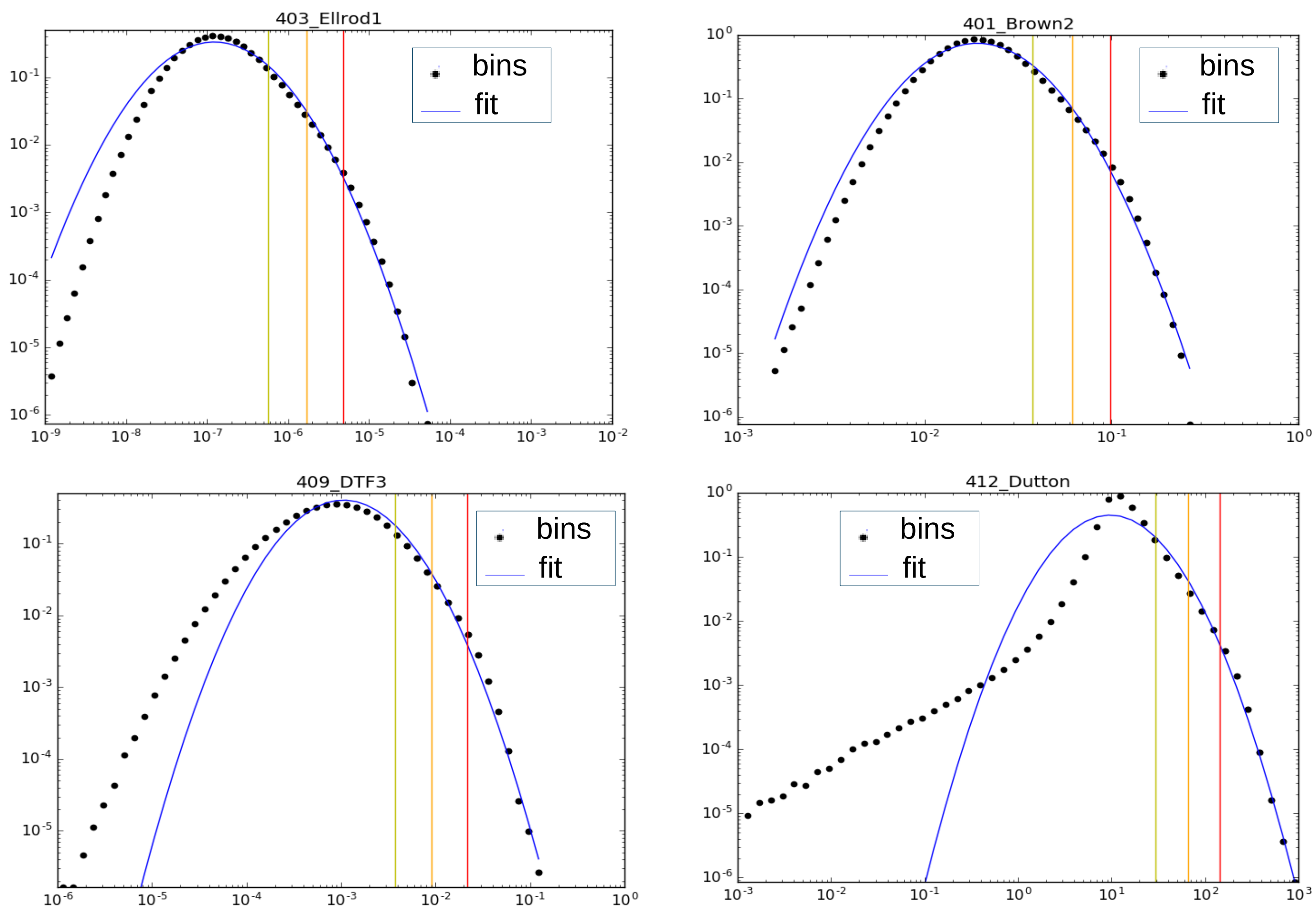



→ Conversion to EDR by using a *lognormal to lognormal* transformation.

