Combining satellite- with ground-based measurements for continuous, near-real-time monitoring of atmospheric stability, atmospheric water vapor and liquid water

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Motivation

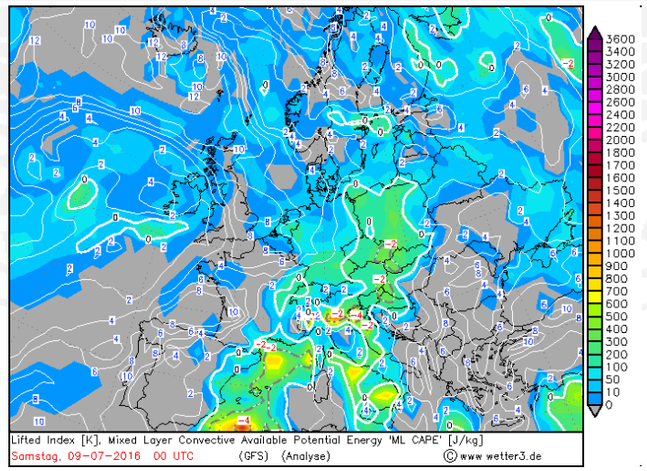
Atmospheric stability
→ T, q profiles
→ Stability indices (STI)

Stability indices – typically a difference between temperature, dew point temperature or equivalent potential temperature at different pressure levels.

- Should be always used with other type of information such as orography, synoptic situation etc.

Lifted index:
LI = T(500hPa) – T(parcel from surface → 500hPa)

Here:
KI, KO, LI, TTI, LI, Showalter Index, CAPE, FogThreat



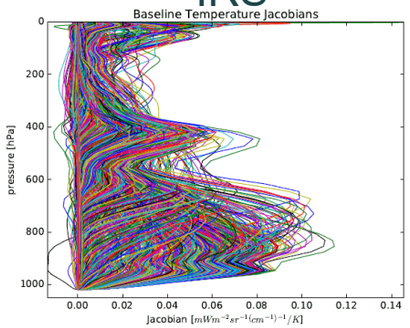
A virtual Remote sensing Observation Network for continuous, near-real-time monitoring of atmospheric stability

Satellite observations

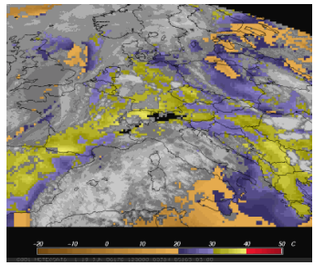
SEVIRI (geostationary):
~15min, 3-10 km

IRS (geostationary):
~30min, 4*4 km (nadir)

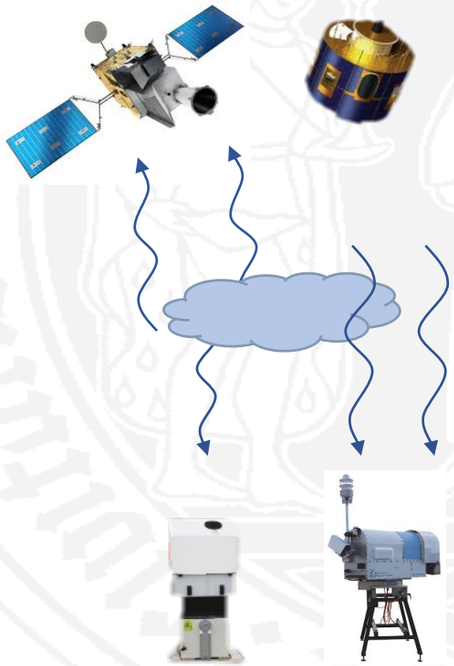
IRS



SEVIRI-GII



Indices: KI,KO, LI, TPW
Physical retrieval
Only in clear sky conditions



Network of ground-based instruments:
- Microwave Radiometer (MWR)
- WV-DIAL

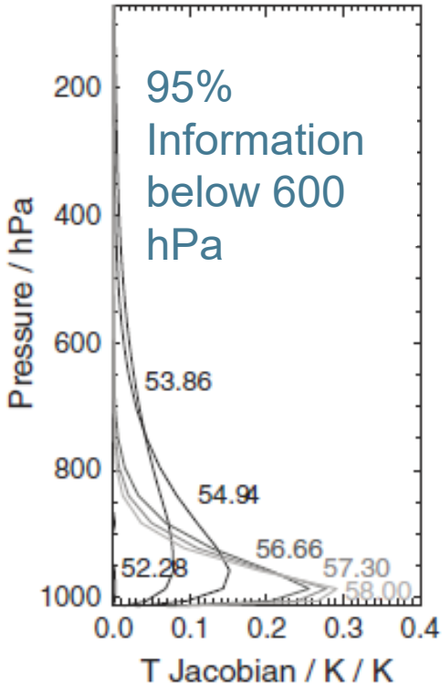
(Illingworth et al, 2019)
(Roininen et al, 2017)

- Improved accuracy and resolution of T, q - profiles (Ebell et.al., 2013)
- Identification of region where convection can occur in the next 1-2 hours
- Imrovement of short term forecast of ground fog, lifted stratus (at night-time, over snow covered surfaces)

Ground based instruments

HATPRO : Commercially available since ~10 years, ready for network applications

- path integrated cloud liquid water **LWP** (most reliable method)
- Integrated water vapor **IWV**
- **T-profiles in ABL,** low resolution profile above
- low resolution **water vapor profiles**



RTTOV-gb → simulated measurements (Tb), (De Angelis et.al. 2016)

O-B statistics→ http://www.tinyurl.com/MWR-O-B-JOYCE

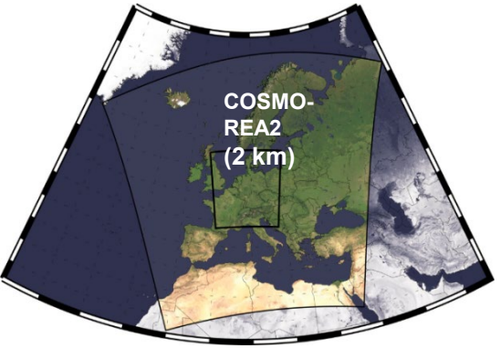
The prototype Vaisala DIAL system: commercially available ~2021

- **WV profiles up to 3km (100m) or up to cloud base**

absolute humidity uncertainty within 10% compared to RS

- Network suitable, compact and low cost instruments
- 24/7 unattended, automatic **all-weather** operation

Stability index retrieval



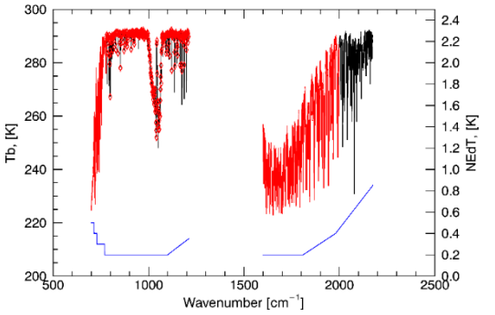
COSMO-REA2
7 years, summertime
1D, clear & cloudy sky , T, p, q & hydrometeor profiles

(Bollmeyer et. al. 2015)

RTTOV-gb, RTTOV

Ground-based observations
MWR (14 channels*5 el. angle)
DIAL (q-profile, 100-1900m)

Geostationary satellite observations
SEVIRI (MSG, 6 channels)
IRS (MTG, 20 PCs)



1113 channels. CO_2 und H_2O absorption.
Principal Component Analysis
→ 20 PC's

Retrieval for STI via Neural Networks

- **Assumptions**:
- Horizontal homogeneous, aerosol-free atmosphere, mid-latitude site
- Constant profiles of trace gases

