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

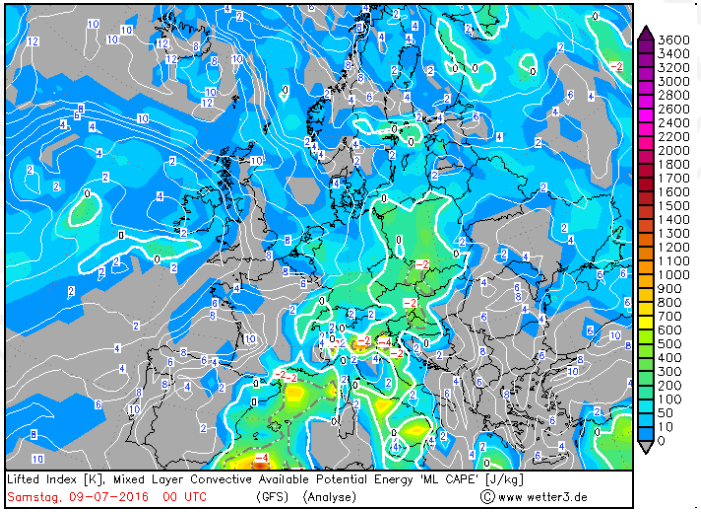
Atmospheric stability

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:

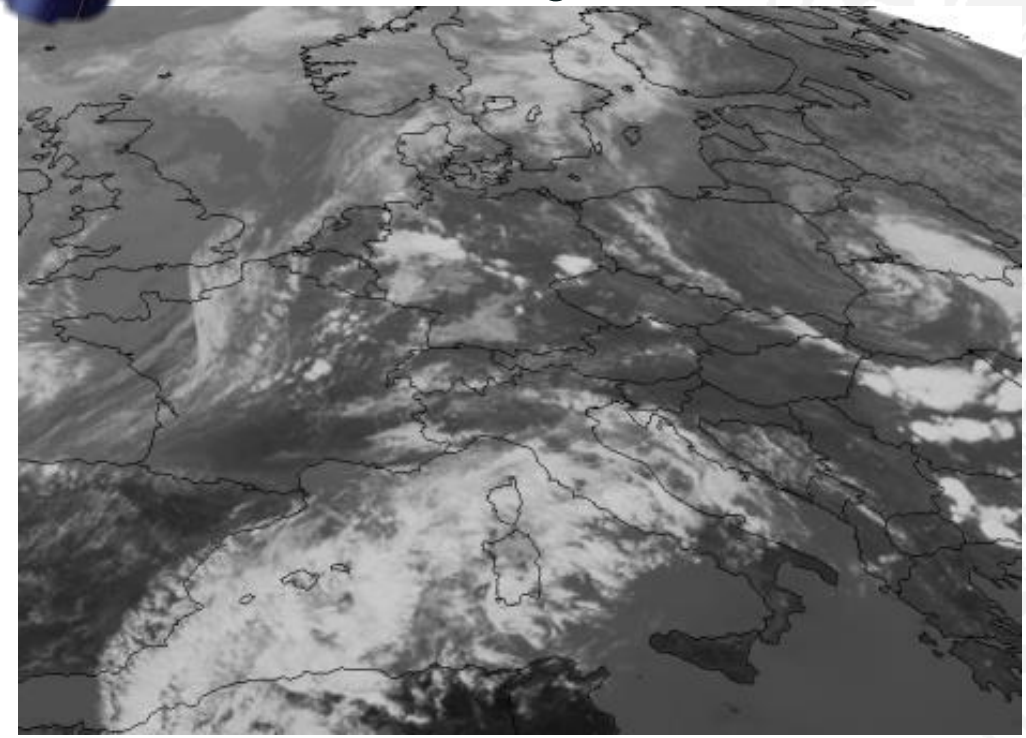
LI = T(500) – T(parcel from surface → 500)

KI, KO, TTI, Showalter Index, CAPE

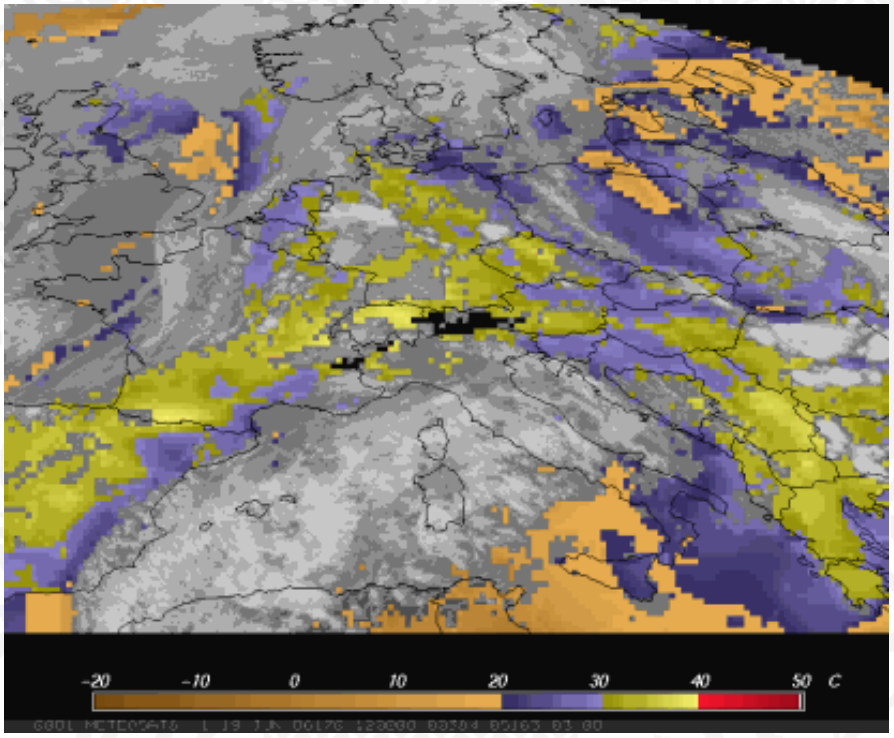
Stability Indices from Satellite Observations

Meteosat Global Instability Indices Product (GII)

SEVIRI Image



K-Index

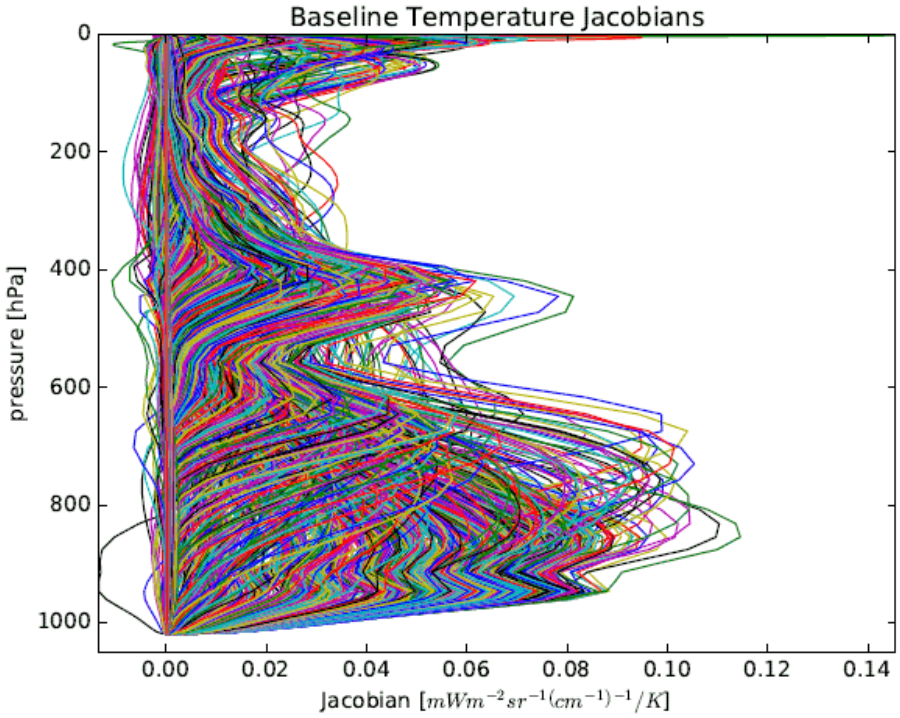


Indices: K, LI, TPW

Only in clear sky conditions, limited accuracy, depend on surface emissivity

Meteosat Third Generation: InfraRed Sounder

- Launch – 2023
- Spectrally highly resolved measurements in IR (1738 channels)
- Temporal resolution -30 min over Europe
- Horizonal resolution 4*4 km in Nadir