$$D_{\mathrm{Ellrod}\rightarrow\mathrm{edr}} = e^{a} D^{b}_{\mathrm{Ellrod}}$$

# 1. GTG pre-processing step: Conversion of individual diags to EDR

*Distribution fitting for the **other diagnoses**: Log-log vizualisation*



# 2. GTG feature selection & combination step

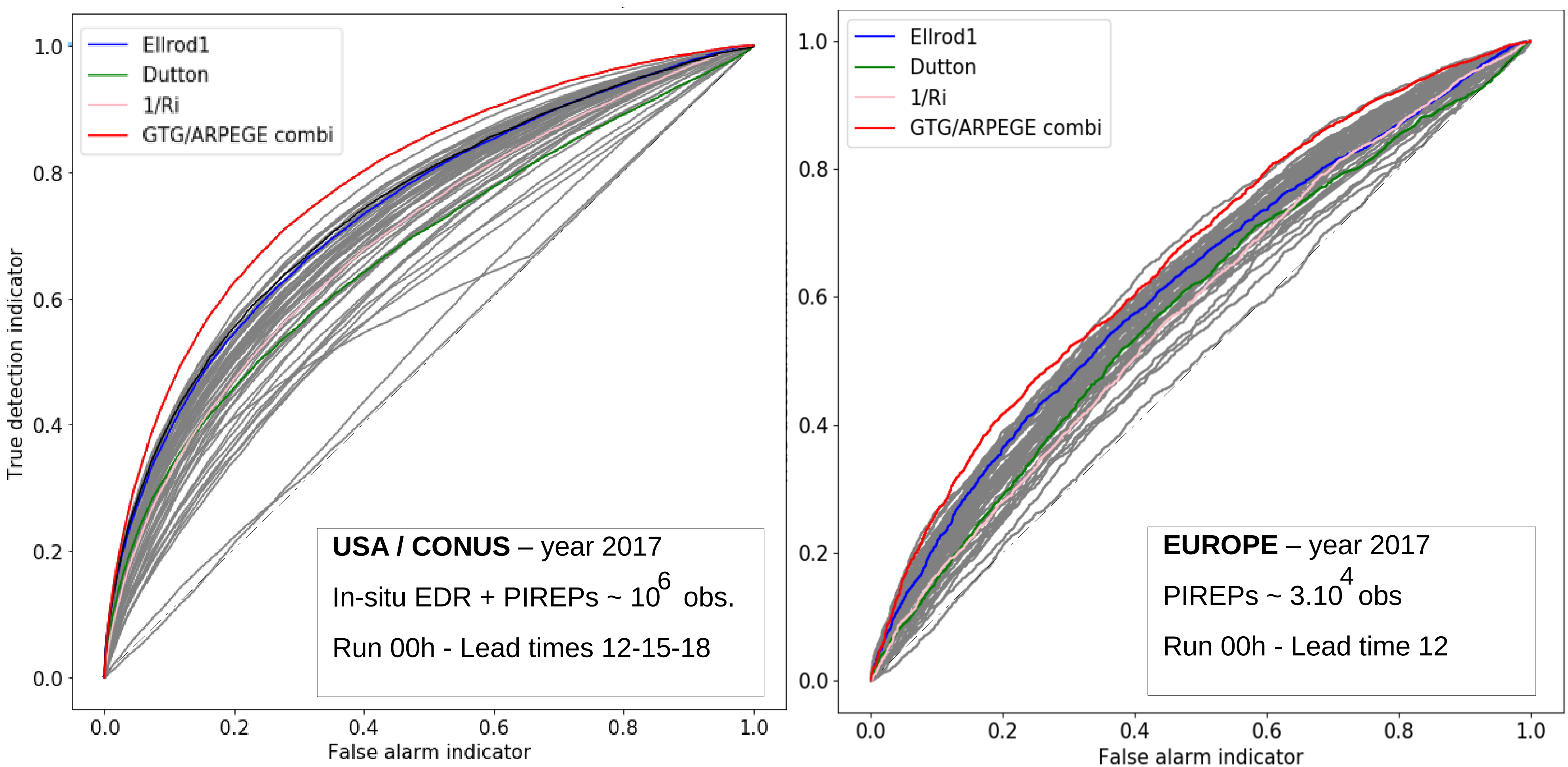
- **Selection**: iterative forward selection.
- **Combination**: ensemble mean of **EDR-scaled diagnoses**.
- **Metric**: Area Under ROC Curve score (AUC) for Moderate Or Greater turbulence events (MOG) i.e. EDR> 0.22 $m^{2/3} s^{-1}$.

<u>Selection</u>

Selected individual diags (previously scaled to EDR).

| ARPEGE 0.25 Combination | Sharman et al. 2017 (GFS 0.25) | Kim et al 2018 (WAFC) |
|---|---|---|
| NCSU2/Ri | NCSU2/Ri | NCSU2/Ri |
| Fth/Ri | Fth/Ri | Fth/Ri |
| DEFSQ | DEFSQ | DEFSQ |
| EDRLUN | EDRLUN | EDRLUN |
| wsq | wsq/Ri | wsq/Ri |
| RTKE | EDRLL | EDRLL |
| 1/RiTW | UBF/Ri | RTKE |
| \|DIV\|/Ri | TEMPG/Ri | UBF/Ri |
| -NVA | Ellrod3 | TEMPG/Ri |
| | iawind | Ellrod3 |
| | PVGRAD | iawind ... |

# 3. Scores – MOG turbulence events – ROC curves




Applying GTG methodology with ARPEGE0.25 **calibrated with US observations** shows that:

**- performance is improved** for USA compared to individual diagnoses

- results remain consistent above Europe.

# Météo-France & NCAR collaboration

- Use GTG methodology on ARPEGE 0.25° outputs

- Explore other combination & selection methodologies

# Machine learning (ML) algorithms

- **Previous works:** e.g. J.K. Williams et al.
  - Show good results for several ML methods (eg. Random Forests)
- **To handle operational constraints**
  - Restriction of diagnoses number is needed ~ 10 diags
  - Calibration should be “easy” to perform
  - How to convert Machine Learning outputs to EDR ?