Performance of single instruments
Clear sky

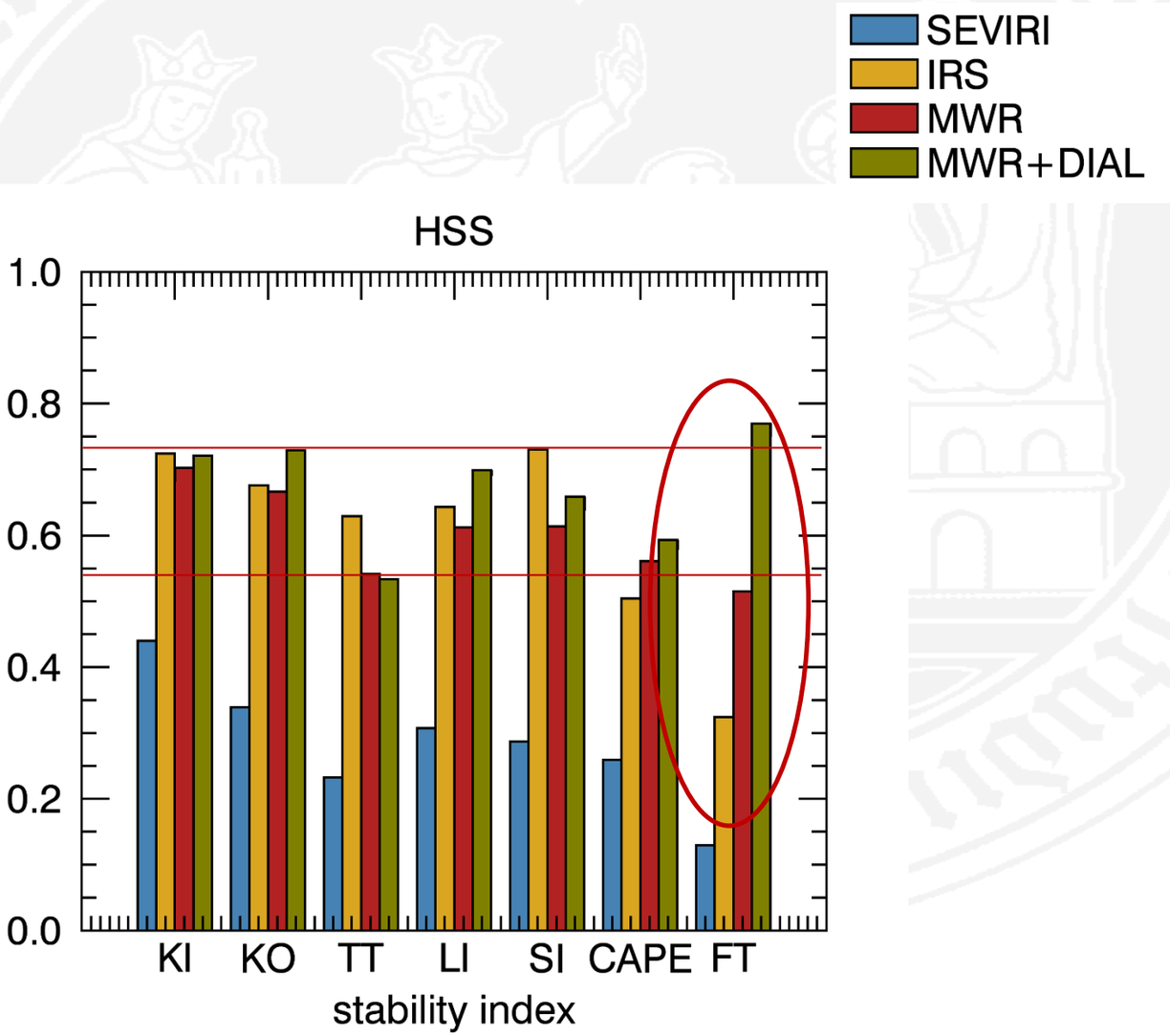
- **IRS**: significant improvements compared to SEVIRI

- **Single IRS and MWR** → ~50-75% skill

- **MWR**: lower HSS for 5 STI better results for CAPE and Fog Threat

lowest layers are not captured by IRS but by MWR

- **MWR+DIAL:** improvements due to additional humidity information from DIAL

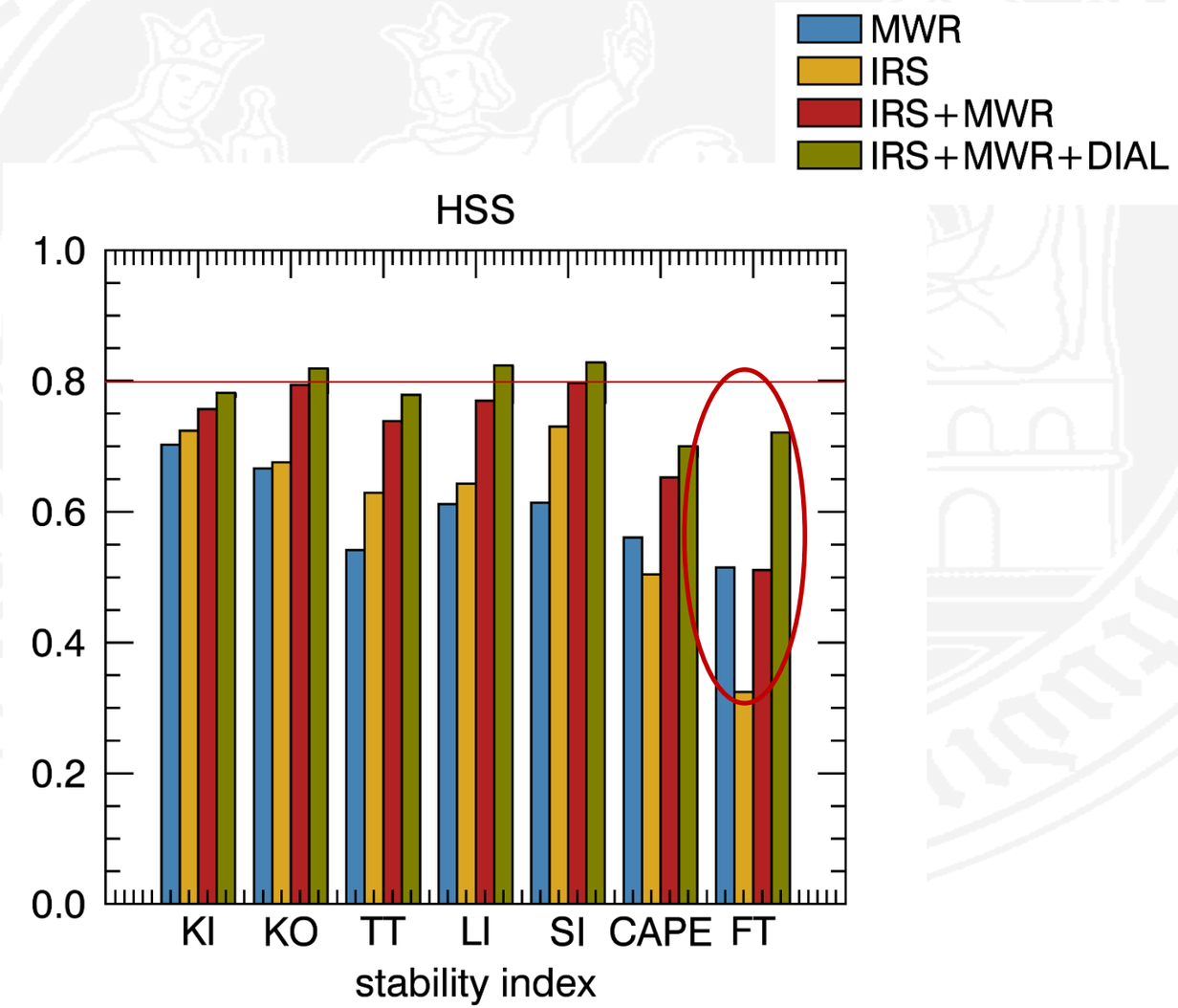


Performance of instruments in synergy
Clear sky

- **IRS+MWR:**
  complement each other→**~80%skill**
  → increase of 4-20% in skill compared to IRS

