Can small-scale orographic gravity waves provide the missing drag in the stable boundary layer?

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ECMWF drag workshop

Impact Stable Boundary Layers

Stable Boundary Layers

Many small scale processes and non-linear interactions not fully understood

Realistic ("shallow tail") turbulence schemes improve the representation of low-level jet, wind turning, boundary-layer depth, diurnal cycle, et cetera…

But, result in negative impact on larger scale model performance (e.g., filling of cyclones):

Can small-scale orographic waves explain missing drag?

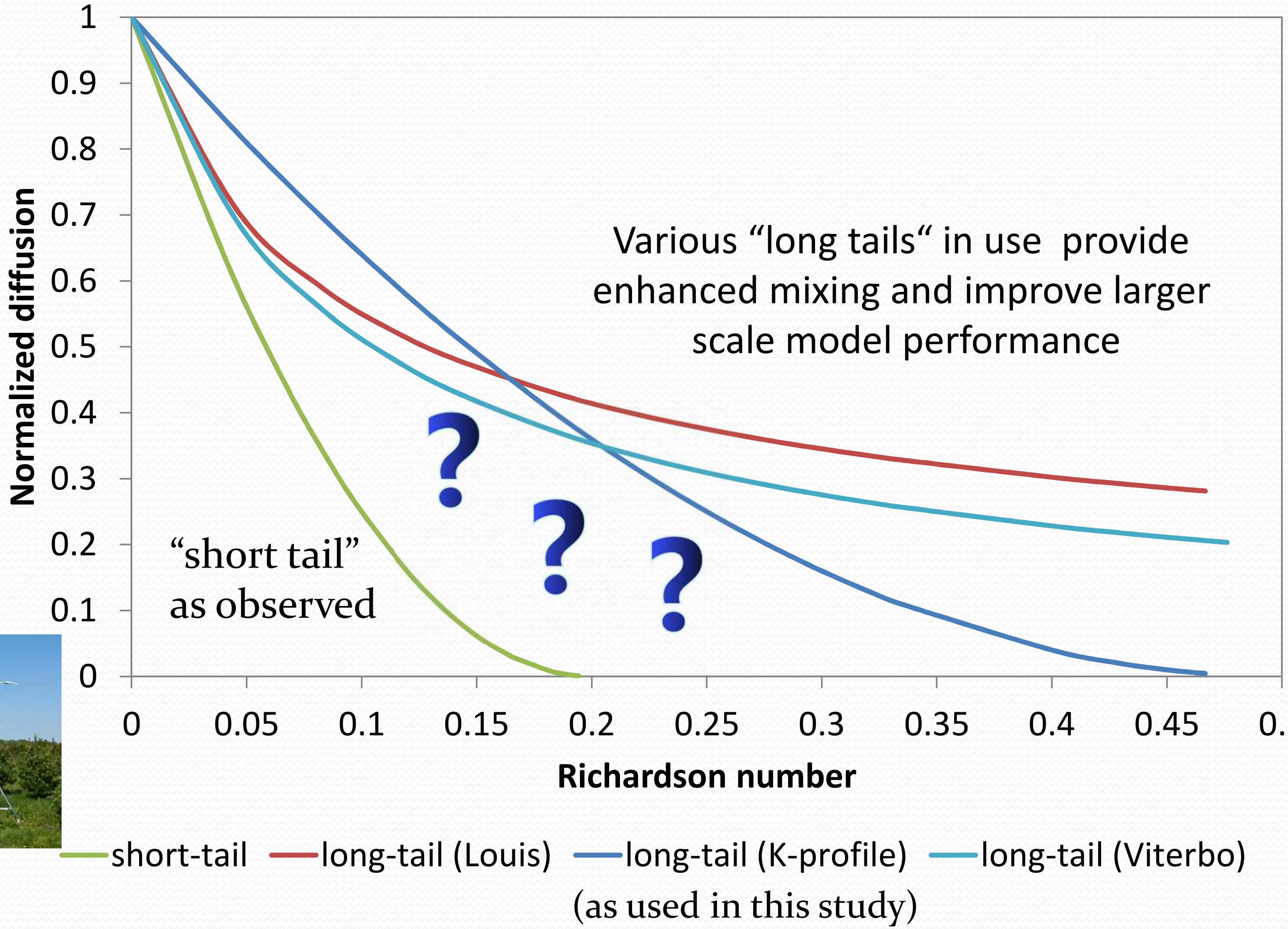
Also connection to land-atmosphere coupling, sloping terrain, et cetera

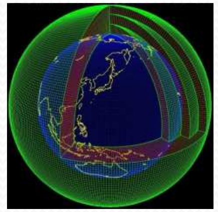
GABLS

GEWEX Atmospheric Boundary Layer Study

(Louis, 1979; Mahrt, 1987, 2014; Beare et al, 2006; Cuxart et al, 2006; Steeneveld et al., 2008; Svensson et al, 2011; Sandu et al., 2013; Holtslag et al., 2013, Bosveld et al, 2014; among many others)

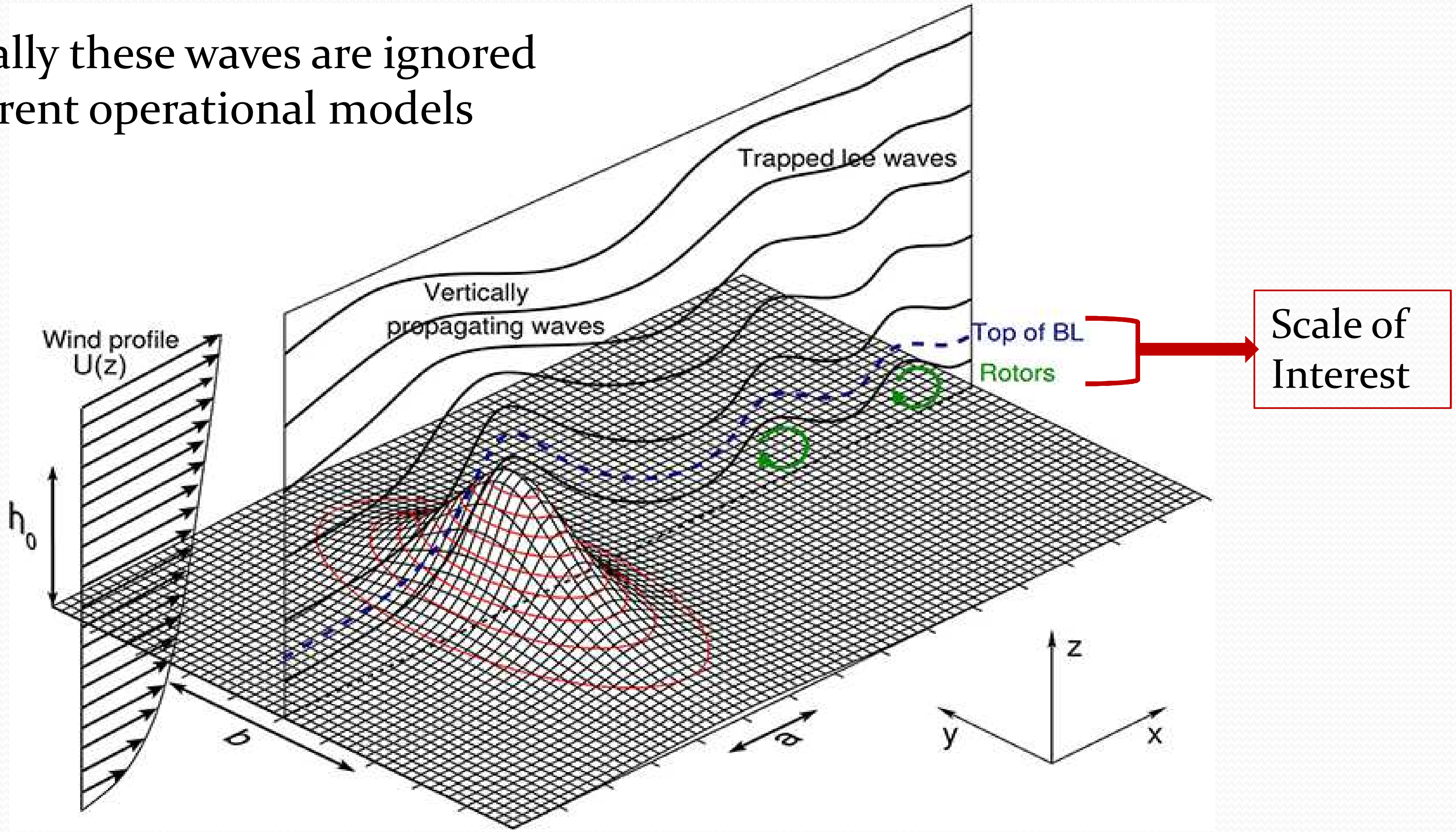
Normalized diffusion from short and long tail functions





