Probabilistic Wake Vortex Predictions using Time-Based Ensemble Weather Predictions

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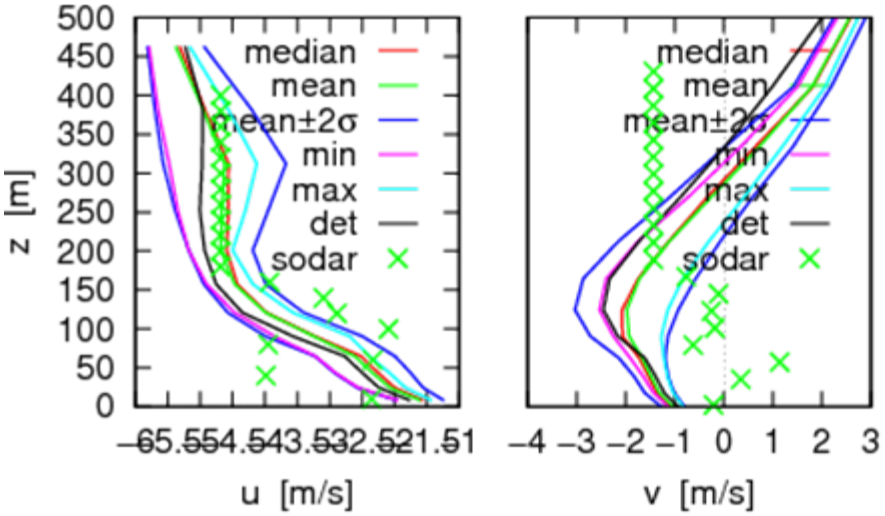
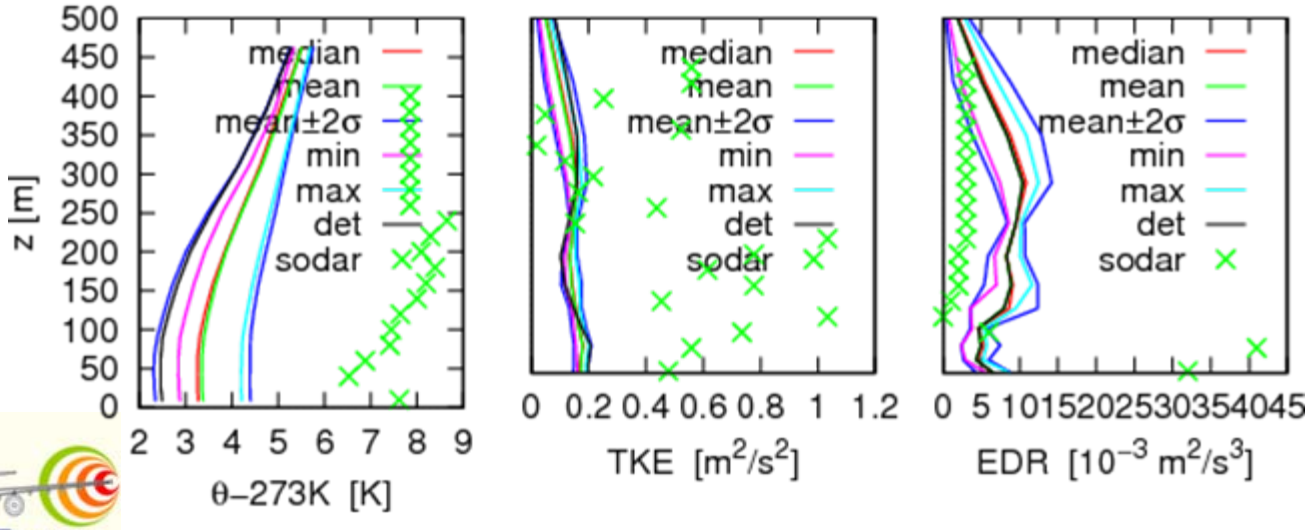
- processing of time-lagged ensemble predictions
- use of TLE averages for deterministic WV predictions
- use of TLE spread for probabilistic WV predictions
- skill scores for optimal use of TLE spread

processing of 6 members of TLE predictions



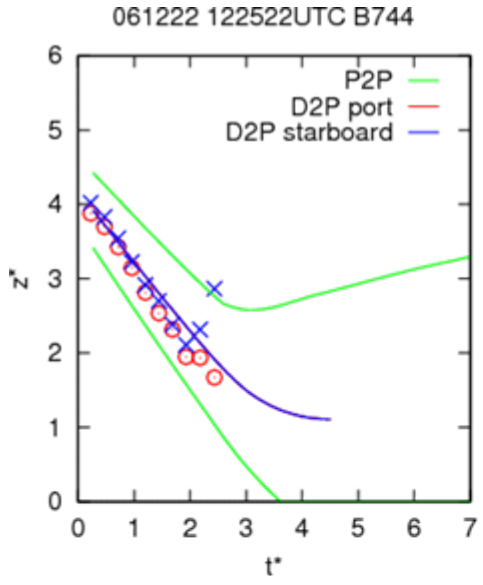
ensemble spread
only partially
encloses observations

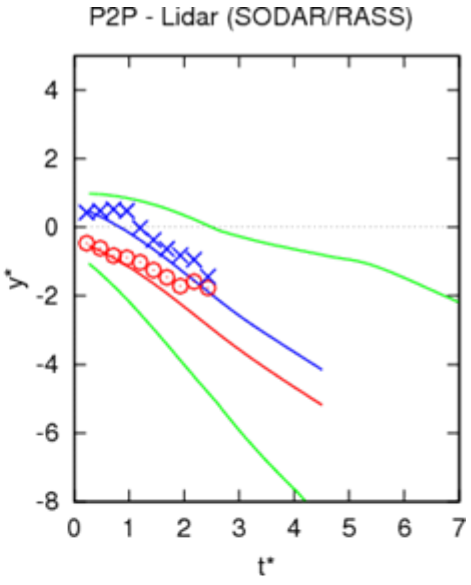


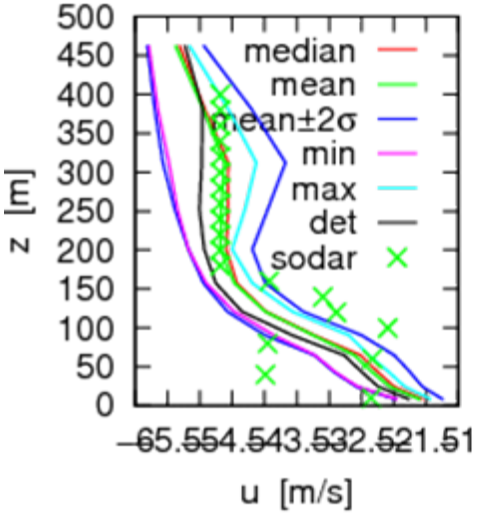
WakeNet3-Europe
A network on Aircraft Wake Turbulence