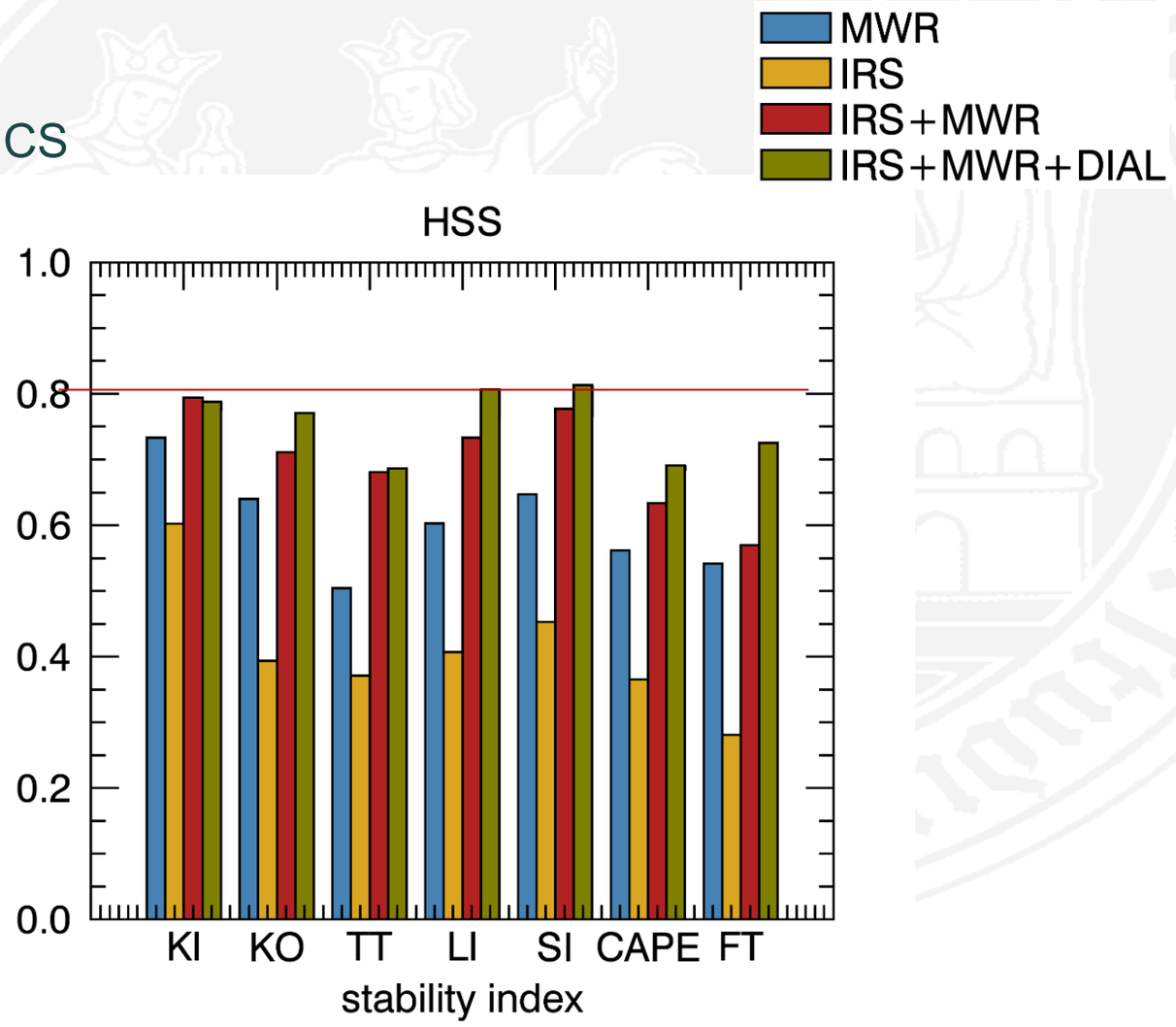
- **CAPE_**→ benefits from ground-based observations **→ +30% skill**

- **FOG THREAT** → information comes from ground-based instruments
  +60% skill due to MWR



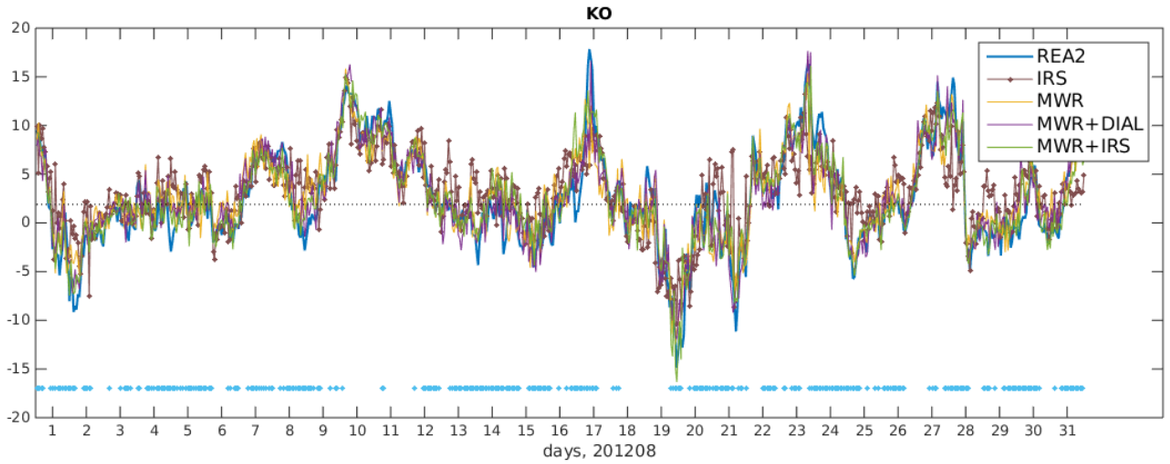
Performance of instruments in synergy cloudy

- **IRS**: significantly lower (10-23%) HSS compared to CS
- **MWR**: HSS 20-40% higher compared to IRS
- **IRS+MWR**: all STI benefit from synergy
- **IRS+MWR+DIAL: → ~80% skill**
  → increase of 30-70% in skill compared to IRS

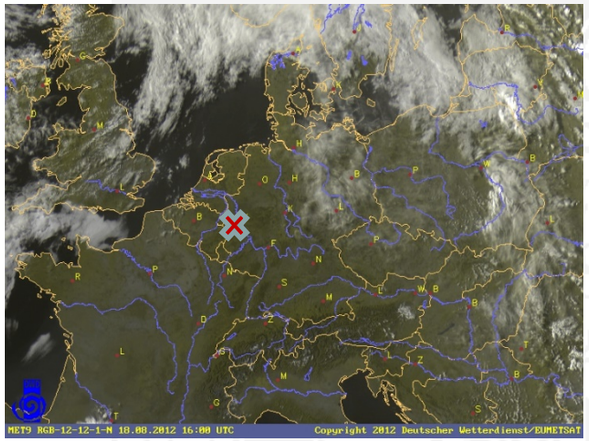


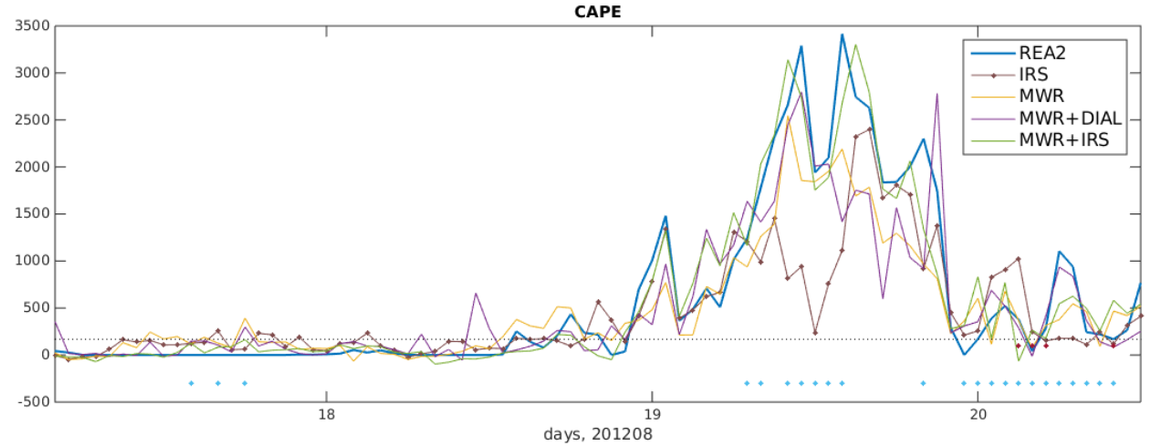
corr	SEV	IRS	MWR	IRS+MWR
LWP	0.43	0.52	0.99	0.99
IWV	0.71	0.9	0.99	0.99

Timeseries JOYCE



HRV 18.08.12, 18:00





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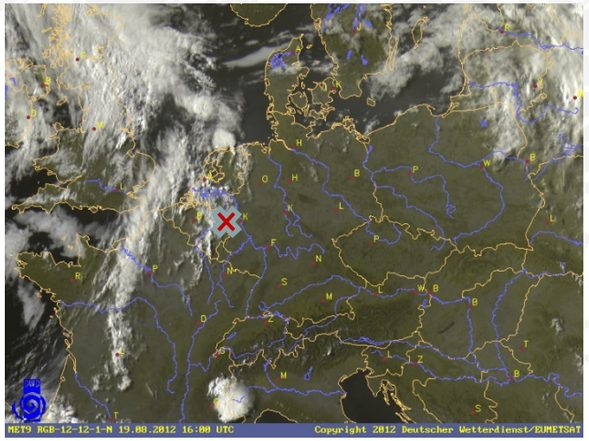


Conclusions

Clear sky

- Satellite- and ground-based sensors complement each other in an optimal way, each providing information from higher and lower layers, respectively.

