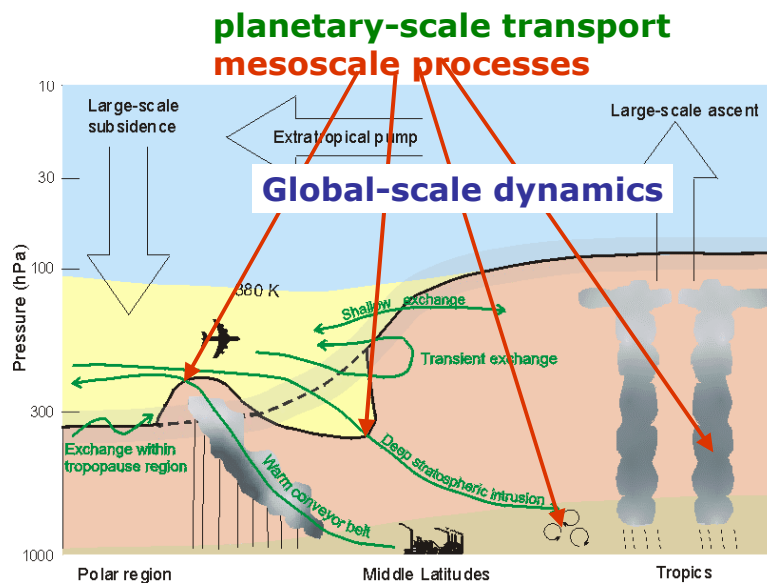


Cross tropopause transport: processes and quantification based upon ECMWF analyses

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Stohl et al. 2003 (BAMS)

STE: a multi-disciplinary topic

Understanding exchange processes:
mesoscale to global dynamics

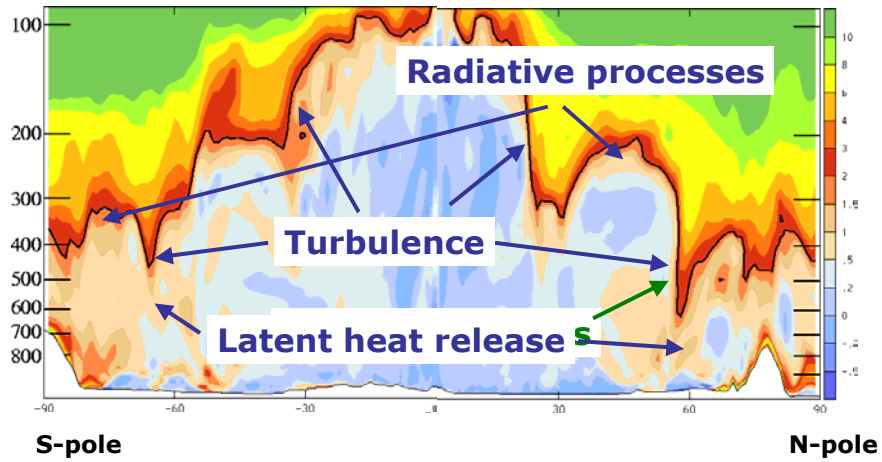


Linkage:
planetary-scale transport



Effects:
chemistry and climate

The 2-pvu tropopause



Transport across the 2-pvu TP

$$\frac{D}{Dt} PV = 0 \quad \text{for adiabatic flow}$$

⇒ **Cross tropopause transport requires diabatic processes**

$$\frac{D}{Dt} PV = \rho (\vec{f} \cdot \vec{k} + \nabla \times \vec{u}) \cdot \nabla \dot{\theta} + \rho \nabla \theta \cdot (\nabla \times \vec{F})$$

↑
**latent heat release
radiative processes**

↑
**turbulence
surface friction**

Questions

Understanding exchange processes

- (1) relevant **mesoscale processes** (turbulence, radiation, ...)?
- (2) (sub)synoptic-scale **structures** that host the exchange events (TP folds, streamers, cut-off decay, ...)?
- (3) larger-scale processes leading to these structures (Rossby wave breaking, cyclogenesis, blocking, ...)?

Questions

Implications for chemistry and climate

- (4) **quantification** of climatological exchange fluxes (mass, ozone, water vapour, ...)?
- (5) **geographical distribution** of exchange?
- (6) typical **transport pathways**: „origin“ and „destination“ of exchange air parcels?
- (7) typical **residence times** of exchange air parcels?