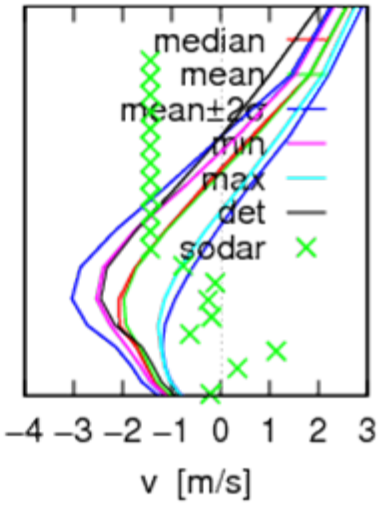
DLR

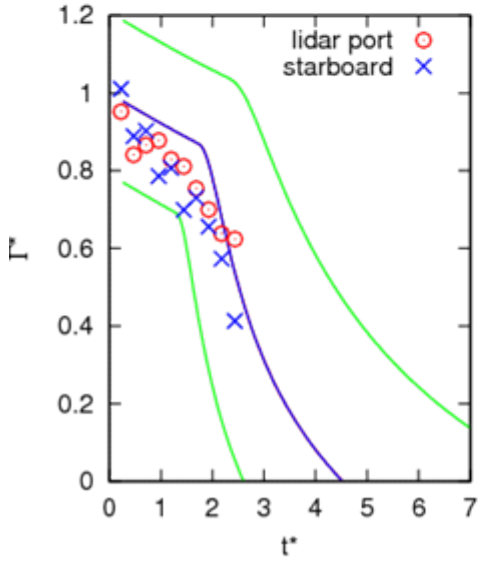
CREDOS EDDF-1, departures, 22.12.06 - nice example