➡ **Test of two ML methods which provide selection**

— Logistic regression LASSO

— Random Forests with predictor selection

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➡ **Test of two ML methods which provide selection**
- Logistic regression LASSO
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# 1. Logistic LASSO regression

- Logistic LASSO Regression → L1 penalization on coefficients

$$\log\left(\frac{p}{1-p}\right) = \beta_0 + \sum_{j=1}^{m} \beta_j \bar{D}_j$$

*Normalized diagnoses* ~$\mathcal{N}(0,1)$

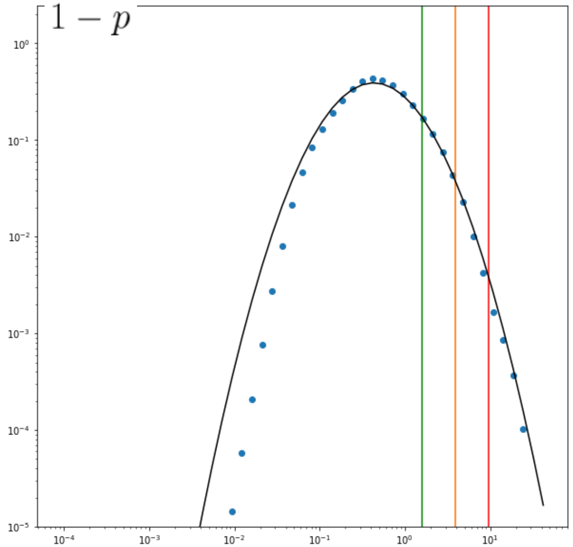
$p$ = probability of MOG event

**Property**: Maximization of **L1-penalized log likelihood** provides **variable selection ($\beta_j = 0$)**

- Conversion to EDR

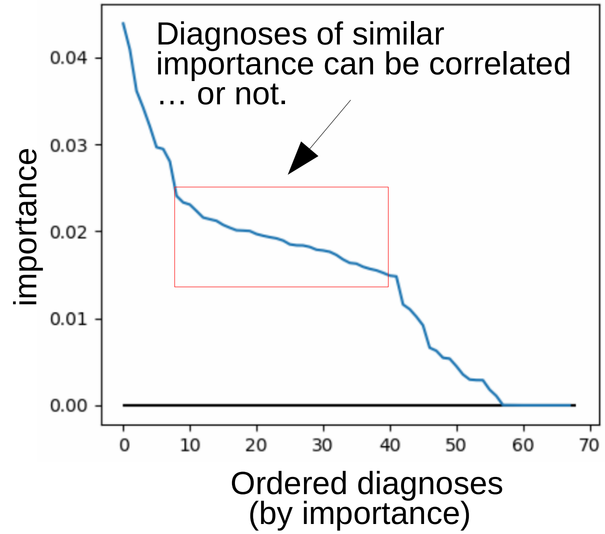
$$\frac{p}{1-p} \sim \log \mathcal{N}(\mu, \sigma)$$ → *convertible to EDR*

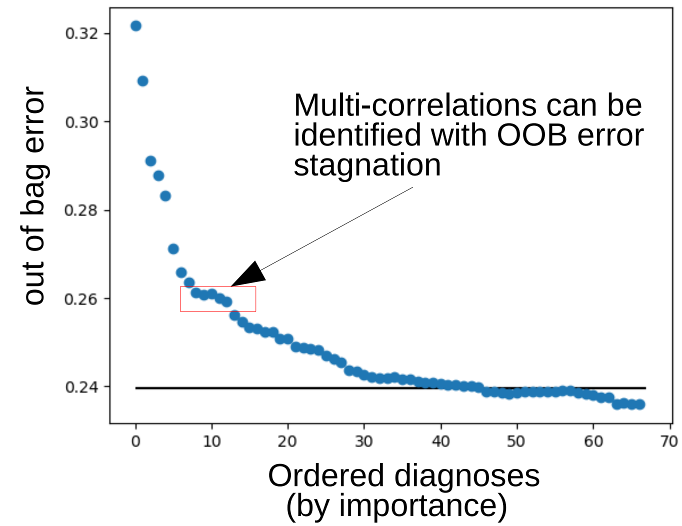
$\frac{p}{1-p}$ *distribution – year 2017*



# 2. Random Forests with selection

- Genuer et al. 2015 – Feature selection with Random Forests based on
  - **Diag importance** in the tree growing process
  - **Out of the bag error (OOB)**

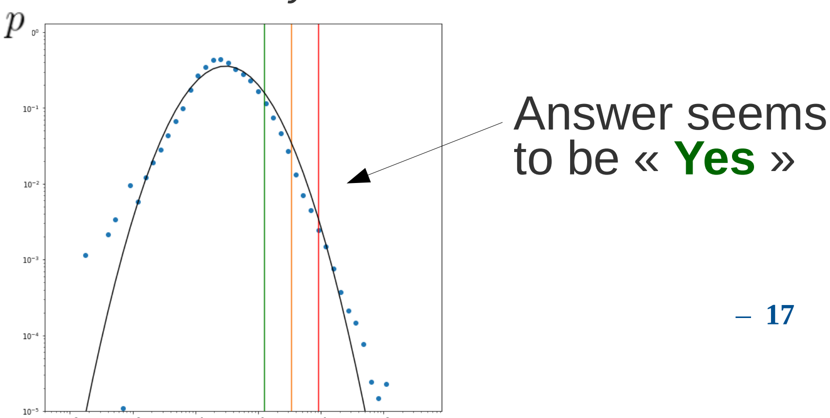



- Conversion to EDR

is $\frac{p}{1-p}$ fitting a lognormal distribution ?

