REMOTE SENSING – A FUTURE TECHNOLOGY IN PRECISION FARMING

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Summary, keywords

The paper briefly reports the principles of remote sensing with optical sensors and radar. Progress in satellite and air borne remote sensing is demonstrated with special reference to the future potential in precision farming.

Foreseeable advantages in precision farming that can be achieved by remote sensing are:

- *tracing target areas with abnormal appearance; early recording of hidden faults in field crops and on site identification of their causes*
- *improved partitioning of fields into zones of uniform crop management*
- *mapping of the spatial expansion of diseases and pests in field crops throughout the growing season; revision and enhancement of measures of pest control*
- *continuous or stage dependent mapping of the crop nutrient demand, e.g. nitrogen; revision and enhancement of measures of fertiliser application*
- *successive control of the effectiveness of crop management actions.*

Successful introduction of remote sensing in precision farming depends on the availability of ready to use products for the farmers. In order to transform remote sensing data in practicable site specific applications, close cooperation between the operators of satellite systems and agro-consultants will be necessary.

Keywords: remote sensing, precision farming

Zusammenfassung

Im Beitrag werden technische Prinzipien der Fernerkundung (FE) mit optischen Sensoren und Radar erläutert. Mit Anwendungsbeispielen der Satelliten- und Flugzeugfernerkundung wird der technische Fortschritt von Satellitensystemen vorgestellt und das Anwendungspotential der Fernerkundung im Präzisionspflanzenbau (PP) aufgezeigt.

- *Als praktische Vorteile sind für den PP durch den Einsatz der FE unter anderem absehbar:*
- *Auffinden von Teilflächen mit abnormem Erscheinungsbild; frühe Erfassung von Mängeln in Pflanzenbeständen und Ursachenermittlung vor Ort,*
- *bessere Unterteilung der Flächen in einheitliche Bewirtschaftungszonen als z.B. mit Bodenkarten oder Bodenuntersuchungen,*
- *fortlaufende Kartierung der Ausbreitung von Krankheiten und Schädlingen; strategische Verbesserung und Optimierung der Kontrollmaßnahmen,*
- *fortlaufende oder stadienbezogene Kartierung des Stickstoff-Bedarfs der Pflanzen; strategische Verbesserung und Optimierung der Düngung (auch andere Dünger, Bodenverbesserer etc.),*
- *laufende Erfolgskontrolle aller Maßnahmen in den Flächen.*

Wichtig für eine erfolgreiche Einführung der Fernerkundung in den Präzisionspflanzenbau wird sein, daß die Landwirte mit möglichst fertigen Produkten beliefert werden und bei der Übersetzung von Fernerkundungsdaten in feldbezogenen Anwendungen die Betreiber von Satellitensystemen und Fachberater in der Landwirtschaft zusammenwirken.

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Úvod - Introduction

Precise actions in farming requires precise information on the crop status in terms of time and area. Remote sensing by aircraft in a few cases has already been used to contribute to precision farming with spectral information. In the near future also satellite remote sensing will play a major role in precision farming. Principles and potential of remote sensing, as applied in precision farming, and perspectives with new satellite systems will be reported, and examples of applied remote sensing in the field of precision farming will be shown.

Metody - Methods

Precision Farming

Physical status and appearance of the solid earth, even of ice and sea water do not perform homogenous surfaces over area and time. This is especially true in agricultural fields. The normal status of an individual field plot is, under all criteria available to us, heterogeneity. Even arable land, new reclaimed with one single soil type, will never appear homogenous, but will consist of a number of sub units differing in soil moisture, soil color, color and biomass of growing crops etc. . Meanwhile, also for small field plots inhomogeneity is accepted to be normal, hence the purpose of precision farming (PF) will rather be to respect the differing field sub units, than to make them uniform. In addition, precision farming takes into consideration the change of crop layer in terms of area and time including ecological, as well as economic rules. Key technologies in PF are :

1. geographical positioning systems on farm implement (like the GPS) while recording the crop status or any kind of agricultural actions from seeding to harvest,
2. relyable recording of crop and soil status by sensors in the field,
3. high resolution/precision techniques to perform agricultural actions,
4. geographical information system (GIS) to register and document crop and soil status, as well as actions applied.