Level 2 products:

- convection probability
- T-, q-profiles

https://www.eumetsat.int

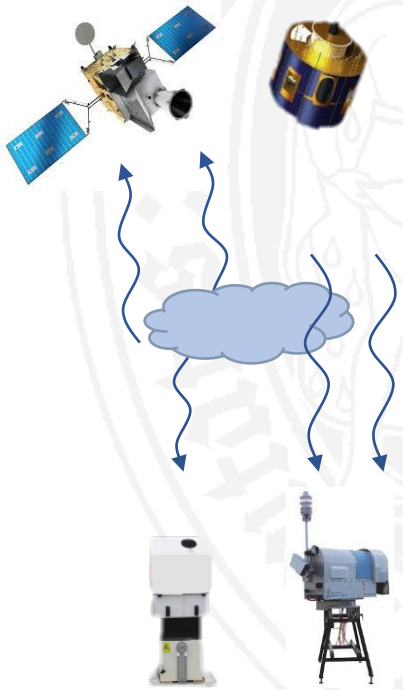
ARON-Project

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)



Network of ground-based instruments:

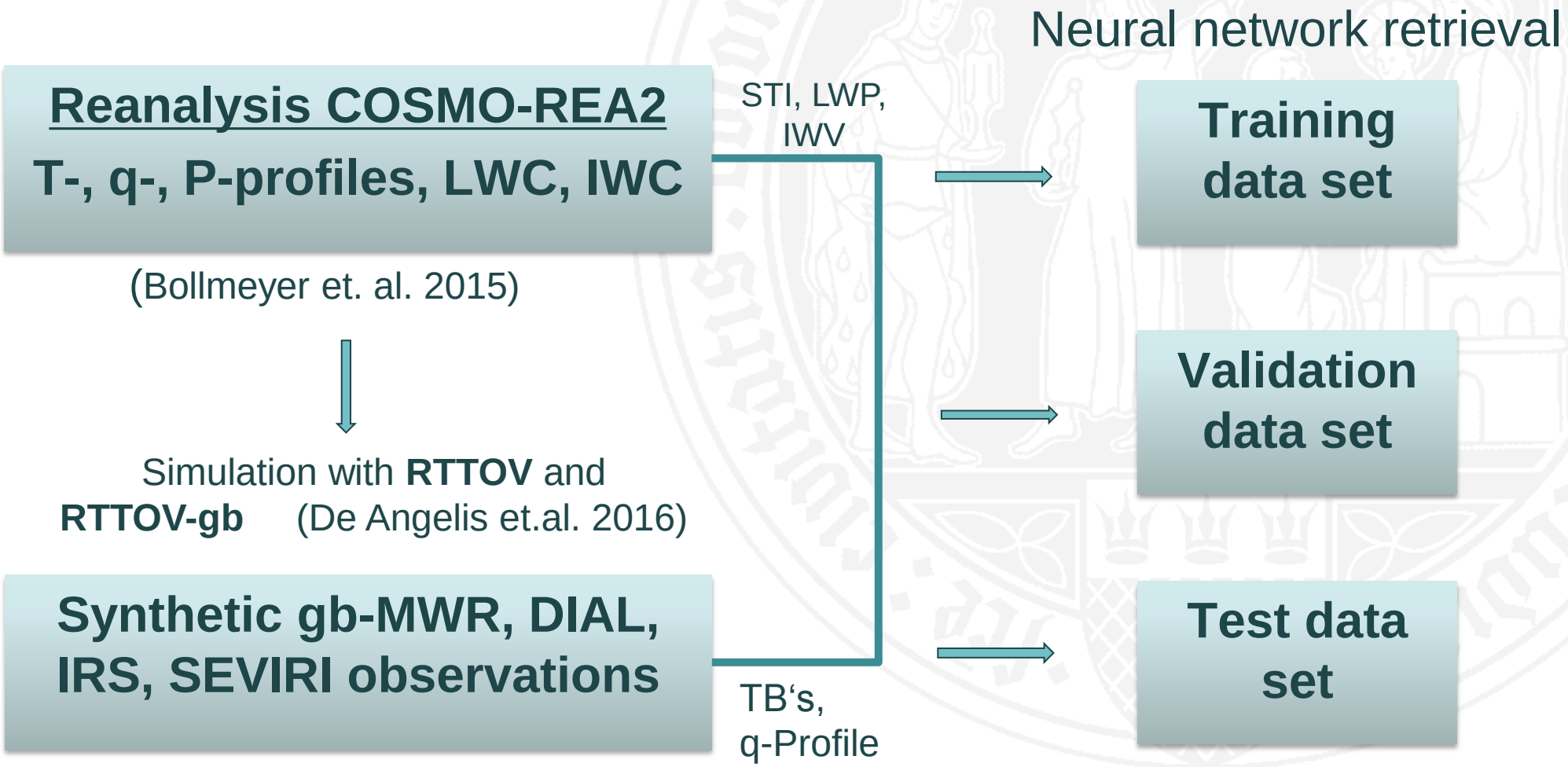
- Microwave Radiometer (MWR)

- DIAL

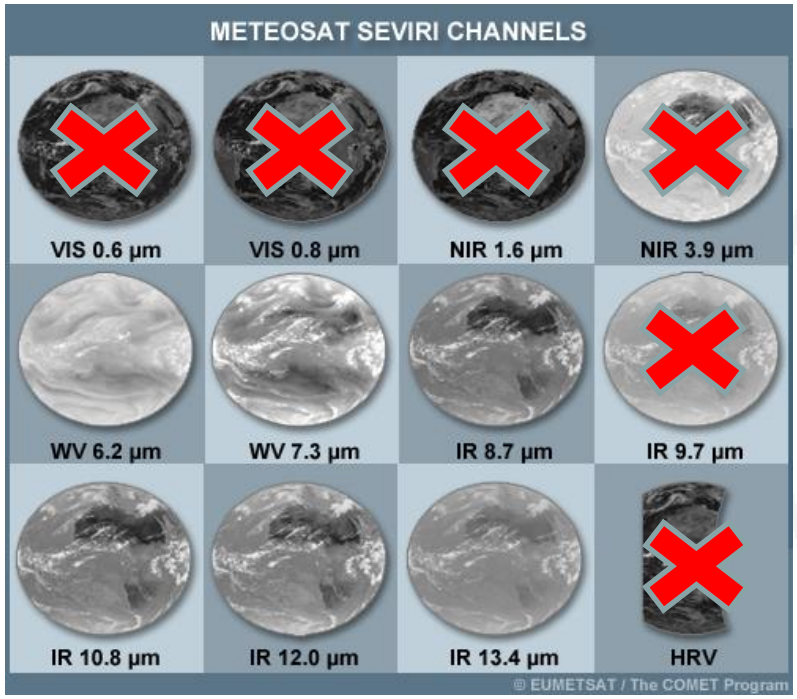
- Improved accuracy and resolution of T, q - profiles (Ebell et.al., 2013)
- Identification of region where convection can occur in the next 1-2 hours
- Imrovement of short term forecast of ground fog, lifted stratus (at night-time, over snow covered surfaces)

Experiment setup:

STI retrieval from simulated satellite and ground-based measurements



RTTOV, Simulation of Satellite Measurements

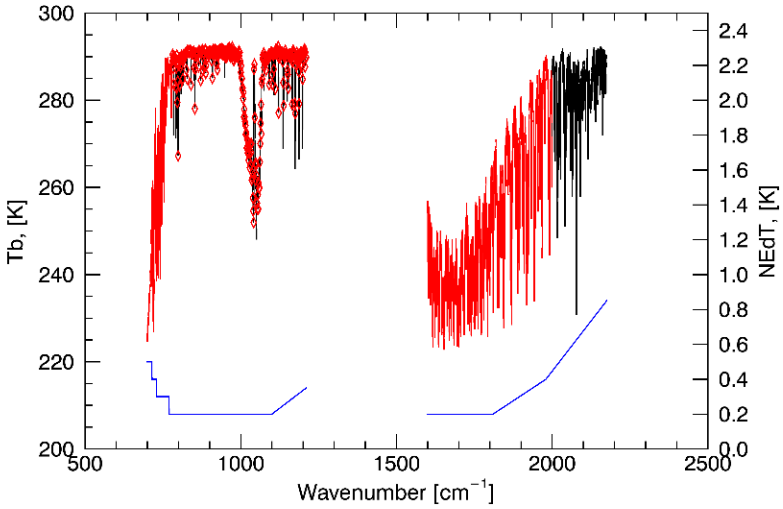


SEVIRI: 6 channels geostationary, „always“ available

3 km horizontal Resolution

IRS: 1738 channels with 0.5-0.625 cm^{-1} spectral resolution geostationary

4km horizontal resolution



1113 channels. CO_2 und H_2O absorption.

Principal Component Analysis
→ 15 PC‘s

Ground Based Instruments

HATPRO : IWV, LWP, profiles of T and WV

14 Channels, 5 elevation angles

RTTOV-gb → simulated measurements (Tb)

The prototype Vaisala DIAL system: WV profiles up to 3km (100m)

10 levels between 100 and 1900 m

absolute humidity uncertainty within 10%

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

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

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

Performance of Single Instruments
Clear Sky

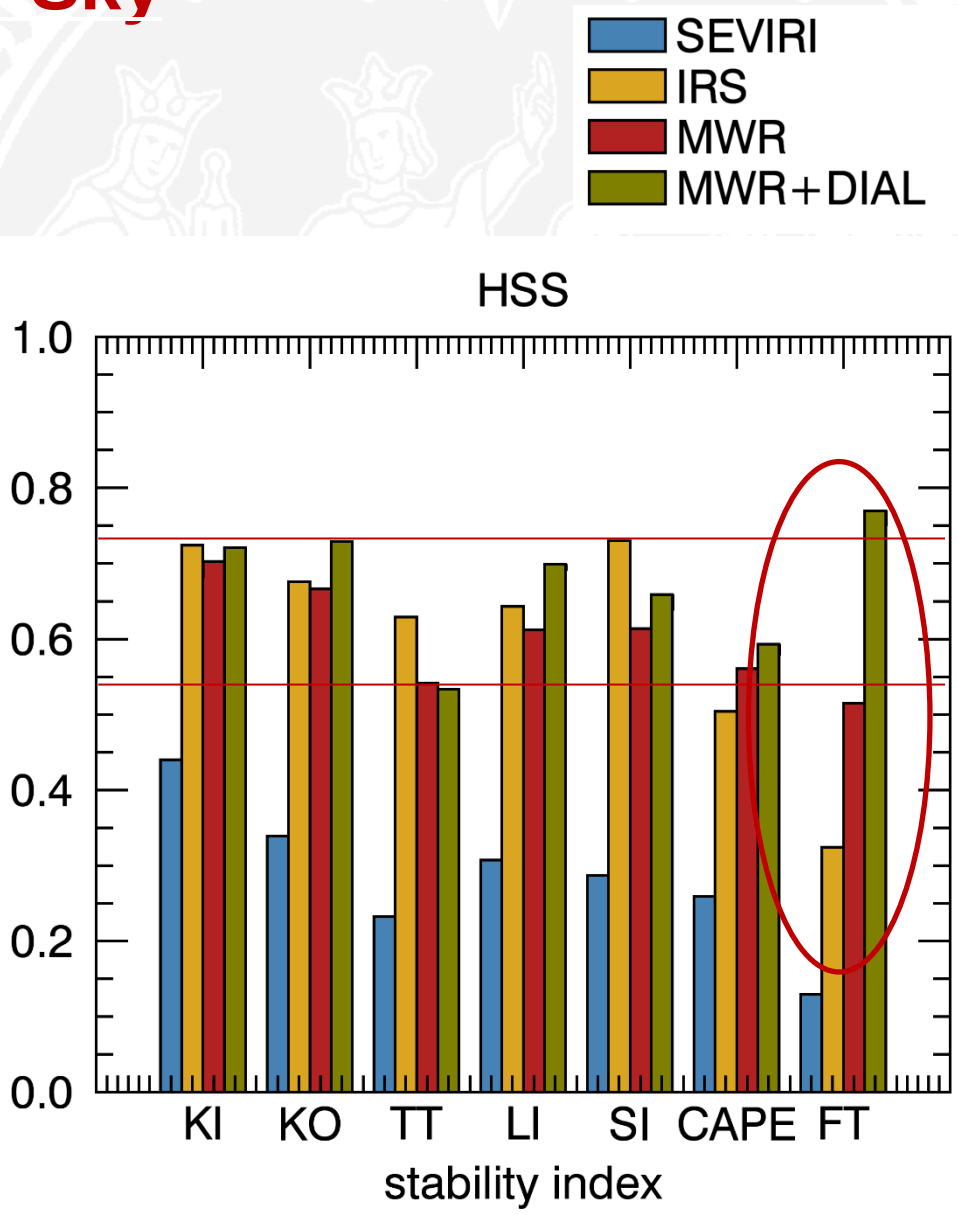
- **IRS**: significant improvements compared to SEVIRI