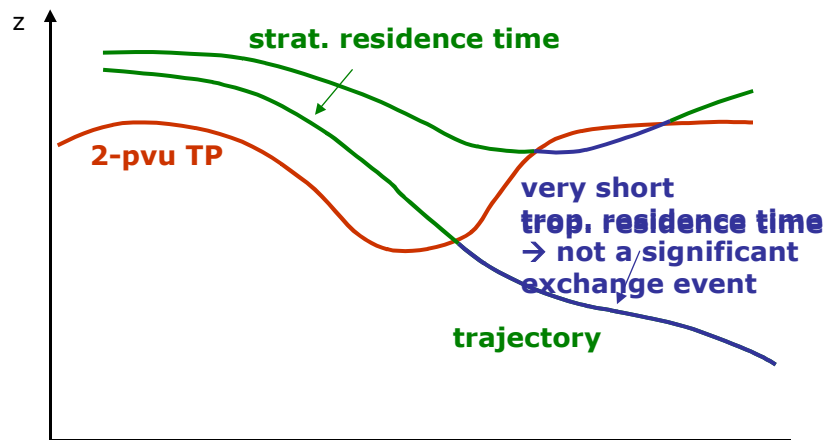
Questions

Methods, Data, Verification

- (8) What is the appropriate **method** to diagnose STE?
 - (9) Use and quality of **data**: observations, models, reanalyses?
 - (10) **Verification** of exchange estimates?
-
- ```
graph TD; A[aircraft in situ observations] --> B[Lagrangian]; B --> C[↑]; C --> D[Use and quality of data: observations, models, reanalyses?]; E[ERA15/40] --> D; E --> F[Verification of exchange estimates?];
```
- aircraft *in situ* observations**
- Lagrangian**
- ERA15/40**

8

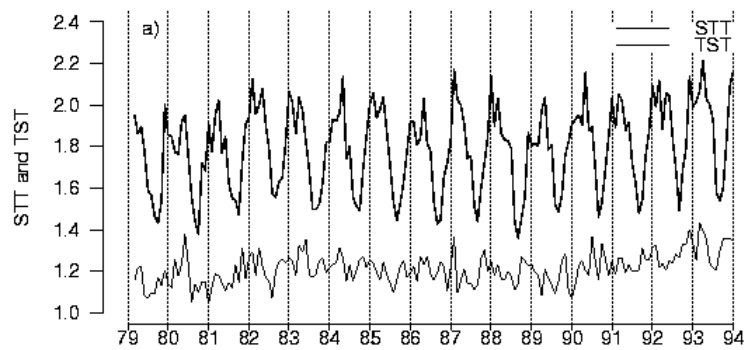
## The Lagrangian approach



4

## ERA15 climatology

NHEM STT and TST mass flux

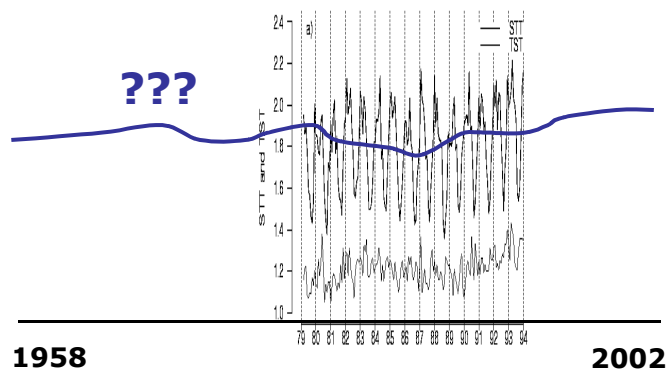


Sprenger and Wernli 2003 (JGR)