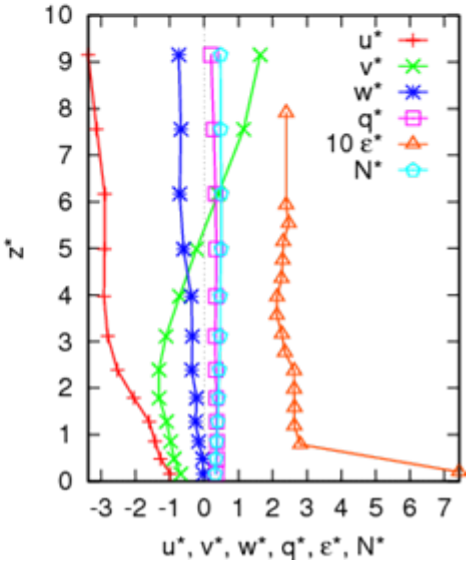


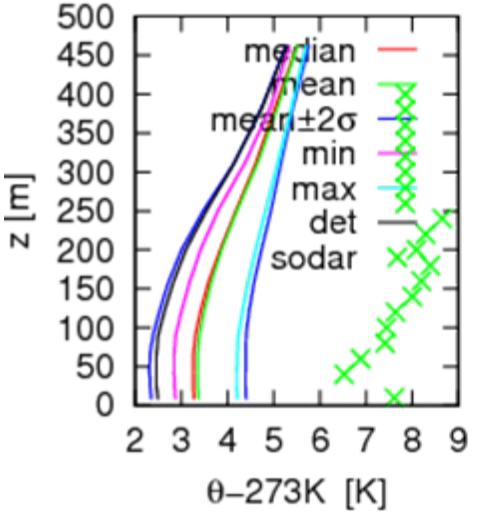


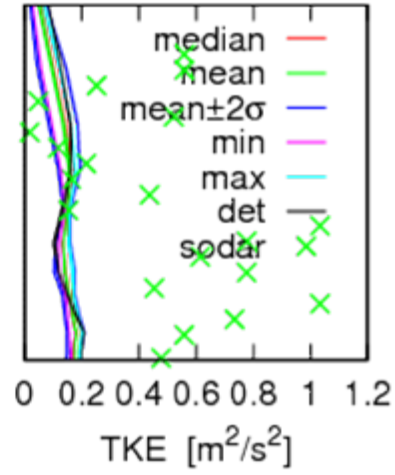




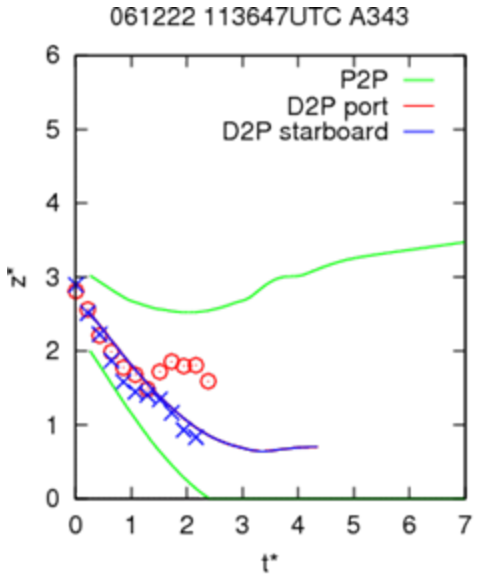


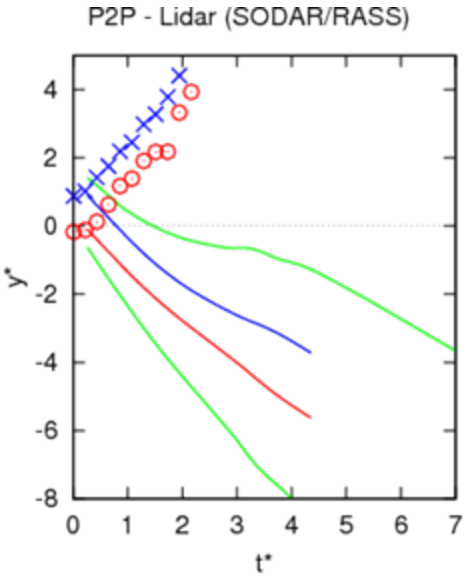


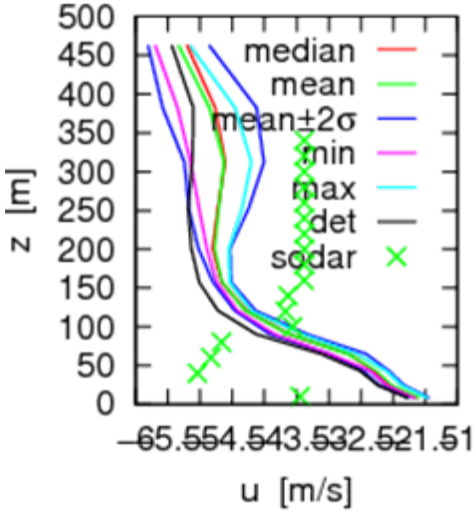


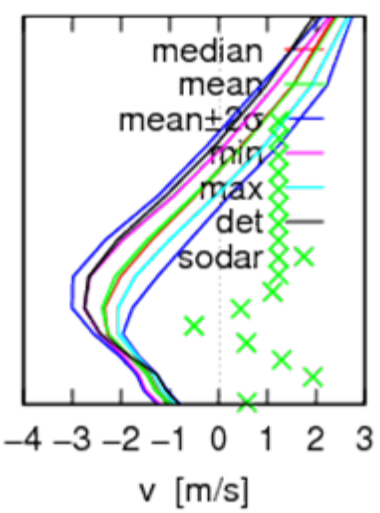


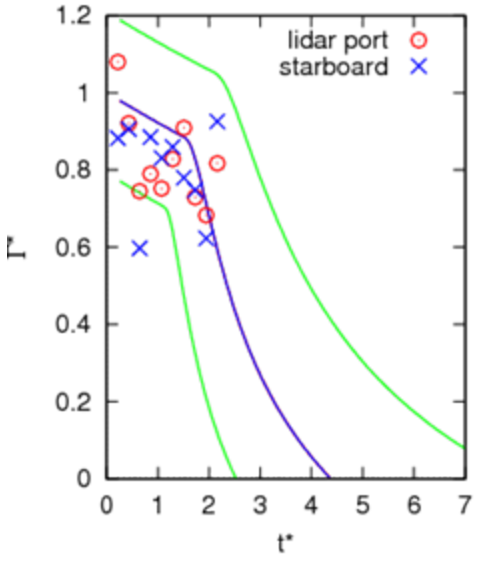
CREDOS EDDF-1, 22.12.06 - 11:30 - 12:00 bad crosswind pred.

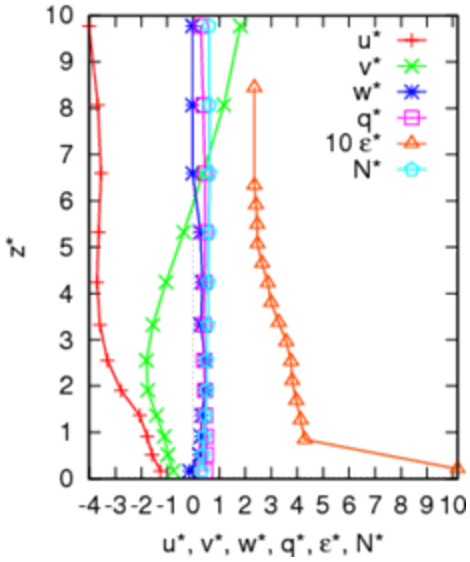


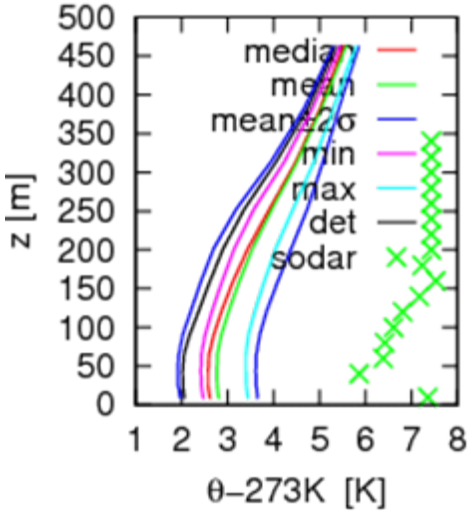


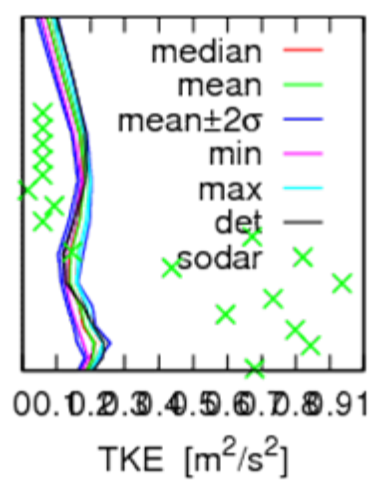












Time-Lagged Ensembles - **use of averages**
CREDOS EDDF-1, 22.12.06, 27 departures
(strong headwind ⇒ variable crosswind)

	y*	**z***	**Γ***	meteo input
RMS median	1.133	**0.400**	0.159	deterministic
	1.063	0.410	**0.149**	TLE-0
	0.854	0.407	0.152	TLE mean
	0.920	0.404	0.154	TLE median
RMS mean	1.516	**0.509**	0.182	deterministic
	1.300	0.515	**0.165**	TLE-0
	1.261	0.511	0.174	TLE mean
	1.260	**0.509**	0.174	TLE median
RMS 90th	3.194	**0.907**	0.306	deterministic
	2.505	0.922	0.277	TLE-0
	2.842	0.918	**0.265**	TLE mean
	2.785	0.918	0.272	TLE median
BIAS median	0.891	**0.041**	-0.035	deterministic
	0.385	0.056	-0.052	TLE-0
	0.620	0.054	**-0.032**	TLE mean
	0.712	0.051	-0.039	TLE median
BIAS mean	1.139	**0.154**	**0.0014**	deterministic
	0.493	0.173	-0.0214	TLE-0
	0.792	0.170	-0.0067	TLE mean
	0.806	0.168	-0.0050	TLE median

- lateral transport clearly better with TLE
- mean & median meteo input similar

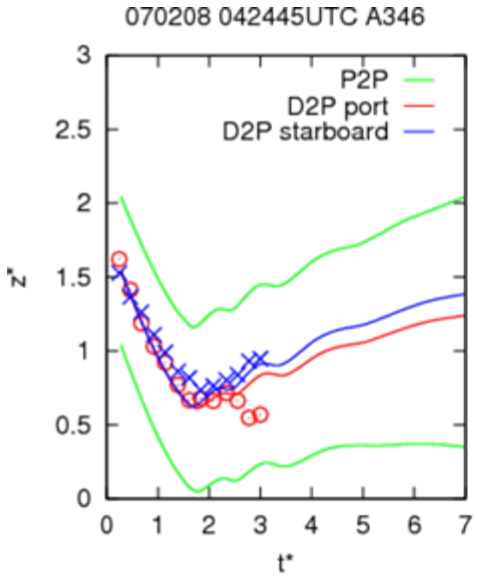
BIAS: meas. - pred.
(dzu = 0)

