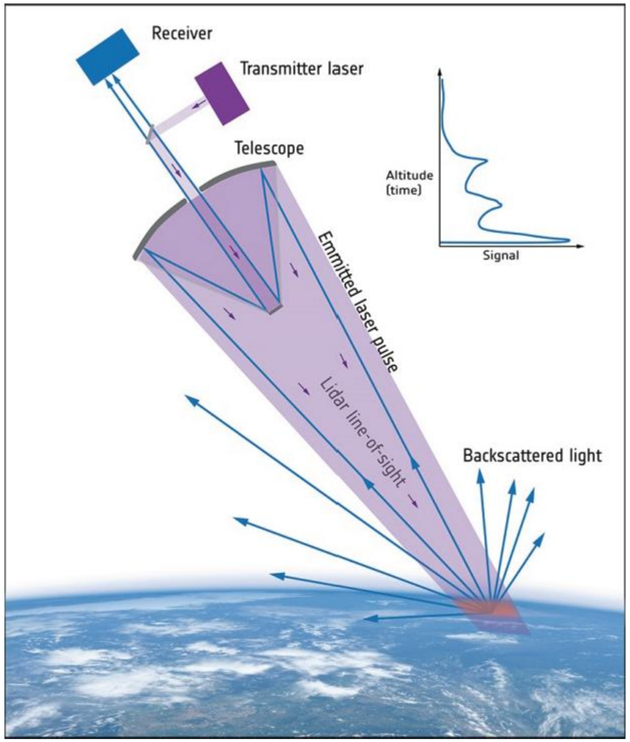
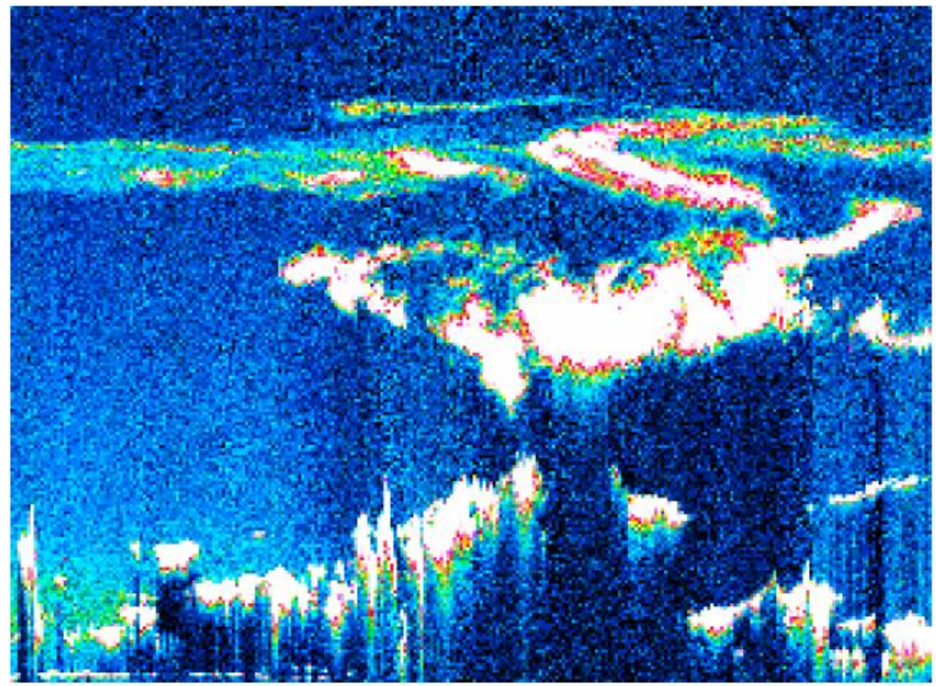


Expected impact of Aeolus for NWP (focus on the tropics)



Gert-Jan Marseille, Ad Stoffelen,
András Horányi, Lars Isaksen,
Michael Rennie

Overview

- Introduction
- Need for wind profiles
- Impact experiments
  - OSRE – Observing System Replacement Experiments
    - What is benefit of wind relative to mass (temperature, humidity) measurements?
    - What is the benefit of HLOS (single component) wind data compared to full vector wind (dual component) data?
    - Will degraded quality (random and systematic errors) HLOS wind data still lead to improved forecast quality?
  - OSSE (+SOSE/EDA) – Observing System Simulation Experiments
    - Added value of DWL winds on top of the global observing system
- Atmosphere heterogeneity – impact on Aeolus wind quality
- Conclusions (+ reference list)

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ECMWF

aeolus
because wind matters

DRAFT FINAL REPORT ON ESA STUDY CONTRACT 9063/90/HGE-I:

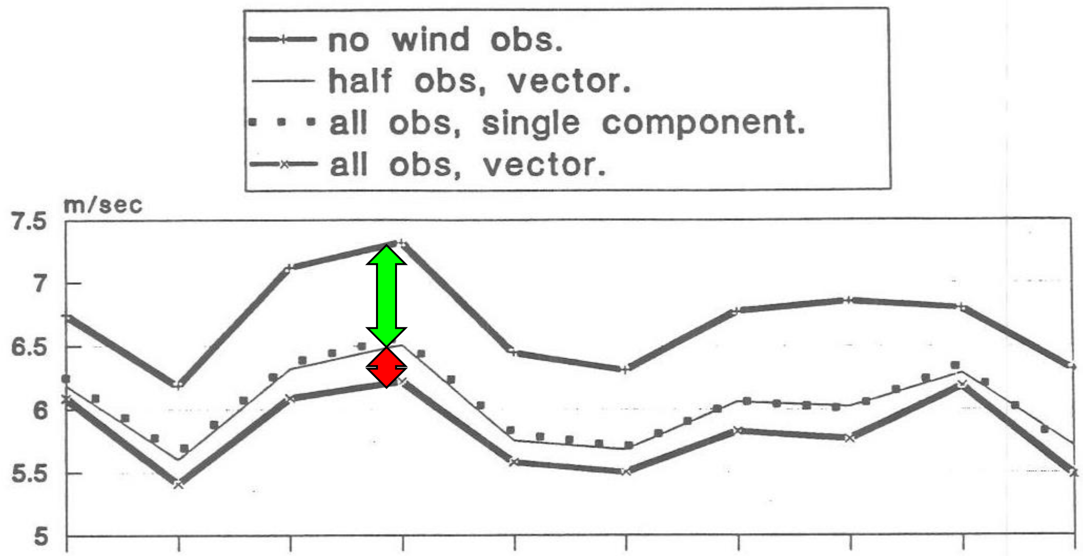
"STUDY OF PREPARATION FOR THE USE OF DOPPLER WIND LIDAR INFORMATION IN METEOROLOGICAL ASSIMILATION SYSTEMS"

A.C.Lorenc, R.J.Graham, I.Dharssi, B.Macpherson, N.B.Ingleby, R.W.Lunnon

U.K. Meteorological Office

December 1991.

RMS fit to wind observations 22N-22S.
6 hr forecasts using wind data:

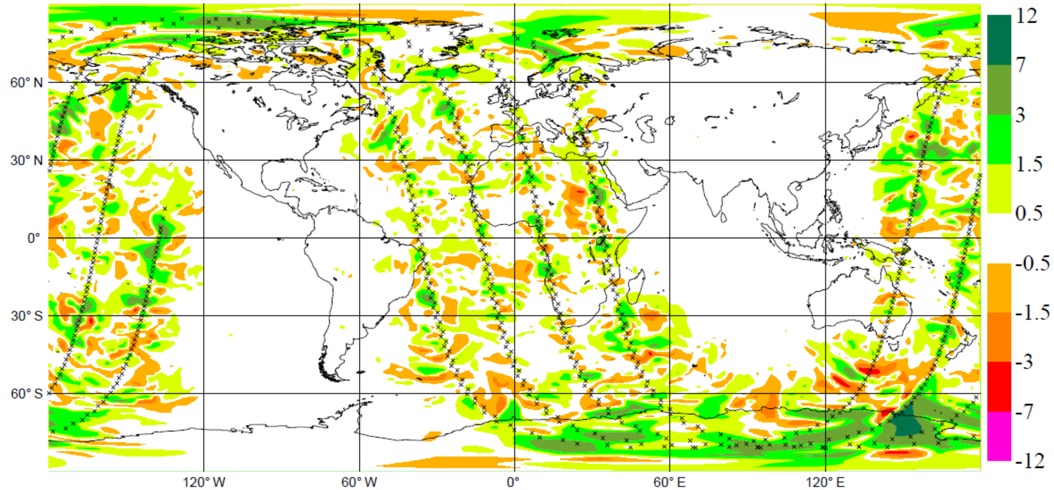


Plotted every 6 hrs, for a 60 hr test period.

assimilating a single wind component gives more than half the impact of assimilating the complete wind vector

conclusion was the same: the impact of the observations was as expected from the number of data values; there was no detrimental effect from having single component winds.

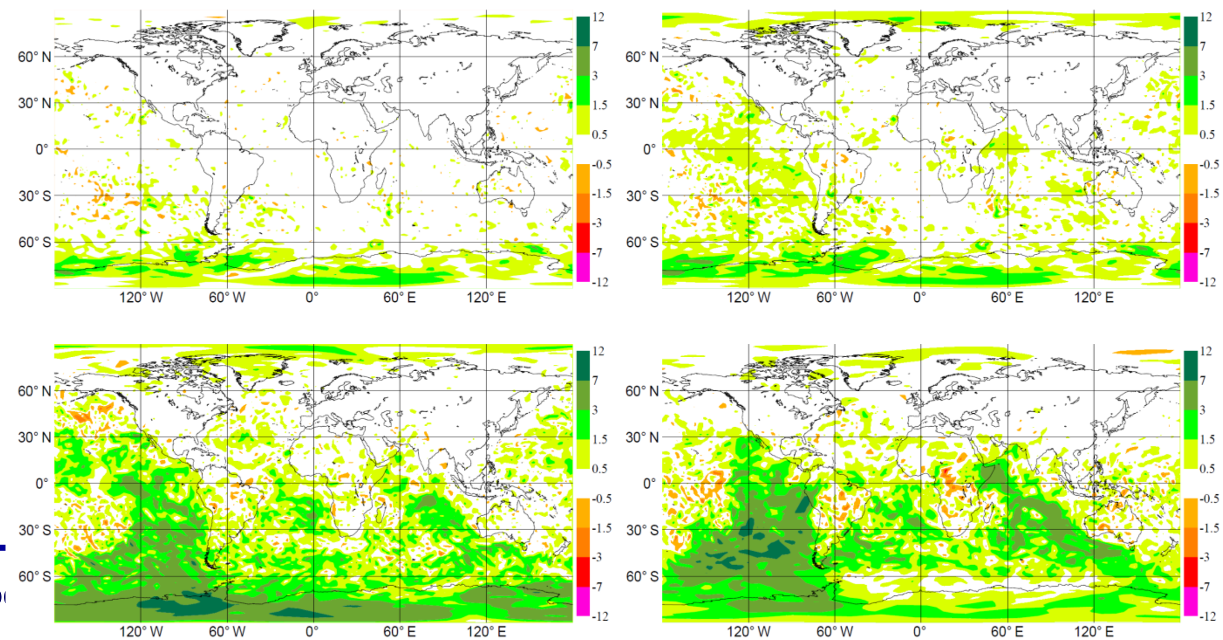
Grenada 1999 – mission selection



- ADM-Aeolus vs. Earth Radiation Mission (now EarthCare)
- OSSE
  - Positive impact of Aeolus in operational ECMWF system

Stoffelen et al., 2006

Having dynamics correct is a prerequisite for getting cloud/aerosol correct



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ECMWF

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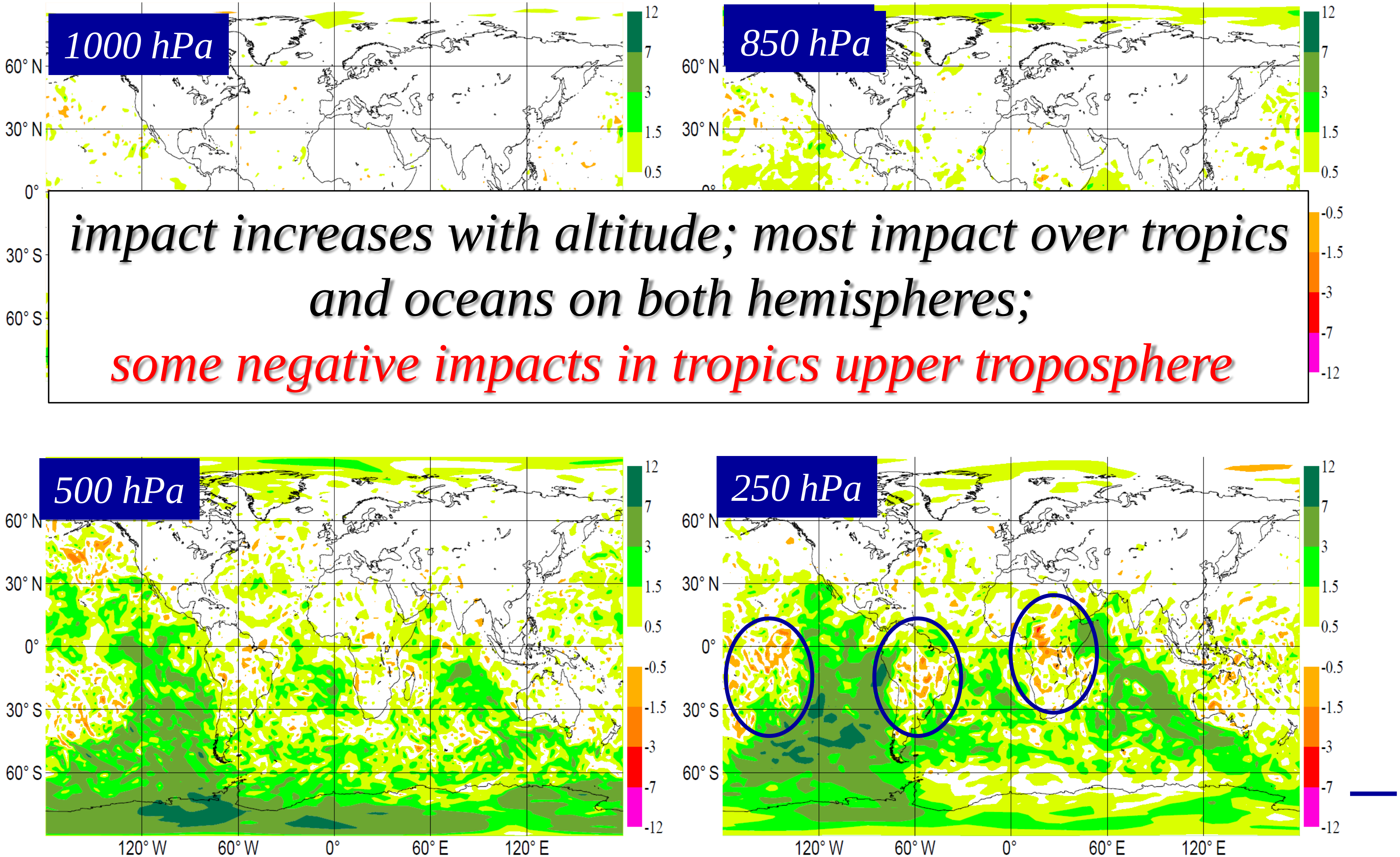
because wind matters