- **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

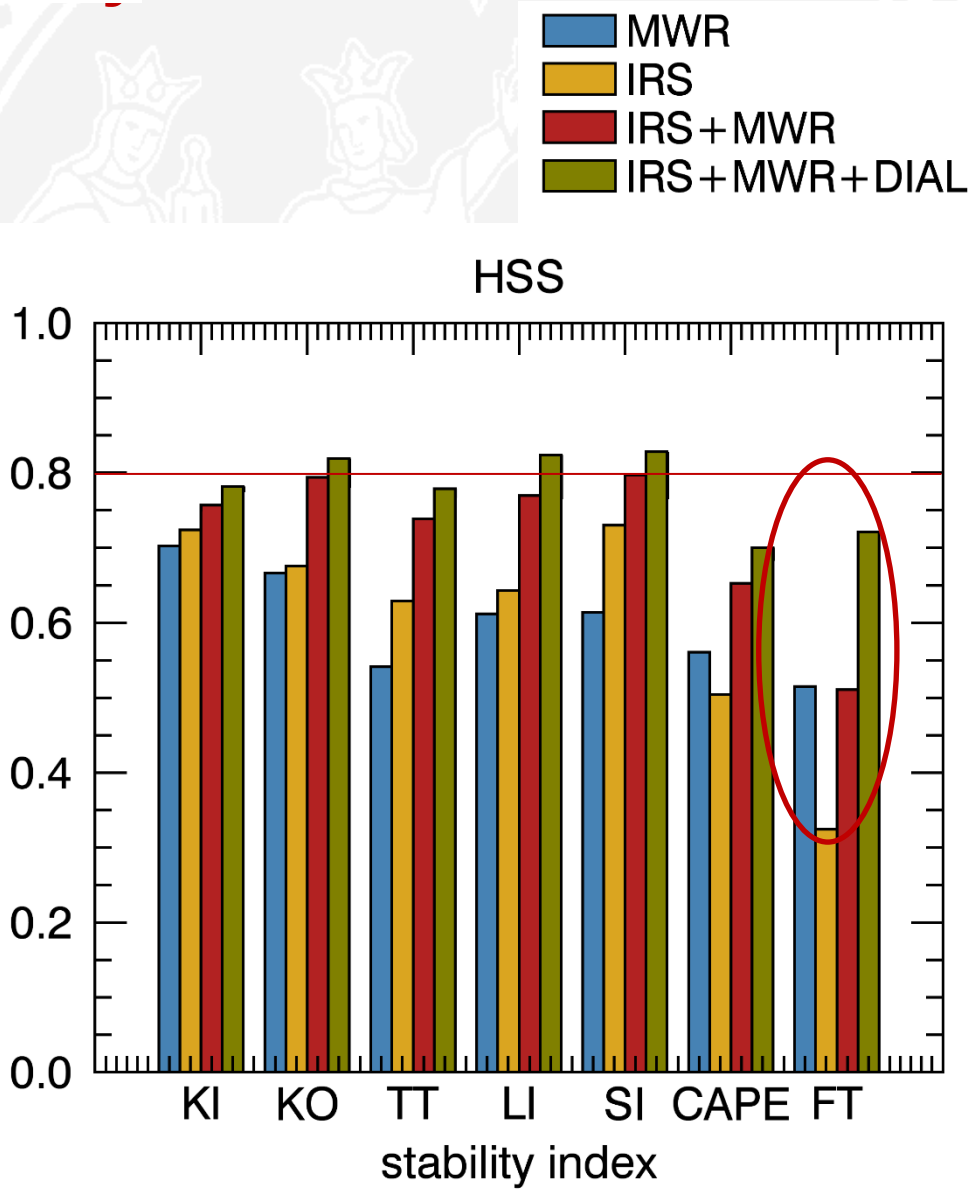


Performance of Instruments in Synergy
Clear Sky

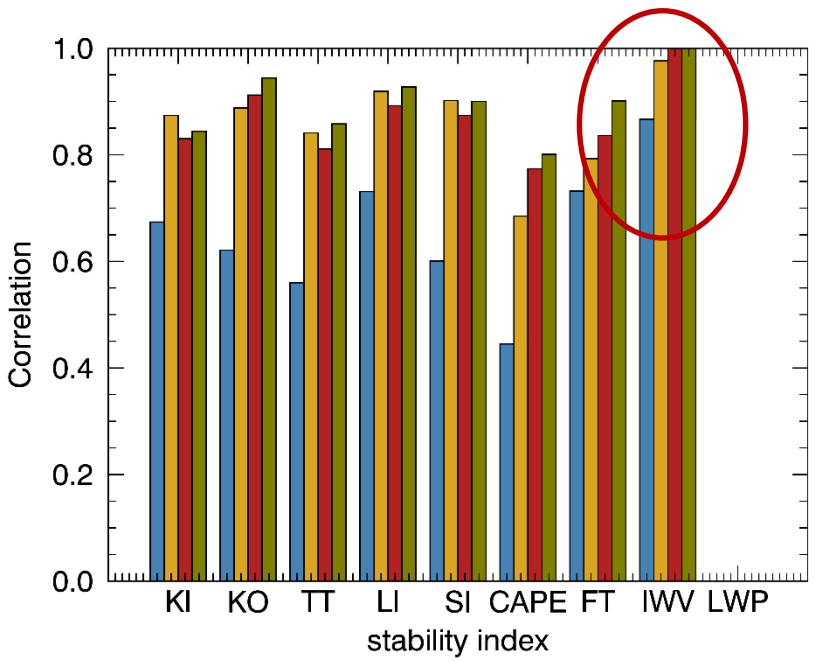
- **IRS+MWR:**
  complement each other→**~80%skill**
  → **increase of 4-20% in skill compared to IRS**

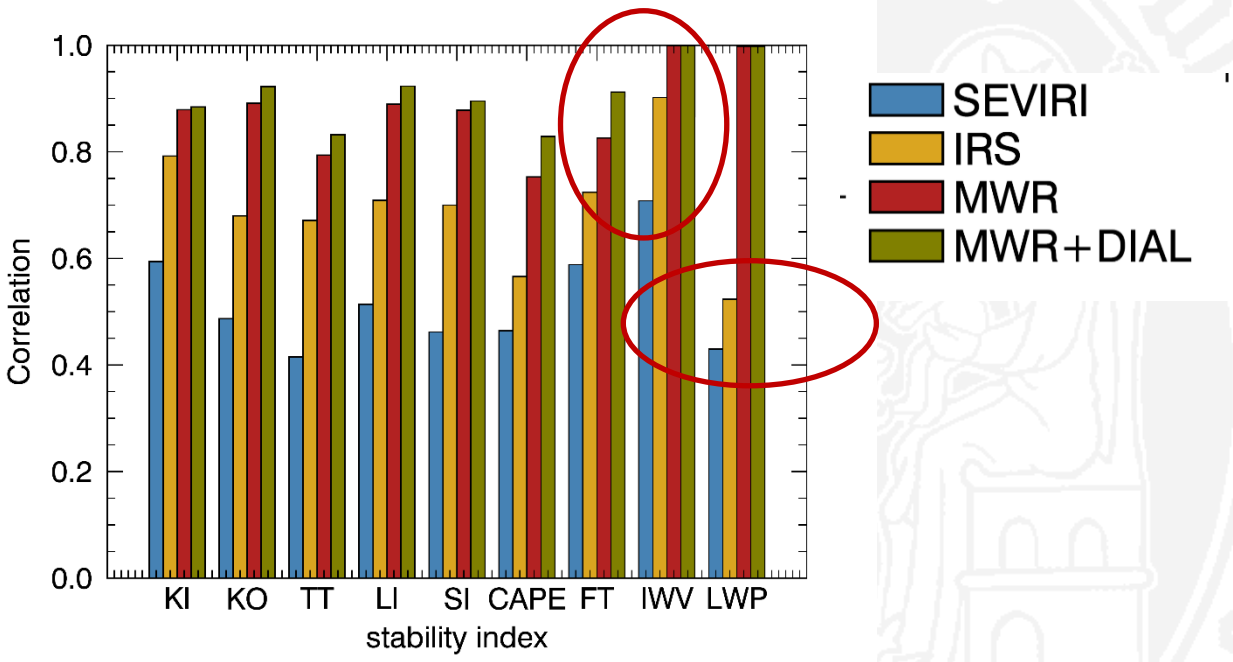
- **CAPE_**→ benefits from ground-based observations → **+30% skill**