- Additional ground-based observations are most beneficial for indeces dependend on temperature and humidity close to the surface (CAPE, FT).

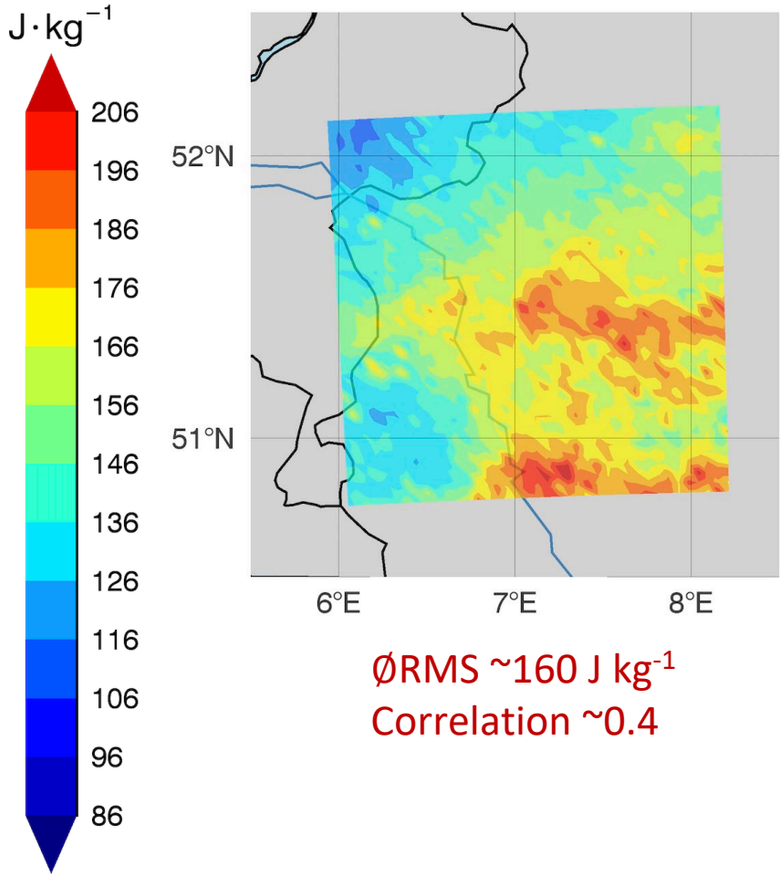
Cloudy

- Clouds hinder the satellite IR observations. Accuracy of retrieval decreases significantly.

- Ground-based observations are essential for assessment of atmospheric stability, potential of fog (FT) and liquid water path (LWP) under cloudy conditions.

Domain Retrievals („Rhineland“)

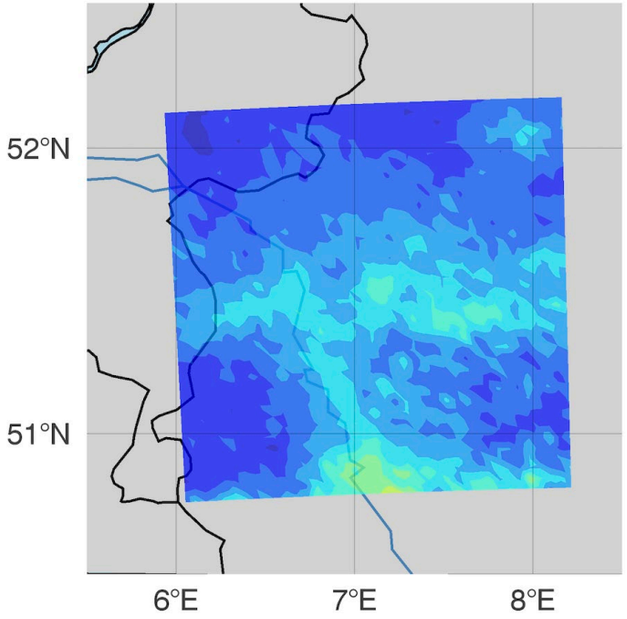
IRS – CAPE RMS



ØRMS ~160 J kg^{-1}
Correlation ~0.4

32 x 32 MTG pixels (~4 km),
NN trained for summer 2010

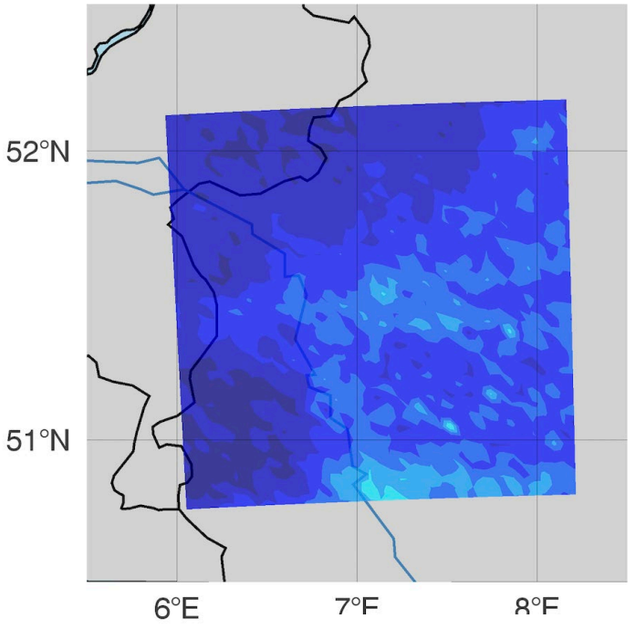
gb-MWR – CAPE RMS



Ø RMS ~115 J kg^{-1}
Correlation ~0.7

Same data set,
32 x 32 = 1024 gb MWR!