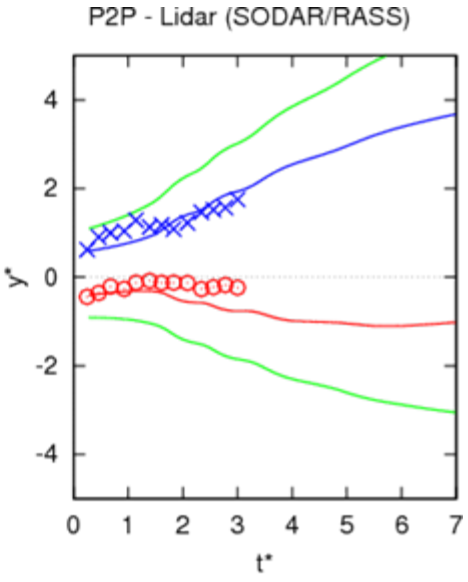
WSVBS, 8.2.07, 32 arrivals
(moderate headwind & crosswind)

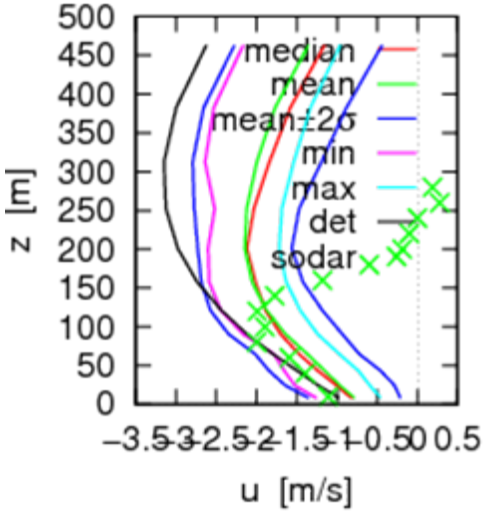
- only lidar measurements of wake vortex trajectories + a/c type
- specification of initial circulation:

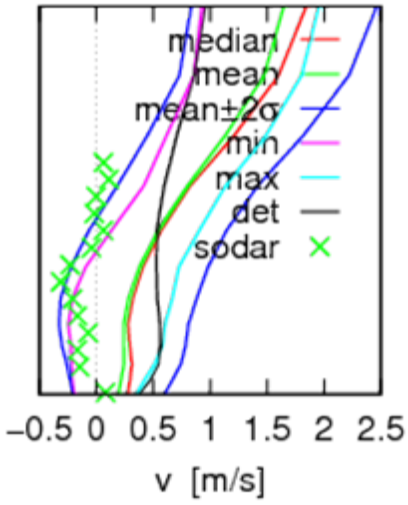
$$\Gamma_0 = \frac{g\left(\mathrm{OEW} + 1.25\mathrm{h}\,\mathrm{fuelflow/h} + 0.8\,\mathrm{PAX}_{\max}\,100\mathrm{kg/PAX}\right)}{1.2\,\mathrm{kg/m}^3\ \pi/4\ \mathrm{span}\ \mathrm{U}_{\mathrm{final}}}$$

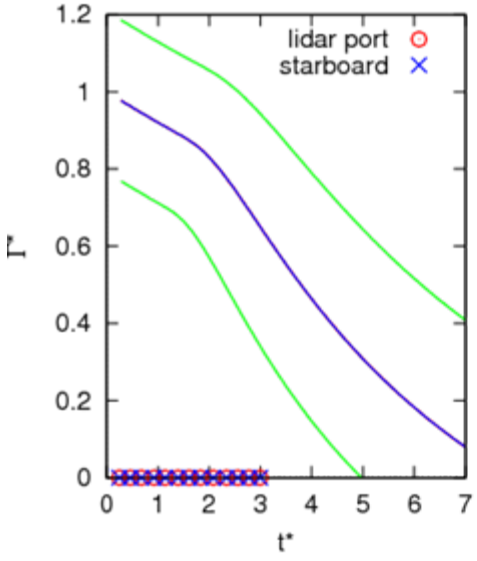
WSVBS, 8.2.07, arrivals, $z_0^* = 1.5 - 2.0$