OSSE; Aeolus analysis impact average over 2-weeks period

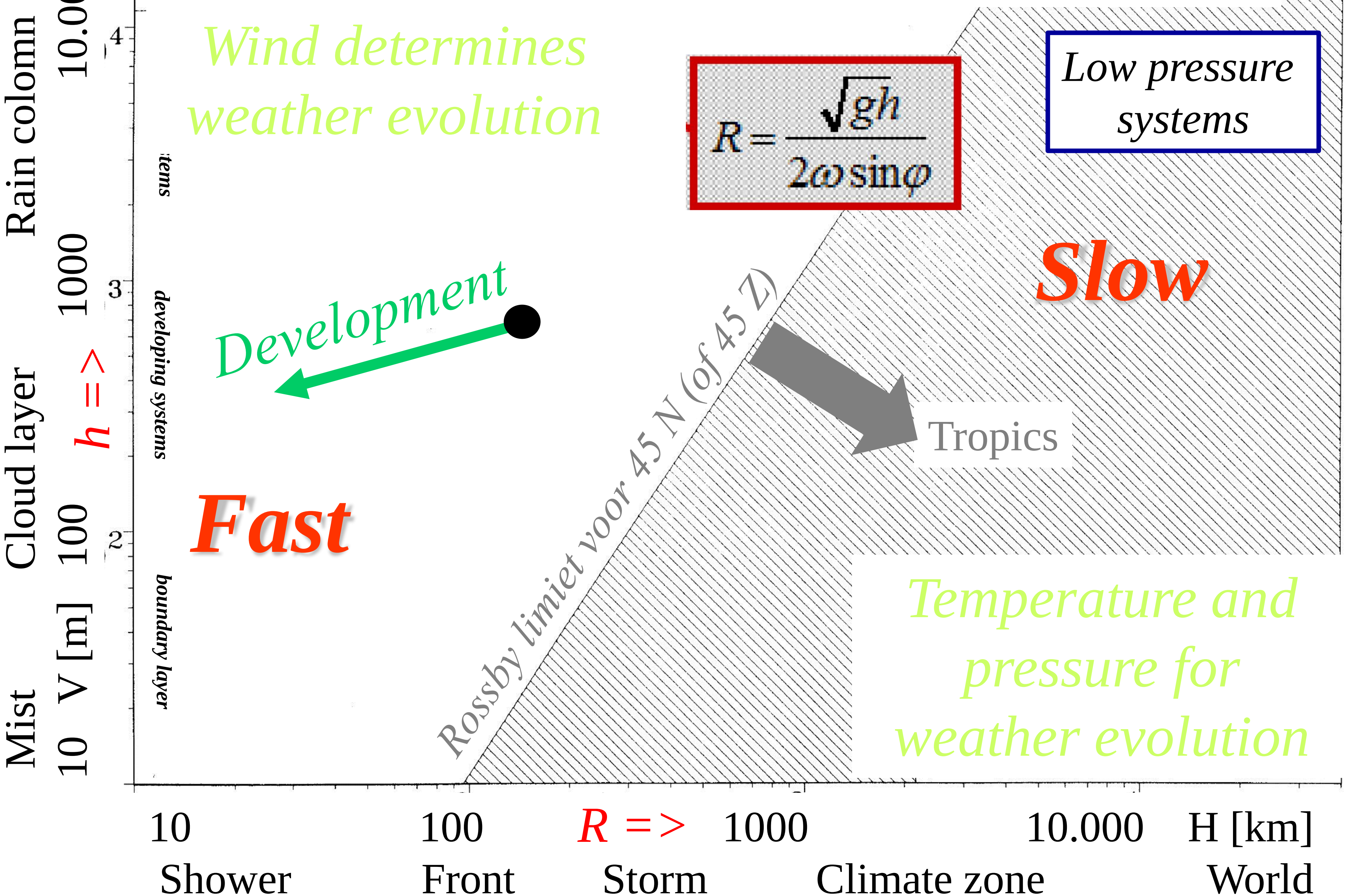


impact increases with altitude; most impact over tropics and oceans on both hemispheres;

some negative impacts in tropics upper troposphere

Need for wind profiles

Need for wind profiles: Rossby radius of deformation



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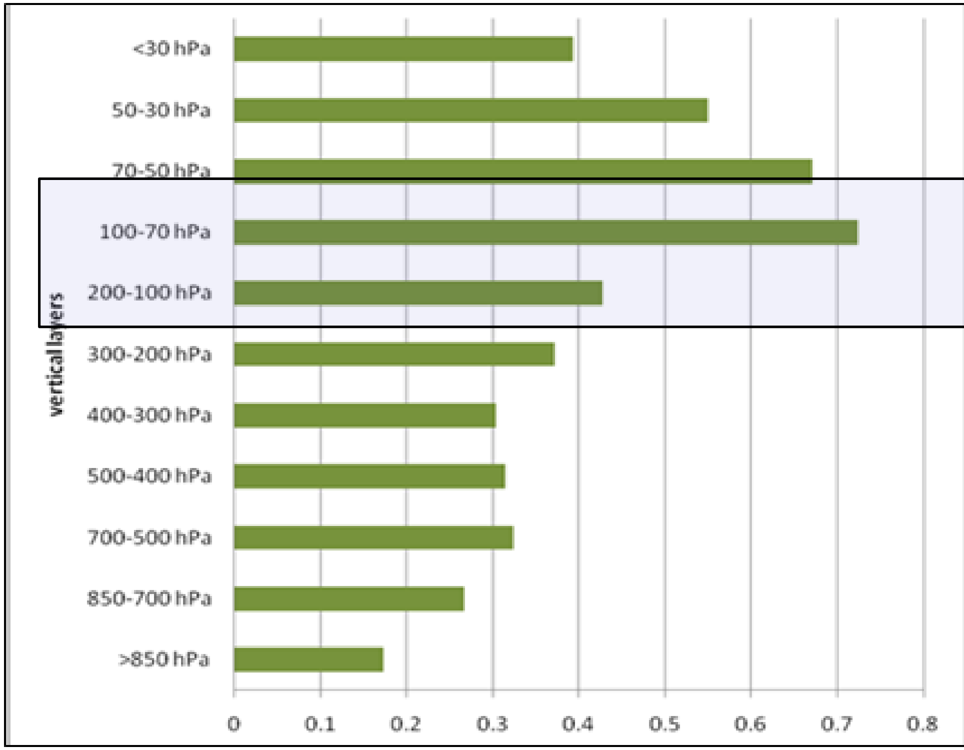
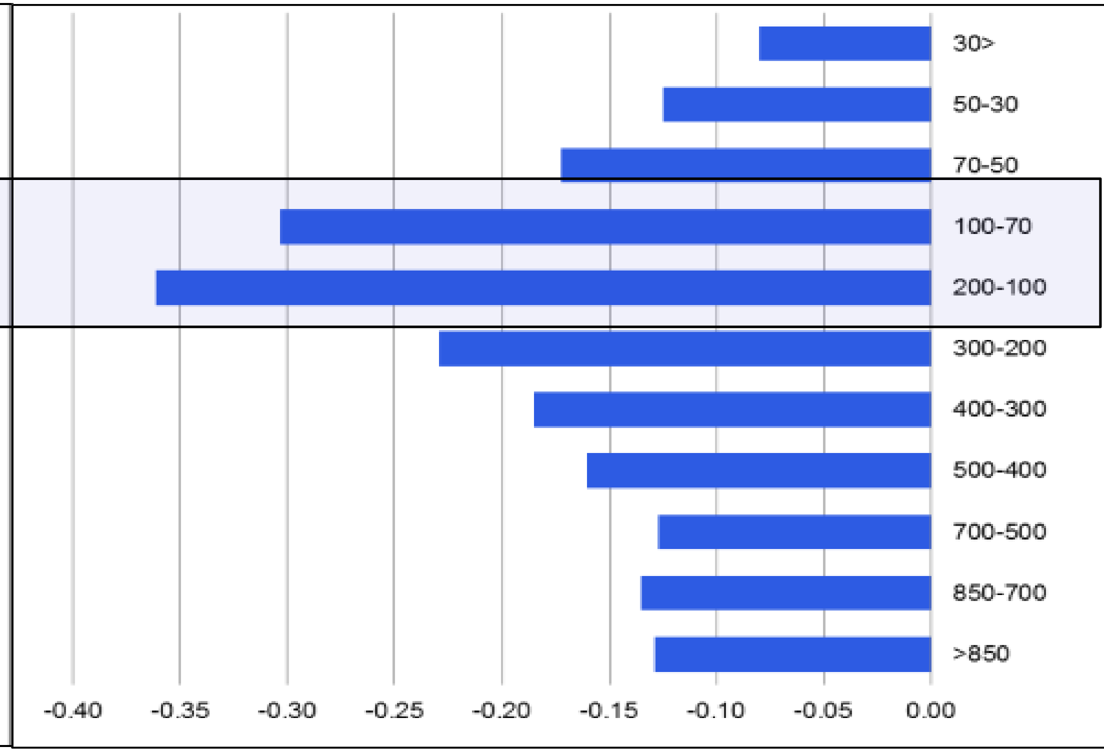
Wind vector impact per ob; dependence on height

DFS per ob



Forecast error contribution per ob



70-200 hPa winds provide most impact per observation. New observations would be most beneficial here – Aeolus should provide lots of Rayleigh and Mie winds here

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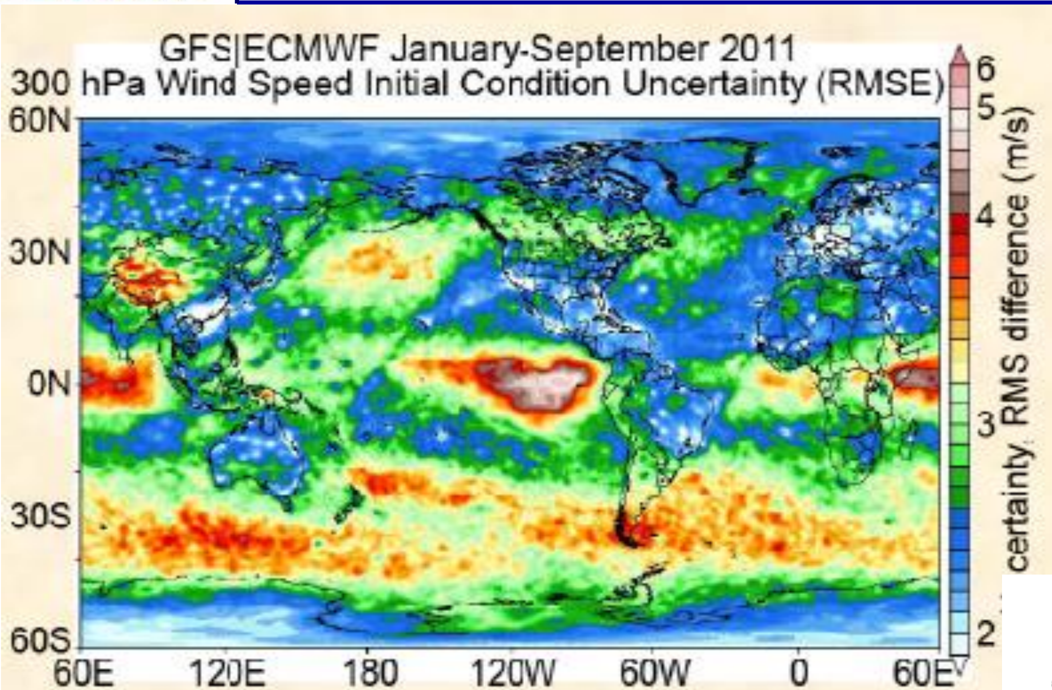
ECMWF

How accurate are global wind analyses?

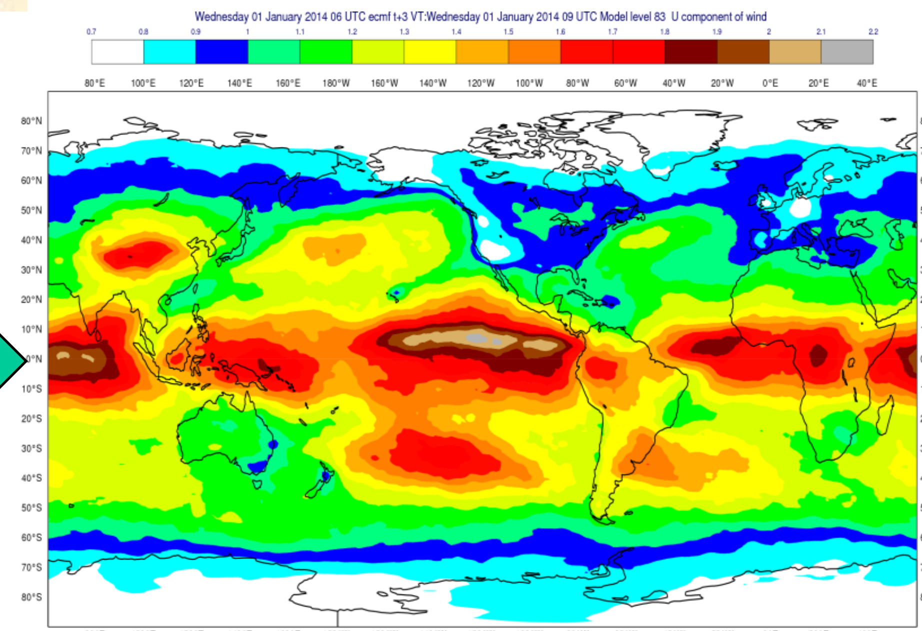
aeolus because wind matters



W. Baker et al., 2014

- e.g. 300 hPa wind speed RMS difference between GFS and ECMWF
- Largest uncertainties in poorly observed areas

Similar structures in ECMWF Ensemble of Data Assimilation (EDA) spread, 12-h FC 300 hPa zonal wind, mean Jan-Sep <u>2014</u>



OSRE

Observing System Replacement Experiments

Horányi et al., QJRMS 2015 – Part I

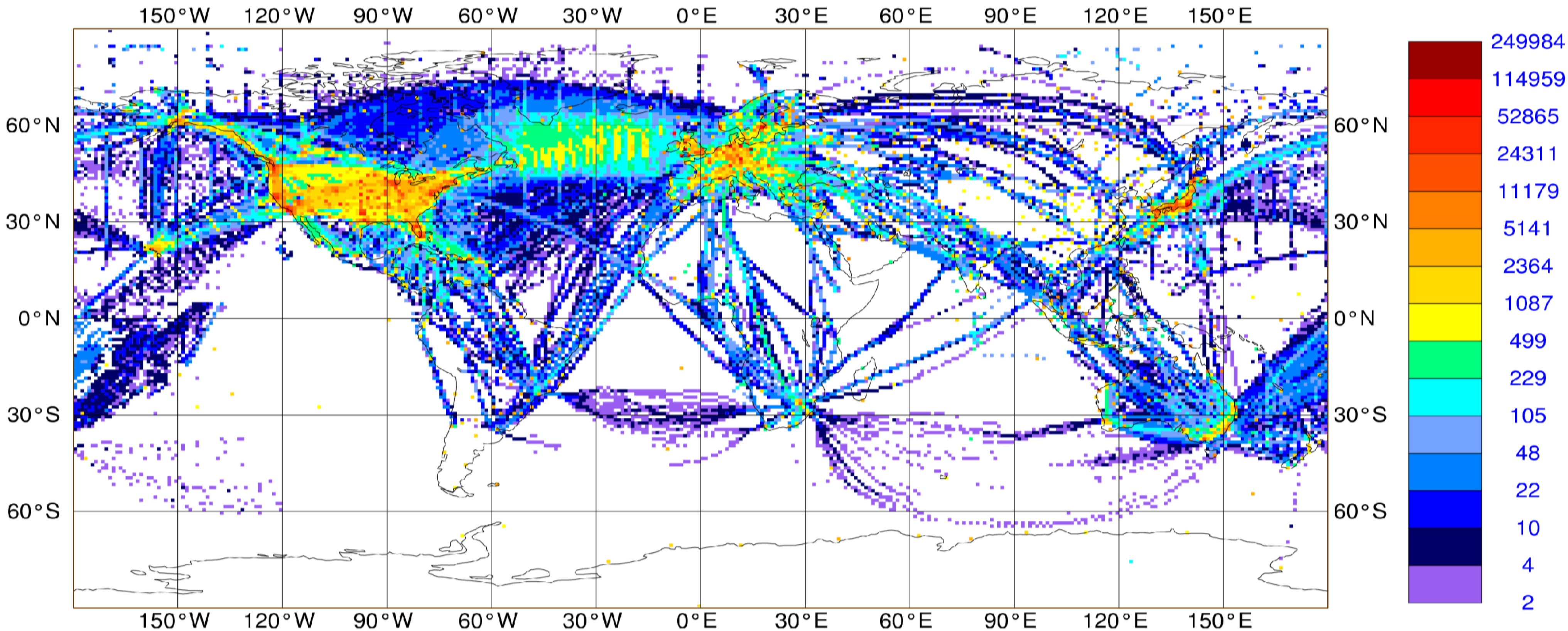
Horányi et al., QJRMS 2015 – Part II

OSRE

- 1 month OSEs using *in situ* observations
  - aircraft; radiosondes; PILOT and wind profilers

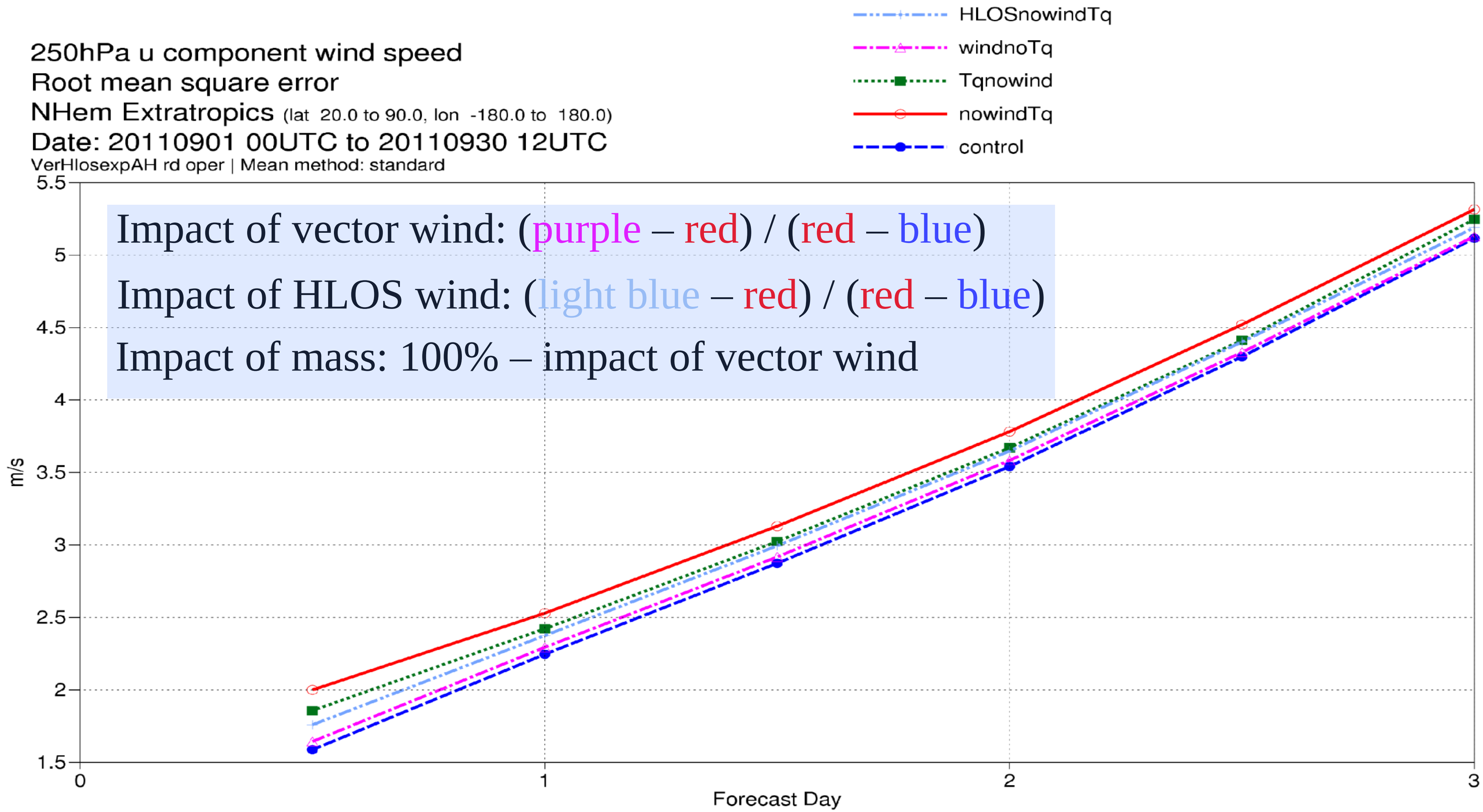
- Assessed impact of:
  - combinations of wind and mass obs (u, v, T and q)
    - ➢ which gives most impact relative to current observing system?
  - Assimilation of HLOS winds
    - ➢ convert (u, v) → HLOS
    - ➢ can real single-component wind give useful impact?
  - Increasing HLOS random and systematic error
    - ➢ what reduction in accuracy can we tolerate?
    - ➢ indications for Aeolus