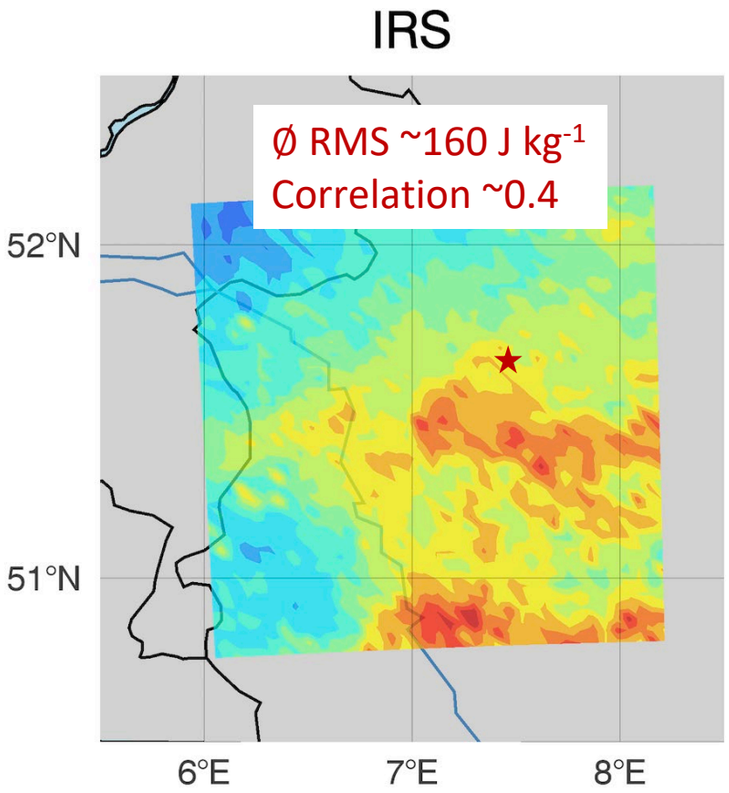
IRS + gb-MWR



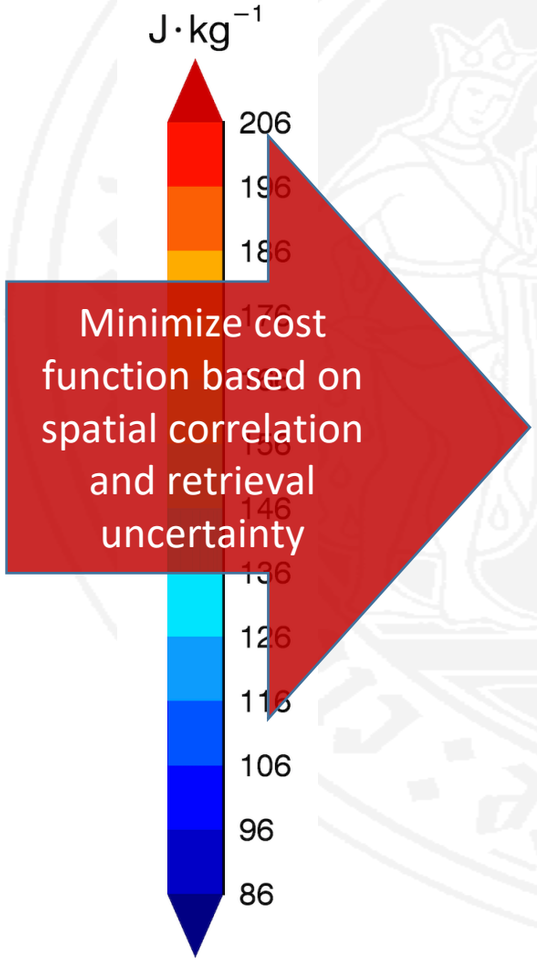
Ø RMS ~100 J kg^{-1}
Correlation ~0.8

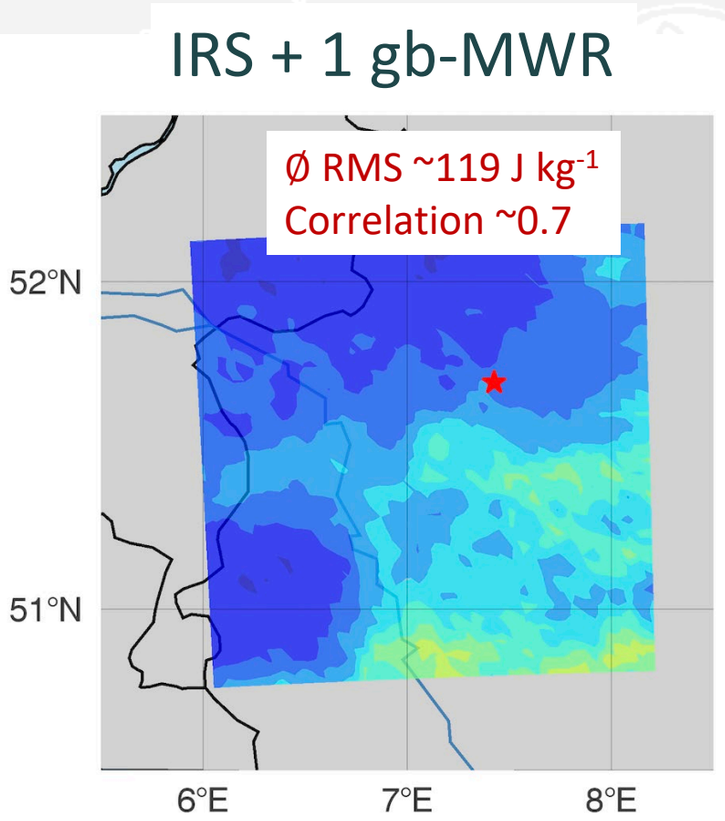
Complementary information, but
unrealistic scenario..

Domain Retrievals („Rhineland“)



Now, only use 1 GB-MWR in the domain to update IRS…





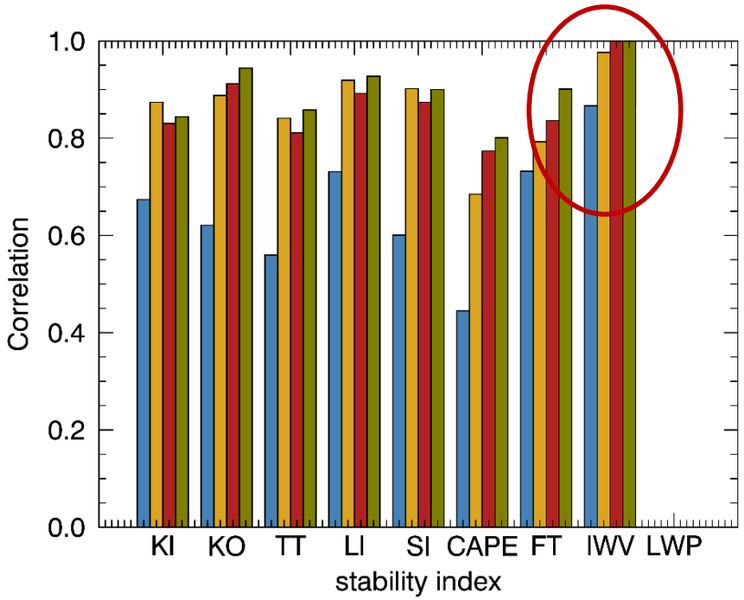
Still significant improvement

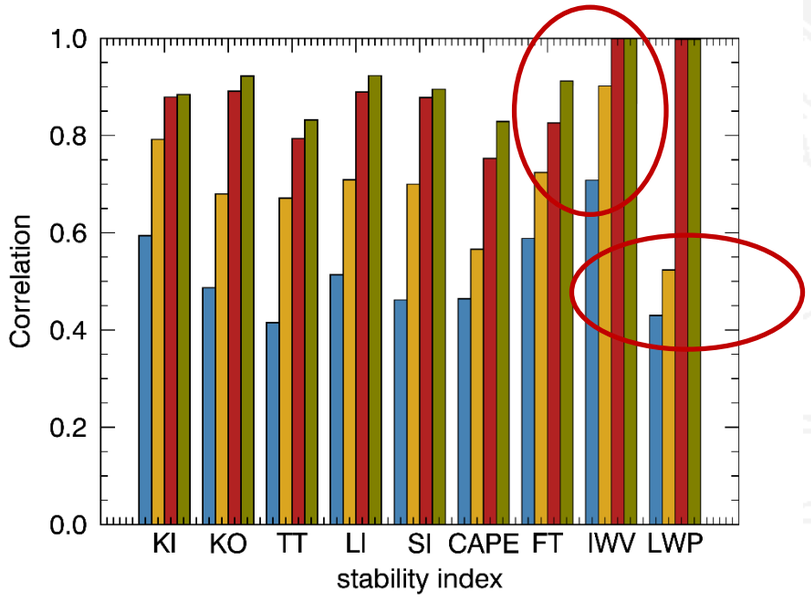
Next steps…

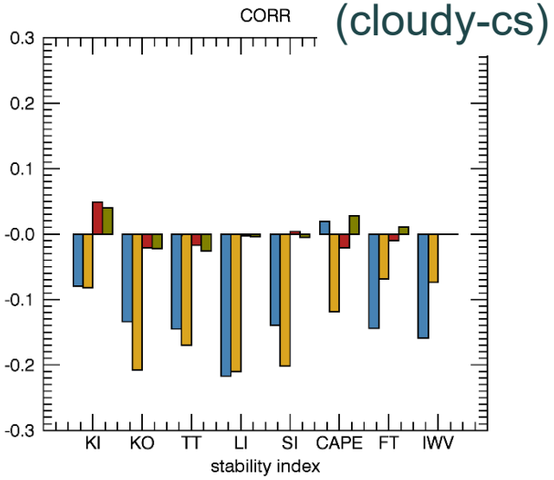
- Perform sensitivity studies to density and setup of GB-profiling network
- Compare to influence of radiosondes (temporal aspect..)
- Investigate cases with extreme weather
- Include water vapor lidar
- OSSE experiments