$\frac{p}{1-p}$ *distribution – year 2017*



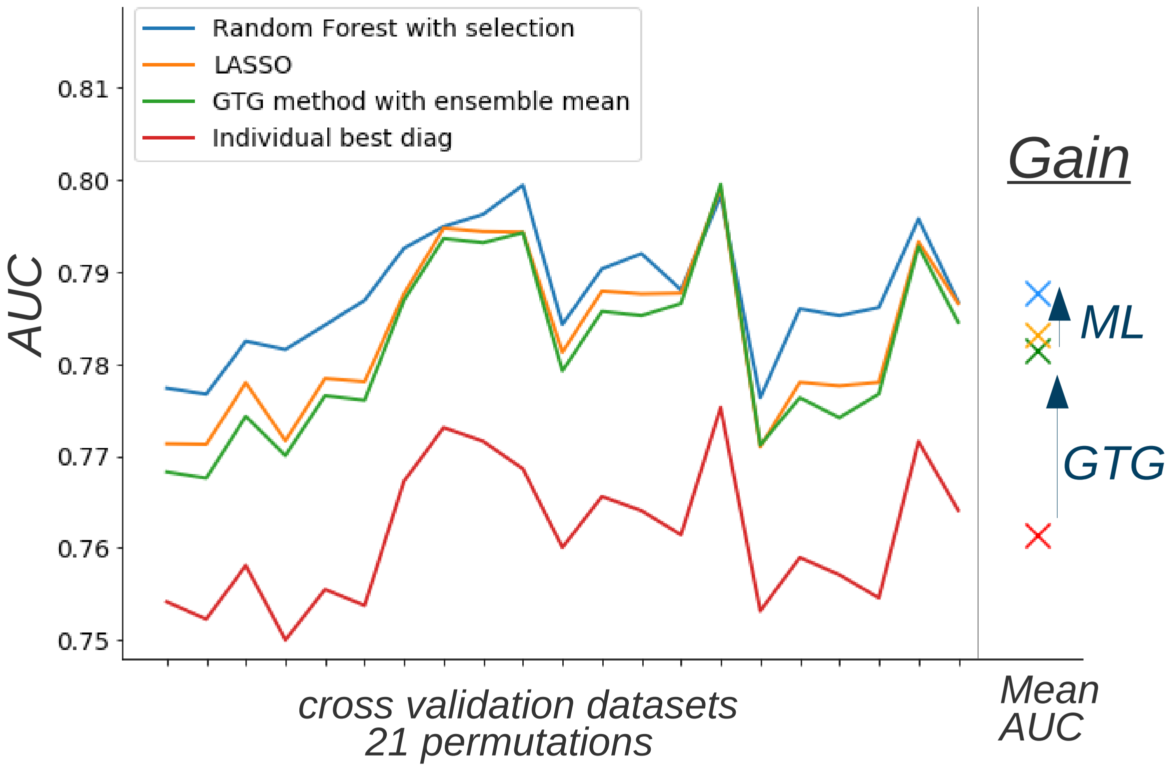
# Results

## Cross validation: feature selection

| GTG Fwd selection + Ensemble mean | LASSO regression | RF with selection |
|---|---|---|
| NCSU2/Ri 21 | NCSU2/Ri 21 | NCSU2/Ri 21 |
| Fth/Ri 21 | Fth/Ri 21 | RTKE 21 |
| RTKE 21 | RTKE 21 | DEFSQ/Ri 21 |
| 1/RiTW 21 | 1/RiTW 21 | RTKE/Ri 21 |
| DEFSQ 16 | EDRLL 21 | F3D/Ri 21 |
| EDRLL 16 | -NVA 21 | 1/RiTW 20 |
| Wsq 20 | EDR 21 | SPEED 20 |
| + others | Brown1 21 | F2D/Ri 20 |
| | SGSTKE/Ri 21 | \|DIV\|/Ri 17 |
| | LAZ 16 | Fth/Ri 17 |
| | + others | + others |