Small scale gravity waves are caused by forced vertical motions in the stable boundary layer and they do transport momentum

Typically these waves are ignored in current operational models



Gravity wave drag theory

Non-linear equation for gravity wave drag:

$$t_{wave} = \begin{cases} \frac{1}{2}\rho_0 k_s (HU)^2 \sqrt{\frac{N^2}{U^2} - k_s^2} & ,\frac{N}{U} > k_s \\ 0, & \frac{N}{U} < k_s \end{cases}$$

Linear version for weak winds:

$$t_{wave} = \frac{1}{2}\rho_0 k_s H^2 N U$$

U : Background wind
N: Brunt-Vaisala frequency
H: amplitude subgrid scale orography
ks: orographic wave number
t wave: wave drag
h: SBL height

Divergence of gravity wave drag with height:

$$t_{wave}(z) = t_{wave}(0)\left(1 - \frac{z}{h}\right)^2$$

(Nappo, 2002; Kim and Doyle, 2005; Steeneveld et al, 2008)

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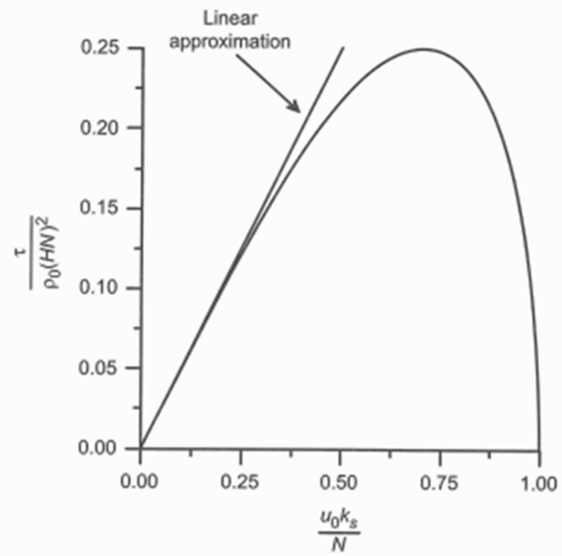

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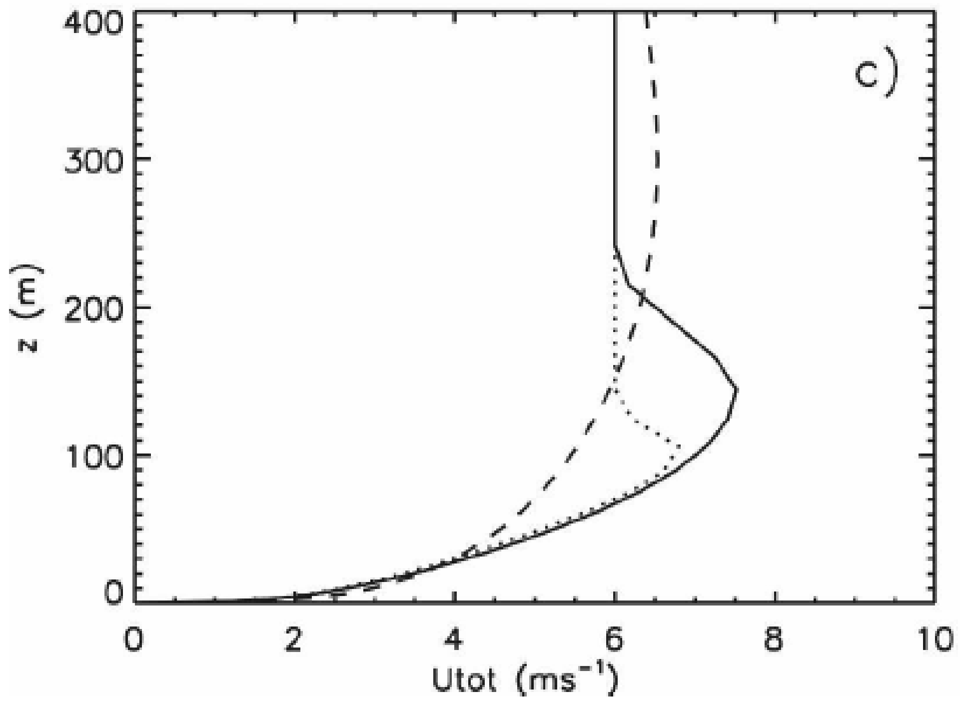
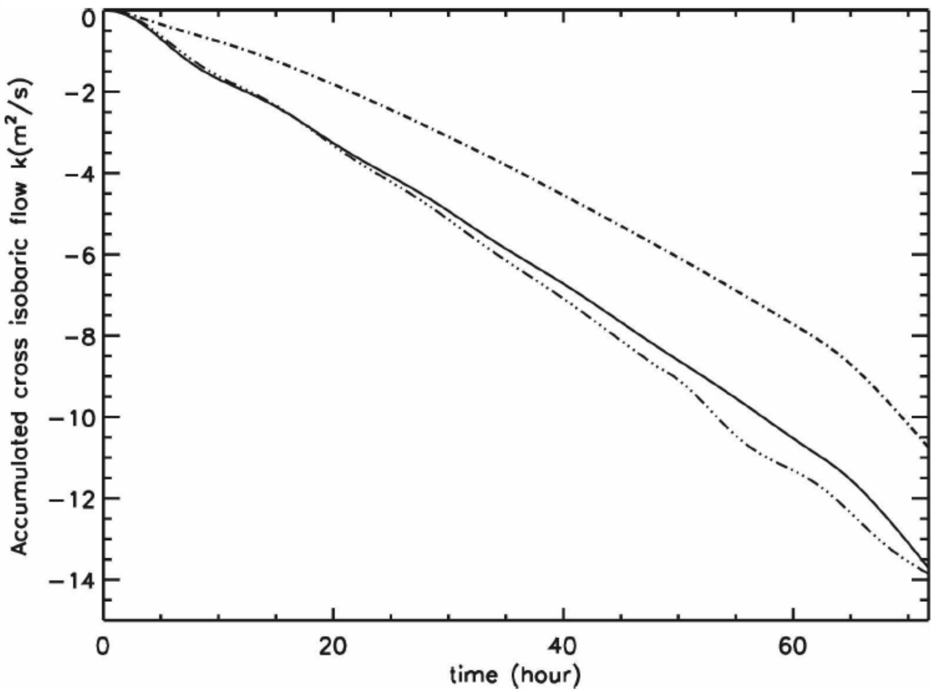
1D model results L=1000 m and H= 10 m