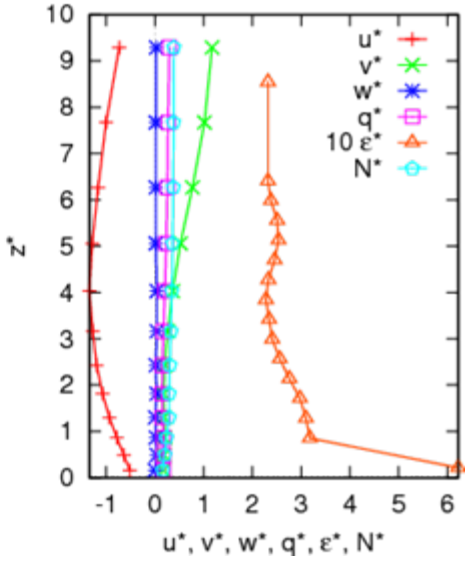


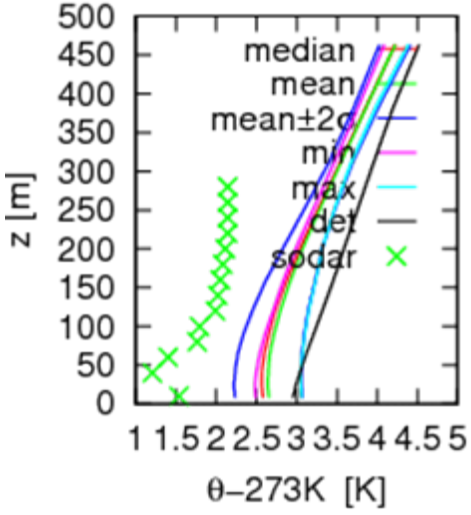


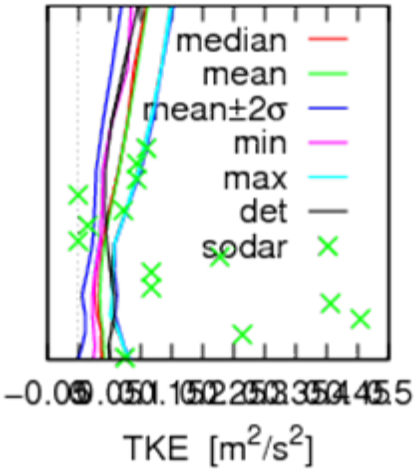




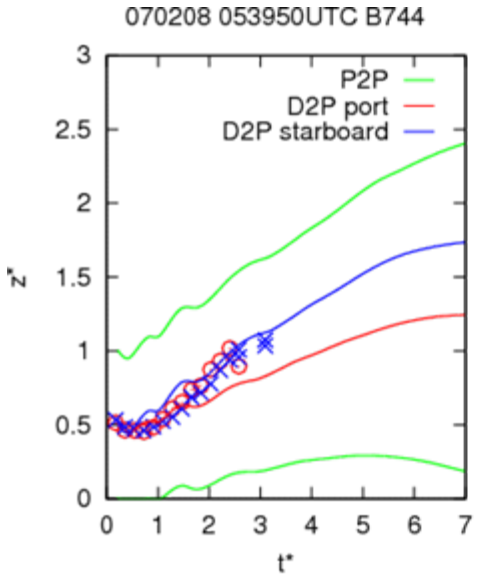


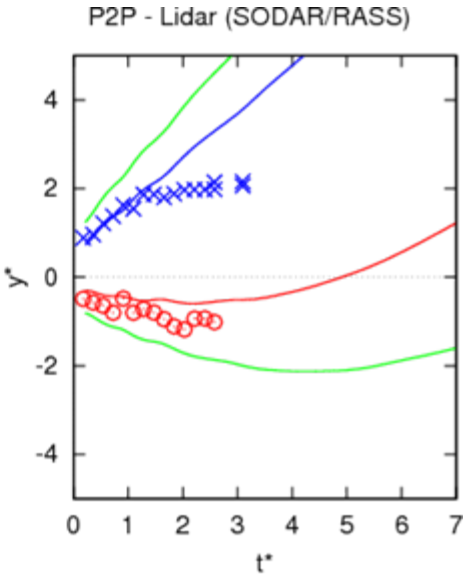


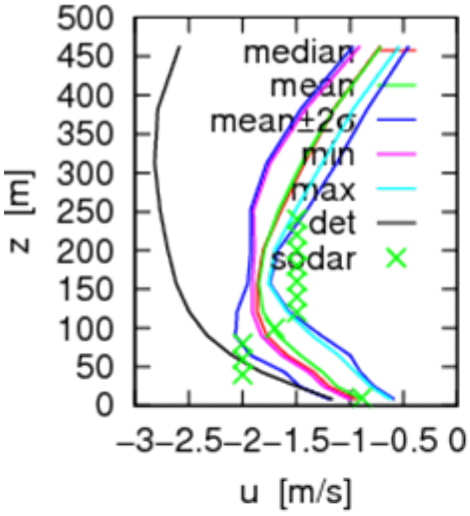


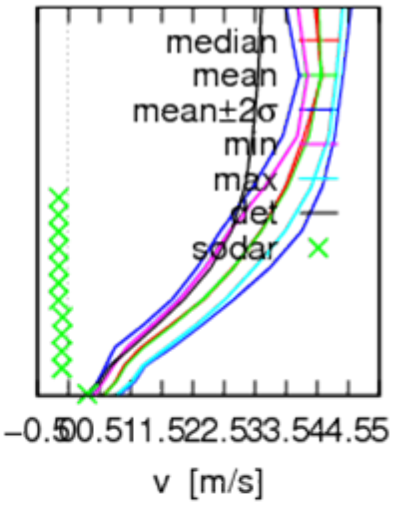


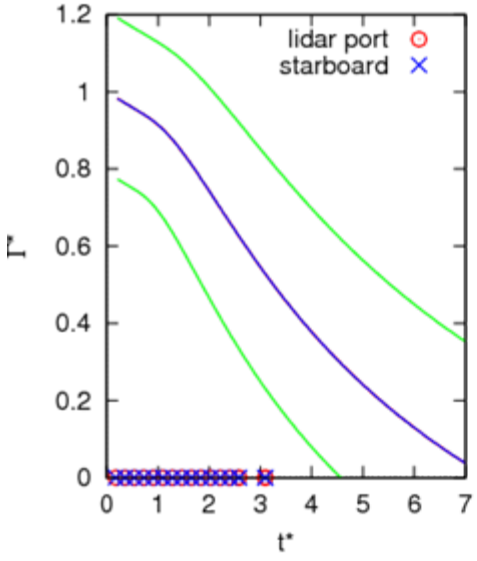
WSVBS, 8.2.07, arrivals, $z_0 \approx 0.5$

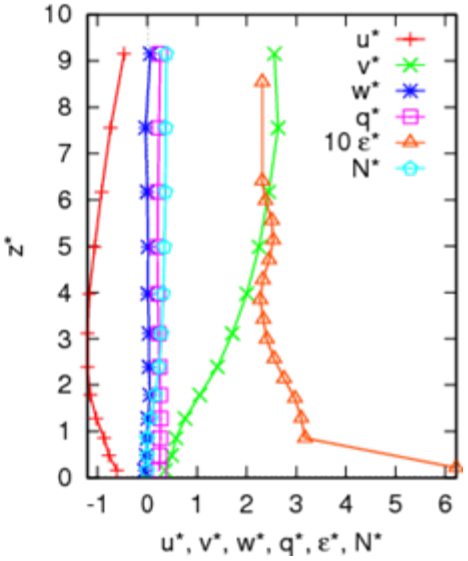


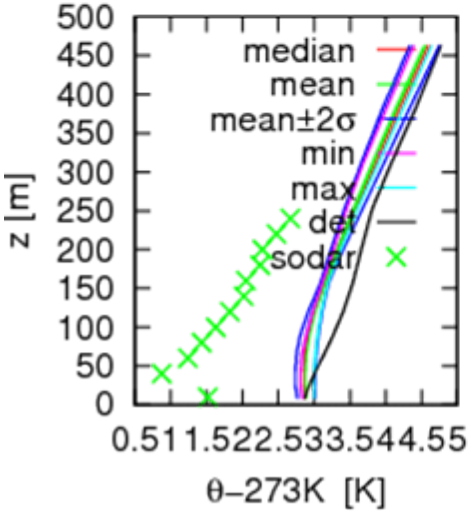


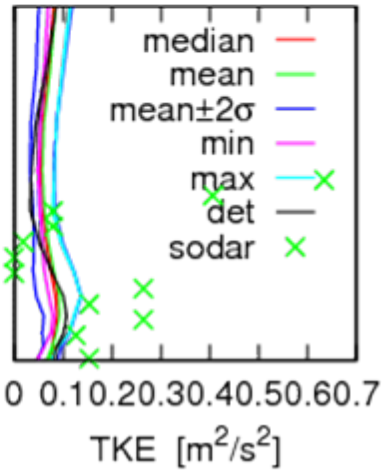












Time-Lagged Ensembles (6 members) - **use of averages**
WSVBS, 8.2.07, 32 arrivals
(moderate headwind & crosswind)

	y*	**z***	**Γ***	meteo input
RMS median	0.440 0.566 0.450 **0.438**	**0.128** 0.140 0.130 0.129	-	deterministic TLE-0 TLE mean TLE median
RMS mean	**0.577** 0.689 0.606 0.599	0.140 0.143 **0.139** **0.139**	-	deterministic TLE-0 TLE mean TLE median
RMS 90th	**1.121** 1.329 1.176 1.171	0.206 **0.202** 0.206 0.207	-	deterministic TLE-0 TLE mean TLE median
BIAS median	-0.281 -0.272 **-0.241** **-0.241**	-0.0134 -0.0081 -0.0083 **-0.0075**	-	deterministic TLE-0 TLE mean TLE median
BIAS mean	-0.375 **-0.325** -0.339 -0.338	-0.0084 -0.0089 -0.0037 **-0.0035**	-	deterministic TLE-0 TLE mean TLE median