4

## ERA40 climatology ?

NHEM STT and TST mass flux

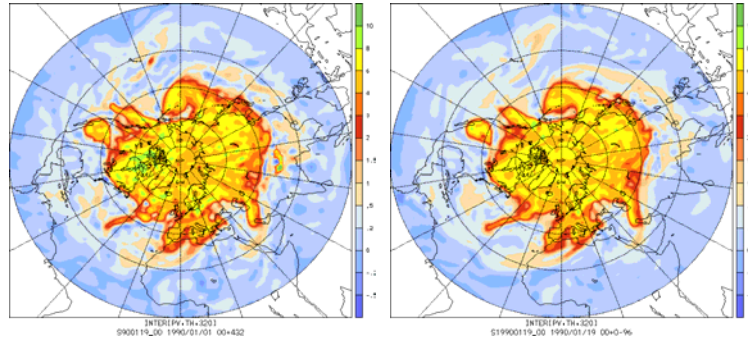


## ERA15 vs. ERA40

9

ERA15: T106 L31 optimum interpolation  
 ERA40: T159 L60 3D var

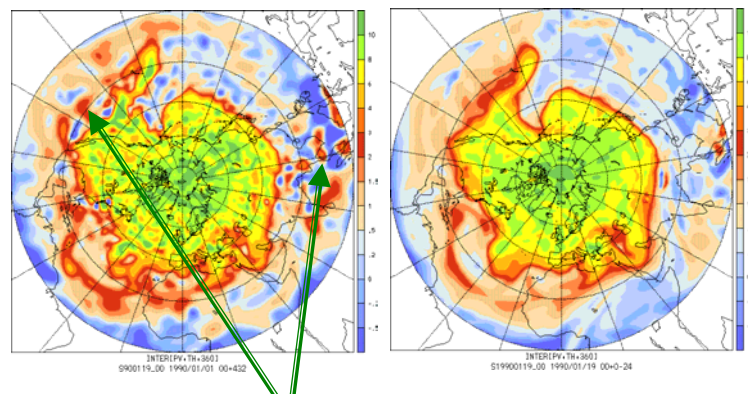
PV on 320 K: 00 UTC 19 Jan 1990



## ERA15 vs. ERA40

9

PV on 360 K: 00 UTC 19 Jan 1990



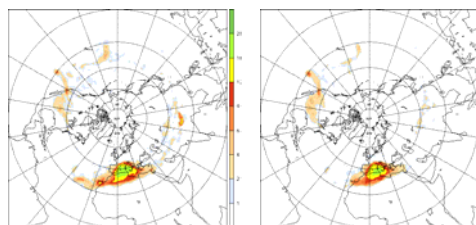
„blobby“ PV structures!

## ERA15 vs. ERA40

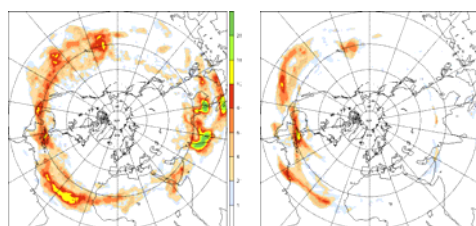
9

Comparison of cut-offs with  $PV > 2\text{pvu}$

320K  
 very similar

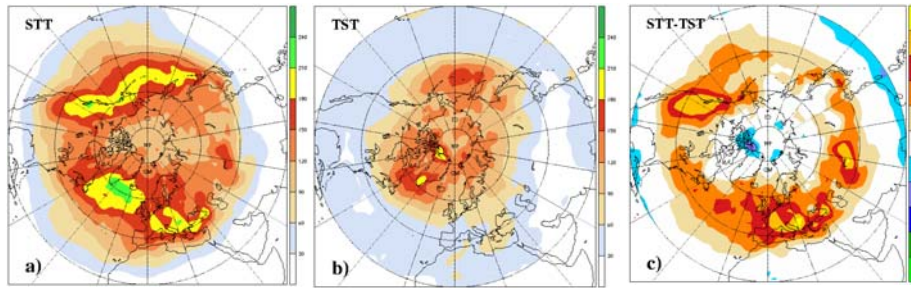


360K  
 significant differences!



## ERA15 climatology

### Annual mean geographical distribution of mass fluxes



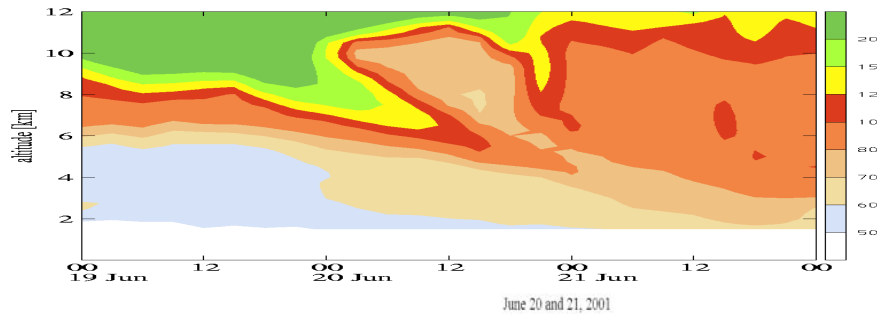
**STT: large zonal variability**  
 maxima near centre and end of storm-tracks