Thank you for attention!

clear sky vs cloudy: single instruments







- **SEVIRI, IRS**: CORR decrease by 10-23% for all indices.
  IR channels get saturated in presence of clouds
- **MWR, MWR+DIAL:** CORR change only slightly.
- IWV: CORR > 85% for all sensors under CS
- LWP: IRS → 50% CORR
  MWR → 99% CORR

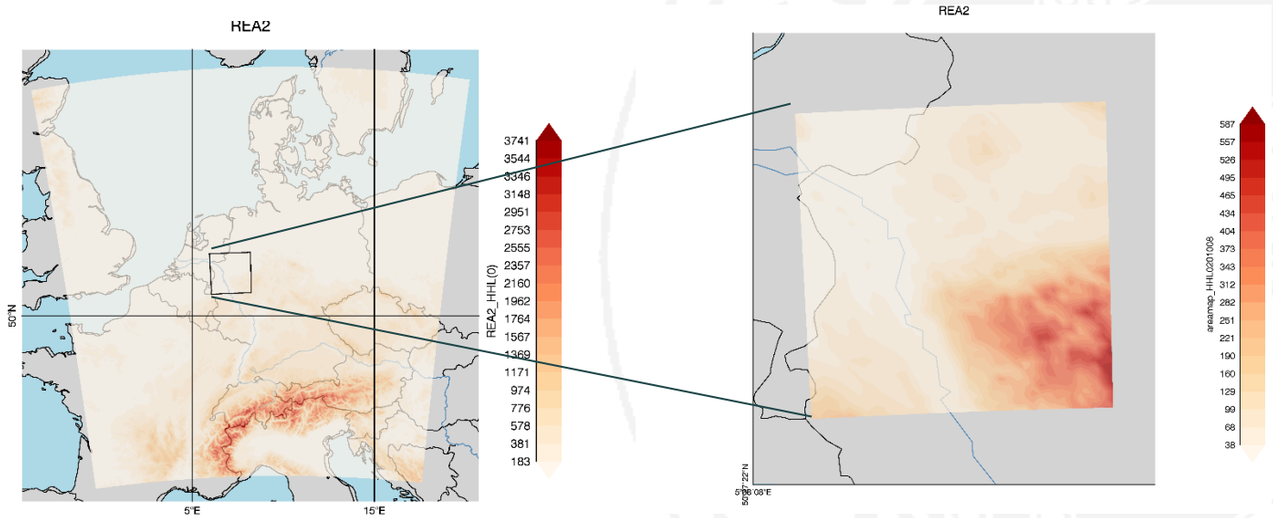
Stability indices
Dependence on T and q in different pressure levels

Index	$500hPa$	$700hPa$	$850hPa$	$1000hPa$	q_{lcl}	sfc	thresh
KI	✓ T	✓	✓				> 21
KO	✓	✓	✓	✓			< 1.9
TT	✓ T		✓				> 46.7
LI	✓ T					✓	< 1.6
SI	✓ T		✓				< 4.2
CAPE	✓ T	✓ T	✓ T	✓ T		✓	> 168
FT			✓	✓	✓	✓	< 3

IWV

LWP

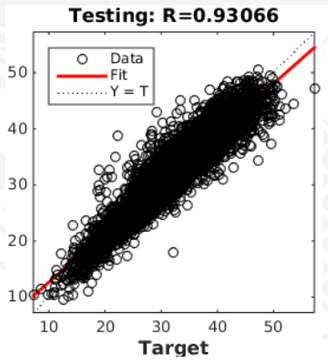
Outlook
representativeness of observations of single MWR



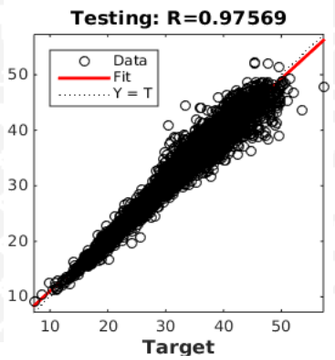
150*150km^2
4km horizontal and
1h temporal resolution

- NN-Retrieval for CAPE, IWV and LWP
- Instruments: IRS, MWR und IRS+MWR
- Different configurations of MWR-networks.
- Impact on the retrieved CAPE-, IWV- and LWP-fields

IRS

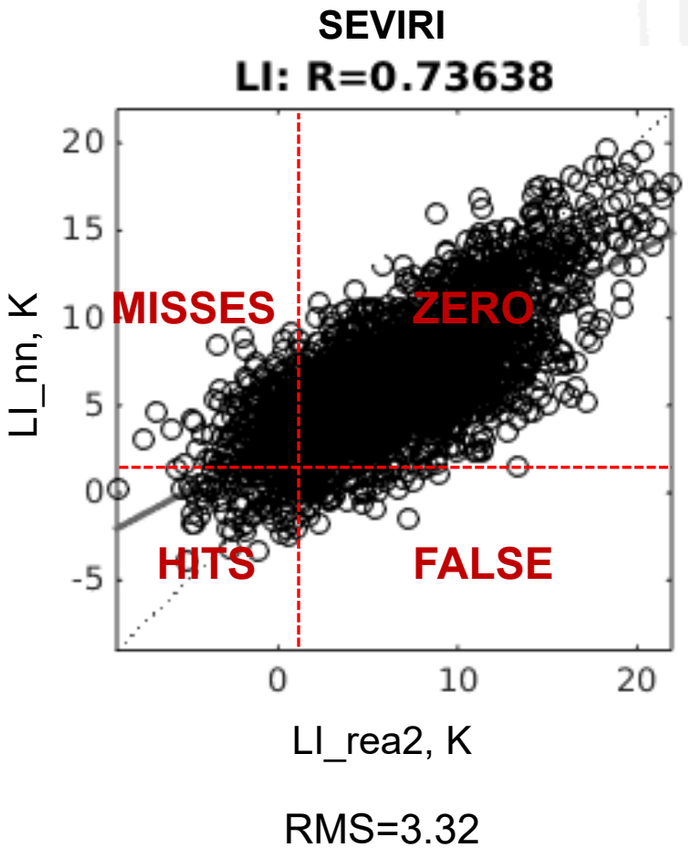


IRS+MWR



Contingency table, verification parameters

Instabilität: yes or no?
POD: #correct instability predictions/#instabilities
FAR: #incorrect instability predictions/ #instability predictions
Heidke Skill Score: perfect pred., 0=no skill, <0 guessing is better
What was the accuracy of the forecast relative to that of random chance?



RMS=3.32

Probability of detection=H/(H+M)

False alarm rate = F/(H+F)

Heidke skill score = [-1:1]

→ 1: perfect forecast

→ 0 : no forecast skills

→ -1: guessing is better

Valuable for now-casting: Stability Indices (SI)

→ especially when available in high temp- resolution!