Remote sensing (RS), a few years ago, was far away from being applicable in the field of PF. First of all, spacial and temporal resolution by RS have been inadequate. In the last few years , however, new satellites have been launched which may demonstrate the potential of RS in PF. Further, we are expecting improved full cover RS-systems which will reduce the weather risk in the optical RS.

Remote Sensing

Sensors applied in RS, principly record phenomena, not causal things; the causal analysis has to be done by the user. To create images with orthorectified informations takes experts, experience, expertise, time and money. We are still missing the cheap and fast routines, because there are too many different types of systems and organisations involved and still there is no real profitable market. However, fast routines generating RS-data, will play a keyrole in PF applications, since over the entire vegetation-period there is fast changes in the appearance of all major crops.

RS with optical waves differs distinctly from that with microwaves (Radar). Optical sensors record that portion of sun light which is not absorbed by the crop or soil. Radar on the other hand, uses active sounders, is sending polarized pulsed micro-waves (MW) and receives the intensity of backscatter. Another peculiarity of radar is that the spacial resolution on ground is achieved by measuring the different running- time of neighboring wave bands.

The signal received from crop canopies in the optical range, is made up by reflexion and absorption of the sun light with significant influences of atmosphere and weather conditions. The intensity of microwave-signals received, depends on diminishing of the scattering and change in polarization of the radar wave emitted. Radar, as an active system, is day and night capable and to a great extent weather independent. The differing behaviour of optical and radar waves allows to record different characters of the plant canopy as shown in Table 1.

Optical RS reacts very well with pigment and water concentration in the vegetation layer. Full cover of vital plant canopies perform strong absorption in the Blue and Red of the spectrum and because of the multiple leaf layers, a high level of reflexion in the NIR. Higher reflexion of soils in the visible spectrum and stronger absorption in the NIR, in most cases enables to distinguish soils from vegetation. In addition, up to a saturation value, in the Red and NIR the process of developing canopies can be reproduced. Quite common in optical RS are vegetation indices representing the vitality of the vegetation layer. The so-called „Red-NDVI“ (NDVI = Normalized Difference of Vegetation Index) combines the reflexion in the Red and in the NIR (NDVI = R(NIR)-R(Red) / R(NIR) + R(Red).This index is a widely used measure of crop vitality. In addition, there are a number of other vegetation indices described in the literature, which suit to classify certain characters of plant canopies more or less selectively (Gitelsen 2001).

The radar waves penetrate the crop canopy and react primarily with their volume and their structural elements, leaves and stems; long waves penetrate deeper than short waves. The orientation and size of the canopies structural elements and the more horizontal or vertical distribution of water mass within, will have crucial influence on the intensity of backscatter. Because of the penetration, only at small incidence angles and short waves (i.e. X-Band), with radar an exclusive plant-layer-signal might be expected. Long waves of radar, like the L-Band, and steep incidence angles on the other hand, even with full cover canopies, always create a mixed signal originating from the plant layer and the soil under it (Ulaby et al. 1982).

These physically very complex relationships makes it still difficult to understand radar signals from crops.

The advantage of optical RS is the much better understanding of the received signals: Low NDVI-values indicate for instance, a poor or senescent vegetation or a deficit in water and/or nutrient supply. Taking the phenological development of certain crops into account, quite often conclusive informations can be produced from the RS-signal. Another advantage of optical RS: with a few consecutive scenes, and sometimes with one single scene field plots and subunits can be distinguished by simple pixel-by-pixel analysis. The major disadvantage of optical RS is, that it will not work without sun light and under cloudy conditions. Therefore, in humid regions the well known RS systems Landsat and Spot cannot be successfully applied for continuous observations of crop canopy developments along the season. Even classification of crop types is difficult with these systems in some years. Aircraft based RS, so far, has a much better potential for reasonable resolution over time. However, RS with aircraft is expensive related to the small area recorded, and almost nothing is standardised, neither the repetition rate, nor the area frame or spectral and spacial resolution. This makes it difficult to develop routines and to get standardised products (see below).