- deterministic input as good as TLE
- median input slightly better
- WSVBS much better than CREDOS

Use of Time-Lagged Ensembles for Probabilistic WV Predictions

larger spread for less predictible situations and vice versa
$\Rightarrow$ more compact probabilistic predictions on average

Use of Time-Lagged Ensembles for Probabilistic WV Predictions

extension of P2P

- envelope of **3 × 4 runs**:
- fast decay: $\upsilon_{2,u}^{*}, 0.8T_2^{*}, N^{*}+2\sigma_{N^{*}}, \varepsilon^{*}+2\sigma_{\varepsilon^{*}}$
- intermediate (det.) decay: $\upsilon_{2,mean}^{*}, T_2^{*}$
- slow decay: $\upsilon_{2,l}^{*}, 1.2T_2^{*}, N^{*}-2\sigma_{N^{*}}, \varepsilon^{*}-2\sigma_{\varepsilon^{*}}$

3 runs

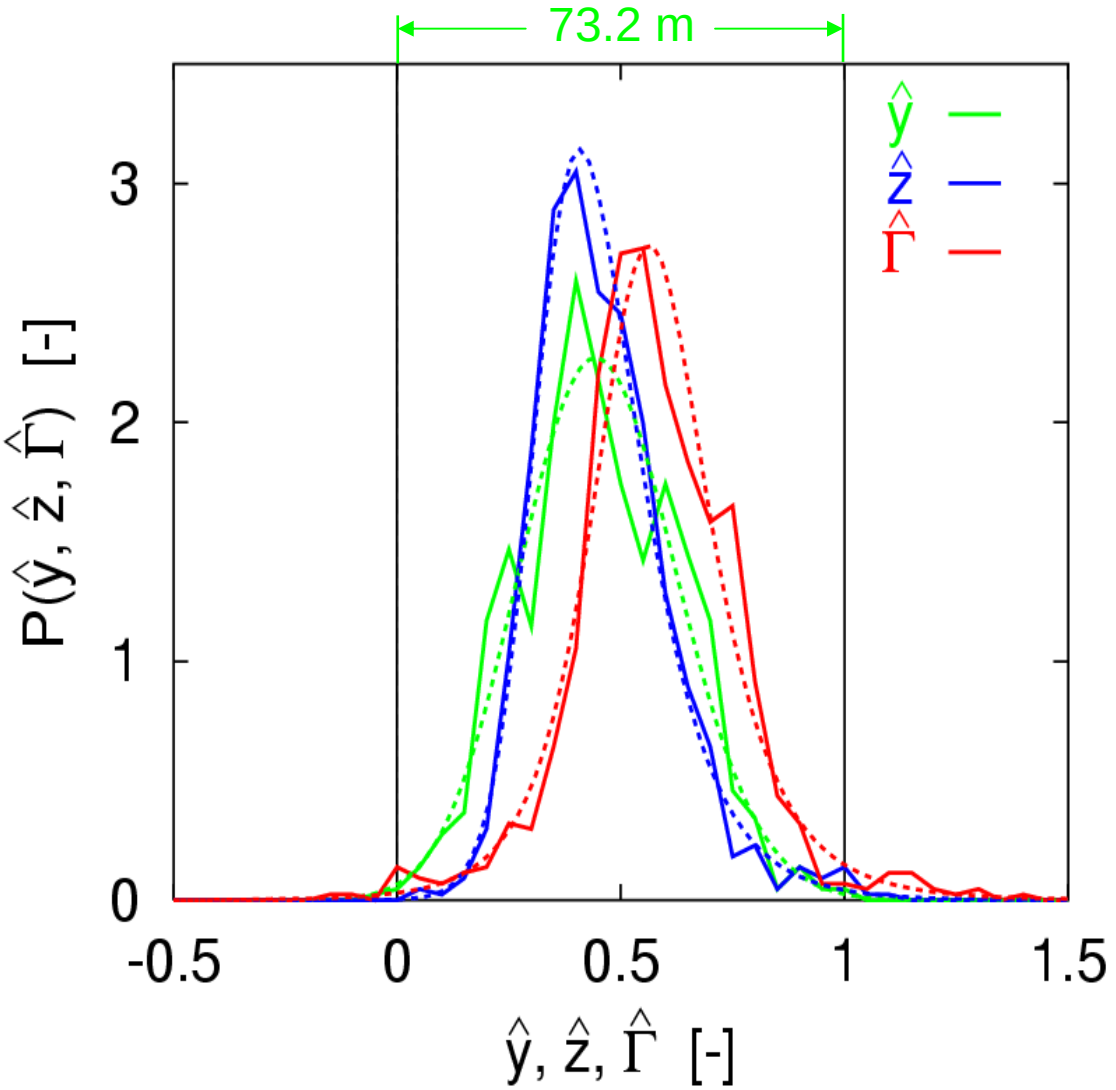
- wind envelopes: $u^{*}\pm 2\sigma_{u^{*}}, v^{*}\pm 2\sigma_{v^{*}}$