K Index KI= (T(850) – T(500)) + T_d(850) – (T(700) – T_d(700))

Konvektiv-Index KO= 0.5*($\theta_e(700) + \theta_e(500) - \theta_e(1000) - \theta_e(850)$)

Total Totals index TT = (T(850) – T(500)) + (T_d(850) – T(500))

Lifted index LI = T(500) – T(parcel from surface → 500)

Showalter index SI = T(500) – T(parcel at 850 → 500)

CAPE: Convective Available Potential Energy

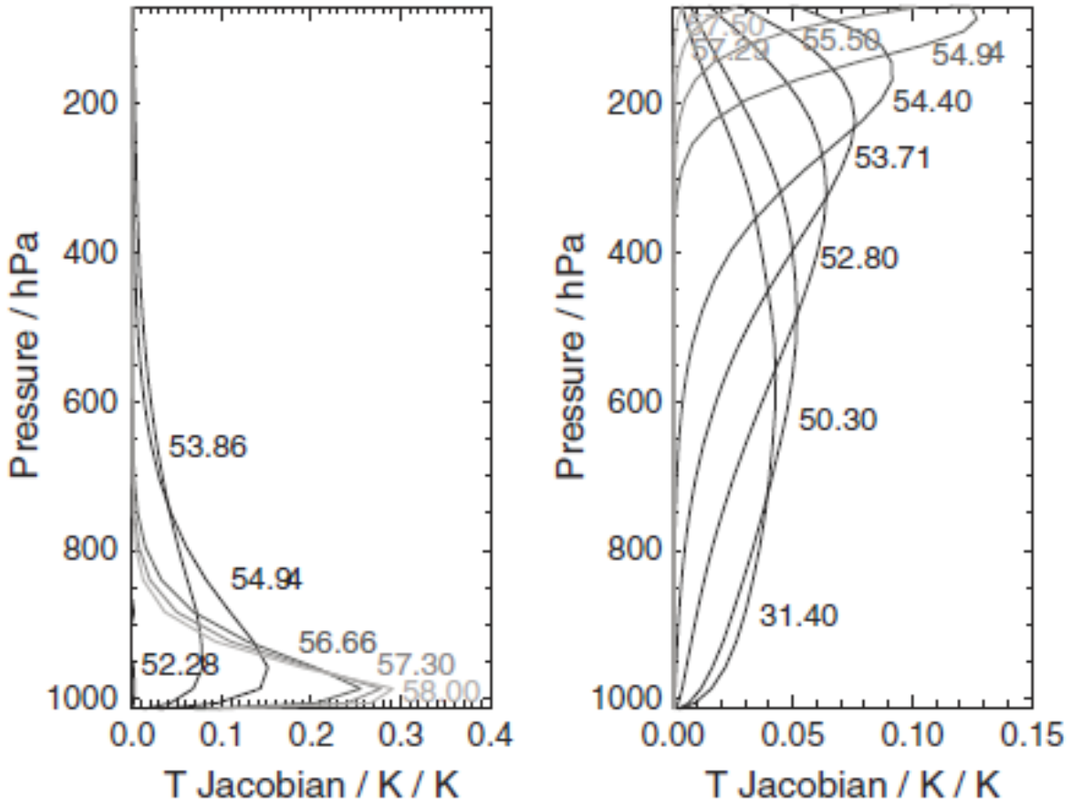
$$CAPE = R_d \int_{p=surface}^{p=TOA} \left(T_v(parcel) - T_v\right) d\ln p$$

$T_{v,parcel} > T_v$

Synergy potential: gb-MWR and Satellite observations

→ For T profiles: 95% MWR-Information below 600hPa

→ Satellites (AMSU-A) provide informations from layers above 500 hPa

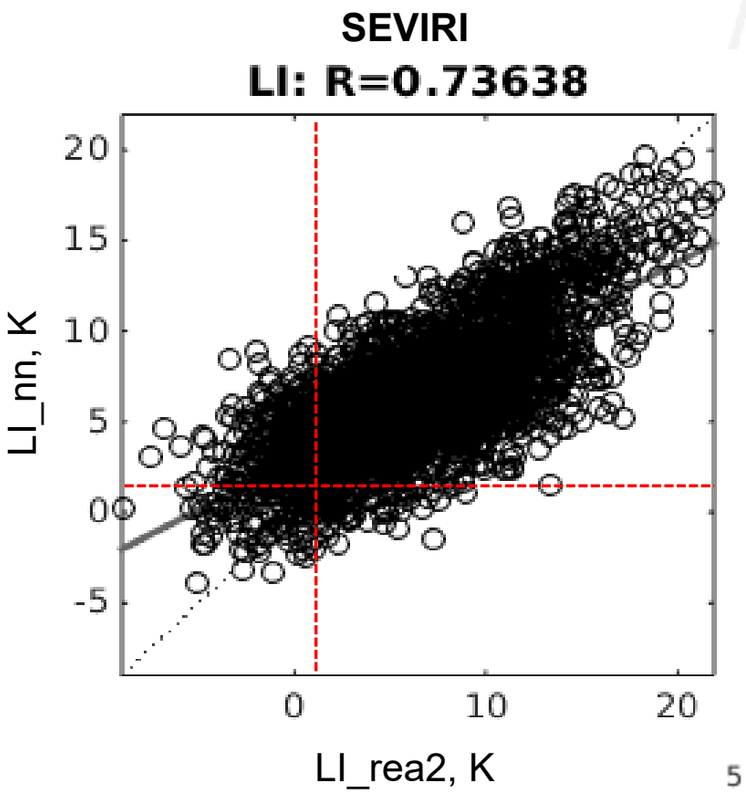


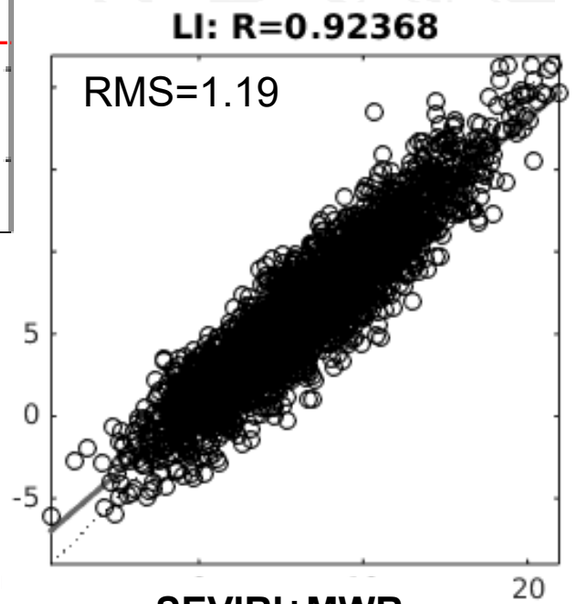
Ebell et.al. 2013

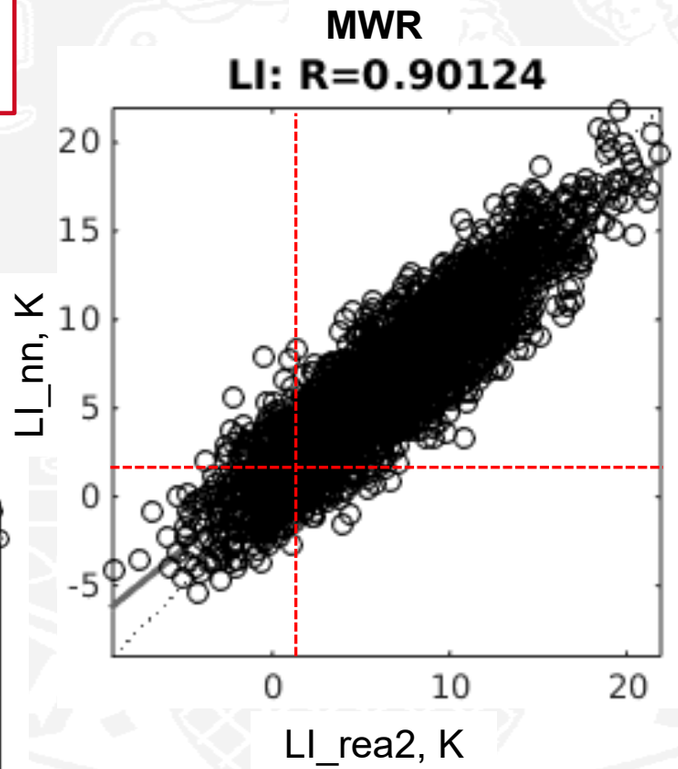
SEVIRI vs. gb-MWR

Lifted Index =T(500) – T(parcel from surface → 500)
LI < 1.6 K → increasing instability