Because of the all weather and day and night capability, radar performs at reliable repetition rates. Further, microwaves are very sensitive for fresh biomass. However, there are major disadvantages like the difficult physical background mentioned above. Part of these difficulties is the fact that neighboring microwaves may interfer, enhancing and distinguishing with each other. This creates the so called „speckle“ which makes the images unsharp so that pixel-by-pixel evaluation of the scenes is inappropriate and small structures may be completely hidden. Even multi-temporal radar images are less clear, as compared to one single image from an optical sensor. With labor-intensive filtering, and comprising the backscatter values of individual pixels within a field plot, or a subunit of a field plot, the application of radar-RS can be improved. Since for PF fast and routine evalutions are essential, the difficult radar phyisics deserves special attention.

Výsledky - Results and Discussion

Precision Farming and Remote Sensing

Precision Farming (PF), in certain fields of agricultural crop production, already happens without RS. In a number of applied precison techniques, RS will not be competitive enough or will not be necessary. Recognition of weed species**,** for instance, will remain with digital cameras, because of the very high spacial resolution required (Sökefeld et al. 2000). Also, the Hydro-N-Sensor is working in the near range (Heege and Reusch 1996). Ground based sensors, however, cannot be used repeatedly any time. This, in particular, will be the advantage and the future field of application of RS in PF. The appearance of crop stands and the duration and sequence of the time windows for related actions in the field, are changing very much from year to year and between crop types. Only satellite-RS has the potential to satisfy the requirements of frequent and continuous observations of agricultural crops, or to record the success of each field action applied by the farmer.

Hence, RS in the domain of PF can be taken as a kind of „tactical field inspection“ (Blakeman 2002). The farmer, for instance, knows the symptoms of nutrient deficiencies or diseases, but there is a permanent lack of information, when and where these deficiencies start to appear in the field, and the related area size of the wanted phenomena will remain unknown. Therefore, the PF requires RS. The following advantage of RS in applied PF may be expected:

- tracing target areas with abnormal appearance; early recording of hidden faults in field crops and on site identification of their causes
- improved partitioning of fields into zones of uniform crop management
- mapping of the spatial expansion of diseases and pest in field crops throughout the growing season; revision and enhancement of measures of pest control

- continuous or stage dependent mapping of the crop nutrient demand, e.g. nitrogen; revision and enhancement of measures of fertiliser application
- successive control of the effectiveness of crop management actions.

At present, fertilizing and plant production actions are almost exclusively based on the farmers experience, his personal field inspections, soil and plant samples. Many of these informations/actions are missing detailled resolution over time and across the area of the field plots to the subunits of the field plots.

In a number of research projects, the potential of RS to improve the farmers information about his crop, has already been demonstrated.

Aircraft and satellite images in many ways have been used to record vegetation indices. From the retrospective, these images can be applied to the next crop which is grown in the same field plot - quite similar to the yield maps, generated with combine harvesters, equipped with yield sensors and GPS-antennas (Auernhammer and Demmel 1998). The spreading of weeds, the appearance of diseases and antagonists, as well as, nutrient and water deficiencies became observed by RS (Blakeman 2002, Brown et al. 1994, Büker et al. 1992, Jürgens 2000, Vogt and Somma 2000). Further, it is well accepted that even from single images and from the retrospective, farmers can get suitable information.

But probably no more than 5% of all existing satellite images have ever been looked at one single time (Taylor 2000).

With existing satellites it can be pretty good recognized, if farming in a certain region is more or less sustainable (Kühbauch 1993). Figure 1 shows the ecological dimension of PF applicable over large areas. In this example a very high area proportion of arable land is covered by wheat and barley. Both crop types are getting quite similar treatments and have the same major antagonists. The high percentage of wheat and barley in this crop rotation supports their specific diseases and antagonists, and in return increases the demand for pesticides and nutrients. So, merely from the number of main crops cultivated, reasonable information, as related to sustainability, can be derived.