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

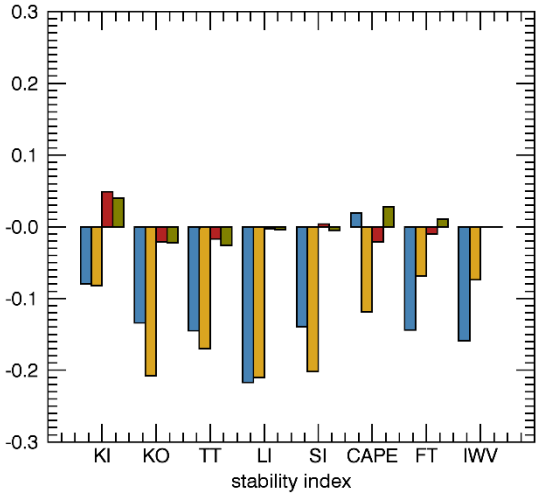


Clear Sky vs Cloudy: Single Instruments





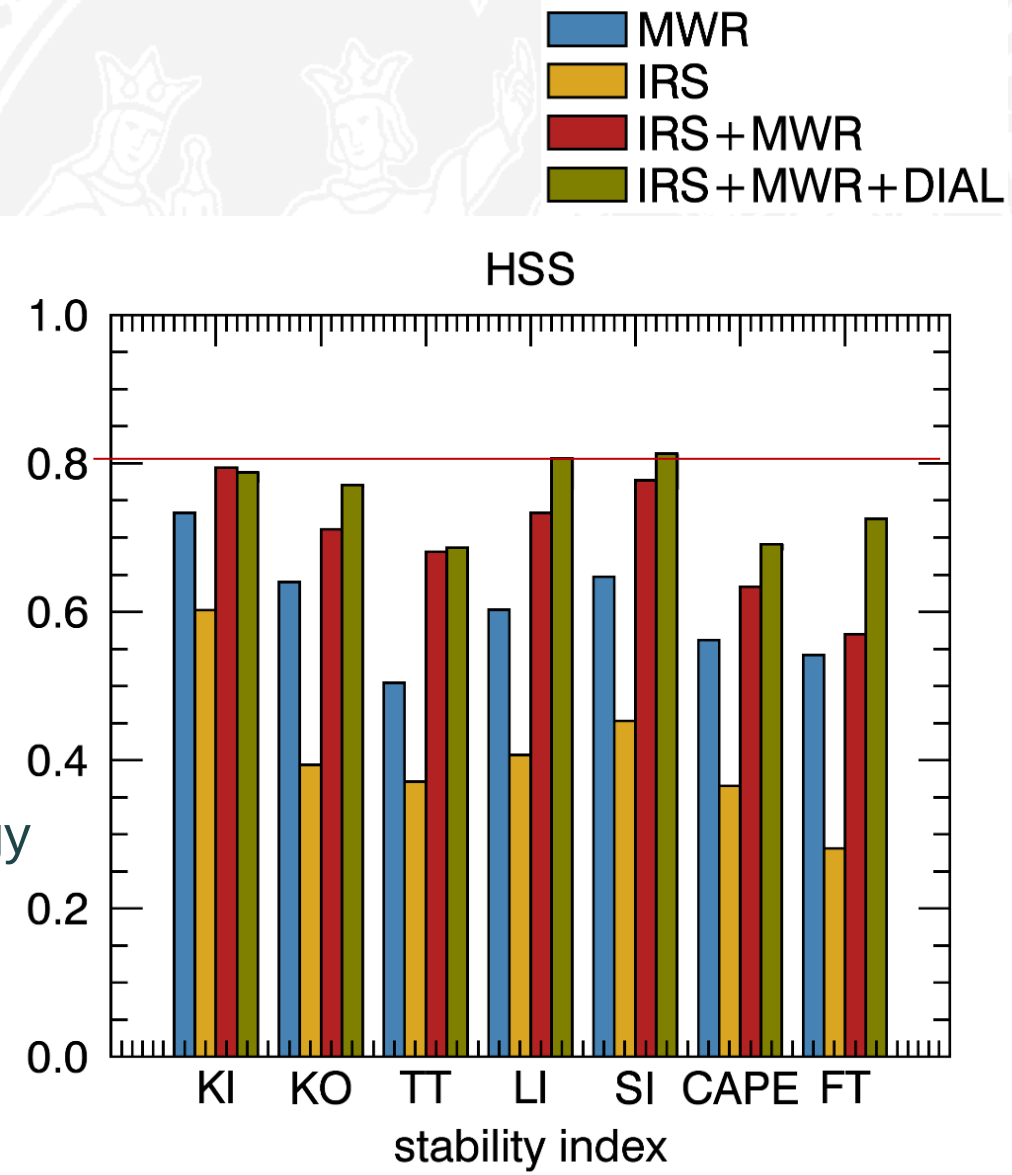
(cloudy-cs)



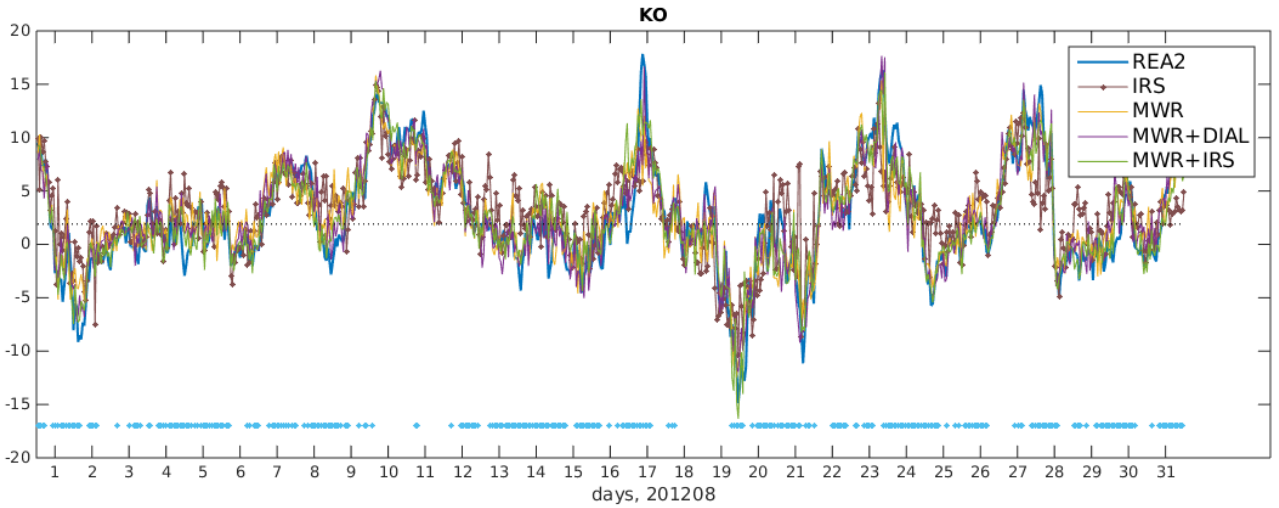
- **SEVIRI, IRS**: CORR decrease by 10-23% for all indices. IR channels get saturated in presence of clouds
- **MWR, MWR+DIAL:** CORR change only slightly.
- IWV: CORR > 85% for all sensors under CS
- LWP: IRS → 50% CORR
  MWR → 99% CORR

Performance of Instruments in Synergy
Cloudy

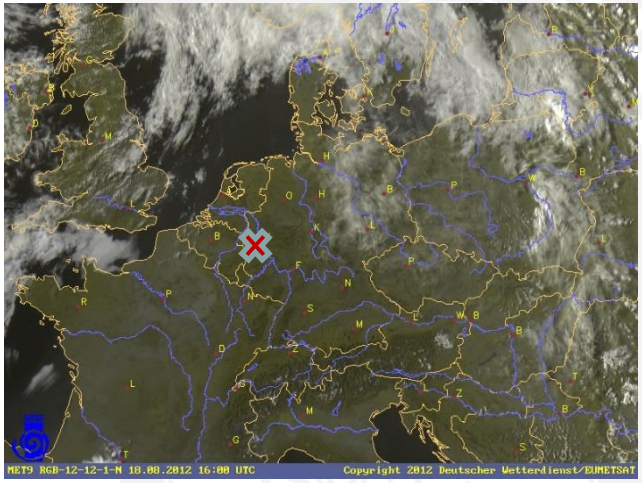
- **IRS**: significantly lower HSS compared to CS
- **MWR**: HSS 20-40% higher compared to IRS
- **IRS+MWR**: all STI benefit from synergy
  IRS+MWR+DIAL: → ~80% skill
  → increase of 30-70% in skill compared to IRS