**TST: less zonal variability**  
 maxima near Greenland and Aleuten

**Net (STT-TST): pos. in mid-latitudes**  
 weakly neg. in Arctic / subtropics  
 maxima towards end of storm-tracks

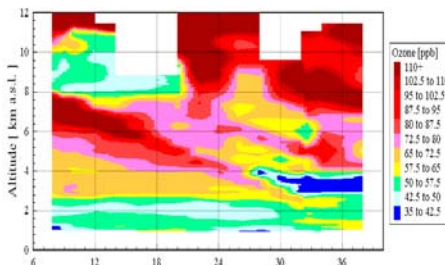
Sprenger and Wernli 2003 (JGR)

## ECMWF analyzed ozone field 4, 10



**Lidar observations**  
**Garmisch**  
**20/21 June 2001**

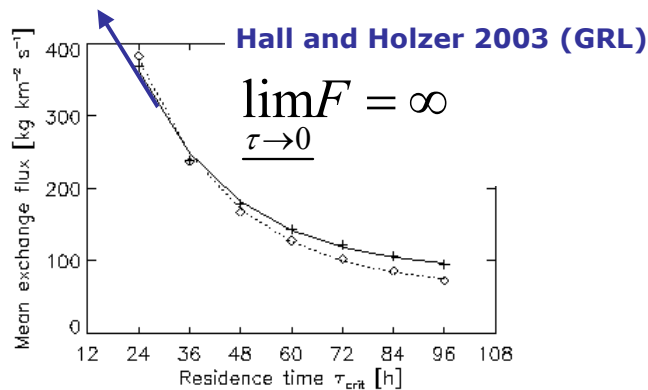
Zanis et al. 2003 (ACP)



7

## ERA15 climatology

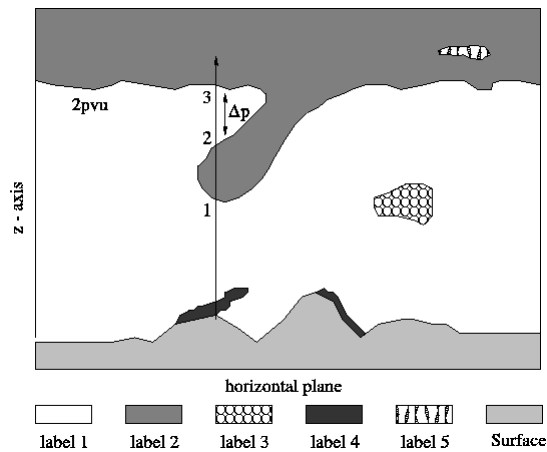
### Sensitivity to residence time threshold



Bourqui 2002

## The relevance of tropopause folds

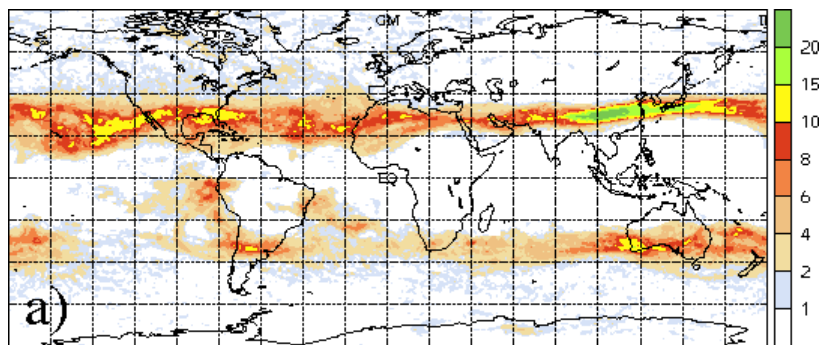
### Objective identification of folds



Sprenger et al. 2003 (JGR)