HLOS data coverage from radiosondes, aircraft and wind profilers



Advantage: good quality, real data are used
Disadvantage: non-uniform coverage

HLOS DATA ASSIMILATION: HLOS WIND VS. VECTOR WIND VS. MASS



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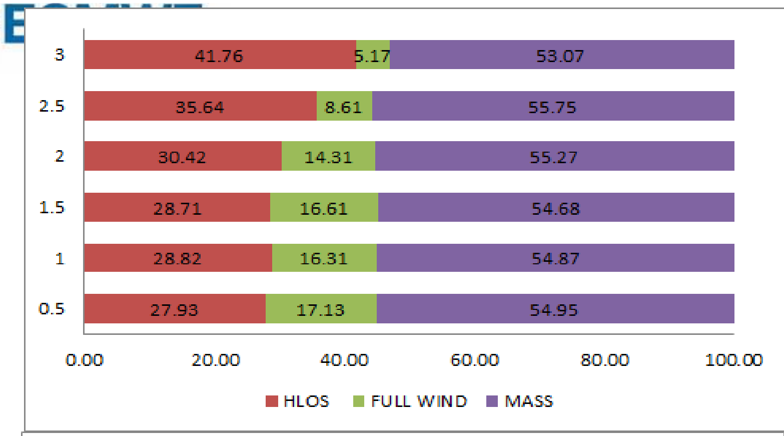
NWP impact of HLOS wind vs. vector wind vs. mass
Northern Hemisphere extra-tropics

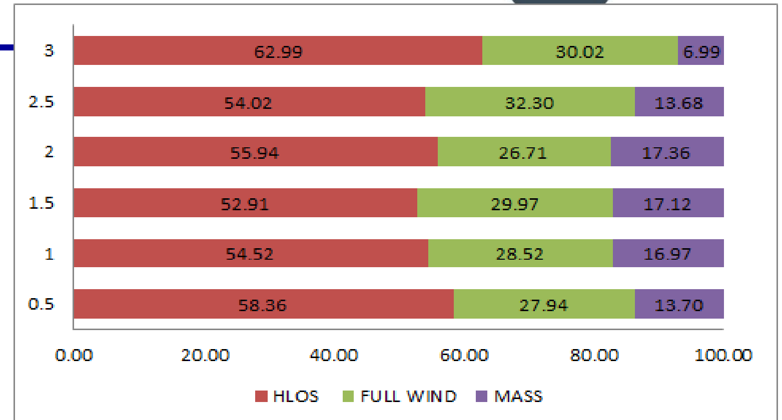
aeolus
because wind matters

temperature forecast

zonal wind forecast

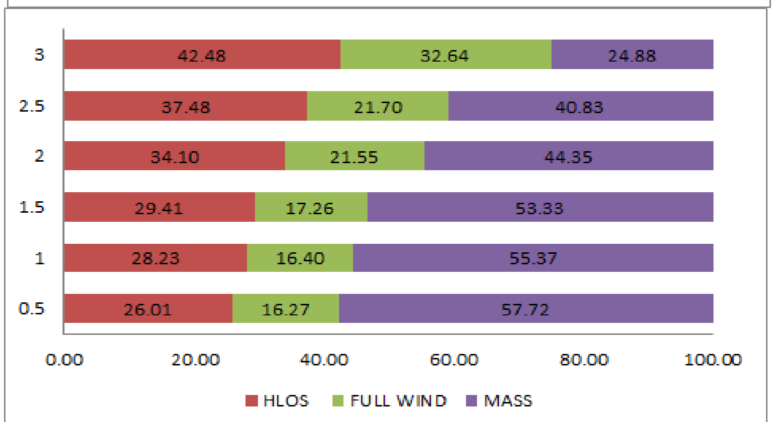
250 hPa

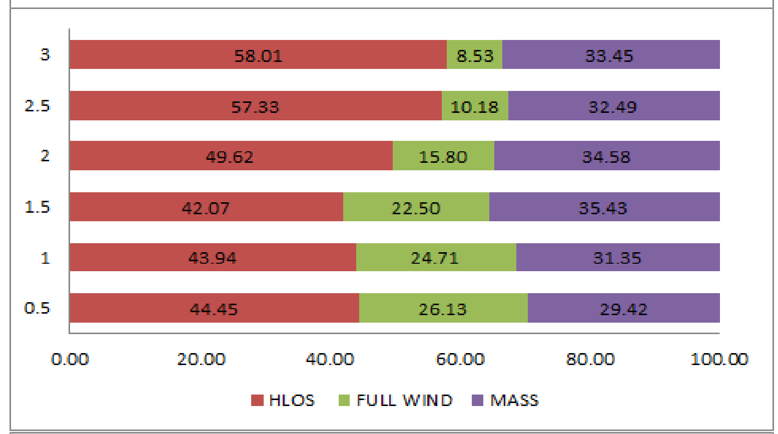




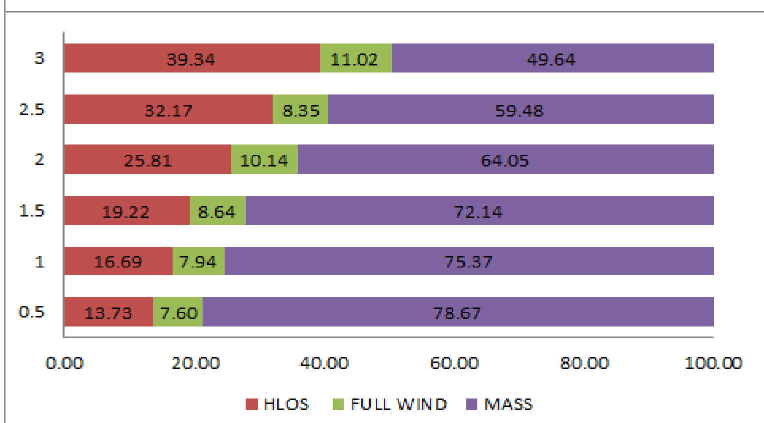
HLOS
FULL WIND
MASS

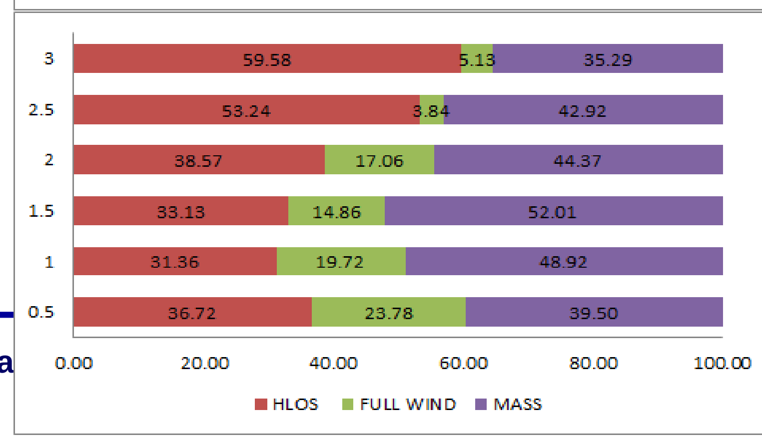
500 hPa





850 hPa





lelling, observations a

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NWP impact of HLOS wind vs. vector wind vs. mass
in the tropics

aeolus
because wind matters

temperature forecast

250 hPa

HLOS
FULL WIND
MASS

500 hPa

850 hPa

elling, observations a

zonal wind forecast

HLOS wind vs. vector wind vs. mass: general conclusions

<u>Impact on temperature forecast performance</u>

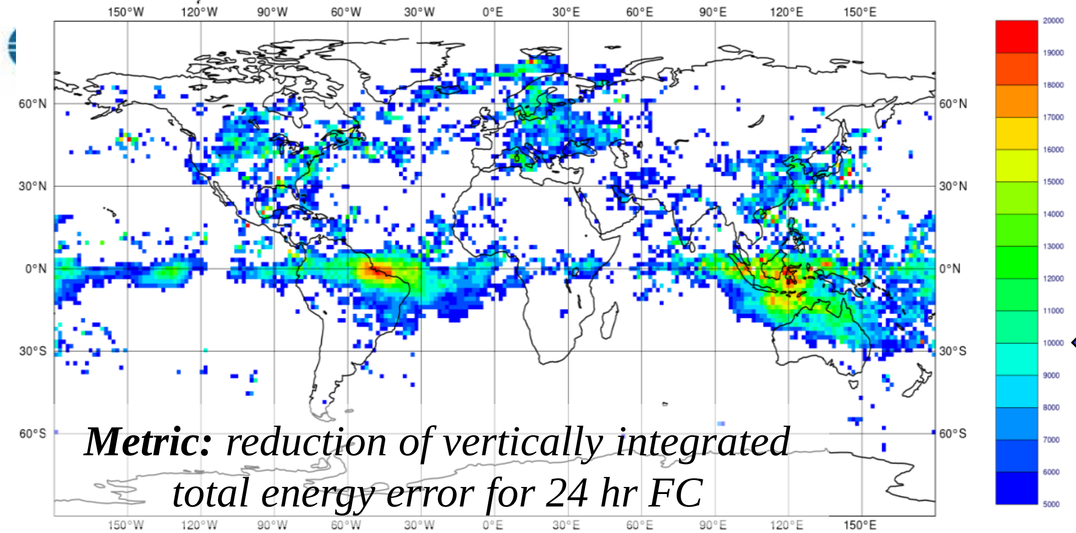
- The mass data contributes most to the temperature predictions
- BUT: wind information has increasing role with the altitude especially at the tropics

<u>Impact on wind forecast performance</u>

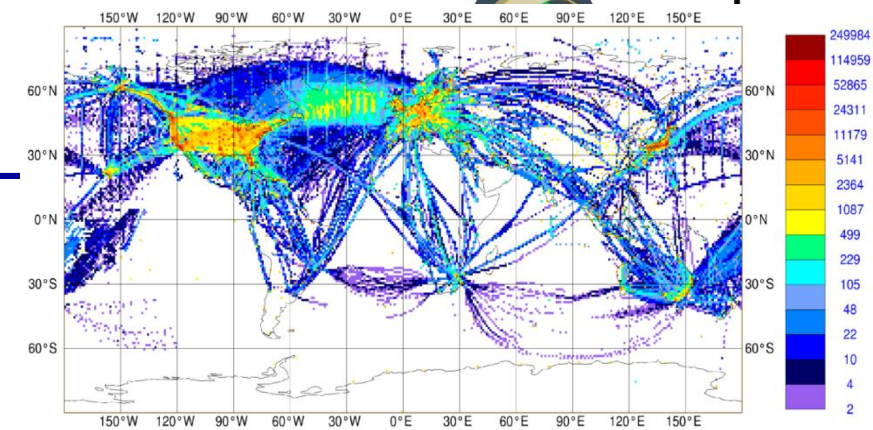
- The impact of wind data is overwhelming, particularly at the higher altitudes and the tropics

<u>HLOS vs. vector wind</u>

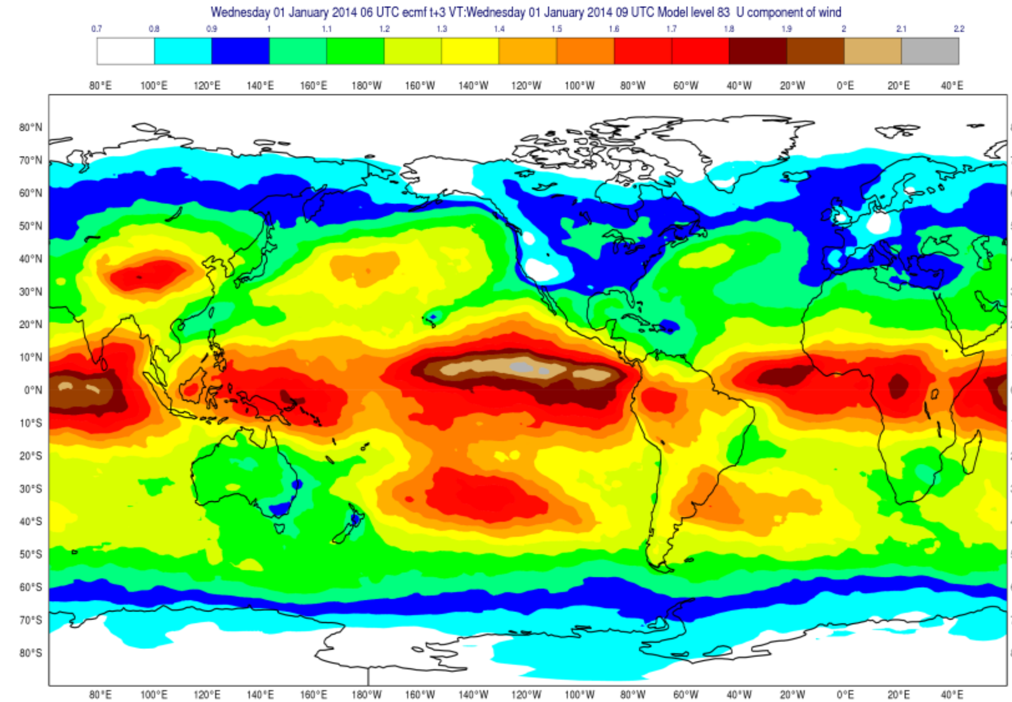
- Single component wind information contributes approximately 75% in average to the full vector wind



Metric: *reduction of vertically integrated total energy error for 24 hr FC*



Distribution of observations
mostly aircraft at 100-400 hPa



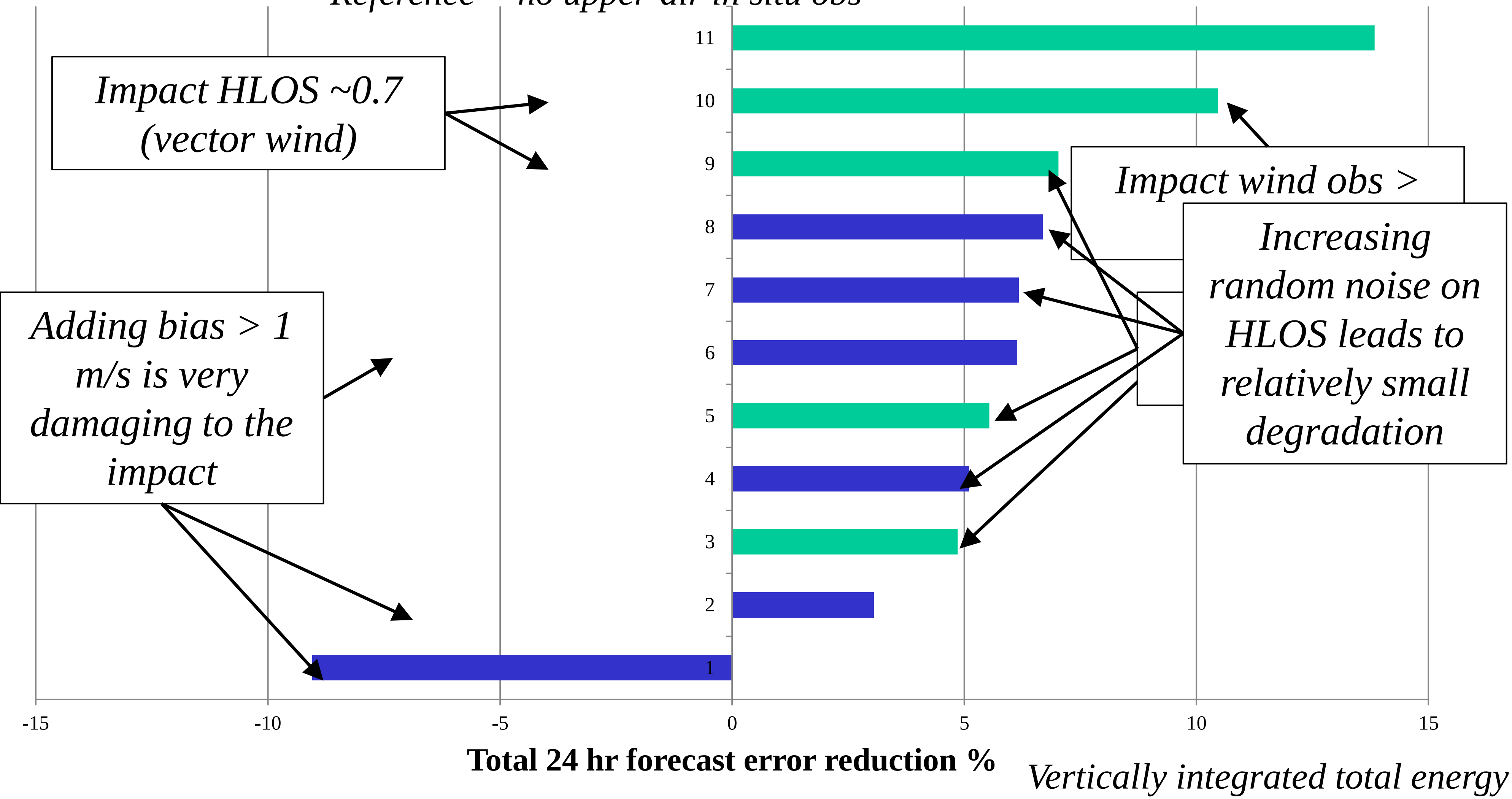
OSE results: Impact of zonal HLOS

- *largest in tropical regions*
- *impact also in data-rich areas*

Expected largest improvements of Aeolus in areas where model errors are largest!!