**Yellow: 3 common selections**
**Pink: 2 common selections**

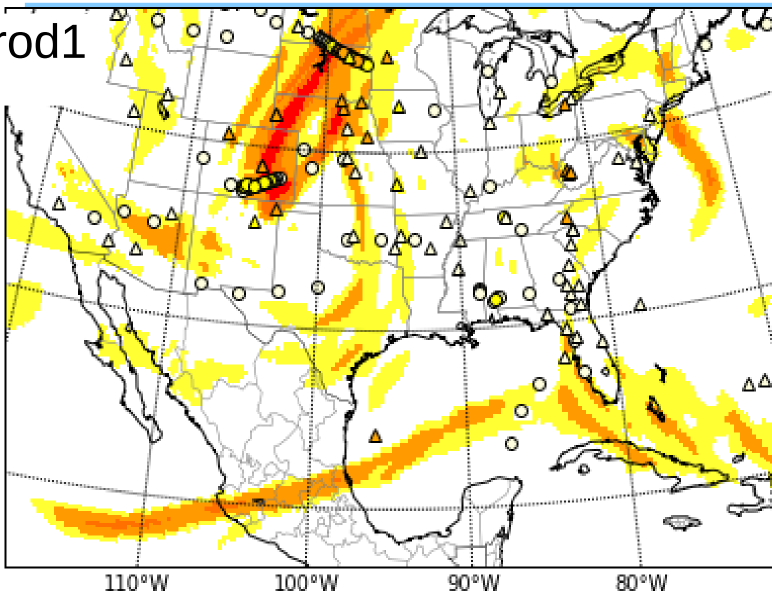
## Cross validation: AUC scores - USA



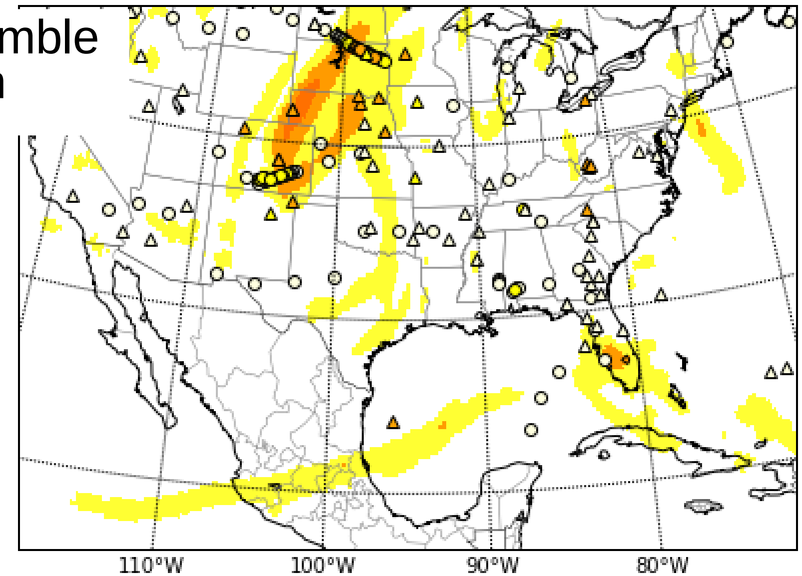
# Case-study

30th April 2017 – FL340 – Run 00UTC – Lead time 15UTC

Ellrod1




Ensemble mean