## The relevance of tropopause folds

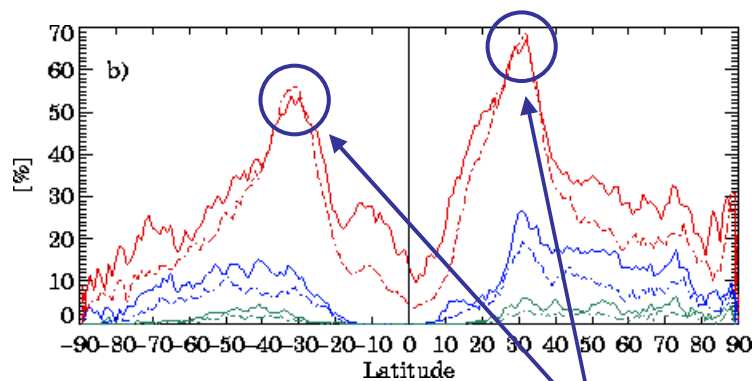
### Frequency of tropopause folds during DJF 2000/01



Sprenger et al. 2003 (JGR)

## The relevance of tropopause folds

### Link between exchange events and TP folds

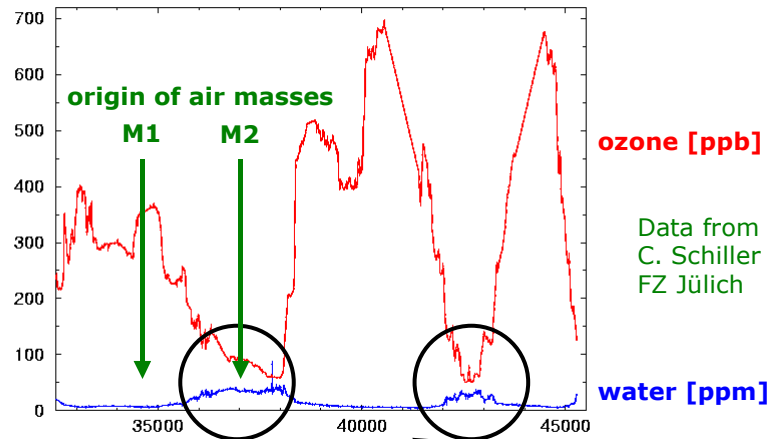


Sprenger et al. 2003 (JGR)

**in subtropics:  
50-70% of STE in folds**

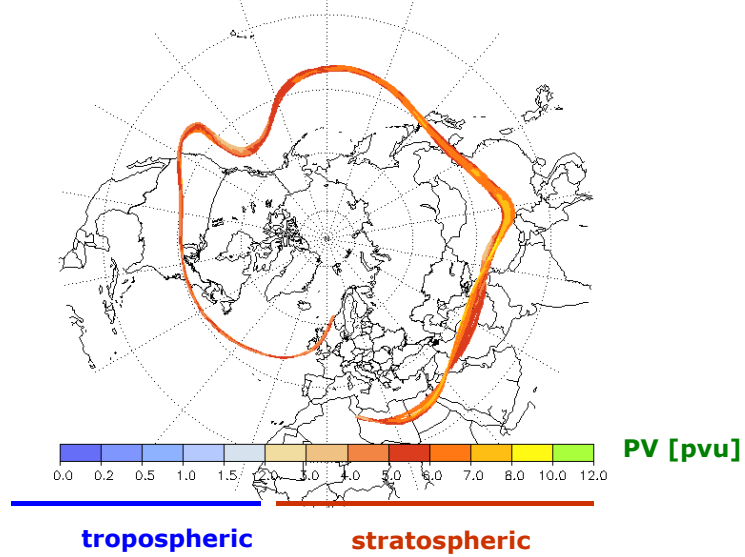
## Aircraft observations in the stratosphere 10