OSE results: comparison of different experiments

Reference = no upper-air in situ obs



Impact experiments GOS + Aeolus

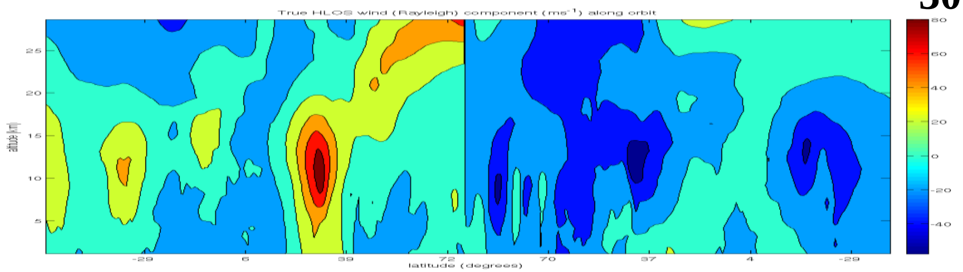
- OSSE – Observing System Simulation Experiment
  - ☹ requires the simulation of the total GOS plus Aeolus
- EDA – Ensemble Data Assimilation based experiments
  - ☺ requires the simulation of Aeolus only
- SOSE – Sensitivity Observing Simulation Experiment
  - ☺ requires the simulation of Aeolus only

➢ Relative to OSRE
  - ☺ Impact on top of existing GOS
  - ☺ Allows impact simulation of various instrument configurations, e.g., Aeolus follow-on
  - ☹ Potentially much more complex

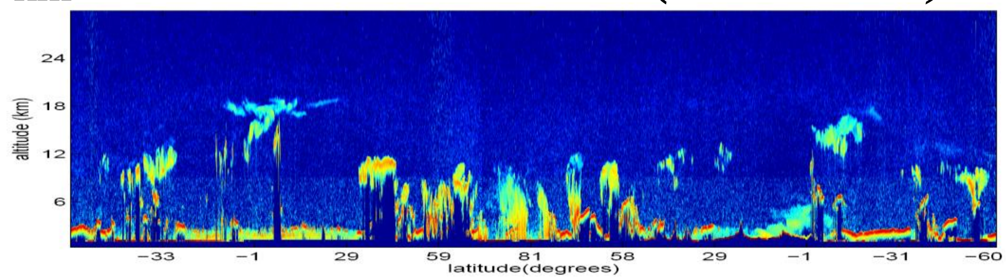
Aeolus simulations: LIPAS tool

true HLOS wind (UKMO)

30 km

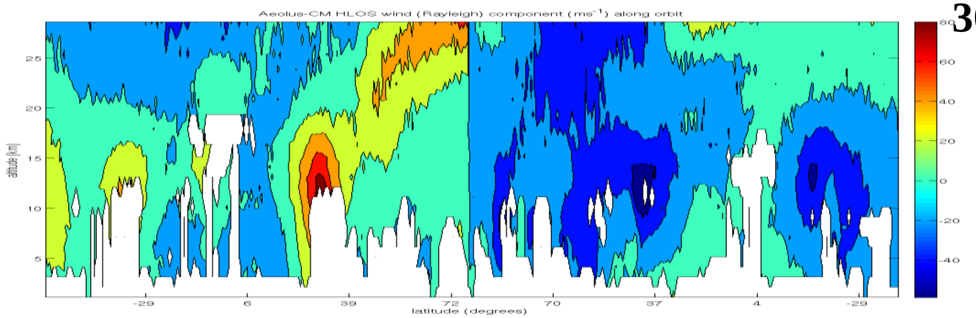


true cloud/aerosol (CALIPSO)



Aeolus Rayleigh channel

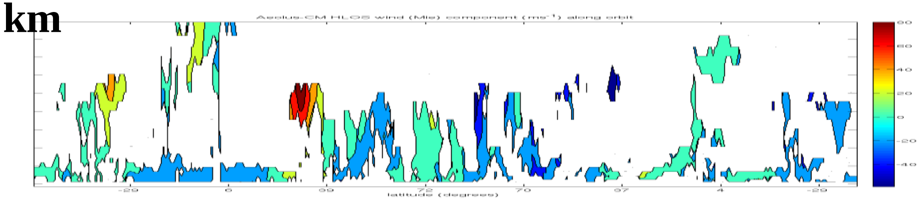
30 km



1 orbit, simulations with LIPAS

Aeolus Mie channel

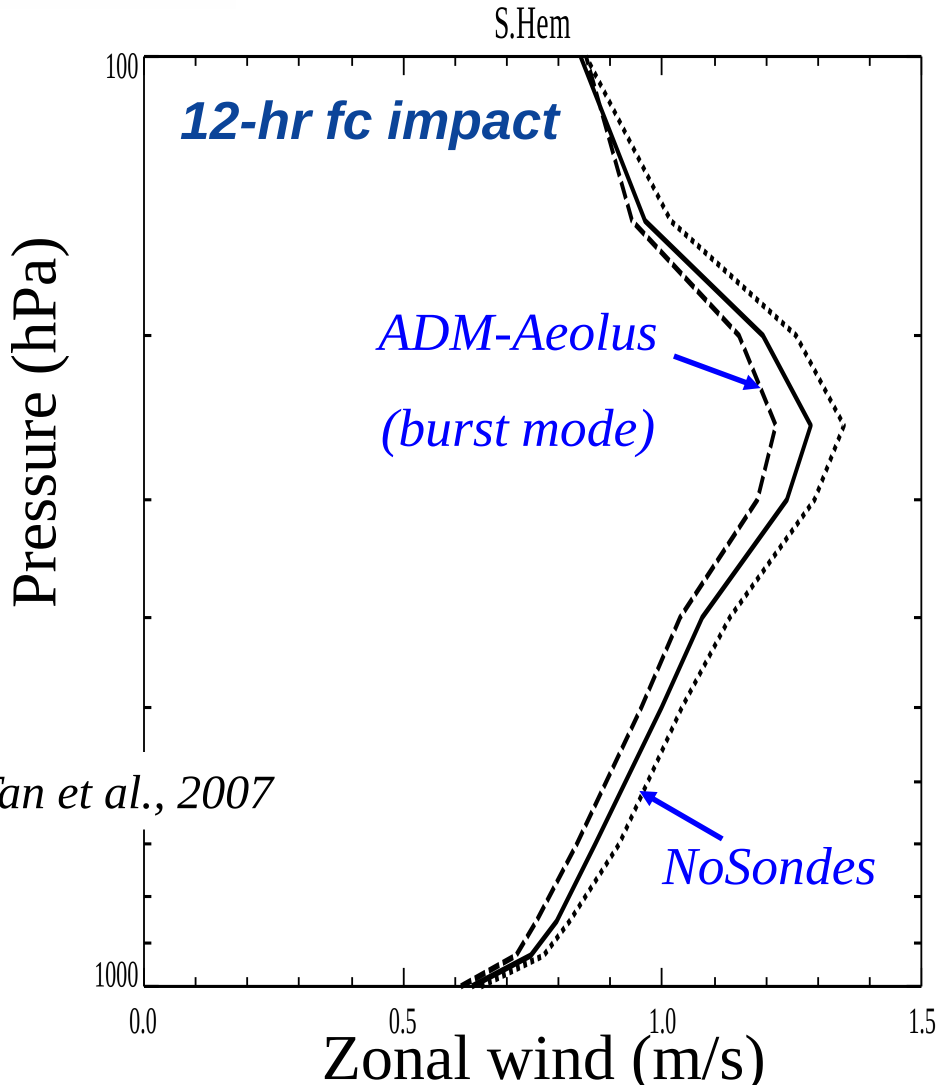
18 km



Marseille et al., 2011

- Rayleigh clear Mie, cloud/aerosol => complementary
- Clear area dominates => Rayleigh channel is most important for Aeolus
- No winds below (optically) dense clouds

Aeolus EDA impact assessment (burst mode)



Tan et al., 2007

Spread in zonal wind (U, m/s)

Scaling factor ~ 2 for wind error

Tropics, N. & S. Hem all similar

Simulated DWL (UKMO truth) adds value at all altitudes and in longer-range forecasts (T+48,T+120)

Differences significant (T-test)

Supported by information content diagnostics

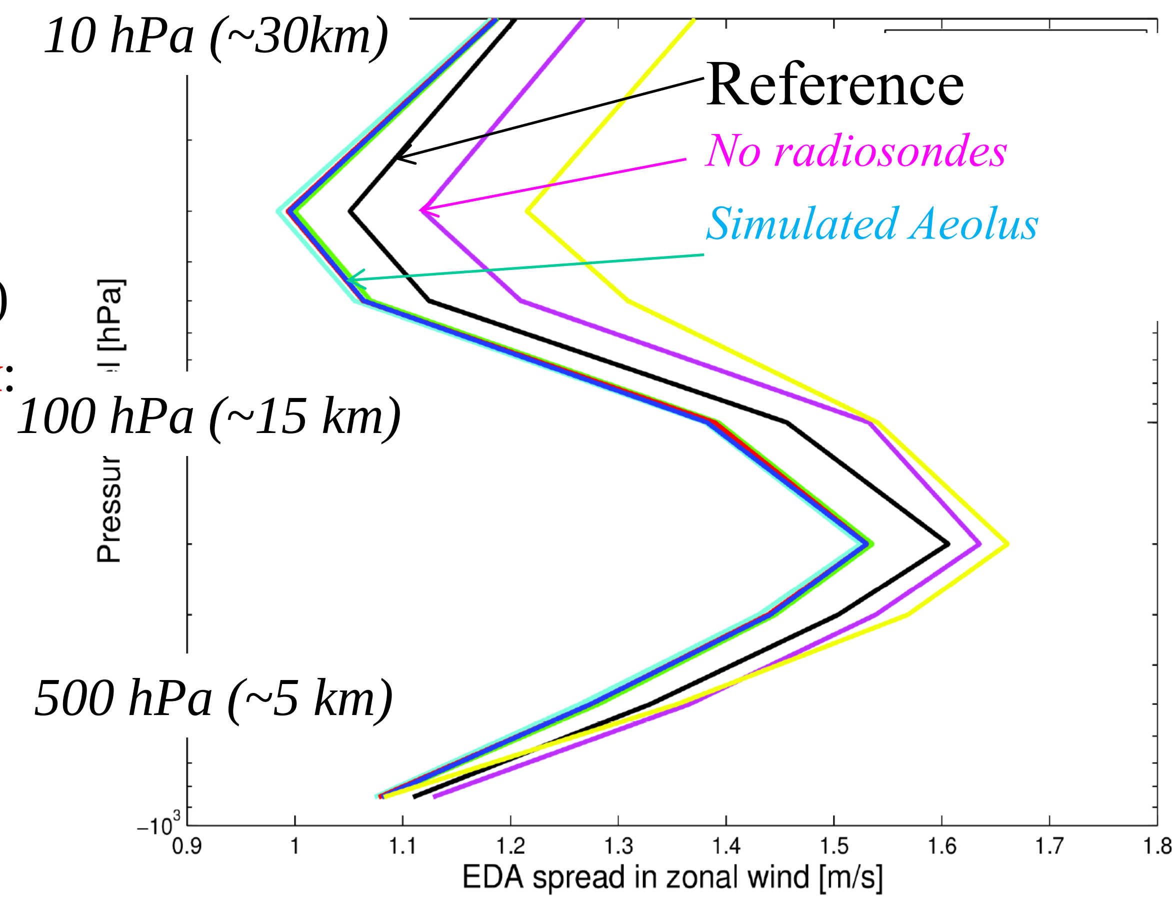
Cheaper than OSSEs

Aeolus EDA impact assessment (continuous mode)

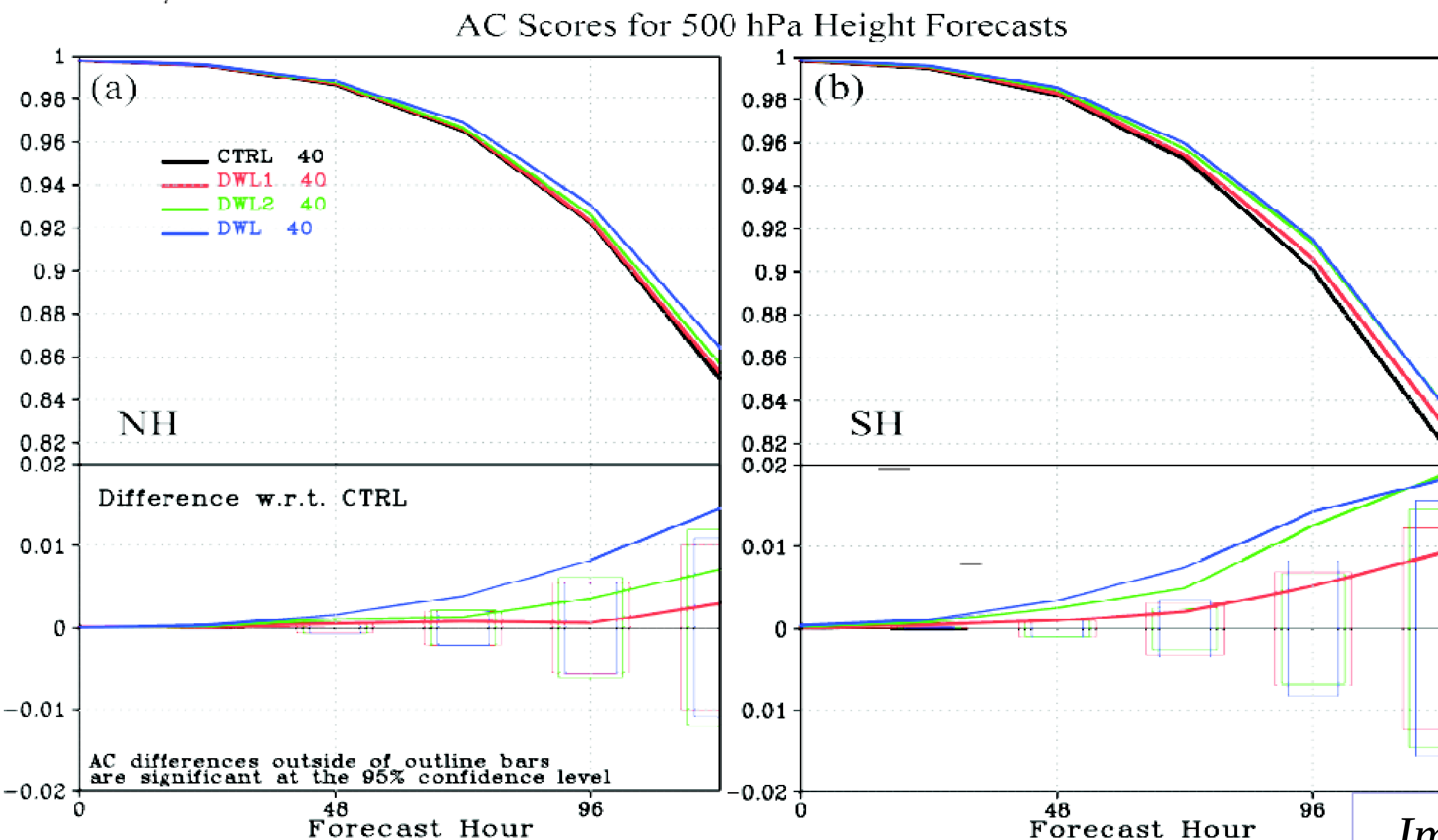
- Reduction in ensemble spread → positive impact
- Aeolus continuous mode simulation (UKMO truth)
- ECMWF, T399 (wind impact for small-scales could be underestimated)
- Impact *similar to radiosonde network*:
  - Largest at ~200 hPa, tropical oceans and winter poles
  - ~5 % improvement short-range – could lead to 1-3 hrs impact

ESA VHAMP final report,
L. Megner, H. Körnich, H. Schyberg,
G.J. Marseille, A. Stoffelen, J. de Kloe

Global mean 12 hr EDA spread of zonal wind



OSSE by JCSDA



Zaizhong et al., 2013
Images courtesy JCSDA

- NCEP GSI/GFS system, 2009
- Different DWL satellite configurations tested

NH impact 500 hPa Z:

4-look DWL, ~5 hrs

1-look DWL, ~ 1 hr

SH impact 500 hPa Z:

4-look DWL, ~6 hrs

1-look DWL, ~ 3 hrs

Impact on tropical winds; 15% reduction in RMSE, short-range at 200 hPa, but lost after 5 days (NCEP system?)

SOSE – Sensitivity Observing System Exp.