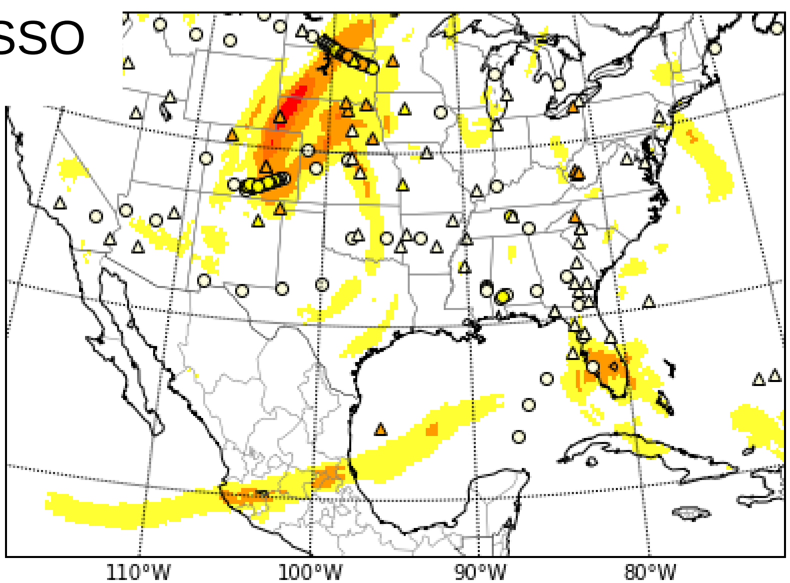



**Observations**

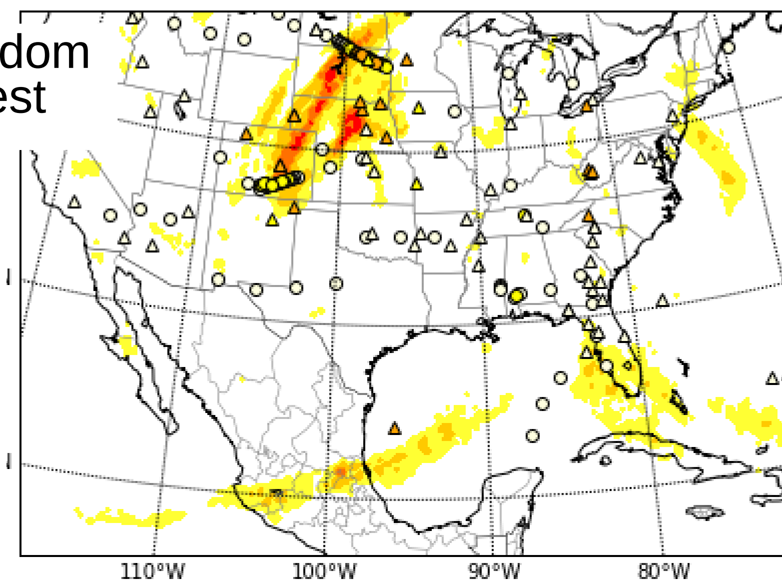
Time window +/- 30 min

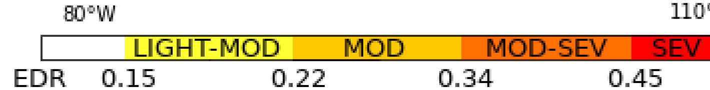
Levels +/- 20 FL

LASSO




Random Forest



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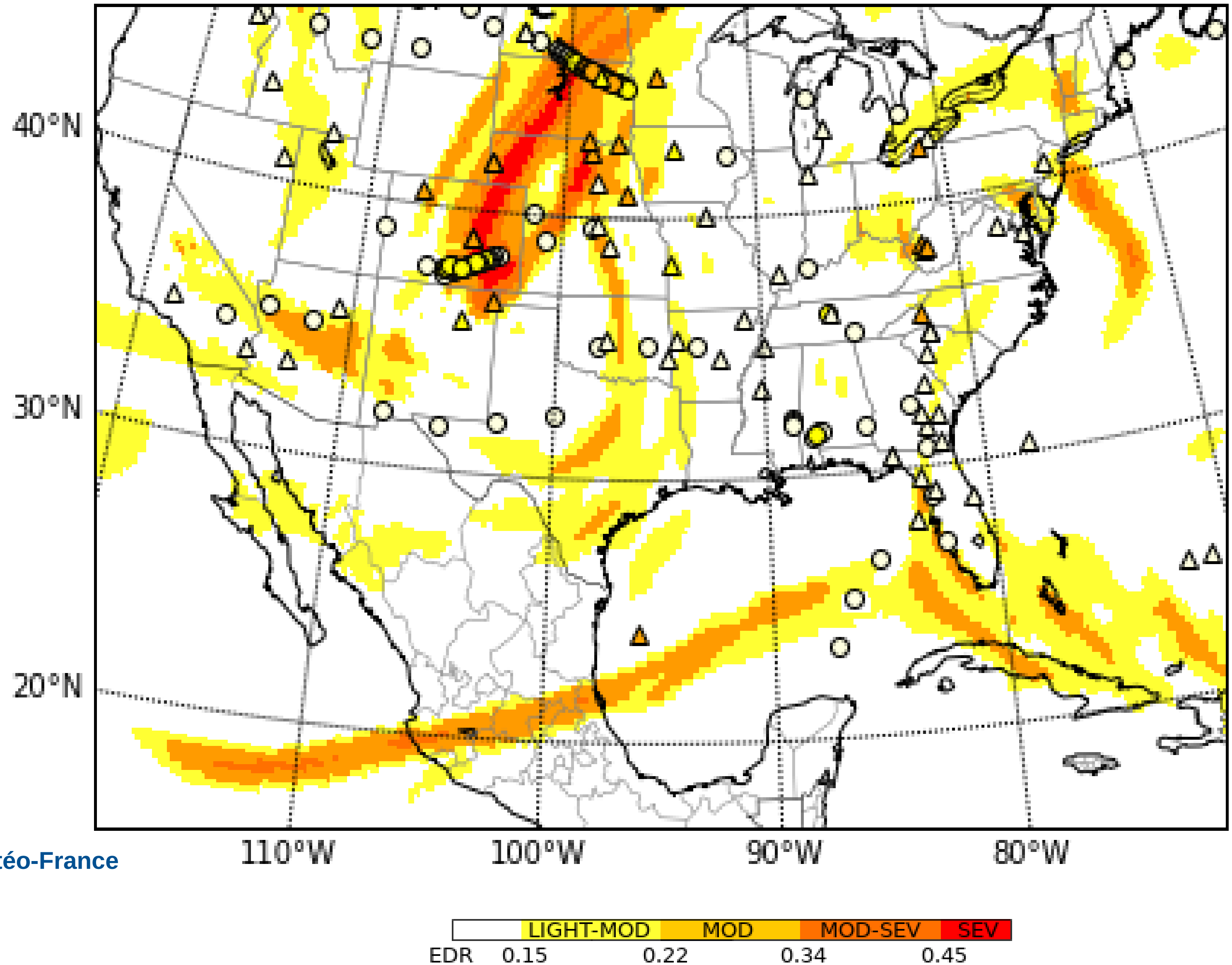