The red shift at the „red edge“ in the optical reflectance of a vegetation has been described early in the RS-literature (Guyot and Barret 1988); it is very sensitiv for plant vitality. In an aircraft RS mission, late in the eighties (a joint venture with the Netherlands and Great Britain), we measured the red shift in grassland plots that received different amount of N-fertilizer (Büker et al. 1992). As a result, we found a very close relation between this red shift and the level of N application. In Figure 2 the position of the main inflexion point of the red edge is compared with the level of N applied to the respective plots.

Figure 3 shows the spacial variation of biomass in very large fields of winter barley at Mecklenburg-Vorpommern at shooting (April 19, 1999, Hawlitschka et.al. 2001) From previous investigations with multipolar MW's, we learned that radar-backscatter of different polarizations, related to each other, correlated very well with fresh and dry biomass (Steingiesser and Kühbauch 1998). The results shown in the figure became elaborated within the „ProSmart“ cooperative mission, initiated and coordinated by DORNIER company (1999). The biomass of barley has been derived from the L(vv)/X(hh) radar signals.

Also in this application, an aircraft was the platform of the sensor. PF, however, as mentioned above, needs continuous observation. Only by that means, one can meet the time windows required for the various actions, which have to be done in the field plots during the season. For more detailed analysis beyond the trivial question „how green and vital is a crop canopy“, also better spectral and radiometric resolution of RS-signals will be required. Application of RS in PF needs therefore, enormous technical efforts, mainly with respect to spacial and time resolution. The very promising technological development of the satellite systems applied in RS is given in the next table (Table 2).

As compared to the early Landsat series with the MSS-sensor, the newer systems have a much better resolutions in any term. Of major interest for PF is geometric (ground) resolution and repetition rate. At present, none of the available satellite systems fulfill all requirements. From our own experience, even a repetition rate of 2 to 3 days is not sufficient under our (West- and Mid-Europe) weather conditions. What we need for PF is daily repetition (appearance of the satellite at the same place each day).

Ikonos and Quickbird perform very good geometric and spatial resolution. But the repetition rate of these systems look better as they are. A major disadvantage of these high ground resoluton systems is the relatively small area frame or swath width which makes the images very expensive. Very attractive is the daily repetition of the Rapid Eye-System combined with a good spectral and, in most cases, sufficient ground resolution. The enormous area taken in one swath, is at least a pre-requisite to make the satellite images affordable for farmers. In my opinion, ground resolution below 5 to 6 meters in most cases of application, will not be necessary. Since hyper-spectral resolution in satellite systems will be at the expense of ground resolution (signal to noise – relation has to be taken into account), this could rather be the domain of aircraft RS. In PF optical satellite systems, priority should be given to the repetition rates at reasonable spectral and ground resolution, since by that means, the weather risk will be reduced. MW-RS in the form of SAR,on the other hand, could contribute to the optical RS by their weather independence, which in principle guarantees continuum records. Further, MW-RS adds other characters of the crop canopy, as optical sensors do.

Most important for RS applied in PF will be, to deliver ready-to-go products for the farmers, where RS-Signals are translated into the state of the respective crop. In order to achieve very fast routines, it will be crucial to create the field data each day at any time.

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Table 1: Remote Sensing with Optical Sensors and Radar; crop characters influencing spectral reflexion of optical waves (VIS und IR) and microwaves (Radar).

Fernerkundung mit optischen Sensoren und Radar; Pflanzenbestands-merkmale, welche die Reflexion von Optischen- und Mikrowellen beeinflussen.