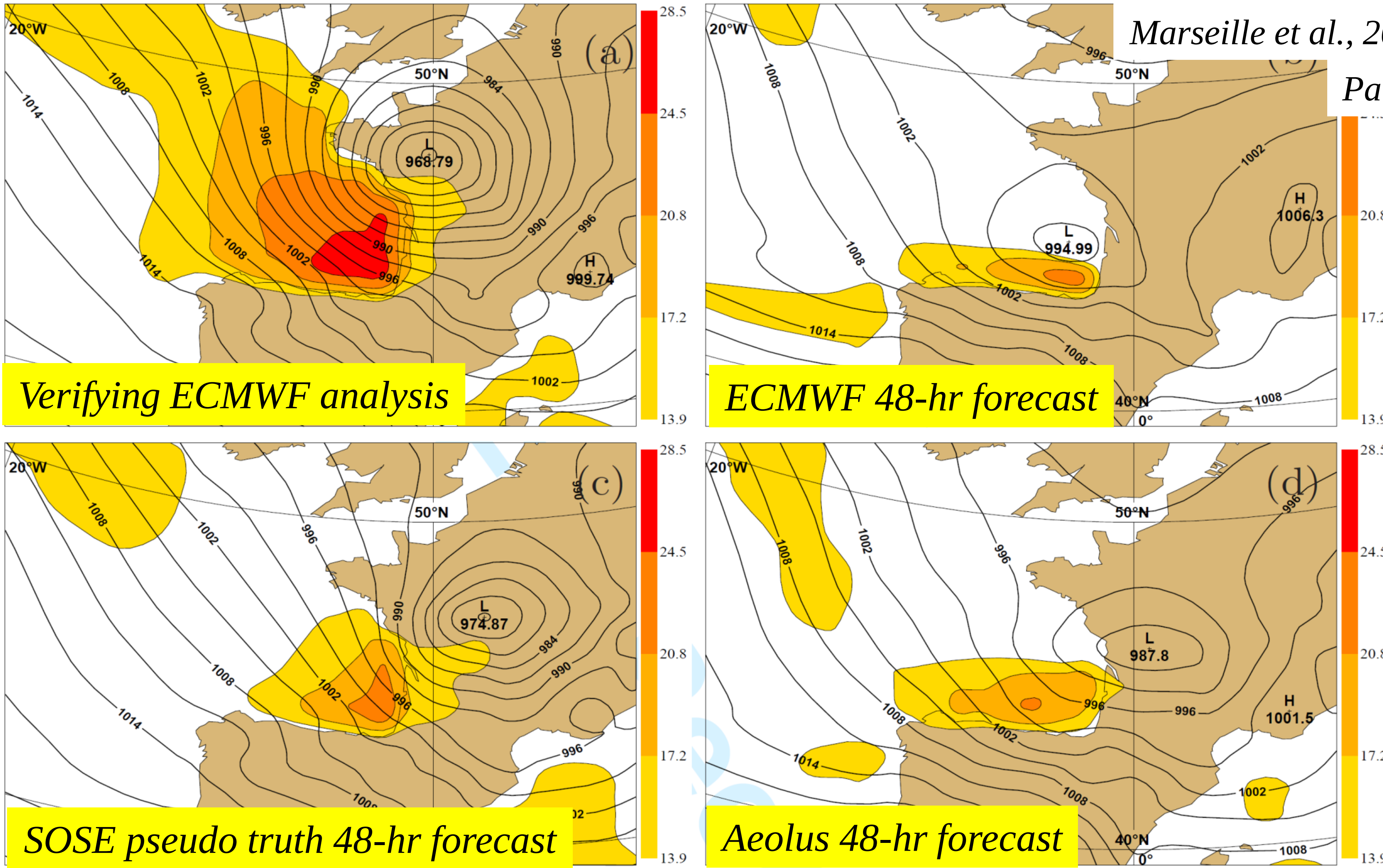
Marseille et al., 2008
Part-1

- TRUTH = AN + δ
- δ (key analysis error) is obtained from a sensitivity calculation such that
  - the forecast initiated from TRUTH improves the 2-day forecast
  - The TRUTH is compliant with all observations from the existing GOS
- Simulate Aeolus from TRUTH
- OSE type experiment
  - Control and Control+Aeolus; impact: compare to TRUTH

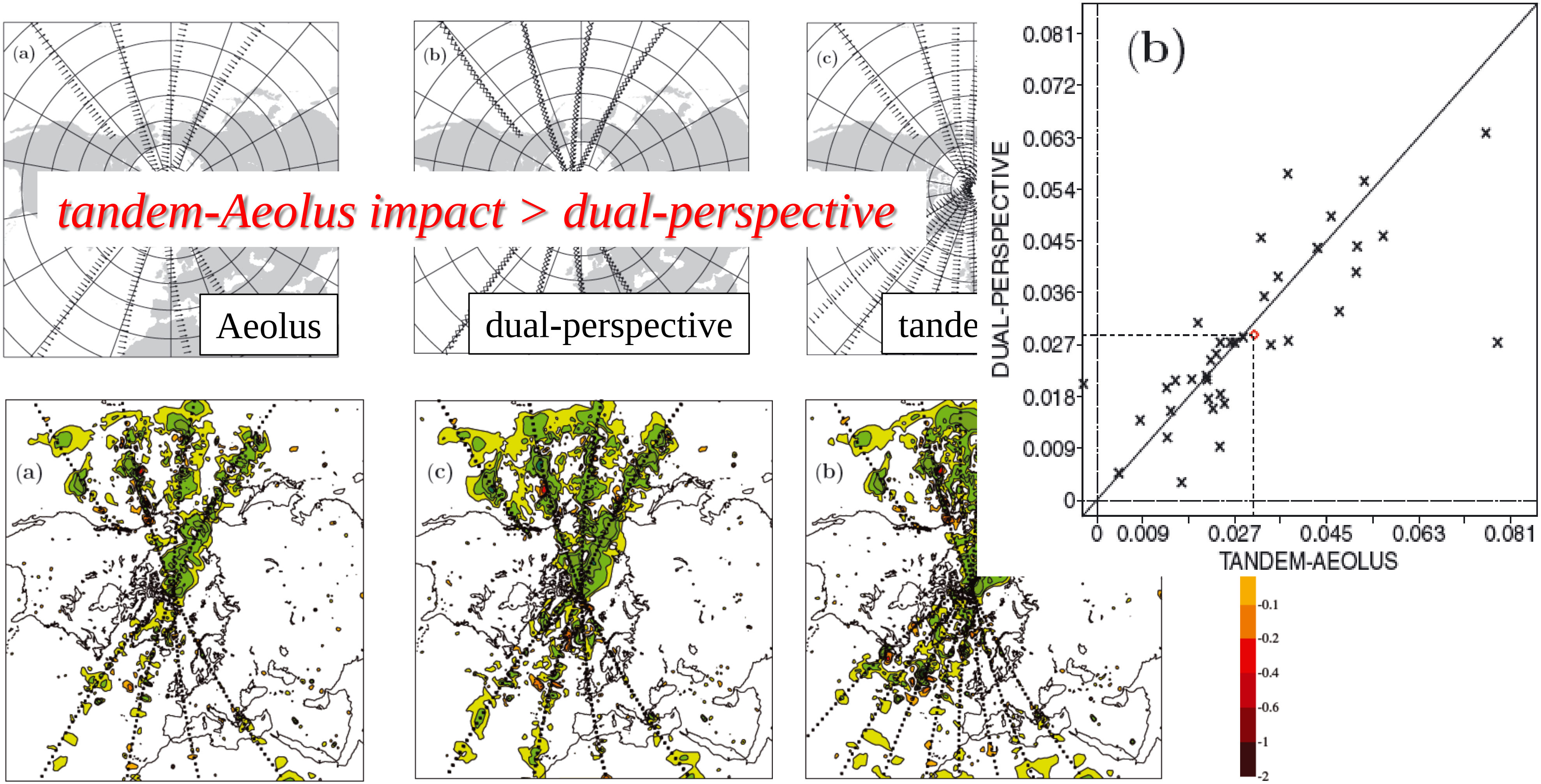
Xmas 1999 storm “Martin” – 27 Dec. 18UTC

Marseille et al., 2008

Part-3

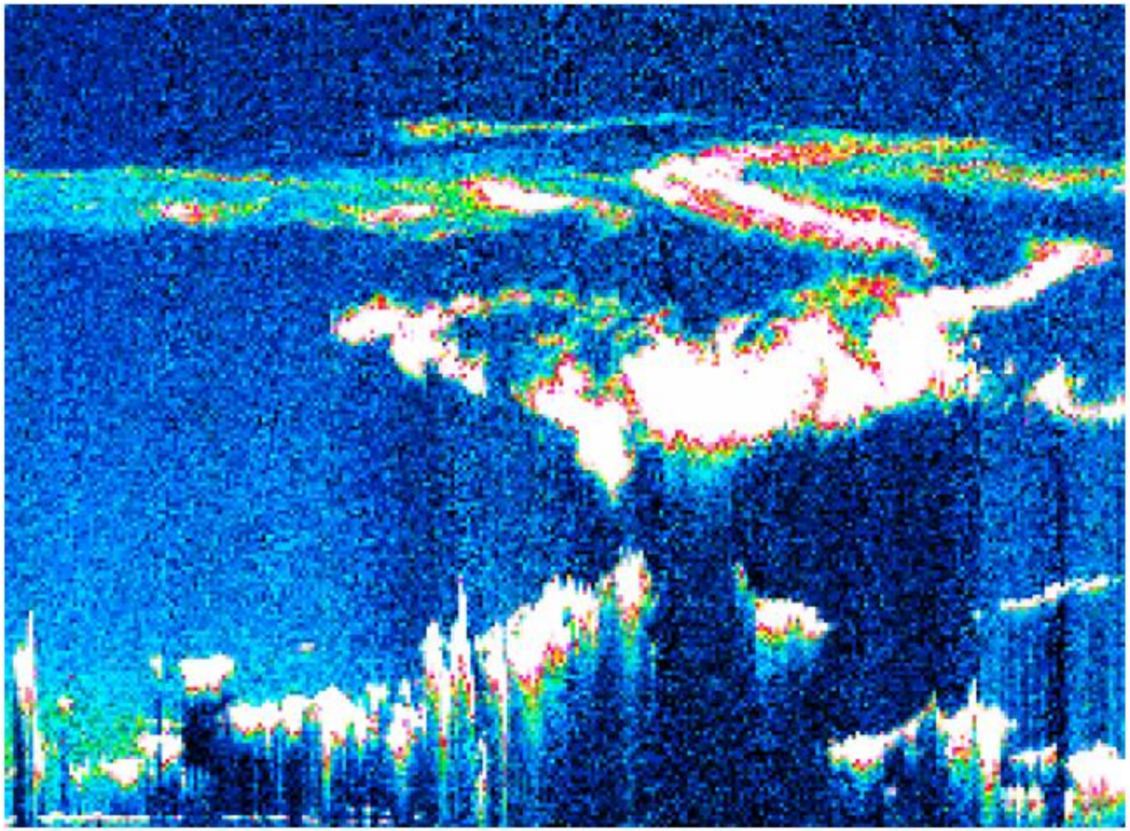


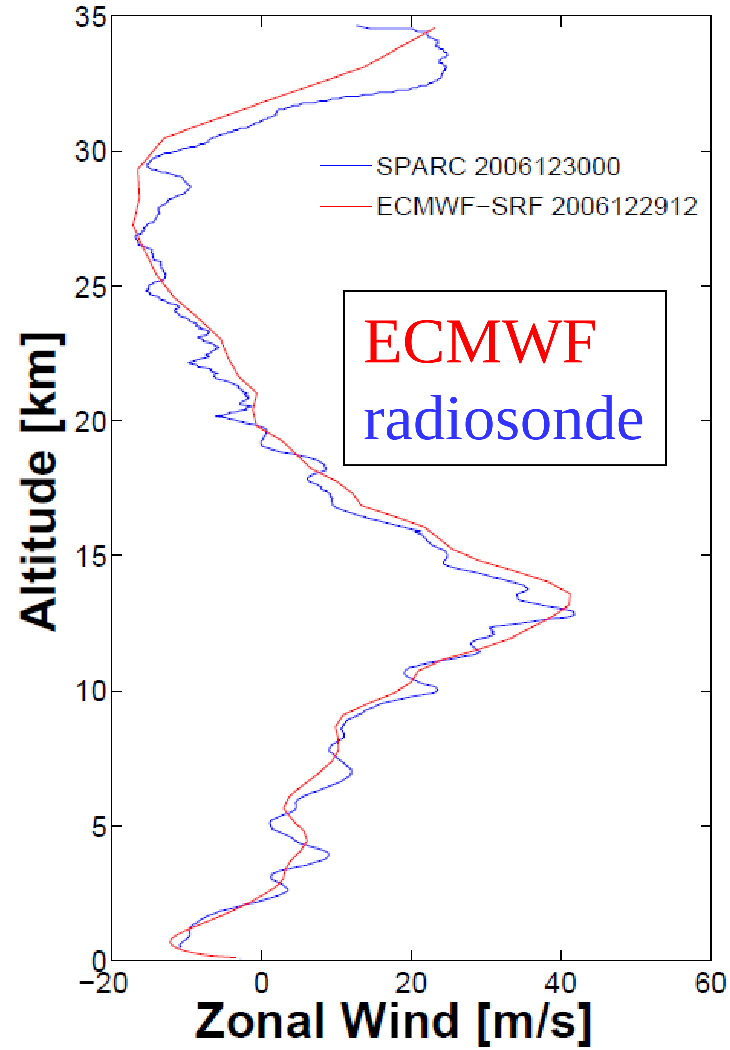
Optional future DWL scenarios



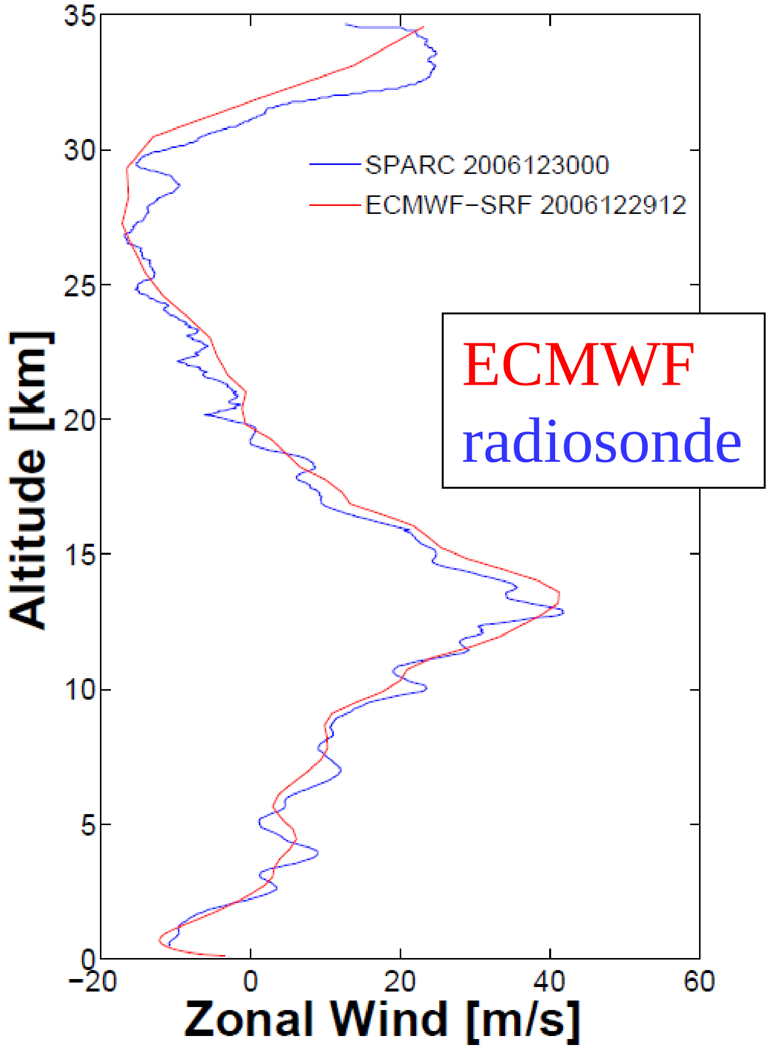
Marseille et al.. 2008
Part-2

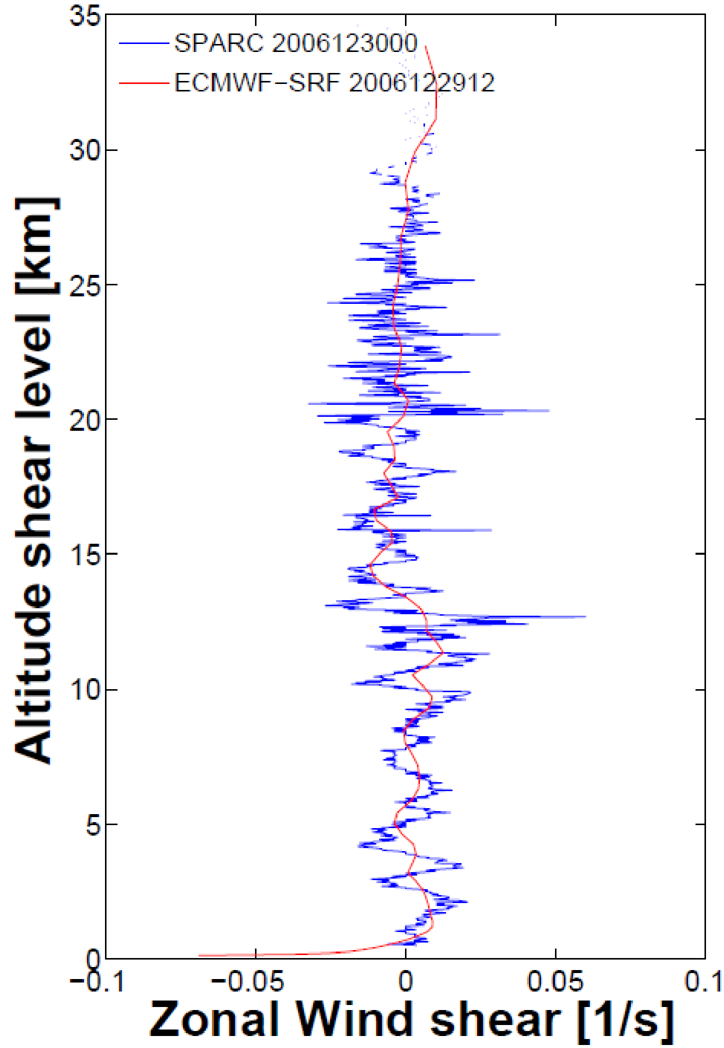
Atmosphere heterogeneity





Global model vs. real atmosphere





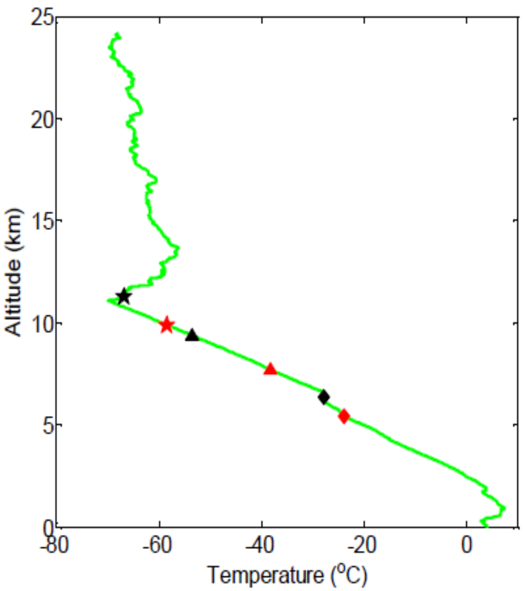
- Models are very smooth relative to real data
- ECMWF underestimates real atmospheric wind shear by a factor of 3