19 January 2002 (project SPURT)

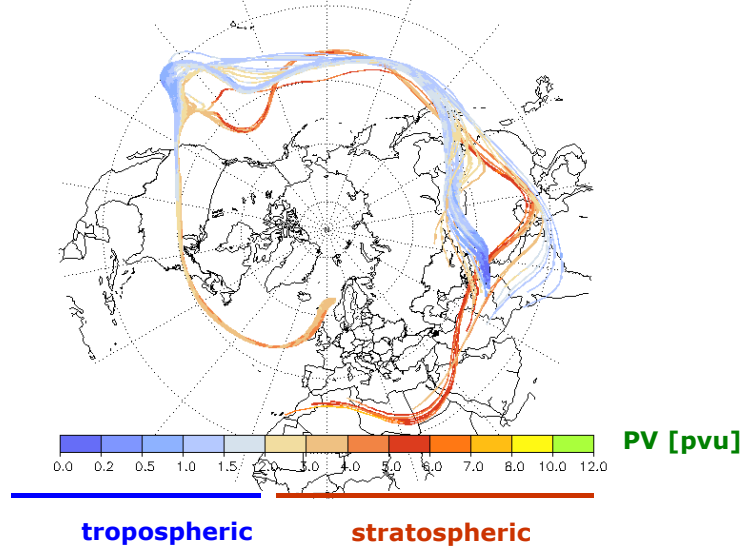


tropospheric air in the stratosphere

## Pathway of air mass M1 10



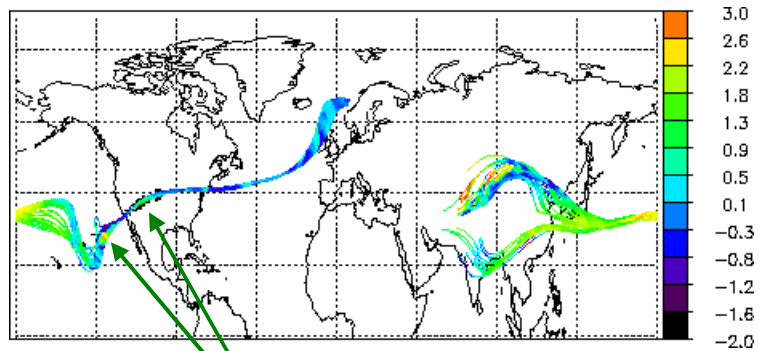
## Pathway of air mass M2 10





### ERA40 turbulence field

1,10

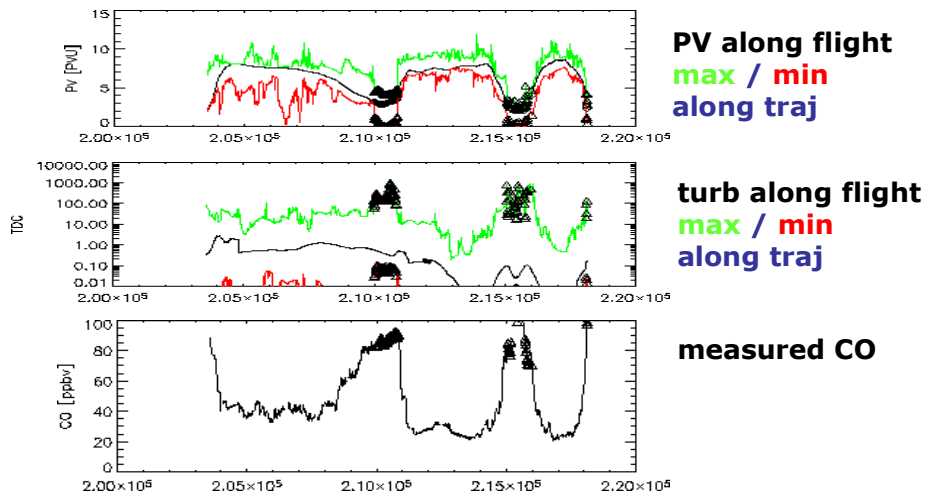


**TST associated with parameterized turbulence**

Peter Hoor

### Verification of diagnosed TST

1,10



Peter Hoor

## Summary (1)

- (1) Mesoscale processes: ERA40 turbulence field gives useful information
- (2) Synoptic-scale structures: TP folds very important in sub-tropics, less in extra-tropics
- (3) Larger-scale processes: Qualitative agreement between maxima of STE and storm tracks
- (4) Quantification of mass fluxes: ~robust seasonal cycle and no trends for ERA15 period
- (5) Geographical distribution of exchange: large zonal asymmetries

## Summary (2)

- (6) Transport pathways:
- (7) Residence time: large sensitivity
- (8) Method: Lagrangian approach
- (9) Data: significant differences ERA15 vs. ERA40 near TP
- (10) Verification: fruitful combination of diagnostics based upon ECMWF analyses and in-situ observations