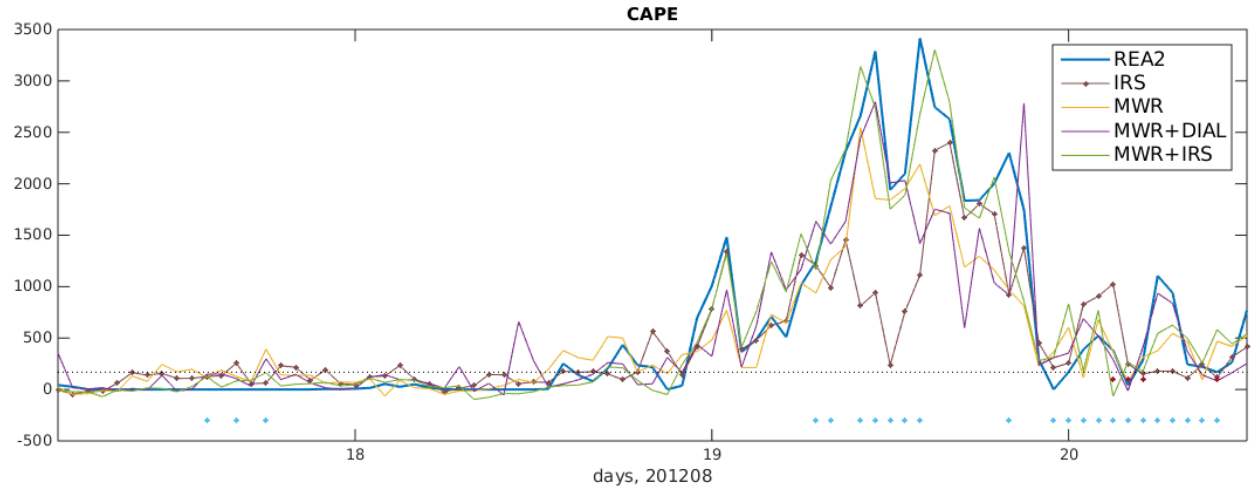


Timeseries JOYCE

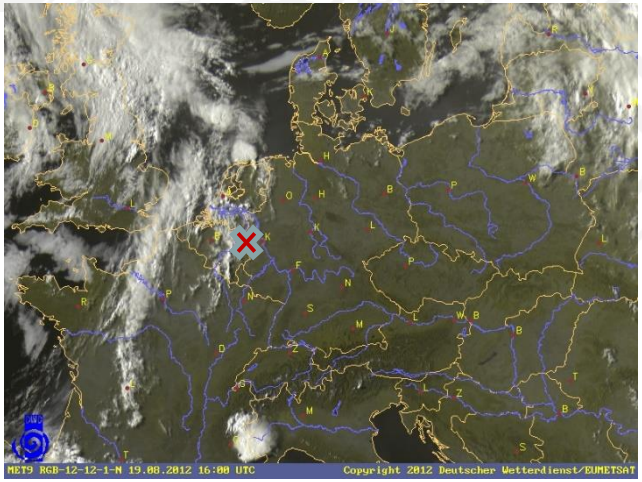


HRV 18.08.12, 18:00





HRV 19.08.12, 18:00



Conclusions

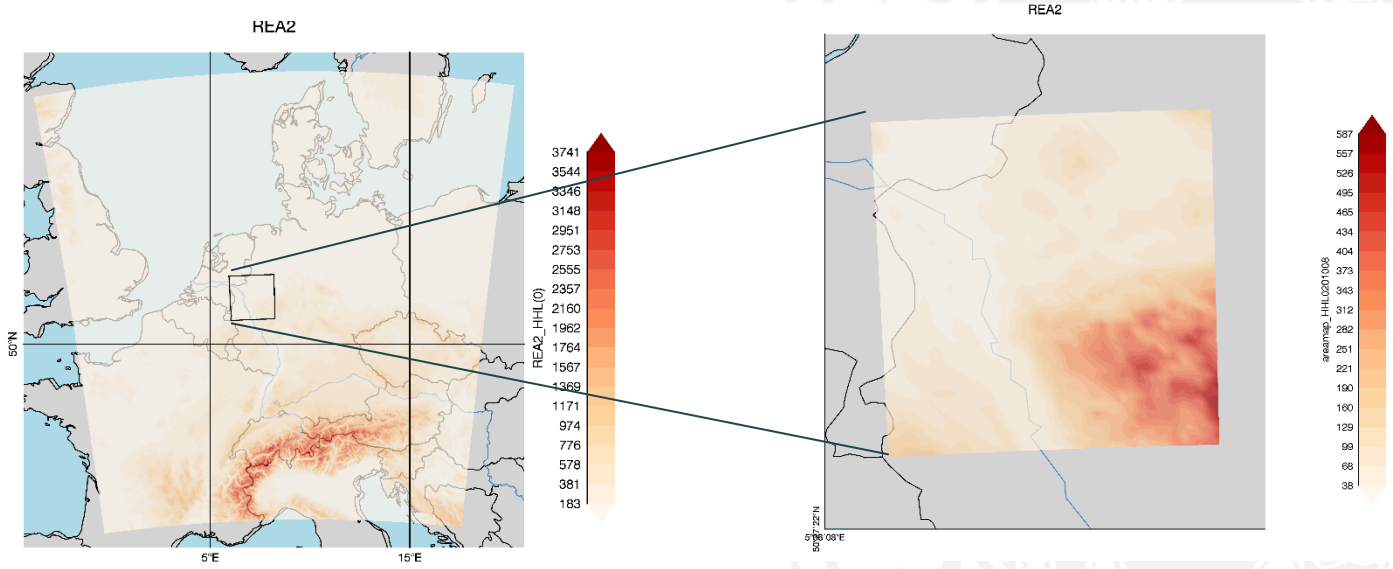
Clear sky

- 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.

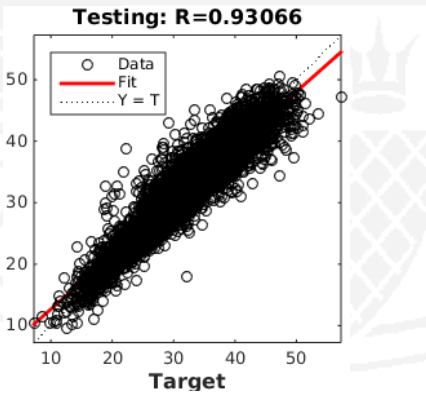
Outlook
Representativeness of Observations of Single MWR



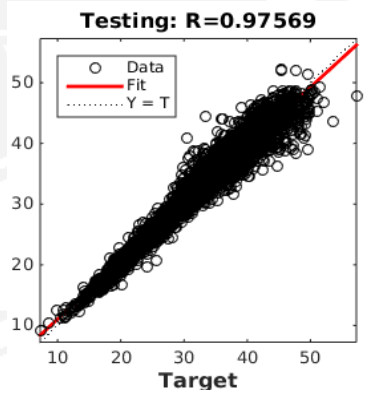
150*150km^2
4km horizontal and
1h temporal resolution

- 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



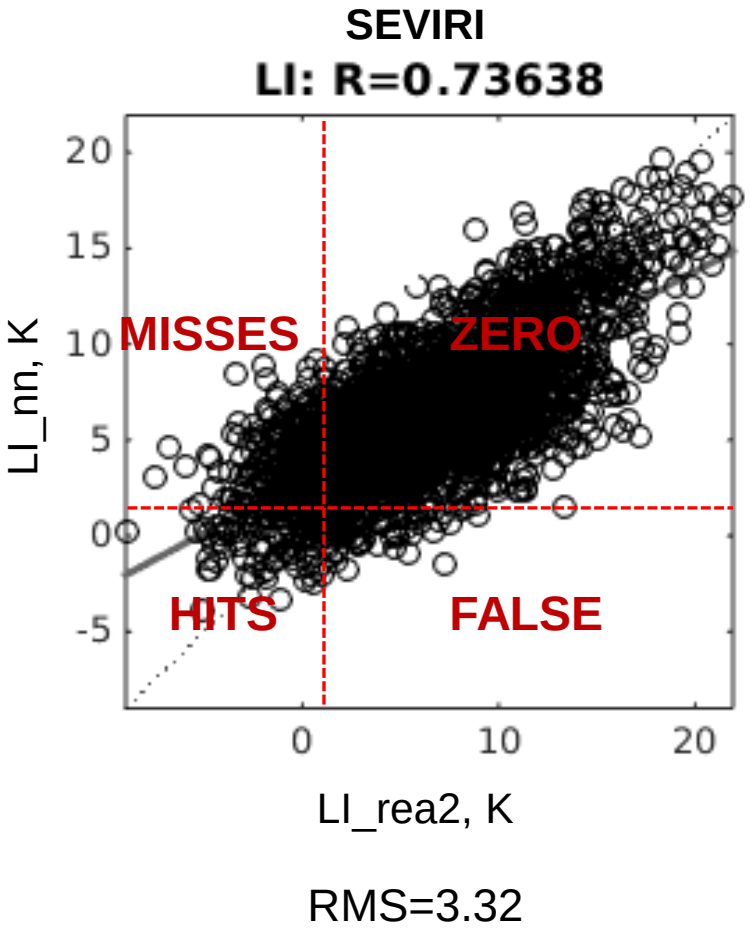
IRS+MWR



Thank you for attention!