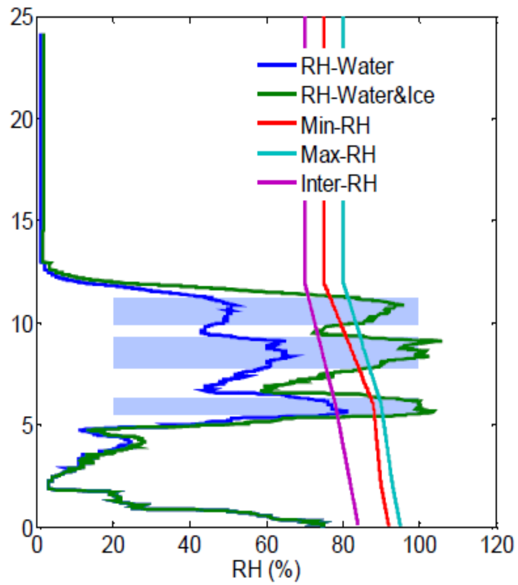
Houchi et al., 2010

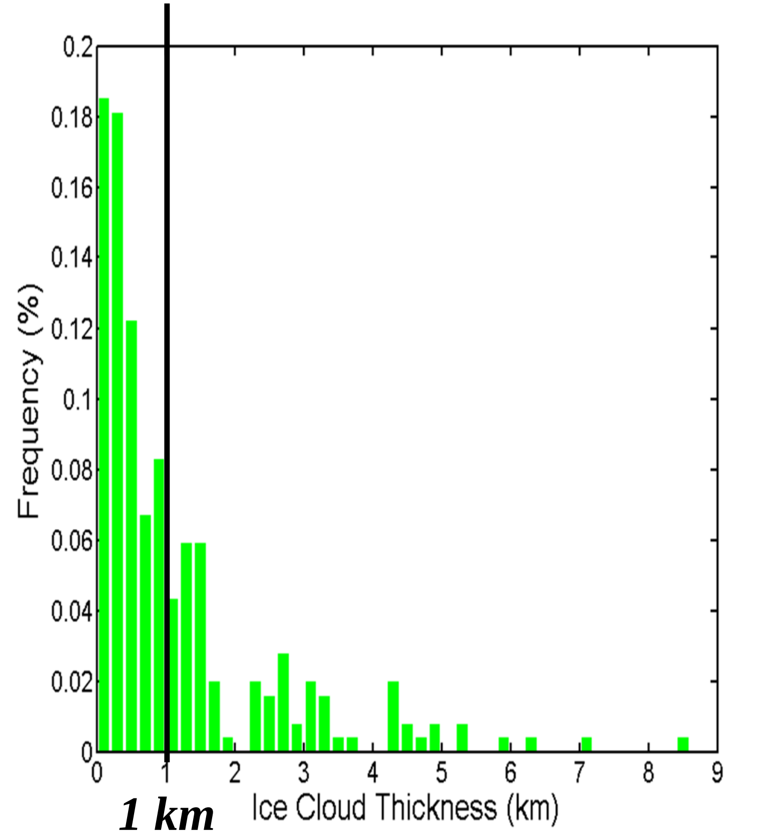
High-resolution radiosonde database

- Radiosondes provide wind, temperature, humidity and pressure at 10-m resolution
- cloud layers detected from humidity along the radiosonde path (Zhang et al., 2010). Applied to De Bilt radiosonde

Sun et al., 2014



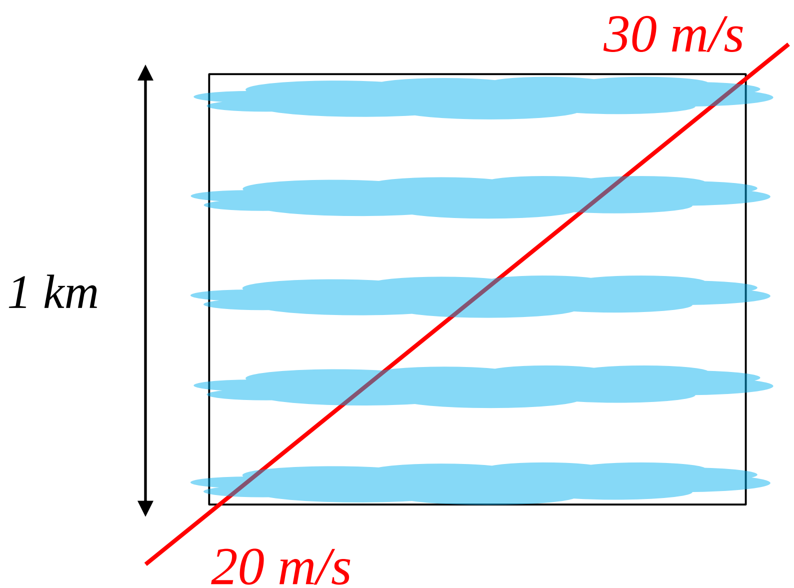




Aeolus height bins are typically 1 km, but 1/3 of cloud layers are thinner than 400 m

Cloud/aerosol layer inside Aeolus bin

2-way cloud layer transmission: 0.7
10 m/s /km wind wind shear



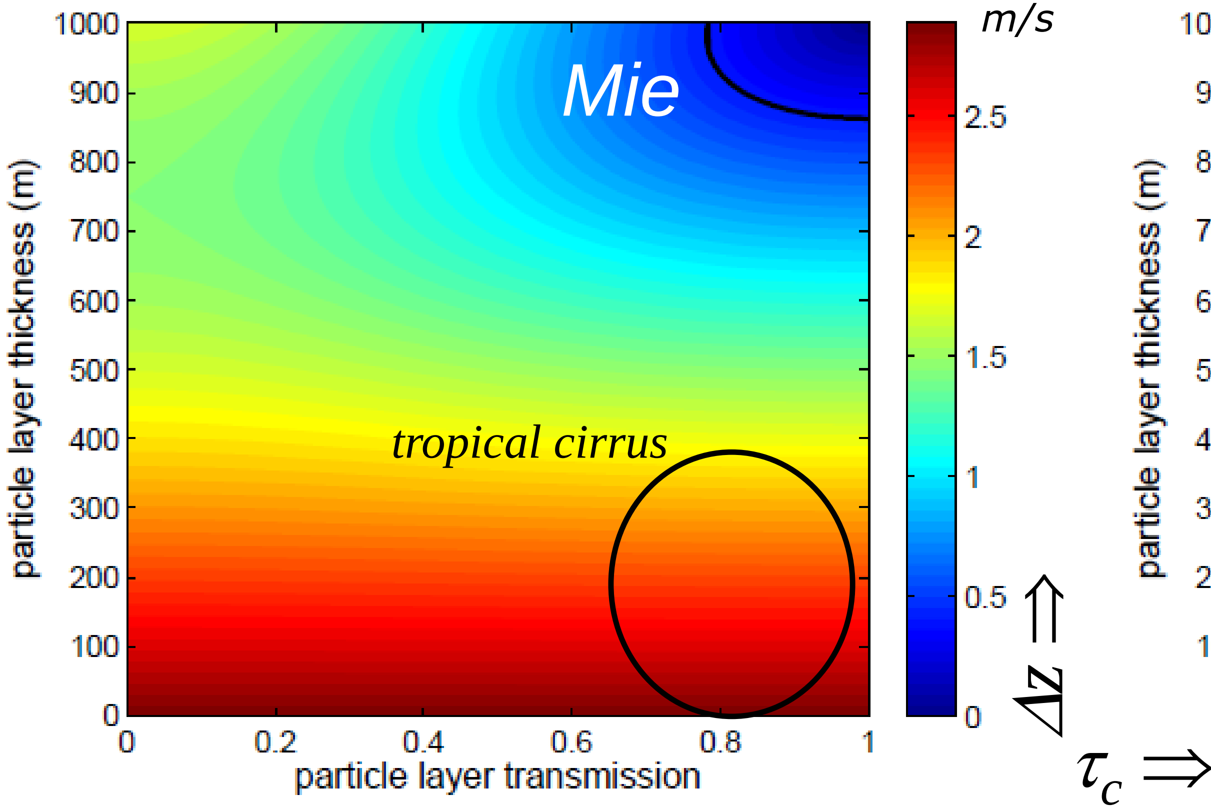
Mie	error	Rayleigh	error
30.0	+10.0	25.10	+0.10
27.5	+2.5	25.36	+0.36
25.0	+0.0	25.44	+0.44
27.5	+2.5	25.30	+0.30
20.0	-10.0	25.07	+0.07

Aeolus wind error can be large depending on (i) bin size, (ii) cloud/aerosol layer location inside the Aeolus bin, (iii) layer size, (iv) layer transmission and (v) wind-shear over the bin

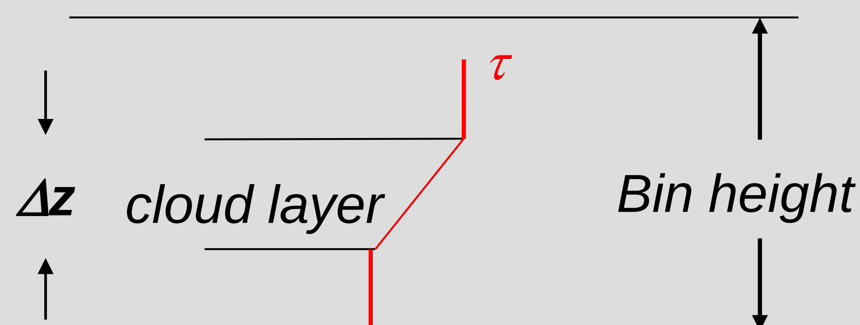
Mie wind errors are very sensitive to atmospheric heterogeneity !!

RMSE wind error

Sun et al., 2014



- Rayleigh ΔHLOS insensitive to Δz, but sensitive to particle layer transmission τ_c
- τ_c can be obtained from Rayleigh channel signal
- Rayleigh winds are under control
- Mie ΔHLOS however sensitive to Δz



Conclusions

- A large number of various experimental setups provide similar conclusions over a large time period: robustness
- There is still a need for wind profiles
  - wind more beneficial than mass when added on top of the full satellite observing system
  - wind is particularly important in the tropics and at high altitudes
- HLOS gives large fraction (~75%) of vector wind impact – promising for Aeolus
  - Larger random errors than predicted not too damaging
  - 2 m/s bias: large negative impact – therefore critical to minimise Aeolus "unknown" biases
- Expected Aeolus impact similar to radiosondes
- Most impact expected over oceans and in the tropics
  - *But be careful with the use of Mie winds in NWP!*

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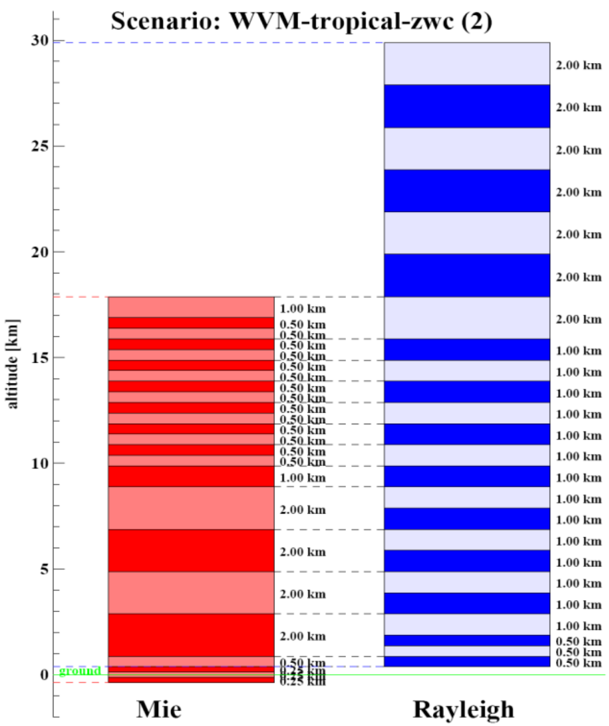
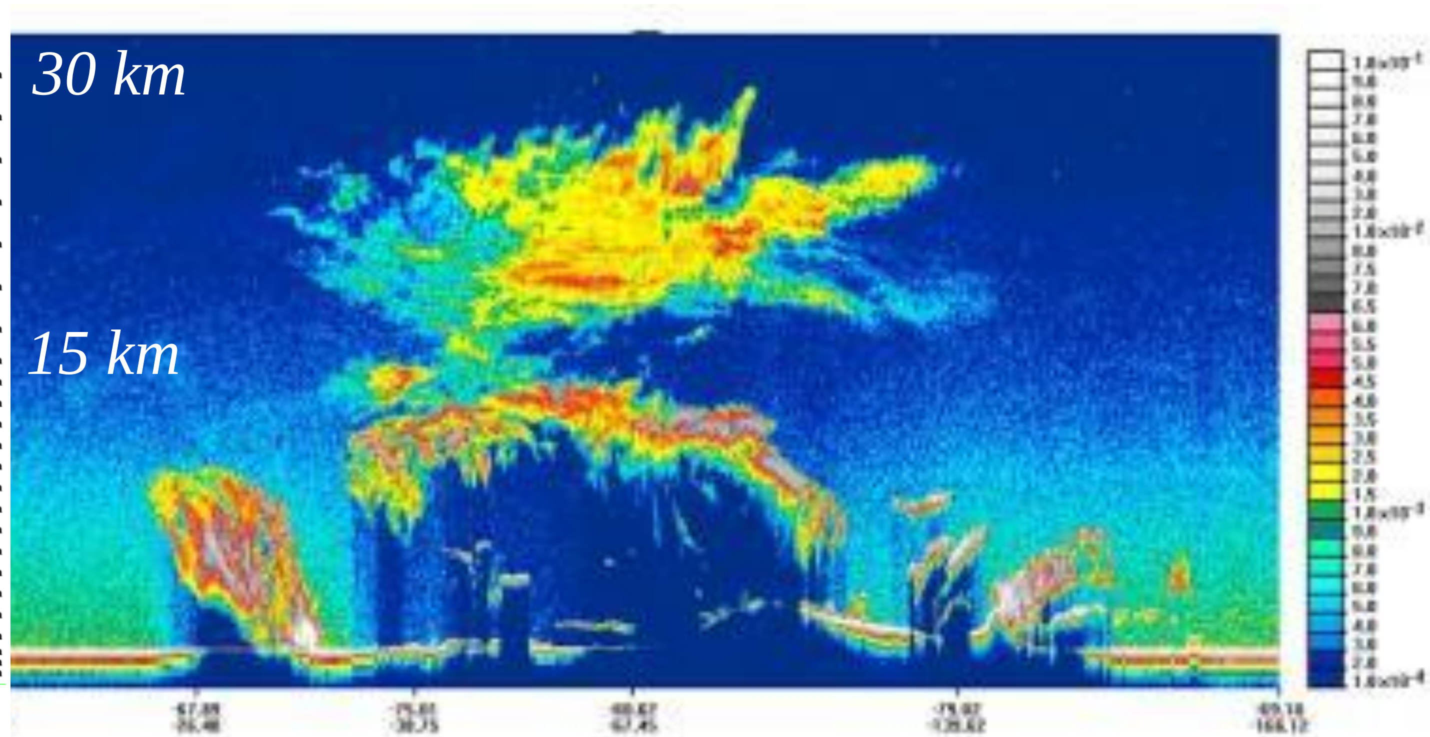
backup