VIS und IR (λ, θ, Φ)	Radar (λ, θ, ρ, Φ)
- pigment composition 1) - pigment concentration 1)	- volume (stand height) 1) - vertical and horizontal distribution of plant organs 1)
- turgidity 2) - cell stucture 2)	- size, form and orientation of plant organs - distribution of fresh and dry biomass and phenology 1) - row direction
- senescence 1) 2) - phenology 1) 3) - leaf area index 3) - soil pigmentation 4) - soil moisture 4)	- soil roughness - soil moisture

λ =wavelength; θ =incidence angle; ρ =polarization; Φ = azimuth angle (look direction); 1)-4) related characters

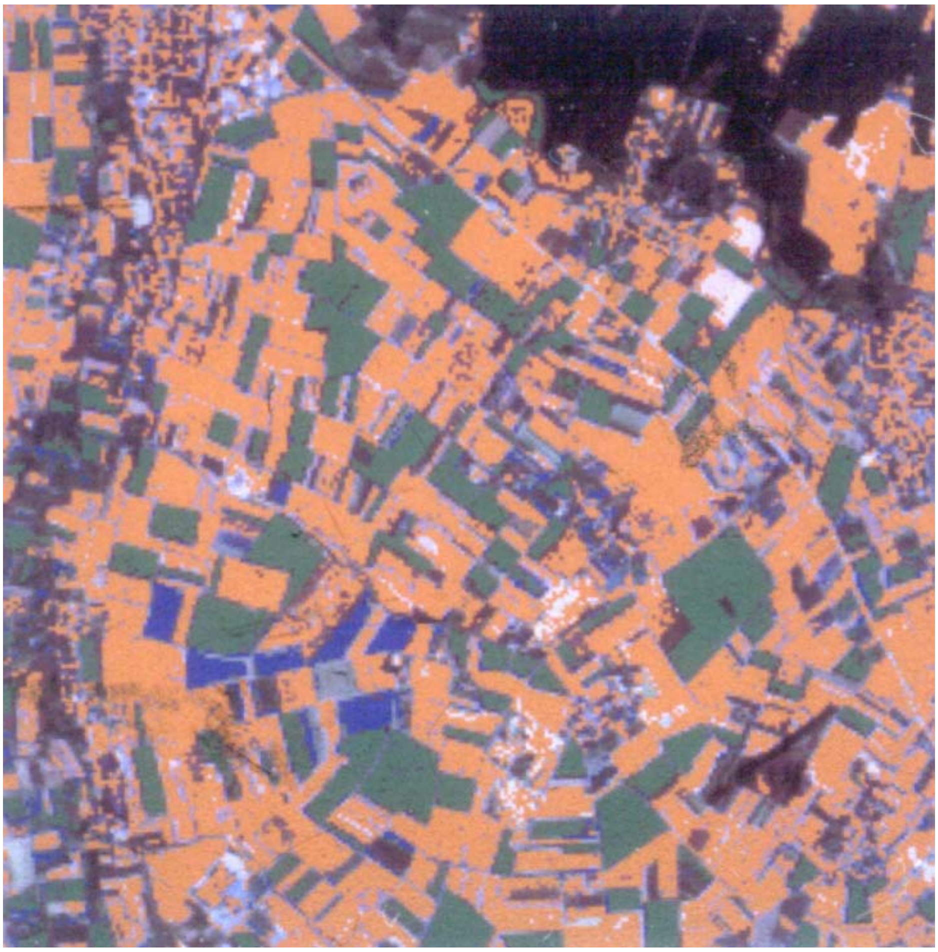

Fig. 1: False colour image of aggregated winter wheat and winter barley plots (yellow) and sugar beets (green).
Falschfarbendarstellung der zusammengefassten Felder von Winterweizen und Wintergerste in Orange-Gelb, Zuckerrüben in Grün.