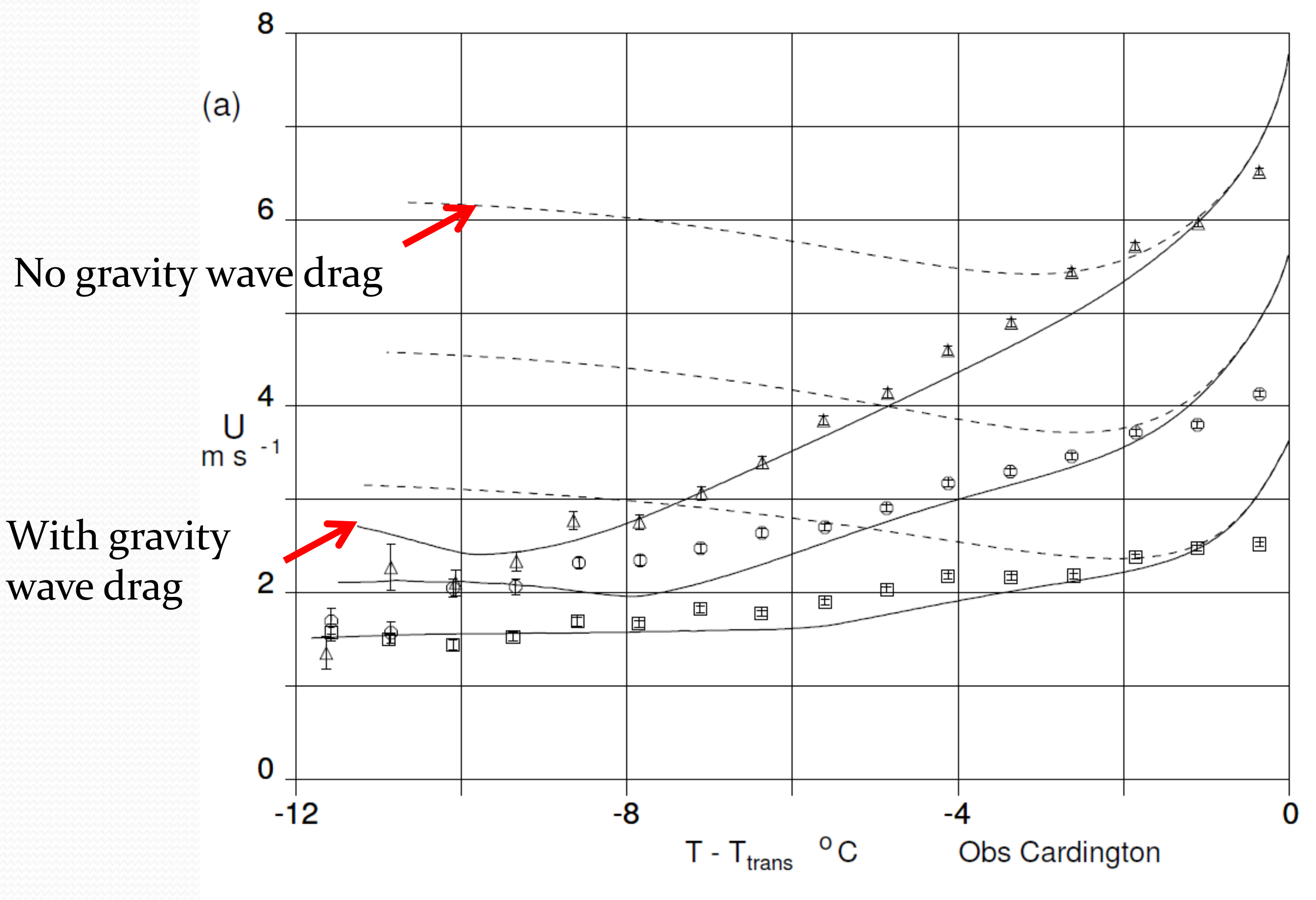




·····: ST; ——: ST+GWD; —·····—: LT

(Steeneveld et al, 2008, 2009)

Recent 1D results at Cardington



Lapworth and Osborne, 2016, QJ

3D Experimental setup

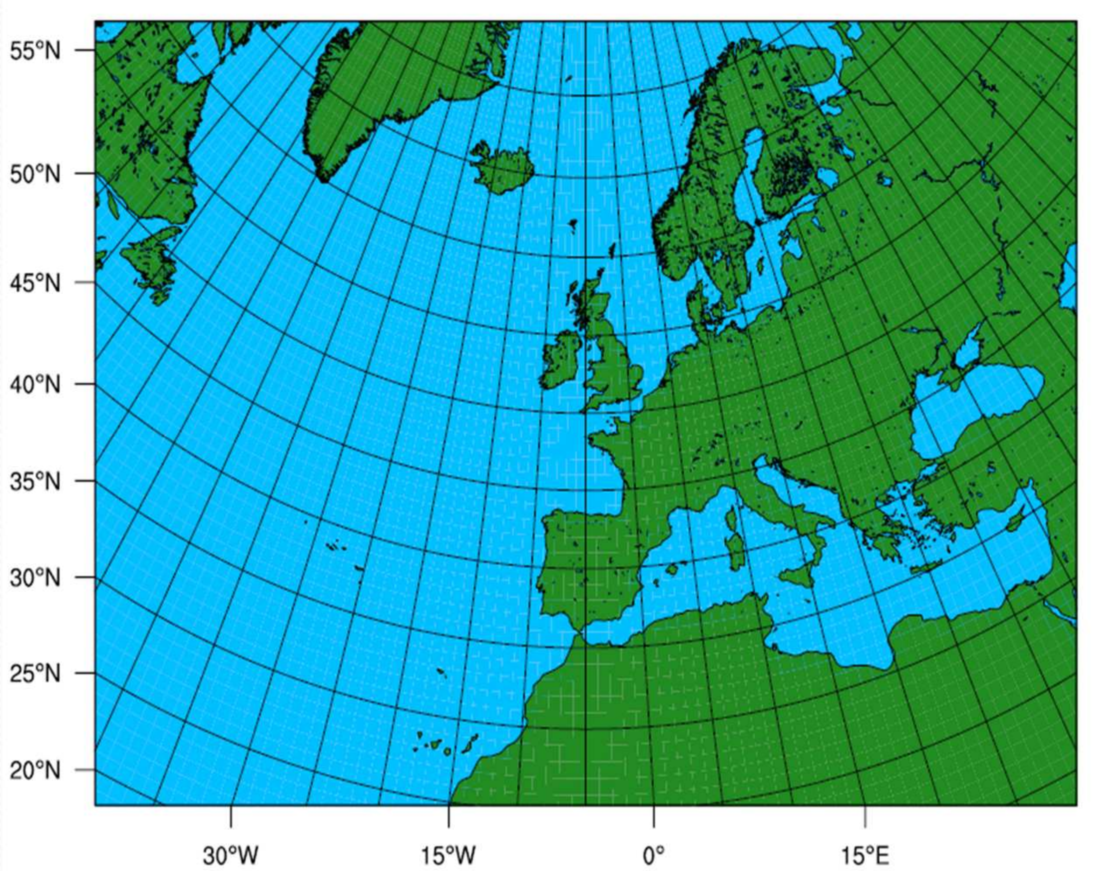
WRF 3.5 Configuration

Domain:

- 315x226 gridcells
- 25x25 km horizontal resolution
- 34 vertical levels (16 levels below 900 hPa)

Parameterization schemes:

- Boundary Layer (YSU)
- Microphysics (WSM-3)
- Surface Layer (Monin-Obukhov MM5)
- Shortwave (Dudhia)
- Longwave (RRTM)
- Cumulus (Kain-Fritsch)
- OGWD (Hong)



Experimental setup

3 different model setups

- GWDSBL
- ST
- LT

16 model runs

- 8-days for each model run
- Initialized at 12 UTC
- Period 15 December 2011 to 22 January 2012

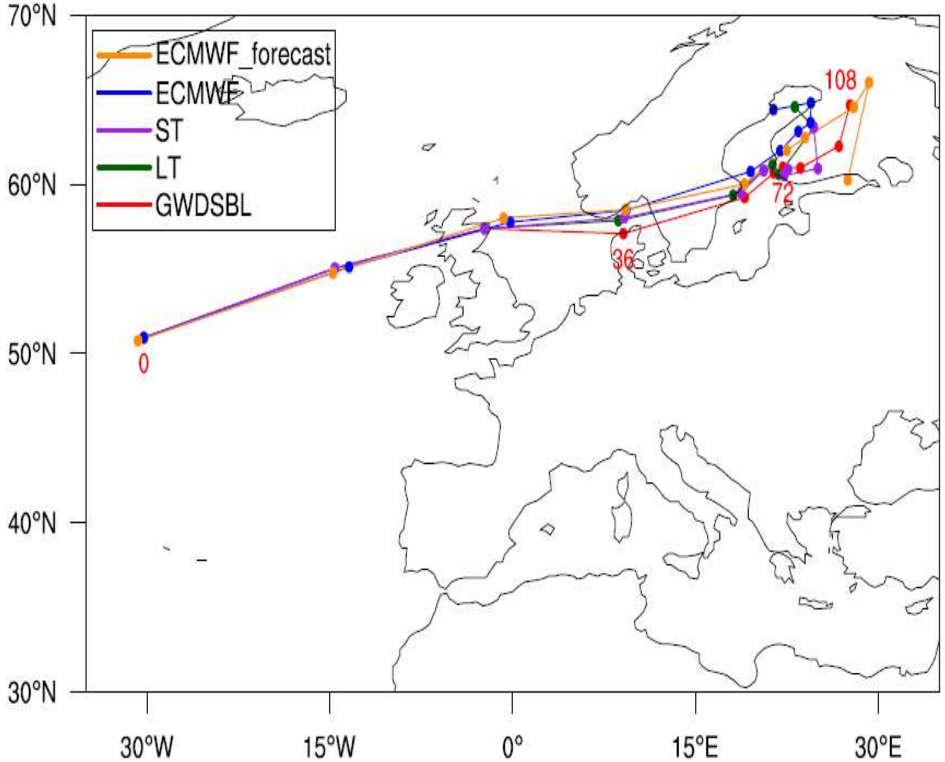
Results are shown for 2 cyclones in period 2^{nd} to 10^{th} of January