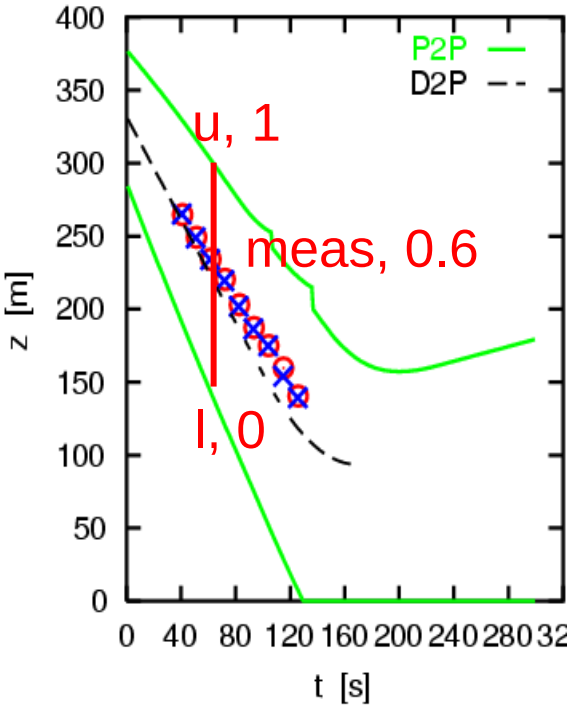
4 runs

- uncertainty allowances: $\pm 0.2\Gamma_0, \pm 0.5b_0$

$$y_{u(l)}^{*}, z_{u(l)}^{*} = y^{*}, z^{*} + (-)\int \sqrt{\left(C_q q^{*}\right)^2 + \left(C_{sh} v_{sh}^{*}\right)^2}\, dt^{*}$$

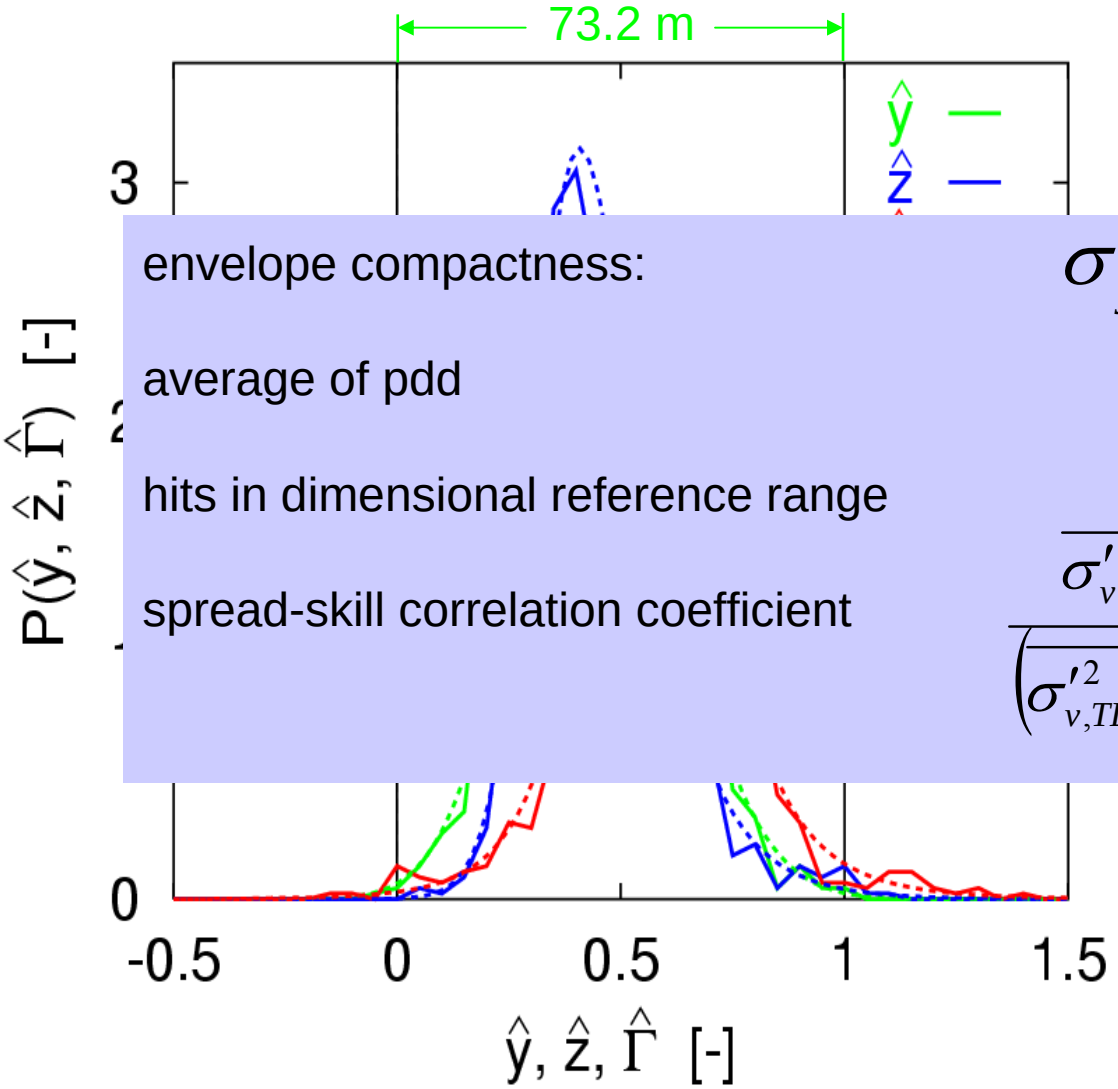
Skill Scores for Optimal Use of TLE Spread

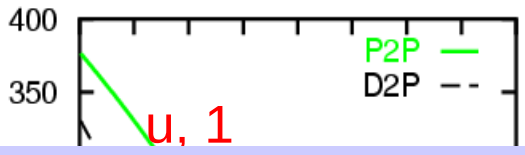




$$\hat{z} = \frac{z_{meas} - z_l}{z_u - z_l}$$

Skill Scores for Optimal Use of TLE Spread





envelope compactness: $\sigma_{\hat{y}} \cdot \Delta y$, optimum <

average of pdd , optimum 0.5

hits in dimensional reference range , optimum >

spread-skill correlation coefficient $\dfrac{\overline{\sigma'_{v,TLE}\,\sigma'_{\Delta y^*}}}{\left(\overline{\sigma'^2_{v,TLE}}\;\overline{\sigma'^2_{\Delta y^*}}\right)^{1/2}}$, optimum 1