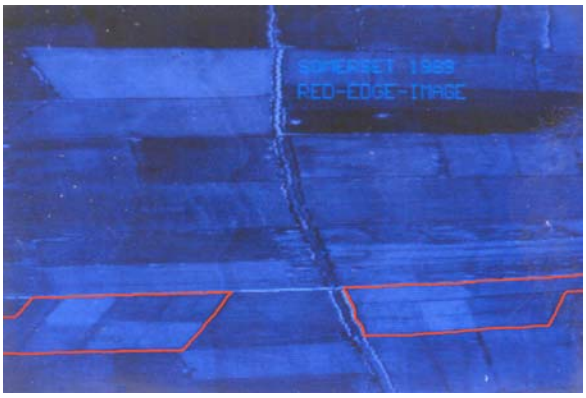

Fig. 2a

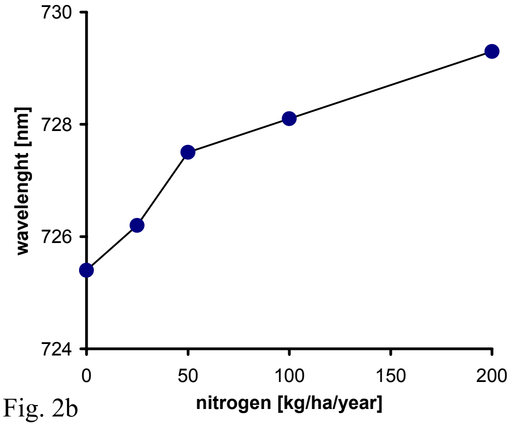

Fig. 2b

Fig. 2a: Position of main inflection point (HWP) of the Red/NIR edge is illustrated in greyscale according to $R_{HWP}=(R_{670}+R_{780})/2$ and $HWP=700+40 * (R_{HWP}-R_{700})/(R_{740}-R_{700})$.
Position des Hauptwendepunktes (HWP) der Rot/NIR-Flanke abgebildet in Graustufen nach der Formel: $R_{HWP}=(R_{670}+R_{780})/2$ *und* $HWP=700+40 * (R_{HWP}-R_{700})/(R_{740}-R_{700})$.

Fig. 2b: **Position of main inflection point of the Red/NIR edge of reflectance of grassland plots fertilized with 0 to 200 kg N/ha.**
Hauptwendepunkt der Rot/NIR-Flanke des Reflexionsspektrums von Grünlandparzellen mit N-Düngung 0 bis 200 kg N/ha.

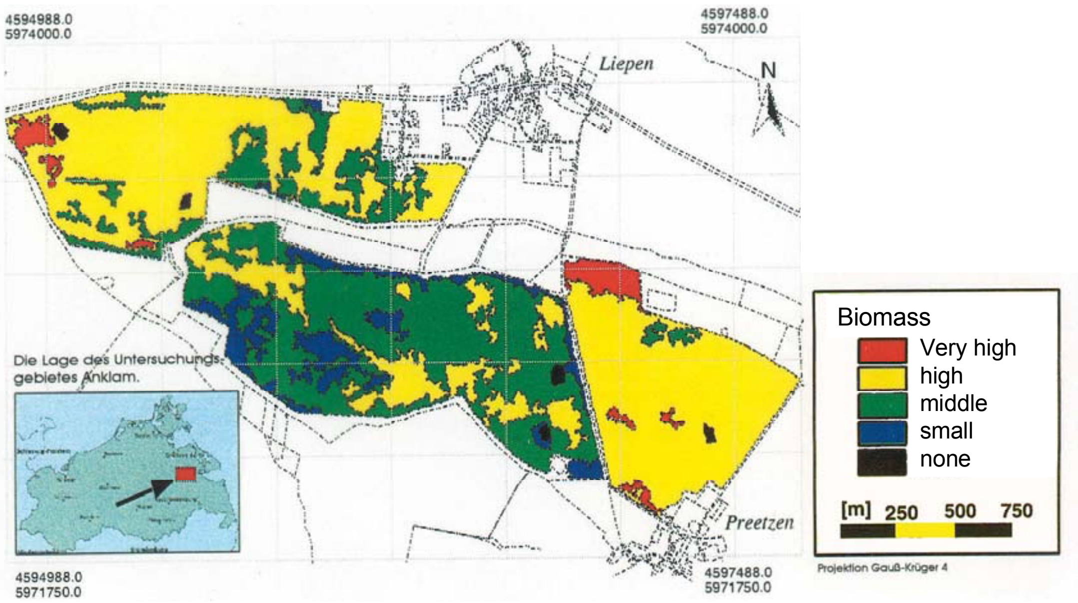

Fig. 3: Pattern of fresh biomass in winter barley plots at the beginning of shooting, 19 April 1999 in Mecklenburg-Vorpommern ProSmart-Projekt with Dornier-Daimler-Chrysler Aerospace (DORNIER 1999, HAWLITSCHKA et al. 2001).
Verteilung der frischen Biomasse in Wintergerstenfeldern zu Beginn des Schossens am 19.04.1999 in Mecklenburg-Vorpommern - ProSmart-Projekt mit Dornier-Daimler-Chrysler Aerospace (DORNIER 1999, HAWLITSSCHKA et al. 2001).