Sensitivity tests

- Nonlinear GWD
- 61 Vertical Levels
- Initialization time

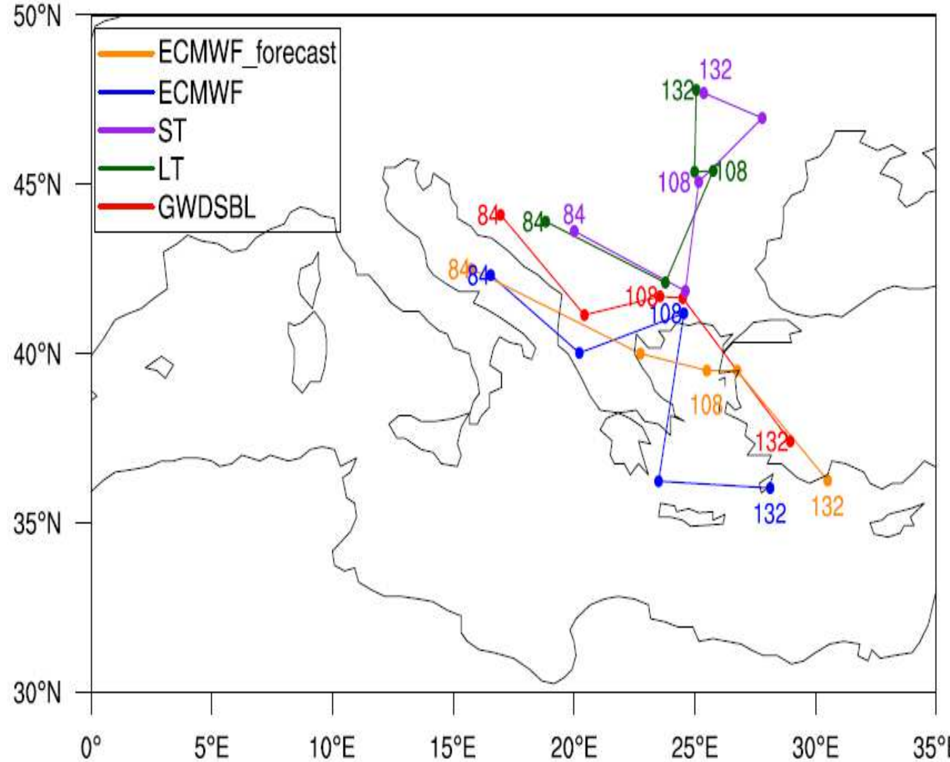
Track of the cyclone cores

Cyclone 1



Cyclone 1 starts Jan 2, 2012

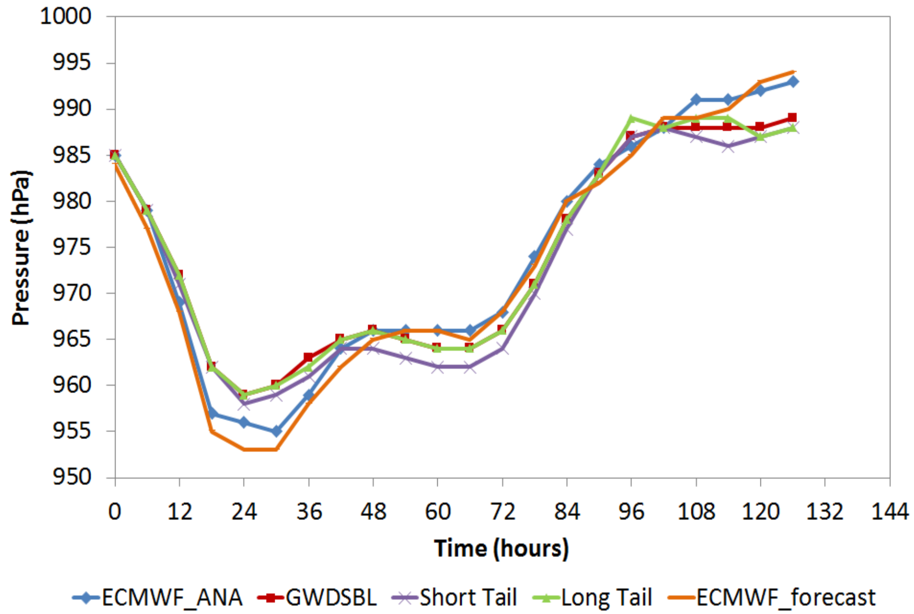
Cyclone 2



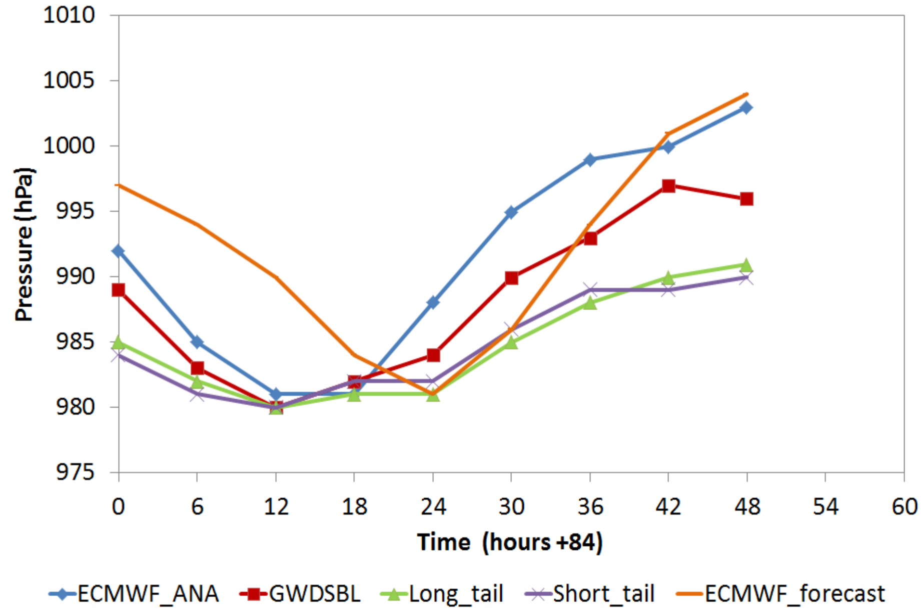
Cyclone 2 starts Jan. 5, 2012

Results : Cyclonic Core Pressure

Cyclone 1

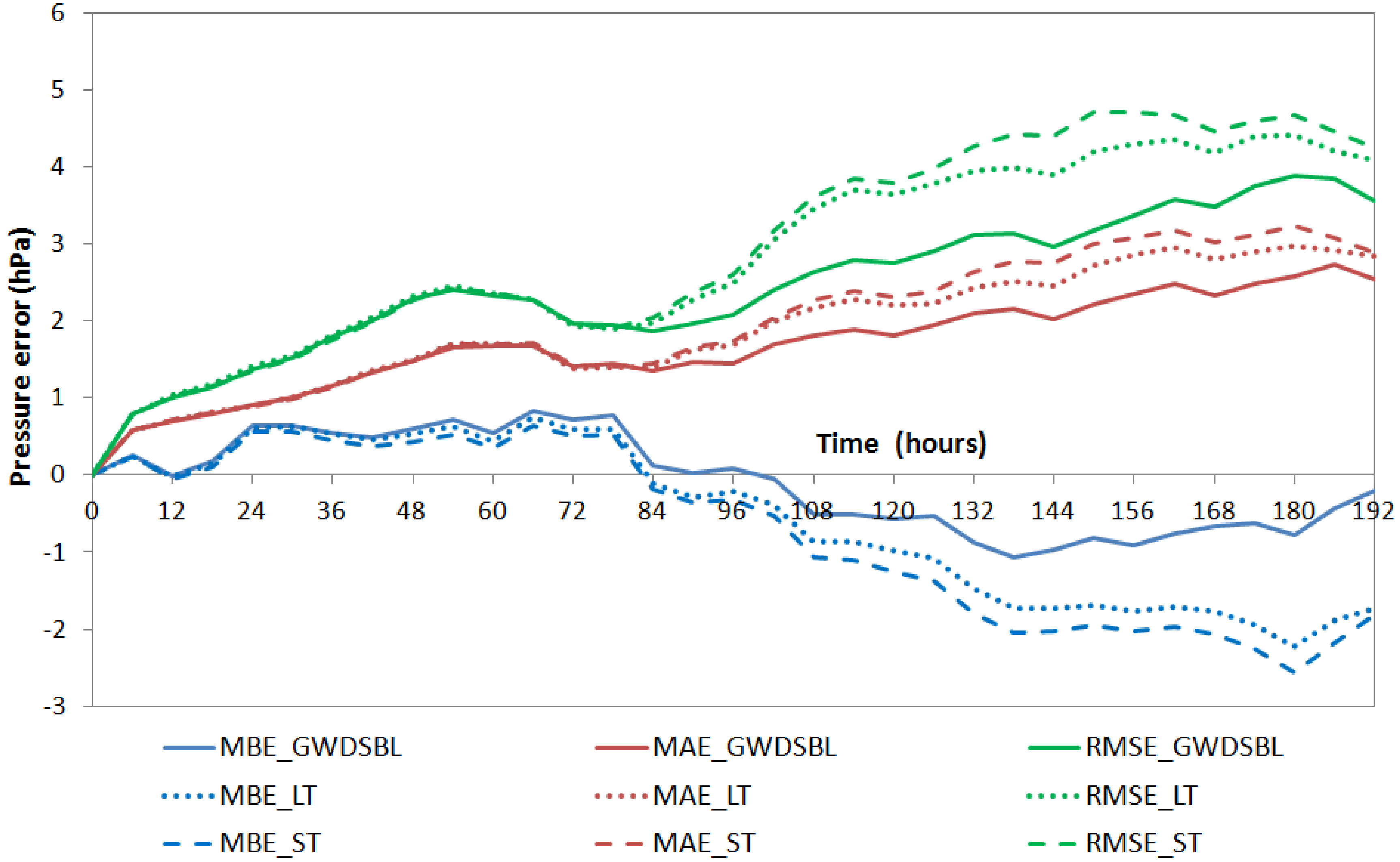


Cyclone 2



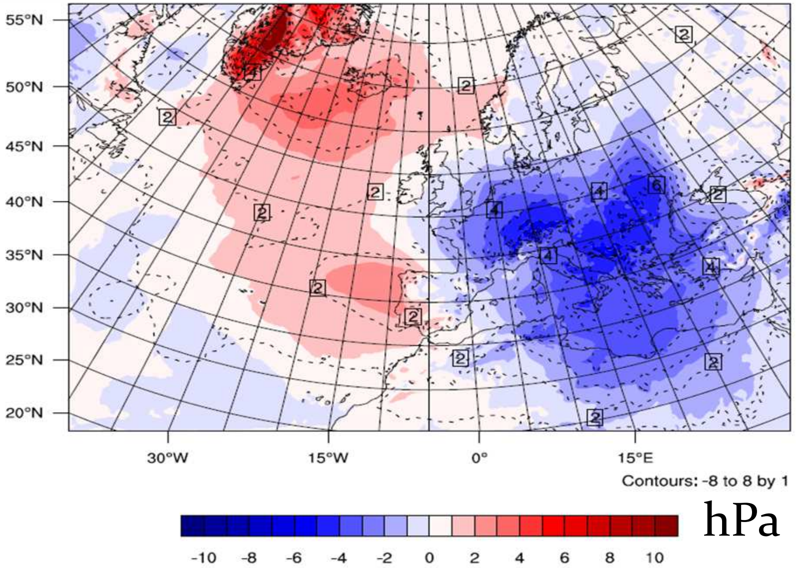
Cyclone 1	GWDSBL (hPa)	LT (hPa)	ST (hPa)	ECMWF_ forecast (hPa)	Cyclone 2	GWDSBL (hPa)	LT (hPa)	ST (hPa)	ECMWF_ forecast (hPa)