$$\hat{z} = \frac{z_{meas} - z_l}{z_u - z_l}$$

Skill Scores for Use of TLE Spread

	WSVBS y $\sigma_u=\sigma_v=0$	WSVBS y $\sigma_u\neq\sigma_v\neq0$	WSVBS z $\sigma_u=\sigma_v=0$	WSVBS z $\sigma_u\neq\sigma_v\neq0$	EDDF-1 y $\sigma_u=\sigma_v=0$	EDDF-1 y $\sigma_u\neq\sigma_v\neq0$	EDDF-1 z $\sigma_u=\sigma_v=0$	EDDF-1 z $\sigma_u\neq\sigma_v\neq0$	EDDF-1 Γ $\sigma_u=\sigma_v=0$	EDDF-1 Γ $\sigma_u\neq\sigma_v\neq0$
$\sigma_{\hat{\phi}}$ [–]	0.3437	0.2786	0.1351	0.1319	1.133	0.5633	0.3840	0.3700	0.3126	0.2742
env. width [m]	76.34	99.22	51.31	52.42	52.18	110.5	73.12	76.03	236.80	253.69
EC [m]	**26.24**	27.64	6.93	**6.92**	**59.11**	62.25	**28.07**	28.10	74.02	**69.55**
EC* [-]	**0.545**	0.574	**0.144**	**0.144**	**1.211**	1.271	**0.575**	0.576	0.173	**0.163**
$\overline{\phi}$ [m]	**-14.74**	-15.53	0.65	**0.58**	**37.39**	39.48	6.19	**5.33**	**-1.98**	-2.81
hits [%]	**88.3** (100 m)	86.3 (100 m)	**99.4** (50 m)	99.2 (50 m)	65.6 (100 m)	**70.1** (100 m)	77.1 (50 m)	**77.6** (50 m)	91.2 (200 m^2/s)	**93.4** (200 m^2/s)
spread-skill correl.	-	0.121 (-0.104)	-	-	-	-0.399 (-0.024)	-	-	-	-

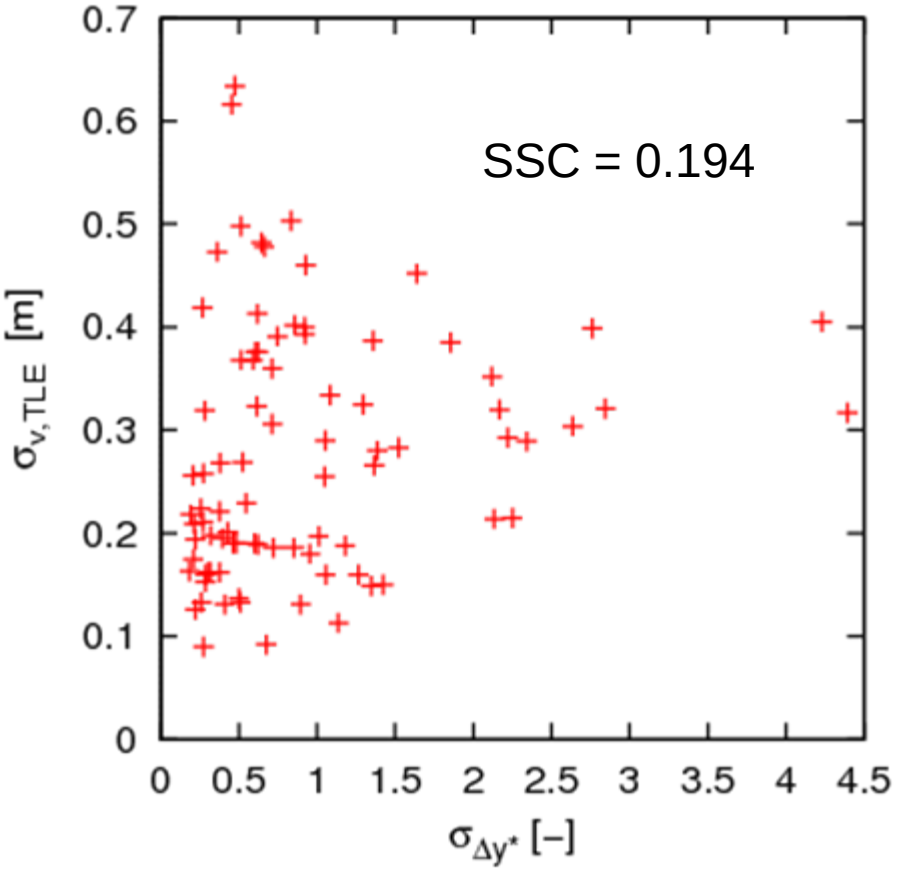
Skill Scores for Use of TLE Spread (24.1.07)

	EDDF-1 y $\sigma_u=\sigma_v=0$	EDDF-1 y $\sigma_u\neq\sigma_v\neq0$	EDDF-1 z $\sigma_u=\sigma_v=0$	EDDF-1 z $\sigma_u\neq\sigma_v\neq0$	EDDF-1 Γ $\sigma_u=\sigma_v=0$	EDDF-1 Γ $\sigma_u\neq\sigma_v\neq0$
$\sigma_{\hat{\phi}}$ [–]	1.279	0.4741	0.2593	0.2600	0.2830	0.2812
env. width [m]	48.74	96.31	92.45	92.98	227.73	237.02
EC [m]	62.34	**45.66**	**23.97**	24.16	**64.46**	66.65
EC* [-]	1.280	**0.936**	**0.491**	0.495	**0.127**	0.132
$\overline{\phi}$ [m]	46.90	**38.51**	**-7.97**	-8.11	-19.40	**-16.61**
hits [%]	61.8 (100 m)	**61.9** (100 m)	**70.1** (50 m)	69.3 (50 m)	**97.9** (200 m^2/s)	96.9 (200 m^2/s)
spread-skill correl.	-	0.0575	-	-	-	-

Spread Skill Correlation Coefficient (all 3 cases)

$$\frac{\overline{\sigma'_{v,TLE}\,\sigma'_{\Delta y^*}}}{\left(\overline{\sigma'^2_{v,TLE}}\;\overline{\sigma'^2_{\Delta y^*}}\right)^{1/2}}$$

ensemble spread



RMS $\Delta y / b_0$

Conclusions

mean and median of TLE superior to deterministic predictions

ensemble spread only partially encloses observations

method for use of TLE spread in P2P

various skill scores established (single skill score not sufficient)

the various skill scores indicate heterogeneous trends because the underlying pdds of vortex parameters are quite non-uniform

hypothesis / hope: probabilistic wake-vortex prediction skill correlates with spread-skill correlation coefficient not verified

spread-skill correlation coefficient only slightly positive

benefit of probabilistic meteo predictions not yet evident

scientific questions - priorities for future research

- what is the spatial and temporal correlation of the required meteo parameters?
- which is the most effective weather prediction method for different lead times?
- (how) can we quantify the predictability of particular weather scenarios for short-term predictions?
- how to introduce disturbances to ensemble prediction methods for short-term predictions?
- which probabilistic nowcasting methods are available / appropriate?
- how to improve spread-skill correlation?
- can we improve ensemble prediction skill sufficiently to justify the effort?

- how to use meteo uncertainty information optimally by the WV predictors?
- how to quantify improvements of probabilistic prediction chain?

- quantify effects of uncertainties of input parameters on WV properties!
- compare skills of probabilistic nowcasting with ensemble weather prediction!