Table 2: Technological Progress of Satellite Systems with Optical Sensors 1972 to 2005 – incompletely.
Technische Daten von optischen Satellitensystemen 1972 bis 2005 – unvollständig.

RS-Systems and year of launch (Responsible Agency)	Orbit (km)	Spectral Resolution (µm)	Ground Resolution (m)	Radio-metric Resolution (bit)	Time Resol. (days)	Sight area (km*km)
Landsat 1 and 2, MSS-Sensor 1972 and 1975 (NASA)	907	0,5 – 0,6 0,6 – 0,7 0,7 – 0,8 0,8 – 1,1	57 x 79	6	18	98
IKONOS 2, 1999 (Space Imaging)	681	0,45 - 0,52 0,52 - 0,60 0,63 - 0,69 0,76 - 0,90 Pan	4 1	11	< 3	11 - 14
Quickbird 2, Start Okt. 01 (Digital Globe US), First data avaibable Febr. 02	450	Pan: 0,45 - 0,90 multispectr.: 0,45 - 0,52 0,52 - 0,60 0,63 - 0,69 0,76 - 0,89	Pan: 61 cm multispectr.: 2,5m in market with 70cm und 3m	11	3,5	16,5
RapidEye 2004/2005 (RapidEye)	610	0,44 - 0,52 0,52 - 0,60 0,63 - 0,69 0,69 - 0,73 0,76 - 0,90	6,5	10	1	159 x 1500
From 1998 to 2008 more than 50 new earth observation satellites have been or will be established (JOHANNSEN 1998, CAB-Abstr.)						

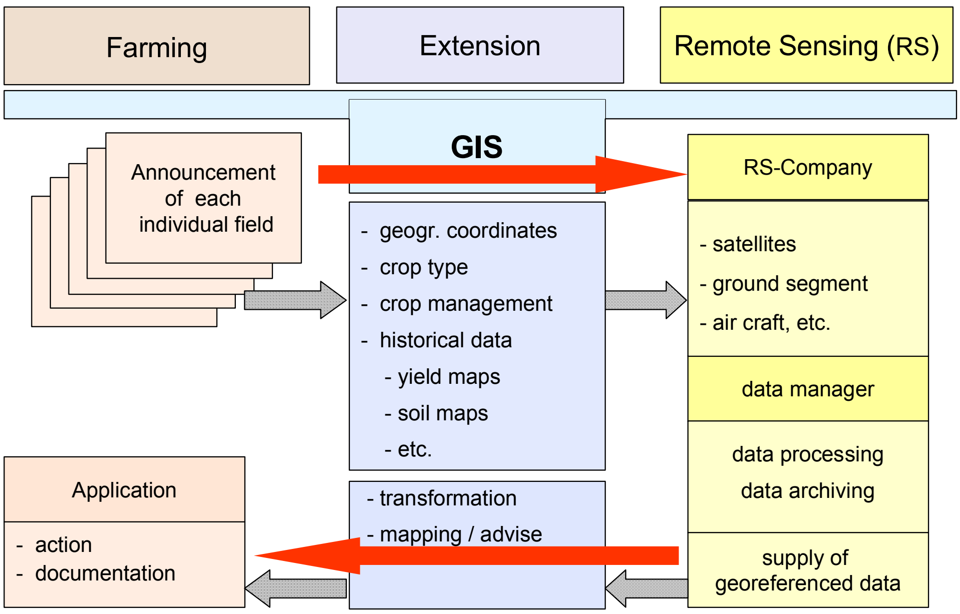

Fig. 4: Data Flow: Remote Sensing Applied in Precision Farming.
Datenfluss im Präzisionspflanzenbau mit Fernerkundung.