MAE	2.23	2.27	2.72	1.13	MAE	3.22	6.00	6.11	4.89
MBE	-0.23	-0.18	-1.27	-0.86	MBE	-3.00	-6.00	-5.89	0.22
RMSE	2.72	2.79	3.25	1.40	RMSE	3.96	7.63	7.64	6.03

Temporal evolution of domain-averaged sea level pressure errors



Results : Sea Level Pressure

GWDSBL-ANA

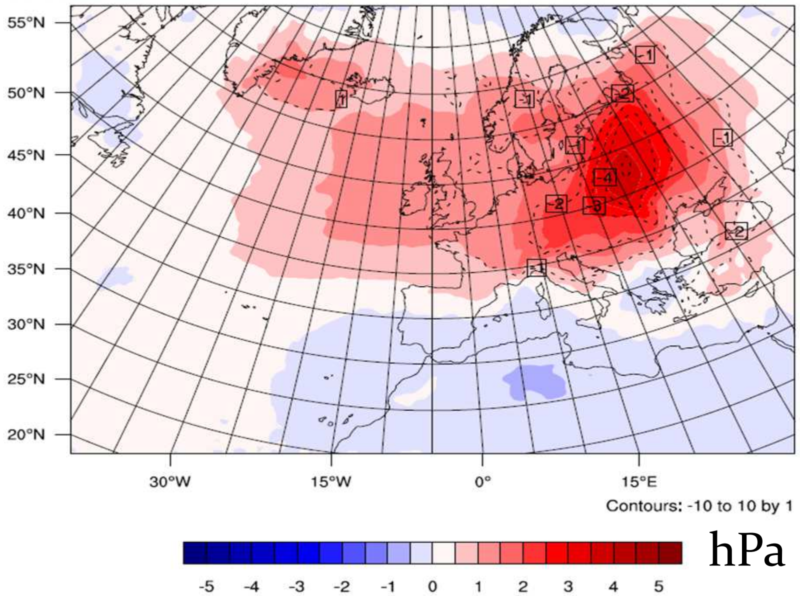


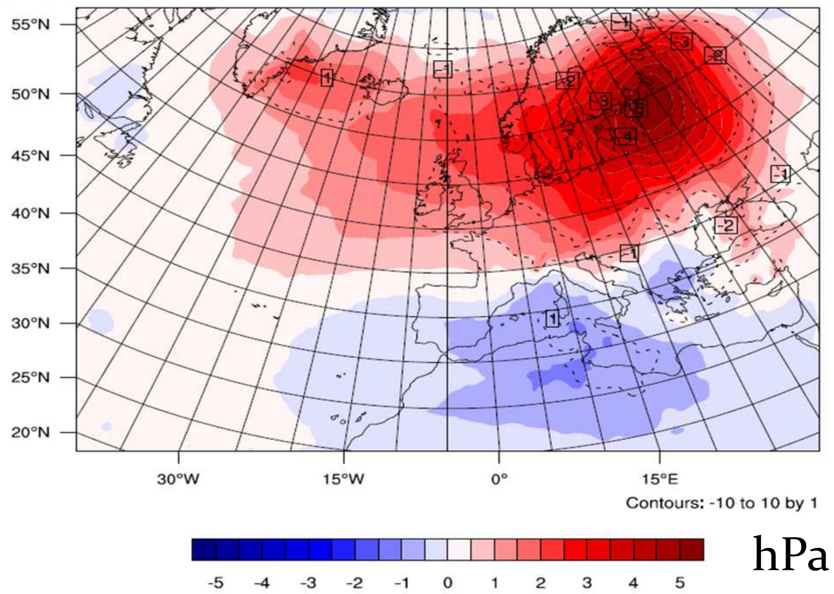
Up left: MBE(filled contours) and RMSE(dotted) of SLP for GWDSBL experiment.

Down left: Difference in MBE (filled) and RMSE (dotted) between GWDSBL and LT (GWDSBL-LT)

Down right: Difference in MBE (filled) and RMSE (dotted) between GWDSBL and ST (GWDSBL-ST)