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?



Probability of detection=H/(H+M)

False alarm rate = F/(H+F)

Heidke skill score = [-1:1]

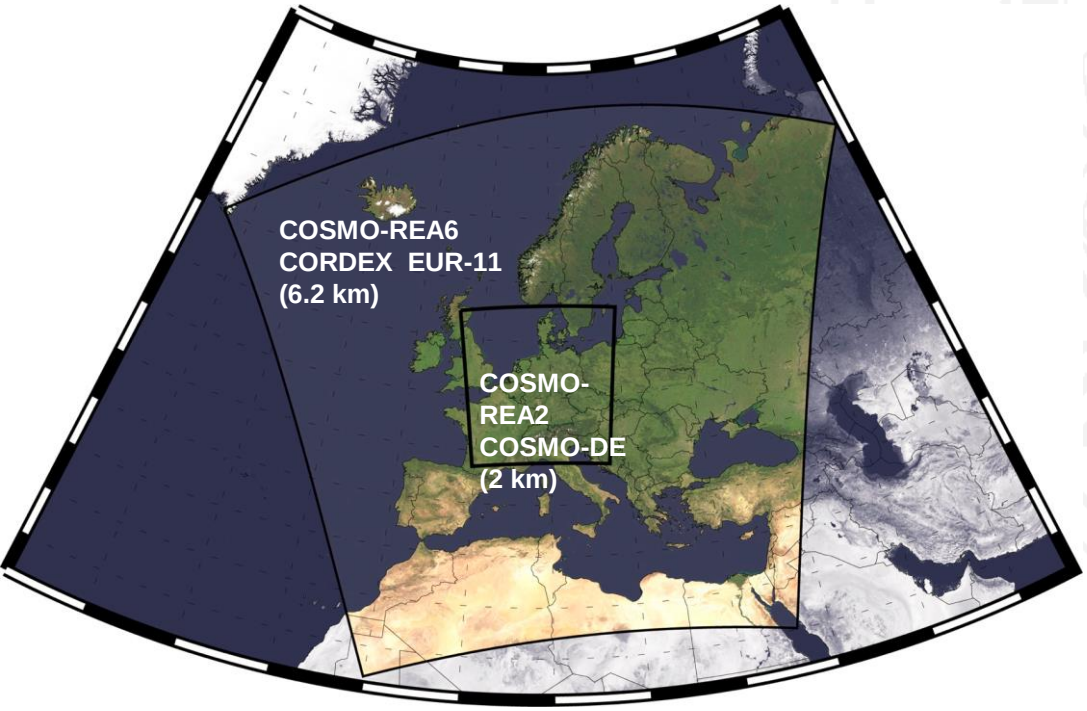
→ 1: perfect forecast

→ 0 : no forecast skills

→ -1: guessing is better

ARON-Project

- MWR/DIAL-Network doesn‘t yet exist
- Virtual network will be simulated by using multi-year reanalyses based on COSMO model (i.e. COSMO-REA2)



High resolution regional reanalysis for Europe and Germany (Bollmeyer et al., 2015)

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

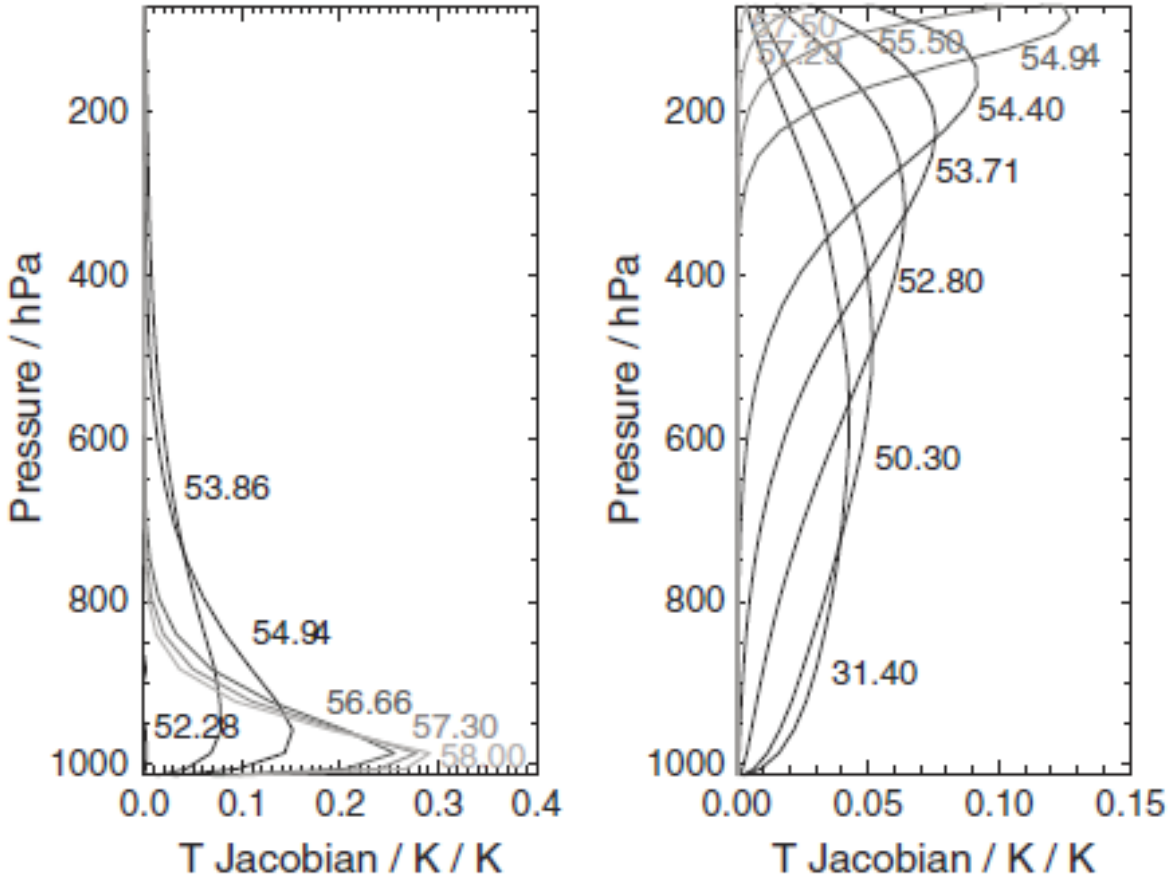
$$CAPE = R_d \int_{p=surface}^{p=TOA} \left(T_v(parcel) - T_v\right) d\ln p$$