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+/- 30 min

Levels
+/- 20 FL

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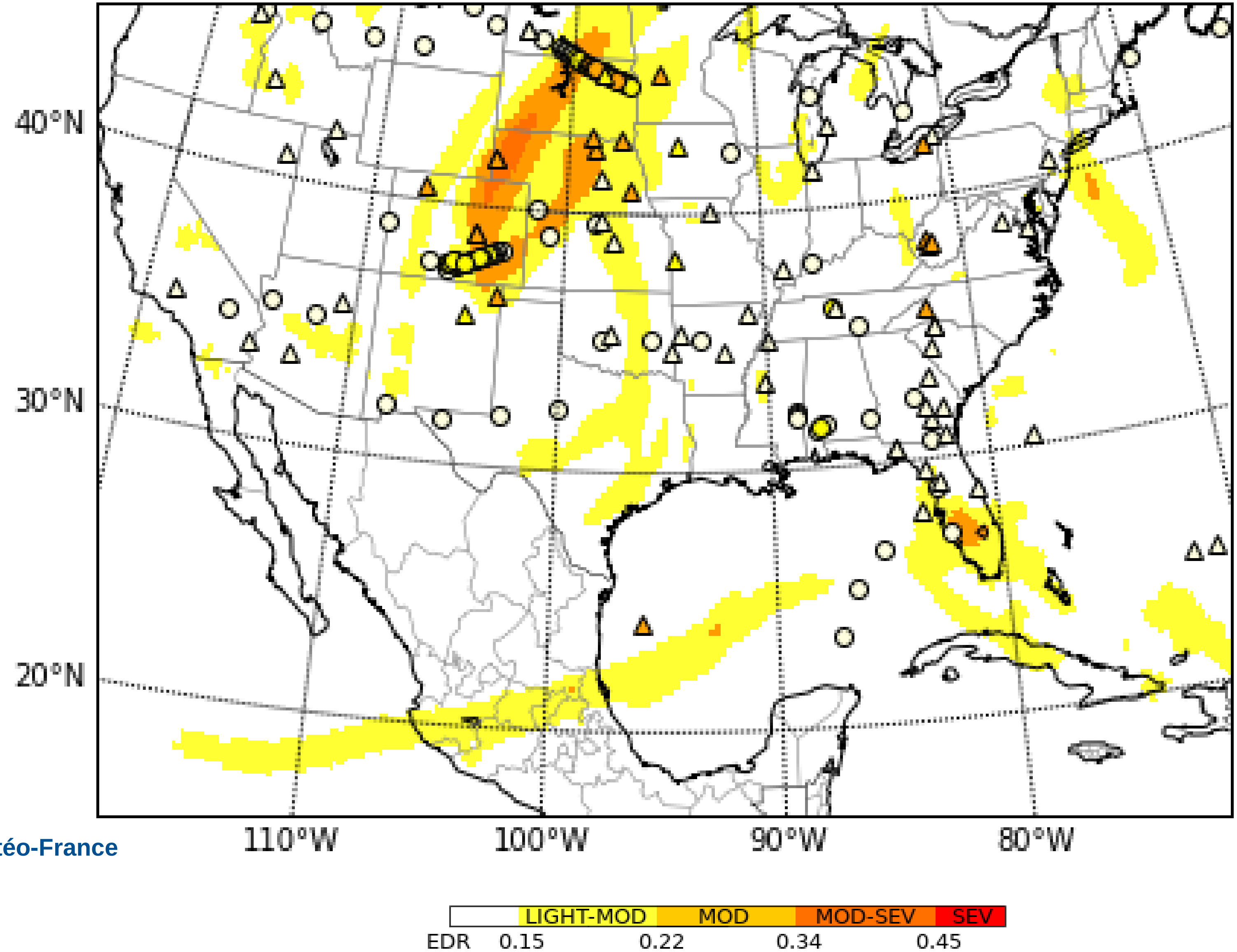
GTG - Ensemble mean




**Observations**

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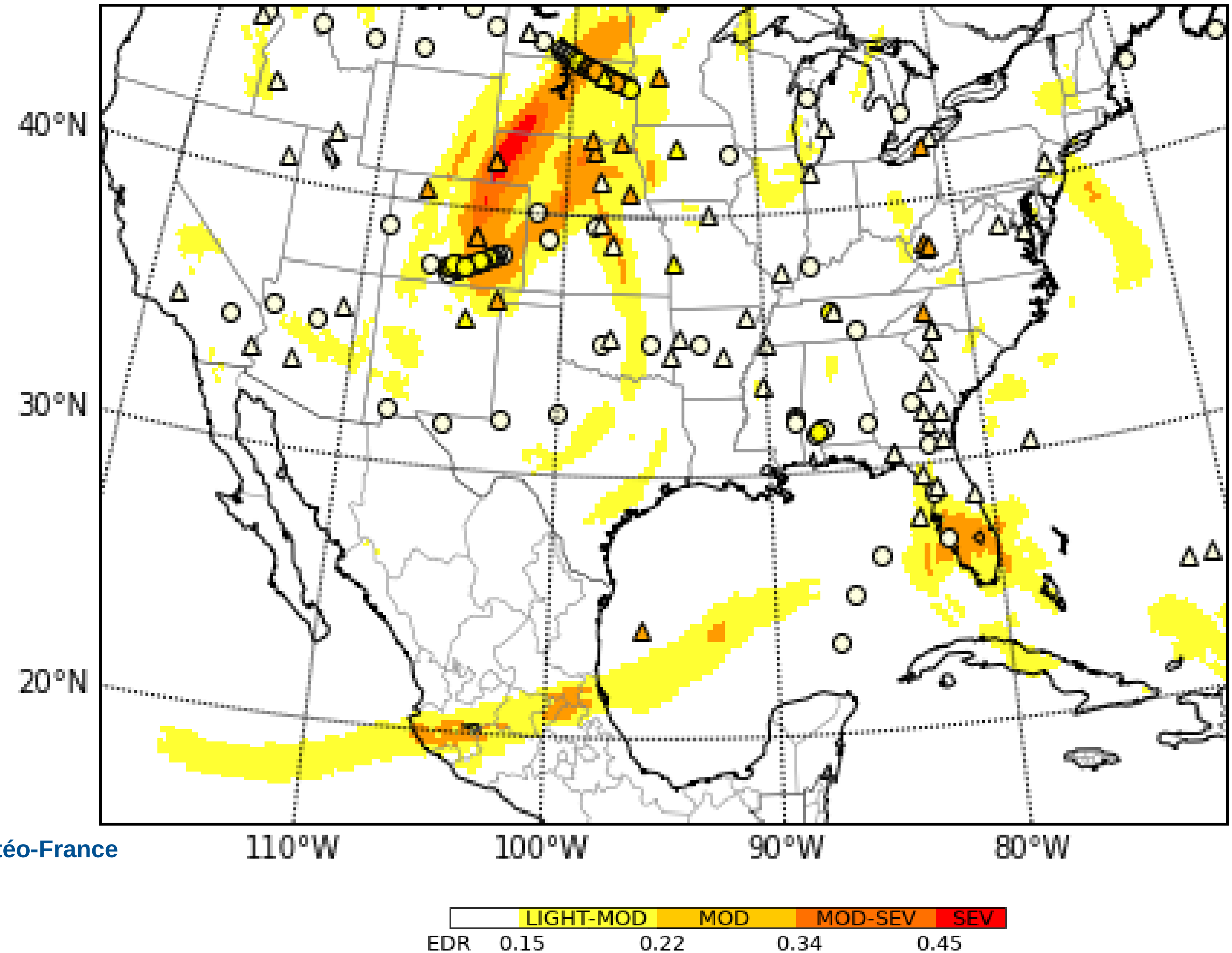
LASSO regression