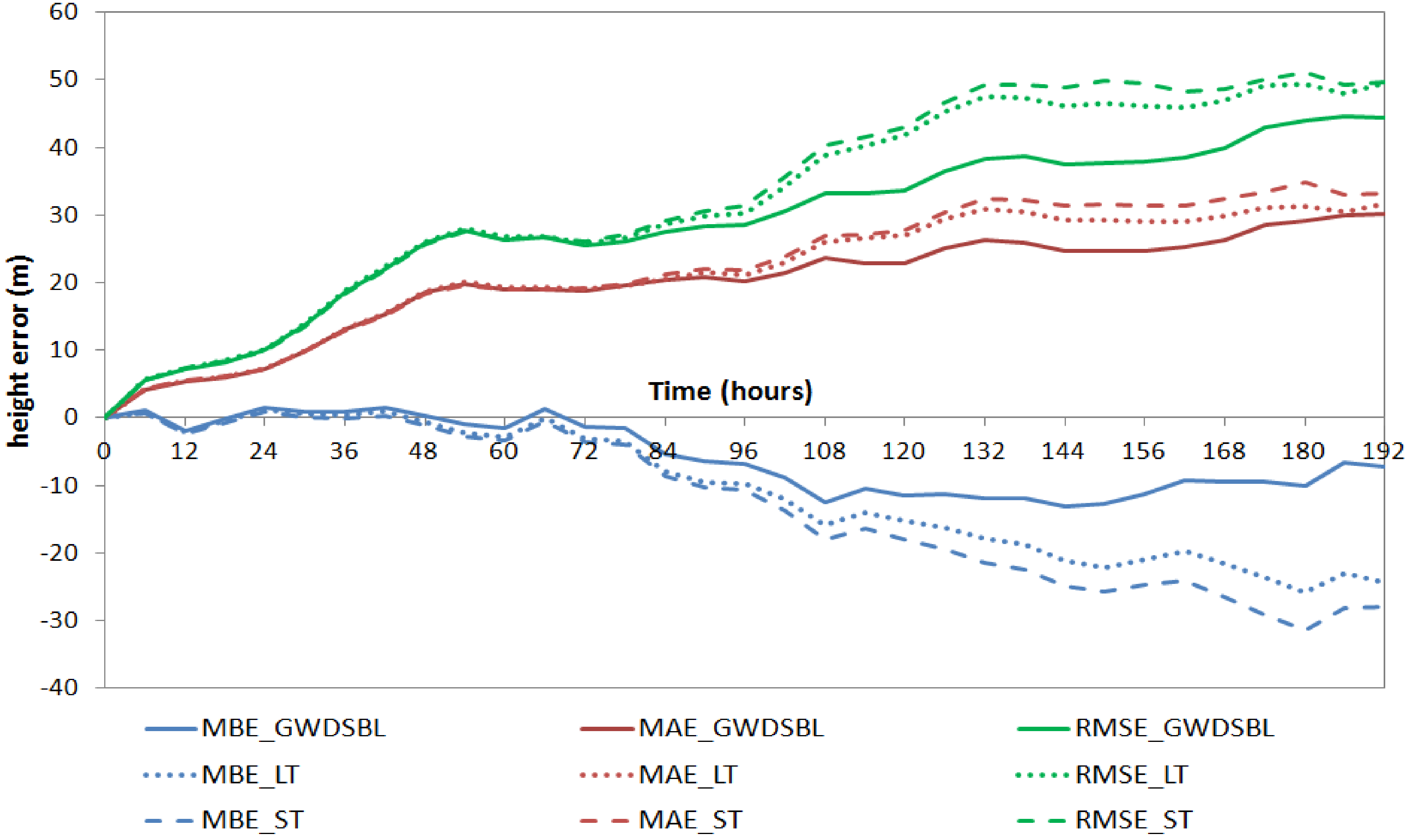
MBE GWDSBL-MBE LT



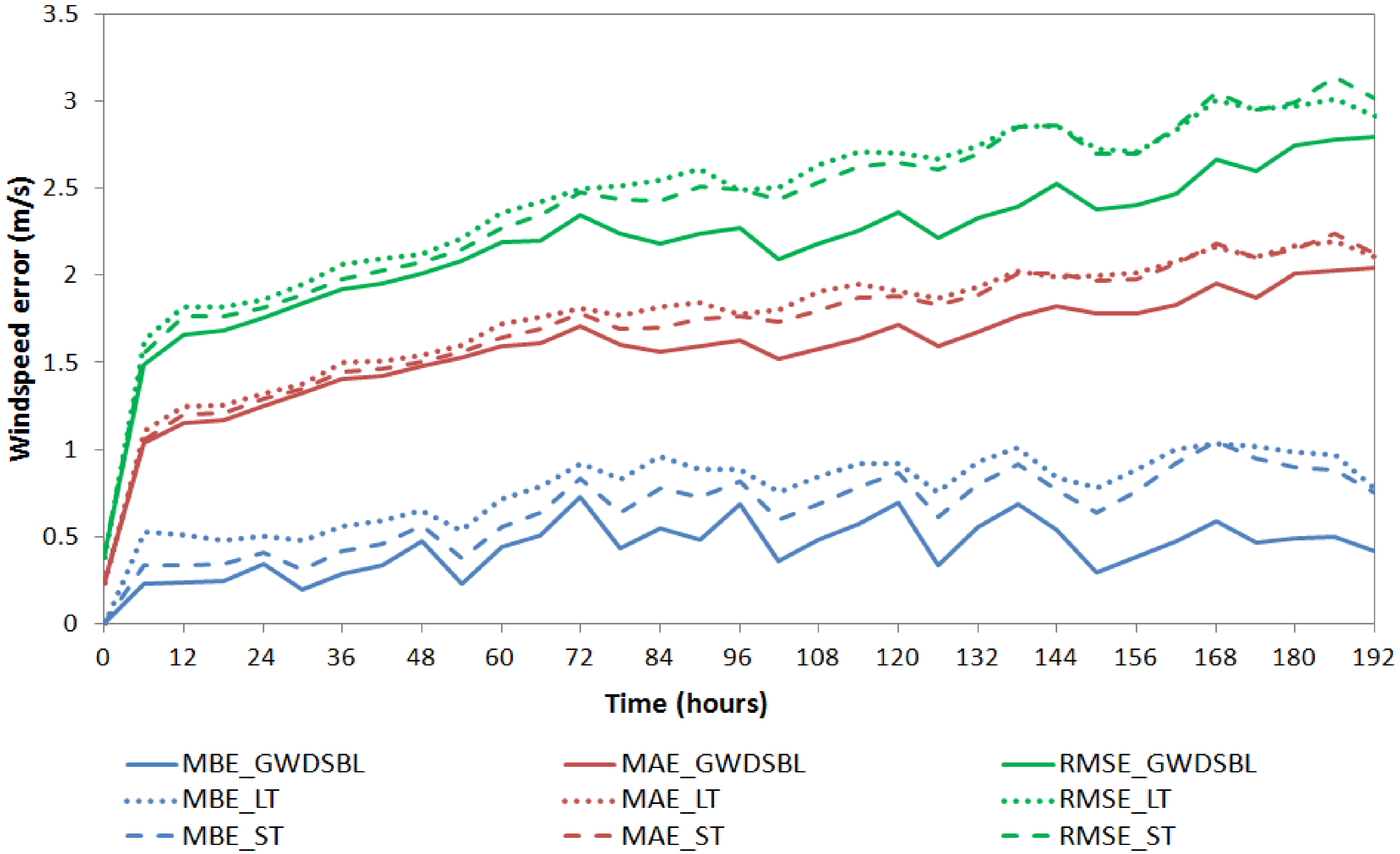


MBE GWDSBL-MBE ST

Temporal evolution of the domain-averaged height errors of the 500 hPa field



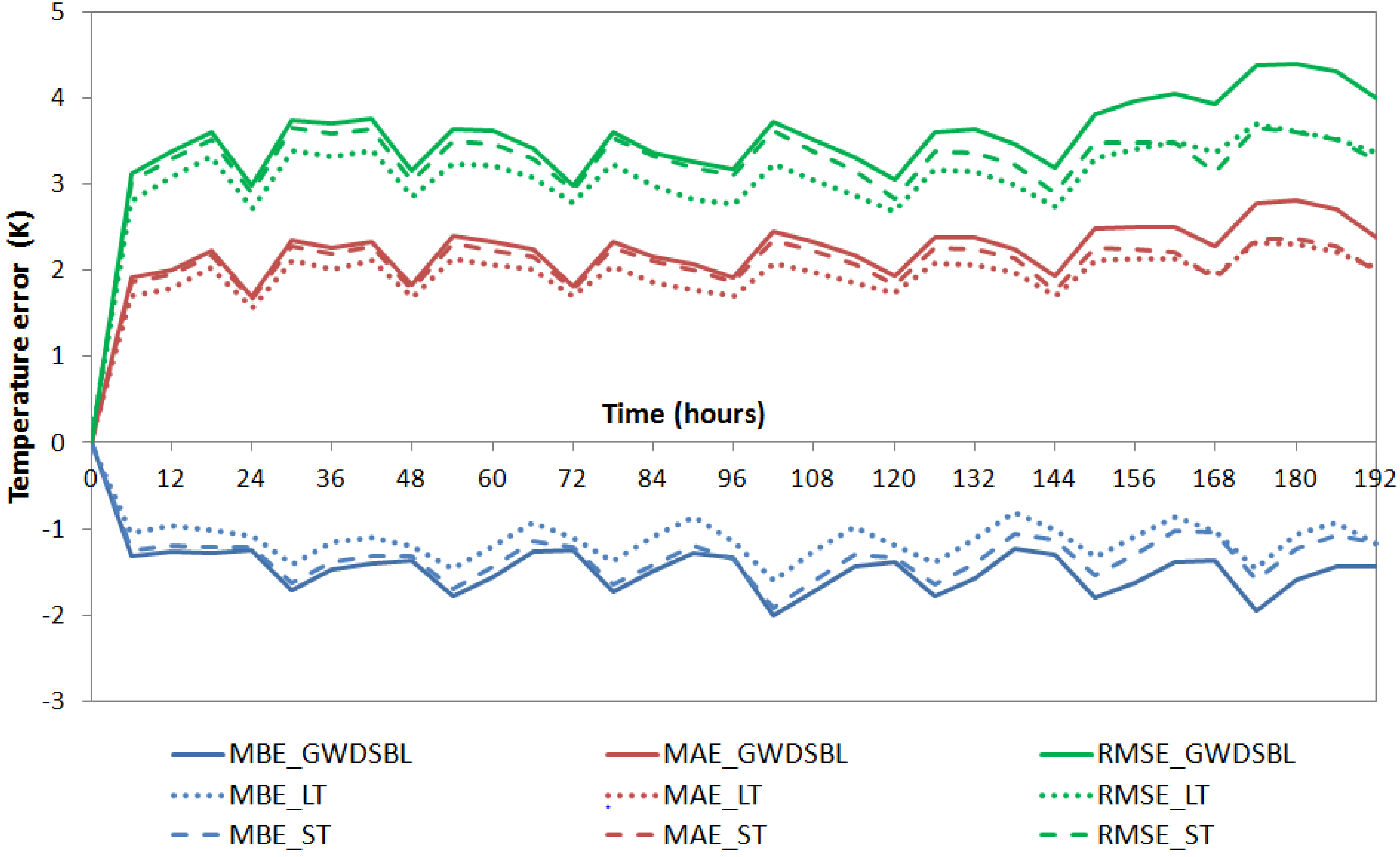
Temporal evolution of the domain-averaged 10m wind speed errors