Polar Stratospheric Clouds

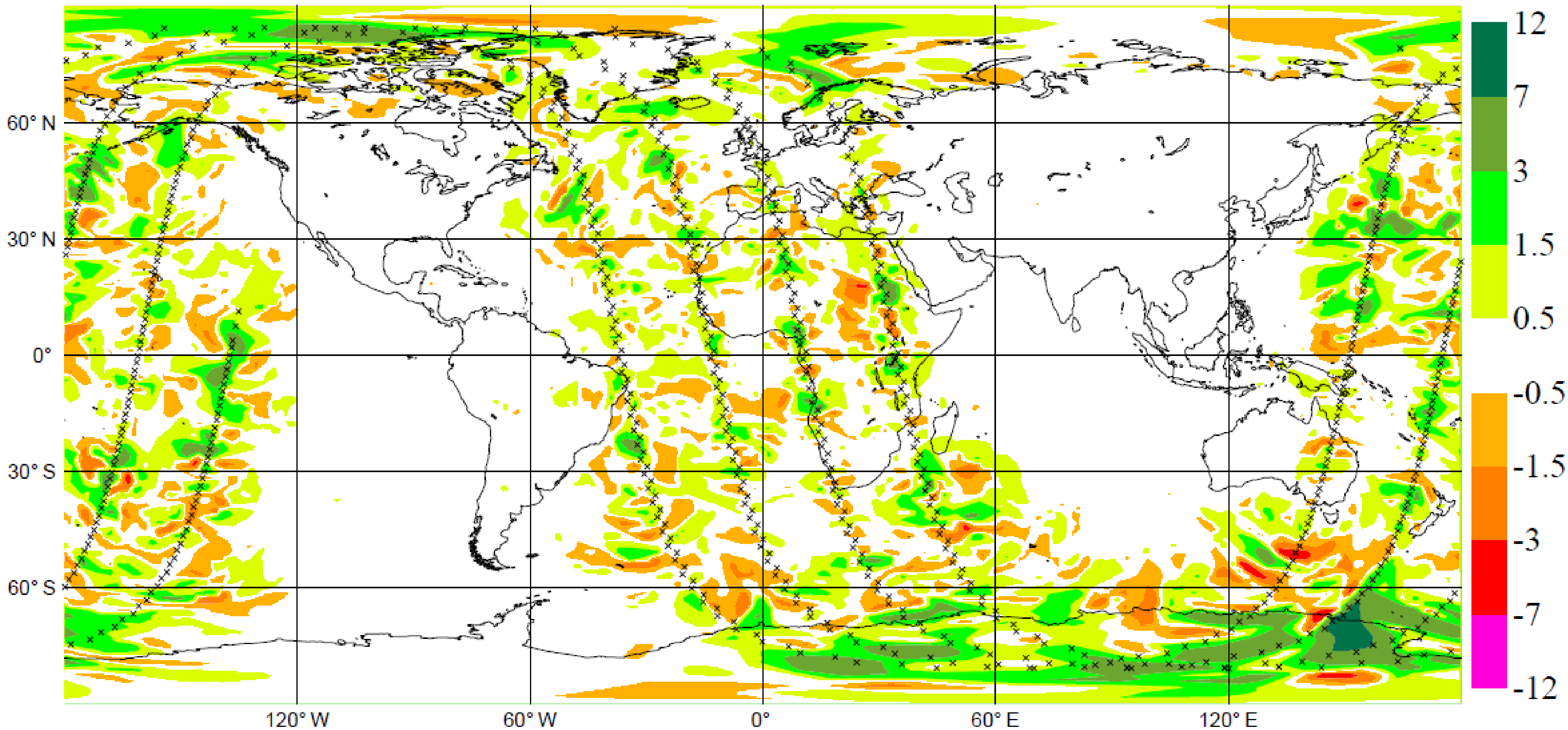
- Quite a lot over Antarctic in August and Arctic in January





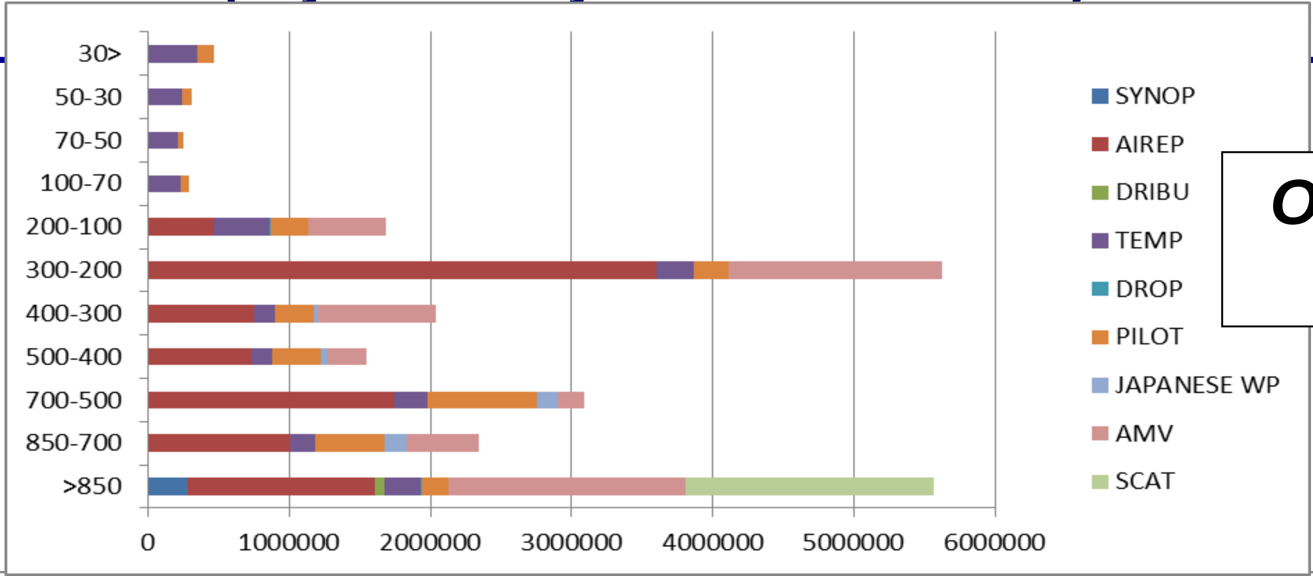
➢ *PSC not always well sampled with the Mie channel*

Observing System Simulation Experiment

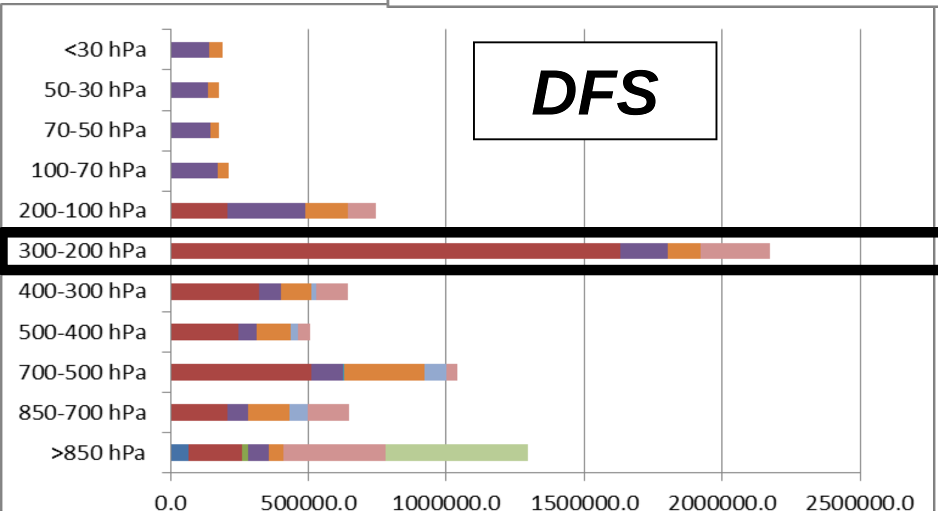


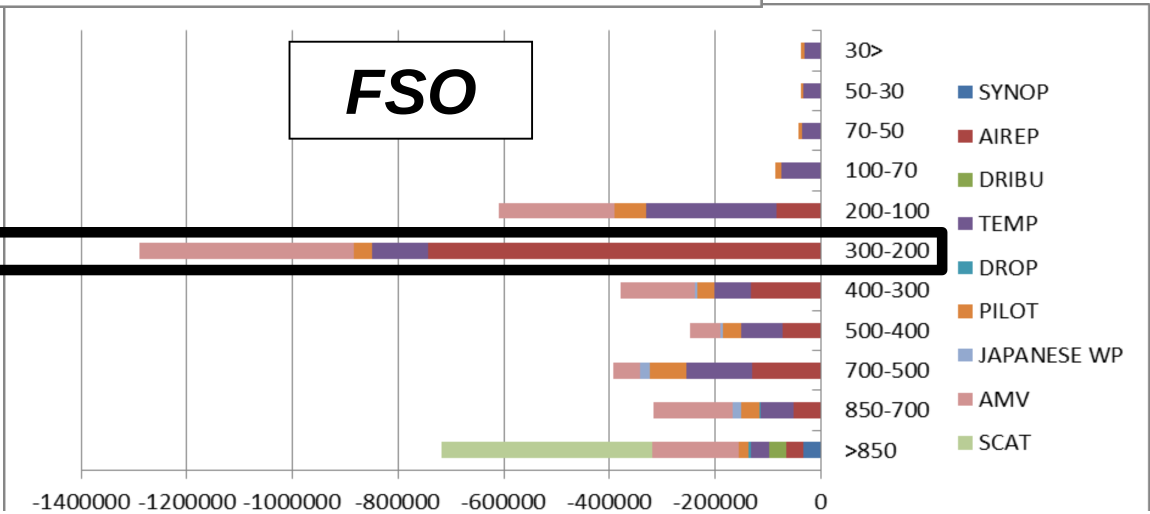
The role of wind measurements in the analysis and the short-range forecasts (in function of the vertical levels)

ECMWF



Observation amount





The highest amount of wind information is available below 850 hPa and at 200-300 hPa (due to aircraft data) and the DFS/FSO values are in agreement with the data amounts

The OSE experiments

An HLOS data assimilation suite had to be designed, built and executed with the following settings:

- A one-month period: September, 2011
- Forecast/outer loop resolution T511/L91 and T95/T159/T255 for the analysis inner loops
- IFS Cycle 38r1 used

HLOS data assimilation

- The experiments are using HLOS data extracted from existing direct wind measurements (radiosondes, aircraft and wind profilers)
- The real vector wind data are transformed to a single component zonal line-of-sight wind data
- The original wind information is blacklisted - no double use of the data
- Temperature and humidity data from radiosondes and aircraft were blacklisted in most experiments – to better simulate Aeolus wind scenarios (no indirect wind information)

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ECMWF

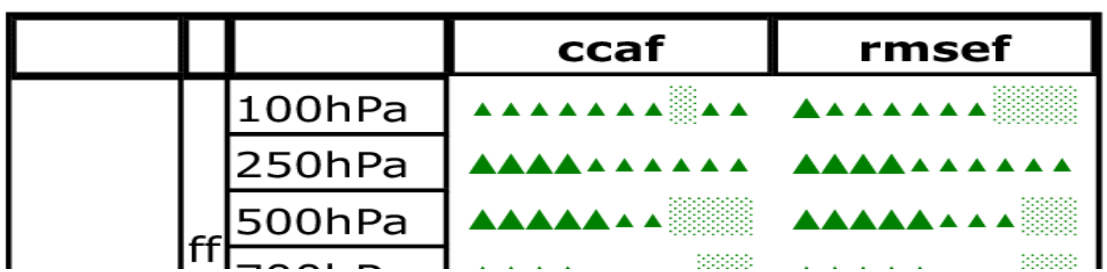
HLOS DATA ASSIMILATION: HLOS WIND VS. NO WIND, TEMPERATURE AND HUMIDITY

aeolus because wind matters

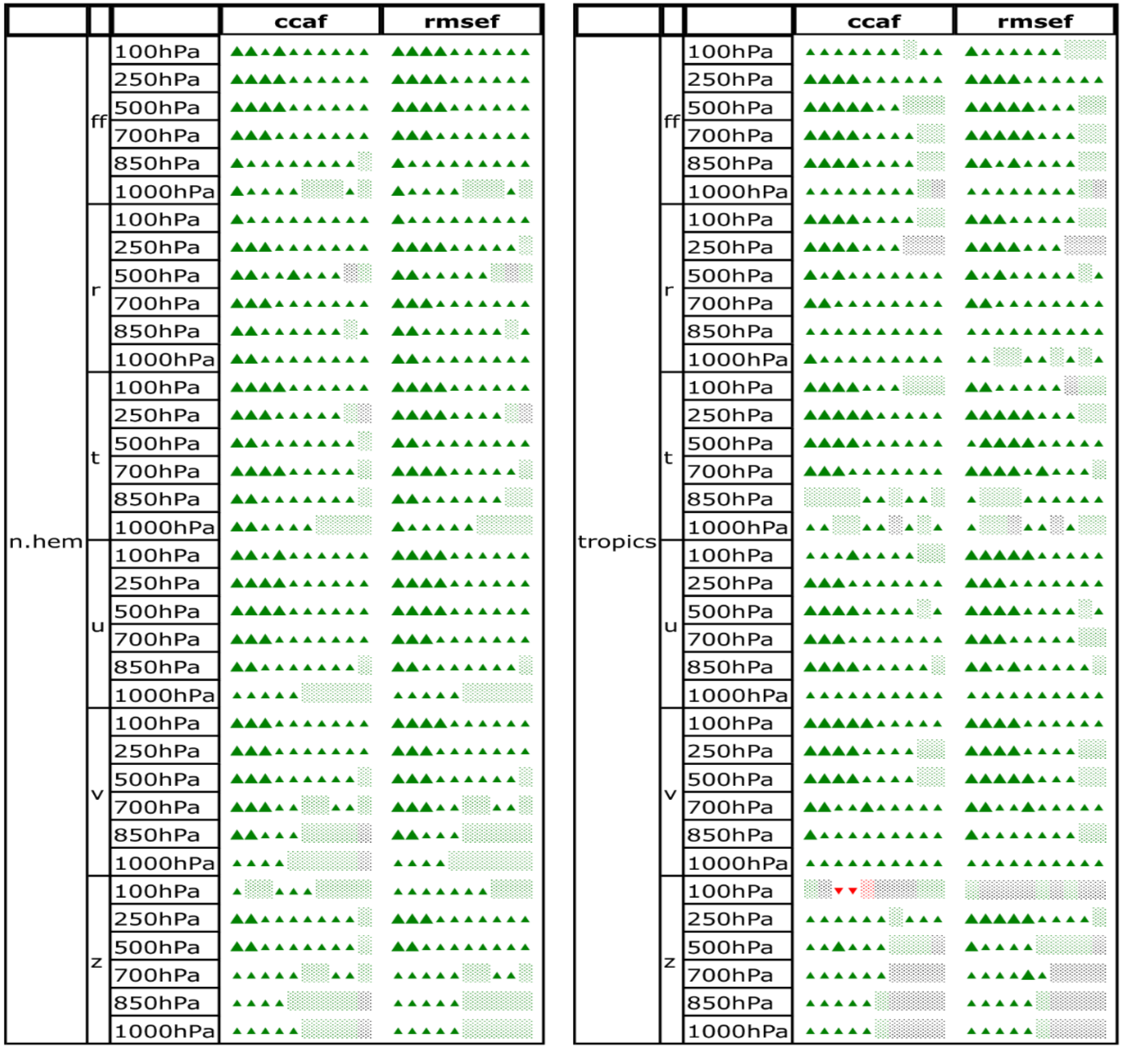
HLOS EXPERIMENTS	
zonHLOS	Zonal wind components as HLOS winds
NO WIND, NO T and NO Q	Neither wind nor temperature and humidity

Scorecards will be used for compact evaluation. They contains:

- *Anomaly correlation and root mean squared error differences between the two experiments verified against the operational analysis*
- *Scores for every 12 hours, up to five day forecast range*
    - *Green/red triangles indicate that the differences are significant (small triangles: significant; big triangles: very significant; shaded:not significant)*



HLOS assimilation vs. nowindTq



HLOS (zonal) wind significantly improves (green triangles) the forecasts, especially in the Northern Hemisphere extra-tropics and tropics (and the impact is kept for the longer forecast ranges as well)

HLOS WIND VS. VECTOR WIND VS. MASS

CONTROL (REFERENCE) EXPERIMENTS	
BASELINE	All available observations
T and Q, NO WIND	Only mass variables
WIND, NO T and Q	Only wind variables
zonHLOS	Zonal wind components as HLOS winds
NO WIND, NO T and NO Q	Neither wind nor temperature and humidity