$T_{v,parcel} > T_v$

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



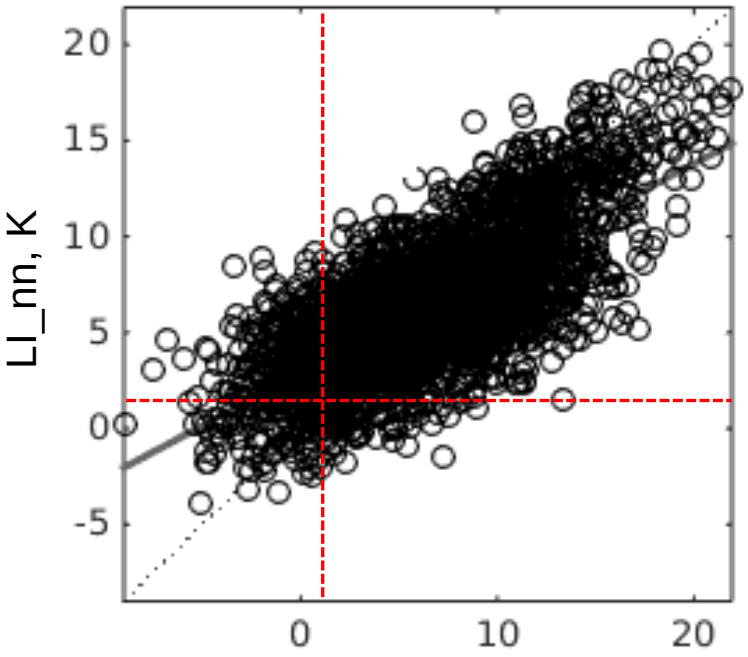
Ebell et.al. 2013

SEVIRI vs. gb-MWR

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

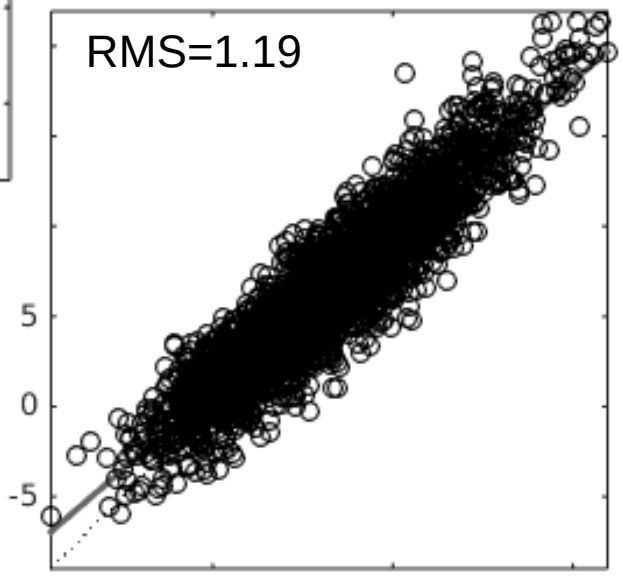
Uncertainty reduced by > 30%

SEVIRI
LI: R=0.73638



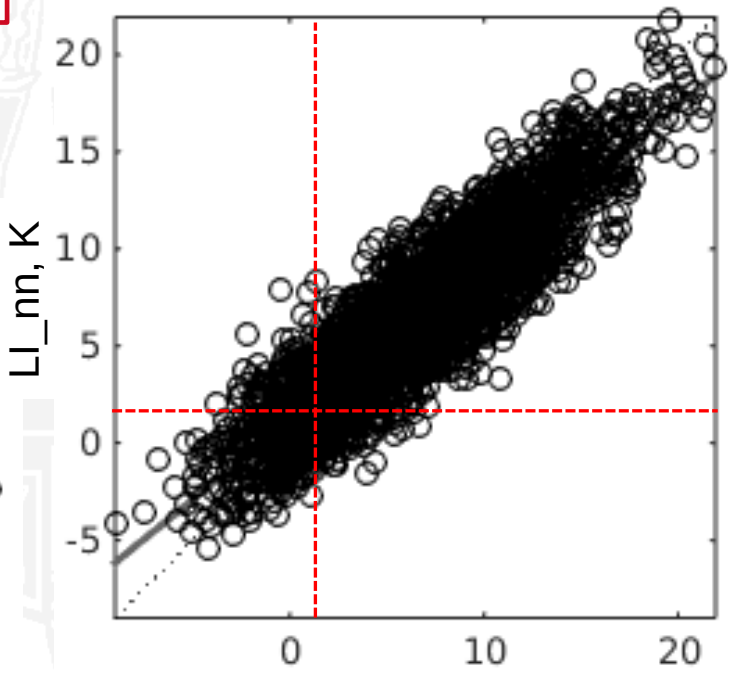
RMS=3.32

LI: R=0.92368



SEVIRI+MWR

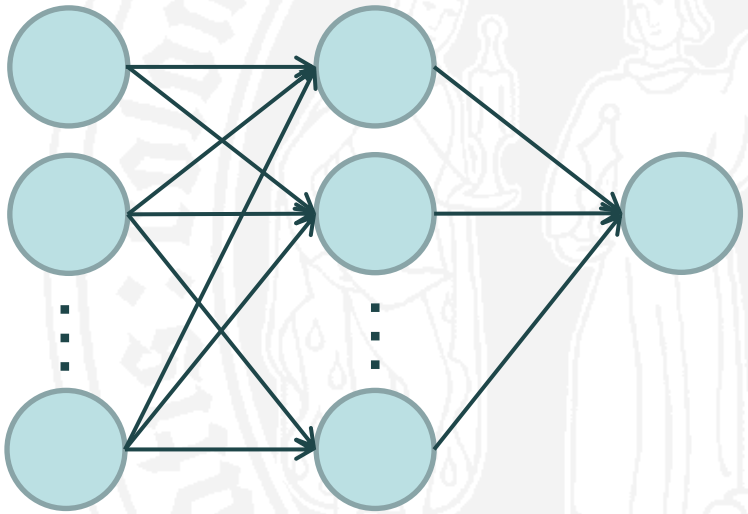
MWR
LI: R=0.90124



RMS=2.13

STI-Retrieval für COSMO-REA2 Reanalyse

- Tbs (MWR, AMSU-A/MHS, SEVIRI)
- q-Profil (DIAL)
- PCs (IASI, IRS)



Ca. 8000 Profile
- 50% Trainingsset
- 20% Validationset
- 30% Testset

Forward simulations: RTTOV

RTTOV – fast radiative transfer model → Simulation of radiances for visible, IR and MW satellite instruments

Regression coefficients

+

Input:
Temperature and humidity profiles,
surface properties,
optional:
trace gases,aerosols,
hydrometeors

⬇

Output:
TOA radiances, Tb,
Jacobians

RTTOV-gb, simulation of ground based observations

RTTOV-gb → ground based HATPRO observations

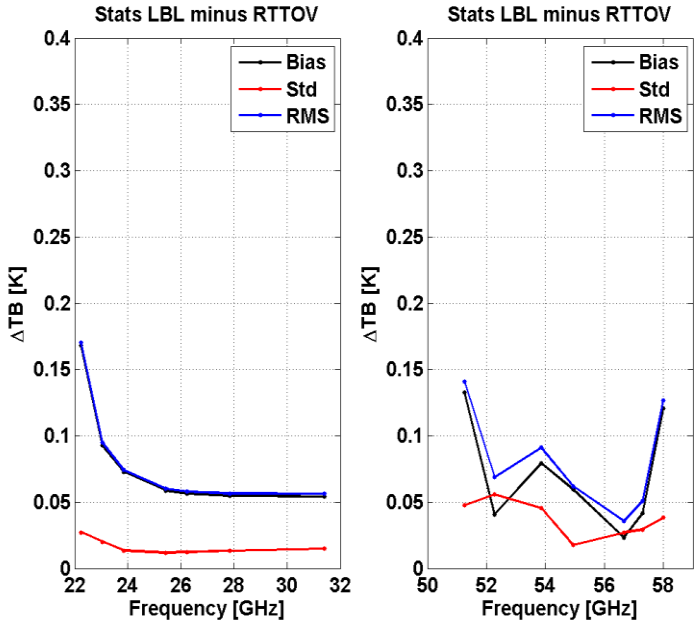
Input: temperature and humidity profiles,
surface parameter
cloud liquid water

+

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.