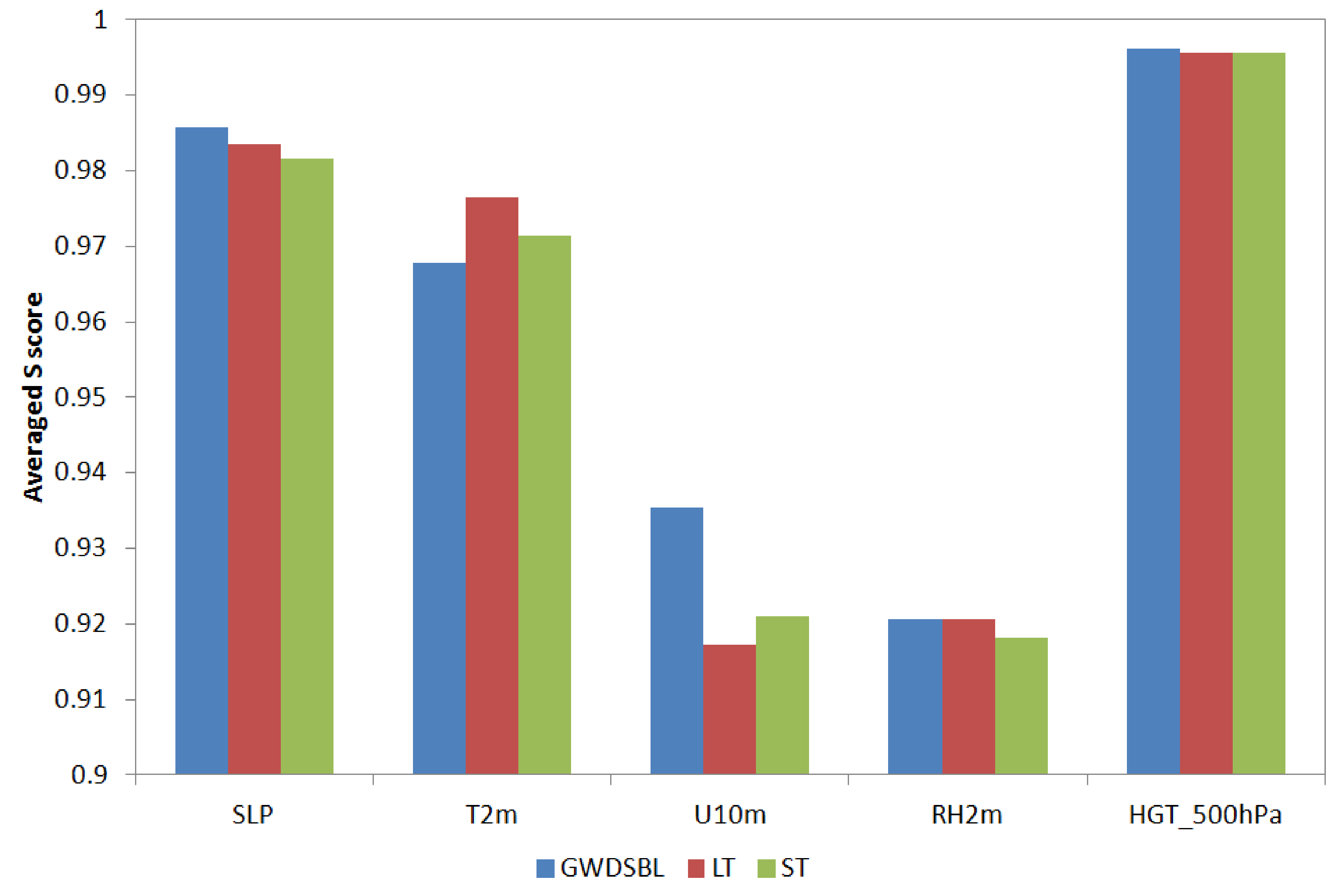
Statistical scores for the 10 m wind speed (m/s) with the three schemes at 5 different locations (WMO) across Europe

Station	Experiment	MBE	MAE	RMSE
Cabauw (The Netherlands)	GWDSBL	0.28	1.21	1.59
	LT	1.29	1.28	2.22
	ST	0.64	1.37	1.74
Barajas (Spain)	GWDSBL	0.93	1.95	2.45
	LT	1.14	2.09	2.70
	ST	0.83	1.91	2.52
Okecie (Poland)	GWDSBL	2.13	2.52	3.03
	LT	2.41	2.89	3.37
	ST	1.61	2.15	2.66
Blagnac (France)	GWDSBL	2.60	3.17	4.52
	LT	3.70	3.92	5.19
	ST	3.00	3.45	4.73
Zurich-Flunteren (Switzerland)	GWDSBL	1.92	2.38	2.85
	LT	3.58	3.66	4.23
	ST	3.17	3.38	3.97

Temporal evolution of the domain-averaged 2m temperature errors



Averaged Taylor (2001) model skill scores for all 16 model runs



Can small-scale orographic gravity waves provide the missing drag in the stable boundary layer?

- Yes, overall our results confirm that the updated GWDSBL scheme (eg combining a short tail with small-scale gravity wave drag) scores better or equivalent than the long and short tail schemes
- Improvements in cyclonic core pressure, sea level pressure, the height of the 500 hPa field, and the 10m wind speed
- However, 2m temperature scores are somewhat lower due to wind impacts
- Similar conclusions have been found for the majority of the model runs

(Tsiringakis et al, 2016, Submitted QJ, June 2016)