***Note*: temperature is measured only by aircraft and radiosondes; humidity is only measured by radiosondes.**

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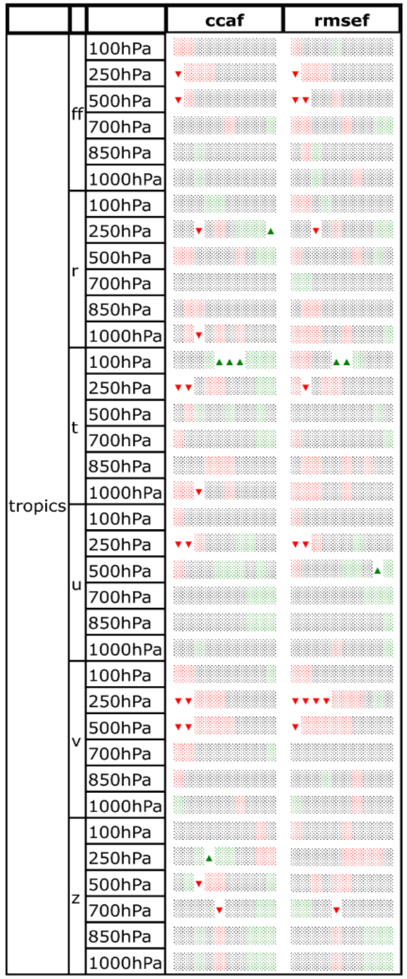
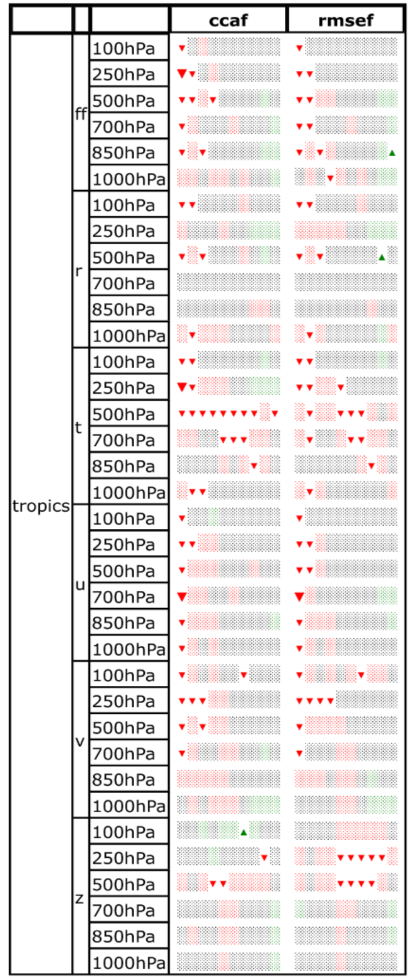
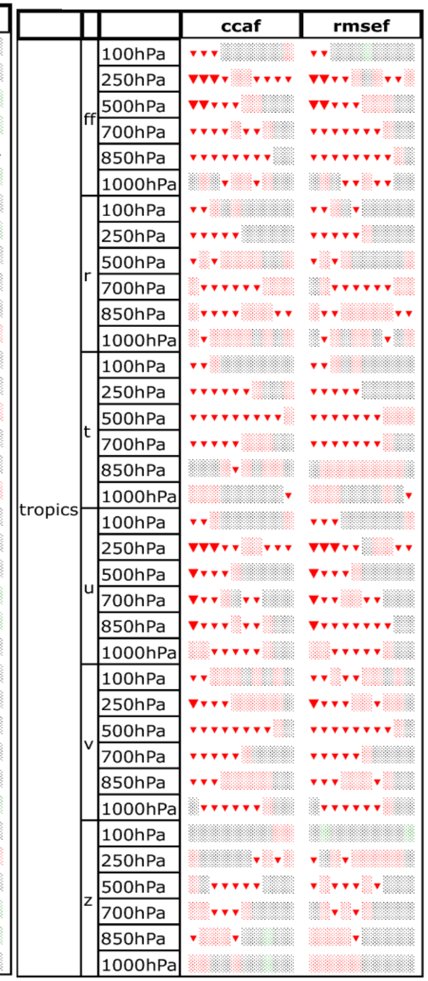
Scorecards: HLOS vs. degraded HLOS, tropics
(25/50/100% increase of obs. error + additional observation noise)

25% obs. error increase + noise	50% obs. error increase + noise	100% obs. error increase + noise





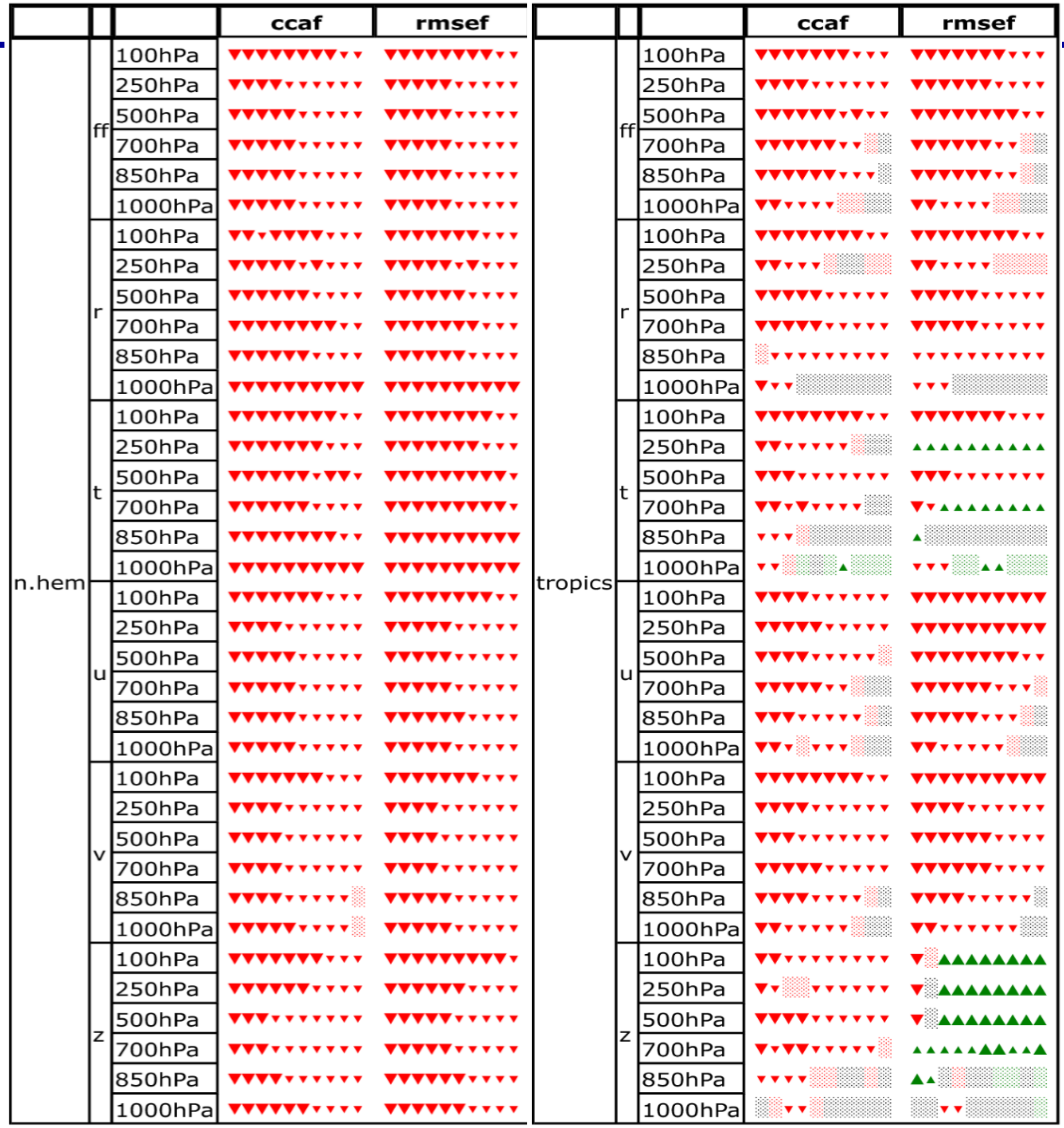


Results for the tropics similar to Northern Hemisphere extra-tropics

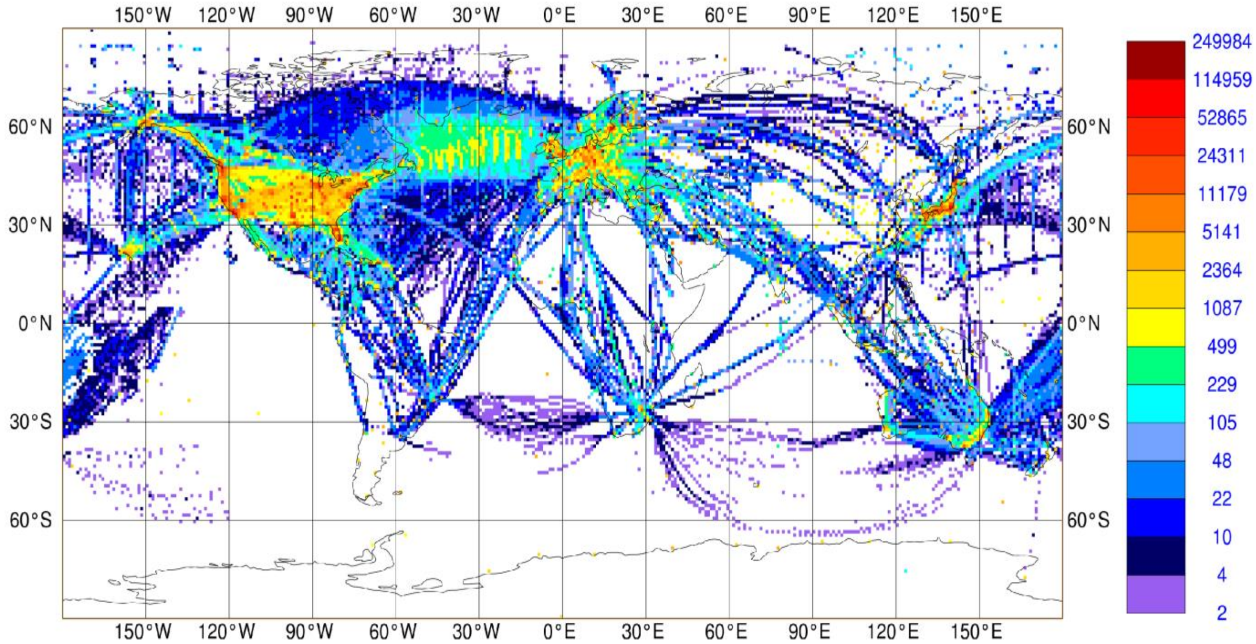
HLOS DATA ASSIMILATION: IMPACT OF DEGRADED HLOS OBSERVATIONS (SYSTEMATIC ERRORS)

HLOS EXPERIMENTS	
zonHLOS	Zonal wind components as HLOS winds
zonHLOSbias0.5/1/2	Zonal HLOS wind with adding constant bias

Biased (2 m/s) HLOS vs. HLOS: Northern Hemisphere extra-tropics and tropics

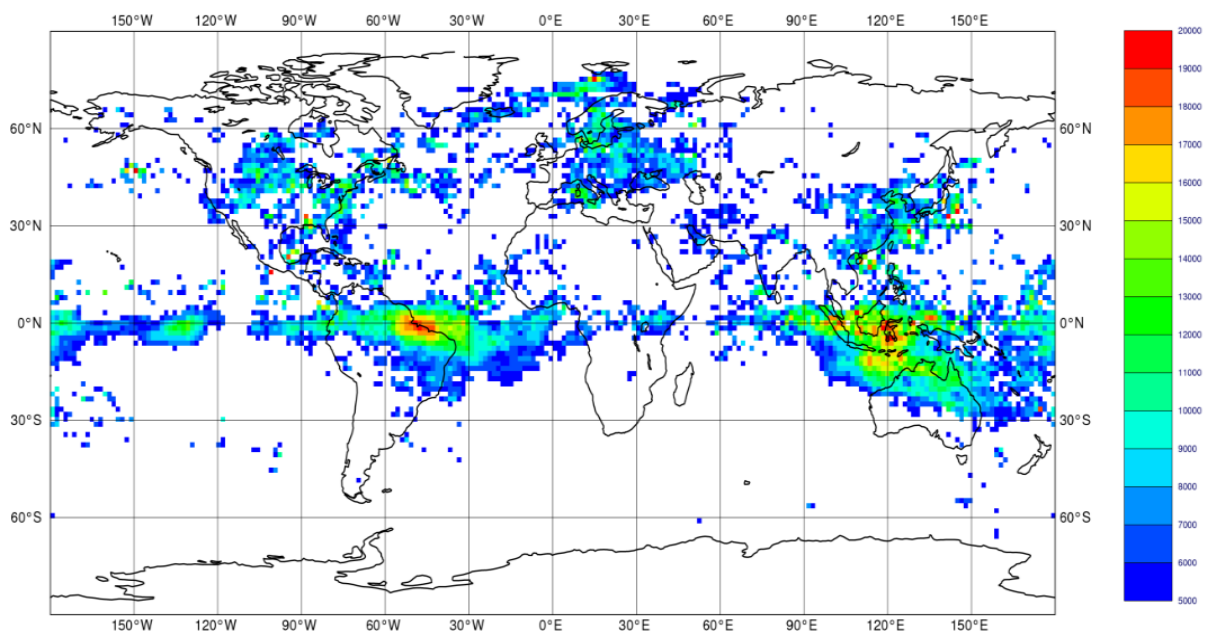


Adding a bias has a very large <u>negative impact</u> on the verification scores



Distribution of observations

- *mostly aircraft at 100-400 hPa*



OSE results: Impact of zonal HLOS

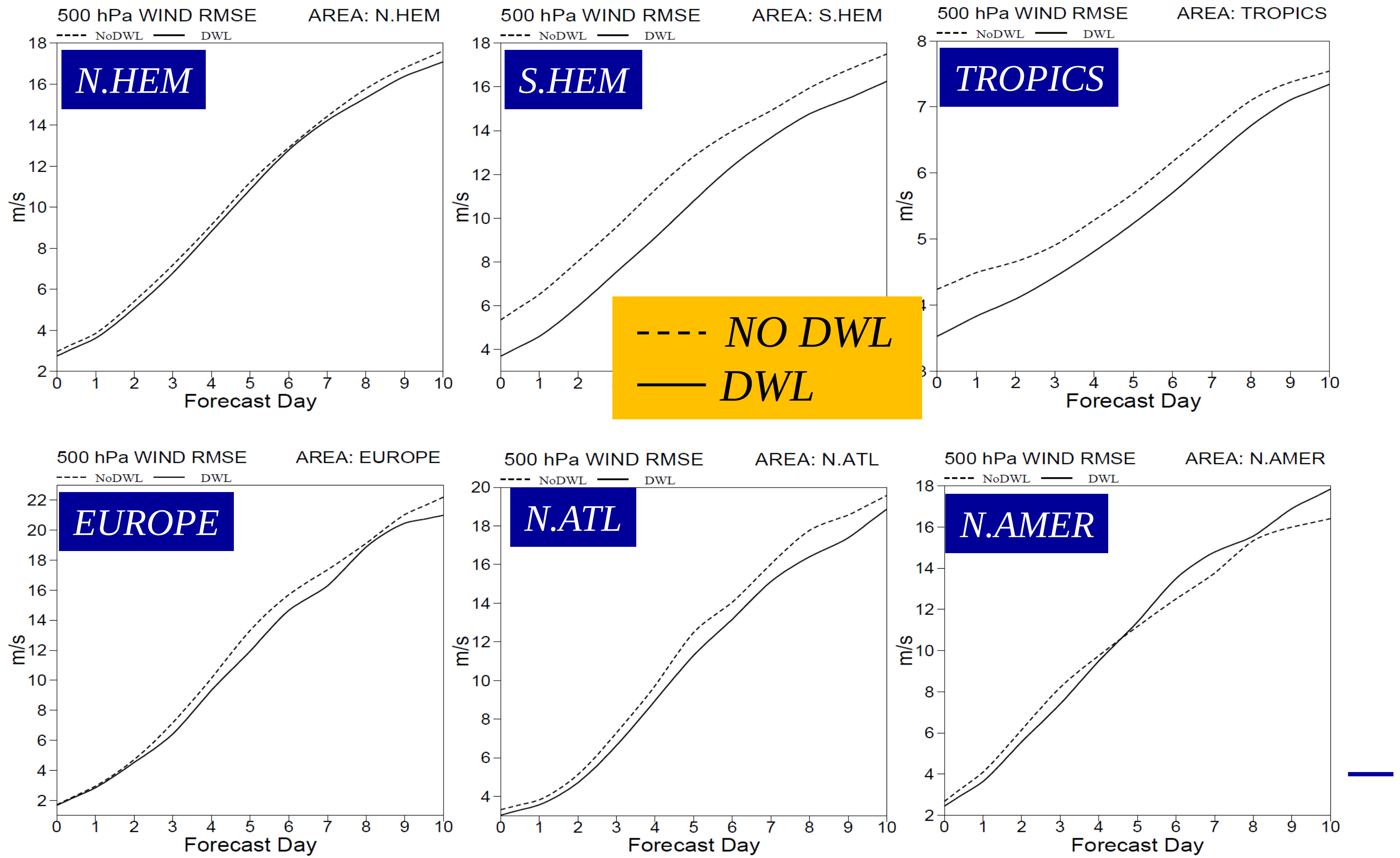
- *largest in tropical regions*
- *Impact also larger in data-rich areas*

Metric: *reduction of vertically integrated total energy error for 24 hr FC*

Tentative expected impact for Aeolus

- *If* mission error specifications are met:
  - Extratropics:
    - 500 hPa geopotential: 1-3 hrs, 2-5% analysis improvement:
      - Difficult for any one observation type to show "large" impact now
    - Expect similar impact for wind
  - Tropics:
    - Evidence of locally large impacts, e.g. up to 15% improvements in upper tropospheric winds at analysis time
  - But the proof of the pudding is …

OSSE; Aeolus forecast impact @500 hPa



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HLOS DATA ASSIMILATION: IMPACT OF DEGRADED HLOS OBSERVATIONS (RANDOM ERRORS)

HLOS EXPERIMENTS (ALSO DEGRADED QUALITY)	
zonHLOS	Zonal wind components as HLOS winds
zonHLOS25/50/100noise	Zonal HLOS wind with the increase of observation error and adding Gaussian white noise to the observations

The background errors are unchanged and the observations errors are increased as prescribed (25%/50%/100% corresponds to 2 m/s → 2.5, 3, 4 m/s respectively)