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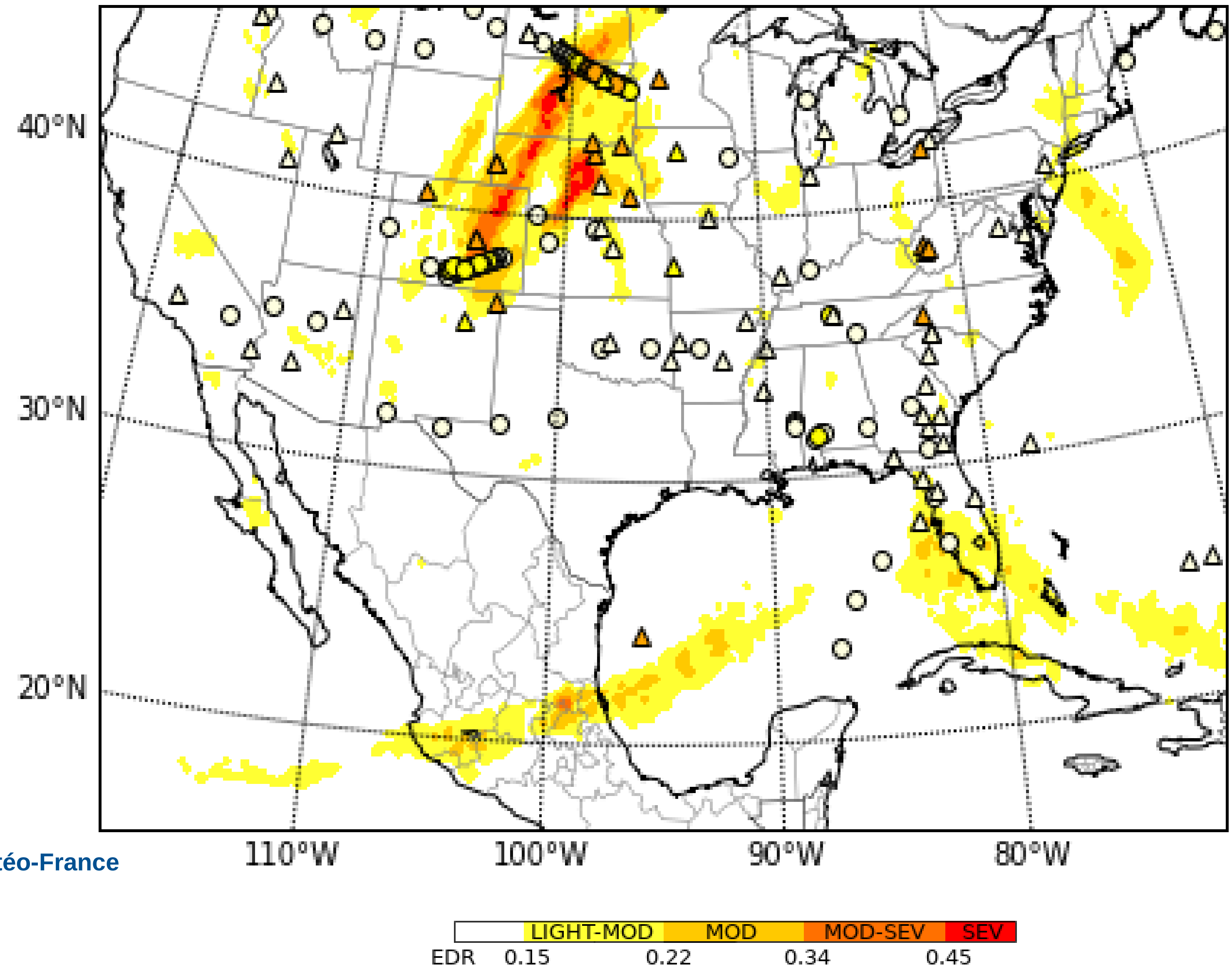


**Observations**

Time window
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# Conclusion

- GTG methodology applied with ARPEGE model:
  - Improvement compared to individual diagnoses
  - Diagnosis selection depends on NWP model (but common selected diagnoses appear)

- LASSO regression and Random Forests methods:
  - can be used to combine diagnoses while providing selection
  - have their output convertible to EDR
  - RF method improves AUC score ↔ more complex to implement

**Thank you. Questions ?**

# Météo-France

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