Uncertainty reduced by > 30%







RTTOV-gb, simulation of ground based observations

RTTOV-gb → ground based HATPRO observations

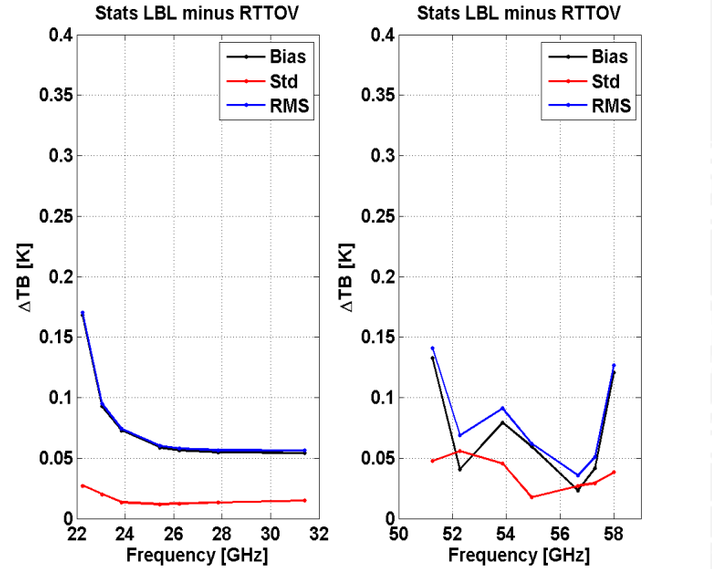
Input: temperature and humidity profiles,
surface parameter
cloud liquid water

+

Regression coefficients

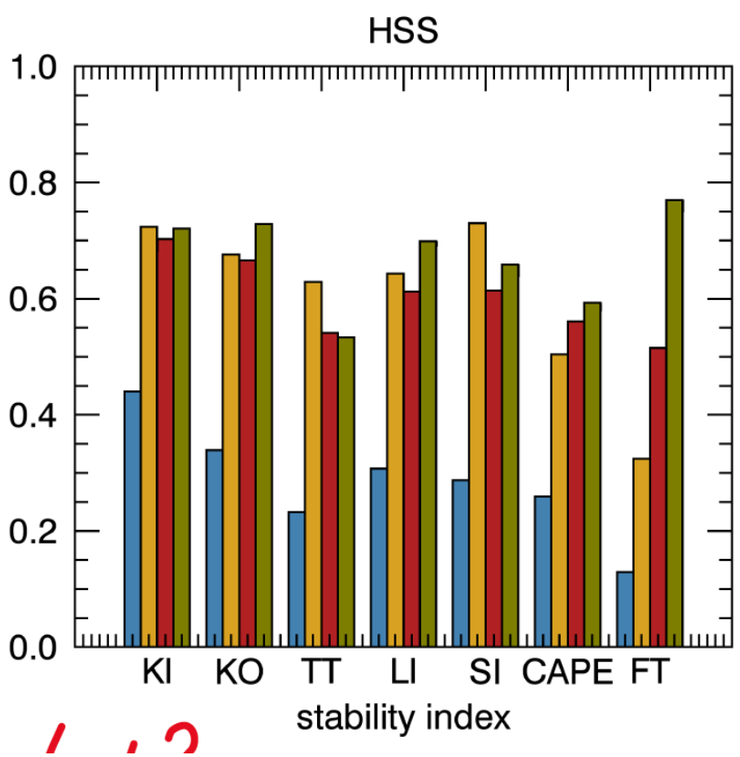
⬇

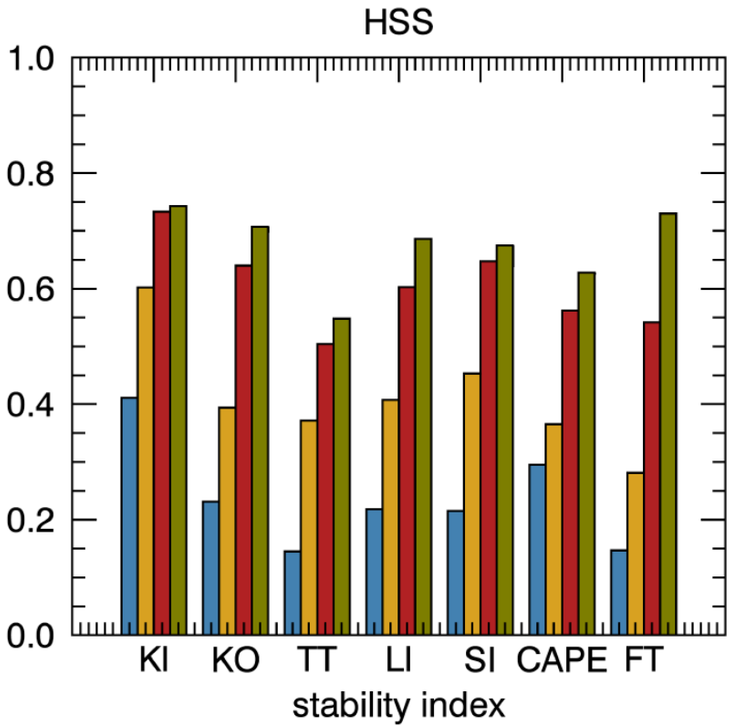
Output: layer transmitances,
Brightness temperatures at 14 frequencies,
jacobians



Bias (black), standard deviation (red), and RMS (blue) of differences between Tb simulated with RTTOV-gb and LBL model for clear sky conditions and at 90° elevation angle. Left: K-band channels. Right: V-band channels.

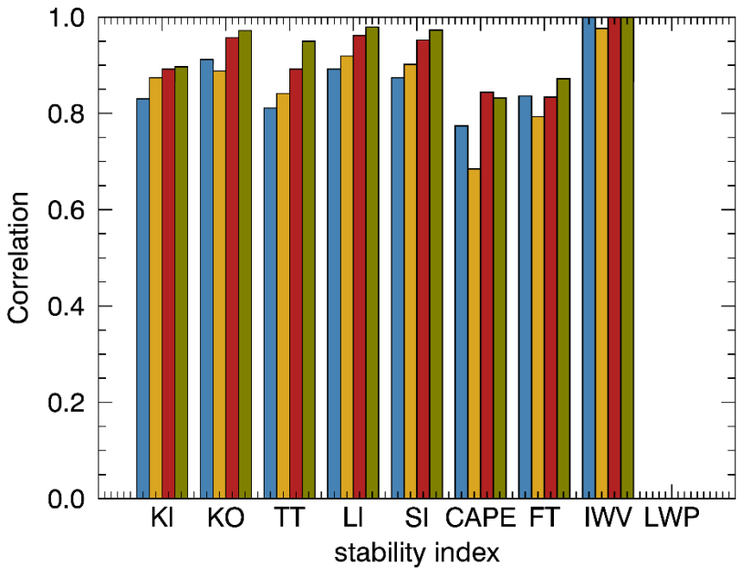
clear sky vs cloudy: single instruments

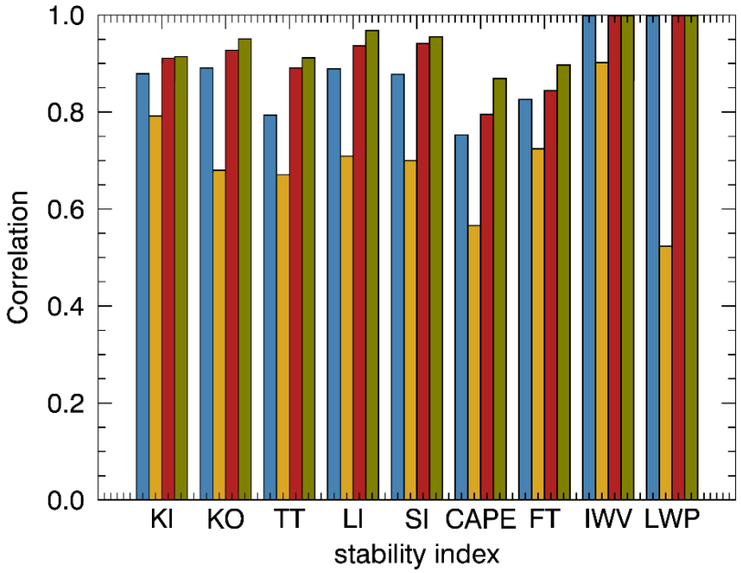




SEVIRI
IRS
MWR
MWR+DIAL

clear sky vs cloudy: synergy instruments





MWR
IRS
IRS+MWR
IRS+MWR+DIAL

clear sky vs cloudy: synergy instruments